B1 (b) SCHOOL OF CELTIC STUDIES

ANNUAL REPORT (PART 2) 2010

Annual report of the Governing Board of the School of Celtic Studies for the year ending 31 December 2010.

Bord Rialúcháin Scoil an Léinn Cheiltigh / Governing Board of the School of Celtic Studies (until 31 March 2010).

Professor Anders Ahlqvist (*Chairman*); Professor Angela Bourke; Professor Máire Herbert; Professor Liam Mac Mathúna; Dr Eilís Ní Dheá; Professor Dónall Ó Baoill; Dr Nollaig Ó Muraíle; Professor Ruairí Ó hUiginn; Dr Katharine Simms; Professor Liam Breatnach; Professor Pádraig A. Breatnach (*Director*);Professor Fergus Kelly

Bord Rialúcháin Scoil an Léinn Cheiltigh / Governing Board of the School of Celtic Studies (from 1 April 2010).

The Board met twice during the year, on 10 June 2010 and 18 November 2010.
Professor Anders Ahlqvist (*Chairman*); Professor Máire Herbert; Professor Jim McCloskey; Dr Uáitéar Mac Gearailt; Dr Eilís Ní Dhea; Dr Máire Ní Mhaonaigh;
Professor Ailbhe Ó Corráin; Professor Ruairí Ó hUiginn; Dr Nollaig Ó Muraíle;
Dr Katharine Simms; Professor Liam Breatnach; Professor Pádraig A. Breatnach (*Director*);
Professor Fergus Kelly

Foireann agus Scoláirí / Staff and Scholars
Senior Professors: Pádraig A. Breatnach (Director), Liam Breatnach, Fergus Kelly
Professors: Malachy McKenna, Pádraig Ó Macháin
Assistant Professors: Aoibheann Nic Dhonnchadha, Michelle O Riordan (Publications Officer)
Bibliographer: Alexandre Guilarte
Dialectologist: Brian Ó Curnáin
Bergin Fellows: Clodagh Downey, Roisin McLaughlin (to 8 May, 2010)IRCHSS Postdoctoral Fellowship)
O'Donovan Scholars: Nora White, Freya Verstraten Veach, Eoin O'Flynn, Anna Matheson, Helen Imhoff .
Librarian: Margaret Kelly
Library Assistant: Órla Ní Chanainn
School Administrator: Eibhlín Nic Dhonncha
Technical Staff: Anne Marie O'Brien (ISOS)
IT support: Andrew McCarthy (part-time), Stephen McCullagh (part-time)
IRCHSS Postdoctoral Fellow (from 1 October 2010): Roisin McLaughlin

1.1 TAIGHDE/RESEARCH

Canúneolaíocht / Dialect studies
Malachy McKenna continued work on a draft of *The Irish of Rann na Feirste: a phonemic study*, revising this and remedying lacunae with the aid of speech recordings and questionnaires put to informants on field trips to Rann na Feirste. Work included observation of visual cues of speech based on video recordings of speakers from which still-photographs were produced to enable capture of the positions of the lips, the teeth and the tongue that characterise a given segment. A final draft will be submitted to the School of Celtic Studies publications committee during 2011. He also revised his article 'Comhcheol guthach v. comhshamhlú guthach sa Ghaeilge agus i nGaidhlig

na hAlban' for publication in a forthcoming *Festschrift*.

Eagarthóireacht théacsúil etc. / Textual editions etc.

Liam Breatnach continued work on his edition of the Old Irish law tract *Córus Bésgnai*, as well as collecting material for his projected *Grammar of Middle Irish.*

P. A. Breatnach edited a previously unpublished poem by Séamas Beag Mac Coitir *Mo léansa an galar so do shearg mé i sírghéibheann* (17 vv.) for the series 'Togha na hÉigse 1700-1800' (*Éigse* and *Celtica*); he also edited a group of texts on the death of Sir James Cotter (1720), including *Aisling do chuala ar maidin do bhuair me*, and *Léan ort a Chorcaigh*. His edition of the Irish apocryphal text *Airdena inna cóic lá ndéc ria mbráth* was finalised. He advanced his edition of the poems of Dubhthach Óg Ó Duibhgeannáin addressed to O'Neill and O'Donnell for his *Chronicle poems of the Nine Years' War* (in preparation).

Fergus Kelly continued with his edition of the Legal Treatise attributed to Giolla na Naomh Mac Aodhagáin (*Corpus Iuris Hibernici* ii 691.1-699.4). He also continued to work on his edition of an Old Irish text on legal disputes within marriage (*Corpus Iuris Hibernici* i 144.5–150.16). He completed his article 'The Place of women in early Irish law, with special reference to the law of marriage' for publication in *Proceedings of the Seventh Australian Conference of Celtic Studies*) (forthcoming).

Pádraig Ó Macháin continued research on unpublished remnants of the poetry of Tadhg Dall Ó hUiginn and on the unpublished poetry of Fearghal Óg Mac an Bhaird, with results presented in separate publications.

Clodagh Downey continued her research on the poetic corpus of the Middle Irish poet, Cúán ua Lothcháin which involved consultation and transcription of many manuscripts containing this poetry, the edition and collation of these transcriptions, translation and annotation of the texts and study of the life and background of the poet.

Helen Imhoff continued working on an edition of *Fástini Airt meic Cuind.*

Anna Matheson advanced her corrections/additions to her doctoral dissertation on 'The depiction of madness as a form of purgative suffering in 10th to 12th century Irish and "Scotttish" texts (*Mór Muman ocus Aided Chuanach meic Cailchíne, Buile Shuibne,* and *Lailoken A)*. She prepared articles on the topic of mental impairment in the vernacular law tracts.

Roisin McLaughlin continued work on the edition of *Mittelirische Verslehren III* and *In Lebor Ollaman* as part of a project for IRCHSS Post-doctoral Fellowship.

Staidéar lámhscríbhinní, clárú lámhscríbhinní / Manuscript studies, cataloguing of manuscripts

P. A. Breatnach revised and added chapters to his monograph on the scribal history of the works of the Four Masters *The Four Masters and their manuscripts* (for publication 2011); he continued work on his catalogue of Irish manuscripts in the Brussels collection (Bibliothèque royale de Belgique).

Aoibheann Nic Dhonnchadha continued work on cataloguing the Irish medical manuscripts in the Library of Trinity College Dublin, dating from the fifteenth and sixteenth centuries. She completed draft descriptions of the collation and contents of some 20 Irish medical manuscripts from the collection of Trinity College Dublin, and made these available in digitised form along with the manuscript images on the School of Celtic Studies/ISOS website, viz. TCD catalogue Nos. 1299, 1302, 1310, 1312, 1313, 1314/2, 1316/1, 1319/2/1, 1319/2/8, 1319/2/9, 1321, 1323, 1333, 1334, 1386, 1388, 1398/71, 1432, 1698.

Pádraig Ó Macháin edited the proceedings of the 2009 School of Celtic Studies one-day conference on the newly digitised the Book of the O'Conor Don (10 papers). He provided descriptions of Australian manuscript material newly digitised for the ISOS project, and descriptions of some of ancillary documents in Clonalis House. He carried out preliminary research on uncatalogued manuscripts in the Royal Irish Academy. He also researched palaeographical aspects of the Ó Cianáin manuscript (UCD-OFM MS A 21) this research was presented at the 400th

anniversary conference in Mater Dei Institute of Education in December.

1.3.4 Stair liteartha agus chultúrtha / Literary and cultural history

Aoibheann Nic Dhonnchadha worked on a survey of Galenic learning in Irish medical texts of the fifteenth and sixteenth centuries and on the sources of a major Galenic commentary found in a fifteenth-century manuscript in Trinity College Dublin (ms 1299) as a contribution to a specialist international seminar on the historical significance of the writings of the Greek physician Galen (*c.* 130-*c.* 201) to be held in June 2011 (part of the celebration of the tercentenary of the School of Medicine of the University of Dublin).

Michelle O Riordan continued her research on seventeenth-century political poetry and emotive poetry between the twelfth and seventeenth centuries for the Arlen Press Pamphlets series (for publication 2011).

Eoin O'Flynn continued work on his PhD thesis: 'Clann Cholmáin c. 550-916'. Specific issues examined included (i) how the kingship of Mide and the delegation of kingly title was used by Clann Cholmáin dynasts to secure and consolidate political support in the midlands; (ii) Clann Cholmáin's response to the initial appearance of Vikings in the midlands and subsequent development of periodic alliances with the kings of Dublin; (iii) the nature of the various 'disturbances' recorded at Óenach Tailten in which Clann Cholmáin were often involved.

Freya Verstraten Veach continued research concerning William 'gorm' de Lacy (early thirteenth-century history) for an article to be published in 2011. She also continued to work towards publication of her thesis on 'The Anglicisation of the Gaelic Irish nobility, c.1169 – c.1366' (2011).

1.2 Meamram Páipéar Ríomhaire / Irish Script on Screen (ISOS)

The Irish Script on Screen project (ISOS) continued under the direction of Pádraig Ó Macháin. Digitisation was carried out on manuscripts from the Royal Irish Academy collection (January). The first part of the collaboration with the National Library of Scotland was carried into effect with the processing and display by ISOS of the digital version of the sixteenth-century Book of the Dean of Lismore. A digital version of the description of this manuscript from the unpublished catalogue of manuscripts in the National Library of Scotland by Ronald Black was also processed and displayed on the ISOS website by kind permission of the author, and with his generous collaboration.

ISOS collaborated with the National Museum of Ireland with regard to the digital display of manuscript materials as part of the High Crosses Exhibition at the Museum's premises at Collin's Barracks.

Agreement was reached with the State Library of Victoria, Australia, regarding the processing and display of digital versions of the three Irish manuscripts in their holdings. This work will be carried out in 2011. Agreement was also reached with the Library, University College Cork, to establish a pilot project for the digitisation, processing and display of several Irish manuscripts; nos. 92, 96, 119,124 from the UCC collection were digitised in December; further collaboration will be carried into effect in 2011.

1.2 Tionscnamh Bibleagrafaíochta/Bibliography Project

Alexandre Guilarte continued work on the compilation of the fourth volume of the "*Bibliography of Irish Linguistics and Literature"*, focusing on material appeared in learned periodicals in the field of Irish studies. He also looks after the maintenance and supervision of its on-line version eBILL.

1.3 Ogham-3D

Nora White carried out work on the Ogham in 3D pilot project. The project is supported by an expert advisory panel including Professors Fergus Kelly, Werner Nahm (Director of the School of Theoretical Physics, DIAS), Damian McManus (TCD) and Fionnbarr Moore (National Monuments Service), and has benefited from assistance of Professor Dáibhí Ó Cróinín, Dr Thierry Daubos and

Sander Westerhout from the Protecting the Inscribed Stones of Ireland project (NUIG). This involved scanning in the National Museum of Ireland and on-site in counties Carlow (Rathglass and Clonmore) and Wicklow (Boleycarrigeen, Donard).

1.4 Tionscnamh *Leabhar Breac* / *Leabhar Breac* Project

Liam Breatnach continued to direct the preparation of a diplomatic edition of the *Leabhar Breac*, with the involvement of the Bergin Fellows and Scholars.

1.5 Eagarthóireacht irisí léannta agus leabhar / Editing of learned journals and books

Liam Breatnach: Co-editor of *Ériu*, vol. LX. Published by the Royal Irish Academy.
Pádraig A. Breatnach: Editor of *Éigse: A Journal of Irish Studies*, vol. XXXVII. 2010 210 pp. Published by the National University of Ireland (November).
Fergus Kelly: Co-editor of *Celtica* XXVI. Published by DIAS, (November). Also edited *Foilseacháin sa Léann Ceilteach: Publications in Celtic Studies* (published by DIAS, September). Also edited *The cult of the sacred centre* (†Proinsias MacCana).
Malachy McKenna: Co-editor of *Celtica* XXVI. Published by DIAS (November).
Aoibheann Nic Dhonnchadha: Comheagarthóir (le Pádraig Ó Macháin) *An Linn Bhuí: Iris Ghaeltacht na nDéise*, Imleabhar XIV.
Pádraig Ó Macháin: Editor, *The book of the O'Conor Don: essays on an Irish manuscript* (DIAS 2010) ix + 278 pp. Editor, *Ossory, Laois and Leinster* vol. XIV. Comheagarthóir (le Aoibheann Nic Dhonnchadha), *An Linn Bhuí: Iris Ghaeltacht na nDéise* Vol. XIV.

1.6 Foilsitheoireacht / Publishing

As one of its statutory functions, in addition to research and publication by its own staff, the School assesses, edits and publishes books and papers by outside scholars.
The publications committee met on three occasions. The following books were published in 2010:

Margo Griffin-Wilson, *The wedding poems of Dáibhí Ó Bruadair.*
ISBN 978-1-85500-216-6
Pádraig Ó Machain (ed.), *The Book of the O'Conor Don: essays on an Irish manuscript*.
ISBN 978-1-85500-217-3
Malachy McKenna and Fergus Kelly (ed.), *Celtica* vol. XXVI.
ISBN 978-1-85500-218-0

Athchlónna / Reprints

The following reprints were seen through the press by Michelle O Riordan, Publications Officer, and Eibhlín Nic Dhonncha, Administrator:
Thomas F. O' Rahilly, *Early Irish history and mythology*
ISBN 978-0-901282-29-3
Fergus Kelly, *Audacht Morainn*
ISBN 978-0-901282-67-5
Eleanor Knott, *Togail Bruidne Da Derga*
ISBN 978-1-85500-064-3
Mario Esposito, *Itinerarium Symonis Semeonis ab Hybernia ad Terram Sanctam*
ISBN 978-1-85500-054-4
D.A. Binchy and Osborn Bergin, *A grammar of Old Irish*
ISBN 978-1-85500-161-9
R.L. Thomson, *Pwyll Pendeuic Dyuet*
ISBN 978-185500-051-3
Sir Ifor Williams *The poems of Taliesin*
ISBN 978-0-901282-01-9

Derick S. Thomson, *Branwen Uerch Lyr*
ISBN 978-1-85500-059-9

1.7 Díolachán Leabhar/Sale of books

Promotion of publications was effected by the School Administrator, Eibhlín Nic Dhonncha, through advertising in national and international newspapers, *Books Ireland, National Concert Hall Annual Brochure, Comhar, Saol, Foinse, Lá, Conradh na Gaeilge: Clár Seachtain na Gaeilge, An tOireachtas: Clár na Féile, Lámhleabhar An Choláiste Ollscoile Baile Átha Cliath, Library News.*

1.8 Foilseacháin na foirne / Staff publications

Liam Breatnach:
'Law and literature in early mediaeval Ireland', in *L'Irlanda e gli irlandesi nell'alto medioevo. Spoleto, 16-21 Aprile 2009.* Atti delle Settimane LVII (Spoleto 2010) 215-38;
'The king in the Old Irish law text *Senchas Már*', in Folke Josephson (ed.), *Celtic language law and letters: proceedings of the tenth symposium of Societas Celtologica Nordica,* Meijerbergs Arkiv för Svensk Ordforskning 38 (Göteborg 2010), 107-28.

P. A. Breatnach:
'The Book of the O'Conor Don and the manuscripts of St Anthony's College, Louvain' in *The Book of the O'Conor Don: Essays on an Irish manuscript,* edited by Pádraig Ó Macháin (Dublin 2010), pp. 103-22;
'On the Ó Cléirigh recension of *Leabhar Gabhála*', *Éigse* 37 (2010), pp. 1-57; [Same issued as booklet (with plates) available from the National University of Ireland (2010)];
'Approbationes', *Éigse* 37 (2010), p. 58;
'Caoineadh Sheamais Óig Mhic Coitir (1720)' *Éigse* 37 (2010), 142-150;
'Togha na hÉigse 1700-1800. (6) *Mo léansa an galar so shearg mé i sírghéibheann* (Séamas Beag Mac Coitir)', *Celtica* 26 (2010), 1-22.
I measc na ngearrcach is na gcearca fraoigh: Scéaltóireacht, filíocht agus mionseanchas ó Pharóiste Mórdhach, An Sagart (2010).

Clodagh Downey:
'Dindshenchas and the Tech Midchúarta', *Ériu* 60 (2010), 1-35.
Reviews of *Lebor Gabála Érenn: Textual history and pseudohistory* (ed. John Carey) and *Lebor Gabala Érenn: the Book of the Taking of Ireland. Part VI: Index of names* (Pádraig Ó Riain) (2009), *Béaloideas* 78 (2010), 239-48.

Fergus Kelly:
'Cauldron imagery in a legal passage on judges (CIH iv 1307.38-1308.7)', *Celtica* 26 (2010), 31-43;
(With Nora White)'The Ogham in 3D Project: a report on work in progress', *Celtica* 26 (2010), 200-204;
'The relative importance of cereals and livestock in the medieval Irish economy: the evidence of the law-texts' in *L'Irlanda e gli irlandesi nell'alto medioevo, 16-21 Aprile 2009*. Atti delle Settimane LVII (Spoleto) 93-110;
'Drifting on the ocean: are Old Irish *cnoe gnáe* to be identified as sea beans?' in *Bile ós Chrannaibh*: *A Festschrift for William Gillies,* ed. Wilson McLeod, Abigail Burnyeat et al., Clan Tuirc, Scotland, 2010, 211-18.

Roisin McLaughlin:
'A Latin-Irish text on fasting in the *Leabhar Breac*', *Ériu* 60 (2010), 37-80.

Michelle O Riordan:

‘Craft and creativity in Tadhg Dall’s poetic *personae*’ in *Tadhg Dall Ó hUiginn: his historical and literary context*, ed. P. Riggs, ITS Subsidiary Series (London 2010) 88-118.

Pádraig Ó Macháin:
‘Cíos, cás agus cathú: teagasc an Athar de Bhál 4’, *An Linn Bhuí* 14 (2010) 151-71.
‘An introduction to the book of the O’Conor Don’, in Ó Macháin (ed.), *The Book of the O’Conor Don; essays on an Irish manuscript* (DIAS 2010) 1-31.
‘The poetry of Tadhg Dall Ó hUiginn: themes and sources’, in Pádraigín Riggs (ed.), *Tadhg Dall Ó hUiginn*: *his historical and literary context* (London 2010) 55-87.
‘An elegy for Seaán Óg Ó Dochartaigh’, Celtica 26 (2010) 89-110.
‘Tuileagna Ó Maoil Chonaire and the Book of Pottlerath’, *Ossory, Laois and Leinster* 4 (2010) 244-8.

Alexandre Guilarte contributed entries on Celtic Studies publications to the *Brepols International Medieval Bibliography.*

Nora White:
(with Fergus Kelly) ‘The Ogham in 3D pilot project: a report on work in progress’, *Celtica* 26 (2010), 200-04.
Review of *Logainmneacha na hÉireann II: Cill i logainmnecha Co. Thiobraid Árann* (Ó Cearbhaill), *Éigse* 37 (2010) 202-05.

Freya Verstraten Veach:
‘The Ó Fearghail lordship of Anghaile’ in *Longford History and Society*, ed. Fergus O’Ferrall and Martin Morris (Dublin 2010) 51-74;
‘De Ierse ridders’ Kelten. *Mededelingen van de Stichting A.G. van Hamel voor Keltische Studies* 47 (2010) 8-11.

Eoin O’Flynn:
‘The career of Máelsechnaill II’, *Ríocht na Midhe* 20 (2009) 29-68.

1.9 Leabharlann/Library

Current and retrospective cataloguing continued. Acquisitions were in subject areas relevant to the research needs of the School. Regular updates on recent accessions and current periodicals (both print and online) were issued. Links to online journals were added to the library catalogue. Research and bibliographical queries from members of the School were dealt with. Inter library loans were ordered, consulted and returned to the lending institution. The map collection was re-housed and re-classified. The library committee advised on library policies, promotion of the library and development and implementation of strategic changes. The library welcomed a group of 30 students from the University of Bonn, Germany during Library Ireland Week (8-13 March). The library became a participating member of ALCID (Academic libraries cooperating in Dublin).

1.10 Imeachtaí/Events

Léacht Reachtúil / Statutory Public Lecture
This year’s Statutory Public Lecture was given by Professor Damian McManus of Trinity College Dublin. Title: ‘The Bardic Poetry database: opportunities and challenges for future scholarship.’ The lecture was delivered at UCD, Belfield, on Friday, 19 November, before an audience of approximately 160 people as part of the annual Tionól of the School of Celtic Studies.

Seiminéir / Seminars
Liam Breatnach conducted a seminar on Early Irish Law and a seminar on Old and Middle Irish verse and prose texts.

Tionól 2010
The School's annual Tionól took place on 19 and 20 November 2010, organised by Clodagh Downey assisted by Roisin McLaughlin, Alexandre Guilarte, and the School Administrator Eibhlín Nic Dhonncha. It attracted a very large attendance with numbers exceeding 100 on both days. Papers on various aspects of Celtic Studies were delivered by 20 speakers from the Netherlands, Sweden, Wales, England, and Ireland

The following is the list of speakers and papers:
Peadar Ó Muircheartaigh (University of Edinburgh): Splendid isolation versus informed appreciation: lessons from linguistics?
Gwen Awbery (Wales): Exploring dialect variation in the past: Welsh language wills.
Ailbhe Ní Chasaide (Trinity College, Dublin): Exploring Irish text-to-speech synthesis for educational purposes/Sintéis na Gaeilge agus áiseanna oideachasúla comhaimseartha.
A.J.Hughes (University of Ulster, Johnstown): Is the 2nd declension really as feminine as they say? That, and other morphological considerations for Modern Irish dictionaries.
Elizabeth Boyle (University of Cambridge): The Trinity and the intellect in a poem attributed to Gilla Pátraic, Bishop of Dublin.
Brent Miles (UCC): Vernacular revision of a Hiberno-Latin theory of kingship in the *Sermo ad Reges.*
Patrick Wadden (Oxford University): *Lex scripta* and *recht aicnid*: written law and national identity in early medieval Ireland.
Doireann Dennehy (NUI Galway): Legacies in stone at Clonmacnoise: the Meic Cuinn na mBocht gravestones.
Nora White (School of Celtic Studies): Ogham in 3D – Pilot Project
Grigory Bondarenko (University of Ulster, Coleraine): the *Dindshenchas* of Irarus
Kicki Ingridsdotter (University of Uppsala, Sweden): The *aideda* in *Táin Bó Cúailnge*
Peter McQuillan (University of Notre Dame): Loneliness versus delight in the eighteenth-century *Aisling*.
Niamh Ní Shiadhail (UCD): Daibhí de Barra and Thomas Ward's *History of the Reformation.*
Niamh Wycherley (UCD): The power of words: the vocabulary of relics in early Christian Ireland.
Cherie N. Peters (TCD): In search of a definition: an exploration into a selection of the terminology for 'famine' in the Irish annals from c.600-1333
Denis Casey (University of Cambridge, UK) *Cogadh Gáedhel re Gallaibh*: history written by the losers?
David Woods (UCC): Adomnán, Plague, and the Easter Controversy
Anthony Harvey (RIA): Lexical influences on the medieval Latin of the Celts.

1.11 Léachtaí (foireann agus scoláirí) / Lectures (staff and scholars)
Liam Breatnach:
'St Patrick's Oath' Seventh Australian Conference of Celtic Studies, University of Sydney (1 October);
'The Early Irish Law Text *Senchas Már* and the Question of its Date' Quiggin Memorial Lecture, University of Cambridge (2 December);
Revised version of lecture 'St Patrick's Oath' Tionól, School of Celtic Studies (19 November)

Pádraig A. Breatnach:
'Scribe and draughtsman in the Annals of the Four Masters' Societas Celtologica Nordica: Eleventh International Symposium, Uppsala University (15 May);

‘Rannaíocht Mhór: gnéithe de stair na haiste’ Research Institute for Irish and Celtic Studies, University of Ulster, Coleraine, (27 April);
‘Continuity and change:developments in the script and style of some early modern Irish autograph manuscripts’ XVIIe Colloque International de Paléographie Latine, Ljubljana (7 September)

Clodagh Downey:
‘Meath in the Dindshenchas’, Meath Landscape and People Seminar, Trim, Co. Meath (September);
‘Some observations on the transmission of the Dindshenchas’, Societas Celtologica Nordica, 11th International Symposium, University of Uppsala (May)

Fergus Kelly:
‘Irish farming before the Norman Invasion’ (New Ross Historical Society, (25 March);
‘The place of women in early Irish law, with special reference to the law of marriage’ Seventh Australian Conference of Celtic Studies, University of Sydney (September).

Malachy McKenna:
‘Is there vowel harmony in Irish and Scottish Gaelic?’ Seventh Australian Conference of Celtic Studies, University of Sydney (October)

Pádraig Ó Macháin: ‘The Irish sermons of Fr Patrick Wall (1778-1834)’, Dungarvan, (February);
‘The digitization of Irish manuscripts’, Univesity of Fribourg (June);
‘Lios Mór Mochuda anallód’, Daonscoil na Mumhan, Rinn Ó gCuanach (August);
‘Donnchadh Ruadh Mac Conmara: texts and manuscripts’, Rossmire, Co. Waterford, (November).

Michelle O Riordan:
‘Idirghabháil an eagarthóra’ UCC (September); ‘Go mbeidh Éire ag Cáit Ní Dhuibhir’ (UCD) (October)

Roisin McLaughlin:
‘Early Irish Satire’, University of Uppsala, Sweden (March);
‘Gnéithe den aoir sa tseanré in Éirinn’ Éigse Cholm Cille, Doire.

Anna Matheson:
‘Mad Mór of Munster and the 8th-10th Century context of Munster Kingship’ University of Bangor (17 March).

Eoin O’Flynn:
‘The “Disturbances” at Óenach Tailten’, James Lydon Research Seminar in Medieval History, TCD (November)

Nora White:
‘Report on Ogham in 3D pilot project’. British Epigraphy Society Lecture (April); ‘Ogham in 3D pilot – project’, Department of Early Irish, UCC (December).

1.12 Scoil Shamhraidh / Summer School 2011
Liam Breatnach chaired the organising committee of the International Summer School in Mediaeval and Modern Irish Language and Literature to be held at the School of Celtic Studies 18-29 July 2011.

1.13 An Chomhdháil Cheilteach / International Congress of Celtic Studies 2011
Liam Breatnach continued as Local President of the Organising Committee of the XIV to be held in

Maynooth, 1-5 August 2011.

1.14 Turais staidéir / Study visits
P. A. Breatnach visited the Bibliothèque royale de Belgique, Brussels, in March in connection with the Catalogue of Irish manuscripts in Brussels.

1.15 Cúrsaí in ollscoileanna Éireannacha / Courses in Irish universities
Michelle O Riordan: 'Irish Literature Module (1st Year Bachelor in Arts and Theology, Mater Dei Institute of Education, Dublin City University (September to April)
Nora White: Early Irish literature course, Department of Adult and Community Education, NUI Maynooth (September–December);

1.16 Scrúdaitheoireacht Sheachtrach, etc./External Examining etc.
Liam Breatnach: external examiner for Early and Medieval Irish, National University of Ireland, Maynooth.
Fergus Kelly: external examiner, Department of Early and Medieval Irish, University College, Cork (2009-'10). External examiner for two M.A. Thesis (Department of Early and Medieval Irish, University College Cork).
Malachy McKenna: examiner for Ph.D. thesis 'the Gaelic of Jura', by George Jones, University of Aberystwyth.
Michelle O Riordan: external examiner for first year BARSI students in DCU (Mater Dei Institute).
Pádraig Ó Machain: external examiner for PhD thesis (University College Cork)

1.17 Na Meáin Chumarsáide agus Aithne Phoiblí / Media and Public Awareness

Suíomh lín / Website of the School of Celtic Studies
New content was added to the School of Celtic Studies website (www.celt.dias.ie) on a continuing basis under the direction of Pádraig Ó Macháin and Andrew McCarthy. Queries from outside scholars, students and the general public were dealt with.

Telefís agus Raidió / Television and Radio
Pádraig Ó Macháin: several interviews on Raidió na Gaeltachta, KCLR (Kilkenny), WLR (Waterford), and TG4.

1.18 Coistí náisiúnta agus idirnáisiúnta /National and international committees
Pádraig A. Breatnach: Member of Comité international de paléographie latine (CIPL); Council member, Royal Irish Academy (2009-10). Ball, Coiste Léann na Gaeilge (Acadamh Ríoga na hÉireann).
Clodagh Downey: Member of Peer Review panel of the journal *Keltische Forschungen*.
Fergus Kelly: Advisory panel member, eDIL (Supplement to the *Dictionary of the Irish Language*) (University of Ulster, Belfast, June); Royal Irish Academy, Dublin (12 November).
Margaret Kelly continued as Secretary of the Academic and Special Libraries section of the Library Association of Ireland.

1.17 Cuairteoirí agus Comhaltaí/Visitors and Associates
Ollúna cuarta / Visiting Professors
Professor James McCloskey, (University of California, USA)
Professor Neil McLeod (Murdoch University, Western Australia)
Professor Markku Filppula (University of Eastern Finland, Finland)
Professor Tomás Ó Cathasaigh (Harvard University, USA)
Professor Pádraig P. Ó Néill (The University of North Carolina at Chapel Hill, USA)
Professor Melita Cataldi (University of Turin, Italy)

Professor Nancy Stenson (University of Minnesota, USA)
Professor Jan Erik Rekdal, (University of Oslo, Norway)

Research associates (until December)
Dr Gwenllian Awbery, University of Wales, Cardiff (1990)
Dr John Carey, National University of Ireland, Cork (1990)
Professor Thomas Charles-Edwards, University of Oxford (1990)
Professor Toshio Doi, Nagoya Women's University, Japan (1991)
Professor David N. Dumville, University of Aberdeen (1989)
Professor D. Ellis Evans, University of Oxford (1990)
Professor William Gillies, University of Edinburgh (1989)
Professor Geraint Gruffydd, Centre for Advanced Welsh and Celtic Studies, Aberystwyth (1989)
Professor Eric P. Hamp, University of Chicago (1989)
Dr Anthony Harvey, Royal Irish Academy (2004)
Professor Donald MacAulay, University of Glasgow (1989)
Professor James McCloskey, University of California, Santa Cruz (2004)
Dr Martin McNamara, MSC, Milltown Institute of Theology and Philosophy (1989)
Professor Toshitsugu Matsuoka, Hosei University, Tokyo (1991)
An tOllamh Donnchadh Ó Corráin, Coláiste na hOllscoile, Corcaigh (1991)
An tOllamh Ruairí Ó hUiginn, Ollscoil na hÉireann, Má Nuad (1999)
Dr Tom O'Loughlin, University of Wales, Lampeter (2003)
Professor Pádraig Ó Néill, The University of North Carolina at Chapel Hill (1990)
Dr Morfydd Owen, Bryn Eithin, Aberystwyth (2003)
Dr Brynley F. Roberts, National Library of Wales, Aberystwyth (1990)
Professor R. Mark Scowcroft, Catholic University of America (1990)
Professor Richard Sharpe, University of Oxford (1988)
Professor Calvert Watkins, Harvard University (1990)

Scoláirí cuarta / Visiting Scholars
Overseas scholars (apart from those listed above under Visiting Professors) who availed of library and research facilities are included in the following list. In addition to these, the School accords library and research facilities to Irish-based scholars when it holds materials which are lacking in the scholars' own institutions and in the major libraries in Dublin.

Jacqueline Borsje (University of Amsterdam, The Netherlands)
Aidan Breen (University of Massachusetts, Boston, USA)
Margo Griffin-Wilson (Harvard University, USA)
Roy Flechner, (Trinity College Cambridge, England)
Juhani Klemola, (University of Tampere, Finland)
William Mahon, (Aberystwyth University, Wales)
Tatyana Mikhailova, (Moscow State University, Russia)
Gordon Ó Riain (Uppsala University, Sweden)
Elizabeth Doyle (University of Cambridge, England)
Patrick Wadden (University of Oxford)
Denis Casey (University of Cambridge, England)
Ranke de Vries (University of Utrecht, The Netherlands)

ANNUAL REPORT 2010

1 Report on Research Work

1.1 Work by Senior Professors and Collaborators

1.1.1 Boundary States in Two-Dimensional Materials

(W. Nahm and M. Leitner)

Dr. Nahm's work with M. Leitner was completed and published.

1.1.2 Partition Functions amd Modular Forms

(W. Nahm & S. Keegan)

A conjecture made by Nahm has become a focus of research of several mathematicians. Its physical motivation lay in two-dimensional quantum field theories, but recent work by Cecotti, Neitzke, and Vafa indicates strong connections to M-theory and four-dimensional gauge theories. Some of the new results by Keegan and Nahm were stimulated by discussions with mathematicians in Bonn and at UCD. The conjecture concerns the modularity of functions of the form

$$f_{ABC} = \sum_{n \in N^r} \frac{q^{Q(n)}}{(q)_{n_1} \cdots (q)_{n_r}}$$

with

$$Q(n) = n^t An/2 + Bn + C$$

, where A is a symmetric $r \times r$-matrix, B an r-vector and C a scalar, all with rational components. In its original form the conjecture stated that for given A modular functions of this form exist if and only if the algebraic equation $A\log(x) = \log(1-x)$ yields torsion elements in the algebraic K-theory group K_3^{ind}. After much numerical testing the if-direction of the conjecture still holds, but the mathematians M. Vlasenko (Max-Planck Institute Bonn) and S. Zwegers (UCD) have found examples of modular f_{ABC} for which only some but not all solutions of the algebraic equation are torsion elements. These examples are few and far between and no understanding has been gained so far. Progress is slowed down by the lack of understanding of the possible values for B, C. Keegan and Nahm have now determined these values for several infinite families of matrices A, using the methods of conformal quantum field theory. This yields a well-defined pattern, which should allow an understanding of at least

those cases where A is given by Cartan matrices.

Analysis of the simplest case $r = 1$, $A = 1$ led to a new identity for sums over lattice paths. In March this identity was intensively discussed during a workshop at the American Institute of Mathematics, but not proven at the time. In August Nahm found a proof during a workshop in Oberwolfach.

1.1.3 Vanishing Theorems

(W. Nahm & F. Laytimi)

During a visit to Lille University, work on vanishing theorems was pursued with F. Laytimi. The aim was to derive the expected optimal theorems for the vanishing of the cohomology groups for ample bundles of typs $\Gamma^\alpha E \otimes \Gamma^\beta F$, but our methods gave optimal results only for $\alpha = 0$ and $\alpha = 1$, not for larger α. Though our new results constitute significant progress, we will have to change our methods to go further.

1.1.4 Chronology

(W. Nahm)

The very slow progress of the climate negotiations makes considerable global warming inevitable. We will have to adapt to a different environment. To be prepared one has to know about probable changes in crop yields, disease patterns, etc. This cannot be done by theoretical prediction alone. One also has to examine the impacts of major historical changes of climate caused by nature itself. The documented history of the world contains few examples of such major changes, such that an extension of the data-base is of great importance. Three important examples concern the Ancient Orient, namely the collapse of empires before the year 2000 BC, the decline of cities in the dark age after the fall of Babylon and the large-scale migrations around 1200 BC. We should learn from these events, but the study of correlations between climate and society is very difficult due to a lack of precise dates. Before 1000 BC there are large uncertainties in the placement of historical events, amounting to more than 100 years for the conquest of Babylon by the Hittites, e.g. Precise dates will be available, once the Assyrian list of eponyms is reconstructed. This list allowed to identify each of about 1300 years by the name of a particular magistrate, in the way of the Roman consular lists. From 910 BC on it is well-known, but for the preceding 1000 years only fragments survive. Recent finds have recovered more than the first 200 names, but the chronological uncertainties make it difficult to place them in our calendar. Nahm now recognised that fragments of the list published in 1920 belonged to a document which enumerated 1320 eponyms starting with the first one. This number was written in the summary phrase at the end of the cuneiform text. Its significance was missed due to the damage to the document and the non-existence of a sign for zero in Assyrian mathematics, which implies that a single stroke can mean 1, 60, 3600 etc. The research was made more difficult by the somewhat inadequate publication of the text and problems in the correct placement of the fragments with respect to each other. This was clarified by the curator of the Vorderasiatische Museum in Berlin, where the surviving fragments are located.

Some further checks would be helpful. Most probably they will be made soon, since several of the world's leading Assyriologists have become interested. The first Assyrian eponym is now placed at 1960 or 1959 BC. Errors in the transmission of the list are of course possible, but the date agrees well with the solar eclipse in the eponymy of Puzur-Ishtar, which can now firmly be identified with the eclipse on 24 June 1833 BC.

1.1.5 Research Overview

(T.C. Dorlas)

This has been a poor year due to personal circumstances. However, two students, Ciara Morgan and Anne Guesquière, completed their Ph.D.s, and some work was continued in the following areas:

1.1.6 Quantum Entanglement

(T.C. Dorlas & A. Ghesquiére)

Together with Anne Guesquiére a study has been undertaken of the decay of entanglement of two particles, initially in a Gaussian entangled state, due to the interaction with a heat bath. T.C. Dorlas and A. Ghesquiére computed the so-called *logarithmic negativity* in two cases: two freely evolving particles, and two particles with harmonic interaction potential. They found that in the case of two freely evolving particles, the entanglement vanishes after a finite time, a phenomenon known as 'entanglement sudden death'. When a harmonic interaction is added to the Hamiltonian, the behaviour changes. Depending on the strength of the interaction, one can distinguish two regimes: underdamping and overdamping. In the latter, the entanglement again vanishes after a finite time, but in the underdamped regime, the entanglement can oscillate and eventually reach a stable nonzero value. This work has been submitted for publication: [STP-10-05].

1.1.7 Bethe Ansatz

(T.C. Dorlas & M. Samsonov)

Work on the thermodynamic limit of the six-vertex model with Dr. Samsonov has continued. T.C. Dorlas and M. Samsonov concentrated on the regime where the interaction parameter Δ takes values in the intervals $(-\infty, -1)$. Writing $\Delta = -\cosh(\lambda)$, the case of large λ had already been resolved but the interesting case where λ is small is still open. Numerically, it seems that also in this case, convergence should hold, though a modified iteration procedure is needed. They have made progress on proving the convergence, but the details are very technical and have yet to be worked out.

1.1.8 A model for an Exciton in a Carbon Nanotube with Impurity

(T.C. Dorlas & P. Duclos)

Progress was made with the mathematical analysis of a simple model of an exciton in a carbon nanotube in the presence of a charged impurity. The model consists of two dynamic particles on a line with opposite charges (the exciton) and an attractive delta-interaction, together with a delta potential which is attracting for one, and repulsive for the other particle. Due to

the competing interactions, the spectrum of this model is not easy to analyse. (In fact, this model is also relevant for another physical situation, namely the stability of the H^- ion.) Numerical approximation is inconclusive for small and large values of the exciton charges. However, in a collaboration with Pierre Duclos[†] (Marseille), T.C. Dorlas managed to show that there is in fact at least one bound state (discrete point in the spectrum) for arbitrarily small values of the charge. On the other hand, they found that for high values of the charge, no bound state exists. In 2010 this analysis was extended to various regimes in the parameter plane (θ, Z), where the masses of the exciton particles are different, the angle θ representing the ratio of the masses, and Z the impurity charge.

1.1.9 Research Overview

(Denjoe O'Connor)

We unfortunately find ourselves writing this research report at a very disheartening time. Especially, after what most would consider a successful year by the school of theoretical physics and its researchers: A year where, an external review committee of the highest international standards, assessed the activities of DIAS over the previous five year period very favourably: A year when this external review committee reiterated the recommendations of the previous committee for an expansion of the researcher base and resources available to the school. It is a time when those, like STP, who followed a prudent approach to the use of the resources available to it finds that it has its funding support virtually wiped out to pay for the profligate excesses of those who squandered and gambled resources they did not possess. The result was the elimination for 2010 of the STP visitor program.

The short term savings accruing from the elimination of the DIAS visitor program will of course have longer term costs that are difficult to quantify, costs which will accumulate with the passage of time. For example it will make DIAS a less attractive place for the best postdoctoral researchers who will no longer be able to count on excellent personal contact with the international research community, a contact that has a significant impact on their future careers. It will make it more difficult for us to justify that a small institution such as STP at DIAS has the all necessary resources to carry out externally funded research on a European or world scale, where granting agencies usually require the institution to state if it has all of the necessary resources for the successful completion of the proposed research. In the past DIAS could proudly point to its international visitor programme and the workshops that it supported.

Of course much of the above is for next years report, however it is wise to signal now the implications of current decisions, in the hope that corrective action will be carried out and resources reinstated next year rather than some years down the line, when significant damage has already been done.

1.1.10 Fuzzy Physics and Emergent Geometry

(Denjoe O'Connor)

In 2010 work continued on the extension and consolidation of some of the ideas involved in emergent geometry. Modest progress was made with the principal effort going into initiating two new students Thomas Kaltenbrunner and Martin Vachovski into their research topics.

This subject is closely related to noncommutative geometry and what is called "fuzzy field theory". Fuzzy field theories are field theories where the algebra of functions of a manifold is replaced by a suitable matrix algebra, with matrix dimension N, and the Laplace-Beltrami operator by a suitable double commutator Laplacian mapping matrices to matrices of the same dimension. The triple of Matrix algebra, norm $< F|F >= \frac{Tr}{N}(F^\dagger F)$ and Laplacian defines the geometry of the fuzzy space.

The "fuzzy approach" provides a regularization of field theory (and hopefully string theory) that is well adapted to the non-perturbative study both commutative and noncommutative field theories including those with chiral fermions. It is also well suited to the study of supersymmetric models as it is possible to truncate the theory to a finite number of degrees of freedom while retaining the exact supersymmetry. The ingredients are then a graded matrix algebra, where the matrix entries now contains both commuting and anti-commuting (or Grassmann) entries and the trace over matrices is replaced a supertrace.

At the level of the classical Euclidean action, the method naturally preserves most of the fundamental symmetries of the theory in question, though these can be broken spontaneously. In recent years a continually increasing number of fuzzy spaces has become available. These include all flag and superflag manifolds as well as a further large class of algebraic varieties.

The new twist is that, when the field theory is of Yang-Mills type, as the parameters of the model are changed the background geometry itself becomes dynamical. This is a phenomenon closely related to that which occurs in $4-d$ supersymmetric Yang-Mills theory, where at strong coupling the model is best described as a $10-d$ supergravity theory or the low energy limit of a superstring theory.

The principal effort of the year was to extend the earlier studies to models including Fermions and to higher dimensional models. The studies are ongoing and involve the use of both analytical and numerical techniques.

1.1.11 Two-Loop Crossover Scaling Functions of the $O(N)$ Model

(Denjoe O'Connor, J.A. Santiago, C.R. Stephens, A. Zamora)

Using Environmentally Friendly Renormalization, we present an analytic calculation of the series for the renormalization constants that describe the equation of state for the $O(N)$ model in the whole critical region. The solution of the beta-function equation, for the running coupling to order two loops, exhibits crossover between the strong coupling fixed point, associated with the Goldstone modes, and the Wilson-Fisher fixed point. The Wilson functions γ_λ, γ_ϕ and γ_{ϕ^2}, and thus the effective critical exponents associated with renormalization of the transverse vertex

functions, also exhibit non-trivial crossover between these fixed points.

1.1.12 The Zero Temperature Phase Diagram of the Kitaev Model

(C. Nash & Denjoe O'Connor)

The stability of massless phases in dimers (i.e. the existence of an "amoeba") is found to be due to the presence of $\mathbb{Z}_2$ charges associated with the zeros. In a Kitaev hexagonal model it is established that the C-phase emerges when these charges annihilate.

1.1.13 Yang-Mills Matrix Models

(Denjoe O'Connor & V. Filev)

It is argued that zero-dimensional Yang-Mills matrix models are well approximated by a joint eigenvalue distribution for the matrices which are at least approximately uniform within a solid sphere of radius $RN^{1/4}$ with R a number of order unity depending only on the number of matrices. The value of R is estimated in a two-loop computation.

1.2 Independent Work by Schrödinger Fellows

1.2.1 String Theory

(V. Braun)

V. Braun's main focus of research has been in the general area of string theory, and, in particular, the geometry and topology of string theory compactifications.

1.2.2 Type IIB Moduli Stabilization

(V. Braun, K. Bobkov, P. Kumar, & S. Raby)

Calabi-Yau compactifications generically predict a low-energy (4-dimensional) field theory with a number of massless scalar fields in addition to gauge and matter fields. These unwanted scalar (moduli) fields must receive a mass in order for the theory to be phenomenologically viable. One particular mechanism has been proposed by Kachru, Kallosh, Linde, and Trivedi (KKLT) and involves non-perturbative effects of D-branes. However, it was not well understood what is necessary to stabilize the compactification manifold at sufficiently large volumes / small curvature radii to trust the supergravity approximation.

Working jointly with K. Bobkov, P. Kumar, and S. Raby, V. Braun investigated the geometry of the Kähler moduli space and found a rather simple criterion for stabilizing all moduli at positive volume. For example, if the non-perturbative contribution to the superpotential comes from a single D7-brane then all moduli are stabilized at positive volume if and only if the D-brane wraps an ample divisor.

1.2.3 Numerical Hermitian Yang-Mills Connections

(V. Braun, B. Ovrut, & L. Anderson)

Part of the supersymmetry equations of string theory is that the gauge field needs to satisfy the Hermitian Yang-Mills equation. Working jointly with with B. Ovrut and L. Anderson, V. Braun numerically computed $SU(n)$ gauge connections on a vari-

ety of Calabi-Yau manifolds. The numerical results nicely illustrated the appearance of shrunk instantons for bundles that allow for a solution of the Hermitian Yang-Mills equations.

1.2.4 Non-Simply Connected Calabi-Yau Manifolds

(V. Braun)

During the course of the year, V. Braun finished the classification of free quotients of complete intersection Calabi-Yau threefolds in products of projective spaces (CICYs). The algorithm and results are described in arXiv:1003.3235. In particular, various new examples of groups that can appear as fundamental groups of Calabi-Yau manifolds were identified. Braun is currently investigating particle physics applications of corresponding discrete Wilson lines in heterotic string theory.

1.2.5 Discrete Wilson Lines in F-Theory

(V. Braun)

F-theory uses an auxiliary elliptically fibered Calabi-Yau fourfold to describe string theory in a particular regime with strong coupling. A non-Abelian gauge theory with chiral matter can arise from 7-branes on the singular locus of the base of the elliptic fibration. Currently, the challenge for F-theory compactifications is to break the GUT gauge group to the standard model. One particular mechanism is the discrete Wilson lines on a non-simply connected 7-brane. While this mechanism has appeared in the literature before, there were no concrete realizations of elliptically fibered Calabi-Yau fourfolds such that the singular locus is multiply connected. In arXiv:1010.2520, V. Braun explicitly constructed such an example using methods from toric geometry. One important tool in the construction was the toric geometry package for the Sage computer algebra system, which he mostly wrote over the course of the last year.

1.2.6 String and Gauge Theory

(S. Kovacs)

Dr. Kovacs' research focuses on the study of the interconnections between string and gauge theory. He has worked on various aspects of the so-called AdS/CFT correspondence relating string theory in certain curved backgrounds to (supersymmetric) gauge theories in flat space.

1.2.7 Light-cone Superspace and Dual Super-Conformal Invariance in $\mathcal{N}$=4 SYM

(S. Kovacs, S. Ananth, & S. Parikh)

The $\mathcal{N}$=4 supersymmetric Yang–Mills (SYM) theory has a number of interesting properties. It possesses the maximal amount of (rigid) supersymmetry and it is an example of interacting conformally invariant theory in four dimensions. It is believed to also be invariant under a strong-weak coupling duality known as S-duality. This theory has been extensively studied in the past few years in the framework of the AdS/CFT correspondence. This is a *holographic* duality relating string theory in a certain manifold, $\mathcal{M}$, to ordinary gauge

theories — $\mathcal{N} = 4$ SYM in the best understood case — defined on the boundary of $\mathcal{M}$. Among the numerous results emerged in this context, a particularly remarkable one is the discovery of an integrability structure underlying the spectrum of gauge invariant operators in the theory.

Another intriguing feature of the $\mathcal{N} = 4$ theory is what has been referred to as *dual super-conformal invariance*. It has recently been observed that 'scattering amplitudes' originally computed in momentum space display a new symmetry when expressed in terms of certain auxiliary 'position variables'. The amplitudes satisfy the constraints of a super-conformal symmetry in the auxiliary space parameterised by the new variables. This symmetry has so far only been studied in relation to scattering amplitudes, which are not proper physical observables in a conformal field theory. Moreover the new symmetry has not been explained from first principles and its origin remains rather obscure.

Dr. Kovacs, in collaboration with Dr. Sudarshan Ananth and Sarthak Parikh (of the Indian Institute of Science Education and Research, Pune, India), is working on this topic utilising the formalism of light-cone superspace, which originally allowed to prove the absence of ultra-violet divergences in the $\mathcal{N} = 4$ SYM theory to all orders in the perturbative expansion.

In a recently completed article Dr. Kovacs and collaborators have derived a new formulation of the $\mathcal{N} = 4$ theory in light-cone superspace. A new form of the $\mathcal{N} = 4$ Lagrangian has been obtained through a canonical field redefinition. This new Lagrangian displays manifestly the known symmetries of the $\mathcal{N} = 4$ SYM theory, while capturing in a more transparent way some of the remarkable features of scattering amplitudes. The formalism developed closely resembles the on-shell description used to analyse the dual superconformal invariance of scattering amplitudes. However, it is also suitable to compute off-shell observables such as correlation functions of gauge invariant operators.

This new formulation of $\mathcal{N} = 4$ SYM is used in a current research project which aims at clarifying what type of constraints the dual superconformal symmetry implies for correlation functions. It will then be interesting to understand how to use these constraints to simplify perturbative calculations. A further extension of the recently completed project will investigate the role of this new symmetry in connection with the integrability of the spectrum of the $\mathcal{N}$=4 SYM theory.

Dr. Kovacs is currently completing two other projects which are briefly described below.

1.2.8 Instantons and Holography

(S. Kovacs)

The AdS/CFT correspondence is a remarkable duality relating a string theory, *i.e.* a theory of quantum gravity, in a certain bulk space, $\mathcal{M}$, to an ordinary quantum field theory that lives on the boundary of this space. As such it is referred to as a 'holographic duality.' The correspondence provides a prescription for computing observables in the boundary theory in terms

of observables of the bulk theory and vice versa. One of the most interesting aspects of this duality is the fact that it relates the weak coupling limit of one theory to the strong coupling regime of the other theory.

The precise nature of the holographic relation between gauge theories and gravity theories has so far remained unclear. Specifically it is not understood how local properties in the bulk are encoded in the boundary theory. The study of instanton effects in the AdS/CFT correspondence provides a unique perspective into this issue. Instanton effects in the gauge theory are related to effects induced by so-called D-instantons in the dual string theory. A very precise relation between these two sources of non-perturbative effects has been established. The calculation of instanton contributions to correlation functions of gauge invariant operators allows to extract certain local properties of the bulk geometry and of the supergravity solution defining the dual background.

Dr. Kovacs is currently working on a research project which focusses on the application of these ideas to a class of deformations of the $\mathcal{N}$=4 SYM theory. Among these theories there are examples for which the gravitational dual is known as well as examples for which the dual geometry is unknown. One of the objectives of this work is to explicitly construct, through the analysis of instanton induced correlators in the gauge theory, the complete supergravity solution describing a dual background which has not been obtained using different arguments. Possible extensions of this project include the application of these ideas to gauge theories at finite temperature which the AdS/CFT dictionary relates to black hole geometries.

1.2.9 M2-branes in Light-cone Superspace

(S. Kovacs, S. Ananth, & H. Shimada)

Different types of extended objects, referred to as *branes*, play an essential role in the dynamics of both string theory and its non-perturbative completion, M-theory. In particular, M2-branes, which extend in two spatial dimensions, are believed to describe the elementary excitations in M-theory. In recent years there has been important progress in the understanding of the low-energy dynamics of a collection of M2-branes. A number of interesting three-dimensional gauge theories have been proposed over the past few years to describe this system. Among these, a novel type of model, in which the fields are valued in a three-Lie algebra, was put forward by J. Bagger and N. Lambert.

Dr. Kovacs, in collaboration with Dr. Sudarshan Ananth and Dr. Hidehiko Shimada (of the Niels Bohr Academy, Copenhagen, Denmark), is studying the model proposed by Bagger and Lambert using the formalism of light-cone superspace. This formalism appears to be especially suited to the analysis of quantum corrections to various quantities. The objective of the present project is to provide a proof of the absence of ultraviolet divergences in the Bagger–Lambert theory to all orders in the perturbative expansion. This analysis will subsequently be generalised to a class of deformations of the original theory.

1.2.10 Quantum Ising Model in a Transverse Magnetic Field

(I. Lyberg with T.C. Dorlas & Y. Suhov)

Together with T.C. Dorlas and Yuri Suhov, Dr. Lyberg has been working on the topic of a quantum Ising model in a transverse magnetic field. They have so far considered a one dimensional spin chain in a transverse magnetic field; that is a system with Hamiltonian

$$\mathcal{H}_N = -J\sum_{n=1}^{N}\sigma_n^x\sigma_{n+1}^x + B\sum_{n=1}^{N}\sigma_n^z$$

where σ^x and σ^z are the usual Pauli spin matrices, and where J and B are (positive) parameters. The partition function is then

$$Z_N = \text{tr } \exp -\beta\mathcal{H}_N$$

The one dimensional Ising model in a transverse magnetic field is a model that can be solved exactly. The Hamiltonian may be diagonalised and the energy eigenstates found by the introduction of the fermionic operators used by Jordan and Wigner and by methods first used by Bogoliubov. The model has a second order phase transition (in the thermodynamic limit $N \to \infty$) when the parameter β approaches infinity. In this limit the correlation function $\langle\sigma_i^x\sigma_j^x\rangle$ in the limit of infinite separation can be found to be

$$\lim_{|i-j|\to\infty}\langle\sigma_i^x\sigma_j^x\rangle = \begin{cases} [1-(B/J)^2]^{1/4} & (0 \le B < J), \\ 0 & (0 \le J \le B). \end{cases}$$

Various authors, such as Grimmett, Osborne and Scudo (arXiv:0704.2981v1), among others, have developed the "space-time Ising model". The interval $[0, \beta]$ is divided into M intervals, and by the Lie-Trotter formula

$$\exp -\beta(-J\sigma_n^x\sigma_{n+1}^x + B\sigma_m^z) = \lim_{M\to\infty} (\exp{(\beta/M)}J\sigma_n^x\sigma_{n+1}^x \exp -(\beta/M)B\sigma_m^z)^M$$

for all n and m. In this way the quantum spin chain can be understood as a two dimensional classical Ising model on the set $\{1, 2, ..., N\} \times [0, \beta]$.

Dr. Lyberg would next like to consider an analogy of the spherical model corresponding to the quantum Ising model. The spherical model is like the classical Ising model with the difference that a spin need not have magnitude 1; only the average of the square of all spins is 1. This has never been studied before and seems very interesting, since this would be a non-commutative analogy of the spherical model. Following this, Lyberg would like to consider the quantum Ising model on a Cayley tree.

Dr. Lyberg is also interested in exploring the relationship between the quantum Ising model and the random cluster model. Smirnov (arXiv:0708.0039v1) investigated the relationship between the classical Ising model and the random cluster model and the stochastic Löwner equation, but so far not so much has been done on the quantum Ising model in this sense.

1.3 Independent Work by IRCSET Fellows

1.3.1 Shuffle Operads and their Applications

(V. Dotsenko & A. Khoroshkin)

To deal with operations possessing symmetries, the notion of an operad is traditionally used. However, for purposes of linear and homological algebra, the fact that operads possess symmetries makes the actual computations really difficult at times. Together with Dr. Anton Khoroshkin (ETH Zürich), in late 2008 and 2009, V. Dotsenko introduced a new notion of a shuffle operad, and developed several effective approaches to shuffle operads. During 2010, two new papers that explore the applications of shuffle operads have been written: one on applications to homological algebra and free resolutions, and another on applications to combinatorics of consecutive pattern avoidance.

1.3.2 Yang-Mills Theory

(V. Filev)

V. Filev's research has been in the area of theoretical high energy physics; and, more specifically, in string theory and the application of the AdS/CFT correspondence to the study of strongly coupled non-abelian gauge theories. He is also interested in Bosonic Matrix Models and in particular various concepts of emergent geometries associated to their ground states.

During the past year, Filev has been following two different lines of research. The first was to study the commuting phase of a bosonic three matrix model via appropriate perturbative field theoretical techniques. The second line was dedicated to the study of strongly coupled flavoured gauge theories holographically dual to the D3/D7 and D3/D5 -brane intersections.

1.4 Independent Work by Research Scholars and Students

1.4.1 Feynman Integral

(M. Beau & T.C. Dorlas)

At the end of the previous century, many new discoveries in quantum physics brought new theoretical problems concerning the quantum gases due to the observation of Bose-Einstein condensates of cold atoms and quantum intrication observations due to Alain Aspect experiments. These fundamental aspects of the quantum world-have brought new technological challenges for the twenty-first century. Theoretical physicists must develop new mathematical techniques to clarify some conceptual problems of quantum mechanics and to solve new theoretical problems.

Working with T.C. Dorlas, M. Beau's research focuses on the Feynman formulation of quantum mechanics via the concept of path integral. The problem is that the Feynman integral, allowing the computation of the propagator of the Schrödinger equation, is not well defined. Thus, they are working on developing a rigorous mathematical formulation of the Feynman integration, and are also interested in looking at a similar integration formulation in sta-

tistical physics called the Feynman-Kac integral. They are researching the possibility of a rigorous derivation of a non-linear equation describing the spatial distribution of the condensates for interacting Bose gas.

1.4.2 Bose-Einstein Condensation, & Molecules in High Magnetic Field

(M. Beau with V. Zagrebnov, R. Benguria, R. Brummelhuis)

M. Beau is also continuing research on other subjects studied in his thesis, such as the generalised Bose-Einstein condensation (concept of M. van den Berg, J. Lewis and J. Pule) and its analogies with polymers (with Valentin Zagrebnov). With R. Benguria, R. Brummelhuis and previously with P. Duclos, he is researching the existence of molecules in high magnetic fields. Last year, he studied the modelisation of a system for the future experience GRANIT on the observation of radiative transitions between quantum states of neutrons in gravitational field with V. Nesvizhevsky at ILL.

1.4.3 Skyrme-Faddeev Model

(D. Foster)

D. Foster has been researching the Skyrme-Faddeev model. He has included a mass-term, which was found to make the solitons increasingly localised, and has placed them onto $S^1 \times \mathbb{R}^2$. Research is still on-going, and he aims to find a stronger correspondence to the new synthetic Hopfion ansatz. He is also in the process of placing Hopfions onto a curved background. This research is very interesting because of potential beyond Derricks theorem consequences. Dr. Foster is also interested in a new $\mathbb{R}^4 \to \mathbb{CP}^2$ nonlinear theorem, a very numerically computationally intensive theorem and he has been able to write down a Chern-Simons term. Hence the map is non-trivial.

1.4.4 Quantum Entanglement

(A. Ghesquiére)

Working with Dr. T.C. Dorlas, A. Ghesquiére examined the loss of entanglement in a two-particle Gaussian system by coupling it to an environment and using the Non-Rotating Wave master equation to study the system's dynamics. A derivation of this equation was also presented.

Two different types of evolution were considered. Under free evolution, entanglement is lost quickly between the particles. When a harmonic potential is added between the particles, two very different behaviours can be observed, namely in the over and under-damped cases respectively, where the strength of the damping is determined by how large the coupling to the bath is with respect to the frequency of the potential.

In the over-damped case, Ghesquiére found that the entanglement vanishes at even shorter times than it does in the free evolution. In the (very) under-damped case, she observed that the entanglement does not vanish. Instead it oscillates towards a stable value.

1.4.5 Study on Matrix Models

(T. Kaltenbrunner)

T. Kaltenbrunner has been using Monte Carlo simulations to gain a better understanding of phase transitions in Matrix Models where a geometry emerges out of a random phase. Studies have already been carried out by O'Connor et. al. for example, on a 3-Matrix-Model. Kaltenbrunner has been trying to improve the understanding of this model and to extend this approach to more complicated models with different symmetries.

1.4.6 Coset Models and Nahm's Conjecture

(S. Keegan)

An interesting open problem in mathematics is the question of when a q-hypergeometric series is modular. A conjecture due to Werner Nahm takes a first step towards tackling this problem, by considering a certain type of r-fold q-hypergeometric series. The conjecture is stated as follows.

[Nahm's Conjecture] Let $A = (A_{ij})$ by a positive definite, symmetric, $r \times r$ matrix with rational entries. Let $B \in \mathbb{Q}^r$ be a vector of length r and C be a rational number. Define an r-fold q-hypergeometric series $f_{A,B,C}$ by

$$f_{A,B,C}(\tau) = \sum_{n=(n_1,\ldots,n_r)\in\left(\mathbb{Z}_{\geq 0}\right)^r} \frac{q^{\frac{1}{2}n^tAn+B^tn+C}}{(q)_{n_1}\ldots(q)_{n_r}},$$

where $\tau \in \mathfrak{h}$, $q = e^{2\pi\imath\tau}$, and

$$(q)_n = \prod_{j=1}^{n}\left(1-q^j\right).$$

For $i = 1, \ldots, r$ we can consider the system of equations

$$x_i = \prod_{j=1}^{r}(1-x_j)^{A_{ij}}.$$

Given any solution $x = (x_1, \ldots, x_r)$ of (**??**), consider the element $\xi_x = [x_1] + \ldots + [x_r] \in \mathbb{Z}(F)$, where $F = \mathbb{Q}(x_1, \ldots, x_r)$. Then there exist $B \in \mathbb{Q}^r$ and $C \in \mathbb{Q}$ such that $f_{A,B,C}(\tau)$ is a modular function if and only if ξ_x is a torsion element of the Bloch group $\mathcal{B}(F)$ for all solutions $x = (x_1, \ldots, x_r)$ of (**??**).

Nahm's conjecture has been checked completely, and found to be correct, for the case when $r = 1$. For $r = 2$ and $r = 3$ extensive computer searches have been carried out, both by Michael Terhoeven and Don Zagier, to check whether the torsion condition is correct. Terhoeven has recently carried out a number of searches for larger values of r. Since this conjecture has been studied relatively little, it may turn out that as more research is done the statement needs to be modified slightly (see for example the work of Masha Vlasenko).

One aspect of Nahm's conjecture that is not well-understood is that of the B-values. Suppose A is a matrix for which there exist values of B and C such that $f_{A,B,C}$ is modular. Is there a way to compute appropriate values of B? Currently this is done by searching through long lists of B-values and checking whether they lead to modular $f_{A,B,C}$. Needless to say this can be a slow and tedious process. It would be very useful to have an algorithm that can compute B given A, and the aim of my work over the past few months has been to find

such an algorithm for a certain special case.

Since Nahm's conjecture originates in physics (with the functions $f_{A,B,C}$ being related to characters of rational conformal field theories), we approach the problem of B-values from the point of view of conformal field theory (CFT). A study of coset models of the form $\frac{\hat{su}(2)_k}{\hat{u}(1)}$ sheds new light on the functions $f_{A,B,C}$, in particular on the choice of B-values. For this coset we have found an algorithm that computes B given A.

Over the next few months we hope to extend these results to other cosets in the hope of gaining a better understanding of how the B-values work in general.

1.4.7 Information-Carrying Capacity of Quantum Channels

(C. Morgan & T.C. Dorlas)

Recent work carried out by C. Morgan, together with T.C. Dorlas, involves the strong converse to the channel coding theorem for a particular quantum channel with memory, namely a periodic quantum channel. The result appears in Morgan's thesis (arXiv:1007.2723).

The channel coding theorem is comprised of two parts, namely the direct part of the theorem, which refers to the construction of the code, and the converse to the theorem. The capacity of a quantum channel Φ provides a limit on the amount of information which can be transmitted reliably per channel use. The direct part of the quantum channel coding theorem states that using n copies of the channel, we can code with exponentially small probability of error at a rate $R = \frac{1}{n}\log|\mathcal{M}|$ if and only if $R \leq C$, in the asymptotic limit, where $\mathcal{M}$ denotes the set of possible codewords to be transmitted. If the rate at which classical information is transmitted over a quantum channel exceeds the capacity of the channel, i.e. if $R > C$, then the probability of decoding the information correctly goes to zero in the number of channel uses. The last statement is known as the strong converse to the channel coding theorem.

The strong converse to the channel coding theorem of a, so-called, classical quantum channel was proved independently by Winter (*IEEE Trans. Info. Theory*, 1999) and by Ogawa and Nagaoka (*IEEE Trans. Info. Theory*, 1999) using different methods. Following the method used by Winter, namely, the method of types which was also used by Wolfowitz (1964), Dorlas and Morgan proved the strong converse for *classical* channels.

They showed that the strong converse does not hold for a periodic quantum channel. This conclusion is drawn based on another result shown in Morgan's thesis, namely that due to the fact that the average and the supremum cannot be interchanged in the formula for calculating the product state capacity of the periodic channel with the amplitude damping channel branches, this formula cannot be re-written in a way which would lead to a direct application of the strong converse theorem.

1.4.8 Topological Phases of Matter

(O. Smits)

Research focuses on topological phases of matter, which constitutes an area of research within condensed matter physics. Topological systems are low-dimensional (2+1) condensed matter systems effectively described by a topological quantum field theory. Such systems are said to be topologically ordered. A novel property of these systems is the presence of (non-)Abelian anyons – quasiparticles which obey a generalized form of exchange statistics compared. Realisations of topologically ordered systems are found in strongly correlated and strongly interacting systems. We currently lack an understanding of the fundamental nature of topological order.

The most renown experimentally realisable system that exhibits topological order is the fractional quantum Hall effect. This effect arises at the interface of nanomaterials, such as certain Gallium arsenide compounds. The electrons are confined to a two dimensional surface and in the presence of a strong magnetic field a topological liquid is formed. The topological order manifests itself through the presence fractionally charged quasiparticles. However, due to way these compounds are created they are notoriously hard to probe making the nature of the topological order difficult to study experimentally. Currently, the best way to study these systems is by looking at the transport properties of the system.

O. Smits research is aimed at understanding the quantum transport properties of these systems from a theoretical perspective. In the FQHE the bulk of the system forms a mobility gap which is accompanied by the formation of gapless states at the edge, an example of a holographic principle. All transport properties are completely determined by what's happening at the edge. From a theoretical viewpoint we think of this edge as one-dimensional strongly correlated system. The most famous example of such a system is the chiral Luttinger liquid, while the more general case corresponds to Kac-Moody current algebras.

Two research projects are described below. All research is done in collaboration with and under supervision of Dr. J. Slingerland, from NUI, Maynooth. Part of this research is done in collaboration with Prof. Steve Simon, from Rudolf Peierls Centre for Theoretical Physics, University of Oxford.

1.4.9 Interferometry in the (Non-Abelian) Fractional Quantum Hall effect

(O. Smits in collaboration with J. Slingerland & S. Simon)

A quantum Hall bar is a typical theoretical setup used for modelling experiments. We can think of it as an infinite strip with two edges. The topological liquid is bound to the strip and along the edges gapless states are responsible for the current. No current can flow from one edge to the other due to gap inside the bulk. A constriction is placed at some point along the bar, which brings the edges together. This narrowing allows for tunneling of quasiparticles through the bulk from one edge to the other. The resulting current is a function of the voltage bias between the edges, the temperature scale and, most importantly, the type of quasiparticles that dominate the tunneling. Specifically, the tunneling

current-voltage relation is highly non-linear due to the strongly correlated nature of the system.

We have studied a system which contains N tunneling junctions and solved for the expression of the tunneling current at first order in perturbation theory. Such a system is interesting as quasiparticles tunneling at different point contacts give rise to interference effects. We find that the current is given in terms of the Lauricella hypergeometric function. The novelty of our approach is that our solution is exact and very general, and applies to all types of FQHE edges at finite temperatures. Results are heading towards publication.

1.4.10 Noise in tunneling junctions in the Fractional Quantum Hall effect

(O. Smits in collaboration with J. Slingerland & S. Simon)

A second project aims at an understanding of the noise in tunneling experiments in the quantum Hall effect. The tunneling current arises due to quasiparticles stochastically tunneling from one edge to the other. Due to the stochastic nature, the current fluctuates around its average and it's these fluctuations which are referred to as noise. The Fourier spectrum of these fluctuations are intimately related with the types of quasiparticles which are responsible for the tunneling current. We are currently investigating how one can extract properties of the quasiparticles, such as their spin and charge, from the power spectrum of the noise.

1.4.11 Matrix Models

(M. Vachovski)

M. Vachovski has been working on the Three-Matrix model, as studied by Dr. Denjoe O'Connor and described in his paper arXiv:0806.0558v4. He has also been studying the behaviour of various quantities such as energy, matrix eigenvalues spectrum, specific heat, etc. near the phase-transition point.

1.5 Work by Research Associates

1.5.1 The Quantum Hall Effect

(B. Dolan & Cliff Burgess)

Ongoing collaboration with Cliff Burgess of the Perimeter Institute, Waterloo, Canada and McMaster University, Hamilton, Ontario, Canada on duality and the modular group in the quantum Hall effect. B. Dolan and C. Burgess are currently investigating the use of AdS/CFT correspondence techniques in condensed matter systems to describe modular symmetries in the quantum Hall effect and other strongly correlated electron systems.

1.5.2 Non-commutative geometry

(B. Dolan, A. Balachandran, C Nash, D. O'Connor, P. Presnajder, A. Stern, K. Gupta, & R. Szabo)

Ongoing programme to develop closed matrix algebras approximating compact manifolds, one aim of which is numerical computation. Research includes a col-

laboration with Richard Szabo of Heriot-Watt University on equivariant dimensional reduction, using fuzzy spaces as internal spaces.

1.5.3 General relativity

(B. Dolan)

Two investigations in general relativity: enthalpy and pressure in black hole thermodynamics and torsion with chiral fermions in the Einstein-Cartan formulation.

1.5.4 Monopoles, dyons and new Chern-Simons solitons

(D.H. Tchrakian)

This research is a review containing a substantial original component. It collects work in the construction of monopoles (and vortices) in all dimensions. New Julia-Zee type dyon like solutions in higher dimensions are also proposed. A new type of Chern–Simons densities is defined via dimensionally reduced Chern–Pontryagin densities. These occur in both odd AND even dimensional spacetimes. The numerical constructions remain to be done.

1.5.5 Gravitating non-Abelian Chern–Simons solutions

(D.H. Tchrakian)

This is ongoing work for the last 5 years. It was first applied to problems in AdS/CFT, in the context of both spherical and planar geometry. A particular result sought is that of thermodynamic stability of the non-Abelian black holes against the Reissner-Nordström black holes.

At present, it is being applied to asymptoticall flat problems (zero comological constant), in $2+1$, $4+1$ and $6+1$ dimensional bulk. The result of thermodynamic stability of the non-Abelian black holes against the Reissner-Nordström black holes when negative comological constant is present, was discovered here too.

1.5.6 Gravitating non-Abelian higher order Yang-Mills curvature solutions

(D.H. Tchrakian)

This is also ongoing work. At present, it is being applied to problems in AdS/CFT, in $2+1$, $4+1$ and $6+1$ dimensional bulk. It appears that the results arrived at in the above two projects, replicate to a large extent when the Chern–Simons densities are replaced by higher order Yang-Mills curvature densities.

1.5.7 Hopfions in all odd dimensional spaces

(D.H. Tchrakian)

Construction of Hopf like solitons in $5+1$ dimensions in a CP^1 sigma model on R^5. These are biazimuthal solutions of 3 dimensional PDE's. Research is ongoing.

1.5.8 Non-Abelian vortices

(D.H. Tchrakian)

Non-Abelian vortices are vortices on R^2 of the Georgi-Glashow model, and, the

model where the Yang-Mills density is replaced by the non-Abelian Chern-Simons density. Further study involves the instability of the vortex in terms of the critical length in the $z-$direction.

1.5.9 Solitins of NEW Chern-Simons models

(D.H. Tchrakian)

The new Chern-Simons densities in terms of Yang-Mills and Higgs fields are defined in both odd and even dimensional spacetimes. The $3+1$ case has $SO(5)$ gauge group and the $2+1$ case has $SO(4)$. Research is ongoing.

2 Publications

2.1 Papers in refereed journals

[1] V. Braun: Three generations on the quintic quotient. *JHEP* **01**(2010) 094.

[2] Ya. Shnir & D.H. Tchrakian: Skyrmion-Anti-Skyrmion chains. *J. Phys. A* **43** (2010) 025401.

[3] Konstantin Bobkov, Volker Braun, Piyush Kuman, Stuart Raby: Stabilizing all Kahler moduli in Type IIB orientifolds. *JHEP* **1012** (2010) 056.

[4] Lara B. Anderson, Volker Braun, Robert L. Karp, Burt A. Ovrut: Numerical Hermitian Yang-Mills connections and vector bundle stability in heterotic theories. *JHEP* **1006** (2010) 107.

[5] Y. Brihaye, B. Kleihaus, J. Kunz, & E. Radu: Rotating black holes with equal-magnitude angular momenta in d=5 Einstein-Gauss-Bonnet theory. *JHEP* **1011** (2010) 098.

[6] D. Foster, P. Bowcock, & P. Sutcliffe: Q-balls, integrability and duality. *J. Phys.* **A 42** (2010) 085403.

[7] D. Foster: Baby Skyrmion chains. *Nonlinearity* **23** (2010) 465474.

[8] F. Navarro-Lerida & D.H. Tchrakian: Non-Abelian Yang-Mills-Higgs vortices. *Phys. Rev. D* **81** (2010) 127702.

[9] Y. Brihaye, E. Radu & D.H. Tchrakian: AdS_5 solutions in Einstein-Yang-Mills-Chern-Simons theory. *Phys. Rev. D* **81** (2010) 064005.

[10] E. Radu, Y. Shnir & D.H. Tchrakian: Non-Abelian solutions of $d = 4 + 1$ Einstein-Yang-Mills and Yang-Mills dilaton theories. *Phys. Atom. Nucl.* **73** (2010) 509.

[11] B.P. Dolan: Modular symmetry and temperature flow of conductivities in quantum Hall systems with varying Zeeman energy. *Phys. Rev. B* **82** (2010) 195319.

[12] B.P. Dolan: Chiral fermions and torsion in the early universe. *Class. Quan. Grav.* **27** (2010) 095010.

[13] B.P. Dolan & R. Szabo: Equivariant dimensional reduction and quiver gauge theories. *Gen. Relat. & Gravit.* **April** (2010) Published online.

[14] V. Dotsenko & A. Khoroshkin: Gröbner bases for operads. *Duke Math. J.* **153, 2** (2010).

[15] W. Nahm & M. Leitner: Boundary states and edge currents for free fermions. *Adv. Theor. Math. Phys.* **14, 3** (2010).

[16] D. O'Connor, J.A. Santiago, C.R. Stephens, A. Zamora: Two-loop crossover scaling functions of the $O(N)$ model. *Int. J. Mod. Phys. A* **25** (2010) 5349-5368.

2.2 Papers in conference proceedings

[1] E. Radu, Y. Shnir & D.H. Tchrakian: Black holes and gravitating axially symmetric non-abelian solitons in d = 3+1 and d = 4+1. *AIP conference proceedings: The sun, the stars, the universe and general relativity: international conference in honor of Ya.B. Zeldovich's 95th anniversary*. 1205 (2010)

[2] W. Nahm: Two-dimensional quantum field theory, modular functions, and lattice paths. *Mathematisches Forschungsinstitut Oberwolfach: Low dimensional topology and number theory, Oberwolfach report*. 35 (2010) 2135.

[3] D. O'Connor: Equivariant vector bundles on fuzzy spaces. *Mathematisches Forschungsinstitute Oberwolfach: Deformation methods in mathematics and physics, Oberwolfach report*. 43 (2010) 2540-2543.

2.3 Preprints

DIAS-STP-

[10-01] B.P. Dolan & R.J. Szabo: Equivariant dimensional reduction and quiver gauge theories.

[10-02] K. Bobkov, V. Braun, P. Kumar & S. Raby: Stabilizing all Kähler moduli in type IIB orientifolds.

[10-03] V. Braun: On free quotients of complete intersection Calabi-Yau manifolds.

[10-04] Y. Brihaye, E. Radu & D.H. Tchrakian: AdS_5 solutions in Einstein-Yang-Mills-Chern-Simons theory.

[10-05] A. Ghesquiére & T.C. Dorlas: Entanglement of a two-particle Gaussian state interacting with a heat bath.

[10-06] L.B. Anderson, V. Braun, R.L. Karp & B.A. Ovrut: Numerical Hermitian Yang-Mills connections and vector bundle stability in heterotic theories.

[10-07] V.G. Filev & R.C. Raskov: Magnetic catalysis of chiral symmetry breaking. A holographic prospective.

[10-08] B.P. Dolan: Modular symmetry and temperature flow of conductivities in quantum Hall systems with varying Zeeman energy.

[10-09] A. Bayntun, C.P. Burgess, B.P. Dolan & Sung-Sik Lee: AdS/QHE: towards a holographic description of quantum Hall experiments.

[10-10] B.P. Dolan: The cosmological constant and the black hole equation of state.

[10-11] V. Braun: Discrete Wilson lines in F-theory.

[10-12] B.P. Dolan: Holomorphic and anti-holomorphic conductivity flows in the quantum Hall effect.

[10-13] J. Erdmenger & V. Filev: Mesons from global anti-de Sitter space.

[10-14] F. Hofmann, S. Keegan & A.M. Korsunsky: Analytical computation of the lattice rotations induced by 3D dislocation.

[10-15] W. Nahm & S. Keegan: Integrable deformations of CFTs and the discrete Hirota equations.

[10-16] Y. Brihaye, E. Radu & D.H. Tchrakian: Asymptotically flat, stable black hole solutions in Einstein-Yang-Mills-Chern-Simons theory.

[10-17] E. Radu & M.J. Rodriguez: New generalized nonspherical black hole solutions.

[10-18] D. Foster: Massive Hopfions.

[10-19] E. Radu & T. Tchrakian: New Chern-Simons densities in both odd and even dimensions.

[10-20] V. Dotsenko & A. Khoroshkin: Anick-type resolutions and consecutive pattern avoidance.

[10-21] D. O'Connor, J.A. Santiago, C.R. Stephens, A. Zamora: Two-loop crossover scaling functions of the $O(N)$ model.

2.4 Theses and other publications

[1] C. Morgan: The information-carrying capacity of certain quantum channels. Ph. D. Thesis, University College Dublin.

[2] A. Ghesquiére: Entanglement in a bipartite Gaussian state. Ph. D. Thesis, National University of Ireland, Maynooth.

3 Programme of Scholarly Events

3.1 Lectures Organised by The School

- J.M. Hill (University of Wollongong, Australia) *New geometric polyhedral models for nanotubes.*, 30 April
- F. Smirnov (LPTHE, Paris) delivered the Annual O'Raifeartaigh Lecture *One-point functions for Sine-Gordon*

model at finite temperature as part of the "Seventeenth Irish quantum field theory meeting", 28-29 May.

3.1.1 Seminars Organised by The Theoretical Particle Physics Group

- B. Stefanski (City University London) *Integrability and the AdS_3/CFT_2 correspondence.* 28 January
- D. Mehta (NUI Maynooth) *Algebraic geometry and Landau gauge fixing on the lattice.* 11 February
- R. Manvelyan (Yerevan State University) *General trilinear interaction for arbitrary even higher spin gauge fields: the beauty of Noether's procedure.* 8 April
- I. Lyberg (DIAS School of Theoretical Physics) *Stochastic integration.* February-June
- S. Kovacs (DIAS School of Theoretical Physics) *Dual superconformal symmetry of scattering amplitudes in $\mathcal{N} = 4$ SYM.* April-July
- I. Lyberg (DIAS School of Theoretical Physics) *Wiener-Hopf sum equations and Szegö's theorem.* October- December
- E. Radu (DIAS School of Theoretical Physics) *Toroidal solutions in field theory: black rings and vortons.* 8 December
- G. Sierra (Instituto de Física Teórica, UAM/CSIC) *On the spectral interpretation of the Riemann zeros.* 9 December

3.2 Symposia, Conferences, Workshops organised

The **Irish Quantum Field Theory Meeting 2010** was held from 28-29 May. The following lectures were delivered.

- A. Hanany. *Chiral operators on the one instanton moduli space.*
- M. Tuite. *Combinatorics of CFT correlation functions.*
- M. Khalid. *K3 surfaces with involutions and their orbifold limits.*
- J. Slingerland. *Experimental signatures of topological field theory.*
- F. Smirnov. *One-point functions for Sine-Gordon model at finite temperature.*
- R. Suzuki. *Five-loop Konishi energy from Mirror.*
- V. Filev. *$1 + 2$ D defect field theory in a magnetic field. A holographic study.*
- W. Nahm. *Random walks and integrability.*
- J. Simon. *Holography and correlation functions.*
- N. Wyllard. *$4dN = 2$ gauge theories, 2d CFTs and matrix models.*

- C. Saemann. *M2-Branes ending on M5-Branes.*
- J.-I.Skullerud. *Large-*$1/Nc$ *QCD at high density: a quarkyonic phase.*
- W. Nahm. *2D gauge theories and integrability after Gerasimov/Shatashvili/Nekrasov.*

Statutory Public Lecture

The Statutory Public Lecture delivered by Dr. Robert Dijkgraaf, University of Amsterdam, President of the Royal Netherlands Academy of Sciences, was hosted by Trinity College Dublin and was held on 15 November. The title was *On the other side of the hill: the importance of basic science for innovation and development.*

4 Presentations at Conferences or Seminars

4.1 Talks and Papers Presented

W. Nahm:

- Talk "Modular functions and algebraic K-theory", at the workshop on "Mock modular forms in combinatorics and arithmetic geometry", American Institute of Mathematics, Palo Alto, California, 9 March.
- Invited talk "Rational conformal field theories, integrable deformations, discrete hirota equations, random walks" at the Symposium in honor of Sander Bais, 15 June.
- Invited talk "Two-dimensional quantum field theory, modular functions, and lattice paths", at the workshop on "Low-dimensional topology and number theory", MFO Oberwolfach, Germany, 15-21 August.

T.C. Dorlas:

- Talk "Principles of quantum information and computing" at Intel, Shannon, 24 May.
- Talk "A simple model for global warming" at the "Biannual meeting on statistical mechanics", Rutgers University, New Jersey, USA on 10 May.
- Plenary talk "The magnetisation of the transverse-field Ising model" at the conference "Algebra, geometry, and mathematical physics" (AGMP10), Tjärnö, Sweden, 24-30 October.
- Talk "Excitons in one dimension with an impurity" at the conference "Quantum dynamics", Marseille, 25-27 November.

Denjoe O'Connor:

- Talk "Matrix models and emergent geometry", Non-commutative structures and non-relativistic (super)symmetries, LMTP Tours, France, 21-25 June.
- Talk "Topological phase transitions", Noncommutative Geometry Network (EU-NCG), 3rd annual meeting, Cardiff, Wales, 28 June-2 July.

- Talk "Equivariant vector bundles on fuzzy spaces" at Oberwolfach Conference on "Deformation methods in mathematical physics", Oberwolfach, Germany, 25 September-1 October.

- Talk "Low dimensional Yang-Mills: matrix models and emergent geometry" at "Models in quantum field theory", St. Petersburg, 18-22 October.

V. Braun:

- Talk "Stabilizing Kähler moduli in type IIB orientifolds" at the "String phenomenology workshop", KITP, Santa Barbara, 29 March-16 April, 22 April-24 April.

- Talk "Computing Calabi-Yau metrics and Hermitian Yang-Mills connections", Ohio State University, 27-29 April.

- Talk "Fundamental groups and heterotic string theory", Oxford University, 12-15 May.

- Talk "Sage and combinatorial geometry" at "Geometry and combinatorics workshop", Goettingen, Germany, 25-27 November.

- Talk "Toric geometry in sage and string/F-theory applications", Munich, Germany, 6-10 December.

B. Dolan:

- Talk "Equivariant dimensional reduction over complex projective spaces and quiver gauge theory", Dublin, Trinity College, 29 March.

- Talk "Chiral fermions and torsion in the early Universe" at the "10th British gravitational meeting (BritGrav10)", Dublin City University, 6-7 April.

- Talk "Enthalpy and the first law of black hole thermodynamics", at the "Workshop on non-commutative field theory and gravity", Corfu, 9 September.

- Talk "Electromagnetic duality in AdS/QHE: magnetic monopoles and the quantum Hall effect", at the "Workshop on Ads_4/CFT_3 and the holographic states of matter", Galileo Galilei Institute of Theoretical Physics, Florence, Italy, 2-6 November.

V. Dotsenko:

- Talk "Operadic homological algebra via shuffle operads" at summer school and conference "Operads and universal algebra", Tianjin, China, 28 June-9 July.

- Talk "Compatible associative products and trees" at the LMS–ARTIN workshop "Integrable systems: algebraic aspects", University of Glasgow, UK, 23-24 April.

- Talk "Anick resolutions, shuffle algebras, and consecutive pattern avoidance" at the "British mathematics colloquium", Edinburgh, UK, 6-9 April.

- Talk "Shuffle operads and their applications" at the conference "Representation theory and quantization", ETH Zürich, 25-29 January.

V. Filev:

- Seminar "Holographic chiral dynamics in external fields", Bulgarian Academy of Sciences, July
- Seminar "A two matrix model at strong coupling", Max Planck Institute for Physics, Munich, November.
- Talk "1 + 2 D defect field theory in a magnetic field. A holographic study" at "17th Irish quantum field theory meeting", Dublin Institute for Advanced Studies, May.
- Talk "Flavored SYM theory on S^3 with various control parameters" at "AdS holography and the quark-gluon plasma", Erwin Schrödinger International Institute for Mathematical Physics, August.
- Talk "Holographic chiral dynamics in external fields (I and II)" at "Aspects of holography and gauge/string duality", APSCTP Headquarters, POSTECH, Pohang, August.
- Talk "$N = 2$ flavoured SYM theory on S3 in an external magnetic field" at "Quantum field theory developments and perspectives", DESY Hamburg, Germany, September.

S. Keegan:

- Talk "Coset models and Nahm's conjecture" at the "K-theory, quadratic forms and number theory seminar series", School of Mathematical Sciences, University College Dublin.

S. Kovacs:

- Talk "Some applications of light-cone superspace" at the Indian Institute of Science Education and Research, Pune, India, 14 January.
- Seminar talk "Dual superconformal symmetry of scattering amplitudes in $\mathcal{N} = 4$ SYM" at DIAS, April-July.

I. Lyberg

- Seminar talk "Stochastic integration" at DIAS, February to June.
- Seminar talk "Wiener-Hopf sum equations and Szegö's theorem" at DIAS, October to December.

O. Smits:

- Talk "Probing the edges of the fractional quantum Hall effect" at DRSTP Spring School, April.

5 Collaboration with the Wider Research Community

5.1 National

Lecture Courses, Conferences and Workshops

W. Nahm:

- Collaboration with Prof. F. Laytimi, Mathematics Department, Universit Lille 1 on questions in algebraic

geometry, and, in particular, on vanishing theorems, July.

- Collaboration with D. Zagier, Director of Max-Planck-Institute for Mathematics, Bonn, 23-30 August.

B. Dolan:

- Postgraduate lecture course on *Condensed matter from string theory: the AdS/CFT correspondence and superconductors*, NUI, Maynooth.

S. Kovacs:

- Course for undergraduates on *Classical mechanics MA1241 & MA1242*, Trinity College Dublin.

S. Keegan

- Collaboration with Prof. Alexander Korsunsky's group in the Department of Engineering Science, University of Oxford. So far, work has been done on lattice misorientation arising from 3D dislocation loops, resulting in the submission of one paper to the journal *Philosophical Magazine*.

O. Smits

- Collaboration with the Dublin Area Quantum Information Science and Technology Group, primarily with the NUI, Maynooth DAQIST group.

- Teaching assistant, Trinity College Dublin, courses include: "Fourier analysis for scientists", "Introduction to group theory", "Equations of mathematical physics" and "Linear algebra".

Staff Acting as External Supervisors

W. Nahm

- External supervisor for exams at the School of Physics and the School of Mathematics, Trinity College Dublin.

T.C. Dorlas:

- Thesis supervisor for Ciara Morgan, who completed her thesis in January 2010, entitled: "The Information carrying capacity of certain quantum channels".

- Thesis supervisor for Anne Guesquière, who completed her thesis in June 2010, entitled: "Entanglement in a bipartite Gaussian state".

Denjoe O'Connor:

- Ph.D. supervisor for Thomas Kaltenbrunner (NUI Maynooth), funded by the EU-NCG Network.

- Ph.D. supervisor for Martin Vachovski (NUI Maynooth), funded by the EU-NCG Network.

S. Keegan:

- S. Keegan supervised a maths project for Míde Ní Ghríofa and Nessa Lahert, two transition year students from Coláiste Íosagáin. They studied sums of powers of integers of the form $\sum_{k=1}^{n} k^p$ and how these sums are related to the Bernoulli numbers. The students took part in the BT Young Scientist and Technology Exhibition

2011, where their project was awarded first place in the Intermediate Chemical Physical and Mathematical Sciences category. They also won two of the special awards, the Foras na Gaeilge award for the best Irish language project, and the Discover Science award that rewards the novel use of mathematical principles in the determination of its results.

Staff Acting as External Examiners

W. Nahm:

- External examiner for the MSc of David Leen, Trinity College Dublin.

T.C. Dorlas:

- External examiner for the doctoral examination of Thomas Jaeck at U.C.D., 6 September 2010. Title of thesis: "The nature of Bose-Einstein condensation enhanced by localisation".
- External examiner for the doctoral examination of Jeroen Wouters, University of Leuven, Belgium, 21 December 2010. Title of thesis: "Quantum hidden Markov chains".

Speakers Sponsored at Outside Conferences/Meetings

- The School sponsored R. Schröder (Max F. Perutz Laboratories, University of Vienna) who delivered the Sixteenth Annual Schrödinger Lecture entitled "The origin of life and the RNA world" at Trinity College Dublin on 4 November.

Research Associates

- AT&T: N. Duffield
- BM Annaba University: B. Ydri
- DCU: E. Buffet, J. Burzlaff, E. O'Riordan
- DIT: D. Gilbert, M. Golden, B. Goldsmith, P Houston, E. Prodanov
- ICTP, Trieste : J. Chela-Flores
- IT, Athlone: M. Daly
- IT, Carlow: D. O Sé
- IT, Tallaght: N. Gorman
- Ludwig-Maximilians-Universität München: I. Sachs
- Meteorological Service: P. Lynch
- NUI, Cork: M. Vandyck
- NUI, Galway: J. Burns, M.P. Tuite
- NUI, Maynooth: B. Dolan, D. Heffernan, C. Nash, A. O'Farrell, J. Slingerland, J. Vala, P. Watts
- Open University: A.I. Solomon
- Oxford University: R.G. Flood
- TCD: P.S. Florides, J. Miller, D. Weaire
- Universiteit Leiden: F. Freire
- UCD: A. Ottewill, J.V. Pulé, W. Sullivan
- UL: S. O'Brien

- University Warwick: N. O'Connell
- Unaffiliated: T. Garavaglia, M. Leitner, G.M. O'Brien, D. Ó Mathuna, J.A. Slevin, D.H. Tchrakian

5.2 International

Visiting Researchers

Short visits (up to one week):

- B. Stefanski (City University, London) 28-29 January.
- T. Mine (Kyoto Institute of Technology) 8 February.
- D. Mehta (NUI Maynooth) 11 February.
- H. Strohmayer (Luxembourg University) 22-24 April.
- D. Foster (University of Durham) 10-13 May.
- G. Ford (University of Michigan) 15-16 June.
- T. Gannon (University of Alberta, Canada) 31 July-9 August.
- D. Evans (University of Cardiff) 1-7 August.
- G. Sierrra (Institute of Theoretical Physics, Madrid) 9 December.

Long visits:

- B. Ydri (Annaba Badji Mokhtar University, Algeria) 1-25 March.
- R. Manvelyan (Yerevan Physics Institute, Armenia) 1-23 April.
- E. Radu (Oldenburg University, Germany) 11-21 April.
- Y. Suhov (University of Cambridge) 4-17 June & 18 August-3 September.
- R.F. O'Connell (Louisiana State University) 9 June-19 July.
- P. Contucci (University of Bologna, Italy) 9-26 July.
- C. Giardina (University of Modena & Reggio Emilia) 9-23 July.

Research Visits by School Staff

W. Nahm:

- Research visit to Mathematics Department, Université Lille 1, July.
- Research visit to Max-Planck-Institute for Mathematics, Bonn, 23-30 August.

T.C. Dorlas:

- Research visits to Cambridge University, 21-23 January & 20-24 April.
- Research visit to Centre de Physique Théorique, Marseille, 10-13 February.
- Visit to Intel, Shannon, 24 May.
- Visit to Katholieke Universiteit Leuven to examine thesis of Jeroen Wouters, 21-22 December.

Denjoe O'Connor:

- Visit to Tours, France, June 2010.
- Visit to Cardiff, Wales, June 2010.
- Visit to Oberwolfach, Germany, September 2010.
- Visit to St. Petersburg, Russia, October 2010.

V. Braun:

- Visit to Ohio State University, 27-29 April.
- Visits to String Theory Group, University of Pennsylvania, 4-20 January, 22-28 March, 30 April-8 May, & 30 October-17 November.
- Visit to Ludwig-Maximilians-University, Munich, 6-10 December.

B. Dolan:

- Visit to McMaster University, Hamilton, Canada, 8-14 August.

V. Dotsenko:

- Research visit to Independent University of Moscow, Moscow, Russia, 5-13 January.

T. Kaltenbrunner:

- Visit to Vienna, Austria, 26 December 2010 to 9 January 2011.

S. Kovacs:

- Visit to Indian Institute of Science Education and Research, Pune, India, 2-16 January.

C. Morgan:

- Visit to the Centre for Quantum Technologies, National University of Singapore, 8 March-19 March.

E. Radu:

- Visit to Max Planck Institute for Gravitational Physics & Carl von Ossietzky University of Oldenburg, Germany, 11-28 October.

D.H. Tchrakian:

- Research visit to Max Planck Institut für Gravitationsphysik (Albert-Einstein-Institut), Potsdam, Germany, 8-11 February.
- Research visit to Joint Institute for Nuclear Research, Yerevan State University, Yerevan, Armenia, 15 August to 1 Sept.

M. Vachovski:

- Visit to Bulgaria, 22 December 2010 to 10 January 2011.

6 Participation in Outside Committees

W. Nahm:

- Chair, Research Subcommittee of the Mathematics Committee, Royal Irish Academy.

T.C. Dorlas:

- Member of: IAMP, AMS, WG, NNV

Denjoe O'Connor:

- Member of the International Advisory Board of the Central European Joint Programme of Doctoral Studies in Theoretical Physics.

7 Attendance at External Conferences, Workshops, Meetings and Lectures

7.1 Conferences/Workshops/ Scientific Meetings Attended

W. Nahm:

- Workshop on "Mock modular forms in combinatorics and arithmetic geometry", American Institute of Mathematics, Palo Alto, California, 8-12 March.
- Symposium in honour of Sander Bais, 15 June.
- Workshop on "Low-dimensional topology and number theory", MFO Oberwolfach, Germany, 15-21 August.
- Plenary meeting of the Academy of Sciences and Literature, Mainz, 5-6 November.

T.C. Dorlas:

- Biannual meeting on statistical mechanics, Rutgers University, New Jersey, USA, 9-11 May.
- Conference "Algebra, geometry, and mathematical physics" (AGMP10), Tjärnö, Sweden, 24-30 October.
- Conference "Quantum dynamics", Marseille 25-27 November.

Denjoe O'Connor:

- Conference "Non-commutative structures & non-relativistic (super) symmetries", LMPT, Université François Rabelais, Tours, France 21-25 June.
- Conference "The 3rd annual meeting of the EU network in noncommutative geometry", Cardiff, 28 June-2 July.
- Conference "Deformation methods in mathematics & physics", Oberwolfach, Germany, 25 September to 01 October.
- Conference "Models in quantum field theory", St. Petersburg, Russia, 18-22 October.

M. Beau:

- International conference in honor of Pierre Duclos "Quantum dynamics", CIRM, Marseille, 25-27 November.

V. Braun:

- Workshop "String phenomenology", Kavli Institute for Theoretical Physics, Santa Barbara, 29 March to 24 April.

- Workshop "Hodge theoretic reflections on the string landscape", ICMS conference, University of Edinburgh, 13-18 June.
- ESI workshop "Topological string theory, modularity & non-perturbative physics", Vienna, 20-28 June.
- Simons workshop, SUNY, Stony Brook, New York, 25 July-1 August.
- Workshop "Geometry & combinatorics", Goettingen University, 24-27 November.

B. Dolan:

- "10th British gravitational meeting (BritGrav10)", Dublin City University, 6-7 April.
- School and workshop on "The standard model and beyond - cosmology", Corfu, 29 August-5 September.
- Workshop on "Fields and strings: theory-cosmology-phenomenology", Corfu, 5-8 September.
- Workshop "Non-commutative geometry field theory and gravity", Corfu, 8-9 September.
- Workshop "Ads_4/CFT_3 and the holographic states of matter", Galileo Galilei Institute of Theoretical Physics, Florence, Italy, 2-6 November.
- "Annual high energy theory meeting", Durham, England, 16-18 December.

V. Dotsenko

- Summer school and conference "Operads and universal algebra", Tianjin, China, 28 June-9 July.
- LMS–ARTIN workshop "Integrable systems: algebraic aspects", University of Glasgow, UK, 23-24 April.
- Conference "Anick resolutions, shuffle algebras, and consecutive pattern avoidance", British Mathematical Colloquium, Edinburgh, 6-9 April.
- Conference "Representation theory and quantization", ETH Z$\acute{}$urich, 25-29 January.

V. Filev

- Workshop "17th Irish quantum field theory meeting", DIAS, 28-29 May.
- Workshop "Summer school SFP 10", Technical University Munich, 25 July-1 August.
- Workshop "AdS holography and the quark-gluon plasma", Erwin Schrödinger International Institute for Mathematical Physics, Vienna, 2-8 August & 17-20 August.
- Workshop "Aspects of holography and guage/string duality", APSCTP Headquarters, POSTECH, Pohang, 9-16 August.
- Workshop "Quantum field theory developments and perspectives", DESY Hamburg, Germany, 21-24 September.

D. Foster

- "Non-perturbative techniques in field theory", LMS Symposium, 18-25 July.
- Theory meeting, Durham University, 16-18 December.

A. Ghesquiére:

- "North-South quantum information Winter school", N.U.I. Maynooth, 25-27 January.

T. Kaltenbrunner:

- Conference on "Planar algebras", Cardiff, 15-20 February.
- LMS regional meeting and workshop on "Operator algebras and physics", Cardiff, 21-25 June.
- EU-NCG 3rd Annual Meeting, Cardiff, 28 June-2 July.
- School and workshops on "The standard model and beyond cosmology", Corfu, 29 August.
- School and workshops on "Fields and strings: theory, cosmology, phenomenology", Corfu, 5-12 September.
- Satellite workshop on "Noncommutative field theory and gravity", Corfu, 8-12 September.

S. Keegan:

- "Prospects in q-series and modular forms", University College Dublin, 14-16 July.
- Workshop on "Low dimensional topology and number theory", Mathematisches Forschungsinstitut Oberwolfach, Germany, 15-21 August.

S. Kovacs:

- Workshop "17th Irish quantum field theory meeting", DIAS, 28-29 May.
- Workshop "Hodge theoretic reflections on the string landscape", International Centre for Mathematical Sciences, Edinburgh, 14-18 June.

O. Smits

- "North-South quantum information Winter school, 2010", Winter school on quantum information theory, NUI Maynooth, 25-27 January.
- "DRSTP Spring school", Dutch Research School of Theoretical Physics, Driebergen, Spring school on statistical physics and theory of condensed matter, 12-22 April.
- Conference "17th Irish quantum field theory meeting" at the Conference on quantum field theory, DIAS, 28-29 May.
- "INSTANS Summer school", Summer school on topological aspects of condensed matter theory and its relation with quantum information, Centro de Ciencias de Benasque Pedro Pascual, 20 June-01 July.

D.H. Tchrakian:

- XIV international conference on "Symmetry Methods in Physics (SYMPHYS XIV)", Tsakhkadzor, Armenia, 16-22 August.
- 1st international workshop "Supersymmetry in integrable systems", Yerevan State University, Yerevan, Armenia, 24-28 August.

M. Vachovski:

- "Period on planar algebras and physics", Cardiff, 14-20 February.
- LMS regional meeting and workshop on "Operator algebras and physics", Cardiff, 21-25 June.
- "Third annual conference on noncommutative geometry", Cardiff, 28 June-2 July.

7.2 Lectures and Organisational Meetings Attended

T.C. Dorlas:

- Schrödinger lecture by Prof. Renée Schröder, University of Vienna, on *The origin of life, and the RNA world.* Trinity College, 4 November.
- Statutory public lecture by Professor Robbert Dijkgraaf, University of Amsterdam, on: *On the other side of the hill: the importance of basic science for innovation and development.* RDS, 15 November.

I. Lyberg:

- Participated in weekly seminar organised by T.C. Dorlas & J. Pulé.

8 Research Grants/External Funds Secured

Denjoe O'Connor:

- A grant of computer equipment from SUN Microsystems valued at approximately € 100,000 for the purposes of implementing the testing phase of the matrix approach to field theory.
- 2007-2011: Node of Marie Curie Research Training Network € 233652.73.
- 2008-2010: An Embark Initative Postdoctoral Fellowship to Veselin Filev funded by IRCSET for a period of two years with effect from 1 October 2008.
- 2008-2010: An Embark Initative Postdoctoral Fellowship to Vladimir Dotsenko funded by IRCSET for a period of two years with effect from 1 October 2008.
- 2010-2012: An INSPIRE Initiative Postdoctoral Fellowship to Veselin Filev funded by IRCSET and Marie Curie.
- 2009-2011: Marie Curie Early Stage Research Fellowship to T. Kaltenbrunner, MRTN-CT-2006-031962
- 2009-2011: Marie Curie Early Stage Research Fellowship to M. Vachovski, MRTN-CT-2006-031962

V. Braun:

- ICHEC Project "A prelude to numerical Calabi-Yau geometry" (class C) was approved.

9 Honours/Awards/ Special Achievements Received

W. Nahm

- Elected member of the Academy of Sciences and Literature, Mainz, February.

10 Public Awareness Activities

10.1 Public Lectures

B. Dolan:

- Talk "Nature through the looking glass" at Dublin's Ignite Series, Science gallery, Trinity College, 10 March.

2010 Research Report
School of Cosmic Physics: Geophysics Section

Contents

1 General

1.1 Research highlights

Article on the deformation of the Aegean lithosphere, co-authored by Sergei Lebedev and Celine Tirel together with their co-workers in Germany, has been accepted for publication in *Nature Geoscience*. The article described how seismic Rayleigh-wave anisotropy indicated viscous flow within the lower-crustal and mantle parts of the Aegean lithosphere and revealed a previously unknown pattern of continental deformation.

1.2 New external funding received in 2010

1.2.1 Proposals funded:

An SFI PI2010 proposal by Jones entitled "IRETHERM: Developing a strategic and holistic understanding of Ireland's geothermal energy potential through integrated modelling of new and existing geophysical and geological data" was submitted in March, 2010. A positive funding decision was received in December, 2010.

1.3 External funding requested in 2010

1.3.1 Proposals submitted:

An SFI RFP2011 proposal was submitted by Lebedev entitled "Ireland Array: A geophysical investigation of Ireland's evolution, seismicity, and new energy resource potential".

An SFI RFP2011 proposal was submitted by Martinec entitled "Combined glacial-isostatic adjustment and thermomechanical ice-sheet modelling to reconcile ice-mass variations inferred from sea-level and satellite observations (GIANICE)".

An SFI RFP2011 proposal was submitted by Muller entitled "CAMTEX: Central African MagnetoTelluric Experiment".

An ERC Starting Grant proposal was submitted by Lebedev.

2 Electromagnetic research activities

Group Leader: Senior Professor Alan G. Jones

2.1 Research Focus on Sustainable and Renewable Energy in Ireland

M. Muller, A.G. Jones

DIAS's entry into this new area of research, of high societal relevance to Ireland, has been realised through the successful submission during 2010 of a geothermal energy research proposal ("IRETHERM") to the Principal Investigator program of Science Foundation Ireland – by Principal Investigator Jones and collaborator Muller at DIAS, together with academic-government-industry collaborators at UCD, UCC, GSI, GSNI and SLR. The project, which aims to comprehensively assess the geothermal energy potential of Ireland's (all-island) subsurface geological formations, has been funded by SFI to a value of €850,000 over a fifty-four month period, starting in March 2011 (SFI grant number 10/IN.1/I3022).

During the course of 2010, the MT Group also initiated three projects in Ireland, through independent collaborations with GSI, GSNI and Gaelectric (a Dublin based wind-energy company), that collectively contribute to a sustainable and renewable energy research focus. These projects examine: (i) the geothermal energy potential of the Mourne Mountains granite (as an Enhanced Geothermal System prospect), (ii) the carbon capture and sequestration (CCS) potential of the Ross Sandstone Formation in the Clare Basin, and (iii) the compressed-air energy storage (CAES) potential of the Triassic and Permian halite deposits of the Larne Basin.

2.1.1 IRETHERM

Background

Little is currently known of the potential of Ireland's subsurface geology to provide geothermal energy for district-scale space-heating and electricity generation. Both applications require identification and assessment of deep, permeable aquifers or large-volume, hot, radiogenic granitic intrusions. Ongoing technological advances in utilizing medium-temperature (110–160°C) groundwaters provide real potential for electricity generation within the upper range of thermal gradients observed in Ireland (~28°C/km). However, such potential can only be realised in the future if deep (4–5 km) geothermal source rocks can be identified within the country's subsurface.

Research plan

IRETHERM is a new academic-government-industry collaborative project starting in 2011, funded by a Science Foundation Ireland award to Principal Investigator Prof. Alan Jones at DIAS, which aims to develop a holistic understanding of Ireland's (all-island) low-enthalpy geothermal energy potential through integrated modelling of new and existing geophysical and geological data. Official collaborators include Dr. Mark Muller (DIAS), Prof. Stephen Daly (UCD), Dr. Alistair Allen (UCC), Monica Lee and Taly Hunter Williams (GSI), Derek Reay (GSNI) and Roisin Goodman (SLR Consulting).

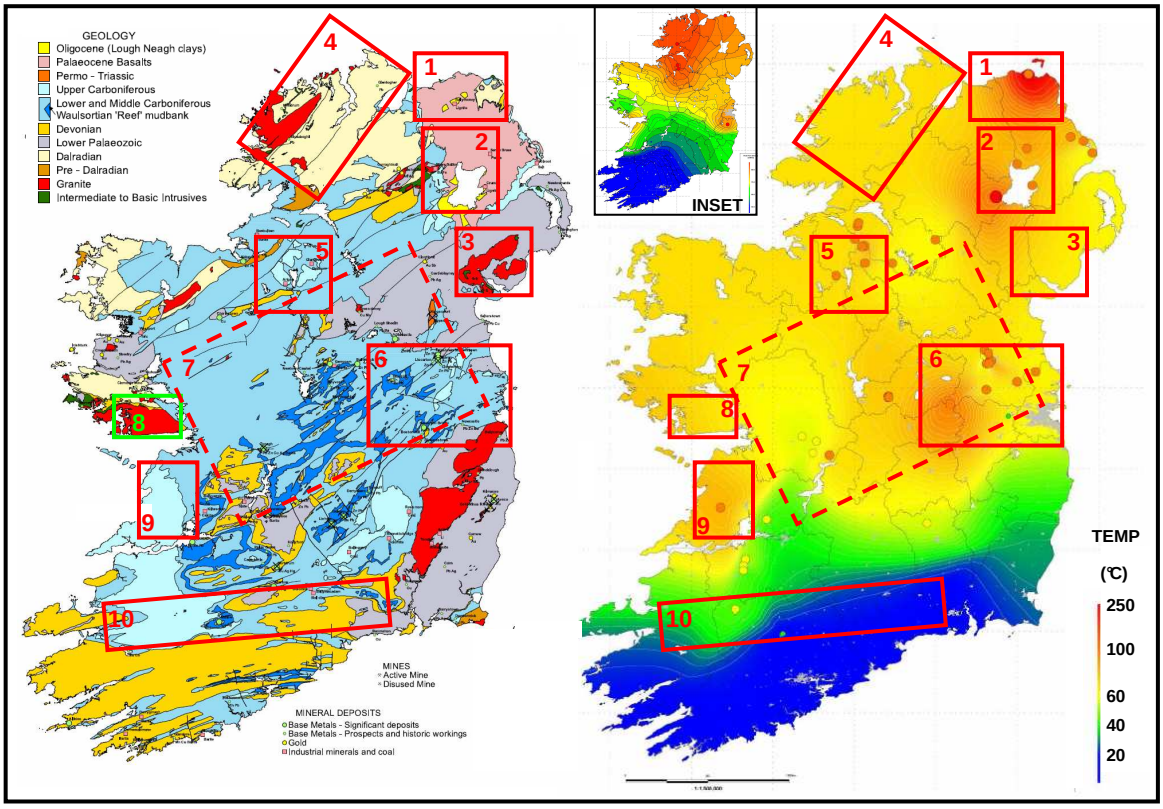


Figure 1: IRETHERM's planned survey areas (labeled 1 to 10) to assess eight different geological environments for their geothermal energy potential. On the left, the target areas are overlain on the surface geology map of Ireland (courtesy GSNI and GSI), and on the right, on modelled crustal temperatures at 2,500 m depth (courtesy R. Goodman, SLR Consulting). The inset figure shows regional heat-flow density contours, from ~40 mW/m^2 (blue) to ~80 mW/m^2 (red). The eight geological target types are: Permo-Triassic sandstones, radiogenic granites, warm-spring lineaments, high heat-flow and high-temperature areas, deeply penetrating fault zones, gravity anomalies of unknown origin, areas of current seismicity and basal sediments of the Carboniferous and Devonian successions.

IRETHERM's overarching research objective, over the 4½ year period of funding, is to establish those geological settings and localities in Ireland with the greatest potential to provide significant volumes of hot geothermal waters or hot, dry rock. The project plans to:

(i.) Develop multi-parameter modelling and interpretation software tools that advance state-of-the-art geophysical (electromagnetic, gravity, seismic) imaging of shallow and deep aquifers and granitic intrusions.

(ii.) Understand both the 3D spatial variation in Ireland's radiogenic crustal heat-production and the origin of the local and regional heat-flow variations. New measurements of crustal heat-production in 3D (using mid- to lower-crustal xenoliths and borehole core) and of temperature and heat-flow variation will be modelled with existing constraints on the structure and thermal properties of the crust and lithosphere.

(iii.) Test a strategic set of eight "type" geothermal targets with a systematic program of field electromagnetic surveys (MT, CSEM) (Figure 1), interpreted using our new modelling/inversion tools. Aquifer prospectivity will be based on high estimated

porosity, subsurface continuity and depth, while granite (EGS) prospectivity will be based on large volume and depth extent and high radiogenic heat-production, in both cases in the presence of an elevated temperature gradient.

The IRETHERM project starts in March 2011 and will employ 2 post-doctoral research fellows and 3 geophysics PhD students (all based at DIAS and supervised variously by Jones, Muller and Dr. Alistair Allen at UCC) and 1 geochemistry PhD student (based at UCD and supervised by Jones and Prof. Stephen Daly).

2.1.2 Geothermal energy potential of the Mourne Mountain granites

The high radiogenic element (uranium, thorium and potassium) concentrations associated with the Mourne Mountain granites in Northern Ireland make this granitic intrusion one of the most prospective in Ireland for provision of Enhanced Geothermal System (EGS) energy. The major unknown parameters in terms of the potential for geothermal energy provision are the depth extent and volume of the intrusion. High geothermal energy potential would be indicated if the granites are found to have a significant volume and depth extent below 4,000 m. In a project logistically supported and funded by Geological Survey of Northern Ireland, DIAS conducted an MT survey across the Mourne Mountains during July-August 2010 to determine the subsurface geometry of the granites. Fifty-three AMT/MT sites, at roughly 1 km intervals, were recorded along three profiles across the Mournes.

Research on these data is currently being carried out by two University of Birmingham MSci students, Laura Ayres and Chris Yeomans, under the supervision of Muller at DIAS, co-supervised by Dr. Carl Stevenson at Birmingham. The students' research dissertations, focussing on both the geothermal energy potential of the Mournes and the mechanism of granitic melt emplacement into the crust, are due for completion in May 2011.

2.1.3 Carbon capture and sequestration (CCS) potential of the Clare Basin

Ireland's largest single-point source of Carbon Dioxide emissions is Moneypoint Power Station (approximately 4 Mt CO2 per annum) is located in County Clare and lies within the geology of the Clare Basin. The geological structure of the Clare Basin was considered as a potential for Carbon Capture and Sequestration (CCS), however recent appraisals of collected data have inferred that the potential reservoir for CCS within the basin, the Ross Sandstone Formation, is unsuitable, based on porosity and permeability estimates. In a project logistically supported and funded by Geological Survey of Ireland (GSI), DIAS conducted an MT survey across the Clare Basin during June 2010 with the following scientific objectives: (a) defining the geological structure of the Ross Sandstone Formation within the Clare Basin and (b) to investigate the relationship between the electrical resistivity and porosity of the sandstone. The results from this pilot-study will conclude if there is any potential for CCS within the Clare Basin. Twenty-seven AMT/MT sites, at roughly 1 km intervals, were recorded along one profile across the Clare Basin. Research on these data is currently being investigated by Colin Hogg under the supervision of Mark Muller and Prof. Alan Jones. A preliminary report has been submitted to the GSI providing an initial geoelectric model and upper constraints on the porosity of the Ross Sandstone

Formation. An extra phase of fieldwork will be carried out by Hogg in 2011 to extend the main profile towards Loop Head, where recent borehole drilling has taken place. These boreholes will constrain lithological boundaries in further geoelectrical model generations and sophisticated wireline logs will help further constrain the porosity estimates of the geology.

2.1.4 Compressed-air energy storage (CAES) potential of halite deposits in the Larne Basin

One of the drawbacks associated with electrical power generation using wind turbines is that the power generation is variable in time and dependent on the strength of the prevailing winds – with energy surpluses generated during periods of high wind, and shortfalls occurring during quiescent periods. One approach to balancing the power supply from wind generation is to utilise compressed-air energy storage (CAES), in which compressed-air is pumped into subterranean cavities during periods of power surplus, to be released through electricity-generating turbines during periods of low wind.

The Dublin-based wind-power company, Gaelectric, is investigating the possibility of dissolving suitable caverns for CAES in the Triassic and Permian halite deposits of the Larne Basin in Northern Ireland, within an 18 km^2 exploration area which they hold under license. Suitability of the halite deposits for CAES depends on the depth, thickness and lateral continuity of the halite layers – all of which are currently poorly known. DIAS, in a project funded by Gaelectric, is currently investigating the subsurface geological structure of the Larne Basin and its halite deposits using magnetotellurics. DIAS conducted an MT survey within Gaelectric's exploration license area during September 2010 and acquired sixty-seven AMT/MT sites, at roughly 500 m intervals. These data have been processed and modelled using 1-D modelling approaches and these results indicate that the depth and thickness of the halite zone in the subsurface is well constrained across the survey area: the halites are characterised by significantly higher electrically resistivities than apparent for the overlying Mercia mudstones and underlying Sherwood sandstones.

DIAS has taken on an MSc student, Sara Sihelnik, within the IDEA League Joint Masters program in Applied Geophysics (run by ETH, Aachen and Delft Universities), who will pursue advanced research into the geological structure of the Larne Basin by incorporating gravity, seismic reflection and borehole wireline log data, under the supervision of Muller and Jones at DIAS in 2011. The research dissertation is due for completion in August 2011.

2.2 Southern African Magnetotelluric Experiment (SAMTEX)

A.G. Jones, M. Muller, D. Khoza, M. Miensopust, P.-E. Share, and colleagues from WHOI

2.2.1 ZIM profile

Two-dimensional (2D) isotropic inversion of the ZIM line finalised and interpreted. The resulting resistivity model shows a thick, resistive lithospheric mantle beneath the Zimbabwe Craton, a thinner and less resistive lithospheric mantle beneath the Ghanzi-

Chobe Mobile Belt and no information can be provided about the LAB depth beneath the Magondi Mobile Belt due to lack of penetration. At crustal depth, the boundary between the resistive Ghanzi-Chobe Mobile Belt and the more heterogeneous and in overall more conductive Magondi Mobile Belt is northwards dipping. Additionally, mid- to lower-crustal conductors have been found, which coincide with early mapped and possible large-scale conductors of so far unknown origin. Another crustal feature is the resistive Okavango dyke swarm, which caused unusual and unexplainable structures such as a downwraped conductor when isotropic modelling and inversion is applied. Therefore, anisotropy tests have been performed (more details see anisotropy section).

Publication:

Miensopust, M.P., **A.G. Jones**, **M.R. Muller**, X. Garcia, and R.L. Evans, 2011. Lithospheric structures and Precambrian terrane boundaries in northeastern Botswana revealed through magnetotelluric profiling as part of the Southern African Magnetotelluric Experiment, *J. Geophys. Res.*, **116**, B02401, doi:10.1029/2010JB007740.

Presentations:

Miensopust, M.P., **A.G. Jones**, **M.R. Muller**, X. Garcia, R.L. Evans, **D. Khoza**. Lithospheric structures and Precambrian terrane boundaries in northeastern Botswana revealed through magnetotelluric profiling. AGU Fall Meeting, San Francisco, USA, 13 - 17 December 2010.

Miensopust, M.P., **A.G. Jones**, **M.R. Muller**, X. Garcia, and R.L. Evans. Lithospheric structures and geometries in northeastern Botswana revealed through SAMTEX magnetotelluric profiling. 20th Workshop of IAGA WG 1.2 on Electromagnetic Induction in the Earth, Giza, Egypt, 18 - 24 September 2010.

Miensopust, M.P., **A.G. Jones**, **M.R. Muller**, R.L. Evans, and the SAMTEX team. Lithospheric structures and geometries in northeastern Botswana revealed through SAMTEX magnetotelluric profiling. EGU Meeting, Vienna, Austria, 2-7 May 2010.

Thesis:

Miensopust, M.P., Multidimensional Magnetotellurics: A 2D case study and a 3D approach to simultaneously invert for resistivity structure and distortion parameters. NUI Galway, defended successfully on 8th March, 2010.

2.2.2 Petrophysical modelling

Two lines of ongoing research with respect to understanding the lithospheric structure and evolution of Southern Africa are being followed by Muller and Jones, in collaboration with Fullea, at DIAS.

(i) SAMTEX 2-D electrical resistivity models across the Kaapvaal Craton indicate a lithospheric thickness of the order of 220 km or greater for the central core of the craton. In contrast, a recently published S-wave receiver function study and several surface wave studies suggest that the Kaapvaal lithosphere is characterised by an approximately 160 km thick high-velocity “lid”, the base of which is inferred to represent the “lithosphere-asthenosphere boundary”. Evidence from mantle xenolith

pressure-temperature arrays derived from Mesozoic kimberlites found across the Kaapvaal Craton requires that the base of the "thermal" lithosphere be at least 220 km deep, while the presence of richly diamondiferous kimberlites across the Kaapvaal Craton is also impossible to reconcile with a 160 km lithospheric thickness.

The recently developed LitMod software package is being used to derive both seismic-velocity and electrical-resistivity models for the lithosphere that are fully chemically, petrologically and thermodynamically consistent. These models will provide the basis for assessing whether the above apparently disparate views of the Kaapvaal lithosphere – provided by seismic, magnetotelluric and xenolith studies – can be reconciled.

(ii) 2-D electrical resistivity models of the Rehoboth Terrane, constrained by chemistry and pressure-temperature (P-T) studies of mantle xenoliths from the Gibeon kimberlite field, indicate that the Rehoboth is characterised by a present-day lithospheric thickness of ~180 km, a ~45 mWm^{-2} geotherm and a chemically refertilised lower lithospheric-mantle. There is also evidence from these xenolith studies to suggest that the Rehoboth Terrane might have, at some time in its past, been characterised by a cooler "Kaapvaal-like" palaeo-geotherm (40 – 42 mWm^{-2}) and a thicker lithosphere (~210 – 220 km). It has been proposed that Mesozoic thermalism and magmatism at ~ 75 Ma might account for the modifications observed in lithospheric structure of the Rehoboth Terrane – i.e., chemical refertilisation and lithospheric thinning. Such modifications would generate a significant and predictable isostatic response that can be tested against the geological record of erosion (of Karoo Supergroup stratigraphy) and deposition (of Kalahari Group sediments) since 75 Ma.

The LitMod approach is being used to derive petrophysically consistent models of lithospheric-mantle density and predictions of the isostatic response to the putative lithospheric modifications described above. In tandem, we are systematically re-modelling SAMTEX data across the Rehoboth and adjacent terranes, focussing on the shallow crustal structure above 2,000 m depth, to determine whether the extent of preservation and/or erosion of the Karoo Supergroup and the thickness the Kalahari Group deposits can be reconciled with these predictions of isostatic uplift and/or subsidence.

Presentations:

Muller, M.R., J. Fullea, and **A.G. Jones**. Magnetotelluric and xenolith constraints on the thermal and chemical lithospheric-mantle structure of the Kaapvaal Craton and Rehoboth Terrane, Southern Africa. 20th Electromagnetic Induction Workshop, Giza, Egypt, 18-24 September 2010.

Muller, M.R., J. Fullea, and **A.G. Jones**. Reconciling electromagnetic and seismic constraints on lithospheric thickness and composition of the Kaapvaal Craton, South Africa. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

2.3 Central African Magnetotelluric Experiment (CAMTEX)

Dr. Mark Muller, collaborating with Prof. Alan Jones, submitted in September 2010 a research proposal ("CAMTEX-I: Central African Magnetotelluric Experiment. Phase I: Craton to Rift") to the Research Frontiers Program of Science Foundation Ireland. The proposed research aims to image and understand the lithospheric structures and processes taking place within the most distal sector of the East African Rift System (EARS) in western Zambia that is characterised by very early-stage (incipient) rifting.

Continental rifting, particularly its inception, is a poorly understood fundamental plate-tectonic process. With CAMTEX, the focus will shift from structures and processes present in old Precambrian terranes (as studied by SAMTEX) to those present in regions of active tectonics and in the transition zone between the two. CAMTEX will investigate how active tectonics interacts and modifies the ancient cores of the continents. The active tectonic process occurring in eastern Africa is continental breakup through the propagation of the EARS into south-central and southern Africa.

While the outcome of our SFI research proposal will only be decided in April 2011, CAMTEX has had expressions of support from industry collaborators (in the form of funding and donations of existing data in the DRC) that would allow the project to proceed in some form regardless of the outcome of the funding proposal. CAMTEX will link with and lever a current NSF-funded multidisciplinary investigation in eastern Zambia of the southern extension of the EARS with prior SAMTEX work in Botswana and existing industry data. Deep-probing magnetotelluric surveys will interrogate the nature and geometries of structures within the lithospheric- and asthenospheric-mantle for signatures of rifting, particularly lateral thermal variations, given the high sensitivity of electrical conductivity to temperature, and also to identify the dominant stress direction from electrical anisotropy.

2.4 PICASSO-TopoMed

A.G. Jones, J. Fullea (PDF), J. Schmoldt (PhD), D. Kiyan (PhD)

The PICASSO and TopoMed projects have a common theme of studies to understand the dynamics of the Western Mediterranean. PICASSO funding, from SFI, essentially covers research in the Iberian Peninsula, whereas TopoMed funding, from IRCSET, covers research in Morocco.

Both of these are Irish efforts as part of larger multi-national, multi-institutional, multi-disciplinary programmes. PICASSO involves scientists from Spain, Morocco, Ireland, U.S.A., Canada, and Ireland. TopoMed involves scientists from the Netherlands, Germany, Italy, Spain, and Ireland.

In addition, there is a marine EM component, AMELIE, in the Alboran Sea between the Iberian Peninsula and Morocco that is being undertaken by Spanish, German and U.S.A. scientists.

2.4.1 PICASSO

PICASSO: Programme to Investigate Convecting Alboran Sea System Overturn

The PICASSO project is funded by Science Foundation Ireland (SFI) and is linked with international research institutes within Europe and North America (USA and Canada). Phase I of the PICASSO project investigates the Iberian Peninsula

subsurface in order to enhance knowledge about the local geology as well as improve understanding of the Miocene Africa-Europe continental collision.

Inferred electric conductivity distribution is used to identify subsurface structures of the Iberian mainland, such as Mohorovičić discontinuity and Lithosphere-Asthenosphere Boundary (LAB). Results from the PICASSO project are contrasted with findings from various other geophysical studies and conclusions are drawn about alpine orogenic and subsequent tectonic processes which shaped the Iberian Peninsula.

Motivated by the observed oblique strike direction at crust and mantle depths beneath central Iberia, a novel approach for inversion of electromagnetic responses was invented and employed. The approach utilises advantages of recent anisotropic inversion algorithms to significantly improve reconstruction of subsurface structures using 2D inversion techniques for subsurfaces with oblique strike directions. Results of the PICASSO project have been presented to a wide audience at international conferences in Cairo and the USA.

PICASSO web site: http://www.geophysics.dias.ie/projects/PICASSO/index.htm

Presentations:

Schmoldt, J.-P., A.G. Jones, M. Muller, D. Kiyan, C. Hogg, and O. Rosell. Realizing 2D magnetotelluric inversion in the case of divergent geoelectric strike directions in the crust and mantle. AGU Fall Meeting, San Francisco, 13 - 17 December 2010.

Schmoldt, J.-P., A.G. Jones, C. Hogg, and O. Rosell. Magnetotelluric investigation of the Iberian lithosphere and asthenosphere beneath Tajo Basin and Betic Cordillera (PICASSO Phase I). 20th IAGA EM Induction Workshop, Cairo, 18 - 24 September 2010.

2.4.2 TopoMed

TopoMed: Plate re-organization in the western Mediterranean: Lithospheric causes and topographic consequences

A Common Research Project within the TOPO-EUROPE EUROCORES programme

Despite several scenarios have been proposed to explain the tectonic evolution of the western Mediterranean region, the geodynamics of the region is still a matter of debate. The TopoMed project's main goal is to determine the nature of the major crustal and upper mantle boundaries and to define electric structures that provide information on understanding the tectonic evolution of the Atlas Mountains of Morocco.

In this study, the magnetotelluric (MT) experiment across the Atlas Mountains region that started in September, 2009 and ended in February, 2010, comprising acquisition of both broad-band (BBMT) and long-period (LMT) MT data along two profiles (**Figure 1**). One profile is oriented N-S crossing the Middle Atlas through the Central High Atlas to the east, while the other is NE-SW oriented crossing the western High Atlas towards the Anti Atlas in the west. Along the profiles 24 LMT and 44 BBMT stations were deployed at approximately 20 km and 10 km intervals, respectively. Since completion of fieldwork all MT data have been processed with modern robust multi-remote reference methods, and submitted to comprehensive strike and dimensionality analysis. For the first profile, MEK, two clearly depth-differentiated

strike directions are apparent for crustal (5-35 km) and lithospheric (50-150 km) depth ranges. These two orientations are approximately consistent with the NW-SE Africa-Eurasia convergence acting since the late Cretaceous, and the NNE-SSW Middle Atlas, where Miocene to recent Alkaline volcanism is present. Two-dimensional (2-D) anisotropic electrical resistivity models were derived independently for both 50^o and 20^o E of N strike directions. Our preliminary results from the MEK profile reveal a middle to lower crustal conductive layer stretching from the Middle Atlas southward towards the High Moulouya basin. Another conductive area at lower crust found beneath the Anti Atlas. The most resistive (and therefore potentially thickest) lithosphere is found beneath the Central High Atlas.

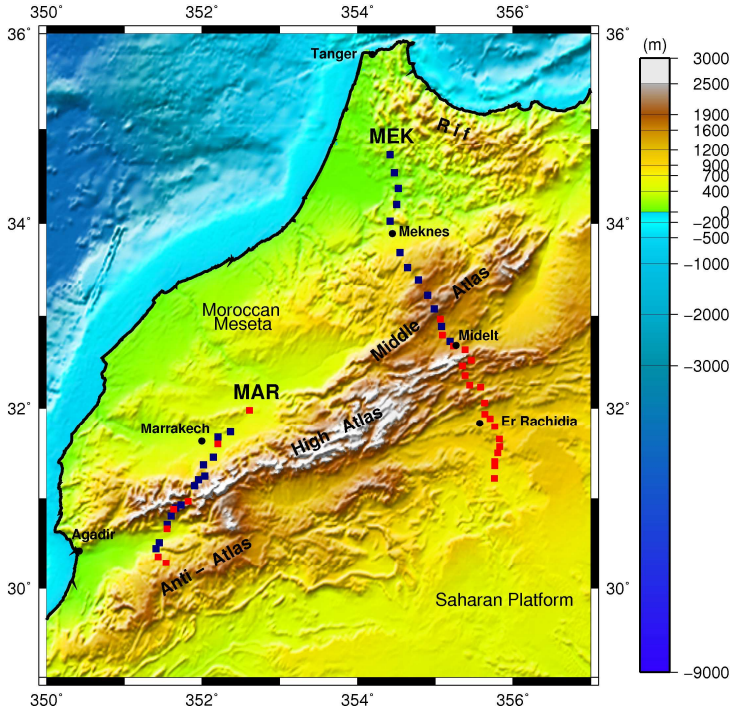


Figure 1: Topographic map of the study area showing the MT site locations across the Atlas Mountains. The red squares represent broad-band only sites and the blue ones represent both broadband and long period sites.

In the framework of future work, the geoelectrical modelling results will be tested against other geophysical observables (i.e., topography, geoid and gravity anomalies, surface heat flow and seismic velocities) using the software package LitMod. This software combines petrological and geophysical modelling of the lithosphere and sub-lithospheric upper mantle within an internally consistent thermodynamic-geophysical framework, where all relevant properties are functions of temperature, pressure and composition.

Publication:

Ledo, J., **A.G. Jones**, A. Siniscalchi, J. Campanyà, **D. Kiyan**, G. Romano, M. Rouai, and TopoMed MT Team, 2011. Electrical signature of modern and ancient tectonic processes in the crust of the Atlas mountains of Morocco, *Physics of the Earth and Planetary Interiors*, accepted, 24 January 2011.

Presentations:

Kiyan, D., A.G. Jones, C. Hogg, J. Ledo, A. Siniscalchi, and the PICASSO Phase II Team. PICASSO Phase II – TopoMed. MT investigations over the Atlas Mountains of Morocco: preliminary results. 20th Electromagnetic Induction Workshop, Egypt, 18–24 September 2010.

Kiyan, D., A.G. Jones, J. Fullea, C. Hogg, J. Ledo, A. Siniscalchi, M. Rouai, J. Campanyà, P.P. Moretti, G. Romano, and the PICASSO Ph. II Team. Magnetotelluric data from the Atlas Mountains of Morocco as part of TopoMed: preliminary results. 6th TOPO□EUROPE Workshop, Hotel Klækken, Hønefoss, Norway, 4-7 November 2010.

Kiyan, D., A.G. Jones, J. Fullea, C. Hogg, J. Ledo, A. Siniscalchi, J. Campanya, and the PICASSO Phase II Team. Crustal and lithospheric imaging of the Atlas Mountains of Morocco inferred from magnetotelluric data, AGU Fall Meeting, San Francisco, USA, 13–17 December 2010.

Schmoldt, J.-P., A.G. Jones, C. Hogg, and O. Rosell. Magnetotelluric investigation of the Iberian lithosphere and asthenosphere beneath Tajo Basin and Betic Cordillera (PICASSO - Phase I). 20th Electromagnetic Induction Workshop, Giza, Egypt, 18-24 September 2010.

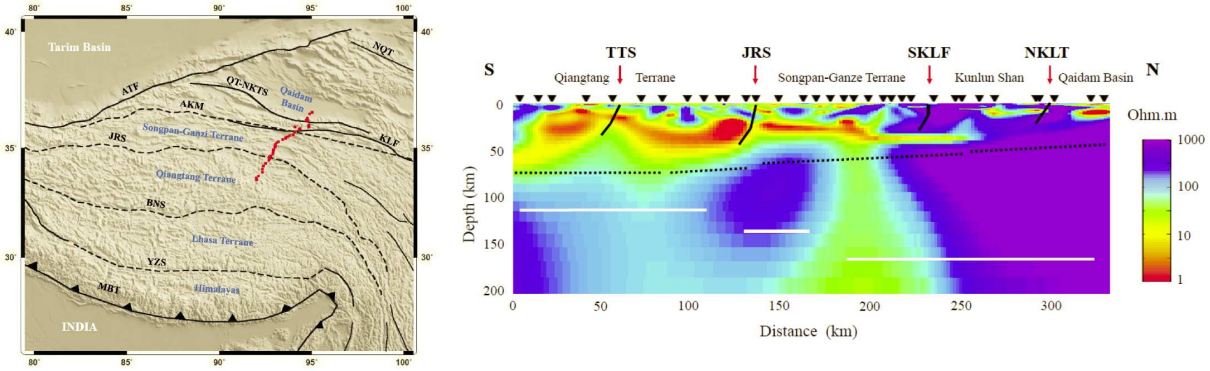
Schmoldt, J.-P., A.G. Jones, M. Muller, D. Kiyan, C. Hogg, and O. Rosell. Realizing 2D magnetotelluric inversion in the case of divergent geoelectric strike directions in the crust and mantle - Case study using synthetic models and real data from the Tajo Basin (Spain). AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

2.5 INDEPTH

A.G. Jones, J. Vozar (PDF), F. Le Pape (PhD), with colleagues from China University of Geosciences Beijing, the University of Alberta, Cornell University, Stanford University, and INDEPTH collaborators

Magnetotelluric (MT) data from the Phase III 600 line of INDEPTH (International Deep Profiling of Tibet and Himalaya) project were re-analyzed and re-modelled in preparation for the MT Phase IV of the project focusing on the northern margins of the Tibetan Plateau. Although, in general, the dominant features in the new model are the same as the prior models, the new model is far more focussed, and fits the data better, both overall and locally. It is less "smooth" and geometrically more complex, exhibiting greater lateral variability. The South Kunlun Fault (SKLF) can be identified as a boundary between a conductive middle crust weakened by (wet) partial melt, and a dry and cold resistive crust north of the fault, and can be reasonably concluded to be a rheological boundary. However, crustal anisotropic modelling raises an interesting issue concerning a possible injection of partial melt further north, creating melt interconnectivity in the northeast direction only. This feature may be associated to the northward growth of the Tibetan Plateau. Finally, the mid-crustal conductive features, south of the profile, exhibit an interesting correlation with the surface thrusting of the northern Tibetan plateau, implying structural control of the conductivity distribution. This correlation raises an interesting issue concerning the time relation between the tectonic features of the area and partial melt, which we will continue to explore with the new data acquired in 2010. Between May and July 2010,

long-period MT (LMT) data were acquired as part of the INDEPTH Phase IV in collaboration with the CUGB China and the University of Alberta Canada. The acquisition includes a profile east of the 600 line to complement seismic data already collected in the area. This new profile is still in a processing stage. However, once associated with the 600 line results and the seismic data, it will provide a good support in understanding the northern margins of the Tibetan Plateau.



New 600 line resistivity model associated to the local tectonic. The anisotropic modelling defines three models, xx (horizontal resistivity across profile), yy (horizontal resistivity along profile) and zz (vertical resistivity). However, the model presented here is only the yy result. Apart from showing the same structures as for xx and zz models, the yy model characterizes the best the profile as it highlights the extension of the crustal conductor further north. This particular feature can be interpreted as northward melt injection beneath the Kunlun Shan. Furthermore, the different offets in the conductive layer show some correlation with the local thrusting. The moho (dark dotted line) and LAB (white line) depths are taken from Jimenez-Munt et al., 2008.

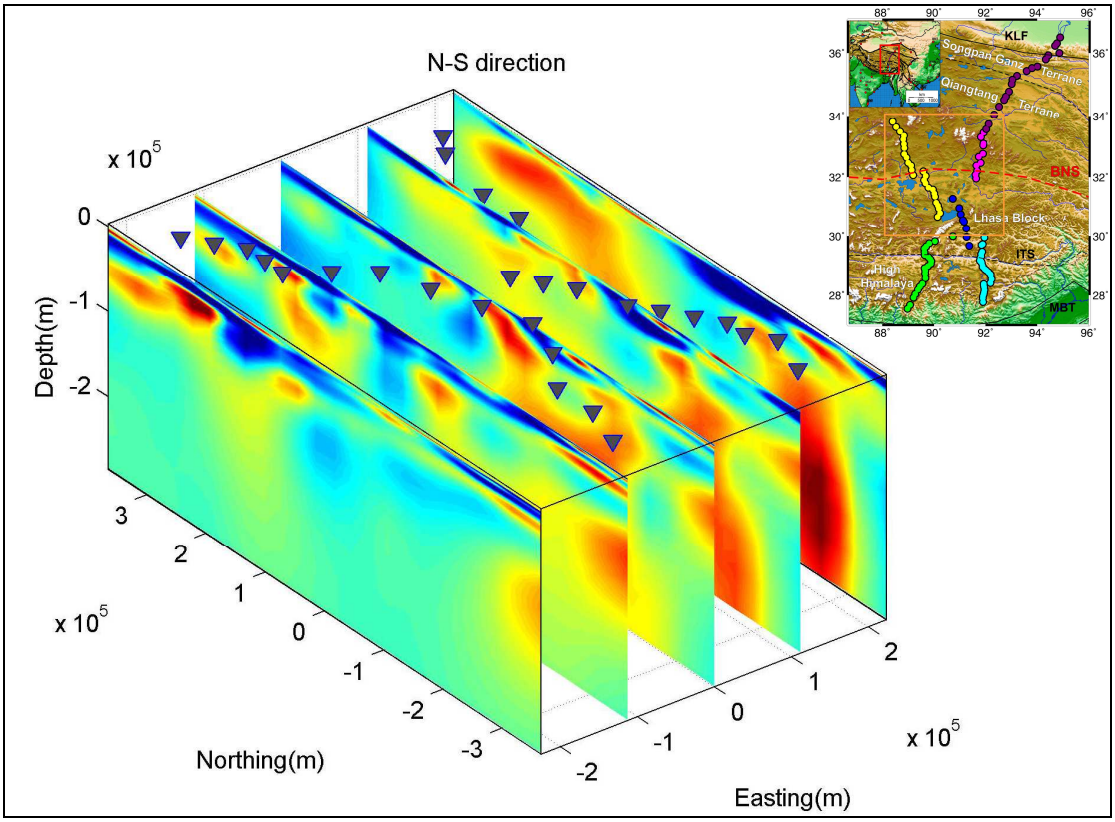
Ref: Jimenez-Munt, I., M. Fernandez, J. Verges and J. P. Platt (2008), Lithosphere structure underneath the Tibetan Plateau inferred from elevation, gravity and geoid anomalies, Earth and Planetary Science Letters, 267, 276-289.

The research of Vozar focused on 1D, 2D and 3D deep-probing electromagnetic studies of the Tibetian Plateau. In a frame of the SFI grant INDEPTH IV, the re-modelling of existing INDEPTH data was carried out, applying new inversion tools and new considerations such as anisotropy investigations. From May to July 2010, he was part of the INDEPTH IV field work team which acquired the long period magnetotelluric (LMT) data in the northern margins of the Tibetan plateau in collaboration with the CUGB China and the University of Alberta Canada. The survey is characterized by two profiles crossing the Altyn Tag fault and one profile crossing the Kunlun fault.

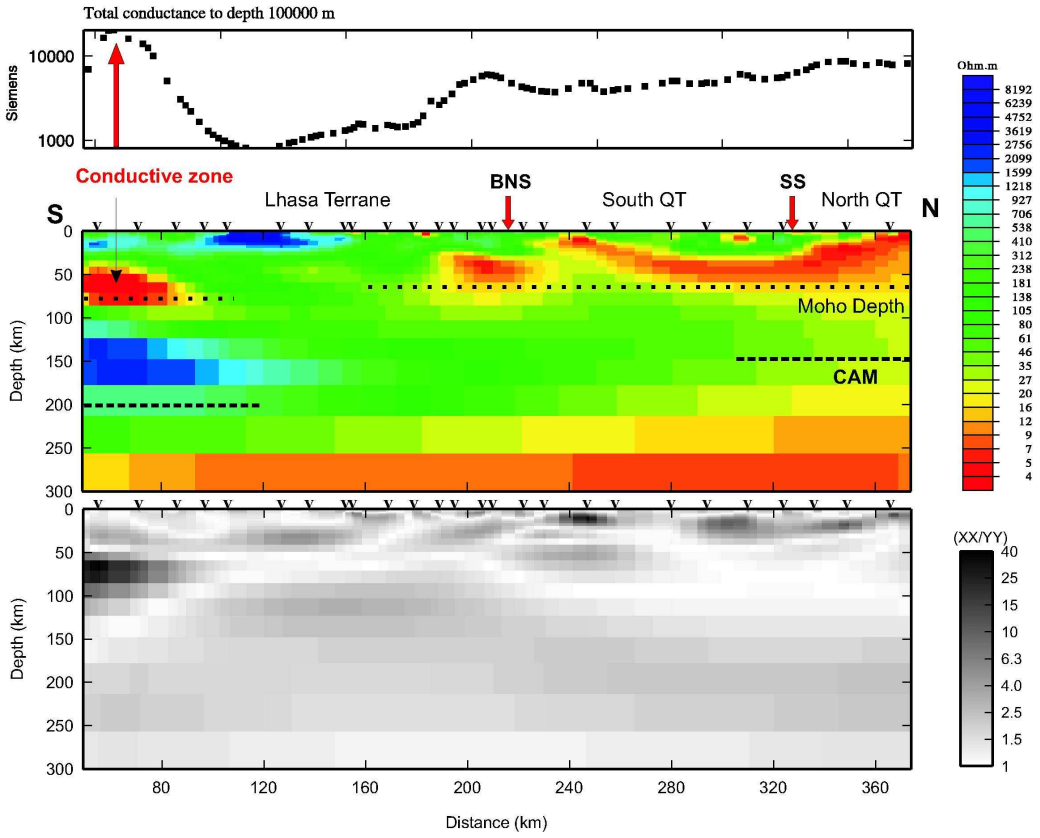
The studies presented on conferences and in the paper using MT INDEPTH data and observatory magnetovariational data describe the along-strike and across-strike geoelectrical structures of the Banggong-Nujiang Suture, thickness of lithosphere in INDEPTH region and developing new magnetovariational method improves merged electromagnetic responses data. The MT models exhibit that the most conductive lower crust anomaly is situated in the lower crust of the southern part of the 500 line, i.e., in Lhasa Terrane, and estimation of its conductance is similar to the conductive channels described in recent papers. Also anisotropic modelling indicates strong

anisotropy oriented in regional strike direction for this southern part of profile. The bottom boundaries of the conductive layers resulting from 2-D MT inversions are in agreement with the Moho boundary depth for this region, although recent Receiver Function estimates suggest that the Moho is some 8 km shallower beneath the Qiangtang Terrane than beneath the Lhasa Terrane, which could explain the far higher conductance of the middle and lower crust beneath that terrane compared to the Lhasa Terrane. The deep resistivity models and also previous 2D models show the existence of upper mantle conductive layers localized at a depth more than 200 km in southern part of the profile and more than 100km in northern. These layers can indicate asthenosphere and estimate thickness of the lithospheres in the India-Euroasia collision zone. As an additional constrain we propose a more petro-physically driven approach to modelling MT data based on the software package LitMod. The geoelectrical modelling results are tested against other geophysical observables (i.e., topography, geoid and gravity anomalies, surface heat flow and seismic velocities) using the LitMod.

The results present new geometrical complexities and exhibit interesting features in crust and upper mantle missed on the initial interpretations to understand the nature of the Plateau and its evolution.



3D MT inversion model for Central Tibetan Plateau.



Line 500 final interpretation for long period sites. BNS - the Banggong-Nujiang Suture, QT - the Qiangtang Terrane, horizontal gray lines Niblett- Bostick depths, SS - Shuanghu Suture, ···· - Moho Depth, ----- - CAM (Conductive upper mantle). Upper part of figure is total conductance distribution along profile. Bottom part is estimation of anisotropy.

Publications:

Le Pape, F., **A.G. Jones**, **J. Vozar**, M.J. Unsworth, W. Wei, and the INDEPTH MT team, 2010. Evolution of crustal and upper-mantle structure in Northern Tibet from INDEPTH magnetotelluric data. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010, Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Vozar, J., A.G. Jones, F. Le Pape, W. Wei, M.J. Unsworth, and the INDEPTH MT team, 2010. Electromagnetic studies of Banggong-Nujiang suture architecture from INDEPTH magnetotelluric profiles and magnetovariational data. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010, Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Wei, W., Jin Sheng, G. Ye, **A.G. Jones**, M.J. Unsworth, and the INDEPTH MT team, 2010. Regional resistivity structure of the Tibetan Plateau. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010, Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Wei, W., S. Jin, G. Ye, M. Deng, J. Jing, M. Unsworth, and **A.G. Jones**, 2010. Conductivity structure and rheological property of Lithosphere in Southern Tibet

inferred from super-broadband magnetotelluric sounding. Science in China Series D: *Earth Sciences*, **53**, 1–14.

Presentations:

Le Pape, F., A.G. Jones, J. Vozar, M.J. Unsworth, W. Wenbo, and the INDEPTH MT Team. Evolution of the crust and upper mantle structure in Northern Tibetan Plateau from INDEPTH magnetotelluric data. 25th Himalaya-Karakoram-Tibet Workshop San Francisco, June 2010.

Le Pape, F., A.G. Jones, J. Vozar, M.J. Unsworth, W. Wenbo, and the INDEPTH MT Team. Evolution of the crust and upper mantle structure in Northern Tibetan Plateau from INDEPTH magnetotelluric data. 20th Electromagnetic Induction Workshop, Giza, Egypt , 18 - 24 September 2010.

Le Pape, F., A.G. Jones, J. Vozar, M.J. Unsworth, W. Wenbo, and the INDEPTH MT Team. Northern Tibet crustal and lithospheric mantle structures inferred from INDEPTH magnetotelluric data. AGU, San Francisco, USA, 13 - 17 December 2010.

Vozar, J., A.G. Jones, F. Le Pape, W. Wenbo, M.J. Unsworth, and the INDEPTH MT Team. Electromagnetic studies of Banggong-Nujiang suture architecture from INDEPTH magnetotelluric profiles and magnetovariational data. 25th Himalaya-Karakoram-Tibet Workshop, San Francisco, USA, June 2010.

Vozar, J., A.G. Jones, F. Le Pape, M.J. Unsworth, W. Wenbo, J. Sheng, Y. Gaofeng, and the INDEPTH MT Team. Electromagnetic studies of the central Tibetan Plateau from INDEPTH magnetotelluric profiles and magnetovariational data, IAGA WG 1.2 on Electromagnetic Induction in the Earth. 20th Workshop, Giza, Egypt, 18-24 September 2010.

Vozar, J., A.G Jones, F. Le Pape, M.J. Unsworth, W. Wenbo, and the INDEPTH MT Team. Electromagnetic studies of Lithospheric Mantle and Crust in the Central Tibetan Plateau from INDEPTH magnetotelluric profiles and magnetovariational data. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

2.6 Magnetotelluric theory

2.6.1 Electrical anisotropy

The dykes of the 50-60 km wide and about 1500 km long Okavango dyke swarm have an average width of 17m. Therefore, the dykes are more an anisotropic feature rather than a 2D structure for the MT scale. Hence, simple synthetic tests based on a layered background have been performed. An anisotropic block of variable width, thickness and anisotropy strike direction were placed in the crust, responses were calculated using forward modelling and then the synthetic data were analysed and processed analogous to the real data. Finally a standard 2D isotropic inversion was performed. The results showed that the effects of the presence of an anisotropic block vary from negligible to significant depending on the scenario. The scenario most similar to the Okavango dyke swarm case history indeed shows a downwards bending of the lower crustal conductor as found in the real data 2D isotropic resistivity model. Not only the crustal structures are represented incorrectly but there is also a potentially overestimation of the LAB depth.

Publication:

Miensopust, M.P., **A.G. Jones**, 2011. Artifacts of isotropic inversion applied to anisotropic magnetotelluric data. Paper prepared in 2010 and will be submitted to *Geophys. J. International* in 2011.

Presentation:

Miensopust, M.P., and **A.G. Jones**. Artifacts of isotropic inversion applied to anisotropic magnetotelluric data. 20th Workshop of IAGA WG 1.2 on Electromagnetic Induction in the Earth, Giza, Egypt, 18 - 24 September 2010.

2.7 Other electromagnetic research

Publications:

Cook, F.A., D.J. White, **A.G. Jones**, D.W.S. Eaton, J. Hall, and R.M. Clowes, 2010. How the crust meets the mantle: Lithoprobe perspectives on the Mohorovicic discontinuity and crust–mantle transition, *Canadian Journal of Earth Sciences*, **47**, 315–351, doi: 10.1139/E09-076.

Garcia. X., and **A.G. Jones**, 2010. Internal structure of the western flank of the Cumbre Vieja volcano (La Palma, Canary Islands) from land magnetotelluric imaging, *J. Geophys. Res. - Solid Earth*, **115**, B07104, doi: 10.1029/2009JB006445.

Jones, A.G., J. Plomerova, T. Korja, F. Sodoudi, and W. Spakman, 2010. Europe from the bottom up: A statistical examination of the central and northern European lithosphere-asthenosphere boundary from comparing seismological and electromagnetic observations, *Lithos*, **120**, 14-29.

Vozar, J., and V. Y. Semenov, 2010. Compatibility of induction methods for mantle soundings, *J. Geophys. Res*., **115**, B03101, doi:10.1029/2009JB006390

3 Petro-physical modelling

J. Fullea (PDF), A.G. Jones, M. Muller (Schrödinger Fellow)

3.1 TOPO-MED

In this work we study the present-day thermal and compositional 3D structure of the lithosphere beneath the Atlantic-Mediterranean Transition Region (AMTR). The AMTR comprises the western segment of the Africa-Eurasia plate boundary, encompassing two main large-scale tectonic domains: the Gibraltar Arc System and the Atlas Mountains. We apply an integrated and self-consistent geophysical-petrological methodology (LitMod3D) that combines elevation, gravity, geoid, surface heat flow, and seismic data and allows modelling of compositional heterogeneities within the lithospheric mantle. Our results reveal large variations in the depth of the Moho and the lithosphere-asthenosphere boundary (LAB) as well as a lack of spatial correlation between the thicknesses of these two boundaries. The Moho essentially mimics the topography whereas the LAB is shallower beneath the central and eastern Alboran Basin and all along the High, Middle and Anti Atlas, coinciding with the loci of Cenozoic volcanism. Deeper LAB depths are found along the central and western Betics and the Moroccan Atlantic margin with values exceeding 230 km

beneath the Rif and the Sahara Platform. We find that the average bulk composition of the lithospheric mantle corresponds to that of a typical Tecton (i.e. Phanerozoic) domain, with the exceptions of the Sahara Platform, the Alboran Basin, and Atlas Mountains. Distinct mantle compositions are required in these areas to make model predictions and geophysical observables compatible.

3.2 SAMTEX

In a case-study from southern Africa we examine the Proterozoic Rehoboth Terrane and the Archaean Kaapvaal Craton. The LAB of the two terranes has been investigated using the software package LitMod. This software combines petrological and geophysical modelling of the lithosphere and sub-lithospheric upper mantle within an internally consistent thermodynamic-geophysical framework, where all relevant properties are functions of temperature, pressure and composition. In particular, LitMod is used in this work to define realistic temperature, pressure, density and electrical conductivity distributions within the upper mantle, and to characterize the mineral assemblages given bulk chemical compositions as well as water contents. This allows us to determine the topography (local isostasy), surface heat flow and magnetotelluric responses for different models of lithospheric composition and structure. Critically, we also assess the extent to which the lithospheric and sub-lithospheric mantle might be wet or dry within each terrane and the implications of the (potentially depth-variable) hydration state with respect to the lithospheric evolution of each terrane.

3.3 Other Activities

Collaboration with other researchers from DIAS: S. Lebedev (joint inversion of Rayleigh and Love dispersion curves, elevation, surface heat flow and mantle composition in Mongolia-Baikal Rift area), J. Vozar (lithospheric modelling of MT, elevation, surface heat flow and mantle composition data in the Qiangtang and Lhasa Terranes, Tibet); and outside DIAS: Dr. Zuzana Tasarova from the Inst. of Geosciences, Univ. zu Kiel, Germany (3D petrophysical-geophysical modelling of Western Carpathian-Pannonian Basin region using LitMod3D) and Dr. Sofie Gradmann from NGU, Trondheim, Norway (modelling the topography of the Scandes using LitMod3D).

Publications:

Jiménez-Munt, I., M. Fernàndez, J. Vergés, D. Garcia-Castellanos, **J. Fullea**, M. Pérez-Gussinyé, and J.C. Afonso, 2010. Decoupled crust-mantle accommodation of Africa-Eurasia convergence in the NW-Moroccan margin, submitted to *J. Geophys. Res*.

Fullea, J., J.C. Afonso, M. Fernàndez, J. Vergés, 2010. The structure and evolution of the lithosphere - asthenosphere boundary beneath the Trans-Mediterranean region, *Lithos*, **120**, 1-2, 74-95.

Jiménez-Munt, I., M. Fernàndez, J. Vergés, J.C. Afonso, D. Garcia-Castellanos, and **J. Fullea,** 2010. The lithospheric structure of the Gorringe Bank: insights into its origin and tectonic evolution, *Tectonics*, **29**, TC5019, doi:10.1029/2009TC002458.

Presentations:

Fullea, J., M.R. Muller, and **A.G. Jones**. The electrical conductivity of the continental lithospheric mantle: new insights from integrated geophysical and petrological modelling. Application to the Kaapvaal Craton and Rehoboth Terrane, southern Africa. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010, T21C-2172.

Muller, M.R., J. Fullea, A.G. Jones. Reconciling electromagnetic and seismic constraints on lithospheric thickness and composition of the Kaapvaal Craton, South Africa. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010, DI11A-1839.

Kiyan, D., A.G. Jones, J. Fullea, C. Hogg, J. Ledo, A. Siniscalchi, J. Campanyà, and the PICASSO Ph. II Team. Crustal and lithospheric imaging of the Atlas Mountains of Morocco inferred from magnetotelluric data. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010, T23C-2281.

Fullea, J., M. Fernàndez, **A.G. Jones, D. Kiyan**. Lithospheric structure in Atlantic-Mediterranean Transition Region. Insights from integrated geophysical and petrological modelling. 6th TOPO-EUROPE Workshop, Hønefoss, Norway, 4–6 November 2010.

Kiyan, D., A.G. Jones, J. Fullea, C. Hogg, J. Ledo, A. Siniscalchi, M. Rouai, J. Campanyà, P.P. Moretti, G. Romano, and the PICASSO Ph. II Team. Magnetotelluric data from the Atlas Mountains of Morocco as part of TopoMed: preliminary results. 6th TOPO-EUROPE Workshop, Hønefoss, Norway, 4–6 November 2010.

Gradmann, S., J. Ebbing, C. Pascal, and **J. Fullea.** Integrated modelling investigating the link between topography and lithosphere of the Scandes. GeoMod 2010, Lisbon, 27-29 September 2010.

Muller, M.R., J. Fullea, and **A.G. Jones**. Magnetotelluric and mantle xenolith constraints on the thermal and chemical lithospheric-mantle structure of the Kaapvaal Craton and Rehoboth Terrane, southern Africa. 20th Electromagnetic Induction Workshop, Egypt, 18-24 September 2010.

Fullea, J., M. Fernandez, J.C. Afonso, J. Verges, and H. Zeyen. The structure and evolution of the lithosphere - asthenosphere boundary beneath the Atlantic-Mediterranean Transition Region. EGU, General Assembly, Vienna, EGU2010-2532, (solicited).

Fullea, J., M.R. Muller, A.G. Jones, and **D. Khoza**. Fully self-consistent modelling of the southern African lithospheric/sublithospheric mantle using elevation, surface heat flow, magnetotelluric, surface wave, and petrological data. EGU, General Assembly, Vienna, EGU2010-6807-1.

Alasonati-Tasarova, Z., M. Bielik, H-J. Götze, J.C. Afonso, and **J. Fullea.** New large-scale lithospheric model of the Western Carpathian-Pannonian Basin region based on the 3-D gravity modelling. EGU, General Assembly, Vienna, EGU2010-4199.

4 Joint Inversion

A.G. Jones, E. Roux (PDF), E. Mandolesi (PhD)

The joint inversion of seismic surface waves and MT data for anisotropic 1D Earth structure was completed and the first paper submitted for publication (Roux et al., 2011).

After successful results obtained by joint inversion of long-period MT data and teleseismic Receiver Function (RF) and Surface Wave (SW) dispersion curves for a 1D isotropic media using Genetic Algorithm (Moorkamp et al., 2007, 2010; Roux et al., 2011), further investigation led to development of a different approach to the constraining scheme in the inversion process.

A 2D inversion scheme based on GA and a geometrical link between electromagnetic data and a fixed seismic structure has been presented at IAGA 2010 (Mandolesi et al., 2010) and the inefficiency of GA in a 2D environment was emphasized in this work.

Genetic Algorithm, inefficient in a 2D isotropic media, has been replaced by a classic Levenberg-Marquardt (LM) method while the concept of maximization of mutual information (MI) has been introduced. MI is a measure of distance between two images, so its introduction of the scheme allows to drive the inversion result in toward a reference model independently on the reference source.

1D isotropic inversion code has been developed an tested on synthetic data and the results were presented at the AGU Fall Meeting (Mandolesi and Jones, 2010). Due the high feedback from this presentation we, Mandolesi, Jones, and colleagues, decided to test the MI driven inversion process to a real dataset from Kaapval craton. This work is in progress and results will be presented at EGU 2011 conference.

Publications:

Moorkamp, M., **A.G. Jones**, and S. Fishwick, 2010. Joint inversion of receiver functions, surface wave dispersion, and magnetotelluric data. *J. Geophys. Res.*, **115**, B04318, doi:10.1029/2009JB006369.

Roux, E., M. Moorkamp, **A.G. Jones**, M. Bischoff, B. Endrun, **S. Lebedev**, and T. Meier, 2011. Joint inversion of long-period magnetotelluric data and surface-wave dispersion curves for anisotropic structure: Application to data from Central Germany. *Geophys. Res. Lett.*, **38**, L05304, doi:10.1029/2010GL046358, pp 5.

Presentations

Mandolesi E., **A.G. Jones,** and **E. Roux.** Inversion of magnetotelluric data with seismic constraints using a structural approach. Contributed paper at IAGA (poster), Giza, Egypt, 18-24 September 2010.

Mandolesi E, A.G. Jones, and **E. Roux**. Inversion of magnetotelluric data with seismic constraints using a structural approach. Contributed paper at BGA (poster), Bristol, U.K., 2010.

Mandolesi E., and **A.G. Jones.** Seismic constraints in magnetotelluric inversion. Contributed paper at AGU Fall Meeting (poster), San Francisco, USA, 13-17 December 2010.

Roux, E., M. Moorkamp, and **A.G. Jones**. Joint Inversion of long-period magnetotelluric data and surface-waves dispersion curves for anisotropic structure: application to Central Germany. 20th Electromagnetic Induction Workshop, Giza, Egypt, 18-24 September 2010.

5 Geodynamic research activities

Group Leader: Professor Zdenek Martinec

Zdenek Martinec continued in glacial isostatic adjustment (GIA) modelling, the estimates of present-day mass balances in Antarctica and Greenland, interpreting CHAMP magnetic data and preparing for interpreting SWARM magnetic data by modelling magnetic field induced by ocean circulations and by formulating the adjoint method for downward continuation of magnetic secular variations field from the Earth's surface down to the core-mantle boundary.

The Gravity Recovery and Climate Experiment (GRACE) provide important constraints on glacial-isostatic adjustment and present-day ice-mass change. Martinec and colleague Dr. I. Sasgen (GeoForschungsZentrum Potsdam) performed a joint inversion of GRACE gravity data from August 2002 to August 2008 and InSAR data (years of outflow measurement 1992, 1996 and 2006) to determine the mass balances of eight West Antarctic drainage basins. Depending on the GRACE errors approximately three to five combined drainage basins can be resolved by GRACE data alone. For the reduced number of four combined drainage basins, values from InSAR and GRACE agree within ∼±5 Gt/yr for most of the drainage basins.

The GRACE total mass loss in West Antarctica is of −91.0 ± 3.5 Gt/yr (years 2002 to 2008), which is, despite being in agreement with previous GRACE estimates, by ∼26 Gt/yr lower than the values derived from InSAR. There is evidence that this difference arises from anomalously large accumulation within the GRACE time interval (August 2002 to August 2008) in the Amundsen Sea sector and possibly from an overestimation of ice thickness for parts of the Bellinghausen Sea sector underlying the InSAR mass-budget values.

We further used the GRACE gravity data to estimate interannual ice-mass variations along the Antarctic Peninsula (AP) and in the Amundsen Sea Sector (AS) for the years 2002 until 2009. These data correlate well ($r \approx 0.7$) with accumulation variations based on the net precipitation from the European Centre for Medium Range Weather Forecasts. Moreover, mass signals for AP and AS are anti-correlated in time ($r \approx -0.4$) and contain El Niño Southern Oscillation signatures related to the strength of the Amundsen Sea Low pressure system, that has a dominant influence on West Antarctic atmospheric moisture transports. The GRACE interannual mass variations exhibit root-mean squared amplitudes of: 16.4 ± 4.1 Gt (AP) and 28.6± 10.5 Gt (AS), which are significant compared to the mean annual mass loss of −110.2 ± 6.7 Gt/a in coastal West Antarctica.

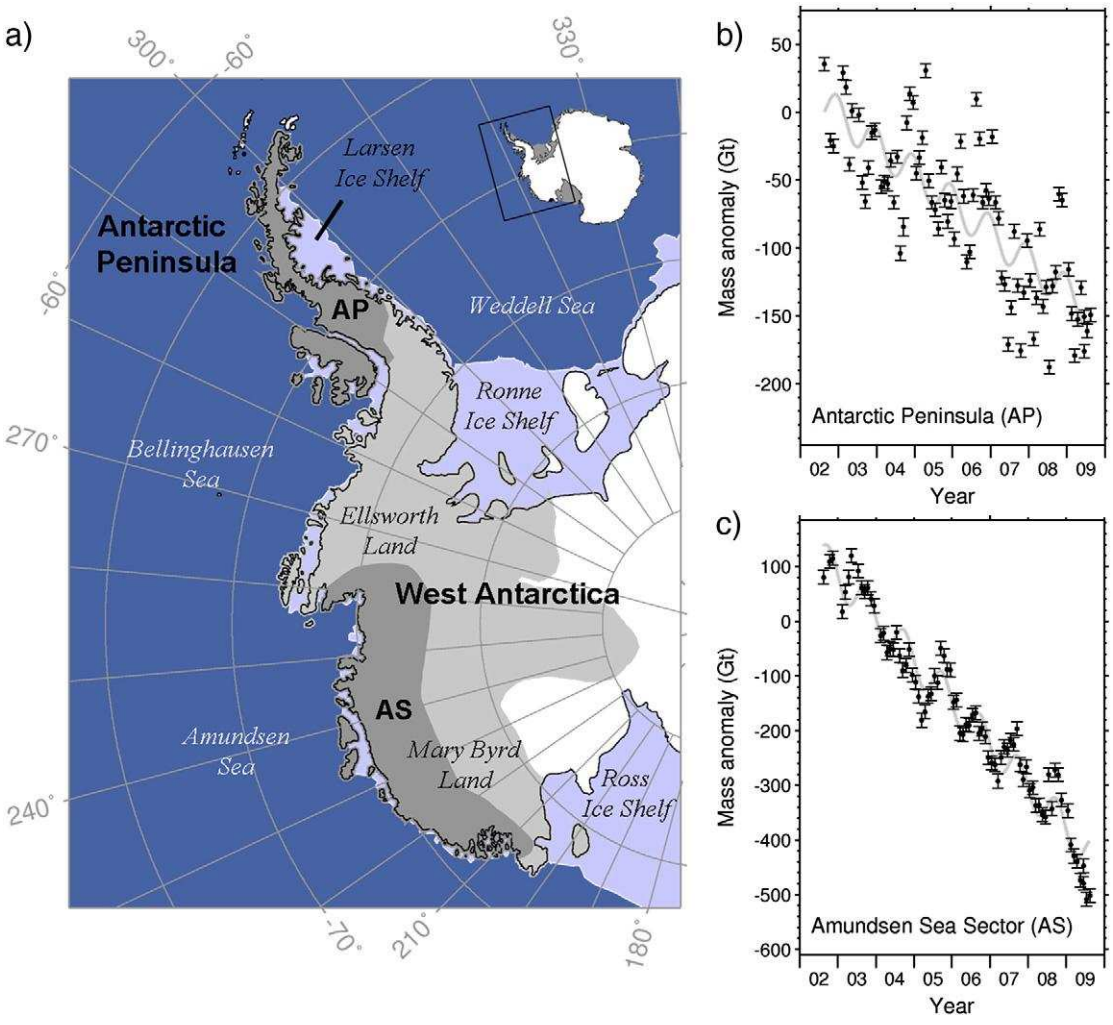


Figure 1: a) The region of interest and mass change estimates from GRACE gravity fields along **b)** the Antarctic Peninsula (AP, dark grey) and **c)** in the Amundsen Sea Sector (AS, dark grey). Both regions receive annual accumulation N400 mm/a based on ECMWF ERA-40 data (Genthon and Cosme, 2003). Remaining areas with accumulation N100 mm/a are shown in light grey. Grey curves in b) and c) indicate the least-squares fit of an annual oscillation, offset and linear trend. Error bars in b) and c) reflect the sum of a posteriori errors of the 4-parameter fit, as well as uncertainties of the GRACE atmospheric correction.

In cooperation with Dr. I. Rogozhina (GeoForschungsZentrum Potsdam), we analyzed the memory of the Greenland Ice Sheet (GIS) with respect to its past states. According to ice core reconstructions, the present-day GIS reflects former climatic conditions dating back to at least 250 thousand years before the present (kyr BP). This fact must be considered when initializing an ice sheet model. The common initialization techniques are paleoclimatic simulations driven by atmospheric forcing inferred from ice core records and steady state simulations driven by the present-day or past climatic conditions. When paleoclimatic simulations are used, the information about the past climatic conditions is partly reflected in the resulting present-day state of the GIS. However, there are several important questions that need to be clarified. First, for how long does the model remember its initial state? Second, it is generally acknowledged that, prior to 100 kyr BP, the longest Greenland ice core record (GRIP) is distorted by ice-flow irregularities. The question arises as to what extent do the

uncertainties inherent in the GRIP-based forcing influence the resulting GIS? Finally, how is the modeled thermodynamic state affected by the choice of initialization technique (paleo or steady state)? To answer these questions, a series of paleoclimatic and steady state simulations is carried out. We conclude that (1) the choice of an ice-covered initial configuration shortens the initialization simulation time to 100 kyr, (2) the uncertainties in the GRIP-based forcing affect present-day modeled ice-surface topographies and temperatures only slightly, and (3) the GIS forced by present-day climatic conditions is overall warmer than that resulting from a paleoclimatic simulation.

Modern modelling approaches to GIA are based on several techniques ranging from purely analytical formulations to fully numerical methods. Various European teams nowadays are independently working on the post-glacial rebound process in order to constrain the rheological profile of the mantle and the extent and chronology of the late-Pleistocene ice sheets which are prerequisites for the determination of the GIA contribution to geodetic observables. Martinec contributed to the benchmark study performed within the Working Group 4 of the ESF COST Action ES0701 “Improved constraints on models of Glacial Isostatic Adjustment”. The results of the benchmark have been submitted for publication in Geophysical Journal International and now are in press.

The oceans play a specific role in electromagnetic induction due to their relatively high conductivity and the dynamo effect of ocean currents. Observations of the ocean-induced magnetic field by the CHAMP magnetic space mission have the potential to be used as a constraint when examining ocean dynamics. This has initiated theoretical studies on the prediction of the ocean-induced magnetic field. These studies predict the poloidal magnetic field induced by the horizontal ocean-circulation flow by employing a single-layer approximation. Since the toroidal magnetic field cannot be modelled by this approximate model, Martinec and colleague J. Dostal (GeoForschungsZentrum Potsdam) treated the ocean as a layer of finite thickness and modeled the toroidal magnetic field by a matrix-propagator technique with a source of electrical currents in the ocean layer. Although this primary toroidal magnetic field is not observable outside the oceans, it couples with a strong conductivity contrast between the oceans and continents and generates a secondary poloidal magnetic field. This field is observable by magnetic satellite missions and ground-based magnetic observatories situated close to the shoreline. We found that the toroidal magnetic field induced by ocean tide circulation flow is extremely sensitive to the vertical gradient of the horizontal ocean velocities. This result is promising in the respect that, if the secondary poloidal magnetic field is detected by SWARM satellite after its launch then SWARM satellite data would constrain ocean dynamics. The theory and numerical results are now being written in the form of a paper.

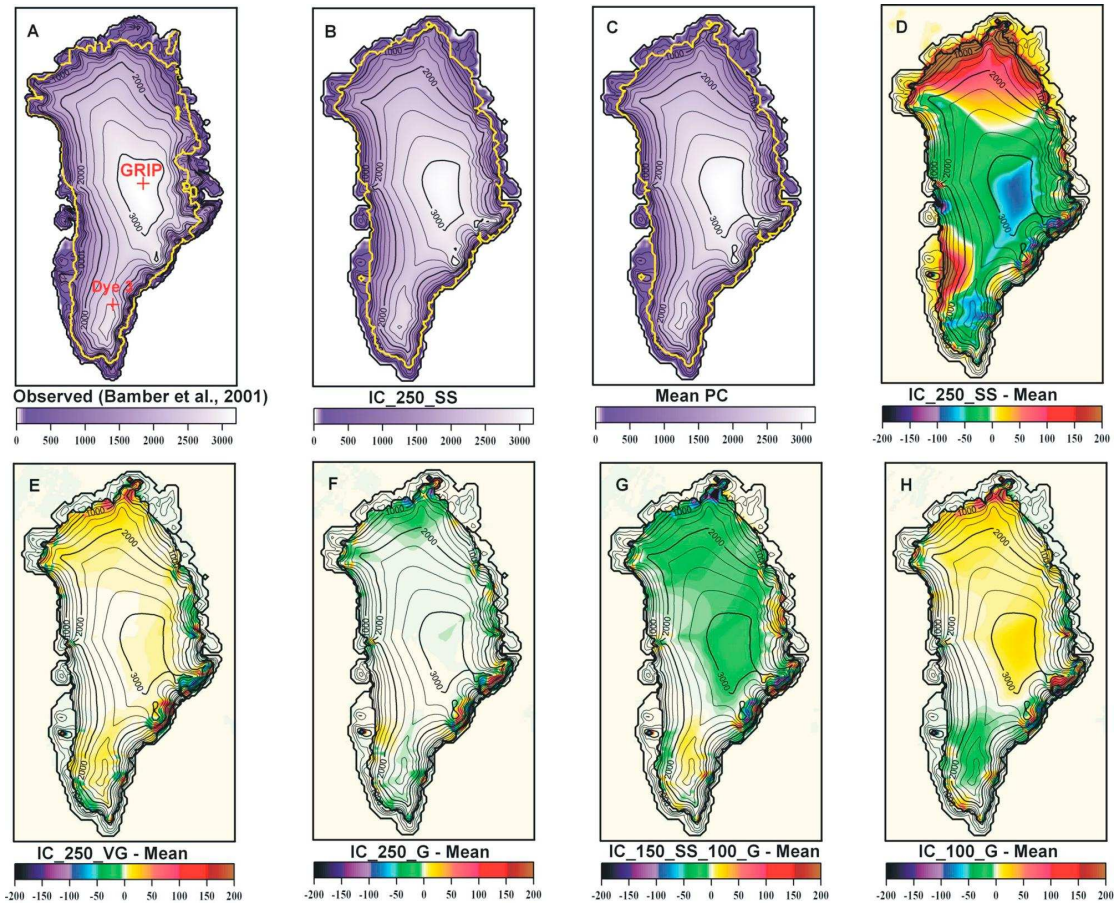


Figure 2: (a) Observed present-day surface elevation [Bamber et al., 2001; Layberry and Bamber, 2001]. **(b)** Present-day surface elevation computed by the steady state simulation (run IC_250_SS). **(c)** Mean values calculated based on the present-day surface elevation fields computed by transient simulations (runs IC_250_VG, IC_250_G, IC_150_SS_100_G, and IC_100_G). **(d)** Differences between the present-day surface elevations computed by the steady state run IC_250_SS and the mean values shown in Figure 7c. Departures of the present-day surface elevation computed by runs **(e)** IC_250_VG, **(f)** IC_250_G, (g) IC_150_SS_100_G, and (h) IC_100_G from the mean topography shown in Figure 7c. Yellow contours indicate the observed and modeled ice-land boundaries.

Publications:

Sasgen, I., **Z. Martinec,** and J. Bamber, 2010. Combined GRACE and InSAR estimate of West Antarctic ice-mass loss, *J. Geophys. Res.*, **115**, F04010, doi:10.1029/2009JF001525.

Sasgen, I., H. Dobslaw, **Z. Martinec,** and M. Thomas, 2010. Satellite gravimetry observation of Antarctic snow accumulation related to ENSO, *Earth and Planetary Science Letters*, **299**, 352-358, doi: 10.1016/j.epsl.2010.09.015.

Klemann, V., and **Z. Martinec**, 2010. Contribution of glacial-isostatic adjustment to the geo-center motion. *Tectonophysics*, doi:10.1016/j.tecto.2009.08.031 (in press, available online).

Tanaka, Y., V. Klemann, **Z. Martinec,** and R.E.M. Riva, 2010. Spectral-finite element approach to viscoelastic relaxation in a spherical compressible Earth: application to GIA modelling., *Geophys. J. Inter.*, doi:10.1111/j.1365-246X.2010.04854.x (in press).

Rogozhina, I., **Z. Martinec,** J. Hagedoorn, and M. Thomas, 2010. On the long-term memory of the Greenland Ice Sheet., *J. Geophys. Res.*, Earth Surface, (in press).

Spada, G., V.R. Barletta, V. Klemann, R.E.M. Riva, **Z. Martinec,** P. Gasperini, B. Lund, D. Wolf, L.L.A. Vermeersen, and M. King, 2010. A benchmark study for post-glacial rebound codes. *Geophys. J. Inter.*, (in press, available online).

Sasgen, I., V. Klemann, and **Z. Martinec,** 2010. Towards the joint inversion of present-day ice-mass changes and GIA in North America and Greenland. Submitted to *Journal of Geodynamics*.

Soucek, O., and **Z. Martinec**, 2010. ISMIP-HEINO experiment revised, effect of higher-order approximation and sensitivity study. Submitted to *Journal of Glaciology*.

Martinec, Z., 2010. The forward and adjoint methods of global electromagnetic induction for CHAMP magnetic data. Handbook of Geomathematics, Springer-Verlag Berlin Heidelberg, 565-624.

Grafarend, E.W., M. Klapp, and **Z. Martinec,** 2010. Spacetime modeling of the Earth's gravity field by ellipsoidal harmonics. Handbook of Geomathematics, Springer-Verlag Berlin Heidelberg, 159-252.

Kuvshinov, A., J. Velímský, P. Tarits, A. Semenov, O. Pankratov, L. Töfner-Clausen, **Z. Martinec,** N. Olsen, T.J. Sabaka, and A. Jackson, 2010. Level 2 products and performances for mantle studies with Swarm. Swarm Science Study, Final Report, pp.173, http://esamultimedia.esa.int/docs/EarthObservation/Induction Study 150110.pdf

Presentations:

Martinec, Z., J. Bamber, I. Sasgen, and M. van den Broeke. Regional ice-mass variability in Greenland from GRACE, InSAR and surface-mass balance modelling. 2010.

Sasgen, I., H. Dobslaw, **Z. Martinec**, and M. Thomas. Antarctic snow accumulation variability related to ENSO from GRACE. 2010.

Rogozhina, I., R. Calov, **Z. Martinec**, J. Hagedoorn, and M. Thomas. Memory of the Greenland Ice Sheet. 2010.

Sasgen, I., V. Klemann, and **Z. Martinec**. Glacial-isostatic adjustment in North America inferred from GRACE., Poster presentation. 2010.

Klemann, V. and **Z. Martinec**. Implementation of non-linear rheology in spectral finite-element code., Poster presentation. 2010.

Tanaka, Y., V. Klemann, and **Z. Martinec**. Spectral finite-element approach to three-dimensional viscoelastic relaxation in a spherical earth -extension for material compressibility., Poster presentation. 2010.

Soucek, O., and **Z. Martinec**. The role of longitudinal stresses in the ISMIP-HEINO experiment., Poster presentation. 2010.

Spada, G., and the COST Action ES0701 WG4 Team. A new benchmark study for post-glacial rebound codes., Poster presentation. 2010.

6 Seismological and geodynamic modelling activities

Group Leader: Assistant Professor Sergei Lebedev

6.1 Seismic study of the structure and dynamics of Tibet

M. Agius, S. Lebedev

Seismic structure of the crust and underlying upper mantle beneath Tibet reflects the physical state of the rock at depth and offers essential information on the dynamics and evolution of the plateau. Data from a number of broad-band seismic experiments conducted in recent years, together with data from permanent stations in the region, produce dense coverage of the plateau and its surroundings. We constrain variations in the crustal and lithospheric structure across Tibet using phase velocities of seismic surface waves. A mid-crustal low-velocity zone (LVZ) in the 20-45 km depth range is observed across the plateau. This LVZ coincides with a low-resistivity layer inferred from magnetotelluric studies, interpreted as evidence for partial melting. Surface-wave data also reveal anisotropy within this layer, indicative of West-East horizontal flow. Radial seismic anisotropy is required by the data in west Tibet and preferred in east-central Tibet. The lithospheric mantle is highly heterogeneous. West Lhasa in southern Tibet is underlain by thick, cold, cratonic Indian lithosphere, whereas Central Lhasa is not. In central and northern Tibet, shear velocities in the uppermost 50 km of the mantle are low to very low but a high velocity (cold) anomaly is present below 125 km depth. In order to investigate the finer detail within the shallow lithosphere we perform an extensive series of test inversions. We find that surface-wave dispersion measurements alone are consistent both with models that have low S-velocity just beneath the Moho, increasing with depth below, and with models that display a thin high-velocity mantle lid underlain by a LVZ (asthenosphere). We address the model non-uniqueness by combining our surface-wave measurements with data of other types, including receiver functions and Sn measurements.

Publications:

Agius, M.R., and **S. Lebedev**, 2010. Shear-velocity profiles across the Tibetan Plateau from broadband, surface-wave, phase-velocity measurements. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010, Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Lebedev, S., and **M.R. Agius**, 2010. Lithospheric structure and dynamics of Tibet: Constraints from shear-velocity distribution. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010, Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Presentations:

Agius, M.R., and **S. Lebedev**. Crustal and lithospheric structure of Tibet from shear-velocity profiles. IGRM 2010. Belfast, Northern Ireland, 20 February 2010.

Agius, M.R., and **S. Lebedev**. Lithospheric structure across the Tibetan Plateau, from broadband surface-wave analysis. Cooperative Institute for Dynamic Earth Research 2010 Summer Program, Kavli Institute for Theoretical Physics, University of California - Santa Barbara, 28 June – 18 July 2010.

Agius, M.R., and **S. Lebedev**. Lithospheric structure across the Tibetan Plateau, from broadband surface-wave analysis. Study of the Earth's Deep Interior, 12th Symposium, Santa Barbara, California, 18-23 July 2010.

Agius, M.R., and **S. Lebedev**. Shear velocity profiles in the crust and lithospheric mantle across Tibet. AGU Fall Meeting, San Francisco, USA, 13 - 17 December 2010.

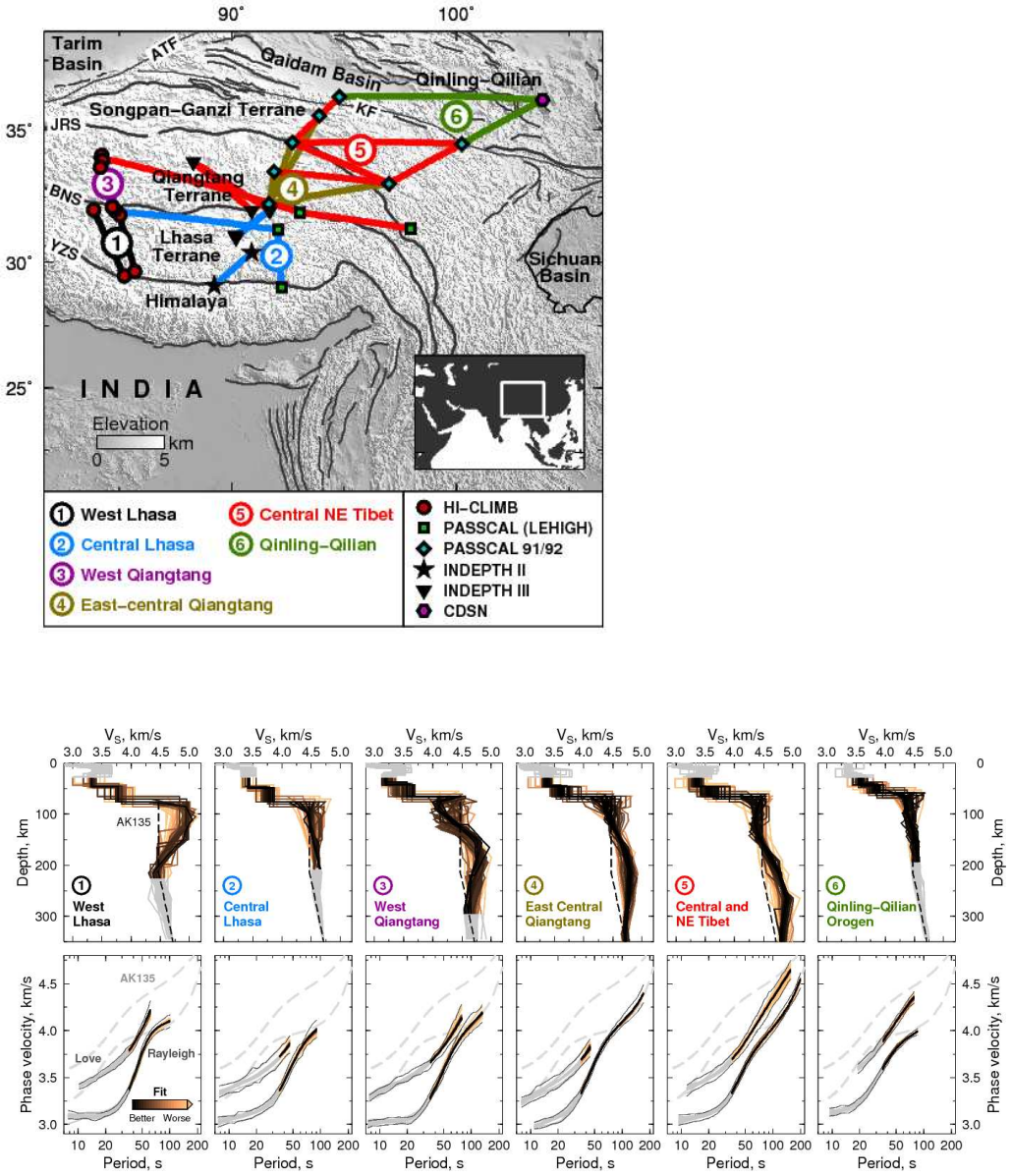


Figure 1: Top: Interstation paths within 6 colour-coded sub-regions within Tibet. Different symbols identify stations of different networks. Black lines indicate tectonic boundaries: YTS (Yarlung-Zangbo suture), BNS (Bangong-Nujiang suture), JRS (Jinsha River suture), KF (Kunlun Fault) and ATF (Altyn Tagh fault). Bottom: 1-D isotropic shear-velocity profiles (top row) and the corresponding synthetic phase-velocity curves within the standard deviation for the 6 sub-regions (bottom row).The colour scale indicates the data-synthetic RMS misfit over both the Rayleigh and Love-wave phase velocity curves at periods >35 seconds (sensitive primarily to the mantle lithosphere). The well-constrained (coloured) depth ranges of the Voigt isotropic average shear speeds Vs(iso) = (2Vsv + Vvsh)/ 3) are determined by the frequency range and sensitivity of the corresponding dispersion curves. Dashed line: the AK135 reference model.

6.2 Seismic anisotropy beneath the cratons of southern Africa

J. Adam, S. Lebedev

Southern Africa contains some of the oldest crust on Earth, with the ancient Kaapvaal Craton neighboured to the north by the Archean Limpopo orogenic belt. A major seismic experiment in the area (SASE) has produced, previously, shear-wave splitting measurements of surprisingly small amplitude (0.6 s on average), about half the continental average. The pattern of fast-propagation directions was proposed to be due to anisotropy in the lithosphere. Shear-wave splitting data, however, lack vertical resolution, and the 3-D distribution of anisotropic fabric beneath southern Africa has remained unclear.

In order to infer the past and present deformation in the lithosphere and asthenosphere, we measured thousands of seismic surface wave dispersion curves and determined the distribution of azimuthal anisotropy in the crust and upper mantle. We measured interstation phase-velocity curves of both Rayleigh and Love waves using a combination of cross-correlation and waveform inversion approaches. To obtain particularly robust phase velocities and their azimuthal dependence, we grouped them into four subsets, each for a sub-region with a relatively homogeneous structure within it. The robust, accurate isotropic-average dispersion curves are obtained in the very broad period range of 5-200 s, sampling from the upper crust down to the deep asthenosphere.

The largest azimuthal anisotropy is observed in the upper crust of the Limpopo Belt. It is aligned with the average stress direction, suggesting that the anisotropy is associated with cracks within the brittle crust. The Limpopo Belt is the northernmost part of the study region, and the large, stress-induced anisotropy there is likely to be related to the south-ward propagation of the East African Rift. In the lower crust and uppermost mantle, azimuthal anisotropy across the entire region is very small, less than 0.5 percent in most places. This is much smaller than typical anisotropy in Phanerozoic lithospheres. Radial anisotropy in the lower crust and lithospheric mantle, in contrast, is around 3-4 precent beneath the entire southern Africa. The pronounced difference in the amounts of radial and azimuthal anisotropy is matched by the fabric observed in some xenoliths and may indicate the pattern of deformation that accompanied the formation and assembly of the cratons.

Anisotropy is greater in the lower mantle lithosphere. Beneath the Limpopo Belt, the East-West fast directions in this depth range match the fast directions given by SKS splitting, indicating that the splitting originates largely in the lower lithosphere. In the asthenosphere, anisotropy beneath the entire region indicates fabric trending roughly parallel to the plate motion. Shear-wave splitting outside the Limpopo Belt can be accounted for by anisotropy in the asthenosphere. The surface-wave and SKS-splitting anisotropy measurements are, thus, consistent and complementary. The 3-D distribution of anisotropic fabric, with the puzzling lack of azimuthal anisotropy in the lower crust and shallow mantle and its preferential occurrence in the lower lithosphere, offers important clues on the mechanisms of the formation and evolution of cratons.

Presentations:

Lebedev, S. Seismic imaging of the lithosphere's structure and deformation. Invited seminar, USC, Los Angeles, June 2010.

Lebedev, S. Seismic imaging of anisotropy and deformation of the lithosphere and asthenosphere. Anisotropy Workshop, Dublin, November 2010.

6.3 S-velocity structure and anisotropy of the upper mantle: Global and continental-scale seismic tomography.

A. Schaeffer, S. Lebedev

The continued development and deployment of large-scale high-resolution seismic arrays (*e.g.*, the Earthscope USArray) are producing massive new datasets that sample the Earth at scales from tectonic units to continent-wide domains and enable resolution of structures and deformation of the lithosphere previously possible only at regional scales. With this resolving power come new challenges relating to efficient management and processing of such large data volumes. In this study, we have assembled a massive global dataset (with focus on North America) of three-component broadband seismic waveforms collected from more than 2000 stations, and have carried out full waveform inversions resulting in more than 750,000 successfully fit vertical-component seismograms. We augment available US Array stations with additional stations of the GSN and affiliates, Canadian National Seismograph Network, regional arrays, past worldwide PASSCAL experiments, and other stations from Europe, Iceland, Greenland, Central and South America, the Caribbean, and several Mid-Atlantic Islands. We exploit the resolving power of this unprecedentedly large dataset using Automated Multimode Inversion of surface- and S-wave forms. Vertically polarized shear waves (Rayleigh waves) are inverted for path-averaged linear constraints on elastic structure along the source-receiver paths. Of these three-quarters of a million waveform fits, many provide constraints not only on the fundamental mode, but higher modes as well. These linear equations are then simultaneously solved for a high-resolution 3D upper mantle shear velocity and azimuthal anisotropy model. Embedded multi-resolution grids afford higher model resolution in regions where data sampling (*i.e.*, station distribution) justifies, and permit the exploration of features at both global and regional scales.

We have produced a global model of upper mantle shear velocity and azimuthally anisotropic structure down to the 660 km discontinuity. In continental domains, clearly identifiable boundaries between different tectonic features such as basins and relic mountain ranges are readily observable, as well as the signature of deep cratonic roots versus juvenile accretionary margins. Both active and fossil subduction zones are marked by clearly discernible slab signatures deep in the upper mantle and extending through the transition zone (Figure A). In oceanic regions, spreading ridges are clearly visible down to depths of 100-110 km, and the evolution (cooling and thickening) of lithosphere away from the spreading ridges clearly matches with the expected signature from geodynamic and thermal modeling.

The pattern of azimuthal anisotropy in the ocean basins, in particular the Pacific Ocean, aligns with the paleo-spreading orientations at shallow depths within the lithosphere and modern plate motions at greater depths within the asthenosphere (Figure B). However, there are exceptions, where the observed azimuthal anisotropy

does not necessarily follow such a pattern, such as parts of the Atlantic Ocean. Through the computation and ongoing integration of full waveform fits from horizontally polarized Love waves, we are assembling high-resolution constraints on the global distribution of radial anisotropy throughout the upper mantle and transition zone.

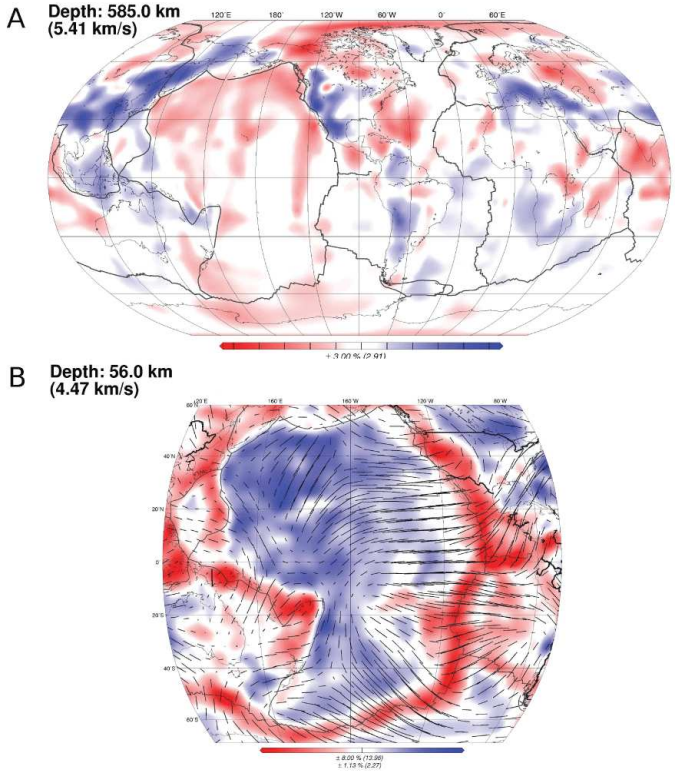


Figure 1: (**A**) Cross section through global model at 585 km depth. Perturbations range ±3% from the mantle reference velocity of 5.41 km/s, where red are slow regions and blue represents faster regions. The global distribution of slabs within the transition zone is clearly identified by the blue regions around subduction zones. (**B**) Cross section through the Pacific Ocean basin to illustrate the distribution of azimuthal anistropy at 56km depth. Shear velocity varies ±8% from 4.47 km/s, while anisotropy varies over a little more than 1%. The pattern of anisotropy correlates with the frozen-in orientation of paleo-spreading during the formation of the oceanic lithosphere. At greater depths, the direction rotates to match modern day plate motion.

Presentations:

Schaeffer, A., and **S. Lebedev**. Seismic structure of the lithosphere and upper mantle of North America from the inversion of Surface and S waveforms. Incorporated Research Institutions for Seismology 2010 Workshop, Snowbird Resort, Utah, USA, 9-11 June 2010. Poster presentation.

Schaeffer, A., and **S. Lebedev**. Seismic structure of the North American lithosphere and upper mantle imaged using Surface and S waveform tomography. AGU Fall Meeting, Session T46. San Francisco, California. 13-17 December 2010. Poster presentation.

6.4 Geodynamic modelling of continental deformation

C. Tirel, S. Lebedev, in collaboration with J.-P. Brun (Rennes), E. Burov (Paris VI)

A dynamic orogen reveals various tectonic processes brought about by subduction: accretion of oceanic and continental crust, exhumation of UHP-HP rocks, and often, back-arc extension. In the Mediterranean, orogeny is strongly affected by slab retreat, as in the Aegean and Tyrrhenian Seas. In order to examine the different dynamic processes in a self-consistent manner, we perform a parametric study using the fully coupled thermo-mechanical numerical code PARAFLAM. The experiments reproduce a subduction zone in a slab pull mode, with accretion of one (the Tyrrhenian case) and two continental blocks (the Aegean case) that undergo, in sequence, thrusting, burial and exhumation. The modeling shows that despite differences in structure between the two cases, the deformation mechanisms are fundamentally similar and can be described as follows. The accretion of a continental block at the trench beneath the suture zone begins with its burial to UHP-HP conditions and thrusting. Then the continental block is delaminated from its subducting lithosphere. During the subduction-accretion process, the angle of the subducting slab increases due to the buoyancy of the continental block. When the oceanic subduction resumes, the angle of the slab decreases to reach a steady-state position.

The Aegean and Tyrrhenian scenarios diverge at this stage, due to the differences of their accretion history. When continental accretion is followed by oceanic subduction only, the continental block that has been accreted and detached stays at close to the trench and does not undergo further deformation, despite the continuing rollback. The extensional deformation is located further within the overriding plate, resulting in continental breakup and the development of an oceanic basin, as in the Tyrrhenian domain. When the continental accretion is followed first by oceanic subduction and then by accretion of another continental block, however, the evolution of the subduction zone is different. The angle of the subducting slab increases again, following the arrival of the second continental block. The first continental block is now disconnected from the trench and is strongly heated by the asthenosphere that rises to just below the Moho. The locus of extension, originally in the overriding plate, moves to the first continental block, resulting in the development of metamorphic core complexes, as in the Aegean domain. Simultaneously, the second continent undergoes burial to UHP-HP conditions, thrusting and exhumation.

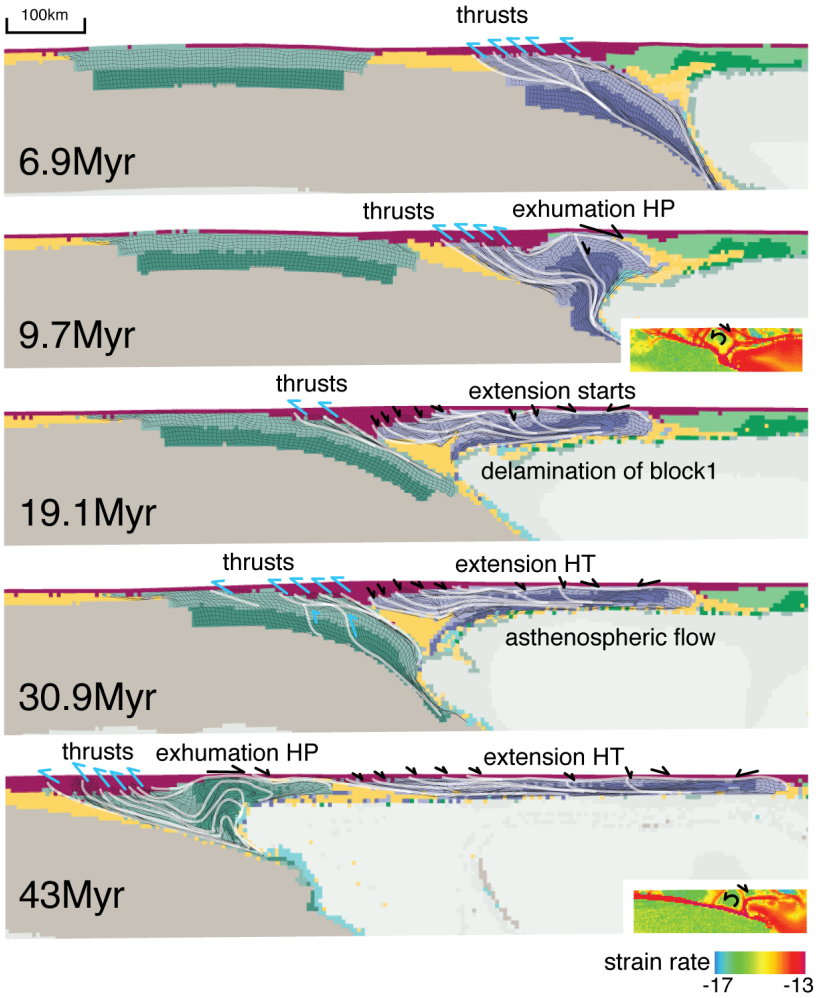


Figure 1: Steps-by-step geodynamic evolution of the Aegean region.

Presentations:

Tirel, C., J.-P. Brun, E. Burov, and **S. Lebedev**. Subduction and exhumation of continental crust in collisional orogeny. 53rd IGRM 2010, Belfast, 19-21 February 2010. Poster presentation.

Tirel, C., E. Burov, J.-P. Brun, and **S. Lebedev**. Subduction, accretion and exhumation: Dynamics of the Aegean and Tyrrhenian Seas. ESC 2010, Montpellier, 6-10 September 2010.

Tirel, C. Dynamics of continental deformation: insights from numerical modelling. Invited seminar at Trinity College, Dublin, Department of Geology, 5 November 2010.

Tirel, C., J.-P. Brun, E. Burov, M.J.R. Wortel, and **S. Lebedev**. Dynamics of subduction, accretion, exhumation and slab roll-back: Mediterranean scenarios. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

6.5 Structure and Deformation of Tuscany's Lithosphere

S. Lebedev, J. Adam, C. Tirel, P. Keogh

The opening of the Tyrrhenian basin in the western Mediterranean was associated with an eastward retreat of a subduction zone where Adriatic lithosphere subducted westward. The Apennines orogen now forms the Adriatic-Tyrrhenian boundary. Whether any subducted lithosphere is still present beneath it is debated. The mechanism of extension of the overriding-plate lithosphere and the nature of sub-lithospheric mantle flow below are also poorly known.

The project on seismic study of the structure and deformation of Tuscany's lithosphere was initiated in a 2009 summer internship of Paula Keigh, a TCD graduate (now in an M.Sc. program in the UK). We measure dispersion of seismic surface waves and determine shear-speed structure and the layering of seismic anisotropy beneath Tuscany. Azimuthal anisotropy in the crust shows an E-W fast-propagation direction, matching the direction of paleo-extension inferred from stretching lineations in exhumed metamorphic rocks. The anisotropy indicates fabric that is likely to be a record of pervasive flow in the middle and lower crust. We infer that it was such flow that accommodated lithospheric extension. Anisotropy in the asthenosphere shows a NW-SE fast-propagation direction, implying asthenospheric flow parallel to the Apennines. The region-average S-velocity profile shows a 40-km thick crust and a 60-80 km thick lithosphere. The anisotropy (and, by inference, flow) within the lithospheric mantle are similar to those in the crust. A high-velocity anomaly is detected at depths below 100-150 km and probably shows a slab remnant beneath Tuscany.

Presentations:

Keogh, P., **J. Adam,** and **S. Lebedev**. Structure and dynamics of Tuscany's lithosphere, from broadband surface-wave dispersion. IGRM 2010, Belfast, Northern Ireland. 20 February 2010.

Lebedev, S., J. Adam, P. Keogh, and **C. Tirel**. Structure and subduction-induced deformation of Tuscany's lithosphere, from broadband surface-wave analysis. Abstract T/MO/O2, ESC General Assembly, Montpellier, France, September 2010.

Lebedev, S., B. Endrun, T. M. Meier, **J. Adam,** and **C. Tirel**. 3D deformation and evolution of Mediterranean Basins: Insights from crustal and mantle anisotropy. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

6.6 Seismic study of the Cenozoic uplift and volcanism in Western Mongolia

S. Lebedev, M. Agius, D. Middleton

Tectonic set-up of west-central Mongolia is dominated by the vast Hangai Dome, its Cenozoic uplift accompanied by diffuse basaltic volcanism. Convective flow in the mantle could be responsible for both the uplift and the magmatism, but the nature of the flow is unknown. This seismic study of the mechanisms of the uplift and volcanism continued in 2010, after being initiated in the 2009 summer internship at DIAS of Damien Middleton, a DCU undergraduate.

We measure dispersion of Rayleigh and Love seismic surface waves and constrain crustal and upper-mantle structure across Mongolia and Siberia. Western Mongolia is underlain by a lower crust with anomalously low seismic velocities, 3.5-3.7 km/s at 30-50 km depths. The asthenosphere beneath a thin (70-80 km) lithosphere is

moderately slow seismically, likely to be only moderately warm, and is underlain by a high-velocity feature at 200-400 km depths.

The lack of a pronounced low-velocity zone beneath either Western Mongolia or Siberia to the North suggests that the rise of the Hangai Dome is unlikely to have been due to an active, hot mantle upwelling (plume). Instead, both the uplift and the volcanism could be caused by convective removal of the lower mantle lithosphere beneath the dome. The apparently cold material that we detect beneath 200 km depth may indicate (fragments of) the lithospheric "drip".

Presentation:

Middleton, D., **M.R. Agius,** and **S. Lebedev**. The cause of Cenozoic uplift and volcanism in Western Mongolia: A seismic study. IGRM, Belfast, Northern Ireland, 20 February 2010.

6.7 A low-velocity zone atop the transition zone in northwestern Canada

Andrew Schaeffer (collaboration with M. Bostock, UBC)

Seismic studies over the past decade have identified an *S* wave low-velocity zone (LVZ) above the transition zone at various locations around the globe. This layer is hypothesized to be a lens of dense, hydrous, silicate melt ponding atop the 410 km discontinuity, beneath the silicate melt-density crossover predicted to exist within the upper mantle. This work is a continuation of Andrew Schaeffer's study on the subject together with Michael Bostock (UBC, Canada).

We have assembled a *P* and *S* receiver function data set to quantify the physical properties and geographical extent of the layer in northwestern Canada. Geographic profiles formed from 1-D migration of receiver functions computed for the Canadian Northwest Experiment (CANOE) and Portable Observatories for Lithospheric Analysis and Research Investigating Seismicity (POLARIS) Slave arrays reveal an LVZ beneath many stations at a nominal depth of ∼340 km. To constrain layer thickness and Poisson's ratio, we performed a grid search over a suite of 1-D velocity profiles to model the relative delay times of direct conversions and reverberations from the top of the LVZ and 410 km discontinuity, as recorded at the Yellowknife array. In addition, we performed linearized inversion of transmission coefficient amplitudes to estimate *S* velocity contrasts at the bounding interfaces. The LVZ is characterized by a thickness of ∼36 km with an *S* velocity contrast of −7.8% and Poisson's ratio of 0.42. Taken at face value, the two latter results require an increase in *P* velocity into the LVZ. The Poisson's ratio lies well above the IASP91 average of ∼0.29–0.3 for this depth range and favors the presence of high melt or fluid fractions.

Publication:

Schaeffer, A.J., and M. Bostock, 2010. A low-velocity zone atop the transition zone in northwestern Canada. *J. Geophys. Res.*, **115**, B06302, 2010, doi:10.1029/2009JB006856.

Presentations:

Schaeffer, A.J., and M. Bostock. A low-velocity zone atop the transition zone in Northwestern Canada. IGRM, Belfast, Northern Ireland, 20 February 2010.

Schaeffer, A.J., and M. Bostock. A low-velocity zone atop the transition zone in Northwestern Canada. Cooperative Institute for Dynamic Earth Research 2010 Summer Program, Kavli Institute for Theoretical Physics, University of California - Santa Barbara, 28 June - 18 July 2010. Poster presentation.

Schaeffer, A.J., and M. Bostock. A low-velocity zone atop the transition zone in Northwestern Canada. Study of the Earth's Deep Interior. 12th Symposium, Santa Barbara, California, 18-23 July 2010. Poster presentation.

Becker, T.W., J.W. Crowley, M. Gérault, T. Höink, **A.J. Schaeffer**, P.H. Barry, J. Frost, J. Girard, M. Nunez-Valdez, M. Hirschmann, S. Hier-Majumder, and R.J. O'Connell. Deep water cycle: its role in Earth's thermal evolution and plate tectonics. AGU Fall Meeting, Session U15, CIDER 2010 Research Presentation, San Francisco, California, 13-17 December 2010.

Schaeffer, A.J., and M. Bostock. The Transition Zone low-velocity-zone: properties in Northwestern Canada. AGU Fall Meeting, Session DI06, Invited Talk, San Francisco, California, 13-17 December 2010.

6.8 Seismic study of the deformation of the Aegean lithosphere

S. Lebedev, C. Tirel, in collaboration with B. Endrun (Potsdam), T. Meier (Kiel), W. Friederich (Bochum).

Continental lithosphere can undergo pervasive internal deformation, often distributed over broad zones near plate boundaries. However, because of the paucity of observational constraints on three-dimensional movement at depth, patterns of flow within the lithosphere remain uncertain. Endmember models for lithospheric flow invoke deformation localized on faults or deep shear zones or, alternatively, diffuse, viscous-fluid-like flow.

In this project, we determine seismic Rayleigh-wave anisotropy in the crust and mantle of the Aegean region, an archetypal example of continental deformation. Our data reveal a complex, depth-dependent flow pattern within the extending lithosphere. Beneath the northern Aegean Sea, fast shear wave propagation is in a North–South direction within the mantle lithosphere, parallel to the extensional component of the current strain rate field. In the south-central Aegean, where deformation is weak at present, anisotropic fabric in the lower crust runs parallel to the direction of palaeo-extension in the Miocene. The close match of orientations of regional-scale anisotropic fabric and the directions of extension during the last significant episodes of deformation implies that at least a large part of the extension in the Aegean has been taken up by distributed viscous flow in the lower crust and lithospheric mantle.

Publication:

Endrun, B., **S. Lebedev**, T. Meier, **C. Tirel,** and W. Friederich, 2010. Complex layered deformation within the Aegean crust and mantle revealed by seismic anisotropy. *Nature Geoscience*, accepted, December 2010.

Presentations:

Lebedev, S., B. Endrun, **C. Tirel,** and T. Meier. Crustal and mantle flow in the Aegean region: Evidence from seismology and geodynamics. IGRM, Belfast, Northern Ireland, 20 February 2010.

Lebedev, S., B. Endrun, T. M. Meier, **J. Adam,** and **C. Tirel**. 3D deformation and evolution of Mediterranean Basins: Insights from crustal and mantle anisotropy. AGU Fall Meeting, San Francisco, USA, 13-17 December 2010.

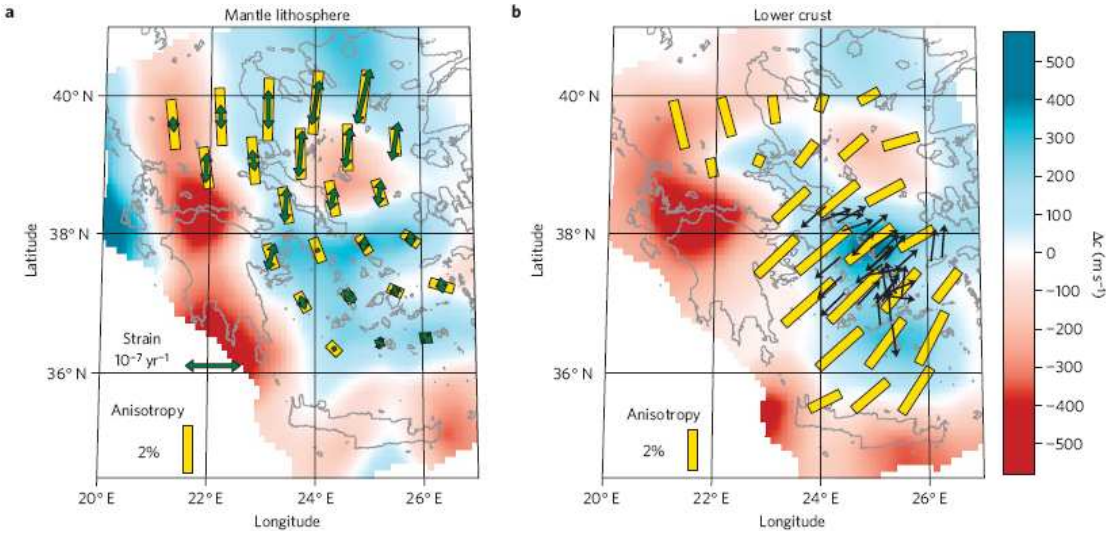


Figure 1: Anisotropic phase-velocity maps, indicating directions of flow within the lithosphere. Rayleigh waves at the periods sampling primarily the lithospheric mantle (30 s, average reference velocity 3:77 km/s, **a**) and the lower crust (15 s, average reference velocity 3:24 km/, **b**). Yellow bars indicate fast axes of anisotropy. Green arrows in **a** show the extensional component of the current strain field from the Global Strain Rate Map project. Black arrows in **b** show Miocene stretching lineations indicative of directions of palaeo-extension. From Endrun et al. (2010).

6.9 Imaging the Earth with Seismic Surface Waves

S. Lebedev

Surface-wave observations in broad frequency bands constrain the layering of shear-speed structure and anisotropy in the entire lithosphere-asthenosphere depth range. Thanks to the deployment of a growing number of dense broadband arrays and the development of suitable surface-wave techniques, it is becoming increasingly feasible to image the 3-D distribution of seismic structure and anisotropy at the scale of tectonic units and tectonic processes.

Two powerful complementary approaches, in particular, enable high-resolution seismic imaging at scales from regional to global. Multimode waveform inversions are effective in constraining continental-to global-scale tomographic models of the entire upper mantle. The automated multimode inversion of surface- and S-wave forms (Lebedev et al., 2005) has been benchmarked using numerical wave propagation modelling and applied to constrain the global upper mantle structure (Lebedev and van der Hilst, 2008) and anisotropy. The large-scale anisotropy patterns

revealed by the surface-wave imaging correlate strongly with predictions from geodynamic flow modelling (Becker, 2010).

Cross-correlations of surface-wave signals form the basis for another class of methods, particularly effective in applications to seismic array data. Studies in different tectonic environments have now shown that substantial azimuthal anisotropy is present, as a rule, in both the lithosphere and asthenosphere. Beneath currently stable continents, anisotropic fabric in the crust and lithospheric mantle is "frozen in" since the last major deformation episodes. In actively deforming lithosphere and in the asthenosphere, the observed anisotropy reveals the current and recent deformation and flow.

Presentations:

Legendre, C., T. Meier, **S. Lebedev**, W. Friederich, and the EGELADOS Working Group. Large-scale shear velocity structure of the upper mantle beneath Europe and surrounding regions. Abstract EGU2010-10303, EGU General Assembly, 2-7 May 2010.

Legendre, C., T. Meier, **S. Lebedev**, W. Friederich, and the EGELADOS Working Group. Large-scale shear velocity structure of the upper mantle beneath Africa and surrounding regions. Abstract EGU2010-10030, EGU General Assembly, 2-7 May 2010.

Lebedev, S. Seismic imaging of lithospheric deformation. Invited Keynote. Lithospheric Deformation Symposium, Bochum, Germany, 25-28 May 2010.

Legendre, C., T. Meier, **S. Lebedev,** and W. Friederich. Large-scale shear velocity structure of the upper mantle beneath Europe and surrounding regions. Lithospheric Deformation Symposium, Bochum, Germany, 25-28 May 2010.

Legendre, C., T. Meier, **S. Lebedev,** and W. Friederich. Large-scale shear velocity structure of the upper mantle beneath Africa and surrounding regions., Lithospheric Deformation Symposium, Bochum, Germany, 25-28 May 2010.

Lebedev, S. Seismic imaging of the structure and deformation of the lithosphere and asthenosphere. Invited seminar, University of Montpellier, France, 2 September 2010.

Lebedev, S. Deformation and anisotropy in 4D: the lithosphere-asthenosphere system. Invited, Abstract DI33C-01 (publication only), AGU Fall Meeting, San Francisco, California, 13-17 December 2010.

7 Seismological and potential field activities

Group Leader: Assistant Professor Brian O'Reilly

7.1 PIMS (Porcupine Irish Margin Seismics)

B.M. O'Reilly, P.W. Readman and F. Hauser

This wide-angle seismic experiment profile was undertaken in 2004. The experiment employed an array of three airguns fired at 100-150 m intervals with twenty-five 3 and 4-component ocean bottom seismometers deployed at 10-12 km spacing along an axial N-S profile in the Porcupine Basin. Forward modelling based on first arrivals

and reflections was completed during the year. Results were integrated with newly analysed RAPIDS4 (Rockall And Porcupine Irish Deep Seismic, phase 4) data to resolve details of the sedimentary and crustal structure within the basin. Seismic wide-angle data from seven land stations deployed in southwest Ireland by the Dublin Institute for Advanced Studies during the PIMS experiment, are employed to monitor crustal structure between the basin centre and the Irish Mainland Platform.

Prominent primary and secondary arrivals indicate that the continental crust is extremely thin (locally less than 2 km) across the basin centre along both the PIMS and RAPIDS4 profiles. A sedimentary succession of up to 12 km thick is imaged and comprises five distinctive seismic layers. The four uppermost layers are interpreted as mostly a post-rift succession of Cretaceous and Cenozoic strata. The lowermost layer thins rapidly towards the basin centre along both the transverse and the axial profiles and is interpreted as a succession of predominantly Jurassic syn-rift and older sediments. A "mixed shear" mode of extension and the subsidence that it induced is interpreted to have controlled the basin geometry. The maximum amount of crustal thinning is greater than in the Rockall Basin and local exhumation of continental mantle lithosphere may have occurred in central parts of the basin. Upper mantle P_n velocities beneath the Porcupine Arch are compatible with larger amounts of mantle serpentinisation than found beneath the Rockall Basin. The results from these studies were used as a basis for optimising the design of planned forthcoming experiments within the Porcupine Seabight Basin (see NAPSA).

These results are detailed in a report submitted to PIPCo Limited (Contract No. IS06/01). Additional results from the onshore component of the study were published in Geophysical Journal International. They indicate that the velocity structure of lower crustal and its fine structure relate to partial melting and metamorphism of accreted crust at the end of the Caledonian orogenic cycle (the Acadian Orogeny). The subsequent Mesozoic extensional deformation of the lithosphere that formed the North Atlantic basin system appears to have had little effect on the structure of lower crust beneath Ireland. Compilation of recently published geological information on the structural and tectonic history of the Irish continental crust was begun in order to prepare a paper on the geological implications of the results of the seismic research.

Publications:

O'Reilly, B.M., F. Hauser, and **P.W. Readman**, 2010. The fine-scale structure of upper continental lithosphere from seismic waveform methods: insights into Phanerozoic crustal formation processes. *Geophys. J. Inter.*, **180**, 101-124. doi: 10.1111/j.1365-246X.2009.04420.x.

Reports:

Hauser, F., B.M. O'Reilly, P.W. Readman, and C.J. Bean, 2010. Porcupine Irish Margins Seismic (PIMS) experiment: Wide-angle seismic profiles in the Porcupine Basin. Final Report for PIPCo Limited, Contract No. IS06.

7.2 HADES (Hatton Deep Seismic)

P.W. Readman, B.M. O'Reilly and A. Chabert, with P.M. Shannon, UCD School of Geological Sciences

Anne Chabert submitted her PhD thesis during the year. This was granted subject to minor corrections.

7.3 TRIM (Tobi Rockall Irish Margins)

B.M. O'Reilly, and colleagues from University College Dublin, the University of Ulster and Durham

The proposal entitled "Deep-water sediment transport on the margins of Rockall Trough: new interpretation from high-resolution multibeam and sidescan sonar TOBI data" began in 2010. This project was funded by INFOMAR (INtegrated Mapping FOr the Sustainable Development of Ireland's MARine Resource).

Multibeam bathymetric data gathered by the Geological Survey of Ireland within the Irish Exclusive Zone and high resolution TOBI backscatter data were reprocessed. Interpretation and data integration started in late 2010 and preliminary results were presented at the Geoscience Ireland conference in November 2010. The project investigates slope failure and sediment transport processess in the Rockall Trough and provides information about slope stability and dynamics along the Irish continental margins.

Presentations:

Sacchetti, F., S. Benetti, A. Georgiopoulou, P. Dunlop, R. Quinn, P. Shannon, and **B.M. O'Reilly**. Geomorphology of the Irish Rockall Trough mapped from INSS improved multibeam bathymetric and backscatter dataset. GEOSCIENCE 2010 Conference, Dublin, 3-4 November 2010.

7.4 ISLE (Irish Seismological Lithospheric Experiment)

P.W. Readman and B.M. O'Reilly, with J.P. O'Donnell and E. Daly, NUI Galway

The nature and extent of the regional lithosphere-asthenosphere interaction beneath Ireland and Britain remains unclear. Although it has been established that Caledonian signatures pervade the lithosphere, more recent tertiary structure related to the Iceland plume has been inferred to dominate the asthenosphere. In an attempt to resolve this apparent contradiction in the literature, we image the 3-D structure beneath Ireland via non-linear, iterative joint teleseismic-gravity inversion using data from the ISLE (Irish Seismic Lithospheric Experiment), ISUME (Irish Seismic Upper Mantle Experiment), and GRACE (Gravity Recovery and Climate Experiment) projects.

We consider that the anomalies imaged in the lithosphere reflect compositional rather than plume-driven thermal contrasts, either due to terrane accretion resulting from the closure of the Iapetus Ocean, frozen decompressional melt generated during the opening of the North Atlantic Ocean, frozen Iceland plume related magmatic intrusions, or a combination of these effects. To explain the continuation of the anomalous structure into the asthenosphere, we suggest that compositional contrasts in the lithosphere may have initiated small-scale convection at the base of the lithosphere. The coherent velocity and density uppermost mantle models thus demonstrate that Tertiary asthenospheric structure is likely to be intimately related to (possibly ancient) lithospheric structure.

The study on joint inversion of Irish gravity and ISLE seismic data (with J.P. O'Donnell, E. Daly (NUIG Galway) and C. Tiberi (Université Pierre et Marie Curie-Paris 6) was finalised and J.P. O'Donnell was awarded his PhD in March 2010. In the later part of the year a paper was accepted for publication in *Geophysical Journal International*.

Publication:

O'Donnell, J.P., E. Daly, C. Tiberi, I.D. Bastow, **B.M. O'Reilly, P.W. Readman,** and **F. Hauser,** 2010. Lithosphere-asthenosphere interaction beneath Ireland from joint inversion of teleseismic P-wave delay times and GRACE gravity. *Geophys. J. Inter.*, **184**, 1379-1396, doi: 10.1111/j.1365-246X2011.04921.x

Presentations:

O'Donnell, J.P., E. Daly, C. Tiberi, I.D. Bastow, **B.M. O'Reilly, P.W. Readman,** and **F. Hauser**. Lithosphere-asthenosphere interaction beneath Ireland from joint inversion of teleseismic P-wave delay times and GRACE gravity. 53rd Irish Geological Research Meeting, Ulster Museum, Belfast, 2010.

O'Donnell, J.P. Lithosphere-asthenosphere interaction beneath Ireland from joint inversion of teleseismic P-wave delay times and GRACE gravity. Stochastic modelling and Joint inversion workshop, DIAS, Dublin, 18-19 March 2010.

7.5 ISUME (Irish Seismological Upper Mantle Experiment)

P.W. Readman, B.M. O'Reilly, F.Hauser and G. Polat

Data collection continued throughout 2010 with the servicing and re-deployment of stations to more strategic positions particularly in the north of Ireland in order to increase the geographical coverage. A detailed analysis of suitable teleseismic data gathered since 2006 using the SKS/SKKS splitting method was continued during the year and presented at the EGU meeting in Vienna.

The results of this new data strongly support the results obtained from the earlier ISLE experiment that were published previously in 2006. The new results indicate that the strong back-azimuthal dependency of the fast polarisation direction is also observed in the new measurements in the north of Ireland. The results suggest that a significant component of the detected anisotropy resides below the lithosphere, and probably below 200 km, between this depth and the Earth's core-mantle boundary.

In addition phase velocities of seismic surface waves were measured in order to constrain variations in the crustal and mantle structure beneath Ireland and the Irish Sea. Phase velocities of the fundamental-mode Rayleigh waves are measured by cross correlating pairs of vertical component seismograms, using the two-station approach.

Measured inter-station Rayleigh wave phase velocities constrain shear-velocity structure in the depth range from the upper crust to the uppermost mantle. The Rayleigh-wave measurements are inverted for azimuthally anisotropic phase-velocity maps at periods from 10 to 40 s. The tomographic maps display isotropic heterogeneity that indicates substantial lateral variations in the structure of Ireland's

lithosphere. Azimuthal anisotropy reveals fabric within the crust and mantle lithosphere that is probably related to flow during the last major deformation episodes.

Presentations:

Polat, G., P.W. Readman, B.M. O'Reilly, and **F. Hauser.** Deep anisotropy beneath Ireland from shear-wave splitting measurements. 53rd Irish Geological Research Meeting, Ulster Museum, Belfast, 2010.

Polat, G., P.W. Readman, B.M. O'Reilly, and **F. Hauser.** Deep-source anisotropy beneath Ireland: new shear-wave splitting and controlled-source results. EGU General Assembly 2010, Geophysical Research Abstracts, Vol. 12, EGU2010-13959.

Polat, G., S. Lebedev, P.W. Readman, B.M. O'Reilly, and **F. Hauser.** Surface-wave tomography in Ireland. BGA Postgraduate Research in Progress Meeting, 2010.

Polat, G., S. Lebedev, P.W. Readman, B.M. O'Reilly, and **F. Hauser.** Surface-Wave tomography of Ireland. AGU Fall Meeting, San Fransisco, USA, 13-17 December 2010.

7.6 NAPSA (North Atlantic Petroleum Systems Assessment group)

B.M. O'Reilly, and colleagues from Memorial University, Newfoundland and University College Dublin

Brian O'Reilly in collaboration with Canadian and Irish collegues, was invited to submit a full proposal for a new series of novel seismic experiments to probe the deep structure of the offshore Irish and Newfoundland sedimentary basins. These basins once formed a single structurally interlinked system in the late Cretaceous geological period, when Ireland and Newfoundland were joined together into a single landmass, prior to the opening of the present day North Atlantic Ocean. The proposed work programme is stimulated by fundamental scientific questions, but it has immediate economic implications for the hydrocarbon prospectivity of Ireland's vast underexplored offshore region. Phase 1 of the programme has been designed in detail, and this was presented at various workshops and conferences to academic, government and industry people.

A related project involving plate tectonic reconstructions of the Irish and Newfoundland region and the opening of the North Atlantic region was begun in late 2010. This is funded by the Irish Government and the Irish Petroleum Infrastructure Programme (PIPCo - a consortium of Irish based oil companies and the Petroleum Affairs Division of the Department of Energy and Natural Resources) and involves industry and academic partners from Ireland and Canada. This new project is founded upon the large amount of collective experience accumulated in DIAS and UCD over several decades in marine geology, seismology and potential fields.

The Irish – Newfoundland Partnership of the Department of an Taoiseach provided additional funding through the Irish Newfoundland Partnership (INP) to attend workshops and meetings in St John's Newfoundland during 2011 to further discuss research initiatives and objectives. The visit is intended to further consolidate collaboration in comparative research of the conjugate north Atlantic margin regions

of Newfoundland and Ireland with a view towards reconstructing the geological evolution of the entire system.

Publications:

Welford, J. Kim, P.M. Shannon, **B.M. O'Reilly,** and J. Hall, 2010. Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from constrained 3-D gravity inversion. *Geophys. J. Inter.*, **183**, 79-95, doi: 101111/j.1365/246X.2010.04735.x.

Presentations:

O'Reilly, B.M. Optimised seismic acquisition parameters for proposed new WARRP profile across the Porcupine Seabight Basin, offshore Ireland. NAPSA/PIPCo Workshop, Dublin, 10 August 2010.

O'Reilly, B.M. Some ideas regarding the new plate reconstruction project across the Irish and Newfoundland continental margins. NAPSA Workshop, Dublin, 28 October - 1 November 2010.

O'Reilly, B.M., P.M. Shannon, and J. Kim. Welford. Proposed Atlantic margin WARRP seismic acquisition offshore Ireland and Newfoundland: ISPSG PROJECT ISO9/06. Atlantic Ireland 2010 Conference, Dublin, 2 November 2010.

O'Reilly, B.M., P.M. Shannon, and **P.W. Readman.** Phase 1 of WARRP seismic acquisition: southwest Ireland to Porcupine Abyssal Plain: ISPSG PROJECT ISO9/06 (PHASE1). Atlantic Ireland 2010 Conference, Dublin, 2 November 2010.

O'Reilly, B.M., P.M. Shannon, **P.W. Readman**, J. Kim Welford, and **F. Hauser.** WARRP seismic acquisition across the conjugate North Atlantic margins (Experiment Phase 1 - southwest Ireland to Porcupine Abyssal Plain: ISPSG PROJECT ISO9/06). Atlantic Ireland 2010 Conference, Dublin, 2 November 2010.

Lebedev S., C. Horan, P. Readman, L. Collins, F. Hauser, and **B.M. O'Reilly.** Ireland Array. A seismic investigation of Ireland's evolution, seismicity and new energy potential. Atlantic Ireland 2010 Conference, Dublin, 2 November 2010.

7.7 Collaborations

- UCD School of Geological Sciences: ISUME, TRIM, HADES, PIMS
- Applied Geophysics Unit, NUI Galway, ISUME
- University of Ulster (Colraine), TRIM
- Memorial University, St Johns, Newfoundland, NAPSA
- University of Liverpool, NAPSA
- University of Durham, TRIM

8 The Irish National Seismic Network (INSN).

Thomas Blake

The year 2010 was a very busy year for the INSN. Several very large and devastating earthquakes occurred throughout the world and some nearer home that made both local and international news. These events were registered by our stations at DSB, Dublin Mountains and VAL, Caherciveen Co. Kerry. The most significant were:

Haiti, 12th January, Magnitude 7.1

Maule, Chile, 27th February Magnitude 8.8
Libertator, Chile, 11th March, Magnitude 7.2
Honshu, Japan, 14th March, Magnitude 6.8
South Island, New Zealand, 3rd September, Magnitude 7.0
Kepulauan Mentawai Region Indonesia, 25th October, Magnitude 7.5

Nearer home, there were 3 events within as many days in North Donegal in January with magnitudes of around 1.8. More significantly, the largest onshore earth tremor recorded in Ireland since records began, occurred in North Clare on 6th May, 2010, Magnitude 2.8.

The development and expansion of the INSN continued throughout the year. Site tests were carried out in Donegal and Wexford and bunkers for the three new seismic stations in Wexford, Galway and Donegal were constructed. (Figures 1, 2, 3.).

Figure 1: IDGL, Inch Donegal.

Figure 2: IGLA, Galway.

Figure 3: IWEX, Wexford.

The international codes for the stations are as follows:

IDGL, Inch Island, Co Donegal, operational since November, 2010
IGLA, Glengowla Mine, Oughterard,Co Galway, operational since November, 2010
IWEX, Scullaboge, Co Wexford, to be deployed in early 2011

This now brings the INSN to a total of five real-time permanent seismic stations. The location of the stations are shown in the map below (Figure 4.).

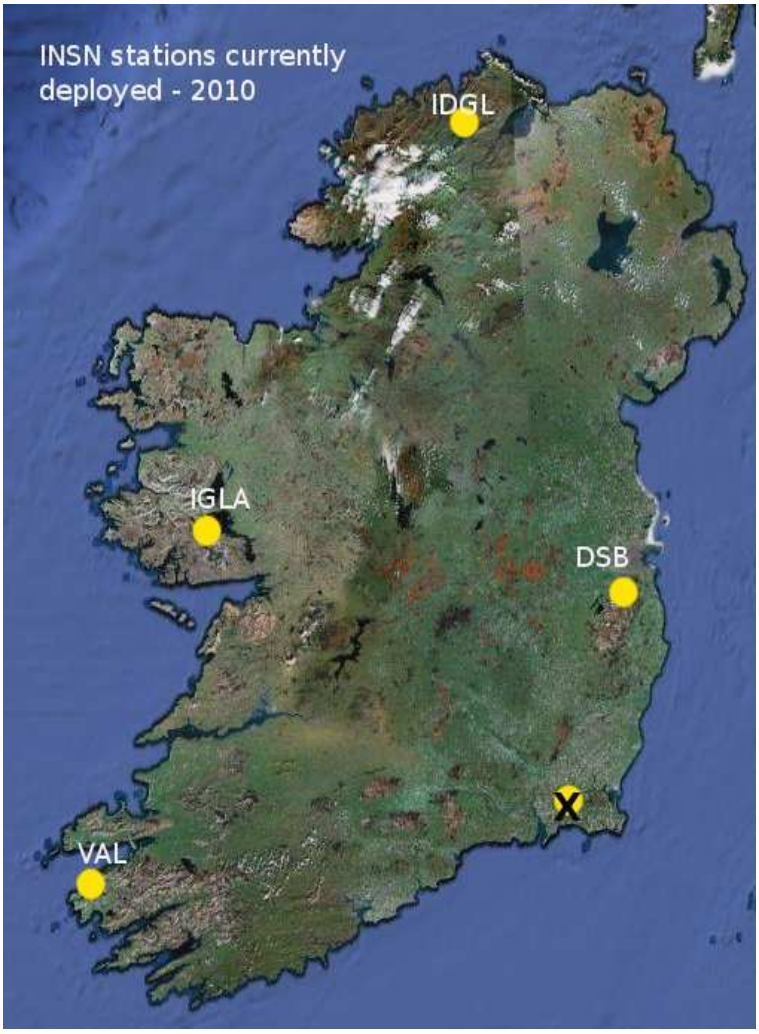


Figure 4: INSN stations currently deployed – 2010

There are plans to expand the network by a further two stations in 2011 but site locations have not yet been determined.

The Seiscomp3 Usergroup meeting in GFZ, Potsdam was attended by T Blake and P Grange and the data comms station configuration for IDGL, IGLA and IWEX was carried out by P Grange, S O'Sullivan and T Blake. The permanent station deployment was carried out by T Blake, G Wallace, C Horan, L Collins and P Grange. Seismic network meetings were held regularly throughout the year to discuss and monitor the development of the permanent stations and to oversee the build and outfitting of the station on-site.
The webpage development of 'recent earthquakes' continues to be improved and expanded by Andrew Schaeffer, PhD student, assisted by L Collins and is proving a very useful tool for quick reference to recent seismic events. The page gets updated within 30 minutes of the notification of the occurrence of the event and displays the data from DSB, VAL and IGLA seismic stations.

This is a very useful web-link to deal with the various public inquiries we continue to receive regarding seismic and other related events.

9 CTBTO - Comprehensive Nuclear Test Ban Treaty Organisation, National Data Centre (NDC).

T. Blake

The outfitting of the NDC in 5 Merrion Square, was carried out during the year. The computer hardware has been purchased and is on-site for development. T Blake attended the CTBTO Working Group B sessions and the meetings of the Waveform Expert Group in February and August. The surrogate Inspector training programme, of which T Blake is the Irish representative was held in Hungary in June-July. As part of the CTBTO SAMS (Seismic Aftershock Monitoring System) expert group, T Blake attended a meeting of the group in December in Baden, Austria.

10 Collaboration with wider research community

10.1 Visitors

- Prof. James Ni (New Mexico State University), March 15-16, 2010.
- Dr. Tiffany Barry (Open University, UK), April 8-9, 2010.
- Dr. Bill Fry (GNS, New Zealand), March 24-25, 2010.
- Prof. Evgenii Burov (University of Paris VI), November 2-4, 2010.

11 Public outreach: Seismology in Schools (Seismeolaíocht sa Scoil) Project

T. Blake

The SIS project continued in 2010 in the 50 participating schools throughout Ireland. Teachers and students continued to monitor the seismometer activity in the classroom and to receive the earthquake alerts from DIAS each time a significant earthquake occurs. New members to the project included St Mary's Secondary School, Dundalk, Co Louth, Mayfield Comprehensive Secondary School, Cork City and the National Museum in Dublin. A workshop was held in DIAS for 2 teachers from Donegal and Cork to introduced them to the project. During the year, twenty seven schools registered with the IRIS (Incorporated Research Institutions for Seismology) International Seismographs in Schools website and have been sharing their data with other schools around the world (Figure 1.).

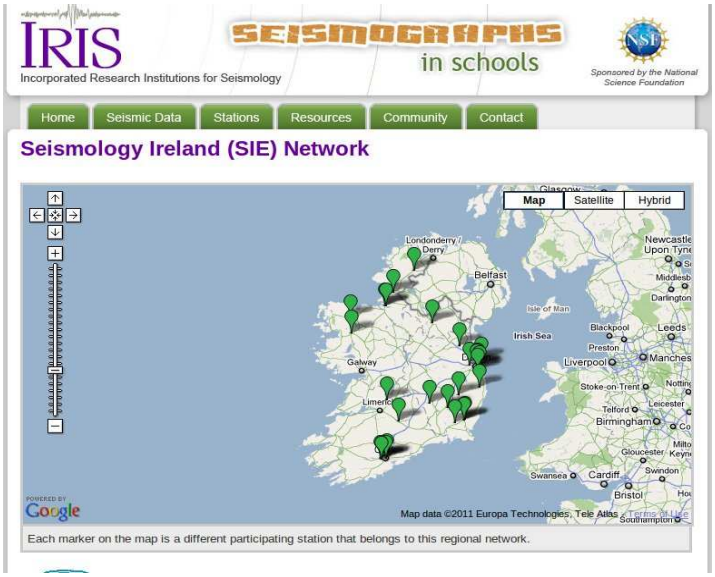


Figure 1: Irish participating schools registered with IRIS

A part-time assistant coordinator (Ms Grace Campbell) was appointed in September 2010, to take over the operation of the Seismology in Schools (Seismeolaíocht sa Scoil) Project. She now liaises with all the schools and trouble-shoots any problems teachers may have with the project. Teachers and students continue to upload data from the earthquakes they have recorded with their seismometers to the IRIS web-site.

12 Short Courses and Workshops

12.1 Workshops

12.1.1 Stochastic Modelling/Joint Inversion, DIAS February 18th – 19th, 2010

A 2-day Workshop on Stochastic Modelling and Joint Inversion was held in Merrion Square on 18-19 February. Some 20 people from Europe and North America attended.

12.1.2 ORFEUS Workshop, TCD May 23rd – 27th, 2010

The ORFEUS (Observatories and Research Facilities for EUropean Seismology) annual meeting was held in Trinity College, Dublin from 23rd – 27th May, 2010. The scientific programme for the meeting included talks on:

- European seismic networks, outreach and educational tools
- C3: current status, developments, implementations
- Earthworm (Network acquisition and processing systems) current status, developments, implementations

There were discussions on SEED tools and applications for observatories as well as a very successful poster presentation of various European projects.

This event coincided with the celebration of the bicentenary of the birth of Irish Scientist Robert Mallet '*Father of Controlled Source Seismology*'.

A series of lectures, workshops, poster presentations and a field trip all formed part of the meeting which was officially opened by the Minister of State for Science Technology and Innovation, Mr Conor Lenihan (Figure 1.).

Figure 1: Opening address at ORFEUS Workshop, TCD by Minister of State Conor Lenihan TD

Figure 2: Local Organizing Committee, DIAS , l to r, L Collins, C Horan, M Agius, T Blake, A Schaeffer, and A Sewielska (not in picture).

Figure 3: Group photo of the participants at the ORFEUS Workshop 2010

The workshop was attended by 67 seismologists from Europe, Middle East and America despite serious travel difficulties as a result of the eruption of the Icelandic Eyjafjallajökull volcano.

12.1.3 Continental Anisotropy, DIAS, October 8th – 9th, 2010

A 2-day Workshop on Continental Anisotropy was held in Merrion Square on 8-9 October. Some 20 people from Europe and North America attended.

12.2 Short Courses

12.2.1 Short Course on Magnetotellurics, DIAS, March 1st – 5th, 2010

Jones presented a Short Course on Magnetotellurics at the offices of DIAS to some 30 people from across the globe.

12.2.2 Short Course on Magnetotellurics, Beijing, October 11th – 13th, 2010

Jones presented a Short Course on Magnetotellurics at the China University of Geosciences, Beijing some 50 Chinese students.

12.2.3 Short Course on Continental Anisotropy, DIAS, November 22nd – 26th, 2010

Dr. Walter Mooney, of the United States Geological Survey, presented a Short Course on Continental Anisotropy from 22-26 November.

13 Exhibitions

13.1 BT Young Scientist Exhibition Jan 2010.

The DIAS participation in BT Young Scientist Exhibition, RDS, January 13th – 16th, 2010 was made possible by an invitation from The Geological Survey of Ireland (GSI) to share their stand with the theme of 'Planet Earth'. The stand was manned jointly by DIAS staff, PhD students, postdocs and by Geological Survey of Ireland (GSI) staff (Figure 1.).

Figure 1: Ph.D students Andrew Schaeffer (left) and Matthew Agius (right) with students at BTYSE

It was an extremely successful event. The interactive seismic experiments exhibited by the Geophysics Section proved very popular with both young and old alike who visited the stand. The strong earthquake in Haiti on 12 January, occurred just the day before the opening of the Exhibition, and so DIAS staff were able to give out a handout of the earthquake recording as it was registered by the Irish National Seismic Network seismic station, DSB, in the Dublin Mountains.

13.2 Bicentenary of the birth of Robert Mallet (1810 – 1881) & associated Exhibition

Robert Mallet, a graduate of Trinity College, is widely regarded as a true polymath and the 'Father of Controlled Source Seismology'. He was born in Ryder's Row near Capel Street, Dublin on June 3rd, 1810. In 2010 we celebrated the Bicentenary of his birth. After graduating from Trinity College he worked in his fathers iron foundry as an experimental scientist, helping in the family business. He was always fascinated by science and carried out many ground breaking experiments in relation to the physical properties of materials and metals. He was particularly fascinated by earthquakes and began to study how earthquakes occurred.

From 1845 onwards, Mallet embarked on one of his most important scientific research projects which is widely regarded as the birth of modern day seismology. Using kegs of powder explosive, he carried out experiments on Killiney Beach, Co Dublin in 1849 to examine how fast the shock waves from the explosions traveled through sand and later rock. The effects of the shock waves were observed on a

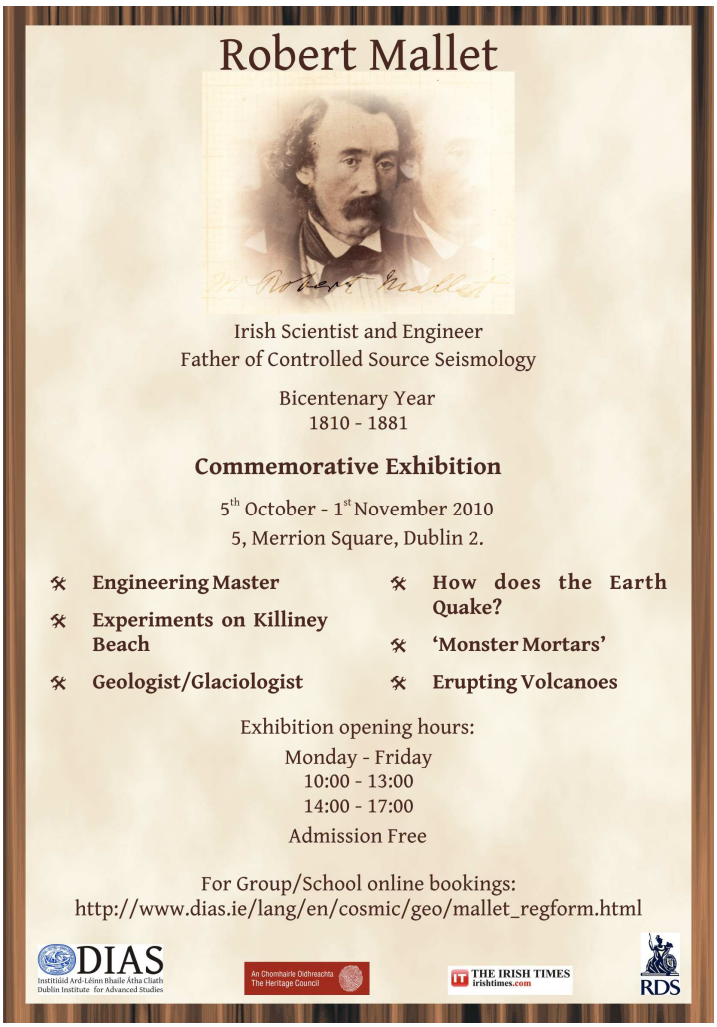
seismoscope or primitive seismometer. He is responsible for introducing the terms seismoscope and isoseismal maps to the English language.

He also carried out very significant research in Italy after the Great Neapolitan earthquake of 17th December, 1857 in which many people died. His report to the Royal Society on this event is regarded as the first real attempt to understand seismic risk and hazard.

He was the first scientist to use the new science of photography to report his earthquake observations, and to report on the seismic risks and hazards associated with earthquakes. The report he presented to the Royal Society in London on his Italian research was a significant landmark in seismological research.

Along with his son, John, he produced a Mercator Map of the distribution of all known earthquake epicentres around the globe at that time. This was the first time that such a map had been produced to help understand the nature of global seismicity. The contribution of Robert Mallet to the advancement of seismology undoubtedly earns him the title of "Father of Controlled Source Seismology". The Mallet Exhibition has put together a collection of images of his research including part of the BBC documentary on the recreation of the explosions on Killiney Beach in 2008.

The Robert Mallet Exhibition was launched on 18th August in the Royal Dublin Society, Ballsbridge, Dublin.



The Official opening, by Leo Enright, NASA Space Agency Correspondent, RTE, of the Mallet Exhibition in DIAS, Merrion Square, took place on October 4th, and the exhibition ran until November 1st, 2010. Grace Campbell was the curator of the Exhibition. This very successful exhibition in DIAS was open to the public and was the first of its kind to be held in 5, Merrion Square.

14 Miscellanea

T. Blake

- **Art – Science Crossover**

In April Ms Siobhan McDonald, a Masters student from the Dun Laoghaire College of Art and Design, sought assistance regarding paper seismograms, their properties, methods of paper blackening, and the nature of the work of Robert Mallet as material for her Masters Degree. T Blake has being acting as her mentor in this regard. She expects to complete her Masters programme in 2011 with an exhibition of her work as influenced by the scientific material to which she has been exposed.

- RTE News at One, with Rachel English, re: Aftermath of the Chilean Earthquake and Tsunami, 28th February, 2010
- Newstalk Radio, The Pat O'Mahony Show, re: Icelandic volcanic eruption 24th April, 2010
- Clare FM, Ed Myers re: Clare Earthquake, 7th May, 2010
- BBC Northern Ireland Radio, re: earthquakes in Clare and volcano in Iceland, 17th May, 2010
- RTE with Leo Enright, re: Clare earthquake and general information on tsunamis, August, 2010
- Highland Radio, Donegal, Shaun Doherty Show, re: Earthquakes in Donegal, 15th November, 2010.

A.G. Jones

- Appointed a member of the Royal Irish Academy.
-

S. Lebedev

- Associate Editor, *Geochemistry, Geophysics, Geosystems (G-cubed)*
- Institutional representative, *Incorporated Research Institutions for Seismology (IRIS)*
- National co-representative, *European Plate Observing System (EPOS)*
- Titular Member (member for Ireland), *European Seismological Commission (ESC)*
- "The Earth's Core" interview, Science Spinning on Dublin City FM, April 27.

15 Productivity

15.1 Publications in International Literature

1. Cook, F.A., D.J. White, **A.G. Jones**, D.W.S. Eaton, J. Hall, and R.M. Clowes, 2010. How the crust meets the mantle: Lithoprobe perspectives on the Mohorovicic discontinuity and crust–mantle transition. *Canadian J. Earth Sciences*, **47**, 315–351, doi: 10.1139/E09-076.
2. Endrun, B., **S. Lebedev**, T. Meier, **C. Tirel,** and W. Friederich, 2010. Complex layered deformation within the Aegean crust and mantle revealed by seismic anisotropy. *Nature Geoscience*, accepted, December 2010, doi: 10.1038/NGEO1065.
3. Evans, R.L., **A.G. Jones**, X. Garcia, **M. Muller**, M. Hamilton, S. Evans, S. Fourie, J. Spratt, S. Webb, H. Jelsma, and D. Hutchins, 2011. The electrical lithosphere beneath the Kaapvaal Craton, Southern Africa. *J. Geophys. Res. - Solid Earth*, accepted 3 February, 2011.
4. **Fullea, J.**, J.C. Afonso, M. Fernàndez, J. Vergés, 2010. The structure and evolution of the lithosphere - asthenosphere boundary beneath the Trans-Mediterranean region. *Lithos*, **120**, 1-2, 74-95.
5. Garcia, X., and **A.G. Jones**, 2010. Internal structure of the western flank of the Cumbre Vieja volcano (La Palma, Canary Islands) from land magnetotelluric imaging. *J. Geophys. Res. - Solid Earth*, **115**, B07104, doi: 10.1029/2009JB006445.
6. Grafarend, E.W., M. Klapp, and **Z. Martinec,** 2010. Spacetime modeling of the Earth's gravity field by ellipsoidal harmonics. Handbook of Geomathematics, Springer-Verlag Berlin Heidelberg, 159-252.
7. **Jones, A.G**., J. Plomerova, T. Korja, F. Sodoudi, and W. Spakman, 2010. Europe from the bottom up: A statistical examination of the central and northern European lithosphere-asthenosphere boundary from comparing seismological and electromagnetic observations. *Lithos*, **120**, 14-29.
8. Jiménez-Munt, I., M. Fernàndez, J. Vergés, D. Garcia-Castellanos, **J. Fullea**, M. Pérez-Gussinyé, and J.C. Afonso, 2010. Decoupled crust-mantle accommodation of Africa-Eurasia convergence in the NW-Moroccan margin. Submitted to *J. Geophys. Res.*
9. Jiménez-Munt, I., M. Fernàndez, J. Vergés, J.C. Afonso, D. Garcia-Castellanos, and **J. Fullea,** 2010. The lithospheric structure of the Gorringe Bank: insights into its origin and tectonic evolution. *Tectonics*, **29**, TC5019, doi:10.1029/2009TC002458.
10. Klemann, V., and **Z. Martinec**, 2010. Contribution of glacial-isostatic adjustment to the geo-center motion. *Tectonophysics*, doi:10.1016/j.tecto.2009.08.031 (in press, available online).
11. Kuvshinov, A., J. Velímský, P. Tarits, A. Semenov, O. Pankratov, L. Töfner-Clausen, **Z. Martinec,** N. Olsen, T.J. Sabaka, and A. Jackson, 2010. Level 2 products and performances for mantle studies with Swarm., Swarm Science Study, Final Report, pp.173, http://esamultimedia.esa.int/docs/EarthObservation/Induction Study 150110.pdf
12. Ledo, J., **A.G. Jones**, A. Siniscalchi, J. Campanyà, **D. Kiyan**, G. Romano, M. Rouai, and TopoMed MT Team. Electrical signature of modern and ancient tectonic processes in the crust of the Atlas Mountains of Morocco. *Physics of the Earth and Planetary Interiors*, accepted, 24 January, 2011.

13. **Martinec, Z.**, 2010. The forward and adjoint methods of global electromagnetic induction for CHAMP magnetic data. Handbook of Geomathematics, Springer-Verlag Berlin Heidelberg, 565-624.
14. **Miensopust, M.P.**, **A.G. Jones**, **M.R. Muller**, X. Garcia, and R.L. Evans, 2011. Lithospheric structures and Precambrian terrane boundaries in northeastern Botswana revealed through magnetotelluric profiling as part of the Southern African Magnetotelluric Experiment. *J. Geophys. Res.*, **116**, B02401, doi:10.1029/2010JB007740.
15. **Miensopust, M.P.**, **A.G. Jones**, 2011. Artifacts of isotropic inversion applied to anisotropic magnetotelluric data. Paper prepared in 2010 and submitted to *Geophys. J. Intern.* in 2011.
16. Moorkamp, M., **A.G. Jones**, and S. Fishwick, 2010. Joint inversion of receiver functions, surface wave dispersion, and magnetotelluric data. *J. Geophys. Res.*, **115**, B04318, doi:10.1029/2009JB006369.
17. Rogozhina, I., **Z. Martinec,** J. Hagedoorn, and M. Thomas, 2010. On the long-term memory of the Greenland Ice Sheet. *J. Geophys. Res.*, Earth Surface, (in press).
18. O'Donnell, J.P., E. Daly, C. Tiberi, I.D. Bastow, **B.M. O'Reilly, P.W. Readman,** and **F. Hauser,** 2010. Lithosphere-asthenosphere interaction beneath Ireland from joint inversion of teleseismic P-wave delay times and GRACE gravity. *Geophys. J. Intern.*, **184**, 1379-1396, doi: 10.1111/j.1365-246X2011.04921.x.
19. **O'Reilly, B.M., F. Hauser,** and **P.W. Readman**, 2010. The fine-scale structure of upper continental lithosphere from seismic waveform methods: insights into Phanerozoic crustal formation processes. *Geophys. J. Intern.*, **180**, 101-124. doi: 10.1111/j.1365-246X.2009.04420.x.
20. **Roux, E.**, M. Moorkamp, **A.G. Jones**, M. Bischoff, B. Endrun, **S. Lebedev**, and T. Meier, 2011. Joint inversion of long-period magnetotelluric data and surface-wave dispersion curves for anisotropic structure: Application to data from Central Germany. *Geophys. Res. Lett.*, **38**, L05304, doi:10.1029/2010GL046358, pp 5.
21. Sasgen, I., **Z. Martinec,** and J. Bamber, 2010. Combined GRACE and InSAR estimate of West Antarctic ice-mass loss. *J. Geophys. Res.*, **115**, F04010, doi:10.1029/2009JF001525.
22. Sasgen, I., H. Dobslaw, **Z. Martinec,** and M. Thomas, 2010. Satellite gravimetry observation of Antarctic snow accumulation related to ENSO. *Earth and Planetary Science Letters*, **299**, 352-358, doi: 10.1016/j.epsl.2010.09.015.
23. Sasgen, I., V. Klemann, and **Z. Martinec,** 2010. Towards the joint inversion of present-day ice-mass changes and GIA in North America and Greenland. Submitted to *Journal of Geodynamics*.
24. **Schaeffer, A.,** and M. Bostock, 2010. A low-velocity zone atop the transition zone in northwestern Canada. *J. Geophys. Res.*, **115**, B06302, 2010, doi:10.1029/2009JB006856.
25. **Soucek, O.,** and **Z. Martinec**, 2010. ISMIP-HEINO experiment revised, effect of higher-order approximation and sensitivity study. Submitted to *Journal of Glaciology*.
26. Spada, G., V.R. Barletta, V. Klemann, R.E.M. Riva, **Z. Martinec,** P. Gasperini, B. Lund, D. Wolf, L.L.A. Vermeersen, and M. King, 2010. A benchmark study for post-glacial rebound codes. *Geophys. J. Intern.* (in press, available online).

27. Tanaka, Y., V. Klemann, **Z. Martinec,** and R.E.M. Riva, 2010. Spectral-finite element approach to viscoelastic relaxation in a spherical compressible Earth: application to GIA modelling. *Geophys. J. Intern.*, doi:10.1111/j.1365-246X.2010.04854.x (in press).
28. **Vozar, J.,** and V. Y. Semenov, 2010. Compatibility of induction methods for mantle soundings. *J. Geophys. Res.*, **115**, B03101, doi:10.1029/2009JB006390.
29. Wei, W., S. Jin, G. Ye, M. Deng, J. Jing, M. Unsworth, and **A.G. Jones**, 2010. Conductivity structure and rheological property of Lithosphere in Southern Tibet inferred from super-broadband magnetotelluric sounding. *Science in China Series D: Earth Sciences*, **53**, 1–14.
30. Welford, J. Kim, P.M. Shannon, **B.M. O'Reilly,** and J. Hall, 2010. Lithospheric density variations and Moho structure of the Irish Atlantic continental margin from constrained 3-D gravity inversion. *Geophys. J. Intern.*, **183**, 79-95, doi: 101111/j.1365/246X.2010.04735.x.

15.2 Publications in Proceedings Volumes

Agius, M.R., and **S. Lebedev**, 2010. Shear-velocity profiles across the Tibetan Plateau from broadband, surface-wave, phase-velocity measurements. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010. Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Lebedev, S., and **M.R. Agius**, 2010. Lithospheric structure and dynamics of Tibet: Constraints from shear-velocity distribution. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010. Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Le Pape, F., **A.G. Jones**, **J. Vozar**, M.J. Unsworth, W. Wei, and the INDEPTH MT team, 2010. Evolution of crustal and upper-mantle structure in Northern Tibet from INDEPTH magnetotelluric data. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010. Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Vozar, J., **A.G. Jones, F. Le Pape**, W. Wei, M.J. Unsworth, and the INDEPTH MT team, 2010. Electromagnetic studies of Banggong-Nujiang suture architecture from INDEPTH magnetotelluric profiles and magnetovariational data. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010. Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

Wei, W., Jin Sheng, G. Ye, **A.G. Jones**, M.J. Unsworth, and the INDEPTH MT team, 2010. Regional resistivity structure of the Tibetan Plateau. *In:* Leech, Mary L., Klemperer, Simon L., and Mooney, Walter D., eds., 2010. Proceedings of the 25th Himalaya-Karakoram-Tibet Workshop: U.S. Geological Survey Open-File Report 2010-1099 [http://pubs.usgs.gov/of/2010/1099/].

15.3 Unreferred Publications

Hauser, F., B.M. O'Reilly, P.W. Readman, and C.J. Bean, 2010. Porcupine Irish Margins Seismic (PIMS) experiment: Wide-angle seismic profiles in the Porcupine Basin. Final Report for PIPCo Limited, Contract No. IS06.

15.4 Theses

Chabert, A., The crustal and sedimentary architecture of the Hatton Basin and Hatton Continental Margin. UCD.

Miensopust, M.P., Multidimensional Magnetotellurics: A 2D case study and a 3D approach to simultaneously invert for resistivity structure and distortion parameters. NUI Galway, defended successfully on 8th March, 2010.

15.5 Invited presentations

Blake, T. Seismology in the classroom using animated software. Invited talk, Open University Meeting, UCD Belfield, 30 January 2010.

Blake, T., S Lebedev, M Agius and **A. Schaeffer.** Mallet, seismology and DIAS. Ministerial Address, ORFEUS Workshop, TCD, 23 May 2010.

Blake, T. Seismology in Schools (Seismeolaíocht sa Scoil) Project – an Irish perspective. ORFEUS Workshop, TCD, 23 May 2010.

Blake, T. Seismology in Schools (Seismeolaíocht sa Scoil) Project – an Irish perspective. ESC Meeting Montpelier, France, 5-10 September 2010.

Blake, T. Shake, rattle and roll, getting to grips with Irish seismicity. IGA, in UCD, Belfield, Invited guest lecturer, 15 September 2010.

Blake, T., A. Jones and **G. Campbell.** Seismology in Schools, an integrated approach to funding, developing and implementing a coordinated programme for teachers and high school students. AGU Fall Meeting, San Francisco, USA, 10-18 December 2010.

Jones, A. Lithospheric and asthenospheric anisotropy: Lessons from Southern Africa and Joint Inversion of Seismic and Electromagnetic data for an Anisotropic Earth. Invited seminar to the Geosciences Department, Montpellier University, 23 April 2010.

Lebedev, S. Seismic imaging of the lithospheric deformation. Invited Keynote, Lithospheric Deformation Symposium, Bochum, Germany, 25-28 May 2010.

Lebedev, S. Seismic imaging of the lithosphere's structure and deformation. Invited seminar, USC, Los Angeles, June 2010.

Lebedev, S. Seismic imaging of the structure and deformation of the lithosphere and asthenosphere. Invited seminar, University of Montpellier, France, 2 September 2010.

Lebedev, S. Deformation and anisotropy in 4D: The lithosphere-asthenosphere system. (Invited), Abstract DI33C-01 (publication only), AGU Fall Meeting, San Francisco, California, 13-17 December 2010.

Martinec, Z. Statistical filtering of GRACE gravity data. COST ES0701 WG3: Noise characteristics of station coordinate time series/velocities. Nottingham University, 18-19 March 2010.

Schaeffer A.J. and M. Bostock. The Transition Zone low-velocity-zone: properties in Northwestern Canada. AGU Fall Meeting, Session DI06, Invited Talk, San Francisco, California, 13-17 December 2010.

15.6 Lecturing

Z. Martinec

In the summer term 2010, Martinec two semester courses (each course consists of 15 lectures of 2.5 hour duration)

- Continuum Mechanics - Basic Principles (for Ph.D. students and post-docs at DIAS)
- Continuum Mechanics - Rheology (for undergraduates and Ph.D. students at the Charles University in Prague)

Astronomy and Astrophysics
Research Report 2010

Presented in draft form to the Governing Board
of the School of Cosmic Physics
on 26 April 2011,
final version adopted by circulation on
.....

Contents

1 Research Reports

1.1 High-Energy Astrophysics

1.1.1 Development of the ASTRO-H satellite

A. Bamba, F. A. Aharonian and the ASTRO-H collaboration

ASTRO-H is the next generation X-ray satellite under construction in Japan. A. Bamba and F. A. Aharonian are main members of ASTRO-H mission contributing to the hardware development and science case study. Aya Bamba has a responsibility to avoid out-gas in the satellites and designed the out-gas shield for X-ray CCDs onboard ASTRO-H. Aya Bamba is also the leader for the public outreach of ASTRO-H. Felix Aharonian has been invited to the selected Science Working Group of ASTRO-H, whose main task is discussing the main science cases of ASTRO-H and making requirement for the detector design.

1.1.2 X-ray/Gamma-ray studies of Galactic accelerators

A. Bamba, A. Hayato (GSFC), T. Sato (ISAS/JAXA), K. Someya (ISAS/JAXA), Y. Terada (Saitama U.), T. Anada (ISAS/JAXA), H. Yamaguchi (RIKEN), S. Yamauchi (Nara Womens U.), et al.

We have made X-ray studies of Galactic accelerators, such as supernova remnants, superbubbles, pulsars, and white dwarfs. The most exciting discovery is the Suzaku observational fact that pulsar wind nebulae (PWNe) keep expanding up to ~100 kyr, although the timescale of the synchrotron X-ray emission is only ~60 yr for typical magnetic fields of 100 μG. Our result suggests that the accelerated electrons up to ~80 TeV can escape from the PWNe without losing most energies.

Aya Bamba joined the Very high energy gamma-ray (VHE) telescope Cherenkov Telescope Array (CTA). We made design studies of the array, from the point of view of studying Galactic accelerators. This work was reflected to an invited talk in November.

1.1.3 Diffuse emission of the galactic disk

F. A. Aharonian, S. Casanova, Y. Fukui, S. Gabici, D. I. Jones, A. Kawamura, T. Onishi, G. Rowell, K. Torii, H. Yamamoto

The observations of galactic gamma-rays with the Fermi LAT telescope in the MeV/GeV energy band and with the HESS array of imaging atmospheric Cherenkov telescopes in the TeV energy band, together with the recently reported data on the distribution of the molecular hydrogen in the Galaxy on a sub-degree scale, provides a unique opportunity for exploration of the cosmic ray density throughout the Galaxy, both on large (kpc) and small (pc) scales. In particular, we proposed a new method to address the question how γ-ray observations – when combined with the data on the molecular hydrogen obtained by the NANTEN mm-telescope – can be used to study the large-scale spatial variations of cosmic rays in our Galaxy [14]. In the second paper [13] we modeled the propagation of cosmic rays on smaller (10 to 100 pc) scales, in particular in the vicinity of young supernova remnants. Cosmic rays escaping from supernova remnants diffuse into the interstellar medium and collide with the ambient atomic and molecular gas. This results in production of gamma-rays which contain direct information about the parent population of runaway cosmic rays. We discussed such a scenario of gamma-ray production in the surroundings of the shell-type supernova remnant RX J1713.7-3946. The spectral and spatial distributions of the emission, which depend upon the source age, the source injection history, the diffusion regime, and the distribution of the ambient gas, as mapped by the NANTEN surveys, have been studied. The results may have important implications for interpretation of the results obtained with current and future gamma-ray experiments.

1.1.4 The Galactic Centre

F. A. Aharonian, M. Chernyakova, R. Crocker, S. Casanova, D. Jones

The production of the diffuse gamma-ray emission within the central ~ 300 pc region of the Galaxy has been studied in a series of papers [88, 91, 90].

In the paper by Chernyakova et al. [88], we described and sought to explain the very high energy gamma-ray emission from the central few parsecs of our Galaxy as detected by the Fermi and HESS instruments (see fig. 1). This study investigated the morphological, spectral and temporal characteristics of this central source coincident with the Galaxy's (~ 4×10^6 solar mass) super-massive black hole (SMBH). The detailed numerical calculations demonstrated that the inflected γ-ray spectrum of this source can be explained within a model where cosmic ray ions, injected by processes associated with the SMBH, undergo a transition from diffusive propagation of cosmic ray protons and nuclei at low energy to rectilinear propagation at high energy.

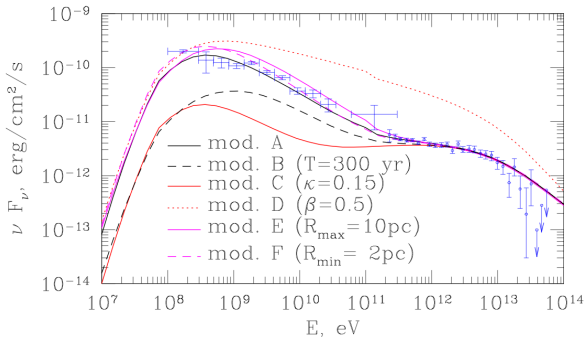


Figure 1: Observed spectrum and models for the Galactic centre's central, point-like γ-ray source [88]. The different curves correspond to different choices of the parameters describing the diffusion of cosmic rays in the GC.

These results show the acceleration of cosmic rays by the central SMBH in principle should be able to to sustain the flux of cosmic rays in the several hundred parsec region of GC. Other candidates for significant contribution are the GC region's supernovae. Even so, the TeV gamma-ray data show that even very high energy cosmic rays ($E > 10$ TeV) do not have time to penetrate into the dense cores of the region's giant molecular gas; this can be attributed to the fact that a rather fast (400-1200 km/s) wind removes them quickly from the region. This result finds observational confirmation in the radio observations with the Australia Telescope Compact Array of the Sgr B cloud. The escape of cosmic rays produced in the galactic center region and their accumulation outside the Galaxy over the time comparable to the age of the Galaxy can explain [90] the enormous features in the gamma-ray sky observed by the Fermi-LAT instrument: bilateral 'bubbles' of emission centered on the core of the Galaxy and extending to around 10 kpc above and below the Galactic plane. These structures are coincident with a non-thermal microwave 'haze' found in WMAP data and an extended region of X-ray emission detected by ROSAT. The bubbles' gamma-ray emission is characterised by a hard and relatively uniform spectrum, relatively uniform intensity, and an overall luminosity 4 x 10^37 erg/s, an one order of magnitude larger than their microwave luminosity while more than order of magnitude less than their X-ray luminosity. In ref. [90] we demonstrate that the bubbles are naturally explained as due to a population of relic cosmic ray protons and heavier ions injected by processes associated with extremely long timescale (10 Gyr) and high areal density star-formation in the Galactic center.

1.1.5 Very High Energy gamma-rays and neutrinos from RX J1713.7-3946

F. A. Aharonian, V. Zirakashvili, F. Visanni

A new numerical code, designed for the detailed numerical treatment of nonlinear diffusive shock acceleration, has been used for the modeling of particle acceleration and radiation in young supernova remnants [59]. The model is based on spherically symmetric hydrodynamic equations complemented with transport equations for relativistic particles. For the first time, the acceleration of electrons and protons by both forward and reverse shocks is studied through detailed numerical calculations. The energy spectra and spatial distributions of nonthermal emis-

sion of the young SNR RX J1713.7-3946 have been modeled and the the spectral and morphological properties of this object obtained in broad energy band from radio to very high-energy gamma rays have been calculated. The advantages and shortcomings of the so-called hadronic and leptonic models, which assume that the observed TeV gamma-ray emission is produced by accelerated protons and electrons, have been critically discussed. A new "composite" scenario has been proposed when the gamma-ray flux from the main parts of the shell has inverse Compton origin, but with a non-negligible contribution of hadronic origin from dense clouds interacting with the shell. The neutrino fluxes expected in different hadronic models have been calculated in the context of the potential of the several km-cube neutrino detector in the Mediterranean Sea.

1.1.6 Gamma-ray Flares from Star/Jet Interactions in M 87

F. A. Aharonian, M. Barkov, V. Bosch-Ramon

Non-blazar active galactic nuclei have been recently established as a class of gamma-ray sources. M87, a nearby representative of this class, shows fast TeV variability on timescales of a few days. A scenario has been proposed [10] to explain the flare gamma-ray emission in this object based on a red giant (RG) interacting with the jet at the base. We solved the hydrodynamical equations that describe the evolution of the envelope of an RG blown by the impact of the jet. If the RG is at least slightly tidally disrupted by the supermassive black hole, enough stellar material will be blown by the jet, expanding quickly until a significant part of the jet is shocked. This process can render suitable conditions for energy dissipation and proton acceleration, which could explain the detected day-scale TeV flares from M87 via proton-proton collisions. Since the radiation produced would be unbeamed, such an event should be mostly detected from non-blazar AGNs. They may be frequent phenomena, detectable in the GeV-TeV range even up to distances of 1 Gpc for the most powerful jets. The counterparts at lower energies are expected to be not too bright. M87, and nearby non-blazar AGNs in general, can be fast variable sources of gamma-rays through RG/jet interactions.

1.1.7 Limitations on the photo-disintegration process as a source of VHE photons

F. A. Aharonian, A. Taylor

We studied whether photo-disintegration is ever able to provide an effective mechanism for the production of VHE gamma-ray emission from astrophysical sources. We find that the efficiency of this process is always smaller by a factor A/Z^2 than that of nuclei cooling through Bethe-Heitler pair-production. Furthermore, for sources optically thin to TeV emission, we find that the efficiency of this process can be no more than $3 \times 10^{-5}(R_{\rm source}/R_{\rm Larmor})$, where $R_{\rm source}$ is the source size and $R_{\rm Larmor}$ is the CR nuclei Larmor radius. We conclude that, this process is not able, in contrast to the recent optimistic claims, to provide an effective mechanism for VHE gamma-ray emission from astrophysical sources [3].

1.1.8 Point like non-variable extragalactic gamma-ray sources associated with accelerators of highest energy cosmic rays

F. A. Aharonian, S. Kelner, Y. Prosekin

Ultra-high energy cosmic-rays cannot reliably point back to their acceleration sites due to their deflection by the intergalactic magnetic field (IGMF). Moreover, a “direct” localisation is limited by the interactions of CRs with the cosmic microwave background (CMB) radiation within a radius of ~ 100 Mpc. However, after the passage of ~ 10 Mpc, protons only slightly deviate from initial direction provided that IGMF does not exceed 10^{-8} G. Remarkably, 10 Mpc propagation length appears sufficient to produce a considerable amount of secondary ultra-relativistic particles whose propagation is in the same direction as the parent particle. In interactions with CMB, protons lose their energy mainly via

photo-meson processes leads to the production of gamma-rays, electrons, positrons, and neutrinos. If $B \geq 10^{-10}$ G, these secondary electrons are cooled predominantly via synchrotron emission if . Since the cooling times of electrons are very short, the electrons lose the bulk of their energy before any significant deviation. This results in a small apparent angular size of gamma-ray sources.

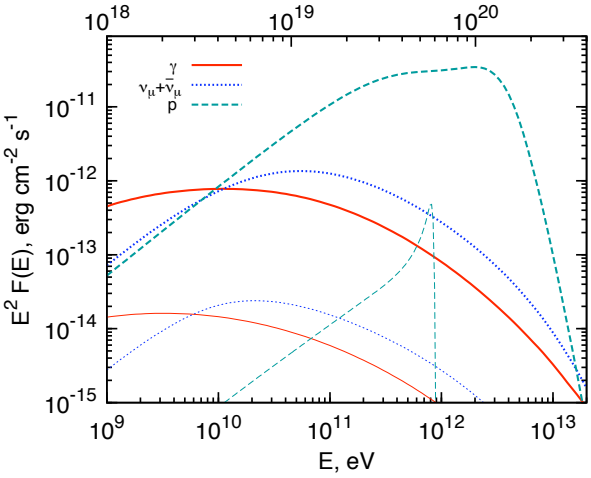


Figure 2: Spectra of gamma-rays, muon neutrinos and protons observed within a polar angle of 3° from two identical sources located at $r = 30$ Mpc (thick lines) and $r = 300$ Mpc (thin lines). The upper energy scale is for protons and neutrinos, the lower energy scale is for gamma-rays. The calculations are performed for the proton spectrum $E^{-2}\exp(-E/(3\cdot 10^{20}\text{eV}))$, and a total power of injection 10^{44} erg/s with a IGMF strength of 1 nG.

Characterising proton propagation from sources depends on the strength and large-scale structure of the IGMF. A feasible solution of this problem is to model the IGMF as a purely turbulent magnetic field which has a coherence length of 1 Mpc. Deflections of protons can then be treated as small-angle scattering on the irregularities of the IGMF. By solving the Boltzmann transport equation in the limit of the small-angle and continuous energy-loss approximations, we have calculated [5] the energy and angular distribution of protons for spherically symmetric sources with power-law injection spectra and an exponential cutoff .

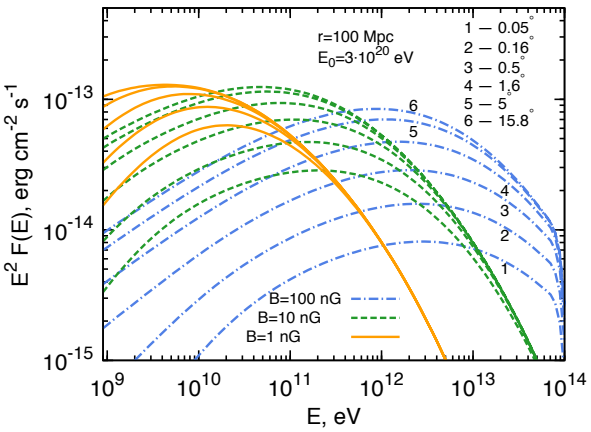


Figure 3: Spectra of gamma-rays observed within different polar angles from a source located at a distance $r = 100$ Mpc. The calculations are performed for three different IGMF strenths; $B = 1, 10$ and 100 nG.

Figure 2 shows the results of detailed numerical calculations. It illustrates that the proton fluxes within small observation angles are considerably suppressed due to deflections (at low energies) and p-γ interactions (at high energies). The angular distribution of gamma-rays appears narrow and at very high energies the source becomes point-like as it is demonstrated in Figure 3.

1.1.9 High-energy emission from outflow sources

V. Bosch-Ramon

Galactic and extragalactic sources presenting relativistic outflows are powerful non-thermal emitters of radiation from radio to gamma-rays. This emission can be produced in the base of a jet, through interactions of the plasma within the jet itself or with the external medium, or at the termination region. In the case of galactic gamma-ray binaries, one can explain the observed correlations between different wavelengths adopting non only radiative but also non-radiative losses, which are expected to occur in the complex environment of these sources. The termination region of galactic high-mass microquasar jets have properties that strongly depend on the environment, which to its turn depends on the age of the jet source. Jets could be either completely dis-

rupted or generate a hot-spot/radio lobe structure like in the FRI/FRII dichotomy of extragalactic AGN. In the case of the latter, FRI jets interacting with the medium could be emitters of non-thermal radiation detectable in the whole spectral range. At small scales, AGN jets could be powerful gamma-ray and lower energy emitters due to interactions with inhomogeneities present in the jet base, like stars and clouds.

1.1.10 A compact pulsar wind nebula model of the γ-ray-loud binary LSI +61° 303

A. Zdziarski, A.Neronov, M.Chernyakova

We study a model of LSI +61° 303 in which its radio to TeV emission is due to interaction of a relativistic wind from a young pulsar with the wind from its companion Be star. The detailed structure of the stellar wind plays a critical role in explaining the properties of the system. We assume the fast polar wind is clumpy, which is typical for radiatively driven winds. The clumpiness and some plasma instabilities cause the two winds to mix. The relativistic electrons from the pulsar wind are retained in the moving clumps by inhomogeneities of the magnetic field, which explains the X-ray variability observed on timescales much shorter than the orbital period. We calculate detailed inhomogeneous spectral models reproducing the average broad-band spectrum from radio to TeV. Given the uncertainties on the magnetic field within the wind and the form of the distribution of relativistic electrons, the X-ray spectrum could be dominated by either Compton or synchrotron emission. The recent Fermi observations constrain the high-energy cut-off in the electron distribution to be at the Lorentz factor of 2×10^4 or 10^8 in the former and latter model, respectively. We provide formulae comparing the losses of the relativistic electrons due to Compton, synchrotron and Coulomb processes versus the distance from the Be star. We calculate the optical depth of the wind to free-free absorption, showing that it will suppress most of the radio emission within the orbit, including the pulsed signal of the rotating neutron star. We point out the importance of Compton and Coulomb heating of the stellar wind within and around the ?-ray emitting region. Then, we find the most likely mechanism explaining the orbital modulation at TeV energies is anisotropy of emission, with relativistic electrons accelerated along the surface of equal ram pressure of the two winds. Pair absorption of the TeV emission suppresses one of the two maxima expected in an orbit.

1.1.11 The High-energy, Arcminute-scale Galactic Center Gamma-ray Source

M. Chernyakova, D. Malyshev, F. A. Aharonian

Employing data collected during the first 25 months of observations by the Fermi-LAT, we describe and subsequently seek to model the very high energy (>300 MeV) emission from the central few parsecs of our Galaxy. We analyze the morphological, spectral, and temporal characteristics of the central source, 1FGL J1745.6-2900. The data show a clear, statistically significant signal at energies above 10 GeV, where the Fermi-LAT has angular resolution comparable to that of HESS at TeV energies. This makes a meaningful joint analysis of the data possible. Our analysis of the Fermi data (alone) does not uncover any statistically significant variability of 1FGL J1745.6-2900 at GeV energies on the month timescale. Using the combination of Fermi data on 1FGL J1745.6-2900 and HESS data on the coincident, TeV source HESS J1745-290, we show that the spectrum of the central gamma-ray source is inflected with a relatively steep spectral region matching between the flatter spectrum found at both low and high energies. We model the gamma-ray production in the inner 10 pc of the Galaxy and examine cosmic ray (CR) proton propagation scenarios that reproduce the observed spectrum of the central source. We show that a model that instantiates a transition from diffusive propagation of the CR protons at low energy to almost rectilinear propagation at high energies can explain well the spectral phenomenology. We find considerable degeneracy between different parameter

choices which will only be broken with the addition of morphological information that gamma-ray telescopes cannot deliver given current angular resolution limits. We argue that a future analysis performed in combination with higher-resolution radio continuum data holds out the promise of breaking this degeneracy.

1.1.12 Search for transient sources and new gamma-ray loud systems in the GeV sky

M.Chernyakova, D. Malyshev

gamma-ray-loud binary systems (GRLB) are a newly identiÞed class of X-ray binaries in which either accretion onto the compact object (a neutron star, or a black hole), or interaction of an outflow from the compact object with the wind and radiation emitted by the massive companion star leads to the production of very-high energy (VHE) gamma-ray emission. Four such systems PSR B1259-63, LS 5039, LSI +61° 303 and HESS J0632+057, have been firmly detected as persistent or regularly variable TeV gamma-ray emitters. Most of the variable and transient Galactic sources of GeV gamma-ray are expected to belong to the GRLB class.

In order to find new GRLBs we analysed all the data collected by Fermi satellite and build several variability maps of the Galactic Plane on weekly and monthly timescales. Analysis of the obtained results revealed several interesting transient sources of unknown nature. Now we are looking in more details into each particular case. The work is ongoing.

1.1.13 Gamma Ray Bursts: REM Telescope observations and afterglow lightcurves

E. J. A. Meurs, L. Norci and P. Ward (DCU), S. Covino et al. (Brera Observatory)

Observations obtained with the automatic REM Telescope and other telescopes of the Gamma Ray Burst GRB060908, from less than one minute after the high-energy event up to a year later, were used to show that existing interpretative scenarios encounter difficulties in modelling all of this dataset. Well-observed cases like GRB060908 will be necessary for advancing theories of Gamma Ray Bursts.

1.1.14 High resolution echelle spectroscopy of GRB afterglows

E. J. A. Meurs, L. Norci and P. Ward (DCU), F. Fiore, V. D'Elia et al. (Rome Observatory)

High-resolution echelle spectroscopy is a relatively new and exciting tool for GRB astronomy. Data may now be obtained only minutes after a burst has occurred, which is important because of the transient nature and decreasing brightness of the afterglows. The echelle spectroscopy highlights the presence of intervening material along the line of sight, in the immediate surroundings of a burst as well as in separate intervening systems.

The high-resolution, high signal-to-noise spectrum of the 'naked-eye' burst GRB080319B was analyzed for intervening absorbers lying along the line-of-sight to this burst. The lack of variability of the column density of certain absorbing species in the distinct components of four such absorbing systems leads to rejecting the hypothesis that observed differences between GRB and quasi-stellar object MgII absorbers would be due to the different size of the respective emitting regions.

1.1.15 Echelle spectroscopy of normal OB stars

E. J. A. Meurs, L. Norci (DCU), V. F. Polcaro (Rome), R. Gualandi (Loiano)

Further spectroscopic observations of OB stars were secured at Loiano Observatory (Italy) with the 1.52 m telescope. The programme that is carried out aims at completing a census of all Northern OB stars with magnitude V<9, to find hitherto unrecognized runaway stars.

1.1.16 High-energy emission from young stellar clusters

E. J. A. Meurs, P. J. Kavanagh and L. Norci (DCU)

The youngest Galactic stellar clusters are examined at X-rays, primarily with data from the Chandra satellite, in order to investigate existing ideas about the sources of high-energy emission from these very young clusters, without having the complications of evolved binaries (i.e., X-ray binaries) or supernova remnants. The clusters were selected with ages less than 5 million years and with well-exposed Chandra observations available. This led to a sample of 13 clusters being studied for their point sources (stellar objects) as well as any diffuse emission component due to the combined effect of stellar winds.

A detailed interpretation was pursued for the cluster Westerlund 1 (Wd1), probably the most massive young stellar cluster in our Galaxy. By exception, X-ray observations with the XMM-Newton satellite were utilized for this cluster. Having established that the diffuse hard X-ray emission in Wd1 is thermal in origin (based on a spectral analysis that led to the discovery of Fe 6.7keV line emission), several potential sources for this diffuse component were examined. The origin of the diffuse hard X-ray component is most likely stellar winds, with conceivably a contribution from Pre-Main Sequence stars, while a contribution by supernova remnants is to be discarded.

A notable feature of Wd1 is that only one case of an end product of stellar evolution (that is, a stellar remnant) is known, which is a so-called magnetar (a neutron star with an extraordinarily strong magnetic field). A nearby normal stellar member of Wd1 presents itself as a possible former binary companion to the magnetar, because of its high proper motion: this could be acquired when a binary is disrupted after the supernova explosion of one member of the binary Ð the magnetar progenitor in this case. Based on this scenario, a magnetar progenitor mass not much higher than the assumed upper stellar mass for neutron star production can be deduced, thus diminishing recent claims in the literature for substantially higher progenitor masses for the Wd1 magnetar.

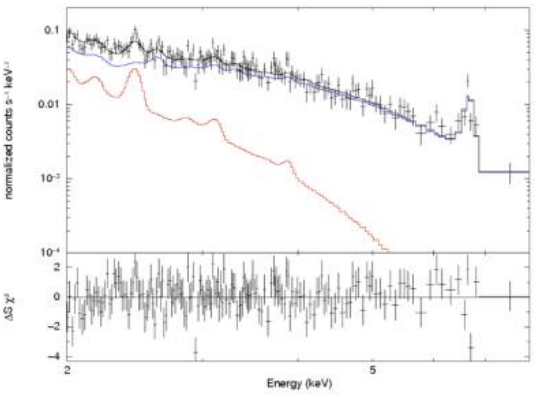


Figure 4: X-ray spectrum of the massive, young star cluster Westerlund 1, with Fe 6.7keV line emission. The XMM-Newton spectrum (points with error bars) has been fitted with a two temperature thermal model (black line). The low and high temperature components are indicated with red and blue lines, respectively. The lower panel shows the differences between the observed data points and the two temperature model fit.

1.1.17 Distribution and population size of Black Hole Binaries in the Galaxy

E. J. A. Meurs, G. O'Halloran, L. Norci and P. J. Kavanagh (DCU)

A map has been constructed showing the location of currently confirmed Black Hole Binaries in our Galaxy, based on a comprehensive review of their distances to the Sun. The observed Galactic Black Hole Binary distribution is used to obtain a population size of 1800 objects, assuming a distribution like Population II objects in view of the generally low mass stellar companions. When recurrence times and unconfirmed, candidate Black Hole Binaries are taken into account, the total number may increase to 10000 objects.

1.1.18 The distribution of core-collapse supernovae in spiral galaxies

E. J. A. Meurs, M. Molloy, L. Norci and P. J. Kavanagh (DCU)

Core-collapse supernovae are exploding massive stars and are therefore expected to occur in the disks of spiral galaxies. Yet several such supernovae have been observed away from the disks of their host galaxies. An analysis has been carried out of observational data on supernovae in edge-on spiral galaxies, in order to quantify the occurrence of core-collapse supernovae outside the disks of their host galaxies. A possible explanation for such displaced supernovae is that they acquired substantial space velocities after a companion star in a binary system exploded as supernova and an interpretative model is developed that can account for the observed galactic height distribution of the supernovae in edge-on galaxies.

1.2 Star Formation

1.2.1 Anomalous Microwave Emission

A. Scaife

The complete characterization of the "anomalous" microwave emission from spinning dust grains is a key question in both astrophysics and cosmology. It probes a region of the electromagnetic spectrum where a number of different astrophysical disciplines overlap. It is important for CMB observations in order to correctly characterise the contaminating foreground emission; for star and planetary formation it is important because it potentially probes a regime of grain sizes that is not otherwise easily observable.

Although recent results from the Planck satellite have significantly strengthened the case for its existence, the characteristics both environmental and intrinsic that affect the emission from spinning dust are still largely unconstrained.

AS is working on the identification and characterization of the anomalous emission attributed to spinning dust. As such she has been involved in a number of observational projects. Notable amongst these is the radio follow-up programme for the Spitzer and Herchel Nearby Galaxies samples (SINGS/KINGFISH), which is currently being undertaken using the GBT, AMI and ATCA telescopes in both the Northern and Southern hemispheres. This project has the joint aim of constraining the contamination of radio star formation tracers by anomalous microwave emission and using the derived corrections to employ free–free emission as a 'gold standard' for mid-infrared derived star-formation rates.

AS is PI of an observing programme with the ATCA telescope which represents the first direct use of anomalous microwave emission. This project is using the emission from the spinning dust grains to constrain the contribution of a very small grain population to the dust chemistry of circumstellar disks. This project has implications for both disk and planetary formation.

AS is the working group leader for the spinning dust working group of the MeerKAT telescope Galactic survey (MeerGAL), which was accepted in 2010 as one of the key survey projects for the new MeerKAT telescope.

1.2.2 Radio follow-up of low-luminosity protostars

A. Scaife

AS is leading an extensive programme of radio follow-up to the Spitzer cores to disks project. This project is looking at the radio luminosity of embedded protostars in the low- and very-low luminosity limit. These objects are of particular interest as they all violate the theoretical lower luminosity limit for star formation via steady accretion. Notable results from this ongoing work are the derived correlations between radio luminosity and the IR characteristics of the sources, as well as observational differences in the detection rates of protostars of differing evolutionary class. AS is also PI of a proposed extension to this programme with the ATCA telescope in the Southern hemisphere.

1.2.3 YSO NIR spectral survey: L1641 star forming region

A. Caratti o Garatti, R. Garcia Lopez, S. Antoniucci (INAF-OAR), T. Giannini (INAF-OAR), J. Eislöffel (TLS), B. Nisini (INAF-OAR), T. Ray

Low mass Young Stellar Objects (YSOs) are usually classified by the shape of their Spectral Energy Distribution (SED) into an empirical evolutionary sequence, which forms the basis of our understanding of the YSO formation process. In recent years, this classification has be shown to be limited in providing precise information on the YSO real evolutionary state. For instance geometrical effects have led to misclassifications between Class I and II objects. We carried on an in-depth study of a flux-limited sample of 27 Class I and II YSOs in L1641, based on low-resolution spectroscopy and photometry, ranging from optical to mid-IR wavelengths. The aim of this survey is to investigate the nature of these sources, deriving the main physical parameters from their spectra. Although Class I objects in our sample do not have bolometric luminosities dominated by accretion, we find that, on average, they are typically younger than CTTs. Similarly, we infer that the youngest objects have the highest accretion rates.

1.2.4 The outburst of an embedded low-mass YSO in L1641

A. Caratti o Garatti, R. Garcia Lopez, A. Scholz, T. Giannini (INAF-OAR), J. Eislöffel (TLS), B. Nisini (INAF-OAR), F. Massi (INAF-OAA), S. Antoniucci (INAF-OAR), T. Ray

Strong outbursts in very young and embedded protostars are rare and not yet fully understood. They are believed to originate from an increase in the mass accretion rate ($\dot{M}_{acc}$) onto the source. We report the discovery of a strong outburst in a low-mass embedded young stellar object (YSO), namely $2MASS-J05424848-0816347$ or $[CTF93]216-2$, as well as its photometric and spectroscopic follow-up. Using near- to mid-IR photometry and NIR low-resolution spectroscopy, we monitor the outburst, deriving its magnitude, duration, as well as the enhanced accretion luminosity and mass accretion rate. $[CTF93]216-2$ increased in brightness by ~4.6, 4.0, 3.8, and 1.9 mag in the J, H, K_s bands and at 24 μm, respectively, corresponding to an L_{bol} increase of ~20 $L_\odot$. Its early spectrum, probably taken soon after the outburst, displays a steep almost featureless continuum, with strong CO band heads and H_2O broad-band absorption features, and Brγ line in emission. A later spectrum reveals more absorption features, allowing us to estimate $T_{\rm eff}$~3200 K, M_*~0.25 $M_\odot$, and $\dot{M}_{acc}$~1.2×10^{-6} $M_\odot$ yr^{-1}. This makes it one of the lowest mass YSOs with a strong outburst so far discovered.

1.2.5 The Spitzer Survey of Interstellar Clouds in the Gould Belt. III. A Multi-Wavelength View of Corona Australis

D. E Petersson (CfA), A. Caratti o Garatti, T. Ray and the Spitzer Gould Belt Team

We present Spitzer Space Telescope IRAC and MIPS observations of a 0.85 deg^2 field including the Corona Australis (CrA) star-forming region. At a distance of 130 pc, CrA is one of the closest regions known to be actively forming stars, particularly within its embedded association, the Coronet. Using the Spitzer data, we identify 51 young stellar objects (YSOs) in CrA which include sources in the well-studied Coronet cluster as well as distributed throughout the molecular cloud. Twelve of the YSOs observed are new candidates, one of which is located in the Coronet. Known YSOs retrieved from the literature are also added to the list, and a total of 116 candidate YSOs in CrA are compiled. Based on these YSO candidates, the star formation rate is computed to be 12 $M_\odot$Myr^{-1}, similar to that of the Lupus clouds. A clustering analysis was also performed, with the finding that the main cluster core, consisting of 68 members, is elongated (having an aspect ratio of 2.36), with a circular radius of 0.59 pc and mean surface density of 150 pc^{-2}. In addition, we analyze outflows and jets in CrA by means of new CO and H_2 data. We present 1.3 mm interferometric con-

tinuum observations made with the Submillimeter Array (SMA) covering RCrA, IRS 5, IRS 7, and $IRAS18595-3712$ (IRAS 32). We also present multi-epoch H_2 maps and detect jets and outflows, study their proper motions, and identify exciting sources. The Spitzer and ISAAC/VLT observations of IRAS 32 show a bipolar precessing jet, which drives a CO (2-1) outflow detected in the SMA observations. There is also clear evidence for a parsec-scale precessing outflow, E-W oriented, and originating in the SMA2 region, likely driven by SMA2 or IRS 7A.

1.2.6 NIR spectroscopic survey of jets from massive YSOs

A. Caratti o Garatti in collaboration with B. Stecklum (Tautenburg), C. Davis (JAC), H. Linz (MPIA), T. Stanke (ESO), H. Zinnecker (AIP).

The detection and study of jets and outflows from high-mass young stellar objects (HMYSOs) is of primary importance to understand the mechanism which produces massive stars. We undertook an unbiased spectroscopic follow-up of the H_2 emission detected during our previous imaging runs (ESO-NTT/SofI, TNG/NICS), to clarify the nature and the origin of such emissions (shock vs fluorescence; jet vs photo-dissociation region), derive their excitation conditions (T, A_V), and the flow properties (mass, mass ejection rate, H_2 luminosity), correlating them with the evolutionary stage of the driving YSO.

1.2.7 Project on YSO variability

A. Caratti o Garatti, R. Garcia Lopez, A. Scholz, T. Ray, K. Covey (Uni. Cornell), J. Stauffer (SSC-CALTECH), M. Morales-Calderon (SSC-CALTECH), L. Rebull (CALTECH), R. Gutermuth (Five Col.)

We have begun a new project aimed to prove the episodic nature of the accretion mechanism in early stage YSOs, pinpointing those events produced by burst magnetospheric-accretion, and deriving an average burst frequency. This has been achieved through REM NIR time-series photometry of the sample, which have been then compared to previous archival photometric data.

We also asked for ground-based optical/NIR time-series observations with the (Rapid Eye Mount) REM telescope on La Silla, to support the Spitzer Space Telescope variability monitoring campaign of the Serpens Star Forming Region in May-June 2011. We will combine REM and Spitzer observations to investigate both short (<1 day) and long-term (up to 6 years) flux variability of the young stellar objects (YSOs) in this region, to discern the different mechanisms originating the YSO variability. In particular, REM photometry will monitor the stellar variability, whereas Spitzer data will trace changes in the circumstellar disk and envelope. Our data will be matched with proper radiative transfer models, that predict light-curve amplitude and phase as a function of wavelength. Since we cannot spatially resolve the stellar-disk system in our targets, studying variability at different wavelengths can probe their 3-dimensional geometry and structure, as well as the physical processes that are taking place.

1.2.8 X-Shooter Survey of Accretion and Ejection Properties in Very Low Mass Stars and Brown Dwarfs

A. Natta (DIAS/INAF-OAA), A. Scholz, T. Ray, E. Rigliaco (INAF-OAA)

Accretion and ejection of matter play a fundamental role in shaping the structure and evolution of circumstellar disks and, therefore, the formation and properties of planetary systems. In 2010, we have started a large project aimed at studying accretion and ejection properties in a relatively large sample of very low mass young stars and brown dwarfs using the new spectrometer at ESO/VLT X-shooter, which provides simultaneous coverage of the whole wavelength range from 300 to 2500 nm with a spectral resolution of 5000-10000. The first results for an actively accreting brown dwarf in the σ Ori star forming region have shown the potential of this instrument, which allows us to measure simultaneously a large number of accretion and mass-

loss indicators, avoiding the problem of time variability. We are now analyzing the spectra of about 15 objects in the same region.

1.2.9 The Properties of the Lowest Mass Young Stars, Brown Dwarfs and Planemos

A. Scholz, P. Dawson, T. Ray

Our understanding of star and planet formation is guided by observations of stars in the process of formation. One fundamental part of such projects is to survey star forming regions and to compile a complete census of young stars down to the lowest masses and the earliest ages. With the help of sensitive infrared instruments, it becomes feasible to achieve this goal.

Schrödinger Fellow Aleks Scholz is leading a long-term program to identify and characterise young stellar objects and their environment. The main focus of this program is the very low mass regime, the so-called brown dwarfs and planemos with 10-100 Jupiter masses, to answer the following questions:

1) What is the lowestmass an object can have to be formed like the Sun?

2) Can these objects still harbour planetary systems?

In 2010, A. Scholz has continued to build an international collaboration to work on these problems, including team members in Toronto (Canada), Arcetri (Italy), Garching (Germany), St. Andrews (UK), Tokyo (Japan), and Zurich (Switzerland). He was able to secure a Research Frontiers grant from Science Foundation Ireland, primarily to foster these collaborations and to fund a new PhD student Paul Dawson, who has started his work on a brown dwarf survey of several star forming regions based on data from the UKIDSS project. Over the last year, the team has applied successfully for highly competitive observing time at large ground-based and space telescopes (e.g., ESO/VLT, Subaru, Gemini, and Herschel).

1.2.10 A Near-Infrared Variability Study of the Star Forming Cloud IC1396W

A. Scholz, D. Froebrich (U. Kent), C. J. Davis (JAC, Hawaii), and H. Meusinger (TLS, Tautenburg)

In collaboration with colleagues at the University of Kent (UK), the Joint Astronomy Centre (USA), and the Observatory Tautenburg (Germany), A. Scholz has finished a census of the star formation activity in the compact region IC1396W in Cepheus. The team developed a new method to identify young stars based on a combination of variability and colours. IC1396W was found to have a very low star formation efficiency of 1%, which points to an early evolutionary state (Scholz, Froebrich, Davis, Meusinger, MNRAS, 2010, 406, 505).

1.2.11 Studies of Benchmark Objects

A. Scholz and Others

The brown dwarf FU Tau is an object with properties that challenge current models for the formation and early evolution of very low mass objects. In 2010 the team published evidence for unusually strong X-ray emission for FU Tau which allows a detailed study of the accretion and activity properties. Further characterisation of this enigmatic source is in progress (Stelzer, B., Scholz, A., Argiroffi, C., Micela, G., MNRAS, 2010, 408, 1095). In another project focused on the protostellar binary IRAS04326+2512, A. Scholz and his collaborators demonstrated that turbulence plays a major role in driving the fragmentation of the cloud cores to multiple systems, one of the the major open questions in star formation (Scholz, A., Wood, K., Wilner, D., et al., MNRAS, 2010, 409, 1557).

1.2.12 Accretion in Young Stellar Objects

G. Costigan, A. Scholz, T. Ray

The process by which young stars accumulate material from their environment is the focus of

the work of PhD student G. Costigan. Based on about 600 high-resolution spectra taken in 2009 and 2010 with the ESO-VLT she has measured the variability in several diagnostics for accretion. She found that accretion rates are mostly stable and vary predominantly on rotational timescales (i.e. a few days). This result puts important limits on models for magnetically controlled accretion and serves as useful guide for future observations.

1.2.13 Rotation in Young Stars

A. Scholz and Others

Rotation is a key parameter in the early evolution of stars. It is controlled by the interaction between stars and disk, magnetically channeled winds, and is intimately linked to the interior changes of stars, which undergoes fundamental changes within the first 100 Myr of their evolution. Understanding the coupling between rotation and magnetic activity may provide constraints for theories on the long-term evolution of the solar activity and thus the Earth's climate, which provides a primary motivation for this research field.

Building on a series of previous publications, A. Scholz has continued his work on the rotational evolution of very low mass stars. Leading a team of researchers from Harvard (USA), Cambridge (UK), Grenoble (France) and Tautenburg (Germany), he has published a new, large sample of rotation periods for stars in the open cluster Praesepe. The study demonstrates that stars with masses below 0.3 solar masses are fast rotators with periods less than 2 days) for at least 600 million years. For comparison, the Sun's rotation period is almost one month. This difference attributed to:

a) the fact that very low mass stars have fully convective interiors in contrast to solar-type stars and

b) their atmospheres are relatively cool which hampers the efficiency of the stellar wind in braking the rotation (Scholz, Irwin, Bouvier, et al., MNRAS, in press).

1.2.14 Observing Outflows Close to the Ejection Engine

D. Coffey, T. Ray, F. Bacciotti (Arcetri), J. Eislöffel (Tautenburg)

Research continued to consolidate findings that jets from young stars rotate, in order to address the issue of how angular momentum is removed during star formation. There are several observational indications that we can indeed observe a rotation signature in jets from young stars. However, there remains some controversy over this interpretation. In particular, in the case of the classical T Tauri star RW Aur, it appears that the direction of the jet rotation is opposite to that of the disk. This paradox must be resolved. Data analysis was conducted on new observations obtained from the Hubble Space Telescope in the near ultraviolet which it is hoped will shed some light on this controversial case.

1.2.15 The Herbig Ae star DK Cha: Accretion and Circumstellar Properties.

R. Garcia Lopez, A. Caratti o Garatti, T. Ray, B. Nisini (Rome), S. Antoniucci (Rome), D. Lorenzetti (Rome), T. Giannini (Rome), J. Eislöffel (Tautenburg)

Very little is known about the properties of the circumstellar material around young and embedded Herbig Ae stars, since they are rare and their nearby circumstellar surroundings are usually hidden from us. Here, we have performed an analysis of the excitation and accretion properties of the young Herbig Ae star DK Cha. The nearly face-on configuration of this source allows us to have direct access to the star-disk system through the excavated envelope and outflow cavity. Based on low-resolution optical and infrared spectroscopy obtained with SOFI and EFOSC2 on the NTT in Chile, we have derived the spectrum of DK Cha from ~0.6 μm to ~2.5 μm. From the detected lines we have investigated the conditions of the gas emitting the HI IR emission lines and have obtained insights into the origin of the other permitted emission lines. In addition, we have derived the mass accretion rate ($\dot{M}_{acc}$)

from the relationships relating the luminosity of the Brγ and Paβ lines with the accretion luminosity (L_{acc}). Numerous forbidden and permitted atomic and molecular emission lines were detected. Some of the permitted emission lines were identified as being excited by fluorescence. Paschen and Brackett decrements were derived and compared with different excitation mechanisms. The Paβ/Brγ ratio is consistent with optically thick emission in LTE at a temperature of ~3500 K, coming from a compact region of ~5 $R_\odot$ of size. The line opacity however decreases in the Br lines from high upper N levels. A good fit to the data is obtained by assuming an expanding gas in LTE, having an electron density at the wind base, n_e ~10^{13} cm^{-3} . In addition, we find that the observed Brackett ratios are very similar to those reported in previous studies of low-mass CTTSs and Class I sources, indicating that these ratios are not dependent on masses and ages. Finally, L_{acc} ~9 $L_\odot$ and M_{acc} ~3×10^{-8} $M_\odot yr^{-1}$ values were found, similar those in classical Herbig Ae stars. This indicates that DK Cha is in a final stage of accretion, with an L_{acc} /L_{bol} less than 0.5, or that most of the matter is accumulated in outbursts of accretion that could be responsible for the high variability of the object.

1.2.16 Emission lines as accretion tracers in YSOs: results from an optical-NIR survey of the Chamaleon I and II regions.

S. Antoniucci (Rome), R. Garcia Lopez, B. Nisini (Rome), T. Giannini (Rome), A. Caratti o Garatti, J. Eislöffel (Tautenburg), D. Lorenzetti (Rome), T. Ray, F. Bacciotti (Arcetri), S. Cabrit (Paris), C. Dougados (Grenoble), E. Whelan (Grenoble).

As part of the Poisson spectral survey, we have analysed a sample of 47 sources in the Cha I and II star-forming clouds. The sample was selected from Class I/II objects identified through Spitzer surveys, considering sources with spectral index $\alpha_{2-24\mu m} > -1$ and K-band magnitude <12. The data sample consists of low-resolution spectra taken with EFOSC2 and SOFI on the NTT telescope. We have detected many emission lines, commonly observed in YSOs, tracing accretion/wind regions at few AU from the central source and shocks at the base of jets. The large spectral coverage has allowed us to derive the accretion luminosity of the sources using different tracers. For instance, the accretion luminosity was derived using the [OI] 6300Å, Hα, CaII 8542 Å, Paβ and the Brγ lines. The accretion luminosity derived from these tracers present very different levels of scattering for similar values of stellar luminosity, while the one derived from the Brγ line shows the smallest dispersion. In addition, it was found that L_{acc} <L_* over the entire range of stellar luminosities. From the accretion luminosity and stellar parameters the group has also derived the mass accretion rate ($\dot{M}_{acc}$). We found that $\dot{M}_{acc}$ increases with the stellar mass (M_*) by a factor of $M_*^{1.7}$. This value is similar to the one observed in other low-mass star-forming regions, such as Ophiucus and Taurus, while it differs from the one measured for instance in L1641.

1.2.17 Magnetic topologies of late M dwarfs

J. Morin, J.-F. Donati (Toulouse), P. Petit (Toulouse), X. Delfosse (Grenoble), T. Forveille (Grenoble), M. Jardine (St. Andrews)

Fully-convective stars, either main-sequence M dwarfs or T Tauri stars, are challenging objects for stellar dynamo theories. Since they lack a tachocline, i.e. a thin layer of strong shear located at the base of the solar convection zone, magnetic field generation in these objects is likely to rely on processes that differ from solar-type stars. The first spectropolarimetric survey of M dwarfs has already revealed a sharp transition in large-scale magnetic topologies close to the fully convective limit.

The final results of this spectropolarimetric survey of a small sample of active M dwarfs have been released and it focuses on 11 fully convective late M dwarfs (spectral types M5-M8). Tomographic imaging techniques were applied to time-series of circularly polarized profiles of six stars, in order to infer their large-scale magnetic

topologies. For three other stars such magnetic maps could not be produced, because of the low variability of the circularly polarized signatures, but we were able to derive some properties of the magnetic fields. For the two remaining objects circular polarization in spectral lines was not detected in individual spectra, although we report a marginal detection for VB 10 by averaging the time-series.

Two distinct categories of magnetic topologies are found: on the one hand strong and steady axisymmetric dipolar fields (similar to mid M dwarfs), and on the other hand weak fields generally featuring a significant non-axisymmetric component, and exhibiting large temporal variations. Comparison with unsigned magnetic fluxes demonstrates that the second category of magnetic fields shows less organization (less energy in the large scales), similar to partly convective early M dwarfs. Stars in both categories have similar stellar parameters, and the data do not show any evidence for a separation between these two categories in the mass-rotation plane. The complex magnetic field recently observed on the low-mass fully convective T Tauri star V2247 Oph could be related to this second group of magnetic topologies.

1.2.18 Dynamo processes in fully convective stars

J. Morin, B. Dintrans (Toulouse)

Direct numerical MHD simulations of dynamo action in fully-convective stars using the PENCIL CODE have been performed in parallel with the spectropolarimetric survey. The primary aim is to assess the effect of stellar rotation on the geometry of the dynamo-generated magnetic field and on differential rotation. First results indicate that for fast rotation a significant axial dipolar component is generated, and that the magnetic field is able to inhibit differential rotation. However, toroidal fields represent a large fraction of the total magnetic energy, in contradiction with spectropolarimetric observations, and the reason for this discrepancy is not yet clear.

1.2.19 Geodynamo results in the stellar context

J. Morin, E. Dormy (ENS Paris), M.Schrinner (ENS Paris), J.-F. Donati (Toulouse)

Despite the very different nature of planetary and stellar interiors, recent studies have strengthened the idea that dynamo generation in rapidly-rotating fully-convective stars, and planets do not fundamentally differ. First, numerical simulations of geodynamo can switch from a steady dipole dominated magnetic field to solar-like dynamo waves simply by changing the aspect ratio of the dynamo region (thick versus thin shell). Secondly, a scaling law for the surface magnetic field strength initially derived from geodynamo simulations and theoretically based on energetics has been shown to be compatible with the observed magnetic fields of Earth and Jupiter as well as fully convective rapidly rotating stars (main sequence M dwarfs and T Tauri stars). We have therefore started to investigate how theories developed in the frame of the geodynamo can reproduce the properties of stellar magnetism in the fully convective regime, in particular two main results of the first spectropolarimetric survey, *i.e.* the sharp transition to dipolar magnetic fields close to the fully-convective boundary and the co-existence of two groups of stars with radically different magnetic fields but having similar stellar parameters.

1.2.20 Modelling non-solar coronae from spectropolarimetric and radio observations

J. Morin, G. Hallinan (Berkeley), M. Jardine (St Andrews), J.-F. Donati (Toulouse)

The recently discovered radio pulses on ultracool dwarfs have been attributed to electron cyclotron maser instability (ECMI) associated with the presence of strong large-scale magnetic fields. Similar pulses have been observed on a fully convective M4 dwarf and are compatible with the large-scale topology extrapolated from Zeeman-Doppler Imaging. Preliminary modelling in this area is now being pursued by us. In particular

contemporaneous radio and spectropolarimetric observations allow us to model more accurately the ECMI emission and disentangle pulses from flares. We are also investigating the evolution of the pulses properties in order to assess the potential of radio observations of ECMI emission to study stars out of the reach of spectropolarimetry.

1.2.21 Hydrogen Cyanide and Isocyanide in Prestellar Cores

M. Walmsley, M.Padovani (Barcelona), M.Tafalla (Madrid), P.Hily-Blant (Grenoble), G. Pineau des Forets (Paris)

This research forms part of a systematic investigation of the kinematics and structure of prestellar cores: that is cores with the potential to form stars in that there is approximate balance between thermal pressure gradients and gravitation. We are interested in particular in discovering useful tracers of the densest regions of these cores (above n(H2)=3 10^4cm^{-3}) where many species and in particular CO deplete onto dust grain surfaces. This research uses IRAM 30m observations to examine 3 nearby cores in Taurus and it has shown that both HCN and HNC remain in the gas phase at higher densities than CO. It has also shown that one can use the 13C substituted versions of these species to confirm recent collision rate calculations.

1.3 The Mid-Infrared Instrument (MIRI) for the James Webb Space Telescope

1.3.1 Background

DIAS is supporting, at the 2 FTE level, test and data analysis software for the Mid-Infrared Instrumet (MIRI) on the James Webb Space Telescope (JWST). The instrument itself is currently being prepared for Flight Model (FM) testing, around the middle of 2011, in the cryo-chamber of the Rutherford Appleton Laboratory and will then be delived to NASA Goddard later that year. The software team is led by Dr. Fred Lahuis from SRON in Groningen and consists of approximately 6 FTEs. The team reports to the MIRI European Consortium (MIRI-EC) at their regular meetings. Software development is in close collaboration with the Space Telescope Science Institute in Baltimore (STScI) using a common environment. The two software developers employed under contract with DIAS effectively starting in 2010 were J. Morin (JM), formerly from the University of Toulouse, and A. Scaife (AS), from the University of Cambridge.

1.3.2 MIRI development environment

A programming language (python) and a first set of libraries have been selected by STScI for the development of JWST calibration and analysis software. It has been decided by the MIRI-EC that new MIRI-specific software developments should use this environment to facilitate their further integration by STScI. JM has identified publicly available compatible software to complete the development environment. This includes science and visualization libraries providing the required functionalities as well as development tools. The development framework for MIRI-EC software developers has been designed and set up. This includes the code repository architecture, documentation and testing framework, reference code examples as well as the software installation procedures for all the supported platforms. This framework ensures that the requirements in terms of code documentation, quality and availability can be fulfilled. The corresponding technical documentation is available online for MIRI-EC and STScI developers and is regularly updated.

1.3.3 Support for simulators and analysis software

JM has been assisting with writing the first two major items of MIRI software developed in the new environment. The performed tasks include software design, python coding, and support for usage of the environment. The first piece of software is SCASim which simulates the response

of the MIRI Sensor Chip Array to a given illumination map. It has been adapted from a previous implementation included in SpecSim (the Medium Resolution Spectrometer Simulator), with the aim of providing a unique tool for the simulators developed for the various instrument modes. SCASim is already used to prepare the flight model performance test campaign. The second piece of software is the image reconstruction package described below.

1.3.4 Common tools and data products definition

The various MIRI software components need a number of common tools including various levels of data products (corresponding e.g. to science data for different instrument modes, at different processing levels). JM has designed and implemented first product prototypes, they use the object-oriented paradigm to gather data structure definition, input/output functionalities and specific operations. They are now used by the aforementioned SCA simulator. A second step has consisted in gathering the requirements and first design ideas for the whole set of required data products and to define their level of compatibility with the data types used by softwares designed for the MIRI test campaigns. The design phase for these MIRI data products, as well as the implementation of a prototype system to manage the metadata associated with all types of MIRI data are presently on-going. The generic data products and software tools are available to the MIRI-EC and STScI developers in a package maintained by JM.

1.3.5 Image reconstruction software for the MIRI Imager

AS has been developing a Bayesian image reconstruction package for the MIRI Imager. This package is intended to replace the "Drizzle" image reconstruction method employed to reconstruct undersampled images from multiple offset, or dithered, positions. Initial versions of the new imager were based around a massive inference design which implemented a Maximum Likelihood plus Maximum Entropy minimisation algorithm initially through a Metropolis Hastings MCMC method and later through a Nested Sampling method. The implementation was designed in such a way that additional user defined constraints on image reconstruction, such as sparsity, could be easily incorporated. This algorithm was designed to reconstruct images at "super-resolution", removing the effects of both the pixelization introduced by undersampling, and the convolution from the point spread function of the MIRI optics. The original "Drizzle" algorithm corrects only for the first of these. The methods were implemented in Python in order to be consistent with the MIRI pipeline. After initial testing and consultation with colleagues it was decided that a direct minimisation route would provide a more elegant solution and for this new implementation the powerful MemSys library, provided gratis by MaxEnt Data Consultants for use with MIRI, is currently being linked in to the test version. Substantial reworking of the MemSys I/O is required to perform joint reconstruction of multiple dither frames and this is currently on-going. Once in place the first use of the "MEMDrizzle" imager will be to determine the optimal dither spacing for image reconstruction using simulated data. The original MCMC minimisation code is now being used by colleagues at STScI to investigate the effect of correlated noise on slope fitting for MIRI.

1.4 General Theory

1.4.1 Particle escape from shock acceleration

L. Drury

The escape of charged particles accelerated by diffusive shock acceleration from supernova remnants was shown to be a more complex process than normally appreciated . Using a box model it was shown that the high-energy end of the spectrum can exhibit spectral breaks even with no formal escape as a result of geometrical dilution and changing time-scales. The bulk of the cosmic ray particles at lower energies must be produced and released in the late stages of

the remnant's evolution whereas the high energy particles are produced early on; this may explain recent observations of slight compositional variations with energy. [99]

1.4.2 Electron acceleration by plasma shocks

G. Murphy, L. O'C. Drury, M. Dieckmann (U. Linkoping)

The prompt emissions of gamma-ray bursts (GRBs) are seeded by radiating ultrarelativistic electrons. Kinetic energy dominated internal shocks propagating through a jet launched by a stellar implosion, are expected to dually amplify the magnetic field and accelerate electrons. We explore the effects of density asymmetry and of a quasi-parallel magnetic field on the collision of two plasma clouds. We demonstrate how a magnetic field structure resembling the cross section of a flux tube grows self-consistently in the current sheet of the shock transition layer. Plasma filamentation develops behind the shock front, as well as signatures of orthogonal magnetic field striping, indicative of the filamentation instability. These magnetic fields convect away from the shock boundary and their energy density exceeds by far the thermal pressure of the plasma. Localized magnetic bubbles form. Energy equipartition between the ion, electron and magnetic energy is obtained at the shock transition layer. The electronic radiation can provide a seed photon population that can be energized by secondary processes (e.g. inverse Compton). [39, 37]

1.4.3 Nonlinear wave steepening in plasma

G. Murphy, L. O'C. Drury, M. Dieckmann(U. Linkoping)

Nonlinear steepening acoustic waves are potential sources which could seed magnetic field amplification in the interstellar medium. We perform kinetic particle-in-cell simulations of a steepening acoustic wave in 2D. The crest of the wave overtakes the trough, exciting higher harmonics in the nonlinear system. Localized density spikes form. Fast-moving electrons escape from the dense spikes and create a Debye sheath of negative charge around a core of positively charged ions. The sheath degenerates rapidly in a Coulomb explosion (CE) driving a thermal anisotropy which seeds the Weibel instability increasing the magnetic field intensity. Electron phase space tubes are driven away from the explosion site. Such conditions could be useful to seed the further growth of magnetic fields through cosmic-ray driven instabilities.

1.4.4 Filament formation in counterstreaming plasma

G. Murphy, L. O'C. Drury, M. Dieckmann (U Linkoping), G. Sarri, K. Quinn, M. Borghesi (QUB)

The magnetic fields which are inferred in observations of gamma ray bursts and supernova remnants can originate from plasma effects. 2D particle simulations model the filamentation instability. Our results show that exponential growth is followed by saturation of the magnetic field. The composition of the beams affects the growth of the electrostatic field and the in-plane current coherency and correlation scale. The growth rate is close to the analytical value of $\beta\sqrt{2/\Gamma_b}$. The hypothesis that two-stream instability can contribute to breakup of filaments is confirmed by numerical simulation.

1.4.5 Large scale magnetic fields in viscous resistive accretion disks

G. Murphy, J. Ferreira (Laboratoire d'Astrophysique de Grenoble), C. Zanni (U. Torino)

Cold steady-state disk wind theory from near Keplerian accretion disks requires a large scale magnetic field at near equipartition strength. However the minimum magnetization has never been tested. We investigate the time evolution of an accretion disk threaded by a weak vertical magnetic field. The strength of the field is such that the disk magnetization falls off rapidly with radius. Numerical simulations of viscous resis-

tive accretion disk are performed using the magnetohydrodynamic code PLUTO. The large scale magnetic field introduces only a small perturbation to the disk structure, with accretion driven by the dominant viscous torque. A super fast magnetosonic jet is observed to be launched from the innermost regions and remains stationary over more than 900 Keplerian orbits. Ejection is made possible because the magnetization reaches unity at the disk surface, due to the steep density decrease. However, no ejection is reported when the midplane magnetization becomes too small. The asymptotic jet velocity remains nevertheless too low to explain observed jets due to the negligible power carried away by the jet. Astrophysical disks with superheated surface layers could drive analogous outflows even if their midplane magnetization is low. Sufficient angular momentum would be extracted by the turbulent viscosity to allow the accretion process to continue. The magnetized outflows would be no more than byproducts, rather than a fundamental driver of accretion. However, if the midplane magnetization increases towards the center, a natural transition to an inner jet dominated disk could be achieved.

1.4.6 Computational studies of ISM turbulence

T. Downes (DIAS/DCU), S.O'Sullivan (DIT)

Observations of molecular clouds indicate that they are turbulent. This turbulence is dynamically significant and may well affect both the overall evolution of molecular clouds as well as the progress of star formation within these clouds. However, the properties of turbulence in such clouds is not well understood. Although much work has been done on studying turbulence in these clouds under the assumption of ideal magnetohydrodynamics we know that multifluid effects are important on scales of less than a parsec or so.

In collaboration with Prof Alexander Lazarian (Univ Wisconsin, USA) initial studies on the so-called resurrection of turbulence at small scales in multifluid MHD systems were undertaken. Initial results appear to suggest that this affect may be reproducible in our numerical simulations and work on this is ongoing.

The second phase of a comprehensive study of the decay of multifluid MHD turbulence in molecular clouds using HDYRA was submitted to ApJ in late 2010. It showed that, as expected from previous work, multifluid effects enhance the rate of decay of turbulence and decreases the amount of structure present in the mass distribution on small scales. Interestingly, it would appear that the gross features of multifluid turbulence can be modeled rather well by approximating the influence of the multifluid effects by spatially and temporally constant resistivities.

Finally, 3 million core hours on the JUGENE system were obtained under the DEISA DECI-6 call to perform simulations of driven, multifluid MHD turbulence. This will allow us to investigate the statistical steady state of such turbulence. This is of considerable importance as it is generally believed that turbulence in molecular clouds is continually driven by some, as yet unknown, process and hence the dynamical influence of turbulence on processes such as star formation can only be understood by such studies.

1.4.7 The multifluid MHD Kelvin-Helmholtz instability

A. Jones (DCU), T. Downes (DCU/DIAS)

AJ submitted her PhD thesis on the multifluid MHD KH instability. The main focus of the thesis is an in-depth study of the influence of multifluid effects on the behaviour of the KH instability in weakly ionised plasmas with particular reference to molecular clouds.

It was found that non-ideal effects do not alter the linear regime of the instability. However, at saturation the magnetic energy in the system is considerably reduced by the presence of ambipolar diffusion and, indeed, the system returns to a quasi-steady state more quickly when this effect is important. On the other hand, if the Hall effect dominates the non-ideal effects then strong dy-

namo action is observed and the system does not return to a quasi-steady state at any point.

1.4.8 The petascale multifluid MHD code HYDRA

T. Downes (DCU/DIAS)

Previous work involving PRACE prototype testing led to TD being invited by PRACE to present on his experiences at the prestigious ISC'10 conference in Hamburg. In addition, Cray Inc licensed the multifluid MHD HYDRA code from TD, via DCU, in order to help to profile the performance of their systems with a petascale code. This resulted in a collaborative effort between TD and Cray Inc to gain an understanding of the interaction of the HYDRA code with the Cray environment.

1.5 Miscellaneous

1.5.1 Space Dosimetry - DOBIES and Theseus

D. O'Sullivan

The ESA Prodex Meeting was held at Enterprise Ireland, Dublin 3 on April 13th and D O'Sullivan reported on the latest results from the DOBIES Project. Analysis of data acquired on the Space Shuttle flight 13S in 2008 was completed and confirmed the early results reported last year. The project is now finished [58].

D O'Sullivan continued as a member of the European Science Foundation Theseus Project (http://www.theseus-eu.org) and attended the first meeting of the Space Radiation Expert Group (April 6th-9th) at Sasbachwalden, Germany. He contributed to the first draft of a major ESF publication on space radiation with special emphasis on the dosimetry of heavy cosmic ray nuclei and solar events. This project is due to continue until late 2011.

1.5.2 The Magnetic Universe

A. Scaife

AS is part of the management team for the LOFAR Magnetism Key Science Project (MKSP). This KSP aims to investigate fundamental astrophysical questions on the distribution of magnetic fields in the Universe in order to understand the origin of cosmic magnetism. Polarimetry with LOFAR will allow investigations of the so far unexplored domain of extremely weak magnetic field strengths via Faraday rotation. This is a large international project with contributions from 12 countries. AS has also been heavily involved in the formation of the Irish LOFAR consortium (I-LOFAR) and is a primary contributor to the white paper.

AS is leading the "polarized sky" working group of the MeerKAT International GigaHertz TierEd Extragalactic (MIGHTEE) Survey, accepted as a key survey for the South African MeerKAT telecope, and is also a member of the survey executive committee. This is a wide-area deep continuum survey in the Southern hemisphere which will use the alignment of intrinsic polarization angles and large-scale structure to investigate the problem of cosmic bi-refringence.

AS is PI of the BEOWULF: B-field Estimation and Observational Wide-field Understanding of Large-scale Faraday-structure Survey for the Apertif telescope which is Phased Array Feed (PAF) pathfinder instrument for the SKA telescope. This project will use finely spaced rotation measure grids to constrain the magnetic field strengths in filaments of inter-cluster gas in the Perseus-Pisces supercluster of galaxies with a view to determining the origin of cosmic magnetism. This survey has passed the first round of reviews and will face a second round in early 2011.

AS is an invited member of the European SKA Science Working Group (ESSWG) and has been nominated as Magnetism Co-ordinator. In this role she will be responsible for collating and drafting the magnetism science case for Phase I of the SKA.

1.5.3 The Sunyaev–Zel'dovich Effect

A. Scaife

AS leads the Galactic science program for the AMI telescope (UK) and is part of the consortium for the blind SZ cluster survey being carried out with this instrument. SZ cluster surveys will provide an important constraint on the structure formation of the Universe, which is not well understood from CMB cosmology. 2010 has seen the first wave of SZ science from the AMI telescope as well as a first blind detection of new SZ structure. AS has been involved in both the analysis of SZ data and of the 10C survey of high frequency radio sources, which is the deepest high frequency radio survey of significant extent by over two orders of magnitude in completeness.

AS is leading a follow-up programme of high resolution SZ measurements with the MUSTANG camera on the GBT to the Planck satellite new cluster detections catalogue. This project is in collaboration with colleagues in the US and the UK.

2 Invited talks

- Aya Bamba
    1. “Are dark particle accelerators really DARK?”, GeV to TeV Connection, Ringberg, 11-16, January
    2. “X-ray measurement of particle injection and escape from SNR shocks”, Exploring Supernova Remnants and Pulsar Wind Nebulae in X-rays: before and after ASTRO-H, Kanagawa, 18-19, February
    3. “Cosmic ray production in Supernovae and SNR”, IXO Science Meeting, Paris, 27-29, April
    4. “SNR study with CTA”, CTA General Collaboration Meeting, Oxford, 9-11 November
- Anna Scaife
    1. “Anomalous Microwave Emission from Spinning Dust: Current Observational Evidence”, University of Groningen, 23 April
    2. “The Arcminute Microkelvin Imager”, University of Oxford, 12 July
    3. “Spinning Dust: Review”, Workshop on Hyper-Compact HII Regions, CSIRO Sydney, 7 September
    4. “Cosmic Magnetism with Next Generation Telescopes”, European SKA Science Working Group, Cambridge, 9 December
- Luke Drury
    1. “High acceleration efficiency versus thermal heating in SNRs" Invited talk at JAXA workshop, Tokyo, 18 Feb.
    2. “The origin of the Galactic cosmic rays - what clues do we have and how close to a solution are we?” Invited review at COSPAR session E18, Bremen, 20 Jul.
    3. “Escaping the Accelerator: How, When, How Many?” Invited talk at ICATPP Conference on Cosmic Rays for Particle and Astroparticle Physics, Como, Italy, 8 Oct.
    4. “Particle acceleration theory” Invited plenary talk at 25th Texas Symposium on Relativistic Astrophysics, Heidelberg, 10 Dec.
- Felix Aharonian
    1. “Gamma-ray sources and magnetic fields”, Bern, Switzerland, Large-scale magnetic fields in the Universe (01.03.-05.03.2010)
    2. “Cosmic Rays and gamma-ray astronomy from the ground”, Catania, Italy, CRIS 2010: “100 years of Cosmic Ray Physics: from pioneering experiments to physics in space” (13.09.- 17.09.2010)
    3. “Very High Energy Source Populations”, Cape Town, South Africa, 5th International Conference on Beyond the Standard Models of Particle Physics, Cosmology and Astrophysics (01.02.-06.02.2010)
    4. “HTRA with Cerenkov Telescopes”, Crete, Greece, High Time Resolution Astrophysics (HTRA) IV (05.05.-07.05.2010)

5. “High Energy Sources above 10 MeV”, Dublin, Ireland, 8th INTEGRAL Workshop: The Restless Gamma-ray Universe (27.09-30.09.2010), also Durham, England, European Conference
6. “Overview of recent observations of very high energy gamma-rays”, Moscow, Russia, HEA-2010: High Energy Astrophysics (21.12.-24.12.2010)
7. “On the origin of very hard spectra of TeV blazars”, Trieste Italy, SCINEGHE 2010, Gamma-ray Astrophysics in the Multimessenger context (08.09.-10.09.2010)
8. “Sources of highest energy cosmic rays, intergalactic magnetic fields, and formation of extended gamma-ray structures”, Nice, France, Non-thermal phenomena in colliding galaxy clusters (15.11-18.11 2010)

- Valenti Bosch-Ramon
  1. “Review of microquasar modeling and future directions”, 38th COSPAR assemly, Germany, July
  2. “Non-thermal processes in microquasars”, IAU Symposium 275: Jets at all Scales, Argentina, September
  3. “Extragalactic astrophysical sources of gamma-rays”, 8a Reunión de la Sociedad Española de Astronomía, Spain, September
  4. “Gamma-rays from black-hole binaries”, Accretion and Outflow in Black Hole Systems, Nepal, October
  5. “Theoretical review of Gamma-ray binaries”, ISSI meeting on gamma-ray binaries, Switzerland, November
  6. “Radiation absorption and reprocessing: cascading and secondary synchrotron emission”, Variable galactic gamma-ray sources, Germany, December
- A. Caratti o Garatti
  1. “Investigating Class I sources: real youth or make-up?”, Dublin Institute for Advanced Studies, 17 June
  2. “Corona Australis observed with IRAC and MIPS”, Spitzer Gould Belt Survey Meeting, Dublin (23-27/8/2010), 23 Aug.
- R. Garcia Lopez
  1. “NIR diagnostics of Class I protostars: the jets”, Max Planck Institut für Radioastronomie, Bonn, Germany, 16 June
- J. Morin
  1. “Exploring the magnetic topologies of cool stars”, IAUS 273, Ventura, USA, 24 Aug.
  2. “Observations of magnetic topologies across the fully convective threshold”, Cool Stars XVI, Seattle, USA, 1 Sept.
  3. “Magnétisme stellaire à travers la limite entièrement convective”, Programme National de Physique Stellaire, Marseille, France, 7 Oct.
- T. Ray

1. “Jets and Outflows from Brown Dwarfs”, University of New South Wales, Sydney, Australia, 16 Feb.
2. “Outflows from Young Stars and Brown Dwarfs”, University of Canterbury, Christchurch, New Zealand, 25 Feb.
3. “The Mid-Infrared Instrument (MIRI) on the James Webb Space Telescope”, Enterprise Ireland, 13 April
4. “The Potential of Exploring SN1987A with MIRI”, Ringberg Castle, Bavaria, Germany, 21 October

3 Externally funded projects and grants of resources

3.1 Observing Runs: Completed or Awarded in 2010

- A detailed study of Class I YSOs in CrA. Apr-Sept. 2010 - 19 hrs at VLT (ISAAC). A. Caratti o Garatti, R. Garcia Lopez, S. Antoniucci (INAF-OAR), D.E. Peterson (CfA), B. Tyler (CfA), Barreyre L., and Ray T.
- An REM/TNG study of IR variability in embedded Young Stellar Objects. Aug 2010 - Jan 2011 - 4 hrs + 96 hrs at TNG/REM, service. A. Caratti o Garatti, F. Massi (INAF-OAA), R. Garcia Lopez, B. Nisini (INAF-OAR), A. Scholz, S. Antoniucci (INAF-OAR), T. Giannini (INAF-OAR), D. Coffey, T. Ray
- An REM/Spitzer survey of the optical/IR variability of Young Stellar Objects in Serpens. Apr 2011 - May 2011, 30 hrs at REM, service. A. Caratti o Garatti, K. Covey (Uni. Cornell) , R. Garcia Lopez, A. Scholz, J. Stauffer (SSC-CALTECH), M. Morales-Calderon (SSC-CALTECH), L. Rebull (CALTECH), R. Gutermuth (Five Col.)
- HST Program Title: Investigation of Jet Rotation in Young Stars via High Resolution UV Spectra. Aug 2010 - Feb 2011 - 18 Orbits of HST PI/CoI: *F. Bacciotti (Arcetri), D. Coffey, J. Eislöffel (Tautenburg), T. Ray*
- Nov-Dec 2010: 5 nights at Calar Alto Observatory (2.2m/CAFOS), PI/CoI: A. Scholz (DIAS), J. Eisloeffel (Tautenburg), B. Stelzer (Palermo), G. Costigan (DIAS)
- Nov 2010: 1 night at Subaru Telescope (FMOS), PI/CoI: A. Scholz (DIAS), K. Muzic (Toronto), R. Jayawardhana (Toronto), M. Tamura (Tokyo)
- May 2010: 2 nights at Subaru Telescope (FMOS), PI/CoI: A. Scholz (DIAS), K. Muzic (Toronto), R. Jayawardhana (Toronto), M. Tamura (Tokyo)
- Jan 2010: 6 nights at INT (MOSAIC), PI/CoI: A. Scholz (DIAS), J. Irwin (Harvard), S. Hodgkin (Cambridge), J. Bouvier (Grenoble), J. Eisloeffel (Tautenburg)
- Jan 2010: 6 nights at CTIO/Blanco (MOSAIC), PI/CoI: A. Scholz (DIAS), J. Irwin (Harvard), S. Hodgkin (Cambridge), J. Bouvier (Grenoble), J. Eisloeffel (Tautenburg)
- 13 hours at Herschel (PACS/SPIRE) awarded for 2011, PI/CoI: A. Scholz (DIAS), A. Natta (Florence), L. Testi (ESO), G. Meeus (Madrid), R. Jayawardhana (Toronto), J. Greaves (St. Andrews), Kenneth Wood (St. Andrews), A. Brandeker (Stockholm)

- GBT (16hr) Characterization of anomalous emission in extra-galactic HII regions (PI: Murphy; co-I: Scaife)
- ATCA (40hr) Anomalous microwave emission from spinning dust in circumstellar disks (PI: Scaife)
- Effelsberg (40hr) Characterization of spinning dust in Galactic HII regions (AGE HII programme; PI: Scaife)
- GBT (14hr) Characterization of spinning dust in Galactic HII regions (AGE HII programme; PI: Scaife)
- LOFAR (multiple runs) Polarization commissioning (PI: Beck; co-I: Scaife)

3.2 Current Research Project Grants

- Luke Drury
  1. PRTLI-4 e-INIS, Project Coordinator
  2. SFI RFP, one postdoc
- Felix Aharonian
  1. EU FP6 Design Study KM3NeT, 40K, Preparatory Phase 30K
  2. SFI RFP, two postgrads
  3. EU Marie Curie Fellowship
- Tom Ray
  1. PRODEX MIRI, two scientific officers
  2. SFI RFP, one postdoc and one postgrad
  3. IRCSET, two postdocs
  4. Lindsay Scholarship (DIAS & Armagh Observatory), one postgrad
- Aleks Scholz
  1. RFP10/AST2780 (1 postgraduate student)
- Denis O'Sullivan (emeritus)
  1. DOBIES - from Enterprise Ireland under PRODEX, 24k over 2 years

3.3 Proposals submitted

- L. Drury (with A. Shearer, NUIG, and J. Morrison, UCC)
  - SFI PI2010 call "Data Centric Computing" (unsuccessful)
- G Murphy
  - European Research Council starter grant "Shocks: Understanding Relativistic Plasma Acceleration Systems" (pending)

4 Contributions to Teaching

- F. A. Aharonian
  - 40th Saas-Fee Lecture Series: Astrophysics at Very High Energies (10 lectures), Les Diablerets, Switzerland, March 15-20, 2010
- E. J. A. Meurs
  - Course of 4th year lectures on High Energy Astrophysics, DCU.
  - Supervision of three final year undergraduate research projects in DCU
- D. Coffey
  - Introduction to Gravitation & Relativity, 1 semester, NUI, Maynooth
- T. Ray
  - Astronomy and Astrophysics (PY1P10), 1st Year, 1 semester, TCD
  - Stellar and Galactic Structure (PY3A03), 3rd Year, 1 semsester, TCD
  - PhD Viva, H. Wheelwright, University of Leeds, 17 December
- A. Scholz & T. Ray
  - Supervision of Final Year Astrophysics Project, “Accretion in Young Stars”, 1 semester, Sarah Killeen, TCD
- M. Chernyakova
  - Module on High-Energy Astrophysics, Loughborough University, UK

5 Community Service, Awards and Distinction

- Luke Drury:
  1. Member of the ICHEC oversight board;
  2. Member of the H.E.S.S. Collaboration Board;
  3. Member of the Council of the RIA (until 16th March)
  4. Member of the Grid-Ireland board
  5. Honorary Andrews’ Professor of Astronomy, TCD
- Felix Aharonian:
  1. Adjunct Professor in the School of Physics UCD
  2. co-PI of the ROTSE project;
  3. member of the H.E.S.S. Collaboration Board;
  4. member of the Consortium of the KM3NeT;
  5. member of the working group “Science with NeXT" (Japanese next generation X-ray mission);

6. member (“Principal Scientist/Professor”) of the Heidelberg Graduate School of Fundamental Physics at the University of Heidelberg;
7. Adjunct Professor of the International Center for Relativistic Astrophysics Network, Pescara/Rome
8. external scientific member of the MPIK in the High Energy Astrophysics Group
9. co-director of LEA - European Associated Laboratory on High Energy Astrophysics (jointly supported by CNRS and MPG);
10. member of the European Astronet Infrastructure Roadmap Panel A: “High energy, astroparticle astrophysics and gravitational waves";
11. member of the International Review Panel of the Helmholtz Association: "Astroparticle Physics"
12. an Editor of the International Journal of Modern Physics D.

- Evert Meurs:
  1. member of the REM consortium;
  2. member of the RIA Astronomy and Space Science Committee;
  3. member of the Space Strategy Working Group (Space Industry Skillnet);
  4. Adjunct Professorship Dublin City University;
- Tom Ray
  1. Co-PI of the MIRI project;
  2. Member of the e-MERLIN Steering Committee (Steering committee for national radio astronomy facilities in the UK);
  3. Robert Ball Professorship Trinity College Dublin;
  4. Member of the Herschel Observatory Time Allocation Committee;
  5. Member of the Physical and Chemical Sciences Committee, Royal Irish Academy
  6. Member of the European MIRI Steering Committee (an ESA committee)
  7. Member of the Gogarty Scholarship Committee to assist students attend the international Space Studies Program or complete a M.Sc. in Space Studies or Space Management
  8. Member of the Management Committee of Armagh Observatory
- Masha Chernyakova
  1. Member of the XMM-Newton AO-10 proposal review panel.
- Denis O’Sulllivan
  1. Member of the expert panel at the Chief Scientific Adviser’s Office. He was commissioned to review the present status of the possible health effects of exposure to electromagnetic fields from power lines and produce a position paper on behalf of the Office. The paper, which was published on the Office’s website concluded that such effects were scientifically unconvincing and that they were impossible according to well established physics and biological principles.

6 Contributions to research infrastructures

Advanced research in Astronomy and Astrophysics nowadays increasingly relies on access to advanced observing facilities and also to an advanced computational e-infrastructure. In fact for its observational work the section relies entirely on access to international resources such as the space observatories Chandra, Fermi and the Hubble Space Telescope and shared international facilities on the ground such as the European HESS consortium gamma-ray telescopes in Namibia as well as major ground-based optical and radio facilities. At European level the section is a member of two major projects identified in the European Strategic Forum for Research Infrastructures roadmap, the next-generation Cherenkov Telescope Array project (CTA) and the KM3NeT project for neutrino astronomy and has an interest in the radio projects LOFAR and SKA. During the year L. Drury attended meetings of the Irish ESFRI participants to brief the national representatives on CTA and KM3NeT.

The need for an accompanying advanced e-infrastructure was the main motivation for proposing the PRTLI-4 funded project e-INIS which aims to establish on a pilot basis an integrated national e-infrastructure bringing together advanced networking, high-performance computing, and high-capacity data services. During the year the first user-controlled light path connections were lit on the Irish Research Optical Network and demonstrated to sustain 10Gb/s throughput. In addition to providing research infrastructure, the e-INIS project has delivered improved levels of expert user-support and facilitated access to shared ICT resources. A key challenge with such shared services is that of user authentication, which the e-INIS Edugate activity has sought to address. Edugate provides a federated identity management system for all national researchers and has this year successfully transitioned from pilot to full production status. The main national computational resource, Stokes, which was the first significant capital investment under the project in 2008, was this upgraded and extended with direct contributions from five national universities further strengthening the provision of shared services in Ireland. With ever increasing volumes of data, both as the raw material and by-product of research, its storage, management and sharing has become an integral component of modern e-Infrastructures. The first phase of the federated national data-store was further advanced this year with a capacity approaching one Petabyte. Researchers from a broad spectrum of disciplines have become early adopters of the data management services and have already begun to fully exploit the available storage and network bandwidth capacity. The BlueGene computer systems Schroedinger and Lanczos, operated on behalf of the National Capability Computing Consortium by the Institute, reached their planned three-year life at the end of the year. An evaluation of the impact of the systems concluded that they had exceeded expectations and been a major factor in propelling Ireland and Irish researchers into the field of true capability computing. An impressive demonstration of this was the success of Turlough Downes, working in the Section on secondment from DCU, in obtaining proto-type testing access on two of the largest supercomputers in Europe for his Hydra code.

7 Public Outreach

Outreach events focused on the use of Dunsink as a public observatory and location for meetings. An extensive programme of redecoration and renovation in Observatory House was carried out over the Summer months at a time when it caused minimal disruption to the outreach activities and the buildings are now in much better condition. Table 1 lists the main outreach events that tool place during the year. The popular scheme of inviting a primary school to visit Dunsink during the day and a secondary school during the evening was followed again in science week 2010.

Table 1: Dunsink events in 2010

Date	Event	Principal Speaker or Participants
18th Jan	Sky viewing event	IAS Members
04th Feb	Public Open Night	Paul Dempsey (Creme/Dias)
15th Feb	Software instruction IAS	Michael Murphy IAS
17th Feb	Public Open Night	Masha Chernyakova
22th Feb	Practical Telescope Instruction	John Murphy IAS
24th Feb	UCD Mature Student	Peter Duffy UCD
03rd Mar	Public Open Night	Anna Scaife
10th Mar	Public Open Night	Deirdre Kelleghan
24th Mar	Irish language evening	Colin Melody
01st Apr	TCD Physics sociiety	Peter Gallagher TCD
16th Apr	Sky viewing event	Ronald Buta IAS
17th Apr	International Speaker	Ronald Buta IAS
26th Apr	Software instruction	Michael Murphy IAS
05th May	Public Open Night	John Flannery SCD Astronomy
10th May	AGM IAS	IAS members
12th May	TCD retreat day	TCD graduate students
12th Jun	Solarfest	TCD/IFAS
16th Jun	Astronomy Badge Event	Various
17th Sep	IFAS Social Evening	Michael O'Connell
16th Oct	Hamilton/Maths Event	Nui Maynooth, DIAS
18th Oct	Teaching the Sky	John O'Neill IAS
20th Oct	Public Open Night	David Malone NUIM
22th Oct	International Young People's Star Party	Masha Chernyakova
03rd Nov	Public Open Night	Perikles Rammos
08th Nov	Secondary School D13	Paul Dempsey (Creme)
09th Nov	St Killian D14	Denys Malshev
09th Nov	E-Inis meeting	E-Inis members
09th Nov	Hartstown Community	Gareth Murphy
10th Nov	Holy Child Boys	Julien Morin
10th Nov	TCD Solar Group TY's	TCD
10th Nov	Girl Guide group	Aleks Scholz
11th Nov	Holy Child Boys	Grainne Costigan
11th Nov	Parents/Childs Evening	Alessio Caratti O Garatti
12th Nov	Holy Child N/S	Rebeca Garcia Lopez
12th Nov	IAS Jupiter Watch	Telescope Viewing Evening
17th Nov	Public Open Night	Aleks Scholz
18th Nov	South County Dublin	John Murphy IAS
20th Nov	O'Raifeartaigh family event	Una Ni Raifeartaigh
13th Dec	NUI Maynooth	Fiona Mc Groarty DIT
14th Dec	IAS Meeting	Michael Murphy IAS
15th Dec	Public Open Night	Paul Dempsey (Creme)

8 Conferences Organised

- F. A. Aharonian and A. Bamba held an international meeting “Exploring Supernova Remnants and Pulsar Wind Nebulae in X-rays: before and after ASTRO-H”, at ISAS/JAXA, Japan, Feb. 18–19, which attracted more than 70 participants.
- F. A. Aharonian, V. Bosch Ramon, D. Khangulyan organised a workshop in Heidelberg, Germany, on “Variable Galactic Sources” (30.11.-03.12.2010)
- F. A. Aharonian was chair of the local organising committee for the 25th TEXAS Symposium on Relativistic Astrophysics held in Heidelberg, Germany (06.12.-12.12.2010).
- A. Caratti o Garatti, E. Flood and T. Ray organised a Spitzer Gould Belt Team Meeting, DIAS, 10 Burlington Road, Dublin, 23 - 27 August.
- A. Scaife organised a meeting of the LOFAR Magnetism Key Science Project in 10 Burlington Road, Dublin, 26-27 October.

9 Detailed Bibliography of Publications

Note that where possible hyperlinks have been provided to the journal article and preprint version.

9.1 Peer-reviewed Publications in 2010

[1] F. Acero et al. "First detection of VHE γ-rays from SN 1006 by HESS". In: A&A 516 (June 2010), A62+. DOI: 10.1051/0004-6361/200913916. arXiv:1004.2124 [astro-ph.HE].

[2] F. Acero et al. "Localizing the VHE γ-ray source at the Galactic Centre". In: MNRAS 402 (Mar. 2010), pp. 1877–1882. DOI: 10.1111/j.1365-2966.2009.16014.x. arXiv:0911.1912 [astro-ph.GA].

[3] F. Aharonian and A. M. Taylor. "Limitations on the photo-disintegration process as a source of VHE photons". In: *Astroparticle Physics* 34 (Dec. 2010), pp. 258–266. DOI: 10.1016/j.astropartphys.2010.08.004. arXiv:1005.3230 [astro-ph.HE] (cit. on p. 6).

[4] F. Aharonian et al. "Discovery of VHE γ-rays from the BL Lacertae object PKS 0548-322". In: A&A 521 (Oct. 2010), A69+. DOI: 10.1051/0004-6361/200912363. arXiv:1006.5289 [astro-ph.HE].

[5] F. A. Aharonian, S. R. Kelner, and A. Y. Prosekin. "Angular, spectral, and time distributions of highest energy protons and associated secondary gamma rays and neutrinos propagating through extragalactic magnetic and radiation fields". In: Phys. Rev. D 82.4 (Aug. 2010), pp. 043002–+. DOI: 10.1103/PhysRevD.82.043002. arXiv:1006.1045 [astro-ph.HE] (cit. on p. 7).

[6] T. Anada et al. "X-Ray Studies of HESS J1809−193 with Suzaku". In: PASJ 62 (Feb. 2010), pp. 179–. arXiv:0912.1931 [astro-ph.HE].

[7] D. Arzoumanian et al. "The contribution of star-spots to coronal structure". In: MNRAS 410 (Feb. 2011), pp. 2472–2480. DOI: 10.1111/j.1365-2966.2010.17623.x. arXiv:1008.3613 [astro-ph.SR].

[8] A. Bamba, K. Mori, and S. Shibata. "Chandra View of Pulsar Wind Nebula Tori". In: ApJ 709 (Jan. 2010), pp. 507–511. DOI: 10.1088/0004-637X/709/1/507. arXiv:0912.1103 [astro-ph.HE].

[9] A. Bamba et al. "X-ray Evolution of Pulsar Wind Nebulae". In: ApJ 719 (Aug. 2010), pp. L116–L120. DOI: 10.1088/2041-8205/719/2/L116. arXiv:1007.3203 [astro-ph.HE].

[10] M. V. Barkov, F. A. Aharonian, and V. Bosch-Ramon. "Gamma-ray Flares from Red Giant/Jet Interactions in Active Galactic Nuclei". In: ApJ 724 (Dec. 2010), pp. 1517–1523. DOI: 10.1088/0004-637X/724/2/1517. arXiv:1005.5252 [astro-ph.HE] (cit. on p. 6).

[11] M. Benisty et al. "The 2008 outburst in the young stellar system Z CMa. I. Evidence of an enhanced bipolar wind on the AU-scale". In: A&A 517 (July 2010), pp. L3+. DOI: 10.1051/0004-6361/201014776. arXiv:1007.0682 [astro-ph.EP].

[12] E. Bressert et al. "The spatial distribution of star formation in the solar neighbourhood: do all stars form in dense clusters?" In: MNRAS 409 (Nov. 2010), pp. L54–L58. DOI: 10.1111/j.1745-3933.2010.00946.x. arXiv:1009.1150 [astro-ph.SR].

[13] S. Casanova et al. "Modeling the Gamma-Ray Emission Produced by Runaway Cosmic Rays in the Environment of RX J1713.7−3946". In: PASJ 62 (Oct. 2010), pp. 1127–1134. arXiv:1003.0379 [astro-ph.HE] (cit. on p. 4).

[14] S. Casanova et al. "Molecular Clouds as Cosmic-Ray Barometers". In: PASJ 62 (June 2010), pp. 769–. arXiv:0904.2887 [astro-ph.HE] (cit. on p. 4).

[15] M. S. Clemens et al. “Starburst evolution: free-free absorption in the radio spectra of luminous IRAS galaxies”. In: MNRAS 405 (June 2010), pp. 887–897. DOI: 10.1111/j.1365-2966.2010.16534.x. arXiv:1002.3334 [astro-ph.GA].

[16] D. Coffey et al. “Hydrogen Permitted Lines in the First Near-IR Spectra of Th 28 Microjet: Accretion or Ejection Tracers?” In: ApJ 719 (Aug. 2010), pp. 505–514. DOI: 10.1088/0004-637X/719/1/505. arXiv:1006.5400 [physics.space-ph].

[17] S. Covino et al. “Challenging gamma-ray burst models through the broadband dataset of GRB 060908”. In: A&A 521 (Oct. 2010), A53+. DOI: 10.1051/0004-6361/201014994. arXiv:1007.4769 [astro-ph.HE].

[18] R. M. Crocker et al. “γ-rays and the far-infrared-radio continuum correlation reveal a powerful Galactic Centre wind”. In: MNRAS 411 (Feb. 2011), pp. L11–L15. DOI: 10.1111/j.1745-3933.2010.00983.x. arXiv:1009.4340 [astro-ph.GA].

[19] C. del Burgo, C. Allende Prieto, and T. Peacocke. “PHASES: a concept for a satellite-borne ultra-precise spectrophotometer”. In: *Journal of Instrumentation* 5 (Jan. 2010), pp. 1006–+. DOI: 10.1088/1748-0221/5/01/P01006. arXiv:1001.1879 [astro-ph.IM].

[20] V. D’Elia et al. “Non-variability of intervening absorbers observed in the UVES spectra of the ‘naked-eye’ GRB080319”. In: MNRAS 401 (Jan. 2010), pp. 385–393. DOI: 10.1111/j.1365-2966.2009.15648.x. arXiv:0906.3191 [astro-ph.CO].

[21] M. E. Dieckmann et al. “Particle-in-cell simulation of a mildly relativistic collision of an electron-ion plasma carrying a quasi-parallel magnetic field . Electron acceleration and magnetic field amplification at supernova shocks”. In: A&A 509 (Jan. 2010), A89+. DOI: 10.1051/0004-6361/200912643.

[22] J.-F. Donati et al. “Complex magnetic topology and strong differential rotation on the low-mass T Tauri star V2247 Oph”. In: MNRAS 402 (Mar. 2010), pp. 1426–1436. DOI: 10.1111/j.1365-2966.2009.15998.x. arXiv:0911.1080 [astro-ph.SR].

[23] J.-F. Donati et al. “Magnetospheric accretion and spin-down of the prototypical classical T Tauri star AA Tau”. In: MNRAS 409 (Dec. 2010), pp. 1347–1361. DOI: 10.1111/j.1365-2966.2010.17409.x. arXiv:1007.4407 [astro-ph.SR].

[24] A. Giuliani et al. “AGILE detection of GeV γ-ray emission from the SNR W28”. In: A&A 516 (June 2010), pp. L11+. DOI: 10.1051/0004-6361/201014256. arXiv:1005.0784 [astro-ph.HE].

[25] D. Hammer et al. “The HST/ACS Coma Cluster Survey. II. Data Description and Source Catalogs”. In: ApJS 191 (Nov. 2010), pp. 143–159. DOI: 10.1088/0067-0049/191/1/143. arXiv:1005.3300 [astro-ph.GA].

[26] A. Hayato et al. “Expansion Velocity of Ejecta in Tycho’s Supernova Remnant Measured by Doppler Broadened X-ray Line Emission”. In: ApJ 725 (Dec. 2010), pp. 894–903. DOI: 10.1088/0004-637X/725/1/894. arXiv:1009.6031 [astro-ph.HE].

[27] HESS Collaboration et al. “Multi-wavelength observations of H 2356-309”. In: A&A 516 (June 2010), A56+. DOI: 10.1051/0004-6361/201014321. arXiv:1004.2089 [astro-ph.HE].

[28] HESS Collaboration et al. “PKS 2005-489 at VHE: four years of monitoring with HESS and simultaneous multi-wavelength observations”. In: A&A 511 (Feb. 2010), A52+. DOI: 10.1051/0004-6361/200913073. arXiv:0911.2709 [astro-ph.CO].

[29] HESS Collaboration et al. “VHE γ-ray emission of PKS 2155-304: spectral and temporal variability”. In: A&A 520 (Sept. 2010), A83+. DOI: 10.1051/0004-6361/201014484. arXiv:1005.3702 [astro-ph.HE].

[30] J. Mackey and A. J. Lim. “Dynamical models for the formation of elephant trunks in HII regions”. In: MNRAS 403 (Apr. 2010), pp. 714–730. DOI: 10.1111/j.1365-2966.2009.16181.x. arXiv:0912.1499 [astro-ph.GA].

[31] M. A. Malkov et al. “Probing Nearby Cosmic-ray Accelerators and Interstellar Medium Turbulence with MILAGRO Hot Spots”. In: ApJ 721 (Sept. 2010), pp. 750–761. DOI: 10.1088/0004-637X/721/1/750. arXiv:1005.1312 [astro-ph.GA].

[32] D. Malyshev et al. “A simple model for electron plasma heating in supernova remnants”. In: A&A 521 (Oct. 2010), A14+. DOI: 10.1051/0004-6361/200913841. arXiv:1007.0890 [astro-ph.HE].

[33] E. J. A. Meurs. “The Objective Lens of the Dunsink Ramsden Circle”. In: *Journal for the History of Astronomy* 41 (Nov. 2010), pp. 504–+.

[34] E. J. A. Meurs et al. “Runaway star production and the quest for the missing neutron stars”. In: New A Rev. 54 (Mar. 2010), pp. 62–64. DOI: 10.1016/j.newar.2010.09.019.

[35] J. Morin et al. “Large-scale magnetic topologies of late M dwarfs”. In: MNRAS 407 (Oct. 2010), pp. 2269–2286. DOI: 10.1111/j.1365-2966.2010.17101.x. arXiv:1005.5552 [astro-ph.SR].

[36] G. C. Murphy, M. E. Dieckmann, and L. O. Drury. “Magnetic vortex growth in the transition layer of a mildly relativistic plasma shock”. In: *Physics of Plasmas* 17.11 (Nov. 2010), pp. 110701–+. DOI: 10.1063/1.3493627.

[37] G. C. Murphy, M. E. Dieckmann, and L. O’C Drury. “Kinetic Particle-In Simulations of Asymmetric Quasi-Parallel Mildly Relativistic Plasma Collisions:. Field and Electron Dynamics”. In: *International Journal of Modern Physics D* 19 (2010), pp. 707–713. DOI: 10.1142/S0218271810016737 (cit. on p. 20).

[38] G. C. Murphy, J. Ferreira, and C. Zanni. “Large scale magnetic fields in viscous resistive accretion disks. I. Ejection from weakly magnetized disks”. In: A&A 512 (Mar. 2010), A82+. DOI: 10.1051/0004-6361/200912633. arXiv:1003.4471 [astro-ph.SR].

[39] G. C. Murphy et al. “Magnetic field amplification and electron acceleration to near-energy equipartition with ions by a mildly relativistic quasi-parallel plasma protoshock”. In: A&A 524 (Dec. 2010), A84+. DOI: 10.1051/0004-6361/201015294. arXiv:1010.1146 [astro-ph.HE] (cit. on p. 20).

[40] T. Ray. “Cosmic Rays from Cosmic Birth”. In: *Science* 330 (Nov. 2010), pp. 1184–. DOI: 10.1126/science.1199141.

[41] T. Sato et al. “Identification of CXOU J171405.7−381031 as a New Magnetar with XMM-Newton”. In: PASJ 62 (Oct. 2010), pp. L33–L36. arXiv:1008.0234 [astro-ph.HE].

[42] A. M. M. Scaife and K. J. B. G. Grainge. “SZ science with an ALMA band 1 receiver system”. In: *Bulletin of the Astronomical Society of India* 38 (Dec. 2010), pp. 185–193. arXiv:1002.1895 [astro-ph.CO].

[43] A. M. M. Scaife et al. “High-resolution AMI Large Array imaging of spinning dust sources: spatially correlated 8μm emission and evidence of a stellar wind in L675”. In: MNRAS 403 (Mar. 2010), pp. L46–L50. DOI: 10.1111/j.1745-3933.2010.00812.x. arXiv:0910.4011 [astro-ph.GA].

[44] A. M. M. Scaife et al. “Microwave observations of spinning dust emission in NGC6946”. In: MNRAS 406 (July 2010), pp. L45–L49. DOI: 10.1111/j.1745-3933.2010.00878.x. arXiv:1004.4897 [astro-ph.CO].

[45] A. Scholz et al. “A multiwavelength view of the protostellar binary IRAS 04325+2402: a case for turbulent fragmentation”. In: MNRAS 409 (Dec. 2010), pp. 1557–1569. DOI: 10.1111/j.1365-2966.2010.17397.x. arXiv:1007.3995 [astro-ph.SR].

[46] A. Scholz et al. “A near-infrared variability study in the cloud IC1396W: low star-forming efficiency and two new eclipsing binaries”. In: MNRAS 406 (July 2010), pp. 505–516. DOI: 10.1111/j.1365-2966.2010.16680.x. arXiv:1003.2632 [astro-ph.SR].

[47] K. Someya, A. Bamba, and M. Ishida. "Suzaku Observations of the Supernova Remnant N23 in the Large Magellanic Cloud". In: PASJ 62 (Oct. 2010), pp. 1301–1306. arXiv:1007.4393 [astro-ph.HE].

[48] B. Stelzer et al. "The enigmatic young brown dwarf binary FUTau: accretion and activity". In: MNRAS 408 (Oct. 2010), pp. 1095–1102. DOI: 10.1111/j.1365-2966.2010.17182.x. arXiv:1006.2717 [astro-ph.SR].

[49] Y. Terada et al. "X-ray Observation of AM Herculis in a Very Low State with Suzaku". In: ApJ 721 (Oct. 2010), pp. 1908–1918. DOI: 10.1088/0004-637X/721/2/1908. arXiv:1008.0759 [astro-ph.HE].

[50] C. T. Tibbs et al. "Very Small Array observations of the anomalous microwave emission in the Perseus region". In: MNRAS 402 (Mar. 2010), pp. 1969–1979. DOI: 10.1111/j.1365-2966.2009.16023.x. arXiv:0909.4682 [astro-ph.GA].

[51] M. Türler et al. "INTEGRAL hard X-ray spectra of the cosmic X-ray background and Galactic ridge emission". In: A&A 512 (Mar. 2010), A49+. DOI: 10.1051/0004-6361/200913072. arXiv:1001.2110 [astro-ph.CO].

[52] E. T. Whelan et al. "The 2008 Outburst in the Young Stellar System Z CMa: The First Detection of Twin Jets". In: ApJ 720 (Sept. 2010), pp. L119–L124. DOI: 10.1088/2041-8205/720/1/L119. arXiv:1008.0111 [astro-ph.SR].

[53] H. Yamaguchi, M. Sawada, and A. Bamba. "Searching for Diffuse Nonthermal X-Rays from the Superbubbles N11 and N51D in the Large Magellanic Cloud". In: ApJ 715 (May 2010), pp. 412–420. DOI: 10.1088/0004-637X/715/1/412. arXiv:1004.0753 [astro-ph.HE].

[54] S. Yamauchi et al. "A New Candidate of a Cluster of Galaxies, 2XMM J045637.2+522411". In: PASJ 62 (Apr. 2010), pp. 219–.

[55] F. Yuan et al. "GRB 081008: From Burst to Afterglow and the Transition Phase in Between". In: ApJ 711 (Mar. 2010), pp. 870–880. DOI: 10.1088/0004-637X/711/2/870. arXiv:1002.0581 [astro-ph.HE].

[56] F. Yuan et al. "The Exceptionally Luminous Type Ia Supernova 2007if". In: ApJ 715 (June 2010), pp. 1338–1343. DOI: 10.1088/0004-637X/715/2/1338. arXiv:1004.3329 [astro-ph.CO].

[57] A. A. Zdziarski, A. Neronov, and M. Chernyakova. "A compact pulsar wind nebula model of the γ-ray-loud binary LS I +61°303". In: MNRAS 403 (Apr. 2010), pp. 1873–1886. DOI: 10.1111/j.1365-2966.2010.16263.x. arXiv:0802.1174.

[58] D. Zhou et al. "Radiation measured for MATROSHKA-1 experiment with passive dosimeters". In: *Acta Astronautica* 66.1-2 (2010), pp. 301 –308. ISSN: 0094-5765. DOI: DOI:10.1016/j.actaastro.2009.06.014. URL: http://www.sciencedirect.com/science/article/B6V1N-4WTRWHJ-1/2/e2cad2aeb2482b625b27a19cc0dfea87 (cit. on p. 22).

[59] V. N. Zirakashvili and F. A. Aharonian. "Nonthermal Radiation of Young Supernova Remnants: The Case of RX J1713.7-3946". In: ApJ 708 (Jan. 2010), pp. 965–980. DOI: 10.1088/0004-637X/708/2/965. arXiv:0909.2285 [astro-ph.HE] (cit. on p. 5).

9.2 Publications in 2010 (not subject to peer-review)

[60] A. Bamba. "High energy aspects of SNRs". In: *American Institute of Physics Conference Series*. Ed. by A. Comastri, L. Angelini, & M. Cappi. Vol. 1248. American Institute of Physics Conference Series. July 2010, pp. 33–36. DOI: 10.1063/1.3475253.

[61] D. Coffey et al. "Unveiling the Role of Jets in Star Formation". In: *The Impact of HST on European Astronomy*. Ed. by Macchetto, F. D. 2010, pp. 65–+. DOI: 10.1007/978-90-481-3400-7_13.

[62] J.-F. Donati et al. "Magnetic field and velocity of early M dwarfs (Donati+, 2008)". In: *VizieR Online Data Catalog* 739 (June 2010), pp. 545–+.

[63] T. P. Downes and S. O'Sullivan. "Non-ideal MHD Turbulent Decay in Molecular Clouds". In: *Astronomical Society of the Pacific Conference Series*. Ed. by N. V. Pogorelov, E. Audit, & G. P. Zank. Vol. 429. Astronomical Society of the Pacific Conference Series. Sept. 2010, pp. 3–+.

[64] J. Ferreira, G. Murphy, and C. Zanni. "Large scale magnetic fields in discs: advection and jet launching". In: *American Institute of Physics Conference Series*. Ed. by G. Bertin, F. de Luca, G. Lodato, R. Pozzoli, & M. Romé. Vol. 1242. American Institute of Physics Conference Series. June 2010, pp. 276–287. DOI: 10.1063/1.3460135.

[65] J. Ferreira et al. "Jet Emitting Discs: a New Accretion Flow Solution". In: *Astronomical Society of the Pacific Conference Series*. Ed. by L. Maraschi, G. Ghisellini, R. Della Ceca, & F. Tavecchio. Vol. 427. Astronomical Society of the Pacific Conference Series. Oct. 2010, pp. 49–+.

[66] S. Gabici et al. "Constraints on the cosmic ray diffusion coefficient in the W28 region from gamma-ray observations". In: *SF2A-2010: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics*. Ed. by S. Boissier, M. Heydari-Malayeri, R. Samadi, & D. Valls-Gabaud. Dec. 2010, pp. 313–+. arXiv:1009.5291 [astro-ph.HE].

[67] P. J. V. Garcia et al. "The hydrogen emission of young stellar objects: key science for next-generation instruments and facilities". In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7734. Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference. July 2010. DOI: 10.1117/12.858302.

[68] J. M. Kirk et al. "The Cepheus flare observed with IRAC and MIPS (Kirk+, 2009)". In: *VizieR Online Data Catalog* 218 (Mar. 2010), pp. 50198–+.

[69] T. Kohmura et al. "Measuring the EUV and optical transmission of optical blocking layer for x-ray CCD camera". In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7732. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. July 2010. DOI: 10.1117/12.856767.

[70] F. Malbet et al. "The 2008-2009 outburst of the young binary system Z CMa unraveled by interferometry with high spectral resolution". In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7734. Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference. July 2010. DOI: 10.1117/12.857586. arXiv:1007.5382 [astro-ph.SR].

[71] A. Morgenthaler et al. "Long-term magnetic field monitoring of the sun-like star ξ Bootis A". In: *SF2A-2010: Proceedings of the Annual meeting of the French Society of Astronomy and Astrophysics. Eds.: S. Boissier, M. Heydari-Malayeri, R. Samadi and D. Valls-Gabaud, p.269*. Ed. by S. Boissier, M. Heydari-Malayeri, R. Samadi, & D. Valls-Gabaud. Dec. 2010, pp. 269–+. arXiv:1012.0198 [astro-ph.SR].

[72] H. Mori et al. "Current status of the pre-collimator development for the ASTRO-H x-ray telescopes". In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7732. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. July 2010. DOI: 10.1117/12.856803.

[73] J. Morin et al. "Magnetic field and velocity of mid M dwarfs (Morin+, 2008)". In: *VizieR Online Data Catalog* 739 (June 2010), pp. 567–+.

[74] J. Morin et al. "Polarisation of a sample of late M dwarfs (Morin+, 2010)". In: *VizieR Online Data Catalog* 740 (June 2010), pp. 72269–+.

[75] M. Raue et al. "Discovery of VHE γ-rays from Centaurus A". In: *Astronomical Society of the Pacific Conference Series*. Ed. by L. Maraschi, G. Ghisellini, R. Della Ceca, & F. Tavecchio. Vol. 427. Astronomical Society of the Pacific Conference Series. Oct. 2010, pp. 302–+. arXiv:0904.2654 [astro-ph.CO].

[76] T. P. Ray. "Primeval Jets from Young Stars". In: *Highlights of Astronomy* 15 (Nov. 2010), pp. 241–242. DOI: 10.1017/S1743921310009038.

[77] J. L. Skilton et al. “Radio and X-ray Observations of the Possible New Gamma-ray binary HESS J0632+057”. In: *Astronomical Society of the Pacific Conference Series*. Ed. by J. Martí, P. L. Luque-Escamilla, & J. A. Combi. Vol. 422. Astronomical Society of the Pacific Conference Series. May 2010, pp. 128–+.

[78] B. Stelzer and A. Scholz. “NGC 7129 pre-main sequence stars (Stelzer+, 2009)”. In: *VizieR Online Data Catalog* 350 (Sept. 2010), pp. 70227–+.

[79] T. Takahashi et al. “Study of the Gamma-Ray Binary LS5039 with Suzaku”. In: *American Institute of Physics Conference Series*. Ed. by A. Comastri, L. Angelini, & M. Cappi. Vol. 1248. American Institute of Physics Conference Series. July 2010, pp. 211–212. DOI: 10.1063/1.3475210.

[80] T. Takahashi et al. “The ASTRO-H Mission”. In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7732. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. July 2010. DOI: 10.1117/12.857875. arXiv:1010.4972 [astro-ph.IM].

[81] Y. Terada et al. “Systematic surveys of the non thermal emission from white dwarfs with Suzaku and INTEGRAL”. In: *American Institute of Physics Conference Series*. Ed. by A. Comastri, L. Angelini, & M. Cappi. Vol. 1248. American Institute of Physics Conference Series. July 2010, pp. 215–216. DOI: 10.1063/1.3475212.

[82] H. Tsunemi et al. “Soft x-ray imager (SXI) onboard ASTRO-H”. In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7732. Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series. July 2010. DOI: 10.1117/12.856087.

[83] E. T. Whelan et al. “Classical T Tauri-like Outflow Activity in the Brown Dwarf Mass Regime”. In: *Highlights of Astronomy* 15 (Nov. 2010), pp. 754–754. DOI: 10.1017/S1743921310011397.

[84] G. S. Wright et al. “Progress with the design and development of MIRI, the mid-IR instrument for JWST”. In: *Society of Photo-Optical Instrumentation Engineers (SPIE) Conference Series*. Vol. 7731. Presented at the Society of Photo-Optical Instrumentation Engineers (SPIE) Conference. July 2010. DOI: 10.1117/12.857262.

[85] O. Zacharopoulou, D. Khangulyan, and F. Aharonian. “On the Shape of Intrinsic Gamma-Ray Spectra of Distant Blazars”. In: *Astronomical Society of the Pacific Conference Series*. Ed. by L. Maraschi, G. Ghisellini, R. Della Ceca, & F. Tavecchio. Vol. 427. Astronomical Society of the Pacific Conference Series. Oct. 2010, pp. 310–+.

9.3 Preprints posted in 2010

[86] M. V. Barkov et al. “Rapid TeV variability in Blazars: Proton-Synchrotron Radiation of blobs produced at by Jet-Star Interaction”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.1787 [astro-ph.HE].

[87] A. Caratti o Garatti et al. “The outburst of an embedded low-mass YSO in L1641”. In: A&A 526 (Feb. 2011), pp. L1+. DOI: 10.1051/0004-6361/201016146. arXiv:1012.0281 [astro-ph.SR].

[88] M. Chernyakova et al. “Galactic center at very high-energies”. In: *ArXiv e-prints* (Sept. 2010). arXiv:1009.2630 [astro-ph.HE] (cit. on p. 5).

[89] D. Coffey et al. “Searching for jet rotation in Class 0/I sources observed with GEMINI/GNIRS”. In: A&A 526 (Feb. 2011), A40+. DOI: 10.1051/0004-6361/200913988. arXiv:1011.6619 [astro-ph.SR].

[90] R. M. Crocker and F. Aharonian. “The Fermi Bubbles: Giant, Multi-Billion-Year-Old Reservoirs of Galactic Center Cosmic Rays”. In: *ArXiv e-prints* (Aug. 2010). arXiv:1008.2658 [astro-ph.GA] (cit. on p. 5).

[91] R. M. Crocker et al. “Wild at Heart:-The Particle Astrophysics of the Galactic Centre”. In: *ArXiv e-prints* (Oct. 2010). arXiv:1011.0206 [astro-ph.GA] (cit. on p. 5).

[92] M. L. Davies et al. “10C Survey of Radio Source at 15.7 GHz: II - First Results”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.3659 [astro-ph.CO].

[93] T. M. O. Franzen et al. “10C Survey of Radio Sources at 15.7 GHz: I - Observing, mapping and source extraction”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.3711 [astro-ph.CO].

[94] B. Giebels, F. Aharonian, and H. Sol. “Active Galactic Nuclei and gamma rays”. In: *ArXiv e-prints* (May 2010). arXiv:1005.2330 [astro-ph.HE].

[95] HESS Collaboration et al. “H.E.S.S. constraints on Dark Matter annihilations towards the Sculptor and Carina Dwarf Galaxies”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.5602 [astro-ph.HE].

[96] J. Morin et al. “Exploring the magnetic topologies of cool stars”. In: *ArXiv e-prints* (Sept. 2010). arXiv:1009.2589 [astro-ph.SR].

[97] G. C. Murphy, M. E. Dieckmann, and L. O’C Drury. “Multidimensional simulations of magnetic field amplification and electron acceleration to near-energy equipartition with ions by a mildly relativistic quasi-parallel plasma collision”. In: *ArXiv e-prints* (Nov. 2010). arXiv:1011.4406 [astro-ph.HE].

[98] G. C. Murphy, M. E. Dieckmann, and L. O’C. Drury. “Observation of the growth of a magnetic vortex in the transition layer of a mildly relativistic oblique plasma shock”. In: *ArXiv e-prints* (Mar. 2010). arXiv:1003.1275 [astro-ph.HE].

[99] L. O’C. Drury. “Escaping the accelerator; how, when and in what numbers do cosmic rays get out of supernova remnants?” In: *ArXiv e-prints* (Sept. 2010). arXiv:1009.4799 [astro-ph.GA] (cit. on p. 20).

[100] M. Olamaie et al. “Parameterization Effects in the analysis of Sunyaev-Zel’dovich Observations”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.4996 [astro-ph.CO].

[101] C. Rodriguez-Gonzalvez et al. “Sunyaev-Zel’dovich observation of the Bullet-like cluster A2146 with the Arcminute Microkelvin Imager”. In: *ArXiv e-prints* (Nov. 2010). arXiv:1011.0325 [astro-ph.CO].

[102] A. M. M. Scaife and K. J. B. Grainge. “SZ Science with an ALMA Band 1 Receiver System”. In: *ArXiv e-prints* (Feb. 2010). arXiv:1002.1895 [astro-ph.CO].

[103] A. M. M. Scaife et al. “AMI Large Array radio continuum observations of Spitzer c2d small clouds and cores”. In: *ArXiv e-prints* (Sept. 2010). arXiv:1009.0348 [astro-ph.GA].

[104] A. C. T. W. Shimwell et al. “A blind detection of a large, complex, Sunyaev–Zel’dovich structure”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.4441 [astro-ph.CO].

[105] K. G. Stassun et al. “The M4 Transition: Toward a comprehensive understanding of the transition into the fully convective regime”. In: *ArXiv e-prints* (Dec. 2010). arXiv:1012.2580 [astro-ph.SR].

[106] E. T. Whelan et al. “Brown Dwarf Jets: Investigating the Universality of Jet Launching Mechanisms at the Lowest Masses”. In: *ArXiv e-prints* (Oct. 2010). arXiv:1010.0539 [astro-ph.SR].

[107] V. N. Zirakashvili and F. A. Aharonian. “Radioactivity and Electron Acceleration in Supernova Remnants”. In: *ArXiv e-prints* (Nov. 2010). arXiv:1011.4775 [astro-ph.GA].

[108] J. T. L. Zwart et al. “Sunyaev-Zel’dovich observations of galaxy clusters out to the virial radius with the Arcminute Microkelvin Imager”. In: *ArXiv e-prints* (Aug. 2010). arXiv:1008.0443 [astro-ph.CO].