ANNUAL REPORT
SCHOOL OF COSMIC PHYSICS, 1999

Annual Report of the Governing Board of the School of Cosmic Physics for the year ending 31 December 1999 adopted at its meeting on 15 November 2000.

1 STAFF, SCHOLARS AND ASSOCIATES

Senior Professors: L.O'C. Drury (Director, from 01 November), A.W.B. Jacob, E.J.A. Meurs (Director, to 31 October).

Professors: A. Thompson, D. O'Sullivan, T.P. Ray.

Assistant Professors: P.W. Readman, B.M. O'Reilly (contract basis).

Research Assistants: I. Elliott, (two vacancies).

Experimental Officers: T.A. Blake, B.D. Jordan, J.Walsh (computer manager, contract basis).

Visiting Scientists: P.A. Allen (Department of Geology, TCD), D. Bartlett (NRPB, UK), C.J. Bean (Department of Geology, UCD), P. Beck (ARCS, Vienna), S. Bennett (Department of Geology, TCD), E. Benton (USF, USA), J-F Bottollier (IPSN, Paris), C. Bray (Ordnance Survey, 16 June), E. Criley (USGS, Menlo Park, 09-23 March), A.L. Densmore (Department of Geology, TCD), S.H. Harder (University of Texas at El Paso, 07-25 March), C. Isaacs (BG), H. Jepsen (University of Copenhagen, 08-22 March), P. Jørgensen (University of Copenhagen, 08-22 March), B. Katz (University of Nebraska, USA), N. Kenyon (Southampton Oceanography Centre, 09-12 February, 03-06 August), A. Lawrence (Institute for Astronomy, Edinburgh), L. Lindborg (SSI, Stockholm), L. Norci (Visiting Professor from 15 January), A. McCafferty (Statoil), M. Mahoney (Met Éireann, Valentia Observatory, 04-05 May), J. Makris (University of Hamburg, 06-08 October), G. Meesen (University of Ghent), W.D. Mooney (USGS, Menlo Park, 05-09 October), K. Nolan (Enterprise Oil), T. Parker (PASSCAL, 21 March - 01 April), R. Pasquali (Department of Geology, TCD), W.E.A. Phillips (Department of Geology, TCD), O. Quezada (UTEP, 07-25 March), H. Schraube (GSF, Munich), U. Schrewe, PTB, Braunschweig), P.M. Shannon (Department of Geology, UCD), D. Sheridan (Enterprise Oil, 29 July), M.D. Smith (Armagh Observatory), C. Snelson (UTEP, 07-25 March), C. Solla (Department of Geology, TCD), T. Sullivan (Met Éireann, Valentia Observatory, 04-05 May), L. Tommasino (ANPA, Rome), J. Vink (Astrophysikalisches Institut, Potsdam), A. Walsh (Statoil), A. Wheeler (UCC, 12 April).

Technical and Clerical Staff: A. Byrne, A.M. Callanan, E. Clifton, P. Daly (part-time), W. Dumpleton, E. Flood, A. Grace-Casey, C.M. Horan, S. Ledwidge (on career break until 05 October), L. Quigley, M. Smyth, H. Sullivan, G. Wallace, (two vacancies).

Scholars: M. Carr, J. Cunniffe, J. Donnelly, J. Hodgson, M. Landes, K. McGrane (to 30 September), L. Norci (to 15 January), A. O'Brien, S. O'Sullivan (to 31 March), V.Unnithan, Z. Zang, D. Zhou.

Project Supported Positions: S. Annibaldi (Turbulent Fusion Plasmas), F. Bacciotti (European Space Agency Fellow), Y. Gallant (01 May – 30 September), F. Hauser (COMBONET, to 31 March), T. Lery (Enterprise Ireland, from 01 July), G.D. Mackenzie (RAPIDS III, from 01 April), E. Parizot (TMR Astroplasmaphysics Network).

Professors Emeriti: H.A. Brück, T. Murphy.

Research Associates: C.J. Bean (UCD), M. Cawley (SPCM), D. Corcoran (DCU), P. Duffy (UCD), A.J. Keane (ITB), R. Keary (GSI), A. Lawrence (Edinburgh), B. McBreen (UCD), J. Makris (Hamburg), P. Morris (British Antartic Survey), N.P. Murphy (BP), F. Murtagh (Garching), W.E.A. Phillips (TCD), V.F. Polcaro (IAS, Frascati), C. Prodehl (Karlsruhe), S.C. Russell (UCD), P.M. Shannon (UCD).

Project Students: G. Fennell (TCD, 01 October – 31 December).

Vacation Students: E. Devine (TCD, 06 July – 24 September), C. Heverin (UCD, 02 June – 03 September), S.T.F. Jacob (TCD, 21 June – 31 December).

2 RESEARCH ACTIVITIES IN THE GEOPHYSICS SECTION

2.01 LEGS (LEinster Granite Seismics)

J.A. Hodgson, P.W. Readman, B.M. O'Reilly and other Geophysics Section staff with P.S. Kennan, UCD and colleagues from UTEP, PASSCAL and the University of Copenhagen

During January and February the seismic instrument deployment pattern was finalised, and site and shot locations were surveyed and permissioned. The main seismic experiment was carried during March. Three hundred digital seismic recording instruments (borrowed from the Univerity of Texas at El Paso (UTEP) and the University of Copenhagen) were deployed along one axial and two transverse profiles across the Leinster Granite. Fourteen underwater shots were fired in the Irish and Celtic Seas into these profiles using the R.V. Celtic Voyager. Four land shots, and a quarry shot, were fired at the intersection of the axial and transverse profiles, and at the western ends of the transverse profiles.

Three colleagues from the University at El Paso (Steve Harder, Cathy Snelson, Oscar Quezada) and two from Copenhagen (Peer Jørgensen and Henrik Jepsen) participated in the experiment. At the end of the acquisition, Tim Parker from PASSCAL visited to help with the data download and initial processing. In addition, help was enlisted for the instrument deployment from two geophysics students from UCD. In total there were 17 people involved in the deployment of the instruments, three involved in the shooting on land and four for the shooting at sea (in addition to the crew of the Celtic Voyager).

The experiment was very successful. Data quality and recovery were excellent compared to similar experiments,

with good P- and S-wave energy from the shallow crust to the upper mantle observed across the granite. The amount of the data recorded is well in excess of that originally envisaged, and the slight delay in starting the field experiment proved very well worthwhile. In terms of the number of instruments in a single deployment this has been the largest ever in Ireland, and ranks with some of the largest world-wide. Processing of the over 5000 seismic records was completed during April/May and preliminary forward modelling of the large dataset comprising 57 seismic sections was started. The modelling up to the present has focussed on the uppermost 10 km of the crust and indicates that primary P-wave phases show a good correlation with the surface geology. An indication of individual granitic bodies can be seen with the depth of the granite bodies increasing to the southwest. Wide-angle reflections define an interface at about 4 km depth beneath the main granite body.

As part of the preparation for this project James Hodgson spent one week during February in El Paso to familiarise himself with the instruments and the data handling procedures. During his visit the instruments were tested by recording a large mine blast.

2.02 Gravity (Investigation of onshore sediment transport routes)

P.W. Readman and B.M. O'Reilly with colleagues from TCD

A project in collaboration with A. Phillips and others at Trinity College Dublin has been started to test a hypothesis that there is a system of Tertiary-aged river channels and lake deposits traversing Ireland which links the Irish Sea with sediments in the Porcupine and Donegal Basins. The original proposal has been partially funded by Enterprise Ireland so that a few exploratory wells can be drilled. A research assistant has been employed in TCD and a detailed compilation of available data relevant to the possible location of such deposits started in October. Central to the investigation are variations in the gravity anomaly and as a start a possible area has been chosen in Co. Westmeath on this basis. Some further gravity observations have been made to more precisely define the gravity anomaly pattern in the area.

Related to this project, new gravity measurements have also been made in the northwest of the country in Co. Mayo. Previously it has been difficult to gain access to large areas of bogland and to obtain accurate gravity readings and 3-D positions on top of the bog. Now that areas of the bog has been partially stripped, and with the use of GPS, and the help of Bord na Mona it was possible to significantly increase the coverage of our gravity readings and better define detail in the large anomaly low in the area.

These additional gravity measurements will help in testing geological models of Tertiary tectonics in northwest Ireland. They are also important in our ongoing studies of the relationship between gravity variations and the structural controls on the siting of onshore mineral deposits.

2.03 VARNET (VARiscan NETwork)

A.W.B. Jacob, M. Landes, B.M. O'Reilly, P.W. Readman with colleagues from UCD and University of Karlsruhe

This year saw the conclusion of detailed seismic modelling along the eastern profile stretching from the Old Head of Kinsale to Galway Bay (a paper on this is now in press). Integration of the results from the onshore experiments with existing offshore reflection and wide-angle refraction data in the Irish and Celtic Seas areas was completed. This reveals three crustal units separated by near-horizontal detachment surfaces. Structural linkage between the upper and middle crust can be demonstrated suggesting only a moderate change in ductility across the upper surface. The lower detachment surface at 20-24 km depth is interpreted as the crustal brittle-crustal transition. Major Variscan thrusts either flatten along the top of this layer or are overprinted by post-Variscan lower crustal re-equilibration.

An S-wave model for the western profile was developed using the P-wave model interfaces. This allowed V_p/V_s ratios, which depend on the mineralogy and composition of the crust, to be calculated. Low ratios in the upper 15 km indicate the presence of granitic inclusions. A region of high V_p/V_s ratios in the lower crust mark a change to a more mafic composition. This region is a possible source for the granitic intrusions inferred in the upper crust.

The final report for this project was submitted to the relevant EU funding agency during the year. Further interpretation of the results is continuing. The main effort is now with seismic and gravity 3-D modelling.

2.04 AIRS (Atlantic Irish Rockall Survey)

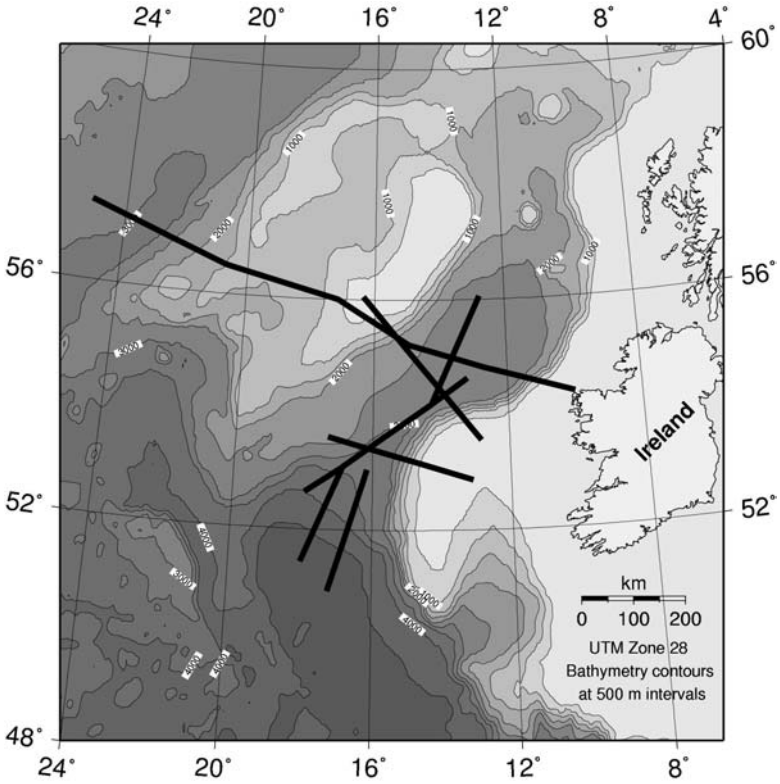
K. McGrane, P.W. Readman, A.W.B. Jacob with colleagues from UCD and GSI

Interpretation of the GLORIA (Geological LOng Range Inclined Asdic) data collected from the Rockall Trough during the AIRS project continued and has been refined in both DIAS and UCD. The DIAS PhD student (K. McGrane) has concentrated on integrating the GLORIA results with those of other geophysical studies, in particular marine gravity and magnetic anomalies, whereas the UCD PhD student (Vikram Unnithan) has worked mainly on the sedimentological aspects of the project. The manuals on GLORIA data processing were completed, and preparation of the final report started. Funding for the project finished in September and it anticipated that the two students will finish their PhD theses during the next year.

2.05 TRIM (TOBI Rockall Irish Margins)

P.W. Readman, B.M. O'Reilly, A.W.B. Jacob with P.M. Shannon, UCD

The preliminary interpretation based on the TOBI (Towed Ocean Bottom Instrument) shipboard mosaic was completed. Detailed maps of acoustic facies were traced onto transparent sheets at a scale of 1:50 000 and interpreted in terms of sedimentological and slope processes. Processing of the digital data recorded was completed and a set of mosaics made. The geographical registration is more accurate on these and they show more detail in some areas. The interpretations were subsequently refined, digitised and integrated into a geographical information system. A set of interpretation maps depicting



RAPIDS offshore seismic lines

sedimentological processes along the continental shelf and slope regions of the Rockall Trough were produced.

A wide range of sedimentological features were identified in the area. Submarine canyons, associated with depositional lobes and sediment aprons were resolved along much of the surveyed eastern margin. These are associated with extensive areas of typically tabular raft/slab slope failure. The detailed form of a carbonate mound population on the upper slope area of the Porcupine Bank was clearly imaged. The survey resolved in detail a region of extensive slope wastage, mostly in the form of mud-prone tabular raft/slab failure, on the western margin of the Rockall Trough.

Evidence for contour-parallel currents was found on both margins of the Trough suggesting a cyclonic bottom current circulation pattern. Changes in the slope geomorphology and the details of slope failure processes occur along the eastern magin of the Trough from north to south. These changes indicate that the influence of glaciomarine sedimentation processes decreases to the south along the margin and that palaeo-climatological factors play an important part in controlling these processes. Seismicity may also be a factor, as a seismic event on the western margin of the Rockall Trough was recorded on the DIAS seismic network in September. The precise age of the slope failure events is unknown but many of the more recent sediment flows and tabular escarpments are likely to be late Pleistocene to Holocene in age.

A comprehensive interim report was completed and submitted to the Rockall Studies Group. The report was well received and very favourable comments were returned. Testing of the interpretation against other datasets will begin next year.

2.06 RAPIDS III (Rockall and Porcupine Irish Deep Seismics)

A.W.B. Jacob, G.D. Mackenzie and other Geophysics Section staff with P.M. Shannon, UCD and colleagues from the University of Hamburg

The continental shelf to the west of Ireland remains a relatively unexplored region. The area contains several large deep water sedimentary basins whose origins, and nature of the underlying crust, is poorly understood. The RAPIDS 3 project builds upon the results of two previous RAPIDS projects undertaken by DIAS, UCD and the University of Hamburg. It involves the acquisition, processing and interpretation of four new wide-angle seismic profiles within the Rockall Basin. The overall objectives of the project are (a) to provide a three-dimensional constraint on crustal and on broad sedimentary geometries, and (b) to test the new differential crustal stretching model which has been developed on the basis of RAPIDS I and RAPIDS II projects.

Four wide-angle reflection and refraction profiles were obtained across the Rockall region during April and May. The seismic data was recorded on Ocean Bottom Seismometers (OBS) deployed by the Russian research ship PETROV. Airguns operated from the PETROV were used as the seismic source along the lines. In order to aid deeper penetration below the crust several shots were also fired by the Irish research vessel CELTIC VOYAGER.

Data quality is in general excellent with energy propagating in many cases to beyond 80 km from the smaller airgun sources. Initial data processing and conversion to SEG-Y format has been conducted by DIAS and Hamburg staff in Hamburg. Preliminary modelling of the sedimentary succession has also been conducted in Hamburg and Dublin and is now continuing in Dublin.

This project has been funded as part of the Petroleum Infrastructure Programme (PIP) sponsored by a consortium of oil companies, the Rockall Studies Group (RSG). The project was co-proposed by the Dublin Institute for Advanced Studies and University College Dublin.

2.07 Teleseismic Study of the Hawaiian Plume

A.W.B. Jacob, G. Wallace, C. Horan and L. Quigley with R. Kind from GFZ Potsdam and colleagues in the University of Hawaii

Following the successful COMBO study of fine structural detail at the Core-Mantle Boundary (CMB) under the Pacific Plate southeast of Hawaii, a project was set up to study the Hawaiian Plume and its Mantle structure. Plumes originate at or near the CMB so this was a logical extension of Geophysics Section studies in deep Earth structures and mechanisms. The current study is using eleven DIAS Geophysics Broad-Band stations distributed on four different islands (Hawaii, Maui, Oahu and Kauai) together with a Very Broad Band station from Potsdam on Maui. Some supplementary data may also be available from USGS stations recently installed. There are important questions to be resolved about the physics of this rather spectacular plume (one of the volcanoes on Hawaii is the most active in the world). Some good data have already been gathered and converted phases from horizons in the mantle will be used to map past and present behaviour of the plume.

Initially, five DIAS stations were installed on Hawaii (4) and Oahu (1) in June 1999. A further six stations were installed in November, one more on Hawaii, two on Maui and three on the westernmost large island, Kauai. This gave a spread of about 600 km to the network. The stations are either on private land or in schools whose owners or teachers have agreed to change the data disks periodically (every three or six weeks) and post them to the University of Hawaii. From there they are sent to Ireland where the data is archived, releasing the disks for further use in the network.

2.08 The Seismic Network (DNET, ENET, DSB and VAL)

A.W.B. Jacob, T. Blake, G. Wallace, C. Horan and L. Quigley

1. Recorded events

There were two onshore events here in Ireland in 1999. Macroseismic surveys have been carried out for both events which occurred in North East Donegal. The first was a 1.7 M_L event on 30 April, which had a felt intensity of III-IV in Kerrykeel. The second was a 1.5 M_L event on 29 August, which had a felt intensity of II-III in the Milford/Buncrana area. There were a number of offshore events, the first of them in the Irish Sea, southwest of Holyhead on 10 March with a magnitude of 0.9 M_L. On 07 September an event was recorded in the Rockall Trough, and on the 29 September an event of 3.0 M_L occurred in the Lousy Bank area. Three other offshore events were recorded off the coast of Wexford on the 15 October, 30 October and 8 November, for which there were no felt reports.

The UK had its fair share of events greater than 3.0 M_L. The most notable occurred on the Isle of Arran, Strathclyde on the 4 March with a magnitude of 4.0 M_L and a felt intensity of IV. No damage or injuries were reported. On the 25 October an event occurred in Sennybridge, Wales, with a magnitude of 3.5 M_L and a felt intensity of V.

There were a large number of significant earthquakes during the year. Perhaps the most destructive was one with a magnitude 7.8 M_s in Izmit, Turkey, which occurred on the 17 August and resulted in enormous casualties. At least 12,500 were killed and over 200,000 people were left homeless. Istanbul was badly damaged too. Other large events occurred in NE China, 08 April, 7.2 M_w; Athens, Greece, 07 September, 6.0 M_w; Central Taiwan, 20 September, 7.6 M_s; Mexico, 03 September, 7.5 M_s; Southern California, 16 October, 7.3 M_s; and Duzce, North Turkey, 12 November, 7.2 M_w.

Requests for information on earthquakes, volcanoes etc. were received from schoolchildren, archaeologists and engineers.

2. DSB Very Broad-Band (VBB) station

The DSB Broadband seismic recording station continued to function well. There was a major upgrade of the hardware and software during the year to make the station more efficient, and also Y2K compliant.

The VME Seislog short period seismic recording system at Lyons Farm is not Y2K compliant. A decision was taken not to spend any further time or money on its development and to let this system become obsolete. A new Earth Data seismic recording system was put in place during the year and is working satisfactorily.

3. Broadband station at Valentia Meteorological Observatory

After discussions with Met Éireann last year, it was decided that the WWSN seismic station run by the Met Eireann in Valentia Observatory (VAL) since the 1960s would be replaced by a digital recording system, supported by the Geophysics section. DIAS have lent a digital recorder and Met Éireann purchased a broad-band seismometer, a workstation (assembled by DIAS) and some ancilliary equipment. It is important to keep this station running as it considerably extends the coverage of the DIAS network and is the most western seismic station in Europe. An Earth Data recording system and Guralp CMG T40 broadband seismometer was installed in Valentia Observatory by Geophysics section staff during May. A workstation for digital seismic data processing was prepared in the Section and installed at Valentia in December.

3 RESEARCH ACTIVITIES IN THE ASTRONOMY SECTION

3.01 IRAS galaxies at high energies

E.J.A. Meurs, J. Cunniffe and L. Norci with A. Antonelli (Rome Observatory, Monte Porzio), K. Koyama and H. Awaki (Kyoto)

IRAS galaxies are often detected at X-rays, which in view of the generally strong star formation in such galaxies could be caused by stellar evolution products, or also by a hidden active nucleus. There could also be the combined effect of these two emission components. Clues about the origin of the observed X-ray emission may be obtained from X-ray spectra with sufficient spectral resolution. Some of these cases were therefore studied with data from the ASCA and SAX satellites, that cover the 1-10 keV band with the important 6-7 keV iron features. The investigations focused on two different samples of IRAS galaxies. In one instance, the IRAS galaxies are a rather general selection of these objects, in order to study galaxies of that type as they are commonly found. If significant emission is detected from iron lines then stellar mechanisms are no longer sufficient to explain the high energy output. The conventional interpretation of these Fe features is that one is seeing emission from hot material accreting onto a supermassive black hole and that thus an active core makes a substantial contribution.

The second sample comprises a selection of IRAS galaxies with particularly high levels of X-ray emission. One of these latter objects, the Spiral galaxy NGC 3147, was examined in some detail with the addition of high-resolution imaging X-ray data from the ROSAT satellite. Earlier results from the ASCA satellite had been taken as indicating that the bulk of the high-energy emission from this galaxy is due to a hidden active nucleus. The group's own SAX spectrum is however well fitted by a two-temperature thermal model, which can be interpreted as starburst activity. This is supported by the ROSAT HRI data, which reveal a very extended source coincident with the main body of NGC3147.

3.02 Searching for active cores in Local Group galaxies

Z.Zang and E.J.A. Meurs

To investigate the occurrence of nuclear activity in galaxies to the lowest possible levels, a search has been conducted for central sources in two-thirds of the members of the Local Group of galaxies, to which the Milky Way system belongs. These galaxies are the nearest stellar systems and can be examined to lower levels of X-ray emission than any other galaxies, with the X-ray regime of the spectrum expected to be particularly relevant for recognizing weak signs of any nuclear activity. The Andromeda Nebula (M31) satellite M32 was investigated in considerable detail. This small spheroidal system is known to contain a comparatively strong X-ray source located in its central region. Possible interpretations of this source that could be proposed are a Supernova Remnant or a weakly active galaxy nucleus, with greater weight attributed to the latter option.

Besides the four largest galaxies, the further members of the Local Group did not reveal central sources till low levels of X-ray flux, except for two Irregular galaxies (NGC 6822 and the WLM galaxy). In both these cases however, the catalogued optical positions may not refer to proper nuclei and the two sources were considered "suspicious". Omitting these two, only four positive or possible detections are known, in four of the largest Local Group systems; three of these are the most luminous of these galaxies, which comprise all the Spiral galaxies in the Group. While the most luminous Elliptical yields the fourth possible detection, none of the Irregulars produces more than a "suspicious" detection. Our own Galactic Centre source Sgr A* remains the lowest level of nuclear activity within the Local Group. Some of the non-detections of smaller members could still reveal some nuclear sources at the level of Sgr A*.

The four central X-ray sources thus found are candidate massive black holes, for which confirmation can come from data at other wavelengths or from dynamical studies. There could thus be at least (and quite possibly at most) four massive black holes immediately around us. The circa 20 smaller Elliptical, dwarf-spheroidal and Irregular systems do not appear to be big enough to host central massive black holes.

3.03 Long-term variability of nuclear X-ray sources in galaxies

J. Cunniffe and E.J.A. Meurs

Most normal galaxies do not show any signs of high energy emission from accretion onto a central black hole. It is known however from observations of stellar dynamics in these galaxies that most have a massive (10^5-10^9 Msolar) black hole at their core. One hypothesis as to why we do not see central activity from these galaxies is that there is no material available to fall onto the black hole and radiate. However, if a stellar disruption event were to occur then there would be a short-term accretion disk formed and radiation would be visible for this duration. In order to determine the frequency of occurence of such stellar disruption flares, observations of a sample of the brightest galaxies, of which 1774 have X-ray detections, have been examined. No strong candidates for a flare were found yet but constraints were put on the variability associated with normal versus active galaxy types. Further work will include a more complete sample of galaxies as well as other X-ray catalogues in order to search for flare candidates.

An interesting case, however, is the Elliptical galaxy NGC 4552. During the ROSAT PSPC observation period (June 1990 - October 1994), this object showed an increase in brightness of a factor 5 followed by a decay back to its previous level, as observed in the ultra-violet with the Hubble Space Telescope. This may have been the result of the disruption of a star on a close flyby of the galactic nucleus. The star's material would increase the accretion rate onto the black hole leading to increased light output. In such a scenario, the X-ray output would in particular be expected to increase. Work has begun on an analysis of all the existing X-ray data for NGC 4552 in order to detect any variation associated with the 1993 UV event.

3.04 The contents of voids in the distribution of galaxies

M. Carr and E.J.A. Meurs

Voids may be checked for the presence of absorbing material by examining spectra of galaxies from the front and back of the void and comparing for intergalactic absorption. Following a pilot study on this work, three voids from the CfA redshift survey have been selected and the galaxies surrounding the void were cross-correlated against the WGA ROSAT point source catalogue. In those cases where sources were found, the original data were retrieved and analysed. For most of the successful correlations, the source statistics are not sufficient however to produce reliable spectra, thus spectral Hardness Ratios were calculated. For the three voids selected the current analysis indicates the presence of some absorbing gas. The next step is to model spectra and spectral Hardness Ratios to interpret any absorption towards the sources that exceeds the Galactic absorption in terms of the amount of intervening gas present, or set upper limits on it.

3.05 High-energy studies of star forming regions in extragalactic context

L. Norci and E.J.A. Meurs

Evolving young stellar populations throughout the Universe are interesting to observe at X-rays, due to the noticeable presence of binaries containing compact objects (Neutron Stars, in particular) and of young Supernova Remnants. Work has continued on a population synthesis computer programme, with which a young stellar population can be simulated and be followed in time. At the moment a population consisting of single stars (most of which do exhibit appreciable X-ray emission) can be monitored for its high-energy output, examples of which have been run for a variety of star formation parameters. Preparations were made for the crucial addition of binary stars to this computer simulation programme.

3.06 X-ray characteristics of Starburst galaxies

E.J.A. Meurs and E. Devine (TCD) with L. Norci

Some further data reduction was carried out to complete a study of the general X-ray properties of a sample of Starburst galaxies. The data used in this work have been obtained with the Position Sensitive Proportional Counter (PSPC) of the ROSAT satellite. The observed level of X-ray luminosities and the comparative hardness of the emission spectra are the noticeable features of this work.

3.07 Studies of clusters of galaxies

L. Norci and E.J.A. Meurs with R. Nesci (Istituto Astronomico Universita' di Roma), H. Böhringer, R.

Treumann, W. Voges (MPE, Garching) and H. Ebeling (Hawaii)

Several improvements in the analysis of ROSAT All Sky Survey data on the sample of so-called EMSS clusters were pursued. During the Einstein X-ray satellite Extended Medium Sensitivity Survey 835 serendipitous sources have been detected, of which 105 were recognised as clusters of galaxies. The ROSAT All Sky Survey offers improved evaluation of the extension and shape of the X-ray emitting region. Within the survey limits, the source extension can be defined and a sensible measurement of the background contribution can be made. The morphology of these clusters, the energy flux and luminosity as well as the Hardness Ratios were determined for the whole EMSS cluster sample.

Detailed work on one of the EMSS clusters, A3186, was carried out with the help of ROSAT HRI data. The X-ray morphology of this cluster indicates a recent merger between galaxy clusters or groups. A small cooling flow is probably present in the inner area of the main cluster.

2.08 Studies of massive stars

L. Norci with V.F. Polcaro, R. Viotti (IAS, Rome) and C. Rossi (Istituto Astronomico Universita' di Roma)

The WO stars are a subclass of the Wolf-Rayet stars, which are generally believed to be the descendants of massive O stars. They experience very strong winds and very high mass loss, which brings nucleosynthesis products to the stellar surface thus indicating late stages of stellar evolution. The prevalence of emission lines of C and O lead to adopting subtypes as WC and WO, respectively.

An extensive sample of spectral data on WC and WO stars was used to investigate quantitatively the influence of binarity and metallicity of the parent galaxy on the stellar populations. With regard to the binarity, a systematic decrease of the line strength in composite spectrum stars was found. After excluding the composite spectra, the spread of line strength within each subtype is greatly reduced. This allows one to determine in a quantitative way the trend of the intensity and width of the 465, 559 and 581 nm emission features across the WC and WO types. For the binary systems, the deviations from the mean imply light emission ratios between the components that are in some cases as large as 20. This is an observational confirmation of the strong decrease in luminosity of the more evolved component following the O supergiant phase. In order to investigate the effect of the metallicity of the parent galaxy, the strength of the C IV 581 nm line in single stars in our Galaxy and in the Large Magellanic Cloud (LMC) have been compared. It is found that this line is on average 1.9 times stronger in the WC4 LMC stars with respect to the Galactic WC4 stars. An even larger difference is found between non-Galactic and Galactic WO stars. A good match is found instead between the strengths of the O V 559 nm line in both the Galactic and non-Galactic WO and WC4 stars, indicating that this line is a good temperature tracer for the hotter stars, and that the C IV anomaly has to be attributed to different physical conditions (e.g. mass loss or luminosity).

3.09 The origin of runaway stars

E.J.A. Meurs and G. Fennell (TCD)

Some of the young massive stars appear to have left their places of birth at great speed, as “runaway” stars, which may have been caused either by being part of a binary system of which one member exploded as Supernova or by strong gravitational interactions with other massive stars during an early stage shortly after their birth when they were very close together. If they are post-Supernova binaries, then the expectation is that they are accompanied in many cases by the Neutron Star that was formed at the explosion. High-energy data that should reveal the presence of such condensed companions have been analysed but do not detect the anticipated X-ray sources corresponding to Neutron Stars. This clear result shows that the gravitational ejection from dense stellar groups may be the more likely mechanism for producing the runaway stars.

3.10 UV and X-ray emission from TTauri stars

L. Norci and E.J.A. Meurs with V. Costa and T. Lago (CAUP)

Additional ROSAT measurements of three TTauri stars (Young Stellar Objects of low mass) were processed in order to achieve a better description of their temporal behaviour. Some variation is present but flaring activity was not observed. Their spectra indicate a variety of temperatures for the emitting hot plasma and in each case at least two temperatures are required for obtaining acceptable model fits. Their UV continua can be explained by the sum of the stellar black body radiation plus the emission from a hydrogenic component; a third component of intermediate temperature is needed in addition for one of the stars. For all three stars, the UV emission is enhanced relatively to the Sun and is seen to extend smoothly into the X-ray regime.

3.11 Optical Monitoring Camera for The INTErnational Gamma-Ray Astrophysical Laboratory

B.D. Jordan, M. Smyth and E.J.A. Meurs with B. McBreen (UCD), F. Quilligan (UCD), D. Walton (MSSL) and P. Thomas (MSSL)

The Qualification Model of the Optical Monitoring Camera (OMC) Focal Plane Assembly and Readout Electronics were fabricated to ESA flight model standard in the clean room facilities at MSSL, Dorking, UK. The imaging Electrical Ground Support Equipment (EGSE) provided by Dunsink was modified to incorporate a level shift interface to make it compatible with the Qualification and Flight Models. The EGSE incorporating this new interface was delivered to MSSL for testing the first Qualification Model. A second Ground Support Equipment system was developed and built at Dunsink. This system is designed to monitor and control the various house keeping functions of the whole camera including the Optical System and Baffle assembly. The system is controlled by National Instruments Lab View software and incorporates all the electronics necessary to monitor four critical temperatures, on/off control of two calibration LED light sources, on/off control of four heater elements and open/close control of the instrument cover and monitoring of its status. The OMC Qualification Model, the modified imaging EGSE and the house keeping EGSE were delivered to INTA, Madrid, and installed in the clean room laboratory at INTA. A full documentation set for the CCD, the Focal Plane Assembly, the imaging EGSE and the house keeping EGSE was prepared and submitted to the INTEGRAL documentation library.

4 RESEARCH ACTIVITIES IN THE ASTROPHYSICS SECTION

4.01 Strange transport in electrostatic drift wave turbulence

S V Annibaldi and L Drury with G Manfredi (Nancy), K Hopcraft (Nottingham) and R Dendy (Culham)

Evidence for "strange" (non-Gaussian) kinetics has been found in numerical studies of the transport of test particles in the Hasegawa-Mima model of drift wave turbulence. The poloidal transport undergoes a qualitative change from diffusive, through supradiffusive to ballistic as a result of the interplay of the linear dispersive term and the nonlinear term in the Hasegawa-Mima equation. Possible connections to Levy processes are being explored.

4.02 Analytic approximations for SNR evolution

L Drury with V Dwarkadas (Sydney)

Using an approach based on some work of the late Franz Kahn, analytic models have been developed for the early phase of the evolution of supernova remnants. Unlike the well-known approximate solutions of Truelove and McKee these do not contain a free parameter which has to be fixed by comparison with numerical solutions. A simple interpolation formula which matches this solution for the outer shock to the Sedov solution has also been found and shown to give an excellent fit to numerical solutions. An elegant analytic treatment of the late-phase implosion of the reverse shock can also be given, but unfortunately we have not been able to find any simple way to match this solution to the early-phase solution.

4.03 Implosion-Explosion Duality

L Drury with T Mendonca (Lisboa)

For the perfect gas with ratio of specific heats 5/3 there exists a remarkable duality transform of the Euler equations of gas dynamics. This transformation can be used to turn the problem of a cloud of uniformly expanding explosion ejecta interacting with a stationary ambient medium into that of a stationary cloud of material surrounded by a uniformly imploding medium. One can thus, in a precise sense, relate the dynamical evolution of an explosion to that of an implosion and turn the problem "inside out". The origin of this remarkable transformation has been clarified and its possible applications are being considered.

4.04 Evolution of Plerions

L Drury and A Atoyan

The possible impact of strong synchrotron cooling on the early evolution of pulsar nebulae was discussed with particular reference to the Crab.

4.05 The KLEM Project

A.Thompson and L.Drury with G.Bashindzhagyan et al (Moscow State University), J.Adams (NASA Marshall Space Flight Center), M.Simon (University of Siegen, Germany), A.Chilingarian (Yerevan), N.Egorov et al (Zelenograd, Russia), J.Procureur (CENBG Nuclear Research Center, France) and O.Saavedra (Torino University, Italy)

A longstanding goal of cosmic ray research is to measure the elemental energy spectra of cosmic rays up to and through the "knee" ($\approx 3 \times 10^{15}$ eV). It is not currently feasible to achieve this goal with an ionisation calorimeter because the mass required to be deployed in Earth orbit is very large (at least 50 tonnes). During the year, the Astrophysics Section joined an international collaboration to develop an alternative approach to the problem. This is based on measuring the primary particle energy by determining the angular distribution of secondaries produced in a target layer using silicon microstrip detector technology. The proposed technique can be used over a wide range of energies (10^{11}–10^{16}eV) and gives an energy resolution of 60% or better. Based on this technique, a design for a new lightweight instrument, KLEM (Kinematic Lightweight Energy Meter), has been developed. Due to its light weight, this instrument can have a large aperture allowing a dramatically increased exposure factor and enabling the direct measurement of cosmic ray nuclei to be extended to 10^{16} eV. A reduced scale version of KLEM has already been accepted for exposure in the Russian Segment of the International Space Station to test and confirm the new technique under flight conditions. It is planned to submit a proposal next year to the Russian Academy of Sciences and Russian Space Agency to deploy a full scale version of KLEM in orbit aboard a dedicated spacecraft. The full scale instrument, with a collecting area of $4m^2$ and a three-year exposure, has the capacity to address the "knee" problem with a data base sufficiently large to include at least 25 particles with $E>10^{16}$ eV.

4.06 The Ultra Heavy Cosmic Ray Experiment (UHCRE) on the LDEF Mission

D. O'Sullivan, A. Thompson, J. Donnelly and L.O'C. Drury with K.-P. Wenzel (ESTEC)

The main achievement during the year was the completion of the selective extraction, by means of an "actinide-skim" procedure, of cosmic ray actinide candidate events from the remaining unmeasured UHCRE detector stacks. In practice, choice of selection criteria, in particular threshold values for signal strength, were such that about 25% of the candidates were found to be actinides following full analysis. All the actinides have now been extracted from the entire accessible collecting area of the LDEF/UHCRE solid state nuclear track detector (SSNTD) array. This accessible collecting area involves 164 UHCRE detector stacks, which is equivalent to an exposure (the product of geometry factor and time) of about 150 m^2 sr y. The final yield was a sample of 30 cosmic ray actinide nuclei. Based on this sample, the current UHCRE value for the relative abundance of cosmic ray actinides, defined as $(Z \geq 88)/(74 \leq Z \leq 87)$, is found to be $0.0144 \pm 0.0031/0.0026$. This value is fully consistent within statistical error with that calculated by Brewster et al for propagated primordial solar system material (0.013). The fact that the UHCRE value for the actinide to subactinide ratio is consistent with standard primordial solar system abundances supports the view of Meyer, Ellison and Drury that the origin of the cosmic ray material is predominantly normal interstellar gas and dust. The actinide results, along with the updated ultra heavy cosmic ray spectrum, were presented at the

26th International Cosmic Ray Conference (Salt Lake City, USA) during August.

The charge assignment error for individual UHCRE events in the actinide region is estimated to vary from about ±1.5e to about ±2.5e. The overall charge resolution of the actinides is expected to improve with the utilisation of further calibration exposures with beams of ultra-heavy ions in detector plates containing cosmic ray actinide events in order to identify possible systematic errors. Towards the end of the year, a programme was initiated to refine the charge spectrum further, especially in the actinide region, with the ultimate objective of measuring the thorium/uranium ratio with sufficient confidence for astrophysical significance. This programme involves the experimental derivation of correction factors for small systematic differences in signal from etch to etch in relevant UHCRE detector plates from the many etches employed during the entire period of UHCRE data extraction.

4.07 Cosmic Rays at Aircraft Altitudes

D O'Sullivan, D Zhou and E Flood

This year saw the final phase of this European project co-ordinated by D O'Sullivan. Work continued on experiments and data analysis. The results from the DIAS experiments and those of the other four partners were compiled at DIAS and an 83 page report (DIAS Report 99-9-1) was published in December. The results comprise a very comprehensive data set on cosmic rays in the Earth's atmosphere during Solar minimum and will provide a basis for determining the extent to which aircrew are exposed to radiation at aircraft altitudes as well as improving our knowledge of the complicated physics involved. The results are a major contribution to the requirements of recent European/Euratom directives both in terms of the accumulated data base of dose equivalent rates as a function of altitude, latitude and stage of solar cycle, and in the development of instrumentation, active and passive, for dosimetry at aviation altitudes.

It was decided during the year that a proposal for continuation of the work through the Solar Maximum period be written and that funding be requested from the EC 5th Framework Programme. This would allow a complete study to be made over one solar cycle and provide an excellent opportunity to investigate galactic and solar particles and their secondaries at aircraft altitudes in a comprehensive and controlled way for the first time. D O'Sullivan was appointed co-ordinator and prepared a draft proposal which was finalised at the end of September during a three day meeting at DIAS, attended by partners from the UK, Germany, Italy, Austria and Sweden. CERN will also be involved. A total of one million euros was requested. The proposal was submitted early in October and successful candidates are expected to be informed by February/March 2000.

4.08 Physical Conditions in Herbig-Haro Jets

F. Bacciotti and T.P. Ray with R. Mundt (Heidelberg) and J. Eislöffel (Tautenburg)

Herbig-Haro (HH) -type jets emanating from Young Stellar Objects (YSOs) have been recognized as an essential element of the star formation process. Many of their basic features, however, are poorly understood. In particular, the hydrogen ionisation fraction and, as a consequence, the total density and mass loss rate of the flow are often not known, or determined in a model-dependent way, and with poor spatial resolution. Moreover, the nature of the different velocity components, observed near the source in ground-based moderate spatial resolution spectra, have yet to be explored. This could provide interesting insights in the acceleration mechanism of the flow.

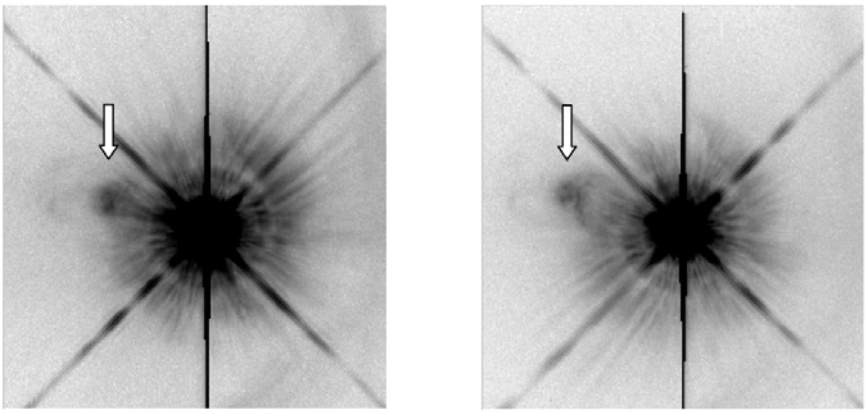
In order to fill these gaps in our knowledge, narrowband images of the HH 30 bipolar jet, taken with the Wide Field Camera 2 (WFPC2) aboard the Hubble Space Telescope (HST), and newly acquired proprietary Space Telescope Imaging Spectrograph (STIS) HST spectra of the jet from DG Tau have been analysed by means of both standard and novel spectral diagnostic techniques. Both sets of data possess unprecedented high spatial resolution (about 0".1) and the long-slit STIS spectra are the first of a YSO jet taken from space to date. Observations, using a ground-based wide field camera, were also made of many well-known HH jets in order to investigate their proper motions, structural changes and kinematics. The necessary time baseline for such observations is typically a few years.

For the HH 30 jets an average ionisation fraction of about 0.1 was derived, implying a total density of a few $10^4 cm^{-3}$ and a mass loss rate of $\sim 2.10^{-9} M_{\odot} yr^{-1}$. The ionisation increases at the beginning of the flow to reach a plateau at about 2" from the source, then it smoothly decreases following a recombination curve. At the same time the temperature sharply decreases in the first arcsecond of the jet before decaying gently along the rest of the beam. Both types of behaviour are reminiscent of what is predicted by several models for the cooling region of a steady, radiative oblique shock located in the proximity of the source. Other interesting results are that the filling factor turned out to be of order unity in this flow, and that the jet knots are clearly correlated with local temperature maxima. The ionisation fraction and the electron and total densities do not show any evident increase at the same positions. If confirmed, this latter finding could indicate the presence of a substantial magnetic field in the body of the jet.

For the case of the DG Tau jet, STIS spectra were taken in seven different slit positions, parallel to the outflow but with appropriate offsets in the transverse direction, providing 3-D intensity-velocity "datacubes" in various lines, which were analysed with IRAF. High spatial resolution synthetic line images of the region close to the star, in distinct radial velocity intervals, were then constructed. It was found that the jet is on the axis of a pear-shaped limb-brightened bubble which extends between 0".4 and 1".5 from the source and which we interpret as a bow shock. The outflow is found to be spatially wide close to the source in its low velocity component, but it becomes denser and more collimated at higher velocity. These findings are consistent with a unified model for the origin of the low and high velocity components (LVC and HVC respectively) forbidden line emission. That is that the forbidden line emission ultimately arises from shocks powered by a jet, rather than in a two-component disk wind/jet model as has been suggested by some authors. In the DG Tau case, the LVC seems to be emission from the wings of the external shocks close to the source. Further studies are required, however, to investigate whether any disk wind component might be identified with the so-called Near Rest Velocity forbidden line emission.

The line ratios derived from the same spectra have been utilized to map the electron density, ionisation fraction and temperature along and (for the first time) across the flow, in

each of the chosen velocity bins. Given the huge dataset, an improved automated version of our original diagnostic technique has been utilized. The most interesting results is that the ionisation fraction is seen to increase gently, and the temperature to decrease rapidly in the first 1".5 from the source, as in the case of HH 30. This suggests that the same mechanism might operate at the base of these two, and possibly all, jets. The fact that the density and excitation increase in the higher bins is consistent with the jet plus bow shock scenario.



HST Archive images of the DG Tau jet taking in September 1995 and February 1998 (left and right image respectively) showing the expansion in the Herbig-Haro flow. The position of the Herbig-Haro bowshock is indicated by means of an arrow in both frames.

4.09 Ambipolar Diffusion in Astrophysical Nebulae

F. Bacciotti and T. Lery with D. Galli (Arcetri Observatory, Florence) and C. Chiuderi (University of Florence)

Nebulae can present a wide range of ionisation conditions, sometime rapidly varying in time and space. In particular neutrals may affect the dynamics through ambipolar diffusion, i.e. the slippage of magnetic field lines (and of the ionised component) with respect to the bulk of the matter. Ambipolar diffusion has been considered largely in the context of the gravitational collapse of molecular clouds, where the ionisation degree is extremely low ($\sim 10^{-7}$). Nevertheless, applications to situations in which the ionisation is substantially higher (as YSO jets) have recently been presented. Existing results, however, are sometimes contradictory, and it is not always clear whether ambipolar diffusion is important in certain situations, or if the three-fluid description, normally adopted for its treatment, is the most appropriate. Also, it is not always obvious how the effects of ambipolar diffusion change as the physical properties vary in space and time. Thus, it appears that a unified treatment, valid in a range of different ionisation conditions could be very useful in the field of star formation.

Following these ideas, the generalised MHD equations for the evolution of the three vector quantities characterizing the gas, that is the centre-of-mass velocity **U**, the current density **J**, due to the drift between the electrons and neutrals, and the drift speed $\mathbf{u_d}$ between the neutrals and ions, were re-derived in a rigorous manner. In this approach one has to consider the drift velocities when defining the relevant one-fluid effective "temperature". Thus, observed quantities have sometimes to be re-defined in order to properly use the experimental data in the unified system. As a start, several rates for collisions between various species relevant to astrophysical situations have been re-calculated. When reduced to particular regimes, this system of equations give the well-known sets used in the description of molecular clouds, as well as in recent work on YSO jets. A first application to the inter-cloud medium and to the solar corona has also been investigated. Each case was critically re-examined taking into account a number of often-neglected relevant factors apart from the characteristic ionisation: for example, the orientation angle of the bulk speed with respect to the magnetic field and the importance of thermal versus magnetic pressure. At present, the main result of this investigation is that, in those cases studied, ambipolar diffusion is indeed the dominant mechanism for the breakdown of the flux-freezing approximation, unless the plasma is almost completely ionised. The ambipolar diffusion term, however, seems to be of limited use, unless the system is in quasi-static evolution or the bulk velocity is strictly parallel to the magnetic field.

4.10 Models for Jets and Outflows during Star Formation

T. Lery and T.P. Ray with A. Frank (Rochester University, New-York) and R.N. Henriksen (Queen's University, Ontario, Canada)

From a theoretical perspective, magnetic collimation seems to be the most likely mechanism through which YSO jets are collimated. This is in line with observations that suggest magnetic fields play a very important role in star formation. Moreover magnetic confinement complements the idea that the expulsion of the jet material is electro-dynamic in origin. Since it is thought that outflows, including highly collimated jets, are related to in-falling flows and accretion, it is important to understand the relationship between these various elements.

Current work is concentrated on an improved self-similar inflow-outflow model in combination with a jet that includes the effect of Poynting flux, and time dependence. In this theoretical framework, the self-similar gravitationally driven convective quadrupolar circulation around a heated proto-stellar envelope is solved rigorously. The molecular outflow is regarded as a natural consequence of the circulation established by the collapse of the pre-stellar cloud as required by observations. General results about magnetized outflows and jets and a classification of magnetic rotators have been obtained.

A study has also been performed of the stability of the ensuing equilibrium and of several general magnetic configurations. Both 2D and 3D simulations of MHD YSO jets have also been made to try to solve the key outstanding problems of jet propagation.

4.11 Sub-millimeter Polarimetry of the Serpens Dark Cloud

T.P. Ray with C. Davis and H.E. Matthews (Joint Astronomy Center, Hilo)

A polarization study of the 850μm dust emission in the Serpens star formation region was carried out using the new Sub-millimeter Common-User Bolometer Array (SCUBA) at the James Clarke Maxwell Telescope (JCMT). This emission is associated with a number of Class 0/I protostars and the data were used to infer the magnetic field morphology in the region. The polarization vectors around the SMM-NW cluster of sources are more ordered than those observed near the SMM-SE cluster. Toward SMM-NW, the vectors are generally orientated north-south; between the intensity peaks in the SMM-SE region, the vectors are approximately east-west. In both regions, it is suggested that the polarization pattern may be dictated by a large-scale magnetic field. It was examined whether the rough northwest-southeast ridge of sub-millimeter sources was formed via cloud collapse along field lines that run perpendicular to this ridge. However, the data offer only very tentative support for this hypothesis. It was further noted that, although overall the polarization pattern in Serpens does not appear to be affected by the many outflows in the region, toward the most luminous source, SMM 1, the source of the Serpens radio jet, the vectors deviate considerably from the general pattern, instead being roughly perpendicular to the flow axis, as one would expect from a B-field oriented parallel with the flow.

4.12 Image Deconvolution Techniques

R. Butler with A. Shearer and Seathrun O'Tuairisg (University College Galway)

Work in this area has concentrated on improved image restoration and photometry in crowded-fields, such as the densely populated central regions of globular clusters. Of particular interest is the search for stars that, through their variability and/or photometric properties, are indicative of dynamic interactions or important late phases of stellar evolution.

The techniques employed are diverse and often novel; for example, the study aims to discover variable stars by means of high-accuracy image registration, point spread function (PSF)-matching and sigma-map computation using stacked globular-cluster core images from ground-based telescopes. Already a number of variables in the core of M15 have already been confirmed and additional candidates have been discovered.

Image restoration techniques developed by Butler, based on maximum entropy methods (MEM), but appropriate to densely packed regions, are also now being applied systematically to very large archival HST datasets.

4.13 The Propagation of Jets from Young Stars

S. O'Sullivan and T.P. Ray

Although YSO jets are cooled radiatively via atomic and molecular species, it is only in the past few years that computer simulations have incorporated these effects. Moreover there is now general agreement that magnetic fields play a very important role in their dynamics.

S. O'Sullivan, as part of his PhD thesis, has developed a new multi-dimensional magneto-hydrodynamic second order upwind code that includes energy losses due to radiation effects, atomic hydrogen ionisation/recombination and molecular hydrogen dissociation. Fluxes at cell interfaces are calculated using a linear approximation and if this fails a non-linear iterative solver. The condition $\nabla \mathbf{B} = 0$ is maintained by including small source terms in the conservation equations or by means of a staggered mesh algorithm.

It was found that the propagation dynamics and morphology of magnetised radiative jets are significantly different to those of a purely hydrodynamic nature. In particular magnetic fields for all three configurations used (helical, toroidal, and poloidal) enhance the jet collimation. It was found that a longitudinal fields component restricts the lateral motion of the flow and that a purely toroidal component, through hoop stresses, constricts the flow towards its axis. This results in the toroidal field cases exhibiting extended nose cones, enhanced bow shock speeds, and disruption of internal working surfaces (knots) formed by velocity variations in the flow. The poloidal field cases maintained a more stable degree of collimation and the knots were not destroyed. Cooling also improved the jet collimation as it reduced the thermal support in the cocoon making it narrower than its adiabatic counterpart. Cooling also gave rise to Rayleigh Taylor type unstable configurations at the head of the jet causing the bow shock to periodically break up into smaller structures that sunk back into the jet cocoon. This could explain some of the knotty structures seen in Herbig-Haro bows.

4.14 Light Element Nucleosynthesis and evolution in the Galaxy

E. Parizot and L. Drury

The light elements ($_6$Li, $_7$Li, $_9$Be $_{10}$B and $_{11}$B) are known to be produced by spallative nucleosynthesis, i.e. through nuclear reactions involving heavier nuclei (mostly O and C) and energetic particles interacting in the interstellar medium (ISM). Recent observations have shown that the efficiency of these spallative reactions must have remained constant during the whole lifetime of the Galaxy, i.e. it must be roughly independent of the ISM metallicity. We have proposed two distinct mechanisms satisfying this requirement, both involving supernova remnants (SNRs) and shock acceleration. In the first one, some ambient material is accelerated at the forward shock of the SNR, and then confined within the remnant for about 10^5 years (Sedov-like phase), where it interacts with the freshly ejected C and O nuclei, producing significant amounts of Li, Be and B (LiBeB). In the second mechanism, the O-rich supernova ejecta are directly accelerated at the reverse shock, and then interact with the ambient ISM to produce LiBeB in flight. In both cases, we have calculated the total LiBeB production, both analytically and numerically (taking into account the time-dependent acceleration of particles due to the SNR evolution as well as the adiabatic losses) and we have compared it to the LiBeB production required to account for the abundances observed in low-metallicity stars. We have found that LiBeB was underproduced at least by an order of magnitude, which also automatically excludes other scenarios which have been proposed on purely qualitative grounds. Analysing the reason for this 'failure', we have identified a possible scenario which could be exempt from the drawbacks of the previous models (notably the dilution of the ejecta with ambient low-metallicity material, the relative weakness of the reverse shock, and the adiabatic losses). This new scenario takes advantage of the collective effect of repeated

supernovae occurring in OB associations, where most massive stars are to be found. We have then build a coherent model of light element production in the vicinity of so-called superbubbles (large structures blown by the winds and explosions of several tens of Supernovae) and shown that this model accounts successfully for both the qualitative and quantitative aspects of LiBeB evolution in the Galaxy (namely the constancy of the Be/Fe and B/Fe ratios as a function of Fe/H, as well as the total amount of LiBeB present in the Galaxy).

5 FACILITIES

5.1 Computers and Network

Astrophysics Section Following extensive testing over a period of two months by HEANET and DIAS of a low power radio link between Number 5 Merrion Square and the HEANET headquarters in Marine House it was decided in March to adopt this as the primary connection between DIAS and the academic research networks. Half the capital costs of the installation were paid by HEANET and there are no recurrent costs. The effective bandwidth of the connection is about 512kbits/sec and it has proved remarkably stable in operation. The former 128k line which the radio link replaced was relocated to Burlington Road and the old 64k line between Merrion Square and Burlington Road was removed. As a side effect of this upgrade a new Cisco 2500 router was installed in Merrion Square and the old router reconfigured and moved to Dunsink Observatory. The router in Dunsink also means that the bandwidth allocation on the leased-line can now be controlled to give users a better connection to the internet.

The continued increase in the number of computers, and more importantly the continued increase in sustained data throughput from the newer hard disc drives, began to place a noticable strain on the internal ethernet sytem in Number 5 which is still largely based on coaxial technology. This was alleviated by introducing UTP cabling between certain critical machines and the purchase of a 3Com network switch, but ultimately it will be necessary to recable the whole site using the more modern UTP technology.

The nonevent of the year was surely the Y2000 problem. Considerable time was spent monitoring the solaris, linux and NT web sites for last minute software patches and appplying these where appropriate. As a precaution all nonessential machines were closed down in preparation for the date roll-over. The DIAS Y2000 computer committee monitored progress throughout the year and reported as required on the Institute's degree of compliance.

Various more or less routine upgrades and improvements were made to the system throughout the year. By the end of the year all PCs were running under Windows NT and the old netware system could be closed down. The main disc server was expanded and now runs under Solaris 2.6. The Beowulf cluster was upgraded to Redhat Linux 6.x and MPICH release 1.2.0 was installed. The installation of a Smartview KVM switch now allows all the cluster machines to be controlled from one monitor and keyboard.

Numerous problems with user programs and applications were diagnosed and where possible fixed. In particular J Walsh produced an extensive list of bug fixes for RayInvr (a seismic ray tracing inversion progamme); these have now been implemented by the research staff at the Geological Institute of the University of Copenhagen.

There have been considerable computer hardware additions in Merrion Square, including the installation of two new Sparc stations, 50 Gb of disk storage space, a 36 inch inkjet colour plotter, a DLT (Digital Linear Tape) tape drive and a Fast Ethernet SuperStack switch for the computer network. One of the new Sparc platforms, Mir, is now the new disk farm server and is a replacement for Atlas. A system for making data backups, in duplicate, for all users at the end of each calendar month has been put into operation. A procedure was also put in place for the backup, using DLT, of data from Hawaii.

5.2 Nuclear Track Equipment

The transfer of etching facilities from the main building to Track Lab #3 was completed during the first half of the year, leaving the two old etching rooms in the main building completely vacated and ready for redevelopment. Track Lab #3 was refurbished and fitted with services and equipment appropriate to the requirements of the final stages of the LDEF/UHCRE programme and for the continuation of the IRMA work. Etch Tank #1, which had been relocated to Track Lab #3, was installed with its associated equipment, commissioned and maintained in continuous operation for the rest of the year. The temperature stability continued to be better than $\pm$ 0.005 °C. Etch Tank #2 was shut down, decommissioned and disassembled. Etch Tank #3, which had been decommissioned towards the end of last year, was also disassembled, leaving Etch Tank #1 as the only large (150 litre capacity) etching tank facility available. A small etching tank facility (10 litre capacity) was also relocated to Track Lab #3 and installed.

Etching equipment was maintained and serviced as necessary during the year. Replacement sub-systems or components included a new ceramic heater unit, thyristor control unit and contact-thermometer unit. The primary etch tank temperature display and recording equipment was refurbished. In addition, an independent etch tank power supply was set up and several etch tank detector mounting frames were reconstructed.

The six Leitz-ASL track measuring microscope stations, the Nikon-Heidenhain track measuring microscope station and the six Nikon stereo scanning microscope systems were also maintained and upgraded as necessary during the year. In particular, the linear displacement transducer fitted to one of the Leitz-ASL stations in Track Lab #2 was reconditioned and the optical components in the head of a second Leitz-ASL station were refurbished. In addition, a third Leitz-ASL station in Track Lab #2 was completely overhauled.

5.3 La Palma Observatory

5.3.1 La Palma Advisory Committee (LPAC)

Meetings of the La Palma Advisory Committee (LPAC) were held on 07 May and 19 November. It was agreed that P. Callanan be the Irish representative on the Particle Physics and Astronomy Research Council (PPARC) Panel for the Allocation of Telescope Time (PATT).

Enterprise Ireland (formerly Forbairt) continued to provide an annual subvention for the travel and subsistence expenses of non-DIAS observers, in view of the importance of access to the La Palma Observatory and other PPARC groundbased facilities by Ireland.

5.3.2 Observing runs in 1999

Runs are listed alphabetically, with the PATT reference numbers where applicable. Non-PATT runs, supported by DIAS, are also noted.

Smith (CIT) et al: (J/99A/20) *Quasar variability*, JKT, one week.

Smith (CIT) et al: (J/99B/12) *Quasar variability*, JKT, one week, grey time.

Ray (DIAS) et al: (I/99B/32) INT, one week bright time with Wide Field Camera. The purpose of this run was to image a number of stellar outflows using the Isaac Newton Wide Field Camera. Data were taken in a range of filters to determine excitation conditions and, in some cases, to provide second epoch images for proper motion studies. The emphasis was on outflows from intermediate luminosity young stars. The weather conditions were reasonable during this run.

Shearer (UCG) et al: ("P25"), WHT, two bright plus two grey nights.

Ray (DIAS) et al: (U/99B/33) UKIRT, three bright nights. A total of three nights was awarded on UKIRT in November to observe shocked molecular hydrogen emission from a number of embeddened young stars. The observations were carried out in excellent seeing conditions using the CGS4 spectrometer in echelle mode. A number of molecular hydrogen "microjets" were discovered, which have been seen optically in partially ionised species before but not in molecular hydrogen emission.

Callanan (UCC) et al: Keck Telescope, one night.

To be completed

6 SEMINARS, COLLOQUIA, LECTURES

6.1 Statutory Public Lecture

T. Ray (DIAS) delivered the Annual Statutory Public Lecture for the School of Cosmic Physics. The lecture was entitled *Making Stars and Planets* and took place at University College Dublin (Arts Block, Belfield), on 09 November. This year, the Statutory Public Lecture doubled as a Science Week Public Lecture.

6.2 Seminars and Open Lectures in the School

P. Carolan (Culham): *Fusion Plasma Research at Culham*, 19 March.

A. Codino (University of Perugia and INFN, Perugia, Italy): *Antinuclei in the Primary Cosmic Radiation*, 01 December.

K. Hopcraft (University of Nottingham): *Levy Flights and Multi-Cascades*, 14 July.

A. Lawrence (Institute for Astronomy, Edinburgh): *SCUBA sources, failed stars, and the dark matter*, 25 November.

M.D. Smith (Armagh Observatory): *The violent birth of stars*, 27 April

J. Vink (Astrophysikalisches Institut, Potsdam): *X-ray studies of Cas A: New perspectives on a 320 yr old remnant*, 13 July

M. Wilkinson (IoA, Cambridge): *The Masses of the dark halos of the Milky Way and Andromeda Galaxies*, 13 April

As in the previous year, a number of informal internal seminars were held at Dunsink Observatory in order to foster discussions of the staff and students at the observatory about the research that is carried out. These meetings can be in the form of talks about the on-going work or may be critical discussions of relevant research papers. The following talks were scheduled during the year:

M. Carr, *An overview of redshift surveys*, 28 May; E. Devine, *X-ray characteristics of Starburst galaxies*, 09 June; J. Cunniffe, *Candidate X-ray flares from galaxy cores*, 14 July; M. Carr, *X-rays through Voids*, 22 July; Z. Zang, *Cores of Local Group galaxies at X-rays*, 24 November; S. Power, *Simulation and detection of high-redshift galaxies in the Hubble Deep Fields*, 15 December.

6.3 Contributions to Scientific Meetings

S.V. Annibaldi: *Regimes of particle transport in strong electrostatic turbulence* (poster paper), The 26th Plasma Physics Conference, Pitlochry, Scotland, 29 March – 01 April; *Modelling different regimes of particle transport in strong electrostatic turbulence* (poster paper), The 26th EPS Conference on Controlled Fusion and Plasma Physics, Maastricht, The Netherlands, 14-18 June; *Super diffusive and ballistic particle transport in strong electrostatic turbulence*, *Anisotropic particle transport with Levy statistics* (poster papers), The 8th European Fusion Theory Conference, Como, Italy, 27-29 October; *Super diffusive and ballistic particle transport in strong electrostatic turbulence* (poster paper), Nonlinear Science Festival II, Risoe National Laboratory, Denmark, 01-04 December.

M. Carr: *Voids in the Large Scale Structure*, ASGI Spring Meeting, University College Galway, 09 April; *X-raying the Voids in the Large Scale Structure*, ASGI Autumn Meeting, Dunsink Observatory, 17 September; *X-raying the Voids in the Large Scale Structure*, Workshop on "Large Scale Structure in the X-ray Universe", Santorini, Greece, 20-22 September.

J. Cunniffe: *Long term X-ray variability of galactic nuclei* (poster paper), ASGI Spring Meeting, University College Galway, 09 April.

J Donnelly: *New Results on the Relative Abundance of Actinides in the Cosmic Radiation*, The 26th International Cosmic Ray Conference, Salt Lake City (Utah), USA, 17-26 August.

L Drury: *Franz Kahn, Supernova Remnants and Cosmic Rays*, Conference on Astrophysical Dynamics, Evora, Portugal, 14-16 April; *Interpreting the Cosmic Ray Composition*, Particles and Nuclei International Conference, Uppsala, Sweden, 09-16 June; *Environmental and Age Limits on Particle Acceleration in Supernova Remnants* and *Strongly Nonlinear Synchrotron Dominated Shocks in a Pure Pair Plasma*, The GeV-TeV Gamma Ray Astrophysics Workshop, Snowbird (Utah), USA, 13-16 August; *On "box" models of shock acceleration and electron synchrotron spectra*; *Strongly nonlinear synchrotron dominated shocks in a pure pair plasma*; *Spallative production of Li, Be and B in supernova remnants*; *Spallative production of Li, Be and B in superbubbles*, The 26th International Cosmic Ray Conference, Salt Lake City (Utah), USA, 17-26 August.

J.A. Hodgson: *LEinster Granite Seismic Project (LEGS): preliminary results of a geophysical study*, Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October; *Leinster Granite Seismic Project (LEGS): a wide-angle study of a late Caledonian granite*, AGU (American Geophysical Union) Fall Meeting, San Francisco, 13-17 December.

A.W.B. Jacob: *Robert Mallet - the earliest controlled-source seismologist*, Commission on Controlled Source Seismology Workshop, Dublin 06-08 October; *An integrated shear wave study along the VARNET96 line B profile in SW Ireland including Vp/Vs ratios*, AGU (American Geophysical Union) Fall Meeting, San Francisco, 13-17 December.

M. Landes: *VARNET-96: 3-D Modelling of seismic refraction data, SW Ireland*, Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October.

K. McGrane: *Depositional and erosional processes in the Rockall Trough imaged by GLORIA*, North-East Atlantic Slope Processes: Multi-disciplinary approaches Workshop, Southampton 24-27 January; *Recent sedimentary features in the Rockall Trough*, The Petroleum Exploration of Ireland's Offshore Basins Conference, Dublin, 29-30 April; *Reconnaissance survey of the Irish continental shelf/shelf edge*, Marine Institute In-House Workshop: Marine Survey Projects, 19 May.

E.J.A. Meurs: *X-ray candidates for a population of nuclear cores in Local Group galaxies*, conference on "Black Holes in Binaries and Galactic Nuclei", ESO, Garching, Germany, 05-09 September; *Prospects for extragalactic research with big telescopes*, ASGI Autumn meeting, Dunsink Observatory, 17 September; *The origin of the X-ray emission from the IRAS galaxy NGC3147*, ESLAB Symposium 33, Noordwijk, the Netherlands, 01-06 November.

B.M. O'Reilly: *Thermal evolution of the lithosphere: impact on Cretaceous/early Tertiary sedimentation patterns in the NE Atlantic and Hydrocarbon prospectivity*; *Slope failure features in the Rockall Trough*, The Petroleum Exploration of Ireland's Offshore Basins Conference, Dublin, 29-30 April; *Geographical extent of early Tertiary uplift in the northeast Atlantic and its relationship to the thermal history of the lithosphere*, AGU (American Geophysical Union) Fall Meeting, San Francisco, 13-17 December.

D O'Sullivan: *Cosmic Rays and their influence on Air Crew* (invited talk), The International Conference on Radiation Research, Dublin, 18-23 July; *Cosmic Rays and Air Crew*, The Workshop on Environmental Dosimetry, Avignon, 21-25 November.

E. Parizot: *Time dependent models for Li, Be and B production in the early Galaxy*, Conference on "LiBeB, cosmic rays and gamma-ray line astronomy", Institut d'Astrophysique de Paris, France, 09-11 December (1998); *Spallative nucleosynthesis in supernova remnants and superbubbles*; *Superbubble evolution and associated gamma-ray line emission*, The 19th Texas Symposium, Paris, 13-18 December (1998); *Galactic Cosmic Rays and the Light Elements*, The ISSI meeting on "The Astrophysics of Galactic Cosmic Rays", Bern, Switzerland, 18-22 October; *Superbubbles and the Galactic evolution of Li, Be and B*, IAU Symposium Number 198 ("The Light Elements And Their Evolution"), Natal, Brazil, 22-26 November.

T.P. Ray: *What Drives Molecular Outflows from Young Stars*, Conference on Astrophysical Dynamics (a conference in honour of Franz Kahn), Evora, Portugal, 14-16 April.

P.W. Readman: *Gravity fabrics, basin structuring and morphology in the Rockall Trough and Porcupine Basin*, The Petroleum Exploration of Ireland's Offshore Basins Conference, Dublin, 29-30 April; *Slope instability features in the Rockall Trough, offshore Ireland*, AGU (American Geophysical Union) Fall Meeting, San Francisco, 13-17 December.

6.4 External Seminars

S.V. Annibaldi: *Regimes of particle transport in strong electrostatic turbulence*, Laboratoire de Physique des Milieux Ionises, Universite Henri Poincare, Nancy, France, 10 March; *Transporto Supradiffusivo di Particelle in Turbolenza Elettrostatica Forte*, ENEA, Frascati, Italy, 17 September.

J. Cunniffe: *UV and X-ray transient activity in galactic nuclei*, Osservatorio Astronomico, Roma, 31 August.

L Drury: *Particle Astronomy*, IoPiI (Institute of Physics in Ireland) lecture, UCC, 01 February; *What do we really know about the origin of cosmic rays?*, Joint Astronomy Colloquium, ESO, Munich, 08 April; *Current status of the cosmic ray origin problem*, UCD, 22 April; *What have cosmic rays got to do with interstellar dust?*, Heidelberg Astronomical Seminar, 29 June; *Cosmic Rays and Interstellar Dust*, University of Sydney, 09 November; University of New South Wales, 10 November.

E.J.A. Meurs: *The X-ray source associated with M32*, Sterrenkundig Instituut "Anton Pannekoek", University of Amsterdam, 29 July; *An X-ray examination of the cores of Local Group galaxies*, Centro de Astrofisica, Porto, Portugal, 20 October.

K. McGrane: *The Geophysical Anatomy of the Rockall Trough, Offshore Ireland*, Cork Geological Association, 30 March; *Geophysical and GLORIA studies in the Rockall Trough,* University College Dublin, 06 April.

B.M. O'Reilly: *Passive continental margins*, Department of Geology, Trinity College Dublin, 20 April.

D O'Sullivan: *Cosmic Rays and Aircrew*, CERN, Geneva, 08 June; *The Nature of Cosmic Rays*, The Aviation Health Institute, London, 29 June.

E. Parizot: *The LiBeB story*, Max-Planck Institut, Heidelberg, Germany, 10 November 1999.

Z. Zang: *An X-ray Search for Active Cores in Local Group Galaxies*, Space Research Organization Netherlands, Utrecht, The Netherlands, 17 November; *An X-ray Search for Active Cores in Local Group Galaxies*, University of Erlangen-Nürnberg, Bamberg, Germany, 19 November.

6.5 Lecture Courses

L. Drury, E.J.A. Meurs and L. Norci together with colleagues from UCD and SPCM: Joint course of eight hours on *Topics in High-energy Astrophysics* at TCD during Michaelmas term.

E.J.A. Meurs: Lecture course of eighteen hours on *Stellar Dynamics* at TCD during Hilary term; Course of nine hours on *Physics of Galaxies* at TCD during Hilary Term. Guidance provided for 4th year TCD physics student.

L. Norci: Course of nine lectures on *Stellar Structure and Evolution* in TCD during Hilary term.

T.P. Ray: Lecture Course on the *Interstellar Medium* to Senior Sophister (final year) students at the Department of Physics, TCD, during Hilary Term.

L. Drury: Lecture Course 343 (*Astrophysical Gas Dynamics*) at the Department of Mathematics, TCD, during Michaelmas term.

6.6 Popular Lectures

I. Elliott: Presentation on Teaching Junior Certificate Astronomy, H.Dip.Ed. course, UCD, 26 January; *Celestial Fireworks*, Inaugural Lecture of the Astronomy Society of the Dundalk Institute of Technology, 15 April; *Celestial Fireworks*, Irish Astronomical Society, Dublin, 04 October; *Dunsink Through the Centuries*, lecture for National Science Week (Ireland), Dunsink Observatory, 11 November; *Millennium Madness*, Irish Astronomical Association, Belfast, 17 November.

B. Jordan: *The Electrical Ground Support Equipment for the OMC for INTEGRAL*, Institute of Electrical Engineers in Ireland, 16 December.

E.J.A. Meurs: *Stories of the Polar star*, Irish Astronomical Society, 01 March; *Dunsink, History and Research*, Irish Astronomical Society (at Dunsink Observatory), 08 May; *The European Southern Observatory: the astronomy of the future*, lecture for National Science Week (Ireland), Dunsink Observatory, 12 November; *Dunsink, History and Research*, TCD Astronomy and Space Society (at Dunsink Observatory), 16 November; *Stories of the Polar star*, TCD Astronomy and Space Society, 17 November; *The expanding view of our Universe during the 20th century*, "Lectures at eight", Enniscorthy, 22 November.

D O'Sullivan: *Astronauts, Aircrew and Cosmic Rays*, lecture for National Science Week (Ireland), Dunsink Observatory, 10 November.

T.P. Ray: *Peering at the Edge of Creation*, Irish Astronomical Society, Dublin, 18 January; Irish Astronomical Association, Belfast, 20 January; *What Did Our Solar System Look Like 5 Billion Years Ago?*, Physics Society, University of Limerick, 02 December; *Archaeoastronomy: Fact or Fiction?*, Trinity Astronomical Society, TCD, 09 December.

P.W. Readman: *The Earth as a Magnet*, lecture for National Science Week (Ireland), Dunsink Observatory, 13 November.

7 ORGANISATION OF MEETINGS, EXPOSITIONS AND PUBLIC FACILITIES.

7.1 EADN Summer School

The European Astrophysical Doctoral Network (EADN), under the chairmanship of T.P. Ray, organised a summer school supported by the European Union Training and Mobility of Researchers Programme on "Selected Topics in Binary Stars: Observations and Physical Processes". It was hosted by the Faculty of Physics at the University of La Laguna, Tenerife, Spain, from 06 September to 17 September. Lectures were delivered in the Aula Magna of the Faculties of Physics and Mathematics. Each of the invited lecturers developed a topic in five lectures. The Scientific Director of the School was Professor C. Lazaro.

The subject of this school was chosen because of the important role played by binary stars in modern Astrophysics. At present, it is believed that more than half of the stars in the Galaxy are born and evolve as binary or multiple stellar systems. This makes the study of binary stars essential to the understanding of stellar evolution. The physics of binary stars is a very active subject in which recent major advances have taken place both in theory and observations. During their evolution, many of the binary stars interchange appreciable amounts of mass and energy. The interchange of matter between the stellar components has a profound influence on the evolution of the stars, modifying their evolutionary paths considerably in comparison to that of a single star with the same mass. Also the transfer of matter between the stellar components produces a lot of new phenomena that are interesting from both a theoretical and an observational viewpoint. The Interacting Binary Class, as it is known, contains a zoo of astrophysical exotica: condensed matter stars in the form of white dwarfs and neutron stars, candidate black holes, stars that produce eruptive phenomena such as novae and occasionally supernovae, high energy radiation, etc.

The school programme attempted to cover a wide range of topics within the field. Subjects included the determination of absolute stellar parameters and their comparison with models of stellar structure and evolution; the physical processes affecting the evolution of binaries; analysis and interpretation of observational data; orbital and rotational evolution by tidal interaction between the stellar components; mutual irradiation of the stellar atmospheres; magnetic activity; and short period binaries.

The intention in organising the school was to allow the students acquire new knowledge of the theoretical problems involved in the study of binary stars, to learn about new techniques for observing them, such as surface mapping, and to gain an understanding of current research topics in this active field. As with previous schools the students also got an opportunity to present their own work either in the form of a short talk or as a poster. Activities during the school included a visit to the Observatorio del

Teide in Tenerife, were the participants could see several working telescopes. They were also brought to the Instituto de Astrofisica de Canarias, in La Laguna, where they were able to view the institute's computing, instrumental and library facilities. The students and lecturers were accommodated in the Hotel Nivaria, within the historical centre of La Laguna and within walking distance from the Faculty of Physics.

7.2 The 1999 CCSS Workshop: Active and Passive Seismic Techniques Reviewed

(*A.W.B. Jacob, staff of the Geophysics Section and C.J. Bean, UCD)*

The Geophysics Section had the honour to be invited to host a Workshop of the international Commission on Controlled Source Seismology (CCSS). These Workshops generally take place somewhere in the world about once every three years. The leading researchers in the field of controlled source seismology, together with some post-graduate and post-doctoral students, hold a Workshop where all the participants are invited. It is not an open conference. A pleasant feature of the Workshop was that it was dedicated to an eminent Irish scientist and engineer, Robert Mallet, MRIA, FRS (1810-1881) who was born and brought up in Dublin and who, in October 1849 carried out the world's first controlled source seismic experiment (on Killiney Beach). The Workshop was thus exactly 150 years after his pioneering work in the field. Mallet is even credited with coining the word "seismology" and other associated terms.

After discussions with the Chairman of the Commission, W. Mooney (USA), the organisers, A.W.B. Jacob and C.J. Bean, had their ideas on widening the scope of the Workshop accepted. For the first time, the rapidly expanding field of passive seismic studies was also included. The result was a very productive three days in which ideas from both the active and passive fields were freely exchanged and argued about. The joint use of such methods is going to expand greatly in the future. The Geophysics Section is, indeed, already carrying out combined work of this nature.

The Workshop was very successful and was followed by a field trip to the site of Robert Mallet's earliest experiments and to the Wicklow Granites. The Proceedings of the Workshop will be published.

7.3 Numerical methods in AstroPlasmaPhysics

A specialist workshop on "Numerical methods in AstroPlasmaPhysics" was held in 5 Merrion Square on 20 and 21 September. The meeting was attended by A Atoyan, T Bell, M Dieckmann, T Downes, L Drury, P Duffy, J Kirk, Y Gallant, S Lucek, A Marcowith, E Parizot, S O'Sullivan and E van der Swalup.

7.4 National Science Week (Ireland)

For "National Science Week Ireland", four public lectures were given by members of the School at Dunsink Observatory on 10,11,12 and 13 November (see Section 6.6). In addition, the James South Refractor and the Solar System Display were on view to the public on mornings and afternoons during Science Week (08-13 November).

7.5 Irish Astronomical Staff Meetings

On the initiative of E.J.A. Meurs, observational astronomical staff in Ireland met several times at Dunsink Observatory to discuss possible future observational facilities for Ireland. The most favoured options are the European Southern Observatory, a radio telescope (to be linked with the MERLIN array and with the European VLBI Network) or a robotic telescope. These meetings were held on 20 May, 16 July, 03 September and 24 October.

7.6 Dunsink Open Nights, Visitor Facilities and Public information

The interactive Visitors' Facility in Dunsink Observatory was again actively used throughout the year for demonstrations to groups (from schools and otherwise) and to visitors generally. During the year the Office of Public Works completed the recoppering of the two domes at the Observatory.

As in other years, Open Nights for the general public were held twice monthly during the winter half year, led by W. Dumpleton. Members of the Irish Astronomical Society were again instrumental with their support on these occasions. Several additional single-group visits, in the evenings (or sometimes during daytime), took place during the year. In August public information regarding the total solar eclipse that was visible in Europe was provided. General information services included, amongst other issues, viewing data for satellites, background to various celestial phemomena and precise timings for sunrise and sunset, Lighting Up Times, beginnings of seasons and changes between winter and summer times.

7.7 Launch of Strategic Plan 1999-2003

A Strategic Plan for the School of Cosmic Physics covering the period 1999-2003 was published during the year. This Plan was launched by the Chairman of the Board on 8th November at a function in 5 Merrion Square. This function, which included a reception and exhibition, was attended by representatives of the Department of Education and Science, the Office of Science and Technology, members of the Council and Boards of DIAS, members of staff and other interested parties. The published booklet covers (l) Information on the school, (2) Relationships, (3) Research now in progress, (4) Training, publications and other contributions and (5) Charting the way forward. Section 5 of the document is concerned, in particular, with scientific objectives and staffing for the five year period.

8 EXTERNAL WORK

8.1 Geophysics Section

T.A. Blake: LEGS seismic station deployment and recovery, various periods, 09-20 March; RAPIDS-3 project on board the Akademik Boris Petrov, 13 April - 09 May; Installation of seismic station and computer at Valentia Observatory, 19-20 May and 6-8 December; ERDAS Imagine Users Group Meeting, Cambridge, 01-02 September; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October.

F. Hauser: VARNET Workshop, Karlsruhe, 25-28 February; LEGS seismic station deployment and recovery, various periods, 09-20 March.

J.A. Hodgson: LEGS seismic recording site location finding and permissioning, extended periods during January and February; LEGS seismic station deployment and recovery, various periods, 09-20 March; Visit to University of Texas at El Paso, ??-?? February; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October; American Geophysical Union Fall Meeting, San Francisco, 13-17 December.

C. Horan: LEGS seismic recording site location finding and permissioning, extended periods during January and February; LEGS seismic station deployment and recovery, various periods 09-20 March; RAPIDS-3 project on Celtic Voyager, 25-30 May; Installation of seismic station, Valentia Observatory, 19-20 May; Installation of seismic recording stations, Hawaii, June and November.

A.W.B. Jacob: VARNET Workshop, Karlsruhe, 25-28 February; LEGS Land shot-firing, 12-13 and 15-16 March; Petroleum Exploration of Irish Offshore Basins Conference, Dublin Castle, 29-30 April; RAPIDS-3 project meeting, Hamburg, 21-24 June; Seabed Survey Meeting, Athlone, 12-13 September; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October; RAPIDS-3 project meeting, Hamburg, 15-17 November.

R. Keary: RAPIDS-3 project on Celtic Voyager, 10-16 May and 25-30 May.

M. Landes: VARNET Workshop, Karlsruhe, 25-28 February; LEGS seismic station deployment and recovery, various periods, 09-20 March; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October.

K. McGrane: LEGS seismic station deployment and recovery, March; AIRS project visit to SOC (the Southampton Oceanography Centre) and the Northeast Atlantic Slope Processes Workshop, Southampton, 24-27 January; Petroleum Exploration of Irish Offshore Basins Conference, Dublin Castle, 29-30 April; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October.

G. McKenzie: RAPIDS-3 project on Celtic Voyager, 21-29 April; RAPIDS-3 project on Akademik Boris Petrov, 09 May - 03 June; RAPIDS-3 project work, Hamburg, 21 June - 09 July; 19 July - 13 August; 24 August - 21 September; 17 October - 05 November and 14 November - 03 December.

B.M. O'Reilly: AIRS project visit to SOC (the Southampton Oceanography Centre) and the Northeast Atlantic Slope Processes Workshop, Southampton, 24-27 January; Irish Geological Research Meeting, TCD, 26-28 February; LEGS seismic station deployment and recovery, various periods, 09-20 March; Petroleum Exploration of Irish Offshore Basins Conference, Dublin Castle, 29-30 April; TRIM project visit to SOC, Southampton, ??-?? July; Seabed Survey Meeting, Athlone, 12-13 September; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October; Gravity fieldwork, 22 October - 03 November and 25-27 November; American Geophysical Union Fall Meeting, San Francisco, 13-17 December.

L. Quigley: LEGS seismic recording site location finding and permissioning, extended periods during January and February; LEGS seismic station deployment and recovery, various periods, 09-20 March; RAPIDS-3 project on Celtic Voyager, 10-16 May; Installation of seismic processing computer at Valentia Observatory, 06-08 December.

P.W. Readman: AIRS project visit to SOC (the Southampton Oceanography Centre) and the Northeast Atlantic Slope Processes Workshop, Southampton, 24-27 January; VARNET Workshop, Karlsruhe, 25-28 February; LEGS seismic station deployment and recovery, various periods, 09-20 March, Celtic Voyager sea shot-firing, 12-17 March; Petroleum Exploration of Irish Offshore Basins Conference, Dublin Castle, 29-30 April; RAPIDS-3 project on Celtic Voyager, 21-29 April; Commission on Controlled Source Seismology Workshop, Dublin, 06-08 October; Gravity fieldwork, 22 October - 03 November and 25 -27 November; American Geophysical Union Fall Meeting, San Francisco, 13-17 December.

P.M. Shannon: RAPIDS-3 project meeting, Hamburg, 21-24 June; RAPIDS-3 project meeting, Hamburg, 15-17 November.

V. Unnithan: LEGS Celtic Voyager sea shot-firing, 12-19 March.

G. Wallace: LEGS Celtic Voyager sea shot-firing, 12-19 March; RAPIDS-3 project on Celtic Voyager, 21-29 April, 10-16 May and 25-30 May; Installation of seismic recording stations, Hawaii, June; Seabed Survey Meeting, Athlone, 12-13 September; Installation of seismic recording stations, Hawaii, November.

8.2 Astronomy Section

M. Carr: Spring Meeting of the Astronomical Science Group of Ireland, University College Galway, 09 April; Autumn Meeting of the Astronomical Science Group of Ireland, Dunsink Observatory, 17 September; Workshop on "Large Scale Structure in the X-ray Universe", Santorini, Greece, 20-22 September.

J. Cunniffe: Spring Meeting of the Astronomical Science Group of Ireland, University College Galway, 09 April; Osservatorio Astronomico, Rome, 17 August - 04 September; Autumn Meeting of the Astronomical Science Group of Ireland, Dunsink Observatory, 17 September.

I. Elliott: Spring Meeting of the Astronomical Science Group of Ireland, University College Galway, 09 April; Autumn Meeting of the Astronomical Science Group of Ireland, Dunsink Observatory, 17 September.

B. Jordan: OMC Consortium Progress and Critical Design Review meetings, INTA, Madrid, 12-14 July; OMC Critical Design Review meetings, MSSL, Dorking, UK, 05-06 October; Delivery of imaging EGSE and first tests of OMC Qualification Model, MSSL, Dorking, UK, 18-19 October; Delivery of OMC Qualification Model, Imaging EGSE, House Keeping EGSE and test of OMC Qualification Model, INTA, Madrid, 15-17 November.

E.J.A. Meurs: Istituto Astronomico, University of Rome, 21 June - 02 July; Sterrenkundig Instituut "Anton Pannekoek", University of Amsterdam, 26 July - 06 August; Total solar eclipse, Virton, Belgium, 09-12 August; Conference on "Black Holes in Binaries and Galactic Nuclei", ESO, Garching, Germany, 05-09 September; Sterrewacht Leiden, 10 September; Centro de

Astrofisica, Porto, Portugal, 18 - 20 October; ESLAB Symposium 33, Noordwijk, the Netherlands, 01-06 November.

L. Norci: Istituto d'Astrofisica Spaziale, Rome, 21 June - 02 July; Autumn Meeting of the Astronomical Science Group of Ireland, Dunsink Observatory, 17 September.

Z. Zang: Autumn Meeting of the Astronomical Science Group of Ireland, Dunsink Observatory, 17 September; Space Research Organization Netherlands, Utrecht, The Netherlands and University of Erlangen-Nürnberg, Bamberg, Germany, 15-20 November.

8.3 Astrophysics Section

S.V. Annibaldi: Collaboration meeting (Manfredi et al), Universite Henri Poincare, Nancy, France, 04-13 March; The 26th Plasma Physics Conference, Pitlochry, Scotland, 29 March – 01 April; Collaboration meeting (Dendy et al), Culham, UK, 26-29 May; The 26th EPS Conference on Controlled Fusion and Plasma Physics, Maastricht, The Netherlands, 14-18 June; The 8th European Fusion Theory Conference, Como, Italy, 27-29 October; Nonlinear Science Festival II, Risoe National Laboratory, Denmark, 01-04 December.

F. Bacciotti: La Palma, Canary Islands, 21 November – 02 December.

J Donnelly: The 26th International Cosmic Ray Conference, Salt Lake City (Utah), USA, 17-26 August.

L Drury: APP network workshop, Le Barp, France, 02-05 March; Management committee meeting, Armagh. 23 March; Visit to MPI fuer Extraterrestrische Physik, Munich, Germany, 07-09 April; Memorial meeting for Franz Kahn, Evora, Portugal, 13-18 April; Heidelberg, Commission on the future of the MPI fuer Kernphysik, 29 April - 02 May; The 15th Particles and Nuclei International Conference (PANIC 99), Uppsala, Sweden, 10 - 16 June; APP network workshop, Kittendorf, Germany, 22-25 June; Visit to MPI fuer Kernphysik Heidelberg, Germany, 25-30 June; MPI fuer Kernphysik Commission meeting in Stuttgart, Germany,11-12 July; The TeV gamma-ray astronomy workshop, Snowbird (Utah), USA, 12-17 August; The 26th International Cosmic Ray Conference, Salt Lake City (Utah), USA, 17-26 August; Represented the IUPAP Commission on Cosmic Rays (C4) at the IUPAP Council meeting in CERN, Geneva, Switzerland, 30 September - 03 October; ISSI (International Space Science Institute) workshop "Astrophysics of Galactic Cosmic Rays", Bern, Switzerland, 17-24 October; Visitor in the Research Center for Theoretical Astrophysics, University of Sydney, Australia, 27 October to 29 November.

E. Flood: Detector calibration exposures at CERN and IRMA-2 Contractors Meeting, Geneva, Switzerland, 05-10 June.

T. Lery: Paris Observatory, 13-19 September; University of Strasbourg, 20-27 October.

D O'Sullivan: Presentation of near final results of the Air Crew project to the International Steering Committee, GSF, Munich, 16 March; Exposures at the CERN Cosmic Ray Reference Field, CERN, 05-10 June; Discussions on air crew matters, ANPA Laboratories, Rome, 09-12 September; Workshop on Environmental Dosimetry, Avignon, 21-25 November.

E. Parizot: Conference on "LiBeB, cosmic rays and gamma-ray line astronomy", Institut d'Astrophysique de Paris, France, 09-11 December (1998); The 19th Texas Symposium, Paris, 13-18 December (1998); APP network workshop, Le Barp, France, 02-05 March; APP network workshop, Kittendorf, Germany, 22-25 June; ISSI Workshop "Astrophysics and Galactic Cosmic Rays", Bern, Switzerland, 17-24 October; APP network workshop, Zeist, The Netherlands, 26-29 October; IAU Symposium Number 198, "The Light Elements And Their Evolution", Natal, Brazil, 22-27 November.

T.P. Ray: Queens University Belfast, 20 January; Thesis examination, University of Turin, Italy, 11-12 February; Conference on "Optical and Infrared Spectroscopy of Circumstellar Matter", Tautenburg Observatory, Jena, Germany, 09-14 March; Spring Meeting of the Astronomical Science Group of Ireland, University College Galway, 09-10 April; MERLIN meeting, University of Cambridge, 25 May; University of Evora, Portugal, 13-18 April; Queens University Belfast, 10 June; Paris Observatory, 29 June – 03 July; Royal Astronomical Society, National Astronomy Meeting, Guernsey, Channel Islands, 09-13 August; United Kingdom Infrared Telescope, Mauna Kea Observatory, 21-28 November; University of Limerick, 02 December; PATT meeting, Swindon, England, 07-08 December.

J. Walsh: Conference on Metadata for Physics documents on the WWW, Oldenburg, Germany, 09-14 October; HEANET Seminar on Computer Security, National College of Ireland; Seminar on CHEST (software acquisition).

9 MISCELLANEA

L.O'C. Drury continued to serve as Vice-Chairman of the *Commission on Cosmic Rays* of the International Union of Pure and Applied Physics and as the DIAS representative on the *National Committee for Physics* of the Royal Irish Academy.

A.W.B. Jacob continued to serve as Chairman of the National Committee for Geodesy and Geophysics of the Royal Irish Academy.

E.J.A. Meurs continued to serve as Honorary President of the *Trinity Astronomy and Space Society*. He further served on the *National Committee for Astronomy and Space Research* of the Royal Irish Academy and as Chairman of the *La Palma Advisory Committee*.

T.P. Ray continued to serve as the DIAS representative on the *National Committee for Astronomy and Space Research*, as Chairman of the *European Astrophysical Doctoral Network* and as a member of the *MERLIN Time Allocation Group* within the Panel for Allocation of Telescope Time (PATT).

D O'Sullivan was appointed Chairman of the *Institute of Physics in Ireland* and as a member of the *National Committee for Physics* of the Royal Irish Academy, he undertook a campaign to encourage Ireland's membership of CERN. This effort, which involved meetings with senior CERN staff and senior Irish civil servants, was at an advanced stage by the end of the year.

P.W. Readman was elected to the National Committee for Geodesy and Geophysics of the Royal Irish Academy. He was also appointed as a Research Associate of University College Dublin (Department of Geology).

A.W.B. Jacob, with C.J. Bean, convened the Commission for Controlled Source Seismology 1999 Workshop, "Active and Passive Seismic Techniques Reviewed", in Dublin at DIAS.

In the Astrophysics Section K. Farrell and S. O'Sullivan successfully defended their PhD theses (see section 10.3). The external examiners were D. Duncan (Heriot-Watt University, Edinburgh) and J. Stone (University of Maryland) respectively.

In the Astronomy Section Z. Zang successfully defended his PhD thesis (see section 10.3) at Trinity College Dublin on 26 November.

I. Elliott continued as a member of the National Committee for Science and Engineering Commemorative Plaques, as a Council member of the Royal Dublin Society and as a member of its Science and Technology Committee. He continued as chairman of the Irish Science Centres' Association Network (ISCAN) which held meetings in Wexford (24 April) and Armagh (16 October). A special ISCAN lecture on *Astronomy at 2 in the Morning* was given at Dunsink by Alex Barnett on 15 October.

B.M. O'Reilly was appointed to the editorial board of the Irish Journal of Earth Sciences.

Louise Quigley continued to edit *Survey Ireland*.

T. Lery was awarded a NASA grant, with A. Frank and T. Jones, for a project on "2-D and 3-D numerical simulations of YSO Jets".

F. Bacciotti was granted an extension of her European Space Agency Fellowship to continue working in the Astrophysics Section Star Formation Group on Hubble Space Telescope data.

A final year project by a Diploma student in the Electrical Engineering Department of the Dublin Institute of Technology was supervised by B. Jordan. The project concerned a remote control unit for the South Dome rotator motor. The completed working unit was demonstrated as a bench model by the student for his practical examinations.

F. Buckley, Physics Department, TCD, was supervised by T.P. Ray from September to December for his final year project using data from the HST Archive.

I. Elliott served as a lecturer and commentator on the Irish Ferries vessel Normandy for the total solar eclipse on 11 August which was observed off the coast of Alderney in the Channel Islands. He was assisted by an astronomical team: Dipanker Banerjee (Armagh Observatory), Ruth Colgan (NUI-Maynooth), John Cunniffe (DIAS), Cliona Golden (UCD & Princeton), Lynn Moran (UCD), Brian O'Halloran (UCD) and Eoghan O'Shea (QUB). The event was broadcast on the Worldwide Web.

I.Elliott gave a talk entitled *Exploring Space and Time* in the series of Thomas Davis Lectures on "Science and Technology at the end of the 20th Century", RTE Radio-1, 03 May; E.J.A. Meurs was interviewed on Anna Livia Radio on 13 May; I.Elliott spoke about the astronomer Margaret Huggins on a programme about Irish women scientists, Anna Livia Radio, 24 June; Dunsink Observatory featured on the City Scenes TV programme, broadcast 18 and 19 September.

The Grubb heliostat which was used in the historic test of General Relativity at the 1919 total solar eclipse was refurbished by J. Daly, who then turned his attention to a restoration of the eyepieces of the Dunsink Grubb telescope.

Members of the Astronomical Science Group Ireland convened at Dunsink Observatory on 17 September for their annual Autumn Meeting.

I.Elliott prepared 24 certificates of Lighting-up Time for legal cases involving road traffic accidents. Information on sunrise and sunset was supplied to the Irish Aeronautical Association and to the Millennium Commission. Routine information on the positions of the Sun and Moon was supplied to architects, sporting organisations and film companies. In addition, responses to a number of historical enquiries were also provided.

10 PUBLICATIONS

10.1 Journals and other Refereed Publications

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F. Bacciotti, J. Eislöffel and T.P. Ray: *The physical properties of the HH30 jet from HST and ground-based data*, Astron. Astrophys., Vol 350, pp 917-927 (1999).

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T. Lery, R. Henriksen and J. Fiege: *Magnetised protostellar bipolar outflows I Self-similar model with Poynting flux*, Astron. Astrophys., Vol. 350, pp 254-274 (1999).

F. Masson, F. Hauser and A.W.B. Jacob: *The lithospheric trace of the Iapetus suture in SW Ireland from teleseismic data*, Tectonophysics, Vol 302, pp 83-98 (1999).

B.M. O'Reilly, P.W. Readman, P.W. and T. Murphy: *Gravity Lineaments and Carboniferous-hosted base metal deposits of the Irish Midlands,* in Fractures, Fluid Flow and Mineralization (eds K.J.W. McCaffrey, L. Lonergan and J.J. Wilkinson), Geological Society, London, Special Publications, Vol 155, pp 313–321 (1999).

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N.J. Vermeulen, P.M. Shannon, M. Landes, F. Masson and the VARNET GROUP: *Seismic evidence for subhorizontal crustal detachments beneath the Irish Variscides,* Irish Journal of Earth Sciences, Vol 17, pp 01-18 (1998/9).

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10.2 Conference Proceedings

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10.3 Books, Theses, Reports and Sundry Publications

I. Elliott: An article on "Astronomy" in the Blackwell Companion to Modern Irish Culture, edited by William J. McCormack; Blackwells (1999).

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