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Contents

In 2012 the Institute produced a new strategic plan covering the period 2012-2016[1]. As part of the development of this overarching Institutional strategy each school also produced its own strategic programme of activities. In the case of the School of Cosmic Physics this identified four broad 'pillars' that together support the school. The first and most important of these is the School's reputation for pioneering and excellent research, the others being its contributions to the third-level educational system, its involvement in shared research infrastructure and general public service and finally its work in public outreach. This report aims as far as possible to follow this structure.

1 Research Work

1.1 High-Energy Phenomena

1.1.1 Radiation processes

Felix Aharonian

The exploration of specifics of high energy radiation processes in different astrophysical environments has been one of the major topics of my research over the last 30+ years. In this regard the period of 2012-2013 was quite productive. Together with my colleagues, I developed an analytical approach for calculations of radiation of relativistic electrons in highly turbulent magnetic fields. We found several interesting features of radiation in both the synchrotron and the so-called "jitter" regimes. These results might have broad implications in astrophysics. We also have studied the character of radiation of relativistic charged particles in regular magnetic fields using, for the first time, the Hamiltonian formalism for determination of trajectories of particles in extremely strong fields. The gamma-radiation components emitted by relativistic electrons in the synchrotron and curvature-radiation regimes have been explored on a quantitative level. The other two studies currently being under consideration, are nuclear reactions in very hot astrophysical plasmas, and precise analitical parametrizations of the cross-sections of proton-proton interactions from sub-relativistic to ultra high energies. Finally, we have conducted a principally new study of modification of radiation emitted by relativistically moving objects due to the effects of special relativity.

Jitter Radiation *S.R. Kelner, F.A. Aharonian, D. Khangulyan*

In a small-scale turbulent medium, when the nonrelativistic Larmor radius $R_L = mc2/eB$ exceeds the correlation length λ of the magnetic field, the magnetic Bremsstrahlung radiation of charged relativistic particles unavoidably proceeds to the so-called jitter radiation regime. The cooling timescale of parent particles is identical to the synchrotron cooling time, thus this radiation regime can be produced with very high efficiency in different astrophysical sources characterized by high turbulence. The jitter radiation has distinct spectral features shifted toward high energies, compared to synchrotron radiation. This effect makes the jitter mechanism an attractive broad-band gamma-ray production channel, which, in highly magnetized and turbulent environments, can compete or even dominate over other high-energy radiation mechanisms. In this paper, we present a novel study of the spectral properties of the jitter radiation performed within the framework of perturbation theory. The derived general expression for the spectral power of radiation is presented in a compact and convenient form for numerical calculations. The work is published in The Astrophysical Journal[22].

Synchrotron-to-curvature transition regime of radiation of charged particles in a dipole magnetic field *A. Prosekin, S.R. Kelner, F.A. Aharonian*

The details of trajectories of charged particles become increasingly important for proper understanding of processes of formation of radiation in strong and curved magnetic fields. Be-

[1] http://www.dias.ie/images/stories/admin/Strategystatements/diasstrategic%20plan2012-2016.pdf

cause of damping of the perpendicular component of motion, the particle's pitch angle could be decreased by many orders of magnitude leading to the change of the radiation regime – from synchrotron to the curvature mode. To explore the character of this transition, we solve numerically the equations of motion of a test particle in a dipole magnetic field, and calculate the energy spectrum of magnetic bremsstrahlung self-consistently, i.e. without a priori assumptions on the radiation regime. In this way we can trace the transitions between the synchrotron and curvature regimes, as well as study the third (intermediate or the so-called synchro-curvature) regime. We briefly discuss three interesting astrophysical scenarios, the radiation of electrons in the pulsar magnetosphere in the polar cap and outer gap models, as well as the radiation of ultrahigh energy protons in the magnetosphere of a massive black hole, and demonstrate that in these models the synchrotron, synchro-curvature and curvature regimes can be realized with quite different relative contributions to the total emission. The work is submitted to Astrophysical Journal[78].

Analytical Approximations for Treatment of Inverse Compton Scattering of Relativistic Electrons in the Blackbody Radiation Field *Khangulyan, S.R. Kelner, F.A. Aharonian*

The inverse Compton (IC) scattering of relativistic electrons is one of the major gamma-ray production mechanisms in different environments. Often, the target photons for IC scattering are dominated by blackbody (or graybody) radiation. In this case, the precise treatment of the characteristics of IC radiation requires numerical integrations over the Planckian distribution. Formally, analytical integrations are also possible but they result in series of several special functions; this limits the efficiency of usage of these expressions. The aim of this work is the derivation of approximate analytical presentations that would provide adequate accuracy for the calculations of the energy spectra of upscattered radiation, the rate of electron energy losses, and the mean energy of emitted photons. Such formulae have been obtained by merging the analytical asymptotic limits. The coefficients in these expressions are calculated via the least-squares fitting of the results of numerical integrations. The simple analytical presentations, obtained for both the isotropic and anisotropic target radiation fields, provide adequate (as good as 1%) accuracy for broad astrophysical applications. This work is now published in The Astrophysical Journal, Volume 783, Issue 2, article id. 100, 11 pp. (2014).

The beaming pattern of External Compton Emission from relativistic outflows *S.R. Kelner, E. Lefa, F. Rieger, F.A. Aharonian*

The beaming pattern of radiation emitted by a relativistically moving source like jets in microquasars, AGN and GRBs, is a key issue for understanding of acceleration and radiation processes in these objects. In this paper we introduce a formalism based on a solution of the photon transfer equation to study the beaming patterns for emission produced by electrons accelerated in the jet and upscattering photons of low-energy radiation fields of external origin (the so-called External Compton scenario). The formalism allows us to treat non-stationary, non-homogeneous and anisotropic distributions of electrons, but assuming homogeneous/isotropic and non-variable target photon fields. We demonstrate the non-negligible impact of the anisotropy in the electron distribution on angular and spectral characteristics of the EC radiation. The work is submitted to Astrophysical Journal[74].

1.1.2 High Energy Radiation of Astrophysical sources

TeV gamma rays from blazars beyond $z = 1$? *F.A. Aharonian, W. Essey, A. Kusenko, A. Prosekin*

At TeV energies, the gamma-ray horizon of the Universe is limited to redshifts $z \leq 1$, and, therefore, any observation of TeV radiation from a source located beyond $z =$ would call for a revision of the standard paradigm. While robust observational evidence for TeV sources at redshifts

$z \geq 1$ is lacking at present, the growing number of TeV blazars with redshifts as large as $z \approx 0.5$ suggests the possibility that the standard blazar models may have to be reconsidered. We show that TeV gamma rays can be observed even from a source at $z \geq 1$, if the observed gamma rays are secondary photons produced in interactions of high-energy protons originating from the blazar jet and propagating over cosmological distances almost rectilinearly. This mechanism was initially proposed as a possible explanation for the TeV gamma rays observed from blazars with redshifts $z \approx 0.2$, for which some other explanations were possible. For TeV gamma-ray radiation detected from a blazar with $z \geq 1$, this model would provide the only viable interpretation consistent with conventional physics. It would also have far-reaching astronomical and cosmological ramifications. In particular, this interpretation would imply that extragalactic magnetic fields along the line of sight are very weak, in the range $10^{-17}\,\mathrm{G} < B < 10^{-14}\,\mathrm{G}$, assuming random fields with a correlation length of 1 Mpc, and that acceleration of $E \geq 10^{17}$ eV protons in the jets of active galactic nuclei can be very effective. This work is published in Physical Review D[5].

Evidence for a Second Component in the High-energy Core Emission from Centaurus A? *N.V. Sahakyan, R. Yang, F.A. Aharonian, F.M. Rieger*

We report on an analysis of Fermi Large Area Telescope data from four years of observations of the nearby radio galaxy Centaurus A (Cen A). The increased photon statistics results in a detection of high-energy (>100 MeV) gamma-rays up to 50 GeV from the core of Cen A, with a detection significance of about 44σ. The average gamma-ray spectrum of the core reveals evidence for a possible deviation from a simple power law. A likelihood analysis with a broken power-law model shows that the photon index becomes harder above $E_b \approx 4\,\mathrm{GeV}$, changing from $\Gamma_1 = 2.74 \pm 0.03$ below to $\Gamma_2 = 2.09 \pm 0.20$ above. This hardening could be caused by the contribution of an additional high-energy component beyond the common synchrotron self-Compton jet emission. No clear evidence for variability in the high-energy domain is seen. We compare our results with the spectrum reported by H.E.S.S. in the TeV energy range and discuss possible origins of the hardening observed. The work is published in The Astrophysical Journal Letters[38].

Star-Jet Interactions and Gamma-Ray Outbursts from 3C454.3 *D. V. Khangulyan, M. V. Barkov, V. Ramon-Bosch, F.A. Aharonian, A.V. Dorodnytsin*

We propose a model to explain the ultra-bright GeV gamma-ray flares observed from the blazar 3C454.3. The model is based on the concept of a relativistic jet interacting with compact gas condensations produced when a star (a red giant) crosses the jet close to the central black hole. The study includes an analytical treatment of the evolution of the envelope lost by the star within the jet, and calculations of the related high-energy radiation. The model readily explains the day-long that varies on timescales of hours, GeV gamma-ray flare from 3C454.3, observed during 2010 November on top of a plateau lasting weeks. In the proposed scenario, the plateau state is caused by a strong wind generated by the heating of the stellar atmosphere due to nonthermal particles accelerated at the jet-star interaction region. The flare itself could be produced by a few clouds of matter lost by the red giant after the initial impact of the jet. In the framework of the proposed scenario, the observations constrain the key model parameters of the source, including the mass of the central black hole: $M_{\rm BH} \approx 10^9 \mathrm{M}_\odot$, the total jet power: $L_j \approx 10^{48}\,\mathrm{erg\,s^{-1}}$, and the Doppler factor of the gamma-ray emitting clouds: $\delta \approx 20$. Whereas we do not specify the particle acceleration mechanisms, the potential gamma-ray production processes are discussed and compared in the context of the proposed model. We argue that synchrotron radiation of protons has certain advantages compared to other radiation channels of directly accelerated electrons. An injected proton distribution $\nu \propto E^{-1}$ or harder below the relevant energies would be favoured to alleviate the tight energetic constraints and to avoid the violation of the observational low-energy constraints. The work is published in The Astrophysical Jour-

nal[23].

Unraveling the high-energy emission components of gamma-ray binaries. *V. Zabalza, V. Ramon-Bosch, D.V. Khangulyan, F.A. Aharonian*

The high and very high energy spectrum of gamma-ray binaries has become a challenge for all theoretical explanations since the detection of powerful, persistent GeV emission from LS 5039 and LS I +61 303 by Fermi/LAT. The spectral cut-off at a few GeV indicates that the GeV component and the fainter, hard TeV emission above 100 GeV are not directly related. We explore the possible origins of these two emission components in the framework of a young, non-accreting pulsar orbiting the massive star, and initiating the non-thermal emission through the interaction of the stellar and pulsar winds. The pulsar/stellar wind interaction in a compact-orbit binary gives rise to two potential locations for particle acceleration: the shocks at the head-on collision of the winds and the termination shock caused by Coriolis forces on scales larger than the binary separation. We explore the suitability of these two locations to host the GeV and TeV emitters, respectively, through the study of their non-thermal emission along the orbit. We focus on the application of this model to LS 5039 given its well-determined stellar wind with respect to other gamma-ray binaries. The application of the proposed model to LS 5039 indicates that these two potential emitter locations provide the necessary conditions for reproduction of the two-component high-energy gamma-ray spectrum of LS 5039. In addition, the ambient postshock conditions required at each of the locations are consistent with recent hydrodynamical simulations. In summary, the scenario based on the interaction of the stellar and pulsar winds is compatible with the GeV and TeV emission observed from gamma-ray binaries with unknown compact objects, such as LS 5039 and LS I +61 303. This work has been published in Astronomy and Astrophysics[49].

Nonthermal radiation of young supernova remnants: the case of Cas A *V.N. Zirakashvili, F.A. Aharonian, R. Yang, E. One-Wilhelmi, R.J. Tuffs*

The processes responsible for the broad-band radiation of the young supernova remnant Cas A are explored using a new code which is designed for a detailed treatment of the diffusive shock acceleration of particles in nonlinear regime. The model is based on spherically symmetric hydrodynamic equations complemented with transport equations for relativistic particles. Electrons, protons and the oxygen ions accelerated by forward and reverse shocks are included in the numerical calculations. We show that the available multi-wavelength observations in the radio, X-ray and gamma-ray bands can be best explained by invoking particle acceleration by both forward and reversed shocks. Although the TeV gamma-ray observations can be interpreted by interactions of both accelerated electrons and protons/ions, the measurements by Fermi LAT at energies below 1 GeV give a tentative preference to the hadronic origin of gamma-rays. Then, the acceleration efficiency in this source, despite the previous claims, should be very high; 25% of the explosion energy (or approximately $3 \cdot 10^{50}$ erg) should already be converted to cosmic rays, mainly by the forward shock. At the same time, the model calculations do not provide extension of the maximum energy of accelerated protons beyond 100 TeV. In this model, the acceleration of electrons is dominated by the reverse shock; the required 10^{48} erg can be achieved under the assumption that the injection of electrons (positrons) is supported by the radioactive decay of ^{44}Ti. The work is accepted for publication in Astrophysical Journal[81].

The Jet and Arc Molecular Clouds toward Westerlund 2, RCW 49, and HESS J1023–575; ^{12}CO and ^{13}CO (J = 2-1 and J = 1-0) observations with NANTEN2 and Mopra Telescopes *Furukawa, N.; Ohama, A.; Fukuda, T.; Torii, K.; Hayakawa, T.; Sano, H.; Okuda, T.; Yamamoto, H.; Moribe, N.; Mizuno, A.; Maezawa, H.; Onishi, T.; Kawamura, A.; Mizuno, N.; Dawson, J. R.; Dame, T. M.; Yonekura, Y.; Aharonian, F.; de Oña Wilhelmi, E.; Rowell, G. P.; Matsumoto, R.; Asahina, Y.; Fukui,*

Y.

We have made new CO observations of two molecular clouds, which we call "jet" and "arc" clouds, toward the stellar cluster Westerlund 2 and the TeV γ-ray source HESS J1023–575. The jet cloud shows a linear structure from the position of Westerlund 2 on the east. In addition, we have found a new counter jet cloud on the west. The arc cloud shows a crescent shape in the west of HESS J1023–575. A sign of star formation is found at the edge of the jet cloud and gives a constraint on the age of the jet cloud to be Myr. An analysis with the multi CO transitions gives temperature as high as 20 K in a few places of the jet cloud, suggesting that some additional heating may be operating locally. The new TeV γ-ray images by H.E.S.S. correspond to the jet and arc clouds spatially better than the giant molecular clouds associated with Westerlund 2. We suggest that the jet and arc clouds are not physically linked with Westerlund 2 but are located at a greater distance around 7.5 kpc. A microquasar with long-term activity may be able to offer a possible engine to form the jet and arc clouds and to produce the TeV γ-rays, although none of the known microquasars have a Myr age or steady TeV γ-rays. Alternatively, an anisotropic supernova explosion which occurred Myr ago may be able to form the jet and arc clouds, whereas the TeV γ-ray emission requires a microquasar formed after the explosion. The results are published in The Astrophysical Journal, Volume 781, Issue 2, article id. 70, 20 pp. (2014).

1.1.3 HESS related activity

Felix Aharonian

During 2002 to 2007 I was the first convener of the working group of the HESS collaboration on galactic sources. Most of the HESS discoveries reported during the first several years have been conducted in this working group. Recently I was asked to take again the leadership of the same working group, given the accumulated huge amount of data, and a need for quick publications of at least the most exciting result. Currently more than 50% of my research time goes to the organization of the activity of the working group. In particular, with a help of my two deputy-conveners, we have organized task group with an ambitious aim of preparation and submission of more than 30 papers over the next 8 to 12 months, including three important papers for the high impact journals Nature and Science on the discovery of (i) VHE gamma-ray sources in the Large Magellanic Cloud, (ii) model-independent derivation of the distribution of electrons up to 300 TeV, and the distribution of the highly turbulent magnetic fields in the pulsar wind nebula Vela -X, (iii) on the evidence of proton acceleration in the vicinity of the massive black hole located in the the centre of our Galaxy.

1.1.4 Electromagnetic Cascades, UHECR, and Neutrinos

Andrew Taylor

Search for Extended γ-ray Emission around AGN with H.E.S.S. and Fermi-LAT *K. Stycz, S. Ohm, A. M. Taylor et al., for the HESS collaboration*

Very-high-energy ($E > 100$ GeV) γ-ray emission from blazars inevitably gives rise to electron-positron pairs through their interaction with the Extragalactic Background Light (EBL). Depending on the magnetic fields in the proximity of the source, the cascade initiated from pair production can result in either an isotropic halo around an initially beamed source or a magnetically broadened cascade flux. Both extended pair halo (PH) and magnetically broadened cascade (MBC) emission from regions surrounding the blazars 1ES 1101-232, 1ES 0229+200 and PKS 2155-304 were searched for, using VHE γ-ray data taken with the High Energy Stereoscopic System (H.E.S.S.), and high energy (HE; 100 MeV $< E <$ 100 GeV) γ-ray data with the Fermi Large Area Telescope (LAT). By comparing the angular distributions of the reconstructed γ-ray events to the angular profiles calculated from detailed theoretical models, the presence of PH and MBC was investigated. Upper lim-

its on the extended emission around 1ES 1101-232, 1ES 0229+200 and PKS 2155-304 were found to be at a level of few percent of the Crab nebula flux above 1 TeV, depending on the assumed photon index of the cascade emission. Assuming strong Extra-Galactic Magnetic Field (EGMF) values, $> 10^{-12}$ G, this limits the production of pair halos developing from electromagnetic cascades. For weaker magnetic fields, in which electromagnetic cascades would result in magnetically broadened cascades, EGMF strengths in the range $(0.3-3)\times 10^{-15}$ G were excluded for PKS 2155-304 at the 99% confidence level, under the assumption of a 1 Mpc coherence length. This work is to be published in Astronomy and Astrophysics.

Measuring the correlation length of intergalactic magnetic fields from observations of gamma-ray induced cascades *A. Neronov, A. M. Taylor, C. Tchernin, Ie. Vovk*

The imaging and timing properties of γ-ray emission from electromagnetic cascades initiated by very-high-energy (VHE) γ-rays in the intergalactic medium depend on the strength B and correlation length λ_B of intergalactic magnetic fields (IGMF). We study the possibility of measuring both B and λ_B via observations of the cascade emission with γ-ray telescopes. For each measurement method, we find two characteristics of the cascade signal, which are sensitive to the IGMF B and λ_B values in different combinations. For the case of IGMF measurement using the observation of extended emission around extragalactic VHE γ-ray sources, the two characteristics are the slope of the surface brightness profile and the overall size of the cascade source. For the case of IGMF measurement from the time delayed emission, these two characteristics are the initial slope of the cascade emission light curve and the overall duration of the cascade signal. We show that measurement of the slope of the cascade induced extended emission and/or light curve can both potentially provide measure of the IGMF correlation length, provided it lies within the range $10\,\mathrm{kpc} < \lambda_B < 1\,\mathrm{Mpc}$. For correlation lengths outside this range, γ-ray observations can provide upper or lower bound on λ_B. The latter of the two methods holds great promise in the near future for providing a measurement/constraint using measurements from present/next-generation γ-ray-telescopes. Measurement of the IGMF correlation length will provide an important constraint on its origin. In particular, it will enable to distinguish between an IGMF of galactic wind origin from an IGMF of cosmological origin. This work has been published in Astronomy and Astrophysics[33].

The Spectra of the Brightest Flaring Objects Observed by Fermi *F. Aharonian, C. Romoli, A. M. Taylor*

We are presently studying the flaring spectra of the brightest objects in the GeV domain observed by Fermi. The shape and evolution of these spectra whose origin, on dimensional grounds, must be from a compact region, hold important clues about the particle acceleration process at play. In particular, the shape of the cutoff at the high energy end of the spectrum, which is thought to be formed through either inverse Compton or synchrotron emission processes, is expected to reflect the underlying cutoff in the parent electron population. For two of the brightest objects we observe, namely the Vela pulsar and the blazar 3C 454.3, the "stretched exponential" shape of the cutoff is well measured, allowing the degree of stretching to be determined with reasonable accuracy. This work is in preparation for publication.

Ensemble Fluctuations of the Flux and Nuclear Composition of Ultra-High Energy Cosmic Ray Nuclei *M. Ahlers, L. A. Anchordoqui, A. M. Taylor*

The flux and nuclear composition of ultra-high energy cosmic rays depend on the cosmic distribution of their sources. Data from cosmic ray observatories are yet inconclusive about their exact location or distribution, but provide a measure for the average local density of these emitters. Due to the discreteness of the emitters the flux and nuclear composition is expected to show ensemble fluctuations on top of the statistical variations, i.e. "cosmic variance". This ef-

fect is strongest for the most energetic cosmic rays due to the limited propagation distance in the cosmic radiation background and is hence a local phenomenon. For the statistical analysis of cosmic ray emission models it is important to quantify the possible level of this variance. In this work we present a completely analytic method that describes the variation of the flux and nuclear composition with respect to the local source density. We also highlight that proposed future space-based observatories with exposures of O(10^6 km^2 sr yr) will attain sensitivity to observe these spectral fluctuations in the cosmic ray energy spectrum at Earth relative to the overall power-law fit. The work is published in Physical Review D[6].

The need for hard spectra sources of nearby heavy cosmic rays *A. M. Taylor*

Using recent Auger energy spectrum and composition analysis results, an investigation is carried out into the requirements placed on the UHECR sources. The spatial distribution of these sources is investigated along with the energy distribution of UHECR they output. These investigations reveal the need for local UHECR sources which output a hard spectrum of intermediate/heavy UHECR. These results demand that local (< 80 Mpc) UHECR sources exist, placing exciting and difficult requirements on the local extragalactic candidate sources. None negligible (> 0.01 nG) extragalactic magnetic fields are noted to further strengthen these results. This work was published as proceedings EDP Sciences[68].

UHECR Composition Models *A. M. Taylor*

In light of the increasingly heavy UHECR composition at the highest energies, as observed by the Pierre Auger Observatory, the implications of these results on the actual source composition and spectra are investigated. Depending on the maximum energy of the particles accelerated, sources producing hard spectra and/or containing a considerably enhanced heavy component appear a necessary requirement. Consideration is made of two archetypal models compatible with these results. The secondary signatures expected, following the propagation of the nuclear species from source to Earth, are determined for these two example cases. Finally, the effect introduced by the presence of nG extragalactic magnetic fields in collaboration with a large (80 Mpc) distance to the nearest source is discussed. This work is to be published in Astroparticle Physics.

Constraints on the Source of Ultra-High Energy Cosmic Rays using Anisotropy vs Chemical Composition *R. Liu, A. M. Taylor, M. Lemoine, X. Wang, E. Waxman*

The joint analysis of anisotropy signals and chemical composition of ultra-high energy cosmic rays offers strong potential for shedding light on the sources of these particles. Following up on an earlier idea, we investigate the anisotropies produced by protons of energy $> E/Z$, assuming that anisotropies at energy $> E$ have been produced by nuclei of charge Z, which share the same magnetic rigidity. We calculate the number of secondary protons produced through photodisintegration of the primary heavy nuclei. Making the extreme assumption that the source does not inject any proton, we find that the source(s) responsible for anisotropies such as reported by the Pierre Auger Observatory should lie closer than 20-30, 80-100 and 180-200 Mpc if the anisotropy signal is mainly composed of oxygen, silicon and iron nuclei respectively. A violation of this constraint would otherwise result in the secondary protons forming a more significant anisotropy signal at lower energies. Even if the source were located closer than this distance, it would require an extraordinary metallicity $> 120, 1600, 1100$ times solar metallicity in the acceleration zone of the source, for oxygen, silicon and iron respectively, to ensure that the concomitantly injected protons do not produce a more significant low energy anisotropy. This offers interesting prospects for constraining the nature and the source of ultra-high energy cosmic rays with the increase in statistics expected from next generation detectors. This work is published in Astrophysical Journal[25].

Detection Potential of the KM3NeT Detector for High-Energy Neutrinos from the Fermi Bubbles *S. Adrian-Martinez and A. M. Taylor et al., for the Km3NeT collaboration*

A recent analysis of the Fermi Large Area Telescope data provided evidence for a high-intensity emission of high-energy gamma rays with a E^{-2} spectrum from two large areas, spanning 50 degrees above and below the Galactic centre (the "Fermi bubbles"). A hadronic mechanism was proposed for this gamma-ray emission making the Fermi bubbles promising source candidates of high-energy neutrino emission. In this work Monte Carlo simulations regarding the detectability of high-energy neutrinos from the Fermi bubbles with the future multi-km^3 neutrino telescope KM3NeT in the Mediterranean Sea are presented. Under the hypothesis that the gamma-ray emission is completely due to hadronic processes, the results indicate that neutrinos from the bubbles could be discovered in about one year of operation, for a neutrino spectrum with a cutoff at 100 TeV and a detector with about 6 km^3 of instrumented volume. The effect of a possible lower cutoff is also considered. This work was published in Astroparticle Physics[24]

1.1.5 High energy emission from binary systems.

Maria Chernyakova - DCU and DIAS

PSR B1259-63 *M. Chernyakova, A. Neronov, D. Malyshev, Yu. Babik, et al.*

In 2013 we have finished data processing from our extensive multi-wavelength observations of the 2010-2011 periastron passage of the gamma-ray loud binary system PSR B1259-63. High resolution interferometric radio observations establish extended radio emission trailing the position of the pulsar. Observations with the Fermi Gamma-ray Space Telescope reveal GeV gamma-ray flaring activity of the system, reaching the spin-down luminosity of the pulsar, around 30 days after periastron. There are no clear signatures of variability at radio, X-ray and TeV energies at the time of the GeV flare. Variability around periastron in the H_α emission line, can be interpreted as the gravitational interaction between the pulsar and the circumstellar disk. The equivalent width of the H_α grows from a few days before periastron until a few days later, and decreases again between 18 and 46 days after periastron. In near infrared we observe the similar decrease of the equivalent width of Br_γ line between the 40th and 117th day after the periastron. For the idealized disk, the variability of the H_α line represents the variability of the mass and size of the disk. We discuss possible physical relations between the state of the disk and GeV emission under assumption that GeV flare is directly related to the decrease of the disk size. The paper about all this findings is accepted by MNRAS.

LS 5039 *A. Neronov, D. Malyshev, M. Chernyakova*

LS 5039 is another high-mass X-ray binary for which the spectral energy distribution is dominated by emission in high-energy gamma-ray band. We investigate orbital modulation of the flux from LS 5039 in the 0.1-100 GeV energy band, with the aim to understand the origin of the high-energy gamma-ray emission. We perform orbital phase resolved spectral analysis based on the data of five year long monitoring of the system with Fermi telescope and supplement the high-energy gamma-ray data with the multi-wavelength data, from radio to very-high-energy gamma-rays. The orbital phase resolved spectra reveal the presence of two spectral components. One component is modulated in time, while the other component, dominating the flux above several GeV is (almost) not variable. The variability pattern of the modulated component dramatically changes below and above 100 MeV energy. This change is readily explained as being due to the orbital-phase dependent shift of the high-energy cut-off in the spectrum of the modulated component. We interpret this modulated component as the synchrotron emission from the interior of the binary system and the shift in high-energy cut-off as being due to the orbital modulation of the magnetic field strength.

We show that the non-variable component of the gamma-ray spectrum could be self-consistently explained as the high-energy IC counterpart of extended radio synchrotron emission originating from a region 10^3 times larger than the binary system size.

Cyg X-1 *Malyshev, Denys; Zdziarski, Andrzej A.; Chernyakova, Maria*

We have also searched for the GeV emission from the classical X-ray binary Cyg X-1. We have obtained measurements and upper limits on the emission of Cyg X-1 in the photon energy range of 0.03-300 GeV based on observations by Fermi. In the hard state, we detect a weak steady emission in the 0.1-10 GeV range with a power-law photon index of $\Gamma = 2.6 \pm 0.2$ at a 4σ statistical significance. This measurement, even if considered to be an upper limit, strongly constrains Compton emission of the steady radio jet, present in that state. The number of relativistic electrons in the jet has to be low enough for the spectral components due to Compton upscattering of the stellar blackbody and synchrotron radiation to be within the observed fluxes. If optically thin synchrotron emission of the jet is to account for the MeV tail, as implied by the recently claimed strong polarization in that energy range, the magnetic field in the jet has to be much above equipartition. The GeV-range measurements also strongly constrain models of hot accretion flows, most likely present in the hard state, in which γ-rays are produced from decay of neutral pions produced in collisions of energetic ions in an inner part of the flow. In the soft state, the obtained upper limits constrain electron acceleration in a non-thermal corona, most likely present around a blackbody accretion disc. The coronal emission above 30 MeV has to be rather weak, which is most readily explained by absorption of γ-rays in pair-producing photon-photon collisions. Then, the size of the bulk of the corona is less than a few tens of the gravitational radii. This work is published in MNRAS[29]

1.2 General Theory

1.2.1 The problem of small angular scale structure in the cosmic ray anisotropy data

L. O'C. Drury

A puzzling feature of the cosmic ray arrival direction distribution on the sky at TeV energies (which is now rather well determined as the background in a number of gamma-ray and neutrino experiments) is that there is clear evidence of structure on quite small angular scales (a few to twenty degrees on the sky). While it is easy to produce low order dipole, quadruple etc anisotropies in most transport theories, the small scale structure (first seen by the Milagro experiment in its report of two "hot spots" in the arrival distribution) is much harder to explain in terms of transport processes. The amplitude of the signal is quite low at about 10^{-4} but it is statistically significant and the observations by several independent groups agree and must be taken seriously.

While there has been some speculation linking the small scale structure to heliospheric processes, this has generally been dismissed on the basis that the energy scales are wrong and that heliospheric effects (such as solar modulation) are negligible above about a GeV. However the amplitude of the signal is only at the level of 10^{-4} and thus if all particles coming from a given direction have their energy shifted slightly by a retarding or accelerating electric field of order 100MV (which is easily generated in the heliosphere by simple electromagnetic induction) it is possible to create a signal at the level of 10^{-4} in the flux of TeV particles.

This process requires incoming particles that travel in an essentially rectilinear way through the heliosphere while probing the local electric fields which naturally explains why the effect is seen at TeV energies. It also naturally explains the low observed amplitude without any fine-tuning. A further implication of the model is that negative as well as positive signals should occur (i.e. there should be cold spots and not just hot spots)

as appears to be observed.

This idea was presented at the 2013 International Cosmic Ray Conference[77].

1.2.2 Magnetic field generation in shock precursors

Turlough Downes and Luke Drury

Following on from work in 2012, the toy model developed by Drury & Downes (2012) has been further explored from the point of view of the dimensionality of the system, the angle of the initial magnetic field to the shock normal, and through incorporating a simplified radiative cooling treatment in the simulations. The dimensionality of the system considered, while clearly influencing the nature of the turbulence generated in the precursor of the blastwave, does not significantly influence the magnetic field amplification achieved. The angle of the initial magnetic field to the shock normal is found to be an important factor in determining the field amplification with a parallel shock leading to amplification roughly a factor of three less than that for a perpendicular shock. The incorporation of radiative cooling might, at first glance, appear to be likely to make a significant difference to the field amplification since it gives rise to more severe compressions in the gas in the precursor and therefore more differential acceleration. However, in spite of a detailed parameter space survey radiative cooling was found to have little impact.

The nature of the turbulence in the 2D and 3D simulations of this model was further investigated with Aoife Curran, a final year TCD project student. She calculated a series of time-averaged power spectra for different regions of the precursor, and for each of the sets of simulations described above. The 3D simulations lead, as expected, to a cascade of energy from large to small lengthscales while 2D simulations lead to the reverse. The cascading to small lengthscales leads to kinetic energies at these lengthscales which are less than that in the local magnetic field, resulting in lower amplification in 3D.

1.2.3 Analytic Solution for Self-regulated Collective Escape of Cosmic Rays from Their Acceleration Sites

M. A. Malkov, P. H. Diamond, R. Z. Sagdeev, F.A. Aharonian, Moskalenko I.A.

Supernova remnants (SNRs), as the major contributors to the galactic cosmic rays (CRs), are believed to maintain an average CR spectrum by diffusive shock acceleration regardless of the way they release CRs into the interstellar medium (ISM). However, the interaction of the CRs with nearby gas clouds crucially depends on the release mechanism. We call into question two aspects of a popular paradigm of the CR injection into the ISM, according to which they passively and isotropically diffuse in the prescribed magnetic fluctuations as test particles. First, we treat the escaping CR and the Alfvén waves excited by them on an equal footing. Second, we adopt field-aligned CR escape outside the source, where the waves become weak. An exact analytic self-similar solution for a CR "cloud" released by a dimmed accelerator strongly deviates from the test-particle result. The normalized CR partial pressure may be approximated as

$$P(p,z,t) = 2[|z|^{5/3} + z_{dif}^{5/3}(p,t)]^{-3/5} \exp[-z^2/4D_{ISM}(p)t],$$

where p is the momentum of CR particle, and z is directed along the field. The core of the cloud expands as $z_{dif} \propto \sqrt{D_{NL}(p)\,t}$ and decays in time as $P \propto 2z_{dif}^{-1}(t)$. The diffusion coefficient D_{NL} is strongly suppressed compared to its background ISM value D_{ISM}: $D_{NL} \approx D_{ISM}\exp(-\Pi) \ll D_{ISM}$ for sufficiently high field-line-integrated CR partial pressure Π,. When $\Pi \gg 1$, the CRs drive Alfvén waves efficiently enough to build a transport barrier ($P \approx 2/|z|$—"pedestal") that strongly reduces the leakage. The solution has a spectral break at $p = p_{br}$, where p_{br} satisfies the equation $D_{NL}(p_{br}) \simeq z^2/t$. This work is published in the Astrophysical Journal[28].

1.3 Star Formation

1.3.1 Characterization of Infrared Dark Clouds: NH_3 Observations of an Absorption-contrast Selected IRDC Sample

R.-A. Chira (Heidelberg), H. Beuther (Heidelberg), H. Linz (Heidelberg), F. Schuller (ESO), C. M. Walmsley, K. M. Menten (Bonn), and L. Bronfman (Santiago)

Despite increasing research in massive star formation, little is known about its earliest stages. Infrared Dark Clouds (IRDCs) are cold, dense and massive enough to harbour the sites of future high-mass star formation. But up to now, mainly small samples have been observed and analysed. To understand the physical conditions during the early stages of high-mass star formation, it is necessary to learn more about the physical conditions and stability in relatively unevolved IRDCs. Thus, for characterising IRDCs studies of large samples are needed. Walmsley et al. have investigated a complete sample of 218 northern hemisphere high-contrast IRDCs using the ammonia (1,1)- and (2,2)-inversion transitions. They detected ammonia (1,1)-inversion transition lines in 109 of their IRDC candidates. Using the data they were able to study the physical conditions within the star-forming regions statistically. They compared them with the conditions in more evolved regions that have been observed in the same fashion as their sample sources. Their results show that IRDCs have, on average, rotation temperatures of 15 K, are turbulent (with line width FWHMs around 2 kms^{-1}), have ammonia column densities on the order of 10^{14} cm^{-2} and molecular hydrogen column densities on the order of 10^{22} cm^{-2}. Their virial masses are between 100 and a few 1000 solar masses. The comparison of bulk kinetic and potential energies indicate that the sources are close to virial equilibrium. IRDCs are on average cooler and less turbulent than a comparison sample of high-mass protostellar objects, and have lower ammonia column densities. Virial parameters indicate that the majority of IRDCs are currently stable, but are expected to collapse in the future. This work was published in Astronomy and Astrophysics [8].

1.3.2 X-Shooter spectroscopy of young stellar objects: Impact of chromospheric emission on accretion rate estimates

C.F. Manara (ESO), L. Testi (ESO), E. Rigliaco (Arizona), J.M. Alcala (Naples), A. Natta, B. Stelzer (Palermo), K. Biazzo (Naples), E. Covino (Naples), S. Covino (Merate), G. Cupani (Trieste), V. D'Elia (Rome), S. Randich (Arcetri)

The lack of knowledge of photospheric parameters and the level of chromospheric activity in young low-mass pre-main sequence stars introduces uncertainties when measuring mass accretion rates in accreting (Class II) young stellar objects. A detailed investigation of the effect of chromospheric emission on the estimates of mass accretion rates in young low-mass stars is still missing. This can be undertaken using samples of young diskless (Class III) K and M-type stars. With these ideas in mind, Natta and her collaborators have measured the chromospheric activity of Class III pre-main sequence stars to determine its effect on the estimates of the accretion luminosity (L_{acc}) and mass accretion rate ($\dot{M}_{acc}$) in young stellar objects with disks. Using VLT/X-shooter spectra, they have analyzed a sample of 24 non-accreting young stellar objects of spectral type between K5 and M9.5. They identified the main emission lines normally used as tracers of accretion in Class II objects, and they determined their fluxes in order to estimate the contribution of the chromospheric activity to the line luminosity. They have used the relationships between line luminosity and accretion luminosity derived in the literature for Class to evaluate the impact of chromospheric activity on the accretion rate measurements. They find that typical chromospheric activity would bias the derived accretion luminosity by $L_{acc,noise} < 10^{-3}\,L_{sun}$, with a strong dependence on the T_{eff} of the objects. The noise on $\dot{M}_{acc}$ depends on stellar mass and age, and the typical values of log $\dot{M}_{acc,noise}$ range between -9.2 to -11.6 M_{sun}/yr. In summary, values of $L_{acc} \leq 10^{-3}\,L_{sun}$ obtained in accreting low-mass pre main sequence stars

through line luminosity should be treated with caution because the line emission may be dominated by the contribution of chromospheric activity. These results have been published in Astronomy and Astrophysics [31].

1.3.3 An Empirical Correction for Activity Effects on the Temperatures, Radii, and Estimated Masses of Low-Mass Stars and Brown Dwarfs

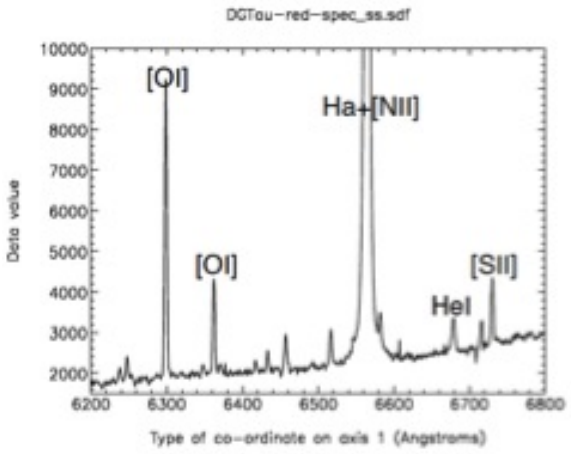
K. Stassun (Vanderbilt University), K.M. Kratter (Harvard), A. Scholz, T.J. Dupuy (Harvard)

Scholz and his collaborators have presented empirical relations for determining the amount by which the effective temperatures and radii—and therefore the estimated masses—of low-mass stars and brown dwarfs are altered due to chromospheric activity. They base their relations on a large set of low-mass stars in the field with Hα activity measurements, and on a set of low-mass eclipsing binaries with X-ray activity measurements from which they indirectly infer the Hα activity. Both samples yield consistent relations linking the amount by which an active object's temperature is suppressed, and its radius inflated, to the strength of its Hα emission. These relations are found to approximately preserve bolometric luminosity. They have applied these relations to the peculiar brown-dwarf eclipsing binary 2M0535-05, in which the active, higher-mass brown dwarf has a cooler temperature than its inactive, lower-mass companion. The relations correctly reproduce the observed temperatures and radii of 2M0535-05 after accounting for the Hα emission; 2M0535-05 would be in precise agreement with theoretical isochrones were it inactive. The relations that they present are applicable to brown dwarfs and low-mass stars with masses below 0.8 M_{sun} and for which the activity, as measured by the fractional Hα luminosity, is in the range -4.6 < log $L_{H\alpha}/L_{bol}$ < -3.3. They expect these relations to be most useful for correcting radius and mass estimates of low-mass stars and brown dwarfs over their active lifetimes (few Gyr) and when the ages or distances (and therefore luminosities) are unknown. Accurate estimates of stellar masses and radii are especially important in the context of searches for transiting exoplanets, which rely upon the assumed stellar radius/density to infer the planet radius/density. They have also considered the implications of this work for improved determinations of young cluster initial mass functions. These results were presented at the January American Astronomical Society (AAS) Meeting at Long Beach, California.

1.3.4 Long-Term Monitoring of Accretion and Outflows in Young Stellar Objects: Searching for the Temporal Connection

A. Scholz, T.P. Ray, C. Davis (Liverpool), D. Froebrich (Kent), M.D. Smith (Kent)

The combined accretion and outflow process for young stars is a violent and episodic affair: Young Stellar Objects (YSOs) usually exhibit photometric variability, while the Herbig-Haro (HH) jets they drive often comprise chains of knots that probably result from variable mass loss rates and jets speeds. Scholz, Ray et al. have begun a long-term (several year) program on the robotic Liverpool Telescope (LT) on La Palma in the Canary Islands to monitor variability in young stars and, specifically, to probe the temporal link between infall and outflow using (primarily) Hα and forbidden [OI] emission lines as proxies. Their intention is to establish how rapidly a change in accretion translates into a variation in the outflow mass loss rate and in what manner as this can reveal details of the outflow mechanism. Test observations carried out early in 2013 clearly demonstrate that the LT is very well suited to this long-term monitoring campaign.



Liverpool Telescope FRODOSpec spectrum of a outflow source.

1.3.5 Non-thermal Radio Emission from Young Stellar Object Outflows

R. Ainsworth, T.P. Ray, A. Taylor, A. Scaife (Southampton) and D. Green (Cambridge)

Most protostellar outflows have been found to produce thermal radio emission consistent with bremsstrahlung radiation from 10^4 K gas (i.e. the gas that also produces the optical/near-infrared emission by which these jets are seen). Hints however of non-thermal emission has been found in a few cases and so it was decided to image a small number of young stars at much lower radio frequencies (around 300 and 600 MHz) than normally used. These observations were carried out by R. Ainsworth (DIAS PhD student) at the Giant Metre Wave Telescope (GMRT) near Pune, India. In all cases long wavelength emission was detected, and its radio spectrum appears inverted as expected from non-thermal radiation. The origin of this emission is currently unclear but could come from diffusive shock acceleration of electrons in the outflow. Surprisingly all targets are low mass stars, suggesting low mass young stars may be a source of low energy cosmic rays.

1.3.6 Very Large Array Observations of DG Tau's Radio Jet: A Highly Collimated Thermal Outflow

C. Lynch (Iowa), R. Mutel (Iowa), M. Güdel (Vienna), T. P. Ray, S.L. Skinner (Colorado), P.C. Schneider (Hamburg), and K.G. Gayley (Iowa)

The active young protostar DG Tau has an extended jet that has been well studied at radio, optical, and X-ray wavelengths. This group have reported sensitive new Very Large Array (VLA) full-polarization observations of the core and jet between 5 GHz and 8 GHz. Their high angular resolution observation at 8 GHz clearly shows an unpolarized inner jet with a size of 42 au (0.″35) extending along a position angle similar to the optical-X ray outer jet. Using their nearly coeval 2012 VLA observations, we find a spectral index $\alpha = +0.46 \pm 0.05$, which combined with the lack of polarization, is consistent with bremsstrahlung (free-free) emission, with no evidence for a non-thermal coronal component. By identifying the end of the radio jet as the optical depth unity surface, and calculating the resulting emission measure, they find that their radio results are in agreement with previous optical line studies of electron density and consequent mass-loss rate. They also detect a weak radio knot at 5 GHz located 7″ from the base of the jet, coincident with the inner radio knot detected by Rodríguez et al. in 2009 but at lower surface brightness. They interpret this as due to expansion of post-shock ionized gas in the three years between observations. These results have been published in the Astrophysical Journal [26].

1.3.7 New brown dwarf discs in Upper Scorpius observed with WISE

P. Dawson, A. Scholz, T.P. Ray, K.A. Marsh (Cardiff), K. Wood (St. Andrews), A. Natta, D. Padgett (NASA Goddard), and M.E. Ressler (JPL)

This group have presented a census of the disc population for UKIDSS selected brown dwarfs in the 5-10 Myr old Upper Scorpius OB asso-

ciation. For 116 objects originally identified in UKIDSS (United Kingdom Infrared Digital Sky Survey), the majority of them not studied in previous publications, they obtain photometry from the Wide-Field Infrared Survey Explorer (WISE) data base. The resulting colour-magnitude and colour-colour plots clearly show two separate populations of objects, interpreted as brown dwarfs with discs (class II) and without discs (class III). They have identified 27 class II brown dwarfs, 14 of them not previously known. This disc fraction (27 out of 116, or 23%) among brown dwarfs was found to be similar to results for K/M stars in Upper Scorpius, suggesting that the lifetimes of discs are independent of the mass of the central object for low-mass stars and brown dwarfs. 5 out of 27 discs (19%) lack excess at 3.4 and 4.6 μm and are potential transition discs (i.e. are in transition from class II to class III). The transition disc fraction is comparable to low-mass stars. They estimate that the time-scale for a typical transition from class II to class III is less than 0.4 Myr for brown dwarfs. These results suggest that the evolution of brown dwarf discs mirrors the behaviour of discs around low-mass stars, with disc lifetimes of the order of 5-10 Myr and a disc clearing time-scale significantly shorter than 1 Myr. This work has been published in Monthly Notices of the Royal Astronomical Society [26].

1.3.8 Protoplanetary Disk Masses from Stars to Brown Dwarfs

S. Mohanty (Imperial), J. Greaves (St. Andrews), D. Mortlock (Imperial), I. Pascucci (Arizona), A. Scholz, M. Thompson (Hertfordshire), D. Apai (Arizona), G. Lodato (Milan), and D. Looper (Hawaii)

This group have presented SCUBA-2 850μm observations for 7 very low mass stars (VLMS) and brown dwarfs (BDs): 3 in Taurus, 4 in the TW Hydra Association (TWA), and all classical T Tauri (cTT) analogs. They detect 2 of the 3 Taurus disks, but none of the TWA ones. Their 3 sigma limits correspond to a dust mass of 1.2 Earth masses in Taurus and a mere 0.2 Earth masses in the TWA (3–10 times deeper than previous work). They have combined their data with other sub-mm/mm surveys of Taurus, rho Oph and the TWA to investigate trends in disk mass and grain growth during the cTT phase. They find: (1) The minimum disk outer radius required to explain the upper envelope of sub-mm/mm fluxes is 100 au for intermediate-mass stars, solar-types and VLMS, and 20 au for BDs. (2) While the upper envelope of disk masses increases with central object mass from BDs to VLMS to solar-types, no increase is seen from solar-type to intermediate-mass stars. They propose this is due to enhanced photoevaporation around intermediate masses. (3) Many disks around Taurus and rho Oph intermediate-mass and solar-type stars evince an opacity index β of 0–1, indicating large grains. Of the only four VLMS/BDs in these regions with multi-wavelength data, three are consistent with large grains, though optically thick disks are not ruled out. (4) For the TWA VLMS (TWA 30A,B), combining their fluxes with accretion rates and ages suggests substantial grain growth by 10 Myr. The degree of grain growth in the TWA BDs (2M1207A, SSPM1102) remains largely unknown. (5) A Bayesian analysis shows that mean ($\log[M_{disk}/M_{star}]$) = -2.4, roughly constant all the way from intermediate-mass stars to VLMS/BDs, and (6) the disk mass in close solar-type Taurus binaries is significantly lower than in singles (by a factor of 10), while that in wide solar-type Taurus binaries is closer to that in singles (lower by a factor of 3). (7) They discuss the implications for planet formation, and for the dependence of accretion rate on mass of the central object. This work has been published in Astrophysical Journal [32].

1.3.9 A systematic survey for eruptive young stellar objects using mid-infrared photometry

A. Scholz, D. Froebrich (Kent) and K. Wood (St. Andrews)

Accretion in young stellar objects (YSOs) is at least partially episodic, i.e. periods with high accretion rates, i.e. bursts, are interspersed by quiescent phases. These bursts manifest themselves as eruptive variability. Scholz et al. have

presented a systematic survey for eruptive YSOs aiming to constrain the frequency of accretion bursts. They have compared mid-infrared photometry from Spitzer and WISE separated by about 5 years for two samples of YSOs, in nearby star-forming regions and in the Galactic plane, each comprising about 4000 young sources. All objects for which the brightness at 3.6 and 4.5 μm is increased by at least 1 mag between the two epochs may be eruptive variables and burst candidates. For these objects, they have carried out follow-up observations in the near-infrared. They have discovered two new eruptive variables in the Galactic Plane that could be FU Ori-type objects, with K-band amplitudes of more than 1.5 mag. One object known to undergo an accretion burst, V2492 Cyg, is recovered by their search as well. In addition, the young star ISO-Oph-50, previously suspected to be an eruptive object, is found to be better explained by a disc with varying circumstellar obscuration. In total, the number of burst events in a sample of 4000 YSOs is 1-4. Assuming that all YSOs undergo episodic accretion, this constraint can be used to show that phases of strong accretion ($>10^{-6}\,M_{sun}\,yr^{-1}$) occur in intervals of about 10^4 years, most likely between 5000 and 50,000 years. This is consistent with the dynamical time-scales for outflows, but not with the separations of emission knots in outflows, indicating that episodic accretion could either trigger or stop collimated large-scale outflow. These results have been published in Monthly Notices of the Royal Astronomical Society [41].

1.3.10 Water in star-forming regions with Herschel (WISH): A survey of low-J H_2O line profiles

F. van der Tak (SRON), L. Chavarria (Bordeaux), F. Herpin(Bordeaux), F. Wyrowski (Bonn), M. Walmsley, E. van Dishoeck (Leiden), and the WISH Coordinating Team

To understand the origin of water line emission and absorption during high-mass star formation, this group have decomposed high-resolution Herschel-HIFI line spectra toward 19 high-mass star-forming regions into three distinct physical components. Protostellar envelopes are usually seen as narrow absorptions or emissions in the H_2O 1113 and 1669 GHz ground-state lines, the H_2O 987 GHz excited-state line, and the $H_2{}^{18}O$ 1102 GHz ground-state line. Broader features due to outflows are usually seen in absorption in the H_2O 1113 and 1669 GHz lines, in 987 GHz emission, and not seen in $H_2{}^{18}O$, indicating a low column density and a high excitation temperature. The H_2O 1113 and 1669 GHz spectra show narrow absorptions by foreground clouds along the line of sight, which have a low column density and a low excitation temperature, although their H_2O ortho/para ratios are close to 3. The intensities of the H_2O 1113 and 1669 GHz lines do not show significant trends with luminosity, mass, or age. In contrast, the 987 GHz line flux increases with luminosity and the $H_2{}^{18}O$ line flux decreases with mass. Furthermore, appearance of the envelope in absorption in the 987 GHz and $H_2{}^{18}O$ lines seems to be a sign of an early evolutionary stage. They conclude that the ground state transitions of H_2O trace the outer parts of the envelopes, so that the effects of star formation are mostly noticeable in the outflow wings. These lines are heavily affected by absorption, so that line ratios of H_2O involving the ground states must be treated with caution. The average H_2O abundance in high-mass protostellar envelopes does not change much with time. The 987 GHz line appears to be a good tracer of the mean weighted dust temperature of the source, which may explain why it is readily seen in distant galaxies. This work has been published by Astronomy and Astrophysics [47].

1.3.11 High-resolution ammonia mapping of the protostellar core Cha-MMS1

M. Väisälä (Helsinki), J. Harju (Turku), M. Mantere (Helsinki), O. Miettinen (Helsinki), and M. Walmsley

This group have mapped the nearby protostellar core Cha-MMS1 in the NH_3 (1, 1) line and the 1.2 cm continuum using the Australia Telescope Compact Array, ATCA. In addition, observations from the Spitzer Space Telescope and Herschel Space Observatory were used to help the inter-

pretation. An elongated condensation with a maximum length of 9000 au is seen in ammonia. The condensation has a clear velocity gradient directed perpendicularly to the axis of elongation. The gradient can be interpreted as rotation around this axis. They suggest that the observed ammonia structure delineates a rotating envelope and dense gas entrained by a very young protostellar outflow. This work has been published in IAU Symposium 292, Molecular Gas, Dust and Star Formation in Galaxies.

1.3.12 Explaining millimetre-sized particles in brown dwarf disks

P. Pinilla (Heidelberg), T. Birnstiel (Harvard), M. Benisty (Grenoble), L. Ricci (Caltech), A. Natta, C.P. Dullemond (Heidelberg), C. Dominik (Amsterdam), and L. Testi (ESO)

Planets have been detected around a variety of stars, including low-mass objects, such as brown dwarfs. However, such extreme cases are challenging for planet formation models. Recent submillimetre observations of disks around brown dwarf measured low spectral indices of the continuum emission that suggest that dust grains grow to mm-sizes even in these very low mass environments. To understand the first steps of planet formation in scaled-down versions of T-Tauri disks, this group have investigated the physical conditions that can theoretically explain the growth from interstellar dust to millimetre-sized grains in disks around brown dwarf. They have modelled the evolution of dust particles under conditions of low-mass disks around brown dwarfs. They used coagulation, fragmentation and disk-structure models to simulate the evolution of dust, with zero and non-zero radial drift. For the non-zero radial drift, they considered strong inhomogenities in the gas surface density profile that mimic long-lived pressure bumps in the disk. They studied different scenarios that could lead to an agreement between theoretical models and the spectral slope found by millimetre observations. They find that fragmentation is less likely and rapid inward drift is more significant for particles in brown dwarf disks than in T-Tauri disks. They present different scenarios that can nevertheless explain millimetre-sized grains. This work has been published in Astronomy and Astrophysics [36].

1.3.13 Physical properties of the jet from DG Tauri on sub-arcsecond scales with HST/STIS

L. Maurri (Arcetri), F. Bacciotti (Arcetri), L. Podio (Grenoble), J. Eislöffel (Tautenburg), T. P. Ray, R. Mundt (Heidelberg), U. Locatelli (Rome), and D. Coffey (UCD, Dublin)

Stellar jets are believed to play a key role in star formation, but the question of how they originate is still under debate. This group derived the physical properties at the base of the jet from DG Tau along and across the flow, and as a function of velocity. They analyze seven optical spectra of the DG Tau jet, taken with the Hubble Space Telescope Imaging Spectrograph. The spectra were obtained by placing a long-slit parallel to the jet axis, and stepping it across the jet width. The resulting position-velocity diagrams, in optical forbidden emission lines, allowed access to plasma conditions via calculation of emission line ratios. In this way, they produced a 3-D map (2-D in space and 1-D in velocity) of the jet's physical parameters i.e. electron density n_e, hydrogen ionization fraction x_e, and total hydrogen density n_H. They find at the base of the jet a high electron density, $n_e \sim 10^5$, and a very low ionization, $x_e \sim 0.02 - 0.05$, which combine to give a total density up to $n_H \sim 3\text{x}10^6$. Furthermore, a spatial coincidence is revealed between sharp gradients in the excitation parameters and supersonic velocity jumps. This strongly suggests that the emission is caused by shock excitation. The derived global properties of the DG Tau jet are demonstrated to be consistent with magneto-centrifugal theory. However, non-stationary modeling is required in order to explain all of the features revealed at high resolution. This work has been accepted by Astronomy and Astrophysics.

1.3.14 Near-Infrared spectroscopy of young brown dwarfs

P. Dawson, A. Scholz, T.P. Ray, D.E. Peterson (CfA, Harvard), and D. Rodgers-Lee

Spectroscopic follow-up is a pre-requisite for studies on the formation and early evolution of brown dwarfs. This group have obtained NASA IRTF/SpeX near-infrared spectroscopy of 30 candidate members of the young Upper Scorpius Association (UpSco), selected from their previous survey work. All 24 high confidence members are confirmed as young very low mass objects with spectral types from M5 to L1, 15-20 of them are likely brown dwarfs with masses between 0.01 to 0.08 solar masses. This high yield confirms that brown dwarfs in UpSco can be identified from photometry and proper motions alone, with negligible contamination from field objects. They demonstrate that some very low mass Class II objects exhibit radically different spectra, with strong excess emission increasing towards longer wavelengths and partially filled in features in the Z and Y band. Thus, they caution against the uncritical use of near infrared spectral types for objects with discs. Furthermore, they show that hints of the same characteristics can be seen in most Class II and even a significant fraction of Class III objects (approximately 30%), indicating that some ′disc-less′ objects are still surrounded by traces of circum-(sub)-stellar dust. This work has been submitted to Monthly Notices of the Royal Astronomical Society.

1.3.15 Temperaments of young stars: Rapid mass-accretion rate changes in T Tauri and Herbig Ae stars

G. Costigan, J. Vink (Armagh), A. Scholz, T.P. Ray, L. Testi (ESO)

Variability in emission lines is a characteristic feature in young stars and can be used as a tool to study the physics of the accretion process. This group conducted a study of Hα variability in 15 T Tauri and Herbig Ae stars (B2 -K7) over a wide range of time windows, from minutes, to hours, to days, and years. They have assessed the variability using line-width measurements and the time series of line profiles. All objects show gradual, slow profile changes on timescales of days. In addition, in three cases there is evidence for rapid variations in Hα with typical timescales of 10 min, which occurs in 10% of the total covered observing time. The mean accretion-rate changes, inferred from the line fluxes, are 0.01-0.09 dex for timescales of < 1 h, 0.1-0.4 dex for timescales of days, and 0.15-0.46 dex for timescales of years. This strongly suggests that accretion rate variability in young stars is dominated by timescales of days, in line with the upper limit found in Costigan et al. (2012). A plausible explanation for these gradual variations over days is an asymmetric accretion flow resulting in a rotational modulation of the accretion-related emission, although other interpretations are possible as well. In conjunction with their previous work, they find that the timescales and the extent of the variability is similar for objects ranging in mass from 0.1 to several solar masses. This indicates that a single mode of accretion is at work from T Tauri to Herbig Ae stars – across a wide range of stellar masses.

1.3.16 New observations of a "dust trap" around a young star with ALMA

Nienke van der Marel (Leiden), Ewine F. van Dishoeck (Leiden, Garching), Simon Bruderer (Garching), Til Birnstiel (CfA), Paola Pinilla (Heidelberg), Cornelis P. Dullemond (Heidelberg), Tim A. van Kempen (Leiden), Markus Schmalzl (Leiden), Joanna M. Brown (CfA), Gregory J. Herczeg (Beijing), Geoffrey S. Mathews (Leiden) and Vincent Geers

This group have reported the detection of a dust trap in the disk around the young star Oph-IRS 48 using observations from the new Atacama Large Millimeter/submillimeter Array (ALMA). The 0.44 mm wavelength continuum map shows high-contrast crescent-shaped emission on one side of the star originating from millimetre-sized grains, whereas both the mid-infrared image (micrometer-sized dust) and the gas traced by CO J=6-5 indicate ring-like emission centered on the star. The difference in distribution of big grains

versus small grains/gas suggests the action of a vortex-shaped dust trap triggered by a companion. Recent disk and dust evolution models have predicted the formation of dust traps, as an answer to the long-standing "meter-sized barrier" to dust growth and eventual planet formation. These models were applied here to predict the evolution of dust size inside the trap. For the conditions in this system, the dust trap is predicted to grow particles from millimeter to comet size. This work appeared in Science [46].

1.3.17 The SONYC survey: Towards a complete census of brown dwarfs in star forming regions

C. K. Mužić (ESO), A. Scholz, V.C. Geers, R. Jayawardhana (Toronto), M. Tamura (Toyko), P. Dawson and T. Ray

SONYC, short for "Substellar Objects in Nearby Young Clusters", is a survey program to provide a census of the substellar population in nearby star forming regions. The group have conducted deep optical and near-infrared photometry in five young regions (NGC1333, rho Ophiuchi, Chamaeleon-I, Upper Sco, and Lupus-3), combined with proper motions, and followed by extensive spectroscopic campaigns with Subaru and VLT, in which they have obtained more than 700 spectra of candidate low-mass objects. They have identified and characterized more than 60 new sub-stellar objects, among them a handful of objects with masses close to, or below the Deuterium burning limit. Through SONYC and surveys by other groups, the sub-stellar IMF is now well characterized down to 5 - 10 Jupiter masses, and they find that the ratio of the number of stars with respect to brown dwarfs lies between 2 and 6. A comprehensive survey of NGC 1333 reveals that, down to 5 Jupiter masses, free-floating objects with planetary masses are 20-50 times less numerous than stars, i.e. their total contribution to the mass budget of the clusters can be neglected [63].

1.3.18 Investigating Proper Motions in the 2M1207A Jet

E. Whelan (Tübigen/DIAS), T. Ray, F. Cameron (ESO), F. Bacciotti (Arcetri), P. Kavanagh (Tübingen)

The 24 Jupiter Mass brown dwarf (BD), 2MASSJ12073347-3932540 (2M1207A), was first discovered to be driving an outflow through the spectro-astrometric analysis of its [OI]6300 emission region. It is now known to drive a bipolar outflow with a position angle (PA) of 65 degrees. [SII] narrowband images obtained by the group revealed a series of knots along the PA of the outflow. The furthest knot from the BD was bow-shock shaped and these results confirmed for the first time that BD outflows could be well collimated i.e. are jets, and episodic. In order to conduct a proper motion study of the knots they obtained follow-up images in [SII] and Hα using FORS-2/VLT, in early 2013. The proper motion of the source is an important consideration as it is approximately along the same direction as the jet and likely has a similar magnitude. While no significant proper motion is detected in the [SII] knots there are morphological changes. It is possible that the velocity of the knots has slowed significantly with distance. From the comparison of the [SII] and Hα images, Hα seems to trace the shock fronts whereas [SII] the cooling zone behind the shock front. Future work includes simulating the jet to try to understand how the proper motion of the source affects the morphology of the jet and an analysis of the spectra of the knots.

1.3.19 Sub-arcsecond high-sensitivity measurements of the DG Tau jet with e-MERLIN

R. Ainsworth, T. Ray, A. Scaife (Southampton), J. Greaves (St. Andrews), and R. Beswick (Manchester)

The group have presented very high spatial resolution deep radio continuum observations at 5 GHz (6 cm) made with the new extended Multi-Element Radio Linked Interferometer Net-

work (e-MERLIN) of the young stars DG Tau A and B. Assuming it is launched very close (≈ 1 au) from the star, their results suggest that the DG Tau A outflow initially starts as a poorly focused wind and undergoes significant collimation farther along the jet (≈ 50 au). They derive jet parameters for DG Tau A and find an initial jet opening angle of 86°within 2 au of the source, a mass-loss rate of 1.5×10^{-8} solar masses per year for the ionized component of the jet, and the total ejection-to-accretion ratio to range from 0.06 to 0.3. These results are in line with predictions from magneto-hydrodynamic jet-launching theories and have been published in Monthly Notices of the Royal Astronomical Society [7].

1.3.20 Constraints on the radial distribution of the dust properties in the CQ Tauri protoplanetary disk

F. Trotta (Bologna), L. Testi (ESO), A. Natta, A. Isella (CalTech), and L. Ricci (CalTech)

Grain growth in protoplanetary disks is the first step towards the formation of the rocky cores of planets. Models predict that grains grow, migrate, and fragment in the disk and predict varying dust properties as a function of radius, age, and physical properties. High-angular resolution observations at more than one (sub-)mm wavelength are the essential tool for constraining grain growth and migration on the disk midplane. The group have developed a procedure to analyse self-consistently multi-wavelength (sub-)mm continuum interferometric observations of protoplanetary disks to constrain the radial distribution of dust properties. They have applied this technique to existing multi-frequency continuum mm observations of the disk around CQ Tau, an A8 pre-main sequence star with a well-studied disk. In CQ Tau, the best-fitting model has a radial dependence of the maximum grain size, which decreases from a few cm in the inner disk (≤ 40 au) to a few mm at 80 au. Nevertheless, the currently available dataset does not allow them to exclude the possibility of a uniform grain size distribution at a 3σ level. A paper on this topic has been published in Astronomy and Astrophysics [45].

1.3.21 The main sequence of three red supergiant clusters

D. Frobrich (Kent) and A. Scholz (DIAS/St. Andrews)

Massive clusters in our Galaxy are an ideal testbeds to investigate the properties and evolution of high-mass stars. They provide statistically significant samples of massive stars of uniform ages. To accurately determine the intrinsic physical properties of these stars, we need to establish the distances, ages and reddening of the clusters. One avenue to achieve this is the identification and characterization of the main-sequence (MS) members of red supergiant (RSG) rich clusters. The group have utilized publicly available data from the UKIDSS Galactic Plane Survey. They show that point spread function photometry in conjunction with standard photometric decontamination techniques allows them to identify the most likely MS members in the 10-20 Myr old clusters RSGC 1-3. They confirm the previous detection of the MS in RSGC 2 and provide the first MS detection in RSGC 1 and RSGC 3. There are in excess of 100 stars with more than 8 solar masses identified in each cluster. These MS members are concentrated towards the spectroscopically confirmed RSG stars. The group have utilized the J - K colours of the bright MS stars to determine the K-band extinction towards the clusters. The differential reddening is three times as large in the youngest cluster RSGC 1 as compared to the two older clusters RSGC 2 and RSGC 3. Spectroscopic follow-up of the cluster MS stars should lead to more precise distance and age estimates for these clusters as well as the determination of the stellar mass function in these high-mass environments. A paper has been published in Monthly Notices of the Royal Astronomical Society [10].

1.3.22 Angular momentum and disk evolution in very low mass systems

A. Scholz (DIAS/St. Andrews)

A. Scholz has recently reviewed observational results regarding the evolution of angular momentum and disks in brown dwarfs. The observations

clearly show that brown dwarfs beyond ages of 10 Myr are exclusively fast rotators and do not spin down with age. This suggests that rotational braking by magnetic winds becomes very inefficient or ceases to work in the sub-stellar regime. There is, however, some evidence for braking by disks during the first few Myrs in evolution, similar to stars. Brown dwarf disks turn out to be scaled down versions of circumstellar disks, with dust settling, grain growth, and in some cases cleared out inner regions. The global disk properties roughly scale with central object mass. The evolutionary timescales in sub-stellar disks are entirely consistent with what is found for stars, which may be challenging to understand. Given these findings, it is likely that brown dwarfs are able to form miniature planetary systems [66].

1.3.23 Accurate determination of accretion and photospheric parameters in Young Stellar Objects: the case of two candidate old disks in the Orion Nebula Cluster

C. F. Manara (ESO), G. Beccari (ESO), N. Da Rio (ESA), G. De Marchi (ESA), A. Natta, L. Ricci (CalTech), M. Robberto (STScI), L. Testi (ESO)

Current planet formation models are largely based on the observational constraint that protoplanetary disks have lifetimes around 3 Myr. Recent studies, however, report the existence of PMS stars with signatures of accretion (strictly connected with the presence of circumstellar disks) and photometrically determined ages of 30 Myr, or more. This group have presented a spectroscopic study of two major age outliers in the Orion Nebula Cluster (ONC). They use broad band, intermediate resolution VLT/X-Shooter spectra combined with an accurate method to determine the stellar parameters and the related age of the targets to confirm their peculiar age estimates and the presence of ongoing accretion.The analysis is based on a multi-component fitting technique, which derives simultaneously spectral type, extinction, and accretion properties of the objects. With this method they confirm and quantify the ongoing accretion. From the photospheric parameters of the stars they derive their position on the HR Diagram, and the age given by evolutionary models. Together with other age indicators like the lithium equivalent width they estimate with high accuracy the age of the objects. Their study shows that the two objects analyzed are not older than the typical population of the ONC. Their results show that, while photometric determination of the photospheric parameters are an accurate method to estimate the parameters of the bulk of young stellar populations, those of individual objects with high accretion rates and extinction may be affected by large uncertainties. Broad band spectroscopic determinations should thus be used to confirm the nature of individual objects. Their analysis shows that this method allows one to obtain an accurate determination of the photospheric parameters of accreting YSOs in any nearby star-forming region. They suggest that our detailed, broad- band spectroscopy method should be used to derive accurate properties of candidate old and accreting YSOs. This work has been published in Astronomy and Astrophysics [30].

1.3.24 Discovery of the magnetic field in the pulsating B star β Cephei

H. Henrichs (Amsterdam), J. de Jong (Amsterdam), E. Verdugo (ESA), R. Schnerr (Amsterdam), C. Neiner (Meudon), J. Donati (Toulose), C. Catala (Meudon), S. Shorlin (Ontario), G. Wade (Ontario), P. Veen (Amsterdam), S. Nichols (Harvard), E. Damen (Amsterdam), A. Talavera (ESA), G. Hill (Keck Observatory), L. Kaper (Amsterdam), A. Tijani (Amsterdam), V. Geers, K. Wiersema (Amsterdam), B. Plaggenborg (Amsterdam), K. Rygl (Amsterdam)

This group published the results from a long running survey (1998-2005) of circular polarisation spectroscopy of the pulsating B star β Cephei, which was suspected to host a strong magnetic field, based on the periodicity and variability in its UV wind lines, even though not helium-enriched. Results showed that β Cep hosts a sinusoidally varying magnetic field, with an amplitude of 97 ± 4 G and an average value of -

6 ±3 G. This represents the first confirmed detection of a dipolar magnetic field in an upper main-sequence pulsating star. This work was published in Astronomy and Astrophysics [11].

1.3.25 The evolution of [pseudo]bulges in disk galaxies in the last 8 Gyrs

R. Azzollini, I. Trujillo (IAC, Tenerife), C. Conselice (Nottingham)

The surface brightnesses and colours of the [pseudo-]bulges of two samples of galaxies at z ~ 0 (742) and 0.1<z<1.1 (170) were compared using deep, archive, imaging from SDSS and HST-ACS/WFC3. This group found a significant evolution of these properties in the surveyed cosmic time (~ 8 Gyr): these central structures decreasing in surface brightness by μ_0(g) of 2.5 mag/arcsec^2, and their rest-frame g-r color reddening by 0.3 mags. These variations are almost parallel to the evolution of the stellar disks, but a slight, relative over-reddening of the centres seems to agree with an inside-out progressive dearth of star formation. Further observations however are still required to confirm this.

1.4 Invited talks and other conference activities

Felix Aharonian IAP Colloquium, Paris, Jan 11, 2013, *Astrophysics and Cosmology with next generation gamma-ray detectors*; 2nd Bego Rencontres School, 13-31 May 2013, Nice, France, *Gamma Ray Sources and Source Populations*; Chair of SOC for the 4th Workshop on High Energy Phenomena in Relativistic Outflows (HEPRO IV) 23-26 July, 2013 Heidelberg.

Luke Drury Co-chair of the SOC for meeting *Cosmic Ray Origins - beyond the Standard Model(s)* to be held in San Vito, Italy, 16-22 March 2014.

Tom Ray Plasma Astrophysics Workshop, Turin, 12-14 March; EChO Meeting, Rutherford Appleton Laboratory, 9-11 April; ESO OPC, Munich, 21-24 April; MIRI Consortium, Chalmers, Sweden, 28-31 April; Protostars and Planets, Heidelberg, 15-19 July; SFI Summit, Athlone, 4-5 November; ESO OPC, Munich, 18-21 November.

Vincent Geers ETH Zurich Institute of Astronomy, March; MIRI Consortium, Chalmers, Sweden, 28-31 April; Protostars and Planets, Heidelberg, 15-19 July; Space Telescope Science Institute, September.

Ruymán Azzollini MIRI Consortium, Chalmers, Sweden, 28-31 April; EChO Consortium Meeting, Imperial College London, 10-13 September; Deconstructing Galaxies: Structure and Morphology in the Era of Large Surveys, ESO, Santiago, Chile, 18-22 November.

Rachael Ainsworth The Lowest Frequency Observations of Young Stars with the GMRT, The Metrewavelength Sky, Pune, India, 9-13 December.

2 Contributions to Third-level Education

2.1 Lecture courses delivered

Tom Ray gave a course of 9 lectures on introductory Astronomy and Astrophysics to Junior Freshman students and 14 lectures on Galactic Dynamics to Junior Sophister students in TCD. He also gave a seminar on the James Webb Space Telescope as part of the course for a Masters in Space Science and Technology at UCD, Dublin

Luke Drury gave a guest lecture on shock physics to the TCD taught MSc in plasma physics.

2.2 PhD students

Rachael Ainsworth Registered in TCD and supervised by Tom Ray and Anna Scaife worked on radio observations of young stellar objects, see section 1.3.5.

Iurii Babik co-funded with DCU and supervised by Masha Chernyakova worked on gamma-ray observations of binary systems, see section 1.1.5.

Grainne Costigan the Lindsay Scholar (jointly funded with Armagh Observatory), registered in QUB and supervised by Tom Ray and Aleks Scholz successfully defended her PhD thesis on “Accretion Variability in Young Stellar Objects” in October 2013.

Paul Dawson Registered in TCD and supervised by Tom Ray and Aleks Scholz worked on brown dwarf surveys, see section 1.3.7

Nakisa Nooraee Registered in UCC and supervised by Paul Callanan and Luke Drury submitted her thesis on "X-ray and optical studies of soft X-ray transients in M31". The oral examination was held in Munich on July 18th and the thesis was accepted subject to significant corrections.

Donna Rodgers-Lee Registered in TCD and supervised by Tom Ray, Antonella Natta and Aleks Scholz worked on multi-wavelength studies of circumstellar discs, see section 1.3.14

Carlo Romoli registered in DCU and supervised by Felix Aharonian, Andrew Taylor and Masha Chernyakova began work on Fermi observations of transient sources, see section 1.1.4.

2.3 Student final year projects

Luke Drury Is supervising two theoretical physics students in TCD, Andrew Thornbury and Nikki Truss, working on analytic and computational estimates of the power requirement for re-acceleration models of cosmic ray propagation in the Galaxy.

Tom Ray supervised two Final Year Astrophysics student projects (those of Victoria McCormac and Brian Doherty) in TCD for 3 months.

2.4 Secondment

Senior technical officer Mike Smyth was seconded to UCD to assist with the development of their taught MSc programme in space technology.

3 Contributions to research infrastructure and public service

3.1 HESS, Fermi, ASTRO-H, KM3NeT, CTA

The high-energy and astroparticle physics group in DIAS remains an active member of the HESS collaboration and participates in the production of high-impact papers of HESS. We also are involved in the data analysis, interpretation and publication of results based on the publicly available data banks of the the Fermi Large Array Telescope (LAT). We actively participate in the process of writing papers on the potential of the future gamma-ray (CTA) and neutrino (KM3NeT) telescopes. Finally, we play an important role in the preparation of scientific program of the future X-ray mission ASTRO-H.

3.2 MIRI, EChO and LBASS

3.2.1 MIRI

The Mid-Infrared Instrument (MIRI) for the James Webb Space Telescope (JWST) was placed inside the Integrated Science Instrument Module (ISIM) in May in the clean room facilities at NASA Goddard (see figure). Integration was carried out using the appropriately named Horizontal Integration Tool (HIT!). Metrology tests have shown that the positioning of MIRI appears perfect and it underwent its first cryo-test in August (see below).

DIAS-related MIRI Activities:

R. Azzollini now chairs the Medium Resolution Spectroscopy (MRS) Pipeline Working Group. This involves liaising with the Software Science Branch at the Space Telescope Science Institute (STScI) as regards the JWST pipeline, coordinate actions with the other software groups regarding common issues, etc.

V. Geers worked with the Software Science Branch at STScI and Steven Beard at the UK Astronomical Technology Center (UKATC) Edinburgh to create and expand MIRI definitions and data models, and to ensure continuing compatibility between these and the JWST software created by STScI.

R. Azzollini and V. Geers worked on producing and collecting MIRI calibration data products (CDPs) from the European Consortium team. They also updated these CDPs to be compatible with the JWST MIRI data models and pipeline reduction software. The results were part of the official deliveries of CDPs from ESA to NASA, the first delivery was made in March and the second in November of 2013.

R. Azzollini has been working on the definition and implementation of an algorithm for the optimal extraction of spectra from the MRS directly from the detector. This approach has several benefits over doing it from "spectral cubes". He is also developing a polynomial parametrisation of the spectral and spectral distortion of MRS spectra on the detector.

V. Geers worked on implementing code to insert World Coordinate System (WCS) from housekeeping logs, to prepare "dithered" data sets for testing the data reduction pipeline.

R. Azzollini and V. Geers attended several team meetings such as:

MRS working group in Leiden (April), on Optimal Extraction

MIRI test team meeting in Sweden on ISIM Cryo-Vac test campaigns, pipeline working

group activities, CDPs, etc.

R. Azzollini and V. Geers also played a major role (requiring several working weeks on site) in the JWST ISIM Cryo-Vac 1 testing campaign at NASA Goddard which MIRI was part of. Prior to this V. Geers also participated in the warm MIRI System Functional Testing at Goddard, in part as training to work on the ISIM Cryo-Vac test campaigns.

Finally R. Azzollini and V. Geers participated in testing and reviewing Build 2 of the STScI JWST Pipeline in December.

The MIRI team has reached an agreement with PASP (Publications of the Astronomical Society of the Pacific) to produce a monograph about MIRI to be published in 2014. These papers will stand as a reference for astronomers applying for time to JWST/MIRI in the future.

3.2.2 Exoplanet Characterisation Observatory (EChO)

EChO is a proposed ESA medium sized mission to determine atmospheric conditions in planets orbiting nearby stars using planetary transits. The University College London (UCL) lead consortium (G. Tinnetti as Principal Investigator), which includes DIAS as a partner (T. Ray as a Co-Principal Investigator) was successful in its proposal to ESA to be considered for the next Cosmic Vision medium mission (M3) launch in 2024. It is proposed that DIAS provide the EChO filters and beam-splitters and assist with the detector software development.

3.2.3 L-BASS

L-BASS is a proposed L-Band All Sky Survey (Jodrell Bank/TCD/DIAS) with the goal of making a low-resolution (13 degree), absolutely calibrated radio map of the sky at 1.4 GHz with unprecedented accuracy (<0.1K). It is proposed to site the instrument at Birr, Co. Offaly. The project is now at a sufficiently advanced stage that a request has been submitted to the Paul Instrument Fund (administered by the Royal Society) to finance the building of LBASS. The novel features are: a twin tipping beam architecture using two large symmetric waveguide horns with exceptionally low sidelobes and with high polarisation purity; the use of the celestial pole as an intermediate temperature reference and use of an active cryostat to cool a matched load to produce the absolute temperature reference. The results will settle a current astrophysical controversy concerning the reality of an excess of low frequency radio emission (ARCADE 2); enhance the interpretation of the latest maps of the cosmic microwave background (CMB) radiation by enabling superior foreground subtraction; and place constraints on distortions of the CMB spectrum arising from energy inputs in the early universe.

3.3 DELL HPC summit in Dunsink

DELL held its 2nd annual HPC summit in Dunsink Observatory on 28 Nov 2013.

Following the format of last year's meeting, it featured a comprehensive programme of interactive discussions, debates and activities including an examination of the challenges facing the HPC community in both the academic and industrial space. The agenda was developed by and for the HPC community, with expert speakers and panelists from across the community, the Dell HPC team and carefully selected specialists in the field.

09:30 - 10:00	Registration & Coffee
10:00 - 10:15	Welcome and Introduction
10:15 - 11:00	Acceleration and scaling of molecular dynamics on specialist and massively-parallel hardware platforms
11:00 - 11:45	Using space-filling curves for efficient scaling in HPC
11:45 - 12:30	Power and Cooling for modern HPC
12:30 - 13:30	Lunch
13:30 - 14:15	PRACE Use Forum
14:15 - 14:45	Green MPI and Code optimization
14:45 - 15:15	Coffee Break
15:15 - 15:45	Industrial Compute Cluster for Oil and Gas
15:45 - 16:15	Many-Core Computing
16:15 - 16:45	Big Data Analytics
16:45 - 17:00	Q&A and Close

3.4 ICHEC launch of new super-computer

The Irish Centre for High-End Computing, co-founded by the section, continues to have a close association with DIAS and participates in a number of Institute events such as culture night. To announce the name and formal launch of their new super-computer (funded largely through an SFI infrastructure grant submitted by DIAS on behalf of ICHEC) an event was held in Dunsink on 13 November attended by a number of coderdojo groups, ICHEC staff, the President of DCU and the Minister of State for Research and Innovation, Sean Sherlock TD. The Minister officially named the new machine Fionn after the legendary Irish giant.

3.5 Training week for National School teachers

In association with the Department of Education and Skills a training week for National School science teachers was held in Dunsink from 1 to 5 July.

3.6 Individual Contributions

Felix Aharonian continued as vice president of the division of the International Astronomical Union (IAU) 'High Energy Phenomena and Fundamental Physics'; as an ESA representative in the ASTRO-H project; served as an editor of the International Journal of Modern Physics; chaired the International Advisory Council of the Institute of Sciences of the Cosmos at the University of Barcelona; and was a Member of the Scientific Advisory Committee of Astroparticle Physics European Consortium (APPEC).

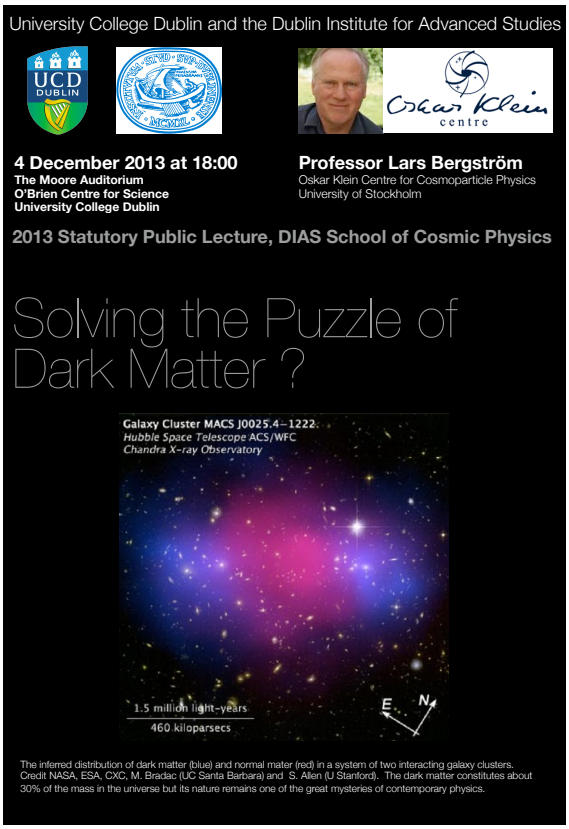
Luke Drury served as President of the Royal Irish Academy.

Tom Ray served as a Panel Chair (Interstellar Medium, Star Formation and Solar System) for the Observing Programme Committee (OPC) of the European Southern Observatory; on the Marie Curie Fellowship Physics Panel; on the Council of the Royal Irish Academy; as Postgraduate Studies Adviser to the School (until June 2013), on the Science and Technology Facilities Council (STFC) e-MERLIN Steering Committee; on the RIA Astronomy and Space Science Committee; on ESA's MIRI Steering Committee, as a member of the Irish Fulbright Panel, on the Management Committee of the Armagh Observatory and Planetarium and on the Management Committee of ORIGINS (a European Commission COST project).

Malcolm Walmsley continued to serve as an editor of Astronomy and Astrophysics.

4 Public Outreach

4.1 Statutory Public Lecture



The statutory public lecture of the School for 2013 was given by Professor Lars Bergstrom of the Oscar Klein Centre for Cosmoparticle physics in the University of Stockholm. His title was "Solving the Puzzle of Dark Matter?" and the lecture was hosted by University College Dublin in the Moore auditorium of the new O'Brien Centre for Science. A recording of the lecture is available on https://www.youtube.com/watch?v=sQ8EA7U2GWI.

4.2 Irish Astronomy Trail and proposed European Route des Observatoires

Within the framework of the project "Route of astronomical observatories" and of the programme "World Astronomical Heritage" of UNESCO, a preparatory mission was organized in Ireland by the French Embassy from 26th to 30th of September 2013. The main event was a meeting held in the Crawford Observatory, Cork, on the 27th September and attended by Luke Drury and Hilary O'Donnell , Dunsink Observatory; Prof. Paul Callanan, University College Cork; Dr. Niall Smith, Blackrock Castle Observatory; Prof. Nandivada Rathnasree, Nehru Planetarium Director (India); Dr. Roger Ferlet, Institut d'Astrophysique de Paris (IAP, France); Dr. Jean-Marc Bonnet-Bidaud, Commissariat à l'Energie Atomique (France); and Dr. Claude Detrez, Embassy of France in Ireland. The Irish Astronomy Trail was presented at the meeting and it was agreed that this was a useful and simple starting point which should be replicated in France. Dr Ferlet and Prof Bonnet-Bidaud subsequently visited Dunsink Observatory on their way back to France.

4.3 Dunsink

4.3.1 General

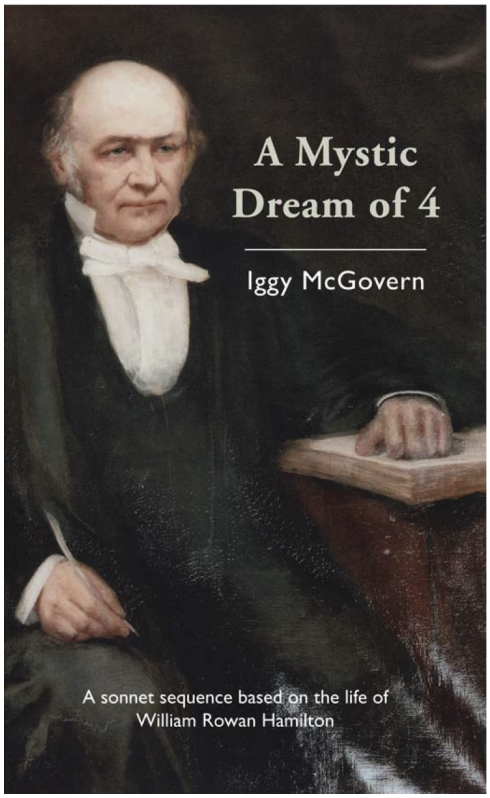
With the assistance of R. Jones, T.P. Ray carried out an audit of historical items held by the Observatory using the 1992 inventory produced by the late Patrick Wayman (Senior Professor in the School of Cosmic Physics). Of approximately 90 listed artefacts, almost all were recovered with the exception of 2 items that are currently being sought. In advance of these items being moved to make way for redecoration of the basement of Observatory House, it is intended to both retag and photograph all artefacts. In the course of this work, and as a result of an investigation using the archives of the Royal Irish Academy, Royal Society London and the Royal Astronomical Society, a very important historical item was recovered, a Grubb 4-inch lens (of 19 foot focal length) that is not listed in the inventory. This lens was used at Sobral, Brazil to test Einstein's Theory of General Relativity. The lens was sent to University College London, following a recommendation from the Conservation Department of the Royal Greenwich Observatory, to be dismantled and cleaned.

Albert McClure from Belfast, a professional en-

gineer who restores and maintains telescopes, has carried out routine maintenance work on the Grubb 12-inch Refractor including an overhaul of its polar axis clock, slow motion controls, finder and dome. Following discovery of rot in the dome windows, the Office of Public Works (OPW) has agreed not only to refurbish the windows but also carry out essential maintenance and preservation work on the rest of the building. It was discovered, using a historical image from the time of its construction, that the dome woodwork (including benching) is original. The OPW agreed to preserve as much of the original structure as possible.

4.3.2 A Mystic Dream of 4

Physicist and poet Iggy McGovern launched his latest volume of poetry, "A Mystic Dream of 4", a sequence of sonnets based around the life of Sir William Rowan Hamilton in Dunsink Observatory on 15 October.

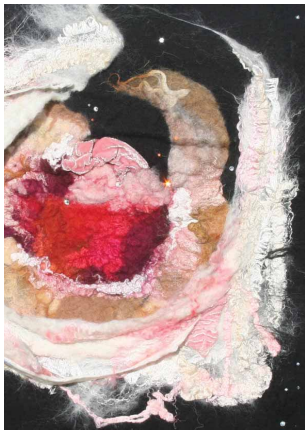


4.3.3 Annual Hamilton Walk

The annual Hamilton walk, organised by NUIM in association with DIAS, took place as usual on the 16th October and attracted about a hundred participants, including some who had travelled from as far away as Finland. Sir Roger Penrose gave a short address before the walkers set off.

4.3.4 "Light Echo" exhibition

Artist Bernadette Dignam exhibited a series of textile works entitled "Light Echo" and inspired by astronomical images in Dunsink Observatory from 5-23 November. The exhibition vernisage was held on 9th Nov with a short address by Christy Dignam and a performance of two specially composed pieces for the dulcimer by musician Ute Schmidt.



light
echo
at dunsink observatory.

An exhibition of work by Bernie Dignam

Opening reception
Saturday 9th November 2013 at 1.30pm
Opened by Christy Dignam

Bernie requests the pleasure of your company at the launch where musician **Ute Schmidt** will perform a recital of ***Light Echo Tone*** and ***Light Echo Fantasy*** especially composed by Ute for this exhibition

Dunsink Observatory Castleknock, Dublin 15

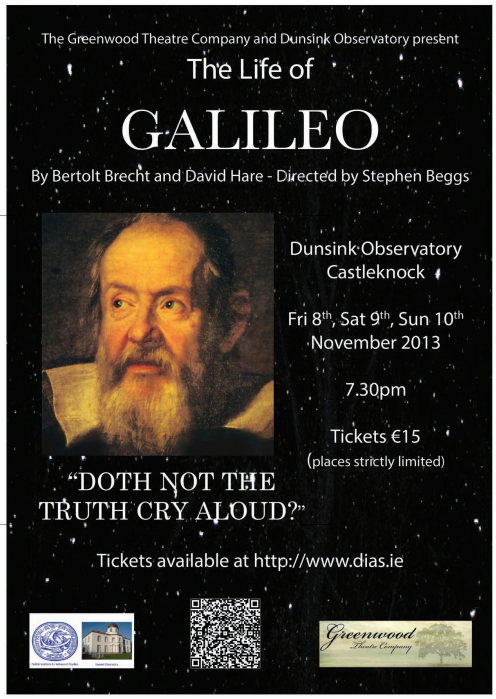
Exhibition open from 5th - 13th November 2013

Image **Light Echo II** *Mixed media*

www.berniedignam.com

4.3.5 Brecht's "The Life of Galileo"

As part of the lead up to Science Week, and on the initiative of Tom Ray, the Greenwood Theatre Company's acclaimed production of Brecht's "The Life of Galileo" was staged in Dunsink Observatory in a specially adapted version by David Hare from 8-10 November.



The players did four performances in total including one for Transition Year students. There was also a school's workshop held on the morning of Friday November 8 involving St Killian's German School, Clonskeagh, and Malahide Community School.

4.3.6 Open nights and other similar events

Hilary O'Donnell et al

Continuing a long tradition the observatory runs 'public open night' (PON) events, normally on the first and third Wednesday of each month, during the winter months. In addition a large number of special events were organised for interested parties, schools, graduate associations, scout groups etc. The typical programme involves a short presentation on the solar system while people assemble followed by a short introduction to the history of the observatory and a presentation by one of our researchers or associates before, weather permitting, people are allowed to look through the Grubb refractor. This programme is run in partnership with the Irish Astronomical Association whose assistance is gratefully acknowledged.

January 2013 Wednesday 9th/16th/30th PON; Thursday 31st Dean Mc Carthy and his 1st and 2nd year students from Physics NUIM

February 2013 Friday 1st Family Evening Event; Monday 4th Mature Student Group UCD; Tuesday 5th PON; Wednesday 6th Family Evening event; Thursday 7th Family Evening Event Tuesday 19th Youth Study Groups from secondary schools in D15; Wednesday 20th PON; Thursday 21st Transition Students UCD

March 2013 Tuesday 5th PON; Wednesday 6th TCD Graduates association evening group; Thursday 7th Pop Up Group Evening; Friday 8th Scout Group Evening Astronomy Badge D13; Tuesday 12th PON; Wednesday 13th PON; Thursday 14th Family Evening Event; Tuesday 26th PON; Wednesday 27th Family Evening Event; Thursday 28th Pop Up Group Evening

April 2013 Wednesday 10th Association Evening Event from Co Meath; Thursday 11th French School Group from Normandy; Friday 12th Group from an International English School in Dublin; Thursday 18th Pop Up Evening Group; Friday 19th St Finian's College Mullingar

May 2013 9th/10th May Scout/Guides Groups Evening Astronomy Badge D8/15; 28th May Training Day for the Science Summer Workshop for National School Teachers scheduled for July 2013

June 2013 18th/19th International English School evening visit; Saturday 29th Solarfest all day event

July 2013 1st/5th July 2013 Training Week for National Schools science Teachers; 8th/9th International English School Visit evening visits; Saturday 13th July 2013 Round Wood History Society Visit afternoon/evening; 25th July IAA evening visit (Irish Architectural Archive Group)

September 2013 17th National School visit from West Dublin; 18th National School Visit from Ashbourne; Friday 20th Culture Evening; Friday 27th Two groups of Cubs came together, Astronomy Badge, Lucan Area

October 2013 Wednesday 2nd/17th/23rd PON; 15th Book Launch TCD Poetry; 16th Hamilton Walk afternoon; 16th Secondary School Visit, Claremorris Co Mayo; 19th Antiquarian Visit; 29th/30th Family Evening Events

November 2013 6th Arrival of players and crew for the Life of Galileo; 7th Rehearsal day for the play itself; 8th Workshop plus play for the two school groups (afternoon); 8th/9th/10th Life of Galileo performance nights; 9th Launch of Light Echo, art work stayed in situ through to the New Year; Science Week 11th/12th/14th/15th Two School visits each day; 13th November ICHEC Launch event with Minister Sean Sherlock; 13th November Social group event later that evening from Birr; 20th PON; 27th Fine Arts Group from the National College of Art; 28th Dell HPC day

December 2013 03rd Transition Students from all over Ireland through TCD afternoon and evening event; 05th/18th PON

4.4 Other Outreach Contributions

Tom Ray The James Webb Space Telescope, Astrofest, Galway, February 2; Astronomy and the Tides, Royal Irish Yacht Club, February 7, 2013 and Malahide Yacht Club, February 27; From Pebbles to Planets: Our Changing Ideas of How Planets Form, Irish Astronomical Association, Belfast, March 6; The Life and Times of Thomas and Howard Grubb, Maynooth Astronomical Society, April 6; Making Billiard Tables, Money and Telescopes: The Life and Times of the Grubbs, Malahide Historical Society, November 13; From the Solstice to Pulsars: Measuring Time in Astronomy, Solstice Public Lecture, Slane, December 20.

5 Detailed Bibliography of Publications

Note that where possible hyperlinks have been provided to the journal article and preprint version.

5.1 Peer-reviewed Publications in 2013

[1] A. Abramowski et al. "Constraints on axionlike particles with H.E.S.S. from the irregularity of the PKS 2155-304 energy spectrum". In: Phys. Rev. D 88.10, 102003 (Nov. 2013), p. 102003. DOI: 10.1103/PhysRevD.88.102003. arXiv: 1311.3148 [astro-ph.HE].

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