Armagh Observatory
Annual Report
Calendar Year 1999

Prepared by the Director

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Contents

1 Astronomy in Armagh

1.1 Armagh Observatory

The Armagh Observatory, founded in 1790 by Archbishop Richard Robinson, is a modern astronomical research institute with a rich heritage. The Observatory is set in 14 acres of landscaped gardens and parkland close to the centre of the City of Armagh, and is the oldest astronomical observatory in the UK still functioning as an independent research establishment on its original site.

The Observatory is about the size of a small university department, but with the greater responsibilities and the higher public profile of an independent institution. Following the establishment of devolved structures within Northern Ireland during 1999, responsibility for the Observatory was transferred from the Department of Education Northern Ireland (DENI) to the new Department of Culture, Arts & Leisure (DCAL). In recent years the Observatory has received an annual budget from the DENI in the range £400k–£500k together with external income, mostly originating from the UK Particle Physics and Astronomy Research Council (PPARC), amounting to roughly 50% of this, i.e. £200k–£300k per year.

There are currently (end December 1999) 25 research staff, including 8 senior astronomers and research associates, 5 postdoctoral research assistants, and 12 research students. The majority of the students are registered for postgraduate degrees (MPhil or PhD) at the Queen's University of Belfast (QUB). Discussions with QUB during 1999 have led to recognition of the Observatory as an approved institution for supervision and examination at postgraduate level. The research, academic and public outreach activities of the Observatory are supported by 7 staff, 4 of whom have responsibilities for core activities such as library, computers, meteorology readings, buildings and grounds, while 3 others provide administrative, secretarial, financial and general personnel support. The Administrator occupies a joint position with the Armagh Planetarium. The current staff position of the Armagh Observatory is given in Appendix A.

1.2 Armagh Planetarium

The Armagh Planetarium was founded in 1968 by Dr E.M. Lindsay, seventh director of the Armagh Observatory, as a public outreach facility of the Observatory. The Planetarium educates and informs visitors of all age groups, promotes the public understanding of science, and is one of the leading visitor attractions in Northern Ireland and Armagh City and District. The Armagh Observatory primarily carries out astronomical research, and is an internationally recognised centre of research excellence with an organization and infrastructure geared to achieve that aim.

Senior management responsibility for the Armagh Observatory and the Armagh Planetarium rests with a joint Board of Governors and a joint Management Committee, the two organizations sharing the position of a joint Administrator. The membership of the Armagh Observatory and Planetarium Board of Governors and Management Committee is given in Appendix B.

1.3 Mission Statement

The joint mission statement of the Armagh Observatory and Planetarium is:

> *To advance the knowledge and understanding of astronomy and related sciences through the execution, promotion and dissemination of astronomical research nationally and internationally in order to enrich the intellectual, economic, social and cultural life of the community.*

1.4 Research Areas and Facilities

The principal research interests of Observatory staff now include

1. <u>Stellar Astrophysics</u>: including star formation, astrophysical jets, the Sun, cool stars, hot stars, helium stars, star-spots, flares, circumstellar dust;

2. <u>Solar System Astronomy</u>: including celestial mechanics, planet formation, dynamical evolution of comets and asteroids, interplanetary dust; and

3. <u>Solar System – Terrestrial Relationships</u>: including solar variability, climate, accretion of interplanetary dust and comet/asteroid impacts.

These areas of astronomy, namely: Stellar Astrophysics, the Sun, Solar System Astronomy, and the Earth's Climate, encompass those areas of astronomy which promise to have maximum impact on our lives over the next decade or two. In the short-term, the value of astronomy in Armagh can also be measured by the amount of external income (and number of people) attracted into Northern Ireland by Armagh Observatory staff, and by the positive publicity generated for Northern Ireland on both the national and international scenes.

In addition to these principal research areas, staff at the Observatory have also carried out research on (i) the structure of meteor streams; (ii) the puzzling apparent quantization discovered in extragalactic redshifts; and (iii) climate change at Armagh during the past two hundred years. The Armagh climate series, which is one of the longest in the world from a single site, has special value in being (a) virtually continuous since its inception in 1795, and (b) only slightly affected by surrounding urban development.

The 20–30 astronomers of graduate or postdoctoral status who work at the Armagh Observatory come from many countries, and are actively involved in many research collaborations and international partnerships, including scientific links with almost 60 groups from more than a dozen countries around the world. These are listed in Appendix E. Full details about the Armagh Observatory and its current research programmes are available from the Observatory web-site: http://www.arm.ac.uk/.

The astronomical research facilities at Armagh Observatory, including those for computing and data reduction, are mostly excellent, and include a local Starlink node funded in part by the Particle Physics and Astronomy Research Council (PPARC) and partly by the DENI/DCAL, and (from March 2000) an Origin 2000 supercomputer. Armagh Observatory staff receive regular awards of telescope time and research grants from the PPARC and other organizations, and are eligible to apply for grants from the Natural Environment Research Council (NERC) and other grant awarding organizations.

1.5 Public Understanding of Science

In addition to its principal function as an astronomical research institute, the Armagh Observatory has a responsibility to disseminate widely the results of its astronomical research. The Observatory plays a major role in the promotion of astronomy and the public understanding of science, both locally (i.e. within Armagh City and District and Northern Ireland) and abroad. The Observatory's public outreach focuses primarily on e-visitors to its web-site (http://www.arm.ac.uk), on mass-media interest in astronomy (via the national and local press, radio and television), and on the development, preservation and restoration of the Observatory's two-hundred year astronomical heritage, comprising written records and archives, scientific artefacts, historic buildings and telescope domes, scientific instruments, telescopes, and grounds. It is estimated that tens of millions of people were reached last year through the various media contacts, with a further 100,000 e-visitors being recorded from over 100 different countries.

The more than 200 years of continuous astronomical activity in Armagh encompass essentially the whole of modern astronomy. This provides the research scientists who work in Armagh with a unique opportunity to explain the motivation for the development of their subject over this period, specifically in Armagh, and the context in which their present research is carried out. The grounds in which the Observatory is located are attractively laid out, and include a scale model of the universe known as the Armagh Astropark. The Astropark is now being developed as part of the Observatory's public understanding of science programme.

1.6 Highlights 1999

- **Explaining the 1998 Leonid Fireball Outburst**: David Asher, Vacheslav Emel'yanenko (visiting the Observatory from Chelyabinsk, Russia) and Mark Bailey explained the unexpected Leonid fireball outburst in the early hours of 17 November, which occurred more than half a day earlier than the predicted meteor shower on the night of 17/18 November 1998. The explanation for the 1998 Leonid fireball outburst attracted much scientific and public interest, and gave rise to media reports in many newspapers and magazines around the world, including The Times, Der Neue Zuercher Zeitung (Zurich), Scientific Computing World, Science News, The Boston Globe, and The Dallas Morning News.

- **Predicting the 1999 Leonid Storm**: David Asher also explained previous Leonid meteor storms (notably the great storms of 1833 and 1966), and together with Rob McNaught (Australian National University, Siding Spring Observatory) made accurate predictions for the times of the 'normal' storm trails of the Leonids. The prediction for the 1999 storm (for November 18 02^{h} 08^{m}) turned out to be 'spot-on', and made headlines around the world. The success of the Asher/McNaught approach in predicting the time of the meteor storm was hailed by the editor of the International Meteor

Organization[1] as equal in importance to the basic understanding of how meteors work, following the famous 1833 storm. David Asher has also computed the circumstances of the Leonid meteor showers for 2000, 2001, 2002 and 2006 (see http://www.arm.ac.uk/leonid). The 2000 event involves the Earth's first passage through the 4-revolution trail of meteoroids ejected from the comet in 1866. Observations of these meteoroids will be crucial for predicting the precise meteoroid flux in 2001 and 2002.

- **Stellar Evolution Following Stellar Merger**: Simon Jeffery, in collaboration with Hideyuki Saio (University of Tohoku, Japan) has developed a new evolutionary model for the pulsating helium star V652 Herculis. In this model, two helium white dwarfs in a binary system coalesce. The increased mass of the new star allows nuclear burning to begin and the star becomes a giant. Its subsequent evolution provides models which match the observed properties of V652 Her almost perfectly.

- **Pulsation Mass for Second Helium Star**: In two studies of a pulsating helium star LSS 3184, which has properties very similar to V652 Her, Simon Jeffery, Vincent Woolf and collaborators at the South African Astronomical Observatory have measured the radius and mass. Somewhat surprisingly, the results were somewhat smaller than expected. Since LSS 3184 has a carbon-rich surface, while V652 Her has a nitrogen-rich surface, this raises new questions about their possible evolutionary origin.

- **Rare Earth**: John Chambers, in collaboration with George Wetherill (Carnegie Institution, Washington), has made computer simulations of the origin and formation of the Earth and inner planets, yielding Earth-like planets moving on almost circular orbits, allowing them to have potentially stable climates. The fraction of planets with orbits lying entirely in the habitable or 'Goldilocks zone' around other stars (neither too hot nor too cold) is very small, suggesting that living organisms as complex as those found on Earth might be of exceptionally rare occurrence in the Universe.

- **Solar Influence on Climate**: A new correlation between the global low cloud factor and cosmic-ray flux, found by Enric Pallé Bagó and John Butler, suggests that a substantial fraction of the global warming since the late-nineteenth century can be explained by a combination of the direct (solar luminosity change) and indirect (cosmic-ray induced change in cloudiness) effects of solar activity.

- **Detection of Nano-Flares**: Gerry Doyle and Luca Teriaca have interpreted red-shifted spectral lines in the solar atmosphere (temperatures 20,000–200,000K), and blue-shifted features at higher temperatures, in terms of nano-flares in a magnetic loop around the O VI formation temperature.

- **Honorary Professorship**: Gerry Doyle was awarded an Honorary Professorship from QUB, starting 1999 June 1.

- **Minor Planet for DENI**: The asteroid (9140) Deni was formally announced by the International Astronomical Union Minor Planet Center on 1999 April 2 (ref. MPC 34351). The citation reads:

  > "**(9140) Deni = 4195 T-3.**
  > Discovered 1977 October 16 by C.J. van Houten and I. van Houten-Groeneveld on Palomar Schmidt plates taken by T. Gehrels. Named after the Department of Education for Northern Ireland for its support of the Armagh Observatory, where Ernst Öpik carried out seminal work on the collisional evolution and dynamics of small bodies. The DENI has promoted lifelong learning and research across many disciplines, encompassing higher education, schools, museums, recreation and culture. It has sought for many years to advance knowledge and understanding of the natural world, and to provide the means by which as many people as possible may appreciate and continue to develop Northern Ireland's rich cultural heritage, its diversity and contributions to the scientific, intellectual and social life of the community."

- **Centre Stage in Dublin**: A fictional account of the life of Robert Hogg, assistant astronomer at Armagh Observatory in the 1790s and early 1800s, provided the inspiration for Darragh Carville's Gothic Sci-Fi thriller "Observatory", which was shown at the The Peacock Theatre Dublin, during April 1999.

[1] Rendtel, J., 2000, *Editorial*, WGN, The Journal of the International Meteor Organization, 28, 1.

- **Media Coverage**: The Observatory is one of the principal points of contact for astronomy in both Northern Ireland and the Republic of Ireland, receiving many public enquiries and citations in the national and international press, and on radio and television. During 1999, the Observatory was noted in one or another such medium at least 233 times. These identified media mentions, which are a subset of the whole, are listed in Appendix F.
- **External Grant Income**: Total external grant income during the financial year 1999/2000 was £293k, an increase on the previous year and a significant fraction (65%) of the total DCAL recurrent grant-in-aid (£452k). Total external income (excluding £125k in kind through the Joint Research Equipment Initiative) was £305k.

2 Research

A subset of the total research output of Observatory staff, namely the list of 32 refereed journal publications during 1999, is given in Appendix C. A second subset, namely the list of more than 65 public and professional talks delivered by Observatory staff during 1999, is given in Appendix E.

These examples illustrate two of the many routes by which the research results of Observatory staff are communicated to a wider public: through talks or popular articles in the local, national or scientific media; at conferences, seminars and workshops; in books; in refereed scientific publications and journals (some of which nowadays are entirely in electronic form, e.g. The Journal of Astronomical Data); in conference proceedings; and in a variety of non-refereed publications. It is notable that the proceedings of the Brendan Byrne Memorial Meeting[2] were published within 6 months of the meeting taking place.

These forms of research activity all help to raise the profile of astronomy on the national and international scenes and highlight in particular the role of astronomy in Armagh.

A second indication of the quality and volume of the Observatory's research output is the amount of external research income, raised mostly through a process of competitive grant application and peer review. This is a fluctuating quantity which has fallen in recent years, due in part due to a temporary shortage of funding for external PPARC research grants. The total external grant income for 1999/2000, namely ∼£293k, therefore represents an exceptionally good performance, being a substantial fraction (65%) of the total DENI/DCAL recurrent grant-in-aid for the financial year in question.

External income generation and the overall level of research activity are areas where economies of scale work extremely well. In view of the Observatory's relatively small size, further improvements would be possible given appropriate investment in additional research staff.

The remainder of this section summarises, under the headings of the Observatory's senior research staff and associates, some of the principal research results obtained in 1999 by these staff and their colleagues.

2.1 C.J. Butler, Research Astronomer

2.1.1 Stellar Astrophysics

Observations and Modelling of Stellar Flares A new PhD student, David García Alvarez, began work with Dr John Butler and Professor Gerry Doyle in October 1999 to continue the analysis and modelling of stellar flares started by Eric Houdebine and John Butler in the late 1980s and early 1990s, subsequently continued by Darko Jevremović from 1995–1999. Dr Jevremović completed his thesis ('Hydrogen Balmer Lines in Stellar Flares') and was awarded his degree in 1999.

In his thesis work, Darko Jevremović developed a new tool for analysing the Balmer decrements which made it possible to estimate the electron density and electron temperature of the flare plasma and the temperature of the underlying background source. Applied to data of flares on Gliese 866 he was able to estimate the area of hydrogen emitting flare regions as 1–13% of the stellar surface. The physics of the flare process was taken back a further stage towards its initial cause by the development of a new gas-dynamic radiative transfer code with heating by energetic electron beams. This code satisfactorily predicted the behaviour of the $H\gamma$ line during a flare observed on AD Leo with the William Herschel Telescope (WHT) in 1998.

[2] Butler, C.J. & Doyle, J.G., 1999, *Solar and Stellar Activity: Similarities and Differences*, Astron. Soc. Pacific Conf. Ser., **158**.

Angular Momentum of Late-Type Cluster Members A paper with Dr Armin Theissen, giving full details of the astrometric and photometric observations of the open cluster Stock 2, has been accepted for publication. Proposals for follow-up medium-resolution and high-resolution spectroscopic observations of probable members of this cluster did not receive the requisite allocation of telescope time, and as a result it was decided to adopt a different and less observationally demanding approach to our goal of establishing the rotational velocities of cluster members. This involved photometric monitoring using a wide-field CCD camera on a medium-sized telescope. Seven nights were awarded on the 1 m Ritchey-Chrétien Telescope at Siding Spring by the Mount Stromlo and Siding Spring Observatory in February 1999 and again in January 2000. In the first run, mediocre weather conditions prevented successful photometric tranfers, but did allow some variability studies to be made. During the second run, in January 2000, two photometric nights allowed photometric transfers to be completed. The data are in the process of reduction and analysis.

COROT Satellite The French satellite programme COROT, which will be dedicated to micromagnitude photometric observations of main-sequence stars, has now received a firm commitment for launch. The project has two main objectives: (1) to determine the internal structure of main-sequence stars using asteroseismology techniques; and (2) to search for Earth-like planets around main-sequence stars from optical occultations.

The selection of the target list using high-resolution spectroscopic data of around 1000 candidate stars is a major observational programme which requires international collaboration. As partners in the project, Armagh Observatory has been asked to contribute to the selection process in exchange for priority access to the data which will eventually flow from the satellite. A one-week run on the South African Astronomical Observatory (SAAO) 1.9 m telescope using the 'Giraffe' Echelle Spectrograph was awarded to this programme. About 80 high-resolution spectra were obtained, which have now been reduced and classified by Claude Catala. A further application for time on the WHT has been made. In addition to the selection of COROT targets, this project will result in a substantial databank of high-resolution spectra which will be made available for stellar atmosphere studies. Eventually, when the satellite is operational, Armagh Observatory will gain priority access to a vast and highly original databank of unparalled photometric accuracy on a wide variety of stars.

2.1.2 Solar Variability and Climate

It is now widely accepted that solar activity plays some role in climate change, but the relative strength of its influence compared to the enhanced greenhouse effect is still a subject of dispute. The solar activity effect can be divided into two parts: (1) the direct effect of a solar luminosity change associated with solar activity, which many agree can explain roughly 10–20% of the current global warming; and (2) an indirect effect, that is difficult to quantify, but which depends on the influence of solar activity on other less easily identifiable physical processes. One such possible process is the influence of changes in solar activity on cosmic-rays and their effect on the Earth's cloud factor.

An anlaysis of data from the International Satellite Cloud Cover Project (ISCCP), by Enric Pallé Bagó and John Butler has shown that previously identified correlations between the total cloud cover over oceans and cosmic-ray flux for the period 1984–1991, do not continue during the period 1991–1994. However, when the data are separated into low, medium and high clouds, a clear correlation is evident between cosmic-ray flux and low clouds over the whole period covered by the ISCCP data from 1984–1994. Assuming there is no feedback mechanism or other long-term changes, it is then possible to compute the enhanced warming by low clouds and their influence on the Earth's albedo. Preliminary results suggest that much of the global warming since the late nineteenth century can be explained by a combination of the direct and indirect (cosmic-ray induced) effects of solar activity.

2.1.3 Other Activities

John Butler wrote short biographies of several former Armagh Observatory staff (E.M. Lindsay, J.L.E. Dreyer and E.J. Öpik) for the book *People and Places in Irish Science*, edited by Charles Mollan (Royal Irish Academy, Dublin), and served on several external committees including the Court of the University of Ulster and the Birr Scientific Heritage Trust. He has also been the principal point of contact between Armagh Observatory and Trinity College Dublin (TCD), for the programme in which, each autumn, Armagh Observatory staff develop and supervise undergraduate astronomy projects for final-year TCD students.

2.2 J.E. Chambers, Research Astronomer

2.2.1 Research Highlights

John Chambers has refined and expanded an alternative scenario for the formation of the asteroid belt in collaboration with George Wetherill, Carnegie Institution of Washington, USA. Using numerical simulations on computers, they have shown how planets may have formed in the asteroid belt. However the orbits of these planets were made unstable by gravitational perturbations by the giant planets Jupiter and Saturn. As a result, the planets in the asteroid belt were all lost, falling into the Sun or being thrown into interstellar space, leaving no planets in the asteroid belt today.

Building on this work, John Chambers and collaborators at Nice Observatory, France, have shown that most small asteroids would also have been lost, leaving only the ones we see today. They have also explained why many of the remaining asteroids have highly eccentric and inclined orbits, unlike the planets in the Solar System.

This same collaboration has shed light on an old mystery: why the Earth has water and organic material on its surface. This is a long-standing problem since theories for the origin of the Solar System predict that planetary building blocks ("planetesimals") that formed at Earth's distance from the Sun should be very dry. For a long time it was thought that comets collided with the young Earth, bringing the water and organic material needed for life to form. However recent work has shown this idea is untenable. The Nice workers and John Chambers have shown that protoplanets forming in the asteroid belt can supply this material to Earth instead. In collaboration with workers at NASA Ames, John Chambers is extending this theory to extrasolar planetary systems.

John Chambers has made new detailed computer simulations of the origin and formation of Earth and the inner planets. These have overcome many shortcomings of earlier simulations, and produce systems of planets that resemble those in the inner Solar System in many respects. However some differences remain, suggesting that our planetary system may be special in some way. Dr Chambers is now examining whether this is related to events that occurred in the asteroid belt and outer Solar System, with the aim of developing a single coherent model for the formation of our planetary system.

"Mercury", the computer package for calculating orbital evolution developed by John Chambers, has now been made publicly available on the Armagh computer FTP site. Collaborations with Marc Murison at the US Naval Observatory and others should further improve this package in the near future.

2.2.2 Collaborations and Other Activities

During the year, John Chambers undertook scientific collaborations with: J.J. Lissauer and E. Rivera at the NASA/Ames Research Center, on the formation of the inner planets and the Moon; P.N. Sleep and B. Jones at the Open University, on the stability of terrestrial planets in extra-solar planetary systems; A. Morbidelli and J.-M. Petit at the Observatoire de Nice, on the origin and early evolution of the asteroid belt; M. Kress and R. Bell at NASA/Ames, on delivery of volatile materials to Earth-like planets in extra-solar planetary systems; E. Thommes and M. Duncan, Queen's University Canada, on the formation of the outer planets and the asteroid belt; M.A. Murison at the US Naval Observatory, on developing better computer algorithms for solving the N-body problem; G.W. Wetherill at Carnegie Institution of Washington, on planet formation and the formation and evolution of the asteroid belt; and G. Stewart, University of Colorado, on N-body integrators.

John Chambers also served as external examiner for a PhD student at Oxford University, refereed a number of papers and grant applications for PPARC, NASA and the Austrian Science Council, and presented a number of papers at colloquia and scientific conferences.

2.3 J.G. Doyle, Research Astronomer

The major research effort in 1999 was again directed towards Solar Physics and in particular towards SOHO activities, although some effort was directed towards the cool star area.

2.3.1 Solar Physics

This work can be broadly divided into four areas, each of which is briefly discussed below. In addition to Gerry Doyle, those involved include Luca Teriaca, Ilía Roussev, Elena Pérez, and Dipankar Banerjee.

Coronal Holes SUMER/SOHO and CDS/SOHO data were obtained for spectral lines from two ions formed at high temperatures, Si VIII and Si IX. Lines from these ions provide both an estimate of the local electron density and micro-turbulent plasma velocity. From the combined dataset we find a radial dependence of the electron density, varying in the range 1–2$R_\odot$ as r^{-8}, from 2–4$R_\odot$ as r^{-4} and then as r^{-2}. By 8$R_\odot$, the electron density has fallen to $\sim 4 \times 10^3\,\mathrm{cm}^{-3}$, from $1.5 \times 10^8\,\mathrm{cm}^{-3}$ at 1.0$R_\odot$. Combining the Si VIII half-width at 1/e of the peak intensity with the UVCS/SOHO O VI half-width, we find a small increase of the half-width from 1.0–1.2$R_\odot$, then a plateau until 1.5$R_\odot$, thereafter a sharp increase until 2$R_\odot$, and finally a more gradual increase reaching 550 km s^{-1} at 3.5$R_\odot$. Our data suggest that the magnetohydrodynamic (MHD) waves responsible for the excess line broadening tend to become non-linear as they reach 1.2$R_\odot$.

Chromospheric Oscillations We examine spectral time-series of two lower-chromospheric lines observed with SUMER/SOHO (N I and C II). Intensity power spectra of C II are affected at higher frequencies by streams of emitting structures. Using contrast-enhanced time slices we show that (1) there exists a grain-like pattern which is found in both network and inter-network regions; (2) streams of supersonically moving structures probably outline a wave interference pattern; and (3) the sizes of structures observed in N I are smaller than when observed in C II. At various points our findings disagree with earlier results.

Explosive Events Two examples of explosive events observed with SUMER/SOHO in transition region spectral lines are reported here; one detected in C IV 1548Å, in a region within the northern polar coronal hole, and the other in O VI 1032Å, in an active region. The event measured in C IV lasted approximately 3 minutes, with velocities reaching around 150 km s^{-1} in the blue wing and 100 km s^{-1} in the red wing. The active region events were more energetic and in total lasted ∼6 m. More precisely, we have at least two consecutive events occurring in a short time interval (∼12 m) separated by ∼3 arc sec. The explosive events seen in O VI showed a very complex structure of subsonic and supersonic velocity flows, both red-shifted and blue-shifted. The apparent maximum velocity reached in the blue wing was approximately 250 km s^{-1} and 215 km s^{-1} in the red wing.

There appears to be evidence of super-granular cells, with the increase in electron density occurring along the network boundaries. At some locations, periodicities of between 8 and 16 minutes are visible in the electron density variations.

In order to learn more about these explosive events, simulations were made assuming semi-circular magnetic flux tubes in a hydrodynamic code. The temporal evolution of the thermodynamic state of the loop was converted into C IV 1548Å line profiles. Departures from ionization equilibrium were assessed for the first time under conditions such as those encountered in explosive events. Work is well advanced on developing a 2-D MHD code.

Doppler Line Shifts The ultraviolet spectral lines formed at transition region temperatures in the solar atmosphere, show a prevailing line-shift. The velocities increase from a red-shift of ∼0 km s^{-1} at ∼20000 K, to 10 km s^{-1} at 1.9×10^5 K for the quiet Sun, and to ∼15 km s^{-1} at 1.0×10^5 K for the active region. At higher temperature an opposite behaviour is observed. In the quiet Sun a blue-shift of ∼2 km s^{-1} is observed at the Ne VIII formation temperature (6×10^5 K), while in the active region a blue-shifted value around ∼8 km s^{-1} is observed for the same spectral line. With these data we explore the idea that the occurrence of nano-flares in the magnetic loop around the O VI formation temperature could explain the observed red-shift of mid-to-low transition region lines as well as the blue-shift observed in low coronal lines. Performing an integration over the entire period of simulations, a red-shift of ∼6 km s^{-1} is found in C IV, while a blue-shift of ∼2 km s^{-1} and ∼10 km s^{-1} were derived for O VI and Ne VIII, respectively, in reasonable agreement with observations.

2.3.2 Cool Stars

These results are divided into three principal areas, as discussed below, and include work by Ferhat Ozeren and Darko Jevremović.

Algol-Type Binaries We present radio interferometric observations of the Algol-type binary system V505 Sagitarii made with the ATNF Compact Array at 6 cm and 3.6 cm over one orbital cycle (1.18 days). The radio flux level shows a clear modulation with evidence of eclipses of the emission region at both conjunctions of the binary, which may indicate the existence of an intra-binary region of activity. This has important consequences for the details of coronal formation and field interaction in active close binary stars.

CVn-Type Binaries We investigate the extent to which the Wilson-Bappu relationship holds for chromospherically active binaries using the Mg II h and k lines of 41 RS CVn stars observed with the International Ultraviolet Explorer satellite (IUE). The resulting fits are different from the relationships obtained for single, less active stars. Within a particular luminosity class the relationship is good, but it tends to break down when we incorporate objects ranging in luminosity from Class I to V. From model calculations there is very little dependence of the Mg II line-width on effective temperature. The line-width does however depend on the column mass at the transition region boundary showing increased line-width at lower column mass. There is also a dependence on the column mass adopted for the temperature minimum, although the major and dominant parameter is the surface gravity, g, scaling as $g^{-1/4}$. Within a given luminosity class more active objects will show larger line-widths, reflecting a higher column mass deeper in the atmosphere, e.g. at the temperature minimum level.

Carbon and Oxygen-Rich Systems We have developed a new method to determine the physical properties and the local circumstances of dust shells surrounding Carbon and Oxygen-rich stars for a given pulsation phase. The observed mid-infrared dust emission feature(s), in conjunction with both near-infrared and far-infrared photometry, are modelled from radiative transport calculations through the dust shell using a grid of detailed synthetic model input spectra.

2.4 C.S. Jeffery, Research Astronomer

2.4.1 Star Deaths

Stellar corpses are the burnt-out remains of stars which have exhausted their reserves of energy and have ceased to shine. All that may be seen is the glowing cinder as the star gently cools, or the signature of energized material trapped in their enormous gravitational and magnetic fields. Well known examples include black holes, white dwarfs and neutron stars. They are amongst the most exotic objects in the Galaxy — our mission is to discover how normal and benign stars like the Sun reach such macabre ends. In pursuing it, we also study the origins of elements essential to human life, the physics of matter under extreme conditions and processes that affect the evolution of entire galaxies.

The conventional paradigm has a Sun-like star swell up to become a red giant as it finishes converting hydrogen to helium. Pausing to convert helium to carbon and oxygen, the expansion then continues until the star sheds its outer layers as a planetary nebula and shrinks to become a white dwarf. However many stars do not fit comfortably into this picture, particularly those which have become so mixed up that even their outer layers have no hydrogen left. These are the helium stars and the hot subdwarfs.

The problem demands that we study stars that are in transition between hydrogen burning and death. Such phases frequently do not last long — a few thousand years or less — and hence such stars are rare. We must measure their properties in as much detail as possible. For instance, we would like to know their mass, radius and luminosity at the very least. The chemical composition of their surface layers can provide clues to past evolution, particularly if material processed by nuclear reactions in the interior has been exposed at the stellar surface. It is also important to know if the star is or was one of a pair — a binary star — because such stars can exchange mass with their companion as they evolve.

The Armagh approach combines high-quality observations with the best possible theoretical models, covering every aspect of stellar structure from the deep interior to the outermost layers of the atmosphere. Our theoretical work involves making hypotheses about the origin of given stars. These define boundary conditions for solving the time-dependent equations of stellar structure. Such solutions show long-term evolution in response to changes in chemical composition at different points within the star, and short-term changes (pulsations) in response to instabilities in the energy flow from the star. Our theoretical work also involves the construction of detailed models of the outermost layers of the star and the spectrum of radiation they emit.

2.4.2 Major Research Results

In 1999, Simon Jeffery and Hideyuki Saio (Japan) completed a new evolutionary model for the origin of one particular helium star, V652 Herculis, which involves two helium white dwarfs in a binary. The capture of one white dwarf by the other provides a new source of nuclear fuel so that the star is able to expand briefly to become a giant. Unlike most stars which burn from the inside out, nuclear reactions are ignited on the outside of the original white dwarf and then start to burn inwards. As it does so, the star's properties change so that at one point they match the current properties of V652 Her almost perfectly.

The analysis of stellar spectra can be a time-consuming and subjective task which involves the fitting of models with many free parameters to observations of varying quality. An important development in 1999 was the initiation of a project to build software for the automatic, efficient and objective analysis of stellar spectra. By the middle of the year, we were able to measure the effective temperatures, apparent diameters and the interstellar extinctions for both single and binary stars from their observed flux distributions. This enabled observational studies of evolution and pulsation in helium stars and of the physical dimensions of hot subdwarfs with cool companions to be rapidly progressed. The new software will be extended to measure other properties of stellar atmospheres during 2000.

The third major achievement of 1999 were two detailed studies of the pulsating star LSS 3184 — a helium star very similar to V652 Her. The first was based on observations obtained by Simon Jeffery at the South African Astronomical Observatory in 1995. Although normally impossible to measure for a single non-variable star, radius and distance can be measured for a pulsating star by observing its colours and surface motion through a pulsation cycle. Together with a previous measurement of surface gravity, these observations pointed to a mass too small to be realistic. Dr Vincent Woolf joined the Armagh team as a postdoctoral research assistant in 1999 July, and commenced work on very high-quality observations obtained by Simon Jeffery with the Anglo-Australian and the Hubble Space Telescopes in 1996/1997. These set new and tight constraints on the radius of LSS 3184 and partially resolved the mass problem.

2.4.3 Other Work and Activities

In 1900, FG Sagittae was an uknown faint blue star. Since then it expanded to become a cool giant helium star. With Schönberner (Potsdam), Simon Jeffery commenced a project to measure changes in its surface composition during the expansion using archival spectra. This complements an ongoing project with Don Pollacco (QUB) to study the chemical evolution of Sakurai's object — an even more rapidly expanding star which suddenly appeared in 1996.

Short-period non-radial pulsations in hot subdwarfs were discovered during the early 1990's using photometric techniques. Simon Jeffery and Don Pollacco made high-speed measurements of their surface motions; 2600 spectra were have been analyzed and exciting new results will be announced in 2000.

Because they are rare, the identification of new helium stars and helium star classes is an ongoing task of stellar pathology. New surveys and instruments provide thousands of new spectra which require classification and analysis. The definition of a spectral classification system for hot subdwarfs (with John Drilling, Louisiana) is nearly complete. Brian Mahon (Trinity College Dublin) and Simon Jeffery applied neural network software to the automatic classification of subdwarf spectra.

Regina Aznar Cuadrado and Simon Jeffery also made observations of binary subdwarf B stars and extreme helium stars with the Isaac Newton and Jacobus Kapteyn Telescopes in La Palma. An inconclusive search for periodic variations (pulsations) in two hot helium stars was presented at IAU Symposium 176 in Budapest. Regina Aznar Cuadrado is using spectra and photometry of hot subdwarfs to measure the absolute dimensions of those stars with faint companions.

Pilar Montañés Rodríguez studied the effect of projection on the profiles of spectral lines in pulsating helium stars and presented her results at IAU symposium 176. She commenced hydrodynamical calculations of the pulsations in luminous helium stars.

Vincent Woolf made spectroscopic observations of post-AGB stars with the Anglo-Australian Telescope, with a view to exploring the surface exposure of elements produced by the nuclear s-process while the star was a red giant.

Observations made by Simon Jeffery with the International Ultraviolet Explorer of the helium-rich white dwarf HS2253+8023 containing traces of hydrogen and metals were analysed and shown to be consistent with a relatively cool (15 000 K) white dwarf accreting material from the interstellar medium.

During the year Simon Jeffery also obtained a number of external research grants (including a 3-year PPARC PDRA grant to support Dr Woolf), and presented colloquia locally and abroad, and a number of popular talks.

2.5 M.D. Smith, Research Astronomer

2.5.1 How do Stars Form?

A collapse or implosion of a cloud of gas containing molecules and dust may lead to a low-mass star like our Sun. High-mass stars could form through the accretion of smaller protostars. By studying the physics of molecular clouds, we hope to learn if and why the collapse occurs.

We have investigated the nature of the molecular clouds by performing computer simulations. These new simulations account for many, but not all, realistic cloud properties. In three dimensions, with supersonic turbulence and magnetohydrodynamics, we have analysed the fields of shock waves produced. In work carried out together with Mac Low (New York), Zuev (Colorado), Heitsch (Heidelberg) and Klessen (Leiden), we have been able to distinguish between decaying turbulence, producing an exponential spectrum of shock speeds, and driven turbulence, producing a specific power-law spectrum.

A Unification Scheme for protostars was developed and extended in several directions. Clear predictions were made which have proven invaluable in stimulating and motivating new research projects. The scheme adopts the hypothesis that the mass of cloud gas is redistributed through several components. The core, envelope, accretion disc, jets and outflow all evolve on the same time-scales, passing through distinct stages from birth (Class 0 protostar), toddler (Class 1), childhood (Class 2), puberty (Class 3) to adolescence (Pre-Main Sequence).

The simple rules yield evolutionary tracks on diagrams relating any two of the above components. In a collaboration with Stanke (Bonn) and Zinnecker (Potsdam), work is now underway to test these predictions against statistics obtained from wide-field infrared surveys. An extension of the Unification Scheme to lower mass proto-brown-dwarfs suggests that they too will possess detectable outflows.

2.5.2 Herbig-Haro Objects

The interaction of young stars with their surroundings are accentuated within Herbig-Haro Objects, where streams and 'bullets' of ejected gas impact on the ambient molecular clouds. Infrared observations penetrate the clouds and reveal the processes occurring deep within. We are progressing with a programme of infrared observations and interpretations of the outflows. This includes a large-scale imaging study of bow shocks in the Orion Molecular Clouds (with Ka Chun Yu and Bally et al., Colorado) and spatially-resolved excitation and kinematic studies of well-known outflows (with Eislöffel, Tautenburg, Germany; and Davis, UKIRT, Hawaii) such as HH 1/2 and HH 46/47.

The question how objects can be accelerated to and maintain high speeds is important not only to astronomers. Projectiles — be they torpedoes, rocks, missiles or people — are slowed down by friction as they try to penetrate their environments, creating bow waves, sonic booms and turbulent wakes. In our Galaxy, in regions associated with young stars and star formation, we now realize that there are swarms of projectiles called Herbig-Haro Objects, named after the two scientists who first researched them. They appear to move ballistically — like cannonballs. But what are they doing there, where are the cannons and why were they fired?

We have now detected many jets of these interstellar bullets amidst narrow streams of gas. The jets are sometimes found in symmetric pairs, at the centre of which we can often only just see some highly obscured star-like bodies. These bodies turn out to be protostars: the stars-to-be. The moment a star is born is signalled by a round of cannon-fire!

The astrophysical jets are spectacular. But why should star birth be accompanied by such violent events? Recent work has shown that they are essential to the whole star-formation process. A star cannot easily form in isolation because of angular momentum conservation: it would wind up spinning so fast that it would be unable to collapse. It appears that the jets and bullets carry away the angular momentum during the final collapse. Michael Smith and collaborators have searched for, and found, the first evidence of rotation within the jets.

Observed over several years, the associated interstellar bullets are found to move at hundreds of kilometres per second. This leaves us with new questions: how can molecules survive such shattering speeds, and how do the cloud and protostar contrive to transfer angular momentum from the cloud to the bullets? Michael Smith hopes that finding the answers to these problems will ultimately contribute to our ability to control energy resources and to fly faster, on top of the direct goal of understanding our Universe. To this end, he is now undertaking a new programme of supercomputer simulations in which models for the interstellar bullets can be tested.

2.5.3 Other Work and Activities

In addition to this work on star-forming regions in our own Galaxy, Michael Smith has also begun a new study of star formation in external galaxies, particularly the very energetic 'starburst' galaxies often associated with distant interacting, or colliding stellar systems. In these objects new stars, especially massive stars, are being formed at rates, and under extreme conditions, not matched anywhere within our own Galaxy.

During the year, Michael Smith delivered a number of scientific and popular talks to groups both locally and abroad, and supervised two QUB undergraduates on summer project work. Towards the end of the financial year he obtained a research grant through the Joint Research Equipment Initiative to purchase a Silicon Graphics Origin 2000 supercomputer. Under this scheme, the cost of the supercomputer, approximately £250k, is funded partly by the PPARC (£125k), with the balance being provided by the industrial partner, in this case Silicon Graphics Inc. (SGI). Michael Smith also successfully obtained a PPARC research grant to support a postdoctoral research assistant for three years to work on the project 'The Origin and Evolution of Protostars: Tracking with Magnetohydrodynamic Numerical Simulations'.

2.6 M.E. Bailey, Director

2.6.1 Near-Earth Objects

During 1999 the Armagh Observatory played a major role in raising public awareness of the comet and asteroid impact hazard to civilization and in discussions of what, if anything, the UK government should be encouraged to do about the problem. Following the Adjournment Debate in the House of Commons on Project Spaceguard, on 1999 March 3, M.E. Bailey was among several astronomers invited to review the Parliamentary Office of Science and Technology (POST) report #126 (1999 April) 'Near Earth Objects', and was subsequently invited to present a talk on the subject to the Parliamentary Astronomy and Space Environment Group (PASEG) in the House of Lords (1999 May 10). A copy of this talk, together with links to related research work and other web-sites, is available at http://star.arm.ac.uk/paseg/.

A subsequent meeting attended by Mark Bailey, Jay Tate (Spaceguard UK), Nigel Holloway (Atomic Weapons Establishment), Richard Tremayne-Smith and Paul Murdin (British National Space Centre), together with Sir Crispin Tickell, Lembit Öpik MP and Lord Sainsbury, was held at the Department of Trade and Industry on 1999 July 8. This meeting reaffirmed the seriousness with which the government views the comet/asteroid impact hazard, and led to the establishment of a Near-Earth Object 'Task Force' to investigate possible UK options for contributing to the international spaceguard programme. The Task Force, chaired by Dr Harry Atkinson, will deliver a report on the subject to the government in 2000.

2.6.2 Leonid Meteor Research

Research by David Asher and Mark Bailey, of Armagh Observatory, Vacheslav Emel'yanenko, of South Ural University, Chelyabinsk, Russia, and Rob McNaught, of the Australian National University, Siding Spring Observatory, has explained the unexpected, spectacular shower of bright meteors seen in the small hours of 1998 November 17 and fine structure seen in the incidence of meteors associated with the Leonid meteor shower of 1999 November 18.

The Leonid meteor display occurs between 15 and 21 November each year, with peak activity on the night of the 17/18 November. The observed meteors are produced by collisions with the Earth's atmosphere of small dust particles ejected from the parent comet, Tempel-Tuttle. This object, which is a ball of dust and ice about 3–5 km across, moves around the Sun in an elliptical orbit with a period of revolution approximately 33 years. The dynamical features of the orbit are similar to those of Halley's comet, and comet Tempel-Tuttle is therefore classified as a Halley-type short-period comet. Owing to the extreme inclination of the cometary orbit (162 degrees), the dust grains collide almost head-on with the Earth, at a relative velocity of about 71 kilometres per second. At such a speed, a centimetre-size particle has the same kinetic energy as a speeding truck on a motorway.

A meteor shower is seen every year, but every 33 years or so, owing to the much higher spatial density of dust grains close to the comet, the intensity of the display is greatly enhanced. In fact, strong meteor showers, known as 'meteor storms', have been seen many times during the past thousand years, notably the events of 1799, 1833, 1866 and 1966. The earliest record of Leonid activity dates back to 899.

November 1998 therefore saw astronomers preparing for a possible meteor storm during the night of 17/18 November. However, although a moderately strong shower peak was observed as predicted, the meteor shower as a whole was dominated by the earlier appearance of hundreds of exceptionally bright meteors, known as fireballs. These were seen by observers at European longitudes during the previous night, 17 November, more than 16 hours ahead of the predicted peak.

In fact, meteor storms come in two types: a 'normal' storm, comprising many visual meteors per second, and explained as the result of the Earth running into particles that have been recently released from the comet; and a 'fireball' storm, in which the overall meteor count is lower but the event is dominated by hundreds of spectacularly bright meteors or fireballs.

The 1998 event was of the second kind, and the intensity and duration of this exceptional event indicated that the Earth must have passed through an extremely dense, narrow stream of large dust grains, having sizes ranging up to several centimetres. The timing of the event, more than 16 hours ahead of schedule, suggested that these dust particles occupied an orbit significantly different from that of the main stream of small grains. The orbital difference showed that the meteoroids must have left the cometary nucleus many hundreds of years ago; but it posed the question: how could the stream have maintained its coherence and high spatial density for so long?

To solve the problem, David Asher and co-workers calculated the motion of large dust grains ejected from the comet at each of its last 42 perihelion passages. They checked each case to see whether any of the particles could explain the fireballs seen in 1998, and identified the perihelion passage of September 1333 as the time when most of the observed particles were released. These particles had avoided spreading out as a result of a dynamical process known as a resonance, analogous to the mechanism leading to the fine structure seen in Saturn's rings.

Many comets and asteroids swing around the Sun in orbits that are simple multiples of the orbital period of Jupiter, the most massive planet in the solar system and the biggest disturbing influence on cometary orbits. Comet Tempel-Tuttle is no exception to this rule, having entered one of these 'resonant' orbits as long ago as the seventh century AD. For every fourteen revolutions of Jupiter, comet Tempel-Tuttle makes five, and the same relation holds true for the largest dust particles gently released by the comet.

The large grains with average orbital periods very close to that of the comet are therefore kept in step by the metronome effect of Jupiter's gravitational perturbations. Instead of spreading around the whole orbit, they are concentrated into a rather short orbital arc, leading to the formation of a dense strand of large particles, distinct from the 'normal' trails of small particles, ahead of and behind the comet. The structure of the meteoroid stream close to the comet can be visualized as rather like a telephone wire, made up of many separate, narrow strands. These form a complex, braided structure of material within the broader envelope of the meteoroid stream as a whole.

The calculations by David Asher and co-workers showed that in November 1998 most of the resonant arcs missed the Earth by a wide margin, but the arc of particles released in 1333 cut right through the Earth's orbit. What proved that this really explained the observations perfectly was that, although an encounter with one or another trail might normally be possible at any time within a day or two of the predicted Leonid maximum, the calculated intersection of the 1333 arc with the Earth matched the observed fireball maximum to the hour.

This remarkable result was the first observational demonstration of one of the most important dynamical features of meteoroid streams associated with Halley-type short-period comets, namely the effect of mean-motion resonances, previously studied by Emel'yanenko and Bailey. The work highlighted the presence of fine structure within meteoroid streams, and suggested a number of important new avenues for research. For example, the detailed variation of the meteor rate close to the time of the shower peak could be used to infer the precise distribution in space of the meteor-producing strands, and correlating the variations in meteor rate with changes in the meteor brightness distribution would give insight into the history of cometary mass loss over many revolutions.

In closely related work, David Asher also explained previous Leonid meteor storms (notably the great storms of 1833 and 1966), and together with Rob McNaught made accurate predictions for the time of the 'normal' storm trails of the Leonids. Their principal results were as follows:

- meteor storms generally only occur when the Earth passes within ~100,000 km of a trail of recently released meteoroids (i.e. within ~15 Earth radii of the centre of the trail);
- the predicted time of the peak of the meteor display can be improved by introducing a topographic correction, the final results being accurate to $\pm 5^{\mathrm{m}}$;
- the dust trails are slightly flattened in the cometary orbital plane;
- the 1999 Leonid shower was dominated by meteoroids comprising the 3-revolution dust trail emitted by comet Tempel-Tuttle at its perihelion passage of 1899, peaking (for the UK) at 1999 November 18 $02^{\mathrm{h}}\ 12^{\mathrm{m}}$, including a topographic correction of 4^{m}; and
- future years offer even better chances of a strong meteor shower, for example the 4-revolution trail of meteoroids ejected from the comet in 1866 is predicted to produce a zenith hourly rate (ZHR) $>$ 10,000 at 2001 November 18 $18^{\mathrm{h}}\ 19^{\mathrm{m}}$. The first encounter of the Earth with this particular trail occurs at 2000 November 18 $07^{\mathrm{h}}\ 51^{\mathrm{m}}$, with a predicted ZHR in the range 100–5,000, so the 2000 observations will be crucial to confirming or otherwise the likely meteoroid flux in 2001.

In summary, David Asher and Rob McNaught showed — for the first time — how to predict the timing and strength of meteor storms, taking full account of the complexity of the dynamics and the extremely narrow transverse dimensions in space of the recently ejected meteoroid streams.

In conclusion, it is interesting to note that good news for meteor observers can be a concern for satellite operators. Very high speed dust impacts can cause plasma to be generated, leading in turn to electrical failure in satellites. There is evidence, for example, that the Olympus communications satellite was disabled as a result of the impact of a meteoroid from the Perseid stream in 1993.

Thus, while there is an awareness of the hazard from man-made space debris, and of the hazard to civilization from impacts of large bodies, advance knowledge of the detailed structure of the Leonid stream also has potential commercial value. Satellite operators could use this information to minimise the risk from the Leonid dust trails, for example by adjusting the satellite's orbit to place the satellite in the Earth's 'shadow', or as far as possible from the centre of the dust trail, at the time of the peak meteoroid flux. By defining the structure of these trails more accurately than ever before, Asher and McNaught have therefore pioneered a new technique for mitigating the cometary debris impact hazard.

2.6.3 Scientific Administration

During the year, Mark Bailey was also appointed as Chair of the Astronomical Science Group of Ireland (ASGI), for a two-year period from 1999 October 1, and as a member of the RAS Education Committee, for a three-year period starting 1999 September 1. He was also appointed Editor-in-Chief of the journal *Earth, Moon, and Planets.*

2.7 M. de Groot, Consultant Research Associate

2.7.1 Correlation between Spectroscopy and Photometry in P Cygni

Data from the Automatic Photoelectric Telescope Service in Arizona continued to be collected. A paper analysing the photometry of P Cygni during the 20th century is in preparation in collaboration with C. Sterken, Brussels, and A. van Genderen, Leiden.

An investigation of Hα spectroscopy and *UBV* photometry of P Cygni covering the period 1990 to 1994 has shown that the star varies on a number of different time-scales ranging from a few months to 7 years. The longer time-scale variations are caused by normal S Dor variations; non-radial pulsations — s-mode or g-mode — are the suspected cause of the shorter time-scale variations. Real variations in the stellar wind are found to be connected to processes in P Cygni's photosphere. A paper in collaboration with N. Markova (Bulgaria), S. Scuderi (Italy), and N. Panagia (USA), has recently been submitted.

On the invitation of its Editor, a review article on P Cygni, in collaboration with G. Israelian (Tenerife) was produced for *Astrophysics and Space Science.*

2.7.2 Investigation of the S Dor Phenomenon in Luminous Blue Variables

A photometric study of η Carinae covering the period 1974 to 1998 has provided further evidence that this star is more complex than hitherto believed: a normal S Dor variable showing both long-term (a few years) and short-term (a few months) photometric variations seems to be surrounded by a hot luminous disc. The nature of η Carinae is being debated in the literature and at scientific meetings. We — de Groot, Sterken, and Van Genderen — do not find convincing evidence for binarity as proposed by others.

Visual observations of some 20 southern luminous blue variable stars, most of them in the Large Magellanic Cloud, continued to be collected by Albert Jones (New Zealand) and to be made available for analysis by a Nuffield Science Bursary student. Quasi-periodic light variations were found in several of these stars.

2.7.3 Other Activities

During 1999, Mart de Groot served as Co-Editor of The Journal of Astronomical Data. He also delivered a number of popular lectures in various parts of the world, and supervised two Nuffield Science Bursary students. He is currently Chairman of the Scientific and Local Organizing Committee of the international workshop "P Cygni 2000: Four Hundred Years of Progress", to be held in Armagh from 20–23 August 2000. The conference has been financially supported by sponsorship from the First Trust Bank, Armagh.

2.8 W.M. Napier, Senior Research Fellow

2.8.1 Zodiacal Cloud

The zodiacal cloud is a disc of dust orbiting within the inner planetary system. It is supplied erratically by the disintegration of comets entering the solar system, and by dust feeding in from collisions in the asteroid belt. The cloud can be seen at certain times of the year as a second 'Milky Way' along the ecliptic. Existing models of the zodiacal cloud have always adopted an equilibrum assumption, in which the input from comet and asteroid disintegration balances the output from collisional grinding between the dust particles and their removal by the Poynting-Robertson effect. A long-term project by Bill Napier has been the construction of a model zodiacal cloud in which the assumption of a steady-state balance is no longer made.

The significance of this study is that it puts into quantitative form the suggestion that the cometary component of the zodiacal cloud is highly variable, and that in the wake of giant comet entry into a short-period, near-Earth orbit, the dust influx to the Earth's atmosphere may acquire a climatically significant optical depth. The output from the programme is thus intended to be an input to Mie scattering studies of radiative transfer in the stratosphere and mesosphere, and to models of global climatic change.

This model was developed throughout 1999 to the state where quantitative results were being obtained. The cloud is specified by a three-dimensional grid, each element of which contains the numbers of dust particles as a function of semi-major axis, eccentricity and mass. The evolutionary pathways of dust particles due to radiation pressure are described by fixed transition probabilities connecting the grid elements. Other elements are absorbing states representing infall to the Sun or ejection to infinity: particles entering these states are removed from the system. Mass is injected from the breakup of comets entering short-period, high-eccentricity orbits at random times, and removed through collisional disintegration, the Poynting-Robertson effect and radiation pressure.

The detailed results confirm preliminary analyses that the annual flux of cometary dust on to the Earth may on occasion approach a million tons a year, almost two powers of ten higher than current values. Thus the zodiacal cloud is confirmed to be a highly variable entity, a fact which will inform future studies of climatic effect of cometary and asteroidal dust over long time-scales.

2.8.2 Quasar Redshifts

Continuing a long-standing interest in the statistical aspects of 'anomalous redshift' claims, Bill Napier, in collaboration with Geoffrey Burbidge (University of California at San Diego), has been investigating claims that there is a periodicity of 0.089 in the $\log(1+z)$ frequency distribution of quasars, with peaks occurring at redshifts $z = 0.06, 0.30, 0.60, 0.96, 1.41, \ldots, 4.46$. This claim is about 30 years old but a possible rationale has recently emerged in that such oscillations may be a generic feature of scalar-tensor theories of gravity in the post-inflation phase of expansion. The claim, if confirmed, would therefore have profound implications for cosmology. Selection effects are the major problem with this periodicity claim, and samples were chosen with a view to minimizing these. By the end of 1999 a definitive answer to the issue had still not been obtained.

3 Visitors and Seminars

The Observatory maintains an active visitors programme, encompassing students, postdoctoral research assistants and more senior researchers, and hosts a research seminar approximately once per week during the academic year. The calendar year 1999 saw working visits from 7 astronomers of postdoctoral status or higher, with additional visits by 2 Ph.D. students based elsewhere. During 1999 Observatory staff also supervised 7 school work-experience students, 2 A-level summer students under the Nuffield scheme, 2 QUB undergraduates on project work, 2 Trinity College Dublin (TCD) final-year undergraduate projects, and 1 undergraduate on a summer research programme. The programme of research colloquia for 1999 (numbering 28 separate talks) is listed in Appendix D. It is notable that more than half of these seminars were provided by external speakers.

Another aspect of the visitors programme is the high frequency of visits by members of the public and small groups. Observatory tours are usually conducted by the Librarian, who in 1999 showed approximately 750 individuals from 8 different countries around the Observatory. This highlights the success of the Armagh Observatory's 'open door' policy to attract small numbers of visits by interested members of the public, groups and societies.

These visitors included tours from more than a dozen groups and societies, including the Reading Astronomical Society, the Friends of St. Columbs Cathedral Londonderry, the Irish Science Centres Association Network, the Irish Astronomical Society, school parties (e.g. Armagh Saints and Scholars Integrated Primary School, the John Scottus School, Dublin), local societies (e.g. the Armagh Diocesan Society, the Friends of St. Patrick's Church of Ireland Cathedral), and students from Queen's University Armagh.

However, a far greater number of people now visit the Observatory electronically through the web-site (http://www.arm.ac.uk/), in the form of 'e-visitors'. The improvements in the web-site, upgraded during 1999 by the Starlink Manager Martin Murphy and other staff (principally Michael Smith and

Scott Manley), have now led to a position where the Observatory attracts more than 100,000 unique e-visitors per year, from more than 100 countries around the world. This highlights an additional role of the Armagh Observatory, as a gateway for the promotion of Northern Ireland, and Armagh City and District, on the world stage.

Finally, the Observatory hosted visits during 1999 by a number of VIPs and television personalities. Mr Lembit Öpik MP (Liberal-Democrat Spokesman for Northern Ireland) and family visited the Observatory on 1999 March 22, to present an academic sash to the Observatory, received by him from the Estonian Academy of Sciences on behalf of his grandfather, Dr Ernst Öpik, Acting Director of the Observatory from 1974–1976. The Minister for Education, Mr John McFall MP, visited the Observatory on 1999 April 8; and the actress Hannah Gordon spent a day at the Observatory whilst filming the television programme 'Watercolour Challenge'. This resulted in a broadcast on 1999 October 20, featuring interviews with Observatory staff and images of the Armagh Observatory and Astropark.

4 Public Understanding of Science

1999 included a total solar eclipse (August 11) visible from the UK mainland and a Leonid meteor storm (November 18), both 'once-in-a-lifetime' events almost guaranteed to attract media attention and to raise public interest in astronomy. Staff at the Armagh Observatory played a major role in explaining these phenomena to the general public, and were prominent in providing assistance as required both to individuals and the various mass-media. The Observatory exceeded by a large margin the record set the previous year (1998) for the total number of identified media mentions in a single calendar year, with the result that the Armagh Observatory probably received greater coverage on the national and international scene during 1999 than any other research group of comparable size in the UK or Ireland.

4.1 Total Solar Eclipse

Armagh Observatory staff were active in many ways. Aileen McKee, Martin Murphy, Lawrence Young and summer student Jonathan Horner helped the Planetarium cope with the large influx of visitors on eclipse day. Other Armagh astronomers observed the solar eclipse from various parts of Europe, ranging from places in Cornwall (cloudy), Alderney (clear), Northern France (cloudy), to Germany, Austria, Hungary, Bulgaria and Turkey (all clear). Reports from several of these observations were recorded in various media, including national radio, television and newspapers. The Irish Astronomical Association published an excellent summary of eclipse reports in the September issue of *Stardust*.

The Librarian's solar eclipse leaflet, prepared the previous year in readiness for the total solar eclipse (and also distributed through the Observatory's web-page: http://www.arm.ac.uk/eclipse99.html), was in great demand throughout the year, and a second print run was made. In total, almost 1500 hard copies of the eclipse leaflet were distributed to individuals and various organizations, the latter including the Royal Astronomical Society, the Royal Irish Academy, the PPARC, the English Riviera Tourist Board, and Devon County Council.

4.2 Press, Radio and Television

The number of identified mentions of the Armagh Observatory and its staff in various mass-media has increased from 11 in 1994 to 233 in 1999. Whilst many of these 'media mentions' (about 30%) are in the local press (e.g. the Ulster Gazette, Armagh Observer etc.), some of which have among the highest local impact factors in the UK, a substantial number of reports occur in specialist and technical magazines, on radio or television, or in the national and international press.

The number of identified media mentions is sufficiently large that it is of interest to consider the breakdown versus type of publication. This is shown in Table 1. Many of these newspapers and radio or television programmes reach millions of people simultaneously, and it is clear that many tens of millions of people must have been exposed to 'Astronomy in Armagh' during 1999.

The Observatory also issues press releases on various meteorological and astronomical topics of local or general interest, and on news items that specifically concern Armagh Observatory staff or their research results. In 1999, the Librarian and other staff produced 42 such media releases, of which at least 40 were published in one form or another in the local or national press, an exceptionally high 'hit' rate. In addition to media releases, astronomer Gerry Doyle published a series of 11 articles in the local newspaper 'The Ulster Gazette', while Bill Napier's novel *Nemesis*, a fictionalized account of a threat asteroid, published in paperback on December 1999, has sold a total of 50,000 copies. The book has now been translated into German and Japanese, with sales of a similar order expected in each of these countries.

Programme or Medium	Citations
UK and Republic of Ireland local newspapers	71
Popular astronomy and specialist magazines	33
UK national newspapers excluding Northern Ireland	30
UK local radio and Republic of Ireland radio	22
Northern Ireland and Republic of Ireland national newspapers	18
UK and Republic of Ireland national television	14
UK national radio	9
Foreign newspapers	7
Northern Ireland local television	6
Foreign radio	3
Foreign television	2
Miscellaneous items	18

Table 1: Breakdown of known media citations for 1999. The 233 identified citations include 30 reports in UK national newspapers (e.g. Times, Guardian, Independent, Daily Telegraph, Daily Mail, Daily Express, and corresponding Sunday papers); 18 in Northern Ireland and Republic of Ireland national newspapers (e.g. Belfast Telegraph, Irish News, Newsletter, Irish Times, Irish Independent, Sunday Tribune); and 22 UK local radio stations (e.g. Radio Ulster, Radio Foyle, Downtown Radio and others in Britain) and Republic of Ireland stations (RTE and local stations). The Observatory was featured 14 times on UK and Republic of Ireland national television news and documentary programmes (e.g. BBC1, BBC2, ITV3, ITV4, Channel 5, Sky, RTE), and 9 times on UK national radio (e.g. BBC Radio 4 Today and PM programmes, and Radio 5). The figure of 2 citations on foreign television is obviously an extreme lower limit, due to under-reporting.

The Librarian (and occasionally other staff) also regularly answers questions from members of the public on different aspects of astronomy, the list for 1999 extending to 265 distinct enquiries.

4.3 Astropark

During 1999, responsibility for the Armagh Astropark was transferred from the Planetarium to the Observatory (with effect from 1999 March 24). The Observatory is committed to developing and improving the facilities in the Armagh Astropark and seeks to improve this public facility as and when time and other resources allow. The vision is to make the Armagh Astropark the leading outdoor exhibit for the public understanding of science in Ireland.

Initial steps towards this objective were taken by Simon Jeffery with the completion and installation of five Astropark display boards during early 1999, and by Lawrence Young, Shane Kelly and Colin McKeown (Armagh Planetarium), to replace the model terrestrial planets which had previously been vandalized or stolen. The broken central cube, part of the hyper-cube exhibit, was repaired on a temporary basis by Colin McKeown.

4.4 History

4.4.1 Meteorological Record

During 1999, grant applications were progressed by Mark Bailey and John Butler (with the assistance of other staff, especially Lawrence Young and Martin Murphy) to obtain external funding to widen public access to the Observatory's long series of meteorological records which commenced on a regular basis in 1795 and continue to the present day. The applications were to enable outside users to obtain access to scanned images of all records, and to provide access to calibrated daily data on air temperature, humidity, rainfall, pressure and sunshine. By the end of the financial year two such applications were successful, providing funds in future years to complete a substantial meteorological project.

The successful grants were a Heritage Lottery Fund application 'Developing Access to Northern Ireland's Meteorological Record', to place on the internet the Observatory's 7500 pages of hand-written meteorological records, and an Irish Sailors and Soldiers Land Trust grant 'Compilation of the Irish Climate Archive', to enable the written record to be verified and calibrated and to facilitate research into general aspects of global warming contained within the Armagh climate archive.

4.4.2 Heritage

As the first stage of a larger conservation and archive project, an application has also been prepared to the Heritage Lottery Fund to restore three historic telescopes and their associated domes. One of the telescopes, the 15-inch reflector (1834) by Grubb, is of exceptional historical interest as the first large reflector to be mounted on an equatorial mounting with a clock drive. As such it is the forerunner of many of the large Grubb reflectors which followed in the nineteenth and twentieth centuries. The telescope will be rebuilt from the surviving parts and placed in its original location in the 1827 dome. The 18-inch Calver/Schmidt telescope will also be restored, probably to its original Calver Newtonian design. This project will be progressed by John Butler with the assistance of the architect Stephen Leighton, and David Sinden of the Sinden Optical Company.

5 Staff

The staff position at the Armagh Observatory on 31 December 1999 is shown in Appendix A. Individuals are identified by their 3-letter (sometimes 2 or 4) Starlink computer username (full e-mail address: xxx@star.arm.ac.uk), together with their job-title and an indication of their principal function in the Observatory. A high proportion of Observatory staff are involved in core research and support activities, the entire administration being supported by only three staff (mc, ambn, lfy), one of whom (lfy) is shared equally with the Planetarium.

5.1 Staff Movements

Mr Shane Kelly, the new Grounds and Meteorological Officer, arrived at the Observatory on 1999 October 1; and a new research student Ilía Roussev arrived at the beginning of the year to work with Gerry Doyle on analyses of SOHO data from the solar transition region, in particular on modelling ultraviolet explosive events on the quiet Sun. Two new PhD students were recruited in October, namely: Tigran Khanzadian, to work with Michael Smith on the environments of protostars; and David García Alvarez, to work jointly with John Butler and Gerry Doyle on modelling flares on late-type stars.

One new PPARC PDRA grant came into effect during the year, namely that relating to Vincent M. Woolf. Dr Woolf arrived in 1999 July, to work with Simon Jeffery on 'Pulsations in Early-Type Stellar Remnants'. One other PDRA, namely Dipankar Banerjee, left the Observatory early in 2000 to take up an appointment at the University of Leuven, Belgium. Dr Banerjee organized the Observatory seminars during 1999.

Two students, namely Darko Jevremović and Elena Pérez Pérez, successfully defended their PhD theses. The respective subjects were: 'Hydrogen Balmer Lines in Stellar Flares', and 'Dynamic Events in the Solar Atmosphere'.

6 Research Activity and Funding Trends

The scientific output and research activity of Armagh Observatory staff over the past seven years are summarised in Table 2. During this period, virtually all relevant performance indicators show a significant improvement: the number of refereed journal publications has trebled, the amount of external income has increased by a factor greater than five, and the number of identified media citations has increased by a factor greater than twenty.

However, Table 2 also highlights a worrying trend, namely a significant real-term decrease in the amount of DENI/DCAL funding. Without increased core funding, it will not be possible to maintain the positive trends seen in the above performance indicators; research activity at the Observatory will decline; and the fruits of the substantial financial and intellectual investment in astronomy at Armagh since the mid-1980s will have been wasted.

The 1998 Annual Report closed with a number of 'Items of Concern', the first of which concerned the issue of access to a sufficiently high bandwidth connection to the internet through the Joint Academic Network (JANET). The difficulty of resolving this issue may be attributed in part to funding issues, in part to the Observatory's unique status in the UK academic/research scene. The interests and objectives of the Armagh Observatory do not appear to fit closely with the strategic aims of any single Northern Ireland government department, but it is important that the Observatory should not be penalised by 'falling between stools'.

In fact, compared to its position a decade ago, the Observatory has 'lost' a number of funding possibilities in comparison with opportunities open to other similar institutions and research groups in the

Financial Year	External Grant Income (£000s)	Refereed Journal Publications	Identified Media Citations	Total DENI Grant-in-Aid (£000s)	DENI Income Normalised to 1993/1994 prices
1993/1994	35	13	–	445.0	445.0
1994/1995	58	22	11	425.6	414.9
1995/1996	172	19	14	468.5	442.1
1996/1997	264	45	45	480.0	442.3
1997/1998	275	42	108	473.2	425.7
1998/1999	195	43	147	443.0	383.1
1999/2000	293	32	233	458.5	390.2

Table 2: Increase in research activity over the years. The numbers of refereed journal publications and identified media citations refer to the corresponding calendar year (e.g. publications in financial year 1999/2000 corresponds to calendar year 1999). The total external income in 1999/2000 was £305k. The sixth column shows the value of the announced grant-in-aid for each financial year normalised to 1993/1994 prices, the values being corrected for rising costs by the Retail Prices Index. This *underestimates* the effects of salary inflation and other unavoidable additional running costs. The DCAL grant-in-aid for 2000/2001 has been announced at £458.5k, equivalent to only £380.3k at 1993/1994 prices.

UK. These include: (1) the lack of a Northern Ireland research studentship quota following the transfer, in the early 1990s, of research studentship funds from the SERC to the DENI; (2) the replacement, in the mid-1990s, of a primary connection to the JANET with a 'sponsored' connection through QUB at a much lower bandwidth (256 kbps) than that (2 Mbps) available to a university department; (3) the lack of any funding uplift in proportion to RAE-assessed improvement in 1996; (4) the omission in 1999 of the Observatory from plans to extend JANET access to both universities and FE colleges in Northern Ireland, and exclusion from plans for a high-bandwidth Northern Ireland Municipal Area Network; and (5) the apparent omission of the Observatory from funding opportunities under the JREI from 2000, when (under the DENI) it was eligible in 1999.

It seems important to underline with clarity the nature of the current threat, due to underfunding and other factors, to the continuing success of the Observatory. The following remarks are taken from the conclusion of the Operational Plan for 1999/2000[3], prepared at the start of this 1999 reporting year. Finding a resolution of the funding problem was identified as the key strategic issue to be progressed during 1999.

> "Looking to the future, irrespective of whether the government decides to fund a UK Spaceguard programme, it is essential that the Observatory should continue to strengthen its research capability. The alternative is to shrink, putting us in a weaker position for participation in the 2001 Research Assessment Exercise, and facing eventual decline. It is well known that the Observatory has not benefitted from any additional funding since the 1996 RAE, proportional to its improvement between the 1992 and 1996, and that this together with the rather flat funding regime of the past five or six years presents a rather dismal outlook for the future. Despite the enormous increase in research productivity indicated in Table 1 [see Table 2 above], the Observatory's total DENI grant-in-aid for 1999/2000 is virtually identical in cash terms to that given in 1992/1993. It cannot be emphasized too strongly that this cut in funding, in real terms, combined with the accumulation of unavoidable additional costs (e.g. the internal audit, salary inflation and a greater NILGOSS employer's pension contribution), has now reached a point where the Observatory may, within a few years, be facing a crisis comparable only to the long-term decline of the 1920s and 1930s, following the resignation of Dr J.L.E. Dreyer.
>
> In short, the issue of chronic underfunding of the Observatory must be resolved. Compared to this, the other objectives that we seek to achieve during the coming financial year are relatively straightforward. The Observatory must convince the new Northern Ireland executive to continue its past, generous investment in astronomy, and to provide the Observatory with a sufficient level of funding to recruit and retain the number of senior research and support staff necessary for it to operate efficiently and influentially both on the UK and international astronomical stage. The Observatory has a rich heritage and can make an immense contribution to the cultural, economic and social life of the community."

[3] *The Armagh Observatory and Planetarium Operational Plan 1999/2000*, April 30, 1999

A Armagh Observatory Staff 1999

	Title, Name and Starlink Username		Position	Notes	Base	Cost Centre
1	Professor Mark E. Bailey	meb	Director		OBS	OBS
2	Dr C. John Butler	cjb	Research Astronomer		OBS	OBS
3	Dr John E. Chambers	jec	Research Astronomer		OBS	OBS
4	Professor J. Gerry Doyle	jgd	Research Astronomer		OBS	OBS
5	Dr C. Simon Jeffery	csj	Research Astronomer		OBS	OBS
6	Dr Michael D. Smith	mds	Research Astronomer		OBS	OBS
7	Dr Bill M. Napier	wmn	Senior Research Fellow		OBS	OBS
8	Mr Geoff Coxhead	gc	Software/Hardware Support		OBS	OBS
9	Mr H. Martin Murphy	hmm	Starlink Manager		OBS	OBS
10	Mrs Margaret Cherry	mc	Accounts Officer		OBS	OBS
11	Mr Shane T. Kelly	stk	Grounds/Meteorological Officer		OBS	OBS
12	Mr John McFarland	jmf	Librarian/PRO/Archivist		OBS	OBS
13	Mrs Aileen McKee	ambn	Secretary/Admin. Support		OBS	OBS
14	Mr Lawrence F. Young	lfy	Joint Administrator		OBS/PLA	OBS/PLA
15	Dr David J. Asher	dja	Postdoctoral Research Assistant	PPARC	OBS	OBS
16	Dr Dipankar Banerjee	dipu	Postdoctoral Research Assistant		OBS	OBS
17	Mr Darko Jevremović	djc	Postdoctoral Research Assistant	PPARC	OBS	OBS
18	Dr Armin Theissen	ath	Postdoctoral Research Assistant	PPARC	OBS	OBS
19	Dr Vincent M. Woolf	vmw	Postdoctoral Research Assistant	PPARC	OBS	OBS
20	Ms Sandra V. Jeffers	svj	Research Student (MPhil)	F/T QUB	OBS	OBS
21	Mr David García Alvarez	dga	Research Student (PhD)	P/T QUB	OBS	OBS
22	Mr Enric Pallé Bagó	epb	Research Student (PhD)	P/T QUB	OBS	OBS
23	Ms Regina Aznar Cuadrado	rea	Research Student (PhD)	P/T QUB	OBS	OBS
24	Mr Tigran Khanzadian	tig	Research Student (PhD)	P/T QUB	OBS	OBS
25	Mr Scott P. Manley	spm	Research Student (PhD)	P/T QUB	OBS	OBS
26	Mr Kassios Mitrou	kam	Research Student (PhD)	P/T Athens	Self	OBS
27	Mr Ferhat F. Ozeren	ffo	Research Student (PhD)	F/T Ankara	OBS	OBS
28	Ms Elena Pérez Pérez	epp	Research Student (PhD)	P/T QUB	OBS	OBS
29	Ms Pilar Montañés Rodríguez	pmr	Research Student (PhD)	P/T QUB	OBS	OBS
30	Mr Ilía Iankov Roussev	ilr	Research Student (PhD)	P/T QUB	OBS	OBS
31	Mr Jim V. Scotti	jvs	Research Student (PhD)	P/T QUB	Tucson	OBS
32	Mr P. Nick Sleep		Research Student (PhD)	P/T Open Univ.	Home	Self
33	Mr Luca Teriaca	lte	Research Student (PhD)	P/T QUB	OBS	OBS
	Dr Mart J.H. de Groot	mdg	Consultant Research Associate	Retired	Home	OBS

Armagh Observatory staff position at 1999 December 31.

B Board of Governors and Management Committee 1999

B.1 Board of Governors

The Board of Governors comprises the Church of Ireland Archbishop of Armagh (Chairman), the Dean and Chapter of the Church of Ireland Cathedral of Armagh, 1 DENI nominee, 1 QUB nominee, and up to 3 additional members nominated by the Governors.

- Chairman: His Grace, The Most Reverend Dr R.H.A. Eames, The Lord Archbishop of Armagh
- The Very Reverend Dean H. Cassidy, Armagh
- The Venerable Archdeacon R.G. Hoey, Newry
- The Reverend Canon J.M. Barton, Newry
- The Reverend Canon A. Dawson, Cookstown
- The Reverend Canon C.F. Moore, Whitecross
- The Reverend Canon H.J.W. Moore, Cookstown
- The Reverend Canon R.J.N. Porteus, Cookstown
- The Reverend Canon F.D. Swann, Dungannon
- The Reverend Canon W.R. Twaddell, Portadown
- Professor A.E. Kingston, Queens University Belfast (QUB Nominee)
- Dr E. Haughey, Ballyedmond Castle, Rostrevor (Governors Nominee)
- Professor Sir Martin Rees, Astronomer Royal, IoA Cambridge (Governors Nominee)
- Professor D. Lynden-Bell, IoA Cambridge (Governors Nominee)

B.2 Management Committee

The Management Committee comprises the Church of Ireland Archbishop of Armagh or his nominee (Chairman), 3 members of the Board of Governors, 4 DENI nominees, 1 QUB nominee, 1 PPARC nominee, 1 DIAS nominee, and up to 4 additional members nominated by the Governors.

- Chairman: His Grace The Most Reverend Dr. R.H.A. Eames, The Lord Archbishop of Armagh
- The Venerable Archdeacon R.G. Hoey, Newry (Board of Governors)
- Professor A.E. Kingston, Queens University Belfast (Board of Governors)
- Professor D. Lynden-Bell, IoA Cambridge (Board of Governors)
- Professor A.E. Roy, University of Glasgow (DENI Nominee)
- Professor P.L. Dufton, Queens University Belfast (QUB Nominee)
- Professor M.S. Merrifield, University of Nottingham (PPARC Nominee)
- Professor L. Drury, Dublin Institute for Advanced Studies (DIAS) (DIAS Nominee)
- Dr F.N. Byrne (Deputy Chairman), Ballynahinch (Governors Nominee)
- Sir Kenneth Bloomfield, Chairman NIHEC (Governors Nominee)
- Professor D.A. Williams, University College London (Governors Nominee)
- Mr D.J. Clement, Antrim (Governors Nominee)

C Refereed Journal Publications 1999

1. Albayrak, B., **Özeren, F.F.**, Ekmekci, F., Demircan, O., 1999, "Period variation of six RS CVn-type binaries with possible light-time effect", Rev. Mex. Astron. Astrofis., 35, 3–12.

2. **Amado, P.J., Butler, C.J., Byrne, P.B.**, 1999, "Photometric modelling of starspots — I. A Barnes-Evans-like surface brightness-colour relation using $I_c - K$", MNRAS, 310, 1023–1032.

3. **Asher, D.J.**, 1999, "The Leonid meteor storms of 1833 and 1866", MNRAS, 307, 919–924.

4. **Asher, D.J., Bailey, M.E.**, Emel'yanenko, V.V., 1999, "The resonant Leonid trail from 1333", Irish Astron. J., 26, 91–93.

5. **Asher, D.J., Bailey, M.E.**, Emel'yanenko, V.V., 1999, "Resonant meteoroids from Comet Tempel-Tuttle in 1333: the cause of the unexpected Leonid outburst in 1998", MNRAS, 304, L53–L56.

6. **Bailey, M.E., Napier, W.M.**, "The fluctuating population of Earth impactors", J. Brit. Interplanet. Soc., 52, 185–194.

7. **Chambers, J.E.**, 1999, "A hybrid symplectic integrator that permits close encounters between massive bodies", MNRAS, 304, 793–799.

8. **Chambers, J.E.**, 1999, "N-body simulations of planet formation: varying the initial number of planetary embryos," Earth, Moon & Planets, 81, 3–6.

9. Davis, C.J., **Smith, M.D.**, Eislöffel, J., Davies, J.K., 1999, "Excitation and kinematics in H_2 bow shocks: near-infrared observations of HH 99 and VLA 1623A (HH 313)", MNRAS, 308, 539–550.

10. **Doyle, J.G.**, Keenan, F.P., Ryans, R.S., Aggarwal, K.M., Fludra, A., 1999, "Electron densities above a polar coronal hole based on improved Si IX density diagnostics", Solar Physics, 188, 73–80.

11. **Doyle, J.G., Teriaca, L., Banerjee, D.**, 1999, "Coronal hole diagnostics out to $8R_\odot$", A&A, 349, 956–960.

12. **Doyle, J.G.**, van den Oord, G.H.J., O'Shea, E., **Banerjee, D.**, 1999, "Exploring the dynamical nature of the lower solar chromosphere", A&A, 347, 335–347.

13. Friedrich, S., Koester, D., Heber, U., **Jeffery, C.S.**, Reimers, D., 1999, "Analysis of UV and optical spectra of the helium-rich white dwarfs HS 2253+8023 and GD 40", A&A, 350, 865–874.

14. Gunn, A.G., Brady, P.A., Migenes, V., Spencer, R.E., **Doyle, J.G.**, 1999, "Eclipsing behaviour of the radio emission in the Algol system V505 Sagittarii", MNRAS, 304, 611–621.

15. Israelian, G., **de Groot, M.**, 1999, "P Cygni: an extraordinary luminous blue variable", Space Sci. Rev., 90, 493–522.

16. **Jeffery, C.S.**, Hill, P.W., Heber, U., 1999, "The chemical composition of the pulsating helium star V652 Her", A&A, 346, 491–500.

17. **Jeffery, C.S.**, Saio, H., 1999, "Non-adiabatic linear pulsation models for low-mass helium stars", MNRAS, 308, 221–227.

18. Kameswara, R.N., Lambert, D.L., Adams, M.T., Doss, D.R., Gonzalez, G., Hatzes, A.P., Renée, J.C., Johns-Krull, C.M., Earle, L.R., Pandey, G., Reinsch, K., Tomkin, J., **Woolf, V.M.**, 1999, "The 1995–96 decline of R Coronae Borealis: high-resolution optical spectroscopy", MNRAS, 310, 717–744.

19. Kilkenny, D., Koen, C., **Jeffery, C.S.**, Hill, N.C., O'Donoghue, D., 1999, "The pulsating hydrogen-deficient star LSS 3184 (BX Cir)", MNRAS, 310, 1119–1127.

20. **Löbel, A., Doyle, J.G.**, Bagnulo, S., 1999, "Modelling the spectral energy distribution and SED variability of the Carbon Mira R Fornacis", A&A, 343, 466–476.

21. McNaught, R.H., **Asher, D.J.**, 1999, "Variation of Leonid maximum times with location of observer", Meteoritics & Planet. Sci., 34, 975–978.

22. McNaught, R.H., **Asher, D.J.**, 1999, "Leonid dust trails and meteor storms", WGN, Journal of the Int. Meteor Org., 27, 85–102.

23. **Özeren, F.F., Doyle, J.G., Jevremović, D.**, 1999, "The Wilson-Bappu relation for RS CVn stars", A&A, 350, 635–642.

24. **Pérez, M.E., Doyle, J.G.**, Erdélyi, R., Sarro, L.M., 1999, "Explosive events in the solar atmosphere", A&A, 342, 279–284.

25. **Pérez, M.E., Doyle, J.G.**, O'Shea, E., Keenan, F.P., 1999, "Temporal variability in the electron density at the solar transition region", A&A, 351, 1139–1148.

26. Sarro, L.M., Erdélyi, R., **Doyle, J.G., Pérez, M.E.**, 1999, "Modelling explosive events in the solar atmosphere", A&A, 351, 721–732.

27. **Teriaca, L., Banerjee, D., Doyle, J.G.**, 1999, "SUMER observations of Doppler shift in the quiet Sun and in an active region", A&A, 349, 636–648.

28. **Teriaca, L., Doyle, J.G.**, Erdélyi, R., Sarro, L.M., 1999, "New insight into transition region dynamics via SUMER observations and numerical modelling", A&A, 352, L99–L102.

29. van Genderen, A.M., Sterken, C., **de Groot, M.**, Burki, G., 1999, "Photometric behaviour of Eta Carinae, a celestial Chinese lantern", A&A, 343, 847–860.

30. Völker, R., **Smith, M.D.**, Suttner, G., Yorke, H.W., 1999, "Numerical hydrodynamic simulations of molecular outflows driven by Hammer jets", A&A, 343, 953–965.

31. **Woolf, V.M.**, Lambert, D.L., 1999, "Three very young Hg-Mn stars in the Orion OB1 Association", ApJ, 520, L55–L58.

32. **Woolf, V.M.**, Lambert, D.L., 1999, "Mercury elemental and isotopic abundances in Mercury-Manganese stars", ApJ, 521, 414–431.

D Armagh Observatory Seminars 1999

Date	Speaker	Affiliation	Title
[illegible] Jan 1999	D.J. Asher	Armagh	Asteroid Astrometry and Orbit Determination
[illegible] Feb 1999	C.S. Jeffery et al.	Armagh	Discussion Meeting on Burbidge & Hoyle's Proposed New Steady State Cosmology
1 Mar 1999	C.S. Jeffery et al.	Armagh	Discussion Meeting on Giant Extrasolar Planets in Short Period Orbits
15 Apr 1999	J. Papaloizou	QMW, London	Planet Formation and Migration in Protoplanetary Discs
22 Apr 1999	C. Lunardelli	Univ. of Milan, and DIAS, Dublin	Study of the Stability of the Sun-Jupiter-Saturn System in the Light of KAM Theory
27 Apr 1999	U. Heber	Universität Erlangen Nürnberg	Hot Subdwarfs: Properties in General and Pulsations in Particular
6 May 1999	T. Smith	NICER, Stranmillis College	The Armagh CD-ROM for Schools
[illegible] May 1999	C.S. Jeffery	Armagh	Helium Stars in the Galaxy
13 May 1999	D. Banerjee	Armagh	Solar Eclipses
[illegible] May 1999	L. Teriaca	Armagh	Fine Structure in the Solar Atmosphere
27 May 1999	D.W. Hughes	University of Sheffield	An 'Accurate' Calculation of the Present-Day Earth's Cratering Rate
[illegible] Jun 1999	M. Murphy	Armagh	Computer and Network Security I
[illegible] Jun 1999	S.P. Marley	Armagh	Computer and Network Security II
17 Jun 1999	N.T. Holloway	Atomic Weapons Establishment	Deflecting Near-Earth Objects: Fact and Fiction
24 Jun 1999	D.I. Steel	Spaceguard Australia	God's Longitude or The Calendrical Meridian
15 Jul 1999	C.D. Impey	Steward Observatory, Tucson	Are We Alone? Implications of Modern Cosmology for the Origin of Life
2 Sep 1999	M. Johnston-Hollitt	University of Adelaide	A3667: A Dramatic Cluster Merger
9 Sep 1999	E. O'Shea	QUB	Oscillations in the Active Regions of the Sun
[illegible] Oct 1999	S.V. Jeffers	Armagh	Comparing the Lunar Cratering and the Small Near Earth Asteroid Size Distribution
[illegible] Oct 1999	V.M. Woolf	Armagh	H_α in H_α M Stars
27 Oct 1999	A.G. Gunn	NRAL, Jodrell Bank	Gyroemission from Active Close Binaries
27 Oct 1999	A.G. Gunn	NRAL, Jodrell Bank	MERLIN and EVN: Galway and Armagh's Contribution
11 Nov 1999	M.S. Madjarska	Institute of Astronomy, Sofia	Plasma Diagnostics of Solar Prominences as Observed by SUMER, CDS, EIT on SOHO
2 Dec 1999	M.D. Smith	Armagh	Astrophysical Turbulence
[illegible] Dec 1999	C.S. Jeffery	Armagh	Evolutionary Constraints Imposed by the Pulsations in Extreme Helium Stars
9 Dec 1999	J.K. Davies	UKIRT, JAC, Hawaii	Physical Properties of Trans-Neptunian Objects
14 Dec 1999	J. Drilling	Louisiana State University	Spectral Classification of Hot Subdwarfs
16 Dec 1999	W.J. Couch	University of New South Wales, Sydney, Australia	Star Formation Activity in Distant Rich Clusters of Galaxies: Going Beyond the Core

Table 1: Seminars at Armagh Observatory, calendar year 1999. Organized by D. Banerjee.

E Talks by Armagh Observatory Staff 1999

Date	Speaker	Location	Title
1999	J. McFarland	Armagh Observatory	49 Tours of Armagh Observatory Given in 1999
1999	C.S. Jeffery	Professur Astrophysik, Universitat Potsdam, Germany	Stellar Remnants: Chemical Evolution and Binary Companions
Jan 1999	J.E. Chambers	Nice, France	Making the Terrestrial Planets
Wed 20 Jan 1999	M. De Groot	Sao Paulo, Brazil	The Origin and Future of the Universe
Sat 6 Feb 1999	M.E. Bailey	Irish Physics Student Association Meeting, QUB	The Increasing Threat from Space
Wed 3 Mar 1999	M.E. Bailey	Press Conference, House of Commons, London	The Impact Hazard
Wed 10 Mar 1999	M.D. Smith	Tautenburg Observatory, Germany	The Unification Scheme for Protostellar Outflows: Version 3
Wed 17 Mar 1999	C.J. Butler	Royal Meteorological Society, Imperial College, London	Solar Signals in Climate Data
Sat 20 Mar 1999	S.V. Jeffers	Armagh Planetarium, Mothers & Daughters Day	Earth in the Cosmic Shooting Gallery
Sat 20 Mar 1999	M.E. Bailey	COSMOS 99, Tullamore Astron. Soc., Tullamore	The Increasing Threat from Space: Comets, Asteroids and NEOs
Apr 1999	E. Pallé Bagó	EGS Meeting 1999, The Hague, The Netherlands	Sunshine Records from Ireland, Cloud Factors and their Link to Solar Activity and Cosmic Rays
Fri 9 Apr 1999	J.G. Doyle	ASGI Meeting, Galway	Irish Telescopes
Fri 9 Apr 1999	D.J. Asher	ASGI Meeting, Galway	The 1998 Leonid Fireball Outburst
Fri 9 Apr 1999	E. Pallé Bagó	ASGI Meeting, Galway	An Investigation into Sunshine Records from Ireland and their Link to Solar Variability
Mon 12 Apr 1999	D.J. Asher	Leonid MAC Workshop, NASA Ames, USA	Modelling of the Leonid Meteor Shower
Tue 27 Apr 1999	M.D. Smith	Dunsink Observatory	The Violent Birth of Stars
May 1999	J.G. Doyle	Keynote presentation on SOHO Workshop, Paris	Coronal Hole Diagnostics
Thu 6 May 1999	C.S. Jeffery	Armagh Observatory	Helium Stars in the Galaxy
Mon 10 May 1999	M.E. Bailey	PASEG Meeting, House of Lords, London	Near-Earth Objects: Origin, Collision Rate and Actuarial Risk
Thu 13 May 1999	D. Banerjee	Armagh Observatory	Solar Eclipses
Fri 14 May 1999	M.E. Bailey	Royal Astronomical Society, London	Fireballs from Comet Tempel-Tuttle: A Blast from the Past
Thu 20 May 1999	L. Teriaca	Armagh Observatory	Line Shifts in the Solar Atmosphere
Wed 16 Jun 1999	H.M. Murphy	Armagh Observatory (Joint talk with Scott Manley)	Computer and Network Security
Mon 28 Jun 1999	S.P. Manley	NISTRO Pupil Science Initiative, King's Hall, Belfast	Earth in the Cosmic Shooting Gallery
Jul 1999	J.E. Chambers	Stanford University, California, USA	Planet Formation
Thu 29 Jul 1999	C.J. Butler	South African Astronomical Observatory	Global Warming — Man or Nature?
Aug 1999	M. de Groot	Perrenport, Cornwall	6 Lectures on the Total Solar Eclipse, and the Origin and Future of the Universe

Presentations by Armagh Observatory staff, 1999 January 1 to 1999 August 31.

Date	Speaker	Location	Title
Sep 1999	J.E. Chambers	NASA Ames Research Center, California	Meet the Postdocs
Sep 1999	J.E. Chambers	NASA Ames Research Center, California	Planets in the Asteroid Belt
Wed 8 Sep 1999	D.J. Asher	Queen's University Belfast	Dust Trail Dynamics and Meteor Storm
Fri 17 Sep 1999	C.J. Butler	ASGI Meeting, Dublin	Patrick Wayman and Irish Astronomical Observing Facilities
Fri 17 Sep 1999	C.S. Jeffery	ASGI Meeting, Dublin	Observations of Hot Subdwarfs from the La Palma Observatory
Fri 17 Sep 1999	W.M. Napier	Cesena, Italy	Periodicity in the Redshift Distribution of Quasars
Mon 20 Sep 1999	M.D. Smith	Goettingen, Germany	The Evolution of the Environments of Proto-Brown Dwarfs
Tue 21 Sep 1999	J. McFarland	Markethill High School, Elim Church	Astronomy (Practical) - I
Fri 24 Sep 1999	D.J. Asher	International Meteor Conference, Frasso Sabino Italy	Predicting Leonid Meteor Storms
Tue 28 Sep 1999	J. McFarland	Markethill High School, Elim Church	Astronomy (Practical) - II
Oct 1999	J.E. Chambers	Abano, Italy	Planets in the Asteroid Belt
Mon 4 Oct 1999	J. McFarland	East Antrim Astron. Soc., Ballyrobert, Co. Antrim	The Ingenious Mr (Kenny) Edgeworth
Mon 4 Oct 1999	J. McFarland	East Antrim Astron. Soc., Ballyrobert, Co. Antrim	The Bible and Astronomy
Wed 6 Oct 1999	M. de Groot	Takoma Park, Maryland, USA	The Origin and Future of the Universe
Wed 6 Oct 1999	S.V. Jeffers	Armagh Observatory	Comparing the Lunar Cratering and the Small Near-Earth Asteroid Size Distribution
Thu 7 Oct 1999	V.M. Woolf	Armagh Observatory	Mercury in Hg-Mn Stars
Fri 8 Oct 1999	S.V. Jeffers	Royal Astronomical Society, London	Comparing the Lunar Cratering and the Small Near-Earth Asteroid Size Distribution
Sun 10 Oct 1999	D.J. Asher	Whirlpool Star Party, Birr	Leonid Dust Trails and Meteor Storms
Wed 13 Oct 1999	D.J. Asher	Liverpool John Moores University, Liverpool	Accurate Predictions of Leonid Meteor Storms
Tue 19 Oct 1999	J. McFarland	Markethill High School, Elim Church	Astronomy (Practical) - III
Tue 19 Oct 1999	M.D. Smith	MPIA, Heidelberg, Germany	The Shocks in Supersonic Turbulence
Wed 20 Oct 1999	D.J. Asher	Irish Astronomical Association, Belfast	The Leonid Meteor Storm
Sat 30 Oct 1999	M. de Groot	Annual Meeting of AMALF, Normandie, France	Origine et Future de l'Univers
Wed 3 Nov 1999	D.J. Asher	Armagh Planetarium	The Leonids: Can Meteor Storms be Predicted?
Wed 3 Nov 1999	M.D. Smith	Irish Astronomical Association, Belfast	The Birth of a Star: a Spectacular Display of Jets and Shocks
Mon 8 Nov 1999	D.J. Asher	Astronomy Ireland, Dublin	The History of Meteor Astronomy and Coming Leonid Storms
Tue 9 Nov 1999	J. McFarland	Markethill High School, Elim Church	Astronomy (Practical) – IV
Fri 12 Nov 1999	M.E. Bailey	Royal Astronomical Society, London	Predictions of a Fine Display of Leonids on 18 November 1999
Sat 13 Nov 1999	D.J. Asher	The 1999 Jordanian Leonid Meteors Conference	Dynamics of Leonid Dust Trails (The Cause of Storms)
Mon 15 Nov 1999	C.S. Jeffery	Tohoku University, Sendai, Japan	The Evolutionary Status of Hydrogen-Deficient Stellar Remnants
Mon 22 Nov 1999	C.S. Jeffery	Gunma Observatory Workshop on Binary and Variable Stars, Gunma Astronomical Observatory, Gunma	Evolutionary Constraints Imposed by Pulsations in Extreme Helium Stars
Wed 24 Nov 1999	C.S. Jeffery	Dept. of Astronomy, Tokyo University, Japan	Evolutionary Constraints Imposed by Pulsations in Extreme Helium Stars
Thu 2 Dec 1999	M.D. Smith	Armagh Observatory	Astrophysical Turbulence
Fri 3 Dec 1999	C.S. Jeffery	Armagh Planetarium	The Star of Bethlehem
Mon 6 Dec 1999	M.D. Smith	Tautenburg Observatory, Germany	The Signatures of Supersonic Turbulence in Star Forming Regions
Mon 6 Dec 1999	C.S. Jeffery	Armagh Observatory	Evolutionary Contstraints Imposed by the Pulsations in Extreme Helium Stars
Tue 7 Dec 1999	C.J. Butler	Physics Department, Imperial College, London	Sunshine, Clouds and Cosmic Rays
Mon 13 Dec 1999	C.S. Jeffery	Armagh Planetarium	The Star of Bethlehem

Presentations by Armagh Observatory staff, 1999 September 1 to 1999 December 31.

F Identified Media Mentions 1999