Armagh Observatory

Annual Report

Calendar Year 1998

Prepared by the Director

M.E. Bailey

This report briefly summarizes research and other activities of the Armagh Observatory during the calendar year 1998.

Contents

1 Introduction

The Armagh Observatory, founded in 1790 by Archbishop Richard Robinson, is a modern astronomical research institute with a rich heritage. It is situated close to the centre of the City of Armagh in grounds which include the Armagh Planetarium and a scale model of the universe known as the Armagh Astropark. The Observatory, which is one of the UK and Ireland's leading scientific research establishments, receives baseline support from the Department of Education Northern Ireland (DENI) to maintain the grounds, the Grade A listed building and some 15 core-funded research and support staff.

In addition to these established posts, there is a fluctuating population of short-term research staff, currently numbering 18. These include research students, postdoctoral research assistants, senior research associates, and visitors, many of whom are engaged on fixed-term research contracts for periods ranging from one to three years or more. Overall, around 25 astronomers of graduate or postdoctoral status are actively studying Stellar Astrophysics, the Sun, Solar System astronomy, and the Earth's climate.

Facilities at Armagh Observatory for computing and data reduction are mostly excellent and include a local Starlink node funded by the Particle Physics and Astronomy Research Council (PPARC). Observatory staff receive regular awards of telescope time and research grants from the PPARC and other organizations.

Research interests of Observatory staff currently include (i) Stellar Astrophysics (including star formation, astrophysical jets, the Sun, cool stars, hot stars, helium stars, star-spots, flares, circumstellar dust), (ii) Solar System Astronomy (including celestial mechanics, planet formation, dynamical evolution of comets and asteroids, interplanetary dust), and (iii) Solar System – Terrestrial Relationships (including solar variability, climate, accretion of interplanetary dust and cometary impacts). In addition, Observatory staff maintain an active programme of Public Understanding of Science (PUS), via lectures, popular astronomy articles and interviews with the press, radio and television. Further details concerning the research interests of all the Observatory staff may be obtained from the Observatory web-site at: http://www.arm.ac.uk/.

The 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.*

The Armagh Observatory participates in the UK Research Assessment Exercise, held in 1992, 1996 and again in 2001. Staff at the Observatory achieved a Grade 4 in the Physics Unit of Assessment (on a seven-point scale 1-5*, with 5* the highest) in each of the 1992 and 1996 RAEs. This grade corresponds to 'Research quality that equates to attainable levels of national excellence in virtually all sub-areas of activity, possibly showing some evidence of international excellence, or to international level in some and at least national level in a majority.'

2 Principal Areas of Research

Staff at the Armagh Observatory carry out research in the following principal areas:

1. Stellar Astrophysics, including star formation, astrophysical jets, the Sun, so-called 'cool' stars, evolved hot stars and helium stars, star-spots, flares, the physics of stellar chromospheres (the transition layer between the stellar surface and the extremely hot outer layers of stellar atmospheres known as the corona), the mechanisms of coronal heating in active stars including the Sun, the environments around evolved stars, and stellar clusters.

2. Solar System Astronomy, including celestial mechanics, numerical and semi-analytic methods, the origin and dynamical evolution of comets, asteroids and meteorites, the evolution of interplanetary dust; the formation of Edgeworth-Kuiper belt objects, the origin and evolution of planetary systems, and the structure and evolution of extra-solar planetary systems.

3. Solar System – Terrestrial Relationships, including solar variability and climate (mediated by Sunspot and solar flare activity, and galactic cosmic rays), the effects of accretion of cosmic dust and larger bodies (comets and asteroids) on the Earth, the impact hazard posed by comets and asteroids, and the possible link between interplanetary bodies and the historical and climatological records.

Staff at the Observatory have also carried out research on (i) meteor streams, (ii) testing the 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, is of particular interest in being (a) virtually continuous since its inception in 1795, and (b) only slightly affected by surrounding urban development.

A few highlights from 1998:

- Brendan Byrne Memorial Meeting: a highly successful conference with more than 60 participants from 15 countries, 1998 September 2–4. The proceedings of the conference *Solar and Stellar Activity: Similarities and Differences,* edited by C.J. Butler & J.G. Doyle, were published as volume 158 in the ASP Conference Series.

- 1998 Robinson Lecture: delivered by Professor John C. Brown of the University of Glasgow, Astronomer Royal for Scotland. Professor Brown's lecture 'Life in a Stormy Universe' was well received and published in summary form in the Irish Astronomical Journal **26,** 21–22, 1999. The lecture was followed the next day by a Schools Lecture 'Black Holes and White Rabbits'. The events were well attended and enjoyed by all.

- Media Coverage: The Observatory is the principal point of contact for astronomy in both Northern Ireland and the Republic of Ireland, with frequent mentions in the national and international press, and on radio and television. The 147 identified occasions on which the Observatory was noted in one or another medium during the calendar year 1998, up almost 40% from the number in the previous year, are listed in Appendix E. The success of this activity, which promotes astronomy and disseminates the research output of the Observatory to a non-professional audience, highlights the strength of public interest in astronomy and related sciences, and in particular in work currently carried out at Armagh.

- External Grant Income: Total external grant income was £195k during the financial year 1998/1999, a significant fraction (47%) of the DENI recurrent grant-in-aid. Total external income during the year was £213k.

3 Staff Movements

The Grounds and Meteorological Officer, Mr John McGinn, left the Observatory at the end of 1998 June for a new position in the south of England prior to seeking work abroad. Pending an external review of the grading of the position, completed towards the end of 1998, the post was left vacant with essential grounds maintenance work being carried out by contractors. During this time, meteorological readings were taken primarily by the Librarian with assistance from other staff.

Two new PPARC PDRA grants came into effect during the year, namely those relating to David J. Asher and Darko Jevremović. These in effect replaced two other postdoctoral grants (relating to Victor Clube's Leverhulme Fellowship and Alex J. Löbel's PPARC PDRA position), which finished during the same period.

Dr Michael D. Smith joined the Observatory as Research Astronomer on 1998 October 1. Dr Smith has research interests in star formation, stellar and galactic jets and magnetohydrodynamics.

Five new postgraduate students were welcomed to the Observatory: Ms Sandra Jeffers (studying for an M.Phil.), Mr Ferhat Ozeren (visiting from Ankara, Turkey), Ms Pilar Montañés Rodríquez, Mr Enric Pallé Bagó, and Mr Ilía Roussev (all studying for a Ph.D.). Mark Bailey and John Chambers began co-supervision of another Ph.D. student, namely Mr Nick Sleep, who is a part-time student working primarily with Dr Barrie W. Jones of the Open University.

Four students were awarded the degree of Ph.D. in 1998, namely Mr Duncan C. Foster, Ms María Teresa Eibe, Mr Pedro J. Amado and Mr Luis Sarro. A fifth student, namely Mr Alan D.S. Coughlin, gained an M.Phil.

4 Staff

The staff position at the Armagh Observatory on 31 December 1998 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. Funding to support these staff comes primarily from the DENI grant-in-aid (£443k) and external income (£213k), the latter mostly in the form of research grants obtained through competitive application and peer review from the PPARC.

The Observatory runs an extremely lean administration, currently comprising three staff (mc, ambn, lfy), one of whom (lfy) is shared equally with the Planetarium. The gross cost of salaries for this administrative support is less than 7% of total income. In addition, the Observatory is fortunate in being able to draw on some very capable support staff (two computer staff, one Librarian/PRO/Archivist, and one Grounds/Meteorological Officer), whose salaries together account for a further ∼11% of total income. It is a credit to all these staff that the entire administrative, academic and grounds support for the Observatory is achieved at a total cost for salaries of less than 20% of the total income.

5 Visitors and Seminars

The Observatory maintains an active research visitors programme, encompassing students, post-doctoral research assistants and more senior researchers, and hosts a research seminar approximately once per week during the academic year. The calendar year 1998 saw working visits from 9 astronomers of post-doctoral status or higher, with additional visits by three Ph.D. students based elsewhere. During 1998 Observatory staff also supervised 6 school work experience students, 4 A-level summer students under the Nuffield scheme, 4 QUB undergraduates on project work, 1 Trinity College Dublin (TCD) final-year undergraduate project, and 5 other undergraduates on miscellaneous summer work. The programme of research colloquia for 1998 (numbering 33 separate talks) is listed in Appendix C. It is notable that more than 20 of these seminars were provided by external speakers.

A further aspect of the visitors programme is the high frequency of visits by members of the public and by small groups. Observatory tours are usually conducted by the Librarian, who in 1998 showed approximately 1000 individuals from more than 16 countries around the Observatory. This number is up by 100% compared to the previous year, a remarkable result which suggests heightened public interest in astronomy in Armagh City and District, and indicates the success of the Armagh Observatory's 'open door' policy to attract members of the public, groups and societies.

It is recognised, however, that visitor numbers should be kept under review, and that they should not increase to the extent of impeding or interfering with the primary research activity and objectives of the institution. A new policy of attracting electronic visitors ('e-visitors'), via the Observatory's web-site (http://www.arm.ac.uk/), was introduced during the year, and it is anticipated that steady improvements in the number of visits to the Observatory's web pages will take place in future years. The number of e-visits is already measured in tens of thousands per year.

Visitors during 1998 included nearly 20 group tours, ranging from specialist groups and societies (e.g. the Armagh and District Radio Club, the Clerical Reading Society, Astronomy Ireland, and the Irish Astronomical Association), to school children (e.g. the Heartstone Project, the John Scottus School, Dublin) and local groups (e.g. the Armagh and Dungannon Soroptimists, the Armagh Natural History and Philosophical Society etc.). In addition, the Observatory received a number of VIPs, including Mr Lembit Öpik MP, a party of senior civil servants from Bangladesh, Professor George Bain (QUB Vice-Chancellor) and Professor John Brown (Astronomer Royal for Scotland).

6 Research

The scientific reputation of the Armagh Observatory depends largely on peer assessment of sometimes highly technical scientific publications, and on the one-to-one interactions between Armagh Observatory staff and other research scientists, whether at conferences, or in collaborative research projects between the Observatory and groups in other countries. A subset of the total research and other public output, namely the list of refereed journal publications during 1998, is given in Appendix B. A second subset, namely the list of more than 50 public talks delivered by Observatory staff during 1998, is given in Appendix D.

These examples illustrate the variety of routes by which the research results of Observatory staff are communicated, namely through talks or popular articles in the local, national or scientific media; at conferences, seminars and workshops; in books; in refereed scientific publications, journals or conference proceedings; and in a variety of non-refereed articles, some of which nowadays are in entirely electronic form (e.g. contributions to CD-ROMs such as 'Deep Impact: An Interactive and Educational Guide to Comets and the Universe', United International Pictures & Dreamworks Pictures, April 1998). All these forms of public output, which are substantial, help to raise the national and international profile of astronomy, and in particular of astronomy at Armagh.

A further indicator of the Observatory's research activity is the amount of external research income, raised mostly through a competitive process of grant application and peer review. In 1998, the total

external grant income was ~£195k, representing a substantial fraction (47%) of the total DENI recurrent grant in aid. Research activity and external income generation are areas where economies of scale work extremely well: larger research groups attract the lions share of available research council funding and, in view of the Observatory's current size, there remains room for improvement, given investment in additional research staff.

The remainder of this section summarises some of the research results obtained in 1998 by the Observatory's senior research staff and associates.

6.1 M. de Groot, Senior Research Associate

Dr Mart de Groot continued his research into the behaviour of Luminous Blue Variables (LBVs):

1. In collaboration with Drs Van Genderen (Leiden, Holland) and Sterken (Brussels, Belgium) papers XV and XVI in the series 'Light Variations of Massive Stars' were published. These dealt with the brightness variations of several massive stars in the two nearest neighbour galaxies, namely six stars (R85, R99, R103, R110, R123 and R128) in the Large Magellanic Cloud (LMC) and two (R42 and R45) in the Small Magellanic Cloud (SMC). Several of these stars were identified as genuine LBVs, pulsation periods were determined for all of them, and theoretical models were discussed.

2. As a part of the same collaboration, paper II in the series 'Cyclicities in the light variations of LBVs' was published. It dealt with R40 in the SMC which was found to be subject to normal S Dor (slow pulsation-like) phases.

3. Also in the same collaboration, another paper on the brightness variations of one of the brightest stars in our Galaxy, η Carinae, was completed. This confirmed earlier findings, and also allowed refinement of the previous model in terms of the complicated interaction of the colliding winds from the two stars present in this binary and the hot luminous disk around one of them.

4. Research on the peculiar LBV P Cygni continued with regular observations done by the Automatic Photoelectric Telescope Service in Arizona. An investigation in collaboration with Dr Markova of the Bulgarian National Observatory and Dr Scuderi of the Catania Astrophysical Observatory (Italy) into the behaviour of P Cygni's spectral lines, especially in relation to the star's brightness variations, was started and almost concluded. This should be published by the end of 1999.

5. On the invitation of the Editor of Space Science Reviews, an article reviewing our present knowledge of P Cygni was written in collaboration with Dr Israelian from the Astrophysical Institute of the Canaries, Spain. At the time of writing this report it has been accepted for publication.

6. In preparation for a study of the brightness variations of P Cygni during the last 50 years, many observations were collected from a variety of sources and subjected to detailed analysis to arrive at a set of data that is as homogeneous as possible; this is not an easy task when so many different observers and instruments are involved!

7. Two summer students from QUB worked on a project to investigate a possible correlation between the behaviour of a selected number of spectral lines and the simultaneous photometric variations of P Cygni. Some tentative conclusions were drawn, but these need further investigation as under item 4. Two further summer students, grant-aided under the Nuffield scheme, worked on different data sets of LBVs to find (quasi-)periods in a number of them, supporting research related to that under point 1 above.

8. PUS: On the invitation of the Curaçao Astronomy Club the total solar eclipse of 1998 February 26 was observed, and two lectures delivered on the origin and future of the Universe. Four extensive radio interviews about the eclipse were given for three different radio stations, for a total of 4 hours 45 minutes.

6.2 W.M. Napier, Senior Research Fellow

Dr Bill Napier continued his research into the origin and evolution of interplanetary dust, the effects of dust and small-body impacts on the Earth, and the analysis of extragalactic redshifts.

1. A variable zodiacal cloud model was developed in order to investigate the variable accretion rate of extraterrestrial dust on the Earth. The model considers a population of comets, injected at random into short-period, Earth crossing orbits, where they disintegrate, producing dust. The dust

particles so produced undergo mutual collisions as well as spiralling into the Sun under the influence of radiation pressure. Preliminary results show that large fluctuations in the dust population are likely to result.

2. An analysis of the recession velocities of nearby galaxies (103 with velocities less than 500 km s^{-1}, out to a distance of ~10 Mpc) was carried out with a view to checking whether a redshift periodicity of 37.5 km s^{-1} exists in this dataset, as had been found in other extragalactic datasets. The new analysis yielded a local cosmological expansion of 62 ± 5 km s^{-1} Mpc^{-1}, closely similar to the corresponding values 64 ± 6 and 63 ± 4 found by the two groups studying Type Ia supernovae. However, the most significant (and extraordinary) result to emerge from this study was the confirmation that there is indeed a periodicity of 37.5 km s^{-1} in the recession velocity of these nearby galaxies, a result previously found by Napier and a co-author in a more accurate dataset extending to 2600 km s^{-1}.

3. Reviews of the small-body impact hazard, and the dust hazard, on timescales relevant to civilization, were prepared and published.

4. Miscellaneous activities: student supervision at various levels (e.g. two QUB undergraduates, one school work experience student), and acting as external examiner to a Ph.D. student at the University of Wales at Cardiff. The alleged meteorite crater near Belleek was investigated early in the year with Mark Bailey and Tom Mason and shown not to be meteoritic.

5. PUS: five presentations were made, ranging from IAU Symposium 194 (Armenia) to colloquia and popular talks. In addition, a popular review ('Comets, Dragons and Prophets of Doom') was published in the PPARC journal *Frontiers*, and a novel ('Nemesis'), a thriller with a science base exploring the issue of the asteroid impact hazard to civilization, was written and published by Hodder Headline plc. These outreach activities resulted in wide media coverage, including interviews for television documentaries, full-page reports in the national press as well as interviews on national BBC radio. The book 'Nemesis' has currently sold more than 15,000 hardback copies. The PPARC-funded STEM course on scientists and the media was found to provide a useful introduction to dealing with the various mass media.

6.3 C.J. Butler, Research Astronomer

Dr John Butler has carried out activities in the following main areas:

1. Observation and modelling of stellar flares: Two observing runs were undertaken (with D. Jevremović) in 1998, as part of this project, one at the Observatoire de Haute Provence and the other with the William Herschel Telescope (WHT) on La Palma. The second run provided excellent high time-resolution optical spectrophotometry of a flare on the nearby active dwarf AD Leo, using a new drift-scan technique on a CCD. This is believed to be the first time that optical spectroscopy of a stellar flare has been obtained with a time-resolution better than 5 seconds.

   A computer model, based on the MULTI model atmosphere code, has been used to fit the time profiles of the emission lines of hydrogen. Whilst broad overall agreement in the shape of the profiles is found, there are differences in their detailed behaviour and in the relative fluxes of the lines as modelled and observed. Further computations are in progress.

   D. Jevremović has continued to write up his thesis on the behaviour of the Balmer lines during stellar flares.

2. Angular momentum of late-type cluster members: This programme (with Dr Armin Thiessen) has continued during the year with the preparation and submission of a paper containing the results obtained by Duncan Foster on the cluster Stock 2. An observing proposal for direct imaging time on the 40-inch Ritchey-Chrétien Telescope at Siding Spring Observatory received an award of a week in February 1999.

3. COROT: Several applications were made for high-dispersion spectroscopic time on 2-metre class telescopes to assist our French colleagues in the selection of suitable targets for this very interesting space project on stellar seismology. No allocation of telescope time was made for 1998, but one week has been granted by the South African Astronomical Observatory (SAAO) in 1999 July.

4. Climatology: A new PhD student, Enric Pallé Bagó, has started a project on the link between solar activity and cosmic rays on clouds and their possible influence on the Earth's mean temperature. A preliminary examination of the sunshine data for Armagh and three other Irish sites indicates (1) a gradual increase in the cloud factor since the late 19th century, probably as a result of the gradually increasing sea surface temperature associated with global warming. A correlation between the cloud factor and solar cycle length is apparent, but it is not yet clear if this represents a true physical connection.

5. Meteorology: Collaboration with two external scientists has allowed some progress to be made in the compilation of those daily meteorological readings not previously entered on to computer. David Smyth of the University of Edinburgh has undertaken the verification of the daily rainfall data previously compiled and some additional data are currently being compiled by the Department of Agriculture Northern Ireland.

   Professor Alistair Dawson of the University of Coventry is currently compiling the pressure data for a joint study on the pressure oscillation of the North Atlantic region over the past two centuries.

6. Historical Studies: Several short biographies of previous members of staff at Armagh and Dunsink Observatories have been written.

7. Conference: A three-day conference entitled 'Solar and Stellar Activity: Similarities and Differences' was organised and held in Armagh in 1998 September to commemorate the life's work of Dr Brendan Byrne. It was attended by more than 60 scientists working in the field, many of whom had previously collaborated with Dr Byrne. The proceedings of the meeting were edited by C.J. Butler and J.G. Doyle and published by the Astronomical Society of the Pacific in their conference series.

8. Administration: An Equal Opportunities policy was agreed and ratified by the MSF Union and the Observatory's Governing Board. Discussions on Grievance, Disciplinary Procedures and Conditions of Employment, continue.

9. Further Research Plans: Future progress in the flare modelling project will require an additional Ph.D. student to take over from Darko Jevremović (djc). If appointed he/she will be supervised jointly by John Butler and Gerry Doyle, with assistance from djc. We propose to use similar codes to those employed by djc to model solar flares as well as other stellar flares for which we already have data in hand. An XMM proposal for this project has been made.

   The cluster programme is currently handicapped by the lack of success in obtaining additional spectroscopic time on telescopes of 2–4 metre class. Applications have been made for time on the Isaac Newton Telescope (INT) and the WHT which could allow further progress to be made. A switch in emphasis to wide-field imaging, if successful, promises to be a faster route to the end result than the previously attempted techniques involving high-resolution spectroscopy.

   Examination of the influence of solar activity on cloudiness via the sunshine data will continue. Also it is planned to use the new data banks on cloud factors to make a thorough reappraisal of the effect of cosmic rays on cloud factors.

6.4 J.E. Chambers, Research Astronomer

Dr John Chambers has made detailed computer simulations of the origin and formation of the Earth and the inner planets. These build upon earlier work by Chambers and George Wetherill, of the Carnegie Institution of Washington, whose computer calculations had predicted that planets would tend to have elliptical orbits rather than the almost-circular ones we see in the Solar System. If true, this would have profound implications for the habitability of extra-solar planets, as elliptical orbits induce large swings in climate. The new simulations have a more interesting range of outcomes. Several calculations yielded Earth-like planets moving on almost circular orbits, which allows them to have stable climates. However, a significant fraction of planets are likely to have highly elliptical orbits, so that they are unlikely to be able to support life.

A new algorithm has also been developed for solving the N-body problem — a tough computational task necessary to understand many aspects of astrophysics. In particular, the new method has considerably speeded up computer simulations of planet formation, making it possible to get a better understanding of how the Earth, the Moon, the planets, and the asteroids formed.

Michael Brown (a final-year student at Trinity College, Dublin) extended earlier work on the stability of planetary systems. He finds that many systems become unstable if one waits long enough. This

instability is especially likely if the planets have a wide range of masses, due to the occurrence of chaotic motion generated by repeated configurations of the planets.

Other activities include:

1. Successful application for an NRC grant (USA) for a one-year sabbatical to work at NASA/Ames Research Center, California. In-depth investigations of the origin of the Earth and Moon, the inner planets, and the asteroid belt will be carried out in collaboration with planet expert Dr Jack Lissauer.

2. On-going research collaborations, for example with: J.J. Lissauer and E. Rivera at NASA/Ames Research Center, on the formation of the inner planets and the Moon; A. Morbidelli and J.-M. Petit at the Observatoire de Nice, on the origin and early evolution of 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; N.W. Evans and S. Tabachnik at Oxford University, on possible primordial belts of asteroids in the inner solar system.

3. Presentations: included lectures at University of Durham, the University of Oxford and Queen Mary College, London, on the origin of the terrestrial planets and on the formation of planetary systems. In addition, lectures were given at various national and international astronomy meetings, including Lisbon (Portugal), Namur (Belgium) and Madison (USA).

6.5 J.G. Doyle, Research Astronomer

During 1998 Dr Gerry Doyle was involved with three PPARC PDRA research grants, and was also a co-organiser of two international conferences (the COSPAR Symposium 'Activity Observed in the Sun and in Similar Stars', and the Armagh Cool Star Workshop 'Solar and Stellar Activity: Similarities and Differences'). He was Associate Scientist with the CDS and SUMER instruments on SOHO. Many refereed and other papers or research notes were published during the year, while research visits were undertaken to NASA (Goddard), and the DIAS (Dublin). He acted as external examiner to a Ph.D. student at the University of Glasgow.

Gerry Doyle leads the solar physics group at Armagh, with a particular focus on using data from satellites such as SOHO to infer the structure of the Sun's surface layers and its outer atmosphere or corona. One of the main questions in this field is how the corona is heated to temperatures in excess of one million degrees compared to the surface temperature of 6,000 K. Over the years many different theories and models have been proposed, most of these based around wave-type heating.

Nano-flares In the mid-eighties, John Butler and Gerry Doyle, while comparing the radiative energy output from the quiet corona of some twenty stars similar in many ways to our own Sun, found that there was close to a one-to-one correspondence with the total amount of energy radiated by flares on these stars during a period of say one day. We suggested the term micro-flaring to describe this result, and proposed that the outer atmospheres of these stars were heated via flare-like activity.

At around the same time, an astronomer (E. Parker) in the USA was working on a similar idea but applied to the Sun. His suggestion was similar to ours, but the scale was slightly different. He suggested that the outer atmosphere was heated by a large number of very small events, each having the energy of only a billionth that of a large solar flare, hence the term nano-flare.

What has SOHO seen? SOHO is a joint ESA/NASA mission, which was launched in 1996 with an array of different instruments, designed to study various aspects of solar activity, including heating of the solar corona. Over the last few years, we and others have obtained many different sequences of observations which have allowed us to search for fast time-scale enhancements in radiative intensity, line-shifts (i.e. the line centre being shifted from its normal rest wavelength), and whether there is evidence that these events recur with certain periods.

Previous observations have shown that there is a slight shift from the rest wavelength of lines formed between the chromosphere, which has a temperature of 20,000 K, and the corona. However, all of the previous work suggested that this line shift should disappear at about 250,000 K. With SOHO we have shown that this is not the case, in fact the line shift changes from being red-shifted below 400,000 K (i.e. it is moving away from us, in other words down towards the surface of the Sun) while hotter gas (at temperatures in excess of 400,000 K) moves towards us, i.e. upwards, away from the Sun.

We have now started to develop models to explain this. Our present models suggest that some form of magnetic reconnection takes place at a temperature of about 250,000 K, thereby producing mostly down-flowing material below this value (For example, the strong C IV line formed at 100,000 K shows precisely this behaviour.) On the other hand, the strong Ne VIII line formed at 500,000 K shows the opposite behaviour. Output from detailed spectral modelling clearly shows that both lines are initially at their rest position, but following a nano-flare the spectral lines start to move in opposite directions at a few km s^{-1} in very good agreement with observations.

We have now followed up our early observations with some long time-series studies involving a line formed at 250,000 K. This is extremely interesting because one can clearly see a series of short impulses, each lasting only about 30 seconds, occurring every 200 seconds and sometimes more often. We believe that this is strong evidence in favour of micro-flaring and are currently up-dating our modelling codes to make it easier to vary the key input parameters such as energy, duration of the nano-flare, initial electron density and temperature etc.

Although we believe that nano-flaring is a prime source for coronal heating, we do not believe that it is the main one. In fact it is likely that several different mechanisms are working simultaneously, depending on the local conditions of the plasma. For example, observations taken from regions close to the solar limb (again taken in a spectral line formed at 200,000 K) show a clear periodicity of perhaps 20 to 30 minutes in the intensity, which takes us back to some of the early theories on wave heating. Although a great deal has been learned about the Sun from SOHO, there is still a lot more to be done, not only observationally, but also from theoretical modelling.

6.6 C.S. Jeffery, Research Astronomer

During the final stages in its life, a star is transformed in ways which remain poorly understood. It is well known that, at the end of hydrogen burning, a star expands to become more luminous and cooler — a red giant. Thereafter, a low-mass star may contract and expand several times over, becoming alternately hotter/smaller (subdwarfs) and cooler/larger (giants) than the Sun. Each transformation is a response to changes in chemical composition in the stellar interior as nuclear reactions convert one source of fuel into another. In some cases these changes can take less than ten thousand years, in contrast to the Sun's hydrogen-burning lifetime of about ten billion years. Consequently, the number of stars currently in these late stages of stellar evolution is comparatively small.

The goal of our research is to trace how stars progress through these stages until they ultimately become white dwarfs. However, there are major difficulties. For most stars, we do not know how far away they are or precisely how large, luminous or massive they are. Secondly, we cannot look inside stars in order to deduce what chemical changes have taken place. We therefore use a variety of indicators, including the chemical composition of the stellar surface, pulsational properties, and binary companions to deduce this information.

The surfaces of *extreme helium giants* — very luminous stars devoid of hydrogen – carry a 'fossil record' of the star's previous evolution. An analysis of three such stars, begun in 1997 with the help of summer students Hamill and Jeffers, demonstrated the oxygen and carbon-rich nature of these stars and pointed to large-scale mixing between the surface and a highly-processed interior, these changes occurring sometime in the recent past. This work also led to the improvement of the modelling software used in the analysis and will be crucial in future research at Armagh.

Extreme helium giants evolve rapidly and pulsate. Measurements of their spectra in ultraviolet light are sensitive to small changes in temperature. An analysis of about 150 spectra obtained with the International Ultraviolet Explorer (IUE) was begun with the help of summer student Starling and showed that measurable changes are taking place in a number of helium giants.

The extremely *helium-rich subdwarf* V652 Her was studied intensely. A chemical analysis proved that its surface is predominantly nitrogen-rich, pointing to an evolution quite distinct from that of the helium giants. New observations were obtained with the William Herschel Telescope and will lead to a very accurate description of its pulsation properties, whilst a theoretical study of its pulsations provided additional new insights. Meanwhile, new theoretical models of pulsation in this and other helium-rich subdwarfs identified a potential new class of variable star.

Extreme helium stars and helium-rich subdwarfs are examples of a larger class of stellar remnant broadly identified as *hot subdwarfs*. Previous work, with Drilling and others, on the spectral classification of hot subdwarfs has continued. Just as the Hertzsprung-Russell diagram for normal stars eventually helped to explain the evolution of young stars, the classification diagram for subdwarfs will help to explain the evolution of stellar remnants. Simon Jeffery and Ph.D. student Pilar Montañés Rodríguez began to calibrate the classification diagram using model atmospheres.

The origin of the largest class of hot subdwarf — *the subdwarf B stars* — remains a puzzle. Essentially naked helium cores, red giant stars stripped of their hydrogen-rich outer layers, the method for the removal of hydrogen is not known. One possibility is that the hydrogen could have been transferred onto a binary companion. The detection of infrared calcium lines in several sdB stars in 1997 demonstrated the unambiguous signature of a cool companion. Simon Jeffery and Ph.D. student Regina Aznar Cuadrado made further observations of sdB binaries in order to measure precise dimensions for both stars.

Much of this work is part of an ongoing programme with substantial results on V652 Her due for early completion, and other theoretical work and new observations already carried out.

Other activities included:

1. Telescope time and research grants: observations of binary and pulsating subdwarf B stars were made with the Isaac Newton and William Herschel Telescopes in La Palma. A PPARC research grant awarded for studies of pulsations in stellar remnants and announced in late 1998, will provide for a 3-year postdoctoral position, commencing 1999 July.

2. Collaborative visits, conferences, and talks: a parallel session was organised and a presentation made on spectral analysis at the National Astronomy Meeting held in St Andrews in March 1998. Collaborative research visits were made to Japan (under the auspices of a 3-year British Council award) and to La Palma, to work with colleagues Hideyuki Saio and Don Pollacco. Colloquia were given on both occasions.

3. PUS: The Armagh Astropark interpretation project progressed to the completion of designs for 5 display panels (now installed in the Astropark). Copies of these panels are included in Appendix G. This work was supplemented by a project to refurbish the interior of the Schmidt telescope dome to make it accessible to visitors and to provide an area for scientific displays (realised with the assistance of summer students Marshall and Tipper). Simon Jeffery also made a presentation of new results on the origin of gamma-ray bursts and wrote invited articles for popular astronomy magazines on the evolution of stars and on the origin of water on the Moon. He attended a PPARC-funded training course on Science and the Media.

6.7 M.D. Smith, Research Astronomer

Dr Michael Smith has focused mainly on the earliest stages of stellar evolution: the processes leading to star formation from an initially unstable, collapsing cloud of gas, and the energetic outflows — jets and winds — associated with the formation and early evolution of protostars and pre-main-sequence stellar objects.

The observed events associated with star formation are related to diverse physical and dynamical mechanisms. Research has begun in Armagh to determine the relationships between these mechanisms and hence to uncover how low-mass stars like our Sun, as well as more massive stars, even star clusters and stellar systems, form.

The basic building sites for stars are gigantic clouds of cool molecules. The clouds are in limbo: their tendency to gravitational collapse is held up by strong magnetic fields and turbulent motions. The turbulence, revealed by spectroscopic observations, takes the form of chaotic motions at speeds exceeding the speed of sound. The balance is crucial to the appearance of our Universe; without it, the rate at which stars form would be (or, more correctly, would have been) about 30 times faster.

We have ideas about what may be the source of the turbulence (internal jet streams, external shock waves, stellar winds or the Galactic shear) but progress has been hampered by our ignorance of this brand of turbulence: supersonic molecular magnetohydrodynamics. Together with colleagues Mac Low (New York) and Burkert (Heidelberg), we have employed numerical simulations to show that all forms of turbulence decay extremely fast. A range of Mach numbers and magnetic energies has been explored, from which the need for the turbulence to be constantly regenerated has been concluded.

In contrast to our everyday experiences with gases and fluids, magnetic fields are almost frozen into the star-forming material. The pressure of the magnetic field must eventually be relieved if the embryonic star, or 'protostar', is to arise. Michael Smith is studying how this occurs. It turns out that the field can gradually slip out of the denser clumps of molecules by a process called ambipolar diffusion (a decoupling process: charged ions become rare, and the neutral molecules then slip between them). Alternatively, the magnetic lines of force can reconnect into new configurations which allow the magnetic pressure to escape or to change form.

At first, a protostar is extremely difficult to detect. It is deeply embedded in its parent molecular cloud, totally obscured at infrared wavelengths as well as in the visible. Spectacular jets of molecules, however,

betray its presence. Such jets have been observed emanating from the very youngest protostars. We have been engaged in discovering the cause of the jets and their effects on the parental clouds. Michael Smith has undertaken numerical experiments, using a molecular hydrodynamics code, to try to understand some of the observed structures. The project involves Yorke (Jet Propulsion Laboratory, California), Zinnecker (Potsdam) and students Völker and Suttner (Würzburg). A major aim is to disentangle environmental and protostellar factors. Three-dimensional simulations demonstrate the consequences of jet dynamics: precession, pulsation, shear and spray.

It has recently been recognised that the respective evolution of the jets emitted from the protostar and the reservoirs of accumulated ejected gas (termed the 'bipolar outflows') could evolve synchronously with that of the protostar, the surrounding accretion disc, and the residual cloud (termed the 'envelope'). An attempt has been made to unify these basic components within a simple model framework. The model makes the least controversial assumptions to derive the relationships between outflow mechanics, jet dynamics and protostellar luminosity. Stages in jet behaviour are thus recognisable, as well as diagnostics for the age of an outflow. The model also emphasizes our lack of understanding: the high rate at which energy is liberated and momentum is transferred into the bipolar outflow requires a remarkably efficient mechanism for jet formation.

Other activities and results during 1998 are summarised as follows:

1. detection of hot molecules with the Infrared Space Observatory; distinguishing shock and fluorescent excitation in DR 21; and constructing infrared and submillimetre maps of the high-mass outflow W75N, a gigantic outflow generated in the wakes of bow shocks.

2. Michael Smith has also been involved in preliminary discussions concerning the formation of a European-wide Star Formation Network, and has given seminars on the subject of stellar jets at the University of Newcastle and at the Armagh meeting of the Astronomical Science Group of Ireland.

3. Future research in this area will continue with an intensified observational programme employing ISO data and new infrared data to understand individual outflows, and with a new focus on star formation on larger scales, namely the galactic-size 'Starbursts' seen in external galaxies. In addition, Michael Smith and Mac Low (New York) will study ambipolar diffusion employing new numerical and analytical techniques, and will examine in detail the formation of bow shock waves and the fragmentation caused by unstable behaviour which leads to current sheets.

6.8 M.E. Bailey, Director

Professor Mark Bailey completed work with the former PDRA Vacheslav Emel'yanenko on the capture of Halley-type comets from the long-period cometary flux. He also completed a paper with Ph.D. student Scott Manley on collision probabilities between small solar system bodies, and together with PDRA David Asher and visiting research fellow Vacheslav Emel'yanenko provided the explanation for the unexpected outburst of Leonid fireballs on the morning of 1998 November 17. M.Phil. student Sandra Jeffers began a study of the size and number distribution of potential projectiles in the inner solar system that may, by physical collision with comets, dominate the process of cometary physical evolution.

The motivation for investigating the dynamical capture of Halley-type comets bears on the long-standing question of the origin of short-period comets, defined to be those with periods $P < 200\,\mathrm{yr}$. There are fundamentally two different types of short-period comet: those with periods $P < 20\,\mathrm{yr}$, referred to as Jupiter-family comets; and those with slightly longer periods $20 < P < 200\,\mathrm{yr}$, called Halley-types. The Jupiter-family comets, it appears, largely originate from orbits resembling those of a class of objects called Centaurs, a group of objects which move through the outer planetary system (roughly between Saturn and Neptune) in low-inclination orbits, and which in turn are believed to derive largely from a belt or disc of objects beyond Neptune, known as the Edgeworth-Kuiper belt.

Halley-types, on the other hand, are produced as a result of planetary perturbations acting on initially very long-period cometary orbits originating in the Oort cloud, a vast nearly spherical cometary reservoir extending roughly halfway to the nearest star. Given the observed long-period flux, the calculated transfer probability from such an orbit to a Halley-type orbit, and the dynamical lifetime of the latter, it is straightforward to predict the number of observed Halley-type objects.

The calculated result, however, is at least two orders of magnitude too large. Therefore, either the observed Halley-type sample is enormously incomplete (for example, the comets could be covered with a layer of very dark, insulating material, and therefore be not easily found), or the comets must be destroyed by some process during their dynamical evolution, possibly disintegrating to dust.

Either of these possibilities presents new avenues for research. For example, if the Halley-type objects are simply very dark, essentially asteroidal in form, then their absolute numbers in space are sufficiently high as to dominate the terrestrial cratering rate for objects larger than ∼5–10 km in diameter. On the other hand, if these Halley-type 'asteroids' do not exist, the structure of the meteoroid streams produced by the disintegration of Halley-type comets becomes an even more urgent problem to address.

These arguments led to research publications on the nature and origin of the dominant impactors on the Earth, the implications for the resulting impact hazard to civilization, and the collision probabilities of comets and asteroids with respect to the terrestrial planets and other objects. The work carried out with Asher & Emel'yanenko provided an exceptionally interesting confirmation of the complex structure of meteoroid streams produced by Halley-type comets, in this case the Leonid meteoroid stream associated with comet 55P/Tempel-Tuttle.

In addition to astronomical research, M.E. Bailey attended several conferences (e.g. the Thessaloniki International Seminar on Current Issues of Astronomical and Planetary Concern, 1998 April; and the ESO (Garching) conference on Minor Bodies in the Outer Solar System, 1998 November), and presented a large number of seminars and public talks, notably at the Seventh European Astrofest meeting (Kensington, 1998 January), at the Thessaloniki meeting, and to astronomical societies in the UK and Ireland. Many press, radio and television interviews were carried out, including appearances in several television documentaries concerning comets and asteroids.

7 Public Understanding of Science

7.1 Press, Radio, Television and Film

Following two years aided by the appearance of unusually bright comets (Hyakutake in 1996 and Hale-Bopp in 1997), the Observatory might be excused for making a reduced public impact in 1998. In fact, however, staff were in even greater demand to express a professional opinion about one or another new result in astronomy, and often made the news concerning aspects of their own research. The number of identified media mentions in 1998 (namely 147) is up by almost 40% compared to the equivalent number (108) noted in 1997, itself a substantial improvement on the 45 in 1996. The Observatory can now expect an average of at least one substantial (i.e. national) media mention per week, and is the leading professional point of contact for astronomy in both Northern Ireland and the Republic of Ireland.

From time to time the Observatory also issues press releases on meteorological and astronomical topics of local or general interest, and on news items that specifically concern Armagh Observatory staff or their research results. In 1998, the Librarian issued 28 such media releases, of which at least 22 were published in the local or national press in one form or another, an extremely high 'hit' rate. The Librarian (and occasionally other staff too) also answers many requests from members of the public on different aspects of astronomy, the list of ∼180 such requests during 1998 being included for information in Appendix F. Looking to the future, the Librarian produced a solar eclipse leaflet in readiness for the 1999 August 11 total solar eclipse, the first such total solar visible from the UK mainland for two generations. This leaflet, also available from the Observatory's web-page (http://www.arm.ac.uk/eclipse99.html), has been in much demand.

7.2 Astropark

Dr Simon Jeffery, working with the assistance of summer students, has produced the first of a number of fine display panels to be placed in the Armagh Astropark, illustrating various aspects of astronomy and of the exhibits on view there. Copies of these display panels are included for information in Appendix G. The Observatory is committed to developing and improving the facilities in the Armagh Astropark, and will seek to improve this public facility as and when time and other resources allow.

7.3 Heritage

The Armagh Observatory is a unique establishment, and continues to flourish as a working astronomical observatory on its original site. The history of the Observatory encompasses the whole of modern astronomy, while the Georgian Grade A listed building, with its many unique and distinctive architectural features, houses one of the most valuable scientific archives and book collections in Northern Ireland. The Observatory also has an important collection of historic instruments and other documents, which can be used to illustrate the wide range of scientific work carried out at the Observatory for more than 200 years, from the late 18th century to the present.

These are important assets, and the Governors of the Armagh Observatory and Planetarium have an unrivalled opportunity to develop a centre for the public understanding of science, explaining the history and motivation for the development of astronomy and related sciences over more than 200 years, and the context in which present research is carried out. The Observatory is currently investigating possibilities for obtaining Heritage Funding to develop this side of its activities, the proposal to include the restoration of three of the Observatory's historic telescopes and their domes. This project will be progressed during 1999 and 2000 with the assistance of the architect Stephen Leighton, and David Sinden of the Sinden Optical Company.

8 Items of Concern

- JANET Access: The Observatory continues to require internet access to the Joint Academic Network (JANET) on the same basis as UK university departments. The present arrangement, namely a 'sponsored connection' with the Queen's University of Belfast (QUB), provides a bandwidth of only 256 kbps. This is barely sufficient for current requirements and does not provide a long-term solution to the needs of a modern astronomical research institute into the next millennium, particularly in the light of increasing use of the internet world-wide. A cost-effective 2 Mbps primary connection to JANET would require an uplift in funding of ~£35k per year.

- It is notable that the Observatory operates with a very high ratio of core research activities to the cost of administrative and support staff, and with a similarly successful ratio of external grant income to DENI grant-in-aid. Further economies of scale, consolidation of the present high level of research activity, and further increases in external income would be achievable were the DENI to invest in additional research infrastructure and research staff positions.

- DENI Recurrent Grant-in-Aid: increases in the DENI grant continue to fall substantially behind rising costs, as indicated in the following Table 1. The results described in this report have been achieved against a background of a reduction in real funding levels; the level of research output and external income generation are unlikely to be sustainable if such cuts continue. Were the DENI to reward success and provide the Observatory with a stable funding regime, much more could be achieved.

Financial Year	Total DENI Grant-in-Aid (£000s)	DENI Income Normalised to 1993/1994 prices	External Grant Income (£000s)	Refereed Journal Publications
1993/1994	445.0	445.0	35	13
1994/1995	425.6	414.9	58	22
1995/1996	468.5	442.1	172	19
1996/1997	480.0	442.3	264	45
1997/1998	473.2	425.7	275	42
1998/1999	443.0	383.1	195	43

Table 1: DENI grant-in-aid over the years. The third column shows the value of the announced grant-in-aid for each financial year normalised to 1993/1994 prices, the values corrected for rising costs by the Retail Prices Index. The number of refereed publications refers to the corresponding calendar year (e.g. publications in financial year 1998/1999 corresponds to calendar year 1998). It is notable that the total external income in 1998/1999 was £213k. The DENI grant-in-aid for 1999/2000 was announced at £458.5k (equivalent to £390.2k at 1993/1994 prices).

A Armagh Observatory Staff, 1998

	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	Dr 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	Dr Mart J.H. de Groot	mdg	Senior Research Associate	Retired	Home	OBS
9	Mr Geoff Coxhead	gc	Software/Hardware Support		OBS	OBS
10	Mr H. Martin Murphy	hmm	Starlink Manager		OBS	OBS
11	Mrs Margaret Cherry	mc	Accounts 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			Grounds/Meteorological Officer	Post Vacant	OBS	OBS
16			Assistant Groundsman	Post Vacant	OBS	OBS
17	Dr David J. Asher	dja	PDRA	PPARC	OBS	OBS
18	Dr Dipankar Banerjee	dipu	PDRA	PPARC	OBS	OBS
19	Mr Darko Jevremović	djc	PDRA	PPARC	OBS	OBS
20	Dr Alex J.R. Löbel	ajrl	PDRA		OBS	OBS
21	Dr Armin Theissen	ath	PDRA	PPARC	OBS	OBS
22	Dr S. Victor M. Clube	svmn	Visiting Research Fellow		Home	OBS
23	Ms Sandra V. Jeffers	svj	Research Student (MPhil)	F/T QUB	OBS	OBS
24	Ms Regina Aznar Cuadrado	rea	Research Student (PhD)	P/T QUB	OBS	OBS
25	Mr Enric Pallé Bagó	epb	Research Student (PhD)	P/T QUB	OBS	OBS
26	Mr Scott P. Manley	spm	Research Student (PhD)	P/T QUB	OBS	OBS
27	Mr Kassios Mitrou	kam	Research Student (PhD)	P/T Athens	Athens	Self
28	Mr Ferhat F. Ozeren	ffo	Research Student (PhD)	F/T Ankara	OBS	OBS
29	Ms Elena Pérez Pérez	epp	Research Student (PhD)	P/T QUB	OBS	OBS
30	Ms Pilar Montañés Rodríguez	pmr	Research Student (PhD)	P/T QUB	OBS	OBS
31	Mr Ilía Iankov Roussev	ilr	Research Student (PhD)	P/T QUB	OBS	OBS
32	Mr Jim V. Scotti	jvs	Research Student (PhD)	P/T QUB	Tucson	OBS
33	Mr P. Nick Sleep		Research Student (PhD)	P/T Open Univ.	Home	Self
34	Mr Luca Teriaca	lte	Research Student (PhD)	P/T QUB	OBS	OBS

Armagh Observatory staff position at 1998 December 31.

B Refereed Journal Publications, 1998

1. **Asher, D.J.**, Steel, D.I., 1998, "On the possible relation between the Tunguska bolide and Comet Encke", Planet. Space Sci. 46, 205–211.

2. **Asher, D.J.**, Izumi, K., 1998, "Meteor observations in Japan: new implications for a Taurid meteoroid swarm", MNRAS 297, 23–27.

3. **Asher, D.J.**, Clube, S.V.M., 1998, "Towards a dynamical history of 'proto-Encke"', Cel. Mech. Dyn. Astron. 69, 149–170.

4. Bagnulo, S., **Doyle, J.G.**, Andretta, V., 1998, "Observations and modelling of spectral energy distributions of carbon stars with optically thin envelopes", MNRAS 296, 545–563.

5. **Banerjee D.**, 1998, "Magnetoatmospheric oscillations in flux tubes", IAJ 25, 113–118.

6. **Banerjee, D., Teriaca, L., Doyle, J.G.**, Wilhelm, K., 1998, "Broadening of Si VIII lines observed in the solar polar coronal holes", A&A 339, 208–214.

7. **Butler, C.J., Coughlin, A.D.S.**, Fee, D., 1998, "Precipitation at Armagh Observatory 1838–1997", Proc. Roy. Irish Acad. Biology and Environment 96B, 123–140.

8. **Byrne, P.B.**, Abdul Aziz, H., **Amado, P.J.**, Arevalo, M.J., Avgoloupis, S., **Doyle, J.G., Eibe, M.T.**, Elliott, K.H., Jeffries, R.D., Lanzafame, A.C., Lazaro, C., Murphy, H.M., Neff, J.E., Panov, K.P., **Sarro, L.M.**, Seiradakis, J.H., Spencer, R.E., 1998, "The photosphere and chromosphere of the RS Canum Venaticorum star, II Pegasi. II. A multi-wavelength campaign in August/September 1992", A&AS 127, 505–519.

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10. Corradi, R.L.M., **Aznar, R.**, Mampaso, A., 1998, "Orientation of planetary nebulae within the Galaxy", MNRAS 297, 617–623.

11. **Coughlin, A.D.S., Butler, C.J.**, 1998, "Is urban spread affecting meteorological observations at Armagh Observatory?", IAJ 25, 125–128.

12. Davis, C.J., **Smith, M.D.**, Moriarty-Schieven, G.H., 1998, "A textbook case of bow shock entrainment in a YSO outflow", MNRAS 299, 825–833.

13. di Martino, M., Carusi, A., Dotto, E., Lazzarin, M., Marzari, F., **Migliorini, F.**, 1998, "Dynamical and physical properties of comet-asteroid transition objects", A&A 329, 1145–1151.

14. **Doyle, J.G., Banerjee, D., Perez, M.E.,** 1998, "Coronal line-width variations", Solar Phys. 181, 91–101.

15. **Doyle, J.G., Short, C.I., Byrne, P.B., Amado, P.J.**, 1998, "Chromospheric and coronal activity levels in the nearby faint M dwarf Gl105B", A&A 329, 229–232.

16. **Doyle, J.G.**, van den Oord, G.H.J., **O'Shea, E., Banerjee, D.**, 1998, "Waves in the solar transition region", Solar Phys. 181, 51–71.

17. Drilling J.S., **Jeffery C.S.,** Heber U., 1998, "Spectral analysis of the extreme helium star LSS 3184" A&A 329, 1019–1027.

18. Erdélyi, R., **Doyle, J.G., Perez, M.E.**, Wilhelm, K., 1998, "Center-to-limb line width measurements of solar chromospheric, transition region and coronal lines", A&A 337, 287–293.

19. Emel'yanenko V.V., **Bailey M.E.**, 1998, "Capture of Halley-type comets from the near-parabolic flux" MNRAS 298, 212–222.

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21. Harris N.W., **Bailey M.E.**, 1998, "Dynamical evolution of cometary asteroids", MNRAS 297, 1227–1236.

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25. **Jeffery C.S.**, Pollacco D.L., 1998, "The detection of binary companions to subdwarf B stars", MNRAS 298, 179–184.

26. **Jevremović, D., Butler, C.J.**, Drake, S.A., O'Donoghue, D., van Wyk, F., 1998, "Ultraviolet and optical flares on Gl 866", A&A 338, 1057–1065.

27. Mac Low, M.-M., Klessen, R.S., Burkert, A., **Smith, M.D.**, 1998, "Kinetic energy decay rates of supersonic and super-Alfvénic turbulence in star-forming clouds", Phys. Rev. Lett., 80, 2754–2757.

28. **Manley, S.P., Migliorini, F., Bailey, M.E.**, 1998, "An algorithm for determining collision probabilities between small solar system bodies", A&AS 133, 437–444.

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31. **Napier, W.M.**, 1998, "NEOs and impacts: the Galactic connection", Cel. Mech. Dyn. Astron. 69, 59–75.

32. **O'Shea, E., Doyle, J.G.**, Keenan, F.P., 1998, "The solar transition region: a time-varying interface between the chromosphere and corona?", A&A 338, 1102–1108.

33. **Short, C.I., Byrne, P.B.**, Panagi, P.M., 1998, "The chromosphere of II Pegasi: multi-line modelling of an RS Canum Venaticorum star", A&A 338, 191–199.

34. **Short, C.I., Doyle, J.G.**, 1998, "Pa-beta as a chromospheric diagnostic in M dwarfs", A&A 331, L5–L8.

35. **Short, C.I., Doyle, J.G.**, 1998, "Chromospheric modelling of the Hα and Na I D lines in five M dwarfs of low to high activity level", A&A 336, 613–625.

36. **Smith, M.D.**, Eislöffel, J., Davis, C.J., 1998, "ISO observations of molecular hydrogen in the DR 21 bipolar outflow", MNRAS 297, 687–691.

37. Sterken, C., **de Groot, M.**, van Genderen A.M., 1998, "Cyclicities in the light variations of luminous blue variables. II. R 40 developing an S Doradus phase", A&A, 333, 565–570.

38. Thomas, N., Keller, H.U., Arijs, E., Barbieri, C., Grande, M., Lamy, P., Rickman, H., Rodrigo, R., Wenzel, K.-P., A'Hearn, M.F., Angrilli, F., **Bailey, M.**, Barucci, M.A., Bertaux, J.-L., Briess, K., Burns, J.A., Cremonese, G., Curdt, W., Deceuninck, H., Emery, R., Festou, M., Fulle, M., Ip, W.-H., Jorda, L., Korth, A., Koschny, D., Kramm, J.-R., Kührt, E., Lara, L.M., Llebaria, A., Lopez-Moreno, J.J., Marzari, F., Moreau, D., Muller, C., Murray, C., Naletto, G., Nevejans, D., Ragazzoni, R., Sabau, L., Sanz, A., Sivan, J.-P., Tondello, G., 1998, "OSIRIS — the optical, spectroscopic and infrared remote imaging system for the Rosetta Orbiter", Adv. Space Res., 21, 1505–1515.

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41. Zappalà, V., Cellino, A., Gladman, B.J., **Manley, S., Migliorini, F.**, 1998, "Asteroid showers on Earth after family breakup events", Icarus, 134, 176–179.

42. Zhou, K., **Butler, C.J.**, "A statistical study of the relationship between the solar cycle length and tree-ring index values", J. Atmosph. and Solar Terrestrial Phys., 60, 1711-1718.

43. **Zboril, M., Byrne, P.B.**, 1998, "Metallicity and photospheric abundances in field K and M dwarfs", MNRAS 299, 753–758.

Date	Speaker	Affiliation	Title
Wed 21 Jan 1998	D. Jevremovic	Armagh	Balmer Decrements as Diagnostics of Stellar Flare Plasma
Wed 4 Feb 1998	A. Lobel	Armagh	Long-Term High-Resolution Spectroscopy of the Cool Hypergiant Rho Cassiopeiae
Wed 18 Feb 1998	**T. Mason**	**Armagh Planetarium**	**The Belleek Event**
Wed 25 Feb 1998	M.E. Bailey	Armagh	NEO Hazards: Dynamical Constraints on Impactor Populations
Wed 4 Mar 1998	S.P. Manley	Armagh	Collisions in the Solar System
Thu 12 Mar 1998	**F. Murtagh**	**University of Ulster**	**Environmental and Climatic Modelling of Relevance to Astronomy**
Wed 25 Mar 1998	**D. Campbell**	**Meteorological Office, Belfast**	**The Climate of Northern Ireland**
Wed 8 Apr 1998	**D. Lynden-Bell**	**Queen's University Belfast**	**Extraordinary N-Body Problems**
Wed 22 Apr 1998	**J. Venables**	**Meteorological Office, Aldergrove**	**Weather Forecasting**
Wed 6 May 1998	**C. Ruggles**	**Leicester and QUB**	**Prehistoric Astronomy in Ireland and Britain**
Wed 13 May 1998	L. Teriaca	Armagh	Redshifts in the Solar Chromosphere and Transition Region: Observation and Analysis
Wed 13 May 1998	R. Aznar	Armagh	The Evolutionary Status of Subdwarf Binaries
Wed 20 May 1998	**P. Dufton**	**QUB**	**Chemical Composition of Our Own and Other Galaxies**
Wed 27 May 1998	**I. Banks**	**Ballynahinch**	**Men's Health and Risk Taking**
Tue 2 Jun 1998	**J. Cohen**	**NRAL, Jodrell Bank**	**Magnetic Fields in OH Maser Regions**
Wed 3 Jun 1998	**I. Sanders**	**Trinity College Dublin**	**Meteorites as Constraints on Astrophysical Models for Nebular Processes**
Tue 9 Jun 1998	**S. Bagnulo**	**University of Vienna, Austria**	**Modelling of Magnetic Fields of Chemically Peculiar Stars**
Wed 10 Jun 1998	**D. Roscoe**	**University of Sheffield**	**Mach's Principle Revisited: A Quasi-Fractal Universe and its Dynamics**
Wed 24 Jun 1998	**H. Pretka**	**Astronomical Observatory, Poznan**	**Planetary and Galactic Perturbations in the Motion of One-Apparition Comets**
Wed 1 July 1998	J.E. Chambers	Armagh	Symplectic Integrators — a New Way to Make Planets
Wed 8 Jul 1998	**D. Pollacco**	**Isaac Newton Group, La Palma**	**Planetary Nebulae and their Central Stars, including Sakurai's Object, a Recent Born-Again Red Giant**
Wed 15 Jul 1998	**B. Miller**	**Leiden Observatory**	**Globular Clusters and the Evolution of Elliptical Galaxies**
Tue 21 Jul 1998	**R. Walsh**	**University of St. Andrews**	**Bright Tangles on the Sun: Heating Active Region Loops**
Wed 22 Jul 1998	**J. Nuth III**	**NASA Goddard Space Flight Center**	**Silicate Annealing, Herbig AeBe Stars and the Formation of Comets**
Wed 29 Jul 1998	**I. Bonnell**	**Institute of Astronomy, Cambridge**	**Star Formation in Clusters**
Wed 9 Sep 1998	**S.V.M. Clube**	**Department of Physics, Oxford**	**J.H. Oort and the Oort Cloud**
Wed 16 Sep 1998	D.J. Asher	Armagh	Approach Directions of Colliding Asteroids
Wed 23 Sep 1998	D. Banerjee	Armagh	Dynamical Nature of the Quiet Solar Atmosphere
Thu 29 Oct 1998	**A.G. Gunn**	**NRAL, Jodrell Bank**	**SETI Observations at Jodrell Bank**
Fri 30 Oct 1998	**S. Isobe**	**National Astron. Observatory, Japan**	**The Japanese Near-Earth Object Telescope Project**
Mon 16 Nov 1998	**Nine Speakers**	**Armagh and Beyond**	**One-Day Solar System Workshop**
Wed 25 Nov 1998	J. McFarland	Armagh	An Armchair Tour of Armagh Observatory
Wed 2 Dec 1998	A. Löbel	Armagh	Modelling the Spectral Energy Distribution and Variability of Asymptotic Giant Branch Stars

Seminars at Armagh Observatory, calendar year 1998. Organized by A.D.S. Coughlin and D. Banerjee.

D Talks by Armagh Observatory Staff, 1998

Date	Speaker	Location	Title
1998	J. McFarland	Armagh Observatory	66 Tours of Armagh Observatory given in 1998
Wed 21 Jan 1998	D. Jevremovic	Armagh Observatory	Balmer Decrements as Diagnostics of Stellar Flare Plasmas
Wed 21 Jan 1998	W.M. Napier	Rutherford Appleton Laboratory	Quantized Redshifts
Fri 30 Jan 1998	M.E. Bailey	Seventh European AstroFest, Kensington, London	The Threat from Space
Sat 31 Jan 1998	M.E. Bailey	Seventh European AstroFest, Kensington, London	Comet Hale-Bopp: Origin and Dynamical Evolution
Wed 4 Feb 1998	A. Löbel	Armagh Observatory	Long-Term High-Resolution Spectroscopy of the Cool Hypergiant Rho Cassiopeiae
Fri 6 Feb 1998	M.E. Bailey	Irish Physics Student Association Meeting, QUB	The Increasing Threat from Space
Wed 25 Feb 1998	M.E. Bailey	Armagh Observatory	NEO Hazards: Dynamical Constraints on Impactor Populations
Wed 4 Mar 1998	S.P. Manley	Armagh Observatory	Collisions in the Solar System
Mon 23 Mar 1998	M.E. Bailey	Lurgan Rotary Club	Research at Armagh Observatory
Apr 1998	J.E. Chambers	Lisburn, Portugal	N-Body Simulations of Planet Formation
Mon 6 Apr 1998	M.E. Bailey	Thessaloniki, Greece	The Threat from Space: Dynamical Constraints on Impactor Populations
Mon 6 Apr 1998	M.E. Bailey	Thessaloniki, Greece	Origin of Comets and the Evolution of the Oort Cloud
Fri 17 Apr 1998	M.E. Bailey	ASGI Meeting, Cork	The Impact Hazard: Source Populations and Dynamical Constraints
Fri 17 Apr 1998	W.M. Napier	ASGI Meeting, Cork	Galactic Dark Matter and the Marine Fossil Record
Mon 27 Apr 1998	M.E. Bailey	TCD Astronomy & Space Society, Dublin	The Threat from Space: Dynamical Constraints on Impactor Populations
May 1998	J.E. Chambers	London	Planetary System Formation Theory
Mon 11 May 1998	C.S. Jeffery	Armagh Rotary Club	Gamma-Ray Bursts
Wed 13 May 1998	R. Aznar	Armagh Observatory	The Evolutionary Status of Subdwarf Binaries
Wed 13 May 1998	L. Teriaca	Armagh Observatory	Redshifts in the Solar Chromosphere and Transition Region: Observation and Analysis
Jun 1998	J.E. Chambers	University of Durham	Making the Terrestrial Planets
Fri 5 Jun 1998	M.E. Bailey	Queen Mary and Westfield College, London	Impacts of Minor Bodies with the Earth
Sun 21 Jun 1998	M.E. Bailey	IAA Solstice Spectacular, Armagh Planetarium	The Increasing Threat from Space

Presentations by Armagh Observatory staff, 1998 January 1 to 1998 June 30.

Date	Speaker	Location	Title
Jul 1998	J.E. Chambers	Namur, Belgium	A Symplectic Integration Scheme that Allows Close Encounters between Massive Bodies
Wed 1 Jul 1998	J.E. Chambers	Armagh Observatory	Symplectic Integrators: A New Way to Make Planets
Wed 1 Jul 1998	M. de Groot	Salzburg, Austria	The Origin of the Universe
Wed 8 Jul 1998	M. de Groot	Jongny, Switzerland	The Future of the Universe
Tue 21 Jul 1998	M.D. Smith	Jena, Germany	Turbulence, Protostars and Jets
Thu 30 Jul 1998	M.D. Smith	Max Planck Institut für Radioastronomie, Bonn	The Unification Scheme
Thu 20 Aug 1998	W.M. Napier	IAU Symposium No. 194, Armenia	Quantized Redshifts: New Physics or Old Muddle?
Mon 24 Aug 1998	M.D. Smith	Bad Honnef, Germany	Protostellar Outflows
Sep 1998	C.S. Jeffery	Tohoku University, Sendai, Japan	Stellar Remnants: Chemical Evolution and Binary Companions
Sep 1998	C.S. Jeffery	Isaac Newton Group, La Palma, Spain	Stellar Remnants: Chemical Evolution and Binary Companions
Mon 7 Sep 1998	C.J. Butler	British Society of Soil Scientists, Department of Agriculture, Belfast	Global Warming: Man or Nature?
Wed 9 Sep 1998	J. McFarland	Meeting of the UK Eclipse Education and Coordination Working Group, BAAS, Cardiff	Solar Eclipse of 11 August 1999
Sun 13 Sep 1998	S.P. Manley	EADN Summer School on Solar and Extrasolar Planets	Collision Probability Determination
Wed 16 Sep 1998	D.J. Asher	Armagh Observatory	Approach Directions of Colliding Asteroids
Sun 20 Sep 1998	W.M. Napier	Whirlpool Star Party, Birr	Big Bang Cosmology
Wed 23 Sep 1998	D. Banerjee	Armagh Observatory	Dynamical Nature of the Quiet Solar Atmosphere
Oct 1998	J.E. Chambers	DPS Meeting, Madison, Wisconsin	How Special is the Earth's Orbit?
Fri 9 Oct 1998	D.J. Asher	Royal Astronomical Society, London	Historical Variability of the Interplanetary Complex
Sat 10 Oct 1998	M.E. Bailey	Open University Graduate Day, Milton Keynes	Orbital Evolution of Small Bodies in the Solar System
Sat 10 Oct 1998	M.E. Bailey	Runnymede Astronomical Society, Maidenhead	Populations of Impacting Objects
Tue 13 Oct 1998	M.D. Smith	Heidelberg, Germany	The Unification Scheme
Wed 21 Oct 1998	D.J. Asher	Irish Astronomical Association, Belfast	Astrometry of Near-Earth Objects
Thu 22 Oct 1998	C.S. Jeffery	ASGI Meeting, QUA, Armagh	The Pulsating Helium Star V652 Her
Thu 22 Oct 1998	M.D. Smith	ASGI Meeting, QUA, Armagh	Protostellar Outflows
Thu 5 Nov 1998	M.E. Bailey	ESO Conference Garching, Germany	Minor Bodies in the Outer Solar System: Conference Summary
Mon 9 Nov 1998	W.M. Napier	Armagh Rotary Club	Nemesis
Thu 12 Nov 1998	M.D. Smith	University of Newcastle	Numerical Simulations of Jets
Mon 16 Nov 1998	J.E. Chambers	Armagh Observatory	Circumstellar Discs
Wed 25 Nov 1998	J. McFarland	Armagh Observatory	An Armchair Tour of Armagh Observatory
Thu 26 Nov 1998	M.D. Smith	Max Planck Institut für Astronomie, Heidelberg	The Inflow-Outflow Questions
Dec 1998	J.E. Chambers	University of Oxford	Making the Terrestrial Planets
Wed 2 Dec 1998	A. Löbel	Armagh Observatory	Modelling the Spectral Energy Distribution and Variability of Asymptotic Giant Branch Stars

Presentations by Armagh Observatory staff, 1998 July 1 to 1998 December 31.

E Identified Media Mentions, 1998

F Public Queries, 1998

G Astropark Display Panels

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