Armagh Observatory

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A Short History of Armagh Observatory

by *C.J. Butler*

Note added in 1995.
The standard history of Armagh Observatory is **"Church, State and Astronomy in Ireland - 200 Years of Armagh Observatory"** by *J.A. Bennett* , published by *The Institute for Irish Studies,* Queens University, Belfast and Armagh Observatory in 1990. Available from Armagh Observatory in paperback, price 10.00 pounds sterling + post and packing.

Text taken from an illustrated catalogue prepared for the exhibition to commemorate the bicentenary of Armagh Observatory in 1990/91, ***Seeing Stars*** , C.J. Butler, Armagh Observatory 1990. Copies available from Armagh Observatory, price one pound plus post and packing.

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1. The City of Armagh

Following the last great ice-age, which ended about 10,000 BC, the landscape of Ireland evolved from a bleak tundra to, first birch, then oak forest. As the ice receded it revealed the undulating countryside which covers much of the counties of Armagh, Monaghan and Cavan today. Also, where rocky outcrops had withstood the grinding ice, prominent hills, such as the one which lies in the centre of the City of Armagh , became exposed. It was to this hill that the earliest known settlers of Armagh came - the neolithic people. Remains of their occupation are still to be seen in various stone monuments which were erected in the neighbouring countryside. One such site was recently revealed by excavations in Scotch Street, Armagh.

Whilst we have no written records from this period, (5,000 - 2,300 BC), the interest of the neolithic peoples in the movement of astronomical bodies is demonstrated in the layout of some of their major constructions, such as the great burial tumulus at Newgrange. Here the alignment of the passageway leading to the central chamber with the midwinter sunrise displays to posterity the architectural skill and the interest in astronomy of these early settlers of Ireland.

In succeeding centuries, the centre of occupation moved from the hill of Armagh to a site about 2 miles west, where, on the hill of Navan, one of the celtic Queens called **Macha** built a magnificent palace. Here, at the Capital of Ulster, the exploits of the legendary Cuchullain and the Kings of Ulster were preserved in the oral tradition.

After the destruction of Navan, the centre of influence moved back to the present site of Armagh, probably in the 5th century AD. In this century, also, following his conversion of the King to Christianity, St Patrick founded his first church in Armagh. For the next four centuries Armagh was renowned throughout Europe as an ecclesiastical centre and was regarded as the **Metropolis of Ireland**. During this period the religious colleges in Armagh were said to have had several thousand students.

Amongst the various duties of the teachers at the monastic university was the recording of important historical events. Many of these relate to the activities of the ruling families, outbreaks of wars and civil disturbances etc, but occasionally they also noted various astronomical apparitions, such as comets or eclipses. These are the earliest recorded astronomical observations from Armagh and are compiled in the medieval manuscript The Annals of Ulster.

In later centuries, following the Viking and Norman invasions, the centre of power in Ireland moved to coastal towns such as Dublin and Drogheda and by 1600 Armagh was only a collection of ruins and thatched cabins (contemporary map .) During this period, Armagh and its surroundings, became a battlefield for the continuing strife between the opposing forces of the Earl of Tyrone and Elizabeth.

The Archbishops of Armagh at this time only visited their primatial capital occasionally and preferred to reside in Drogheda. One such Archbishop, the great scholar James Ussher, is renowned for his calculation of the age of the world.

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2. The Rise of Astronomy in the 18th Century

The 18th century, often referred to *as the age of enlightenment* saw a steady increase in the study of the sciences. The abstract theorising of the Greek philosophers and the hit-and-miss approach of the medieval alchemists gave way to the sound scientific methods of experimental science as founded by Galileo and Newton in the previous two centuries. Basically this involved the testing of theories by experiment or observation; thereby establishing whether or not the theory was correct. Astronomy in the 18th century, although it followed the rising tide of experimental and observational science, was also seen as important for the practical science of Navigation. Towards the end of the century several events and influences brought astronomy to prominence in the public eye.

These were:

- The importance of Astronomy for navigation which was necessary to facilitate trade with distant countries
- The success of Newton's theory in predicting the movements of the planets and comets in the solar system
- Captain Cooke's voyages of discovery and the Transit of Venus of 1769
- The discovery of Uranus by Herschel

Trade and Navigation

During the 17th and 18th centuries, trade with the Empire, particularly with the new world and India, was becoming increasingly important to Great Britain. With only primitive navigational methods at their disposal many ships were lost on the high seas and it soon became evident to the maritime authorities that improvements in the techniques of navigation were required. This lead directly to the setting up of the Royal Greenwich Observatory in 1675 which was charged with the duty of improving the accuracy of the positions of stars which could be used by mariners for determining their position at sea.

Understanding the motions of the planets

In the 17th century the great mathematician, Sir Isaac Newton, had proclaimed *The Universal Law of Gravitation*, which postulated that the same force that pulled the falling apple to the ground also held the moon in its orbit around the Earth and the planets in their orbits around the Sun. To accurately test Newton's theory, precise measurements of the planets were required, these were to be provided by the new observatories.

The Transit of Venus and the Voyages of Captain Cook

As knowledge of the motions of the planets improved it became possible to make more precise predictions for the future. In 1769 it was predicted that the planet Venus would transit across the face of the sun as viewed from the Earth. It was realised that this rare event would provide a unique opportunity to determine the basic unit of the solar system, the distance from the earth to the sun, (called *the Astronomical Unit*) provided it could be observed from several stations around the world.

The Royal Society commissioned Captain Cooke to voyage to the Pacific to observe this event from the South Seas and to this end he carried with him an astronomer. It was during this voyage that Cooke annexed Australia. (Drawing by Cooke of transit of Venus).

Observations of the transit were also made by King George III from his new observatory at Kew, built specially for the purpose. The telescope by Short used by George III for this historic observation was presented to Armagh Observatory by Queen Victoria. A clock, by Shelton of London, was used by George III to determine the exact time of the apparition.

The transit of Venus in 1769 was also observed from Ireland using special instruments brought from London for the purpose. They were carried out at Cavan, a townland near Strabane, by Charles Mason (of Mason-Dixon Line fame).

The discovery of Uranus by Sir William Herschel

Sir William Herschel, a musician from Germany who settled in England, was probably the greatest astronomer and telescope builder of the 18th century. His telescopes, which were the largest and most powerful of their day, gave him a distinct advantage over his contempories and enabled him to discover many new nebulae and clusters of stars.

Planets, unlike stars, have a visible disc in a large telescope and in 1781 Herschel discovered a new planet which he named *Georgium Sidus* after George III, his patron. This was the first planet to be discovered since the time of the ancient Greeks and, not surprisingly, its discovery had a profound effect on the public; no longer were the heavens seen to be immutable from ancient times - there were new discoveries to be made in the solar system and beyond. The new planet later came to be known as Uranus.

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3. An Observatory for Armagh.

Richard Robinson, Archbishop of Armagh, was a rich and influential man who embodied the spirit of his age. He was the leader of the established church, the Church of Ireland, and as such received tithes from landowners. He was, however, independently wealthy and by modern standards he would have been a multi-millionaire.

As an educated and enlightened man he resolved to use his wealth and power to found and maintain charitable and educational institutions, particularly in his Primatial City of Armagh. He employed some of the foremost architects of his day: Thomas Cooley, and Francis Johnston, to design buildings and plan his cathedral city.

It is believed that Archbishop Robinson may have been influenced to found an observatory in Armagh by the Reverend J.A. Hamilton, who was to become its first Director. Hamilton, at that time, was Rector of Cookstown, Co. Tyrone, where he had a small private observatory. In 1782 he observed a transit of Mercury and communicated his observations to Maskelyne, the Astronomer Royal for England who presented them to the Royal Society of London. It is reported that Archbishop Robinson was so impressed with Hamilton's observations that he decided to include an Observatory in his plans for Armagh City.

The Observatory, like several of the Archbishop's foundations, was built on a hill so that it could be seen against a natural woodland setting from his new palace. It was designed by Francis Johnston, the city architect, who was responsible for several fine buildings in Dublin; notably, the Chapel Royal and the GPO in O'Connell Street.

The new observatory was the second to be established in Ireland; (the first was Dunsink Observatory near Dublin). It is the oldest scientific institution in Northern Ireland.

In some 17th C observatories, notably Paris (1667), the architectural elegance of the structure was considered more important than its practicality for astronomy This was true to a lesser extent in Wren's design for the Royal Observatory (1675) at Greenwich where, in spite of its grand facade, the structure did not actually impede observations. Normally, at that time, observations were made from either an outside platform or alternatively from inside a large room with tall windows. The instruments were usually portable, with a mounting which simply rested upon a table or the floor and therefore were easily shaken by the movement of people across the room. As instruments increased in size during the 18th and 19th centuries they required more substantial support to avoid vibration.

The buildings of Dunsink (1785) and Armagh (1790) Observatories represent a revolution in observatory design. At Dunsink and Armagh, for the first time, the requirements for the stability of the instruments took priority over aesthetic considerations. Unlike the dome of the King's Observatory, Kew (1768), which is insubstantial and appears almost as an afterthought, the domes at Dunsink and Armagh dominate the structure and form the central theme of the building. In addition the stability of the instruments was guaranteed by placing them on substantial stone pillars brought up from the substrata below the building. At Dunsink these pillars were free standing and not joined to the rest of the building. In this way, any vibrations originating in the main part of the structure, were not transmitted to the instruments. These principles of construction have been employed in most subsequent observatory buildings throughout the world.

Both Dunsink and Armagh Observatories have only sparse ornamentation on their exteriors which is very much in keeping with the new scientific practicality they represented. However, the ornamentation on the exterior at Armagh, restrained as it is, is continued around the building on all sides, quite unlike many 18th C Irish buildings which had a single ornamental facade.

The interior design of Armagh Observatory has a number of unusual features - such as the frequent use of circular motifs; e.g. curved corners to the rooms and bowed chimney breasts. It has one of the best preserved 18th C interiors in N. Ireland.

From the inception of the Archbishop's plan to found an Observatory in Armagh the Reverend J.A. Hamilton, who was to be the first Director, was in touch with one of the leading astronomers of his day, Neville Maskelyne, the Astronomer Royal for England. Maskelyne wrote a letter detailing the requirements for a modern observatory and offered to vet and purchase equipment in London for the Primate's new Observatory.

The principal requirements for serious work on the position of stars were: a transit instrument, a meridian circle and an accurate clock. Whilst, Maskelyne successfully obtained for Armagh two of the finest astronomical clocks available, the two masterpieces by Thomas Earnshaw, he was not so successful with the other instruments.

Observatory Medal by Mossop.

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4. Hamilton and the Early Instruments.

Dr J A Hamilton, later Rector of Mullabrack, was closely involved in the conception of the Observatory at Armagh and may well have made the initial suggestion to his Archbishop. It was natural that he should be chosen as its first director.

Though generously supported by its founder, the Archbishop, his early death in 1794 resulted in the loss of a number of instruments originally ordered for the Observatory. As a result Hamilton's observations were not as comprehensive as they might have been. Nevertheless he initiated the early series of meterological recordings and observations of stars which paved the way for the future scientific work of the observatory. From the beginning, he expressed a desire to work closely with the astronomer at the other public observatory in Ireland, Dunsink Observatory in Dublin - a cooperation that has continued until the present day.

The need for accurate positions of stars was one of the principal reasons for the establishment of the observatory at Armagh. They were required firstly for navigation and secondly to provide a framework for the measurement of the positions of the planets.

The second reason was scientifically more important as it was only by careful, frequent and accurate observations of the planets, that Newton's law of gravitation, one of the most fundamental laws of physics, could be verified. Indeed, during the 18th century, French astronomers believed they had observed discrepancies in the motions of the planets, which were not accounted for by Newton's laws. English astronomers disputed these findings and were anxious to vindicate the reputation of the great Newton. Whilst in fact the English astronomers on this occasion were proved right - it was the small discrepancies that were discovered in the orbit of the planet, Mercury, in the 19th century, that eventually brought down Newton's theory of gravitation, and lead to Einstein's theory of general relativity.

The positions of the stars and how they were measured

With the need for accurate positional observations established, how were they to be obtained?

Firstly, we must understand the coordinate systems for stars. In a directly analogous way to latitude and longitude on the earth, astronomers used celestial latitude, (termed declination) and celestial longitude, (termed right ascension). If one imagines the earth's coordinate system, (latitude and longitude), projected onto the celestial sphere, (the sky), one can grasp the basic similarity. Just as we can measure the latitude of a point on the earth's surface by it's distance from the equator, (or 90 degrees minus its distance from the pole), similarly we can determine the declination by measuring the distance of a star from the celestial equator, (or 90 degrees minus the distance from the celestial pole). Also, just as we measure longitude on the earth from an arbitrary zero line, the Greenwich Meridian, we measure right ascension or celestial longitude from an arbrtrarily defined point in the sky called the first point of Aries.

To measure these coordinates for a particular star the simplest and most commonly used instruments were the meridian and transit circles. Both of these instruments consist of a simple refracting telescope which swivels around a horizontal axis which lies exactly east-west. The telescope has a small field of view and is only capable of observing stars in a very narrow strip of the sky. This strip, adjacent to the meridian, passes through: the south and north horizon points, the celestial pole, and the zenith directly overhead. From the time at which the stars cross the meridian astronomers can deduce their right ascension or celestial longitude.

The Troughton Equatorial Telescope

The first major instrument purchased for Armagh Observatory, the telescope made by Troughton of London, is a masterpiece of English instrument-making of the 18th century, only one other instrument of its type exists in the world today. It was purchased by Archbishop Robinson on the recommendation of the Astronomer Royal of England who was very impressed with its novel design.

As explained earlier, the simplest method of measuring the coordinates of stars and planets was to record the time at the instant they crossed the meridian using a transit circle. However the major difficulty with this technique is that observers had only one opportunity per night to make such a measurement - when a star crossed the meridian. Troughton and some of the other instrument makers of his time realized that, if instead of using a horizontal east-west axis, they could mount an instrument on an axis that pointed to the celestial pole, it would be possible to measure the coordinates of a star at any time of the night when that star was visible. This would be particularly valuable if one were trying to obtain a sequence of planetary observations in a poor climate when clouds obscure the sky for much of the night. The astronomers were somewhat dubious that the instrument makers of the day could accomplish the high standard of stability and accuracy, in this more complicated design, than in the simple and well tried meridian and transit circles. Manufacturers, and particularly Troughton, felt they could. To improve stability Troughton used massive stone pillars for support and for rigidity used conical brass tubes to support the central telescope ring.

In the final outcome, although many useful observations were made by this telescope by J A Hamilton, the astronomers were proved right, in that the telescope could not match the accuracy of the simple transit and meridian circle. It was an expensive mistake.

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5. The Earnshaw Clocks and the Board of Longitude Prize.

The measurement and keeping of time was, for centuries, one of the most important functions of an observatory. Thus it was necessary to ensure that observatories possessed the most accurate clocks available. In the 18th century the art of making pendulum clocks improved remarkably and one of the most outstanding clock makers at that time was Thomas Earnshaw of London who is known as the *father of the chronometer*. He was principally known as a watchmaker, and when asked by Nevil Maskelyne if he would make a clock, for Armagh said he did not even know how many wheels were in one. In fact he produced a masterpiece, which is recognised by horologists today as one of the world's most important clocks. It incorporated Earnshaw's new design of escapement and had a number of novel features including its air-tight case (designed to reduce dust and draughts). It was highly praised by Thomas Romney Robinson in the 19th century who at that time believed it to be the most accurate clock in the world. Its purchase price was 100 pounds in 1794 and Earnshaw charged 100 pounds to travel with it to Armagh and set it up in the new Observatory. Partly as a result of the excellent performance of this clock, its maker, Earnshaw was awarded a prize of 3000 pounds by the government. The Observatory also purchased Earnshaw's second clock which was operated at sideral rate with the Troughton Equatorial Telescope.

By the late eighteenth century the basic principles of how to determine latitude and longitude from observations of the Sun and stars were well understood. The latitude, in the northern hemisphere at least, could be easily established by measuring the altitude of the pole star above the horizon, which with a small correction, gave the latitude directly. The determination of longitude is more difficult as it requires comparison of local time with the time at Greenwich. It is from the difference in local time, say midday as determined from the Sun's highest point, from the Greenwich time at that instant, that ships were able to measure their longitude. (The Longitude Problem).

The most serious problem with this proceedure is that it required a ship to carry a clock which could be relied upon to keep accurate Greenwich time for the many months, even years, it took for a voyage around the world. At that time the only reasonably accurate clocks were regulated by pendulums and these were notoriously unstable at sea due to the rocking of the ships on which they were carried. Many ingenious devices were tried to stabilize pendulum clocks but the problem proved intractable and to encourage inventors the British Government, in 1714, offered a prize of 20,000 pounds to the first person to develop a clock which, after a voyage lasting six weeks, allowed the ship's position to be determined better than 30 miles. It is quoted that "*the prize at once became the immediate and accessible target of every crank, swindler, fanatic, enthusiast and lunatic in or out of Bedlam*" but in addition, for over 50 years, the prize eluded many serious clockmakers as well.

Eventually after several attempts, with ever more complicated machines, half of the prize was awarded to John Harrison, a Yorkshire man, with little or no formal education. The investigating body, the Board of Longitude, were eventually forced into accepting his claim after the intervention of George III, who had taken a personal interest in testing Harrison's time pieces at his own observatory in Kew. Annoyed by the intervention of the King and Parliament on Harrison's behalf, the Board of Longitude denied Harrison the right to the other half of his prize under the pretext that his clock could not be copied. A further prize was announced for the construction of a simple chronometer that could be cheaply made. Two famous London clockmakers vied with each other for this prize; John Arnold, and Thomas Earnshaw the maker of two of the Armagh Observatory clocks. Two clocks by Earnshaw's arch-rival, Arnold, are to be seen at Dunsink Observatory Dublin.

Earnshaw developed a simple type of clockwork chronometer that is to all intents and purposes identical to those made until the middle of this century when quartz clocks became available. It could be mass produced comparatively easily and was within the financial reach of any ship owner. Eventually, after considerable wrangling, when Earnshaw's health was nearly broken, he was awarded \pounds 3000 for his efforts. His appeal to Parliament for compensation was bitterly expressed and in a letter to Dr. J.A. Hamilton Director of Armagh Observatory he requests Hamilton's testimony as to the accuracy of his first clock, Earnshaw No 1. As a result of this evidence, plus that of Maskelyne and others, Parliament finally acceded to Earnshaw's request.

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6. Thomas Romney Robinson and the New Instruments.

Thomas Romney Robinson, the third director of the Observatory, was, by all accounts, a remarkable man of many interests. He was also a child prodigy - able to read poetry by his third year and to write verse by his fifth. He published a book of poems in his thirteenth year. As a schoolboy his technical and scientific interest developed rapidly and in his poem *The Triumph of Commerce*, which he wrote in his ninth year, he combined his practical interests with his artistic abilities to praise his friend Mr. W. Richie the founder of the Belfast Shipyards. Robinson continued his brilliant academic career by taking his BA at sixteen years old and becoming a fellow of Trinity College, Dublin at 21.

In 1823 he was appointed director of Armagh Observatory a post which he retained for a total of 59 years and a world record for an observatory director which still stands today. Whilst at Armagh he retained his living as rector of Carrickmacross which supplemented his rather meagre income as Observatory director. He was a brilliant orator and was popular amongst the learned societies of Ulster where his rousing speeches were met with rapturous applause. He was a founder member of the Armagh Natural History and Philosophical Society, President of the Royal Irish Academy in Dublin and President of the British Association for the Advancement of Science. He married twice, first Elizabeth Rambaut, and secondly, Lucy Jane Edgeworth, a sister of Maria Edgeworth the author.

After the death of Archbishop Richard Robinson, (no relation to TRR), in 1794, his successors, who had no interest in science, made little provision for the improvement of the Observatory. To be truthful this may have well have partly resulted from the lack of enthusiasm of the second director, W. Davenport (1815-1823), whose contribution to astronomy was practically nill and who, after eight fruitless years, committed suicide in his study . This could easily have been the end of the story for Armagh Observatory but, it was not to be so; and as the young and energetic Thomas Romney Robinson took up his office he quickly dispelled any remaining doubts.

T R Robinson was fortunate in that, by the time of his appointment, Primate John George Beresford, was created Archbishop of Armagh. He was a rich and generous person who obviously took a great deal of interest in science and in the Observatory. He contributed several thousand pounds of his own money to refurbish the Observatory with the best instruments available.

T R Robinson made it plain in his report to the Governors that in his opinion "*the job of an observatory was to furnish accurate observations of the stars (positions of stars)*." Theoretical astronomy, by which he meant principally celestial mechanics, could be carried out anywhere, and by anyone, with sufficient mathematical knowledge.

In spite of its novel design, the Troughton Equatorial Telescope never fullfilled expectations and Robinson, quite rightly, saw no alternative but to return to the more straight-forward transit and meridian circle type of instrument. By this time, (late eighteen twenties), the old *meridian quadrant* design used in the 18th century, had been superseded by the *mural circle* - where the telescope and its assemblage of divided circle and microscopes were fixed to a stone wall of massive construction. This design provided the rigidity and stability that is required for careful measurement of star positions. Both the Mural Circle and the Transit Instrument were built by Jones of London whose reputation as an instrument maker was rapidly increasing at that time.

Together the two instruments were a powerful combination and, though similar pairs were set up in UK and Commonwealth countries during the nineteenth century, those at Armagh are the only pair known to survive to this day on their original site.

The tedious work of measuring the positions of stars occupied astronomers at Armagh Observatory for most of the nineteenth century. The computations required to correct measurements for small errors introduced by the alignment of the telescope, refraction and various other effects, were extremely laborious in those days of hand calculation. Nevertheless, eventually, Robinson was able to compile the first Armagh Catalogue of stars which he published in 1859. It is a monument to the enthusiasm and perseverance of himself and his dutiful assistants and it established the position of Armagh Observatory as a scientific institution of national and international importance. The stellar positions recorded in this book were ultimately combined with those from other observatories around the world to form a fundamental catalogue of stars which defines *the reference frame of the Universe* against which the movements of the planets are measured.

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7. T.R. Robinson and the development of the reflecting telescope.

Thomas Romney Robinson was a close friend of the Dublin instrument maker Thomas Grubb; the founder of one of the most important telescope building companies in the nineteenth century. In 1834 Thomas Grubb built for Armagh Observatory a 15 inch diameter reflecting telescope which incorporated several revolutionary innovations which have subsequently become widely accepted in telescope design.

- It was a Cassegrain telescope, rather than a Newtonian, as were almost all other reflecting telescopes built in Britain or Ireland at that time.

The Cassegrain design had never previously been used in a large telescope.
- It was the first large reflecting telescope to be mounted on a polar axis with a clock drive.
- It incorporated a novel lever support system for the primary mirror.

Whilst, regrettably, this unique telescope was dismantled and largely broken up in the 1920's its place in the history of telescope design is ensured.

The Cassegrain versus the Newtonian telescope design.

As telescopes increased in size in the late eighteenth and early nineteenth centuries, the inconvenience of the Newtonian system where the observer perches precariously at the top of the telescope exposed to wind and the elements, became apparent. The Cassegrain telescope design avoids this by using a curved secondary mirror, which projects the image downwards through a hole in the primary mirror, to a focus just below the bottom of the telescope. Here the image is conveniently positioned for an observer on the ground.

Robinson was a life-long proponent of the Cassegrain design for large telescopes and it was after his experiments with the *Armagh 15 inch Grubb Telescope* that he pushed this design in preference to the rival Newtonian design for the Great Southern Telescope built by the state of Victoria in Melbourne, Australia in 1870. From that time until the modern era most large telescopes feature a Cassegrain focus.

The polar or equatorial mounting and clock drive.

The great telescopes built by Sir William Herschel in England, in the late eighteenth century, dramatically increased the power of telescopes available to astronomers. However they suffered from several serious disadvantages.

Firstly they used an alt-azimuth form of mounting which, in order to reach any particular part of the sky, required the telescope to move both in azimuth and altitude. Once the celestial object had been located it was then only possible to follow the object as it moved across the sky, (due to the earths rotation), by moving the telescope in both azimuth and altitude simultaneously. For a large telescope this required a minimum of two assistants who turned the winches to move the telescope on instructions shouted by an observer at the top.

Robinson and Grubb realised the tremendous advantages and greater simplicity of the alternative, equatorial or polar mounting, such as had been used by Troughton in the instrument he built for Armagh in 1795. In order to keep the star in view, such a telescope required movement in only one direction (about the polar axis) and this movement was at a uniform rate of 4 degrees per minute (or 1 rotation per day). Conversely the movement in altitude and azimuth in the old style alt-azimuth mounting was non-uniform in both directions. The requirement of a uniform rotation about the polar axis could easily be provided by driving a telescope with a clock. This innovation was in fact first used on the great *Dorpat Refractor* in 1824 by the German astronomer Fraunhofer. The Armagh 15 inch Grubb telescope is the first large *reflecting* telescope in which this principle was used.

The lever mirror-support cell.

Telescope mirrors of the eighteenth and early nineteenth century were made of an alloy of copper and tin called speculum metal. It is an extremely fragile material which shatters with the least disturbance or even application of heat. It was used because of its high reflectivity.

One of the problems encountered by the telescope makers of the day was the support of this very heavy and fragile mirror in the telescope. If it simply rested on a flat bed, small humps on the back surface of the mirror took a disproportionate amount of the weight and, as a result, the mirror bent slightly and the image became distorted. To overcome this problem Grubb invented the lever support system for the Armagh reflector whereby the supporting pressure is evenly distributed over the back surface of the mirror. This design was later incorporated in the mirror cell for Lord Rosse's Six-Foot Reflector and the *Great Southern Telescope* at Melbourne and has been copied, in one form or another, in many of the large telescopes built to this day.

Thomas Grubb and his son Howard Grubb were two of the most important telescope makers of their day and the Company which bears their name *Grubb Parsons* recently built the 2.5 metre Isaac Newton Telescope and the 4.2 metre William Herschel Telescope in the Canary Islands.

The Great Six-Foot Telescope At Birr.

In addition to Thomas and Howard Grubb of Dublin, Ireland produced a third great telescope builder of the nineteenth century, perhaps the greatest of them all; William Parsons the third Earl of Rosse. It was at his country seat in Birr, County Offaly that the world's largest telescope stood for 70 years, until it was superseded by the 100 inch reflector on Mount Wilson during this century. Thomas Romney Robinson was closely involved in the construction of this telescope and vividly described the casting of the great, 6 foot diameter, speculum mirror.

On this occasion, besides the engrossing importance of the operation, its singular and sublime beauty can never be forgotten by those who were so fortunate as to be present. Above, the sky, crowded with stars and illuminated by a most brilliant moon, seemed to look down auspiciously on their work. Below, the furnesses poured out huge columns of nearly monochromatic yellow flame, and ignited crucibles, during their passage through the air, were fountains of red light, producing on the towers of the castle and foliage of the trees, such accidents of colour and shade as might almost transport fantasy to the planets of a contrasted double star.

He was present with Sir James South at the first viewing with the *Leviathan of Parsonstown*, as the telescope came to be known, and described many observations of nebulae. This instrument was the first to show the spiral nature of the external galaxies, which, like our own Milky Way, are made up of millions of faint stars.

In 1852 Robinson was asked by the Royal Society to chair a committee to report on the best design for a large telescope to be built in the southern hemisphere. This telescope which came to be known as the *Great Southern Telescope* was built by Grubb in Dublin and incorporated many of the innovations which Robinson, Grubb and Lord Rosse had pioneered. Also, it marked the start of the involvement in southern hemisphere astronomy by Irish Astronomers - an involvement that has continued at Armagh and Dunsink Observatories to the present time.

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8. Meteorology at Armagh and the Robinson Anemometer.

Meteorlogy is often confused in the public mind with astronomy, and, in the case of Armagh Observatory, there is good reason for this, as it has always been an aspect of the work carried out there. The Observatory archives contain meterological observations going back to 1784; well before the establishment of the Observatory.

The meterological recordings, which are continued to this day, represent the longest series of continuous weather records in Ireland. This is a valuable resource for the climatologists and historians of the future.

Robinson, besides his commitment to astronomy made many experiments in other fields of science. One of his most enduring interests was the study of meteorology and in particular the measurement of wind speed. He invented the cup-anemometer a device that has subsequently been widely used throughout the world. It is reported that the design was originally suggested to him by Richard Lovell Edgeworth.

When in 1867 the Board of Trade decided to establish seven, automatically-recording, weather stations around the British Isles, it was natural, knowing Robinson's interests that Armagh was chosen as one of the sites. Every hour for 50 years the wind direction and speed were recorded at Armagh. Though this large body of data has never been properly analysed, it remains one of the earliest complete wind surveys undertaken.

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9. The financial position of Armagh Observatory in the 19th century.

The Observatory, on its foundation in 1790 by Primate Robinson, was endowed with land to provide an income for the director. This amounted to 200 pounds per annum and was later supplemented by tithes from a area near Carlingford which would normally have been payable to the Archbishop.

The payment of tithes by land-lords and tenants to the established church was far from popular with protestant farmers and even less so with their catholic counterparts who felt that they were being asked to subsidise a rich and alien church. The series of reforms that took place throughout the nineteenth century from catholic emancipation in 1820 to the land acts of the 1890's had significant repercussions for the pursuit of science in Ireland. In the case of Armagh Observatory, the disestablishment of the Church of Ireland in 1869 took away *"the right to tithes"* and consequently dramatically reduced the Observatory's income. This resulted in the first financial crisis of the Observatory. A second came later in the century when the Observatory's tenants were enabled to buy their land through a Government purchase scheme.

In spite of many petitions to Government for compensation the requests fell on deaf ears and it was not until the late nineteen twenties that the Government (then the Government of Northern Ireland) recognised the importance of the Observatory's work with an annual grant of 100 pounds per annum. Currently the Observatory and Planetarium are financially supported by the Northern Ireland Department of Education by an annual *grant in aid* of approximately 500,000 pounds per annum.

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10. John Louis Emil Dreyer.

Thomas Romney Robinson died on the 28 February 1882 at the age of 89 after occupying the position of Director of Armagh Observatory for 59 years. His work continued to within days of the end of his life as is witnessed by his correspondence. He was succeeded by J.L.E. Dreyer, a Dane, who had previously worked at Birr Castle and Dunsink Observatory Dublin. When he came to Armagh he continued the fight which Robinson had begun for government assistance and eventually he was rewarded by a grant from the treasury of 2000 pounds, together with a clear indication that this was a once-only payment, not to be repeated. With this money, Dreyer was able to purchase a 10 inch refracting telescope, built by Howard Grubb, and with which he immediately set to work studying the many nebulae he had previously observed at Birr.

One of the problems he tackled was the question of whether the nebulae were inside our own galaxy (the Milky Way) or were indeed, as was suspected, island universes outside of our own galaxy. Some astronomers had previously suggested that the nebulae were variable in position, and therefore were likely to be nearby, however careful measurements with a micrometer on the 10 inch refractor, and later on photographic plates, showed that the earlier claims were false and that no movement could be detected. It was observations such as as these which eventually lead to the realization in the early twentieth century that the spiral galaxies were not truly nebulous but were, in fact, distant systems of stars similar to our own milky way.

Dreyer's **NGC** catalogue, or **"New General Catalogue of Nebulae and Clusters of Stars"** to give it its full name, is probably the single most important contribution to science to have come from Armagh Observatory. Even though it was compiled over 100 years ago it remains to this day the principal catalogue of nebulae and galaxies used by astronomers around the world. In it Dreyer listed and classified all the nebulae and star clusters previously observed by Sir William and Sir John Herschel and subsequently by Lord Rosse and his associates in Birr and by himself in Armagh.

The government grant of 1883 had alleviated some of the immediate problems faced by the Observatory following the dis-establishment of the Church of Ireland; however no on-going commitment could be extracted from the government of the day and, when the various Irish land reform bills were passed at the end of the nineteenth century, serious financial problems arose once more. As a result Dreyer was no longer able to afford an assistant to help with observations and was forced to give up this part of the work.

Dreyer, as a Dane, had a life-long interest in the great Danish astronomer Tycho Brahe, on whose work the great Kepler had based his laws of planetary motion. Tycho Brahe's observations were the most comprehensive of any from the pre-telescopic era. When funds for observing ran out at Armagh, Dreyer decided to undertake a task that he had previously not had time to tackle; that of compiling and publishing the life's work of Tycho Brahe.

It was remarkable omission, that for 300 years, the observations which had lead Kepler to his famous laws of planetary motion, had lain unpublished in the Royal Library in Copenhagen. It was with this data that Kepler had proved the helio-centric theory of the solar system, (ie that the earth moves around the sun and not vice versa); probably the single most important discovery in the history of astronomy. One by one the manuscripts were sent from Copenhagen to Armagh where they were compiled for publication.

Dreyer became the most prominent historian of astronomy of his day and wrote **The History of the Planetary System from Thales to Kepler** a classic work which has been frequently reprinted.

11. The decline of scientific research in the early twentieth century in Ireland.

Scientific research in the eighteenth and nineteenth centuries had, in general, been a pursuit of the rich and well educated anglo-irish landowners. The age of free university education for all, regardless of background, had not yet arrived. Consequently, when the economic power of the landlords was finally broken by the various land reform bills of the late nineteenth and early twentieth centuries, they were no longer able to support and indulge in scientific activity. The great private observatories in Ireland at Markree Castle, Birr Castle, and Daramona, Co Westmeath, which had contributed so much to science, were finally abandoned at this time. Armagh Observatory, although set up as a public institution, was basically financed by land endowments and thus it fell victim to the new legislation. It finally lost its estates in 1914.

The decline in income inevitably lead to a drop in scientific activity. Dreyer moved to Oxford in 1916 to complete his historical studies of Tycho Brahe and his successor J A Hardcastle died before he took up his position.

Dunsink Observatory, the only other Irish Observatory at that time, similarly entered a period of inactivity as funds from its parent institution Trinity College, Dublin dried up.

The precarious financial position of Armagh Observatory, following the loss of its estates, continued to inhibit activity in the period between the wars. The next Director, F A Ellison, was probably chosen partly because of his expertise in telescope maintenance and building. The fact that he was able to undertake such technical improvements himself reduced the financial burden on the Observatory of providing new instruments. In fact he presented the observatory with a large reflecting telescope by Calver.

The art of making telescope mirrors of fine quality had, since the eighteenth century, been a closely guarded secret. Sir William Herschel, the greatest telescope maker of the eighteenth century, was able to charge high fees for his mirrors and therefore was reluctant to divulge his techniques of construction. The cost of a mirror, made for George III **"with peculiar care"** by Herschel, was 200 pounds an enormous sum of money in those days. Ellison, quite rightly, felt that the cause of science was not served by secrecy and after learning the techniques of telescope mirror grinding and polishing he published a book entitled **"The Amateur's Telescope"** which described his methods. This book, which was reprinted many times, was the first book to describe telescope making procedures.

12. The re-birth of Irish Astronomy in the mid-twentieth century.

Throughout the nineteenth century repeated appeals to the Government for direct and regular assistance to Armagh Observatory were refused. Only sporadic, though sometimes generous, lump-sum payments were made, with no continuing commitment. The mould was finally broken in 1927, when the newly constituted Government of Northern Ireland at Stormont, recognised the important work of the Observatory by making an annual grant of 100 pounds. Though this was barely enough to maintain the fabric of the building it provided a precedent which could be invoked by later requests. At Dunsink, the only other extant Irish observatory, things had fared no better and the Observatory was effectively closed throughout the 1930's.

The appointment of Dr Eric Lindsay to the directorship of Armagh signalled a change in the fortunes of Irish astronomy. Born in Portadown, Co Armagh and educated at the King's Hospital School, Dublin and Queen's University, Belfast, Eric Lindsay was on familiar terms with many of the Irish leaders of his time, both from Northern Ireland and the Republic. He was equally at ease with Mr Eamon De Valera, the Prime Minister of the Republic, and with the unionist leaders from Stormont and with both he was able to use his influence to benefit Irish astronomy.

In the Republic it was partly through his friendship with De Valera that the Dublin Institute for Advanced Studies was set up, took over the defunct Dunsink Observatory formally belonging to Trinity College Dublin, and incorporated it into a new section called the School of Cosmic Physics.

In Northern Ireland, he realised that a small institution such as Armagh Observatory, could not hope to prosper without modern equipment and that this could best be provided by collaboration with other institutes. After the end of the second world war he proposed that the two Irish observatories, Armagh and Dunsink, should, combined with Harvard University, build a telescope that would chart the skies of the southern hemisphere. The agreement by the two governments of Ireland to jointly fund this telescope was a triumph of diplomacy for Eric Lindsay and is believed to be the first such agreement between the two governments to cooperate on a joint venture.

13. Southern Hemisphere Astronomy and the ADH telescope.

In the mid-twentieth century a map showing the position of the world's large telescopes would have looked very different to that of today. At that time almost all of the world's large telescopes were in the northern hemisphere close to the centres of population in the USA and Europe. Today there are a number of new observatories with large telescopes in remote desert regions of the world where sky conditions are best suited to astronomy. These include the Hawaian Islands, the Canary Islands, Chile, Northern China, South Africa and Australia.

The heavy concentration of telescopes in the first half of this century in the northern hemisphere, had lead to a striking imbalance in observational astronomy. Several of the most interesting astronomical objects can only be seen from the southern hemisphere, notably

- The centre of our galaxy (the Milky Way) which is in the constellation of Sagattarius
- The nearest external galaxies to our own: the two Magellanic Clouds.

The plan to set up a large telescope, committed to surveying southern skies was intended, both to fill this gap in astronomical knowledge and to give Irish astronomers, north and south, access, once more, to world class equipment. The telescope, to be named the Armagh-Dunsink-Harvard telescope (ADH), was to be set up at the Harvard Southern Station near Bloemfontein, South Africa, where clear skies were guaranteed. Following the participation of the two Irish observatories several other European countries including Belgium, Sweden and West Germany joined with Ireland and the USA to form the first international observatory Boyden Observatory, South Africa.

The Armagh-Dunsink-Harvard Telescope was built by the Perkin Elmer Corporation of the USA and financed by a 5,000 pounds grant from each of the two Irish observatories and by Harvard College. It was a telescope of unique design, which was capable of giving first class images of stars over a wide field, (circa 10 degrees). The design, by James Baker of Harvard, was based on the principles of the *Schmidt* telescope design developed in Hamburg, Germany by the brilliant german optician Bernhard Schmidt. This design avoided most of the optical abberations which had previously afflicted telescopes; namely, astigmatism, chromatic abberation and coma. Baker's modification was to use a secondary mirror to form the image behind the primary mirror. This was a distinct advantage over the classical Schmidt design which formed its image inside the main telescope tube above the primary mirror.

The telescope, which was almost entirely used for photography of stars and galaxies, made a valuable contribution to the study of the southern Milky Way and the Magellanic Clouds. In 1951 it was fitted with a large objective prism; at that time the largest glass prism in the world. This additional element caused the normally point-like stellar image to become extended into a short spectrum for each star. With the ADH, plus objective prism combination, it was possible to record the spectra of up to a thousand stars simultaneously; a very cost effective method of observing. The ADH was finally superseded in the 1960's by two large southern classical Schmidt Telescopes, one in Australia (the UK Schmidt Telescope) and the other in Chile (European Southern Observatory).

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14. Professor Ernst Julius Öpik.

EJ Öpik, one of the most outstanding astrophysicists of his generation, came to Armagh Observatory in 1948 as a refugee from Eastern Europe. He had for a while been head of the Astronomy Department at the University of Tashkent, Astronomer at the Tartu Observatory, Estonia and later Rector of the Baltic University, Hamburg. In the tranquil surroundings of Armagh Observatory, he wrote prolifically on a wide range of astronomical subjects until he retired in 1981. His published papers on Astronomy extend over a period of over seventy years from 1912 to his death in 1985.

His discoveries, which were many and various, include:

- The discovery of degenerate stars, eg white dwarfs, in his calculation of the density of o2 Eridani, in 1915.
- The first 'proof' of the extragalactic nature of M31, the Andromeda galaxy, in his calculation of the distance of M31 as 450,000 parsecs from the Sun. He obtained this result, which is close to the modern value, by dynamical considerations, in 1922.
- The computation of evolutionary models of main-sequence stars into giants, carried out in the 1930's, over a decade earlier than the computations of Hoyle and Schwarzschild.
- The prediction of the density of craters on the surface of Mars which were confirmed 15 years later by planetary probes.

Öpik's theory of the Ice Ages

His theory of the internal structure of the Sun, which he developed to explain the Ice Ages, was recently resuscitated when it was realised that it was capable of explaining the solar neutrino flux.

In recent times there has been considerable media coverage of possible changes in the earth's climate brought about by man's activities. This might lead one to suppose that the earth's climate would normally be stable and unchanging. This, in fact, is not the case, as through unknown natural causes, the earth's climate has often changed in the past. Most notable amongst these changes are the periodic ice-ages, when vast ice sheets covered much of Europe and North America.

From geological studies we know that the ice-ages typically last several hundred thousand years and are separated by long hot periods lasting for up to 250 million years. The ice-ages themselves are broken up by short, temporary, recessions of the ice, known as *inter-glacial periods*. It is just such a period that we are now in. The inter-glacial periods last for 10 - 30 thousand years; a very short time on the geological time scale.

It has been evident to scientists for many years that the ice-ages are periodic and many explanations for this periodicity have been proposed. One of the leading theories of the origin of the ice-ages was developed and published by Öpik at Armagh.

Öpik suggested that the rate of energy production in the centre of the sun varied from time to time, due to changes in the pattern of convection in the sun's core. However, due to the way the sun's atmosphere reacts to changes in energy production, the solar energy incident on the earth's surface, would actually drop as the core of the sun heated up. It has not yet been possible to verify or reject Öpik's theory although it received some further study recently when it was realised that it might be capable of explaining the low neutrino flux that has been observed from the sun by the new underground neutrino detectors.

Öpik's theory of the evolution of the Sun

Probably Öpik's most important contribution to science was his study of the evolution of stars, published in 1938. In this pioneering paper he discussed the various processes that would follow the conversion of hydrogen into helium by thermonuclear reactions in the centre of the Sun and other stars. He showed how, when eventually the hydrogen had become exhausted, the central core would contract and its temperature rise above 10,000,000 degrees C. At the same time the outer atmosphere would expand until, in the case of the Sun, it filled the orbit of the planet Venus. By this time, with the increased energy radiated onto the earth and the close proximity of the solar surface, the oceans would boil and the earth would become a scorched and dead planet. It is now generally believed by astronomers that this overall picture is correct and that the expansion of the sun will terminate all life on earth in about 5,000 million years from the present.

Öpik's remarkable study to show how stars evolve in time, was carried out using hand calculations. The results he obtained were finally confirmed about ten years later by Hoyle and Schwarzschild using electronic computers.

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15. The Planetarium and the Lindsay Hall of Astronomy.

In the 1950's and 60's, as both the USA and USSR competed with each other in launching satellites and space probes, interest in astronomy by the general public rose rapidly. Within just two decades even space travel by man moved from the realm of fantasy to reality. The great rise in the public conciousness of the universe that followed lead to many requests for visits to the Observatory. However, the Observatory, as a research institution, was not equipped for this influx and in 1964 it was agreed that a Planetarium should be built in Armagh which would cater for public education in astronomy. The first Director was Patrick Moore the famous broadcaster and TV personality.

Later, under its former director, Mr Terence Murtagh, the Planetarium expanded with the addition of a large exhibition hall named the Lindsay Hall of Astronomy. In this building many exciting exhibitions have been staged, including displays of meteorites, moonrock and various equipment from the Apollo missions. It is probably the most comprehensive facility for education in astronomy in the British Isles.

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16. Armagh Observatory in the Space Age.

For the first 150 years of the Observatory's existence it relied primarily on observations carried out in Ireland in what has often been described as `one of the worst astronomical climates in the world.' It is not just the frequency of cloudy weather that inhibits observations in Ireland, but the constantly changing transparency of the atmosphere. As equipment and techniques of observation have improved the accuracy of the observations became more and more limited by the use of poor quality, low altitude sites.

Since 1950, with the advent of cheap air travel, it has become possible for Armagh astronomers to make observations of high accuracy with telescopes at moderately high altitudes, in dry semi-tropical regions of the world. Often the best quality sites are to be found on volcanic islands in the Pacific or Atlantic Oceans, such as the Canary Islands or the Hawaiian Islands. These new observatories are of an international character, similar to the pioneering Boyden Observatory set up earlier in South Africa. The five observatories most commonly used by astronomers at Armagh are at Hawaii, La Palma in the Canary Islands, the Anglo-Australian Observatory, New South Wales, the European Southern Observatory, Chile and the South African Astronomical Observatory, Cape Province.

During the 1970's and the 80's a number of earth satellites have been launched which are designed specifically to make astronomial observations from above the earth's atmosphere. Mostly, these orbiting observatories, study the emission of stars and galaxies in parts of the spectrum not accessible from the ground, such as X-rays and the extreme ultraviolet. Astronomers at Armagh Observatory have been making such observations since 1979 when they made the first observation of a flare in the ultraviolet on the dim, nearby, star Gliese 867A. Subsequently, Armagh astronomers have employed the European satellite EXOSAT and the Japanese satellite GINGA to make X-ray observations of stars and the NASA satellite SMM to observe the Sun.

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17. Current Research Programmes at Armagh Observatory.

Throughout the nineteenth century the work at Armagh was primarily concerned with the measurement and cataloguing of the positions of stars, nebulae and galaxies. As our understanding of the physical nature of matter has progressed in this century the emphasis has shifted from *positional astronomy* to *astrophysics*.

In astrophysics, we attempt to relate the composition and structure of stars and galaxies to the basic physical processes we can study, theoretically and experimentally, on Earth. An example is the application of our knowledge of nuclear physics and the transmutation of elements, (e.g. H -> He), to the structure of the Sun and stars. Sometimes, however, the procedure is reversed and we discover a basic law of physics by attempting to interpret astronomical observations. Such an example would be our understanding of the very dense matter which exists in white dwarfs, neutron stars and black holes; states of matter which do not exist on Earth.

In the present decade three areas of astrophysics have been prominent at Armagh; the Sun, Cool stars, and Hot stars.

The Sun.

Throughout our lives we take for granted that the radiation from the Sun, sunlight, will continue at its present level. Even small variations, of a few percent, could be sufficient to plunge the Earth into a new ice-age, or alternatively back into one of its prolonged tropical periods. The study of the Sun's radiation and how it relates to the structure of the Sun has been a topic studied at Armagh since Öpik's pioneering work in the 1940's and 1950's.

The radiation from the Sun with which we are most familiar is the rather yellow sunlight that our eyes can detect. However, the Sun also radiates at many other wavelengths, from the radio to X-rays. A picture of the Sun in radio or X-rays looks very different to a picture in white light (as seen by our eyes). Whereas the white light picture of the Sun is a relatively uniformly illuminated disc, the X-ray picture is extremely patchy, showing bright regions on a dark background. When we compare the X-ray picture with the distribution of sunspots on the surface of the Sun, we see that the X-ray bright patches lie in the vicinity of the dark sunspots. Such areas on the surface of the Sun may change their appearance within a few hours, or even minutes, and are known as *active regions*. Armagh astronomers have studied the behaviour of active regions; for instance, what proportion of their energy is emitted in different parts of the spectrum and how much is involved in moving jets of material.

Cool Stars.

The Sun is the only star for which we have direct spatial information; all other stars are merely points of light in even the most powerful telescope. Thus, although the Sun gives us considerable insight into the behaviour of other stars, it is only one example, and if we wish to generalise our knowledge we must observe other stars of a similar type.

Approximately ninety percent of all stars in the sky are cooler than the Sun, with surface temperatures around 4,000 degrees C, as opposed to 6,500 degrees C on the Sun. They are inconspicuous to the casual observer, however, because they are dim and usually too faint to be seen with the naked eye. Many of these *cool stars* are believed to have huge spotted areas on their surfaces. This conclusion is not based on direct pictures but on the variation of the brightness of the stars as they rotate. The relationship between the spots on stars and the *active regions* that accompany them has been closely studied by astronomers at Armagh in recent years.

On both cool stars and the Sun we occasionally see sudden eruptions called flares. These explosions release the equivalent of thousands to millions of hydrogen bombs into the atmosphere of the star. How this amount of energy can be stored up and then released in a star such as the Sun is not fully understood at present - however it is believed that the energy is stored in the strong magnetic fields which occur in the vicinity of sunspots. The magnetic fields become stretched by the turbulent motions in the star's atmosphere and eventually when stressed to their limit they snap like an elastic band and release the energy. The study of flares on the Sun and cool stars has been an important part of the work carried out at Armagh over the past twenty years. Eventually these studies may help us understand how the hot gases are contained in solar and stellar flares and possibly how they could be contained on Earth in future, controlled fusion, reactors. The containment of hot plasmas on Earth has been a major stumbling block in progress towards the exploitation by man of the ultimate energy source, thermonuclear fusion.

Hot Stars.

Stars vary from objects of almost planetary size, termed *brown dwarfs*, up to the exceedingly bright supergiants, which are about 100 times more massive than the Sun. These *Searchlights of the Universe* are 10,000 times brighter than the Sun and emit so much light that the pressure of the photons leaving the star blows away much of the star's atmosphere. In addition, their interiors are so hot, that they rapidly burn up their nuclear energy supply and eventually finish their profligate existence in enormous explosions called supernovae. One such supernova, SN1987A, was observed recently in the nearby, southern hemisphere galaxy, The Large Magellanic Cloud.

One of these, extremely hot stars, P Cygni, has been studied in detail at Armagh. It is expected that, eventually, it will end its life in a similar catastrophic explosion, which will completely disrupt the star and create a vast gaseous nebula. It is believed by astronomers that the heavier elements, such as iron, copper etc are all produced in the final stages of these huge cosmic explosions.

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18 National and International Collaboration.

Coordinated Observing Projects.

Stars emit radiation, not just in the optical region of the spectrum to which our eyes are sensitive, but also in radio waves, infra-red rays, ultraviolet light and X-rays. When a star is variable in brightness, for instance during a flare, we cannot get a full picture of its behaviour unless we observe it at all wavelengths simultaneously. This is difficult to do as it involves operating satellites and ground-based telescopes, all at the same time.

Over the past decade, Armagh astronomers have specialised in this type of work and have coordinated a number of observing programmes involving two satellites and, up to 20 ground-based telescopes, simultaneously. Often, in order to get continuous coverage of a particular star, telescopes around the world are required.

Starlink comes to Northern Ireland

Ten years ago, the United Kingdom Science and Engineering Research Council set up a network of computers based at various centres of astronomical activity. The underlying philosophy was to encourage astronomers to pool their resources for the analysis of astronomical data. Rather than each group of astronomers writing their own computer software and thereby duplicating effort, each group undertook to provide the software in their area of expertise, and to make this available to all. Also, the links between the various machines in the network encouraged interaction between astronomers working in isolation.

Armagh Observatory, together with Queen's University Belfast, became a node in the Starlink network in 1988. This network will probably eventually provide the system for remote observing with telescopes abroad.