

Projects for *Astrophysics* Students 2016/17

1.

An statistical analysis of the solar eruptive activity associated with solar energetic particle events

Supervisor: Dr. Eoin P. Carley and Professor Peter Gallagher

Location: TCD

Eruptive activity in the solar corona is known to produce large-scale waves, shocks and coronal mass ejections (CMEs). This kind of activity is often associated with the in-situ detection of solar energetic particles (SEPs). However, the exact mechanism by which eruptions in the corona produces SEPs is still subject to much debate. In this study, the student will analyse the coronal activity associated with multiple SEP events. This will involve observations of EUV waves using NASA's Atmospheric Imaging Assembly (AIA), which can provide more accurate wave/shock kinematics than has been achieved in the past. This will be combined with a detailed investigation of the particle acceleration and shock activity using existing and new radio spectrographs (e.g., Orfées, Nancay) and the Nancay Radioheliograph, whenever possible. Added to this will be a detailed analysis of CME kinematics and energetics using both the SOHO and STEREO coronagraphs. All analysis will be combined into a statistical study of the physical properties of these events, leading to a better understanding of the coronal conditions that lead to the acceleration of solar energetic particles.

2.

Measuring abundances in a Red Giant Atmosphere

Supervisor: Professor Brian Espey

Location: TCD

The aim of this project is to determine the abundance, & temperature in the atmosphere of a red giant using ultraviolet spectra from HST and the Far-Ultraviolet Spectroscopic Explorer (FUSE) satellite. Data were obtained by observing the spectrum of a white dwarf companion as it orbited into eclipse behind the red giant and became increasingly absorbed. The aim of this work is to probe the atmosphere at a number of points to map the variation with giant radius. Expertise with IDL required.

3.

Short-term Stellar Variability using data from the Monck Observatory

Supervisor: Professor Brian Espey

Location: TCD

This project will utilise data from the Monck Observatory to study short-term variability in RR Lyrae and Cepheid variables which are used as distance indicators in astronomy. Data will be analysed to determine the variability in terms of type, amplitude, and duration. Some experience with IDL or Python is required, as is a good set of warm clothes! Note that data-taking is weather-dependent, so may also include historical data from the Monck, as well as data from other sources.

4.

The Light Pollution Effect of Irish Towns

Supervisor: Professor Brian Espey

Location: TCD

Ground-based and satellite measurements of light at night will be assessed to determine the area around a sample of Irish towns that is affected by their light in order to see if a typical template region can be found for estimating how the amount of light, and area covered, scales with population. These data will form part of current research on light pollution and energy efficiency. Some experience with image processing is recommended.

5.

Radio Imaging of the Solar Corona with LOFAR during a Solar Eclipse

Supervisor: Professor Peter Gallagher

Location: TCD

On March 20, 2015 a partial solar eclipse occurred over northern Europe. The Low Frequency Array (LOFAR) in the Netherlands captured a unique sequence of interferometric observations of the passage of the Moon across the solar disk. The Moon's limb be used as a moving knife edge (e.g., Ramesh et al., ApJ, 2012) to search for small-scale spatial structures in the solar corona with a resolution in excess of the theoretical spatial resolution of LOFAR. The aim of this project is to create a sequence of interferometric images of the solar corona during the eclipse and to search for fine-scale structures in the coronal plasma. These observations will be compared with high resolution optical images of the eclipse obtained from an Irish Air Corp CASA marine surveillance aircraft.

6.

How supernova progenitors respond to eruptive mass loss

Supervisor: Professor Jose Groh

Location: TCD

Supernovae explosions are the final act in the evolution of stars more massive than about 8 solar masses. Determining the progenitors of these explosive events and how massive stars are linked to the different SN types are topics of major significance for several fields of astrophysics. Recent observations show that some supernova progenitors have massive eruptive events before dying, but their effects on the progenitor has yet to be investigated. In this project, the student will use state-of-the-art software to compute the final acts of a star before death under different mass loss conditions. The results will be the theoretical standard for comparison with existing and upcoming supernova observations obtained with the largest optical telescopes in the world and the Hubble Space Telescope.

7.

Investigating survivors from massive stellar explosions

Supervisor: Professor Jose Groh

Location: TCD

The most massive and luminous stars in the Universe undergo violent stellar explosions as they evolve. These events are non-terminal, and the star survives doomsday after ejecting tens of solar masses into the interstellar space. The frequency, amount of mass lost, and physical mechanism behind these massive stellar explosions are poorly known. In this project, the student will use stellar evolution models as a time machine to constrain the properties of stars at the time of a massive explosion, such as its chemical composition, luminosity, and temperature.

8.

The role of magnetic fields and mass loss on interacting binary stars

Supervisor: Professor Jose Groh

Location: TCD

Most stars are not born in isolation, but rather with close siblings. As stars evolve, they interact with their close companion stars and exchange mass and angular momentum. This phenomenon of binary interaction has an irreversible effect on the remaining evolution of stars and has had significant impact across the history Universe. In this project, the student will employ numerical simulations of stellar evolution to investigate how stellar magnetic fields, mass loss, and convection on the top of the central nuclear burning core affect the fraction of stars that undergo binary interaction. Among many of the important implications for astrophysics, the results and predictions from the student will serve as guidance for observers looking for the first stars in the Universe.

9.

Testing stellar evolution theory with Gaia Data Release 1

Supervisor: Professor C.S. Jeffrey

Location: Armagh Observatory

The Gaia spacecraft was launched in December 2013 to map the positions and motions of about one billion stars in our Galaxy, the Milky Way. The distance of a star is one of the most difficult measurements to make. Consequently direct measurements of luminosity and mass, which are crucial for understanding how stars work, have still only been achieved for a modest number of nearby stars.

The first Gaia data release is scheduled to occur during summer 2016.

In combination with data from a previous astrometry mission (Tycho), the Tycho-Gaia astrometric solution (TGAS) will deliver positions, parallaxes and annual proper motions for the 2.5 million Tycho-2 stars, with sub-milliarcsecond accuracy.

This project will establish the luminosities and masses of a significant number of highly-evolved stars, by combining TGAS data with measurements of other properties, such as effective temperature and surface gravity. The luminosities and masses will be used to test stellar evolution models for these stars.

Further information:

<http://sci.esa.int/gaia/>

10.

Exoplanet transit timings with the Armagh Robotic Telescope

Supervisor: Professor C.S. Jeffrey

Location: Armagh Observatory

Evidence of planets orbiting stars other than the Sun has transformed astronomy over the last two decades. The major discovery-technique in recent years has been the transit method. High-precision photometry is necessary to detect the small-amplitude eclipses. Transit timings can be used to refine orbital properties, and obtain evidence for additional planets in the exoplanet system.

This is primarily an observational project using the Armagh Robotic Telescope (ART).

The goal will be to identify and observe exoplanet transits visible from Armagh during October - December. The primary experimental steps will be to:

- i) obtain differential photometry using the ART,
- ii) reduce the data to obtain differential light curves,
- iii) obtain accurate timings, reduced to a standard time system,
- iv) compare with published ephemerides to look for possible deviations.

Given the unpredictability of Irish weather, this project will include options to study the theoretical interpretation of exoplanet transit lightcurves in terms of stellar and

exoplanet properties, and to make observations of stellar oscillations in, for example, subluminescent B stars. The close link between PLANetary Transits and stellar Oscillations is recognized by the name of the next ESA medium-sized mission - PLATO.

Although the ART can be operated remotely, it should be assumed that the student will be present in Armagh and available at night to monitor the observations. Demonstrable competence in experimental procedures is required. On-site accommodation is available; terms are negotiable.

11.

A statistical analysis of the signatures of solar eruptions

Supervisor(s): Dr. David Long / Dr. David Pérez-Suárez (Group Head: Dr. Sarah Matthews)

Location: Mullard Space Science Laboratory, University College London, Surrey, UK

TCD Local Contact: Prof. Peter Gallagher

Solar eruptions are the most spectacular events in our solar system and are associated with many different features and signatures of energy release such as solar flares, coronal mass ejections, global waves, radio emission, accelerated particles and many more. Although each of these signatures provides a different insight into the physics underpinning the initiation and evolution of the eruption, they tend to be studied in isolation or as part of single event studies, in some cases leading to conflicting interpretations and conclusions. However, multiple space missions over the past 10-20 years (particularly the Solar Dynamics Observatory, SDO) have resulted in a vast archive of observations that may be used to develop a more statistically rigorous understanding of the relationship between each of these signatures of solar eruptions.

This project will investigate the relationship between different solar phenomena using a statistical approach. This will allow the circumstances under which different signatures are observed to be understood, potentially providing improved capabilities for space weather forecasting and prediction of eruptions. The project will involve building and mining a database as well as original coding in IDL/Python, basic shell scripting and a keen interest in big data analysis!

The student will spend the project working with the Solar Physics Research Group at Mullard Space Science Laboratory, a department of University College London located in the Surrey Hills. The Solar Group has strong research links with research groups in Japan, France, Belgium, Argentina, Ireland and the USA and has a deep involvement with both current and future space missions (including Hinode, Solar Orbiter and Solar-C). Accommodation will be provided in a nearby village.

12.

Imaging the Inner and Outer Wind of the Closest Red Supergiant with the Jansky VLA

Supervisor(s): Dr. Eamon O’Gorman

Location: School of Cosmic Physics, Dublin Institute of Advanced Studies

TCD Local Contact: Prof. Peter Gallagher

Red supergiants are among the most largest of stars in the Universe and are major contributors of heavy elements to the interstellar medium. Their immense mass-loss rates (up to 10 orders of magnitude greater than the solar value) play a key role in galactic chemical evolution but represent a challenge to the theory of mass-loss in evolved stars. Their sheer size allows the closest red supergiants to be spatially resolved with the most powerful radio interferometers available. In this project, we will use data from the new Jansky VLA (located in New Mexico, USA) to spatially resolve the inner wind of the nearest red supergiant star Antares (alpha Sco: M1 lab +B2.5 V) at multiple frequencies (4 – 30 GHz) for the very first time. This will allow the mean gas temperature to be derived as a function of distance from the star. We will also image the inhomogeneous and multicomponent outer wind of Antares (which is illuminated by the presence of a hot main sequence stellar companion) at unprecedented resolution and wavelength coverage to search for flow structure in the outer wind. Our results will be compared with existing theories of mass-loss in red supergiants.

The data sets are large (>100GBs) and will first need to be calibrated using existing pipelines. The student will then create their own code in CASA (The Common Astronomy Software Application package) to model the visibilities (i.e., the raw data), create images and compare different imaging techniques.

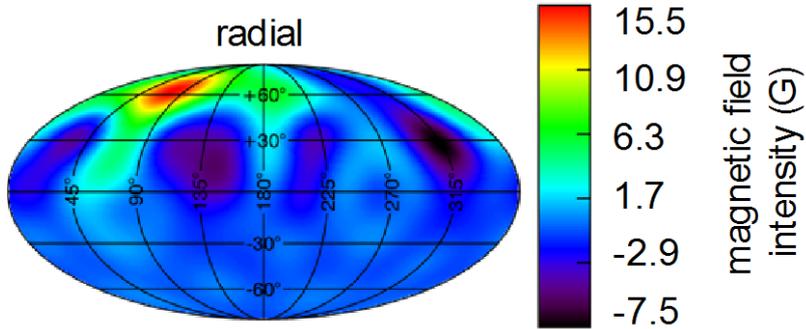
13.

Investigating the interplay between stellar rotation and magnetism

Supervisor: Professor Aline Vidotto

Location: TCD

During their main-sequence phase, isolated stars spin down as they age. This rotational braking is ultimately caused by stellar winds, which, outflowing along the stellar magnetic field lines, carry away angular momentum of the star. Recently, a new scenario concerning the rotation evolution of stars has been proposed. In this scenario, stars are born as fast rotators, but very weakly coupled to their winds. Eventually, at later phases, the scenario suggests that stars can randomly switch to being strongly coupled to their winds, leading to a rapid spin down. The difference between the weakly and strongly coupled modes is ascribed to different stellar magnetic field topologies. In this project, the student will have access to magnetic field maps for a sample of stars. By investigating the topologies of stellar magnetic field, the student will be able to directly test this recently proposed scenario.



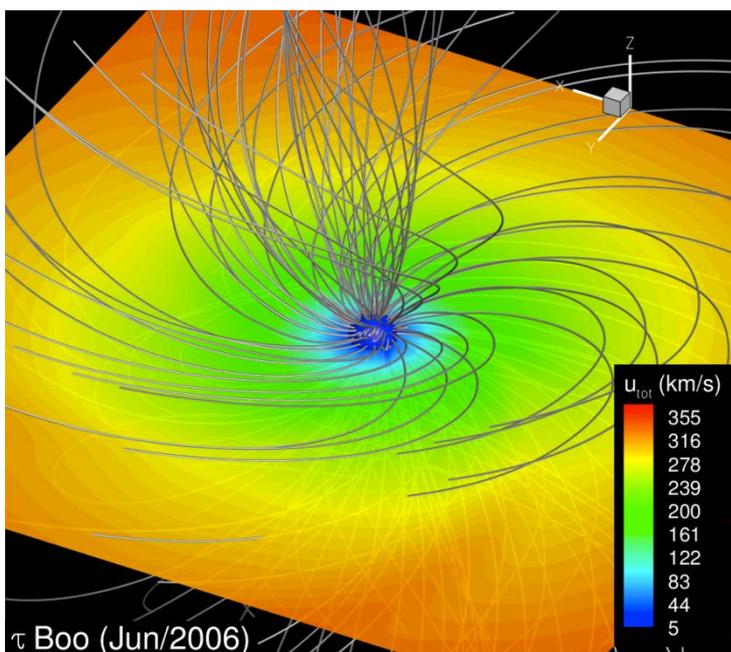
14.

Characterising the interplanetary media of exoplanetary systems

Supervisor: Professor Aline Vidotto

Location: TCD

Stars lose mass in the form of quiescent winds and bursty ejecta. As these particles outflow from the star, they permeate the interplanetary medium, interacting with any orbiting exoplanet. Although in the solar system, the solar wind can be probed *in situ*, there are no direct methods to detect the winds of other solar-like stars. Through stellar wind modelling, it has been shown that the variety of observed rotation rates, stellar activity, magnetic field intensities and topologies of cool, dwarf stars can lead to stellar winds significantly different from the solar wind. In this project, the student will analyse a set of 3D magnetohydrodynamics simulations of stellar winds to characterise the interplanetary media surrounding other exoplanets. The goal will be to quantify the differences between the environment surrounding exoplanets and those encountered by solar system planets.



15.

Energetic particles and shocks from the Sun

Supervisor(s): Dr. Pietro Zucca

Location: LESIA, Paris Observatory, France

TCD Local Contact: Prof. Peter Gallagher

The acceleration of electrons and charged nuclei to high energies is a phenomenon occurring at many astrophysical sites throughout the universe. In the heliosphere, processes related with the sudden release of magnetic energy stored in regions of the solar atmosphere called “active” causes a variety of dynamic and highly energetic activity. The abrupt strong electromagnetic emission from gamma-ray to radio-waves known as solar flares and the ejection of clouds of magnetic plasma called coronal mass ejections (CMEs) are the most energetic natural particle accelerators in the heliosphere, sometimes accelerating electrons and ions to relativistic energies.

It is still not fully clear how flares and CMEs produce such energetic particles. In particular, open questions remain on the mechanisms accelerating the particles and how do they propagate in the outermost part of the Sun's atmosphere (solar corona) and in the interplanetary (IP) space. Shocks driven by CMEs play an important role on accelerating particles, as well as the energy release during flares.

Radio emission carries a conspicuous amount of information and traces the energetic of the electrons while EUV, soft X-rays are mostly due to thermal plasma. This project involves the analysis of EM emission with particular focus on the radio signatures of flares and CME-driven shocks.