Projects for Physics & Astrophysics Students 2019/20

Projects Located in TCD

101. Energy use and light output in a world context  
Supervisor: Professor Brian Espey  
Location: TCD

Using satellite imagery, the light output from towns and cities across Europe and beyond will be compared to estimate light use/waste per capita for different countries with the aim of identifying best practice in this regard. It is known that the US as a whole produces more light per capita on a national basis and some European cities produce much less, but the situation in Ireland has not been examined in detail. The project work will involve using the R shareware package with georeferenced data such as CSO and European shapefiles and databases.  

102. Ground and space measurements of light pollution - closing the gap  
Supervisor: Professor Brian Espey  
Location: TCD

Historical and current night sky light measurements taken from the ground (including from TCD) will be compared with satellite observation of light sources. The goal of this work is to estimate the amount of light scattered by molecules and aerosols and to determine whether there has been any growth in light waste, particularly since the introduction of cheaper LED lighting. Additionally, an attempt will be made to estimate the region around a ground site that predominantly contributes to the sky pollution levels. This project will involve the use of the R shareware package, which can be run on a laptop.  

103. Atmospheres of alien worlds: transmission spectra of exoplanets with the Hubble Space Telescope  
Supervisor: Professor Neale Gibson  
Location: TCD

In the last decades, radial velocity and transit surveys have made enormous progress in detecting the population of exoplanets in our Galaxy, yet we still know very little about the planets themselves. Transiting planets, those that periodically eclipse their host stars, play a special role in our understanding of exoplanets, as they allow us to characterise their atmospheres in detail using a technique called transmission spectroscopy. This is a measurement of the effective planetary radius as a function of wavelength. As starlight filters through the upper atmosphere of a planet during transit, this leaves a spectral imprint that can reveal the chemical composition and physical properties of an exoplanet's atmosphere. This project will use data from the Hubble Space Telescope to measure the near-infrared transmission spectrum of a hot-Jupiter, searching for molecular features including water. The emphasis will be on the use of
advanced statistical techniques to model the impact of time-dependent instrumental systematics on the analysis of transit light curves.

104. 
**Atmospheres of alien worlds: high-resolution transmission spectra of exoplanet atmospheres**  
**Supervisor:** Professor Neale Gibson  
**Location:** TCD

In the last decades, radial velocity and transit surveys have made enormous progress in detecting the population of exoplanets in our Galaxy, yet we still know very little about the planets themselves. Transiting planets, those that periodically eclipse their host stars, play a special role in our understanding of exoplanets, as they allow us to characterise their atmospheres in detail using a technique called transmission spectroscopy. This is a measurement of the effective planetary radius as a function of wavelength. As starlight filters through the upper atmosphere of a planet during transit, this leaves a spectral imprint that can reveal the chemical composition and physical properties of an exoplanet's atmosphere. This project will use a technique called Doppler-resolved transit spectroscopy. This uses high-resolution time-series spectra during transit to try and disentangle light from the star and planet by exploiting the large Doppler shift of the exoplanet's spectral signature compared to its host star, with the goal of searching for atomic and molecular features in a hot-Jupiter. The emphasis will be on the use of signal processing techniques to recover the exoplanet's signal after filtering out the (much larger) stellar and telluric signatures.

105. 
**The effects of mass loss, rotation and convection on the evolution of massive stars**  
**Supervisor:** Professor Jose Groh  
**Location:** TCD

About 90% of massive stars exist on the main sequence, burning hydrogen in their cores. The physics of the evolution of massive stars on the main sequence has significant consequences for their appearance, the rest of their evolution after the main sequence and is ultimately of importance for several other fields in astrophysics, such as gravitational wave sources. Recent observations of massive stars indicate a surprising discrepancy with stellar evolution models, showing that massive stars on the main sequence may span a larger region on the HR diagram than current predictions. The goal of this project is to investigate how this discrepancy may be explained by the effects of mass loss, rotation, and convection. This will be achieved by computing state-of-the-art numerical stellar evolution models, which will allow the student to make predictions of surface properties of massive stars evolving under different scenarios. The student will also compare the results from their models to observations already obtained from major telescopes such as the VLT (European Southern Observatory, Chile).
106.  
The origins of metal-poor supernovae  
Supervisor: Professor Jose Groh  
Location: TCD

Stars that explode as core-collapse supernovae eject large quantities of material in their surrounding medium before their deaths. When the star explodes, the supernova ejecta will crash into this material and distinguishable features will appear in both photometric and spectral observations. The spectra will show unmistakable narrow emission lines while the light curves will be boosted due to the conversion of kinetic energy of the ejecta into radiation. While recent studies have investigated the physics of interacting supernovae at solar metallicity, little is known about the evolutionary channels leading to these events in low-metallicity environments. In this project, the student will determine the properties of metal-poor interacting supernovae using the state-of-the-art radiative transfer code CMFGEN. The information gained from this work offers the possibility of distinguishing between the different evolutionary channels leading to these progenitors, allowing the students to predict the spectral signatures that could be detectable by ongoing observational surveys.

107.  
Spectroscopic modelling of thermonuclear supernovae  
Supervisor: Dr Mark Magee (Professor Kate Maguire’s group)  
Location: TCD

Supernovae are some of the most explosive events in the universe. They can enrich the cosmos with synthesised heavy elements and can outshine entire galaxies for a short period of time. Type Ia supernovae are the most commonly observed supernova type, and are fundamental to cosmology and our understanding of the Universe. In spite of this, their exact origin remains unclear. By taking spectra of these supernovae we are able to interrogate whether suggested explosion scenarios are in agreement with what is observed. This project is focused on constructing models from proposed explosion scenarios and comparing these to observations. Some basic background in programming (Python) would be beneficial, but is not essential.

108.  
Uncovering hidden circumstellar interaction in Type Ia supernovae  
Supervisor: Professor Kate Maguire  
Location: TCD

Type Ia supernovae are the violent deaths of white dwarfs in close binary systems. They are essential for understanding the endpoints of stellar evolution as well as fundamental probes of dark energy. Despite their use in precision cosmological measurements, the mechanism by which they explode is not well understood. Some otherwise normal Type Ia supernovae have been shown to have unexpected late-time excesses in their light curves. This additional source luminosity has been linked to interaction with distant circumstellar material that has been ejected from the stellar system and can provide vital clues to how Type I supernovae explode and what their elusive companion stars are. The aim of this project is to search for previously unidentified candidate events in large transient survey datasets, such as the Zwicky Transient Survey and ATLAS, by looking
for objects that appear like normal Type Ia supernovae but become brighter again at late times. These candidates will then be triggered for spectroscopic confirmation at robotic facilities and compared to previously identified events to try to determine the origin of these rare events and the link to normal Type Ia supernovae.

109.
When stars explode; the case of SN 2018giu
Supervisor: Dr Simon Prentice (Professor Kate Maguire’s group)
Location: TCD

A few hundred million years ago, in a distant galaxy, the interior of one particular star reached the conditions required to burn silicon to iron, the final step in stellar nucleosynthesis. Approximately one day later, the inert iron core succumbed to gravitational pressure and collapsed, beginning a series of events that quickly led to the violent expulsion of the stellar envelope; the star went supernova. In 2018 the light of this event finally reached Earth and it was given the designation SN 2018giu and classified as a type Ic supernova. In this project, the student will use existing data acquired with the Liverpool Telescope to investigate the physical properties of SN 2018giu by examination of its light curve, spectra, and host galaxy. The results can then be set it into context against other supernova events. This project will involve some coding in Python.

110.
The impact of cosmic rays in protoplanetary disk evolution
Supervisor: Dr Donna Rodgers-Lee (Professor Aline Vidotto’s group)
Location: TCD

The disks of dust and gas surrounding young stars are the birthplace of exoplanets. How these protoplanetary disks physically and chemically evolve depends sensitively on the sources of ionisation present. X-rays from the central star and radioactive decay alone as sources of ionisation struggle to explain certain observations of these disks. While galactic cosmic rays are thought to be excluded from the system due to strong stellar winds, cosmic rays emanating from the young star itself may play an important role. This project focuses on constraining the contribution that stellar cosmic rays may have to the overall ionisation rate in protoplanetary disks. Specifically, the student will apply a cosmic ray propagation code to recent ALMA observations of the density profiles of these disks. The student will investigate the transport properties of cosmic rays which best fit the observational data. This is a theoretical project, which requires python skills for data visualisation and basic programming skills.
111. How does rotation affect magnetic fields in stars?
Supervisor: Dr Gopal Hazra (Professor Aline Vidotto’s group)
Location: TCD

Stars with an outer convection zone also show a cyclic behaviour in their magnetic activity, similarly to the 11-year magnetic activity cycle of the Sun. The Zeeman Doppler Imaging technique is able to reconstruct the large-scale structure of the stellar magnetic fields. However, the technique cannot recover the small-scale field component. 3D dynamo models, on the other hand, are able to predict the total magnetic field of the star (small- and large-scale components). In this project, the student will use 3D simulations of stars with a range of rotation rates to predict how the surface magnetic field changes as rotation increases. This will help us to understand what types of dynamo are operating inside stars and their dependency on rotation periods. This is a theoretical project that requires IDL or Python for data visualisation.

112. What can radio emission tell us about winds of red supergiant stars?
Supervisor: Professor Aline Vidotto
Location: TCD

Red supergiants have dense winds that generate thermal emission at radio wavelengths. In this project, the student will use a range of stellar wind models to predict the radio emission of red supergiant stars. The aim is to derive the physical conditions of the stellar winds that best reproduce radio/sub-mm observations, conducted with radio telescopes, such as the VLA and ALMA. This is a theoretical project that requires IDL or Python for data analysis and will involve running magnetohydrodynamic stellar wind simulations.

113. Optical absorption due to high-Z elements in optical afterglows of kilonovae.
Supervisor: Cormac McGuinness
Location: TCD

This is a computational project to carry out a comparison of methods and atomic structure codes for calculating line and continuum optical photoabsorption/photoionisation data, required to understand optical afterglows arising from kilonova neutron star mergers relevant to r-process nucleosynthesis.

Nucleosynthesis of the heaviest isotopes of elements beyond iron (Z=26) is thought to occur only through neutron star mergers via the “r-process” or rapid neutron capture allowing for nuclei with Z > 26 that are particularly neutron rich (i.e. heavy) to be synthesised. Through VIRGO/LIGO gravitational wave detection, the optical afterglows of kilonovae or neutron-star mergers may now perhaps be routinely captured. The expanding cloud of ejecta from these mergers represents low electron temperature lowly-ionised plasmas containing the newly synthesised elements via this r-process. Optical measurements of the blackbody spectra of these expanding clouds will have line-of-sight absorption through columns of these newly synthesised elements, which may contribute to absorption (or emission) features superimposed on the blackbody background. Surprisingly there is a lack of data, both calculated and experimental, for the optical photoabsorption and photoionisation continua of the second and third ionisation stages of
many of these elements. This project seeks to look at the possibility of applying an atomic structure code such as the Cowan code [1], to the elements Z=37-74, for first, second and third ionisation stages, their energy levels and the optical absorption/photoionisation spectra arising from these in a programmatic way. A comparison should be made to other methods such as the Autostructure code [2] or R-matrix methods. Physical insight, an interest in and affinity with atomic physics, experience with unix/linux, some python programming or scripting ability and careful thought will be required for this investigation.


Projects located in institutions outside TCD

114. Characterisation of Low Frequency Antennas for Radio Astronomy
Supervisor: Professor Peter Gallagher
Location: Dublin Institute for Advanced Studies

Radio waves at low frequencies (<100 MHz) can offer an insight into the properties of plasmas in astrophysical objects such as planets, stars and galaxies. Phased arrays, such as the Low Frequency Array (LOFAR; www.lofar.org) and the Long Wavelength Array (LWA; lea.umn.edu), have been developed in recent times using a large number of low cost antennae together with receiver systems that use recent advances in digital signal processing. In this project, the student will set up and observe the radio sky at ~10-90 MHz using a LOFAR Low Band Antenna (LBA) and a Long Wavelength Array (LWA) antennae. The student will then compare their performances using a state-of-the-art digital signal processing board. Note: This project would best suit a student with an aptitude for instrumentation and software.

115. Spectroscopy of Solar Radio Bursts using I-LOFAR
Supervisor: Professor Peter Gallagher
Location: Dublin Institute for Advanced Studies

The solar corona is highly dynamic, releasing energy across a wide range of temporal and spatial scales. These bursts can produce radio emission at low frequencies, which can be observed by radio telescopes such as the Low Frequency Array (LOFAR; www.lofar.ie) at Birr Castle. Recently, we have developed the REALtime Transient Acquisition Cluster (REALTA; www.lofar.ie/realta) to capture data from I-LOFAR at sub-second sampling rates. The aim of this project is to create dynamic spectra of rapidly varying radio emission captured using I-LOFAR and REALTA, and to identify and characterise a large sample of such features. These small-scale bursts may give us an insight into fundamental energy release mechanisms in the solar corona.
Radiation-hydrodynamic models for the evolution of Wolf-Rayet Nebulae  
Supervisor: Dr Jonathan Mackey  
Location: Dublin Institute for Advanced Studies

Many Galactic Wolf-Rayet stars are surrounded by bright and spatially extended nebulae, for example M1-67 around the star WR124. These nebulae are formed by the strong wind and intense radiation from the Wolf-Rayet star interacting with material ejected by previous phases of stellar evolution. This project will take predictions from single-star evolutionary calculations that produce Wolf-Rayet stars, and use them to simulate the evolution of the circumstellar nebula using 2D and 3D fluid-dynamics simulations of the expanding stellar wind. The aim is to see whether the properties of observed Wolf-Rayet nebulae can be explained by existing single-star evolution calculations with standard mass-loss prescriptions, or if additional ingredients such as eruptive mass loss are required. To this end, synthetic X-ray, optical, infrared and radio emission maps will be calculated from the simulations and compared with observed nebulae. Background requirements:  
- understanding of the astrophysics of stars and the interstellar medium,  
- background in fluid dynamics (not necessarily astrophysical), and  
- keen interest in computer programming, ideally with experience in C/C++ and python.  
Links:  
https://homepages.dias.ie/jmackey/  
https://en.wikipedia.org/wiki/Wolf%E2%80%93Rayet_star

How does the spin of a halo impact the initial mass function of the first stars?  
Supervisor: Dr John Regan  
Location: DCU

The Renaissance simulation is a set of high resolution physics rich simulations of the early Universe. The simulations capture the essence of the formation of the formation of the first galaxies in our Universe and allow us to probe in a self-consistent manner the environments of the formation of the first stars, their feedback effects through both radiation and metal enrichment. These feedback effects directly impact the timescale for re-ionisation as well as probing the sources of re-ionising which is still under some debate. Finally, the renaissance simulations also allow us to probe the formation of the first black holes in the Universe. https://www.youtube.com/watch?v=js6KGG9hJ1I.

The angular momentum of gas in dark matter haloes is thought to be a factor in determining what initial mass function stars will have in that galaxy. For this project the student will analyse the output of a number of snapshots from the Renaissance simulation suite. The student will write algorithms to determine the 'spin' of star formation hosting haloes and correlate the spin of the halo with the IMF of individual haloes. The method can also be applied to metal free haloes potentially hosting direct collapse black holes.
118.
Binary star progenitors of Type Ia supernovae
Supervisor: Dr. Ashley Ruiter
Location: University of New South Wales Canberra, Australia

Supernovae are the explosive deaths of stars. These explosions result in the synthesis and expulsion of heavy elements that are then recycled back into space and used to make future generations of stars and planets. A certain type of supernova - called a Type Ia - results from the explosion of a white dwarf star that has achieved a high density due to mass accretion from another nearby star. Though Type Ia supernovae have been critical in our understanding of cosmology (Nobel Prize in Physics, 2011), we still don't know what types of double (binary) star systems will lead to these explosions. Since Type Ia supernova progenitors are both rare in our Galaxy and extremely faint in electromagnetic light, we can't study them directly. However, we can study similar binary star systems (lower-mass counterparts) to better understand Type Ia supernova progenitor evolution. This project will involve comparing properties of interacting binary stars from observations with the properties of interacting binary stars from evolutionary models. The main goal of the project is to see which evolutionary model population(s) best-represents the observational data of interacting binaries, thereby bringing us a step closer to understanding Type Ia supernova progenitor evolution and origin.

119.
Type Ia supernova remnant tomography
Supervisor: Dr. Ivo Seitenzahl
Location: University of New South Wales Canberra, Australia

Type Ia supernovae – the violent deaths of compact white dwarf stars in close binary systems – play a fundamental role as cosmological probes of dark energy (Nobel Prize in Physics 2011). Furthermore, a sub-class of Type Ia supernovae is likely the sought-after site for the production of most of the anti-matter (positrons) in our Galaxy. Despite the importance of these results, the debate about the nature of their progenitors remains unsettled and we still do not understand how they explode. In deep integral field observations from the ground, we have recently discovered broad coronal line emission from iron and sulphur in young Type Ia supernova remnants in the Large Magellanic Cloud. This is the first detection of optical emission from the shocked ejecta of Type Ia supernova remnants. This discovery opens a new window into the kinematic and compositional structure of Type Ia supernova remnants, complementary to the established field at X-ray wavelengths. With our new method we can uniquely visualize different layers of the supernova explosion. We therefore refer to this new analysis technique as “supernova remnant tomography”. In the data cube, we observe measurable differences in Doppler shift of the centroid of the broad [Fe XIV] emission line. The aim of this project is to reconstruct the spatial distribution of the emitting iron by fitting these Doppler-shifts to produce the first three-dimensional view of the ejecta of a thermonuclear supernova. Prior experience with Python is desired.