'Oscillations in the Sun and Stars (OscSunStars)' Abstracts

Talks

The impact of modelling approaches and data precision on massive pulsating eclipsing binaries

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Abstract
Understanding the structure and evolution of massive stars is key for understanding a myriad of concepts in physics, including galactic evolution, black holes and neutron stars. Most massive stars exist in multiple systems with eclipsing binaries being some of the most powerful laboratories for testing stellar physics. This is because eclipsing binaries allow the determination of model independent masses and radii. A significant amount of these massive eclipsing binaries also pulsate. Asteroseismology, the study of pulsations, probes stellar structure and when combined with binarity provides ultra-precise constraints on interior physics such as rotation and mixing. However, there is currently a variety of different approaches to binary modelling of massive pulsating eclipsing binaries. Differences arise both in the binary-modelling techniques such as geometrical assumptions imposed by different modelling codes and in the photometric and spectroscopic data-processing pipelines used. In this presentation we show the impact of different binary modelling approaches and different precision data using the binary modelling code PHOEBE. We take two different approaches for a sample of pulsating massive eclipsing binaries and compare conducting iterative pre-whitening to identify pulsation mode frequencies in time-series space photometry before and after the binary modelling. We compare the results obtained from different combinations of TESS light curves extracted using different extraction methodologies together with archival and new radial velocity data. This allows for a direct comparison and quantification of the impact of the different modelling approaches and data on the masses and radii. We test the impact that the geometrical assumptions imposed by different modelling codes have on the derived best fit parameters. Understanding the impacts of different approaches is important as the dynamical masses and radii found from binary modelling are needed to put ultra-precise constraints on stellar structure and evolution models in binary asteroseismology. By using the most up-to-date data and advanced processing techniques, we evaluate whether different modelling approaches can converge on a consistent solution under optimal conditions. We conclude that understanding which approach is better is vital to test the accuracy of stellar structure models, and using Roche geometry affects the radii extracted from our sample.

Large ensemble study of variations in oscillation frequencies of 15,000 Kepler red giants

Authors

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Abstract

Solar and stellar oscillation frequencies and their amplitudes have been observed to shift systematically with surface magnetic activity cycles, providing an important diagnostic for inferring magnetic-cycle-like behaviour in other stars without high-resolution spectroscopic measurements. In our study, we provide a first-of-its-kind large ensemble of measurements of these frequency shifts using a cross-correlation method on 15,000 Kepler red giant stars. We observe over 250 stars displaying significant frequency shift amplitudes: peak-to-peak amplitudes greater than 3 times their uncertainties. Additionally, we compare these measurements with various stellar parameters to determine which parameters may affect stellar variability. Such variability measurements play a vital role in our ability to infer accurate physical stellar parameters from oscillation frequencies.

Novel PSF light curves from TESS combined with BLOeM spectroscopy reveal pulsation properties of SMC massive stars.

Authors
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Abstract
Massive stars, the progenitors of neutron stars and black holes, play a crucial role in shaping the chemical and radiative properties of entire galaxies through their winds and explosive deaths. Convective regions in massive stars excite gravity waves, which facilitate efficient chemical mixing and angular momentum transport, with both being essential for a star's evolution and ultimate fate. However, the occurrence and efficiency of convection is strongly dependent on a star's metallicity, which remains largely uncalibrated in evolution models. The study of stellar pulsations – asteroseismology – allows us to take a data-driven approach to calibrating the physics of stellar evolution models. This is because pulsations in massive stars are particularly sensitive to rotation and mixing processes. For the first time, the NASA TESS space telescope is providing high-precision and long-duration light curves of thousands of massive stars across the sky, including those in the low-metallicity SMC galaxy. However, obtaining TESS light curves for massive stars in the SMC is challenging, since the stars are faint and contaminated due to heavy crowding. In this talk, I present Lemons, a novel PSF-based light curve extraction method overcoming these challenges and demonstrate the limitations of the often-used simple aperture photometry (SAP) method for faint crowded stars. With this PSF technique, optimal light curves of 91 SMC massive stars for which contamination is minimised reveal a variety of variability types, including eclipsing binaries and stellar pulsations (e.g. coherent modes and SLF variability). We construct an HR diagram to map variability among massive stars. When combined with the ongoing ESO BLOeM spectroscopic survey of the SMC, these light curves allow ensemble studies for binarity and pulsations in low-metallicity massive stars. We find that despite the weaker subsurface convection for these SMC stars predicted by stellar evolution models, the observed SLF variability has a comparable morphology to that of Galactic massive stars, illustrating that mechanisms other than surface convection, such as gravity waves excited by the convective core, must play a role. Therefore, asteroseismology of this unique sample opens a new window for probing stellar interiors at low metallicities and improving stellar evolution models.

How accurately could we infer the helium ionisation zone properties using PLATO data?

Authors

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Abstract

The helium ionisation zone in solar-like stars produces a characteristic oscillatory signature in their oscillation frequencies. Observing this signature enables a detailed seismic investigation of the local properties of the helium ionisation zone. It further allows reliable inferences of the surface helium abundance in cool solar-like stars. In this study, we investigate in detail how accurately we could recover the properties of the helium ionisation zone using the data expected from the upcoming ESA PLATO mission. To achieve this, we used the PLATO Solar-like Light-curve Simulator to generate 34 synthetic light curves for targets with visual magnitude V = 9. These time series span two years at a 25-second cadence and have PLATO-like photometric precision. The underlying stellar models cover a wide parameter space: effective temperatures in [5000, 7000] K, logarithm of surface gravities > 4 dex, masses in [0.7, 1.8] Msun, initial metallicities in [-0.6, 0.5], initial helium abundances in [0.22, 0.36], mixing-lengths in [1.4, 2.4], core overshoots in [0.0, 0.04], and ages < 14 Gyr. The power spectrum was fitted using the PBjam tool to extract the oscillation frequencies for all simulated stars in our sample. Since the amplitude of the helium signature is small, we need high-quality seismic data to reliably infer the properties of the helium ionisation zone. Following a careful quality assessment of the resulting seismic data, we selected a final set of 10 targets exhibiting at least five consecutive radial orders for each of the radial (l=0), dipole (l=1), and quadrupole (l=2) modes, all with frequency uncertainties below 1.5 microHz. Our analysis of the helium signature reveals that its average amplitude, acoustic width, and acoustic depth are determined with median relative uncertainties of approximately 28%, 28%, and 15%, respectively. We calculated the acoustic width and depth of the helium ionisation zone using the sound-speed profiles of the stellar models. These values are in excellent agreement with our inferred results--mostly within 1 sigma--indicating that systematic uncertainties are significantly smaller than the corresponding statistical uncertainties. For our 10 selected targets, the effective temperatures range from 5700 to 6300 K. This suggests that the helium signature is most robustly characterised within this temperature interval, given the data quality expected from the PLATO mission.

Massive Star Asteroseismology with Kepler and TESS

Authors

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Abstract

Massive stars are important across many fields of astrophysics due to their explosive deaths as supernovae and because they are progenitors of gravitational wave sources. Through their strong winds and high mass loss rates they energise their environments with radiation and provide chemical enrichment. At the ends of their lives, their supernova explosions provide metals for later generations of stars and planets, by which they drive galactic chemical evolution. However, our understanding of several important aspects is ultimately reliant on how well we know the physics of stellar interiors. The study of pulsations with asteroseismology, which is highly sensitive to the physical processes inside massive stars, is an invaluable tool to understand the impact of massive stars on the universe.

Asteroseismology has entered a new age with the arrival of space missions such as CoRoT and Kepler. However, higher-mass stars were relatively understudied in these data sets. On the other hand, the ongoing TESS mission continues to provide time-series photometry for millions of stars across the sky, and is being exploited to study a large number of massive stars with asteroseismology for the first time.

In this talk, we present a comparison of modelling results using light curves from the Kepler and TESS space missions for a sample of main-sequence B-type pulsators. We demonstrate the important factors that affect the precision and accuracy of forward asteroseismic modelling of such stars for light curves of different quality and length. Moreover, we show empirically for the first time the necessary length of TESS light curves to emulate results obtained from the Kepler mission, and report on the precision and accuracy of rotation rates and mixing processes constrained in stellar structure and evolution models. We also present the analysis of a particularly interesting rapidly rotating pulsating B-type star which was observed by both Kepler and TESS. Our combined photometric and multi-epoch spectroscopic analysis reveals significant variability in the pulsation mode amplitudes and frequencies, which may be caused by an as-yet unseen binary companion. This evidences a paradigm shift of massive star asteroseismology away from the assumption of single-star evolution theory. With the upcoming launch of the PLATO mission, and with TESS continuing to assemble long-term light curve data, future asteroseismic studies will benefit from this analysis and further improve our understanding of stellar interiors.

The Asteroseismology Pipeline for Solar-like Oscillators Observed By PLATO

Authors

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Abstract

PLATO is set to observe several hundred thousand stars over the course of the first few years of the mission lifetime. The majority of these will be stars with convective envelopes that may exhibit solar-like oscillations in their light curves. The asteroseismic analysis module in the Plato Stellar Analysis System is tasked with identifying solar-like oscillation modes in Plato light curves and measuring their frequencies. The pipeline must deal with stars all the way from the lower main-sequence to the base of the red giant branch. It therefore implements a range of knowledge from previous observations from the Kepler and TESS missions to inform the measurements. To detect the oscillations we for example require that the observed power density spectrum exhibit features that are at the correct location and scale for a given set of input parameters. Once oscillations are confirmed the algorithm uses state-of-the-art methods for comparing the observed frequencies with those we expect based on previous observations, this includes the well-known asymptotic behavior of p-mode oscillations, but also the often difficult to interpret mixed-mode frequencies observed in sub-giant stars. This collection of algorithms form the basis of the asteroseismic analysis of the Stellar Analysis System, and will help PLATO fulfill the mission goals of characterizing earth-like planets around solar-like stars.

Pseudomodes as probes of subsurface structure and activity in the Sun and stars

Authors

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Abstract

Helio- and asteroseismic observations reveal a rich high-frequency structure in oscillation power spectra above the acoustic cut-off frequency, characterised by alternating peaks and troughs commonly referred to as pseudomodes. These features are interpreted as interference patterns of high-frequency acoustic waves excited below the photosphere and propagating into the atmosphere. Despite being well observed, their diagnostic potential and physical origin remain incompletely understood.

In this work, we investigate the formation and variability of pseudomodes using an analytical framework based on a Klein–Gordon subsurface cavity model. In this picture, the acoustic cavity acts as an effective Fabry–Perot interferometer, where constructive and destructive interference of high-frequency waves arises between the excitation source and the lower turning point. We derive an effective dispersion relation that explicitly separates the roles of the excitation source location and the photospheric acoustic cut-off frequency in shaping the pseudomode spectrum.

The model successfully reproduces the observed peak–trough structure of the high-frequency spectrum for realistic parameter ranges, constrained through Bayesian MCMC fitting to GONG helioseismic data. We further demonstrate that temporal variations in the excitation source location and the photospheric acoustic cut-off frequency lead to distinct seismic signatures: solar-cycle-related shifts in the excitation source depth produce predominantly anti-phase frequency variations of pseudomodes, while cyclic changes in the acoustic cut-off frequency introduce harmonic-dependent behaviour, allowing for both in-phase and anti-phase shifts.

These results establish pseudomodes as sensitive diagnostics of subsurface stratification, excitation, and atmospheric reflection properties. Beyond the Sun, this framework opens new opportunities for exploiting high-frequency seismic signals in stars, providing complementary constraints on stellar structure, magnetic activity, and their temporal variability.

Automated identification of dipole mixed modes in red-giant stars

Authors

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Abstract

Dipole mixed modes in red-giant stars provide key constraints on stellar interiors, offering insights into their structure and evolution. However, identifying these modes is challenging due to degeneracies in the mixed-modes parameter space, stellar rotation, and spurious peaks or missing modes. In this talk, we introduce an automated method that uses a spectral similarity measure to overcome such challenges.
This similarity is calculated as the overlap between the observed and model spectra, with the model spectrum constructed from frequencies predicted by the asymptotic mixed-mode relation. Then, the similarity is maximised using a genetic algorithm. We tested the method on synthetic spectra of red-giant branch and core helium-burning stars, generated using the asymptotic formalism. We also included rotational splittings and stellar inclination-dependent mode visibilities, as well as cases with missing modes and spurious peaks. In more than 90% of the synthetic spectra, the method recovers over 95% of the dipole modes, demonstrating robustness to observational limitations. Furthermore, we applied this method to three red-giant stars and obtained mode identifications and parameters consistent with previous studies. These results show that the method can be applied to a broad population of evolved stars, enabling large-scale, homogeneous asteroseismic analyses of red giants.

An overview of pulsations in intermediate to high mass stars on the main sequence (Invited)

Authors

Simon Murphy (1)

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Abstract

Early type stars play host to a variety of classes of pulsation, providing unique seismic probes of the physics of intermediate- and high-mass stars. This talk summarises the observed pulsation landscape, covering recent results on δ Scuti, γ Doradus and roAp stars as spectral types A and F, to slowly pulsating B stars, β Cephei variables, and stochastic low-frequency variability at earlier spectral types. Particular attention will be paid to how this observed landscape has changed through the all-sky photometry afforded by TESS. The overview highlights recent results, current challenges, and future prospects for asteroseismology of intermediate and high-mass stars.

Observational Astero- and Helio-seismology (Invited)

Authors

Yvonne Elsworth (1)

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Abstract

It is now well known that many stars in diverse parts of the Hertzsprung-Russell diagram oscillate and that the characteristics of the oscillations provide significant information about the interiors of those stars and are a key input to theories of stellar structure and evolution. This is the subject of helio- and astero-seismology. In this talk I will discuss the range of methods used to observe these oscillations in low to medium mass stars. From the ground, individual stars can be studied to high precision; from satellites in space, whole populations can be studied. In all cases, the signals to be detected are small. For modelling purposes the seismic data are used in combination with spectroscopic and other data.

Posters

HUNTING EXOPLANET TRANSITS WITH THE ISABELLA HOLDEN TELESCOP

Authors

Sreelakshmi Bimal (1), Dr. Mark Norris (1)

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Abstract

This study aims to analyze stellar variability and exoplanetary transits with the Isabella Holden Telescope (IHT) at the Alston Observatory, University of Lancashire. This project builds on the work of the MOSES Survey in 2018 (Ramukwella-Gill 2020, Dabbs 2023), which used the Moses Holden Telescope (MHT) to classify variable stars. In this survey, 87,397 unique stars were catalogued, of which 29,399 stars had high-quality repeat observations for variability analysis. Compared to the MHT, the IHT offers a wider field of view and higher quantum efficiency, which facilitates the detection of a larger number of stellar sources and lower-amplitude photometric variations.

The observations span seven years with nights dedicated to capturing known transit ephemerides using the confirmed planetary transits from TESS (Ricker et al., 2015) and Kepler Satellites (Borucki et al., 2010). Additionally, we are investigating the potential planetary candidates observed by TESS and aiming to confirm their planetary nature through our survey. A potential candidate (TIC 12980264) was identified from multiple sectors of the TESS phase-folded light curves, showing consistency in the transit dip of ~0.6 mmag. We use transit photometry to detect exoplanets by measuring the periodic dip in the brightness of a star as a planet passes in front of it, blocking its light. Firstly, the reduction of raw telescope data is done through a Python pipeline. Secondly, astrometric calibrations and extract sources were performed using astrometry.net (Lang et al. 2010) and Source Extractor (Bertin & Arnouts 1996), respectively. Finally, we apply Aperture/ Differential photometry to obtain transit curves, which we use to estimate stellar and planetary parameters.