University of Birmingham
School of Physics and Astronomy

TASC3/KASC10 Abstracts

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Contents

Part I

Oral Presentations

Setting the Scene for TESS and TASC

George Ricker: Unlocking the Secrets of Nearby Exoplanets with the *Transiting Exoplanet Survey Satellite* (Invited Review)

Institute: MIT

The *Transiting Exoplanet Survey Satellite* (TESS) will discover thousands of exoplanets in orbit around the brightest stars in the sky. In a two-year survey, TESS will monitor $>$ 200,000 bright stars in the solar neighbourhood at a 2-minute cadence for planetary transits. This first-ever spaceborne all-sky transit survey will identify planets ranging from Earth-sized to gas giants, around a wide range of stellar types and orbital distances.

TESS stars will typically be 30 – 100 times brighter than those surveyed by the *Kepler* satellite. Thus, TESS planets will be far easier to characterize with follow-up observations, enabling studies of masses, sizes, densities, orbits, and atmospheres of a large cohort of small planets, including a sample of rocky worlds in the habitable zones of their host stars.

TESS will also provide full frame images (FFI) at a cadence of 30 minutes. These FFI will provide precise photometric information for every object within the 2300 square degree instantaneous field of view of the TESS cameras. In total, more than 30 million stars and galaxies brighter than magnitude I=16 will be precisely photometered during the two-year prime mission. A selection of bright TESS asteroseismology targets will be monitored at a sub-minute cadence. In principle, the lunar-resonant TESS orbit will provide opportunities for an extended mission lasting more than a decade, with data rates of $\sim$100 Mbits/s.

An extended survey by TESS of regions surrounding the North and South Ecliptic Poles will provide prime exoplanet targets for characterization with the James Webb Space Telescope (JWST), as well as other large ground-based and space-based telescopes of the future.

A NASA Guest Investigator program is planned for TESS. The TESS legacy will be a catalog of the nearest and brightest main-sequence stars hosting transiting exoplanets, which should endure as the most favorable targets for detailed future investigations.

A status update for the TESS mission will be presented, as well as a discussion of how best to coordinate TESS operations in support of asteroseismology observations. TESS is currently on target for launch in March 2018 as a NASA Astrophysics Explorer mission.

Roland Vanderspek: TESS Instrument Status (Invited)

Institute: MIT

TBC

Hans Kjeldsen: TASC Target Selection and Data Products (Invited)

Institute: Stellar Astrophyiscs Centre, Aarhus University

The goals of the TASC science program are to perform an asteroseismic characterization of planet-hosting stars, including mass, age and particularly radius. In addition TASC will also measure general stellar properties, including stellar structure modelling, and contributing to stellar characterization. In order to do this TASC will identify stars suitable for asteroseismic analysis and provide the selection of targets for the asteroseismic program to be observed by the mission. The numbers of targets available for asteroseismology for each 27-day pointing are 750 targets with standard 2-min sampling. TASC will also extract time series for millions of stars from the TESS Full Frame Images (FFI's) and observe stars in special modes of operations with shorter cadence. In the present talk I will discuss the status of the TASC target selection procedure and the prioritization of the TASC targets. The selection of individual targets by TASC takes place in the working groups and the TASC target list is dynamic and will be updated throughout the TESS mission, as needed, in order to optimize the TASC science. The first version of the TASC target list was ready in June 2017 and I will describe the procedures for updating tis list with the aim optimizing the quality of the target lists. I will also discuss the 30 min cadence and the plan for extraction of time series data for all identified targets in the FFIs.

Mikkel N. Lund and Rasmus Handberg: TESS Data Preparation (Invited)

Institute: University of Birmingham and Stellar Astrophyiscs Centre, Aarhus University

With data from the The Transiting Exoplanet Survey Satellite (TESS) the seismic community is faced with a new set of challenges concerning the preparation of data. The TESS Asteroseismic Science Operations Center (TASOC) is tasked with delivering light curves ready for asteroseismic analysis to the TESS Asteroseismic Science Community (TASC) for each target observed by TESS. This includes the extraction of data from full frame images (FFIs), obtained every 30 minutes, and preparation of a large number of targets observed with a 20 and 120 second cadence. In this talk we will present the current status of the preparations for the delivery of photometric data products, stellar classification, and data facilitation.

Theme Reviews

Courtney Dressing: TESSting Theories of the Structure and Evolution of Planetary Systems (Invited Review)

Institute: Caltech

Decades of exoplanet surveys have uncovered thousands of planets and enabled statistical investigations of planetary properties. We now know that multi-planet systems are common and that smaller planets are more prevalent than larger planets, but tracing the present-day properties of exoplanets back to their formation histories is more complicated. Fortunately, the modern architectures of planetary systems and the compositions of individual planets within them hold clues to when, where, and how the planets might have formed. The NASA TESS mission will further advance our understanding of the structure and evolution of planetary systems by detecting thousands of planets orbiting stars throughout the sky. Conveniently, the TESS mission will probe a wide variety of Galactic environments and comparisons of planetary systems orbiting stars with a range of masses, metallicities, and multiplicities will reveal correlations between stellar and planetary properties. Due to the bright magnitudes of the TESS targets, TESS planets will be well-suited for radial velocity follow-up observations to determine masses and constrain possible planetary compositions. Some TESS planets will also be favourable targets for atmospheric characterization with JWST, HST, and Spitzer, providing further insight into the formation histories of exoplanets and significantly increasing the sample of well-characterized worlds.

Maurizio Salaris: Current Challenges for Stellar Physics and Stellar Evolution Models (Invited Review)

Institute: ARI, Liverpool John Moores University

The current main open problems in stellar physics and stellar evolution certainly involve the treatment of (semi)convection, plus chemical- and angular momentum transports in radiative regions. These uncertainties play an important role when stellar models are employed to decode information gathered from photometric and spectroscopic surveys of stellar populations. This talk will review how the current generation of stellar models treat chemical and angular momentum transports, the temperature gradients in (semi)convective regions, and the role played by asteroseismology in helping to improve our modelling of stellar interiors.

Silvia Toonen: Challenges in the Evolution of Stellar Binaries and Triples (Invited Review)

Institute: Amsterdam

Even though the principles of single stellar evolution and binary evolution have been accepted for a long time, many questions remain, and some quantitative predictions of the model are still in conflict with observations. I will review our current understanding of binary evolution, and its recent progress. I will focus in particular on the remaining challenges, such as mass transfer, common-envelope evolution and mergers. Shortly, I will discuss the evolution of triple-star systems, which is a field that has been gaining interest in recent years. I will show examples of how triple evolution differs from binary evolution.

Gerry Gilmore: Stellar Populations and Galactic Archaeology – Open Questions (Invited Review)

Institute: IoA Cambridge

Gaia, the several large spectroscopic survey projects now underway, especially in combination with asteroseismology, are allowing significant advances in knowledge of the Galaxy and its history. The weakest current link is reliable determination of stellar ages, although substantial advances are becoming possible. Ages will allow progress in many major open issues, from the importance of radial orbit migration to the role of mergers in disc evolution, and the enigmatic structure of the outer Galactic disc.

Challenges for Understanding the Structure and Evolution of Exoplanet Systems

Daniel Huber: Asteroseismology – Exoplanet Synergies in the TESS Era: What Will We Learn? (Invited)

Institute: University of Hawaii

One of the major successes of the space photometry revolution has been the systematic application of asteroseismology to exoplanet host stars, yielding precise constraints on radii, masses and dynamical architectures of planetary systems. In this talk I will review recent highlights of using asteroseismology to characterize exoplanets and discuss how the TESS Mission will continue this legacy of *Kepler*/K2, in particular by constraining gas-giant planet occurrence rates around evolved stars and by studying the connection of stellar obliquities to the formation of hot Jupiters. I will also discuss synergies between TESS asteroseismology and Gaia to characterize exoplanet host stars, and comment on the complementary role of ground-based radial velocity campaigns to detect oscillations in cool dwarfs hosting small planets.

Suzanne Aigrain: Getting the Most Out of Light Curves of Exoplanet Host Stars (Invited)

Institute: Oxford Astrophysics

I will give a broad overview of the key challenges associated with the analysis of stellar light curves gathered by space-based transit surveys, including the treatment of instrumental systematics, the disentangling of stellar and planetary signals, and the robust inference of planetary parameters from transit observations. Using examples drawn from the last decade of CoRoT, *Kepler* and K2 studies, I will show how we are moving from a simplistic, sequential approach to light curve analysis, to a more flexible, more holistic and more powerful approach. “Nuisance” signals are increasingly modelled alongside the (planetary) signals of interest, rather than “filtered”. Complex stochastic processes can now be incorporated into our models explicitly using techniques such as Gaussian Process regression. Finally, hierarchical Bayesian modelling enables us to exploit the synergy between transit modelling, asteroseismology and other sources of information such as spectra and the signature of rotating star spots in the light curve. I will finish by highlighting a few specific aspects of these challenges that will be particularly relevant for TESS, and ultimately PLATO.

Joshua Pepper: The Construction of the TESS Input Catalog and Exoplanet Search Target List

Co-authors: K. G. Stassun, M. Paegert, R. Oelkers, N. De Lee
Institute: Lehigh University

The TESS mission will conduct a photometric search for small transiting planets, obtaining 30-minute Full Frame Images and 2-minute observations of 200,000 to 400,000 selected stars. The Target Selection Working Group has been assembling the TESS Input Catalog (TIC) and an associated Candidate Target List (CTL). The TIC will provide basic stellar parameters for many stars in the sky, while the CTL will have a much more vetted and detailed set of physical stellar parameters. I will describe the current status of both the TIC and the CTL, describing the bulk properties of the stars, known issues with the catalogs, along with future plans for further catalog development.

Samuel Grunblatt: Using Asteroseismology to Resolve the Mystery of Planet Inflation

Co-authors: Daniel Huber, Eric Gaidos, Eric Lopez, Daniel Foreman-Mackey
Institute: Institute for Astronomy, University of Hawaii

Determining the mechanism that causes inflation of highly irradiated gas giant planets has eluded us since the radius of an exoplanet was first measured 17 years ago. Here, we present the discovery and characterization of the first transiting planets orbiting asteroseismic host stars found with K2, K2-97b and EPIC228754001.01, which support the theory that planet inflation is caused by the direct deposition of stellar irradiation into the planet interior. These planets orbit at moderate ($\sim$10 day) orbital distances around stars which recently evolved into red giants. By precisely constraining the mass, radius, and evolutionary history of these systems using Keck/HIRES radial velocity measurements, asteroseismology, and a novel method to model stellar variability as a Gaussian process, I show that these planets likely crossed the observed irradiation threshold for planet inflation during post-main sequence evolution. This suggests that the planets recently became re-inflated, as opposed to retaining initial heat and size from formation. Furthermore, these results suggest that TESS will vastly improve the opportunity to test planet inflation models by observing an order of magnitude more evolved stars than K2.

Dennis Stello: Massive or Not Massive That is the Question

Co-authors: J. Lloyd, M. Ireland, D. Huber, T. Bedding, and the SONG team
Institute: University of New South Wales

The study of planet occurrence rates informs our understanding of how planets form. One important aspect is how the occurence rates depend on stellar mass; however, measuring masses of field stars is often difficult.

Over the past decade, a controversy has arisen about the inferred planet occurance rate around evolved intermeadiate-mass stars – the so-called retired A-stars. Particularly, the high masses of these evolved planet hosts, derived using spectroscopic information and stellar evolution models, has been called into question with arguments that they are unlikely to be that high.

We aim to resolve the controversy by determining the mass of six evolved planet hosting stars using asteroseismology. In this talk I will present our findings based on data from the SONG telescope of bright nearby planet hosting stars. We find a significant one-sided offset between the previous spectroscopy-based masses and our seismic results, suggestive that the former are overestimated.

Challenges for Studies of Stellar Evolution and Stellar Interiors Physics

Patrick Eggenberger: Modelling Dynamical Processes in Stellar Interiors in the Light of Asteroseismic Measurements (Invited)

Institute: Université de Genève

Asteroseismic data obtained by space missions have led to the characterization of solar-like oscillations for a large number of stars. This has opened the way to the determination of the internal properties of these stars. In this presentation, we discuss how these measurements can help us progress in our understanding of dynamical processes in stellar interiors with a special emphasis on the modelling of the internal transport of angular momentum.

Sebastien Deheuvels: Using Quadrupolar Mixed Modes to Probe the Internal Rotation of Red Giants

Institute: IRAP (Toulouse, France)

The *Kepler* space mission has made it possible to measure the rotational splittings of mixed modes in red giants, thereby providing an unprecedented opportunity to probe the internal rotation of these stars. Asymmetries have been detected in the rotational multiplets of several red giants. This is unexpected since all the red giants whose rotation has been measured so far were found to rotate slowly. The lack of understanding of multiplet asymmetries has been the main obstacle to the use of the rotational splittings of l=2 mixed modes in rotation inversions.

We here show that the reported asymmetries are caused by near-degeneracy effects arising because of the combined effects of rotation and mode mixing. Such effects have not been taken into account so far. We also propose and validate a method based on the perturbative approach to probe the internal rotation of red giants using multiplet asymmetries. We successfully apply our method to the asymmetrical l=2 multiplets of the *Kepler* young red giant KIC7341231 (Otto) and obtain a precise estimate of its mean rotation in the core. We also obtain a much more precise measurement of the envelope rotation rate than the one that had been found with dipolar modes only.

Our study opens the possibility of performing rotation inversions that include quadrupolar mixed modes, which have been almost unexploited so far. This should improve the precision of the inferred rotation profiles of red giants. We also test the possibility of combining l=1 and l=2 rotational splittings to probe latitudinal differential rotation in red giants.

Charlotte Gehan: The Era of Large-Scale Measurements of Red Giant Core Rotation

Co-authors: B. Mosser, E. Michel
Institute: Meudon

Red giant stars have proved to be asteroseismic targets of choice: conditions in their interior are met to couple pressure waves propagating in the envelope and gravity waves propagating in the core. Thus, we have a direct view on their core through mixed modes, which is not the case for main-sequence stars. In particular, asteroseismology of red giants gives us the opportunity to study their internal rotation, especially their core rotation. Rotation is known to deeply impact the evolution of stars, but including rotation in stellar evolution models is still challenging. Models predict central rotation rates at least ten times too large compared to asteroseismic measurements. This implies that angular momentum transport is at work in stellar interiors, whose physical mechanisms are not yet fully understood.

It is thus of prime importance to know how internal rotation evolves in time. This is particularly true for red giants, in order to better characterize the physical processes operating in the deepest region of these stars. Such a study requires core rotation measurements for a maximum number of red giants. In this context, I have developed an automatic method to determine the mean core rotation of red giant stars presenting different evolutionary stages with *Kepler* data. In the future, obtaining mean core rotation rates for thousands of red giants will improve the characterization of the physical mechanisms causing angular momentum transport in these stars, and therefore our understanding of stellar evolution. I will present preliminary results that I obtained with a new and promising method to determine automatically core rotation rates of red giants. Such an automated measurement of the core rotation of red giants will moreover be required to analyse the hundreds of thousands of oscillation spectra that PLATO should provide in a few years. Hence this automated method is paving the way for the future PLATO data.

Jamie Tayar: Core and Surface Rotation Rates of Evolved Intermediate Mass Stars

Co-authors: P.G. Beck, M.H. Pinsonneault, S. Mathur, R.A. Garcia
Institute: Ohio State University

Intermediate mass stars (M $\sim$ 2.0 - 3.0 Msun) provide important tests of the role of rotation in the structure and evolution of stars because they live in an important transitional regime. Like massive stars, they rotate rapidly on the main sequence and have convective cores. However, they evolve to become secondary red clump stars, where their structure and internal rotation can be measured with the tools of red giant asteroseismology developed for lower mass stars. Compared to prior studies, we have focused our efforts on measuring surface rotation rates and studying trends in representative samples. The slow surface rotation rates of these stars provides conclusive evidence for some combination of strong post-MS angular momentum loss and differential rotation with depth in convective envelopes. We compare the measured core and surface rotation rates, find that the contrast is smaller than in first ascent red giants, and discuss evidence for core-envelope recoupling during the core helium burning phase. Finally, we discuss trends in both core and surface rotation with mass, metallicity, and surface gravity and their implications for internal angular momentum transport and loss models.

Evelyne Alecian: The Impact of Magnetic Fields on Stellar Evolution (Invited)

Institute: IPAG (Université Grenoble Alpes)

Magnetic fields are known to play important roles in many astrophysical processes, mostly at high-energy. Some of them involve stellar object. These processes are mostly the evidence of interaction of stellar magnetic field with stellar environment. But what about the star itself? How do stellar magnetic fields show their presence? Are they just a consequence of star formation, stellar internal structure, or stellar evolution? Or are they also playing an important role on the evolution of stars? I propose to address these questions by reporting recent observational and theoretical studies of magnetic fields in stars.

Shyeh Tjing (Cleo) Loi: Asteroseismology with a Twist: An Efficient Damping Mechanism for Oscillations in Red Giants with Magnetised Cores

Co-authors: J. C. B. Papaloizou
Institute: DAMTP Cambridge

Magnetic fields in stellar interiors make only a relatively small contribution to the total energy budget, and their effects on stellar oscillations are often neglected in comparison to the dominant forces arising from pressure and buoyancy. However, observations of anomalously weak dipole modes in many red giant stars suggest an additional source of damping localised to the core, with indirect evidence pointing to the role of a deeply buried magnetic field. Further evidence indicates that the g-mode character of depressed modes is preserved, but damping mechanisms postulated so far have been unable to accommodate this aspect.

In this talk, I will present recent work on the development of a new mechanism to explain this phenomenon that allows for the preservation of the g-mode structure within red giant cores. The damping of dipole (and higher multipole) modes is achieved via resonant interactions with torsional Alfvén modes of high harmonic index. Associated damping rates, computed using realistic stellar models and magnetic field strengths, are quantitatively on par with those associated with turbulent convection, and lie in the range required to explain observations.

Rhita-Maria Ouazzani: Angular Momentum Transport on the Lower Main Sequence as Revealed by γ Doradus Stars

Co-authors: M.-J. Goupil, J.P. Marques
Institute: LESIA - Paris Observatory

With four years of nearly-continuous photometry from *Kepler*, we are in a good position to use asteroseismology to infer the internal structure of γ Doradus stars. In particular, for the first time, several analyses have successfully measured internal rotation on the lower main sequence from high-order gravity modes. Rotational splittings and tilted period spacing allow us to determine both slowly and rapidly rotating cores for these stars. Thus, γ Dor stars provide valuable constraints on angular momentum processes on the lower main sequence, which remain difficult to obtain even for solar-like stars. As intermediate-mass stars, with spectral types from late F to early A, they provide us with the opportunity to unfold long lasting puzzles of stellar physics such as the transition between rapid and slow rotators, known as the Kraft break, or the problem of Lithium depletion. Furthermore, the γ Dor stars, being progenitors of red giants, appear as unique targets to explore angular momentum transport along evolution. In this context, we confront the observed values of internal rotation for γ Dor stars to stellar evolution models including rotationally induced transport, and draw conclusions in terms of angular momentum transport along evolution for low-to-intermediate-mass stars.

Othman Benomar: Asteroseismic Measure of the Latitudinal Differential Rotation

Institute: NYU Abu Dhabi

Recent asteroseismic studies on the differential rotation of low mass stars unambiguously point toward a weak radial differential rotation on the main-sequence (Benomar et al. 2015, Saio et al. 2015, Kurtz et al. 2014). The radial differential rotation for sub-giants/red giants is also relatively weak (e.g. Deheuvels et al. 2014). This is viewed as an evidence for an efficient angular momentum transport that acts in the radial direction, similarly to what is observed in the Sun. However, little is known on the latitudinal rotation. So far, the applied methods to investigate the rotation in latitude are mostly indirect. For example, some use the doppler imaging to track chromospheric features and their migrations (Donati et al. 2010). Others look at the photometric variability (Olah et al. 2009). In another hand, asteroseismology provides means to constraint the latitudinal rotation of stars in a more direct way (e.g. Schou et al. 1998). By describing the rotational splitting in terms of a-coefficients, we have measured the latitudinal differential rotation of an ensemble of solar-like stars observed by the *Kepler* instrument. We report that most of the analysed solar-like stars have a pole rotating slower than the equator, similarly to the Sun. For the best stars of our sample, we could also perform a seismic inversion of the rotation profile, following what is proposed in Gizon & Solanki 2004. These results are of great importance regarding constraining the models of dynamo generation and maintenance for the Sun and other stars.

Jennifer van Saders: Tracking Magnetism and Angular Momentum Loss with Rotating Stellar Populations

Institute: Carnegie Observatories

Stellar rotation is intimately tied to stellar properties such as age and mass, and measurements of rotation are now uniquely accessible in the era of large, precise, long-duration, time-domain surveys. The spin-down of cool main sequence dwarfs with time via magnetized winds makes rotation a particularly intriguing tool for determining stellar ages. Efforts to use *Kepler* asteroseismic targets to calibrate and test these period-age relations have yielded surprises, suggesting that magnetic braking in old stars is far weaker than expected. If this weakened braking is indeed a generic feature of old stars, we expect it to manifest itself in the larger but more coarsely studied population of *Kepler* field stars. Using a galactic population model and theoretical braking laws, we show that the paucity of detected long-period rotators in the *Kepler* field may, in fact, be such a signature. Stars appear to undergo a transition either in their spottedness or magnetic braking properties, and do so under the same conditions (Ro $\sim$ solar) that the seismic sample displays a change in spin-down properties. We motivate and describe future tests of this interpretation with TESS, and address the confounding influences of binaries, blends, and coarsely measured stellar properties.

Benoit Mosser: Mixed Modes in Red Giants: Stellar Information versus Alternative Facts

Institute: Meudon

The power of asteroseismology relies on the capability of global oscillations to infer the stellar structure. For evolved stars, we benefit from unique information directly carried out by mixed modes that probe their radiative cores. Large progress has been made for understanding the mixed-mode pattern. I will present the recent findings (coupling factors, mode widths, mode visibilities) and show how they can be used to deliver stringent tests for probing the stellar interior. Clear properties can be revealed, which can be expressed in terms of ensemble asteroseismology or can be used to analyse in detail a given star. In all cases, the physics of mixed modes makes it possible to separate astrophysical information from alternative facts.

Jie Yu: Asteroseismology of 16000 *Kepler* Red Giants: Global Oscillation Parameters, Masses and Radii

Co-authors: Timothy Bedding, Daniel Huber, Dennis Stello, and Marc Hon
Institute: The University of Sydney

The *Kepler* mission has provided exquisite data to perform ensemble asteroseismic analysis on evolved stars. In this work we systematically characterized the solar-like oscillation power excess for 16,121 oscillating red giants, using all available long-cadence data. We produced a homogeneous catalog of seismically-derived stellar mass, radius and surface gravity. This is the largest homogeneous analysis of *Kepler* red giants, and allows to study their ensemble properties more clearly than before. Thanks to a large red-giant sample, we found the power-law relation between the frequency of maximum power (νmax) and the large frequency separation ($\Delta\nu$) is valid for red giant branch (RGB) stars, but it needs to be modified for red clump stars and secondary clump stars. We found that low mass helium-core burning (HeB) stars show the same oscillation amplitude while the higher mass HeB stars show lower amplitude compared to RGB stars. We also discovered that the power excess width is an increasing function of stellar mass. The distributions and mass dependencies of oscillation amplitude, granulation amplitude and power-excess width of red giants are valuable to investigate the excitation and damping of solar-like oscillations and their relation with convection. Our asteroseismic stellar properties can be used as reliable distance indicators and age proxies for dating and mapping the Galactic disk observed by *Kepler*. It will also provide an excellent opportunity to test asteroseismology using Gaia parallaxes, and lift degeneracies in deriving atmospheric parameters in large spectroscopic surveys such as APOGEE and LAMOST.

Saskia Hekker: Exploring Cupling Between Pressure and Gravity Modes in Red-Giant Stars

Co-authors: Y. Elsworth, G.C. Angelou
Institute: Max Planck

The discovery of mixed pressure-gravity modes in red-giant stars some years ago opened the possibility to explore the deep interiors of red giants with unprecedented detail. The observational data still contain information that is, as yet, under exploited.

Here, we use the data to explore some characteristics of the evanescent region that separates the p-mode cavity from the g-mode cavity. We present an investigation of the observationally and theoretically determined coupling factors and use them to elucidate the physical connection to the evanescent zone. Additionally, we investigate the impact of the boundaries of the evanescent zone on the oscillations.

JJ Hermes: Rumblings in the Stellar Graveyard: White Dwarf Pulsations with K2 and TESS (Invited)

Institute: University of North Carolina at Chapel Hill

Space-based observations of pulsating white dwarfs are finally coming of age in the era of K2. I will review exciting new discoveries in white dwarf asteroseismology enabled by K2, with an eye towards the potential offered by TESS to continue exploring the interiors of objects in the stellar graveyard. For example, we have begun to observe a possible link between high mass and fast rotation, such that white dwarfs descended from >3 solar-mass ZAMS progenitors rotate faster than those descending from less-massive progenitors; white dwarfs hold the key to understanding the final stages of internal angular momentum evolution. Additionally, K2 has given us a new way to empirically measure the efficiency of convection in white dwarfs, based on changes to mode linewidths. We have also uncovered a new outburst phenomenon in the coolest pulsating white dwarfs, which appears to be a nonlinear resonance capable of transferring more than 10^{34} erg of energy in a matter of hours. With relatively short g-mode periods of 100-1400 s, even 28-day datasets are sufficient to resolve all pulsations present, and TESS will continue these discoveries for the brightest pulsating white dwarfs.

Jing Luan: Red Edge of DAVs and Outbursts in Cool DAVs

Institute: UC Berkeley

DAVs (ZZ Ceti stars) are white dwarfs of typical mass, 0.6Msun, exhibiting gravity mode (g mode) oscillations with periods of minutes as they cool cross the temperature range, 12000 K $>$ T $>$ 11000 K. Mode excitation is due to convective driving, although it is sometimes mistakenly attributed to kappa mechanism. Support for convective driving is provided by the trend that the periods of the most visible modes increase at lower temperatures (Clemens 1993). No oscillations were detected below the red edge established by ground based observations. Recently, owning to its superior photometry, *Kepler* revealed the existence of a few DAVs below the previously established red edge. Surprisingly, the periods of their oscillations are shorter than expected by extrapolating the observational trend first reported by Clemens (1993). Remarkably, some of these cool DAVs show outbursts that recur on few day timescales (e.g. Keaton et al. 2015). A good case can be made that this new phenomenon involves resonant nonlinear couplings of the driven mode to pairs of lower frequency daughter modes. My talk will offer plausible quantitative explanations for both the red edge and the outbursts discovered in *Kepler* data.

Francisco Cesar De Gerónimo: The Impact of Pre-White Dwarf Evolution on the Asteroseismological Inferences of ZZ Ceti Stars

Co-authors: L. G. Althaus, A. H. Córsico and A. D. Romero
Institute: Universidad Nacional de La Plata, Argentina

ZZ Ceti stars are pulsating white dwarfs with a carbon-oxygen core build up during the core helium burning and thermally pulsing Asymptotic Giant Branch (TP-AGB) phases. Through the interpretation of their pulsation periods by means of asteroseismology, details about their origin and evolution can be inferred. The whole pulsation spectrum exhibited by ZZ Ceti stars strongly depends on the inner chemical structure. At present, there are several processes affecting the chemical profiles that are still not accurately determined. We present a study of the impact of the current uncertainties of the white dwarf formation and evolution on the expected pulsation properties of ZZ Ceti stars. Our analysis is based on a set of carbon-oxygen core white dwarf models that are derived from full evolutionary computations from the ZAMS to the ZZ Ceti domain. We considered models in which we varied the number of thermal pulses during the TP-AGB phase, the amount of overshooting during core He burning, and the 12 C(α, γ) 16 O reaction rate within their uncertainties, and explored their impact on the chemical structure and the expected pulsation spectrum. We also assessed the impact of those uncertainties on the asteroseismological fits.

Margarida S. Cunha: A Universal Approach to the Analytical Modelling of Period Spacings in the Presence or Absence of Buoyancy-Related Glitches

Co-authors: M. Vrard, P. P. Avelino, J. Cristensen-Dalsgaard, S. Jiang, D. Stello
Institute: Porto

The period spacings and period-echelle diagrams of red-giant stars are unique in their potential to reveal the physical conditions within the stellar cores. Moreover, detailed information about particular transition layers, and associated physical processes, can in principle be inferred when these layers are associated with buoyancy glitches. The effect on the oscillation periods of such buoyancy glitches is also known to be present in other evolutionary phases, such as in intermediate-mass, main-sequence stars, and at the end of a star's life, when it becomes a white dwarf. In all cases, a deep understanding of the period spacing and/or period-echelle modulation due to mode coupling (when present) and glitches is essential to relate the observations to the actual physical phenomena that are causing the modulation.

In this contribution we will present a universal approach to the analytical modelling of period spacings in the presence or absence of buoyancy-related glitches. Based on a single, explicit, analytical expression, that requires no interpolation, we will discuss: (1) the case of buoyancy glitches in stars with pure gravity waves, showing how the different types of glitches lead to different signatures; (2) the case of mode coupling in red-giant stars when no glitch is present, showing how the coupling parameter depends on frequency, and (3) the case of red-giant stars in the presence of a buoyancy glitch, arguing that the two phenomena must be modelled simultaneously. Finally, for the case of the red-giant stars, we will show, based on simulated data, the effect of mode coupling and realistic glitches on the stretched period-echelle diagram previously introduced in the literature by Mosser et al. (2015).

Diego Bossini: *Kepler* Red-Clump Stars in the x000C Field and in Open Clusters: Constraints on Core Mixing

Co-authors: A. Miglio, M. Salaris, M. Vrard, S. Cassisi, B. Mosser, J. Montalbn, L. Girardi, A. Noels, A. Bressan, A. Pietrinferni, J. Tayar
Institute: University of Birmingham

The precise asteroseismic measurements of gravity-modes period spacing (DP1) has opened the door to detailed studies of the near-core structure of low-mass He-core-burning stars, which had not been possible before. This has allowed us to perform two crucial tests of mixing near the boundary of convective cores: First, we focus on red-clump stars and provide stringent tests of various core-mixing scenarios in the core-He-burning phase against the largely unbiased population of red-clump stars belonging to the old open clusters monitored by *Kepler*. We find that models with moderate overshooting successfully reproduce the range observed of DP1 in clusters. In particular, we show that there is no evidence for the need to extend the size of the adiabatically stratified core, at least at the beginning of the HeCB phase. Moreover, we show that in red-clump stars, while DP1 has no appreciable dependence on the mass, it shows a clear dependence on metallicity, which is also supported by predictions from models. Second, we extend our study to stars in the secondary clump. We make use of the dependence of DP1 on the mass of the He core to calibrate the efficiency of convective-core overshooting during the main-sequence phase as a function of stellar mass, and compare our results with independent calibrations based e.g. on eclipsing binaries and clusters.

Thomas Kallinger: Seismic Scaling Relations 2.0

Institute: University of Vienna

Mass and radius are amongst the most fundamental stellar parameters. Their knowledge is essential to characterise a star, but also a prerequisite to characterise a planet orbiting that star. During the last years the scaling relations for numax and Dnu have become the standard method to determine these fundamental parameters for cool stars with a convective envelope, delivering precise masses and radii for thousands of stars. The scaling relations themselves, however, remained essentially unvalidated and only recently the analysis of eclipsing binary systems with at least one red-giant component revealed that the seismic scalings systematically overestimate the mass and radius of red giants. We use these findings to formulate new, nonlinear, and entirely model-independent scaling relations, that lift this discrepancy. We test the new scalings with independent measurements and find them to give precise and accurate fundamental parameters for stars from the main sequence to the red clump. We will further show that the nonlinearity of the seismic scalings has substantial impact on various applications, like the RGB mass and age of clusters observed in the *Kepler* field.

Warrick H. Ball: Surface Effects in Evolved Solar-Like Oscillators

Co-authors: L. Gizon
Institute: University of Birmingham

The mode frequencies of solar-like oscillators cannot be compared with observations until one has somehow dealt with the systematic differences caused by poor modelling of the stars' near-surface layers, known as the "surface effect". So far, the surface effect has mainly been studied in main-sequence dwarfs. I present a comparison of several corrections of the surface effect when applied to six subgiants and low-luminosity red giants, which all have clear mixed modes. The results broadly show that the solar-calibrated power-law of Kjeldsen et al. is inappropriate for these evolved stars, and that the uncertainty in the choice between the remaining corrections introduces uncertainties on the model parameters that are roughly twice as large as the uncertainties in each model fit. Overall, the total uncertainties on the masses, radii and ages of the stars remain less than 1, 2 and 6 per cent.

Kuldeep Verma: Seismic Estimate of the Envelope Helium Abundance for Stars in the *Kepler* Seismic LEGACY Sample

Institute: Stellar Astrophysics Centre, Department of Physics and Astronomy, Aarhus University, Denmark

The observed oscillation frequencies from CoRoT and *Kepler* space missions contain enormous amount of information about the stellar interiors, and have been successfully used to study them. Unfortunately, the current forward methods can not exploit the full diagnostic potential of the observed frequencies due to our poor understanding of the near surface layers, and therefore, some of the stellar parameters are not as tightly constrained as they otherwise would be. The initial helium abundance is one of the least constrained parameter, and through its correlations with mass and age, it makes their determinations uncertain. In this presentation, we would talk about a signature in the oscillation frequencies arising due to the helium ionization. We would show that this signature can be used to estimate the envelope helium abundance of a sun-like star. We would also present the results obtained using the method for the stars in the *Kepler* seismic LEGACY sample.

Angela R. G. Santos: Seismic Signatures of Magnetic Activity in *Kepler* Data: Results from a Bayesian Peak-Bagging Analysis of 87 Solar-Type Stars

Co-authors: T. L. Campante, W. J. Chaplin, M. S. Cunha, R. Kiefer, R. A. Garcia, D. Salabert
Institute: Porto

In the Sun, the frequencies of the acoustic modes are observed to vary in phase with the activity level. These frequency variations are expected to be common in solar-type stars and contain information about the activity-related changes that take place in their interior. The unprecedented high-quality long-term photometric time-series obtained by *Kepler* provide an unique opportunity to detect and characterize stellar magnetic cycles through asteroseismology. In this work, we analyse a large sample of solar-type stars, combining the LEGACY sample and 25 *Kepler* Objects of Interest (KOIs). The original data sets are split in 90-d segments overlapped by 45-d. For each segment, the individual frequencies are obtained through a Bayesian peak-bagging analysis and used to compute the mean frequency shift. For each star, the temporal variation in the frequency shifts is then compared with that obtained from a cross-correlation method, as well as with the variation in: (1) the mode heights; (2) the granulation characteristic timescale; and (3) the photometric magnetic activity proxy. For some of the stars, we find evidences for (quasi-)periodic variations in the acoustic frequencies accompanied by variations in other activity proxies. Surprisingly, there are cases in which the mode heights appear to vary in phase with the frequency shifts, rather than the expected anti-phase. Our results also suggest that the amplitude of the frequency shifts increases with the stellar effective temperature and decreases with the surface rotation period.

Challenges for Understanding Stellar Evolution in Binary/Multiple/Interacting Systems

Andrej Prsa: The Potential of TESS for Advancing Studies of Binary Systems (Invited)

Institute: Villanova University

TESS is opening up a new frontier in binary/multiple star research. Operating on the bright end, this ambitious mission has the potential to continue the revolution started by Kepler and K2, especially thanks to the accessible ground-based follow-up. In this talk I will present the current state of the field, with a focus on our understanding of binary/multiple populations across galactic latitudes and spectral types. I will then present a pilot study based on the Galaxia model that estimates the expected yield of eclipsing binary stars by the TESS mission. Based on the personal experience, I will discuss some of the open questions that TESS will be able to address, and conclude with the questions that will need to be deferred to Plato and other future missions.

Simon Murphy: Compact Objects and Hierarchical Triples: Kepler Delta Scuti Stars in Binary and Multiple Systems

Co-authors: Bedding, T., Moe, M., Shibahashi, H., Kurtz, D., et al.
Institute: Sydney

We reveal the nature of companions to delta Scuti stars discovered via modulation of their pulsation phases in Kepler data. We show that for binaries with periods over 100 d, main-sequence companions are skewed heavily towards low-mass stars. We also show that white dwarf companions are common in 1000-d orbits at low eccentricity, implying tidal circularisation and/or mass transfer during the red giant phase. We present early results from an RV follow-up programme of high-mass companions, many of which appear to be binaries themselves, hence the systems are hierarchical triples.

Tanda Li: Modeling Kepler Red Giants in Eclipsing Binaries: Constraining the Mixing Length Parameter

Co-authors: Timothy R. Bedding, Daniel Huber, et al.
Institute: The University of Sydney

It is an exciting time for Asteroseismic studies of red giants since space telescopes achieve excellent data and provide clear pictures of stellar oscillations. Acoustic modes constrain the envelope, and mixed modes probe the core, which bring the best knowledge of red giants we ever had. In this work we show our modelling results of six Kepler red giants in eclipsing binaries. For identifying mixed modes with low S/N, we use models as a guide during peak bagging. We address that theoretical mixed modes are also affected by surface term, as the acoustic wave for calculating p-g mixing are biased at first place. The current method of correction, however, fail to fixed those g-dominated modes when period spacing is small. Since the mass and radii of these stars are known from binary analysis, we have a great opportunity to examine the mixing length parameter and the surface term for red giants. Mixing length parameter (alpha) is found about 0.2 higher than that calibrated by the Sun. The surface term shows good correlations with surface characteristics (Teff and logg), and decreases when star becomes more evolved.

Challenges for Stellar Populations and Galactic Archaeology Studies

Luca Casagrande: Stellar Population Studies with Solar Like-Oscillators: What We Have Learnt So Far, and the Promise of TESS (Invited)

Institute: Australian National University

Owing to their long life-times, cool stars can be regarded as fossils from different epochs of the formation and evolution of the Galaxy. Cool stars are also characterised by solar like-oscillations, which allow us to determine stellar parameters that otherwise we would not have access to. Thanks to the wealth of data provided by CoRoT and *Kepler*/K2 on solar like-oscillators, asteroseismology has now emerged as a new and uniquely powerful tool for studying stellar populations in the Galaxy. I review some of the main results obtained in this quest, and conclude with a glimpse on what we might expect next from TESS.

Emese Plachy: Cepheid and RR Lyrae Studies with TESS: What Could 27 Days Give Us? (Invited)

Institute: Konkoly Observatory, MTA CSFK

Space photometry revolutionized our knowledge about well-known variables such as Cepheids and RR Lyrae stars. However, only a small part of the sky has been observed by the CoRot, *Kepler* and MOST space telescopes so far. In contrast, TESS will provide a large survey of the short-period Cepheids and the population of nearby RR Lyrae stars, covering almost the entire sky. Homogeneous investigations of pulsation states and metallicity will be available. In this talk I will summarize the most pressing questions concerning present day Cepheid and RR Lyrae investigations where TESS may provide important contributions. These include nonradial modes, dynamical phenomena, as well as modulation and granulation. TESS will make it possible to search for and study the longest-period Cepheids in the Magellanic Clouds that populate Leawitt's law in the long-period region.

Aldo Serenelli: The First APOKASC Catalog of *Kepler* Dwarf and Sub-Giant Stars

Co-authors: J. Johnson, M. Pinsonneault, D. Huber and the APOKASC collaboration
Institute: Institute of Space Sciences (IEEC-CSIC)

We present the first APOKASC catalog based on spectroscopic and asteroseismic data for dwarfs and subgiants. Asteroseismic data for our sample of 415 objects is based on *Kepler* short cadence data and effective temperatures and metallicities are derived from APOGEE H-band (infrared) spectra and SDSS ugriz bands photometry. These stars are important calibrators for exoplanet host star characterization. Previous samples were either smaller or lacked metallicity information. We compare our results using standard scaling relations to estimate masses and radii with grid modeling (using classical evolutionary tracks to constrain mass and radius as well as seismology) and studies that employ more sophisticated treatment of the asteroseismic data. We find reasonable overall agreement but also identify systematic offsets between pure scaling relation estimates and more refined modeling techniques. We also carry out a thorough assessment of random and systematic error sources in the spectroscopic and asteroseismic data, as well as in the grid based modeling determination of the stellar quantities provided in the catalog. Median uncertainties (statistical + systematic) are 0.01 dex, 2.8%, 2.2%, 5%, and 20% for logg, mean density, radius, mass and age respectively. We perform a comparison with asteroseismic results based on analysis of individual frequencies that renders strong support to global seismic studies, an important result for K2 and especially for the oncoming mission Transiting Exoplanet Survey Satellite (TESS). However, we point out some factors that should be improved in the path to better determination of stellar mass, radii and, ultimately, ages.

Henryka Netzel: Non-Radial Modes in First-Overtone RR Lyrae Stars – the Complete Analysis of the OGLE Data for the Galactic Bulge

Co-authors: R. Smolec

Institute: Nicolaus Copernicus Astronomical Center

We present results of the analysis of more than 10000 first-overtone RR Lyrae stars (RRc) observed in the Galactic bulge in the fourth phase of the Optical Gravitational Lensing Experiment (OGLE). The excellent quality of OGLE data, together with a big number of regularly monitored stars, allow the detection of rare pulsation forms and statistical study of their properties.

One of the puzzling phenomena in RR Lyrae stars is a presence of additional non-radial modes. In one of the recently identified groups, there is a short-period signal besides the first-overtone . It forms characteristic period ratio around 0.61 with the first overtone. Our previous analysis of the selected OGLE data led to the discovery of more than 200 such stars. The complete analysis of the full Galactic bulge OGLE sample increases the number of know stars to more than 500. Properties of these stars (e.g. frequency content, distribution of amplitudes, stability) will be discussed in detail. Our analysis favours the model proposed by Dziembowski. In his model, the observed signals are due to non-radial modes of degrees 8 and 9. This interpretation opens a new window of asteroseismic studies of RR Lyrae stars.

Our previous analysis of a small sample of RRc stars based on OGLE-IV data resulted in a discovery of an entirely new double-periodic group. In these stars the additional signal has period even longer than the fundamental mode (which is not detected in these stars). It means that the additional signal cannot be a radial mode. The period ratio of the first-overtone to the additional signal is around 0.686. So far, 19 stars were detected in the OGLE data and one star was detected in the *Kepler* data. Here we report the discovery of almost fifty new members of this still puzzling group and discuss their properties in detail.

Victor Silva Aguirre: Age Dissection of the Milky Way Disk Using Asteroseismology

Co-authors: D. Slumpstrup, J. A. Johnson, M. H. Pinsonneault
Institute: Aarhus University

Stellar ages allow us to unveil the formation and evolution of the Milky Way. Thanks to asteroseismology and space-borne missions, we can measure ages for thousands of stars across the Galaxy. In this talk I present results obtained combining *Kepler* asteroseismic measurements with APOGEE spectroscopic and kinematic information. We identified the chemical and kinematic components of the populations in this region of the Galaxy based on an unbiased selection of stars, and dissect the age properties of the disk(s) to put firm constraints on its formation history and evolution. Our results are compared to chemo-dynamical models of the Milky Way, and highlight the potential for studies that combine ground-based surveys with asteroseismology from CoRoT, *Kepler*, K2, and TESS.

Future Opportunities and Challenges

Joris De Ridder: The Gaia Astrometric Mission (Invited)

Institute: KU Leuven

Gaia is an ambitious mission to create a three-dimensional map of our Galaxy. Gaia will provide positional and radial velocity measurements with the accuracies needed to produce a stereoscopic and kinematic census of about one billion stars in our Galaxy. We will give an overview of the achievement of the first Gaia data release and outline what can be expected for the upcoming data releases.

Kevin Belkacem: Asteroseismology with PLATO (Invited)

Institute: LESIA - Paris Observatory

A brief description of the status of the ESA PLATO project will be presented as well as the expected performances and the scientific outputs of the mission. Particular emphasis will be given to the role of the *Kepler* legacy and TESS mission for preparing plans for asteroseismology with PLATO.

Part II

Posters

Posters for Theme 1

Challenges for Understanding the Structure and Evolution of Exoplanet Systems

1.1 Pedro J. Amado: The CARMENES NIR and VIS High-Resolution Spectrographs For Exoplanet Science, Asteroseismology, Magnetic Activity and Other Science Cases

Institute: Instituto de Astrofísica de Andalucía, IAA-CSIC

CARMENES (Calar Alto high-Resolution search for M dwarfs with Exoearths with Near-infrared and optical chelle Spectrographs) is the next generation instrument built for the 3.5m telescope at the Centro Astronmico Hispano-Alemn (Calar Alto Observatory; CAHA, Almera, Spain), which is jointly operated by the Spanish National Research Council (CSIC) and the Max-Planck-Society (MPG). CARMENES has been built by a large international consortium of 11 institutes in Spain and Germany. It consists of two separate highly-stabilized, high-resolution echelle spectrographs covering both the visible, from 550 to 950 nm, and the near-IR, from 950 to 1700 nm, wavelength ranges with spectral resolution of R$\sim$82,000. They are fed by fibres from the Cassegrain focus of the telescope and were designed and built to achieve high-accuracy radial velocities ($\sim$1 m/s) of nearby M-dwarf stars. In this presentation, I will briefly review the current status of the project and of its main science case one year after the start of its Guaranteed Time Observations survey. I will provide a description of the potential of this instrument for asteroseismic studies and other science cases, like magnetic activity, stellar physics and (exo-) planetary atmospheres. This potential arises from two unique features in CARMENES: i) its NIR spectrograph and ii) the combined use of VIS and NIR simultaneous observations, what is becoming a reference for this type of instrument, as shown by upcoming projects.

1.2 Quentin Andre: Layered Semi-Convection and Tides in Giant Planet Interiors

Co-authors: Adrian J. Barker, Stephane Mathis
Institute: CEA Saclay

In the context of TESS, CHEOPS and PLATO forthcoming space missions, tidal dissipation is one of the key mechanisms to take into account in order to understand the architectures of newly discovered planetary systems. In turn, the rates of tidal dissipation depend very strongly on the internal structure of the planets involved. In particular, it has been shown recently that regions of layered semi-convection could exist in giant planet's gaseous envelopes: it is a strong candidate to explain Saturn's luminosity excess and may partly explain the abnormally large radii of some hot Jupiters. I will describe our new analysis of the transmission of internal (gravity or inertial) waves across a region of layered semi-convection and their associated density staircases (consisting of convective layers separated by thin stably stratified interfaces). Then, I will discuss the impact of layered semi-convection upon the rates of tidal dissipation, and show that it can be enhanced over a standard uniformly convective model. Thus, layered semi-convection stands as a good candidate that may help to explain recent observations suggesting higher tidal dissipation rates than previously thought in our Solar system's giant planets. Thus, its presence in extrasolar giant planets could have an impact on the long-term evolution of any planetary systems.

1.3 Thomas Barclay: The TESS Science Support Center and the Guest Investigator Program

Institute: NASA Goddard Space Flight Center

The TESS Mission will have a robust Guest Investigator (GI) program that will be run by the TESS Science Support Center located at NASA Goddard Space Flight Center. Following the highly successful *Kepler*/K2 Guest Observers (GO) program, the TESS Science Support Center will support the astronomical community in preparing proposals and providing tools and user support for data retrieval, processing and analysis. I will present the overall structure and plan for the GI program, and discuss data products, GI allocations, observing modes, tools and support as we prepare for the first proposals proposal cycle.

1.4 Tiago Campante: The Impact of TESS Asteroseismology on the Characterisation of Known Exoplanet Systems

Institute: University of Göttingen

TESS will perform an all-sky survey for planets transiting bright nearby stars. Furthermore, TESS's excellent photometric precision will also enable asteroseismology. Asteroseismology of solar-like oscillations is maturing into a powerful tool whose impact is being felt more widely across different domains of astrophysics, noticeably that of exoplanetary science. TESS thus offers the exciting prospect of conducting asteroseismology of exoplanet-host stars. I will discuss the impact of having additional constraints from TESS asteroseismology on the characterisation of known exoplanet-host stars and hence on their planetary systems. With over 100 solar-type and red-giant known hosts predicted to have detectable solar-like oscillations, this will represent a truly invaluable stellar sample. I note that the vast majority of these systems were discovered using radial velocity measurements and will thus be potential prime targets for the upcoming ESA CHaracterising ExOPlanet Satellite (CHEOPS), which will be monitoring bright known hosts anywhere in the sky for transiting planets. Consequently, TESS could be providing asteroseismic measurements for a significant number of potential CHEOPS targets. The implications of this synergy will also be addressed as part of this presentation.

1.5 Frank Grundahl: SONG – Getting Ready for TESS

Co-authors: V. Antoci, M.F. Andersen, P. Pallé, L. Deng
Institute: SAC Aarhus University

The 1m Hertzsprung SONG telescope on Tenerife has been in operation since early 2015 and the second node of the network, in China, has demonstrated a performance similar level of performance. We present here some initial results and experiences based on the two-site operation and prospects for work during the first year of TESS operation.

1.6 Shoya Kamiaka: Joint Analysis of Spin–Orbit Angle in Exoplanet Systems by Adopting Asteroseismology and Transit Spectroscopy

Co-authors: Othman Benomar (NYUAD), and Yasushi Suto (UTokyo)
Institute: University of Tokyo

In extrasolar planetary systems, the angle between stellar spin axis and planetary orbital axis (spin-orbit angle) and its distribution probe the formation process of exoplanets and their dynamical evolution. Since the direct measurement of spin-orbit angle is difficult, this angle is often inferred by other observables, including stellar spin inclination, planetary orbital inclination, and projected spin-orbit angle. So far, discussion on spin-orbit angle has been made mainly for hot Jupiter systems through its projected spin-orbit angle via transit spectroscopy. Since asteroseismic framework reveals stellar spin inclination, asteroseismology is expected to provide complementary information on spin-orbit angle in not only hot Jupiter systems but also various kinds of exoplanetary systems. Fabrycky & Winn (2009) had found with 11 projected spin-orbit angles that the majority of exoplanet system shows small spin-orbit angle, and similar tendency is also reported from asteroseismic inference with 25 stars in Campante et al. (2016a). We extend their work by adopting ~50 projected spin-orbit angles in literatures to infer the underlying spin-orbit angle distribution following the method in Fabrycky & Winn (2009). We also analyse acoustic oscillations of ~35 stars to derive their stellar spin inclination angles and convert their distribution to the spin-orbit angle distribution with Bayesian framework following Morton & Winn (2014). Then we compare spectroscopically- and asteroseismically-estimated spin-orbit angle distributions and plan to present its implications.

1.7 Thomas North: Weighing in on the Masses of Retired A stars with Asteroseismology

Institute: University of Birmingham

Here we investigate the masses of “retired A Stars” in an ensemble fashion, through the use of asteroseismic observations made with *Kepler* and K2. All targets have been subject to long term radial velocity observations to detect any orbiting bodies. We investigate the possibility that stellar masses, derived from spectroscopy, have been systematically overestimated. No strong evidence of systematic bias between stellar mass estimates recovered using asteroseismology and other methods is found. We find that any mass difference can be explained through use of differing constraints during the recovery process. Finally, we find that the use of optimistic uncertainties on input parameters has the potential to significantly bias the recovered stellar masses, which coupled with resulting underestimated uncertainties on the recovered mass, may be artificially creating a population of stars that do not exist.

Posters for Theme 2

Challenges for Studies of Stellar Evolution and Stellar Interiors Physics

2.1 Victoria Antoci: Wildly Oscillating Stars – A New Physical Phenomenon? Eliminating the Impossible to Find the Improbable

Institute: SAC Aarhus University

Here I present a sample of gamma Dor and hybrid pulsators that exhibit (additional) frequency patterns inconsistent with anything we know about these type of stars. More precisely we find peaks, that show nice long ridges reminiscent of consecutive high radial order g-modes, however, their period spacings do not match the expected values for main sequence stars but rather those of compact objects. Beyond the problem of explaining the short period spacings, the pulsation periods, which are too short for gamma Dor stars, only partly overlap with known examples of sdB pulsators. Recent theoretical predictions of mode instability in compact stars suggest that gravity modes in precursors of extremely-low-mass white dwarfs might be consistent with our observations.

On the other hand, if we assume that the peaks are split in frequency instead of periods we find repeating patterns of multiplets (in some cases septuplets!) reoccurring in a very narrow frequency range, situated exactly between the g and p modes excited in A and F stars on and near the main sequence. We find it very unlikely that these peaks are rotationally split modes as in some cases we can clearly exclude this hypothesis. Further, we also find it implausible that the splittings are induced by geometrical effects, as they are not exactly equally spaced. In some cases we can confirm binarity, nevertheless, we find no clear evidence that the lower-mass companions may be the origin of these signals.

We have low resolution spectra for several of the stars and confirm their late A/early F spectral type. Additionally we have high-resolution spectra for two of our target stars and find a low v sin i and abundance patterns similar to the chemically peculiar star rho Puppis.

This phenomenon occurs in several stars, not always at the same frequency and with the same separation, which leads us to conclude that these signals are intrinsic to the stars and may describe a new phenomenon in A and F stars on and near the main sequence.

2.2 Dominic Bowman: On the Detection and Interpretation of Internal Gravity Waves in Massive Stars

Co-authors: Conny Aerts (IvS, KU Leuven, Belgium), Andrew Tkachenko (IvS, KU Leuven, Belgium), Tamara Rogers (Newcastle University, UK), Philipp Edelmann (Newcastle University, UK)
Institute: KU Leuven

Understanding the physics at work within massive stars is an important goal for asteroseismology as these stars are dominant in stellar and galactic evolution theory. Without observational constraints of internal rotation and mixing processes in massive stars, which can strongly influence stellar lifetimes, the accuracy of stellar models is limited – see Aerts (2015) for a recent review. The high quality observations from the *Kepler* Space Telescope provide an excellent opportunity to study physics that is not currently included in evolutionary models. Specifically, prescriptions for angular momentum transport by convectively driven Internal Gravity Waves (IGWs) need to be formulated using constraints from asteroseismic observables. Numerical simulations show that IGWs are effective at transporting angular momentum within a star (Rogers et al. 2013), which has been utilised to explain the radial rotation profiles observed in only a handful of massive stars (e.g. Triana et al. 2015).

Any star with a convective core is able to generate IGWs, with changing properties imposed by rotation or strength of a magnetic field. The combined effect of hundreds of IGWs at the stellar surface is predicted to produce an excess of red noise in a star's frequency spectrum, which may be detectable in hundreds of massive stars observed by *Kepler*. To date, few detections of IGWs in massive stars exist (Blomme et al. 2011; Aerts & Rogers 2015; Aerts et al. 2017) with more needed to constrain numerical simulations and ultimately improve our understanding of stellar structure and evolution for massive stars. We will present the methodology, preliminary results, and physical implications from an ongoing search for signatures of IGWs in hundreds of massive stars observed by the *Kepler* Space Telescope.

2.3 Gaël Buldgen: Seismic Inversion of the Solar Entropy: New Lights on Standard Solar Models and their Limitations

Co-authors: S. J. A. J. Salmon, A. Noels, R. Scuflaire, D. R. Reese, M-A. Dupret, J. Colgan, C. J. Fontes, P. Eggenberger, P. Hakel, D. P. Kilcrease, S. Turck-Chize
Institute: Université de Liège

The Sun is the most constrained and well-studied of all stars. As a consequence, the physical ingredients entering solar models are used as a reference to study all other stars observed in the Universe. However, our understanding of the solar structure is still imperfect, as illustrated by the current debate on the heavy element abundances in the Sun. Beyond the question of the abundances, this problem is intimately related to the microscopic and macroscopic physical ingredients used to compute solar models. The uncertainties on these physical processes are the main limitations when determining stellar fundamental parameters, such as mass, radius and ages, using current asteroseismic data from CoRoT and *Kepler*, or future observations from Tess and Plato. We present results of a new seismic indicator combined with the most up-to-date opacity tables. Thanks to this new seismic inversion, we are able to unveil the radial profile of an entropy proxy of the solar plasma. This analysis allows us to probe more efficiently the regions of highest uncertainty in solar models, such as just below the convective zone, thus paving the way for new in-depth analyses of the Sun.

2.4 Orlagh Creevey: A Poor Old Giant Singing Away

Co-authors: F. Grundahl, F. Thevenin, P. Palle, D. Salabert, R. Collet, L. Bigot
Institute: Observatoire de la Cote d'Azur

HD122563 is a metal-poor ([M/H] = -2.5) old Population II star. It is one of the few nearby metal-poor stars that can be studied in detail. Such a benchmark star is important for understanding the physics of stellar atmospheres in the not-so-solar metallicity regime, understanding oscillations and stellar interiors in the context of metallicities, and providing a reference point for calibrating large galactic spectroscopic surveys such as Gaia. This star has been well studied using spectroscopic, photometric, and interferometric data. Since just over a year, we have been obtaining radial velocity data from the ground-based SONG Hertzsprung telescope with typically one point per night. We see clear evidence of oscillations and initial analyses point towards the global seismic quantity, numax, in clear disagreement with that predicted from the known radius and mass. We present the current status of HD122563 and our initial asteroseismic results.

2.5 Jacqueline den Hartogh: Combining Asteroseismic and s-Process Nucleosynthesis Observations to Constrain Stellar Evolution of Low Mass Stars

Co-authors: Umberto Battino, Raphael Hirschi, Patrick Eggenberger and NuGrid collaboration
Institute: Keele University

After the central He burning is exhausted, low mass stars start the AGB phase. In this phase the s-process takes place, which is believed to be at the origin of half of all elements heavier than iron. Observations of AGB stars, planetary nebulae and presolar grains give us observational constraints for this process. Rotation and magnetic fields play a key role in stars and their impact on the AGB phase could be crucial. Asteroseismic observations of internal rotational properties of stars give us another set of important observational constrains, which indicate the presence of an unknown process of angular momentum transport. We use the combination of both sets of observational constraints to analyse our stellar evolution models calculated with MESA. We will present models with an initial mass of 0.8-2.0 solar masses, including rotation and magnetic fields. The unknown process of angular momentum transport will be investigated by adding a constant artificial viscosity to our models. We will show how rotation, magnetic fields and the added viscosity contribute to the total diffusion coefficient, the s-process, and the angular momentum transport.

2.6 Maria Pia Di Mauro: On the Structure Inversion for the Red Giant Stars

Co-authors: R. Ventura, E. Corsaro
Institute: INAF

We will present results on our attempt to seismic inversion for sound speed and density for the red giant star “Pooh” after analysis of the entire 4 years period observations obtained by *Kepler*.

2.7 Noemi Giammichele: Asteroseismology of Hydrogen-Deficient White Dwarfs : Evidence of a New Evolutionary Channel?

Co-authors: Charpinet, S., Fontaine, G., and Brassard, P.
Institute: IRAP / OMP / Université de Toulouse

White dwarf stars can be seen as stellar fossiles that keep buried in their interior many features from their past evolution. By studying their internal chemical compositions, we have access to a wealth of information regarding key processes in stellar physics. We contrast the seismic results obtained for two pulsating hydrogen-deficient white dwarfs from the *Kepler* and *Kepler* 2 fields and discuss the possible events that can lead to these distinct internal chemical signatures.

2.8 Rasmus Handberg: NGC 6819: Testing the Asteroseismic Mass Scale, Mass Loss, and Evidence for Products of Non-Standard Evolution

Co-authors: K. Brogaard, A. Miglio, D. Bossini, Y. Elsworth, D. Slumstrup, G. R. Davies, W. J. Chaplin
Institute: SAC Aarhus University

We present an extensive peakbagging effort on *Kepler* data of ∼50 red giant stars in the open star cluster NGC 6819. By employing sophisticated pre-processing of the time series and Markov Chain Monte Carlo techniques we extracted individual frequencies, heights and linewidths for hundreds of oscillation modes.

We show that the "average" asteroseismic parameter $\delta\nu_{02}$, derived from these, can be used to distinguish the stellar evolutionary state between the red giant branch (RGB) stars and red clump (RC) stars.

Masses and radii are estimated using asteroseismic scaling relations, both empirically corrected to obtain self-consistency as well as agreement with independent measures of distance and age, and using updated theoretical corrections. Remarkable agreement is found, allowing the evolutionary state of the giants to be determined exclusively from the empirical correction to the scaling relations. We find a mean mass of the RGB stars and RC stars in NGC 6819 of 1.61$\pm$0.02 Msun and 1.64$\pm$0.02 Msun, respectively. The difference ΔM= 0.03$\pm$0.01 Msun is almost insensitive to systematics, suggesting very little RGB mass loss, if any.

Stars that are outliers relative to the ensemble reveal overmassive members that likely evolved via mass-transfer in a blue straggler phase. We suggest that KIC 4937011, a low-mass Li-rich giant, is a cluster member in the RC phase that experienced very high mass-loss during its evolution. Such over- and undermassive stars need to be considered when studying field giants, since the true age of such stars cannot be known and there is currently no way to distinguish them from normal stars.

2.9 Patricia Lampens: Spectroscopic Study of A/F Type Candidate Hybrid Pulsators of the *Kepler* Mission

Co-authors: Y. Frémat, L. Vermeylen et al.
Institute: Koninklijke Sterrenwacht van België

In an effort to better understand and unravel the enigma of the low frequencies in the brighter A/F-type candidate hybrid pulsators of the *Kepler* mission, we started a radial-velocity monitoring campaign with the high-resolution HERMES spectrograph of the Mercator telescope since 2013. With at least four spectra per object, we determined the radial velocities, projected rotational velocities, atmospheric properties and provided a classification scheme on the basis of the cross-correlation functions and the radial velocities as a function of time. Orbital solutions were obtained for seven different systems. Our results consist of 1) revised atmospheric parameters for all observed targets, 2) the detection of new short- and long-period binary as well as multiple spectroscopic systems, 3) characterization of their components, and 4) a determination of the multiplicity fraction among our sample of candidate hybrid stars. For some systems, a combined analysis of the photometric time delays (affecting the short-period pulsation frequencies) and the radial velocities enables to derive a well-defined orbital solution.

2.10 Jakob R. Mosumgaard: Improving Stellar Models with 3D Atmospheres

Co-authors: V. Silva Aguirre, A. Weiss, W. Ball, J. Christensen-Dalsgaard, R. Trampedach
Institute: SAC Aarhus University

One of the basic ingredients in astrophysics is the understanding of stellar structure and evolution. This understanding is primarily based on one-dimensional numerical models and the comparison of these with observations. Many of today's stellar models share common shortcomings; amongst these are the use of an artificial analytic atmosphere to describe the outer layers of the star, and the use of the mixing-length formulation to describe convection.

To address this, we have consistently implemented results from three-dimensional simulations of stellar atmospheres into the GARching STellar Evolution Code (GARSTEC), the Aarhus STellar Evolution Code (ASTEC), and Modules for Experiments in Stellar Astrophysics (MESA). Our implementation substitutes the non-physical atmosphere with a more appropriate T-tau-relation – which depends on the physical properties of the star – to set up more realistic outer boundary conditions. Furthermore, to refine the treatment of convection, the mixing-length parameter is calibrated from the 3D simulations and changes as the star moves in the HR-diagram.

We investigate the impact of our implementation on low-mass stars by examining evolution, interior structure and stellar oscillation characteristics. Furthermore, we analyse the impact on the temperature during evolution on the red giant branch.

2.11 Benard Nsamba: Exploring Uncertainties in Stellar Physics Models of Solar-Type Stars

Co-authors: T. L. Campante, M. J. P. F. G. Monteiro
Institute: IA, University of Porto

Using asteroseismic data from the *Kepler* satellite, we explore the systematic uncertainties arising from changes in the input physics used when constructing evolution models of solar-type stars. We assess the impact of including diffusion of hydrogen and gravitational settling of heavier elements (i.e., ^{4}He, ^{16}O, and ^{56}Fe) and changes in the initial chemical composition of stellar models on the derived fundamental stellar parameters (i.e., mass, radius and age). Stellar models with diffusion produce lower ages compared to models without diffusion. We find diffusion to be an efficient transport process in stars with masses ranging from 0.8 $M_{\odot}$ to 1.2 $M_{\odot}$. We explore the systematic uncertainties by comparing models with and without diffusion, resulting in 0.6%, 1.8%, and 14%, in radius, mass, and age, respectively. The grids constructed based on Asplund et al. (2009) chemical composition produce stellar models with lower values of initial helium abundance compared to grids with Grevesse & Sauval (1998). We find the systematic uncertainties resulting from models with a difference in chemical composition to be 0.6% in radius, 1.7% in mass, and 8% in age. The systematic uncertainties in the radius, mass, and age are consistent with those in literature.

2.12 May Gade Pedersen: Unraveling the Shape of Convective Core Overshooting From Period Spacing Series of Slowly Pulsating B-type Stars

Co-authors: C. Aerts, P. I. Ppics, T. M. Rogers and J. McElwaine
Institute: KU Leuven

The treatment of convective core overshooting provides one of the largest uncertainties in stellar structure and evolution models of massive stars. Stars with gravity mode pulsations, which probe the deep stellar interior, provide the best opportunity to constrain core overshooting and any additional mixing in the near-core regions of our models. Gravity modes are highly sensitive to the amount of mass in the overshoot layer, as well as the chemical gradient left behind as the convective core retreats during the main-sequence evolution. Uniform period spacings of gravity modes, and deviations from them, provide information on the mixed core and additional mixing processes just above it. We aim to demonstrate how the choice of the description of the convective core overshooting influences the shape of theoretically predicted period spacing series of slowly pulsating B-type stars. Furthermore, we investigate any correlations which may exist between the descriptions. With this study we focus on three overshooting descriptions (step, exponential and extended exponential overshooting), which are currently implemented in the state of the art stellar structure and evolution code MESA. Additionally, we show initial results of including mixing profiles from 2D hydrodynamic simulations in MESA, and explore their influence on the predicted period spacing series.

2.13 Aldo Serenelli: Solar tests for new opacities

Co-authors: N. Vinyoles, F. Villante
Institute: Institute of Space Sciences (IEEC-CSIC)

Experimental results on radiative opacities (Bailey et al. 2015) suggest that commonly used radiative opacity calculations underestimate the true opacity of stellar matter at conditions similar to the base of the solar convective envelope. This opens up a possible solution to the long standing problem of the solar abundance problem. Recently, new calculations of radiative opacities have become available: the new Los Alamos opacities (OPLIB, Colgan et al. 2016) available for stellar interiors, and OPAS (Mundet et al. 2015) appropriate just for solar models. Here, we use these new opacities to compute standard solar models and compare predictions with helioseismic and solar neutrino data. Our results show that, while OPAS leads to solar models with low-Z that are globally in reasonable agreement with the data, the OPLIB opacities create serious discrepancies between models and data, particularly regarding predictions for the solar helium abundance and the well measured 8B and 7Be neutrino fluxes. As a corollary, we emphasize that stellar models and isochrones based on OPLIB opacities should be tested thoroughly if they are going to be adopted as a next standard for radiative opacities in stellar model calculations.

2.14 Amalie Stokholm: HR 7322: A Benchmark for Stellar Evolution

Co-authors: Tim White, Vctor Silva Aguirre, Poul Erik Nissen
Institute: SAC Aarhus University

HR 7322 is a subgiant star in the *Kepler* field. It is a type F6 star with a magnitude of V=6.00. This star has not been the subject of detailed studies before, but has mostly been used as a comparison star in spectroscopy and photometry. Here a more detailed study of HR 7322 using interferometry and asteroseismology is presented.

2.15 Wojciech Szewczuk: KIC3240411 – The β Cep/SPB Hybrid Pulsator with Period Spacing Pattern for g Modes

Co-authors: Jadwiga Daszyńska-Daszkiewicz, Przemyslaw Walczak
Institute: University of Wroclaw

KIC3240411 is the β Cep/SPB hybrid pulsator (Balona et al. 2011). We reanalyse the *Kepler* time series photometry and identify the regular period spacing pattern for g mode frequencies. Thus, the star belongs to the group of B-type pulsators exhibiting asymptotic properties (e.g. Papics, 2014, 2015, 2017). Our very preliminary models point that frequencies that make up period series are associated with the dipole prograde g-modes. However, taking into account the position of the star on the Kiel diagram (log $T_{\rm eff}$ =20980, log g=4.01, Lehmann et al., 2011) we encountered a problem with g-mode excitation, i.e., all theoretical modes in our representative models are pulationaly stable. This is a well know problem encountered in other β Cep/SPB pulsators and such objects are excellent laboratory to study microphysics and stellar evolution theory. We perform comprehensive seismic modelling which enable us to reproduce observed frequencies and stability conditions. Our modelling is based on evolutionary calculations with MESA code and on the traditional approximation for including the effects of the Coriolis force on g-mode pulsations. The effect of various mixing processes (e.g., convective overshooting, diffusion, rotationally induced mixing) and increasing of opacity are investigated.

2.16 Felix Ahlborn: Influence of Kernel Sensitivities on Rotational Inversion Results

Co-authors: Saskia Hekker
Institute: Max Planck Institute for Solar System Research

As stars turn off the main sequence the stellar core spins up while the envelope spins down, creating a radial differential rotation profile. Here, we analyse the radial rotation profile of a red giant model from a set of oscillation modes for which we computed rotational kernels using rotational inversions. We investigate redundancies in this set of kernels by means of a singular value decomposition. We deduce a high degree of redundancy in a set of dipole modes and a lack of sensitivity between 0.1 and 0.9 in stellar fractional radius. Introducing modes with different spherical degrees will tentatively add sensitivity at intermediate radii. A better spatial resolution in radius sets constraints on the shape of the rotational profile. Additionally, it can localise significant changes in the rotation rate which sets more constraints on dominant processes of angular momentum transport.

2.17 Jérôme Ballot: SoFAR – Seismology of Fast Rotating Stars

Co-authors: Zs. Bognár, A. Garca Hernández, F. Lignières, E. Michel, E. Moravveji, R. M. Ouazzani, M. Paparó, V. Prat, D. R. Reese, M. Rieutord, Á. Sódor, J. C. Suarez
Institute: IRAP

Thanks to the space missions CoRoT and *Kepler*, asteroseismology has successfully probed stellar interiors, especially of solar-like stars and red giants. Such a success has not been achieved yet for non-evolved intermediate-mass and massive stars, as the oscillation spectra of pulsating stars in this mass range exhibit complex patterns that are not well understood. Rapid rotation, a very common feature of these stars, is an identified source of complexity. Substantial progress has recently been achieved both in theory and observations. The space missions CoRoT and *Kepler* have provided seismic data with unprecedented quality for classical pulsators such as δ Scuti stars, γ Doradus or SPB (slow pulsating B-type) stars. It allowed us to accurately determine the frequencies of hundreds of oscillation modes in these stars. The mode identification, i.e. associating each frequency with a mode, is a prerequisite for any further seismic inference. This identification needs theoretical support. In the last years, new theoretical approaches as well as new 2D codes taking into account the centrifugal deformation have been developed to model the internal structure of rotating stars and to compute their oscillation spectra. We are now close to a convergence between theory and observation. Indeed a first breakthrough has been made with the detection of regular patterns that were predicted by the models. We built a new international team at ISSI (International Space Science Institute, Bern, CH) that gathers observers who have analysed CoRoT and *Kepler* data of classical pulsators, and modellers who have developed new 2D codes and theoretical seismic tools. This poster presents the team and its work.

2.18 Paul Beck: Lithium Abundance and Rotation of Seismic Solar Analogues

Co-authors: J.-D. do Nascimento Jr., T. Duarte, D. Salabert, A. Tkachenko, S. Mathis, S. Mathur, R. A. Garca, M. Castro, P. L. Pallé, R. Egeland, D. Montes, O. Creevey, M. F. Andersen , D. Kamath , and H. van Winckel
Institute: Instituto de Astrofisica de Canarias

Lithium abundance and surface rotation are known as good diagnostic tools to probe the internal mixing and angular momentum transfer in stars. These processes are sensitive to the stellar mass, a parameter which is very difficult to determine precisely for stars outside stellar clusters or binary systems. In this poster, we present the analysis of a sample of 18 stars, with the stellar mass from asteroseismology and rotation rate derived from *Kepler* photometry. These so-called solar analogues present a consistent sample of stars, which have similar masses (M/Mo = 1.0±0.15) and metallicity (0.0±0.3 dex) to the Sun. The presence of surface variation ensures that these stars also exhibit magnetic activity. In addition to *Kepler* photometry, we obtained 53 hours of high-resolution spectroscopy, leading to a consistent spectroscopic survey of lithium and fundamental parameters for sample stars. From these observations, we present 6 new binary systems.

By comparing the surface rotation rate with the measured abundance of lithium, we find a well-defined relation between the two parameters. For four non-binary stars in this sample, individual-frequency modeling with the “Asteroseismic Modeling Portal” code is available, providing precise estimates for the stellar mass and age (1 to 9 Gyr). Comparing a grid of models, calculated with the Toulouse-Geneva stellar evolution code, including rotational internal mixing and calibrated to reproduce solar chemical properties shows a good agreement between the measured A(Li) and the predicted A(Li) evolution.

The correlation between the lithium abundance and the rotation period supports the gyrochronological concept for stars younger than the Sun. The consensus between measured lithium abundance for solar analogues with model grids, calibrated onto the Sun’s chemical properties suggests that these targets share the same internal physics. In this light, the solar lithium value and rotation rate appear to be normal for a star like the Sun.

Link to the accepted paper: https://arxiv.org/abs/1702.01152

2.19 Xinghao Chen: Rotational Splitting and Asteroseismic Modeling of the Delta Scuti Star EE Camelopardalis

Co-authors: Yan Li

Institute: Yunnan Observatories, Chinese Academy of Sciences

Delta Scuti stars are multi-period pulsators, and are therefore considered to be important targets of asteroseismology. Based on 37 independent frequencies extracted by Breger et al. (2015) from the 300+ nights photometric data of the delta Scuti star EE Cam, we tried to search for frequency splitting of pulsation due to the stellar rotation. Two kinds of frequency splitting value (3.256μHz and 5.403μHz) are found, and their ratio (0.603:1.0) perfectly meets the asymptotic relation for the rotational splitting of nonradial g-mode pulsation. We hence identify five sets of $l = 1$ multiplets, and ten sets of $l = 2$ multiplets. Then we calculated a grid of stellar models with two adjustable parameters(i.e., the metallicity Z and the stellar mass M), and compared theoretical pulsation frequencies of each stellar model with frequencies of two identified $m = 0$ nonradial modes and a fundamental radial mode through the ↓2 fitting. We found that the ↓2 value of the theoretical model with Z=0.028 and M $=$ 2.04 M$_\odot$ is much smaller than that of other theoretical models. We finally determined the best fitting model to be a post main sequence star, with its mass 2.04M$_\odot$, metallicity Z=0.028, effective temperature 6433K, radius 4.12R$_\odot$, and luminosity 26.06L$_\odot$. The star is composed of a helium core and a hydrogen-abundant envelope, and the helium core mass is estimated to be $0.181 M_\odot$.

2.20 Giovanni Mirouh: Non-Adiabatic Oscillations of Fast-Rotating Stars: the Example of Rasalhague

Co-authors: D.R. Reese, M. Rieutord

Institute: Scuola Internazionale di Studi Superiori Avanzati (SISSA), Trieste

Fast rotation is a key ingredient which intervenes in the structure of massive and intermediate-mass main sequence stars, and has a significant impact on their oscillation spectra. For fast rotators, mode identification is difficult as the effects of differential rotation and modal properties are not well known. In this contribution, I will present a study case based on the main-sequence A star Rasalhague (alpha Ophiuchi), in which 57 oscillation frequencies have been measured with MOST, and for which some regularities have been exploited. We model the star in two dimensions with the ESTER code taking centrifugal flattening, differential rotation and heat diffusion into account. We then compute both its adiabatic and non-adiabatic oscillations with the TOP code. I will discuss the differences between the two calculations and present various diagnostics (e.g. visibilities, damping/growth rates, ...) to help us match the computed modes to the observed ones for Rasalhague. I will also show how we can get new constraints on the physical parameters of this star.

2.21 Martin Nielsen: Limits on Radial Differential Rotation in Sun-Like Stars from Parametric Fits to Oscillation Power Spectra

Co-authors: H. Schunker, L. Gizon, J. Schou, and W. Ball
Institute: NYU Abu Dhabi

Rotational shear in Sun-like stars is thought to be an important ingredient in models of stellar dynamos. So far, research has focused on the more easily measured latitudinal differential rotation, but little progress has been made on constraining the radial part of the differential rotation in Sun-like stars. Using asteroseismic measurements of rotation we apply a new technique to constrain the radial shear in five Sun-like stars observed by *Kepler*. We apply a parametric model of the radial rotation rate which allows for two different rotation rates, one in the radiative interior and one in the convective envelope. This model is used in a fit to the full oscillation spectrum of each of the five stars. Since rotation can also be measured from starspot signals in these stars, we apply a prior on the convective envelope rotation rate based on the rotation rate measured from surface features. Using this approach we find that the interior rotation rate does not differ from the envelope by more than approximately $\pm 30\%$.

2.22 Vincent Prat: Anisotropic Shear-Driven Turbulent Transport in Stellar Radiative Zones and Consequences for the Rotational Evolution of Stars

Co-authors: S. Mathis, L. Amard, C. Charbonnel, A. Palacios
Institute: CEA Saclay

Helio- and asteroseismology have allowed us to probe the internal rotation of the Sun and of an increasing number of distant stars in the whole HR diagram. This reveals a strong transport of angular momentum within stellar interiors. In this framework, current stellar evolution rotating models fail to reproduce the relatively flat rotation profile of the solar radiative zone and the weak core-to-surface rotation contrast of other stars, including subgiant and red giant stars. To reduce the discrepancies between predictions of models and observations, it is thus crucial to find what processes are responsible for the observed missing transport.

In this context, we developed a new theoretical model of horizontal turbulent transport due to the shear instability in stellar radiation zones that includes for the first time the combined effects of rotation, stable stratification, and radial shear. We will present the key theoretical advances provided by our new model and the important implications for the rotational evolution of stars. A key feature is that it predicts a strong enhancement of the horizontal turbulent transport and of the meridional circulation that efficiently transports angular momentum outwards, thus leading to rotation profiles that are in better agreement with observations.

2.23 Tao Wu: Rotational Splits and Mode Identifications in SPB Stars

Institute: Yunnan Observatories, Chinese Academy of Sciences

Slowly pulsating B (SPB) stars are main sequence stars of intermediate mass ($3 \sim 8\ M_{\odot}$). Its effective temperatures ranges from 10000 K to 20000 K and the period of those non-radial g-modes about from 0.5 days to 3 days. For this kinds of pulsating stars, they have larger convective cores due to hydrogen burning in stellar center and many of them always have rotations. In Kepler field view, there are six SPB stars are thought to be of faster rotators. Its rotational periods are obviously smaller than that of oscillation modes. It leads to the intrinsic oscillation modes and the split modes distribute into different frequency ranges in oscillation power spectra. Unfortunately, those intrinsic modes always can not be clearly detected from the power spectra. Therefore, those clearly detected split modes are almost the only feasible inform ation for analyzing inner structure and status of those pulsating stars via the method of asteroseismology. And it becomes important to decide the rotational periods, period spacings, and to identify those modes, before we deeply analyze the interior status. In this poster, we will discuss those questions.

2.24 Tim Bedding: Surface Gravities for 15,000 *Kepler* Stars measured from Stellar Granulation

Co-authors: D. Pande and D. Huber
Institute: University of Sydney

The surface gravity of a star is one of its most fundamental parameters. Asteroseismology with *Kepler* provides accurate surface gravities for the brighter main-sequence and subgiant stars, but only if their oscillations are observed at short cadence. For those tens of thousands of stars which only have long-cadence data, it may still be possible to infer log g by measuring the low-frequency photometric fluctuations from granulation. This method was used by Bastien et al. (2013, 2014, 2016), who derived log g for nearly 28,000 stars with a typical precision of about 0.1 dex. Somewhat controversially, they found that stellar radii of exoplanet hosts stars are, on average, 20% – 30% larger than previous measurements had suggested.

To build on this work, we have developed a method to estimate log g by measuring the granulation background in the Fourier power spectrum. We calibrated the method using stars for which asteroseismology has been possible with short-cadence data, demonstrating a precision in log g of about 0.05 dex. We also derived a correction for white noise as a function of *Kepler* magnitude by measuring white noise directly from observations. We then applied the method to the same sample of long-cadence stars as Bastien et al. (2016). We found that about half the stars are too faint for the granulation background to be reliably detected above the white noise. For the remainder, we have derived values of log g (and uncertainties) for about 15,000 stars. We confirm that previous measurements of log g were overestimated, but not by as much as reported by Bastien et al. (2014). Our results provide the most accurate log g available for these 15,000 stars, and the method can also be applied to data from K2 and TESS.

2.25 Earl Bellinger: Seismic Inference on Stellar Interiors: Inversion for the Sound Speed Profile of 16 Cyg A

Co-authors: Basu, S., Hekker, S., and Ball, W.
Institute: Yale University

Measurements of stellar pulsation frequencies provide strong constraints on evolutionary models of solar-like stars. However, pulsation frequencies of best-fitting stellar models still bear significant differences with the stars they are fitting. These differences arise both due to differences in internal structure between the observed star and the stellar model, and due to near-surface errors in modelling (i.e., the surface term). Here we extend the seismic inversion technique of Optimally Localized Averages to draw inferences on the deep interiors of asteroseismic targets. We present an algorithm for automatic determination of inversion parameters that is robust to imprecise stellar mass and radius estimates. We validate the method using hare-and-hound exercises, and then apply the method to measure the isothermal sound speed profile of one of the best-observed solar-like stars, 16 Cyg A. Finally, we remark on the differences in the internal sound speed profile between 16 Cyg A and its best-fitting evolutionary model.

2.26 Attila Bódi: Variability of M Giant Stars Based on *Kepler* and OGLE Photometries: Asteroseismic Analysis and Physical Parameters

Co-authors: L.L. Kiss
Institute: Konkoly Observatory, MTA CSFK

M giant stars show long-period, high-amplitude light variations, which have long been explained by fundamental mode and low-order radial oscillations. With the advent of space missions and ground-based long-time span surveys, regular structures in the frequency spectra, previously hidden by the lower quality of the data, were identified as due to non-radial oscillations. These have led to a new avenue in the asteroseismic analysis of late-type stars. Here we present a combined analysis of several hundreds of *Kepler* M-giants and about 10,000 OGLE semiregular variables. For the first time, we take advantage of the combination of asteroseismic information with ground-based spectroscopic measurements, such as those of the APOGEE and LAMOST surveys. We extend the low-frequency end of the $\nu_{\max}$-$\Delta\nu$ relation and identify the apparent breaking points that can be correlated with the evolutionary stages. We also present and discuss the granulation properties and the distribution of asteroseismic and physical parameters. The results of the combined analysis are confronted with the theoretical expectations from evolutionary calculations.

2.27 Lisa Bugnet: The New POWVAR Metric Provides Constraints on Both Global Seismic Parameters and Physical Properties of Stars

Co-authors: G.R. Davies, E. Corsaro, R.A. Garcia, and S. Mathur
Institute: CEA Saclay

Our understanding of stars through asteroseismic data analysis is limited by our ability to take advantage of the huge amount of data provided by satellites such as CoRoT, *Kepler*, K2 and very soon TESS and PLATO. Nowadays, global seismic pipelines provide global stellar parameters such as mass and radius using the mean seismic parameters, $\nu_{\rm max}$ and $\Delta\nu$, as well as the effective temperature. These pipelines are commonly used blindly on thousands of stars observed by K2 for 3 months (and soon TESS for 1 month). Therefore, new validation techniques are required to assess the quality of these results. In this poster we present a new metric called POWVAR, which takes into account the average variability at all measured wavelengths of a star. We demonstrate that POWVAR follows a quasi linear trend with the global seismic parameters and, therefore, it is related to the surface gravity from main sequence to RGB and clump stars. It allows us to estimate the reliability of seismic parameters estimated from global pipelines in a few seconds. POWVAR can be used to identify stars without detected modes, stars dominated by the harmonics of the K2 Thrusters, and super-Nyquist stars (i.e., stars for which the p-mode excess power is above the observational Nyquist frequency). Dipole modes with depressed amplitudes in red giants are also highlighted among *Kepler* targets due to their lower power in the range of their mode frequencies. Moreover, POWVAR dependance on surface gravity has been used to confirm the influence of stellar metallicity on the granulation activity in evolved cool stars from cluster red giants.

2.28 Derek Buzasi: Applying the Hilbert–Huang Transform to Asteroseismology

Institute: Florida Gulf Coast University

Fourier analysis is typically the "go-to" tool for analysis of stellar oscillations. However, tools based on the Fourier basis functions do not serve well for nonstationary data or for oscillations which depart significantly from sinusoidal forms, and both of these characteristics are frequently seen in stars showing either oscillatory or rotational variability. Wavelet approaches have been adopted with some success, but here we examine the use of the Hilbert-Huang transform for the analysis of stellar variability. The Hilbert-Huang transform is based on an empirical algorithm which decomposes a time series into a set of intrinsic mode functions (IMFs) and characterizes the signal in terms of modulated amplitude and associated instantaneous frequencies. These IMFs are local, highly adaptive, and nearly orthogonal, and thus provide a natural set of basis functions for the time series. We illustrate the application of the Hilbert-Huang transform to asteroseismology and stellar variability with several examples drawn from *Kepler* and K2 data.

2.29 Peter De Cat: Spectroscopic Analysis of A and F Stars Observed in the K2 Fields

Co-authors: F. Kahraman Alicavus, P. De Cat, T. Van Reeth, M. Van de Sande, D. Kamath, P.I. Pápics, R. De Nutte, H. Van Winckel, G. Van De Steene, L. Dumortier
Institute: Royal Observatory of Belgium

We present results of the detailed spectroscopic analysis of a sample of A and F stars observed during the K2 mission. The high-resolution spectra were taken with the HERMES spectrograph at the 1.2-m Mercator telescope (Roque de Los Muchachos Observatory; La Palma; Canary Islands). Atmospheric parameters (effective temperatures, surface gravities) were determined by using photometric and spectroscopic methods. Chemical abundances, microturbulences, and projected rotational velocities were obtained with spectrum synthesis. The analysed sample includes chemically peculiar stars of Ap and Am types, as well as stars with approximately solar chemical abundances. Fundamental atmospheric parameters and detailed abundance patterns are the necessary ingredients for further asteroseismology of pulsating A and F stars observed with K2, as well as for precise investigation of atmospheres of chemically peculiar stars.

2.30 Sebastiano de Franciscis: Fractal Analysis Applied to Light Curves of Pulsating Stars

Co-authors: Javier Pascual Granado, Rafa Garrido Haba
Institute: Instituto de Astrofísica de Andalucía, IAA-CSIC

Fractal behaviours, i.e. scale invariance in spatio-temporal dynamic, have been found to describe and model many systems in nature, in particular fluid mechanics and geophysical related geometrical objects, as the convective boundary layer of cumulus cloud fields, topographic landscapes, river networks, solar granulation patterns, and observational astrophysical time series, like light curves of pulsating stars.

The main interest in the study of fractal properties in such physical phenomena lies in the close relationships they have with different underlying dynamic, i.e. depending on the system, chaos, turbulence, stochastic reaction-diffusion processes.

In this poster we introduce some statistical tools for fractal analysis of light curves. In addition to the most common Rescaled Range Analysis and Multifractal Spectra Analysis, particular attention will be paid to the Coarse Graining Spectral Analysis (CGSA), a Fast Fourier Transform based algorithm, exploiting the peculiar phase distribution in self-similar time series in order to discriminate in a general time series the stochastic fractal power spectra from the harmonic one.

An interesting application of fractal analysis in asteroseismology concerns the joint use of all these tools in order to develop classification criteria and algorithms for delta Scuti, gamma Doradus and solar-like pulsating stars. In fact from the fractal and multifractal fingerprints in light curves we could infer the mechanism of modes excitation and/or on the magnetic activity in the outer convective region.

2.31 Andres Garcia Saravia Ortiz de Montellano: Automated Asteroseismic Peak Detections

Co-authors: Saskia Hekker
Institute: Max Planck Institute For Solar System Research

The power density spectrum (PDS) of solar-like oscillators contains rich information that allows a precise determination of fundamental stellar properties provided that individual oscillation mode parameters are measured accurately. There are several thousand red-giant stars measured by *Kepler* for which we still lack precise individual oscillation mode parameters. One of the challenges preventing the peak-bagging of this large sample is identifying the number of oscillation modes visible in the observed PDS. Therefore we need a reliable peak-finding algorithm capable of estimating oscillation mode parameters with minimal human intervention. We present here a peak-finding algorithm that is capable of estimating location, width and height of the oscillations modes visible in red-giant stars observed by *Kepler*. The detailed knowledge of these oscillations for a large number of stars will lead to a more complete understanding of the internal structure of red-giants as well as their population statistics and dynamics, specially when complementary data from TESS and PLATO becomes available.

2.32 Yvonne Elsworth: Ratio of Observed to Asymptotic Period Spacing is a Diagnostic for Mass

Co-authors: S. Hekker, A. Miglio, B. Mosser, M. Vrard, J. Montalban
Institute: University of Birmingham

The spacing in period of mixed modes in red-giant spectra are an important diagnostic of the conditions in the internal regions of the stars. There are several excellent methods for finding both the asymptotic and observed average period spacings. Here we compare two such methods and show that the ratio between the observed average period spacing from Elsworth et al (2017) and the asymptotic period spacing of Vrard et al (2016) is a linear function of mass. We discuss this result in the context of expectations from models.

2.33 Oliver Hall: Mixture Models for Correcting TESS Backgrounds

Co-authors: G. R. Davies
Institute: University of Birmingham

The correct extraction of photometry from space based missions is a crucial component of both asteroseismic and planetary research. This work aims to create a program that provides robust estimation of the sky background for TESS postage stamps using no other measurements. To this end, we use mixture models to simultaneously fit simple models to the sky background and the foreground stars as point sources. To test its robustness, we run on *Kepler* postage stamps and compare to their observed estimate for the sky background, as well as estimation methods used for K2. We find that that there are noticeable differences between various methods, but that all follow the same variation in time. Changes to various transits between methods are currently being investigated to test their applicability and robustness.

2.34 Erich Hartig: K2: A Search for Very Red Stellar Objects

Co-authors: T. Lebzelter, K. Hinkle
Institute: University of Vienna, Austria

This poster presents preliminary results of the analysis of Long Period Variables(LPVs)observed as part of the *Kepler* K2 mission. LPVs are highly evolved stars of low and intermediate mass. They are characterized by large amplitude variations in the visual, periods of a few 10 to several 100 days and very red colour due to both the low surface temperature and the circumstellar reddening by dust. They are typically the reddest stellar objects in the *Kepler* FOV.

The *Kepler* K2 mission is not perfectly suited to study these stars due to the time limit of 80 days. However, LPVs can be identified from a short piece of their lightcurve already, allowing to explore further their frequency among the reddest objects. Furthermore, the high time resolution of the light curves allows us to study semiregularity on short time scales. Finally, the data provide a key reference for handling long time variations in the *Kepler* K2 data. After some first results presented in 2016, we now show our results on campaign 3 data. Testing various approaches for data extraction and analysis we find the K2SFF-results (SelfFlatFielding Correction) by A. Vanderburg and J. A. Johnson to provide the best results for long time variations.

2.35 Daniel Huber: Asteroseismology and Gaia: Testing Scaling Relations Using 2200 *Kepler* Stars with TGAS Parallaxes

Co-authors: Joel Zinn, Mathias Bojsen-Hansen, Marc Pinsonneault, Aldo Serenelli, Victor Silva Aguirre, Christian Sahlholdt, Keivan Stassun, Dennis Stello, Jamie Tayar, Fabienne Bastien, Timothy R. Bedding, Lars A. Buchhave, William J. Chaplin, Guy R. Davies, Rafael A. Garcia, David W. Latham, Savita Mathur, Benoit Mosser, Sanjib Sharma
Institute: University of Hawaii

We present a comparison of parallaxes and radii from asteroseismology and Gaia DR1 (TGAS) for 2200 *Kepler* stars spanning from the main sequence to the red giant branch. We show that previously identified offsets between TGAS parallaxes and distances derived from asteroseismology and eclipsing binaries have been partially overestimated for stars beyond 100pc, and can be in part compensated by adopting a hotter Teff scale (such as the infrared flux method) instead of spectroscopic temperatures for dwarfs and subgiants. Residual systematic differences are at the $\sim$2% level in parallax across three orders of magnitude. We use TGAS parallaxes to empirically demonstrate that asteroseismic radii are accurate to $\sim$5% or better for stars between $\sim$0.8-8Rsun. We find no significant offset for main-sequence ($<\sim$1.5Rsun) and low-luminosity RGB stars ($\sim$3–8Rsun), but seismic radii appear to be systematically underestimated by $\sim$5% for subgiants ($\sim$1.5 – 3Rsun). We find no systematic errors as a function of metallicity between [Fe/H] $\sim$ -0.8 to +0.4 dex, and show tentative evidence that corrections to the scaling relation for the large frequency separation (Dnu) improve the agreement with TGAS for RGB stars. Finally, we demonstrate that beyond $\sim$3kpc asteroseismology will provide more precise distances than end-of-mission Gaia data, highlighting the synergy and complementary nature of Gaia and asteroseismology for studying galactic stellar populations.

2.36 Young-Beom Jeon: Ground-Based Observation for *Kepler* RR Lyrae and Cepheid Variables: Preliminary Spectroscopic and Photometric Results for an RR Lyrae Star, SU Dra

Co-authors: B.-C. Lee, G.-H. Jeong and H.-I. Oh.
Institute: Korea Astronomy and Space Science Institute

SU Dra is an RRab star. It is listed in "The TESS RR Lyrae Survey" (Szabo et al.) known a binary candidate. The magnitude of SU Dra is V=9.73. We obtained spectroscopic time series data for four nights using BOES (BOao Echelle Spectrograph). We set R=30,000 to acquire S/N $>$ 70 for 1800s exposure. BOES is the main device of a 1.8m telescope in BOAO (Bohyunsan Optical Astronomy Observatory). BOES is a fiber fed spectrograph which has three kinds of fibers; 80m (R=90,000), 200μm (R=45,000), 300μm (R=30,000). If we use Iodine cell, the resolution of radial velocity is accurate to 5m/s. We want to know the metallicity and check binary characteristics of SU Dra from the long-term based observation. And also we will check the limiting magnitude for the faint targets. We proposed spectroscopic and multi-color photometric observations for the TESS and *Kepler* RR Lyrae and Cepheid variable stars to BOAO 1.8m and LOAO 1m telescopes.

2.37 Nada Jevtic: Looking Towards TESS: A Nonlinear Look at *Kepler* A and F Stars

Co-authors: P. Stine
Institute: Bloomsburg Univeristy of Pennsylvania

Looking towards the TESS shorter light curves, we revisit nonlinear noise reduction of one-month LC data of a wide range of *Kepler* A and F stars. For a sub-dwarf B star (KIC 8054179) nonlinear noise reduction results in a reduction of noise at the highest frequencies by a factor of 100,000. This sub-dwarf and a gamma Doradus star (KIC 2301163) are presented as examples of stars with traditional significant low-frequency power spectrum contributions. Noise reduction for stars with high-frequency contributions such as an Am star (KIC 11445913) and a number of delta Scuti stars (i.e. KIC 98356020) is shown to be unexpectedly efficient. Though initially classified as a g Dor/d Sct candidate, KIC 98356020, after noise reduction "in reverse", of only one month of data, resulted in a dScuti-like spectrum extending towards the lowest frequencies. Other g Dor/d Sct candidates reveal a range of power spectra. Though some of the g Dor/d Sct hybrid candidates (KIC 4999763, KIC 10134571) retain both the low and high frequency features in their power spectra, KIC 9005210 has further noise suppression above the d Sct frequencies. For some hybrid candidates such as KIC 3941524 reduction reveals a low-amplitude "central" bump in the power spectrum which wasnt visible before noise reduction. Contrary to such behavior, the "central" bump in the power spectrum of KIC 11445913 disappears after noise reduction. After nonlinear noise reduction, this g Dor/d Sct candidate also has delta Scuti-like power-spectrum lines down to the lowest frequencies. Looking towards TESS, nonlinear noise reduction could enable the desktop classification and discrimination of g Doradus, d Scuti and hybrid stars.

2.38 Kibeom Kim: Relations Between Gaussian Width of Power Excess and Other Global Seismic Properties of Main and Subgiant Sequence Stars

Institute: Kyungpook National University

Quantitative and qualitative photometric time series data of solar-like stars are provided by *Kepler* space mission. Through these data, it is possible to investigate statistical study of seismic properties of oscillating stars. Global seismic properties - large frequency separation ($\Delta\nu$), frequency of maximum power ($\nu_{\rm max}$) and amplitude of Gaussian envelope (A) are widely used to determine empirical scaling relations for inferring the stellar physical quantity mass, age, temperature. We aim to find the characteristics of width of Gaussian envelope on power excess ($\delta\nu$env) from main to subgiant sequence stars for confirming whether or not they can be used with parameter of scaling relation. We have demonstrated that $\delta\nu$env has high correlation with $\Delta\nu$ and $\nu_{\rm max}$. We have also found the break of $\delta\nu$env $\Delta\nu$ and $\nu_{\rm max}$ relations.

2.39 Laszlo Kiss: RV Tauri-Type Stars: A Fresh Look at the Pulsation Patterns

Co-authors: A. Bódi
Institute: Konkoly Observatory, MTA CSFK

The RV Tauri stars constitute a small group of classical pulsating stars with some dozen known members in the Milky Way and a similar number of variables in the Magellanic Clouds. Their light variations are dominated by pulsations, but these alone do not explain the full complexity of light curves. High-quality photometry of RV Tau-type stars is very rare. In the original *Kepler* field, there is only one star, DF Cygni, for which independent analyses were recently published by Bódi et al. and Vega and collaborators. Both studies pointed out that DF Cygni shows very rich behaviour on all timescales, while our group found evidence of strong non-linear effects that are directly observable in the *Kepler* light curve. Inspired by these results, we extended our investigation to further RVa/RVb-type stars using OGLE-data of the galactic bulge and the Magellanic Clouds. Here we report the initial findings on the interplay between the oscillations and the long-term modulation in RVb stars that is thought to be caused by time-variable dust obscuration.

2.40 Gang Li: Automatic Detection of Period Spacing in γ Doradus Stars Based on Cross-Correlation

Co-authors: Timothy R. Bedding, Simon J. Murphy
Institute: University of Sydney

We report an automatic method to detect the variable period spacing in γ Doradus stars.

Asymptotic theory predicts that the period should be equally spaced when $n \gg l$. However, due to the stellar rotation, the frequency is split uniformly hence the period (the inverse of frequency) is separated on the value of the azimuthal order m. What's more, the corresponding period spacing shows a approximately linear relation on the period. The slope is related to the rotation speed and the azimuthal order m. These phenomena make the automatic detection challenging.

We use four-year data from *Kepler* satellite and implement cross-correlation with Markov Chain Monte Carlo (MCMC) algorithm to find the period spacing pattern and deduce its changing rate with period. A template, determined by the period, the period spacing and the slope, is created to describe a theoretical period spacing pattern and the difference with observation is denoted by the production between the template and the power spectrum. MCMC algorithm is used to maximize the product so that we can get the value of the period spacing and its slope.

So far we have discovered hundreds of patterns from our samples. We find a positive correlation between the period and the period spacing and give some statistic distributions of these parameters. Some stars show the patterns with different azimuthal order m and different degree l, which are promising to be investigated further.

2.41 Mariel Lares Martiz: Phase Differences Studies in High-Amplitude Delta Scuti Stars Observed by *Kepler*

Co-authors: R. Garrido, J. Pascual-Granado
Institute: Instituto de Astrofísica de Andalucía, IAA-CSIC

It is known since long time ago that high amplitude delta Scuti stars (HADS) present non-linear interactions of the main periods. Some of these stars present such a high dense frequency spectrum that it is difficult to discriminate combination from spurious frequencies. This problem is addressed in [1] by checking the fulfillment of two criteria based on the response of the non-linear system: one is related to phase differences and the other is related to amplitudes ratios. Up to date there is no check of these relations in the literature using the ultra-precise data obtained by space satellites.

Here we perform a frequency analysis of two HADS stars observed by *Kepler*: KIC5950759 and KIC9408694, and check whether the non-linear relations still hold. These are the only two HADS stars observed by *Kepler* according to the usual definition of HADS [2]. These results form part of a wider study that includes small amplitude delta Scuti stars too.

[1] Garrido, R., Rodrguez, E., 1996, MNRAS, 281, 696-702 [2] Balona, L., 2016, MNRAS, 459, 1097-1103

2.42 Andy Moya: Frequency Relations in the Oscillation Spectrum of A-F Stars

Co-authors: J.C. Suárez, A. García Hernández and M.A. Mendoza
Institute: Universidad de Granada

Asteroseismology is witnessing a revolution thanks to high-precise asteroseismic space data (MOST, CoRoT, *Kepler*, BRITE) and their large ground-based follow-up programs. Those instruments have provided an unprecedentedly large amount of information, which allow us to scrutinize its statistical properties in the quest for hidden relations among pulsational and/or physical observables. This approach might be particularly useful for stars whose pulsation content is difficult to interpret. This is the case of intermediate-mass stars classical pulsators (i.e. γ Dor, δ Scuti, hybrids) for which current theories do not properly predict the observed spectra. In this work, we establish a first step in finding such hidden relations from Big Data inference techniques for these stars. We test preliminary semi-empirical relations on the well-studied HD174966 star and discuss the results.

2.43 Filipe Pereira: Using Gaussian Processes to Characterize Granulation in Red-Giant Stars

Co-authors: Tiago Campante, Margarida Cunha, Nuno Santos, Susana Barros
Institute: IA, University of Porto

Detection of exoplanets around red giants requires dealing with the star's granulation, whose timescale is similar to the transit duration. In this work we use gaussian processes in an attempt to characterize granulation in red giants in the time domain and compare the results with the ones obtained from an analysis of granulation in the corresponding Fourier spectra.

2.44 Magdalena Polińska: The Atmospheric Parameters and Chemical Abundances of A- and F-type Stars Observed in the *Kepler* Field.

Co-authors: Ewa Niemczura, Peter De Cat, Katrien Uytterhoeven
Institute: Institute Astronomical Observatory, Adam Mickiewicz University in Poznań

We present results obtained from a spectroscopic analysis of high-resolution spectra observed with the ESPaDOnS spectrograph at the Canada-France-Hawaii Telescope and the Sophie spectrograph installed on the 1.93 m telescope at the Haute-Provence Observatory. The presented data were collected for A- and F-type stars observed in the *Kepler* field. We determined atmospheric parameters (effective temperature, surface gravity, metallicity [M/H], microturbulence velocity) and chemical abundances for selected stars. The presented sample of stars consists of objects with the projected rotational velocities lower than 60 km/s. The atmospheric parameters, abundances and rotational velocities were calculated using the iSpec code with spectrum synthesis technique. The observed spectra were compared with series of synthetic spectra calculated with the Kurucz codes ATLAS9 and SYNTHE. The atomic data were taken from VALD database.

2.45 Ian Roxburgh: Anomalies in the *Kepler* Asteroseismic Legacy Project Data: New Analyses of 16 Cyg A&B, KIC8379927 and 6 Solar-Like Stars

Institute: Queen Mary University of London

I compare values of the frequencies, separation ratios, errors and covariance matrices from a new analysis of 9 solar-like stars from the Legacy project with those reported by Lund et al and, for 16Cyg A&B and KIC8379927, with values derived by Davies et al. There is good agreement between my results (using Davies power spectra) and Davies's but no such agreement with the Legacy project results (using the Legacy power spectra). My frequencies differ from the Legacy values, there are anomalies in Legacy frequency covariance matrices which can give negative χ^2 when comparing frequencies, and in the estimated errors on separation ratio which can be up to 20 times larger than mine (and Davies's), and which exceed upper limits (derived here) by large factors. Davies's and Roxburgh's values are less than these limits. A re-evaluation of the ratio errors using Legacy data gives substantially smaller values which satisfy the upper limits. Similar anomalies exist for covariance matrices and separation ratios for the 66 stars in the full Legacy set.

2.46 Thomas Shutt: High Resolution Spectroscopy and the Categorisation and Analysis of Potential Gamma Dor Type Stars in the MUSICIAN Program

Institute: University of York

We will present a summary of high resolution spectroscopy techniques carried out under the MUSICIAN program based at The University of Canterbury, contributing to new insight on the internal structure and dynamics of two suspected Gamma Dor type stars and a suspected double lined spectroscopic binary.

Preliminary results will be presented in the search for Gamma Dor type oscillations, as well as discussions of the fundamental physical properties of the stars derived from our data.

2.47 Marek Skarka: Follow-Up Observation of TESS RR Lyrae Stars in Cooperation with Amateur Observers

Co-authors: L. Smelcer, R. Auer, R. Dreveny
Institute: Konkoly Observatory, MTA CSFK

We introduce a new international project proposed for follow-up observations of bright TESS RR Lyrae stars in cooperation with amateur observers. We discuss the advantage of such cooperation, working strategy, and demonstrate that high-quality data can be obtained also using relatively cheap equipment that is widely accessible by amateur observers.

2.48 Lucas Viani: Changing the $\nu_{\max}$ Scaling Relation: The Need For A Mean Molecular Weight Term

Co-authors: S. Basu, W. J. Chaplin, G. R. Davies, Y. Elsworth
Institute: Yale University

We examine the $\nu_{\max}$ scaling relation using a grid of stellar models, ranging in mass, age, and metallicity. Similar to studies examining the $\Delta\nu$ scaling relation, we find that the $\nu_{\max}$ scaling relation has deviations. The main source of the deviations can be attributed to the absence of a mean molecular weight term and a Γ_1 term which are generally neglected. Examining the effects of these errors on asteroseismic log g estimates, we find that errors are less than those typically associated with log g uncertainties. However, errors in log g calculations can be decreased if the μ and Γ_1 terms are included in the $\nu_{\max}$ scaling relation. The errors in mass and radius calculations can also be lowered if the $\nu_{\max}$ scaling relation is modified to include the μ and Γ_1 terms while calculating $\nu_{\max}$ for models used in grid-based modeling.

2.49 Emma Willett: Sounds of the Stars: Sonification of Stellar Pulsation Modes

Co-authors: Rafail Panagi, Andrea Miglio et al.
Institute: University of Birmingham

The acoustic pulsations of a solar mass star have been sonified in a way that would help an interested member of the public get an intuitive understanding of what happens to stars as they evolve. Different stellar features have been explored, including pitch change due to radius increase during evolution, frequency splitting due to increased stellar core rotation period, and increased presence of modes of mixed character during the evolution (allowing stars with similar surface properties, yet in different evolutionary stages, to be distinguished). The poster has been made interactive through the use of conductive paint. The user can trigger a sound recording corresponding to the different stellar properties above, using the proximity sensors in different regions of the poster. This creates a tool which allows members of the public to intuitively understand the changes to stars during their evolution, which will be used in outreach events by the Solar and Stellar Physics Group.

2.50 Magnus Johan Aarslev: Modelling Linewidths of *Kepler* Red Giants in NGC6819

Co-authors: Günter Houdek, Rasmus Handberg, Jørgen Christensen-Dalsgaard
Institute: SAC Aarhus University

I shall present a comparison between frequency-dependent damping rate calculations of radial oscillations with observed linewidths of RGB stars in NGC 6819. The calculations adopt a time-dependent non-local convection model, with the turbulent pressure profile being calibrated to 3D hydrodynamical simulation results of stellar atmospheres. The observed linewidths are obtained through extensive peakbagging of *Kepler* lightcurves carried out by Handberg et al. (2017, submitted). The observational results are of unprecedented quality owing to the long continuous observations by *Kepler*. The uniqueness of the *Kepler* mission also means that, for asteroseismic properties, this is the best data that will be available for a long time to come. We therefore take great care in modelling nine RGB stars in NGC 6819 using information from 3D simulations to obtain realistic temperature stratifications and calibrated turbulent pressure profiles. Our modelled damping rates reproduce well the *Kepler* observations, including the characteristic depression in the linewidths around the frequency of maximum power.

2.51 Lionel Bigot: Asteroseismology of a Stellar Cycle: The Case of HD49933

Institute: Lagrange – Observatoire de la Côte d'Azur

Magnetic activity of stars affects the properties of their oscillations. For most stars, the magnetic effects on the resonant cavity are subtle and the corresponding signatures in the acoustic frequencies are very tiny ($\sim$0.01%) and were not observable using asteroseismology, except for the Sun. Recently, thanks to photometric space-borne missions like CoRoT and *Kepler* (and soon TESS), these tiny effects are now detectable for a few targets which opens the possibility of studying stellar magnetic activity and cycles through asteroseismology.

I will show how a strong magnetic field modifies the convective background and the stellar oscillations for both frequencies and amplitudes. I will discuss how it affects the diagnostics of the fundamental stellar properties (e.g. age, mass). I will focus on the case of one of the principal targets of the CoRoT mission - HD49933 - and show that only the presence of a strong magnetic field can explain the properties of its oscillations.

2.52 Enrico Corsaro: The Linewidths of Mixed Dipolar Modes in Red Giant Stars as Seen by the Full *Kepler* Nominal Mission

Co-authors: Rafael A. Garcia, Savita Mathur
Institute: INAF – Osservatorio Astrofisico di Catania

NASA's *Kepler* full nominal mission provides excellent quality light curves of more than four years nearly continuous observations for thousands of stars. These observations have allowed to resolve oscillation modes even in evolved cool stars. In this work we present a careful analysis of the linewidths (lifetimes) of so-called dipole mixed modes, whose detailed properties are still not well known and understood. We use a representative sample of red giant stars that span different evolutionary stages and fundamental properties, and that exhibit a high signal-to-noise ratio oscillation spectrum. We exploit a consistent parametrization of the background signal for all the stars in the sample. For each selected star, an unambiguous mode identification process is made possible thanks to the clear determination of the period spacing for mixed modes. We therefore perform the Bayesian peak bagging analysis based on DIAMONDS to extract the properties of hundreds of mixed dipolar modes. Finally, we show our results on the behaviour of the mode linewidths as a function of the fundamental stellar properties and evolutionary stages covered by our sample.

2.53 Rachel Howe: Parametrization of Solar-Cycle Frequency Variations – A Potential Diagnostic for Seismic Signatures of Stellar Activity

Co-authors: S. Basu, G. R. Davies, W. H. Ball, W. J. Chaplin Y. Elsworth, R. Komm
Institute: University of Birmingham

Both the "surface term" difference between model predictions and observations of solar oscillation frequencies, and the solar-cycle variation of the frequencies, can be decribed using a a simple parametrization with terms proportional to the cube and inverse of the frequency. We have applied this to low- and medium-degree solar oscillation frequencies to show that the solar-cycle variation can be summarized using a small number of parameters, without needing to correlate the frequencies with an activity proxy. This is potentially a useful tool for studying mode-frequency changes in solar-like oscillators where we may not have an independent activity proxy to compare with.

2.54 Andreas Christ Sølvsten Jørgensen: Post-Evolutionary Patching of *Kepler* Stars

Co-authors: A. Weiss, J. R. Mosumgaard, V. Silva Aguirre
Institute: Max Planck

Due to an incomplete treatment of turbulent convection, 1D stellar evolution codes do not agree with asteroseismic measurements at high frequencies. To reduce this so-called surface effect, we perform post-evolutionary patching, i.e. we replace the outermost layers of 1D models with mean 3D simulations of stellar atmospheres from three different codes. For stellar parameters, for which no 3D simulations exist, patching requires interpolation in the grids. We have devised and apply such an interpolation scheme. I present the current stage of our ongoing endeavour to establish a robust and consistent method for the replacement of stellar 1D atmospheres, discussing various different approaches for evaluating the patching point. Furthermore, I present examples for our procedure and the first promising results, including model frequencies for patched models of four *Kepler* stars.

2.55 René Kiefer: Forward Calculation of the Effect of Large-Scale Toroidal Magnetic Fields on Solar and Stellar Oscillations

Co-authors: Ariane Schad, and Markus Roth
Institute: Kiepenheuer Institute for Solar Physics

The temporal variation of the properties of solar and stellar acoustic modes can be used as a proxy for the level of magnetic activity. These variations can be routinely observed in the oscillation parameters for solar-like stars by virtue of the excellent long-baseline photometric timeseries from space missions as CoRoT and *Kepler*. With the Sun as a testbed, we developed a formalism to infer the subsurface magnetic field, its geometric configuration, and its dependence on the activity cycle. If the Lorentz force is added to the equilibrium equation of motion, stellar eigenmodes can couple. In quasi-degenerate perturbation theory, this coupling, also known as the direct effect, can be quantified by the general matrix element. We present the analytic result of the matrix element for a superposition of toroidal magnetic field configurations for the direct effect. The indirect effect of the magnetic field on the oscillation frequencies and eigenfunctions was calculated semi-analytically and is included in the calculations. The indirect effect is due to the perturbation of the mode cavities by the additional force. Mode frequency perturbations for magnetic field models of different configuration and strengths, which are motivated by MHD simulations of the solar dynamo, are shown. These are compared to their observed counterparts for the Sun. By this, we can put limits on the mean configuration and field strength of the subsurface toroidal magnetic field. The resulting frequency perturbations for a subgiant model are also presented.

2.56 David Salabert: Uncovering Stellar Magnetic Activity Cycles in Solar-Like Pulsating Stars Observed by *Kepler*

Co-authors: C. Regulo, F. Perez Hernandez, R.A. Garcia
Institute: CEA Saclay, Sap

We analyzed the observations of main-sequence solar-like oscillating stars collected by the *Kepler* satellite in order to study their magnetic activity through the determination of the variability of the acoustic parameters and the photospheric activity proxy Sph. The frequency shifts were obtained using two independent methods: the cross-correlation analysis and the peak-fitting analysis. The results are compared to each other and to the Sph proxy. Variations in the other acoustic parameters extracted from the peak-fitting method are also studied. To determine if the measured variations are likely to be a genuine signature of magnetic variability or to be noise, we developped original selection criteria based on simulations. Thus, we selected a subset of 10 stars as being good candidates. Out of these 10 stars, 5 stars show evidences for magnetic activity cycle. The frequency shifts of these 5 stars were modelled and compared to the Sun.

2.57 Regner Trampedach: Sharpening the Asteroseismic Focus of *Kepler*

Institute: SAC Aarhus University

The asteroseismic surface effect – a systematic underestimation of p-mode frequencies from our models – has two parts; An expansion of 3D hydrodynamic atmospheres compared to 1D models, expanding the acoustic cavity constitutes the structural part. The direct interactions between modes and 3D convection, is the other part, including the stochastic excitation and coherent damping of modes. I will present recent progress in forward modelling of both parts, based on 3D convection simulations. This will give more realistic eigen-frequencies for stars and improve our analysis of seismic observations - for both the Sun and stars.

2.58 Mathieu Vrard: Radial Mode Widths and Amplitudes in Red Giant Star Spectra Observed by *Kepler*

Co-authors: T. Kallinger, B. Mosser, C. Barban
Institute: IA, University of Porto

The space mission *Kepler* has provided seismic data of unprecedented quality which brought new ways to precisely measure the stellar seismic parameters in red giant star spectra. With now four years of observations, the accurate characterization of the seismic mode parameters can be carried out for solar-like pulsators. Here, we present the results of a large study realized on red giant stars which aim to characterize precisely the amplitudes and widths of radial modes. These parameter provide unique information on the excitation and damping of acoustic oscillations. We will detail the procedure used to determine these two parameters throughout the star spectra. We will then present the results and analyse them throughout the stellar evolution as a function of the star physical parameters. Finally, the implications of the results on the physical processes behind the excitation and damping of the modes will be developed.

2.59 Othman Benomar: Measurement of the Mode Asymmetry in Sun-Like Stars Observed by *Kepler*

Co-authors: M. Nielsen, H. Shibahashi
Institute: NYU Abu Dhabi

The p modes seen in Sun-like pulsators are usually analysed by fitting the power spectrum with a sum of symmetric Lorentzian line profiles. This profile is found by considering each mode as a stochastically excited damped oscillator, with a non-localized excitation source at the surface of the star. However, observations of the Sun (Duvall et al. 1993) show that p-mode line profiles are better described by asymmetric Lorentzians. Here, we investigate the asymmetry of Lorentzian mode profiles for an ensemble of stars observed in photometry by *Kepler*. We find that the asymmetry parameter strongly depends on log(g). Stars with log(g)$<$4.35 show a negative asymmetry of the modes (skewed toward low frequency), while those with higher log(g) have a positive asymmetry. Not only is this important when performing accurate modeling of stellar power spectra, but also for understanding the location of the wave source inside the star, and the connection between oscillations and convection.

Posters for Theme 3

Challenges for Understanding Stellar Evolution in Binary/Multiple/Interacting Systems

3.1 Evelyne Alecian: Magnetic Fields in Intermediate- and High-Mass Close Binaries

Co-authors: Wade, G.A., C. Neiner, and the BinaMIcS collaboration
Institute: IPAG (Université Grenoble Alpes)

Massive close binaries are interesting object on many aspect: star formation, star evolution, star-star interaction, via magnetospheres, tides, envrionment collision. In short-period (Porb $<$ 20 d) binaries, interaction between stellar magnetic fields and magnetospheres can also play important roles one the formation and evolution of the system. Binarity, by the presence of a massive companion in the close vicinity of a star, may also influence the origin and evolution of the magnetic fields. All these questions are being addressed within the Binarity and Magnetic Interaction in various classes of Stars (BinaMIcS) project. The BinaMIcS project has been awarded more than 800 h of telescope time at the CFHT (Hawaii) and at the TBL (France) to get ESPaDOnS and Narval spectropolarimetric observations of more than 200 short-period binaries and to characterize the magnetic properties of intermediate- and high-mass close binaries. I present the results of our investigation and the consequences they have on our understanding on massive binaries formation and evolution.

3.2 Mansour Benbakoura: Pulsating Red Giants in Eclipsing Binary Stars: a Rosetta Stone for Asteroseismology

Co-authors: P. Gaulme, J. McKeever, P. G. Beck, J. Jackiewicz, R. A. Garcia
Institute: CEA Saclay

Asteroseismology is a powerful tool to analyse stellar observation data and infer structural and dynamical parameters of a star. Testing the precision of global asteroseismic scaling relations is a necessity to ensure accurate masses and radii. This can be done by studying eclipsing binary systems hosting a pulsating star for which these quantities can be measured by two independent methods. Gaulme et al. (2016) compared dynamical and seismic masses and radii of 10 red giants in eclipsing binary stars observed by *Kepler*. They found that seismic values were systematically overestimated by a factor of 15% for the mass and 5% for the radius. In this work, we selected 6 new systems among the *Kepler* targets to investigate further this result by coupling photometric light curves to spectroscopic observations performed at the 3.5m telescope at Apache Point Observatory (USA). We also noticed in both samples, that in the shortest orbital period systems, stellar oscillations were not detected. This suggests that tidal interaction in these close binary stars may have triggered a surface magnetic field in the red giant.

3.3 Barna Imre Bíró: Mapping Pulsations in the Eclipsing Binary KIC 3858884

Co-authors: András Bókon
Institute: Baja Observatory of the University of Szeged, Baja, Hungary

We report on our experience on identifying pulsation modes on stars residing in eclipsing binary systems, and a first application on the eccentric eclipsing binary KIC 3858884. Two modelling methods were used, which employ the surface sampling nature of the eclipses: eclipse mapping, a generic surface image reconstruction method, and direct fitting of spherical harmonics. The combined application of these methods allows to map largely general pulsation patterns with an arbitrary symmetry axis. The most attractive feature of this approach is that the mode identification can be carried out independently of (or rather in parallel with) asteroseismic modellings. The most dominant pulsation frequencies were successfully mapped and identified by the above methods. We present these results and their possible implications.

3.4 Zhao Guo: The Synergy Between Binary Stars and Asteroseismology: Post-Mass Transfer Delta Scuti and Gamma Dor Stars and Tidal Asteroseismology of Heartbeat Stars

Institute: Nicolaus Copernicus, Warsaw

Through two case studies, I will demonstrate the assets of studying Delta Scuti and Gamma Dor stars in close binaries. In particular, pulsations of the post-mass transfer Delta Scuti star KIC8262223 can reveal the history of binary evolution: pulsations of high-frequency p-modes of the primary star suggest it has been rejuvenated, which is a direct result of the mass-transfer from its companion; The prograde dipole g-modes in KIC9592855 can reveal the interior rotation of this Gamma Dor/Delta Scuti hybrid, shedding lights into the angular momentum transfer in this circularized and synchronized binary.

In the second part, I will show that the tidally induced oscillations in *Kepler* heartbeat stars can facilitate mode identification from the pulsation amplitudes and phases. They can also provide us information on the energy dissipation and the non-linear mode coupling.

3.5 Kyeongsoo Hong: Photometric Properties of the HW Vir-type Binary OGLE-GD-ECL-11388

Co-authors: Jae Woo Lee, Dong-Joo Lee, Seung-Lee Kim, Jae-Rim Koo
Institute: Korea Astronomy and Space Science Institute

We present the first extensive photometric results for the eclipsing binary OGLE-GD-ECL-11388 with a period of about 3.5 hours located in the Galactic disk. For the photometric solutions, we obtained the BVI light curves from both the KMTNet observations in 2015 and the OGLE-III survey data from 2001 – 2009, which show striking reflection effects and very sharp eclipses. The light curve synthesis indicates that the eclipsing system is a HW Virtype binary with a mass ratio of q = 0.289, an orbital inclination of i = 81.9 deg, and a temperature ratio between both components of T2/T1 = 0.091. A frequency analysis was applied to the light residuals from our binary model; however, no pulsating periodicity from the subdwarf B-type primary component was detected under signal-tonoise amplitude ratios larger than 4.0. A total of 27 minimum epochs spanning 15 yr were used to analyze the eclipse timing variations of OGLE-GD-ECL-11388. It was found that the orbital period has varied due to a continuous period decrease at a rate of $dP/dt = 1.1 \times 10^8$ day yr^{-1} or a sinusoidal oscillation with a semiamplitude of K$=$35 s and a cycle of P3 = 8.9 yr. The period decrease may be explained by an angular momentum loss via magnetic stellar wind braking or may be only a part of the sinusoidal variation. We think the most likely interpretation of the orbital period change, at present, is the light-time effect via the presence of a third body with a mass of M3 sin i3 $=$ 12.5MJup, putting it in the boundary zone between planets and brown dwarfs.

3.6 Edward Jurua: Classification of KIC 5025217 as a Solar Like Oscillating δ Scuti Star

Co-authors: O. Trust and P. O. Abedigamba
Institute: Mbarara University of Science and Technology

The star KIC 5025217 was initially suspected to be a red giant in a binary system in the *Kepler* Open Cluster NGC 6819. Using photometric data from the *Kepler* Input Catalog, we determined the binarity of this star using the time delay method and distance modulus. We confirmed that this is a single δ Scuti star with solar-like oscillations, presenting it as a blue struggler. Using luminosity and V magnitude its distance modulus was determined to be 10.48 mag. Its age is shown to be 4.51 ± 0.18 Gyr. This therefore suggests that this star may not be a member of the *Kepler* Open Cluster NGC 6819.

Keywords: δ Scuti star : Binarity, Open cluster: Membership

3.7 Jae-Rim Koo: The *Kepler* Eclipsing Binary V2281 Cyg with Twin Stars

Co-authors: Jae Woo Lee, Kyeongsoo Hong
Institute: Korea Astronomy and Space Science Institute

We present the physical properties of the eclipsing binary V2281 Cyg which shows a light-time effect due to a supposed tertiary component from its eclipse timing variation according to the *Kepler* observations. The high-resolution spectra and BVR photometric data of the system were obtained at Bohyunsan Optical Astronomy Observatory and Mount Lemmon Optical Astronomy Observatory, respectively. A total of 34 spectra and 1956 sets of three-passband images were secured in 2015. To determine the fundamental parameters of the eclipsing pair and its circumbinary object, we simultaneously analyzed the radial velocities, light curves, and eclipse times including the *Kepler* data. The masses and radii for the primary and secondary stars were determined with accuracy levels of approximately 2% and 1%, respectively, as follows: M1=1.61 ± 0.04 Msun and M2=1.60 ± 0.04 Msun, R1=1.94 ± 0.02 Rsun and R2 = 1.93 ± 0.02 Rsun. If its orbit is coplanar with the eclipsing binary, the period and semi-major axis of the third body were calculated to be P3b=4.1 years and a3b=4.06 au, respectively, and its mass is M3b=0.75 Msun. The evolutionary state of the system was investigated by comparing the masses and radii with theoretical models. The results demonstrate that V2281 Cyg is a detached eclipsing binary which consists of twin main-sequence stars with an age of 1.5 Gyr.

3.8 Jae Woo Lee: KIC 11401845: An Eclipsing Binary with Multiperiodic Pulsations and Light Travel Time

Co-authors: Kyeongsoo Hong, Seung-Lee Kim, and Jae-Rim Koo
Institute: Korea Astronomy and Space Science Institute

We report the *Kepler* photometry of KIC 11401845 displaying multiperiodic pulsations, superimposed on binary effects. Light-curve synthesis represents that the binary star is a short-period detached system with a very low mass ratio of q = 0.070 and filling factors of F_1 = 45 % and F_2 = 99 %. Multiple frequency analyses were applied to the light residuals after subtracting the synthetic eclipsing curve from the observed data. We detected 23 frequencies with signal to noise amplitude ratios larger than 4.0, of which the orbital harmonics (f_4, f_6, f_9, f_{15}) in the low frequency domain may originate from tidally excited modes. For the high frequencies of 13.7−23.8 day^{-1}, the period ratios and pulsation constants are in the ranges of $P_{\rm pul}/P_{\rm orb}$ = 0.020−0.034 and Q = 0.018−0.031 d, respectively. These values and the position on the Hertzsprung-Russell diagram demonstrate that the primary component is a δ Sct pulsating star. We examined the eclipse timing variation of KIC 11401845 from the pulsation-subtracted data and found a delay of 56±17 s in the arrival times of the secondary eclipses relative to the primary eclipses. A possible explanation of the time shift may be some combination of a light-travel-time delay of about 34 s and a very small eccentricity of $e \cos \omega < 0.0002$. This result represents the first measurement of the Rømer delay in non-compact binaries.

3.9 Sanjay Sekaran: Double, Double, Toil and Trouble: An Analysis of Two Eclipsing Binary Systems with Pulsating Components

Co-authors: A. Tkachenko and C. Aerts
Institute: KU Leuven

Eclipsing binary systems with pulsating components are useful objects of study as a number of fundamental parameters, such as mass and radius, can be derived in a model-independent manner, providing more precise inputs for subsequent pulsational modelling. The objective of this research would be to investigate and characterise the variability of two eclipsing binary systems, KIC 6117415 and KIC 10031808, through the analysis of *Kepler* photometry and high-resolution ground-based spectroscopy. Orbital elements were determined separately through *Kepler* orbital-fitting of radial velocities in PHOEBE, and through spectral disentangling using FDBinary. Phase-folded and binned *Kepler* light curves of the two stars were used to model and remove the eclipses, before extracting pulsational frequencies using Fourier decomposition to determine the frequency-spacing patterns for variability characterisation. Stellar fundamental parameters were extracted separately from the PHOEBE-modelled light curves and from the stellar atmospheric modelling of the disentangled spectra.

3.10 Tim White: Bright Stars in Clusters Observed by K2

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Institute: SAC Aarhus University

K2 continues to observe the brightest stars in the ecliptic. Such stars are often already well-studied, and are the most amenable to follow-up observations to precisely determine their properties. As a consequence, these stars can provide us with the most stringent tests of stellar models. I will present results from K2 observations of red giants in the Praesepe and Hyades clusters, and B stars in the Pleiades, along with CHARA interferometric measurements, and spectra from the Hertzsprung SONG telescope. For the red giants, the independent measurements of radii from interferometry provide tests of the asteroseismic scaling relations, while the known ages of these clusters from isochrone fitting provide tests of the ages determined from grid-based asteroseismic modelling. The K2 observations of the Pleiades are shedding light on the link between SPB pulsations and the Be phenomenon, and resolve the long-standing question of Maia's variability. The photometric techniques used to enable observations of such bright stars with K2 will be transferable to the TESS mission, ensuring that stars brighter than fourth magnitude will be observed.

Posters for Theme 4

Challenges for Stellar Populations and Galactic Archaeology Studies

4.1 Geert Barentsen: *Kepler*/K2: The Final Leg & Release of Guide Star Lightcurves

Institute: NASA Ames

The K2 project has expanded the legacy of the *Kepler* mission by using the repurposed spacecraft to survey different Galactic sightlines. I will review the stellar populations sampled by K2 across 14 fields so far, highlighting several characteristics, caveats, and unexplored uses of the public data set along the way. With fuel expected to run out in 2018, I will discuss the closing Campaigns, highlight the final target selection opportunities, and explain the data archive and bespoke software tools the mission intends to leave behind for posterity. Finally, I will present the first public release of ultra-short-cadence lightcurves for 95 bright stars observed by *Kepler*/K2's guide star CCDs, which have recently been unearthed from the spacecraft's telemetry archives and include bursts of unique 0.5-second cadence data.

4.2 Karsten Brogaard: Establishing the Accuracy of Asteroseismic Mass, Radius and Age Estimates of Giant Stars

Co-authors: C. J. Hansen, A. Miglio, D. Slumstrup S. Frandsen, J. Jessen-Hansen, M. N. Lund, D. Bossini, A. Thygesen, G. R. Davies, W. J. Chaplin, T. Arentoft, H. Bruntt, F. Grundahl, R. Handberg
Institute: University of Birmingham

We aim to establish and improve the accuracy level of asteroseismic estimates of mass, radius, and age of giant stars. This can be achieved by measuring independent, accurate, and precise masses, radii, effective temperatures and metallicities of long period eclipsing binary stars with a red giant component that displays solar-like oscillations. We measured precise properties of stars in the three eclipsing binary systems KIC7037405, KIC9540226, and KIC9970396, finding for the giant components their masses to a precision of $1.7\%, 2.8\%$, and 1.3%, and their radii to a precision of $0.7\%, 1.2\%$, and 0.9%. Using log$g$ from these measurements with the disentangled spectra of the giant components we also determined their $T_{\rm eff}$ and [Fe/H]. From these measurements we estimated the ages of the systems to be 5.3 ± 0.5, 3.1 ± 0.6, and 4.8 ± 0.5 Gyr for the adopted stellar model physics. The measurements of the giant stars were compared to measurements of mass, radius, and age using asteroseismic scaling relations and asteroseismic grid modeling, finding general agreement, and no indications of systematic differences at the precision level of the asteroseismic measurements when theoretical correction factors $f_{\Delta\nu}$ are taken into account. Comparisons involving a larger sample of eclipsing binaries studied by Gaulme et al. (2016) suggests that the apparent overestimate of mass from the asteroseismic scaling relations in that study is at least partly due to too low precision on the dynamical measurements assumed to be the true values and systematic overestimates of measured $T_{\rm eff}$ values. However, we cannot rule out that the observed $T_{\rm eff}$ scale is in general slightly too high or that the model $T_{\rm eff}$ scale could be too cool, both of which would affect $f_{\Delta\nu}$ to reduce asteroseismic masses and radii. We found no indication of a need to correct $\nu_{\rm max}$, neither as a general offset or as suggested by Viani et al (2017). The model dependence of $f_{\Delta\nu}$, and potentially also $f_{\nu_{\rm max}}$, coupled with uncertainties in the observed temperature scale and models of giant stars necessitates an extension of the present precision study to a larger sample of eclipsing systems spanning a range in masses, radii, $T_{\rm eff}$ and metallicity. Only through such a calibration set can we establish and improve the general accuracy of asteroseismology of giant stars.

4.3 Anne-Marie Broomhall: The Potential of TESS for the Seismology of Stellar Flares

Co-authors: Anne-Marie Broomhall and the Solar and Stellar QPP flares ISSI team
Institute: University of Warwick

Flares far more energetic than typical solar flares are routinely detected on solar-like stars leading to predictions that these "superflares" occur on stars similar to our Sun "once in 500 to 600 years" (Maehara et al., 2015). However, given the disparity in energies it is reasonable to question whether the same physical processes govern solar and stellar flares. One can also ask how often other stars produce superflares and whether those superflares create the same space weather, as this will impact the habitability of stellar systems. Quasi-periodic pulsations (QPPs), which are quasi-periodic pulses observed in the lightcurve of a flare, appear to be a common feature of both solar and stellar flares. QPPs, therefore, have the potential to provide a solid link between the physics of solar and stellar flares and to advance our understanding of stellar magnetism in general. Before *Kepler*, observations of QPPs were few and far between and often only serendipitously discovered. However, a survey of *Kepler* flaring lightcurves by Pugh et al (2016) substantially increased the number of observed stellar QPPs. Nevertheless numbers are still too low to perform statistical studies and questions remain as to the origin of these QPPs on both the Sun and other stars. We discuss the potential of TESS to vastly increase the number of QPPs observed for stars across the HR diagram. Furthermore, this team will attempt to coordinate TESS observations with other instruments observing at different wavelengths, providing further insights into QPPs and flares in general.

4.4 Corinne Charbonnel: Seismic Archeology in Globular Clusters – Probing the Helium Content of the Multiple Stellar Populations

Co-authors: N. Lagarde, W. Chantereau
Institute: Department of Astronomy, University of Geneva, Switzerland

Globular clusters are key objects for a broad variety of astrophysical questions, from stellar and galactic physics to cosmology. They have witnessed the formation, assembly, and evolution of galaxies and of their substructures, from the early to the present-day Universe. They are among the best benchmarks for stellar evolution theory, and for the derivation of ages for galactic archaeology. However, their formation and early evolution remains largely a mystery. In particular, the origin of the multiple stellar populations they host and which present unique spectroscopic and photometric peculiarities is far from being understood. We present the theoretical asteroseismic properties of tailor-made stellar models with various initial helium enrichment associated to the O-Na anticorrelation. We show the predictions for stars in different areas of the color-magnitude diagram, and discuss how asteroseismology can help disentangling the scenarios that compete to explain the origin of multiple stellar populations in the context of global globular cluster self-enrichment.

4.5 Enrico Corsaro: Metallicity Effect on Stellar Granulation Detected from Oscillating Red Giants in Open Clusters

Co-authors: S. Mathur, R. A. Garcia, P. Gaulme, M. Pinsonneault, K. Stassun, D. Stello, R. Trampedach, J. Tayar, R. Garcia-Dias, I. I. Ivans, C. Jiang, C. Nitschelm, D. Salabert
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The effect of metallicity on the stellar granulation, and hence on the convective motions in general, is still poorly understood. A better understanding of stellar granulation can yield more detailed descriptions of turbulent motions in stellar atmospheres, and therefore improve stellar structure and evolution models. More realistic stellar models improve our capability to retrieve accurate stellar properties, and provide high-quality evolution sequences for ensemble analysis of, e.g., the Galactic formation and evolution.

We show for the first time how we can detect the impact of metallicity on the stellar granulation by discriminating its effect from that of other global stellar properties such as surface gravity, mass, and temperature. We analyse 60 oscillating red giant stars observed by NASAs *Kepler* mission for more than four years, and belonging to the open clusters NGC 6791, NGC 6819, and NGC 6811. We exploit the new metallicity measurements available from APOKASC for most of the stars to derive and calibrate new scaling relations for the granulation and meso-granulation signals that take into account the stellar metallicity. Finally we identify the best scaling relations from the available set of observations by performing a thorough Bayesian parameter estimation and model comparison. We find evidence that the amplitudes and time scales of the granulation and meso-granulation signals increase when the stellar metallicity is higher. We present and discuss our results on the role of metallicity on the individual properties of granulation and meso-granulation, and put them in context of existing realistic 3D hydrodynamical simulations of stellar atmospheres.

4.6 Leo Girardi: Determining and Simulating Stellar Parameters of Asteroseismic Targets: PARAM and TRILEGAL Go Beyond the Use of Scaling Relations

Co-authors: T. Rodrigues, D. Bossini, et al.
Institute: Padova

Asteroseismic parameters allow us to measure the basic stellar properties of field giants observed far across the Galaxy. Most of such determinations are, up to now, based on simple scaling relations involving the large-frequency separation, $\Delta\nu$, and the frequency of maximum power, $\nu_{\rm max}$. We implement $\Delta\nu$ and the period spacing, ΔP, computed along detailed grids of stellar evolutionary tracks, into stellar isochrones and hence (1) in the PARAM code for the Bayesian estimation of stellar parameters, and (2) in the TRILEGAL code to simulate stellar populations in the Milky Way. Their web interfaces (in http://stev.oapd.inaf.it) are being adapted to the new input and output quantities. A few initial applications will be illustrated, regarding e.g. the age determination of *Kepler* targets and simulations of TESS and PLATO fields.

4.7 Kelly Hambleton: Pulsating Stars with LSST

Institute: Villanova University

The Large Synoptic Survey Telescope, LSST, which is due to have first light in 2020, will be a goldmine for pulsating star science. The motto of LSST is "Deep-Wide-Fast" making its ten-year, all-sky survey an obvious choice for longer period variables like RR Lyrae and Cepheid pulsators, with exciting science drivers such as mapping the local galaxy group. The purpose of this presentation, however, is not only to discuss the telescope and survey, and the obvious science cases, but also to address the question "With a cadence of only $\sim$3 points every week, what more can LSST do?". We have transposed thousands of *Kepler* pulsating star light curves to emulate light curves produced by LSST's main 10-year survey, with the goal of assessing LSST's capabilities for pulsating star science. In this presentation we showcase the predicted light curves and discuss the results of our period finding and classification analyses.

4.8 Marc Hon: Deep Learning in Asteroseismology – Teaching a Machine to Recognize Frequency Spectra

Institute: UNSW Sydney

Classifying red giants into hydrogen-shell burning and helium-core burning stars will continue to be an important aspect of seismic analysis; particularly given the large volume of giants observed by current and future space missions. Visually, the oscillation spectra of these populations show significant differences. I present a new method that can separate the red giant populations apart using deep learning, a recent powerful development within artificial intelligence. By learning from an existing set of classified stars, this machine-based "visual-expert" can predict with high accuracy and can easily generalize predictions to thousands of unclassified stars in a matter of seconds, paving the way for very efficient stellar classification in asteroseismology.

4.9 Jennifer Johnson: After Sloan-IV: All-Sky Spectroscopic Observations of TESS

Institute: Ohio State University

We are currently planning the “After-Sloan-IV Survey”, an ambitious all-sky survey that will use two 2.5-meter telescopes, one in Chile and one in New Mexico, equipped with high-resolution infrared and medium-resolution optical spectrographs. These spectra yield precise temperatures, metallicities, and abundance ratios. Among the targets are the TESS red giants with lightcurves lasting more than 60 days, particularly those too faint for abundance ratios from the Gaia RVS. With the planned sample of $>$ 250,000 TESS RGB stars, AS-IV will explore Galactic archaeology north and south.

4.10 Shashi Kanbur: The Structural Properties of Non-Blazhko RR Lyrae Light Curves Observed by *Kepler*

Co-authors: J. Nemec, E. Plechy, L. Molnar, R. Szabo, P. Klagyivik, K. Kolenberg, A. Bhardwaj, D. Richmond, M. Sodano
Institute: SUNY Oswego

We present an study of the structural properties of non-Blazhko RR Lyrae stars observed by *Kepler* in the K2-C0-C6 campaigns. We use Lomb-Scargle methods to determine the period and Fourier analysis to determine light curve structure. We find evidence to suggest that the light curve structure in terms of Fourier parameters follows similar patterns to that seen in amplitude-period plots for Galactic globular clusters: specifically the separation of stars into two distinct groups that are thought to be due to Oosterhoff I and II groups. We also use this Fourier decomposition to find photometric estimates of metallicity using the light curve structure-metallicity estimates developed in Nemec et al (2013). We compare our results with that from OGLE IV and comment possible implications for Stellar Population studies.

4.11 James Kuszlewicz: Are Stellar Inclination Angles Distributed Randomly?

Co-authors: W. J. Chaplin, G. R. Davies
Institute: University of Birmingham

The assumption that stellar inclination angles are distributed randomly in space underpins a large number of analyses and the wealth of red giants observed with *Kepler* enables this assumption to be tested using asteroseismology. By fitting the dipole mixed modes of 90 *Kepler* red giants, their stellar inclination angles were extracted. The underlying distribution was then inferred using Bayesian hierarchical inference, showing that the observed distribution was consistent with isotropy. There are, however, potentially issues relating to subtle selection effects in the results.

4.12 László Molnár: The K2 RR Lyrae and Cepheid Survey: Pulsating Stars Near and Far

Co-authors: Emese Plachy, András Pál, Róbert Szabó, Attila Bódi, Marek Skarka, Ádám Sódor, Áron Juhász, KASC WG7
Institute: Konkoly Observatory, MTA CSFK

Space-based photometry transformed our view of RR Lyrae and Cepheid stars, but the sample sizes of earlier missions were rather limited. With the K2 mission, KASC Working Group 7 aims to observe thousands of RR Lyrae stars and several dozen Cepheids throughout the Ecliptic. We provide customized photometry for these large-amplitude variables that pose unique challenges for most light curve processing pipelines that are suitable for population analysis and present the early results. Beside the field stars, we are also focusing on special targets, such as globular clusters and Local Group galaxies. In particular, we identified some peculiar variables in the RR Lyrae sample that may represent new subgroups or even new variable types. We question the classification of low-amplitude, modulated stars in the globular cluster M80 as RRc stars and propose that they are a different class of multimode variables. We also successfully measured a large number of Cepheids in the nearby dwarf galaxy IC1613, and detected low-amplitude additional modes in some stars there, expanding the asteroseismic capabilities of the mission beyond the Milky Way.

4.13 Marc Pinsonneault: Red Giants in the APOKASC Survey: Tests of the Mass Scale and Future Prospects

Institute: Ohio State University

The APOKASC project is a collaboration between investigators in KASC and the APOGEE project of the Sloan Digital Sky Survey. Here I report on asteroseismic properties inferred from the joint APOKASC data set. We use open cluster and binary star to test the asteroseismic mass scale. We confirm that traditional scaling relations overestimate asteroseismic masses with high statistical significance. We find good agreement with scaling relations modified to include theoretically motivated corrections to the mean density (delta nu) relationship. We then derive modest, but not statistically significant, offsets with the surface gravity (or frequency of maximum power) scaling relationship once the theoretically motivated corrections to delta nu are accounted for. The concordance between different analysis techniques calibrated in this fashion is discussed, and the overall agreement is found to be reasonable. I then discuss future prospects for calibrating asteroseismology of evolved stars in light of the upcoming Gaia DR2, some recommendations for grid modeling techniques for inferred masses of red giants, and overall properties of the APOKASC sample.

4.14 Ben Rendle: The K2 Poles Project – Exploring the Vertical Structure of the Milky Way with K2

Co-authors: A. Miglio, G. Davies, Y. Elsworth, S. Mathur, B. Mosser, M. Lund, M. Valentini, C. Worley, P. Jofre, C. Reyle, R. Garcia, A. Robin
Institute: University of Birmingham

Combining high quality asteroseismic and spectroscopic data is a powerful tool for understanding the evolution of the Milky Way. The K2 mission is expanding upon the original works of CoRoT and the nominal *Kepler* mission and advancing our knowledge of stellar populations further out of the galactic plane than previously explored. Campaigns 3 and 6 in particular highlight this unique opportunity to explore galactic structure, focusing on regions near the northern and southern galactic poles which have never previously been examined in this way. An asteroseismic analysis of these campaign fields has been completed, with complementary spectroscopic data from the RAVE and Gaia-ESO surveys, allowing an in depth, multidisciplinary survey of the vertical structure of the Milky Way focusing in particular on the nature of the existence of a thin and thick disc structure. After comparing the results with a representative synthetic population and cross matching with models of the Milky Way and a carefully appraised selection function, the preliminary results of the project are presented here.

4.15 Mat Schofield: Producing the TESS Asteroseismic Target List for Solar-Like Oscillators

Co-authors: Bill Chaplin, Dan Huber, Tiago Campante and WG1/2 Chairs
Institute: University of Birmingham

TESS will conduct an all-sky survey during its nominal 2-year mission, when it will observe stars at different cadences; full frame image stars will be observed at a 30-minute cadence, while 200,000 high priority targets will be observed at a 2-minute cadence. A few thousand stars will be observed at an even faster cadence of 20-seconds. Some 20,000 2-minute slots have been set aside for asteroseismology. These targets will be chosen by the TESS Asteroseismic Science Consortium (TASC). This presentation will explain how the targets for TASC Working Groups 1 and 2 (Asteroseismology of Exoplanet Hosts and Oscillations in Solar-Type Stars) have been selected, using input data from a variety of sources, including TGAS and Hipparcos parallaxes and magnitudes in different bands.

4.16 Marica Valentini: The Impact of Asteroseismology in Spectroscopic Surveys

Co-authors: C. Chiappini (AIP), F. Anders (AIP), A.Miglio (U. of Birmingham)
Institute: Leibniz-Institut für Astrophysik Potsdam (AIP)

The high precision and accuracy in abundance determination and ages requested by the modern and sophisticate chemo-dynamical models for our Galaxy are not easily achievable, even by the recent spectroscopic surveys. Asteroseismology may provide the necessary help. In fact, in the recent years asteroseismology become an essential tool for spectroscopic surveys, and in particular for determining precise surface gravity, distance and age for red giant stars.

Thanks to the scaling relations that link two seismic observables ($\nu_{\rm max}$ and $\Delta\nu$) to the stellar mass and radius, it is then possible to determine with high precision and accuracy the stellar log(g) and therefore, by fixing the gravity to its seismic value, precise chemical abundances. I developed a pipeline that is able to use iteratively the seismic information in the spectroscopic analysis of red giant stars, allowing a more consistent and precise measurement of the temperature, metallicity and abundance. I will illustrate latest use of this technique in spectroscopic surveys, as in RAVE (Valentini et al. 2017) and GES (Valentini et al. 2016), and the future applications (4MOST spectroscopic survey and K2, TESS and PLATO satellites).

I will focus on the importance of an iterative process for performing spectroscopic analysis using seismology and on the importance of avoiding "a posteriori" corrections or "calibrations" to the atmospheric parameters. I will also present the improvements provided by asteroseismology in terms of element abundances and age determination.