Abstract Book (oral contributions)

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Contents

1 Panspermia in the context of PLATO's long-period exo-Earths

(Dimitri Veras)

With multiple planets in the compact habitable zone of a red dwarf star, the TRAPPIST-1 system motivated detailed panspermia investigations. PLATO will characterise planets located in significantly more distant habitable zones – those around Sun-like stars. I will demonstrate how the likelihood of panspermia would change for multi-planet PLATO systems by deriving a probability distribution function for life-bearing debris to reach different planetary orbits due to asteroid impacts of arbitrary geometries and speeds. I will also describe the survival of microorganisms during planetary ejection, their journey through interplanetary space, and their atmospheric entry into the planets within PLATO systems.

2 The effect of volatile evaporation propultion in planetesimals and its effect the formation of oceans in rocky planets.

(Luciano del Valle)

The amount of available water for a planet in its formation/accretion era it's a crucial ingredient to determine the habitability of such a planet. Typically we expect that farther away from the star, beyond the snow line, the water budget will decrease, making inner planets dryer than the outer ones. For the same reason, in our solar system, in order to explain the formation of an ocean on Earth, different mechanisms of water delivering have been propose. One of the most popular is the dynamical scattering of outer water bearing planetesimals from the outer region of the Solar System toward Earth due to gravitational perturbation produced by the migration, and/or growth, of giant planets. We propose that a similar migratory effect can by achieve if its considered the recoil force, or thrust, due to the out-gassing of volatile elements that are buried on planetesimals. To explore the effect of this thrust force in the evolution of planetesimals we run a set of N-Body simulations using the code Mercury-6. We show that the volatile thrust can drive outer planetesimals (beyond the snow line) toward the inner regions in a few Myrs. Also we show that even in the absence of giant planets the volatile thrust can feed the inner planets with enough water bearing planetesimals in order to form an ocean. Our results have important implications for the formation of oceans in exoplanets and the habitability of inner planets in exoplanetary system where no giant planets exist.

3 Kepler-93 : a testbed for detailed seismic modelling and orbital evolution of super-earths around solar-like stars

(Jérôme Bétrisey)

Thanks to the high-quality data from space-based missions such as CoRoT, Kepler and TESS, great synergies between asteroseismology and exoplanetology were initiated and will further flourish with the future PLATO mission. Indeed, the exoplanets detection itself does not rely on stellar-model-dependent approaches and thus, a detailed characterization of the host star improves significantly the understanding of the exoplanet. In this context, we focused on Kepler-93, whose high-quality data and stellar properties make it a PLATO benchmark target and motivate a new characterization to reach their precision requirements. We carried out a detailed stellar modeling using global and local minimization techniques and considering various changes of the physical ingredients. We completed our analysis with inversion techniques to provide a more robust mean density estimate and test the impact of surface effects. The revised stellar parameters allowed us to update the planetary parameters of Kepler-93b and simulate its orbital evolution under the effects of tides and atmospheric evaporation. We found that a detailed asteroseismic modeling will be able to meet the PLATO standards for such a solar-like star.

4 The Consequences of Binary Exoplanet Host Stars

(Steve Howell)

Using ground-based, high-resolution speckle imaging we have determined that 40-50% of exoplanets are hosted in binary or multiple stars. The stellar orbital separations in such systems are wider, ~100 au, than those of field stars while the mass ratios appear similar. Consideration of and accounting for binary host stars allows the exoplanet properties, (e.g., radius, mean density) to be correctly determined. Additionally, stelar properties may be in error due to (unknown) composite spectra. We have also shown that small, Earth-size planet transits are poorly or not detected at all in binary host star systems leading to gross errors in small planet occurrence rates. This talk will review the current status of binary host stars and examine possible mitigation strategies.

5 The PLATO Input Catalog

(Giampaolo Piotto)
tbd

6 TBD

(Ana M. Heras)

7 Correlations in Planetary System Architecture

(Lokesh Mishra)
Kepler observations indicate the existence of several correlations in the architecture of exoplanetary systems, akin to peas in a pod. Neighbouring planets tend to have similar sizes, mass and are evenly spaced. Adjacent planets show size/mass ordering (outer planet is larger). Large planets tend to have wider orbital spacing, while smaller planets tend to be tightly packed (Weiss et al. 2018, 2020, Millholland et. al. 2017).

First, we are intersted in understanding whether theoretically simulated planetary systems can reproduce these observations? Using synthetic planetary systems from the Bern Model and a new code "KOBE", which extensively accounts for the geometrical limitations of the transit method and detection biases of Kepler, theory is compared with observations (Mishra et. al. in review.). The comparison shows theoretical systems show the peas in a pod architecture trend, in good agreement with observations.

Second, we want to investigate planetary system architecture at the system level. In current studies, the approach to analyse these trends is limited to a population level study using correlation coefficients (exceptions are the works of Alibert 2019 and Gilbert & Fabrycky 2020). These methods, however, are not suitable to analyse the architecture of an individual system. To this end, new metrics are developed which allow the architecture of a single system to be characterized. This novel method allows: a) investigation and quantifiable analysis of the architecture of individual systems, b) comparison of the architecture of different systems, c) unification of architecture trends, d) extension of the peas in a pod trend, and e) link system architecture to initial conditions, among others.

I present the above implications of the new metrics by applying them to the synthetic populations of planetary systems from the Bern Model and observed exoplanets.

8 TBD

(Stéphane Udry)

9 Disentangling the known planet population

(Andrew Winter)
The exotic range of known planetary systems has provoked an equally exotic range of physical explanations for their diverse architectures. However, constraining formation processes requires mapping the observed exoplanet population to that which initially formed in the protoplanetary disc. Numerous results suggest

that (internal or external) dynamical perturbation alters the architectures of some exoplanetary systems. By considering only planets that have not undergone dynamical perturbation, we demonstrate that the observed population supports an upper limit for growth during formation that would be expected due to accretion within the Hill radius during formation. In light of the growing evidence that a subset of planets are dynamically perturbed, we suggest that complex models for population synthesis are no longer justified by the data.

10 High-resolution reconnaissance imaging for fulfilling the PLATO science objectives

(Markus Janson)

The PLATO telescope is highly optimized for wide-field imaging, with a broad Point Spread Function and large pixels. This setup has been selected since it maximizes the candidate yield of the mission. However, it also means that any pixel displaying candidate transit events contains not only the star that hosts the putative planet, but also any stellar companions the star might have, as well as any background star (or stellar system) that happens to align along a similar line-of-sight. Such contaminants will sometimes cause false positive signals in the data, and will always impose a bias into the apparent transit parameters, affecting the apparent radius of the planet. While Gaia can identify some of the contaminants that would be missed by PLATO, a higher spatial resolution is required to identify contaminants to the degree necessary for fulfilling the mission objectives. Here we will discuss what high-resolution reconnaissance imaging will contribute for eliminating false positives and radius bias, and the work that will be done in the PLATO work package that is dedicated for this purpose.

11 Power of Wavelets: Characterization of Transiting Exoplanets in the Presence of Strong Stellar Variability

(Szilárd Csizmadia)

Stellar photometric variability and instrumental effects, like cosmic ray hits, data discontinuities, data leaks, instrument aging etc. cause difficulties in the characterization of exoplanets and have an impact on the accuracy and precision of the modelling and detectability of transits, occultations and phase curves. The research presented in this talk aims to make an attempt to improve the transit, occultation and phase-curve modelling in the presence of strong stellar variability and instrumental noise. We invoke the wavelet-formulation to reach this goal.

The red-noise, the stellar variability and instrumental effects are modelled via wavelets. The wavelet-fit is constrained by cautious mathematical pre-conditions. This helps to avoid the overfit and regularizes the noise model. The approach was tested by injecting synthetic light curves into Kepler's short cadence data and then modelling them.

The method performs well over a certain signal-to-noise (S/N) ratio. We give limits in terms of signal-to-noise ratio for every studied system parameter which is needed to accurate parameter retrieval. The wavelet-approach is able to manage and to remove the impacts of data discontinuities, cosmic ray events, long-term stellar variability and instrument ageing, short term stellar variability and pulsation and flares among others.

We conclude that precise light curve models combined with the wavelet-method and with well prescribed constraints on the noise model are able to retrieve the planetary system parameters, even when strong stellar variability and instrumental noise including data discontinuities are present.

12 Earth-like planets around Solar-like stars

(Vardan Adibekyan)

Young stars and planets both grow by accreting material from the proto-stellar disks. Planetary structure and formation models assume a common origin of the building blocks, yet, thus far, there is no direct observational evidence correlating the composition of rocky planets to their host stars. Here we present evidence of a tight chemical link between rocky planets and their host stars. The iron-mass fraction of the most precisely characterized rocky planets is compared to that of their building blocks, as inferred from the atmospheric composition of their host stars. We find a clear and statistically significant correlation between the two. Our results explain the deviations from the Earth-like densities of planets which have been previously considered as anomalous. We also find that on average the iron-mass fraction of planets is higher than that of the primordial iron content in the planet building blocks, owing to the disk-chemistry and planet formation processes. Finally, our results provide some hints that the giant impact alone is not responsible for the high-densities of super-Mercuries. We conclude that rocky planet composition depends on the chemical composition of the proto-planetary disk and contains signatures about planet formation processes.

13 Alleviating the Transit Timing Variations bias in transit surveys

(Adrien LELEU)

Transit Timing Variations (TTVs) can provide useful informations for systems observed by transit, by putting constrains on the masses and eccentricities of the observed planets, or even constrain the existence of non-transiting companions. However, TTVs can also act as a detection bias that can prevent the detection of small planets in transit surveys, that would otherwise be detected by standard algorithm such as the Boxed Least Square algorithm (BLS) if their orbit was not perturbed. This bias is especially present for surveys with long baseline, such as Kepler and the upcoming PLATO mission. I will introduce a detection method that is robust to large TTVs, and illustrate it by recovering a pair of super-Earth with TTVs of 11 hours of amplitude around KOI-4772. The method is based on a neural network trained to recover the tracks of low-SNR perturbed planets in river diagrams, combined with a photodynamic fit of the lightcurve. The individual transit signal-to-noise of the KOI-4772 planet we detected are about three time smaller than all the previously-known planets with TTVs of 3 hours or more, pushing the boundary in the recovering of these small, dynamically active planets. Recovering this type of object is essential to have a complete picture of the observed planetary systems, solving for a bias not often taken into account in statistical studies of exoplanet populations. In addition, TTVs are a mean of obtaining masses estimations which can be essential to study the internal structure of planets discovered by transit surveys.

14 Analysis of eclipsing binaries in multiple stellar systems: the case of V1200 Centauri

(Frédéric Marcadon)

We present a new analysis of the multiple star V1200 Centauri based on the most recent observations for this system. We used the photometric observations from the Solaris network and the TESS telescope, combined with the new radial velocities from the CHIRON spectrograph and those published in the literature. We confirmed that V1200 Cen consists of a 2.5-day eclipsing binary orbited by a third body. Regarding the third body, we obtained significantly different results than previously published. Indeed, we argue that V1200 Cen is a quadruple system with a secondary pair composed of two low-mass stars. We also determined the ages of each eclipsing component using two evolution codes, namely MESA and CESTAM. We obtained ages of 16-18.5 Myr and 5.5-7 Myr for the primary and the secondary, respectively. In particular, the secondary appears larger and hotter than predicted at the age of the primary. Finally, we concluded that dynamical and tidal interactions occurring in multiples may alter the stellar properties and explain the apparent non-coevality of V1200 Cen.

15 Unveiling the atmospheric evolution of exoplanets

(Andrea Bonfanti)

A thorough characterisation of an exoplanetary system includes also studying the evolution of planetary atmospheres. To this end, we developed a custom tool to estimate the atmospheric content of exoplanets at the dispersal of the protoplanetary disk accounting for the present day system observables. In detail, our tool relies on planetary evolutionary models relating mass, radius and equilibrium temperature with the expected atmospheric mass fraction and mass loss rate, the latter derived from hydrodynamic simulations. The evolution is significantly influenced by the stellar activity level, therefore we employ theoretical stellar evolutionary models to evaluate the high-energy emission over time. Our tool works in a Bayesian framework, it requires to set input priors based on observations, it generates millions of planetary evolutionary tracks, and it retrieves the posterior distributions of the parameters of interests, namely the planetary atmospheric mass fraction at the time of disk dispersal and the evolution of the host star's rotation rate. We successfully applied this framework to a number of recently discovered planets and it is a promising tool for improving our understanding of both planet formation and stellar evolution on the basis of PLATO detections.

16 PLATOSpec, ground based support for PLATO

(Eike Wolf Guenther)
One of the main goals of PLATO is to detect planets with R<2REarth of G- and K-stars, and to determine their masses using ultra-high precision radial-velocity (RV) measurements. Particularly interesting will be those planets in the so-called habitable zone. Given that PLATO will discover 4000 super-Earth of which 40-70 will be in the habitable zone, it will be impossible to determine the masses of all of them with RV-measurements. Furthermore, it is estimated that 80 to 90% of the host stars will be too active to determine the masses of low-mass planets in the habitable zone. We thus have to find out how actives the stars are before we observe them with other instruments. The Astronomical Institute ASCR at Ondrejov, the Universidad Catholica in Chile and the Thüringer Landessternwarte Tautenburg are thus building a dedicated high-resolution spectrograph PLATOspec to be installed at the ESO 1.52-m telescope at La Silla. The first aim of PLATOspec is to determine the stellar parameters including their activity level. The second aim is to study the activity of the host stars, because the photochemistry of planets is affected by the energetic radiation from the host stars. The third aim is to obtain RV-measurements with a precision of up to 3 m/s. Such measurements allow to determine the masses of gas-giant planets and low-mass planets orbiting in short-period orbits. Gas-giants will be also the prime targets for atmospheric characterizations. PLATOSpec will close the gap of missing instrumentation on mid-sized telescopes which are crucial for support of exoplanetary space missions such as now TESS and later PLATO and ARIEL.

17 Asteroseismic probing of low mass solar-like stars throughout their evolution with new techniques

(Martin Farnir)
In this oral contribution we present two new techniques that aim at precisely probing the stellar structure of low-mass solar-like stars. These two methods, that focus on different evolution stages (i.e. the main-sequence stars, subgiants and red giants), provide reliable, accurate, fast and efficient means to tightly constrain the stellar structure through the definition of robust seismic indicators, which we proved to be excellent structural proxies. Indeed, they allow to precisely infer stellar masses, radii, ages and surface helium contents. This is particularly relevant to the field of exoplanetary science, as a precise determination of exoplanetary masses and radii relies on precise stellar properties. We will first present the potential of the WhoSGlAd method (Farnir et al. 2019) to accurately, and automatically, constrain the stellar structure of large samples of main-sequence stars, which is necessary in the context of the PLATO mission (Rauer et al. 2014). By building almost uncorrelated indicators defined to hold precise structural information, this method proposes a brand new approach to the adjustment of the oscillation spectra that these stars display. We will then present a new method to coherently account for the spectra of both sub-giant and red-giant stars, the EGGMiMoSA method (Farnir et al. 2021, submitted). Relying on the asymptotic description of mixed-modes (Shibahashi 1979, Mosser et al. 2012, Takata 2016), this is the first method that is able to follow the evolution of relevant seismic indicators during these phases, namely the period spacing, frequency separation, coupling factor and the pressure and gravity offsets, and therefore constrain the masses, radii and ages of these evolved stars. In

addition, this method reliably provides measurements for these indicators in an automated fashion, which is a great opportunity for the broad characterisation of the large amount of data the PLATO mission is expected to generate. Finally, the combination of these two techniques, which are extremely fast, and their seismic indicators with large scales model search algorithms, such as AIMS (Rendle et al. 2019), could efficiently and robustly provide stellar masses, radii, ages and surface helium abundances for most of the stars observed by the PLATO spacecraft.

18 PLATO-Gaia synergy for studying transiting exoplanets

(Aviad Panahi)

By the time PLATO launches, Gaia data is assumed to be all public, including the epoch data of photometry, astrometry and radial velocities (RV). These data offer many possibilities for augmenting PLATO findings. The high angular resolution of Gaia provides separate light curves of stars included in the wide PSF of PLATO, thus allowing immediate elimination of false positives by background eclipsing binaries and, in other cases, confirming that the PLATO transits are indeed originating from the target stars. In such cases the long-time baseline of the Gaia mission will allow constraining the periods of PLATO candidates, single-transit events in particular. A similar synergy between Gaia and TESS is already taking place using non-public Gaia data. In addition, we suggest using Gaia astrometry and RV together with the PLATO ephemeris to obtain better astrometric or RV periodic solutions, facilitating the study of the transiting planets. We present the details of these various ways by which Gaia data can increase the scientific output of PLATO, and also some results from the current, on-going Gaia-TESS collaboration.

19 Giant white-light flares on fully convective stars occur at high latitudes

(Ekaterina Ilin)

Cool stars produce intense flares that indicate strong stellar magnetic fields and shape the environments of exoplanets in their orbits. In a systematic analysis of fully convective stars observed with TESS, we detected four stars that displayed giant flares which were modulated in brightness by the stars' rapid rotation. The exceptional morphology of the modulation allowed us to directly localize these flares between 55^{deg} and 81^{deg} latitude on the stellar surface, while flares on the Sun typically occur at much lower latitudes below 30^{deg}. Our results imply that strong, dynamic magnetic fields emerge close to the rotational poles in fully convective stars. We show that planets that orbit these stars may be exposed to different amounts of radiation and particles depending on the tilt of the orbital plane with respect to the stellar rotation axis.

20 Extreme exoplanet obliquities due to the tidal migration of unseen moons

(Melaine Saillenfest)

The axis tilt of exoplanets is an important factor ruling their climate stability and habitability. As satellites modify the spin-axis precession rate of their host planet, satellite tidal migration is an efficient driver of resonance sweeping between spin-axis and orbital precession modes. Recent works show that once the planet is captured in resonance, the still ongoing satellite migration may result in a dramatic obliquity increase over a giga-year timescale. I will review this mechanism, and show that the planet eventually evolves towards an obliquity of 90^{deg}, at which point the satellite becomes unstable and may be destroyed and form a massive ring of debris. The resulting planet and its ring are likely to appear in transit data as a "super-puff" exoplanet.

21 Automated planet validation from transit surveys - lessons from Kepler and potential for PLATO

(David Armstrong)
Large transit surveys produce overwhelming lists of candidate transits, with 40000 ‘threshold crossing events’ arising from the Kepler mission and hundreds of thousands expected from the full TESS dataset. Finding the true planets in these samples is a challenge, requiring removing instrumental artefacts and identifying astrophysical false positives reliably. With the huge scale of the data, automated algorithms are becoming a requirement to optimise follow-up resources and enable fast exploitation of the results.

I will present a new machine learning technique which allows full validation of candidate transits, calculating the posterior probability that a given candidate arises from a true planet. Using a Gaussian Process classifier we are able to validate the entire set of Kepler threshold crossing events on a standard desktop computer, training and classifying in minutes once vetting metrics are calculated. Fast, reliable validation allows for improved occurrence rate studies, immediate knowledge of the best candidates, and a probabilistic approach to radial velocity follow-up target selection. I will describe lessons learned from application to the Kepler and TESS datasets and how these techniques can be used to help reach the goals of the PLATO mission.

22 Toward ground-based detection of exoEarths

(Dainis Dravins)
The radial-velocity method is a plausible tool toward ground-based detection of Earth-like planets around solar-type stars. Instrumental precisions are approaching the required level but limitations remain in understanding the complexities of stellar atmospheric dynamics that modulate spectral-line displacements. Solar-type stars are covered by a million granules, each with velocities on order 2 km/s, producing full-disk jittering of the apparent radial velocity of perhaps 2 m/s. From 3D hydrodynamic modeling, time-variable stellar spectra can now be computed, showing correlated variability in different spectral-line parameters (Dravins et al., 2021ab). Blueshifted line components from hot granules in rising motion carry greater photon fluxes while steeper atmospheric gradients enhance local line-strengths. Dependences differ between high-excitation lines from ionized species and those from easily dissociated molecules. Observational calibration is enabled by the recent release of HARPS-N spectra of the Sun seen-as-a-star, where lines with specific astrophysical parameters can be examined for how their fluctuations correlate with excursions in radial velocity. Their calibration might allow to adjust low-noise observations of bright stars to attain their very accurate velocities. (Dravins, Ludwig & Freytag: A&A 649, A16, 2021a; A&A 649, A17, 2021b)

23 Model for a rocky planet around the nearest Sun-like stars

(Haiyang Wang)
Models quantifying the geochemical and geodynamical properties of rocky exoplanets will allow us to make testable predictions that guide future observations. Observations of the chemical compositions of rocky bodies in the Solar System and of polluted white dwarfs lend support to the idea that the chemical composition of terrestrial planets generally reflects that of their host stars for refractory elements, whereas this expression breaks down for volatile elements. Here, we combine a solar-system devolatilization model with photospheric abundance measurements of the nearest Sun-like stars – α Centauri A and B – to estimate the bulk composition of a putative habitable-zone rocky planet in this binary system (“α-Cen-Earth”). Compared to Earth, such a planet is expected to feature (i) a mantle similarly dominated by silicates, albeit poor in FeO and likely enriched in metals and C-bearing phases; (ii) lower overall oxidation state with a slightly larger core mass fraction of 38.4 +4.7/-5.1 wt% (cf. Earth’s 32.5 ± 0.3 wt%); and, (iii) ~25% less intrinsic radiogenic heating from long-lived radionuclides. Taken together, we predict an α-Cen-Earth (if it is found) to host relatively weak mantle convection under a stagnant-lid plate regime under a dense atmosphere.

24 Characterisation of the interior structures and atmospheres of multiplanetary systems.

(Lorena Acuña)
The increasing number of well characterised low-mass planets, combined with the valuable informations from stellar and planetary spectroscopy, opens the way to the modeling of planetary structures and compositions, which can be obtained with theoretical and numerical works. This approach gives a valuable insight to understand the formation of planetary systems in the low-mass range. We present a 1D planetary model where the interior is coupled with the atmosphere in radiative-convective equilibirum within a Bayesian retrieval scheme. In addition to a Fe core and a silicate mantle, we take into account water in all its possible phases, including steam and supercritical phases, which is necessary for systems with a wide range of stellar irradiations.

Our interior-atmosphere model calculates the compositional and atmospheric parameters, such as Fe and water content, surface pressures, scale heights and albedos. We analyse the multiplanetary systems K2-138, TRAPPIST-1 and TOI-178. From the individual composition of their planets, we derive a similar trend for these systems: a global increase on the water content with increasing distance from the star in the inner region of the systems, while the planets in the outer region present a constant water mass fraction. This trend reveals the possible effects of migration, formation location and atmospheric mass loss during their formation history.

25 Water oceans on high-density exoplanets from coupled interior-atmosphere modeling

(Philipp Baumeister)
Liquid water is generally assumed to be the most important factor for the emergence of life, and so a major goal in exoplanet science is the search for planets with water oceans. On terrestrial planets, the silicate mantle is a large source of water, which can be outgassed into the atmosphere via volcanism. Outgassing is subject to a series of feedback processes between atmosphere and interior, which continually shape both atmospheric composition, pressure, and temperature, as well as interior dynamics.

We present the results of an extensive parameter study, where we use a newly developed 1D numerical model to simulate the coupled evolution of the atmosphere and interior of terrestrial exoplanets up to 5 Earth masses around Sun-like stars, with internal structures ranging from Moon- to Mercury-like. The model accounts for the main mechanisms controlling the global-scale, long-term evolution of stagnant-lid rocky planets (i.e. bodies without plate tectonics), and it includes a large number of atmosphere-interior feedback processes, such as a CO2 weathering cycle, volcanic outgassing, a water cycle between ocean and atmosphere, greenhouse heating, as well as the influence of a potential primordial H2 atmosphere, which can be lost through escape processes.

We find that a significant majority of high-density exoplanets (i.e. Mercury-like planets with large cores) are able to outgas and sustain water on their surface. In contrast, most planets with intermediate, Earth-like densities either transition into a runaway greenhouse regime due to strong CO2 outgassing, or retain part of their primordial atmosphere, which prevents water from being outgassed. This suggests that high-density planets could be the most promising targets when searching for suitable candidates for hosting liquid water.

26 The transport of angular momentum in stellar radiative zones in 2D

(Louis Manchon)
Rotation has important consequences for stellar internal structure and evolution. The centrifugal force deforms the star and balances gravity, mimicking a lower mass star. Most importantly, meridional circulations and rotation-induced turbulence mixes chemical elements, extending the stellar lifetime and affecting age

determinations, one of the most important problems in astrophysics. Lastly, the rotation-convection interaction generates magnetic fields. The associated activity has a determining influence on the survival of planetary atmospheres.

Asteroseismic data from the space missions CoRoT and *Kepler* have shown that current 1D models of angular momentum transport in radiative zones (turbulent viscosity and meridional circulation) are not satisfactory. Other mechanisms must be active, such as internal gravity waves, magnetic fields, etc. All models proposed for these mechanisms are incomplete and must, in particular, account for 2D effects.

The 1D description of rotation is usually justified by the fact that turbulence is much stronger horizontally than vertically in radiative zones, suppressing variations of angular velocity. This assumption may not be verified at near the rotation axis. Moreover, because internal gravity waves are generated at the base of convective envelopes, the Doppler shift experienced by these waves when they enter the radiative zone should depend on latitude. These waves are further filtered in the transition zone between the convective and radiative zones, a zone that has a strong differential rotation.

We implemented in a stellar evolution code of a simplified treatment of transport of angular momentum in 2D. This treatment is based on a deformation method that enables the computation of the 2D structure of the star along its evolution, as well as the rotation-induced perturbations of the various fields. The transport of angular momentum is then treated in 2D, and will allow the further study of extra mechanisms of transport.

27 Inclination dependence of Ca II H & K emission variations in solar-like stars

(Sowmya Krishnamurthy)
The S-index, which quantifies the emission in the near ultraviolet Ca II H & K lines, is a prime proxy of stellar magnetic activity. Despite the broad usage of the S-index, the link between the coverage of the stellar disk by magnetic features and Ca II H & K emission is not fully understood. In order to fill this gap we developed a physics-based model to calculate the S-index. To this end, we made use of the distributions of the solar magnetic features derived from surface flux transport simulations, together with the Ca II H & K spectra synthesized using a non-local thermodynamic equilibrium radiative transfer code. We validated our model by successfully reconstructing the observed variations of the solar S-index across four recent activity cycles.

We show that for a solar distribution of magnetic features, the value of the S-index is influenced by the inclination angle between the stellar rotation axis and the observer's line of sight, i.e. the S-index values obtained by an out-of-ecliptic observer are lower than those obtained by an ecliptic-bound observer. This is important for comparing the magnetic activity of stars. We computed time series of the S-index as they would be observed at various inclinations from year 2010 back to 1700. We show that depending on the inclination and period of observations, the activity cycle in solar S-index can appear weaker or stronger than in stars with a solar-like level of magnetic activity. We find that such a time dependence of solar S-index variability can explain the surprising results of several recent studies which suggested that the S-index variability in the Sun is higher than that in majority of stars with near-solar magnetic activity. We show that there is nothing unusual about the solar chromospheric emission variations in the context of stars with near-solar magnetic activity.

28 Seismic diagnosis for rapidly rotating g-mode upper-main-sequence pulsators

(Hachem DHOUIB)
Space-based asteroseismology has revolutionised our understanding of stellar structure, evolution, mixing, and rotation. In particular, intermediate-mass, main-sequence g-mode pulsators like gamma-Dor and slowly pulsating B-type (SPB) stars allow us to probe rotation and mixing at their convective core/radiative envelope interface with a high precision. This constitutes a gold mine for our global understanding of stellar rotation

and related mixing. To fully exploit the information that is provided by detected g-mode pulsations, it is crucial to improve our understanding of how stellar rotation influences g-modes in rapidly rotating stars for which the action of the Coriolis and the centrifugal accelerations have to be taken into account.

In this framework, the Traditional Approximation of Rotation (hereafter TAR) provides a flexible treatment of the adiabatic propagation of gravity modes modified by rotation (i.e. gravito-inertial modes including Rossby modes which propagate under the combined action of the buoyancy force and the Coriolis acceleration), which is extensively used for intensive seismic forward modelling. However, it has been built on the restrictive assumptions of spherical uniformly rotating stars. In this work, we generalise the TAR to take into account simultaneously the centrifugal deformation and differential rotation. We determine the validity domain of this generalised TAR using the state-of-the-art 2D stellar structure and evolution code ESTER. We then demonstrate how these new physics affect the pulsation-period spacings between consecutive g-mode pulsations, which are a common diagnostic that allow us to probe rotation and the chemicals mixing, for instance by convective overshoot or penetration, at the core boundary. We show that the effects induced by the centrifugal acceleration and the differential rotation are detectable using high-precision asteroseismic data. Finally, we discuss how this work can be generalised in a near future to include the effects of stellar magnetic fields and how it will lead to more realistic and accurate asteroseismic modelling of OBA-type stars.

29 Kepler's Small Planets and their Dependence on Stellar Mass

(Galen Bergsten)
The "radius valley" is a feature in the short-period, small exoplanet population in Kepler and K2 data showing an abundance of super-Earths (1-2 Re) and mini-Neptunes (2-3.5 Re), with a relatively scarce population of intermediate-sized planets between the two. By employing updated stellar properties and implementing refined measures of completeness and reliability, we discover that the occurrence of super-Earths over that of mini-Neptune has a period and stellar mass dependence. We use these dependencies to extrapolate the occurrence of super-Earths in the habitable zone of MKGF stars. Finally, we discuss our results in the context of PLATO's search for long-period small planets and their dependence on stellar mass.

30 A robust, empirical approach to determine line-by-line convective blueshift strengths from F to M dwarfs

(Florian Liebing)
With ever increasing instrumental resolutions and stabilities, the limiting element towards detecting low-mass exoplanets using the radial velocity approach has shifted towards the stars themselves. The noise floor is no longer dominated by instrumental effects but by phenomena originating on the stellar surface relating to the complex interaction between magnetic activity and convection. On its own, convection imposes a spectral blueshift due to flux imbalances within convective cells, an effect that gets suppressed and modulated by magnetically active regions rotating in and out of view. To accurately model this modulation, an essential part of future exoplanet detection algorithms, one must first understand the basic pattern of convection and how it changes not just from star to star but also from spectral line to spectral line. To measure the convective blueshift as a function of spectral type we have employed a technique that utilizes the universal nature of the third signature of granulation by scaling an empirical solar signature model, created based on an ultra-high resolution spectrum. We have applied this to HARPS observations of more than 800 stars that span the main sequence from early-M to late-F stars. The results show a well-defined relation between effective temperature and strength of convective blueshift and provide a way to calculate the shift for any spectral line in any star. This clears the way towards an accessible method of identifying the convective blueshift component in the search for small Earth-like exoplanets.

31 fBLS – A fast folding algorithm to produce BLS periodograms in search for transiting planets.

(Sahar Shahaf)
fBLS – A fast folding algorithm to produce BLS periodograms in search for transiting planets. (Sahar Shahaf, Barak Zackay, Pascal Guterman, Tsevi Mazeh, Shay Zucker, Simchon Faigler)

We present fBLS – a novel technique for detecting transiting planets. fBLS simultaneously produces all the binned phase-folded lightcurves for an array of Np 'sufficiently different' trial periods, with O(Np*log(Nt)) arithmetic operations (while regular BLS requires O(Np*Nt) operations). For each folded lightcurve produced by fBLS, we compute the standard BLS statistic, producing a standard BLS periodogram. fBLS is based on the fast-folding algorithm (FFA; Staelin 1969), which is extensively used in pulsar astronomy (e.g., Morello et al. 2020). We present fBLS capabilities by applying it to Kepler data, finding known and new planets. When applied to PLATO lightcurves, it can be used to detect small rocky transiting planets, with periods shorter than one day, a period range for which the computation is extensive. fBLS will also be used to detect transiting planets with varying duration, and transit timing.

32 Analytic Approach for Light Curve Fitting

(Yair Judkovsky)
We present AnalyticLC, a novel semi-analytic method we developed for full light-curve modeling, and results we obtained by applying it to Kepler photometric data.

The method includes non-coplanar interactions, and is based on an expansion of the disturbing function to 4th order in eccentricities and inclinations. The analytic method also includes a previously unrecognized Transit Timing Variation (TTV) pattern which arises in a near-resonant chain of three planets. We show this effect can significantly depart from the traditional pair-wise TTV summation. Such a near-resonant chain occurs commonly in the Kepler population.

Our highly efficient and accurate implementation allows full inversion of a large number of observed systems to derive planetary physical and orbital parameters, including a description of their 3-dimensional orbital geometry. This method can be further used for problems that involve a large parameters space - for example, searching for an unseen/non-transiting companion, or simultaneous fits that include radial velocity measurements. It also offers advantages for analyzing observations with a long time span, such as combined Kepler and PLATO data.

33 Rotation period detectability of solar-like stars - Consequences for recent studies

(Timo Reinhold)
Over the past decades it has been discussed whether the Sun is less active than other stars with near-solar effective temperatures and rotation periods (commonly termed solar-like stars). These quantities mainly determine the stellar magnetic activity, and are therefore responsible for the generation of dark spots and bright faculae, i.e., the main drivers of stellar variability. Photometric variability measurements of the Kepler telescope revealed that (quasi-periodic) solar variability is quite common among stars, for which rotation periods could not be detected. On the contrary, most of the solar-like stars with well-determined rotation periods show quite regular variability, with amplitudes several times higher than that of the Sun. Furthermore, it was shown that early G-type stars with known rotation periods are strongly underrepresented among those stars with measured periods. This observation indicates a detection bias of the rotation period toward more active stars. By simulating stars with solar-like variability, we show that the lack of stars with measured rotation periods can be explained by the conservative detection thresholds used in previous rotation period surveys. We find that the small detection rate of our models, combined with predictions from Galactic evolution models, is consistent with the number of stars with actually measured solar-like periods

and variabilities. We conclude that more period measurements for stars with solar-like variability are urgently needed to unbias recent studies.

34 Detailed Asteroseismic Modeling of Red-giant Branch Stars: The Paradigmatic Cases of the Host Stars KOI-3886 and iota Draconis

(Tiago Campante)
Kepler asteroseismology has played an important role in the characterization of host stars and their planetary systems. Target selection biases, however, meant that this synergy would remain mostly confined to main-sequence stars. The advent of TESS has since lifted this restriction, enabling the systematic search for transiting planets around seismic giants, as well as revisiting previously known evolved hosts using asteroseismology. In this talk, I will present the detailed asteroseismic modeling of two high-luminosity red-giant branch hosts, KOI-3886 and iota Draconis. KOI-3886, observed by Kepler over 4 years and later by TESS over 1 sector, has been a longtime candidate host. iota Draconis, observed by TESS over 5 sectors, is known to host a planet in a highly eccentric orbit. We measured individual mode frequencies across 8 (7) radial orders for KOI-3886 (iota Draconis). We next conducted state-of-the-art forward modeling, having both considered the full mode frequency lists (including g-dominated modes) and pure π modes alone. Furthermore, we tested the impact of varying the input physics, namely, mass loss, on the derived stellar fundamental properties. The precise (~6%) seismic mass derived for iota Draconis was combined with new RV observations to detect an additional long-period companion. Regarding KOI-3886, asteroseismology was key in helping reveal the planet candidate as a false positive and reinterpreting the system as an eclipsing brown dwarf in a hierarchical triple with two evolved stars. This brings to light the importance of asteroseismology in the study of planetary orbital dynamics off the main sequence and its lesser known role in candidate vetting. Moreover, it anticipates the potential of PLATO with regard to the detailed characterization of red giants and their planetary systems.

35 Exploring the variety of small planets with HARPS-N

(Annelies Mortier)
To understand exoplanetary systems, we can study their mass-radius relationship or lack thereof. Kepler, K2, and TESS discover thousands of exoplanet candidates providing precise transit photometry which are then followed up by ground-based spectroscopy to characterise their masses and internal composition. The expertise gained from this process will be invaluable for the PLATO mission when pushing to longer-period small planets. In this talk I will give an overview of the HARPS-N Collaboration's leading efforts to fill and interpret the mass-radius diagram of small planets, including several recent results on small rocky planets orbiting stars with different chemical compositions than our Sun.

36 Simultaneous seismic modelling of multiple stars using correlated parameters

(Warrick Ball)
The asteroseimsology of individual solar-like oscillators generally allows more precise inferences about many stellar model parameters than with only non-seismic constraints. Some of these parameters (e.g. the mass and age) are fundamental physical properties of the star but some (e.g. the mixing-length parameter for near-surface convection) represent uncertainty in the physics of our stellar models. Most asteroseismic modelling takes these parameters as free or fixes them to some value, motivated by other constraints. I will show how one can introduce correlations between the parameter values for different stars to quantify our expectation that, even if we don't know exactly what values these non-fundamental parameters take, we don't expect them to differ much between similar stars. e.g. if two stars have surface gravities and effective temperatures that differ by 0.05 dex and 50 K, respectively, they probably have similar mixing-length

parameters, too. I demonstrate this concept using a binary star system observed in Kepler, in which I also experiment with how close we expect the stars' ages and compositions to be. In principle, the method is not limited to binary stars and, the more efficient the model-fitting for a single star, the more stars can be included in a simultaneous fit that constrains how the non-fundamental parameters vary across a (sub)sample of solar-like oscillators, like the sample that PLATO will study.

37 Asteroseismic measurement of the inclination angle: characterizing exoplanetary systems

(Charlotte Gehan)
Information on stellar inclinations are of prime importance to characterize the formation and dynamics of transiting exoplanetary systems, by helping to constrain the angle between the stellar spin axis and the planetary orbit axis, namely the obliquity. As PLATO will observe about 150 000 main-sequence stars potentially hosting exoplanets, it is crucial to have at hand a fast, robust and automated method to measure the stellar inclination angle.

I will present the method I developed and the results I derived for almost 1200 red giant stars that have been observed by the Kepler space mission, which exhibit mixed modes offering the opportunity to obtain accurate measurements of the inclination angle of the stellar rotation axis. I could characterize the biases affecting inclination measurements, in particular for extreme values close to 0º and 90º. This study allowed me to provide a way to infer the underlying statistical distribution of inclinations for a given sample of stars, free from observational limitations. This method presents the advantage to be able to derive seismic measurements of the inclination angle for any solar-type pulsator with identified oscillation modes.

38 Tracers of Exoplanet Composition

(Amy Bonsor)
Follow-up observations of PLATO planet detections will provide mass and radius measurements of a sample of hundreds of planets. Detailed interior models will be required to constrain planet structures, however, some intrinsic degeneracies will remain. Detailed models that relate planetary composition to broader properties of the planetary system are required. I will discuss how observations of planetary material in the atmospheres of white dwarfs can improve our understanding of what determines planetary composition. In particular, I will present observations of binary companions to white dwarfs that highlight how well stellar abundances trace the composition of planets.

39 On the astrometric jitter due to magnetic activity for Sun-like stars

(Sowmya Krishnamurthy)
The astrometric detections of exoplanets by missions such as Gaia and Small-JASMINE rely on the measurement of tiny changes in the positions of stars, namely the astrometric jitter, arising from the gravitational interaction with their planetary companions. Another source of the astrometric jitter is the magnetic features present on the surface of host stars. The jitter caused by magnetic activity can influence the detection and characterization of Earth-sized planets using astrometric measurements. In this context, we explore the conditions under which the magnetic activity-induced jitter becomes comparable to the planet-induced jitter. For this purpose, we extend the state-of-the-art model of stellar and solar photometric variability for calculating astrometric jitter. In particular, we investigate the dependence of magnetic jitter on inclination (i.e. the orientation of the stellar rotation axis with respect to the observer's line of sight), metallicity and active-region nesting (i.e. the tendency of new active regions to emerge in the vicinity of recent emergences). To obtain the disk distributions of active regions at various inclinations and degrees of nesting, we resort to surface flux transport simulations. We show that, depending on the inclination and metallicity, the jitter for stars with solar-like magnetic activity becomes comparable to the jitter produced by an Earth-sized planet at

1 AU. With increasing degree of nesting, the activity-induced jitter reaches levels that could be detected using continuous measurements from Gaia.

40 Impact of the transport of chemical elements on the internal structure and surface abundances of stars

(Morgan Deal)
Transport of chemical elements in main-sequence stars is still far from understood and leads to large uncertainties in stellar models. The competition between all transport processes leads to variations of stellar abundances and this is only when we will include all these processes in stellar evolution codes, that we will be able to explain surface abundances and internal structure of stars. For example atomic diffusion, including the effect of radiative accelerations on individual elements, leads to variations of the chemical composition inside the stars as well as the surface abundances evolution. Indeed the accumulation in specific layers of the elements, which are the main contributors of the local opacity, modifies the internal stellar structure and surface abundances. Using asteroseimology, we showed that the variations of the chemical composition induced by atomic diffusion and the mixing induced by the rotation in G and F type stars can have a significant impact on their structure, stellar parameters and seismic properties. These processes need to be taken into account in stellar evolution models as the observations are more and more precise, especially in the context of the space missions Kepler, TESS and in the future PLATO.

41 SWEET-Cat v2: What can homogeneous stellar parameters provide to planetary systems studies?

(Sérgio Sousa)
SWEET-Cat, a catalogue of Stars With ExoplanETs was originally introduced in 2013, and since then, many more exoplanets were confirmed increasing significantly the number of host stars listed there. A crucial step for a comprehensive understanding of these new worlds is the precise and homogeneous characterization of their host stars. Better spectroscopic stellar parameters along with new results from Gaia eDR3 provide updated and precise parameters for the discovered planets. A new version of the catalogue is becoming available to the community soon, whose homogeneity in the derivation of the parameters is key to unravel star-planet connections. Here we will present the most relevant updates introduced to SWEET-Cat, and review the updated metallicity distributions of stars hosting planets. We present the current status of different planet-host populations (e.g. low-mass planet host stars, Jupiter-like host stars) which provide observational statistical constrains for the theory of planet formation and evolution. Since SWEET-Cat continues to be updated with the new discoveries of exoplanets it could be also very useful for PLATO, in particular it can be used to access the validation of the already known planet-host stars that will be listed in the PLATO Input Catalogue.

42 Entropy-calibrated models of solar-like stars

(Federico Spada)
The description of convection in the outer envelopes of stars is one of the largest sources of uncertainty in modeling solar-like and low-mass stars. More specifically, the one-dimensional convection formalisms implemented in most stellar evolution codes depend on a “mixing-length” parameter, which needs to be calibrated externally. The radius and the effective temperature of the stellar model are very sensitive to the choice of this convective free parameter. I will present evolutionary models of solar-like stars in which the mixing-length parameter is calibrated using the results of radiation hydrodynamics (RHD) simulations of convection. The specific entropy at the bottom of the convection zone provides the link between the RHD simulations and the stellar evolution code. The calibration is performed at each time step of the evolution, thus taking into account the change in the surface parameters of the star (effective temperature, surface gravity and metallicity). Such a calibration effectively removes the freedom associated with the choice of the

mixing-length parameter. I will discuss the merits of entropy-calibrated stellar evolution models in predicting more accurate radii and effective temperatures of solar-like stars with respect to conventional models, and illustrate the applicability of the method to both main sequence and red giant stars.

43 An analytical model for tidal evolution in co-orbital exoplanets

(Jérémy Couturier)
We develop an analytical model of tidal evolution in co-orbital systems (in a 1:1 mean motion resonance). We use a Hamiltonian version of the constant time-lag tidal model, which extends the Hamiltonian formalism developed for the point-mass case. Our results show that under tidal dissipation, co-orbital systems either favour the Lagrange or anti-Lagrange eigen-mode, and that for all range of parameters and initial conditions, both configurations become unstable. We give precise estimates for the timescale of the destruction and show that this timescale can be larger than the lifetime of the host star. We perform numerical simulations to assess the validity of the analytical results and we finally give, based on these results, an easy-to-use criterion to determine if an already known close-in exoplanet may have an undetected co-orbital companion.

44 Lithium depletion and angular momentum transport in low-mass stars

(Thibaut Dumont)
Robust modelling of solar-like stars is key to understanding the evolution of low-mass stars and understand their environment. So far, no clear consensus appears for which physics is required to reproduce the main observables: the evolution of light elements (e.g. lithium), the evolution of surface rotation with time as observed in open clusters, and the state of the internal rotation obtained with the help of asteroseismology. In order to improve stellar modelling and prepare the PLATO space mission, we need to understand these observations and better characterise internal transport processes in stars.

Using the stellar evolution code STAREVOL, we compute the lithium abundance as well as the surface and internal rotation evolutions from models of main-sequence rotating stars that include atomic diffusion and additional transport for both chemicals and angular momentum. We test for the first time mixing processes including a rotation-dependent penetrative convection (Augustson et al. 2019). We then compare the results to observations of G-type and F-type stars.

We succeed to reproduce the observational constraints at different masses and metallicities during evolution. We discuss the relevance and the efficiency of these different additional transport processes. We show that for the specific case of the Li-dip for F-type stars, we need to involve a stronger shear-turbulence and an additional transport process of angular momentum consistent with internal gravity waves (Dumont et al. 2021a and 2021b under revision).

45 Improving the RV precision to detect Earth-like planets

(Michael Cretignier)
When the m/s level radial-velocity (RV) precision wants to be reached to follow-up transiting candidates, it is mandatory to mitigate at best stellar, instrumental and atmospheric signals.

To do so, we developed a new code, YARARA, that analyses a time-series of high-resolution spectra for any given star, and model, using a combination of data-driven and physically-motivated approaches, the different flux contributions from i) the used spectrograph, ii) the tellurics, and iii) stellar activity. The RV derived from the cleaned HARPS spectra show generally a ~20% decrease in rms, which can be associated to a mitigation of the different perturbing signals. YARARA can be implemented for any high-resolution spectrograph data.

To go a step further in mitigating stellar activity, we can use the line-by-line RVs or spectra provided by YARARA and apply machine learning techniques such as PCA, ICA and others to separate a planetary signal from stellar activity, as the former affects all the spectral lines in the same way, which is not the case for the latter.

YARARA plus data-driven approaches to separate stellar from planetary signal can significantly improve the detection of small-mass exoplanets.

46 HARPS3 and opportunities for RV follow-up of PLATO targets

(Clark Baker)
HARPS3 could be a key tool in the radial velocity (RV) follow-up of PLATO planetary candidates. HARPS3 is an R = 115,000, fibre-fed, Echelle spectrograph with an operational wavelength range of 380–690 nm and a deployable/integrated, dual-beam, full-Stokes polarimeter. The spectrograph is designed to be able to detect about Earth-mass exoplanets with orbital periods of 100+ days around G- and K-type stars and will utilise a robust series of stability measures in order to achieve an instrument stability of around 10cm/s; enabling the study of lower mass planets than previous generation instruments. The spectrograph will be coupled to the upgraded and roboticized 2.54m Isaac Newton Telescope (INT), where up to 50% open-time is available on HARPS3. Furthermore, and of special note, an automated scheduler will enable the flexible scheduling of observations that will be interleaved with the rest of the night's observations, enabling efficient observing strategies that maximise the use of an observers allocated telescope time. HARPS3 will also utilise a trusted and proven data-reduction pipeline for straightforward and reliable extraction of radial velocity data. In this talk, we will discuss the design, specifications and capabilities of HARPS3@INT and how these could provide favourable opportunities for RV follow-up of PLATO targets.

47 Forward modelling of the brightness variations of Sun-like stars

(Nina-Elisabeth Nemec)
The emergence of magnetic flux on stellar photospheres leads to the formation of magnetic features, such as bright faculae and dark spots. These features cause the intrinsic stellar variability, which is a limiting factor for detecting and characterising planets around stars. To explain stellar variability, we start from our understanding of the physical mechanisms causing solar variability and extend and apply these to other stars (i.e. we follow the solar paradigm). By employing the Flux Emergence And Transport (FEAT) model, we obtain the distribution of magnetic flux on the stellar surface, which is then used for forward modelling of stellar photometric variability. We vary the magnetic field distributions on stars depending on their activity level, rotation period, and the degree of nesting (i.e. the tendency of magnetic features to emerge in the vicinity of each other). We modelled the dependence of the photometric variability on the stellar rotation rate and compared our results to findings by the *Kepler* telescope. We conclude that stars rotating 4 times more rapidly than the Sun or faster, the latitudinal emergence of magnetic features shifts towards significantly higher latitudes compared to the Sun. In order to explain the observed light curves of fast rotators, we identified that high degrees of nesting in addition to higher amounts of emergence of magnetic flux (relative to the solar quantities) are needed. This simultaneously leads to more stable (e.g. longer lived) magnetic features and more light curves.

48 Accuracy of transit parameters in presence of stellar noise: the power of wavelets

(Szilárd Kálmán)
Stellar activity and instrumental noise distort the exoplanet transit light curves which in turn results in the appearance of systematic errors in the parameters that characterize them. We aim to show that proper treatment of this correlated noise (e.g. through wavelet-formulation) is necessary for the sufficiently high precision and accuracy of the determined parameters. In order to examine the amount of systematic errors and uncertainty underestimations that is caused by red noise, we simulated noisy transit light curves with a

random segment of a correlated noise model cloned via ARIMA process. Then we solved the resulting light curves. We repeated this process until we had a statistically significant sample size. The fitting was done via the software packages TLCM and FITSH. We have found that without the simultaneous fitting of the transit signal and a noise-model, the distribution of parameters determined through the bootstrapping-like method is far broader when compared to the wavelet-approach. We also present a method for estimating the realistic error bars without handling the red noise component. We conclude that the wavelet-formulation, implemented by the TLCM package, results in self-consistent data with properly estimated uncertainties.

49 Mixed Modes and the Asteroseismic Surface Term

(Joel Ong)
We present new methodological developments regarding the treatment of the asteroseismic surface term in stars with mixed modes. Models of solar-like oscillators yield acoustic modes at different frequencies than would be seen in actual stars possessing identical interior structure, due to modelling error near the surface. This asteroseismic "surface term' ' must be corrected when mode frequencies are used to infer stellar structure. This is typically done by way of likelihood functions intended to diagnose whether or not differences between two sets of mode frequencies are consistent with a structural perturbation localised to the stellar surface. Different choices of these prescriptions modify the posterior distributions of fundamental stellar properties — such as the mass, radius, and age — inferred from individual stars using asteroseismology. These in turn induce population-level systematic biases. Existing prescriptions developed for p-modes are also not immediately applicable to the mixed modes seen in more evolved solar-like oscillators. We examine some outstanding issues in how the surface term is currently treated in stellar modelling with asteroseismology, and how these new methods may address these shortcomings, with a particular focus on the interaction between mode mixing and these systematic effects.

50 Characterization of 12 TESS Exoplanet Hosts with Solar-like Oscillations

(Bernardo Ferreira)
The progress in the study of exoplanets has created an increasing demand for a precise characterization of their host stars since several stellar parameters are necessary for characterizing their planets. In this work, we present accurate determinations of the radii, masses, and ages of 12 exoplanet hosts with solar-like oscillations observed by the recent TESS mission, obtained using asteroseismology. First, we measured the global seismic properties of the oscillation's acoustic modes, namely, the large separation and the frequency of maximum power. For the former, we employed two independent methods and then cross-examined their results. We then measured the latter in a heavily smoothed version of the light curve's spectrum and verified that the quantities obey the empirical relation verified for them. Then, we combined those parameters with previous spectroscopic measurements of the star's effective temperatures and metallicities and GAIA measurements of their distances and apparent magnitudes to obtain, using grid-based modeling, the stellar radii, masses, and ages with the Yale-Birmingham method and the BaSTI grid of stellar evolution models. Results between 3.5 and 10 solar radii for the radii, 1 and 2.2 solar masses for the masses, and 1 and 11 gigayears for the ages, placing those objects in the red giant branch and the horizontal branch. Three of the analyzed stars had their oscillations studied in previous works that found results consistent with ours. For the other stars, our determination has uncertainties 3 to 15 smaller for the radii and three times smaller for the masses than those obtained by other, non-seismic characterizations. Additionally, we found smaller mass values and greater ages than those works, which can be attributed to the better differentiation of models once we include the seismic properties in the analysis. In one particular case, we show that those parameters are fundamental for placing the star in the horizontal branch.

51 From TESS to PLATO: A Galactic archaeology perspective

(Thibault Boulet)
The formation history and evolution of the Milky Way through cosmological time is a complex field of research requiring the sampling of highly accurate and reliable stellar ages for all the components of the Galaxy. Such highly reliable ages are starting to become available due to the synergy between asteroseismology, spectroscopy, and stellar modeling in the era of all-sky astronomical surveys. Based on a sample of 227 red giants in the Galactic disk sampled from the TESS Southern Continuous Viewing Zone, with a mean relative uncertainty on the stellar age of 22% and precise chemical abundances from APOGEE DR16, we aim at finding the best possible Galactic chemical clocks. We proceed by comparing the evolution of the abundance ratios to those predicted by state-of-the-art Galactic evolution models. We identified new chemical clocks ratios that have not been previously considered in the literature and we investigate the non-universality of chemical clocks by taking into account the birth radius across the Galactic disk for stars in our sample. The asteroseismic yields of PLATO for red giant stars are expected to lead to a 10% precision in age dating. Such high reliability makes it the first important mission for the near future research in Galactic archaeology.

52 Stellar characterization, activity, and terrestrial planets: Results from five years of CARMENES spectroscopy

(Ansgar Reiners)
On its mission to find terrestrial planets, the CARMENES project has obtained more than 20,000 visual and near-infrared high-resolution spectra of nearby, low-mass stars. The project so far discovered more than two dozen planets and determined the masses and densities of several transiting planets. From the densely sampled high-resolution data, a wealth of information is available about stellar fundamental parameters and activity, including the measurement of magnetic fields. I will present an overview of CARMENES results relevant to PLATO including ground-based observations of planetary atmospheres and news about stellar activity applicable for sun-like stars.

53 Effect of magnetic activity on centre-to-limb variations

(Veronika Witzke)
Accurate centre-to-limb variations (CLVs) are crucial for various applications. In particular, they affect the shape and depth of a transit light curve, and thus are needed for determining exoplanet parameters. So far models to calculate the centre-to-limb variations neglected the effect of magnetic actvity. However, most main-sequence stars exhibit magnetic activity, which affects the CLVs.

In this study, we focus on the effect of the presence of magnetic fields on the centre-to-limb variations. Using radiative 3D MHD calculations by the MURaM code we simulate Sun-like stars. It is believed that small-scale mixed polarity magnetic features are always present even on the most inactive stars. Thus, we use simulations that include local small-scale dynamo (SSD) to represent quiet stellar surface. In addition, we use purely hydrodynamic simulations for comparison, because in the past they were considered for inactive stars.

To obtain different levels of magnetic activity we introduce initially homogeneous and vertical magnetic fields of different strengths into some of the runs. For the CLVs we calculate the emergent intensities from the 3D cubes using rays at different limb angles and solving the radiative transfer along the ray with the MPS-ATLAS code.

54 Confirming & detecting circumbinary planets using radial-velocities

(Amaury Triaud)
Circumbinary planets are important to better understand the processes behind planet formation. Specifically

their properties encode their protoplanetary disc viscosity and scale-height. In addition they allow us to study accretion of dust, and disc-drive migration.

Thanks to its long photometric stares, PLATO will likely identify multiple transiting circumbinary planets. However the duration of its long stares are insufficient to measure circumbinary planet masses accurately using eclipse timing variations of the central binary. In this talk I will show our efforts on HARPS and SOPHIE to detect circumbinary planets orbiting single-lined eclipse binaries. I will show the first ground-based detections of circumbinary planets made by SOPHIE, HARPS in radial-velocities, and the first circumbinary planet transit obtained from ground, using ASTEP in Antarctica. The methods we are developing are key to prepare for the confirmation of PLATO's circumbinary planets.

55 Mitigating stellar activity in transit characterisation using Gaussian process

(Susana Barros)
With the increase of the precision of observations, stellar intrinsic variability is becoming the dominant limitation in the study and characterization of exoplanets and it will particularly affect PLATO observations. We tested the performance of Gaussian process (GP) regression on the characterisation of transiting planets, and in particular to determine how many components of stellar variability are necessary to describe high cadence, high signal-to-noise light curves expected from PLATO. I will show that to characterize Earth-size planets we need to account for 4-5 components of stellar variability: stellar oscillations, stellar granulation and stellar activity rotational modulation. We find that using a standard linear detrending leads to biased results while using a GP model with just one stellar variability component fails to retrieve the transit because of it is a poor description of stellar activity. Therefore, to analyze Earth-size planets multi–component variability models are really necessary in order to derive robust planetary parameters necessary to constrain their planetary interiors.

56 Redox hysteresis of super-Earth exoplanets from magma ocean circulation

(Tim Lichtenberg)
PLATO will significantly widen our view of the distribution and variability of rocky exoplanets. From an astronomical perspective, planets that formed under similar conditions should exhibit comparable compositional trends, such as volatile inventory, which can be compared to hypothetical M-R relations. However, internal redox reactions may irreversibly alter the mantle composition and volatile inventory of terrestrial and super-Earth exoplanets, which can affect their outgassed atmospheres and decouple the initial accreted composition from long-term climate. The global efficacy of these mechanisms hinges on the transfer of reduced iron from the molten silicate mantle to the metal core. Using scaling analysis I demonstrate that turbulent diffusion in the internal magma oceans of sub-Neptune exoplanets can kinetically entrain liquid iron droplets and quench core formation. This suggests that the chemical equilibration between core, mantle, and atmosphere may be energetically limited by convective overturn in the magma flow. Hence, molten super-Earths possibly retain a compositional memory of their accretion path. Redox control by magma ocean circulation positively correlates with planetary heat flow, internal gravity, and planet size. The presence and speciation of remanent atmospheres, surface mineralogy, and core-mass fraction of atmosphere-stripped exoplanets may thus constrain magma ocean dynamics, which can be probed observationally.

57 Study of Strange Exoplanets

(Srujith BSR)
BSR Srujith, Aditya Engineering College S.Majal Shiny, Karunya Insttute of Technology and Sciences Ever since the discovery of the first exoplanet in 1995, more than 4000 exoplanets have been discovered so far. The majority of the exoplanets were discovered by transit and radial velocity methods. And the numbers are only

likely to increase prominently, with the number of people (space organizations, citizen scientists, amateur astronomers, etc.) searching for new exoplanets. This passion towards exoplanets among the scientific community is mainly triggered by the possibility of finding an Earth-like world among the others. Our search for earth-like planets and intelligent life has given us insights about the planets that we are never aware of. We have detected a wide range of exoplanets including;- Super-Earths, Hot Jupiters, Mini Neptunes, Hot Earths, and many more. Overall these years of search for Earth-like planets astronomers have also come across many unorthodox exoplanets. In this paper, we study some of these non-conventional exoplanets and try to understand what makes them so strange. After years of studying our solar system and other-planet systems, we have a fair idea of planet formations. But the planets which we focus on here defies most of these ideas and makes us question our understanding of the planet formations. Studying these strange exoplanets can help us understand more about planet formation all over the universe.

58 Study of Strange exoplanets

(S.Majal Shiny)
S.Majal Shiny, Karunya Institue of Technology and Sciences BSR Srujith, Aditya Engineering College

Ever since the discovery of the first exoplanet in 1995, more than 4000 exoplanets have been discovered so far. The majority of the exoplanets were discovered by transit and radial velocity methods. And the numbers are only likely to increase prominently, with the number of people (space organizations, citizen scientists, amateur astronomers, etc.) searching for new exoplanets. This passion towards exoplanets among the scientific community is mainly triggered by the possibility of finding an Earth-like world among the others. Our search for earth-like planets and intelligent life has given us insights about the planets that we are never aware of. We have detected a wide range of exoplanets including;- Super-Earths, Hot Jupiters, Mini Neptunes, Hot Earths, and many more. Overall these years of search for Earth-like planets astronomers have also come across many unorthodox exoplanets. In this paper, we study some of these non-conventional exoplanets and try to understand what makes them so strange. After years of studying our solar system and other-planet systems, we have a fair idea of planet formations. But the planets which we focus on here defies most of these ideas and makes us question our understanding of the planet formations. Studying these strange exoplanets can help us understand more about planet formation all over the universe.

59 Asteroseismic modelling of 3000 Kepler red giants: correcting the scaling relation

(Tanda Li)
We present the radial mode identifications and theoretical modelling for ~3,000 red-giant stars observed by the Kepler mission and the correction for the asteroseismic scaling relations for red giants with model-determined masses and radii. We extract radial oscillating mode frequencies and use them to characterise stars. We estimate stellar fundamental parameters with high precision: the median uncertainty is 4.5% for mass, 16% for age, 0.006 dex for surface gravity, and 1.7% for radius. We find a systematic offset of ~15% in the mass and ~7% in the radius between the modelling and scaling relations. Further investigation indicates that the nu_max scaling relation is metallicity-dependent. We also find different scaling relation between Delta nu and mean density for red giants from that for dwarfs: Delta nu value is underestimated by ~4% with the original scaling relation. Lastly, we derive new scaling relations based on modelling-inferred masses and radii for red giants.

60 PLATO Hare-and-Hounds exercise: Modelling main sequence stars

(Margarida Cunha)
In the context of the preparation for the PLATO mission, it is vital to understand the accuracy expected on asteroseismically-inferred stellar properties. To that end, we performed a hare-and-hounds exercise where the

hares simulated data for 6 artificial stars and the hounds inferred their properties based on the data provided and different inference procedures. To mimic a typical pipeline, such as that planed for the PLATO mission, all hounds used the same model grid. Some stars were simulated using the same physics set up as the model grid, others a different one. In this presentation we will show that generally the accuracy on the inferred properties is better than the PLATO requirements. Moreover, we will highlight the impact on the accuracy of the inferred stellar properties from changing different aspects of the physics adopted for the targets, as well as from changing the uncertainties in the classical observations considered in the fit. Interestingly, the results indicate that only a few mode frequencies are required to achieve accurate results on the mass and radius. The same is true for the age, if at least one l=2 mode is detected.

(Presenter: Margarida Cunha on behalf of the PSM WP124)

61 TELESCOPIO NAZIONALE GALILEO as a key-facility for the PLATO follow-up

(Ennio Poretti)
The focal plane instruments mounted at the Telescopio Nazionale Galileo (Roque de Los Muchachos Observatory, La Palma) are currently used to conduct studies on exoplanetary and stellar science, spanning the full visible and near-infrared ranges.

Exoplanetary science at TNG covers topics like blind radial-velocity surveys, mass and density measurements of transiting planets, detection of species by means of transmission and reflection spectroscopy. A particular emphasis has to be given to the results obtained by the Global Architecture Planetary System (GAPS) collaboration, the Italian group born to exploit at best the excellent performances of HARPS-N and GIANO-B.

Accurate radial velocity curves, also from single lines, and detailed abundance analyses of stars at different evolutionary stages are the pillars of the stellar science at TNG.

I intend to the review of the capabilities of the TNG instruments, as well as of new specific techniques, thus showing how the Italian community can play a strategic role in the PLATO follow-up.

62 PBjam: The Prototype Asteroseismology Pipeline for PLATO

(Martin Nielsen)
PBjam is an open source package for Python meant as a prototype of the asteroseismic analysis pipeline for PLATO. The pipeline detects the presence of oscillations in a time series, measures the global asteroseismic parameters, and the frequencies of any oscillation modes that might be present. All of this is done completely automatically, allowing even non-experts access to the information contained in the oscillation frequencies of solar-like stars. PBjam incorporates knowledge gained from previous space missions like CoRoT and Kepler by using simple scaling relations between the physical parameters of a star and the asteroseismic parameters, as well as previous observations to form an informative prior used in the peakbagging process. This approach allows us to continuously update the prior as new measurements from ongoing missions like TESS become available, as well as throughout the duration of the PLATO mission.

63 Automated Recovery of Solar-Like Oscillators: New Detections from TESS

(Emily Hatt)
Plato will provide observations of hundreds of thousands of stars from which asteroseismic candidates will have to be extracted. Therefore, we require an effective method to automate the process, requiring as little supervision as possible. We demonstrate the capabilities of a new detection pipeline built for this purpose by application to TESS data, proving its functionality even when applied to short datasets. In doing so, we present a catalogue of hundreds of new solar-like oscillators, occupying the base of the red giant branch and

extending to the main sequence. These stars occupy a region in seismic parameter space that was sparsely populated by Kepler observations, demonstrating the flexibility of the method across evolutionary phases.

64 Polluted White Dwarfs as Probes of Exoplanetary Interiors

(Andrew Buchan)
The PLATO mission will discover a large number of terrestrial exoplanets, providing measurements of their radii. However, to determine whether an exoplanet is 'Earth-like', we must also understand its geological composition. The composition of a planet has wide ranging implications for its subsequent evolution and habitability. Ground-based follow-up to the PLATO detections can constrain planet masses and inform our knowledge of planetary interiors. In this talk, I will discuss a complimentary technique that can further improve our understanding of planetary composition and the geology of rocky exoplanets.

Polluted white dwarfs which have accreted fragments of rocky objects provide a unique opportunity to probe exoplanetary interiors. These accreted fragments are often rich in either core-like or mantle-like material, which inform us about the core and mantle compositions we can expect to find in exoplanetary bodies.

In this talk, I will present an approach to modelling the abundances of non-Earth-like core and mantle compositions observed in polluted white dwarfs. We use data from metal-silicate partitioning experiments to calculate the effect of non-Earth-like conditions on the distribution of elements between the core and the mantle. The resulting non-Earth-like compositions may be useful for interior structure models of exoplanets.

65 Nonzero eccentricities of warm Neptunes

(Alexandre Correia)
Close-in planets (with orbital periods less than a few days) undergo strong tidal dissipation that should circularise their orbits in a timescale shorter than the age of the system. However, most Neptune-mass planets in this kind of orbits present nonzero eccentricity, typically around 0.15. In this talk we discuss some mechanisms that can oppose to gravitational tides, namely, thermal atmospheric tides, evaporation of the atmosphere, and excitation from a distant companion. We show the limitations of these different mechanisms and how some of them could, depending on specific properties of the observed planetary systems, account for the nonzero eccentricities presently observed.

66 On the photometric magnetic activity and active-region lifetimes of Kepler solar-like stars

(Angela Santos)
The light curves of magnetically active solar-like stars — stars with convective outer layers — may exhibit rotational modulation due to magnetic features, namely dark spots, co-rotating with the stellar surface. In addition to constraints on rotation properties, rotational modulation can also provide details on stellar magnetic activity. Thanks to planet-hunting space missions, hundreds of thousands of solar-like stars (from spectral types mid-F to M) have been photometrically monitored in a continuous way. In particular, from those, the long-term observations collected during the NASA Kepler main mission, and those that will be collected by the future ESA M3 PLATO mission, are preferred for a better characterisation of magnetic activity. In this work, we investigate the temporal variability of the photometric magnetic activity proxy Sph, as well as the characteristic timescale of active-regions in solar-like stars observed by Kepler. The initial target sample corresponds to the 55,000+ stars with detected surface rotation periods from Santos et al. (2019, in press). We find that stars that are on average photometrically more active are also more variable in time. This relationship is known for the ground-based chromospheric activity index, but here we demonstrate that Kepler photometric data show a similar behaviour. We find that there is an additional dependency of the Sph variability on the rotation period, even after accounting and removing for dependencies on the remainder of the stellar parameters. As for the observed active-region timescale, which is a lower limit to the lifetime (Santos et al. submitted), we find that it is dependent on rotation period, photometric activity level, and

effective temperature. Knowledge on both properties, variability of magnetic activity and the lifetimes of the active-regions responsible for such variability, is key to improve the determination of habitable zones of the planetary systems and help to better understand the activity signatures that disguise or mimic the planetary signals.

67 On the synergies of PLATO, the Roman Telescope and next-generation direct-imaging missions

(Óscar Carrión-González)

PLATO and the Nancy Grace Roman Space Telescope are expected to be launched before the end of this decade. Their planned mission lifetimes are 6.5-8 years in the case of PLATO and 5-10 years in that of Roman. Both telescopes will therefore coexist for several years, enabling contemporaneous, synergistic science. In this talk we describe how PLATO measurements of transiting exoplanets may help in the characterization of directly imaged exoplanets with the Roman Telescope's coronagraph. This instrument will be the first to perform direct-imaging observations of exoplanets in reflected starlight. This technique will unveil a population of nearby long-period exoplanets that are not accessible to atmospheric characterization with current facilities. PLATO will study a related population of long-period exoplanets, and some of them might indeed be accessible to both missions. We show that the measurement of the planet radius with PLATO will remarkably improve the prospects for characterizing the atmospheres of directly-imaged exoplanets in reflected starlight. We also present a list of potential targets for the Roman Telescope's coronagraph and discuss the possible overlapping between the target lists of both missions. We conclude that working in tandem, both missions will complement each other and prepare the path for the next generation of direct-imaging telescopes.

68 Solar-like variability can be amplified by active-region nesting

(Emre Isik)

Many solar-type stars with near-solar rotation periods exhibit much stronger variability than the Sun (Reinhold et al. 2020, Sci. 368, 518). Some of these stars show very regular, sine-like light curves. Motivated by the existence of sunspot nests, we developed a numerical model to quantify the effects of active-region (AR) nesting on stellar brightness variations on the rotational timescale. Modelling ARs with facular and spot components, we simulated Kepler-band light curves covering four years. We found that the combined effect of the degree of nesting and the activity level, both being somewhat higher than on the Sun, can explain the whole range of observed light-curve amplitudes of solar-like stars. While nesting at random longitudes can explain variability amplitudes and light-curve morphology in many cases, active-longitude-type nesting reproduces sine-like light curves and the highest observed variability levels. (Ref: Isik et al. 2020 ApJL 901, L12)

69 Radial Velocities and Magnetic Flux Estimates via Least-Squares Deconvolution

(Florian Lienhard)

To push the exoplanet detection threshold, it is crucial to find more reliable radial velocity extraction methods. The Least-Squares Deconvolution (LSD) technique has been used to infer the stellar magnetic flux from spectropolarimetric data for the past two decades. It relies on the assumption that stellar absorption lines are similar in shape and only scale up by a wavelength-specific factor. Although, this assumption is simplistic, LSD provides a good model for intensity spectra and likewise an estimate for the Doppler shift of stellar spectra. We built a pipeline based on LSD, which extracts the radial velocity from 2D echelle-order spectra after applying state-of-the-art preprocessing techniques. Within this pipeline, the flexibility of LSD allows to exclude spectral lines or pixels at will, providing a means to exclude variable lines or pixels affected by instrumental problems. It can be shown that the LSD pipeline delivers better results than, for instance, the HARPS-N CCF RV extraction pipeline. I will present the LSD technique, some intermediate and final pipeline results, and discuss how this technique may be modified and extended to extract a proxy for the magnetic field strength.

70 The amazing properties of the L 98-59 system

(Olivier Demangeon)
For this talk, we like to present a planetary system which is destined to become a corner stone for comparative exoplanetology of terrestrial planets: The L 98-59 system. L 98-59 is a bright M-dwarf located 10.6 pc away around which 11 TESS sectors have revealed three terrestrial size planets. We would like to present the outcome of our radial velocity campaign with the ESPRESSO spectrograph (66 RV points), which complement a campaign with the HARPS instrument (165 RV points). The extreme radial velocity precision of ESPRESSO allowed us to characterize this system in exquisite details. We achieved a new milestone with the measurement of the mass of L 98-59 b, a rocky planet with half the mass of Venus. We also announce the discovery of a fourth non-transiting planet with a minimum mass of 3.06_{-0.37}^{+0.33} M_Earth and an orbital period of 12.796_{-0.019}^{+0.020} days and report hints for the presence of a fifth non-transiting terrestrial planet. If confirmed, with a minimum mass of 2.46_{-0.82}^{+0.66} M_Earth and an orbital period 23.15_{-0.17}^{+0.60}$ days, this planet would sit in the middle of the habitable zone of the L 98-59 system. L 98-59 b and c have densities of 3.6_{-1.5}^{+1.4} and 4.57_{-0.85}^{+0.77} g.cm^{-3} respectively and have very similar bulk compositions with a small iron core, representing only 12 to 14,% of the total mass, and a small amount of water. However, with a density of 2.95_{-0.51}^{+0.79} g.cm}^{-3} and despite a similar core mass fraction, up to 30 % of L 98-59 d's mass could be made of water. The three transiting planets have transmission spectrum metrics ranging from 49 to 255 which put each one of them the best or the second best targets for atmospheric characterization with the James Webb Telescope in their radius range. More generally this three planets offer a unique opportunity to study the diversity of warm terrestrial planets atmospheres without the unknowns associated with different host stars with future and current space and ground-based facilities. This system and the analyses of the large TESS, ESPRESSO and HARPS datasets are a good example of the challenges and rewards that lies ahead with PLATO.

71 Pulsation study of KIC 695142: A single-lined fast-rotating spectroscopic system with hybrid (γ Dor/δ) pulsations

(Anya Samadi-Ghadim)
γ Dor/δ Scuti pulsating variable stars are very important astrophysical objects if we consider the hybrid pulsations of some of these stellar subgroups (i.e with the pulsation modes excited both at close-to-core and close-to-surface regions), their structure that goes through a transition phase (in their envelope) and their role as the progenitors of hot subdwarf B stars and finally the intermediate to fast rotation of most of them. Studying the stellar structure and evolution of γ Dor/δ Scuti Scuti pulsating stars brings us a remarkable understanding of stellar astrophysics in many important aspects. A/F-type stars with γ Dor/δ Scuti pulsations in binary systems are important astrophysics laboratories. The detection of pulsations in binary systems also provides the possibility to check the influence of binarity (e.g. tidal effects ; mass transfer, chemical peculiarities, the presence of a third body, etc.) on stellar structure, evolution, and the excited oscillation modes. Besides, there is also the rotation that can play a significant role in the evolution of a binary system. In this work we have used the unprecedented photometry data from Kepler to detect the pulsations in KIC 695142. The spectroscopic study shows that the target is a long-period single-lined binary system with effective temperature Teff = 7336 ± 186 K, and the projected rotational velocity vsini =123 ± 3 Km/s for the fast rotating companion star. We detected several period spacings patterns for g-modes/r-modes inanition to several multiplets of rotational frequency-splitting among both g- and p-modes.

72 Precise mass for 1.9-Earth-radii sub-Neptune transiting the nearby, bright M dwarf K2-313

(Grzegorz Nowak)

We present an independent discovery and detailed characterisation of a transiting 2-Earth-radii sub-Neptune observed by K2 in campaign 17 orbiting the nearby (d ~28 pc), bright (V = 13.82 mag, J = 10.06 mag) M2.5 dwarf K2-313 with a 5.75-day period. We confirm transiting planet via ground-based photometry and determine its mass using precise radial velocities measured with the CARMENES spectrograph. The radius, mass, and bulk density of the planet are equal to Rb = 1.87 +/- 0.07 R_Earth, M_b = 3.93 +/- 0.80 M_Earth, and rho_b = 3.29 +/- 0.79 g/cm^3. Located very close to the radius gap and with the transmission spectroscopy metric, TSM = 99 +/- 24 is an excellent target for atmospheric studies with the James Webb Space Telescope (JWST), as well as for testing planetary formation, evolution, and atmospheric models.

73 The MPS-ATLAS limb darkening library.

(Nadiia Kostogryz)

All of the techniques used to characterize exoplanets require a good knowledge of stellar limb darkening. We use the recently developed **M**erged **P**arallelised **S**implified ATLAS (MPS-ATLAS) code, based on the ATLAS9 and DFSYNTHE codes, to compute spectral center-to-limb intensities and limb darkening in different broad-band filters (Kepler, TESS, PLATO, CHEOPS) for an extensive grid of stellar model atmospheres. The stellar parameters cover $3500\ K \leq T_{\rm eff} \leq 9000\ K$, $-5.0 \leq M/H \leq 1.5$, and $3.0 \leq \log g \leq 5.0$. Our grid is finer than other available grids and thus leads to smaller interpolation errors. We show that for the solar case the center-to-limb intensity is in excellent agreement with available observations.

74 Tidal dissipation in stars and predictions for planetary orbital decay

(Adrian Barker)

I will present state-of-the art calculations studying tidal dissipation in MKGF stars throughout their evolution. The models incorporate turbulent viscosity acting on equilibrium tides and inertial waves in convection zones, and internal gravity waves in radiation zones, based on our latest understanding of each mechanism. I will use these models to compute tidal evolutionary timescales for the orbital evolution of short-period planets and the spin evolution of the host stars. I will also provide predictions for shifts in transit arrival times due to tidally-driven planetary orbital decay for the closest hot Jupiters that may be detected with NGTS, TESS and PLATO.

75 Optimizing Science Return from Plato's Observations of the Kepler Field

(Jack Lissauer)

The Plato mission could substantially enhance its scientific yield by focusing a significant fraction of its observations with all 24 cameras viewing the Kepler Field of View (FOV). Kepler, while exceptionally productive, did not accomplish its goal of providing a direct measurement of the abundance of Earth-analog planets around sunlike stars. On this issue, Plato observations centered on the Kepler FOV would enable planet searches using the combined data sets to achieve more precise estimates of planetary occurrence rates than obtainable using data from either mission alone. The ecliptic latitude of the Kepler FOV is too low for Plato to observe with 24 cameras year-round, so current plan's for Plato's Northern Stare places the Kepler FOV in the periphery, reducing the number of photons collected from Kepler targets by factors of 2 or 4. We propose instead four ~6 - 8 month Plato stares with 24 cameras observing the Kepler FOV during the Plato primary mission, instead of a single 2 year stare with the Kepler FOV located to the periphery. This change would greatly increase the amount of 'Plato glass' dedicated to the continued study of the Kepler FOV, while still enabling Plato to observe other parts of the sky during the majority of its prime mission. In addition to discovering planets below Kepler's detection threshold, this change would yield transit follow-up of thousands of known exoplanets with an effective throughput of a 0.6 m space telescope. It would also extend the observing baseline of the Kepler FOV to timescales of decades, providing key data for stellar cycles, the analysis of transit timing variations, and other decade-timescale variations. Such a campaign enhances the likelihood of the detection of true Earth-analog transiting planet candidates around sunlike stars, provide the best statistical study of exoplanet systems with transit timing variations and duration variations, and open up the study of stellar variability to new time-domains with precision on large numbers of faint targets that only 24 Plato cameras can provide.

76 LIFE – characterizing the climates of terrestrial exoplanets in the wake of PLATO

(Tim Lichtenberg)
The atmospheric characterization of terrestrial exoplanets and the search for habitable worlds has recently been identified as a cornerstone of the ESA long-term vision in the 2035–2050 time frame. Doing so will require spatially separating the signals from exoplanets and their host stars; the LIFE mission concept (Large Interferometer for Exoplanets; life-space-mission.com) will achieve this by employing a free-flying nulling interferometer that directly probes the emission of the atmospheres and surfaces of terrestrial exoplanets in the mid-infrared wavelength range. In this contribution, we will present the current status, recent results, and ongoing activities that further develop the LIFE mission concept and outline anticipated synergies between PLATO and LIFE. The intensive reconnaissance of planetary system architectures and detailed information on the masses, radii, and ages of terrestrial exoplanets by PLATO will enable LIFE to intimately characterize the climates of nearby, potentially habitable worlds. Constraints on bulk volatile content and the spatio-temporal location of the runaway greenhouse transition will enhance LIFE's capabilities to investigate the occurrence rate of reduced atmospheres, which favour Earth-like biosynthesis. In order to strengthen the scientific case for a European exoplanet flagship mission, we will showcase the current roadmap and opportunities for the exoplanet community to contribute to this long-term goal.

Authors: T. Lichtenberg, D. Angerhausen, C. Dorn, L. Noack, S. P. Quanz, and the LIFE Collaboration

Note: TL submitted another contribution as first author. If selected and one oral presentation is the maximum for one person, please favour this LIFE abstract.

77 Exoplanets in stellar clusters and young associations: the pathway from TESS to PLATO

(Domenico Nardiello)
The accurate knowledge of the ages of stars hosting planets allows us to obtain an overview on the evolution of exoplanets and understand the mechanisms affecting their life. The measurement of the ages of stars in the Galaxy is usually affected by large uncertainties; an exception are the stellar clusters and the associations: for their coeval members, born at the same time from the same molecular cloud, ages can be measured with extreme accuracy through the use of theoretical models. In the context of the project PATHOS, new candidate exoplanets orbiting members in stellar clusters and associations have been found and characterized by using TESS light curves extracted and analysed with appropriate cutting-edge tools. In this context, important results have been already obtained, like the estimate of the frequency of candidate exoplanets around stellar clusters' members and the empirical relationship between stellar age and planetary radius; the same project have provided ancillary results as the gyro-chronological analysis of stars in youthful associations (<10 Myr) and the asteroseismic studies of field RGB stars. However, this is only the tip of the iceberg, and the future combination of TESS and PLATO light curves (combined with the cutting edge tools I developed) will be essential to search for long-period (>1 year), small-radius (1-3 Re) exoplanets orbiting members of

stellar clusters and associations, and shed light on the formation and evolution of planetary systems in the Galaxy.

78 SOAP-GPU: Efficient Spectral modelling of stellar activity using graphical processing units

(Yinan Zhao)
Stellar activity mitigation is one of the major challenges for the detection of earth-like exoplanets in radial velocity measurements. Several promising techniques are now investigating the use of spectral time-series, to differentiate between stellar and planetary perturbations. In this context, developing a oftware that can efficiently explore the parameter space of stellar activity at the spectral level is of great importance. In this talk, I will introduce a new version of the Spot Oscillation And Planet (SOAP) 2.0 code that can model stellar activity at the spectral level using graphical processing units (GPUs). Benchmarking calculations show that this new code improves the computational speed by a factor of 60 while having the same accuracy. On top of that, we implemented a realistic simulation of activity on solar-type stars (number of active regions, evolution), therefore allowing to generate realistic spectral time-series affected by activity perturbations within seconds.

The outcome of this code is essential to test any algorithm that tries improving planetary signal detection by mitigating stellar activity at the spectral level.

79 Eta-Earth Revisited: Estimating a Maximum Number of Earth-like Habitats

(Manuel Scherf)
Our definition of Eta-Earth builds on the concept of a so-called Earth-like Habitat (EH), i.e., a planet within the complex habitable zone for life, at which N_2 and O_2 are simultaneously present as the dominant species while CO_2 only comprises a minor constituent in its atmosphere. By our present scientific knowledge, certain criteria must be fulfilled to allow the existence of such an Earth-like atmosphere which can be subsumed within a new probabilistic formula for the estimation of EHs (see the talk "Eta-Earth Revisited: A Formula for Earth-like Habitats"). Some of these criteria, such as the initial mass function, the bolometric luminosity and XUV flux evolution of a star, or the distribution of rocky exoplanets within the habitable zones of different stellar spectral types, are already rather well studied and can be tested through further observations. Other important criteria, like the prevalence of working carbon-silicate and nitrogen cycles, and of the origin of life are by now poorly constrained. Further factors, like the presence of a large moon or the importance of an intrinsic magnetic field are not only poorly constrained but its significance for the evolution and stability of an EH are even debated. While our new formula for the estimation of EHs can in principle incorporate all these factors as well as unknowns, we by now must restrict ourselves to the ones that are either well understood or can at least be tested soon. Based on our current knowledge, this approach only allows us to probabilistically estimate a maximum number of exoplanets on which an EH can in principle evolve. The real number of EHs might, therefore, be significantly lower than our current best estimate but additional criteria should be verifiable in near future by upcoming ground- and space-based instrumentation such as PLATO or the E-ELT. Such an estimate does further not include any habitats other than EHs.

80 Eta-Earth Revisited: A Formula for Earth-like Habitats

(Helmut Lammer)
A formula that can be used to estimate the maximum number of Earth-like habitats in the Galaxy where N_2-O_2-dominated atmospheres, produced by well working, plate tectonic-based carbon-silicate cycles and aerobic complex life forms, will be presented. Crucial factors that are related to the accretion of terrestrial planets, disk lifetime, the XUV flux history of the planets host stars, sources of a planet's volatiles and geophysical processes that are necessary for carbon-silicate and nitrogen-cycles that work well over billions of

years are discussed. After the definition of these basic requirements and atmospheric limitations for aerobic complex life on potentially habitable rocky exoplanets that resample our Eta-Earth definition, it is shown that it is scientifically not justified to presume an astrobiological Copernican assumption that all potential habitats inside a habitable zone for complex life will evolve similar to an Earth-like planet where aerobic complex life forms can evolve. We introduce a new formula that contains realistic probabilistic arguments that can be constrained by the characterization of their main atmospheric species with future space observatories and large ground-based telescopes such as the EELT for obtaining results that are more accurate compared to previous estimates by formulae such as the highly speculative Drake equation.

81 New Predictions of PLATO's Yield of Earth-sized Transiting Planets in the Habitable Zone of Sun-like Stars

(René Heller)
We present new estimates of the transit detection capabilities of the PLATO satellite for Earth-sized planets in Earth-like orbits around sun-like stars. We use the PLATO Solar-like Light curve Simulator (PSLS) to simulate almost 10,000 light curves with and without transiting planets around bright ($m_V \leq 11$) solar type stars. The cadence of 25 s is roughly representative of the > 15,000 targets in PLATO's high-priority P1 sample (mostly F5-K7 dwarfs and sub-dwarfs). We study light curves from synchronous observations of 6, 12, 18, and 24 of PLATO's 12 cm aperture cameras over both 2 yr and 3 yr of continuous observations. Automated detrending is done with the Wotan software and post-detrending transit detection is performed with the Transit Least Squares (TLS) algorithm. Our transit injection-and-retrieval tests in the combined light curves from 24 cameras demonstrate that Wotan and TLS produce true positive rates (TPRs) near unity (all injected planets are recovered) for planets $\geq 1.2 R_{Earth}$ with two transits in 2 yr light curves of the P1 stars. In 3 yr light curves with three injected transits, planets as small as 1 R_{Earth} are recovered with TPRs near 100 %, highlighting the value of a third transit. In the combined 2 yr (or 3 yr) light curves from 6 cameras, transits of Earth-sized planets get lost in the stellar noise of sun-like stars for $m_V \geq 10$ (or $m_V \sim 11$). We scale the TPRs from our experiment with the expected number of stars in the P1 sample and with modern estimates for the occurrence rates of extrasolar planets and predict the detection of planets with 0.5 $R_{Earth} \leq R_p \leq 1.5 R_{Earth}$ in the habitable zones around F5-K7 solar-type stars. For the (2 yr + 2 yr) strategy of the two long-duration observation phase fields we predict 11-42 detections, for the (3 yr + 1 yr) strategy we predict 8-28 discoveries. These estimates neglect exoplanets with mono transits, serendipitous detections in stellar samples P2-P5, a better removal of the actual PLATO data from systematic effects than in our experiment, and a possible bias of the P1 sample towards brighter stars and high camera coverage due to noise requirements. As an opposite effect, Earth-sized planets might typically exhibit shallower transits around P1 sample stars than we assumed since the sample will be skewed towards spectral types earlier than the sun. Our estimated planet yield for PLATO will mean a major contribution to this yet poorly sampled part of the exoplanet parameter space with Earth-like planets.

82 Can we (really) achieve a 2-5% precision with PLATO in presence of stellar activity ?

(Sophia SULIS)
Stellar activity is known to limit exoplanet detection and characterization. Among this activity, stellar convection evolves during the typical transit timescales (~ hours) and affects the inferred transit parameters.

In this contribution, we present realistic simulations of transiting exoplanets based on solar HMI data. These simulations include planets from 1 to 10 Earth radii with different transit geometries. These simulations comprising hundreds of light curves are already available to the community (https://doi.org/10.5281/zenodo.3686871).

We analysed the data using standard MCMC methods assuming the noise is a) white and Gaussian, or b) a Gaussian Process. We show that, in both case, the resulting planet parameters can be affected by biases, which leads to biased planetary radius measurements. This demonstrates the need to develop robust stellar

noise modelling to achieve PLATO's goal of characterizing exoplanets transiting solar-like stars. Next steps of this study will be to investigate how other noise sources (e.g., flares, spots and faculae) affect the inferred exoplanet parameters.

83 Habitability and loss of hydrogen-helium atmospheres of small planets - the K dwarf advantage

(Katja Poppenhäger)

Evaporation of hydrogen and helium is now directly observable for exoplanets of Jupiter and Neptune size, by using high-resolution spectral observations in the ultraviolet and in the infrared. For even smaller planets, the ongoing loss of a primordial hydrogen-helium atmosphere has not been directly observed yet, but is thought to be relevant for the formation of a habitable atmosphere for life as we know it. The observability of helium escape depends critically on an exoplanet's irradiation in the high-energy regime. M dwarfs, typically a favourite target for habitable zone exoplanet observations, are at a disadvantage here due to their coronal elemental abundance patterns. However, K dwarfs present a suitable starting point for detecting helium escape from planets in their habitable zones, due to their favorable coronal abundances and their higher magnetic activity level compared to G dwarfs. I will discuss relevant examples and outline the impact that modern high-energy surveys can have on the optimal target selection for observing exoplanetary atmospheric escape.

84 what makes a stellar surface facular or spot dominated?

(Eliana Amazo-Gomez)

In Shapiro et. al 2020 and Amazo-Gomez et al. 2020a-2020b we showed that the rotation periods of stars with complex brightness variations, as for the case of the Sun, can be reliably determined from the profile of the gradient of the power spectra (GPS). By characterizing the particular shape generated by facular (M-like shape) or spot (V-like shape) transits recorded in total solar irradiance, we quantified within the solar analogy, whether the stellar surface was dominated by facular or spot regions. Interestingly, we found that Sun-like stars are distributed between three different regimes, spot dominated, faculae dominated, and stars in a transition between the two branches. In particular, those ramifications still happen even for stars with very similar stellar parameters (such as rotation period, effective temperature, and estimated age). This poses the question of what makes a stellar surface faculae or spot dominated?. In order to address this question, we performed an additional spectroscopic analysis of the stellar activity for twin stars and compare these results with the previous photometric characterization. In this contribution, we will present the findings of our photometric and spectroscopic comparison.

85 Transit-Radial Velocity synergy to unveil the young exoplanet population and study the evolution of planetary systems

(Serena Benatti)

The architecture of planetary systems evolves significantly with time, with several mechanisms acting on different timescales: migration within the native disk, expected to occur on few Myrs before disk dissipation; planet-planet dynamical instabilities, gravitational interactions, and circularisation of the orbit by tides from the host stars, which could be active on much longer timescales. Understanding the original configurations of the systems and the timescales on which these various mechanisms work is easier when observing planetary systems at young ages, with planets closer to their formation time and possibly also to their birth-sites. Transit space missions are significantly contributing in our view of young planetary systems at close separations, providing robust candidates to be followed-up with the radial velocity (RV) technique and to investigate their orbital and physical evolution. Indeed, these targets are also useful to validate models of planetary evolution as the result of the atmospheric photo-evaporation due to the high-energy irradiation of the young stellar host. Considering the crucial role played by previous space-based transit missions, PLATO is going to represent an unprecedented source of young planet candidates, allowing this field to enlarge the available sample and finally perform statistical investigations.

86 Science case for the study of Exoplanetary phase curves with PLATO

(Vikash Singh)

The PLAnetary Transits and Oscillations of stars (PLATO) telescope is going to study a large number of extrasolar planetary systems. Given the design of the mission, PLATO will produce long-duration uninterrupted high precision photometry of extrasolar systems. As a result, PLATO is best suited for acquiring optical phase curves of transiting exoplanets in the JWST era. We present a scientific motivation for the observation of short-period, highly-irradiated transiting exoplanets. The close proximity of a short-period planet favors the planet-to-star flux contrast for two reasons. Firstly, the short semimajor axis enhances the reflection of the stellar light by the planet and secondly, the high irradiation leads to thermal emissions detectable even in the optical domain. The signal-to-noise ratio of the secondary eclipse and phase variations increases significantly by phase-folding the light curve obtained over multiple orbits of the planet which is again a noteworthy consequence of prolonged observations with PLATO. Such measurements are crucial for characterizing the atmospheres of exoplanets as they provide estimates on their atmospheric albedo, brightness temperatures, and heat re-distribution around the hemispheres. In addition to that re-observation of Hot-Jupiters can also provide great insights on the variability of winds, clouds, temperature-pressure profile, etc. in response to the stellar activity cycles. Phase curves also contain information on stellar tidal deformation due to a massive companion. Therefore, a well-characterized phase curve also helps in a better characterization of the host star. Lastly, the high-precision phase curve obtained with PLATO also provides a great opportunity to study non-transiting exoplanets, allowing their atmospheric characterization and constraining their orbital inclinations and true masses.

87 Radial velocity follow-up of young transiting planets: promising results from selected case studies

(Mario Damasso)

The blind detection of young planets (with an age from few to few hundreds of Myr) is very challenging, mostly due to the intense stellar activity of their host stars, that can easily mask planet-induced signals in radial velocity (RV) time series. The discovery of such planets transiting their hosts, thanks to Kepler/K2 and TESS in particular, offered very interesting opportunities for their characterisation, leading to growing investment in the spectroscopic follow-up of their hosts. Measuring masses of transiting young planets, therefore increasing the population in a mass-radius diagram, is of primary importance for reconstructing a system formation and early evolutionary history, quantifying the evolutionary time scales, and providing observational constraints to the evolutionary theoretical models. We will present results from RV follow-ups mostly carried out with HARPS-N at TNG within the Italian project GAPS, and with HARPS and other instruments through dedicated observing programs. We will discuss specific young systems, such as TOI-942, DS Tuc A and V1298 Tau, discussing the observational and astrophysical challenges and showing the ongoing development of sophisticated analysis techniques, that are driving the enhancement of physical interpretation frameworks. The experience acquired so far thanks to these case studies, including synergies with other facilities for a multi-messenger follow-up, demonstrates the primary role of PLATO in increasing the demographics of the young planets, and understanding the diversity of the planetary system architectures.

88 On the Potential of the Reynolds Stress Approach to Model Convective Overshooting in Grids of Stellar Evolution Models

(Friedrich Kupka)

Convection is one of the main physical processes probed by means of asteroseismology these days and it is a key topic of several workpackages within the PLATO mission. A lot of attention in this field is currently given to the parameter calibration of fairly simple models by means of 3D RHD numerical simulations or the direct use of the latter in asteroseismological analyses. However, this approach is not available to all situations of interest where convection plays a role in stellar mixing and in the evolution of the thermal structure of a star, particularly not for overshooting and mixing when they take place deeply inside a star. For such cases Reynolds stress models provide an interesting alternative. In this talk I will report on the potential of this method, also for future calculations of model grids for asteroseismology, and summarize earlier results and recent progress made with this approach.

89 How NGTS observations at Paranal can support PLATO

(Peter Wheatley)
I will describe how observations with the twelve high-precision cameras of the NGTS facility at the ESO Paranal observatory can support the PLATO mission. This includes learning how to combine data from multiple camera to achieve maximum precision. NGTS is already being used to test PLATO algorithms, and we routinely achieve a photometric precision of 150 ppm, which is unprecedented for ground-based observations of bright stars. NGTS can also carry out a pre-survey of PLATO fields in the Southern Hemisphere, identifying variable stars, stellar activity and rotation periods with higher spatial resolution than can be achieved with TESS.

90 Study of the effects of magnetic braking on the lithium abundances of the Sun and solar-type stars

(Roque Caballero)
Despite decades of theoretical efforts, a coherent explanation for the lithium abundance, A(Li), discrepancies detected in star clusters cannot be found. In young and old clusters these differences have been documented for stars in both pre-main sequence (PMS) and main sequence (MS) evolutionary stages. In order to settle this question, PLATO represents a great opportunity, since it will characterize in detail a significant number of stars.

In this work, we used the stellar evolution code MESA to model the effects of magnetic braking (MB) on the A(Li) of the Sun and solar-type stars. We have investigated the evolution of the surface A(Li) along the star life-cycle, from PMS to MS, introducing a new routine able to compute the MB. The angular momentum loss (AML) is derived from the torque applied by a magnetically-coupled stellar wind through a semi-empirical approach. We have shown that the effects induced by the combination of both rotation and MB mechanisms point to a solution to the A(Li) problem.

The results presented in this work may have a significant impact in understanding the physical mechanisms of MB and AML. The MB is the base for gyrochronolgy studies and therefore a better understanding will improve our ages estimations. Moreover, all these processes are key for a better characterization of solar-like stars hosting planets, which is the main objective of the PLATO mission.

91 Seismic asphericity of Kepler Sun-like stars

(Othman Benomar)
Since the release of the first Kepler data, our knowledge of the stellar rotation and activity has substantially improved; however it remains challenging to measure their effects in asteroseismic data. The main effect of rotation on oscillations is to produce a rotational splitting between modes that propagate prograde and retrograde (modes with opposite values of the azimuthal order m). Rotation also leads to a centrifugal distorsion of the stellar shape, which causes a frequency shift that depends on the latitudinal sensitivity of the modes (on the unsigned value of m). The presence of a magnetic field at particular latitudes leads to an additional source of asphericity in the seismic data (acoustic modes propagate faster in magnetic regions). All the above effects are measurable in helioseismology. Once the measured helioseismic asphericity is corrected

for rotational oblateness, the Sun appears prolate to seismic waves at cycle maximum (when low-latitude magnetic activity is present, see Woodard & Noyes 1985, Libbrecht & Woodard 1990; Antia et al. 2001). The Sun set aside, very few studies have discussed seismic asphericity in the context of stars (Gizon et al. 2016; Benomar et al. 2018). Using methods derived from Gizon (2002), we show that significant seismic asphericity is measurables in many Kepler main-sequence Sun-like stars. As for the Sun, seismic asphericity on other stars is often incompatible with a pure centrifugal distortion and informs us about the level and latitudinal distribution of stellar magnetic activity.

92 Dynamically Informed Habitable Zones in Circumbinary Planetary Systems

(NIKOLAOS GEORGAKARAKOS)

Abstract: To date more than three dozen binary star systems are known to host circumbinary planets. Determining habitable zones in stellar binaries can be a challenging task due to the combination of perturbed planetary orbits and varying stellar irradiation conditions. The concept of "dynamically informed habitable zones" allows us, nevertheless, to make predictions on where to look for habitable worlds in such complex environments. Here, we present a method for calculating dynamically informed habitable zones in circumbinary systems. We provide analytical estimates for such systems, even when when another giant planet is present in the system. By applying our methodology to Kepler-16, Kepler-34, Kepler-35, Kepler-38, Kepler-64, Kepler-413, Kepler-453, Kepler-1647 and Kepler-1661, we demonstrate that the presence of the known giant planets in the majority of those systems does not preclude the existence of potentially habitable worlds. Among the investigated systems Kepler-35, Kepler-38, and Kepler-64 currently seem to offer the best conditions for an Earth-like analog. Our results can be beneficial to missions such as Plato and increase the impact of new discoveries in exoplanetary systems.

93 What to expect from non-seismic stellar characterisation with PLATO lightcurves

(Lisa Bugnet)

Global stellar parameters such as the mass, radius and surface gravity are key for our understanding of stars and exosystems evolution. However, only a small fraction of observed stars can be precisely studied with Asteroseismology, resulting in a large amount of stars with consequent uncertainties on their global parameters. Seismic-independent methods are, therefore, being developed in order to estimate the surface gravity precisely and automatically for all observed solar-like stars. The FliPer is one of most recent and precise methodologies; it exploits the use of a Random Forest machine learning algorithm to provide an estimation of surface gravity based on the global power density of each star. It has been successfully applied to classify and to characterize evolved solar-like stars observed by Kepler, with a 0.05dex uncertainty in average on the final estimation of their surface gravity. This result makes it the most precise non-seismic method for the characterization of the surface gravity of evolved solar-like stars. The FliPer algorithm, however, has to be re-trained and re-tested when new types of data come into play. In the context of the PLATO mission, most stars that will be observed will be younger than those observed by Kepler. In order to investigate the applicability of the FliPer method for the soon-to-come PLATO data, we present the adaptation of the FliPer method for the characterization of main-sequence stars observed during the TESS mission. The expected precision and accuracy on the measure of the surface gravity are investigated, and the applicability range of the method in term of evolutionary stage and stellar type is presented.

94 Structure and evolution of young stellar objects: the importance of PLATO observations

(Konstanze Zwintz)

Space observations of young stellar objects allow investigating the earliest phases of stellar evolution which

are crucial for our understanding of the complete life cycle of stars and the formation of planets. Thus we have the unique opportunity to connect our knowledge of main sequence and post-main sequence stars to their earlier evolutionary phases. This is particularly important in the domain of solar-like stars and raises the question, if we can find the young Sun. We will illustrate the importance of observing pre-main sequence stars with PLATO.

In collaboration with the T'DA group and TASOC, we have developed a new classifier to identify pre-main sequence stars based on their typical features for the TESS mission. This classifier will also be adapted for the PLATO mission in the future and facilitate research on young stellar objects.

95 Searching for planets around massive stars in open clusters

(Elisa Delgado Mena)
Our ability to detect planets around stars with the radial-velocity (RV) method has a strong dependence on our understanding on the stellar jitter of such stars which can reach dozens of m/s in red giants. This intrinsic RV variability can be caused by stellar magnetic activity, pulsations or granulation and it behaves on a different way depending on the spectral type of the stars and on their evolutionary stage. In this work we present the results of a RV survey to search for planets around intermediate-mass stars in 25 open clusters. The long-term observations allowed us to discover new binaries, brown dwarfs and few planet candidates around stars more massive than 2 solar masses. Additionally, we study the dependence of RV jitter on stellar mass, age and evolutionary status. Finally, we present the intriguing RV signals detected in some stars which mimic long-period planets (P~700 days) and are stable for a period of 15 years. However, these RVs are correlated with the FWHM or the BIS (Bisector Inverse Slope) of the CCF. We discuss the possibility of whether we might be facing a new kind of stellar pulsations or the RV variability is caused by long-term stellar activity.

96 On the age determination of the open cluster α Per with asteroseismology

(David Pamos Ortega)
In this work we discuss a new potential method to determine the age of open clusters based on asteroseismic indices of A-F type stars. The method studies the sensitivity to age of some seismic indices such as low-order spacings (García Hernández et al. 2009, Suárez et al. 2014) or the frequency of maximum amplitude (ν_{max}) for those stars (Barceló-Forteza et al. 2018, 2020). The method consists in four steps: (1) a spectral analysis with our code *MultiModes*, whose precision (as we show here) is similar to that of the well-known SigSpec code, but by ways more efficient in terms of computing time; (2) with the oscillation spectra we applied the method of GH09 to obtain their low-order large spacing ($\Delta\nu$); (3) we compute ν_{max} following BF18 and calculated Teff with the relation ν_{max}-Teff from BF20; (4) we constrained the models representative of those stars with this $\Delta\nu$ and Teff from a pre-computed grid of 1D, rotating, asteroseismic models (including adiabatic oscillation corrected for rotation). We recall the importance of using rotating models in early-type star modelling (even isochrones) as we will show. Here we report the results of applying the method to a sample of δ Scuti stars belonging to α Per open cluster, for which we analyse the short-cadence data obtained by the TESS mission. We discuss the first results obtained as compared with classical dating with isochrones and Li depletion boundary as well as benefits and limitations of this methodology.

97 Evolution of Mixed-mode Coupling Factor in Red Giant Stars: Impact of Buoyancy Spike

(Chen Jiang)
Mixed modes observed in red giants enable us to investigate the interior structures of stars. One of these important structures is the buoyancy spike that is caused by the discontinuity of the chemical gradient left behind during the first dredge-up. The buoyancy spike emerges in low-luminosity red giants and becomes a

glitch with the growing scale in a more evolved stage before the red-giant bump. Here, I will present our recent study about the evolution of the coupling factor with the purpose of studying the impact of buoyancy spike on the mixed modes. The analysis is performed through the comparisons between the asymptotic coupling factors and those obtained from fitting the theoretical frequencies for dipolar mixed modes in a series of red-giant models with different initial masses and chemical abundances. We show that the type of the evanescent zone can be distinguished by taking the location of the buoyancy spike into consideration. The transition from a thin to a thick evanescent zone is found in early red-giant models with a coupling factor around 0.12, corresponding to a large frequency separation between 5 and 15μHz. For more evolved red-giants approaching the luminosity bump, the impact of buoyancy glitch is well modelled with the fitted coupling factors. And an increase dependence of the coupling factor on frequencies is seen, which emphasises again that the dependence cannot be neglected.

98 MARVEL: a new high-throughput high-resolution spectrograph

(Joris De Ridder)
Since the discovery of the first planet outside our solar system in 1995, thousands of other exoplanets have been found, largely thanks to successful space missions such as CoRoT and Kepler. Nowadays the focus of exoplanet research has shifted from finding planets to characterizing them. New photometric space missions like TESS (2019) and Plato (2026) will detect transits of thousands of new exoplanets, and measure their sizes. A detailed analysis of a subset of these exoplanets using spectral decomposition will allow the future ARIEL space mission (2028) to characterize the atmospheres of these planets.

The full scientific exploitation of these space data will demand a large amount of complementary multi-epoch high-precision radial-velocity measurements from the ground, for which dedicated infrastructure is indispensable. Combining photometric transit data with radial velocity measurements provides a direct estimate of the exoplanet's mass and density, and of the distance to their host star. This allows to assess the composition, temperature, and therefore habitability of these distant worlds.

In this talk we will present MARVEL (Monitoring Array for Radial VELocities), a facility based on 4 off-the-shelve telescopes feeding a single high-throughput and high-resolution spectrograph, dedicated to provide RV support for the space missions mentioned above. The facility is fully funded and is currently under construction by an international consortium of Belgian, Australian, Austrian, British, Danish, German, and Swedish collaborators. The facility will become an extension of the Mercator Telescope at the Roque De Los Muchachos Observatory on La Palma in Spain. We will explain the MARVEL setup and how it aims to achieve a similar performance as larger facilities, while keeping a reasonable price tag. To conclude we will outline what types of exoplanets are most suitable to be MARVEL targets, and what RV precision we can expect.

99 From protostar to pre-main sequence pulsator: PLATO and the quest for the classification of young stars

(Thomas Steindl)
The advent of space photometry has brought immense opportunities to the field of asteroseismology. This superb data has led to novel methodologies to infer information about pulsating stars and has proven especially useful for the characterisation of exoplanet host stars. Recent discoveries have spiked interest in the discovery and characterisation of young planets. For this to be successful, however, it is inevitable to perform this in-depth asteroseismic analysis also for pre-main sequence stars: A group of stars, for which the stellar modelling usually suffers from unrealistic assumptions about their initial state. We will present the first pulsational analysis of pre-main sequence models originating from accreting protostars as a more realistic initial scenario. With a suitable observational strategy, PLATO could be the last puzzle stone to skyrocket pre-main sequence asteroseismology and, hence, bring the characterization of the youngest exoplanets‘ host stars to the next level.

100 Evolution of magnetic activity on the main sequence as a function of spectral type using Kepler data

(Savita Mathur)
Stellar magnetic activity studies are very important for different fields of astrophysics. Several spectroscopic surveys have been aimed at characterizing the magnetic activity of solar-like stars, especially to look for cycles. These surveys were mostly led to put the Sun into context and in time compared to other stars. By investigating the magnetic activity of other stars with different conditions (rotation periods, metallicity…), we can provide additional constraints to dynamo models. Stellar magnetic activity has a direct impact on the habitability of exoplanets hosted by those stars. Consequently, it is important to understand how magnetic activity evolves in time and as a function of spectral type.

The recent catalog of rotation periods and photometric magnetic activity proxies for more than 55,000 stars observed by the Kepler mission opens the possibility to study the surface magnetic activity of a large number of stars. In this talk, we will present a subsample of main-sequence stars in order to compare the Sun to Sun-like stars and show the effect of metallicity using high-resolution spectroscopic data. While we see an interesting behavior as a function of metallicity, we also find that the magnetic activity of the Sun is comparable to the one of stars selected to be very similar to the Sun based on effective temperature, metallicity, and Rossby number, which is the ratio of rotation period and the convective turnover time and is a key parameters in dynamo theory. For all the stars of our sample, we also compute ages based on models taking into account the most recent theory of angular momentum transport that reproduce rotation rates for the Kepler asteroseismic sample. This allows us to study the evolution of magnetic activity as a function of Rossby number and age, providing a more complete picture to understand the changes in the dynamo behaviors during the life of the star until the terminal age main sequence.

101 Searching rotational splittings in δ~Scuti stars using pattern finding techniques

(Alejandro Ramón-Ballesta)
Asteroseismology has been able to provide some information on stellar rotation for the Sun, solar-like stars, and compact objects like white dwarfs. However, this study is still rather arduous for intermediate-mass stars, which are moderate-to-rapid rotators. This is so because rotation causes splittings and shiftings in the oscillation modes, thus increasing the complexity of the oscillation spectrum and making it harder to decipher. We present a study of the oscillation patterns of a sample of benchmark δ~Scuti stars that belong to eclipsing binary systems. Our objective was finding the frequency spacing related to the rotational splitting. For this task, we combined three complementary techniques: the Fourier transform, the autocorrelation function, and the histogram of frequency differences. We were able to find the rotational splittings for the majority of the stars, especially when using the last two methods (with both of them showing a similar behaviour). Hence, this is the first time we may clearly state that one of the periodicities present in the p~modes oscillation spectra of δ~Scuti stars corresponds to the rotational splitting. Furthermore, we found that this is true independently of the stellar rotation rate. Additionally, for most of the stars, it was necessary to determine the large separation prior to spot the rotational splitting. These promising results pave the way to find a robust methodology to determine rotational splittings from the oscillation spectra of δ~Scuti stars and, thus, to the understanding of the rotational profile of intermediate-mass pulsating stars.

102 The outer envelopes of low-mass stars: the impact of Coulomb effects on stellar oscillations

(Ana Brito)
Cool dwarfs are the most abundant group of stars in our galaxy. Among these, M dwarfs are known to host a large number of rocky planets compared with more massive stars. PLATO will be observing a sample with thousands of M dwarfs. These stars have outer convective envelopes and thus have the potential to

exhibit solar-like oscillations. In this work we explore the outer layers of stars less massive than the Sun. Our work is based on a set of stellar models ranging from 0.4 to 0.9 $M_{\odot}$. We study the impact on the oscillations of the dominant physical processes occurring in the convective zones of these stars. Namely, the partial ionization of chemical elements and the electrostatic interactions between particles. We find that alongside with partial ionization of the most abundant elements, Coulomb effects can also impact the acoustic spectrum. As expected the influence of Coulomb effects on the oscillations increases with decreasing mass. For the less massive models ($\leq 0.6 M_{\odot}$) the influence of Coulomb effects becomes dominant over partial ionization processes producing a strong scatter of the acoustic spectrum with diagnostic potential for the future.

103 The variable sky as seen by TESS : application to PLATO

(Mauro Barbieri)

In more than 3 years of operation TESS has observed almost all the sky except near the ecliptic equator. The observational capabilities of TESS are very similar to the one foreseen for PLATO, hence here we present some results on the variable sky seen by TESS and its potential application to PLATO.

104 Stellar Companions: Hiding the Earth-sized Transiting Planets

(David Ciardi)

Approximately half of the Sun-like stars are multiple star systems - yet, these systems also harbor planetary systems. The presence of the stellar companions affects our detection and characterization of transiting (and non-transiting) planets and is of specific concern to PLATO which seeks to discovered Earth-sized planets in Earth-like orbits around Sun-like stars. We will present an overview of our long running high resolution imaging program to detect and characterize stellar companions in Kepler, K2, and TESS planetary systems and describe the distribution of the stellar companions detected (and missed), the affects on derived stellar and planetary properties, and how stellar companions need to be taken into account in the determination of planetary frequency and demographics.

105 Phase and amplitude relations of non-linearities in Delta Scuti stars

(Mariel Lares Martiz)

Non-linear theory of pulsations could explain special characteristics observed in many variable star light curves, however, non-linear models are far from being complete. Combination frequencies can be footprints of the non-linear mechanisms that work within a pulsating star and, in this sense, are worth studying further than just to extract them from the power spectra. The ability to detect frequencies corresponding to the interaction between the star's own pulsation modes has increased due to the ultra precise photometric data gathered by the space missions. For this reason, non-linear studies can be resume. In this talk, I will present an empirical study of combination frequencies in Delta Scuti stars power spectra, aiming to characterize their non-linear behavior. The study explores the frequency, phase and amplitude relations given by the Volterra series formulation. The research potentially provides the necessary empirical basis for building non-linear models for Delta Scuti stars, as well as a general basis for the construction of the analytical model that explains the presence of nonlinear terms in variable stars.

106 Improved extinctions and stellar radii for 1.2 million stars observed by Kepler, GALAH, or APOGEE

(Jie Yu)

We provide improved extinction ($\sigma_{A_V} \simeq 0.04$ mag) and stellar radius ($\sigma_R/R \simeq 4\%$) estimates for about 1.2 million stars, which spread across both low- and high-extinction fields and have been observed by either the *Kepler*, GALAH, or APOGEE surveys. Our pipeline performs spectral energy distribution (SED) fitting using MARCS model spectra and broadband Photometry compiled from seven large-volume databases including Gaia EDR3. In our analysis, we place a prior on the effective temperature with values taken from spectroscopic surveys to lift the temperature-extinction degeneracy. To infer the stellar radii, we combine our angular radii yielded from the SED fitting with distances derived from Gaia EDR3 parallaxes. Validation of the derived extinction and radius estimates against Asteroseismology confirms the high precision and accuracy achieved by our pipeline. Our method could be used to infer stellar extinctions and radii for a larger sample of common stars observed by Gaia, particularly when spectrophotometric temperatures become available in the upcoming third Gaia data release.

107 Rotation & activity of M dwarfs: From K2 to TESS and PLATO

(Beate Stelzer)

Rotation and magnetic activity are observational proxies for stellar dynamos, and as such intimately related to each other. Both parameters are also of key importance for the search of planet transits because they introduce variability in photometric lightcurves that might interfere with the detection of transit signals. Moreover, the star's activity has important effects on planet atmospheres, and therefore should be well-characterized in order to assess their past and future evolution in particular with respect to habitability.

I present a summary of our recent studies of K2 and TESS lightcurves of nearby M dwarfs, including those with their habitable zones accessible for planet transit detections. Various signs of magnetic activity in the stellar photosphere such as the amplitude of the rotational signal and flares are analysed, and their relation with the rotation period is examined. We also study the relation between rotation periods determined from photometric space missions and activity in the X-ray band, including first results from the eROSITA all-sky survey. Another key aspect is the connection between optical and X-ray variability. Finally, I outline the application of our flare detection algorithm to simulated PLATO lightcurves and the implications for the characterization of the PLATO targets.

108 High-precision photometry of PLATO targets observed by TESS

(Marco Montalto)

The selection of PLATO targets relies on a set of criteria based on the spectral type, the luminosity class, the apparent magnitude and the expected signal-to-noise ratio of the stars observed by the satellite. However, other complementary information will be useful to rank the targets' list. I will describe a project to extract high-precision, homogeneous, long-term photometry of PLATO targets from TESS Full Frame Images. I will show the expected overlap between PLATO and TESS observations. This photometry is used to identify new transiting planetary systems around PLATO targets, as well as eclipsing binaries and variables. This will help to refine our knowledge of the photometric variability of the targets and identify potential sources of false positives. It will be also relevant in the context of complementary science.

109 Diversity of low-mass planets in the habitable zone of solar-like stars

(Christoph Mordasini)
Very little is currently known about the fundamental (geo)physical properties of small exoplanets in the habitable zone (HZ) of solar-like stars. Sometimes, it is implicitly assumed that an extrasolar planet in the habitable zone with a mass or radius similar to Earth will also share fundamental (geo)physical properties with Earth, like for example a similar water content or a similar atmosphere type.

To elucidate if such an extrapolation holds, we studied fundamental properties of small exoplanets in the HZ as predicted by a sophisticated theoretical model of combined planet formation and evolution. We studied two critical (geo)physical properties of these planets at 5 Gyr:

First, the water content. We found that model planets of 1 Mearth (or less) in the inner part of the HZ are characterised by a large spread in water inventory. A typical water inventory is about 20 Earth oceans, but dry planets with less than 0.1 oceans also exist. However, planets only slightly more massive (2 Mearth) and in the outer parts of the HZ are found to be very rich in water, with thousands of Earth oceans. This high water content is a consequence of orbital migration of very water-rich protoplanets from beyond the iceline into the habitable zone.

Second, we investigated if small planets in the HZ could accrete and keep (against the actions of impact stripping and atmospheric escape) primordial H/He atmosphere. A similar picture as for the water arises: smaller and/or closer planets within the HZ typically do not keep a primordial H/He atmosphere, allowing them to form secondary atmospheres like Earth. But already slightly more massive planets (1.5 Mearth) often still have massive (kbar surface pressure) primordial H/He atmospheres. These atmospheres increase the radii of the planets in a significant, observable way.

In summary, our result point at a high diversity in fundamental geophysical properties. Many exoplanets with similar astrophysical properties as Earth (mass, radius, orbital distance) might be geophysically very different. This has likely important implications for the ability of these planets to actually create and hold an inhabited biosphere.

110 Exploring the Nu2 Lupi system with CHEOPS

(Laetitia Delrez)
Multi-transiting planetary systems around bright stars offer unique windows to comparative exoplanetology. Nu2 Lupi (HD 136352) is a naked-eye (V=5.8) Sun-like star that was discovered to host three low-mass planets with orbital periods of 11.6, 27.6, and 107.6 days via radial velocity monitoring with HARPS. The two inner planets (b and c) were recently found to transit by TESS, prompting us to follow up the system with CHEOPS. This led to the exciting discovery that the outer planet d is also transiting. With its bright Sun-like star, long period, and mild irradiation (~5.7 times the irradiation of Earth), Nu2 Lupi d unlocks a completely new region in the parameter space of exoplanets amenable to detailed characterization. We measured its radius and mass to be 2.56+/-0.09 R_Earth and 8.82+/-0.94 M_Earth, respectively, and refined the properties of all three planets: planet b likely has a rocky mostly dry composition, while planets c and d seem to have retained small hydrogen-helium envelopes and a possibly large water fraction. This diversity of planetary compositions makes the Nu2 Lupi system an excellent laboratory for testing formation and evolution models of low-mass planets.

111 Extremely precise HARPS-N solar RV to overcome the challenge of stellar signal

(Xavier Dumusque)
Authors: X. Dumusque, M. Cretignier, D. Sosnowska, N. Buchschacher, C. Lovis, F. Pepe

Detecting and measuring the masses of Earth-like planets in the presence of stellar signals is the main challenge when using the radial-velocity (RV) technique. Even in the PLATO era where the satellite will provide the period of Earth-like planetary candidates, measuring precisely their mass, which is critical to 1) confirm those candidates, 2) constrain further planetary composition and thus planetary formation and 3) constrain further planetary atmospheres, will be extremely challenging.

Critical to a better understanding of RV variations induced by stellar signals and finding correction techniques is RV data with a sampling and SNR sufficient to probe stellar signals ranging from minutes to years. To address this challenge, we can use the unprecedented data from the solar telescope that feed sunlight into HARPS-N, which allows us to obtain Sun-as-a-star RVs at a sub-m/s precision.

In this talk, I will discuss how to reduce properly the HARPS-N solar data to reach a precision of about 50 cm/s on the short and long-term. This implies optimizing the wavelength solution recipe, carefully selecting the most stable thorium lines, but also compensating for the ageing of thorium-argon lamps inducing a drift of thorium lines with time. I will show how those optimizations improve the quality of the data, and therefore will advise any team working in extremely precise RV to perform similar upgrades.

The obtained solar data, published last October, have already been used in several studies that demonstrate that analyzing the HARPS-N solar spectral (or cross-correlation functions) time-series using machine learning algorithms can mitigate stellar signals down to a level where Earth-like planets in the habitable zone could be detected (30 cm/s in semi-amplitude, signal three times larger than Earth).

112 On the origin of the radius valley: formation and evolution

(Christoph Mordasini)

The detection of a gap or valley separating smaller super-Earth from larger sub-Neptunes has recently attracted much attention. The conventional explanation is the loss of primordial H/He envelopes of rocky cores. We have studied the valley origin with our new multi-planet formation and evolution model. In contrast to our past 1-embryo per disk model, we cannot reproduce the valley with the new model along this conventional explanation: the large diversity in post-formation H/He content caused by giant impact envelope stripping and the diversity of core compositions (including very water rich planets) blurs pure the evaporation imprint too much. This absence of a valley occurs when we assume in the model that water is in a condensed layer. We do however find a clear valley when modelling correctly the phases of water. We then find another explanation for the valley origin: it separates dry lower-mass rocky planets without H/He envelopes that formed inside of the iceline from wet more massive planets with puffed-up steam interiors which migrated in from beyond the iceline. Evaporation is still important to have a clear valley as it causes the rocky planets to lose their H/He, populating the lower edge of the valley. The rocky super-Earth have a lower mass because of limited building block availability inside the iceline. The sub-Neptunes have higher masses because only planets above a certain mass can migrate all the way to the inner system, a consequence of the mass dependency of Type I migration. Most planets just above the valley contain only water but no H/He. With further increasing radius, the H/He content increases. Our hypothesis explains many observations: the locus of the valley, the rocky nature of the planets below it, the densities of the planets above it, the cliff (the strong decrease in planet frequency at about 3.5 Rearth, which is in our explanation the transition from water planets to H/He rich planets), and the observed diversity in He escape rates including planets above the valley lacking He escape. The latter contradicts the conventional explanation. If this interpretation is correct, the valley is a signpost of both formation (specifically, orbital migration) and evolution (evaporation of H/He envelopes).

113 Spatially resolved solar spectroscopy as benchmark for exoplanet observations

(Monika Ellwarth)

For the detection and characterization of exoplanets, observed spectra need to be understood at extremely high detail. Knowledge about the radiation emitted from the host star is of utmost importance, and the Sun is the best available laboratory to understand Sun-like stars. At the Institute for Astrophysics Göttingen, we observe the Sun using a high resolution Fourier Transform Spectrograph (FTS) with a resolution of R~700,000 at lambda~600nm. This provides very high resolution solar spectra at wavelengths between 450 and 1000nm. We obtain spectra from the spatially resolved solar surface with an aperture of 32 arcsec in diameter (23,000 km on the solar centre). Our observations of the resolved Sun provide insight into the variable spectral behaviour across different limb angles, which can provide crucial information about limb darkening, convective velocities, and line profile variability relevant for radial velocity (RV) work. We show first results from our atlas of the solar spectrum at different limb angles that can put models of transit observations and stellar RV variability on a firm footing.

114 Probing the Atmospheres of Exoplanets with Transmission Spectroscopy and Photopolarimetry

(Aritra Chakrabarty)

Transmission spectroscopy is a widely used method in probing the properties of the atmospheres of transiting exoplanets. On the other hand, polarimetric studies of the hot-Jupiters are also gaining momentum in the field of atmospheric characterization of exoplanets. We have developed generic models for the transmission spectra of the exoplanets by including the effect of diffused transmission due to scattering in the optical and NIR region as well as the effect of thermal emission from the night sides in the IR region. Furthermore, polarization phase curves due to reflection also carry signatures of the scattering processes in the atmospheres, especially due to the cloud particles. In this talk, I will present a few models developed for the transmission spectra and the polarization phase curves of the hot Jupiters such as HD 189733 b, WASP-6 b, HAT-P-1 b among many. The upcoming high-end missions such as PLATO, in synergy with the ground-based telescopes, will provide us new targets as well as precise physical properties of the exoplanets which will help us develop generic atmospheric models for the exoplanets with broad range of properties in order to characterize them.

115 Evolution of planetary and multiple-star systems beyond the main sequence

(Patrick Gaulme)

Stars with convective envelopes (M<1.3 Msun) lose spin during the main sequence and enter the red giant phase with slow rotation periods (typically tens of days). Then, their angular momentum is expected to decrease further as ascending the red giant branch. According to dynamo theory, stars with convective envelopes efficiently generate surface magnetic fields (which manifest as magnetic activity: starspots, faculae, flares) when their rotation period is shorter than their convective turnover time. Most red giants, having undergone significant spin down, have slow rotation and no spots. In a recent study based on Kepler time-series, Gaulme+2020 (A&A 639,63) showed that less than 3% of the solar-mass red giants are active on the early red giant branch (R<15 Rsun), but surprisingly they found that over 10% of the solar mass red-clump stars (burning He in their cores) are magnetically active. This observation means that a fraction of low-mass red giants gain spin between the hydrogen-shell and the helium-core burning phases. Knowing that low-mass stars kick the He-core combustion off when their sizes reach 200 Rsun (He flash), it is very likely that the gain of angular momentum originates from a stellar or planetary engulfment. I will present what PLATO can bring in terms of new constraints on the late stages of planetary and multiple-star systems thanks to its long-duration wide field precise photometry.

116 Stability and spacing of tightly packed systems

(Antoine Petit)

Exoplanet transit surveys have revealed the existence of numerous multi-planetary systems packed close to their stability limit. This feature likely emerges from the formation and dynamical history of the system. Understanding it in detail is thus key to constrain our planet formation scenarios. While the stability

limit has been known empirically for decades, no theoretical explanation was proposed yet. I present a mechanism driving the instability of tightly packed system. Based on the chaotic diffusion along the network of three-planet resonances, it reproduces quantitatively the timescale of instability obtained numerically over several order of magnitude in time and planet-to-star mass ratios. I discuss the observational implications of this model, in particular the expected differences between Super-Earths and terrestrial planet systems.

117 Stellar space weather effects on habitable-zone planets

(Aline Vidotto)
Stellar activity can reveal itself in the form of radiation (eg, enhanced X-ray coronal emission, flares) and particles (eg, winds, coronal mass ejections). Together, these phenomena shape the space weather around (exo)planets. As stars evolve, so do their different forms of activity – in general, younger solar-like stars have stronger winds, enhanced flare occurrence and likely more frequent coronal mass ejections. Altogether, these effects can create harsher particle and radiation environments for habitable-zone planets, in comparison to Earth, in particular at young ages. We conducted multi-dimensional numerical simulations to investigate how the evolving solar wind has affected the magnetic protection of the Earth over the past few billion years. These simulations also allowed us to model the effects of the evolving solar wind in modulating energetic particles that are injected into the solar system and, finally, calculate these particle fluxes at the habitable zone.

118 Weighing Earth analogues with HARPS-N: state-of-the-art and future perspectives

(Luca Malavolta)
The installation in 2012 of the high-resolution, ultra-stable spectrograph HARPS-N at the Telescopio Nazionale Galileo has represented a pivotal point for the mass determination of Super-Earths and Mini-Neptunes from the Northern hemisphere. More than a third of the small planets with at least 3-sigma mass determination have been characterized by the HARPS-N Consortium thanks to its Guaranteed Time Observations. However, while high-precision photometry from space is discovering and/or characterizing candidate planets at smaller and smaller radii, starting from CoRoT (CNRS/CNES) to Kepler, TESS (NASA) and CHEOPS (ESA) towards PLATO (ESA), radial velocities are struggling in determining their masses. In this proposed talk, I will review the major challenges that we are facing when attempting to determine the mass of small planets with HARPS-N, including observational sampling, stellar activity, moonlight contamination, and instrument performances. I will introduce the advancements in technology and data analysis that we are undertaking to improve the accuracy of our mass determinations and ultimately allow the next-generation instruments to measure the mass of Earth analogues discovered by PLATO.

119 CARMENES and the Frontiers of High-Resolution Spectroscopy for M dwarfs: Fundamental Stellar Parameters and Chemical Abundances

(Yutong Shan)
Comprehensive understanding of planets is predicated on detailed descriptions of their parent stars. M dwarfs are prolific hosts of planetary systems and form an important sample for the PLATO mission. The prospect for characterizing M dwarfs to a level comparable with Sun-like stars is bright, thanks to recent improvements in atmosphere models and the growing availability of high-resolution spectroscopic data. The CARMENES survey has produced high-quality, R~90,000, multi-epoch spectra in the optical and NIR for hundreds of nearby early- to late-M dwarfs. These spectra have been accurately telluric-corrected and co-added to very high signal-to-noise, making them suitable for identifying and modeling fine features intrinsic to the star. The wavelength coverage (560 — 1710 nm) of the CARMENES spectrograph is one of the widest in the industry and contains a large variety of lines and features. Their resolved profiles are sensitive to temperature,

metallicity, elemental abundances, and exhibit useful quantum effects. We give examples of recent applications using CARMENES spectra to measure fundamental stellar parameters and chemical compositions of M dwarf photospheres. We summarize how lessons from CARMENES spectroscopy of cool dwarfs could inform target selection and characterization efforts from ground-based facilities for PLATO.

120 SINGLETRANS, the search for single transits of small planets in light curves of space missions.

(Sascha Grziwa)
Until today a large number of exoplanets are found using space-based telescopes. Most of these exoplanets are exoplanets with relative short orbital periods due to the relative short observation baseline (CoRoT ~90 days, K2 ~90 days, TESS mainly 30 days). A statistical comparison of the detected periodic transits in TESS and K2 light curves with the detected periodic transits in the longer KEPLER light curves reveals that TESS and K2 light curves should show many additional single transit events which are not detected so far. Single transits of Jupiter-size planets are regularly found while single transits of Neptune- or Earth-size planets are rarely detected. The detection of single transits can reveal long orbital period planet candidates attractive for follow-up observations. The detection of single transits in archival data of past and ongoing missions (e.g. TESS) can help to plan revisits (e.g. PLATO) or additional photometric observations (e.g. CHEOPS). The Rhenish Institute for Environmental Research, department of Planetary Research, at the University of Cologne (RIU-PF) is developing the dedicated pipeline SINGLETRANS to search for single transit events of small planets in light curves. SINGLETRANS is a wavelet based transient search algorithm and shall complements our well-established detection pipeline EXOTRANS. The development of SINGLETRANS is part of the SPP1992 program ("Exploring the diversity of extrasolar planets") funded by the German Research Foundation. SINGLETRANS shall also detect quasi-periodic transits (planets showing strong TTV, circumbinary planets). We present the status of our new SINGLETRANS pipeline.

121 The Gaia-PLATO connection

(Nicholas Walton)
This presentation will provide a status update of the ESA Gaia mission with a focus on the upcoming Gaia DR3 scheduled for release in the first half of 2022. In addition to the contents of the Dec 2020 Gaia EDR3 release of astrometry and photometry of some 1.8 billion sources, the Gaia DR3 will contain a wealth of new data products including a significant number of sources with astrophysical parameters together with the BP/RP and/or RVS spectra. The release of Gaia DR3 will underpin the PLATO definition of its target stars. The Gaia DR3 release will allow a better understanding of the PLATO 'pixel' in terms of decontaminating PLATO source light curves from nearby sources.. I will look ahead to longer term Gaia operations (in flight operations now potentially continuing through to 2025) and future data release planning. I will conclude with comments on recent and emerging use of Gaia for the direct discovery of exoplanets, astrometrically, and in a few cases through photometric transits.

122 The amplitude of large-scale solar convection

(Aaron Birch)
Helioseismic inferences have placed a strong upper limit on the amplitude of solar convection, well below the predictions from simulations. This is one aspect of the "convective conundrum". In order to establish a clear baseline for future work, we rectify several "apples and oranges" comparisons from the literature and provide updated comparisons of the strength of convective velocities on the Sun from helioseismology, feature tracking, and simulations. Observations of other stars could, potentially, help determine if the discrepancy between observations and simulations is specific to the Sun or more general.

123 Detecting and characterising low mass planets with radial velocities

(Nathan Hara)
Radial velocity follow-up will play a key role in the PLATO mission, but stellar activity hinders the detection and mass measurements of low mass planets. In this talk, we present several tools to mitigate stellar activity: new optimised Gaussian process models, a new detection criterion with optimality properties, and methods to analyse of the time series of spectra. We show applications of these tools to the compact systems HD 158259 and TOI 178, and discuss the capability of the new methods to unveil candidates in the habitable zone.

124 Ground-based facilities and techniques for characterising Earth analogues

(Andrew Cameron)
Candidate Earth analogues detected by PLATO will have orbital periods of order hundreds of days, and reflex orbital-motion signals with amplitudes of order 10 cm s^{-1}. In this overview I summarise the instrumental and data-analysis capabilities needed to characterise such planets. High instrumental throughput and long-term thermal stability, precise wavelength calibration and drift monitoring, and efficient mitigation of telluric absorption are mandatory. New instruments are already approaching the necessary precision. The stars themselves present the most formidable remaining challenge, as p-mode oscillations, granular convection and magnetic effects on surface brightness and velocity fields alter the shapes and relative strengths of spectral lines on time scales from minutes to years. Finally, the Sun's reflex motion about the solar-system barycentre reminds us that the radial-velocity signal of a true Earth analogue must be disentangled from the reflex motions of other planets in the same system.

125 Seismic diagnostics of stellar activity cycles

(Valeriy Vasilyev)
Magnetic activity affects the observed properties of solar p modes: mode frequencies and linewidths increase with solar activity. Using VIRGO/SPM data from solar cycles 23 and 24 we show that solar-cycle variations are measurable in the temporal autocorrelation function of the p-modes. Following a method developed for local helioseismology, we measure the p-mode travel times for multiple skips and propose to average these to enhance the signal-to-noise ratio. This method is robust to noise, simpler to implement than peak bagging in the frequency domain, and promising for asteroseismology applications. We estimate that the activity cycles of Sun-like stars may be detectable in long photometric time series.

126 Modelling of center-to-limb intensity perturbation due to stellar oscillations.

(Nadiia Kostogryz)
Helio-/asteroseismology is the study of the interiors of the Sun/stars using observations of oscillations at the surface. The oscillations perturbed the surface and thermodynamical quantities affecting the emergent intensity computations. We consider the oscillations due to various acoustic modes and show that the perturbations to the thermodynamical quantities as well as the geometrical effects due to the wave displacement must always be taken into account to model the intensity perturbations. The geometrical effects lead to a difference in amplitude and a phase shift between temperature perturbations at the surface and emergent intensity perturbations. The phase shifts and amplitude differences between the temperature and intensity perturbations increase towards the limb. This theoretical work is important to understand some of the systematic center-to-limb effects observed in helio/asteroseismology.

127 Inertial modes of Sun-like stars: the solar case

(Laurent Gizon)
The oscillations of a slowly rotating star have long been classified into spheroidal and toroidal modes. The spheroidal modes include the well-known 5-min acoustic modes used in helioseismology. Here we report observations of the Sun's toroidal modes, for which the restoring force is the Coriolis force and whose periods are of order of the solar rotation period. By comparison with the normal modes of a differentially rotating spherical shell, we find an identification for many of the observed modes. As a first application of inertial-mode helioseismology, we constrain the super-adiabaticity and the turbulent viscosity in the convection zone. Since some of these modes are self-excited in the model, one may expect that they will have large amplitudes on some other stars.

128 HIP41378: a foretaste of PLATO

(Alexandre Santerne)
HIP41378 is a fascinating system composed of 5 transiting low-mass exoplanets with orbital periods ranging from 2 weeks to 1.5 year. Three of these planets are near the habitable zone. The host star is a bright late-F dwarf that has exquisite-precision stellar parameters thanks to asteroseismology from the K2 photometry. This system was also extensively observed by HARPS, HARPS-N and HIRES spectrographs with the aim of measuring the planet masses, which are all less massive than Neptune. Since this system hosts low-mass exoplanets at long period transiting a bright star with asteroseismology, it is typical of the planetary systems that PLATO will discover. In this talk, I will present the HIP41378 system, giving a foretaste of the PLATO results. I will also present recent results based on new observations of the system with, in particular ESPRESSO/VLT and WCF3/HST.

129 CHEOPS and HARPS characterisation of a multi-planet system discovered by TESS

(Thomas Wilson)
The study of multi-planet systems can reveal important aspects that challenge our knowledge of planet formation and evolution via determination of planetary system architectures and internal structures. The CHEOPS satellite, launched in Dec 2019, has spent the past year taking high-precision transit photometry of such systems with a key science goal of the mission to further our understanding of this sub-field of exoplanet research.

In this talk, I will present work done to discover and characterise a multi-planet system consisting of a pair of sub-Neptunes, including the development of a novel photometry detrending method. Using space-based CHEOPS and TESS data, and ground-based LCOGT, NGTS, and ASTEP transit photometry, combined with HARPS radial velocities we confirm the system, and interestingly, find that whilst both planets have similar radii (~2.6 and ~2.7 Earth radii) they appear to have different masses (~13.5 and ~2.5 Earth masses) leading to a substantial density disparity. This result also means that planet b is one of the densest, well-characterised sub-Neptunes, and will likely become a benchmark planet for this mass-radius space. From internal structure and atmospheric escape modelling we find that whilst planet b may have a small or non-existent atmosphere, planet c likely has an extended envelope. Key knowledge about this system was unveiled via precise follow-up observations with CHEOPS and ground-based facilities, that underlines the importance of the synergy between detection and accurate follow-up missions. The precise photometry of this system may shed light on the formation of dense, sub-Neptunes, with the apparent density difference a potential relic of the evolution of the system that may be resolved by long-term precise photometric monitoring with missions such as PLATO.

130 High-precision characterizations of K2 and TESS planet candidates from the KESPRINT consortium: Outlook for PLATO

(Hans Deeg)
The European-led KESPRINT consortium consists of over 50 scientists and has become a major player in the ground-based follow-up of planet candidates discovered by the K2 and TESS space missions, leading in many cases to their verification as planets and their state-of-the art characterization. This effort is mainly based on planet-mass measurements from RV observations, but also on high-resolution imaging and time-series photometry, as well as on detailed analyses of the host stars. KESPRINT also runs its own planet detection pipeline which permits the detection of candidates independently from the official mission-releases, thereby also building up expertise in the evaluation and modelling of marginal detections.

The success of KESPRINT stems from the close collaboration between its working groups, bringing together a wide range of expertise, and from the organized allocation of follow-up resources, providing an approach which can be applied to a mission like PLATO. In this talk the contribution of KESPRINT to the field will be reviewed, with particular focus on planets and systems which might be similar to those of interest for the PLATO mission. We pay attention to the issues arising for the characterization of exoplanets due to the available telescope time being distributed across independent teams with sometimes short allocations. We will also count about our experiences from organizing such a large team. These have been ingested into a recently revised version of our internal 'Memorandum of Understanding', which might also be useful to other collaborations in the field

131 Characterization of Exoplanets Using Precise Transit Photometry and Photopolarimetry

(Aritra Chakrabarty)
Transit photometry is an essential tool for the detection and characterization of the exoplanets. We have used the 2m Himalayan Chandra Telescope (Hanle, India) and the 1.3m J. C. B. Telescope (Kavalur, India) to observe the transit events of some hot Jupiters such as WASP-33 b, HAT-P-36 b among others. The data have then been processed and modeled using the pipelines we have developed, which also incorporates denoising techniques such as wavelet denoising and GP regression. I will present the modeled light curves and the physical properties of those planets that we have derived with extremely high precision. However, a major caveat of transit observation is that the orbital planes of the planets have to be aligned (edge-on) with respect to our LOS in order to detect the transit events. On the contrary, photopolarimetric observation of the reflected light from the exoplanets does not have such limitation, rendering this technique suitable for generic study of exoplanets. However, the sensitivity of the instruments poses the biggest challenge in this case. In this regard, I will present the generic polarimetric models developed by us for the reflecting exoplanets by solving the vector radiative transfer equations across the planetary disks. I will also present the models specifically for the well-studied planet HD 189733 b predicting the detectable level of polarization in order to guide the future polarimetric observations. Our ground-based support as well as ready-to-use atmospheric models for exoplanets will be useful in maintaining synergy with the future missions such as PLATO, JWST, among others.

132 Synthetic Evolution Tracks of Giant Planets

(Simon Müller)
Giant planet evolution models play a crucial role in interpreting observations and constraining formation pathways. However, the simulations can be slow or prohibitively difficult.

To address this issue, we calculate a large suite of giant planet evolution models using a state-of-the-art planetary evolution code. Using these data, we create the python program planetsynth that generates

synthetic cooling tracks by interpolation. Given the planetary mass, bulk & atmospheric metallicity, and incident stellar irradiation, the program calculates how the planetary radius, luminosity, effective temperature, and surface gravity evolve with time.

We demonstrate the capabilities of our models by inferring time-dependent mass-radius diagrams, estimating the metallicities from mass-radius measurements, and by showing how atmospheric measurements can further constrain the planetary bulk composition. We also estimate the mass and metallicity of the young giant planet 51 Eri b from its observed luminosity.

Synthetic evolution tracks have many applications, and we suggest that they are valuable for both theoretical and observational investigations into the nature of giant planets.

133 Variability of solar irradiance over last four billion years

(Anna Shapiro)
We calculate the amplitude of the solar irradiance variability over the course of the solar activity cycle as a function of wavelength and solar age. This is done by employing the relationship between the stellar magnetic activity and the age based on observations of solar twins. The magnetic activity is connected to the solar irradiance variability using SATIRE (which stands for Spectral And Total Irradiance Reconstruction) model. Our calculations show that the young Sun was significantly more variable than the present Sun. The amplitude of the TSI variability decreased with solar age and reached its minimum value at 2.8 Gyr. A stronger historical variability of the young Sun could lead to a stronger response of the early Earth's atmosphere as well as of the atmospheres of other planets in the Solar System.

134 Atmospheric habitability factors for Earth-type planets

(Anna Shapiro)
What if the Earth is hosted by another solar-like star instead of the Sun? How would the atmosphere react on this and what does it mean for life? Here, we model the atmosphere for the hypothetical case of the Earth rotating around star with metallicity values from -1 to 1 and effective temperature values from 5300 to 6300 K. We calculate the atmospheric response to different disturbing factors, e.g. increase of stellar activity, volcanic eruptions, supernova explosion.

135 The temperature, gravity, and frequency scaling relation for delta Scuti stars

(Sebastià Barceló Forteza)
Thanks to long-duration high-cadence light curves from space telescopes, we suggest the frequency at maximum power as a proper indicative of the mean temperature and surface gravity for delta Scuti stars. This seismic index do not depend on rotation or inclination unlike photometric and spectroscopic techniques that may be significantly affected by gravity-darkening effect or extinction. Thus, it is posible to improve their distance, age, and habitable zone measurements for this kind of stars.

136 "How to be a connoisseur of stellar light curves" or criteria for reliable frequency extraction in pulsating stars observations

(Javier Pascual Granado)
It is clear that for the identification of pulsation modes a necessary first step is the unambiguous detection and extraction of frequencies from observations. It is no less clear that this task is arduous and full of obstacles. To name just a few: irregular sampling introduce correlation between frequency bins in the periodogram; noise level cannot be estimated properly when the statistical properties deviate from a uncorrelated stochastic process with gaussian distribution; the false alarm test, which is based on a proper estimation of the noise

level, also suffer from biases due to assumptions like an exponentially distributed noise; different fitting methods produce different results, etc. Here I will discuss some of these issues and introduce an ambitious project aimed to formalize a set of consistent criteria for a reliable frequency extraction in pulsating stars observations. This will produce a living recipe with the purpose of serving as a reference for the present and future data analysts of the ultra-precise observations gathered by asteroseismic space missions. That is, the necessary criteria to be a connoisseur of stellar light curves and identify pulsation modes with seismic models.

137 How magnetism of solar-type stars evolve?

(Quentin Noraz)
The solar magnetic field is generated and sustained through an internal dynamo. In stars, this process is determined by the combined action of turbulent convective motions and the differential rotation profile. It can sometimes lead to magnetic cyclic variabilities, like in the Sun with the 11 years cycle. Traces of magnetic cycles have been detected for other solar-like stars as well, ranging from a few years to a few tens of years. How are these cycles controlled? During their life, the rotation of stars is subject to complex evolution. Recent 3D numerical simulations of solar-like stars show that different regimes of differential rotation can be characterized with the Rossby number. In particular, anti-solar differential rotation (fast poles, slow equator) may exist for high Rossby number (slow rotators). If this regime occurs during the stellar spin-down of the main sequence, and in general for slow rotators, we may wonder how the magnetic generation through dynamo process will be impacted. In particular, can slowly rotating stars have magnetic cycles?

We present a numerical multi-D study with the STELEM and ASH codes to understand the magnetic field generation of solar-like stars under various differential rotation regimes, and focus on the existence of magnetic cycles.

We find in self-consistent 3D simulations that short cycles are favoured for small Rossby numbers (fast rotators), and long cycles for intermediate (solar-like) Rossby numbers. Slow rotators (high Rossby numbers) are found to produce only steady dynamo with no cyclic activity. However we find that specific mean-field models can produce magnetic cycles with anti-solar differential rotation only if the alpha effect is fine tuned for this purpose. It is still unclear today whether this latter regime can be achieved self-consistently in global 3D simulations.

We then conclude that slow rotating stars in the anti-solar differential rotation regime can sustain magnetic cycles only for very specific dynamo processes. A detection of magnetic cycles for such stars would therefore be a tremendous constrain on deciphering what type of dynamo is actually acting in solar-like stars, and thus on how their magnetism can evolve. This problematic is particularly relevant in the context of the PLATO mission, which will provide new constraints, in particular on the differential rotation and the magnetic activity taking place in these stars.

138 Can active plate tectonics leave an observational feature in a planet's atmosphere?

(Lena Noack)
Accurate measurements of a planet's mass, radius and age (provided for example by the PLATO mission and follow-up measurements) together with compositional constraints from the stellar spectrum can help us to deduce potential evolutionary pathways that rocky planets can evolve along, and allow us to predict the range of likely atmospheric properties that can then be compared to observations. However, for the evolution of composition and mass of an atmosphere, a large degeneracy exists due to several planetary and exterior factors and processes, making it very difficult to link the interior (and hence outgassing processes) of a planet to its atmosphere. The community therefore thrives now to identify the key factors that impact an atmosphere, and that may lead to distinguishable traces in planetary, secondary outgassed atmospheres. Such key factors are for example the planetary mass (impacting atmospheric erosion processes) or surface temperature (impacting atmospheric chemistry, weathering and interior-atmosphere interactions). Here we investigate the signature that a planet evolving into plate tectonics leaves in its atmophere due to its impact

on volcanic outgassing fluxes and volatile releases to the atmosphere - leading possibly to distinguishable sets of atmospheric compositions for stagnant-lid planets and plate tectonics planets. These preliminary findings will need to be further investigated with coupled atmosphere-interior models including various feedback mechanisms such as condensation and weathering as well as atmospheric escape to space.