Abstract Book

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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.

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.

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.

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.

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.

Non-seismic (and Non-LTE) stellar parameters for the PLATO core sample

(Maria Bergemann)

Accurate stellar parameters, Teff and chemical composition, are imperative for the determination of masses, radii, and ages of PLATO stars. I will present the architecture and input physics of the SAPP pipeline that will be used to determine non-seismic stellar parameters for the PLATO core sample. In this talk, I will discuss how we cope with rapid yet painstaking developments in stellar atmosphere modelling, including radiation hydrodynamics theory, atomic and molecular physics, machine learning and numerical analysis methods, - the developments that form the basis of the unique diagnostic capabilties of the SAPP. I will highlight our successes and challenges, and close with the prospects for PLATO and other future projects that aim to capitalise on unprecendeted data available from ground- and space-based observations.

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.

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.

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.

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.

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.

PLATO Performance Update

(Juan Cabrera)
The PLATO mission (PLAnetary Transits and Oscillations of stars, hereafter abbreviated as PLATO) has been selected as part of ESA's Cosmic Vision 2015–2025 program for the M3 mission launch foreseen in 2026. The main science goal of PLATO is to detect and characterize extrasolar planets, including terrestrial planets in the habitable zone (HZ) of their host stars. Characterization here means to derive accurate planetary radii, masses, and ages. In order to achieve these goals, it is mandatory to characterize the host stars. As transit search is an indirect detection and characterization method, the accurate knowledge of the host star parameters limits the accuracy of the derived planet parameters. PLATO will therefore monitor hundreds of thousands of stars for up to three years in order to fully characterize stars with asteroseismology and to detect transiting planets. The resulting large data set of stellar light curves provides an additional science return of the mission that reaches far beyond the exoplanet science case into stellar, Galactic, and extragalactic research. PLATO Payload features a multi-telescope configuration consisting of 26 cameras, of 12 cm pupil size aperture each, covering a field of view of about 2000 square degrees spread over 104 CCDs of 20 million pixels a piece. PLATO has strict noise requirements achieved through excellent optics transmission and

quantum efficiency, low read-out noise, and stringent pointing requirements. In this talk we will review the drivers for PLATO Performance and present the most recent description of the status of noise budget and verification of main performance requirements (including field of view and pointing performance).

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.

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.

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)

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.

Asteroseismic Data Analysis for Mode Frequencies for PLATO

(Guy Davies)
PLATO will provide dazzling new data with which we can study the structure, dynamics, and bulk properties of many many stars. A very important step in analysing these stars is the interpretation of the asteroseismic information in the periodogram. Traditionally referred to as 'peakbagging' I show current concepts and methods with a particular focus on the automated application of such methods for PLATO. I will show how I believe we can improve on our current methods with the improvement of 'peakbagging' models, better statistics, and the inclusion of better, more rigorous prior information.

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.

Seismic modeling of solar-like pulsators in the Plato era

(Sebastien Deheuvels)
With space missions CoRoT, Kepler, and TESS, asteroseismology has entered a golden age. The Plato

mission is expected to provide high-quality seismic data for about 20 000 dwarfs and subgiants that show solar-like oscillations. This corresponds to an increase in the size of the current catalog by more than one order of magnitude. The Plato pipeline has the challenging task to produce seismic estimates of the masses, radii, and ages for all these stars, with precisions of 15%, 2%, and 10%, respectively, for the reference star (a 10th-magnitude Sun). In this presentation, we show the current version of the pipeline, and outline the challenges that we are still facing. Owing to its unprecedented size, the Plato dataset for dwarfs and subgiants will yield strong constraints on stellar interiors. In a second part of the presentation, we review some of the open questions in stellar physics that will greatly benefit from the Plato data. For this purpose, we focus on some of the recent results obtained with Kepler and TESS that foreshadow what we can expect from Plato data

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.

New insights into Super-Earth interiors

(Caroline Dorn)
The increasing number of newly discovered extrasolar planets reveal a remarkable diversity in planet sizes and mean densities. Among the most frequently occurring planets are super-Earths and mini-Neptunes, whose interiors are largely unknown. Detailed interior characterization is challenging since data are few and have significant uncertainties. Given data of mass and radius alone, many interiors can be modelled and it is key to make additional constraints available. I will discuss a range of additional constraints that help to improve interior estimates and I will highlight main achievements in finding exotic and less exotic worlds.

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).

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).

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.

Detection and Characterization of Exoplanets Using Current and Future US Observatories

(Scott Gaudi)
I review the capabilities of current and future ground- and space-based US observatories for the detection and characterization of exoplanets and their host stars, considering both planned and proposed future observatories. I place the capabilities and expected science returns of these observatories in the overall context of the exoplanet and astrobiology science strategies for the next several decades, as outlined in the recent National Academies reports. Finally, I highlight the complementarity between current and future European and US observatories with regards to the study of exoplanets, with a particular focus on the unique and vital role of the PLATO mission.

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.

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.

Chemical abundances of stars and their impact on the interior structure of rocky planets

(Natalie Hinkel)
Stars and planets are formed at the same time and from the same material. Therefore, meaningful connections can be made between the chemical properties of stars and the make-up of their orbiting, rocky planets. Stellar elemental abundances may be used to help classify planets as being super-Mercuries, mini-Neptunes, super-puffs, or truly Earth-like. In addition, detailed temperature-pressure profiles enable an understanding of planetary interior structure and mineralogy, which impacts the crustal composition, tectonic processes, and other planetary geochemical cycles important for habitability. I will first review some of the current work that leverages stellar abundances to understand the detailed interior structure of rocky exoplanets. I will then discuss how the PLATO science products will greatly influence our understanding of the chemical relationship between stars and their planets. The future for exoplanet science is dependent not only on impactful missions, such as PLATO, but also on building bridges to the geology, planetary science, and data science communities - so that we may establish a holistic (i.e. physical and chemical) definition of planetary habitability.

Planets are Places: Characterization of Other Worlds in the 2020s and Beyond

(Laura Kreidberg)
The past 25 years have revealed a diversity of exoplanets far beyond what was imagined from the limited sample in the Solar System. With new and upcoming observing facilities and a rapidly growing number of nearby planets, we are poised to bring this diversity into focus, with detailed follow-up characterization of the planets' atmospheres. In this talk, I will discuss three frontier questions in exoplanet atmosphere studies: (1) what can we learn about planets' origins and evolution based on their present-day atmospheres? (2) how are the climate and clouds of exoplanets shaped by their extreme irradiation environments? and (3) under what circumstances do terrestrial planets retain their atmospheres? Finally, I will conclude with my outlook on the search for biosignatures in the atmospheres of potentially inhabited planets.

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.

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.

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.

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.

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.

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.

Terrestrial Exoplanet Habitability and Characterization: Opportunities and Challenges

(Victoria Meadows)
The PLATO mission will discover and help characterize the bulk properties, age and space weather environment of small planets in the habitable zones of FGKM dwarf stars. This rich sample will allow us to better understand the conditions under which planets retain the atmospheres and oceans necessary for surface habitability. The PLATO-discovered sample will include planets that have experienced different evolutionary paths driven by a combination of their own intrinsic properties, their host star's evolution, and interaction with other planets in their systems. For targets that are amenable to follow-up, atmospheric characterization using transit observations for M dwarf planets, and reflected light characterization for the more Sun-like FGK stars would be a powerful way to gather even more information on the potential habitability of these planets. This talk will provide an overview of the factors that may impact the habitability of planets orbiting FGK and M dwarfs, and explore how characteristics like planetary size, mass, age and stellar activity may inform our assessment of planetary habitability. The talk will also discuss optimal methods and potential challenges for spectroscopic determination of the presence or absence of habitable surface environments and signs of life, and consider the capabilities of upcoming telescopes for habitability assessment of terrestrial exoplanets.

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.

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.

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.

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.

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.

The TESS Input Catalog and Lessons For PLATO

(Joshua Pepper)
A key task in planning the PLATO mission will be identifying the optimal stellar targets for the mission science goals. That effort requires a stellar catalog with physical and empirical stellar properties. The catalog must also include a census of luminous objects near potential target stars to account for additional flux blended with the target, as well as potential sources of variability among the nearby objects. The TESS mission dealt with the same challenges, and constructed the TESS Input Catalog (TIC) to address them. I will describe the success and challenges of constructing the TIC, its performance for the TESS mission, and lessons learned from the experience for PLATO.

The PLATO Input Catalog

(Giampaolo Piotto)
tbd

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.

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.

Characterizing stellar granulation with 3D stellar atmosphere models

(Luisa Fernanda Rodríguez Díaz)

During the last couple of years, the number of confirmed exoplanets has increased, especially thanks to missions such as CoRoT, Kepler, and TESS. More than 4,400 exoplanets have been confirmed, and more than 3,300 of them have been discovered via transits, making this method the most efficient one to detect exoplanets. We now know that there is a great variety of exoplanets orbiting other stars, but we have also faced challenges, such as detecting and identifying small exoplanets. One of the reasons behind this is, that the transit depth produced by an Earth-size planet in front of a star can be of the same level -or lower- like the brightness fluctuations generated on the stellar photospheres. As a result, better techniques have been needed in order to disentangle the exoplanet signal from the combined signal that telescopes capture. Some of those methods have focused on understanding and characterizing the stellar signal, and that is also what my contribution aims. In this talk, I will present our approach of characterizing the stellar brightness fluctuations, caused by stellar granulation on stellar photospheres, by using long time series of 3D stellar atmosphere models from the STAGGER-grid. I will provide an overview of the method we have developed, and the results obtained mainly for solar metallicity models, by comparing with previous works and observational data.

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.

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.

Stellar models lie at the core of many of the scientific goals of PLATO

(Aldo Serenelli)
Stellar models lie at the core of many of the scientific goals of PLATO. In this talk, I will discuss the current state-of-the-art of field for the stellar models required within PLATO's core program, highlighting the areas in which we believe physical inputs to models are well understood and those in which progress is being made but further work is still required to achieve the full potential of PLATO's scientific return.

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.

The future of exoplanet characterisation - the European route

(Ignas Snellen)
In this presentation. I will discuss the road ahead for European exoplanet science, the plans of ESA and ground-based observatories, and their link to PLATO.

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.

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.

The PLATO Complementary Science program

(Andrew Tkachenko)
In this talk, we will introduce the concept of the PLATO Complementary Science (PLATO-CS) program that will use up to 8% of the total PLATO telemetry budget as its main observational instrument. Following a brief introduction into the organization and management of the PLATO-CS program, we will provide an overview of its individual scientific components that have been identified so far. Each of those components is then given a particular attention, highlighting the state-of-the-art in field as well as the science prospects with the PLATO mission. Furthermore, we discuss the PLATO-CS overarching effort to deliver a fully automated in-depth variability classification of objects that will be targeted by the mission as part of the PLATO-CS program, keeping in mind a possibility for the step-and-stare operations after the nominal PLATO mission. We also highlight the main results of testing and verification of our classification framework on Kepler and TESS space-based photometric data, and outline the plans for the domain adaptation and transfer learning to the PLATO mission data.

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.

An Overview of Transiting Exoplanet Detection

(Andrew Vanderburg)
I will present an overview of exoplanet detection using precise space-based light curves. I will describe the processes of light curve production, transit search, vetting, and conducting follow-up observations to explain the how we go from pixels to planets. I will then discuss some scientific highlights from space-based transiting exoplanet missions, including some of the most challenging planets to detect. Finally, I will conclude by discussing a few of the lessons we have learned from CoRoT, Kepler, K2, and TESS, and how we can apply them going forward in the PLATO era.

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.

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.