LONDON UK EXOPLANET COMMUNITY MEETING 2019
TALK ABSTRACTS

Forming planets: current thoughts and challenges

Farzana Meru – University of Warwick – *Invited speaker*

The theory of planet formation has been forced to be updated again and again as new observations provide us with a diverse set of planet properties as well as diverse properties of discs within which planets form. In this talk I will review the historical view on planet formation as well as recent advances. I will also discuss the current challenges faced by planet formation theory.

Planet formation in the context of stellar clusters

Thomas Haworth – Imperial College London

Planet-forming discs have their size and mass reservoir limited by their stellar cluster environment, which may feed back into the nature of the resulting planetary populations. I'll review recent theoretical and observational developments in our understanding of this phenomenon, and introduce the first multi-dimensional models of intermediate strength UV fields externally photoevaporating planet-forming discs.

Competition between Chemical Processes and Physical Evolution in Discs

Richard Booth – University of Cambridge

Understanding the composition of the solid and gas components in protoplanetary discs is essential for determining the link between planet composition and their formation. Recent studies have shown that, given sufficient time, chemical processing can dramatically change the composition of gas and dust in disc mid-planes. However, these processes must compete with the physical evolution of discs, due to accretion along with the growth and migration of dust. Here I show that these physical processes act to reduce the impact of midplane chemical processing by tranpsorting gas and dust faster than the chemical processing operates. This means that the gas and solid phase abundance of carbon, oxygen, and nitrogen are largely set by the abundance of molecular species being carried in from the outer disc. The only significant exception to this is that the gas phase C/O ratio, which can be reduced from > 1 to around 1 between the methane and carbon dioxide snow lines (2-10 au). This occurs when methane can be depleted from the gas phase, but requires favourable conditions. A consequence of this is that the composition of outer disc comets will place the best constraints on the disc composition in the classical giant planet-forming region.

The interplay between dynamics and chemistry in planet formation

John Ilee – University of Leeds

Recent work has demonstrated the power that planetary atmospheric compositions have to constrain the different modes of planet formation. However, such models are based on simplistic assumptions about the physical and chemical evolution of the planet-forming discs. In this talk, I will discuss our work combining hydrodynamic simulations with gas-grain chemical kinetics models in order to directly track the composition of material during planet formation.

We find that the hydrodynamic evolution of the disc changes the composition raw material available for incorporation into planetary cores and atmospheres, significantly altering their composition when compared to previous assumptions (Ilee et al. 2017). Our models reproduce observations of complex organic molecules in comets, and suggest direct inheritance of biologically-relevant molecules from the protostellar nebula can occur (Quenard, Ilee et al. 2018). Additionally, the growth, fragmentation and drift of dust within the disc is able to significantly alter the distribution of molecules in the disc, and thus change the raw materials available during planet formation (Booth, Ilee & Clarke, in prep.). Therefore, the interplay between dynamic and chemical evolution must be taken into account if we are to reliably and effectively link the composition of planets with their formation conditions.

Giant planets formation and evolution: constraints from the latest direct Imaging surveys

Mariangela Bonavita – University of Edinburgh

Understanding the formation and evolution of giant planets (1 MJup) at wide orbital separation (5 AU) is one of the main goals of direct imaging. Over the past 15 yr, many direct imaging surveys have placed strong constraints on the occurrence rate of wide-orbit giants, mostly based on non-detections, but very few have tried to make a direct link with planet formation theories.

In this talk I will present the results of the first direct comparison between the data from most of the published imaging surveys and state-of-the-art population synthesis models based on the gravitational instability formation scenario, in an attempt to provide meaningful constraints on giant planet formation models.

Our results seem to suggest that even though GI is not common, it predicts a mass distribution of wide-orbit massive companions that is much closer to what is observed than what the core accretion scenario predicts. New dedicated instruments like VLT/SPHERE allow for a further extension of the analysis to the giant planets frequency in the 5-100 AU range and down to a few Jupiter masses.

In the final part of the talk I will show the preliminary results of the extension of the method to the first 2 years of data coming from SHINE (SpHere INfrared survey for Exoplanets), its implication on our previous results and possible future applications.

Formation of Hot Jupiters through Secular Chaos and Dynamical Tides

Jean Teyssandier – Cornell University, USA

The population of giant planets on short-period orbits (hot Jupiters) can potentially be explained by some flavours of high-eccentricity migration. In this talk I will review new developments regarding one such mechanism involving "secular chaos", in which secular interactions between at least three giant planets push the inner planet to a highly eccentric orbit, followed by tidal circularization and orbital decay. In addition to the equilibrium tidal friction, I will discuss the effects of dissipation due to dynamical tides that are excited inside the giant planet. This improved model of tides, which hasn't been coupled with dynamical simulations until now, allows for stronger dissipation and can save planets from tidal disruption. This study represents the first large-scale attempt at characterizing the efficiency of forming hot Jupiters via secular chaos. I will discuss how the predictions of this mechanism regarding the properties of hot Jupiters (period distribution, spin-orbit angle...) compare with observations.

Vortices everywhere: Planets in low viscosity discs

Colin McNally – QMUL

I will discuss our emerging understanding of planet migration in low-viscosity wind-driven discs. This new understanding is derived from several studies in two and three dimensions, including magnetic fields, wind driving, and multiple planets. First, I will present the highest resolution study to date of super-Earths migrating in inviscid and low-viscosity discs. Our models unveil the critical role of vortices in determining the migration behaviour for partial gap-opening planets. Vortices form in pressure maxima at gap edges, and prevent the disc-feedback stopping of migration for intermediate planets in low-viscosity and inviscid discs, contrary to the concept of the 'inertial limit' or 'disc feedback' halting predicted from analytical models. The migration of partial gap-opening planets becomes chaotic for sufficiently low viscosities. At moderate viscosity, a smooth disc-feedback regime is found. At high viscosity classical Type I migration is recovered. For Jupiter-analogue planets transient Type II migration occurs over radial length-scales corresponding to the gap width. I will also present ongoing work on the largest three dimensional simulations of super-Earth-disc interaction performed to date, which include the impact of gas thermodynamics, and for the first time a disc wind driving accretion in the upper layers of a laminar protoplanetary disc.

Close-in Super-Earths: The first and the last stages of planet formation in an MRI-accreting disc

Marija Jankovic – Imperial College London

At the orbital distances of the abundant close-in super-Earths, the inner regions of protoplanetary discs are viscously accreting due to the magneto-rotational instability (MRI). The MRI-induced turbulence limits the size of dust particles in the inner disc, as the particles fragment due to relative turbulent velocities. We show that this leads to enhancement of the dust-to-gas ratio, i.e., to the first stage of planet formation in the inner disc. We further explore how the high temperatures and low gas surface densities of the MRI-accreting inner disc affect the last stages of planet formation, the accretion of planet atmospheres onto solid cores. We calculate how much gas solid cores accrete from the disc, how much of their atmospheres they subsequently lose to photoevaporation, and the resulting planet mass-radius relationship. Finally, we compare the results to the observed exoplanet masses and radii.

Tracing volatile elements from disks to planets

Oliver Shorttle – University of Cambridge – *Invited speaker*

The elements carbon, water, and sulfur, are some of the most abundant in the universe, are major constituents of planetary atmospheres, and are essential constituents of all known life. Yet, their arrival on planets and distribution therein remains uncertain. In large part this is due to their volatile nature: each element may form species that readily enter the gas phase at the temperatures and pressures of planetary differentiation. Here, we combine observations from Earth with observations from protoplanetary disks. Combining geochemical and astrophysical observations in this way gives us new insight into how these elements were partitioned between gas and dust during accretion, and where they are ultimately distributed in planets.

Wave propagation and tidal dissipation in giant planets

Christina Pontin – University of Leeds

Observations of the satellites of Jupiter and Saturn indicate higher tidal dissipation rates in these planets than standard theoretical models predict (Lainey et al. 2009, 2012, 2017), which suggests there is an additional mechanism for tidal dissipation. The presence of heavy element gradients in giant planet interiors, consistent with recent gravity field measurements from Juno (Wahl et al. 2017), can lead to regions where ordinary convection is inhibited but double-diffusive convection occurs. This can lead to a nearly discontinuous staircase-like density structure, consisting of well-mixed convective layers separated by infinitesimally thin interfaces. This staircase structure can strongly modify the propagation of internal waves, and potentially also lead to enhanced tidal dissipation.

I will present calculations to explore how internal wave propagation and tidal dissipation in a giant planet are affected by regions containing double-diffusive staircases. The model adopted here is a Boussinesq system in spherical geometry, which extends previous work in the Cartesian limit (Sutherland 2016, André et al. 2017). I will first present the properties of the free modes of a density staircase and show there are bands of enhanced wave transmission dependent on the staircase properties. Finally, I will present calculations to explore the resulting tidal dissipation.

A water budget dichotomy of rocky protoplanets from 26Al-heating

Tim Lichtenberg – University of Oxford

In contrast to the water-poor inner solar system planets, stochasticity during planetary formation and order of magnitude deviations in exoplanet volatile contents suggest that rocky worlds engulfed in thick volatile ice layers are the dominant family of terrestrial analogues among the extrasolar planet population. However, the distribution of compositionally Earth-like planets remains insufficiently constrained, and it is not clear whether the solar system is a statistical outlier or can be explained by more general planetary formation processes. Here we employ numerical models of planet formation, evolution, and interior structure, to show that a planet's bulk water fraction and radius are anti-correlated with initial 26Al levels in the planetesimal-based accretion framework. The heat generated by this short-lived radionuclide rapidly dehydrates planetesimals prior to accretion onto larger protoplanets and yields a system-wide correlation of planet bulk abundances, which, for instance, can explain the lack of a clear orbital trend in the water budgets of the TRAPPIST-1 planets. Qualitatively, our models suggest two main scenarios of planetary systems' formation: high-26Al systems, like our solar system, form small, water-depleted planets, whereas those devoid of 26Al predominantly form ocean worlds, where the mean planet radii between both scenarios deviate by up to $\approx$10%.

Finding an Alien Biosphere with Computational Chemistry

Clara Sousa-Silva – MIT – *Invited speaker*

At the edge of our present scientific frontier lies the question: "Can we identify the signs of life on an exoplanet?". Establishing whether a planet is habitable, or inhabited, relies both on the observation of an exoplanet atmosphere and, crucially, its subsequent interpretation. This interpretation requires knowledge of the spectral behaviour of every significant atmospheric molecule. However, though thousands of molecular candidates can contribute towards the spectrum of an atmosphere, data exist for only a few hundred gases. Among these, only a fraction have complete spectra (e.g. ammonia, water). This deep incompleteness in the knowledge of molecular spectra presents a pressing vulnerability in the atmospheric study of planets; there exists a strong possibility of mis-assignment, false positives, and false negatives in molecular detections. The work presented here combines structural organic chemistry and quantum mechanics to obtain the necessary tools for the interpretation of astrophysical spectra and, ultimately, the detection of life on an exoplanet. Whether alien life will produce familiar gases (e.g. oxygen) or exotic biosignatures, painting a confident picture of a potential biosphere will require a holistic interpretation of an atmosphere and its molecules. In this talk I will describe the ongoing efforts to decipher exoplanet atmospheres through the identification of volatile molecules, in particular those that might be produced by non-Earth-like life on exoplanets.

Atmospheric convection on tidally-locked Earth-like exoplanets

Denis Sergeev – University of Exeter

On extrasolar planets, many aspects of non-rotating atmospheric dynamics, such as convection, play a crucial role in determining circulation regimes and ultimately their potential habitability. A few previous studies have already hinted at the importance of choosing the convective parameterisation for correct estimates of the onset of runaway greenhouse effect on exoplanets.

While there are plenty of in-situ and remote observations on Earth to constrain and validate convection schemes, no such measurements are available for exoplanets yet. Hence the next best option is to run convection-resolving simulations in a limited-area domain, which in turn can be compared to global model output and used to tune convective parameterisations.

I address these questions by employing the latest version of the UK Met Office Unified Model, adapted for exoplanet simulations, in the so-called nesting suite set-up that allows for a seamless approach to atmospheric modelling at different scales. Preliminary results show differences in the export of heat and moisture from the substellar region to the night side of the planet in simulations with parameterised compared to runs with explicitly-resolved convection.

Separate Ways: Worlds Apart – The Relationship between Mantle Mineralogy and Climate Stability

Laura Lewis – Open University

As seen in our own Solar System, terrestrial planets can evolve in very different ways. Why is Earth so temperate whilst Venus is a hostile, lifeless world? Coupling between plate tectonics and climate is currently only theorised to occur on planets with a large supply of the volatile elements water and carbon dioxide (Foley & Driscoll, 2016). In simulations, the most important factor was found to be the mass of the accreting protoplanet. This was seen to relate to the density of the solids beyond the snow line. This greater density resulted in fewer, larger mass terrestrial planets with higher water contents(Raymond, Quinn, & Lunine, 2004). The composition of the planet's mantle is crucial in the initiation of plate tectonics and a long term carbon cycle vital for an Earth – like climate. Planets with the appropriate Si and Na abundances for plate tectonics are rare in the galaxy, orbiting only one third of stars .(Unterborn et al., 2017) ARIEL will detect a varietyt of chemically important elements and provide insight into the bulk materials of planets (Tinetti, 2018). This investigation could also analyse the compositions of more exotic, carbon or carbide rich planets and their associated geological and climatic regimes.

Evolution of steam atmosphere for early Earth with a coupled climate-interior model

Dr. Nisha Katyal – Technical University, Berlin

In this work, we study the evolution of a pure steam atmosphere during the magma ocean phase of the Earth's Hadean period (4 to 4.5 Ga). Using prescribed surface temperature and pressure from the outgassing model of the interior, we obtain the atmospheric structure which is then used to calculate the Outgoing Longwave Radiation using a line-by-line atmospheric code GARLIC. The resulting flux is balanced with the flux from the interior and the stellar flux to assess the surface temperature as a function of time. In this way we obtain the magma ocean cooling timescale. Emission thermal spectra and transmission spectra are presented for the whole duration of the magma ocean and show distinct water absorption bands. We also study the thermal dissociation of H2O at higher temperatures by applying atmospheric chemical equilibrium which results in the formation of H2 and O2 during the early phase of the magma ocean. As a result, a 1-6% reduction in the OLR is seen associated with the decrease in the surface temperature. We then obtain the effective height of the atmosphere from the calculated transmission spectra. We observe that as the magma ocean cools down, the atmospheric transmission height or the depth of the water bands are reduced from a few thousand km to a few hundred km. We conclude that species such as H2O, H2 and O2 have a significant contribution upon the atmospheric effective height and could be useful for placing observational constraints upon young exoplanets in the magma ocean phase.

The climate of hot exoplanets with coupled fluid dynamics, radiative transfer and chemistry

Ben Drummond – University of Exeter – *Invited speaker*

I will present results from three-dimensional (3D) atmosphere simulations that couple the atmospheric dynamics, radiative transfer and chemistry, highlighting the important effect of wind-driven advection on the chemical composition and climate. The atmospheres of tidally-locked, highly-irradiated planets are both theoretically predicted and observationally shown to be strongly asymmetric structures, requiring the use of a 3D model to accurately capture the relevant physics. Most studies adopting a 3D model so far have made the assumption of local chemical equilibrium, meaning that the chemical composition is only dependent on the local pressure and temperature. This approach ignores the important effect of transport of chemical species by the atmospheric circulation, as well as the effect of photochemistry driven by the intense irradiation received from the host stars of these close-in planets. I will present results from the first 3D atmosphere model to include the effect of transport on the chemical composition consistently with the radiative transfer. This allows for feedback between the composition and the thermal structure, via the atmospheric opacity, and ultimately the atmospheric circulation itself. I will show that, for typical hot Jupiters, relaxing the assumption of chemical equilibrium can lead to significant effects on the predicted transmission spectra, emission spectra and phase curves. In some cases, the departure from chemical equilibrium can also lead to changes in the thermal structure and global circulation of the atmosphere. These results indicate that models that take a consistent approach to important physical processes are required to truly understand the climate of hot exoplanets.

Wave-Mean Flow Interactions in the Atmospheric Circulation of Tidally Locked Planets

Mark Hammond – University of Oxford

The global atmospheric circulation and temperature distribution of tidally locked planets is key to interpreting observations such as phase curves, eclipse maps, and atmospheric retrievals.

We linearize a shallow-water model of the atmosphere on such a planet about the eastward equatorial jet that forms in 3D simulations. We show that the response to day-night forcing is modified by this jet, producing the distinctive eastward hot-spot shift that appears in observations. The hot-spot shift results from a combination of Doppler-shifted stationary waves, and a zonally uniform atmospheric height perturbation from the jet itself.

This suggests that the characteristic hot-spot shift and day-night contrast on these planets should be understood mainly in terms of forced wave patterns, rather than as caused by advection from the equatorial jet. We use the linear model to predict scaling relations for observable quantities, which we test qualitatively in 3D numerical simulations.

We conclude that the wave-mean flow interaction between the stationary waves created by the day-night forcing, and the equatorial jet produced by these stationary waves, is crucial to the global atmospheric circulation on tidally locked planets.

An equatorial jet and polar flow on WASP-49b

Tom Louden – University of Warwick

I present a new analysis of the spectrum of WASP-49b using Terminator, a code developed to spatially resolve the atmospheres of exoplanets. Simulations of hot Jupiters with GCM's predict the presence of a strong equatorial jet, as well as a day-to-night flow. Without spatial resolution, it is only possible to measure an average velocity of the planet, and hence it is not possible to disentangle these contributions. Transit Limb Scanning makes it possible to spatially resolve the atmosphere of an exoplanet during transit. This technique was first used in Louden & Wheatley 2015 to spatially resolve the atmosphere of the hot Jupiter HD 189733b. I build upon this technique and show that it is also possible to separate out contributions from polar and equatorial regions of the planet. I will present an analysis of WASP-49b showing 3 distinct velocity regions in the atmosphere; eastern and western equatorial regions with velocities of -3 +- 1 and 1+-1 km/s, and a polar region with an average velocity of -1 +- 1 km/s. This is only the second time that an equatorial jet has been directly measured on exoplanet, and is the first evidence of a distinct polar region.

Atmospheric circulation of brown dwarfs and directly imaged giant planets

Xianyu Tan – University of Oxford

Brown dwarfs are substellar objects intermediate between stars and giant planets. Currently detected extrasolar giant planets (EGPs) by directly imaging technique generally have high internal flux, negligible external irradiation and possibly fast rotation rate, and can be viewed as low-gravity versions of brown dwarfs. Growing observational evidence has suggested active meteorology in the atmospheres of these substellar objects, motivating an exploration into the fundamental properties of the circulation, the atmospheric mixing of clouds and chemistry, and the overall implications for the observed variability and properties of the near-IR color for brown dwarfs and directly imaged EGPs. In this talk I will present our recent results on the atmospheric circulation of this class of objects, highlighting the role of cloud radiative feedback in shaping the circulation, cloud properties and the implications for observations.

The Effects of Gravity on the Climate and Circulation of a Terrestrial Planet

Dr Stephen I. Thomson – University of Exeter

The climate and circulation of a terrestrial planet are governed by a host of planetary parameters. Here we explore the effects of one of these, the Newtonian gravitational acceleration. We first demonstrate that if the atmosphere obeys the hydrostatic primitive equations, which are a very good approximation for most terrestrial atmospheres, and if the radiative forcing is unaltered, changes in gravity have no effect at all on the circulation except for a vertical rescaling. However, if the atmosphere contains a dilute condensible that is radiatively active, such as water or methane, then an increase in gravity will generally lead to a cooling of the planet because the total path length of the condensible will be reduced as gravity increases, leading to a reduction in the greenhouse effect. Furthermore, the specific humidity will decrease, leading to changes in the moist adiabatic lapse rate, in the equator-to-pole heat transport, and in the surface energy balance because of changes in the sensible and latent fluxes. These effects, and their impacts on the circulation, will be demonstrated both by theoretical arguments and by numerical simulations with moist and dry general circulation models.

Outgassing and clouds on lava planets: A 55 Cnc e test case.

Graham K.H. Lee – University of Oxford

The molten surface of hot super-Earth exoplanets has been suggested to outgas refractory elements such as Silicon, Iron and Sodium. Should these elements reach colder regions of an atmosphere they may recondense to form mineral clouds. Using a 3D Global Circulation Model (GCM) we investigate the link between surface outgassing and cloud formation. We couple an equilibrium magma surface outgassing, spectral radiative transfer and microphysical cloud formation model to the GCM to simulate potential atmospheric compositions of 55 Cnc e. We find that mineral clouds can readily form in the atmosphere and have substantial radiative feedback effects on the atmosphere. Dependent on the background gas and cloud composition, our simulations show that clouds are responsible for radical changes in the temperature and potentially alter the dynamical regimes of the atmosphere. We find that the condensation of solid Sodium cloud particles at high altitudes plays a critical role in regulation of the climate in these objects.

TESS and the Exoplanet Population

David Armstrong – University of Warwick – *Invited speaker*

TESS promises to bring the next step change in our knowledge of exoplanets, both individually and on a population level. The mission has been actively releasing data for several months, with planetary candidates and recently full datasets available to the public. I will overview some of the early TESS discoveries and ongoing programs to characterise TESS candidate planets, before looking at the wide ranging effects TESS will have in the longer term. In particular I will look at the potential to influence our understanding of the exoplanet population, compositions and planetary internal structure brought by an all sky survey. Finally I will introduce a recently detected signature in the planet mass distribution, possibly formed from tidal interactions with the host star. Characterising this signature in detail will require the full TESS mission and the relatively homogenous set of transiting planets with measured masses it will provide.

Using solar observations to identify a proxy for radial-velocity variations induced by magnetic activity in Sun-like stars

Raphaëlle D. Haywood – Harvard College Observatory

The main obstacle to confirming and characterising small planets discovered by Kepler, K2, and TESS is the magnetic activity of the host stars. Indeed, radial-velocity (RV) observations are dominated by rotationally modulated signals that arise from the presence of magnetic features and velocity flows on the stellar surface. To overcome this obstacle, we must identify indicators that correlate strongly with activity-induced RV variations. We reconstruct the RV variations of the Sun seen as a distant, point-like star over the last magnetic cycle, using SDO/HMI data, calibrated against overlapping HARPS-N RV observations of the Sun as a star. We measure the full-disc, unsigned magnetic flux and show that a simple linear fit to it can reduce the rms of RV variations by a factor of two. We thereby confirm that it is an excellent proxy for activity-induced RV variations, and discuss future prospects for measuring the unsigned magnetic flux in Sun-like stars.

A new technique for ultra-precise radial velocity extraction

Vinesh Maguire Rajpaul – University of Cambridge

The radial velocity (RV) method has been responsible for more exoplanet discoveries than all other techniques apart from transit photometry, and is also indispensable for confirming and characterising candidates discovered via other techniques. And yet for several decades, the standard approach to extracting RVs from stabilised spectra has remained essentially unchanged: i.e., cross-correlating observed spectra with a masked, weighted template. In this talk I'll outline many of the drawbacks inherent in this approach, then present a simple new technique that seeks to address these drawbacks. In brief, each observed spectrum is modelled using a Gaussian process (GP); each GP model is then aligned with every other GP model spectrum, so that an RV can be assigned to each spectrum. As it works with an ensemble of spectra, the method also provides straightforward, data-driven ways to mitigate telluric and activity contamination in individual spectra. I'll show that even a crude implementation of this method can yield RVs with better precisions and significantly smaller rms scatter than RVs from a closed-source, industry-standard pipeline. Ultimately, the method should facilitate the study of smaller planets around a wider variety of stars than has previously been possible with Doppler spectroscopy.

Detecting Exoplanets with Convolutional Neural Networks: Application to the Next Generation Transit Survey

Liam Raynard – University of Leicester

Established methods of detecting exoplanet transit signals in stellar light curves, have become outdated in the era of machine learning. Detection is performed either by model fitting or by teasing out the signal with a convolutional kernel whose properties must be hand-designed. Both methods produce vast numbers of false positive candidates (up to 96%) which must then be vetted manually. Such human intervention lacks consistency and is not sustainable in the era of "Big Data". Here I assess the ability of Convolutional Neural Networks to perform the detection task, using data from the Next Generation Transit Survey. When light curves are phase folded on the correct period and epoch, our trained network correctly distinguishes transit from non-transit signals, with 90% accuracy. However, interesting challenges arise when searching over a grid of trial periods and epochs. I will describe our approach for finding the optimal way to train the network and the roles that both simulated and real data can play. New transit detection approaches, e.g. machine learning, will be critical to maximising the yields from TESS and future space survey missions such as PLATO.

The Next Generation Transit Survey: Discoveries and Activity

Oliver Turner – Geneva Observatory

The Next-Generation Transit Survey (NGTS) is a wide-field photometric survey designed to discover transiting exoplanets of Neptune-size and smaller around bright stars (magnitude V<13) from the ground. These objects will be intensely interesting for detailed follow-up as they will allow us to increase our understanding of the mass-radius relation for smaller planets and the brightness of their host stars will make them accessible to present day and upcoming instruments for atmospheric characterisation.

We will present a summary of NGTS activity so far and detail a number of new discoveries. Two such highlights are objects discovered in ?deserts? of parameter space. NGTS-4, a sub-Neptune planet orbiting a K-star, orbits in the so-called ?Neptune desert?, an area of parameter space where it is thought strong stellar irradiation would cause significant mass loss. NGTS-4b is also important as it is the shallowest transiting object to be discovered from the ground, demonstrating the potential to use NGTS to follow-up TESS objects in the future. Meanwhile NGTS-5b occupies the boarder of the sub-Jovian desert. It serves as an important diagnostic for this boarder and how to define it, taking into account the host star.

We will also discuss briefly the planned future activities of NGTS.

The NGTS young clusters program: understanding the early evolution of stellar and planetary systems

Edward Gillen – University of Cambridge

The Next Generation Transit Survey (NGTS) has begun a new observation program to target young open clusters. Our aim is to understand the early evolution of stellar and planetary systems. Planets, for example, evolve most dramatically during their first billion years: by characterising young transiting planets we can quantify timescales for migration, orbital circularisation, evolutionary cooling and atmospheric loss. The complicating factor is the host stars which, at young ages, typically display rapidly evolving activity signals that need to be understood in order to detect and accurately characterise the planets. I will present the NGTS young clusters program, highlight some early results from our first clusters, and discuss future prospects for the survey.

The SPECULOOS transit survey: hunting for red worlds

Laetitia Delrez – University of Cambridge

The thorough characterization of temperate terrestrial exoplanets holds the promise of revolutionizing our understanding of rocky worlds by enabling us to assess their diversity at the galactic scale, not only in terms of orbits, but also in terms of atmospheric compositions, surface conditions, and habitability. In this context, the $\sim$1000 nearest ultracool (M7-type and later) dwarf stars are particularly interesting targets for a transit search, as their proximity combined to their small size and faint luminosity should make possible the characterization of a transiting temperate planet as small as the Earth -and even smaller- with upcoming facilities. I will give here an update on SPECULOOS (Search for habitable Planets EClipsing ULtra-cOOl Stars), a new ground-based photometric survey that aims to explore these small nearby stars for transits. The SPECULOOS Southern Observatory (SSO), the core facility of SPECULOOS consisting of four 1m robotic telescopes, has been successfully installed at ESO Paranal Observatory (Chile) and achieved its official first light in December 2018. I will present the features and performances of the SSO facility, as well as the properties of the data gathered so far and status of the survey.

First Planets From The Dispersed Matter Planet Project

John Barnes – Open University

The Dispersed Matter Planet Project (DMPP) seeks planets orbiting stars with anomalously low stellar activity levels. Our fast-track method identifies potential planet hosting stars with sub-basal Ca II H & K emission, which results from circumstellar enshrouding material due to mass-loss from close-orbiting planets. This approach is proving to be highly efficient. We are carrying out intensive high cadence radial velocity observations, sensitive down to earth-mass planets in < 10 day orbits. DMPP discoveries are key planets for detailed study that orbit bright, nearby stars and have interesting and informative properties. Here we report our first planets: DMPP-1 hosts a compact multiplanet system of low-mass planets; DMPP-2 is the first RV discovery of a planet orbiting a pulsating star; DMPP-3Ab is a unique low-mass circumprimary planet in a 506 d eccentric binary star system containing a minimum mass star DMPP-3B. Our discoveries are challenging formation scenarios and will enable us to investigate the demographics of short orbital period planets by adding planets with precisely determined parameters.

An Updated Study of the Ariel Target List

Billy Edwards – University College London

Thousands of exoplanets have now been discovered with a huge range of masses, sizes and orbits. However, the essential nature of these exoplanets remains largely mysterious: there is no known, discernible pattern linking the presence, size, or orbital parameters of a planet to the nature of its parent star. We have little idea whether the chemistry of a planet is linked to its formation environment, or whether the type of host star drives the processes controlling the planet's birth and evolution.

Progress with these science questions demands a large, unbiased spectroscopic survey of exoplanets and Ariel has been selected as ESA's M4 mission for launch in 2028. By studying a large and diverse population of exoplanetary atmospheres, Ariel will provide insights into planetary formation and evolution within our galaxy.

I will present the latest study of potential targets for Ariel in which we assessed the suitability of currently-known exoplanets and predicted TESS yields. This list of planets has been utilised to form an example Mission Reference Sample to demonstrate that Ariel's mission goals could be met from this planetary population. I will also present the results from the latest studies into the expected scientific capability of Ariel.

Towards JWST: modelling and retrieval strategies for exoplanet atmosphere characterisation

Joanna Barstow – UCL – *Invited speaker*

Our ability to characterise exoplanet atmospheres is reliant on the models that enable interpretation of transmission, eclipse and directly imaged spectra. Simple, parameterised retrieval models have a unique role to play in a data-driven approach to understanding these exotic worlds, and have been extensively applied to current state-of-the-art observations. However, due to limited wavelength coverage and relatively low signal to noise, current retrieval solutions are degenerate and highly model-dependent.

We expect the upcoming James Webb Space Telescope to provide exoplanet spectra of unprecedented precision and detail, which will bring new challenges for the development of retrieval models. The expected improvement in information content will require an overhaul in modelling strategy, with increased complexity in representation of temperature structure, clouds, spatial variability and stellar heterogeneity. I will give an overview of the current state-of-the-art in retrieval approaches, and discuss directions for development in the run up to JWST.

Direcly detecting the atmospheres of irradiated brown dwarfs

Sarah Casewell – University of Leicester

Irradiated brown dwarfs have been described as filling the fourth corner of parameter space between hot Jupiters, isolated brown dwarfs and our solar system planets. Brown dwarfs have cool atmospheres dominated by cloud features, molecules and show features due to weather, much like planets. However, brown dwarfs have a much warmer interior than planets, begging the question - just how like hot Jupiters are irradiated brown dwarfs?

The best examples of these systems are those where the host star is a white dwarf. These rare binaries have very short periods (∼hrs) and the brown dwarf is irradiated by the white dwarf, often with large amounts of UV radiation. However, as the white dwarf primarily emits in the optical, and the brown dwarf emits in the infrared, we can directly detect the flux from the brown dwarf. In this talk I will present my recent results where we have directly detected the atmosphere of irradiated brown dwarfs (including in one eclipsing system), determining the day and nightside temperatures, and how the atmosphere has been affected by the UV irradiation from the white dwarf, in particular evidence of emission and photochemistry caused by this irradiation.

The time domain for brown dwarfs and directly imaged giant exoplanets: the power of variability monitoring

Beth Biller – University of Edinburgh

Variability has now been commonly observed in L and T type field brown dwarfs, primarily at near-IR and mid-IR wavelengths. The probable cause of this variability is surface inhomogeneities in the clouds of these objects (although other mechanisms may also contribute), causing a semi-periodic variability signal when combined with the rotational modulation from the 3 to 20 hour periods expected for these objects. Variability at similar or even higher amplitudes has recently been observed in young brown dwarfs and young planetary mass objects, which share similar effective temperatures as field brown dwarfs, but have considerably lower surface gravities. Variability studies of these objects relative to old field objects is then a direct probe of the effects of surface gravity on atmospheric structure. Here I will present variability results for a number of young planetary mass objects, including results from the first survey for quasi-periodic variability in low-surface gravity brown dwarfs and young planetary mass objects, simultaneous Hubble Space Telescope (HST) WFC3+Spitzer IRAC variability monitoring for the highly variable young (∼20 Myr) planetary-mass object PSO J318.5-22 and an ongoing variability monitoring campaign for the HR 8799bcde planets.

High-Precision Atmospheric Retrievals of Sub-Stellar Objects

Anjali Piette – University of Cambridge

Isolated brown dwarfs provide remarkable laboratories for understanding atmospheric physics in the low-irradiation regime, and can be observed more precisely than exoplanets thanks to their higher temperatures and remoteness from stars. As such, they provide a glimpse into the future of high signal-to-noise observations of exoplanets, which will place atmospheric models under increasing scrutiny. We investigate the importance of considering model uncertainties when interpreting high-quality spectra with atmospheric retrievals, and show that it can be important to allow for model uncertainty explicitly in the retrieval in order to correctly infer atmospheric properties. We will also present a new parametrisation for the P-T profile which avoids over-fitting of the spectrum, and show that it works successfully with test retrievals on simulated data. Finally, we will demonstrate the new retrieval framework on a high-precision spectrum of a brown dwarf.

Correcting Transiting Exoplanet Light Curves for Stellar Spots

Nikos Nikolaou – UCL

The field of exoplanet discovery and characterisation has been growing rapidly in the last decade. However, several big challenges remain, many of which could be addressed using machine learning methodology. For instance, the most successful method for detecting exoplanets, transit photometry, is very sensitive to the presence of stellar spots and faculae. The current approach is to identify the effects of spots visually and correct for them manually or discard the data. As a first step to automate this process, we are organising a competition for the 2019 European Conference of Machine Learning (ECML) on data generated by ArielSim, the simulator of the European Space Agency's upcoming Ariel mission, whose objective is to characterise the atmosphere of 1000 exoplanets. The data consist of pairs of light curves corrupted by stellar spots and the corresponding clean ones, along with auxiliary observation information. The goal is to correct light curves for the presence of stellar spots (multiple signal denoising). This is a yet unsolved problem in the community. In this talk we will discuss the problem, the impact of a solution, introduce the basics of machine learning and present the outline of the competition as well as initial baseline solutions.

Exoplanet atmospheric characterisation at high spectral resolutions

Rebecca Webb – University of Warwick

Observing exoplanet systems using ground-based high resolution spectrographs (R $> 25{,}000$) gives a unique insight into the chemical composition, physical structure and dynamics of its atmosphere. This technique, when used on close-in, giant planets, utilises the fact that the orbital motion of the planet can be directly detected from the large Doppler shift of its molecular signature in a set of time series spectra. This is key in being able to isolate the weak planet signal from the dominating telluric and stellar features and cross-correlating with model atmospheres. This has proven to be a powerful tool for non-transiting systems in particular by currently providing the only means of breaking the sin(i) degeneracy from radial velocity measurements. More recently, a Bayesian atmospheric retrieval framework on high resolution spectra has been developed in order to properly constrain the physical parameters of the atmosphere through a novel technique of mapping the cross-correlation functions to a statistical likelihood. This is the first such retrieval that can be used to characterise the atmospheres of non-transiting planets.

New Avenues in Atmospheric Modelling of Exoplanets

Siddharth Gandhi – University of Cambridge

We are entering the era of high-precision and high-resolution spectroscopy of exoplanets. Such observations require robust self-consistent spectral models custom-built for exoplanets incorporating state-of-the-art numerical methods and opacities. I discuss a new self-consistent atmospheric modelling code, GENESIS, which models radiative-convective and chemical equilibrium atmospheres of exoplanets. I investigate models of irradiated and non-irradiated planets over a range of C/O ratios and metallicities to determine the spectra and P-T profiles of such objects. I have also used this model to enable chemical detections of molecular species using high resolution Doppler spectroscopy of two well known hot Jupiters, HD189733b and HD209458b. Such model spectra are vital given that the era of high resolution spectroscopy will lead to more detailed abundance constraints and atmospheric detections in the future. I will also describe my work on retrievals, and describe my new HyDRA model, capable of analysing the dayside atmosphere of hot Jupiters from spectral observations. This model was coupled to GENESIS to investigate deviation from chemical and radiative-convective equilibrium processes for the planet WASP-43b. Such development of both self-consistent and retrieval methods in tandem will enable greater constraints on such processes that occur in exoplanetary atmospheres in the future.

Twinkle – a low-Earth orbit visible and infrared exoplanet spectroscopy observatory

Twinkle Team – UCL, Blue Skies Space LtD

The Twinkle Space Mission is a space-based observatory that has been conceived to measure the atmospheric composition of exoplanets. This cost-effective spacecraft is being constructed on a short timescale in the UK and is planned for launch in 2022. The satellite is based on a high-heritage platform and will carry a 0.45m telescope with two scientific instruments: a visible spectrograph based on UVIS (which is currently flying on the ExoMars Trace Gas Orbiter) and an infrared spectrograph. Together, these spectrographs provide simultaneous wavelength coverage from 0.4 to 4.5 m with resolving power up to R 300. The spacecraft will be launched into a Sun-synchronous low-Earth polar orbit and will have a baseline lifetime of seven years.

Twinkle will have the capability to provide high-quality visible and infrared spectroscopic characterisation of hundreds of bright exoplanets, including at least 100 currently-known exoplanets. It will also be capable of follow-up photometric observations of 1000 or more exoplanets. Photometric measurements, taken simultaneously in the visible and the infrared bands, will allow orbital parameters of systems to be well-constrained and enable precise measurements of transit timing variations present in multi-planet systems. The exoplanet targets observed by Twinkle will be composed of known exoplanets discovered by existing and upcoming ground- and space-based surveys, including TESS, GAIA, K2, CHEOPS, WASP and HATSouth.

Thanks to its pointing and tracking capabilities, Twinkle will also be able to observe solar system objects including asteroids, comets, the outer planets and their moons. Twinkle could provide a spectroscopic population study of asteroids and comets to study their surface composition, following up on the discoveries of LSST. Given that Twinkle's instrumentation has been optimised for observing exoplanets, it will also be able to obtain high-SNR spectra of the outer planets and moons in our solar system within very brief exposure times. Twinkle's wavelength coverage and position above the atmosphere will make it particularly well-suited for studying spectral features that are obscured by telluric lines from the ground, including hydration features, organics, silicates and CO2.

While Twinkle has been designed with these exoplanet and solar system science cases in mind, the spacecraft itself is a general observatory which will provide on-demand observations of targets at the requests of its users. Scientists worldwide can access telescope time on Twinkle through a simple, streamlined process, and then decide freely how to allocate their observing time.

This presentation will provide an overview of the mission, its core science cases and the telescope access model. For more information, visit www.twinkle-spacemission.co.uk.

Authors (First name, Last name): Max Joshua2, Marcell Tessenyi1,2, Giovanna Tinetti1,2, Jonathan Tennyson1,2, Giorgio Savini1,2

Institutions: Physics and Astronomy Department, UCL, London, United Kingdom Blue Skies Space Ltd., London, United Kingdom

Disentangling the planet from the star in late type M dwarfs: A case study of TRAPPIST-1g

Hannah Wakeford – Space Telescope Science Institute

TRAPPIST-1 hosts seven transiting Earth-sized exoplanets very amenable to atmospheric characterization. However, the star is an ultra-cool dwarf and contains its own molecular signatures which can potentially be imprinted on planetary transit lightcurves due to inhomogeneities in the occulted stellar photosphere. We use a new observation of TRAPPIST-1g, the largest planet in the system, together with previous data to disentangle the atmospheric transmission of the planet from that of the star. I will present a method to use the out-of-transit stellar spectra to reconstruct the stellar flux based on one, two, and three temperature components. I will present the results of the stellar reconstructions, along with the geometry of the planetary transit, using physically motivated stellar and planetary spectra to disentangle the signature of the planet and stellar atmospheres. The method presented in the case study of TRAPPIST-1g is widely applicable to all late type M dwarfs with transiting planets and will be important for future characterization studies.

Studying the Interior Structure of Highly-Eccentric Hot Jupiters via Deep Imaging with VLT-SPHERE

Sasha Hinkley – University of Exeter

I will describe how we have used the VLT-SPHERE instrument to place constraints on the internal structure of a highly-eccentric Hot Jupiter. In the dynamically-driven migration scenario (e.g. Kozai-Lidov cycles combined with tidal friction), a Jupiter mass planet is dynamically excited to a high eccentricity by a third body, and its orbit shrinks and circularizes through tidal dissipation. Using SPHERE, we have obtained very high contrast imaging of the nearby system HD 20782, which hosts a Hot Jupiter with the highest known eccentricity to date (e$\sim$0.96). Our observations eliminate the possibility of 20-60 Jupiter mass companions present in the system at orbital separations $\sim$10-60 AU. Our lack of detections of any companions in the system indicates that the eccentricity of the planet was gained early on and has persisted until the present. The apparent failure of the tidal dissipation mechanism means that we can place extremely powerful constraints on the internal structure of the Hot Jupiter, the tidal quality factor “Q”, as well as the central concentration of the planet. Numerous more highly-eccentric Hot Jupiters will yet be discovered with ongoing precision radial velocity monitoring, illuminating the interior structures of many more Jovian mass planets going forward.

An absolute sodium abundance for a cloud-free 'hot Saturn' exoplanet

Nikolay Nikolov – Johns Hopkins University

Broad absorption signatures from alkali metals, such as the sodium (Na I) and potassium (K I) resonance doublets, have long been predicted in the optical atmospheric spectra of cloud-free irradiated gas-giant exoplanets. However, observations have only revealed the narrow cores of these features rather than the full pressure-broadened profiles. Cloud and haze opacity at the day-night planetary terminator are considered responsible for obscuring the absorption-line wings, which hinders constraints on absolute atmospheric abundances. Here we present an optical transmission spectrum for the 'hot-Saturn' WASP-96b obtained with the Very Large Telescope, which exhibits the complete pressure-broadened profile of the sodium absorption feature. The spectrum is in excellent agreement with cloud-free, solar-abundance models assuming chemical equilibrium. We are able to measure a precise, absolute sodium abundance of log Na = 6.9+0.6-0.4, and use it as a proxy to the planet's atmospheric metallicity relative to the solar value (Zp/Zs=2.3+8.9-0.4). This result is consistent with the mass-metallicity trend observed for solar-system planets and exoplanets.

Molecular opacities for hot rocky super-Earths

Alec Owens – University College London

The atmospheres of hot rocky super-Earths will have very different spectroscopic signatures compared to gas giants or cooler objects. Many of these exoplanets possess short orbital periods, hence hot atmospheres, and will have a lot in common with early Earth; the massive amounts of water and elevated temperatures are expected to turn the atmospheres into a (high pressure) steam bath containing the remains of melted rock. Here, we will discuss recent progress on the production of molecular opacity data for hot rocky super-Earths and present preliminary spectra. A number of molecules containing silicon, alkali and alkaline earth metals are to be included in the ExoMol database. For the temperature and wavelength ranges considered, molecular opacities will have to come from rigorous, first-principles calculations. However, these species pose new challenges and there is a pressing need for laboratory observations to improve the accuracy of our spectroscopic models.

High resolution spectroscopy of exoplanets

Sergey Yurchenko – University College London

The Doppler cross-correlation technique pioneered by I. Snellen [Nature, 465, 1049 (2010)] allows to study spectra of exoplanets at high-resolution. It tracks the Doppler shifts of a large number of spectroscopic lines of a given species, by cross-correlating them to the reference lab data on the line positions. This requires precise (resolving power of 100,000) spectroscopic data as well good spectroscopic coverage (hot transitions, highly excited ro-vibronic states) [Brogi & Line, arXiv:1811.01681]. ExoMol is a major provider of molecular line lists for exoplanetary retreivals. [Tennyson & Yurchenko, MNRAS, 425, 21 (2012)]. Here we present a new method to construct molecular line lists with experimental precision of the line positions. The method is based on the 'MARVELisation' approach [Furtenbacher et al., J. Mol. Spectr. 245, 115 (2007)]: the line positions in the empirical line list are replaced by highly accurate experimental values. The performance of the approach will be demonstrated on the new ExoMol data: the TiO line list ToTo [L. K. McKemmish et al., submitted to MNRAS, 2019] and the water line list POKAZATEL [O. L. Polyansky et al., MNRAS, 480, 2597 (2018)].