The Formation and Evolution of Planets and Their Discs

19.06.-21.06.2017, LRZ, Garching

Abstracts booklet

MONDAY, 19.06.2017

Transition Disks: Observations vs Models Cornelis DULLEMOND

With the enormous progress in high-resolution and high-contrast imaging of protoplanetary disks at optical/NIR and (sub-)millimeter wavelengths, protoplanetary disks have revealed themselves to be highly structured, yet highly “organized”: Rather than displaying a clumpy mess, we see mathematically well-defined shapes: rings, m=2 spirals, shadows, one-sided blobs. This offers a unique chance to study the physics of protoplanetary disks. I will talk about a few lines of thought how we might connect these observations with simple physical mechanisms.

An opening criterion for dust gaps in protoplanetary discs Giovanni DIPIERRO

Recent spectacular spatially resolved observations of gaps and ring-like structures in nearby dusty protoplanetary discs have revived interest in studying gap-opening mechanisms. In this talk I'll describe the two distinct physical mechanisms for dust gap opening by embedded planets in protoplanetary discs: I) A mechanism where low mass planets, that do not disturb the gas, open gaps in dust by tidal torques assisted by drag in the inner disc, but resisted by drag in the outer disc; and II) The usual, drag assisted, mechanism where higher mass planets create pressure maxima in the gas disc which the drag torque then acts to evacuate further in the dust.
Starting from numerical evidences, we derive a grain size-dependent criterion for dust gap opening in viscous protoplanetary discs by revisiting the theory of dust drift to include disc-planet tidal interactions and viscous forces. From this formalism, we derive i) a grain size-dependent criterion for dust gap opening in discs, ii) an estimate of the location of the outer edge of the dust gap and iii) an estimate of the minimum Stokes number above which low-mass planets are able to carve gaps in the dust only. These analytical estimates are particularly helpful to appraise the minimum mass of an hypothetical planet carving gaps in discs observed at long wavelengths and high resolution. We validate the theory against 3D SPH simulations of a broad range of dusty discs hosting an embedded planet. We find a remarkable agreement between the theoretical model and the numerical experiments.

Shadows and spirals in the protoplanetary disk HD100453 Myriam BENISTY

In this talk, I will present observations of the Herbig Ae star HD100453 in polarized scattered light with SPHERE/VLT at optical and near infrared wavelengths. In the observations, we detect a cavity, a rim with azimuthal brightness variations, two shadows and two symmetric spiral arms. I will present our radiative transfer model that accounts for the main characteristics of the features, with an inner and outer disk misaligned by 72 degrees. Finally, motivated by the close proximity of the spirals with the shadows, I will discuss the hydrodynamical consequences of the shadows on the disk.

Warm gas inside the dust cavities of transition disks, planets, and accretion. Andres CARMONA GONZALEZ

Transition disks are protoplanetary disks that have inner dust cavities with sizes of a few to tens of AU. To measure the gas content inside those cavities is important to establish the mechanisms responsible of the transitional disk shape. In this talk, I will review our current knowledge of the warm gas inside the dust cavities of transition disks, and discuss the links to planet formation, disk dissipation, and accretion. I will illustrate the talk with examples of transition disks in which detailed modeling of 4.7 micron CO ro-vibrational emission, [OI] 63 micron emission, and sub-mm CO rotational lines has been performed. I will argue that although dust cavities contain molecular gas, there is significant reduction of the gas density inside them and that the distribution of the gas is compatible with a flat or an increasing surface density profile with radius. I will show that if the gas density drop and dust gaps and cavities are due to a planet, its mass should be lower than a few Jupiter masses. Finally, I will discuss that the measured inner gas surface densities are not compatible with the accretion rates reported if the disks are assumed to be standard alpha disks.

Probing dust trapping in transition disks with (sub-)millimeter polarization observations Adriana POHL

There have been several mechanisms proposed to produce millimeter-wave polarization in the context of evolved planet-forming disks: dust grain alignment with magnetic fields or radiative flux, and self-scattering of thermal dust emission. We claim that, apart from the spectral index, the detection of polarization due to self-scattering is an independent method to constrain the disk grain size distribution. In this context we study the dust trapping scenario proposed for transition disks by predicting the polarization at ALMA bands due to scattered thermal emission, based on planet-disk interaction and self-consistent dust growth models. With radiative transfer calculations we determine the polarization degree in the disk and investigate the polarization map, which shows a characteristic ring pattern. We compare different dust evolution timescales and analyze the wavelength dependence of the polarization degree.

Self-induced dust traps: overcoming planet formation barriers Jean-François GONZALEZ

Planet formation is thought to occur in discs around young stars by the aggregation of small dust grains into much larger objects. The growth from grains to pebbles and from planetesimals to planets is now fairly well understood. The intermediate stage has however been found to be hindered by the radial-drift and fragmentation barriers.
We identify a powerful mechanism in which dust overcomes both barriers. Its key ingredients are (i) backreaction from the dust on to the gas, (ii) grain growth and fragmentation and (iii) large-scale gradients. The pile-up of growing and fragmenting grains modifies the gas structure on large scales and triggers the formation of pressure maxima, in which particles are trapped.
We show that these self-induced dust traps are robust: they develop for a wide range of disc structures, fragmentation thresholds and initial dust-to-gas ratios. They are favored locations for the formation of pebble-sized solids and their subsequent growth into planetesimals, thus opening new paths towards the formation of planets.

Rings, rings, rings: what does CN tell us? Paolo CAZZOLETTI

In the last few years ALMA has shown that ring-like structures are common in protoplanetary disks. They can be found in both gas and dust, and in both full and transitional disks, but the rings differ depending on tracer. CN, one of the brightest molecules in protoplanetary disk, is a particularly interesting case. High-resolution ALMA CN observations often show ring-like structures. We investigate if such structures are due to the morphology of the disk itself or if they are instead an intrinsic feature of the emission of CN. Using the 2D thermochemical code DALI (Bruderer 2013), we run a set of disk models for different stellar spectra, disk masses and disk structures, and by using an updated chemical network accounting for the most relevant CN reactions.

We find that ring-shaped emission is a common feature of all adopted models: the highest abundance is found in the outer regions, the column density always peaks at 50-70 AU (for T Tauri stars), and the emission profile follows the column density. Higher mass disks therefore generally show brighter CN. We also find a strong dependence of the ring brightness and location on the UV field, and in general higher incident UV fluxes result in brighter and larger rings. This happens when the UV radiation impinging on the disk increases because of a Herbig rather than T Tauri star, or due to higher disk flaring. These trends are caused by the fact the main formation route of CN is thrpugh reactions of N with excited $H2^*$, which is formed through FUV pumping of the H2 molecules.

The strong link between FUV flux and CN emission and morphology could therefore provide critical information on the physical structure of the outer part of the disk and on the distribution of dust grains (which affects the UV penetration), and could help to break some degeneracies in the SED fitting. Finally, CN emission is optically thin and comes from the upper layers of the disk, making it an ideal molecule for probing the vertical structure of disks.

The effect of radiative feedback on disc fragmentation Anthony MERCER

Protostellar discs may become massive enough to fragment and produce planets, brown dwarfs or low-mass stars. Accretion of material onto these objects would result in an increase in temperature and heat the surrounding disc. Similar to their higher mass stellar counterparts, we assume that the accretion onto such formed objects could be episodic, occurring in short intermittent bursts. We have simulated massive discs using radiative hydrodynamics to study the effect of radiative feedback from formed objects. We compare the results from cases where the secondary objects provide: no radiative feedback, continuous radiative feedback and episodic radiative feedback. We find that the most objects form when radiative feedback is neglected, and the least when radiative feedback is continuous. Episodic radiative feedback does not suppress further disc fragmentation as the disc cools sufficiently between episodes. Radiative feedback mildly suppresses consequent mass accretion, but the mass accretion history ultimately depends on where the object is formed within the disc, and on further interactions. We find that the masses of secondary objects formed by disc fragmentation are between a few Jupiter masses to a few tenths of a solar mass. Planets formed by fragmentation are typically ejected from the disc. We conclude that wide-orbit planets are unlikely to form by disc fragmentation. Nevertheless, disc fragmentation may be a significant source of free-floating planets and brown dwarfs.

TUESDAY, 20.06.2017

Angular momentum transport in planet-forming disks: constraints from disk observations — Ilaria PASCUCCI

It is well established that young stars accrete disk gas, yet the physical mechanism that enables gas to lose angular momentum, hence accrete onto the star, is still hotly debated. I will discuss how recent disk mass measurements, mass accretion rates, and disk winds diagnostics constrain the two main modes of angular momentum transport in planet-forming disks, i.e. magneto-rotational instability and magnetohydrodynamic disk winds. I will point out how these different modes affect planetesimal and planet formation and examine which data are required to establish which of the two is the main driver of disk evolution.

Protostellar disc 'isochrones' and the evolution of discs in the Mdot-Mdisc plane — Giuseppe LODATO

Recent surveys with ALMA and XSHOOTER to mearure disc masses and accretion rates in young protostellar discs have allowed to probe disc evolutionary models in homogeneous samples, that probably share similar features, starting from their age. Here, I discuss the usefulness of protostellar disc 'isochrones' in the Mdot-Mdisc plane, as a tool to test evolutionary disc models and put constraints on the age of observed star forming regions. As a first approach, we use self-similar viscous evolution models that allow a simple and analytical from of the isochrone. Within the same class of models, we also perform Montecarlo realization of a population of discs, and we compare the results to recent obervations of discs in the Lupus region (Manara et al 2016). The often introduced parameter t_{disc} = Mdisc/Mdot, in the self similar model, is proportional to t_{visc} + t_{age} so that for a given observed t_{disc} we have a degeneracy between age of the system and viscous timescale. However, the degeneracy can be broken by also taking into account the observed scatter around the isochrone, whereby evolved samples tend to cluster around the isochrone with very little scatter, while younger systems show a significant scatter. By applying these ideas to the Lupus survey we derive an age of ~ 0.6 Myr, younger that previous estimates.

Discrete episodes of star formation in the ONC? — Giacomo BECCARI

As part of the Accretion Discs in Halpha with OmegaCAM (ADHOC) survey, we imaged in r, i and Hα a region of 12 × 8 square degrees around the Orion Nebula Cluster. Thanks to the high-quality photometry obtained, we discovered three well-separated pre-main sequences in the colour-magnitude diagram towards the cluster's center. Although several reasons could be invoked to explain these sequences including unresolved binaries, independent high-resolution spectroscopy supports the interpretation that these correspond to discrete episodes of star formation, each separated by about a million years. Our observations reveal that these star-forming events occurred in the densest central regions of the cloud. The stars from the two youngest populations rotate faster than the older ones, in agreement with the evolution of stellar rotations observed in pre-main sequence stars younger than 4 Myr in several star forming regions. If confirmed these results prompt for a revised look at the formation mode, time-scales and early evolution of stars in clusters.

Slow eccentric modes in Self-gravitating Protoplanetary Disks Wing-Kit LEE

In this talk I discuss the slow eccentric modes in self-gravitating protoplanetary disks. These are stable normal modes with m=1 and their corotation lying outside the disk. Previous studies have been focusing on limits where self-gravity is negligible or dominating. Here we discuss the immediate regime where both pressure and self-gravity are of the same order, which is relevant for typical protoplanetary disks.

The ALMA Lupus Disk Survey: CN Rings in Two Disks Sierk VAN TERWISGA

The cyanide radical CN is an abundant molecule in protoplanetary disks, with line fluxes often comparable to those of 13CO.
We present 0.4'' resolution images of the CN N=3-2 transition and the 345 GHz continuum in disks around two low-mass stars in Lupus, Sz 71 (M1.5) and Sz 98 (K7), observed as part of the ALMA Lupus disk survey. In both disks, CN is distributed in a ring around the source center; they also both show evidence of continuum substructure. By combining results from the recently updated disk modelling code DALI with analysis of the dust continuum of the disks, we can conclude that the presence of CN rings is independent of the continuum substructure. Instead, they naturally arise from the competition between UV flux and gas density in the upper disk atmosphere. The CN fluxes in the Lupus disks population as a whole are also used to test our DALI models' predictions, and we discuss their implications.

Growing porous grains in 3D SPH simulations Anthony GARCIA

In protoplanetary discs, micron-sized grains should grow up to reach planetesimal sizes in order to ultimately form planets. However, dynamical studies show that once they reach a critical size, they drift rapidly into the accreting star. This is known as the radial-drift barrier.

In order to overcome this barrier, several methods have been proposed such as particles traps (e.g. vortices or planet gaps) which all involve large-scale dynamics. In this work, we choose to investigate the intrinsic properties of the grains during their growth, in particular their porosity.

We thus consider the growth of grains with variable porosity as a function of their mass in several regimes of compression/expansion (Kataoka et al. 2013, Okuzumi et al. 2012) and implement it in our 3D SPH two-fluid code (Barrière-Fouchet et al. 2005).

We find that growth is accelerated for porous grains that can reach kilometer sizes. On the other hand, drift is slowed down for porous grains that can grow up to larger sizes before drifting towards the star. As a result, grains in the outer regions of the disc reach larger sizes than when porosity is neglected. Those two mechanisms can help grains overcome the radial-drift barrier and form planetesimals.

Accretion of Pebbles onto Gas Giant Planets at Wide Separations Jack HUMPHRIES

3D SPH simulations performed with a modified Gadget 3 code are used to study the accretion of ∼ 1 mm to ∼ 10 cm sized grains (pebbles) and gas onto gas giant planets migrating inwards in the Type I regime from separations ~ 100 AU.
We vary the β disc cooling rate, initial planet mass, pebble size and planetary irradiative feedback to demonstrate the impact that these parameters have on our simulations.
With efficient cooling, planets rapidly accrete gas, open a gap and enter the brown dwarf regime.
In the inefficient cooling case, gas remains too hot to accrete but pebble accretion continues.
These planets become metal enriched and continue in the Type I migration regime to the inner computational boundary.
We also demonstrate that lower mass clumps become more metal overabundant.
Our results may allow gravitational instability planets to reproduce the inverse mass-metallicity correlation for observed exoplanets.

First results from the Planet Earth Building-Blocks - a Legacy eMERLIN Survey (PEBBLeS): DG Tau A Emily DRABEK-MAUNDER

We present early commissioning results from Planet Earth Building-Blocks - a Legacy eMERLIN Survey (PEBBLeS). The PEBBLeS project is mapping 'pebbles' (cm-sized dust grains) at a 5cm wavelength for a selection of protostars at a variety of evolutionary stages and masses. The survey focuses on nearby star-forming regions (120-230 pc) to systematically study discs that have the highest potential for planet-formation. The 40 milliarcsec angular resolution (i.e. beam diameter ~5-9 AU) allows us to separate zones in discs that are comparable to where terrestrial and gas giant planets form in our own solar system. The ability to image grains growing to pebbles within a few AU of young host stars is a unique eMERLIN capability, allowing the investigation of how planetary cores are made and the search for proto-planet candidates. As a demonstration of the science PEBBLeS will achieve, we present early results of the observations of DG Tau. We present images of DG Tau A (a flat spectrum protostar) at 4-6 cm wavelengths, where we find the disc to be both resolved and easily distinguished from regions with jet emission. We find the extended source flux to be significantly higher than predicted, suggesting a pile-up of dust grains with sizes around 1 cm, potentially similar to the TW Hya archetype. We compare DG Tau A to the much weaker emission found from MWC 480 (Herbig Ae), which suggests variations in the dust spectral index and potentially in pebble production that can proceed toward planet formation.

WEDNESDAY, 21.06.2017

Formation of TRAPPIST-1 and other compact systems Chris ORMEL

TRAPPIST-1 is a nearby 0.08 solar mass M-star, which was recently found to harbor a planetary system of at least seven ~Earth-mass planets, all residing within 0.1 au. The configuration is not easily explained by either the in situ or migration model for planet formation. I will present an alternative scenario for the formation and orbital architecture of the TRAPPIST-1 system. In this model, planets form at the H2O iceline (~0.1 au for the Trappist-1 disk) and is fueled by the migration of pebble-size particles from the outer disk. I will argue that this pebble accretion is particularly efficient for low stellar masses as Trappist-1. With some adjustment, the model can also be applied to compact systems of more massive stars, i.e., that many close-in super-Earth systems can be regarded as a scaled-up version of TRAPPIST-1.

Is the Solar System Special? --- Lessons from the orbits of exoplanets Jiwei XIE

While the Solar System planets are on nearly circular (e~0.06) and coplanar (i~3 deg) orbits, the first several hundred extrasolar planets discovered using the Radial Velocity technique are commonly on eccentric orbits (e~0.3). This raises a fundamental question: Are the Solar System and its formation special? The Kepler mission has found thousands of transiting planets, but most of their orbital eccentricities remain unknown. By using the precise spectroscopic host star parameters from the LAMOST observations, we measure the eccentricity distributions for a large and homogeneous Kepler planet sample. We observe an eccentricity dichotomy, a common orbital pattern and the prevalence of near-circular orbits for planets inside and outside the Solar System, which provide insights to answer the above fundamental question.

Pebble accretion for eccentric planets Beibei LIU

Disk migration theory predicts that super-Earth planets would end up at resonance due to their differential migration speed. However, Kepler has found that the period ratios of these planets do not show strong pile-ups near mean motion resonances (MMRs).

We propose a new mechanism, magnetospheric rebound that rearranges the orbits of the resonant planets during the disk dispersal phase when the magnetopsheric cavity expands outward. We conduct N-body simulations of two-planet systems and investigate under which conditions planets can escape resonances. Migration of planets is substantial (minor) in a massive (light) disk. When the outer planet is more massive than the inner planet, the period ratio of two planets increases through outward migration. On the other hand, when the inner planet is more massive, the final period ratio tends to remain similar to the initial one. Larger stellar magnetic field strengths result in planets stopping their migration at longer orbital periods.

In addition, we make a statistical comparison between the Kepler observations and the simulations. Simulations are performed based on the migration and the in-situ formation scenarios. We find that the disparity in the period ratio distribution that initially exists between the two scenarios is substantially reduced after the disk dispersal phase because of magnetospheric rebound.

Secular evolution of planetary eccentricity — Enrico RAGUSA

In the current framework of planetary formation, planets form at relatively large radii in protoplanetary discs and migrate inward due to planet disc interaction. During this process, the planet and the disc exchange energy and angular momentum, which might lead to the excitation (or damping) of eccentricity. In this talk, I will present two long (>10^5 orbits) numerical simulations: (a) one (with a relatively light disc) in which we observe a late growth of the planetary eccentricity and (b) one (with a more massive disc) in which a decrease of the eccentricity occurs. This behavior can be understood invoking a simple toy model in which the disc is treated as a second point-like gravitating body and combinining the pure secular planet-planet interaction with the eccentricity pumping/damping typically provided by discs. Using this toy model it is possible to make some qualitative long time scale predictions about the final values of the planet eccentricity when the disc disperses.

Spectral Analysis of Directly Imaged Planet 51 Eridani b with SPHERE and BACON — Matthias SAMLAND

Spectra of the young (~20 Myr), nearby (~30 pc) and relatively cool (~750 K) directly imaged planet 51 Eridani b have been obtained with SPHERE (Samland et al. 2017). This new data set combined with previous data, now covers all significant features from the Y-band to the L-band (~0.8 to ~4.0 micron). We further use new extensive model grids based on Molliere et al. 2015, 2017 including clouds and non-solar metallicity, the latter having often been neglected in exoplanetary studies. Especially, the prospect of moving planetary metallicity into the regime of being an actual "observable" is interesting in the context of this conference. It provides a link between direct observations of planets and predictions from planet formation theory. Our results for 51 Eridani b suggests a highly super-solar metallicity ([Fe/H] ~ 1.0), which may be hard to explain in some formation paradigms. In order to achieve reliable results, we developed the BACON package (Bayesian Atmospheric CharacterizatiON), for MCMC exploration of the posterior probability parameter distribution of arbitrary atmospheric model grids with photometric and spectroscopic data, while taking into with correct treatment of correlated noise. We are in the process of incorporating a free retrieval code into the code and expand our analyses to transit spectra. BACON will be made public as open-source project to facilitate a common standard for spectral analysis.

The fuzziness of giant planets' cores — Ravit HELLED

Giant planets are thought to have cores in their deep interiors, and the division into a heavy-element core and hydrogen-helium envelope is applied in both formation and structure models. I will briefly discuss the standard model for giant planet formation, and will show that the primordial internal structure of giant planets depends on their growth history, in particular, the ratio of heavy element accretion to gas accretion. I will present the expected primordial internal structure and show that giant planets' core are not well defined - i.e., may not be distinct from the envelope, and even include some hydrogen and helium. In addition, I will show that the deep interior can have an inhomogeneous structure with a gradual decrease of the heavy elements. Finally, I will discuss the importance of these results for analyzing the gravity data of the Juno mission, and on the characterization of giant exoplanets.

Planet-disc interactions in young, massive discs Alex DUNHILL

Interactions between young planets and their parent discs are key to determining their early dynamical evolution and thus the orbital parameters of the exoplanet population observed around mature stars. I will discuss the results of two projects using numerical models of planet-disc interactions, firstly considering the interactions between spiral arms in self-gravitating discs with young embedded planets and the implications for giant exoplanet eccentricities. The second project considers planets migrating in a disc during an FUOr-type accretion event and the impact on migration rates of the heated disc during the outburst. In both cases, the dynamical state of the planets in these discs is strongly affected by the interactions considered and should be taken into account by models of planet formation that occur at these early times (e.g. formation by gravitational fragmentation)

Forecasting Observability of protoplanets embedded in discs using hydrodynamic simulations Enrique SANCHIS

The aim of this work is to model the observed luminosities and magnitudes of protoplanets that are still embedded in circumstellar discs. We focus on a late stage of planet formation when the planet has carved a deep gap in the gas and dust distribution and the disc could be transparent to the planet luminosity at certain wavelengths (typically in infrared). In the past years interferometers like ALMA and LBT have already detected ring-like features and point-like sources that can be explained by the presence of a planet embedded in the circumstellar disc. In order to help future observations, this study focuses on Jupiter-like planets, with a parameter space analysis using different planet masses to probe the influence of the mass on the planet detectability at each band. We use a full 3D-hydrodynamical code (PLUTO, Mignone et al. 2012) where a young planet embedded in a circumstellar disc is orbiting the host star until a gap is formed and a stable state is reached. An estimate for the accretion rate and the column density of the disc region above the protoplanet can be inferred from the HD code. This, together with evolutionary models of young planets and analytical laws of the extinction curves, let us derive the expected magnitudes of the planet at J, H, K, L, M, N infrared bands. First results with a planet of 1 Jupiter mass at ~5AU seems to indicate that the disc transparency highly depends on the band. Near-to-mid infrared M- N- bands with very low extinction rates, intermediate extinction rates for J- and L- bands, and high extinction at J- H- bands. Finally, we test our observability models comparing them with recent observations done by ALMA, in particular detections in the CQTau, HLTau, HD100546 systems.