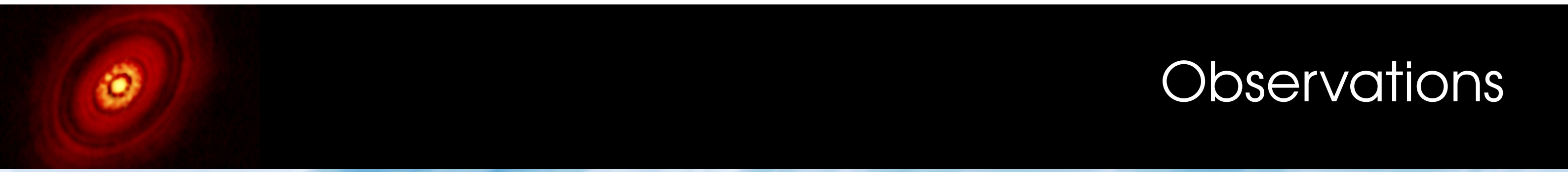
ACCRETION2019 Ringberg

Workshop on Turbulence and Structure Formation in Protoplanetary Disks



Abstract Book

Contents

	Monday 8.7	**Tuesday 9.7.**	**Wednesday 10.7.**	**Thursday 11.7**	**Friday 12.7**
08:00	I = Invited Reviewish Talk 20min + 10min. T = Topical Talk 15min. + 5min. S = Special Talk 10min. + 5min.	**Breakfast**	**Breakfast**	**Breakfast**	**Breakfast**
08:30					
09:00		**Session 3 - Disks/Dust 90 min** **Chair Birnstiel** I05 Shu-ichiro Inutsuka (Disks) T01 Clément Surville (Disks) T02 Gesa H.-M. Bertrang (Disks) T03 Sebastian Stammler (Dust)	**Session 7 - Hydro 90 min** **Chair Kley** I11 Mario Flock (Hydro) I12 Glen Stewart (Hydro) I13 Wladimir Lyra (Hydro)	**Session 11 - Laboratory/RDI 90 min** **Chair Inutsuka** I17 Hantao Ji (Lab) I18 Rixin Li (RDI) I19 Anders Johansen (RDI)	**Session 14 - Winds 90 min** **Chair Goodman** Start Today at 9:30!!! I27 Giovanni Picogna (Winds) I28 Barbara Ercolano (Winds)
09:30					
10:00					
10:30		**Coffee**	**Coffee**	**Coffee**	**Coffee**
11:00		**Session 4 - Dust 90 min** **Chair Bertrang** I06 Takahiro Ueda (Dust) I07 Satoshi Okuzumi (Dust) S05 Hans Baehr (Dust) S06 Christian Lenz (Dust)	**Session 8 - Hydro/Lab. 110 min** **Chair Ji** I14 Wilhelm Kley (Hydro) T07 Natascha Manger (Hydro) I15 Holly L. Capelo (Lab) I16 Gerhard Wurm (Lab)	**Session 11 - RDI/MHD 90 min** **Chair Johansen** I20 Philip Hopkins (RDI) T09 Viacheslav Zhuravlev (RDI) T10 Shoji Mori (MHD) T11 Antoine Riols-Fonclare (MHD)	**Session 15 - Winds/Pl. 40 min + D3** **Chair Wardle** T12 Peter Rodenkirch (Winds) T13 Alexandros Ziampras (Planets) D3: Discussion "What have we learned?"
11:30	**Arrival/Buffet**				
12:00					
12:30		**Lunch**	**Lunch**	**Lunch**	**Lunch-Package/Departure**
13:00					
13:30	13:45Welcome / Logistics				
14:00	**Session1 - Disks 90 min** **Chair Klahr** I01 Jane Huang (Disks) I02 Cornelis Dullemond (Disks) S01 Jozsef Varga (Disks) S02 Kundan Kadam (Disks)	**Session 5 - Dust/Hydro 90 min** **Chair Pascucci** T04 Joanna Drazkowska (Dust) I08 Akimasa Kataoka (Dust) T05 Julio D. Melon Fuksman (Hydro) T06 Arakel Petrosyan (Hydro)	**Session 9 - Laboratory 60 min** **Chair Capello** T08 Niclas Schneider (Lab) S09 Vincent Carpenter (Lab) Poster Flash!	**Session 12 - MHD 90 min** **Chair Flock** I21 Takeru K. Suzuki (MHD) I22 Ilaria Pascucci (MHD) I23 Geoffroy Lesur (MHD)	**Departure**
14:30					
15:00					
15:30	**Coffee**	**Coffee**	**Wandertag / Excursion**	**Coffee**	
16:00	**Session 2 - Disks 90 min + D1** **Chair Dullemond** I03 Kevin Flaherty (Disks) I04 Til Birnstiel (Disks) S03 Robert Latka (Disks) S04 Marcelo Barraza (Disks) D1 Discussion: "Expectations?"	**Session 6 Hydro 90 min + D2** **Chair Lesur** I09 Heloise Meheut (Hydro) I10 Hubert Klahr (Hydro) S07 Loren Everett Held (Hydro) S08 Thomas Pfeil (Hydro) D2 Discussion: "Formulation of Questions."		**Session 13 - MHD/Winds 105 min** **Chair Suzuki** I24 Mark Wardle (MHD) I25 Jeremy Goodman (MHD) I26 Zhaohuan Zhu (Winds) S10 Philip Leung (MHD)	
16:30					
17:00					
17:30					
18:00				**Conference Dinner:** **"Bayerischer Abend"**	
18:30	**Dinner**	**Dinner**	**Dinner**		
19:30	Joined Discussion Round	I0X Orkan Umurhan (Hydro) t.b.c.	Joined Discussion Round	Joined Discussion Round	
20:30	Scientific Splinter Meetings	Scientific Splinter Meetings	Scientific Splinter Meetings	Scientific Splinter Meetings	

Abstracts

Concentration and Growth of Solids in Fragmenting Circumstellar Disks

Hans Baehr
Max Planck Institute for Astronomy

Recent measurements of Jupiter suggest that gas giant planets have considerable solid cores. Planet formation by gravitational instability, unlike core accretion, is essentially a star formation process resulting in objects which more closely resemble stars in composition. This is further complicated by the high temperatures at the center of gas giant planets, which may inhibit the concentration of material into a core. While silicates will evaporate at temperatures around 1400 K, this does not mean solids and heavier elements cannot concentrate through aerodynamic and self-gravitational forces before the core temperature of the fragment becomes too hot. We perform high-resolution local simulations of fragmenting disks showing the sedimentation and concentration of particles at the formation of a fragment can lead to the enrichment of the planetary atmosphere if not the development of a sizable core. Overall metallicities within the Hill sphere of the fragment can increase to nearly 5% compared to the initial ISM ratio (1%) and above typical stellar values.

Dust traps in the protoplanetary disc MWC 758: two vortices produced by two giant planets?

Marcelo Barraza
Max Planck Insitute for Astronomy

Resolved ALMA and VLA observations indicate the existence of two dust traps in the protoplanetary disc MWC 758. By means of 2D gas+dust hydrodynamical simulations post-processed with 3D dust radiative transfer calculations, we show that the spirals in scattered light, the eccentric, asymmetric ring and the crescent-shaped structure in the (sub)millimetre can all be caused by two giant planets: a 1.5-Jupiter mass planet at 35 au (inside the spirals) and a 5-Jupiter mass planet at 140 au (outside the spirals). The outer planet forms a dust-trapping vortex at the inner edge of its gap (at 85 au), and the continuum emission of this dust trap reproduces the ALMA and VLA observations well. The outer planet triggers several spiral arms which are similar to those observed in polarised scattered light. The inner planet also forms a vortex at the outer edge of its gap (at 50 au), but it decays faster than the vortex induced by the outer planet, as a result of the disc's turbulent viscosity. The vortex decay can explain the eccentric inner ring seen with ALMA as well as the low signal and larger azimuthal spread of this dust trap in VLA observations. Finding the thermal and kinematic signatures of both giant planets could verify the proposed scenario.

Influence of vortices on gas accreting planets (Poster)

Camille Bergez-Casalou
Max Planck Institute for Astronomy

(Poster) The accretion of gas onto giant planets has a large impact on the structure of their surrounding disc. We study the influence on the disc of competitive planet gas accretion. We perform isothermal hydrodynamical simulations with the Fargo2D1D code where the accretion is based on recipes from the literature (Kley 1999, Machida 2010). As we are interested into the effects of gas accretion onto the disc structure, we first investigate the influence of the viscosity of the disc for a single accreting planet. After analyzing its behavior, we investigate the case of two planets accreting gas simultaneously. These two planets are placed in different locations corresponding to resonances (4:3, 3:2, 2:1 and 3:1) and are initially not allowed to migrate nor feel each other. The planets have 20 Earth masses initially and are assumed to be in the runaway gas accretion regime. By comparing this result with the single planet case, we are able to deduce the influence of competitive accretion. We find that in low viscosity, as the Rossby Wave Instability is triggered, vortices have a non negligible influence on gas accretion as they push material to the planets Hill sphere. Additionally, even in medium viscosity (alpha = 0.001), vortices can be created in the case of two planets.

On shadows and structures: conclusions drawn from multi-wavelength observations

Gesa H.-M. Bertrang
Max Planck Institute for Astronomy

The disk around the isolated Herbig Ae star HD169142 has been studied extensively at multiple wavelengths. Combining our data with literature, covering 6 years in total, we found that this disk is harboring a number of exiting features. It is composed of several rings showing azimuthally asymmetric sub-structures and host to one of the most promising proto-planet candidates. Our analysis points towards a new, additional suspect: A moving surface brightness dip consistent with a shadow cast by a massive, dust-surrounded planet or brown dwarf on an orbit comparable to Jupiter's. This shadow is likely to trigger temperature perturbations explaining structural changes we observe on the same time-scale. I will present the multi-wavelength observations, radiative transfer model, and hydrodynamical simulation which lead to these findings and suggest that HD169142 might be a young version of a multiple massive planet system such as HR8799.

From Disks to Rings – Dust Evolution in the ALMA Era

Til Birnstiel
LMU Munich

The fact that growing particles are becoming ever more mobile has been known since the 70s and it has since then sparked the imagination of theorists to explain various aspects of the protosolar nebula and other planet forming disks. It is thought to lead to enrichment of the inner disk in water and other volatiles, it leads to size differences between the gas and dust disks, affect the appearance of disks through its opacity effects, it brings dynamics to disk chemistry by sequestration of CO and water, and last but not least, might kick-start planet formation via the streaming instability and speeds up planet growth via pebble accretion.

Until recently these were just ideas, but now ALMA has revolutionized this field, allowing us to observe these effects in great detail. In this talk, I will present the basics of dust growth, transport, and trapping. I will describe some of the observable effects of solid evolution and show what we have learned from ALMA and DSHARP and which new puzzles it has revealed now that we can observe substructure at high angular resolution.

On aerodynamic instability in the flow of a particle stream in a dilute gas

Holly L. Capelo
Physics Institute, University of Bern

A particle-gas two-stream instability was recently discovered in a laboratory flow, which exhibited scale similarity to the same fluid instability predicted to operate in protoplanetary discs. Owing to its ability to aerodynamically concentrate solids, this mechanism has been singled out as a route to enable the gravitational collapse of planetesimals – thus overcoming the meter-size barrier problem – and is one of several ways to generate disc turbulence. I will review these experimental findings and report on progress in developing new rarefied-gas flow facilities geared towards extending these results.

Simulations of the Onset of Collective Motion of Sedimenting Particles

Vincent Carpenter
Max Planck Institute for Astronomy

Niclas Schneider and Gerhard Wurm have conducted experiments at the University of Duisburg-Essen in which they drop hollow glass beads through a rotating chamber filled with air, and have observed a transition in the sedimentation behavior of the particles. For average dust to gas ratios above 0.08 (across the entire chamber), individual particles that are located in closely packed groups sediment faster than isolated particles, with an amount of addition speed that depends on how closely packed the groups are. We attempt to replicate these experiments with numerical hydrodynamics simulations using the Pencil Code, both to validate the code and to allow for detailed exploration of the mechanisms involved in triggering the collective motion. This work is ongoing; here we discuss the current status of the project and present the latest preliminary results (which so far indicate potential agreement with the experiment).

Including dust growth in hydrodynamic simulations of protoplanetary disks

Joanna Drazkowska
Ludwig Maximilian University of Munich

Dust growth is often neglected when building models of protoplanetary disks due to its complexity and computational expense. However, it does play a major role in shaping the evolution of protoplanetary dust and planet formation. I will present numerical model coupling 2-D hydrodynamic evolution of protoplanetary disk and dust coagulation. This is obtained by including multiple dust fluids in a single grid-based hydrodynamic simulation and solving Smoluchowski equation for dust coagulation on top of solving for hydrodynamic evolution. We compare results obtained from this full coagulation treatment to commonly used, fixed dust size approach and to previously applied, less computationally intensive methods for including dust coagulation.

The DSHARP campaign: Learning about dust trapping

Cornelis Dullemond
Heidelberg University

In this presentation I will discuss the Disk Structures at High Angular Resolution Project (DSHARP), which is an ALMA campaign to observe 20 protoplanetary disks at 1.3 mm at 35 mas ($\sim$ 5 au) resolution. I will show the results, and discuss how they can be used to improve our understanding of particle trapping.

Tracing the early planet formation with molecular lines: chemistry of vortex in IRS 48

Natalia Dzyurkevich
ITA, Universität Heidelberg

The millimeter observations of dust in protoplanetary disks show us spectacular structures like numerous gaps, vortices and spirals. In particular, IRS 48 disk demonstrates a large vortex-like structure. Molecular lines provide information about disks that is complementary to dust continuum observations: formaldehyde was found on the inner edge of the IRS 48 vortex, along with detections of SO_2 and CS isotopes. We use a reduced chemical network containing main carbon- and sulfur-bearing species to find the molecular species which can be sensitive to the gaps in dust, as well as to accumulation of the dust grains in the vortex. We find that SO molecule is the main reservoir for sulfur in IRS 48, for adopted disk model as in Bruderer et al. 2014. While SO is very sensitive to the gap edge, it cannot trace the vortex as it is weakly responding to the local increase in dust. Instead, SO_2 molecule abundance can be expected to drop quickly within the vortex, making it an interesting tracer of dust-trapping structure.

The dispersal of planet forming discs and its role on the formation and evolution of planets

Barbara Ercolano

Ludwig-Maximilians-Universität University Observatory Munich (USM)

The formation and evolution of planets is intimately related to the physical conditions, the evolution and the dispersal of their natal planet forming disc. In this talk I will briefly summarise the basics behind photoevaporation models of disc dispersal, emphasising some of their expected influence on planet formation and migration. I will also focus on the predictive aspects of these models and how well they compare with current observations.

Weak Turbulence in Protoplanetary Disks as Revealed by ALMA

Kevin Flaherty
Williams College

Turbulence within protoplanetary disks plays a crucial role in the formation and evolution of planets, through its influence on processes ranging from the collisional velocity of small dust grains to the ability of gas-giant planets to open gaps in the disk. Despite this importance, few direct observational constraints on its strength exist. I will report on our ongoing effort to constrain turbulence using ALMA observations of CO emission from protoplanetary disks, including upper limits on turbulence (HD 163296, TW Hya, V4046 Sgr, MWC 480), as well as the detection of turbulence around DM Tau. When combined with recent studies of dust emission, these results suggest that weak turbulence is not unusual among protoplanetary disks.

The Inner Regions of Protoplanetary Disks: 3D Radiation Magneto-Hydrodynamical Models

Mario Flock
Max Planck Institute for Astronomy

Many planets orbit within an AU of their stars, raising questions about their origins. Particularly puzzling are the planets found near the silicate sublimation front. We investigate conditions near the front in the protostellar disk around a young intermediate-mass star, using the first global 3-D radiation non-ideal MHD simulations in this context.

The results show magnetorotational turbulence around the sublimation front at 0.5 AU. Beyond 0.8 AU is the dead zone, cooler than 1000 K and with turbulence orders of magnitude weaker. A local pressure maximum just inside the dead zone concentrates solid particles, allowing for efficient growth. Over many orbits, a vortex develops at the dead zone's inner edge, increasing the disk's thickness locally by around 10

We synthetically observe the results using Monte Carlo transfer calculations, finding the sublimation front is bright in the near-infrared. The models with vertical magnetic flux develop extended, magnetically-supported atmospheres that reprocess extra starlight, raising the near-infrared flux 20

Radiation-MHD models of the kind we demonstrate open a new window for investigating protoplanetary disks' central regions. They are ideally suited for exploring young planets' formation environment, interactions with the disk, and orbital migration, in order to understand the origins of the close-in exoplanets.

Hydrodynamical simulations of protoplanetary disks including irradiation of UltraViolets and X-rays.

Lizxandra Flores Rivera

Max Planck Institute for Astronomy

Photoevaporation can alter significantly the mechanism for the evolution of protoplanetary disks and so affect planet formation. especially in regions of strong stellar radiation. We attempt to investigate the influence of irradiation of EUV, FUV, and X-ray components within the first 5 AU on the hydrodynamical evolution of the disk. Our photoevaporation model (Ryhoei et al. 2018) are set on a 2.5D hydrodynamical simulations for a typical T-Tauri star (temperature?) with an initial isothermal accretion disk configuration. With this improvement we will be able to obtain the gas temperature in the atmosphere suitable to model for the wind flow in the surface of the disk. Parameters to investigate: 1 step) disk accretion rate by the VSI. 2) find the photevaporation rate and how much does it affect the lifetime of the disk. 3) what happen when the disk accretion is less and/or greater than the photoevaporation rate. 4) we can use a radiative transfer model to generate spectral lines (e.g. [OI] 6300 A and [NeII] 12.8 μm) that diagnose line width in the surface of the disk and compare with previous work (e.g. Picogna et al. 2018) and with observations.

Radiative transfer methods for relativistic MHD

Julio David Melon Fuksman
Sapienza University of Rome

Radiative transfer is of great relevance in many different physical systems, ocurring in a broad range of size scales. In the context of astrophysics, for instance, it is of fundamental importance in the modeling of star atmospheres, pulsars, supernovae, and accretion disks. In some high-energy environments (e.g. gamma-ray bursts), matter can interact with radiation while being accelerated to relativistic speeds, sometimes being simultaneously subject to strong electromagnetic fields. In situations where none of these effects can be disregarded, it is convenient to rely on numerical schemes that can handle them simultaneously. Such methods must be able to resolve timescales that sometimes can differ in several orders of magnitude, which can in general cause stability issues. In this talk, I will present a numerical code applicable to radiation transfer problems in relativistic hydrodynamics and magnetohydrodynamics, designed as an independent module within the freely-distributed PLUTO code. The code can handle both the free-streaming and diffusion regimes of radiative transport, which is achieved by assuming the validity of the so-called M1 closure for radiation fields. As well, I will discuss possible implementations in the context of protoplanetary disks.

Disks, winds, and planets

Jeremy Goodman
Princeton University

I review recent work by my collaborators and others on photoevaporative and magnetized disk winds. Opportunities and challenges for diagnosing these flows via molecular and atomic lines will be discussed. Purely photoevaporative winds tend to be predominantly atomic and are not directly related to the accretion process, but photoevaporation must occur at some level because of the UV and X-ray emissions of Class II protostars. Magnetized winds could have a much larger molecular component and couple inflow to outflow, but relevant magnetic-field strengths are difficult to measure directly. The mechanism of wind launching in the magnetic case is rather different from the centrifugal model by Blandford and Payne. I close with ruminations about alternatives to planetary torques for sculpting rings and cavities recently imaged by ALMA.

Hydrodynamic Convection in Accretion Disks

Loren Everett Held
DAMTP Cambridge University

The prevalence and consequences of convection perpendicular to the plane of accretion disks have been discussed for several decades. Recent simulations combining convection and the magnetorotational instability have given fresh impetus to the debate, as the interplay of the two processes can enhance angular momentum transport, at least in the optically thick outburst stage of dwarf novae. In this talk, we seek to isolate and understand the most generic features of disk convection, and so undertake its study in purely hydrodynamical models. First, we investigate the linear phase of the instability, obtaining estimates of the growth rates both semi-analytically, using one-dimensional spectral computations, and analytically, using WKBJ methods. Next, we perform three-dimensional, vertically stratified, shearing box simulations with the conservative, finite-volume code PLUTO, both with and without explicit diffusion coefficients. We find that hydrodynamic convection can, in general, drive outward angular momentum transport, a result that we confirm with ATHENA, an alternative finite-volume code. Moreover, we establish that the sign of the angular momentum flux is sensitive to the diffusivity of the numerical scheme. Finally, in sustained convection, whereby the system is continuously forced to an unstable state, we observe the formation of various coherent structures, including large-scale and oscillatory convective cells, zonal flows, and small vortices.

Resonant Drag Instabilities in Disks and The ISM

Philip Hopkins
Caltech

I'll describe the properties of a newly-discovered class of instabilities which exist in any coupled dust-gas system. These generalize the 'streaming instability' but also predict the existence of a host of other dust-gas instabilities, some of which have similar behaviors, some of which are qualitatively distinct. In essentially any environment, dust grains streaming through gas are generically unstable, generating fluctuations in the dust-to-gas ratio, and eventually saturating in highly anisotropic turbulence with large dust-to-gas ratio fluctuations and steady-state trapped dust structures (filaments and caustics). These instabilities occur in essentially any medium that supports any kind of linear waves and/or turbulence (magnetized or not, self-gravitating or not, etc.), and the instability and dust-to-gas fluctuations are maximized when there is a 'resonance' between the dust motion and the wavespeeds or eddy turnover times. I'll describe several new instabilities that are examples of this and show how a couple of well-studied instabilities are actually special cases of this. Finally I'll discuss applications of some of the new instabilities that may be relevant for early grain grown in proto-planetary disks, instabilities operating during dust settling to the midplane, in atmospheres, and in the interstellar medium.

The molecular view of disk substructures

Jane Huang
Center for Astrophysics | Harvard & Smithsonian

Although high angular resolution ALMA observations have demonstrated that complex structures are common in protoplanetary disks, the distribution of the molecular gas has not been as well-characterized. Yet, the molecular gas distribution and composition are fundamental for governing how material is incorporated into new planets. I will discuss case studies of recent detections of annular substructures and spiral arms in molecular emission. In some cases, the substructures appear well outside the millimeter continuum, demonstrating that molecular line emission is key for accessing regions of the disk that millimeter continuum observations alone cannot. While dust substructures have increasingly been attributed to planet-disk interactions, it is less clear what the origins of the molecular substructures are. I will address pathways for overcoming the challenge of disentangling chemical and physical effects when interpreting molecular substructures.

The Origin of the Angular Momentum of Molecular Cloud Cores and the Implication to Disk Evolution

Shu-ichiro Inutsuka
Nagoya University

Recent observations have emphasized the critical importance of the formation and evolution of magnetized filamentary molecular clouds in the process of star formation. Theoretical and observational investigations have provided convincing evidence for the formation of molecular cloud cores by the gravitational fragmentation of filamentary molecular clouds, which has important implication for the origin of the stellar initial mass function. On the other hand, the size and total angular momentum of a protoplanetary disk are supposed to be related directly to the rotational property of the parental molecular cloud core where the central protostar and surrounding disk are born. Now we can relate the property of filamentary molecular clouds and angular momenta of cloud cores, which should determines the essential and rather surprising properties of protoplanetary disks. In this talk I summarize our current understanding of the dynamics of filamentary molecular clouds and the origin of angular momenta of molecular cloud cores and protoplanetary disks.

Laboratory Studies of Instabilities and Turbulence Relevant to Protoplanetary Disks at Princeton

Hantao Ji
Princeton University

A concise review is given on recent results from laboratory experiments at Princeton relevant to physics of protoplanetary disks. The motivating problem there is the generation mechanism for the required turbulence in order to explain fast angular momentum transport. Two sister laboratory apparatuses were built to study two main competing candidate mechanisms: (1) a linear instability of magnetized and electrically conducting flow known as magnetorotational instability (MRI); and (2) nonlinear hydrodynamic shear-flow instability. Both of these devices are novel in two respects: large Reynolds numbers ($> 10^6$) and multiple independently driven end rings, either electrically insulating or conducting, to provide optimal controls of boundary effects. Three experimental results will be highlighted: (1) negligible angular momentum transport in quasi-keplerian hydrodynamic flow, even after vigorous perturbations, has been demonstrated; (2) the MRI mechanism to transport angular momentum based on a spring-mass analogue has been demonstrated; and (3) importance of axial boundary conductivity on bulk MHD stability. Implications of these results as well as future prospects for laboratory studies of protoplanetary disks at Princeton will be discussed.

Driving turbulence and forming planetesimals by the streaming instability

Anders Johansen
Lund Observatory

I will present global 2-D simulations of protoplanetary discs that demonstrate that the streaming instability drives turbulence of Mach number 0.01 through the whole gas column. Simulations without back-reaction drag force from dust to gas show the expected evolution of the vertical shear instability, but the inclusion of the back-reaction drag force leads to a rapid growth of the streaming instability in the mid-plane and excitation of large-scale vertical flows. These flows appear to quench the evolution of the vertical shear instability. The observed turbulence in protoplanetary discs may therefore be driven by the streaming instability. I will also present the latest results on the formation of planetesimals by the streaming instability and on connecting the properties of these planetesimals to minor bodies in the solar system.

Particle size constraints from ALMA polarization of protoplanetary disks

Akimasa Kataoka
National Astronomical Observatory of Japan

Polarimetric observations of protoplanetary disks at (sub)millimeter wavelengths have been dramatically developing owing to high-sensitivity and high-resolution observations with ALMA. In this talk, I would like to discuss what can we learn from millimeter polarization. While the mechanism of polarization is under discussion, the self-scattering is one of the dominant mechanisms of millimeter polarization. This constrains the grain size in disks with polarization detected to be around 100 micron because the scattering-induced polarization can be detected only if the grain size is comparable to the observed wavelengths ($\lambda\ 2\pi a$). Furthermore, we find that lopsided disks show polarization of different mechanisms depending on the location. Especially, polarization of less bright regions is dominated by the magnetically aligned grains because of the azimuthal dust trapping. The observations of HD 142527 show that the magnetic fields are in the toroidal direction at least in the south region.

Effect of wind-driven accretion on planetary migration (Poster)

Carolin Kimmig
Max Planck Institute for Astronomy

I study the effect of the magneto-centrifugal wind model on planet migration in protoplanetary discs. The effect of the viscous disc model on planet migration has already been studied extensively. As new observations suggest that the viscosity in discs is much lower than assumed so far, studies on other models for the dynamics in protoplanetary discs are necessary. I investigate the magneto-centrifugal wind model using the FARGO3D hydrodynamics code. Comparing planets in a non-viscous disc with and without magnetic winds, I find that in the former case the planet migrates inwards or outwards while in the latter it stays at its initial orbit. This shows that the magneto-centrifugal wind model indeed causes migration of planets.

Radially and vertically stratified disks are never stable

Hubert Klahr

Max-Planck-Institute for Astronomy

Radial buoyancy and vertical shear are both ingredients that can destabilise disks around young stars. Convective overstability and vertical shear instability are two candidates to efficiently create vortices, zonal flows and provide turbulent mixing and Reynolds stresses. Dust opacities are vital in mapping out regions that will undergo instability because optical depth determines both thermal structure and thermal relaxation. Here I report on latest numerical experiments.

Pebble accretion onto planets in turbulent discs

Wilhelm Kley
University of Tuebingen

Planets are born in protoplanetary discs growing from very small particles to full-grown planets. In the past years, it has been recognized that the growth process can be sped-up by accreting a large number of solid, pebble-sized objects that are still present in the protoplanetary disc. It is still an open question how efficient this process is in realistic turbulent discs.

We present results on the accretion efficiency of pebbles in turbulent discs that are driven by the purely hydrodynamical vertical shear instability (VSI). We perform global three-dimensional simulations of discs with embedded planets of different masses ranging from 5 to 100 Earth masses. Embedded in the flow is a swarm of pebbles in ten size bins that move under the action of drag forces between gas and particles.

For well-coupled particles with unity Stokes number we find an accretion efficiency (rate of particles accreted over particles drifting inward) of about 2

Coupled dust and volatile evolution in protoplanetary disks

Sebastiaan Krijt
The University of Arizona

The formation of pebbles (mm/cm-size solid particles) and their subsequent settling to the midplane and inward radial migration represent the first step of planet formation in protoplanetary disks. I will present simulations in which we simulate the coupled evolution of dust (including pebble formation and dynamics) and important carbon and oxygen-bearing volatiles (e.g., water, CO, CO2, etc.). These simulations allow us to identify how the first stages of planet formation alter the distribution of carbon and oxygen in the protoplanetary nebula. By looking for these signatures in nearby young disks using spatially resolved ALMA observations we can put constrains on the timescales associated with pebble formation/migration and astrochemistry, and learn about how and when carbon and oxygen are delivered to the inner 10 au of the protoplanetary nebula.

Inner Disk Structure and Instabilities in Protoplanetary Disk Simulations

Kundan Kadam

Konkoly Observatory

The formation of low mass stars through protoplanetary disks is a highly complex process which involves wide variety of physical domains. The accretion is also time-dependent, as is evident through the observations of variable young stars called FUors/EXors which show sudden eruptive behavior. The angular momentum transport in an accretion disk is dictated by its viscosity, which in this case arises primarily due to MRI-driven turbulence. However, a typical protoplanetary disk is not fully turbulent; a magnetically ""dead zone"" is thought to form at the midplane, and the disk accretes through a magnetically layered structure.

In this presentation I will talk about our investigations into the accretion through such magnetically layered protoplanetary disks. We conducted global disk simulations, starting with the collapse phase of molecular cloud core so that the initial conditions are carefully taken into account. The smallest possible inner computational boundary was considered and thus disk structures at sub-au scale were captured. We found that the behavior of the magnetically layered disk was remarkably different as compared to a fully MRI active disk. Self-consistent, dynamical, gaseous rings formed within the classical dead zone region, characterized by large surface density and low viscosity. The instabilities in this region gave rise to outbursts similar to those observed in young eruptive stars. I will further discuss the implications of our results on planet formation, and detection of the ring features through the latest observational techniques.

A model for coagulation and drift considering various stellar masses

Robert Latka
Max Planck Institute for Astronomy

From observations, it is clear that planets occur often and in various forms. However, their formation is not fully understood. Somehow, disks of sub-mm particles evolve to planets. In early stages, drift and coagulation are very important processes. I will show a model investigating these early stages of disk evolution. This will be done with special focus on varying the stellar mass.

How the Turbulence Level and the Trap Formation Time Influence Planetesimal Formation

Christian Lenz
Max Planck Institute for Astronomy

It is believed that it needs planetesimals, i.e. the smallest gravitationally bound objects, in order to form planets. Since we cannot observe them in circumstellar disks, we rely on theoretical modeling to figure out how, when, and where they form. I will present a model where we parameterize properties of particle traps and form planetesimals pebble flux-regulated. Focussing on the formation time of the trap structures and the turbulence strength (alpha) we can identify how these parameters influence the final spacial planetesimal distribution in the disk.

Structure formation scenarios in protoplanetary discs

Geoffroy Lesur
Institute of planetology and Astrophysics of Grenoble

In this talk, I will review several of the proposed scenarios for the formation of rings and other structures in protoplanetary discs, including planet-induced, snow line, reconnection and outflow-driven mechanisms.

Magnetic flux transport in protoplanetary discs

Philip Leung
DAMTP Astrophysics

The evolution of a large-scale poloidal magnetic field in an accretion disc is an important problem because it determines the launching of winds and the feasibility of the magnetorota- tional instability to generate turbulence or channel flows. Recent studies, both semi-analytical calculations and numerical simulations, have highlighted the crucial role non-ideal MHD ef- fects (Ohmic resistivity, Hall drift and ambipolar diffusion), relevant in the protoplanetary disc context, might play in magnetic flux evolution in the disc. We investigate the flux transport in discs through the use of two one-dimensional semi-analytic models in the vertical direction, exploring regimes where different physical source terms and effects dominate. Flux transport rates and vertical structure profiles are calculated for a range of diffusivities and disc magnetisations.

Particle Concentration and Planetesimal Formation by the Streaming Instability

Rixin Li
University of Arizona

The streaming instability (SI) is a mechanism to aerodynamically concentrate solids in protoplanetary disks and facilitate the formation of planetesimals over a broad range of disk conditions. I will report that the SI also produces weak zonal flow structures with no pressure maxima. I will then present our new high-resolution SI simulations with self-gravity that produce a broad and top-heavy initial mass distribution of planetesimals. I will highlight our newly developed clump-finding code (PLAN) that allows us to better constrain the initial distribution with robust statistical analyses. We fit models with different parameterization to the mass distribution, weighing more complex models against overfitting penalties for the inclusion of additional parameters. I will show that our simulations produce different mass distributions with different aerodynamic properties of the disk and participating solids. Finally, I will present our preliminary explorations on the particle concentration by the secular gravitational instability.

Hydrodynamical instabilities in protoplanetary disks: a synthesis.

Wladimir Lyra
California State University

This talk will cover recent theoretical developments in our understanding of turbulence in cold, non-magnetically active, planetesimal forming regions of protoplanetary disks which we refer to throughout as “Ohmic zones". I will give a brief background introduction to the subject of disk turbulence followed by the Solberg-Høiland conditions required for stability. This is followed by the three recently identified turbulence generating mechanisms possibly active in protoplanetary disk Ohmic zones, namely, (i) the Vertical Shear Instability, (ii) The Convective Overstability and (iii) the Zombie Vortex Instability. I will summarize the properties of these processes, identify their limitations and discuss where and under what conditions these processes are active in protoplanetary disk Ohmic zones.

Turbulence and Structure Formation in Protoplanetary Disks: A Case Study of the Vertical Shear Instability

Natascha Manger
Max Planck Institute for Astronomy

Disks around young stars are the birth place of planets like our own solar system. Thus, the study of turbulent processes in these "protoplanetary disks" is not only important to understand the transport of angular momentum to explain for example the angular momentum deficit of our own sun, but also to understand how large scale structures emerge, which recently are regularly observed and which also are a crucial puzzle piece in the understanding of how dust grains can grow into planetesimals via gravoturbulent processes. In this thesis, I conduct high resolution studies of three-dimensional global models of turbulent proto- planetary disks using the magneto-hydrodynamics code PLUTO. I focus my studies on the Vertical Shear Instability (VSI), which has been shown to operate efficiently at disk radii beyond a few AU in typical protoplanetary disks. I show that vortices with radial diameters of around 1.5 local pressure scale heights and aspect ratios $\chi > 8$ form in VSI turbulent disks and that these vortices can survive more than 500 orbits. The vortices are forming irrespective of the underlying disk density gradient and aspect ratio and can therefore act as pressure traps for small to medium sized particles over a wide range of the disk. We also show evidence that these dusty vortices are compatible with detections of dust concentrations by current sub-mm interferometers like ALMA. These findings therefore present a crucial puzzle piece which will help the understanding under which conditions and how early after the formation of a disk around a young star planetesimals can form via gravoturbulent planetesimal formation.

Large scale vortices: from simulation to observation

Heloise Meheut
CNRS/Observatoire de la Côte d'Azur

Large scale vortices have received much attention since they have been proposed to explain the crescent shape structures observed in some protoplanetary disks. These vortices were previously studied for their potential role in planet formation as planetesimal formation regions. After introducing how these vortices can participate to planet formation, I will present numerical simulations of the growth of this structures by the Rossby wave instability. I will then discuss some expected observable signatures and how to distinguish these vortices from other asymmetric structures.

Inefficient Magnetic Accretion Heating in Protoplanetary Disks

Shoji Mori
The University of Tokyo

The gas temperature in the inner region of protoplanetary disks is thought to be determined by accretion heating, which is conventionally attributed to turbulent dissipation. However, recent studies have suggested that the inner disk (a few AU) is largely laminar, with accretion primarily driven by magnetized disk winds, as a result of nonideal magnetohydrodynamic (MHD) effects from weakly ionized gas, suggesting an alternative heating mechanism by Joule dissipation. We perform local stratified MHD simulations including all three non-ideal MHD effects (Ohmic, Hall, and ambipolar diffusion), and investigate the role of Joule heating and the resulting disk vertical temperature profiles. We find that in the inner disk, as Ohmic and ambipolar diffusion strongly suppress electrical current around the midplane, Joule heating primarily occurs at several scale heights above the midplane, making midplane temperature much lower than that with the conventional viscous heating model. Including the Hall effect, Joule heating is enhanced/reduced when magnetic fields threading the disks are aligned/anti-aligned with the disk rotation, but is overall ineffective. Our results suggest that the midplane temperature in the inner PPDs is almost entirely determined by irradiation heating. We will also discuss the evolution of the water snow line based on our results and the formation process of the Earth.

Dust growth in disks: the roles of organics and dry ice

Satoshi Okuzumi
Tokyo Institute of Technology

How far dust particles in protoplanetary disks can grow is a long-standing question in planet formation. It is conventionally assumed that solids outside the snow line are icy and sticky, and solids inside the snow line are rocky and poorly sticky. This conventional view neglects minor components like CO/CO2 ices and organics. In reality, however, such minor components can affect or even determine the stickiness of dust particles if they dominate the surface of the particles. In this presentation, I will focus on organics and CO2 ice and discuss how they can change the conventional picture of protoplanetary dust evolution. I will present our new global dust evolution simulations showing that organic matter on silicate grains enables the direct formation of rocky planetesimals in a warm (200-400 K) disk region. I will also argue that recent polarimetric disk observations point to the prevalence of nonsticky materials, such as CO2 ice, in the outer part of the disks. Our dust growth model incorporating CO2-mantled grains successfully reproduces the unidirectionally polarized submillimeter emission from the disk around HL Tau. Taken together, our results suggest that dust in warm regions is sticky whereas dust in cold regions ($<$ 70 K) is nonsticky.

Mass loss rates and MHD-driven disk winds: An Observational Perspective

Ilaria Pascucci
Lunar and Planetary Laboratory/UofA

MHD-driven disk winds are often invoked to enable accretion in planet-forming disks. However, their efficiency and relation to stellar accretion has not been constrained observationally. I will summarize recent results from high-resolution (Dv 7km/s) surveys of young stars targeting optical forbidden lines. These new studies reveal strong kinematic links between jets and low-velocity winds that can be naturally explained by radially-extended MHD-driven winds feeding the jets. Line ratios from different forbidden lines enable, for the first time, estimates of wind mass loss rates. Depending on the scale height of the wind, mass loss rates could be as high as stellar accretion rates, meaning that disk winds might play a major role in the evolution of the disk mass.

Waves, Turbulence and Zonal Flows in Rotating Magnetohydrodynamic Flows

Arakel Petrosyan

Space Research Institute of the Russian Academy of Sciences

A number of new applications in astrophysics and recent space observations actualized the problem of study and description of rotating magnetohydrodynamic fluid behavior. In presentation I review recent achievements in studies of large-scale magnetohydrodynamic flows in rotating frame. We focus on magnetohydrodynamic shallow water approximation for rotating plasma and on two-dimensional magnetohydrodynamic flows on a beta plane. The MHD shallow-water equations in presence of rotation with an external magnetic field are revised by supplementing them with the equations that are derived from magnetic field divergence-free condition. New system reveals the existence of the third component of magnetic field in this approximation and provides relation with the horizontal magnetic field. The presence of a vertical magnetic field significantly changes the dynamics of wave processes in astrophysical plasma compared to the neutral fluid and plasma layer in a horizontal magnetic field. The shallow-water approximation has been used for the development of the weakly nonlinear theory of magneto-Poincare and magneto-Rossby waves both in external vertical magnetic field and in the absence of magnetic field, as well as for stationary states in the presence of a horizontal field (poloidal, toroidal, and their sum). Qualitative analysis of the dispersion curves for the Poincare and Rossby waves in magnetohydrodynamics revealed the possibility of three-wave interactions in the weak nonlinearity approximation. The weakly nonlinear theory of magneto-Rossby waves developed using the method of multiscale asymptotic expansions and three-wave equations for slowly varying amplitudes are briefly outlined. Approximate analysis of the resultant systems of equations has revealed that two types of parametric instability can evolve in the system: parametric decay and parametric amplification of magneto-Poincare and magneto-Rossby waves. The first results of numerical simulation of two-dimensional decaying MHD turbulence on the betta plane are discussed. Numerical simulations demonstrate the formation of zonal flows in MHD turbulence on the betta plane. Zonal flows in MHD turbulence on the betta plane significantly differs from flows in the neutral fluid. Zonal flows in MHD turbulence are unsteady because of the presence of isotropic magnetic islands in the system. The inverse energy cascade in decaying MD turbulence on the betta-plane terminates at the scale that differs from the Rhines scale but is consistent with our new criterion of the boundary between wave dynamics and MHD turbulence.

A Weather Map for Protoplanetary Disks

Thomas Pfeil
Max Planck Institute for Astronomy

Hydrodynamic instabilities in disks around young stars share many properties with typical weather phenomena on earth and depend on the thermodynamic stratification of the disk and on the local rate of thermal relaxation. Here, I present a map of the spatial extent of unstable regions for the Vertical Shear Instability (VSI), the Convective Overstability (COS), and the amplification of vortices via the Subcritical Baroclinic Instability (SBI). We use steady-state accretion disk models, including stellar irradiation, accretion heating, and radiative transfer. We determine the local radial and vertical stratification and thermal relaxation rate in the disk, which depends on the stellar mass, disk mass, and mass accretion rate. If hydrodynamic instabilities or other nonideal MHD processes are able to create α-stresses ($>10^{-5}$) and released accretion energy leads to internal heating of the disk, hydrodynamic instabilities are likely to operate in significant parts of the planet-forming zones in disks around young stars, driving gas accretion and flow structure formation. Thus, hydrodynamic instabilities are viable candidates to explain the rings and vortices observed with the Atacama Large Millimeter/submillimeter Array and Very Large Telescope.

The dispersal of planet-forming discs. A new generation of X-ray photoevaporation models

Giovanni Picogna
USM - LMU Munich

Photoevaporation of planet-forming discs by high energy radiation from the central star is potentially a crucial mechanism for disc evolution and it may play an important role in the formation and evolution of planetary systems. I will present a new generation of X-ray photoevaporation models for solar-type stars, based on hydrodynamical simulations, which account for stellar irradiation from detailed photoionisation and radiation transfer calculations. We are building a library of models which cover the observed parameter space in stellar and disc mass, metallicity and stellar X-ray properties. We model both primordial and transition discs at various stages of their evolution. Our 2D hydrodynamical models are then used to derive simple recipes for the mass-loss rates that are suitable for one-dimensional disc evolution and/or planet formation models. Line profiles from typical wind diagnostics are also calculated for our models and found to be roughly in agreement with previous studies. Finally, we perform a population study of transition discs by means of one-dimensional viscous evolution models including our new photoevaporation prescription and find that roughly half of observed transition discs cavities and accretion rates could be reproduced by our models.

Rings in protoplanetary discs driven by a wind instability

Antoine Riols-Fonclare
IPAG

Rings and gaps have been observed in a wide range of proto-planetary discs, from young systems like HLTau to older discs like TW Hydra. Recent disc simulations have shown that magnetohydrodynamic (MHD) turbulence (in both the ideal or non-ideal regime) can lead to the formation of rings and be an alternative to the embedded planets scenario. In this talk, I will investigate the way in which these ring form in this context and seek a generic formation process, taking into account the various dissipative regimes and magnetisations probed by the past simulations. I will show that a linear instability, driven by MHD winds, might occur and spontaneously form these ring/gaps structures. Given its robustness, the process identified could have important implications, not only for proto-planetary discs but also for a wide range of accreting systems threaded by large-scale magnetic fields.

Global axisymmetric simulations of photoevaporation and magnetically driven protoplanetary disk winds

Peter Rodenkirch

ITA Heidelberg

Photoevaporation and magnetically driven winds are two independent mechanisms to remove mass from protoplanetary disks besides accretion. However, the effect of these two principles acting concurrently could be significant and the transition between those two has not been explicitly quantified yet. In order to contribute to the understanding of disk winds, we present the phenomena emerging in the framework of two- dimensional axisymmetric, non-ideal magnetohydrodynamic simulations including X-ray driven photoevaporation. Of particular interest is the examination of the transition region between photoevaporation and magnetically driven wind, the possibility of emerging magneto-centrifugal wind effects, as well as the morphology of the wind itself depending on the strength of the magnetic field. We use the PLUTO code in a 2.5 D axisymmetric configuration with additional treatment of X-ray heating and dynamic ohmic diffusion based on a kinetic chemical model. We identify the transition region to be in the range of plasma betas $\sim 10^8 - 10^9$, while magnetically driven winds generally outperform photoevaporation for stronger fields. In our simulations, we observe turbulent phenomena which could originate from the MRI in the upper disk layers, affecting photoevaporation rates at weak magnetic field strengths. Overall, our results indicate a wind driven by the magnetic pressure gradient with no significant magneto-centrifugal wind effects.

Dense Particle Clouds in Laboratory Experiments

Niclas Schneider
University Duisburg-Essen

Drag instabilities are an important particle concentration mechanism in protoplanetary disks but the idea is solely based on numerical simulations so far. We carried out experiments to approach these mechanisms in laboratory studies. We observed a particle cloud trapped in a rotating system under Earth's gravity. Particles show collective behaviour above a critical average dust-to-gas ratio, which itself depends linearly on the experiment Stokes number. Furthermore, the sensitivity of particle's sedimentation velocity on solid-to-gas ratio varies depending on Stokes number.

Planetesimal Formation in Dust Traps

Sebastian Stammler
Ludwig Maximilian University of Munich

Recent high-resolution observations with ALMA show dust trapped in ring-like substructures in protoplanetary disks. As a surprising result, the rings in the DSHARP survey show optical depths that all fall within a narrow range between 0.2 and 0.5 – none of the rings is fully optically thick. Since dust traps are thought to be locations of planet formation by converting dust pebbles into planetesimals, this can yield as an explanation for these peculiar optical depths: dust has been transformed into large bodies, reducing the optical depth in the rings. To test this scenario in more detail, we implemented a simple method of planetesimal formation into our dust growth and disk evolution code DustPy. We found that planetesimal formation in dust traps can indeed explain the seemingly fine-tuned optical depths, that are observed in the rings of protoplanetary disks.

Galerkin Projections of the Vertical Shear Instability in Protoplanetary Disks

Glen Stewart
University of Colorado

Rigorous analysis of the vertical shear instability (VSI) in protoplanetary disks is complicated by the fact that the vertical component of gravity is a linear function of the distance from the disk's midplane. Since the gravest unstable modes exhibit only a few nodes over the disk scale height, the physics of these modes can be captured by projecting the equations of motion onto a small number of Hermite basis functions in the vertical coordinate. This situation is analogous to equatorial waves in the Earth's ocean where the latitudinal dependence of the coriolis parameter also leads to a Hermite basis function expansion. The accuracy of this approximation is tested with a linear stability analysis that also yields new insights into the physical nature of the instability. The efficiency of a nonlinear simulation that makes use of a Hermite Galerkin projection in the vertical coordinate and Chebyshev collocation in the radial coordinate will be discussed.

Dusty disks dynamics is not so simple!

Clément Surville
University of Zurich

Since a decade, our understanding of PPDisk dynamics and of planet formation processes has done a big step foreward. However, the increasing amount of disk observations (ALMA, scattered light) show complex structures and dynamics, which are a chalenge for the models. I will show that even with simple physics, disk models can have a very broad range of outcomes. Dust and gas interaction being a simple but formidable source of complexity! When following in details the long term evolution of dusty disks, it comes out that classical, overrepresentated processes like the streaming instability or the pebble accretion are found to be ineffective. The dynamics of planet forming dusty disks is very complex and exploring this diversity is fascinating. It is also mandatory in order to make models really predictive.

MHD in a cylindrical shearing box

Takeru K. Suzuki
University of Tokyo

We develop a framework for MHD simulations in a local cylindrical shearing box by extending the formulation of the Cartesian shearing box. We construct shearing-periodic conditions at the radial boundaries of a simulation box from the conservation relations of the basic MHD equations. Inward mass accretion is induced to balance with the outward angular momentum flux of the MHD turbulence triggered by the magnetorotational instability in a self-consistent manner. We discuss various applications of this framework to numerical simulations of protoplanetary disks.

Planetesimal formation at the inner edge of the dead zone: Implication for the inner solar system formation

Takahiro Ueda

National Astronomical Observatory of Japan

The dynamical configuration of the inner solar system planets invokes that they formed from a narrow annulus of plantesimals. We investigate whether the planetesimal formation at the dead-zone inner edge can reproduce the initial planetesimal distribution invoked from the current configuration of the inner solar system planets. We show that if the disk is visously heated, rocky planetesimals form at ~ 0.7–1 au via the dust-pileup at the dead-zone inner edge. To reproduce the total mass of the planetesimals invoked from the current total mass of the inner solar system planets, the turbulence strength in the dead zone needs to be around 0.001. Although the subsequent evolution of planetesimals is uncertain, this scenario would potentially account for the inner solar system formation.

Observations of the planet-forming region with mid-infrared interferometry

Jozsef Varga
Leiden Observatory

The structure of the 1-10 au region of planet-forming disks can be studied efficiently with interferometers working at mid-infrared wavelengths. The Mid-Infrared Interferometric Instrument (MIDI) at the VLTI left a rich archive of young stellar object observations. Using these data, we performed a statistical analysis of a sample of 82 low- and intermediate-mass young stellar objects. Using geometric and radiative transfer models we found that inner disk holes larger than the dust sublimation radius can be present in around half of the objects. The spectrally resolved MIDI data on the profile and amplitude of the N band silicate spectral feature revealed that the dust in the inner disk regions ($r < 1$ au) is substantially more processed (coagulated, crystallized), compared to the outer parts of disks. We also found indications for time variability in the mid-infrared in some systems, especially in young eruptive stars. I will also present what can be expected from the new VLTI instrument Multi AperTure mid-Infrared SpectroScopic Experiment (MATISSE) which is the successor of MIDI. By combining the light of four telescopes MATISSE will be much more sensitive to disk asymmetries, and by extending the wavelength range to the L band (3-4 um) it will deliver the first interferometric observations of L band spectral features (e.g., from PAHs, nanodiamonds, and ices).

Magnetically-driven winds from protoplanetary disks

Mark Wardle
Macquarie University

I shall outline the MHD effects that underpin the dynamics of magnetically-driven winds from protoplanetary disks, give a brief review of the results of semi-analytic calculations and simulations, and outline open questions and future prospects.

Planetesimal Erosion in Low Gravity, Low Pressure Wind Tunnel Experiments

Gerhard Wurm

University of Duisburg-Essen

Pebble pile planetesimals are weak. Being subject to the gas flow (head wind) in protoplanetary disks, they can be destroyed by erosion under certain conditions. Carrying out low pressure, low gravity wind tunnel experiments on parabolic flights and improving the setup over the last few years, we are now approaching ever closer to conditions of small bodies in protoplanetary disks. We now measure threshold wind speeds (shear stress) at ambient pressures on the order of only 1 Pa and at gravity levels of only 0.01 g. While we confirm models for threshold shear stress at Earth conditions and show that they can be scaled to low pressure and gravity quite a bit, significant differences emerge, eventually. I will present our latest results on this.

On the nature of the resonant drag instability of dust streaming in protoplanetary disc

Viacheslav Zhuravlev
SAI MSU

The recently discovered resonant drag instability of dust settling/streaming in protoplanetary disc is considered as the mode coupling of subsonic gas-dust mixture perturbations. This mode coupling is coalescence of two modes with nearly equal phase velocities: the first mode is inertial wave having positive energy, while the second mode is a settling/streaming dust wave (SDW) having negative energy as measured in the frame of gas environment being at rest in vertical hydrostatic equilibrium. SDW is a trivial mode produced by the bulk settling of dust, which transports perturbations of dust density.

Location and shape of the water iceline in protoplanetary disks

Alexandros Ziampras
University of Tuebingen

Young planets in accretion disks can excite spiral shocks, delivering large amounts of heat to the disk, and even open gaps in their vicinity that may lead to a local drop in temperature. Both of these effects directly influence the overall disk thermal structure, introducing heavily non-axisymmetric features and partitioning the disk into regions with different viscous and radiative properties. We use 2D numerical hydrodynamics simulations with radiation transport to examine the impact of planets of different masses and semimajor axes in disks of varying viscosity and accretion rates on disk thermal structure and highlight the mutable, non-axisymmetric nature of the water iceline in systems with massive planets. We find that both gap opening and shock heating can displace the iceline, with the effects being amplified for massive planets in optically thick disks. Cooling in the gap region can split an initially hot ($T > 170$ K) disk into a hot inner disk and a hot ring just outside of the planet's location, while shock heating can reshape the originally axisymmetric iceline into islands of ice and vapor along spirals. Combinations of the above are also possible. We also find that radiative diffusion does not alter the picture significantly in this context. Overall, shock heating and gap opening by a planet can effectively move and/or reshape the water iceline. This can lead to azimuthal features that follow the trajectory of spiral arms, potentially creating hot zones, "islands" of vapor and ice along spirals which could influence the growth of icy aggregates and, ultimately, second-generation planetesimals.

Global radiation ideal MHD simulations and the implications for FU Orionis outbursts

Zhaohuan Zhu
University of Nevada

We have carried out global ideal MHD simulations to study accretion disks threaded by net magnetic fields. We found that a significant accretion occurs at the disk surface. The disk surface is torqued by the disk midplane. A weak disk wind is launched from high above the disk surface. FU Orionis objects are accreting young stellar objects with a luminous accretion disk and strong disk wind. We have carried out radiation ideal MHD simulations to study FU Ori. Strong magnetic fields have been observed at the disk surface. I will also discuss how such simulations can be compared with observations.

Author Index