50 years of Binaries and Disks: Lubow@75

May 6 – 9, 2024, Barrick Art Museum, UNLV, NV, USA

ABSTRACTS

TALKS

1.
Name: Matthew Bate (University of Exeter)
Title: Young protoplanetary discs
Abstract: I will present results from numerical simulations of young protoplanetary discs, discussing their great diversity and the various evolutionary processes that dictate their formation and early evolution. I will discuss how the disc populations produced by various simulations compare to observed discs, including the properties of circumbinary discs. I will also present results from dust-gas simulations of young protoplanetary discs, investigating how dust growth begins in these discs (i.e. the very earliest stages of planet formation).

2.
Name: Phil Armitage (CCA, Flatiron Institute)
Title: Disk winds
Abstract: TBD

3.
Name: Pawel Artymowicz (University of Toronto)
Title: Disk scenario for the origin of JuMBOs
Abstract: JuMBOs are the 40+ Jupiter Mass Binary Objects discovered in October 2023 by JWST in Trapezium cluster in Orion star forming region. They are free floaters, that is these giant planets are not bound to the stars. Their origin at present is quite mysterious, since their ejection as binaries from forming planetary systems or binding after individual ejection from such systems appears unlikely. Likewise, their formation in direct gravitational collapse would be unexpected, since it contradicts the opacity-limited fragmentation theory. It is important to consider in detail these two possible modes of formation, to verify their plausibility and likelihood. I will illustrate and evaluate the perturbed-disk origin of JuMBOs, in which fast migration in the disk, followed by outside perturbation (leading to truncation of the protoplanetary disk) gives the planets a chance of simultaneous release from a forming planetary system and survival in a gravitationally bound pair.

4.
Name: Robert D Mathieu (University of Wisconsin - Madison)
Title: Blue Stragglers and Blue Lurkers
Abstract: A substantial fraction of late-type stars in the Milky Way have evolved along alternative stellar evolutionary paths in binary systems. As has been the case for single stars, open star clusters are a laboratory to study the alternative pathways. As a case in point, in the 4-Gyr open cluster M67, 25% of the evolved stars do not lie on the single-star evolutionary isochrone. Thus, understanding these alternative stellar evolutionary paths is essential to a complete understanding of stellar evolution, and to correctly interpret population studies of stars.

Today, blue stragglers are seen as the most evident part of a much larger population of evolved stars that do not fall on a classical single-star evolutionary path. Indeed recently this population has suddenly grown further to include a population of such stars lurking within main sequences. These stars are not anomalous; rather they trace major pathways of stellar evolution.

Over the last decade observations have shown that most of these stars are themselves binary stars. Relatedly, theory has argued that they likely form from an array of processes within binary stars, including mass transfer, mergers, collisions and rapid rotation. I will briefly tell some of this discovery journey through the landscape of the clusters of the WIYN Open Cluster Study.

5.

Name: Bill Welsh (San Diego State University)

Title: Circumbinary Planets – The State-of-the-Art Observational Overview

Abstract: We present the latest developments on detecting and characterizing the Kepler and TESS circumbinary planets. After a brief summary of the general properties and on-going puzzles, we discuss the importance of archival eclipse data and precision eclipse timings for O-C diagrams. We then focus on the non-transiting systems, and discuss how to detect them and measure their masses and orbital properties using eclipse timing variations. We describe the observational signature and challenges of estimating their orbital inclination.

6.

Name: Eric Jensen (Swarthmore College)

Title: Orbital alignment, from disks to planets

Abstract: At young ages, the relative alignment between the binary orbit and the circumstellar disks in the system can reveal hints about binary formation mechanisms and/or past dynamical interactions. In older systems, the planetary orbit / binary orbit alignment is important for determining the dynamics of the system, including planet migration. Both of these environments have long been investigated theoretically, but it is only relatively recently that we can get clear observational constraints (from ALMA, TESS, and Gaia) on the extent to which these orbits are aligned or misaligned. At the time of planet formation, our ALMA observations of circumstellar disks in young binary systems show that the two disks in a given system, while not coplanar, are more aligned than would be expected from a random distribution of disk orientations. In older systems, we use a sample of almost 400 binary systems with known orbits from Gaia and transiting planet detections from TESS to investigate the alignment between planetary and binary orbits. We find a strong statistical tendency toward alignment, but only for low-mass planets in binaries with separations less than about 700 AU. The fact that the effect is much stronger for low-mass planets than for hot Jupiters may help shed light on planet migration mechanisms.

7.

Name: Daniel Price (Monash University)

Title: Tidal truncation and planet wakes in protostellar discs (aka: things Lubow got right)

Abstract: I will first discuss observational and theoretical verifications of tidal truncation in circumbinary discs, essentially showing that Artymowicz & Lubow got it right in 1994. However, there are few puzzles including recent VLTI/GRAVITY observations of the binary orbit in HD142527. What was not expected at the time was the idea of disc tearing or breaking in misaligned discs, spectacularly confirmed in observations of GW Ori. I will also discuss recent observational evidence for embedded planets carving gaps and making waves in circumstellar discs (matching Ogilvie & Lubow's predictions) as well as tentative evidence for circumplanetary discs. Finally I will discuss ongoing issues around angular momentum transport in protostellar discs, whether wind, turbulence or planetary driven.

8.

Name: Jeremy Smallwood (ASIAA)

Title: The evolution of misaligned circumbinary discs: gas and dust dynamics

Abstract: The majority of stars born in dense stellar clusters are part of binary star systems. Circumbinary discs of gas and dust commonly surround binary star systems and are responsible for accreting material onto the binary. Misalignments between the circumbinary disc and the binary orbital plane are commonly observed in various phases of stellar evolution. Dissipation causes the disc to evolve to align coplanar with the binary orbital plane or perpendicular (i.e., polar) to the binary orbital plane. We investigate the formation of dust traffic jams in polar-aligning circumbinary discs. We use 3D smoothed particle hydrodynamical simulations of both gas and dust to model an initially highly misaligned circumbinary disc around an eccentric binary. As the circumbinary disc evolves to a polar configuration (perpendicular to the binary orbital plane), the difference in the precession between the gas and dust produces dust traffic jams, which become dense dust rings. We find the formation of dust rings exists for different Stokes number, binary eccentricity, and initial disc tilt. Dust rings are only produced while the circumbinary disc is misaligned to the binary orbital plane. When the disc becomes polar aligned, the dust rings are still present and long-lived. Once these dust rings are formed, they drift inward. The drift timescale depends on the Stokes number. The lower the Stokes number, the faster the dust ring drifts near the inner edge of the disc. The dust rings can have a midplane dust-to-gas ratio greater than unity, which may be a favourable environment for polar planet formation. We apply our results to the primordial disc around 99 Herculis (99 Her) binary system. Our results reveal that the formation of these dust rings is observed across various disc parameters, including the disc aspect ratio, disc viscosity, surface density power law index, and temperature power law index. Using 2D inviscid shearing box calculations, we find streaming instability modes with significant growth rates. The streaming instability growth timescale is less than the tilt oscillation timescale during the alignment process. Therefore, the dust ring will survive once the gas disc aligns polar, suggesting that the streaming instability may aid in forming polar planets around 99 Her.

9.

Name: Jake Simon (Iowa State University)

Title: Can dust grow to pebble sizes in Class 0/I disks?

Abstract: It is becoming increasingly evident that planet formation begins earlier than previously thought, as observations show that there is not enough solid mass available in Class II disks to produce the observed exoplanet population. This evidence strongly motivates an improved understanding of the earliest stages of planet formation, namely, whether very small dust grains inherited from the ISM can rapidly grow to sizes conducive for planetesimal formation.

I will present a new 1D model of dust growth in Class 0/I disks. By simulating a wide range of dynamical processes, including infall from the envelope, (parameterized) MHD and gravitationally induced turbulence, and thermal evolution, we are addressing the question of how and when dust growth occurs in Class 0/I disks. I will present the first results of this model, which demonstrate that the inward radial dust drift and outward (viscously expanding) gas flow (which takes dust along with it) lead to a local enhancement in the dust-to-gas ratio that moves outward in time. While this mechanism seems promising as a region of localized planetesimal formation, we actually find that the dust grain growth is severely limited at these early stages and at radii less than 20 AU. Thus despite the local dust-to-gas ratio, planetesimal formation may be extremely difficult at these times and locations in the disk due to very small grains persisting. I will conclude with implications of these results for planet formation in young disks.

10.

Name: Diego Muñoz (Northern Arizona University)

Title: Searching for a New Paradigm of Binary-Disk Interaction

Abstract: In the last five years, there has been a renewed interest in the classic problem of binary-disk interaction, where two point masses interact with a surrounding accretion disk. This process influences binary growth rate, angular momentum

exchange, and orbital element evolution. Despite advancements in computational models, certain aspects of this decades-old problem remain unclear. Recent findings challenge the established idea that binaries contract; instead, they might expand due to binary-gas coupling. This surprising new behavior has important implications for the evolution of massive black hole binaries and their gravitational wave signatures. In this talk, I will focus on the 'outward migration' conundrum and reevaluate other established beliefs. I will discuss why this unexpected effect went unnoticed for 30 years, and explore what potential physical processes may still ensure the inward migration of binaries.

11.

Name: Cheng Chen (University of Leeds)

Title: On the orbital evolution of binaries with steady state circumbinary disks

Abstract: The disk-binary interaction leads to the evolution of the binary's orbit. The binary could lose its orbital angular momentum transported to the circumbinary disk through Lindblad resonances. At the same time, the binary can acquire specific angular momentum from the disk through viscous torques that cause the formation of spiral arms and the accretion of material onto the binary through these arms. Previous simulations of the SPH code have shown that the evolution of the binary's orbit may be influenced by various parameters of the system. In this study, we improve our setup by considering a steady state disk and vary disk parameters. Most importantly, we only allow the binary to feel the disk after the disk reaches the quasi-steady state, which was not considered in previous SPH studies. Hence, the binary prevents from additional effects of the initial setup of the simulation. Because circumstellar disks form around stars, the binary's orbit can evolve in reverse direction dramatically with mini disks. Hence, the existing of circumstellar disks plays a crucial role for the binary's orbital evolution.

12.

Name: Alessia Franchini (University of Zurich)

Title: Misaligned discs in multi-planet systems around binary stars

Abstract: The discovery of thousands of exoplanets presents a variety of exotic configurations. Some of these might be explained with misaligned disc dynamics in binary stars. In this talk, I will present the several works on misaligned discs I did with Steve and discuss more recent implications of misaligned discs in Be/X-ray binaries.

13.

Name: Gordon Ogilvie (DAMTP, University of Cambridge)

Title: Dynamics of warped discs in binaries

Abstract: Circumstellar and circumbinary discs are known to become warped whenever they are misaligned with the plane of the binary orbit. Over several decades, Steve Lubow and collaborators have revealed many interesting dynamical phenomena involving tilted discs in binaries. These include tilting instabilities, eccentric (Lidov-Kozai) instabilities of tilted discs, polar alignment of discs around eccentric binaries, and breaking of sufficiently tilted discs. In this talk I will discuss some nonlinear aspects of the internal fluid dynamics of warped discs and how they could affect the behaviour of tilted discs in binaries and around black holes. The affine model, in which the disc is considered as a set of fluid columns that undergo translations and linear transformations, provides a Lagrangian perspective and allows a novel interpretation of the dynamics of warped discs. The nonlinear behaviour in the resonant regime of slowly evolving warps in nearly Keplerian discs of low viscosity is of particular interest. An important role is played by the vertical breathing mode of the disc, which can be driven into a nonlinear resonance, leading to a bouncing motion of the dynamical scaleheight. I will discuss the possible connection between this behaviour and the onset of breaking through instability of the warp evolution, as well as the roles of apsidal precession and dissipation. Some applications to tilted discs in binaries will be considered.

14.

Name: Rebecca Nealon (University of Warwick)

Title: Disc breaking in accreting supermassive black hole binaries

Abstract: The inspiral of supermassive black hole (BH) binaries in a gas-rich environment is driven by the presence of an accretion disc and viscous interactions tend to align the spin of the BHs with the orbital angular momentum of the disc. Recent work by Gerosa et al. 2020 introduced a new iterative approach to describe the alignment process and the resulting non-linear evolution of the surrounding warped accretion disc. Their model predicted that BH spins reach either full alignment or a 'critical obliquity' where solutions to the warp equations cease to exist. In this work, we show that this critical region corresponds to the disc breaking phenomenon, where the disc is disrupted into two or more discrete sections. We use 3D hydrodynamical simulations to (i) recover the predictions of the semi-analytic model and (ii) unveil a richer phenomenology where the disc exhibits either unsuccessful, single and multiple breaks. We additionally identify hydrodynamic effects such as spiral arms that are able to stabilize the disc against breaking beyond criticality. Our results show that when disc breaking occurs, the ability of BHs and disc to align is compromised and in some cases even prevented as the binary inspirals.

15.

Name: Ian Rabago (UNLV)

Title: Dynamics of Circumbinary Protoplanetary Disks

Abstract: Binary stars are common outcomes of the star formation process, with nearly half of Sun-like stars forming as part of a binary pair. The presence of a second star adds additional dynamical effects during the planet formation process in the surrounding circumbinary disk and can introduce additional complexity as the disk evolves. We investigate the behavior of circumbinary disks using hydrodynamic modeling, specifically in the case where the disk is misaligned to the binary orbital plane. Around eccentric binaries, highly inclined disks can align themselves perpendicular to the binary orbital plane. These "polar disks" can produce vortices and spiral arms when the disk viscosity is low, which may accelerate the formation of polar-aligned circumbinary planets. Precession induced from the binary can distort the disk and cause it to warp in three-dimensional space. We also examine the behavior of disk warping around a central binary using both analytic and numerical methods, deriving a new criterion for disk breaking. These criteria show consistency with both simulations and observed disks, and may have applications for disk-like structures across many different areas of astrophysics.

16.

Name: Daniel Fabrycky (University of Chicago)

Title: CBPs and Exomoons: configurations inspired by disks in binaries

Abstract: Eccentric binaries can host both disks and planets in configurations in which the angular momentum of that orbit aligns with the major axis of the binary. These "polar" configurations may naturally be discoverable by Eclipsing Timing Variations (ETV), and here we review what signal features we (Zhang & Fabrycky 2019) found are peculiar to polar planets rather than coplanar ones, and compare to the ETV observations. In other exoplanet news, close-in exoplanets have been thought to be devoid of exomoons due to tidal evolution (either into the planet, or out of the Hill sphere). However, we (Kisare & Fabrycky 2024) found that an exomoon will not necessarily be driven out of the Hill sphere. Instead, owing to its own tidal dissipation, it can acquire a tidal equilibrium near the instability limit, analogous to disk truncation in binaries.

17.

Name: Thomas Baycroft (University of Birmingham)

Title: Circumbinary planets: a growing population from radial velocities

Abstract: Circumbinary planets, while expected to be common, are poorly represented in the exoplanetary zoo. Most detections so far have been from transits with Kepler and TESS data, but radial velocity circumbinary planets are gaining prominence. In this talk I will present results from new radial velocity detections of circumbinary planets; discuss the demographics of known circumbinary planets; compare the populations being revealed by the different detection methods; and touch on the future of circumbinary planet detections.

18.

Name: Anna Childs (Northwestern University)

Title: Dynamics of Circumbinary Planets with Large Mutual Inclinations and Circumbinary Disk Evolution with General Relativity

Abstract: Mutually misaligned circumbinary planets may form in a warped or broken gas disk or from later planet-planet interactions. We numerically study the dynamics of a two planet circumbinary disk where the inner planet is polar and the outer planet is coplanar. The polar inner planet causes retrograde apsidal precession of the binary orbit and the stationary inclination is smaller for larger outer planet orbital radius. For a range of outer planet semi-major axes, an initially coplanar orbit is librating meaning that the outer planet undergoes large tilt oscillations. Circumbinary planets that are highly inclined to the binary are difficult to detect -- it is unlikely for a planet to have an inclination below the transit detection limit in the presence of a polar inner planet. These results suggest that there could be a population of circumbinary planets that are undergoing large tilt oscillations. Next, we study the effects of general relativity (GR) on the evolution and alignment of circumbinary disks around binaries on all scales. We implement relativistic apsidal precession of the binary into the hydrodynamics code PHANTOM. We find that the effects of GR can suppress the stable polar alignment of a circumbinary disk, depending on how the relativistic binary apsidal precession timescale compares to the disk nodal precession timescale.

19.

Name: Konstantin Batygin (Caltech)

Title: Origins of Frequency Uniformity in the Inner Edges of Accretion Disks

Abstract: The characteristic orbital period of innermost objects in exoplanetary systems appears nearly universal, typically falling in the range of a few days. In this work, we present a theoretical framework to explain this pattern. We examine the interplay between disk accretion, magnetic field generation, and Kelvin-Helmholtz contraction of host stars, and derive a revised expression for the magnetospheric truncation radius in astrophysical disks. Our derivation shows that the corresponding orbital frequency is independent of the host mass. Applying fiducial physical parameters, we find a typical period of approximately 3 days, although variations in system characteristics may introduce a factor of 2-3 spread. Standard disk migration theory predicts that planets will stabilize at an orbital period slightly longer than the disk truncation. Therefore, we predict that the periods of close-in extrasolar planets should span the range of 2 to 12 days, consistent with observational data.

20.

Name: Jeffrey Fung (Clemson University)

Title: Radiation, Gas, and Dust: Clumping and Disk Recession

Abstract: Dust dynamics under the combined influence of radiation pressure and gas drag can lead to highly complex structures. I will revisit the “irradiation instability” that operates on a disk of perfectly coupled gas-dust mixture that is subjected to radiation pressure, and present new results on models where the drag force is calculated explicitly. We found that the instability regularly generates “dust clumps”, high-density localized disk features. These clumps have a number of significant implications. First, they enhance the local density by orders of magnitude, creating a favorable environment for planetesimal formation. Second, their formation consumes small grains, and so reduces the effective opacity of the disk and allows radiation to leak around the clumps and penetrate deeper into the disk. In some parameter space, the continuous generation of these “clumps” leads to a sustained outward migration of dust grains at speeds that are about a few times 10^-5 the Keplerian speed. This is fast enough to open au-sized dust cavities over the disk lifetime. Our results may explain the high fraction of transition disks around bright Herbig Ae/Be stars, and adds emphasis to the rich and dynamic interaction between radiation, gas, and dust.

21.
Name: Ruobing Dong (University of Victoria)
Title: From simulations to machine learning
Abstract: Tired of waiting for days for hydrodynamic simulations to finish? Machine learning could provide a solution. I will introduce neural networks capable of rapidly generating predictions for hydrodynamic systems. In the specific context of protoplanetary disks, which are accretion disks surrounding newborn stars, a recently developed network can forecast the outcome of the interaction between a disk and a planet in less than a second — using just a laptop. In comparison, achieving the same results with traditional computational fluid dynamics methods may require thousands of CPU hours or more.

22.
Name: Eve J. Lee (McGill University)
Title: Identifying low-turbulence disks using dust-gas dynamics
Abstract: The behavior of disk-induced planet migration is expected to change drastically once the strength of "turbulence" is low enough for the disk to be practically inviscid. Direct measurement of turbulence is challenging however. I'll describe how a combination of simple dust-gas dynamics and the properties of ringed disks can be used to identify the turbulent alpha parameter while also separately solving for the particle Stokes number, thereby constraining the two fundamental parameters that control the early stages of planet formation and planet-disk interaction.

23.
Name: Andrew Youdin (University of Arizona)
Title: ALMA''s Dust Rings: Are they Rossby Wave Stable?
Abstract: The Rossby Wave Instability in disks can arise when radial pressure gradients produce a local minimum in potential vorticity. The RWI thus places limits on the strength of radial pressure gradients in a quasi-equilibrium disk, and the outcome of the RWI includes the production of large-scale vortices. I will describe recent work on the RWI. First, we have used the RWI to constrain the nature of the dust rings observed by ALMA. Second, we have made some progress in a deeper analytic understanding of the RWI including the sufficient criterion for instability and the growth rate in limiting cases.

24.
Name: Shangjia Zhang (UNLV)
Title: Thermal Structure Determines Kinematics: Vertical Shear Instability in Stellar Irradiated Protoplanetary Disks
Abstract: Turbulence is crucial for protoplanetary disk dynamics, and Vertical Shear Instability (VSI) is a promising mechanism in outer disk regions to generate turbulence. We use Athena++ radiation module to study VSI in full and transition disks, accounting for radiation transport and stellar irradiation. We find that the thermal structure and cooling timescale significantly influence VSI behavior. The inner rim location and radial optical depth affect disk kinematics. Compared with previous vertically-isothermal simulations, our full disk and transition disks with small cavities have a superheated atmosphere and cool midplane with long cooling timescales, which suppresses the corrugation mode and the associated meridional circulation. This temperature structure also produces a strong vertical shear at $\mathrm{\tau_*}$ = 1, producing an outgoing flow layer at $\tau_* < 1$ on top of an ingoing flow layer at $\tau_* \sim 1$. The midplane becomes less turbulent, while the surface becomes more turbulent with effective α reaching $\sim10^{-2}$ at $\tau_* \lesssim$1. This large surface stress drives significant surface accretion, producing substructures. By generating synthetic images, we find that substructures are more pronounced in disks with larger cavities. The higher velocity dispersion at the gap edge could also slow particle settling. Both properties are consistent with recent Near-IR and ALMA observations. Our simulations predict that regions with significant temperature changes are accompanied by significant velocity changes, which can be tested by ALMA kinematics/chemistry observations.

25.

Name: Geoffroy Lesur (IPAG/CNRS)

Title: Shaping discs and protoplanets via large scale magnetic fields

Abstract: Over recent years, our understanding of protoplanetary disc (PPD) dynamics have changed dramatically. It is now believed that MHD processes are playing a very important role in the formation and evolution of these objects. While a direct measurement of magnetic fields in PPDs is still lacking, I will show in this talk that several features, such as rings, cavities and planet migration are easily affected by the transport and redistribution of the large scale magnetic field.

26.

Name: Yan-Fei Jiang (Flatiron Institute)

Title: How does Lubow's eccentricity excitation mechanism work with MRI turbulence?

Abstract: Steve proposed the famous mode-coupling mechanism due to the 3:1 resonance in a binary system to explain the eccentricity growth in the accretion disk, which has been widely used to explain the superhump phenomenon. The mechanism has been confirmed in 2D hydrodynamic simulations, but not with magnetic field. I will show some recent studies on how the eccentricity can grow with self-consistent MRI turbulence and demonstrate that Steve's theory still works!

27.

Name: Xiao Hu (University of Florida)

Title: Gap Opening in Non-Ideal MHD Protoplanetary Disks: Asymmetric Accretion and Observational Signatures

Abstract: Recent high-angular resolution ALMA observations have revealed rich information about protoplanetary disks, including ubiquitous substructures and three-dimensional gas kinematics at different emission layers. One interpretation of these observations is embedded planets. Previous 3-D planet-disk interaction studies are either based on viscous simulations, or non-ideal magnetohydrodynamics (MHD) simulations with simple prescribed magnetic diffusivities. This study investigates the dynamics of gap formation in 3-D non-ideal MHD disks using non-ideal MHD coefficients from the look-up table that is self-consistently calculated based on the thermo-chemical code. We find a concentration of the poloidal magnetic flux in the planet-opened gap (in agreement with previous work) and enhanced field-matter coupling due to gas depletion, which together enable efficient magnetic braking of the gap material, driving a fast accretion layer significantly displaced from the disk midplane. The fast accretion helps deplete the gap further and is expected to negatively impact the growth of planetary embryos. It also affects the corotation torque by shrinking the region of horseshoe orbits on the trailing side of the planet. Together with the magnetically driven disk wind, the fast accretion layer generates a large, persistent meridional vortex in the gap, which breaks the mirror symmetry of gas kinematics between the top and bottom disk surfaces. Finally, by studying the kinematics at the emission surfaces, we discuss the implications of planets in realistic non-ideal MHD disks on kinematics observations.

28.

Name: Lee Hartmann (University of Michigan)

Title: Observational constraints for accretion outbursts

Abstract: We have computed observational diagnostics of accretion outbursts in pre-main sequence disks. Using 1-D models, we show that the lag time between infrared and optical outbursts in Gaia 17bpi are consistent with triggering at about 0.1 au and an alpha parameter ~ 0.1. We also point out that large, FU Ori-type outside-in bursts should exhibit an infrared precursor years to decades before the optical outburst; detection of such precursors would be important in pinning down the origin and thus constrain possible triggering mechanisms.

29.

Name: Adolfo Carvalho (California Institute of Technology)

Title: Disk cooling and massive winds in the post-outburst spectra of V960 Mon and HBC 722

Abstract: FU Ori outbursts represent some of the most extreme and energetic events low-mass young stellar objects (YSOs) experience but the detailed physics of the outbursts remain largely unconstrained. FU Ori outbursts occur when the disk-to-star accretion rate increases by a factor of 100 to 10,000 times the typical YSO accretion rate and can last for 10s to 100s of years. The strong accretion flow crushes the stellar magnetosphere, leading to accretion directly onto the stellar surface. The recent outbursts of HBC 722 and V960 Mon enable us to study the evolution of the inner disk in detail as the system evolves in the years following the outburst. Using 10+ years of photometry and spectroscopy of the two systems, we have demonstrated that the major fading events of both are related to decreases in the disk accretion rates and temperatures. We have also shown that the SED evolution of V960 Mon is consistent with the magnetosphere of the star re-establishing itself as the outburst weakens. In HBC 722, we find strong evidence of the outer boundary of the inner disk instability propagating outward in the first 5 years after the outburst. I will discuss these observations in the context of our current understanding of FU Ori outbursts and the instabilities which trigger and sustain them. I will also discuss the unique nature of our observations of these two systems and how the astronomy community can optimize current and future all-sky surveys like ZTF, VVV, LSST, and Roman, to study future outbursts in similar detail.

30.

Name: Jiayin Dong (Flatiron Institute)

Title: Isotropic Stellar Obliquity Distribution of Hot Jupiter Systems

Abstract: The origin of hot Jupiters has been a long-standing puzzle in exoplanetary science. I will first highlight a few lines of recent observational evidence, all of which suggest the importance of high-eccentricity tidal migration in forming hot Jupiters. Then, I will present the inference of stellar obliquity distribution for hot Jupiter systems using a hierarchical Bayesian framework. Misaligned systems are nearly isotropically distributed, with no significant clustering near 90 degrees. The newly inferred isotropic distribution of stellar obliquity suggests that planet-planet interactions are a significant mechanism in forming hot Jupiters.

31.

Name: Stephen Lubow (STScI)

Title: The Role of Theory in Astrophysics

Abstract: Theory has had a range of objectives in astrophysics from explaining observations to making predictions based only on physical principles. I will discuss some examples in which theory has had great success and cases where it could have done better. I will also discuss possible future directions including the role of AI.

32.

Name: Roman Rafikov (University of Cambridge)

Title: Recent developments in the disk-planet interaction theory

Abstract: Gravitational coupling between a gaseous disk and an embedded or external perturber is a subject of great importance in astrophysics, relevant for issues such as planetary migration, gap opening, formation of sub-structures in protoplanetary disks, truncation of circumbinary disks, and so on. This is also the subject on which Steve Lubow has worked for many years. Despite its long history and a number of analytical and numerical studies devoted to it, disk-planet interaction still reveals some surprises in the form of various effects, which can shed light on the global aspects of the disk-perturber coupling. I will present a (subjective) overview of the recent discoveries and progress in understanding the various features of disk-planet interaction – negative torque density phenomenon, torque oscillations in protoplanetary and circumbinary disks, formation of

multiple spiral arms in disks, role of gas thermodynamics in disk-planet coupling – putting them in the context of Steve's contributions to the field.

33.

Name: Doug Lin (University of California, Santa Cruz)

Title: Concurrent gas accretion and migration of emerging planets in protostellar disks and embedded stars in AGN disks

Abstract: Gas giants and Neptune-mass planets have astonishing tendency to migrate while acquiring their gaseous envelope in their turbulent, evolving natal disks. This phenomenon also occurs in AGN disks which the hotbed of in situ star formation and ongoing chemo-dynamic evolution. Although this multi-dimensional nonlinear process has been extensively studied by many investigators, the technical challenges imposed by its complexity over wide ranges of spatial and temporal scales has hitherto limited classical analyses to idealized piecemeal constructions. Here, we report some of our recent attempts towards a fully self-consistent comprehensive study. Depending on the magnitude of the effective viscosity, concurrent gas accretion modifies the rate and/or reverses the direction of migration of nomadic entities. Sufficiently intense turbulence can also induce low-mass companions to undergo stochastic migration and to acquire randomized angular-momentum influx. These factors determine the asymptotic mass distribution, and retention efficiency of emerging planets as well as the kinematic distributions of planetary systems. They also affect the spin rate, obliquity, merger rate of embedded stars and their compact remnants in AGN disks.

34.

Name: Callum Fairbairn (Institute for Advanced Study)

Title: Eccentric Planet-Disc Interactions: Linear Theory and Torque Reversals

Abstract: The interaction between a planet with a gaseous disc is a classic problem dating back nearly half a century, to which Dr Lubow has made outstanding contributions. Yet this topic still bears crucial relevance as we presently observe exoplanetary architectures and disc sub-structures, potentially shaped by such interactions. Whilst much attention is reserved for circular orbits, planets may also form or be excited onto eccentric trajectories. In this talk I will review our semi-analytical, linear framework which is able to describe the eccentric perturber wake morphology in a Keplerian shear flow. Moreover, we will apply this tool to perform a parameter space survey over disc properties and eccentricity amplitude to quantify the back-reaction torque driving planetary migration. We find a transition in behavior as the increasing eccentricity engages transonic radial motions — leading to a torque reversal, stalling inwards migration and causing the eccentricity damping to slow.

35.

Name: Kaitlin Kratter (University of Arizona)

Title: A thermodynamic criterion for circumplanetary disk formation

Abstract: As giant planets contract following runaway growth, it is expected that material with excess angular momentum accreting through the Hill sphere will circularize and form a thick, rotationally supported accretion disk. Modeling of circumplanetary disks is crucial for interpreting and planning observations of young, embedded exoplanets. In this talk, I will present recent numerical work differentiating planets that form weak rotationally supported envelopes from those that form disks. In particular, I will describe the impact of cooling from dynamically evolving dust. I will present a robust thermodynamic criterion for circumplanetary disk formation, that is sufficiently flexible to account for a range of planet masses and disk environments.

36.

Name: Avery Bailey (UNLV)

Title: Multidimensional aspects of circumplanetary disk dynamics

Abstract: In this poster we review and compare pre-existing models of circumplanetary disks alongside high resolution 3D hydrodynamics simulations, testing the fidelity of various 1D and 2D assumptions. With 3D simulations we also test the robustness of inferences made subject to the various numerical treatments of physics like boundary conditions and viscosity. We further highlight important similarities and differences between the dynamics of circumstellar vs. circumplanetary disks. Modern topics in CPD dynamics like instabilities, radiative cooling, and observational signatures are also touched upon from a hydrodynamics perspective.

37.

Name: Zhuo Chen (Tsinghua University)

Title: Radiation hydrodynamic simulations of circumplanetary disks

Abstract: During the final stages of its formation, a gas giant will typically develop a circumplanetary disk (CPD) around the planet, which can accrete some of the surrounding material. Meanwhile, satellites can grow and evolve within the CPD. Currently, there are few observational constraints on the temperature, density, and state of CPDs. In the hope of uncovering the interior of the CPDs, we conduct axis-symmetric 2D radiation hydrodynamic simulations. Our simulations suggest that the CPD of a gas giant may have temperatures as high as 2000K, which can sublimate high-temperature-resistant dust such as silicates and dissociate H2. In addition, the spin of the gas giant can affect the transfer of mass and angular momentum in CPD-gas giant interactions. In this report, I will show some physical processes of gas giant accretion through CPDs and discuss the formation and evolution of gas giants and their satellites under more realistic conditions.

38.

Name: Giuseppe Lodato (Universita' degli Studi di Milano)

Title: Dynamics of misaligned discs in binary/multiple systems

Abstract: In this talk I will discuss the evolution of misalignment and eccentricity in discs around high multiplicity systems (triples and above). I will take the discs surrounding GG Tau A and HD98000 as prototypical examples to explore these dynamics and the several open problems that the existence of these systems pose to theory.

39.

Name: Yihan Wang (UNLV)

Title: JuMBO formation mechanisms

Abstract: Recent observations by the James Webb Space Telescope (JWST) have revealed the presence of Jupiter Mass Binary Objects (JuMBOs), challenging traditional models of planetary formation. Our study utilizes direct few-body simulations to explore the formation mechanisms of JuMBOs, specifically through the ejection of double giant planets during close stellar encounters. Results indicate that these interactions, particularly in nearly aligned configurations at closest approach, can lead to ejection, with JuMBOs exhibiting a semi-major axis triple that of their original orbits and a distinctly superthermal eccentricity distribution. We analyze the formation rates of JuMBOs in both typical and densely populated star clusters, uncovering a notable dependency on environmental density. In dense clusters, formation rates for wide planetary systems can exceed several percent. This study not only provides a mechanism for JuMBO genesis but also proposes comparative analysis with ongoing JWST data to refine our understanding of giant planet formation and test planetary formation theories under varying protoplanetary disk conditions.

40.

Name: J. J. Zanazzi (University of California, Berkeley)

Title: Damping Obliquities of Hot Jupiter Hosts by Resonance Locking

Abstract: When orbiting hotter stars, hot Jupiters are often highly inclined relative to their host star equator planes. By contrast, hot Jupiters orbiting cooler stars are more aligned. Prior attempts to explain this correlation between stellar obliquity and effective temperature have proven problematic. We show how resonance locking --- the coupling of the planet’s orbit to a stellar gravity mode (g mode) --- can solve this mystery. Cooler stars with their radiative cores are more likely to be found with g-mode frequencies increased substantially by core hydrogen burning. Strong frequency evolution in resonance lock drives strong tidal evolution; locking to an axisymmetric g mode damps semi-major axes, eccentricities, and as we show for the first time, obliquities. Hotter stars lack radiative cores, and therefore preserve congenital spin-orbit misalignments. We focus on resonance locks with axisymmetric modes, supplementing our technical results with simple physical interpretations, and show that non-axisymmetric modes also damp obliquity.

41.

Name: Chao-Chin Yang (University of Alabama)

Title: From pebbles to planets: planetesimal formation and pebble accretion

Abstract: Even though thousands of extrasolar planetary systems have been detected, a comprehensive picture of how planets are formed from their natal protoplanetary disks remains to be drawn. I will briefly review our current understanding of the dust-gas dynamics in protoplanetary disks and its consequences on the formation of planets. Specifically, I will examine how and under what conditions cm-/mm-sized pebbles can actively concentrate themselves to high density for km-scale planetesimals to form, the initial mass function of planetesimals, and how pebble accretion assists planet formation, along with some supporting observational evidences.

42.

Name: Wladimir Lyra (New Mexico State University)

Title: Evidence for streaming instability and pebble accretion in the densities of Kuiper belt objects

Abstract: Kuiper belt objects show an unexpected trend, whereby large bodies have increasingly higher densities, up to five times greater than their smaller counterparts. Current explanations for this trend assume formation at constant composition, with the increasing density resulting from gravitational compaction. However, this scenario poses a timing problem to avoid early melting by decay of 26Al. We aim to explain the density trend in the context of streaming instability and pebble accretion. Small pebbles experience lofting into the atmosphere of the disk, being exposed to UV and partially losing their ice via desorption. Conversely, larger pebbles are shielded and remain more icy. We use a shearing box model including gas and solids, the latter split into ices and silicate pebbles. Self-gravity is included, allowing dense clumps to collapse into planetesimals. We find that the streaming instability leads to the formation of mostly icy planetesimals, albeit with an unexpected trend that the lighter ones are more silicate-rich than the heavier ones. We feed the resulting planetesimals into a pebble accretion integrator with a continuous size distribution, finding that they undergo drastic changes in composition as they preferentially accrete silicate pebbles. The density and masses of large KBOs are best reproduced if they form between 15 and 22 AU. Our solution avoids the timing problem because the first planetesimals are primarily icy, and 26Al is mostly incorporated in the slow phase of silicate pebble accretion. Our results lend further credibility to the streaming instability and pebble accretion as formation and growth mechanisms.

POSTERS

1.
Name: Cory Padgett (Clemson University)
Title: CI Tau: Disk Mis-Alignment and Precession Regimes
Abstract: CI Tau is among the handful of exceptional systems where an exoplanet is detected within a protoplanetary disk. These systems are the key to calibrating theoretic predictions of planet-disk interaction. Using NASA IRTF, we took high resolution spectroscopic data of CI Tau’s 12CO and hydrogen Pf-beta line emission, and revealed the complex kinematic structures in the disk that are likely tied to planetary influence. Most notably, the disk is broken at about 0.14 au, where both the inner and outer disks are eccentric, but their arguments of periapsis are anti-aligned. Our hydrodynamical simulations demonstrate that mis-aligned eccentric inner and outer disks is a generic feature of planet-disk interaction that could be as readily observable as planetary gaps. Additionally, precession rates of these eccentric disks are related to planetary and disk parameters. Theoretical predictions of these rates are testable in time-domain observations.

2.
Name: Daniel Godines (New Mexico State University)
Title: On the Mass Budget Problem of Planet Formation Theory: Streaming Instability and Optically Thick Regions
Abstract: We investigate the missing mass problem in protoplanetary disks in the context of the streaming instability. We quantify the effect of the streaming instability on the distribution of mass at varying stellocentric distances, as the instability concentrates dust grains into optically thick filaments and unobservable planetesimals. Radiative transfer calculations are employed to assess the underestimation of disk mass resulting from these overdensities when sub-mm/mm wavelength observations are used to estimate the dust column densities under the assumption of optically thin emission. Analysis of a simulation without self-gravity reveals mass underestimations of up to an order of magnitude, with the mass underestimation increasing further by several factors when simulations that take into account the gravitational collapse of the pebbles into planetesimals are considered. Our results suggest that protoplanetary disks masses may indeed be severely underestimated if streaming instability is the dominant planetesimal formation mechanism.

3.
Name: Madeline Overton (UNLV)
Title: Retrograde discs around one component of a binary
Abstract: Be/X-ray binaries consist of a massive Be main sequence star and a compact object companion which is commonly a neutron star. The Be star hosts a decretion disc of material that may be captured by the compact object. Through the formation process of the neutron star, the binary orbit may become misaligned, and even retrograde, relative to the decretion disc. We use hydrodynamical simulations to investigate the behavior of a retrograde, coplanar disc around one component of the binary in both circular and eccentric binaries. In the circular binary case, we show that the disc can be unstable to global tilting. The disc experiences the largest inclination growth relative to the binary orbit in the outermost radii of the disc, closest to the companion. This tilt instability also occurs for test particles. The coplanar retrograde disc remains circular while a coplanar prograde disc can become eccentric. We suggest that the inclination instability is due to a disc resonance caused by the interaction of the tilt with the tidal field of the binary. In the eccentric binary case, the retrograde disc becomes more eccentric than the prograde case and undergoes rapid apsidal precession. We also investigate the accretion onto the companion and discuss the resulting X-ray outbursts. In the circular binary case, there is very little accretion in the retrograde case compared to the prograde case. With an eccentric binary, we see evidence for type I outburst accretion events, and the fast precession of the retrograde disc produces variability in the outburst magnitude.

4.
Name: Ted Johnson (UNLV)
Title: Investigating the fraction of polar circumbinary disks
Abstract: Circumbinary disks that are misaligned with the orbital plane of their host binary undergo nodal precession due to the torque exerted by the central binary. Viscosity in the disk leads to settling to a stable configuration -- either coplanar to the binary orbit, or polar to the binary orbit (i.e. inclined by 90 degrees with respect to the binary). We use the N-body code REBOUND to simulate three body systems to represent the evolution of a circumbinary disc. With Monte Carlo methods we determine the fraction of disks that are expected to be polar for a given binary eccentricity and disk angular momentum.

5.
Name: Shunquan Huang (UNLV)
Title: Excitation of Binary Eccentricity by Massive Polar-Aligned Circumbinary Disks
Abstract: Many post-AGB star binaries are observed to have relatively high orbital eccentricities (up to 0.6). Recently, AC Her was observed to have a polar-aligned circumbinary disk. We perform Smoothed-Particle Hydrodynamics (SPH) simulations to explore the impact of a polar-aligned disk on the eccentricity of a binary. For a binary system with a 2.1 M_s central mass, we find that the eccentricity can be enhanced from 0.2 up to 0.7 in 5000 yrs by a disk with mass 0.1 M_s and eventually the eccentricity settles around 0.3-0.5. Even if the disk mass is as low as 0.01 M_s, the eccentricity grows within our simulation time while the system remains stable. These eccentricity variations are associated with the variations of the inclination between the disk and the binary orbit due to von Zeipel-Kozai-Lidov oscillations. We show that our results are in good agreement with the analytical estimates.

6.
Name: Stanley A. Baronett (UNLV)
Title: Dust–Gas Dynamics Driven by the Streaming Instability with Various Pressure Gradients
Abstract: The streaming instability, a promising mechanism to drive planetesimal formation in dusty protoplanetary discs, relies on aerodynamic drag naturally induced by the background radial pressure gradient. This gradient should vary in discs, but its effect on the streaming instability has not been sufficiently explored. For this purpose, we use numerical simulations of an unstratified disc to study the non-linear saturation of the streaming instability with mono-disperse dust particles and survey a wide range of gradients for two distinct combinations of the particle stopping time and the dust-to-gas mass ratio. As the gradient increases, we find most kinematic and morphological properties increase but not always in linear proportion. The density distributions of tightly coupled particles are insensitive to the gradient whereas marginally coupled particles tend to concentrate by more than an order of magnitude as the gradient decreases. Moreover, dust-gas vortices for tightly coupled particles shrink as the gradient decreases, and we note higher resolutions are required to trigger the instability in this case. In addition, we find various properties at saturation that depend on the gradient may be observable and may help reconstruct models of observed discs dominated by streaming turbulence. In general, increased dust diffusion from stronger gradients can lower the concentration of dust filaments and can explain the higher solid abundances needed to trigger strong particle clumping and the reduced planetesimal formation efficiency previously found in vertically stratified simulations.

7.
Name: Arturo Cevallos Soto (UNLV)
Title: Interplay of Close-in Planets with Disk Magnetospheric Accretion
Abstract: We present a series of high-resolution 3-D ideal MHD simulations to explore magnetospheric accretion onto a non-rotating solar mass star with embedded planets in various configurations. We examine planets with mass ratios to the star (q) ranging from 0.01 to 10-4, corresponding to approximately 10 M_Jupiter to 30 M_Earth, and orbital radii from 0.45 to 1.8 times the magnetospheric truncation radius (R_T, 10 solar radii or 0.0465 au). Our findings highlight three key aspects of how

magnetospheric accretion influences planet formation. First, we find that planets with a Bondi radius (R_Bondi) smaller than their physical radius (R_P) do not accrete disk material, suggesting that in-situ formation of Hot Jupiters within the stellar magnetosphere is unlikely. For planets where R_Bondi exceed R_P, accretion is initiated, leading to the formation of circumplanetary disks (CPDs). These disks capture part of the stellar magnetic field, effectively creating a planetary magnetosphere that interacts with the stellar field. Second, our analysis of planetary torques reveals a mix of stochastic and periodic effects, with long-lived disk over-densities exerting significant influence on planetary orbits. However, the migration rate due to diffusion is minor compared to typical Type I and Type II migrations. Third, while our periodogram analysis is sensitive to large-scale magnetic bubbles, it appears unable to detect planetary signals, even for the most massive cases.