UNIVERSITÀ DEGLI STUDI DI MILANO

TO MAGNIFICO RETTORE OF UNIVERSITA' DEGLI STUDI DI MILANO **ID CODE 6507**

I the undersigned asks to participate in the public selection, for qualifications and examinations, for the awarding of a type B fellowship at **Dipartimento di Fisica Aldo Pontremoli dell'Università degli Studi di Milano**

Scientist in charge: **Prof. Rosotti Giovanni**

Carolin Nadja Kimmig

CURRICULUM VITAE

PERSONAL INFORMATION

Surname	Kimmig
Name	Carolin Nadja

PRESENT OCCUPATION

Appointment	Structure
Scientific Assistant in a PhD programme	Ruprecht-Karls-Universitaet Heidelberg, Germany

EDUCATION AND TRAINING

Degree	Course of studies	University	year of achievement of the degree
Degree	Master's of Science in Physics	Ruprecht-Karls-Universitaet Heidelberg	2021
Specialization			
PhD	Astrophysics	Ruprecht-Karls-Universitaet Heidelberg	currently pursuing – to be finished in 2024
Master			
Degree of medical specialization			
Degree of European specialization			
Other			

Università degli Studi di Milano – Direzione Trattamenti Economici e Lavoro Autonomo
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assegni.ricerca@unimi.it DTELA_M_CVAssegniENG_rev. 00 del 02/09/2021

REGISTRATION IN PROFESSIONAL ASSOCIATIONS

Date of registration	Association	City

FOREIGN LANGUAGES

Languages	level of knowledge
English	fluent
German	native speaker

AWARDS, ACKNOWLEDGEMENTS, SCHOLARSHIPS

Year	Description of award

TRAINING OR RESEARCH ACTIVITY

With my knowledge and expertise in the theory of protoplanetary disks, I am passionate about the opportunity to contribute to the knowledge in the field, and to connect theory to observations.

Currently, I am pursuing my PhD in astrophysics in Heidelberg in Prof. Cornelis Dullemond's research group. I am working in the field of protoplanetary disks, focusing on modeling warped disks. As such disks have varying orbital planes with distance from the star, they display intriguing shadow features in observations. In order to study their appearance and formation, I investigate them in full 3D hydrodynamic simulations. From those simulations, I can extract observational signatures, such as shadows in scattered light images and kinematics, using radiative transfer models.

In previous work, I investigated the effect of the wind-driven accretion model on planetary migration. For this, I set up an analytical prescription of the magnetic wind's effect on the disk and examined the behaviour of planets in those disks. As a result, I found that magnetic winds can drive planetary migration both inwards and outwards.

PROJECT ACTIVITY

Year	Project
2019	Effect of wind-driven accretion on planetary migration Magnetic fields in protoplanetary disks can have a great influence on the evolution of the disk, as well as on the formation and evolution of planets. This is why this project, I investigated planetary migration in disks influenced by wind-driven accretion. This type of accretion is gaining importance, as more observations indicate that protoplanetary disks have rather low turbulence. In the wind-driven accretion model, magnetic fields cause charged particles to be launched away from the disk in a wind. Those particles are accelerated and remove angular momentum from the disk, which results in an inward accretion of the disk material. In this project, I adopted an analytical parametrization of the net torque resulting from the magnetic wind, which I implemented in the code FARGO3D. I then added planets of different masses in an invicid disk containing wind-driven accretion in order to probe their migration behavior under different accretion strengths. In those simulations, I found that wind-driven accretion indeed can influence planetary migration. I found inward and outward migration, depending on accretion velocity of the gas and planet mass, whereas the planets do not migrate in a test case without wind-driven accretion. Because in an invicid disk planets quickly open a gap, I expected inward migration, as the disk itself accretes inwards and drags the gap edges and in turn the planet with it. However, the outward migration I found in some simulations was surprising. Collaborating with my advisor, I was able to trace the cause of this outward migration to the asymmetry in the corotation region around the planet. With sufficiently fast accretion rates, relating to sufficiently strong magnetic disk winds, the gap carved by the planet can be replenished. This replenishment, however, occurs in an asymmetrical way, as it is only filled from the outer gap edge. This means that material in front of the planet is able to perform its horseshoe turn, while material behind streams away from the planet. The horseshoe streamlines develop an asymmetry, leading to an acceleration of the planet causing outward migration. We published our findings in Astronomy & Astrophysics. This project inspired subsequent investigations throughout the research community, exploring the behavior of planets in magnetized disks further.
2021	Warped disk dynamics Warped disks become more and more prominent in the research field, as multiple observations show evidence that a significant fraction of protoplanetary disks are misaligned. I decided to investigate warped disks in simulations to understand their evolution and subsequently, their appearance in observations. Warped disks have varying orbital planes with distance from the star. A misaligned inner part can cast a shadow onto the outer part of the disk, which shows up as asymmetrical dark regions or narrow shadow lanes. The warp evolution depends on subtle processes, so-called sloshing and breathing motions, triggered by the change in orbital plane. These processes influence kinematic signatures in observations, and the appearance of

	shadows is expected to change in time. In order to predict such features, I conduct one-dimensional models, as well as full three-dimensional hydrodynamic simulations. One-dimensional models of warped disks can greatly improve the understanding of warp evolution, while keeping the computational cost low. In my project, I programmed the evolution code *dwarpy* in Python, parameterizing the disk by splitting it up into concentric annuli. Each annulus plane can be characterized by the unit angular momentum vector, also called tilt vector. Historically, the evolution of the tilt vector is described by two different sets of equations, depending on the viscosity and vertical scale height of the disk. For very thin and viscous disks, the warp evolves diffusively, smoothing it out resulting in a planar disk. Such disks are typically found around black holes. Protoplanetary disks, however, appear to have a much lower viscosity. Here, the warp travels as a wave through the disk, which it is called the wave-like regime. In the past few years, efforts were made to combine these equation sets into a generalized set of equations with the first attempt in an empirical way. Working alongside my team, we were able to physically derive this set of equations by performing detailed shearing box analysis. With my code *dwarpy*, I was able to compare the equation sets and confirm the behavior of the generalized equations in both the diffusive and the wave-like regime. In fact, I intentionally programmed *dwarpy*, so it can easily switch between different sets of equations. I am planning on publishing *dwarpy* as open source project.
2022-2024	My current project focuses on investigating warped disks in three-dimensional hydrodynamic simulations. I chose to use the grid-based code FARGO3D as opposed to Smoothed Particle Hydrodynamics (SPH) methods, because the processes and structure close to the disk surface can be resolved in detail. Additionally, grid-based methods allow for models of much lower viscosity than SPH. So far, mostly SPH methods have been used to model warped disks, which is why I extensively tested the capability of grid-based methods to accurately model them. For this, I set up a planar disk tilted with respect to the disk midplane. Physically, this is the same scenario as an untilted disk, which means that any deviations from the untilted scenario are results of grid effects. I find that for high enough resolution, grid-based methods can model warps surprisingly well. Comparing my three-dimensional simulations to the one-dimensional models with *dwarpy*, I find good agreement, demonstrating the validity of one-dimensional models. However, the three-dimensional disk starts to twist, which is not seen in the one-dimensional models. To get to the bottom of this, I performed a series of tests to investigate whether this is a numerical effect caused by the grid, or a physical effect simply neglected during the linearization process in deriving the equations. The tests seem to indicate that it indeed is a physical effect, which would have implications on observations of warped disks, possibly explaining observed precessing jets. As new project, I am simulating an inclined fly-by scenario as

	possible warped disk formation. In a fly-by event, a star is passing by the disk system. If its trajectory is not perfectly aligned with the disk plane, the gravitation causes a warp. Such scenarios are previously studied in SPH simulations. Using grid-based methods, however, I can resolve the surface structures in much more detail, which allows me to investigate observational signatures using the radiative transfer code RADMC3D. I am especially interested in the kinematics close to the disk surfaces, since those were not resolved well in previous simulations. In addition to a warp, fly-bys cause spiral arms due to tidal effects, which are also commonly observed in protoplanetary disks. I aim to compare my simulations to observations, e.g. AS 205.

PATENTS

Patent

CONGRESSES AND SEMINARS

Date	Title	Place
July 2019	Turbulence and Structure Formation in Protoplanetary Disks 2019: Observation, Theory, and Experiments Poster presentation: Effect of wind-driven accretion on planetary migration	Ringberg, Germany
July 2020	Exoplanets III Member of the LOC	Heidelberg, Germany and Online
December 2020	5 Years after HL Tau Poster presentation: Effect of wind-driven accretion on planetary migration	Online Conference
September 2021	Spinning Fluids: Laboratory Fluid Dynamics for Disks and Planets Talk contribution: Warping through the Universe	Ringberg, Germany
November 2021	Research Unit Transition Disks (RUTD) Kick-Off Phase II Talk contribution: Non-axisymmetric features in PPDs: modeling warped disks	Munich, Germany

August 2022	Formation and Evolution of Planetary Systems: a conference dedicated to the scientific legacy of Willy Kley Talk contribution: Warping through the Galaxy Member of the LOC	Tübingen, Germany
September 2022	Research Unit Transition Disks (RUTD) Full Meeting Talk contribution: Spirals and warps – non-axisymmetric features in protoplanetary disks	Munich, Germany
April 2023	Protostars and Planets VII Poster presentation: Spirals and Warps: Non-axisymmetric features in protoplanetary disks	Kyoto, Japan
October 2023	Core2Disk III Talk contribution: Can magnetic disk winds induce planetary migration?	Paris, France

PUBLICATIONS

Books

Refereed articles
Effect of wind-driven accretion on planetary migration, Astronomy & Astrophysics, Carolin N. Kimmig, Cornelis P. Dullemond, Willy Kley, DOI: https://doi.org/10.1051/0004-6361/201936412, 2020
On the equations of warped disc dynamics, Monthly Notices of the Royal Astronomical Society, C. P. Dullemond, C. N. Kimmig, J. J. Zanazzi, DOI: https://doi.org/10.1093/mnras/stab2791, 2022
Warped disk evolution in grid-based simulations, Astronomy & Astrophysics, Carolin N. Kimmig, Cornelis P. Dullemond, in prep. (submitted)
Binary orbit and disk's properties of RW Aur through ALMA observations, Astronomy & Astrophysics, N. T. Kurtovic, S. Facchini, M. Benisty, P. Pinilla, S. Cabrit, E. L. N. Jensen, C. Dougados, R. Booth, C. N. Kimmig, C. Manara, J. E. Rodriguez, in prep. (submitted)

Congress proceedings

OTHER INFORMATION

Outreach	Public talk at 36C3 in Hamburg, Germany with co-speaker Anna Penzlin, December 2019 https://media.ccc.de/v/36c3-10607-grow_your_own_planet Structured Rings and Gaps: Is This Where We Come From? STRUCTURES Cluster of Excellence Blog Post, November 2021 https://structures.uni-heidelberg.de/blog/posts/2023_11_kimmig/index.php Author for astrobites.org, a daily astrophysical literature journal aimed at undergraduate students, 2022 – 2024 https://astrobites.org/author/lkimmig/
Astrophysical codes	developer of *dwarpy* in Python, a 1D ring code to model the evolution of disk warps expert in FARGO3D for 2D and 3D hydrodynamic simulations
Paricipation in summer schools	Hands-on Numerical Astrophysics School for Exoplanetary Sciences 2022, Workshop of DFG Exploring the Diversity of Extrasolar Planets (SPP 1992), Hanau-Steinheim, Germany, July 2022 IMPRS Summer School: Planet formation in protoplanetary disks, Max-Planck-Institute for Astronomy in Heidelberg, Heidelberg/Online, September 2020 Hands-on Numerical Astrophysics School for Exoplanetary Sciences 2018, Workshop of DFG Exploring the Diversity of Extrasolar Planets (SPP 1992), Kloster Höchst, Germany, June 2018 IAYC - International Astronomical Youth Camp, The International Workshop For Astronomy e.V., Nettlecomb Court, UK, July-August 2016 Science Academy Baden-Württemberg, Course Astronomy, Deutsche JuniorAkademien Adelsheim, Germany, August 2011
Organization of scientific conferences and workshops	Formation and Evolution of Planetary Systems: a conference dedicated to the scientific legacy of Willy Kley, Member of the Local Organizing Committee, Tübingen, Germany, August 2022 Sagan Exoplanet Summer Virtual Workshop – Circumstellar Disks and Young Planets, Hands-on session supervisor, Online, July 2021 Exoplanets III, Member of the Local Organizing Committee, Heidelberg, Germany & Online, July 2020
Teaching experience	Tutor for the lecture "Introduction to Astronomy" at Heidelberg University in three semesters (2021 – 2023) Supervising four student internships (1-2 weeks per student) in the frame of job orientation (2022 – 2024)

Declarations given in the present curriculum must be considered released according to art. 46 and 47 of DPR n. 445/2000.

The present curriculum does not contain confidential and legal information according to art. 4, paragraph 1, points d) and e) of D.Lgs. 30.06.2003 n. 196.

Please note that CV WILL BE PUBLISHED on the University website and It is recommended that personal and sensitive data should not be included. This template is realized to satisfy the need of publication without personal and sensitive data.

Please DO NOT SIGN this form.

Place and date: Heidelberg, 28.03.2024