The Astrophysics of Planetary Habitability

Vienna, Austria

February 8 - 12, 2016

Session topics:

- Formation of planets in protoplanetary disks
- Formation of protoatmospheres
- Stellar radiative and particle output
- Stellar and planetary magnetic fields
- The physics of erosion of planetary atmospheres
- Dynamical interactions in planetary systems
- Collisions, migration, and transport mechanisms

Scientific Organizing Committee:

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Manuel Güdel (A, chair)
Nader Haghighipour (USA)
Wilhelm Kley (D)
Helmut Lammer (A, co-chair)
Douglas Lin (USA)
Rosemary Mardling (AU)
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Klaus Strassmeier (D)
LOC chair: Rudolf Dvorak (A)

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ÖAW ÖSTERREICHISCHE AKADEMIE DER WISSENSCHAFTEN
IWF INSTITUT FÜR WELTRAUMFORSCHUNG

The Astrophysics of Planetary Habitability

Pathways to Habitability: From Disks to Active Stars, Planets and Life

February 8-12, 2016
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SOC (alphabetic listing)	Eric Chassefière, France Manuel Güdel, Austria (chair) Nader Haghighipour, USA Willy Kley, Germany Helmut Lammer, Austria (co-chair) Doug Lin, USA Rosemary Mardling, Australia Elke Pilat-Lohinger, Austria Heike Rauer, Germany Ansgar Reiners, Germany Klaus Strassmeier, Germany
LOC (alphabetic listing)	David Bancelin Akos Bazso Christoph Burger Ernst Dorfi Rudolf Dvorak (chair) Bibiana Fichtinger Colin Johnstone Kristina Kislyakova Theresa Lüftinger (co-chair) Thomas Maindl Daniel Steiner Lin Tu

Local Information

Oral Presentations:

You are welcome to connect your own laptop. Please check connection any time before your presentation (e.g., in breaks; don't forget any special adapters your laptop may need for standard VGA connection!). A PC laptop (Windows 7, MS Office with PPT/PPTX software) will also be available if you bring your presentation on a USB stick (preferably also prepare a PDF as a backup option). Speakers please allow for 5 minutes of questions and discussion.

The duration of the talks is scheduled as follows:

- invited review talks: 30 minutes including discussion,
- contributed talks: 20 minutes including discussion.

Posters:

Poster space is avaibable for A0 format (84 cm wide, 199 cm high). You will receive a number at registration indicating your poster space. For each session, we will organize a short poster tour to introduce the posters in one of the breaks; poster first authors should be present.

On-site Internet/Wireless Access:

Eduroam will be available; additionally, participants receive personalized access with password.

Social Events:

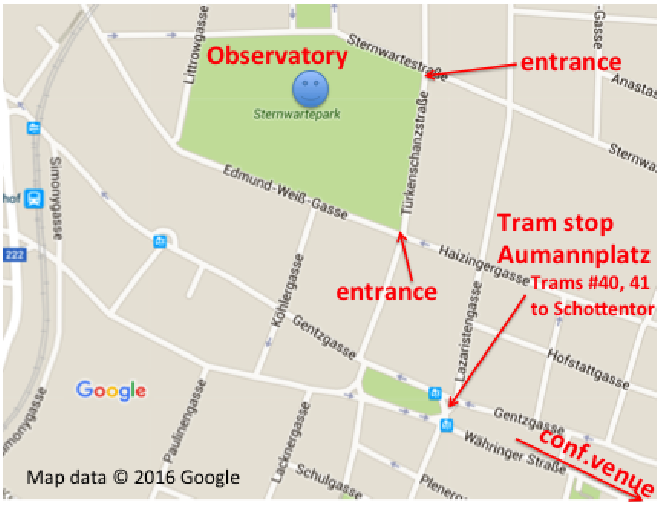
Monday afternoon: monastery Klosterneuburg + reception at University Observatory.

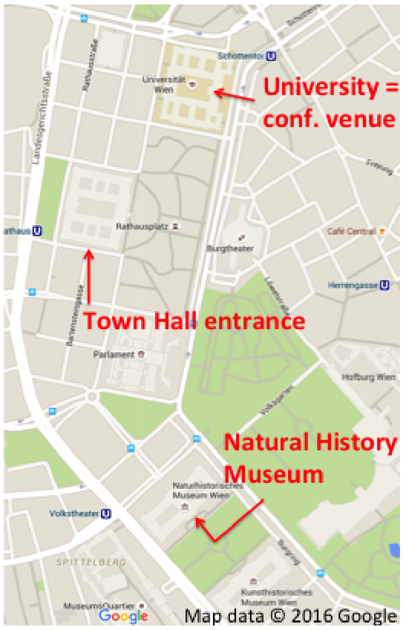
Thursday afternoon: Natural History Museum + conference dinner in Town Hall.

Addressses:

Venue: University of Vienna, Universitätsring 1, 1010 Vienna
Reception, Monday 8 February: University Observatory, Türkenschanzstrasse 17, 1180 Vienna
Natual History Museum, Thursday 11 February: Maria-Theresien Platz, 1010 Vienna
Town Hall, Conference Dinner Thursday 11 February: Friedrich-Schmidt-Platz 1, 1010 Vienna

Maps (Observatory and University/Town Hall/Museum):





Willkommen in Wien!

Program Overview

Monday, February 8, 2016

1. Opening session

Chair: Rudolf Dvorak

13:00–13:20	Opening
13:20–14:00	*V. Meadows*: Factors Affecting The Nature and Identification of Exoplanet Habitability (invited review)
14:00–14:30	*C. Koeberl*: The Bombardment History of the Early Earth (invited review)
14:30–15:00	Coffee break
15:00–	Departure to Klosterneuburg
17:30–	Return to Sternwarte
18:00–	Reception

Tuesday, February 9, 2016

2. The Host Star

Chair: Klaus Strassmeier

09:00–09:30	*T. Lüftinger*: Stars Shaping their Planetary Environments (invited review)
09:30–09:50	*S. Marsden*: The BCool project: Studying the magnetic activity of cool stars
09:50–10:10	*E. Newton*: The rotation of nearby M dwarfs, the ages of planetary systems, and implications for exoplanet discovery
10:10–10:40	Posters and coffee/tea
10:40–11:00	*C. Johnstone*: Stellar Activity Evolution and the Atmospheres of Terrestrial Planets
11:00–11:20	*M. Timpe*: An age-period-activity relation for M dwarfs: implications for planetary habitability
11:20–11:40	*A. Vidotto*: The effects of M dwarf magnetic fields and winds on potentially habitable planets
11:40–12:00	*J. Alvarado Gomez*: Magnetic Fields and Circumstellar Environment around Planet-Hosting Stars
12:00–14:00	Lunch break
14:00–14:20	*J. Villadsen*: Searching for Extrasolar CMEs and Accelerated Particles with Stellar Radio Bursts
14:20–14:40	*M. Endl*: Characterization of the Kepler-452 system, the closest analog to the Sun-Earth system

3. Planet Formation and Habitability

Chair: Theresa Lüftinger

14:40–15:10	*Y. Alibert*: Planet Formation and Habitability (invited review)
15:10–15:30	*M. Lugaro*: Radioactivity and habitability
15:30–15:50	*N. Haghighipour*: New Models of Water Delivery To Earth: The Effect of Ice Longevity
15:50–16:20	Posters and coffee/tea
16:20–16:40	*A. Coustenis*: Habitability potential of icy moons around giant planets and the JUICE mission
16:40–17:00	*E. Vorobyov*: On the feasibility of giant planet formation via disk gravitational fragmentation
17:00–17:20	*G. Picogna*: How do giant planetary cores shape the dust disk?
17:20–17:40	*E. Gaidos*: It's About Time: The Zodiacal Exoplanets in Time (ZEIT) Project
17:40–18:00	*H. Zinnecker*: Chances of earth-mass planets and life around metal-poor stars

Wednesday, February 10, 2016

4. Principles of Habitability

Chair: Nader Haghighipour

09:00–09:30	*R. Kopparapu*: Habitable Zones Around Main-Sequence Stars: Estimates and Applications (invited review)
09:30–09:50	*L. Carone*: Mapping 3D Climates in the habitable zone of M dwarfs
09:50–10:10	*S. Bressler*: A two-band theoretical radiative physical model for predicting the Greenhouse effect
10:10–10:40	Posters and coffee/tea
10:40–11:00	*S. Eggl*: Climate forcing and habitability of Earth-like circumbinary planets
11:00–11:20	*M. Cuntz*: A Joint Approach to the Study of S / P-Type Habitable Zones in Binary Systems: New Results

5. Planetary Atmospheres

Chair: Helmut Lammer

11:20–11:50	*F. Tian*: Planetary atmospheres and their roles for habitability (invited review)
11:50–14:00	Lunch break
14:00–14:20	*M. Mallonn*: Exoplanet transmission spectroscopy and the importance of clouds/hazes in their interpretation
14:20–14:40	*C. Gillmann*: Modeling Venus Surface Conditions Evolution and the Effects of Early Large Impacts
14:40–15:00	*K. Kislyakova*: Solar XUV and ENA-driven water loss from early Venus steam atmosphere
15:00–15:20	*S. Gebauer*: Processes affecting the Evolution of Molecular Oxygen in Earth-like Atmospheres
15:20–15:40	*A. Lincowski*: The Effect of Carbon Dioxide (CO2) Ice Cloud Condensation on the Habitable Zone
15:40–16:10	Posters and coffee/tea
16:10–16:30	*R. Jayawardhana*: Characterizing Atmospheres of Super-Earths
16:30–16:50	*E. Sedaghati*: Detection of Exo-atmospheres with transmission spectroscopy using the VLT
16:50–17:10	*G. Arney*: Pale Orange Dots: Earthlike Worlds with Organic Hazes
17:10–17:30	*A. Stökl*: Accumulation and evolution of primordial atmospheres around terrestrial planets

Thursday, February 11, 2016

6. Planetary Interiors

Chair: Elke Pilat-Lohinger

09:00–09:30	*P. Tackley*: Planetary interiors: Long-term evolution and implications for habitability (invited review)
09:30–09:50	*R. Helled*: Giant planet formation & internal structure
09:50–10:10	*C. Dorn*: Interior structures of low-mass exoplanets: the 5 best constrained cases
10:10–10:40	Posters and coffee/tea
10:40–11:00	*L. Noack*: Geophysical Limitations on the Habitable Zone
11:00–11:20	*J. Tarduno*: The geodynamo during Earth's first billion years: Implications for planetary habitability

7. Observatories: Future Perspectives

Chair: Manuel Güdel

11:20–11:40	*E. Guenther*: The Graz-Tautenburger-Imager: GTI
11:40–14:00	Lunch break
14:00–14:30	*H. Rauer*: Detection and characterization of exoplanets from space (invited review)
14:30–15:00	*S. Udry*: Towards a complete census of planetary system diversity: the role of ground-based observations (invited review)
15:00–	Departure to Museum of Natural History
19:00–	Conference Dinner at Rathaus

Friday, February 12, 2016

8. Planetary System Architecture and Dynamics

Chair: Rosemary Mardling

09:00–09:30	*C. Terquem*: Dynamics and Habitability (invited review)
09:30–09:50	*A. Mustill*: Using Kepler systems to constrain the frequency and severity of dynamical effects on habitable planets
09:50–10:10	*A.-S. Libert*: On the combined action of disc migration and planet-planet scattering in the formation of giant planetary systems
10:10–10:30	*R. Deitrick*: The nature and impact of obliquity evolution on the habitability of Earth-like exoplanets
10:30–11:00	Posters and coffee/tea
11:00–11:20	*J. Horner*: The influence of Jupiter, Mars and Venus on Earth's orbital evolution
11:20–11:40	*M. Read*: Dynamical Constraints on Outer Planets in Super-Earth Systems
11:40–12:00	*D. Carrera*: Survival of habitable planets in unstable planetary systems
12:00–12:20	*K. Antoniadou*: Pathways to long-term stability of highly eccentric resonant exoplanets
12:20–12:40	*N. Georgakarakos*: Habitable zones for planetary systems with gas giants: an analytic approach
12:40–13:00	Concluding remarks

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P2.2 *O. Arkhypov et al.*: Short-period cycles of stellar activity in Kepler photometry

P2.3 *A. S. Brun et al.*: Exo Space Weather

P2.4 *B. Fichtinger et al.*: Radio emission and mass loss rates of young solar-type stars

P2.5 *N. Kostogryz*: A new technique of starspot detection in transiting exoplanetary systems

P2.6 *O. Kuzmychov et al.*: Studying active cool stars with exoplanets with the help of the spectropolarimetry of molecules

P2.7 *M. Leitzinger et al.*: Stellar prominence oscillations and eruptions: The cases of HK Aqr and PZ Tel

P2.8 *J. Linsky et al.*: First Results from the MUSCLES Treasury Survey of the UV and X-ray Emission from K and M Dwarf Stars that Host Exoplanets

P2.9 *S. Mathis*: The variations of tidal dissipation in the convective envelope of low-mass stars hosting planetary systems along their evolution

P2.10 *M. Mengel*: A small survey of magnetic fields of solar-type planet hosting stars

P2.11 *N.-I. Nemec*: The solar wind in time

P2.12 *B. Nicholson et al.*: Characterising the interplanetary environment: the wind of the planet-hosting star Tau Boo

P2.13 *M. Temmer*: Characteristics of solar coronal mass ejections

P2.14 *L. Tu et al.*: Stellar high-energy luminosity evolution for pre-main sequence and main-sequence stars

P2.15 *S. Vauclair and G. Vauclair*: The ultimate fate of planetary systems

P2.16 *S. Vauclair et al.*: The 16 Cygni system: a laboratory for studying the influence of a planetary system on its host star

P2.17 *J. Weingrill and S. Barnes*: Probing the evolution of stellar activity in open clusters

3. Planet Formation and Habitability

P3.1 *C. Burger et al.*: Appropriate solid-body models as initial conditions for SPH-based numerical collision experiments

P3.2 *O. Dionatos et al.*: A panchromatic view of protoplanetary disks

P3.3 *Z. Sándor*: Dynamics of Terrestrial Planet Formation in Binary Stellar Systems

P3.4 *D. Steiner et al.*: Magnetic fields in protoplanetary disks

P3.5 *J. Werner et al.*: Material loss in two-body collisions during planet formation

P3.6 *G. Wuchterl*: Atmospheres of PLATO-planets: the limits of diversity

4. Principles of Habitability

P4.1 *P. Mason*: The Earliest Habitable Planets

P4.2 *Y. Sasunov et al.*: Investigation of scaling properties of a thin current sheet by means of particle trajectories study

P4.3 *R.-S. Taubner et al.*: Habitability Beyond the Snow Line: The Potential of Icy Moons to Serve as a Habitat for Life-as-We-Know-It

P4.4 *F. Trixler*: Quantum tunnelling at the base of planetary habitability and chemical evolution

5. Planetary Atmospheres

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P5.2 *U. Amerstorfer et al.*: Escape of Hot Oxygen and Carbon from the Early Atmosphere of Mars

P5.3 *D. Bisikalo and V. Shematovich*: Precipitation of Electrons into the Upper Atmosphere of a Hot-Jupiter Exoplanet

P5.4 *A. Cherenkov and D. Bisikalo*: On the influence of coronal mass ejections on the hot Jupiter atmosphere

P5.5 *R. Claudi*: Testing Habitability in Laboratory: Atmosphere in a Test Tube Experiment

P5.6 *P. Cubillos*: The Open-source Bayesian Atmospheric Radiative Transfer (BART) Code to Model Exoplanet Atmospheres

P5.7 *M. Khodachenko et al.*: Atmosphere expansion and mass loss of magnetized close-orbit giant exoplanets

P5.8 *N. Konstantinova et al.*: The influence of the colliding stellar winds on the atmosphere of the potentially habitable circumbinary exoplanet KIC9632895

P5.9 *M. Lendl*: Studying exoplanet atmospheres via transmission and emission spectra

P5.10 *P. Odert et al.*: Loss of volatiles and water from planetary embryos

P5.11 *M. Scherf et al.*: Simulation of the Earth's paleo-magnetosphere for the late Hadean eon

P5.12 *Y. Serozhkin*: Climate models of the early Earth's and thunderstorm activity

P5.13 *I. Shaikhislamov et al.*: Interaction of escaping atmosphere of HD209458b with stellar wind

P5.14 *V. Shematovich and D. Ionov*: Energy balance in the upper atmosphere of the hot jupiter with taking into account suprathermal photoelectrons

P5.15 *R. Slapak*: Atmospheric escape from planets: the role of a planetary magnetic field

P5.16 *O. Venot et al.*: Influence of stellar flares on exoplanetary atmospheres and transmission spectra

P5.17 *P. Wurz et al.*: The Atmospheres of Jupiter's Icy Moons

6. Planetary Interiors

P6.1 *S. Benatti et al.*: GAPS: Studying the architecture of planetary systems with HARPS-N at TNG

7. Observatories: Future Perspectives

P7.1 *T. Ratzka*: Probing Planet Formation with the VLTI and the ELT

P7.2 *Z. Regaly*: Age of giant planet embedded in debris disk

8. Planetary System Architecture and Dynamics

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P8.2 *A. Bazso et al.*: Secular resonances in circumstellar planetary systems in binary stars

P8.3 *M. Kanova and M. Behounkova*: Tidal evolution of viscoelastic bodies: a numerical approach

P8.4 *O. Kotsas et al.*: Resonant stable orbital configurations in three-planet systems

P8.5 *A. Leleu*: Orbital perturbation on the rotation of exoplanets

P8.6 *B. Loibnegger and R. Dvorak*: A dynamical study on the origin of the Moon

P8.7 *T. Maindl et al.*: Activating main belt comets by collisions

P8.8 *G. Picogna and F. Marzari*: Decoupling of a planet from its disk in presence of an inclined stellar companion

P8.9 *E. Pilat-Lohinger et al.*: The habitability of eccentric planetary orbits

P8.10 *R. Schwarz et al.*: Binary catalogue of exoplanets

P8.11 *R. Schwarz et al.*: Eclipse timing variations to detect exoplanets in binary star systems

P8.12 *N. Todorovic*: A mean motion resonance as a source of fast routes through the Solar System

Abstracts

Oral Presentations and Posters

1. Opening session

Chair: Rudolf Dvorak

1.1. Factors Affecting The Nature and Identification of Exoplanet Habitability

V. Meadows (1)

(1) University of Washington, Seattle, USA

Habitability is a measure of an environment's potential to support life. For exoplanets, the concept of habitability can be used broadly - to inform our calculations of the possibility and distribution of life elsewhere - or as a practical tool to inform mission designs and to prioritize targets in the search for extrasolar life. Kepler has discovered a handful of confirmed planets - and hundreds of planetary candidates - in or near their stars' habitable zones, indicating that potentially habitable planets are abundant. Although the Kepler targets are typically too distant for follow-up observations to determine further planetary properties, missions under development such as NASA's TESS and ESA's PLATO will search nearby stars for habitable zone planets. These nearby planets will be more amenable to spectroscopic follow-up by telescopes such as the E-ELT and JWST. Which targets we choose as most likely to support life, and how we interpret the hard-won data returned by these telescopes will depend critically on our understanding of the factors that affect planetary habitability. To first order, whether a planet resides in the habitable zone depends primarily on the effect of the host star's stellar type and the planetary semi-major axis on climate balance. Because of its reliance on two readily-observable properties of the planetary system, the HZ remains the best initial method for assessment of the probability that a newly discovered exoplanet is habitable. However, if multiple planets fall within the HZ it is not clear how these should be ranked with respect to each other, based on the HZ criterion alone. Also, the HZ concept assumes that the star interacts only radiatively - rather than gravitationally - with the planet, and that the planet has abundant water, tectonics, and an adequate atmosphere. How the planet acquired these properties, and which planetary system characteristics are more likely to result in a planet with these properties, are not considered. Additionally, astrophysical and planetary factors - including volatile delivery; orbital evolution; host star evolution, activity levels, tidal interactions and spectrum; atmospheric loss; planetary magnetic field; atmospheric protection against surface UV radiation; and the possibly diverse non-Earth-like characteristics of the planet itself - are not part of the HZ assessment. Consequently, as the field of planetary habitability has matured, many additional factors have been identified that can affect the habitability of a planetary environment, and these, often interdependent, factors fall into three main categories: stellar/Galactic, planetary system, and planetary effects. In this interdisciplinary overview we will identify and discuss the factors that can affect whether or not a planet can develop and maintain habitability, and highlight recent advances in modeling the complex interplay of star, planet and planetary system processes that affect habitability. The classical HZ concept can be thought of as a two dimensional slice through a multidimensional set of parameters. The current challenge for the field is to identify these parameters, quantify their relative impact on habitability, and determine their interdependencies. This will allow us to move beyond the HZ concept in assessing potential habitability, to instead focus on determination of an interdisciplinary, multi-parameter "habitability index", that calculates the relative probability for planetary habitability based on a suite of observables, supported by modeling results. This improved understanding of planetary habitability will aid in prioritization of potentially habitable planets for detailed photometric or spectroscopic observations, and identify those global characteristics of habitable planets that may be observable.

1.2. The Bombardment History of the Early Earth

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If a late heavy bombardment during the period from about 3.8 to 4 billion years ago occurred on the Moon, the Earth must have been subjected to an impact flux more intense than that recorded on the Moon. The consequences for the Earth must have been devastating, and may have included partial or total remelting of the crust. So far, no unequivocal record of a late heavy bombardment on the early Earth has been found. The earliest rocks on Earth date back to slightly after the end of the heavy bombardment, al-though there are relict zircons up to 4.4 Ga old (in which no unambiguous impact-characteristic shock features have yet been found). In terms of evidence for impact on Earth, the first solid evidence exists in the form of various spherule layers found in South Africa and Australia with ages between about 3.2-3.4 and 2.5 Ga; these layers represent several (the exact number is still unknown) large-scale impact events. The oldest documented (and preserved) impact structures on Earth have ages of 2.02 and 1.86 billion years. Thus, the impact record for more than half of the geological history of the Earth is extremely poor, and there is little information about the impact record and its effects during the first 2.5 billion years of Earth history.

Impact structures or ejecta are commonly identified from specific characteristics, including either the presence of evidence for shock metamorphism, and/or geochemical indications of the presence of an extraterrestrial component. Only elements that have high abundances in meteorites, but low abundances in terrestrial crustal and mantle-derived rocks are useful for such studies (such as the PGEs). Elevated abundances of siderophile elements in impact melt rocks or breccias (and impact ejecta), compared to target rock abundances, can be indicative of the presence of either a chondritic or an iron meteoritic component. There are, however, cases in which the PGE interelement abundances might be fractionated. These problems can, in part, be overcome by the use of isotopic tracers for extraterrestrial components. Most prominent among these are the Os and Cr isotopic methods. The Os isotopic method, which is based on the decay of Re-187 to Os-187, is very sensitive and can detect sub-percent levels of extraterrestrial component in impact breccias and melt rocks, but it is not possible to determine a meteorite type.

In contrast, the Cr isotopic method relies on the fact that all terrestrial rocks have a uniform Cr isotopic composition, whereas different meteorite types have different isotopic anomalies. The Cr isotopic method is, thus, selective not only regarding the Cr source (terrestrial vs. extraterrestrial), but also regarding the meteorite type.

2. The Host Star

Chair: Klaus Strassmeier

2.1. Stars Shaping their Planetary Environments

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Forming and evolving host stars play an overwhelming role in controlling the evolution of their planetary environments. Short-wavelength radiation (UV, EUV, X-rays), high-energy particles, and stellar ionized winds, all anchored in stellar magnetic activity, play a fundamental role in processing circumstellar material and planetary atmospheres and magnetospheres.

The environment of the young Sun, for instance, was very different from the one today. With levels of magnetic activity orders of magnitude higher than that of the present Sun, its high-energy radiative output and its ionized wind interacted with the atmospheres of the young terrestrial planets much more strongly than at present. In addition, an increased rate of flaring and probably more frequent coronal mass ejections led to further, enhanced escape from the planetary atmospheres.

M dwarfs – with their prolonged high activity and their habitable zones much closer in, offer an environment very much like that of the young solar one.

Such extreme conditions certainly have crucial consequences for the evolution of young stellar-planetary systems - and for the habitability of Earth-like Exoplanets surrounding active (young) stars.

In this review, we will discuss how the magnetic activity of the host star, the ionized winds, high-energy radiation, and particles influence and shape the planetary environment and comment on ongoing controversies, discussions and open issues.

2.2. The BCool project: Studying the magnetic activity of cool stars

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The BCool project is an international collaboration aimed at studying the magnetic activity of stars predominantly using spectropolarimetric observations to directly characterise magnetic fields with Zeeman Doppler Imaging. BCool's focus is on cool stars with over 200 stars observed from 2006 to the present, with around 20 of these having their magnetic topologies mapped. One of the main objectives of BCool is to use these maps to model stellar winds for their potential impact on exoplanets. In this presentation I will present some of the latest results from BCool and what are some of our plans for the future.

2.3. The rotation of nearby M dwarfs, the ages of planetary systems, and implications for exoplanet discovery

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(2) Harvard-Smithsonian Center for Astrophysics, Cambridge, USA

Understanding stellar rotation is critical to the detection and characterization of planets around M dwarfs. Rotation mediates the stellar wind and magnetic field, which can strip the planetary atmosphere. Rotation and its associated activity signals can mimic the radial velocity signatures of orbiting planets. These factors are particularly pertinent for M dwarfs, which remain magnetically active for Gyrs and for which the habitable zone is at only a few tenths of an AU. Furthermore, calibrated age-rotation relations enable the ages of planetary systems to be inferred. Despite the prevalence of low-mass stars, very few of the nearby population had measured rotation periods, and the lack of observational constraints has hampered studies of rotational evolution. In our recent paper, we presented rotation periods for 350 nearby mid-to-late M dwarfs, an order of magnitude increase over the previously-available sample. These measurements are derived from photometry from the MEarth planet-search data, and include detections from 0.1 to 150 days. We used galactic kinematics to estimate the ages of the stars with detected rotation periods. We find that mid M dwarfs in the field are slowly-rotating, with periods of approximately 100 days at 5 Gyr. We show how this information contributes to understanding the age of the newly-discovered terrestrial exoplanet GJ 1132b. We then consider the habitable zones of late-type stars at 5 Gyr and show where stellar rotation may impact the discovery of habitable planets. The MEarth target list comprises the sample of M dwarfs best suited for the discovery and atmospheric characterization of habitable planets. We highlight the subset that, based on their photometric rotation, is well-suited as targets for the upcoming generation of radial velocity surveys dedicated to low-mass stars.

2.4. Stellar Activity Evolution and the Atmospheres of Terrestrial Planets

C. P. Johnstone (1), M. Güdel (1), T. Lüftinger (1), B. Fichtinger (1), L. Tu (1), H. Lammer (2), K. G. Kislyakova (2), P. Odert (2), A. Stökl (1), E. Dorfi (1), N. V. Erkaev (3)

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The evolution of a terrestrial planet's atmosphere is strongly dependent on the X-ray and EUV (together 'XUV') irradiation of it's host star. A star's XUV luminosity is determined primarily by its rotation rate which evolves on evolutionary timescales in non-trivial ways. In this talk, we discuss stellar rotational evolution and its importance for our understanding of the formation of planetary atmospheres. We concentrate on the hydrogen atmospheres of terrestrial planets and show that the initial stellar rotation rate is a fundamentally important parameter for determining atmospheric evolution. Our results illustrate the importance of a detailed understanding of stellar rotation and it's connection to magnetic activity in atmospheric formation models.

2.5. An age-period-activity relation for M dwarfs: implications for planetary habitability

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(2) Georg-August-Universität Göttingen, Göttingen, Germany

We present an age-period-activity relation for M dwarfs and discuss the implications for planetary habitability. Activity in M dwarfs is the result of rotationally-driven magnetic heating in the chromospheric and coronal regions of the star, which manifests as enhanced emission of soft X-rays and extreme ultraviolet (XUV) radiation. Radiation in this wavelength range is capable of driving fast atmospheric loss on nearby planets. We numerically model angular momentum loss in low-mass stars and develop an observationally motivated relationship between stellar rotation and activity to obtain our age-period-activity relation. Applying our relation to models of atmospheric loss for Earth-like planets suggests that planets around M dwarfs residing near the inner edge of the habitable zone are likely to lose several Earth oceans worth of hydrogen unless they can escape runaway greenhouse conditions early on in their history.

2.6. The effects of M dwarf magnetic fields and winds on potentially habitable planets

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Recent results showed that the magnetic field of M dwarf stars, currently the main targets in searches for terrestrial planets, is very different from the solar one, both in topology as well as in intensity (more than 1000 times higher). In particular, the magnetised environment surrounding a planet orbiting in the habitable zone (HZ) of M dwarf stars can differ substantially to the one encountered around the Earth. These extreme magnetic fields can compress planetary magnetospheres to such an extent that a significant fraction of the planet's atmosphere may be exposed to erosion by the stellar wind. Here, we quantitatively investigate the nature of the interplanetary media at the HZ of a sample of M dwarf stars. For that, we simulate the winds of their host stars, in which we directly incorporate their observed surface magnetic field topology, previously derived from tomographic techniques. With that, we compute global quantities of the stellar winds, such as mass loss rates, as well as local wind characteristics at the HZ (temperature, velocity, magnetic field intensity and pressures). We show that hypothetical Earth-like planets with similar terrestrial magnetisation ($\sim$1 G) orbiting at the inner (outer) edge of the HZ of these stars would present magnetospheres that extend at most up to 5.0 (9.7) planetary radii. To be able to sustain an Earth-sized magnetosphere, the terrestrial planet would either need to orbit significantly farther out than the traditional limits of the HZ; or else, if it were orbiting within the life-bearing region, it would require a minimum magnetic field ranging from a few G to up to a few thousand G.

2.7. Magnetic Fields and Circumstellar Environment around Planet-Hosting Stars

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(2) University of Michigan, Ann Arbor, MI, USA

Recent developments in instrumentation and observational techniques have opened a new window for stellar magnetic field studies. In particular, Zeeman Doppler Imaging (ZDI) is now routinely used to recover the large-scale magnetic field topologies of stars different from the Sun, including several planet-hosting stars. These stellar magnetic fields intimately affect the environment around late-type stars by driving the coronal high-energy radiation (EUV/X-rays), transient events (e.g. flares and coronal mass ejections), and the development of stellar winds and astrospheres. These elements can have a strong impact in the evolution of planetary systems via star-planet interactions and erosion of exoplanetary atmospheres. In this context, the initial results from ZDI data-driven, detailed 3D MHD modeling of the coronal conditions and circumstellar environment around three planet hosting stars are presented. For one of the considered systems (HD 1237), we investigate the interactions of the magnetized stellar wind with the exoplanet, assuming a Jupiter-like magnetosphere around it.

2.8. Searching for Extrasolar CMEs and Accelerated Particles with Stellar Radio Bursts

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Coronal mass ejections (CMEs) and accelerated particles from the host star can shape exoplanetary atmospheres, causing atmospheric mass loss and drastic transient departures from chemical equilibrium including biomarker molecules. These effects are predicted to be especially important for planets around M dwarfs, which have a long period of violent youthful magnetic activity; however, these predictions are limited by the lack of observations of extrasolar CMEs and stellar energetic particles. Dynamic spectroscopy of stellar coherent radio bursts offers unique potential to detect extrasolar space weather events, including CMEs and accelerated particles. I will present simultaneous VLA and VLBA observations of active M dwarfs, using wide-bandwidth VLA dynamic spectroscopy to track coronal plasma motion and VLBA imaging to locate the burst relative to the quiescent radio corona. I will also describe the Starburst program, a new radio spectroscopy facility dedicated to monitoring space weather on nearby active stars.

2.9. Characterization of the Kepler-452 system, the closest analog to the Sun-Earth system

M. Endl (1)

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The Kepler 452 system is currently the closest analog to the Sun-Earth system. In this talk we will describe the discovery and validation of the 1.6 Earth-radii transiting planet in the habitable zone of its parent star by NASA's Kepler mission. We will focus on the characterization of the host star. The derived stellar parameters, like luminosity and age of Kepler-452, directly impact the habitability of Kepler-452b. We will also discuss future work to determine the habitability and occurrence rates of small, possibly rocky, planets inside the circumstellar habitable zone of the Kepler target stars. (Michael Endl on behalf of the Kepler team).

P2.1 New results on stellar deep mixing and starspot dynamics from the Kepler photometry

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The preliminary results on deep mixing manifestations in stellar variability (Arkhypov et al. 2015, A&A, 576, A67) are tested using an improved spectral-correlation method and extended data set. We measure the timescales τ_m of the stochastic change in the spectral power of rotational harmonics with numbers m<4 in the light curves of 1361 main-sequence stars from the Kepler mission archive. It is found that the relation of such timescales of τ_1 and τ_2 corresponds the Kolmogorov's theory of turbulence. We interpret this result as a manifestation of deep mixing, because the sub-surface convection is much smaller (m≫2) in accordance with a local height scale. Such deep-mixing manifestation dominates for stars with rotation periods P>4 days.

Moreover, the reduction of τ_1 and τ_2 to the laminar convection timescale $\tau_{\rm lam}$ in deep stellar layers reveals the proximity of $\tau_{\rm lam}$ to the turnover time $\tau_{\rm MLT}$ of the standard mixing length theory. In view of this important result, we use the reduced $\tau_{\rm lam}$ as well as τ_2 at P>4 days instead of $\tau_{\rm MLT}$ in our analysis of the relation between stellar activity and the Rossby number $Ro = P/\tau_{\rm MLT}$. The similarity of our diagrams with previous results and theoretical expectations shows that $\tau_{\rm lam}$ and τ_2 can be used as an analog for $\tau_{\rm MLT}$. This means that the laminar component (giant cells) of stellar convection plays an important role in the physics of stars.

For the cold stars at P<4 day, the longer starspot life-time masks the deep-mixing manifestation. As the important byproducts of the study appear the new data on the decay of starspots and the realistic values of diffusivity of magnetic elements in stellar photospheres.

P2.2 Short-period cycles of stellar activity in Kepler photometry

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We study the short-periodic component of stellar activity with a cycle period of $P_{cyc} < 1000$ days using the *Kepler* mission photometry of fast-rotating ($1 < P < 4$ days) stars with spectra of M4V to F3V. Applying the originally developed two non-spectral methods, we measured the effective period of stellar cycles in 462 objects. The obtained results are in accordance with previous measurements by Vida et al. and do not show the attributes of a beating effect. The performed measurements of Pcyc cluster in a specific branch that covers the previously unstudied region in the Saar & Brandenburg diagram and connects the branch of inactive stars with the area populated by superactive objects. It is shown that the formation of the discovered branch is due to the α-quenching effect, which saturates the magnetic dynamo and increases the cycle periods with the increase of the inverted Rossby number. These finds are important in the context of the discussion on stellar activity evolution and for a theory of magnetic dynamos in stars.

P2.3 Exo Space Weather

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With more than 2000 exo-planetary systems discovered as of today including more than 500 planets orbiting very close (within 10 stellar radii) to their host star, it is now becoming urgent to characterize star-planet interactions for such close-in systems. Extending our knowledge of the solar system and Sun-Earth relationships to these quite different exo-systems requires to develop theoretical and numerical tools that can deal with the large diversity of stellar rotation rates, activity levels and magnetic topologies, stellar wind properties and planet's characteristics. In this seminar I will discuss the recent progress we have made in modeling stellar magnetism, stellar wind and star-planet interactions using 3-D MHD simulations and what we have learned on the space environment surrounding exo-systems.

P2.4 Radio emission and mass loss rates of young solar-type stars

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Observations of free-free continuum radio emission of four solar-type stars are studied to detect stellar winds or at least to give upper limits for their thermal radio emission, which is emitted by the ionized wind. The stars in this sample are members of the Sun in Time Program and cover different ages on the main-sequence and are similar in magnetic activity to the Sun and thus are excellent proxies for representing the Sun at its early age. Mass loss rates of these stars are calculated using the observed radio emission.

The observations are performed with the Karl G. Jansky Very Large Array (JVLA) with wonderful low sensitivities and the Atacama Large Millimeter/Submillitmeter Array (ALMA) in the centimeter wavelength range. The frequency bands for the JVLA are the C-band from 4 – 8 GHz and the Ku-band ranging from 12 – 18 GHz; ALMA observations are performed at 100 GHz. The CASA software package is used for the data preparation, reduction, calibration and imaging. For the estimation of the mass loss, a spherically symmetric wind is assumed first, followed by the study of a stationary, optically thick, anisotropic, ionized wind which ejects in polar direction. We will compare our results to 1) mass loss rate estimates of rotational evolution models and 2) to results of the indirect technique of determining mass loss rates: Lyman- absorption. We will see that our results are quite different to those of Lyman- absorption and furthermore, if the Faint Young Sun Paradox can be solved with a more mass ive young Sun.

P2.5 A new technique of starspot detection in transiting exoplanetary systems

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The discovery of the first exoplanet has led to the rapid development of many new methods for their detection and characterization. Thanks to recent high-accuracy instruments, polarimetry has become a promising technique for characterizing exoplanetary systems that can yield information inaccessible to other methods. One of the interesting polarimetric effect , we consider here, is symmetry breaking of the intensity integrated over the stellar disk during the planetary transit that results in appearance of linear polarization of partially eclipsed star. Similar effect that breaks the stellar disk symmetry and also results in a non-zero linear polarization is the stellar activity, considered here in terms of starspots. A superposition of a planetary transit and starspots create a complex picture of linear polarization signal variations. Starspots can be revealed with transit polarimetry even in the absence of spot-crossing events, thus giving a more complete account of stellar activity. Transit polarimetry allow us to derive such information about starspots as their positions and sizes equally with and without spot-crossing event.

P2.6 Studying active cool stars with exoplanets with the help of the spectropolarimetry of molecules

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Most of the exoplanets known to date are found around M stars, which are in general active stars showing magnetically driven phenomena, such as strong UV and X-Ray emission, stellar winds, surface spots, etc. When studying exoplanet atmospheres, or more generally exoplanet habitability, the activity of the host star needs to be taken into account (e.g., Vidotto 2013). In particular, by applying topological techniques to the surface magnetic field maps of a host star, one can reconstract the magnetic characteristics of its astrosphere (e.g., Longcope 2005).

Using the example of the active M8.5 dwarf LSR J1835, we will demonstrate a new spectropolarimetric technique, which is mainly based on the CrH molecule, for studying surface magnetism in M dwarfs and brown dwarfs (Kuzmychov et al. in prep.; Berdyugina et al. in prep.). For objects ranging from mid-M to mid-L types, this technique has a number of advantages over the conventional ones (e.g., Reiners 2012, Linsky & Schöller 2015). For example, it yields the magnetic field strength and its filling factor independently from each other, and it can be applied to low resolution spectropolarimetric data (Kuzmychov & Berdyugina 2013), providing more reliable input parameters, e.g. for extrapolating the magnetic properties of the astrosphere.

We will discuss the feasibility of using the spectropolarimetry of molecules for detecting magnetic fields in late-L and T dwarfs, and possibly, that of exoplantes.

P2.7 Stellar prominence oscillations and eruptions: The cases of HK Aqr and PZ Tel

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Prominences are manifestations of magnetic fields on stars and have been detected on a handful of stars so far other than the Sun. We have selected two well known prominence-hosting stars, namely the young dMe star HK Aqr and late G type star PZ Tel, to search for prominence variability in form of oscillations. Such have so far not been detected on stars except for the Sun. Using oscillation parameters such as period and amplitude one can estimate the magnetic field strength in prominences. Moreover, prominences and Coronal Mass Ejections (CMEs) are well correlated on the Sun. This makes prominence hosting stars even more interesting as targets to search for CMEs, especially as the detection of stellar CMEs has turned out to be difficult. CMEs have impact on planetary atmospheric and stellar evolution so their investigation is of high importance. We report on the detection of prominence oscillations on HK Aqr. The estimation of oscillation parameters yielded values comparable to solar large-amplitude oscillations. However, during six nights of observations we could not detect any signature of CMEs. Assuming that CMEs produce absorption signatures similar to the prominence signatures, we show that considering the fact that CMEs/prominences are seen in absorption on these stars severely limits the number of detectable CMEs, in contrast to CMEs/prominences which can be seen in emission.

P2.8 First Results from the MUSCLES Treasury Survey of the UV and X-ray Emission from K and M Dwarf Stars that Host Exoplanets

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The UV and X-ray emissions of stars play critical roles in the photochemistry and temperature profiles of exoplanet atmospheres, thereby influencing potential “biomarker” gases. Since nearby stars less massive than the Sun are prime candidates for hosting habitable planets, we have implemented a comprehensive program to obtain stellar fluxes that provide the radiation environment of exoplanets.

The MUSCLES Treasury Survey has recently obtained near simultaneous UV spectra, X-ray fluxes, and optical spectra of 15 K and M dwarf stars that host known exoplanets. We will report here preliminary results from this large program. We obtained UV spectra covering the complete 1175-3200 Å range during 125 orbits of HST time using the COS and STIS instruments. We have also obtained near simultaneous X-ray fluxes of these stars with the Chandra and XMM-Newton observatories and ground-based optical spectra. The time-tagged UV spectra include time intervals with no large flares and times of strong flares on these stars. Even “optically inactive” stars have flares several times per day with energies of 10^{31} erg in the 300-1700 Å spectral region. We will show UV emission lines, Lyman-alpha reconstructed fluxes, and estimated EUV fluxes for these stars. We will also show the very different UV spectral energy distributions of G, K and M stars that control the abiotic production of potential biomarkers like O_2 and O_3.

This work is supported by a grant from the Space Telescope Science Institute to the University of Colorado.

P2.9 The variations of tidal dissipation in the convective envelope of low-mass stars hosting planetary systems along their evolution

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Since 1995, more than 1500 exoplanets have been discovered around a wide variety of host stars (from M- to A-type stars). In this context, tidal dissipation in their convective envelope is one of the key physical mechanisms that shape the orbital architecture of short-period planetary systems. As shown by observations, this dissipation varies over several orders of magnitude as a function of stellar mass, age, and rotation. In this work, our objective is to provide a physical explanation of the origins of these variations, which are still not understood. Using advanced ab-initio semi-analytic hydrodynamical models, we compute the properties of tidal dissipation in rotating stellar convection zones. This dissipation is due to the conversion into heat of the kinetic energy of tidal non-wavelike/equilibrium flow and inertial waves (driven by the Coriolis acceleration) because of the viscous friction applied by turbulent convection. Using grids of stellar models allows us to study the variation of the resulting dissipation as a function of stellar mass, age and rotation on the pre-main sequence and on the main sequence for stars with masses ranging from 0.4 to 1.4 $M_\odot$.

During their pre-main sequence, all low-mass stars may host high amplitude tidal inertial waves in their convective envelopes leading to an increase of the mean tidal dissipation until stars have a critical aspect and mass ratios (respectively $\alpha = R_c/R_s$ and $\beta = M_c/M_s$, where R_s, M_s, R_c, and M_c are the star's radius and mass and its radiative core's radius and mass). Next, the dissipation evolves on the main sequence to an asymptotic value that is highest for 0.6 $M_\odot$ K-type stars and that then decreases by several orders of magnitude with increasing stellar mass because the convective envelope is shallower. Simultaneously, the rotational evolution of low-mass stars with their spin-up during their pre-main sequence and their breaking by magnetic winds during their main sequence strengthens the importance of tidal dynamics during the early phases of evolution of close planetary systems.

P2.10 A small survey of magnetic fields of solar-type planet hosting stars

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Magnetic fields may play significant effects in planetary formation and evolution. We present a survey of the magnetic fields of 19 solar-type planet-hosting stars.

P2.11 The solar wind in time

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In this work we want to present a way of studying the solar wind in relation to the Suns evolution with the knowledge of the solar wind properties. We present a new way of combining magnetic flux transport models and calculating the wind speeds based on the Wang & Sheeley (2006) model of expansion factor- wind speeds relation. Wang & Sheeley use data from ULYSSES and photospheric field measurements from the Mount Wilson Observatory for their model.

The parameter we base our simulations on is the rotation period. We use the Sun as our reference and simulate four cycles for stars with a rotation period of 50, 12, and 2.5 days, respectively. Our aim is to investigate the wind properties in dependence of the rotation period.

Stars slow down with age as angular momentum is removed via the magnetic field. The magnetic field itself has an influence on the stellar wind and thus eventually on planetary atmospheres and magnetic fields. In this investigation we do not take account of Coronal Mass Ejections (CMEs) and flares. Both phenomena have not yet successfully been linked to the stellar age and activity and require further work. For the simulations we use a magnetic flux transport code.

We first model the solar wind and apply the according results directly to our experimental stars.

P2.12 Characterising the interplanetary environment: the wind of the planet-hosting star Tau Boo

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The winds from stars play an important role in the evolution and potential habitability of the planets that orbit them. Here we present results of stellar wind simulations based on observations of the star Tau Bootis (Tau Boo). Tau Boo is a fascinating star that is host to a close in hot jupiter planet, and displays a magnetic cycle similar to that of our Sun, but over a much sorter period of around 720 days, as compared to the Sun's 22 years. We have eight sets of spectropolarimetric observations, used to reconstruct the large-scale magnetic field using Zeeman Doppler Imaging, from May 2009 to January 2015. These are used as input to a three-dimensional magnetohydrodynamic code to simulate the wind from Tau Boo and investigate how it varies over it's magnetic cycle, and infer from that what impact this wind might be having on the orbiting planet.

P2.13 Characteristics of solar coronal mass ejections

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The Sun is an active star and its most violent activity phenomena are flares and coronal mass ejections (CMEs). CMEs abruptly disrupt the continuous outflow of solar wind by expelling huge clouds of magnetized plasma into interplanetary (IP) space with velocities of a few hundred to a few thousand km/s. Earth-directed CMEs reach Earth after transit times of about one to five days, in detail depending on their initial velocity, size, and mass, as well as on the coupling processes with the ambient solar wind flow in interplanetary space. The presentation will cover statistical results on CME energetics and their relation to solar flares observed in hard and soft X-rays, as well as case studies on the propagation behavior of CMEs in interplanetary space (propelling versus drag forces). Recent findings also show a close relation of CMEs sweeping past Earth and the associated neutral density increase in the Earth's thermosphere.

P2.14 Stellar high-energy luminosity evolution for pre-main sequence and main-sequence stars

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For solar-like main-sequence stars, high-energy radiation decays in time owing to stellar spin-down. The early Sun's X-ray (≈1–100 Å) and extreme-ultraviolet (≈100–900 Å) emissions could thus have exceeded the present-day Sun's level by orders of magnitude (Ribas et al. 2005), which drives atmospheric erosion. Such extreme radiation levels were critically important for both the primordial hydrogen atmospheres (e.g., Lammer et al. 2014) and the secondary nitrogen atmospheres (Lichtenegger et al. 2010) of solar system planets. We use a rotational evolution model to predict such luminosity distributions as a function of age, based on a range of initial Ω, and we show that these predictions agree with the observed time-dependent scatter of X-ray luminosity. We derive a radiative evolution model based on the full range of rotation histories for a solar-mass star, and thus find a description of the possible past histories of our own Sun, which is useful to model the corresponding evolution of solar-system planetary atmospheres. We also extend this evolutionary model to stars of lower mass.

P2.15 The ultimate fate of planetary systems

S. Vauclair (1), G. Vauclair (1)

(1) IRAP, Toulouse, France

What happens to the planetary systems at the end of the existence of their host-stars? More and more information and constraints are obtained from the study of white dwarfs, which show evidences of debris disks from infrared observations. Some of these white dwarfs present lines of heavy elements in their spectra, which are the signature of undergoing accretion of planetary matter. The observed abundance ratios of these elements are earth-like. We discuss how these observations may give constraints on planetary systems.

P2.16 The 16 Cygni system: a laboratory for studying the influence of a planetary system on its host star

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The 16 Cygni system consists of two main stars, A and B, both very similar to the Sun. They belong to the Kepler field and have been well studied by asteroseismology. One of them has a planet, not the other one. They have similar metallicities, but the planet-host star has a large lithium deficiency compared to the other one. This system is a good laboratory to show what happens in case of heavy matter accretion from a planetary system. We show that the metallic abundances are unchanged, but lithium may be destroyed by extra mixing induced in the accretion process.

P2.17 Probing the evolution of stellar activity in open clusters

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Revealing the changes of stellar activity with time is the key to understanding the evolution of habitable planets in their host star environment. In our Stella Open Cluster Survey (SOCS) we monitor several clusters at different ages for their photometric and hence magnetic variability. The dominating signal of stellar activity is imposed on the stellar rotation. The measurement of stellar rotation periods is increasingly being used to derive ages for cool stars on the main sequence. Such ages are based on an empirical understanding of how cool stars spin down. By monitoring the photometric variability of stars in open clusters at various ages, we can (a) determine the age of an individual cluster with 10 percent uncertainty and (b) measure the activity in various optical wavelengths as a proxy for the radiation environment. These results can be applied on single (planet hosting) field stars.

3. Planet Formation and Habitability

Chair: Theresa Lüftinger

3.1. Planet Formation and Habitability

Y. Alibert (1)

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Extrasolar planetary systems show an extreme diversity in mass and orbital architecture, and, very likely, in habitability. Explaining this diversity is one of the key challenges for theoretical models and requires understanding the formation, composition and evolution of planetary systems from the stage of the protoplanetary disk up to the full mature planetary system. I will review in this contribution the different models of planet formation and how they can be related to planetary habitability. In a first part, I will review the main planetary system formation models, and how, from these models, the composition of planets can be predicted. In a second part, I will link the results of these early phases of planetary systems, to the potential planetary habitability.

3.2. Radioactivity and habitability

M. Lugaro (1)

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The presence of radioactive nuclei in planetary systems affects the habitability of terrestrial planets. Long-lived (Gyr) elements, such as thorium and uranium, may contribute differently to the heating budget of extra-solar terrestrial planets since abundances of thorium different than in the Sun have been observed in solar twins and analogs. Short-lived (Myr) radioactive nuclei such as aluminium-26 were the major source of heating in the early Solar System for the planetesimals that accreted within the first million years or so. This led to their melting and differentiation and to water circulation and loss in ice-rich planetesimals, with implication for the delivery of water to planets in the habitable zone. The question is if extra solar ice-rich planetesimals have as much aluminium-26 as those in the early Solar System, if not, they can keep their initial ice content and deliver more water to planets in habitable zones. To answer this question we need to first understand the origin of aluminium-26 in the early Solar System. I will review the current hypotheses, from a local nearby stellar source to the chemical evolution of star-forming regions.

3.3. New Models of Water Delivery To Earth: The Effect of Ice Longevity

N. Haghighipour (1)

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It is widely accepted that the vast majority of Earth's water was delivered to its accretion zone by water-carrying planetesimals and planetary embryos from the outer regions of the asteroid belt while Earth was still forming. Modern simulations of the formation of terrestrial planets show this process with high resolution. However, their treatment of the actual delivery of water is still rudimentary. In these simulations, the delivery of water is post-formation assuming that a water-carrying object will maintain all its water content during its journey from its original orbit to the accretion zone of Earth. Models of the ice longevity have, however, shown that the water-ice may not stay intact, and asteroids and planetary embryos may lose some of their original water in form of ice sublimation during the dynamical evolution of these bodies. This could be especially important during the formation of terrestrial planets as this process takes tens to hundreds of million of years. We have developed a more accurate model of terrestrial planet formation for our solar system in which the sublimation of ice during the process of the scattering of icy asteroids and planetary embryos into the accretion zone of Earth is taken into account. Our model includes two different modes of handling ice sublimation, one for sub surface water and one for deeper ice. The results of our simulations put stringent constraints on the initial water distribution in the protoplanetary disk, the location of snowline, and the contribution of water from primordial nebula to the final water budget of Earth. In this paper, I will present the results of our new simulations and discuss their implications for models of solar system formation and dynamics.

3.4. Habitability potential of icy moons around giant planets and the JUICE mission

A. Coustenis (1)

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Looking for habitable conditions in the outer solar system our research focuses on the natural satellites rather than the planets themselves. Indeed, the habitable zone as traditionally defined may be larger than originally conceived. The strong gravitational pull caused by the giant planets may produce enough energy to sufficiently heat the interiors of orbiting icy moons. The outer solar system satellites then provide a conceptual basis within which new theories for understanding habitability can be constructed. Measurements from the ground but also by the Voyager, Galileo and the Cassini spacecrafts revealed the potential of these satellites in this context, and our understanding of habitability in the solar system and beyond can be greatly enhanced by investigating several of these bodies together [1].

Indeed, several of the moons show promising conditions for habitability and the development and/or maintenance of life. Europa, Callisto and Ganymede may be hiding, under their icy crust, putative undersurface liquid water oceans [2] which, in the case of Europa [3], may be in direct contact with a silicate mantle floor and kept warm by tidally generated heat [4]. Titan and Enceladus, Saturn's satellites, were found by the Cassini-Huygens mission to possess active organic chemistries with seasonal variations [5], unique geological features and possibly internal liquid water oceans. Titan's rigid crust and the probable existence of a subsurface ocean create an analogy with terrestrial-type plate tectonics, at least surficial [6], while Enceladus' plumes find an analogue in geysers. As revealed by Cassini the liquid hydrocarbon lakes [7] distributed mainly at polar latitudes on Titan are ideal isolated environments to look for biomarkers. If the silicate mantles of Europa and Ganymede and the liquid sources of Titan and Enceladus are geologically active as on Earth, giving rise to the equivalent of hydrothermal systems, the simultaneous presence of water, geodynamic interactions, chemical energy sources and a diversity of key chemical elements may fulfill the basic conditions for habitability.

Titan has been suggested to be a possible cryovolcanic world due to the presence of local complex volcanic-like geomorphology and the indications of surface albedo changes with time [8,9]. Such dynamic activity that would most probably include tidal heating, possible internal convection, and ice tectonics, is believed to be a prerequisite of a habitable planetary body as it allows the recycling of minerals and potential nutrients and provides localized energy sources. In a recent study by [4], we have shown that tidal forces are a constant and significant source of internal deformation on Titan and the interior liquid water ocean can be relatively warm for reasonable amounts of ammonia concentrations, thus completing the set of parameters needed for a truly habitable planetary body. In the solar system's neighborhood, such potential habitats can only be investigated with appropriate designed space missions, like ESA's L1 JUICE (JUpiter ICy moon Explorer) for Ganymede and Europa [10] and NASA's Europa Clipper mission.

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3.5. On the feasibility of giant planet formation via disk gravitational fragmentation

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Giant planets may play an important role in the sculpturing of a planetary system. They are found at a wide range of orbital distances from a fraction of AU to hundreds AU. The properties of these objects and their host stars vary significantly, making it difficult to explain their origin in the framework of a single formation mechanism. I will critically review the gravitational instability scenario for the formation of giant planets and demonstrate that disk fragmentation alone is unlikely to explain the whole observed spectrum of these objects. Other mechanisms, such dynamical scattering from the inner disk region or pebble accretion, need to be invoked to account for a population of giant planets at orbital distances from 10 AU to 100 AU and giant planets orbiting low-mass (<0.7 Msun) stars.

3.6. How do giant planetary cores shape the dust disk?

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(1) Universität Tübingen, Tübingen, Germany

We are now able, thanks to ALMA, to detect the dust distribution in the regions of active planet formation around young stars. This powerful tool can be combined with numerical simulations of dust and gas evolution in protoplanetary disks that can reproduce the observed images. In this way, we are able to link the observations with the theoretical models, thus improve our understanding of the physical processes at play during the early formation phases of extrasolar planetary systems.

We follow the evolution of a population of dust particles, treated as Lagrangian particles, in a two-dimensional locally isothermal disks where two equal-mass giant planets are present and shape their birth disk. We want to test whether this scenario is able to reproduce the features observed in the HL Tau system and what are the minimum masses required.

We find that the presence of several massive cores are able to recreate the observed features and that the minimum mass required for the inner planet(s) is on the order of 0.07 Jupiter masses, while for the outer one(s) on the order of 0.35 Jupiter masses. These values can be significantly lower if the disk mass turns out to be less than previously estimated. Decreasing the disk mass by a factor 10 we obtain similar gap widths for planets with a mass of 10 Earth masses and 20 Earth masses respectively.

Furthermore, we extend our simulations to more realistic three-dimensional disks, including radiative transport, and we focus on the evolution of different size particles interacting with a giant planet.

3.7. It's About Time: The Zodiacal Exoplanets in Time (ZEIT) Project

E. Gaidos (1)

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The first few hundred million years of Earth history are the most mysterious, but were arguably the most formative. They saw the final accretion of the terrestrial planets, the formation of the Moon, giant impacts during a late cataclysm, exposure to the elevated UV, X-ray, and CME activity of the young Sun, and escape of any primordial atmosphere. They also witnessed the emergence of life. We have essentially no rock record from that time and so other, indirect methods must be used to reconstruct this lost time. One of these is to observe stars and their planets at an equivalent young age. While the Kepler prime mission mostly observed stars of solar age, the K2 successor mission is observing star-forming regions and young clusters of ages of about 1 Myr to 1 Gyr near the ecliptic plane. We are finding planets, as well as the possible precursors to planets around young member stars, specifically M dwarfs. I discuss how these observations may help us understand the early history of planets, conditions at their surfaces, and the possibility of life.

3.8. Chances of earth-mass planets and life around metal-poor stars

H. Zinneker (1)

(1) Deutsches SOFIA Institut, Stuttgart, Germany

I would like to discuss the difficulties of forming earth-mass planets in metal-poor environments, such as those prevailing in the Galactic halo, the Magellanic Clouds, and the early universe. I suggest that, with fewer heavy elements available and thus a smaller dust-to-gas ratio in place, terrestrial planets will be smaller size and lower mass than in our solar system (solar metallicity). Such planets may not be able to sustain life as we know it. Therefore, the chances of very old lifeforms in the universe are slim, and a threshold metallicity (fairly close to solar) may exist for life to originate on large enough earth-like planets (cf. Zinnecker 2004, IAU Symp. 213, 45).

P3.1 Appropriate solid-body models as initial conditions for SPH-based numerical collision experiments

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Providing the simulation algorithm with suitable initial conditions is a crucial first step in almost all numerical computations, except for the most trivial cases. Even the most sophisticated simulation program will not produce meaningful results if not started with an appropriate initial configuration, satisfying demands like isotropy, a low level of noise and physical accuracy. Some of these requirements are unique to Smoothed Particle Hydrodynamics (SPH) – the numerical method considered here - others are of fundamental relevance, independent of the chosen numerical technique. The main focus of this work lies on considerations concerning initial conditions for subsequent SPH simulation runs. The geometrical arrangement of an initial SPH particle setup is discussed, particularly w.r.t. regular lattice configurations and associated symmetry effects. In order to avoid unphysical behavior the initial particle configuration has to be in a relaxed (i.e. equilibrated) state where necessary. This is of particular importance for simulations of giant collisions, where the involved bodies naturally exhibit a hydrostatic internal structure. Beyond the common numerical procedure, a semi-analytical approach for relaxation is introduced and validated, practically eliminating the need for spending significant amounts of valuable computing time solely for the production of a relaxed initial state in a lot of situations. Finally the basic relevance of relaxation itself is studied, focusing on collision simulations in different mass ranges important in the context of planet formation and the transport of water.

P3.2 A panchromatic view of protoplanetary disks

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(2) University of St. Andrews, St. Andrews, United Kingdom

Dust and gas composition of protoplanetary disks hold keys in our understanding of the physical and chemical processes in star-forming systems. Disk content also plays an important role in determining various aspects of planet formation, ranging from the coagulation of first solids down to the primordial composition of planets and their possible atmospheres. Radiation from the central protostar along with the radiation released due to accretion largely determine the dynamical and chemical evolution of disks. Therefore understanding the evolution of protoplanetary disks requires multi-wavelength observations extending from the X-rays to the near-infrared for an accurate description of the accreting star, and from the near-infrared further down to mm/cm wavelengths for the surrounding disk.

In this talk we present a compilation of panchromatic observational datasets for 85 protostellar sources that include both continuum and spectral line observations, developed in the context of the DiskAnalysis (DIANA) EU FP7 project. Datasets were assembled combining data from more than 150 individual photometric and spectral bands collected with more than 50 different observational facilities. Metadata, including high angular resolution maps and line-shapes were also collected from more than 90 published articles. We focus on a meta-analysis of the compiled datasets, with special emphasis on trends between high-energy radiation, accretion, gas line emission from the disk along with other disk properties (e.g. gaps, flaring, inclination) as revealed from modeling of the continuum emission. Finally, we briefly discuss the functionality of the web-portal that provides public access to our data collection.

P3.3 Dynamics of Terrestrial Planet Formation in Binary Stellar Systems

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The existence of terrestrial planets in the habitable zone of binary stars is of great importance, since stars are born not alone, but as members of binary and multiple systems. Therefore it is worth investigating the formation of terrestrial planets in binary and even in multiple star systems.

The formation of terrestrial planets is investigated in various configurations of binary star systems consisting of one solar-type star, and a stellar companion with mass ranging between 0.4 and 1.5 Solar mass. The main aim of our work is to investigate those orbital configurations of the binary system with a giant planet, which may lead to the formation of terrestrial planets in the habitable zone of the solar-type star.

Starting from an already existing embryo population, the final assembly of terrestrial planets has been studied by using gravitational N-body simulations. We reveal the role of the mean motion resonances (MMRs) in governing the dynamics of embryos. We have found that the newborn terrestrial planets are formed either outside the region crowded by strong MMRs, or between the most important MMRs in near resonant configurations. The binary parameters (stellar masses, orbital separation and eccentricity) have observable influence on the formation of terrestrial planets, too.

It can be expected that during the forthcoming observations habitable terrestrial planets might also be found in large and even in mid-separation binary systems enriching the already known large variety of different extrasolar planets.

P3.4 Magnetic fields in protoplanetary disks

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Most protostellar disks are believed to have a large-scale magnetic field, which is inherited from a primordial field and amplified during pre-stellar collapse phase. These fields are approximately axisymmetric and will bend due to an accretion flow towards the disk center. These magnetic fields are very important ingredients for the development of a successful disk evolution model.

Protoplanetary disk winds are a promising mechanism for explaining disk dispersal after a few Myrs. They also provide an explanation for the extraction of angular momentum and mass from disks. Two wind driving mechanisms are equally important for the dynamical evolution, namely magneto-centrifugally accelerated outflows and photoevaporative winds.

The inclination angle of the magnetic field lines with respect to the disk mid plane is one of the most crucial parameters in determining the efficiency of magneto-centrifugally accelerated winds launched from the disk. Most likely these winds play a role (important to what degree is yet to be determined) in the inner disk in removing both mass and angular momentum.

The determination of the inclination angle boils down to having a dynamical description of the gas flow and the magnetic fields simultaneously, since winds launched from the disk bend the magnetic field and therefore cause a magnetic torque feedback on the disk.

Furthermore, in the outer parts of the disk, photoevaporative winds are thought to play the most crucial role in extracting mass and angular momentum from the disk. Magnetic fields can nevertheless support the gas in overcoming the gravitational potential barrier and stream off as a photoevaporative wind.

The science goal is the determination of the importance of the two wind driving mechanisms and its feedback on the disk in terms of angular momentum transport and finally disk dispersal. This can be achieved by simulating the whole disk lifetime of a few Myrs, therefore using an implicit time-evolution scheme and describing only the most important physical processes.

The simulation covers the radial 1D radiation-hydrodynamic evolution of a gas disk employing a vertical hydrostatic equilibrium and also including an axisymmetric description of the poloidal magnetic field structure and also its feedback on the gas. The toroidal structure is obtained by employing a simple wind model, which exerts a torque on the disk, mediated by a toroidal field component.

P3.5 Material loss in two-body collisions during planet formation

J. Werner (1), C. Schäfer (1), C. Burger (2), O. Wandel (1), T. Maindl (2), R. Speith (1), E. Dorfi (1)

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During the formation process of a terrestrial planet, a planetary embryo does not only accrete smaller dust particles but also suffers collisions with larger planetesimals. When simulating these collisions, most N-body codes treat them as perfect merging events, i.e. the resulting body's mass is the sum of the previous ones. In our work, we aim to determine whether this assumption is a justified simplification, specifically focusing on bodies containing volatile elements, such as water.

To analyze this, we have developed a new Smooth Particle Hydrodynamics (SPH) code that includes elasto-plastic dynamics, a damage model for brittle materials and self gravity. It makes use of the Compute Unified Device Architecture (CUDA) and runs on modern GPU architectures which allows for higher resolution in less calculation time.

This enables us to take a precise look at two-body collisions and determine the amount of both transferred and ejected mass according to specific parameters such as mass ratio of impactor and target, porosity, impact velocity, impact angle and water distribution.

P3.6 Atmospheres of PLATO-planets: the limits of diversity

G. Wuchterl (1)

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The frequency of planetary atmospheres and their distributions of masses and photospheric radii have important consequences for detection and characterisation. We determine these distributions (1) at formation, (2) after nebula decompression and, (3) at ZAMS arrival.

To this end we follow the statistical approach by Pecnik, Schönke and Broeg that is based on a nebulae-complete, simple and synoptic sample of self-consistent planetary core-envelope-atmosphere models. We add quasi-static evolutionary calculations to advance the atmospheres in the fluid-regime to all ages to be expected in the PLATO discovery window.

This approach allows to cover an atmospheric host-body mass-range from planetary embryos via super-earth cores to the transition into the "Neptune" regime.

While the main goal is to supply atmospheric initial mass functions for PLATO atmospheric studies, we also show evidence that existing space transit searches may already have indirectly detected planetary atmospheres near Schönke's "minimum mass", that shapes the diversity of envelopes in the regime of sub-critical and super-earth planets.

4. Principles of Habitability

Chair: Nader Haghighipour

4.1. Habitable Zones Around Main-Sequence Stars: Estimates and Applications

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The study of habitable zones (HZs) has received increased attention as a consequence of the discovery of terrestrial mass/size planets from both ground-based surveys and from space-based missions such as CoRoT and Kepler. Classically, the HZ is defined as the circumstellar region around which a terrestrial mass planet, with favorable atmospheric conditions, can sustain liquid water on its surface. Future missions such as TESS and PLATO will deliver more robust statistics on the occurrence rate of transiting potential habitable planets, and provide targets in the solar neighborhood for atmospheric characterization using JWST. Eventually, with a direct imaging flagship mission, closer, non-transiting planets can also be studied. For successful design of such a mission, determining an accurate estimate of stellar HZs is crucial. In this talk, I will review the current estimates of the HZ from both 1-D and 3-D models in the literature, pointing out their strengths and limitations, and suggesting future work in improving these estimates. Recent work has shown that the inner edge of the HZ is much closer to the star for slowly rotating planets around late-K and all M-dwarf stars, because sub-stellar convection causes cloudiness on the planet's dayside, increasing its albedo. This effect occurs because such planets are expected to be synchronously rotating. This result could affect the number of target systems that might be characterized by JWST . Meanwhile, planets near the outer edge of F- and G-star HZs may experience climatic limit cycles in which they alternate between globally glaciated and ice-free states. This may or may not affect their potential for harboring simple life, but it could certainly influence their ability to support complex life, especially land-based animal life. This, of course, includes intelligent life like ourselves. Despite the work that has been done in refining the boundaries of the HZ, significant uncertainties remain. I will argue that different definitions of the HZ should be used for different purposes. When designing a future direct imaging mission, one should use a conservative definition of the HZ because one does not want to undersize the telescope. (Narrower HZs lead to lower estimates of the number of potentially habitable planets, forcing the mission to look at more distant target stars.) But when analyzing data from such a mission, or from transiting planets studied by JWST, one should use a more optimistic HZ definition because one would not want to overlook a possible abode for life. But any analysis of data on a potentially habitable planet must account for its location, as some 'false positives' for life – e.g., high abiotic O_2 levels in a planet's

atmosphere – depend on whether the planet is within or outside the HZ. This is sure to result in vigorous discussions once such data become available.

4.2. Mapping 3D Climates in the habitable zone of M dwarfs

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We will show the results of two large parametric climate state studies for tidally locked terrestrial planets around M dwarf stars. We investigated for an Earth-like atmosphere and thermal forcing, 3D climate states for rocky planets with sizes between 1-2 Earth radii, orbital periods between 1-100 days, and also for different surface friction scenarios.

We will identified distinct climate state transitions that occur for faster and faster orbital periods, that is, towards the inner edge of the habitable zone. In addition, two regions of climate state degeneracies were found. The different climate states - in particular at the inner edge of the habitable zone - show large differences in surface temperatures, circulation and wind systems. Furthermore, different climate states appear to be favoured in our model for different planet sizes and for different surface friction efficiencies.

Our studies provide first "maps" for the 3D circulation system to be expected on tidally locked rocky planets around M dwarfs. They will help to better identify potentially habitable planets with relative short orbital periods.

4.3. A two-band theoretical radiative physical model for predicting the Greenhouse effect

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An important issue for the habitability of Earth-like planets (ELPs), is the stability of their Greenhouse effect (GHE). The literature describes runaway scenarios for ELPs, following a concentration rise of one or more of their atmospheric components. We present a new radiative model by which gradual changes in the concentration of atmospheric components lead to saturation of the temperatures in the atmosphere and the ground. The runaway to an un-bound temperature in atmospheres of ELPs is avoided (Bressler and Shaviv 2015). Our radiative model is based on imposing a wavelength depended energy conservation. This condition is enforced at all heights of the atmosphere. When a change in any of the parameters takes place, a new steady state equilibrium is found. For every change in the parameters of the system the model relaxes to a new temperature distribution T(z) and a new ground temperature T_{grd}. The obtained T_{grd} and P(z)-T(z) profiles conform well with values known for the Earth. In particular, we show in a test case, that $T_{grd} \sim 294$K and the temperature gradient is 4K/km a value known for the Earth. This gross agreement is obtained even before considering refinements due to convection, clouds, scattering, etc. The model provides an estimate of the greenhouse effect for any atmospheric composition and astronomical parameters. As the model is based on physical arguments, the predictions outside the range of the Earth canonical Greenhouse, are trustful. References Bressler, S. and Shaviv, G., 2015, Astronomical Reviews, in press.

4.4. Climate forcing and habitability of Earth-like circumbinary planets

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More than half of the main sequence stars in our galactic neighborhood are believed to be part of double or multiple star systems. Numerous detections of giant planets surviving in such environments suggest that it is only a question of time before potentially habitable exoplanets can unequivocally be confirmed as well. Accurate predictions of habitable zones in multiple star systems can help to speed up the discovery of such worlds. Studying habitability conditions for terrestrial planets in such environments is especially challenging, though, as large-scale insolation forcing can occur on relatively short timescales. The consequences of coupled planetary and stellar dynamics on climate and habitability of terrestrial planets in binary star systems require particular attention. We preset first results of self-consistent General Circulation Model calculations of atmospheres of Earth-like circumbinary planets. The influence of strong short periodic forcing on important atmospheric parameters such as precipitation and mean surface temperature and their influence on habitability will be discussed.

4.5. A Joint Approach to the Study of S / P-Type Habitable Zones in Binary Systems: New Results

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Previously, a comprehensive approach has been devised for the study of S-type and P-type habitable zones in stellar binary systems (Cuntz 2014, 2015) [ApJ 780:14 & 798:101]. It considers a variety of aspects, including the implementation of a joint constraint encompassing planetary orbital stability and a habitable region for a possible system planet through the stellar radiative energy fluxes. It also includes the provision of a combined formalism for the determination of both S-type and P-type habitable regions; in particular, mathematical criteria are devised for which kind of system S-type and P-type habitable zones are realized. My talk will include an elaboration on the potential and limitations of this approach, including applications to multiple stellar systems. Results about alternate definitions of stellar habitable zones (e.g., based on stellar UV radiation, geology, impact of flares & super-flares) will be surveyed as well. Updated studies of planetary climate models will also be considered, including those obtained in 2014 and 2015, which show that planets akin the Earth, Mars, and super-Earths entail different limits for climatological stellar habitable zones; therefore, the type of planet considered also affects the prospect and extent of habitable zones in binaries and multi-stellar systems.

P4.1 The Earliest Habitable Planets

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Extreme cosmic-ray (CR) fluxes have a negative effect on life when flux densities are high enough to cause excessive biological, especially DNA, damage. The CR history of a planet plays an important role in its potential surface habitation. Both global and local CR conditions determine the ability of life to survive for astrobiologically relevant time periods. We highlight two CR life-limiting factors: 1) General galactic activity, starburst and AGN, was up by about a factor of 30 at redshift 1 - 2, per co-moving frame, averaged over all galaxies. And 2) AGN activity is highly intermittent, so extreme brief, but powerful bursts (from Her A for example) can be detrimental at great distances. This means that during such brief bursts of AGN activity the extragalactic CRs might even overpower the local galactic CRs. In addition, as shown by the starburst galaxy M82, the local CRs in can also be quite high during periods of high star formation. Moreover, in our cosmic neighborhood we have several super-massive black holes In M31, M32, M81, and NGC5128 (Cen A), all within about 4 Mpc today, and of course within our own Galaxy. Out to 25 Mpc today there are many more supermassive black holes. Cen A is of course the most famous one now, since it may be a major source of the ultra-high-energy CRs (UHECRs), as predicted already in 1963 by Ginzburg & Syrovatskii. Folding in what redshift implies in terms of cosmic time, this suggests that there may have been little chance for life to survive much earlier than Earth's starting epoch, without substantial planetary protection. Life on planets may be protected by thick atmospheres, strong magnetic fields, and host star winds; but the effectiveness of these protections diminishes with increasing CR energy. So, we suggest that there is a cosmic habitability time horizon due to CRs.

P4.2 Investigation of scaling properties of a thin current sheet by means of particle trajectories study

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One of the fundamental goals of space plasma physics research is to explore and to describe the structural and dynamic features of current sheets (CS). The comphrensive study of current sheet is beneficial because it appears a crucial building block of various astrophysical phenomena, such as planetary magnetospheres, solar and stellar flares, heliospheric and astrospheric large scale currents, exoplanetary magnetodisks. In the solar system, the CSs are observed in the solar wind, in Earth's magnetotail, in the induced magnetosphere of Venus, on the dayside of Mars, in the Mercury's magnetosphere, and in the disk-dominated magnetospheres of Jupiter and Saturn.

In general, it is believed that the energy transformation occurs at the scale of a thin current sheet (TCS), which is embedded within the CS. Several models of TCSs have been proposed where the electric current is mainly formed by special population of transient protons. These models are based on approximate conservation of adiabatic invariant I_z = const, where z- axis is co-directed with the normal to the TCS. Such approach leads to the fact that the TCS theoretical thickness is a function of ratio of the particle thermal to incoming flow velocities. On the other hand, if one imposes another condition on the dynamics of the current-forming protons, namely the conservation of magnetic flux through a segment of trajectory μ = const, then the scaling of a TCS becomes dependent on the ratio of the particle incoming flow to thermal speed. This hypothesis allows to resolve the appeared sometimes inconsistency between the model predictions and spacecraft measurements of thickness of the real TCSs.

In our report, the influence of μ = const protons on the thickness of a thin current sheet is investigated for three cases of TCSs crossings. The TCS thickness is estimated from the magnetic field data by means of Cluster observations. The obtained scaling values for TCSs, are compared with the analytical predicted scaling. The comparison analytical and observed scalings shows a good agreement.

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P4.3 Habitability Beyond the Snow Line: The Potential of Icy Moons to Serve as a Habitat for Life-as-We-Know-It

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Although, about 2000 Exoplanets were detected and confirmed in the last decades, we are still not able to find a second Earth, i.e. an Earth-size planet in the habitable zone around a Sun-like star, not to mention the chance to detect life in such possible habitats. Therefore, we should start our search for extraterrestrial life right on our doorstep, within the Solar System. Although it is just the Earth which is located in the habitable zone around the Sun, there might be some other habitats in the Solar System. Such habitats might be the subsurface oceans of the outer planet's icy moons. The moons Europa, Ganymede, Titan, Enceladus, and Triton are the most promising candidates for such a scenario because subsurface oceans of these bodies were confirmed during the last years or, at least, there is strong evidence for them.

The primary ingredients for life-as-we-know-it in subsurface oceans are six essential elemental ingredients (carbon, hydrogen, nitrogen, oxygen, phosphorus, and sulfur), chemical energy, and water. All of them seem to be available in subsurface oceans: The energy source that keeps the oceans liquid (e.g., radiogenic or tidal heating) should also serve as an energy source for potential life (in addition, radiolysis and possible redox gradients may deliver energy for life) and the presence of organic compounds might be provided by cometary and meteoritic impacts or by hydrothermal vents (e.g., Fischer-Tropsch reactions or catalytic cycles). Microorganisms may live at the ocean's floor, may float freely in the subsurface water reservoir, or may be clustered around possible hydrothermal vents.

One of the potential microorganisms under consideration for these environments is methanogens. Methanogens are obligate anaerobic chemolithoautotrophs or chemolithoheterotrophs belonging to the phylum Archaea, which primarily form C_1-, C_2-, and methylated compound by reduction with H2.

In our ongoing study, we perform experiments in the laboratory, where we test the habitability of icy moons – focusing on Enceladus – concerning methanogens. Here, we test different strains of methanogens (Methanosarcina soligelidi DSM 26065, Methanothermococcus okinawensis DSM 14208, Methanocaldococcus villosus DSM 22612, and Methanothermobacter marburgensis DSM 2133) in various temperature ranges and gas compositions for their feasibility to propagate in Enceladus-like conditions. Here we will present the first results of our survey, including a report about successful cultivation of M. okinawensis and M. villosus tolerating ethen (C_2H_4), which so far was known to be a potential inhibitor for methanogenesis of several methanogenic strains. Furthermore, M. marburgensis is tolerating high concentrations of carbon monoxide (CO). Both, C_2H_4 and CO were found in the plumes of Enceladus.

P4.4 Quantum tunnelling at the base of planetary habitability and chemical evolution

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Tunnelling is a quantum physical phenomenon dominant only at the scale of a few nanometres and below. The phenomenon is based on the wave-particle duality of matter and thus on Heisenbergs uncertainty principle. Tunnelling enables low-energy elementary particles and atoms to permeate a high-energy barrier without the need to overcome it classically. This phenomenon seems to be an exotic process only important for special physical effects and applications such as the tunnel diode or scanning tunnelling microscopy.

Here I show that quantum tunnelling has important implications for planetary habitability in many aspects. This review analyses which physical and chemical processes crucial for models concerning the origin and evolution of life can directly be traced back to quantum tunnelling. The processes include the chemical evolution in stellar interiors and in the interstellar medium, planetary habitability via insolation and geothermal heat, prebiotic chemistry in the atmosphere and subsurface of planetary bodies and the catalytic function of enzymes and other biomolecular nanomachines.

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5. Planetary Atmospheres

Chair: Helmut Lammer

5.1. Planetary atmospheres and their roles for habitability

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20 years after the discovery of the first exoplanet, scientists on the Earth are near the gate of answering the long standing and arguably the most important scientific and philosophical question to human beings: are we alone in the Universe?

Given the limitation of funding and observation time, only the most promising planets will be selected as the targets for future telescope observations. The target selection strategy will certainly be guided by our understanding on planet habitability. For practical purpose, exoplanet habitability is primarily determined by the existence of oceans on the planet's surface, although oceans too deep may impair a planet's habitability. The existence of surface oceans on a planet is determined by its orbital distance from its star, the type of the star, the pressure of its atmosphere, and the composition of its atmosphere. In this talk the roles planetary atmospheres play regarding planet habitability will be reviewed.

5.2. Exoplanet transmission spectroscopy and the importance of clouds/hazes in their interpretation

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Transit events of extrasolar planets offer the opportunity to study the chemical composition of their atmospheres. During the last years our group and others gained first experience about the diversity of exoplanet spectra from Hot Jupiters to super-Earth planets. This observationally very demanding enterprise also teached us to steadily improve on the achieved precision space and ground-based.

But what did we learn so far about the prospects for the future detection of biomarkers by transmission spectroscopy? In this talk I will tell about the importance of clouds and aerosols in the interpretation of current gas giant and super-Earth spectra and how they might complicate the finding of extrasolar live by transmission spectroscopy.

5.3. Modeling Venus Surface Conditions Evolution and the Effects of Early Large Impacts

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We investigate the influence of impacts on the history of terrestrial planets from the point of view of surface conditions. Our work makes use of our previous studies on Venus' long term evolution through a coupled atmosphere/mantle numerical code.

The solid part of the planet is simulated using the StagYY code (Armann and Tackley, 2012) and releases volatiles into the atmosphere through degassing. Coupling with the atmosphere is obtained by using surface temperature as a boundary condition.

Atmospheric escape modeling involves two different aspects: hydrodynamic escape (0-500 Myr) and non-thermal escape mechanisms (dominant post 4 Ga). Constraints include present-day measurements by the ASPERA instrument and recent numerical simulations.

The evolution of surface temperature is calculated from CO2 and water concentrations in the atmosphere with a gray radiative-convective atmosphere model.

Impacts can have different effects: they can bring (i) volatiles to the planet, (ii) erode its atmosphere and (iii) modify mantle dynamics due to the large amount of energy they release We test a wide range of impactor parameters (size, velocity, timing) and different assumptions related to impact erosion (Shuvalov, 2010). A 2D distribution of the thermal anomaly due to the impact is used leading to melting and subjected to transport by the mantle convection. Â

Atmospheric erosion appears to be mitigated by volatiles brought by the impactor. While small (0-10 km) meteorites have a negligible effect on the global scale, medium ones (50-150 km) can have a strong short term influence through volatile release. However, only larger impacts (300+ km) have lasting effects. They can cause multiple volcanic events. Additionally, the amount of volatiles released can modify normal evolution and surface temperatures. This is enough to modify mantle convection patterns. Depending on when such an impact occurs, the surface conditions history can appear radically different. A key factor is thus the timing of the impact.

5.4. Solar XUV and ENA-driven water loss from early Venus steam atmosphere

K. G. Kislyakova (1), H. I. M. Lichtenegger (1), P. Odert (1), N. V. Erkaev (2), H. Lammer (1), H. Gröller (3), C. P. Johnstone (4), L. Elkin-Tanton (5), L. Tu (4), M. Güdel (4), M. Holmström (6)

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We study influence of hydrogen hydrodynamic upper atmosphere escape driven by the solar soft X-ray and extreme ultraviolet radiation (XUV) flux on expected magma ocean outgassed steam atmosphere of early Venus. We also accounted for solar wind produced energetic hydrogen atom (ENA) heating leading to oxygen frictional escape. We calculate the water loss powered by the stellar XUV flux and ENAs from the volume heating rate in a hydrogen dominated thermosphere due to the absorption of the solar XUV flux. We assume that the young Sun after its arrival at the Zero-Age-Main-Sequence (ZAMS) was either a weak or moderate active young G star. The corresponding solar wind interaction and the production of ENAs with a hydrodynamical extended upper atmosphere, including collision-related feedback processes have been studied by means of Monte Carlo models. ENAs that collide in the upper atmosphere also deposit their energy and heat the surrounding gas above the main XUV energy deposition layer. We have shown that precipitating ENAs change the thermal behavior of the upper atmosphere structurem but the enhancement of the thermal escape rates caused by these hydrogen atoms is negligible. Our results indicate also that the majority of oxygen remaining from dissociated H2O molecules is left behind the hydrogen during the first 100 Myr. We suggest that the main part of the remaining oxygen has been absorbed by crustal oxidation.

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5.5. Processes affecting the Evolution of Molecular Oxygen in Earth-like Atmospheres

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We present results from our newly-developed Coupled Atmosphere Biogeochemistry (CAB) model and apply a diagnostic tool called the "Pathway Analysis Program" to perform the first quantitative analysis of catalytic cycles affecting the evolution of atmospheric molecular oxygen in Earth-like atmospheres. In the atmosphere, around the time of the Great Oxidation Rise on Early Earth, results suggest that smog-type reactions play a key role affecting O_2 removal on the lower levels whereas on the upper levels photolysis of carbon dioxide is a key source. In general, results suggest that uncertainties in atmospheric mixing, ocean solubility and mantle/crust properties could strongly affect primary productivity hence surface O_2 fluxes.

5.6. The Effect of Carbon Dioxide (CO_2) Ice Cloud Condensation on the Habitable Zone

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The currently accepted outer limit of the habitable zone is defined by the "maximum greenhouse" limit, where Rayleigh scattering from additional CO_2 gas overwhelms greenhouse warming. Although early researchers noted that CO_2 would condense to form highly reflective CO_2 ice clouds before this limit was reached (Kasting, 1991; Kasting et al, 1993), subsequent investigations showed that scattering of thermal radiation by CO_2 ice clouds could add to the greenhouse effect, countering the cooling due to cloud reflectivity and providing net warming (Forget & Pierrehumbert, 1997; Forget et al, 2013). If this is the case, then CO_2 condensation would not be the primary factor limiting the outer edge of the habitable zone. But if net warming does not result, the condensation of CO_2 could reduce the extent of the habitable zone by nearly half. Previous studies of the radiative effect of CO_2 clouds on the limits of the habitable zone used the two-stream Eddington approximation for radiative transfer, or approximated cloud scattering by a modification to surface albedo. However, recent work by Kitzmann et al (2013) compared the radiative effect of CO_2 clouds using both a two-stream and multi-stream radiative transfer model. Kitzmann et al (2013) showed that the greenhouse enhancement was not as strong as expected when the multi-stream code was used; they found that depending on cloud particle size and optical depth, a significant anti-greenhouse (cooling) effect could occur. To better understand the impact of CO_2 ice clouds on the outer edge of the habitable zone, a more detailed climate study – coupling radiative-convective climate models with a comprehensive multi-stream, multiple-scattering treatment of CO_2 ice cloud effects – is needed. We used the validated multi-stream SMART radiative transfer code (Meadows & Crisp, 1996) to explore the radiative effects of CO_2 clouds. We compare our results with those of Kitzmann et al (2013), which showed that two-stream radiative transfer overestimates CO_2 cloud warming and that the particle size and optical depth of clouds strongly influence the greenhouse (or anti-greenhouse) effect. We are including CO_2 cloud condensation in a versatile 1-D climate model for terrestrial planets (Robinson et al, 2012) that uses SMART for radiative transfer and includes treatment of clouds in the atmosphere, rather than as surface albedo. We will present preliminary results on the interplay between CO_2 cloud particle size and optical depth for a range of atmospheric masses, compositions and host star spectra, and the subsequent effect on surface temperature. We will also present reflectance and transit spectra of these cold terrestrial planets. We will identify the degree of (anti-)greenhouse effect from the CO_2 ice clouds, and any consequences for the outer edge of the habitable zone. This more comprehensive treatment of the outer limit of the habitable zone could impact our understanding of the distribution of habitable planets in the universe, and provide better constraints for statistical target selection techniques, such as the habitability index (Barnes et al, 2015), for missions like JWST and WFIRST-AFTA.

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5.7. Characterizing Atmospheres of Super-Earths

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Confirmation, follow-up, and atmospheric characterization of super-Earths and smaller planets are among the major challenges facing exoplanet researchers in the coming decade. We will discuss the current status of observational efforts, including our own investigations of the super-Earth 55 Cancri e. This planet's average density is lower than that of the Earth, indicating that it could potentially have either a significant water fraction or even a hydrogen-rich envelope, although the latter is expected to have evaporated, given the close-in orbit and extreme dayside temperature. We will present the first ground-based transit detections of 55 Cancri e, and early results from high-resolution spectroscopic observations specifically targeting water vapor. These observations represent key steps towards characterizing the atmospheres and habitability of Earth-like exoplanets. We will also discuss prospects for characterizing super-Earths in the near future, in particular with the NIRISS instrument on the James Webb Space Telescope.

5.8. Detection of Exo-atmospheres with transmission spectroscopy using the VLT

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In the past few years, the study of exoplanets has evolved from pure discovery, to being exploratory in nature. In particular, transmission spectroscopy now allows the study of exoplanetary atmospheres. Such studies rely heavily on space-based, as well as large ground-based facilities, since we needs to perform time-resolved, high signal-to-noise spectroscopy. The recent prism exchange of the FORS2 atmospheric diffraction corrector on ESO's Very Large Telescope has allowed us to obtain transit light curves with higher precision than ever possible before. With this instrument, we have obtained high resolution transmission spectra of two Hot-Jupiter's, with extensive atmospheres, in the visible and NIR. I will highlights the results from ongoing analysis of these spectra, as well as overcoming the challenges that the complex systematics present us with. Such refinements to the current techniques, should pave the way to eventually the detection of atmospheric signals from terrestrial planets, with the next generation of space and ground-based telescopes.

5.9. Pale Orange Dots: Earthlike Worlds with Organic Hazes

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Hazy exoplanets appear to be common (Bean et al. 2010, Sing et al. 2011, Kreidberg et al 2014, Knutson et al 2014), and in our solar system, Venus and Titan have photochemically-produced hazes. There is evidence that Earth itself had a organic haze during the Archean eon (Zerkle et al. 2012, Domagal-Goldman et al. 2008) similar to the haze on Titan and with important climatic effects (Pavlov et al. 2001, Trainer et al. 2006, Haqq-Misra et al. 2008, Wolf and Toon 2010, Arney et al. 2016). Organic haze formation is initiated by methane photolysis by ultraviolet radiation and is sensitive to the ratio of methane to carbon dioxide in the atmosphere. This haze would have had multiple impacts on the early Archean atmosphere and surface environment.

To explore these effects, we have used a 1D coupled photochemical-climate model and a line-by-line radiative transfer model to investigate the climactic and spectral impacts of a fractal hydrocarbon haze on Archean Earth (Arney at al 2016). Classical spherical (mie) particles do not represent the shape of the haze particles in Titan's atmosphere (Rannou et al 1997), so fractals are likely a more realistic shape for these organic haze particles. We find that the haze can cool the surface environment by 20-30 K, but habitable conditions can be maintained given enough warming from greenhouse gases.

This haze also has strong spectral features that may be detectable in exoplanet spectra and may therefore provide additional information on planetary atmosphere composition. In particular, the haze absorbs significantly at wavelengths shorter than 0.5 μm and can strongly suppress the Rayleigh scattering tail, a broadband effect that would be remotely detectable at low spectral resolution. In transit transmission, hazes place an upper limit on the depth an observer can probe into planetary atmospheres, reducing the strength of gaseous spectral features. At visible and near-infrared wavelengths, the hazes produce sloped transit transmission spectra similar to the Titan occultation spectrum recently observed (Robinson et al 2014). At longer infrared wavelengths accessible with JWST, this haze becomes more transparent, and an absorption feature from the haze itself can be seen near 6 microns. Here, we expend our work to investigate the impact of host star spectral type on photochemical haze formation, comparing the production of hydrocarbon hazes in the atmospheres of Archean Earth analog planets around several stellar types: the sun at 2.7 billion years ago (our standard case), the modern sun, the active M dwarf AD Leo, a modeled quiescent M dwarf, the GJ 876, a K2V star, and a F2V star. We find that G and K dwarfs appear to be most optimal for hydrocarbon haze production. M stars with decreased UV flux have decreased rates of methane photolysis and require more methane to produce hazes compared to our "standard" Archean case. Surprisingly, the high UV-output F2V star is also unable to produce hazes in our photochemical model due to efficient destruction of haze precursor gases through reactions involving oxygen radicals generated by H2O and CO2 photolysis. We also find that haze formation is also dependent on the atmospheric temperature structure. Hotter atmospheres produce larger haze particles since faster moving particles collide more rapidly, and thereby decrease the particle coagulation timescale (Tolfo 1977). Because hazes can strongly impact planetary spectra, knowing which stars are more likely to generate hazy atmospheres will help us prioritize targets for future exoplanet observations.

5.10. Accumulation and evolution of primordial atmospheres around terrestrial planets

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In the early, embedded phase of evolution of Earth-like planets, planetary cores can accumulate gas from the circumstellar disk into a planetary envelope. This primordial atmosphere is significant because it forms a thermal insulation around the rocky core and is the starting point for the subsequent phases of atmospheric evolution. The final amount of persistent atmosphere around the evolved planet very much characterizes the planet and is a key criterion for habitability. To study the interdependence of the atmospheric evolution and the cooling planetary core, we performed time-dependent radiation hydrodynamics simulations of the planetary envelope coupled to a simple model for the core temperature based on the internal energy budget of the planetary core. Our 1D-spherical symmetric atmosphere models range from the surface of the planetary core p to the Hill radius and include the hydrodynamics equations, gray radiative transport and convective energy transport. Planetary cores with masses between 0.1 and 5 Earth masses have been investigated.

The results for different core masses show a systematic pattern of evolution tracks, largely following the outline of a sequence of stationary models. The time scale of gas capturing and atmospheric growth depends on the mass of the solid core. The amount of atmosphere accumulated during the lifetime of the protoplanetary disk thus also varies with the mass of the planet. We find that disk embedded planetary cores more massive than about 1 Earth mass almost invariably end up with a massive primordial atmosphere that is unlikely to be removed by later processes such as hydrodynamic escape driven by the high soft-X-ray and extreme ultraviolet radiation of the young host star. For sufficiently massive cores, the atmospheric accumulation can ultimately lead to runaway accretion and the formation of a gas planet.

In many studies of embedded planetary envelopes, a steady accretion flux of planetesimals is assumed to provide the luminosity required to construct stationary atmosphere models. For comparison, we therefore also included two equations describing the motion and erosion of infalling planetesimals through the atmosphere. Despite the uncertainty in frequency, size, and mechanical properties of the planetesimals, we conclude that the accretion of planetesimals is only of minor significance in our evolution scenario.

P5.1 Effect of clouds in molecular spectra of Hot Jupiters and Brown dwarfs

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For the search of biosignatures in exoplanetary atmospheres, the inclusion of clouds as opacity source is very important. Here, we present the theory to model molecular spectra due to scattering in selected molecular bands for hot Jupiter and Brown dwarf atmospheres with and without clouds. We model different atmospheres with varying cloud parameters, namely cloud location, width, dust density, and dust size. We then study how the signal of the light from an atmosphere with clouds is changed due to scattering in molecular lines that are present in the atmospheres of hot Jupiters and Brown dwarfs (such as H_2O, FeH, TiO). With this study, we can probe cloud parameters at different depths, and also help explain the reduction/absence of molecular signatures in exoplanetary and Brown dwarf atmospheres.

P5.2 Escape of Hot Oxygen and Carbon from the Early Atmosphere of Mars

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Nowadays, the atmosphere of Mars is commonly assumed to be much different than in the early times of its evolution. Especially, the escape of water and carbon dioxide is thought to have formed its shape during millions of years. Also the Sun emitted a higher EUV flux in former times, influencing the particle environment around Mars.

We study the escape of oxygen and carbon from the early Martian atmosphere for different EUV fluxes with a Monte-Carlo model. We consider different possible sources of hot oxygen and carbon atoms in the thermosphere, e.g. dissociative recombination of O_2^+, CO^+ and CO_2^+. From the calculated production rate profiles we can get insights into the importance of the different source reactions. The resulting energy distribution functions at the exobase level are used to study the exospheric densities and the escape of hot oxygen and carbon. We discuss the escape rates of those atoms and the importance of different source processes compared to the present situation at Mars.

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P5.3 Precipitation of Electrons into the Upper Atmosphere of a Hot-Jupiter Exoplanet

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We propose a kinetic model that enables the investigation of the penetration and degradation of electron flux in the high-latitude regions of the hydrogen-dominant upper-atmosphere of an exoplanet. The model is based on the numerical solution of the Boltzmann equation. Using the model we simulated the precipitation of electrons of magnetospheric origin in the atmosphere of a typical hot Jupiter exoplanet, and in the atmosphere of Solar System's Jupiter. We assume the Maxwell velocity distribution of electrons and conduct our computations for three values of the specific energy E_0 = 1, 10 and 100 keV. The efficiencies of atmosphere's heating for a typical hot Jupiter and Solar System's Jupiter have been derived. In particular, we have found that the heating efficiency weakly depends (or is even independent) on the specific energy of precipitating electrons. In the upper atmosphere of Solar System's Jupiter the efficiency is also independent on the altitude and lies in a range of 7-9%. The efficiency of heating in the atmosphere of the hot Jupiter, on the contrary, significantly depends on the altitude and varies from 7 to 18%. It is important to note that for hot Jupiters the peaks of energy absorption correspond to high values of the heating efficiency in the case of electrons having low kinetic energies. This effect may amplify the contribution of electron precipitations into the total heating of the atmosphere.

P5.4 On the influence of coronal mass ejections on the hot Jupiter atmosphere

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We present the results of 3D numerical gas-dynamic simulations of the interaction between a hot Jupiter atmosphere and a coronal mass ejection of its host star. When simulating, we assume that the parameters of stellar wind and CME correspond to those of the Sun. We consider specific flow-patterns that form in two cases of a quasi-closed and closed (but distorted by the planet's gravity) gaseous envelope of the planet. We show that a typical CME can sweep out the outer regions (located beyond the planet's Roche lobe) of the asymmetric envelope, which results in a significant increase of the mass-loss rate of the planet's atmosphere when it passes through the propagating CME. In our simulations, the mass-loss rate of the closed envelope grows by 11 times, and that of the quasi-closed grows by 14 times, when the planet interacts with the CME. We also discuss possible consequences of this enhanced loss of material.

P5.5 Testing Habitability in Laboratory: Atmosphere in a Test Tube Experiment

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At the Astronomical Observatory of Padova we are performing laboratory experiments aiming at twofold results. At first we want to understand how photosynthetic biota, once present on an Earth-like planet orbiting in the habitable zone of a star of different spectral type than the sun, can modify its atmosphere. In particular we study how the O_2-CO_2 balance would differ from the terrestrial one. An ancillary output is to understand if the feature of the "red edge" reflecting property and both the pigment composition and concentration of photosynthetic organisms would be influenced by the extended undergoing to a different radiation spectrum. Studying the different reflectance spectra of the pigments inside organisms grown in different light conditions allows to understand these bio-physical properties. In these experiments we use some bacteria like Synechococcus sp., Halomicronema hongdechloris, Acaryochloris marina and Chlorogloeopsis fritschii as well as a micro algae Ostreobium quekettii and Chlamydomonas reinhardtii or mosses (Physcomitrella patens). We analyze their gaseous productions with a laboratory set up mimicking the exoplanetary surface temperature and radiation conditions. With this aim we developed a starlight simulator that reproduce the stellar spectrum in the wavelength range (365-940 nm) overlapping the photosynthetic active range (PAR) (280-850 nm). These measurements could be useful to translate and understand the spectral data coming from the future space missions, in particular the ones dedicated to the study of exoplanetary atmospheres and in general exoplanet characterizations: CHEOPS, PLATO and ARIEL.

P5.6 The Open-source Bayesian Atmospheric Radiative Transfer (BART) Code to Model Exoplanet Atmospheres

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Multi-wavelength secondary-eclipse and transit depths probe the thermochemical properties of exoplanet atmospheres. In recent years, several research groups have developed retrieval codes to analyze the existing Spitzer, HST, and ground-based data and study the prospects of future facilities. However, the scientific community has limited access to these packages. I will present the open-source Bayesian Atmospheric Radiative Transfer (BART) code (https://github.com/exosports/BART). I will discuss the key aspects of the BART components: the Thermochemical Equilibrium Abundances code, TEA (https://github.com/dzesmin/TEA), to calculate species mixing ratios; the one-dimensional line-by-line radiative-transfer code,
Transit (https://github.com/exosports/transit), to calculate transmission or emission spectra; and the statistical package Multi-core Markov-chain Monte Carlo,
MC3 (https://github.com/pcubillos/MCcubed), to estimate best-fitting parameters and posterior sampling using Bayesian principles. I will show the results of the BART retrieval for the HAT-P-11b transmission data and compare against the results of Fraine et al. (2014).

P5.7 Atmosphere expansion and mass loss of magnetized close-orbit giant exoplanets

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Close location of a planet to its host star results in the intensive heating and ionization of the planetary upper atmosphere by the stellar X-ray and EUV radiation, which in their turn lead to the expansion of the ionized atmospheric material, contributing to the so-called planetary thermal mass loss. At higher altitudes, i.e. in the region of direct interaction of the expanding atmosphere with the stellar wind, the escaping planetary plasma is picked up by the stellar wind, resulting in a non-thermal mass loss. Both the thermal and non-thermal mass loss processes operating simultaneously contribute the total planetary mass loss and require their detailed description and quantifying. The planetary intrinsic magnetic field is known to be a crucial factor that influences the planetary mass loss and provides the protective effect for upper atmospheric environment. It has two major aspects. First, the large-scale magnetic fields and electric currents, related to the planetary magnetism, form the planetary magnetosphere, which acts as a barrier for the upcoming stellar wind shielding the upper atmosphere against direct impact of the stellar plasmas. Second, the internal magnetic field of the magnetosphere also influences the streaming of the expanding planetary atmospheric plasma and therefore affects its escape.

A self-consistent model to simulate the mass loss process of a close orbit magnetized giant exoplanet, so-called Hot Jupiter (HJ) will be presented. We generalize the hydrodynamic (HD) model of a HJ's expanding hydrogen atmosphere, proposed in Shaikhislamov et al. (2014), to include the effects of intrinsic planetary magnetic field. The new self-consistent axisymmetric 2D MHD model incorporates radiative heating and ionization of the atmospheric gas, basic hydrogen chemistry for the appropriate account of major species comprising HJ's upper atmosphere and related radiative energy deposition, as well as H_3^+ and Lyα cooling processes. The model also takes into account a realistic solar-type XUV spectrum for calculation of intensity and column density distribution of the radiative energy input, as well as gravitational and rotational forces acting in a tidally locked planet-star system. As result, the model provides deep insights in the crucial structural elements of the exoplanetary inner magnetosphere, such as the close-to-planet "dead-zone" filled with the stagnated hot plasma, "wind-zone" where the planetary escaping wind is streamed away, as well as thin disk of plasma with the typically structured magnetic field, so called magnetodisk. The last is known to play a crucial role in the global scaling of the planetary magnetospheric shield. The performed numerical simulation (Khodachenko et al. 2015) enabled to quantify the influence of the planetary intrinsic magnetic field on the mass loss and to conclude about the field values at which the significant portion of the planetary plasma stays locked inside the dead-zone and appears therefore excluded from the escaping material flow. Moreover, a periodic restructuring of the magnetodisk which results in the ejections of plasma, has been discovered.

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P5.8 The influence of the colliding stellar winds on the atmosphere of the potentially habitable circumbinary exoplanet KIC9632895

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According to standard estimates the circumbinary exoplanet KIC9632895 lies in the habitability zone. In binary stars, the collision of stellar winds results in the formation of strong shocks and regions of enhanced density and temperature that potentially can affect the exoplanet's atmosphere. In the paper we present the results of gas-dynamic simulations of the wind-wind interaction in the KIC96328957 system. We also consider gas-dynamic variations in the atmosphere occurring when the exoplanet passes through the region of interacting winds and discuss how these gas-dynamic effects may influence potential habitability of KIC9632895.

P5.9 Studying exoplanet atmospheres via transmission and emission spectra

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Observations of transiting planets play a paramount role in the study of extrasolar planets, as they provide knowledge about the planet's atmospheric structure and composition. The techniques in development to date will be key in studying the atmospheres of Earth like planets yet to be discovered.

I will present our ongoing observing program targeting hot giant planets with 8m-class ground-based facilities. I will discuss in detail a transmission spectrum of the transiting hot Saturn WASP-49b that was obtained with the FORS2 instrument. I will further present an emission spectrum of WASP-43b, which has been observed with the KMOS instrument, covering the H and K bands. Finally, I will conclude with an outlook on the application of the developed techniques on habitable planets.

P5.10 Loss of volatiles and water from planetary embryos

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Terrestrial planets may form by collisions of smaller building blocks such as Mars- to Moon-sized embryos. Such bodies are able to sustain magma oceans and outgas secondary H_2O/CO_2 dominated steam atmospheres during their solidification. We calculate the loss of such steam atmospheres for a range of embryo masses, atmospheric surface pressures and orbits within the habitable zone of a young Sun-like host star to investigate if larger planets forming at later stages by collisions of such embryos may be drier than previously expected.

P5.11 Atmosphere expansion and mass loss of magnetized close-orbit giant exoplanets

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Simulations of the Earth's magnetosphere obstacle, including the shape of the auroral oval and related field lines for early stages of the solar system are of particular importance for studying the evolution and mass loss of the Earth's atmosphere. Within this presentation, we will present simulations of the terrestrial paleo-magnetosphere of the Earth for the late Hadean, i.e. for ∼4.1 billion years ago. These were performed with an adapted version of the Paraboloid Magnetospheric Model (PMM) of the Skobeltsyn Institute for Nuclear Physics of the Moscow State University, which serves as an ISO standard for the Earth's magnetosphere (see e.g. Alexeev et al., 2003). As an input parameter, the new measurements of the paleomagnetic field strength by Tarduno et al., 2015, are taken. These data from zircons between 3.3 billion and 4.2 billion years old vary between 1.0 and 0.12 of today's equatorial field strength. Available data at ∼4.1 billion years ago are among the lowest field strength values. Another input into the adapted PMM is the solar wind pressure, which was derived from a newly developed solar/stellar wind evolution model (Johnstone et al., 2015a, b), which is strongly dependent on the rotation rate of the early Sun (i.e., a fast rotating Sun produces a much stronger solar wind pressure than a slow rotating Sun).

Our simulations of the terrestrial paleo-magnetosphere with the adapted PMM show that for the most extreme case of a fast rotating Sun and a paleomagnetic field strength with 0.12 of today's value, the stand-off distance of the magnetopause R_s shrinks down from today's 10 R_e to 3.43 R_e (i.e. 2.43 R_e above the Earth's surface). Even for a slow rotating Sun R_s would be at only 4.27 R_e. Taking the same magnetic field strength as that of today and a slow rotating Sun leads to an R_s of 8.23 R_e, which would be the least extreme case for the terrestrial atmosphere. Another outcome of the modelling is that the auroral oval was significantly broader ∼4.1 billion years ago than today, reaching much farther towards the equator than the present day oval. As demonstrated by our calculations, a good approach for the relationship between the auroral oval size θ_{pc} (with θ_{pc} as oval co-latitude) and R_s is $\sin 2\theta_{\mathrm{pc}} = R_e/R_s$.

This equation can be used for the scaling of the paleo-magnetosphere auroral oval to today's one (see also e.g. Alexeev, 2006).

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P5.12 Climate models of the early Earth's and thunderstorm activity

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The basic goal of this work was to discuss the conditions for thunderstorm activity on the early Earth. In dependence from scenario of evolution Earth's earliest atmospheres (step by step escape of primary atmosphere or instantly escape as result of collision Earth with large planetesimal) we can obtain different conditions for thunderstorm activity. Consideration of three stages (charging of snowflakes and ice pellets, spatial separation of charges, breakdown and development of lightning) shows that the nature of modern thunderstorm activity is unique phenomenon because of charges separation mechanism. As a result of this mechanism, at the altitude 6...8 km (pressure about 0.3 bar) by the temperature about -15° C, there is a formation of negatively charged layer with thickness of some hundred meters. This layer consists of negatively charged ice pellets and snowflakes. Positively charged snowflakes form a charge at the top of a cloud, and positively charged ice pellets form positive charge at the bottom of a cloud. The existing of such conditions in early atmosphere is necessary for thunderstorm activity. We have estimated the altitude of this layer because of changing pressure and temperature on Earth's surface. Although we haven't date about the structure and the physical parameters Earth's earliest atmosphere, from analyses of charge separation mechanism in thunder clouds can draw a conclusion about conditions for lightning discharges in terms favorable or unfavorable. For step-by-step evolution we can speak about such favorable periods - 3...3.6 Ga, 0.8...2.2 Ga and 0.5 Ga...present time. Hadean, early Archaean, 2.2...3 Ga and "snowball Earth" are unvavorable for thunderstorm activity. In case of instantly escape of primary atmosphere is possible to add very favorable period for thunderstorm activity at the time when take place formation of secondary atmosphere (about 4.2... 3.8 Ga). As for volcanic lightning, it is possible to assume that in the field of a volcanic cloud must exist conditions for creation of charge reverse layer (pressure 0.3 bar, temperature -15° C), but convective mechanism plays more important role. Under such conditions development of the charge separations in early Earth's is defined by pressure of atmosphere. In this case for preliminary estimation of volcanic thunderstorm activity it is necessary to consider the change in pressure. We can suppose therefore that if the pressure is more than several bars, then probability of volcanic lightning is less than now.

P5.13 Interaction of escaping atmosphere of HD209458b with stellar wind

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The planetary wind of a gas giant at a close orbit is a unique phenomenon not observed in the solar system. Existing theoretical and numerical models reveal that upper atmospheres consisting of hydrogen being heated by intense stellar ionizing radiation develop supersonic outflows, which dramatically changes the plasma environments around Hot Jupiters. Spectral peculiarities observed during transits of close-orbit exoplanets give tantalizing evidence of such environments and their detection possibilities. Another crucial factor in forming a Hot Jupiter environment is the stellar wind which collides with the planetary wind and confines to by the ionopause, or to the magnetopause if the planet possesses a significant magnetic field. Due to the complexity of the problem, this has so far not been fully investigated. The only example of numerical simulations performed remains that of Bisikalo et al. (2013) for WASP-12b. In the present work, a fully self-consistent hydrodynamic numerical model (Shaikhislamov et al. 2014, Khodachenko et al. 2015) is employed to study stellar wind interactions with the planetary wind of an unmagnetized analog of HD209458b. We use a multi-fluid approach which describes the interactions of planetary atoms and ions, stellar protons and Energetic Neutral Atoms (ENAs). The numerical model takes into account realistic a Sun-like spectrum of XUV radiation which ionizes and heats the upper atmospheres of exoplanets, hydrogen photo-chemistry in order to calculate molecular hydrogen and infrared $H3^+$ cooling, and the interactions of plasma flows in a 2D axisymmetric geometry which takes into account charge-exchange between hydrogen atoms and protons. The main goal is to characterize different physical regimes of planetary and stellar wind interactions such as the confinement of planetary material or its fallout toward stars beyond a Roche lobe as determined by the interplay of tidal forces and planet gravities, stellar wind pressure and XUV intensity.

It was found that for the conditions of an unmagnetized analog of HD209458b and analog of a Sun-like plasma wind, the orbital distances in the range 0.06-0.09 divide two principally different regimes of planetary outflow. At larger distances, the stellar wind is capable of stopping the planetary wind, which is fully diverted into the tail.

At closer distances, the tidal force is sufficiently strong to overcome the stellar wind pressure, and the planetary material accelerates and falls off towards the star. In the first case, the planetary outflow should have the comet like form due to the Coriolis force, while in the second case, it should have a double comet form. Therefore, the ENA cloud which forms due to charge-exchange between fast stellar protons and slow planetary atoms around the planet also shows two different spatial structures. It was found that the typical maximum densities of ENA are about several particles per cm^{-3}. The cloud extends in the lateral direction by at least ten planetary radii, while the total line of sight integral amounts to as much as 10^{12} cm^{-2}. This is comparable to test particle simulations (Kislyakova et al. 2014) based on an assumed form of the ionopause boundary and the density of planetary atoms injected through it. Thus, by combining the hydrodynamic and the test particle models, a self-consistent 3D structure of the ENA cloud could be obtained for a more adequate comparison with transit observations in Ly-alpha.

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P5.14 Energy balance in the upper atmosphere of the hot jupiter with taking into account suprathermal photoelectrons

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Results of simulations of heating processes in the upper atmosphere of the hot Jupiter planet HD 209458b are presented. The main specific of the discussed approach is that the calculations were made with taking into detailed account the energy deposition by suprathermal photoelectrons. Since hot Jupiters are orbiting their host stars at distances closer than the orbit of Mercury, the stellar XUV (soft X-rays+EUV) radiation heats the upper atmosphere of the hot jupiter to the relatively high temperatures. The heating efficiency and heating rates are calculated by solving the kinetic Boltzmann equation using Direct Simulation Monte Carlo model. The profiles of heating efficiency by the soft X-ray and EUV-radiation have been calculated. [1] The calculations for various distributions of the neutral components and various spectral energy distributions of the host star are performed. The concentrations of the ionized components and ionization rates are although calculated. It was shown that photoelectrons significantly influence on the energy balance of the atmosphere. Therefore, the interaction of the upper atmosphere with stellar wind is strongly dependent on the energy balance variations and can result in the fundamental change of the dynamic and spatial distributions of the atmospheric gas [2].

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P5.15 Atmospheric escape from planets: the role of a planetary magnetic field

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Measurements of ion fluxes obtained by satellites in the terrestrial magnetosphere and in the shocked solar wind upstream of Earth (with an intrinsic magnetic field), and Mars and Venus (with no or very weak intrinsic magnetic fields) allow us to make estimates of total escape fluxes of atmospheric origin O^+ . The results for the different planets can be considered in order to understand the role of a planetary magnetic field for atmospheric escape. For Earth, the most direct interaction between the solar wind and the ionosphere is constrained to the magnetospheric cusps, causing ion outflow into the magnetosphere. If the subsequent energization in the cusps is sufficient the ions will heat and accelerate enough to escape into the solar wind, either downstream in the tail or directly into the dayside magnetosheath. Cluster observations during high solar activity conditions reveal O^+ escape fluxes typically of the order 10^{25} s^{-1}. Ion escape from Mars and Venus has been estimated to be of the same order of magnitude as that from Earth. It is therefore not clear what role a planetary magnetic field plays for the evolution of a planetary atmosphere. We discuss the similarities and differences between the three planets, and how the current observations can be extrapolated to the time of the early solar system.

P5.16 Influence of stellar flares on exoplanetary atmospheres and transmission spectra

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M stars are very abundant in our galaxy, and thus are very likely to harbor most of planetary systems. Also, these stars are very active: they can undergo important stellar variability like star spots, granulation, flares... From these two points, a question came up: in which extent can a stellar flare modify the chemical composition of an exoplanetary atmosphere and influence the resulting spectra? This question is very important in the context of preparing the future observations that will be performed with JWST, E-ELT, PLATO,... in order to avoid wrong interpretation of the future data.

To answer to this question, we studied two hypothetic planets (sub-Neptune/super-Earth) orbiting around the very active star AD Leo. This star underwent a huge flare in 1985 that has been observed by Hawley & Pettersen 1991. During the flare, the irradiation of the star increased by several orders of magnitude. To study two extreme cases of warm exoplanets, we placed the planets at different distances from the star, resulting in two different equilibrium temperatures (412 K and 1303 K). Using our 1D photochemical model (Venot et al. 2015), we first determined the atmospheric steady-state of the two planets when the star is quiescent. Then, we simulated a flare using the observational data of Hawley & Pettersen 1991. We studied the temporal evolution of the abundances of the main species during the flare and also after the flare until the atmospheres return to steady-state. We also computed the synthetic transmission spectra that we would obtain if the flare happens during an observation.

We found that the increase of the incoming flux during the flare can modify the abundances of important species down to 1 bar. The change in the atmospheric chemical composition is so important that variations on the spectra are also visible and, for the hottest case, could be detectable with current and future facilities.

P5.17 The Atmospheres of Jupiter's Icy Moons

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The European Space Agency is implementing the Jupiter Icy Moons Explorer (JUICE) mission to fly to the Jupiter system and visit the icy moons Europa, Ganymede, and Callisto. One of the selected scientific instruments is the Particle Environment Package (PEP) that includes a Neutral gas and Ion mass spectrometer (NIM). NIM will measure the chemical composition of the exospheres of these three moons during several flybys and in orbit of Ganymede.

Since all these exospheres are in direct contact with the surface of the respective moon, the chemical composition of the surface can be inferred from of the exospheric measurements. Knowing the chemical composition of the surface, and accounting for radiation induced chemistry at and near the surface, one can compare with models of the formation of these icy satellites from the proto-planetary disk from which Jupiter and the icy moons formed. In addition, if the JUICE flyby trajectory allows sampling the recently discovered plume on Europa with NIM we can measure the composition of Europa's ocean, which again can be compared to formation models, which would provide strong constraints on its formation conditions. We will present Monte Carlo calculations of the exospheres of the icy moons including all relevant processes to release particles into their exospheres, which are sublimation, sputtering, and photon stimulated desorption. For the surface composition we compiled composition data from existing spectroscopic observations and from formation models. We derive density profiles for different scenarios (e.g. day / night, in co-rotation flow, ...), and make predictions on the expected NIM measurements for the planned Europa flyby trajectories of JUICE.

6. Planetary Interiors

Chair: Elke Pilat-Lohinger

6.1. Planetary interiors: Long-term evolution and implications for habitability

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Convection of the rocky mantle is the key process that drives the evolution of the interior: it causes plate tectonics, controls heat loss from the metallic core (which generates the magnetic field) and drives long-term volatile cycling between the atmosphere/ocean and interior. Cycling of water and carbon dioxide between the atmosphere/ocean and interior is a key process that is thought to regulate habitability; thus plate tectonics is often considered necessary for planetary habitability. However, plate tectonics is still not well understood; other terrestrial planets like Venus and Mars instead have a stagnant lithosphere. Scaling with planet size is also a source of disagreement. Nevertheless, simple scalings (van Heck and Tackley, EPSL 2011) as well as more complex models (Tackley et al., Icarus 2013) indicate that plate tectonics should be easier on larger planets (super-Earths), other things being equal. Our recent models find that variations in crustal thickness are also important in facilitating plate tectonics. Large terrestrial planets likely started off with partly or mostly molten with global magma oceans; processes occurring during the freezing of these include outgassing and the possible development of compositional layering, which affect both the atmosphere and the interior for a long time period. Large planets take longer to cool so if, as is likely, large terrestrial planets (super-Earths) started off molten then it is likely that their deep interiors are still very hot and active.

6.2. Giant planet formation & internal structure

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A key objective in giant planet studies is linking the three aspects of origin, evolution, and internal structure. Making this link, however, is not trivial – the primordial internal structure has a direct effect on the long-term evolution and on its potential to change with time (mixing, settling, etc). In return, the long-term evolution determines the final structure of the planet. First, we will show the heavy-element distributions inferred from standard core-accretion models. Second, we will present how different primordial heavy-element distributions and convective mixing affect the planetary evolution and cooling rate, and therefore, the M-R relation. In addition, we will show how opacity affects the planetary contraction, and therefore, the planetary radius at a given age. Combining planetary origin, evolution, and internal structure provides a crucial element that is required for understanding giant planets as a class of planetary objects, and for interpreting current and upcoming extrasolar data.

6.3. Interior structures of low-mass exoplanets: the 5 best constrained cases

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The characterization of exoplanet interiors is key for the understanding of habitability. We focus on characterizing five exoplanets for which not only mass and radius are known as constraints for the interior but also additional abundance proxies. These exoplanets are Kepler-10b, Kepler 93b, CoRoT-7b, 55Cnc e, and HD 97658 b. Theoretical studies and empirical evidences from Solar System objects strengthen the possibility that the relative refractory element composition of a planet is directly correlated to its host star composition, namely the ratios of Fe, Mg, and Si. Observations of relative photospheric abundances of host stars with planetary companions make it possible to verify the stellar abundance proxy for exoplanetary systems as outlined by Santos et al. 2015 and Dressing et al. 2015. We proceed along these lines and perform a full probabilistic analysis to determine the range of probable interior structures of the five exoplanets of interest. We study if their interiors can be explained using the abundance proxy testing a direct and non-direct correlation between star and planet. Furthermore we determine by how much constrained interiors differ when taking different stellar abundances.

6.4. Geophysical Limitations on the Habitable Zone

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Planets are typically classified as potentially life-bearing planets (i.e. habitable planets) if they are rocky planets and if a liquid (e.g. water) could exist at the surface. The latter depends on several factors, like for example the amount of available solar energy, greenhouse effects in the atmosphere and an efficient CO2-cycle. However, the definition of the habitable zone should be updated to include possible geophy-sical constraints, that could potentially influence the CO2-cycle. Planets like Mars without plate tectonics and no or only limited volcanic events can only be considered to be habitable at the inner boundary of the habitable zone, since the greenhouse effect needed to ensure liquid surface water farther away from the sun is strongly reduced. We investigate how these geophysical processes depend on the mass and interior structure of terrestrial planets. We find that plate tectonics, if it occurs, always leads to sufficient volcanic outgassing and therefore greenhouse effect needed for the outer boundary of the habitable zone (several tens of bar CO2). One-plate planets, however, may suffer strong volcanic limitations if their mass and/or iron content exceeds a critical value, reducing their possible surface habitability.

6.5. The geodynamo during Earth's first billion years: Implications for planetary habitability

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Geomagnetic field strength is a fundamental parameter defining the nature of magnetic shielding of the planet from the solar wind. Knowledge of when the geodynamo started, therefore, is of crucial importance for understanding the evolution of the atmosphere and ultimately life on Earth, especially given the vigor of solar winds associated with the active young Sun. Paleomagnetic study of rocks formed 3.45 billion years ago indicate a field strength 50 to 75% of the present-day geomagnetic field (Tarduno et al., 2010). Two vastly different models have been proposed for the geodynamo further back in time. The dynamo could have started shortly after core formation, or it could have been delayed by as much as 1 billion years by slow lower mantle cooling. Most recent models suggest that inner core growth commenced at a time younger than the Archean, so the earliest dynamo had to be driven solely by thermal convection. Recent revisions of core thermal conductivity make generation of the early dynamo more difficult, although this is currently a matter of considerable debate. Eoarchean and Hadean rocks have either been completely removed by erosion or rendered unsuitable for paleomagnetic analysis by metamorphism. However, minerals containing magnetic inclusions composing sedimentary rocks could preserve an ancient geodynamo record. Among these, the Jack Hills metaconglomerate (Western Australia) is a focus because it contains Hadean zircons. Moreover, some of these sediments have magnetizations that unblock at high temperatures and pass a conglomerate test. These characteristics exclude pervasive remagnetization, and instead suggest zircons could retain primary magnetizations. This suggestion has recently been confirmed by a positive microconglomerate test on zircons from the Jack Hills (Tarduno et al., 2015). Following work on zircons and other single silicate crystals hosting magnetic inclusions in the Rochester laboratory since 1997, we have recently reported the first paleointensity determinations on zircons (Tarduno et al., 2015). These remanent magnetizations are the weakest recorded on natural materials, and require use of an ultra-sensitive 3-component 2G DC SQUID magnetometer. Our full vector paleointensity measurements of zircons dated to between 3.3 and 4.2 billion-years-old using Pb-Pb SHRIMP ion microprobe analyses record magnetic fields varying between 1.0 and 0.12 times recent equatorial field strengths. These paleointensity and age data suggest the presence of a terrestrial core dynamo more than 750 million years earlier than prior estimates, with dynamo onset in the Hadean eon. Earth, Mars and Mercury all retain records of

early core dynamos suggesting that this is a common feature of terrestrial-like planets. However, beyond shielding from the young Sun, the longevity of a strong internally generated magnetic field is of principal interest for understanding planetary climate evolution. The collapse of the Martian dynamo probably facilitated atmospheric stripping whereas the early start and persistence of atmospheric shielding associated with the long-lived geodynamo was likely a key factor in the development and sustainability of Earth as a habitable planet. Ultimately, a Hadean geodynamo requires a process to cool the mantle allowing core convection, such as early onset of plate tectonics. Generalization of these requirements for terrestrial-like exoplanets will be discussed.
Tarduno, J. A. et al., (2010) Science, 327, 1238-1240. Tarduno, J.A. et al., (2015) Science, 349, 521-524.

P6.1 GAPS: Studying the architecture of planetary systems with HARPS-N at TNG

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The GAPS Project (Global Architecture of Planetary Systems) gathers a large fraction of the Italian community working in the exo-planets research field, also supported by a few foreign scientists. The GAPS members have a wide expertise in high-resolution spectroscopy, stellar activity, formation and dynamics of planetary systems, able to optimize the results and the science return of the project.

The observational program of GAPS is specifically designed to characterize the global architectural properties of exo-planetary systems, taking advantage of the capabilities provided by the HARPS-N spectrograph, mounted at the Italian telescope TNG (La Palma, Canary Island). After six full semesters of observations a dozen of papers has been accepted up to now and several others are submitted or in preparation. Moreover, we ask for a further extension of the observing time to conclude our survey and to confirm promising planet candidates. GAPS is organized in six sub-programs. Among them the monitoring of stars hosting already known planets is aimed to search for low mass planets around a sample of stars hosting long period giant planets (periastron > 1 AU) and long period planets around stars with known transiting giant planets, in order to obtain a more complete view of the architecture of planetary systems.

In this framework we present our revision and refinements of the whole set of parameters of an interesting planetary system characterized by two giant planets in wide orbits. We investigate the dynamical stability of the system and discuss on the possibility to detect further small companions and their allowed location in the system.

7. Observatories: Future Perspectives

Chair: Manuel Güdel

7.1. The Graz-Tautenburger-Imager: GTI

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A serious challenge for all types of exoplanets search programs are false-positives. In the case of transit search programs, false-positives are objects that have light-curves that look like transiting planets but are something else. The most prominent causes for false-positives are eclipsing binaries within the photometric apertures of the instruments. Although current and future space mission remove many false-positives by using the centroid method, not all of them can be removed in this way. For example the centroid method does not work if the difference in brightness between the target and the eclipsing binaries is too large, or if the separation between the two is too small. For the K2 mission and particularly for the TESS mission it is thus essential to implement tools that allow removing false-positives that are not detected with the centroid method in an efficient way. Given the large number of planet candidates that will be found by these missions, it is essential that these methods are relatively simply and fast. Once the false-positives are removed the statistics of planets is obtained right away. Once the false-positives are removed we can calculate the frequency of planets for stars of different mass. This information is an important test for the theories of planet formation, because the different theories make very different predictions what the frequency of planets is for stars of different mass. In here we present a study for a 2-channel imager that allows obtaining simultaneously photometric observations in the blue and in the red. We show that almost all false-positives of the K2 and TESS mission can be detected and removed. In contrast to all other multi-channel photometers this instrument is optimized for the K2, the TESS and in future also the PLATO missions. Compared to other instruments, GTI has several advantages: 1.) The field of view is much larger, which is important for having enough comparison stars of similar brightness 2.) The 2-channels are optimized so that the S/N for a typical target is similar in both channels. 3.) The wavelength-regions in the two channels are very broad to optimise the S/N. 4.) The instrument will be placed at a telescope at a good site. The observing time will be arranged in such a way that all transits visible from that site can be observed. We show that with GTI it is possible to remove false-positives that are not detected by the centroid method in a quick and easy way.

7.2. Detection and characterization of exoplanets from space

H. Rauer (1)

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In recent years a large diversity of planets became evident. This diversity raises new questions to the nature of these planets and their formation and evolution processes, such as: What is the composition and internal structure of these planets? What is their atmospheric composition? And for the smallest planets: are they potentially habitable and how could we detect this? Constraining our understanding of the underlying processes requires an improved knowledge of the basic planet parameters, hence their mean densities, atmospheres and their age. The talk will give an overview on the next steps for the exploration of exoplanets by future space missions, like CHEOPS, TESS and PLATO 2.0 and beyond.

7.3. Towards a complete census of planetary system diversity: the role of ground-based observations

S. Udry (1)

(1) Geneva Observatory, Geneva, Switzerland

Our understanding of planetary systems has tremendously changed over the past 20 years after the detection of exoplanets orbiting other stars similar to the Sun. Radial-velocity surveys of dwarf stars at high-precision have allowed for the detection and characterisation of a large population of exoplanets in the super-Earth and Neptune-mass regime, not observed in the Solar System. Knowledge about those systems is gained through the study of the statistical properties of their orbital elements, the correlation of host-star properties with the planet masses, as well as the occurrence rate of planetary systems around solar-type stars. In parallel transit surveys from the ground opened the way to the study of planet internal composition, taking full advantage of the synergies with radial-velocity measurements. These results will be discussed in the light to our understanding of the formation and evolution of planetary systems, with a special focus on small-mass planets. Next challenges in the field including ground-based observations for the characterisation of planet atmospheres and prospects for the future detection of Earth twins and habitable planets will be discussed as well.

P7.1 Probing Planet Formation with the VLTI and the ELT

T. Ratzka (1)

(1) Institute for Physics, University of Graz, Graz, Austria

Long-baseline interferometry with the mid-infrared instrument MIDI at the Very Large Telescope Interferometer (VLTI) has led to new insights into the composition and structure of disks around young stellar objects. The unprecedented spatial resolution of the spectroscopically resolved N-band data reveals dust growth and planet-induced structural changes in the warm inner parts of the circumstellar disks.

The measurements, however, suffer from the poor coverage of the UV-plane. With the next generation mid-infrared beamcombiner of the VLTI this will change. MATISSE will combine four telescopes and thus allows to reconstruct images. It further opens the L- and M-band to interferometry. In the next decade MATISSE will be followed by METIS, the mid-infrared imager and spectrograph of the European Extremely Large Telescope. METIS will open a completely new domain for observations of protoplanetary disks.

P7.2 Age of giant planet embedded in debris disk

Z. Regaly (1)

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HD95086 is a young (∼17Myr) system that harbours both an extended bright dusty debris disk and a $5M_{Jup}$ giant planet at a distance of ∼62AU with an unknown eccentricity (Rameau et al. 2013). The dust grains are found to be located in two distinct belts and in-between a dust depleted region (presumably a gap carved by the giant planet) formed with a size of ∼80AU (Moor et al., 2013; Su et al., 2015). We modelled the gravitational perturbation of the planet on the debris disk by means of N-body integration with a high performance GPU-based direct N-body code. An eccentric planet excites a spiral pattern in the dust distribution due to its gravitational perturbation (Wyatt 2005). The emerging structure evolves such that the spiral pattern shove off from the star with time . The evolution of this spiral pattern seen on high-resolution synthetic images in millimeter wavelengths is found to be nearly independent of the planetary eccentricity for models that assumes fixed size inner dust hole. Thus, the age of a known mass planet embedded in a debris disk can be estimated by inferring the age of the secular perturbation based on the evolutionary stage of this spiral pattern . Using this novel method a further constraint to planet formation theory can be given by high-resolution ALMA observations of giant planet bearing debris disks.

8. Planetary System Architecture and Dynamics

Chair: Rosemary Mardling

8.1. Dynamics and Habitability

C. Terquem (1)

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Being in the habitable zone is commonly thought to be a necessary condition for a planet to harbor life. This condition, of course, is however not sufficient. In particular, life may be prevented to develop on a planet which orbital elements change too rapidly or which has an orbital eccentricity so large that the planet has excursions outside the habitable zone. Here we review different mechanisms that can affect the orbital elements of a planet in the habitable zone, focusing in particular on eccentricity and inclination evolution.

8.2. Using Kepler systems to constrain the frequency and severity of dynamical effects on habitable planets

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(1) Lund Observatory, Lund, Sweden

On a fundamental level, a planet's habitability is tied to its orbital properties – chiefly semi-major axis and eccentricity – which in turn are affected by other bodies in the system. I describe how the orbits of inner planets both in the habitable zone and closer to the star are affected by the dynamical evolution of outer giant planets beyond 1 au. While few planets are yet known in the habitable zone, the Kepler mission has provided a sample of planets closer to the star large enough for statistical studies. I use the observable properties of planets in the Kepler sample – multiplicities, mutual inclinations, and the occurrence of hot Jupiters – to place constraints on the frequency of violent interactions originating in the outer system that could render habitable planets uninhabitable by changing semi-major axes, exciting eccentricities, and inducing collisions. I focus on two dynamical mechanisms: excitation of a giant planet's eccentricity through the Kozai effect in a stellar binary, and scattering in unstable systems of multiple giant planets, both of which can cause disruption of habitable terrestrial planet systems as an eccentric giant penetrates the inner system. I present both ongoing work and work recently published as Mustill, Davies & Johansen, ApJ, 2015.

8.3. On the combined action of disc migration and planet-planet scattering in the formation of giant planetary systems

A.-S. Libert (1), S. Sotiriadis (1), B. Bitsch (2), A. Crida (3)

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(2) Lund Observatory, Lund, Sweden
(3) Côte d'Azur Observatory, Nice, France

We study the orbital evolution of three giant planets in the late stage of the gas disc, extending the previous work of Libert & Tsiganis (2011) on the combined action of disc migration and planet-planet scattering. Our goal is to investigate the influence of the eccentricity and inclination damping due to planet-disc interactions, on the final configurations of planetary systems. We present the results of $\sim$10000 numerical experiments, exploring different initial configurations, planetary mass ratios and disc masses. Our n-body simulations use the damping formulae for eccentricity and inclination provided by the hydrodynamical simulations of Bitsch et al. (2013), and the disc mass is assumed to decrease exponentially. The simulated population reproduces the observed semi-major axis and eccentricity distributions with a very good agreement, except for low initial disc masses. Concerning the inclinations, most of the systems are found with small inclinations ($<10°$). Even though many systems enter an inclination-type resonance during the migration phase, the disc damps the inclination in a relatively short time scale, leading the planets back to the midplane. Nevertheless, a significant fraction of the systems end up with high mutual inclinations. The percentages of resonant two- and three-body systems in the population are finally discussed.

8.4. The nature and impact of obliquity evolution on the habitability of Earth-like exoplanets

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(1) University of Washington, Seattle, USA
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The obliquity of Earth, which controls our seasons, varies by only ∼2.5 degrees over ∼40,000 years. Nonetheless, this variation has been demonstrated to have influenced Earth's ice ages. The stability of the planet's spin axis is a result of the presence of a large satellite (the Moon). In the absence of such a moon, the obliquity of a terrestrial planet can evolve chaotically and with large amplitude. Mars has experienced chaotic obliquity oscillations of ∼60 degrees, based on numerical calculations of its orbital history and images of its polar regions displaying alternating layers of dust and ice. The habitability of moonless Earth-like exoplanets has been explored and in many dynamical configurations these obliquity cycles extend the outer edge of the habitable zone by preventing runaway glacial formation (snowball states). To properly assess the potential for habitability and prioritize target selection for the characterization of exoplanets, we need to understand their orbital and rotational dynamics. It may be rare for rocky planets to have large moons and difficult, if not impossible, to detect those exomoons. Consequently, it is necessary to quantify the likelihood of a planet's having extreme obliquity cycles in the absence of a moon and to model the potential impact on the planet's climate. We explore the obliquity evolution of known exoplanet systems that could contain Earth-like planets in the habitable zone, with a special focus on the dynamics of these systems. We use the obliquity model developed by Kinoshita (1977), and later used by Laskar (1986) and Armstrong, et al. (2014), in conjunction with a 4th order semi-analytical secular model for the orbital evolution. To model the climate, the orbital/rotational models are then coupled to a simple energy balance model (EBM) that includes ice sheet growth and decay. The EBM is fast and can reproduce the temperature distribution of Earth for realistic starting conditions. Our approach allows for the rapid exploration of a large parameter space and the easy identification of interesting phenomena such as secular resonances, Cassini-states, and snowball Earth conditions. We find that a wide range of behavior is possible, including obliquities that are nearly fixed, to cases in which the obliquities can change by tens of degrees over millennia. Systems with three or more planets are particularly dynamically rich, with planets that undergo obliquity changes of ∼10 degrees over 50,000 years and >30 degrees over a million years. The obliquity amplitude generally

increases with a planet's initial eccentricity and mutual inclination, however, we find that the dependence is highly nonlinear. Parameter space for some systems is filled with secular resonances between the planet's axial precession rate and the myriad of orbital frequencies. In our simulations, secular resonances induce large obliquity oscillations, as suggested for Mars and Saturn. The obliquity amplitude reaches $>\sim 60$ degrees and induces dramatic glacial cycles. If the planet lies near the outer edge of the habitable zone, this type of behavior renders the surface uninhabitable for large periods of time. The diverse outcomes for these simulations demonstrate that dynamical effects on habitability will be highly dependent on system parameters and need to be considered on a system by system basis. In particular, the presence and sizes of planetary companions, and their orbital characteristics will be key observables required to constrain the effects of obliquity and orbital variations on planetary habitability.

8.5. The influence of Jupiter, Mars and Venus on Earth's orbital evolution

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Throughout the history of astronomy, a common theme has been that once the first members of a new population are found, the number known undergoes rapid growth. For that reason, once the first potentially Earth-like planets are found, in the coming years, we will likely discover many more in a relatively short period of time. At that point, the focus of exoplanetary science will shift from simply attempting to find such planets to an intensive effort to search for evidence of life upon them.

Unfortunately, however, that search will be incredibly challenging, and the observations required will be such that only the few most promising 'exo-Earths' can be targeted. So how should we choose the best targets for the search, in order to maximise our chances of success?

Over the years, many different factors have been proposed as playing a role in the Earth's habitability. These range from the behaviour and relative quiescence of the Sun, to the impact rates our planet has experienced over the ages, and even our planet's structure and composition. As we consider the exo-Earths we discover, a driver of the selection process will be the assessment of their potential habitability.

Among the many influences that are thought to have shaped Earth's habitability, the climatic stability of our planet is thought to have played an important role. The Earth's orbit is continually tweaked by the gravitational influence of the other planets, driving the Milankovitch cycles. As the Earth's orbit shifts, the planet's climate responds, an effect that has caused the on-going series of glacial and interglacial periods that have dominated Earth's climate for the past few million years.

But what if the architecture of our Solar system was different? It is highly unlikely that exo-Earths will move in systems that perfectly mirror our own, and so it is likely that those planets will experience Milankovitch cycles of different amplitudes and periods to those experienced by Earth.

Here, we present the preliminary results of several suites of n-body integrations that together examine the influence of the Solar system's architecture on the Earth's Milankovitch cycles. We consider separately the influence of the planets Jupiter, Mars and Venus, each of which contributes to the forcing of Earth's orbital evolution.

Our results illustrate how small changes to the architecture of a given planetary system cna result in marked changes in the potential habitability of the planets therein, and are an important first step in developing a means by which the nature of climate variability on planets beyond the Solar system can be characterised.

8.6. Dynamical Constraints on Outer Planets in Super-Earth Systems

M. Read (1)

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Secular interactions between planets drive orbital evolution. In this talk I will discuss the dynamical evolution of known planetary systems due to secular interactions with an additional hypothetical planet on an eccentric orbit. Specifically I will discuss a general two planet system, showing that a planet on an ellitpcal orbit transfers all of its eccentricity to an initally circular planet if the two planets have comparable orbital angular momentum. I will then present an application of this theory to single Super - Earth system HD38858 and show that an additional hypothetical planet below current radial velocity constraints is unlikely to be present in a significant area of Msini, semi-major axis and eccentricity parameter space, from the eccentricity that would be excited in the known planet (albeit cyclically). I will also show that additional planets in proximity to the known planet could stabilse the system against secular perturbations from outer planets however. An example of which will be given through appliciation to the two Super-Earth system 61Vir. I will finally discuss the possibilty of being able to infer the presence of additional stabilising planets in systems with an eccentric outer planet and an inner planet on an otherwise suspiciously circular orbit.

8.7. Survival of habitable planets in unstable planetary systems

D. Carrera (1)

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Many observed giant planets lie on eccentric orbits. These could be the result of strong scatterings with other giant planets. The same dynamical instability that produces strong giant planet scatterings can also change the orbits of terrestrial planets. For example, a rocky planet in the habitable zone can be taken out of the habitable zone. Therefore, there is a link between observed giant planets and habitability. We modelled the orbital evolution of rocky palnets in planetary systems where giant planets become dynamically stable. We measured the survivability of rocky planets as a function of preent-day masses and orbits of the giant planets. We calculate the survival rate in systems with hierarchical (i.e., unequal mass) giant planets similar to our own solar system. We find that the survival rate depends on the location of the inner giant and the number of rocky planets (collision rates increase with the number of rocky planets). Equal-mass giants give a lower survival rate. The existence of rocky planets in the habitable zone is closely tied by the dynamical history and properties of its planetary companions as seen today.

8.8. Pathways to long-term stability of highly eccentric resonant exoplanets

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With a considerable amount of confirmed exoplanets being locked in mean-motion resonances (MMRs) and evolving on highly eccentric and inclined orbits, their dynamical evolution remains elusive. Given the large deviations of their suggested orbital elements their long-term stability is not guaranteed. We herein utilize the families of stable resonant periodic orbits in the general three body problem and exhaust all possible positions -in terms of survival- of particular exoplanetary systems. Periodic orbits offer a phase protection mechanism, so that exoplanets can avoid close encounters in long timescales. We study HD 82943 and HD 3651 locked in 2/1 MMR, HD 7449 and HD 89744 trapped to 3/1 MMR and HD 102272 evolving in 4/1 MMR and provide the islands of stability in phase space which can host them. In this framework, suggested data yielded by observational astronomers can not only be complemented or constrained, but not least, proposed when not reported.

8.9. Habitable zones for planetary systems with gas giants: an analytic approach

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(2) IMCCE, Observatoire de Paris, Paris, France

Today, almost 2000 planets are known to revolve around stars other than our Sun. Since the detection of planets with comparable size to that of the Earth is an observational fact, an issue of great scientific as well as public interest is whether Earth-analogues may be found orbiting within the habitable zone. Looking at the current observational evidence in and beyond our Solar System, it seems most likely that the presence of gas giants does not preclude the existence of terrestrial planets in the same system. However, the gravitational interactions between possible terrestrial companions and the gas giants can influence the extent of a system's habitable zone. In this work, we determine analytically the limits of the habitable zone for an Earth-like planet in the presence of a gas giant. An application of the method to a sample of currently known exoplanetary systems is also provided.

P8.1 Secular Dynamics of S-type Planetary Orbits in Binary Star Systems

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We analyse the secular dynamics of planets on S-type coplanar orbits in tight binary systems, based on first- and second-order analytical models, and compare their predictions with full N-body simulations. The perturbation parameter adopted for the development of these models depends on the masses of the stars and on the semimajor axis ratio between the planet and the binary.

We show that each model has both advantages and limitations. While the first-order analytical model is algebraically simple and easy to implement, it is only applicable in regions of the parameter space where the perturbations are sufficiently small. The second-order model, although more complex, has a larger range of validity and must be taken into account for dynamical studies of some real exoplanetary systems such as Gamma Cephei and HD 41004A. However, in some extreme cases, neither of these analytical models yields quantitatively correct results, requiring either higher-order theories or direct numerical simulations. Finally, we determine the limits of applicability of each analytical model in the parameter space of the system, giving an important visual aid to decode which secular theory should be adopted for any given planetary system in a close binary.

P8.2 Secular resonances in circumstellar planetary systems in binary stars

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Planet formation around single stars is already a complicated matter, but extrasolar planets are also present in binary and multiple star systems. We investigate circumstellar planets in binary star systems with stellar separations below 100 astronomical units.

For a selection of 11 systems with at least one detected giant planet we determine the location and extension of the habitable zone (HZ), subject to the incident stellar flux from both stars. We work out the stability of additional hypothetical terrestrial planets in or close to the HZ in these systems.

To study the secular dynamics we apply a semi-analytical method. This method employs a first-order perturbation theory to determine the secular frequencies of objects moving under the gravitational influence of two much more massive perturbers. The other part uses a single numerical integration of the equations of motion and a frequency analysis of the obtained time-series to determine the apsidal precession frequencies of the massive bodies. By combining these two parts we are able to find the location of the most important secular resonances and the regions of chaotic motion.

We demonstrate that terrestrial planets interior to the giant planet's orbit may suffer from a linear secular resonance that could prevent the existence of habitable planets. Contrary to this, close-in giant planets are less of a problem, but one has to take into account the general relativistic precession of the pericenter that can also lead to resonances.

P8.3 Tidal evolution of viscoelastic bodies: a numerical approach

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Close-in terrestrial exoplanets are subjected to strong stellar tides, resulting in their long-term orbital evolution and in a possible boosting of their internal dynamical evolution via tidal heating. The process of tidal interaction, however, depends strongly on the rheology assigned to the planet. Rheological assumptions enter the mathematical model when we prescribe a tidal lag (either a phase lag or a time lag between the stress and the displacement) and a potential Love number k. Both of these quantities should be, in general, frequency dependent, but for the sake of simplicity are often treated as constants. Two most prominent classes of models assume either a constant phase lag (e.g. [1]) or a constant time lag (e.g. [2]). Although the simplifications are justified in some cases, they become unsuitable when studying the long-term orbital evolution of terrestrial planets and moons, as they predict a stable "pseudo-synchronous" (non-synchronous) rotation which is not observed. The majority of large moons in the Solar system is actually locked into a synchronous spin state. Analytical treatment of the tidal evolution for more realistic viscoelastic rheologies has already been proposed by several authors (e.g. [3], [4]). Here, we present a numerical approach to the problem enabling us to include a more general viscosity pattern of the evolving body.

The tidal deformation of the planetary mantle is computed in the time domain using a spherical harmonic decomposition in the lateral directions and a staggered finite difference scheme in the radial direction [5]. The resulting deformation and stress fields are used to obtain the rate of the tidal heating on the one hand and the information about the mass excess or deficit at boundaries on the other hand. This enables us to evaluate the disturbing potential or force, which can be understood as a source term in the Gauss planetary equations, describing the evolution of the Keplerian orbital elements. Together with the Gauss equations, we solve the evolution equation for the spin rate. We study the tidal heating and orbital evolution assuming the Maxwell or the Andrade viscoelastic rheology for Earth-like planets with different viscosities (including different 3D viscosity patterns) and various initial orbital parameters. The characteristic features of the results are always associated with the spin-orbit resonances, where the ratio of the rotational and orbital frequency becomes an integer or half-integer (e.g. 1:1, 3:2, 2:1): In the resonant states we get the minima of tidal heating and – in a range of realistic viscosities – zero values of the tidal torque. The pseudo-synchronous rotation is observed in the viscous limit. The capture especially into the 1:1 resonance leads to uneven insolation and temperature contrast on the surface and have important consequences forÂ the cooling of the mantle and the core as well as possible habitability of the planet.

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P8.4 Resonant stable orbital configurations in three-planet systems

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Capture in mean motion resonance of planetary orbits may provide orbital configurations for which multi-planet systems show long-term stability. The problem of resonance capture in two-planet systems has been extensively studied. Such a capture likely occurs when the planets migrate due to dissipative forces, which may originate in the interaction of planets with the protoplanetary disk. Considering a Stokes|s like drag to model the dissipative forces, a planetary system after a possible resonance capture seems to follow particular dynamical paths in phase space that consists of periodic orbits or, equivalently, centers of librations of the resonant angles and the apsidal difference. Along these paths, planetary eccentricities or even inclinations may increase considerably, but they lock the system in a stable evolution.

In this work we examine whether resonance capture and a locking in a stable configuration is possible for systems of three planets. Our study shows that the configurations 1:2:4 (Laplace resonance) and 1:3:6 appear most frequently. Apart from the above cases, other resonant configurations have been found, providing also possible orbital configurations of extrasolar systems, which may evolve regularly for very long time intervals.

P8.5 Orbital perturbation on the rotation of exoplanets

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The habitability of a planet greatly depends on its rotational state. The orbital environment of a planet can have a huge impact on its rotation, including the possibility of being trapped in various spin-orbit resonances, or in a generalised chaotic rotation. I propose to illustrate that on two examples: for planets in a mean motion resonance, and for a planet around a binary star. The presented results can, to some extend, be generalised for other orbital perturbation, and lead to major c riteria for the habitability of an exoplanet.

P8.6 A dynamical study on the origin of the Moon

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The process of the formation of the Moon still yields many open questions. The generally accepted scenario proposes a giant impact of a Mars-sized body onto the proto-Earth between 70 to 100 million years after the formation of the terrestrial planets. According to popular theories the Moon formed from the debris disk generated by this giant impact. The goal of our dynamical studies is to find the initial orbit of the Mars-sized impactor (Theia) by investigating the regarding probability of a collision with Earth. Due to previous studies it is assumed that Theia formed between Earth and Mars at the same time as the other terrestrial planets did. Then the planet has to stay on a stable orbit for tens of millions of years till it may collide with the Earth leaving the rest of the inner solar system almost unaffected. In order to investigate the most probable origin of Theia we did n-body simulations starting a Mars-sized object with semi-major axis between 1.085 AU to 1.119 AU at low inclination altering the mean anomaly for each starting position from 0°–360°. Additionally, simulations with an initial position of Theia inside the orbit of Earth (semi-major axis between 0.875 AU and 0.940 AU) were carried out. In total up to 10000 scenarios were calculated. The used model consists of an inner solar system with Venus, Earth and Mars at their known positions and the additional Theia as well as Jupiter and Saturn at their present orbits. The system was calculated up to 100 million years finding three possible outcomes namely collision with Earth, ejection or stability for the whole calculation period for Theia. Our results place the possible origin of Theia at 1.17 AU where most collisions happen after more than 70 million years. Additionally, the results of the dynamical n-body studies provide important data of the impact such as impact velocity and impact angle which will serve as basis for further detailed investigation of the impact itself by SPH (Smooth Particle Hydrodynamics) computations.

P8.7 Activating main belt comets by collisions

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Since their identification as a new class of bodies by Hsieh and Jewitt in 2006 active asteroids (or Main Belt Comets, MBCs) have attracted a great deal of interest. Given that sublimation of volatile material (presumably water-ice) drives MBC activity, these bodies are probable candidates for delivering a significant amount of Earth's water. Dynamical studies suggest in-situ formation of MBCs as the remnants of the break-up of large icy asteroids. Also, collisions between MBCs and small objects might have exposed sub-surface water-ice triggering the cometary activity of these bodies. In order to advance the effort of understanding the nature of MBC activation, we have investigated these collision processes by simulating the impacts in detail using a smooth particle hydrodynamics (SPH) approach that includes material strength and fracture models. Our simulations cover a range of impact velocities (between 0.5 km/s and 5.3 km/s) and angles, allowing m-sized impactors to erode enough of an MBC's surface to expose volatiles and trigger its activation. We also varied the material strength of the active asteroid's surface to study its influence on crater depths and shapes. As expected, depending on the impact energy, impact angle, and MBC's material strength we observe different crater depths. Across all scenarios however, our results show that the crater depths do not exceed a few meters. This implies that if the activity of MBCs is due to sublimating water-ice, ice has to exist in no deeper than a few meters from the surface.

P8.8 Decoupling of a planet from its disk in presence of an inclined stellar companion

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We present hydrodynamical simulations of the evolution of planet-disk systems that are inclined respect to the orbit of a binary companion star. Starting from the assumption that the planet form within the disk, we explore the evolution of the mutual inclination between the planet and the disk under the gravitational perturbations of the secondary star.

We show that an increasingly larger tilt develops between the angular momentum of the planet and that of the disk because of different timescales of their evolution. The progressive separation of the planet from the disk does not halt its migration towards the star which, in this scenario, is dominated by the friction with the gas during the crossing of the disk plane. We find that this evolution occurs also for binary separations larger than 100 AU and when self-gravity is included in the simulations.

P8.9 The habitability of eccentric planetary orbits

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The huge number of exo-planets discovered so far show an unexpected diversity of planetary systems where most planets indicate eccentricity motion. Since Earth is still the only habitable planet we know and the planetary motion in our Solar system is nearly circular we study possible constraints of habitability in case of eccentric planetary motion.

Previous dynamical studies have shown that the architecture of the giant planets in a system might influence the motion in the habitable zone (HZ). Such orbital perturbations may change the conditions of habitability for a terrestrial planet in the HZ. In this context, it has been shown that a small change in the mutual distance of Jupiter and Saturn would lead to a secular perturbation of Earth orbit with variations in eccentricity from 0.0 to 0.7.

For planetary motion in binary star systems gravitational perturbations play an important role not only for the long-term stability also the habitability can be affected. In this presentation we discuss the problems that will arise in case an Earth-type planet exits the HZ periodically and approaches a Sun-like star up to 0.3 AU where we pay special attention to the Nitrogen-loss from this planet.

P8.10 Binary Catalogue of Exoplanets

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Since 1995 there is a database which list most of the known exoplanets (The Extrasolar Planets Encyclopaedia at http://exoplanet.eu/). With the growing number of detected exoplanets in binary and multiple star systems it became more important to mark and to separate them into a new database, which is not available in the Extrasolar Planets Encyclopaedia. Therefore we established an online database (which can be found at: http://www.univie.ac.at/adg/schwarz/multiple.html) for all known exoplanets in binary star systems and in addition for multiple star systems, which will be updated regularly and linked to the Extrasolar Planets Encyclopaedia. The binary catalogue of exoplanets is available online as data file and can be used for statistical purposes. Our database is divided into two parts: the data of the stars and the planets, given in a separate list. We describe also the different parameters of the exoplanetary systems and present some applications.

P8.11 Eclipse timing variations to detect exoplanets in binary star systems

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This work is devoted to study the circumstances favorable to detect planets in S- or P-Type orbits in close binary star systems by the help of eclipse timing variations (ETVs). A planet in S-Type motion orbits one of the two stars while a planet in P-Type motion orbits both stars. One can detect ETV signals with the help of former (CoRoT and Kepler) and future space missions Plato, Tess and Cheops). To determine the probability of the detection of such ETV Signals with ground based and space telescopes we investigated the dynamics of close binary star systems (stars separated by 0.5 to 3 AU). Therefore we did numerical simulations by using the full three-body problem as dynamical model. The stability and the ETVs are investigated by computing ETV maps for different masses of the secondary star and the exoplanet (Earth, Neptune and Jupiter mass). In addition we changed the planets eccentricity. We can conclude that many ETV amplitudes are large enough to detect planets in S- or P-Type orbits in binary star systems.

P8.12 A mean motion resonance as a source of fast routes through the Solar System

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The 5:2 MMR with Jupiter is a powerful resonance able to deliver material to different parts of the Solar System in relatively short times. Using sophisticated numerical methods based on FLI, we reveal the precise structure of chaos inside the resonance. In fact, we detect the structures of the so called hyperbolic manifolds, which are crucial in the mechanism of chaotic diffusion. In order to demonstrate the role of the observed structures in the dynamical transport mechanisms, 1000 test particles initially placed along them were integrated for 5 Myr.

The resulting orbits evolve in a large variety of dynamical scenaria, throwing a new light on the dynamical structure of the Solar System.

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