# Pathways to Habitability

## Austrian National Key Program

***<u>Understanding astrophysical conditions for habitable environments:</u>***

***Stellar output***
***magnetic fields, radiation, winds***
***magnetospheres, exospheres, atmospheres***
***protoplanetary disks, small bodies, system dynamics***

**"Project Conference"**

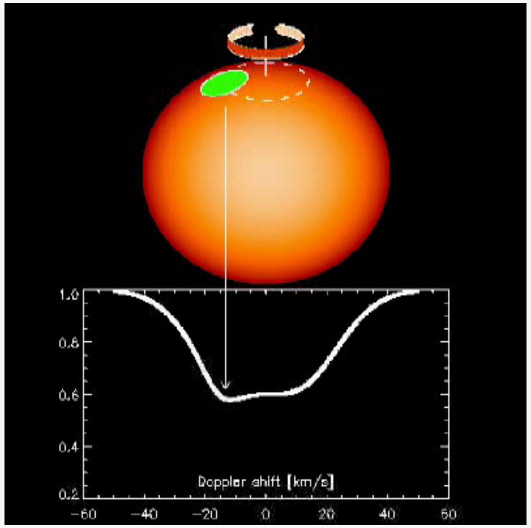
# The Astrophysics of Habitability

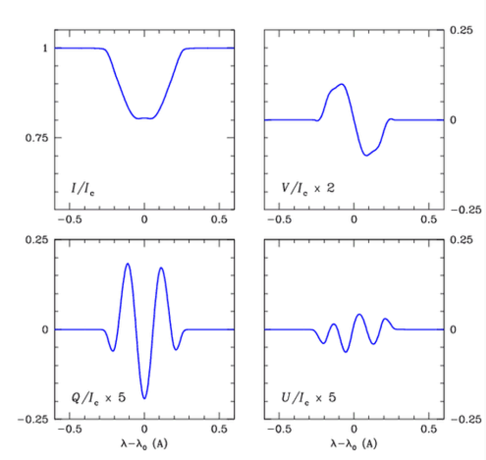
***Vienna, 9-12 February 2016***
***http://habitability.univie.ac.at***

***see you there!***

# Magnetic fields of stars and their influence on the habitability of Exoplanets

Lüftinger, T., Güdel, M., Johnstone, C.P., Kochukhov O., Fichtinger, B., Tu, L.,
Lammer, H., Kislyakova, K.G., Kodachenko, M.





- Zeeman Doppler Imaging (ZDI): reconstruct temperature and magnetic field structures on the surfaces of stars
- Field extrapolation methods allow us to estimate stellar wind characteristics which are crucial for the erosion/buildup of planetary atmospheres

**Observing campaigns:**

- successful survey proposals: HARPSpol and CRIRES@ESO, ESPaDOnS@CFHT: young clusters, snapshots of ~45 T Tauri stars of different evolutionary stages,
- **recently:** 22h Narval@TBL: $\pi^1$ Uma

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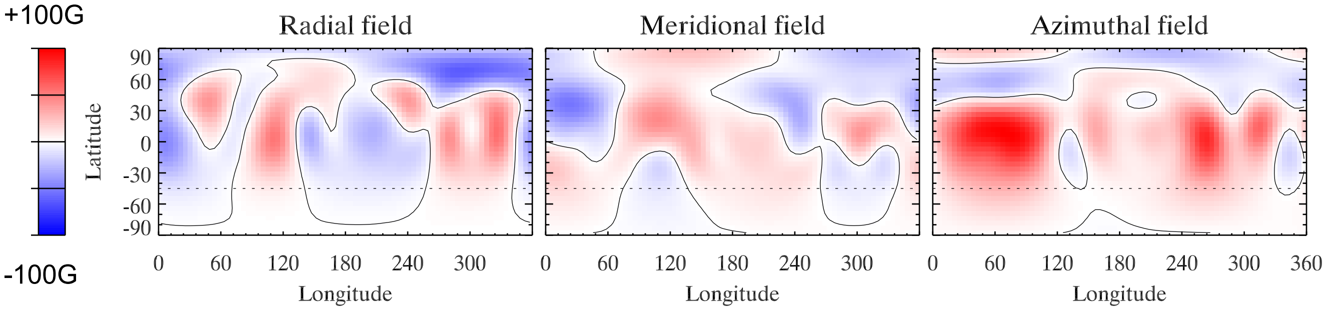
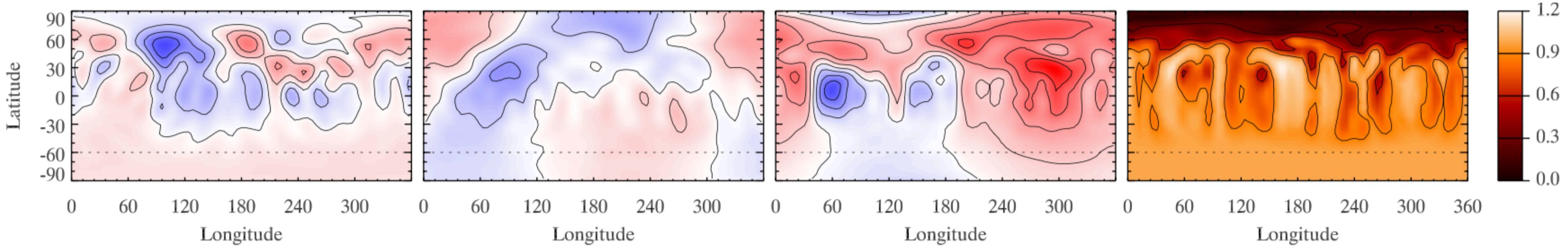
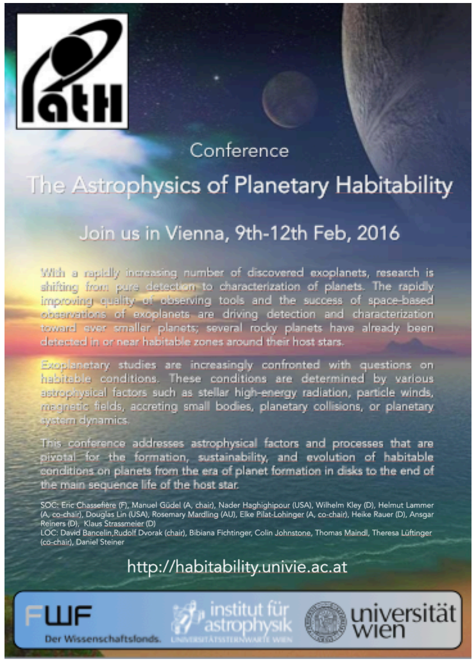
## $\pi^1$ UMa



## V410 Tau





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This conference addresses astrophysical factors and processes that are pivotal for the formation, sustainability, and evolution of habitable conditions on planets from the era of planet formation in disks to the end of the main sequence life of the host star.

SOC: Eric Chassefière (F), Manuel Güdel (A, chair), Nader Haghighipour (USA), Wilhelm Kley (D), Helmut Lammer (A, co-chair), Douglas Lin (USA), Rosemary Mardling (AU), Elke Pilat-Lohinger (A, co-chair), Heike Rauer (D), Ansgar Reiners (D), Klaus Strassmeier (D)
LOC: David Bancelin,Rudolf Dvorak (chair), Bibiana Fichtinger, Colin Johnstone, Thomas Maindl, Theresa Lüftinger (co-chair), Daniel Steiner

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based on InversLSD
*(Kochukhov, Lueftinger et al. 2014)*

*See you in Vienna,*
*February 9-12, 2015!*

# Radio observations of stellar winds of young solar-type stars

Bibiana Fichtinger, Manuel Güdel, Robert L. Mutel, Gregg Hallinan, Eric Gaidos, and Colin Johnstone

- Starting point: the initial solar mass required to solve the Faint Young Sun Paradox would be in the range of 1.03-1.07 $M_{sun}$, thus suggesting an enhanced early wind mass loss rate of order $10^{-12}$ – $10^{-10}$ $M_{sun}$ $yr^{-1}$ (Sackmann and Boothroyd, 2003)

- Radio observations for detecting stellar winds:
intensity fluxes define upper limits for bremsstrahlung of these young stars

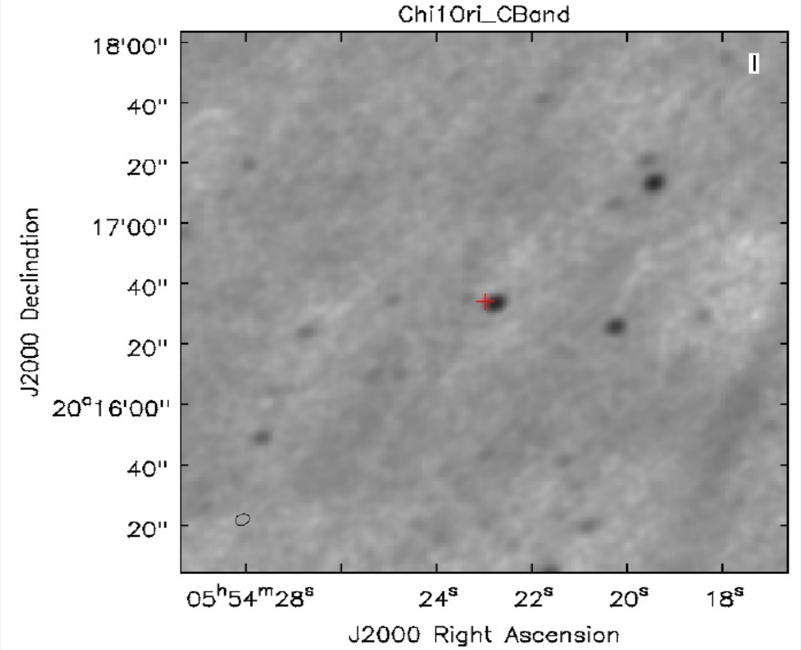

Fig.1: Intensity image of $x^1$ Ori at 6 GHz . The red cross mark the expected position of the source

| Object | $S_\nu[\mu Jy]$ Stokes I | | $S_\nu[\mu Jy]$ Stokes V | |
|---|---|---|---|---|
| | 6 GHz | 14 GHz | 6 GHz | 14 GHz |
| $\chi^1$ Ori | 110 ± 0.7 | 117 ± 2.7 | 14 ± 0.6 | 12 ± 1.1 |
| EK Dra | 593 ± 1.7 | 73 ± 2.4 | -22 ± 0.8 | - |
| $\kappa^1$ Cet | 9 | 9 | 6.9 | 8.7 |
| $\pi^1$ UMa | 23.1 | 6.3 | 8.4 | 6.6 |

Tab.1: Observational radio intensity fluxes for our four solar-type targets with the JVLA in two freqeuncy bands, C-band at 6 GHz and Ku-band at 14 GHz.

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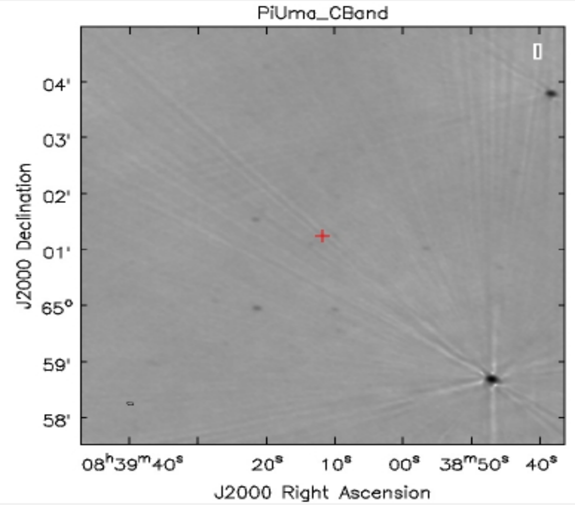


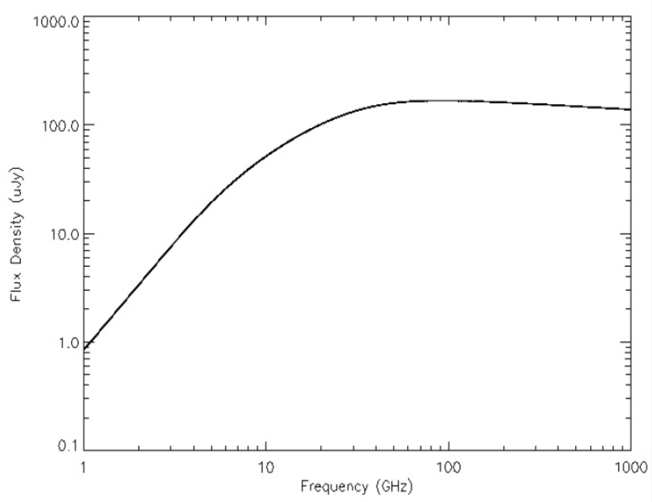
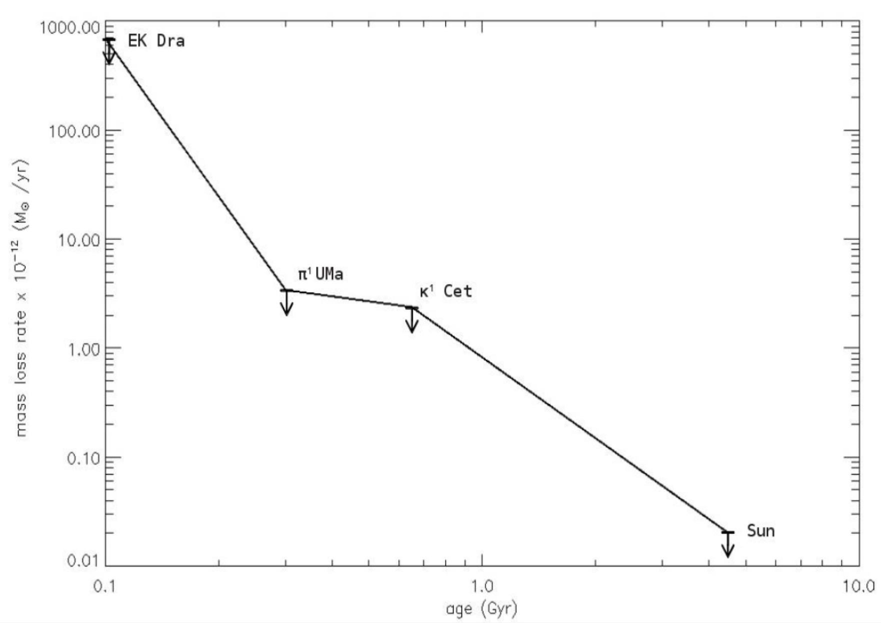


Fig.2: left: radio intensity map around $\pi^1$ UMa without radio signal
right: theoretically derived total radio emission flux with 40° opening angle

- **Early mass loss of the young Sun:** mass loss rates are calculated by assuming ionized, anisotropic, collimated winds ejected in polar direction (Reynolds, 1986)
- integration in time from 300 Myr to 4.5 Gyr → total mass of at most 0.5% resulting in an initial solar mass of 1.005 $M_{sun}$
- Our results indicate that the FYSP is unlikely to be solved by a more massive Sun at younger ages



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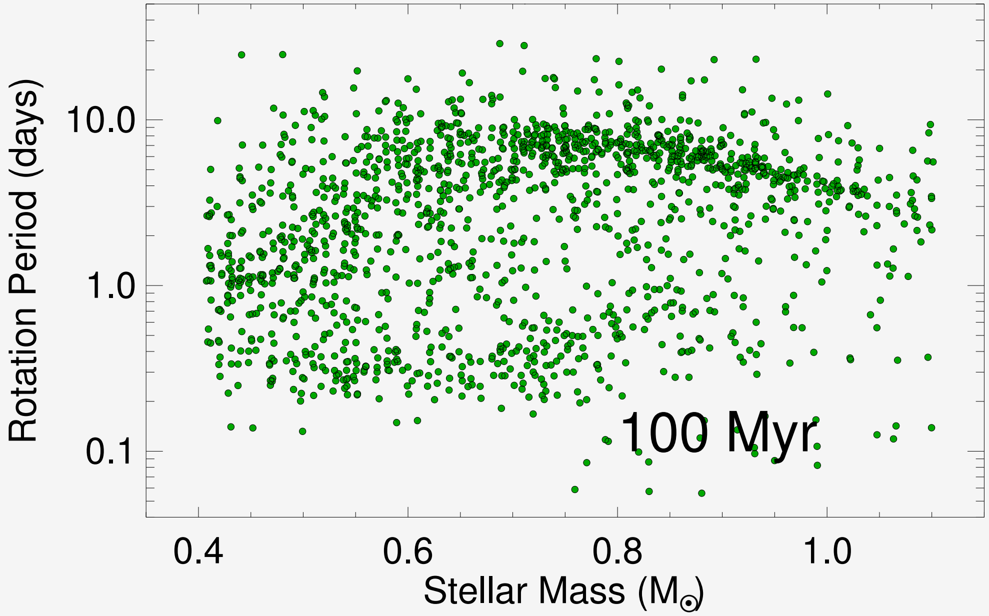
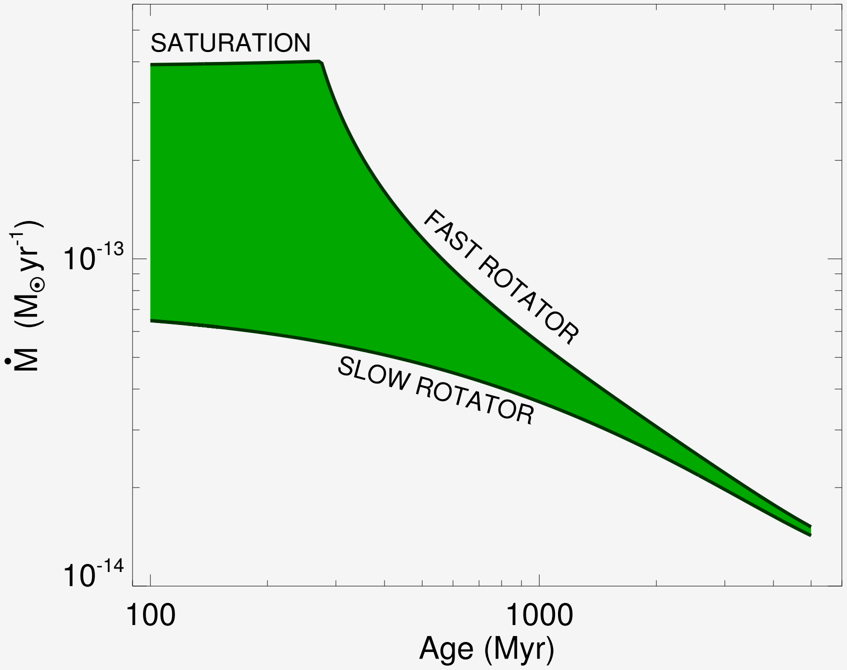
# Stellar winds on the main-sequence

Johnstone, C.P. , Güdel, M. , Tu, L. , Lüftinger, T. , Kislyakova, K.G., Lammer, H., Lichtenegger, H., Brott, I., Khodachenko, M.

## ROTATION AT 100 MYR



## THE SOLAR WIND IN TIME!



Both plots from Johnstone et al. (2015)

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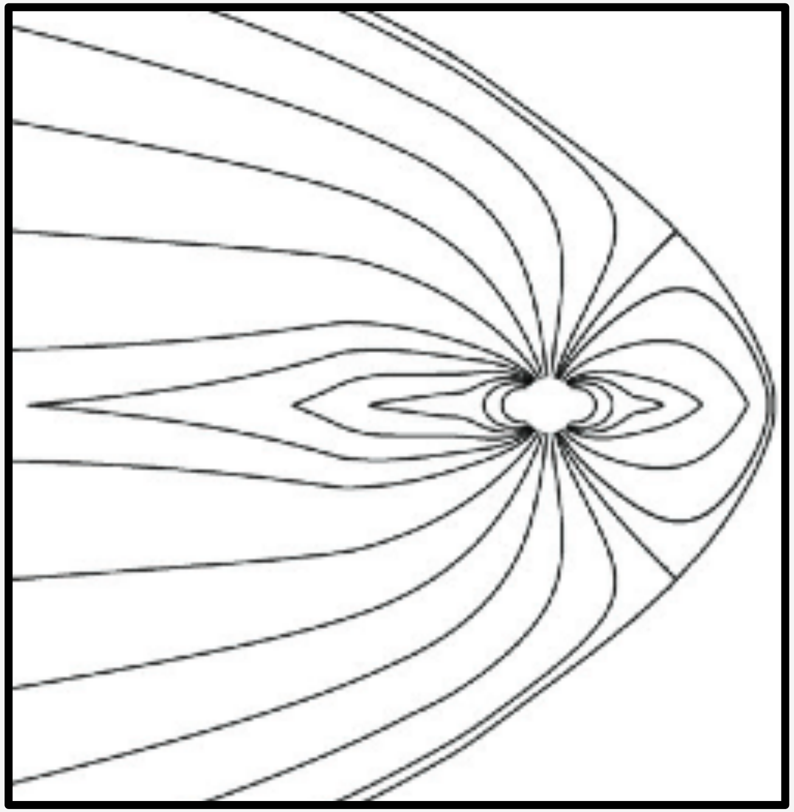
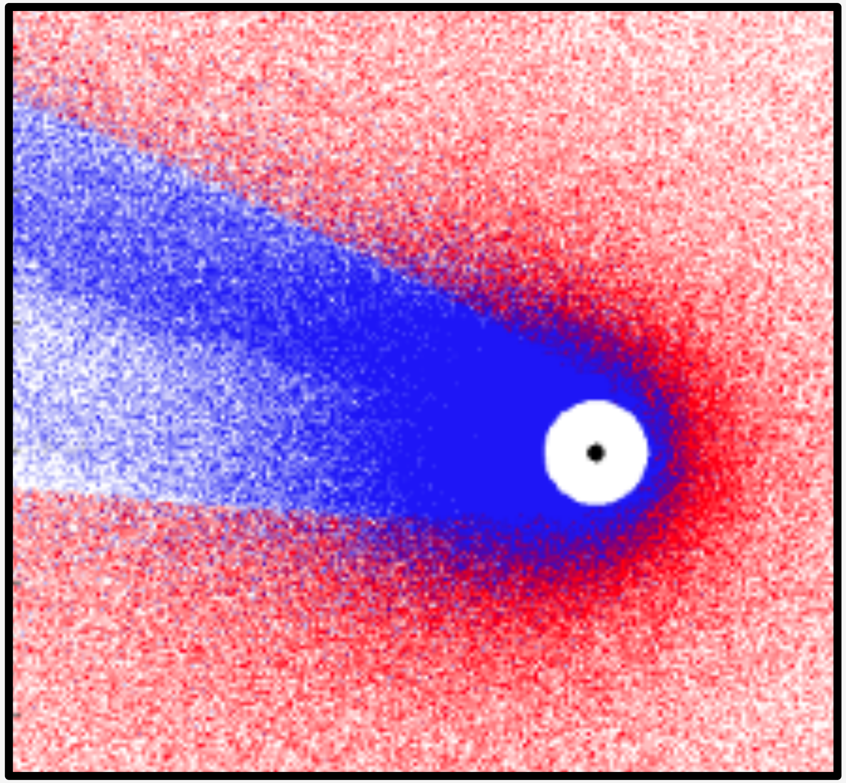
Right: wind-magnetosphere interactions (Khodachenko et al. 2012)





Left: non-thermal interactions (Kislyakova et al. 2014)

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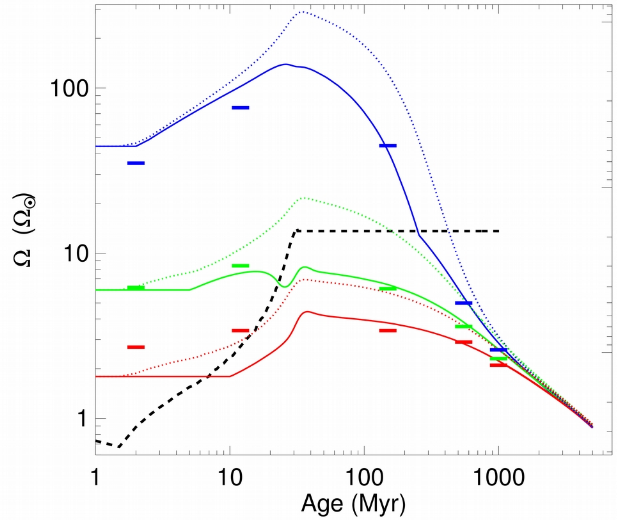
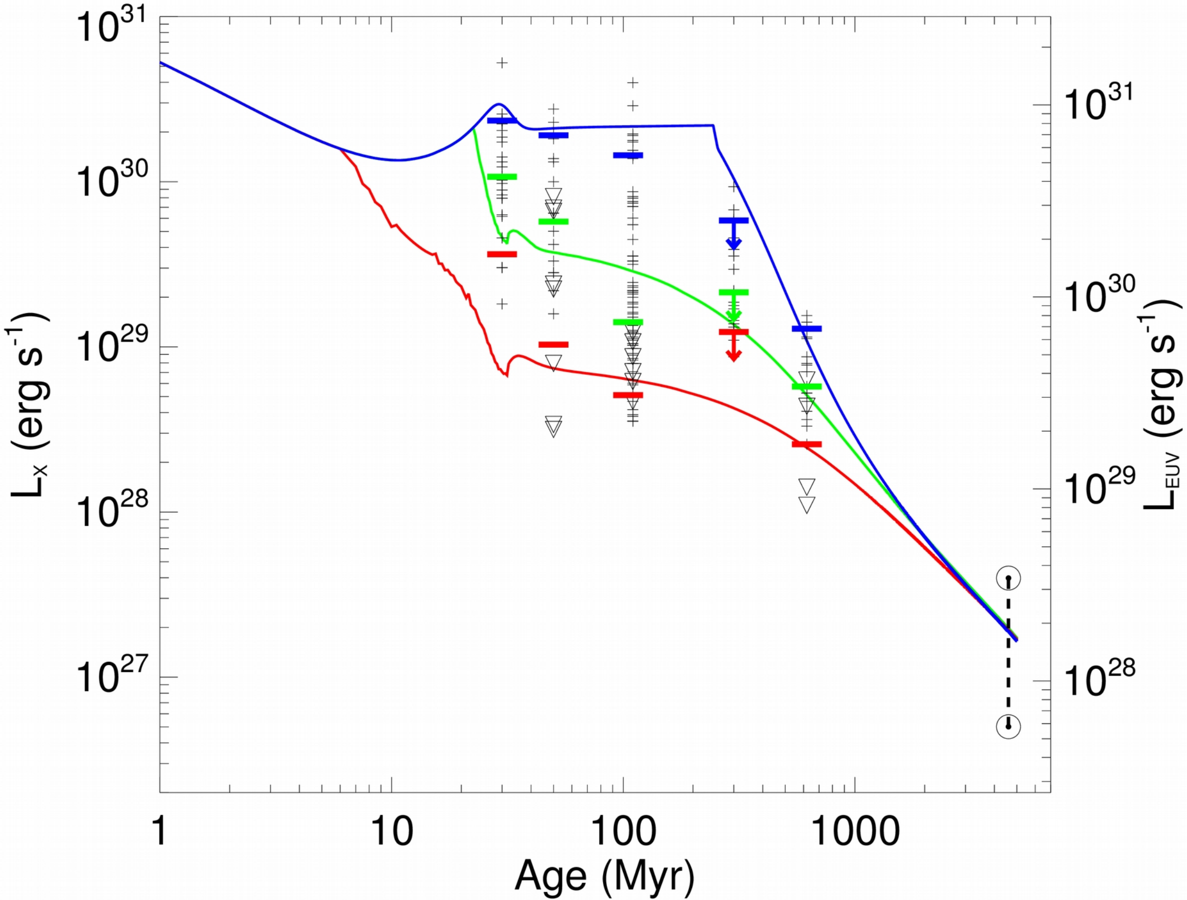
# A Stellar high-energy luminosity evolutionary model

Tu, L., Johnstone, C.P., Güdel, M., Lüftinger, T., Lichtenegger, H.I.M., Kislyakova, K.G., Lammer, H.





**Tu et al., 2015**

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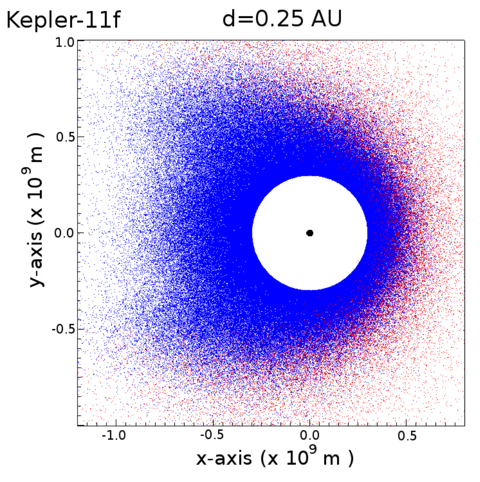
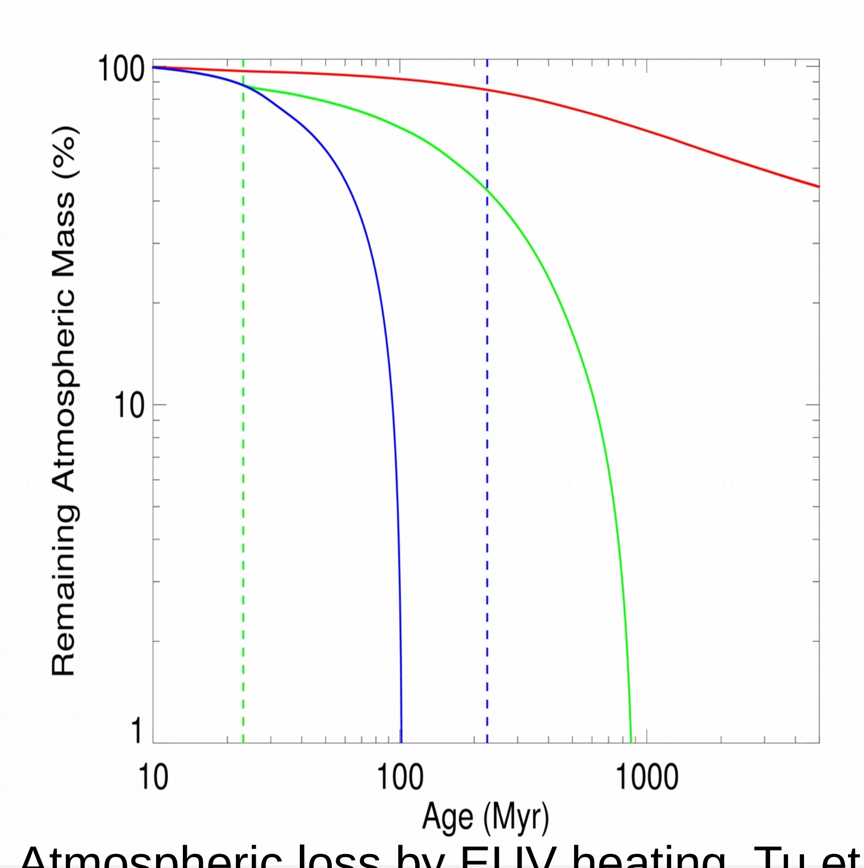


Stellar wind interaction with Kepler 11f atmosphere Kislyakova et al., 2015



Atmospheric loss by EUV heating. Tu et al., 2015

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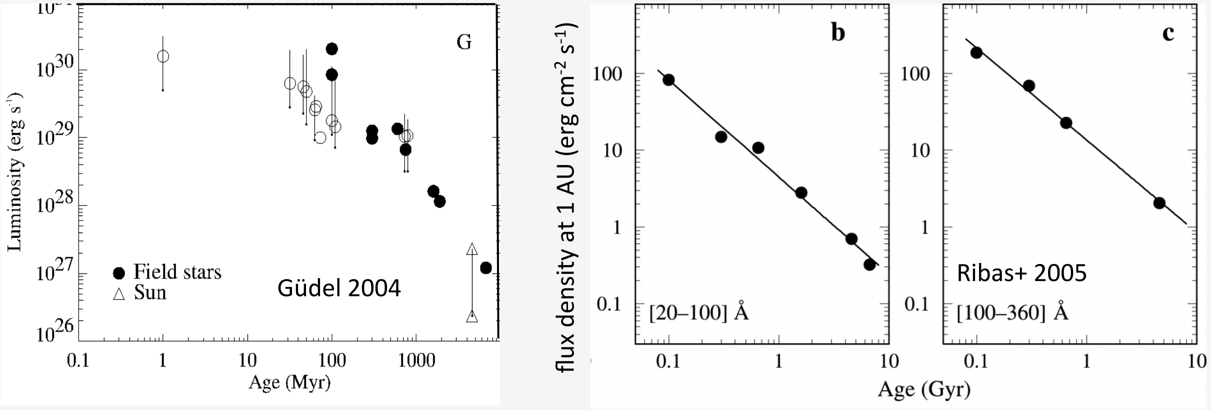
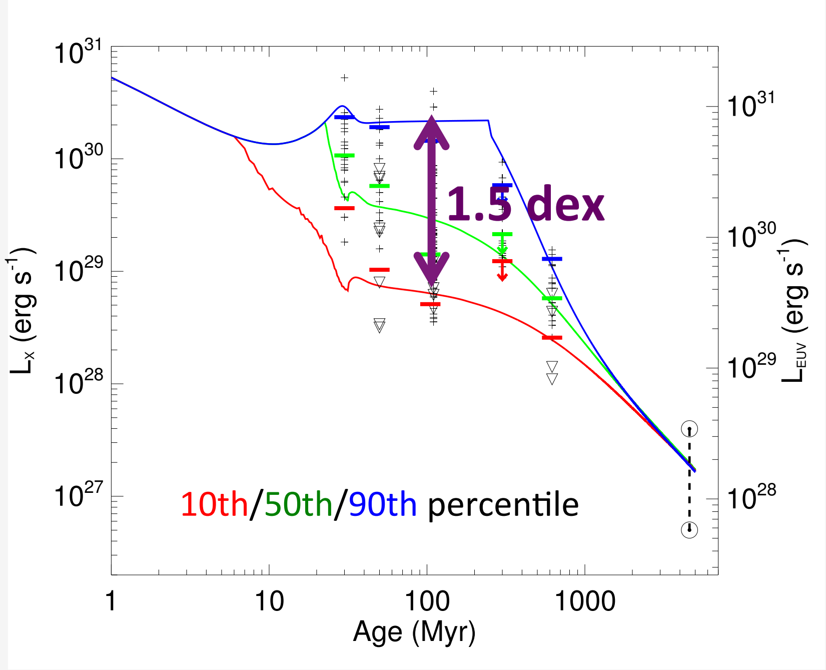
# Planetary Habitability: Constraints from Evolution

M. Güdel, C.P. Johnstone, L. Tu, H. Lichtenegger, T. Lüftinger, K.G. Kislyakova, H. Lammer, B. Fichtinger, P. Odert



Stellar X-ray activity declines with age: The conventional picture



- Large scatter in initial rotation rate
- Broad distribution in X-ray/EUV luminosity
- Wide range of irradiation histories possible
- Look-back: how active was the young Sun?

Johnstone et al. 2015, Tu et al. 2015

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## Venus Experiment:
## Evolution of Outgassed Atmosphere:

- 458 bar $H_2O$/101 bar $CO_2$ atmosphere
- $H_2O$ photodissociates: 2H + O
- H: thermal escape by $L_{XUV}$
- O, $CO_2$: dragged by H

Unless **the Sun was a low-activity star** (30x present-day XUV level), $CO_2$ is entirely lost to space!

*Present-day planetary atmospheres as probes of past solar-system conditions*

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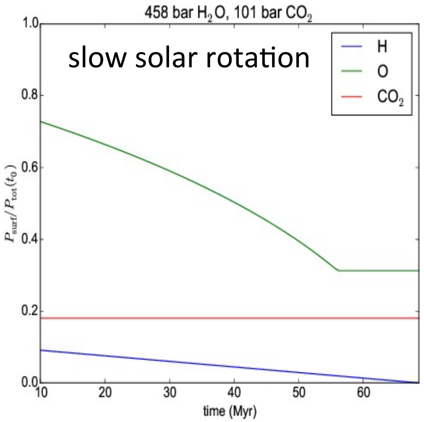

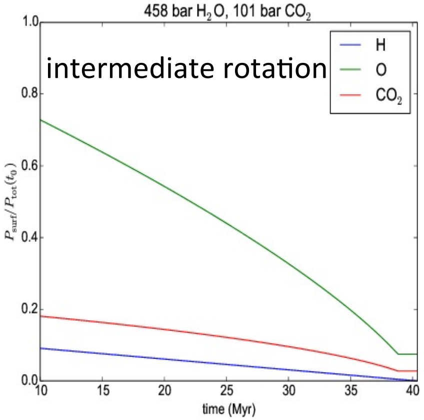

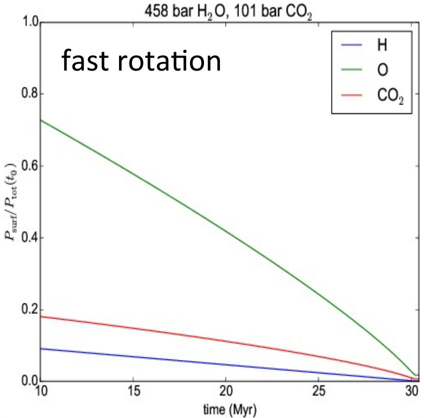

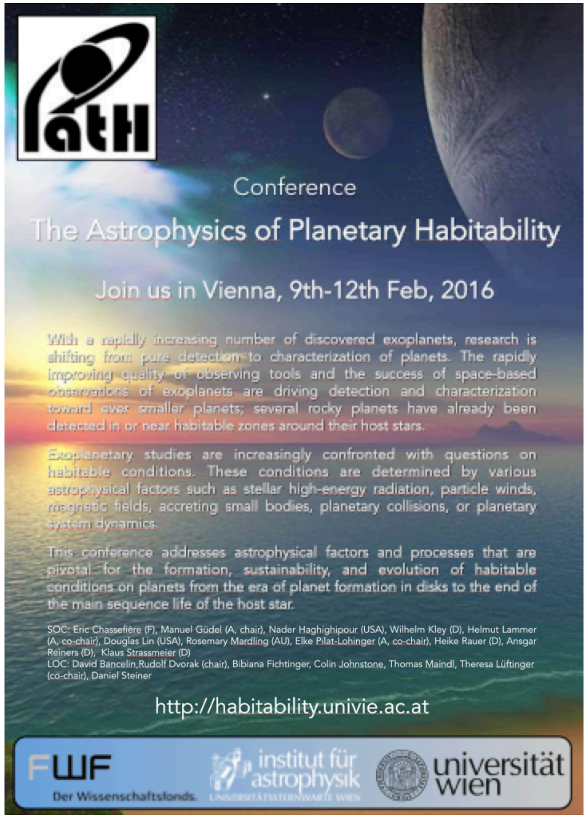

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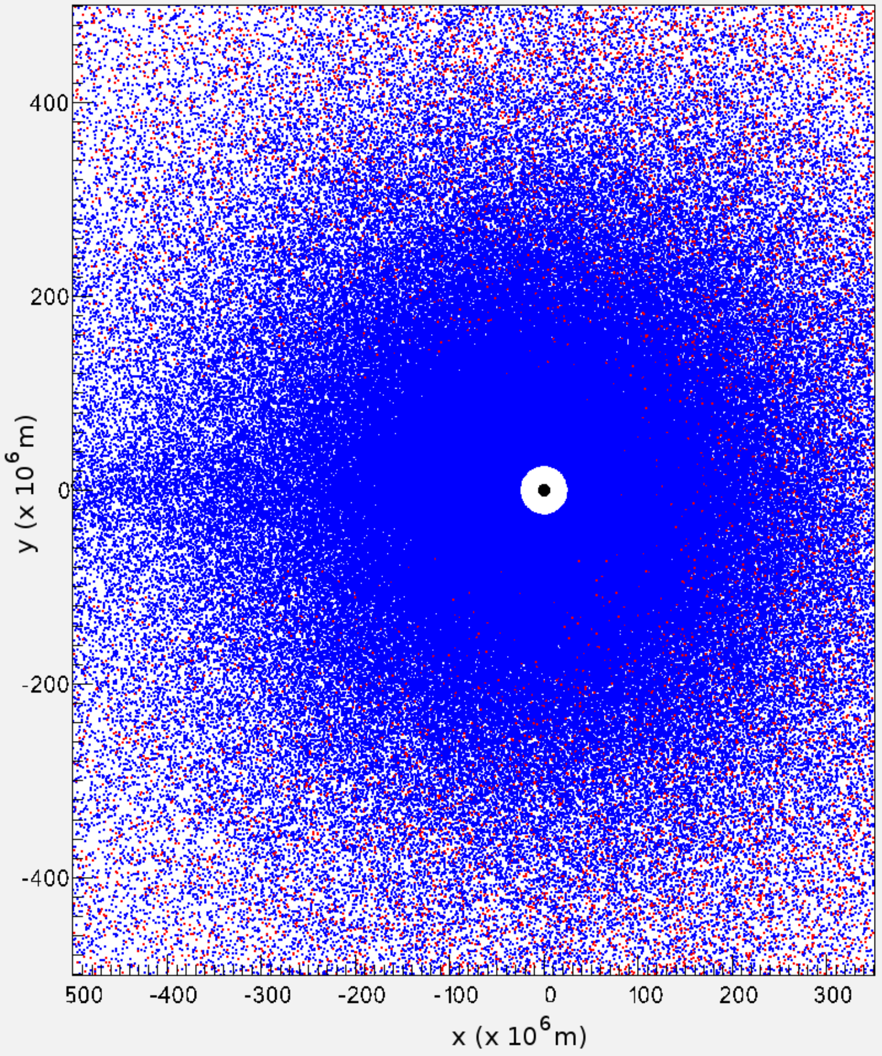
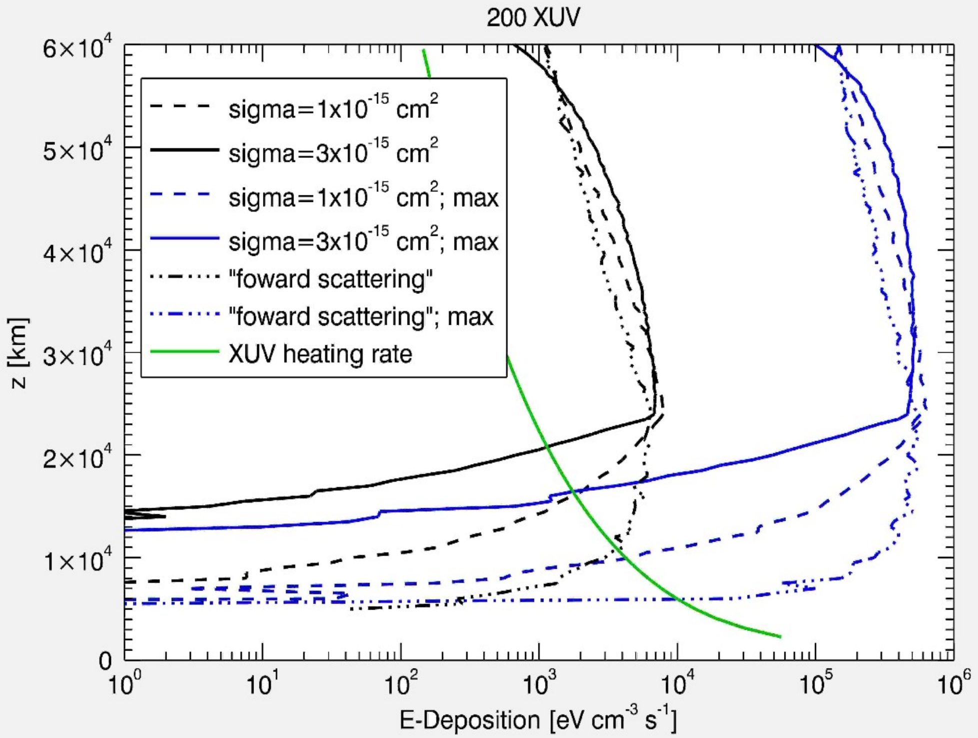
# ENA heating as an additional power for thermal escape of outgassed volatiles from early terrestrial planets

Kislyakova, K.G., Lichtenegger, H.I.M., Erkaev, N.V., Odert, P., Lammer, H., Johnstone, C.P.

Space Research Institute, Graz; University of Vienna, Vienna





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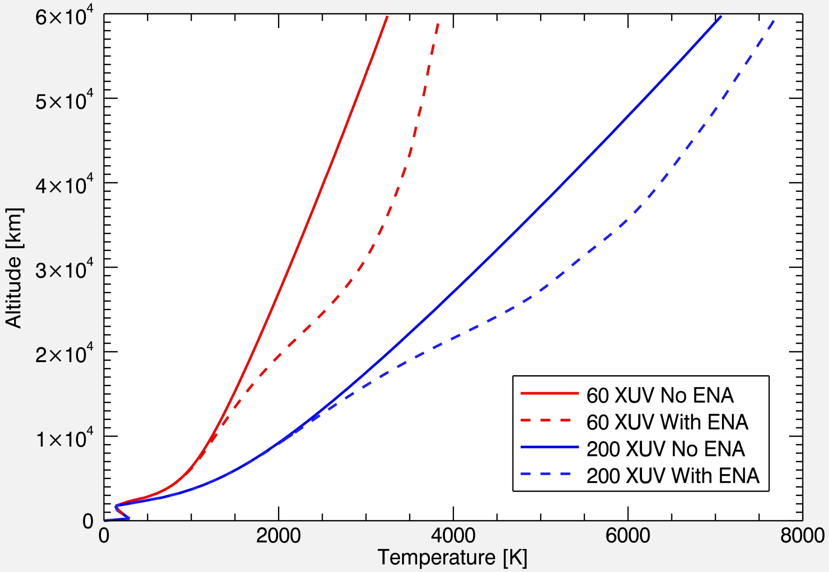
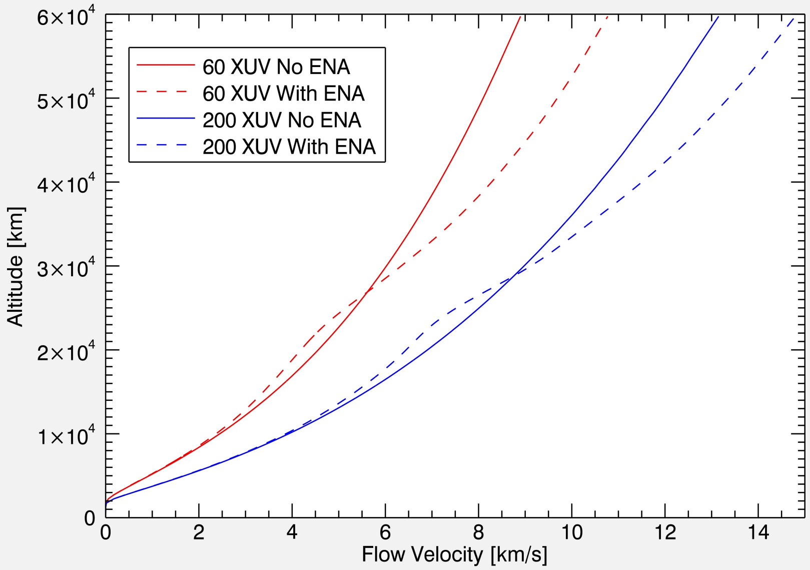
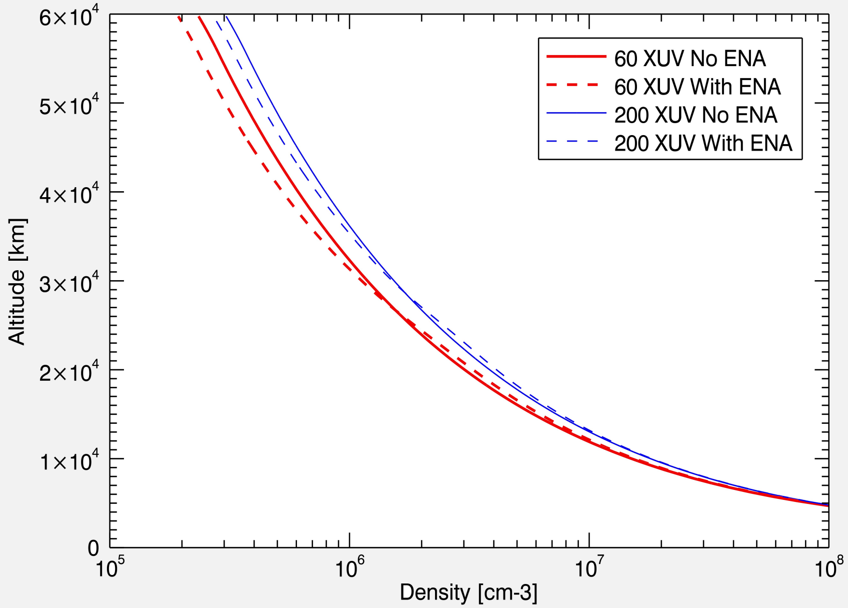
ÖAW Österreichische Akademie der Wissenschaften
IWF Institut für Weltraumforschung







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# Large-scale magnetic fields in disks

Daniel Steiner et al., University of Vienna

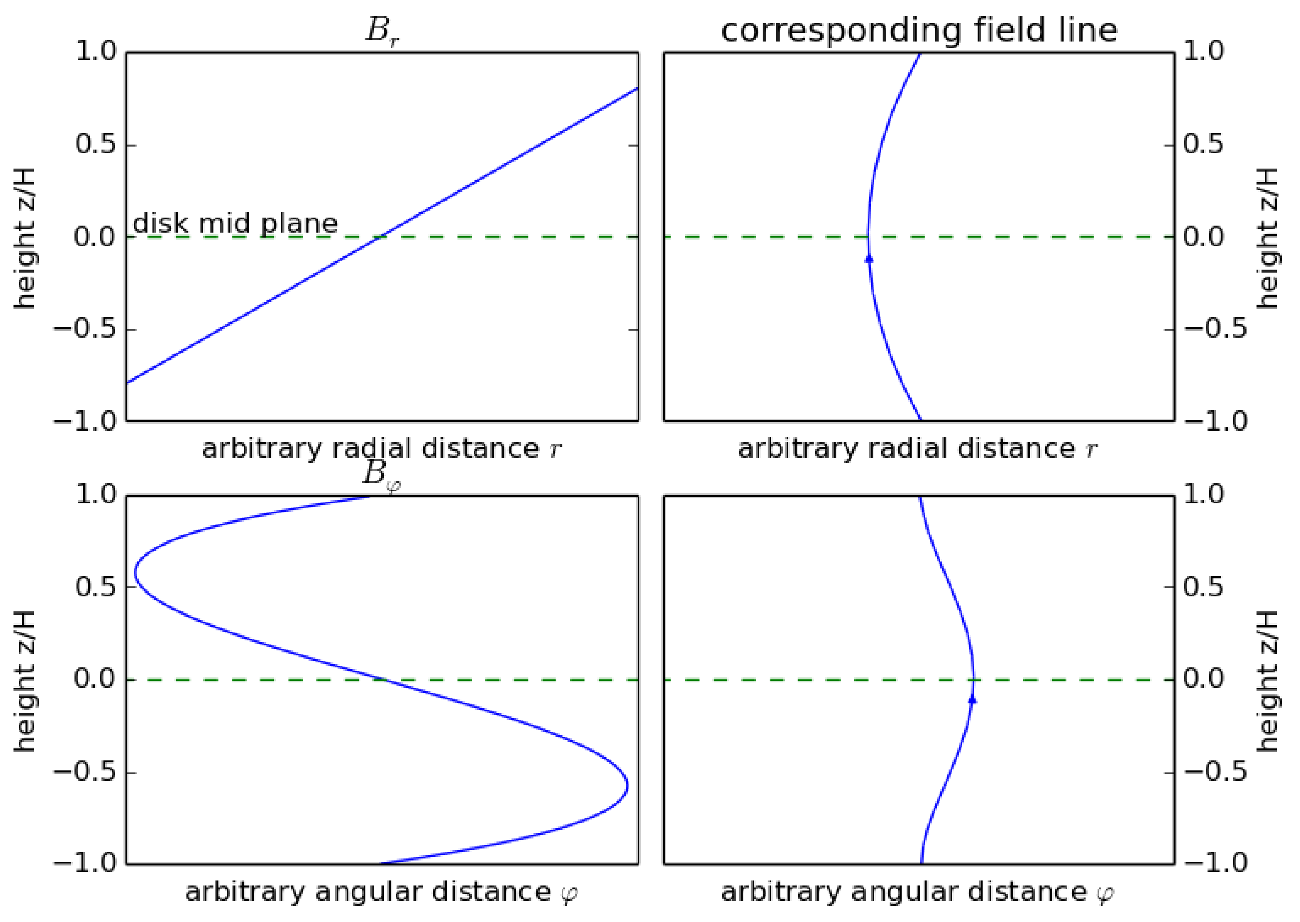

Fig. 1: Sketch of field line approximation inside of disk

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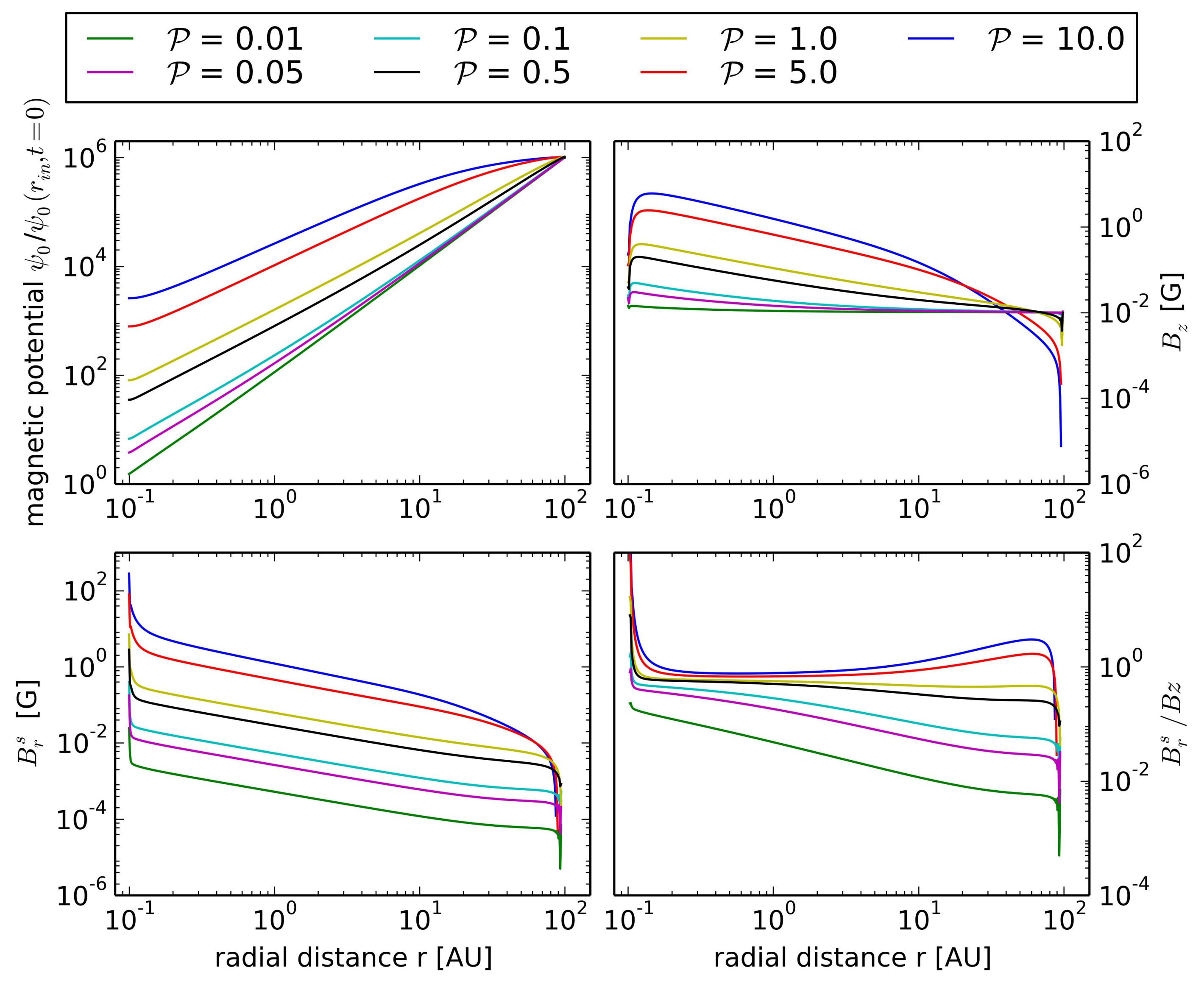

Fig.2: magnetic field topology of poloidal field in stationary state

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# Time-Dependent Simulations of Disk-Embedded Planetary Atmospheres

Alexander Stökl & Ernst Dorfi

- 1D spherical symmetric radiation hydrodynamics simulations spanning from the planetary surface up to the Hill radius.

- Energy budget for the planetary core using a constant, integral specific heat for the core.

- Calculations start with a hot planetary core surrounded by homogeneous nebula gas. Stationary disk environment with $\rho = 5 \times 10^{-10}$ g/cm$^3$ and T = 200 K on the outer boundaries.

- Planetary core cools down and accumulates disk gas into an atmosphere

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# Time-Dependent Simulations of Disk-Embedded Planetary Atmospheres

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&
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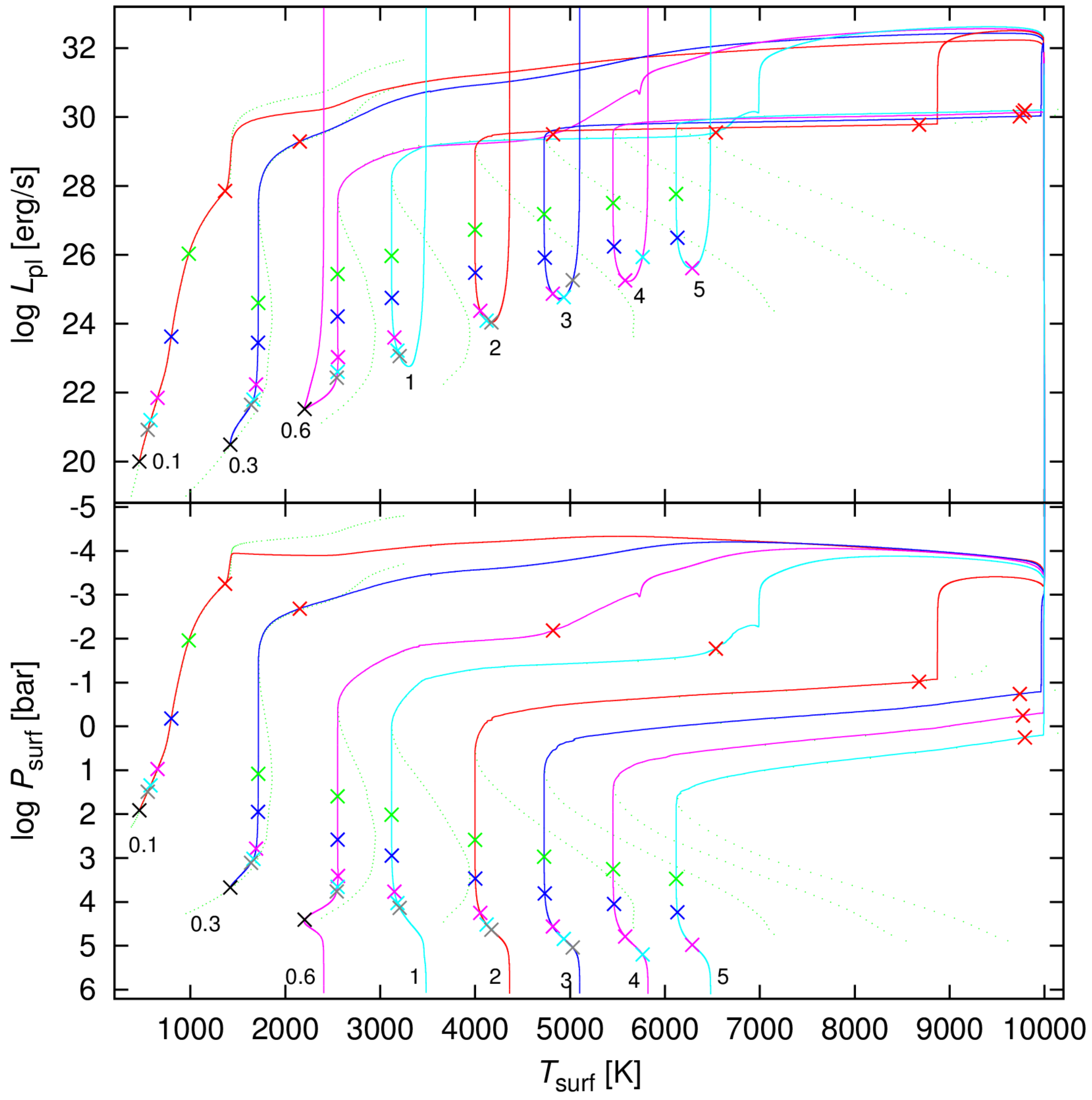
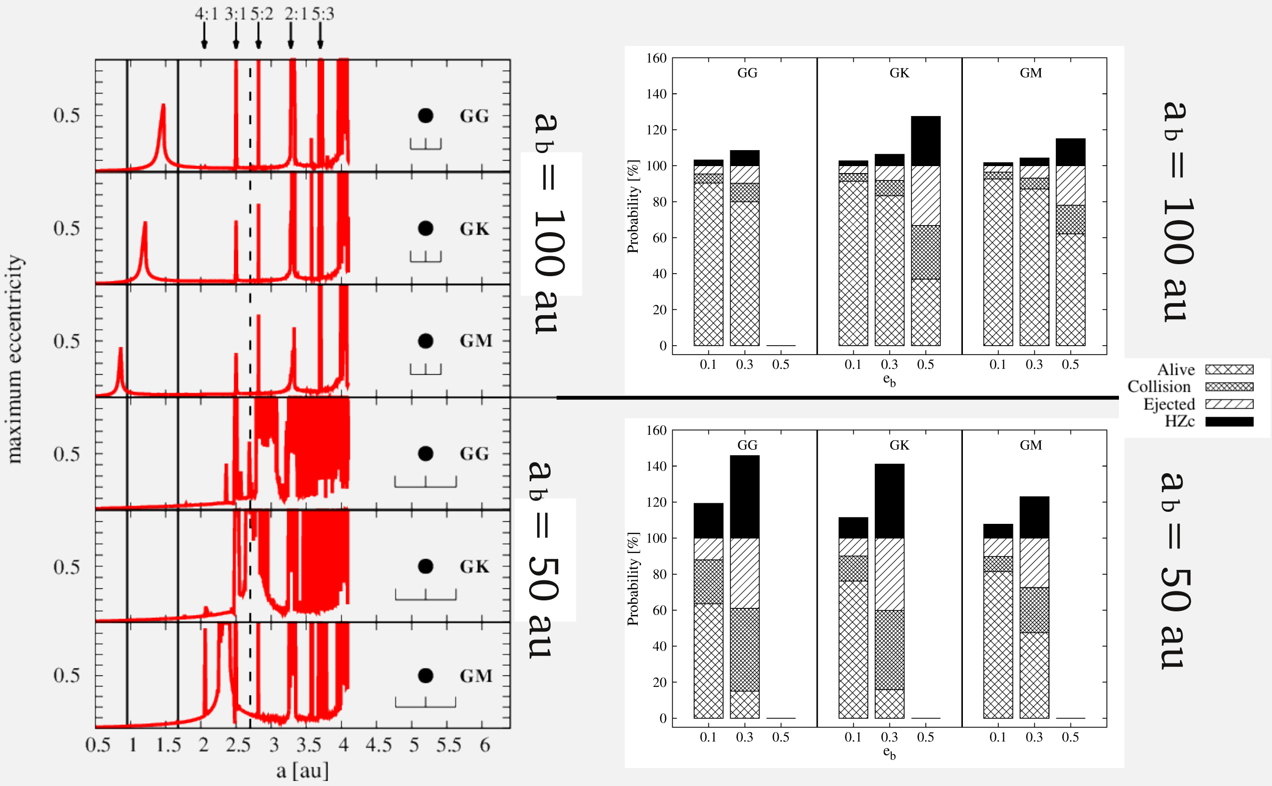


# Water transport into circumprimary habitable zones in binary star systems

D. Bancelin, E. Pilat-Lohinger, T.I. Maindl, S. Eggl, R. Dvorak

## Dynamics of planetesimals in binary star systems



*Left: Maximum eccentricity of test particles*
*Right: Statistics on the dynamics of the disk of planetesimals*

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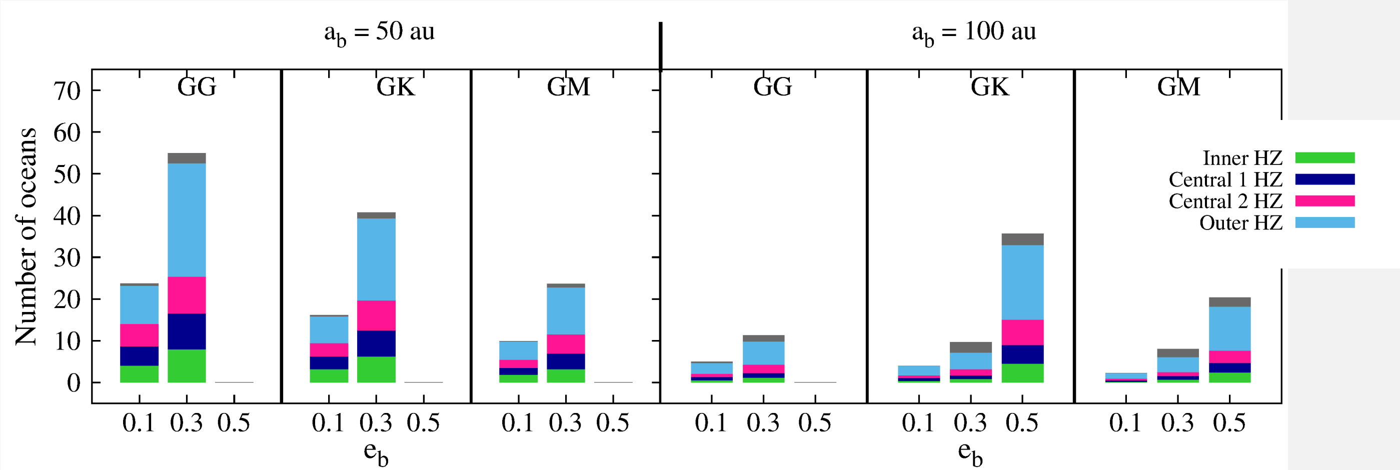
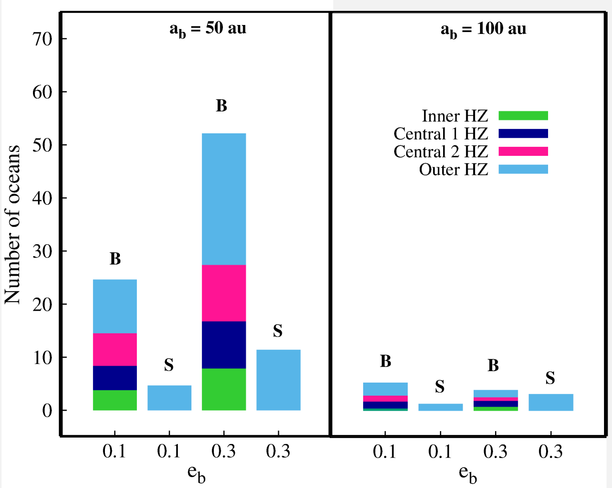
# Consequence for the water transport into the HZ



*Transport and distribution of water in the HZ in various binary star systems (< 6Myr)*

# Comparison with single star systems



*Comparison of water transport in single star (S) and binary star (B) systems*

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Poster ID.: 64594

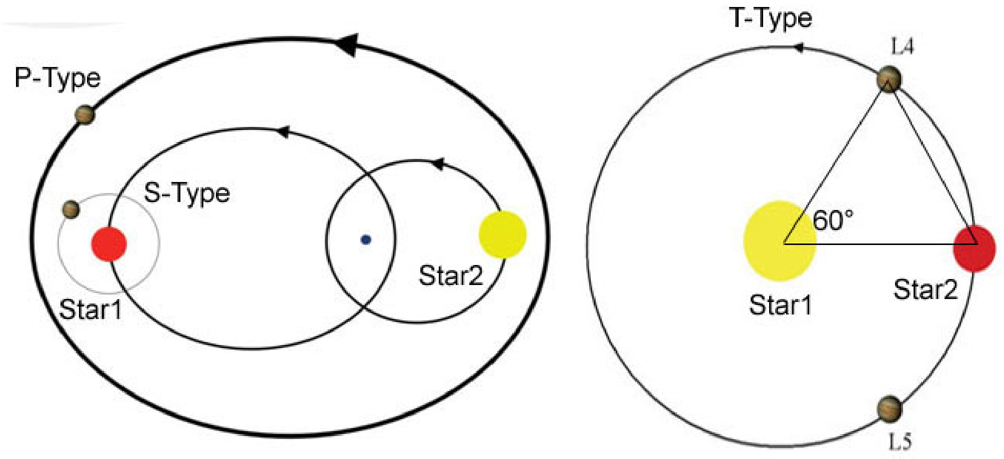
# ETV (TTV) signals of terrestrial Trojan planets in binary star systems

**R. Schwarz**, B. Funk, Á . Bazsó

Email: *richard.schwarz@univie.ac.at*

**Binary Catalogue:**
*http://www.univie.ac.at/adg/schwarz/multiple.html*

## In general, one can distinguish three types of stable orbits for planets in binary systems:



(i) **S-Type**, where the planet orbits one of the two stars,

(ii) **P-Type**, where the planet orbits the entire binary,

(iii) **T-Type**, where the planet orbits close to one of the two equilibrium points $L_4$ and $L_5$ (**Trojan planets**)

Exoplanet.eu
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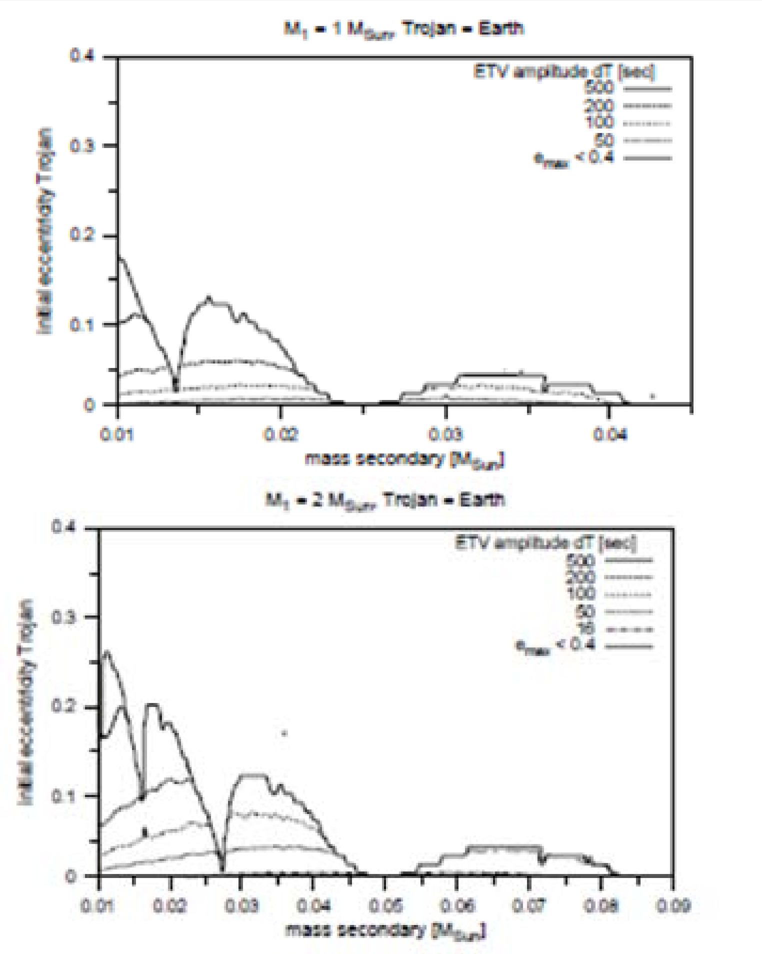
Results published:
Schwarz et al. (MNRAS)
submitted

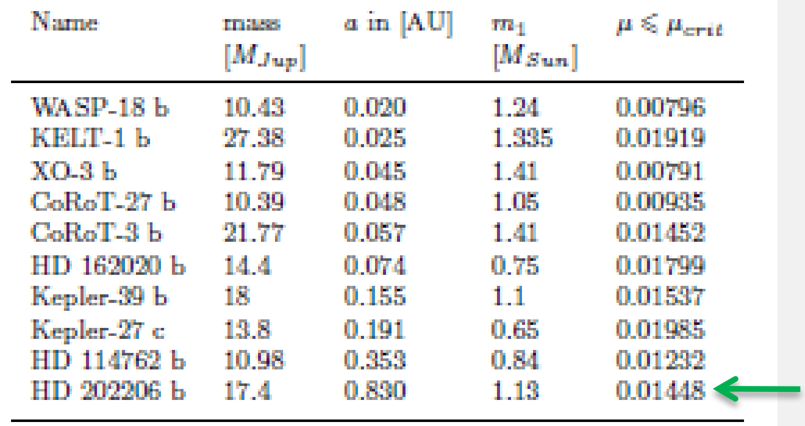


## Conclusion:

- Detectable ETV/TTV signals (**$dt_{max}$=16 sec**) for **all** stable configurations of Trojan planets with 1 $M_{Jup}$ and 1 $M_{jup}$
- Detectable ETV/TTV signals for **most** stable configurations of Trojan planets with 1 $M_{Earth}$
- Detectable ETV/TTV signals for **less than a half** of the stable orbits of Trojan planets with 1 $M_{Mars}$

## List of candidates:

- Binaries: 24 candidates (Antares, $\alpha$ Sco)
- Binary-like star systems:



| Name | mass [$M_{Jup}$] | $a$ in [AU] | $m_1$ [$M_{Sun}$] | $\mu \leqslant \mu_{crit}$ |
|---|---|---|---|---|
| WASP-18 b | 10.43 | 0.020 | 1.24 | 0.00796 |
| KELT-1 b | 27.38 | 0.025 | 1.335 | 0.01919 |
| XO-3 b | 11.79 | 0.045 | 1.41 | 0.00791 |
| CoRoT-27 b | 10.39 | 0.048 | 1.05 | 0.00935 |
| CoRoT-3 b | 21.77 | 0.057 | 1.41 | 0.01452 |
| HD 162020 b | 14.4 | 0.074 | 0.75 | 0.01799 |
| Kepler-39 b | 18 | 0.155 | 1.1 | 0.01537 |
| Kepler-27 c | 13.8 | 0.191 | 0.65 | 0.01985 |
| HD 114762 b | 10.98 | 0.353 | 0.84 | 0.01232 |
| HD 202206 b | 17.4 | 0.830 | 1.13 | 0.01448 |

← **HZ**

**Table 1.** List of candidates to detect possible Trojan planets in binary-like systems. The list is sorted according to the semi-major axis ($a_2$) of the brown dwarf.

**Conference: Astrophysics of PlanetaryHabitability**
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