Pathways to Habitability
Austrian National Key Program

Understanding astrophysical conditions for habitable environments:

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: π¹ Uma
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π¹ UMa

V410 Tau

based on InversLSD
(Kochukhov, Lueftinger et al. 2014)
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 $M_{\odot}$, thus suggesting an enhanced early wind mass loss rate of order $10^{-12} - 10^{-10} M_{\odot} \text{yr}^{-1}$ (Sackmann and Boothroyd, 2003)

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

<table>
<thead>
<tr>
<th>Object</th>
<th>$S_v[\mu\text{Jy}]$ Stokes I</th>
<th>$S_v[\mu\text{Jy}]$ Stokes V</th>
</tr>
</thead>
<tbody>
<tr>
<td>$\chi^1$ Ori</td>
<td>$110 \pm 0.7$</td>
<td>$117 \pm 2.7$</td>
</tr>
<tr>
<td>EK Dra</td>
<td>$593 \pm 1.7$</td>
<td>$73 \pm 2.4$</td>
</tr>
<tr>
<td>$\kappa^1$ Cet</td>
<td>$9$</td>
<td>$9$</td>
</tr>
<tr>
<td>$\pi^1$ UMa</td>
<td>$23.1$</td>
<td>$6.3$</td>
</tr>
</tbody>
</table>

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

Fig.1: Intensity image of $\chi^1$ Ori at 6 GHz. The red cross mark the expected position of the source.
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 \( 1.005 \, M_{\odot} \)

Our results indicate that the FYSP is unlikely to be solved by a more massive Sun at younger ages.
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.

Both plots from Johnstone et al. (2015)
Right: wind-magnetosphere interactions (Khodachenko et al. 2012)

Left: non-thermal interactions (Kislyakova et al. 2014)
A Stellar high-energy luminosity evolutionary model


Tu et al., 2015
A stellar high-energy luminosity evolutionary model

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


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
Venus Experiment: Evolution of Outgassed Atmosphere:

- 458 bar H$_2$O/101 bar CO$_2$ atmosphere
- H$_2$O 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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ENA heating as an additional power for thermal escape of outgassed volatiles from early terrestrial planets


Space Research Institute, Graz; University of Vienna, Vienna
Large-scale magnetic fields in disks

Daniel Steiner et al., University of Vienna

Fig. 1: Sketch of field line approximation inside of disk
Fig. 2: magnetic field topology of poloidal field in stationary state
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
Time-Dependent Simulations of Disk-Embedded Planetary Atmospheres

Alexander Stökl & Ernst Dorfi
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
Consequence for the water transport into the HZ

Comparison with single star systems

Comparison of water transport in single star (S) and binary star (B) systems
ETV (TTV) signals of terrestrial Trojan planets in binary star systems

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Email: richard.schwarz@univie.ac.at

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

Poster ID.: 64594

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)
Conclusion:

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

List of candidates:

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

<table>
<thead>
<tr>
<th>Name</th>
<th>mass $M_2$ [$M_{\text{Jup}}$]</th>
<th>$\alpha$ in [AU]</th>
<th>$m_1$ [$M_{\text{Sun}}$]</th>
<th>$\mu \leq \mu_{\text{crit}}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>WASP-18 b</td>
<td>10.43</td>
<td>0.020</td>
<td>1.24</td>
<td>0.00796</td>
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<tr>
<td>KELT-1 b</td>
<td>27.38</td>
<td>0.025</td>
<td>1.335</td>
<td>0.01919</td>
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<tr>
<td>XO-3 b</td>
<td>11.79</td>
<td>0.045</td>
<td>1.41</td>
<td>0.00791</td>
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<tr>
<td>CoRoT-27 b</td>
<td>10.39</td>
<td>0.048</td>
<td>1.05</td>
<td>0.00935</td>
</tr>
<tr>
<td>CoRoT-3 b</td>
<td>21.77</td>
<td>0.057</td>
<td>1.41</td>
<td>0.01452</td>
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<tr>
<td>HD 162020 b</td>
<td>14.4</td>
<td>0.074</td>
<td>0.75</td>
<td>0.01799</td>
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<tr>
<td>Kepler-99 b</td>
<td>18</td>
<td>0.155</td>
<td>1.1</td>
<td>0.01537</td>
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<tr>
<td>Kepler-27 c</td>
<td>13.8</td>
<td>0.191</td>
<td>0.65</td>
<td>0.01985</td>
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<tr>
<td>HD 114762 b</td>
<td>10.98</td>
<td>0.353</td>
<td>0.84</td>
<td>0.01232</td>
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<tr>
<td>HD 202206 b</td>
<td>17.4</td>
<td>0.830</td>
<td>1.13</td>
<td>0.01448</td>
</tr>
</tbody>
</table>

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.