Stellar Magnetic Fields - and their influence on the Habitability of Exoplanets

Theresa Lueftinger

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and the PatH Collaboration

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Theresa Lueftinger, IAU 305, Punta Leona, Costa Rica 05.12.2014
Stellar magnetic fields responsible for activity -> flares, CME’s, etc. and winds (Space Weather)

these, in turn, crucially influence the atmospheres of surrounding (potentially habitable) planets

**polarimetry**: main tool to study magnetic fields 
- needed to investigate field structures of (young) solar type stars (covering evolution along the PMS)
- wind models, couple to planetary atmospheres
- effect of a host star on the life-friendliness of a planet

- lucky times: ESPaDOnS, NARVAL, HARPSpol

FUTURE Instrumentation: Arago, JWST, PLATO, ELT, SPIRou etc.
Pathways to Habitability
From Disk to Stars, Planets to Life

Manuel Güdel, Theresa Lüftinger,
Ernst Dorfi, Rudolf Dvorak,
Maxim Khodachenko, Helmut Lammer,
Elke Pilat-Lohinger

cia. 40 national & 40 international co-operation partners
“Astronomical” Factors and Interactions

Dynamical stability

Atmosphere-exosphere-magnetosphere system

Stellar winds

protoplanetary disks

High-energy radiation and particles

Central star or binary

Planetary moons

Planetary interior/dynamo/convection/plate tectonics

landmass vs. oceans

“Planetary Factors”

(Kasting & Catling 29003)
## Short Overview – Key Parameters

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Details</th>
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<tbody>
<tr>
<td>Program established</td>
<td>1 March 2012</td>
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<tr>
<td><strong>Type</strong></td>
<td>Excellence/key program, research network</td>
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<td><strong>Funding agency</strong></td>
<td>Austrian Science Fund (FWF)</td>
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<td><strong>Duration</strong></td>
<td>4 + 4 years (until 29 Feb. 2020)</td>
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<td><strong>Institutes</strong></td>
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<td><strong>Positions</strong></td>
<td>12 (~50% PhD students, 50% postdocs)</td>
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<td><strong>Structure</strong></td>
<td>* 6 subprojects, led by project leaders</td>
</tr>
<tr>
<td></td>
<td>* reviewed annually by advisory committee</td>
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<tr>
<td></td>
<td>* 2 team science meetings/yr</td>
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Candidates in the Habitable Zone

As of January 7, 2013

~1822 exoplanets (as of 28.09.2014), 467 in multiple systems
2. Star – Planet Interaction

Consider stellar, interplanetary, and planetary environment as one physical system to be studied under extreme conditions in context:

- Stellar magnetic fields
- Stellar activity
- Stellar winds
- Transport mechanisms

- Magnetosphere-wind interaction
- Radiation-atmosphere interaction
- Magnetosphere-atmosphere system
- Gravitational perturbations
**Field structure and strength on stars**

successful survey proposals: HARPSpol and CRIRES@ESO, ESPaDOnS@CFHT young clusters (Lupus, Taurus Chamaeleon, Ophiuchus, Orion), snapshots of ~45 T Tauri stars of different evolutionary stages.

- **part I:** HARPSpol: 3n  
  CRIRES: 10h  
  CFHT: 25h

- **part II:** HARPSpol: 4n  
  CRIRES: 4h  
  CFHT: 35h

Magnetic field structure, photometric spots and chemical structure (top to bottom) of an A star (Lueftinger et al. 2010)

Magnetosphere of the T Tauri star V2129 Oph based on ZDI (from Donati et al. 2007)
Field structure and strength on stars
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- **part II:** HARPSpol: 4n
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Note: detections in nearly all of them
analysis currently ongoing, ZDI proposal submitted
Maps + potential field extrapolation: AA Tau (left) & V2247 Oph (right)

wind orientation matters
Maps + potential field extrapolation: AA Tau (left) & V2247 Oph (right)

wind speed of our slow and fast wind models (versatile advection code)  
(Johnstone, Guedel, Lueftinger et al., I + II, submitted)
angular velocity of core (dashed) and envelope (solid) rotator models (scaled to solar angular velocity)

Gallet & Bouvier (2013)
evolution of solar wind mass loss rates with age on the MS at the 10\textsuperscript{th} (lower) and 90\textsuperscript{th} (upper) percentiles along the rotation tracks.

Johnstone, Guedel, Lueftinger et al. (submitted)
Evolution of the wind speed at 1 AU for different stellar masses

Johnstone, Guedel, Lueftinger et al. submitted
Evolution of the wind speed at 1 AU for different stellar masses
scaled poloidal wind velocity based on map of V374 Peg

Vidotto et al. (2011)
Some constraints from radio observations

- kappa Cet:
  \[ M_{\text{dot}} < 6.0 \times 10^{-12} \, M_{\odot} / \text{yr} \]

- pi$^1$ UMa: [new NARVAL observations]
  \[ M_{\text{dot}} < 2.5 \times 10^{-11} \, M_{\odot} / \text{yr} \]

- ESPaDOnS/NARVAL observations of:
  - EK Dra (100 Myr),
  - \( \chi^1 \) Ori (300 Myr),
  - \( \kappa^1 \) Cet (700 Myr),
  - pi1 UMa, new set in 2014/15

  \[ \rightarrow \text{ZDI} \]
Transit observations of HD 209458b in Lyman $\alpha$: strong absorption in blue and red wings -> hydrogen atoms escaping from planets atmosphere at high velocities
possible sources: a) acceleration by stellar radiation pressure
b) natural spectral line broadening
c) charge exchange with stellar wind

produced models, that include all these processes

Left: Slice of modeled 3D atomic H corona around HD 209458b
Right: Illustration of near-planet geometry
Magnetic moment and plasma environment of HD 209458b

Left: Slice of modeled 3D atomic H corona around HD 209458b
Right: modeled and observed spectra at mid-transit

Results support a stellar wind of ~400 km/s, and planetary magnetic moment of ~1.6x10^26 amperes per square meter.

-> similar analysis of GJ436b ongoing – planet around red dwarf

more in a recently printed Springer book: ‘Characterizing Stellar and Exoplanetary Environments’, (eds. Lammer, Khodachenko) Linsky et al., Lueftinger et al., Wood et al., etc.

and via: http://path.univie.ac.at/

Conference on Pathways to Habitability:
8 to 12 February 2016, Vienna, Austria
Magnetic fields in Young Stars

ZDI of V410 Tau

[Graph and images showing radial, meridional, and azimuthal fields, as well as brightness]