The search for radio emission from exoplanets using LOFAR low-frequency beamformed observations

Jake Turner
University of Virginia
Laboratoire de Physique et Chemie de l'Environnement et de l'Espace (LPC2E)

Collaborators:
Philippe Zarka (LESIA – Paris Observatory)
Jean-Mathias Grießmeier (LPC2E)
Overview

• Exoplanet Magnetic Fields
• Radio Observations of Exoplanets
• Our LOFAR Observing Campaign
  – Data Pipeline \( (\text{Turner+ 2017, submitted}) \)
  – Jupiter Observations
    • Jupiter as an exoplanet \( (\text{Turner+ 2017, in prep}) \)
  – Preliminary results on 55 Cnc \( (\text{Turner+ 2017, submitted}) \)
Exoplanet Magnetic Fields

**Motivation**

- Formation and evolution
- Interior structure
- Rotation period
- Atmospheric evolution and escape
- Ohmic heating
- Star-planet Interactions
- Moons
- Solar System comparison
- Habitability

Radio Observations

- Electron cyclotron emission in radio
- Best method to study planetary magnetic fields (Grießmeier 2015)

Peak of Emission
\[ f_g = 2.8 \left( \frac{B_p}{G} \right) \text{ MHz} \]

- \(B_p\): Planetary B-field
- 100% circularly polarized
- Flux (Planet) \(\geq\) Flux (star)

Solar System Radio Spectrum

Zarka 1998
Predicting Magnetic Field Strengths

Christensen 2009

Table 1 Proposed scaling laws

<table>
<thead>
<tr>
<th></th>
<th>Rule</th>
<th>Author</th>
<th>Remark</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>$B_p R_p^3 \propto (\rho \Omega R_p^3)^a$</td>
<td>e.g. Russell (1978)</td>
<td>magnetic Bode law</td>
</tr>
<tr>
<td>2</td>
<td>$B^2 \propto \rho \Omega^2 R_c^2$</td>
<td>Busse (1976)</td>
<td></td>
</tr>
<tr>
<td>3</td>
<td>$B^2 \propto \rho \Omega \sigma^{-1}$</td>
<td>Stevenson (1979)</td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>$B^2 \propto \rho R_c^3 q_c \sigma$</td>
<td>Stevenson (1984)</td>
<td></td>
</tr>
<tr>
<td>5</td>
<td>$B^2 \propto \rho \Omega R_c^{5/3} q_c^{1/3}$</td>
<td>Curtis and Ness (1986, modified)</td>
<td>at low energy flux</td>
</tr>
<tr>
<td>6</td>
<td>$B^2 \propto \rho \Omega^{3/2} R_c \sigma^{-1/2}$</td>
<td>Mizutani et al. (1992)</td>
<td>mixing length theory</td>
</tr>
<tr>
<td>7</td>
<td>$B^2 \propto \rho \Omega^2 R_c$</td>
<td>Sano (1993)</td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>$B^2 \propto \rho \Omega^{1/2} R_c^{3/2} q_c^{1/2}$</td>
<td>Starchenko and Jones (2002)</td>
<td>MAC balance</td>
</tr>
<tr>
<td>9</td>
<td>$B^2 \propto \rho R_c^{4/3} q_c^{2/3}$</td>
<td>Christensen and Aubert (2006)</td>
<td>energy flux scaling</td>
</tr>
</tbody>
</table>

• Rotational dependent vs. rotation-independent approaches
• Observations will help disentangle which scaling law should be applied
Radio Flux Predictions: Exoplanets

Zarka+ 2015

Scaling law: average radio power to incident Poynting flux of plasma flow

$10^3 - 10^6 > \text{Jupiter}$
Radio Flux & Frequency Predictions

- Predicted maximum emission frequency for rotation-independent planetary magnetic field and expected radio flux for known planets

Zarka+ 2015; Grießmeier+ 2011

Jake Turner (University of Virginia)
Previous Radio Searches

- Secondary Eclipse of HAT-P-11b at 150 MHz
- Unconfirmed

- Current upper limits
- No Detections

Blue: VLA
Red: GBT
Orange: GMRT
Cyan: UTR-2

Jake Turner (University of Virginia)
LOFAR Observations

- \( \nu \): 26-73 MHz
- IQUV Polarization
- Raw Res: 10 msec & 3 kHz
- 9 arcmin resolution
- 16 mJy sensitivity: 2 mins over full band
- Observational Campaign:
  - 4 exoplanets so far
  - 3 Beams
  - Over full orbital phase

Turner+ 2017 (submitted)
LOFAR Pipeline

Raw

Normalized+ RFI mitigation

Intensity (Sky)

Response of telescope

Jake Turner (University of Virginia)

Radio Habitability: May 11, 2017

Turner+ 2017 (submitted)
Preliminary Results: Pulsar

• Pulsar B0823+26 is detected at high S/N at known period

• Brightness of pulsar changes with time (known previously).

Turner+ 2017 (submitted)

Jake Turner (University of Virginia)
Jupiter Observations

- Scale Jupiter radio emission from Nançay Observatory as if it was an exoplanet (reduce flux by $10^{-3} - 10^{-6}$).

- Produce a set of observables that can be used as a guideline in the search exoplanetary radio emission.
Broadband Observables

Time Series

Integrated Spectrum

Turner+ 2017 (in prep)

Jake Turner (University of Virginia)
Burst Observables

High-pass filtered time series

Number of peaks/power above threshold

Jake Turner (University of Virginia)

Radio Habitability: May 11, 2017

Turner+ 2017 (in prep)
One of best targets for radio observations due small orbital distance, proximity (12.3 pc), and multiplicity (Grießmeier+ 2007).

Emission from 55 Cnc e possible: tens of MHz with flux densities up to hundreds of mJy (Grießmeier+ 2007, Jardine+ 2008).
55 Cnc Preliminary Results:

- Do not observe broadband emission from 55 Cnc
- Full dataset needs to be analyzed
  - Total of 18 hours

![Graph showing intensity and phase with a legend indicating On Beam (55 Cnc) and Off Beam (Sky).]

Turner+ 2017 (submitted)

Jake Turner (University of Virginia)
Conclusions

• Radio observations are the best way to study exoplanet magnetic fields
• LOFAR data is stable and sensitive enough to detect astrophysical signals from the pulsar
• We observed Jupiter as if it was an exoplanet and developed a set of observables as guides
• Initial analysis of 4 hours of LOFAR 55 Cnc e data do no show an exoplanet signal
• The rest of the observational campaign is undergoing analysis
Questions?

Email: jt6an@virginia.edu
Website: https://sites.google.com/site/astrojaketurner

- Expected PHD Defense: August 2018
- Looking for Post-Docs 😊