The search for exoplanetary radio emission: Jupiter as an exoplanet + LOFAR beamformed observations

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Solar system wisdom (Jupiter)

Radio emission
→ detect magnetic field!
→ calculate magnetic field!

[Zarka, 1998]

[Grießmeier 2015]
Beyond the solar system

no (firm) detection yet

Distance = $10^{12}$ m
Rel. signal = 1

Distance = $10^{17}$ m
Rel. signal = $10^{-10}$
Beyond the solar system

theoretical studies: intense emission is possible

(Jupiter $10^3$...$10^7$)

\[ P_{\text{rad}} \text{ (flux radio)} \]

\[ P_{\text{input}} \text{ (Poynting flux)} \]

[Zarka, 2001, 2007]

Hot Jupiters
Theoretical sensitivity limit

LOFAR beamformed observations

- observe well-known exoplanets
- target selection based on predictions
- fine control over RFI mitigation
- need good orbital coverage
- multiple beams (ON + OFF)
- data processing (cleaning)  [Turner et al. 2017]

<table>
<thead>
<tr>
<th>LOFAR cycle</th>
<th>time</th>
<th>target</th>
<th>observation</th>
</tr>
</thead>
<tbody>
<tr>
<td>LC5</td>
<td>18h</td>
<td>55 Cnc</td>
<td>beamformed</td>
</tr>
<tr>
<td>LC6</td>
<td>47h</td>
<td>Ups And</td>
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<tr>
<td>LC7</td>
<td>28h</td>
<td>Tau Boo</td>
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<tr>
<td></td>
<td>10h</td>
<td>V830 Tau</td>
<td>bf+img</td>
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<td>LC8</td>
<td>7h</td>
<td>Corot-7</td>
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Dynamic spectra & diagnostics

![Graph showing frequency vs. UT with labeled slow emission and bursty emission]

slow emission

bursty emission
Slow emission: Jupiter
Slow emission: exoplanet

- apparent ‘ripples’ in OFF-beam data
- cleaning not yet perfect
- data quality problem (bad stations)!
• including bad stations is... bad!
Bursty emission: Jupiter

- Jupiter’s emission is bursty
- search bursts of 1-10 s duration
Bursty emission: Exoplanet

- exoplanets: no bursts detected
- go through data again
- nondetection → upper limits
Dynamic spectra

- bursts of Jupiter $x \times 10^{-4.5}$ would have been detected
- $\rightarrow$ upper limit to bursty emission [Turner et al. in prep.]

- Jupiter $x \times 10^{-4.5}$ [Turner et al. 2019]
- false pos.: $10^{-4}$
- not significant
Lessons learned

• beamformed data → good time-frequency resolution
  → powerful RFI cleaning
• need (at least!) 3 beams
• Stokes V > Stokes I
• need orbital coverage (→ observing time)
• 1 bad station can corrupt the sum!
  → have to exclude bad stations

• slow emission:
  combine with imaging (DynSpecMS; A. Loh, C. Tasse, ...)
• bursty emission:
  beamformed observations, but with quality control

• best test: simultaneous observations
  → UTR-2, NenuFAR (science operations start 07/2019!)
Multibeam setup

\[ \sim 1^\circ \]

ON

OFF_1

OFF_2
Theoretical sensitivity limit

- observe well-known exoplanets
- beamformed observations

\[ \Delta S = \frac{S_{sys}}{(N \sqrt{n_{pol} \tau_r b})} \]

\[ \rightarrow \Delta S = 200 \text{ Jy} \quad \text{(per t-f “pixel” of 10 ms x 3 kHz)} \]
\[ \rightarrow \Delta S = 5 \text{ Jy} \quad \text{(rebinned “pixel” of 1 s x 45 kHz)} \]
\[ \rightarrow \Delta S = 0.01 \text{ Jy} \quad \text{(20 min x 12 MHz)} \]
Orbital phase

- for Jupiter, random observations only give 10-20% detections!
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- emission is always on
- emission is strongly beamed
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- for exoplanets: have to cover orbit
- else: non-detections meaningless
Orbital phase

![Graph showing orbital phase for Tau Bootis with observed duration and total time span.](image-url)