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



Jean-Mathias Grießmeier, Jake D. Turner, Philippe Zarka, Iaroslavna Vasylieva

jean-mathias.griessmeier@cnrs-orleans.fr

# Solar system wisdom (Jupiter)



$$f_c \propto \frac{eB}{m_e}$$

#### radio emission

- $\rightarrow$  detect magnetic field!
- → calculate magnetic field! [Grießmeier 2015]

### **Beyond the solar system**

distance =  $10^{17}$  m rel. signal =  $10^{-10}$ 

# Exoplanet

#### no (firm) detection yet





## **Beyond the solar system**

#### theoretical studies: intense emission is possible (Jupiter x10<sup>3</sup>...10<sup>7</sup>)



## **Theoretical sensitivity limit**



[Grießmeier et al. 2007, 2011, 2018]

# **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]

LOFAR cycle	time	target	observation	
LC5	18h	55 Cnc	beamformed	
LC6	47h	Ups And	beamformed	
LC7	28h 10h	Tau Boo V830 Tau	beamformed bf+img	
LC8	7h	Corot-7	beamformed	

# **Dynamic spectra & diagnostics**



# **Slow emission: Jupiter**



# **Slow emission: Jupiter**



# **Slow emission: exoplanet**



- apparent 'ripples' in OFF-beam data
- cleaning not yet perfect
- data quality problem (bad stations)!

### **Data quality & bad stations**

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#### 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**

#### Jupiter x 10<sup>-4.5</sup> [Turner et al. 2019]



- bursts of Jupiter x 10<sup>-4.5</sup> would have been detected
- → upper limit to bursty emission [Turner et al. in prep.]

### **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**



# **Theoretical sensitivity limit**

observe well-known exoplanets

beamformed observations

$$\Delta S = S_{sys} / (N \sqrt{n_{pol} \tau_r b})$$

 $\rightarrow \Delta S = 200 \text{ Jy}$  $\rightarrow \Delta S = 5 \text{ Jy}$  $\rightarrow \Delta S = 0.01 \text{ Jy}$  (per t-f "pixel" of 10 ms x 3 kHz) (rebinned "pixel" of 1 s x 45 kHz) (20 min x 12 MHz)

...but... ...but... ...but...





- for Jupiter, random observations only give 10-20% detections!





Right Handed Polarizatio





for Jupiter, random observations only give 10-20% detections!
emission is always on
emission is strongly beamed



[Imai Lab., Kochi National College of Technology]





Right Handed Polarizatio





- for Jupiter, random observations only give 10-20% detections!
- emission is always on
- emission is strongly beamed

for exoplanets: have to cover orbitelse: non-detections meaningless

