

# Exoplanets with LOFAR and NenuFAR: where do we stand?

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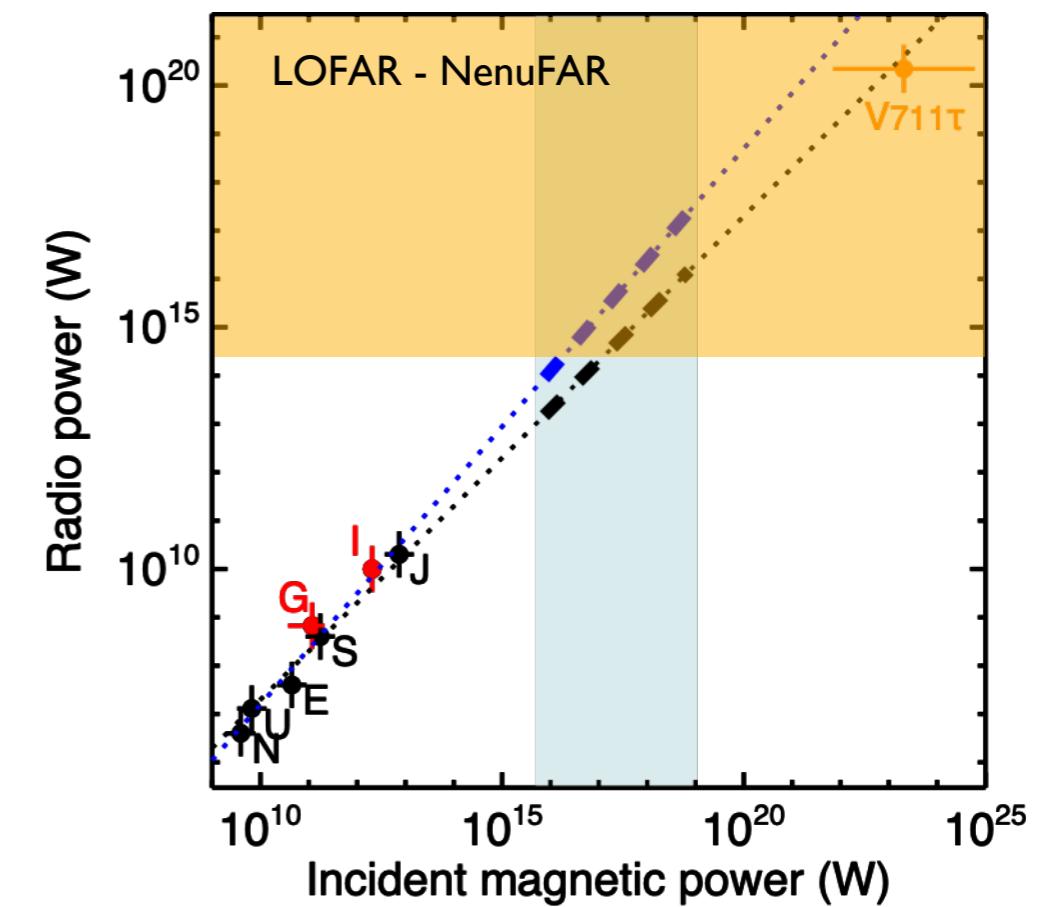
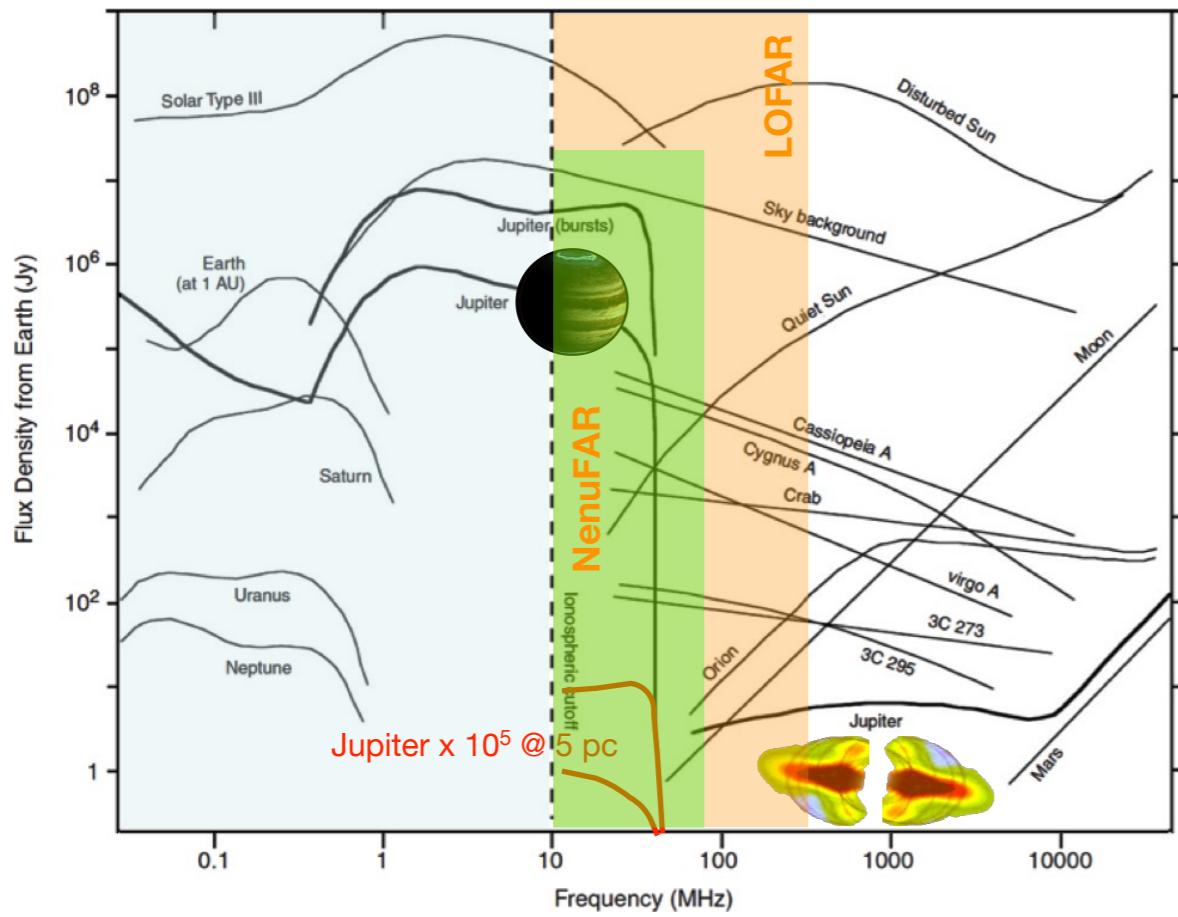
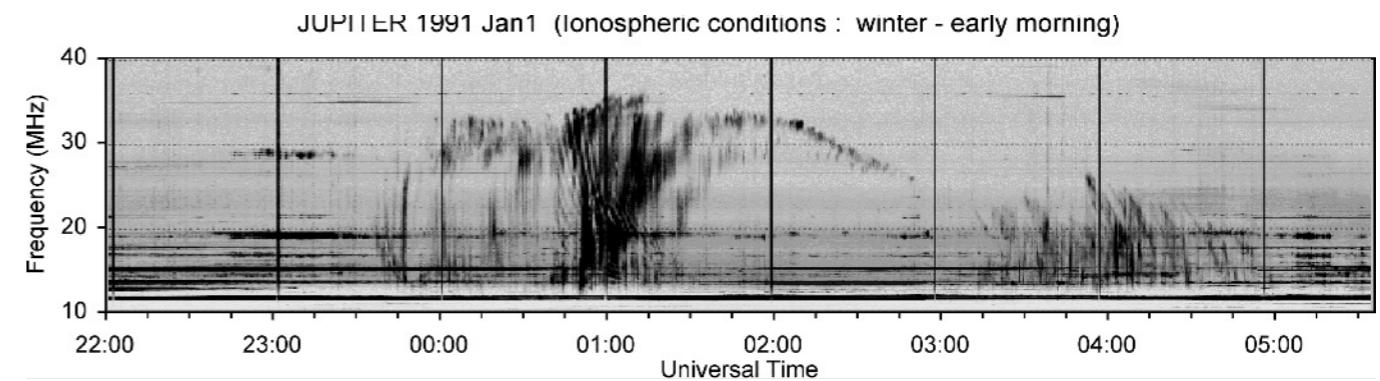


# Motivations

- Comparative (exo-)planetary magnetospheric physics in various regimes, exospace weather
- Energetics and topology of Star-Planet interaction
- Planetary magnetic field, interior, rotation (spin-orbit locking ?)
- Orbit inclination (presence of satellites ?)
- Habitability ? (particle bombardment, CME, atmospheric escape ?)

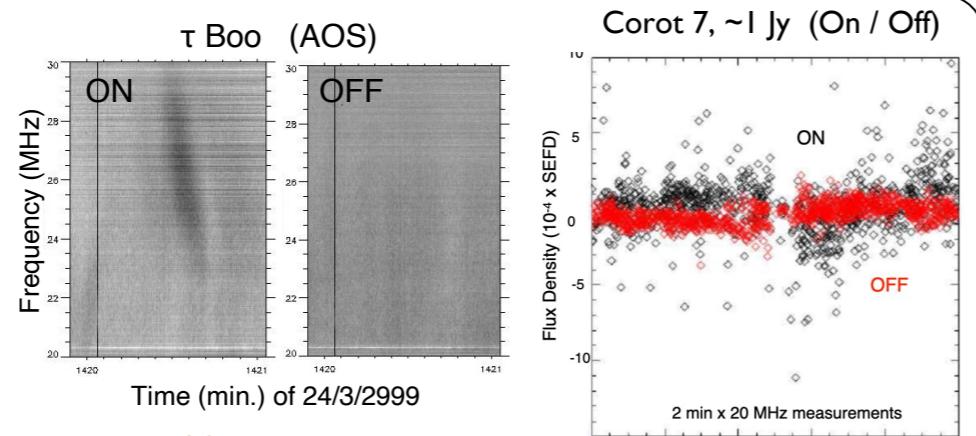
# Predictions for Radio-Exoplanets

- Magnetospheric → Low frequencies
- Star-Planet Interactions → Low & High frequencies
- Circular polarization (Cyclotron-Maser emission)
- + possible linear emission
- Time-frequency structure
- Very weak emissions



# Past radio observations : no confirmed detection

UTR-2 10-32 MHz

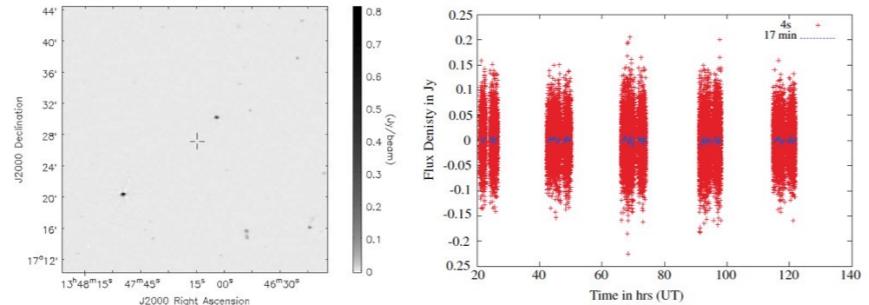


[Ryabov et al., 2004 ; Vasylieva, 2015]

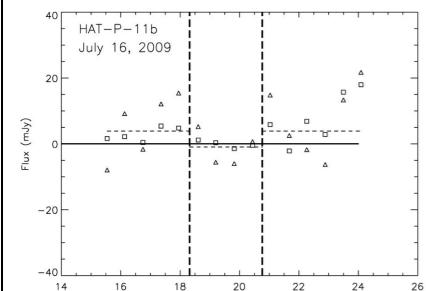
GMRT 150 MHz



$\tau$  Boo, 150 MHz, 1 mJy

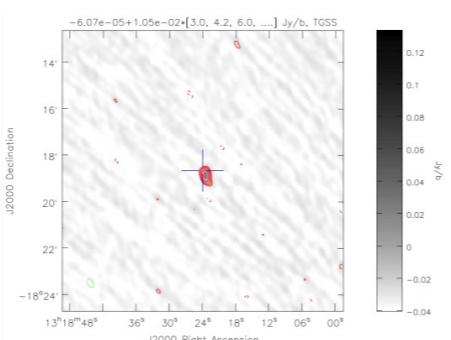


Hat-P-11, 150 MHz, 3.9 mJy



[Lecavelier et al., 2013]

TGSS  $\rightarrow$  4 candidates  
out of 175 exoplanetary  
systems,  $\sim$  18-120 mJy  
[Sirothia, et al., 2014]

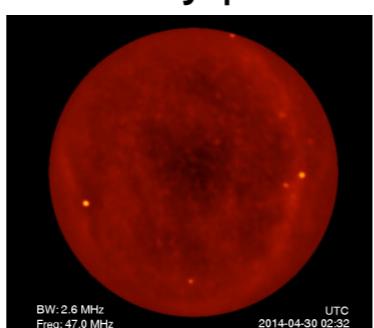


LWA (+ OLWA) 10-88 MHz



[Hartman, Hallinan, et al.]

$\sim$ 5000+ h on  
 $\sim$ 12 Hot Jupiters

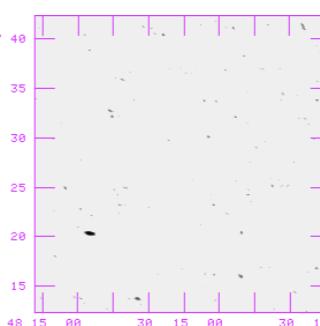


BW: 2.6 MHz  
Freq: 47.0 MHz  
UTC  
2014-04-30 02:32

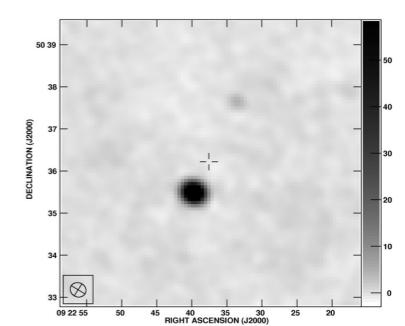
VLA 74 MHz



$\tau$  Boo, 74 MHz, 100 mJy

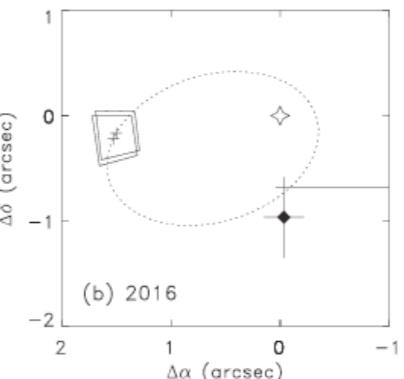
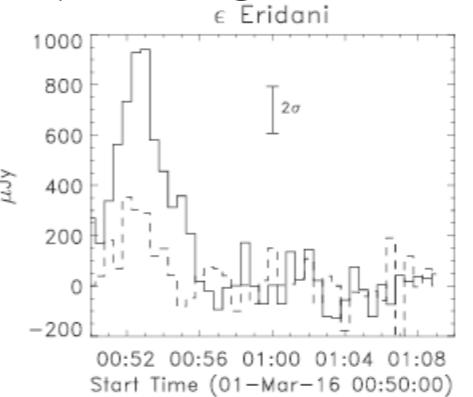


HD80606, 330 MHz, 1.7 mJy



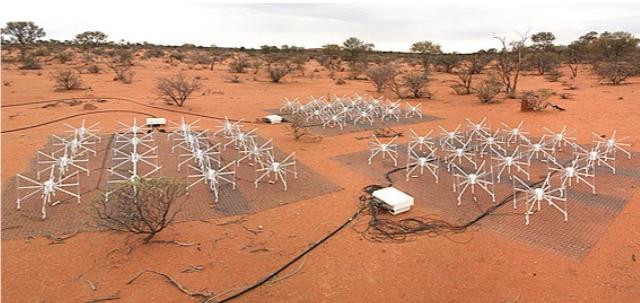
[Farrell et al., 2003, 2004 ; Lazio & Farrell, 2007]

VLA 2-4 GHz



[Bastian et al., 2018]

MWA 163-231 MHz



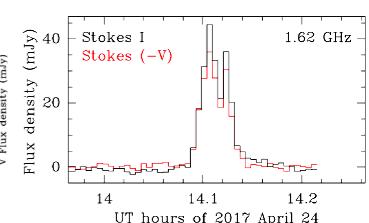
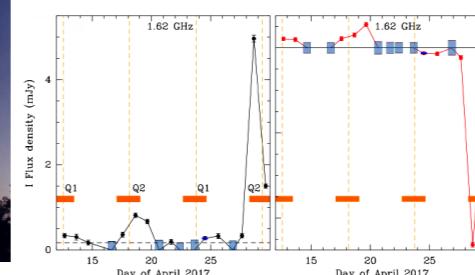
Proxima Centauri, V, 18 mJy ?

[Lenc et al., 2018]

ATCA 1-3 GHz

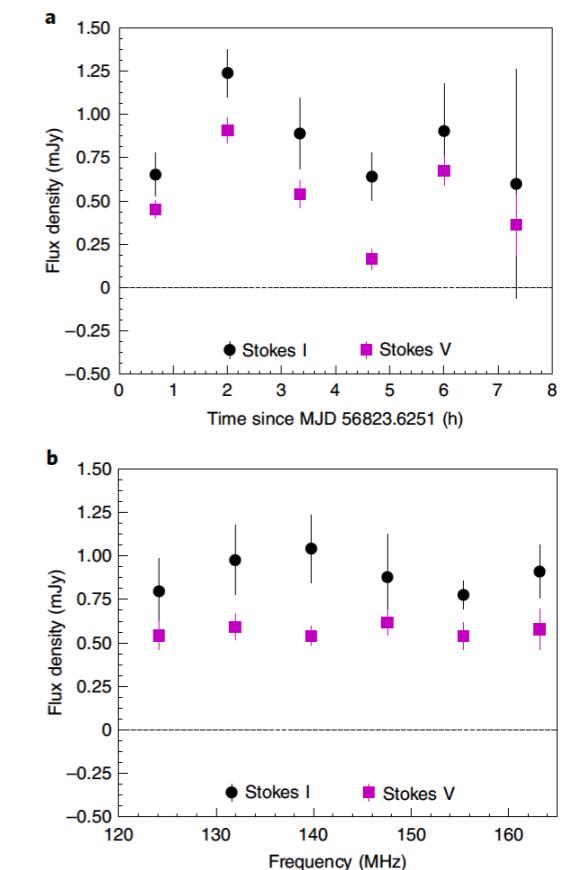
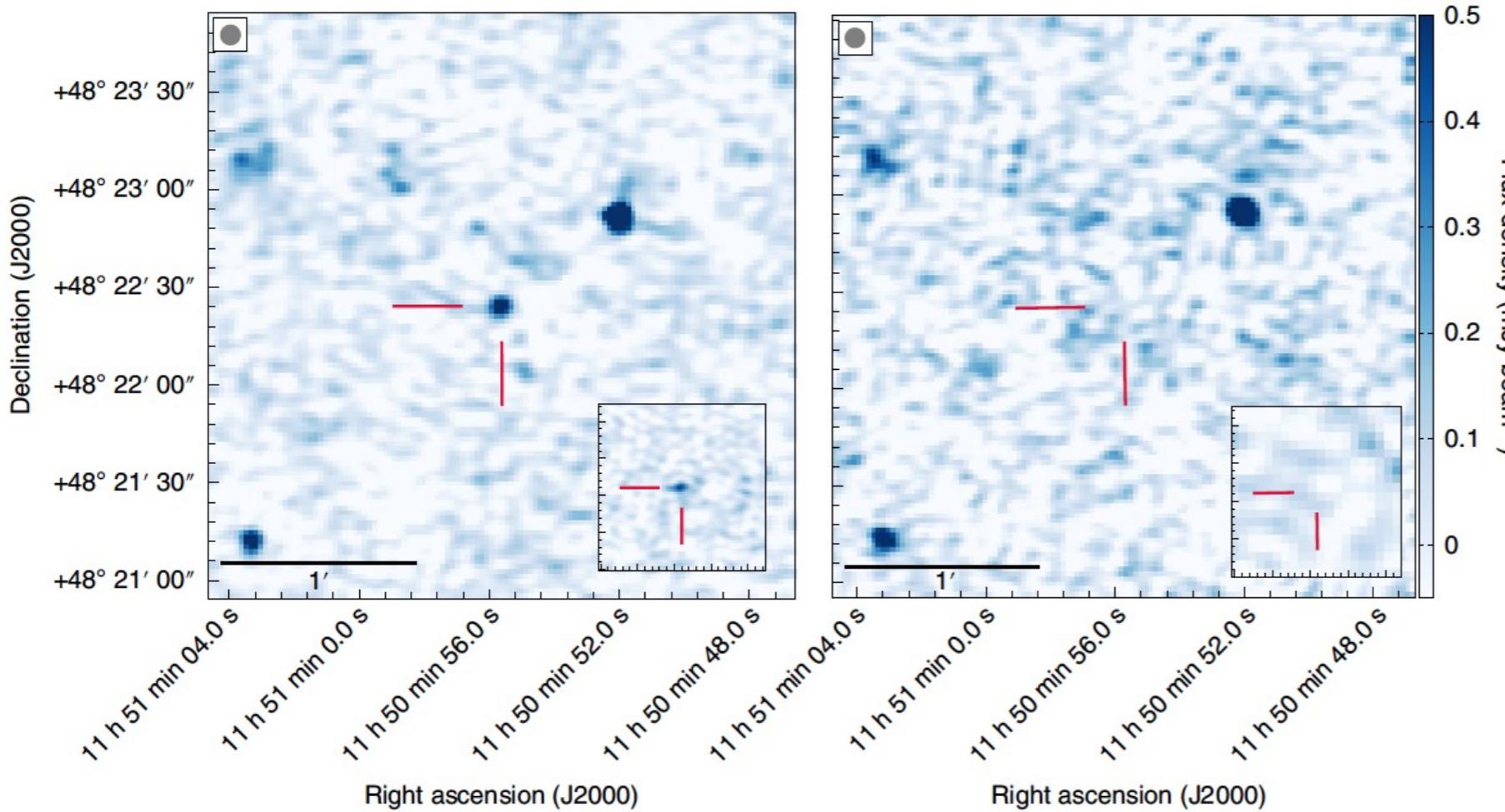


Proxima Centauri, slow periodic  
emission + bursts, V,  $<$  5 mJy ?



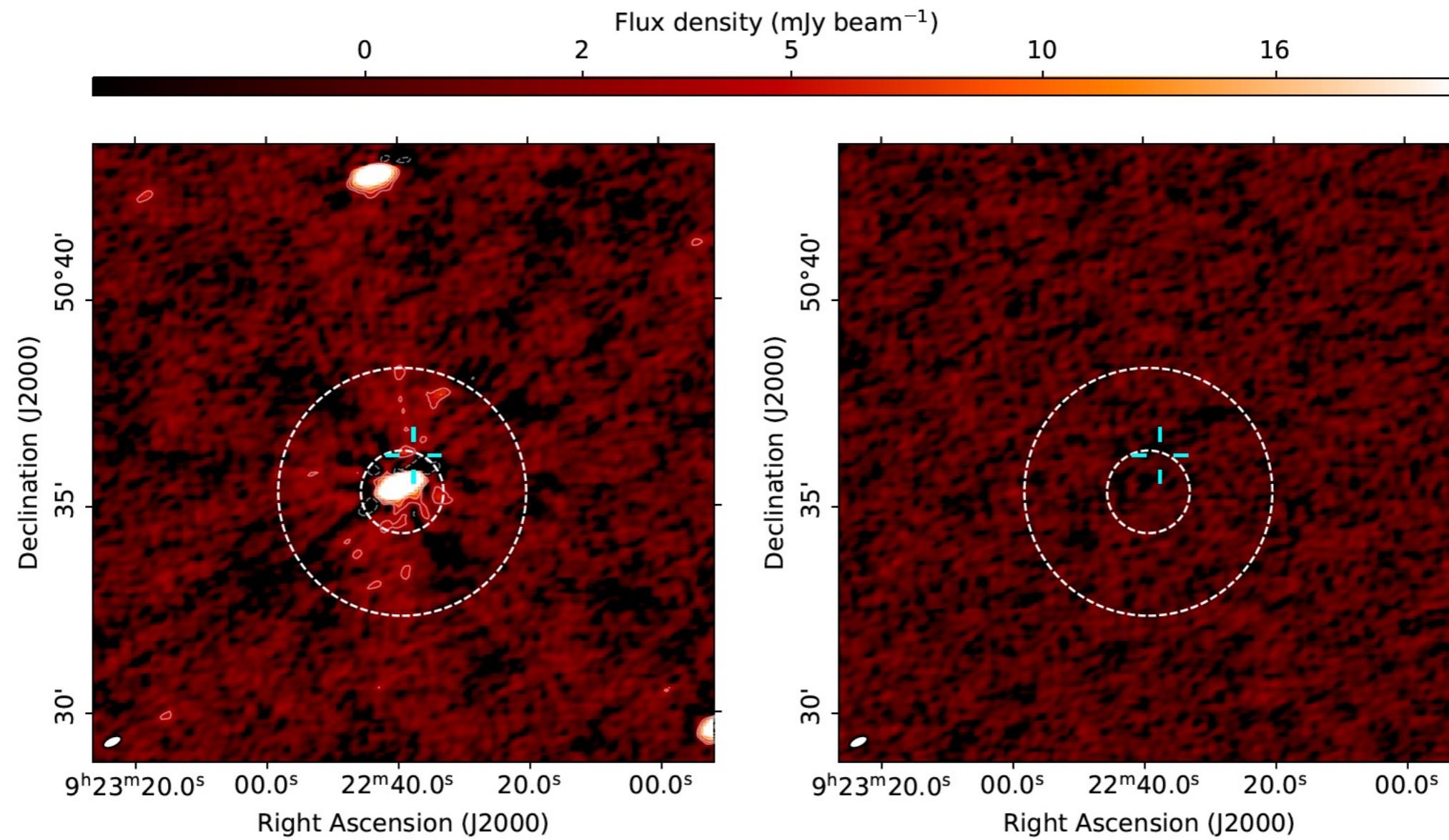
[Perez-Torres et al., 2021]

# LOFAR imaging survey HBA (LoTSS)



- GJ 1151 [Vedantham et al., 2020a ; Pope et al., 2020 ; Mahadevan et al., 2021 ; Perger et al., 2021]
  - 2 Brown Dwarfs [Vedantham et al., 2020b, 2023]
  - 19 M-dwarfs (incl. CR Dra, WX UMa) [Callingham et al. 2021a,b; Davis et al., 2021]
  - 14 (+5) RS CVn, 5 other active stars [Toet et al., 2021; Vedantham et al., 2022]
  - 2 T-Tauri [Feeney-Johansson et al., 2021]
  - ~40 Stellar sources in V-LoTSS [Callingham et al. 2023]
- average emissions, point-like sources + hints on variability

# LOFAR imaging targeted LBA

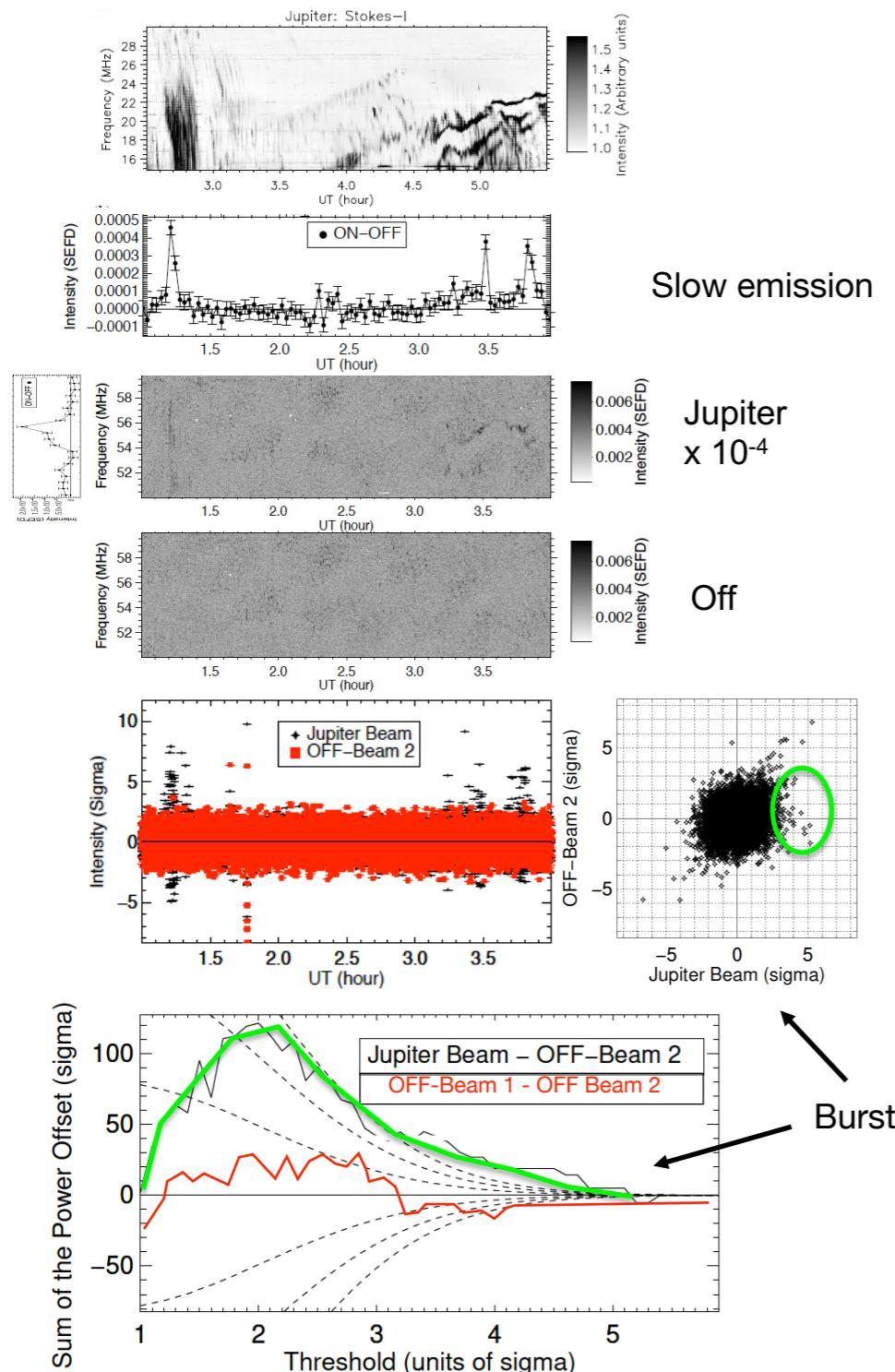


- HD 80606 (30-78 MHz, no detection)

[de Gasperin et al., A&A 2020]

# LOFAR beamformed targeted LBA

Jupiter [Turner, et al., 2019]

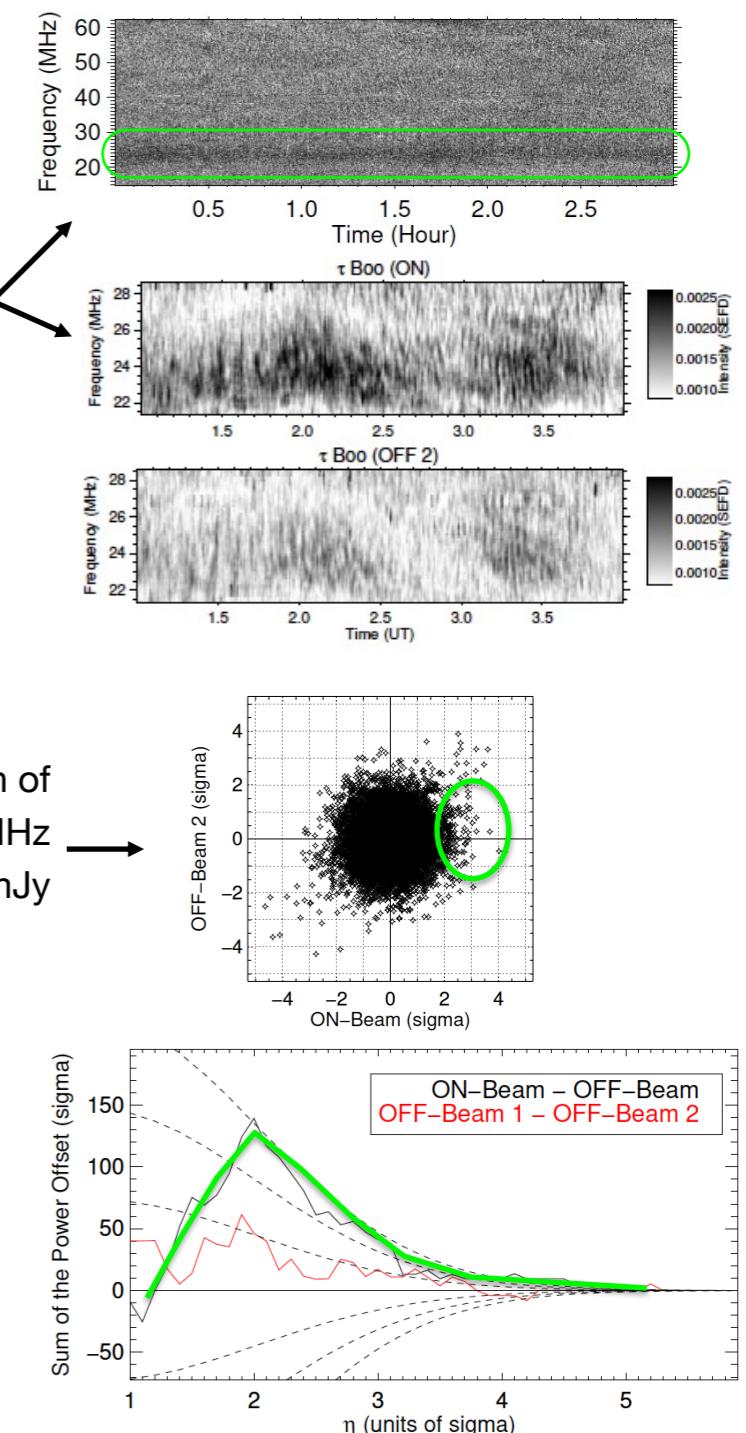


IQUV, 10 msec x 3 kHz,  
3 beams (1 On, 2 Offs)

Spurious slow  
emission 21-28 MHz

Tentative detection of  
LHC 1 sec bursts 15-21 MHz  
3.2 $\sigma$  detection, 100s mJy

Tau Boote [Turner, et al., 2021]

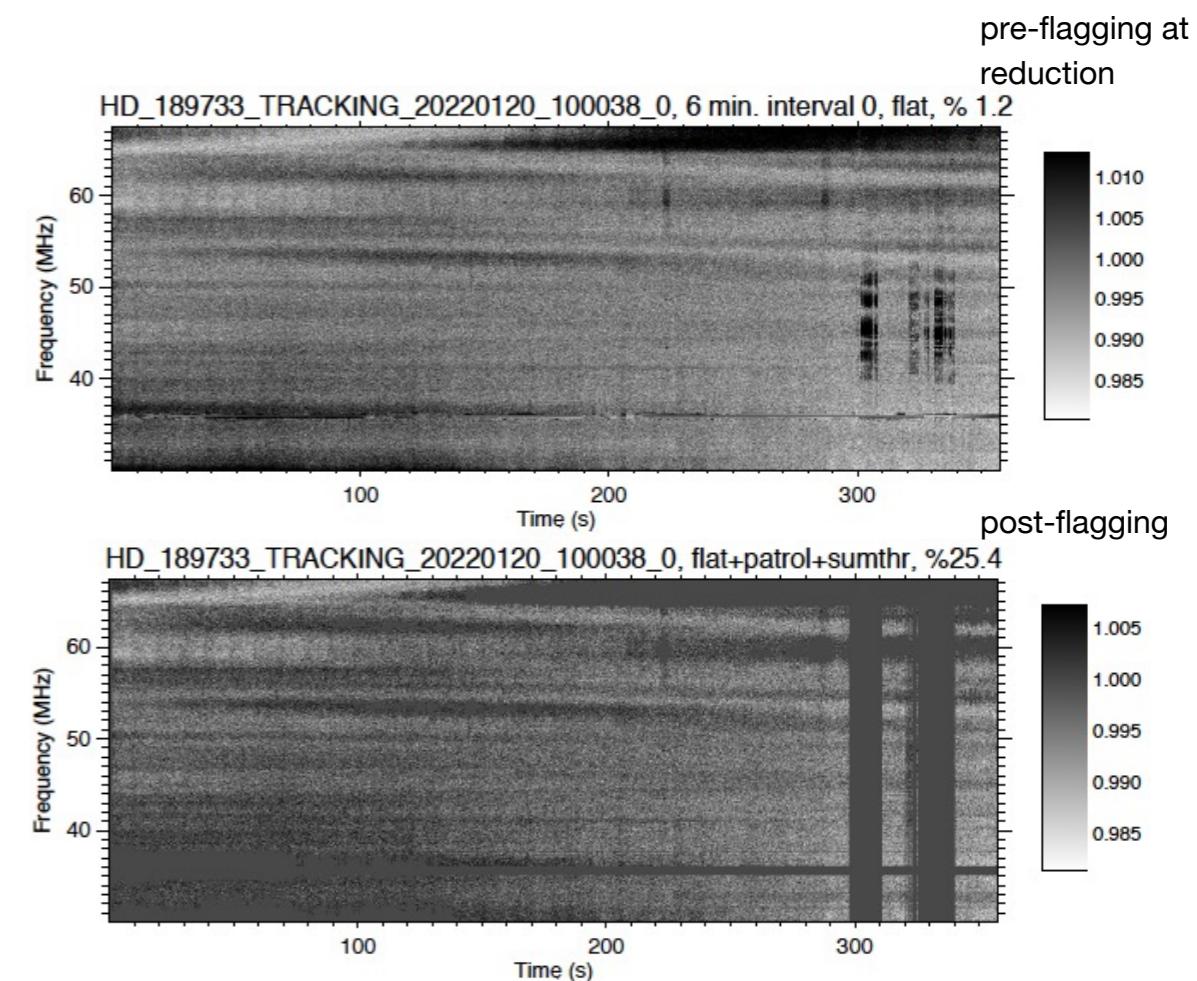
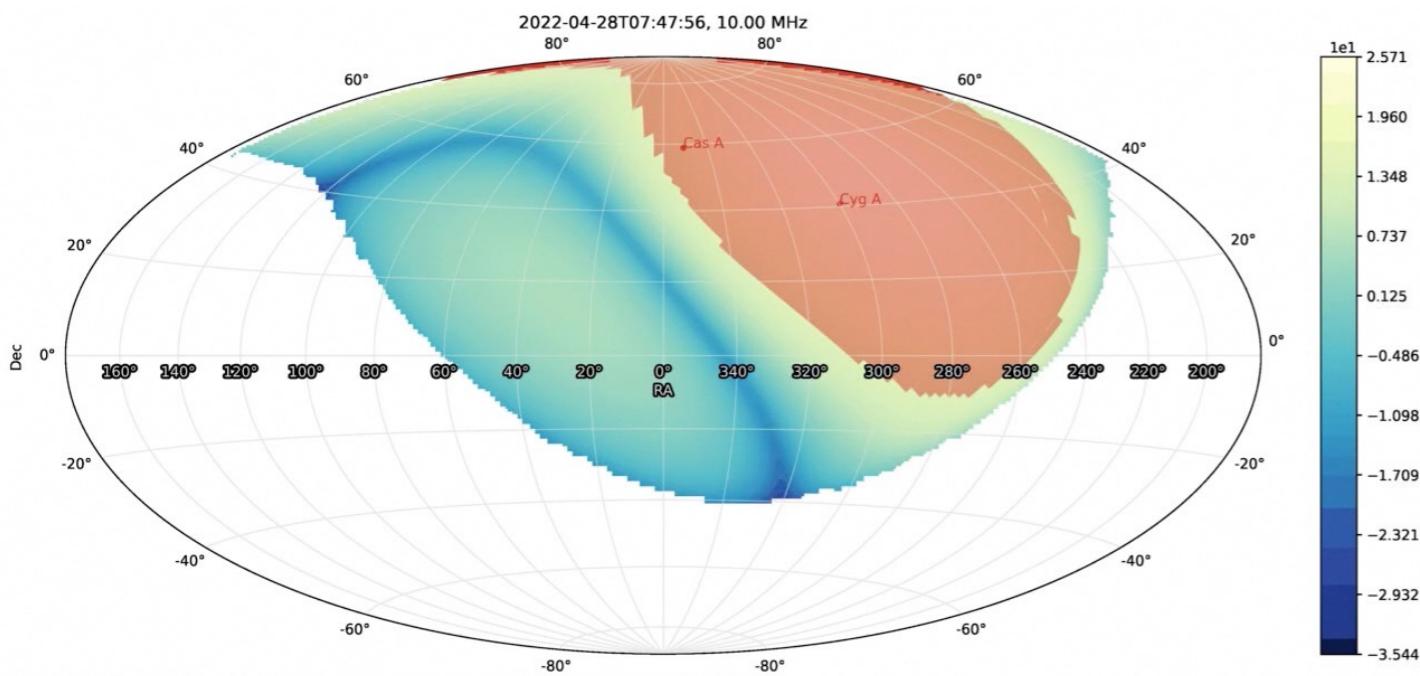


- Ups And (2 $\sigma$ ), 55 Cnc (no detection)

- Re-observation of Tau Boo by LOFAR : no redetection yet → discussion in [Elekes & Saur, 2023]

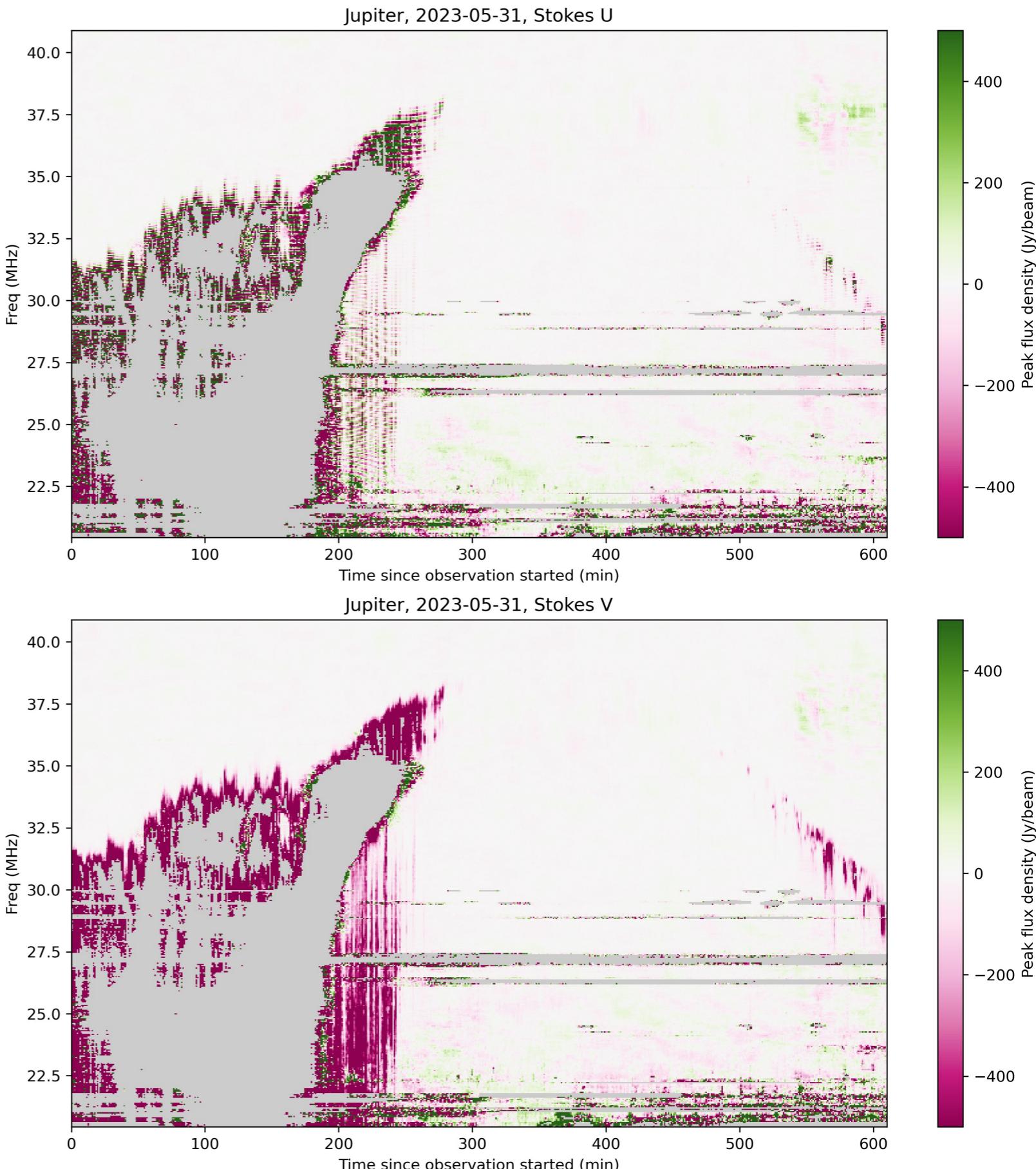
# Exoplanet beamformed searches with NenuFAR

- Massive observations 10-85 MHz (full Stokes)  
~30 known exoplanets (21ms x 3kHz, 1 On+3 Off beams)  
~20 stars (42ms x 3kHz, 1 On+1 Off beams)  
~5000 h in Early Science phase + Cycle 1
- RFI flagging
- Sky contamination modelling/flagging (A-team, Jupiter, Sun, Galaxy)
- Searches in Stokes V + (t,RM) plane
- Processing in progress



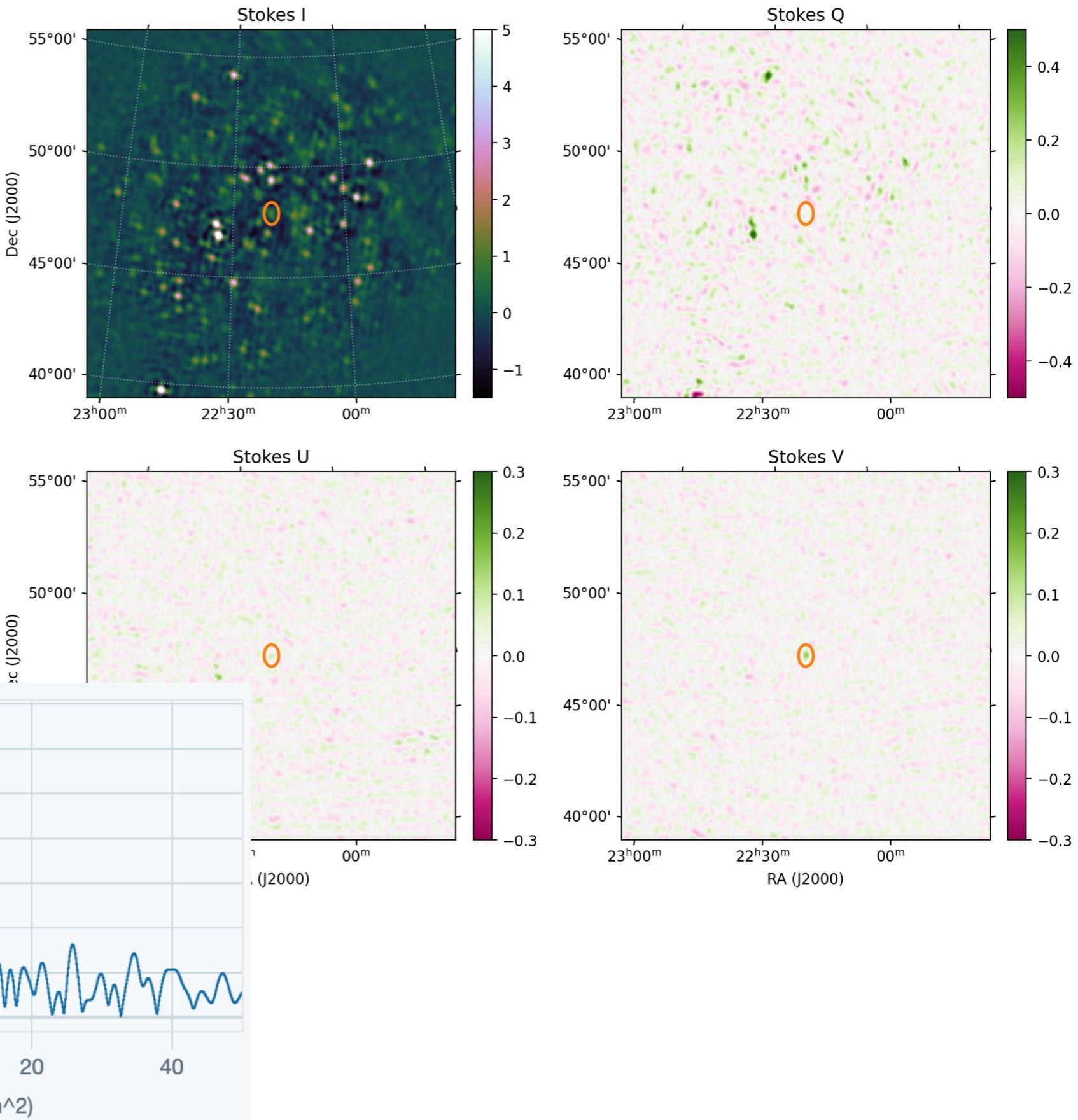
# Exoplanet imaging searches with NenuFAR

- Pipeline development in progress:
  - RFI flagging (very aggressive)
  - Initial calibration with A-team calibrators
  - DD cal + subtract A-team sources
  - Analytic beam model + parallactic angle correction
  - Ionosphere Faraday correction
  - RM synthesis
  - Subtract field sources from visibilities, before generating dynamic spectra



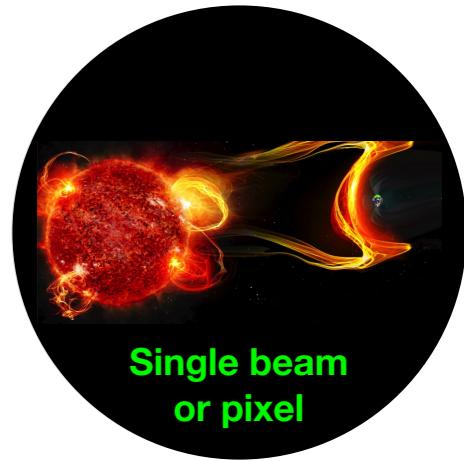
# Exoplanet imaging searches with NenuFAR

- Pipeline test with pulsars
- Detected pulsars in linear + circular polarisation



# Prospective work

- Search for circular (Stokes V) and linear emission (RM synthesis)
- Search for time-frequency variable emission with DynSpecMS (Multi-Object Dynamic Spectroscopy) on NenuFAR (cf. Tasse et al.)
- Dynamic spectrum synthesis for each pixel of the mini-arrays FoV
- Massive targeted observations on selected fields (previous radio observations, target selection code [\[Mauduit et al., 2023\]](#), target-rich FoV...)
- LOFAR 2.0 / LSS



# Summary

- Past radio observations with most telescopes: no confirmed detection
- LOFAR HBA: star-planet interaction (GJ 1151) + lots of stellar objects
- LOFAR LBA: tentative detection (Tau Bootes b)
- NenuFAR: ~5000 h observations + processing in progress

**Are you interested in exoplanets?**

**Thank you!**

**Any questions?**

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**Postdoc: Search for exoplanetary radio signals in NenuFAR observations in beamformed mode**

<https://emploi.cnrs.fr/Offres/CDD/UMR8109-SYLDES-059/Default.aspx?lang=EN>

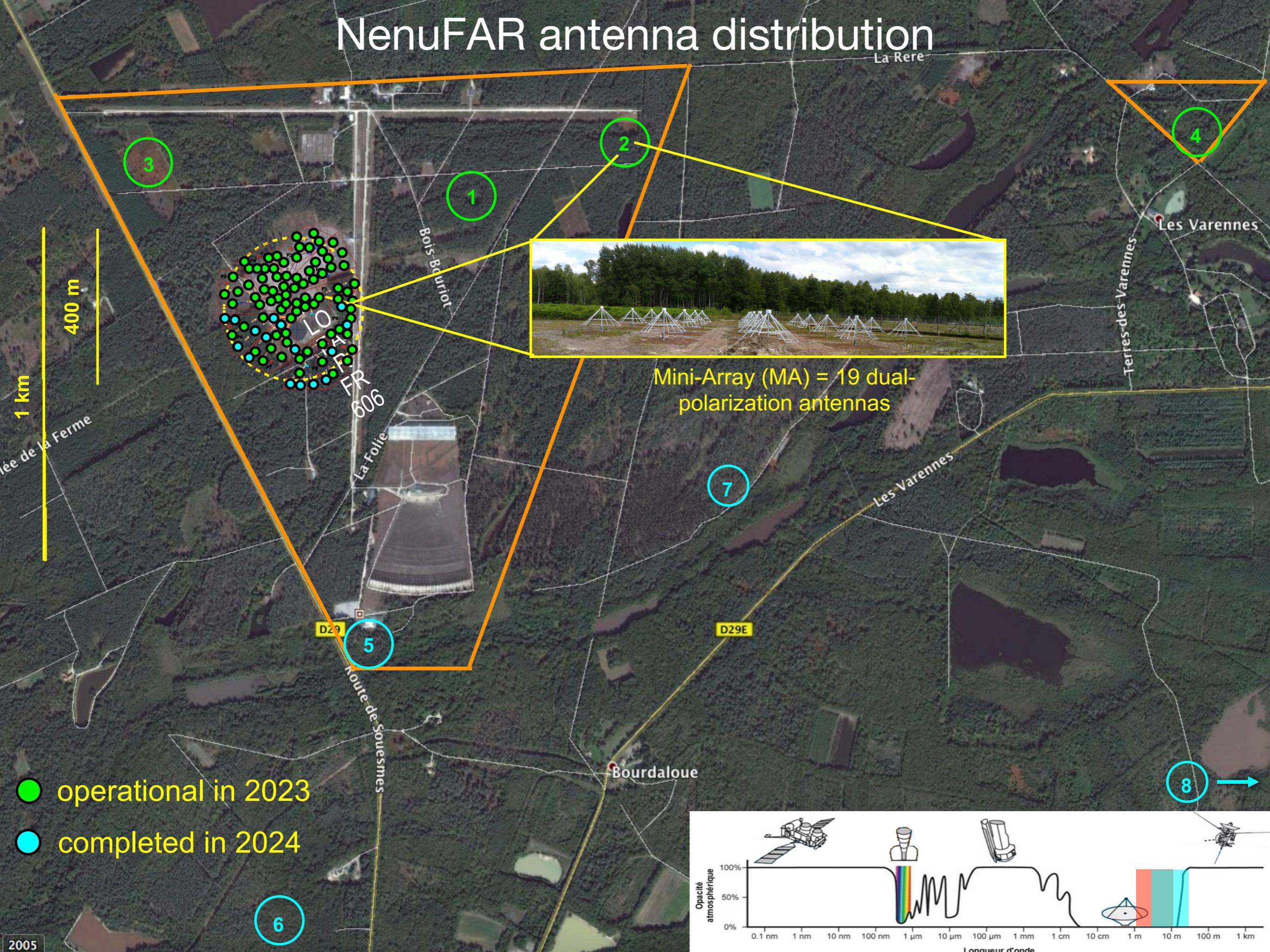
**PhD: Searching for and studying exoplanets using radio interferometric imaging**

<https://emploi.cnrs.fr/Offres/Doctorant/UMR8109-SYLDES-060/Default.aspx?lang=EN>

# NenuFAR (New extension in Nançay upgrading LOFAR)

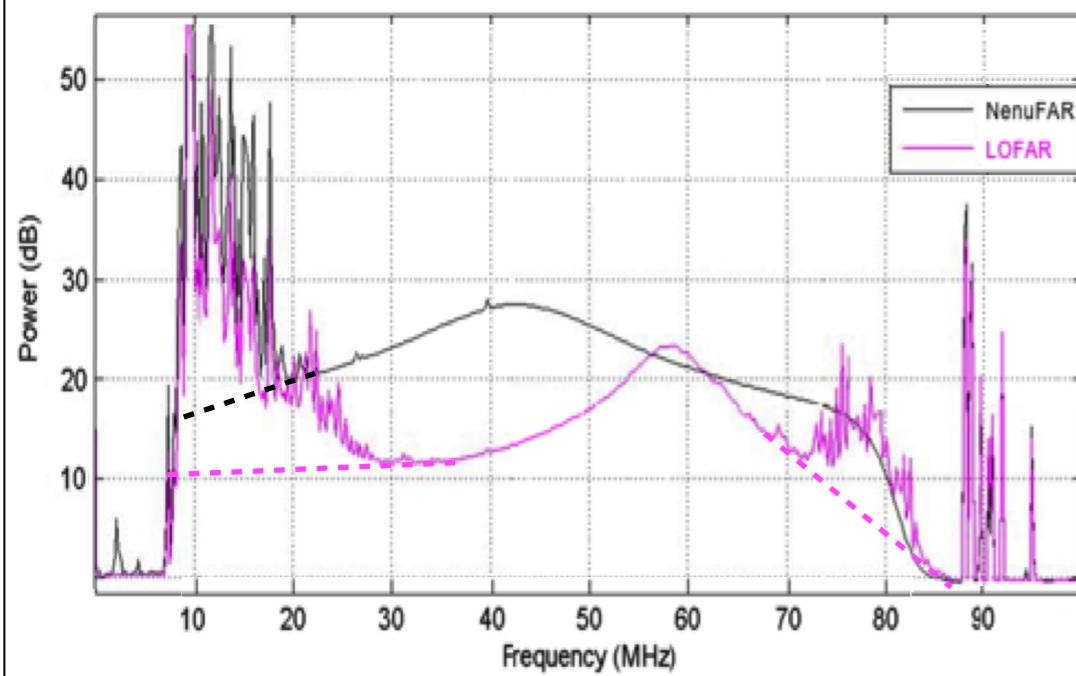
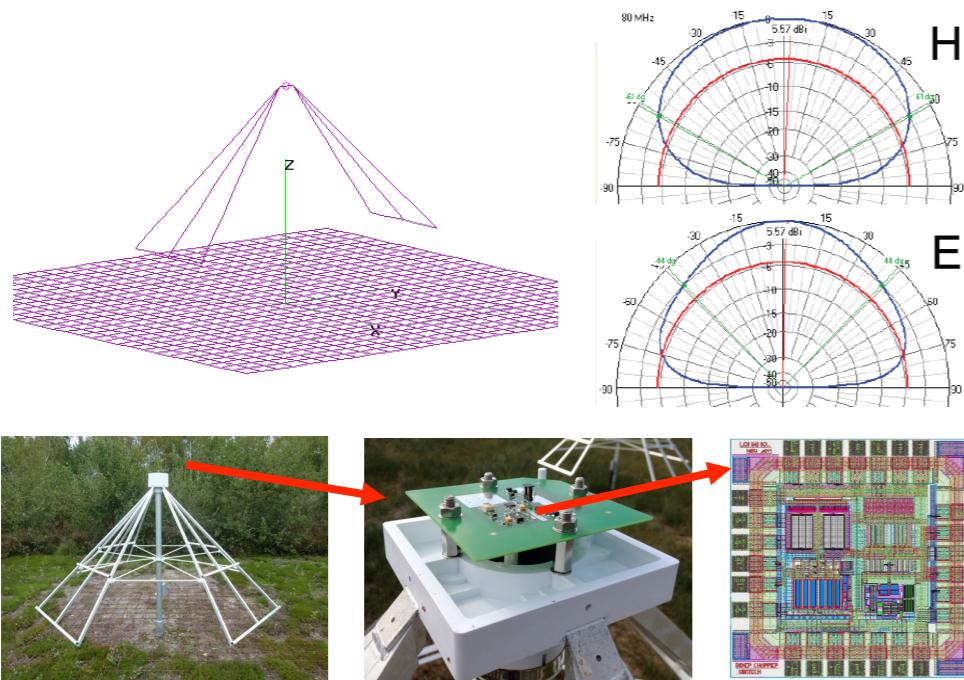


# NenuFAR antenna distribution



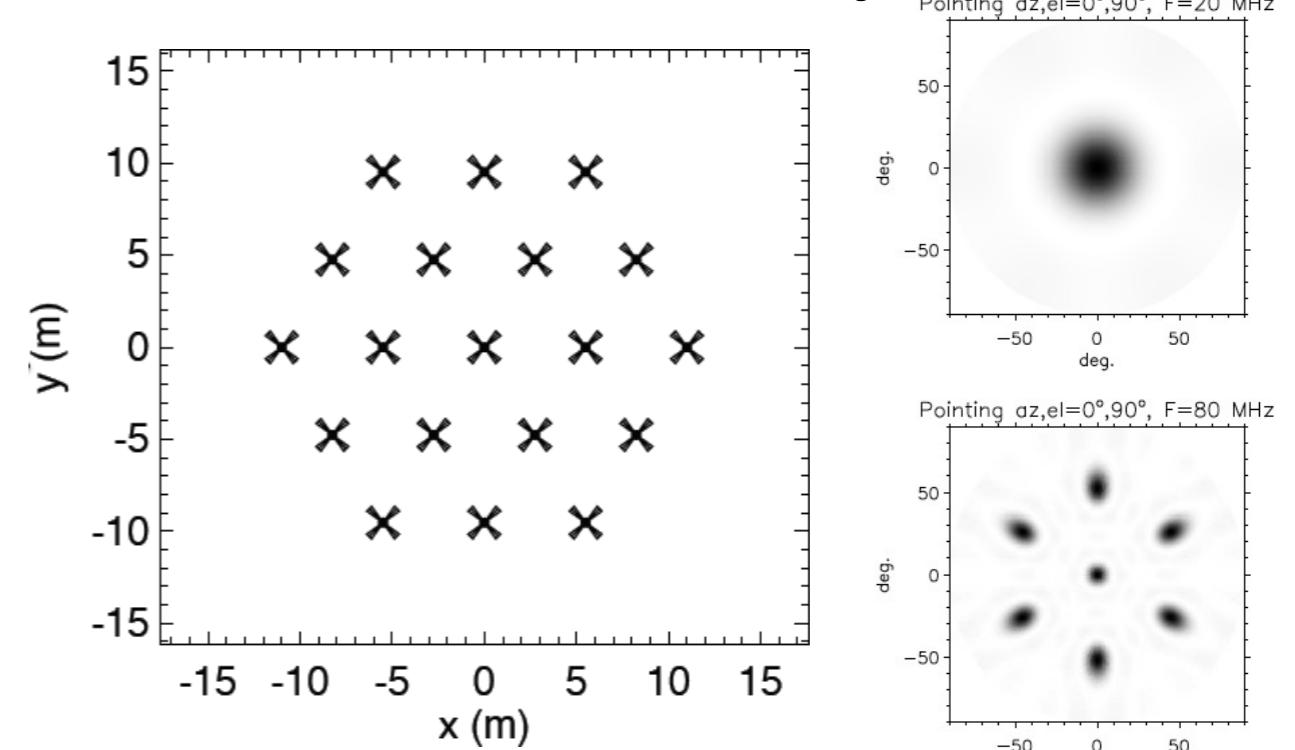
# NenuFAR characteristics

## Sensitive antenna + preamplifier



[Girard, 2013 ; Charrier et al., 2007, 2015]

## 19-antenna analog-phased Mini-Array



[Girard & Zarka, 2023]

## Sensitivity

