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

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AASTCS 5: Radio Exploration of Planetary Habitability
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Collaborators:

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Jean-Mathias Grießmeier (LPC2E)

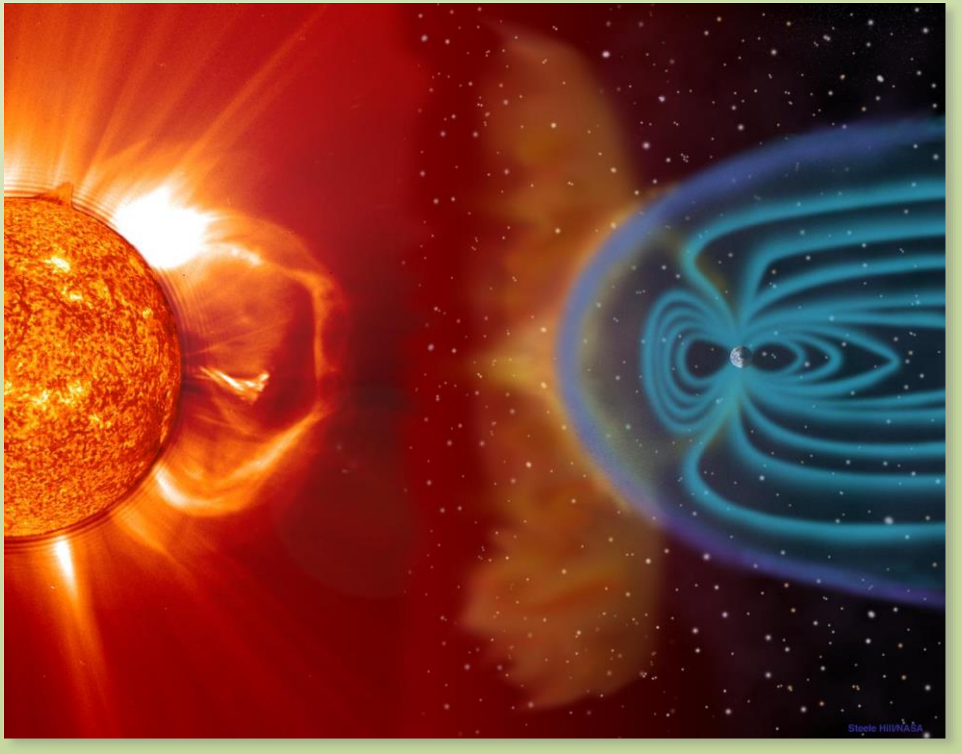
Overview

- Exoplanet Magnetic Fields
- Radio Observations of Exoplanets
- Our LOFAR Observing Campaign
  - Data Pipeline (Turner+ 2017, submitted)
  - Jupiter Observations
    - Jupiter as an exoplanet (Turner+ 2017, in prep)
  - Preliminary results on 55 Cnc (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**



Lazio+ 2010, Grießmeier+ 2005, Rauscher+ 2010, Hess & Zarka 2011, Grießmeier 2015, Zarka+2015

Radio Observations

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

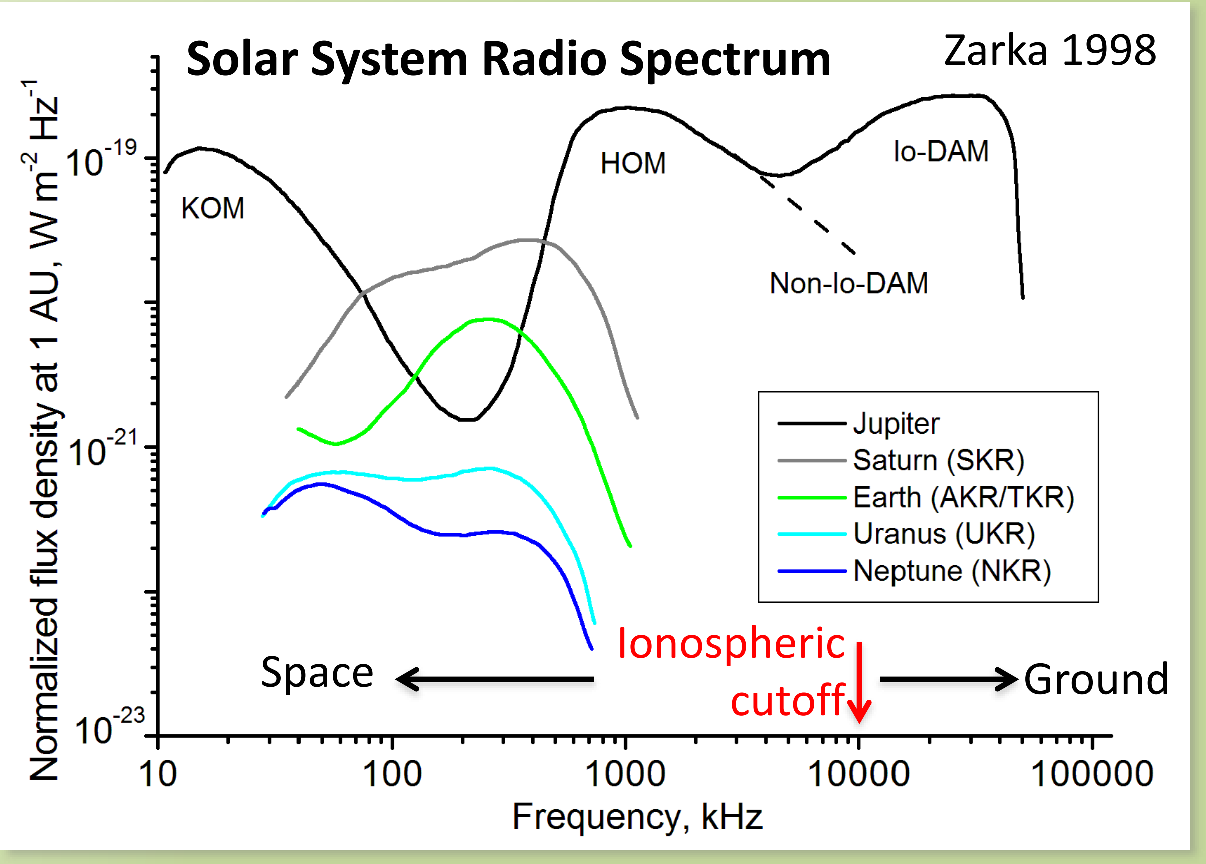
Peak of Emission

$f_g = 2.8\ (B_p/G)$ MHz

B_p: Planetary B-field

100% circularly polarized

Flux (Planet) ≥ Flux (star)



Predicting Magnetic Field Strengths

Christensen 2009

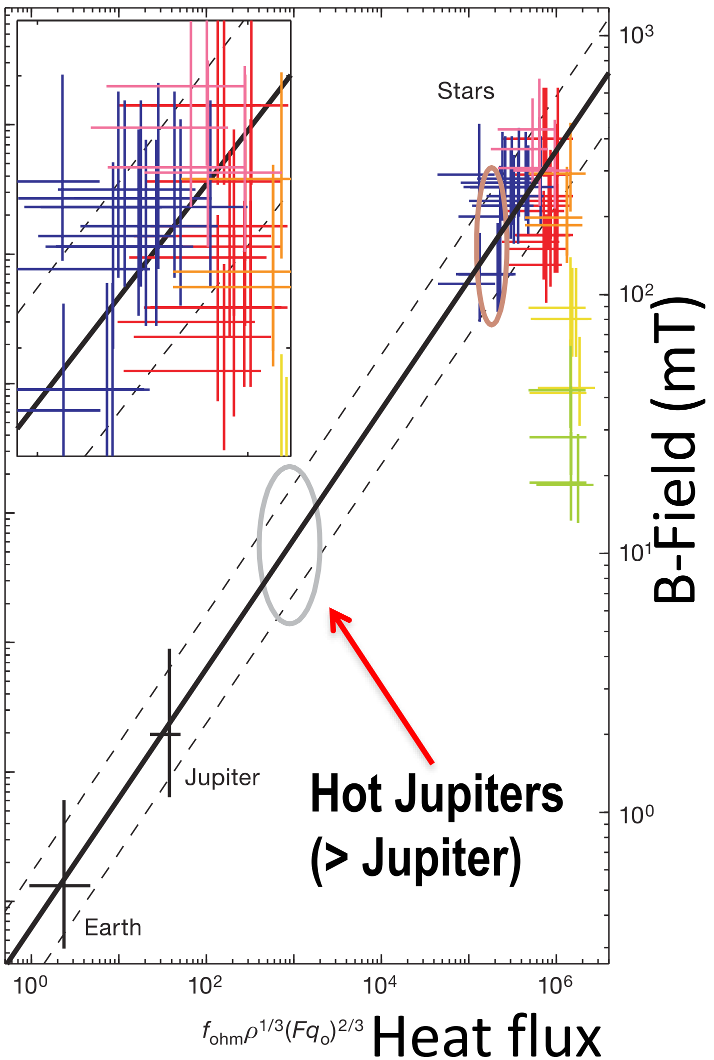
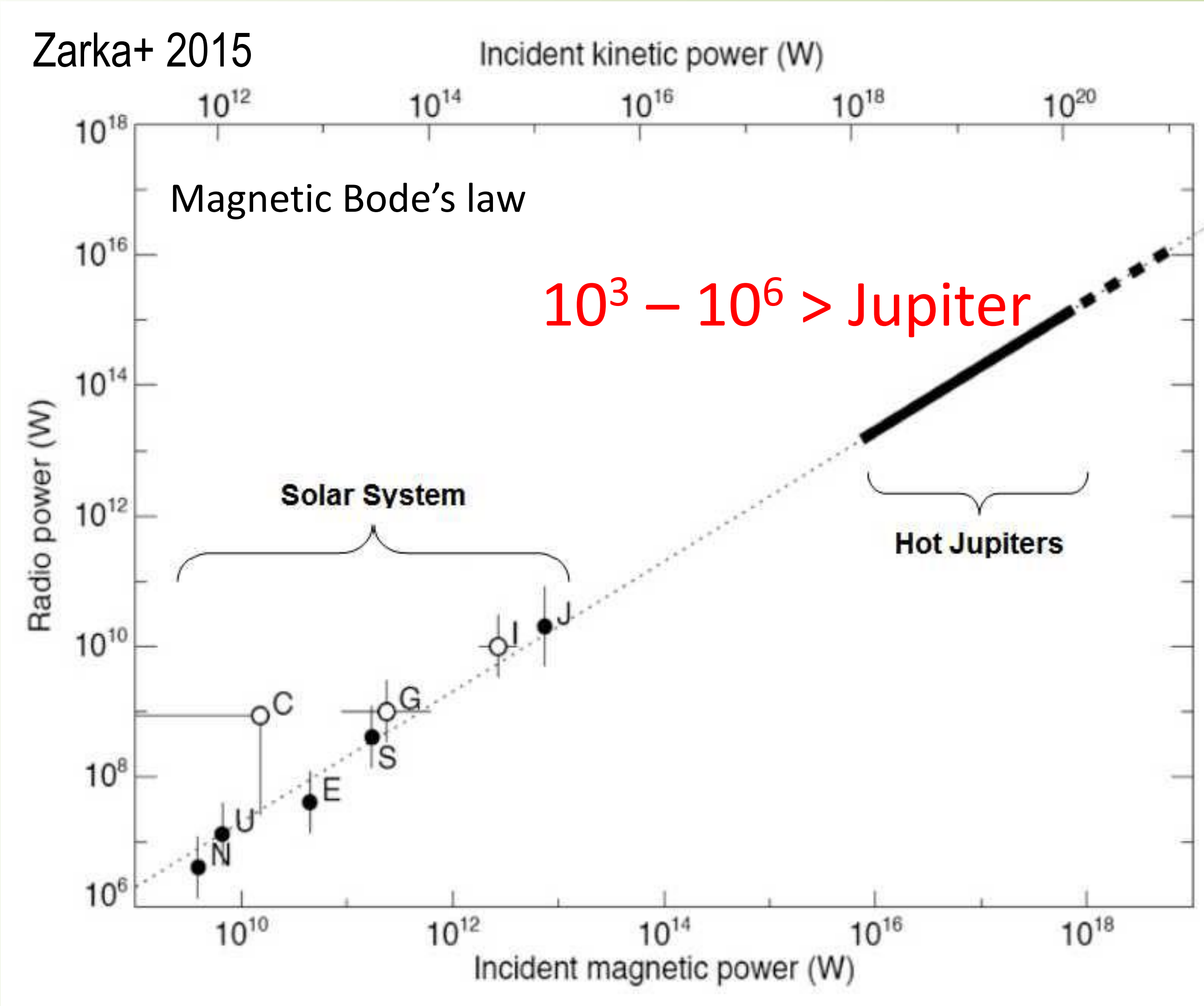


Table 1 Proposed scaling laws — Christensen 2010

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

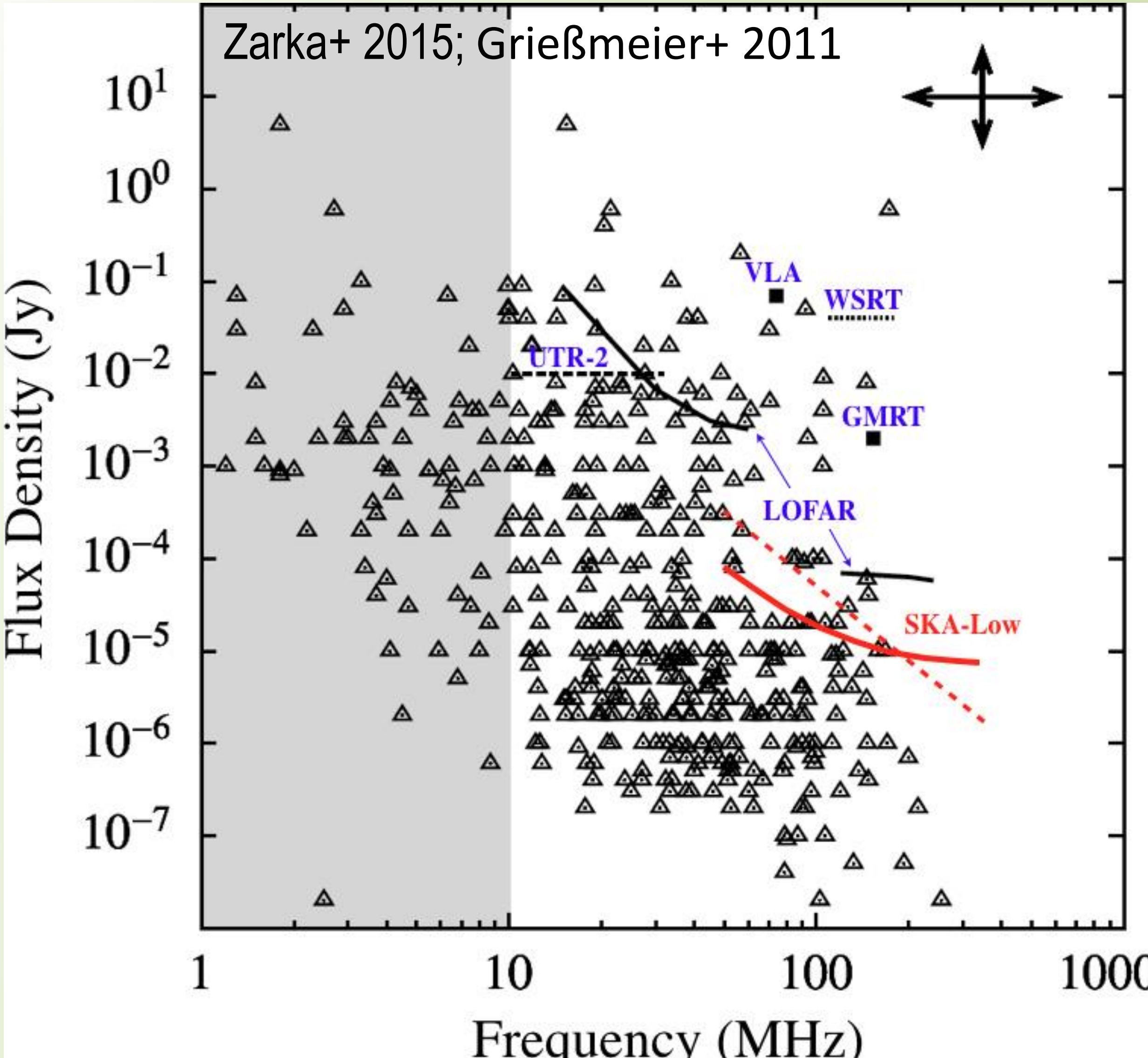
- Rotational dependent vs. rotation-independent approaches
- Observations will help disentangle which scaling law should be applied

Radio Flux Predictions: Exoplanets



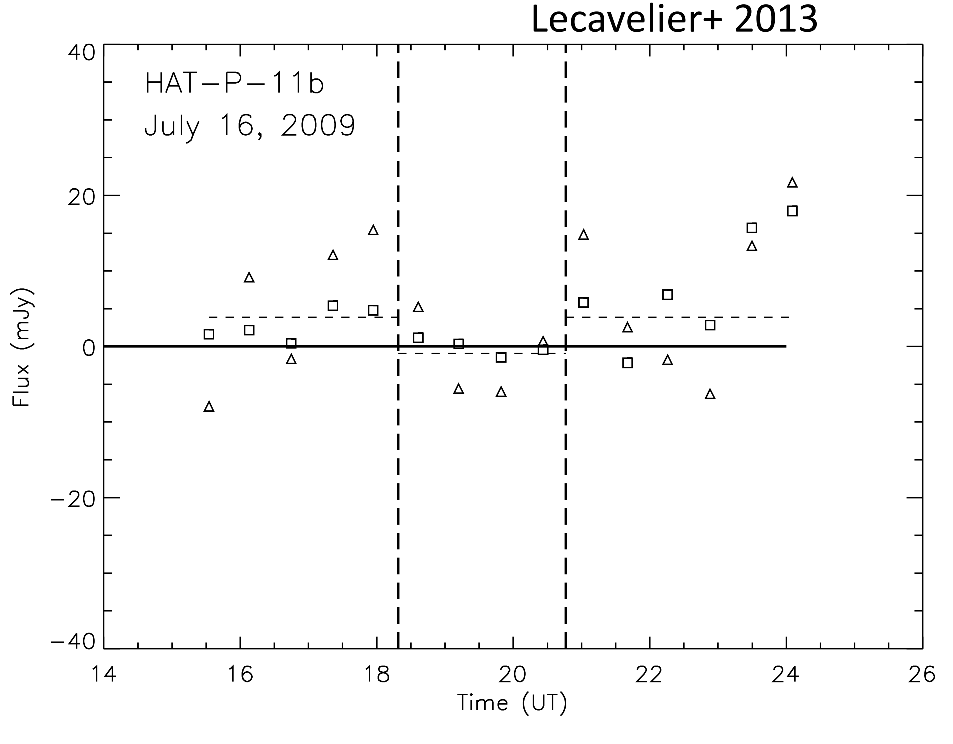
Scaling law: average radio power to incident Poynting flux of plasma flow

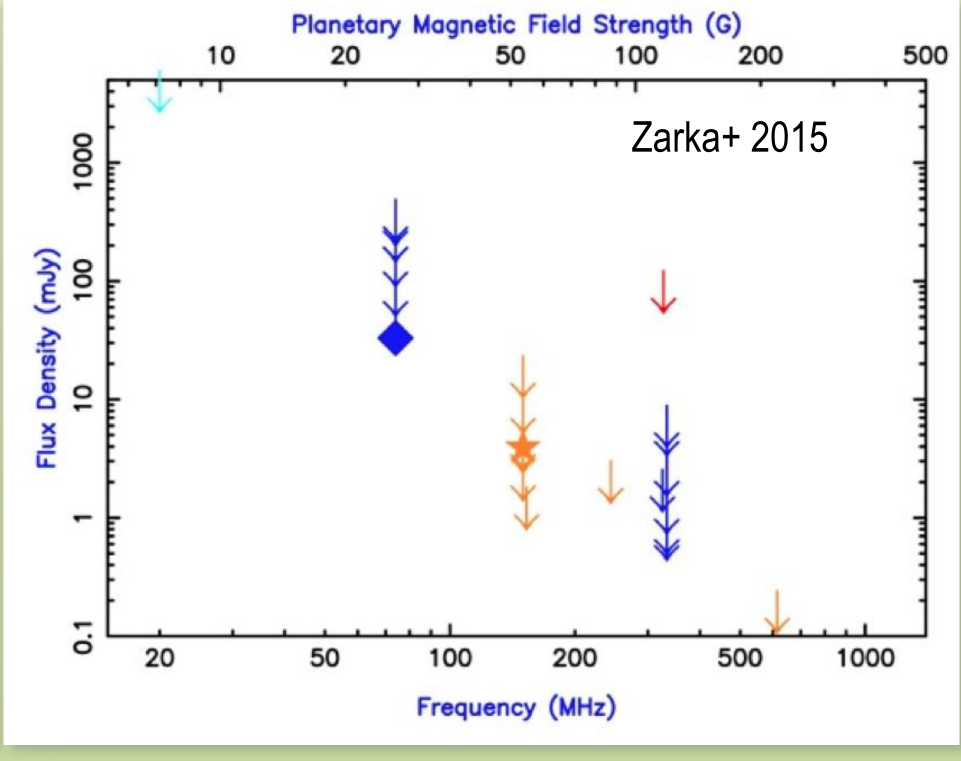
Radio Flux & Frequency Predictions



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

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

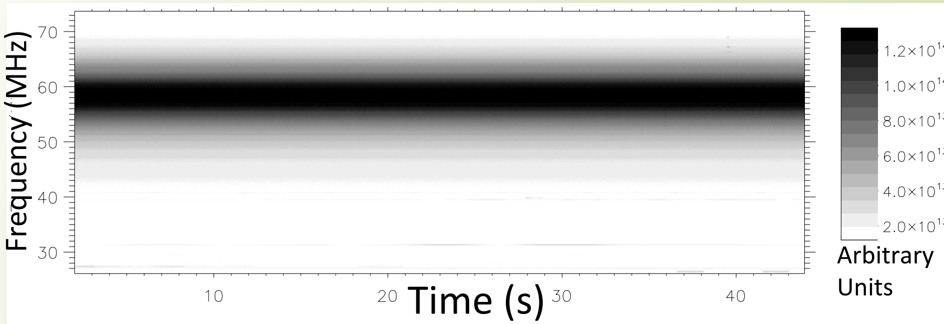
LOFAR Obervations

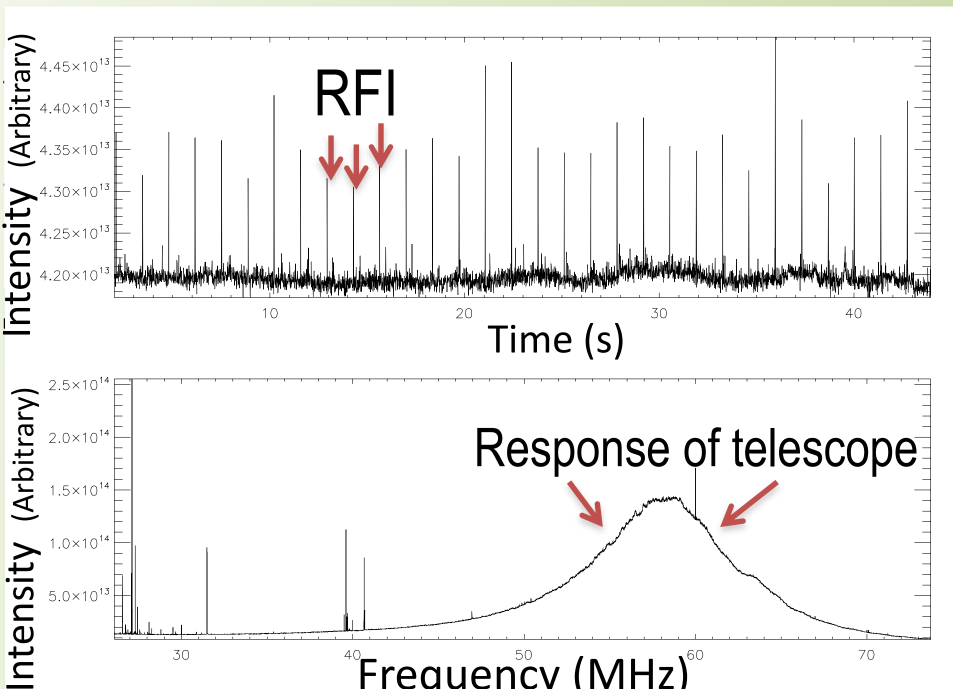
- ν: 26-73 MHz
- IQUV Polarization
- Raw Res: 10 msec & 3 kHz
- 9 arcmin resolution
- 16 mJy sensitivity: 2 mins over full band
- Observational Campaign:
  - 4 exoplanets so far
  - 3 Beams
  - Over full orbital phase

Turner+ 2017 (submitted)

LOFAR Pipeline

Raw





Turner+ 2017 (submitted)

LOFAR Pipeline

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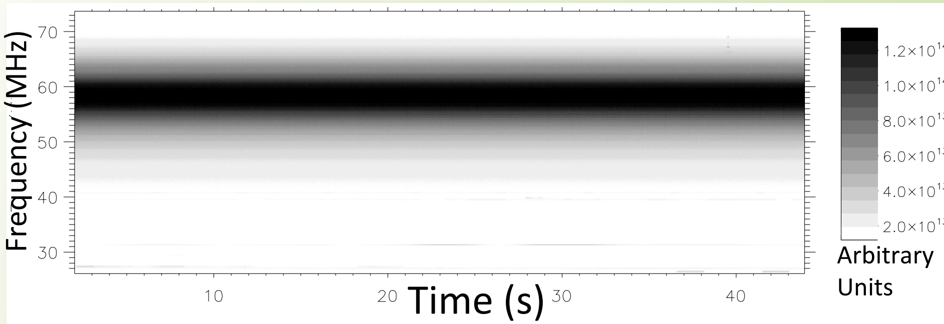
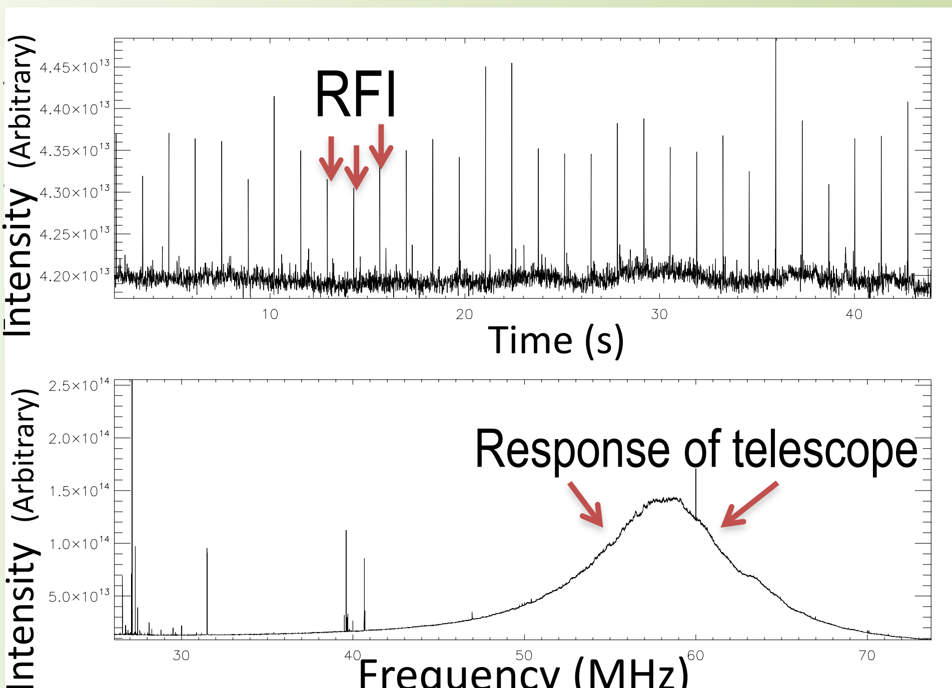
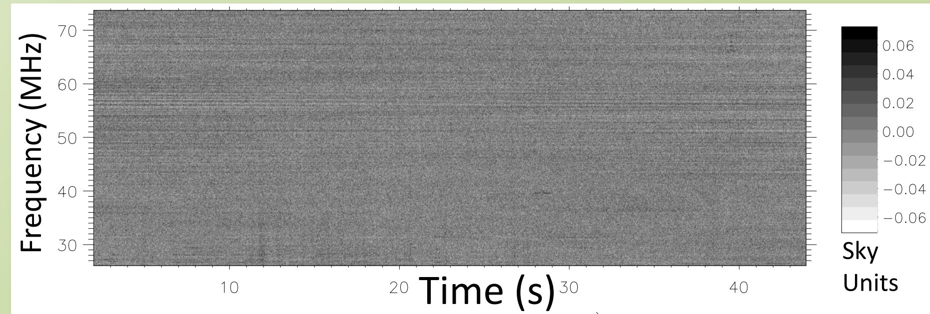
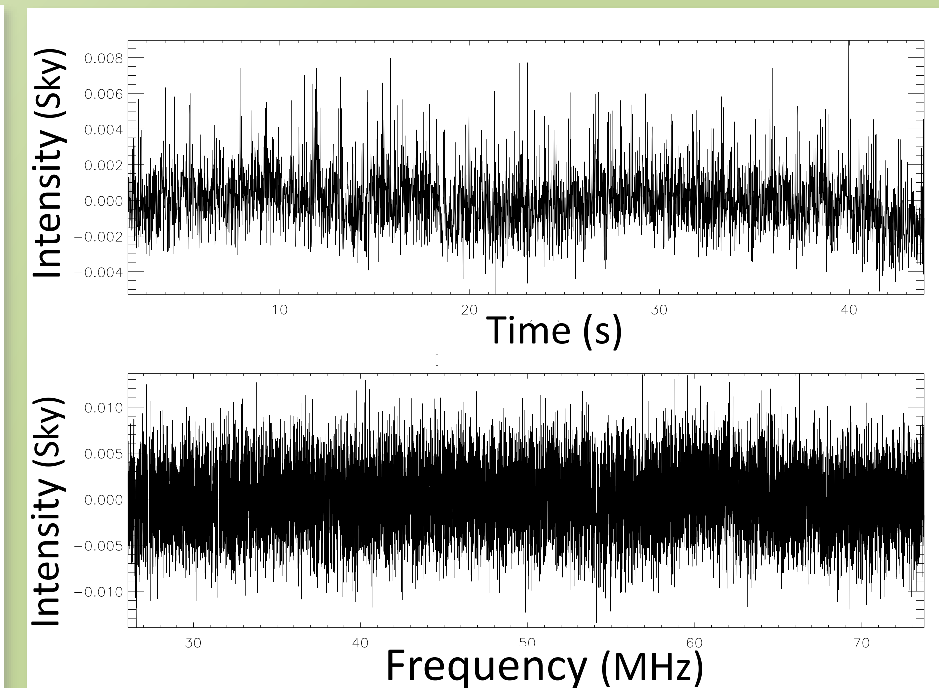




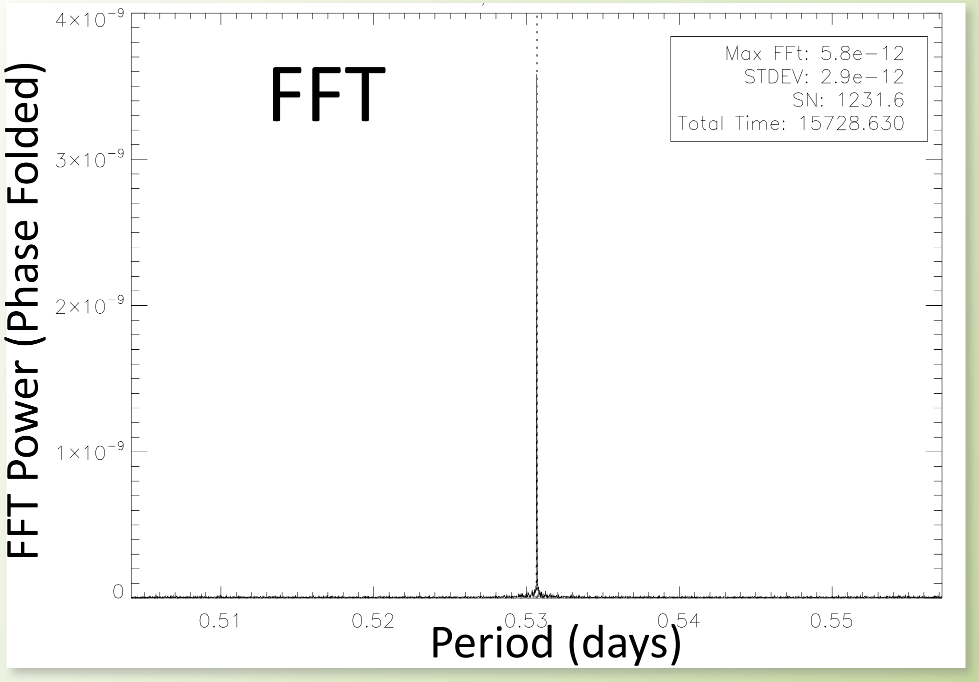
Normalized+ RFI mitigation

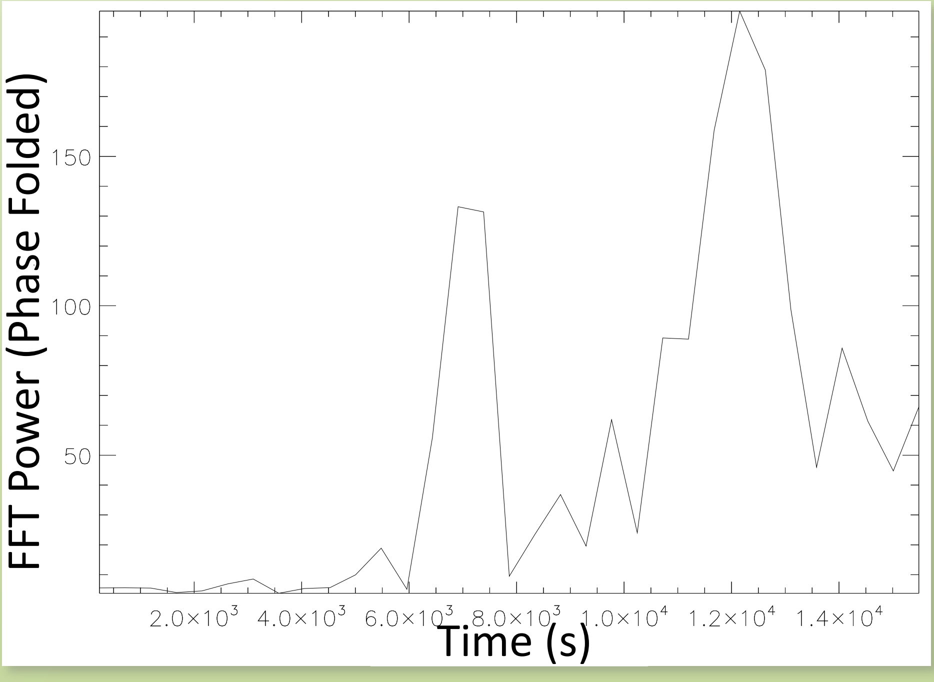




Turner+ 2017 (submitted)

Preliminary Results: Pulsar





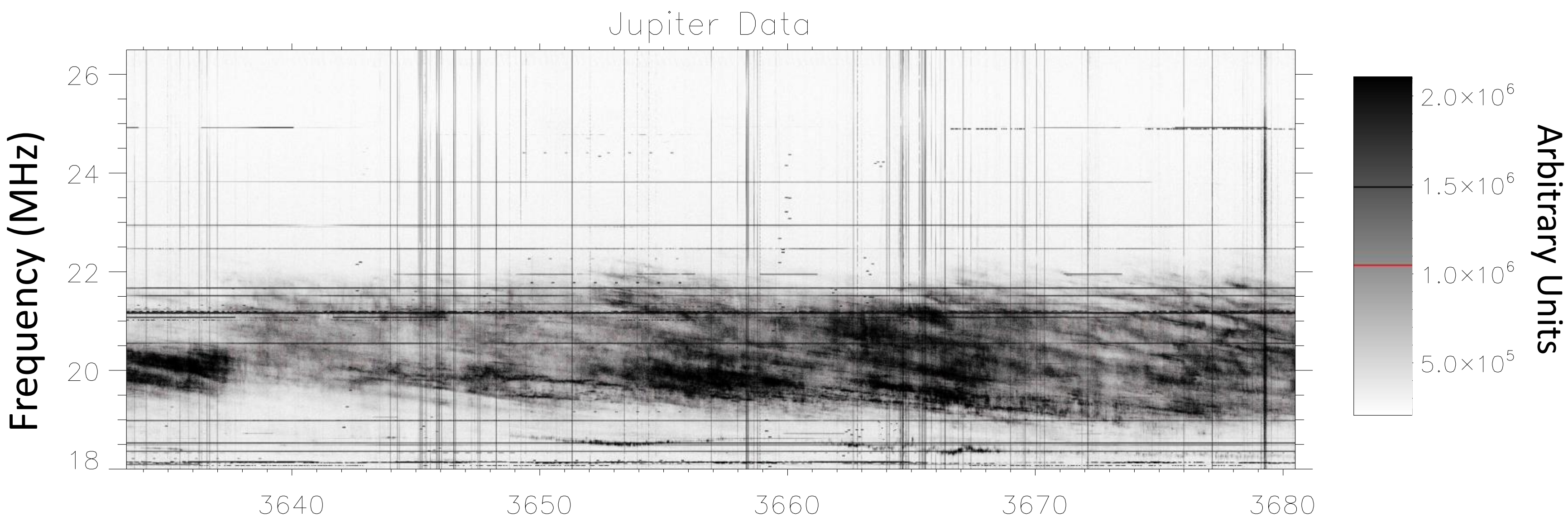
- Pulsar B0823+26 is detected at high S/N at known period
- Brightness of pulsar changes with time (known previously).

Turner+ 2017 (submitted)

Jupiter Observations

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

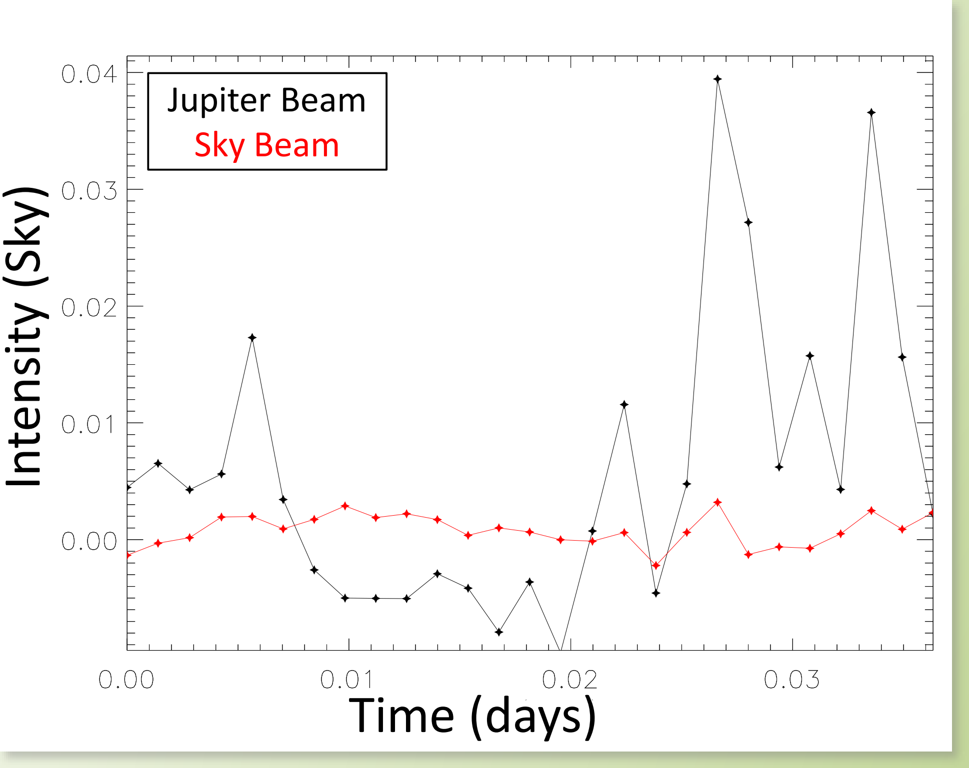
– Produce a set of observables that can be used as a guideline in the search exoplanetary radio emission



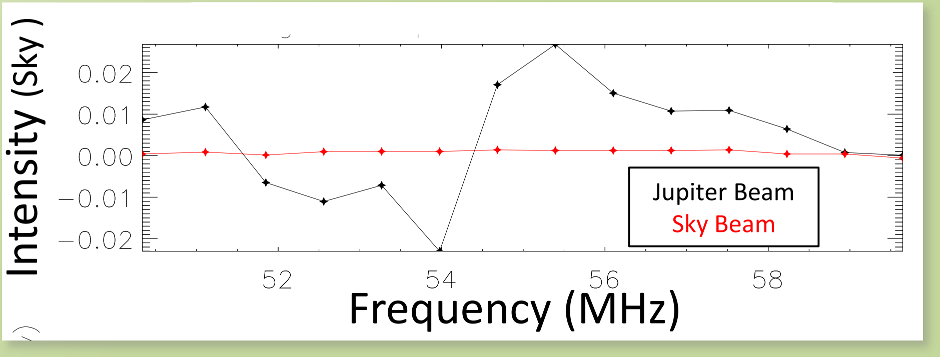
Turner+ 2017 (in prep)

Broadband Observables

Time Series

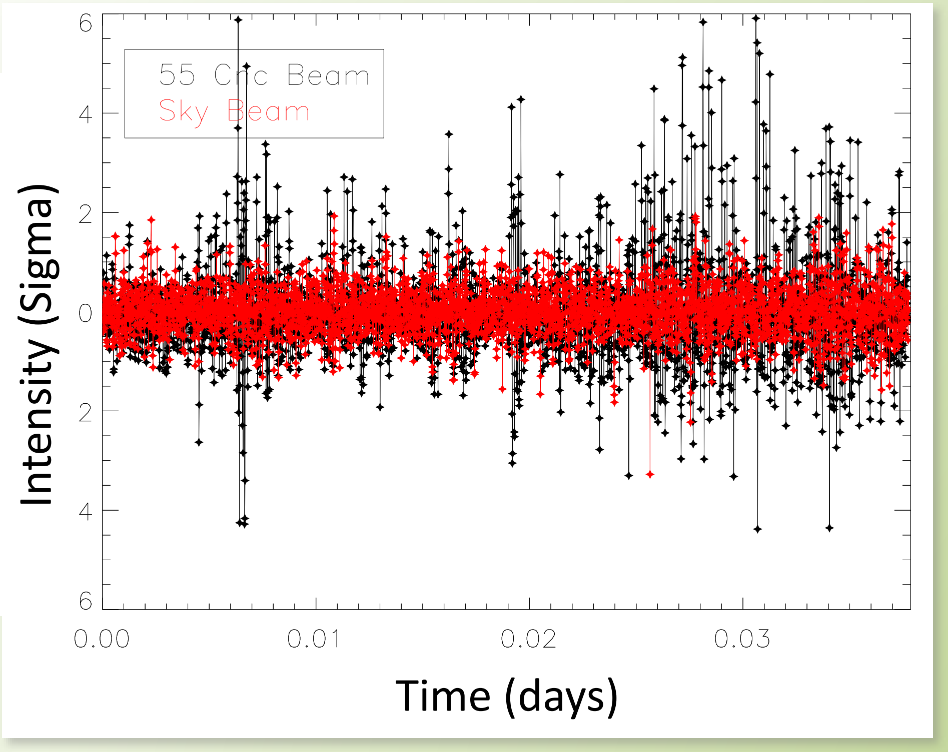


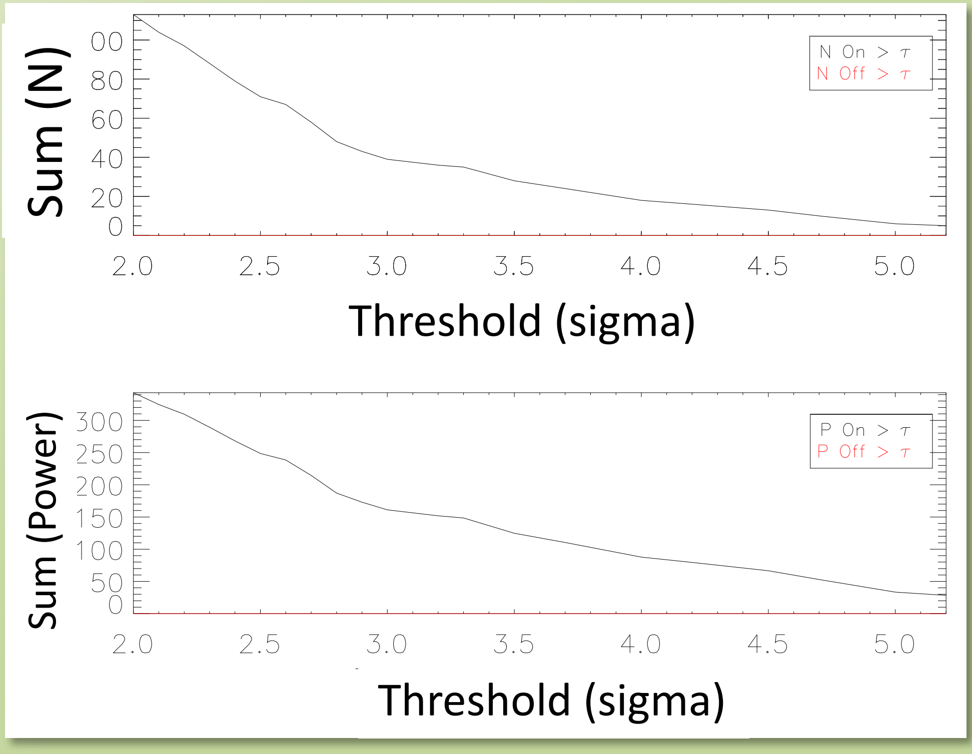
Integrated Spectrum



Turner+ 2017 (in prep)

Burst Observables



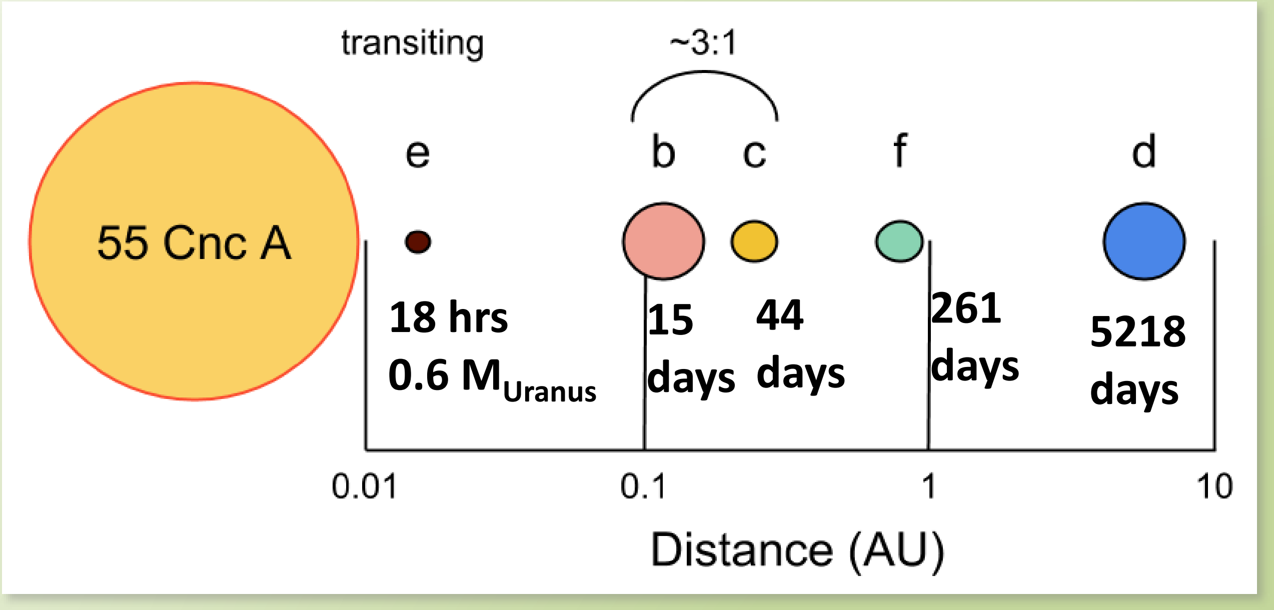


High-pass filtered time series

Number of peaks/power above threshold

Turner+ 2017 (in prep)

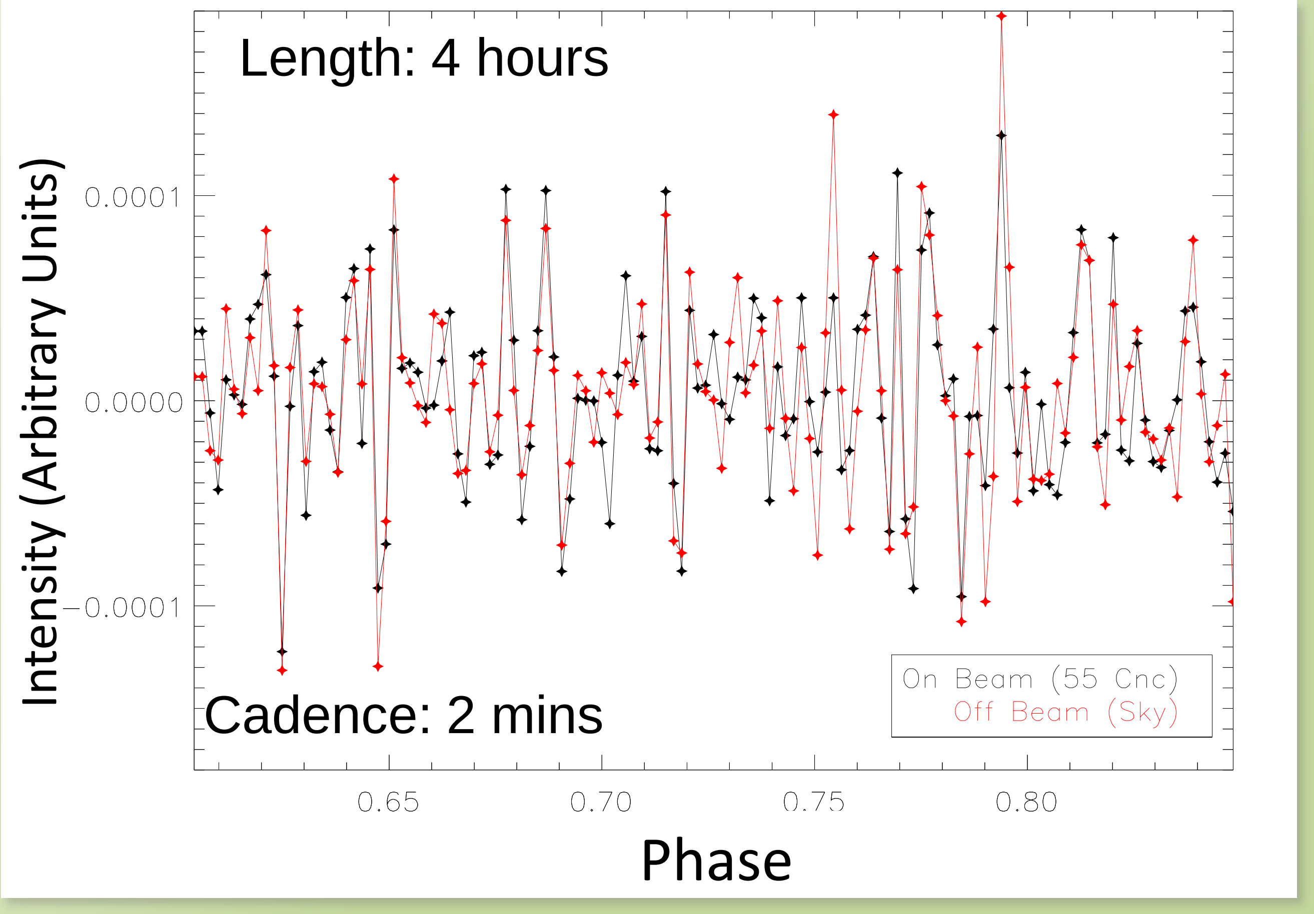
55 Cnc Planetary System



- 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



Turner+ 2017 (submitted)

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?

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