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

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Science at Low Frequencies IV

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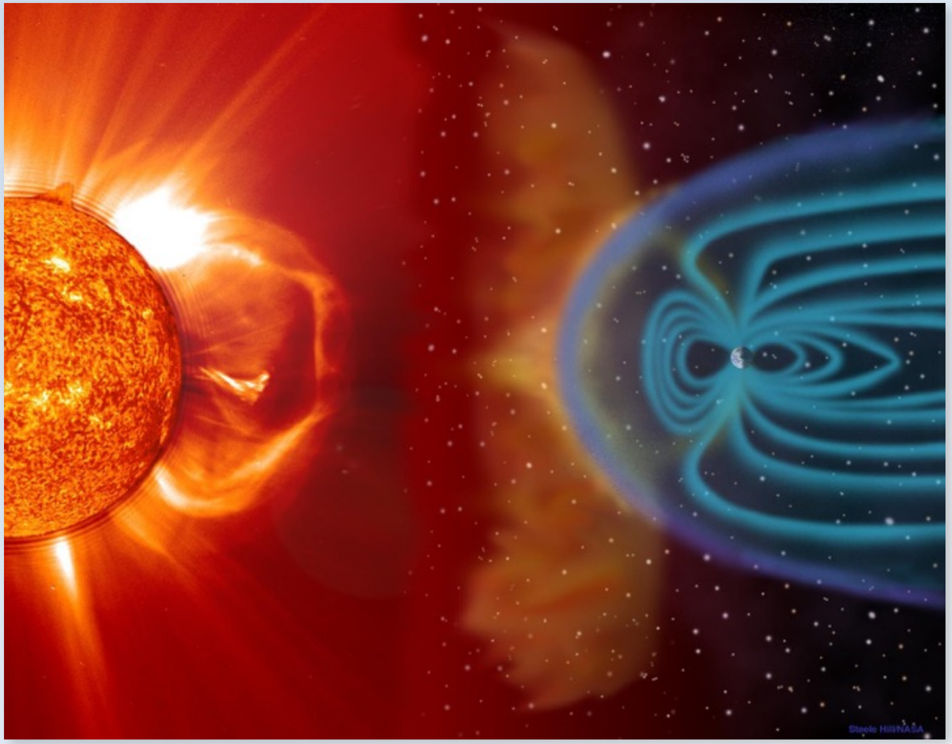
Overview

- Exoplanet magnetic fields
- Radio observations of exoplanets
- Our LOFAR observing campaign
  - Data pipeline (Turner+ 2017)
  - Preliminary results on 55 Cnc (Turner+ 2017)
  - Jupiter observations
    - Jupiter as an exoplanet (Turner+ 2017, in prep)
- Dynamic spectra from imaging observations (Loh+ in prep)

Exoplanet Magnetic Fields

Motivation

- Formation and evolution
- Interior structure
- Atmospheric evolution and escape
- Rotation period
- 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)

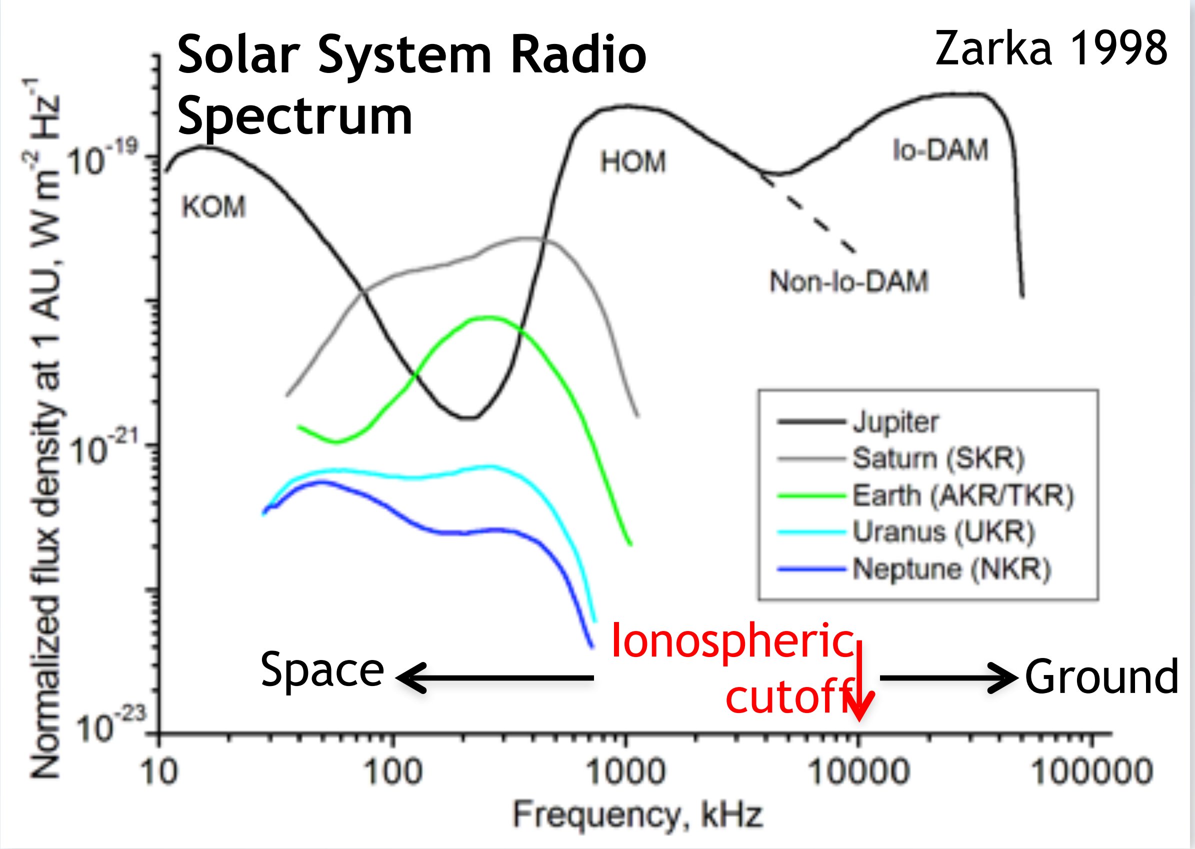
Cutoff of Emission

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

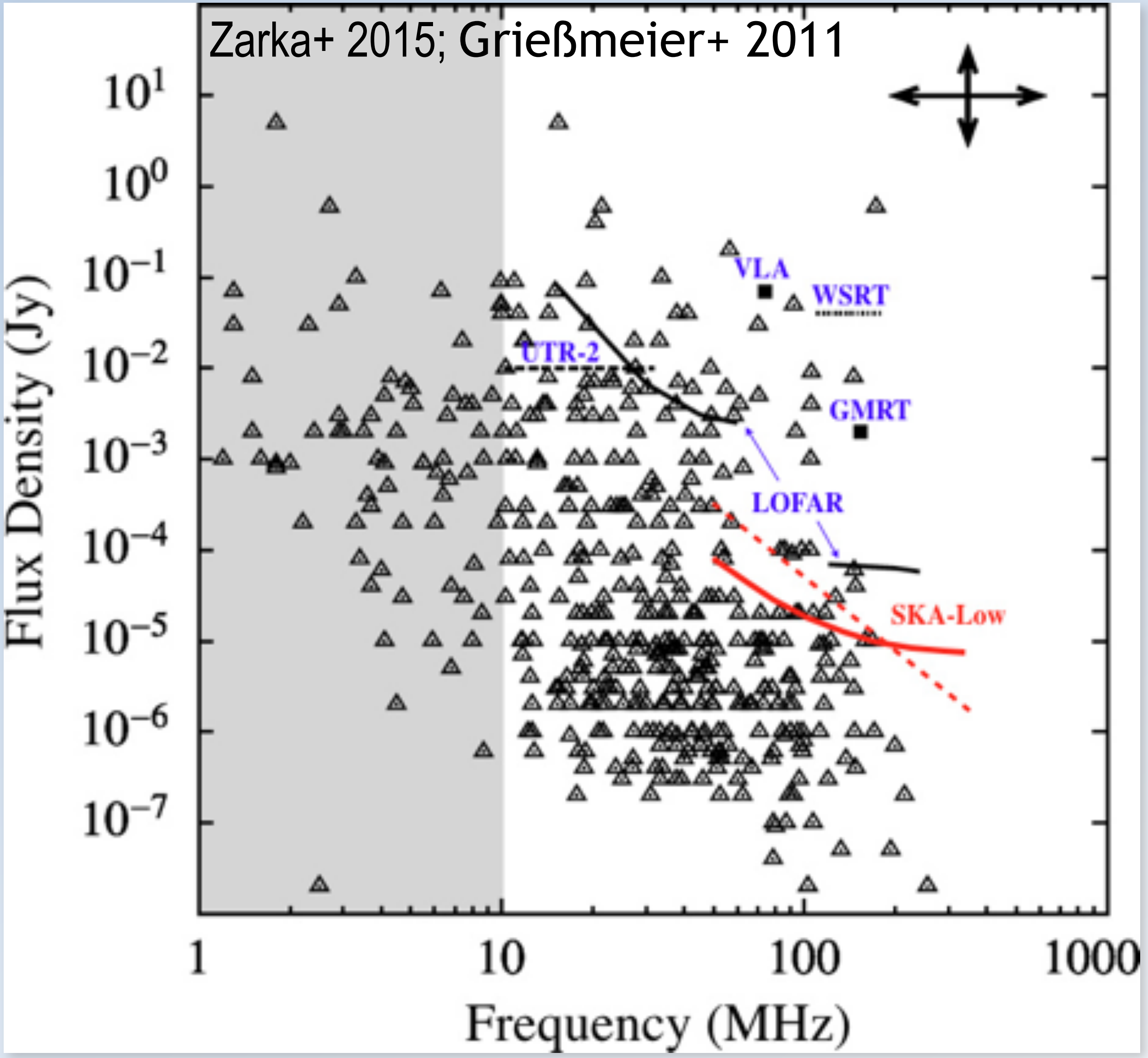
B_p: Planetary B-field

100% circularly polarized

Flux (Planet) ≥ Flux (star)



Radio Flux & Frequency Predictions



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

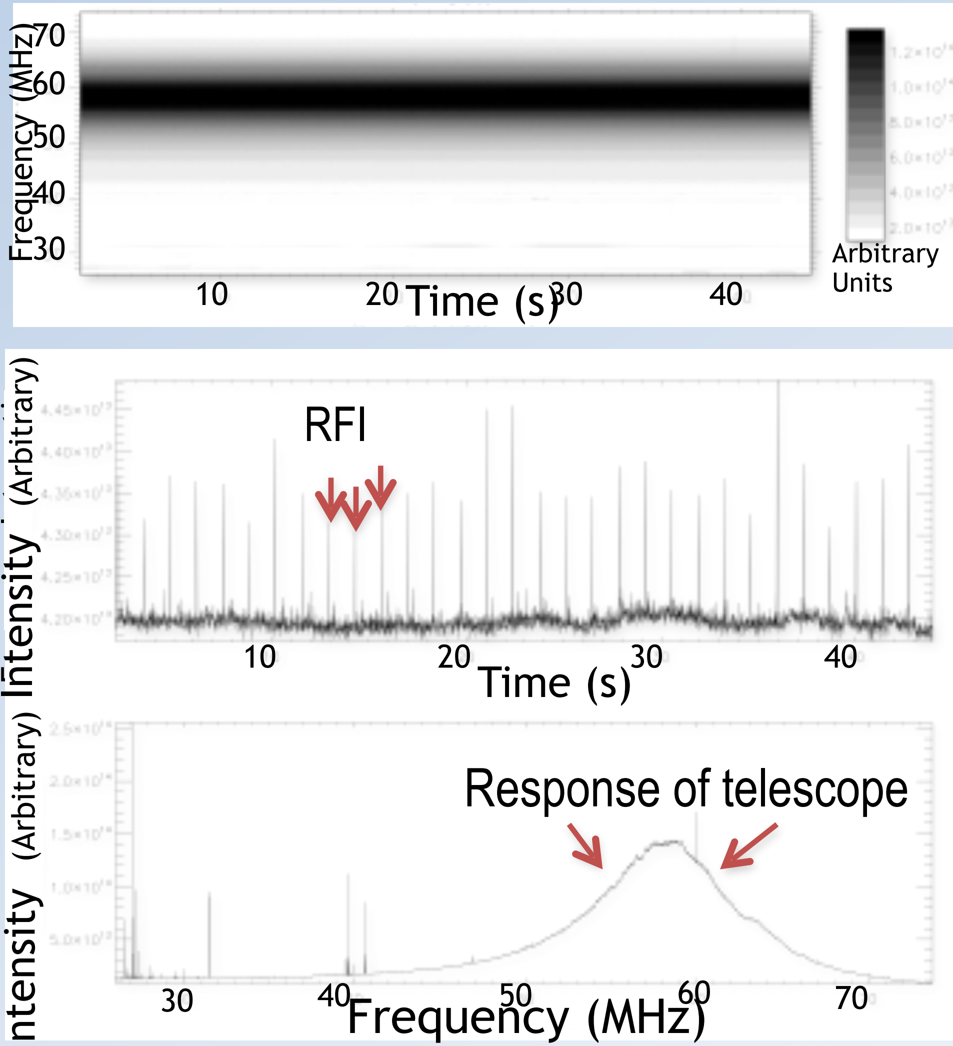
LOFAR Observations

- 16-73 MHz
- IQUV Polarization
- 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

LOFAR Pipeline

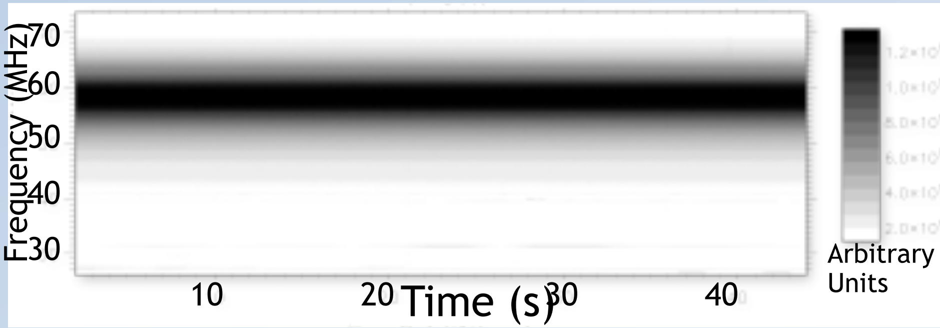
Raw

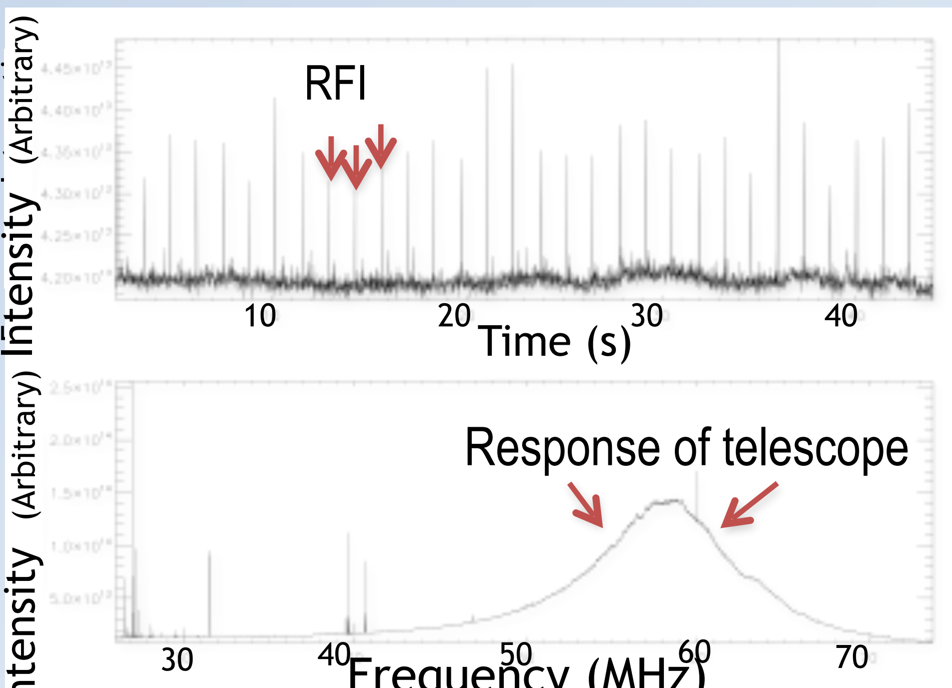


Turner+ 2017

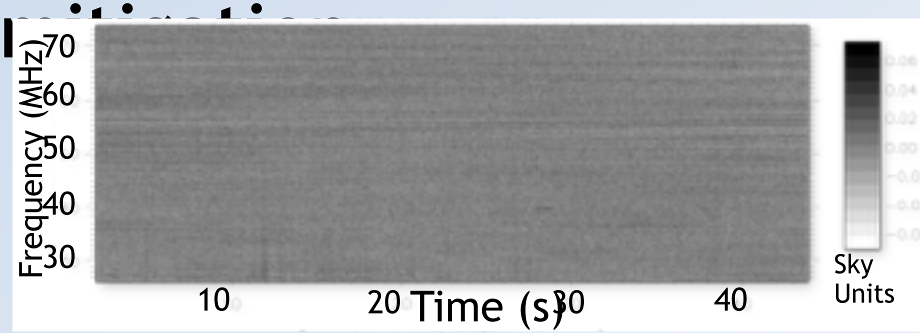
LOFAR Pipeline

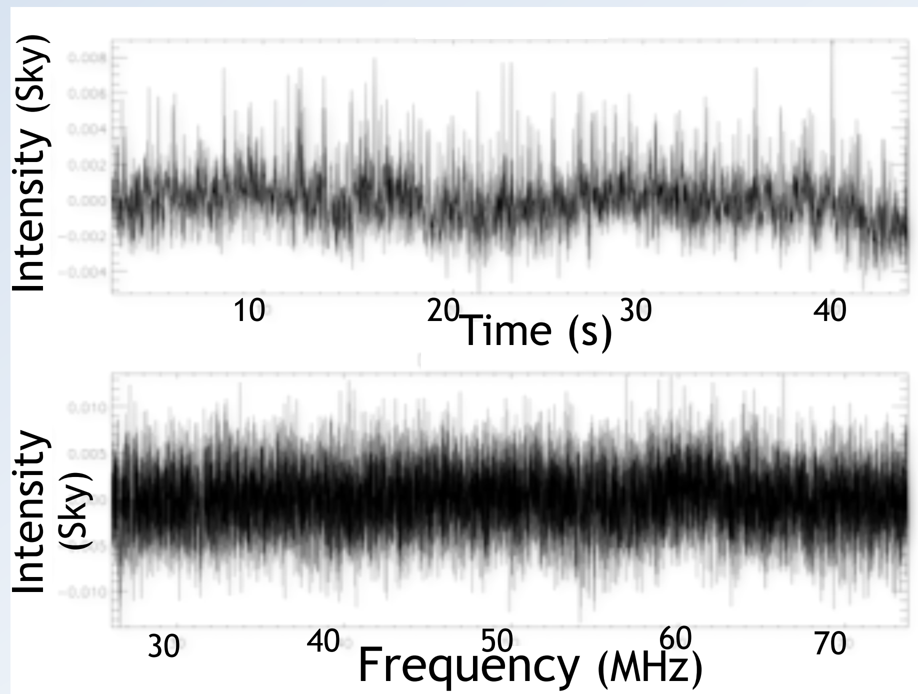
Raw





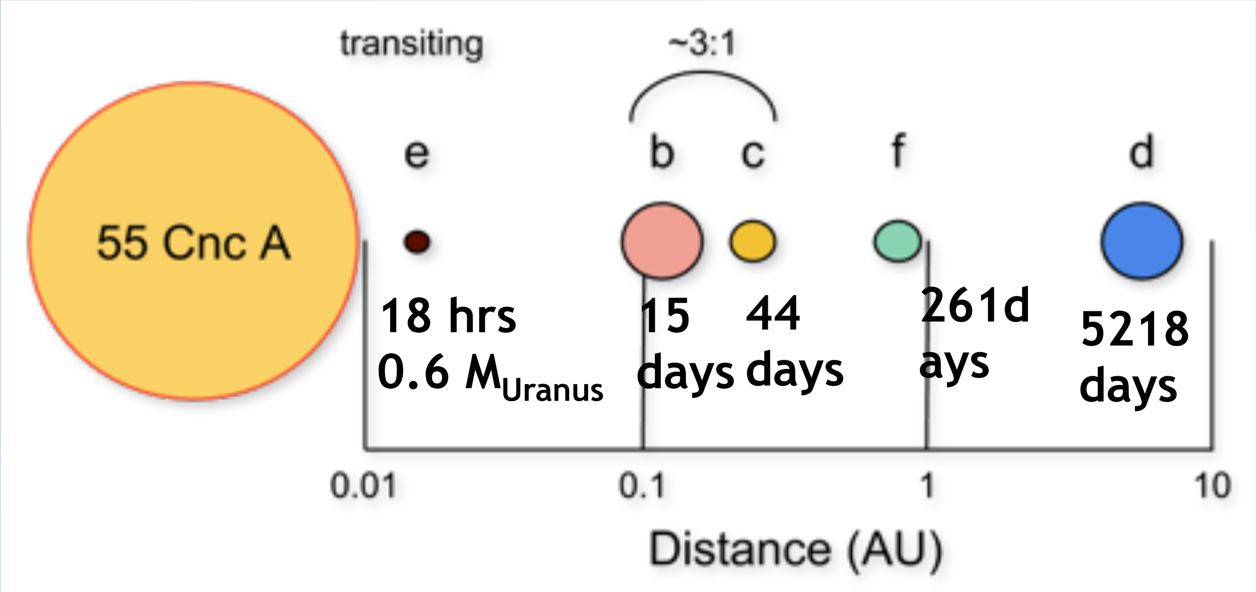
Normalized+ RFI





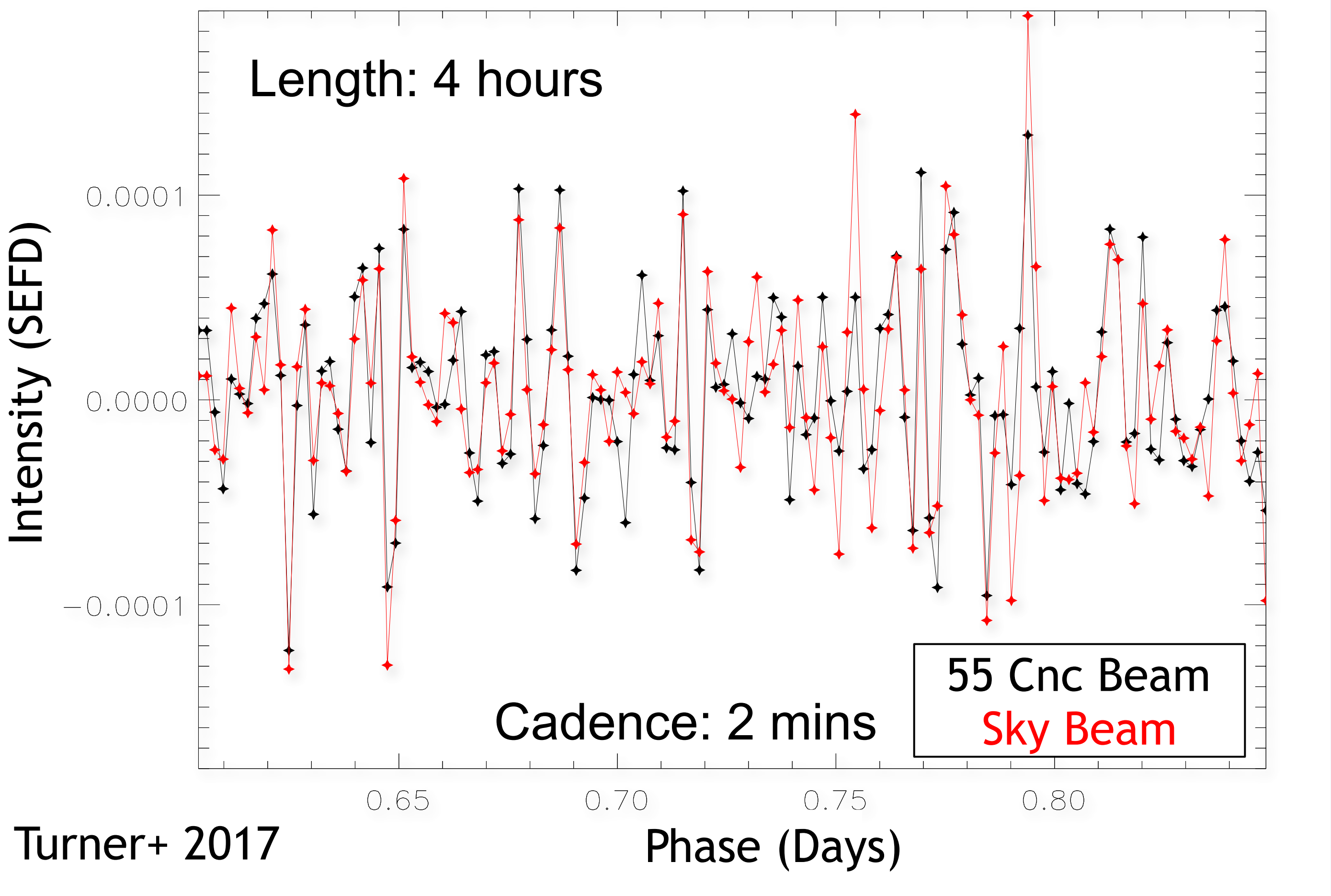
Turner+ 2017

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).

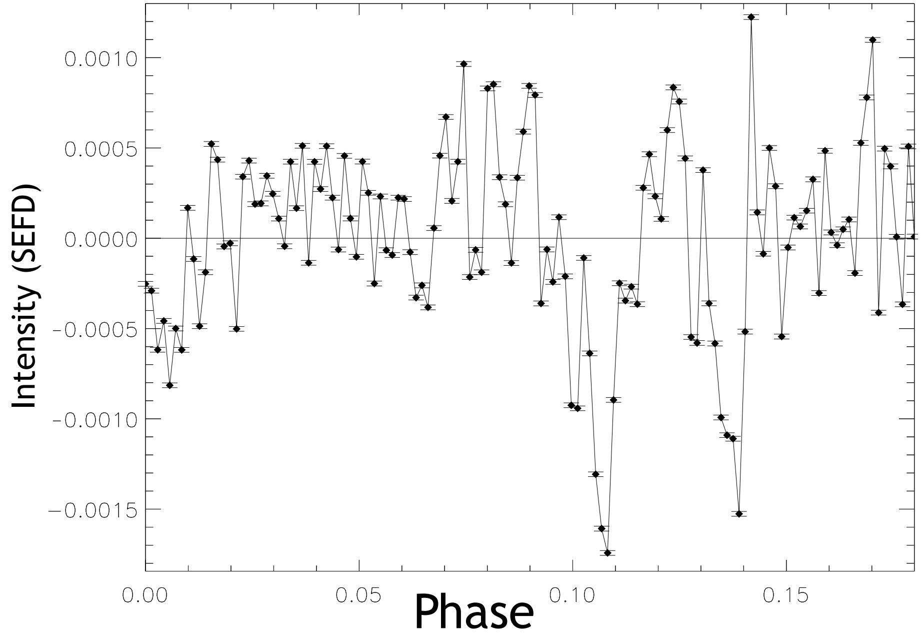
55 Cnc Preliminary Results:



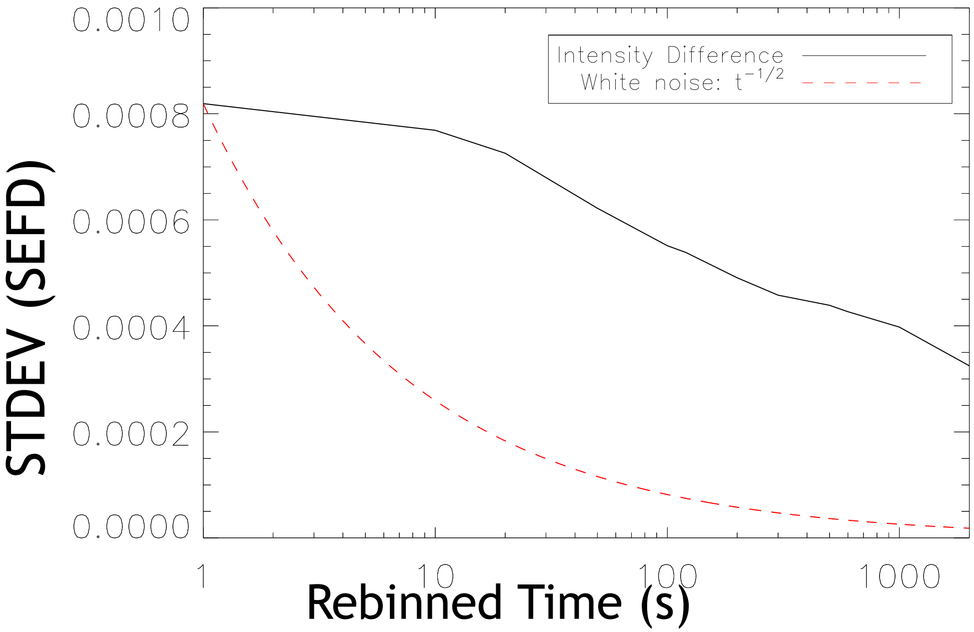
- No emission from 55 Cnc
- Variations are due to ionosphere

55 Cnc Upper Limit

Beam Intensity Difference



Standard Deviation of t-series

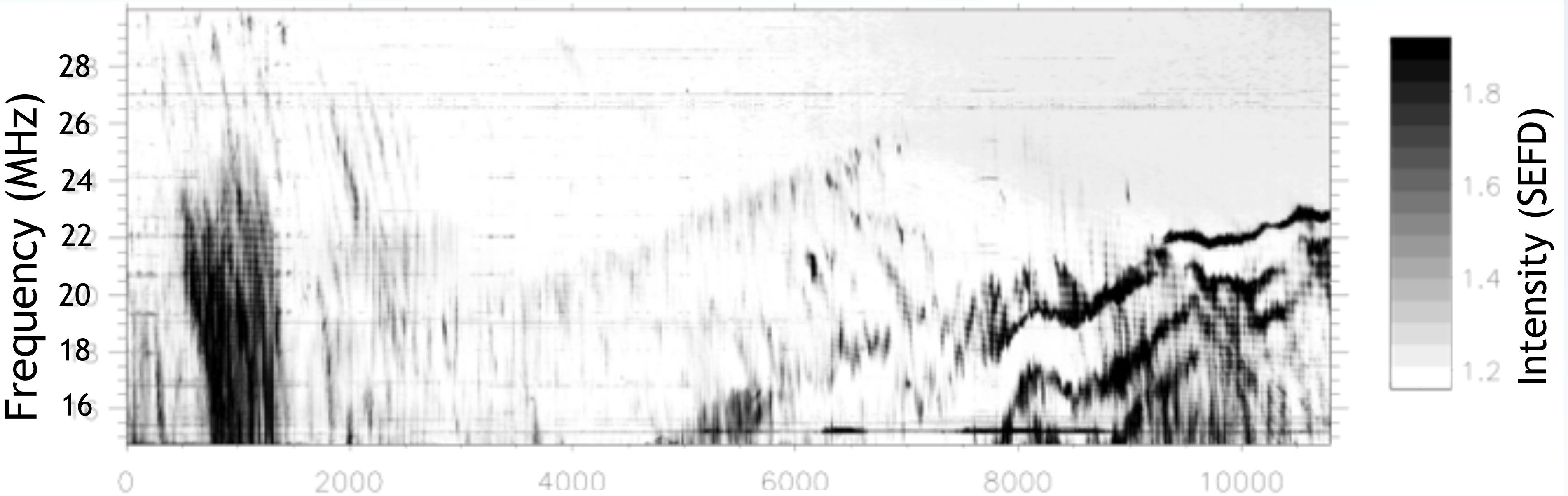


- 3σ upper limit → 2.6 Jy (50x theoretical sensitivity)
- Large-scale differential variations of the ionosphere between the two beams limit sensitivity

Turner+ 2017

Jupiter Observations

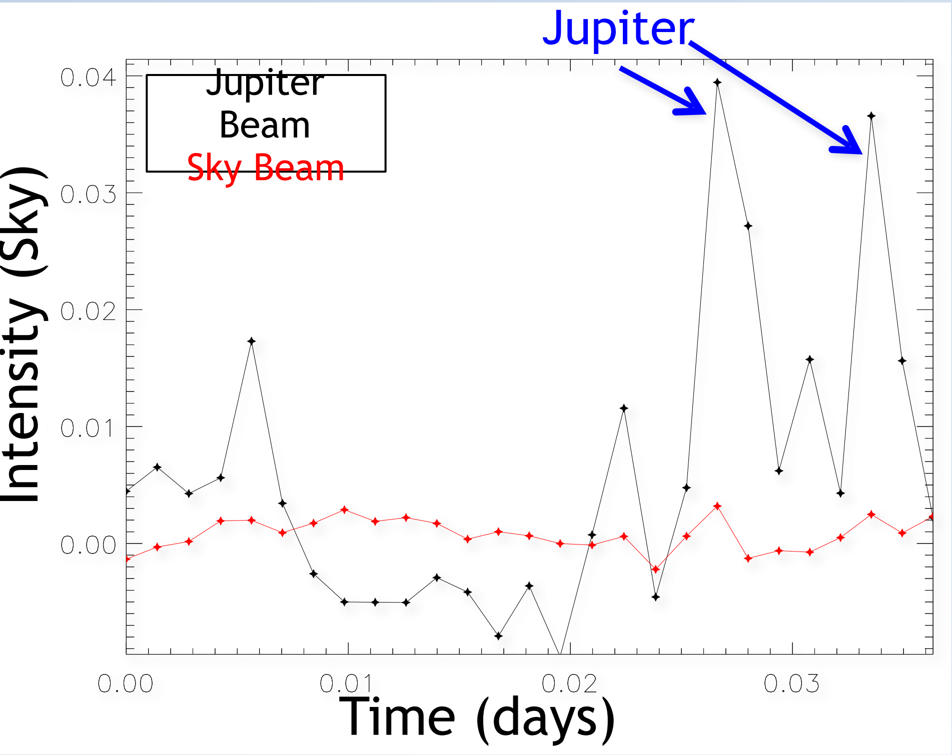
- Scale Jupiter radio emission from LOFAR as if it was an exoplanet (reduce flux by 10^{-3} – 10^{-6}).
- Produce a set of observables that can be used as a guideline in the search exoplanetary radio emission
- Find an upper limit of detectability



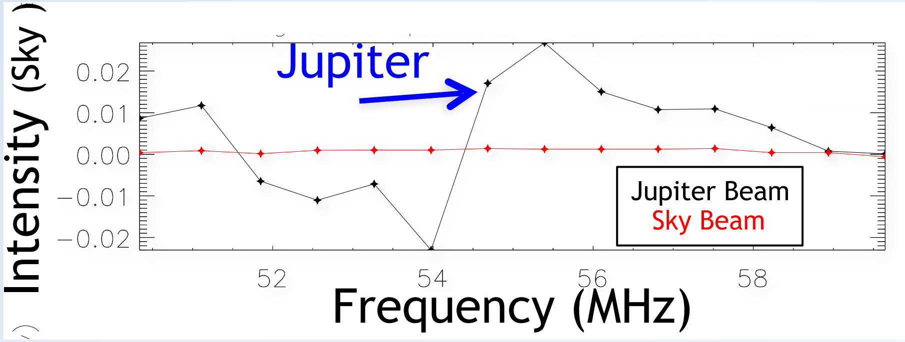
Turner+ 2017 (in prep)

Extended Emission Observables

Time Series



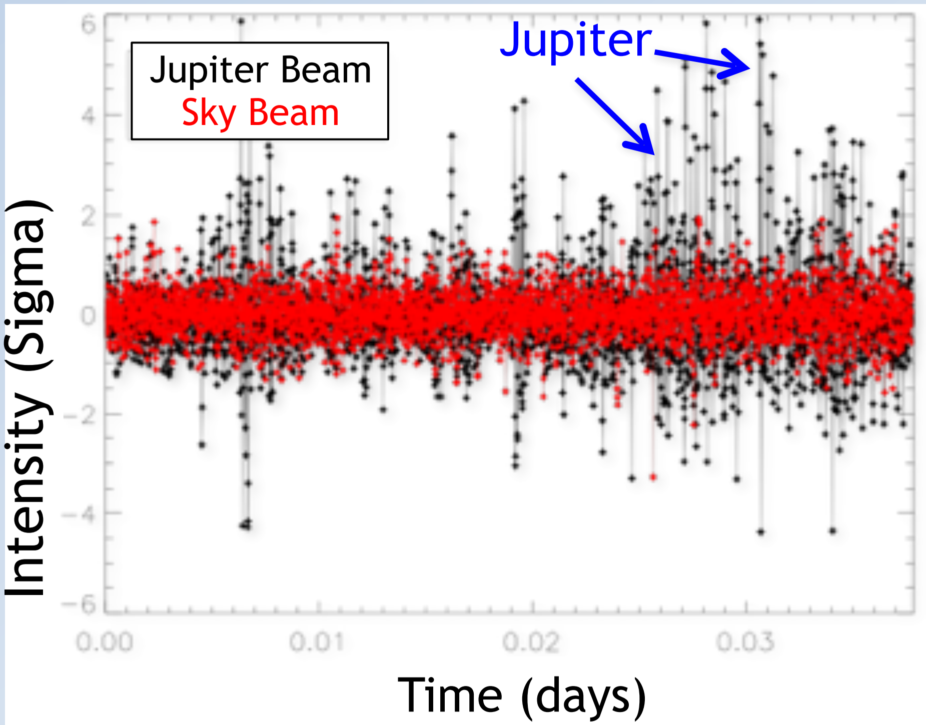
Integrated Spectrum



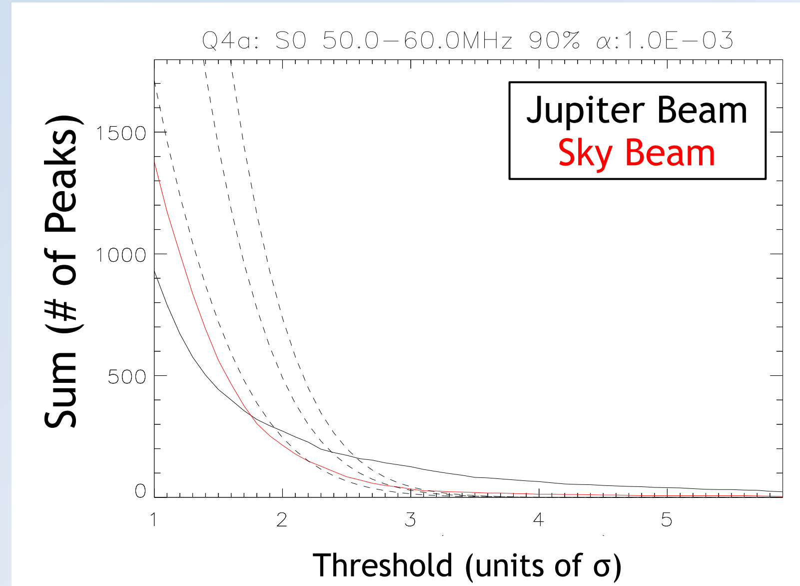
Turner+ 2017 (in prep)

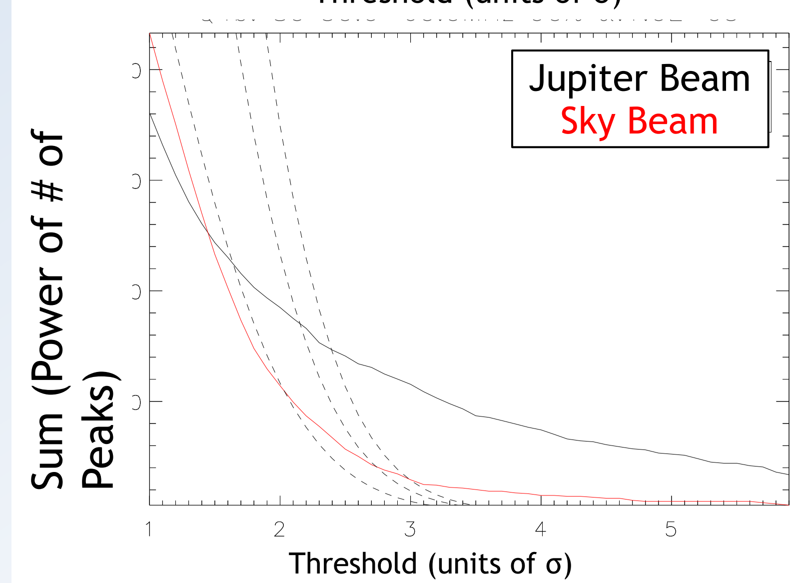
Broadband Observables

High-pass filtered time-series

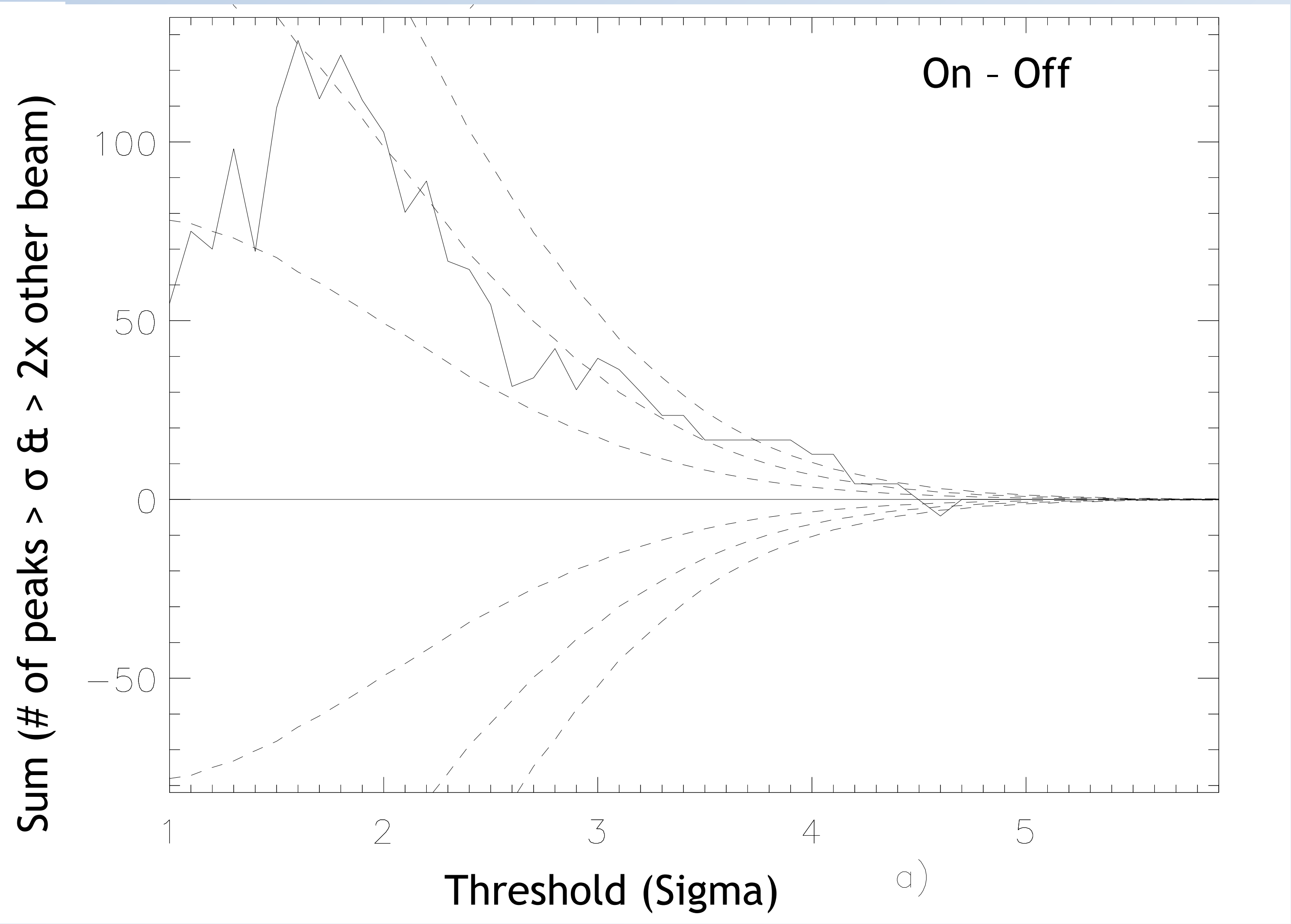


of peaks/power > σ





Detection Limit

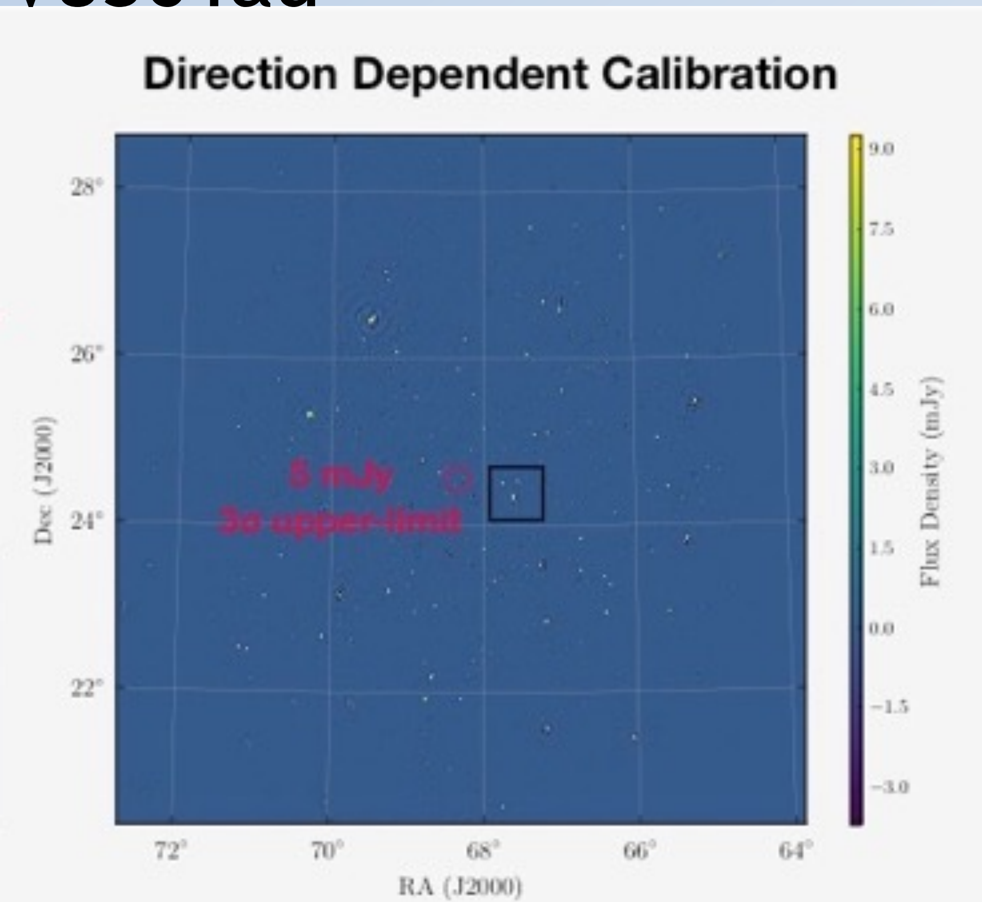


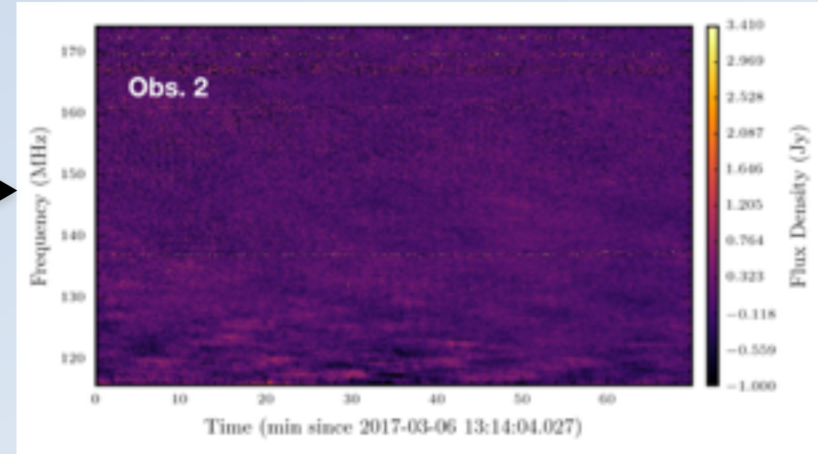
- Limit: ~2x10^5 x Jup bursts at 10pc
- Beyond 20pc is not likely possible

Turner+ 2017 (in prep)

Dynamic Spectra from Imaging

V830Tau





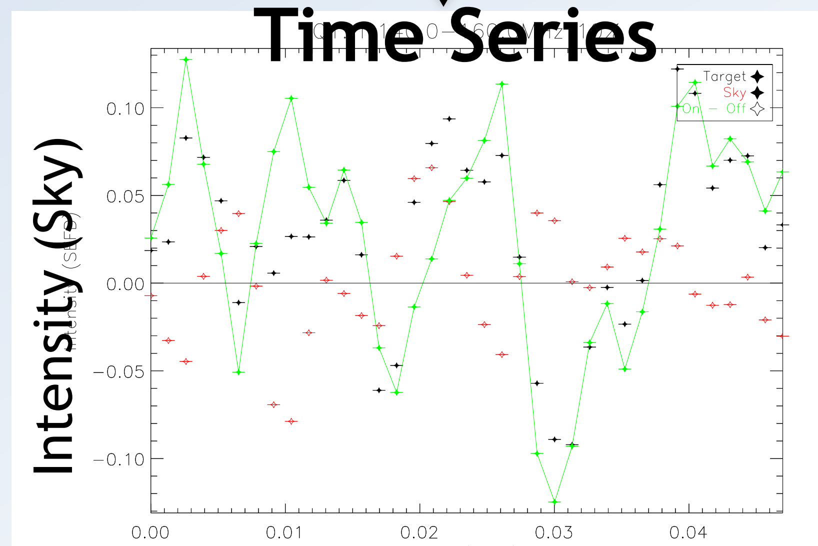


Image curiosity of Alan Loh (LESIA)

Time (days)

LOFAR HBA Data

Loh+ 2017 (in prep)

Conclusions

- Initial analysis of 4 hours of LOFAR 55 Cnc e data do no show an exoplanet signal
  - 3sigma upper limit 50x > theoretical sensitivity due to large scale ionospheric variations
- We observed Jupiter as if it was an exoplanet and developed a set of observables as guides
  - Detection limit is $2x10^5$ x Jup bursts at 10pc
- Can now use dynamic spectra from imaging observations with our pipeline

Predicting Magnetic Field Strengths

Christensen 2009

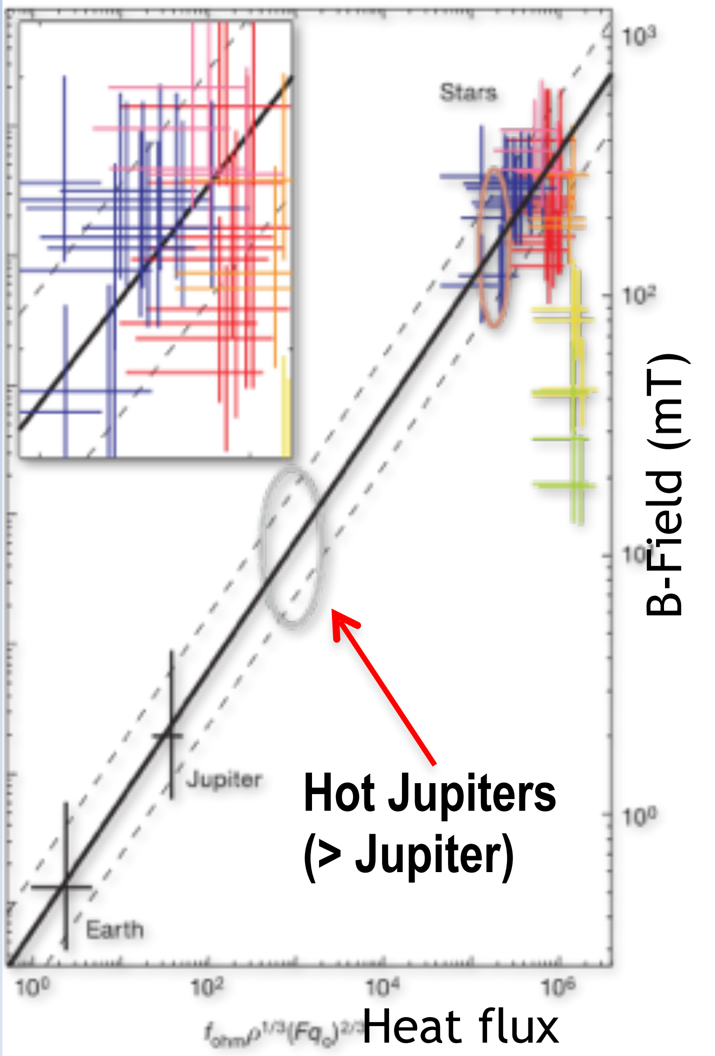


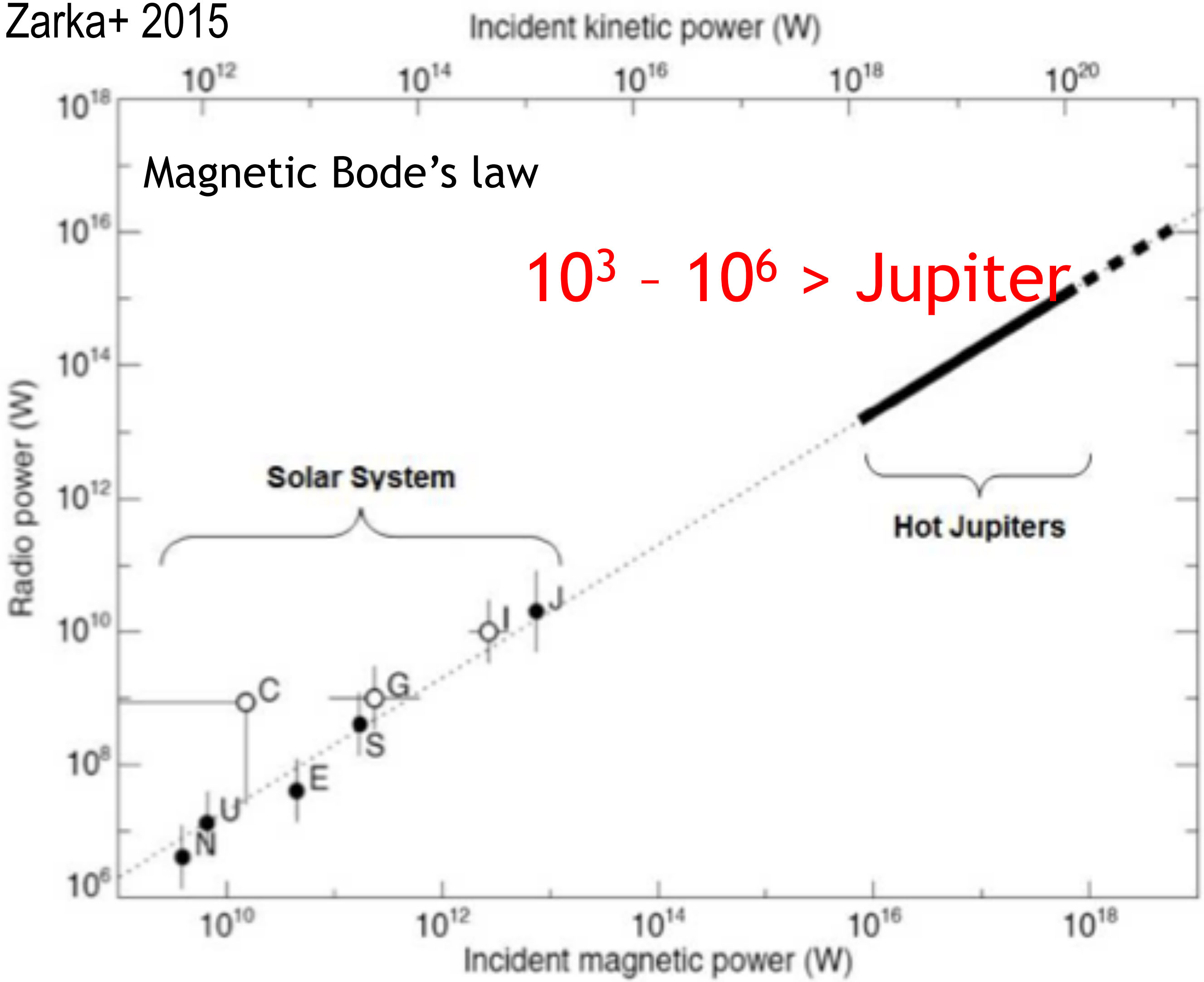
Table 1 Proposed scaling laws Christensen 2010

#	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

Zarka+ 2015



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