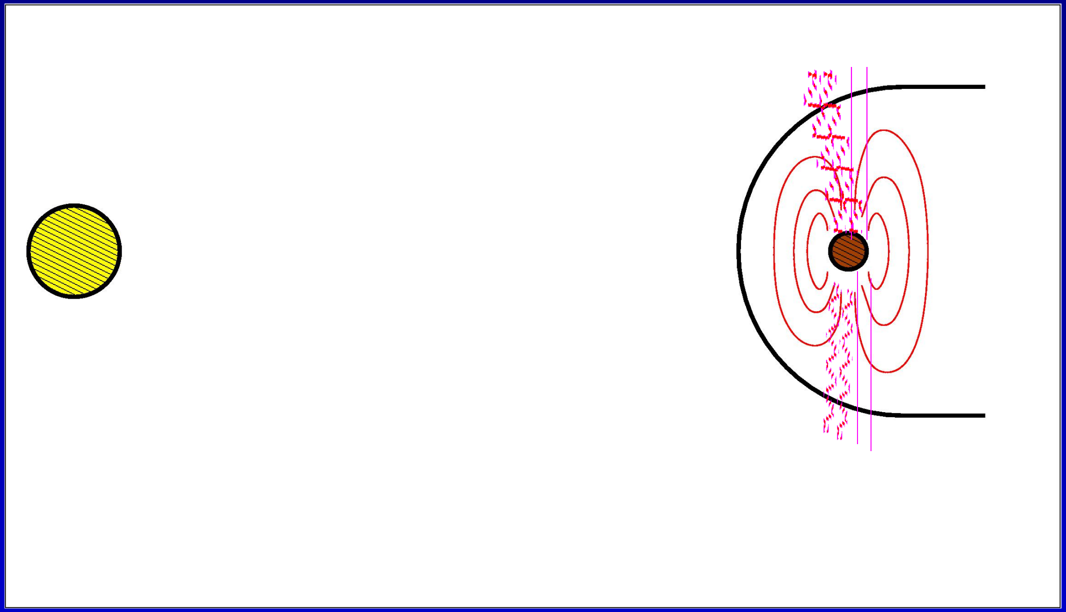
Observation of extrasolar planets at low radio frequencies



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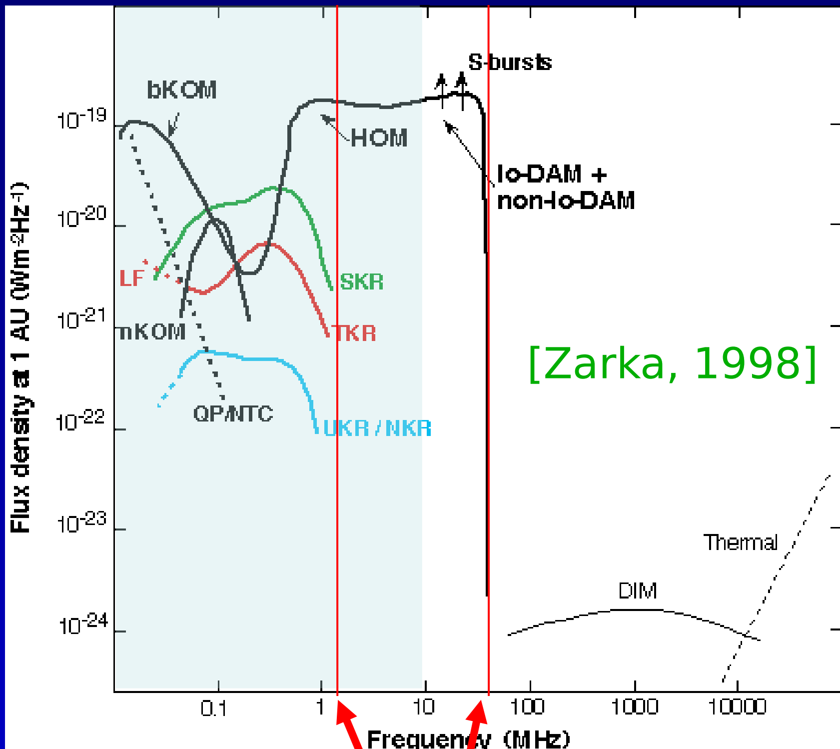
Outline

- why do we want to do this?
- is this possible?
- a LOFAR observation campaign

Solar system wisdom (Jupiter)



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

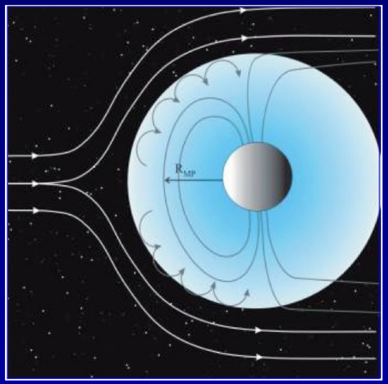
radio emission

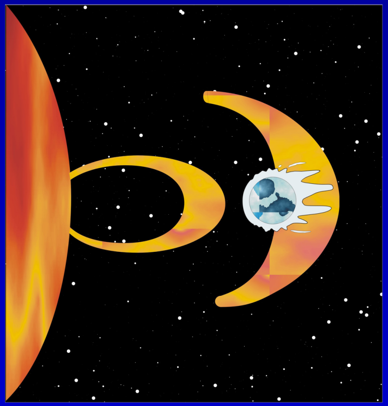
→ detect magnetic field!

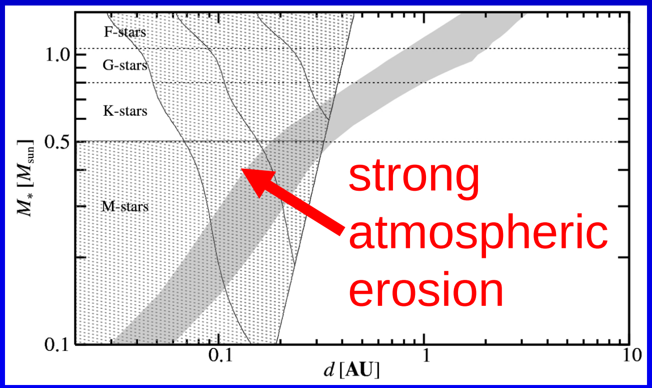
→ calculate magnetic field!

Why are magnetic fields important?

- planetary migration!
- protection against stellar wind!
- protection against stellar CMEs!
- protection against cosmic rays!
- explain observed transit curves!
- understand solar system planets!







How to detect exomagnetospheres?

Superflares	[Rubenstein 2000; Schaefer 2000]
Planetary migration	[Lovelace 2008]
H_3^+ emission	[Skholnik 2006]
Gas giant mass loss	[Lammer 2009]
Chrom. emission	[Saar 2004]
Early ingress	[Fossati 2010]
Transit profiles (ENAs)	[Holmström 2008]
Radio emission	
Atmospheric loss	[Grießmeier 2010; Driscoll 2013]
Cosmic rays	[Grießmeier 2005, 2009]
Comet-like exosphere	[Mura 2011]

[Grießmeier 2015]

How to detect exomagnetospheres?

other effects have similar signature

Observation	Expected effect	False positives?
Superflares	Weak or none	Yes [Maehara 2012; Shibayama 2013]
Planetary migration	Weak	Yes [Lovelace 2008; Vidotto 2009, 2010]
H_3^+ emission	Yes?	Yes [Skholnik 2006]
Gas giant mass loss	Yes	Yes [Lammer 2009; Khodachenko 2012, 2015]
Chrom. emission	Yes	Yes [Saar 2004; Preusse 2006; Kopp 2011]
Early ingress	Yes	Yes [Fossati 2010; Lai 2010; Bisikalo 2013a,b]
Transit profiles (ENAs)	Yes	No? [Holmström 2008; Ekenbäck 2010; Kislyakova 2014]
Radio emission	Yes	No
Atmospheric loss	Yes	Yes [Grießmeier 2010; Driscoll 2013]
Cosmic rays	Yes	Yes?[Grießmeier 2015; Tabataba-Vakili 2015]
Comet-like exosphere	Yes	No? [Mura 2011; Guenther 2011]

[Grießmeier 2015]

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

if B=0 → no emission!

How to detect exomagnetospheres?

Observation	Expected effect	False positives?	Suitable
Superflares	Weak or none	Yes	No
Planetary migration	Weak	Yes	No
H_3^+ emission	Yes?	Yes	No
Gas giant mass loss	Yes	Yes	No
Chrom. emission	Yes	Yes	No
Early ingress	Yes	Yes	No
Transit profiles (ENAs)	Yes	No?	?
Radio emission	Yes	No	Yes
Atmospheric loss	Yes	Yes	No
Cosmic rays	Yes	Yes?	No
Comet-like exosphere	Yes	No?	?

[Grießmeier 2015]

⇒ radio emission is the most promising way to find exomagnetospheres

Outline

- why do we want to do this?
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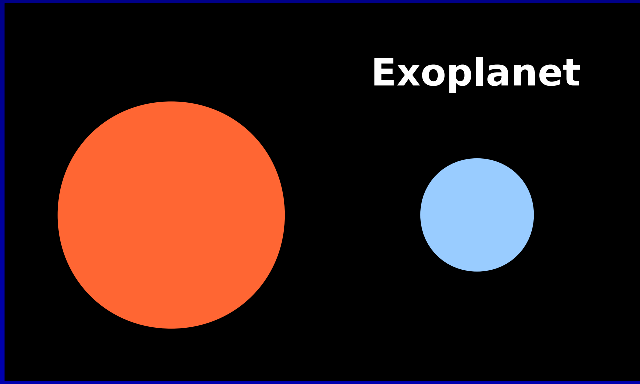
Astronomical distances

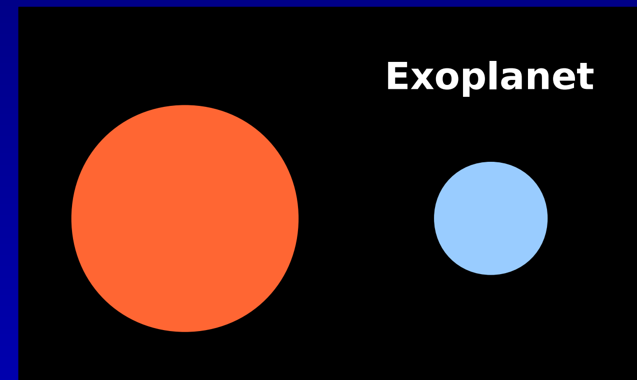
distance = 10^{17} m
rel. signal = 10^{-10}



distance = 10^{12} m
rel. signal = 1

Astronomical distances

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

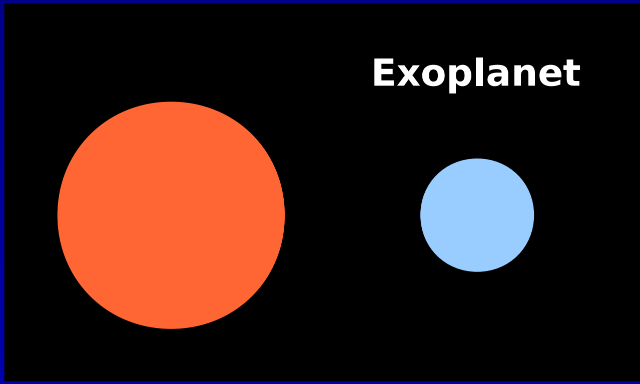


Exo-Jupiter detectable to ~3 pc!

distance = 10^{12} m
rel. signal = 1

Astronomical distances

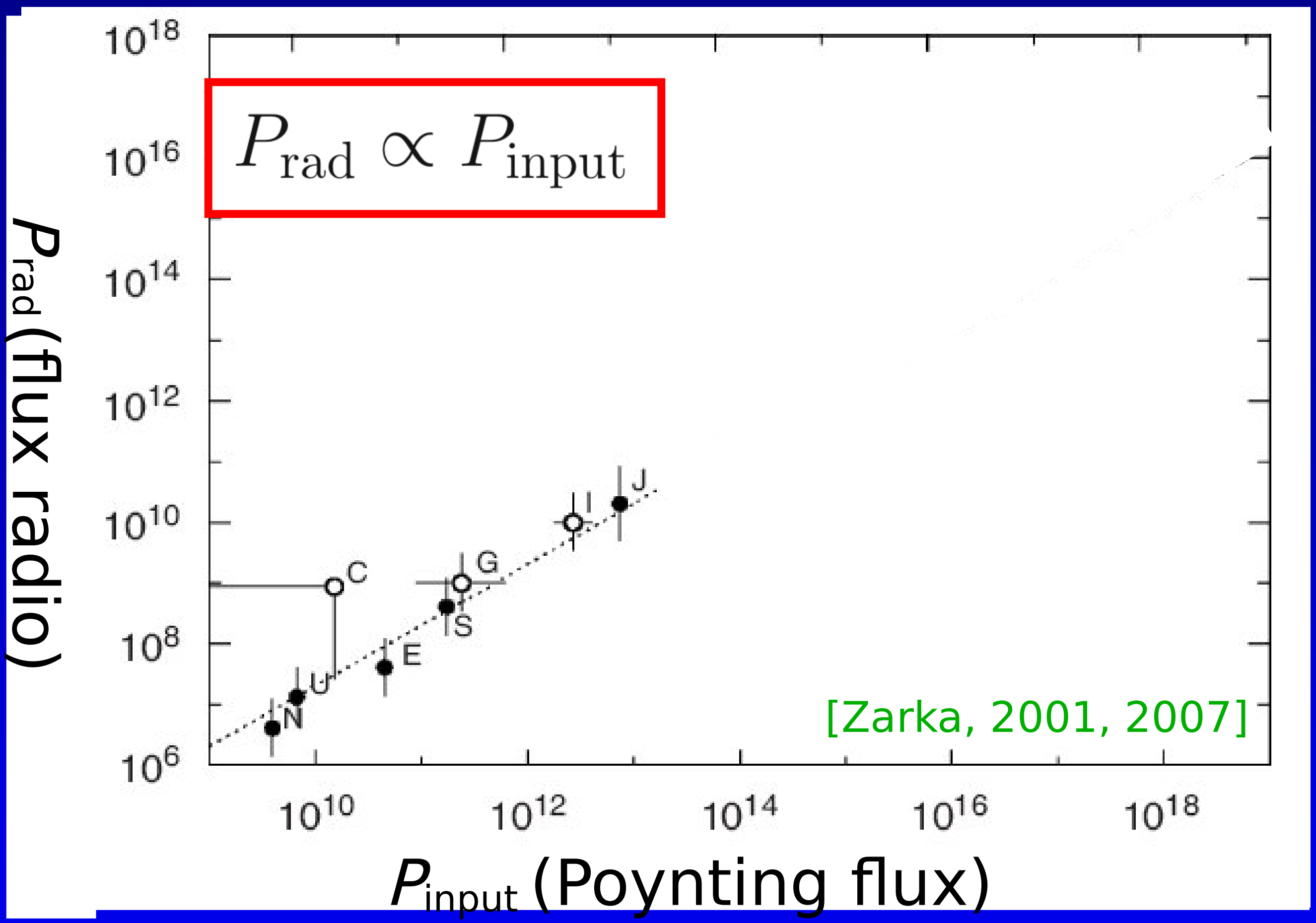
distance = 10^{17} m
rel. signal = 10^{-10}



Exo-Jupiter detectable to ~3 pc!

stronger emission possible?

Solar system wisdom



How to increase P_{input}?

[Grießmeier et al. 2007]

$$P_{\mathrm{input,kin}} \propto n v_{\mathrm{eff}}^3 R_s^2 .$$

$$P_{\mathrm{input,mag}} \propto v_{\mathrm{eff}} B_\perp^2 R_s^2 .$$

$$P_{\mathrm{input,unipolar}} \propto v_{\mathrm{eff}} B_\perp^2 R_{\mathrm{ion}}^2$$

$$P_{\mathrm{input,kin,CME}} \propto n_{\mathrm{CME}} v_{\mathrm{eff,CME}}^3 R_s^2 .$$

large for close-in planets

[Zarka 2007]

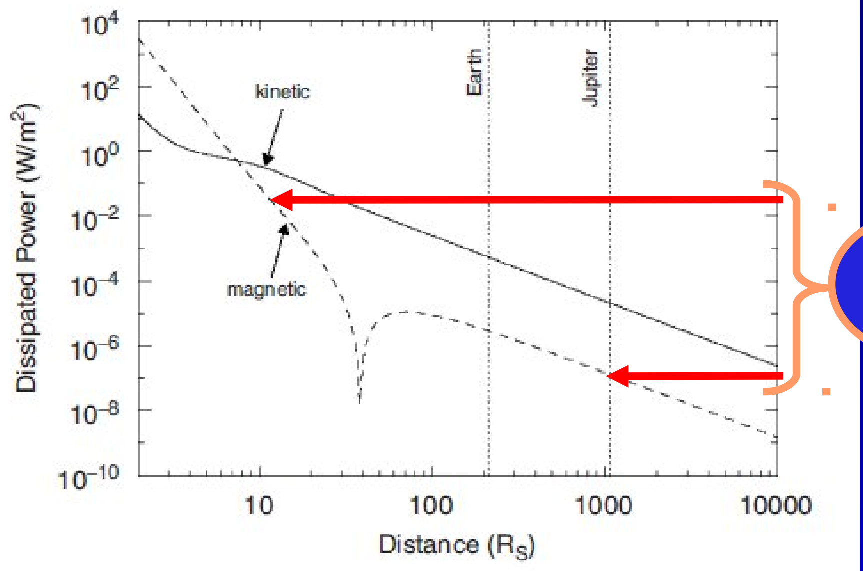


Fig. 11. Dissipated SW magnetic power $(VB_\perp^2/\mu_o)$ and kinetic power (NmV^3) per unit area. Both become comparable at a distance about 10 R_S.

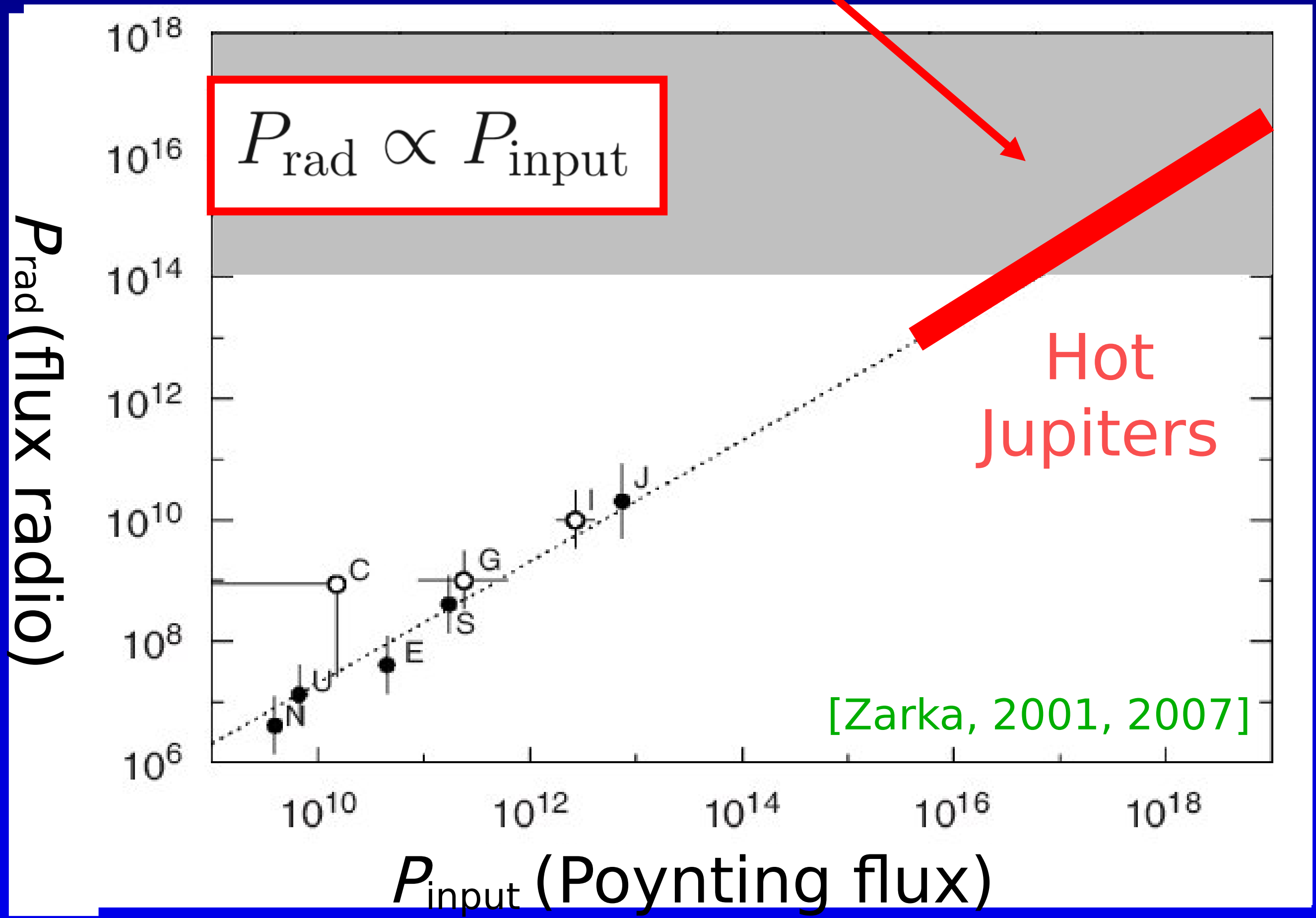
x 10^5

⇒ P_{input} strong for close-in planets

Beyond the solar system

intense emission for
close-in planets!

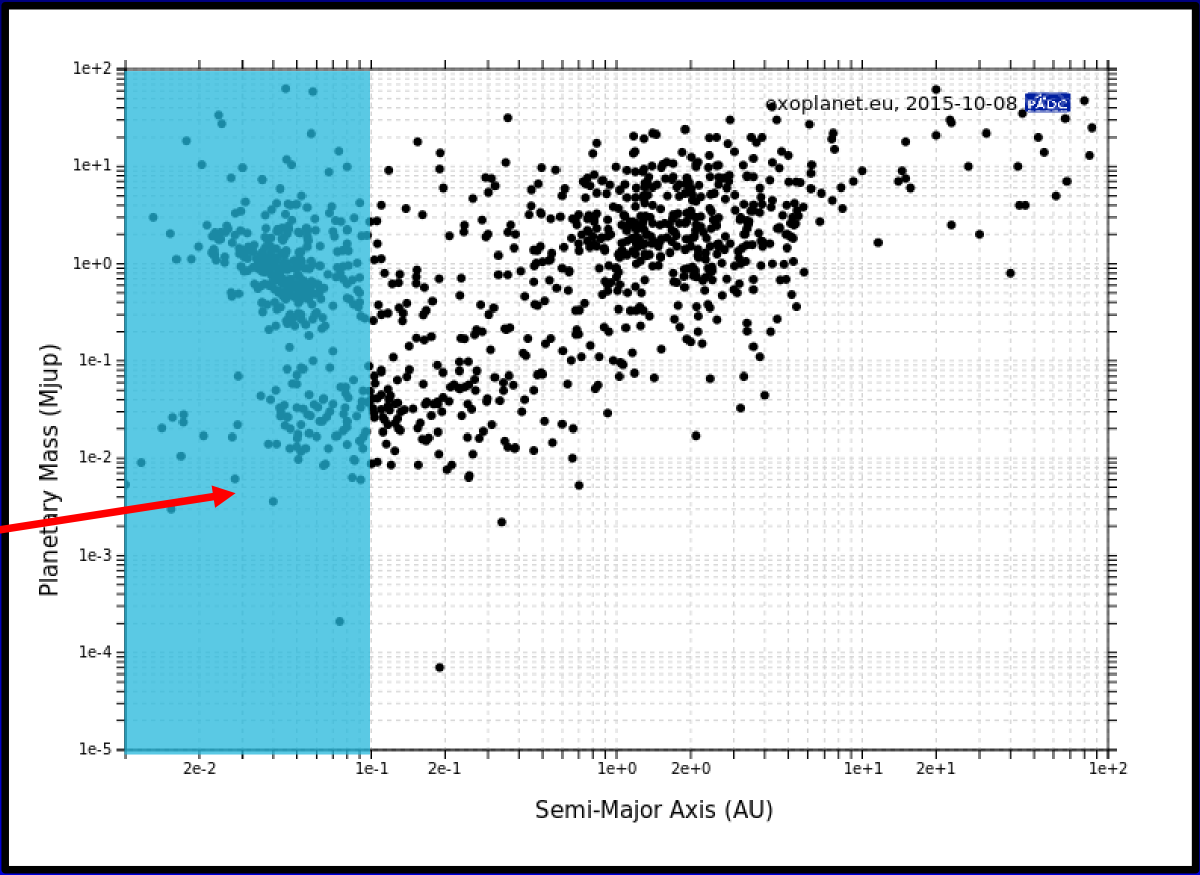
detectable
region



Beyond the solar system

total:
>2000
exoplanets

small orbital
distance

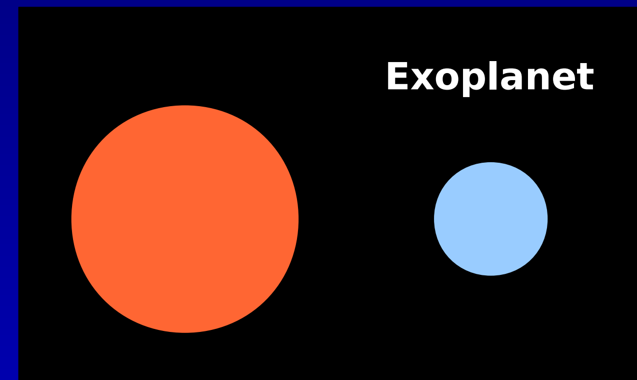


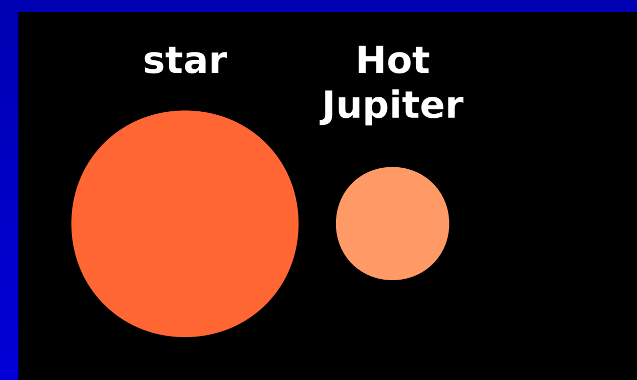
[http://www.exoplanet.eu]

Beyond the solar system

distance = 10^{12} m
rel. signal = 1

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



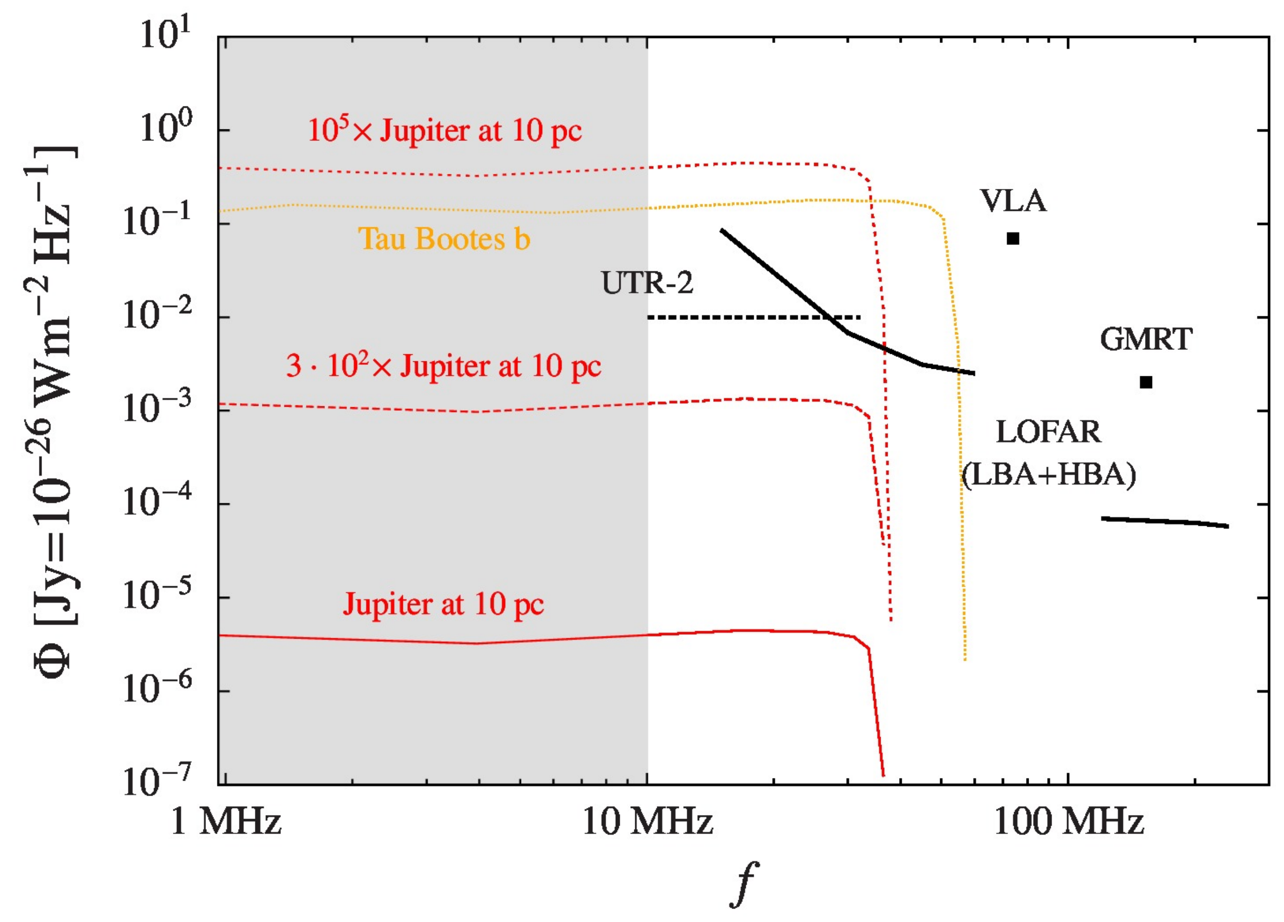


distance = 10^{17} m
interaction x 10^{5}
rel. signal = 10^{-5}

Radio emission: Theoretical studies

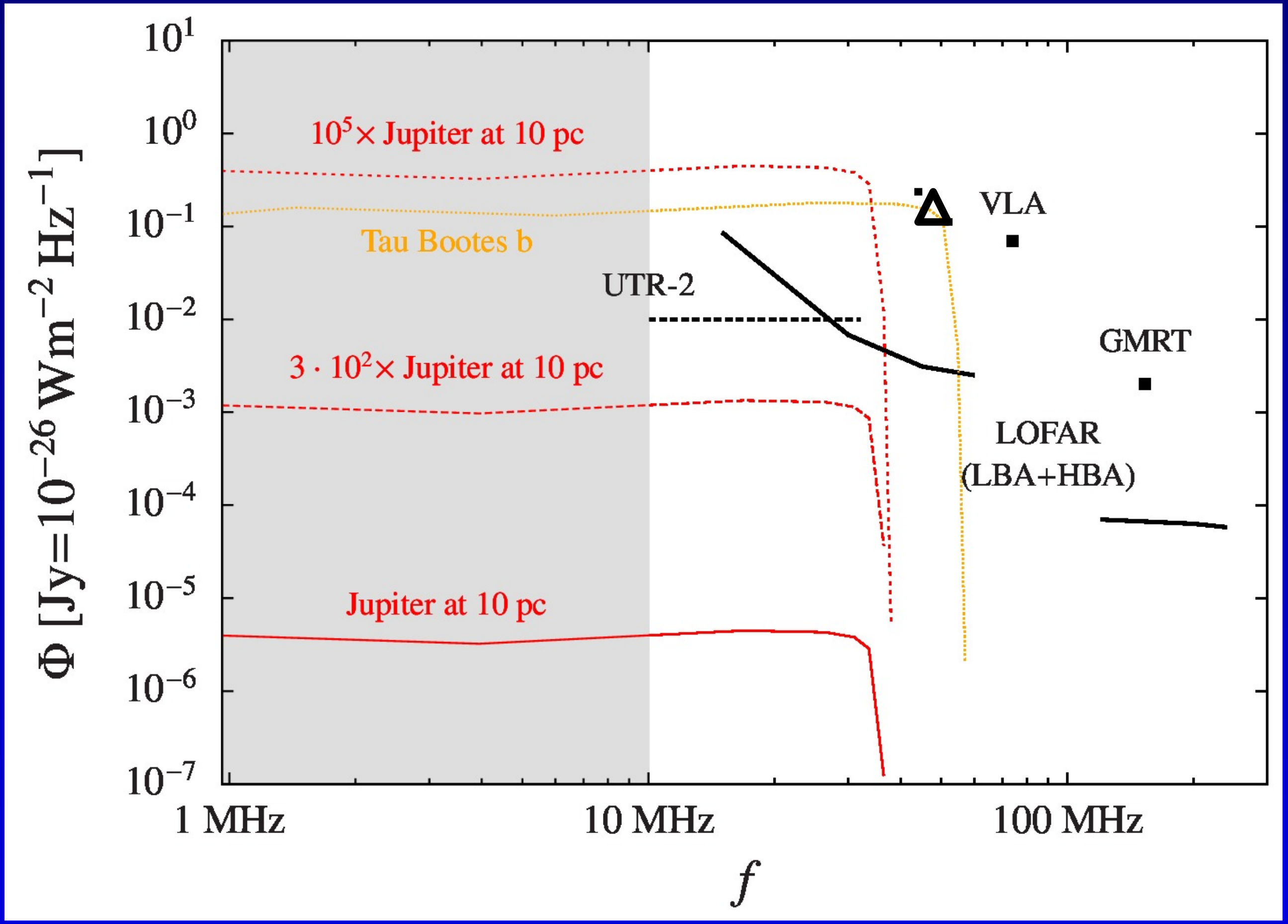
mech-anisms	• kinetic interaction	[Zarka et al 1997, Farrell et al 1999]
	• comparison to stellar emi.	[Zarka et al 1997, Grießmeier et al 2005]
	• magnetic interaction	[Zarka et al 2001]
	• unipolar interaction	[Zarka 2007]
	• acceleration of electrons	[Jardine et al 2008]
	• planets with plasma sources	[Nichols 2011, 2012, Noyola et al 2014, 2016]
	• Dungey-cycle-like interaction	[Nichols et al 2016]
planet	• planetary magnetic field	[Grießmeier et al 2004, Grießmeier 2015]
	• target list	[Lazio et al 2004, Griessmeier et al 2007b, 2011, Driscoll et al. 2011, Nichols 2012]
	• orbital distance	[Grießmeier et al 2007a]
	• orbital inclination	[Hess et al 2011]
star	• influence of stellar age	[Stevens 2005, Grießmeier et al 2005]
	• influence of CMEs	[Grießmeier et al 2006, 2007a]
	• stellar magnetic field	[Fares et al 2010, Vidotto et al 2012, 2015, See et al 2015, Alvarado-Gómez et al 2016]
ab-sorption	• absorption close to star	[Grießmeier et al 2007b, Hess et al 2011]
	• absorption close to planet	[Weber et al 2017]
special cases	• white dwarfs	[Willes et al 2005]
	• evolved stars	[Ignace et al 2010, Fujii et al 2016]
	• T Tauri stars	[Vidotto et al 2010]
	• A stars	[Katarzyński et al 2016]
	• rogue planets	[Vanhamäki et al 2011]

Radio emission



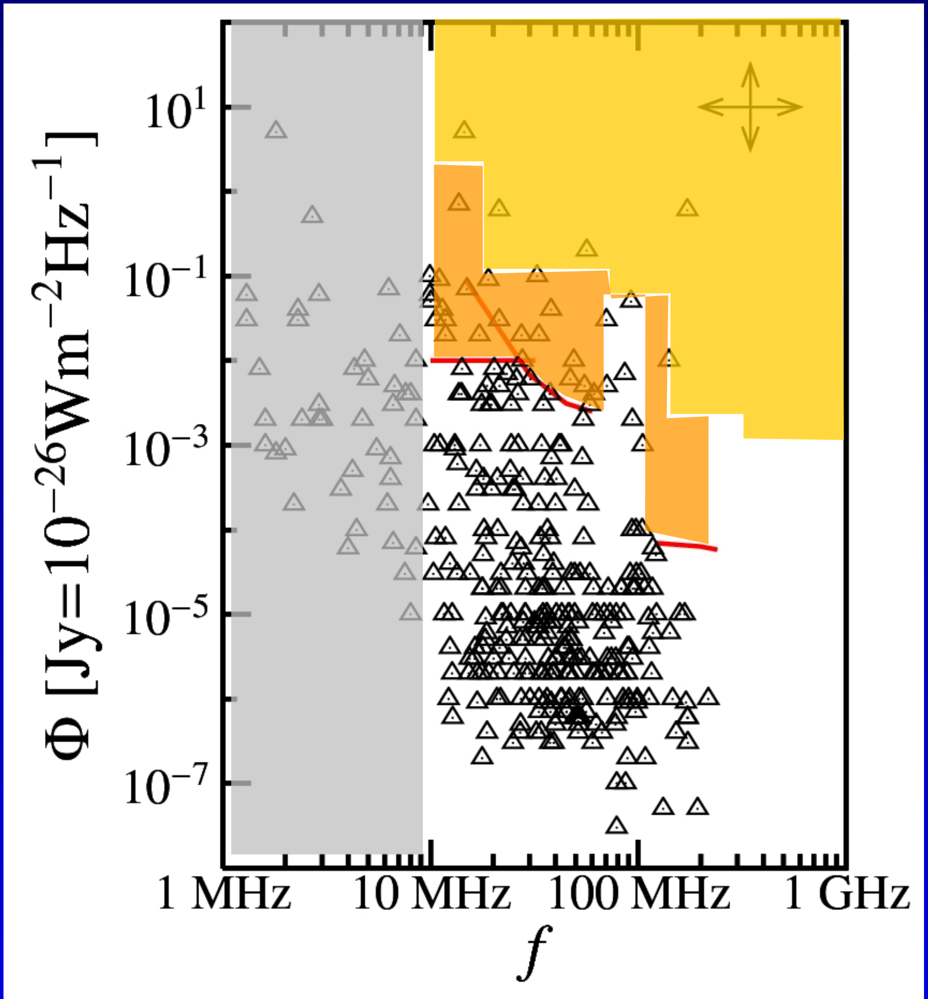
[Grießmeier 2015]

Radio emission



[Grießmeier 2015]

Radio emission



[Grießmeier et al. 2007, 2011]

Outline

- why do we want to do this?
- is this possible?
- a LOFAR observation campaign

Radio emission: Observational studies

- Clark Lake [Yantis et al 1977]
- VLA [Winglee et al 1986, Bastian et al 2000, Farrell et al 2003, Lazio et al 2004, Lazio et al 2007, Lazio et al 2010a, Lazio et al 2010b]
- UTR-2 [Zarka et al 1997, Ryabov et al 2004, Zarka 2011]
- Effelsberg [Guenther et al 2005]
- Mizusawa [Shiratori et al 2005]
- GMRT [Winterhalter et al 2006, Majid et al 2006, George et al 2007, Lecavelier et al 2009, Lecavelier et al 2011, Lecavelier et al 2013, Hallinan et al 2013, Sirothia et al 2014]
- GBT [Smith et al 2009]
- LOFAR [Zarka et al 2011, Turner et al submitted]
- MWA [Murphy et al 2015]
- WSRT [Stroe et al 2012]

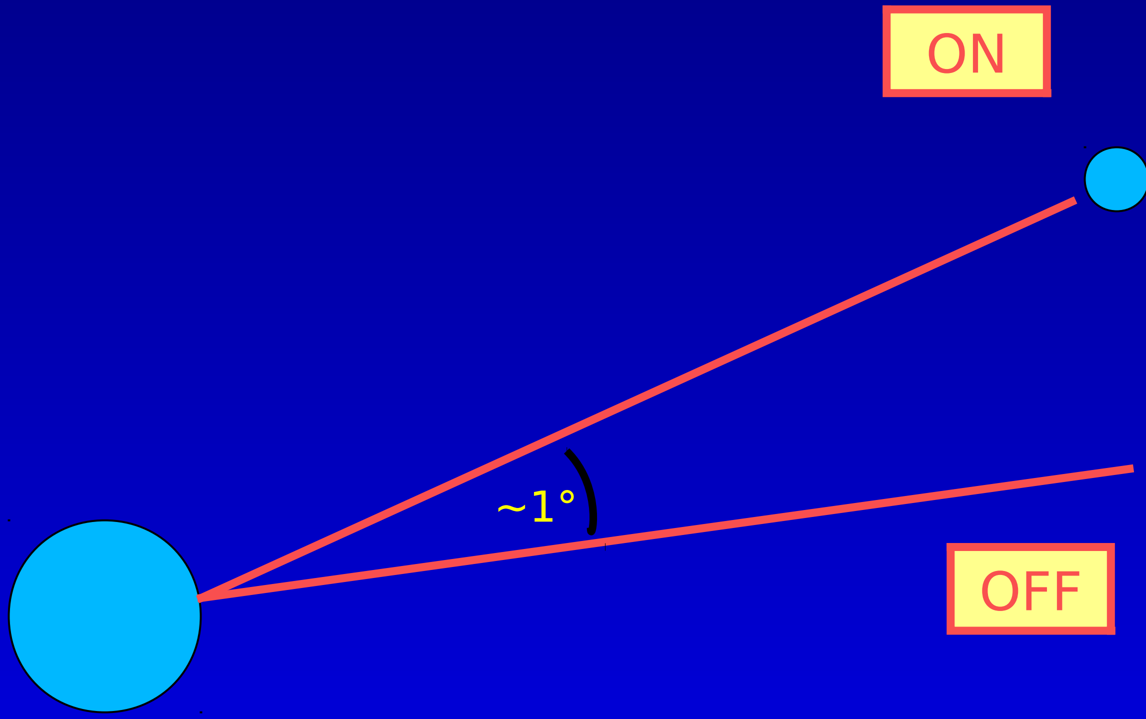
- no (firm) detection yet
- sensitivity ~ predictions
  → observations ongoing

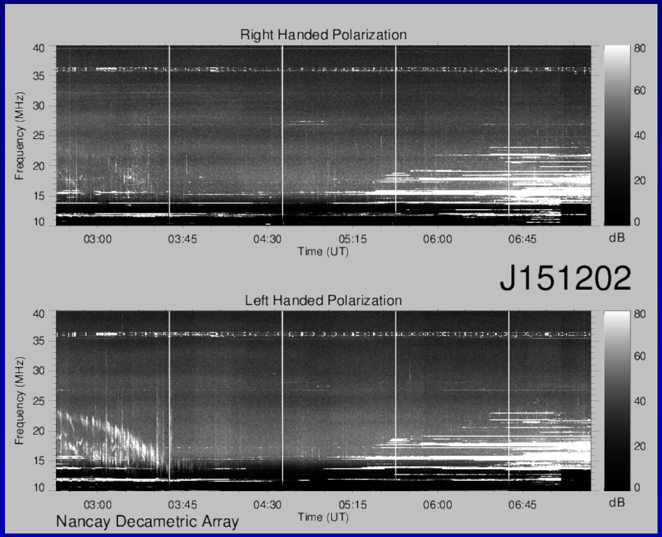
Some recent LOFAR observations

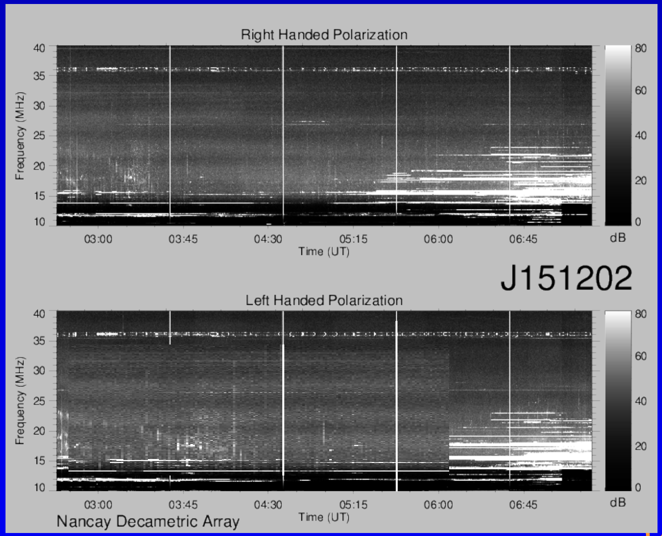
LOFAR cycle	time	target	observation	processing
LC5	18h	55 Cnc	beamformed	ongoing
LC6	47h	Ups And	beamformed	ongoing
LC7	28h	Tau Boo	beamformed	ongoing
	10h	V830 Tau	bf+img (HBA)	ongoing
LC8	7h	Corot-7	req. 11/2017	

- observe well-known exoplanets
- target selection based on predictions
- fine control over RFI mitigation
- multiple beams (ON + OFF)

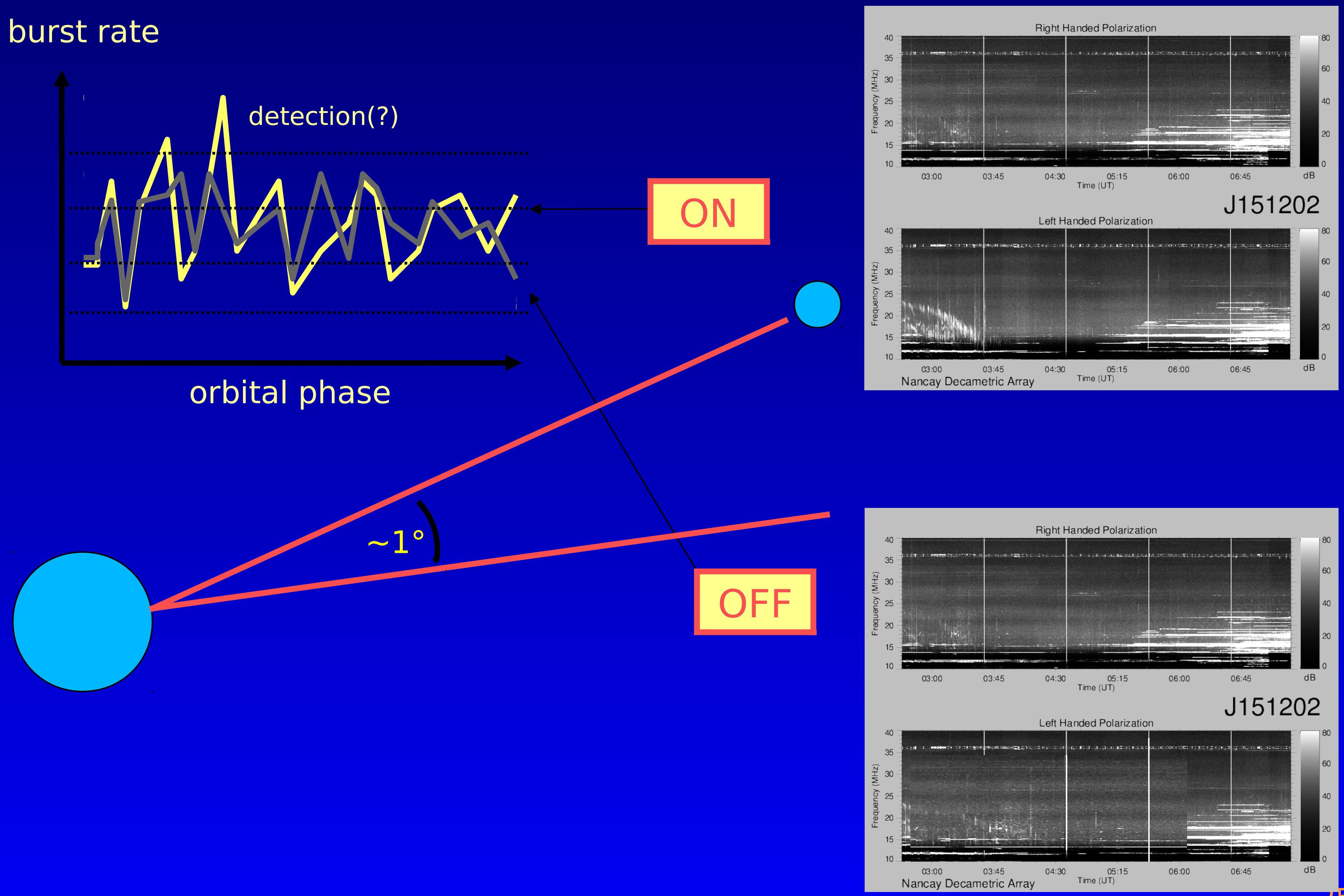
Dynamic spectra



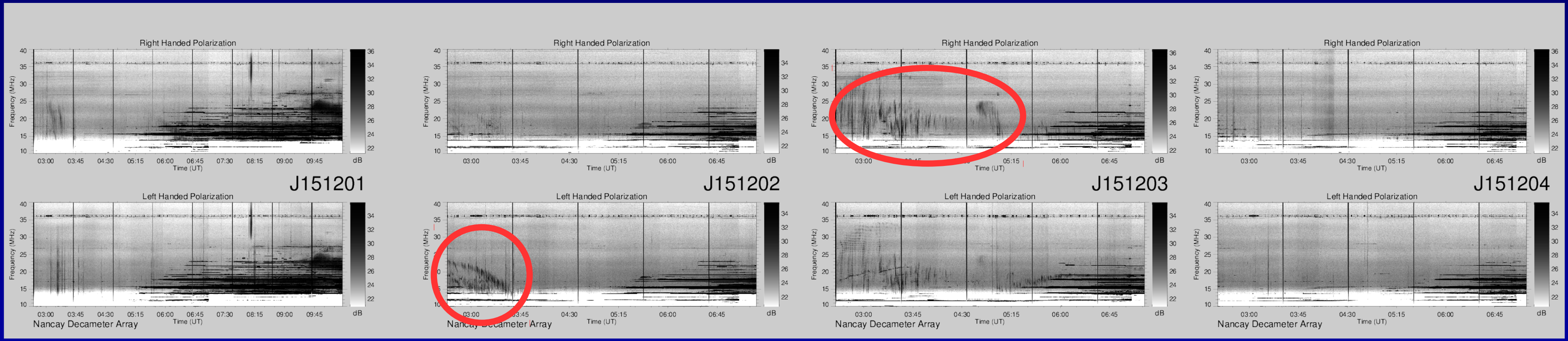




Dynamic spectra

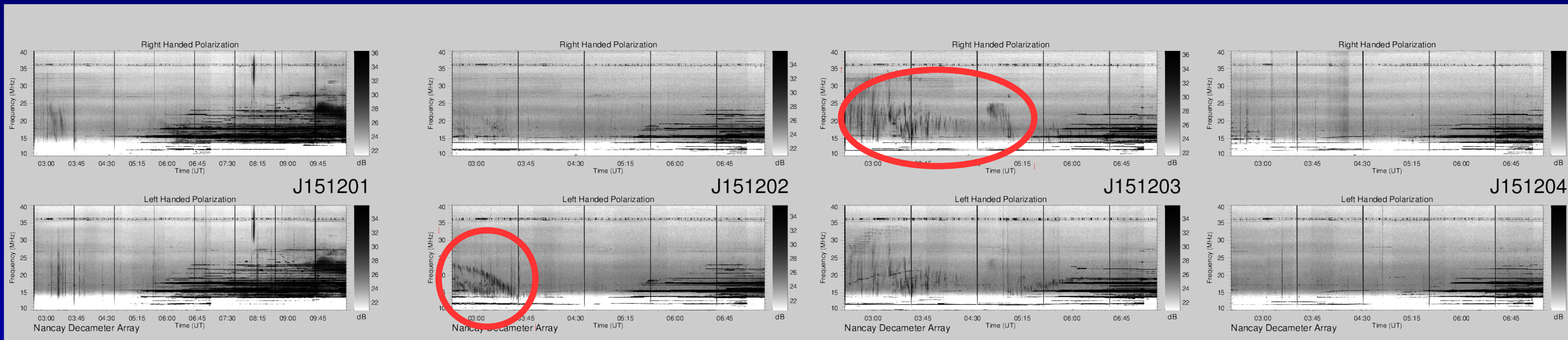


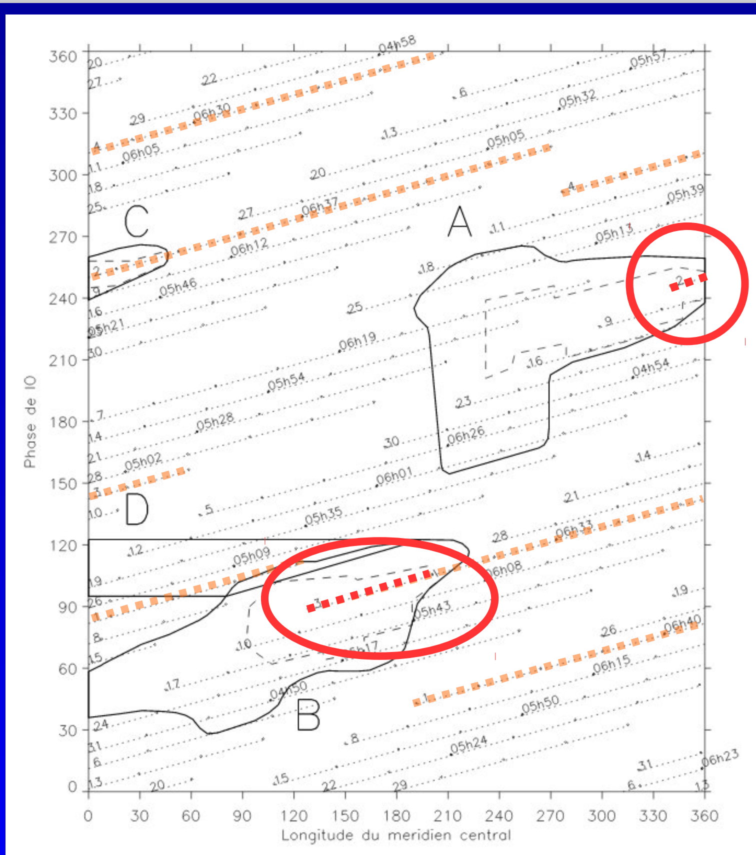
Orbital phase



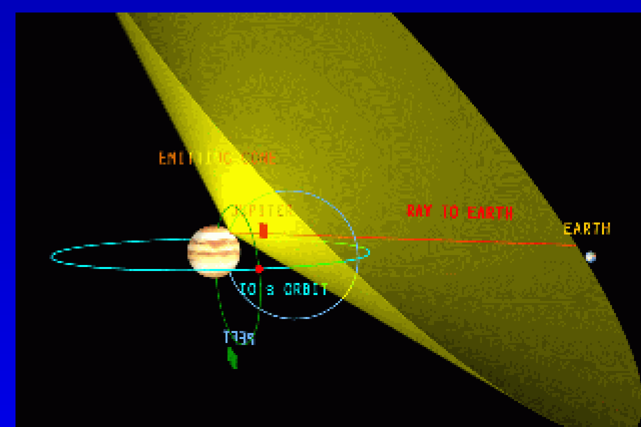
- for Jupiter, random observations only give 10-20% detections!

Orbital phase



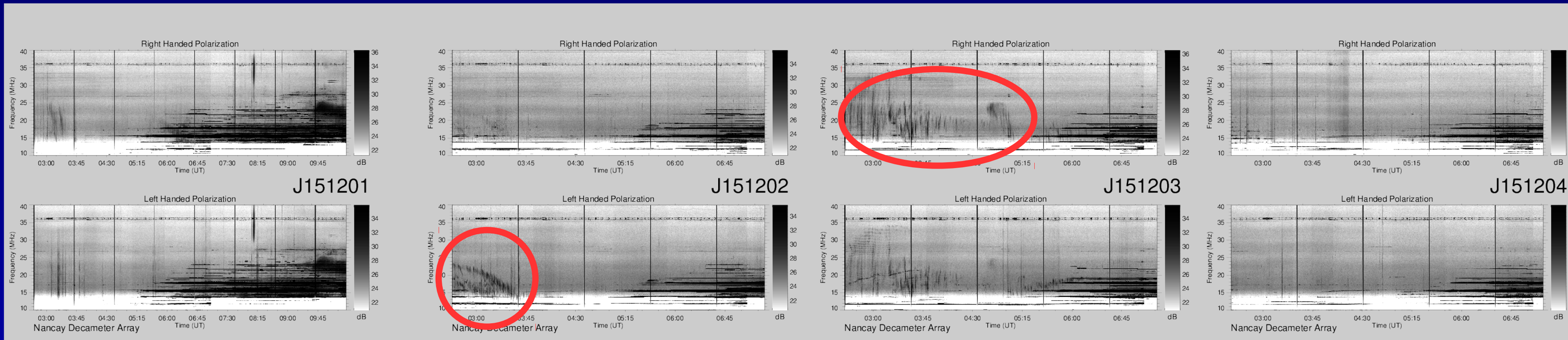


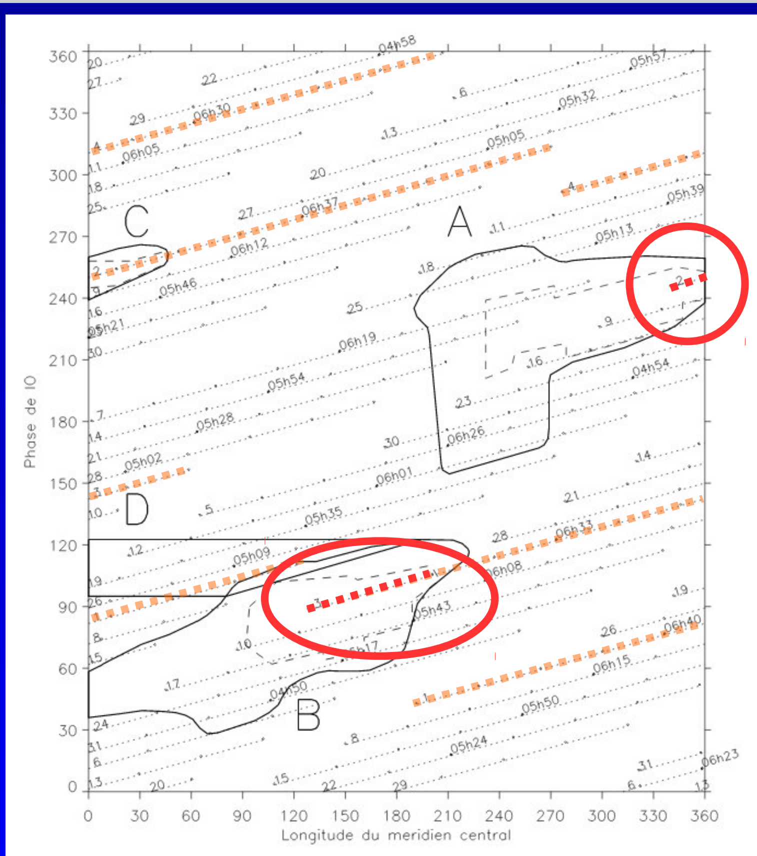
- for Jupiter, random observations only give 10-20% detections!
- emission is always on
- emission is strongly beamed



[Imai Lab., Kochi National College of Technology]

Orbital phase

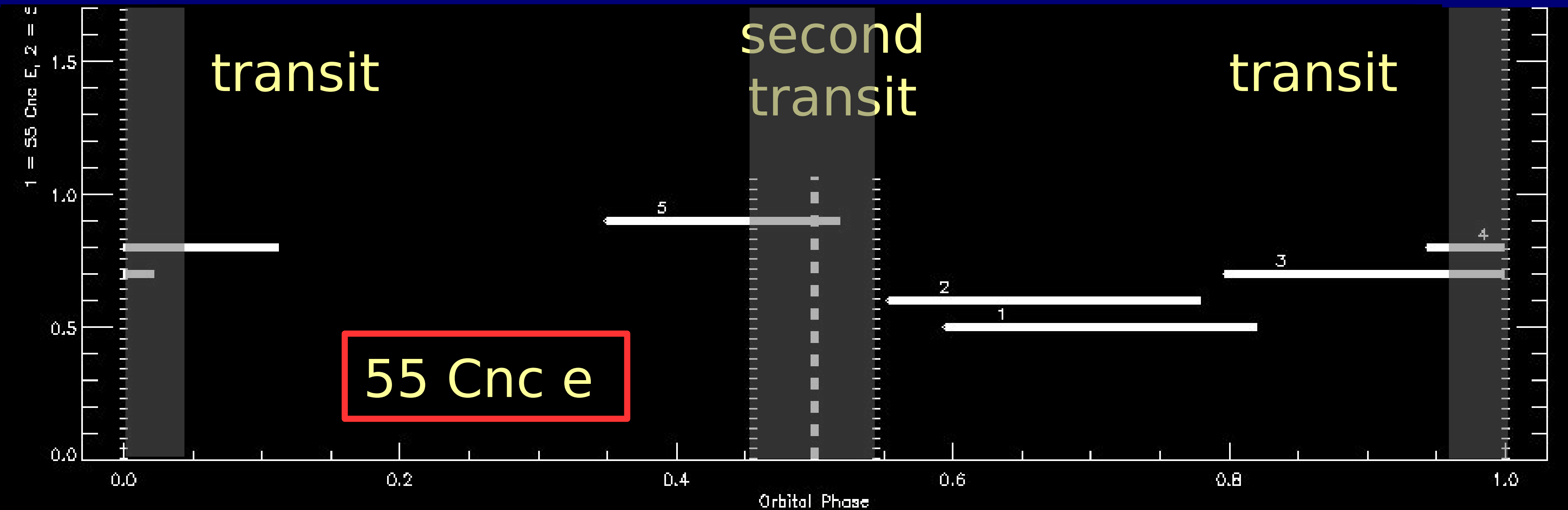


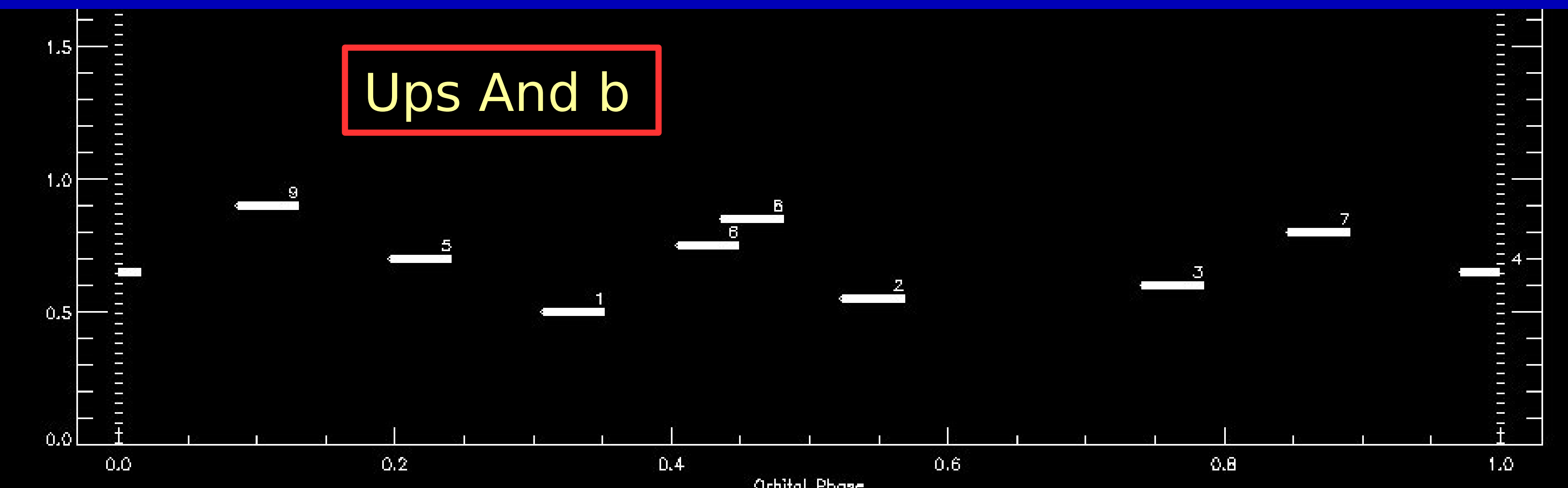


- for Jupiter, random observations only give 10-20% detections!
- emission is always on
- emission is strongly beamed

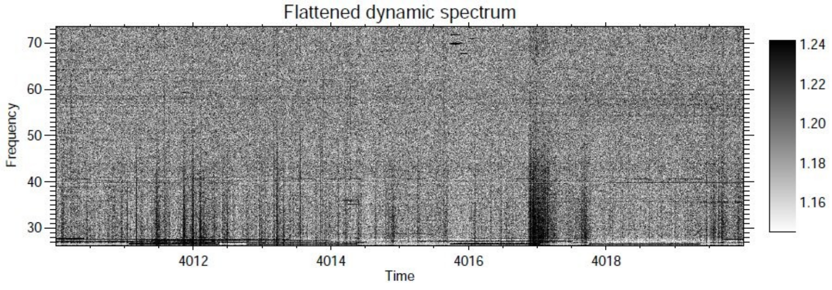
- for exoplanets: have to cover orbit
- else: non-detections meaningless

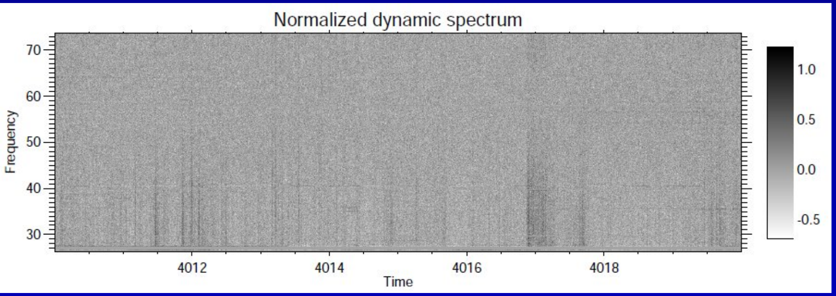
LOFAR observations

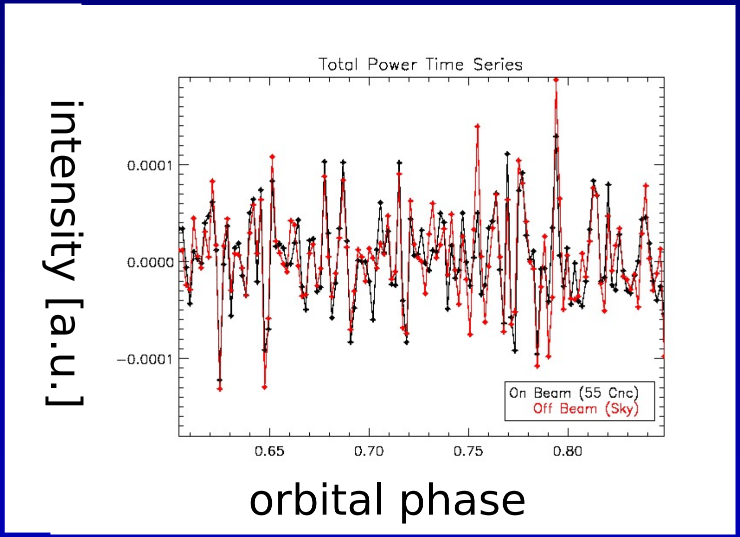




LOFAR observation of 55 Cnc



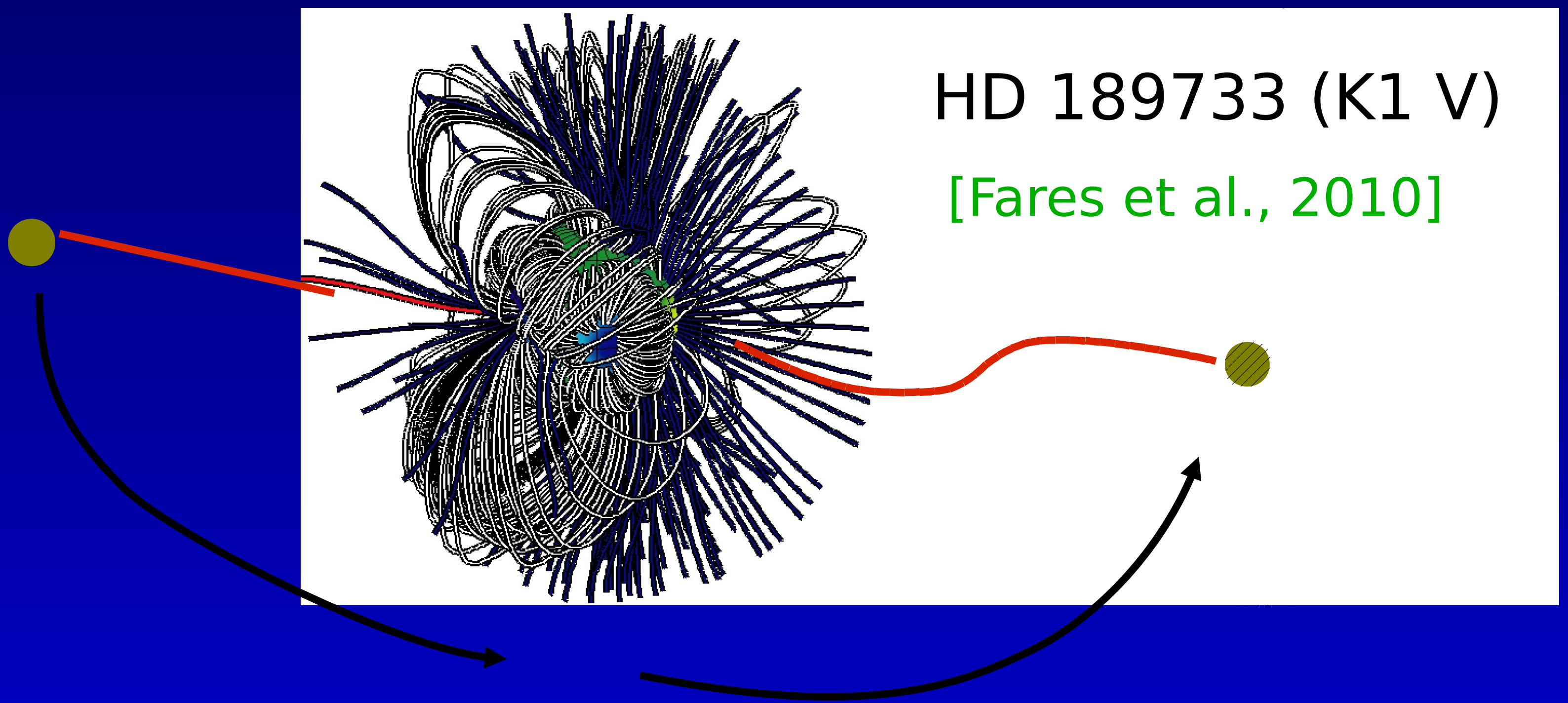




- Pipeline status...
- Jupiter tests...
- Ongoing analysis...

→ presentation by Jake Turner!

Radio emission is variable!

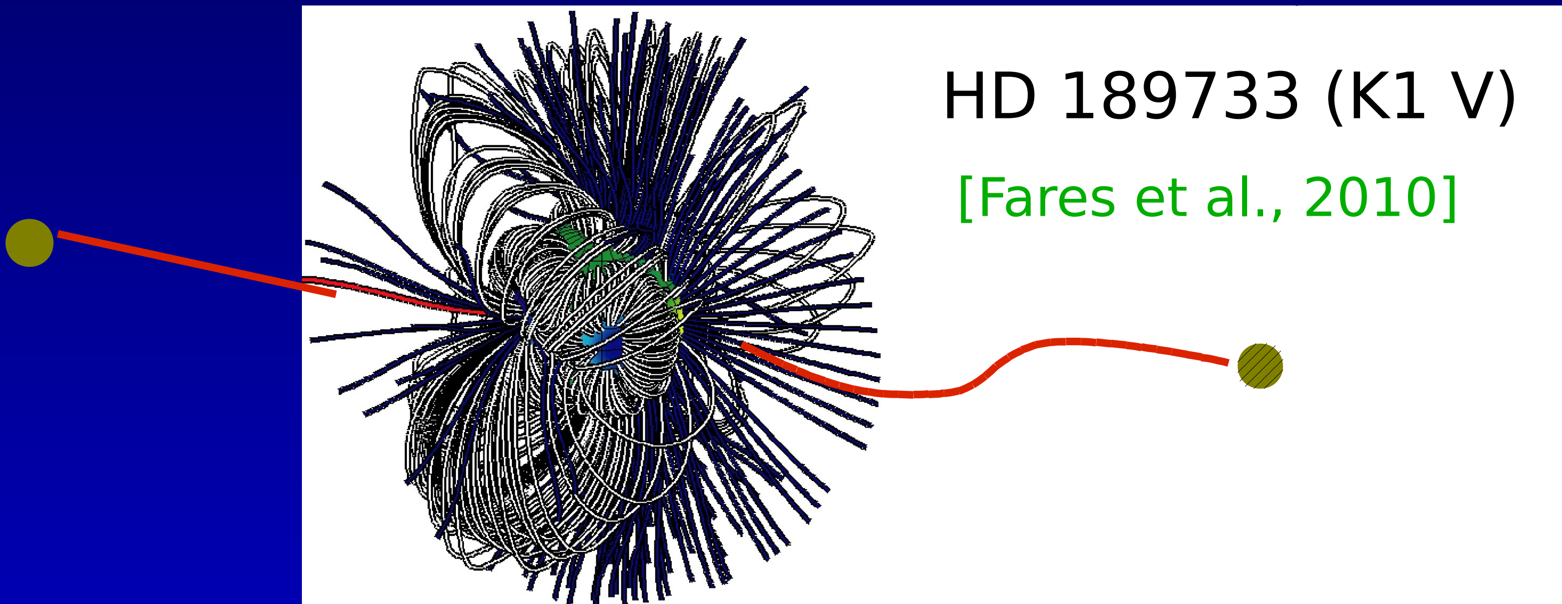


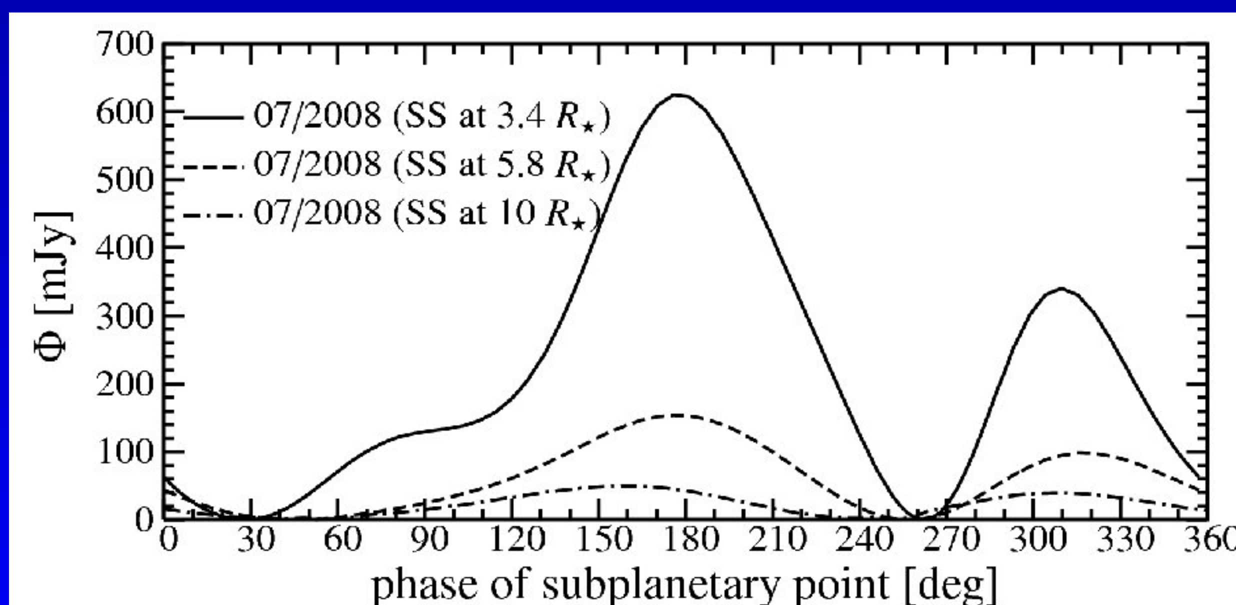
planet encounters different magnetic regions

but B determines P_{radio} → variable radio emission

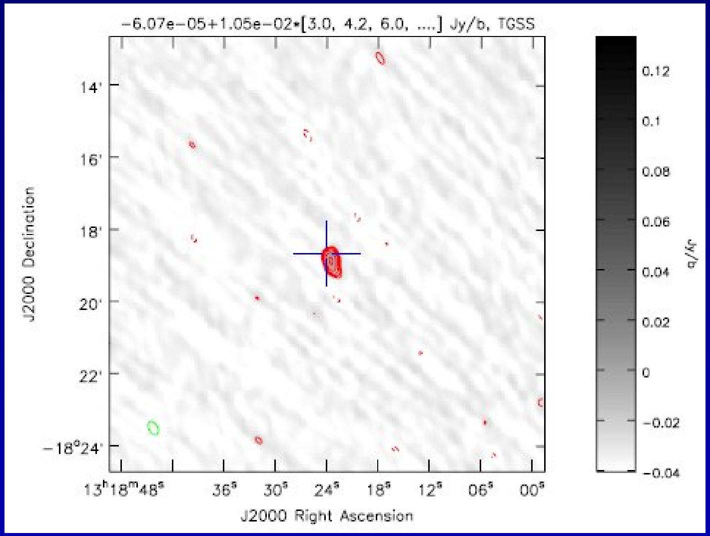
stellar rotation: 12d
planetary orbit: 2.22d

Radio emission is variable!

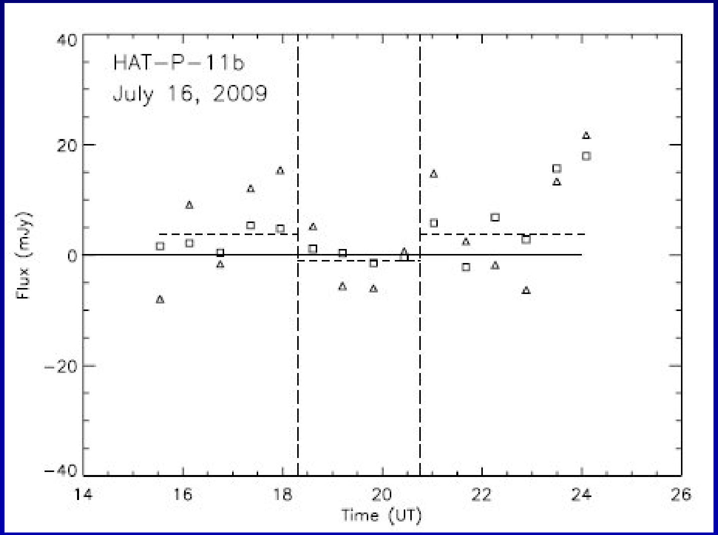




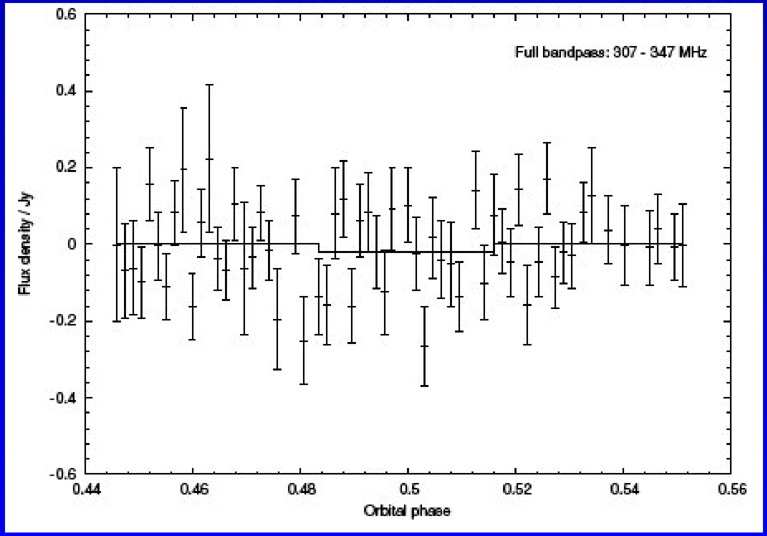
Radio emission: Observational studies



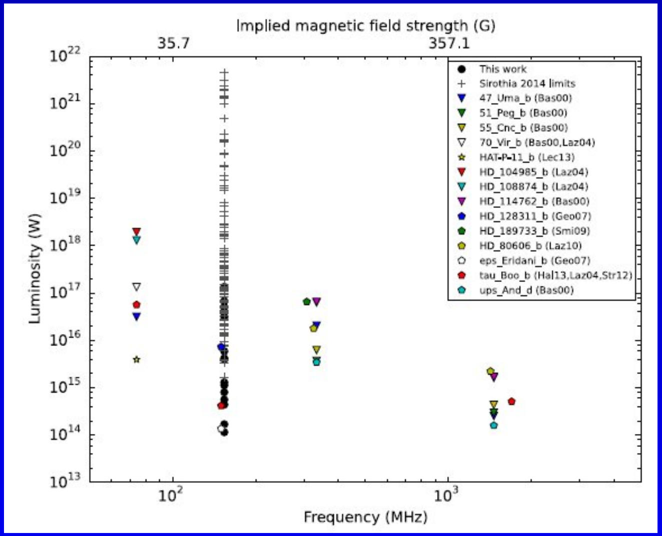
[Sirothia et al., 2014]



[Lecavelier et al., 2013]



[Smith et al., 2009]



[Murphy et al., 2015]

Observations with LOFAR

cycle 3 (Nov. 2014 – May 2015)

cycle 4 (May 2015 – Nov. 2015)

LC4_005	S. Daiboo	Test of optimal strategy for exoplanet detection with LOFAR	15	30
LC4_006***	G. Mann	Energetic electrons generated in solar flares	17.5	35
LC4_007	L. Morabito	Long Baseline Studies of High-redshift Radio Sources: Constraining particle acceleration and cold gas	54	137
LC4_008	P. Best	A joint LOFAR deep field: Elais-N1	100	120
LC4_009	J. van Leeuwen	The Magnetic Fields and Pulsar Spectra in Globular Clusters	12.5	3
LC4_010	I. Polderman	Imaging of extended emission in the Galactic plane	53	54
LC4_011	J. Gelfand	The Physics of Neutron Star Formation and Particle Creation and Acceleration in PWN G54.1+0.3	7	18.3
LC4_012	J. Lazio	A Search for Radio Emissions from Extrasolar Planets on Highly Eccentric Orbits Near Planetary Periastron	90	180
LC4_013	W. Jurusik	The LBA and HBA studies of Cosmic Ray propagation in NGC6946	18.2	91
LC4_014	R. Coppejans	A New Route to High-Redshifts?	12	48
LC4_015	E. Freeland	Detecting a Nuclear Bubble in a Face-on Spiral Galaxy	16	33
LC4_016	E. Kontar	Fine structures in solar radio emission	40	0
LC4_017	K. Sendlinger	Cosmic ray propagation in two nearby spiral galaxies	18	60
LC4_018	D. Winterhalter	A SYSTEMATIC SEARCH OF THE 10 NEAREST STARS FOR PLANETARY MAGNETOSPHERE EMISSIONS	22	88

imaging

cycle 5 (Nov. 2015 – May 2016)

LC5_007	J. Peek	The Unexplained Pressure in the Closest Cold ISM	12,5	10,0
LC5_008	V. Jelic	Studying the local interstellar medium	24,0	0,0
LC5_009	D. Winterhalter	A SYSTEMATIC SEARCH OF THE 10 NEAREST STARS FOR PLANETARY MAGNETOSPHERE EMISSIONS (a continuation from Cycle 4)	20,0	32,0
LC5_010	R. Breton	Deep Observation of Possible Extended Emission Surrounding a Pulsar		
LC5_011	M. Alves	Towards the physical properties of Faraday filaments		

imaging