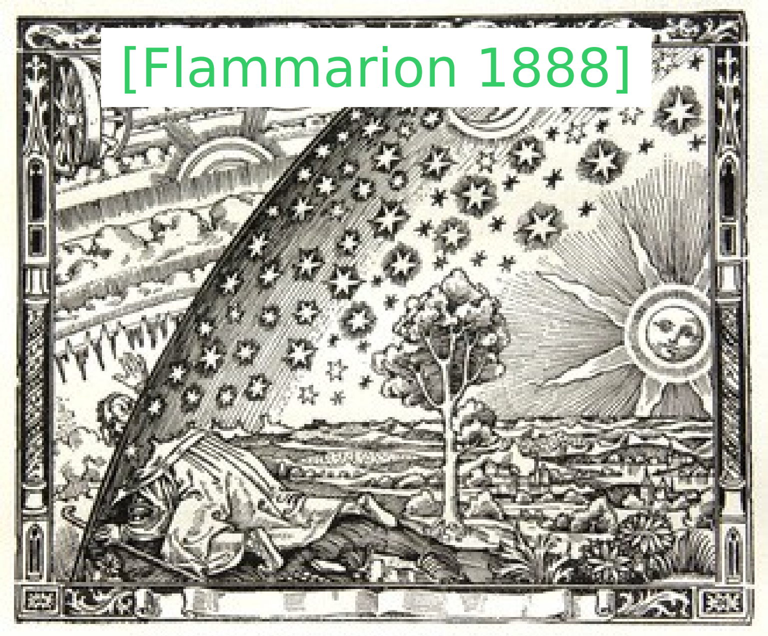
Recherche d'exoplanètes en radio : un point d'étape



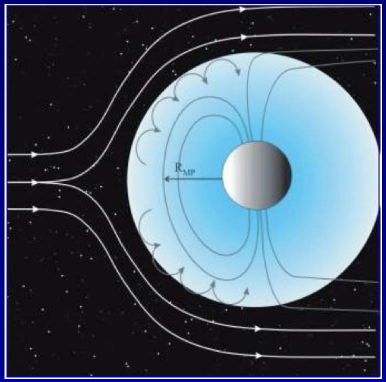
Jean-Mathias Grießmeier

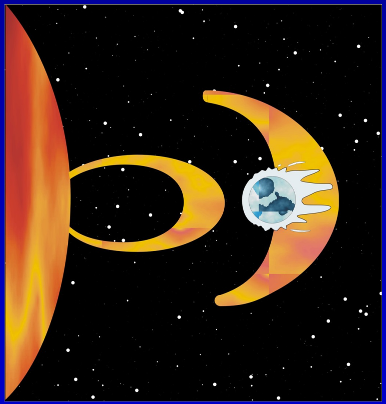
LPC2E/Université d'Orléans/OSUC/CNRS, Orléans, France
Station de Radioastronomie de Nançay, Observatoire de Paris, France

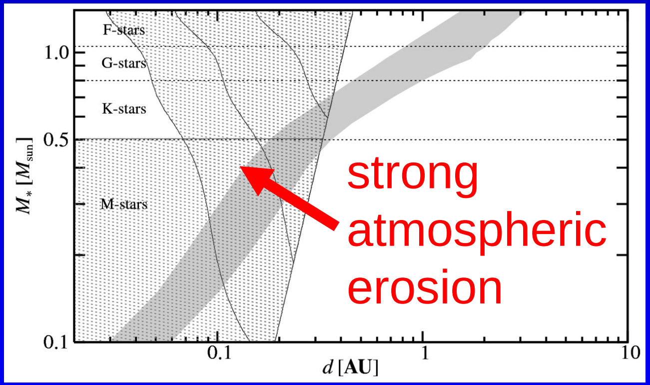
jean-mathias.griessmeier@cnrs-orleans.fr

Why study exomagnetospheres?

- planetary migration?
- protection against stellar wind?
- protection against stellar CMEs?
- protection against cosmic rays?
- explain observed effects?
- understand solar system planets!
- because we like magnetospheres!







How to detect exomagnetospheres?

Observation	
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	
Cosmic rays	[Grießmeier 2005]
Comet-like exosphere	[Mura 2011]

[Grießmeier 2015]

How to detect exomagnetospheres?

other effects have similar signature

Observation	Section	Expected effect	False positives?	
Superflares	11.2.1	Weak or none	Yes	[Maehara 2012, Shibayama 2013]
Planetary migration	11.2.2	Weak	Yes	[Lovelace 2008, Vidotto 2009, 2010]
H_3^+ emission	11.2.3	Yes?	Yes	[Skholnik 2006]
Gas giant mass loss	11.2.4	Yes	Yes	[Lammer 2009, Khodachenko 2012]
Chrom. emission	11.2.5	Yes	Yes	[Saar 2004, Preusse 2006, Kopp 2011]
Early ingress	11.2.6	Yes	Yes	[Fossati 2010, Lai 2010, Bisikalo 2013a,b]
Transit profiles (ENAs)	11.2.7	Yes	No?	[Holmström 2008, Ekenbäck 2010]
Radio emission	11.2.8	Yes	No	
Atmospheric loss	11.3.1	Yes	Yes	
Cosmic rays	11.3.2	Yes	Yes?	[Grießmeier 2015, Tabataba-Vakili 2015]
Comet-like exosphere	11.3.3	Yes	No?	[Mura 2011, Guenther 2011]

[Grießmeier 2015]

How to detect exomagnetospheres?

Observation	Section	Expected effect	False positives?	Suitable
Superflares	11.2.1	Weak or none	Yes	No
Planetary migration	11.2.2	Weak	Yes	No
H_3^+ emission	11.2.3	Yes?	Yes	No
Gas giant mass loss	11.2.4	Yes	Yes	No
Chrom. emission	11.2.5	Yes	Yes	No
Early ingress	11.2.6	Yes	Yes	No
Transit profiles (ENAs)	11.2.7	Yes	No?	?
Radio emission	11.2.8	?	?	?
Atmospheric loss	11.3.1	Yes	Yes	No
Cosmic rays	11.3.2	Yes	Yes?	No
Comet-like exosphere	11.3.3	Yes	No?	?

[Grießmeier 2015]

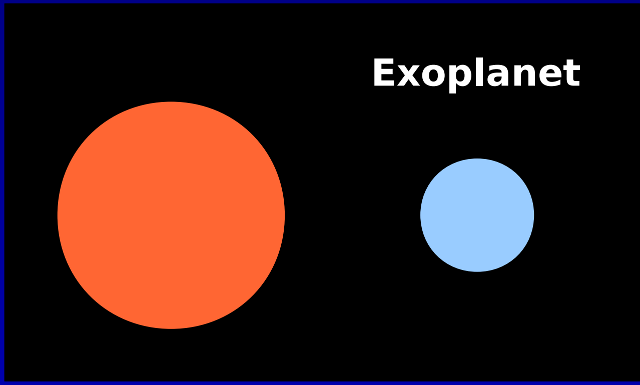
⇒ radio emission is the most promising way to find exomagnetospheres

Outline

- why are exomagnetospheres interesting?
- how can we detect exomagnetospheres?
- is exoplanetary radio emission detectable?
- false negatives? false positives?
- selected theoretical results
- ongoing search programs

Astronomical distances

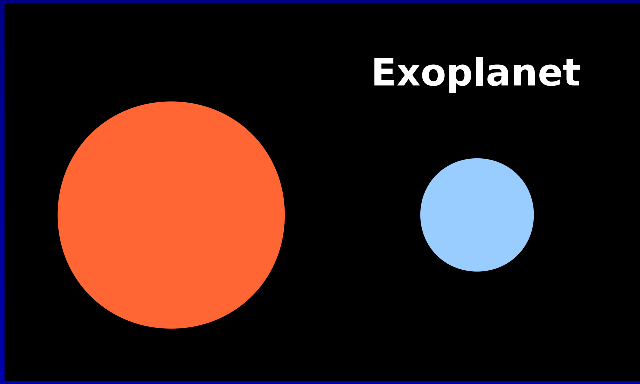
distance = 10^{17} m
rel. signal = 10^{-10}



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

Astronomical distances

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

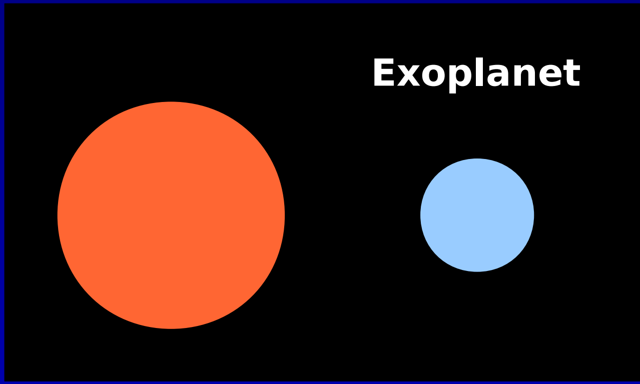


Exo-Jupiter detectable to ~3 pc!

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

Astronomical distances

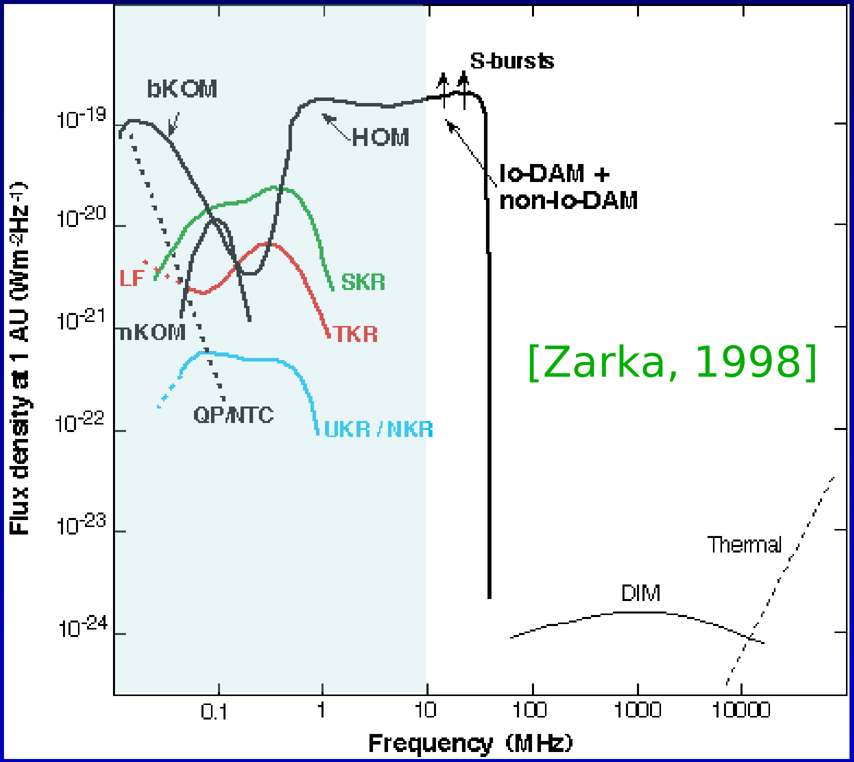
distance = 10^{17} m
rel. signal = 10^{-10}



Exo-Jupiter detectable to ~3 pc!

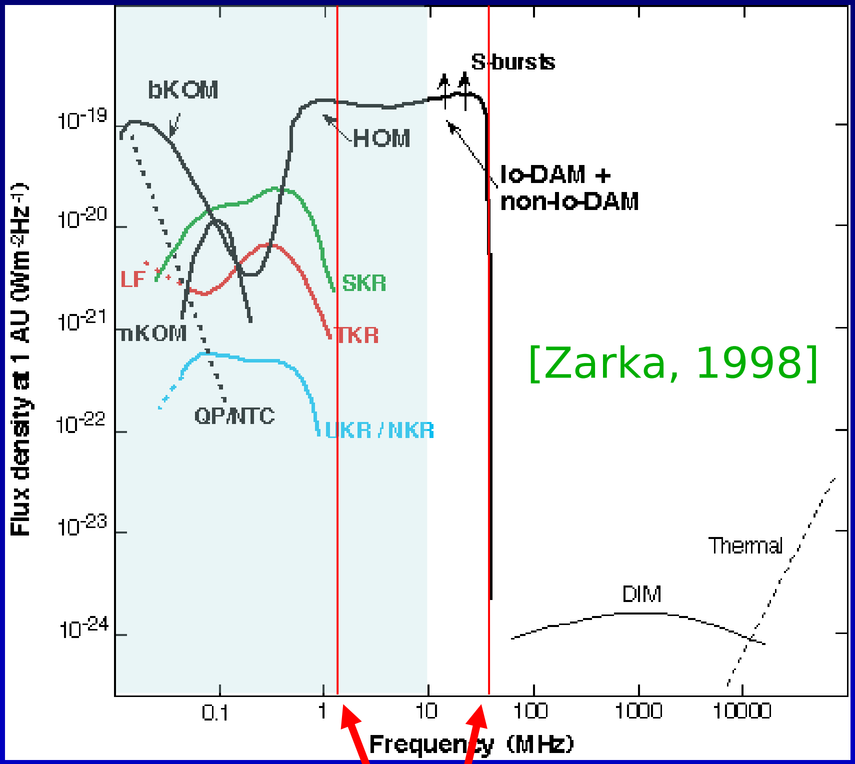
stronger emission possible?

Solar system wisdom



- strongest: auroral radio emission
- requires magnetic field

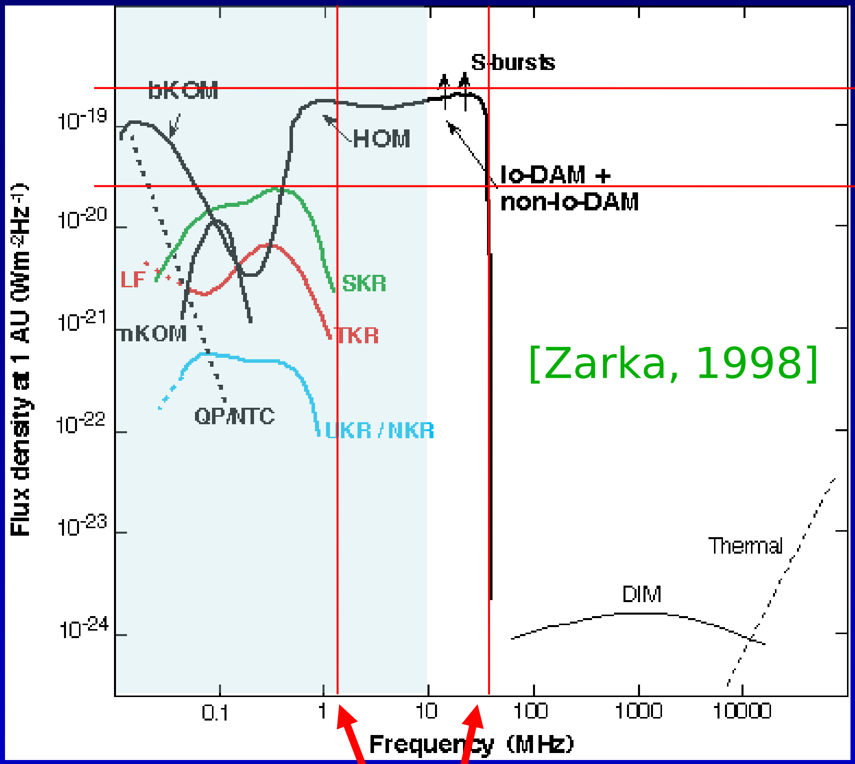
Solar system wisdom



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

- strongest: auroral radio emission
- requires magnetic field

Solar system wisdom



?

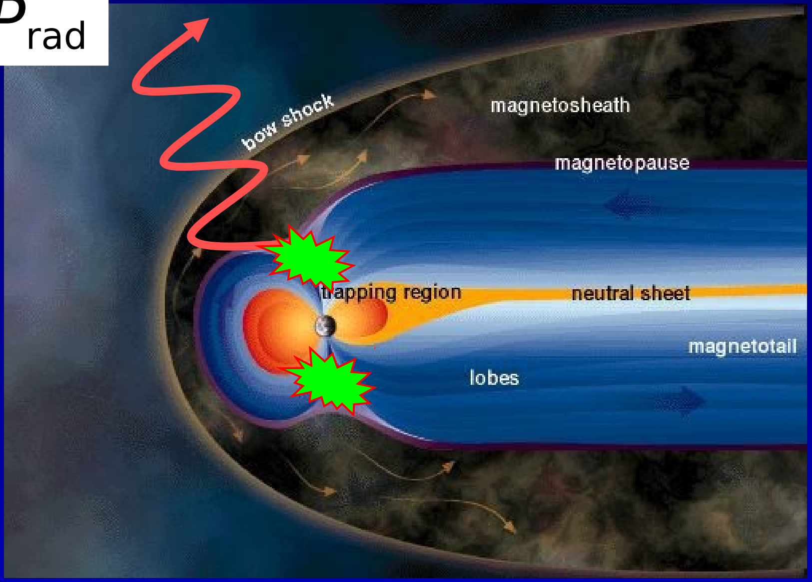
$$f_c \propto \frac{eB}{m_e}$$

- strongest: auroral radio emission
- requires magnetic field

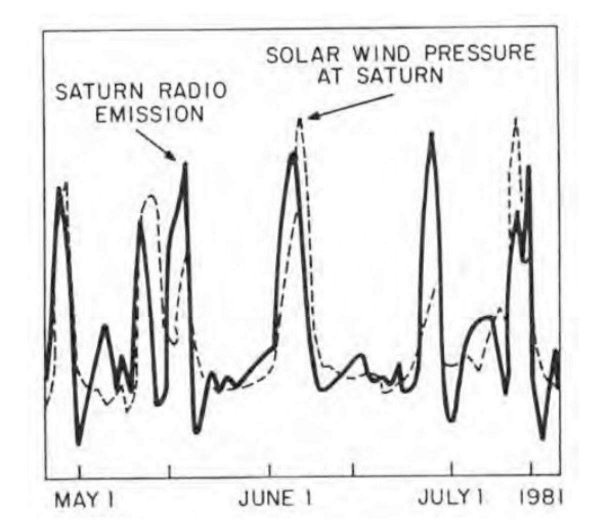
Solar system wisdom

n, v

P_{rad}



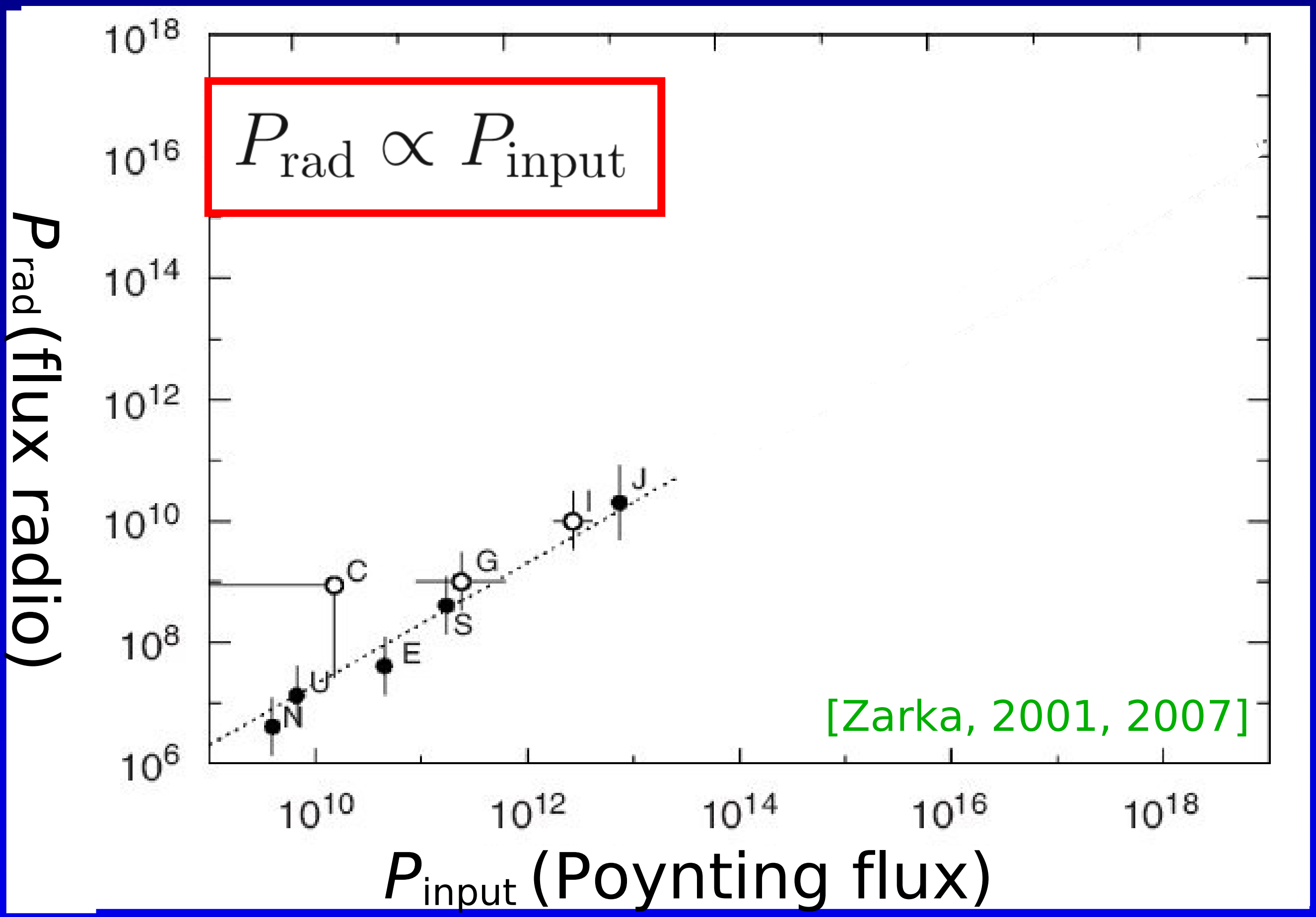
P_{input}



[Bhardwaj et al., 2000]

$$P_{\text{rad}} \propto P_{\text{input}}$$

Solar system wisdom



How to increase P_{input}?

[Grießmeier et al. 2007]

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

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

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

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

large for close-in planets

[Zarka 2007]

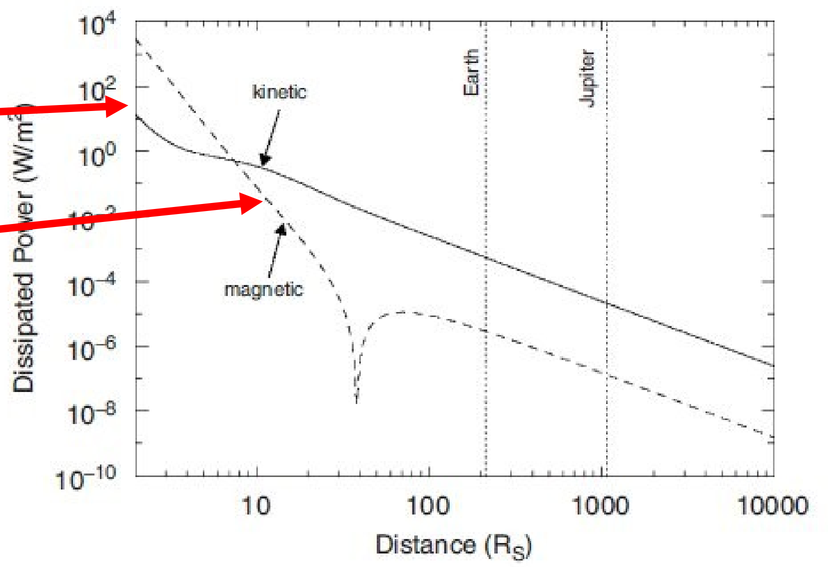
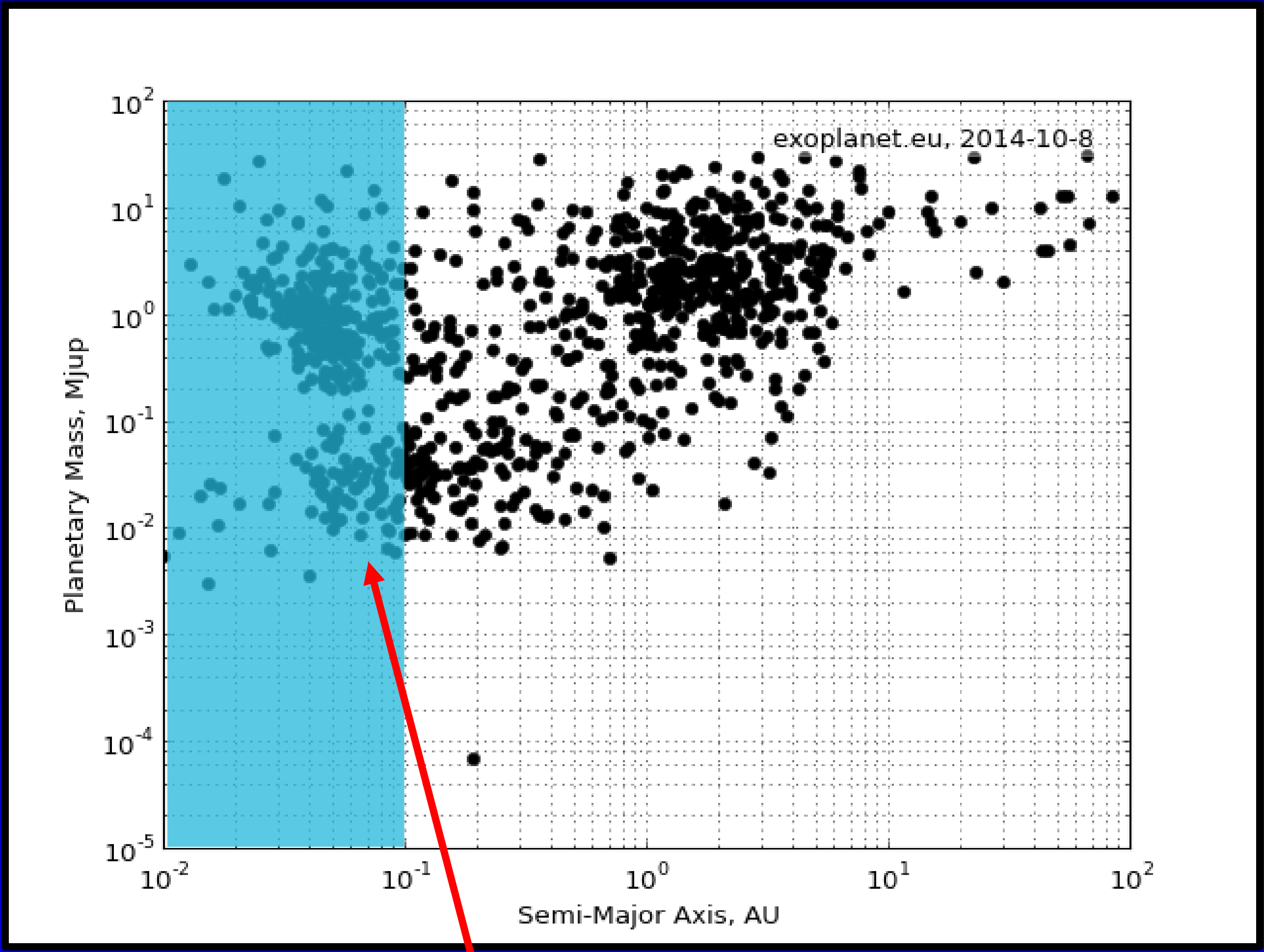


Fig. 11. Dissipated SW magnetic power $(VB_\perp^2/\mu_o)$ and kinetic power (NmV^3) per unit area. Both become comparable at a distance about 10 R_S.

$\Rightarrow$ P_{input} strong for close-in planets

Beyond the solar system



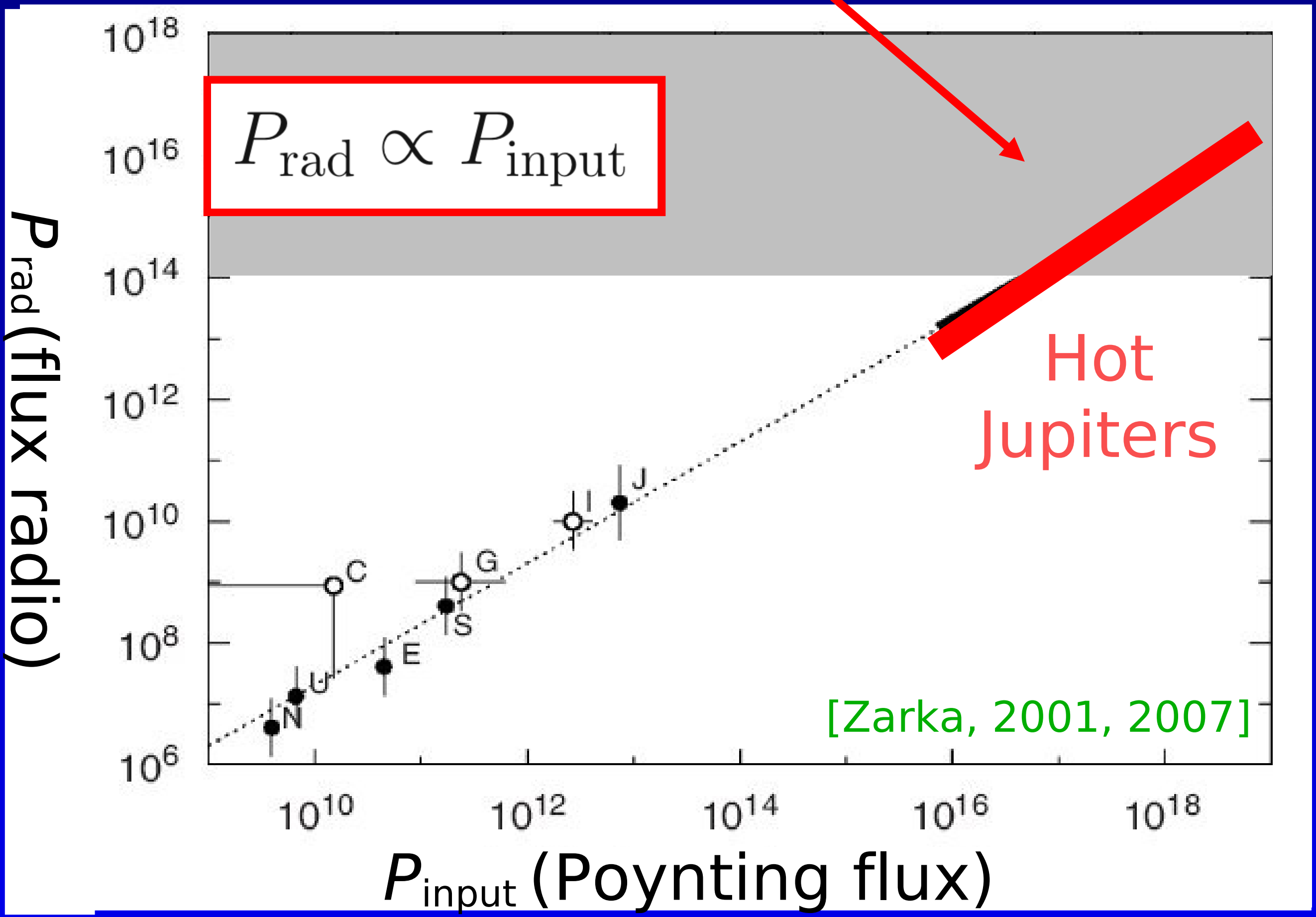
total: ~1800 planets

small orbital distance

Beyond the solar system

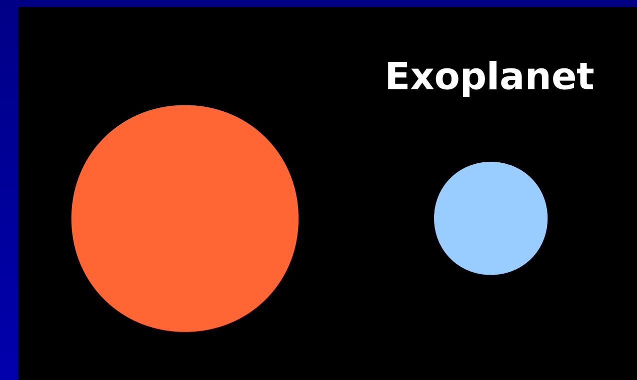
intense emission for close-in planets!

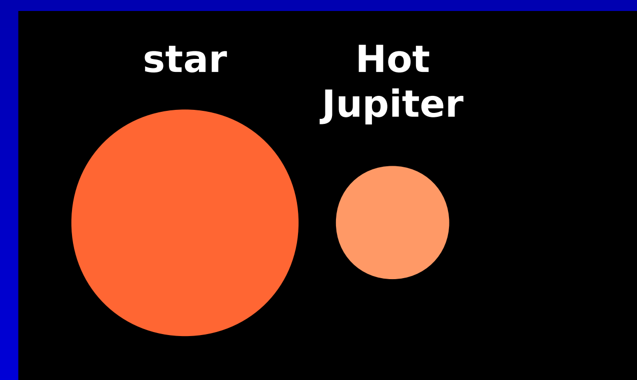
detectable region



Beyond the solar system

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





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

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

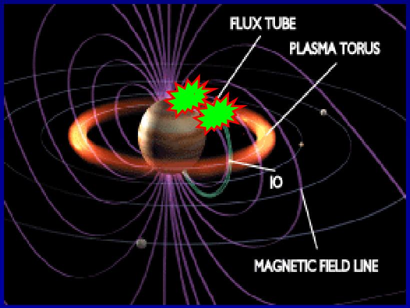
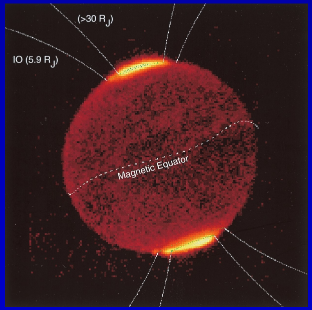
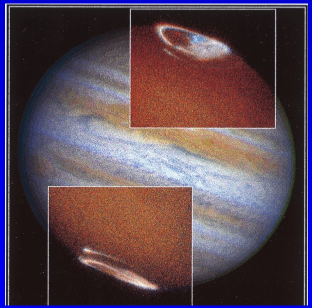
False positives?

Observation	Section	Expected effect	False positives?	Suitable
Superflares	11.2.1	Weak or none	Yes	No
Planetary migration	11.2.2	Weak	Yes	No
H_3^+ emission	11.2.3	Yes?	Yes	No
Gas giant mass loss	11.2.4	Yes	Yes	No
Chrom. emission	11.2.5	Yes	Yes	No
Early ingress	11.2.6	Yes	Yes	No
Transit profiles (ENAs)	11.2.7	Yes	No?	?
Radio emission	11.2.8	Yes	?	?
Atmospheric loss	11.3.1	Yes	Yes	No
Cosmic rays	11.3.2	Yes	Yes?	No
Comet-like exosphere	11.3.3	Yes	No?	?

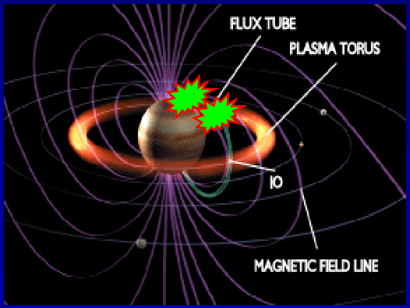
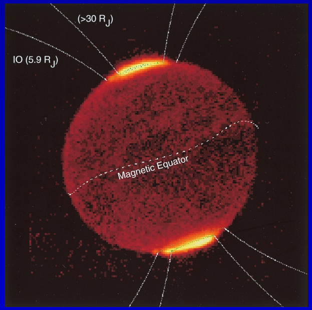
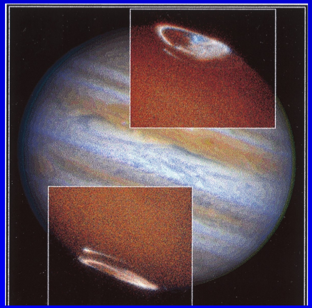
[Grießmeier 2015]

⇒ radio emission is the most promising way to find exomagnetospheres

Exoplanets: False positives?

λ		B=0
radio 	$f_c \propto \frac{eB}{m_e}$	no emission
IR 	B → topology of emission	diffuse emission?
UV 	B → topology of emission	diffuse emission?

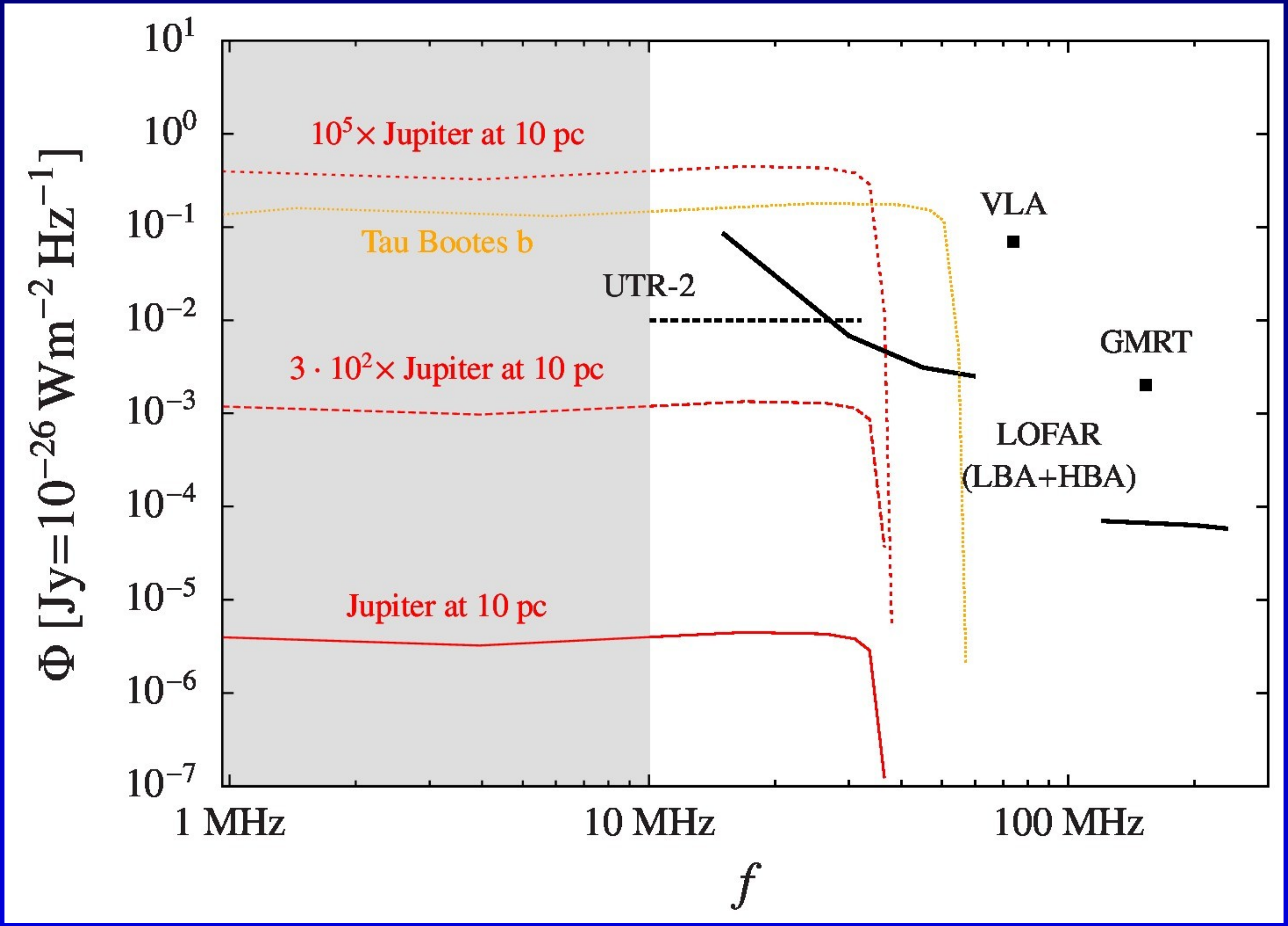
Exoplanets: False positives?

λ		B=0
radio 	$f_c \propto \frac{eB}{m_e}$	no false positives!
IR 	B → topology of emission	false positives possible!
UV 	B → topology of emission	false positives possible!

Outline

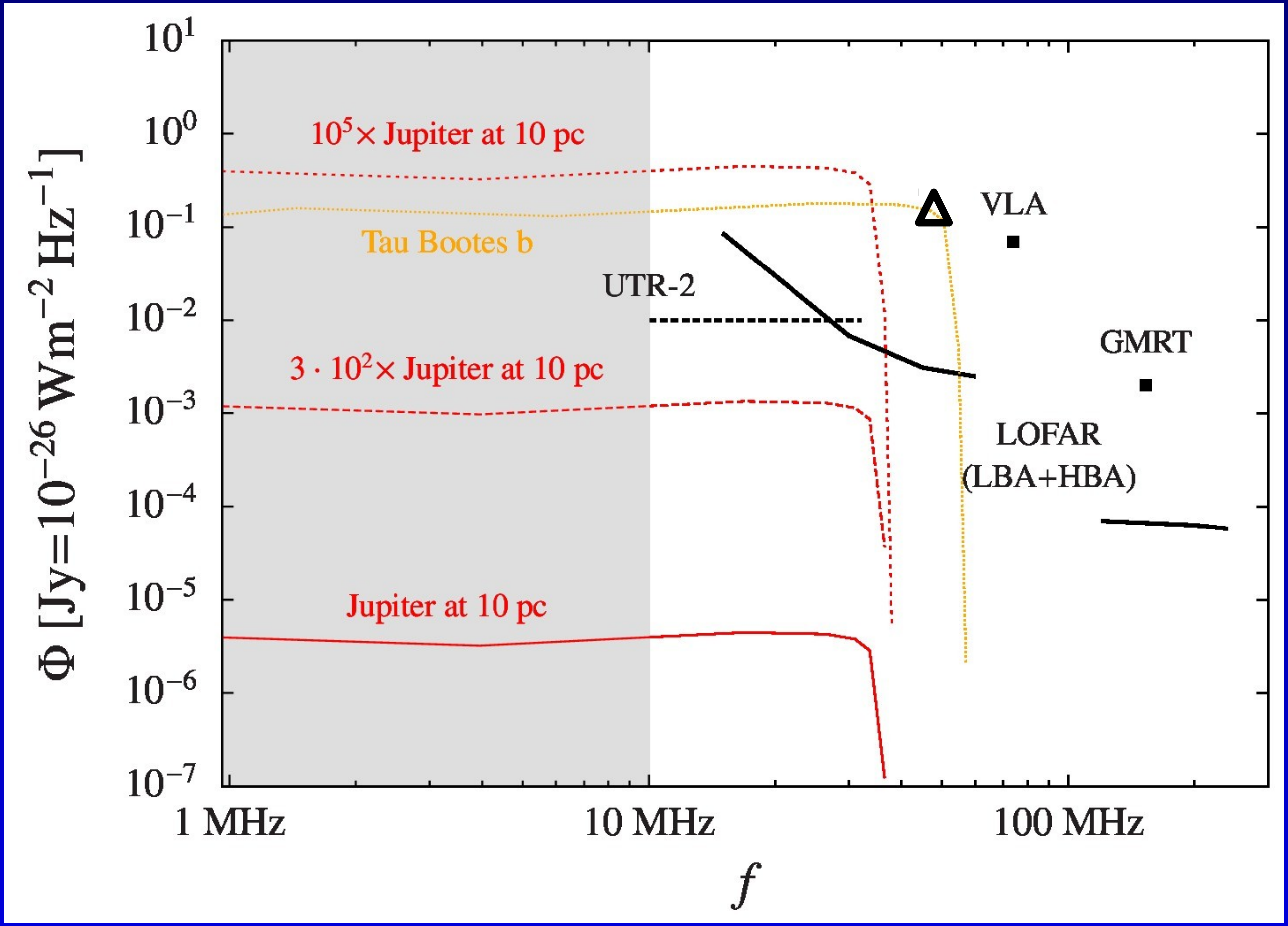
- why are exomagnetospheres interesting?
- how can we detect exomagnetospheres?
- is exoplanetary radio emission detectable?
- false negatives? false positives?
- selected theoretical results
- ongoing search programs

Radio emission



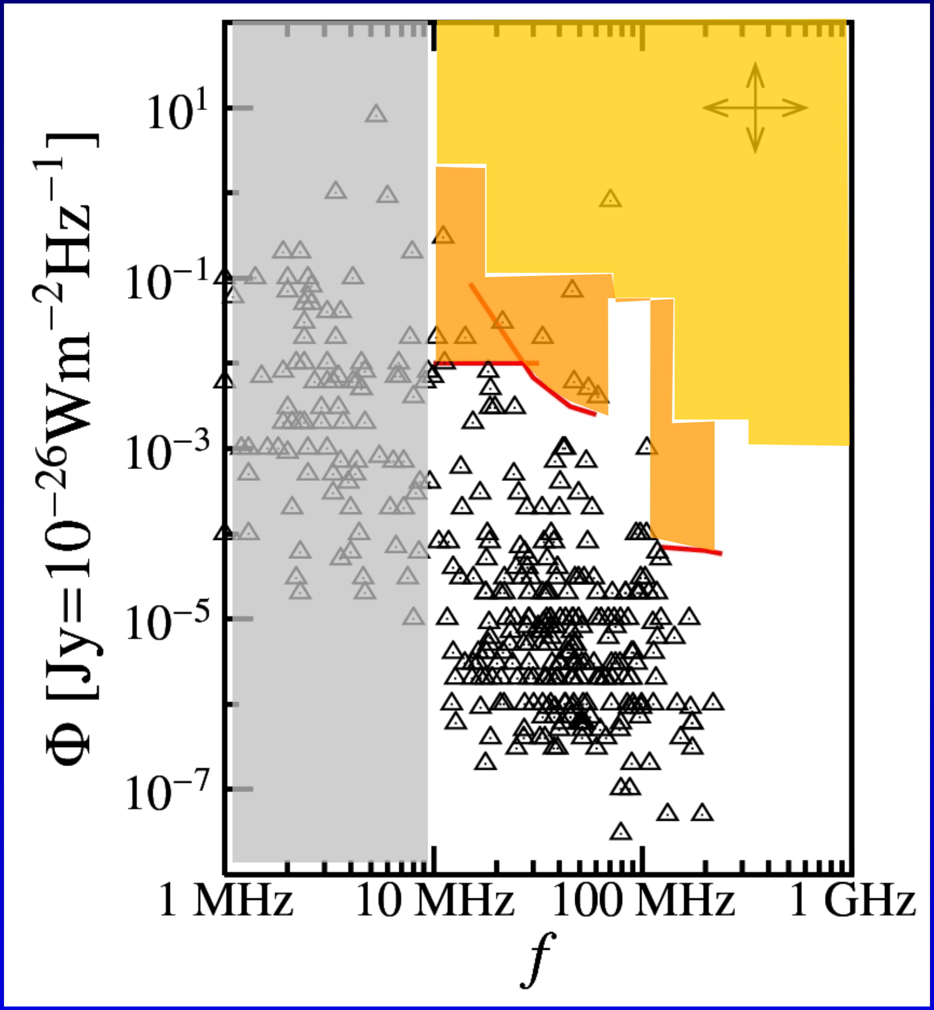
[Grießmeier 2015]

Radio emission



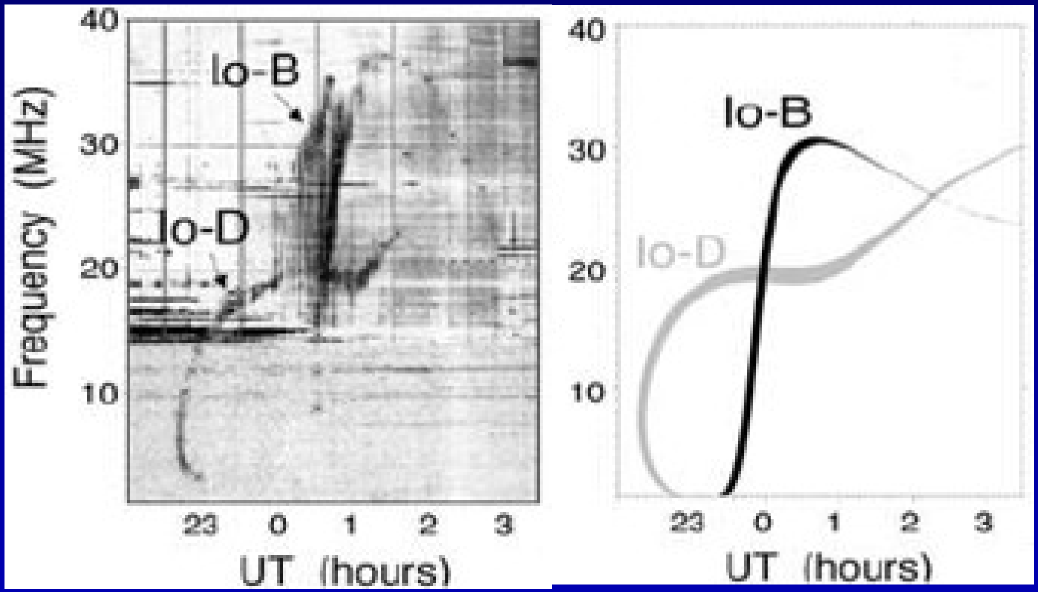
[Grießmeier 2015]

Radio emission



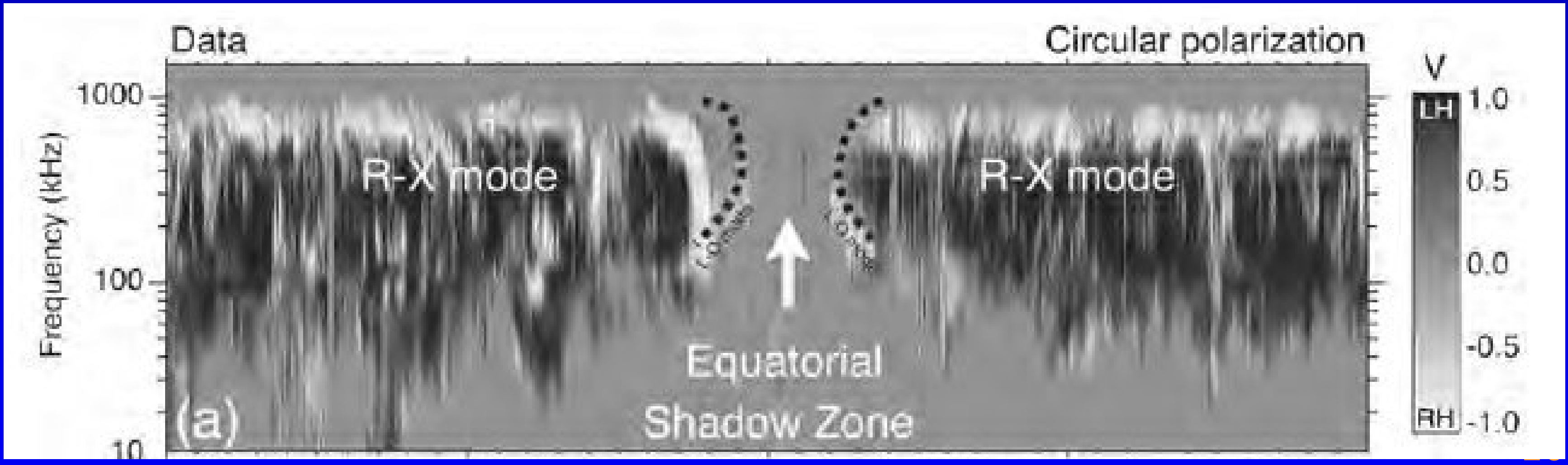
[Grießmeier et al. 2007, 2011]

Radio emission is variable!

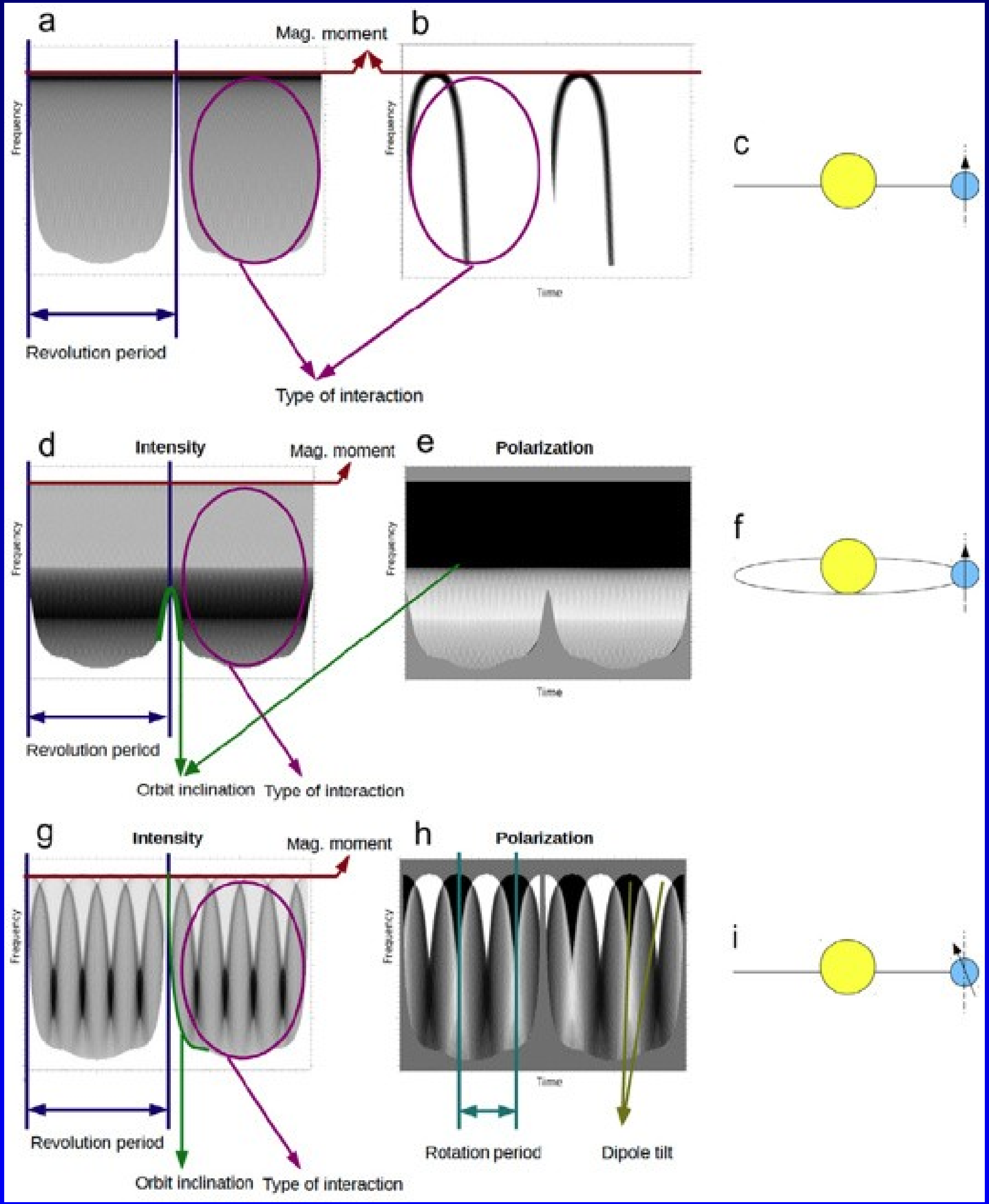


[Hess et al. 2008]

[Lamy et al. 2008]



Information from radio emission



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

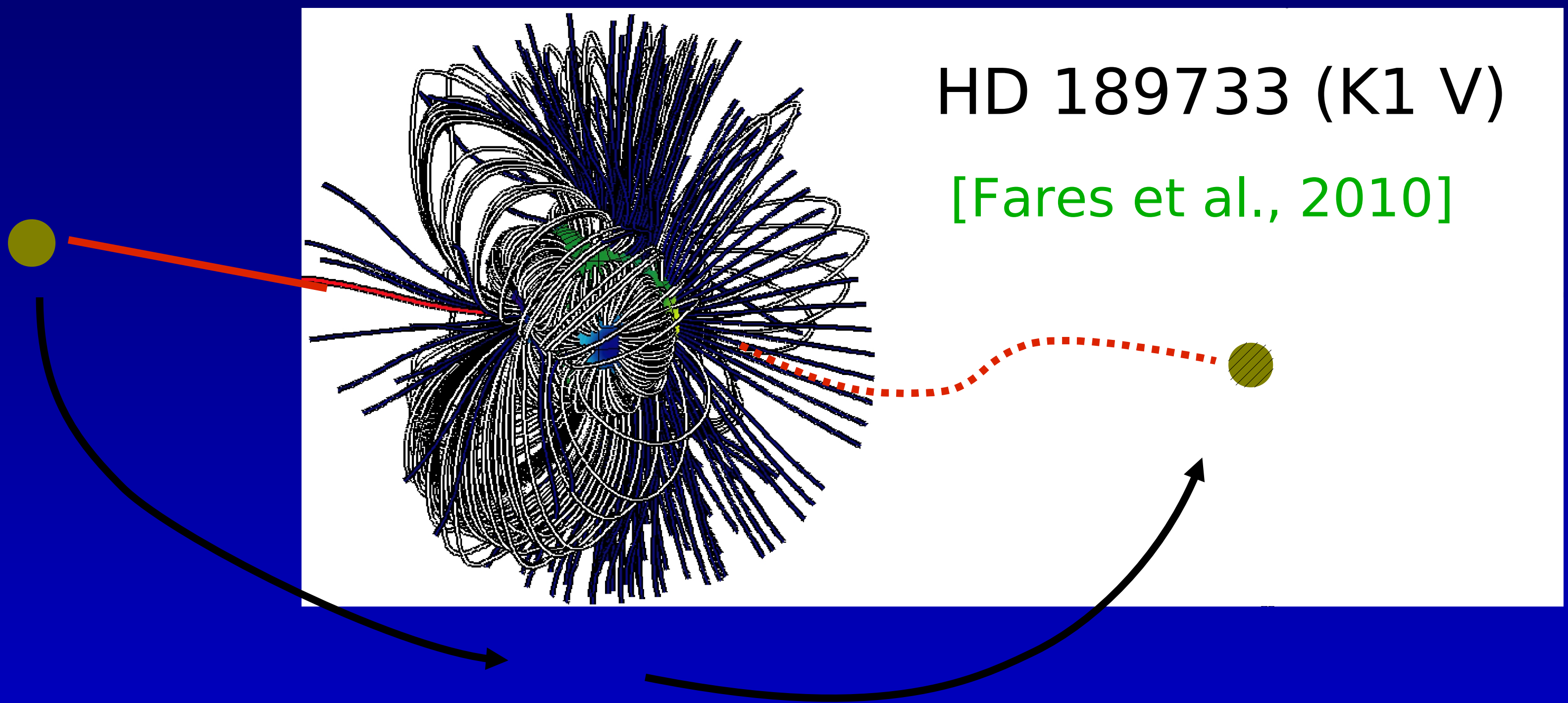
field!

rotation!
emission mode!

inclination!

[Hess et al. 2011]

Radio emission is variable!



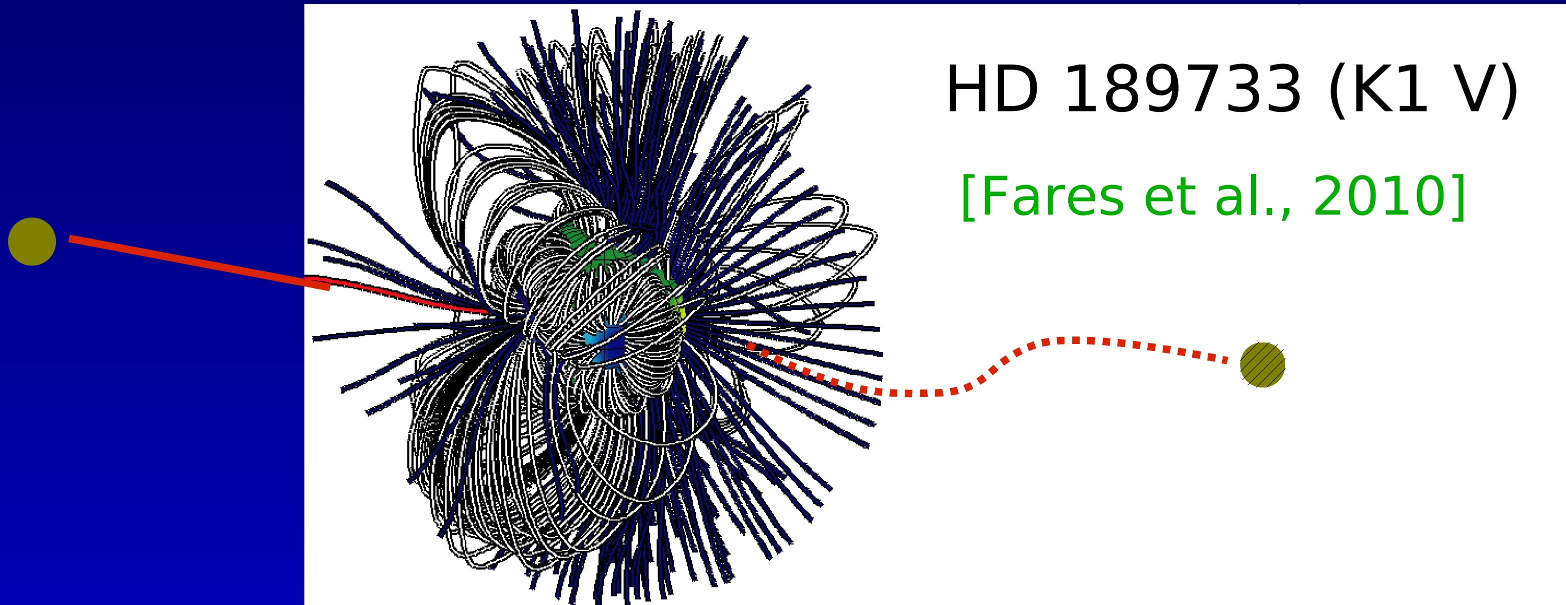
planet encounters different magnetic regions

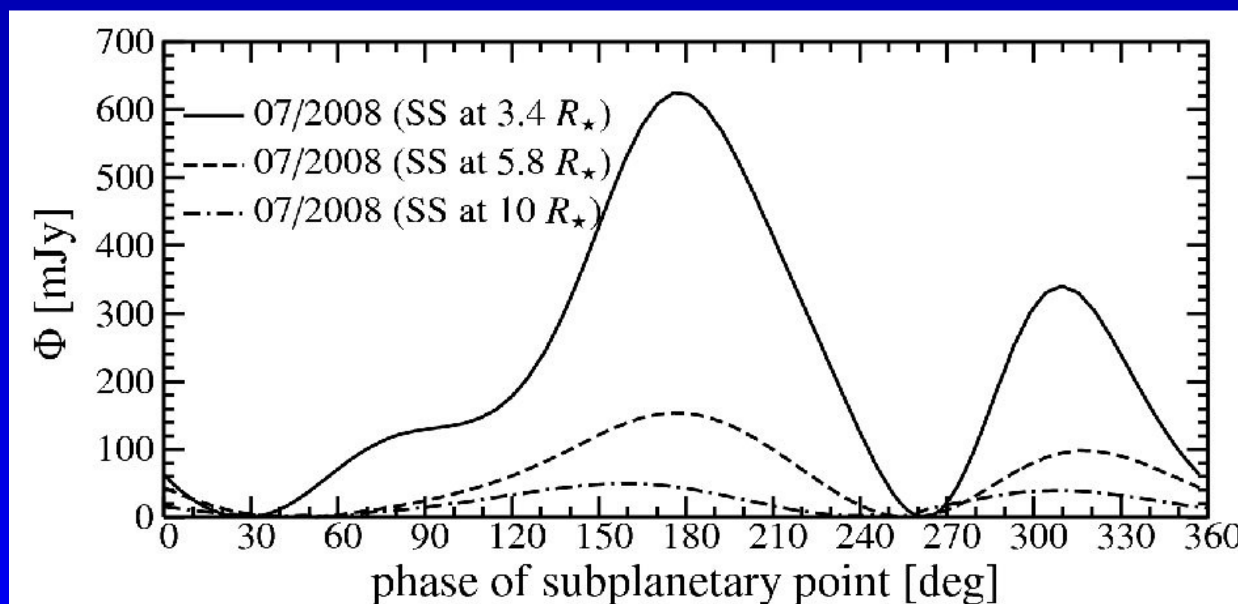
but B determines P_{radio} → variable radio emission

stellar rotation: 12d

planetary orbit: 2.22d

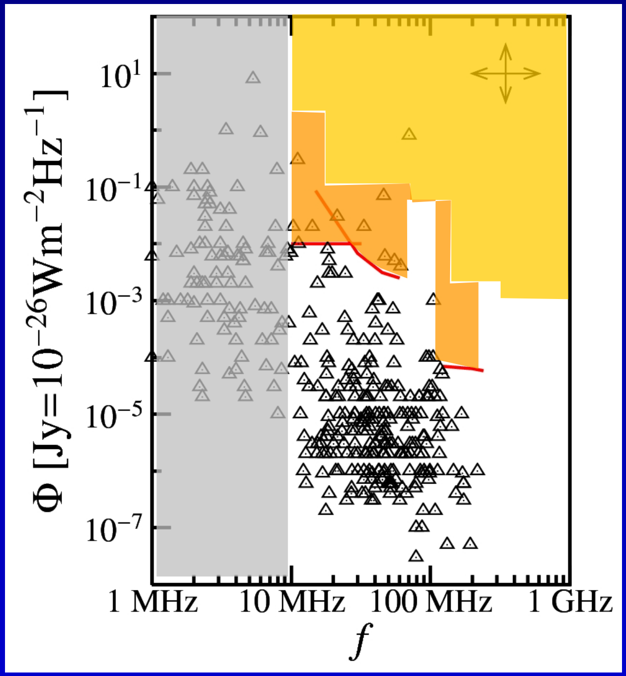
Radio emission is variable!



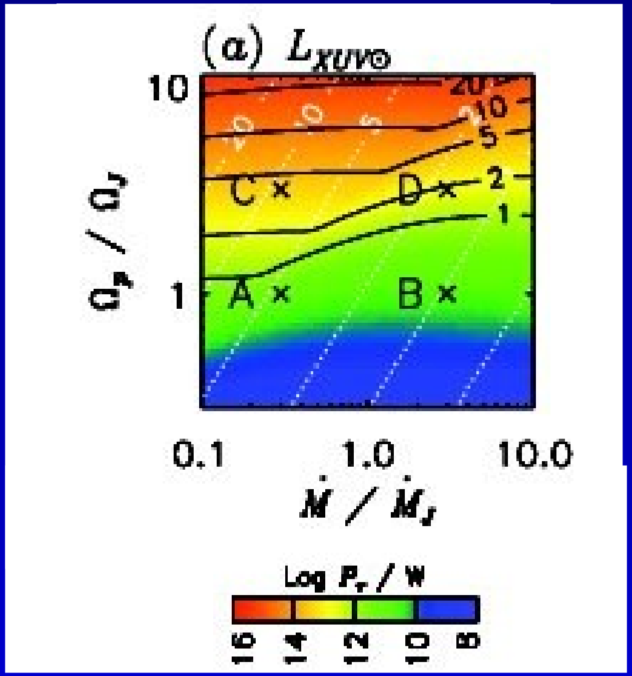


Is rotation important?

magnetic field depends on rotation	plasma source → currents depend on rotation	magnetic field independent of rotation

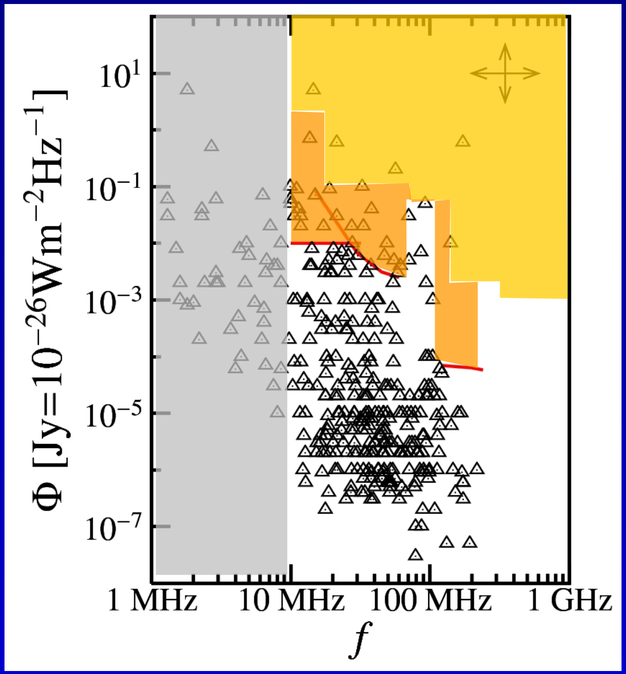


[Grießmeier et al. 2007]



[Nichols 2011]

detectable planets at larger distances?



[Reiners et al. 2010, Grießmeier et al. 2011]

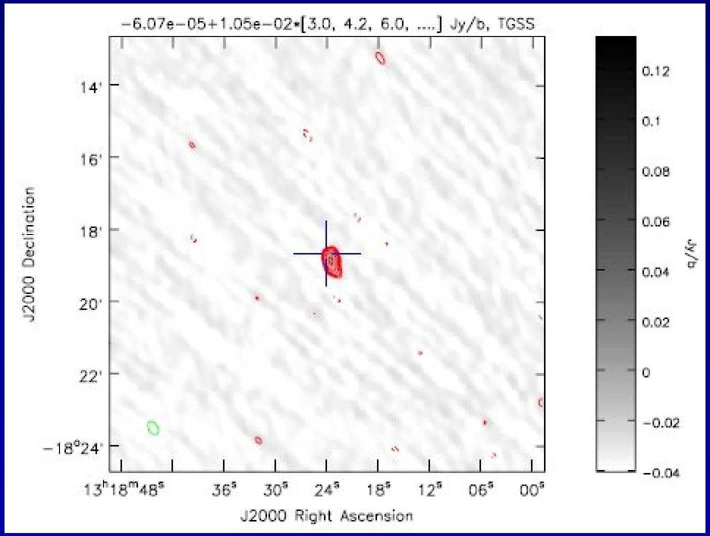
detectable planets x4?

$\Longrightarrow$ observations needed to distinguish models

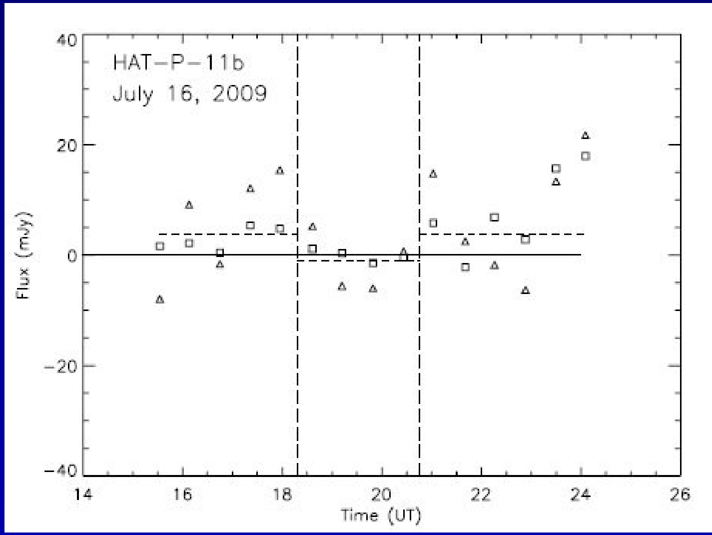
Radio emission: Theoretical studies

• 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]
• magnetospheric model	[Grießmeier et al 2004]
• target list	[Lazio et al 2004, Griessmeier et al 2007b, Driscoll et al. 2011, Nichols 2012]
• influence of stellar age	[Stevens 2005, Grießmeier et al 2005]
• white dwarfs	[Willes et al 2005]
• influence of CMEs	[Grießmeier et al 2006, 2007a]
• orbital distance	[Grießmeier et al 2007a]
• absorption close to star	[Grießmeier et al 2007b, Hess et al 2011]
• acceleration of electrons	[Jardine et al 2008]
• stellar magnetic field	[Fares et al 2010, Vidotto et al 2012]
• evolved stars	[Ignace et al 2010]
• T Tauri stars	[Vidotto et al 2010]
• planets with plasma sources	[Nichols 2011, Nichols 2012]
• orbital inclination	[Hess et al 2011]
• rogue planets	[Vanhamäki et al 2011]
• exomoons	[Noyola et al 2014]

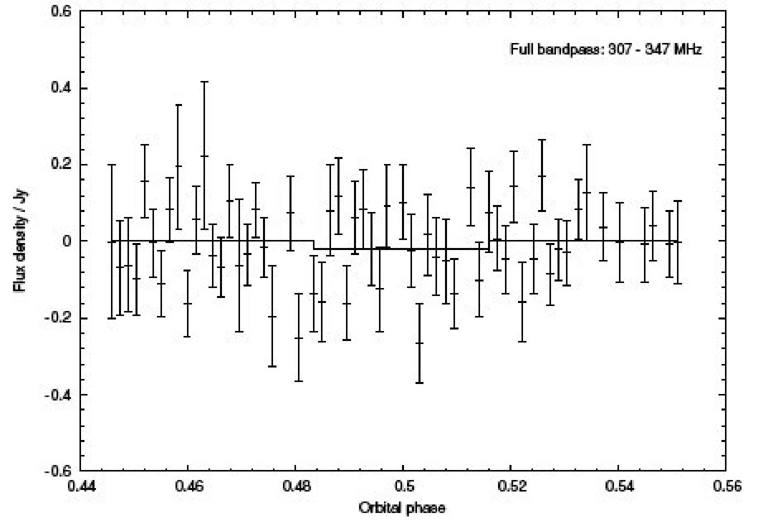
Radio emission: Observational studies



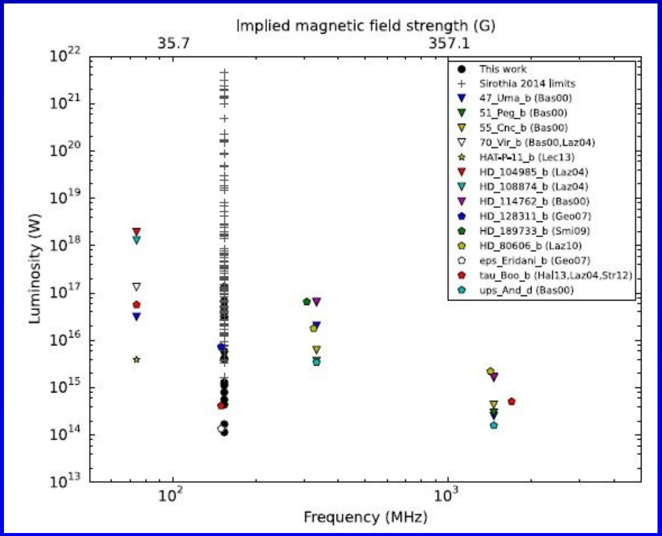
[Sirothia et al., 2014]



[Lecavelier et al., 2013]



[Smith et al., 2009]



[Murphy et al., 2015]

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]
• MWA	[Murphy et al 2015]

- no firm detection yet
- detection seems possible
  → observations ongoing

Outline

- why are exomagnetospheres interesting?
- how can we detect exomagnetospheres?
- is exoplanetary radio emission detectable?
- false negatives? false positives?
- selected theoretical results
- ongoing search programs

Ongoing searches

UTR-2:
- f = 10-30 MHz
- $A_{eff}=10^5\ m^2$
- observations 2006-2009
- mostly "Hot Jupiters" + Corot-7b
- dynamic spectra (2 beams)
- instrumental effects
- data under analysis

LOFAR:
- f = 10/30-240 MHz
- $A_{eff,core}=2.5\ 10^4\ m^2$
- observation of "best targets"
- interferometric images + dynamic spectra (3 beams)
- observations since 2012
- data under analysis

Observations with LOFAR

cycle 0 (Nov. 2012 – Nov. 2013)

Proposal Code	PI	Proposal title	Total observing hours	Total processing hours
LC0_002	Olaf Wucknitz	Location and motion of sources of Jupiter's magnetospheric/auroral decameter emissions	9	9
LC0_003	Rob Fender	Wide field searches for image-plane radio transients	196	249,5
LC0_004	Neal Jackson	Gravitational lenses at low frequencies	30	15
LC0_005	Regis Courtin	A determination of the abundance of water in Saturn's deep atmosphere with LOFAR	10	70
LC0_006	Imke de Pater	LOFAR Observations of Jupiter's Synchrotron Radiation	11,5	35
LC0_007	Philippe Zarka	Exoplanet radio search and characterization	30	167
LC0_008	Ben Stappers	LOFAR studies of pulsars, fast transients and the interstellar medium	85	

imaging

cycle 1 (Nov. 2013 – May 2014)

LC1_029	Raymond Oonk	Extragalactic Radio Recombination Lines: An LTA resource project.	0	0,0
LC1_031	Krzysztof Chyzy	Magnetisation of the Universe - the case of the starbursting irregular galaxy NGC 4449	9,2	12,0
LC1_032	Philippe Zarka	Exoplanet radio search and characterization	17	34,0
LC1_033	Rob Fender	Wide field searches for image-plane radio transients		
LC1_034	Raffaella Morganti	Using LOFAR for detailed studies of AGN, and AGN physics		
		Continued LOFAR Gridding/Timing of Discoveries from the GBNCC		

imaging

cycle 2 (May 2014 – Nov. 2014)

LC2_017	D. Mulcahy	LBA observations of M51 and NGC891	18	25
LC2_018	P. Zarka	Search of radio emission from the 55 Cnc exoplanetary system	32	0
LC2_019	A G de Bruyn	The LOFAR EoR project		
LC2_020	E. Enriquez	First detection of brown dwarfs with LOFAR		

beamformed

Observations with LOFAR

cycle 0 (Nov. 2012 – Nov. 2013)

Proposal Code	PI	Proposal title	Total observing hours	Total processing hours
LC0_002	Olaf Wucknitz	Location and motion of sources of Jupiter's magnetospheric/auroral decameter emissions	9	9
LC0_003	Rob Fender	Wide field searches for image-plane radio transients	196	249,5
LC0_004	Neal Jackson	Gravitational lenses at low frequencies	30	15
LC0_005	Regis Courtin	A determination of the abundance of water in Saturn's deep atmosphere with LOFAR	10	70
LC0_006	Imke		11,5	35
LC0_007	Philip		30	167
LC0_008	Ben		85	

analysis ongoing (S. Daiboo)

imaging

cycle 1 (Nov. 2013 – May 2014)

LC1_029	Raymond Oonk	Extragalactic Radio Recombination Lines: An LTA resource project.	0	0,0
LC1_031		Magnetisation of the Universe - the case of the starbursting irregular galaxy	9,2	12,0
LC1_032			17	34,0
LC1_033				
LC1_034	Raffaella Morganti	Using LOFAR for detailed studies of AGN, and AGN physics		
		Continued LOFAR Gridding/Timing of Discoveries from the GBNCC		

analysis ongoing (S. Daiboo)

imaging

cycle 2 (May 2014 – Nov. 2014)

LC2_017	D		18	25
LC2_018			32	0
LC2_019	A			
LC2_020	E			

analysis ongoing
(P. Zarka, J.-M. Grießmeier)

beamformed

Summary

Observation	Section	Expected effect	False positives?	Suitable
Superflares	11.2.1	Weak or none	Yes	No
Chrom. emission	11.2.5	Yes	Yes	No
Early ingress	11.2.6	Yes	Yes	No
Transit profiles (ENAs)	11.2.7	Yes	No?	?
Radio emission	11.2.8	Yes	No	Yes
Atmospheric loss	11.3.1	Yes	Yes	No

radio emission = most promising way
to find exomagnetospheres [Grießmeier 2015]

observation campaigns at different telescopes
→ so far no convincing detection

LOFAR data under analysis