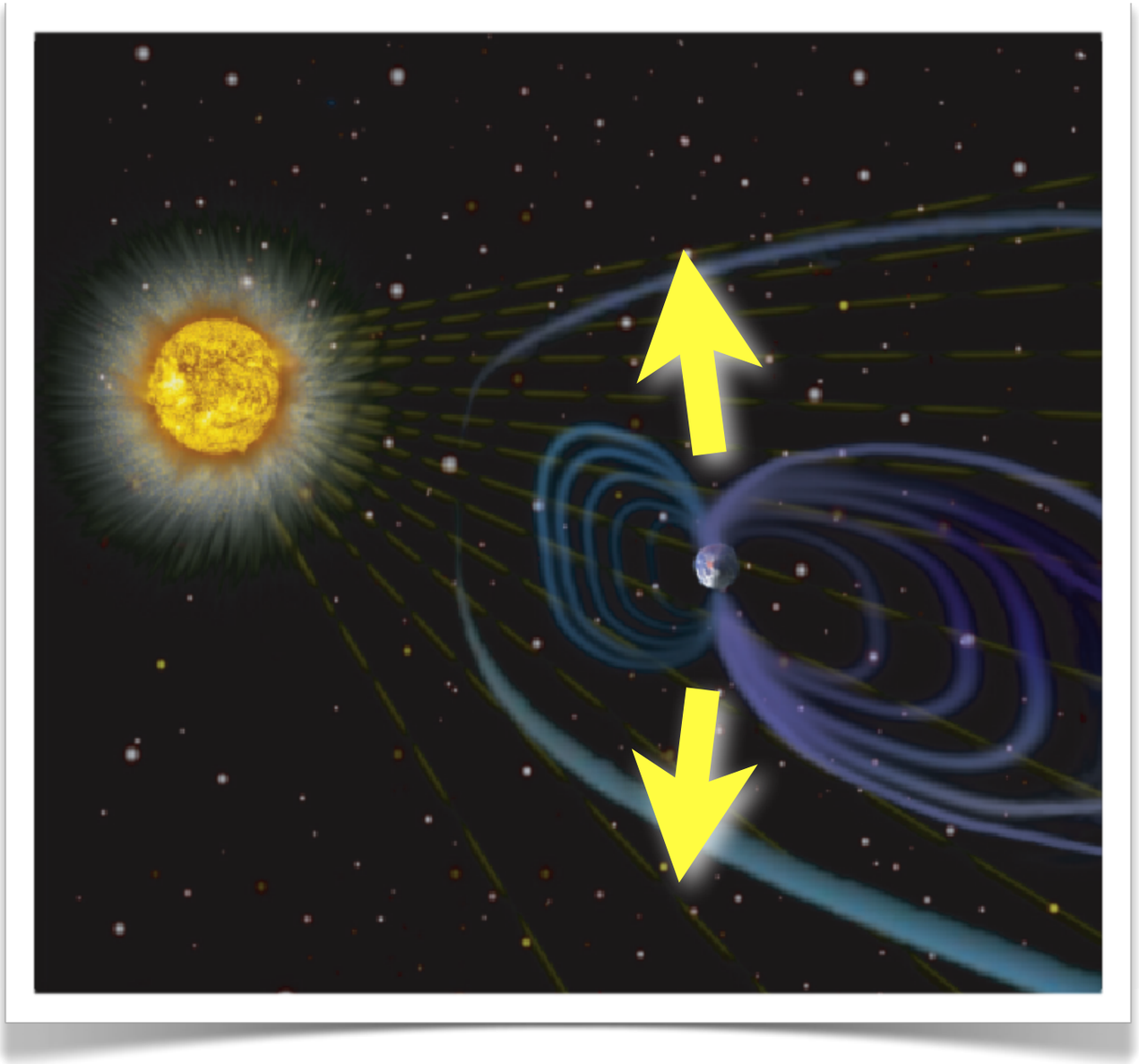
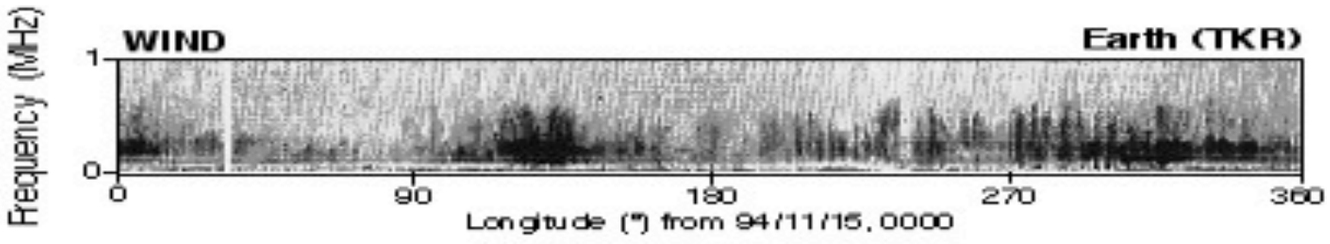
# Search for exoplanetary radio emissions : updated scaling law and detection strategy for NenuFAR

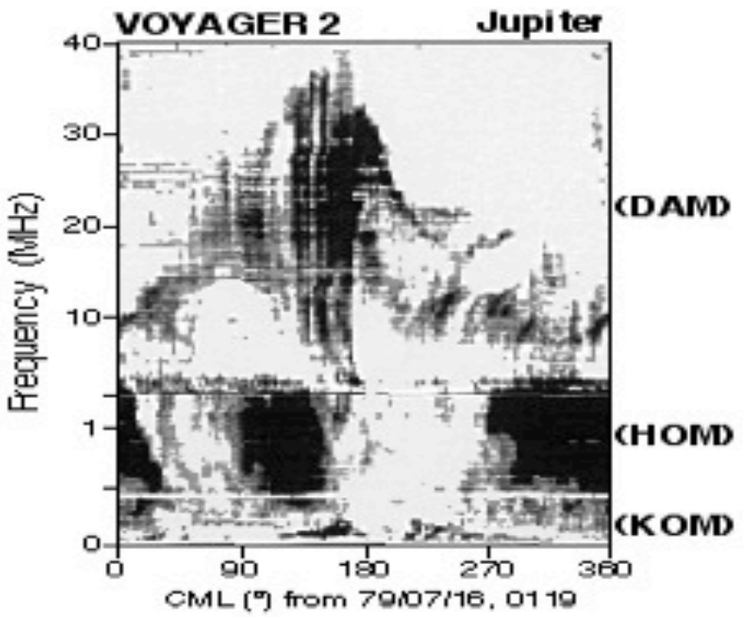


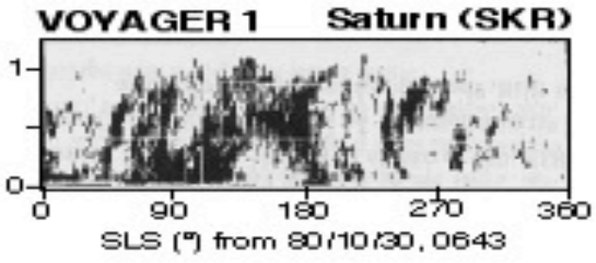

L. Lamy, P. Zarka
*LESIA, Observatoire de Paris - CNRS, Meudon*

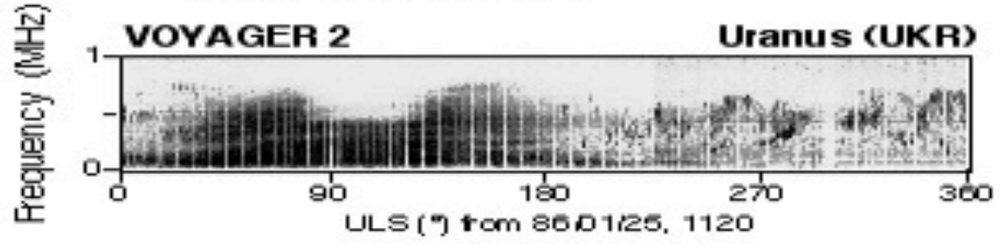
J.-M. Griessmeier
*LPC2E, Orléans*

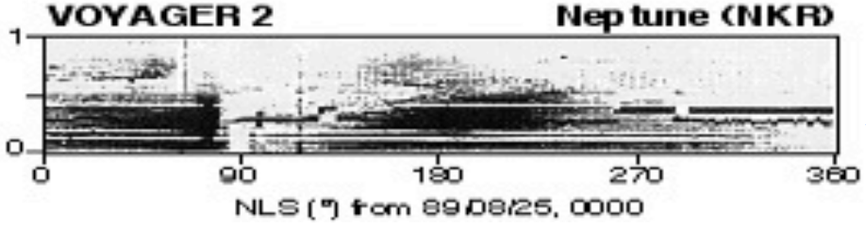
# Solar system




Radio planetary emissions :

- observed where (i) $f_{pe} \ll f_{ce}$ and (ii) e- >1keV
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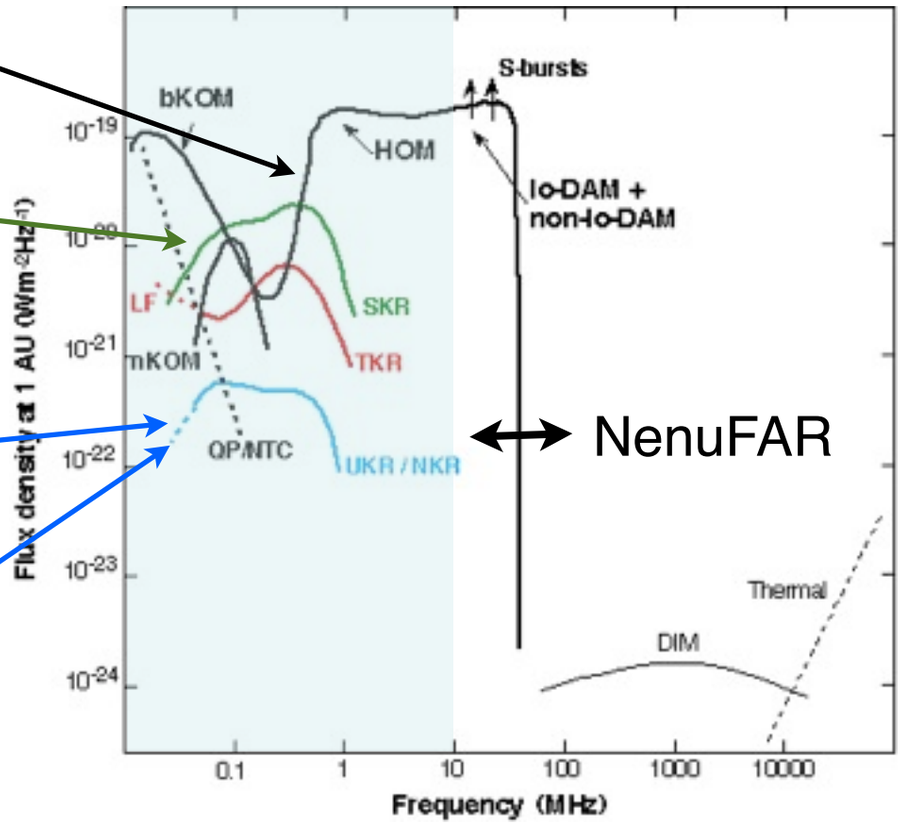


NenuFAR

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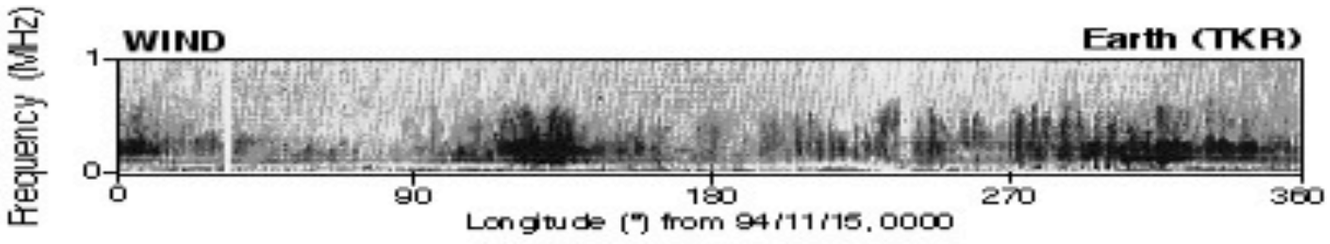


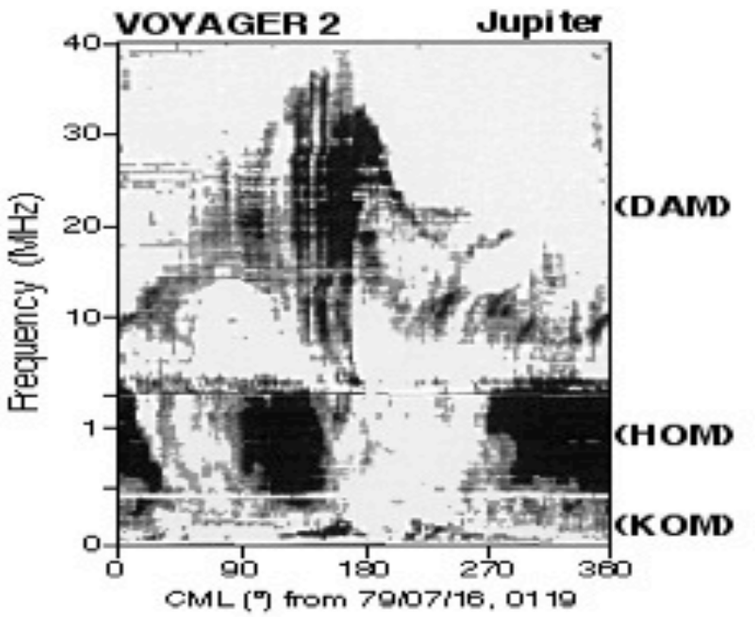


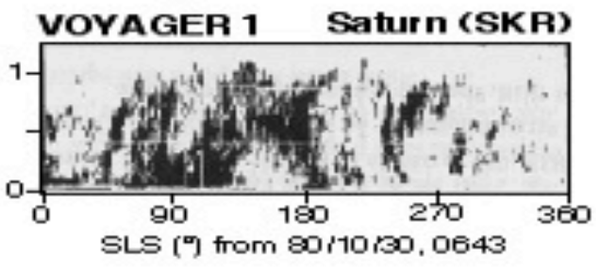


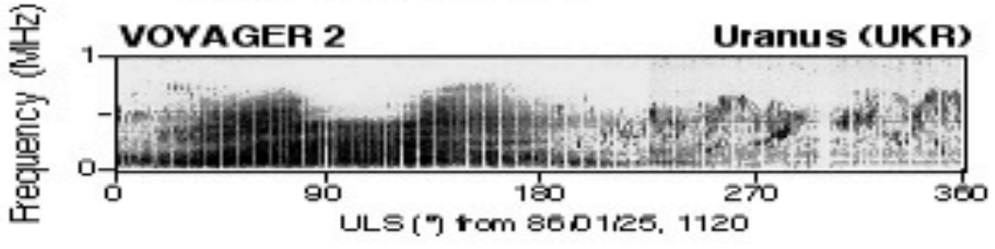


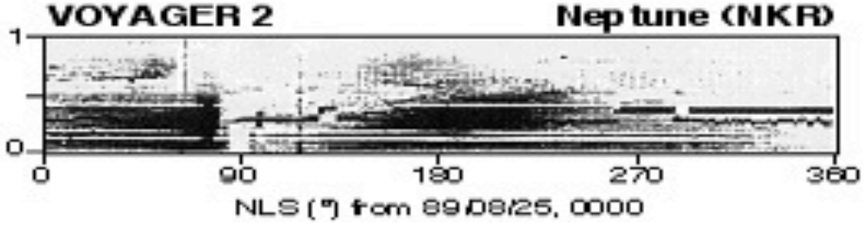


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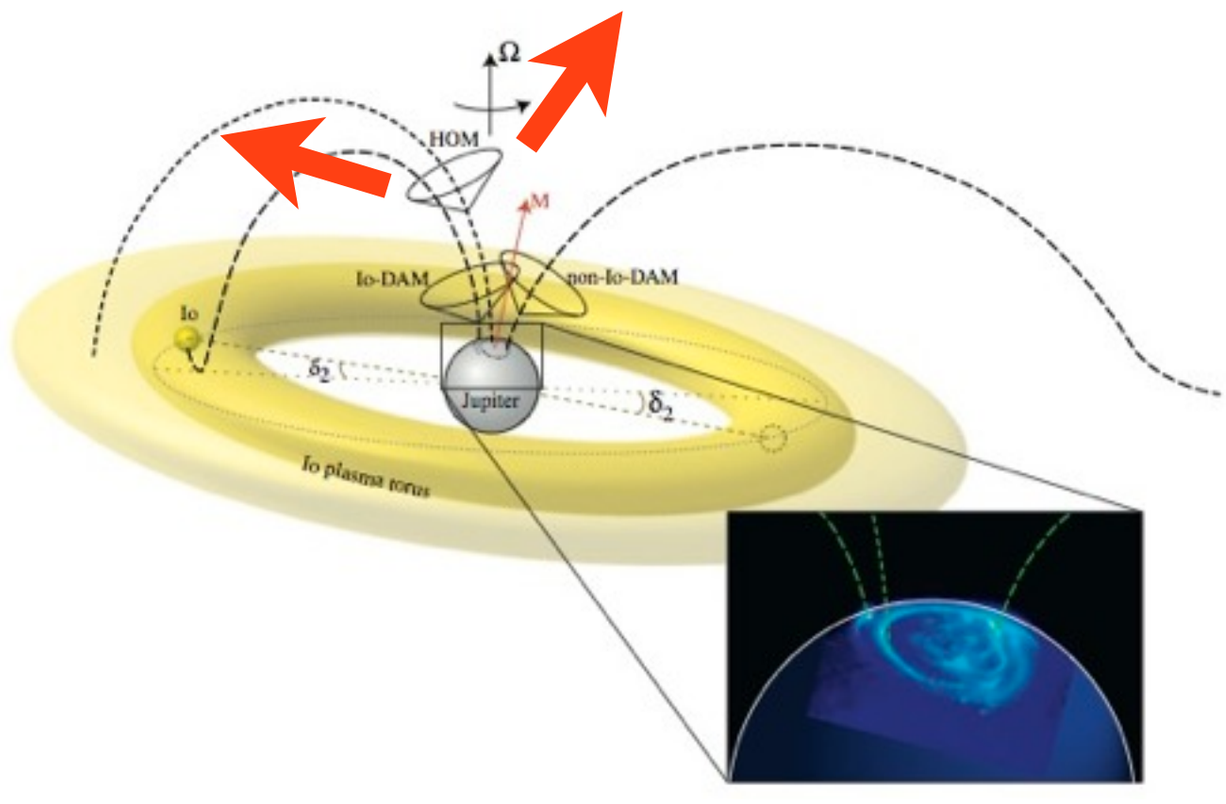

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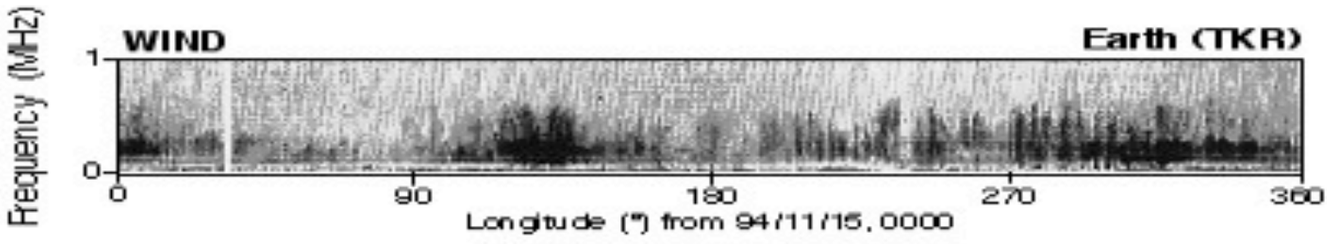


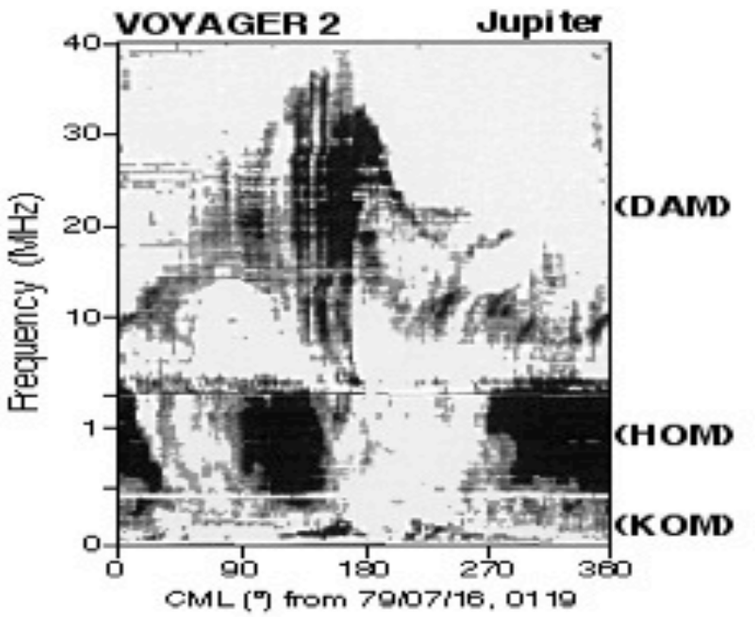


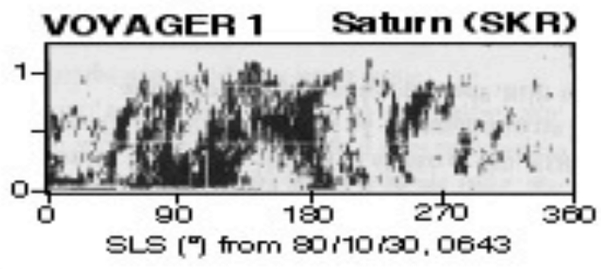


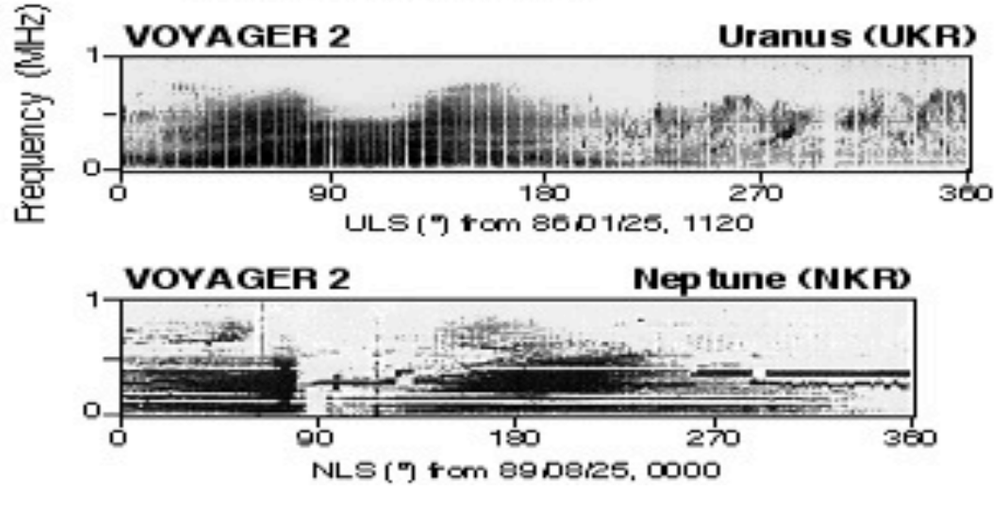


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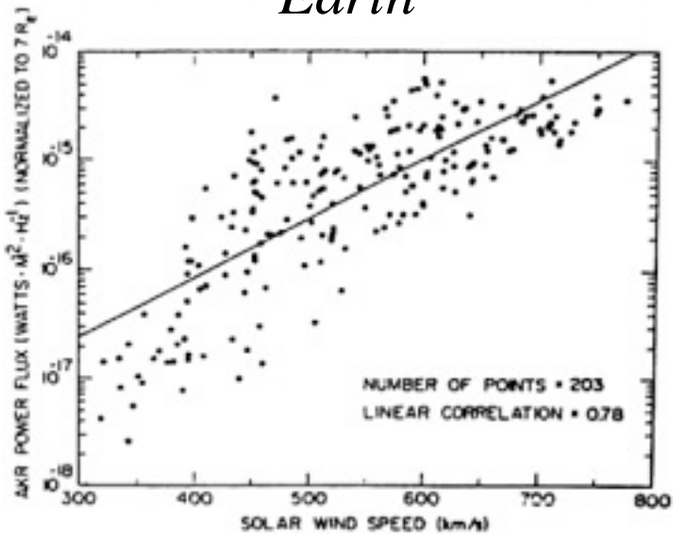
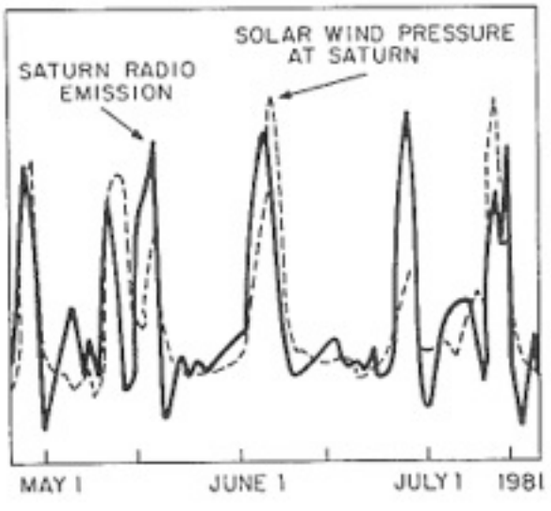
Radio exoplanetary emissions ?

- common driver : **star-planet interaction**

*Earth*




*Saturn*



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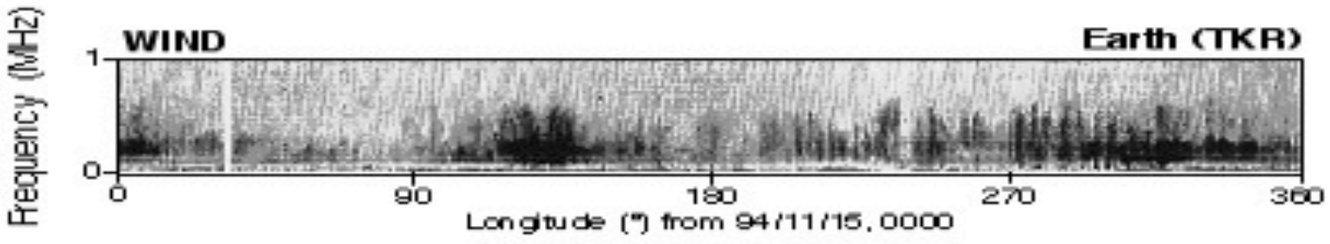


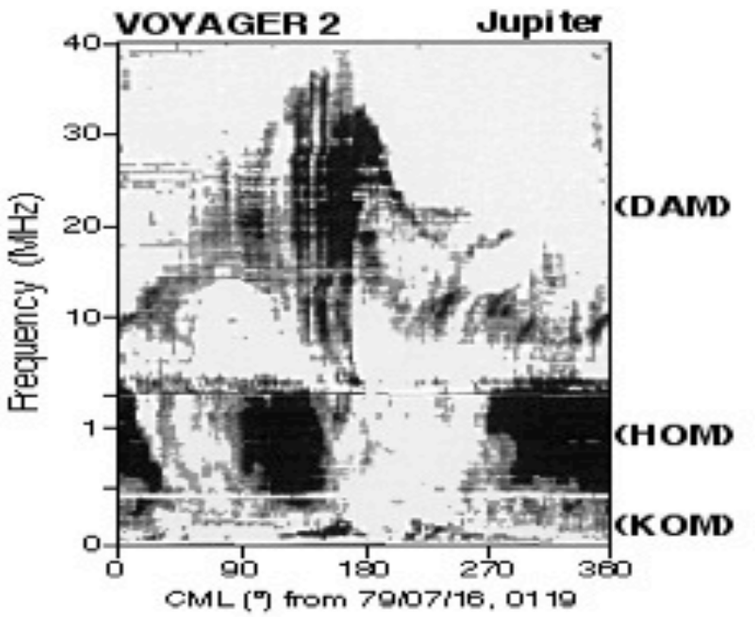


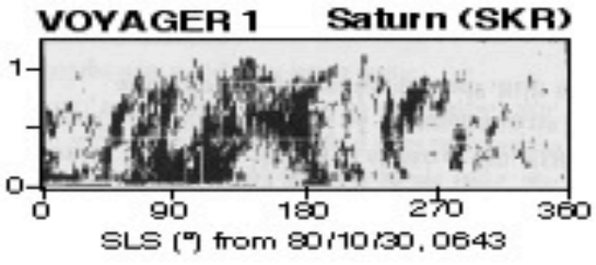


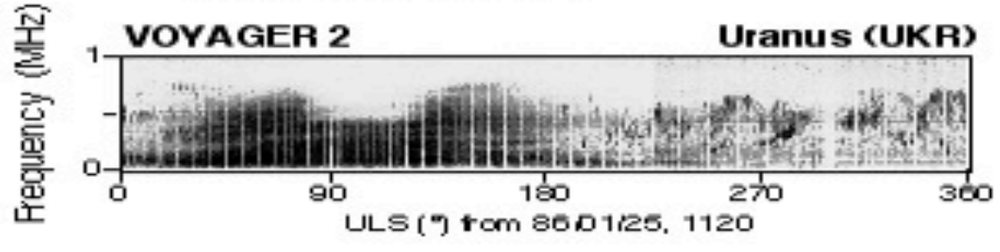


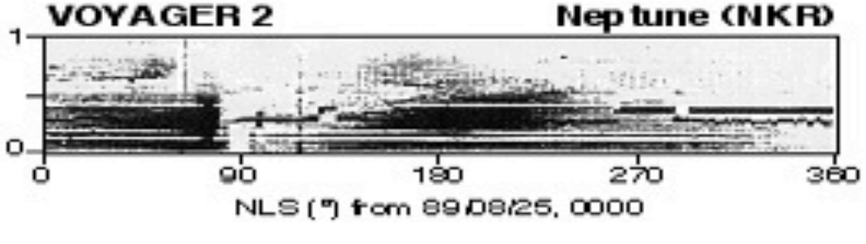


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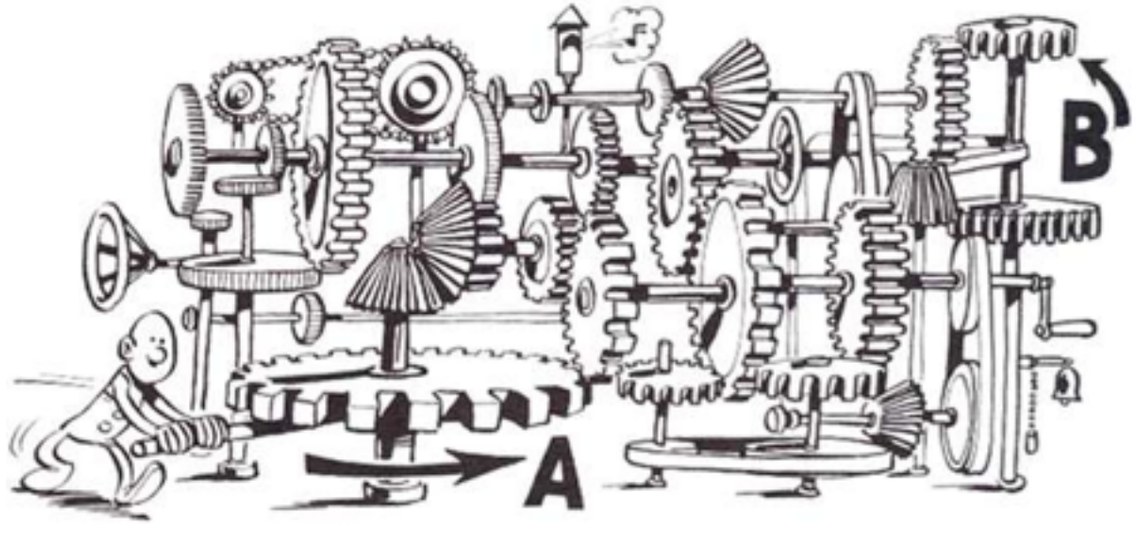
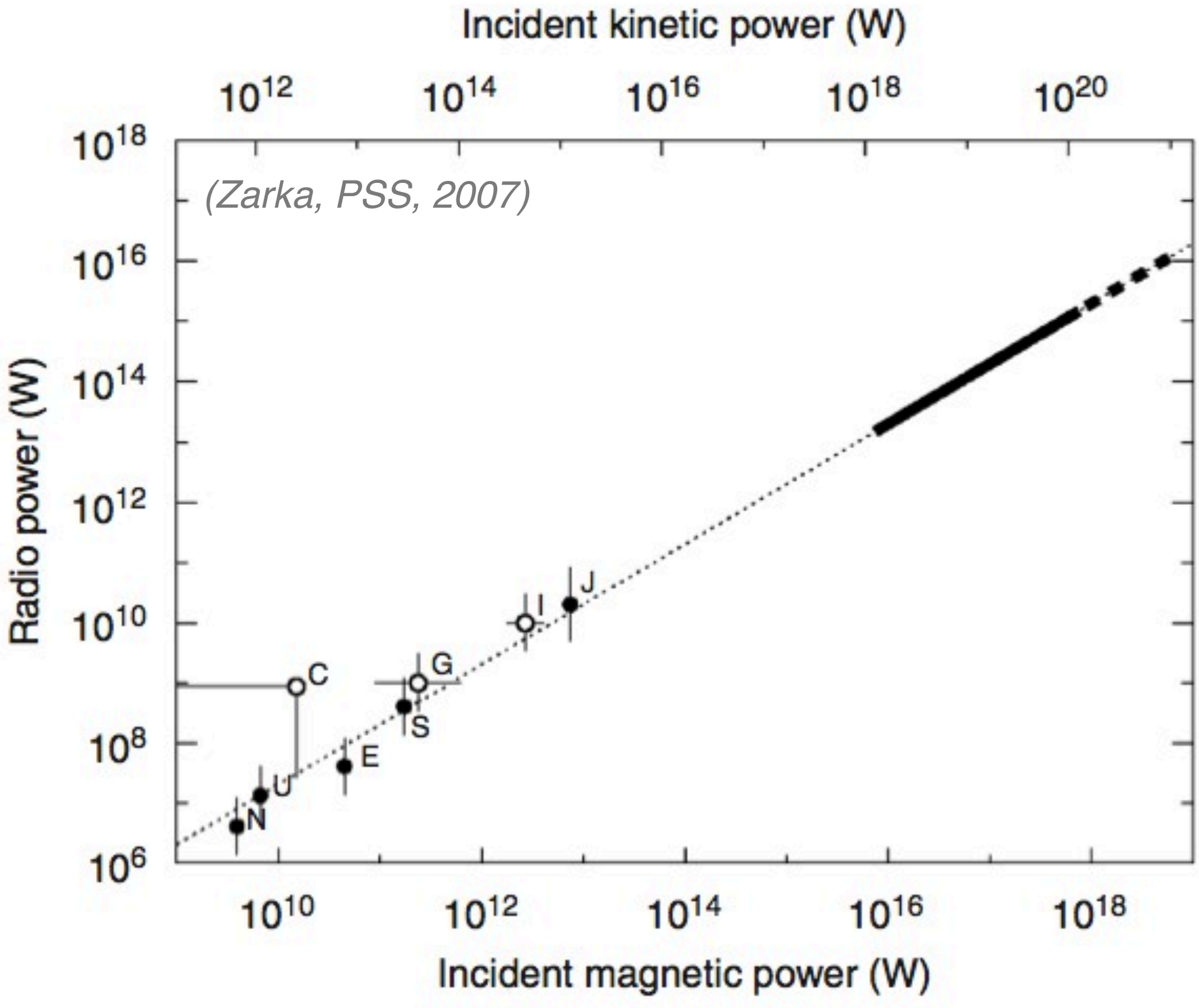
Radio exoplanetary emissions ?

- common driver : **star-planet interaction**

=> predictions of exoplanetary signals : *scaling law*



# « Radio-magnetic » Bode's law



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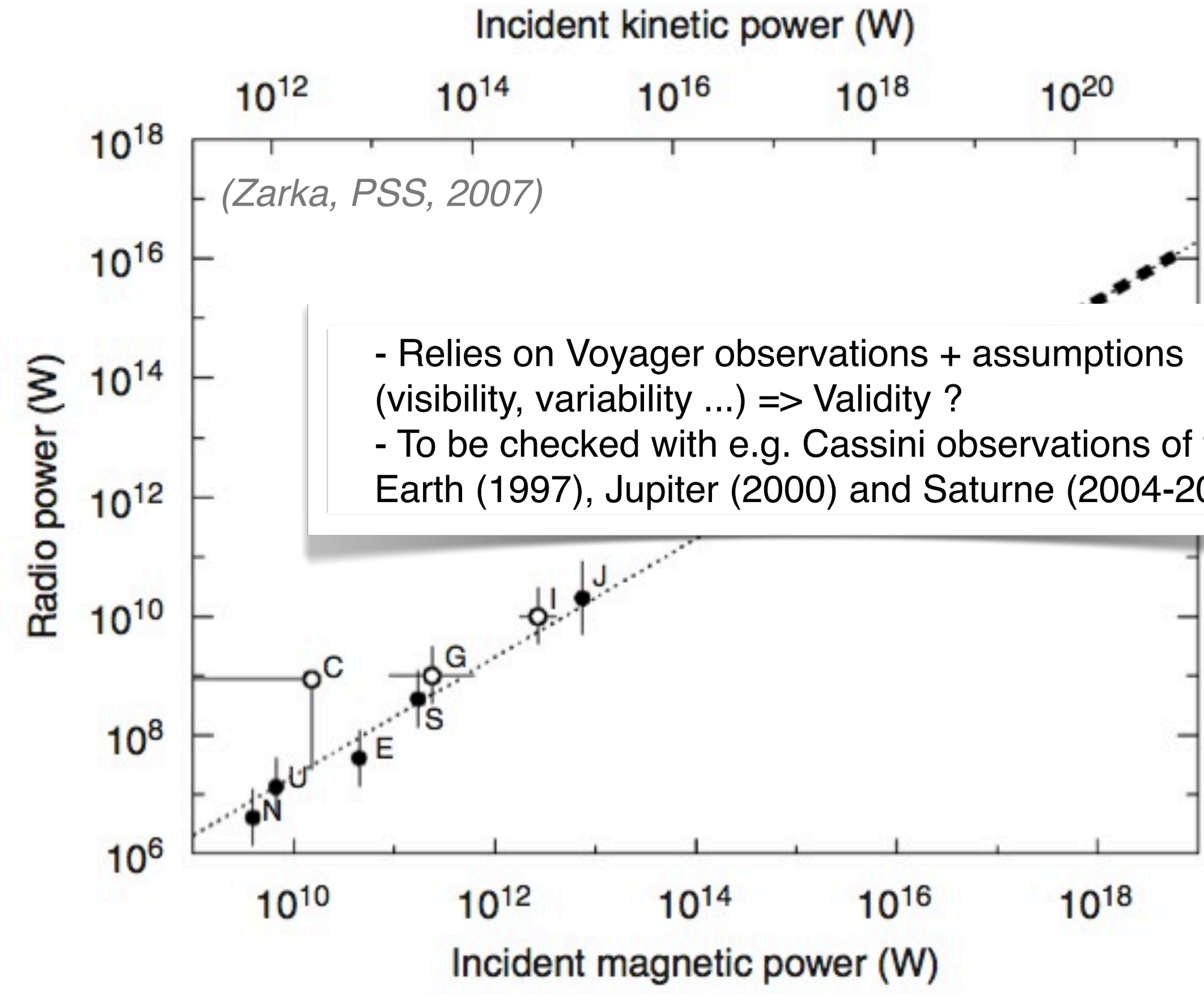


- Relies on Voyager observations + assumptions (visibility, variability ...) => Validity ?
- To be checked with e.g. Cassini observations of the Earth (1997), Jupiter (2000) and Saturne (2004-2012)

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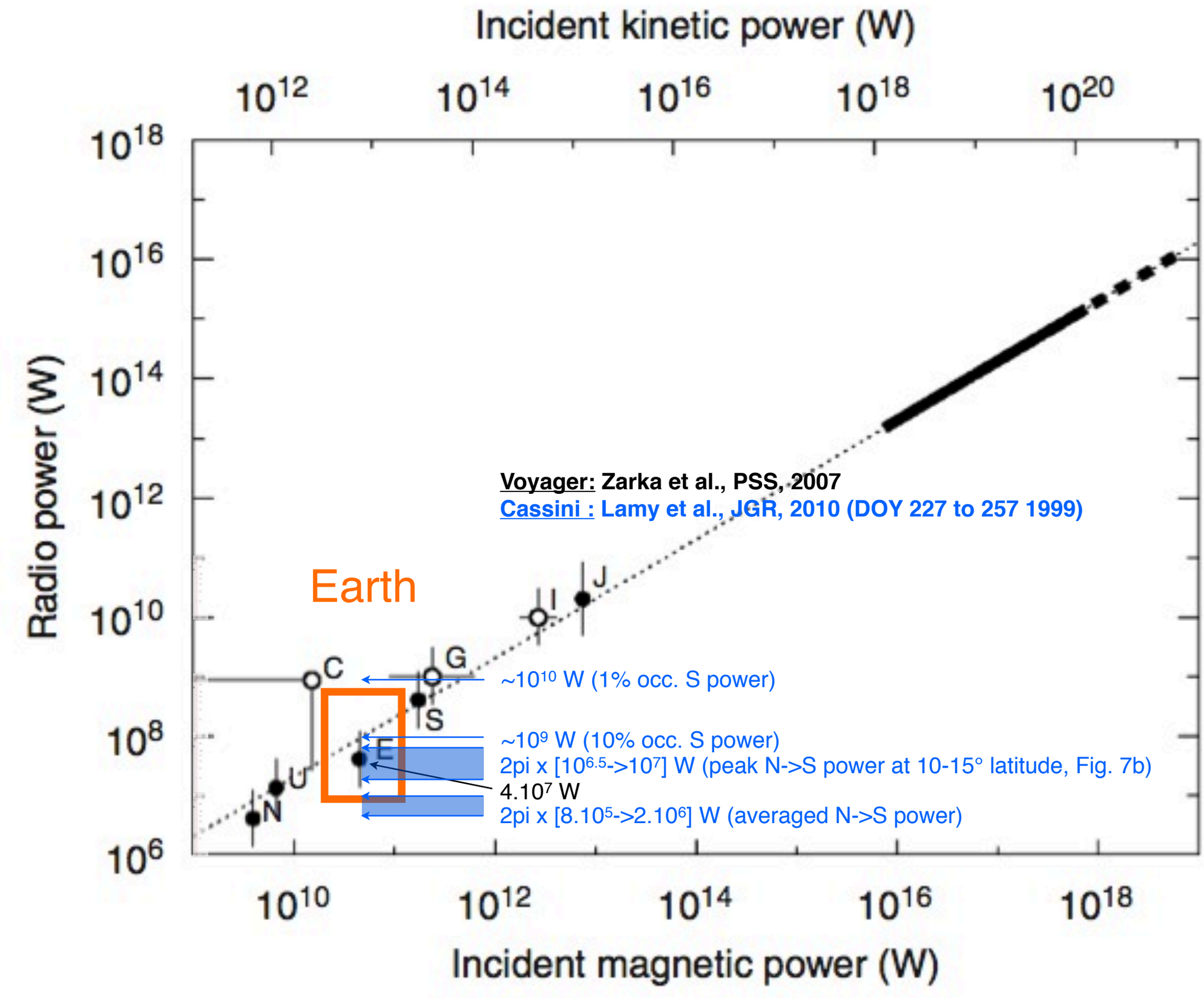

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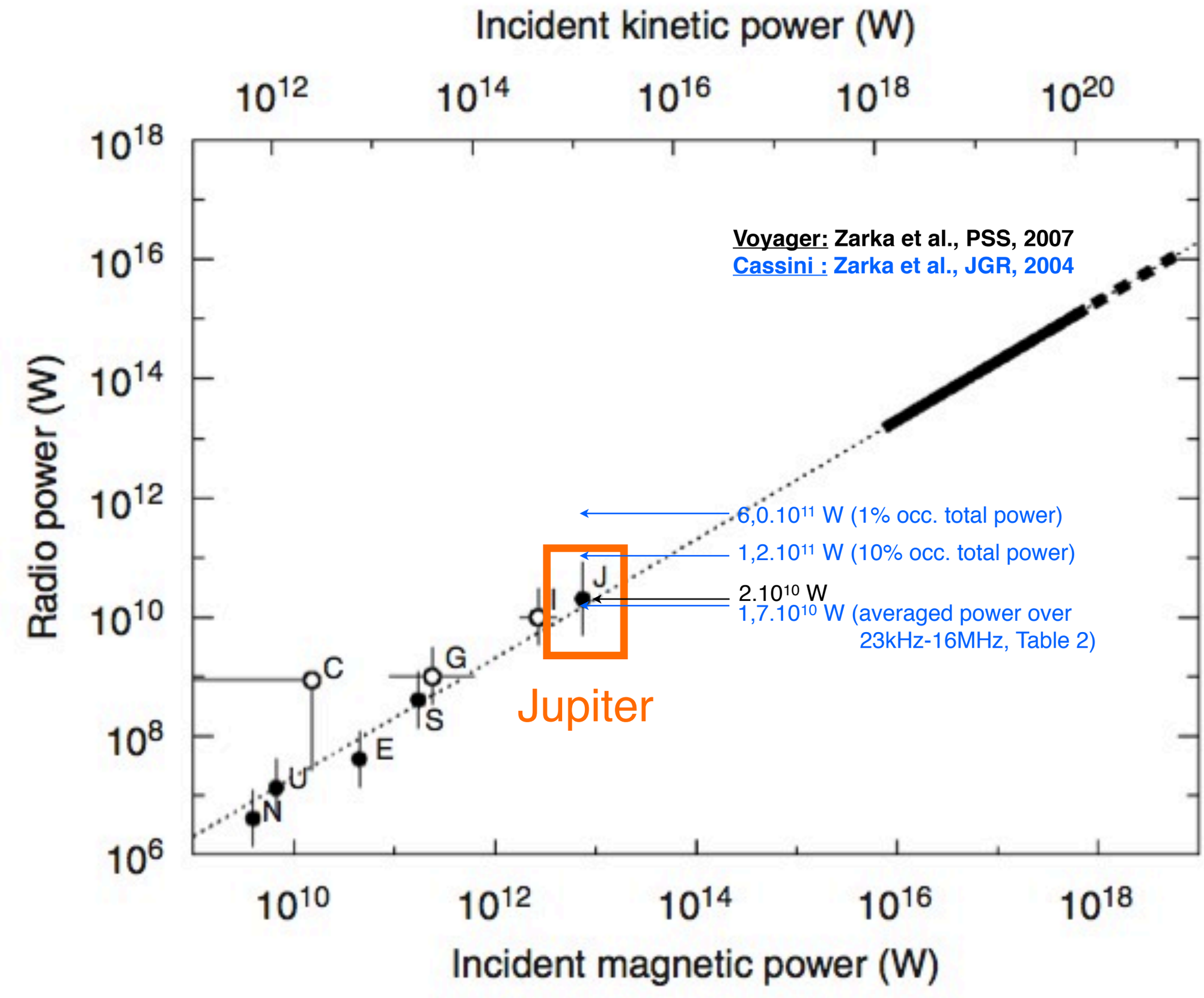

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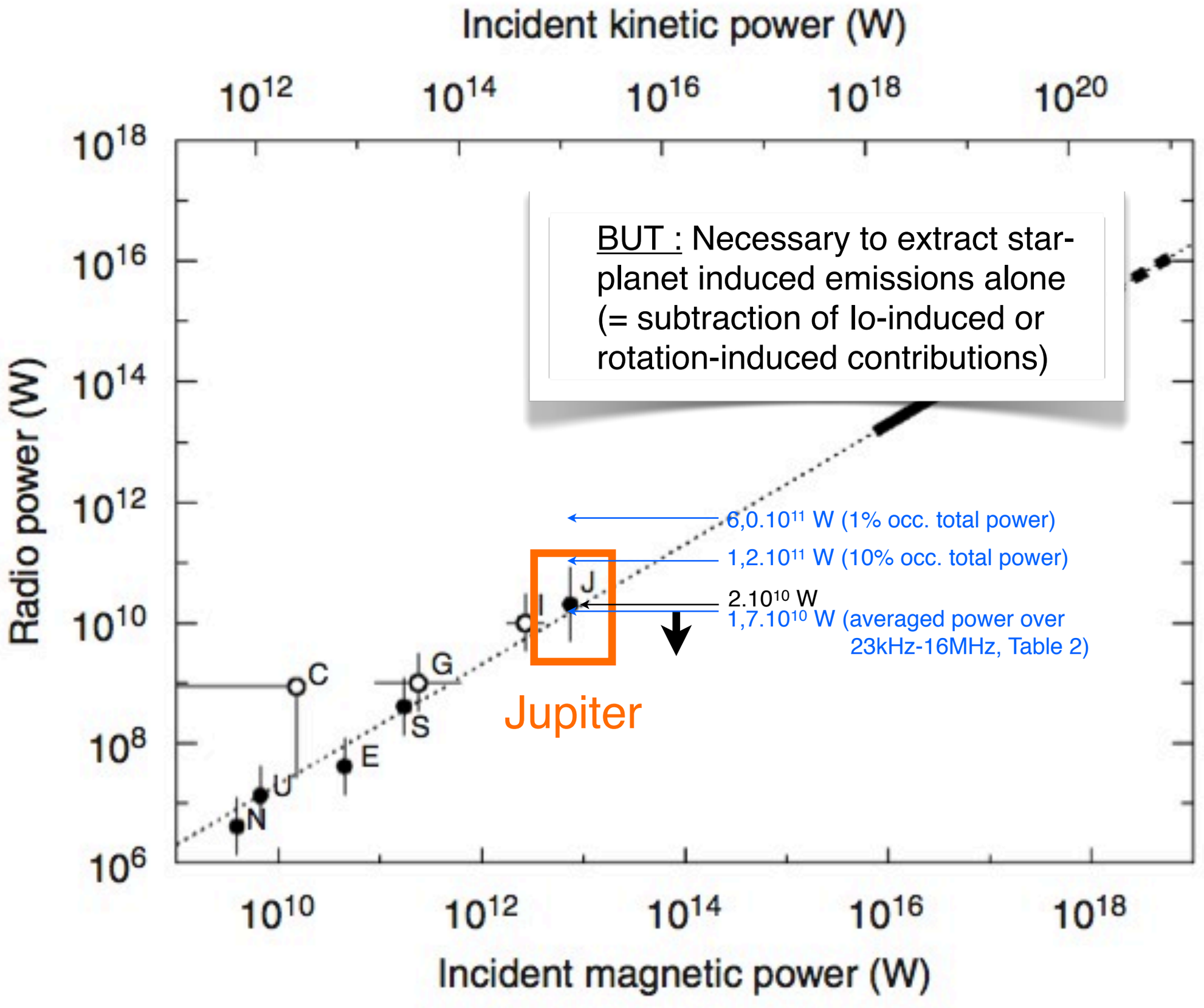

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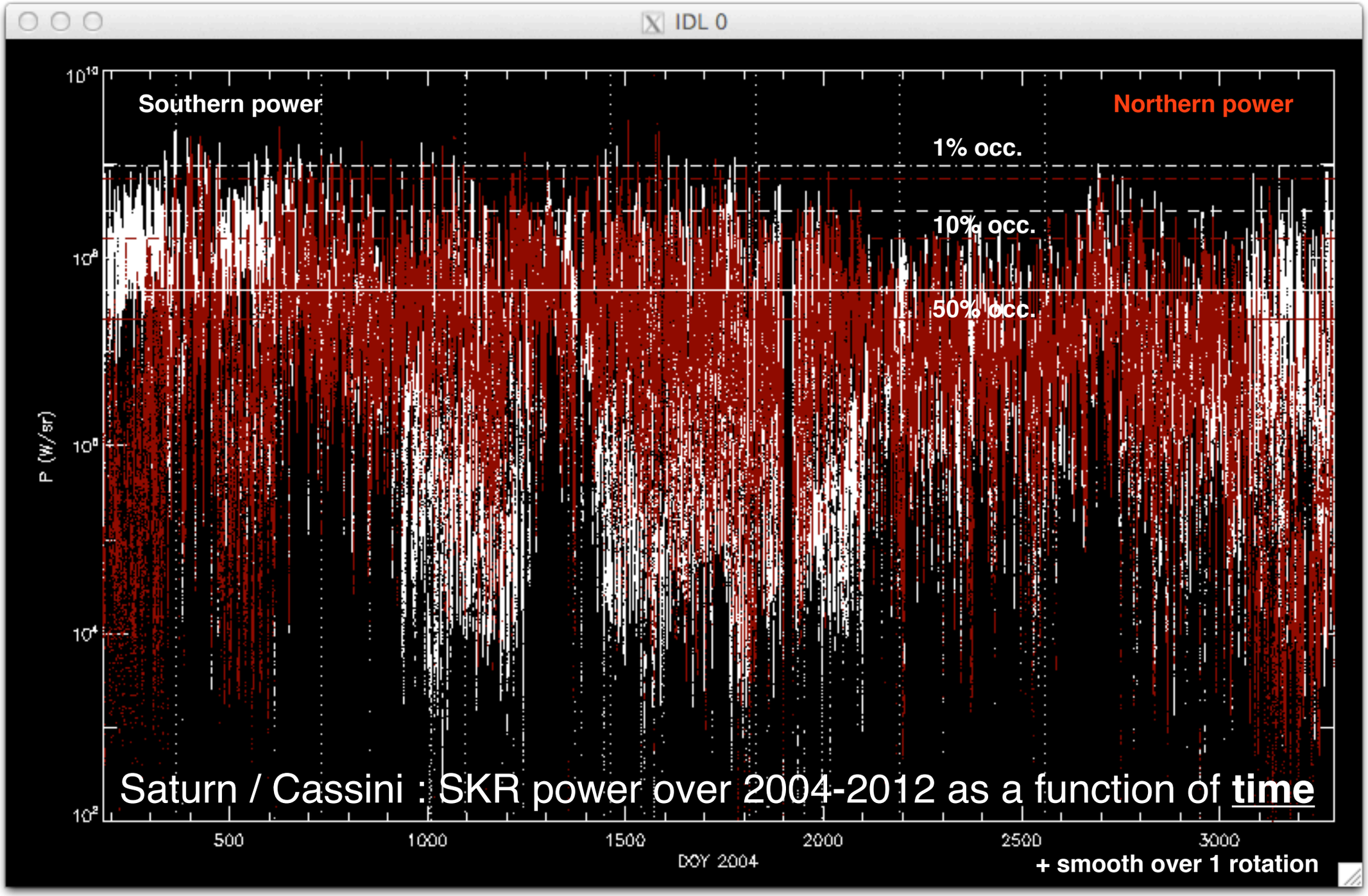


| | | 2004-2012 (here) |
|---|---|---|
| [3.5-1500kHz] power RH->LH | 50% occurrence : | 2,2->4,7.$10^7$ W/sr |
| | 10% occurrence : | 1,6->3,1.$10^8$ W/sr |
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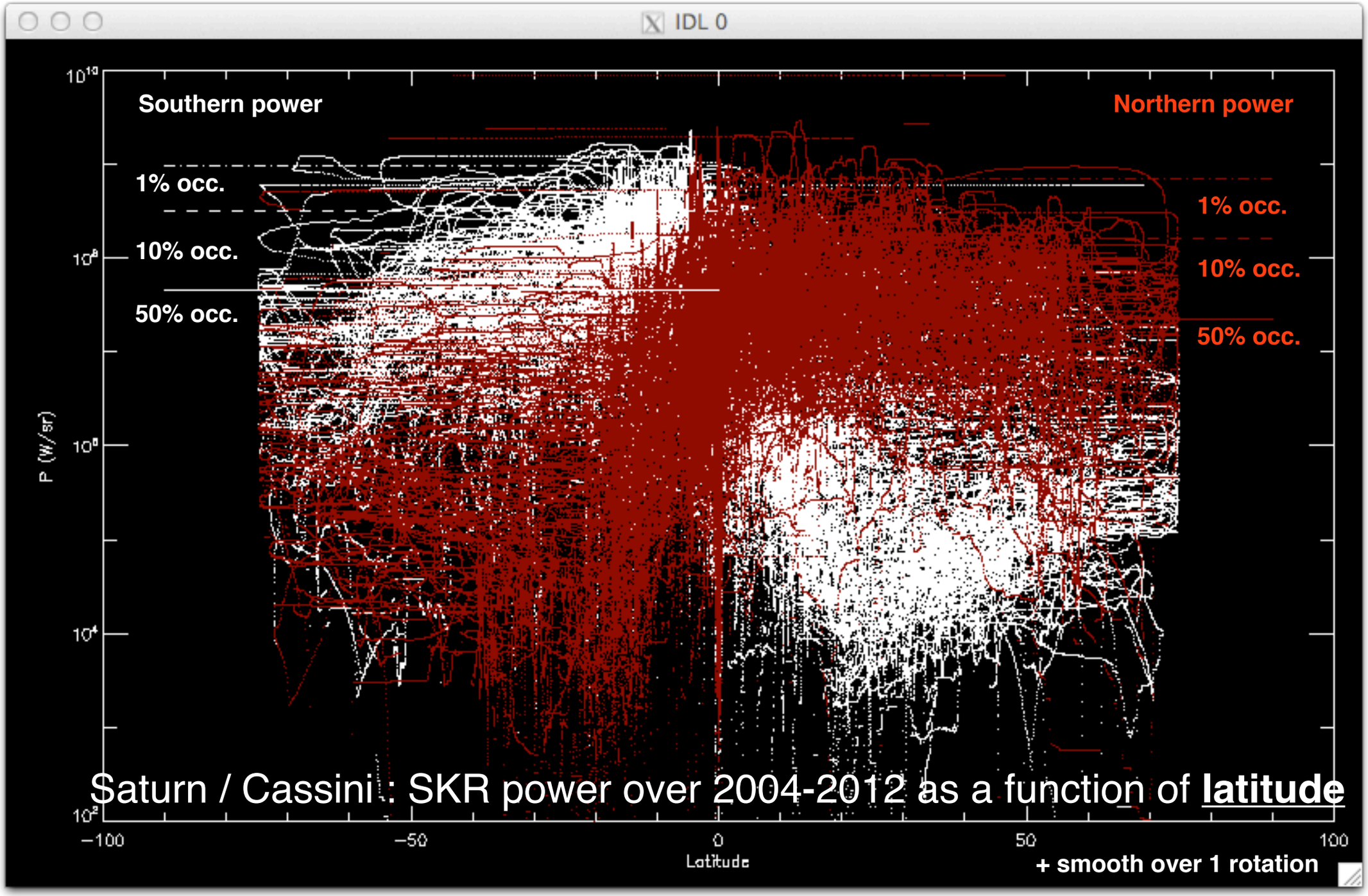


Saturn / Cassini : SKR power over 2004-2012 as a function of **latitude**

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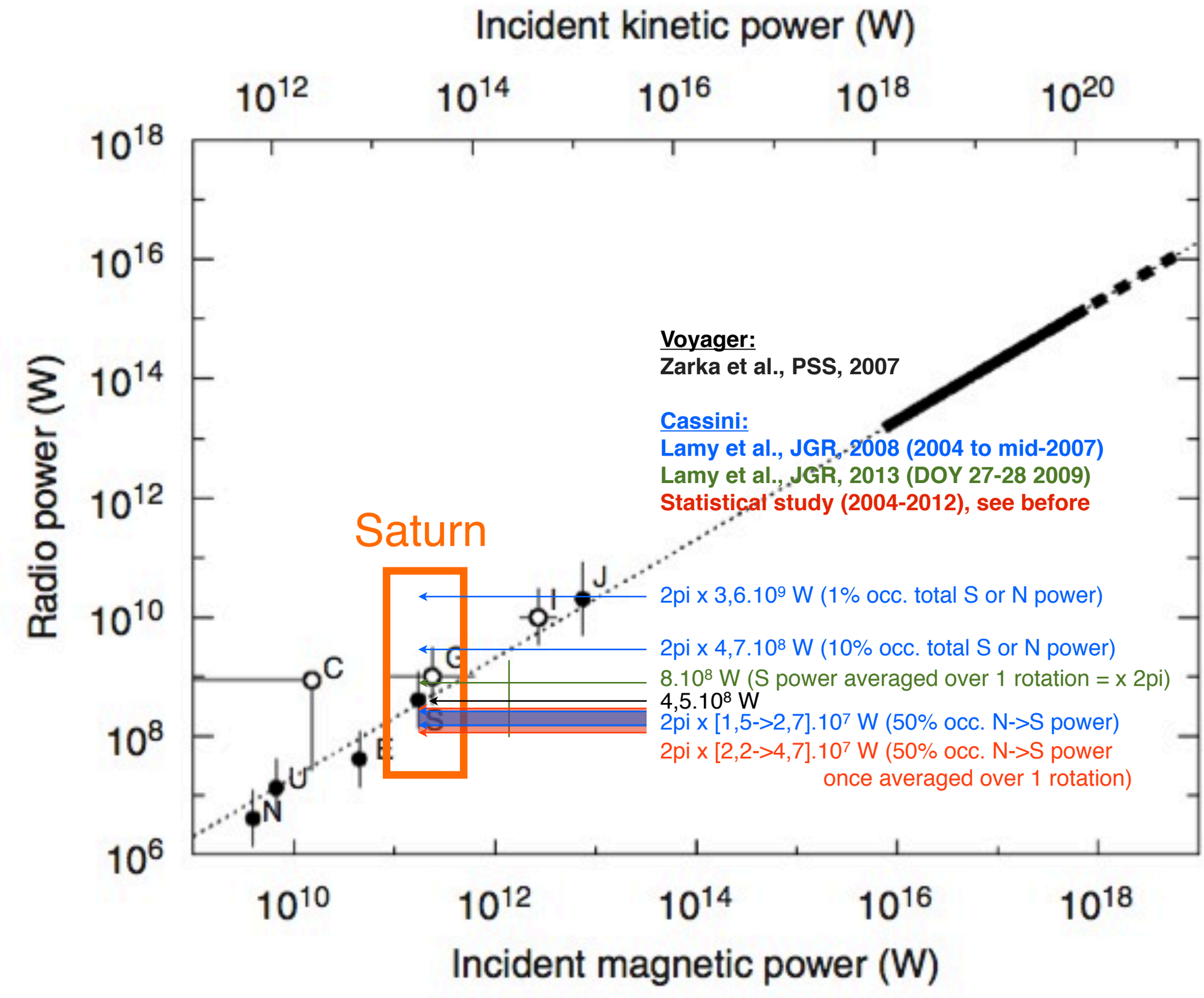

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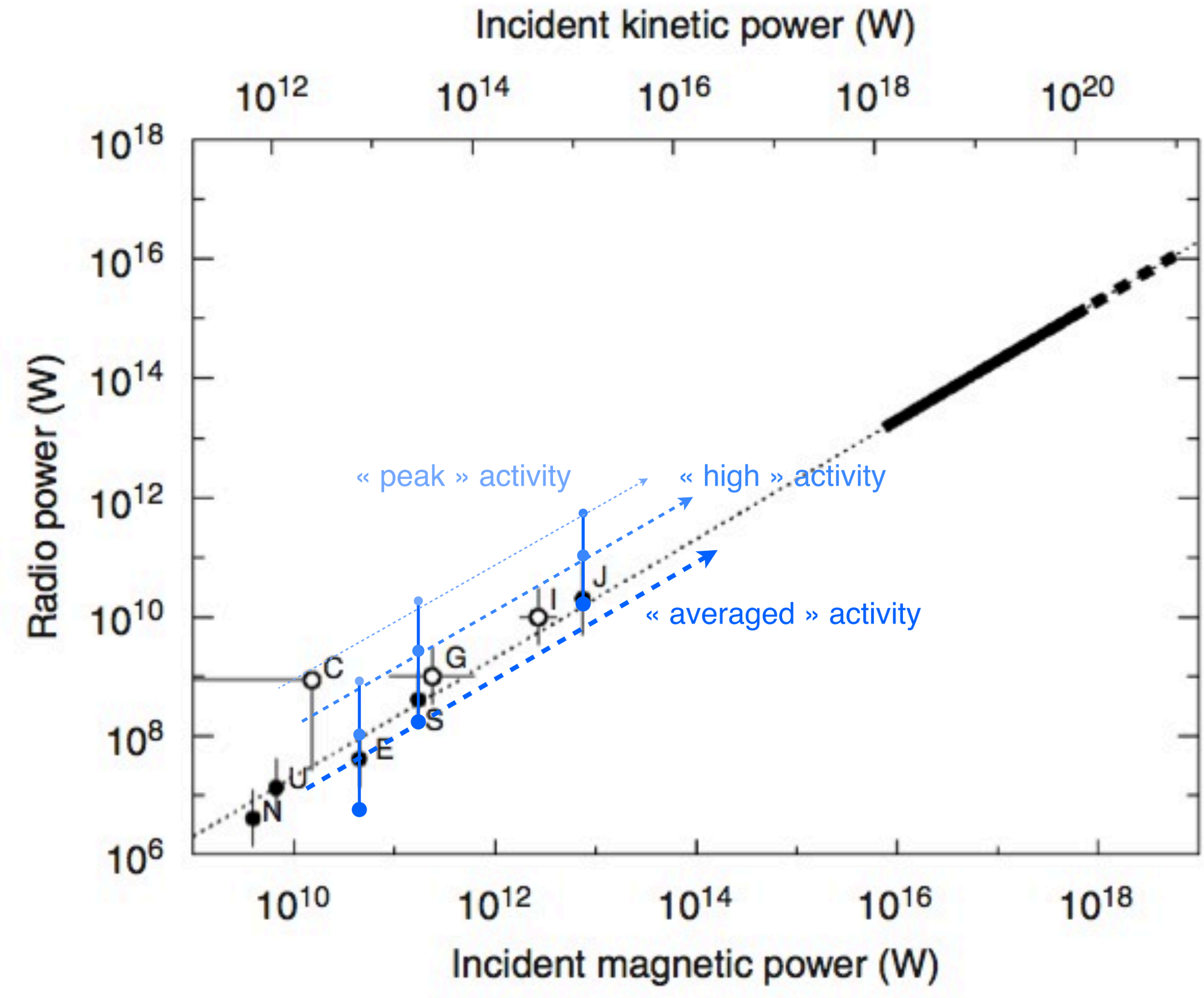
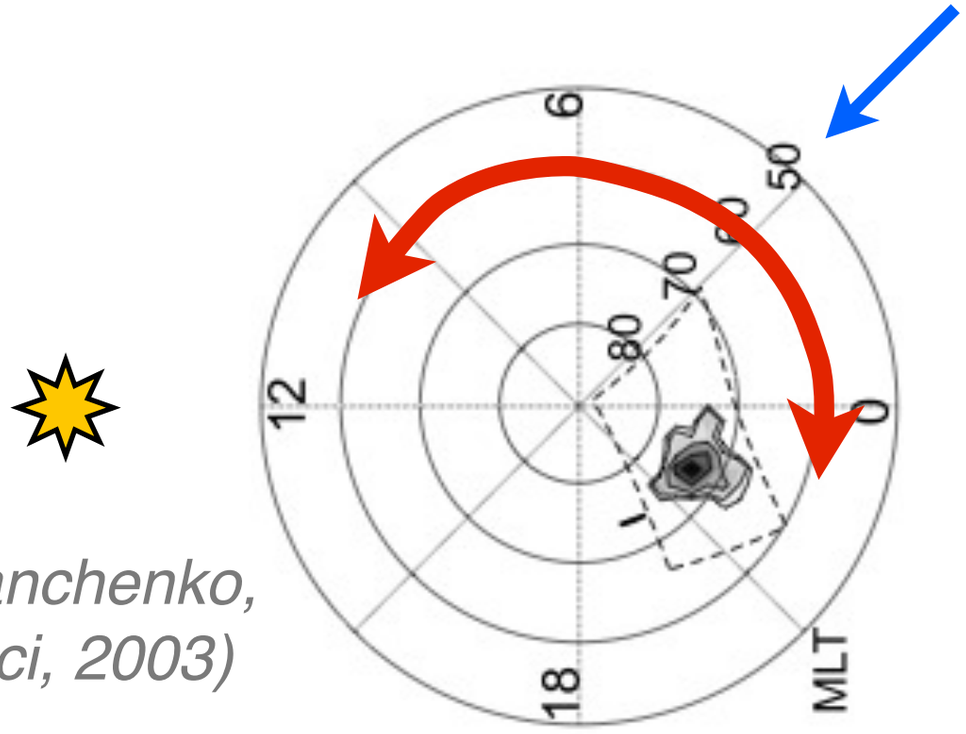
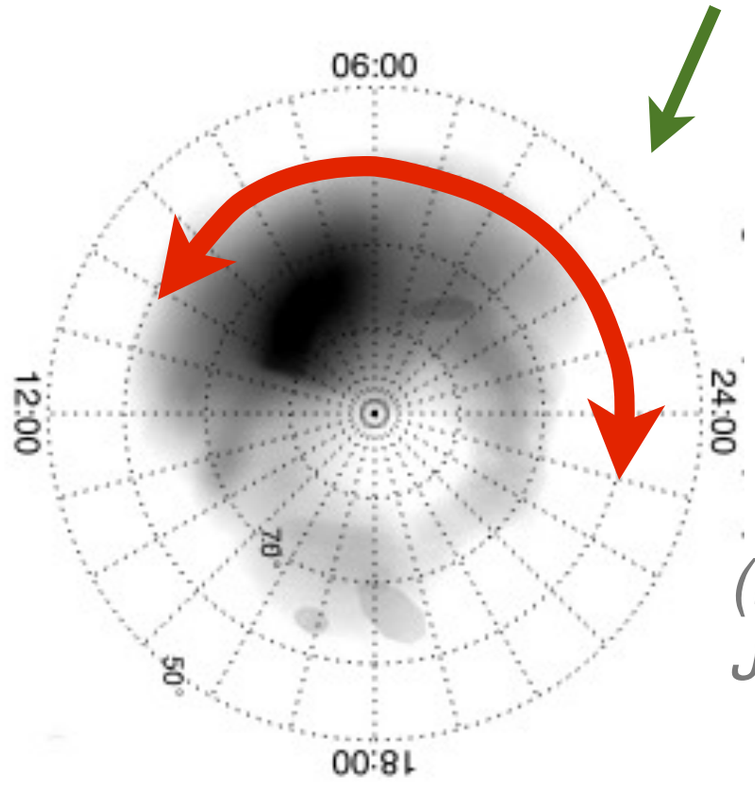


# Visibility of planetary radio emissions

NB : Radio emissions driven by star-planet interactions = controlled by solar wind convection
=> substorm activity through magnetotail reconnexions
=> intenses radio sources located from **~00:00 LT (Earth, Uranus)** to **~06:00 LT (Saturn)**




*(Panchenko, RSci, 2003)*

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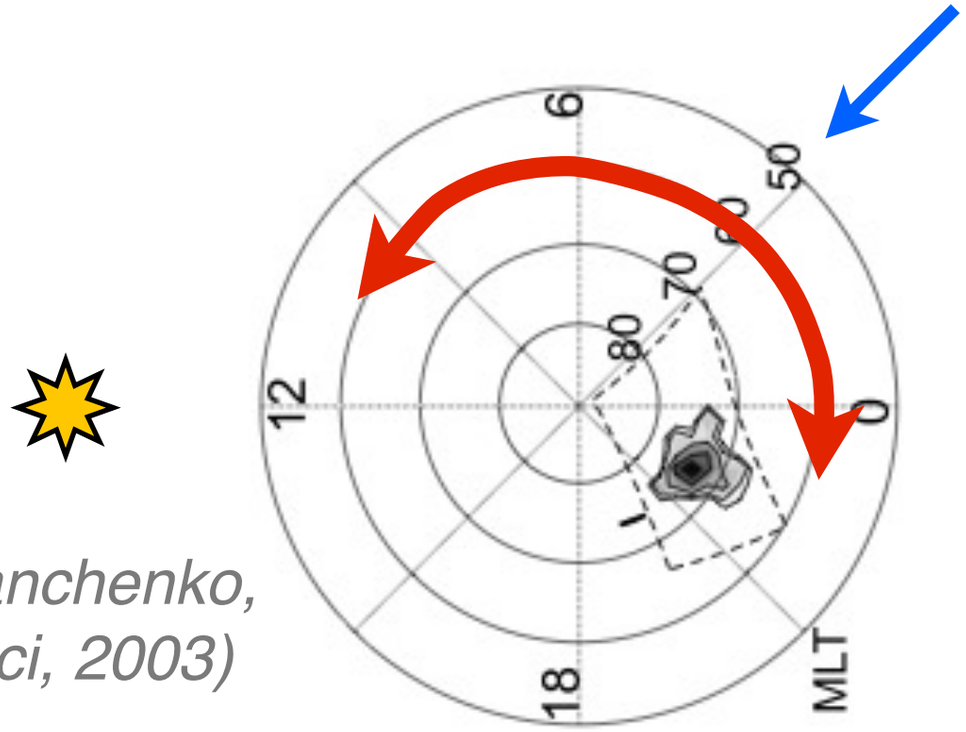


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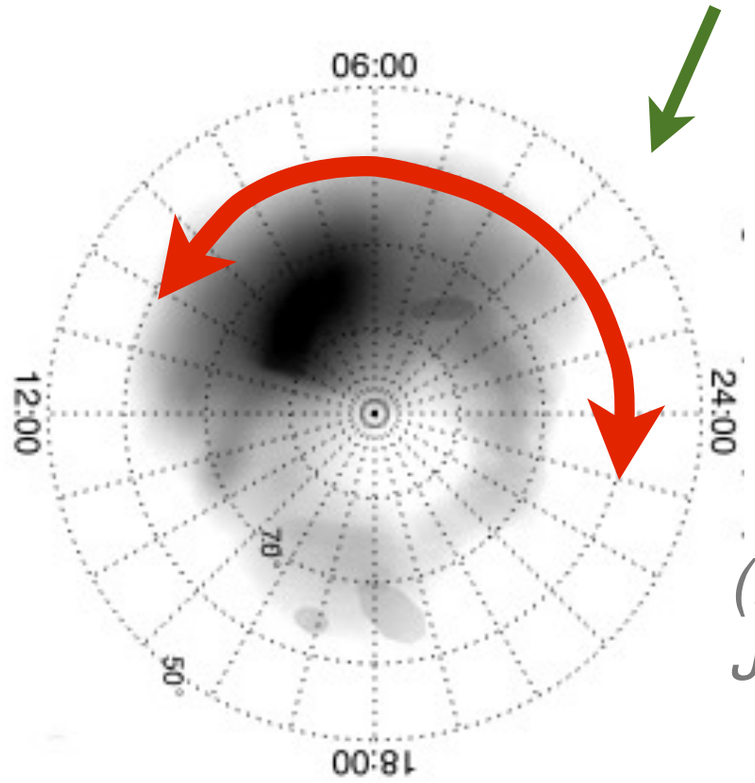


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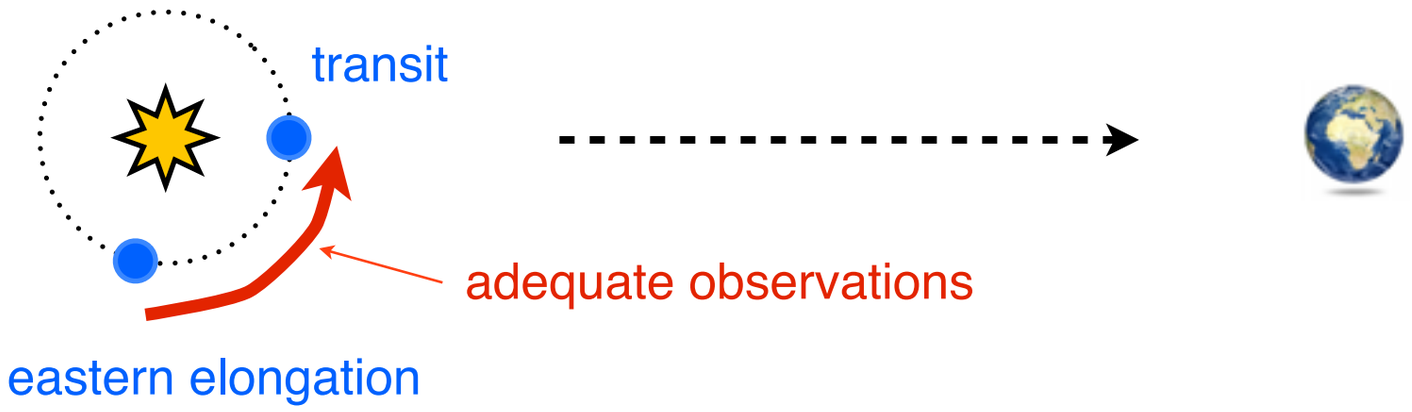

# Search for exoplanets with NenuFAR

Search for exoplanetary radio sources <u>in progress</u> :

(1) Various radiotelescopes : *beam forming and imaging*
- LWA : 10-88 MHz, ~10000 m², 2-8° field, obs. = Flux
- VLA : 74, 330 MHz, ~ 13000 m², obs. = 4 Stokes
- GMRT : 150, 235, 325 MHz, ~ 60000 m², 80-180" field, obs. = 4 Stokes
- UTR-2 : 10-32 MHz, ~150000 m² , ~10°x5° field, dual beam, obs. = Flux + lin. polar.

(2) LOFAR : 30-80 et 110-150 MHz, ~100000 m², ~10° field, obs. = 4 Stokes
- <u>2012 :</u> Prop. LC007 (PI : Zarka)
  + 30h / 6 targets
  + *imaging through interferometry with* 38 stations, 4 Stokes
  + Δf = 24 MHz over [26-62] MHz + Δt = 1s
- <u>2013 :</u> Prop. LC1_032 (PI : Zarka)
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  + $\Delta f$ = 24 MHz over [26-62] MHz + $\Delta t$ = 1s
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But no confirmed detection yet. Why? What can be improved?
- predicted power overestimated? => check scaling law + combine ≠ approaches
- few intense sources? => refine observational strategies (Figure of Merit, visibility, systematic observations < 10pc, survey of the Kepler FOV ...) ?
- few exoplanets observed so far, a few hours each => more and longer observations

# Search for exoplanets with NenuFAR

(3) NenuFAR ?

- high sensitivity, $A_{eff}$ ~ 70-80% $A_{eff\ LOFAR\text{-}LBA}$
- broadband LF array : 10-85MHz (> LOFAR-LBA and UTR-2)
- high t-f resolution

=> « Stand-alone » observations :

- possibility of long observing campaigns

(a) 2 full-band beams with max t-f resolution ($\Delta t \sim 1ms$, $\Delta f = 1kHz$)

(b) 256 pixel (1°-0.1”) maps within a broad FOV (8-60°), with $\Delta t = 1s$

- *test of (a) vs (b) during commissioning on a faint source ?*

=> Combined with LOFAR :

- maximal sensitivity
- better high resolution imaging but limited t-f resolution

# Conclusions

No detection yet.

Predictions : good time to update existing scaling laws and refine observational strategies

NenuFAR is a unique tool for this ongoing search (quest) : multiple useful observational modes

- Maximum distance for Nσ sky-limited detection of a source ζ x Jupiter :

| $\zeta = 10^5$ | $b\tau = 10^6$ *(1 MHz, 1 sec)* | | $b\tau = 2\times10^8$ *(3 MHz, 1 min)* | | $b\tau = 4\times10^{10}$ *(10 MHz, 1 hour)* | |
|---|---|---|---|---|---|---|
| | f = 10 MHz | f = 100 MHz | f = 10 MHz | f = 100 MHz | f = 10 MHz | f = 100 MHz |
| $A_e = 10^4$ m$^2$ (~NDA) ! | 1 | 16 | 3 | 59 | 13 | 220 |
| $A_e = 10^5$ m$^2$ (~UTR-2, LOFAR) | 3 | 50 | 11 | 190 | 40 | 710 |
| $A_e = 10^6$ m$^2$ (~SKA) | 9 | 160 | 33 | 600 | 130 | 2200 |

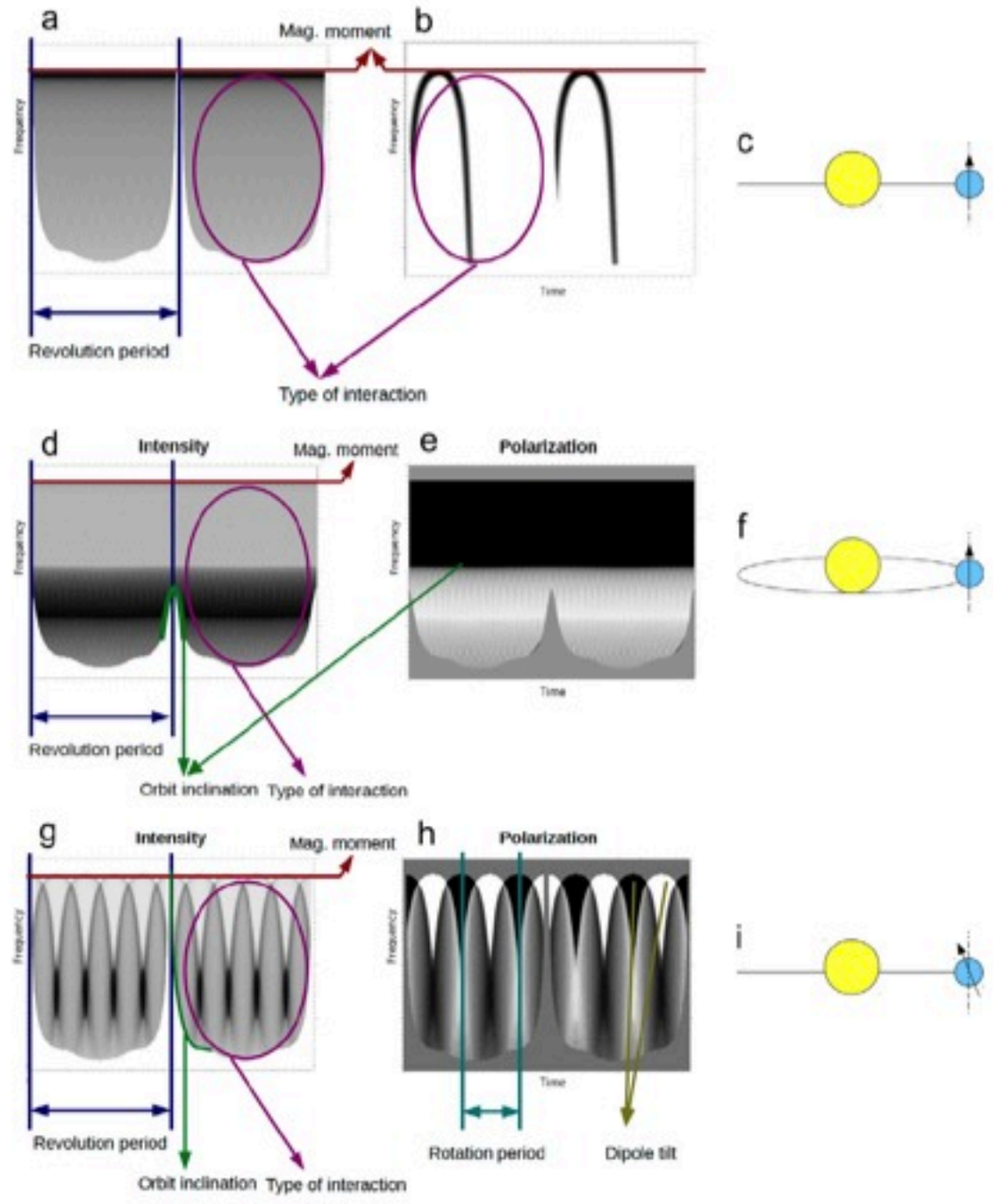
(distances in parsecs)

- turbulence → intermittency [Chian et al., 2010]
- scintillations → radio flux x100 ? [Farrell et al., 1999]

# Search for exoplanets with NenuFAR

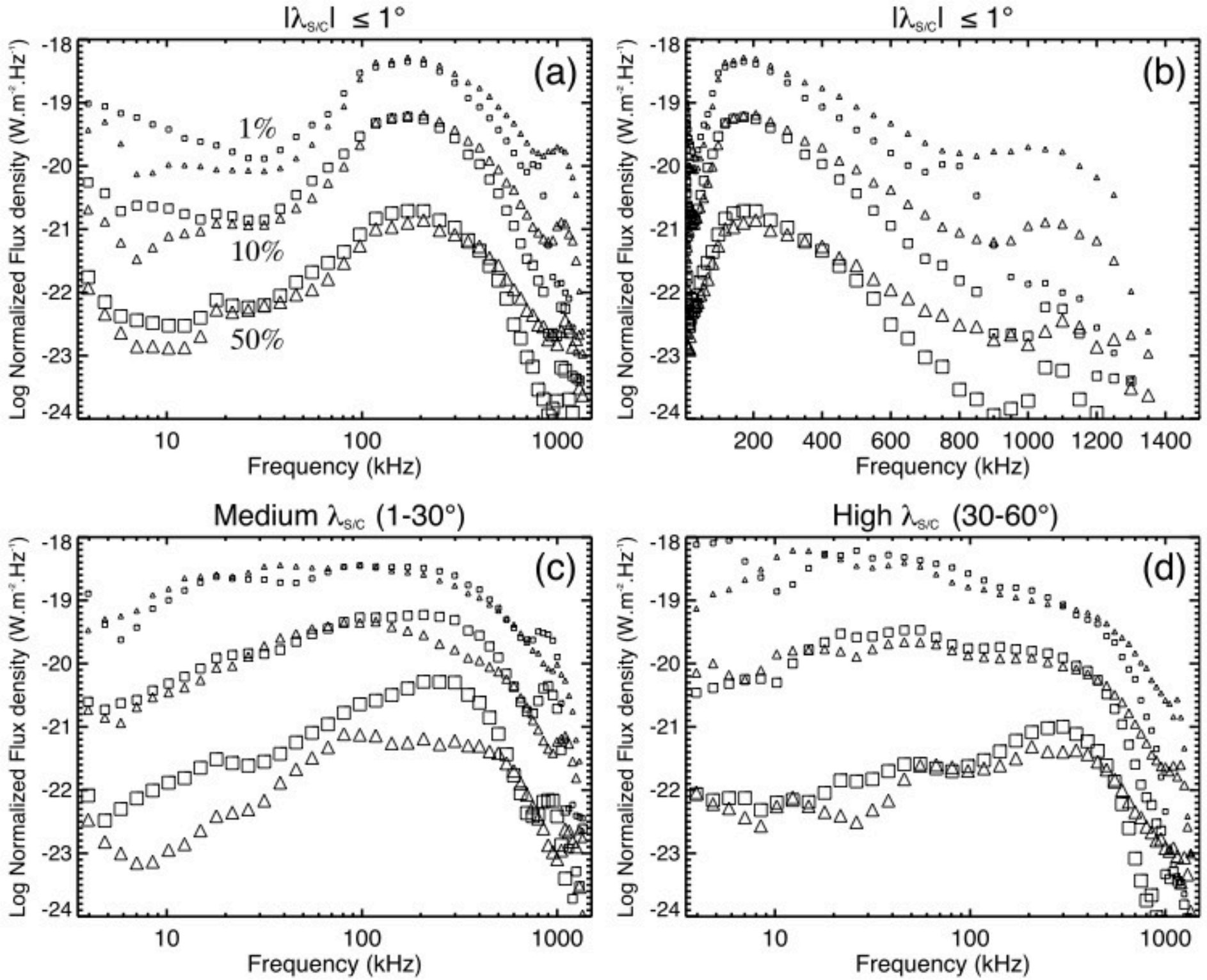
Constraints on exoplanets :

- rotation period
- amplitude/inclination of the planetary magnetic field
- orbit declination
- magnetospheric dynamics (whenever the driver : rotation, stellar wind, others...)




(Hess et Zarka, 2011)

# Saturn


|λS/C| ≤ 1°
(a)
1%
10%
50%
Log Normalized Flux density (W.m-2.Hz-1)
-18
-19
-20
-21
-22
-23
-24
10
100
1000
Frequency (kHz)
|λS/C| ≤ 1°
(b)
200
400
600
800
1000
1200
1400
Frequency (kHz)
Medium λS/C (1-30°)
(c)
High λS/C (30-60°)
(d)

# Planetary magnetic field decay ?

- Radio detection requires f > 10 MHz , i.e. $B_{max\text{-}surface} \geq 4$ G
- Jupiter : $M = 4.2\ G.R_J^3$, $B_{max\text{-}dipole} = 8.4$ G, $B_{max\text{-}surface} = 14$ G, $f_{max} = 40$ MHz
- Spin-orbit synchronisation (tidal forces) → ω↓
- But $M \propto \omega^{\alpha}$ with $\frac{1}{2} \leq \alpha \leq 1$ → M↓ (B decay) ?

- Internal structure + convection models

→ self-sustained dynamo → M could remain ≥ a few $G.R_J^3$

UPPER LIMIT OF MAGNETIC FIELDS IN HOT JUPITERS

| Planet | $M$ ($M_J$) | $P_{orb}$ (days) | $R$ ($R_J$) | $M_D$ (G m$^3$) | $B_s$ (G) |
|---|---|---|---|---|---|
| HD 179949b[a] ..... | 0.84 | 3.093 | 1.3 | $1.1 \times 10^{24}$ | 1.4 |
| HD 209458b ..... | 0.69 | 3.52 | 1.43 | $0.8 \times 10^{24}$ | 0.8 |
| $\tau$ Boo b[a] ..... | 3.87 | 3.31 | 1.3 | $1.6 \times 10^{24}$ | 2 |
| OGLE-TR-56b ..... | 0.9 | 1.2 | 1.3 | $2.2 \times 10^{24}$ | 2.8 |

[Sanchez-Lavega, 2004]