Exoplanets

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- A brief introduction about exoplanets
- Radio observations
- Theoretical predictions
  - planetary magnetospheric radio emissions
  - energy sources
  - scaling laws
  - extrapolation to exoplanets
- Ongoing observations
- Related & Future observations

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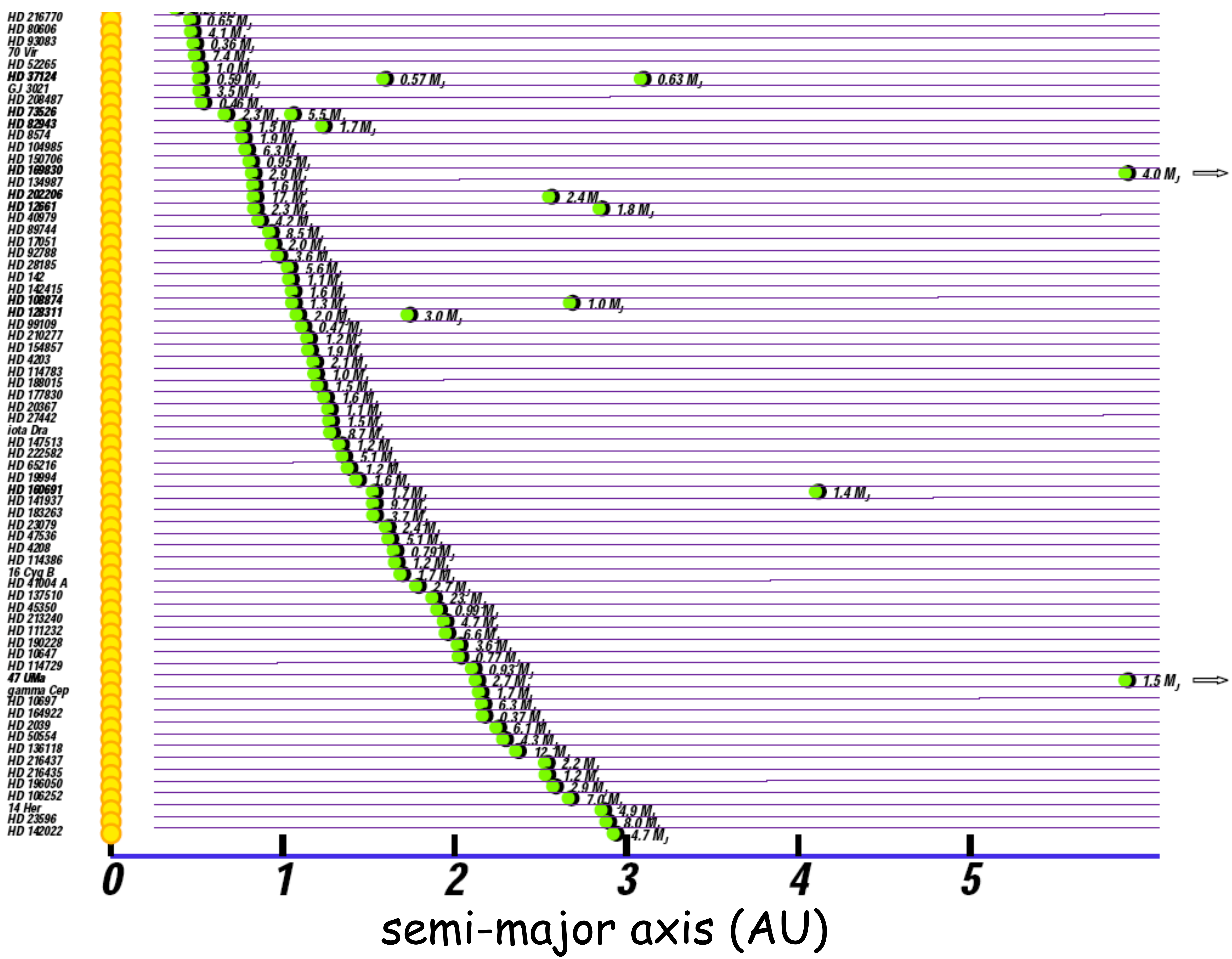
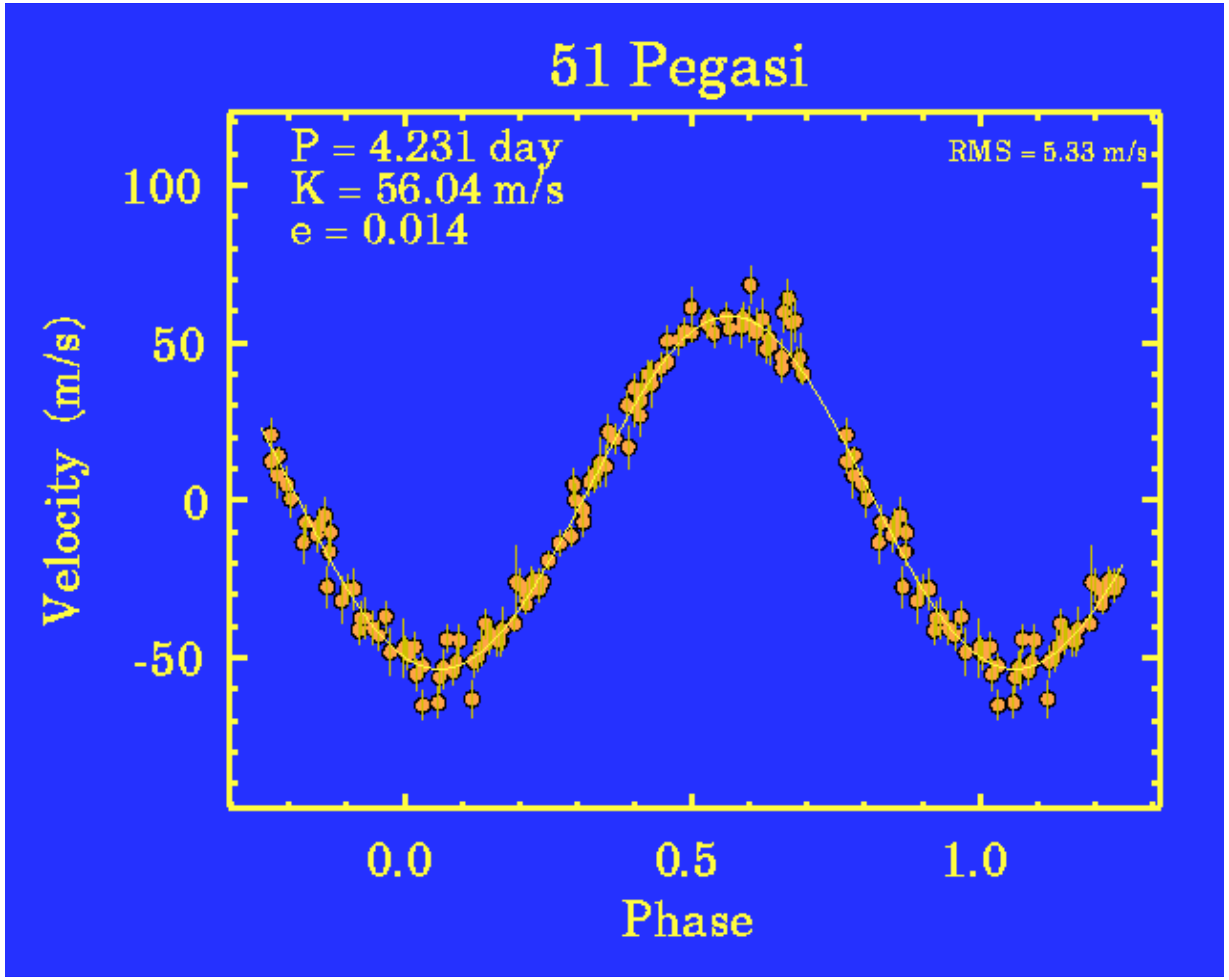
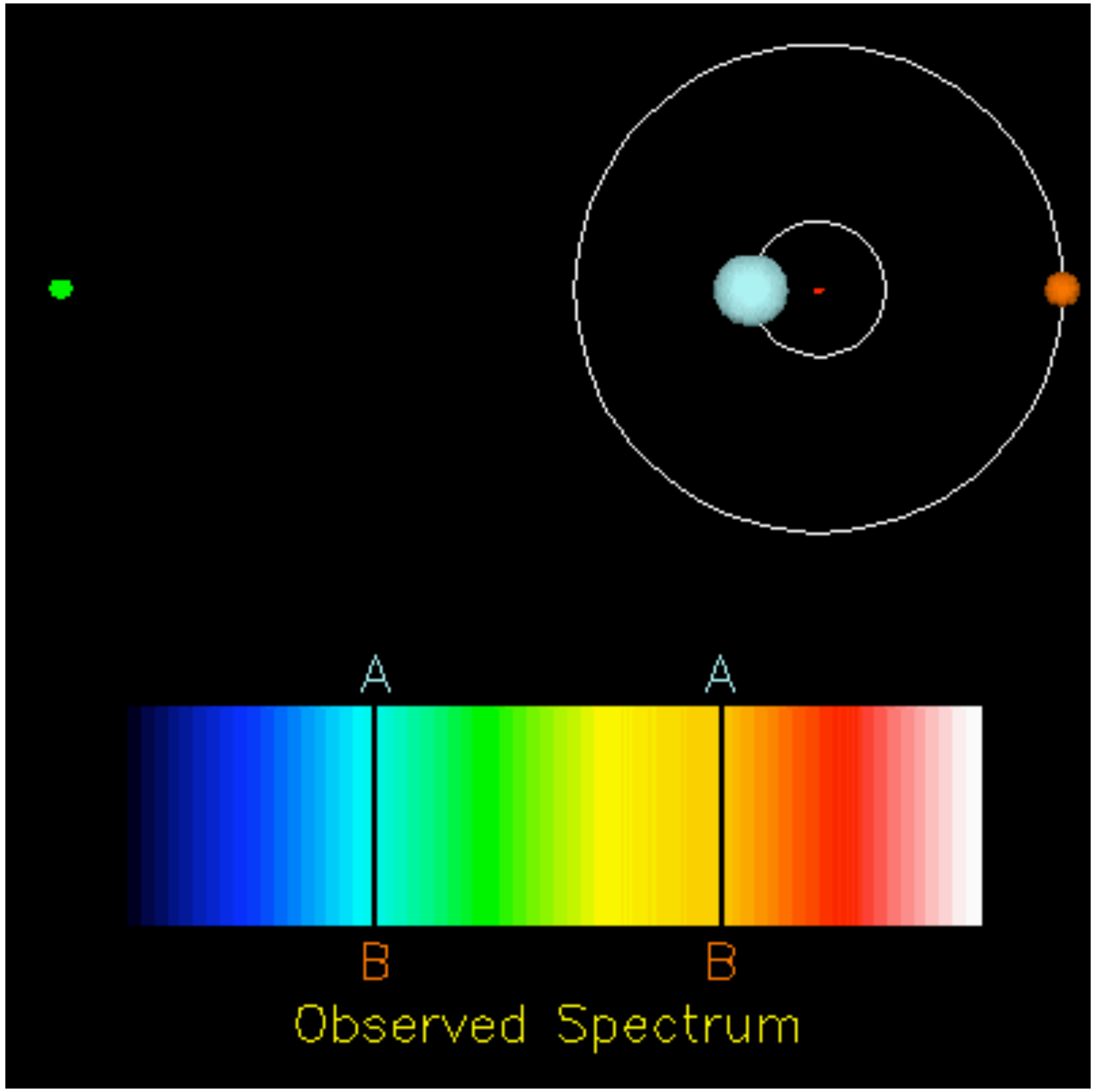
~280 exoplanets in ~240 systems

[www.obspm.fr/planets]



mostly detected via radial velocity measurements since 1995

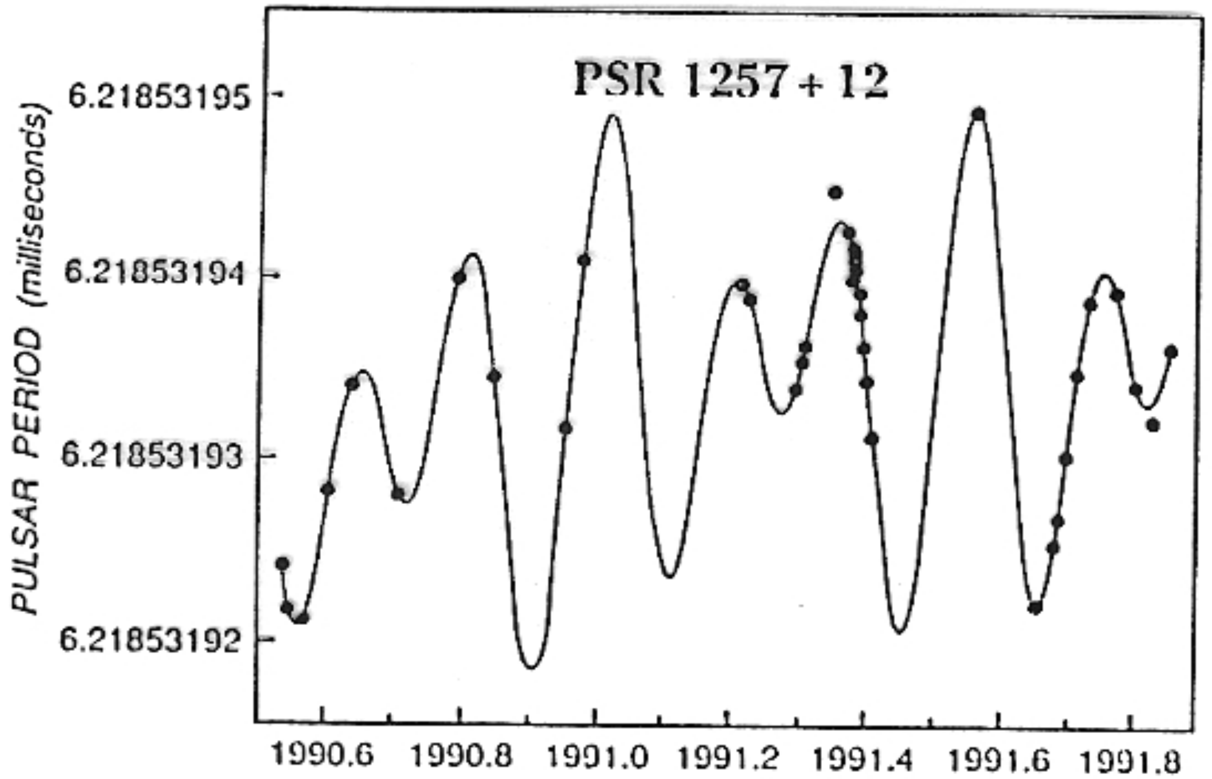




[Mayor & Queloz, 1995]

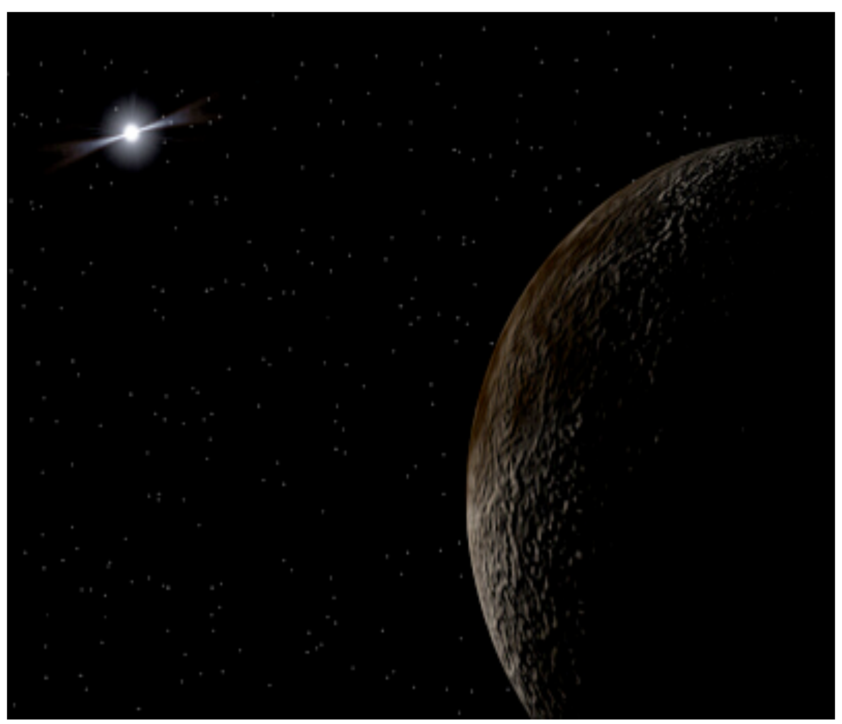
bias favouring large m_p

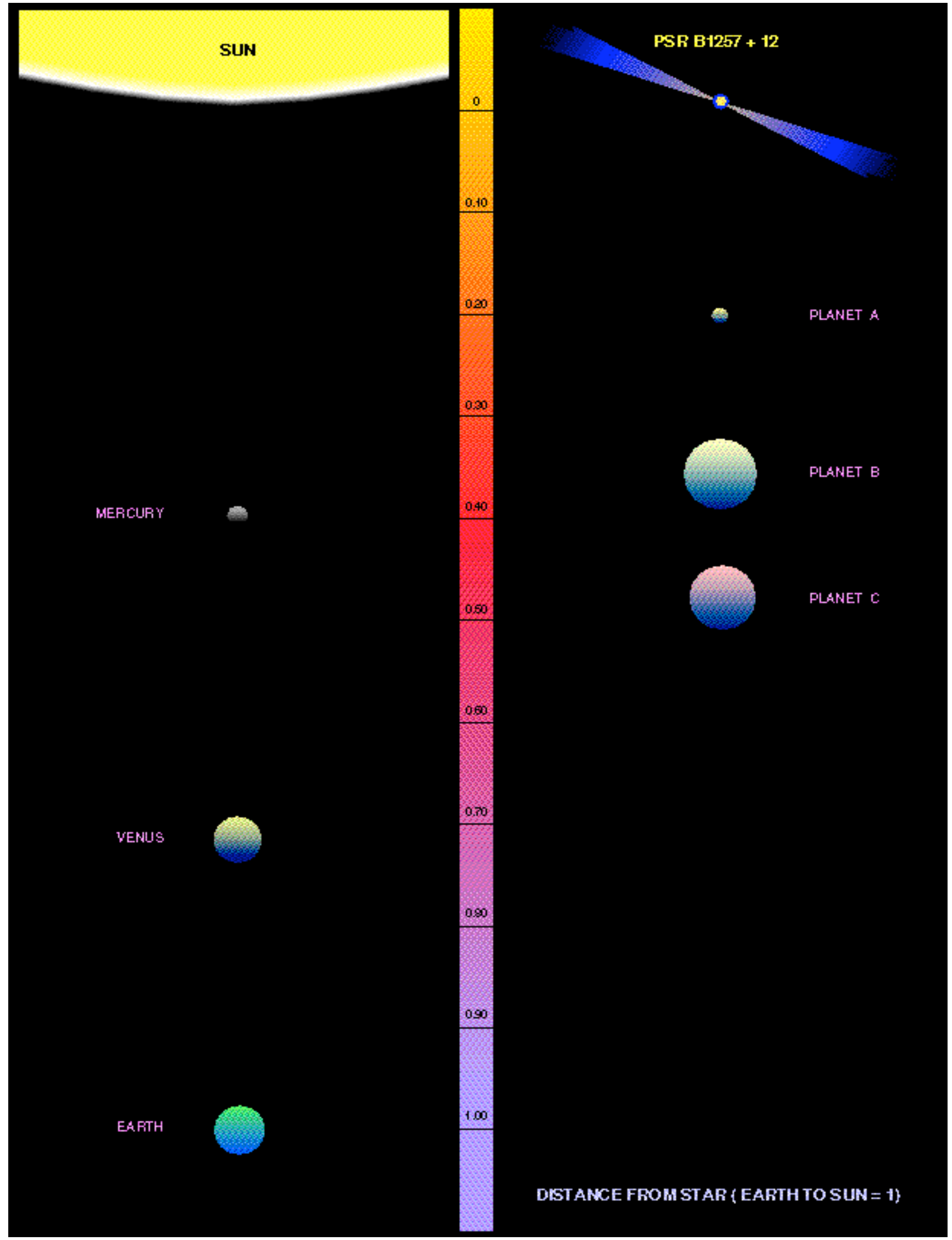
actually since 1992 !



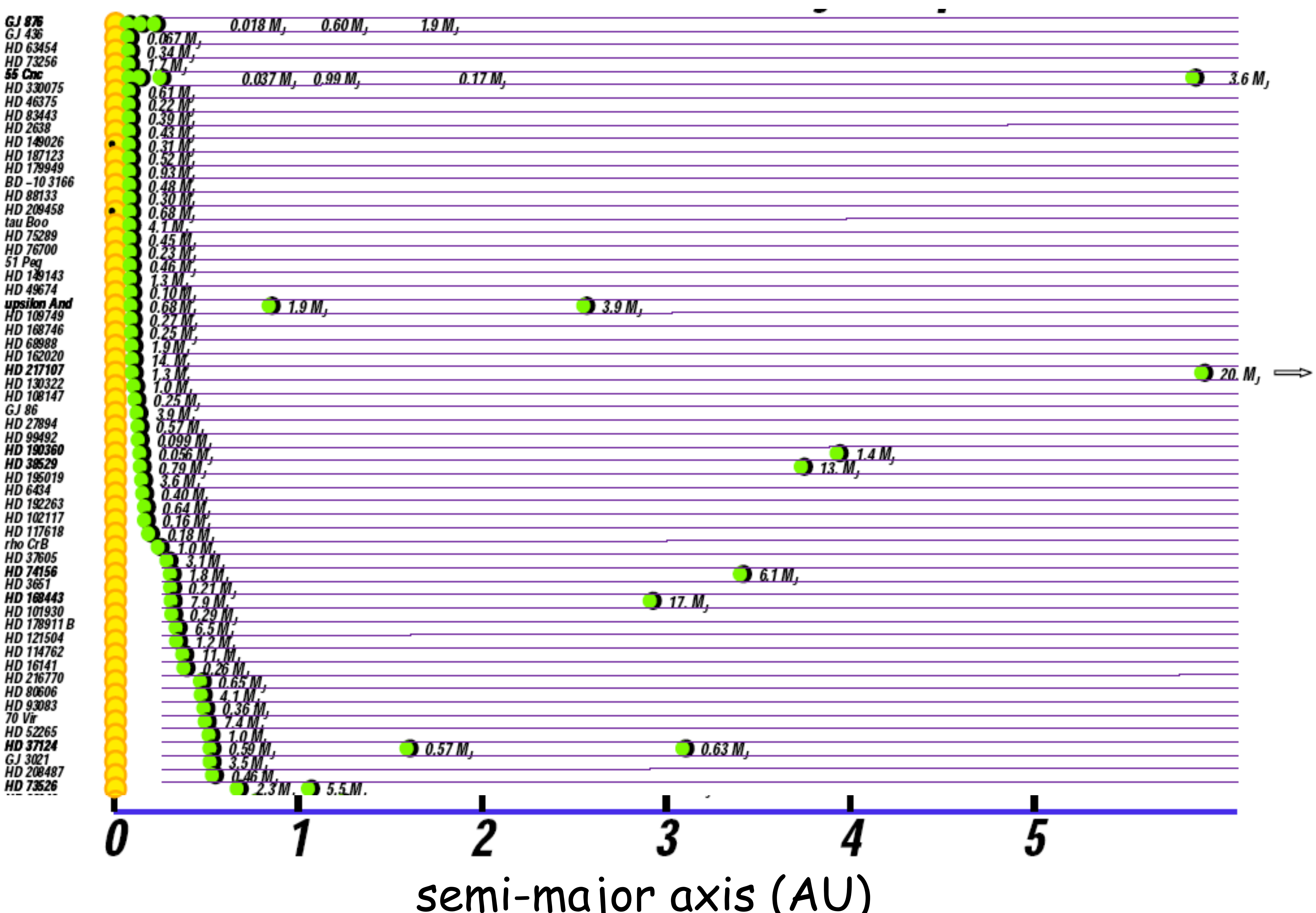
M ($m_\oplus$)	a (AU)	period (d)
0.015	0.19	25.34
3.4	0.36	66.54
2.8	0.47	98.22

[Wolcszan, 1992]

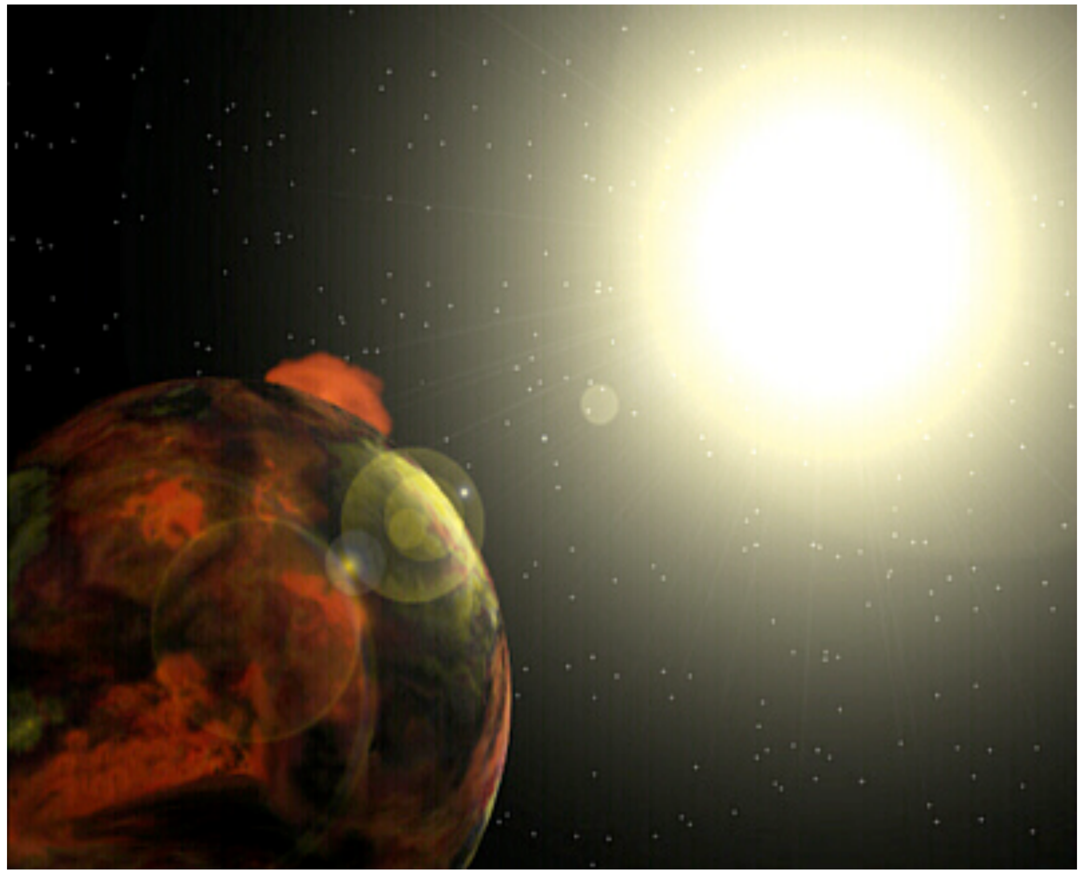


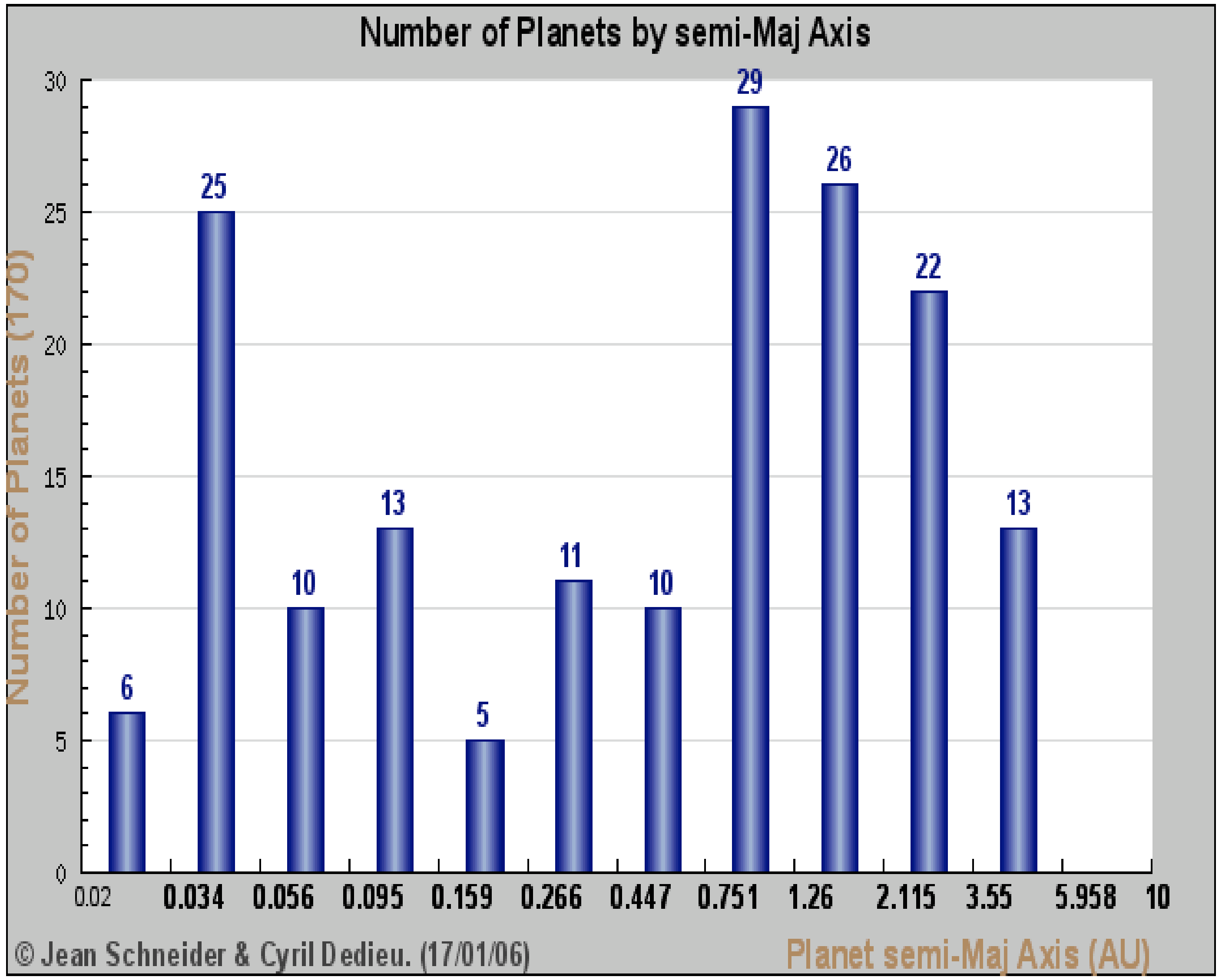


~20% of "Hot Jupiters" at ≲0.05 AU = 10 Rs



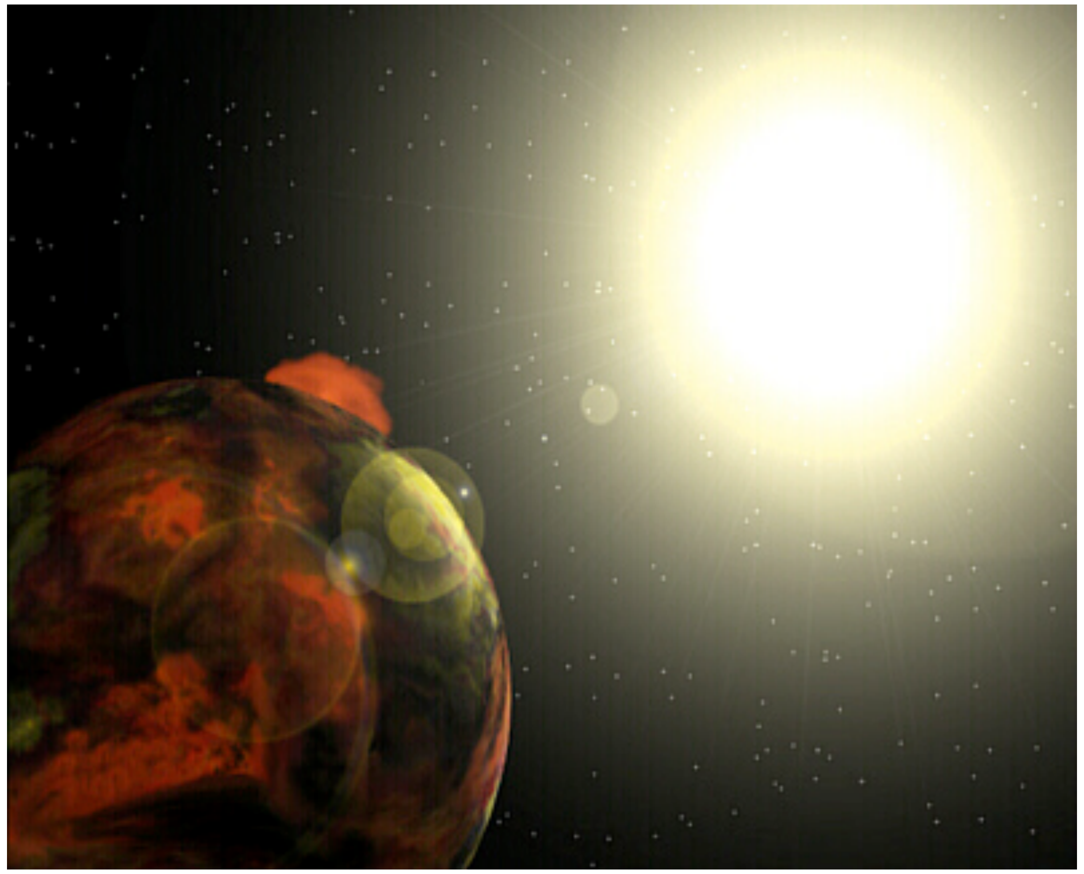
Hot Jupiters

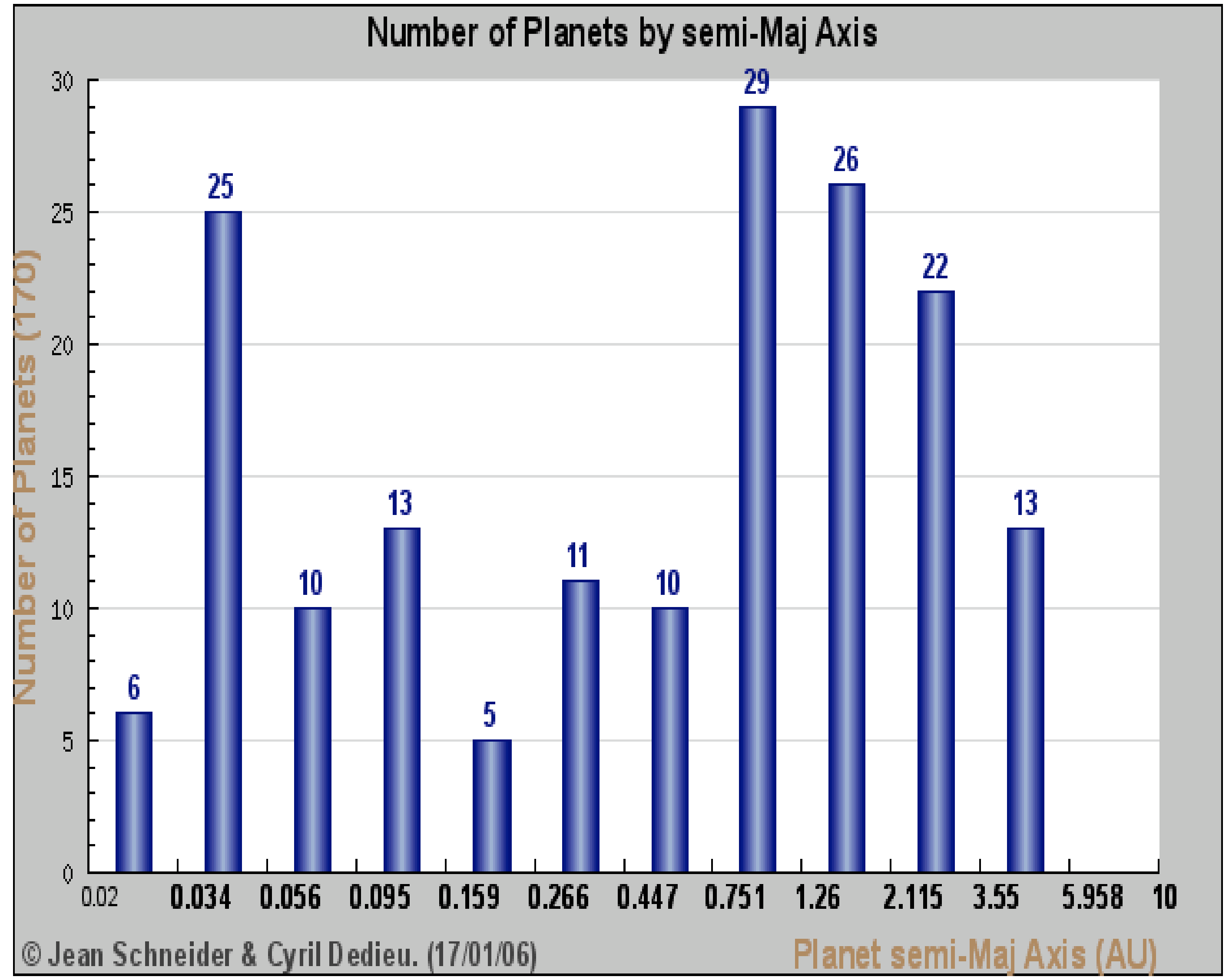




- T > 1000 K → non-local formation
- Bimodal distribution of semi-major axes
  → 2 types of objects and mechanisms

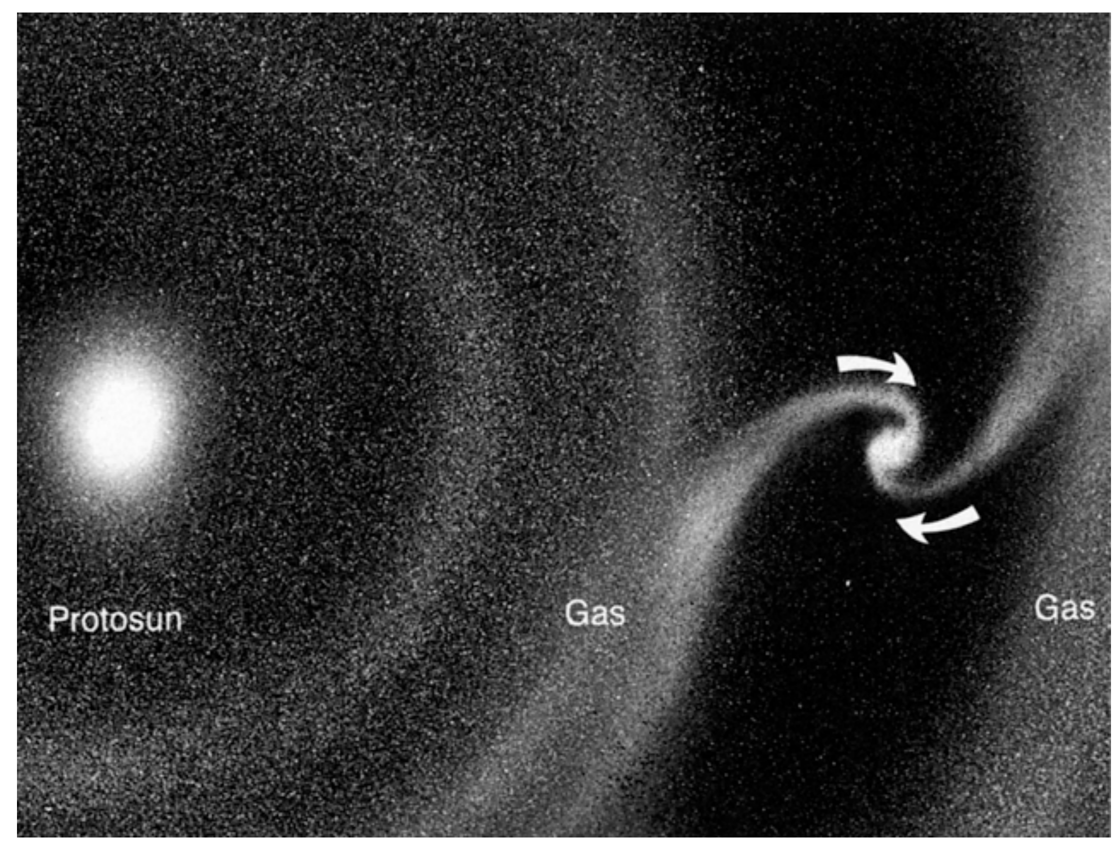
Hot Jupiters



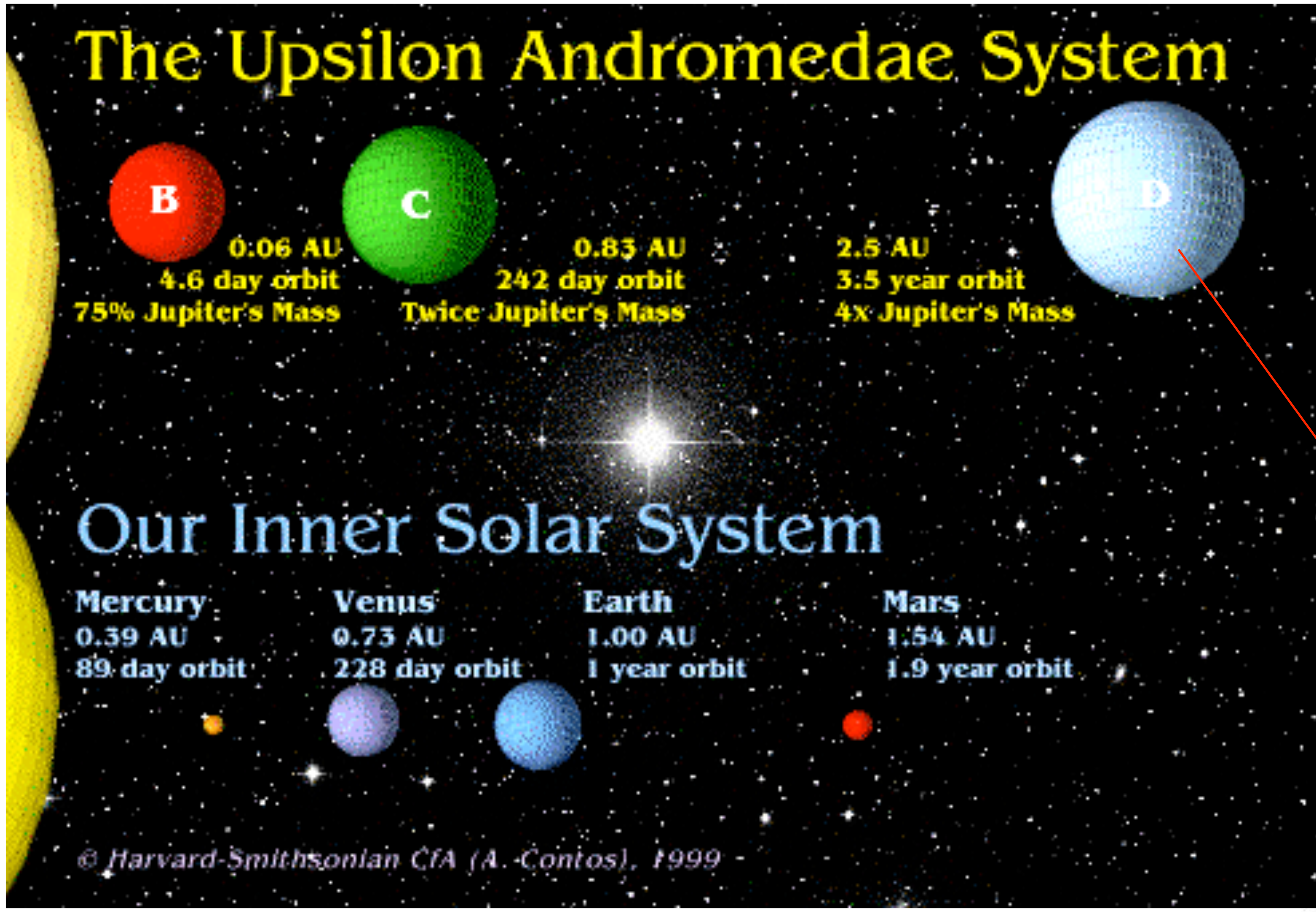


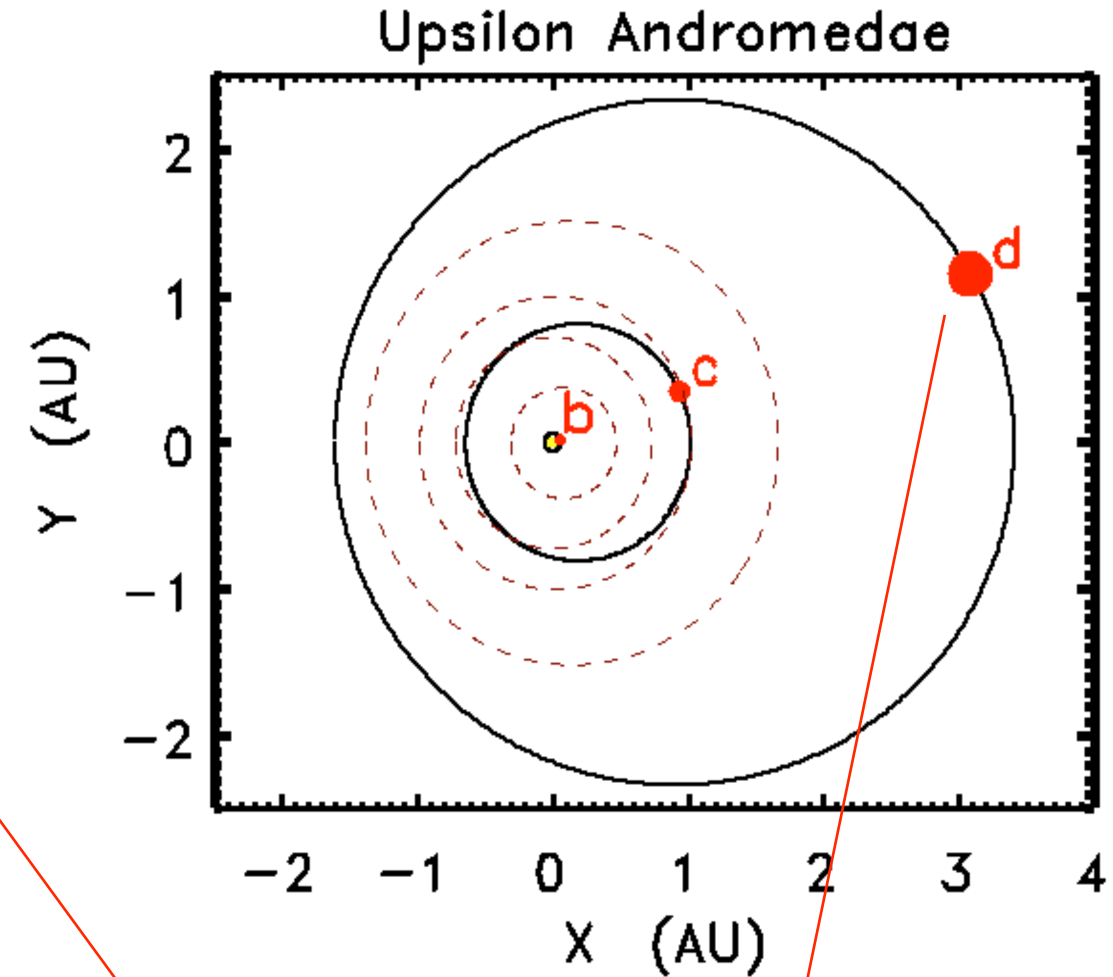
- T > 1000 K → non-local formation
- Bimodal distribution of semi-major axes
  → 2 types of objects and mechanisms

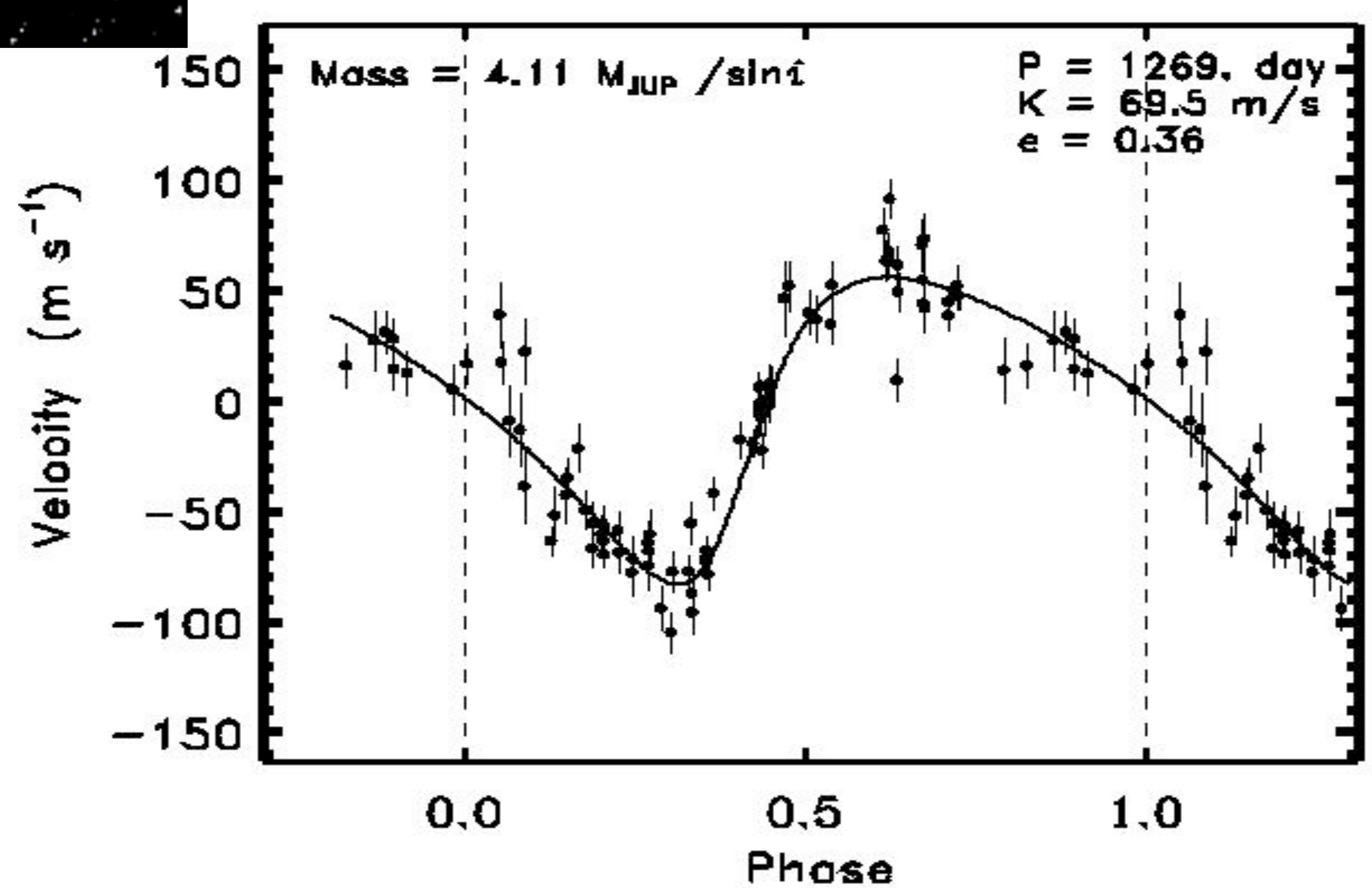
→ Migration



Radial velocities → measurement of $m_p \times \sin(i)$, a, P, e, Φ







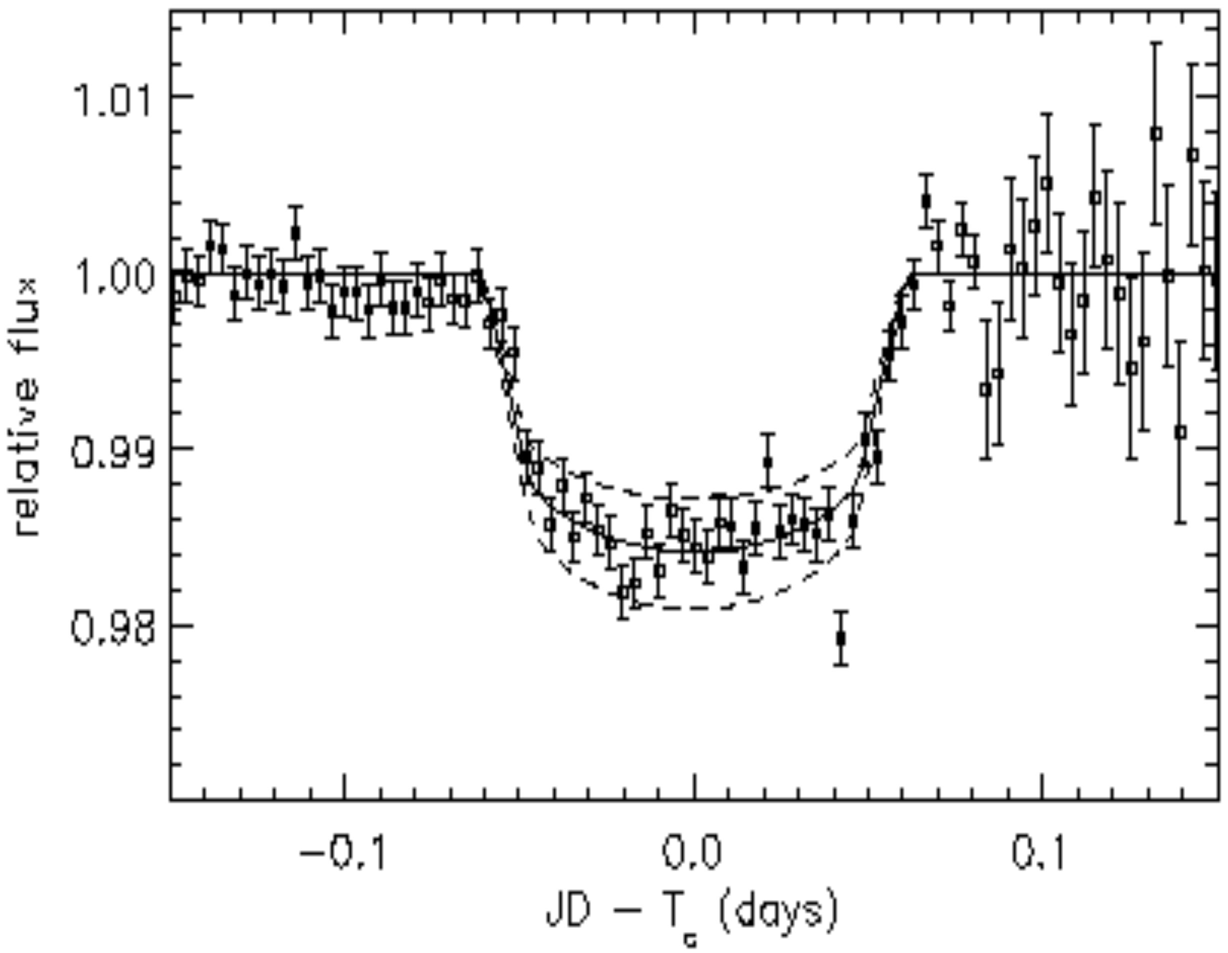
	m (M_J)	a (AU)	P (d)
b	0.71	0.059	4.61
c	2.11	0.83	241.2
d	4.61	2.5	1266.6

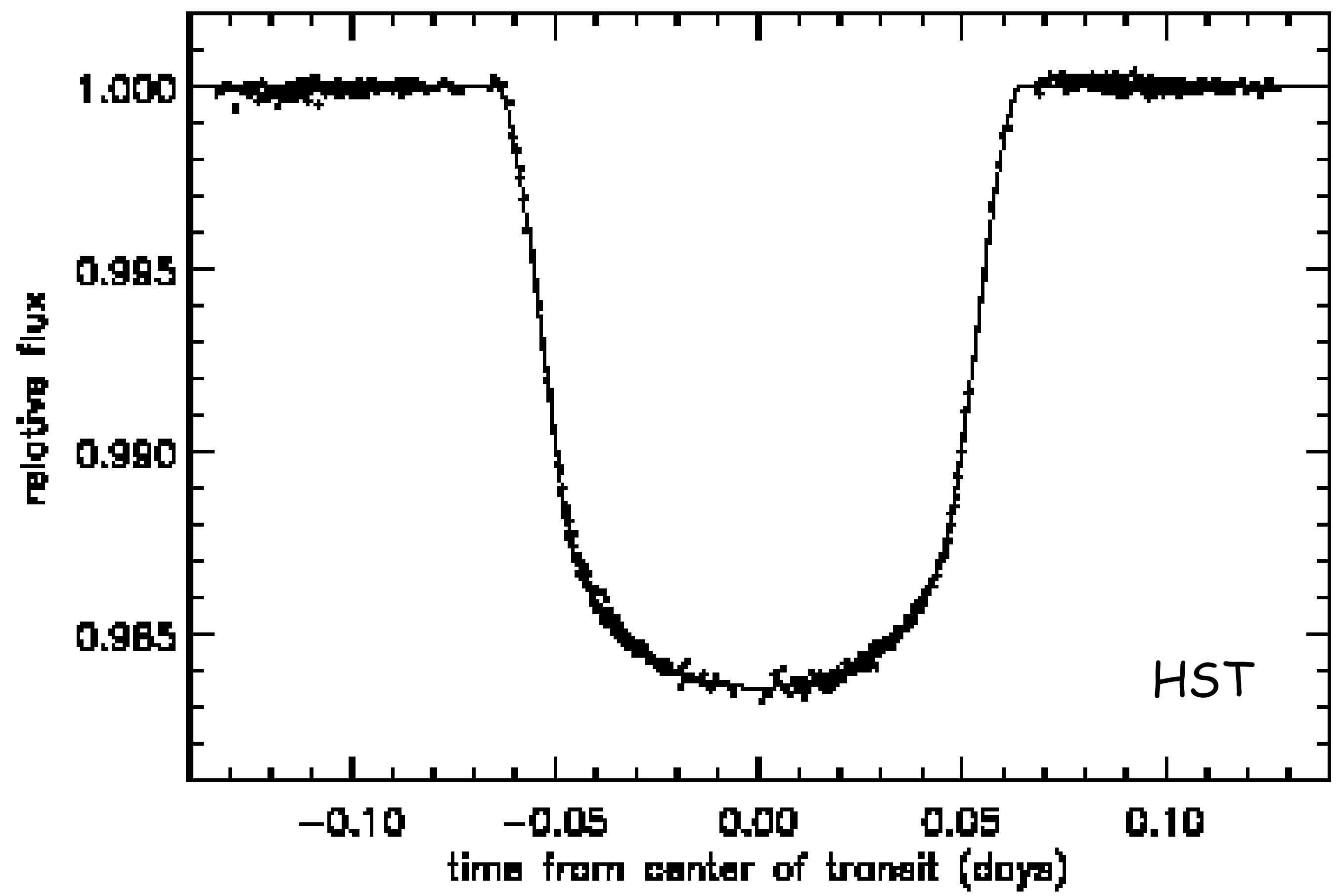
Transits

→ 1^{st} = HD209458b [Charbonneau et al., 2000]

m_p = 0.69 +/- 0.05 M_{jup}

R_p = 1.347 +/- 0.06 R_{jup}





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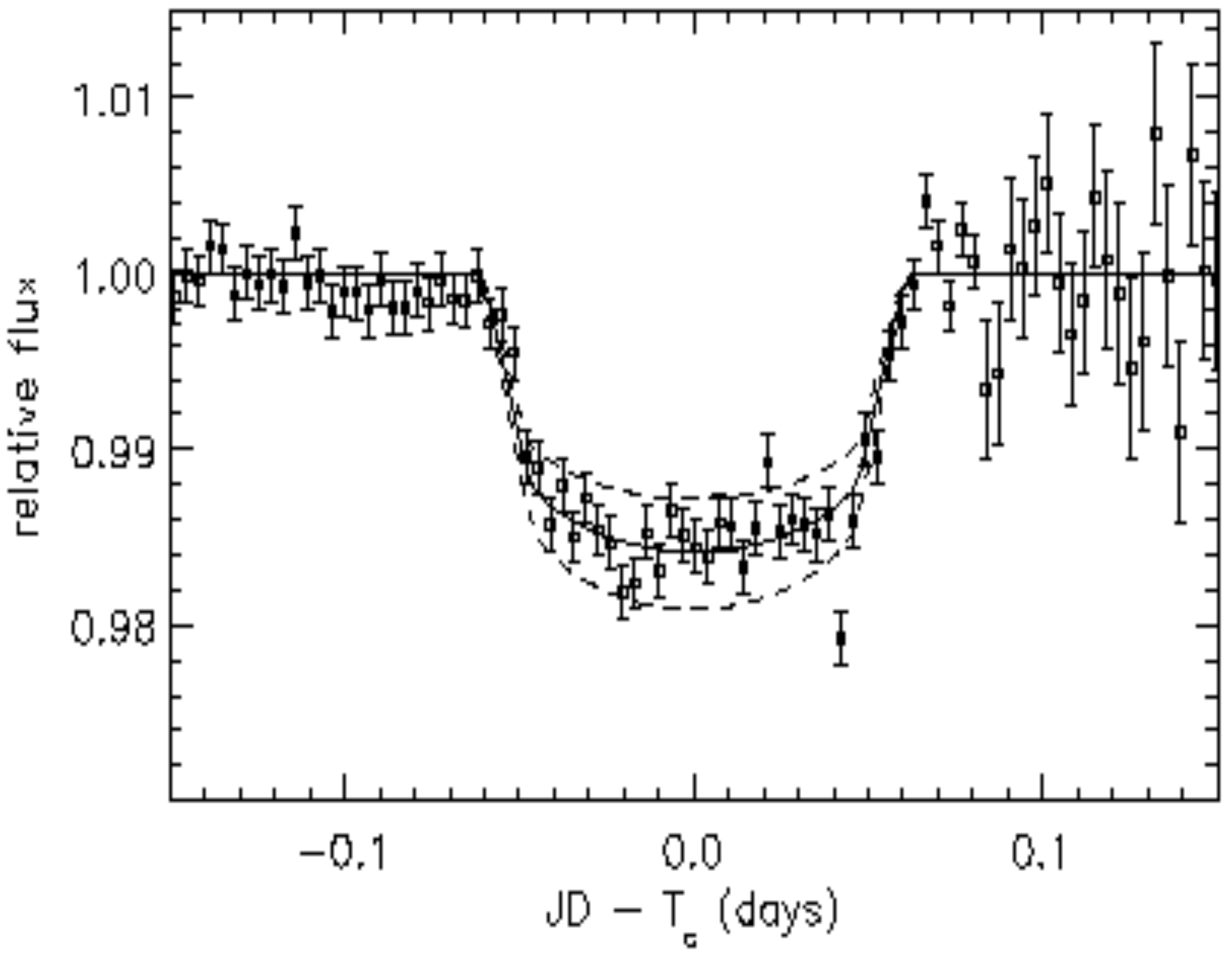
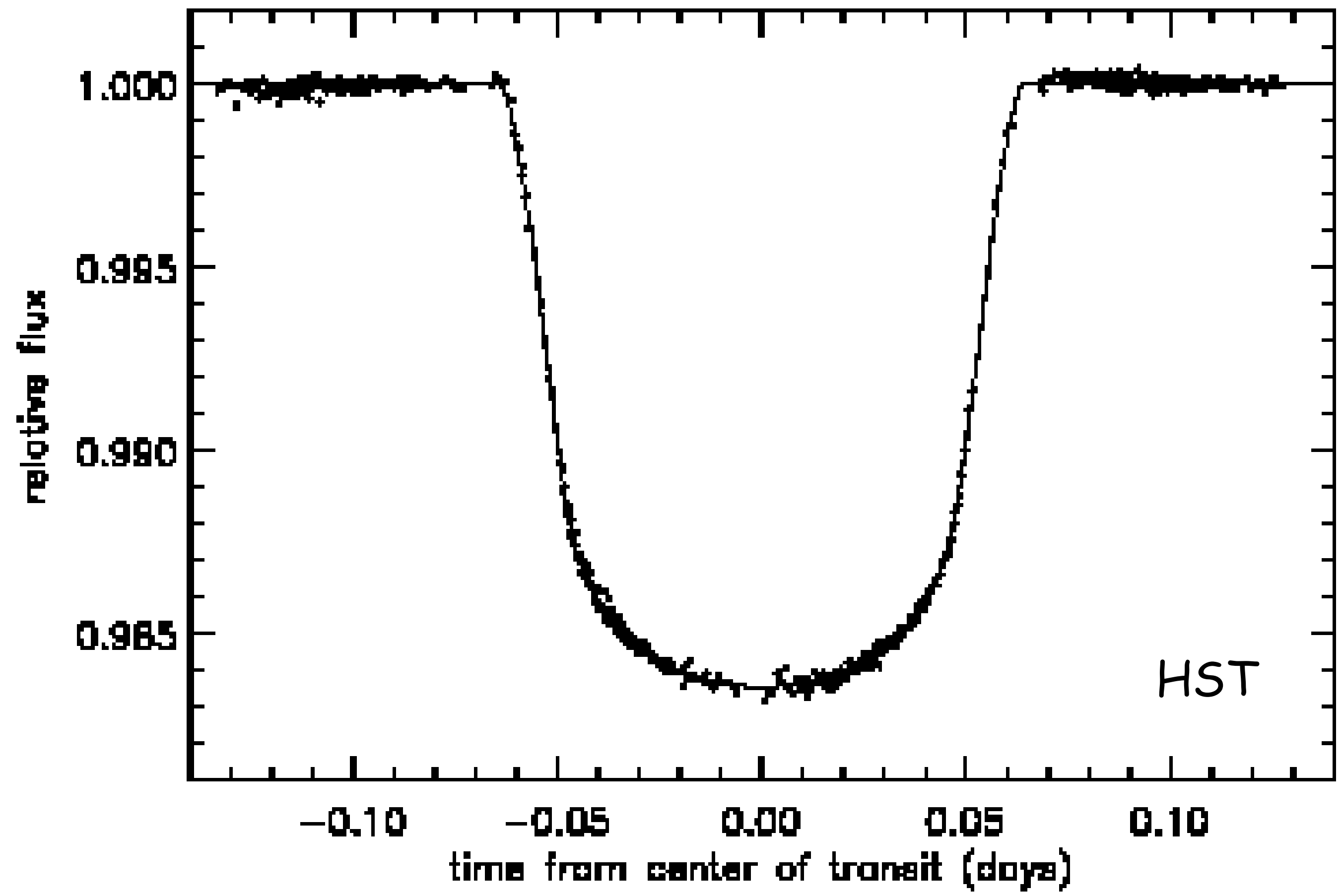
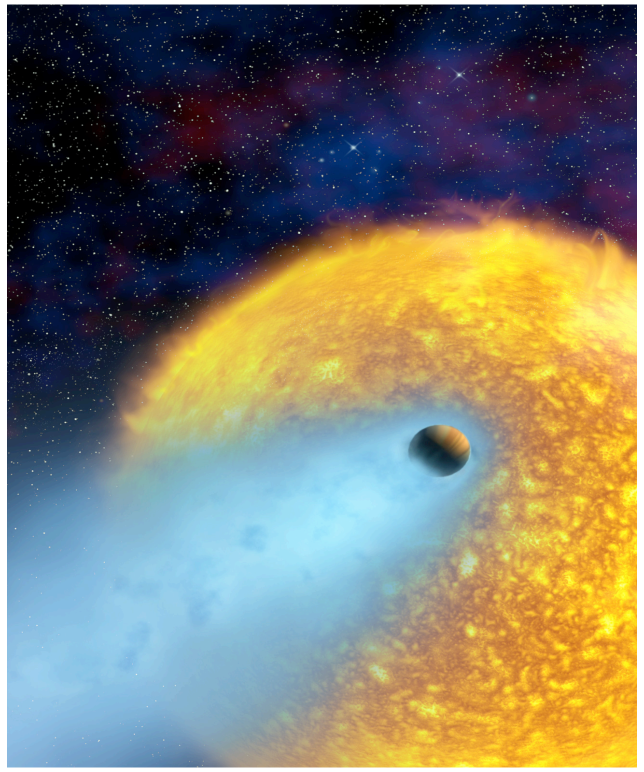




→ atmospheric spectroscopy (H, O, C lines)

[Vidal-Madjar et al., 2003]



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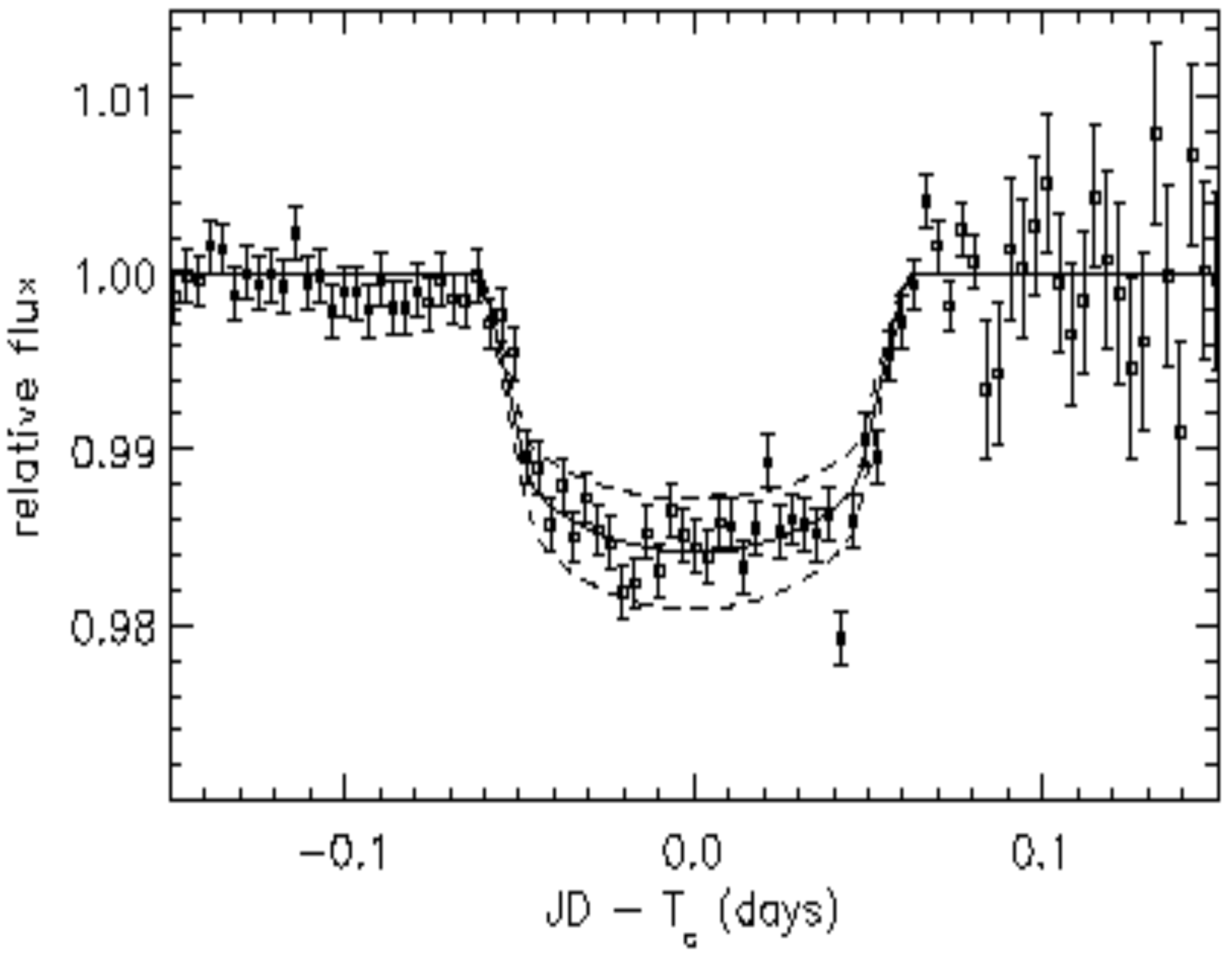

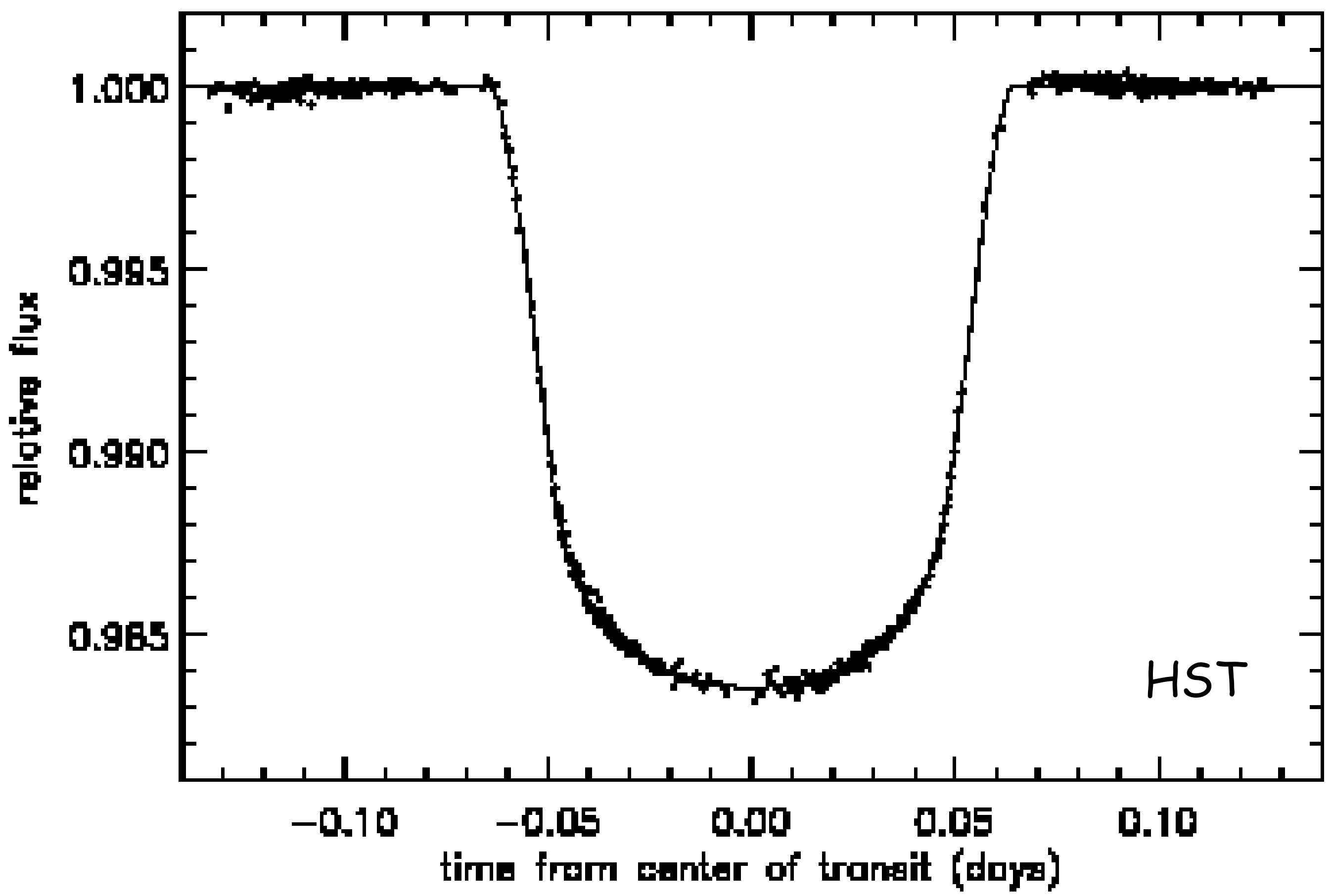

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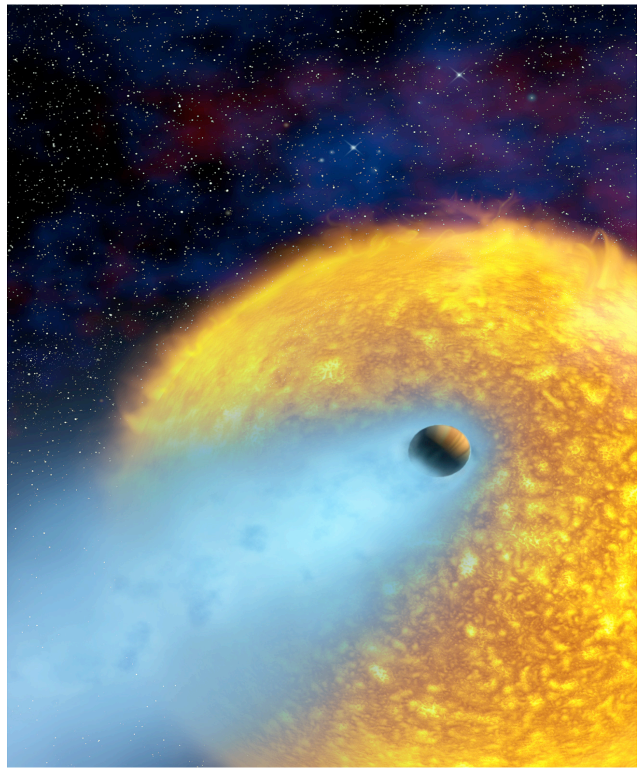

→ ~15 observed today : mesurements of i, P, R_p

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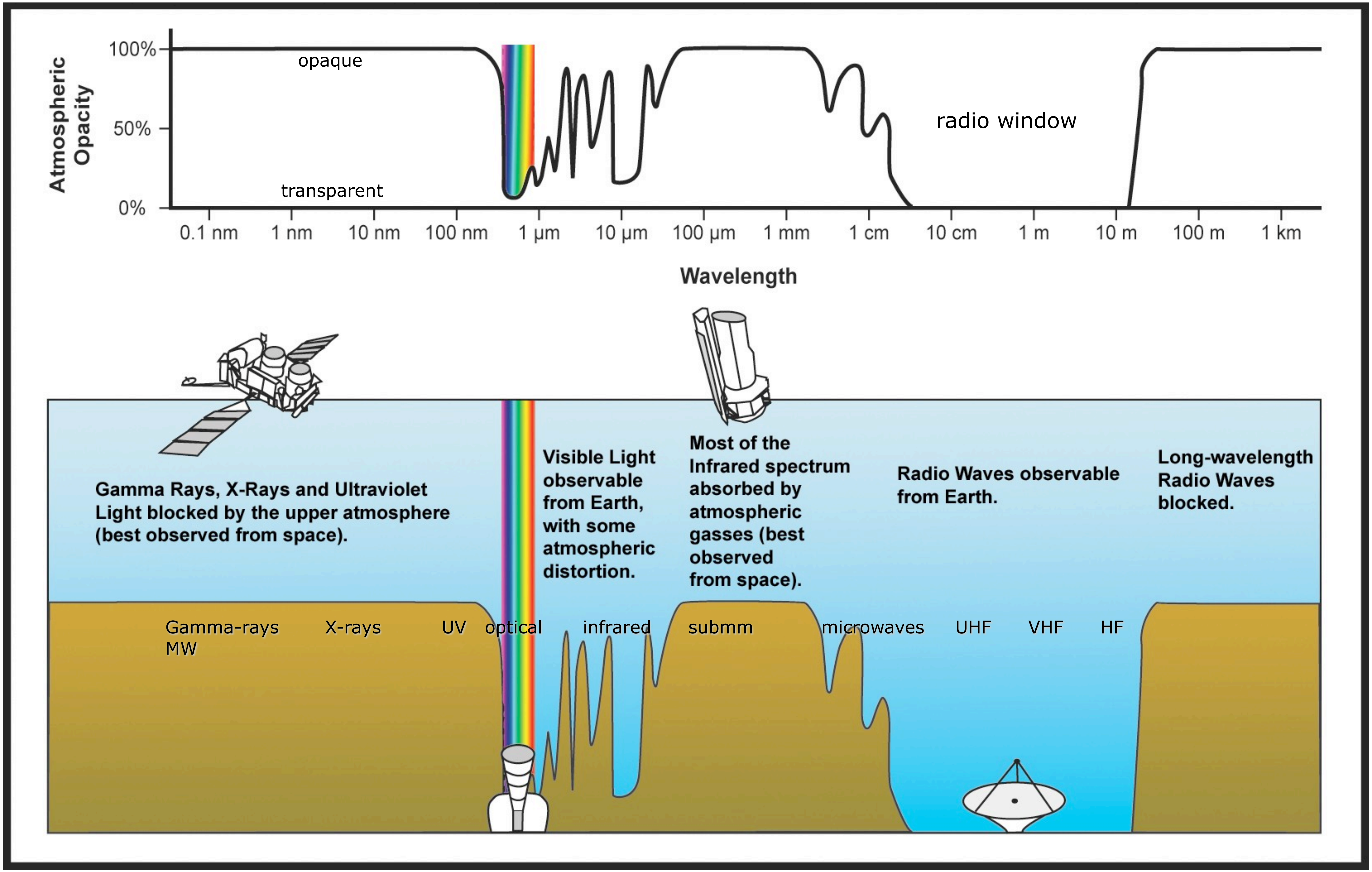
Atmospheric transparency



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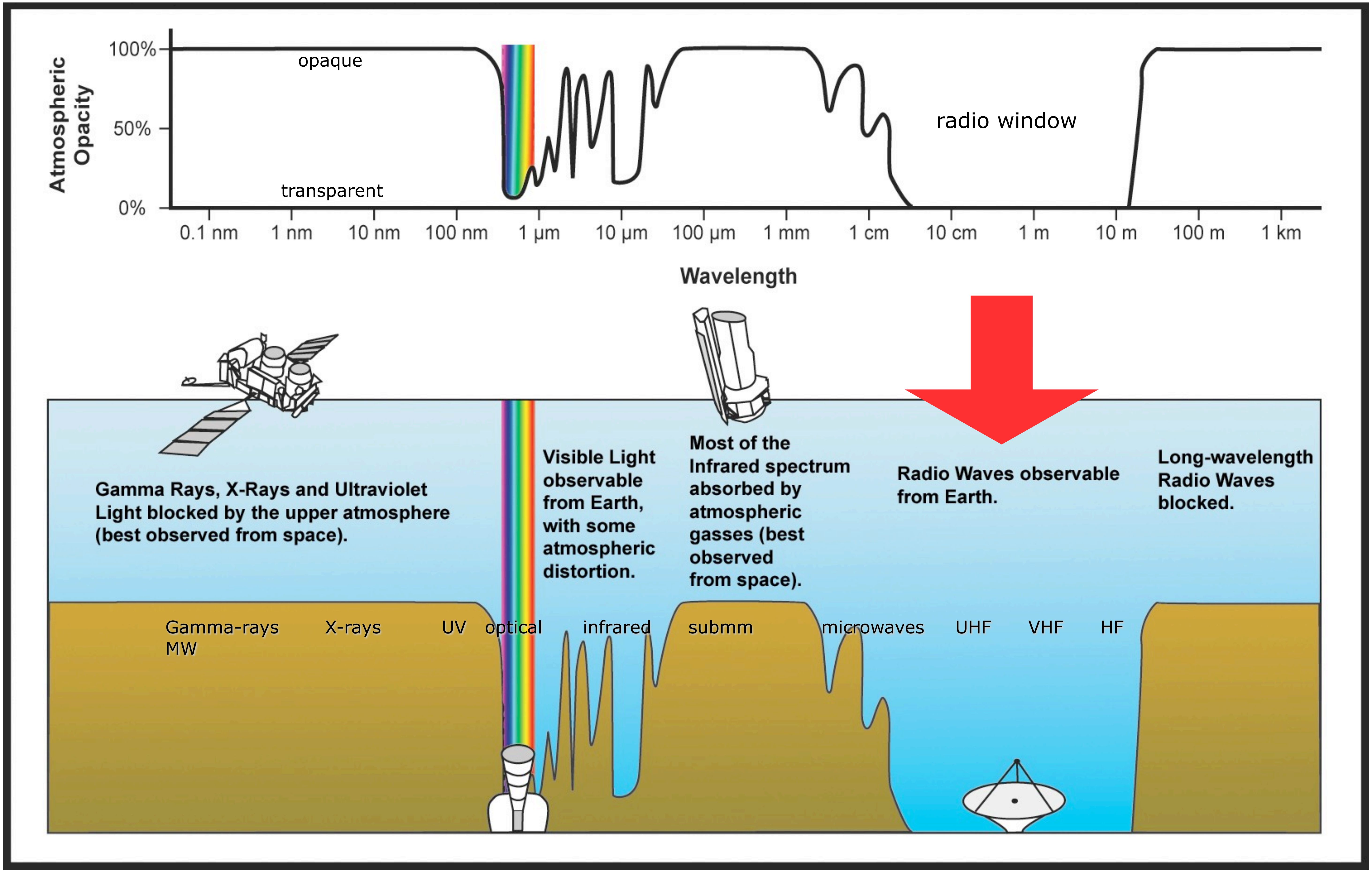
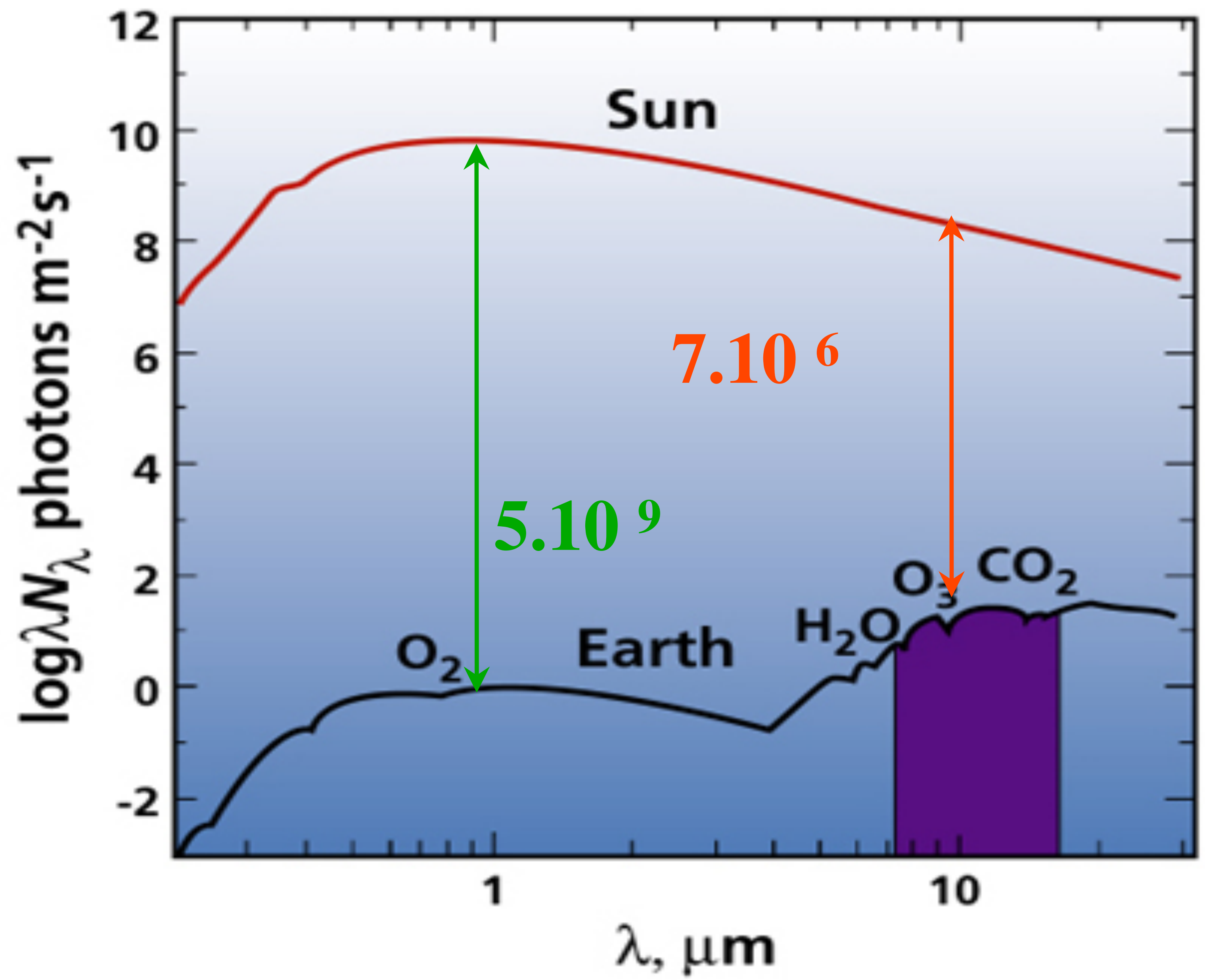
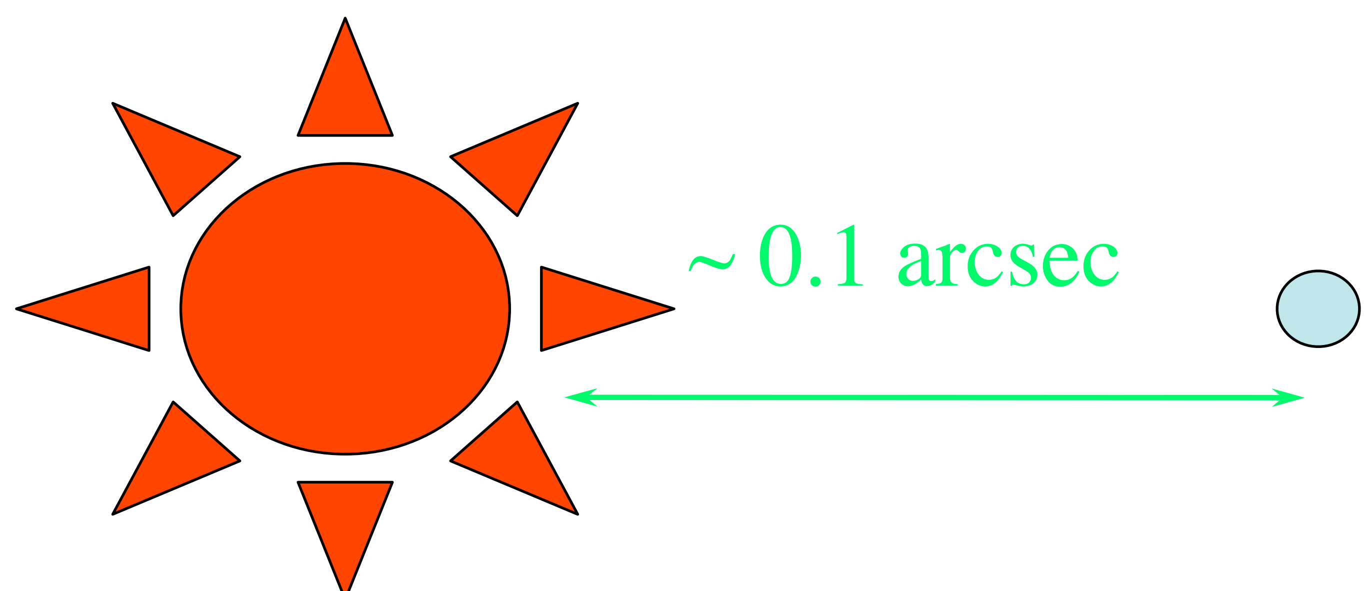


Obstacles to direct exoplanet detection

contrast & proximity star/planet



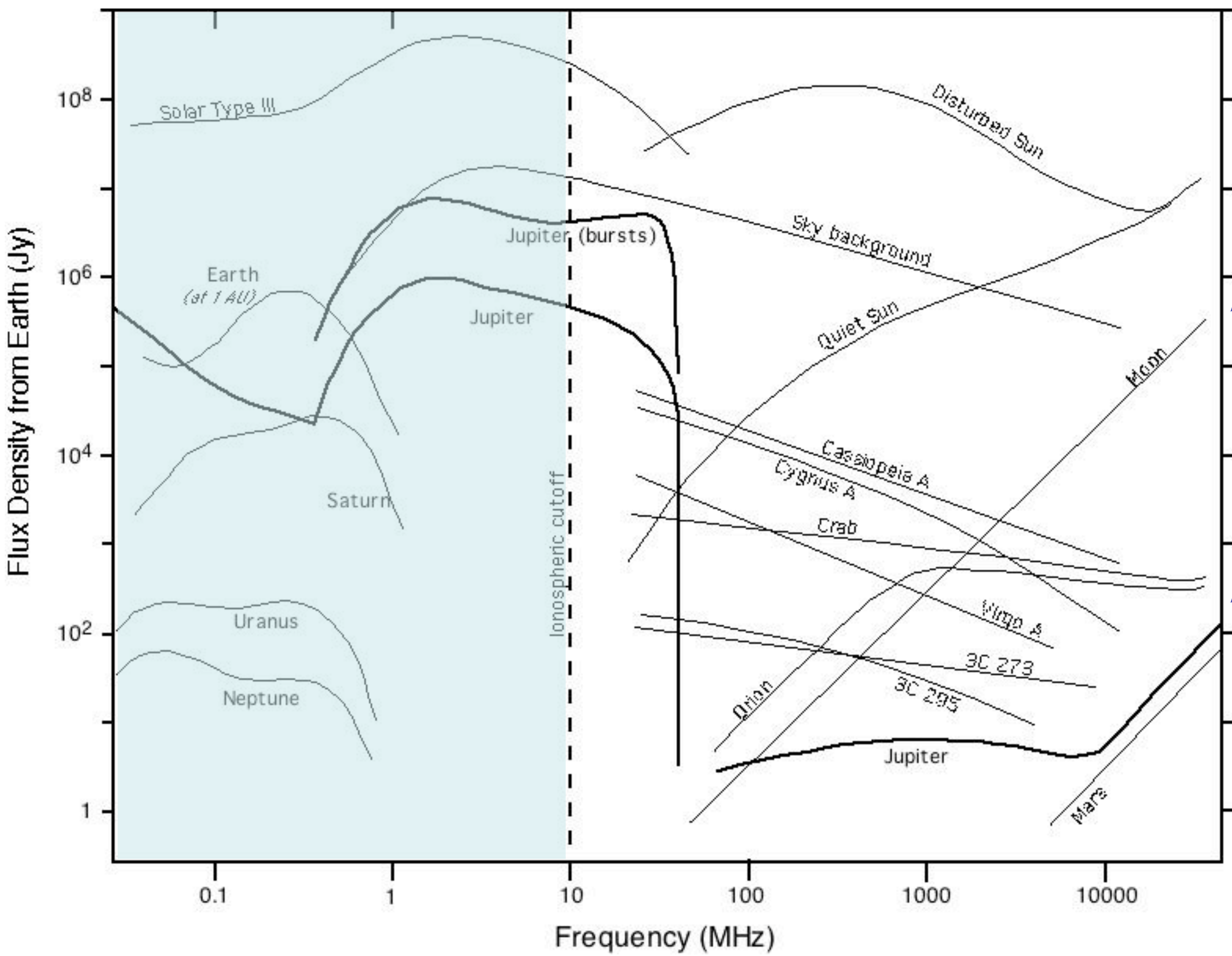


Continuum radiosources

- A low frequencies, thermal spectrum in λ^{-2}

$B(\nu)\, d\nu = 2kT\nu^2/c^2\, d\nu = 2kT/\lambda^2\, d\nu$ $\quad [\mathrm{W m^{-2} Hz^{-1} sr^{-1}}]$ $\quad$ (Rayleigh-Jeans)

- A very low frequencies, solar and planetary spectra ≠ thermal



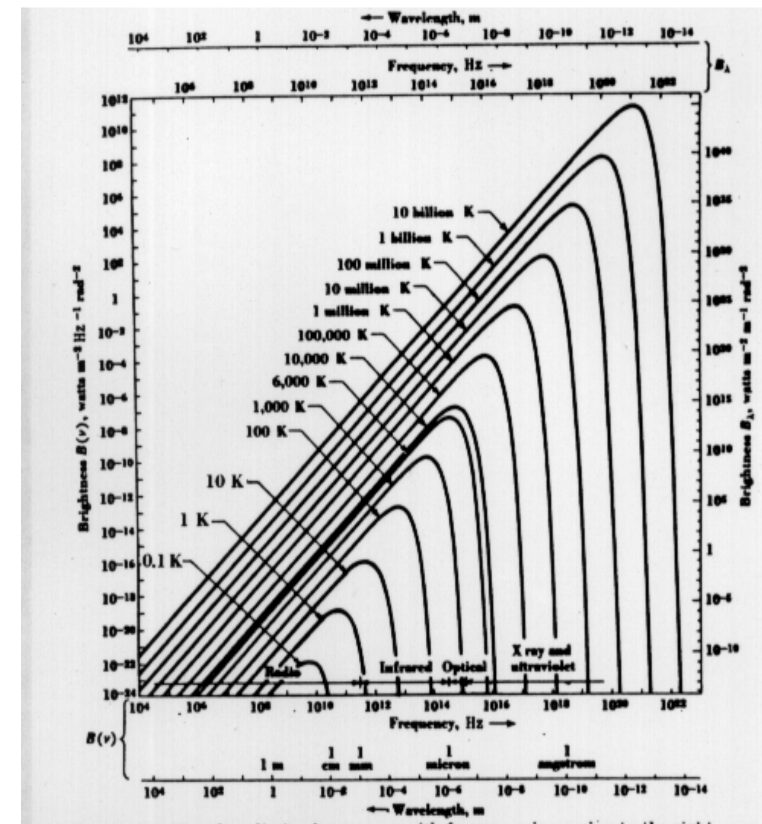
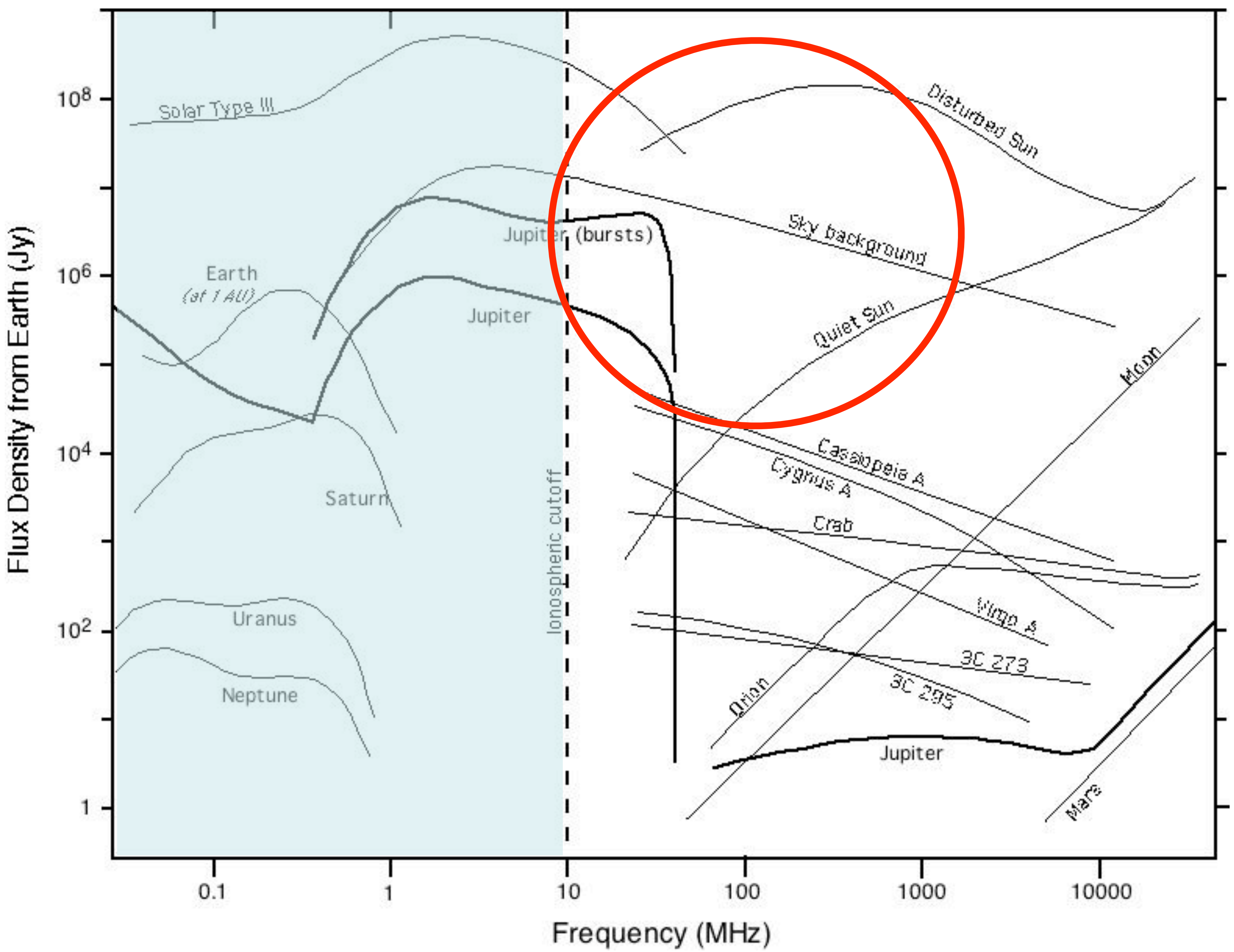
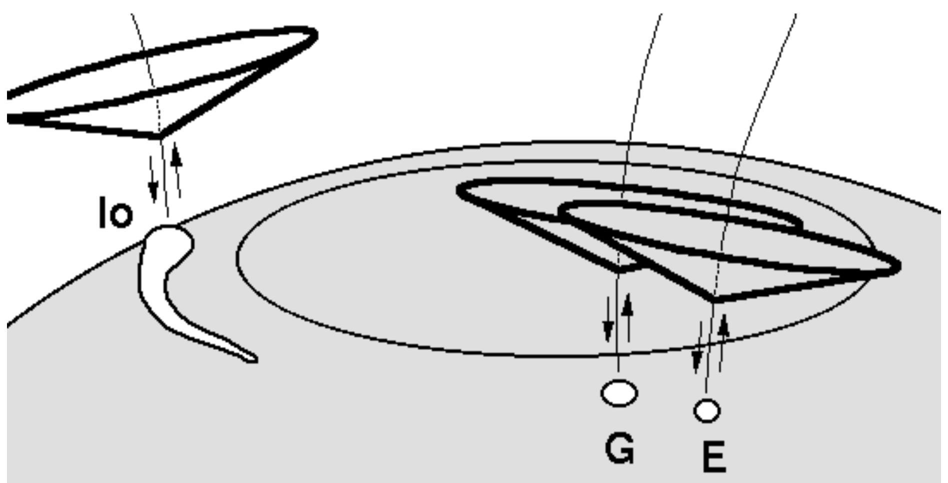


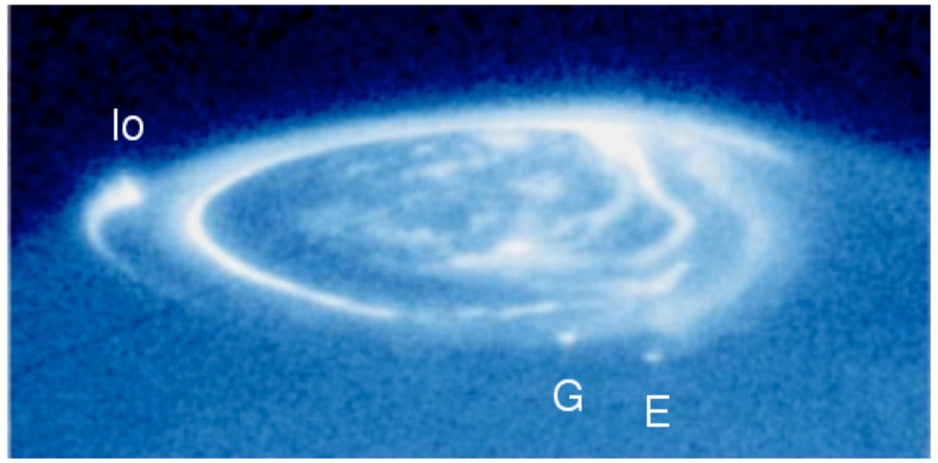
Fig. 3-14. Planck-radiation-law curves with frequency increasing to the right.

Continuum radiosources

- Magnetospheric auroral radio emissions due to coherent « Plasma » processes
  - Contrast Sun/Jupiter ~1 !

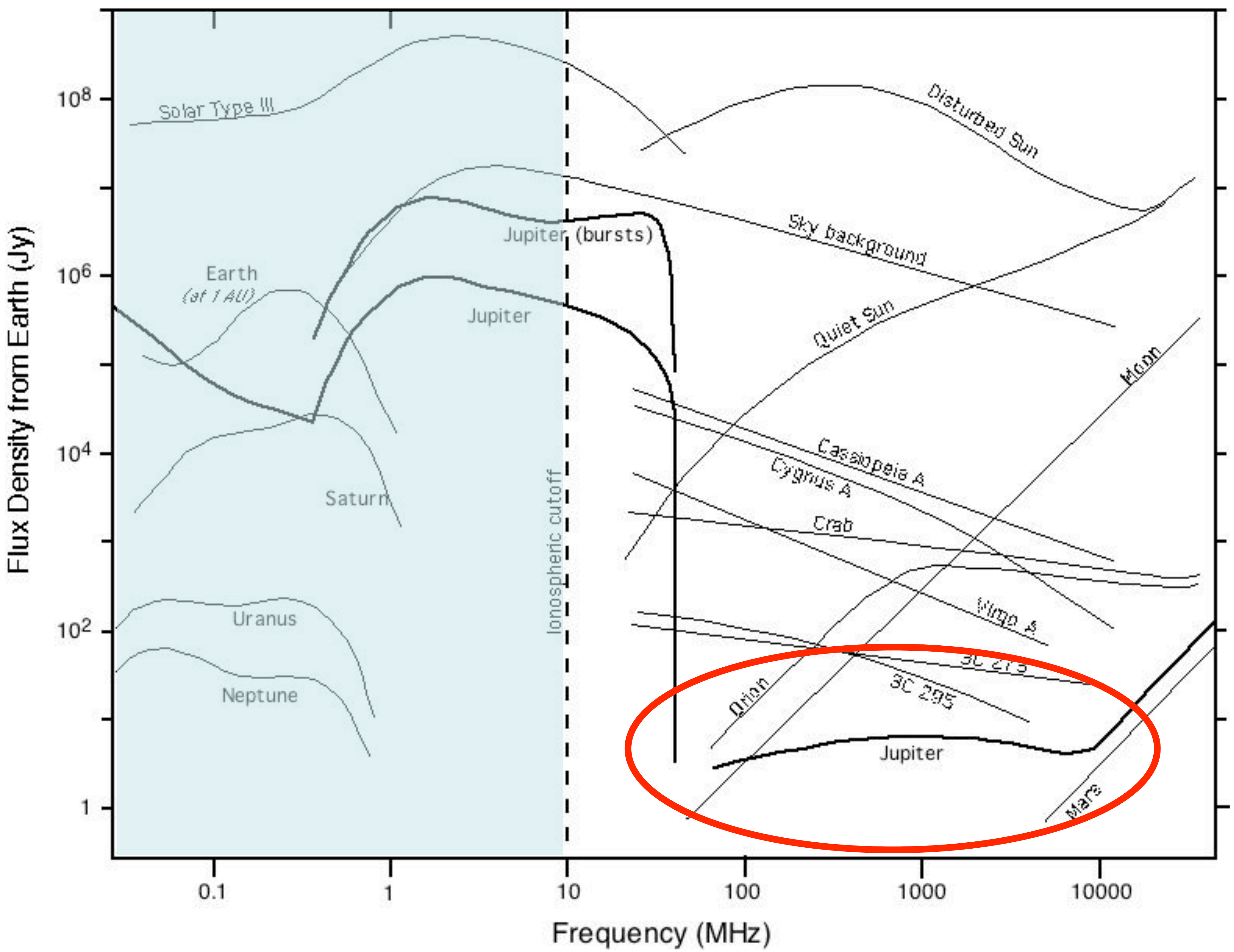


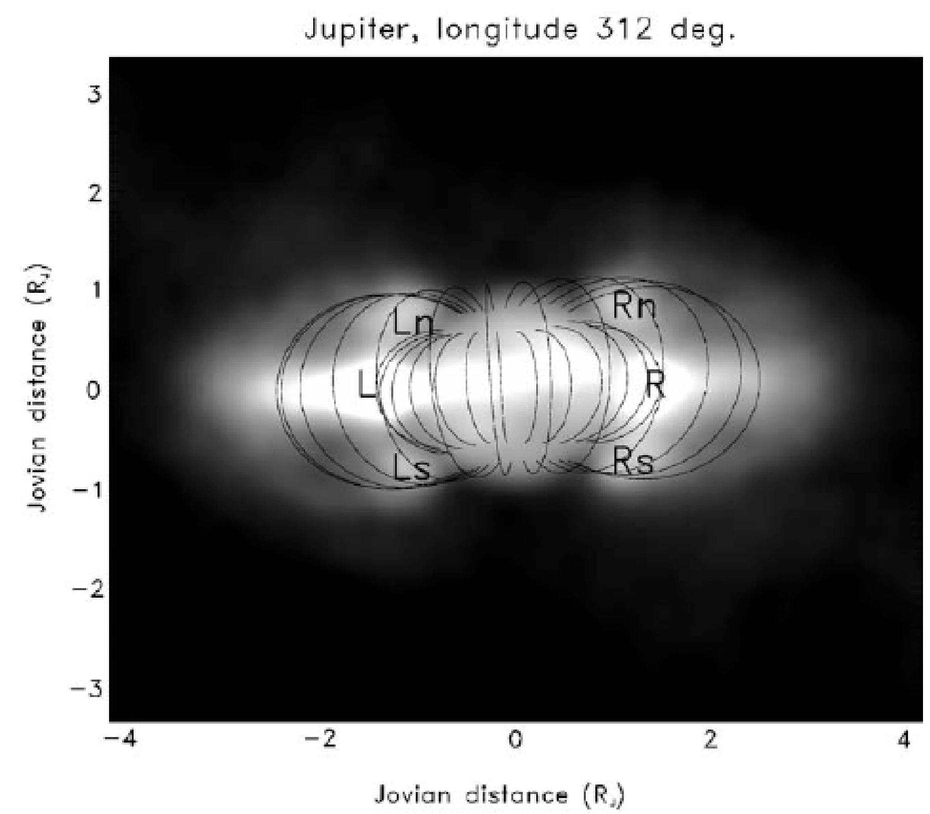




Continuum radiosources

• Synchrotron radio emissions from radiation belts due to incoherent « Plasma » processes ⇒ 5 orders of magnitude weaker

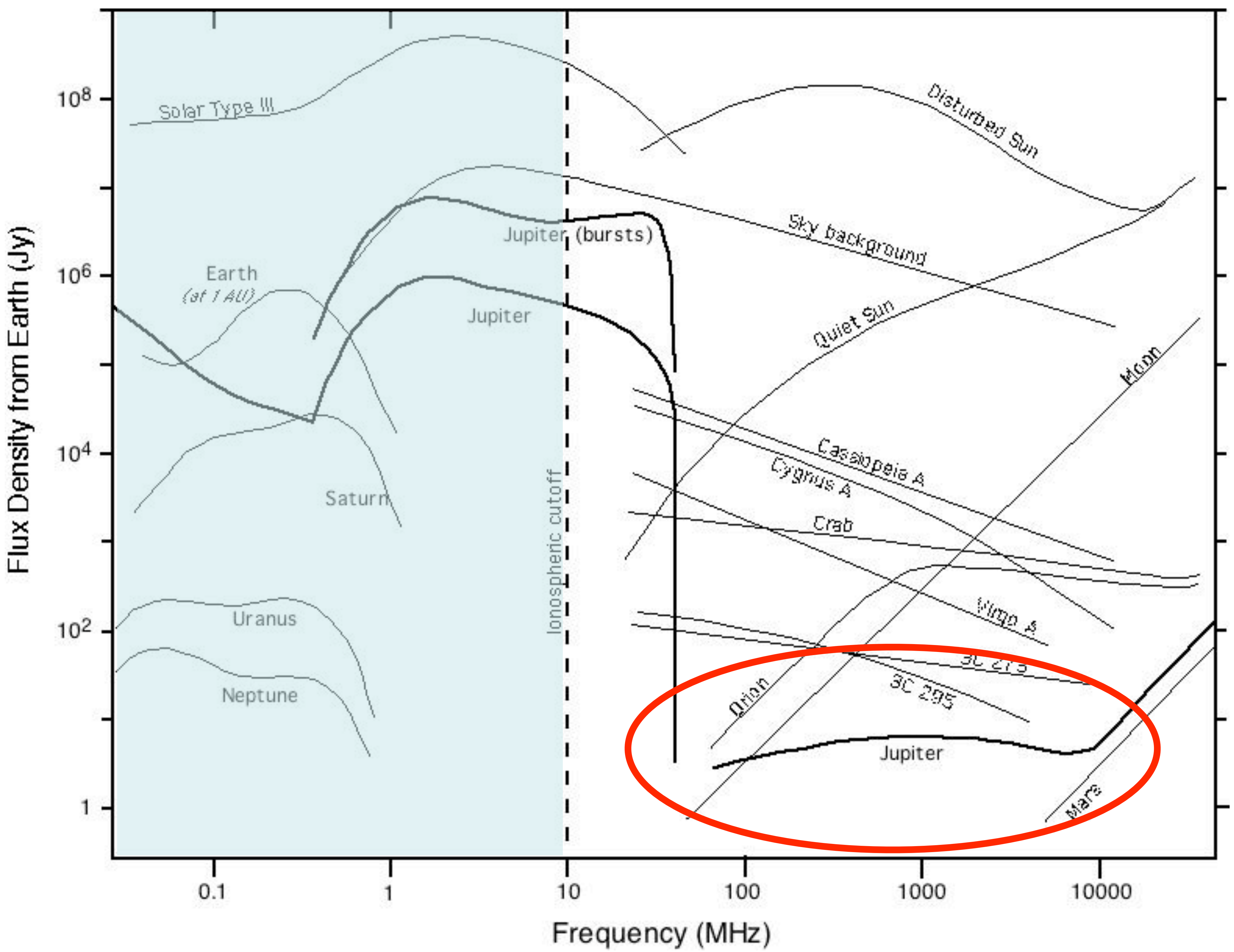


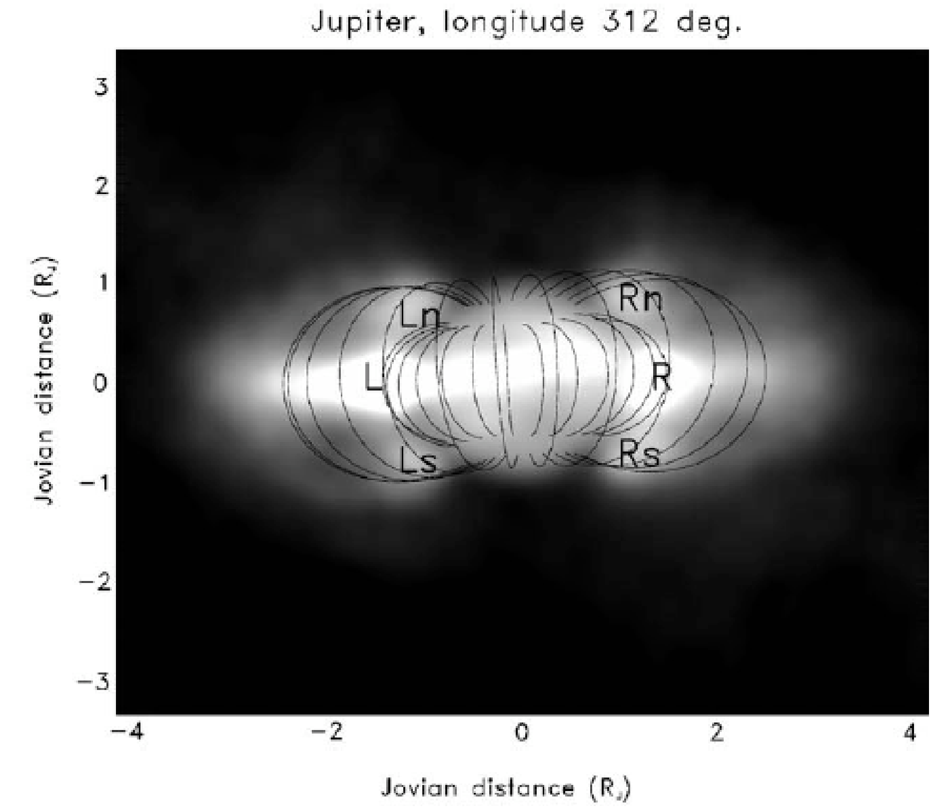


Continuum radiosources

• Synchrotron radio emissions from radiation belts due to incoherent « Plasma » processes ⇒ 5 orders of magnitude weaker

• Other : Lightning ... ⇒ LF & weak



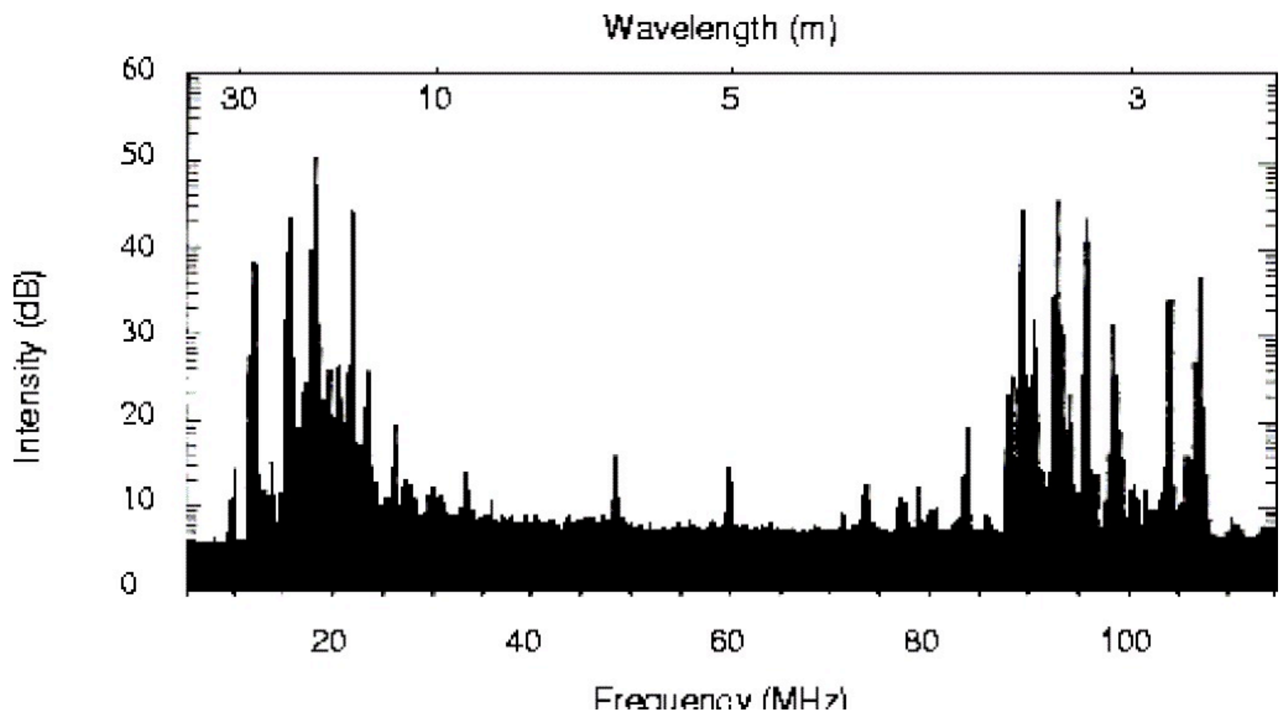


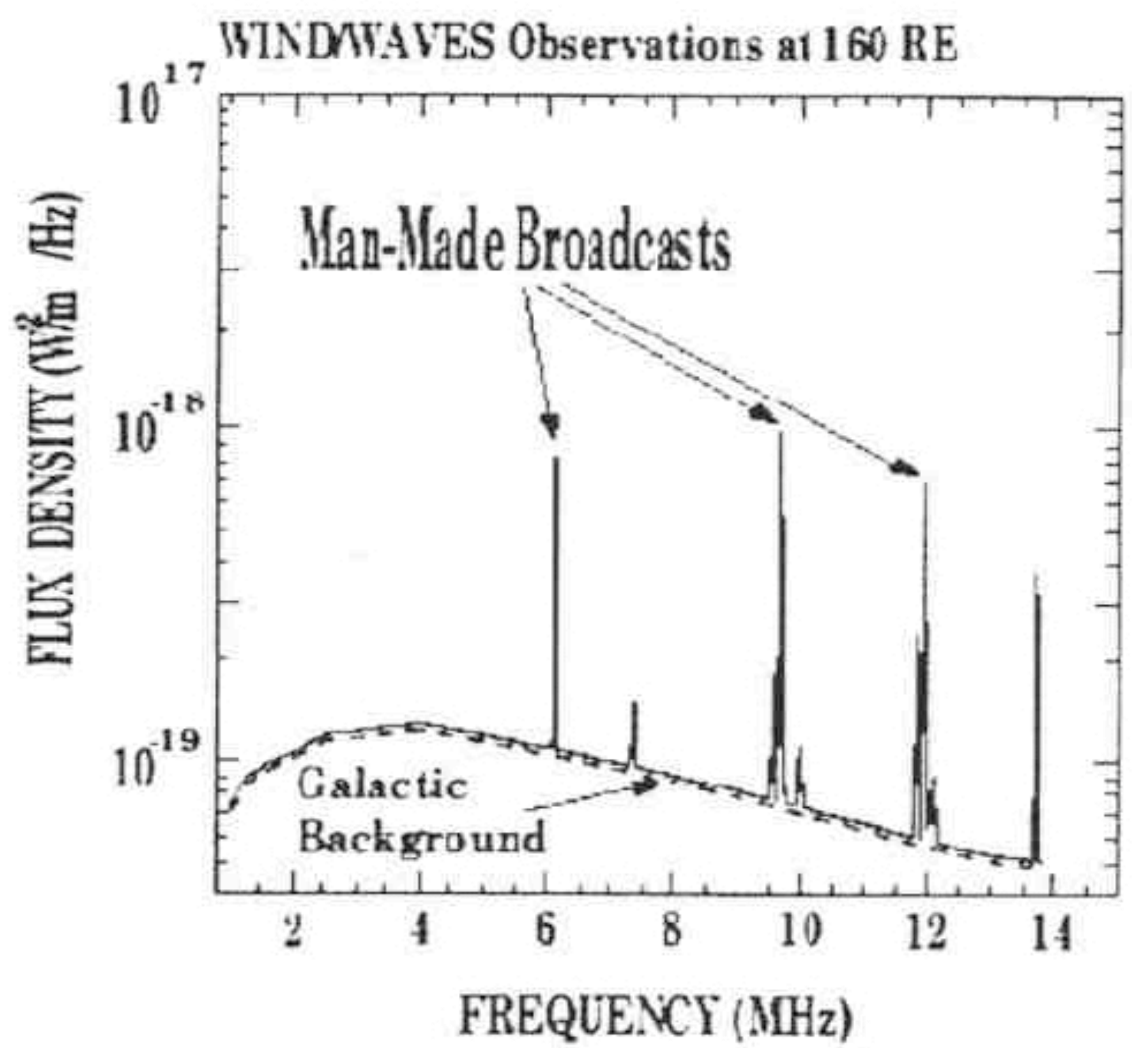
Limitations of Radio observations

- Limited angular resolution (λ/D)
- Very bright galactic background (T_b ~10^{3-5} K)
- RFI (natural & anthropic origin)
- Ionospheric cutoff ~ 10 MHz,

  perturbations ≤30-50 MHz,

  scintillations IP/IS





Sensitivity of Radio observations

- Galactic radio background: $T \sim 1.15 \times 10^8 / \nu^{2.5} \sim 10^{1-5}$ K (10-1000 MHz)

$\rightarrow$ $S = 2kT/A_e$ with statistical fluctuations $\sigma = 2kT/A_e(b\tau)^{1/2}$

$\rightarrow$ $N = s / \sigma$ with $s = \zeta S_J / d^2$

$S_J \sim 10^{-18}$ $Wm^{-2}Hz^{-1}$ (10^8 Jy) à 1 UA

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$S_J \sim 10^{-18}$ Wm^{-2}Hz^{-1} (10^8 Jy) à 1 UA

- Maximum distance for $N\sigma$ detection of a source ζ x Jupiter :

$$d_{max} = (\zeta S_J A/2NkT)^{1/2}(b\tau)^{1/4}$$

$$\Rightarrow d_{max}\,(pc) = 5\times10^{-8}\,(A_e\,\zeta)^{1/2}\,f^{5/4}\,(b\tau)^{1/4}$$

$\Rightarrow \zeta = 1$

	$b\,\tau = 10^6$ (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)	0.003	0.05	0.01	0.2	0.04	0.7
$A_e = 10^5\ m^2$ (~UTR-2)	0.01	0.2	0.03	0.6	0.1	2.2
$A_e = 10^6\ m^2$ (~LOFAR77)	0.03	0.5	0.1	2.	0.4	7.

(distances in parsecs)

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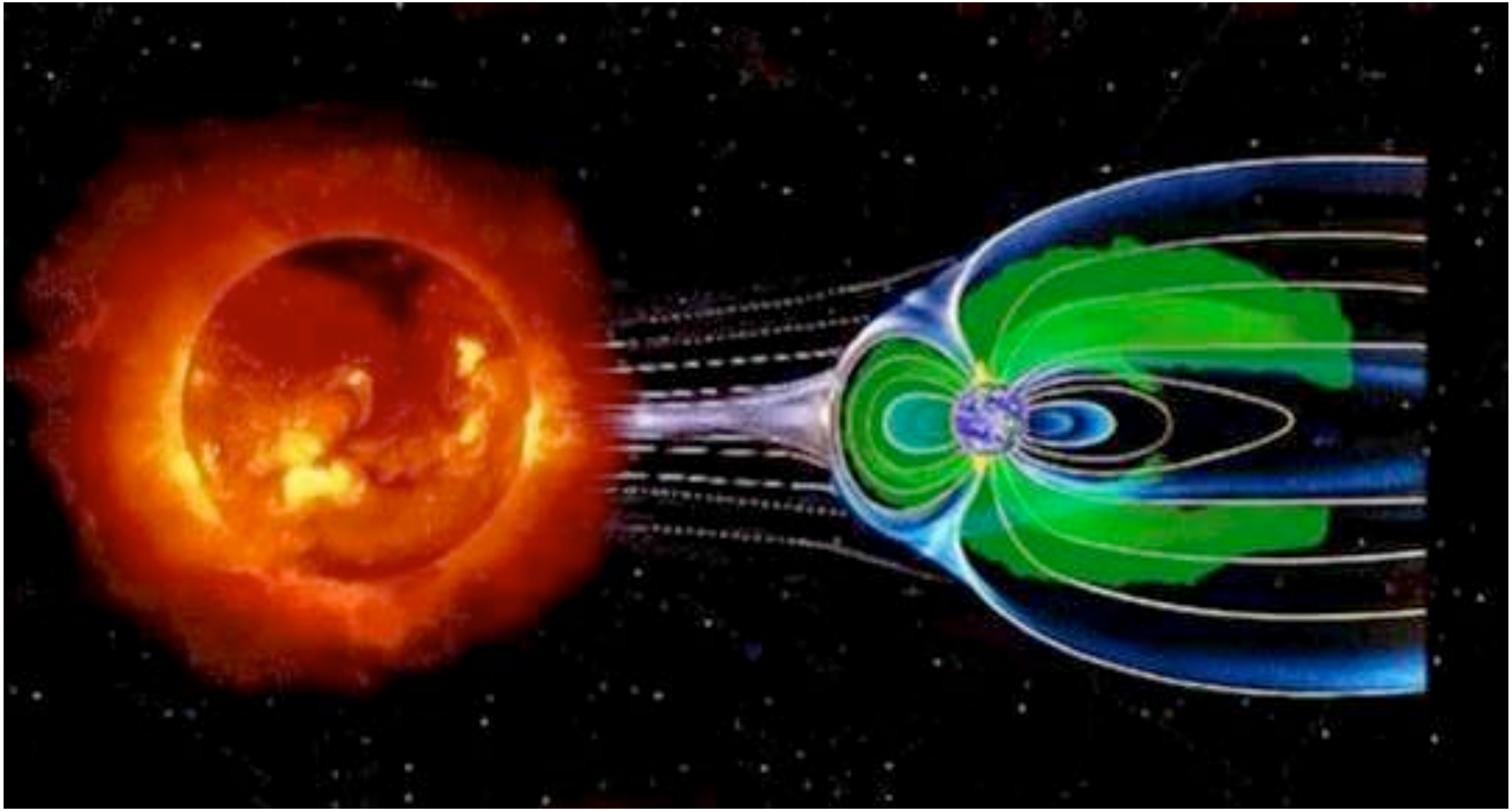
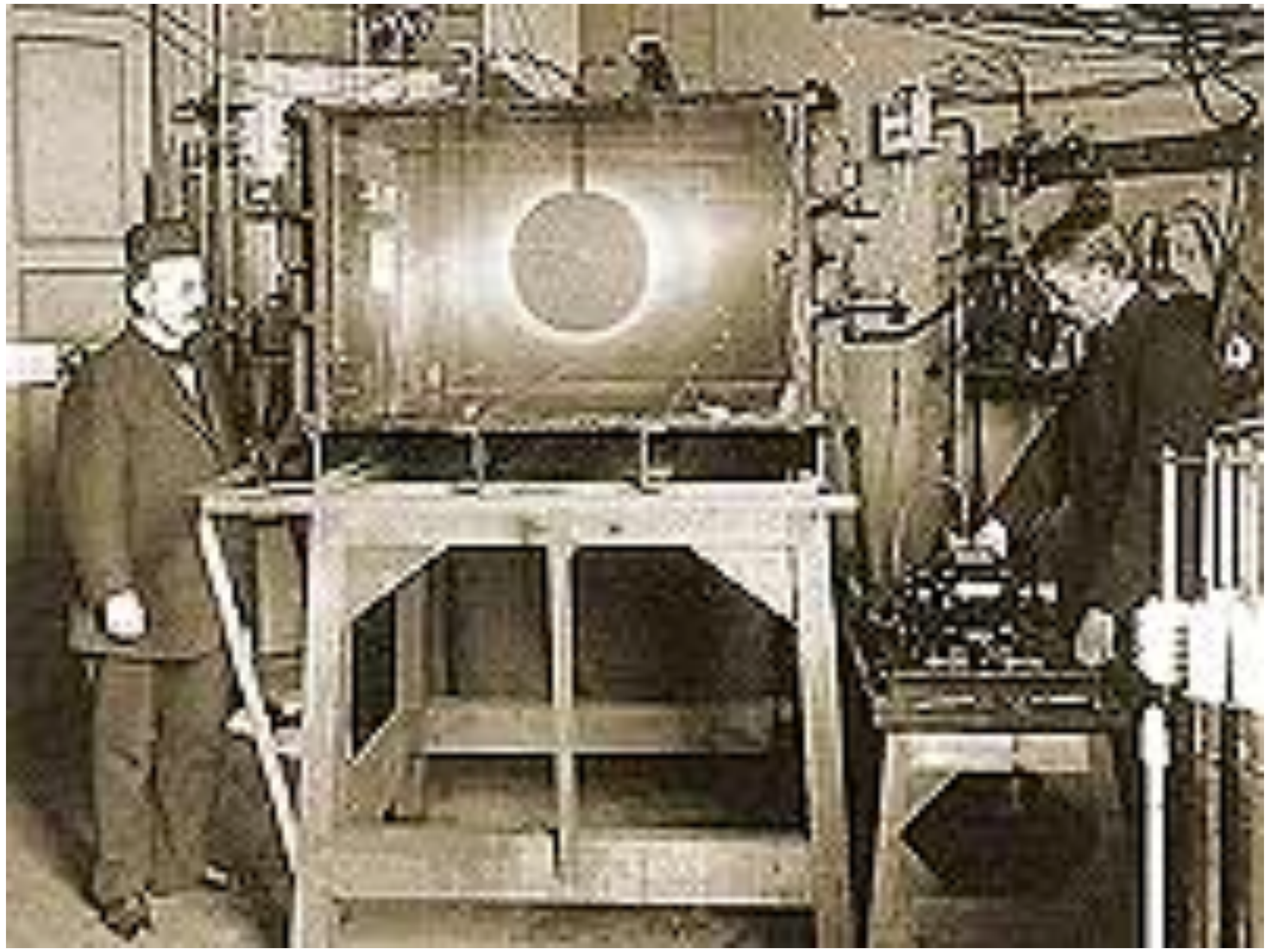
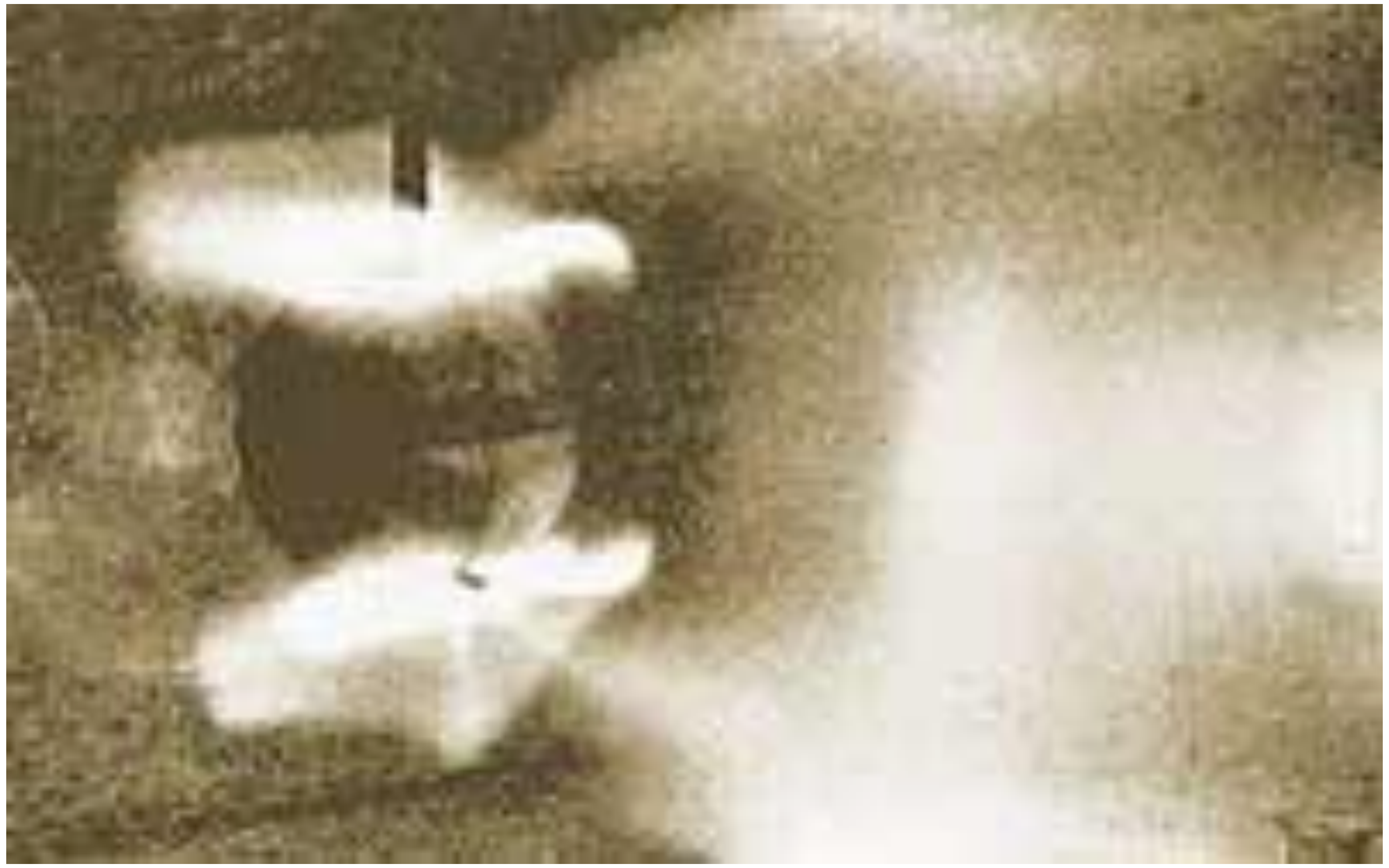
Solar Wind - Magnetosphere Interaction



Aurorae





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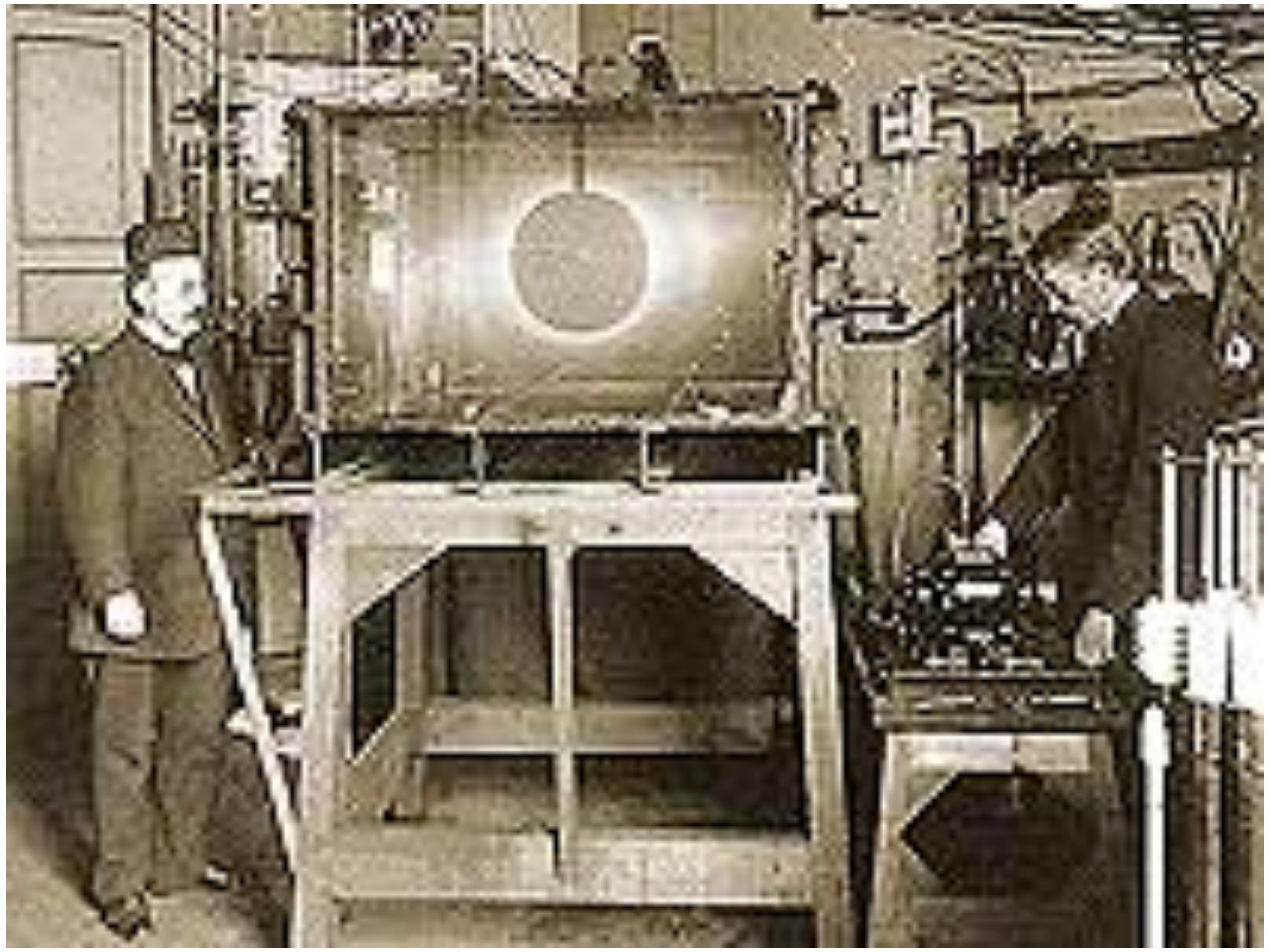
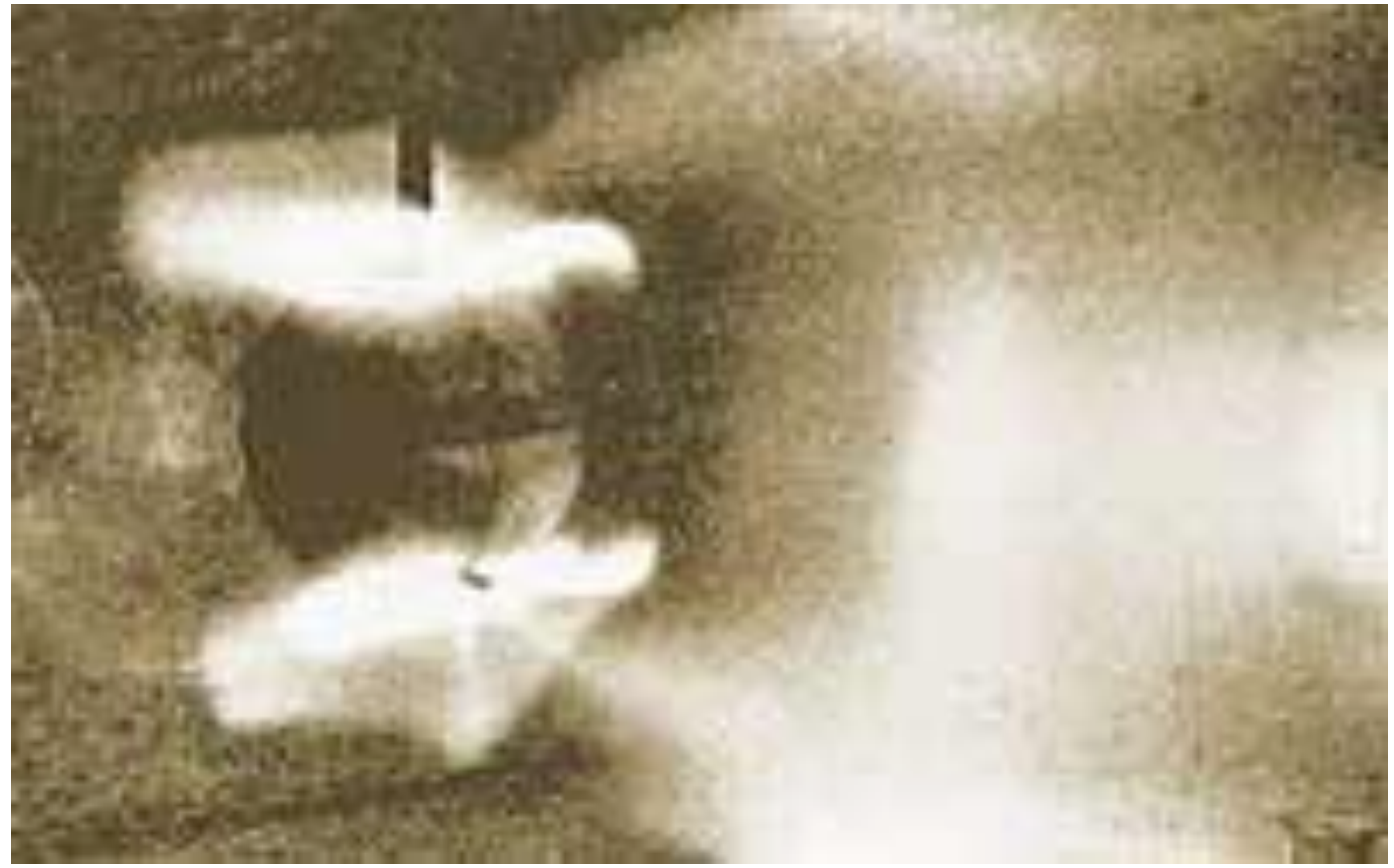
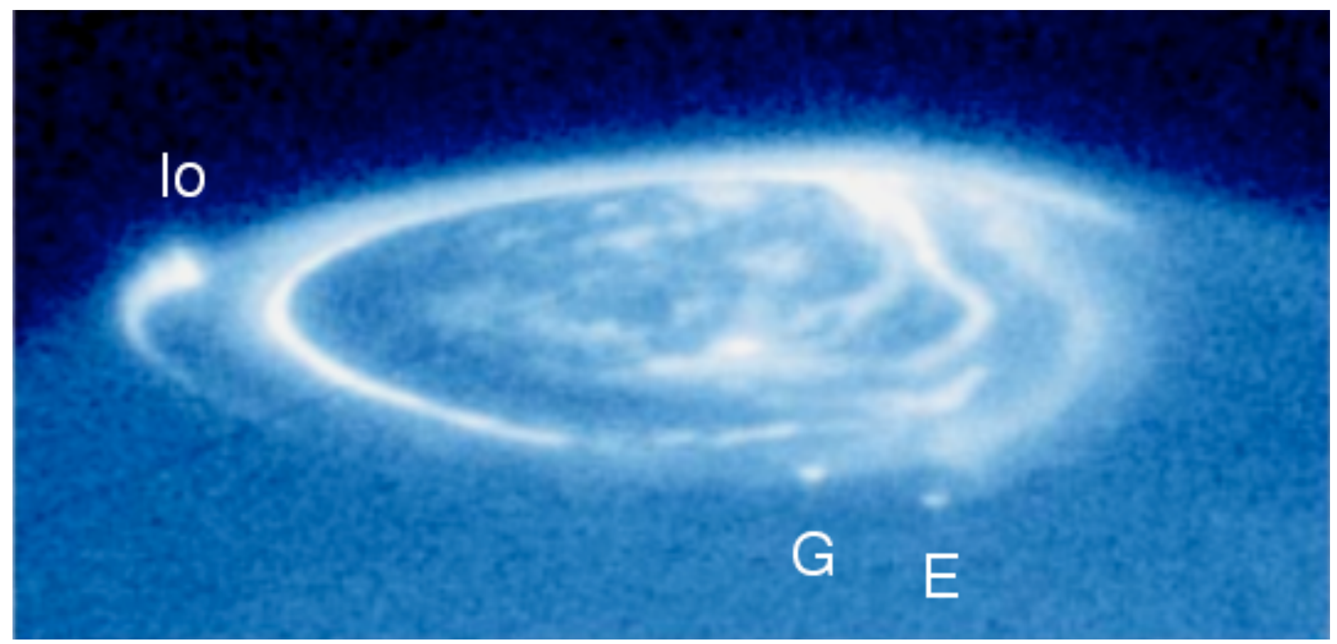
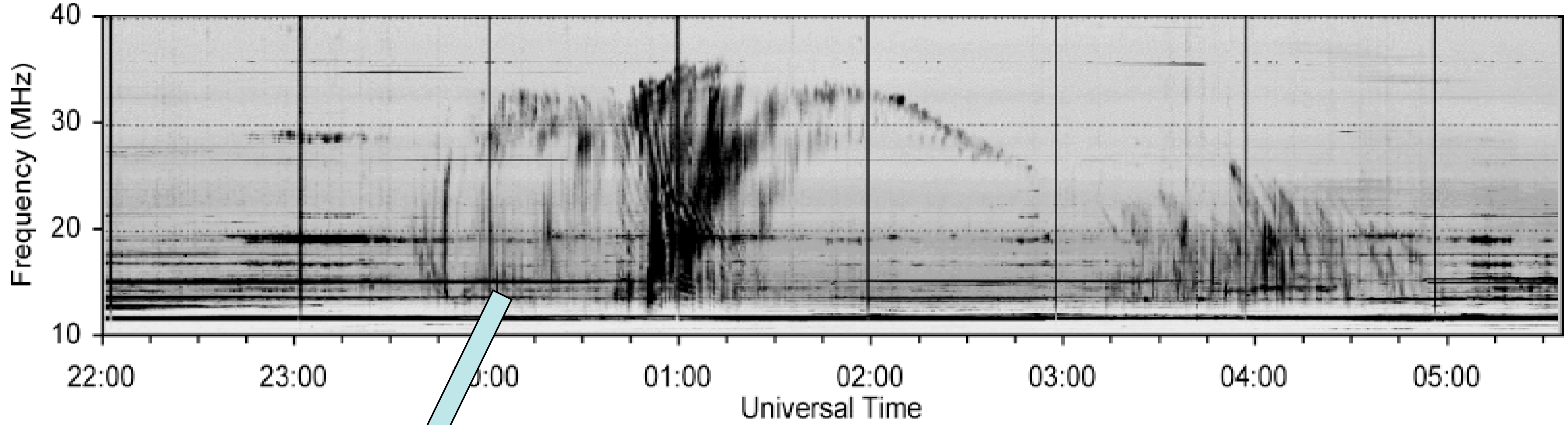
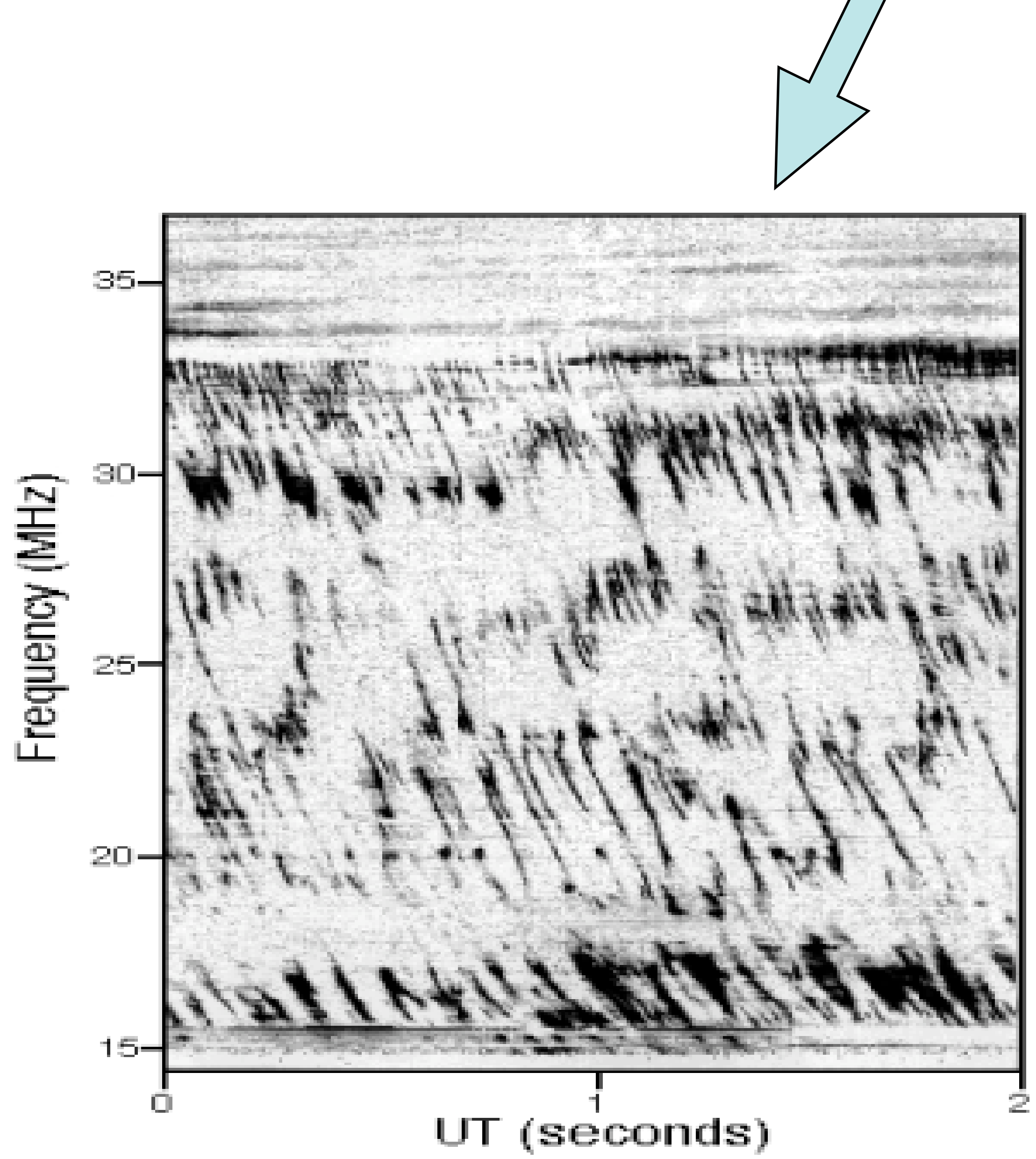


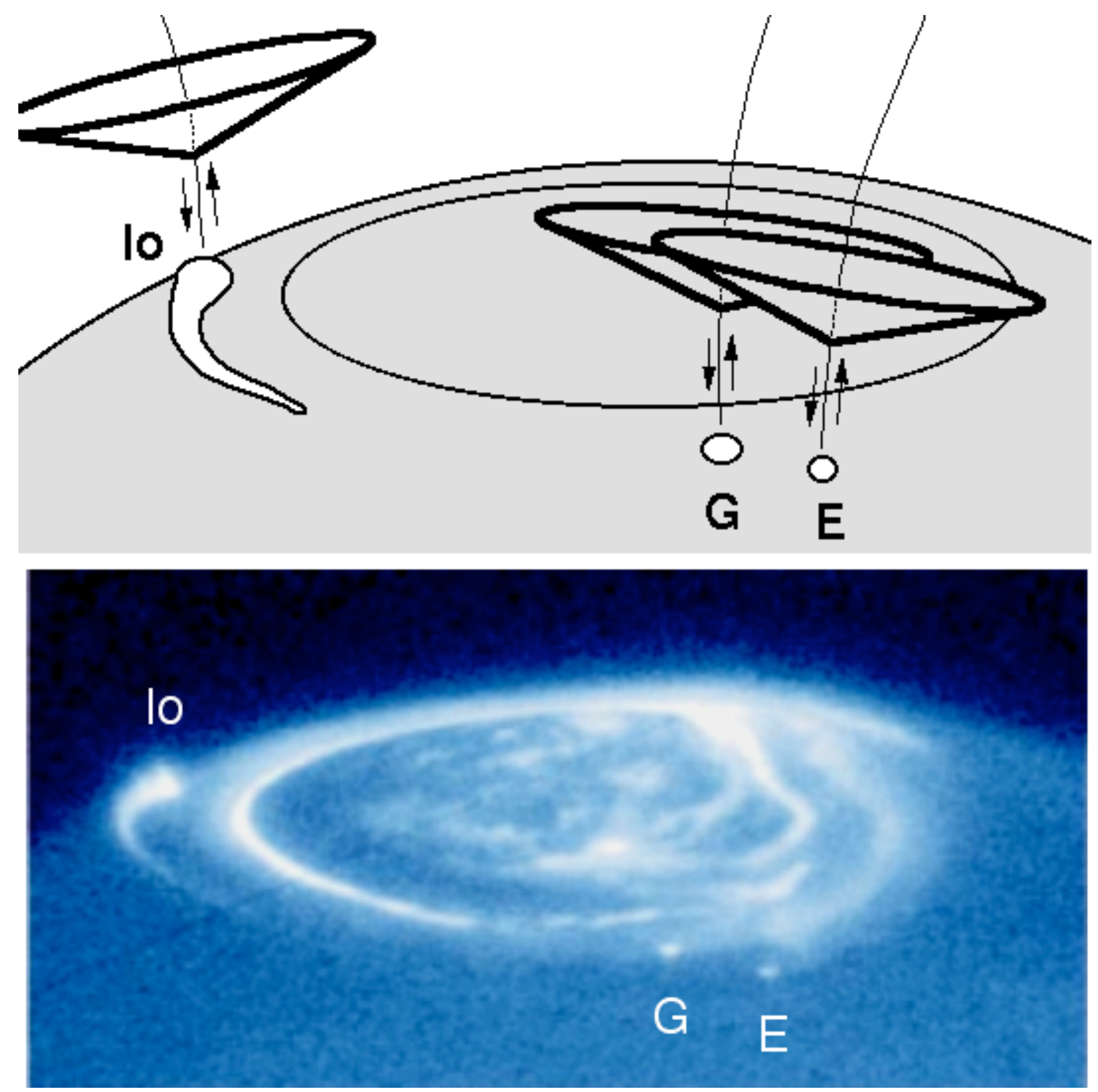




Magnetospheric (auroral) radio emissions

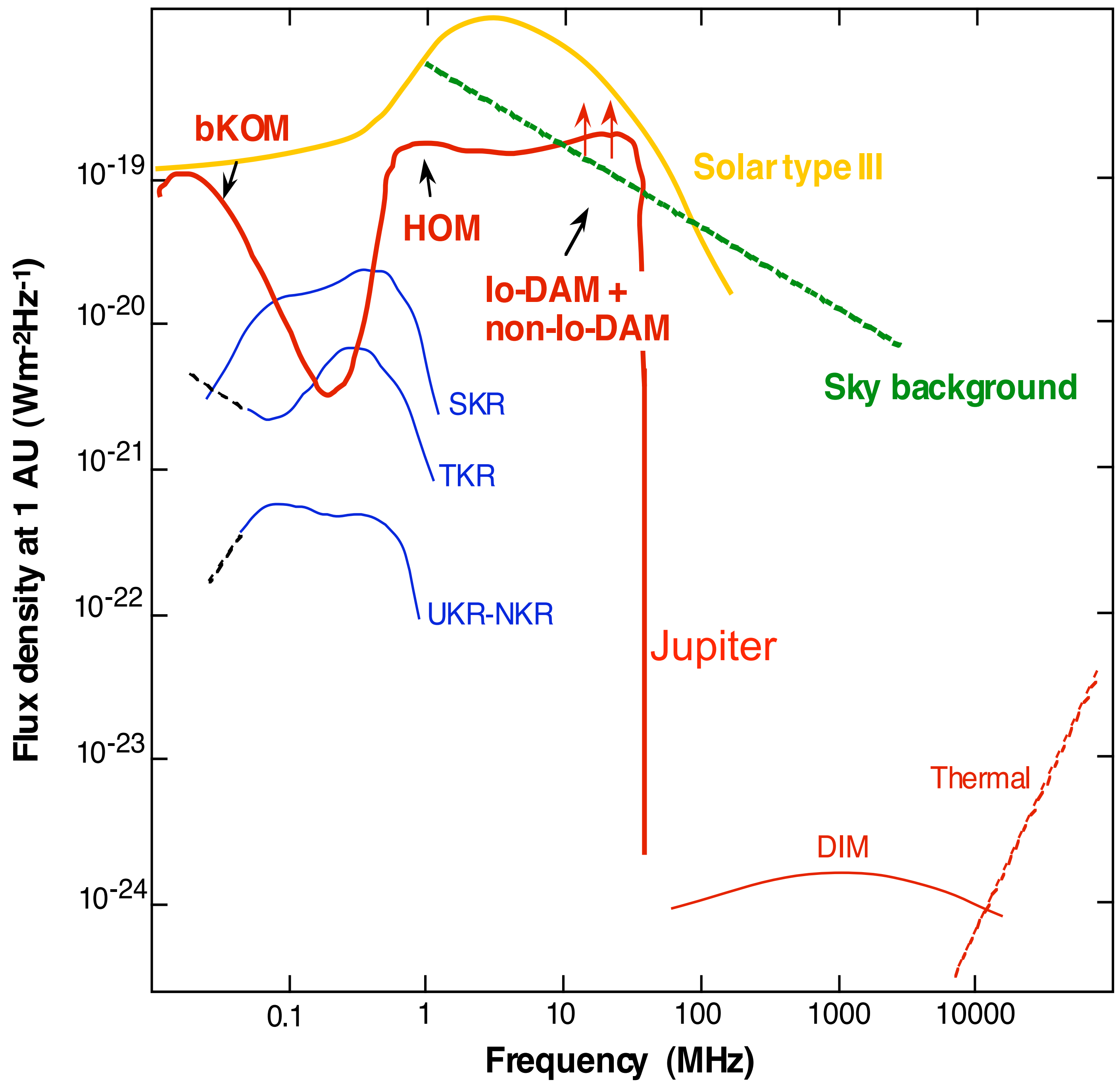






Properties of auroral radio emissions

- $f \sim f_{ce}$, $\Delta f \sim f$
- $T_B > 10^{15}$ K
- circular/elliptical polarization (X mode)
- very anisotropic beaming (conical, $\Omega << 4\pi$ sr)
- variability /t (bursts, rotation, solar wind…)
- correlation radio / UV
- radiated power : 10^{6-11} W



Generation of auroral radio emissions

- Cyclotron-Maser (coherent) emission : 2 conditions within sources :

  - low β magnetized plasma ($f_{pe} \ll f_{ce}$)

  - energetic electrons (keV) with non-Maxwellian distribution

$\rightarrow$ high magnetic latitudes

$\rightarrow$ direct emission at $f \sim f_X \approx f_{ce}$

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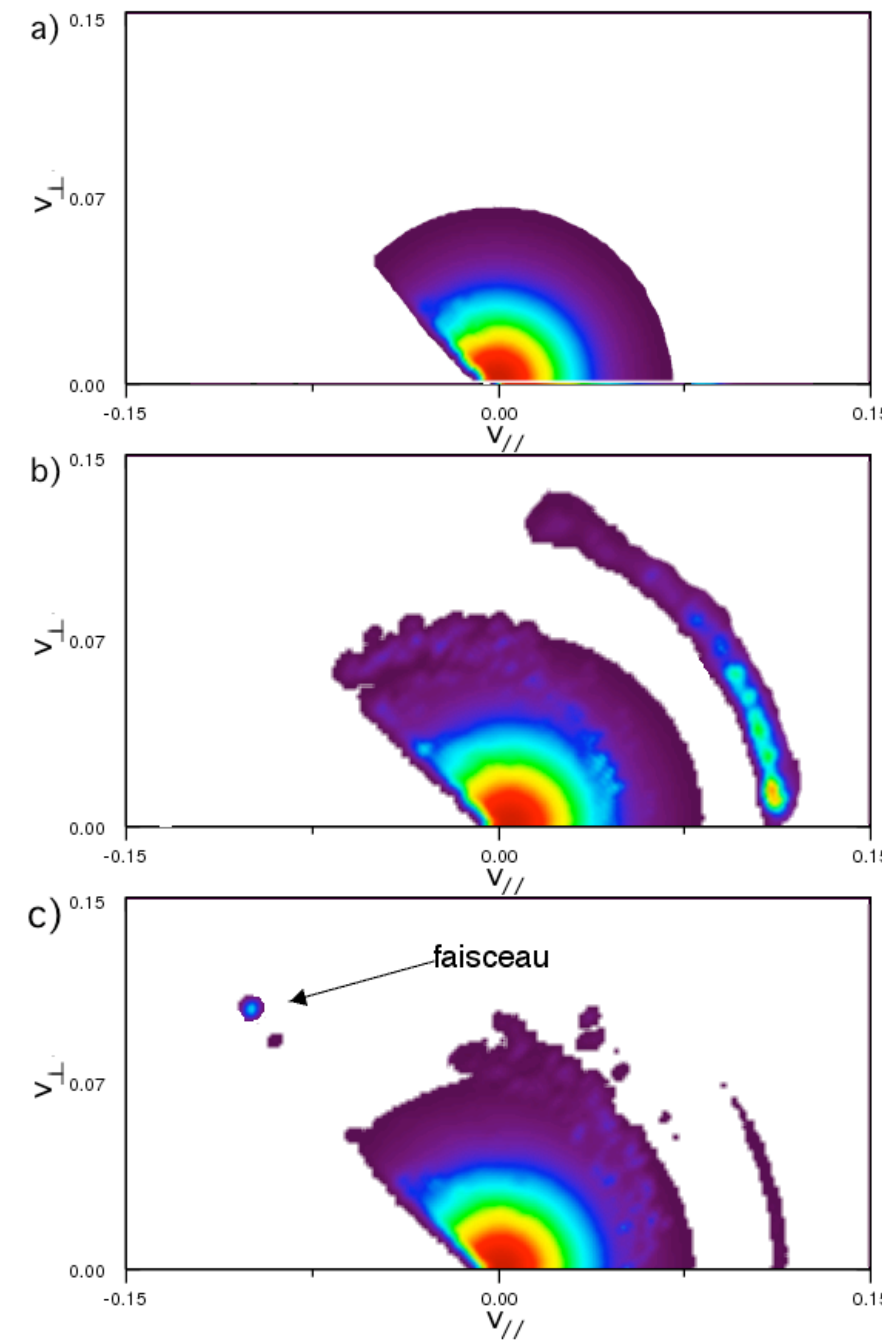

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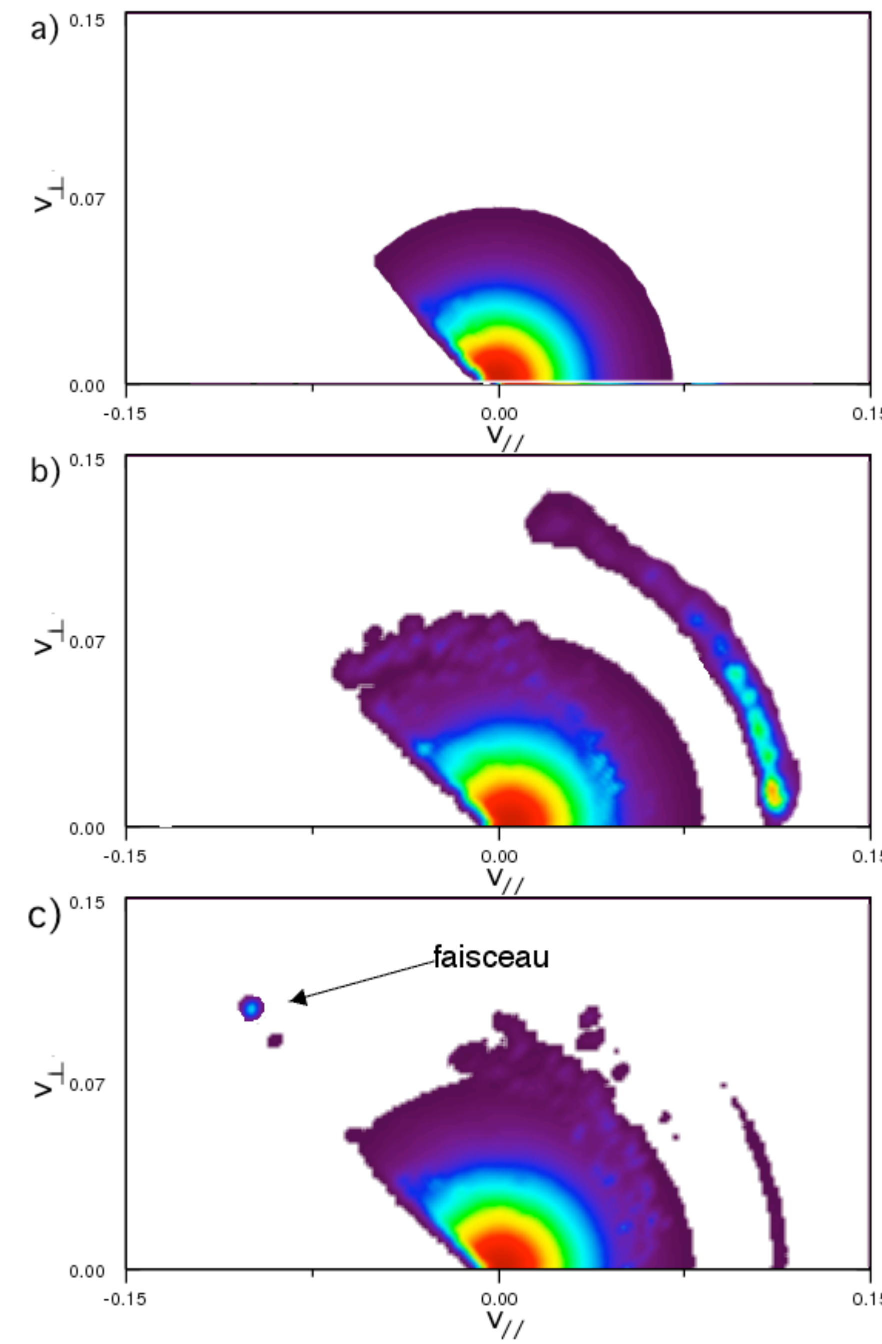


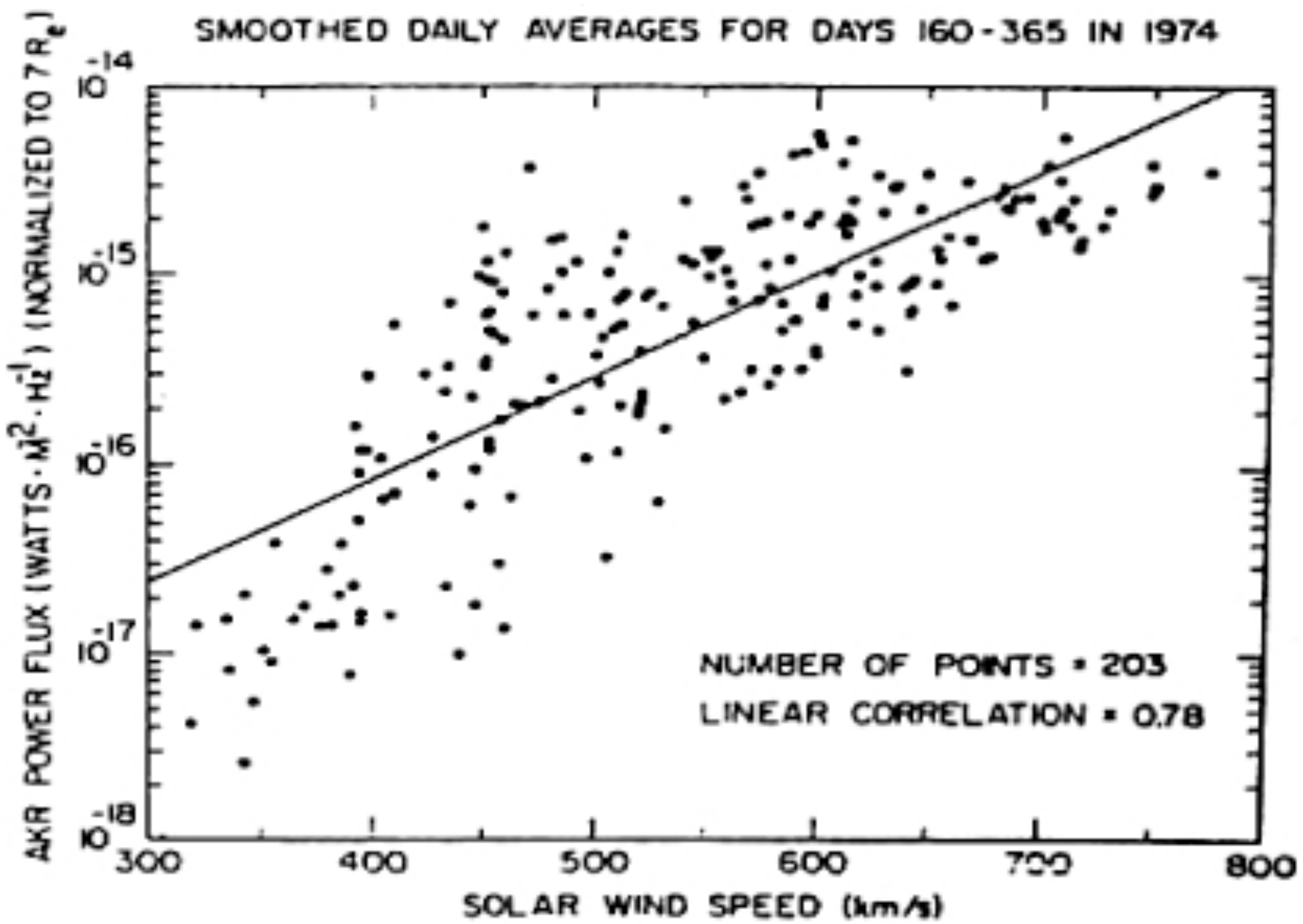
- Acceleration of electrons :

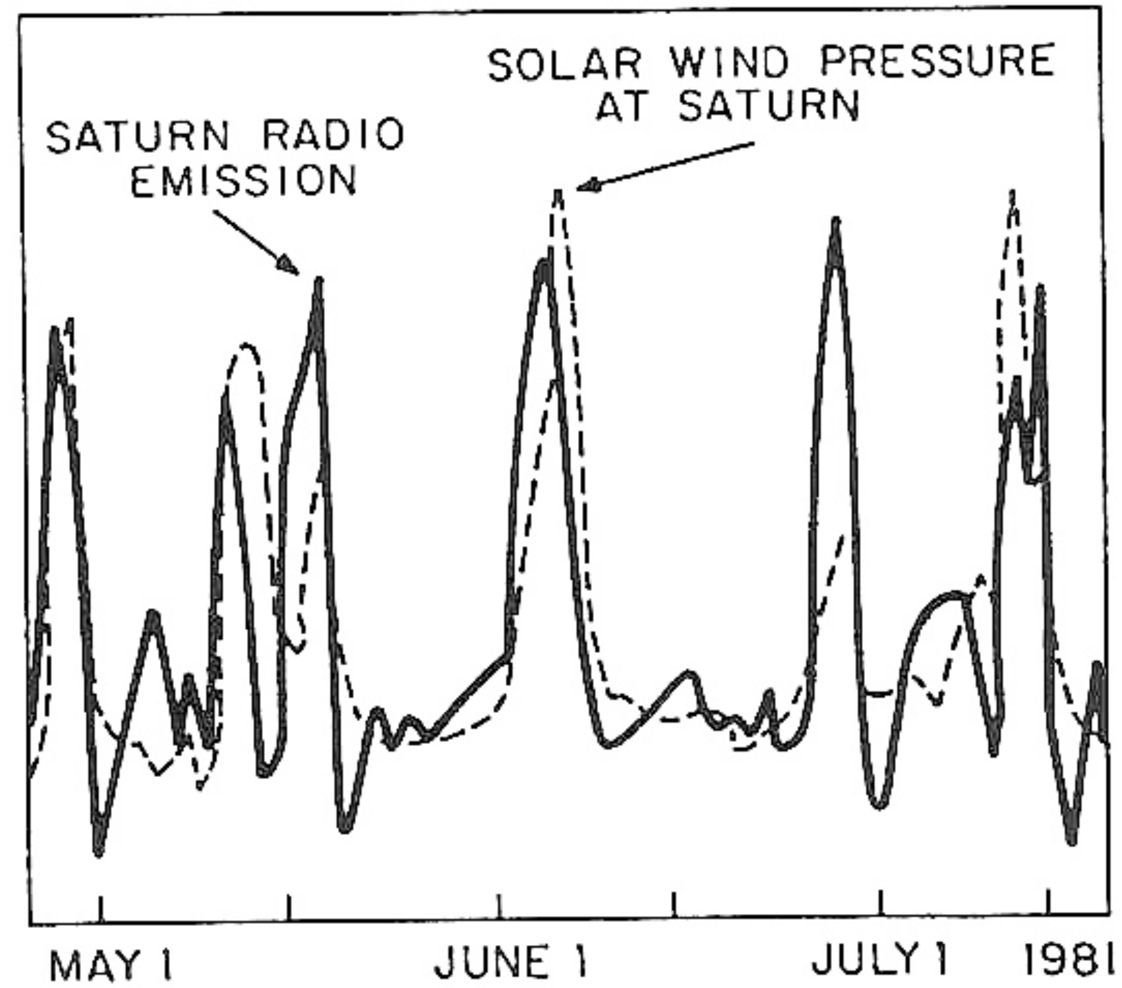
  - interactions B/satellites ▯ $E_{//}$, heating

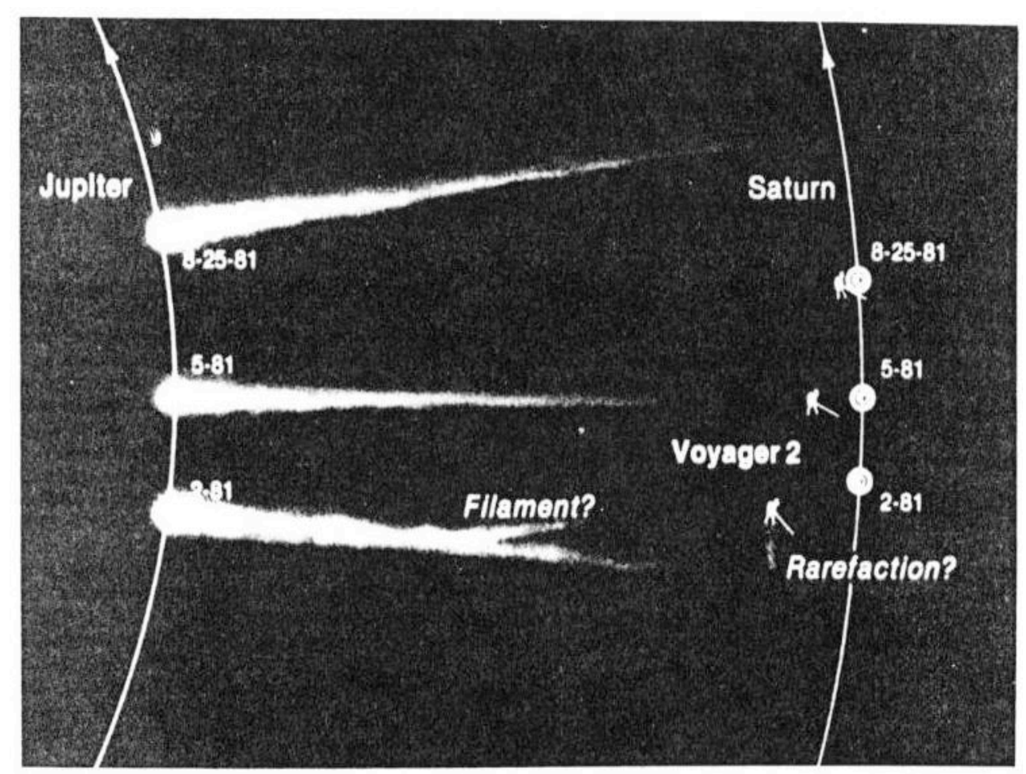
  - magnetic reconnection

  - MS compressions

NB : Strong correlation between Solar Wind (P, V…)
and auroral radio emissions







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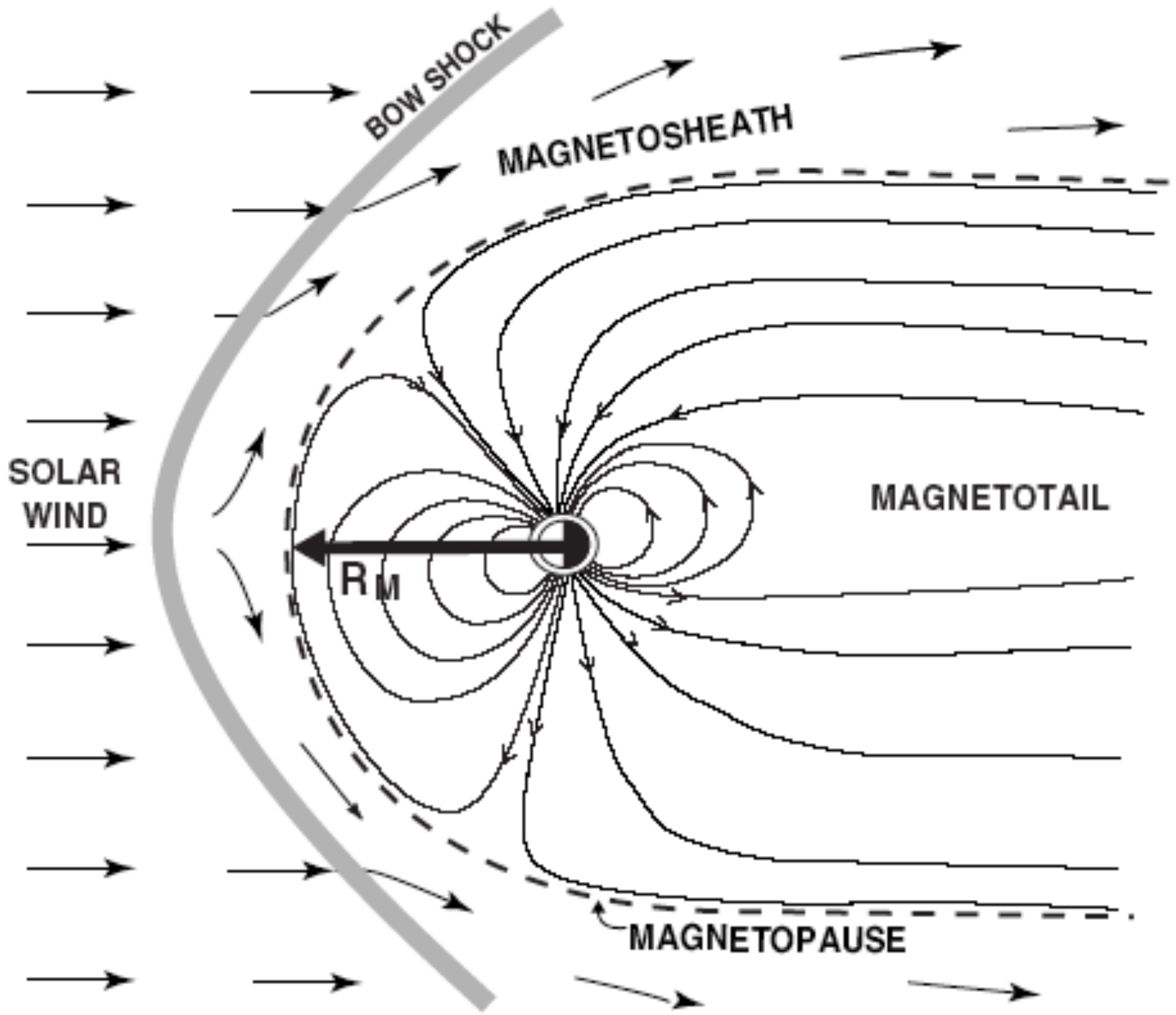

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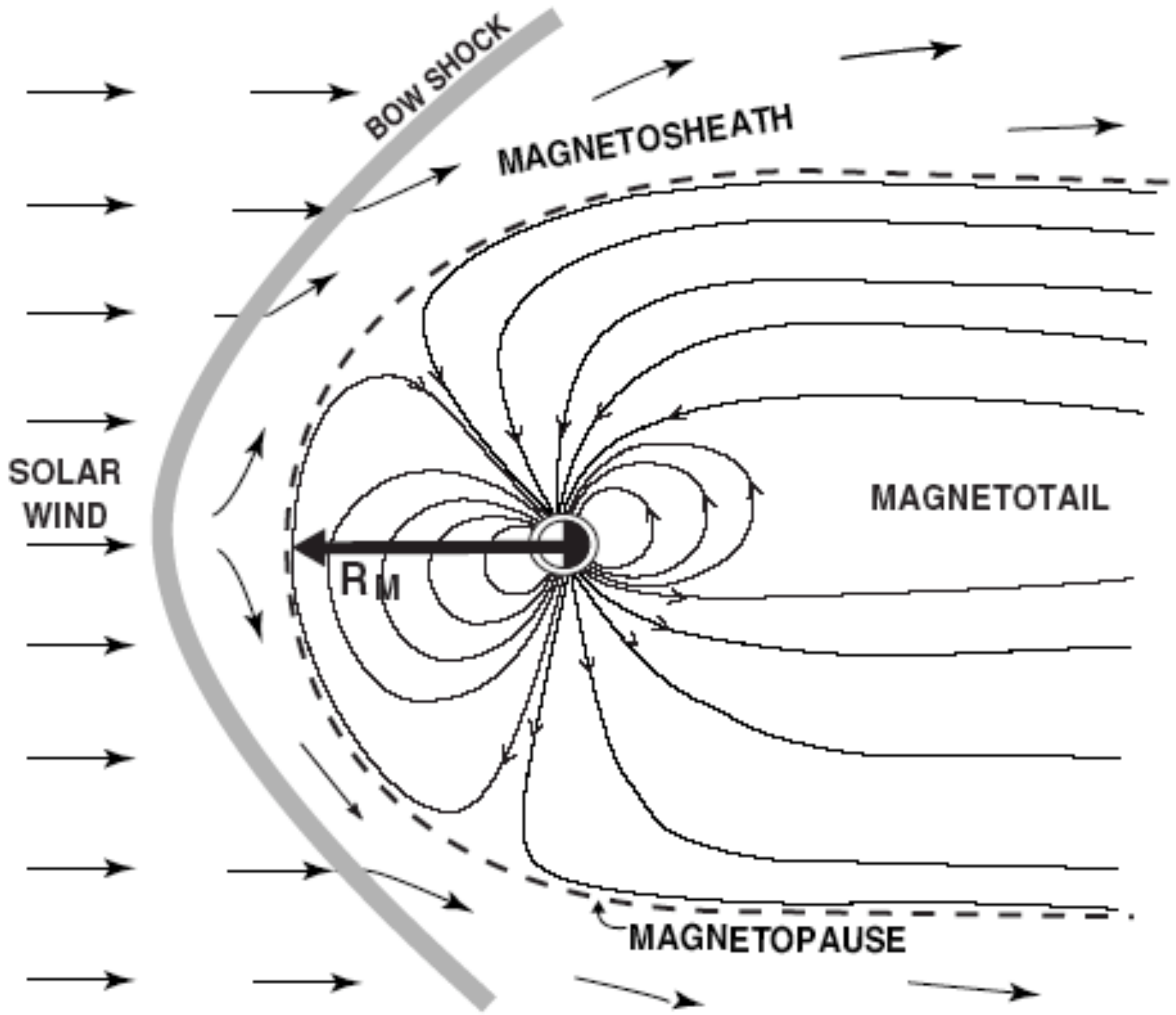
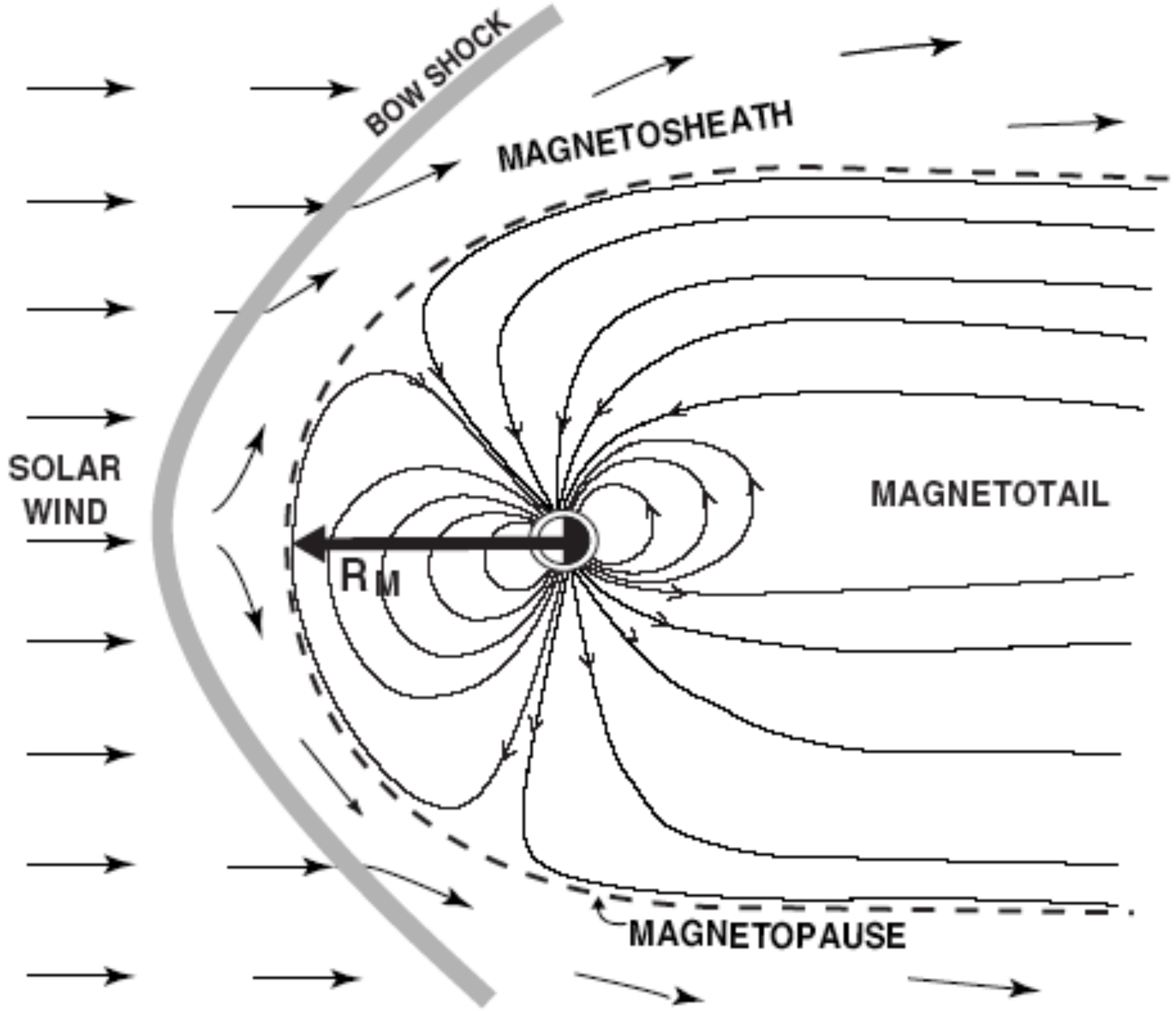


Magnetopause radius R_{MP} from pressure equilibrium :

Solar Wind - Magnetosphere Interaction



Magnetopause radius R_{MP} from pressure equilibrium :

- Kinetic energy flux on MS cross-section : $P_C \sim \; NmV^2 \, V \; \pi R_{MP}^2$

  $N = N_o/d^2 \quad N_o = 5 \text{ cm}^{-3} \quad m \sim 1.1 \times m_p$

- Poynting flux of B_{IMF} on MS cross-section : $P_B = \int_{MP} (\mathbf{E} \times \mathbf{B}/\mu_o).\mathbf{dS}$

  $\mathbf{E} = -\mathbf{V} \times \mathbf{B} \quad \mathbf{E} \times \mathbf{B} = VB_\perp^2$ $\quad\quad P_B = B_\perp^2/\mu_o \, V \; \pi R_{MP}^2$

Solar Wind expansion

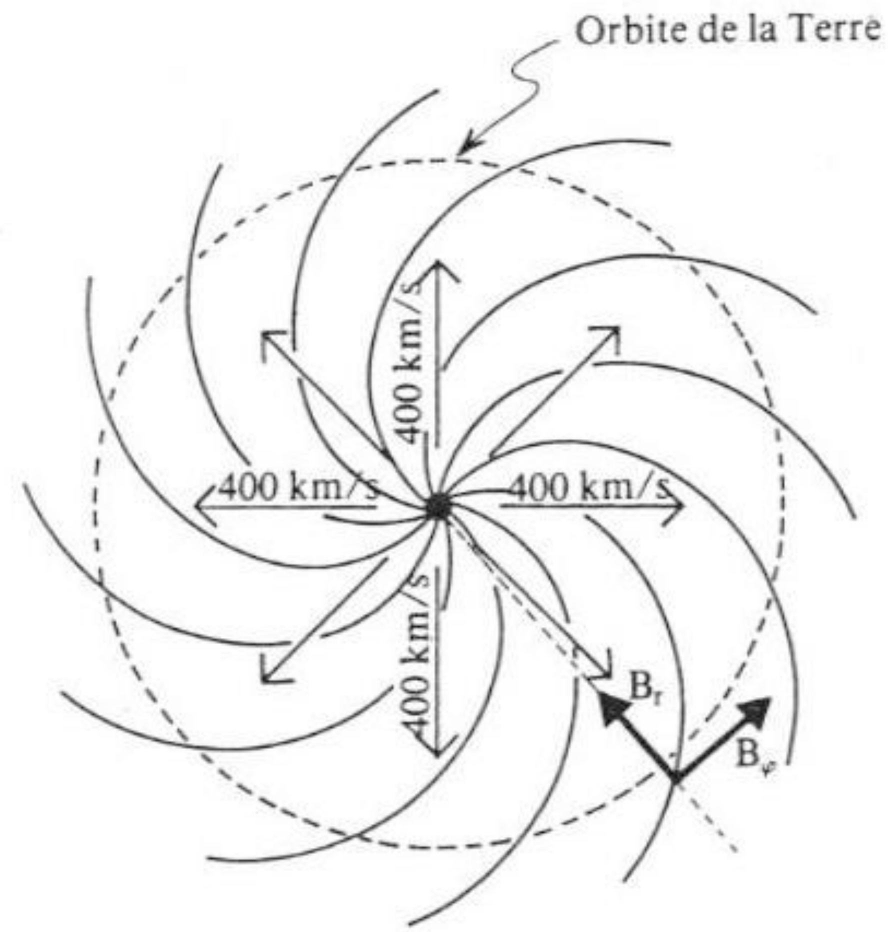
$V \sim c^{te}$

$N \sim d^{-2}$ (mass conservation)

$B_R \sim d^{-2}$ (magnetic flux conservation)

$B\varphi \sim d^{-1}$ ($B_R/B\varphi = V/\Omega d$) $\Rightarrow$ $B \sim d^{-1}$

(beyond Jupiter orbit, $B \sim B\varphi$)



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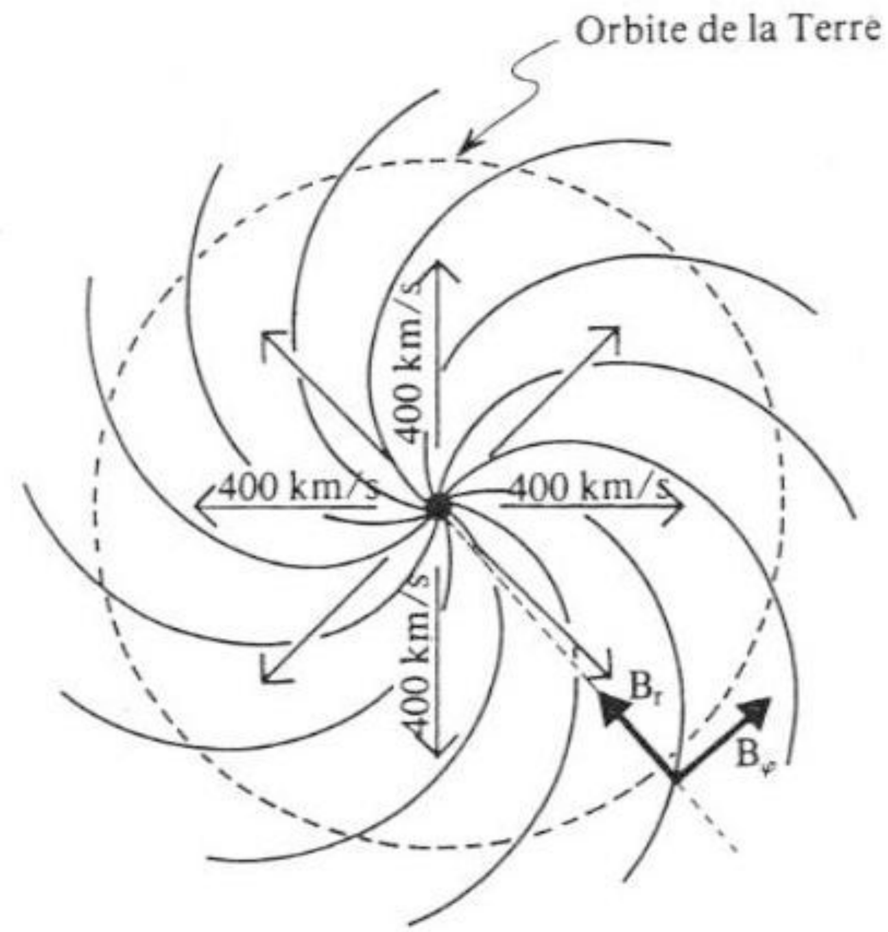

⇒ B^2 varies as NV^2 thus P_C varies as P_B

⇒ $P_C/P_B \sim 170$ beyond 1 UA

Flow / Obstacle	Weakly/Not magnetized *(Solar wind)*	Strongly magnetized *(Jovian magnetosphere)*
Weakly/Not magnetized *(Venus, Mars, Io)*	No Intense Cyclotron Radio Emission	Unipolar interaction ‡ Io-induced Radio Emission,
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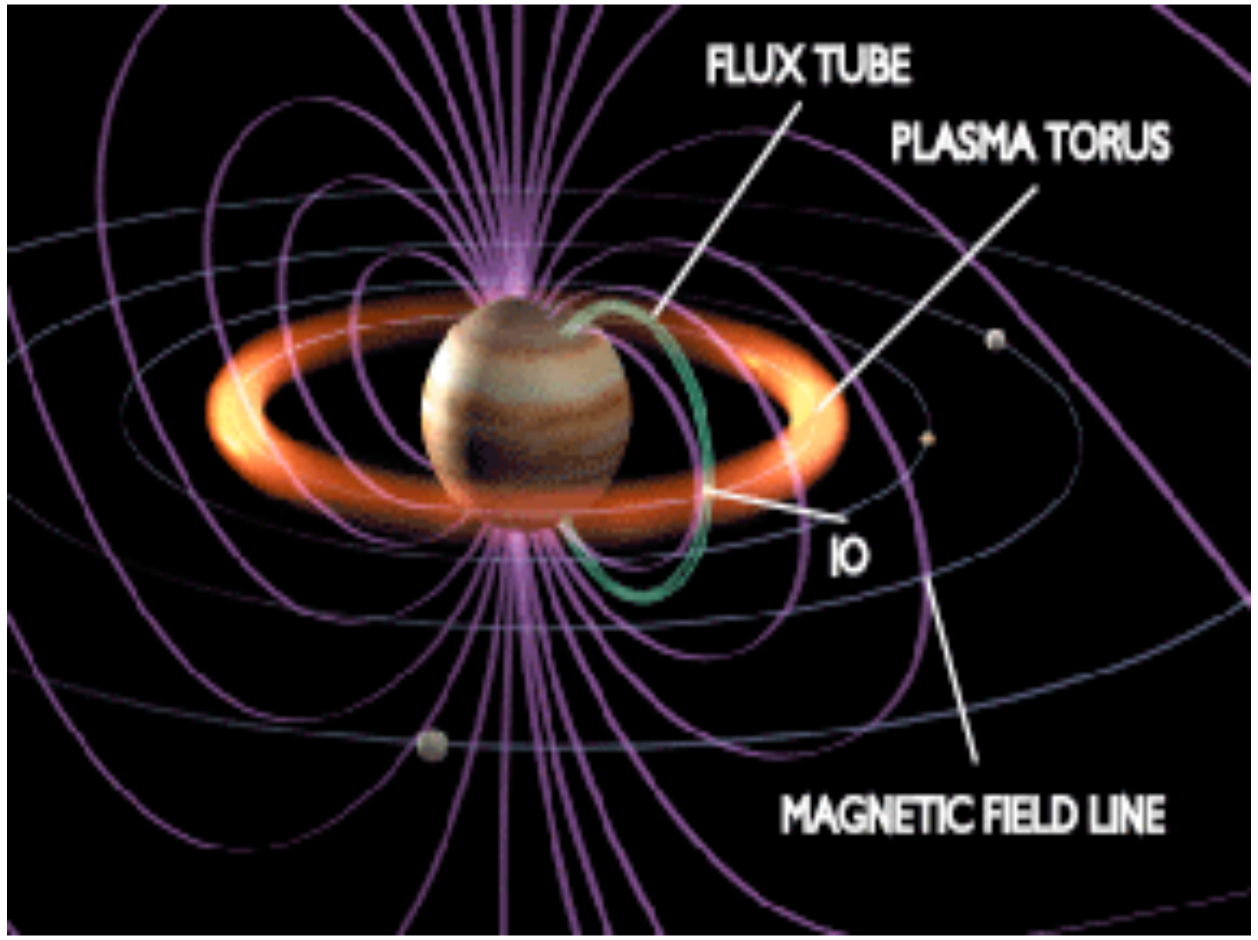
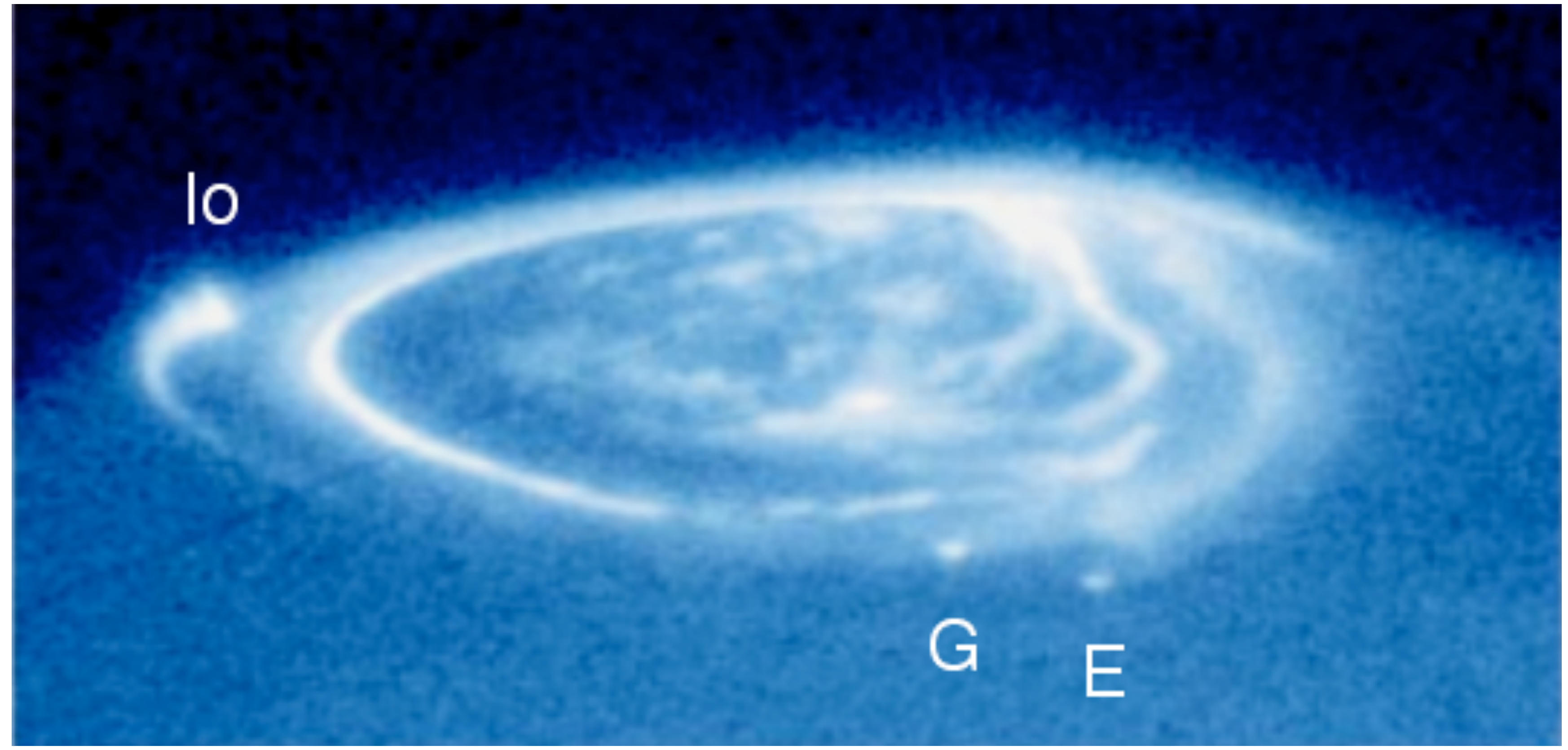
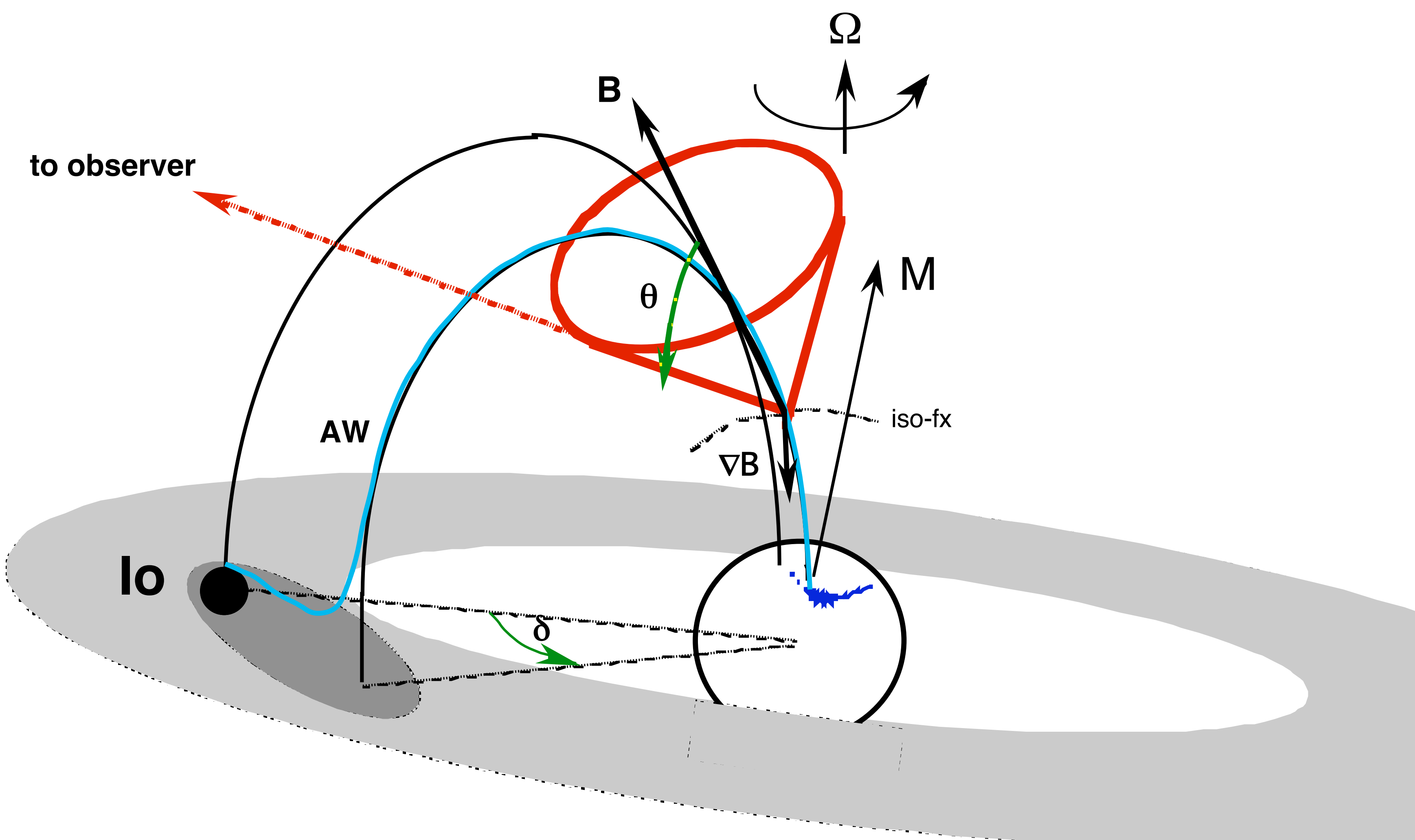
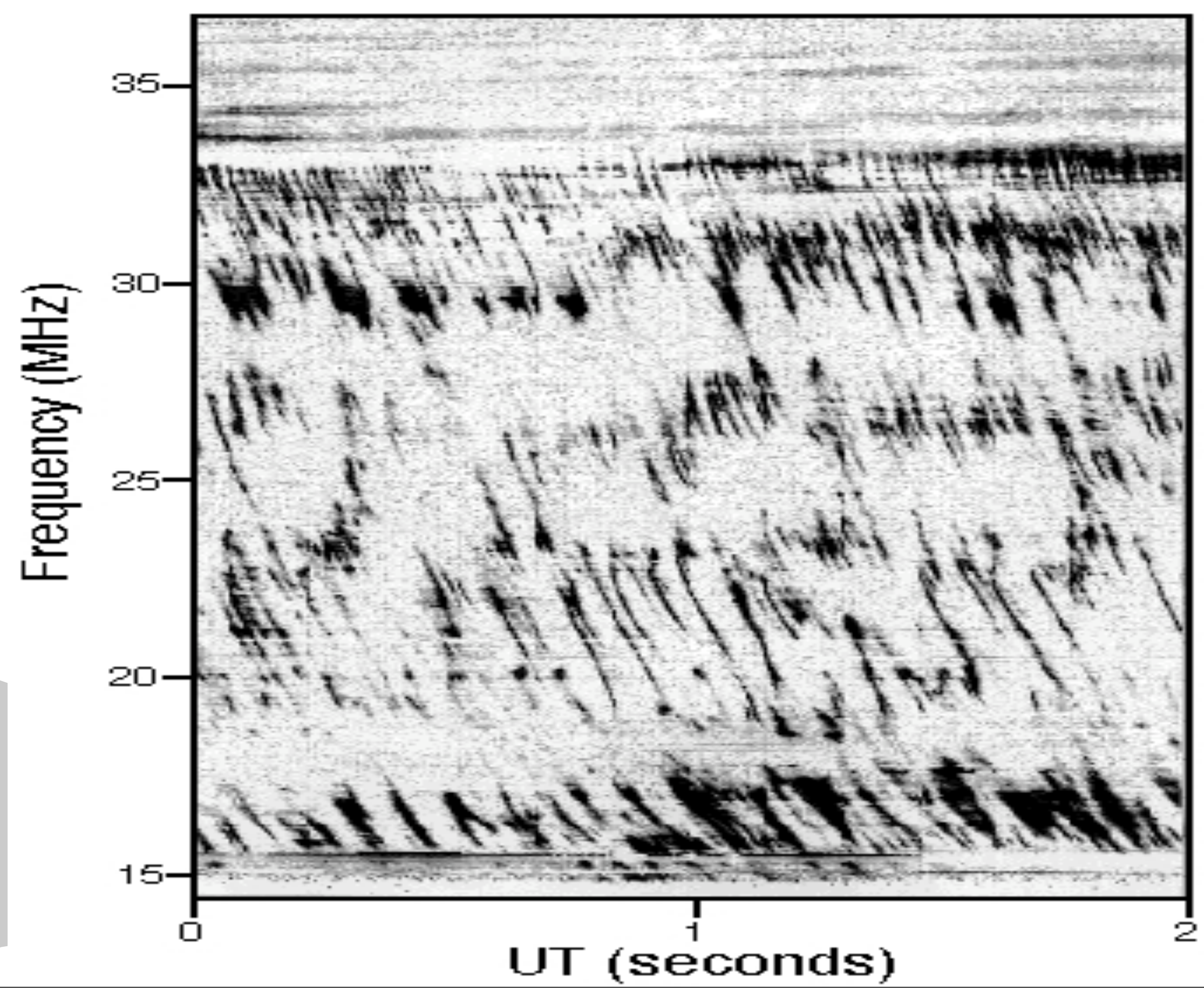
Satellite - $B_{Jupiter}$ interaction









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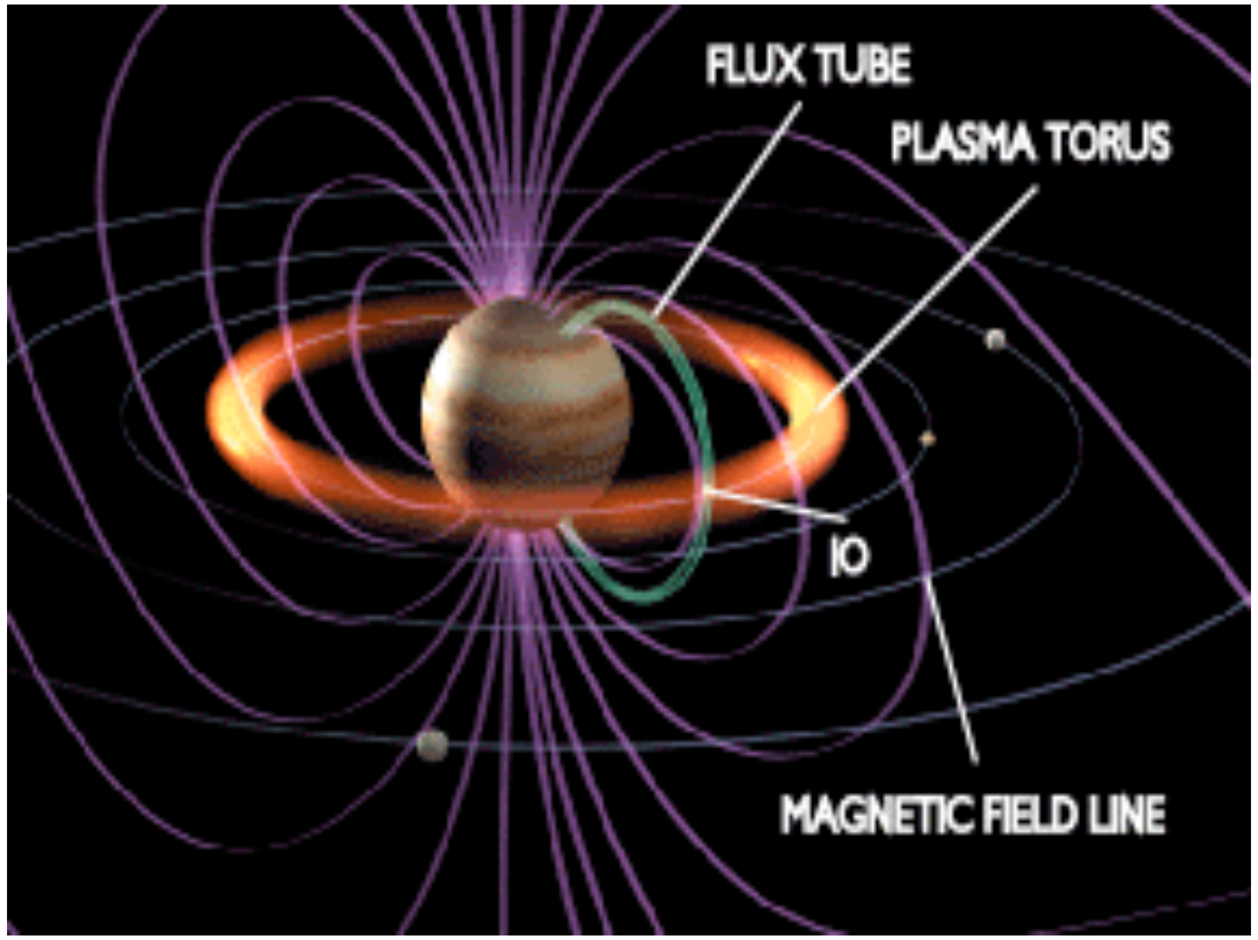

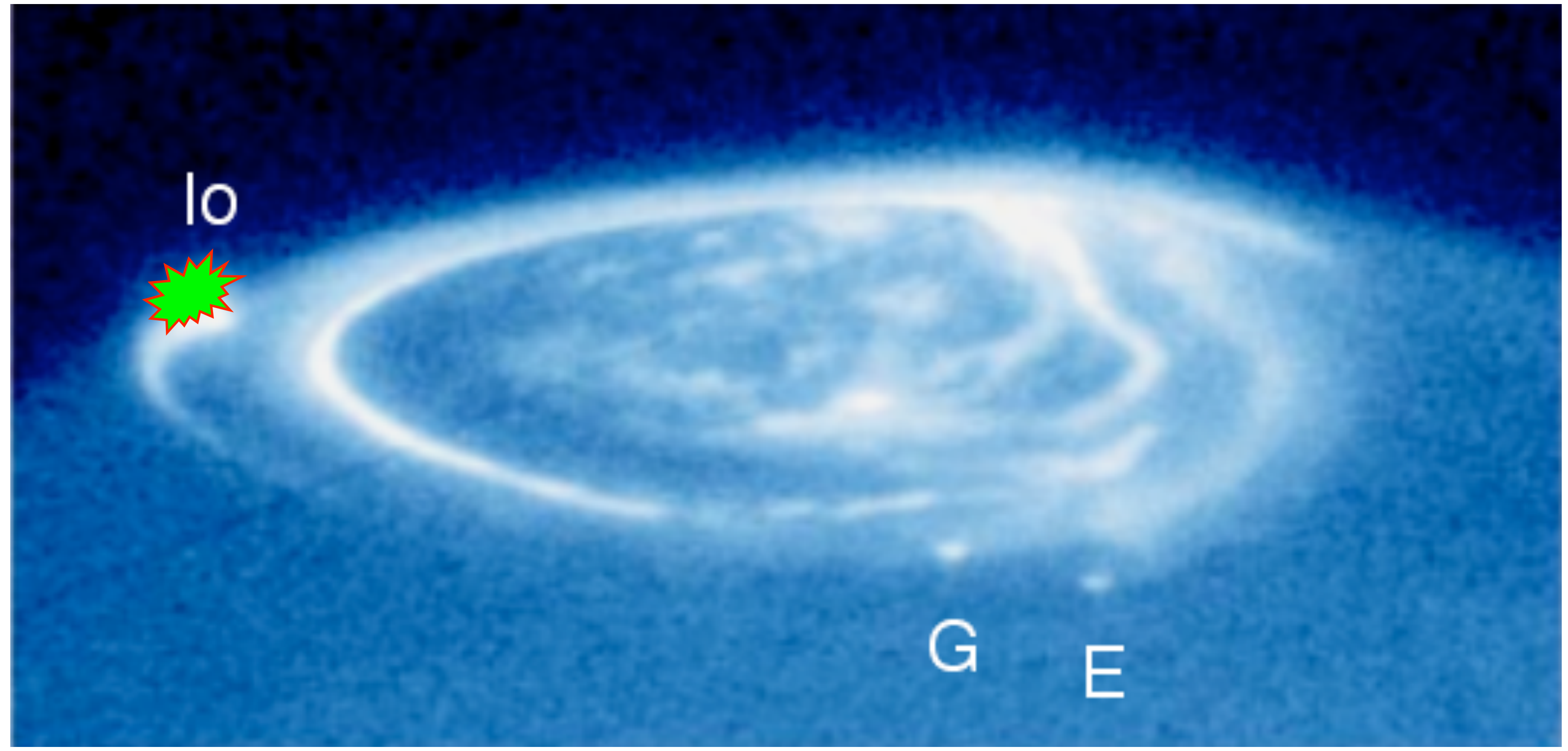

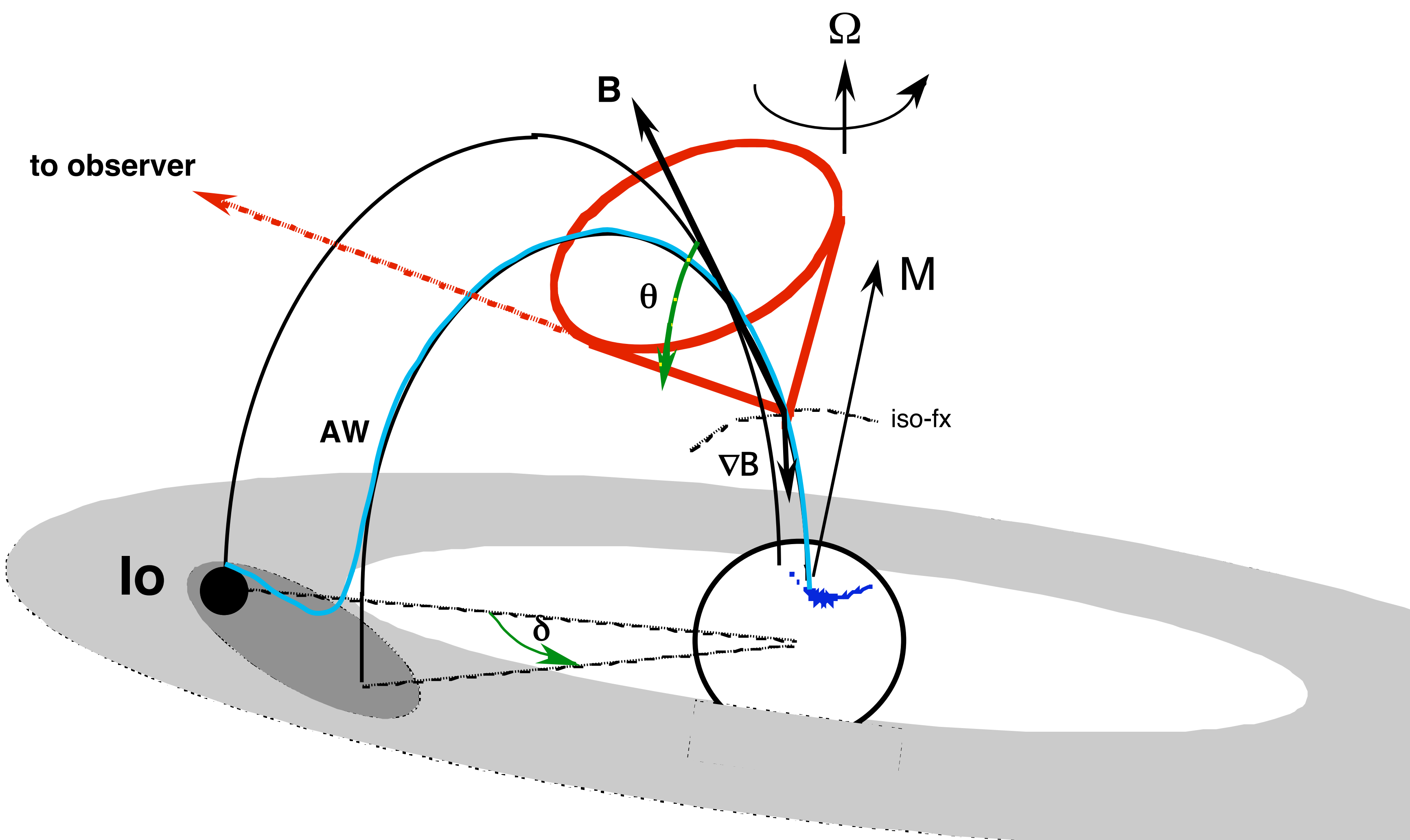

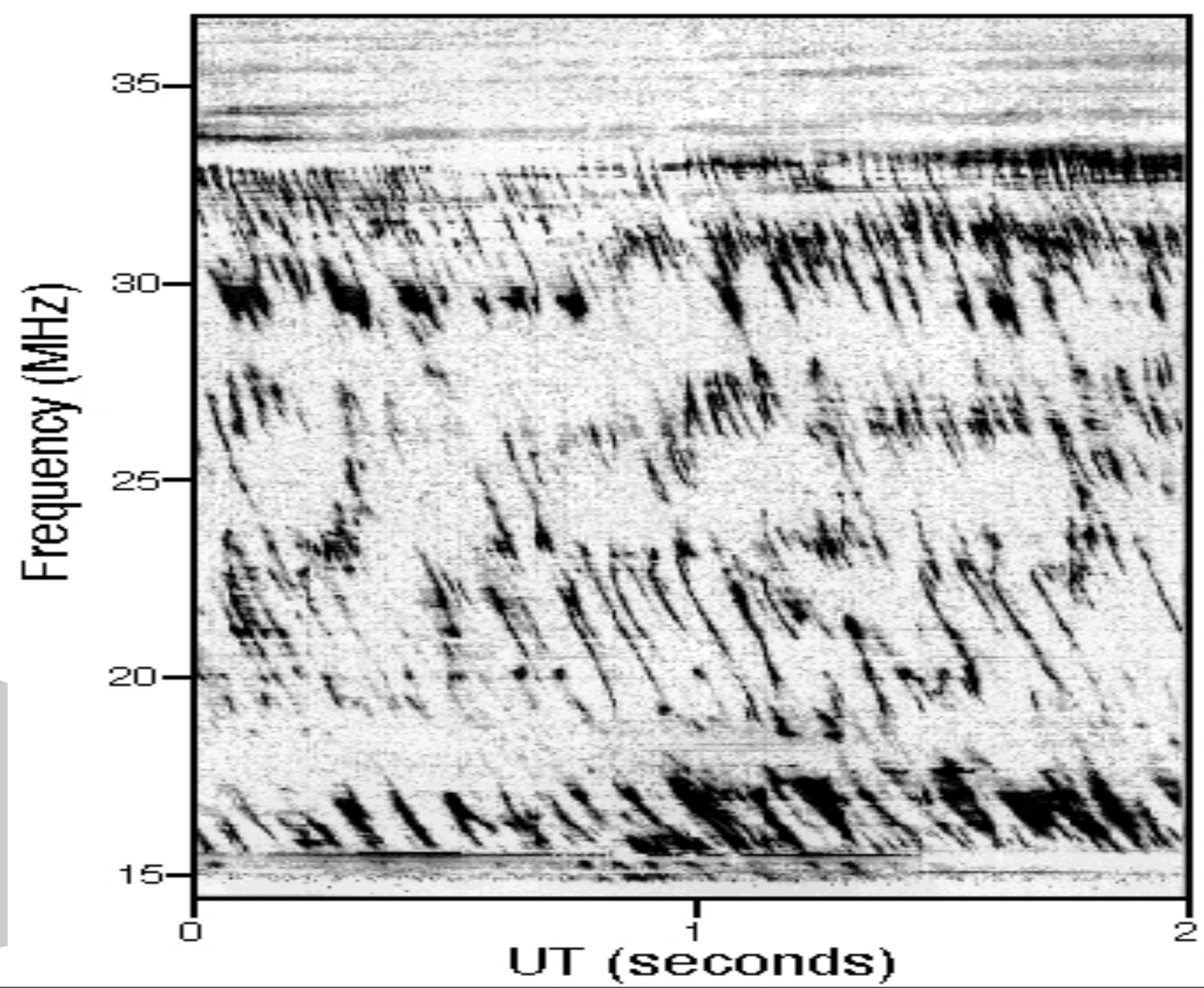

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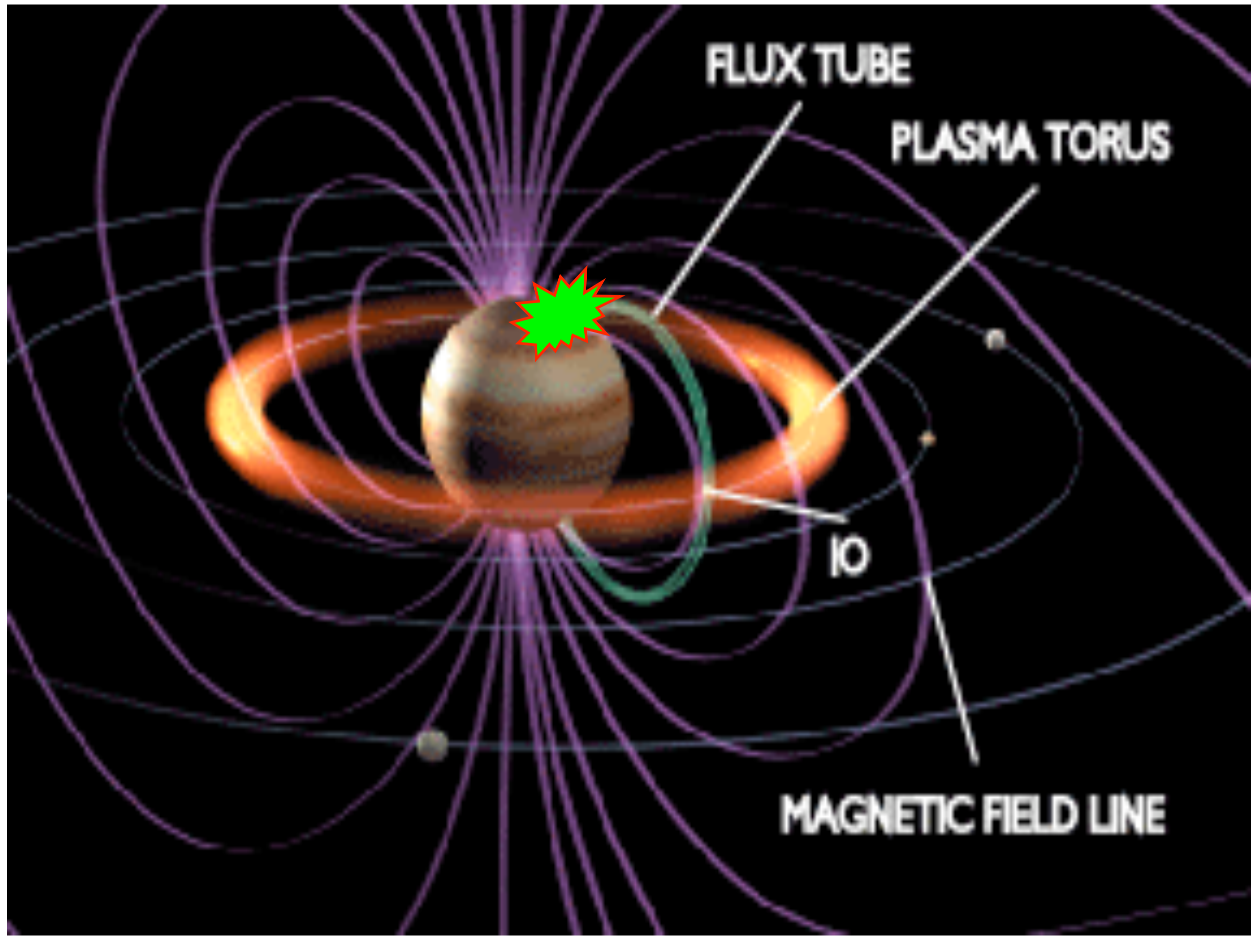
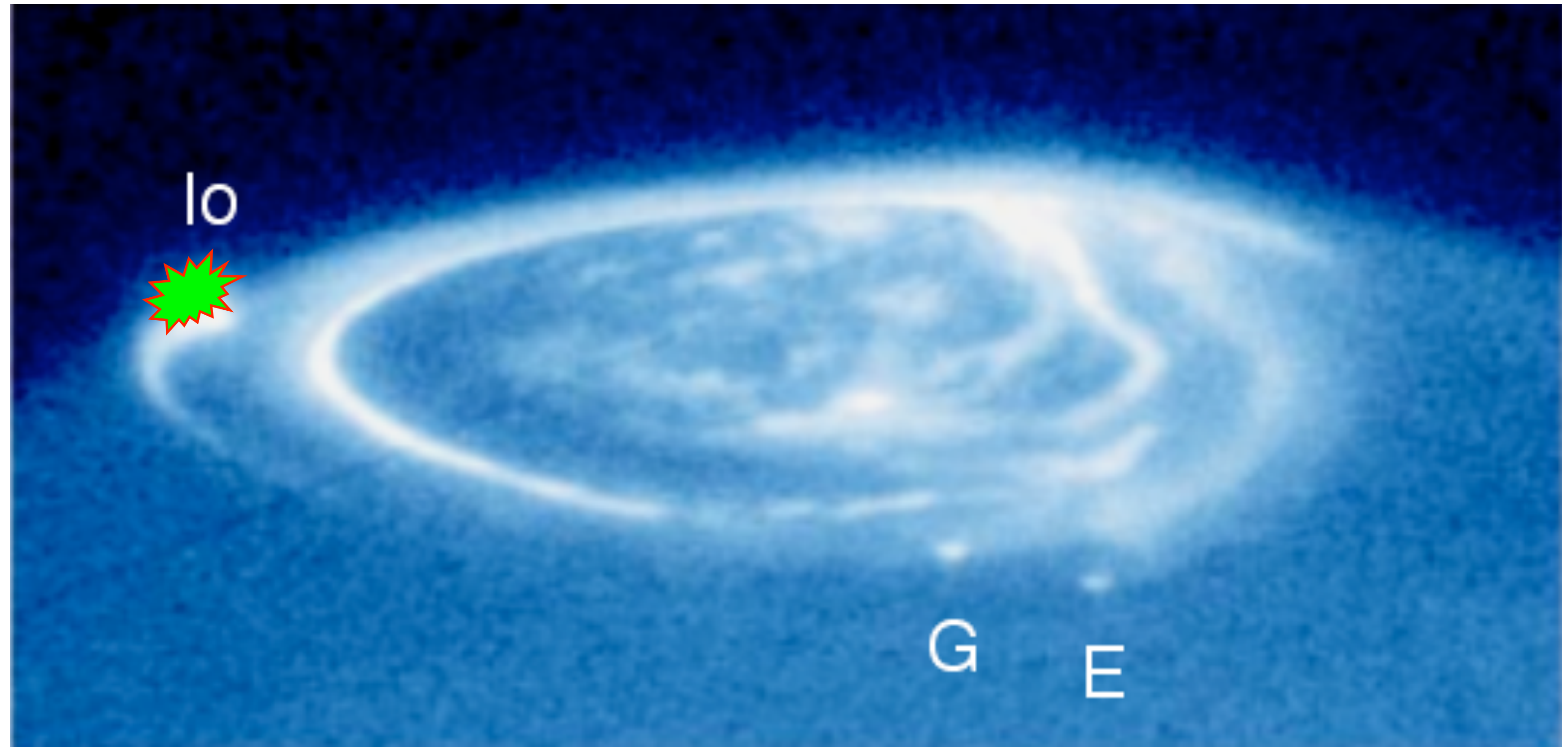
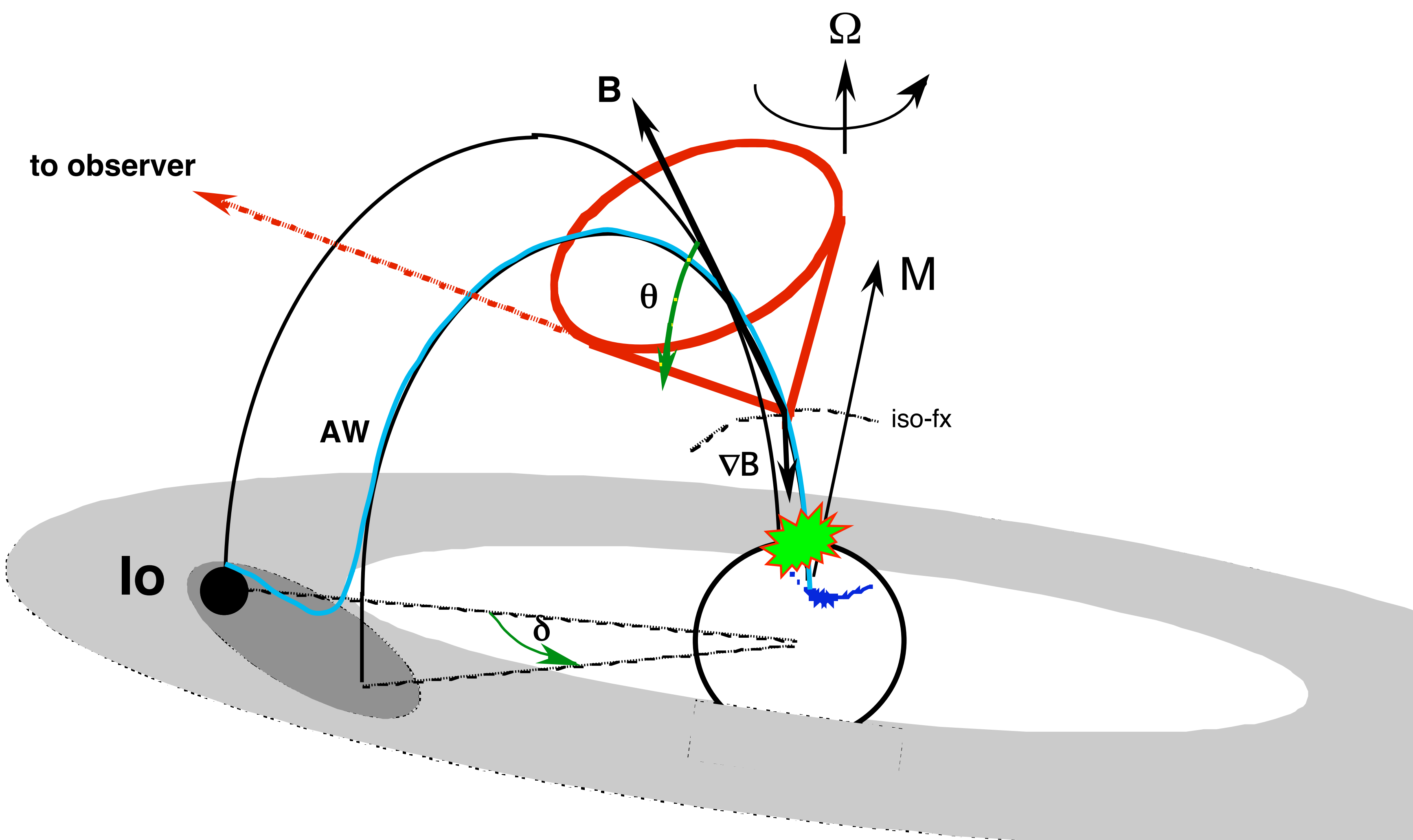
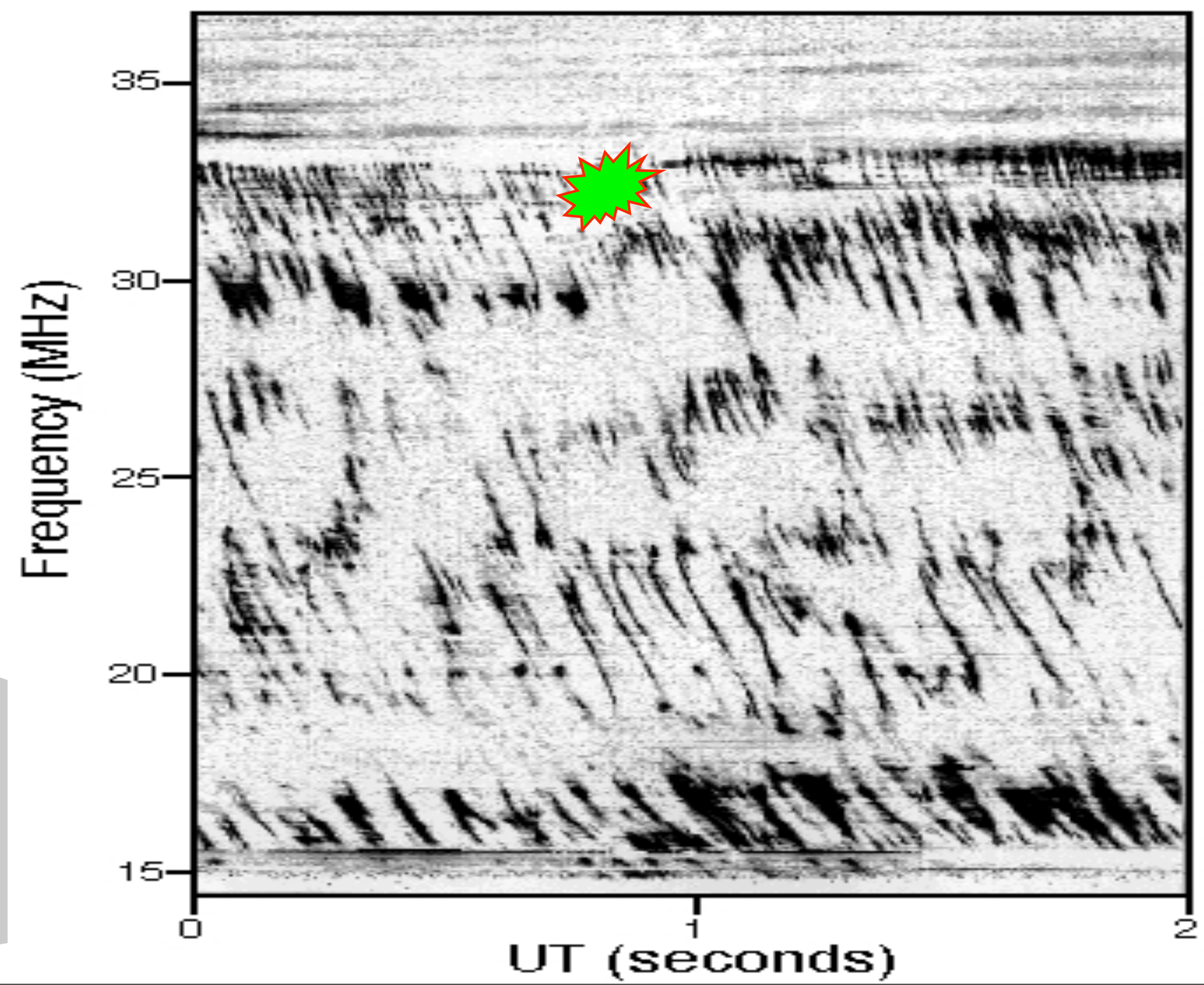
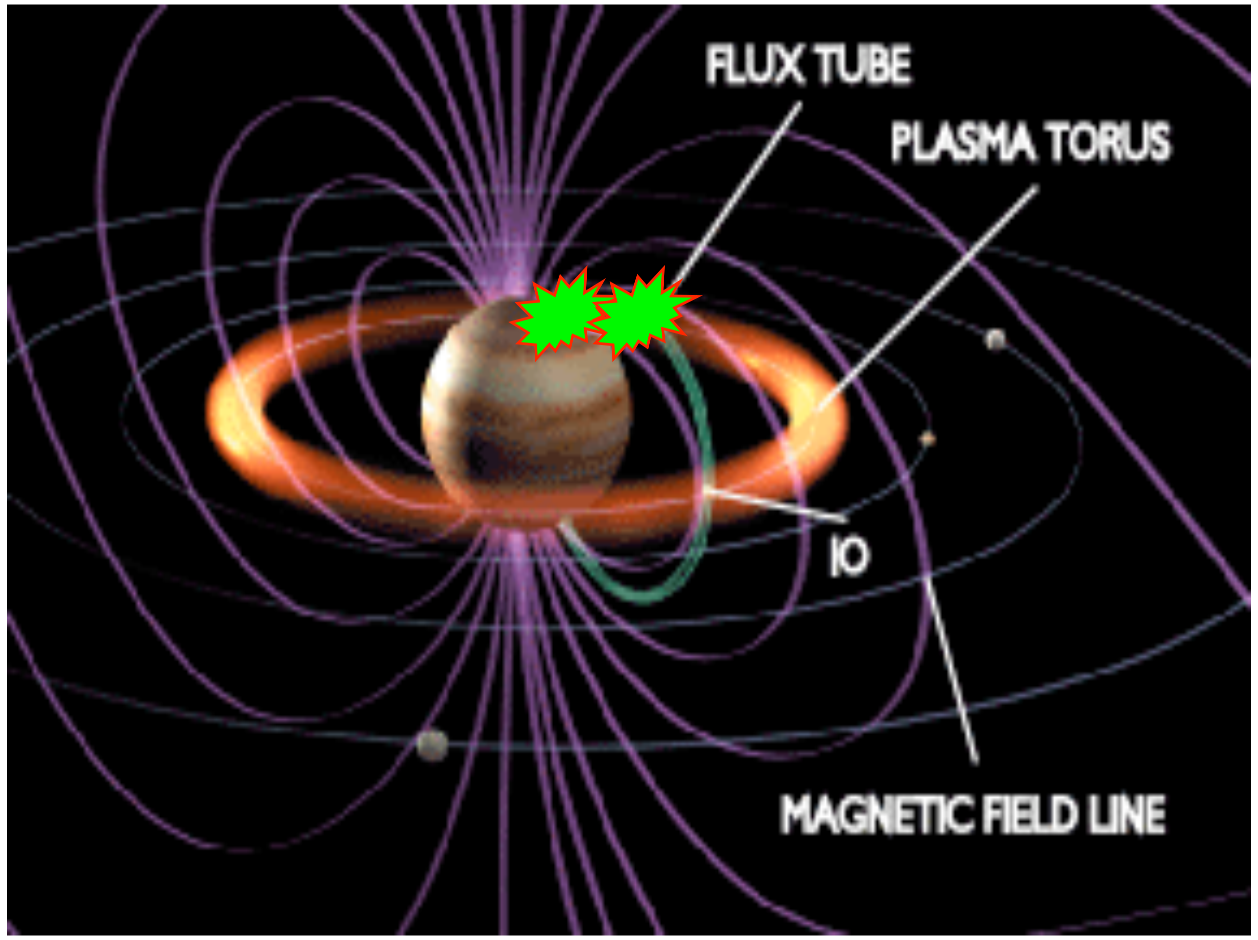


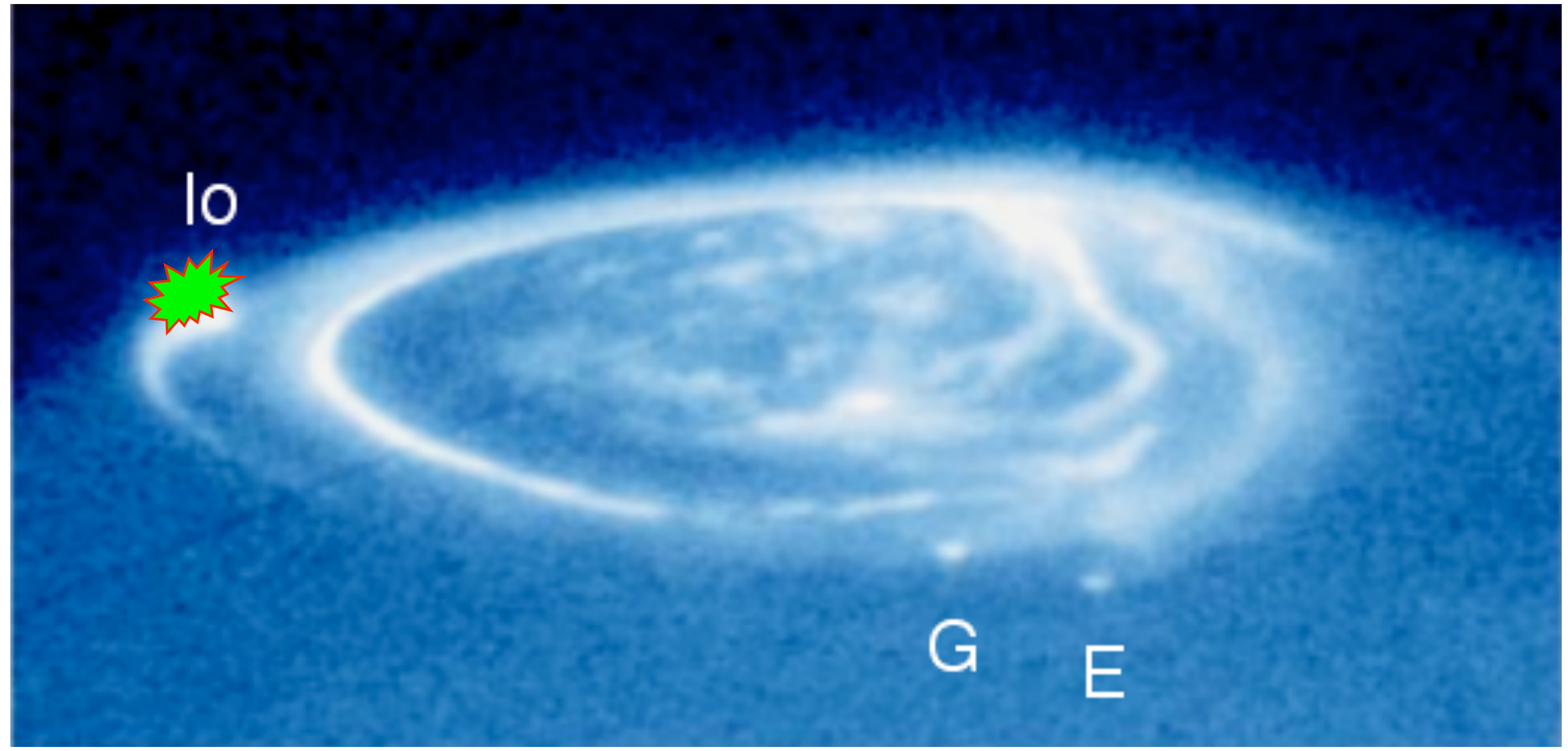


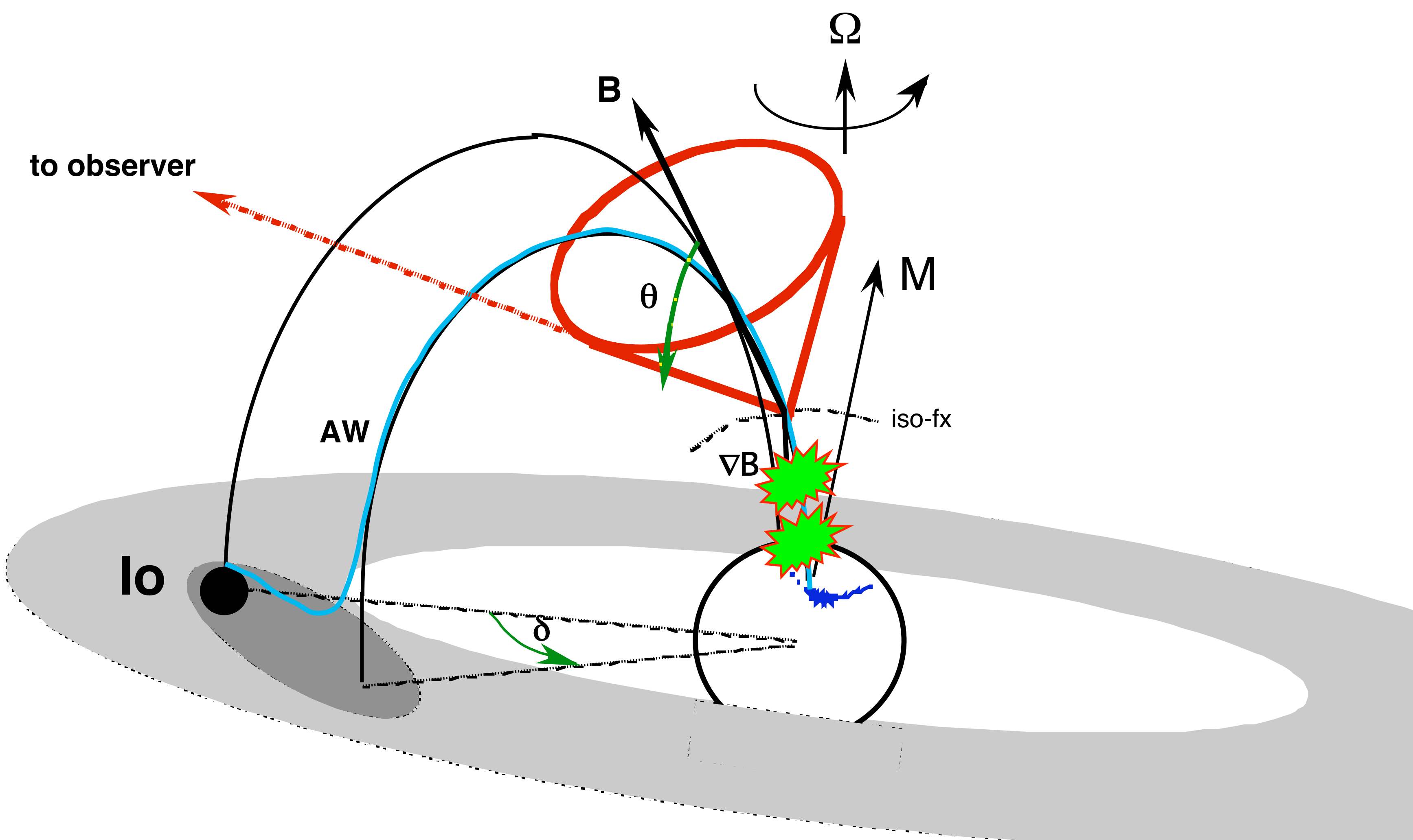


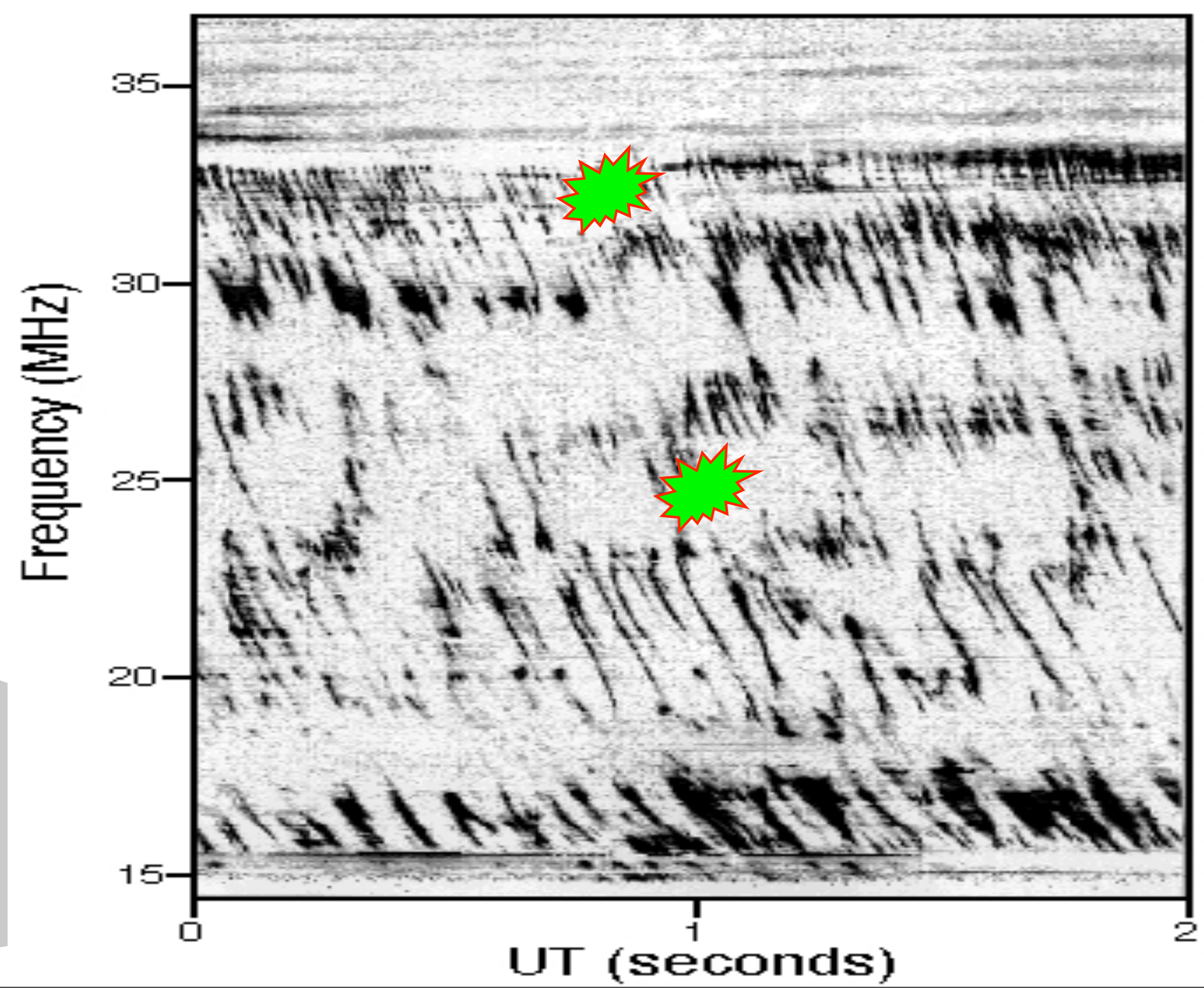


Satellite - $B_{Jupiter}$ interaction









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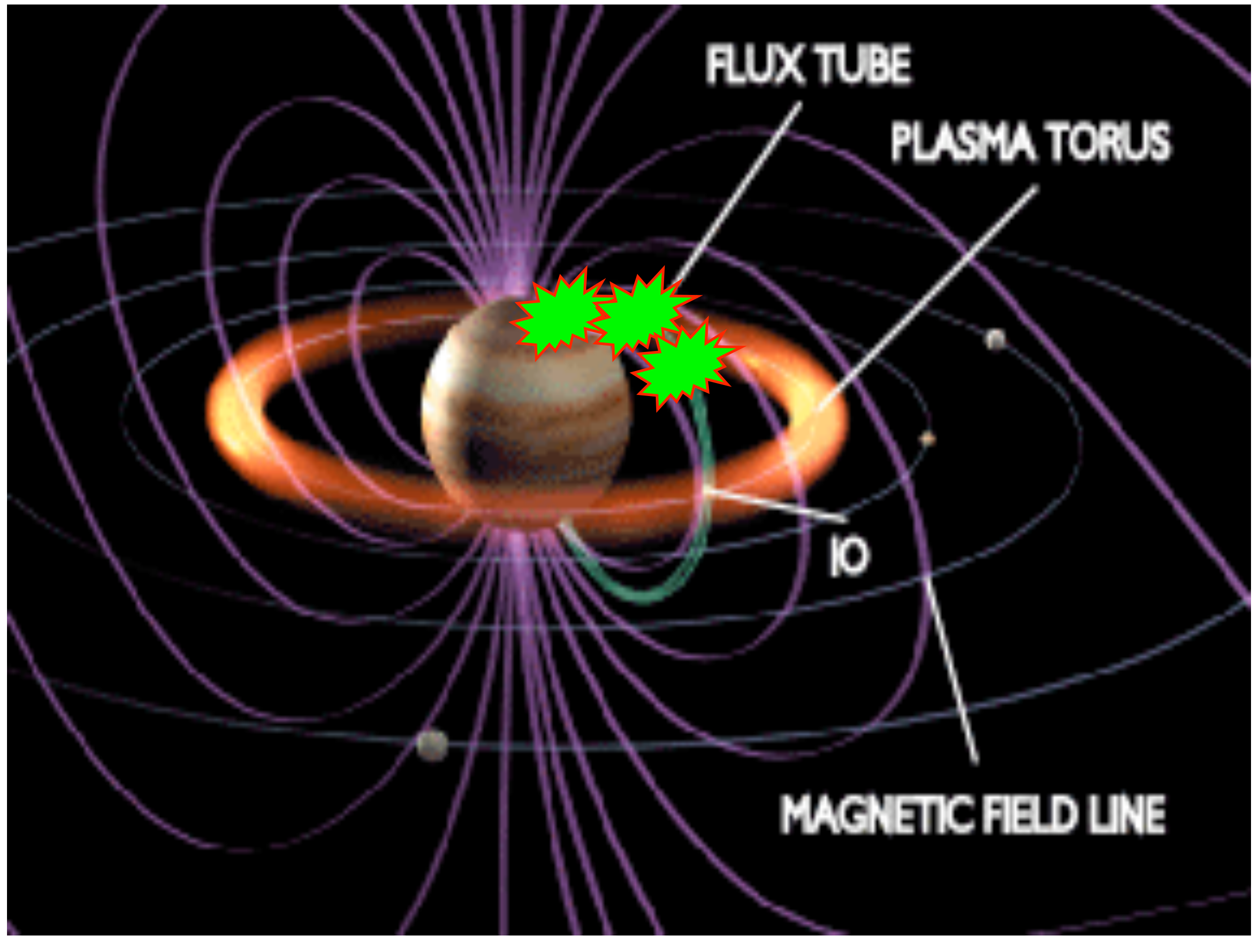
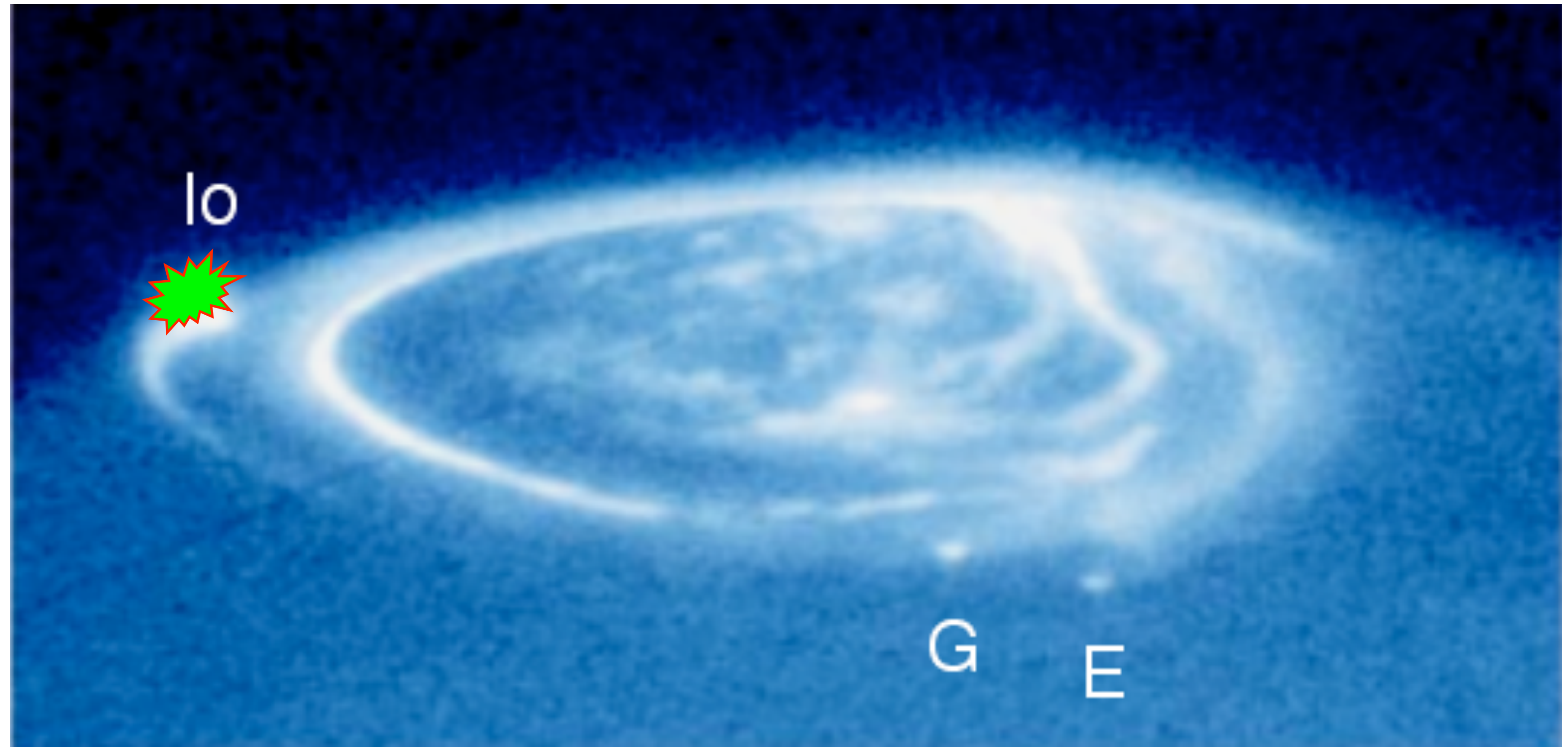
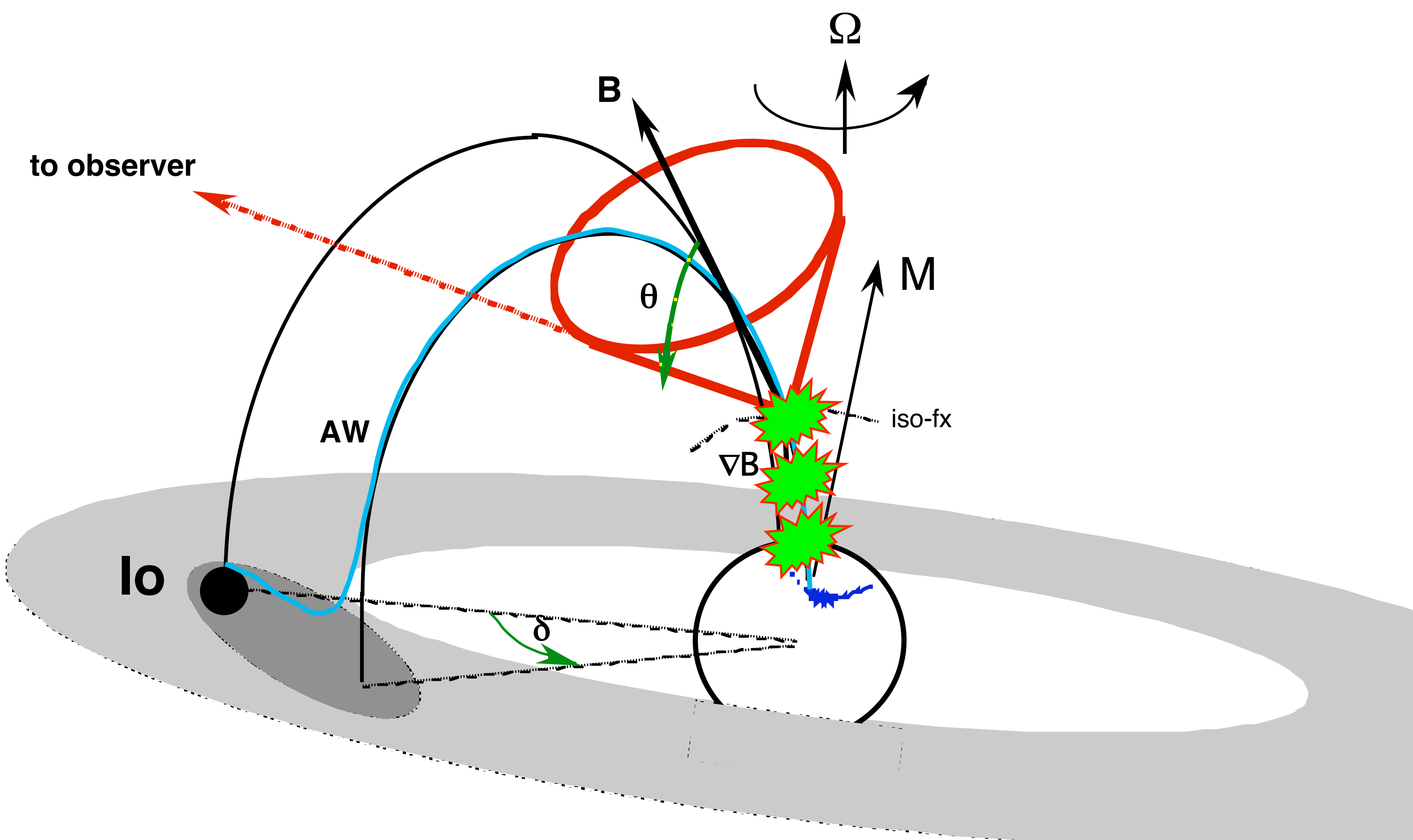
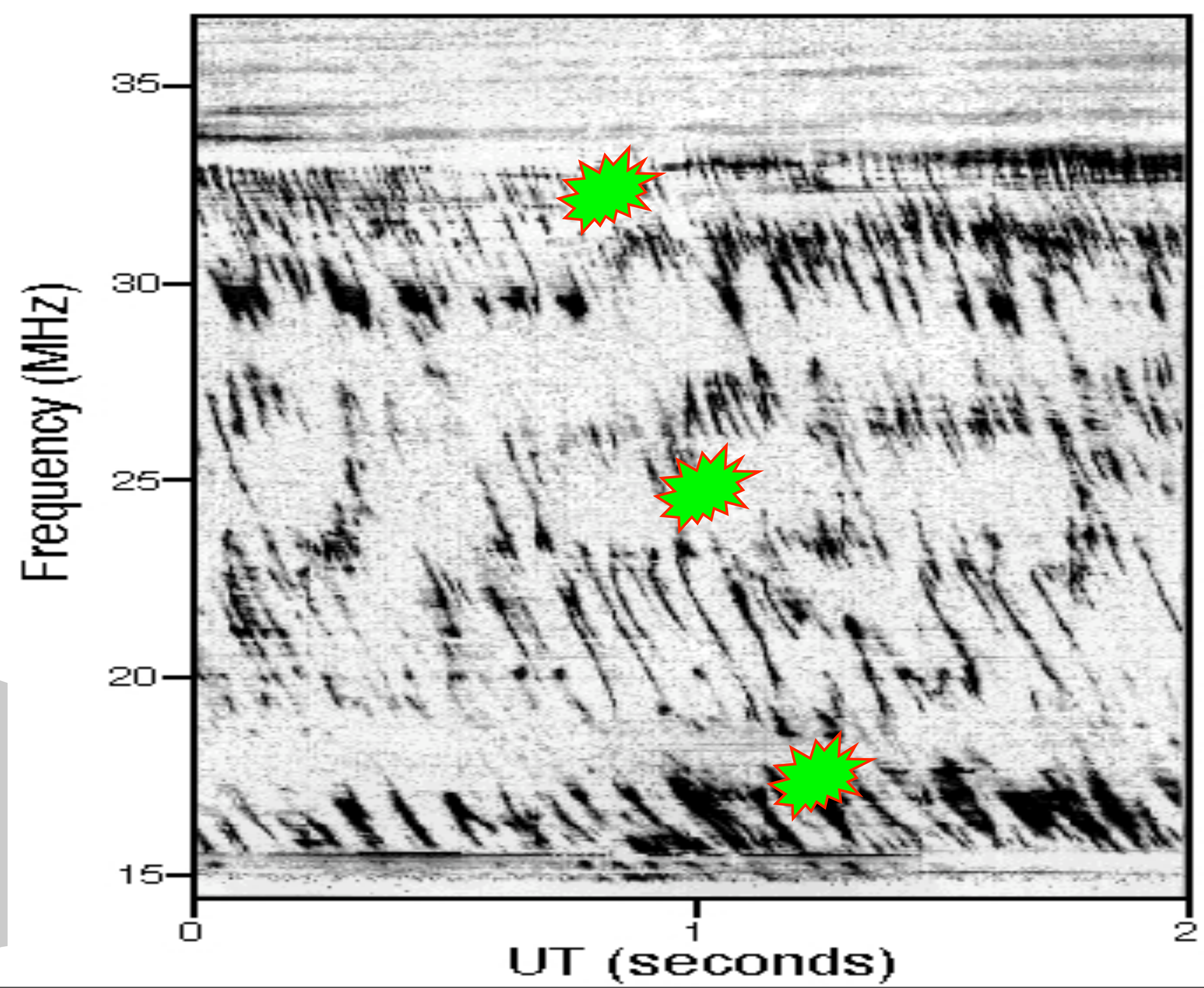








Unipolar interaction

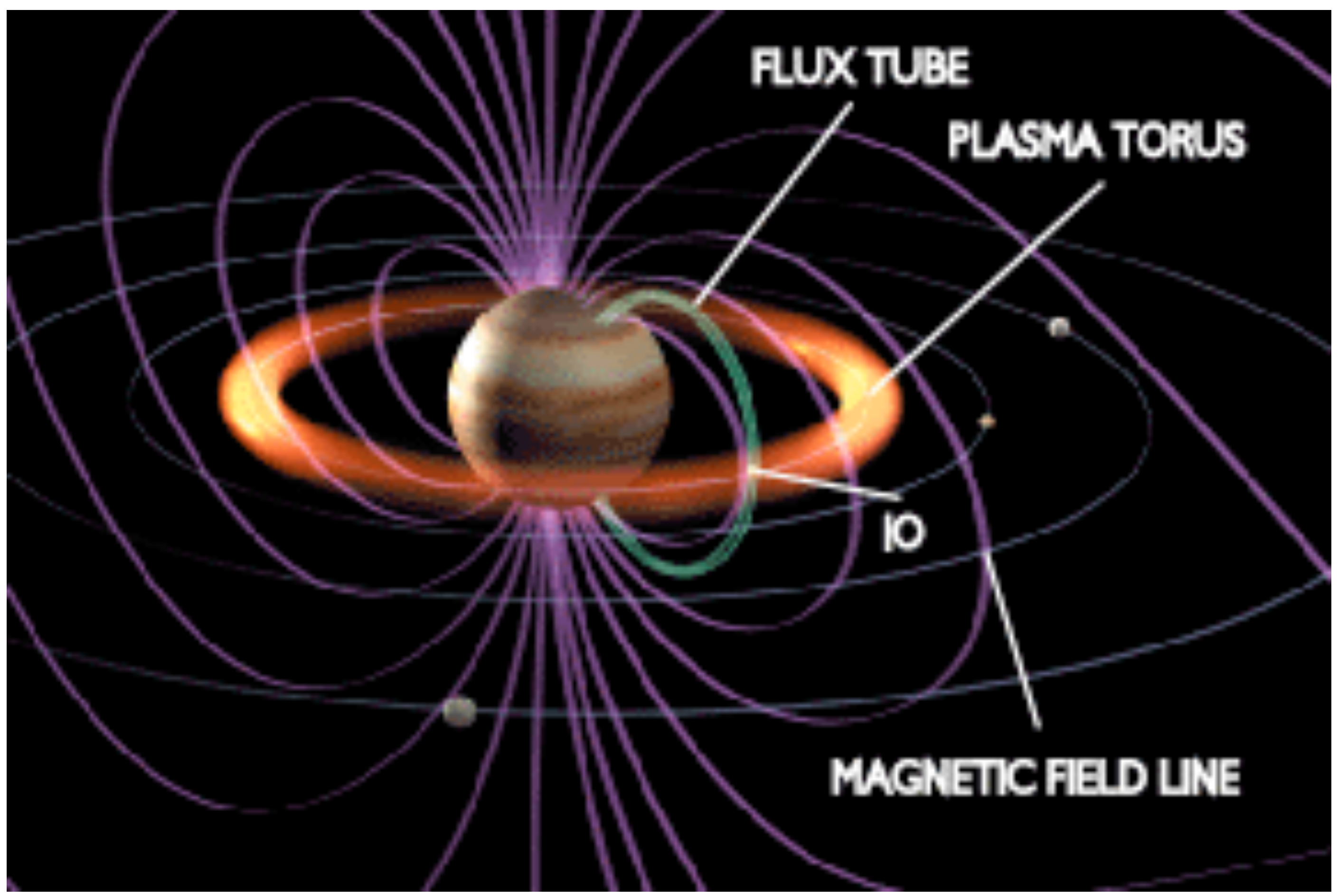
- Interaction via Alfvén waves & currents

(e.g. Io-Jupiter) $\phi = E\times 2R_{obs} = V\times B_{\perp}\times 2R_{obs}$

$P_d = \varepsilon' \, V B_{\perp}^2/\mu_o \, \pi R_{obs}^2$

$\varepsilon' = (1+M_A^{-2})^{-1/2}$ $M_A \leq \varepsilon' \leq 1$

$P_d = \varepsilon' \, P_B$



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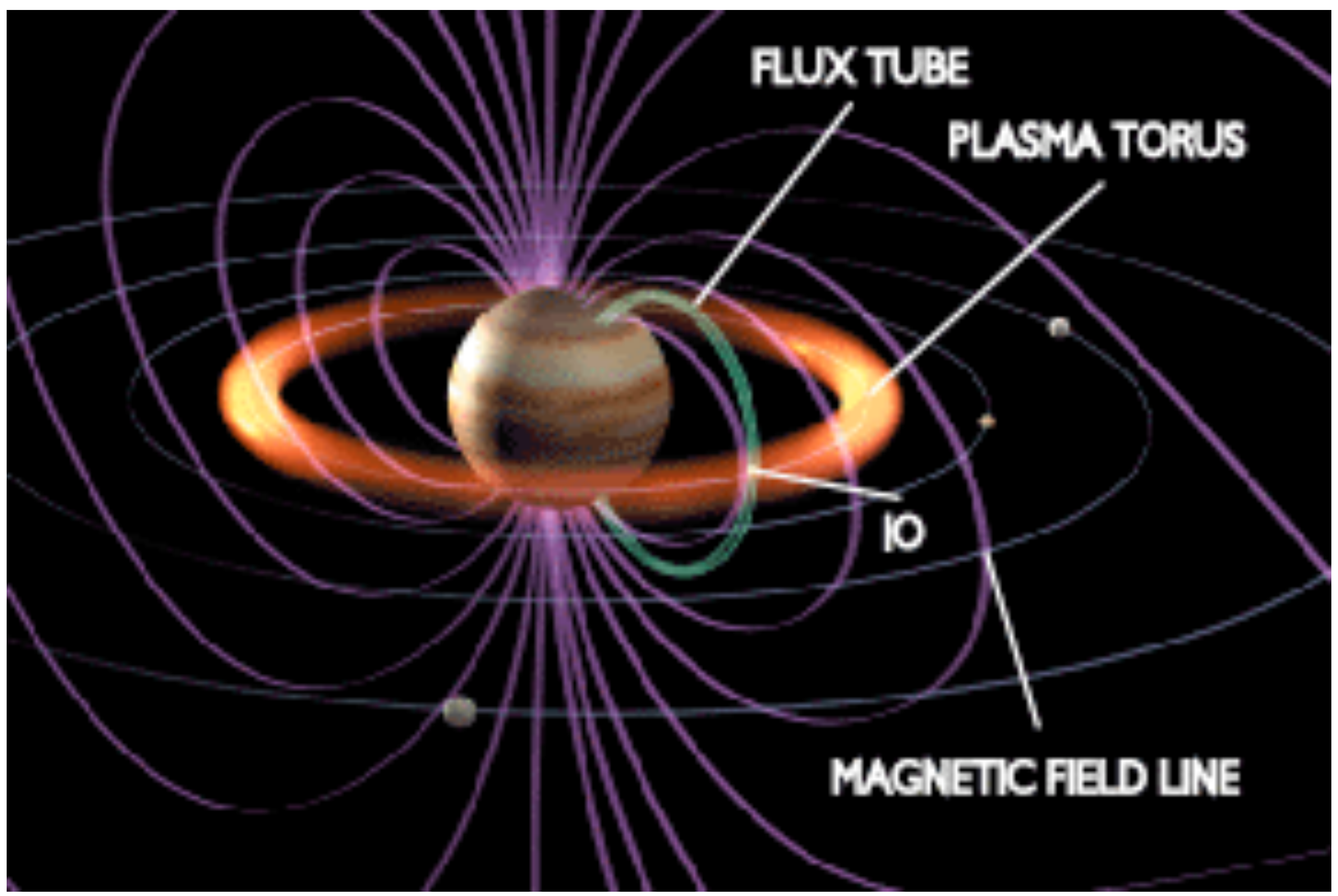

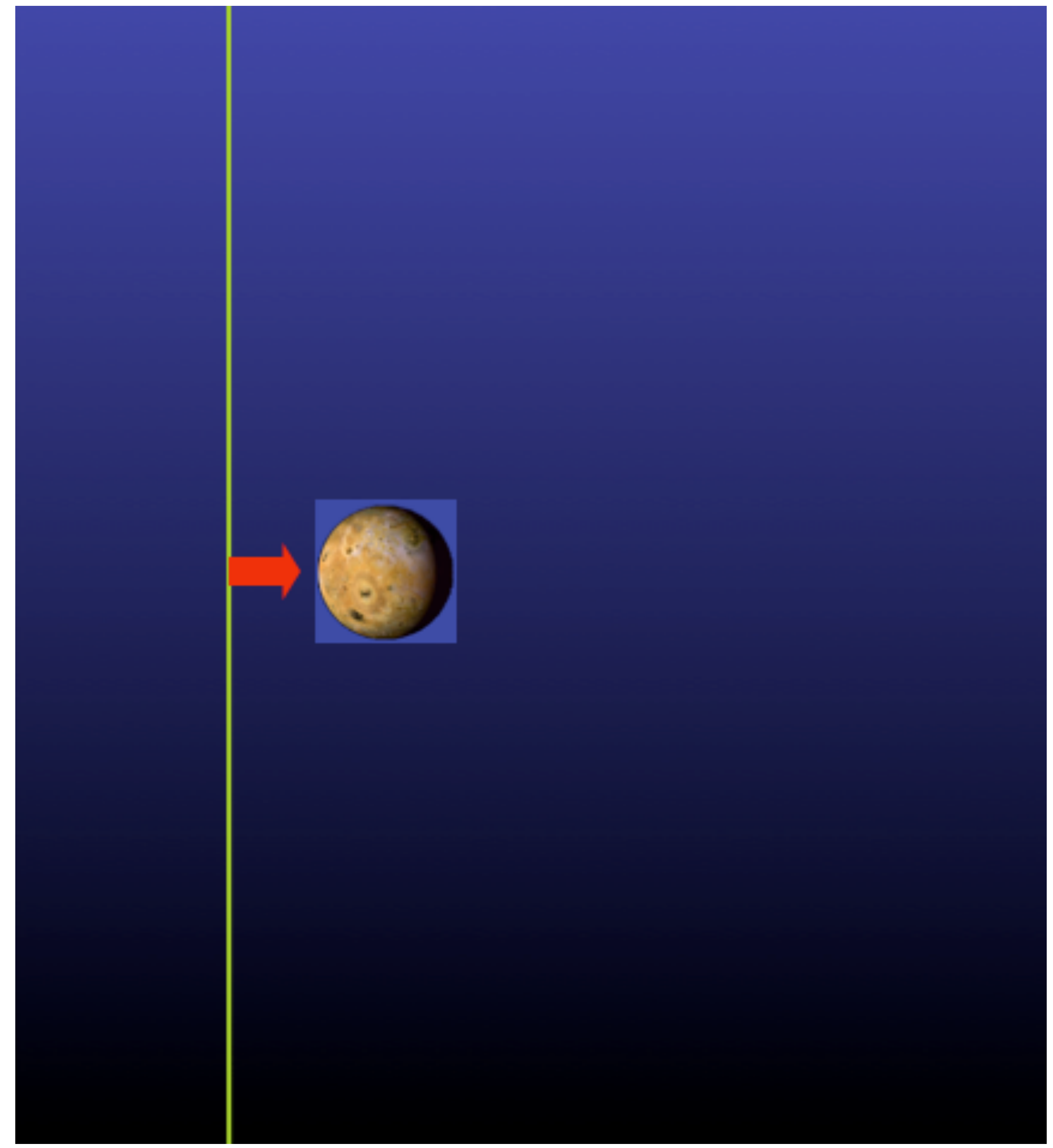

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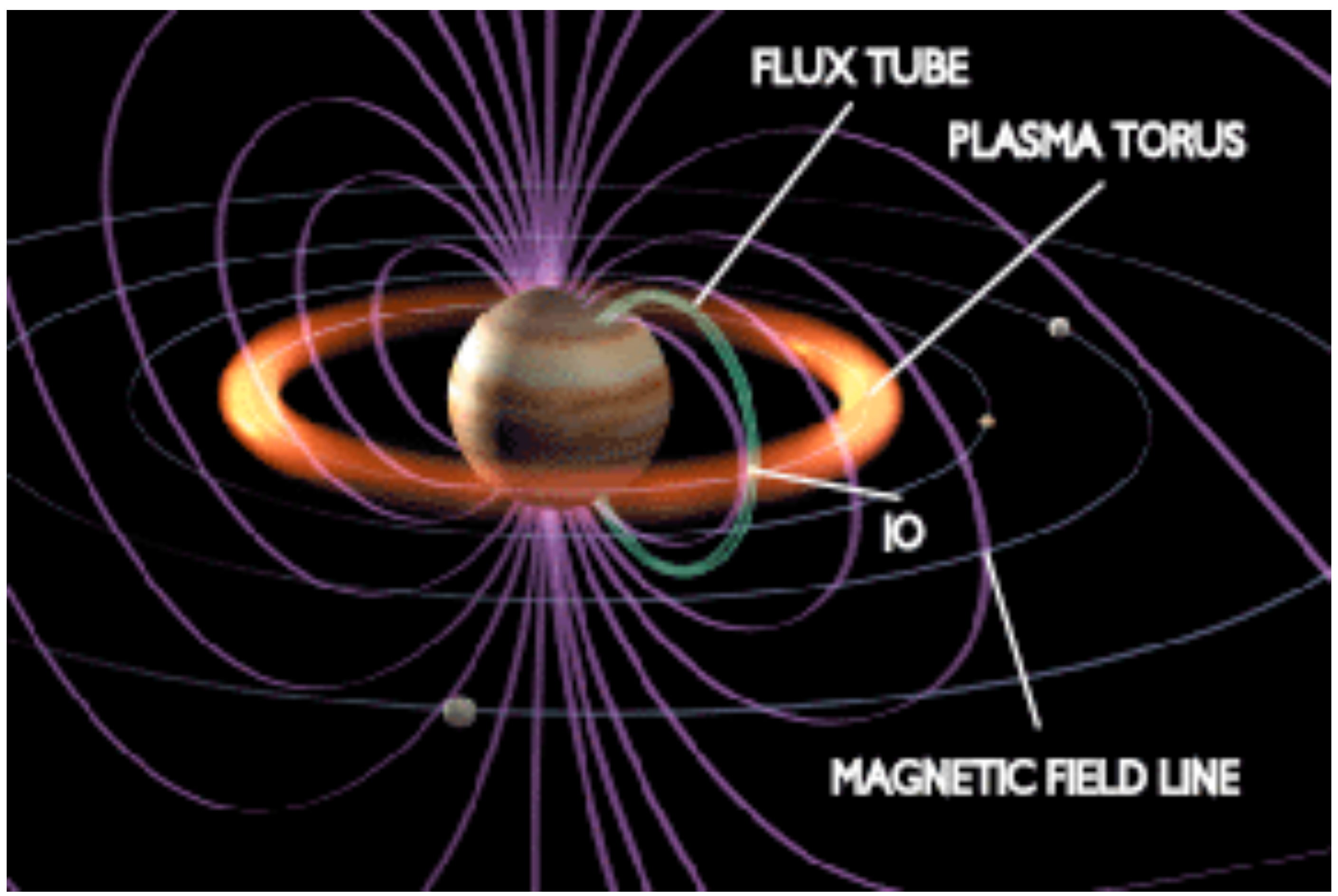

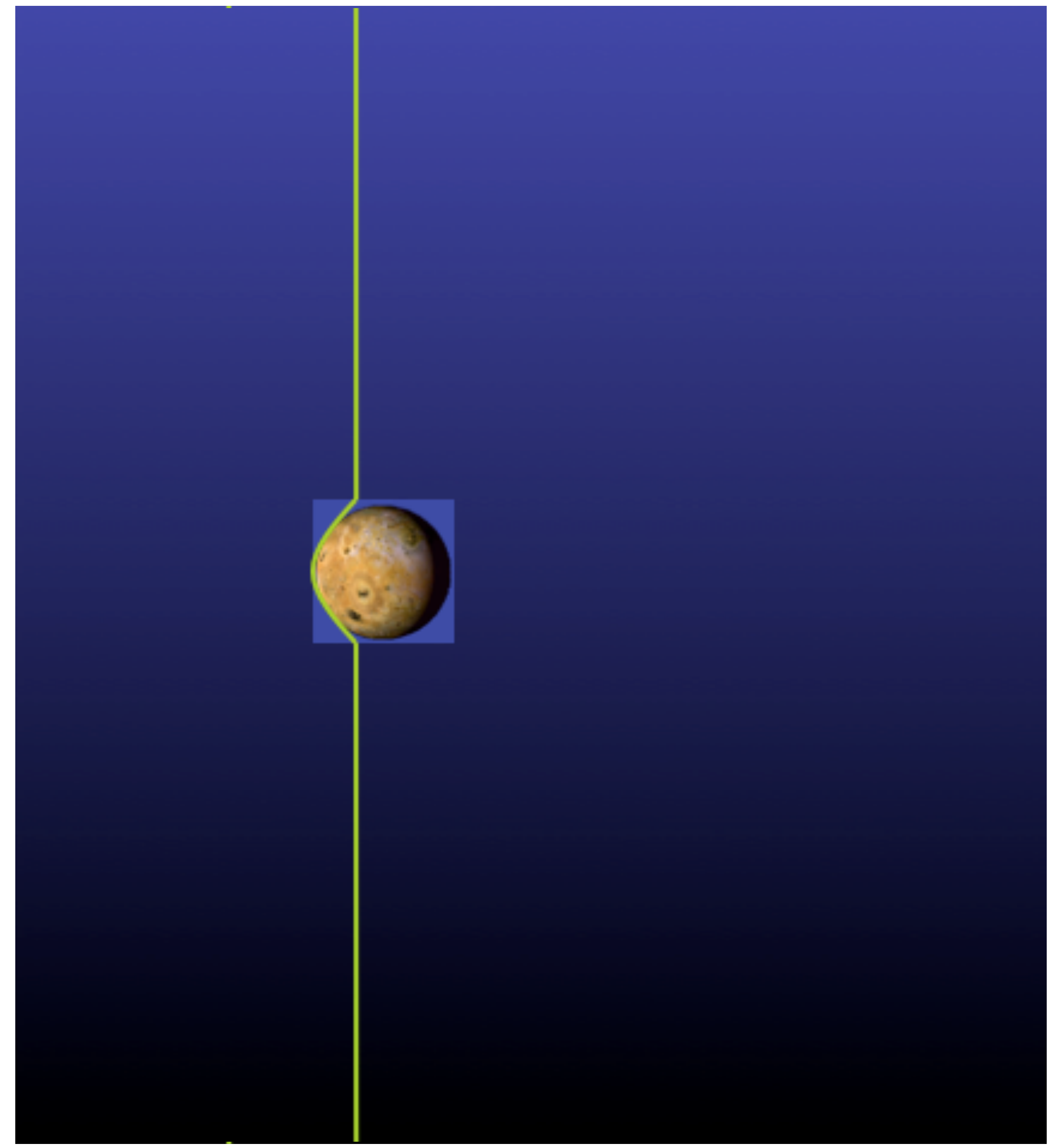

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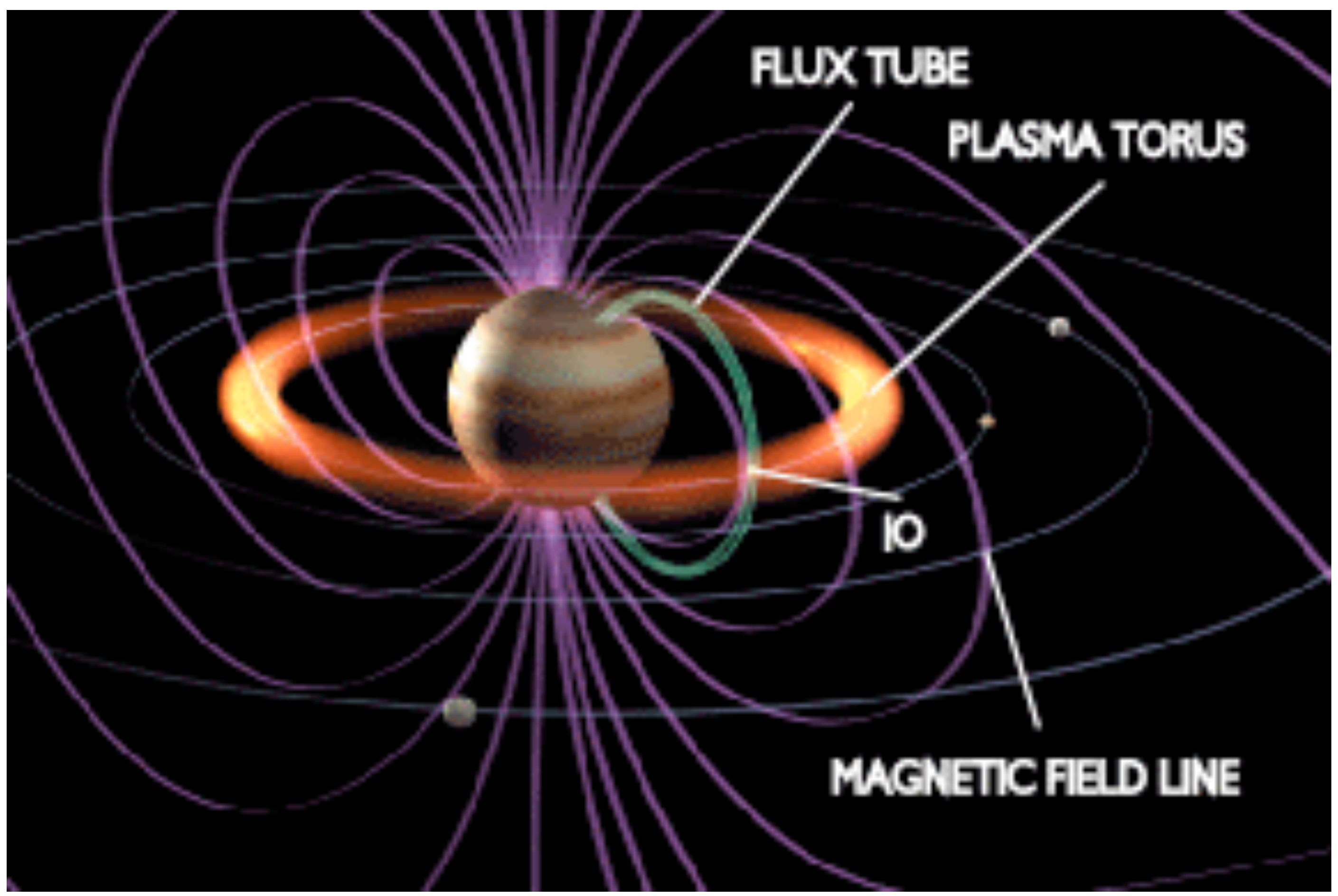

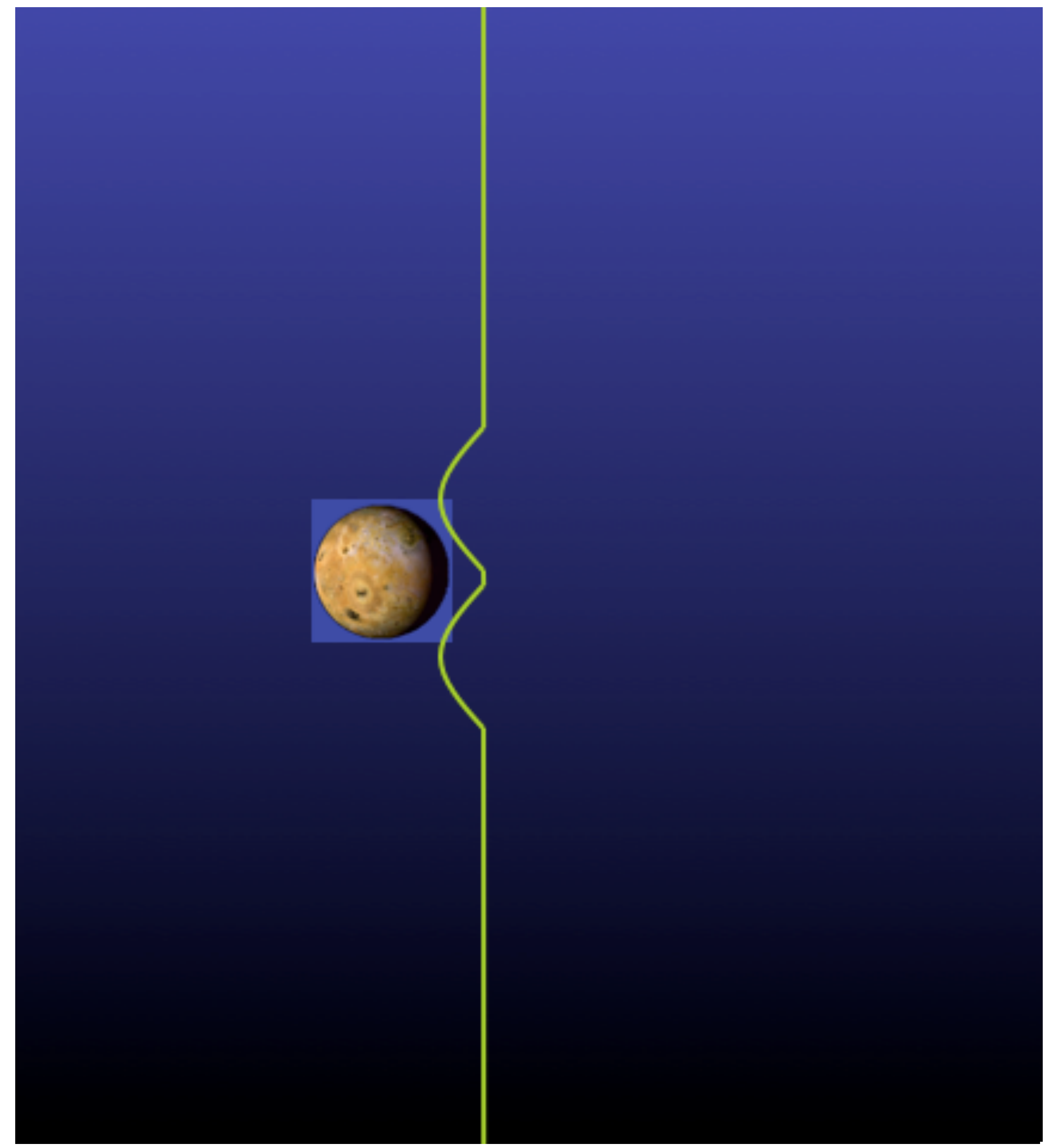

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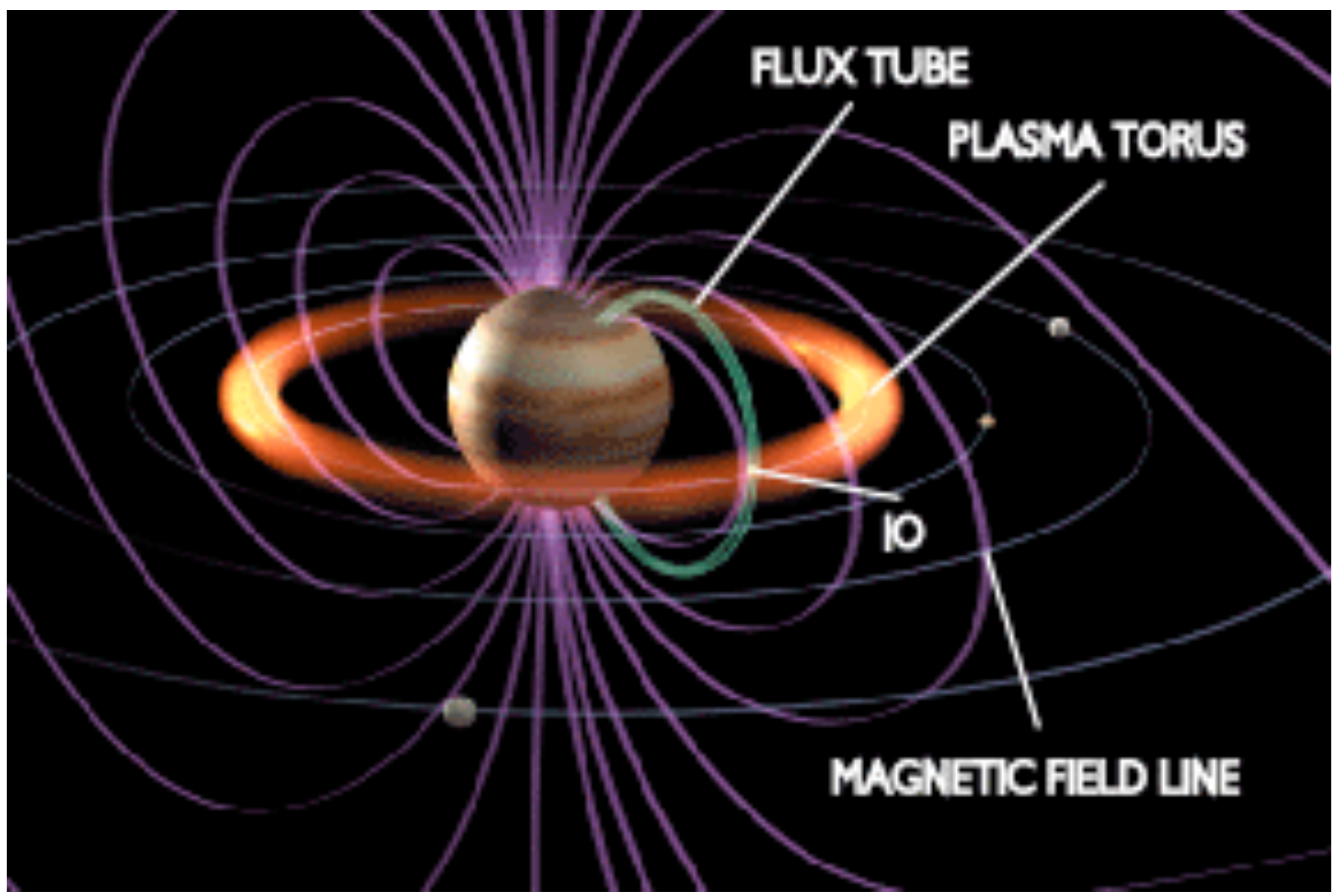

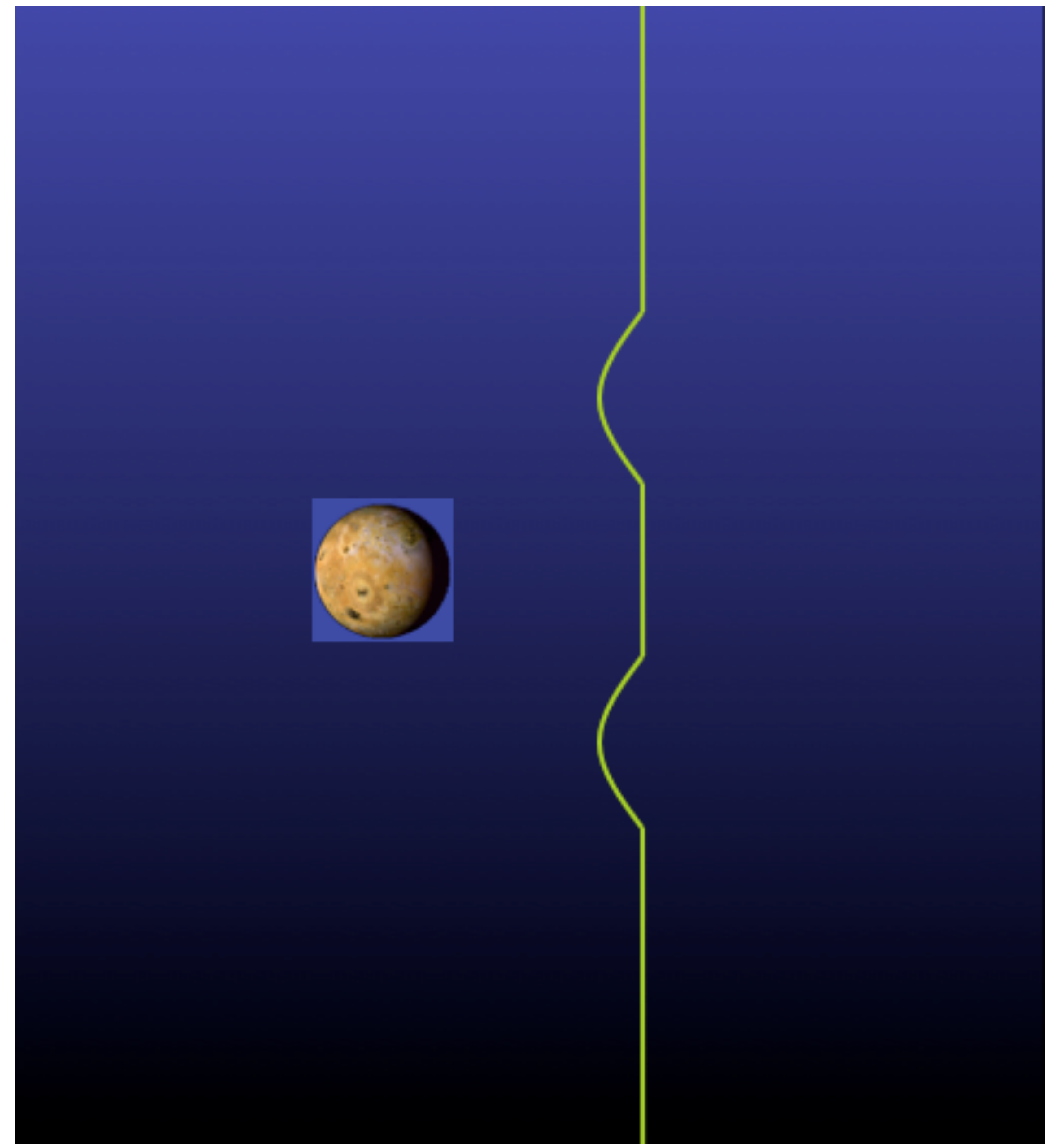

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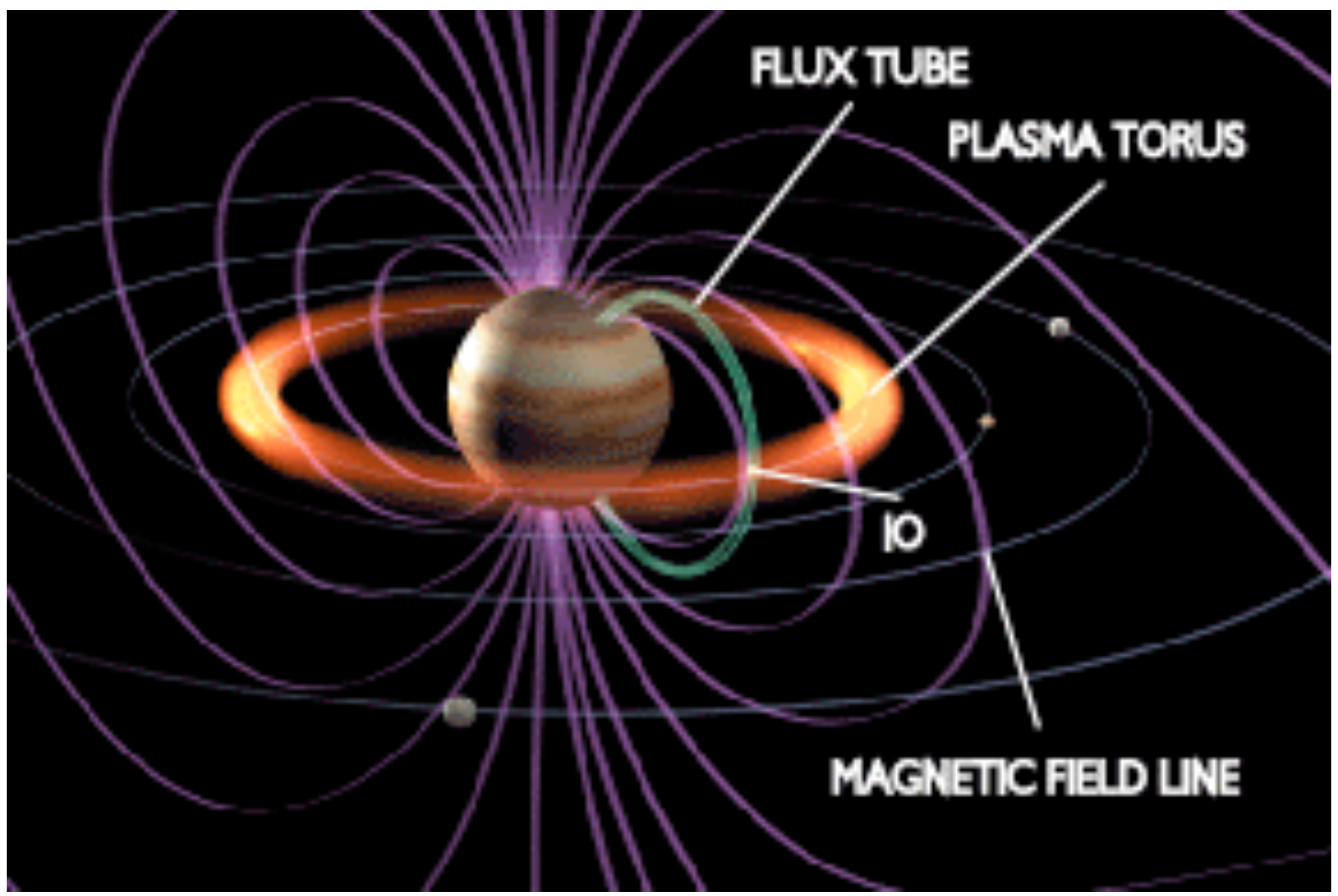

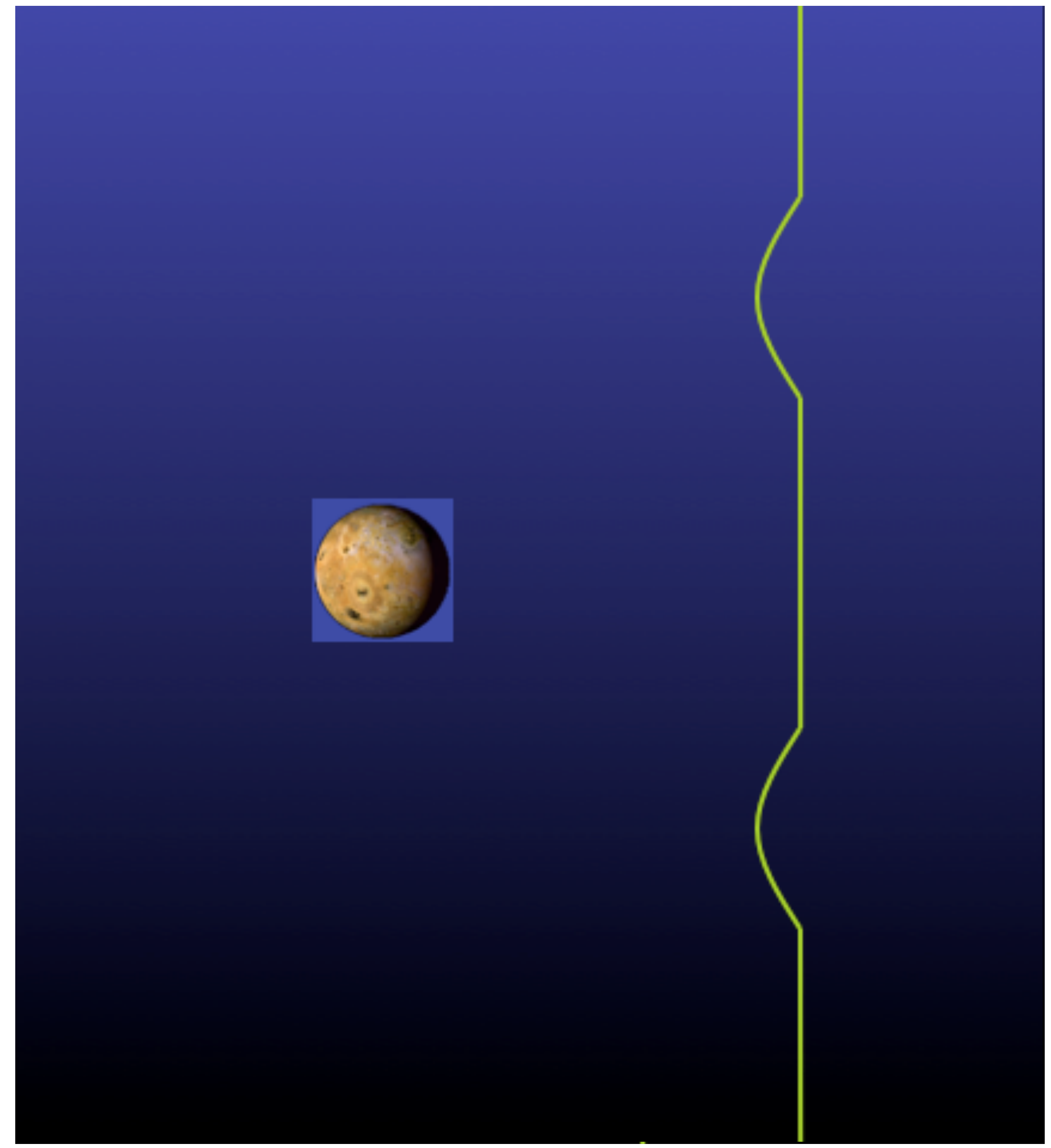

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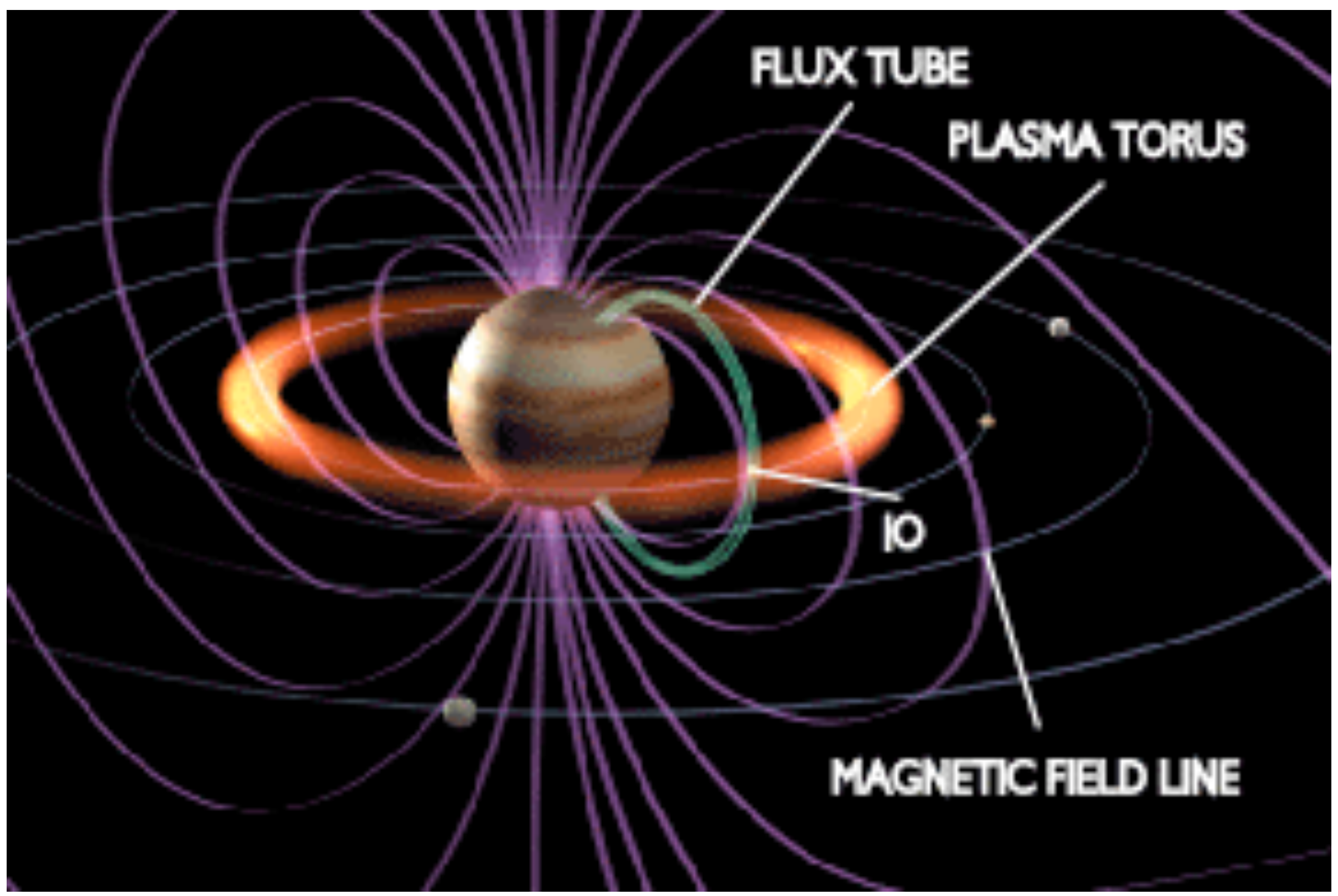

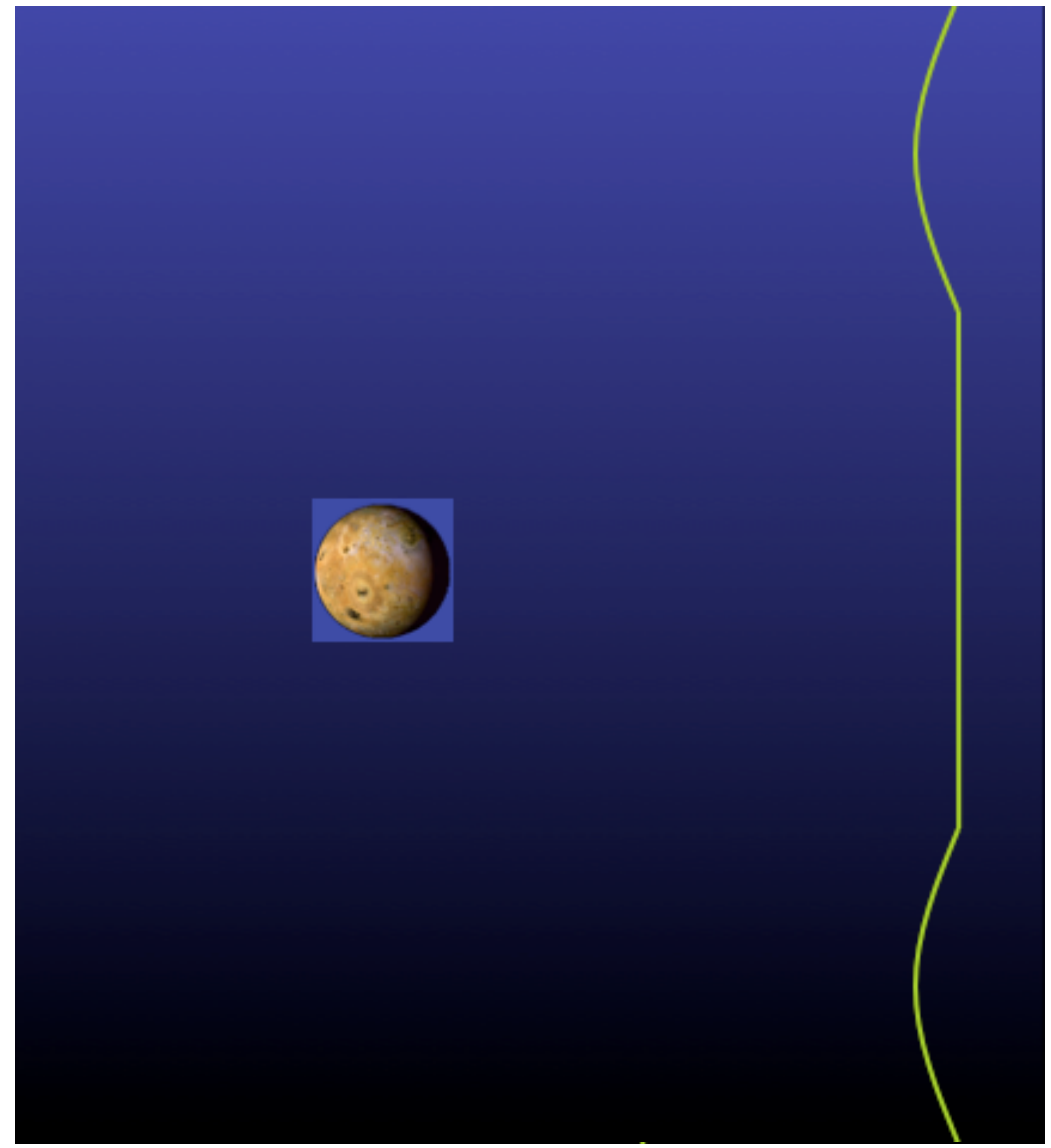

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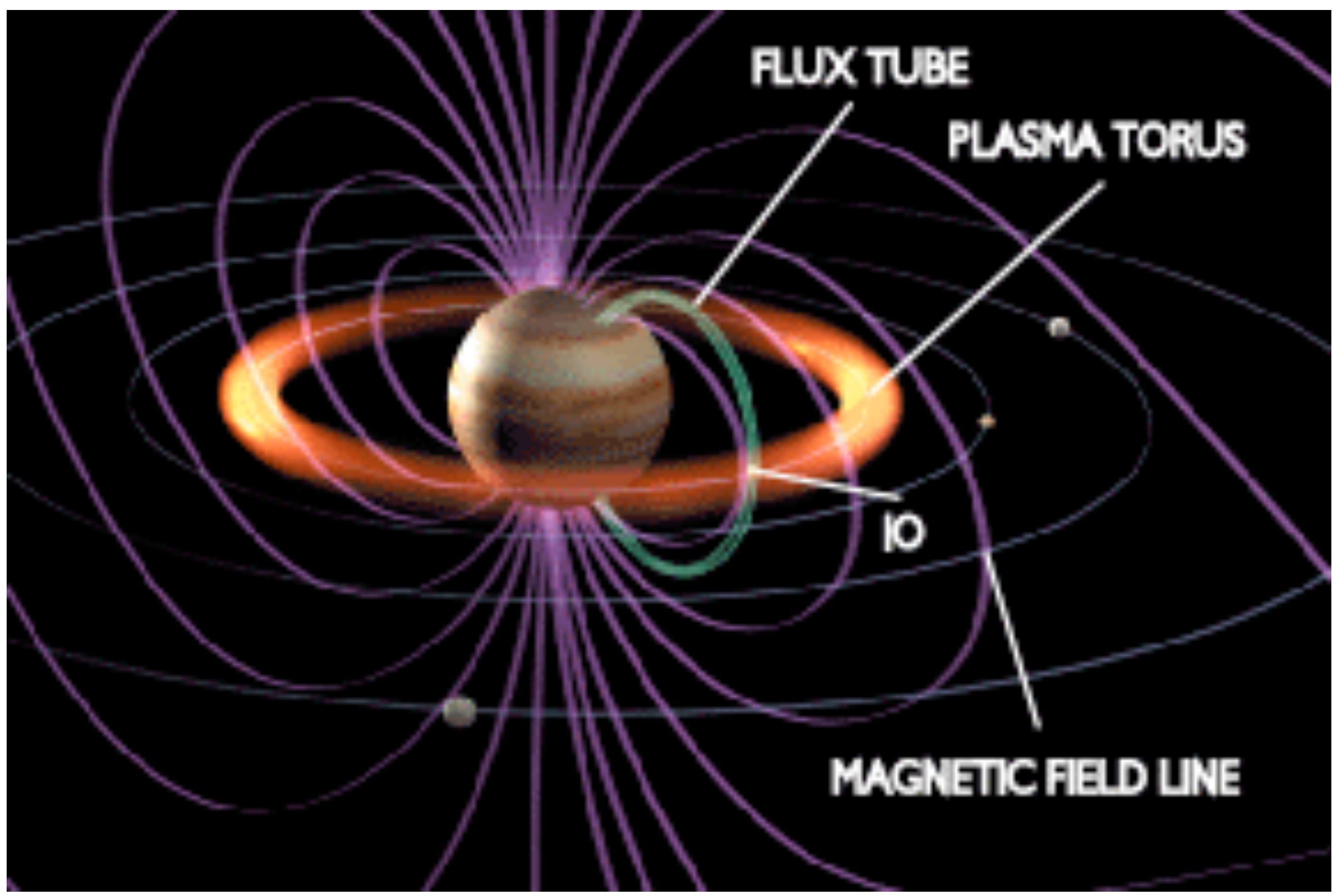

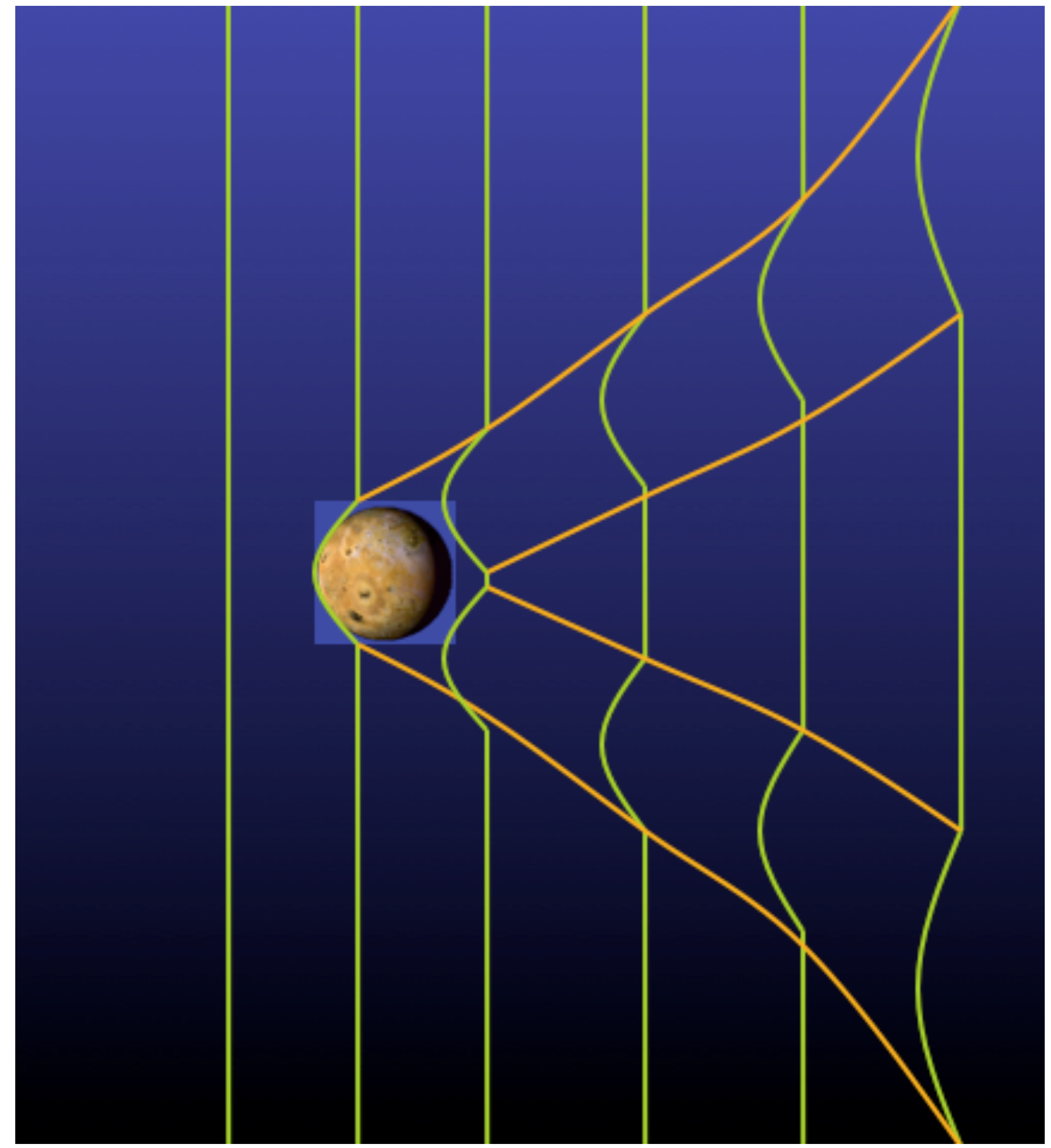

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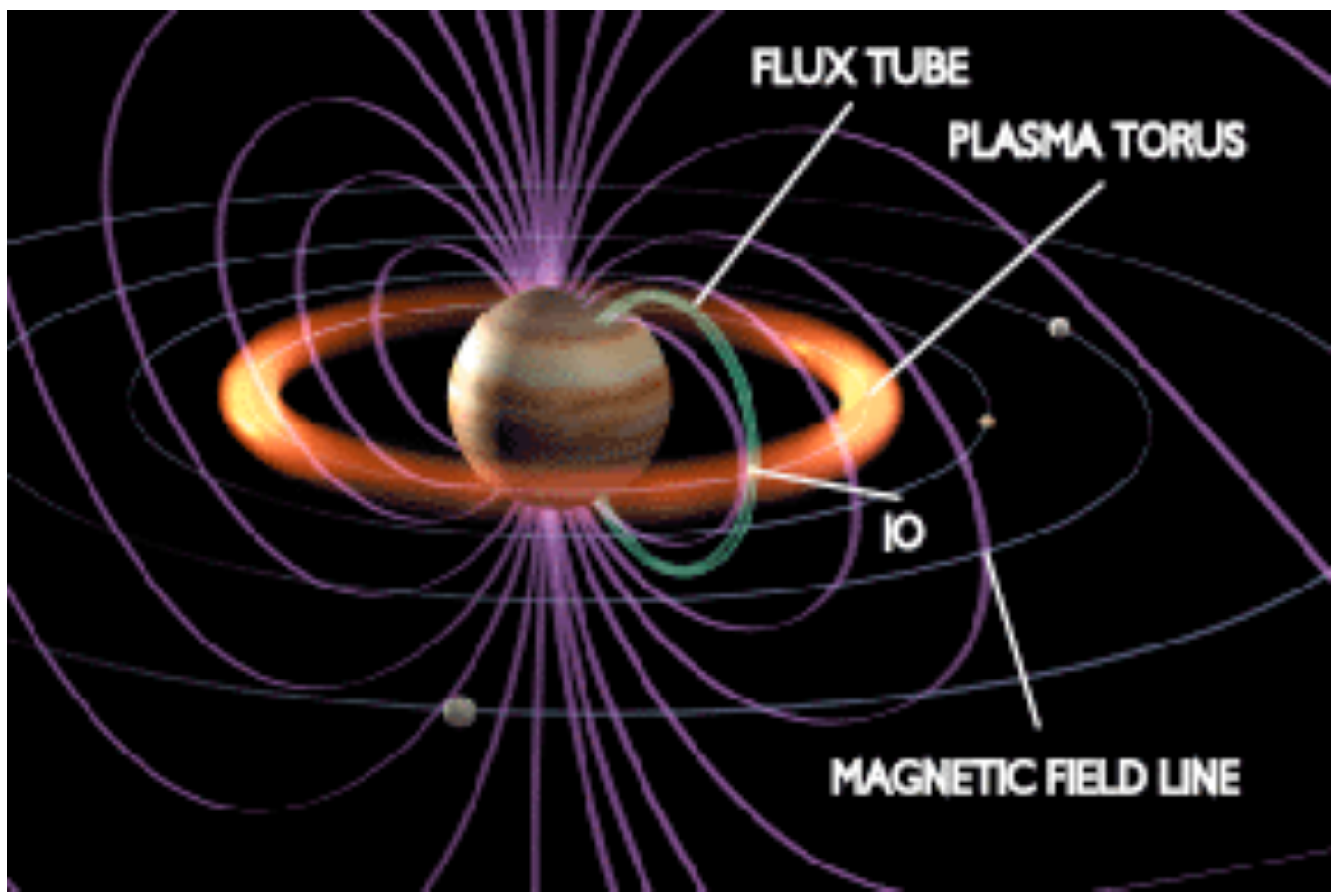

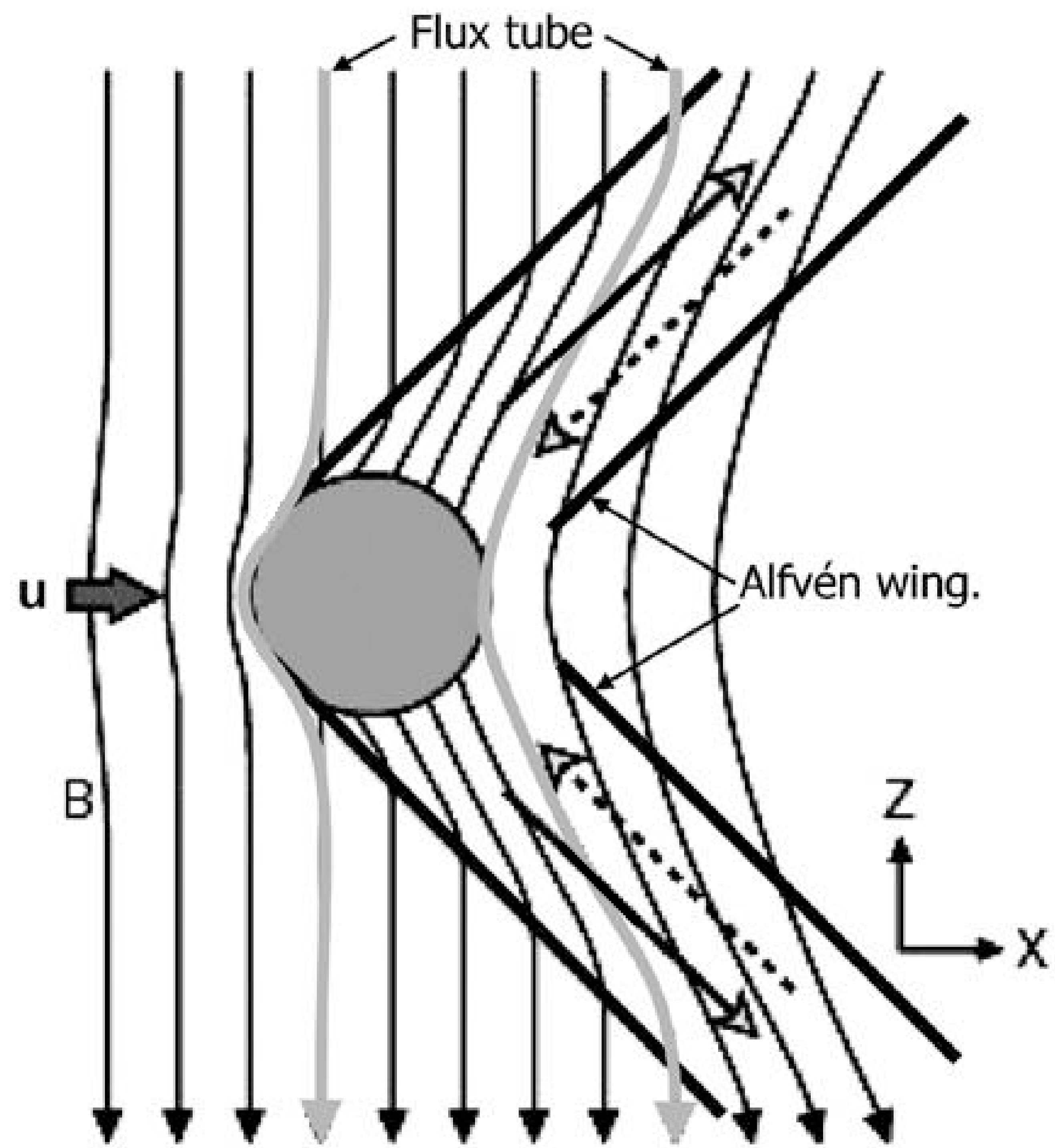

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Dipolar interaction

- Magnetic reconnection

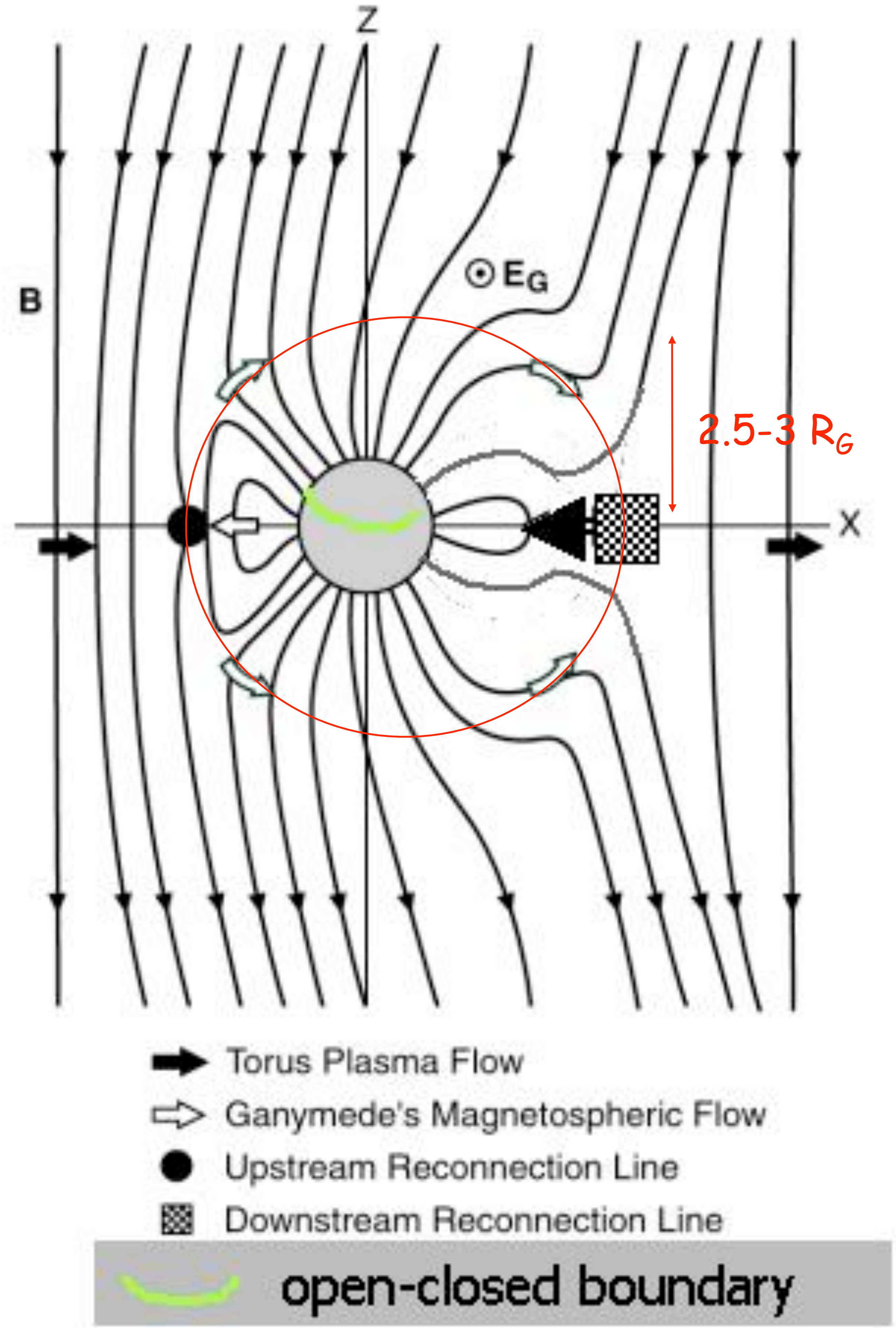
  (e.g. Ganymede-Jupiter)

$P_d = \varepsilon\, K\, V B_\perp^2/\mu_o\, \pi R_{MP}^2$

Efficiency $\varepsilon \sim 0.1–0.2$

$K = \sin^4(\theta/2)$ ou $\cos^4(\theta/2)$

$P_d = \varepsilon\, P_B$



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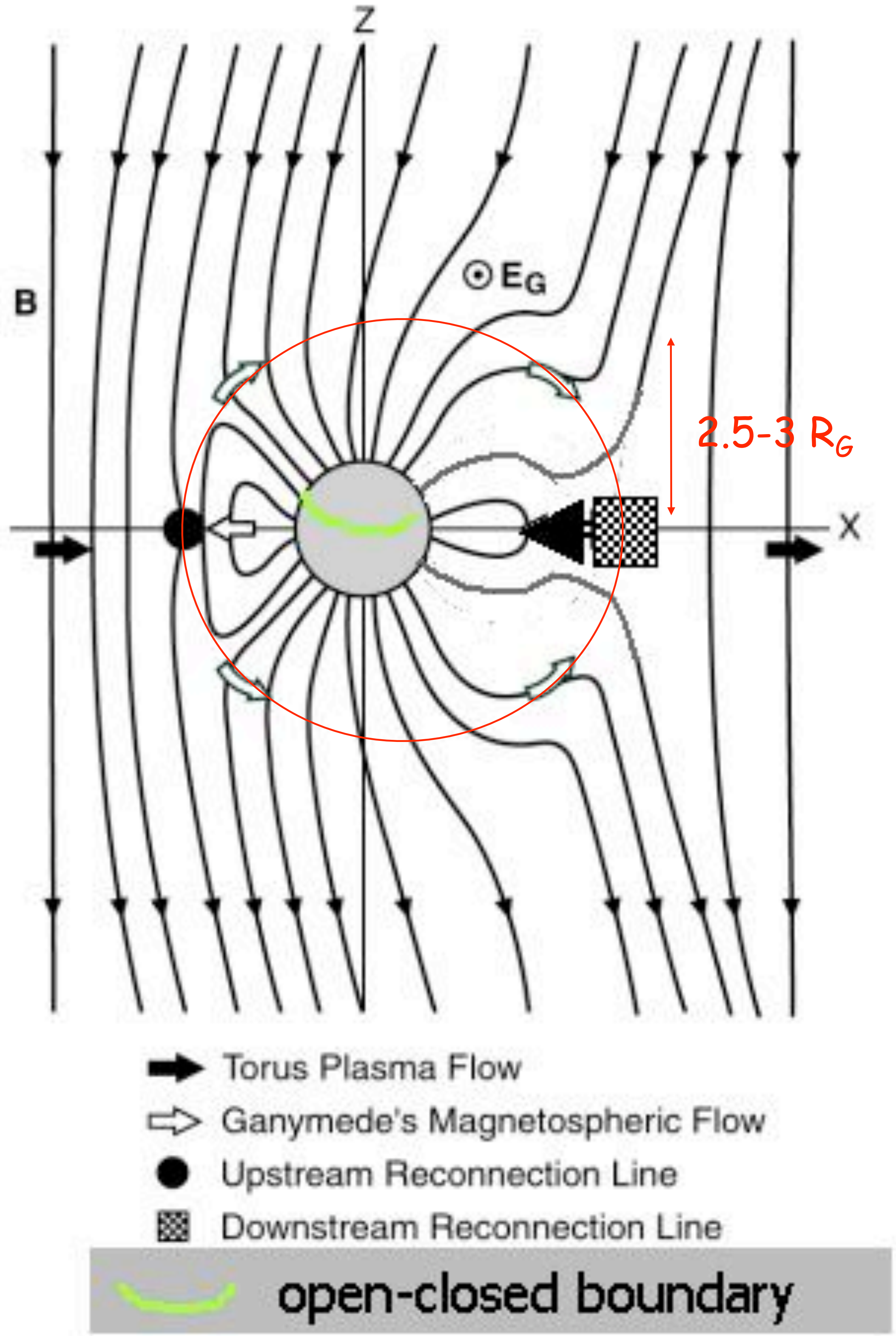
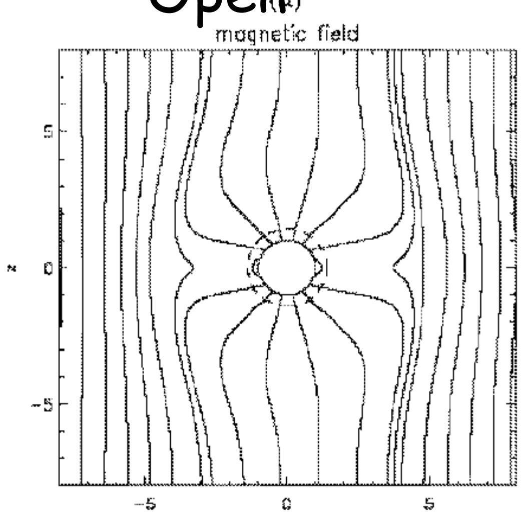
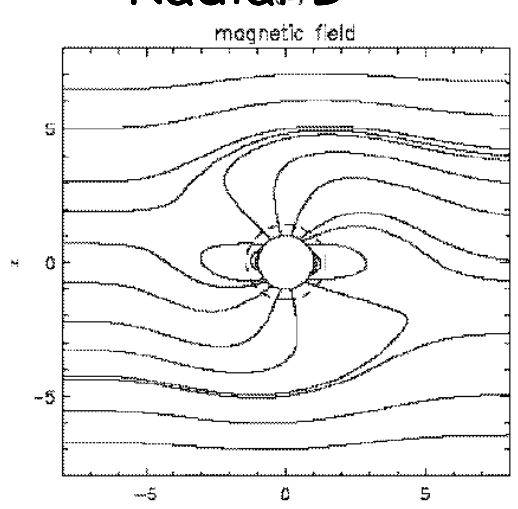


Open



Radial B



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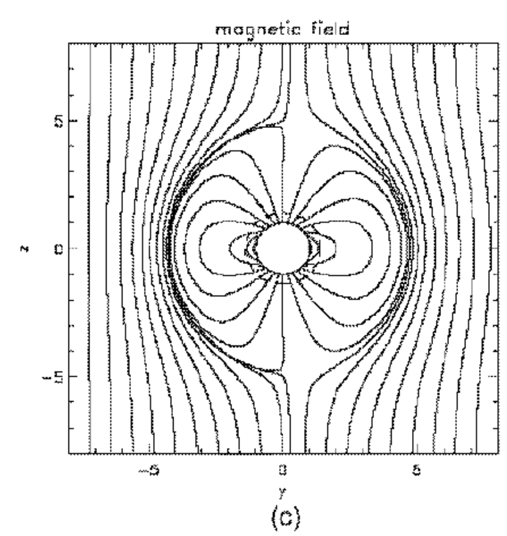

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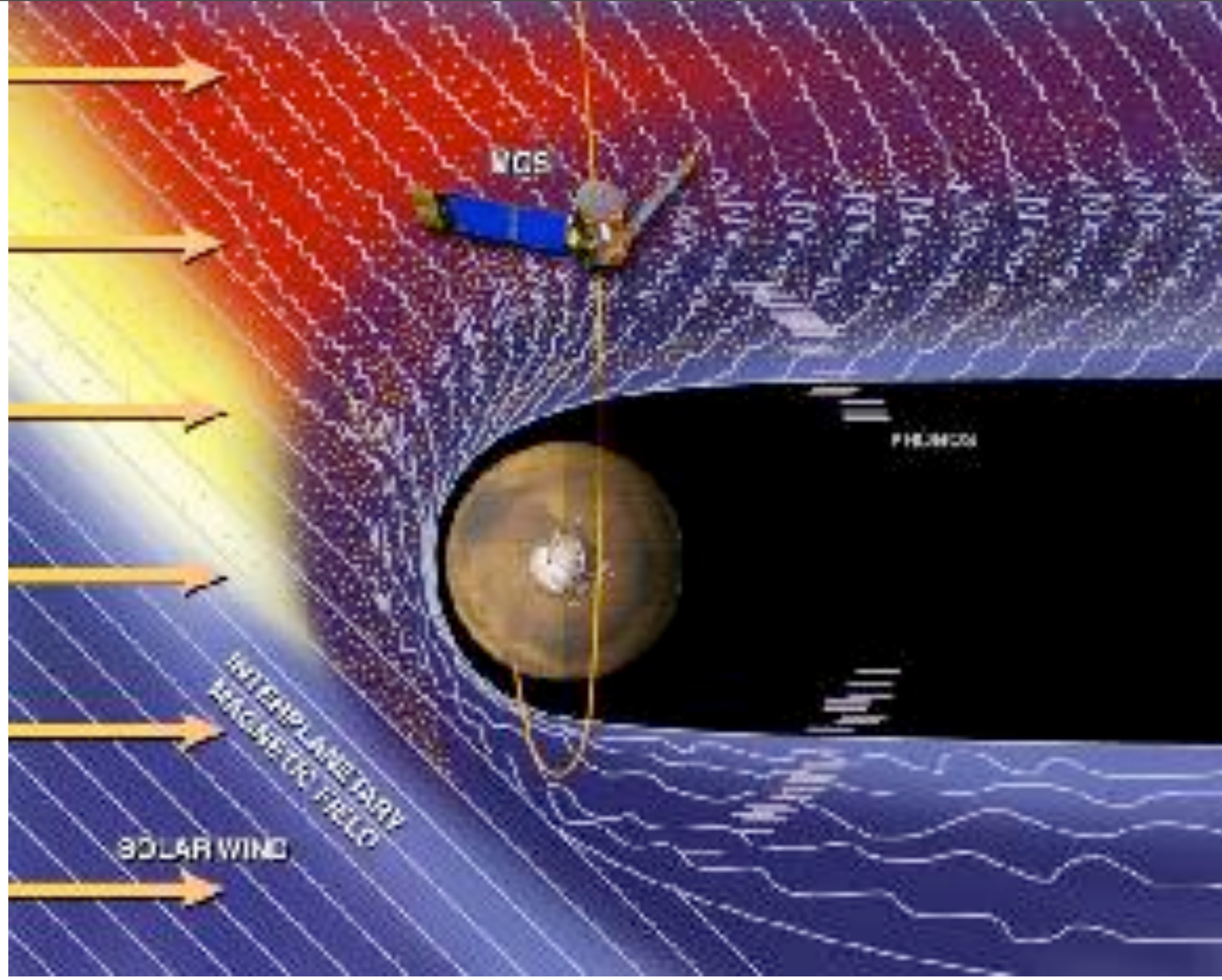
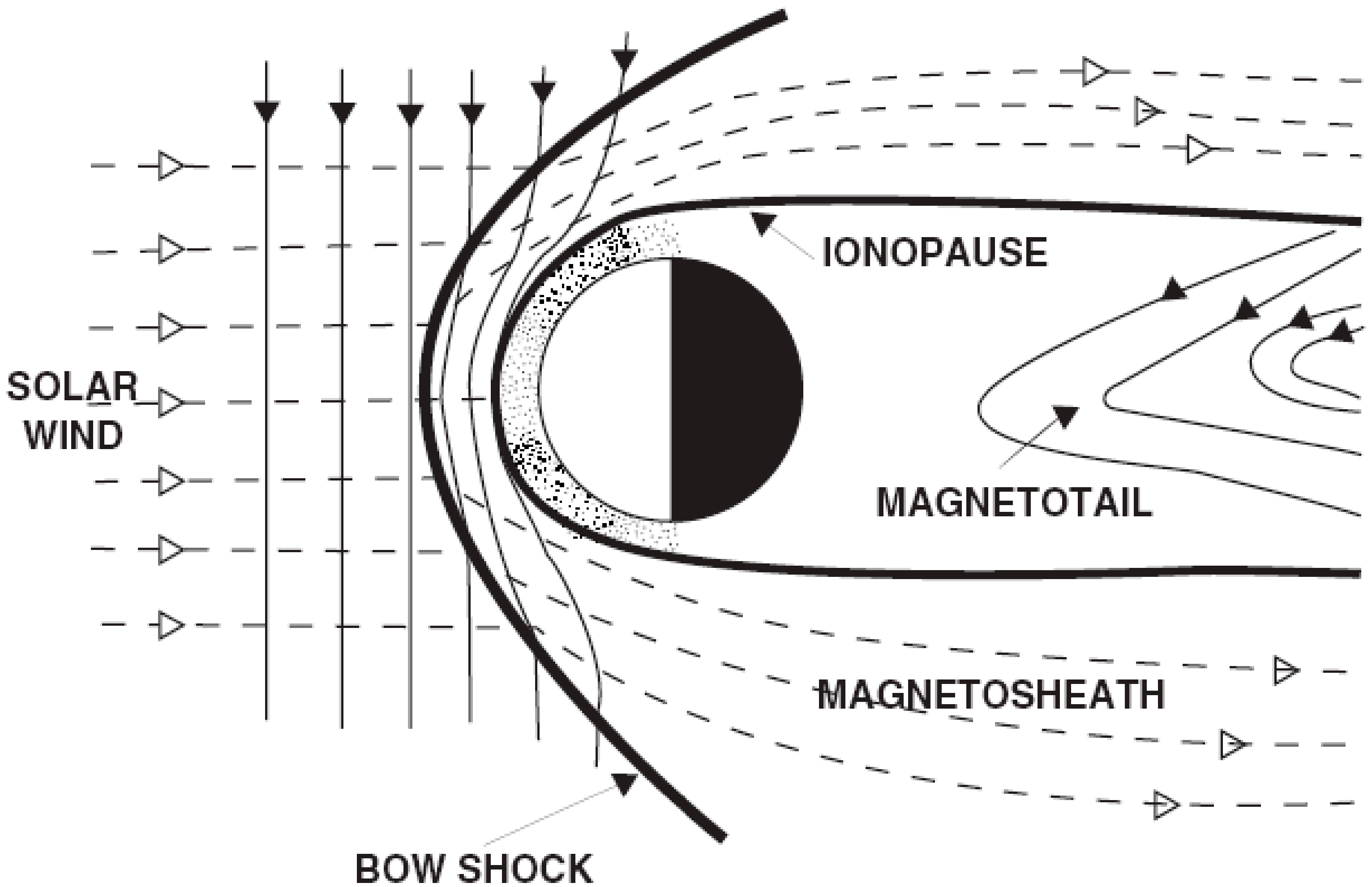
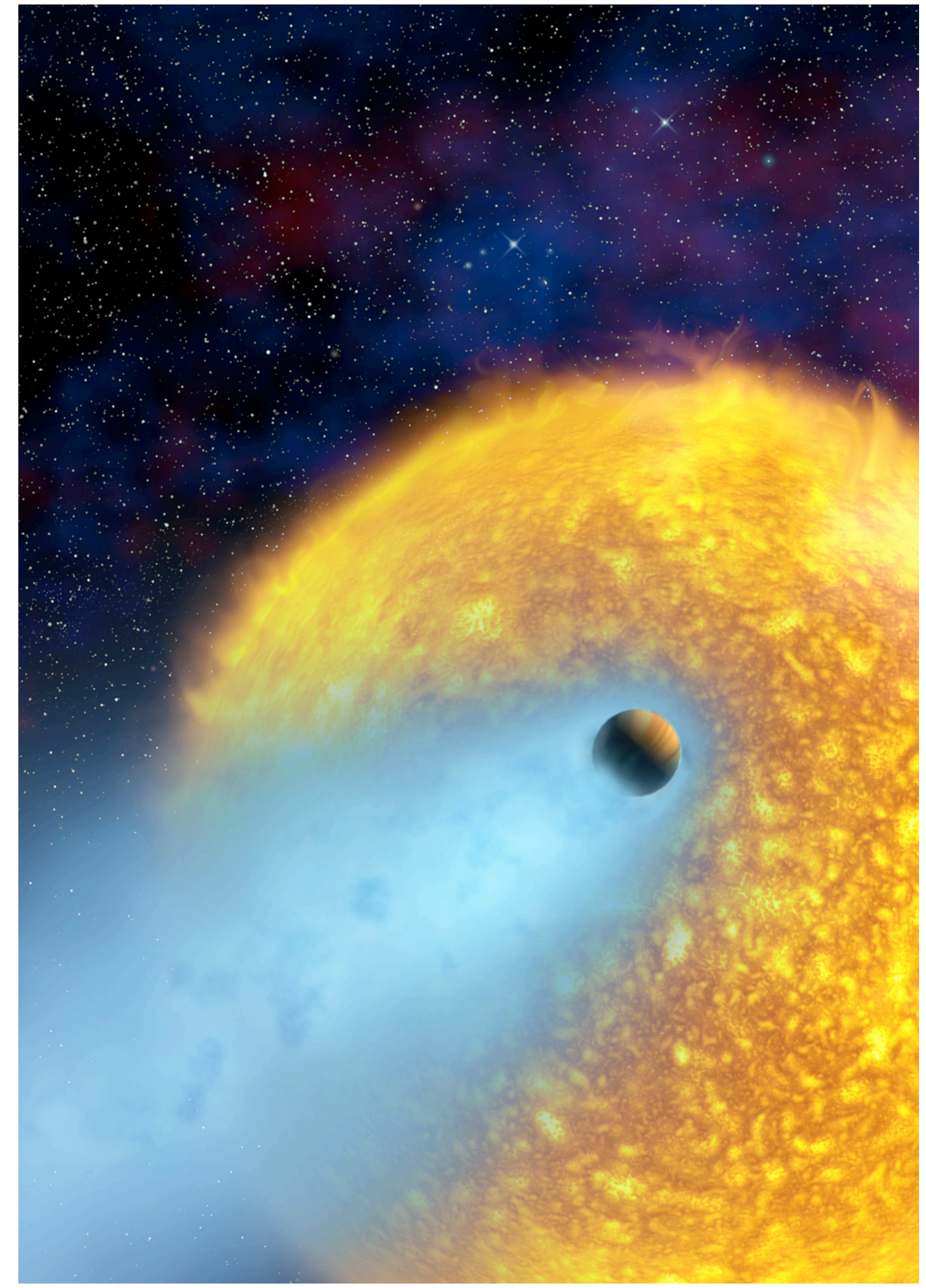
Mars







HD 209458B (Osiris)

[Vidal-Madjar et al., 2003]

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- A brief introduction about exoplanets
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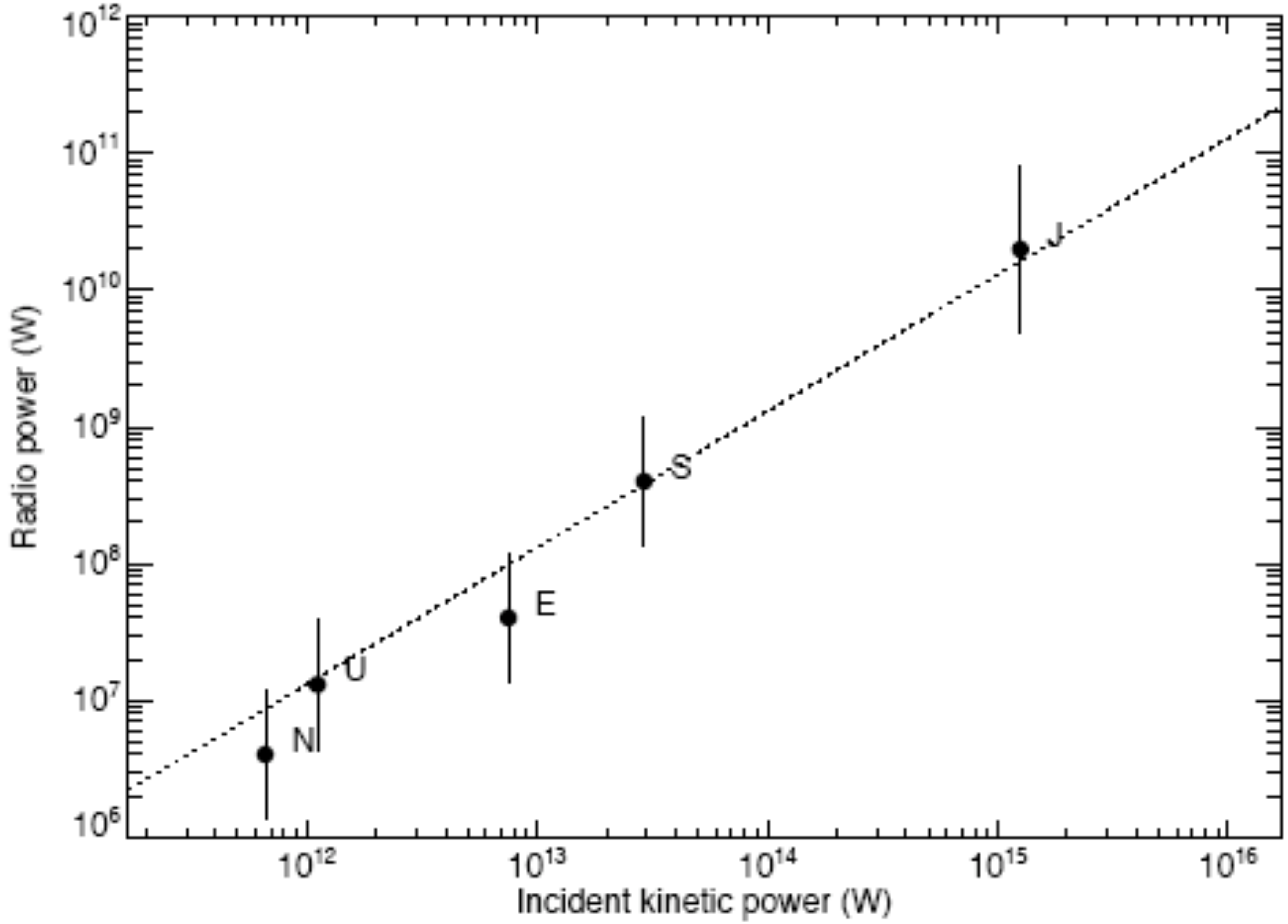
  - energy sources
  - scaling laws
  - extrapolation to exoplanets
- Ongoing observations
- Related & Future observations

« Radio-kinetic Bode's law » (auroral emissions)

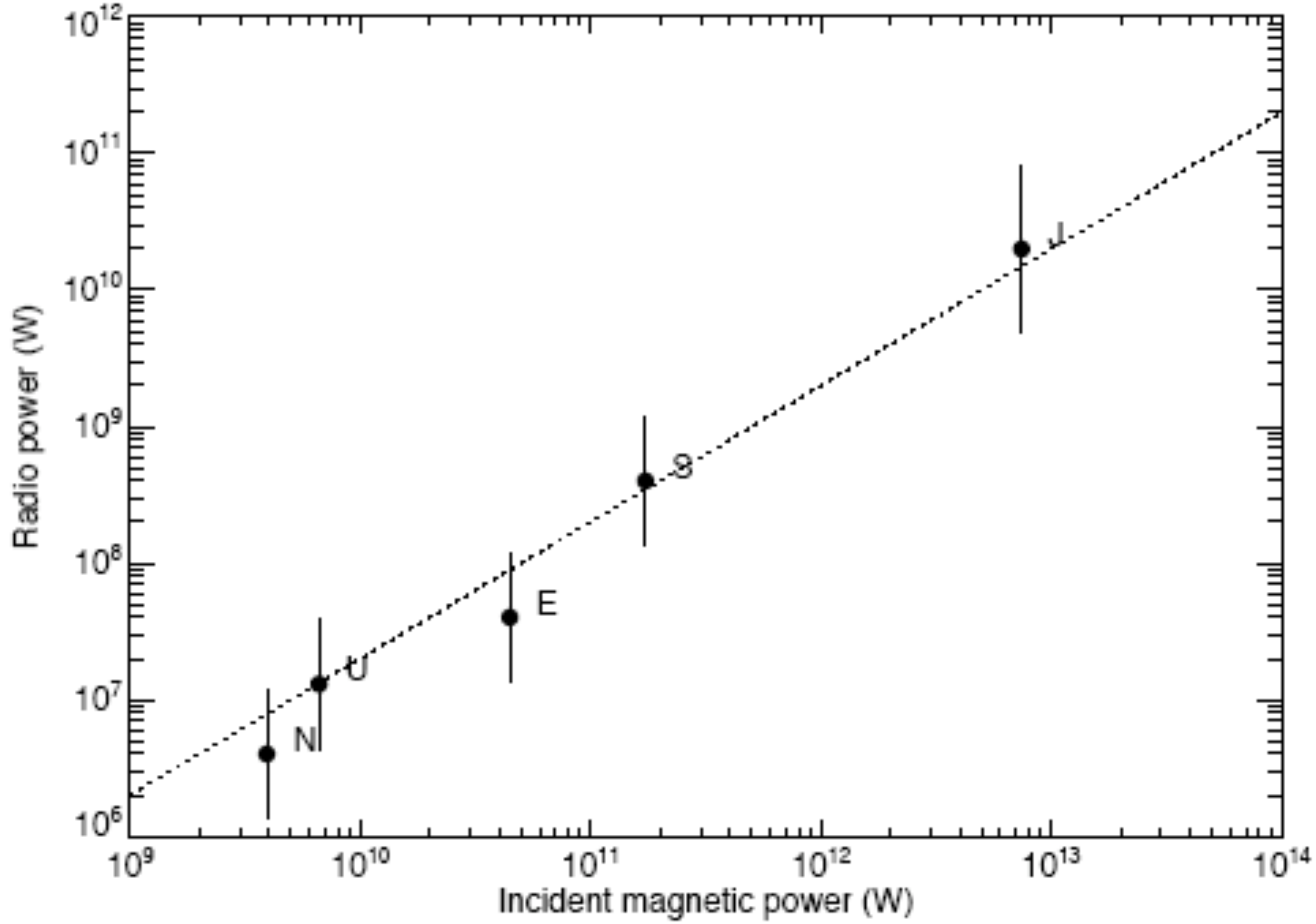
$P_{Radio} \sim \eta_1 \times P_C$ with $\eta_1 \sim 10^{-5}$



[Desch and Kaiser, 1984 ; Zarka, 1992]

« Radio-magnetic Bode's law » (auroral emissions)

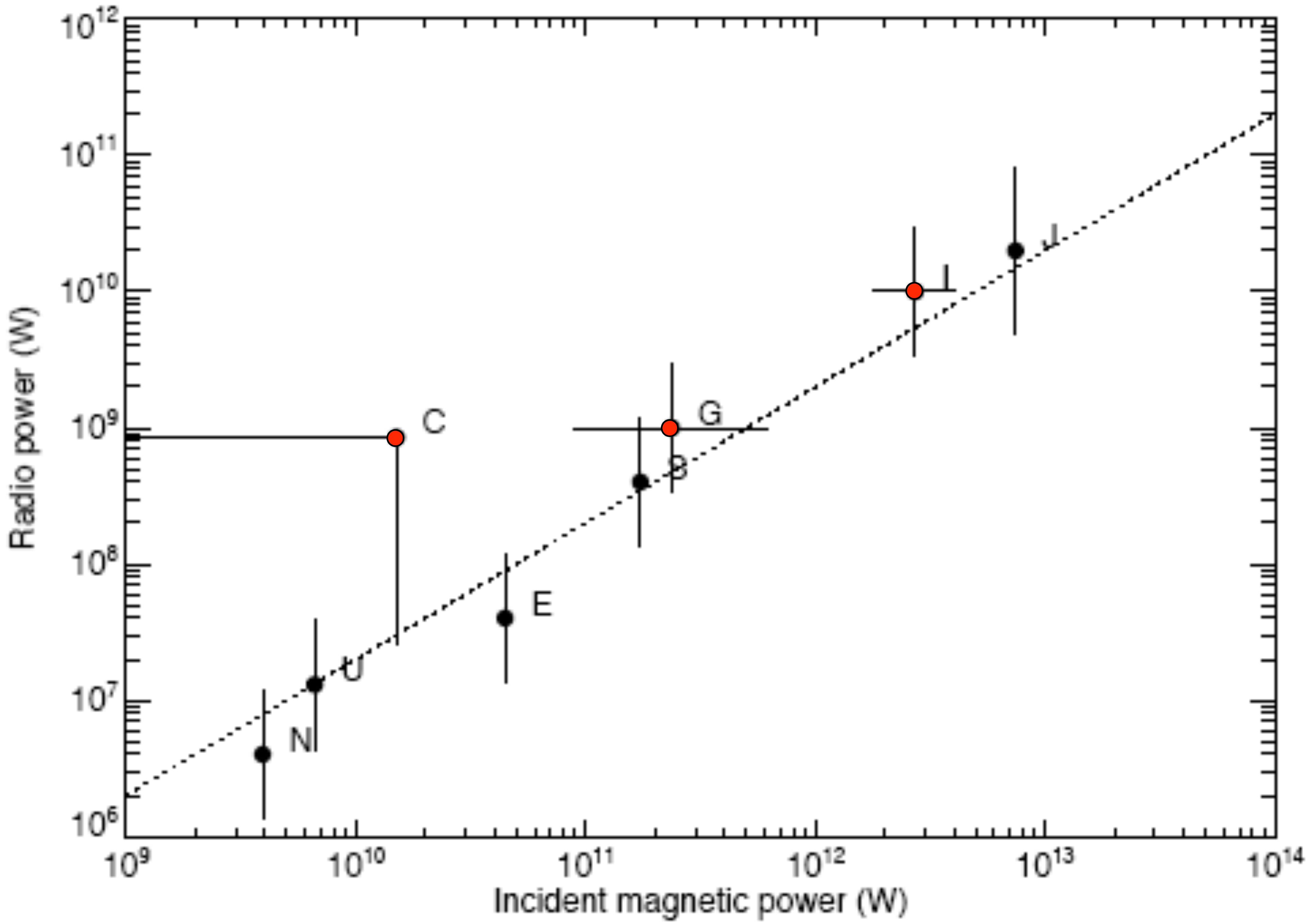
$P_{Radio} \sim \eta_2 \times P_B$ with $\eta_2 \sim 2\times10^{-3}$



[Zarka et al., 2001]

« Generalized radio-magnetic Bode's law » (all emissions)

$P_{Radio} \sim \eta \times P_B$ with $\eta \sim 2\text{-}10 \times 10^{-3}$



[Zarka et al., 2001, 2005]

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- Theoretical predictions
    - planetary magnetospheric radio emissions
    - energy sources
    - scaling laws
    - extrapolation to exoplanets
- Ongoing observations
- Related & Future observations

- ~280 exoplanets (in ~240 systems)

16% with $a \leq 0.05$ UA (10 Rs)

24% with $a \leq 0.1$ UA

□ >40 « hot Jupiters » with periastron @ ~5-10 R_S

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□ >40 « hot Jupiters » with periastron @ ~5-10 R_S

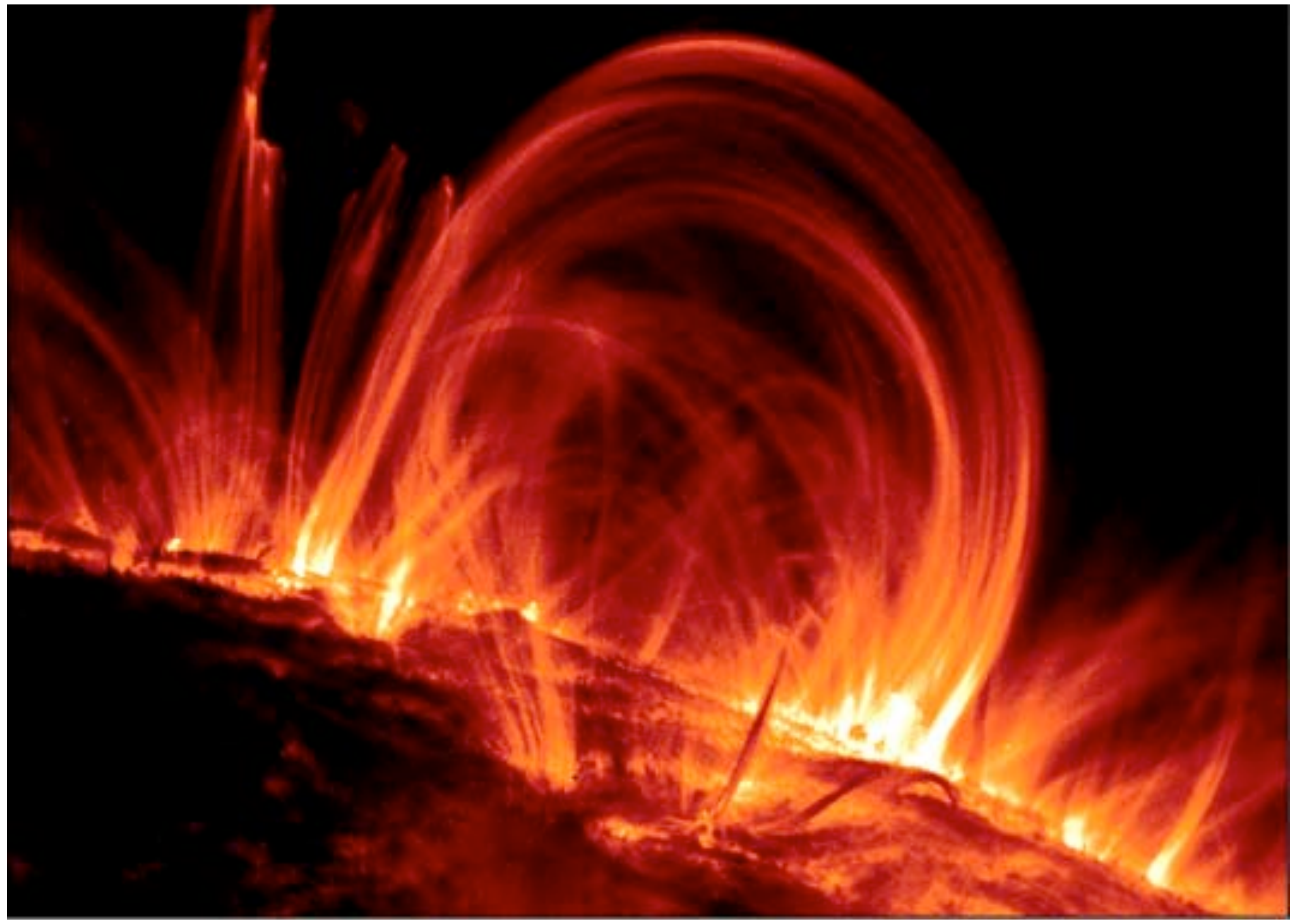
- Magnetic field at Solar surface :

  → large-scale ~1 G (10^{-4} T)

  → magnetic loops ~10^3 G,

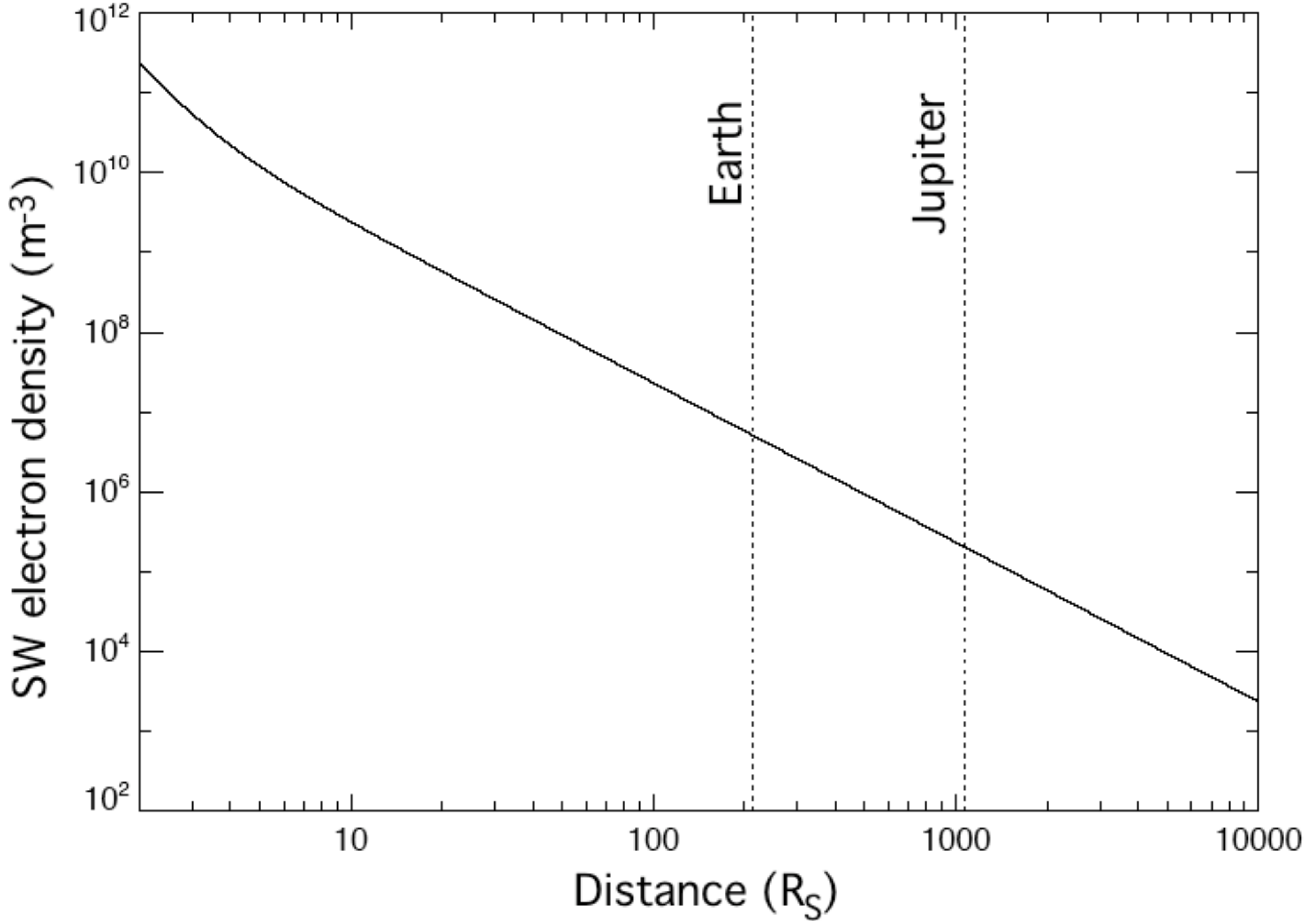
  over a few % of the surface

- Magnetic stars : > 10^3 G

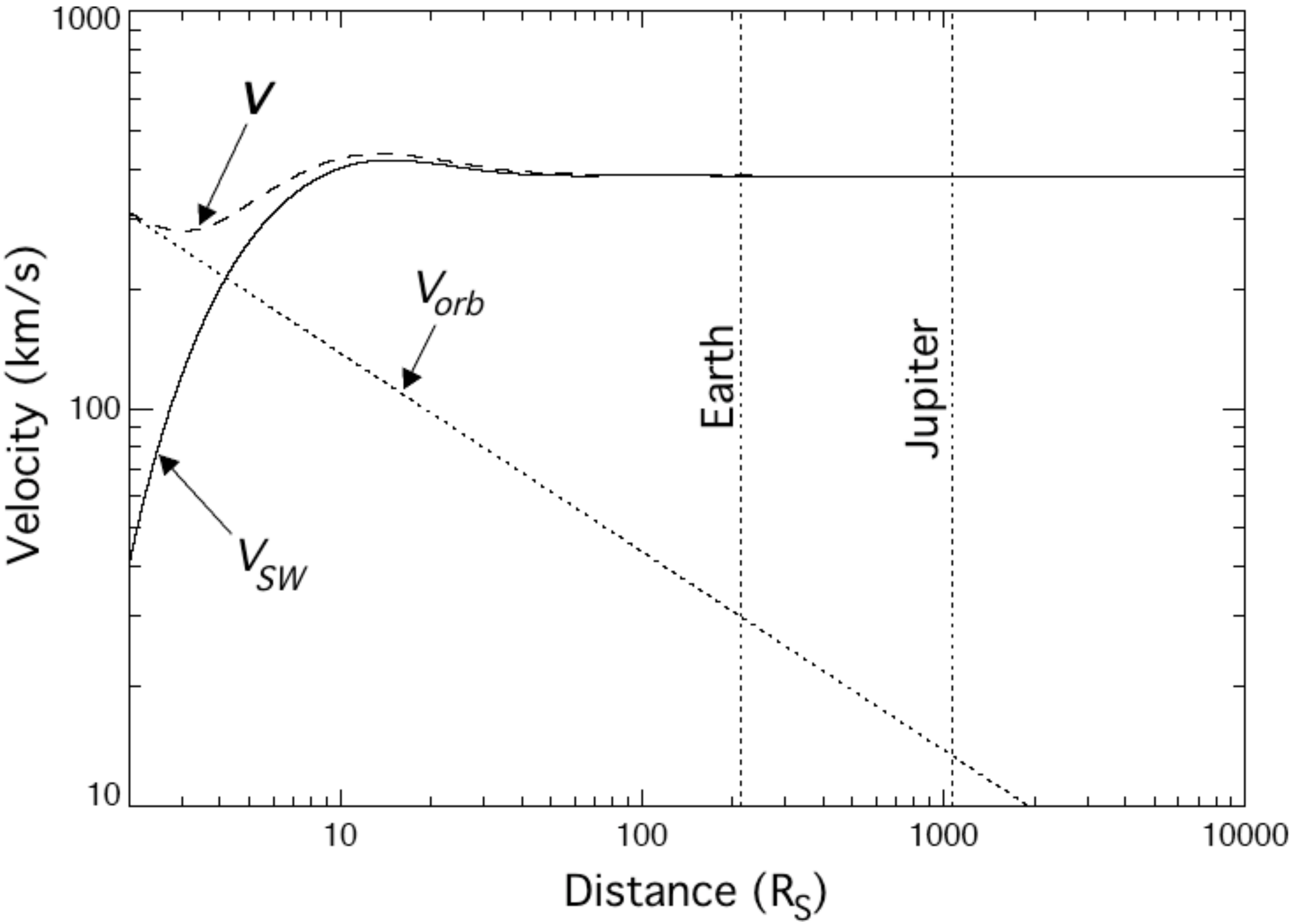


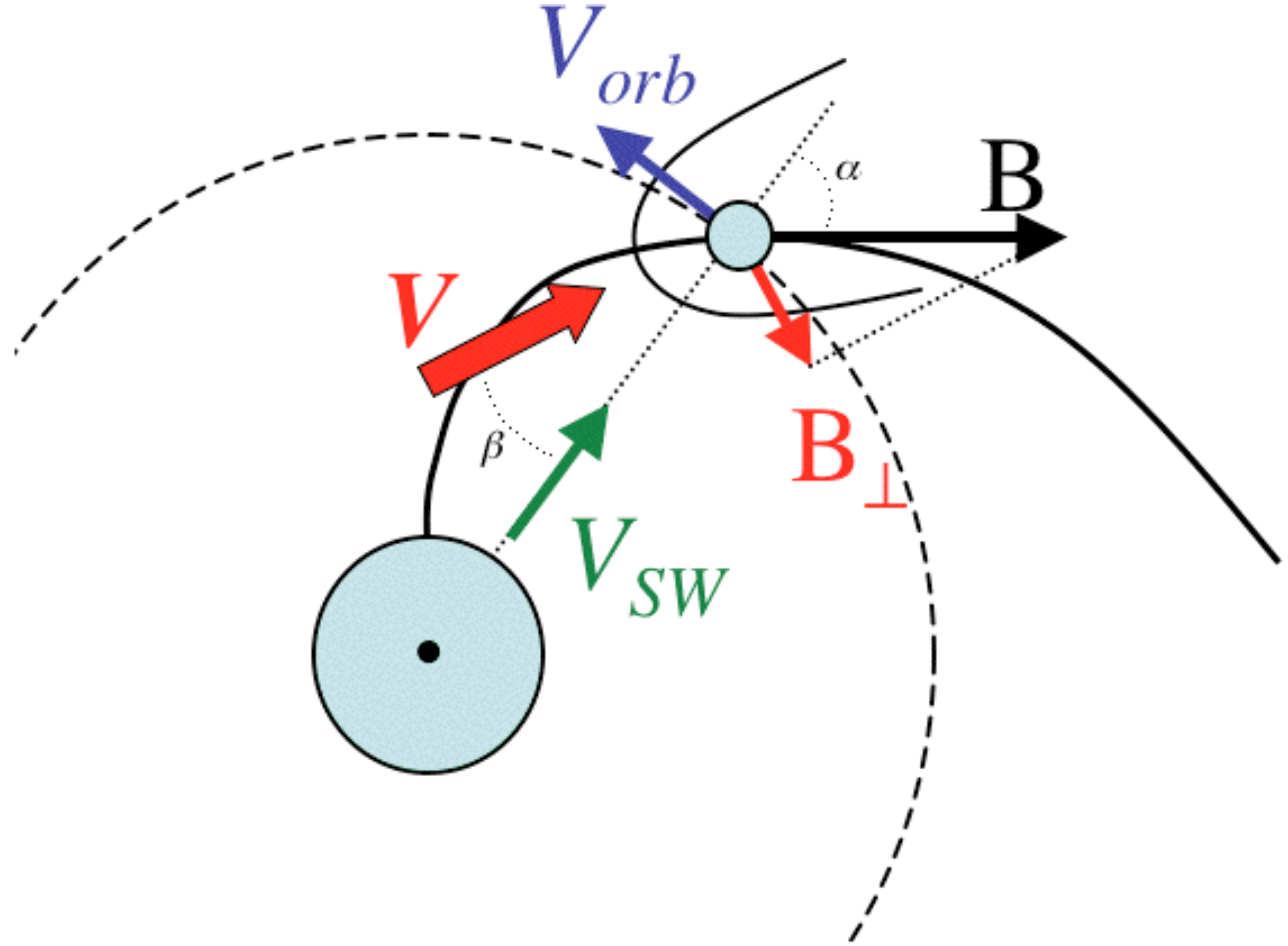
Modelling of a hot Jupiter (magnetized) orbiting a Solar type star

- Electron density in Solar corona

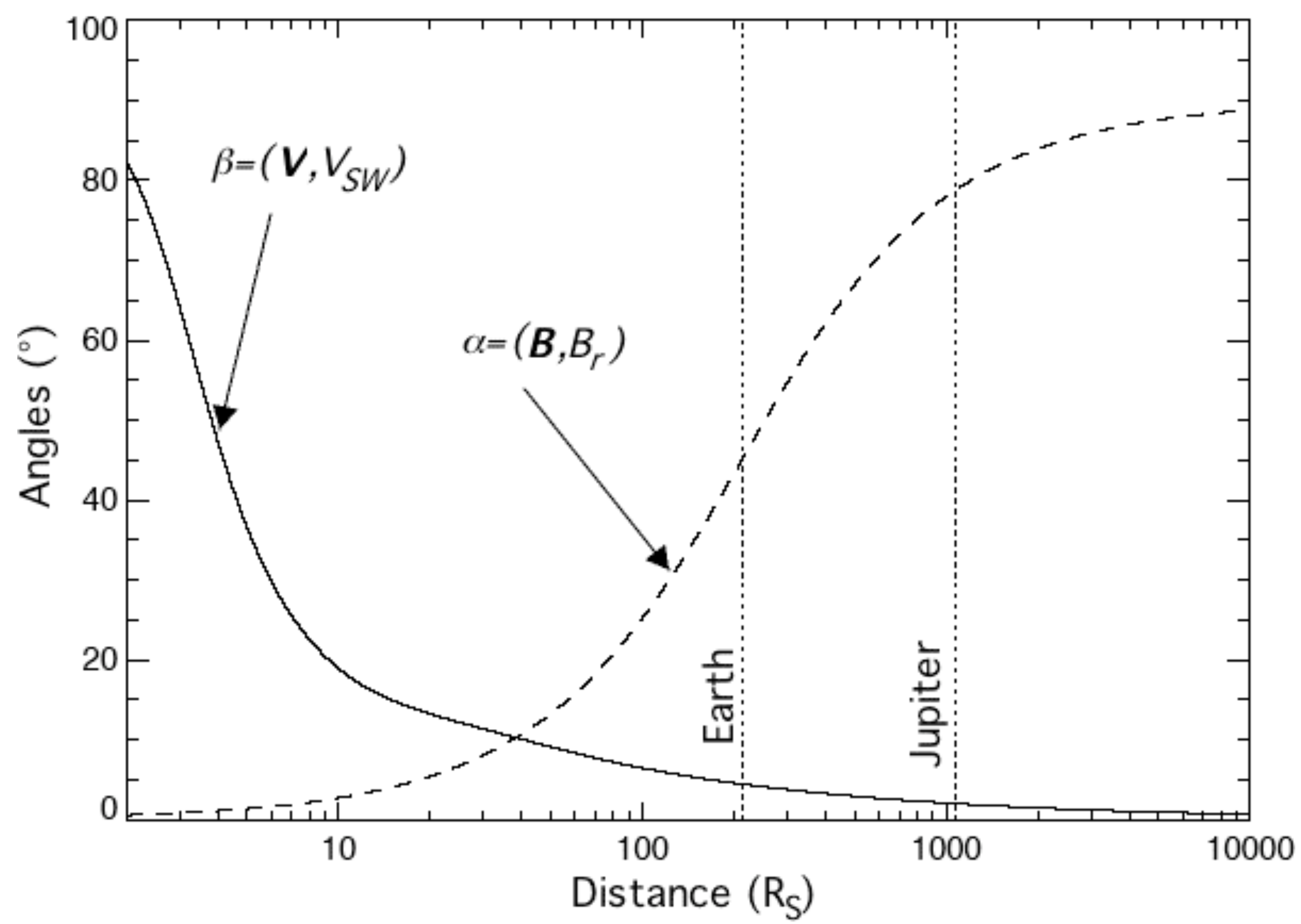


- Solar wind speed in the planet's frame



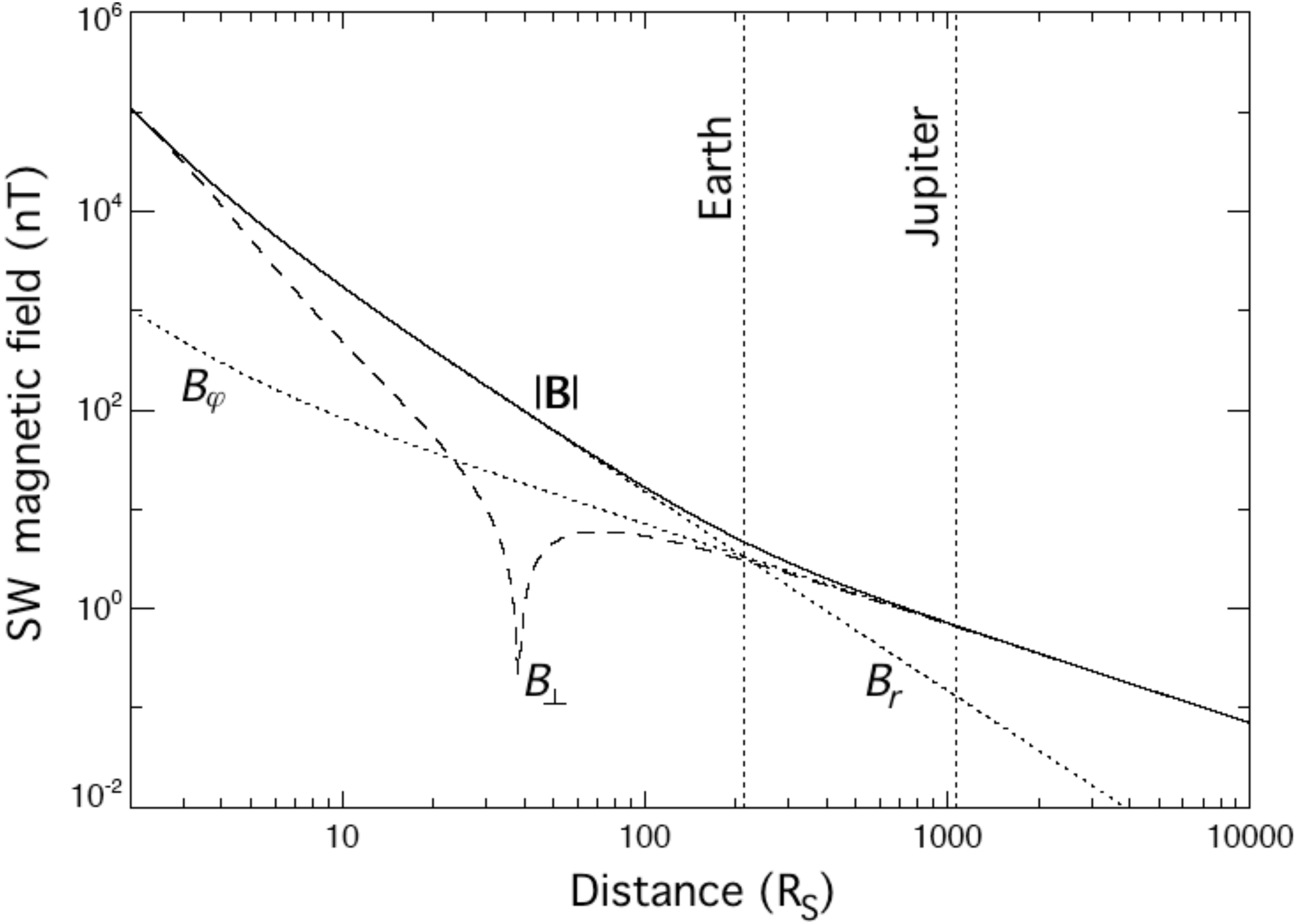


V_{orb}
α
B
V
β
$B_\perp$
V_{SW}

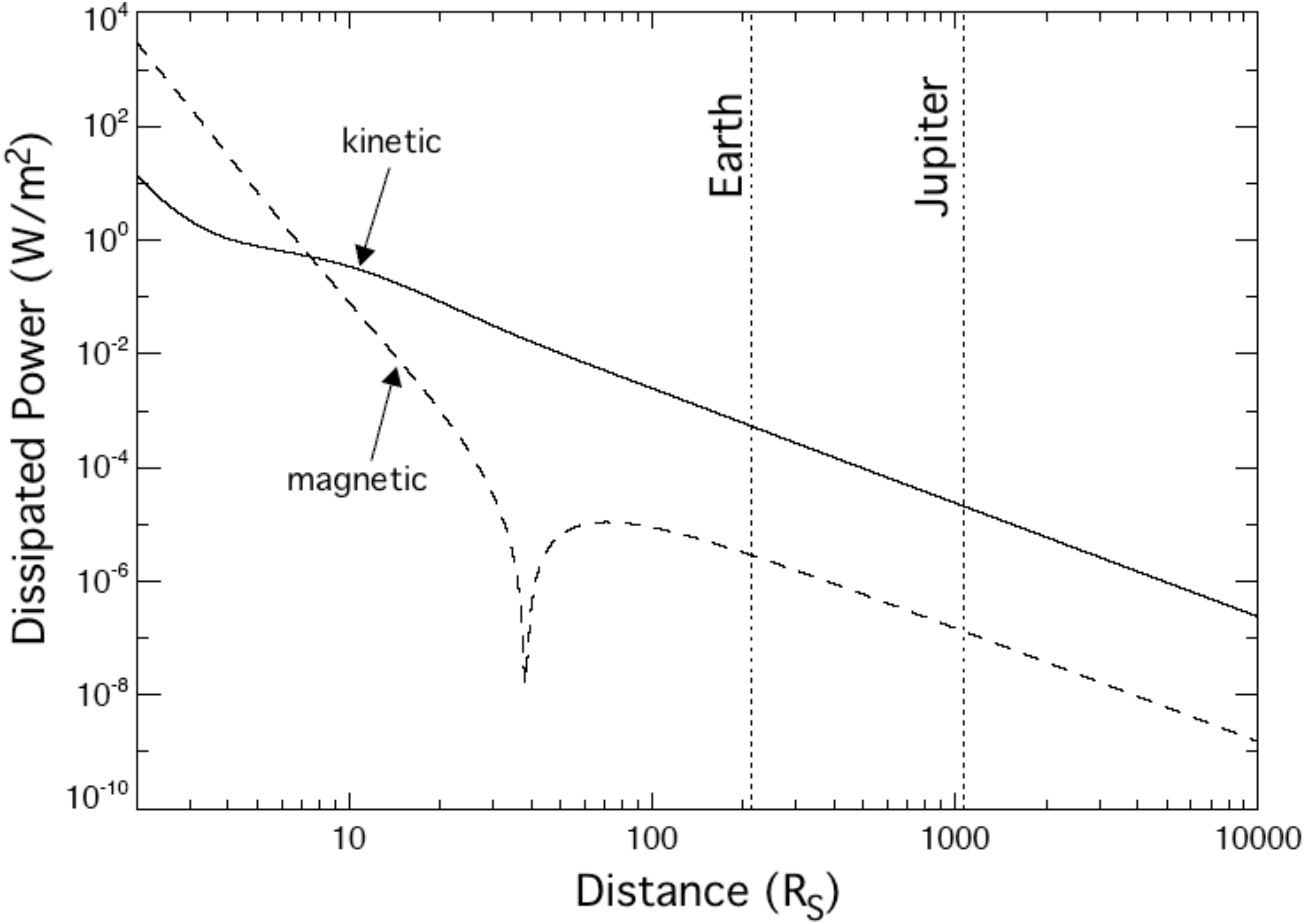


β=(**V**,V_{SW})
α=(**B**,B_r)
Earth
Jupiter
Angles (°)
Distance (R_S)
0
20
40
60
80
100
10
100
1000
10000

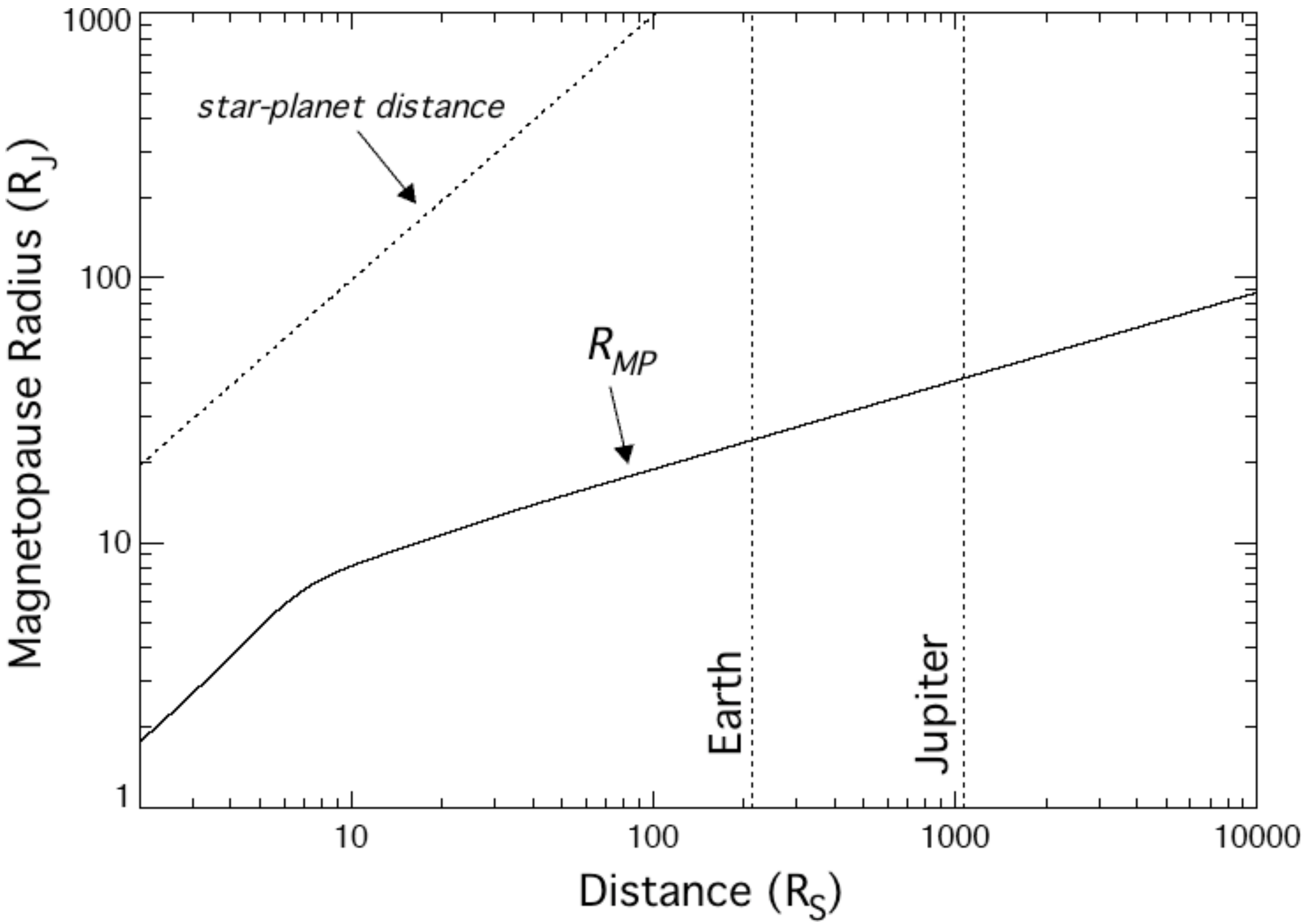
• Interplanetary magnetic field



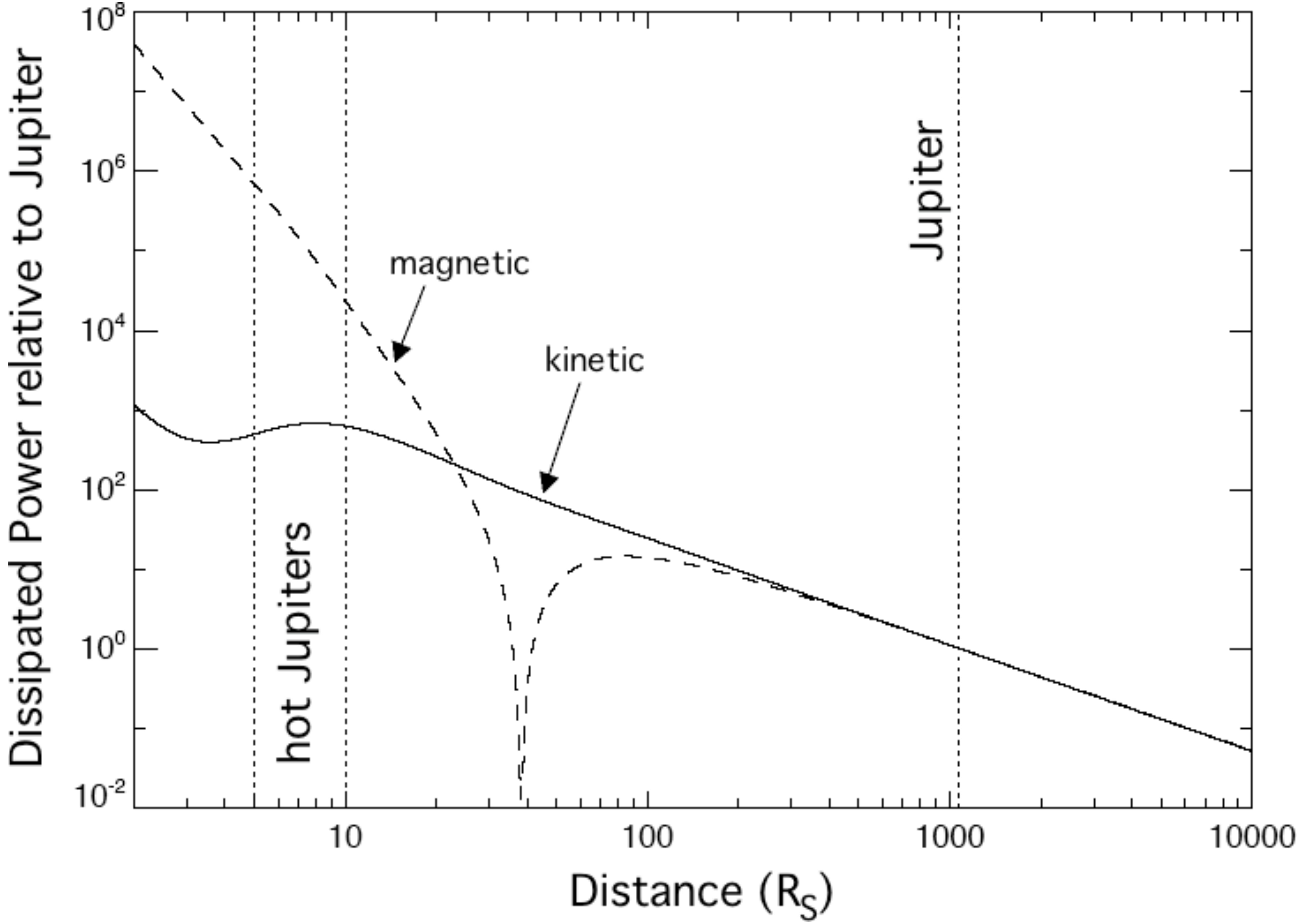
• Dissipated power per unit area of the obstacle



• Magnetospheric compression



• Total dissipated power on obstacle



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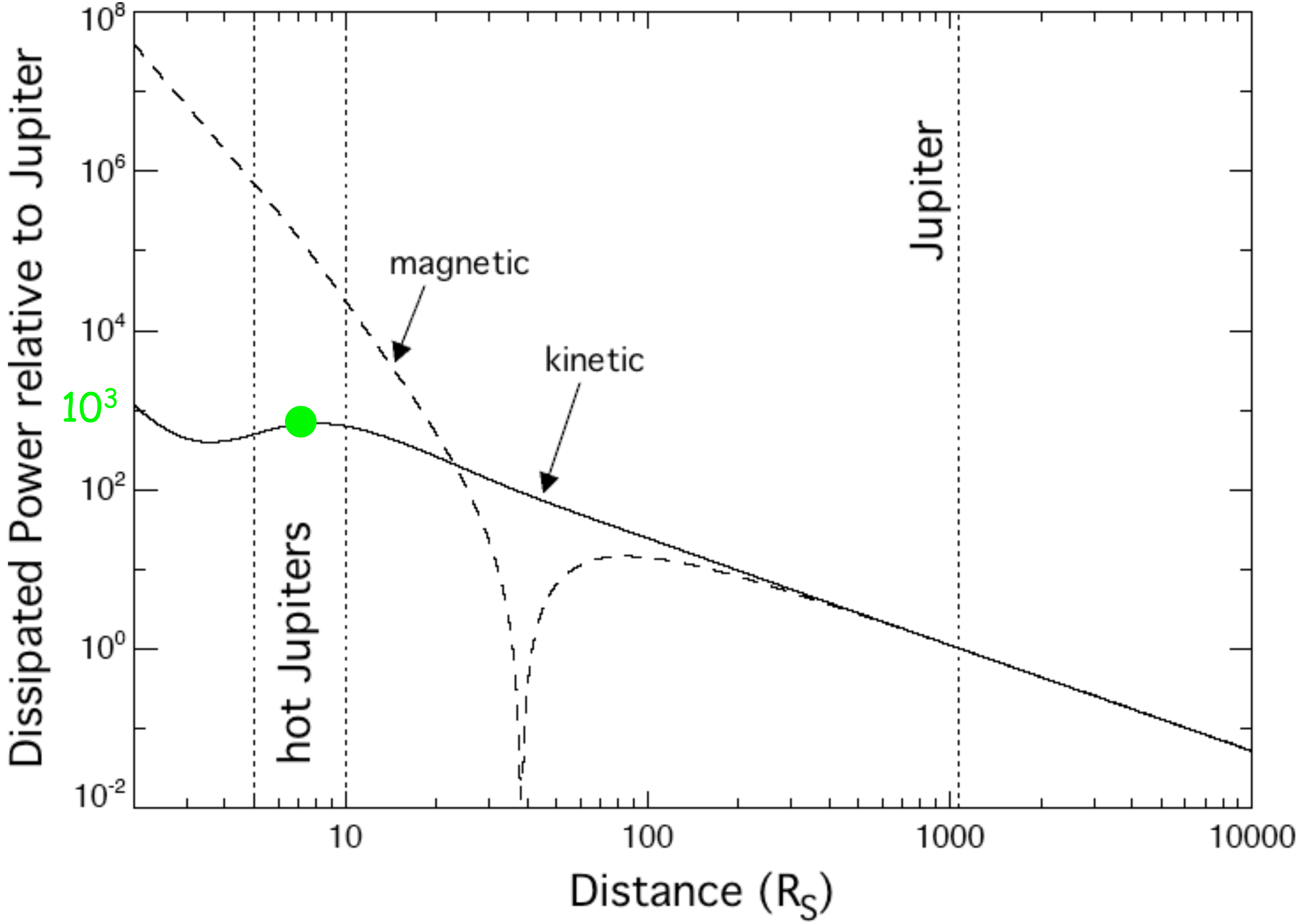

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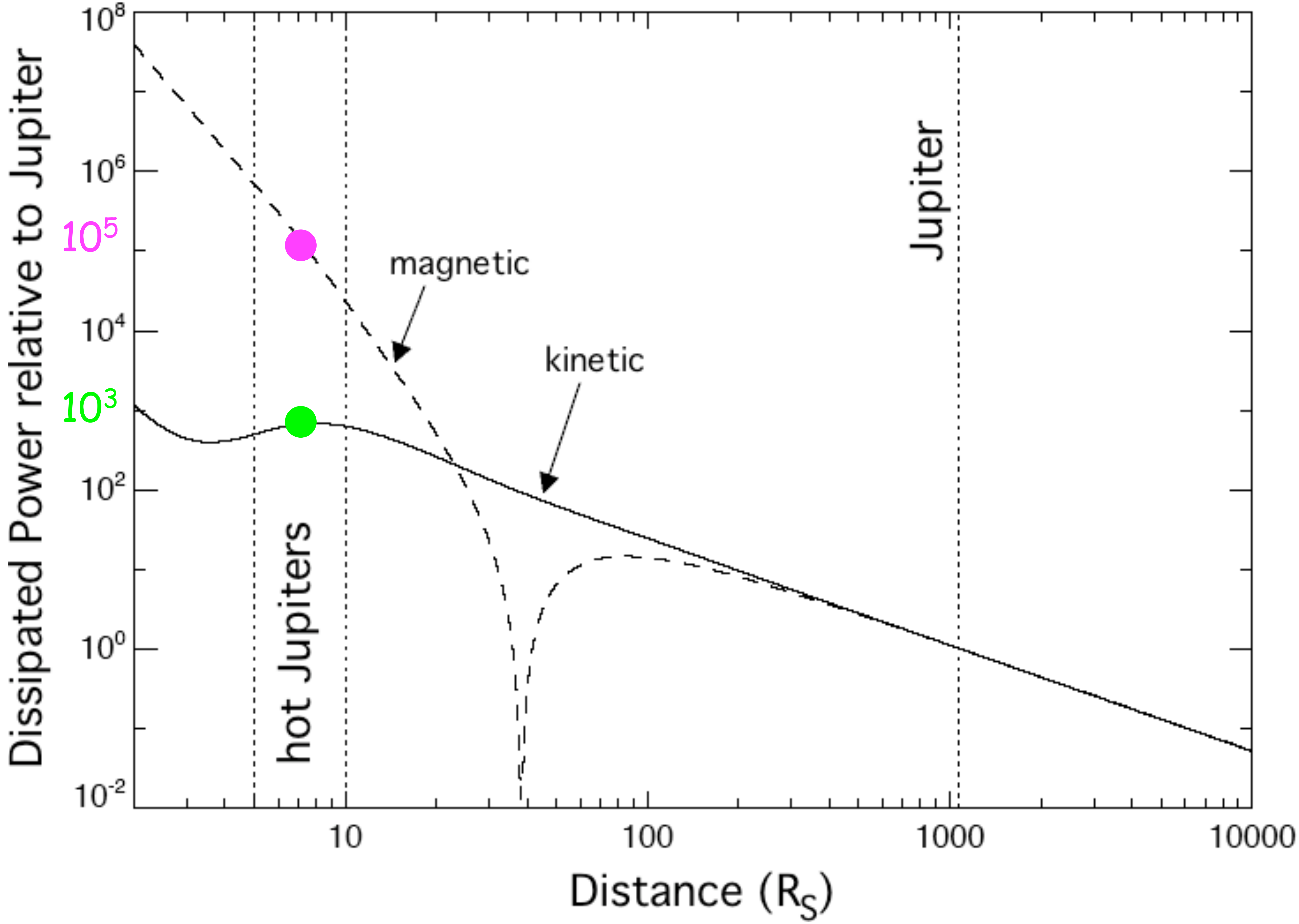
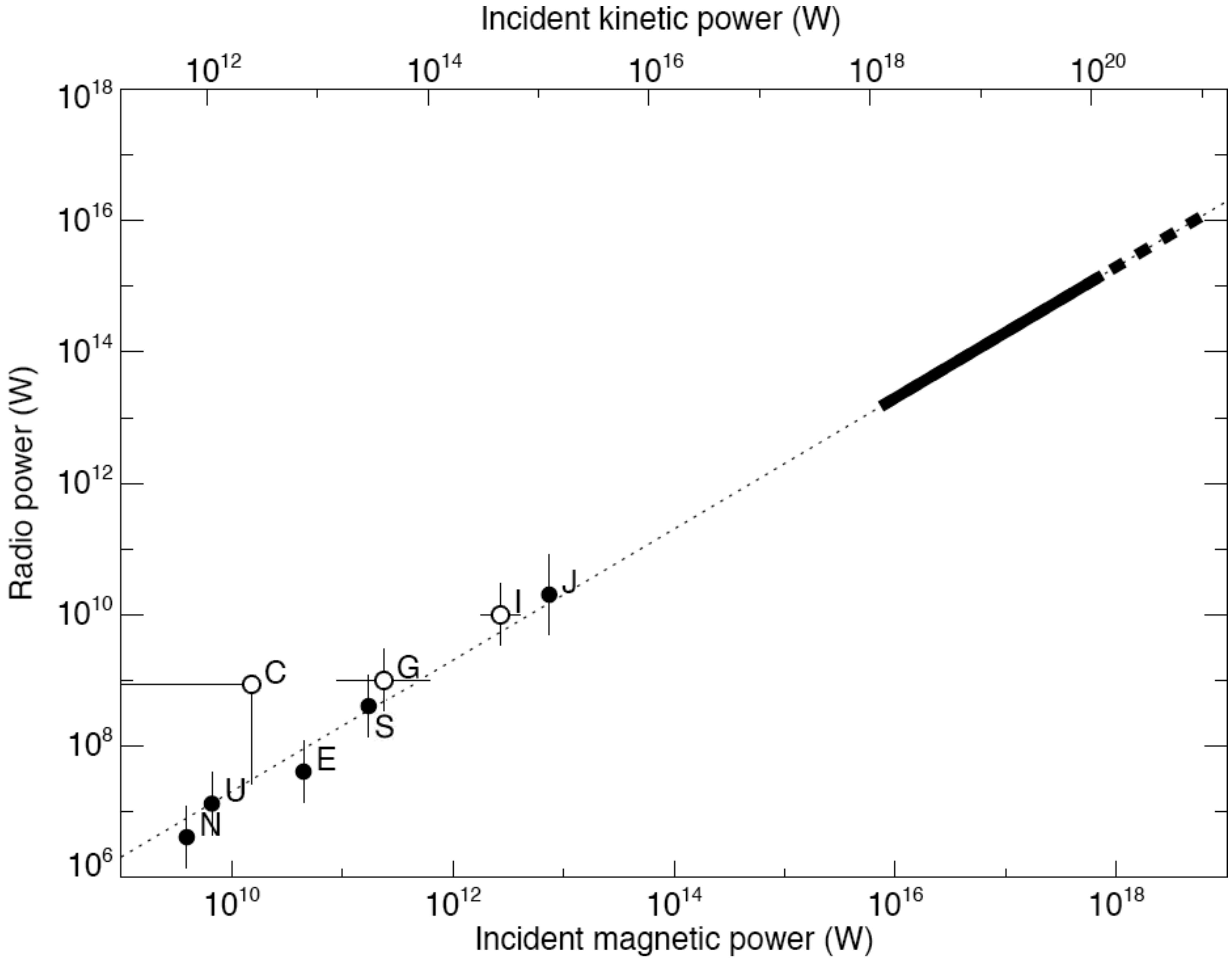
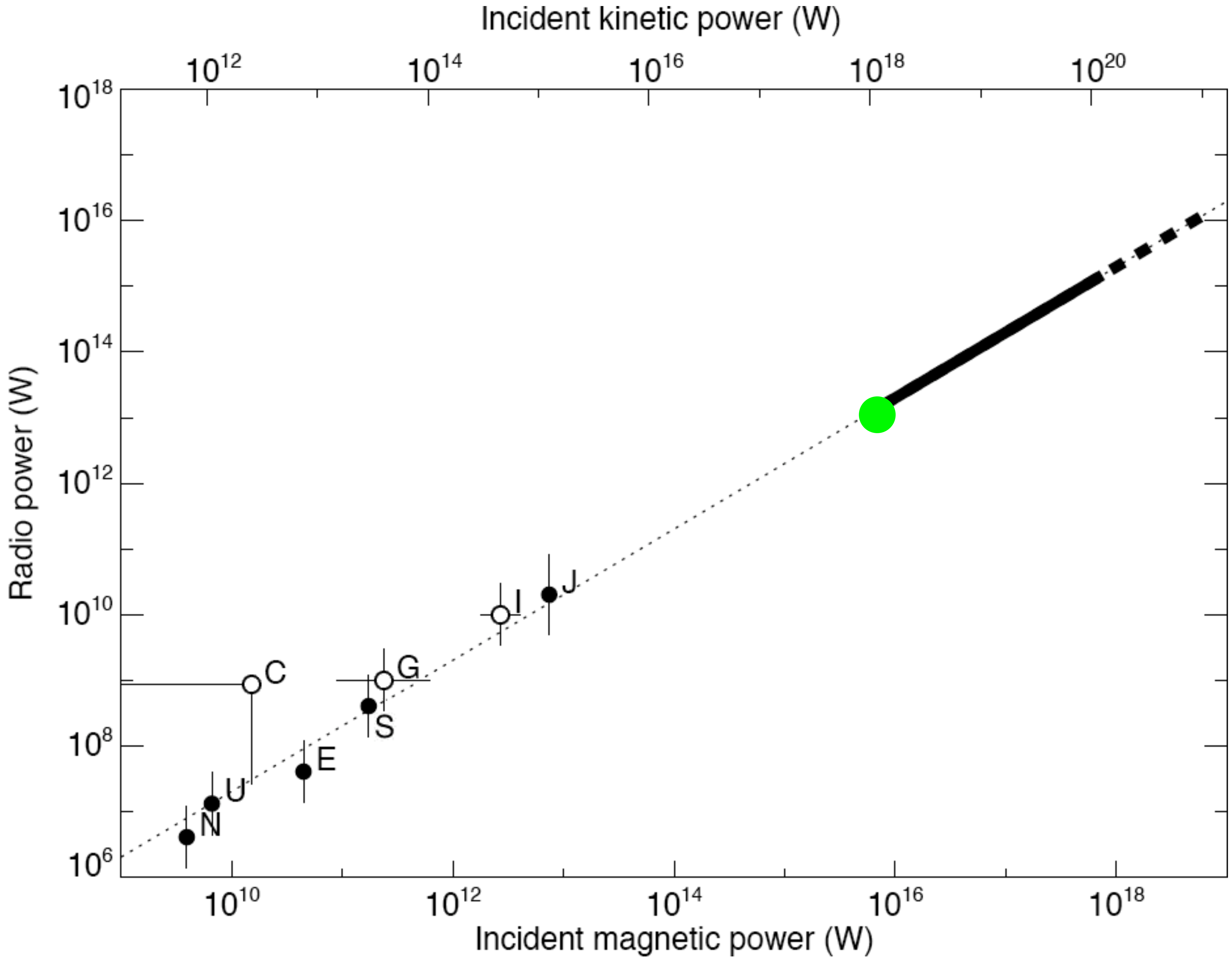


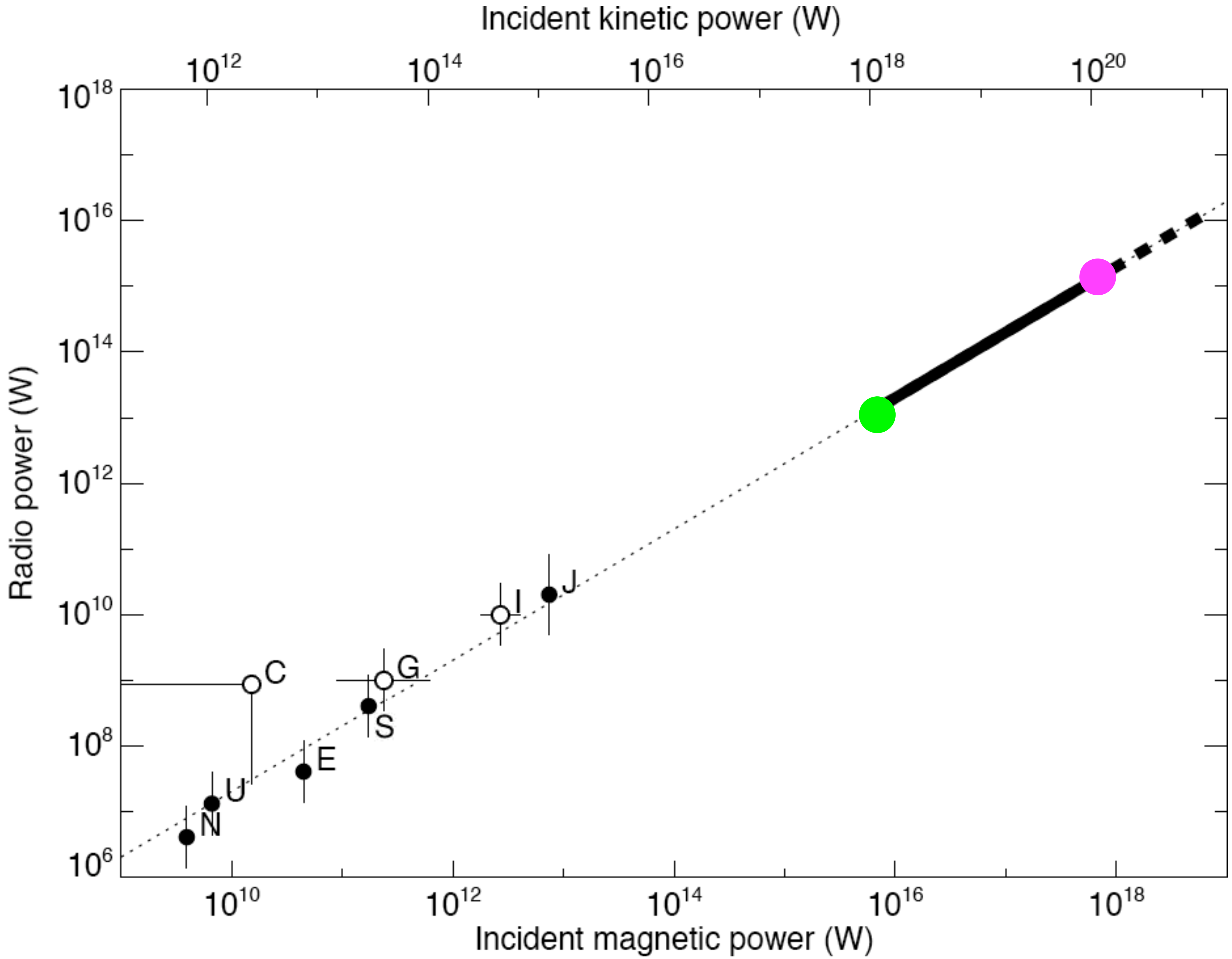

Incident kinetic power (W)
10^12
10^14
10^16
10^18
10^20
10^18
10^16
10^14
10^12
10^10
10^8
10^6
Radio power (W)
C
G
I
J
S
E
U
N
10^10
10^12
10^14
10^16
10^18
Incident magnetic power (W)



- Extrapolation / Radio-kinetic Bode's law

$P_{Radio} = P_{Radio\text{-}J} \times 10^3$

[Farrell et al., 1999, 2004]



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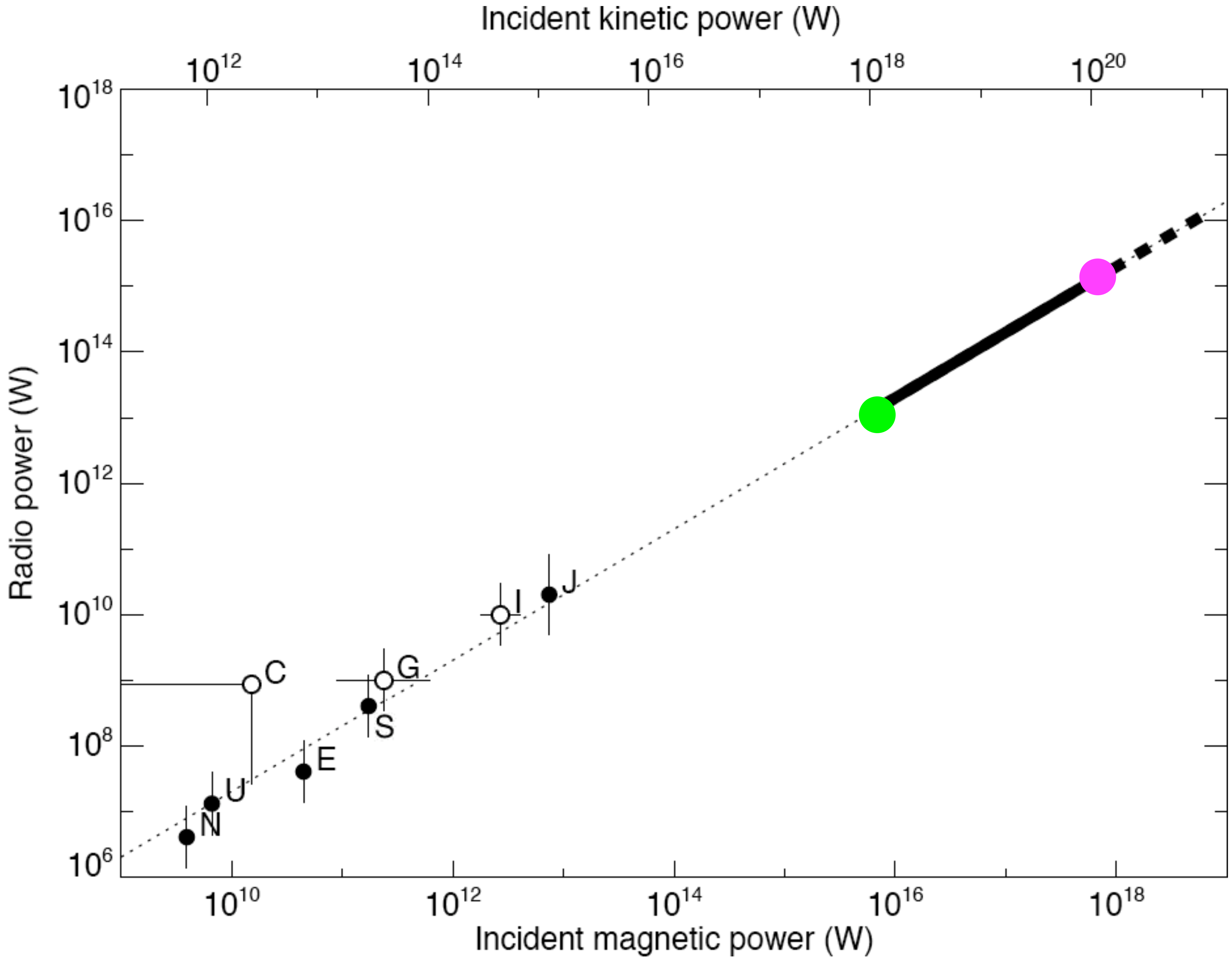
- Extrapolation / Radio-magnetic Bode's law $P_{Radio} = P_{Radio\text{-}J} \times 10^5$

[Zarka et al., 2001, 2005; Zarka, 2007]



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except if there is a « saturation » mechanism

Planetary magnetic field decay ?

- Radio detection $\Rightarrow$ $f > 10$ MHz $\Rightarrow$ $B_{max\text{-}surface} \geq 4$ G
- Jupiter : $\mathcal{M} = 4.2$ 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) $\Rightarrow$ $\omega\downarrow$
- But $\mathcal{M} \propto \omega^{\alpha}$ with $\frac{1}{2} \leq \alpha \leq 1$ $\Rightarrow$ $\mathcal{M}\downarrow$ (B decay) ?

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- Internal structure + convection models

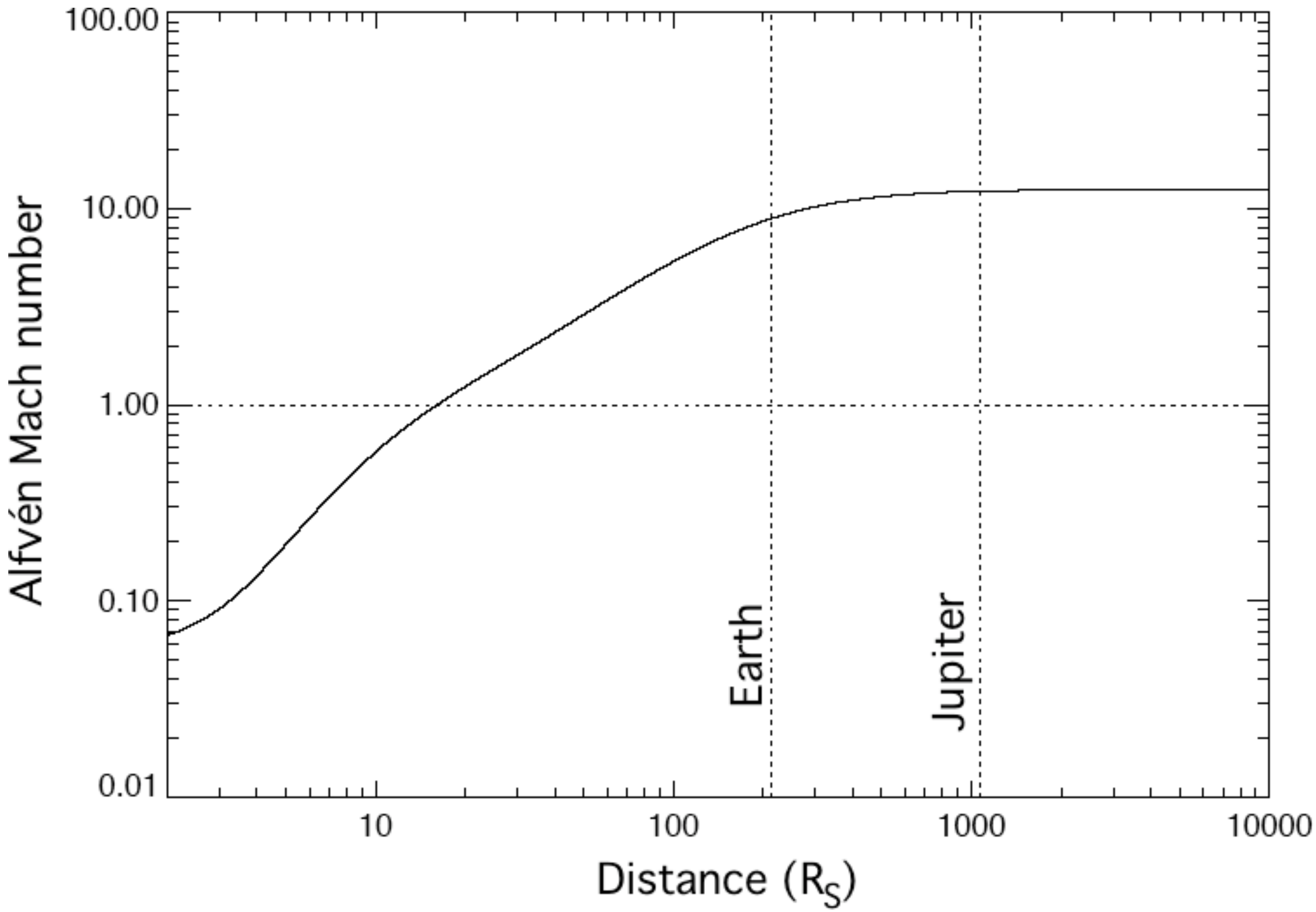
  ⇒ self-sustained dynamo ⇒ $\mathcal{M}$ could remain ≥ a few $G.R_J^3$

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	1.1×10^{24}	1.4
HD 209458b	0.69	3.52	1.43	0.8×10^{24}	0.8
τ Boo b[a]	3.87	3.31	1.3	1.6×10^{24}	2
OGLE-TR-56b	0.9	1.2	1.3	2.2×10^{24}	2.8

[Sanchez-Lavega, 2004]

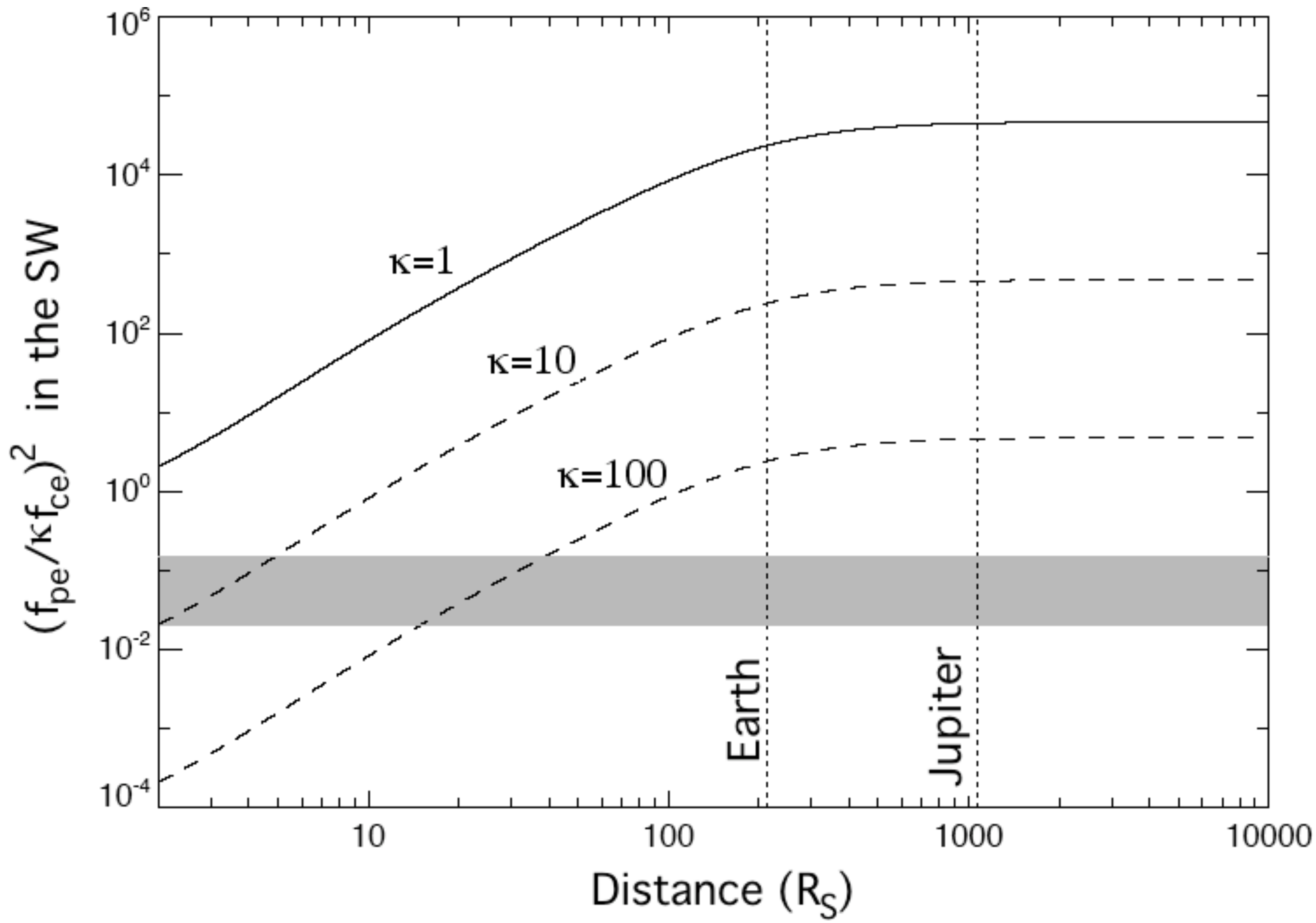
• Unipolar inductor in sub-Alfvénic regime
(as for Io-Jupiter)



- But radio emission possible only if $f_{pe}/f_{ce} \ll 1$

  ⇒ intense stellar B required (κ = 10-100 x B_{Sun})

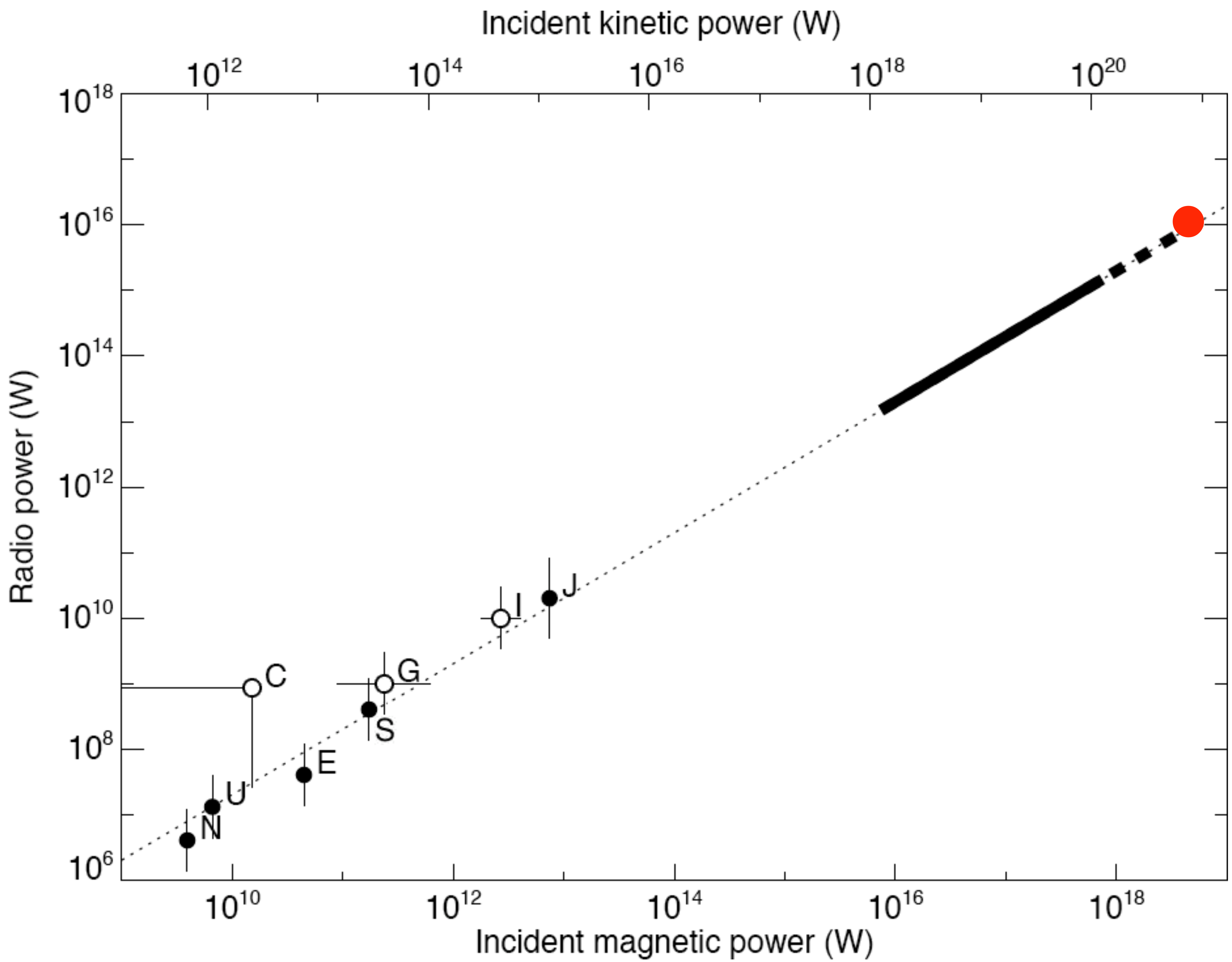
  ⇒ emission ≥30-250 MHz from 1-2 R_S



- Extrapolation / Radio-magnetic Bode's law [Zarka , 2005, 2007]

$P_{Radio} = P_J \times 10^5 \times (R_{exo\text{-}ionosphere}/R_{magnetosphere})^2 \times (B_{star}/B_{Sun})^2$

$= P_{Radio\text{-}J} \times 10^6$



$\Rightarrow \zeta = 10^5$

	$b\,\tau = 10^6$ *(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)*	3	50	11	190	40	710
$A_e = 10^6$ m^2 *(~LOFAR77)*	9	160	33	600	130	2200

(distances in parsecs)

Other published studies ...

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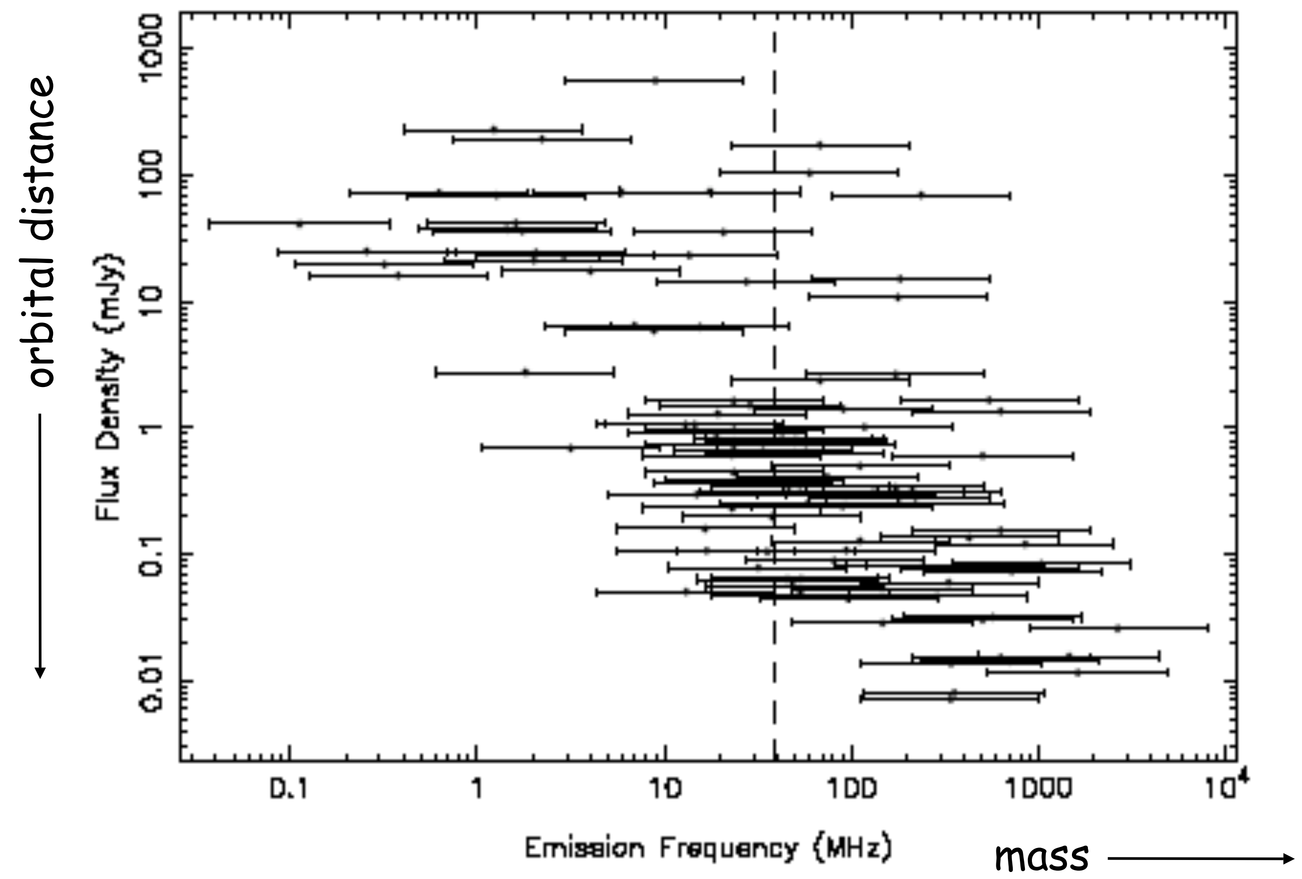
• Predictions for the whole exoplanet census

➡ radio-kinetic extrapolation

[Lazio et al., 2004]



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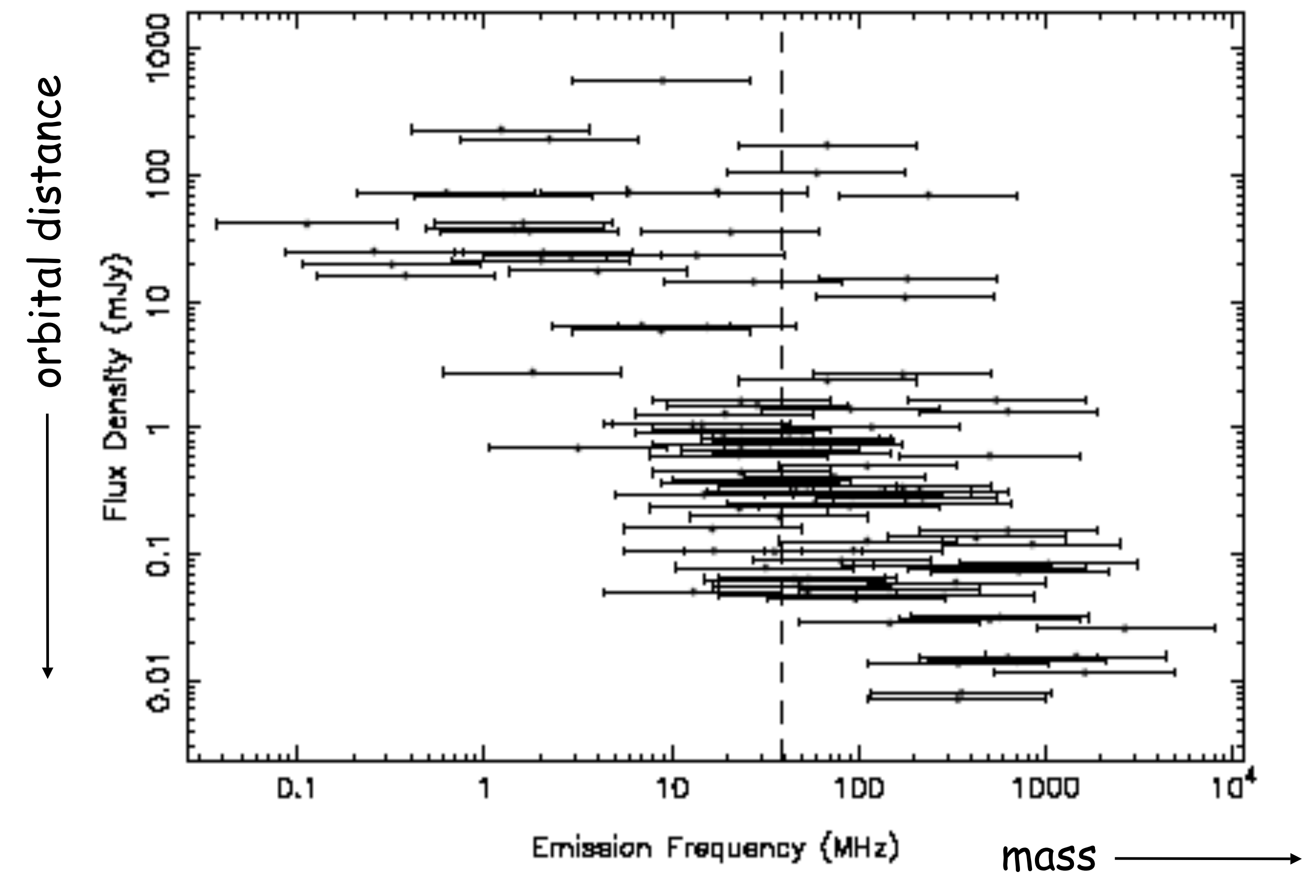

➡ radio-magnetic + CME extrapolations

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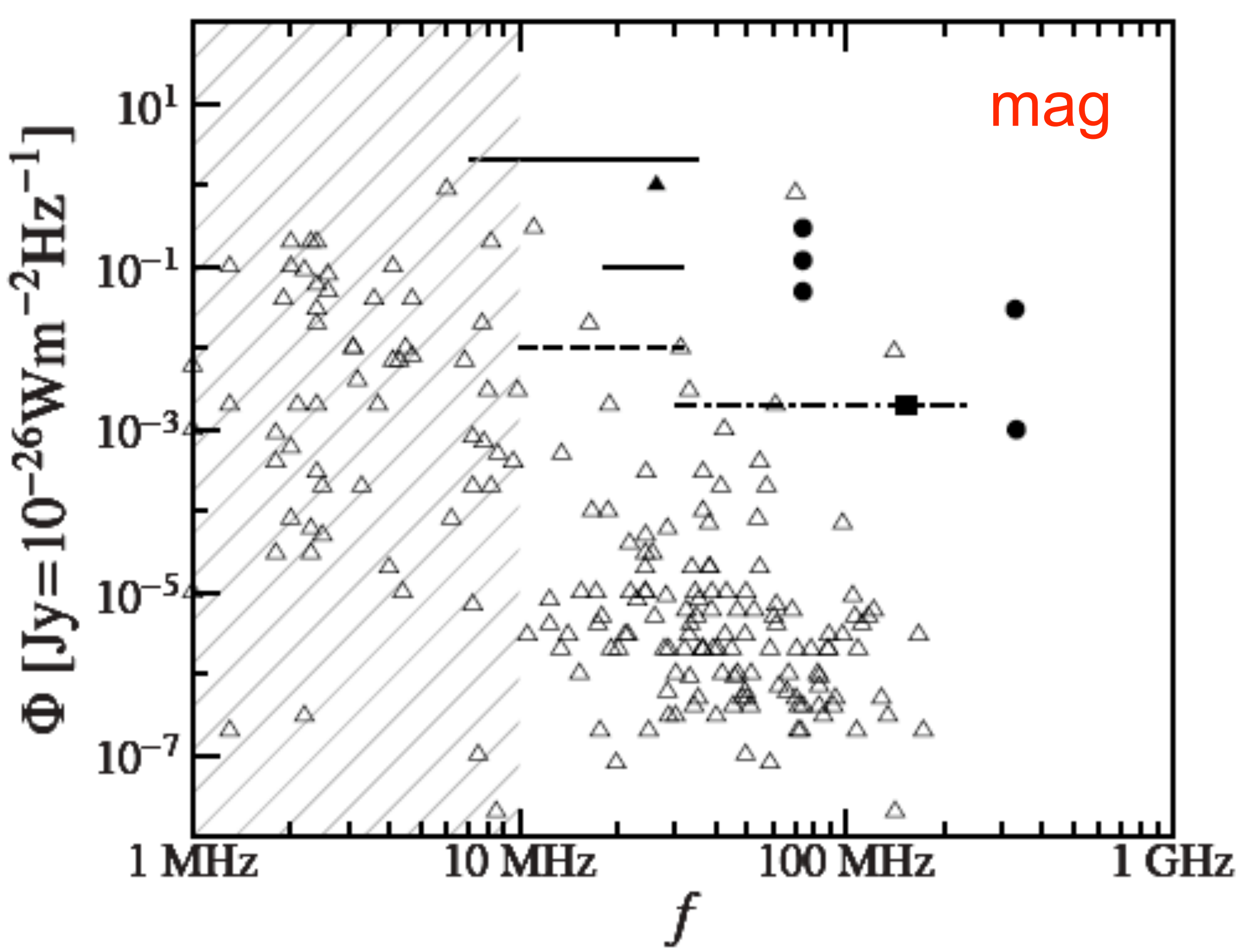

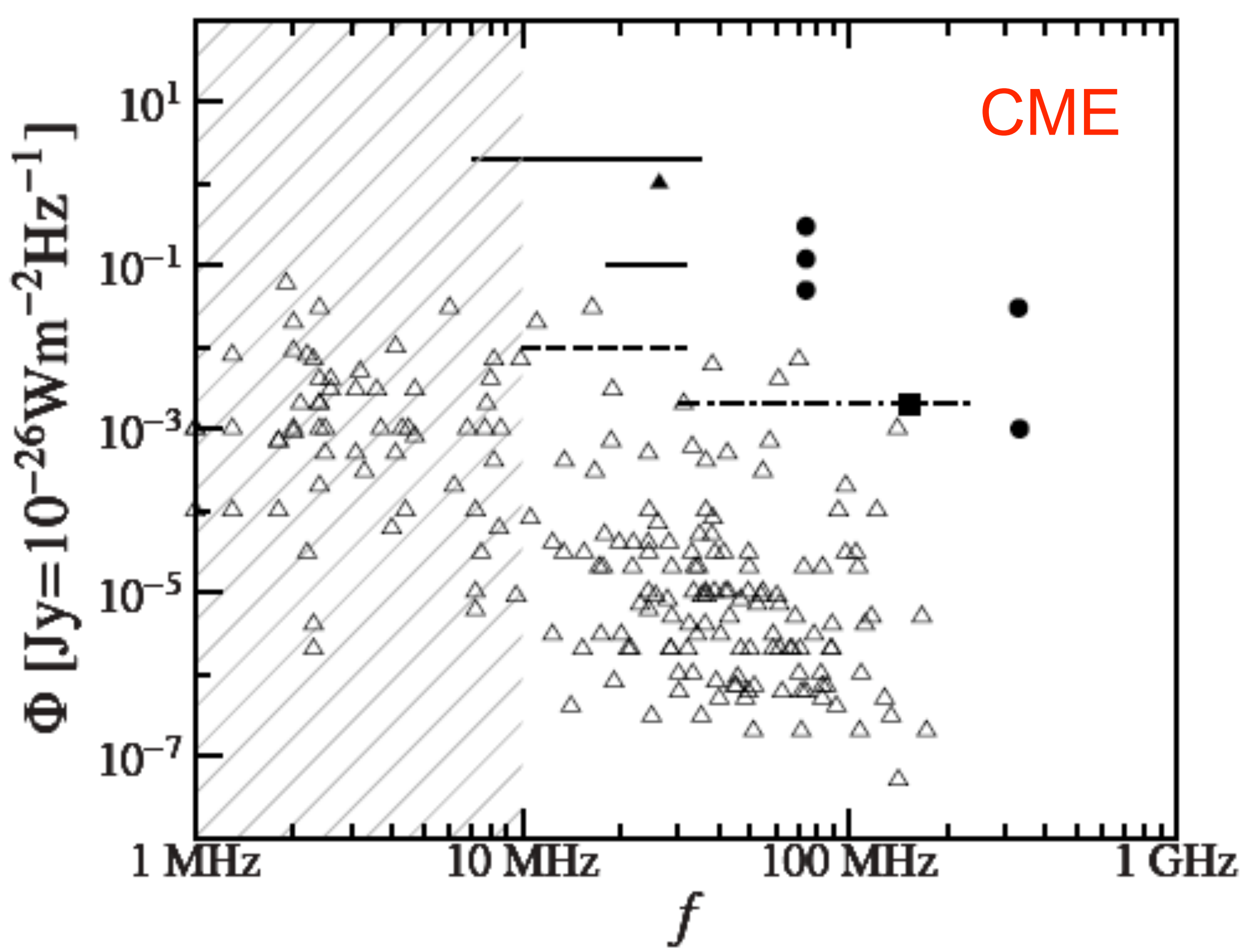

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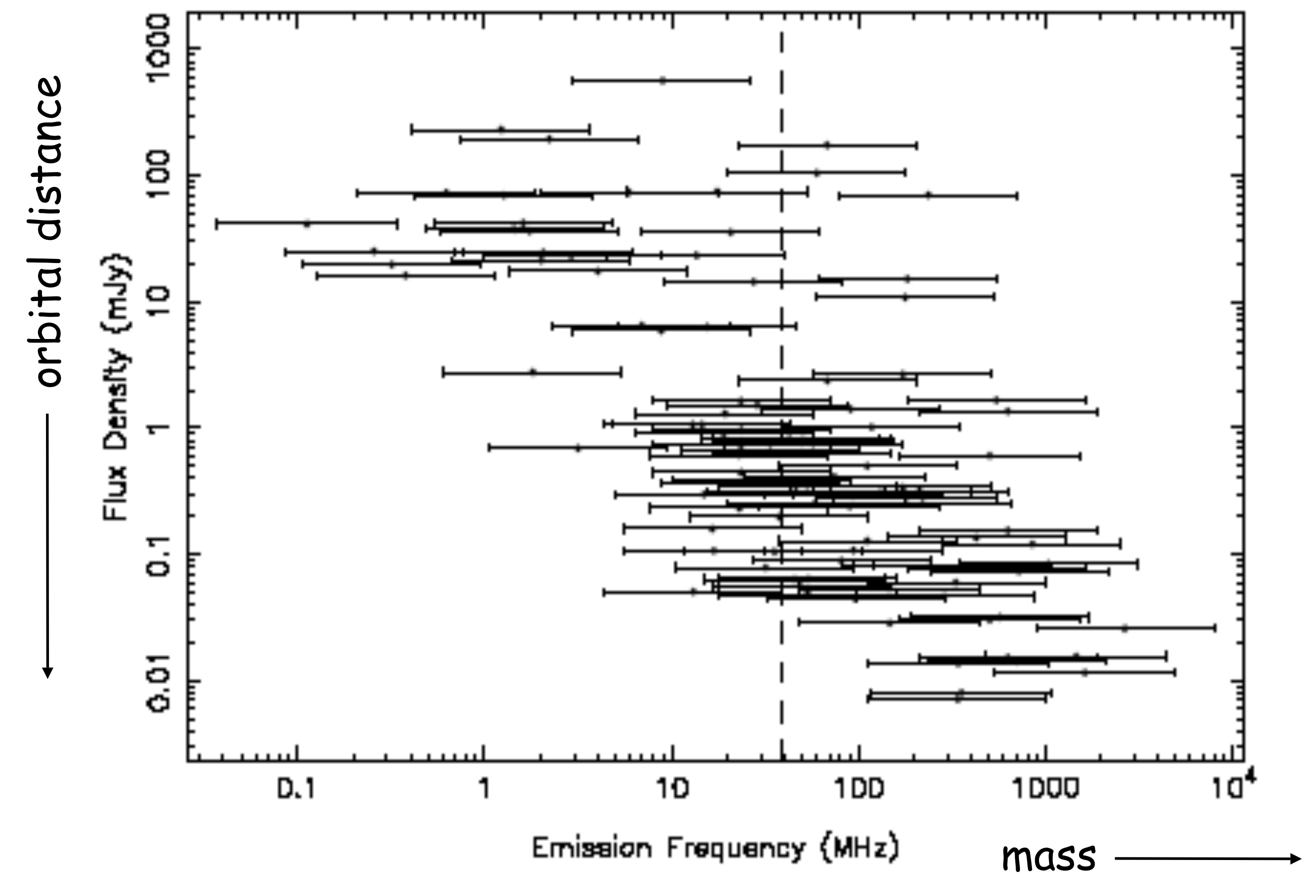

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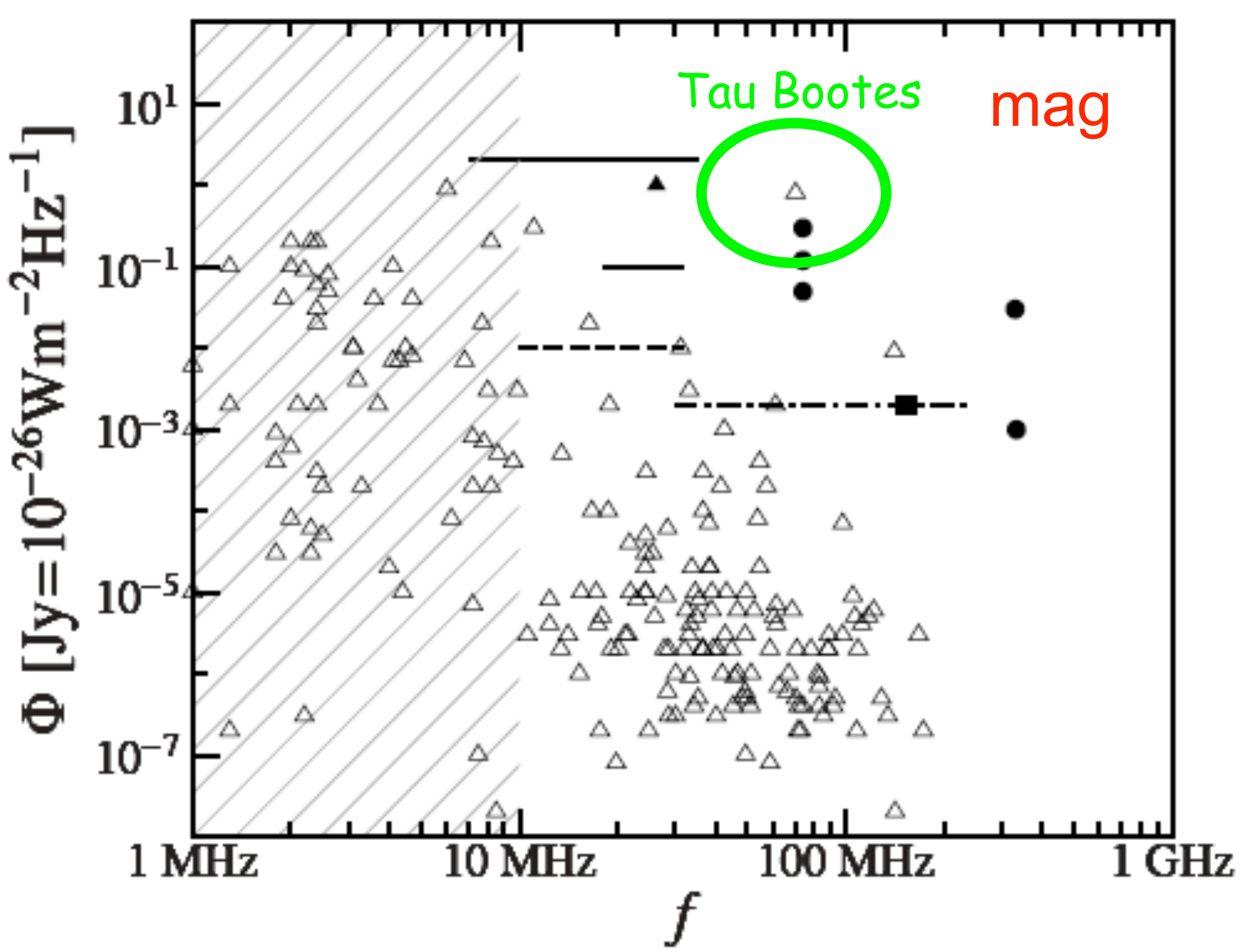

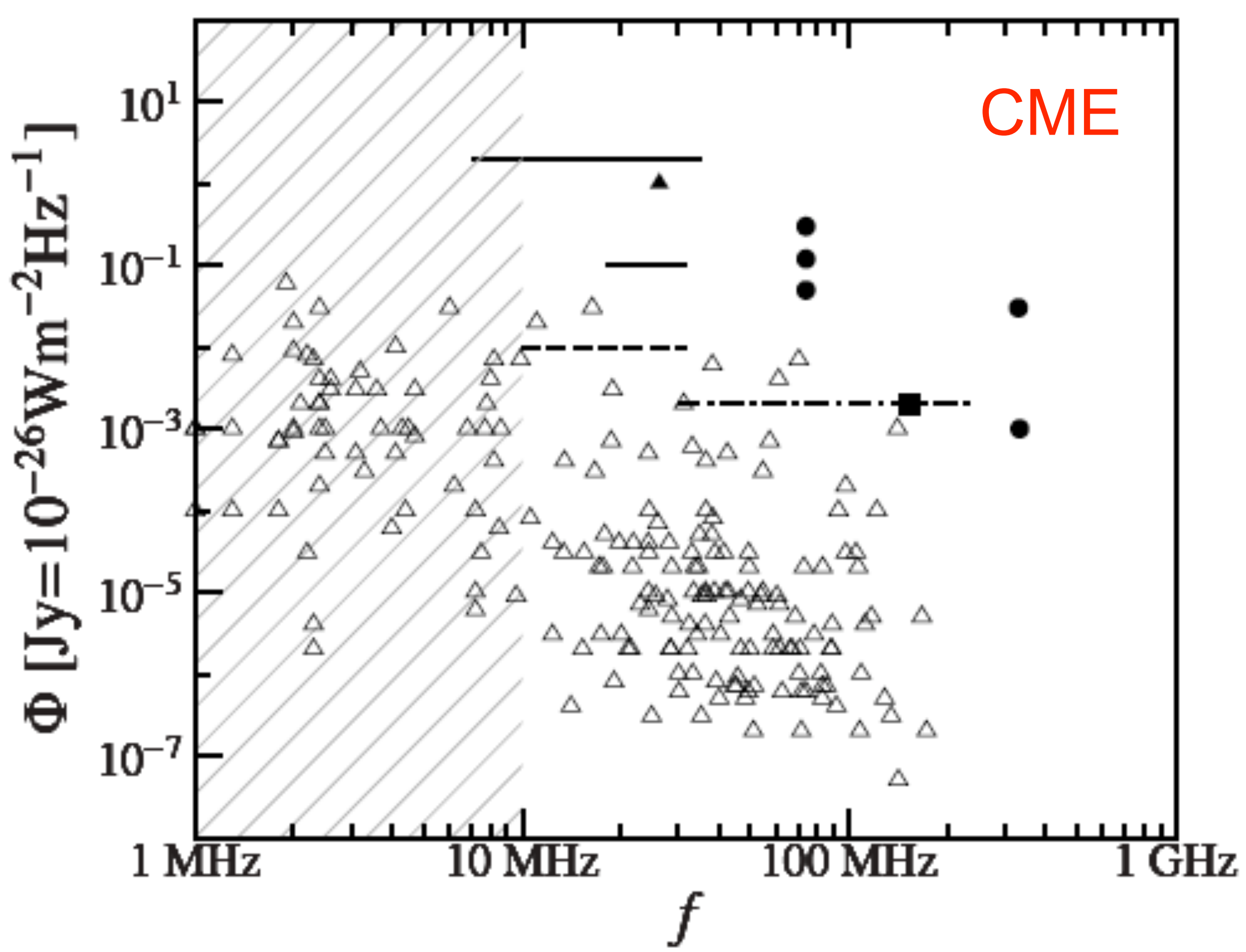

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An Old Idea ...

035-5 A Search for Extra-Solar Jovian Planets by Radio Techniques. W.F. YANTIS, U. Wash. and Goldendale Observatory, W.T. SULLIVAN, III, U. Wash. & W.C. ERICKSON, U. Maryland. - We propose to search for the presence of planets associated with nearby stars through detection of Jovian like decametric radio bursts. Planetary bursts would be distinguished from possible stellar bursts by the presence of a high-frequency cut-off and possibly a modulation associated with the rotation of the planet. A search for such planetary radio bursts at 26.3 MHz is presently being conducted at The Clark Lake Radio Observatory. The sample includes 22 stars within 5 parsecs. The sensitivity limit is 10^{-26} watts m^{-2} Hz^{-1}, about 1,000 times the signal expected from a strong Jovian burst. However, it is expected that the strength of any bursts will depend strongly on the planetary magnetic field and also possibly on the presence of a stellar wind. Initial observations exhibit several non-instrumental features which are under current study. Further results will be reported and monitoring observations are continuing.

[Yantis et al., BAAS, 1977]

LF radio observations

Instrument Name & Location	Description	Frequency range (MHz)	Effective area (m^2)	Beam	Polarisation	Maximum effective sensitivity (Jy)
NDA (Nançay Decameter Array), France	2×72 helix-spiral antennas (rectangular arrays)	10 - 100	~2 × 4000	~ 6° × 10°	2 circular → 4 Stokes	$\sim 10^2$
VLA (Very Large Array), New Mexico, USA	Interferometer : 27 parabolas × 25m ∅ (Y-shape array)	74, 330, ...	~13000	≥ 0.4'	2 polar.	$<10^{-2}$
GMRT (Giant Meterwave Radio Telescope), Pune, India	30 parabolas × 45m ∅ (core + Y-shape array)	150, 235, ...	~30000	0.3'	4 Stokes	$<10^{-3}$
UTR-2, Kharkov, Ukraine	2040 dipoles (T-shape array 1 km x 2 km)	7 - 35	~140000	~30' × 10°	1 linear polar. (EW)	10^0
LOFAR (Low Frequency Array), The Netherlands	Interferometer / Phased arrays of dipoles (core + stations up to >100 km)	10 - 240	$\sim 10^6 \times (15/\nu)^2$	~1.5" ×(100/ν) [ν in MHz]	4 Stokes	$<10^{-3}$

1 UA à 1 pc = 1 " ⇒ no imagery

→ (1) detect a signal, (2) star or planet ?

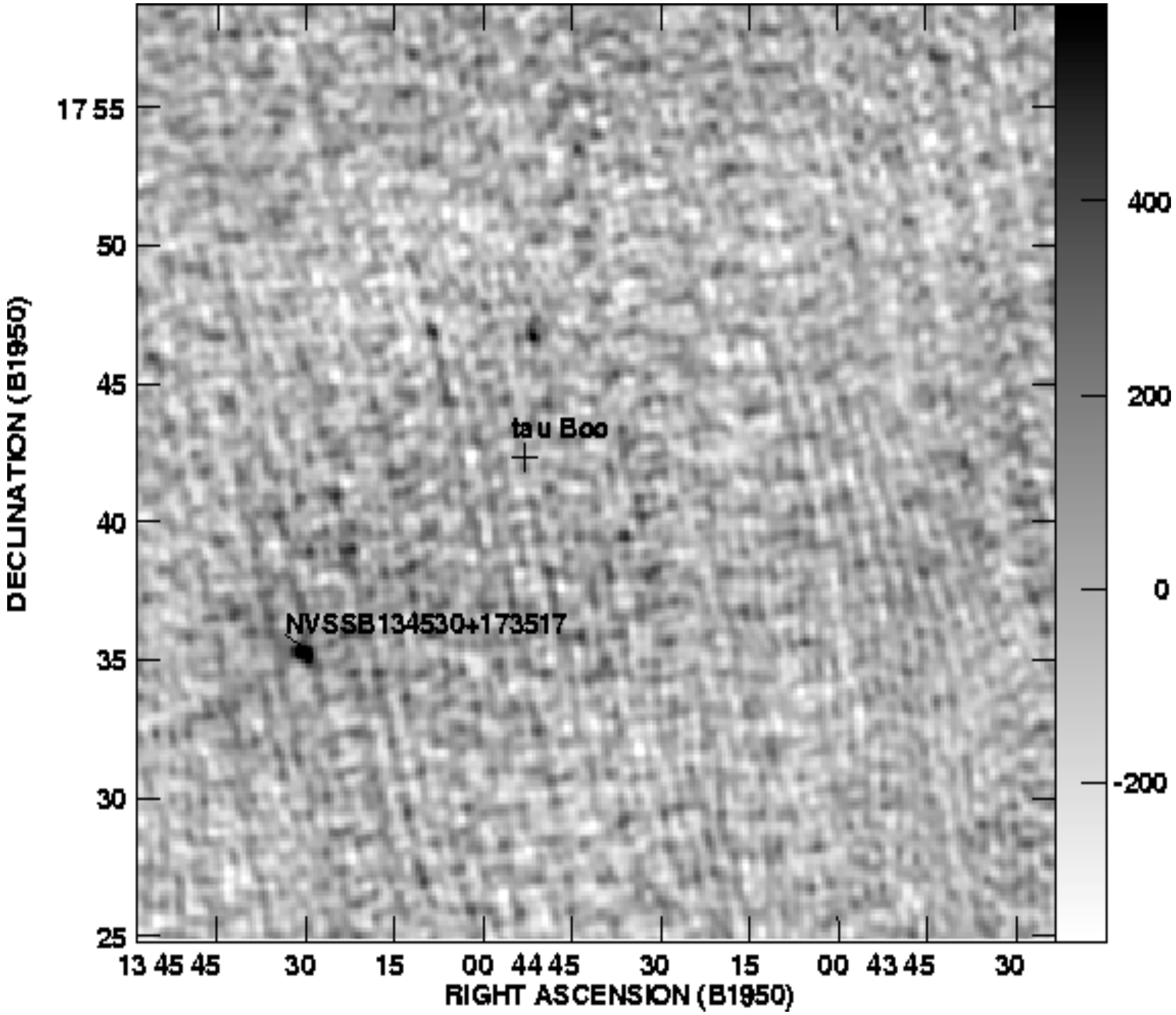
→ discriminate via emission polarization (circ./elliptical) + periodicity (orbital)

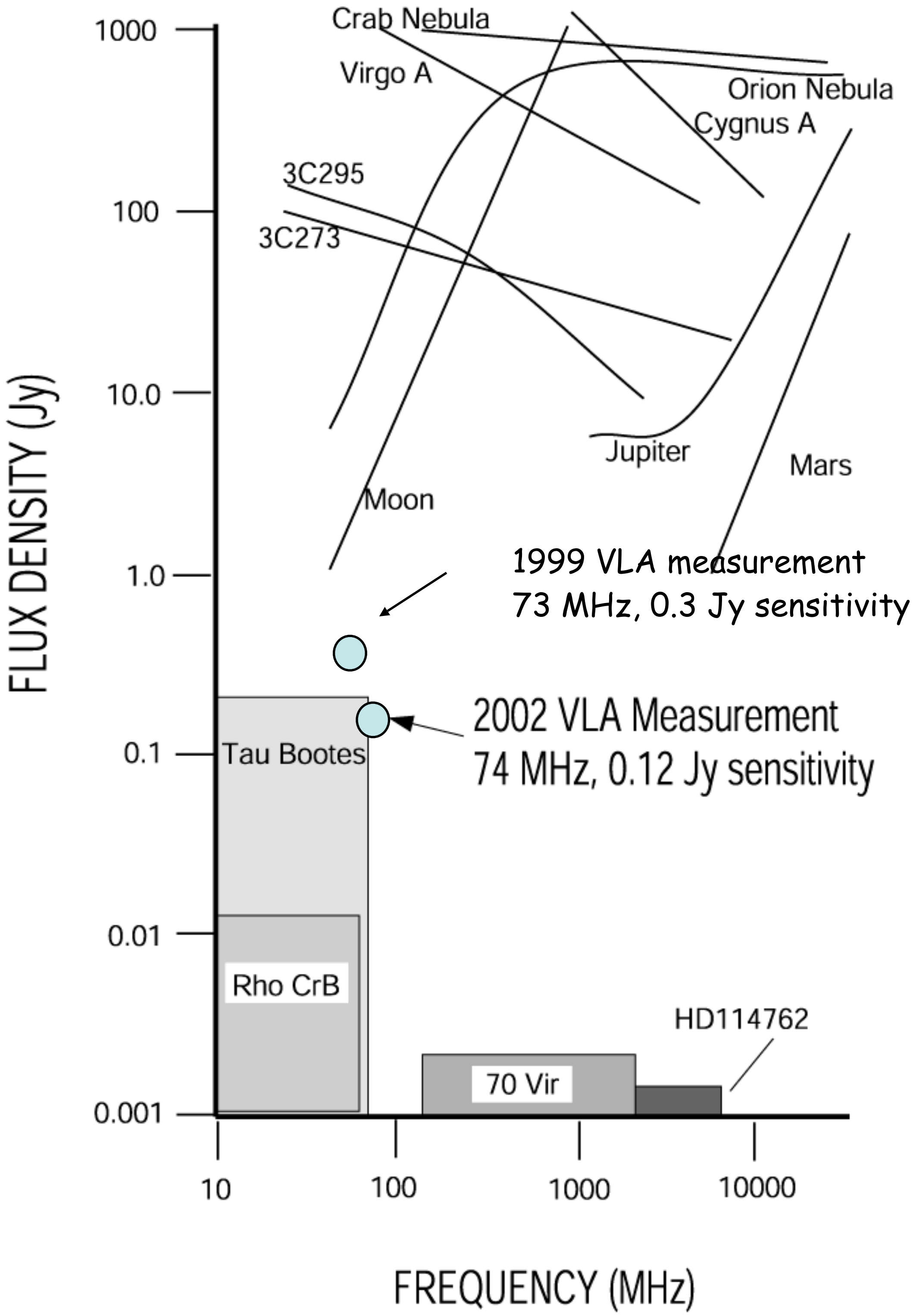
→ search for Jovian type bursts ?

• VLA

[Bastian et al., 2000 ; Farrell et al., 2003, 2004; Lazio & Farrell, 2007]

- f ~ 74 MHz
- target Tau Bootes
- epochs 1999 - 2003
- imaging

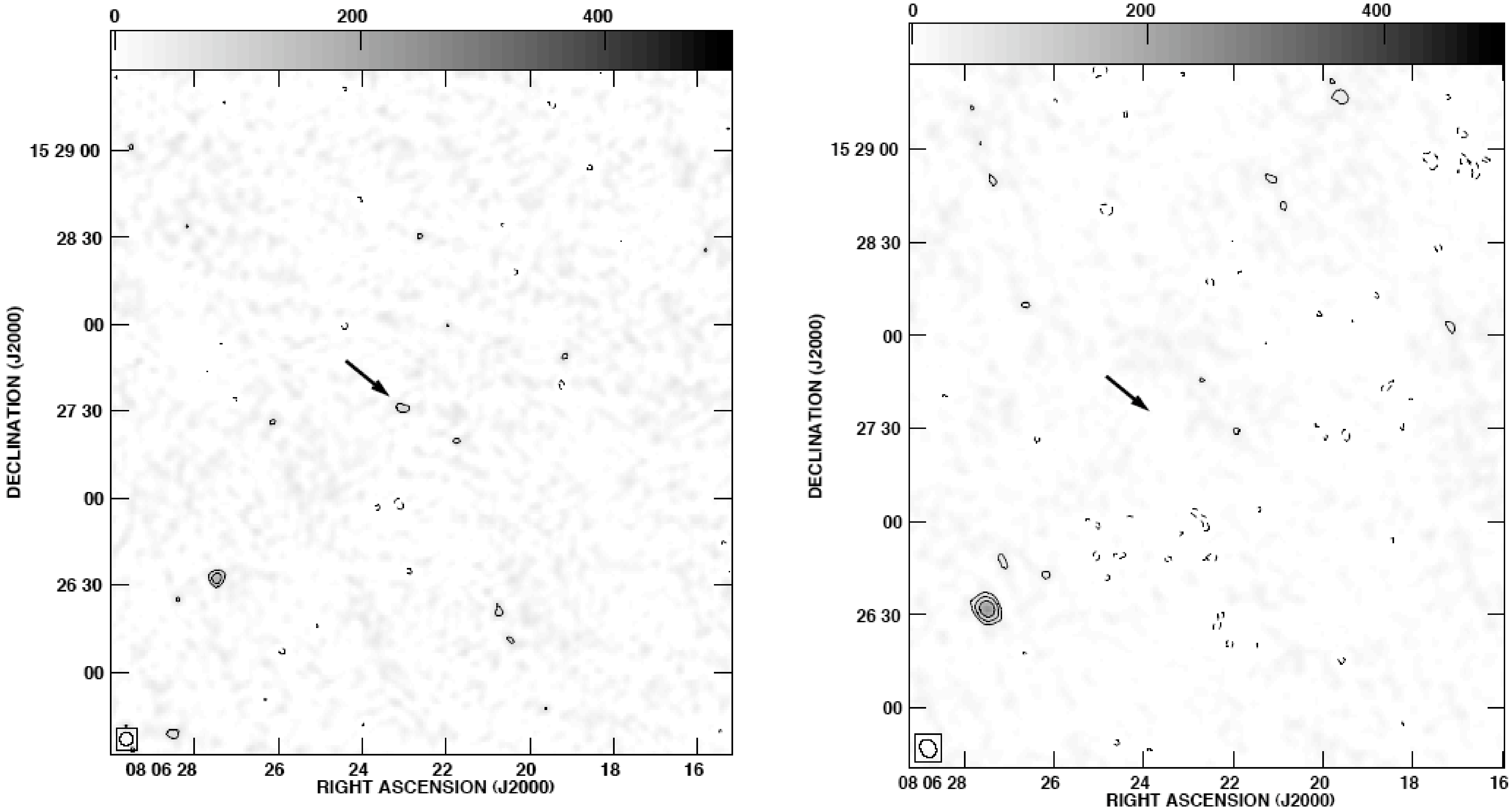




• VLA

[Ramsay et al., 2007]

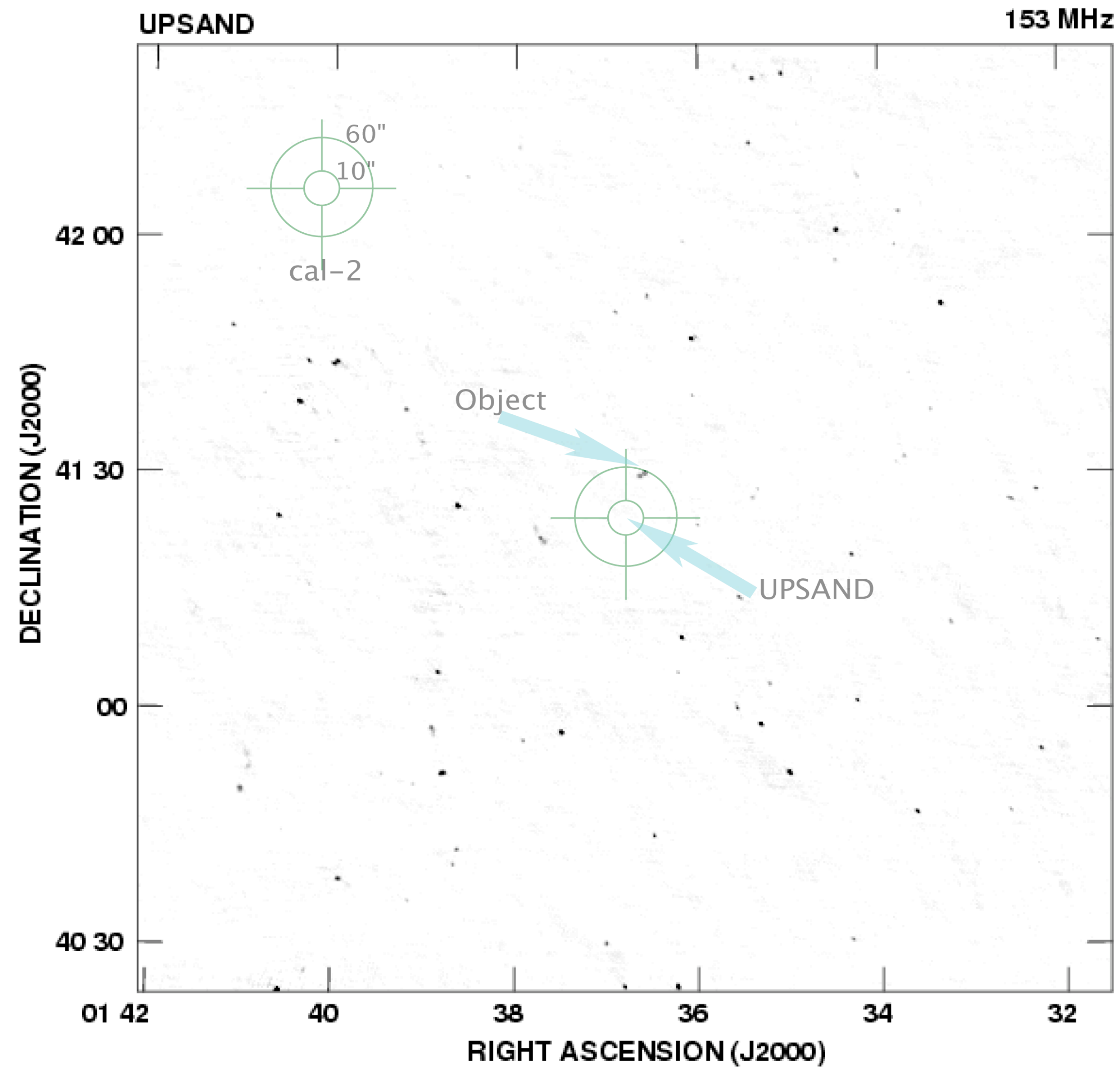
- f ~ 300 MHz
- target RX J0806+15 = binary white dwarf (+ unipolar induction ?)
- epochs 2005 & 2006
- transient ~0.1 mJy

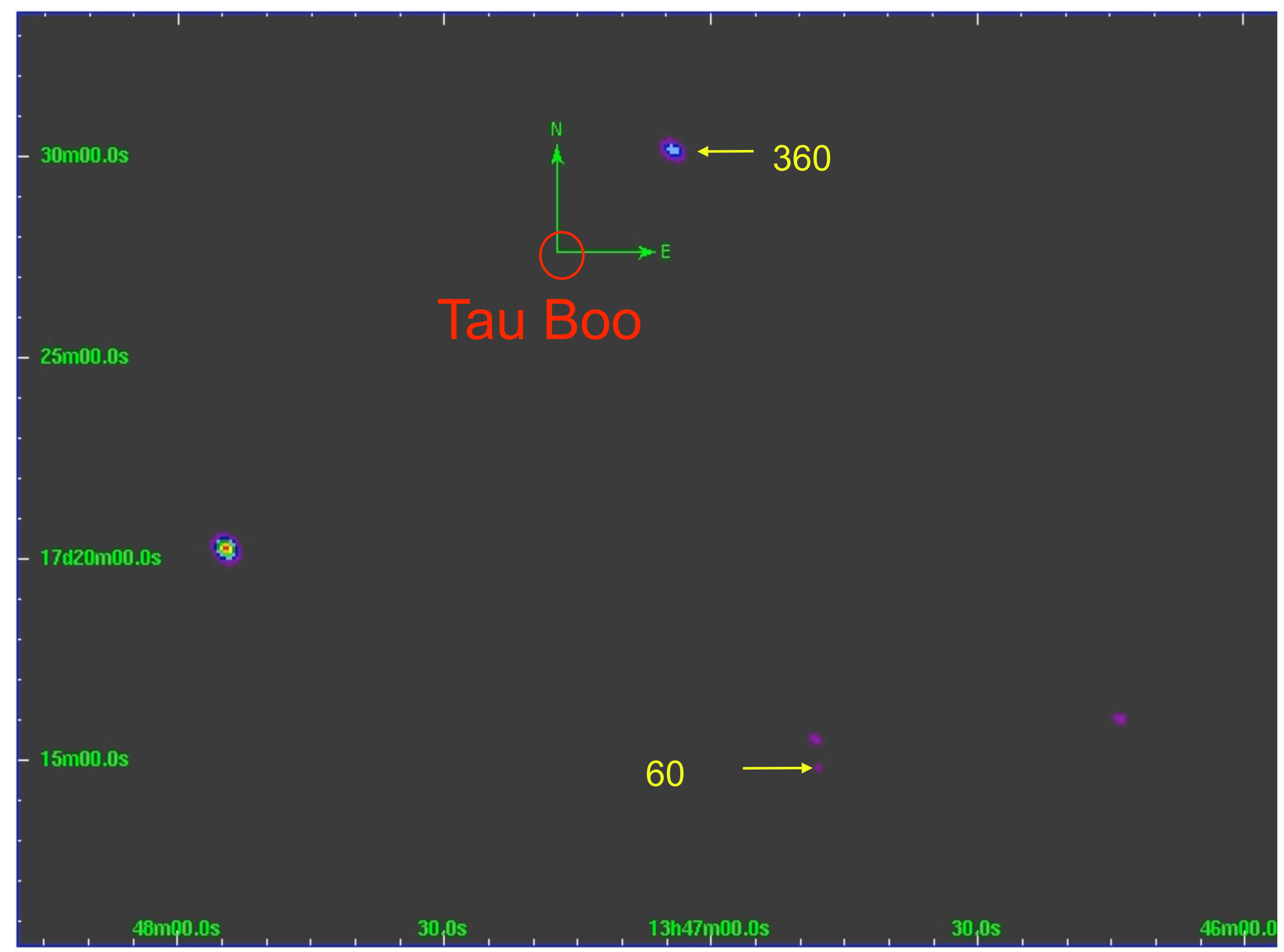


• GMRT

[Winterhalter et al., 2005 ; George and Stevens, 2007 ; ...]

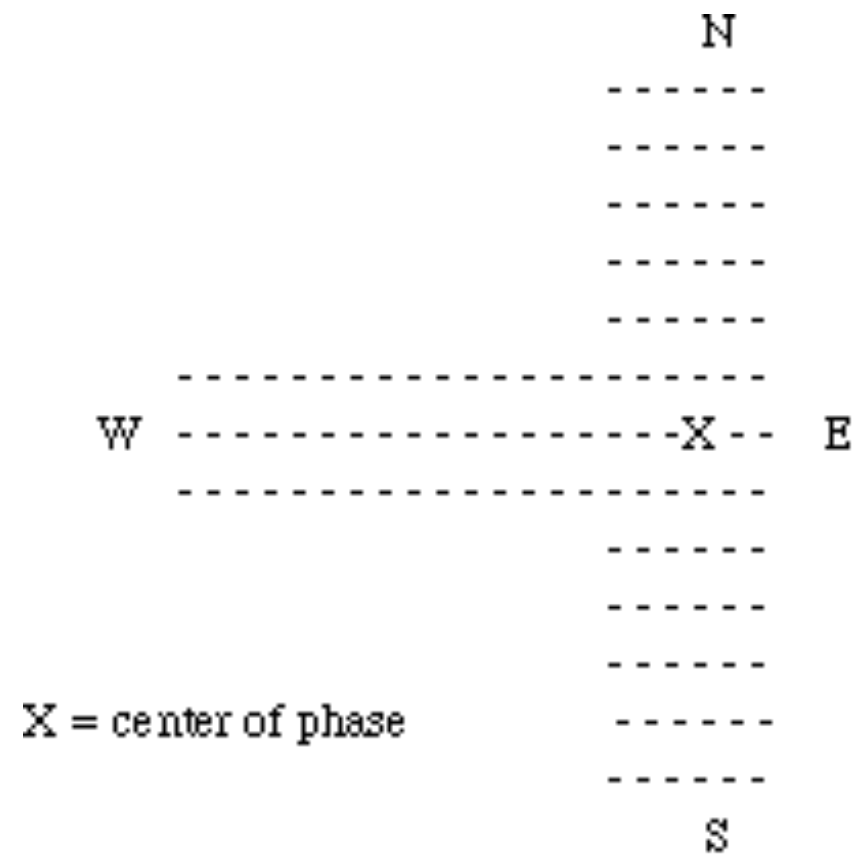
- f ~ 153 MHz
- several targets (Tau Boo, Ups And...)
- epochs 2005 - 2007
- imaging + tied array mode
- sensitivity ~ a few mJy





• UTR-2

[Zarka et al., 1997 ; Ryabov et al., 2004]



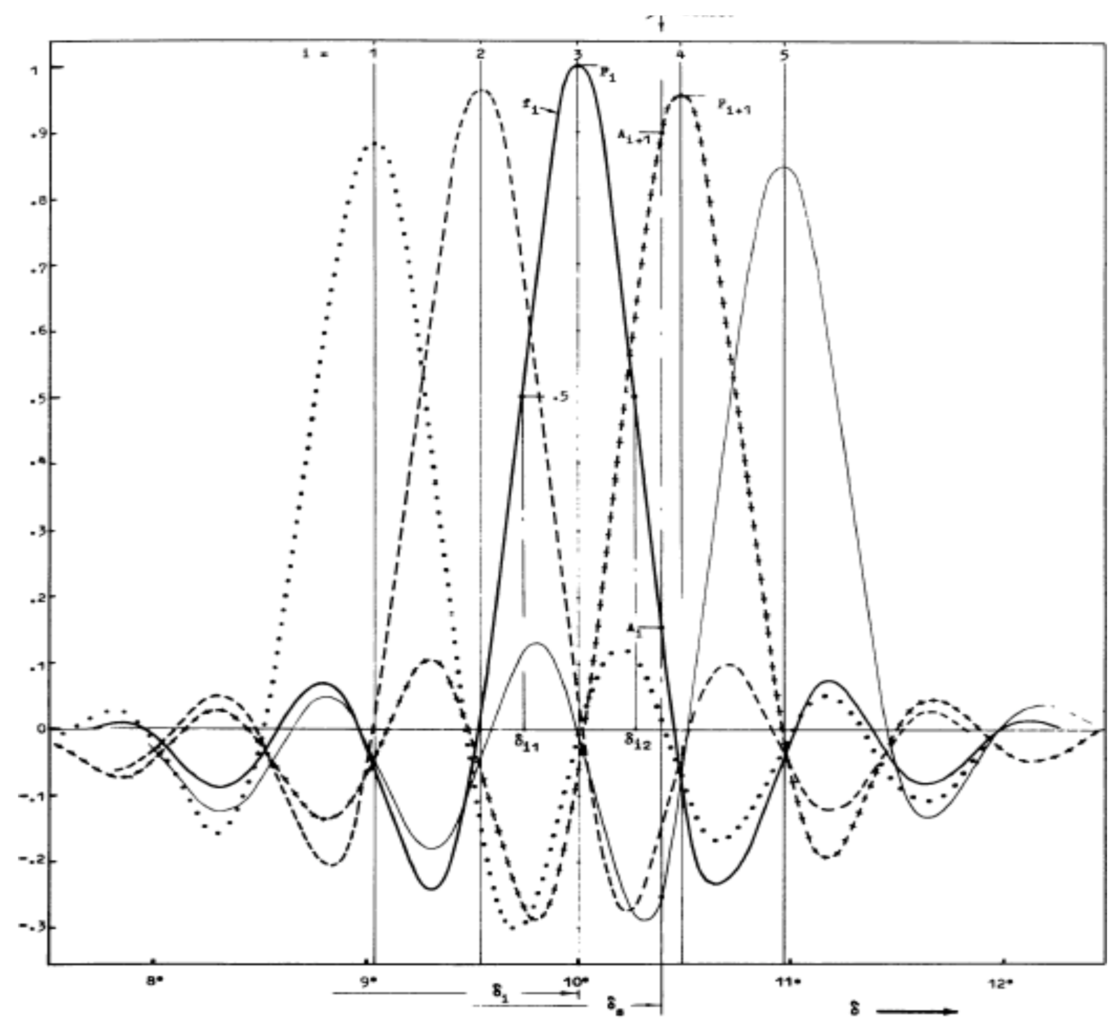
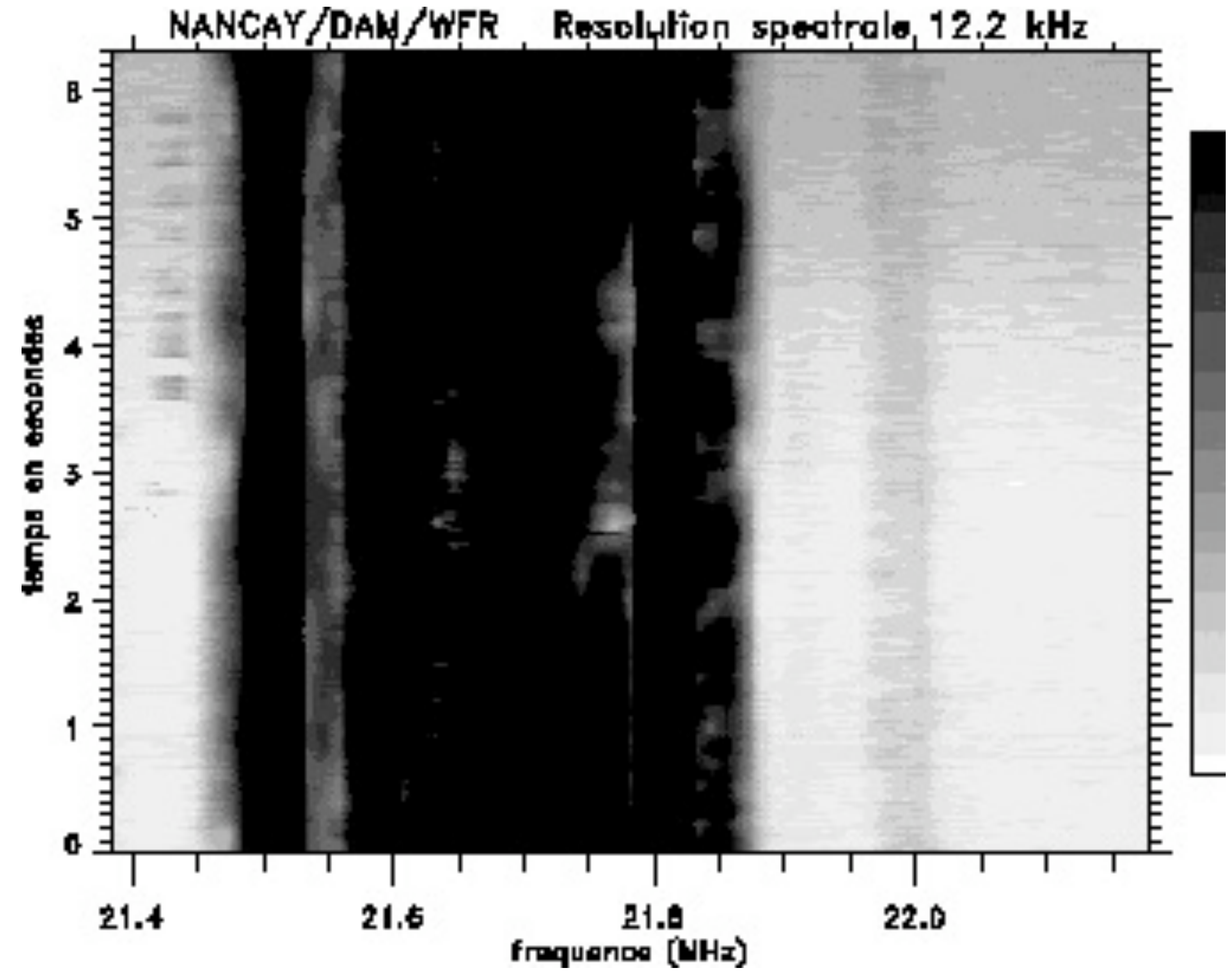


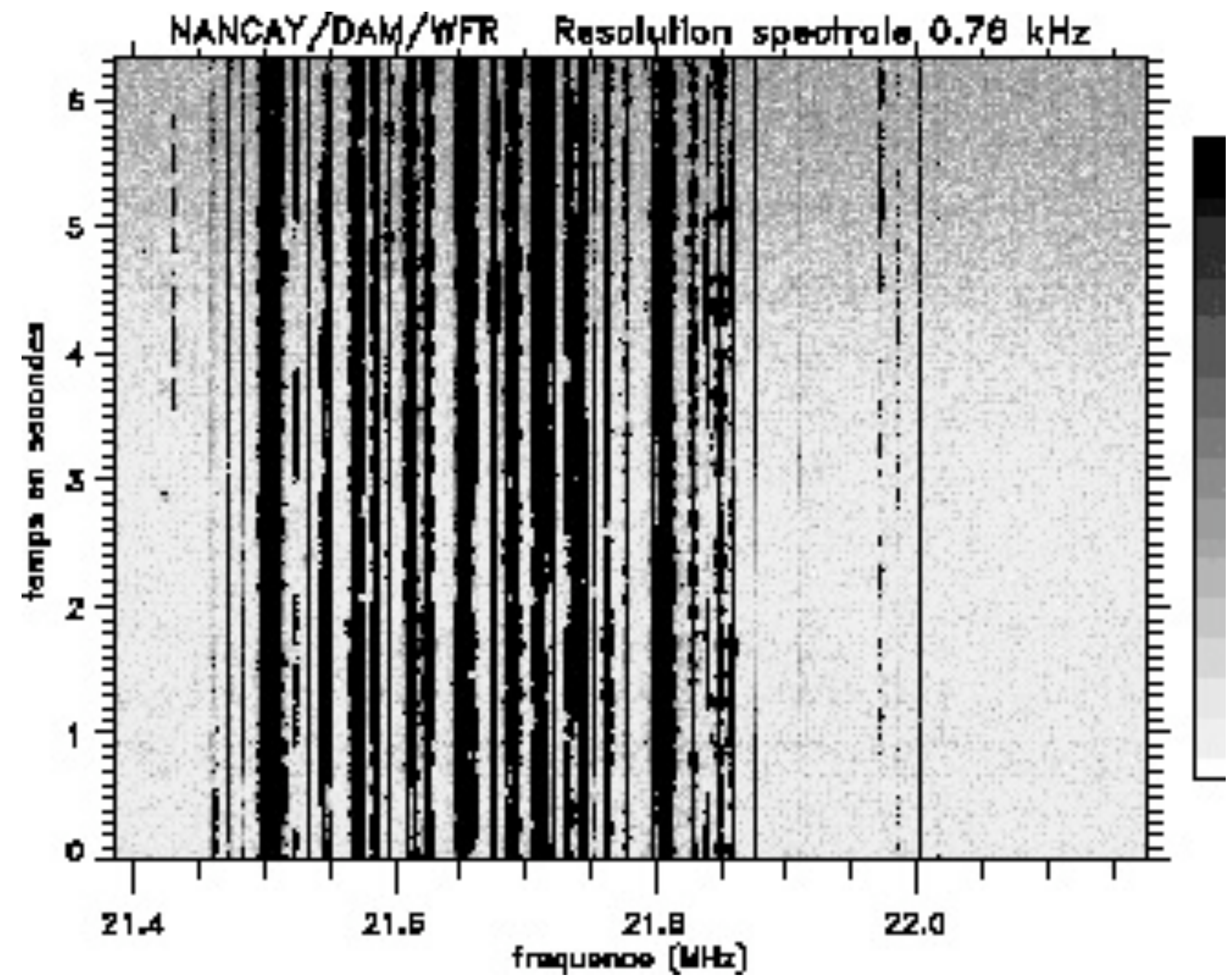
Fig. 5. Five-beam pattern of the north–south array.

- f ~ 10-32 MHz
- a few 10's targets (hot Jupiters)
- epochs 1997-2000 & 2006-2008+
- Simultaneous ON/OFF (2 tied array beams)
- sensitivity ~1 Jy within (1 s x 5 MHz)
- t,f resolution (~ 10 msec x 5 kHz)

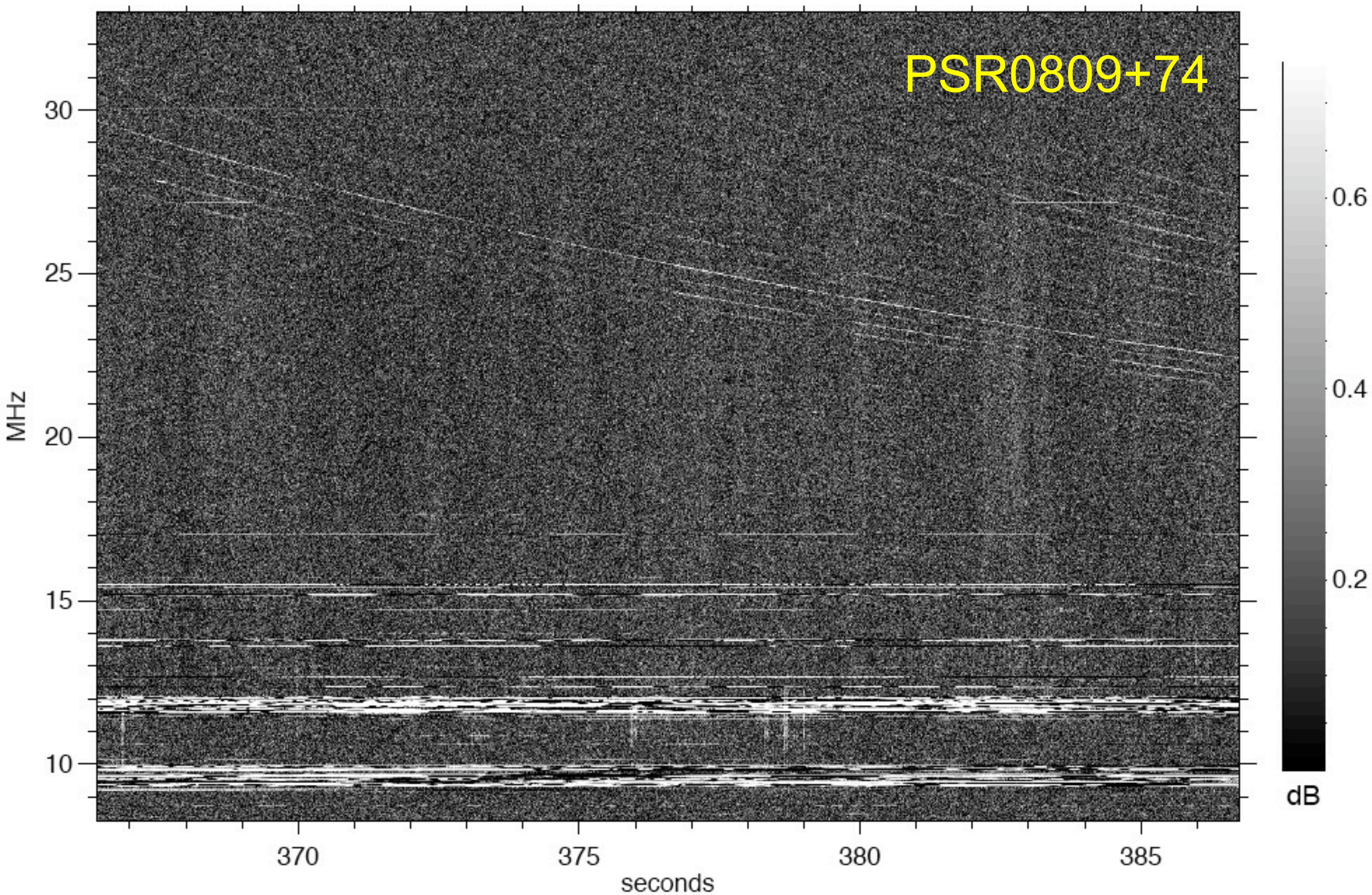
• RFI mitigation



→ High temporal and spectral resolutions + large dynamic range required



- De-dispersion & temporal broadening



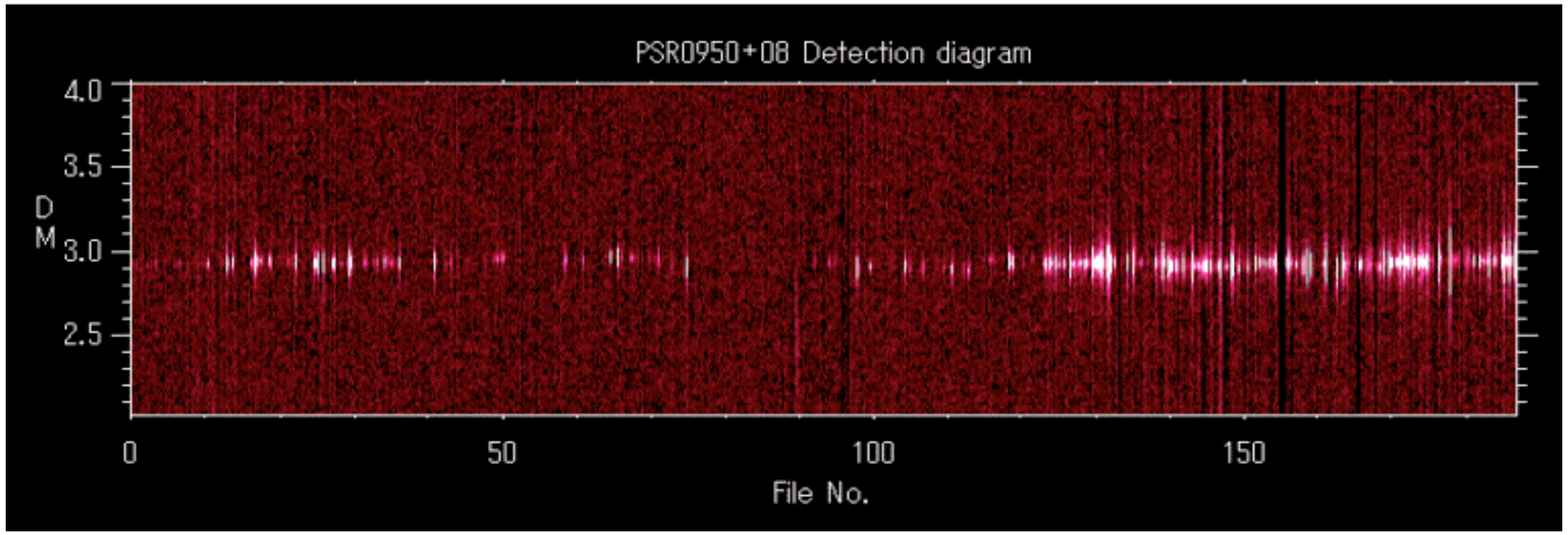
- Dispersion : $\Delta t(\mathrm{sec}) = 4150\ [\mathrm{DM}] / f^2$ (f in MHz)
  → typically 1 - 100 sec

- Pulse temporal broadening : $\tau_B \propto f^{-4.4}$ (Kolmogorov)
  → typically 1 - 100 msec

• Parametric de-dispersion : pulsars

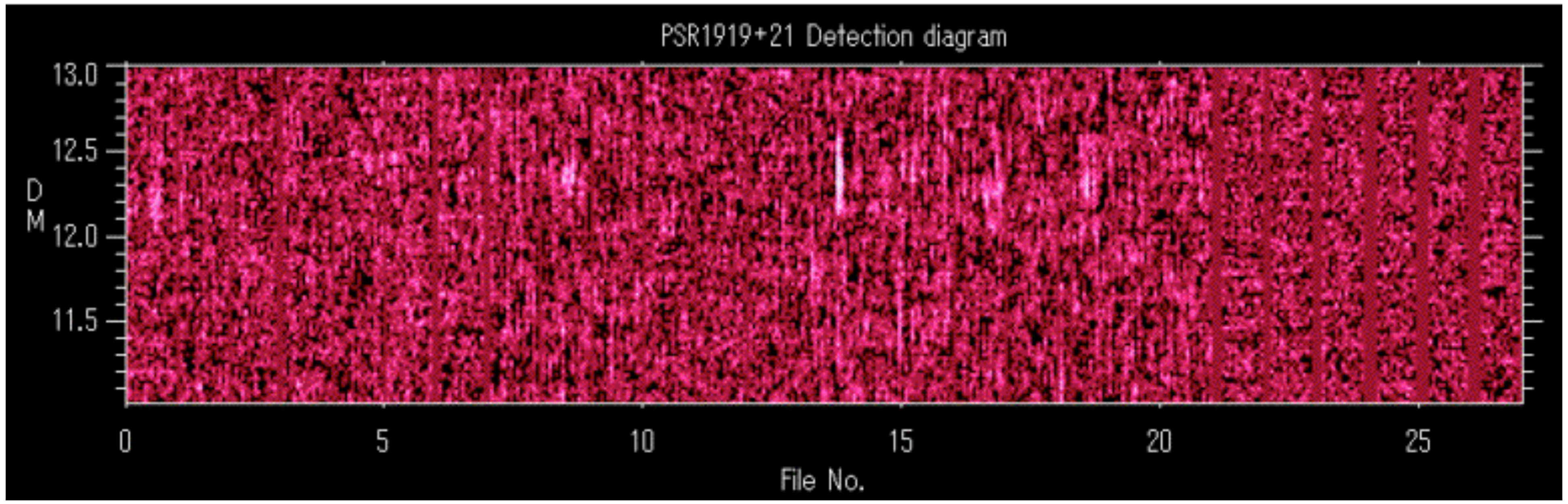
Example of pulse detection: strong signal

PSR0950+08 DM=2.95

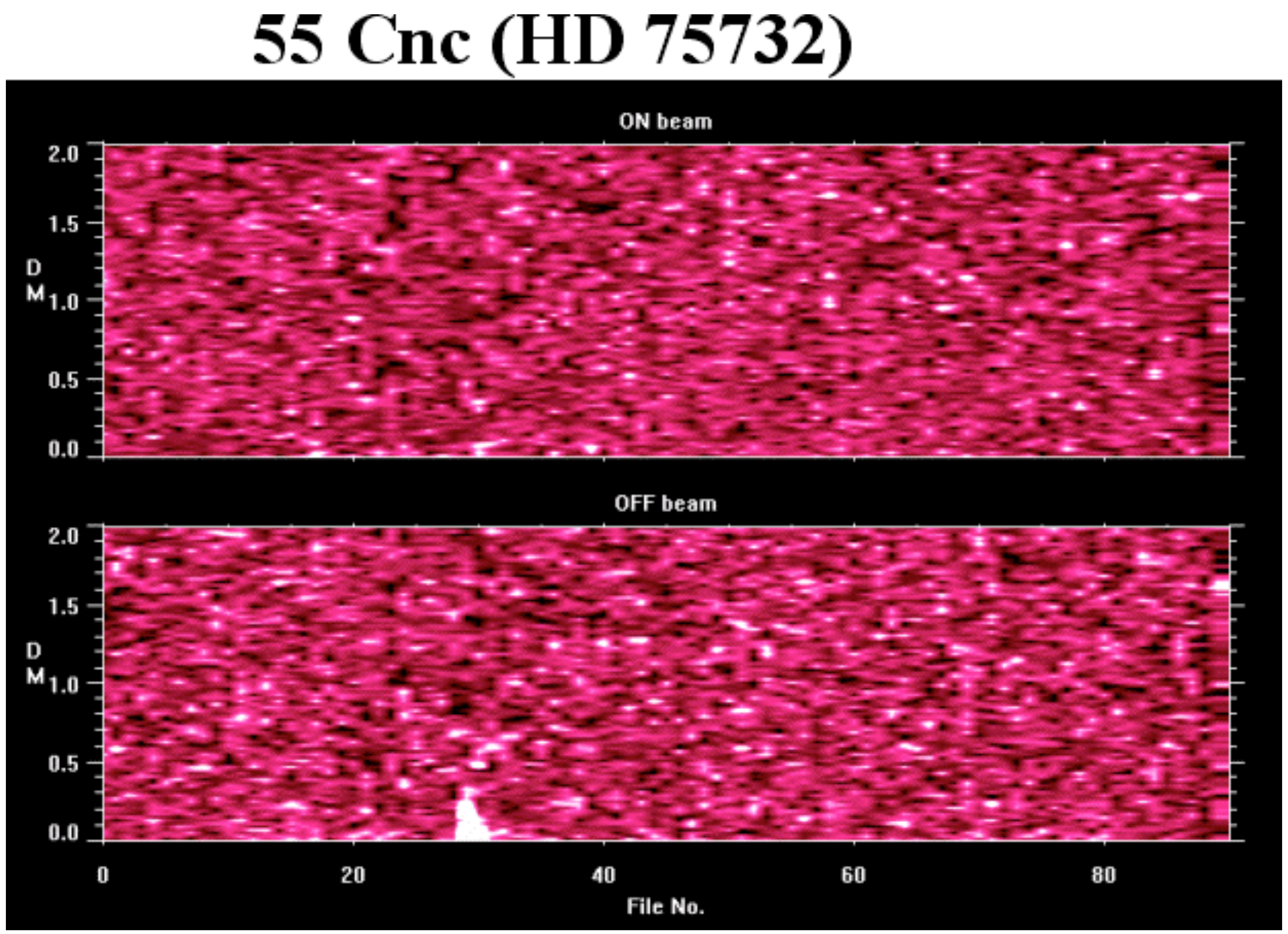


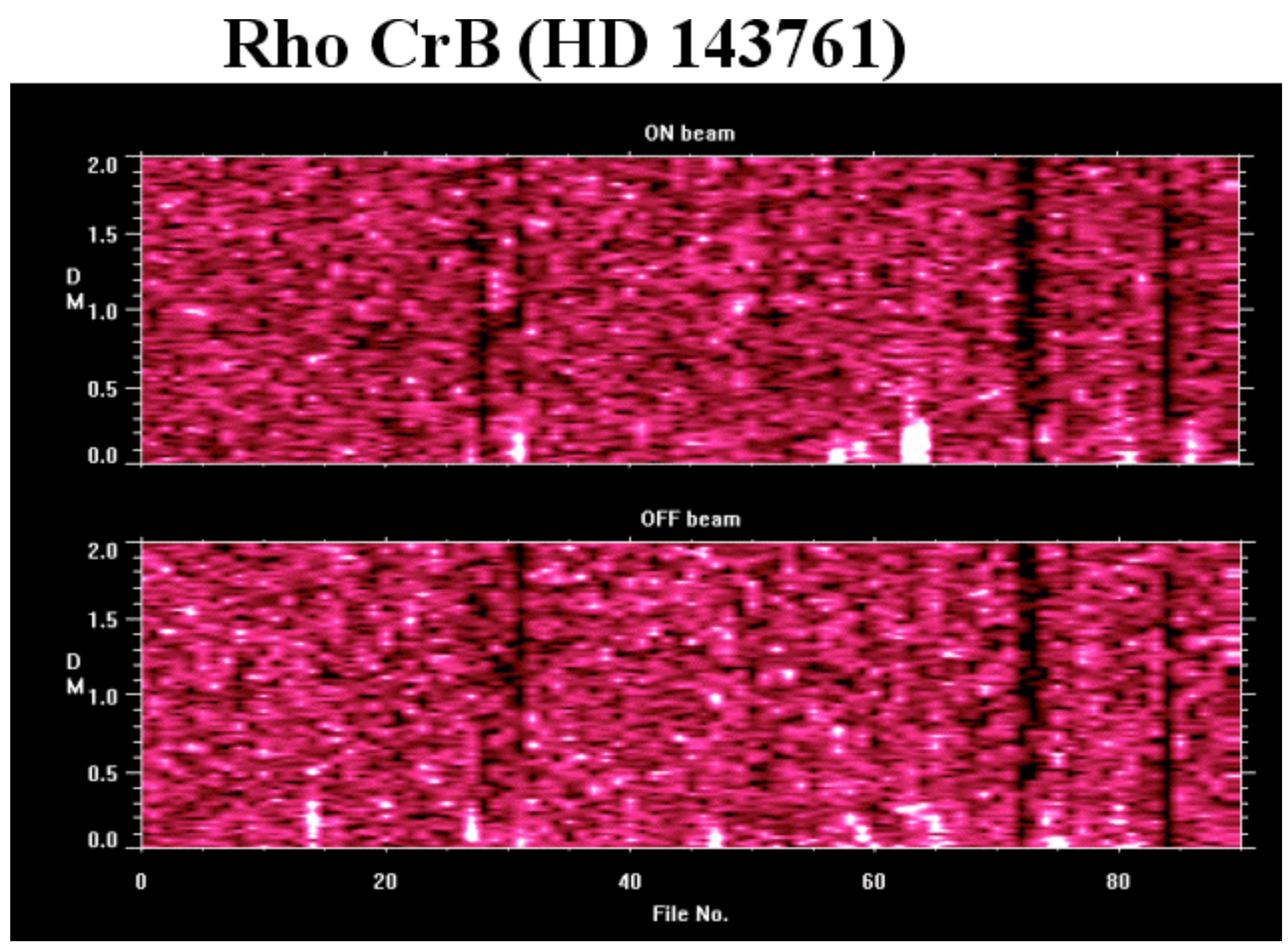
Example of pulse detection: weak signal

PSR1919+21 DM=12.4



• Parametric de-dispersion : candidate exoplanets





- A brief introduction about exoplanets
- Radio observations
- Theoretical predictions
  - planetary magnetospheric radio emissions
  - energy sources
  - scaling laws
  - extrapolation to exoplanets
- Ongoing observations
- Related & Future observations

Optical observations

Optical observations

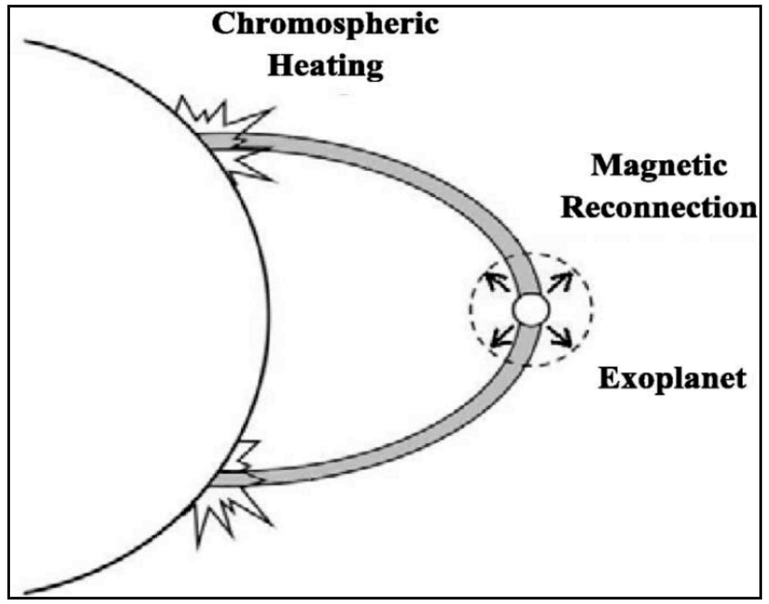
- Super-flares ?

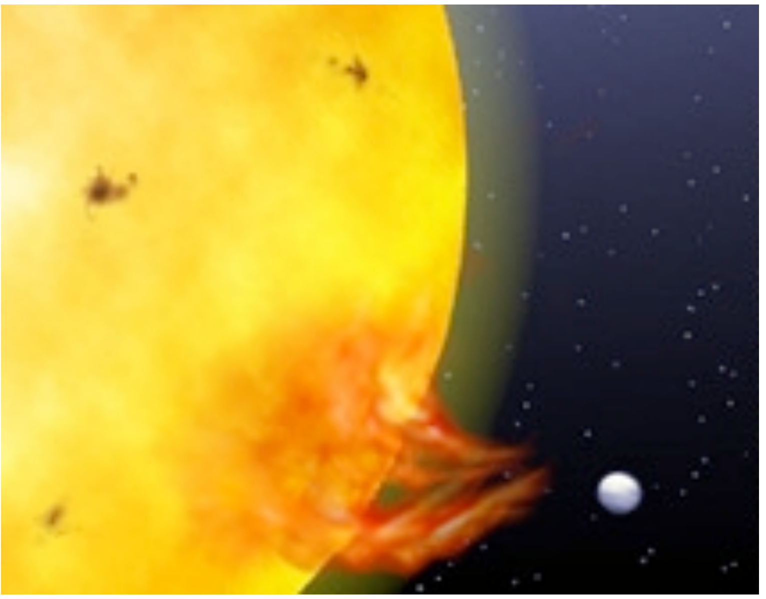
[Rubenstein & Schaefer, 2000 ; Schaefer et al., 2000]

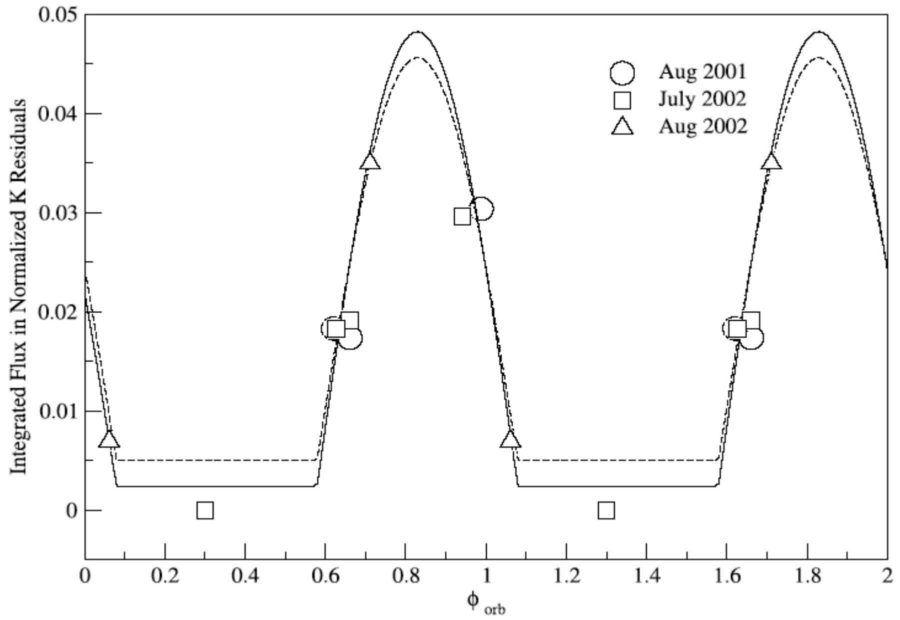
Optical observations

• Super-flares ? [Rubenstein & Schaefer, 2000 ; Schaefer et al., 2000]

• Chromospheric hot spot (optical) on HD179949 + υ And [Shkolnik et al. 2003, 2004, 2005]







➡ unipolar or dipolar interaction ?

Optical observations

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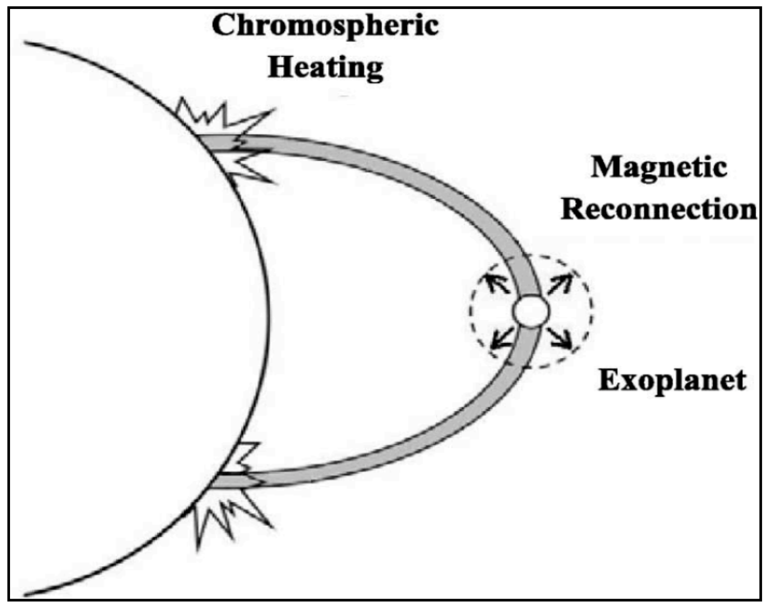
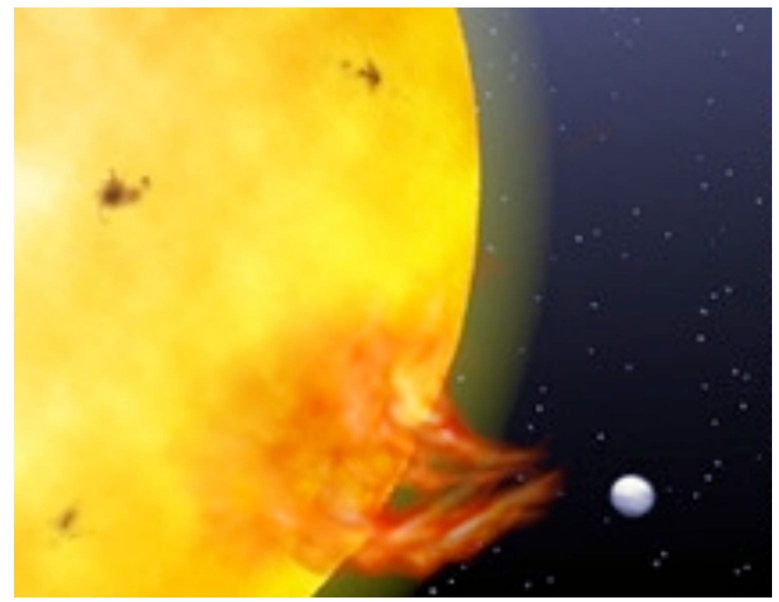
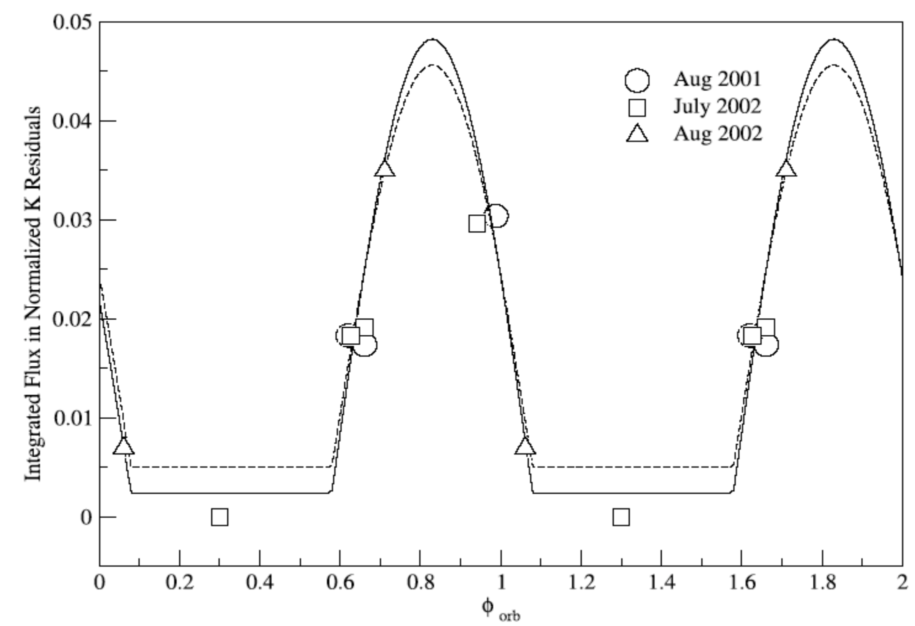






➡ unipolar or dipolar interaction ?

➡ hot spot 60° ahead of sub-planetary point (P=3.1d)

→ Ok wrt "backwards" Alfén waves propagation in the stellar wind [Preusse et al., 2006]

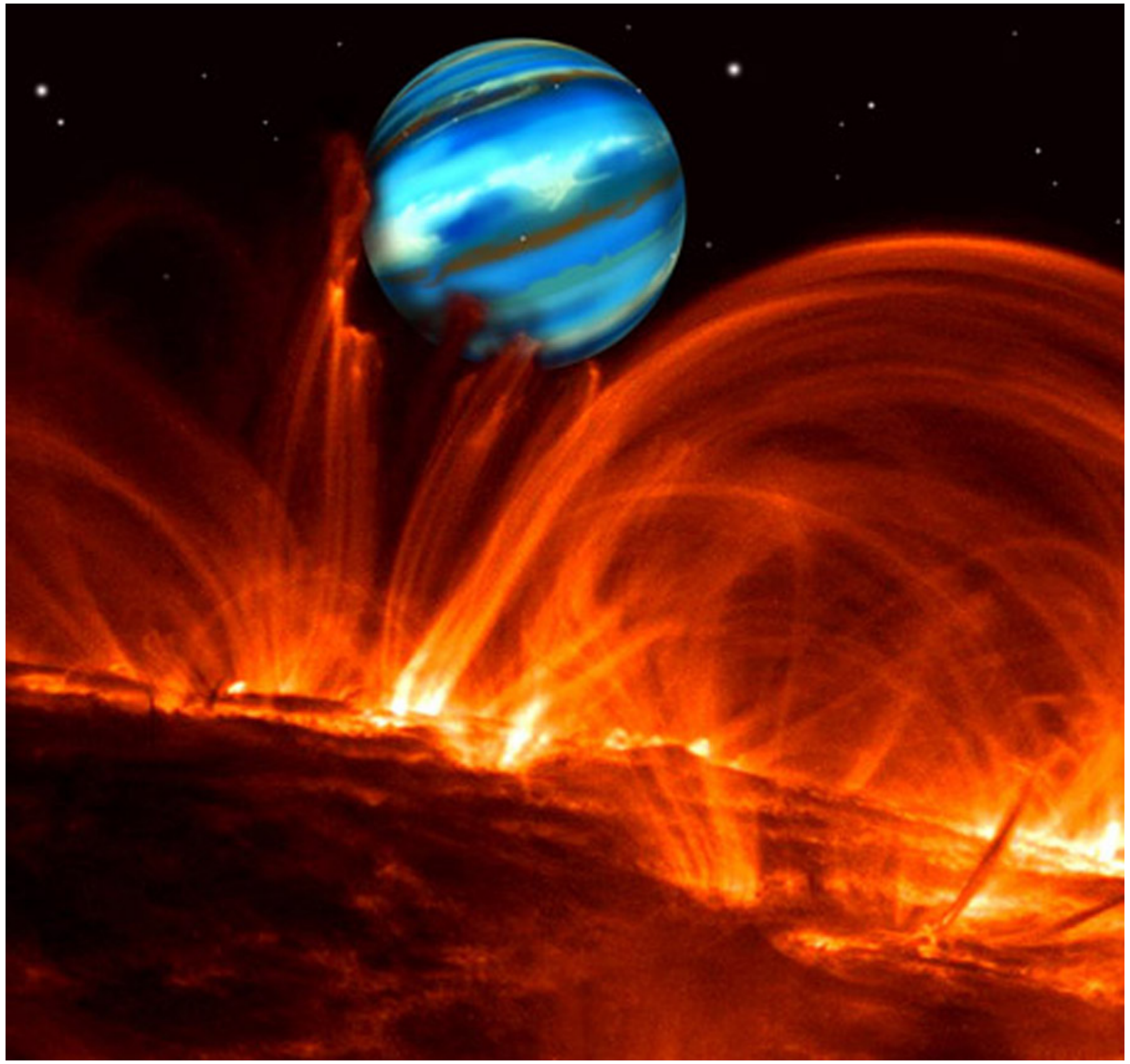
➡ $P_{spot} > 10^{19}$ W but $P_d = 0.15 \times 10^{15} \times \pi R_J^2$ W → energy crisis ?

→ larger obstacle or wind strength + stellar B ? (F_X ~10× solar)

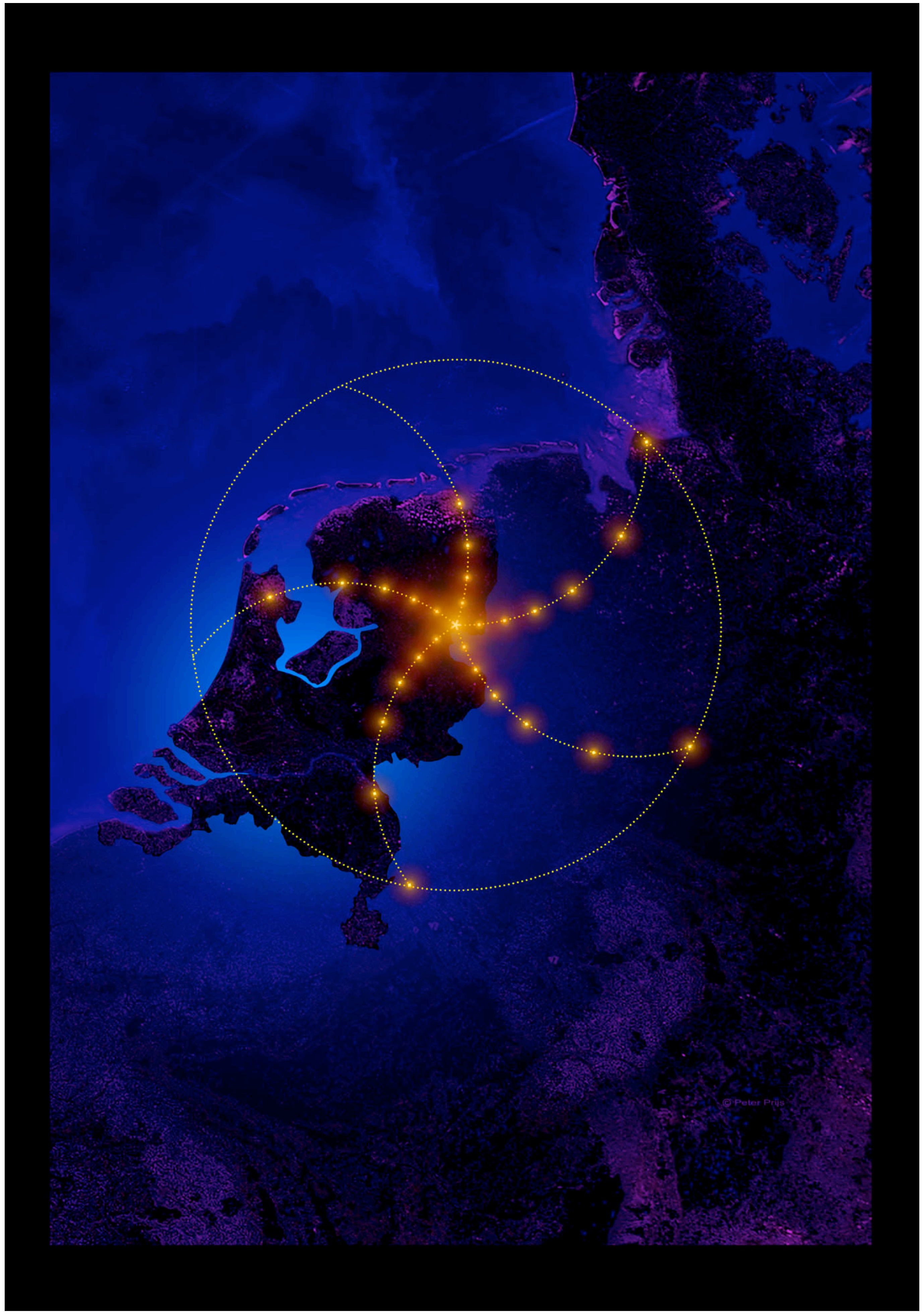
[Shkolnik et al., 2005 ; Zarka, 2007]

ESPaDOnS spectropolarimeter @ CFHT

• Magnetic field of Tau Bootes [Catala et al., 2007]



• LOFAR



• 30-250 MHz

• Epoch 2009+ (solar max. !)

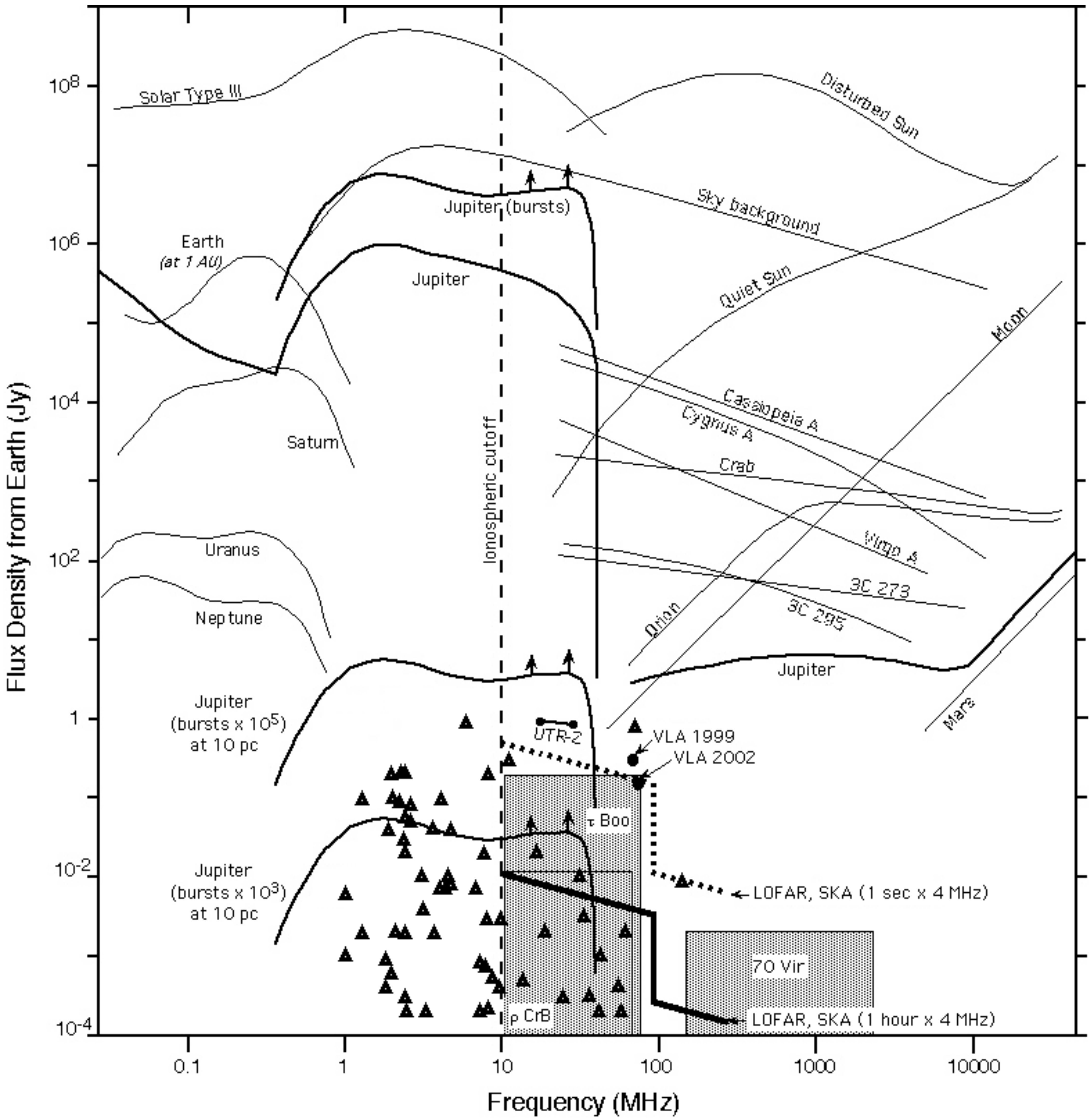
• Sensitivity ~ mJy

• Imaging + tied array modes

• Built-in RFI mitigation & ionospheric calibration

Exoplanet search part of "Transients" KP

Candidate exoplanets + all close-by stars


Solar Type III
Disturbed Sun
Sky background
Jupiter (bursts)
Earth
(at 1 AU)
Jupiter
Quiet Sun
Moon
Casseiopeia A
Cygnus A
Crab
Saturn
Ionospheric cutoff
Uranus
Neptune
Virgo A
3C 273
3C 295
Orion
Jupiter
Mars
Jupiter
(bursts x 10^5)
at 10 pc
UTR-2
VLA 1999
VLA 2002
τ Boo
Jupiter
(bursts x 10^3)
at 10 pc
LOFAR, SKA (1 sec x 4 MHz)
70 Vir
ρ CrB
LOFAR, SKA (1 hour x 4 MHz)
Flux Density from Earth (Jy)
Frequency (MHz)
10^8
10^6
10^4
10^2
1
10^{-2}
10^{-4}
0.1
1
10
100
1000
10000
[Zarka, 2004]

- SKA

- High frequencies (~ 0.2-20 GHz)
- ≥2015-20
- Sensitivity down to μJy ?

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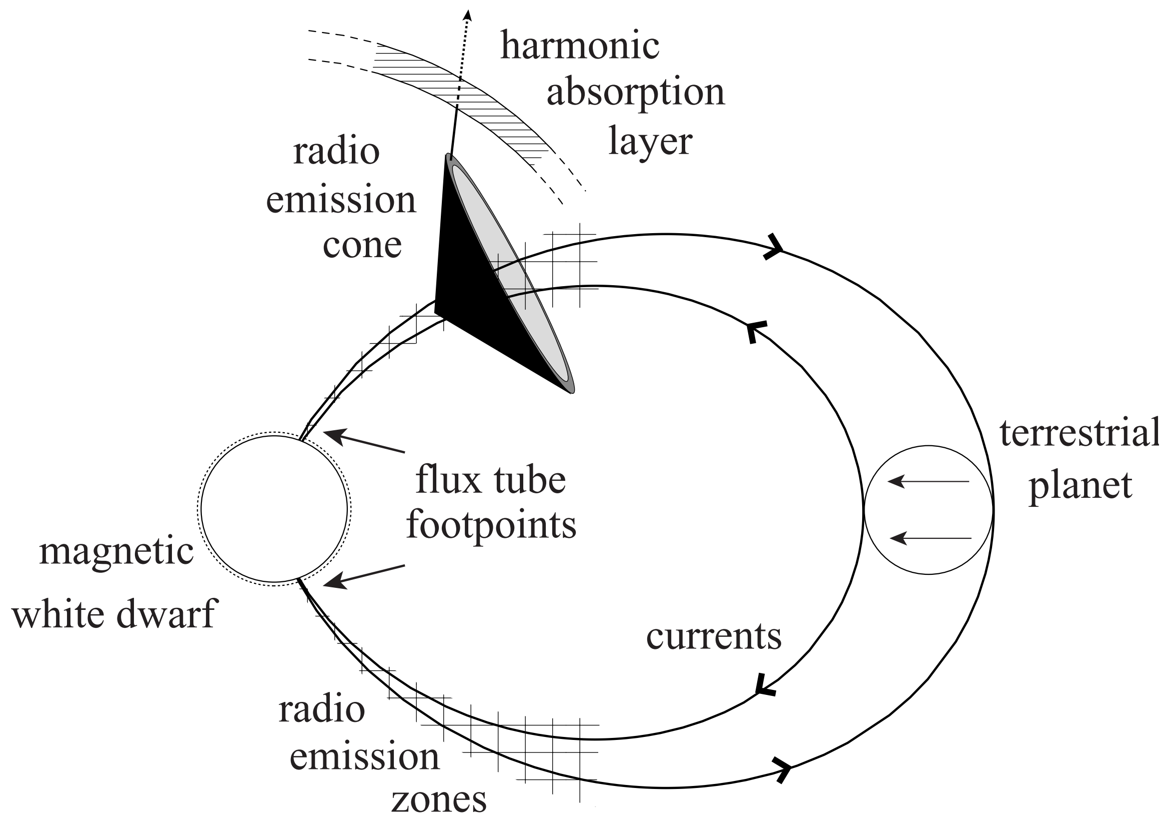
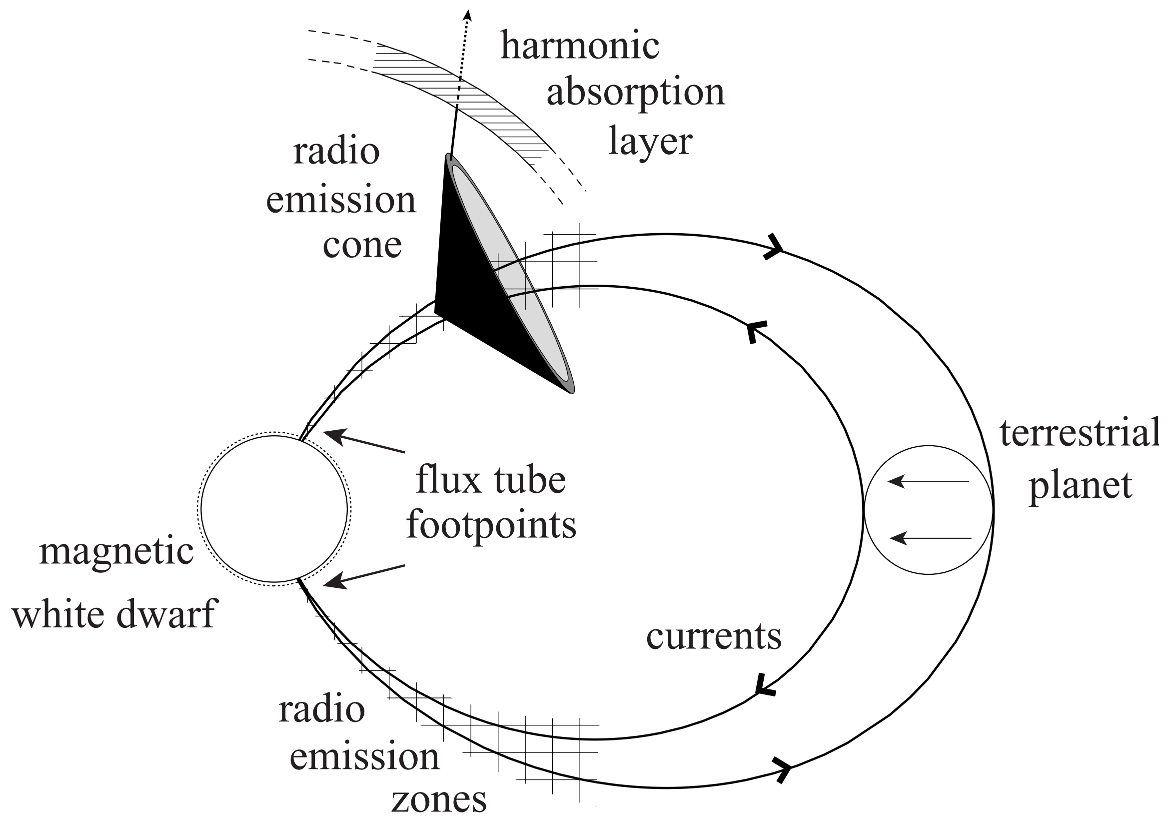
Unipolar inductor systems

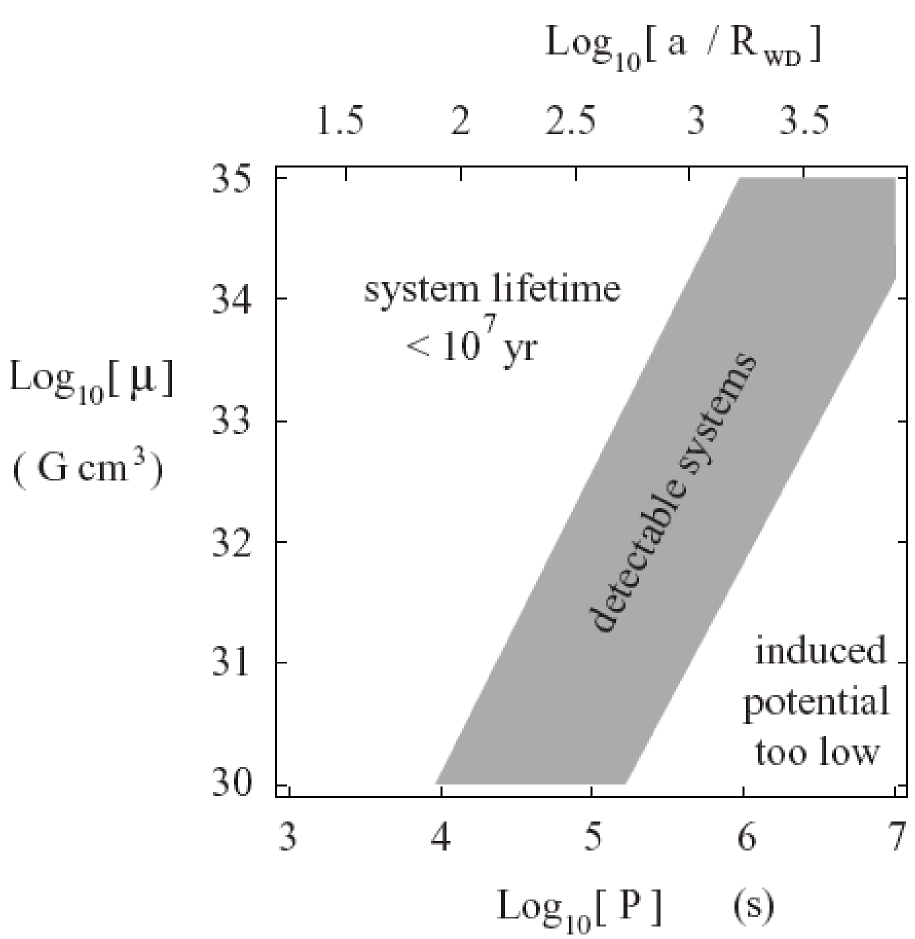
(e.g. hot Earths around White dwarfs)

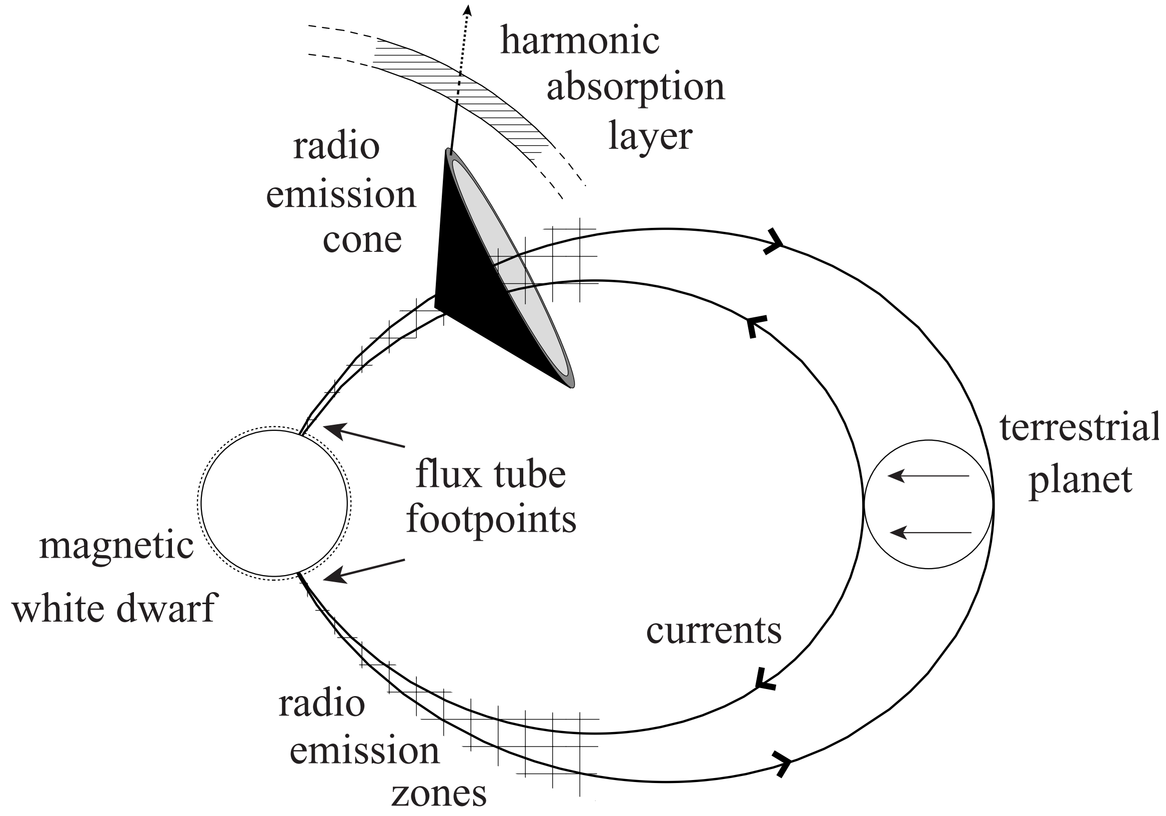


[Willes & Wu, 2004, 2005]

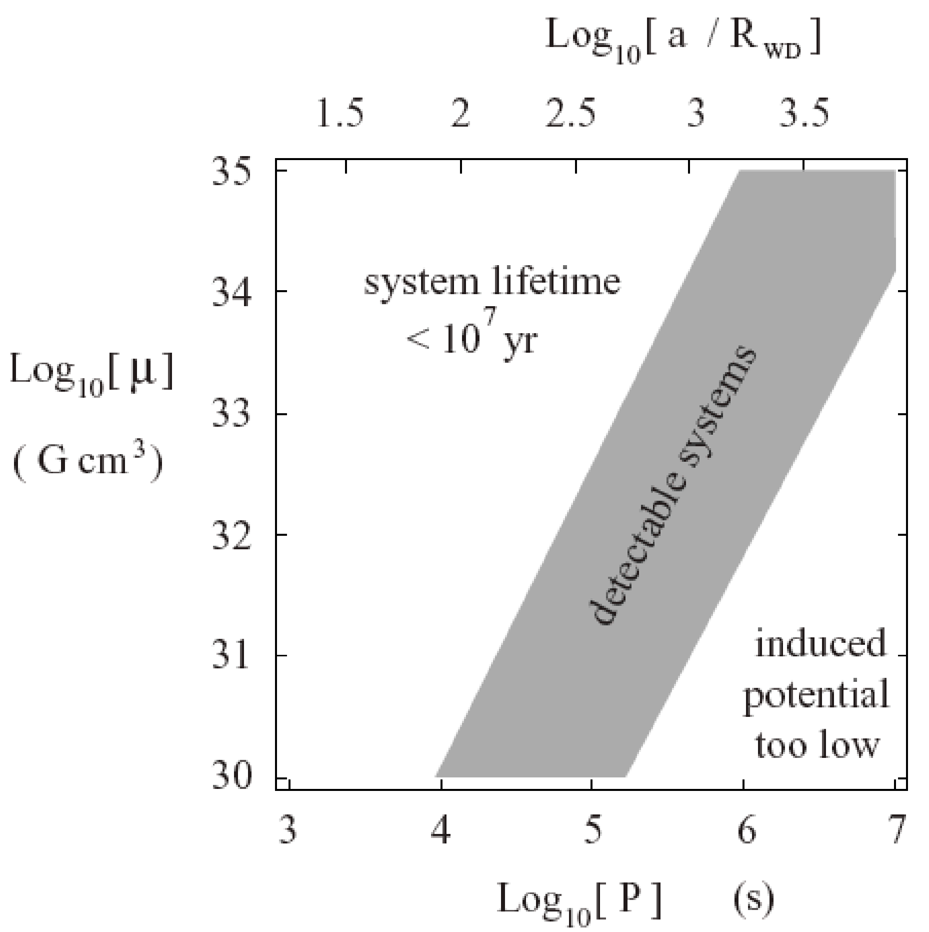


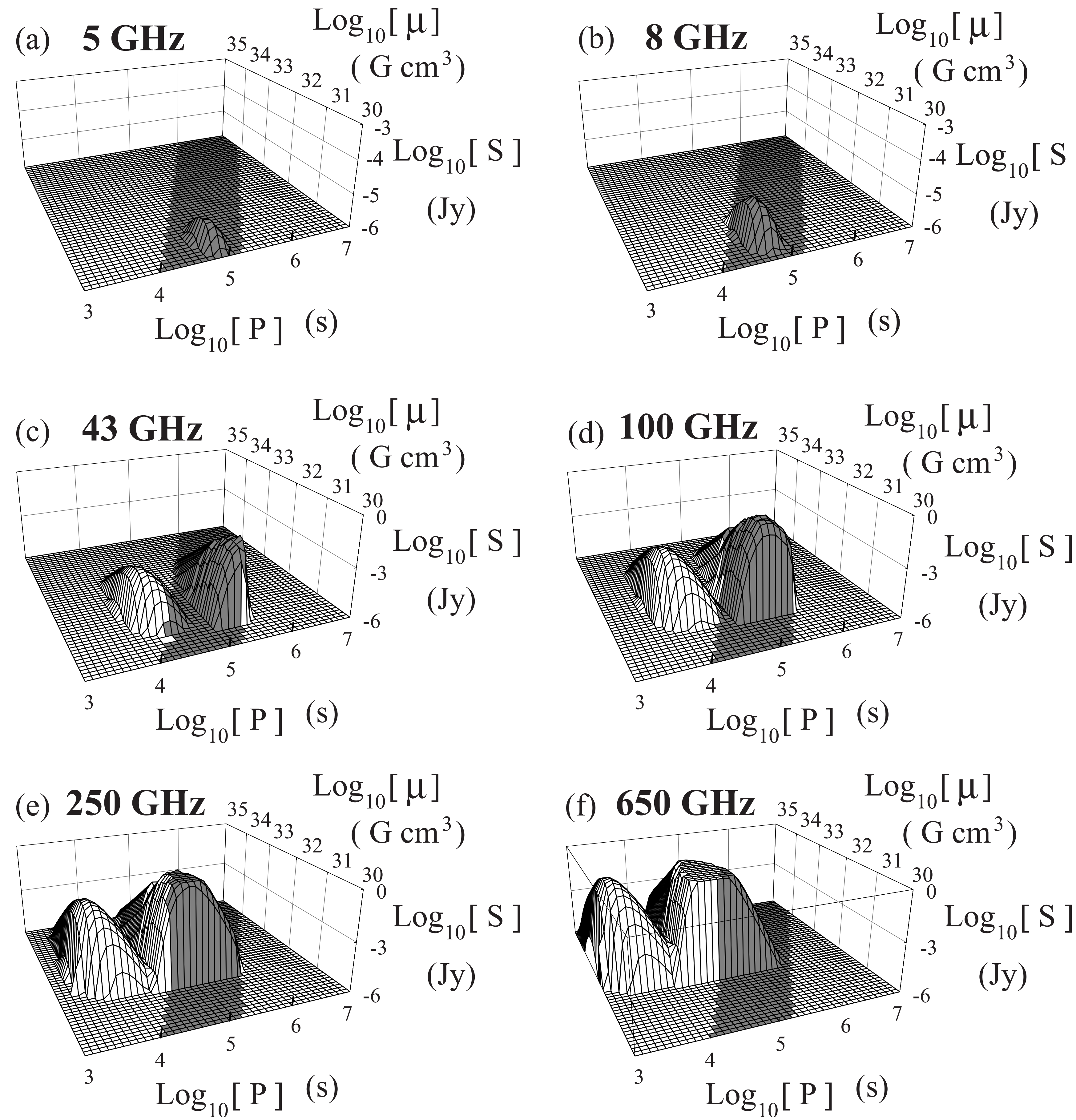
[Willes & Wu, 2004, 2005]





[Willes & Wu, 2004, 2005]





saturated loss-cone driven cyclotron-maser emission

• SKA

- High frequencies (0.2-20 GHz)
- ≥2015-20
- Sensitivity down to μJy ?

Unipolar inductor systems

(e.g. hot Earths around White dwarfs)

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- Unipolar inductor systems

  (e.g. hot Earths around White dwarfs)

- Detection of artificial emissions ?

• SKA

• High frequencies (0.2-20 GHz)

• ≥2015-20

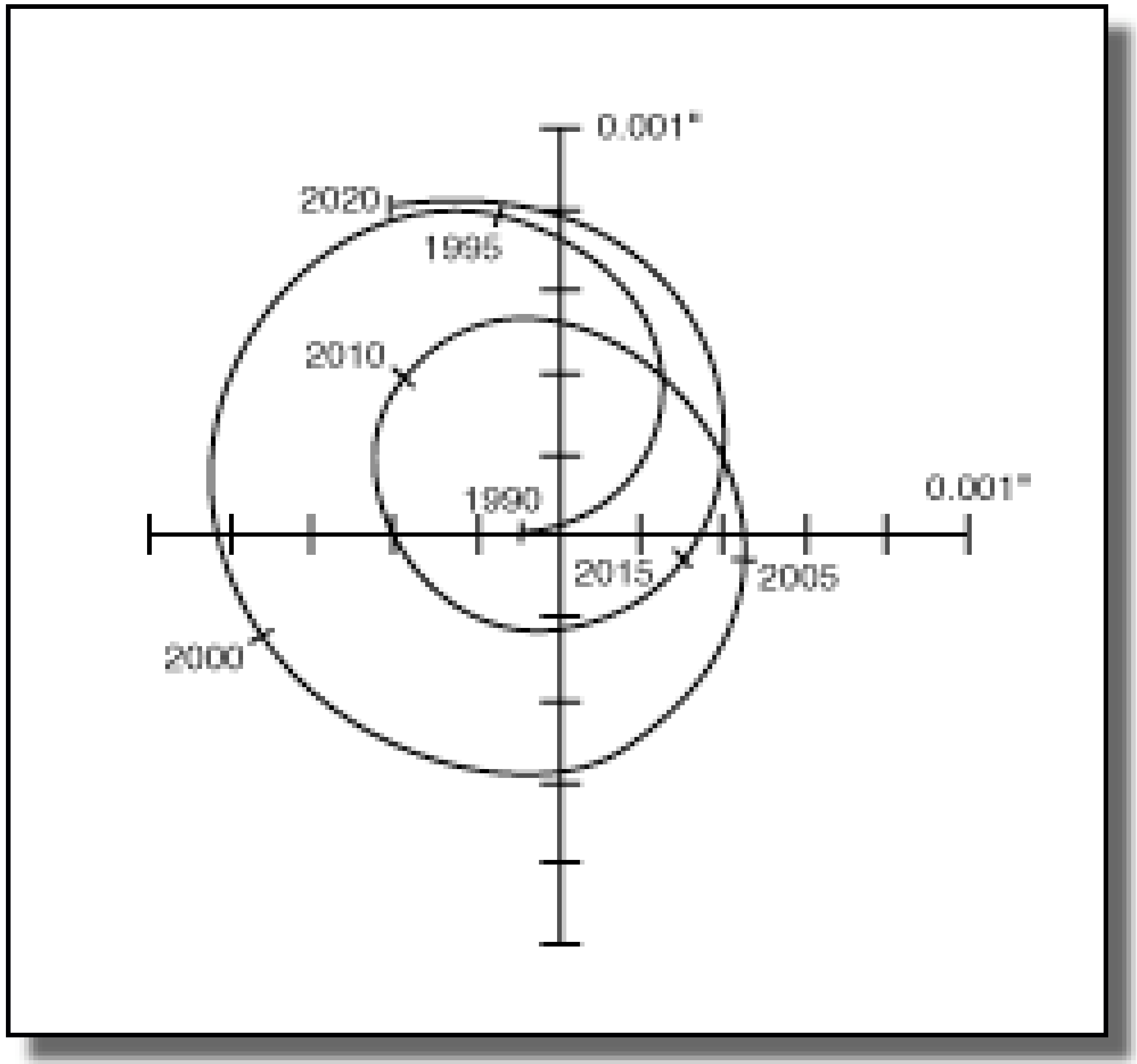
• Sensitivity down to μJy ?

Unipolar inductor systems

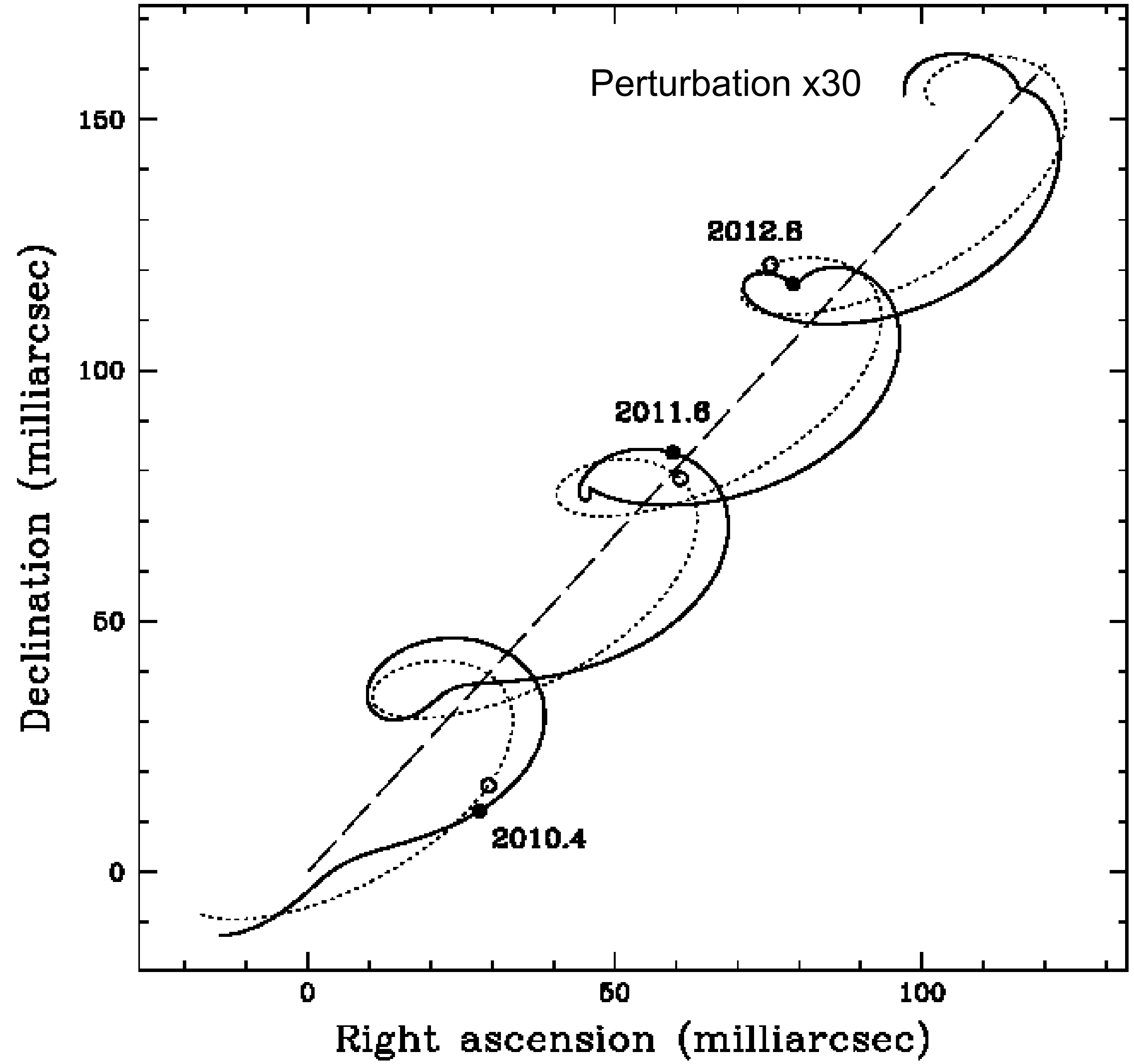
(e.g. hot Earths around White dwarfs)

Detection of artificial emissions ?

Astrometry (planets around M dwarfs)



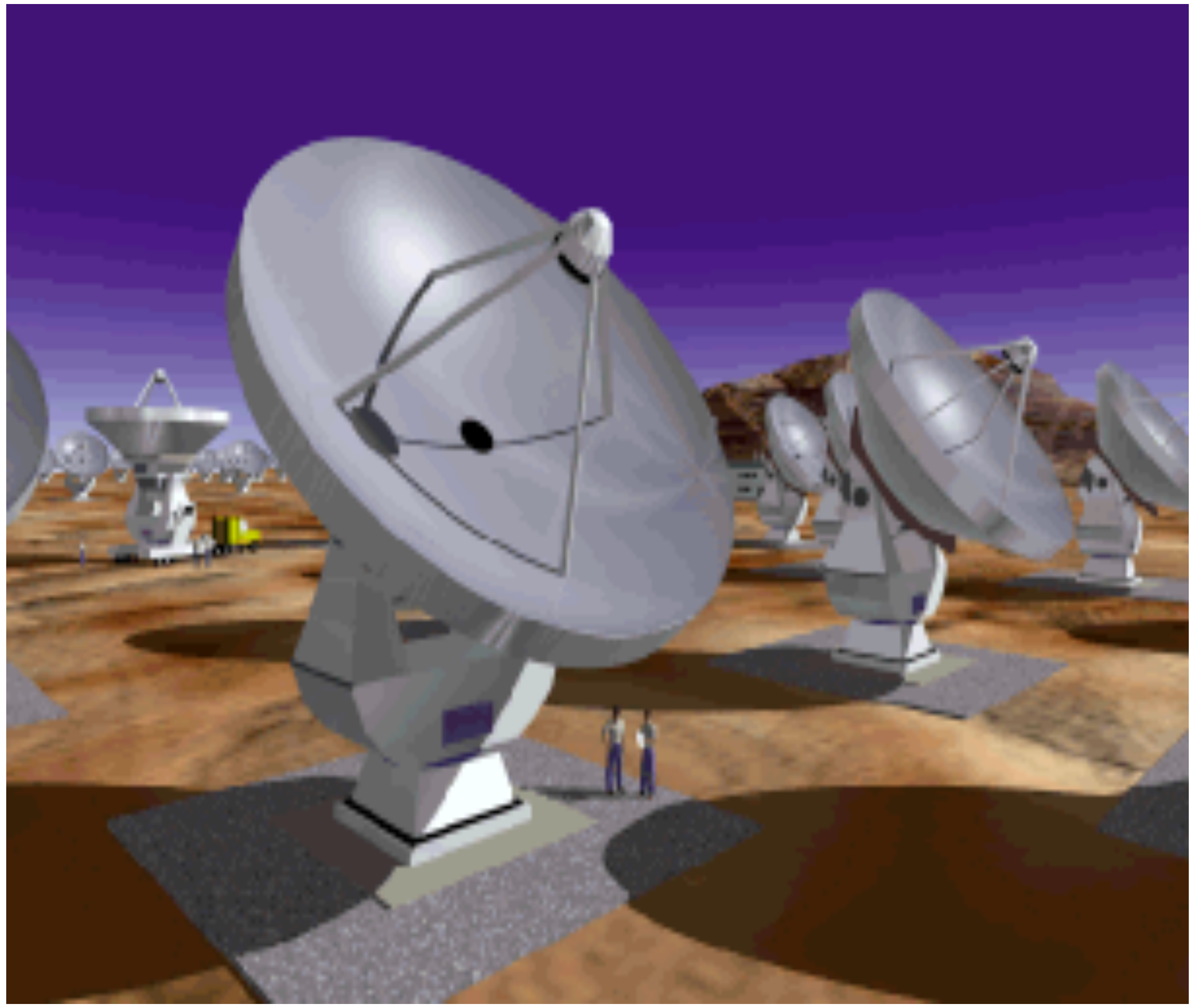
Astrometric displacement of the Sun due to Jupiter as seen from 10 parsecs.



15 Mj, a=0.6 AU, e=0.2, d=50 pc

50 mas/yr

- ALMA



- Very high frequencies (100 - >650 GHz)
- ≥2010
- Sensitivity ~ 0.1-1 mJy

Probe molecular lines in protoplanetary clouds

Planetary formation (cf. next talk)

Objectives for the Search for Exoplanets magnetospheric radio emissions

→ Direct detection (planet-star distinction via
polarization & periodicity)

→ Planetary rotation period

→ Measurement of B ⇒ contraints on scaling laws &
internal structure models

→ Comparative magnetospheric physics (star-planet interactions)

→ Discovery tool (search for more planets) ?