Planetary Science & Exoplanet Detection at Low Radio Frequencies

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- Limitations of ground-based LF radioastronomy :
  - ❑ RFI (man-made, lightning spherics)
  - ❑ Ionospheric cutoff (~10 MHz)
    + propagation effects (≤30 MHz)
  - ❑ Sky background (fluctuations)
  - ❑ IP, IS scintillations
  - ❑ (Solar radio emissions)

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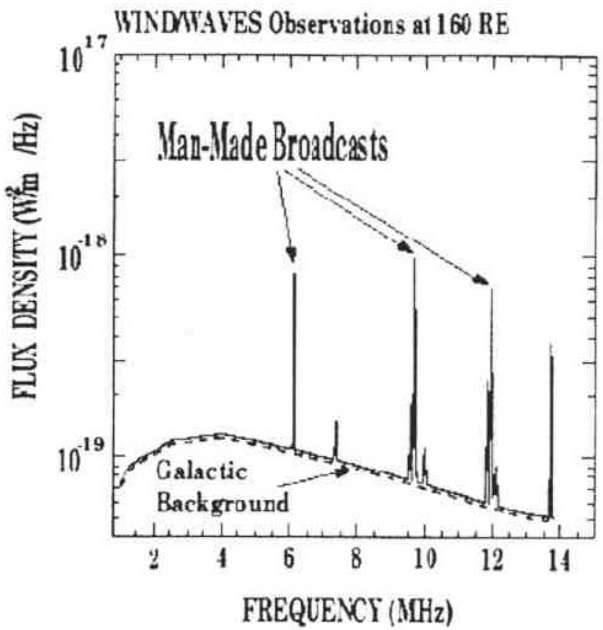

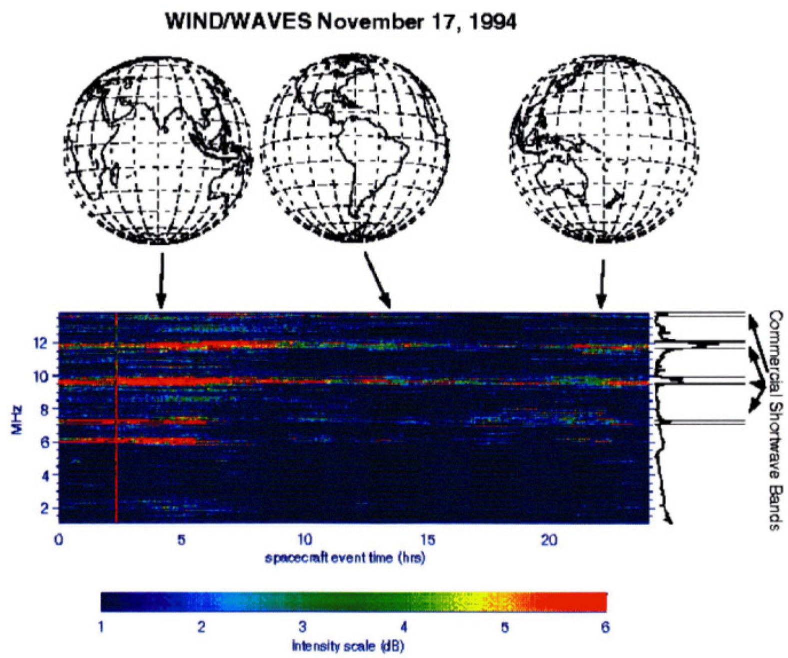

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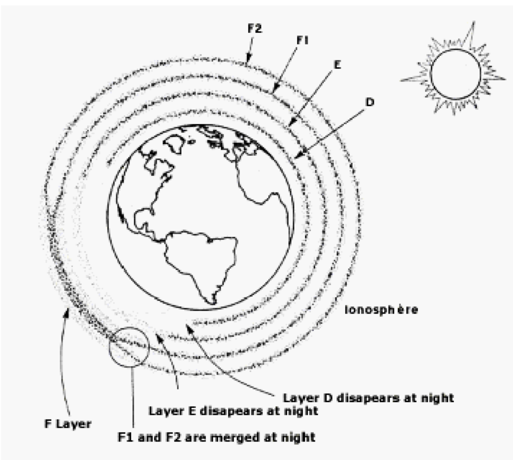

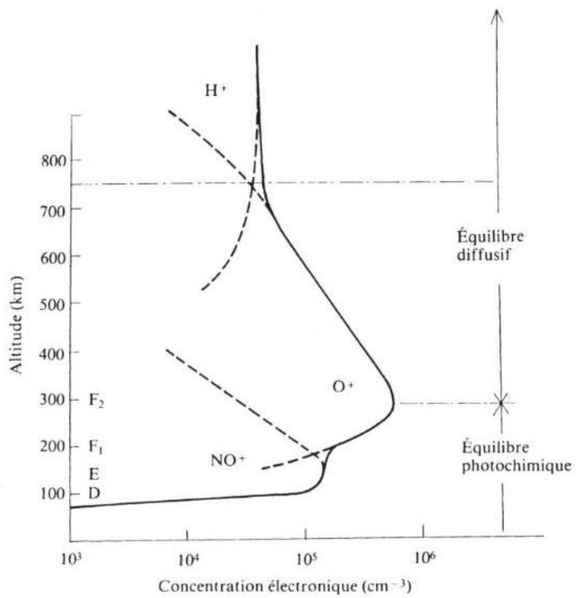

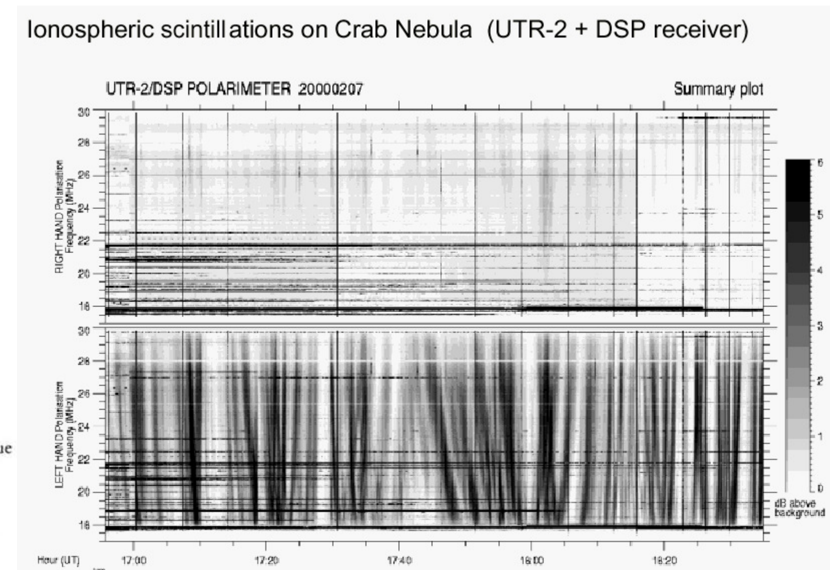

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- Galactic background for a short dipole antenna :

$$S_{gal} = 2kT_{gal}/A_{eff} = 2kT_{gal}\lambda^2/\Omega \qquad (A_{eff}\times\Omega \sim \lambda^2)$$

with Ω=8π/3, A_{eff}=3λ^2/8π, T_{gal}~10^3-10^6 K at LF

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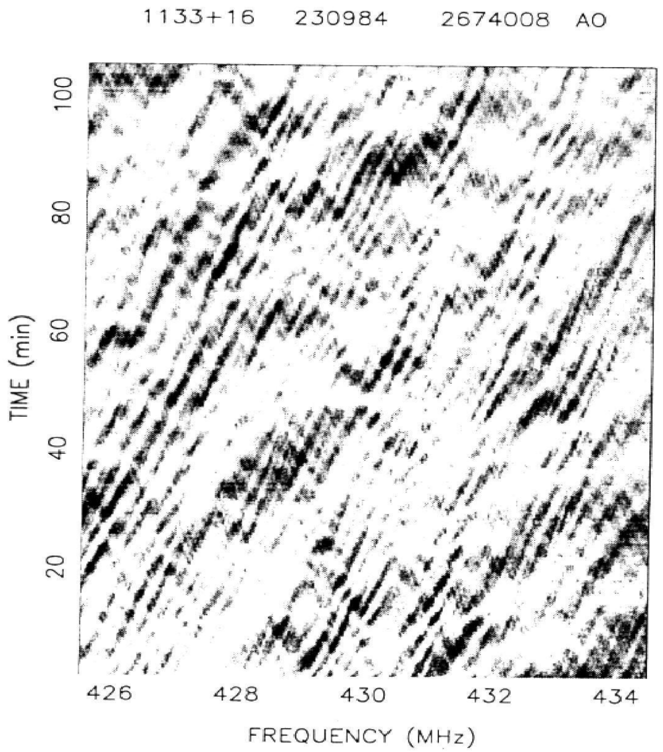

Figure 3. Dynamic spectrum $I(\nu, t)$ for PSR B1133+16 that shows constructive and destructive interference from multipath propagation.

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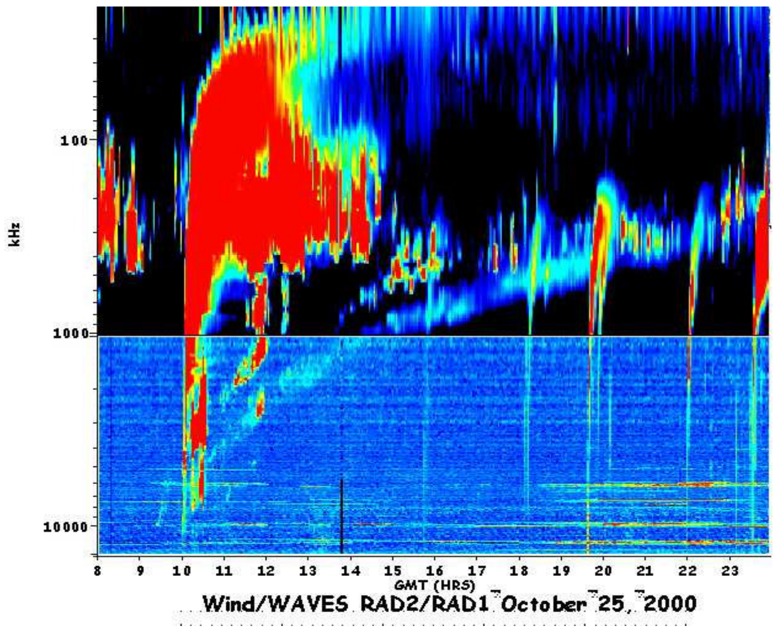


• Limitations of LF radioastronomy in Earth orbit :

- ❑ RFI (man-made, lightning spherics)
- ❑ Sky background (fluctuations)
- ❑ IP, IS scintillations
- ❑ (Solar radio emissions)
- ❑ (Auroral Kilometric Radiation)

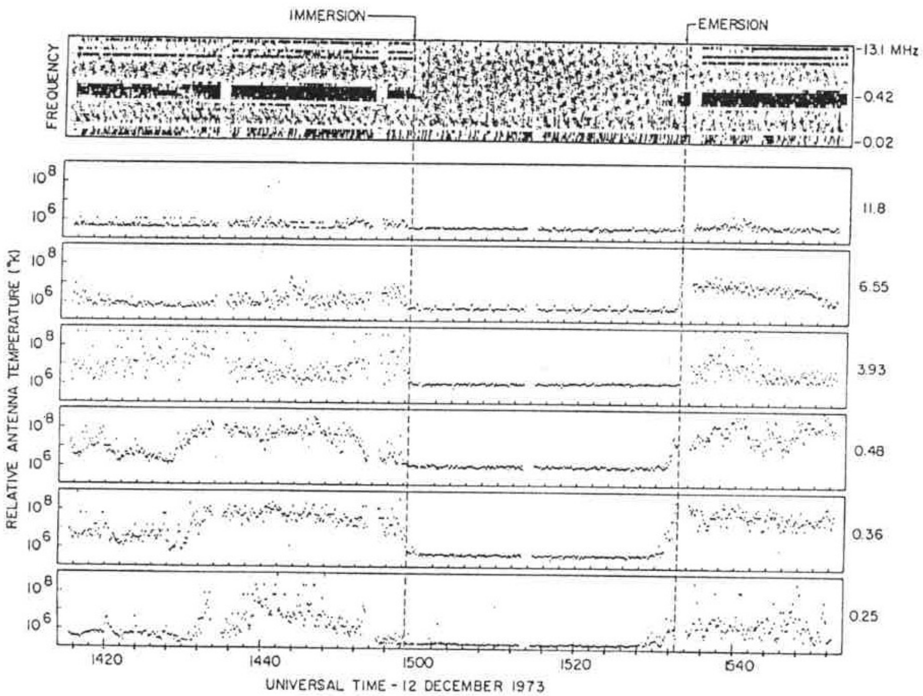
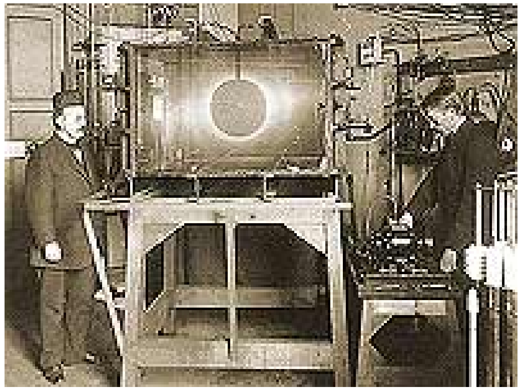
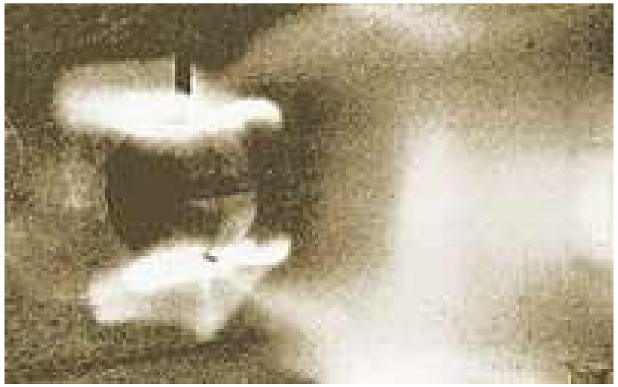
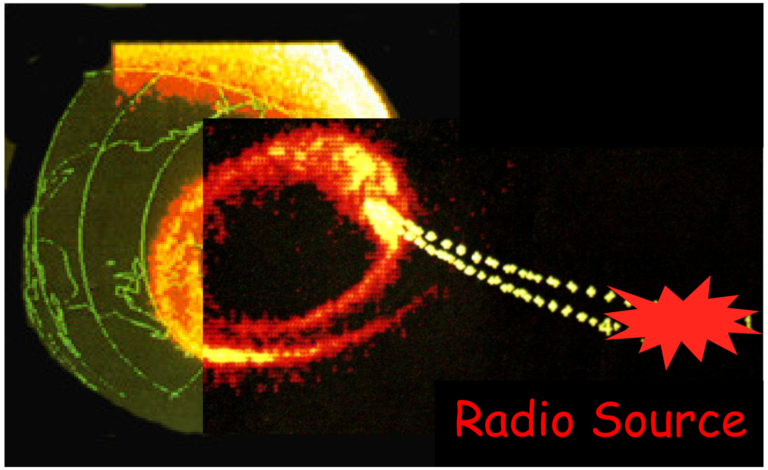
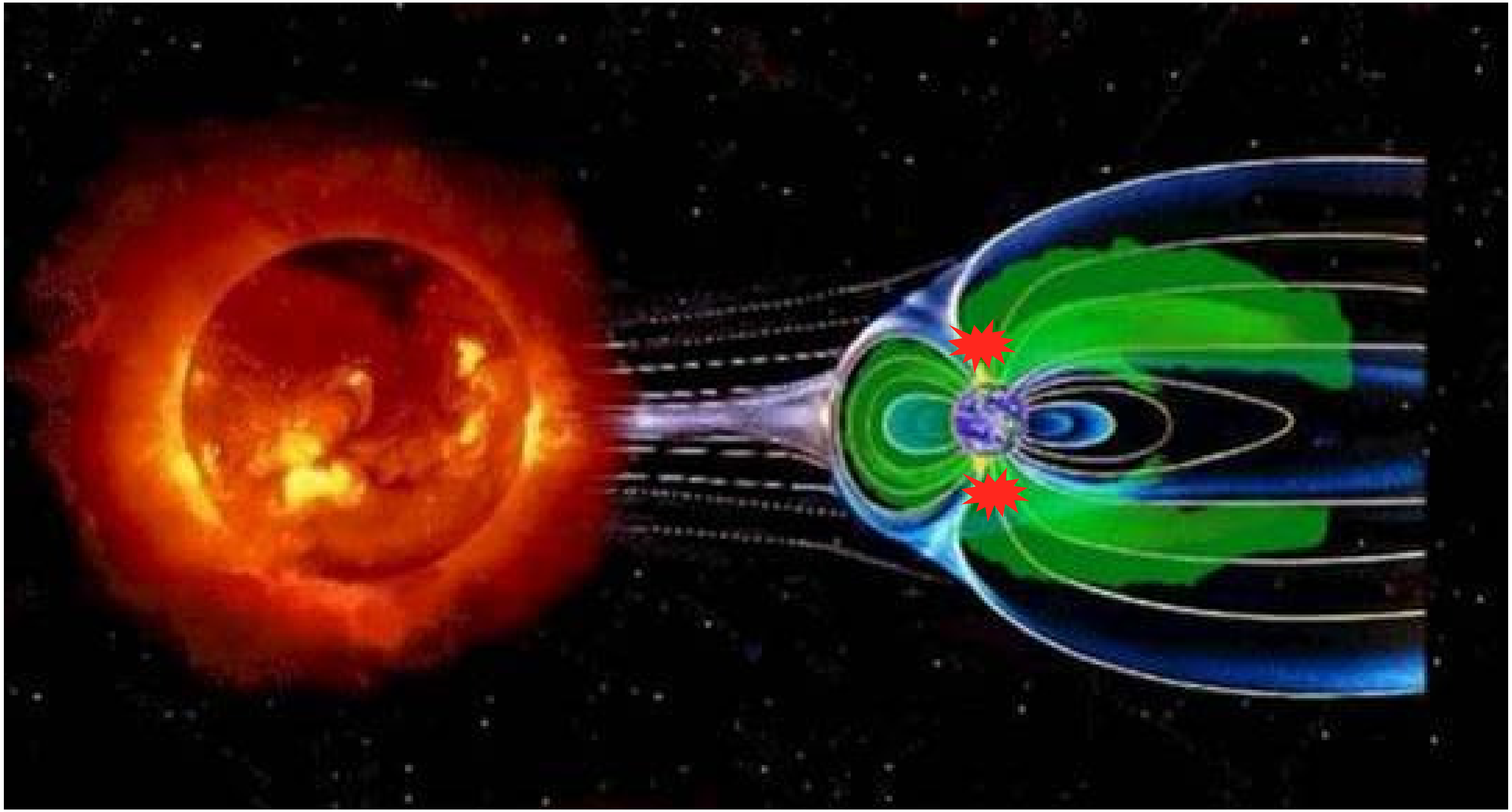


Figure 8. Data from RAE-2 in lunar orbit showing the dramatic disappearance and reappearance of interference from the Earth [*Alexander, et al.*, 1975].



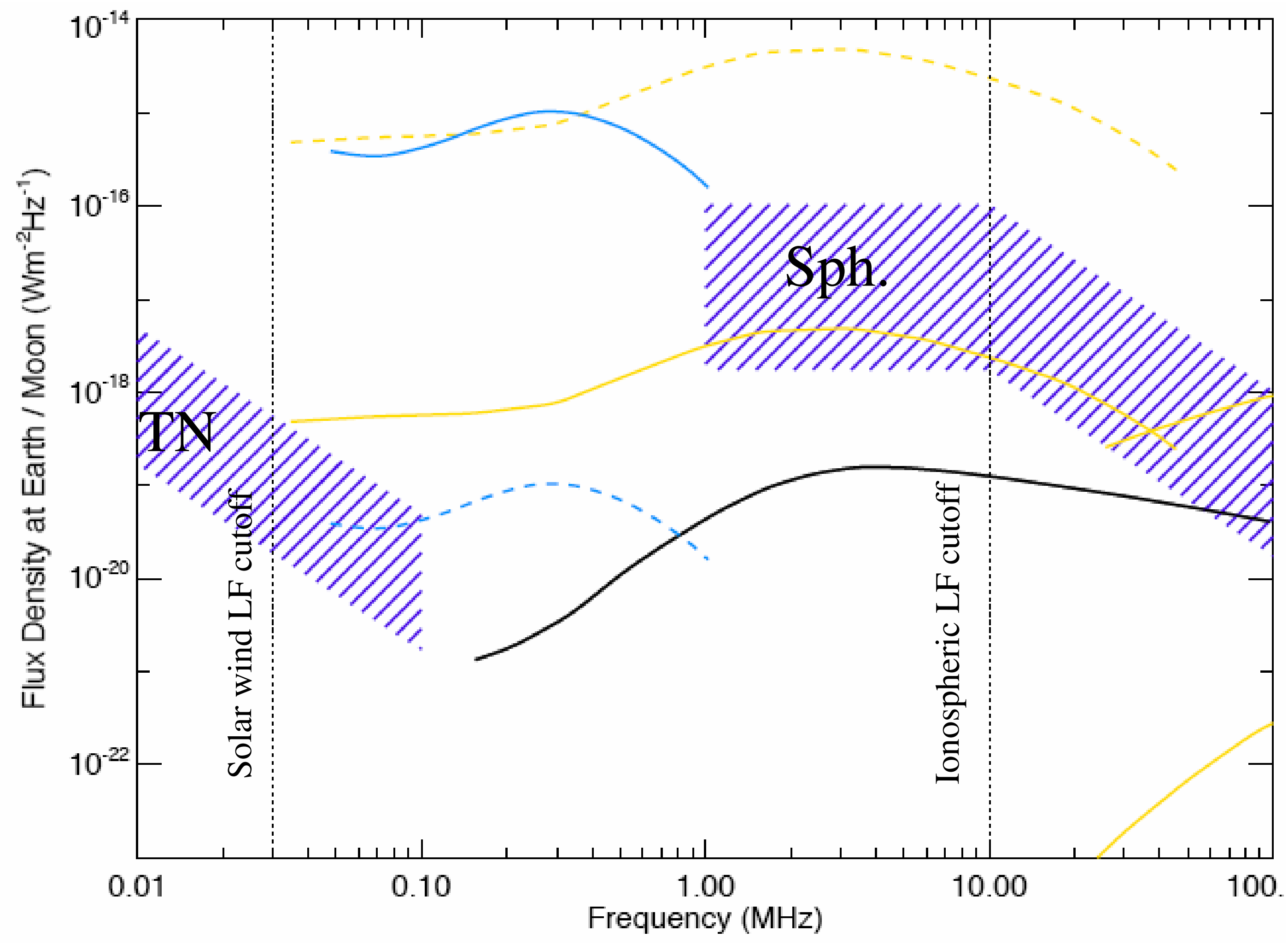



Radio Source

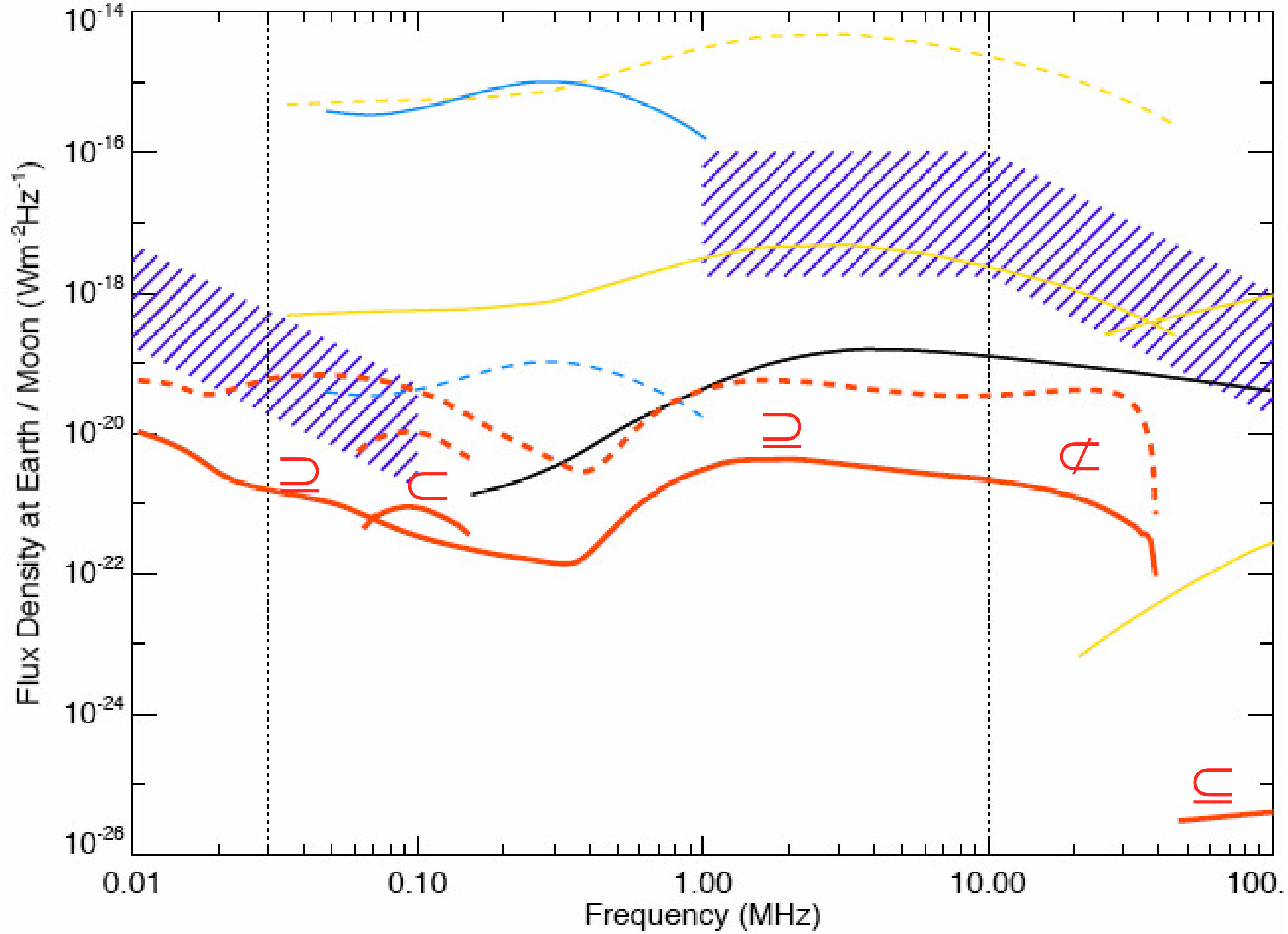


- Earth's LF radio environment :

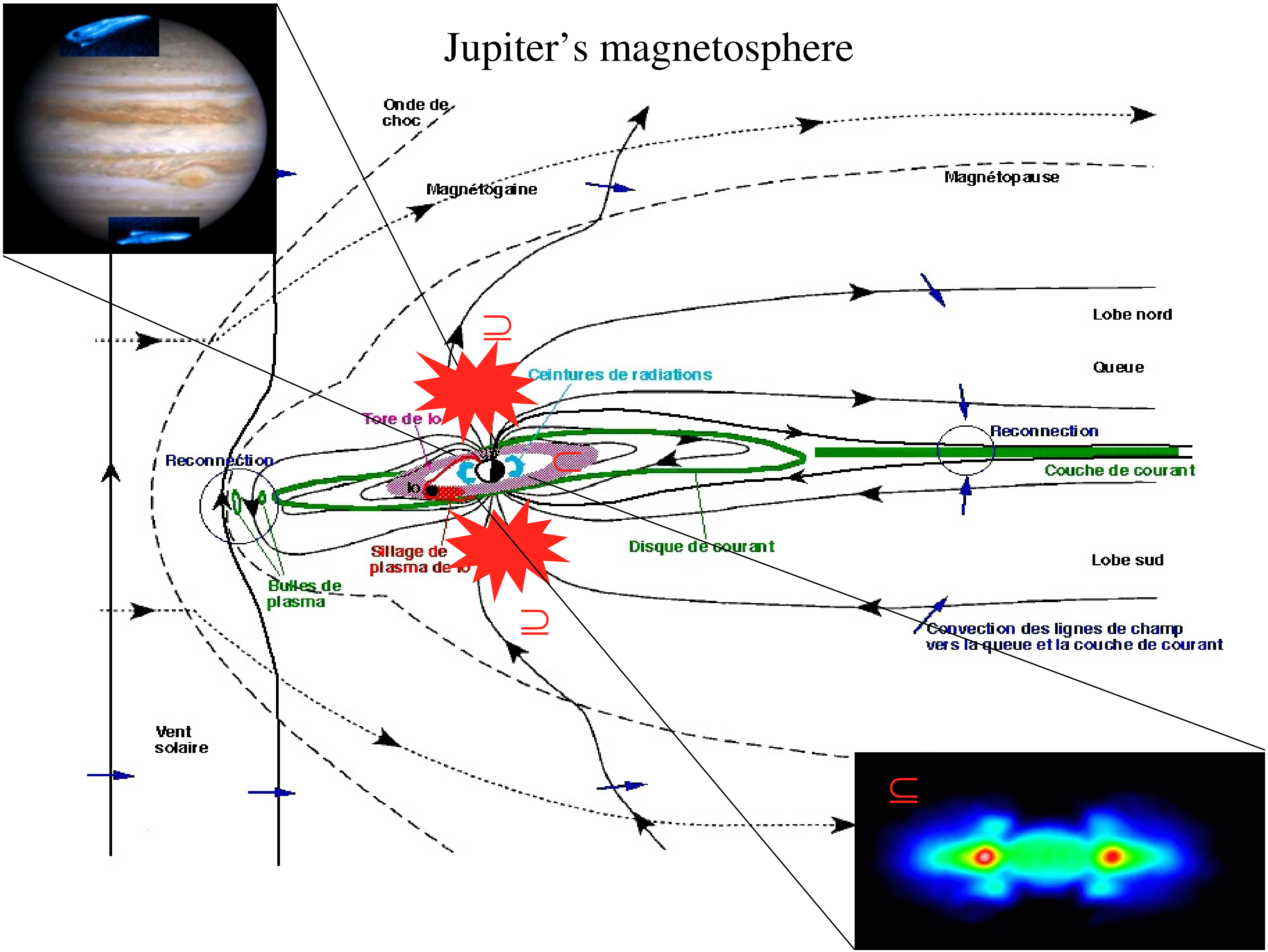
- ❑ Spherics
- ❑ Thermal noise (local)
- ❑ Galactic background
- ❑ Solar emission/ burst/storm
- ❑ AKR day/night (at 60 R_E)



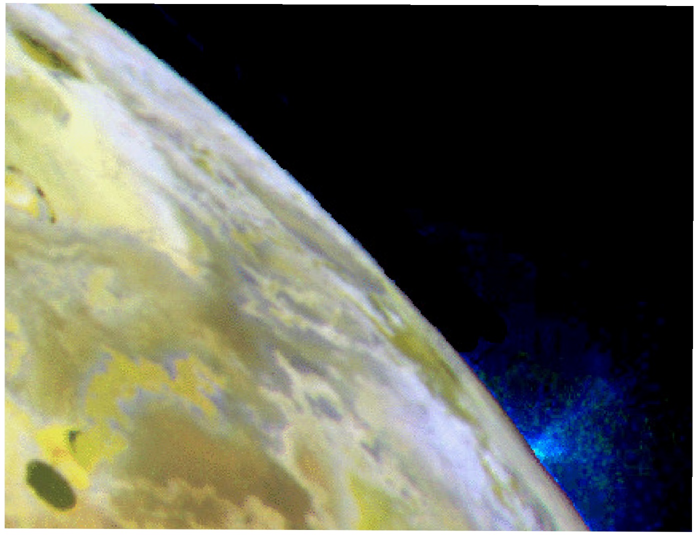
- + Jovian radio emissions (near opposition) :
  - ⊇ Solar wind / magnetosphere interaction (auroral emissions)
  - ⊄ Io/magnetosphere interaction
  - ⊂ Io torus
  - ⊆ Synchrotron from radiation belts (HF)

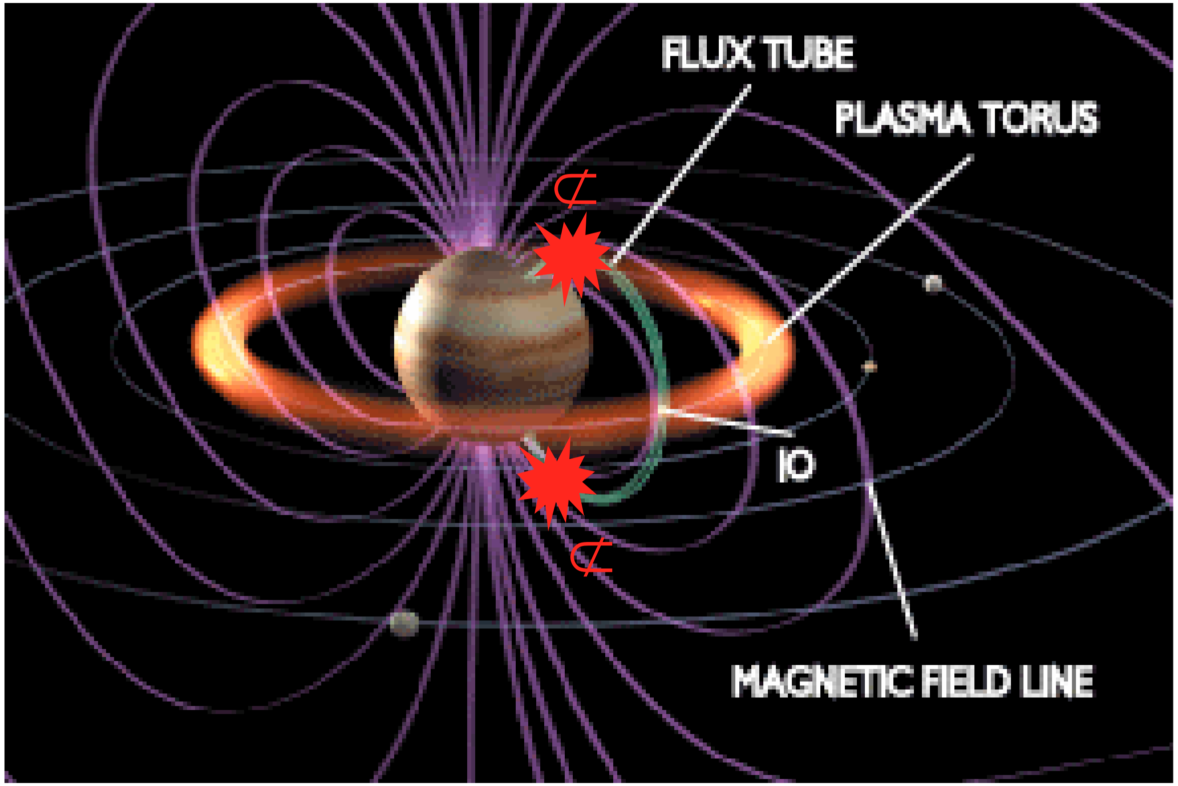


Jupiter's magnetosphere

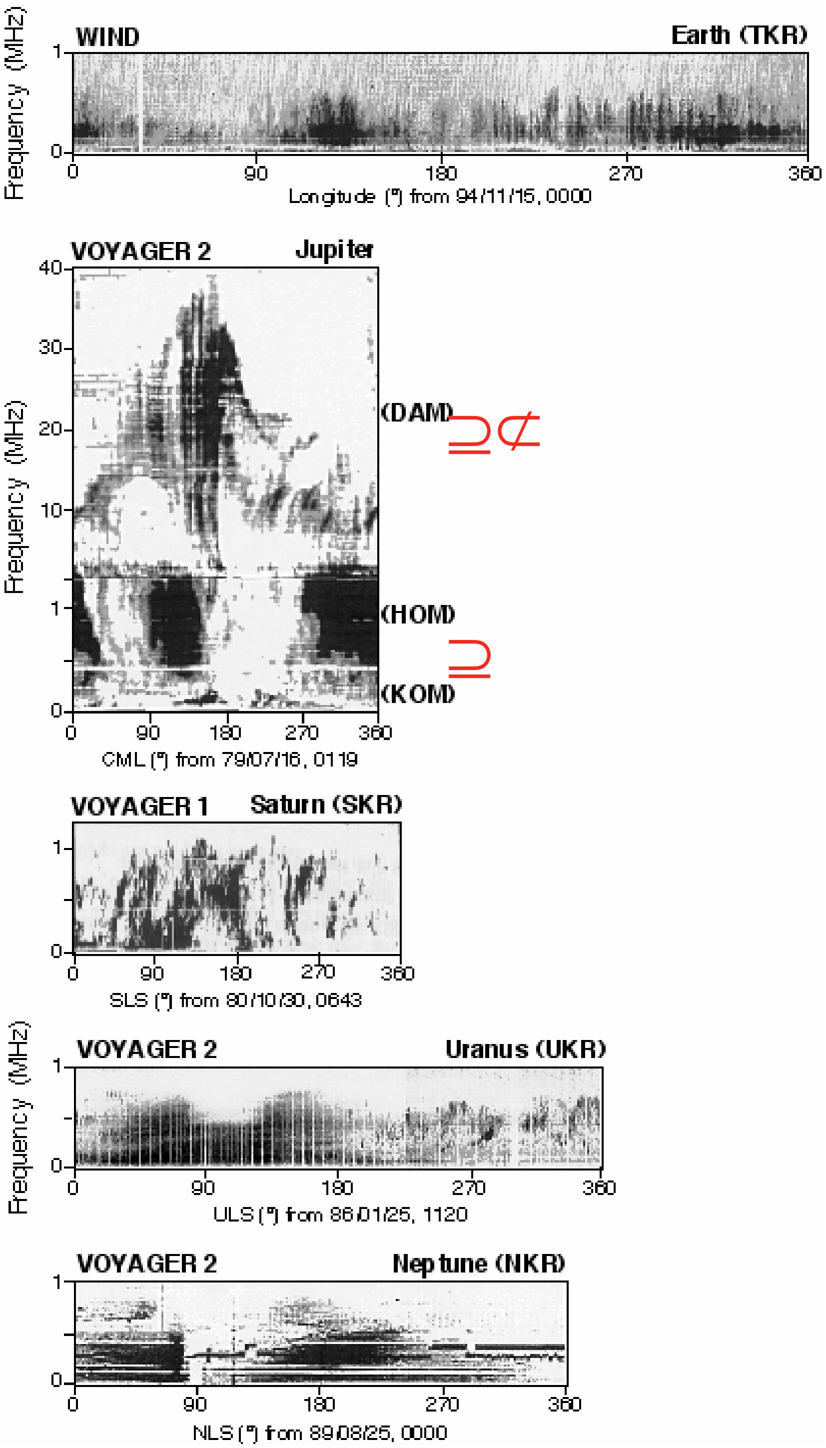


Io-Jupiter plasma interaction

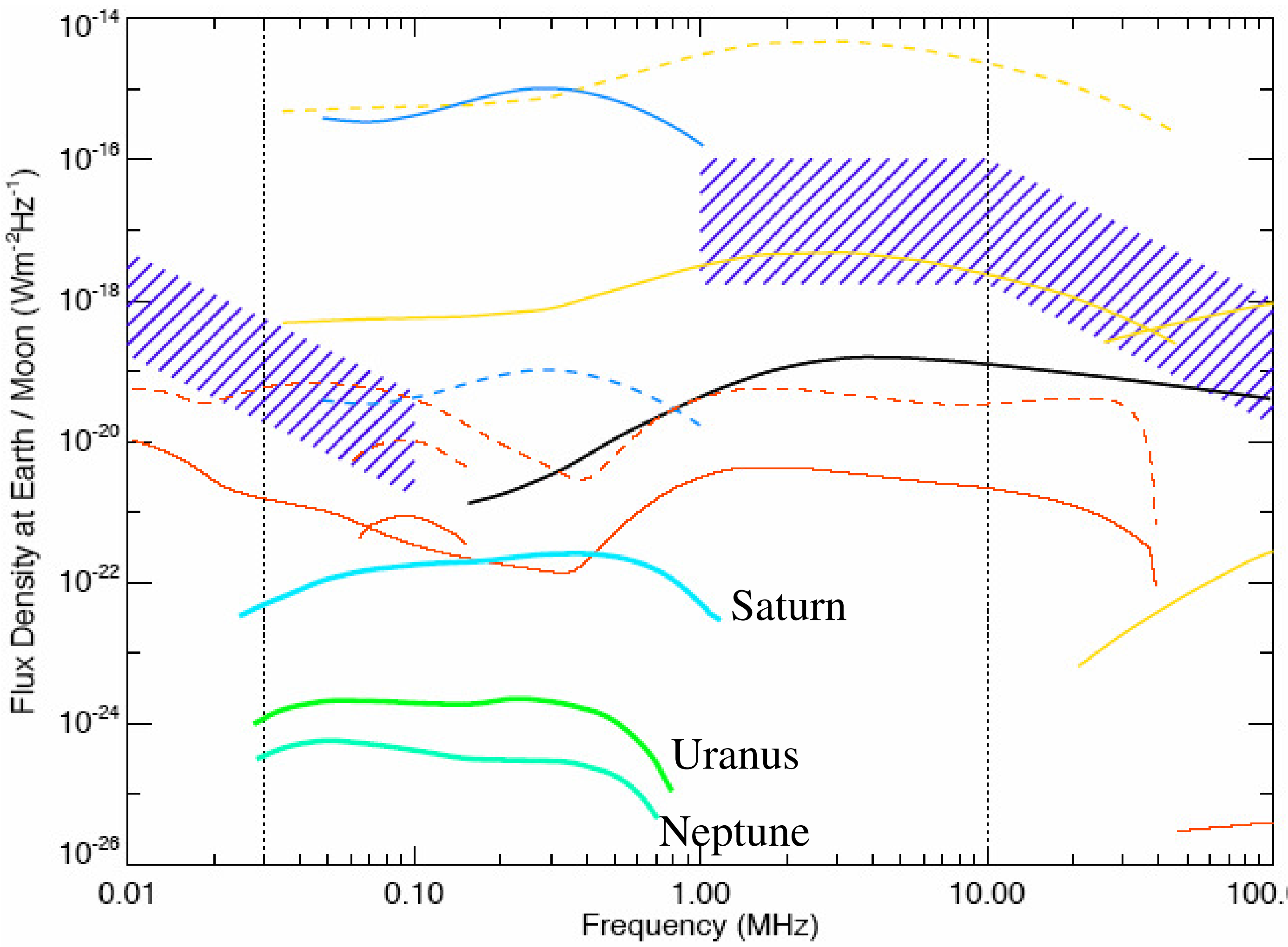




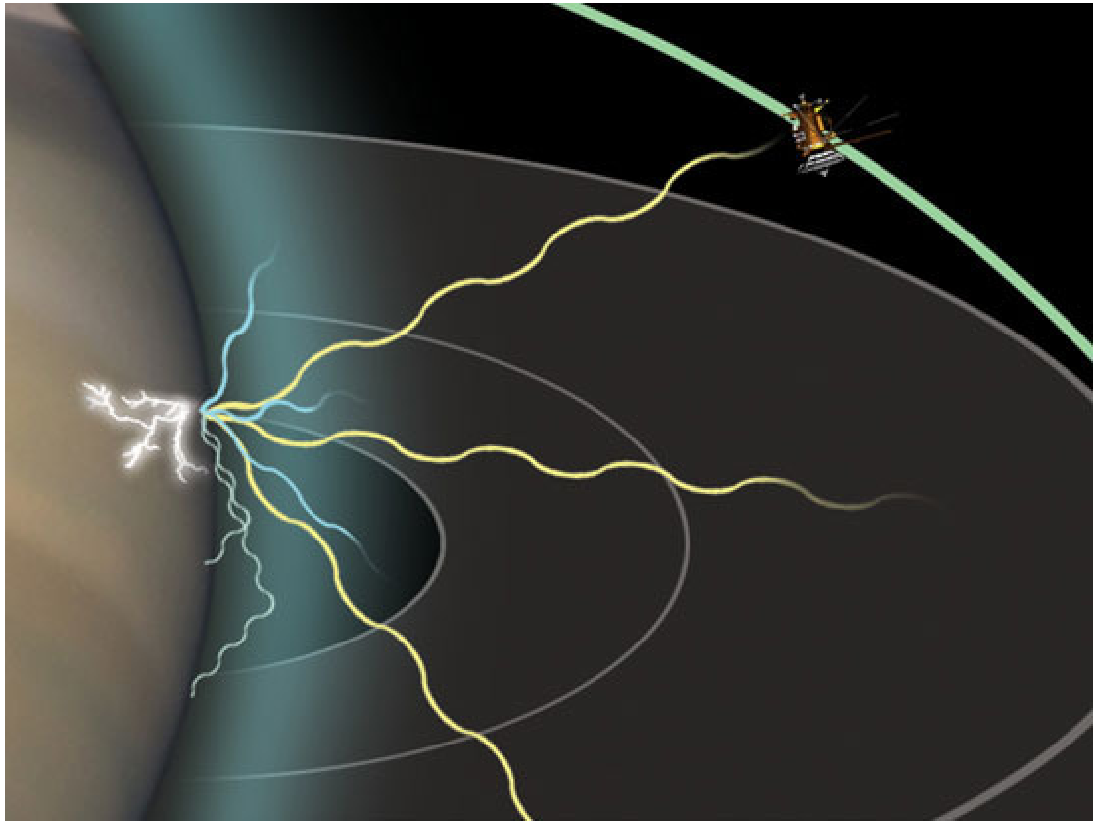
Planetary (auroral) radio emissions

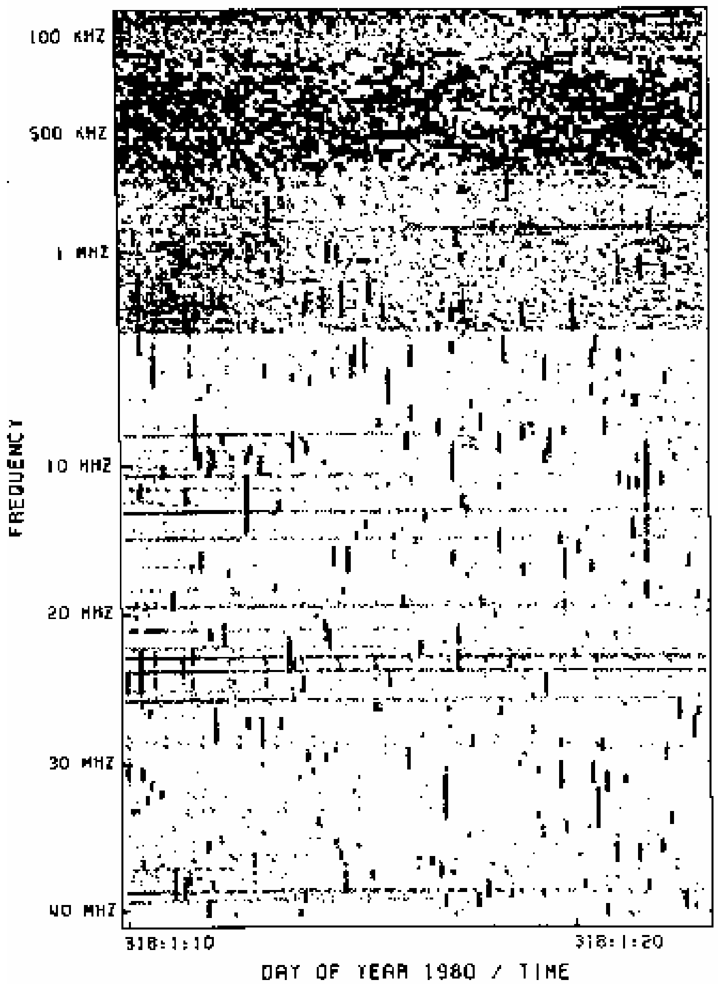


• + Saturn, Uranus, Neptune auroral emissions :



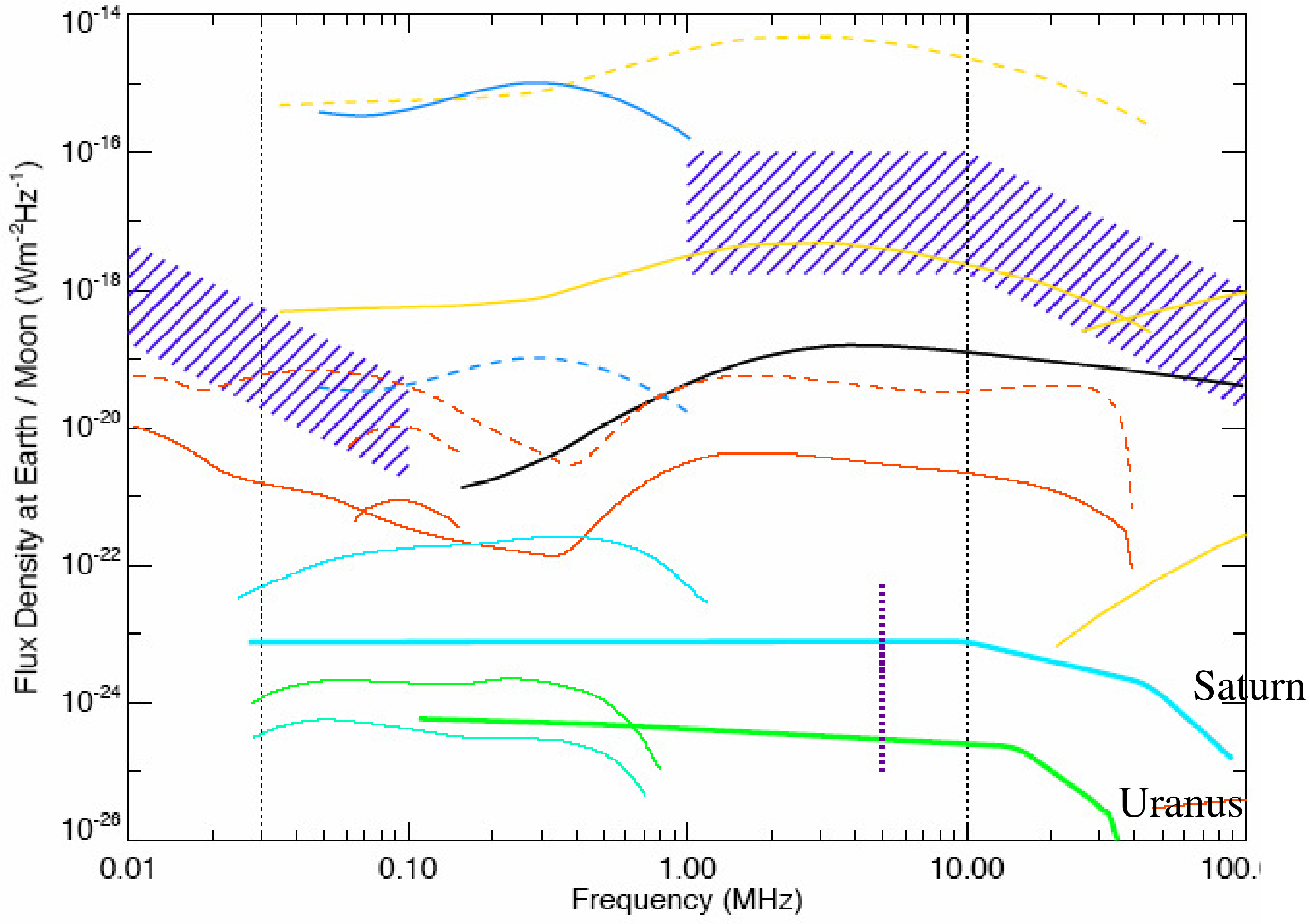
• Saturn, Uranus atmospheric lightning :



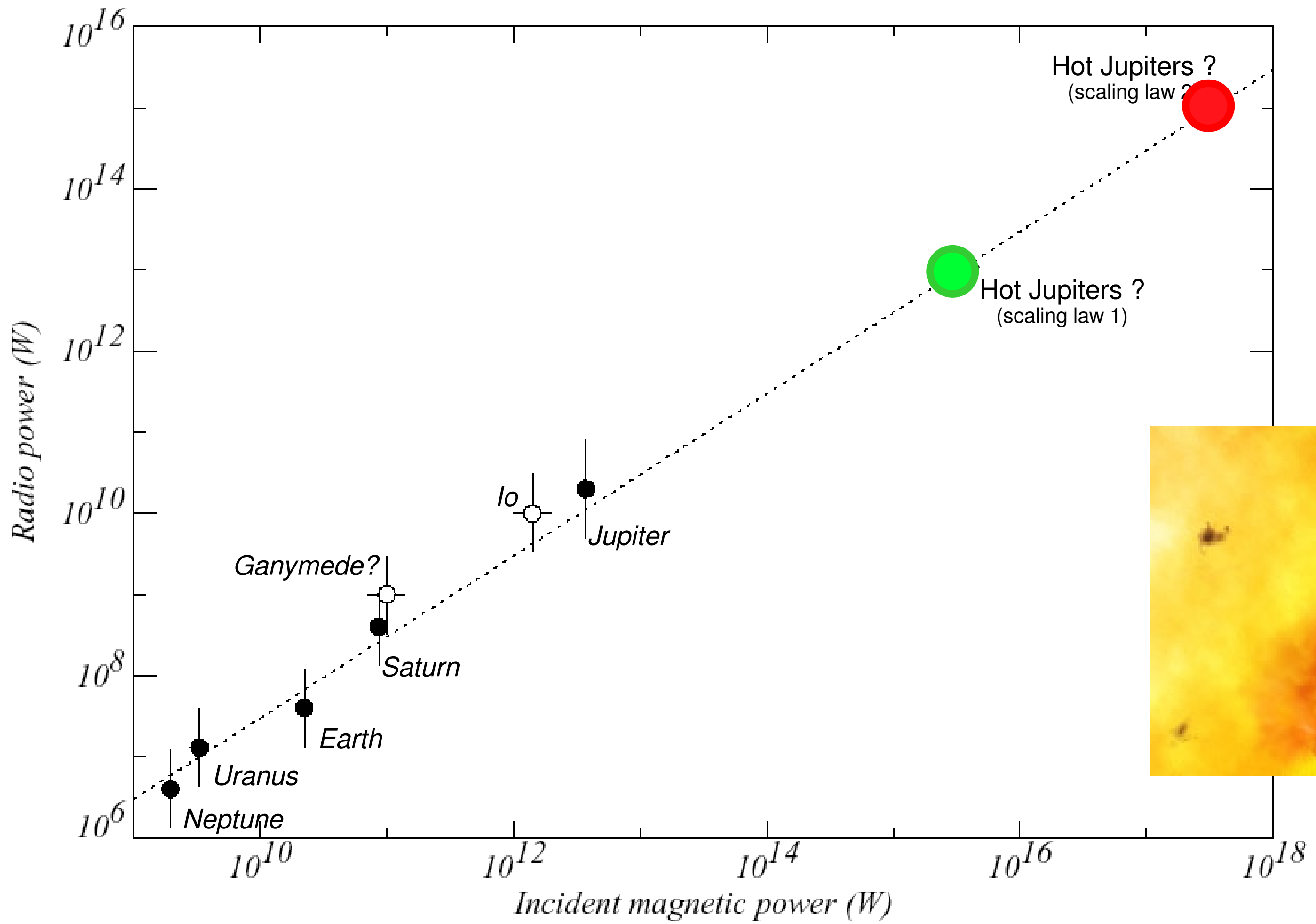


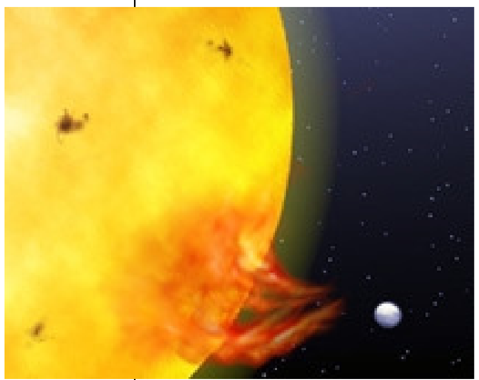
• + Saturn, Uranus atmospheric lightning :

❑ LF cutoff at ~5 MHz → dayside peak ionospheric density

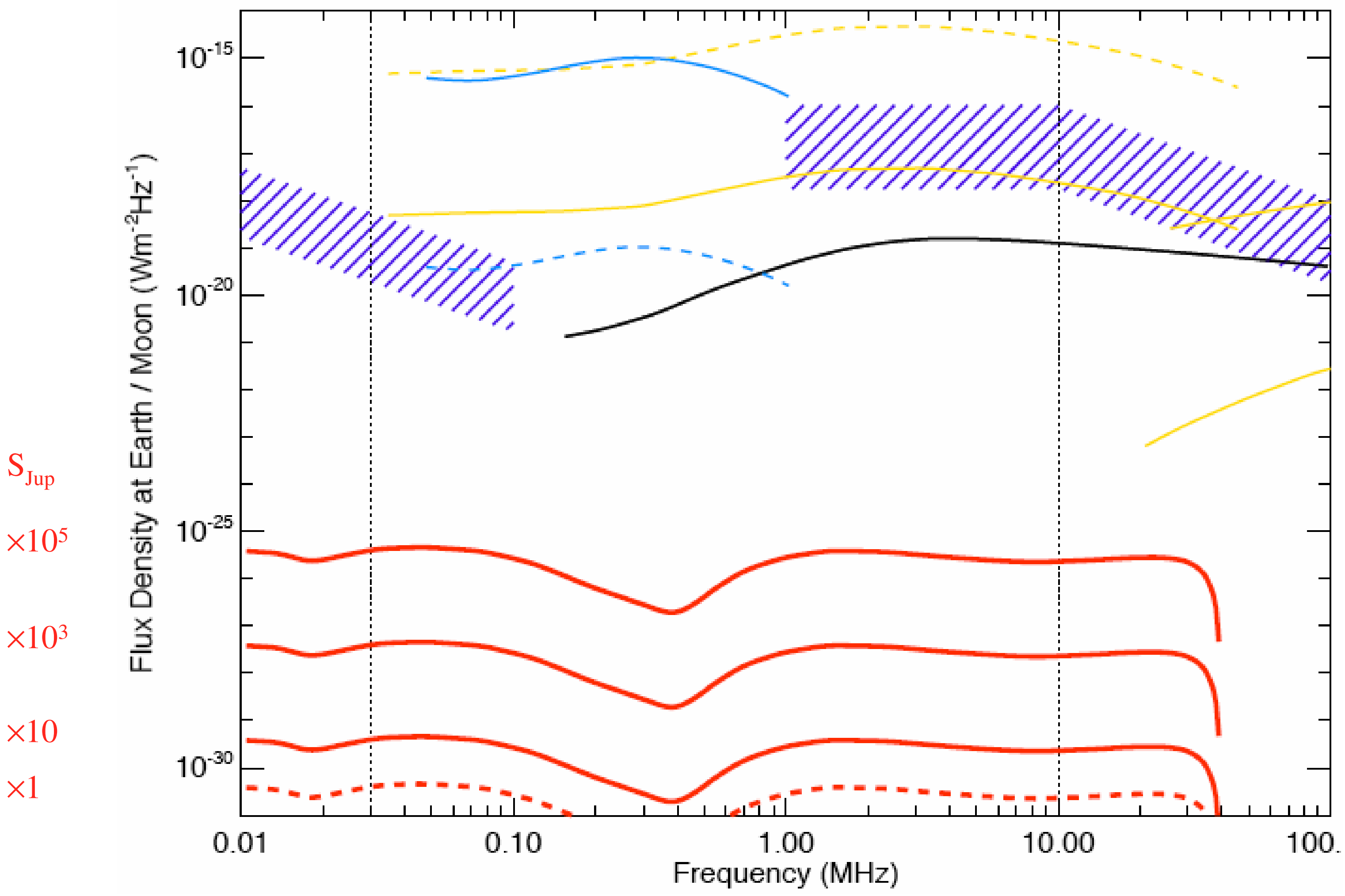


- Extrasolar Jupiter-like radio emissions :
  - ❑ Flux up to $\times 10^5$ Jupiter's strength for magnetized Hot Jupiters with solar-like stellar wind input, or up to $\times 10^{4\text{-}5}$ for unmagnetized Hot Jupiters in interaction with a strongly magnetized star
  - ❑ + possible stronger stellar wind, focussing events, …





• Extrasolar Jupiter-like radio emissions at 10 pc range :



- Detectability from the Earth (ground-based) :

  - ❑ Absence of solar bursts & spherics
  - ❑ Absence of RFI / Successful mitigation
  - ❑ ≥10-20 MHz

  ⇒ Ultimate limit = galactic background fluctuations

$$S_{noise} = S_{gal}/(b\tau)^{1/2}$$

For N dipoles : $A_{eff} \sim N \times A_{eff}(_{1\ dipole})$

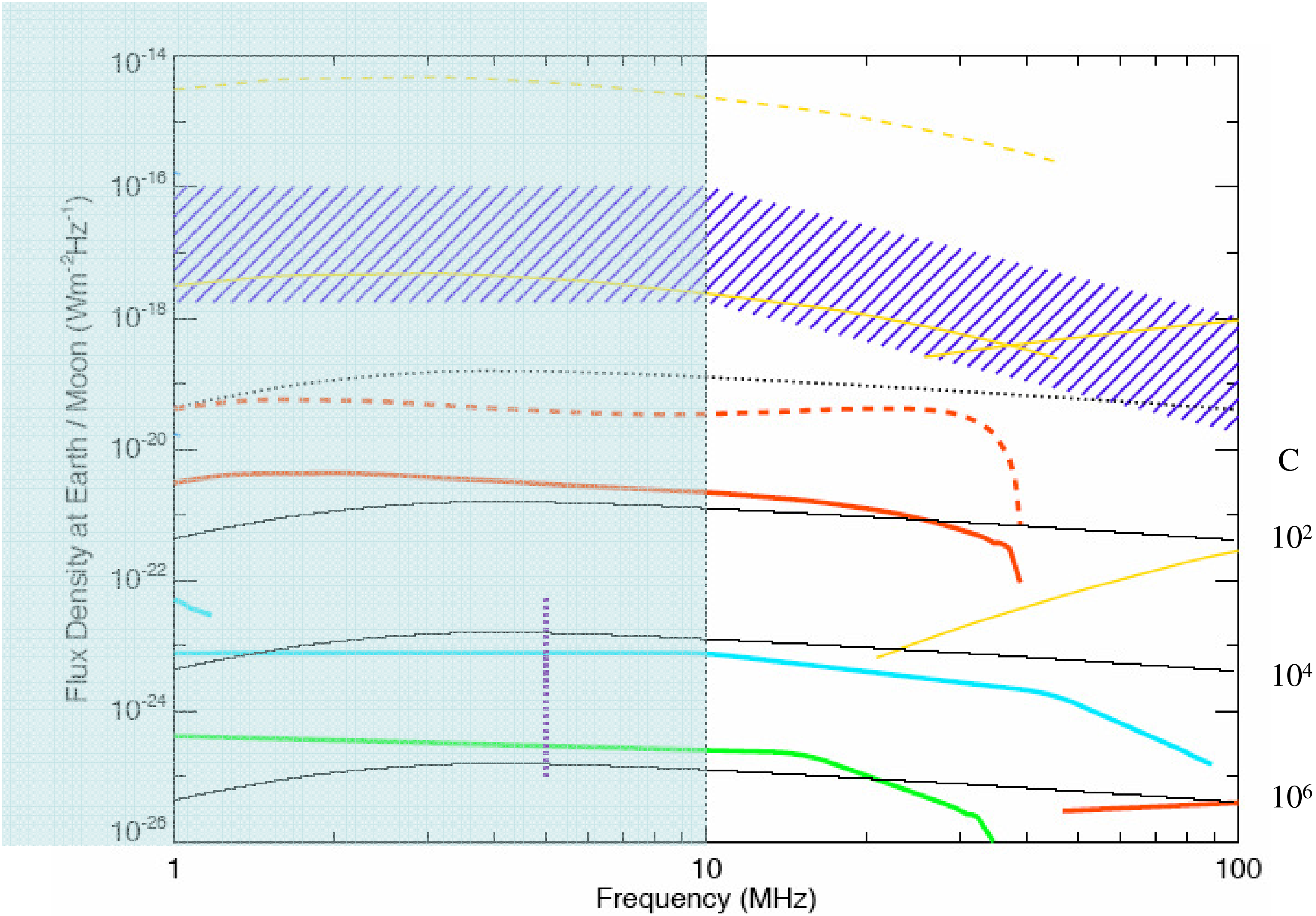
$\Rightarrow S_{noise} \sim S_{gal}(_{1\ dipole})/C$ with $C = N(b\tau)^{1/2}$

- Nançay Decameter Array : N ~ 200 dipoles
- LOFAR : N ~ 10^4 dipoles

- Detectability from the Earth (ground-based) :

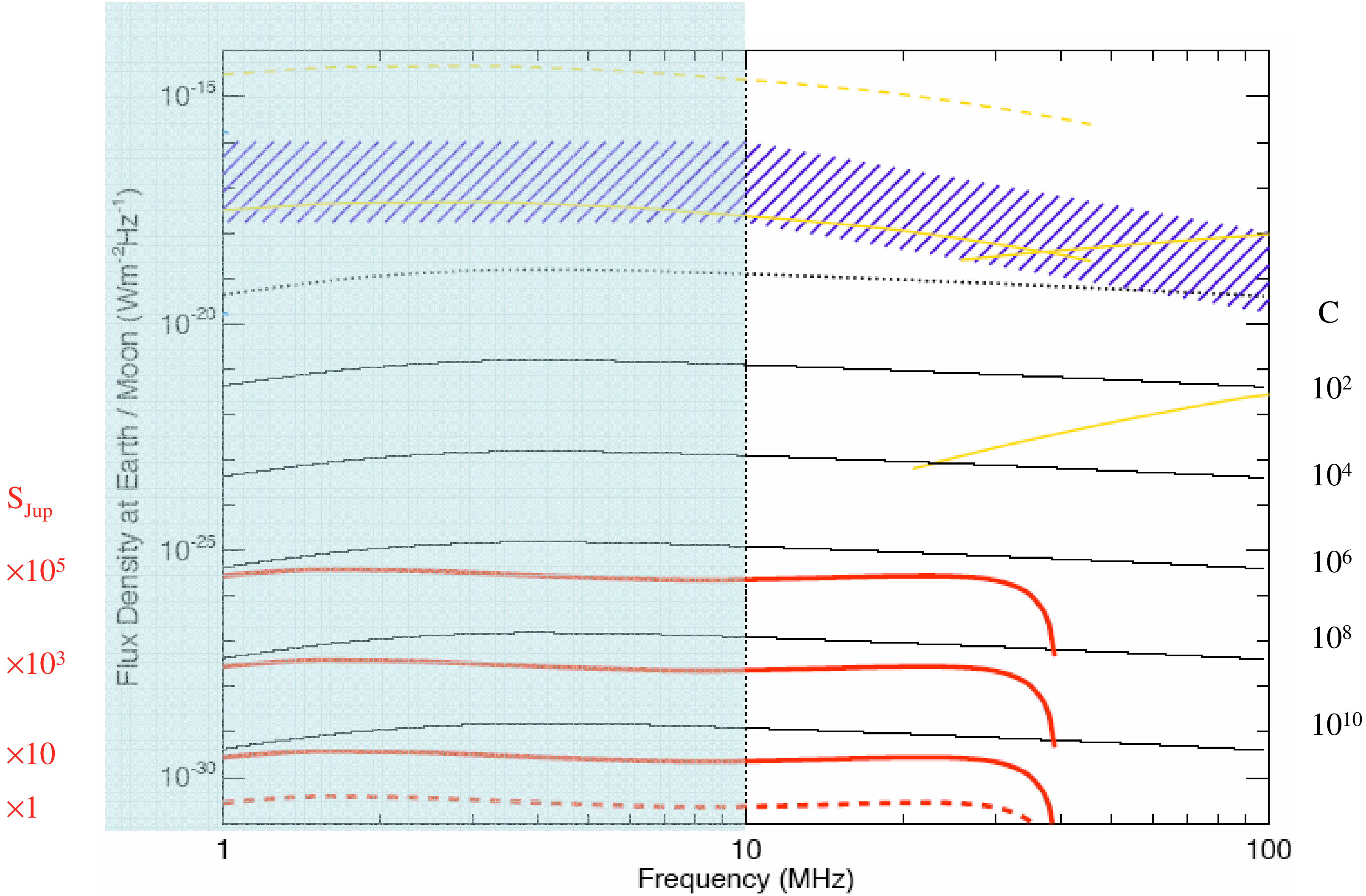
  - ❑ Jovian DAM with $C=N(b\tau)^{1/2} \geq 100$ (ex : N=1, 10 kHz × 1 sec)
  - ❑ Saturn's lightning with $C \geq 10^5$ (N=200, 10 MHz × 25 msec)

    without access to LF cutoff

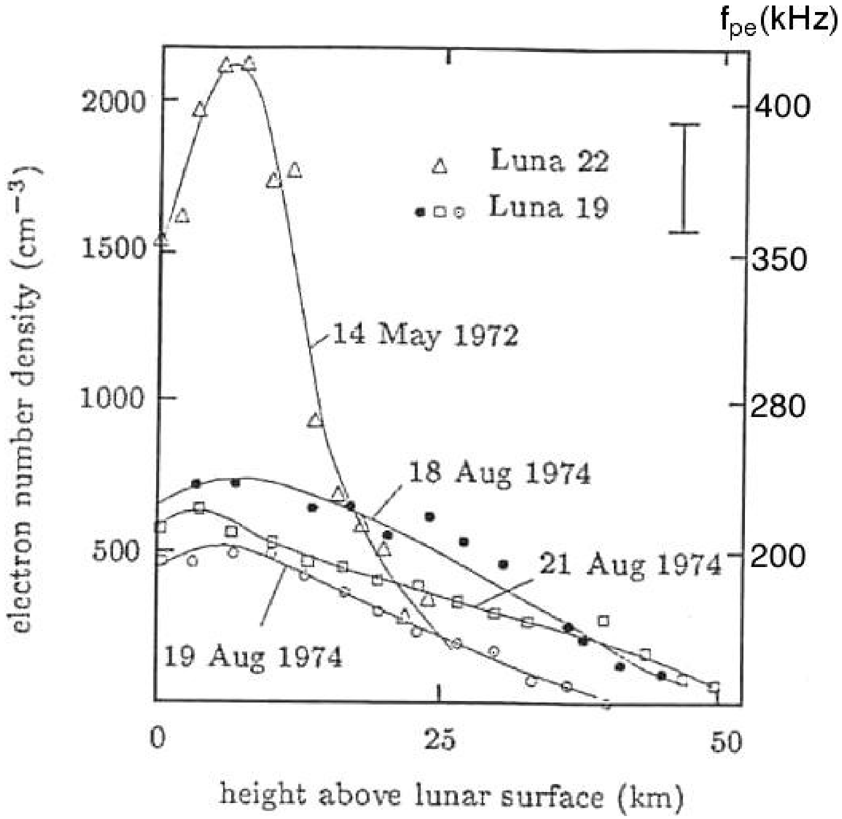


- Detectability from the Earth (ground-based) :
  - Hot Jupiters at 10 pc range → requires $C \geq 10^7$

(N=1000-10000, 1-10 MHz × 1-10 sec)



- Detectability from the Moon :
    - ❑ Shielding of RFI, spherics, AKR, Solar emissions
    - ❑ Only limitation to sensitivity = sky background fluctuations
    - ❑ Ionospheric LF cutoff <<500 kHz



- Detectability from the Moon :

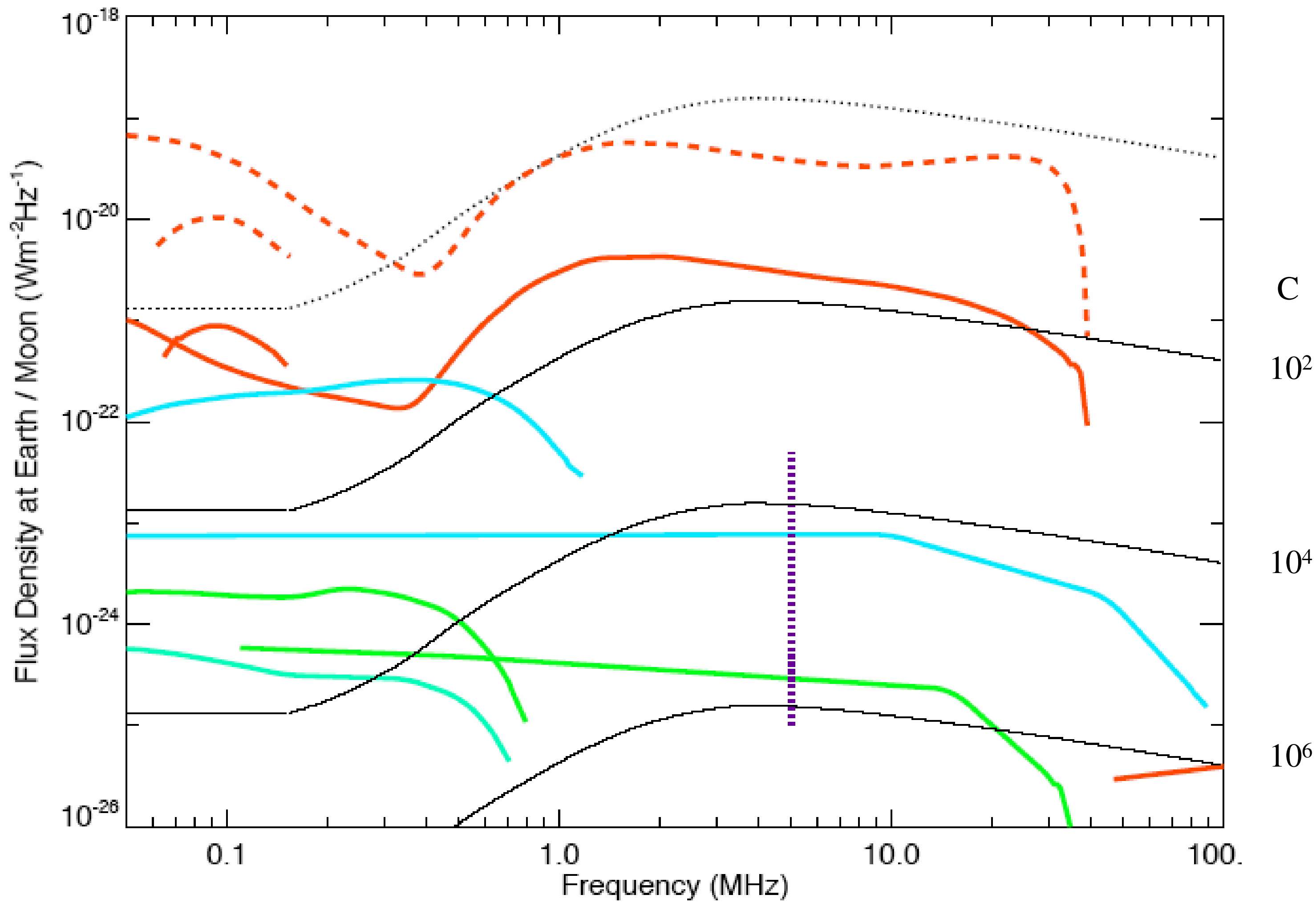
❑ all Jovian emissions + Saturn auroral emissions with $C \geq 10^2$-10^3

(N=1-10, 10 kHz × 1 sec)

❑ + Uranus & Neptune auroral emissions

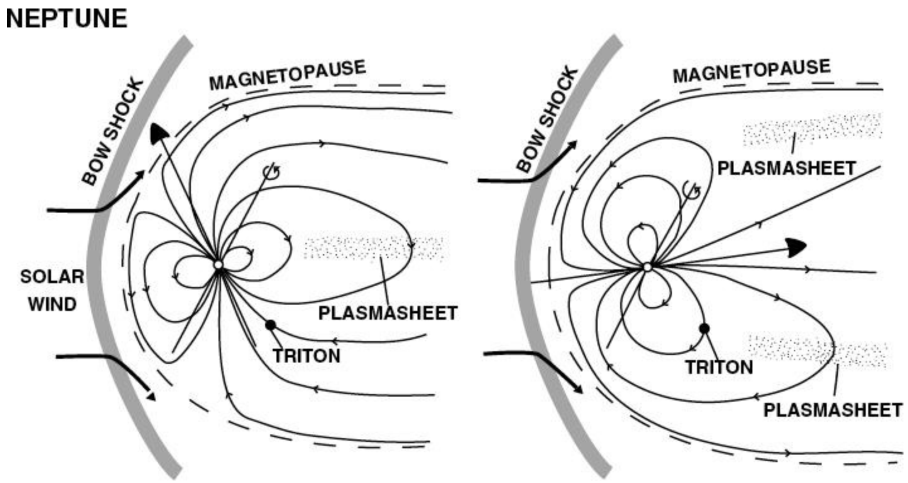
+ Saturn & Uranus lightning (including LF cutoff) with $C \geq 10^4$-10^5

(N=10-100, 200 kHz × 50-500 msec)



- Interest of (solar system) planetary radio emission studies :

  - ❑ Long-term magnetospheric radio observations from a ~fixed vantage point (+ multi-λ correlations)
    - → Variabilities/periodicities (Planetary rotation period)
    - → magnetospheric dynamics
  - ❑ Solar wind / Magnetosphere coupling
    - → Substorms ? SW monitoring from 1 to 30 AU ?
  - ❑ Satellites / Magnetosphere coupling (Io, Titan…)
  - ❑ Io volcanism + torus probing (radio em. + propag. effects)
  - ❑ Magnetic anomalies + secular variations
  - ❑ Uranus & Neptune radio emissions observed only once by Voyager 2 !



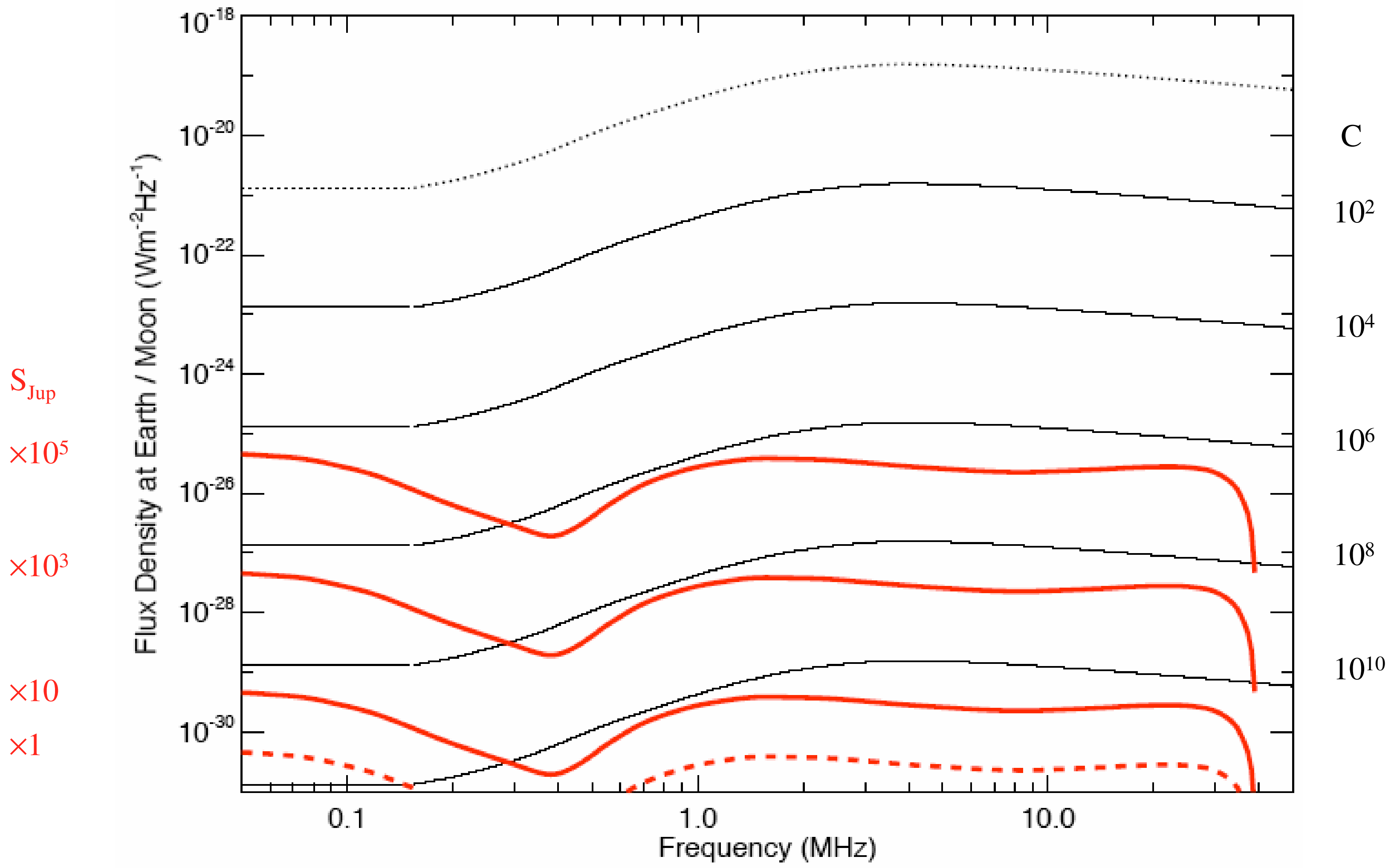
- Interest of (solar system) lightning studies :

  - ❑ Long-term monitoring
  - ❑ Correlation with optical observations
  - ❑ Comparative planetary meteorology

• Detectability from the Moon :

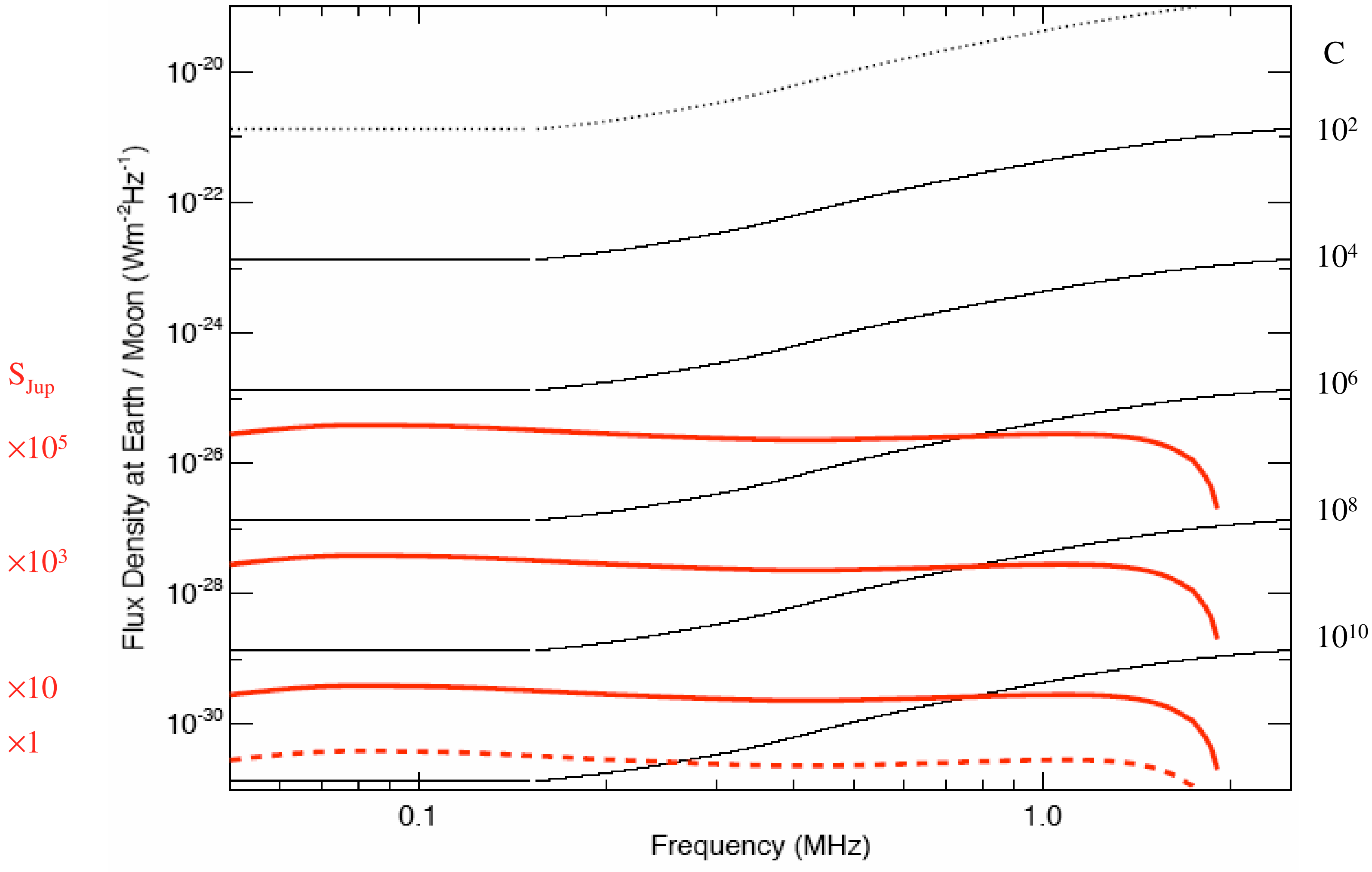
❑ Hot Jupiters at 10 pc range → requires C≥10^7

(N=1000-10000, 1-10 MHz × 1-10 sec)



• Detectability of Hot Jupiters from the Moon (at VLF) :

- ❑ ≥1 order of magnitude better (C ≥ 10^{5-6} : N=100, 1-10 MHz × 1-10 sec)
- ❑ access to less energetic sources (C ≥ 10^{6-7} : N>>100)
- ❑ access to weakly magnetized bodies



- Interest of exoplanetary radio studies :

  - ❑ Direct detection
    (→ validates scaling laws)
  - ❑ Measurement / estimate of magnetic field
    (→ constraint on scaling laws)
  - ❑ Measurement / estimate of rotation period
  - ❑ Comparative magnetospheric physics
  - ❑ Possible discovery of intense radio-exoplanets ?
  - ❑ …

- Final Remarks :

  - ❑ Angular resolution required ~1°-10°
    → D = 6-60 λ
    (18-180 km @ 100 kHz ; 1.8-18 km @ 1 MHz)

  - ❑ if detectability of exo-planetary radio emissions → same for solar-like stellar radio emissions

  - ❑ complementarity to ground-based LOFAR

  - ❑ difficult from space

  - ❑ weak scattering/broadening effects at sources distances <a few 10's pc …
    except temporal broadening at a few MHz
    → probably prevents observations at 1 MHz
    → LF limit ?