(Solar System) PLANETARY SCIENCE WITH LOFAR

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Planetary LF radioastronomy ($\lesssim$100 MHz)

$\Rightarrow$ plasma phenomena

- Solar system planetary lightning
- Radiation belts
- High latitude (auroral) magnetospheric emissions

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 (±0.75), 330, ...	~13000	≥ 0.4'	2 polar.	$10^{-1/-2}$
GMRT (Giant Meterwave Radio Telescope), Pune, India	30 parabolas × 45m ∅ (core + Y-shape array)	(50), 150, 235, ...	~30000	0.3'	4 Stokes	$\sim 10^{-3}$
UTR-2, Kharkov, Ukraine	2040 dipoles (T-shape array)	7 - 35	~140000 (NS: 1800×60, EW: 900×60)	~30' × 10°	1 linear polar. (EW)	10^{0-1}
LOFAR (Low Frequency Array), The Netherlands	Interferometer / Phased arrays of dipoles (core + stations up to 400 km)	10 - 240	$\sim 8\times10^{5} \times (15/\nu)^{2}$	4" ×(100/ν) [ν in MHz]	4 Stokes	$\leq 10^{-3}$

+ built-in RFI mitigation & ionospheric correction

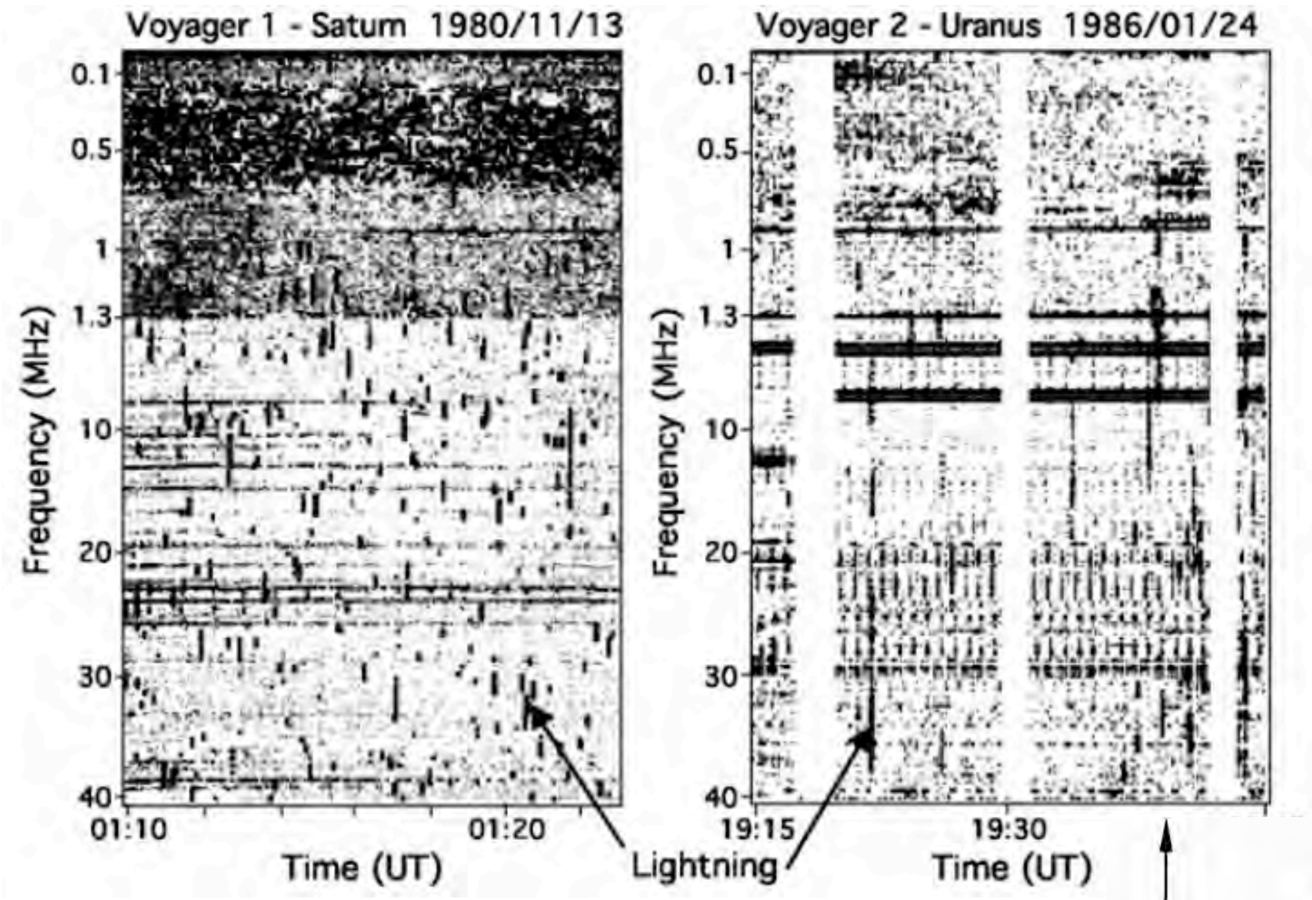
- Solar system planetary lightning

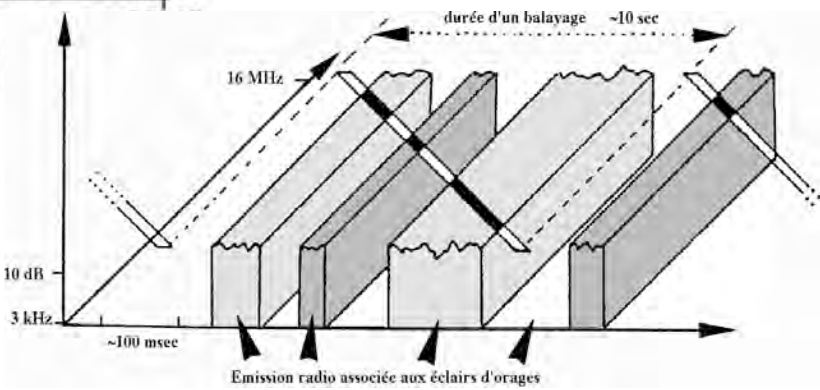
- Radiation belts

- High latitude (auroral) magnetospheric emissions

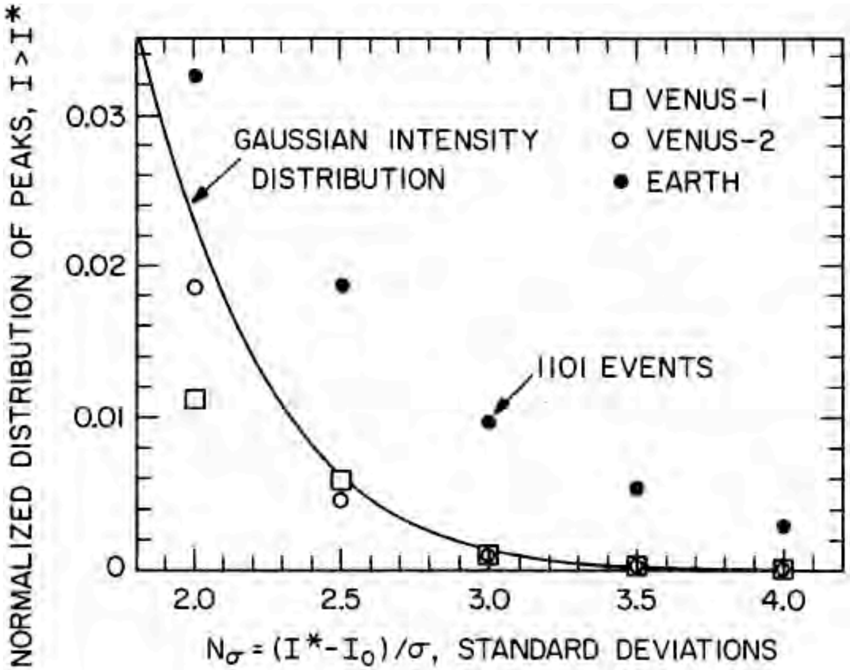
- Observed at Saturn & Uranus (Neptune ?) by Voyager

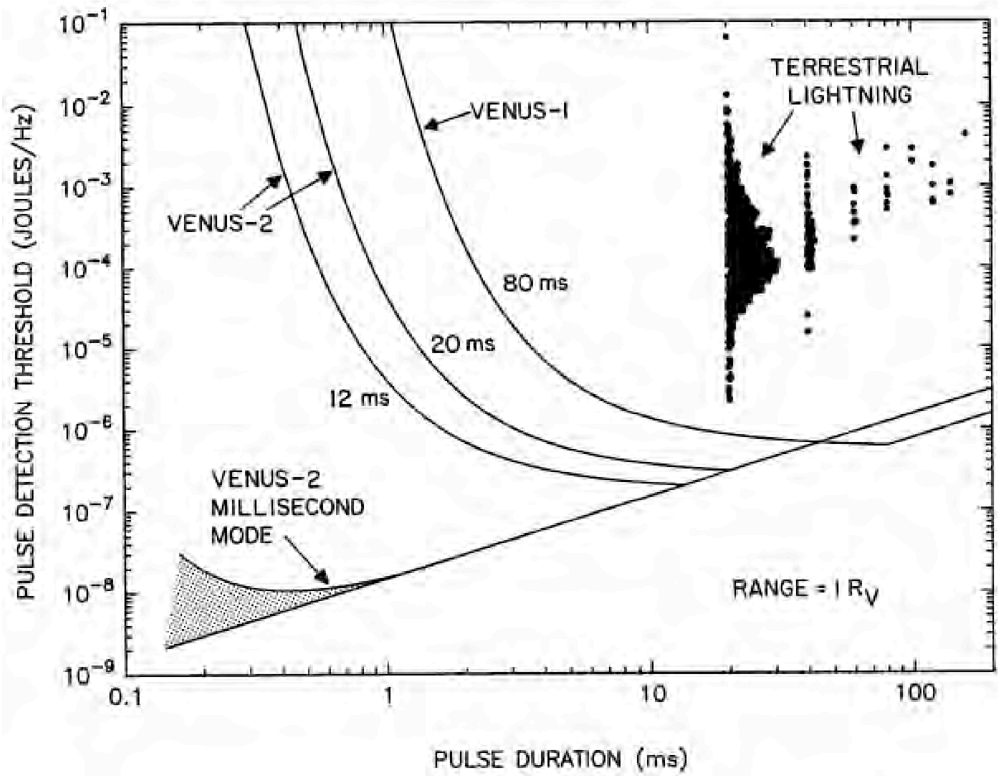
[Kaiser et al., Nature, 1983; Zarka & Pedersen, Nature, 1986]



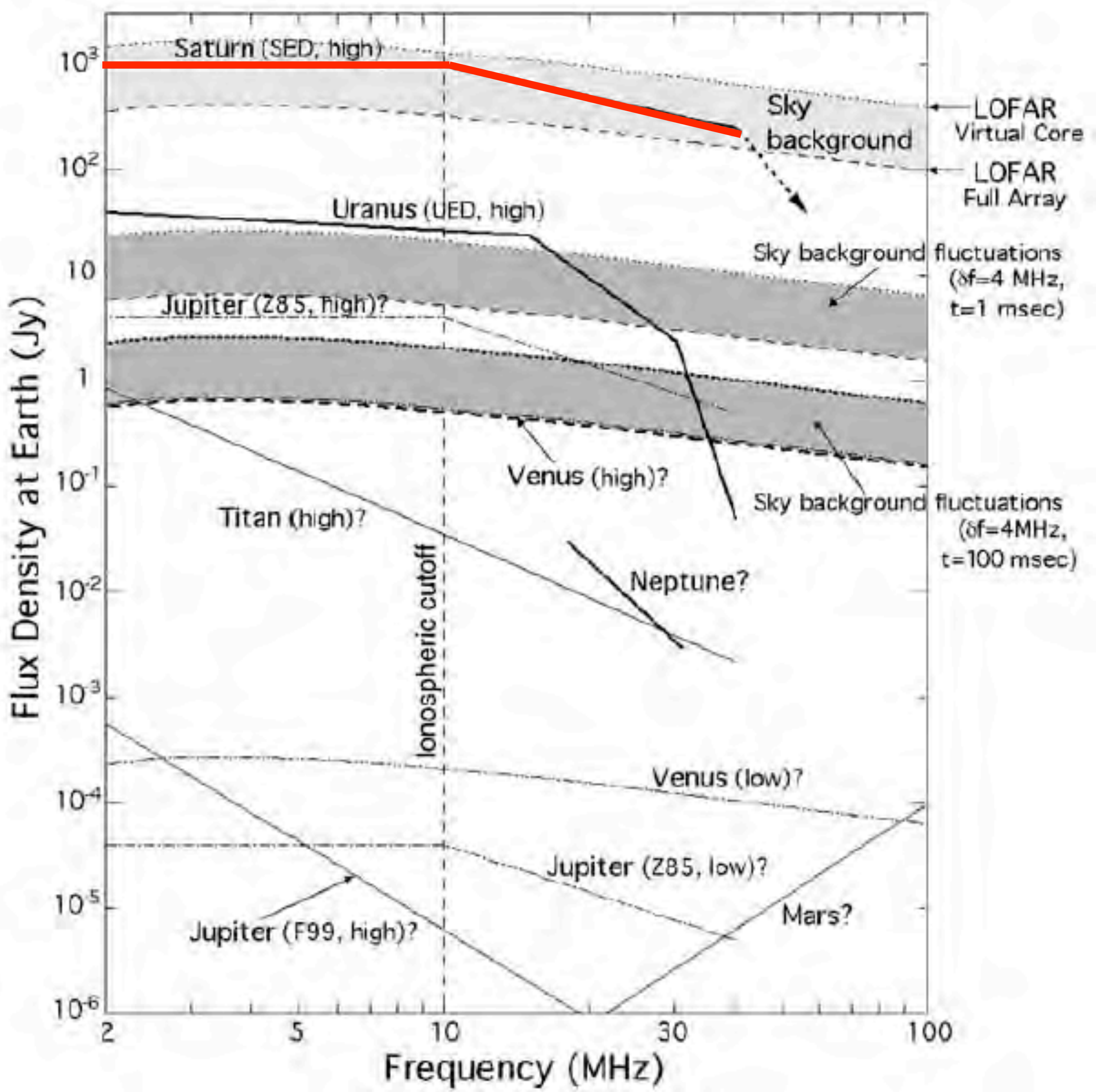


- Absence at Venus (Cassini/RPWS) *[Gurnett et al., Nature, 2001]*



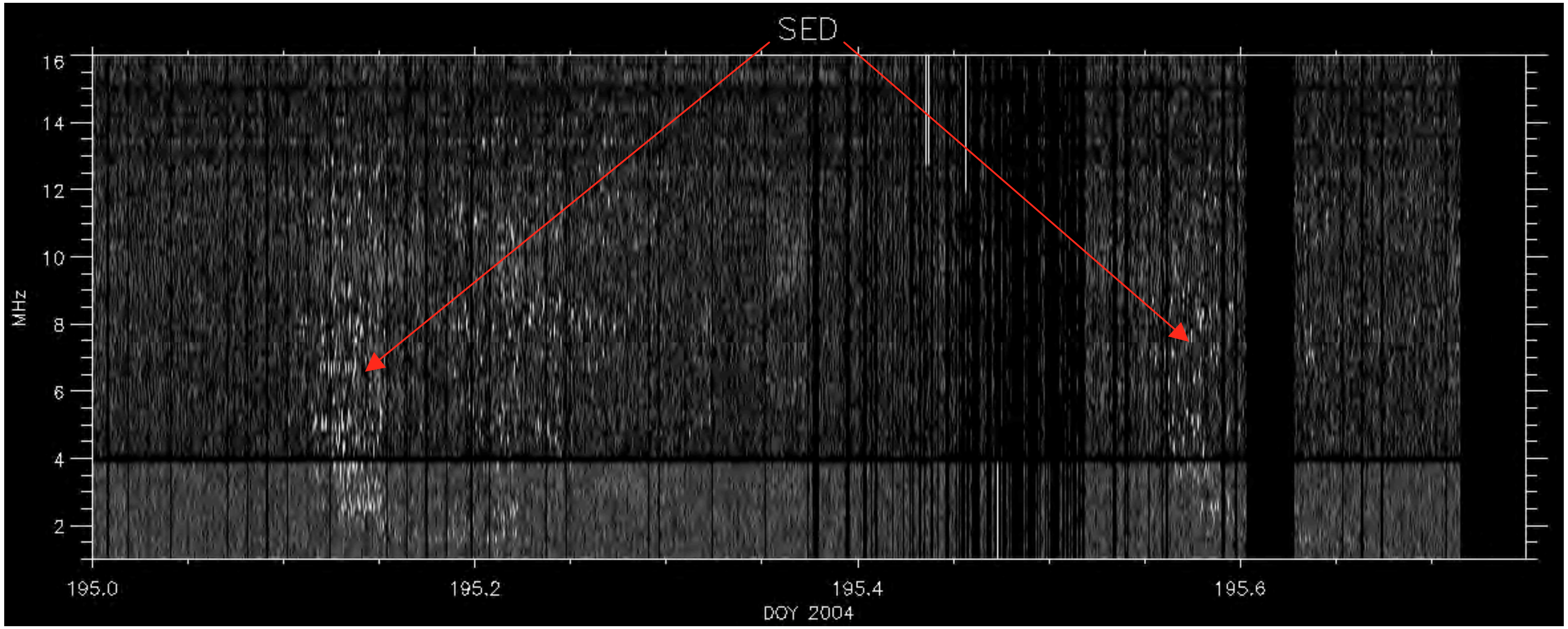


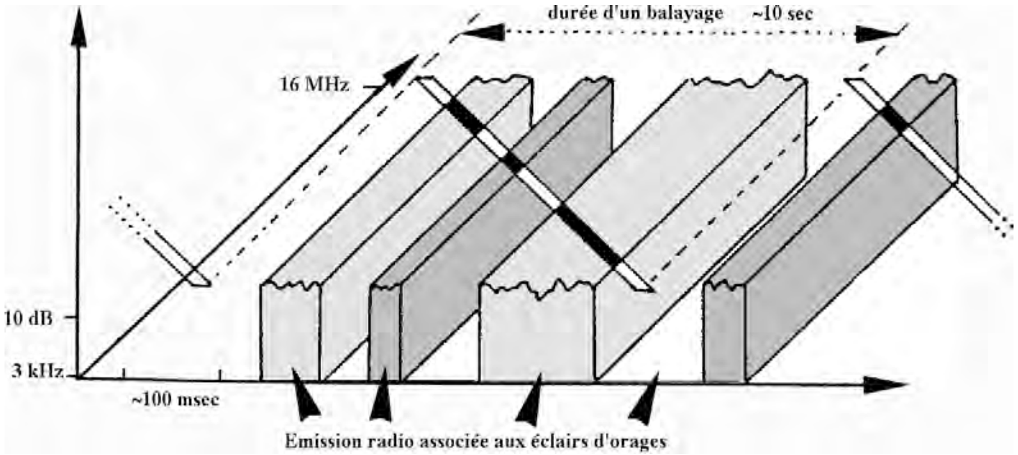
• Detectability from the ground *[Zarka et al., P&SS, 2004]*



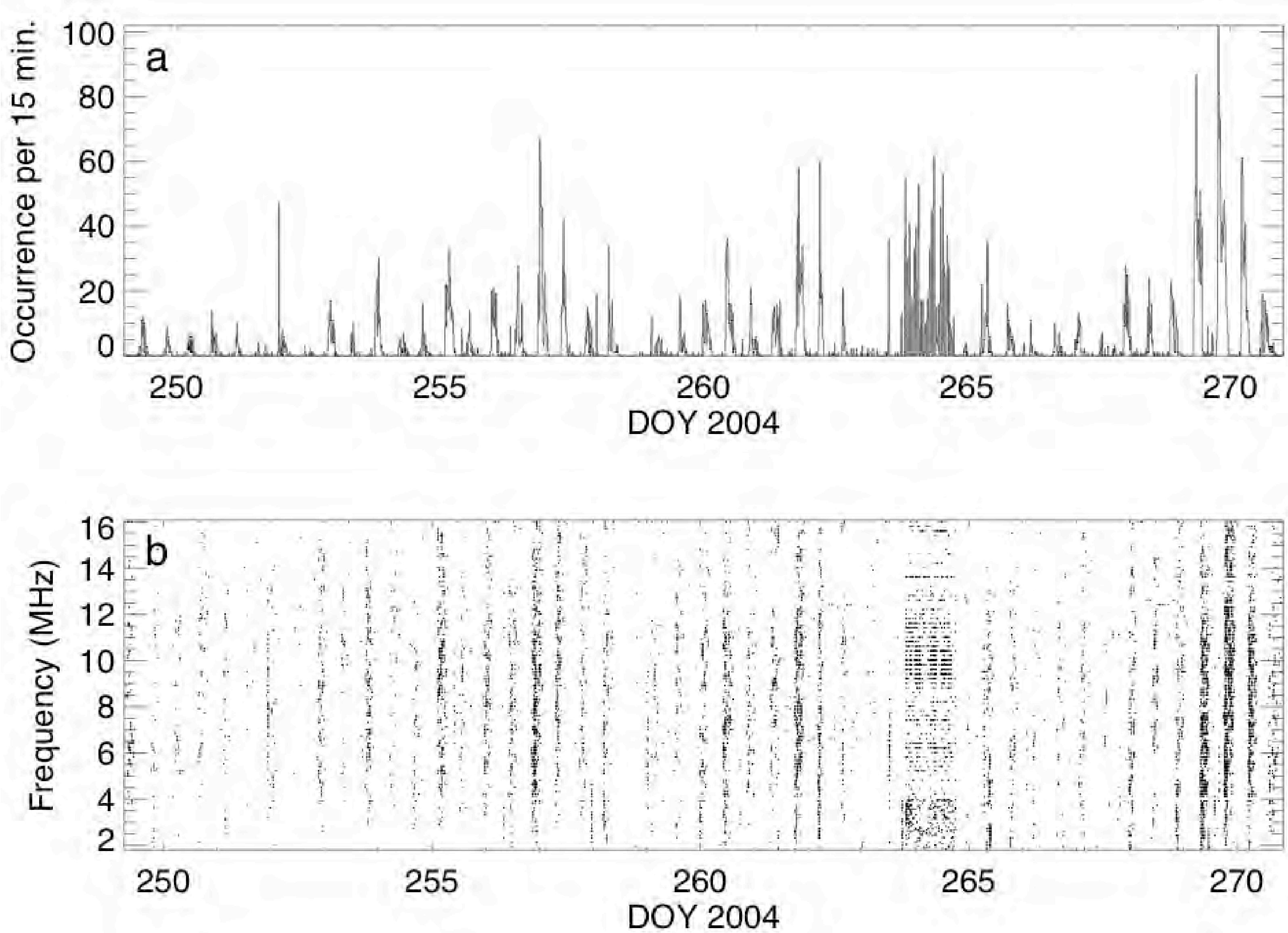
• Cassini observations of SED 10/2004

[Zarka et al., PRE VI 2006; Fischer et al., Icarus 2006]





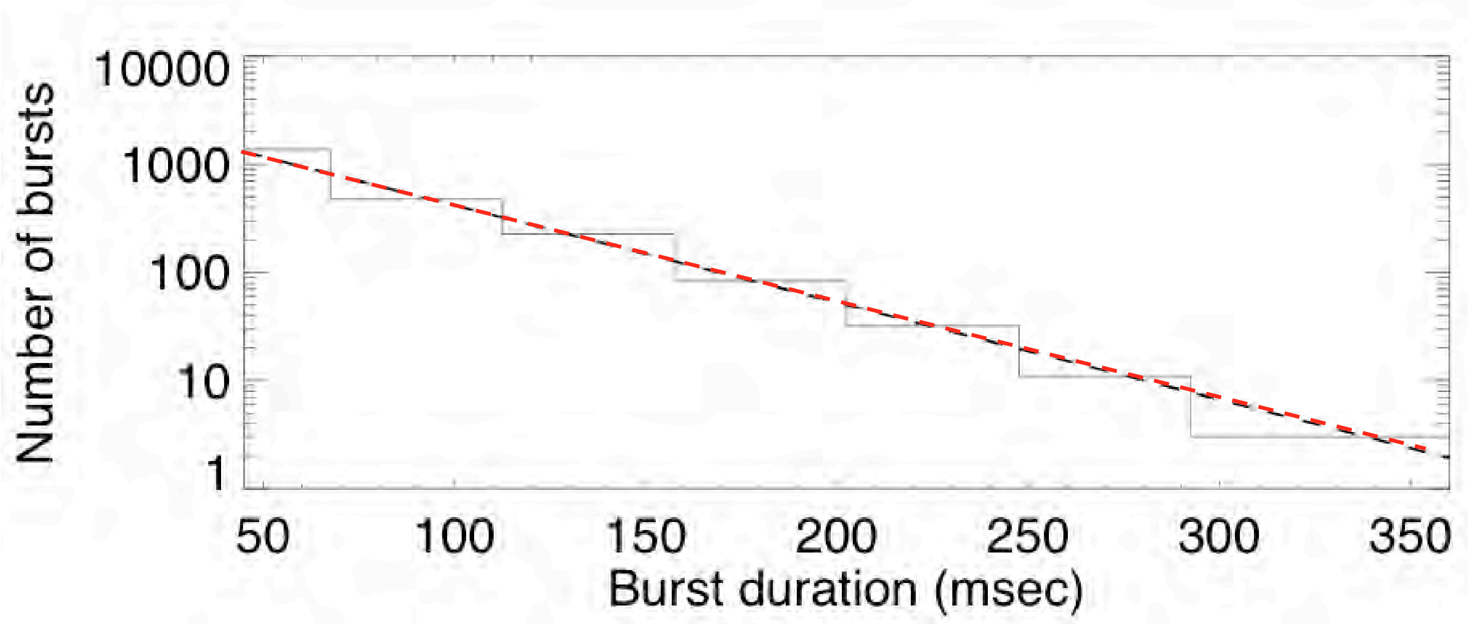
Occurrence



→ P=10.67 hr

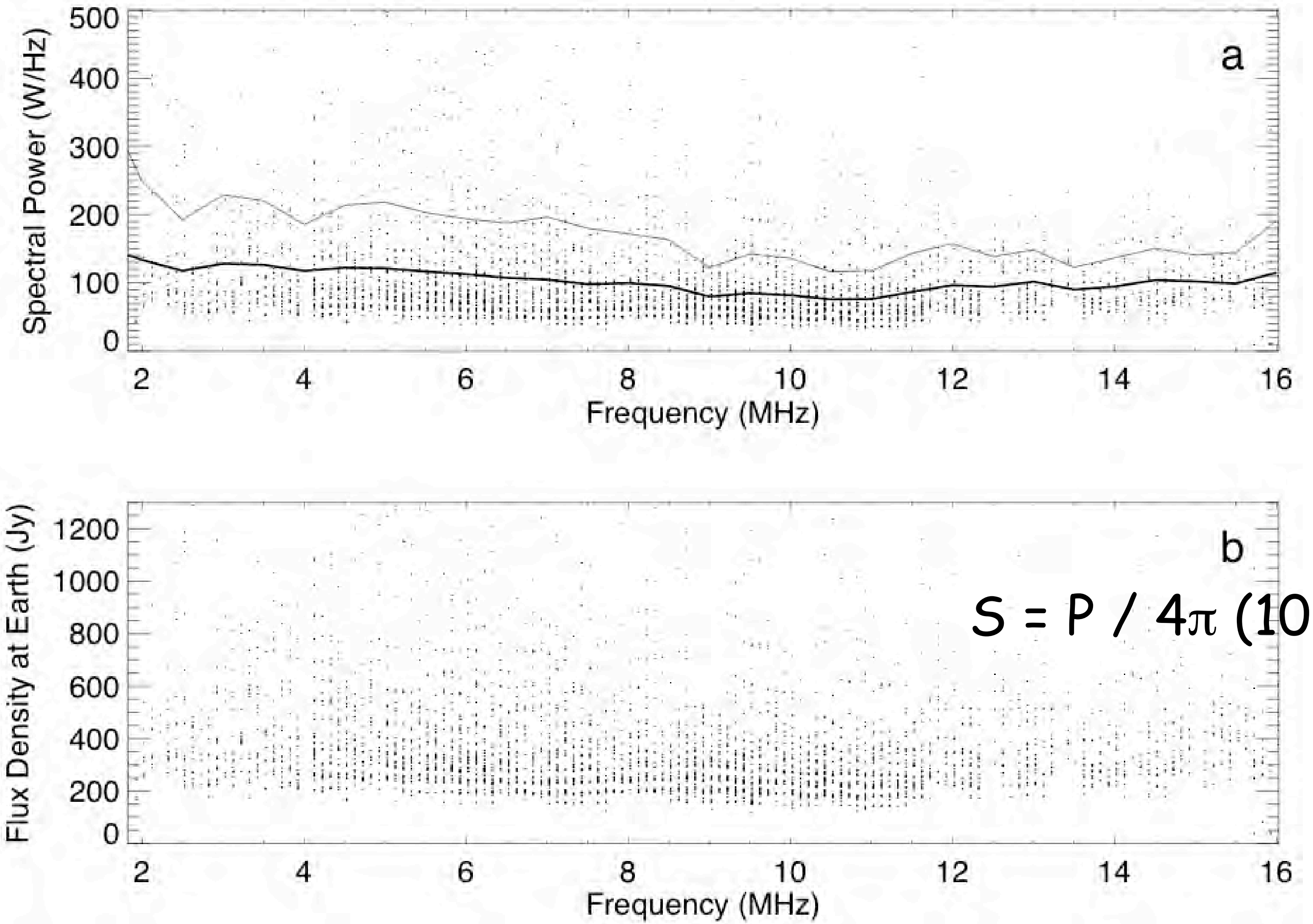
Duration

RPWS integration time above 1.8 MHz for
DOY 249 to 271 = 40 msec (80 on DOY 264)



→ E-folding time 48 msec (~40 msec for Voyager)

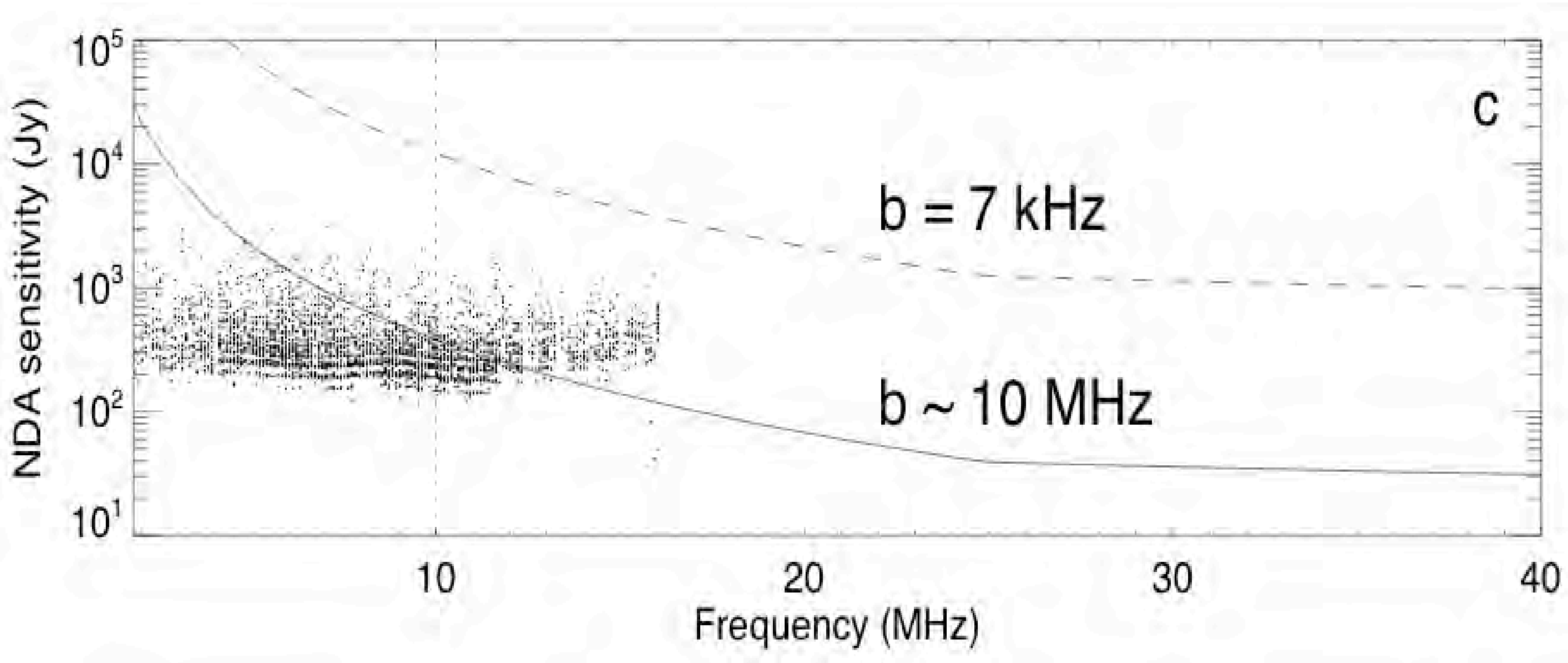
Flux density at Earth



$$S = P / 4\pi\,(10\ AU)^2$$

Detectability with Nançay Decameter Array + digital receiver

τ=19 msec

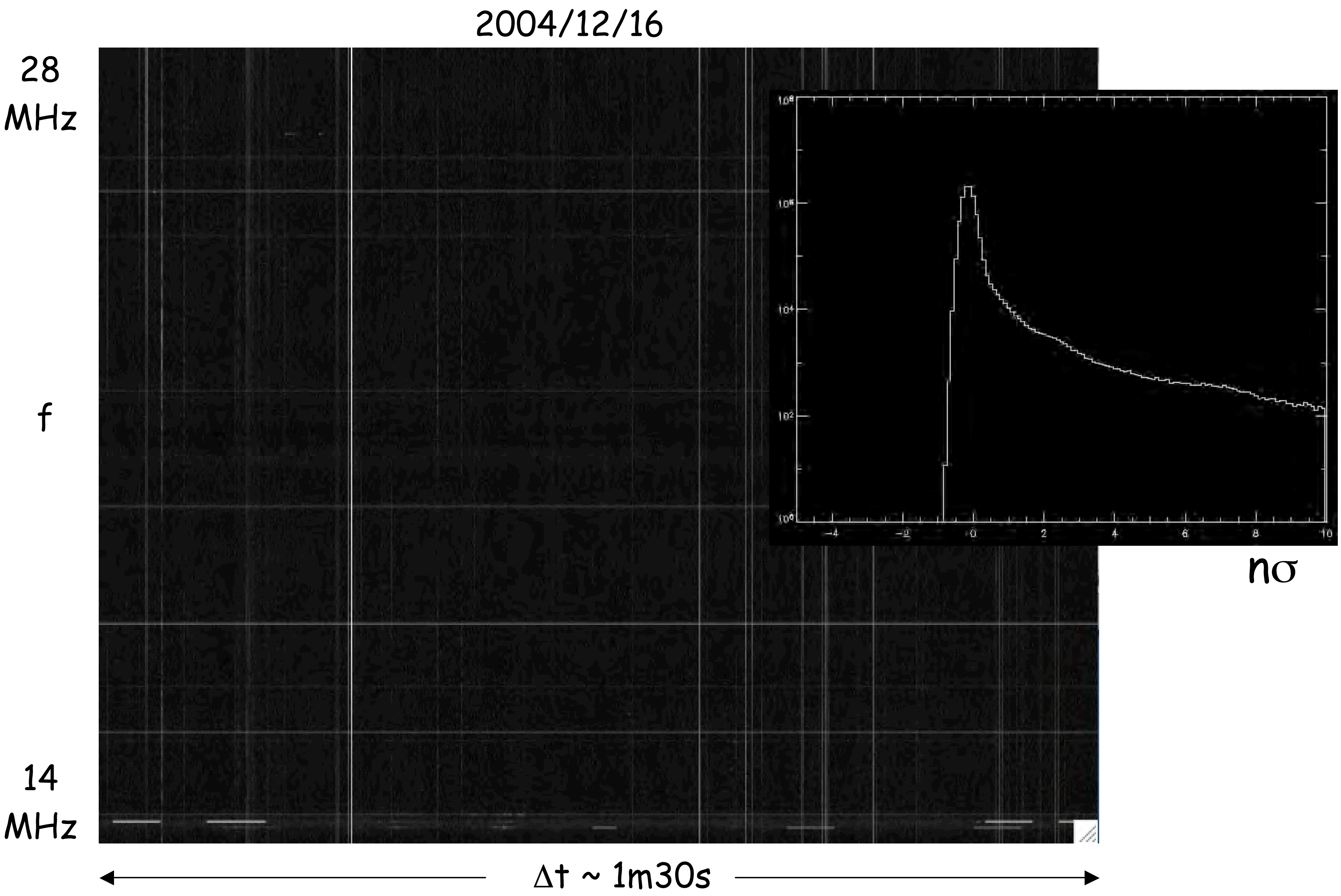


$\sigma_{sky} = 2kT_{sky} / A(b\tau)^{1/2}$ with $A = 48\ \lambda^2 \leq 7000\ m^2$

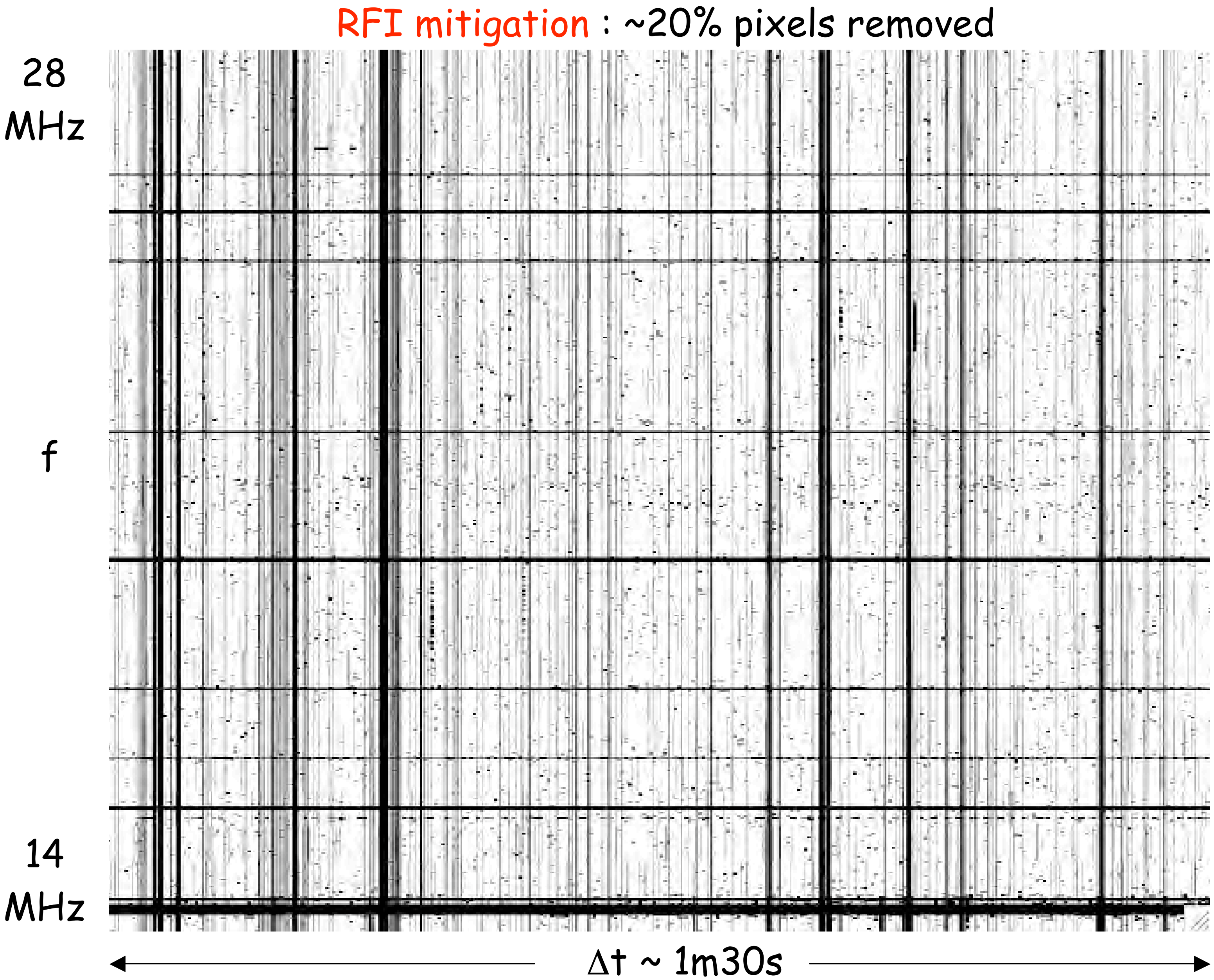
and $T_{sky} = 1.15e8/\ f^{2.5}$ (f in MHz)

• Tentative detection at NDA

[Zarka et al., PRE-VI, 2005]



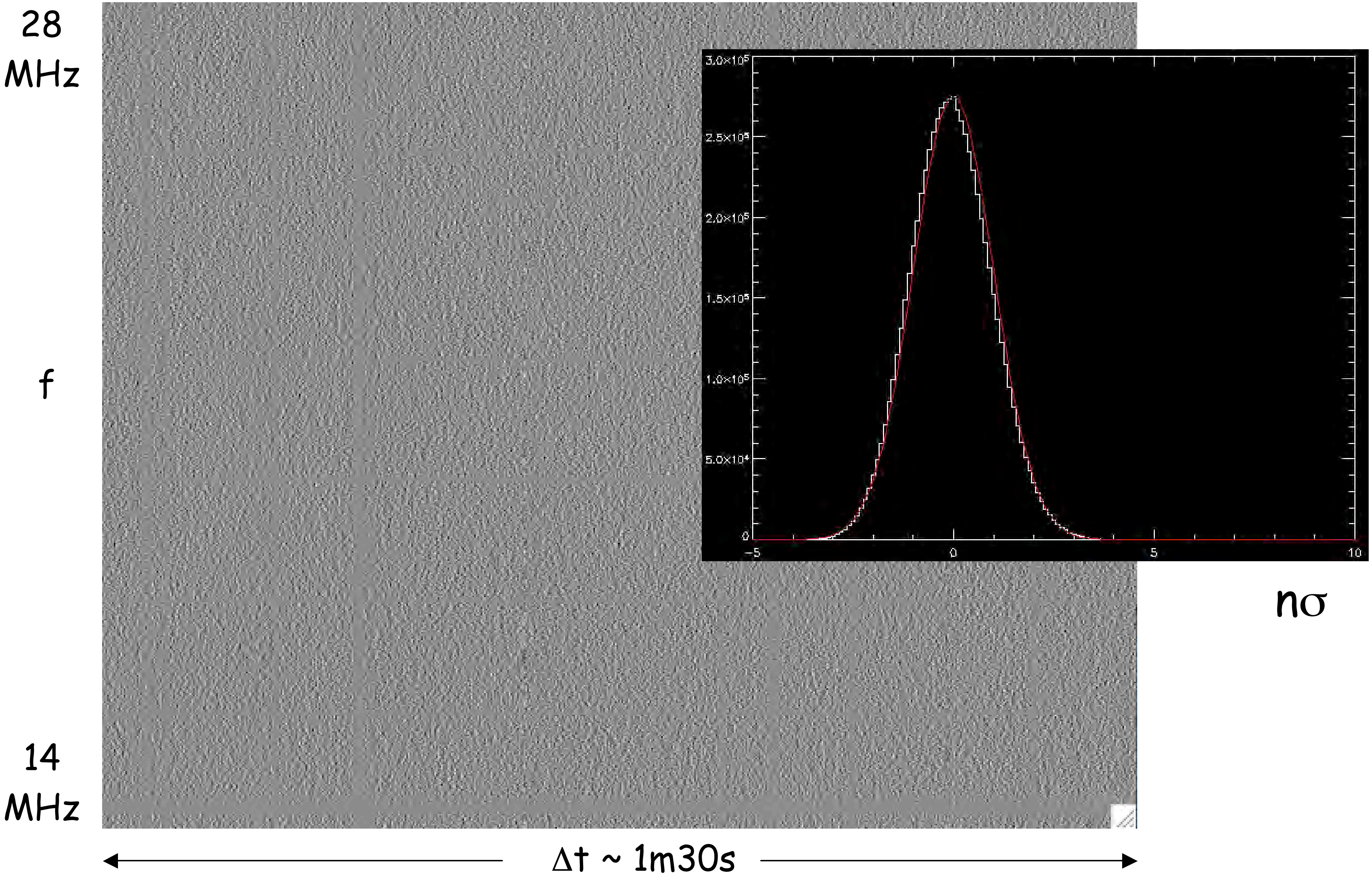
- Tentative detection at NDA *[Zarka et al., PRE-VI, 2005]*



• Tentative detection at NDA

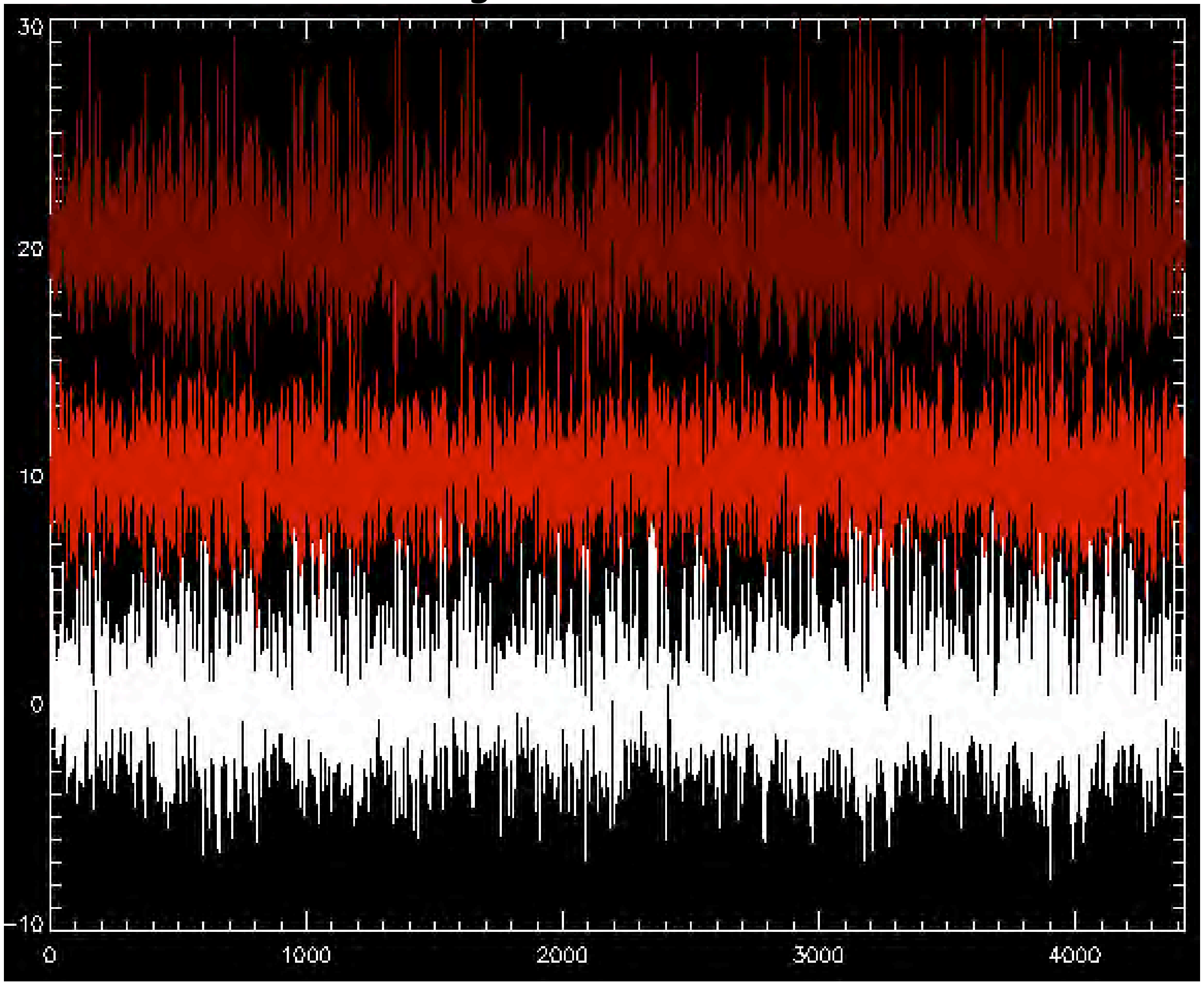
[Zarka et al., PRE-VI, 2005]

+ HiPass filtering



- Tentative detection at NDA *[Zarka et al., PRE-VI, 2005]*

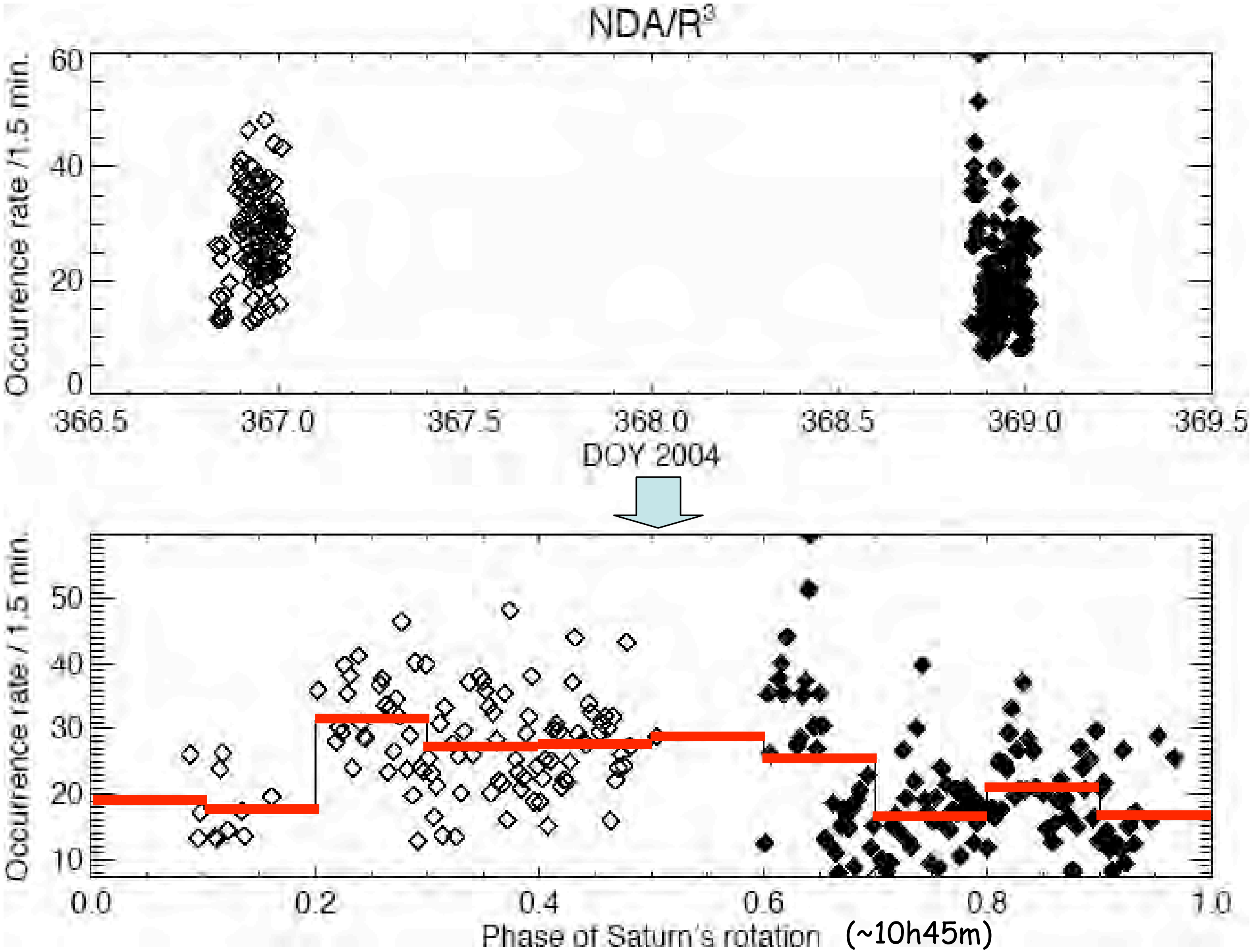
→ integrated time series



Δt ~ 1m30s

• Tentative detection at NDA

[Zarka et al., PRE-VI, 2005]



- Objectives of LF radio observations of planetary lightning

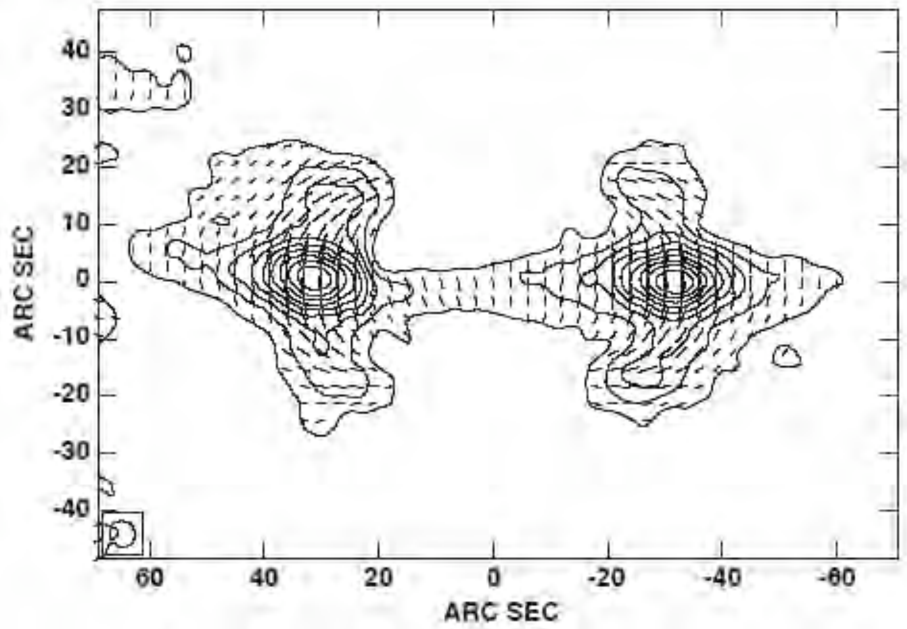
[Zarka et al., P&SS, 2004]

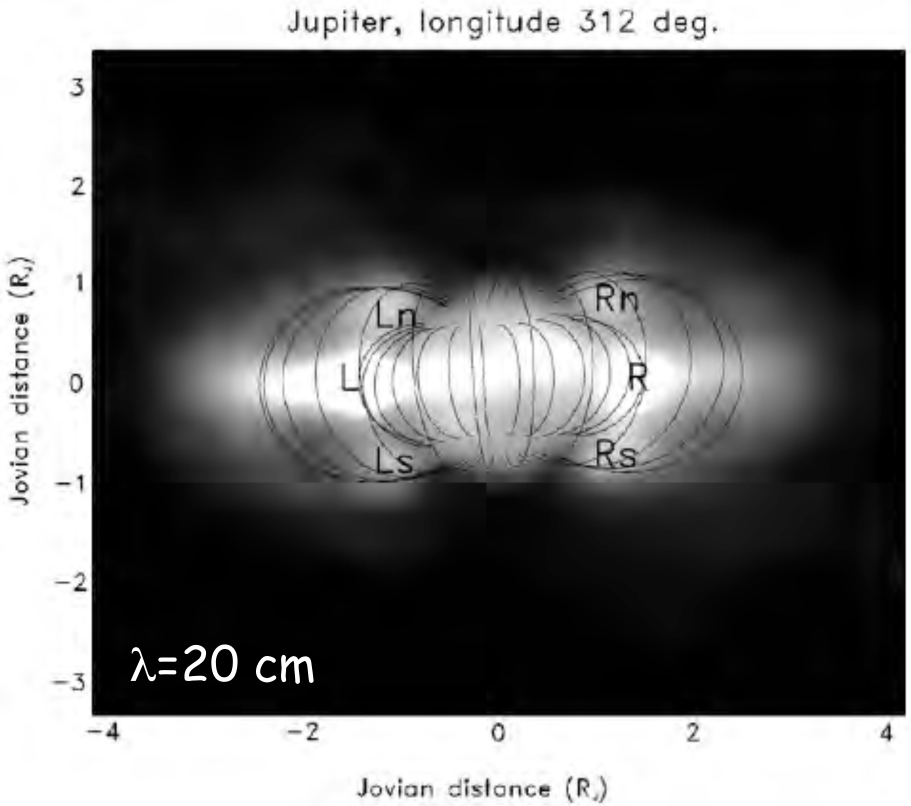
- existence of lightning, discharges (dust devils)
- electrification processes
- atmospheric dynamics and composition
- geographical and seasonal variations
- correlation with optical surveys
- comparison to Earth processes

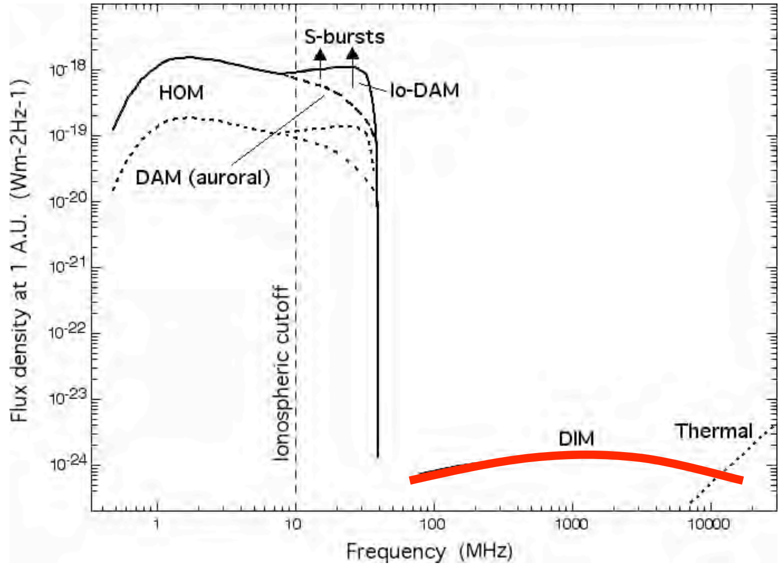
- **Solar system planetary lightning**
- **Radiation belts**
- **High latitude (auroral) magnetospheric emissions**

- First information on Jupiter's B field and Mev e-
  [de Pater, P&SS, 2004]

⊥ to linear polarization at λ=2 cm





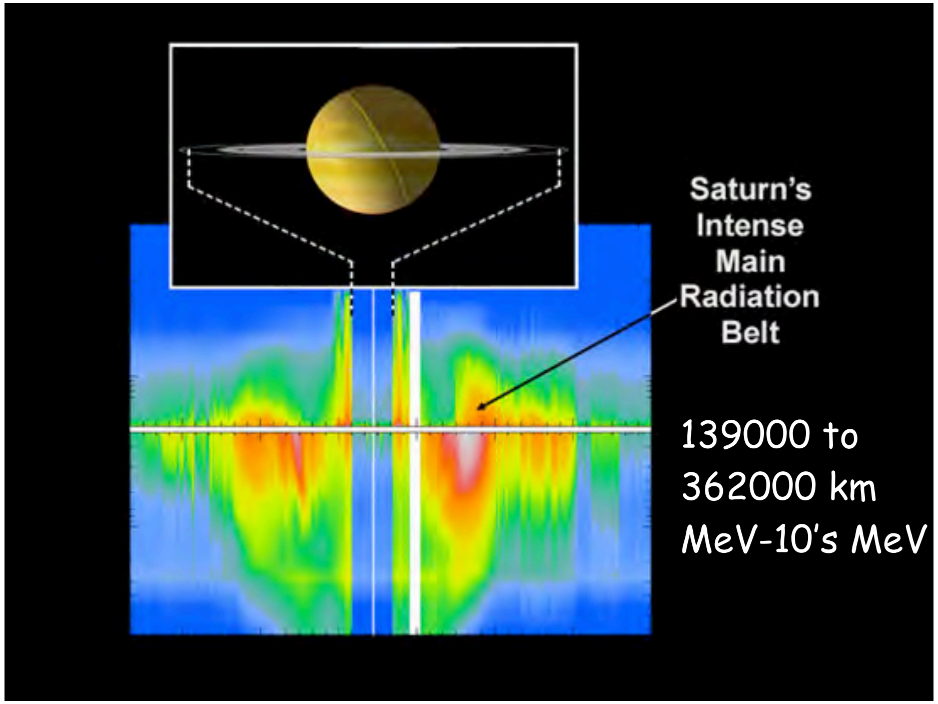


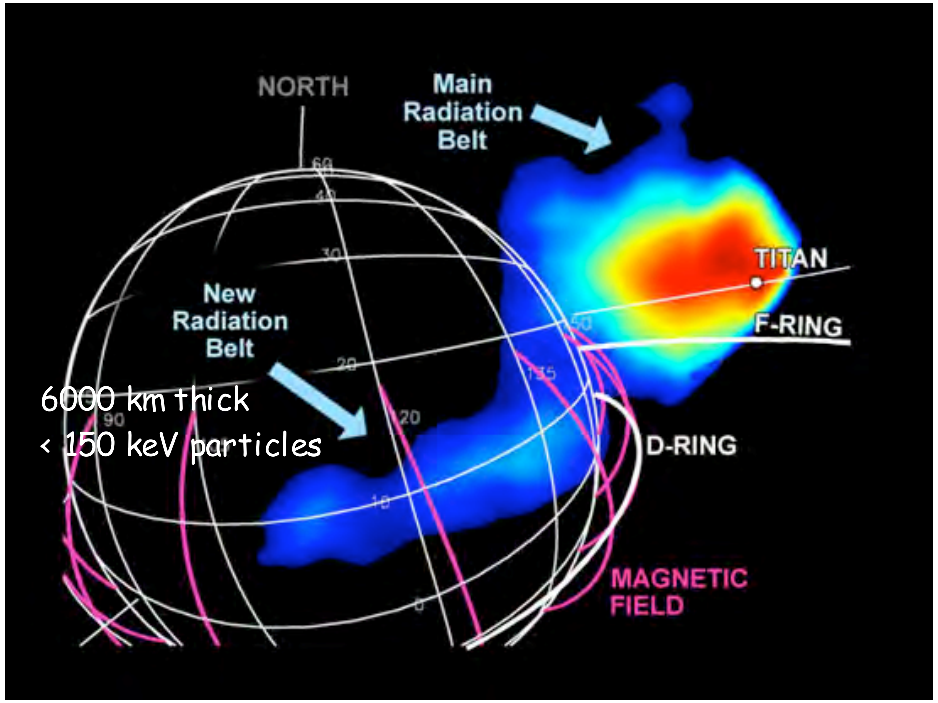
- No synchrotron emission from …

  - Earth ⇐ Strong losses via w-p interactions ?

    [Thorne, ICPP, 2002]

  - Saturn ⇐ absorption by the rings

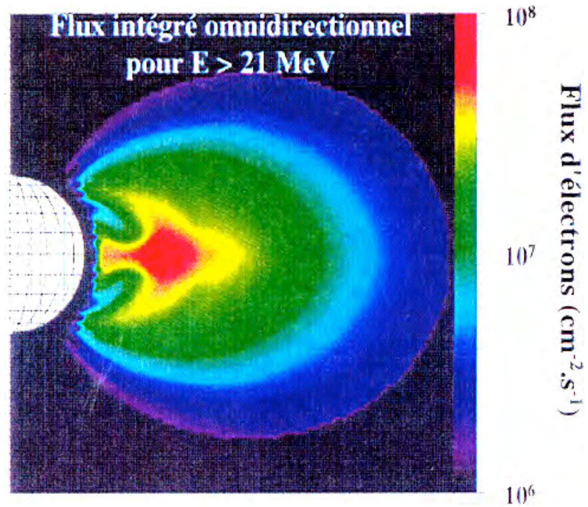




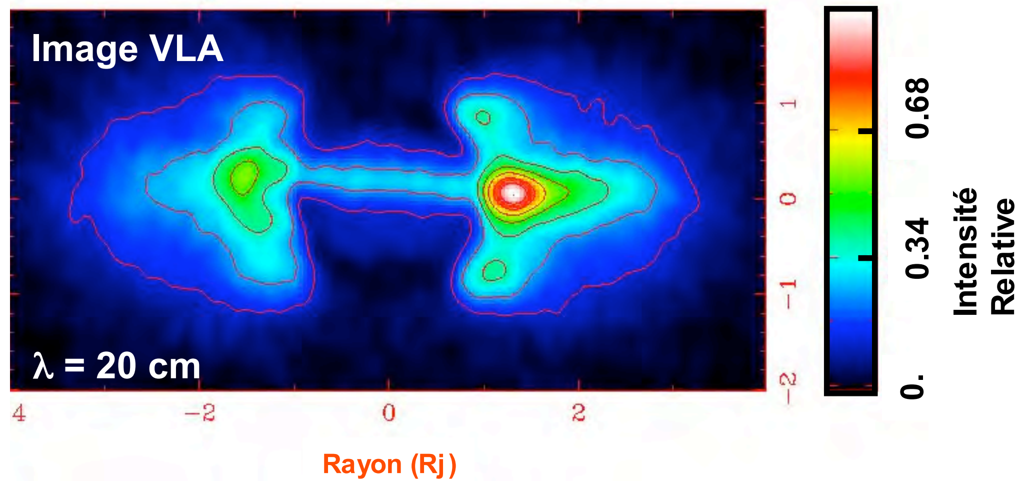
  - Uranus & Neptune N ⇐ Magnetic dipole tilt

- Jovian radiation belt e- & synchrotron modelling

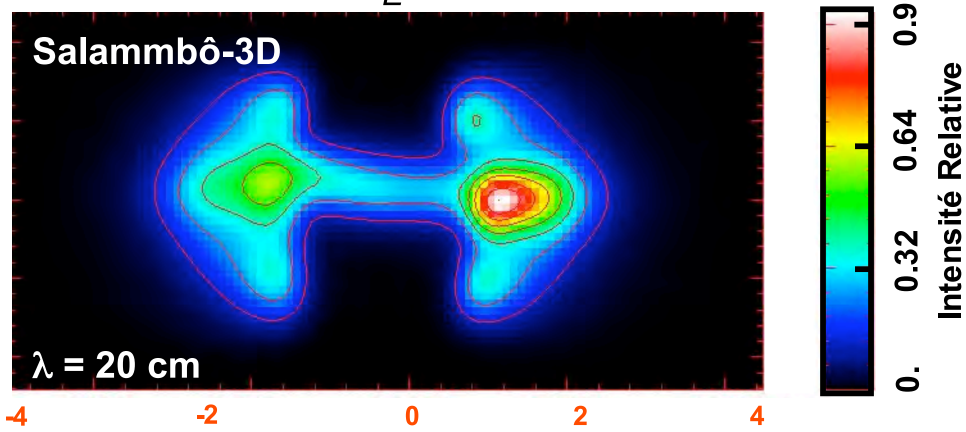
  [Santos-Costa & Bourdarie, P&SS, 2001]



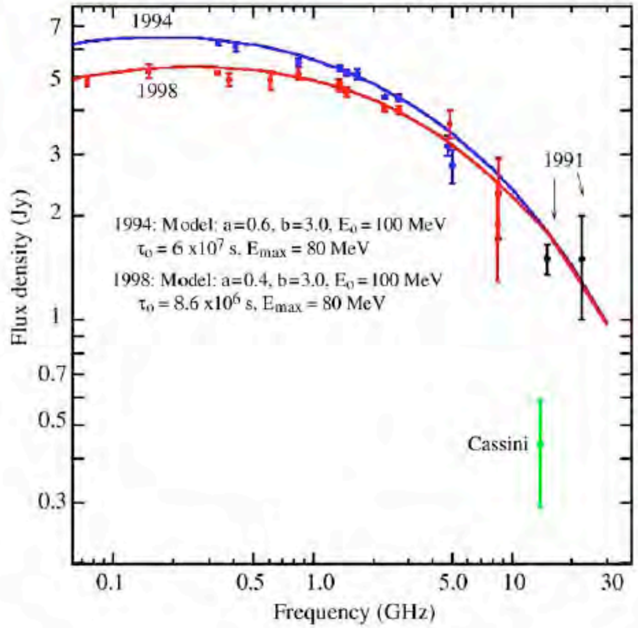
Observations $D_E = 0^0$, $CML = 20^0$



Simulations $D_E = 0^0$, $CML = 20^0$



- Objectives of LF radio observations of synchrotron em. from radiation belts *[de Pater, P&SS, 2004]*



  - high spatial resolution imaging ≤300 MHz (« low » energy e-) over a large relative bandwidth

  - variation with time and solar wind parameters

  - origin and transport of energetic e- in Jupiter's inner radiation belts : pitch-angle scattering by PW, coulomb scattering, interaction with dust ?

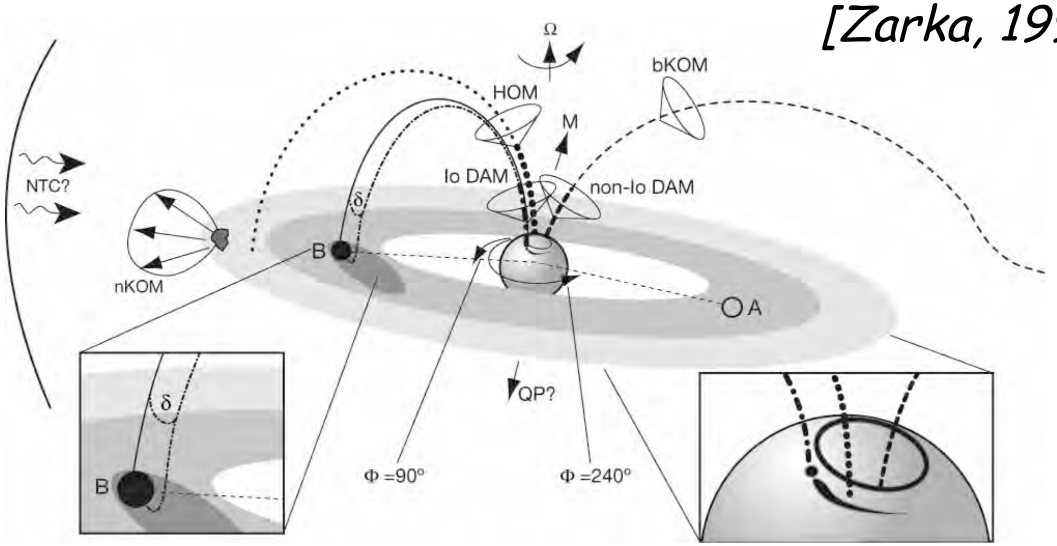
- Solar system planetary lightning

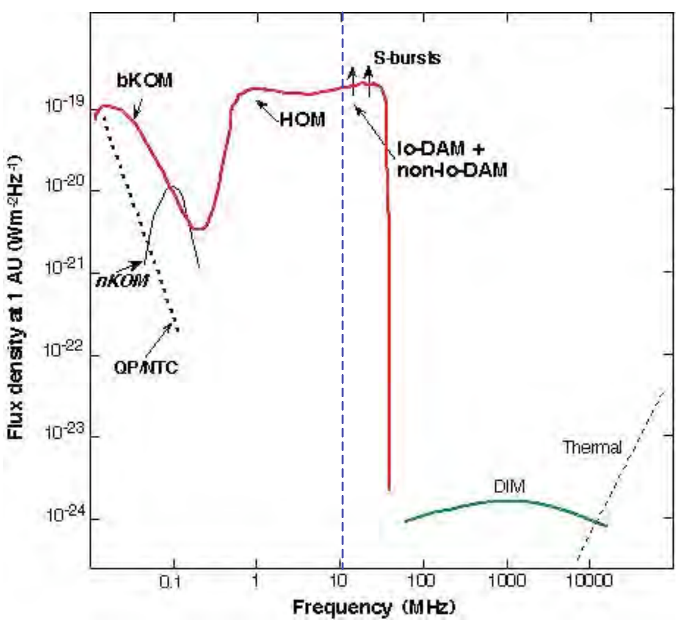
- Radiation belts

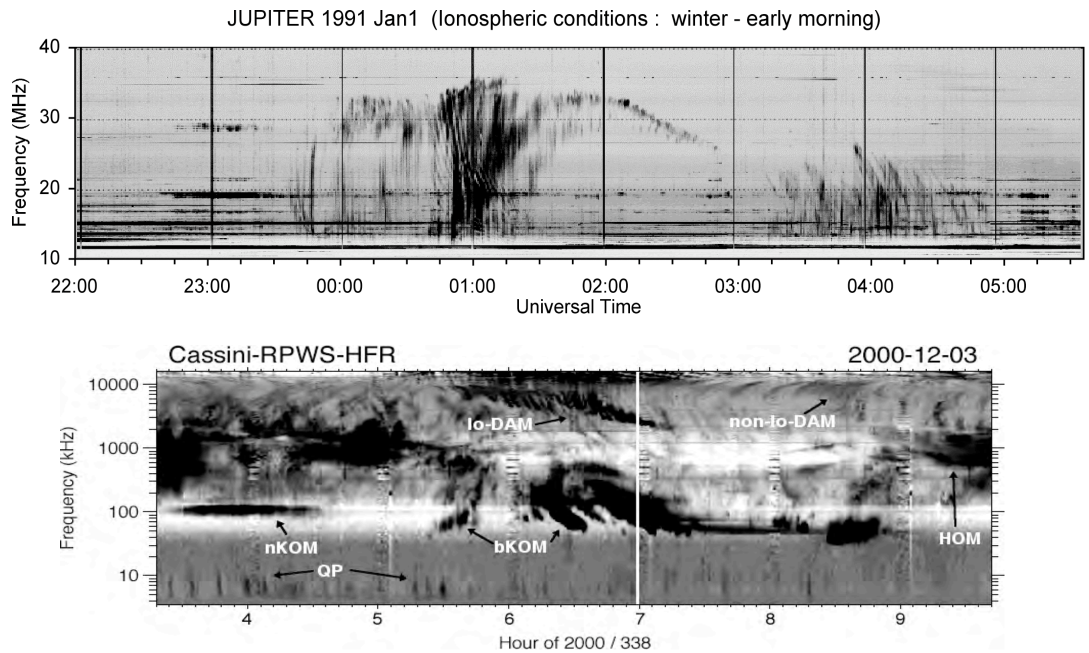
- High latitude (auroral) magnetospheric emissions

• Jovian radiosources (dynamic) spectra, location & beaming

[Zarka, 1998 ; Zarka et al., 2004]

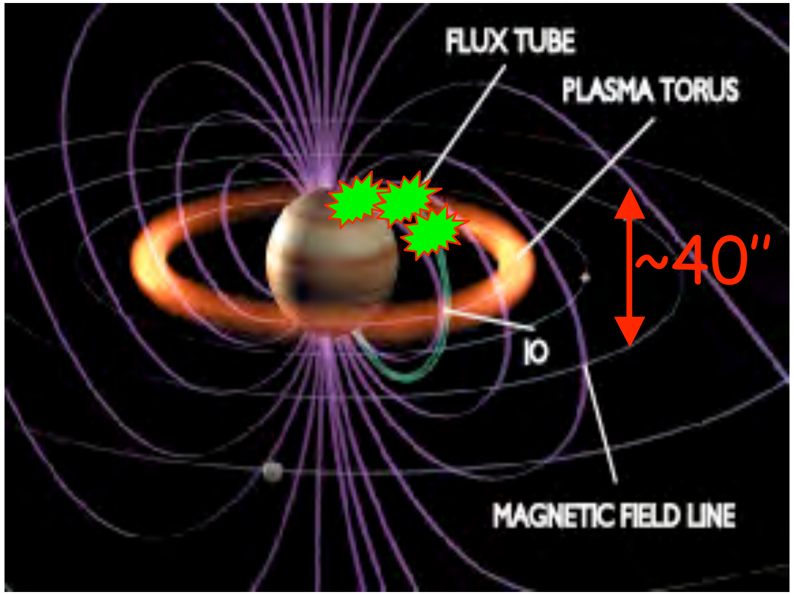


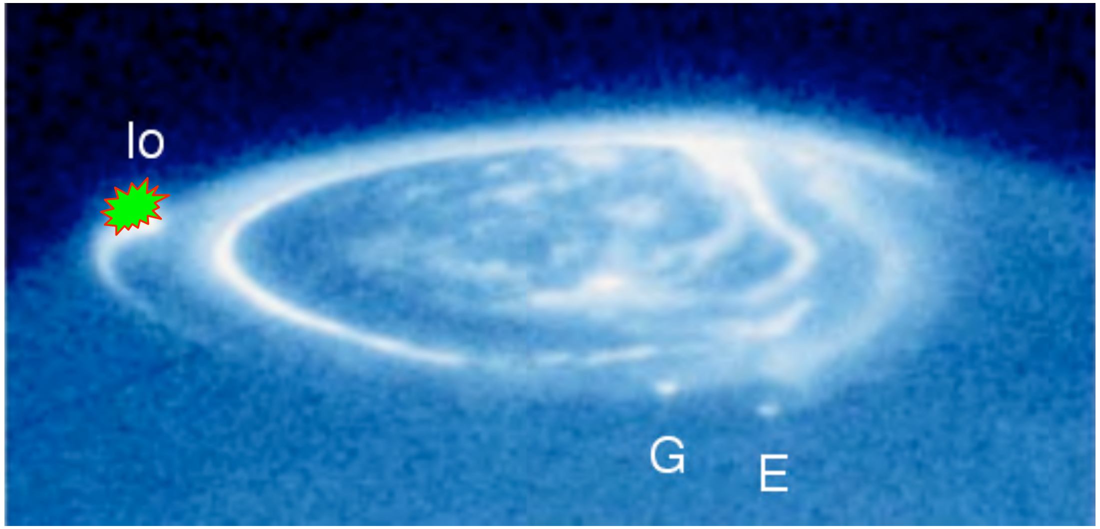


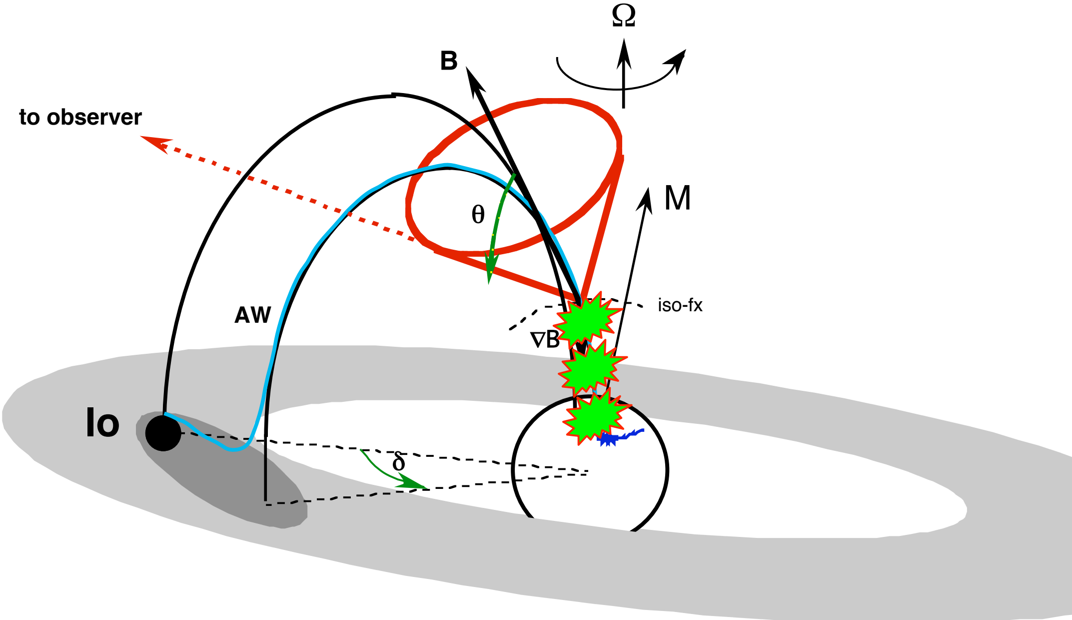


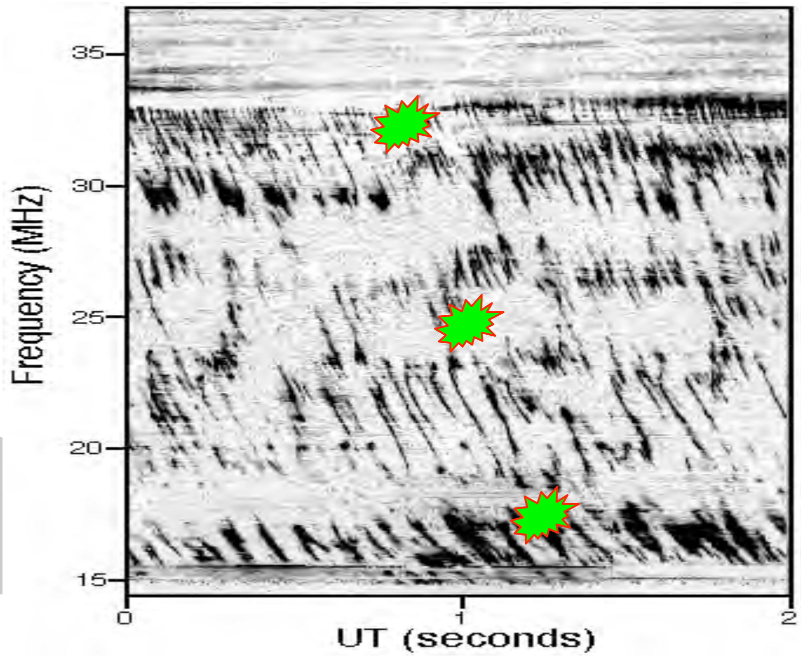
• Io-Jupiter electrodynamic interaction and radio bursts

[Queinnec & Zarka, 1998 ; Saur et al., 2004]







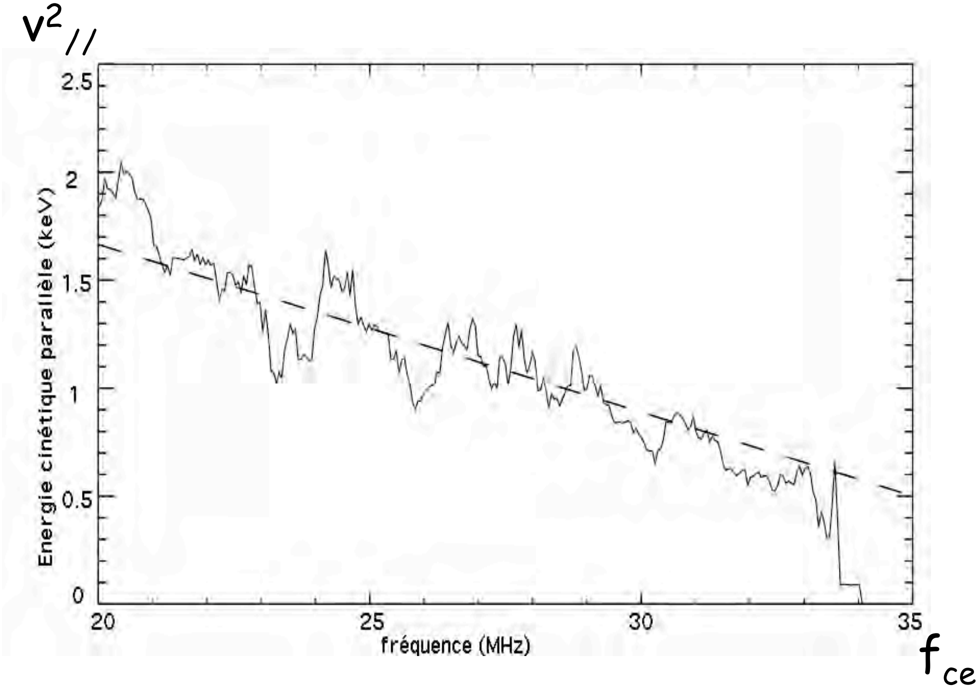


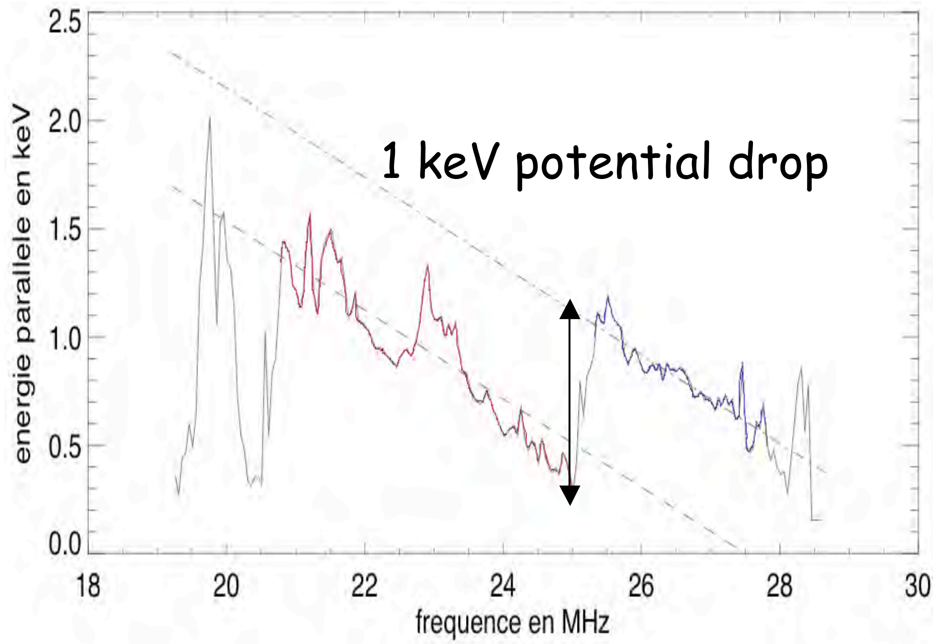
⇒ statistical studies of field-aligned potential drops

[Hess et al., in preparation]

$df/dt = (df/ds)\ (ds/dt) = -K(\theta,\lambda)\ f_{ce}\, v_{//}$

$v^2_{//} = v^2 - v^2_{\perp} = v^2 - \mu . f_{ce}$





⇒ direct imaging ?

- Objectives of fast imaging of LF magnetospheric emissions
  (down to 1 msec) *[Zarka, P&SS, 2004]*

  - surface magnetic field mapping
  - lead angle (physics) of Io(E,G)-Jupiter interaction
  - radio beaming angle → physics of generation process
  - electron bunches & electric fields along Io flux tube
  - torus ∫Ne vs longitude via Faraday rotation
  - « modulation lanes » due to diffraction by torus ?
  - multi-wavelength correlations (Radio, UV, IR, X)

⇒ extended LOFAR with 1-2" resolution at 40 MHz

- **Solar system planetary lightning**

- **Radiation belts**

- **High latitude (auroral) magnetospheric emissions**

VLBI observations ITS/NDA

- Influence of ionosphere :
  - Faraday rotation
  - Phase shifts and variations
  - Frequency dispersion and refraction

$\Rightarrow$ restricted time of

- coherent storage
- frequency band
- self-cal capabilities.

• Previous LF VLBI observations :

- Jupiter @ 34 MHz with 4300 km baseline (USA)

[Dulk, Astrophys. J. 159, 671, 1970]

- Crab Nebula, 3C234 radiogalaxy … @ 20 & 25 MHz with 900 km baseline (URAN)

→ influence of solar elongation (IPS), baseline, hour angle

[Megn et al., Radio Phys. and Radio Astron., 2, 385 (in Russian), 1997 ;

Lecacheux et al., Planet. Space Sci., 52,1357, 2004]

+ European (INTAS) program Fr/Aus/Ukr

- Question : what % at what frequency ?

• VLBI observations of Jupiter bursts

ITS (H. Falcke, A. Nigl, L. Bahren, et al.) + NDA (P. Zarka, L. Denis, et al.)

@ 10-40 MHz, ~900 km baseline,

⇒ Remote control of ITS

⇒ GPS / crystal clock synchro → V(f,t,...)

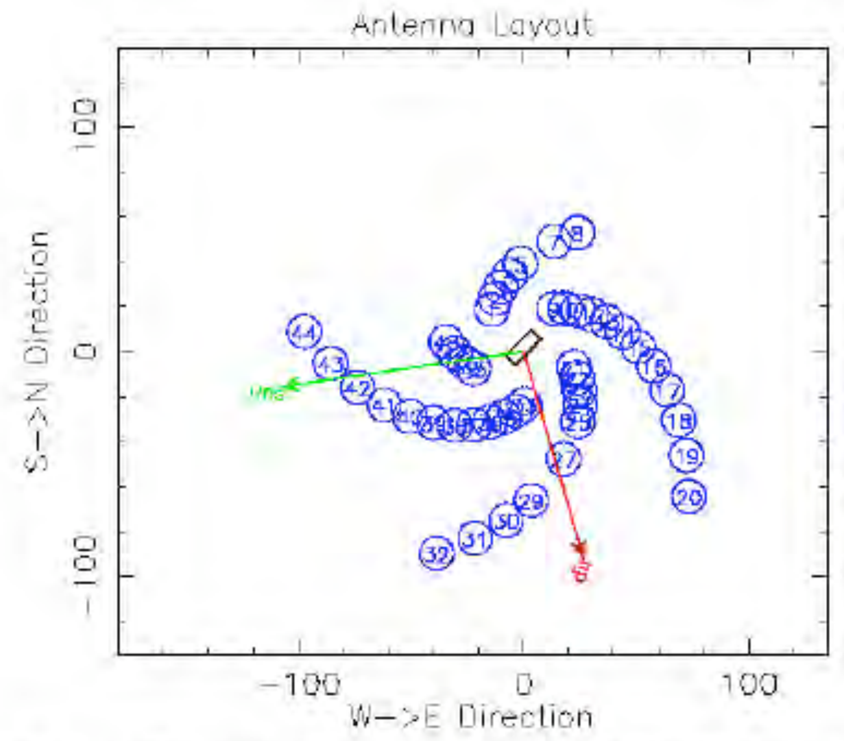
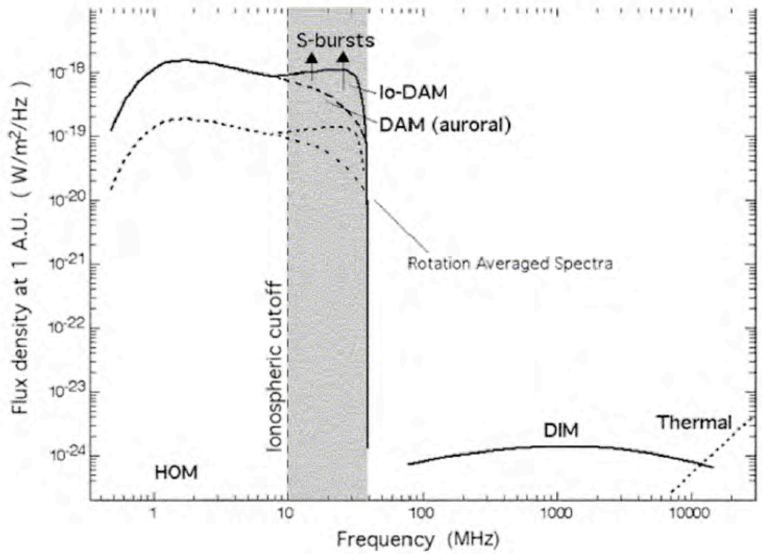


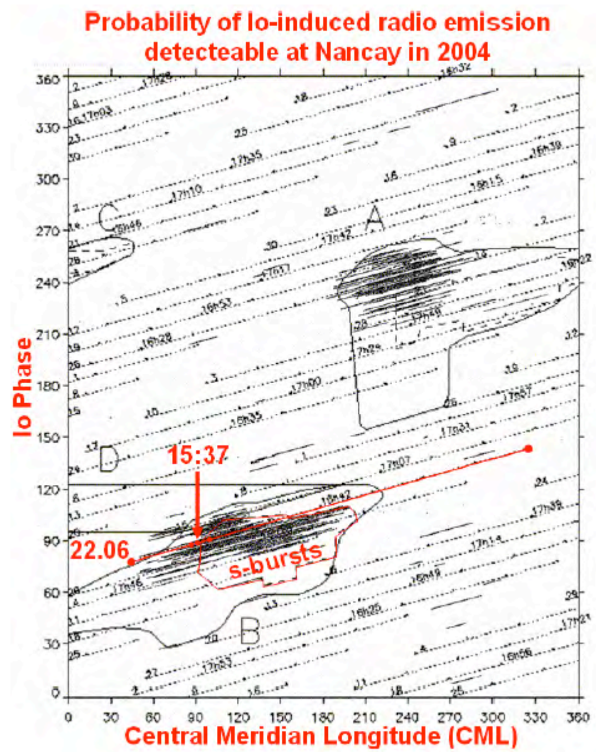
Fig. 3. The picture shows the layout of LOFAR's Initial Test Station (LOFAR/ITS).

Fig. 4. The picture shows the Nançay Decametric Array (NDA) south of Paris.

- Jupiter bursts :
  $>10^{5\text{-}6}$ Jy, point source,
  but … bursty !

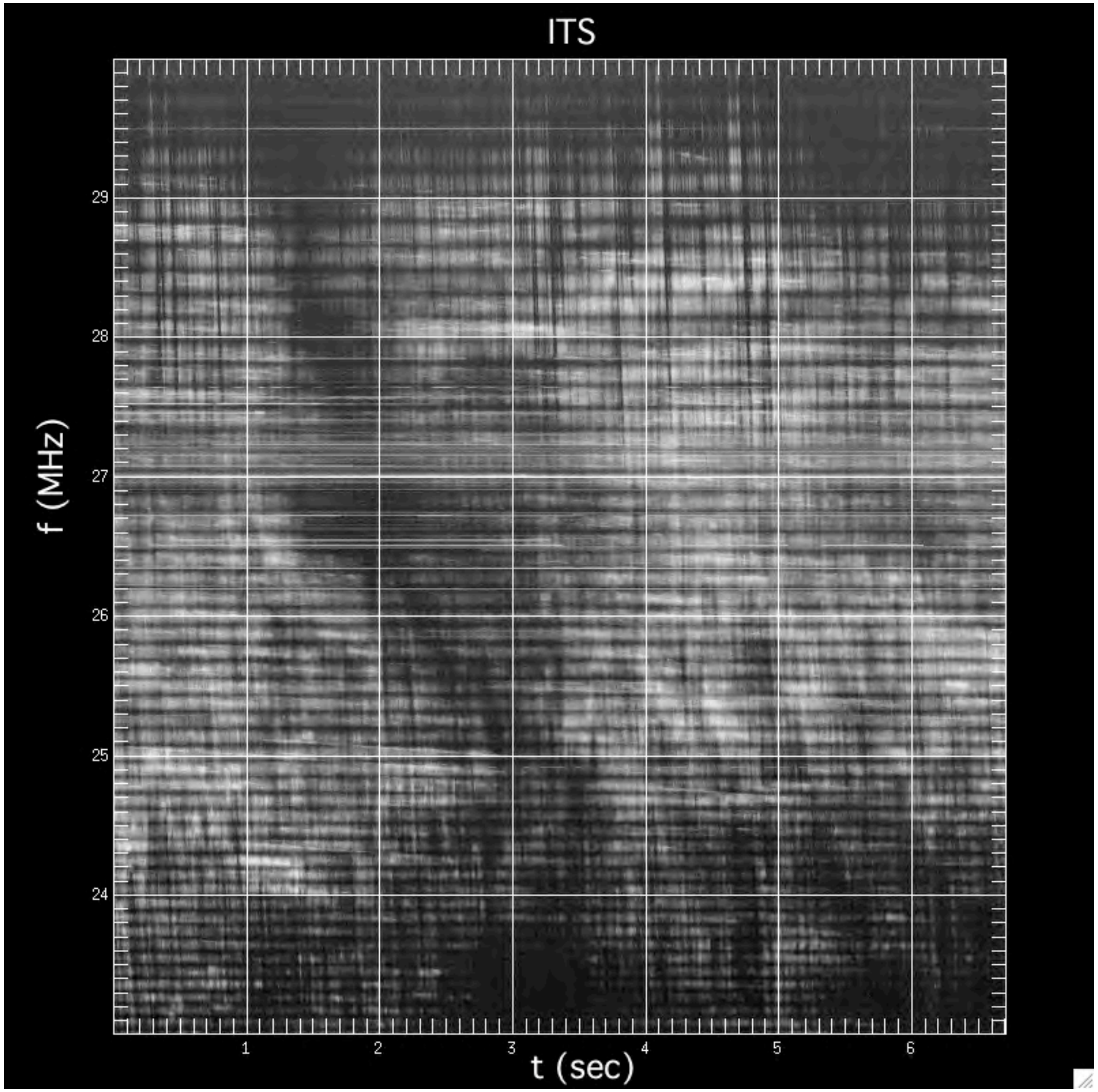


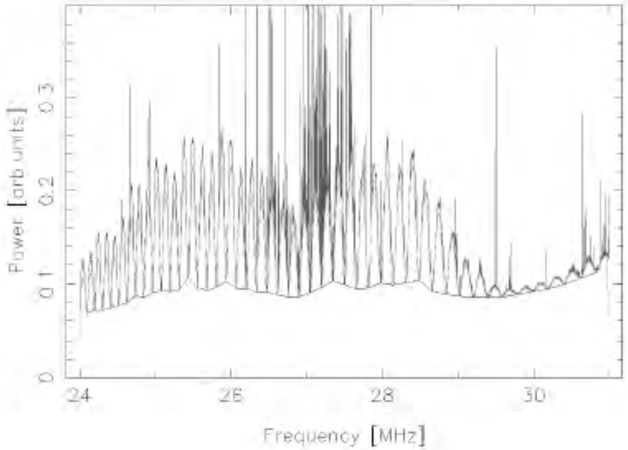
- Prediction of occurrence

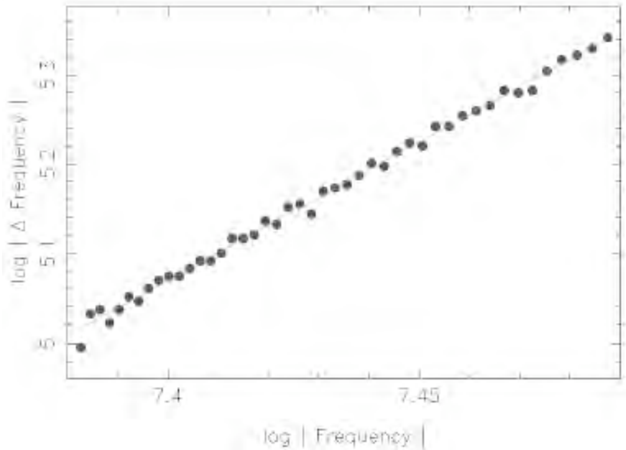


- 6.7 sec waveform @ ITS,
  continuous @ NDA

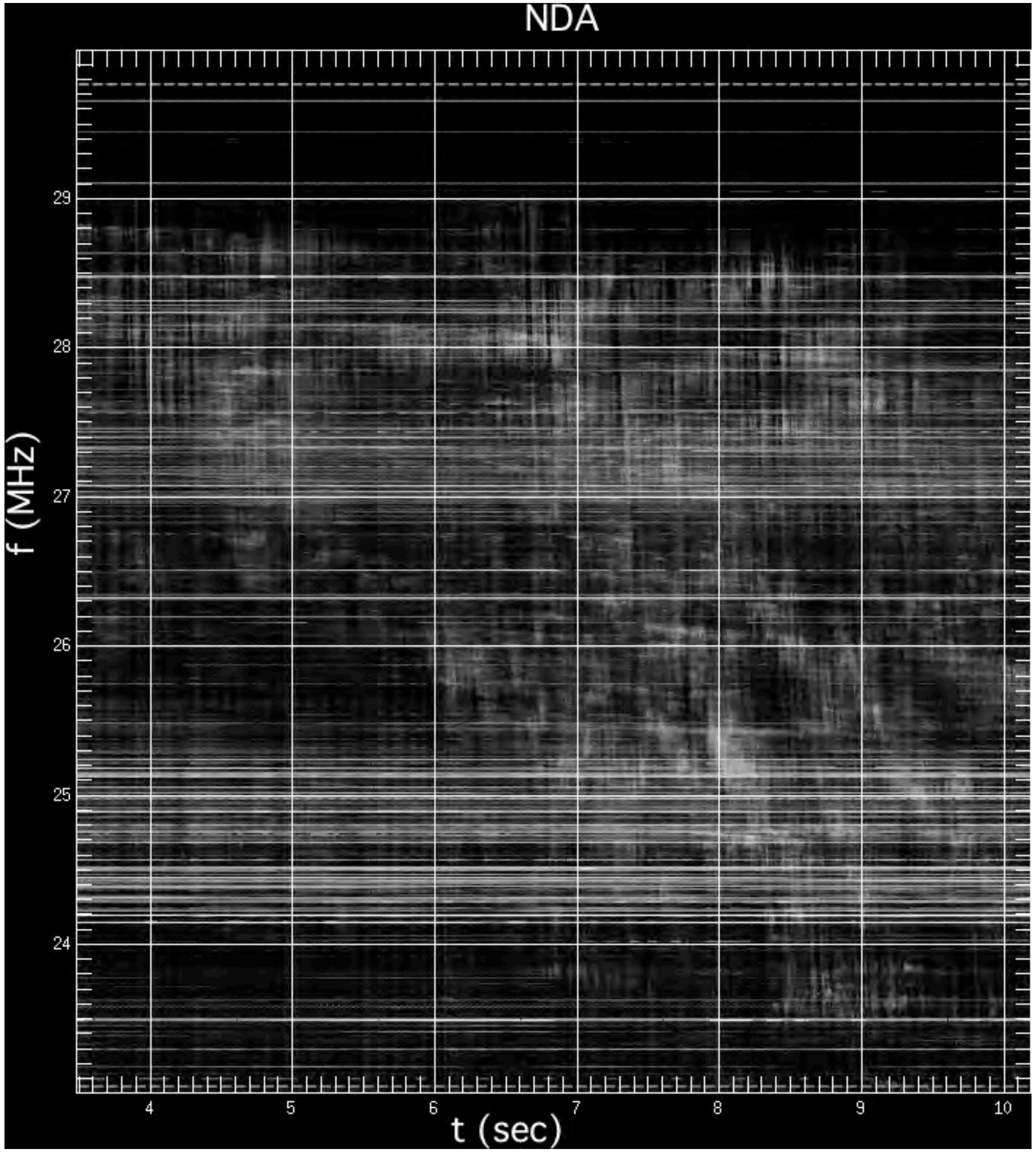
• Observations 2004 : baseband 0-40 MHz (ITS), Faraday fringes







• Observations 2004 : LO + ADC 0-20 MHz (NDA)

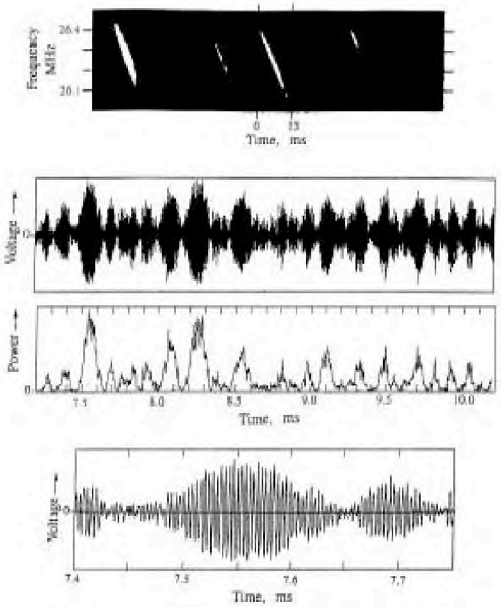


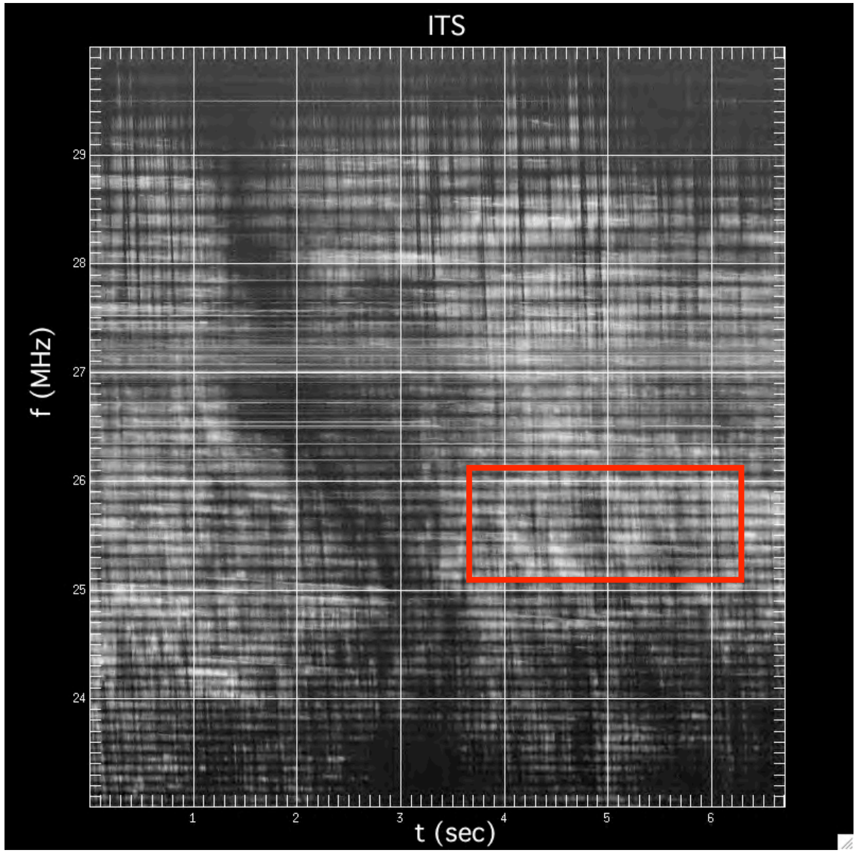
→ coherence : wave packets ~0.1 msec

[Carr & Reyes, J. Geophys. Res., 104, 25127, 1999]

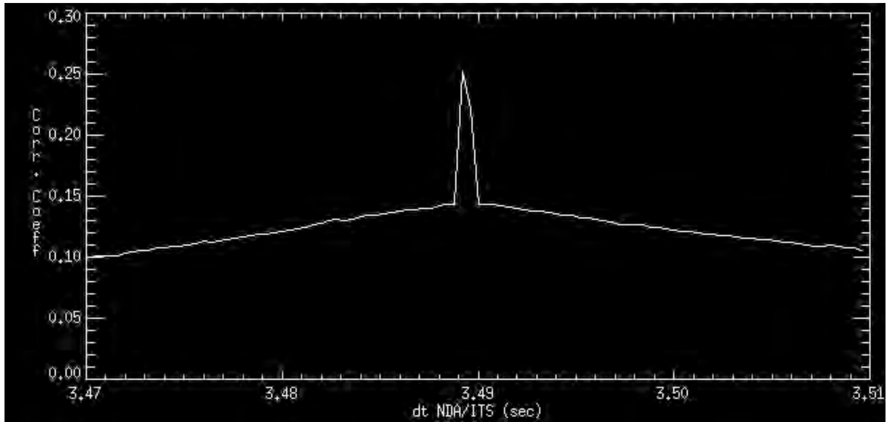
filtering 50-100 kHz

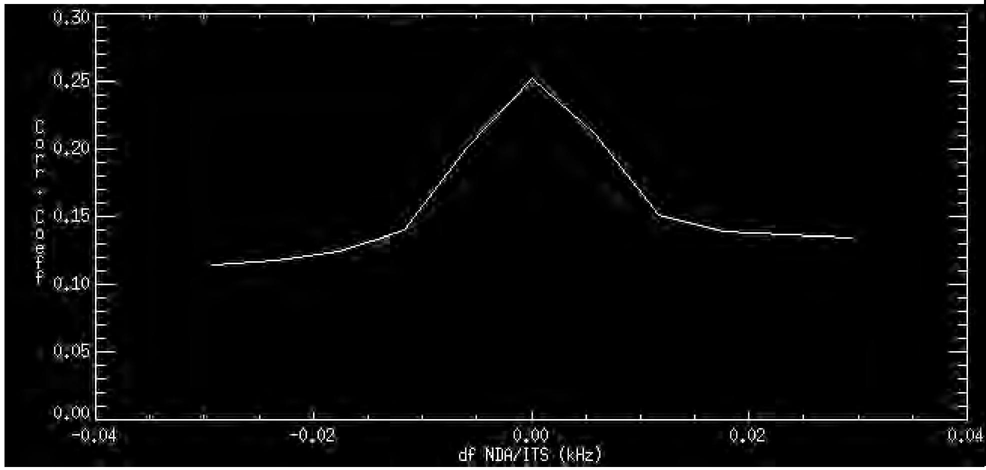
resampling before correlation

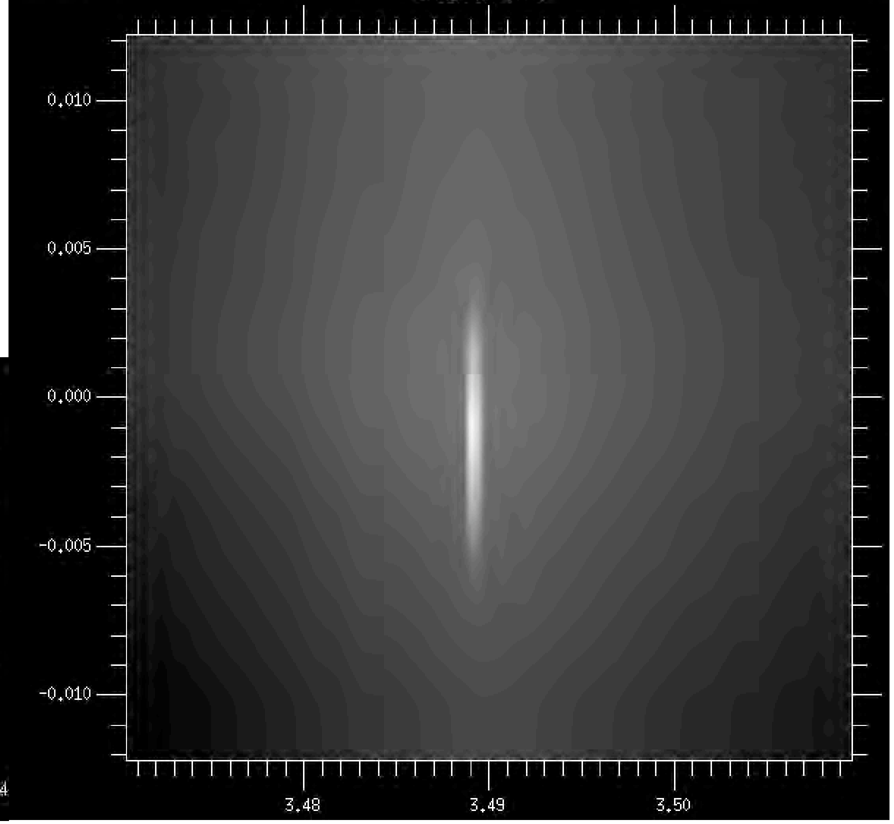




$\Rightarrow C_{max} > 0.25$ @ $dt = 3.489$ s, $df = 0$







- Observations 2005 :

PDA14 receiver at NDA (SC Obs), baseband 0-40 MHz (ITS & NDA)

→ several observation campaigns

http://www.astron.nl/~bahren/wiki/doku.php?id=research:nda-its_observations_of_jupiter

successful 30/11/2005 → ITS beamforming in progress

[A. Nigl et al., VLBI with LOFAR/ITS and NDA, Astron. Astrophys., in preparation]