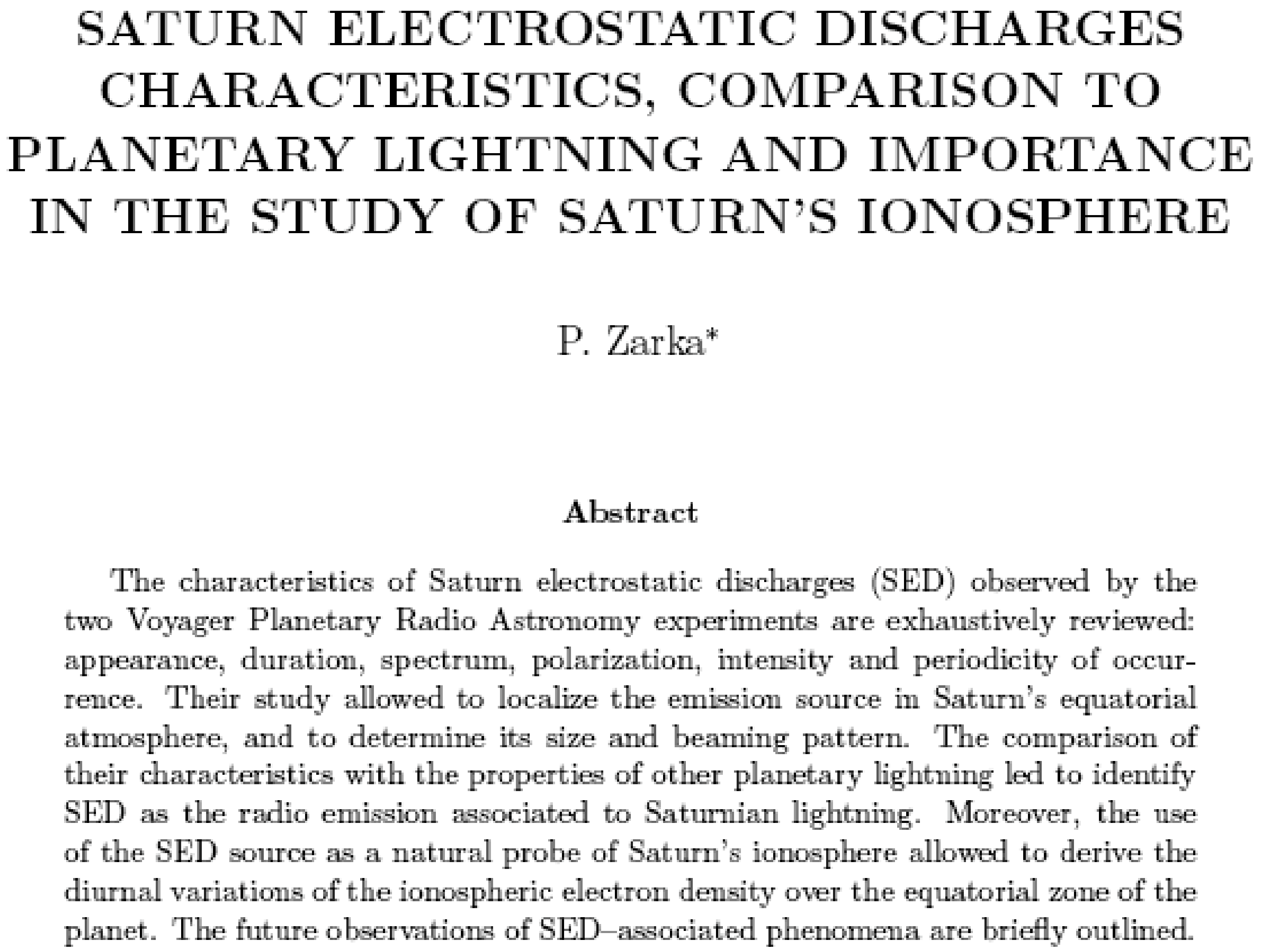
Physical Properties and Detection of Saturn (and Titan ?) Radio Lightning

P. Zarka, B. Cecconi, G. Fischer, H. O. Rucker,
W. S. Kurth and the Cassini/RPWS team

PRE I, 1984 !



SATURN ELECTROSTATIC DISCHARGES CHARACTERISTICS, COMPARISON TO PLANETARY LIGHTNING AND IMPORTANCE IN THE STUDY OF SATURN'S IONOSPHERE

P. Zarka*

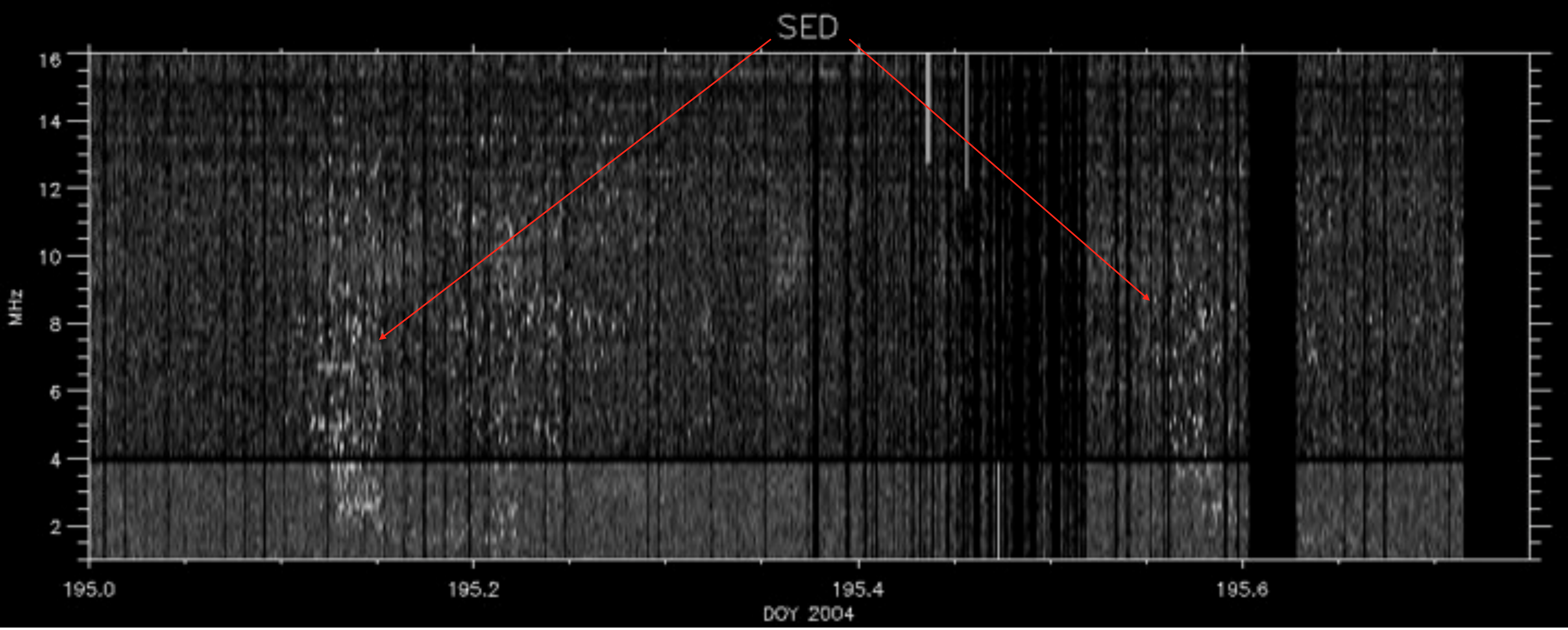
Abstract

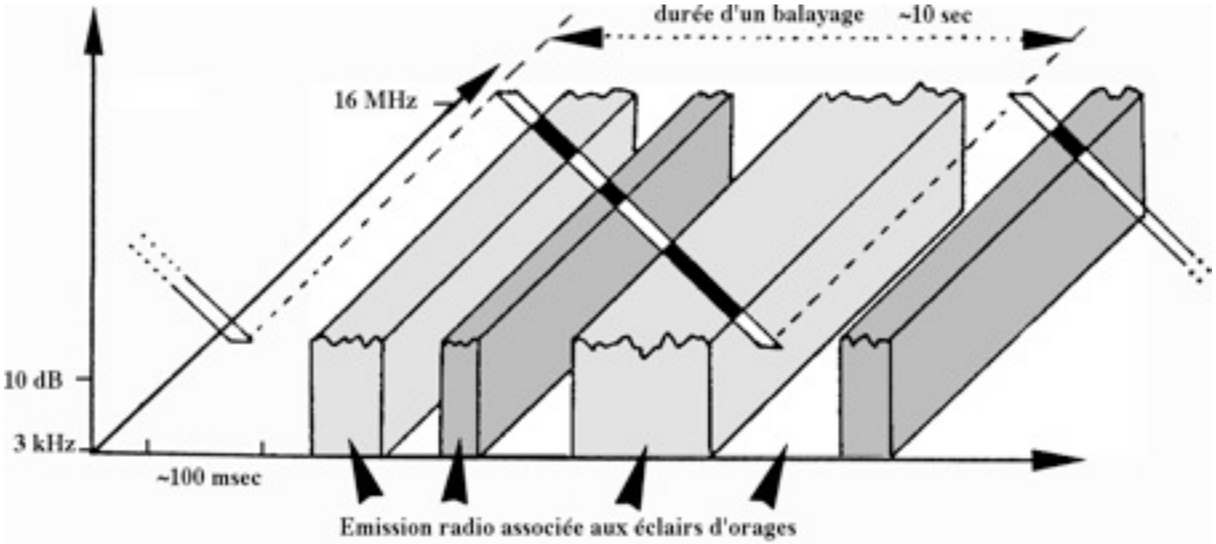
The characteristics of Saturn electrostatic discharges (SED) observed by the two Voyager Planetary Radio Astronomy experiments are exhaustively reviewed: appearance, duration, spectrum, polarization, intensity and periodicity of occurrence. Their study allowed to localize the emission source in Saturn's equatorial atmosphere, and to determine its size and beaming pattern. The comparison of their characteristics with the properties of other planetary lightning led to identify SED as the radio emission associated to Saturnian lightning. Moreover, the use of the SED source as a natural probe of Saturn's ionosphere allowed to derive the diurnal variations of the ionospheric electron density over the equatorial zone of the planet. The future observations of SED–associated phenomena are briefly outlined.

- « SED » properties

- Ground-based detection ?

- Titan lightning ?


SED
16
14
12
10
8
6
4
2
MHz
195.0
195.2
195.4
195.6
DOY 2004


durée d'un balayage
~10 sec
16 MHz
10 dB
3 kHz
~100 msec
Emission radio associée aux éclairs d'orages

- Detection algorithm : > 0.8 dB / surrounding neighbours with same instrument status (frequency, antenna configuration …), f ≥ 1800 kHz

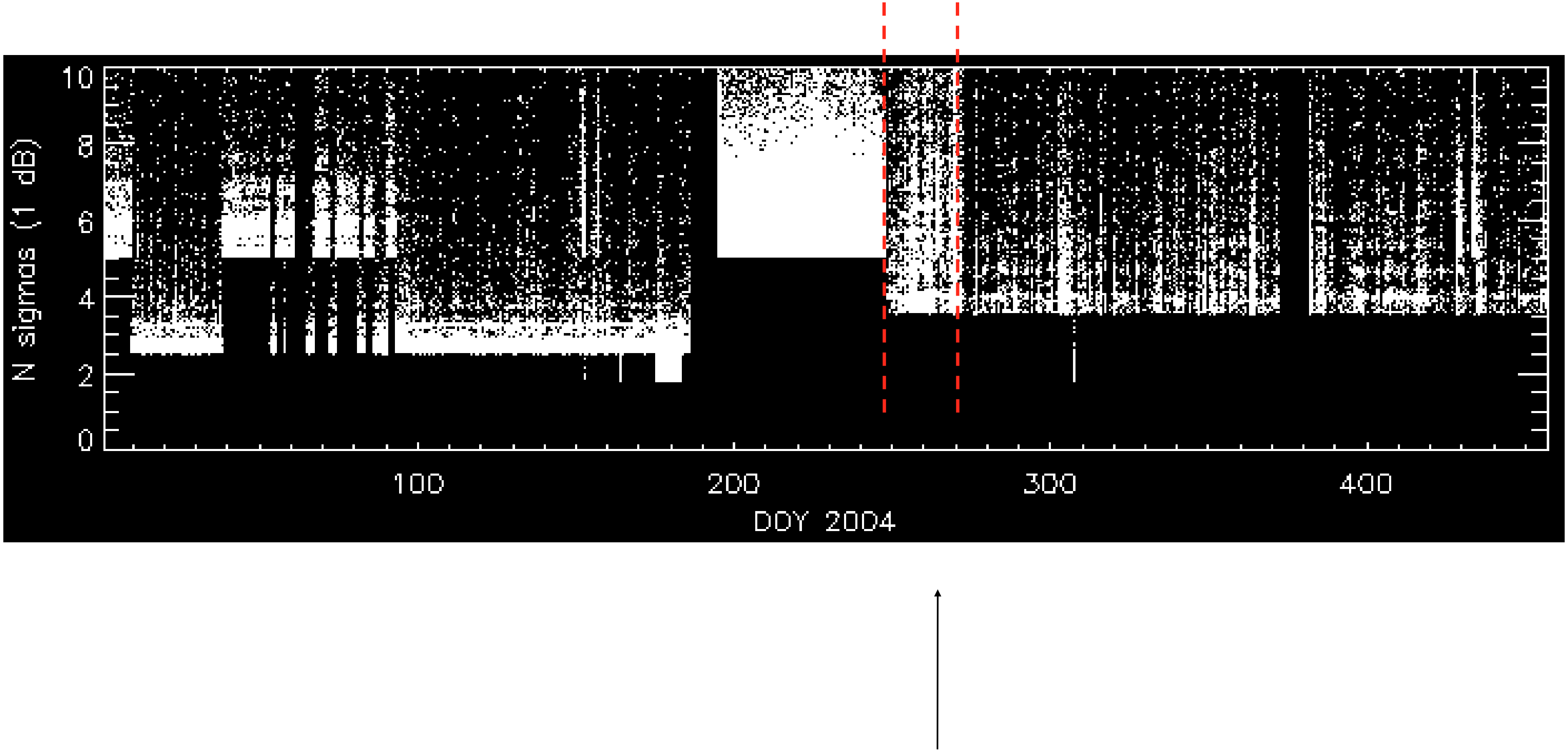
- Further « cleaning » versus f & t

- Further thresholding (1.2 - 1.5 dB), function of instrument mode

- No « visual » confirmation event by event

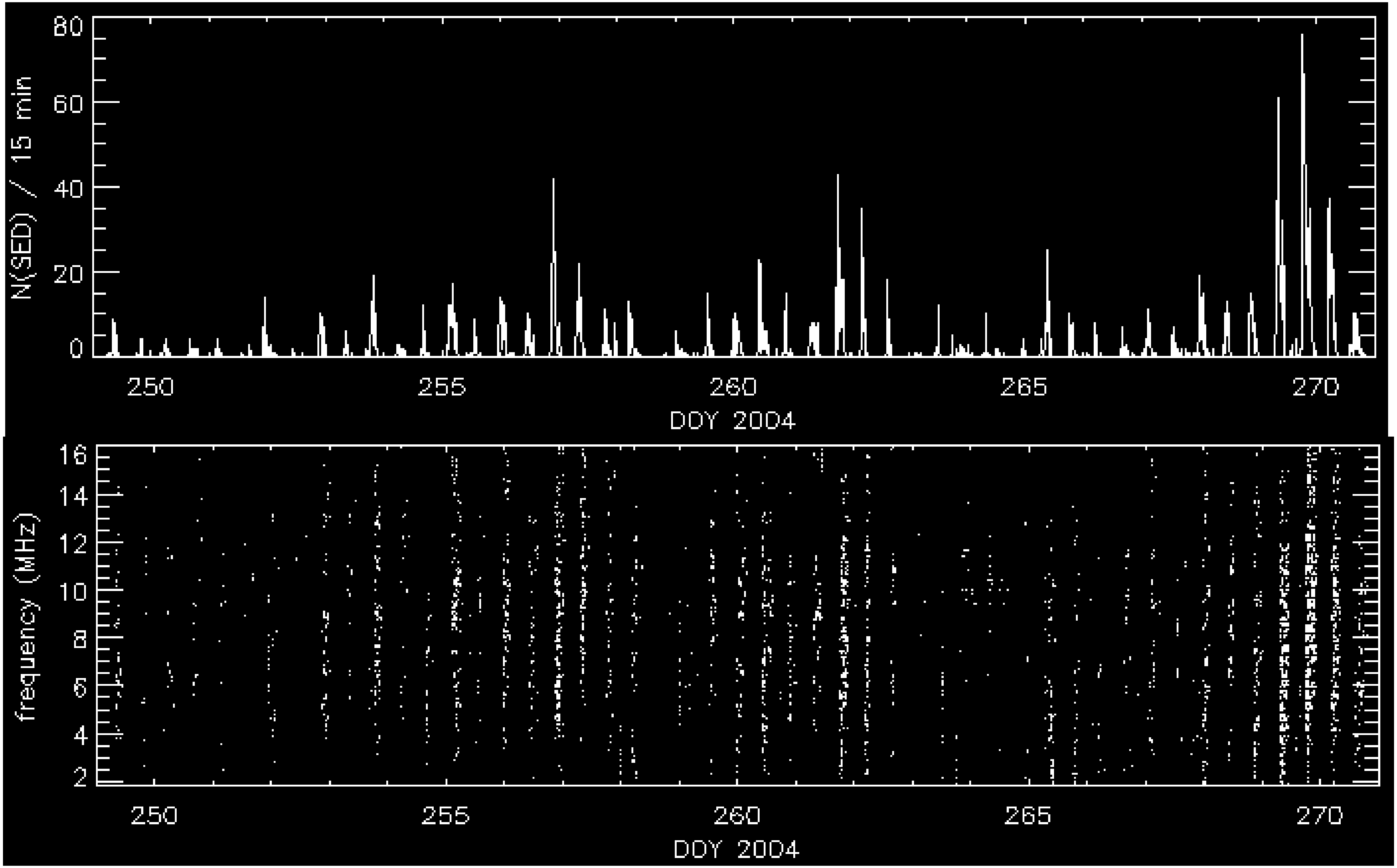
- Period studied : 2004/001 → 2005/090

Detection threshold



~3.6 σ between DOY 249 and 271

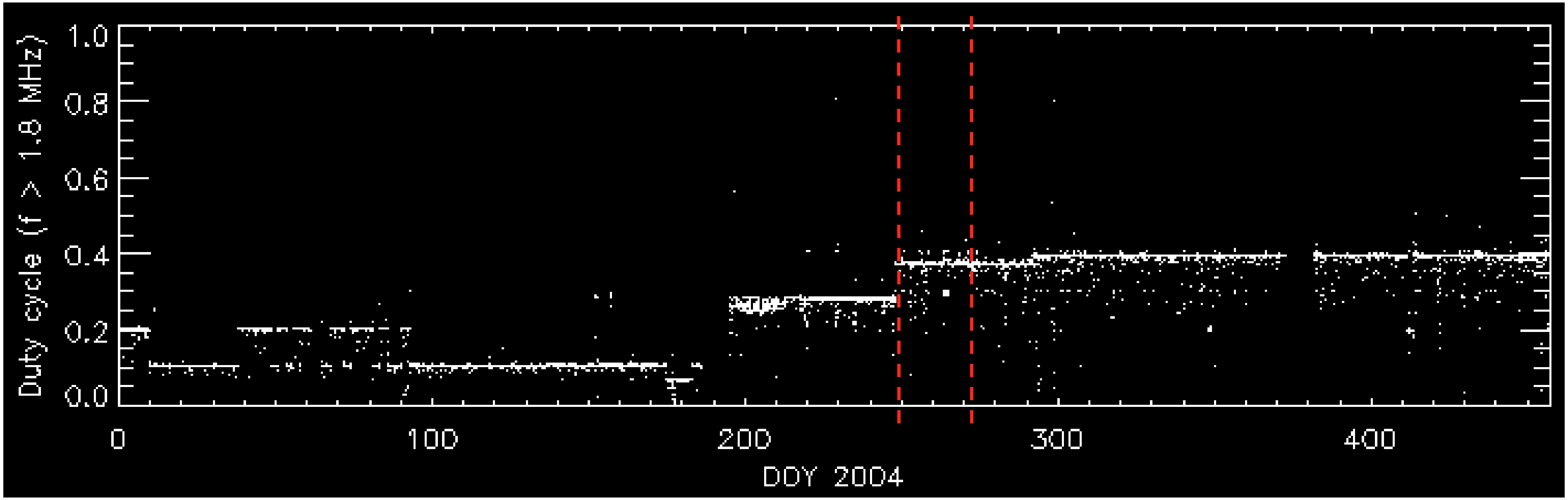
Occurrence



→ P=10.67 hr

Duty-cycle

→ 0.37 between DOY 249 and 271

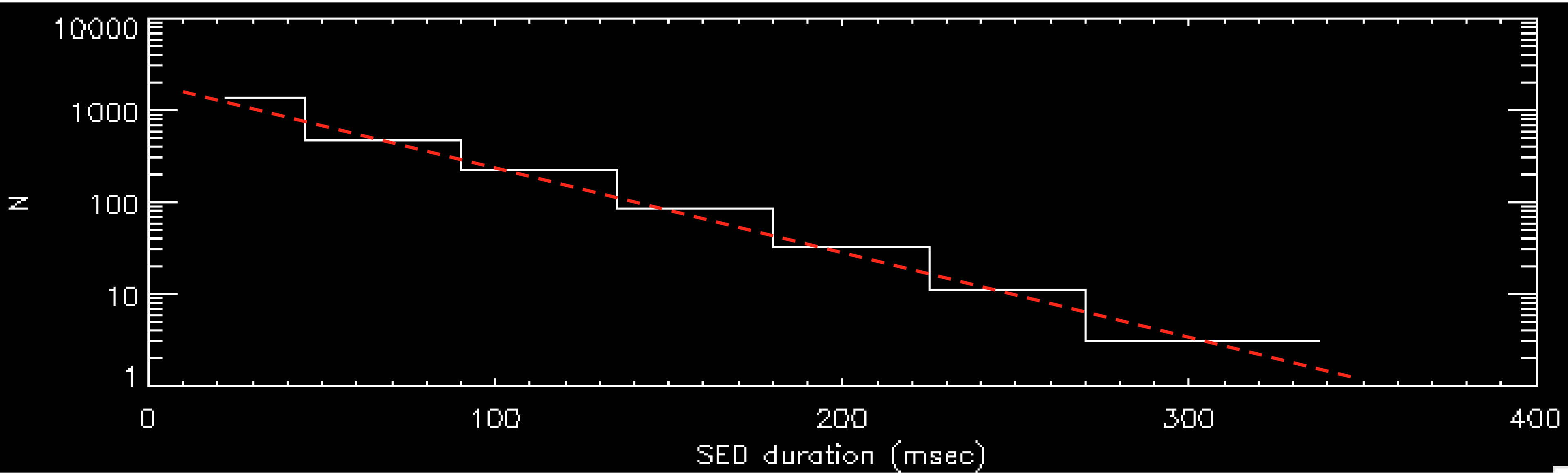


Number of events

- 3600 events detected above 1.5 dB threshold ~ 5.7 σ → ~10000 emitted
- peak rate of one SED / 5s (same as Voyager 1)
- Average similar to Voyager 2, ~1/4x Voyager 1 (but higher threshold)

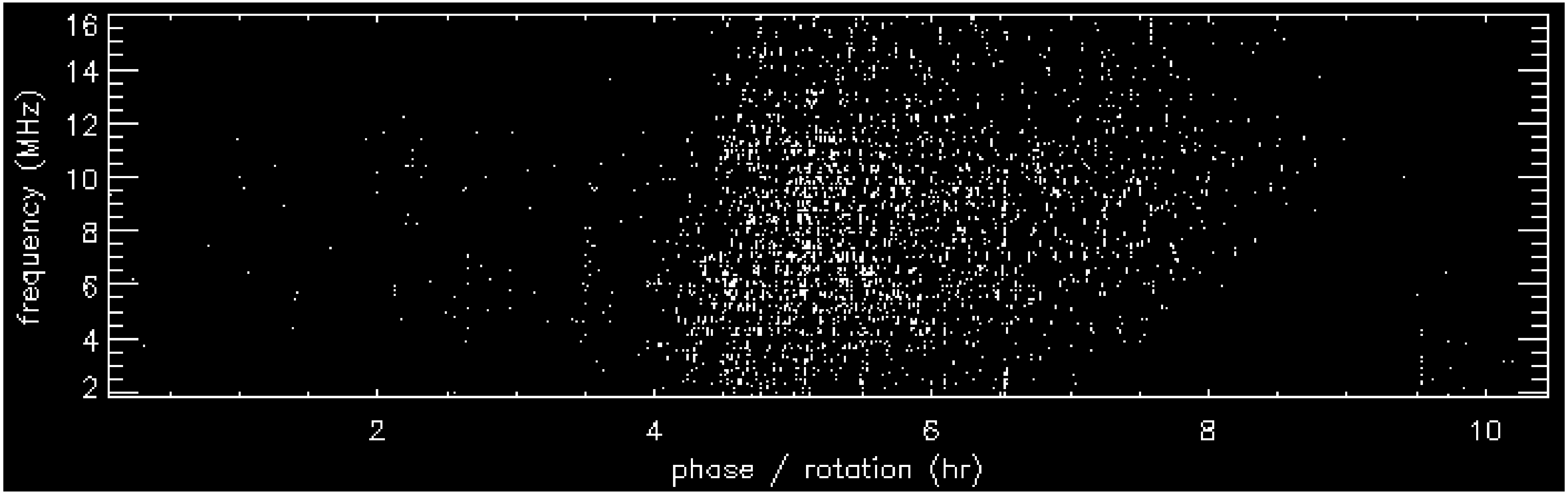
Duration

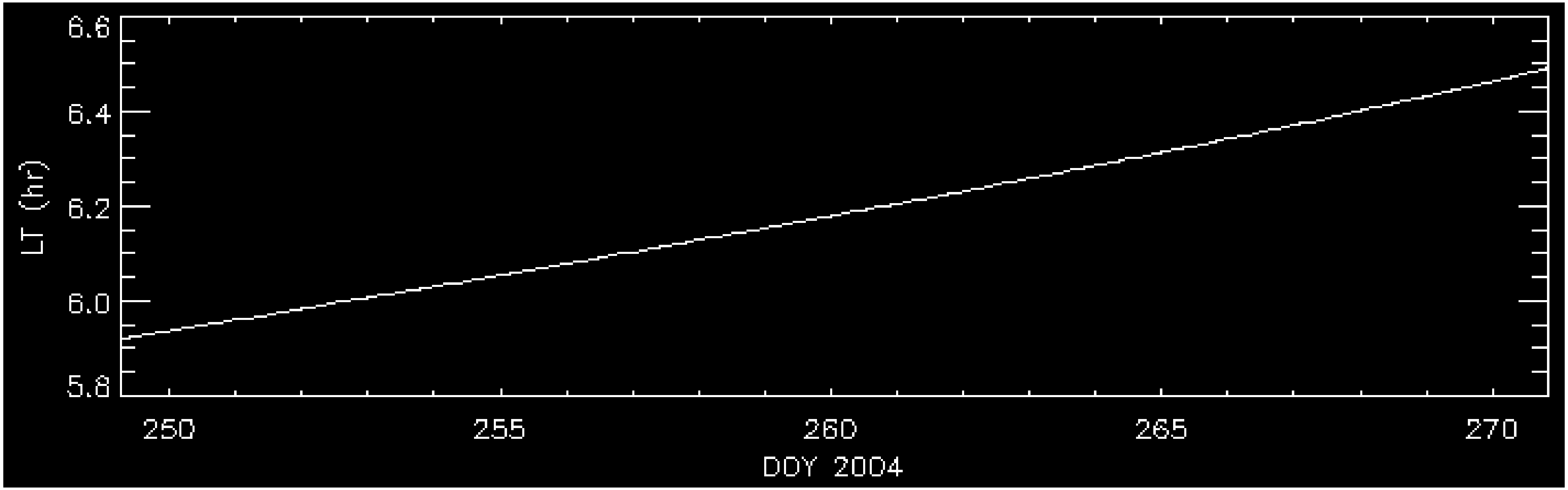
RPWS integration time above 1.8 MHz for DOY 249 to 271 = 40 msec (80 on DOY 264)

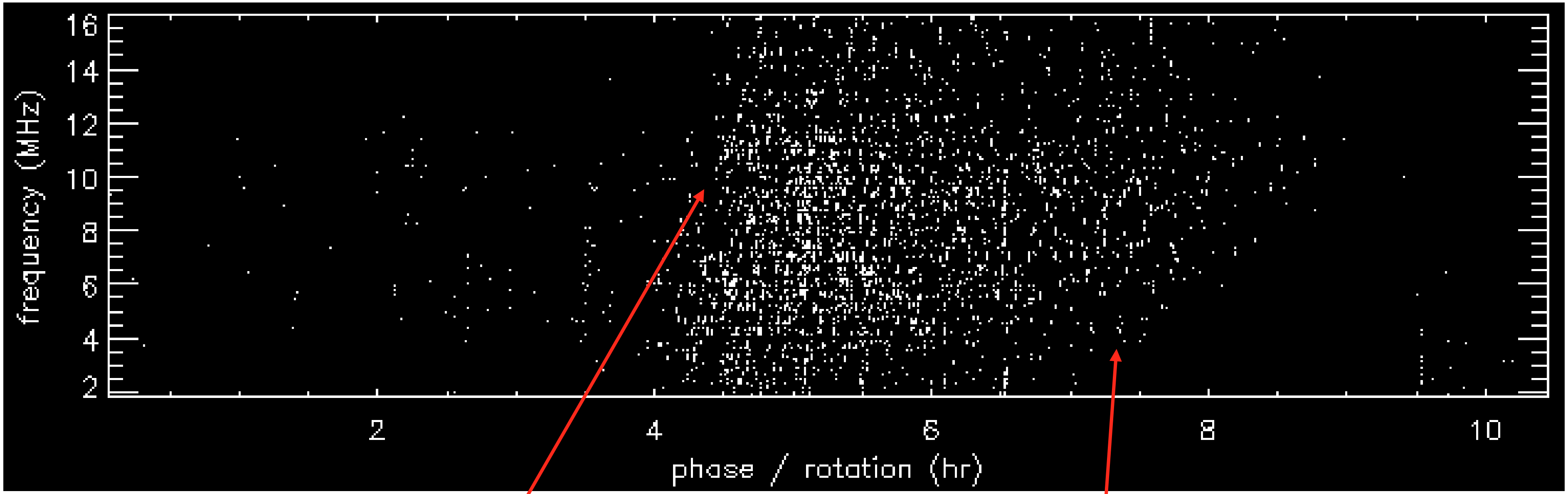


→ E-folding time 48 msec (~40 msec for Voyager)

Occurrence within episode

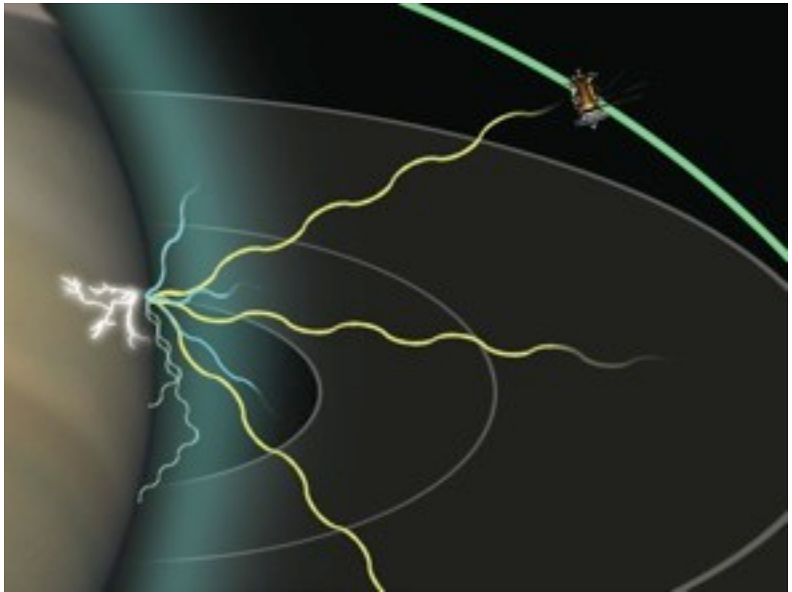




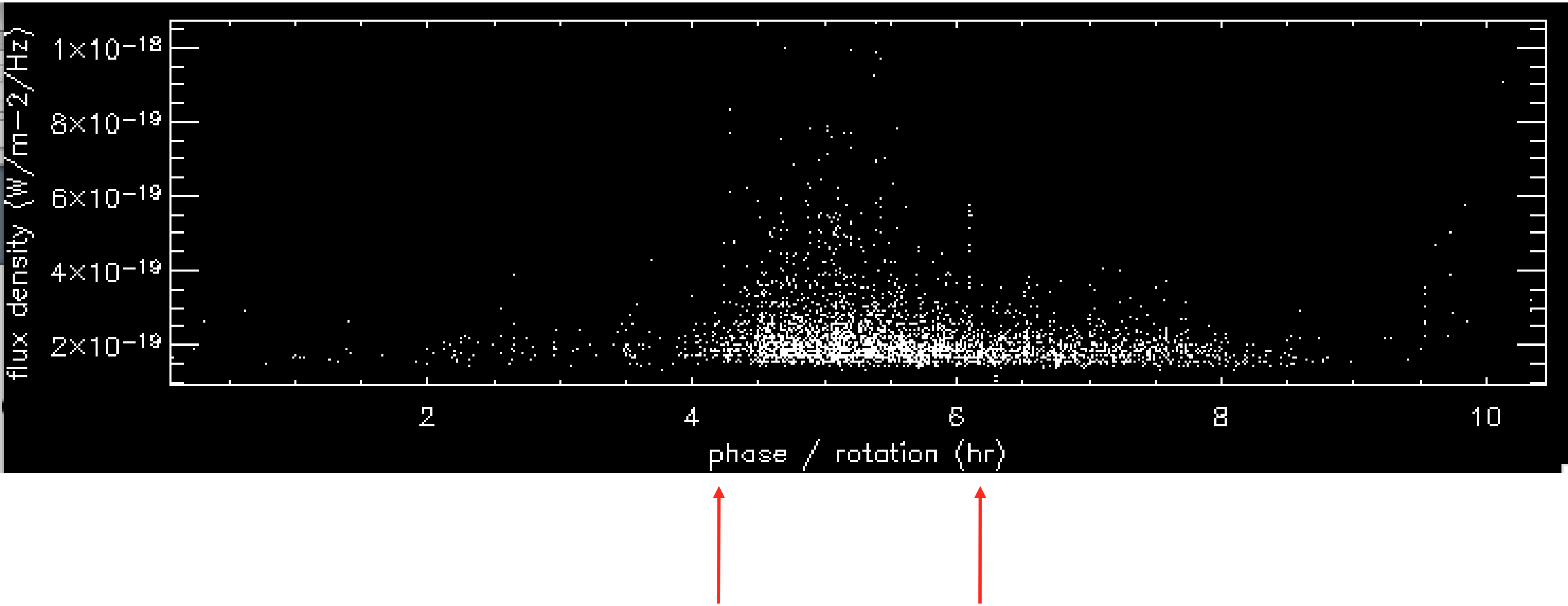


Refraction ?

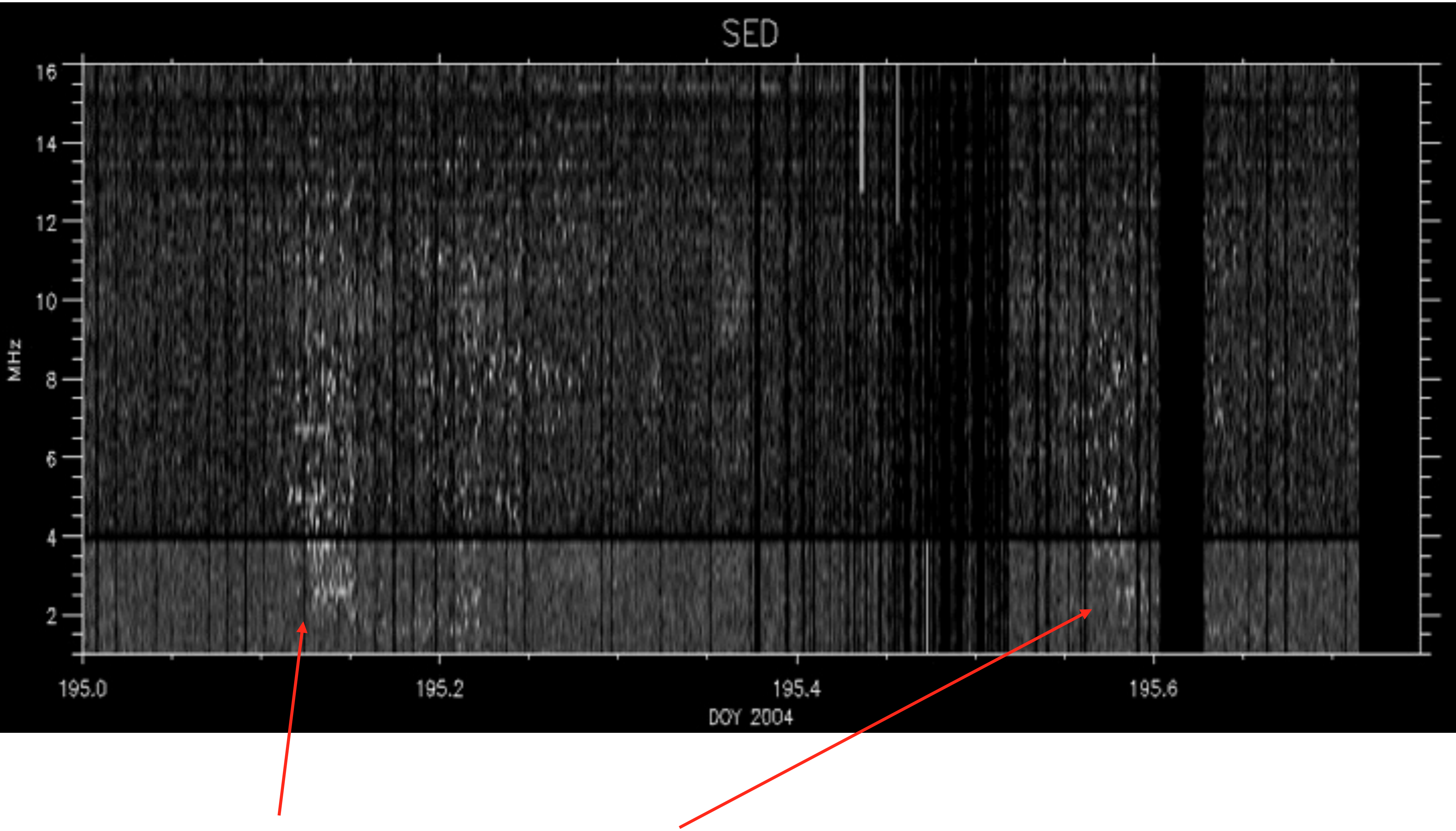
Ionospheric cutoff ?
(~5 MHz for Voyager)



Flux within episode



Attenuation at edges



- opposite situation exists

Flux density calibration for RPWS

[Zarka et al, JGR, 2004]

① Short dipole calibration

(2L << λ/2 → f << 8 MHz, in practice f ≤ 2 MHz)

$(\mathrm{Wm^{-2}Hz^{-1}}) \longrightarrow$

$$S = \frac{P}{Z_o L^2 \boxed{\left(\frac{c_a}{c_a + c_b}\right)^2}}$$

$\longleftarrow (\mathrm{V^2Hz^{-1}})$ [*Manning, 2000*]

limits accuracy

® $(C_a/(C_a+C_b)) \sim 0.4$ (8 dB attenuator)

- At higher frequencies, C_a increases, →∞ at λ/2 resonance

② Galaxy dominates for f ≥ 1 MHz

$$S_g = \left[I_g f^{-0.52} \left(\frac{1 - e^{-\tau}}{\tau} \right) + I_{eg} f^{-0.8} e^{-\tau} \right] \times \Omega \times \eta$$

0.5 MHz ≤ f ≤ 20 MHz,   Ω=8π/3

[*Dulk & Manning, 2001*]

+

$T_b(f)$ for 0.2 MHz ≤ f ≤ 13 MHz

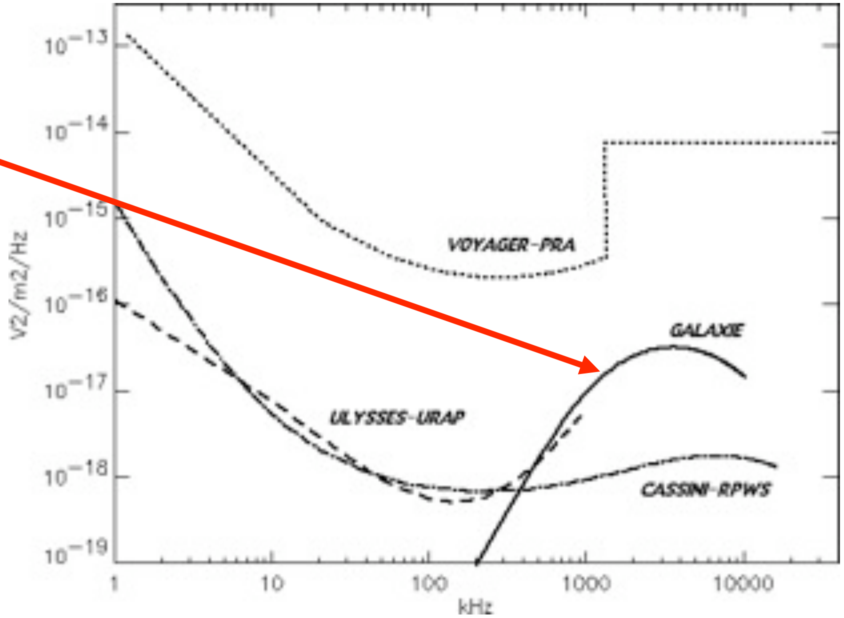
[*Manning & Dulk, 2001*]

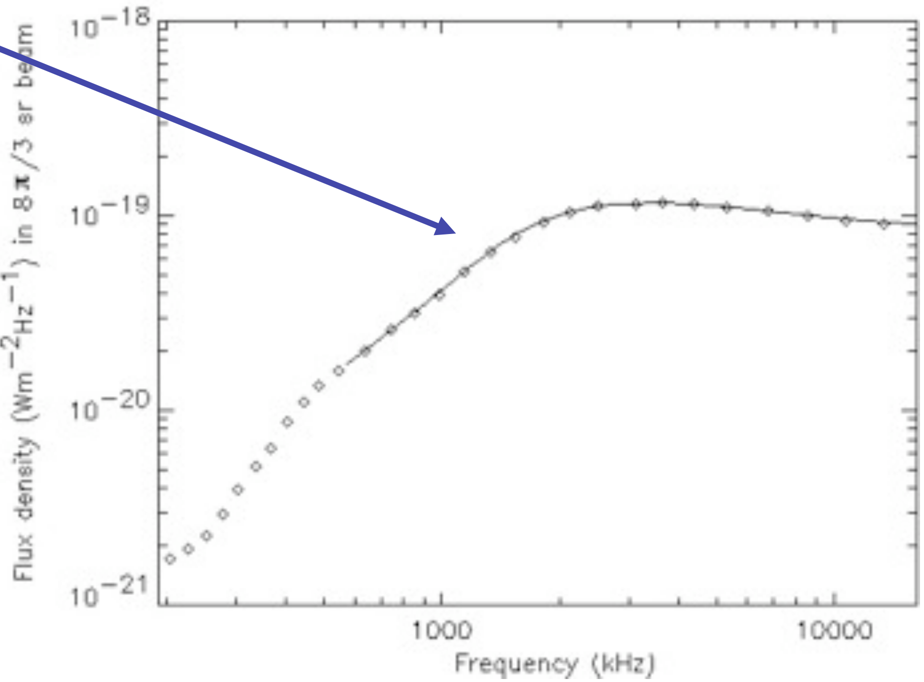
$$S = \frac{P - P_r}{P_g} S_g$$

® Reference galactic spectrum

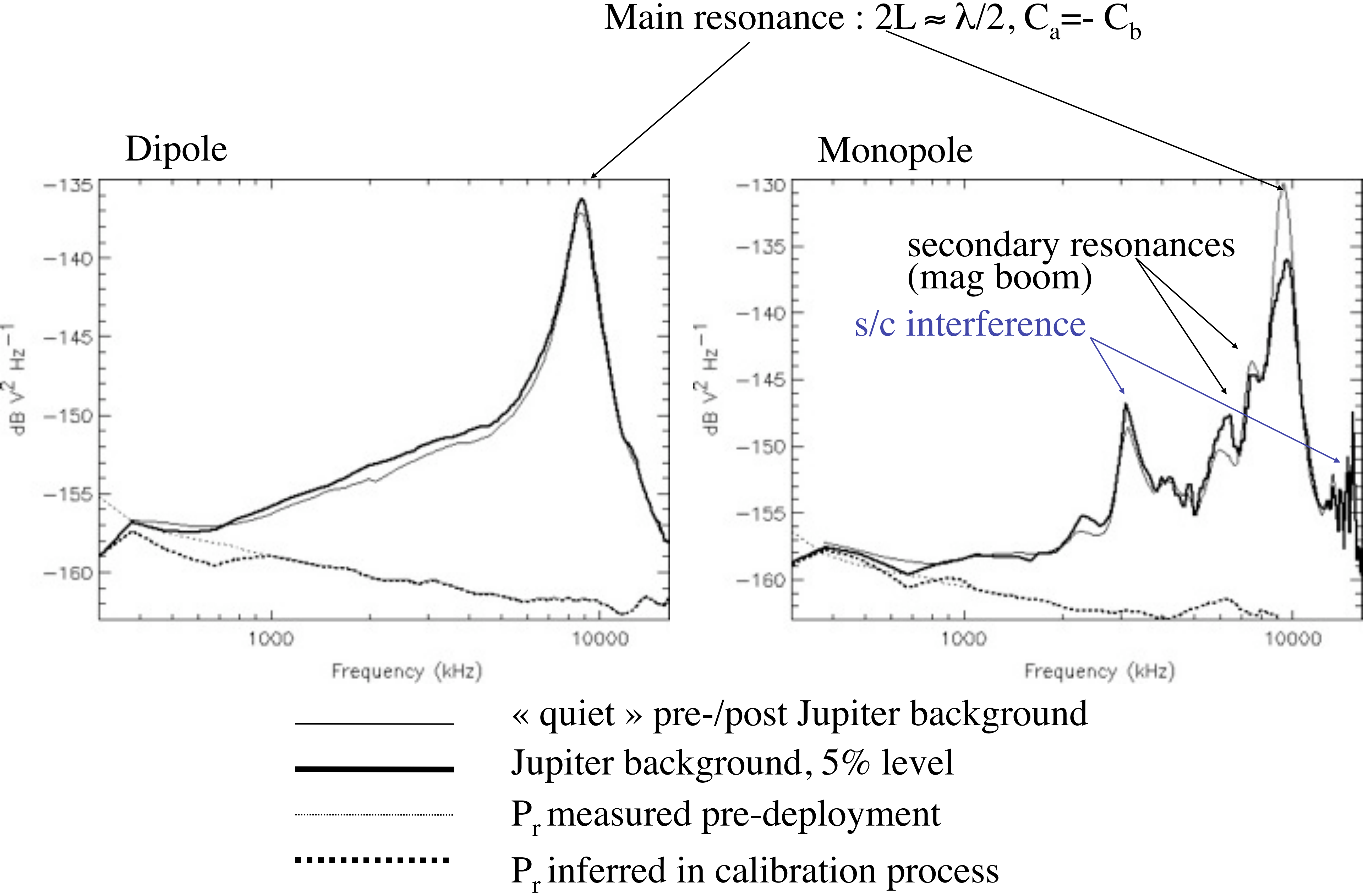
$S_g(f)$

receiver noise





- $(P_g+P_r)(f)$



Main resonance : $2L \approx \lambda/2$, C_a=- C_b

Dipole

Monopole

secondary resonances (mag boom)

s/c interference

─ « quiet » pre-/post Jupiter background

━ Jupiter background, 5% level

┈ P_r measured pre-deployment

▪▪▪ P_r inferred in calibration process

• Inter-calibration LF / HF

① LF (f ≤ 2 MHz)

$$S_1(f) = \frac{P(f) - P_r(f)}{K} \qquad \text{with} \qquad K = Z_o L^2 \left(\frac{c_a}{c_a + c_b}\right)^2$$

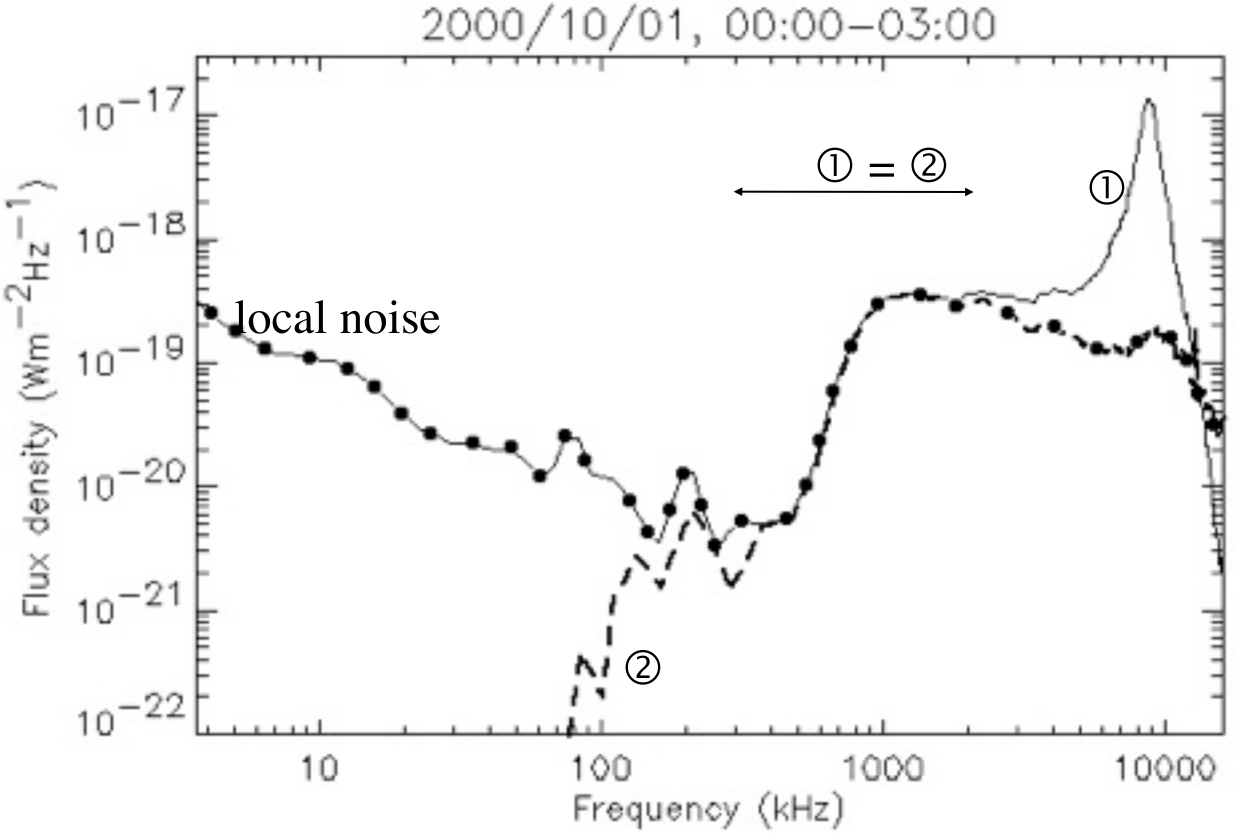
② HF (f ≥ 300 kHz) $$S_2(f) = \frac{P(f) - P_r(f)}{P_g(f)} S_g(f)$$

- 1 MHz ≤ f ≤ 2 MHz : $S_2(f)/S_1(f) = KS_g(f)/P_g(f) = 1$

  → K → $LC_a/(C_a+C_b) = 3.06$ m (dipole) / 1.68 m (monopole)

  + *main resonance position* ⇒ *estimates for L,* C_b

- 0.3 MHz ≤ f ≤ 1 MHz : $P_r(f) = (P_g+P_r)(f) - KS_g(f) \leq 13\ \mathrm{nV.Hz^{-1/2}}$


2000/10/01, 00:00-03:00

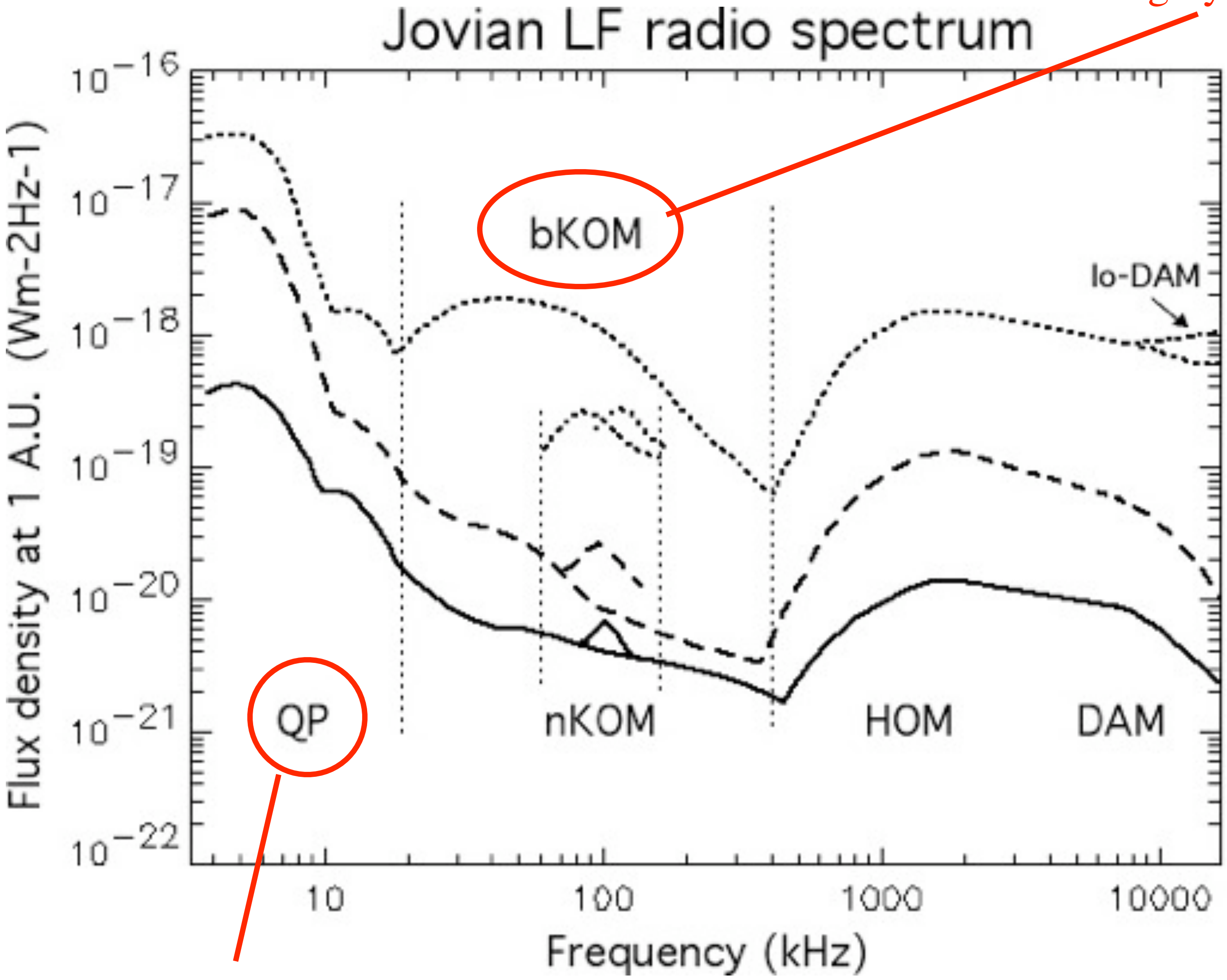
local noise

① = ②

①

②

• • • calibrated spectrum



highly sporadic

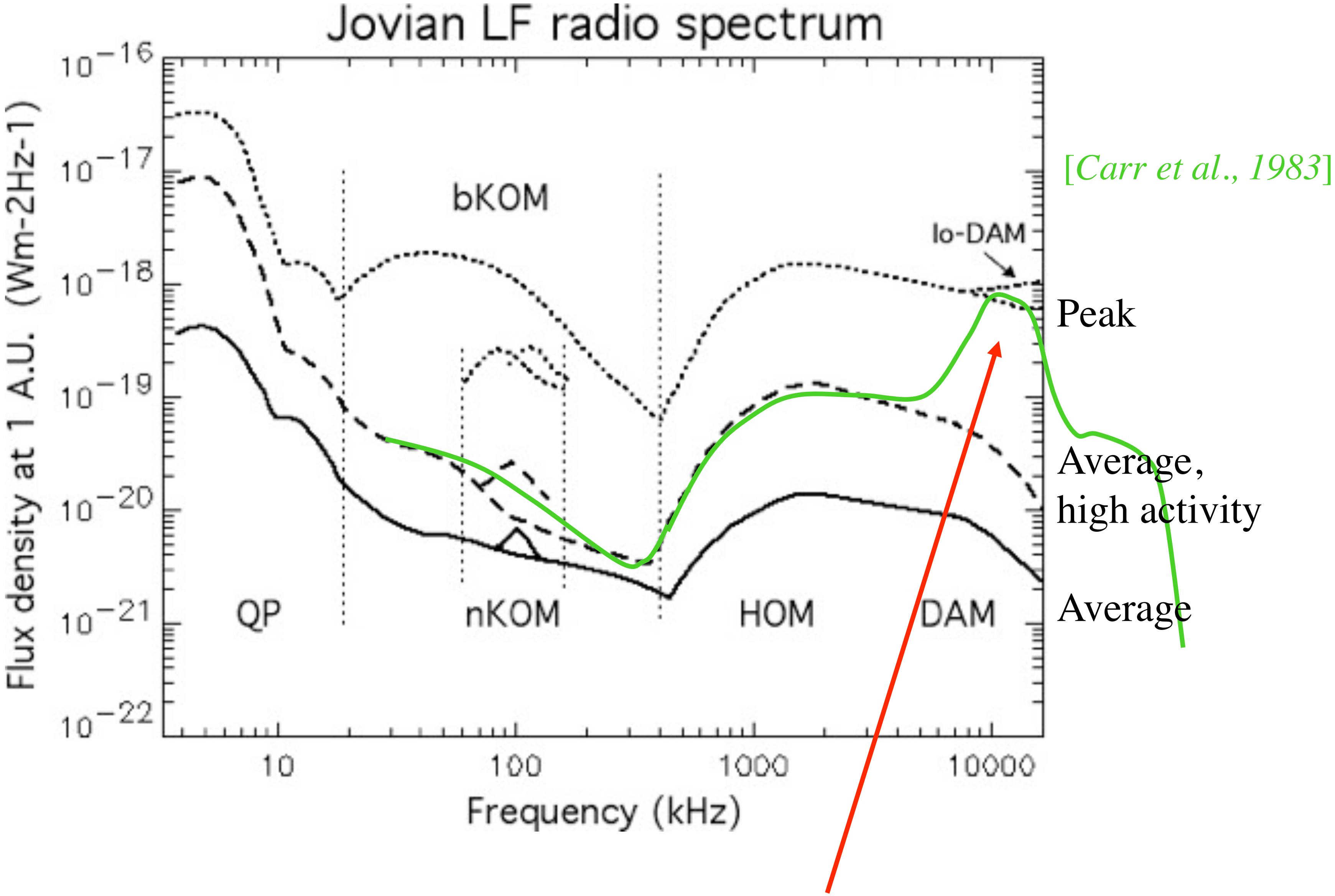
Peak

Average,
high activity

Average

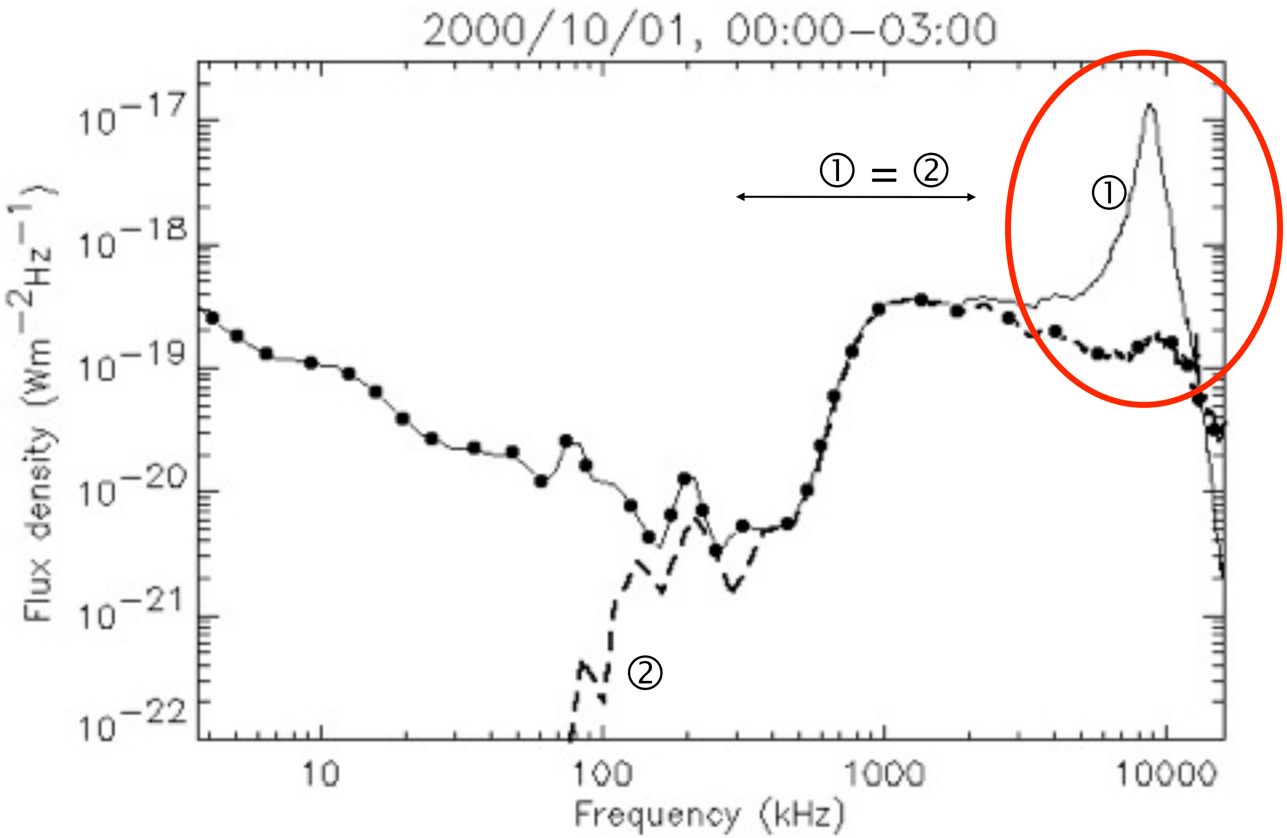
most intense component

~ agreement with previous estimates … except



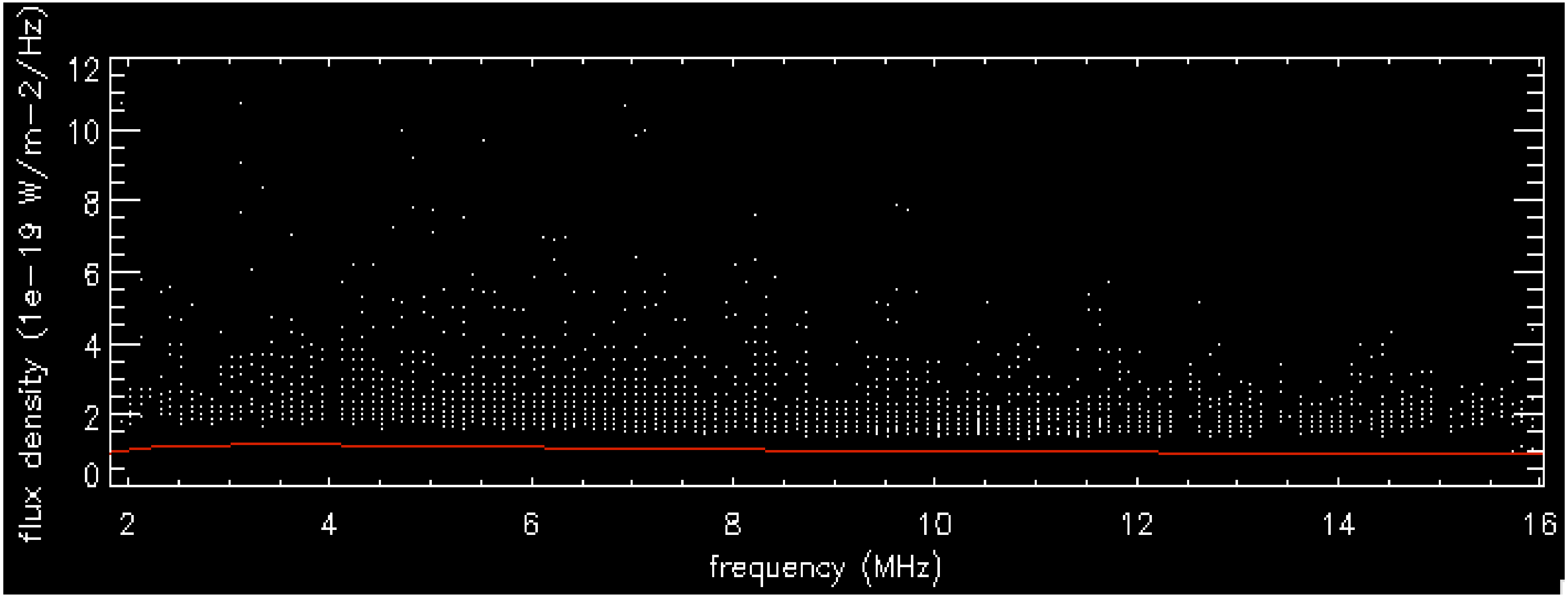
[*Carr et al., 1983*]

Poor calibration of Voyager/PRA response & ~Earth's ionospheric cutoff

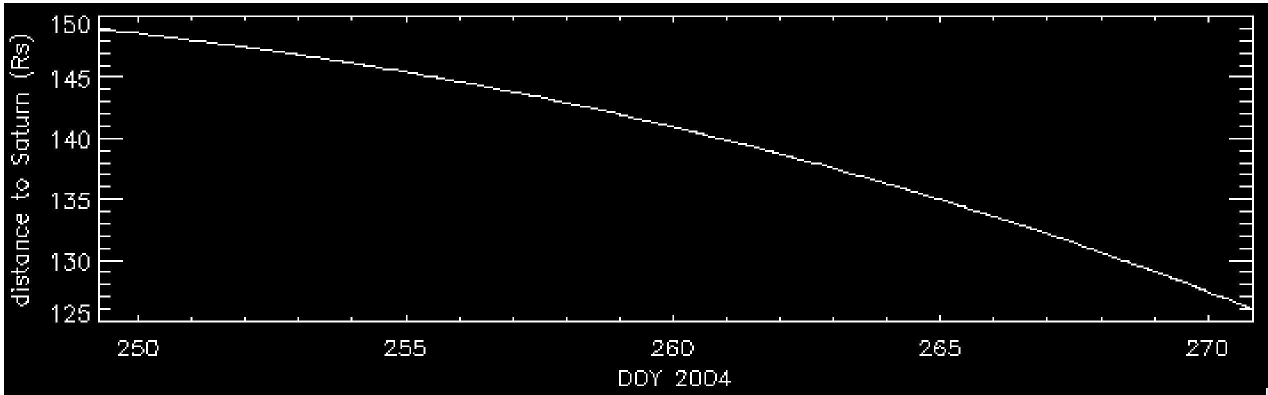


Cassini & Voyager antennas with comparable lengths !

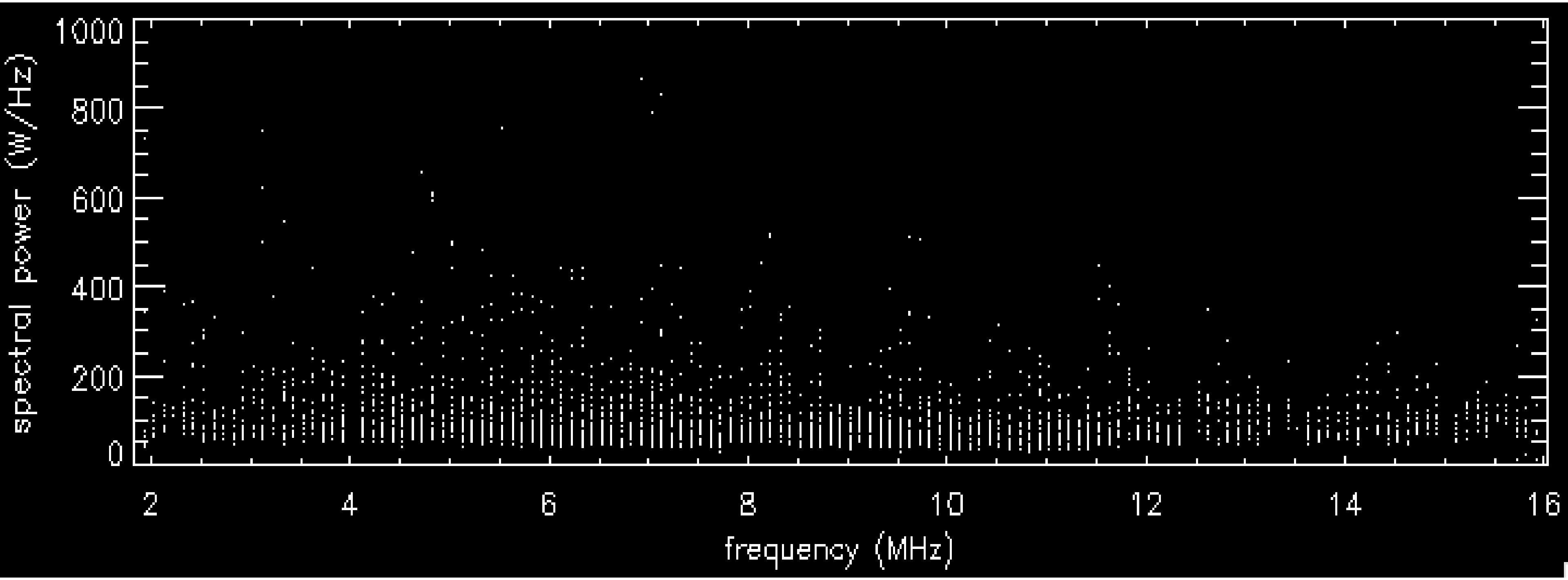
Calibrated SED flux (S)



- Spectral power : $P = 4\pi R^2 S$

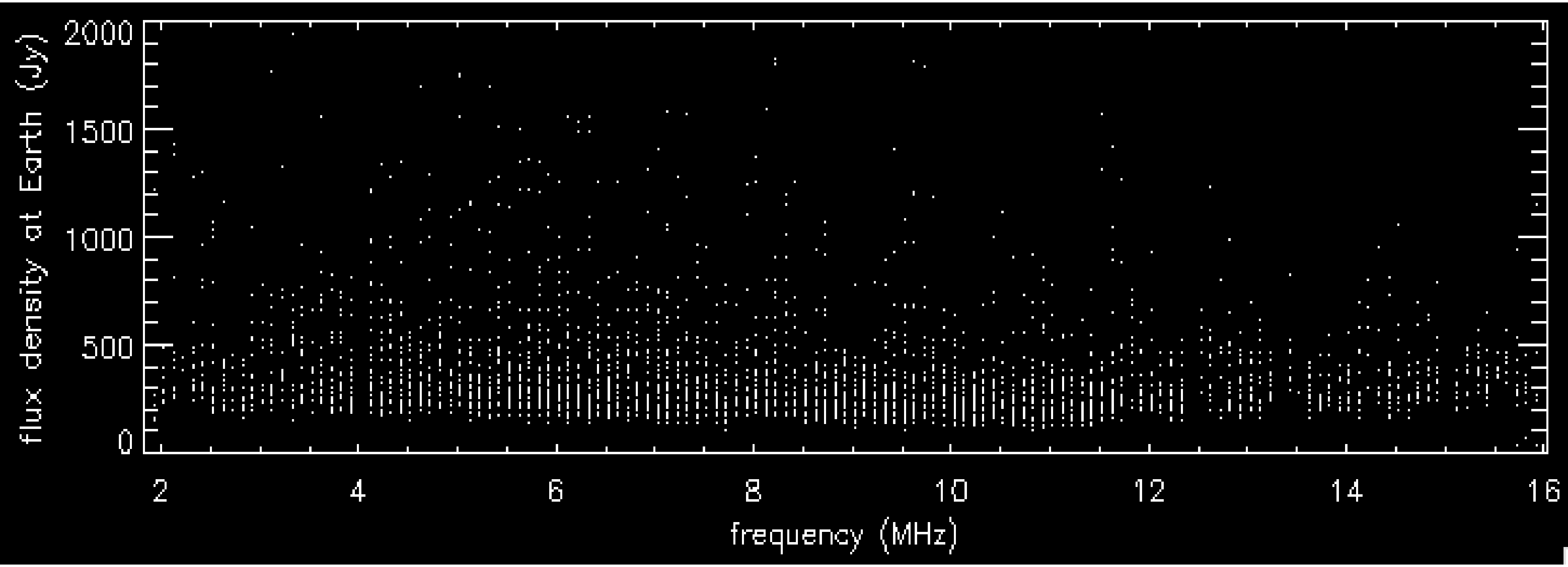


Spectral Power



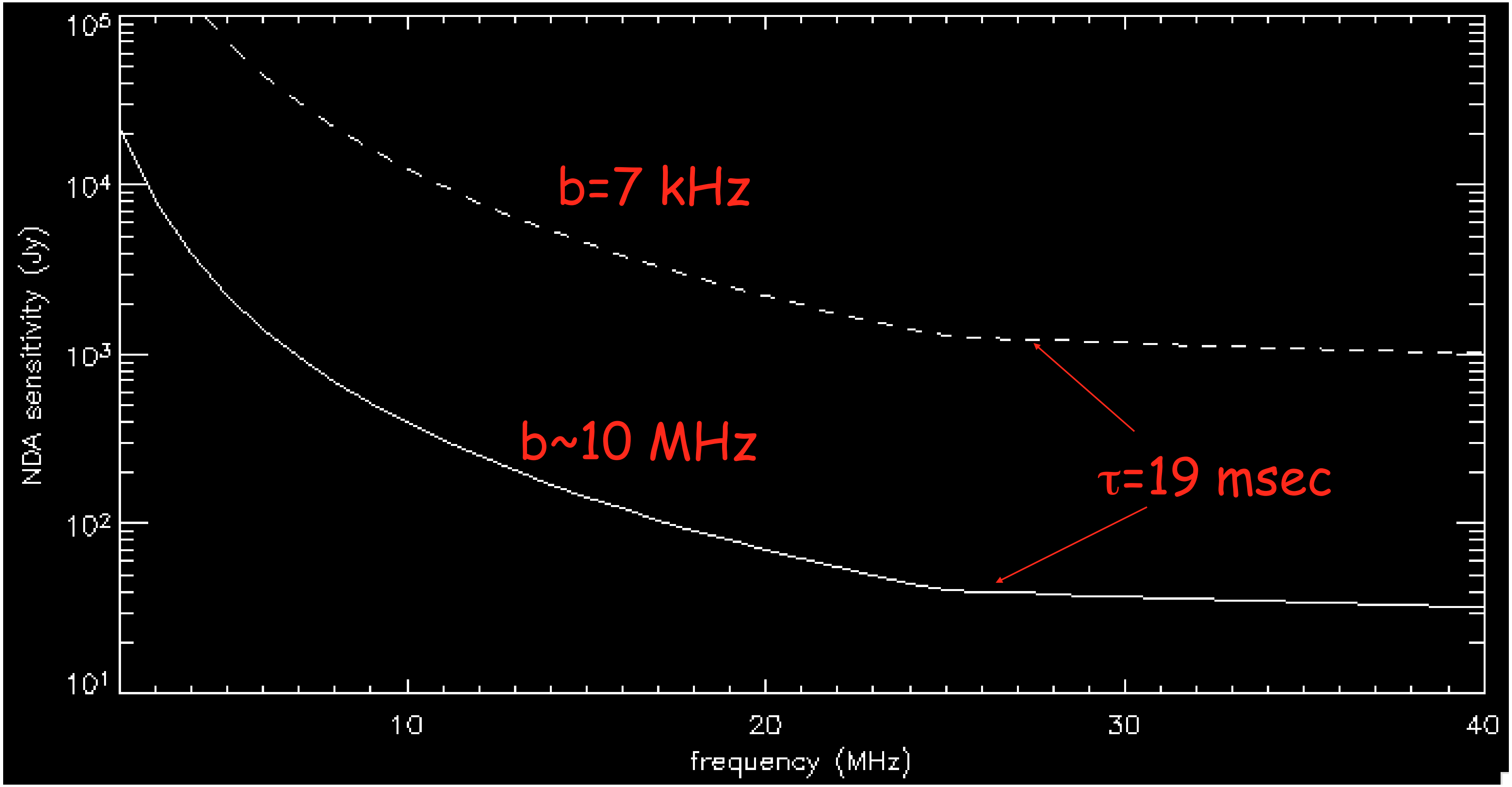
< P > ~100 W/Hz (idem Voyager)

Flux density at Earth



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

Detectability with Nançay Decameter Array + digital receiver

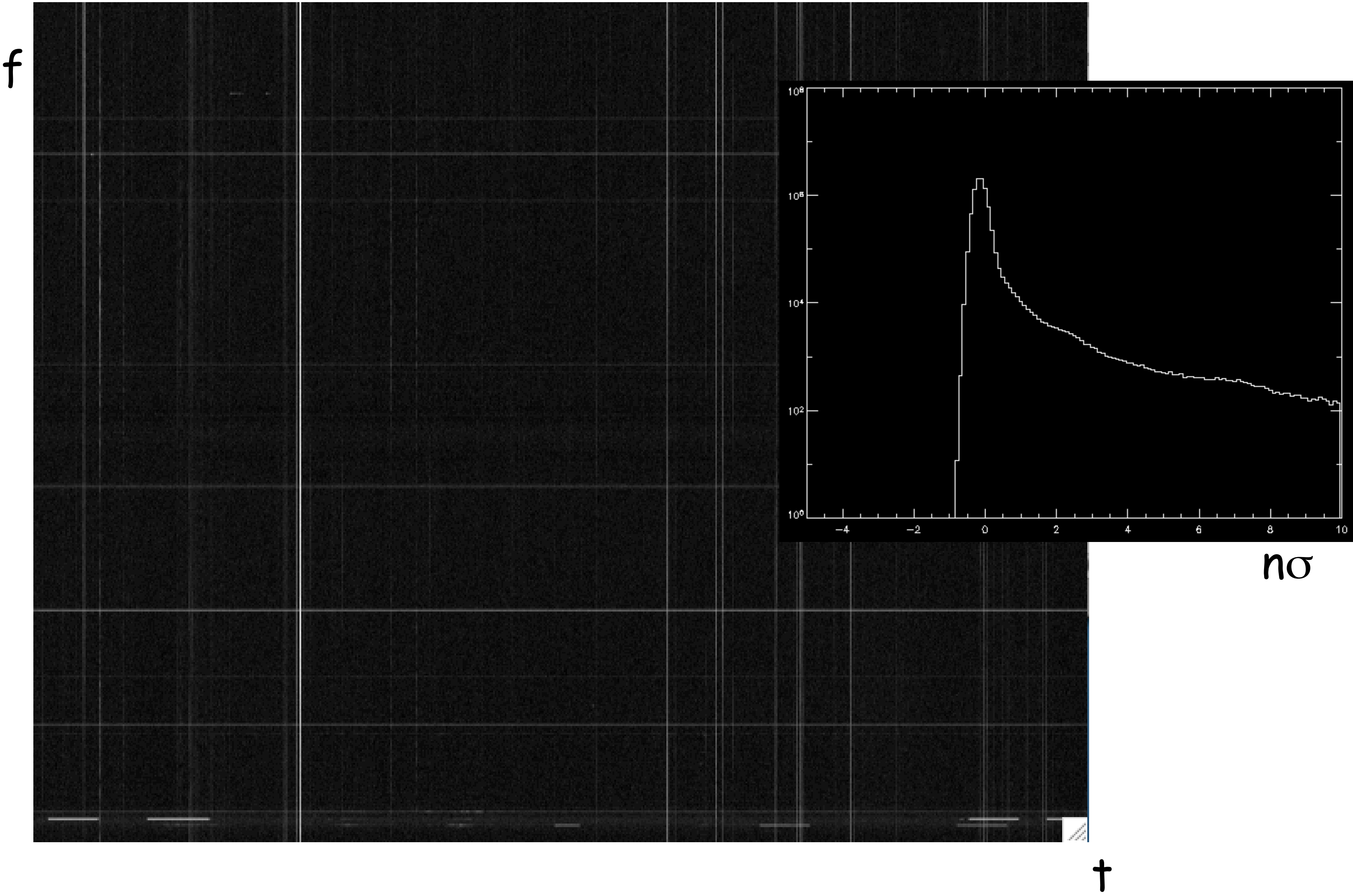


$\sigma_{sky} = 2kT_{sky} / A(b\tau)^{1/2}$ with $A = 48\ \lambda^2 \leq 7000\ m^2$

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

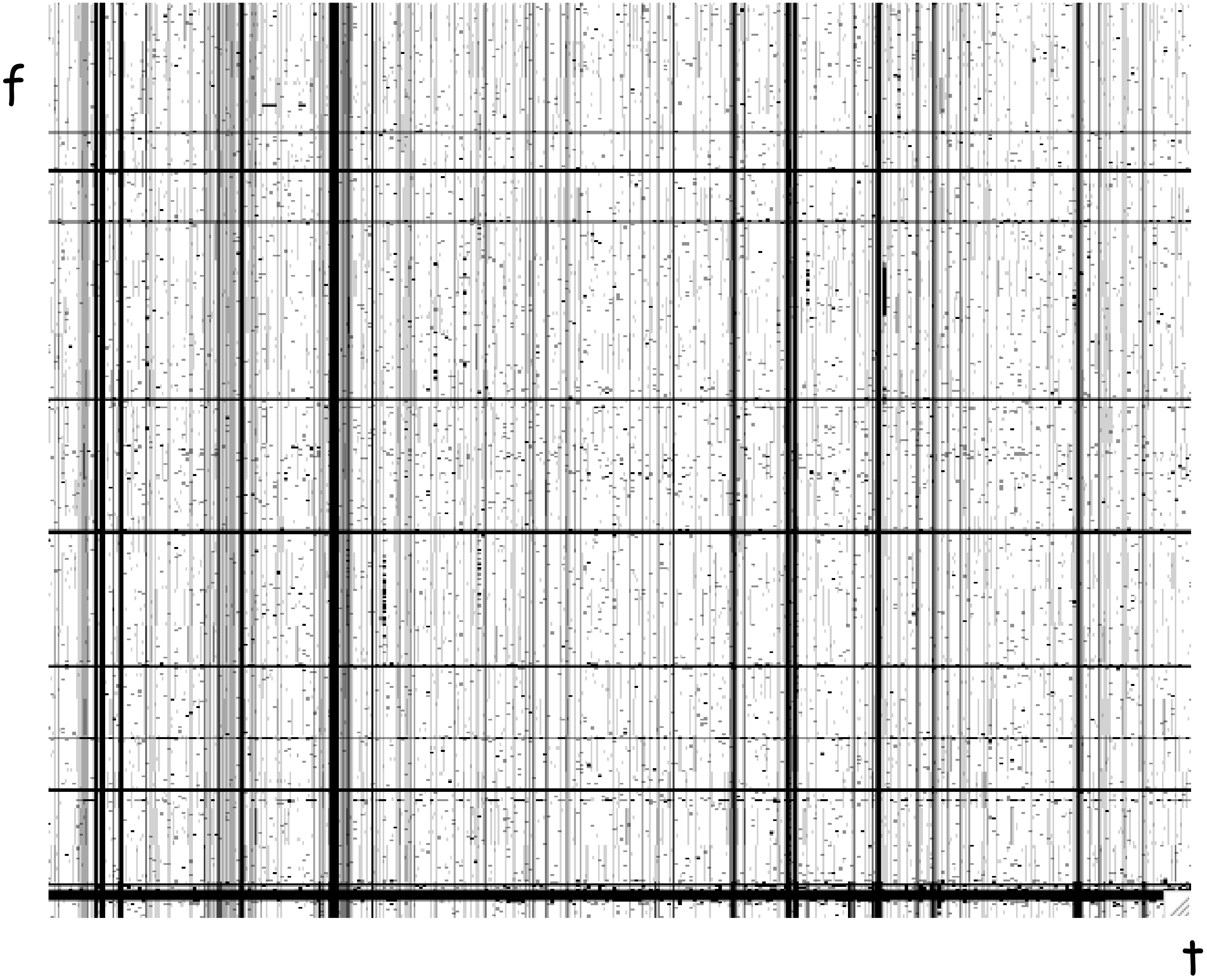
Example of processing

2004/12/16 = 2004/351

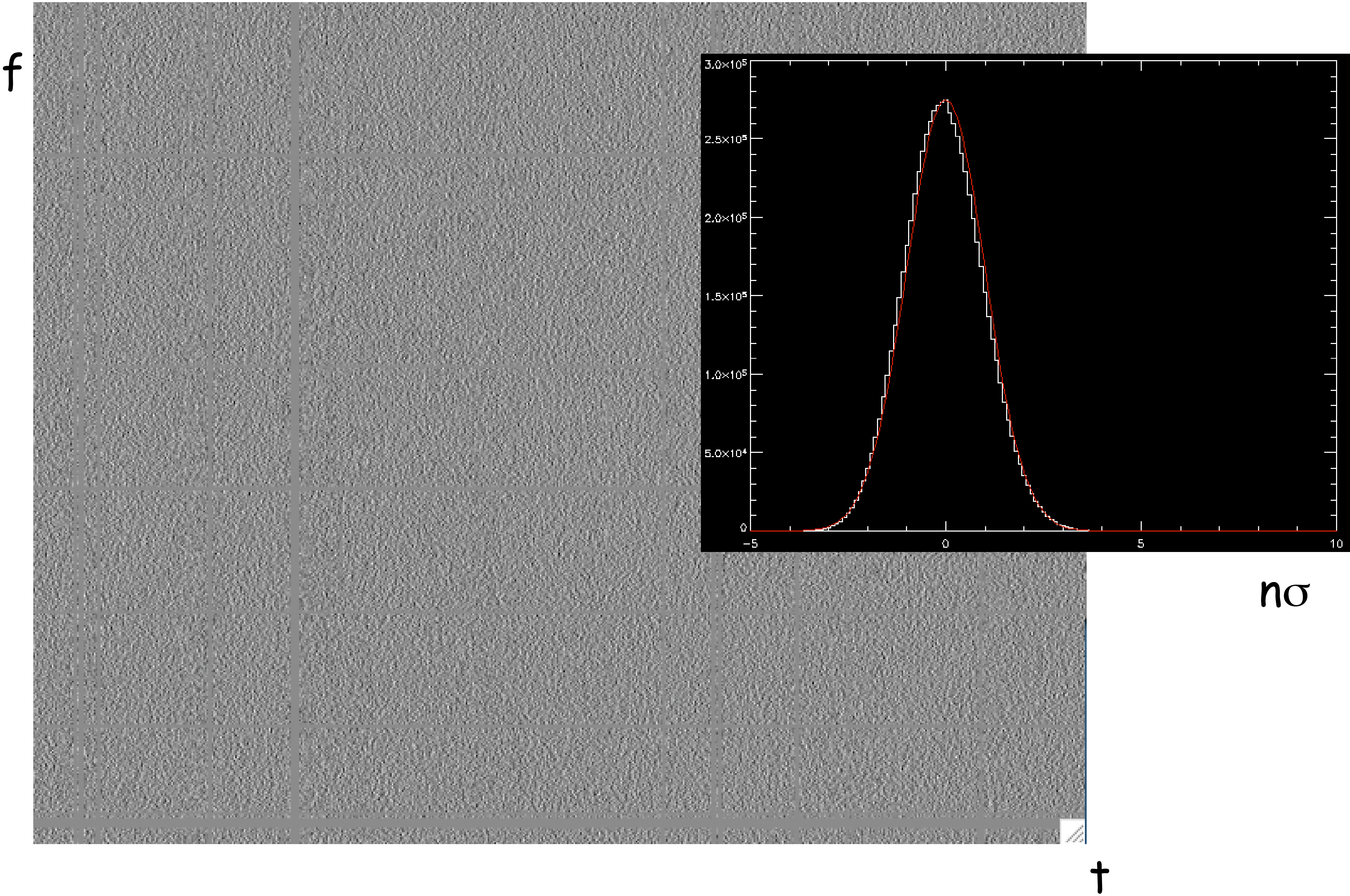


RFI mitigation

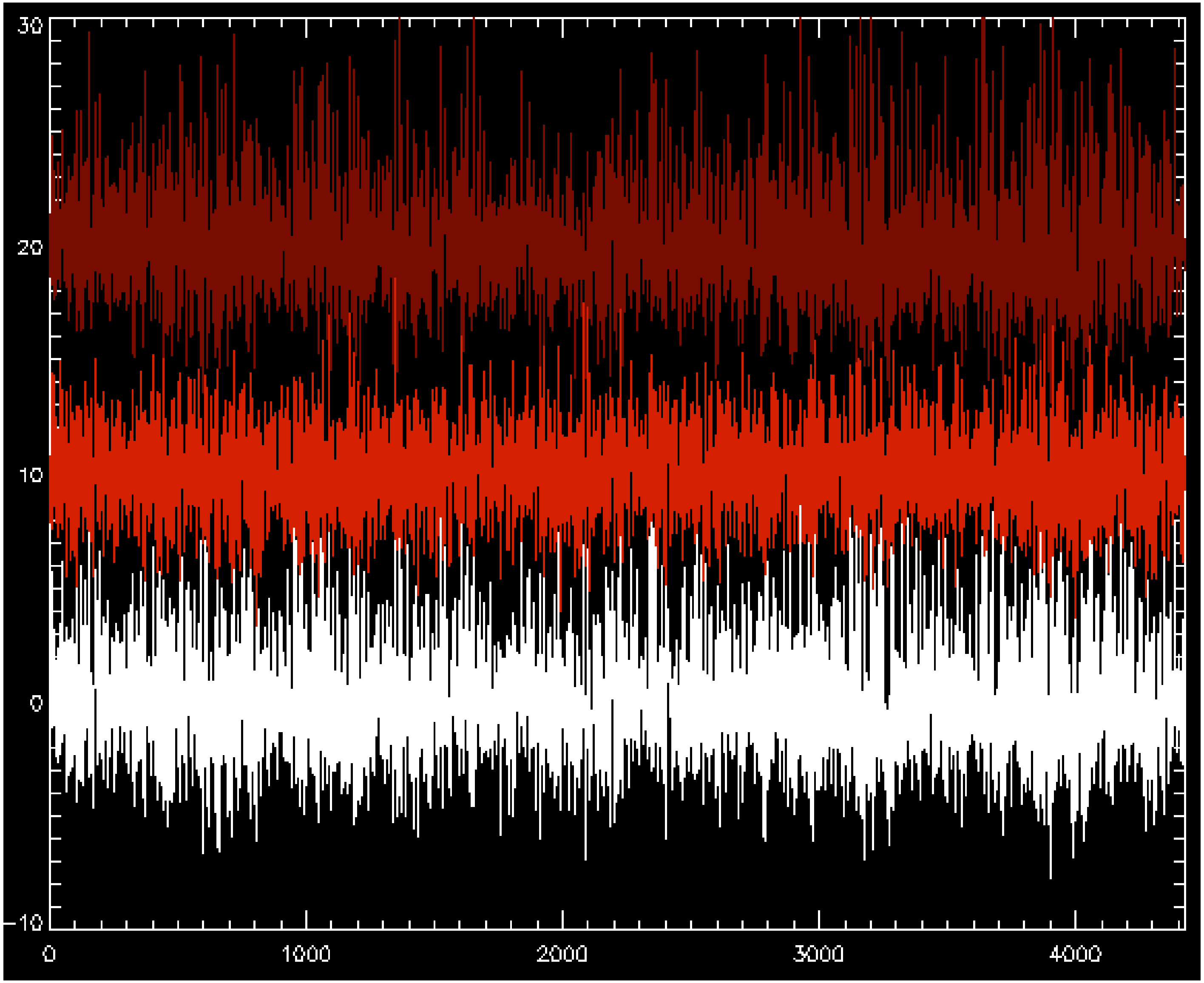
~20% pixels removed



+ Hipass filtering



Integrated time series



14-21 MHz

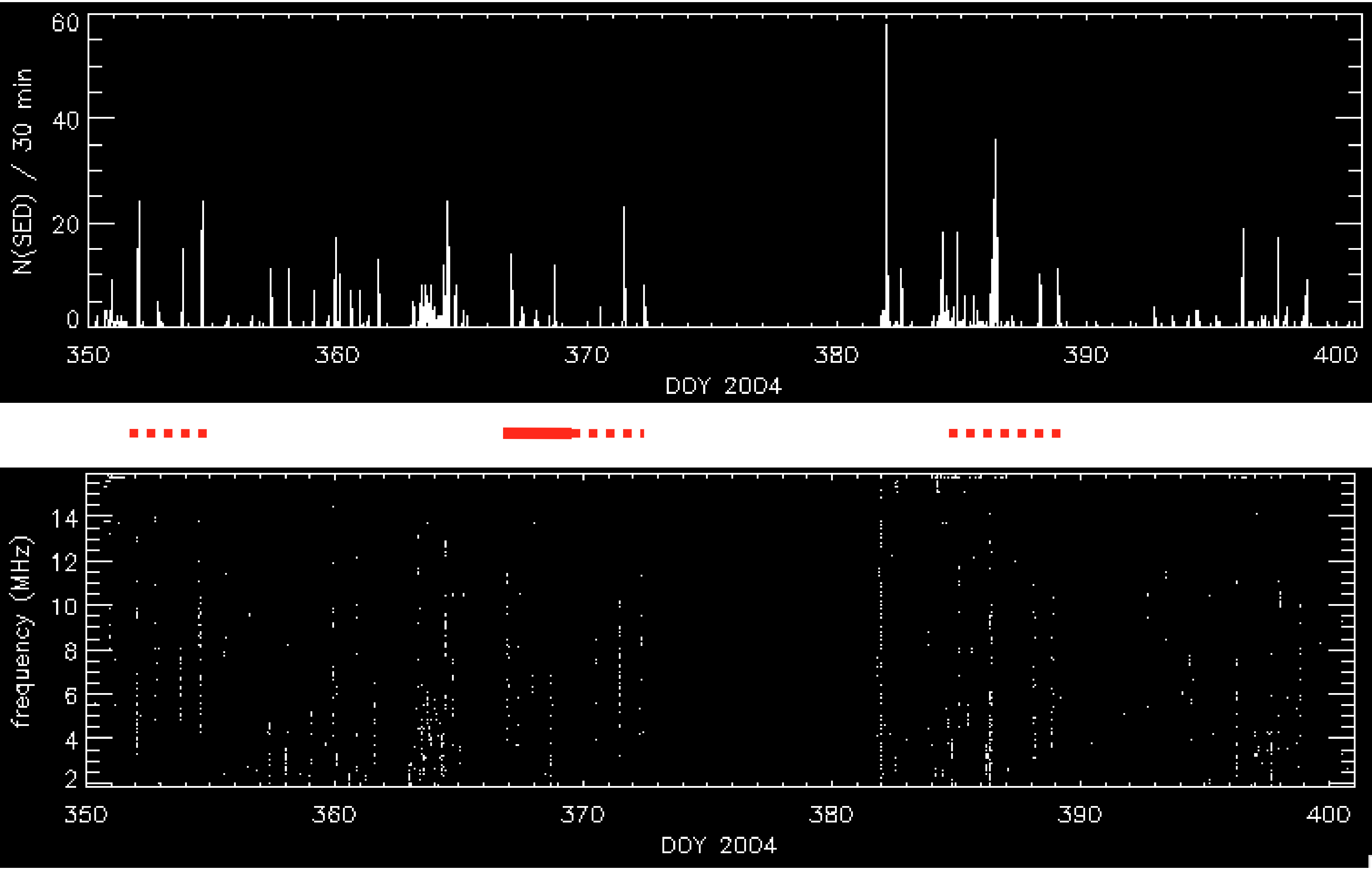
7-14 MHz

7-21 MHz

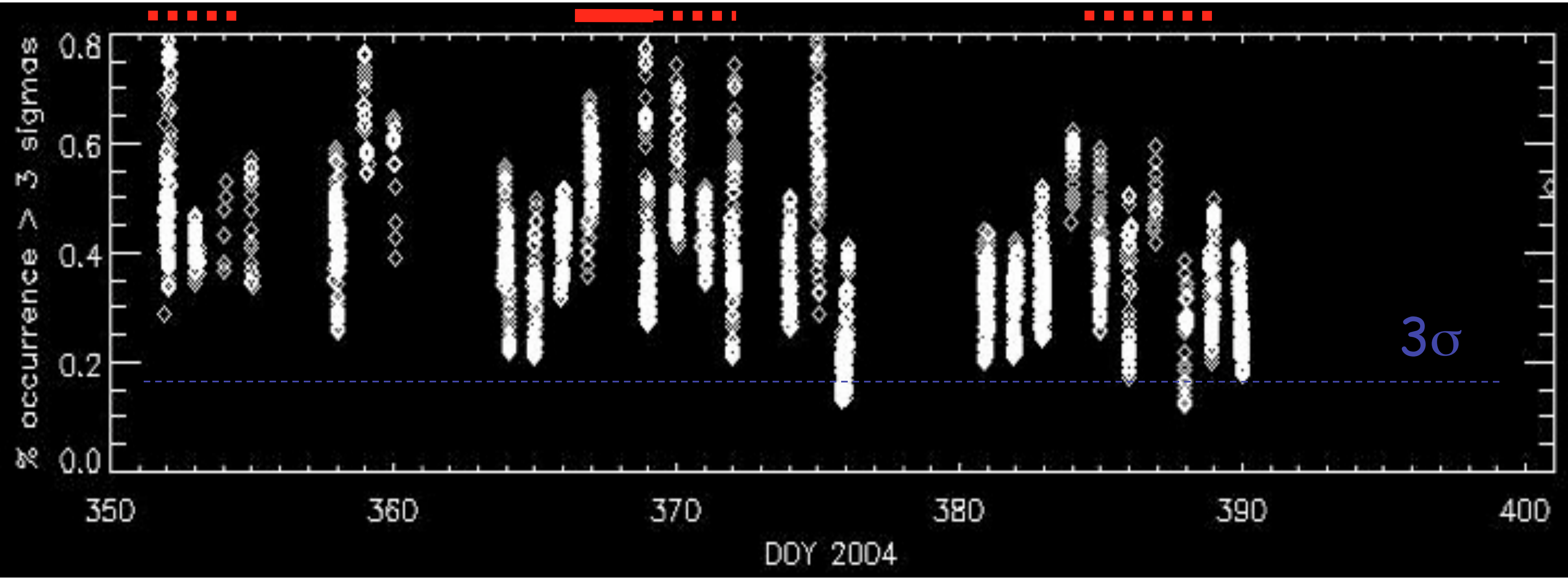
spectrum

Cassini/RPWS peak detection

16/12/2004 → 3/2/2005 : low activity

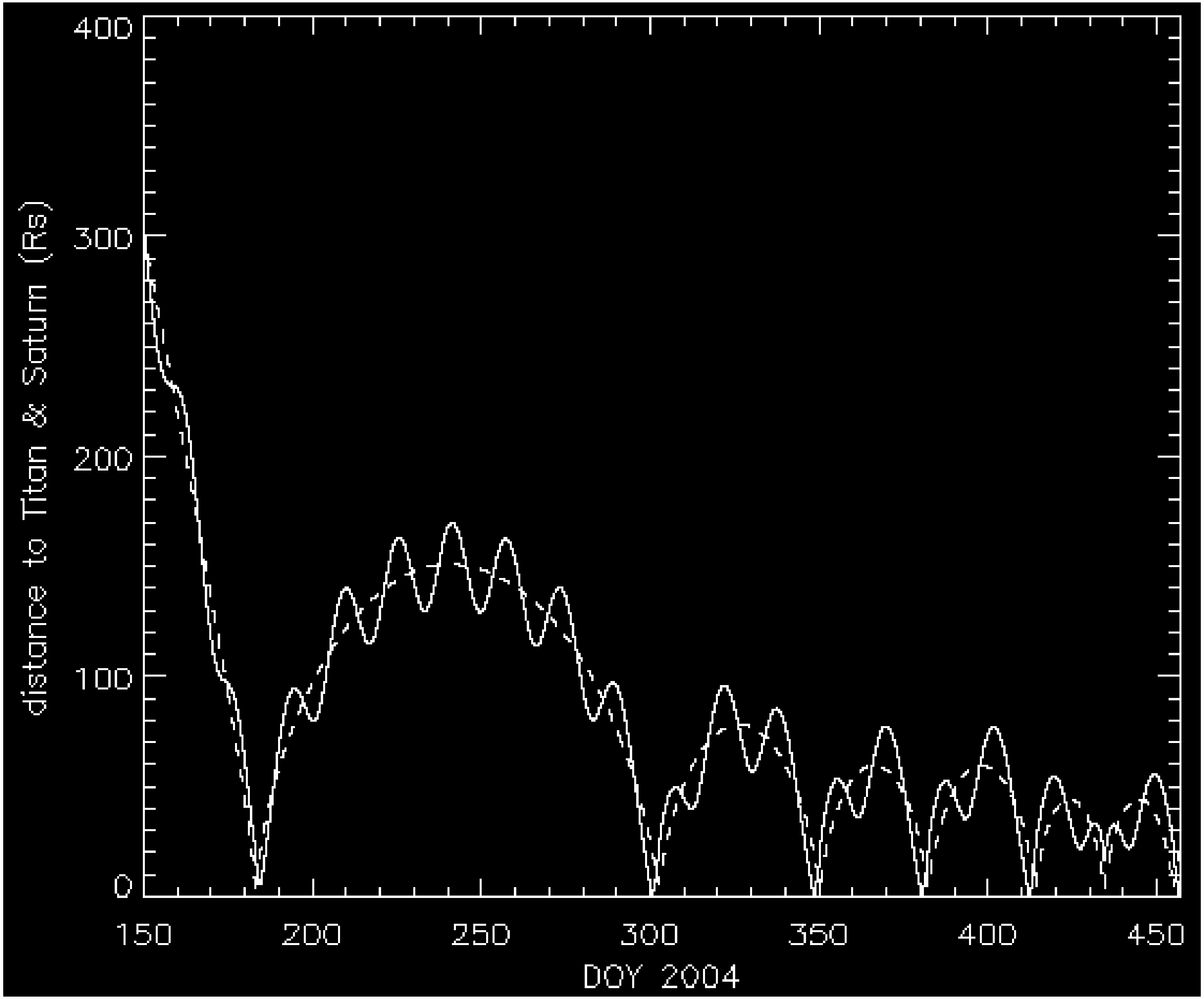


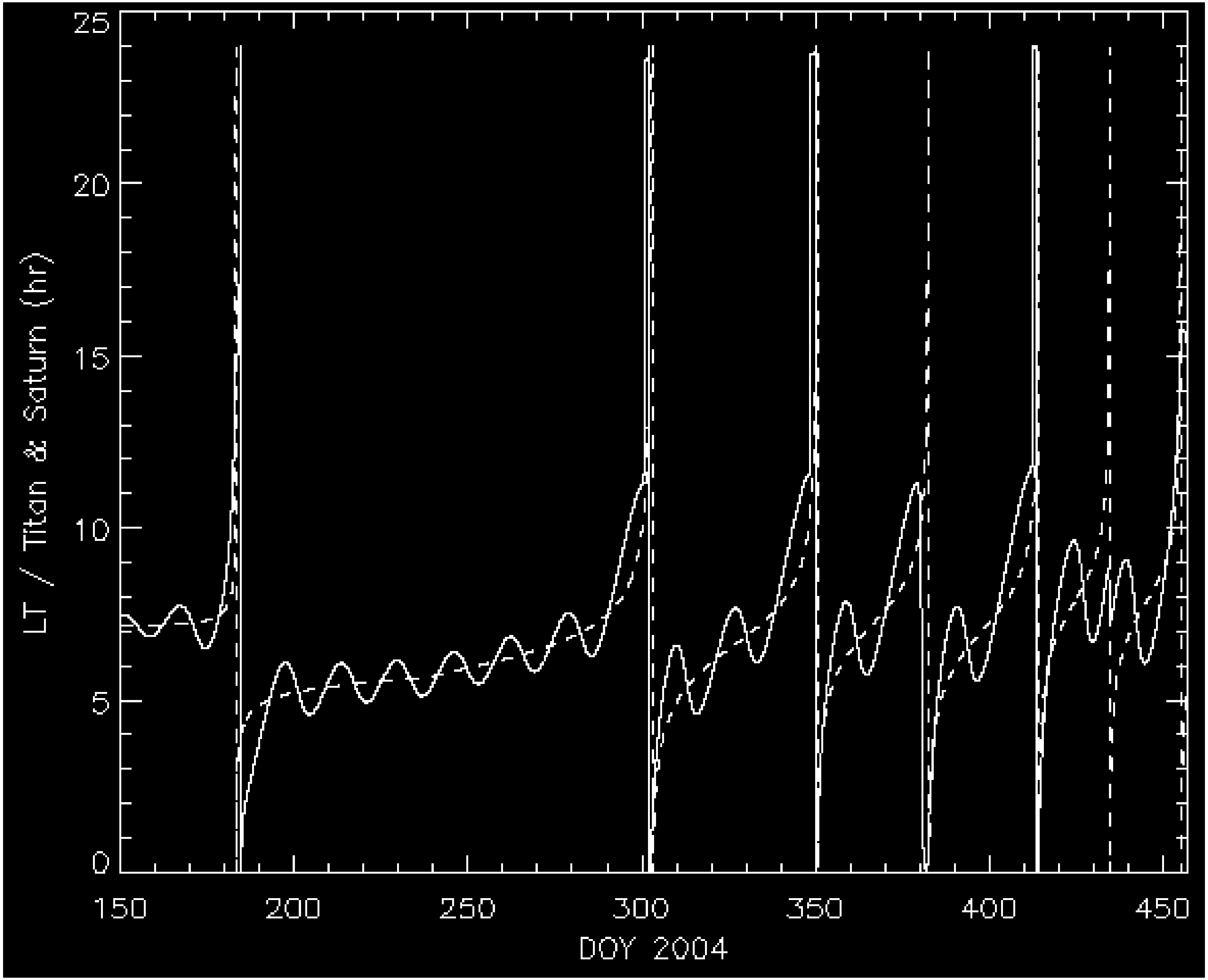
And concurrent Nançay (encouraging) results …



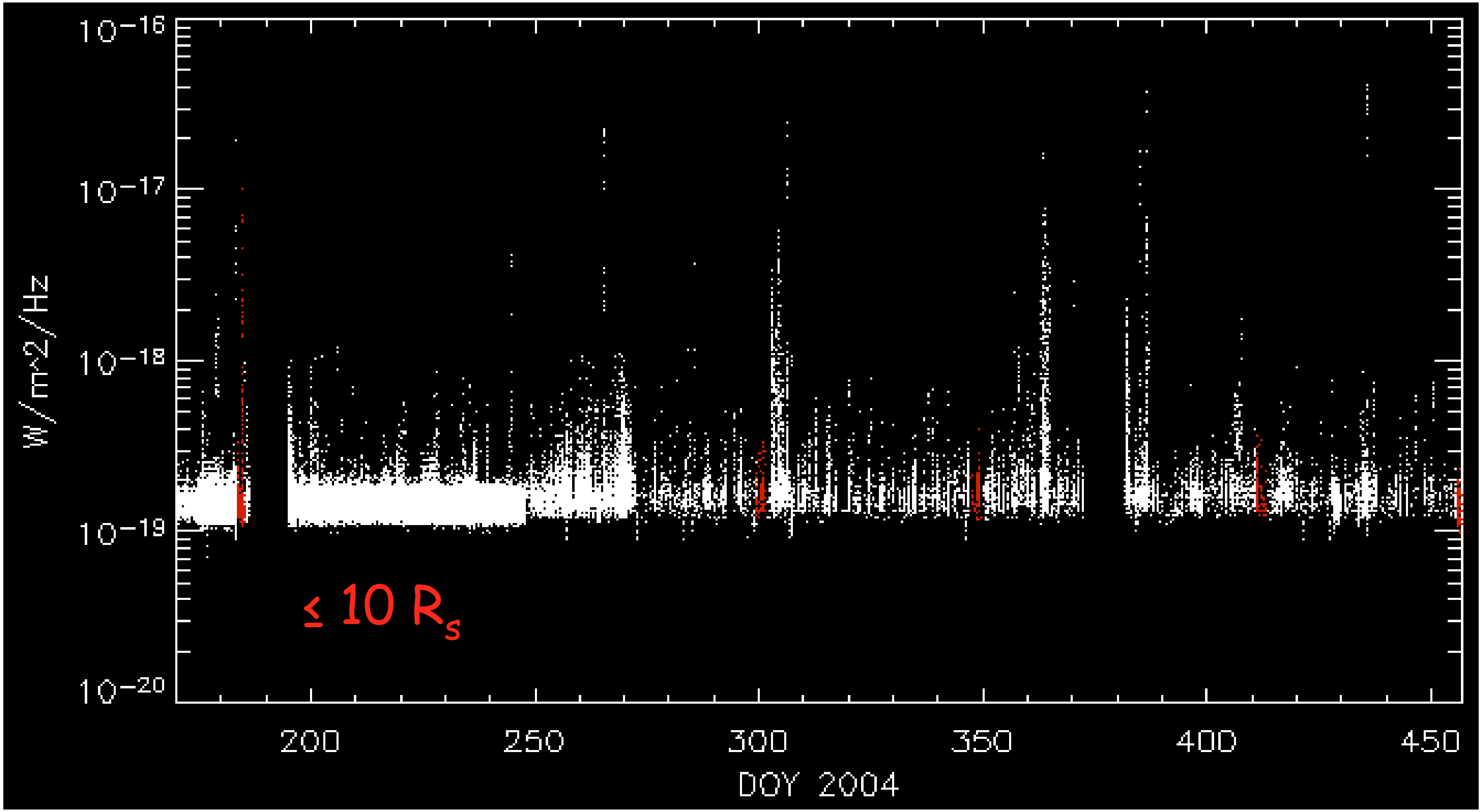
→ New observations when intense SED activity

Titan flybys

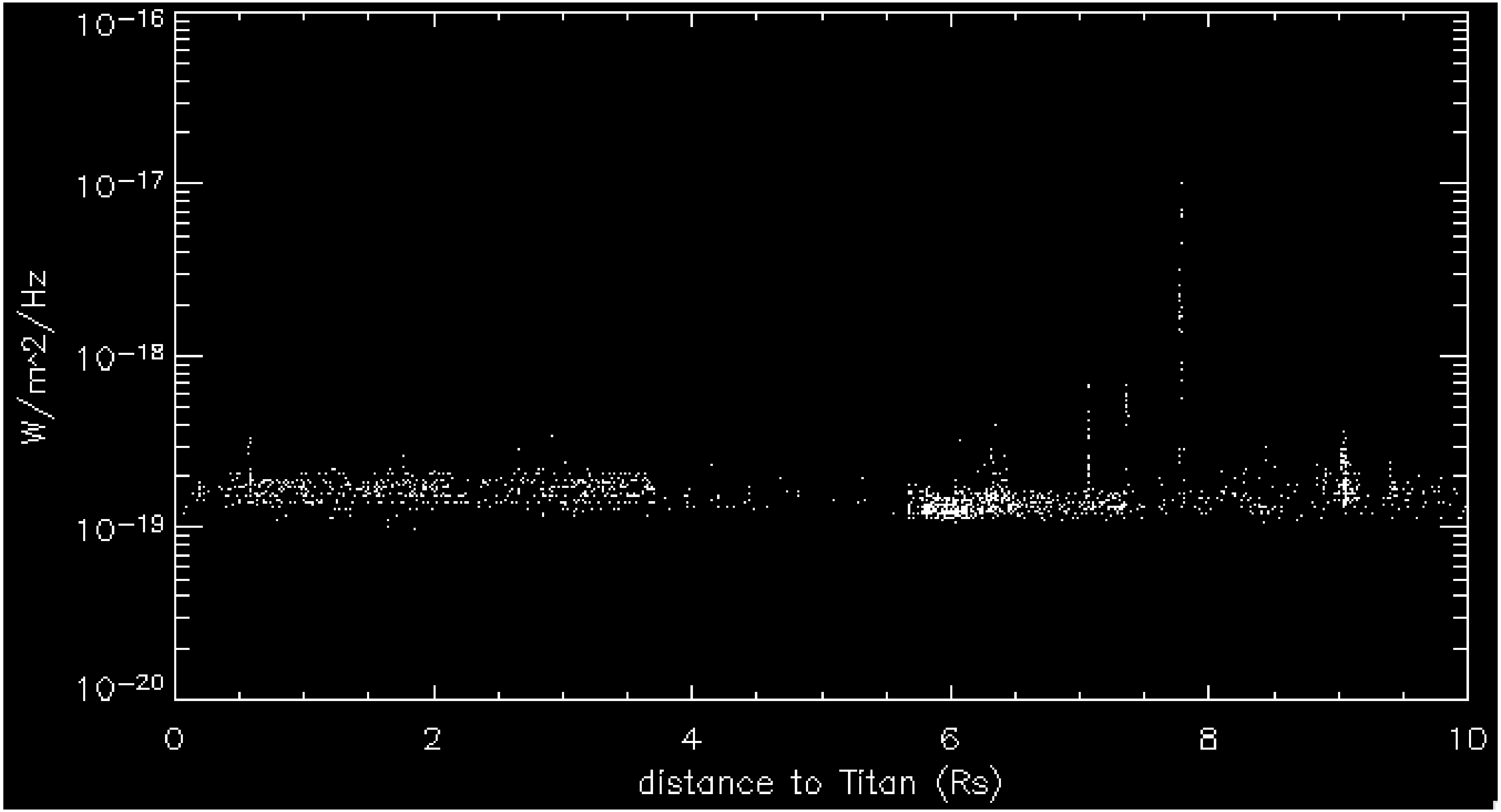



LT / Titan & Saturn (hr)
DOY 2004
0
5
10
15
20
25
150
200
250
300
350
400
450

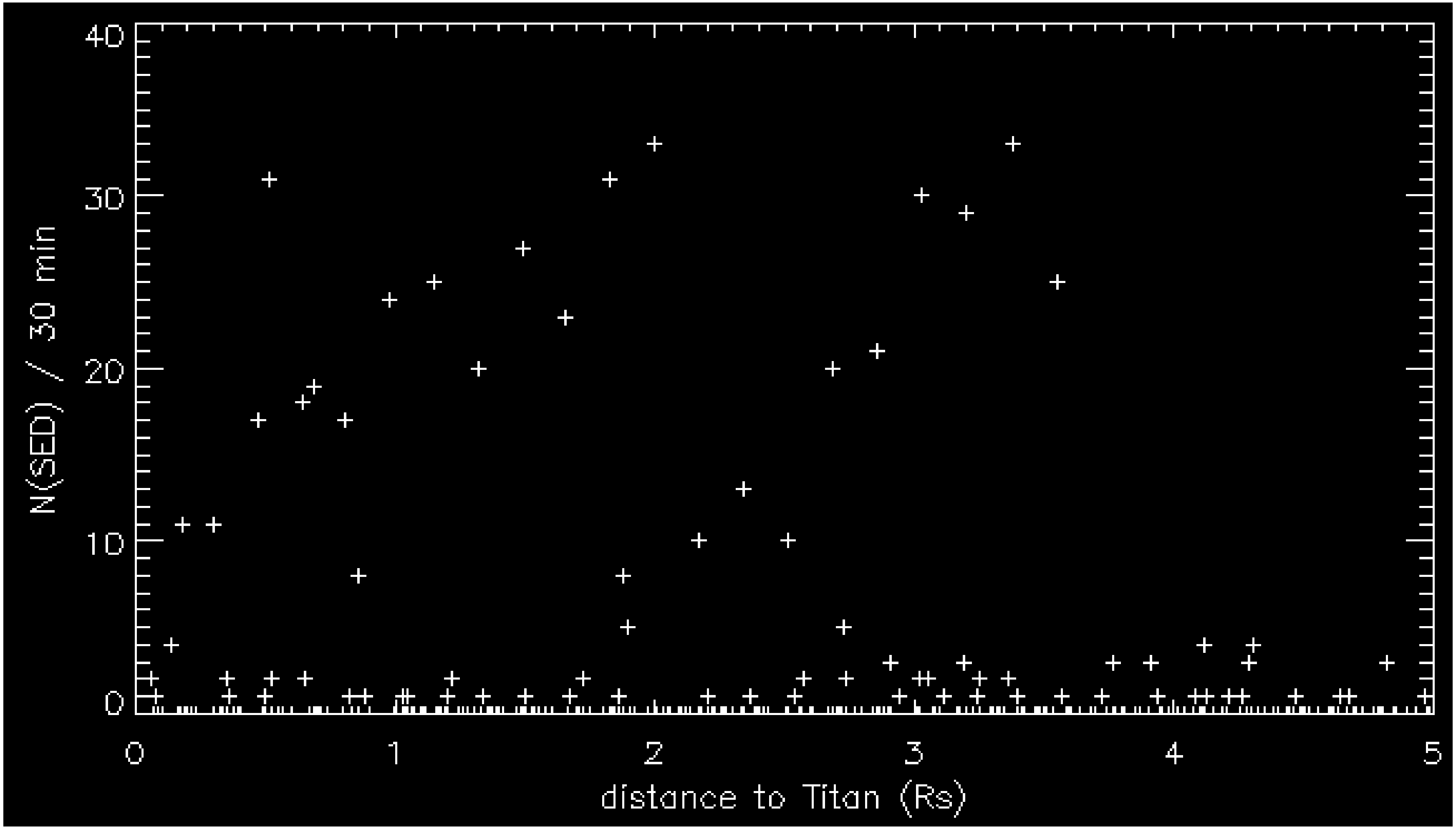
TED (Titan lightning) search



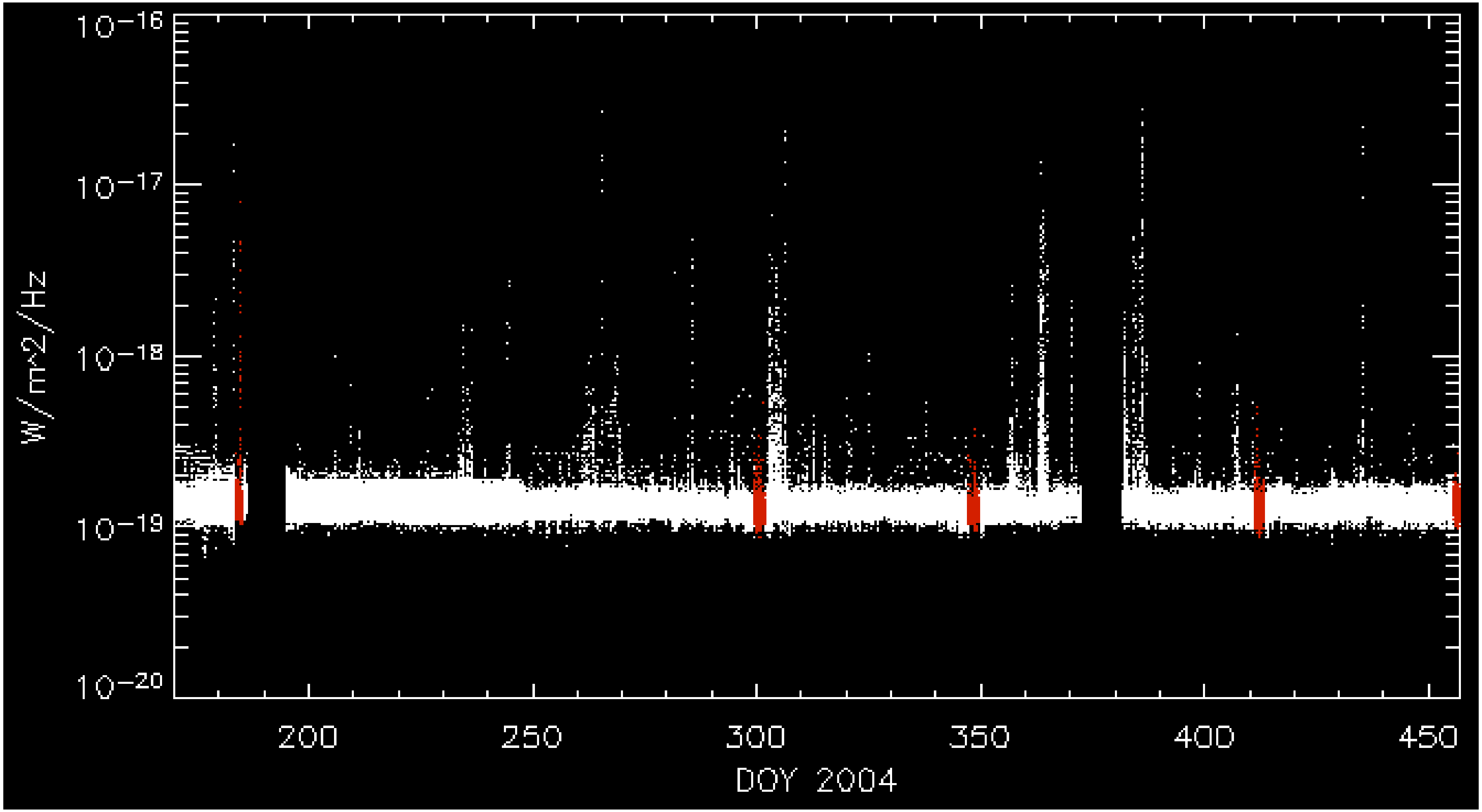
All Titan fly-bys, 1 dB threshold



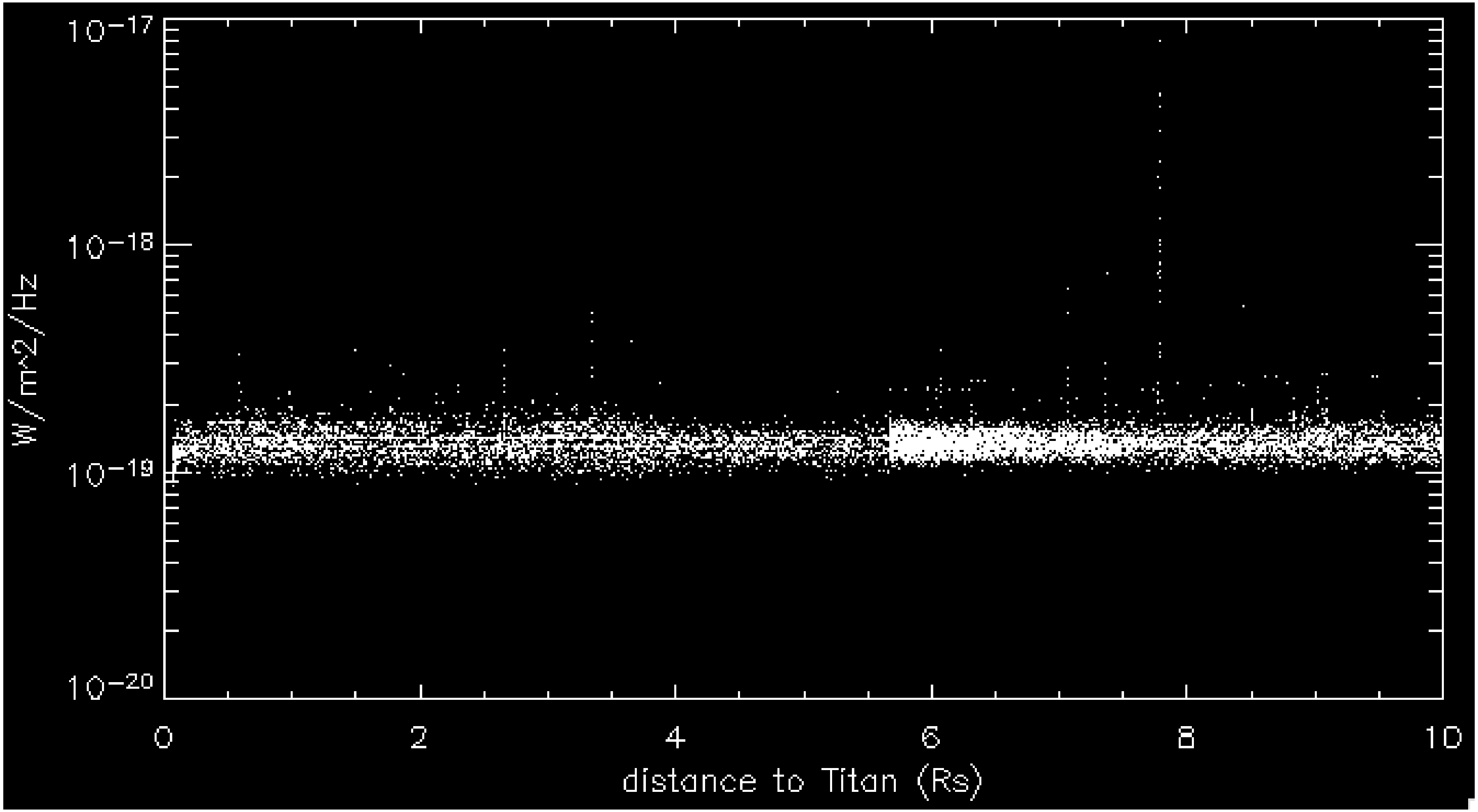
All Titan fly-bys, 1 dB threshold



All Titan fly-bys, 1 dB threshold



All Titan fly-bys, 0.8 - 1 dB range



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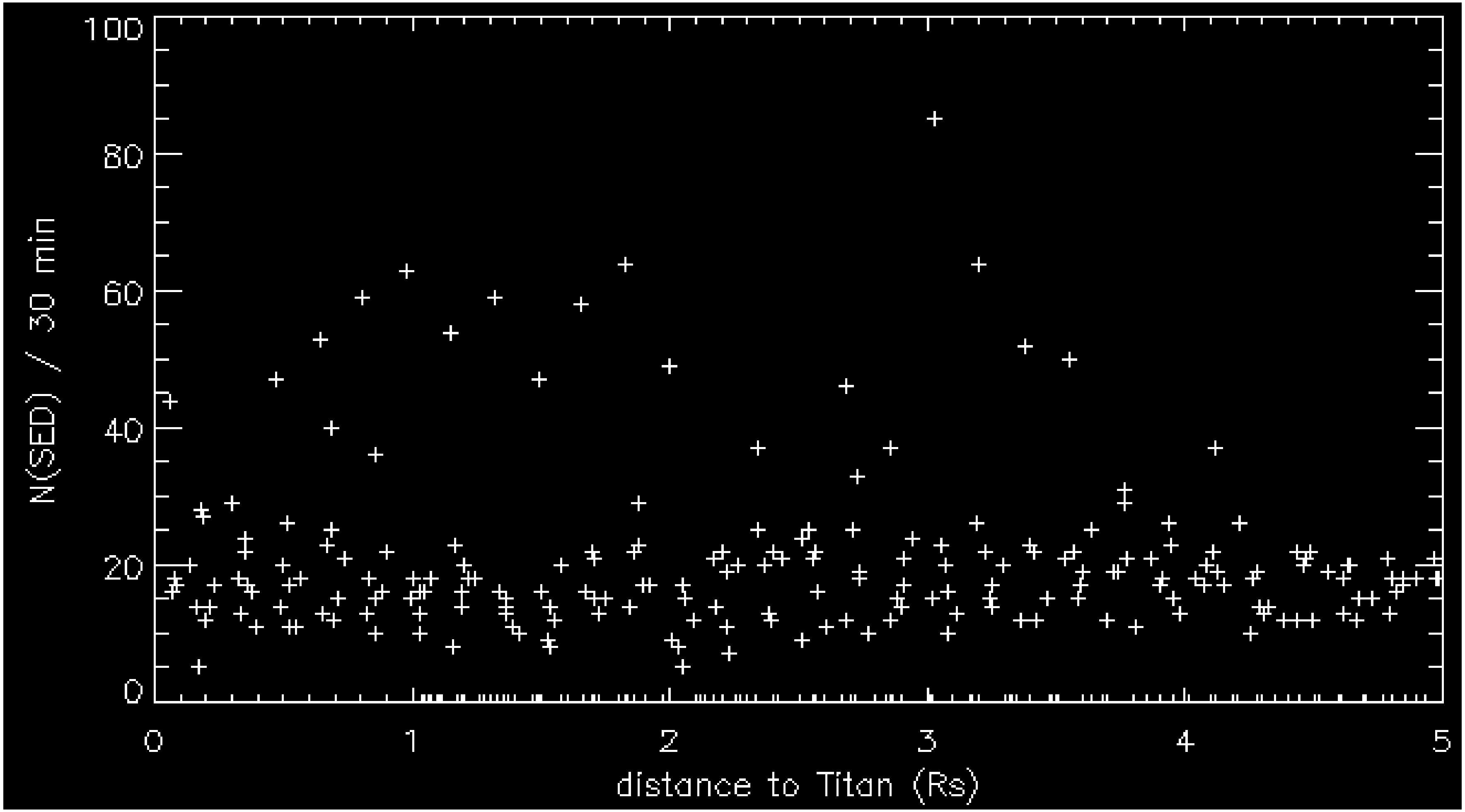
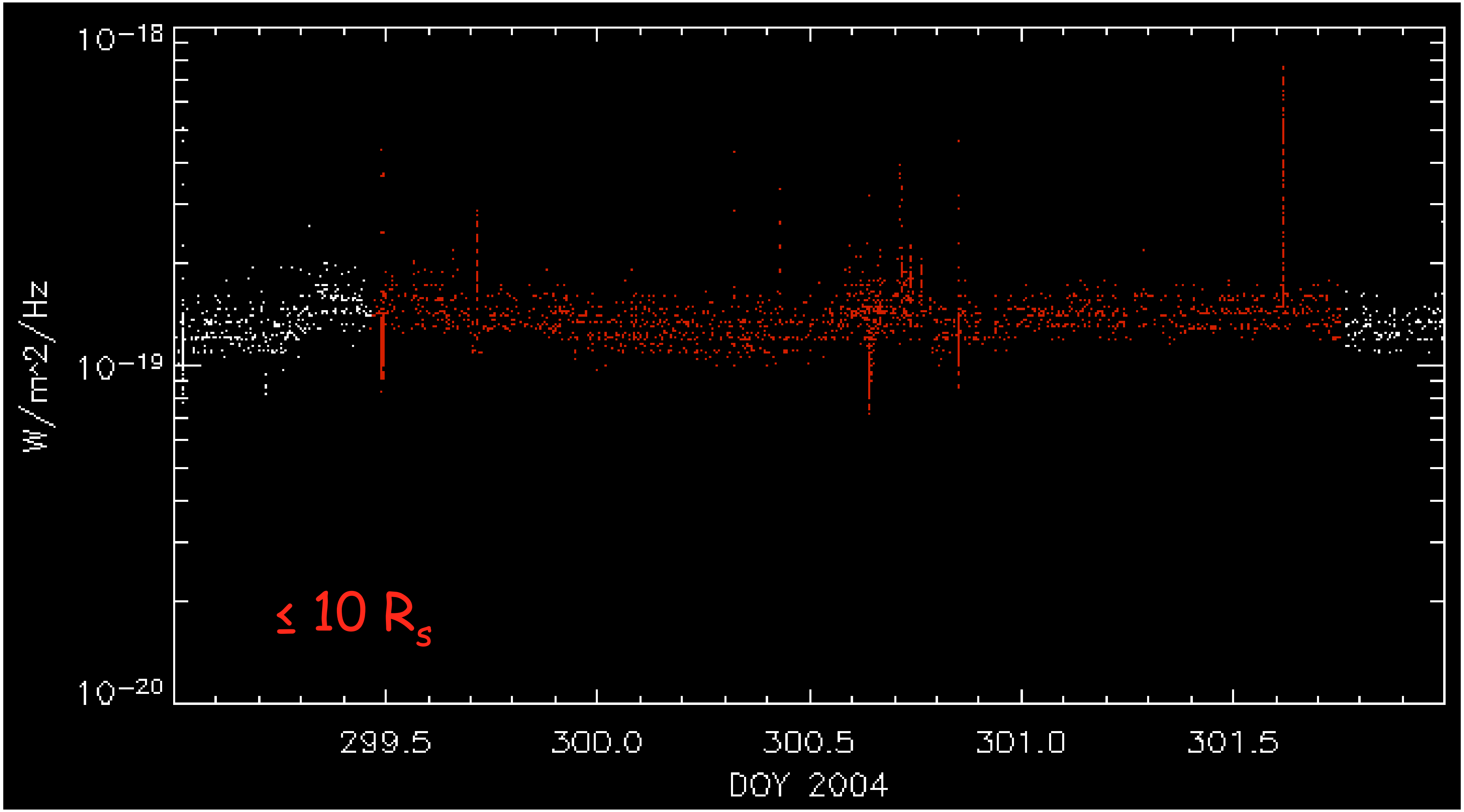
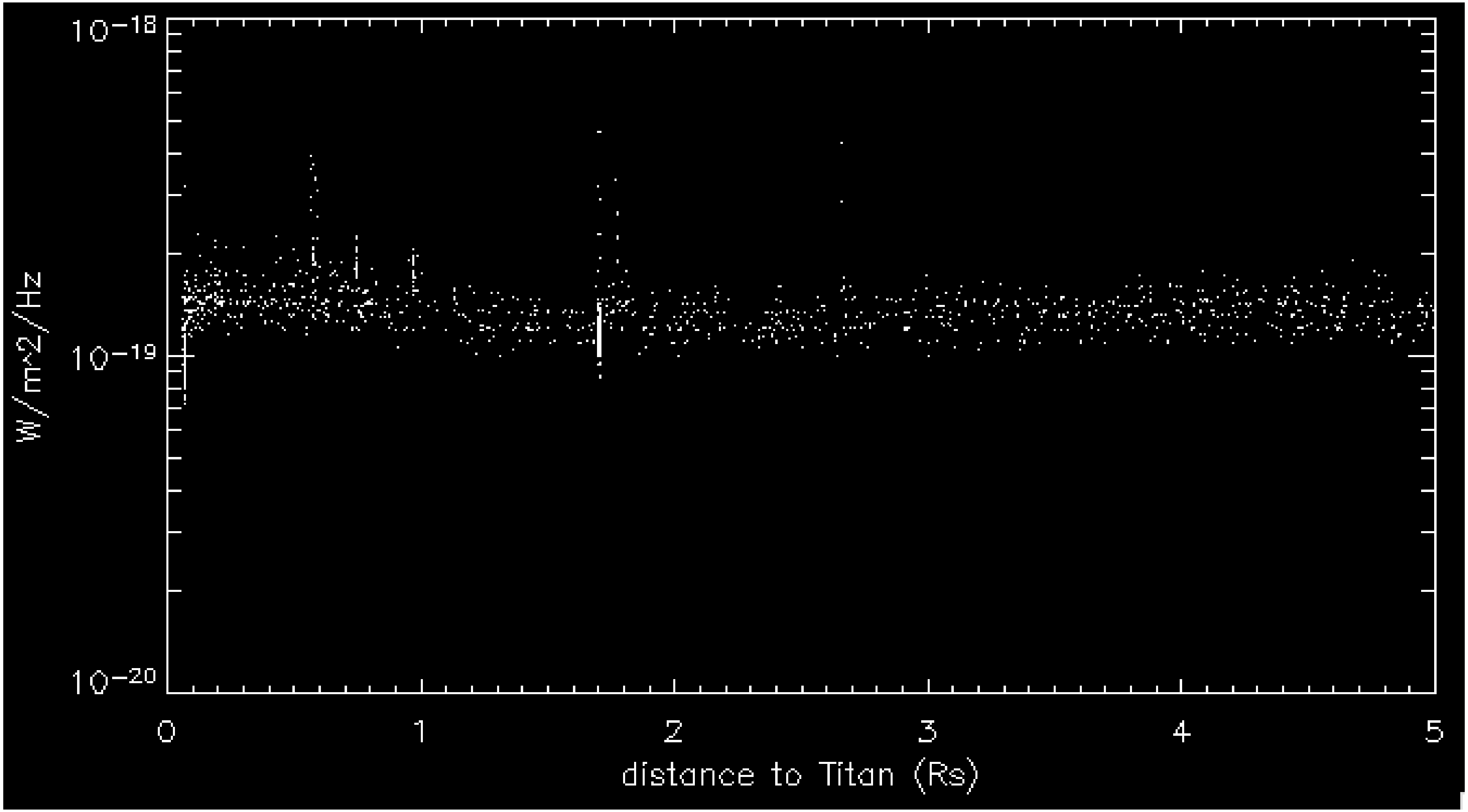


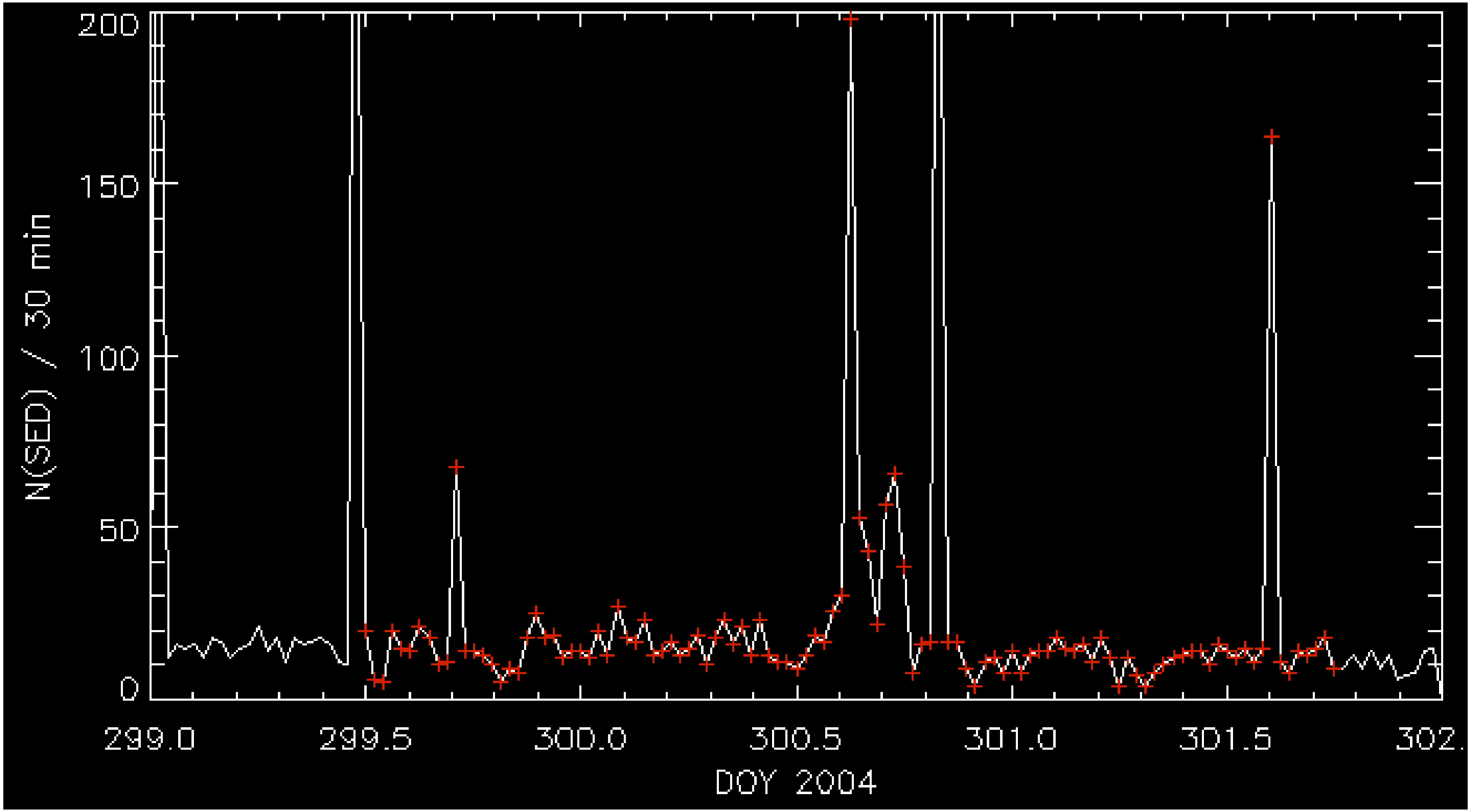
All Titan fly-bys, 0.8 - 1 dB range



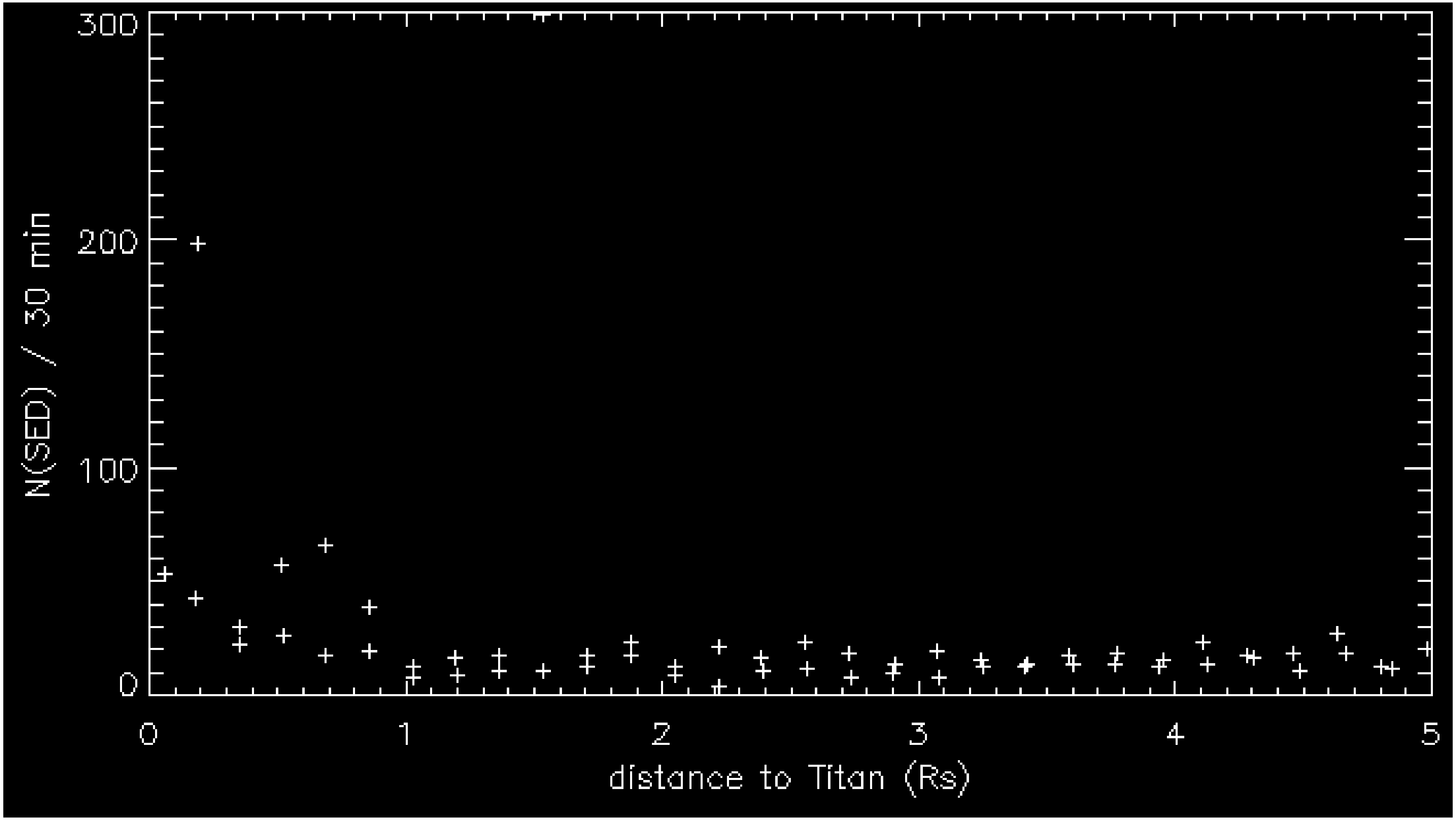
Ta fly-by, 1 dB threshold



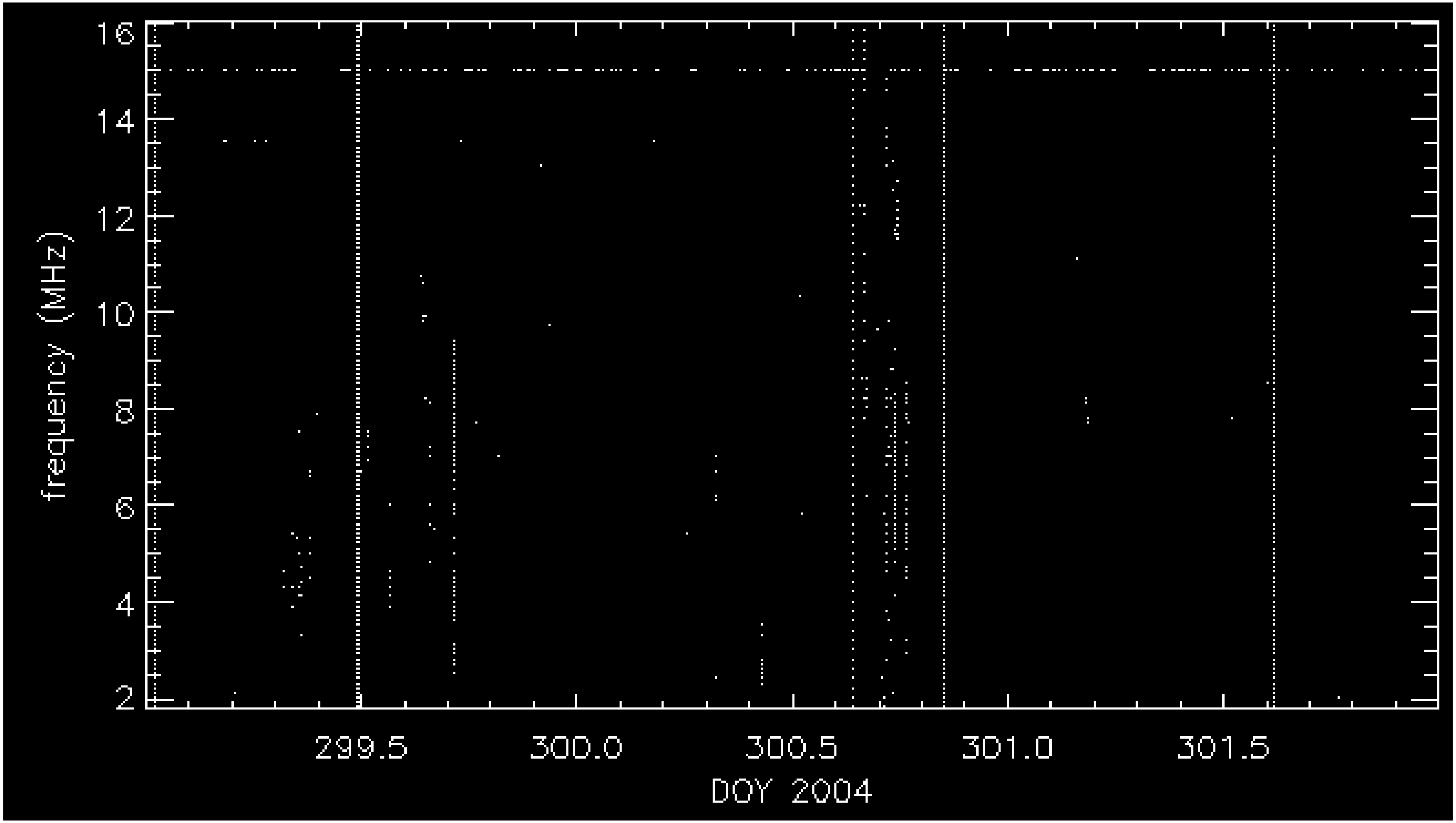
Ta fly-by, 1 dB threshold



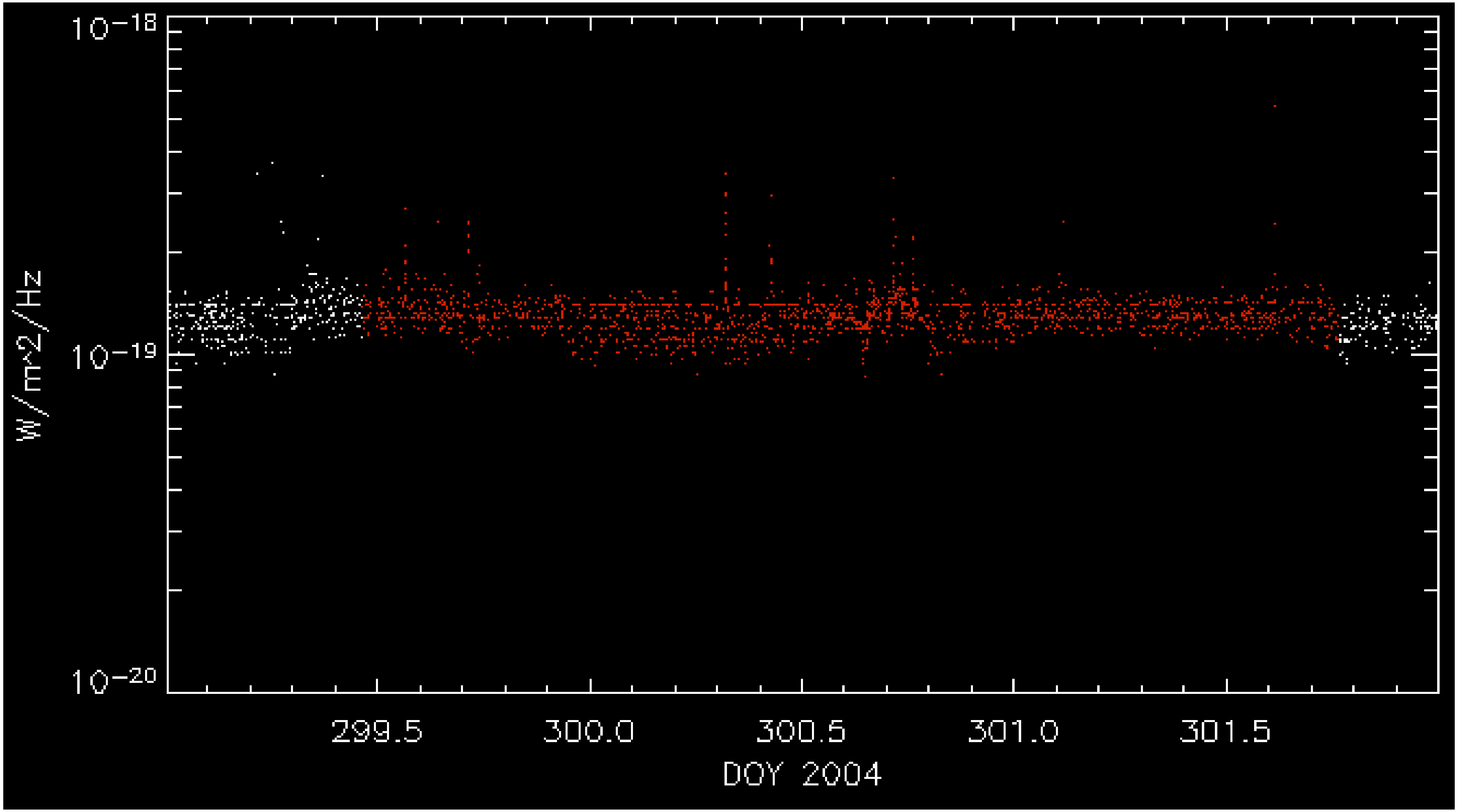
Ta fly-by, 1 dB threshold



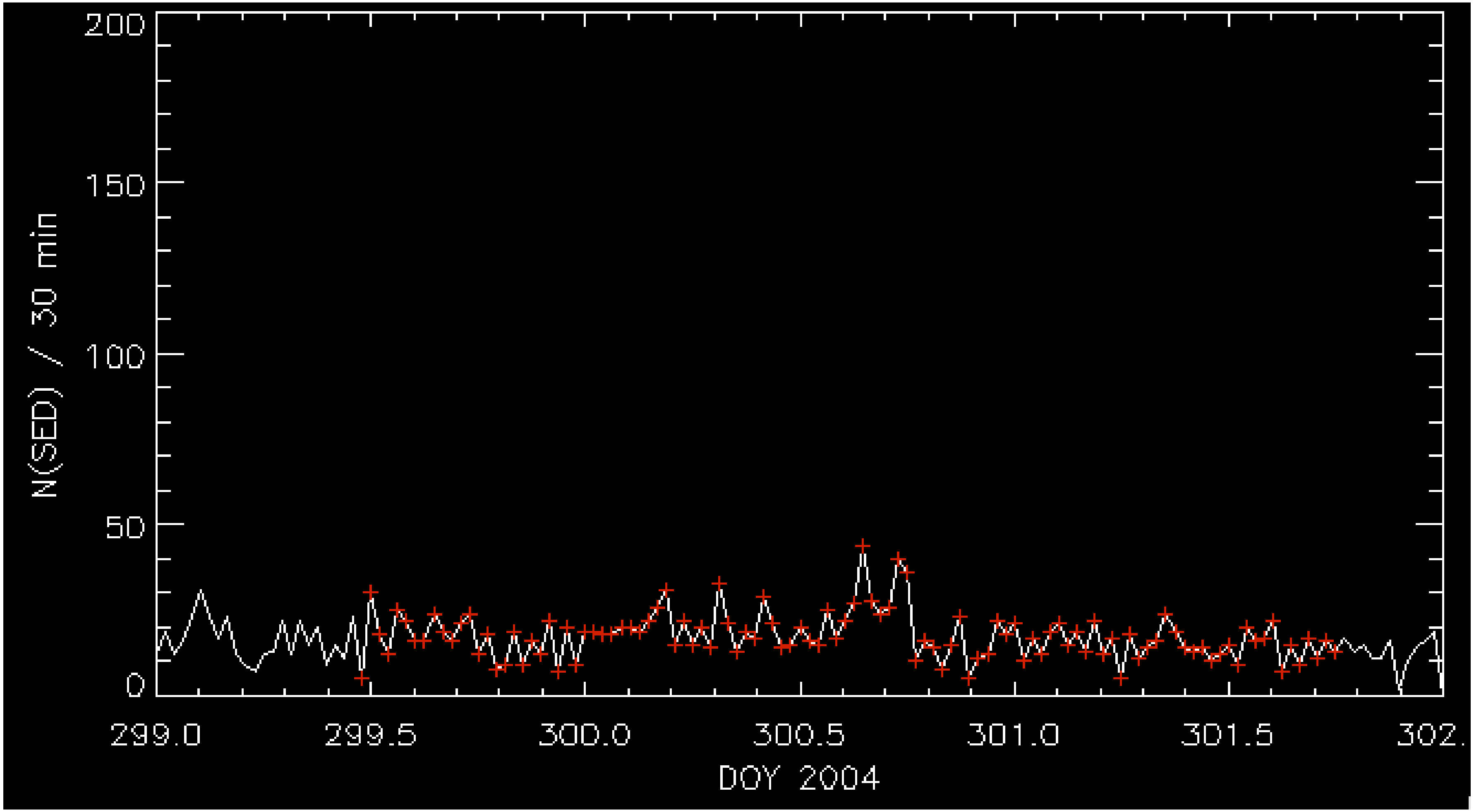
Ta fly-by, 1 dB threshold



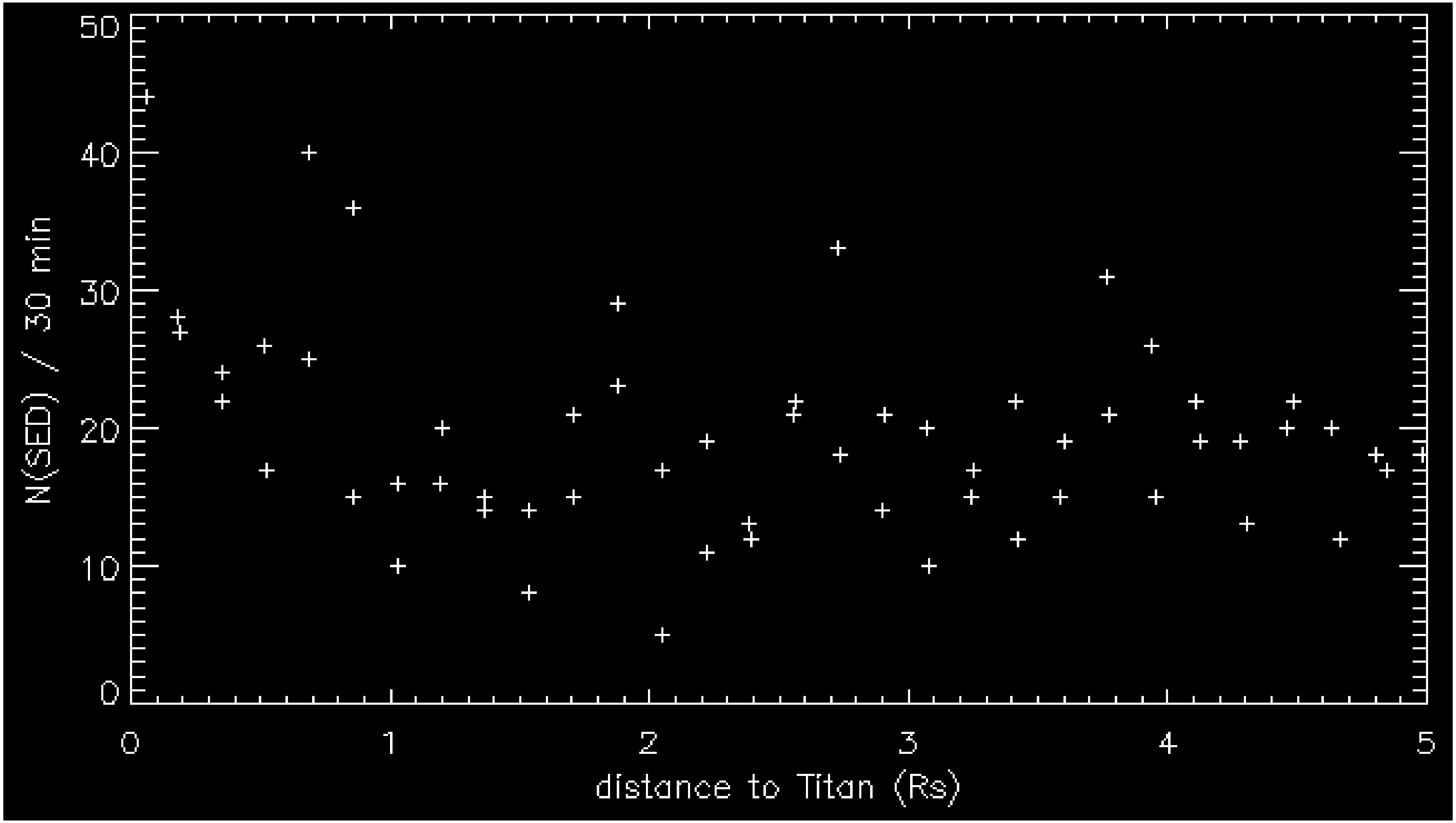
Ta fly-by, 1 dB threshold



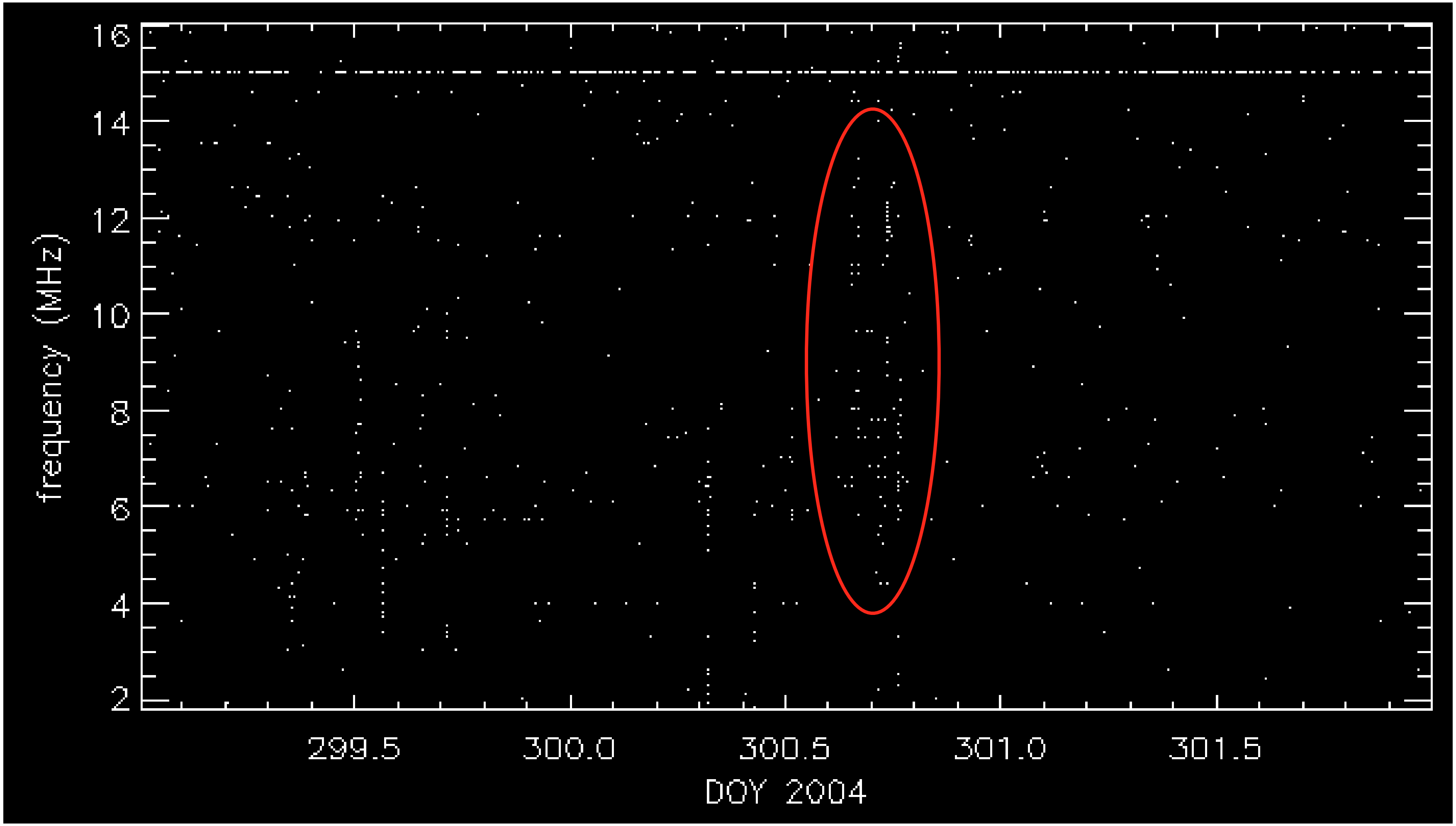
Ta fly-by, 0.8 - 1 dB range



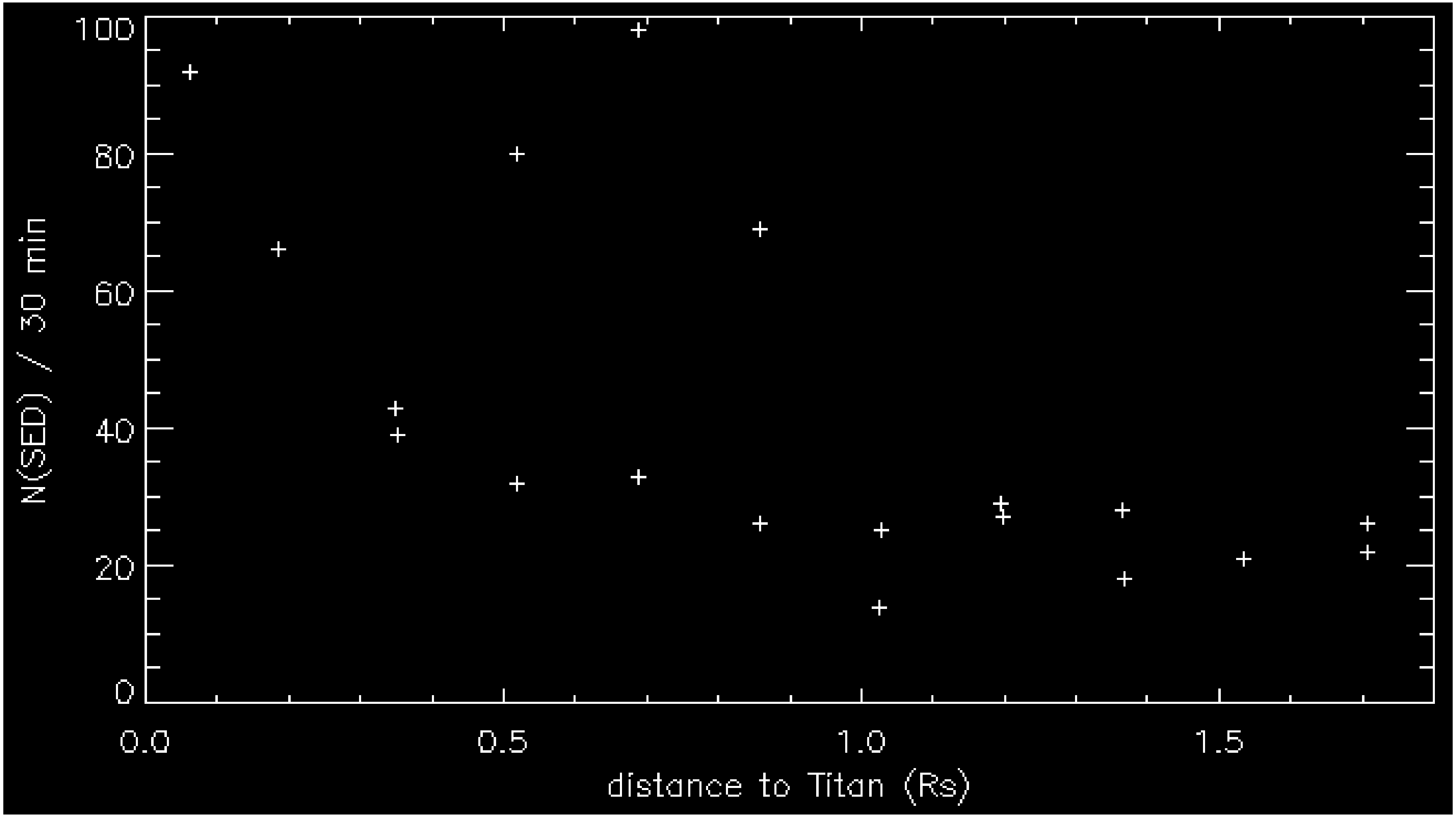
Ta fly-by, 0.8 - 1 dB range



Ta fly-by, 0.8 - 1 dB range

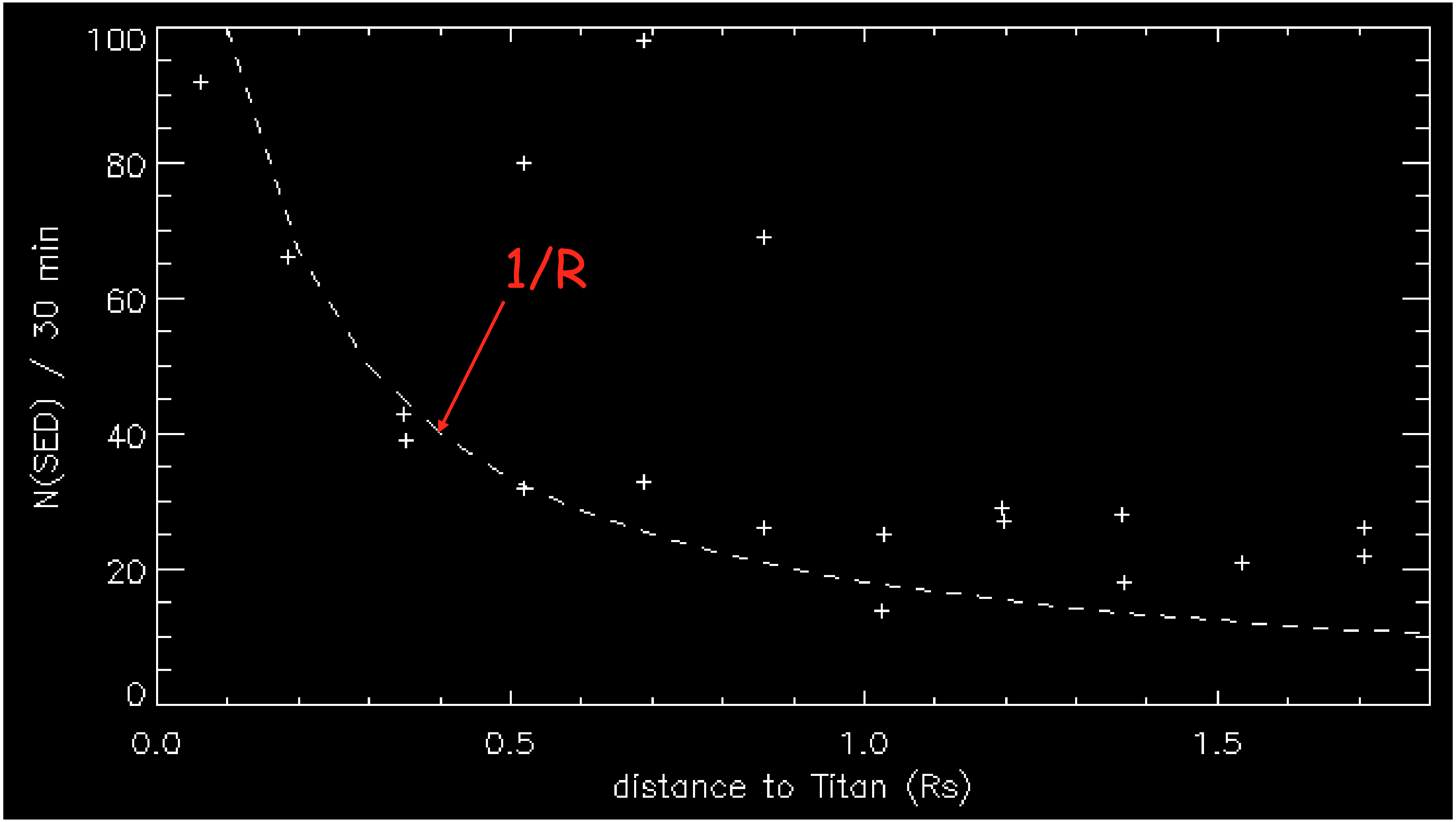


Ta fly-by, 0.8 - 1 dB range



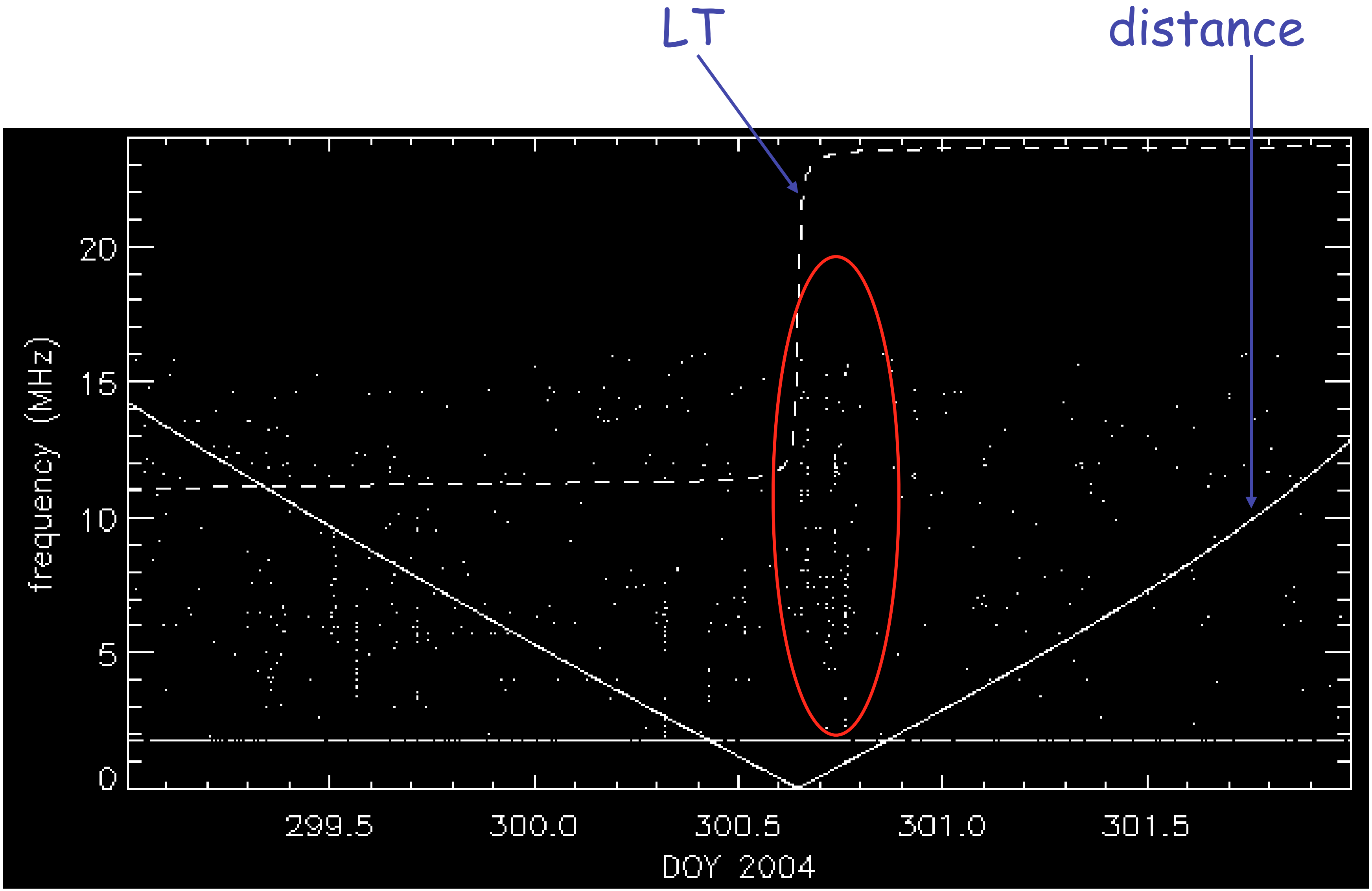
Ta fly-by, 0.8 dB threshold

15.025 MHz line removed

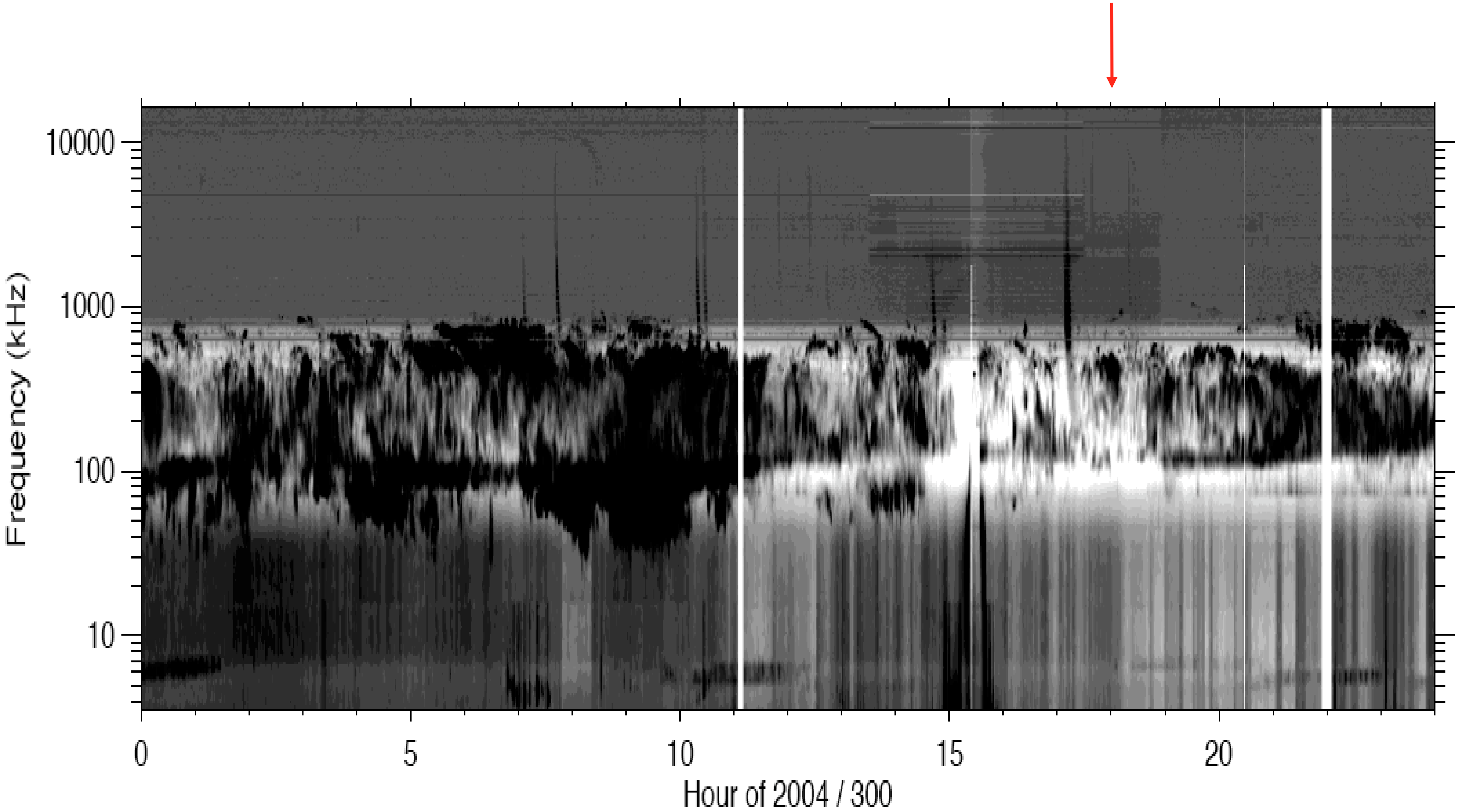


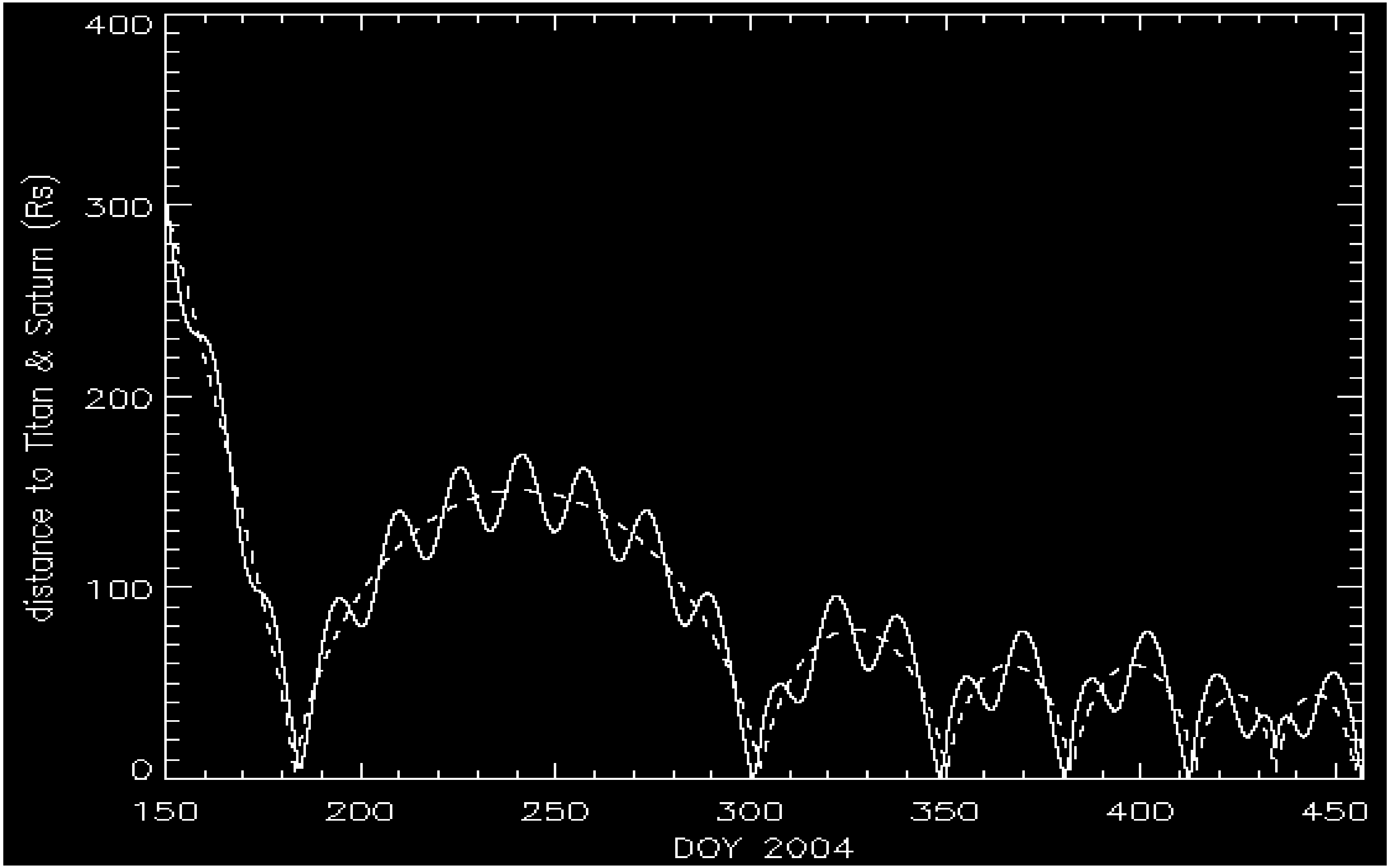
Ta fly-by, 0.8 dB threshold

15.025 MHz line removed


LT
distance
20
15
10
5
0
frequency (MHz)
299.5
300.0
300.5
301.0
301.5
DOY 2004

- to be confirmed (may still be a coincidence)
- explore low frequencies + DF



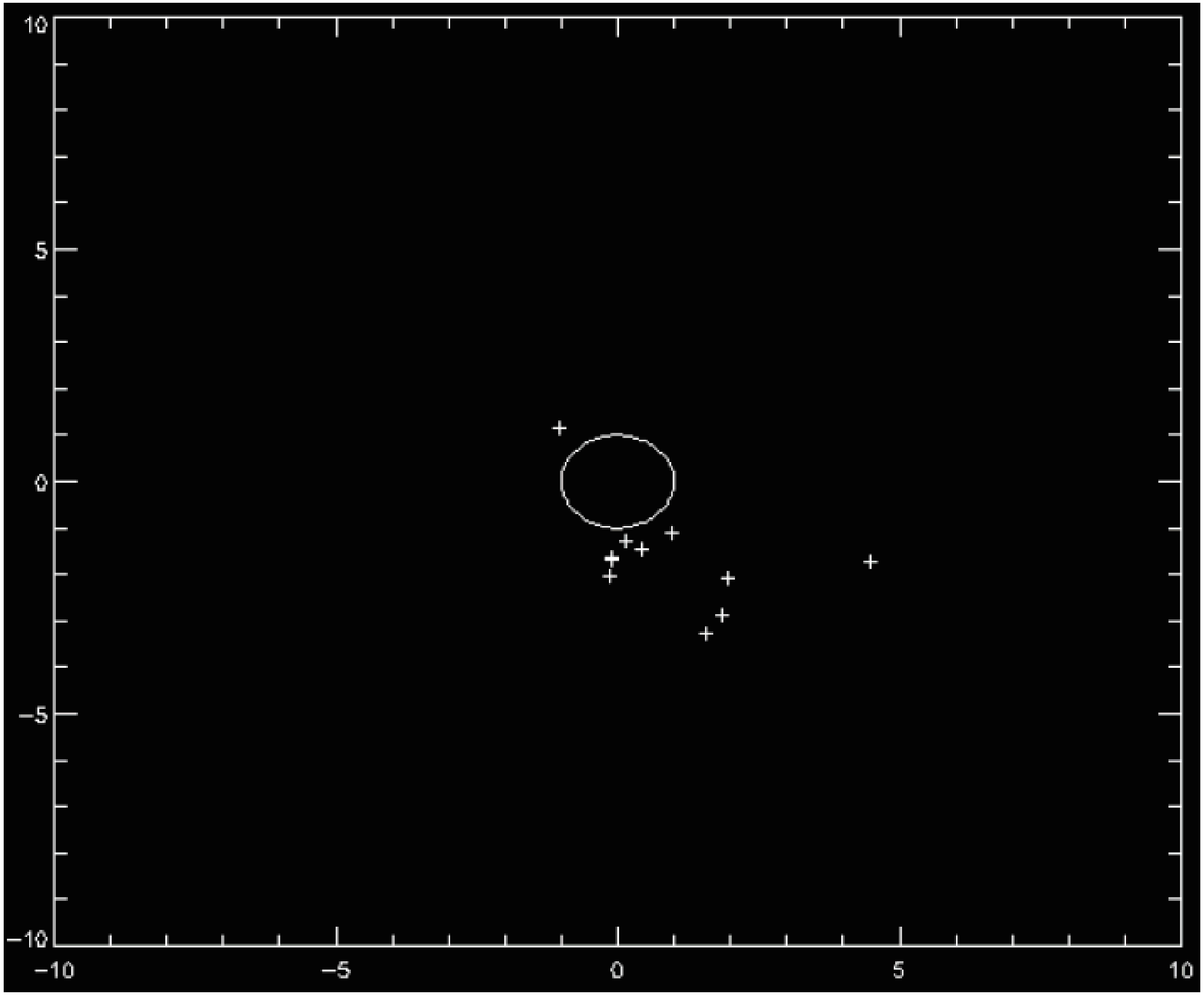


>5 R_s TED? marginal/polluted No No marginal

Preliminary conclusions

- RPWS is a powerful lightning detector
- SED properties similar to Voyager, different occurrence
- Ionospheric propagation effects
- More statistical studies + exploitation of RPWS-DF mode

Preliminary DF results on SED



f~1.825 MHz, S/N>20, 80 msec integration, mostly ~SOI: 2004/181-183

Preliminary conclusions

- RPWS is a powerful lightning detector
- SED properties similar to Voyager, different occurrence
- Ionospheric propagation effects
- More statistical studies + exploitation of RPWS-DF mode
- 40 close Titan flybys to come → TED confirmation ?
- Intense SED episodes detectable from the ground ?
- New ground-based observations when intense SED activity

® lightning physics, atmospheric & ionospheric physics

® testbed for LF ground-based observations at high sensitivity