Decay Times for Interplanetary Type III : observations, simulations and questions

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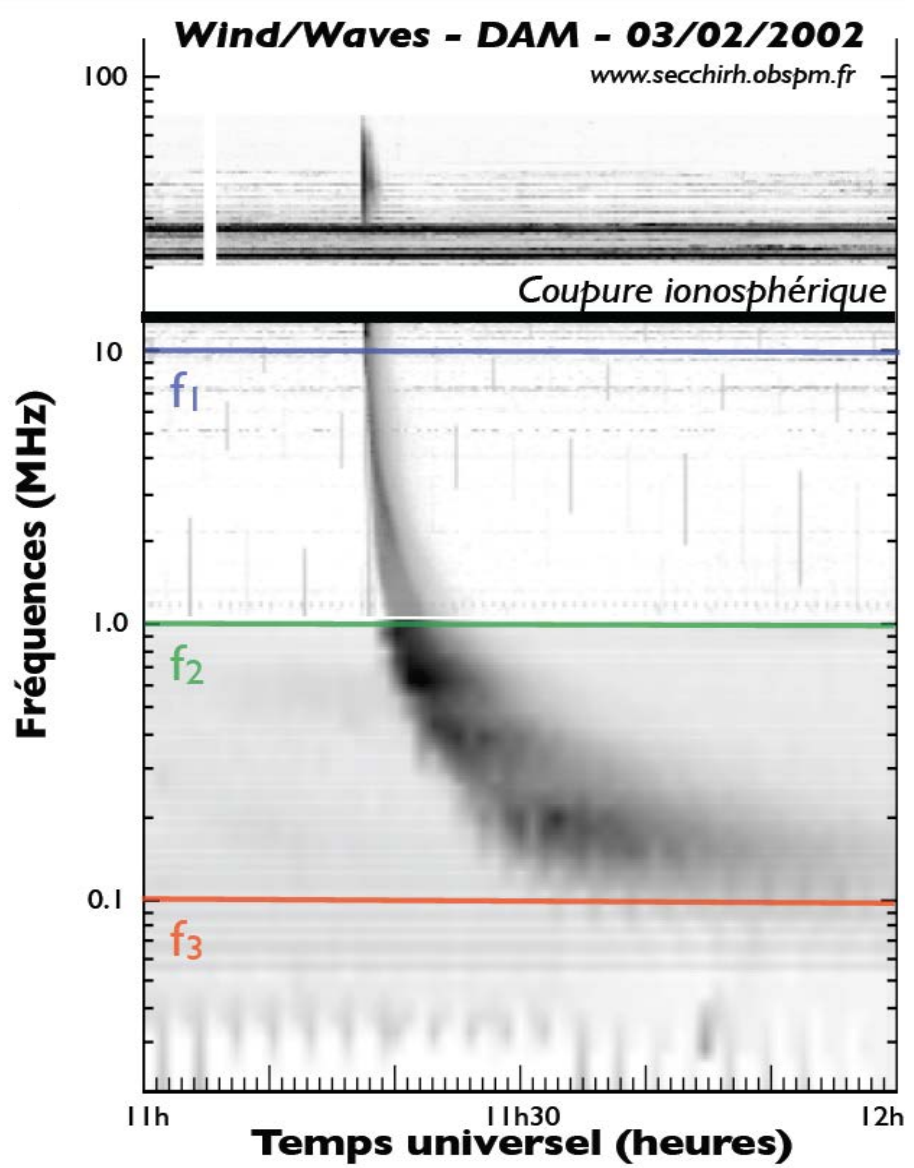
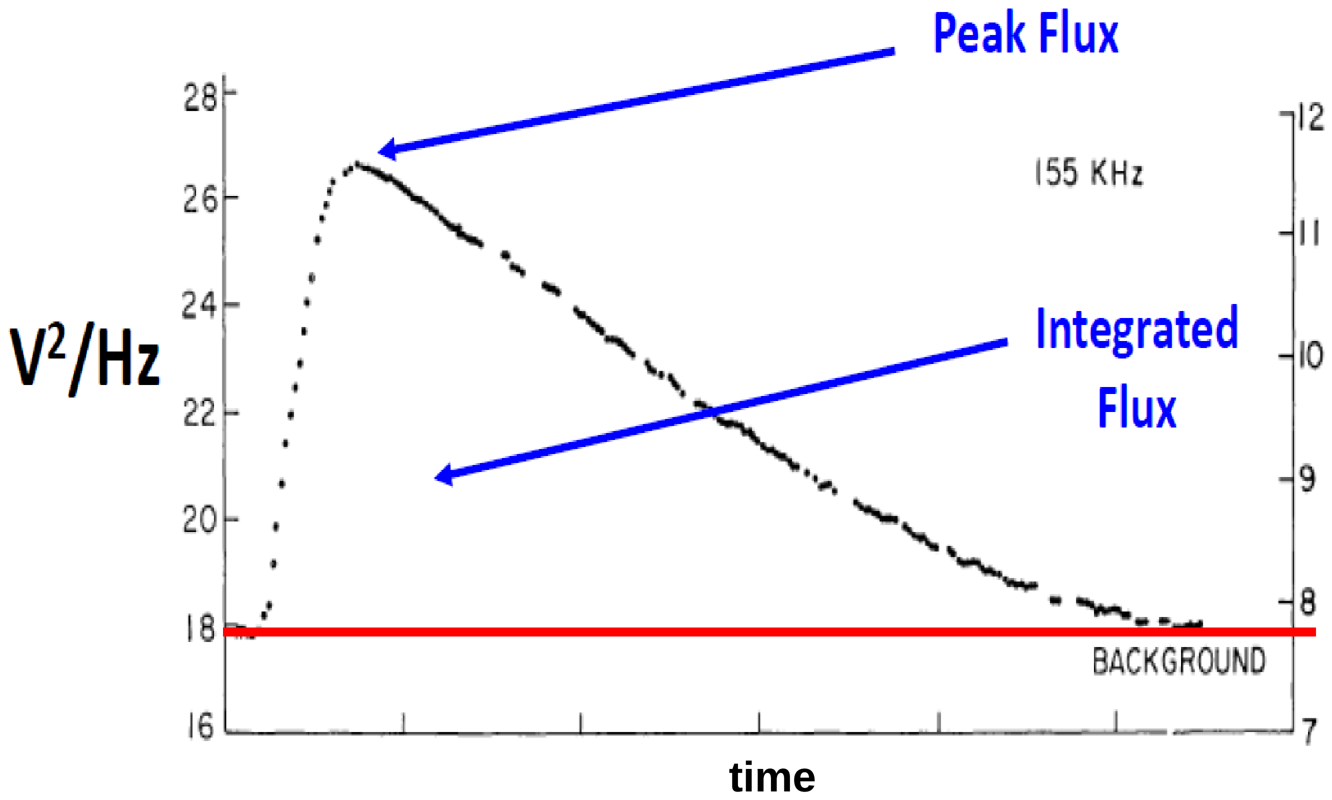
presented by M. Maksimovic & R. Fumachi

Meudon-Glasgow Alliance Meeting-May 2017

Type III Solar Bursts

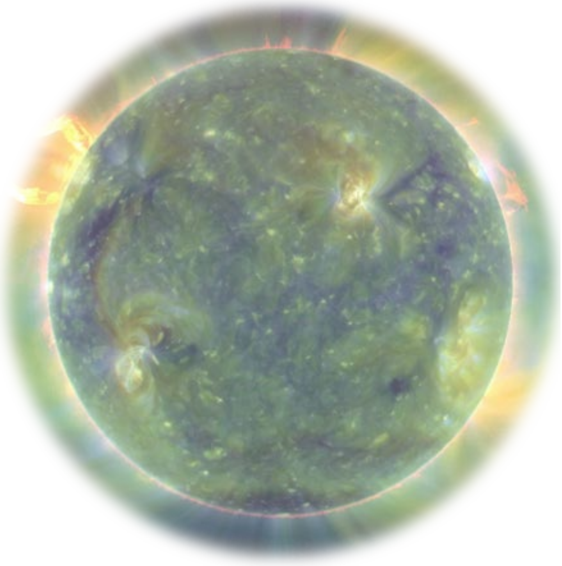


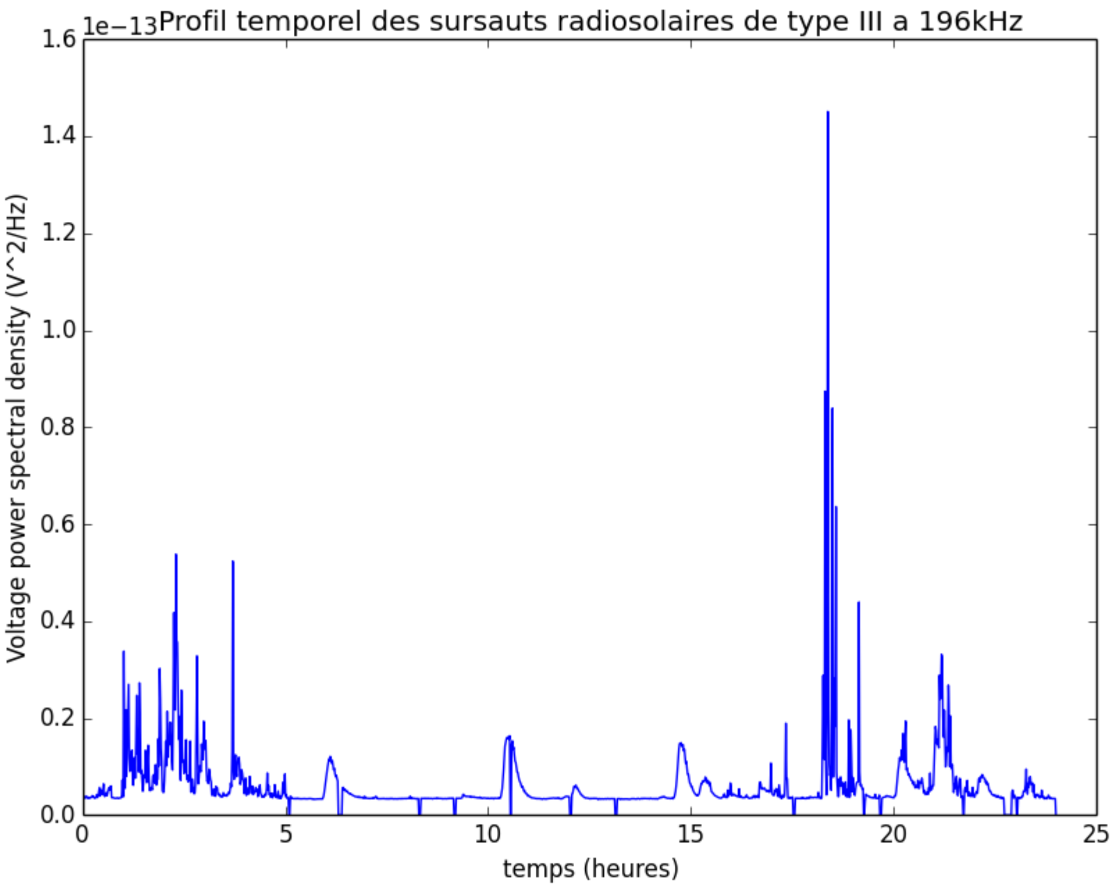
- Short (sec → hrs) & very intense (→10^{-14} $W.m^{-2}.Hz^{-1}$) radio emissions
- Emission frequency decreases rapidly (GHz → kHz).
- Type profile exhibit both increase and decrease exponential times
- With $P(t) = P_0 e^{-t/\tau_D}$ for the decay part Evans (1973) found $\tau_D(f) \propto f^{-1.09\pm0.05}$



Decay time of type III solar radio bursts by WIND at low frequencies

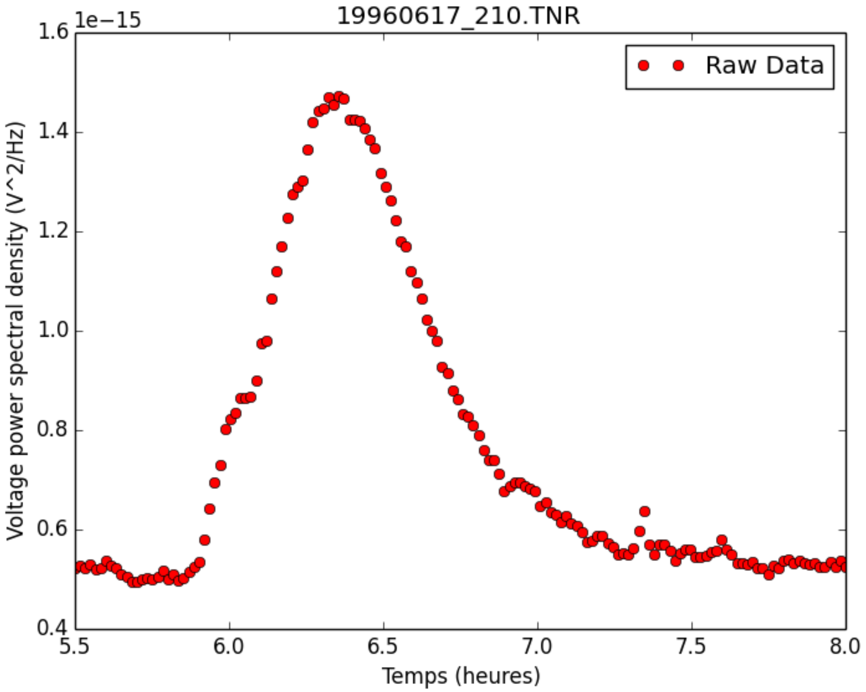
by Ricardo Fumachi, Master 1 Internship at LESIA

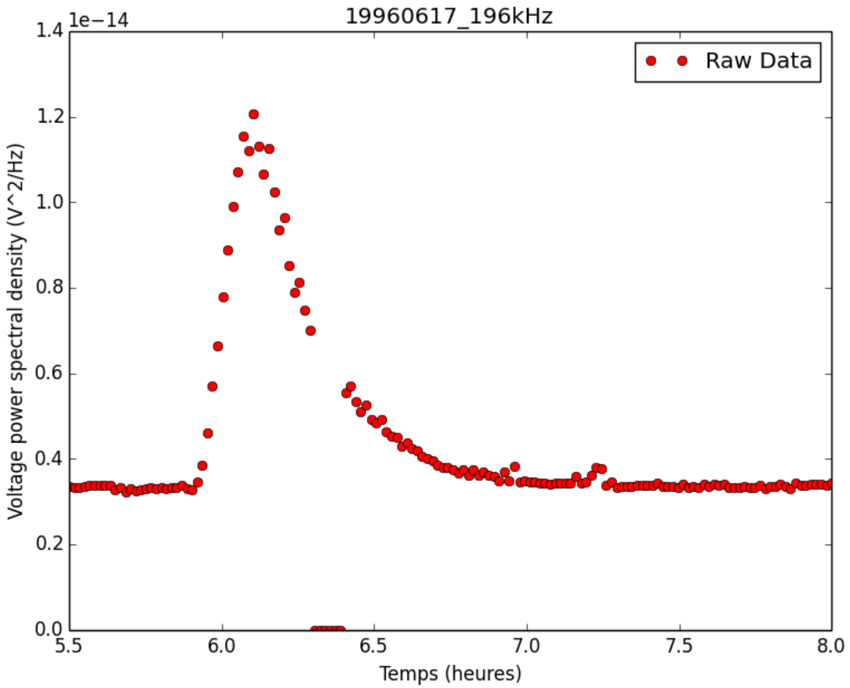




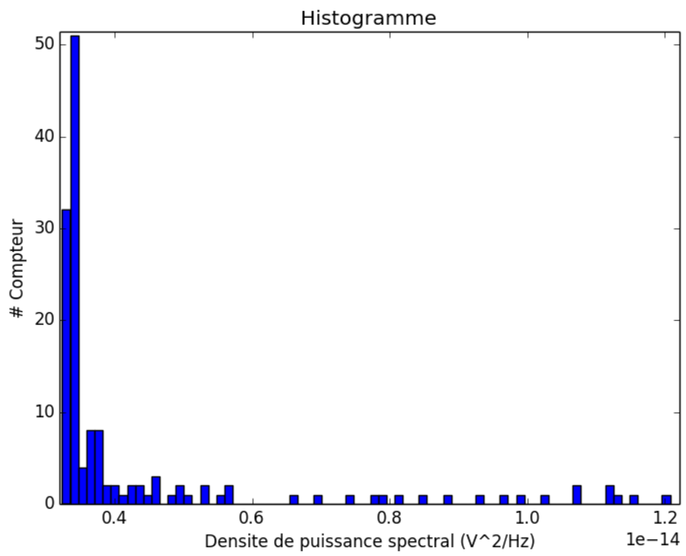
Data

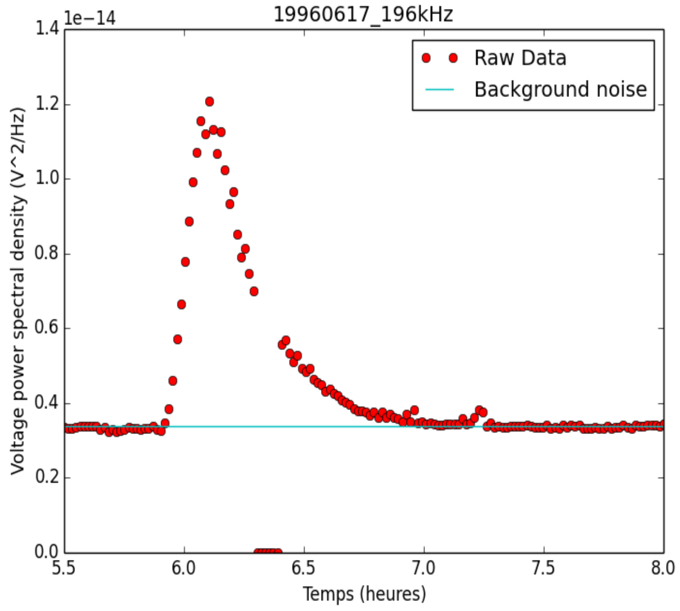
- **Data gathered from TNR and RAD1 :**
  - Thermal Noise Receiver (TNR)
    - Frequency Range: 4 kHz - 256 kHz
    - Number of channels: 32
    - Bandwidth: 400 Hz – 6.4 kHz
  - **Radio Receiver Band 1 (Rad1)**
    - **Frequency Range: 20 kHz - 1040 kHz**
    - **Number of channels: 256**
    - **Bandwidth: 3 kHz**



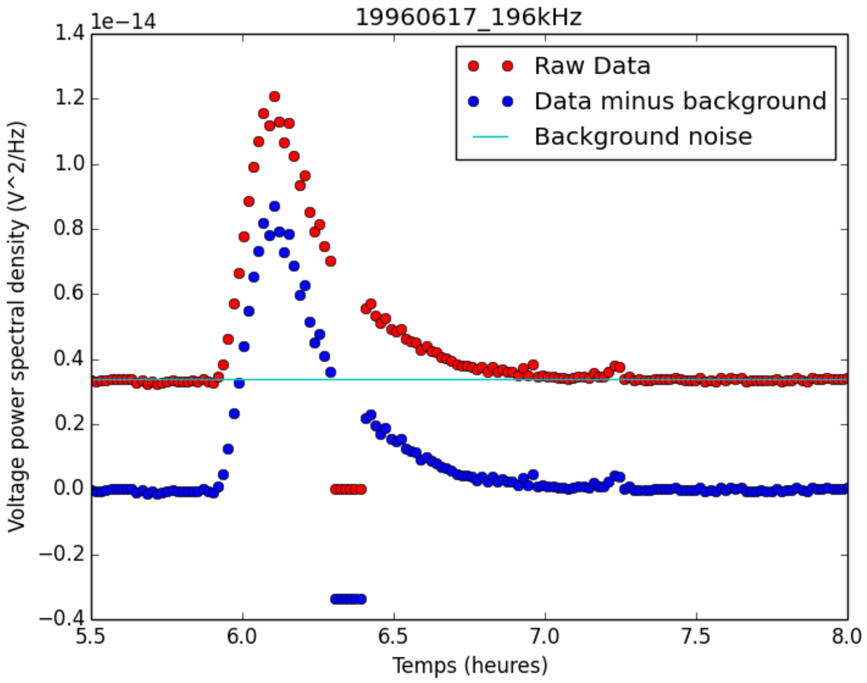


Analysis





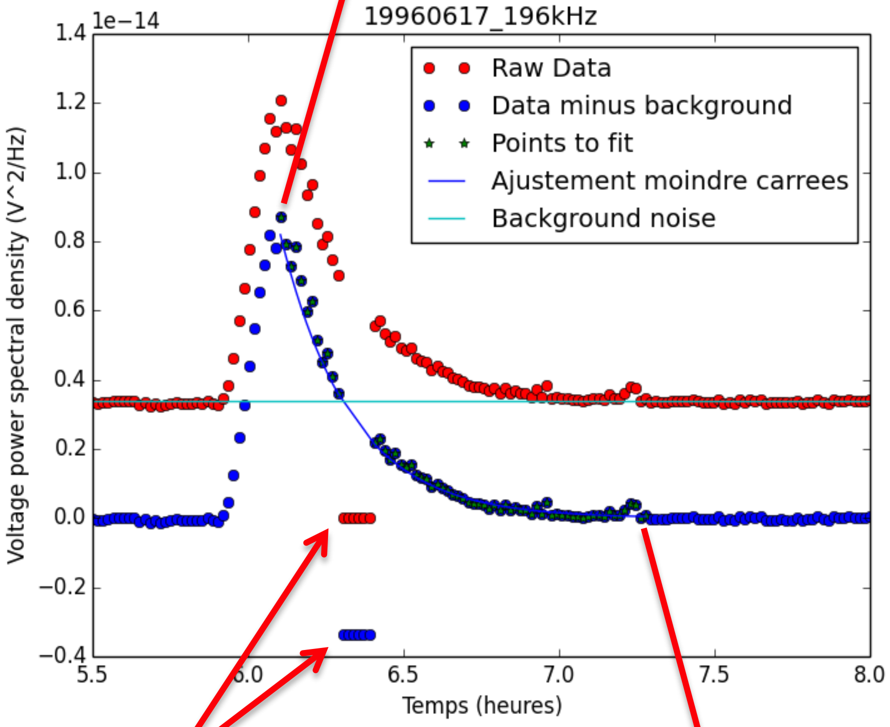
- **Background noise defined via empirical analysis based on the distribution of numerical data.**



- **The data is then offset by the background noise**
  - **Any value equal to the background noise is now set to 0**

Linear and logartithmic curve-fitting

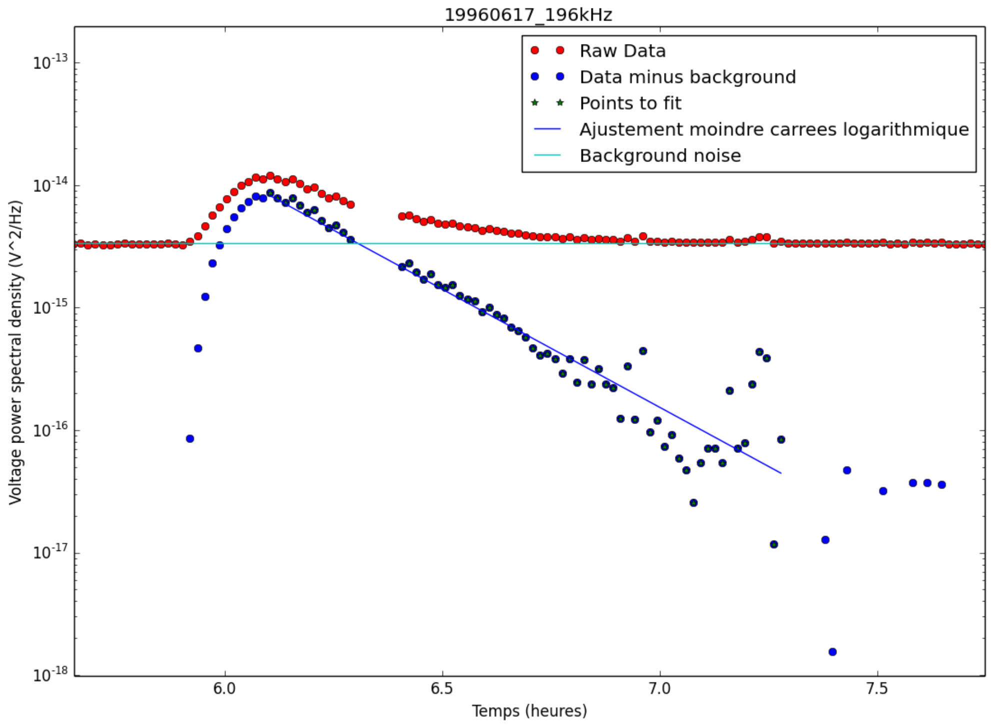
The onset point of the decay is defined as the peak of the data



Zero value artifacts of the receiver

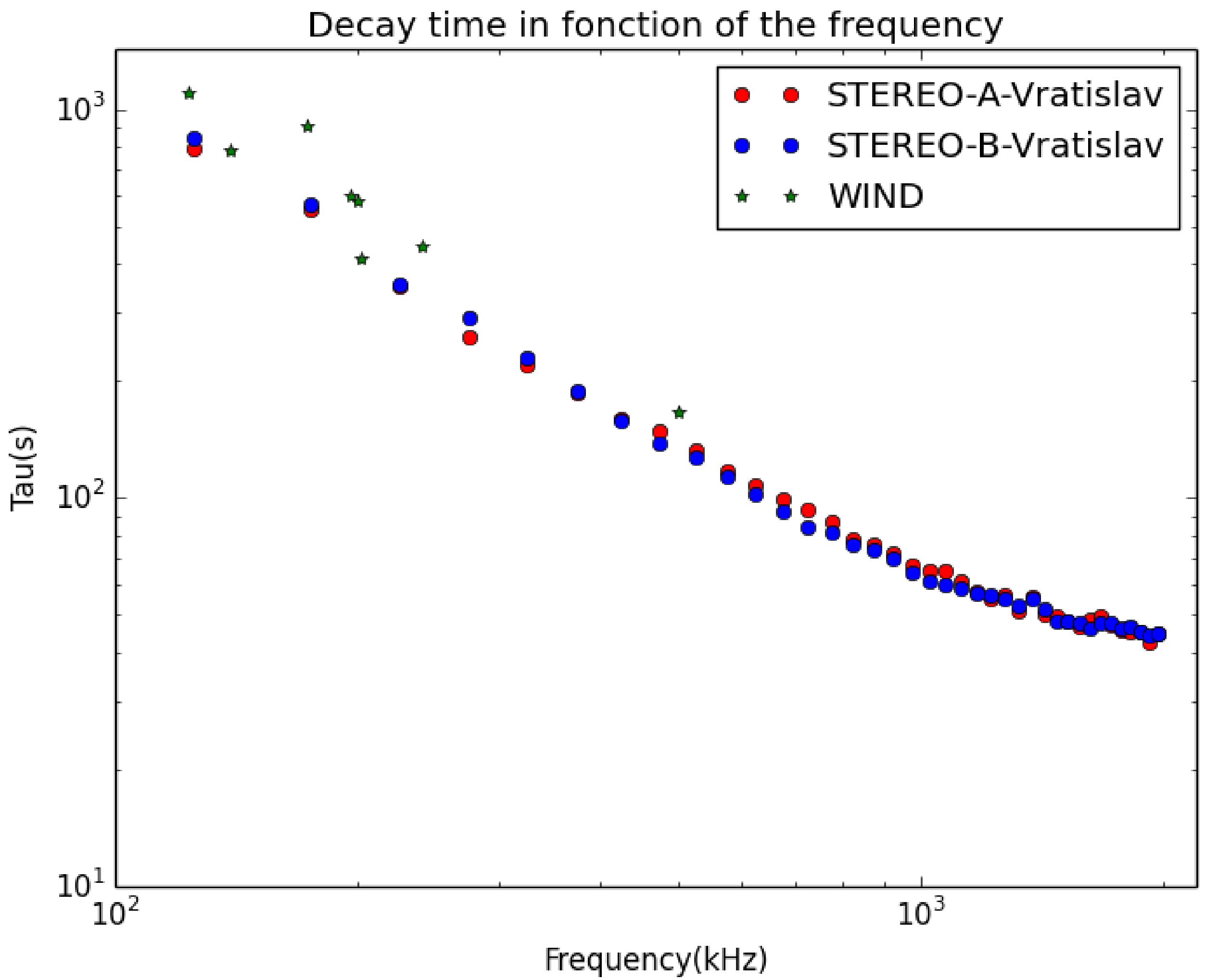
The cutoff point of the outburst is defined as the first negative value after the onset

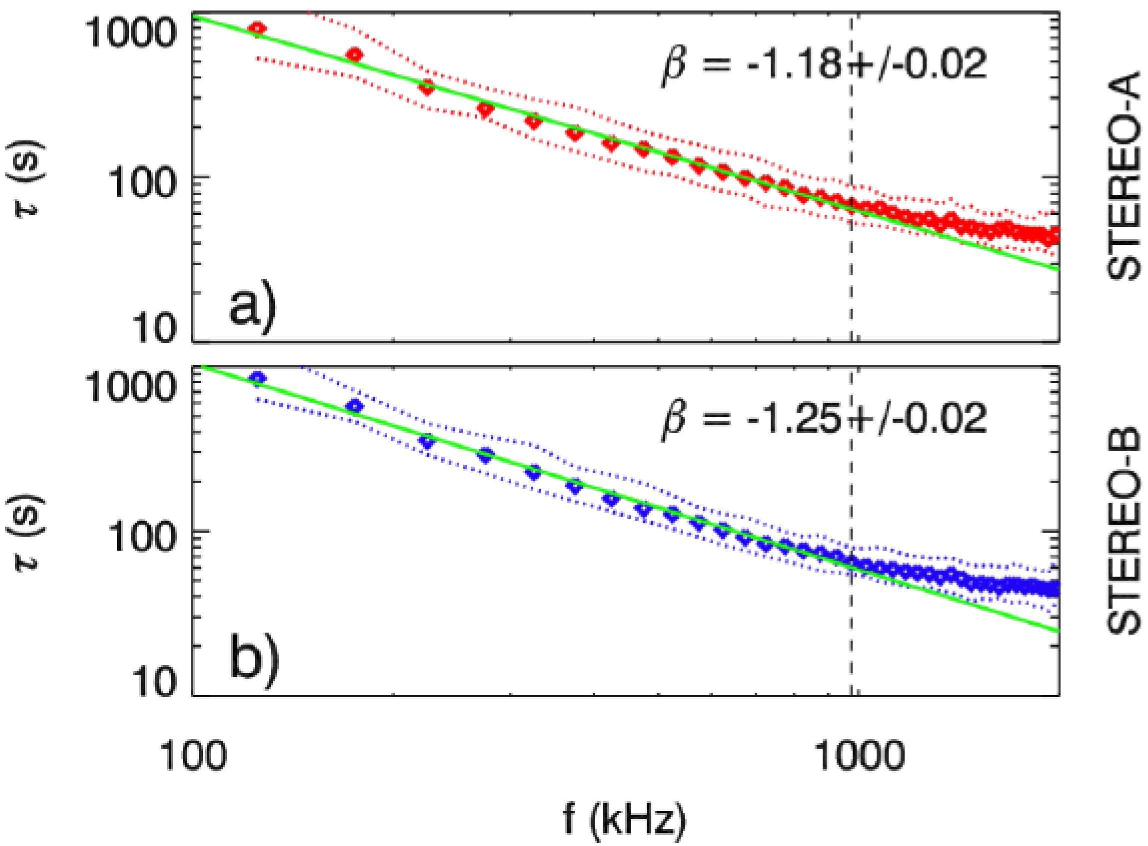
- **The curve-fit is obtained by the method of least mean square (LMS)**



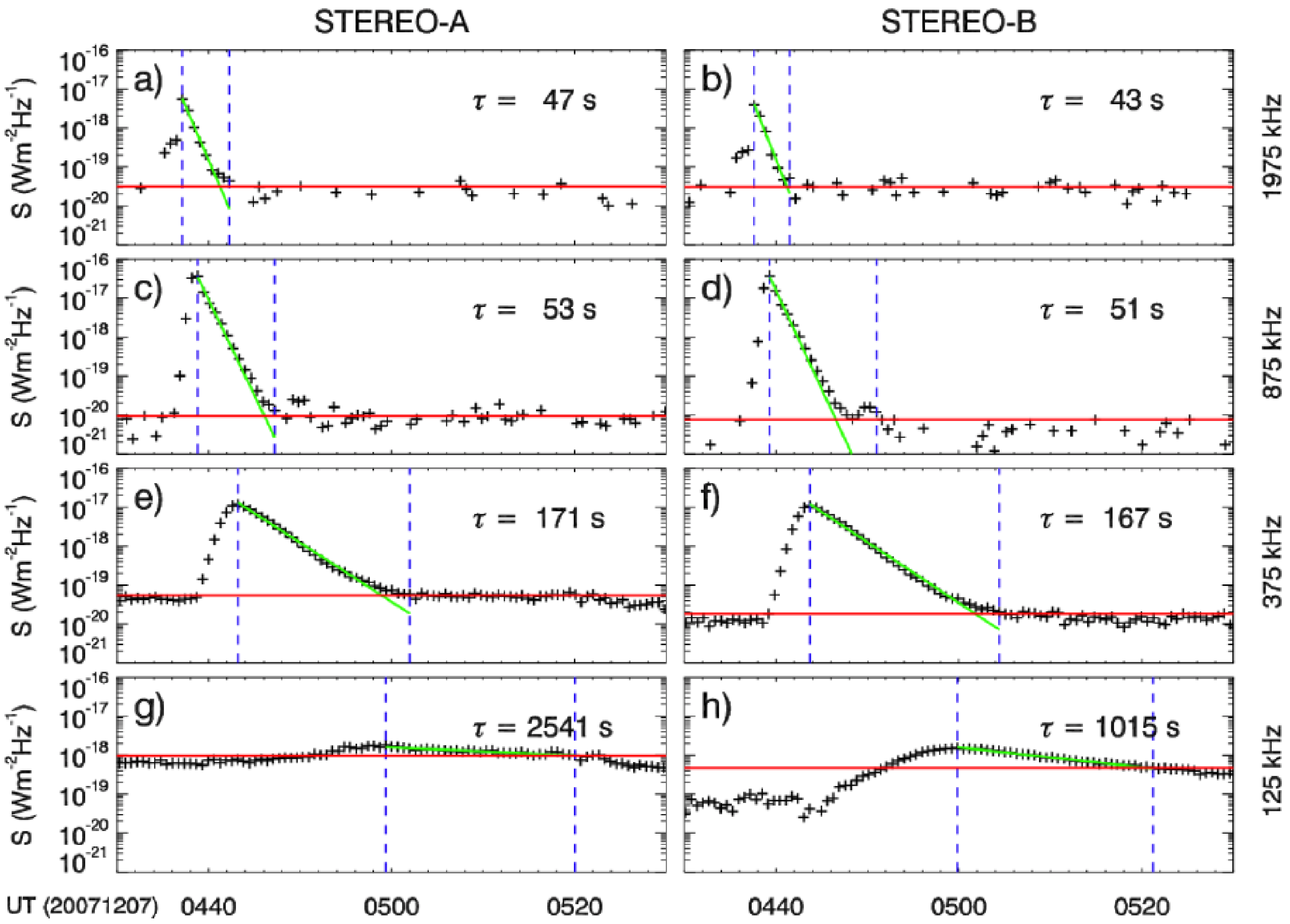
- **The decay time of the type III outburst is obtained using this linear regression**

Decay time in function of the frequency of the outburst



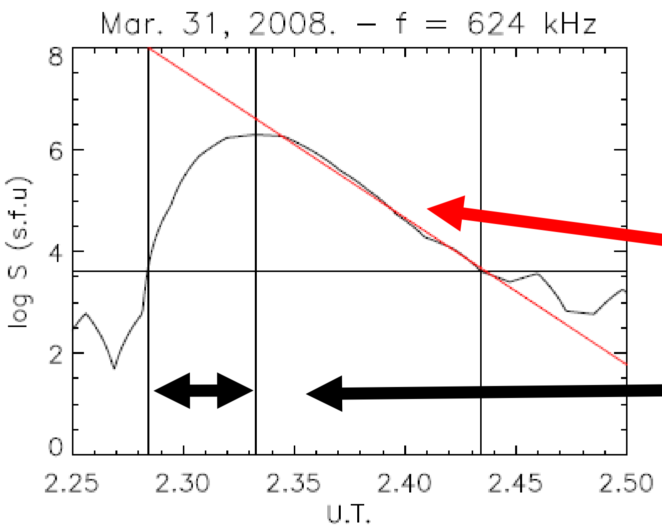


1000
100
10
τ (s)
β = -1.18+/-0.02
a)
STEREO-A
β = -1.25+/-0.02
b)
STEREO-B
100
1000
f (kHz)



- **Stereo time resolution : one spectrum every ~40 seconds**
- **On WIND there are radio data with a resolution up to every 12 seconds**

Decay and rise time of an average type III burst (Zaslavsky & Bonnin)



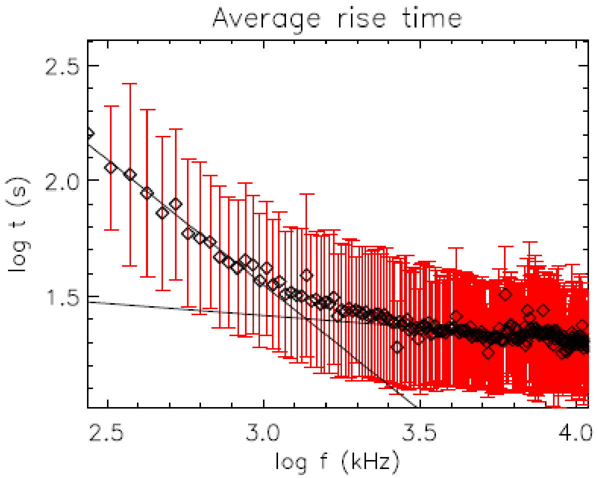
<u>Following the method of Evans et al. (*Sol. Phys., 1973*)</u>

<u>Linear fit</u> : -1/Tdecay

Trise = Tmax - Tonset

~2000 type III events on WIND

<u>POWER LAW FITS :</u>

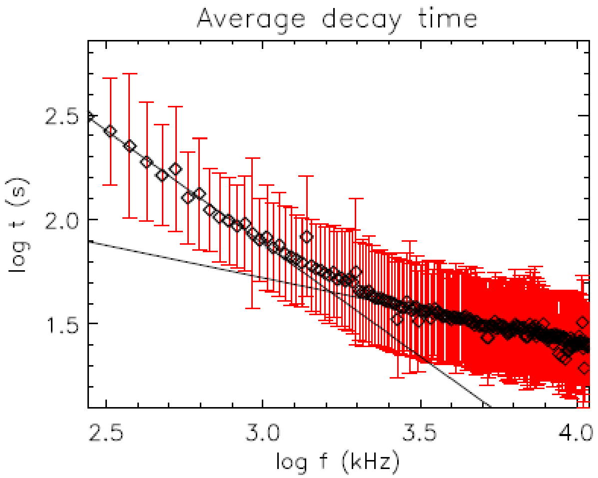


LF band (same result as Evans)

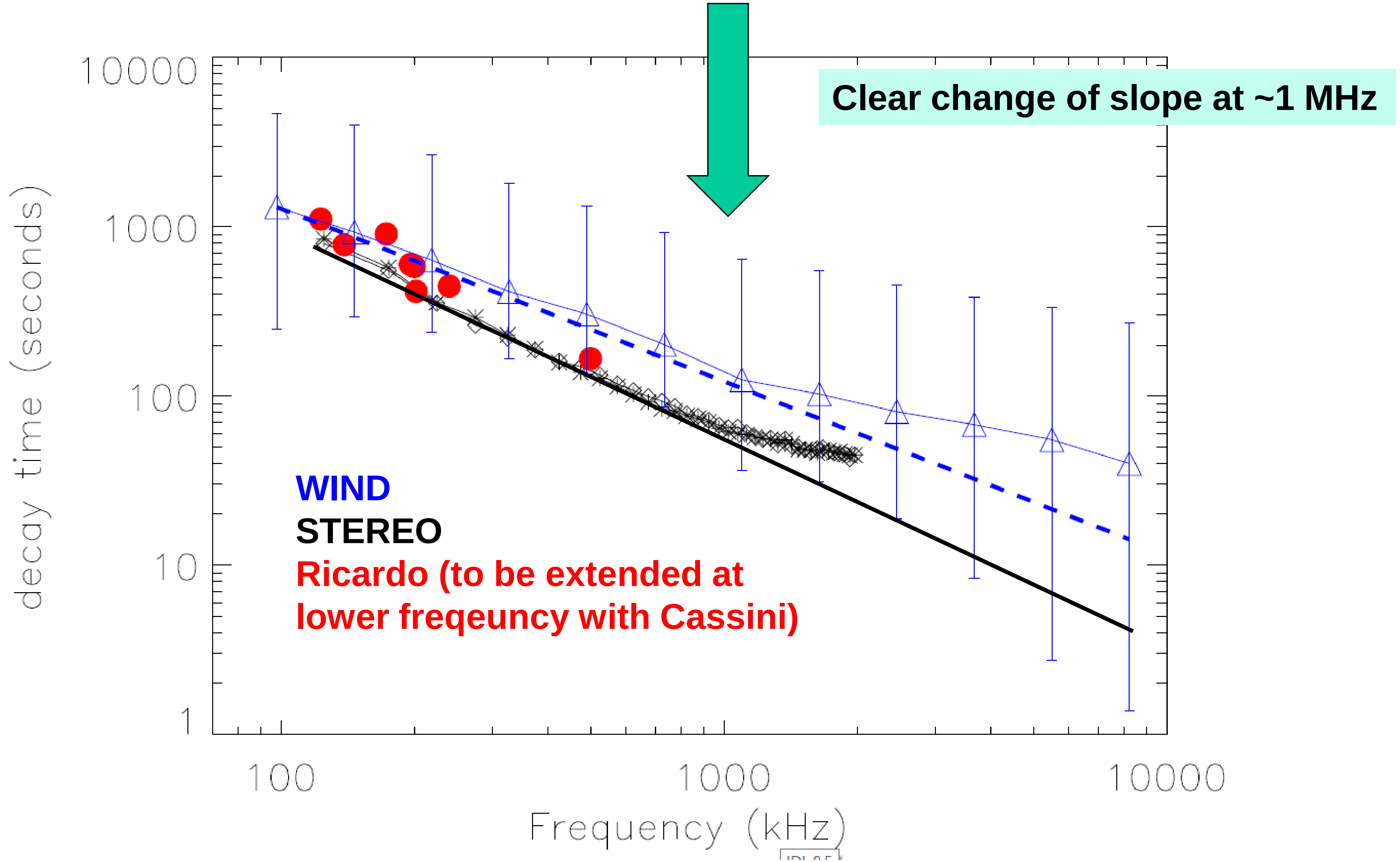
$$T_r \propto f^{-1.08} \qquad T_d \propto f^{-1.08}$$

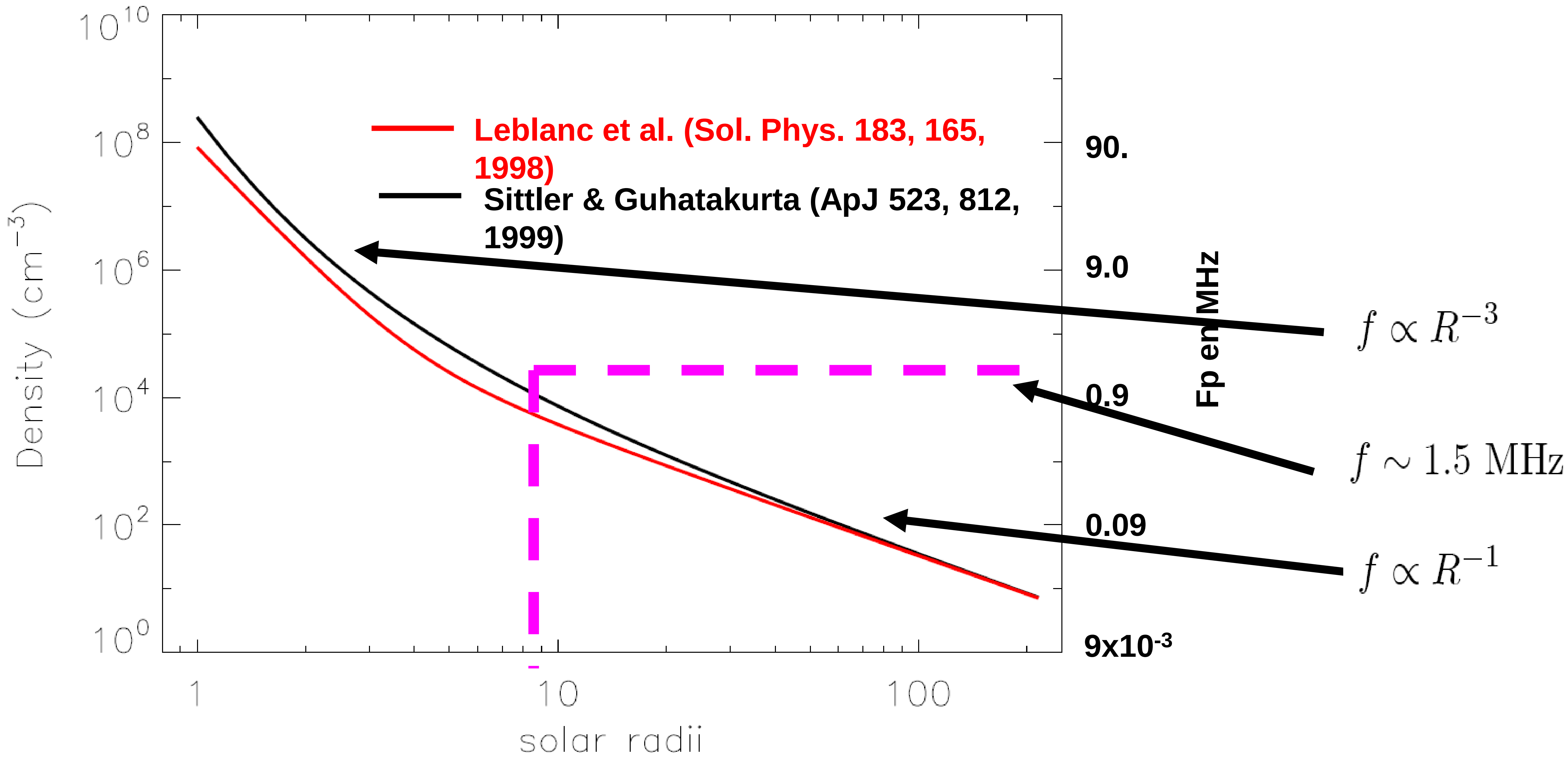
HF band (not covered by Evans)

$$T_r \propto f^{-0.10} \qquad T_d \propto f^{-0.31}$$



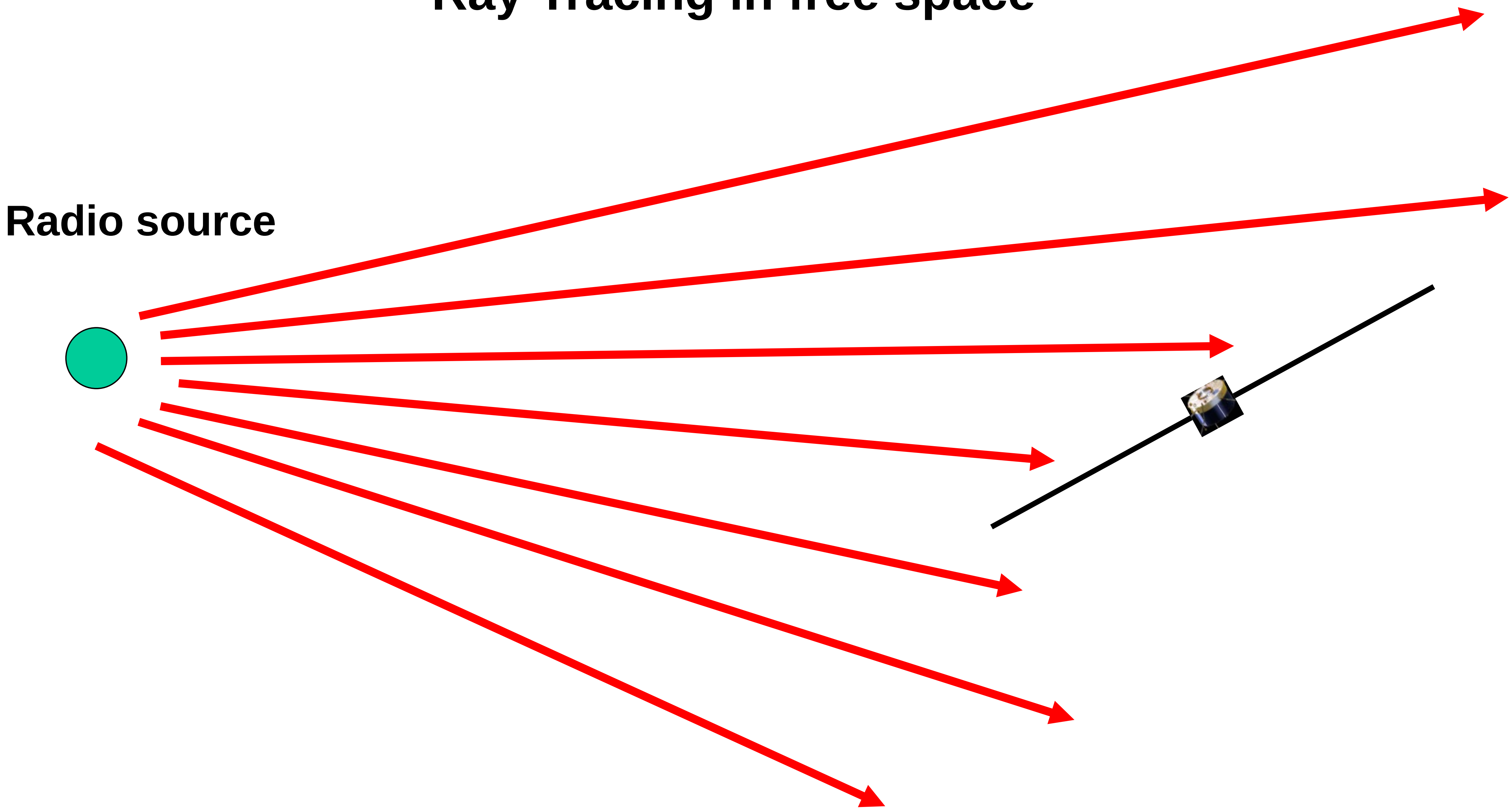
Changes in the power law dependance around f = 1.5 MHz


Clear change of slope at ~1 MHz
10000
1000
100
10
1
decay time (seconds)
100
1000
10000
Frequency (kHz)
WIND
STEREO
Ricardo (to be extended at
lower freqeuncy with Cassini)

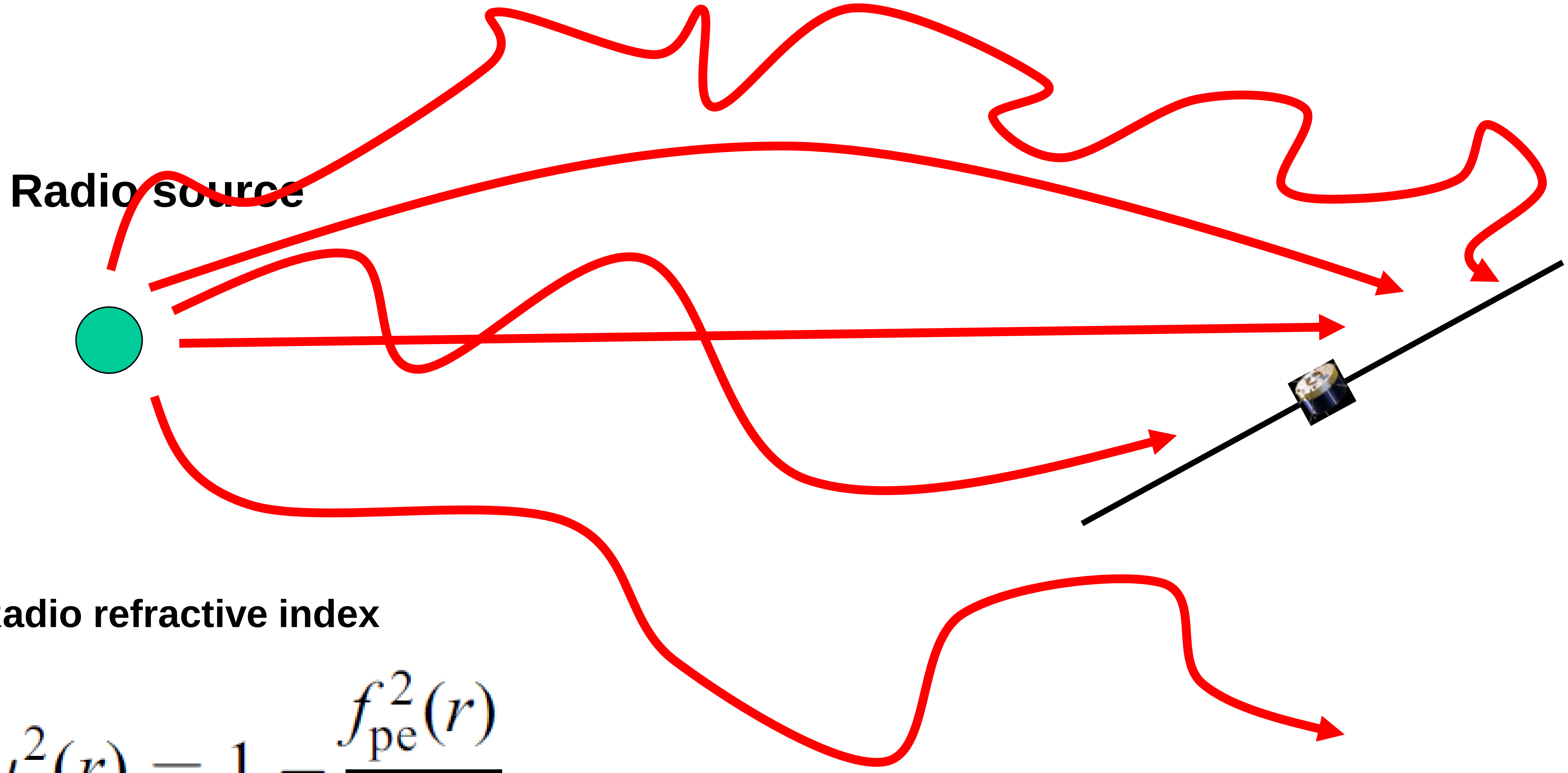


Leblanc et al. (Sol. Phys. 183, 165, 1998)
Sittler & Guhatakurta (ApJ 523, 812, 1999)
Density (cm^{-3})
10^{10}
10^{8}
10^{6}
10^{4}
10^{2}
10^{0}
1
10
100
solar radii
90.
9.0
0.9
0.09
$9x10^{-3}$
Fp en MHz
$f \propto R^{-3}$
$f \sim 1.5$ MHz
$f \propto R^{-1}$

Ray Tracing in free space



Ray Tracing with density fluctuations



Radio refractive index

$$\mu^2(r) = 1 - \frac{f_{\mathrm{pe}}^2(r)}{f^2}$$

MONTE CARLO SIMULATION OF DIRECTIVITY OF INTERPLANETARY RADIO BURSTS

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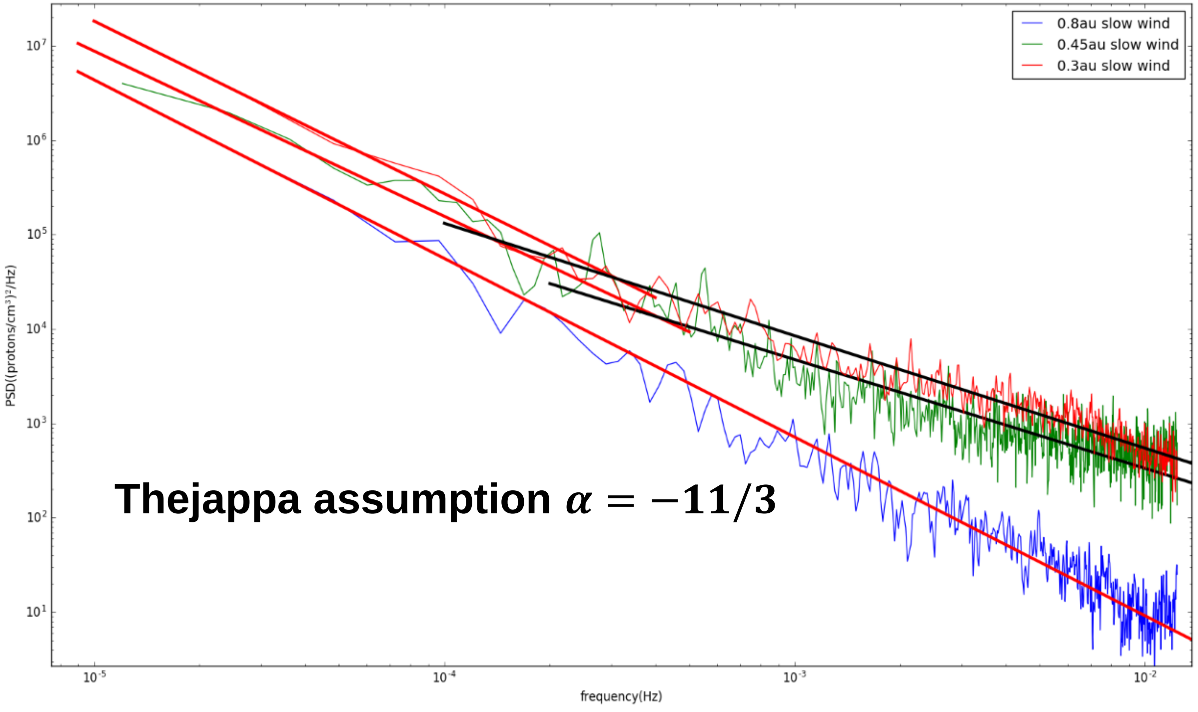
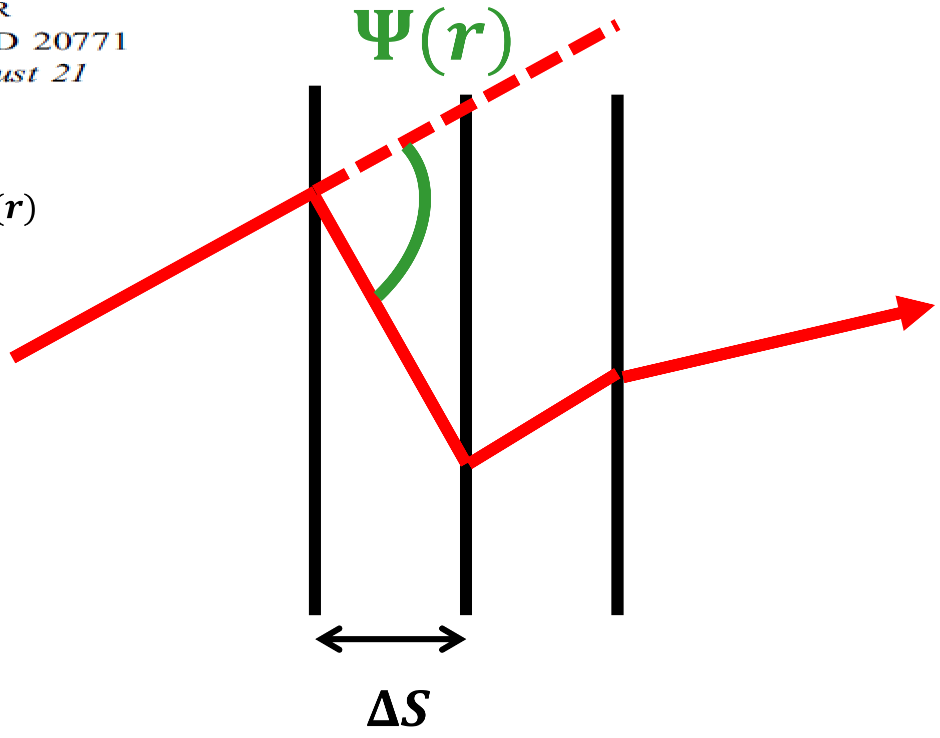
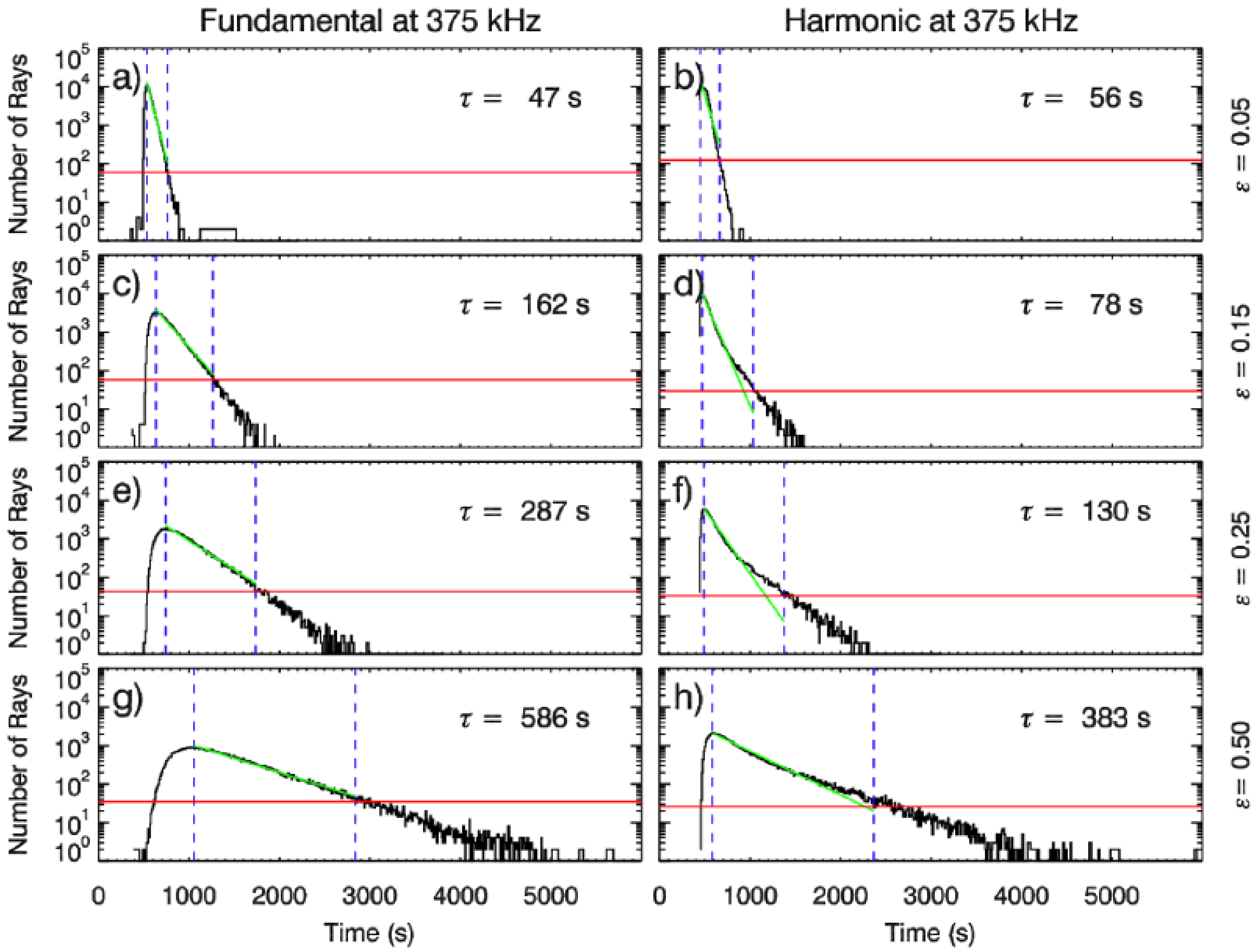
$$\langle \Psi^2 \rangle = \frac{r_e^2 \lambda^4}{\pi \mu^4} \int_{k_0}^{k_i} P_n(k) k^2 d^2k \times \Delta S \qquad P_n(k,r) = \varepsilon \left\langle \left(\frac{\delta n}{n} \right)^2 \right\rangle_0 (r) \times k^{\alpha(r)}$$

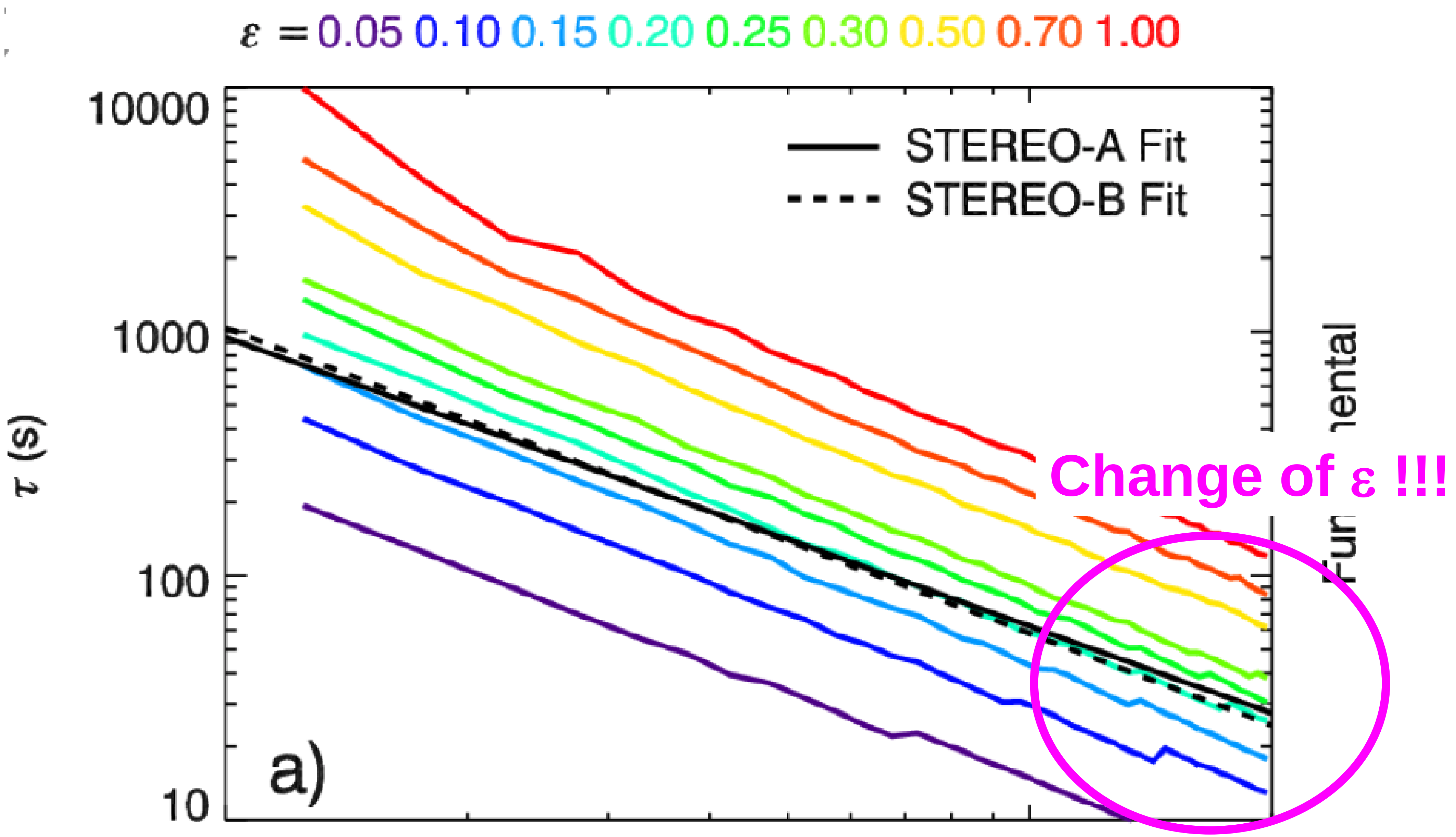




From the spectrum of $\delta n/n$ there is a given distribution of $\langle \Psi^2 \rangle$ from which one can do monte carlo simulations

V. Krupar simulations
To be submitted



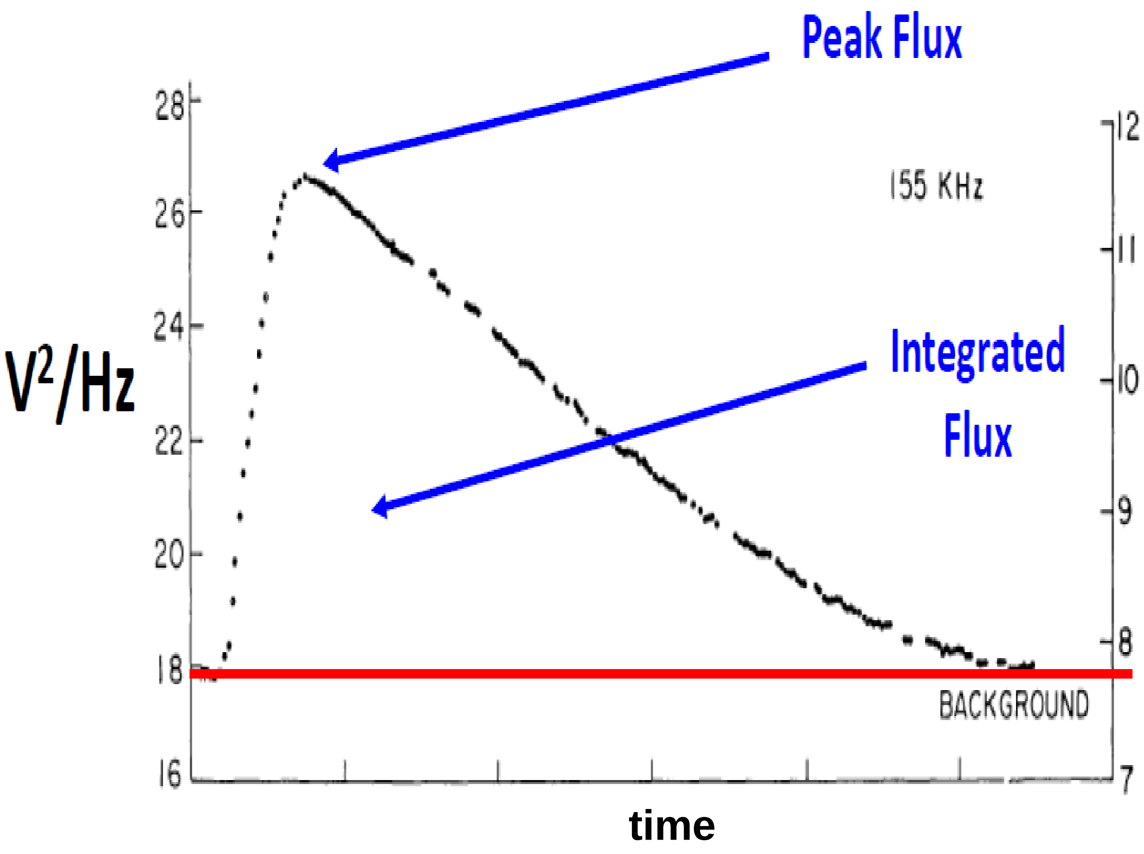


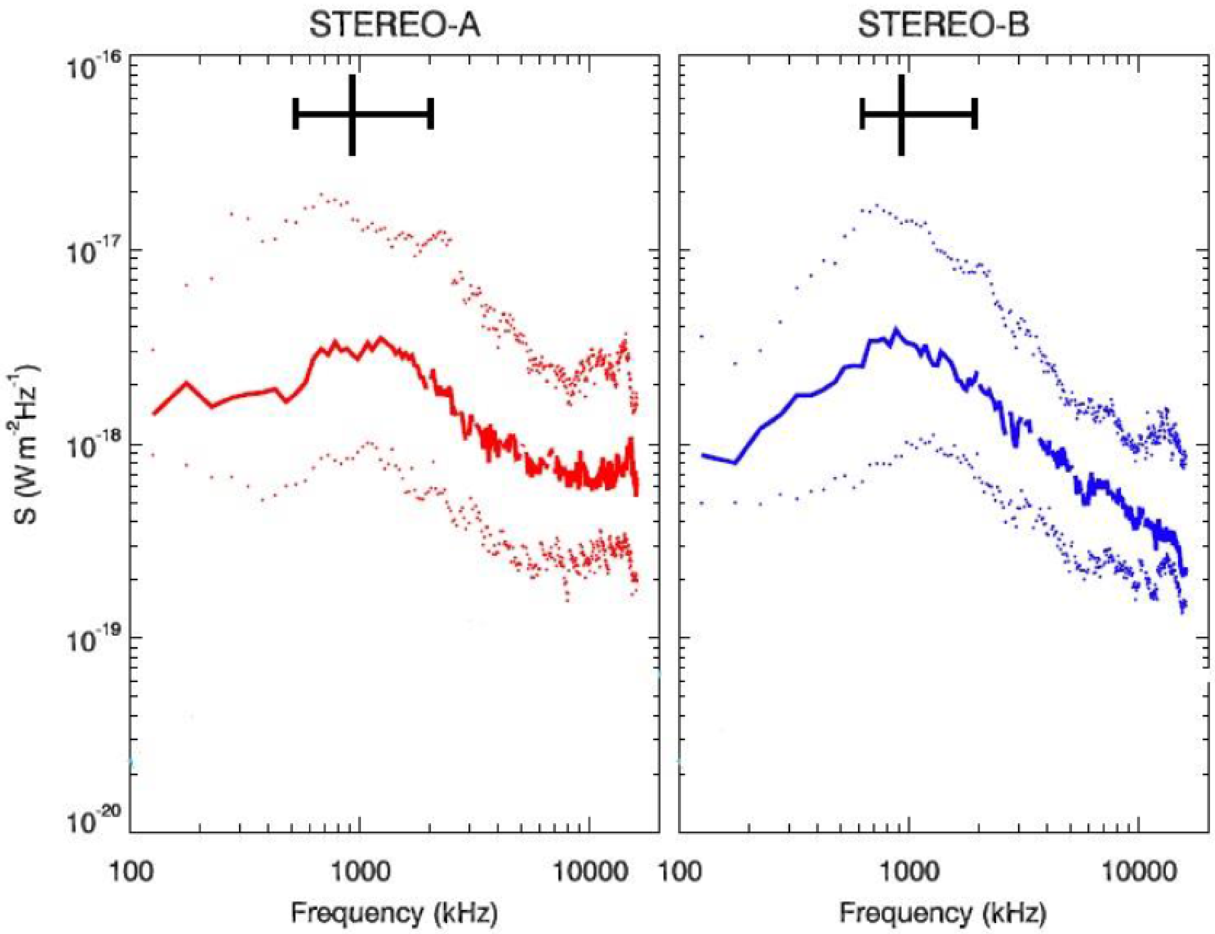
ε = 0.05 0.10 0.15 0.20 0.25 0.30 0.50 0.70 1.00
10000
1000
100
10
τ (s)
STEREO-A Fit
STEREO-B Fit
a)
Change of ε !!!

Krupar, 2012 PhD thesis, Krupar et al. 2013

154 Type III observed both by Stereo A & Stereo B

And the peak flux ?



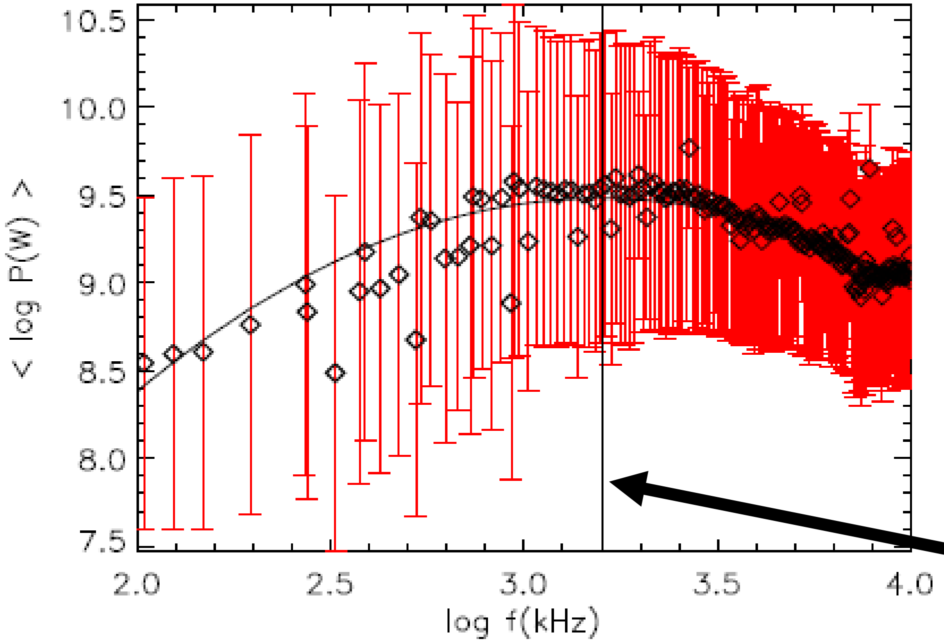


Weber, 1978, Bonnin, 2008

Power Spectrum of an average type III burst

Using the emission diagram, we can deduce from the measured flux the total power radiated by the burst at a given frequency :

$$P(t,f) = \frac{S(t,f,\varphi)\Delta f d^2}{D(f,\varphi)}\Omega$$

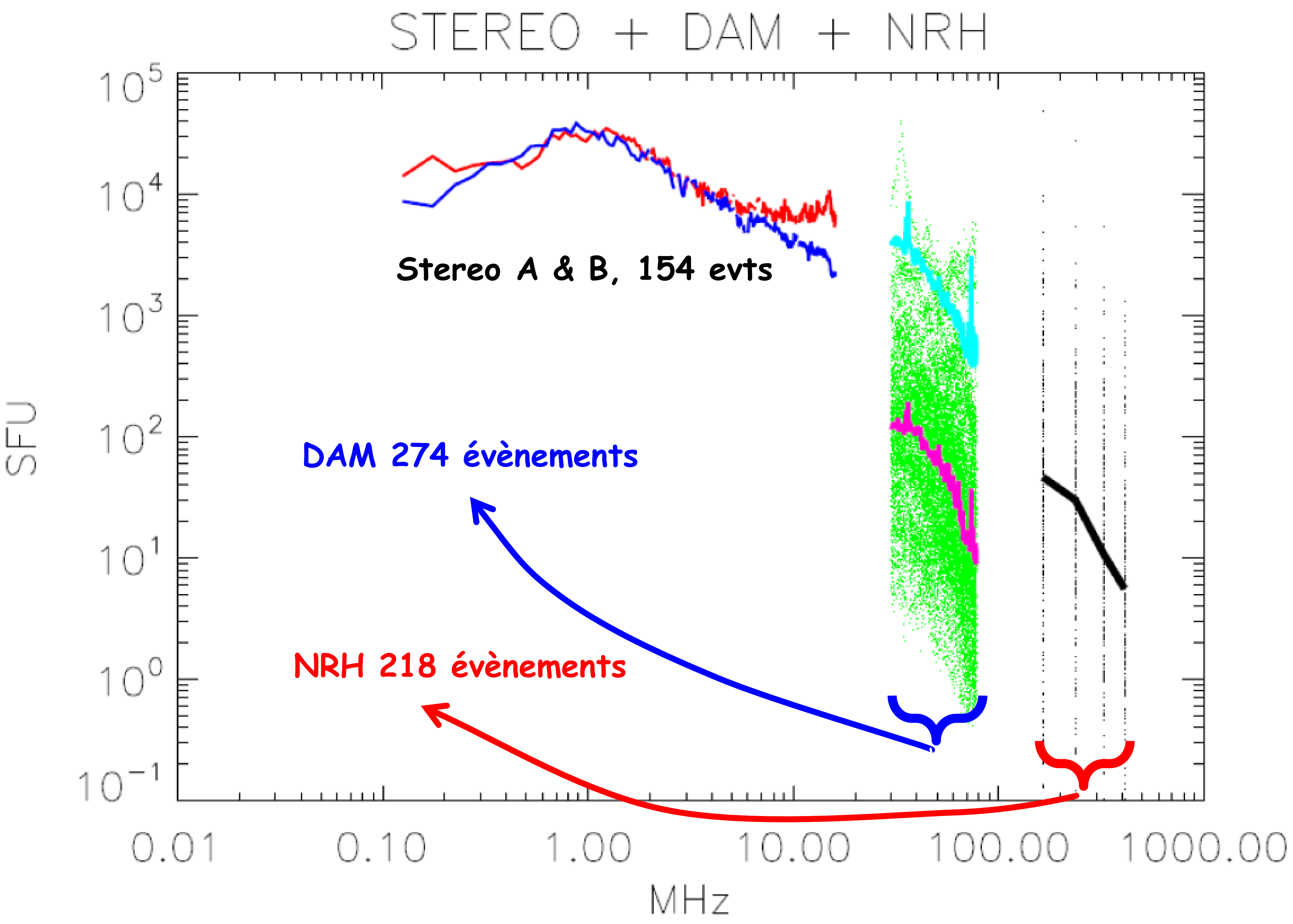


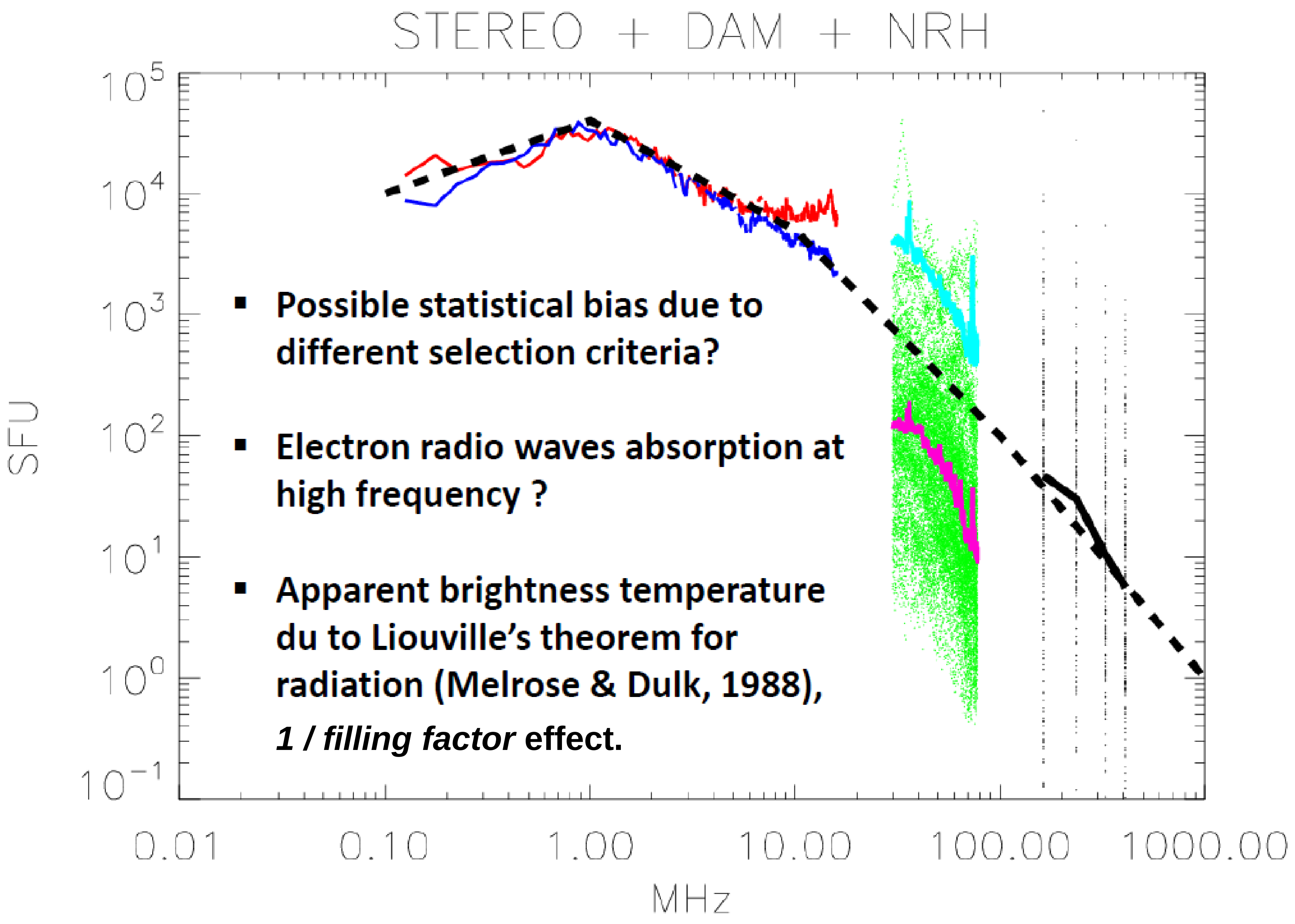
What happens at higher frequencies?

<u>Least-square fitting the measured power spectrum with a parabolla, we obtain</u>

$$\log P\left(f\right) \sim 9.5 + \left(\log f - 3.2\right)^2$$

The spectrum presents a maximum of emissivity around 3 GW at 1.5 MHz

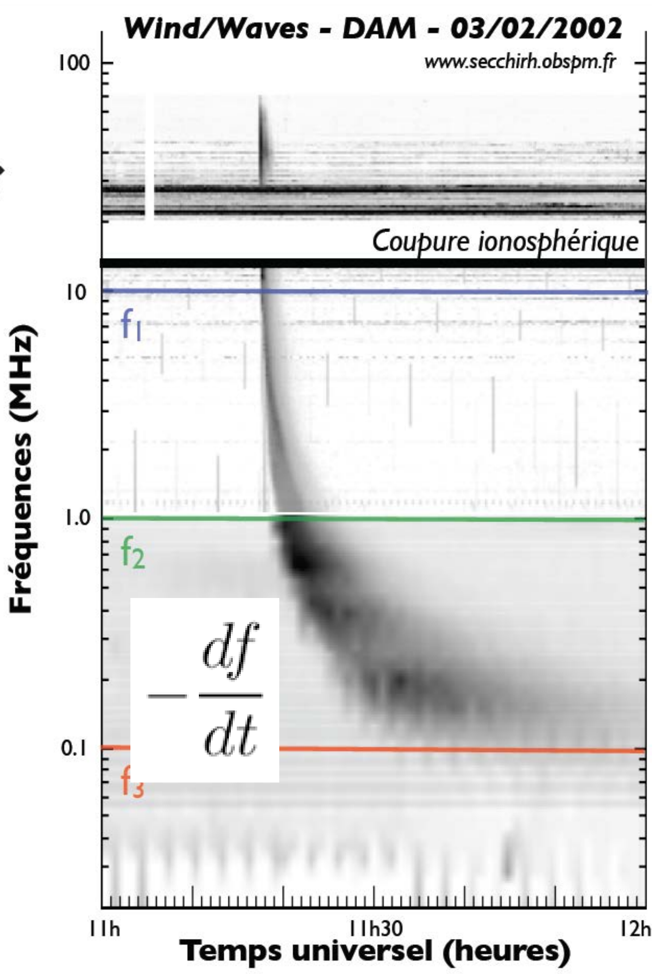

STEREO + DAM + NRH
Stereo A & B, 154 evts
DAM 274 évènements
NRH 218 évènements
SFU
MHz
0.01
0.10
1.00
10.00
100.00
1000.00
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}

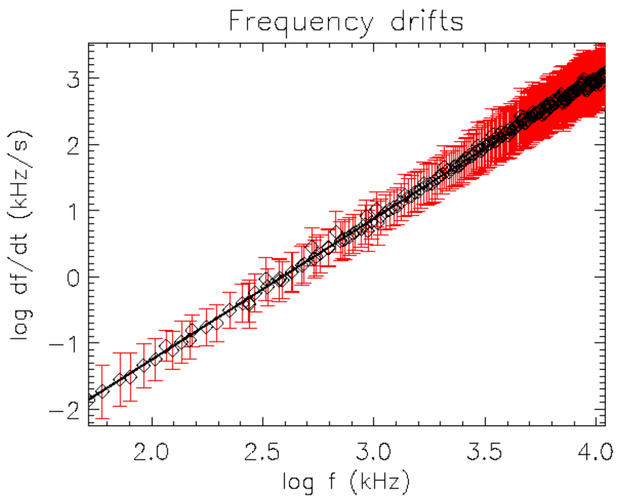


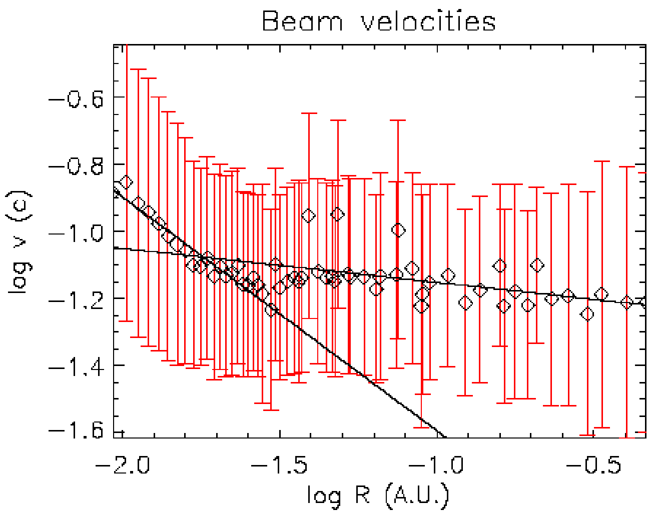
- **Possible statistical bias due to different selection criteria?**
- **Electron radio waves absorption at high frequency ?**
- **Apparent brightness temperature du to Liouville's theorem for radiation (Melrose & Dulk, 1988), *1 / filling factor* effect.**

Drift rates and beam velocities

We calculated for each event the frequency drift as a function of the frequency :







The observed frequency drifts scales with a single power law on all the observed frequencies :

$$-\frac{df}{dt} \propto f^{2.2}$$

Using a solar wind density model, we can recover the velocity profile of the exciters (electron beams) :

$$V = \frac{1}{\cos\psi}\frac{dr}{df}\frac{df}{dt}$$

$$V_{HF} \propto R^{-0.7} \quad V_{BF} \propto R^{-0.1}$$

Change in the power law dependance of the velocity profile at f = 1.5 MHz ?

Conclusions

- Most of the Evan decay time is very likely due to density fluctuations scattering !!!
- Something is happening ~ 1MHz (~10 Rs) ! What excatly ?
  - *Maximum of density fluctuation ?*
  - *Link with the Parker sonic point ?*
- Need to extend the decay time fitting at lower frequencies using Cassini RPWS data (Ricardo)
- Need to have a look at Nançay data at higer frequencies
  - To see how the decay times behave
  - To resolve the apparent calibration issues with the DAM

Assume that all radio emission is at $f \cong 2f_{pe}$ (harmonic emission) and that the emission is at saturation (Melrose, 1980). Then the spectral energy density of harmonic EM emission is proportional to the energy of Langmuir waves:

$$W^{\rm EM}(x,v,t) \simeq W(x,v,t)\,.$$

avec $W(x,v,t) = \frac{M n_b}{v_0 \omega_{pe}} v^4 \left(1 - \frac{v}{v_0}\right)$ Relaxation rapide faisceau/plasma, Kontar 2001

The spectral flux density at the Earth can be estimated (the same if s/c at 1 AU):

$$S = W^{\rm EM} \cdot \frac{dk}{d\omega} \times \mathbf{A} \cdot v_g \cdot \frac{1}{4\pi R_\phi^2}\,,$$

where $\frac{dk}{d\omega} \cong \frac{1}{v_g}$, v_g is the group velocity of the EM wave, $\mathbf{A}$ is the area of the source, and R_ϕ is the 1 AU distance. Hence one finds:

$$S = \frac{M n_b}{v_0 \omega_{pe}} v^4 \left(1 - \frac{v}{v_0}\right) \frac{\mathbf{A}}{4\pi R_\phi^2}\,,$$

For the v at which S is maximum on obtains

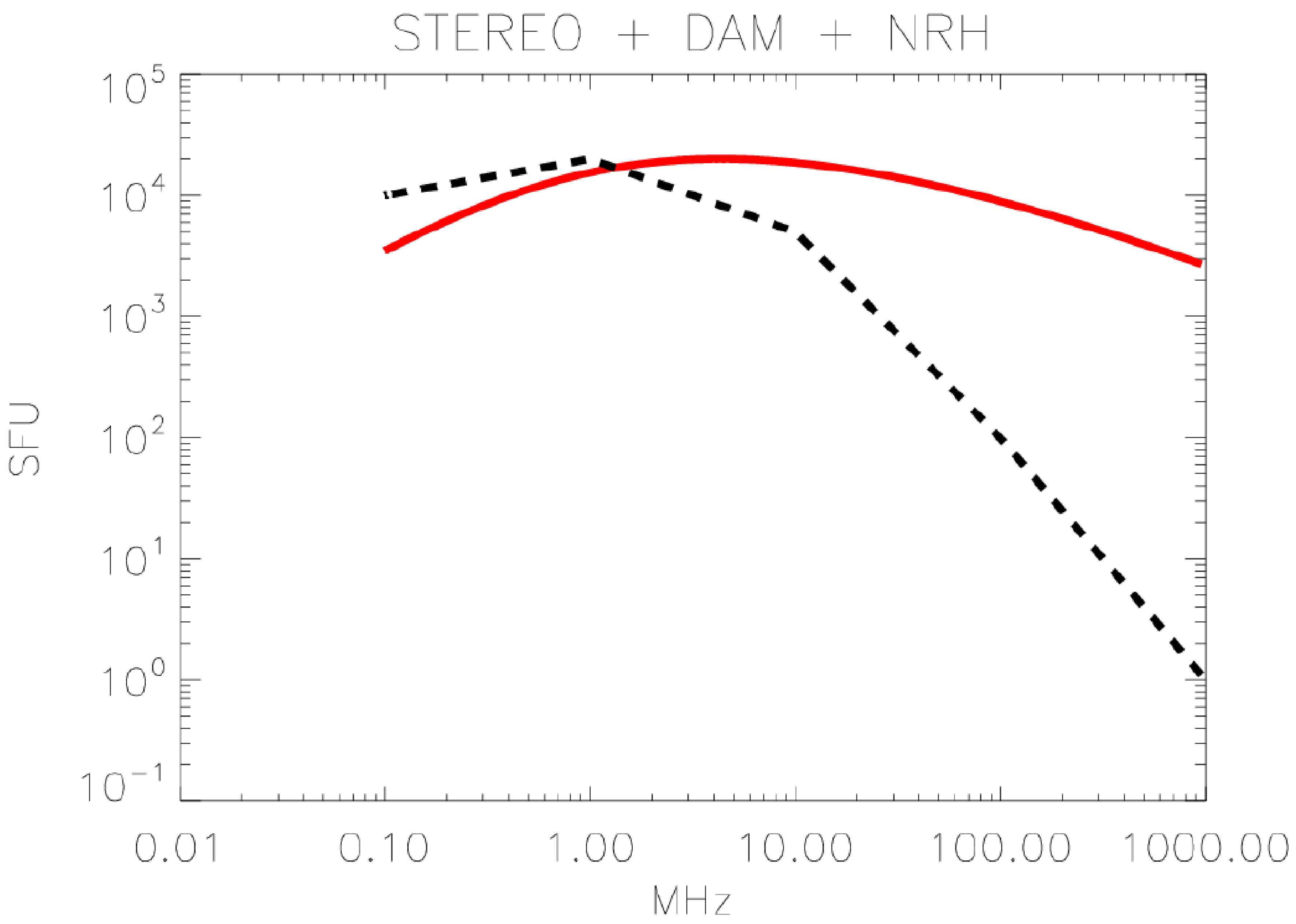
$$S = \frac{n_b \mathrm{A}}{f_{pe}} v_0(\mathbf{r})^3 ,$$

where f_{pe} is the plasma frequency. Let us assume constant speed $v_0 \sim$ const and $n_b S \sim \frac{1}{r^2}$ then:

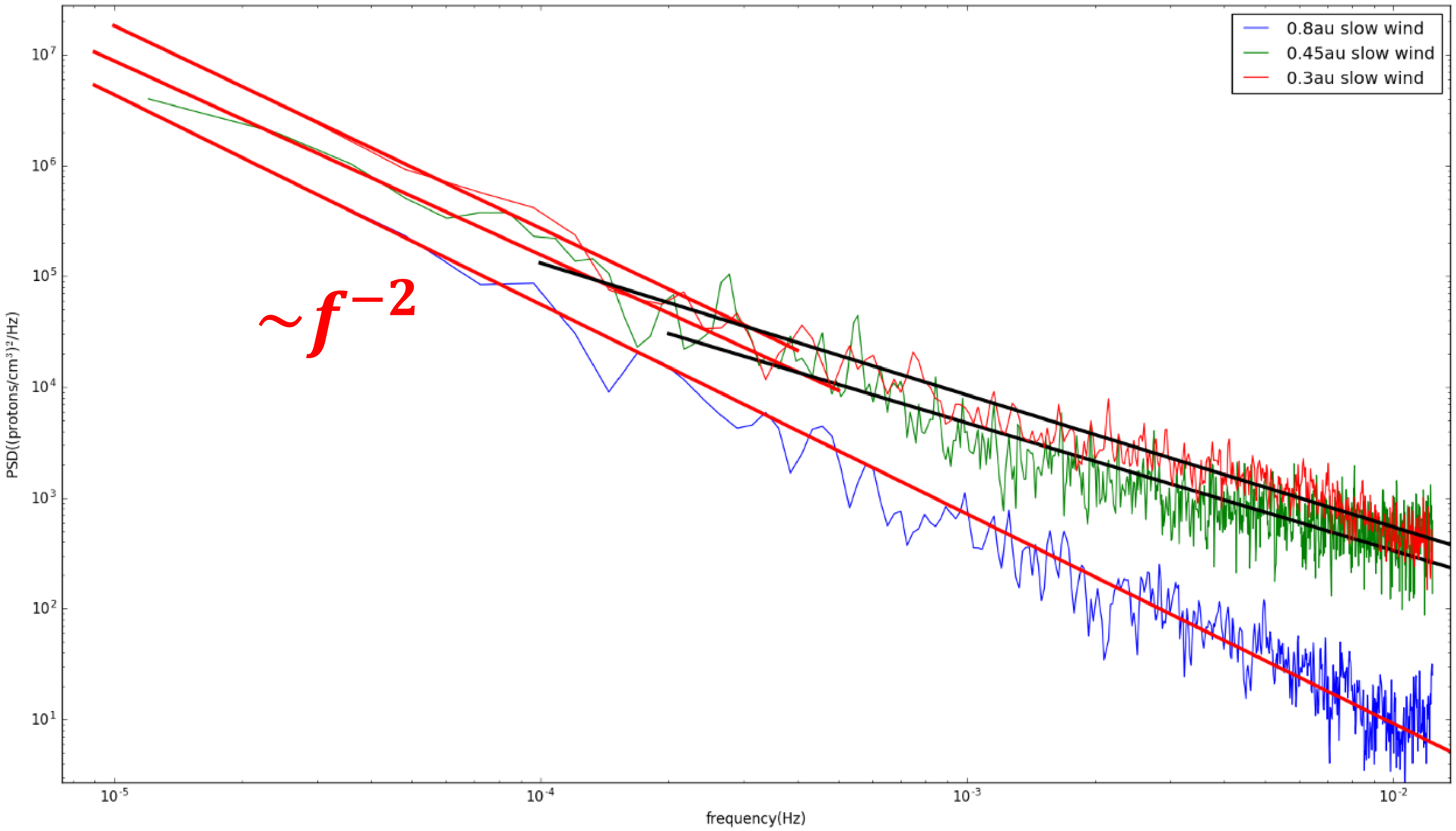
$$S \sim \frac{1}{r^2} \frac{1}{f_{pe}} .$$

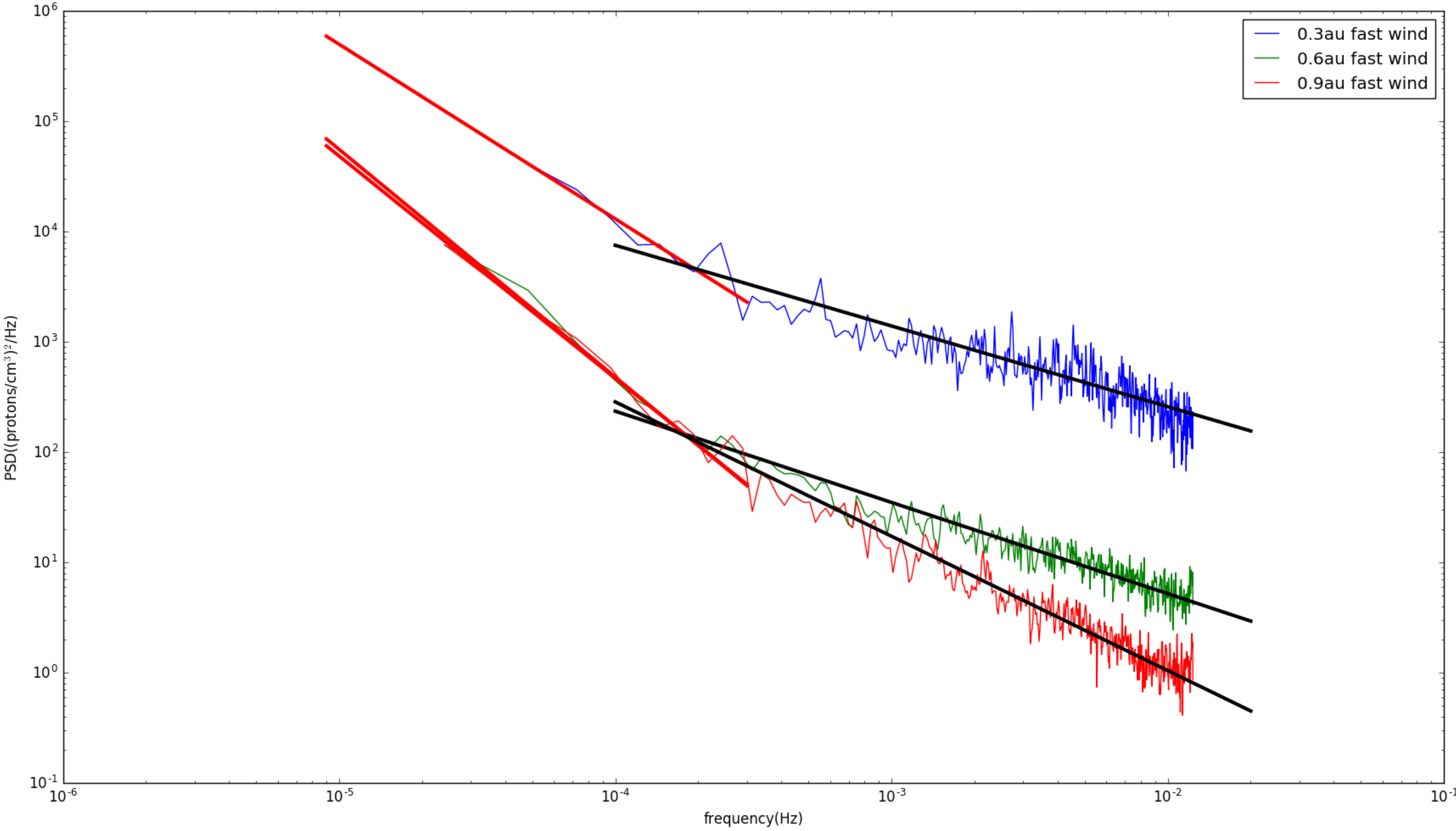
Densité du faisceau

Gradient de la densité ambiante



STEREO + DAM + NRH
SFU
MHz
10^5
10^4
10^3
10^2
10^1
10^0
10^{-1}
0.01
0.10
1.00
10.00
100.00
1000.00


0.8au slow wind
0.45au slow wind
0.3au slow wind
$\sim f^{-2}$
PSD((protons/cm^3)^2/Hz)
frequency(Hz)
10^{7}
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{-5}
10^{-4}
10^{-3}
10^{-2}



0.3au fast wind
0.6au fast wind
0.9au fast wind
10^{6}
10^{5}
10^{4}
10^{3}
10^{2}
10^{1}
10^{0}
10^{-1}
PSD((protons/cm^3)^2/Hz)
10^{-6}
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
frequency(Hz)