Simulations of Langmuir wave generation in the inhomogeneous plasma of the solar wind

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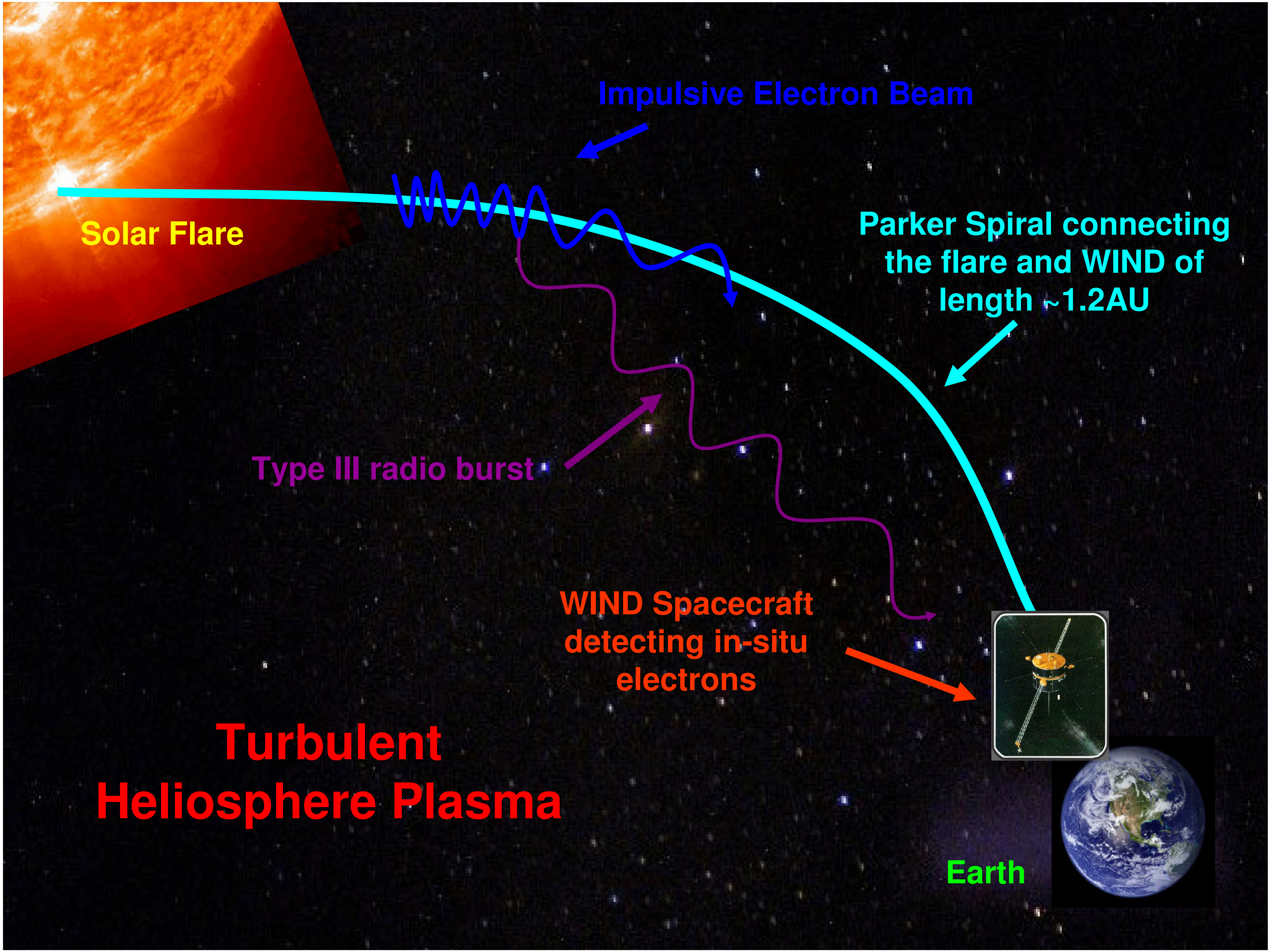
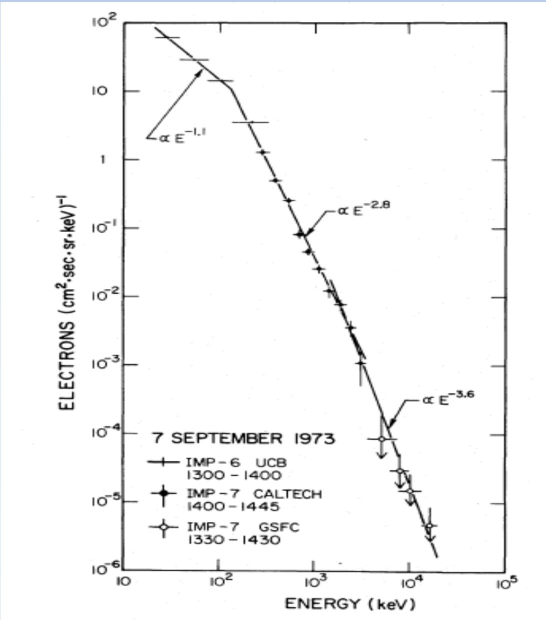
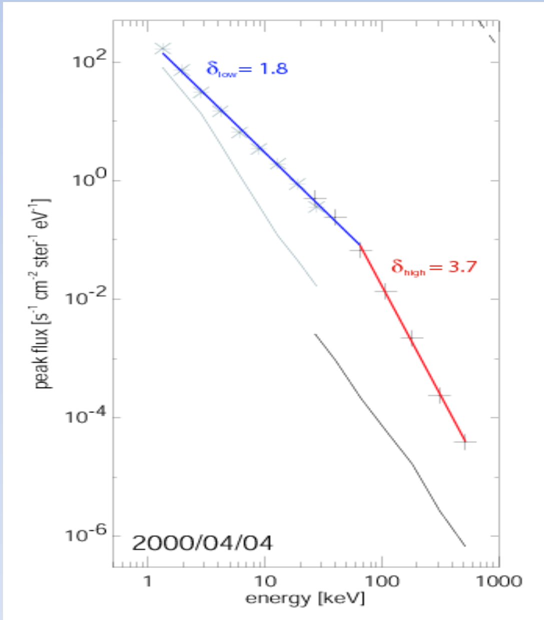

Impulsive Electron Beam
Solar Flare
Parker Spiral connecting the flare and WIND of length ~1.2AU
Type III radio burst
WIND Spacecraft detecting in-situ electrons
Turbulent Heliosphere Plasma
Earth

Solar energetic electrons are observed as a broken power-law distribution at the Earth with lower energies having a flatter power law index than higher energies.



Lin et al 1982

Broken power-law is caused by the density gradient of the background plasma taking plasma waves out of resonance with the electron beam (Kontar & Reid 2009)



Krucker et al, 2009

Initial Conditions

The initial electron beam (at time=0) is dependent on position (as a Gaussian) and velocity (as a power-law)

$$f(v,x,t=0)=g_0(v)\exp\left(\frac{-x^2}{d^2}\right)$$

$$g_o(v)=\frac{(\alpha-1)n_{beam}}{v_{\min}}\frac{v_{\min}^{\alpha}}{v^{\alpha}} \qquad v_{\min}\le v\le v_o$$

The initial, thermal spectral energy density is:

$$W(v,x,t)=\frac{k_b T_e}{4\pi^2}\frac{\omega_{pe}^2}{v^2}\log\left(\frac{v}{v_t}\right)$$

One dimensional quasilinear equations (e.g. Drummond and Pines, 1962) describing the kinetics of energetic electrons and Langmuir waves (Kontar, 2001) (Reid and Kontar 2010 submitted)

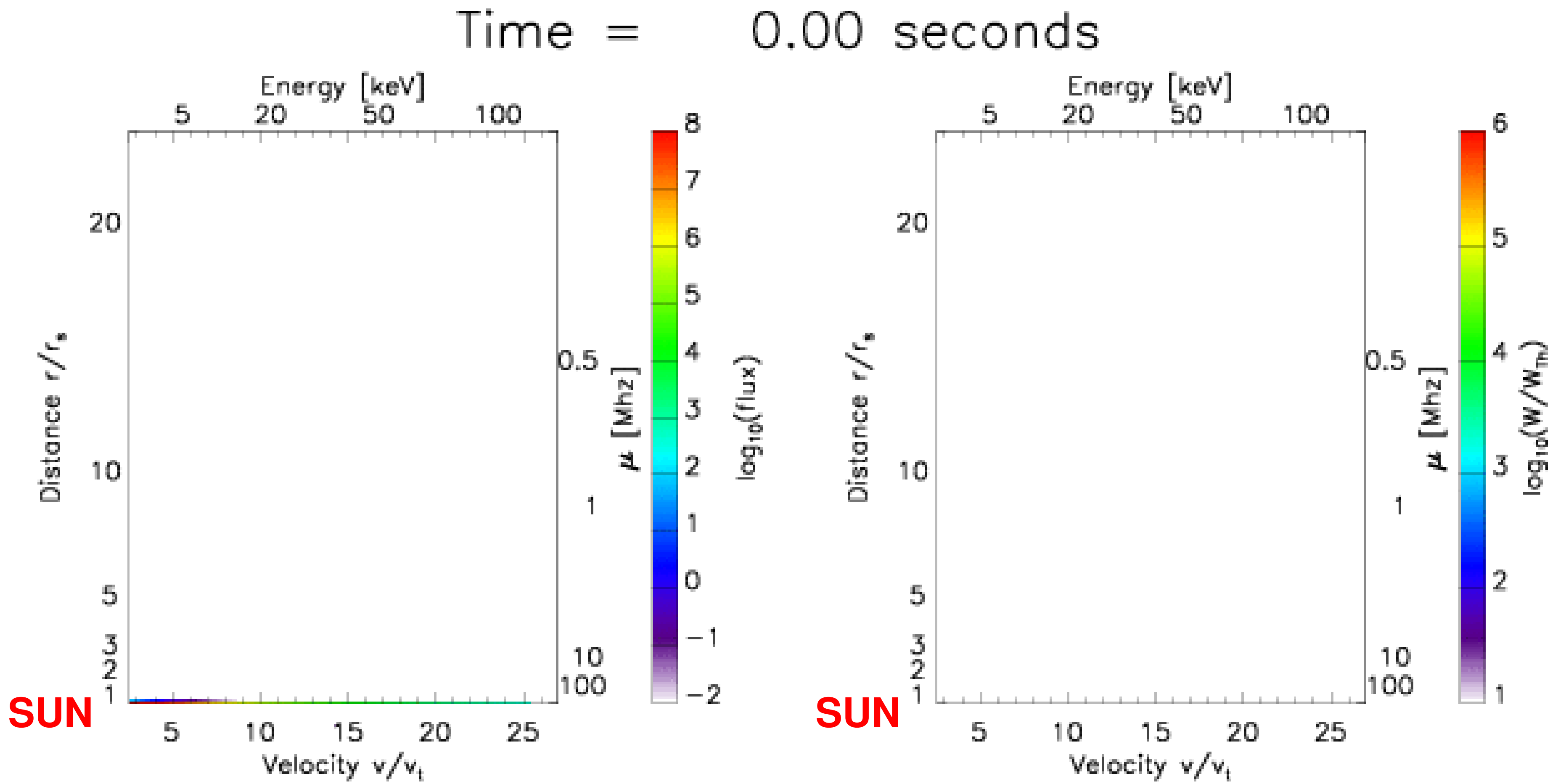
$$\frac{\partial F}{\partial t}+v\frac{\partial F}{\partial x}+\frac{2v}{r}F=\frac{4\pi^2 e^2}{m^2}\frac{\partial}{\partial v}\left(\frac{W}{v}\frac{\partial F}{\partial v}\right)+\gamma_{cp}\frac{d}{dv}\left(\frac{F}{v^2}\right) \qquad \omega_{pe}=kv$$

$$\frac{\partial W}{\partial t}+\frac{v^2}{L}\frac{\partial W}{\partial v}+\frac{3v_{Te}^2}{v}\frac{\partial W}{\partial x}=\frac{\pi\omega_{pe}}{n_e}v^2 W\frac{\partial F}{\partial v}-(\gamma_{cw}+\gamma_L)W+\gamma_s vF\log\left(\frac{v}{v_t}\right)$$

Background Plasma Inhomogeneity

Wave Generation and Absorption

Density Fluctuations

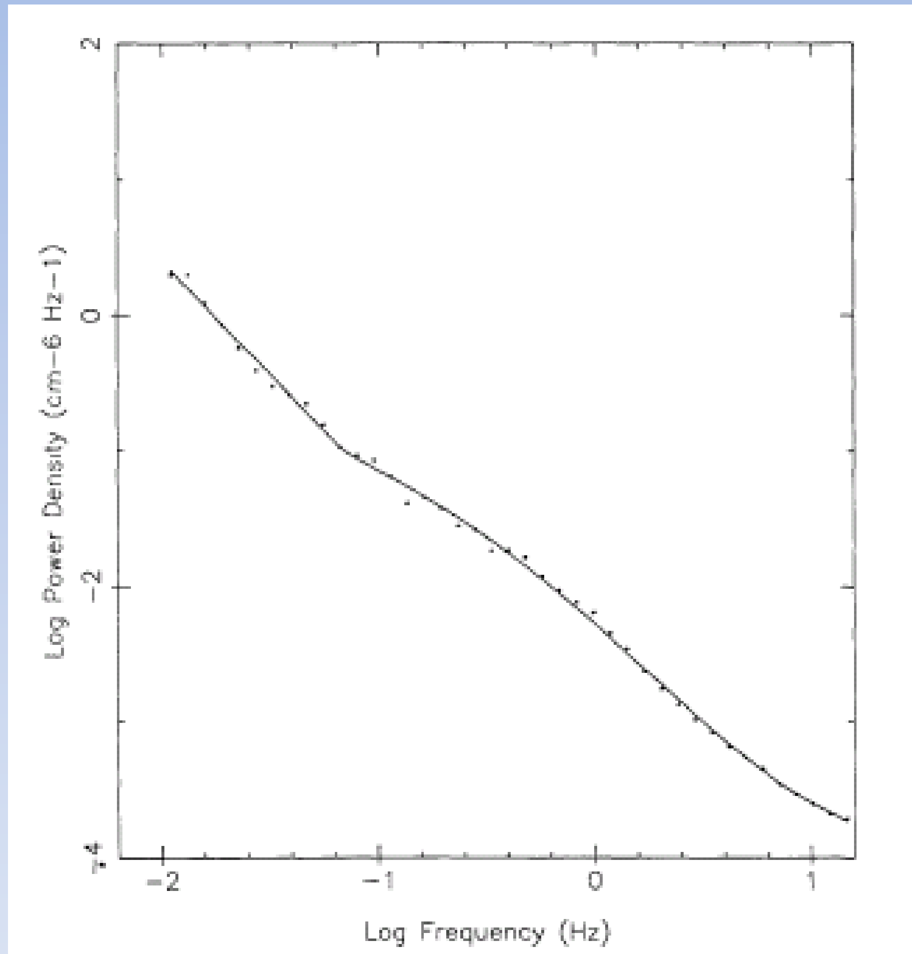


ELECTRON FLUX **WAVE ENERGY DENSITY**

Multiple Density Fluctuations

The solar wind turbulence takes the form of a Kolmogorov 5/3 power-law below a certain frequency

We take this power spectra and directly enter its properties into the code for a background density with multiple fluctuations.



Celnikier et al, 1987

Multiple Density Fluctuations

Change the density fluctuations to a power density spectra more realistic to the solar wind.

$$\delta n(x) = \langle n(x) \rangle C \sum_{n=1}^{N} \lambda_n^{\beta/2} \sin(2\pi x / \lambda_n + \phi_n)$$

The constant C is normalised to the value of <δn(x)> near the Earth (Celnikier et al 1987)

$$C = \sqrt{\frac{2\langle \delta n(x)^2 \rangle}{\langle n(x) \rangle^2 \sum_{i=1}^{N} \lambda_n^{\beta}}}$$

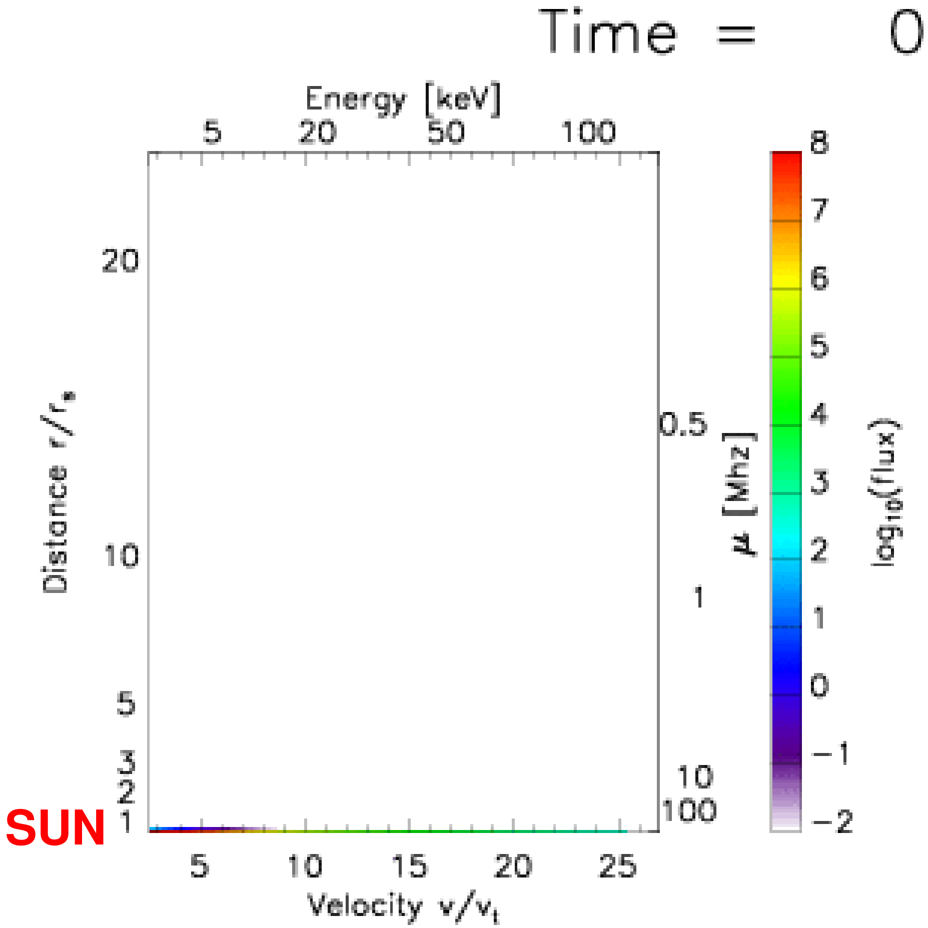
Multiple Density Fluctuations

Density fluctuations close to the Sun are able to be less prolific than density fluctuations close to the Earth.

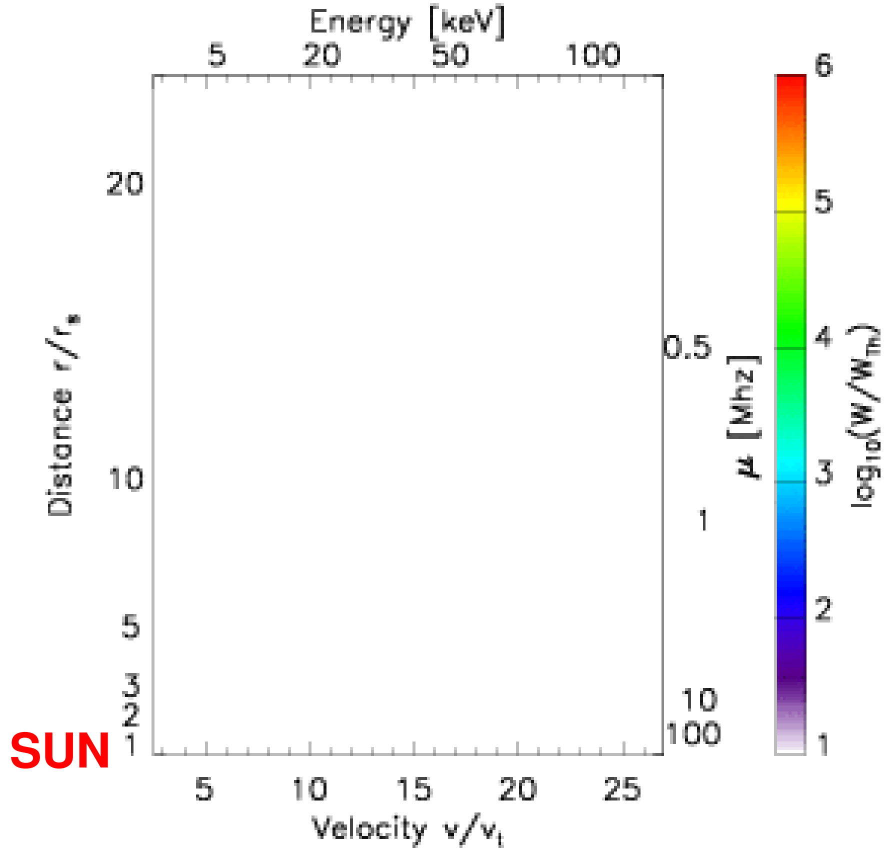
$$\frac{\left\langle \delta n(x_1)^2 \right\rangle}{\left\langle n(x_1) \right\rangle^2} = \left(\frac{n(1AU)}{n(x_2)} \right)^{\psi} \frac{\left\langle \delta n(x_2)^2 \right\rangle}{\left\langle n(x_2) \right\rangle^2}$$

$$\psi > 0$$

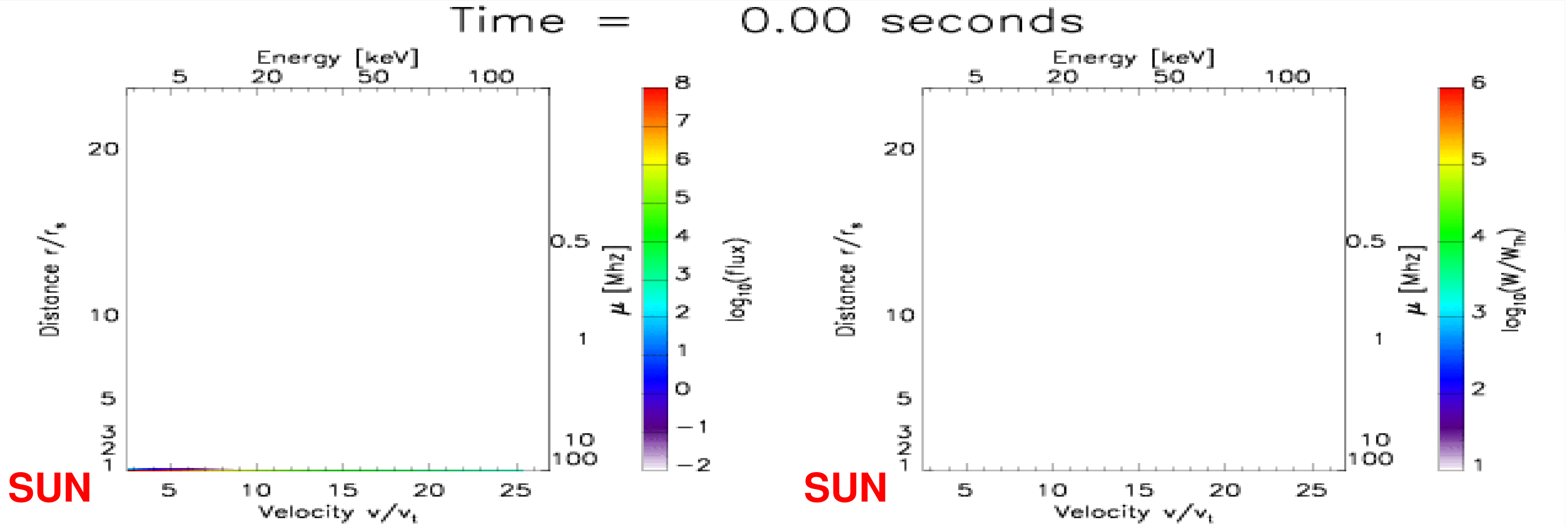
Multiple Density Fluctuations

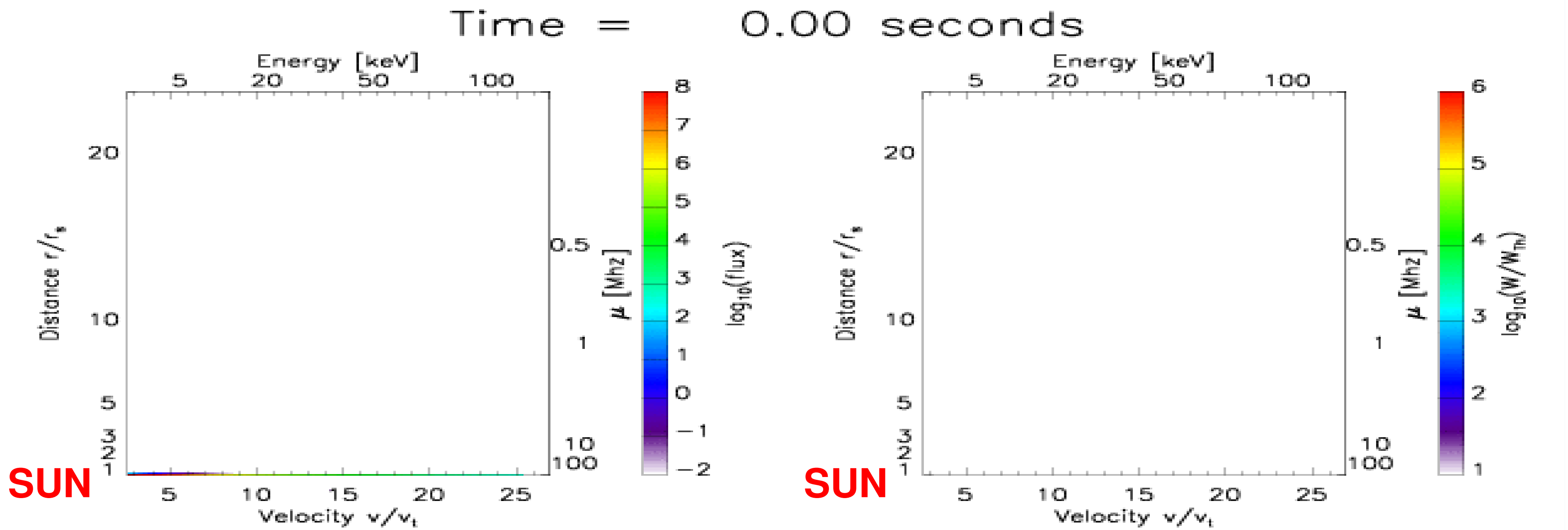


ELECTRON FLUX



WAVE ENERGY DENSITY


Time = 0.00 seconds
Energy [keV]
5 20 50 100
20
10
5
3
2
1
Distance r/r_s
0.5
1
10
100
μ [Mhz]
8 7 6 5 4 3 2 1 0 −1 −2
log10(flux)
5 10 15 20 25
Velocity v/v_t
SUN
Energy [keV]
5 20 50 100
Distance r/r_s
μ [Mhz]
6 5 4 3 2 1
log10(W/W_Th)
Velocity v/v_t
SUN


Time = 0.00 seconds
Energy [keV]
5 20 50 100
20
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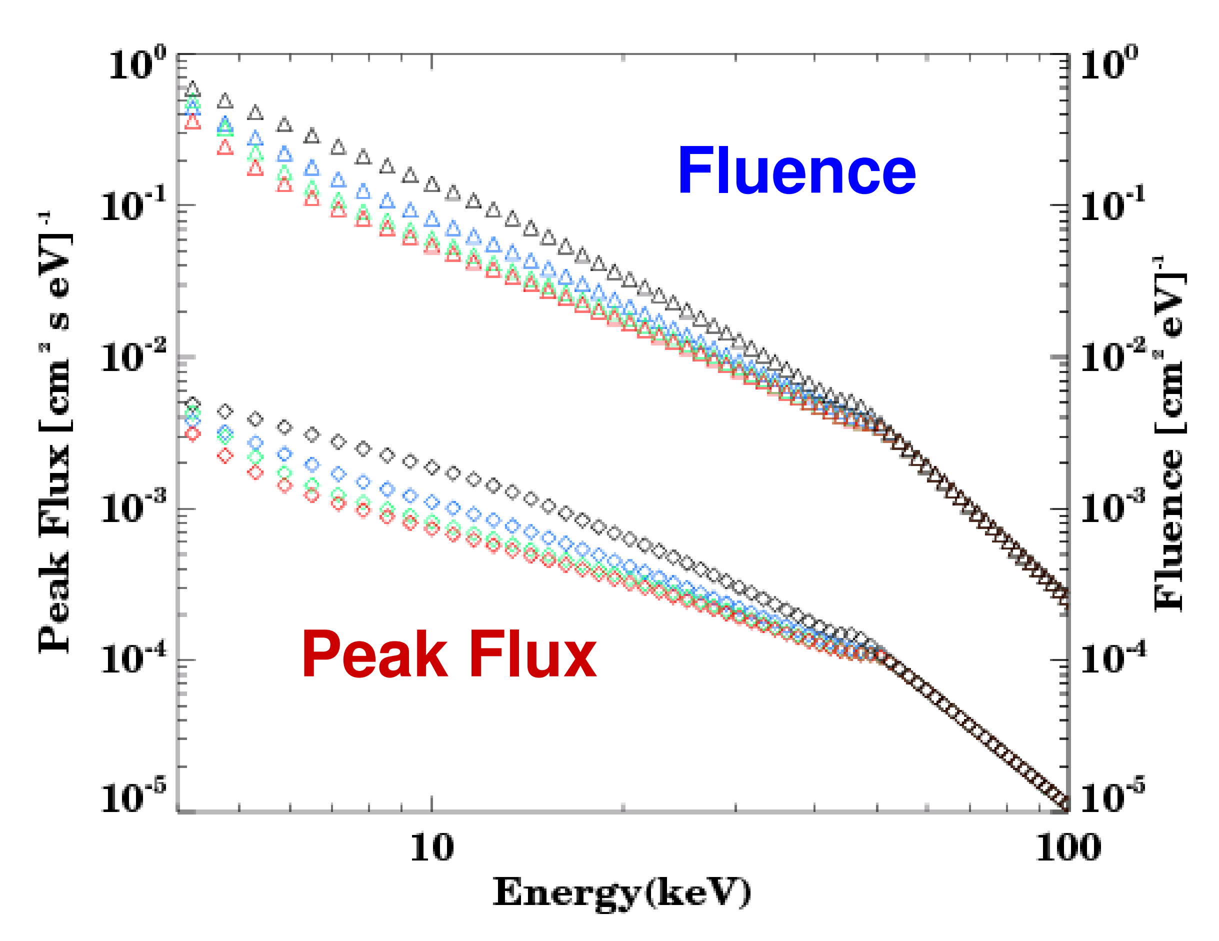
log10(W/W_Th)
Velocity v/v_t
SUN

Multiple Density Fluctuations

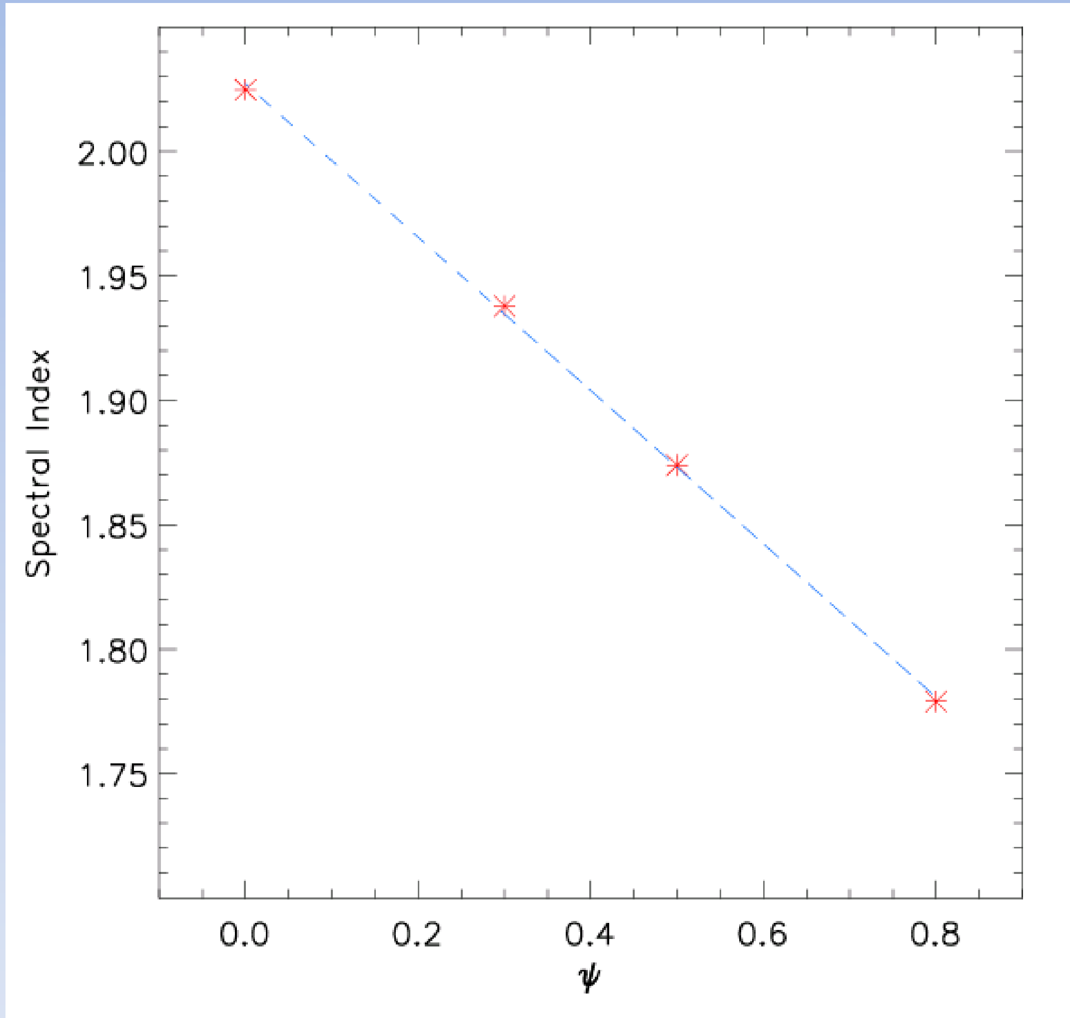
Fluence and
Peak Flux
spectra at
1.2AU

Larger powers of density fluctuations cause the spectral index below the break energy to be higher



Multiple Density Fluctuations

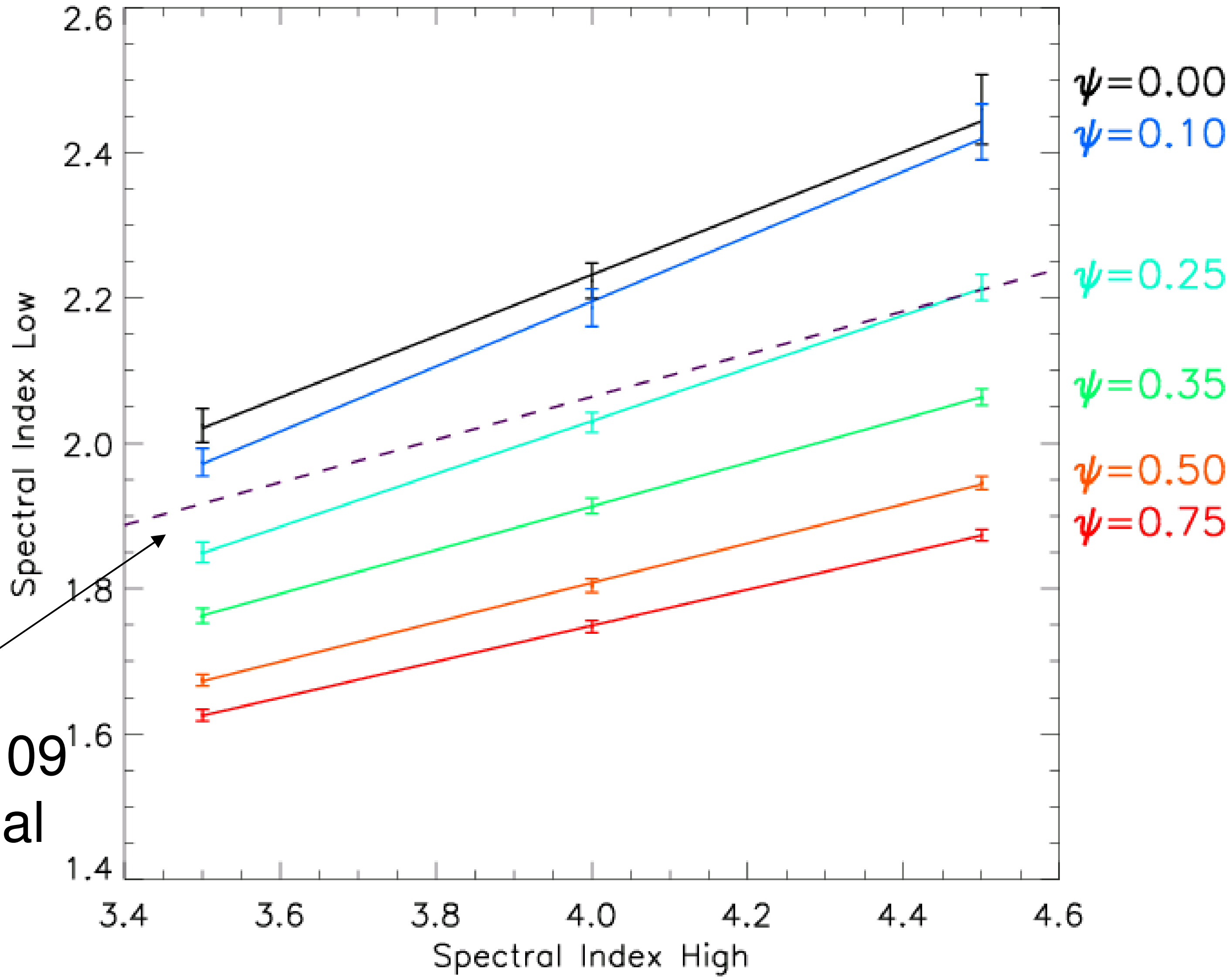
Larger intensities of **turbulence** cause the electron beam to relax less at low energies resulting in a **increased spectral index** below the break energy.



Multiple Density Fluctuations

Error bars are larger for smaller values of ψ

Krucker et al 09 Observational Data Fit



Conclusion

- The structure of the background plasma affects the spatial build up of plasma waves induced by the electron beam.
- Multiple small scale fluctuations are able to reproduce the burst nature of plasma waves observed in-situ
- Different levels of turbulence will cause more or less relaxation of the electron beam due to the production of plasma waves.