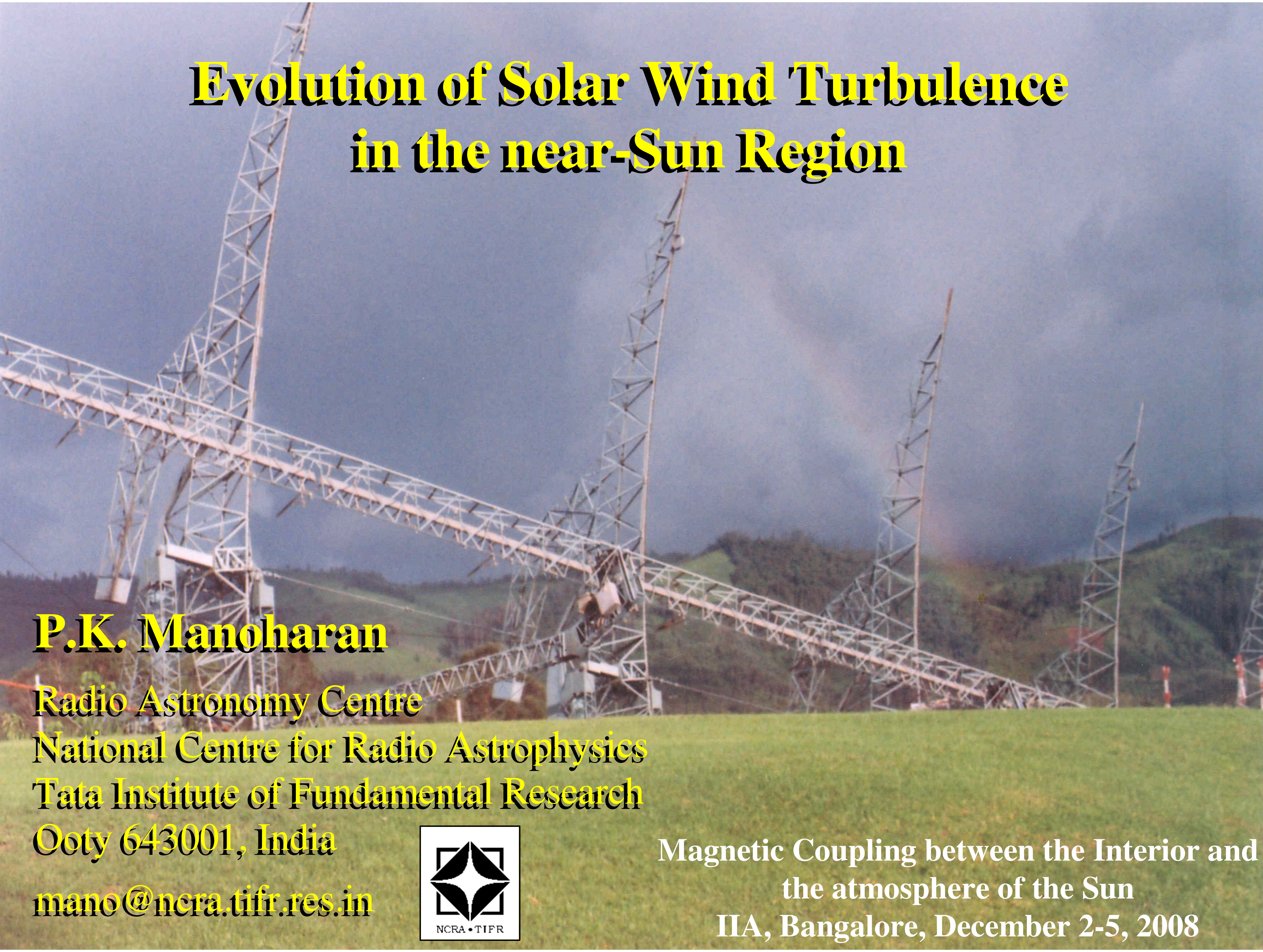

Evolution of Solar Wind Turbulence in the near-Sun Region

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Magnetic Coupling between the Interior and the atmosphere of the Sun
IIA, Bangalore, December 2-5, 2008

Outline

- Solar wind turbulence
- Interplanetary Scintillation (IPS) measurements
- Solar-wind turbulence at distances <50 $R_\odot$
- Summary

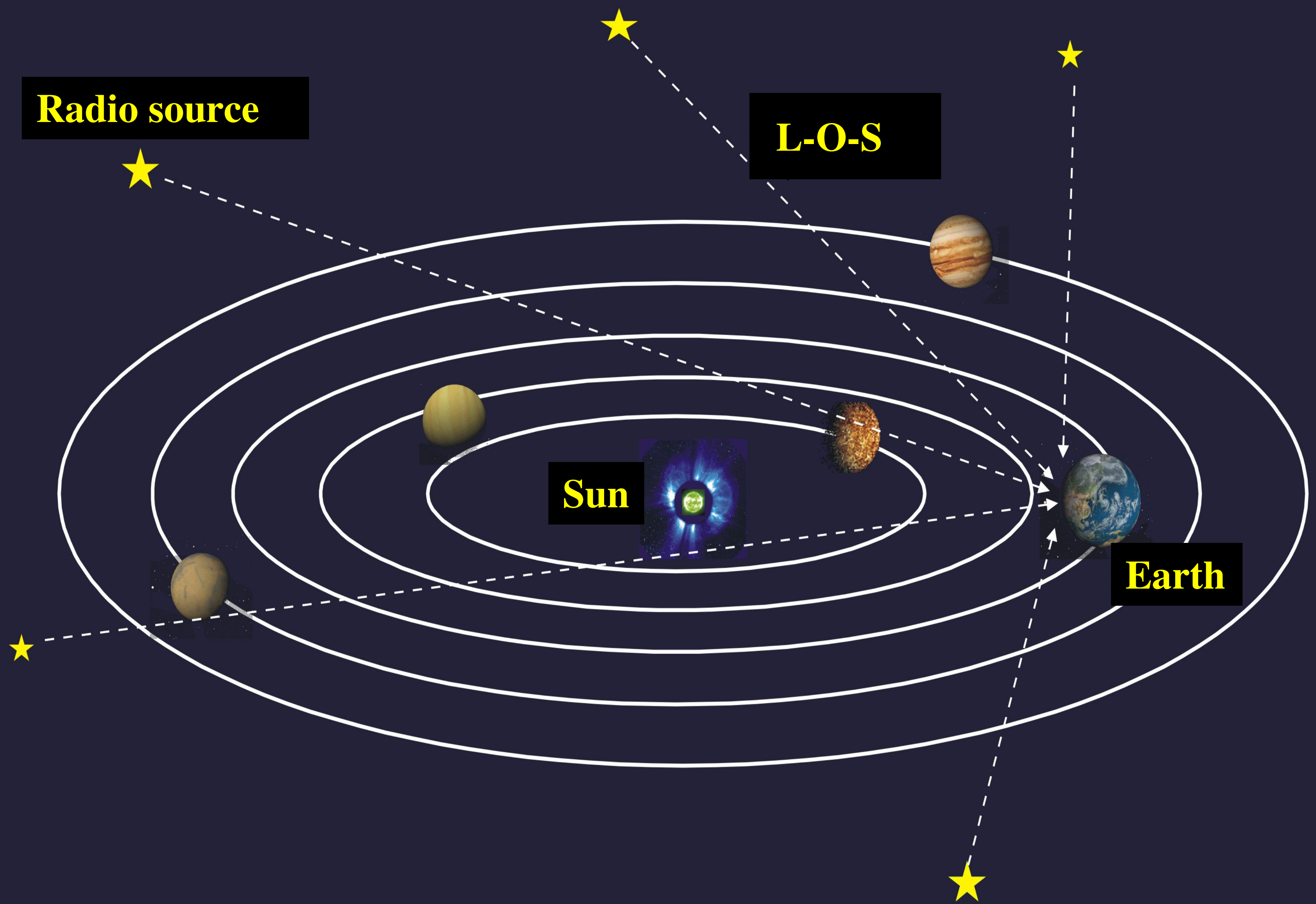
Solar Wind Turbulence

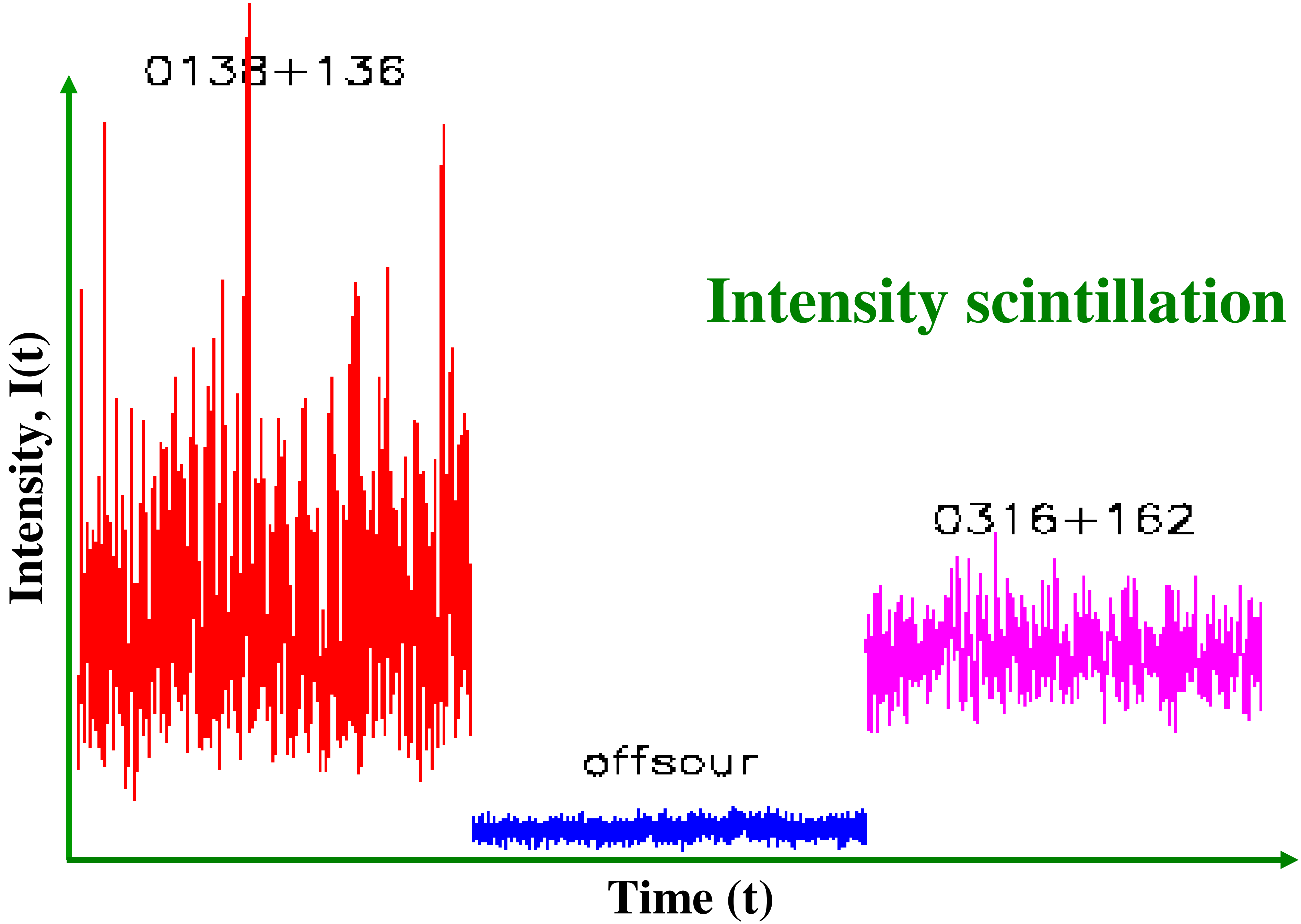
Solar wind – collisionless, magnetized plasma

- Continual, but variable, out flow from the Sun
- Supersonic (and super Alfvenic)
- Hot > 10^5 K
- Rarified (few particles/cm^3 at 1 AU)
- Complex (solar variability, solar rotation, in-situ processes, etc.)

- **Carries waves and turbulence**
  - Evolution of solar wind turbulence in the near-Sun region is important
  - Role of turbulence in accelerating the solar wind
  - Origin of fluctuations themselves
- **Interplanetary scintillation (IPS) technique is useful to probe the level of turbulence in the solar wind**

Interplanetary Scintillation




0138+136
Intensity scintillation
0316+162
offsour
Intensity, I(t)
Time (t)

IPS – Power Spectrum

Space and time correlation of Intensity fluctuations

$$\rho\left(r, t\right) = \left\langle \Delta I(r_o, t_o)\, \Delta I(r_o + r, t_o + t) \right\rangle$$

Transformation of the autocorrelation function gives the power spectrum

$$P_I = \frac{1}{2\pi} \int_{-\infty}^{+\infty} \rho(0, t) \exp(-i2\pi\, f\, t) dt$$

Radial dependence of density turbulence

$$m^2 = \frac{1}{\langle I \rangle^2} \left[\int_{-\infty}^{+\infty} P_I(f) df \right]$$

Scintillation Index (m) – measure of turbulence

$$m^2 \propto \int_{\mathrm{Earth}}^{\mathrm{source}} \Delta N_e^2(R) dz \qquad \Delta N_e^2 \propto R^{-4.4 \pm 0.4}$$

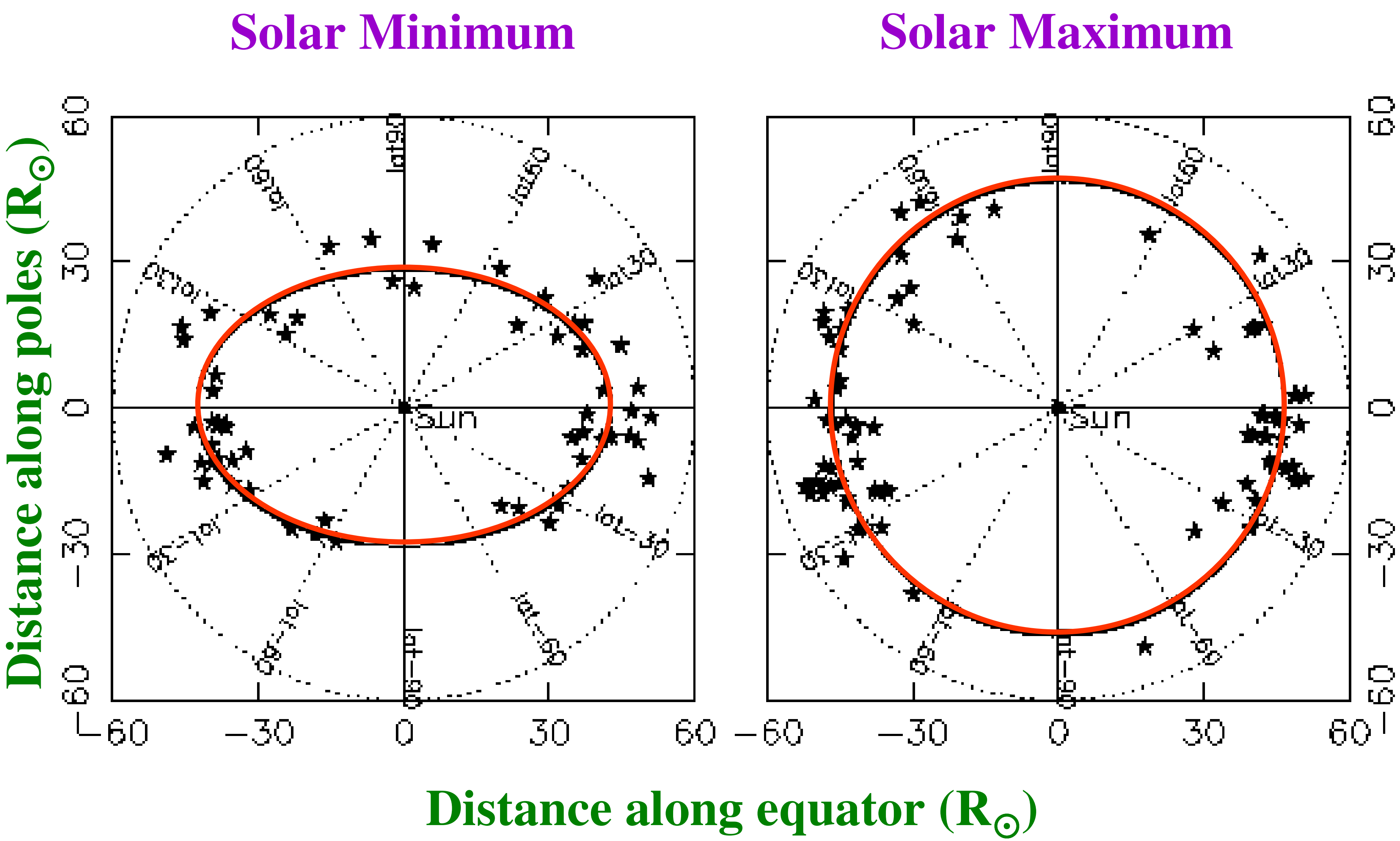
Interplanetary Scintillation (IPS)

- Caused by small-scale density fluctuations (or) turbulence in the solar wind
- IPS temporal power spectrum provides
  - spatial spectrum of turbulence (<400 km)
  - scale-size of density irregularities
  - inner-scale size (cut-off scale)
  - Speed of the solar wind
  - Size of the radio source

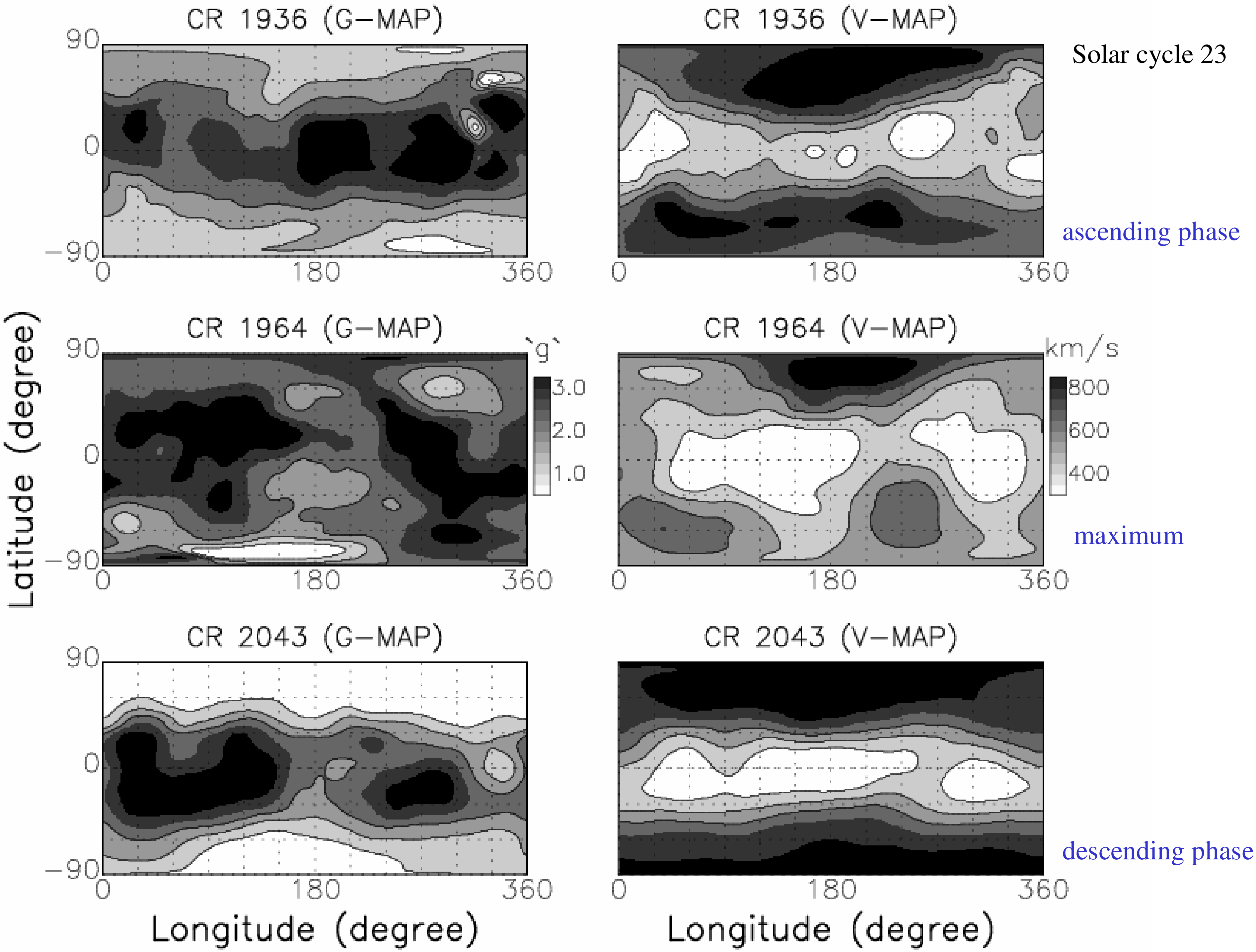
IPS measurements reported here have been made with the Ooty Radio Telescope (India) operating at 327 MHz

Solar wind – Relation to coronal Structures

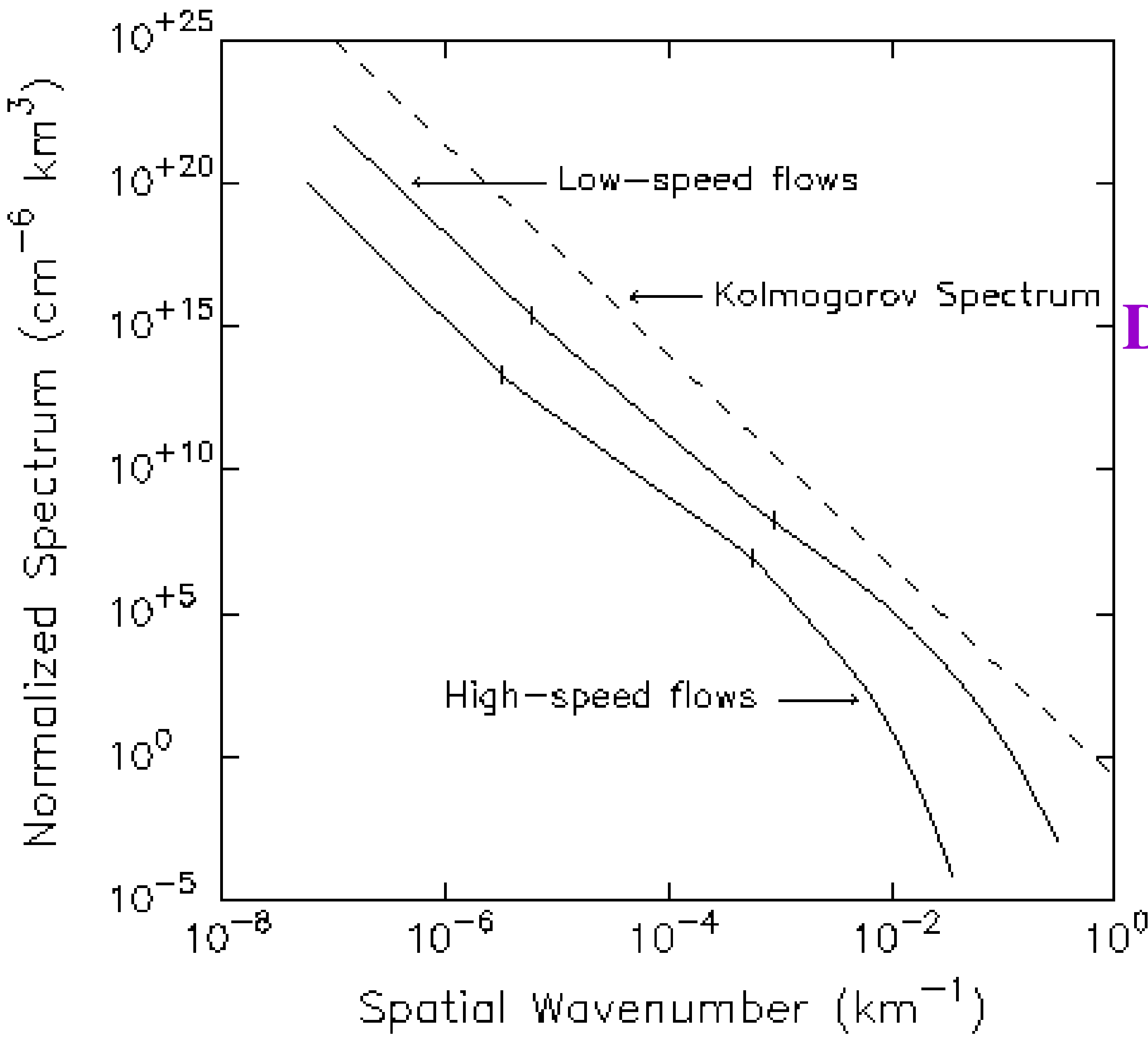
Constant Density Turbulence Contours



Ooty IPS Synoptic Maps – Density Turbulence and Speed



Spectra associated with ambient low- and high-speed solar wind flows



Solar wind
Density turbulence spectrum

cut-off (inertial) scale = V_A/ω_P

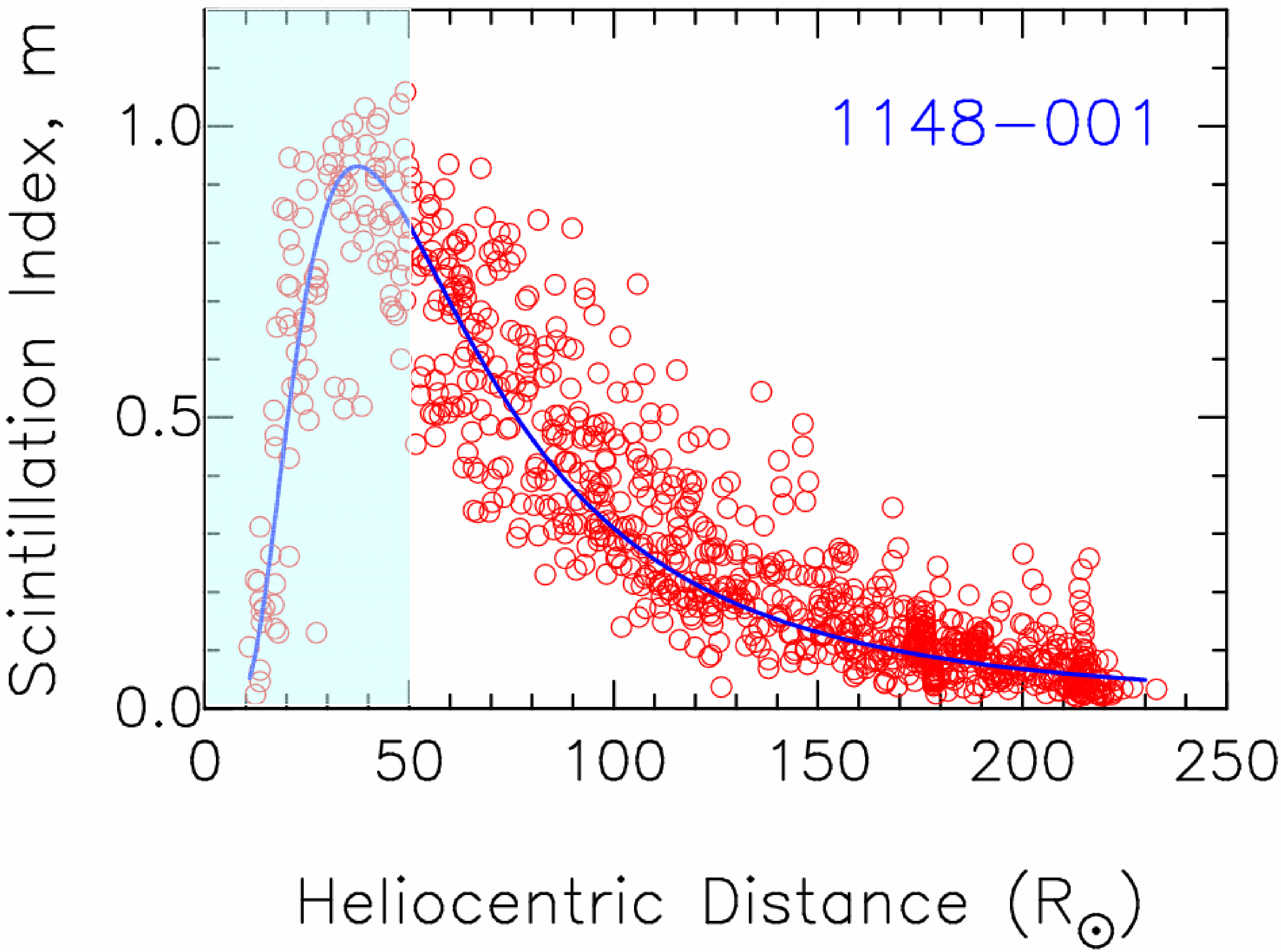
$= N^{-1/2}$

V_A Alfven speed

ω_P Proton cyclotron frequency

N Plasma density

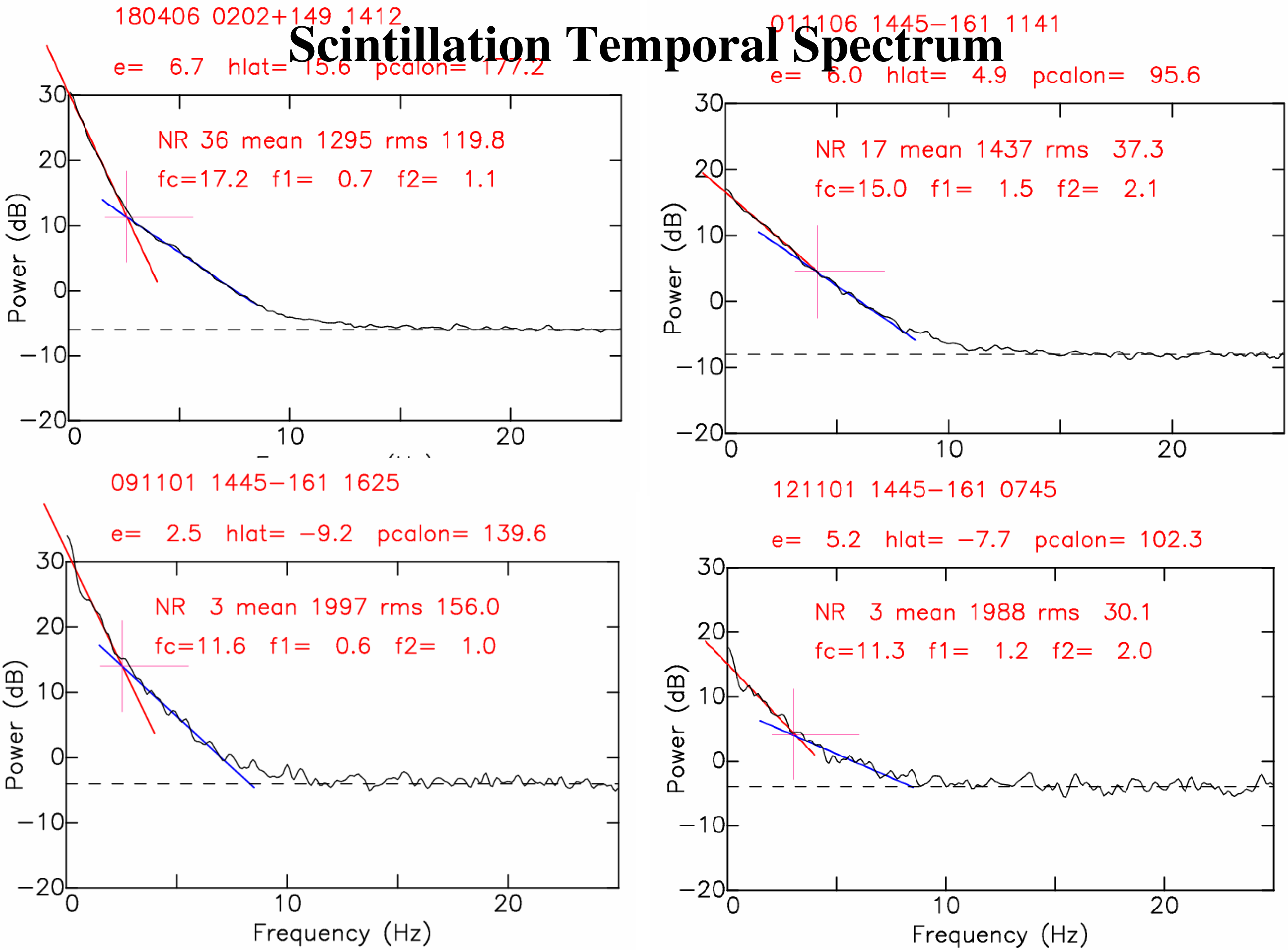
Solar wind Density Turbulence (scintillation index, m)



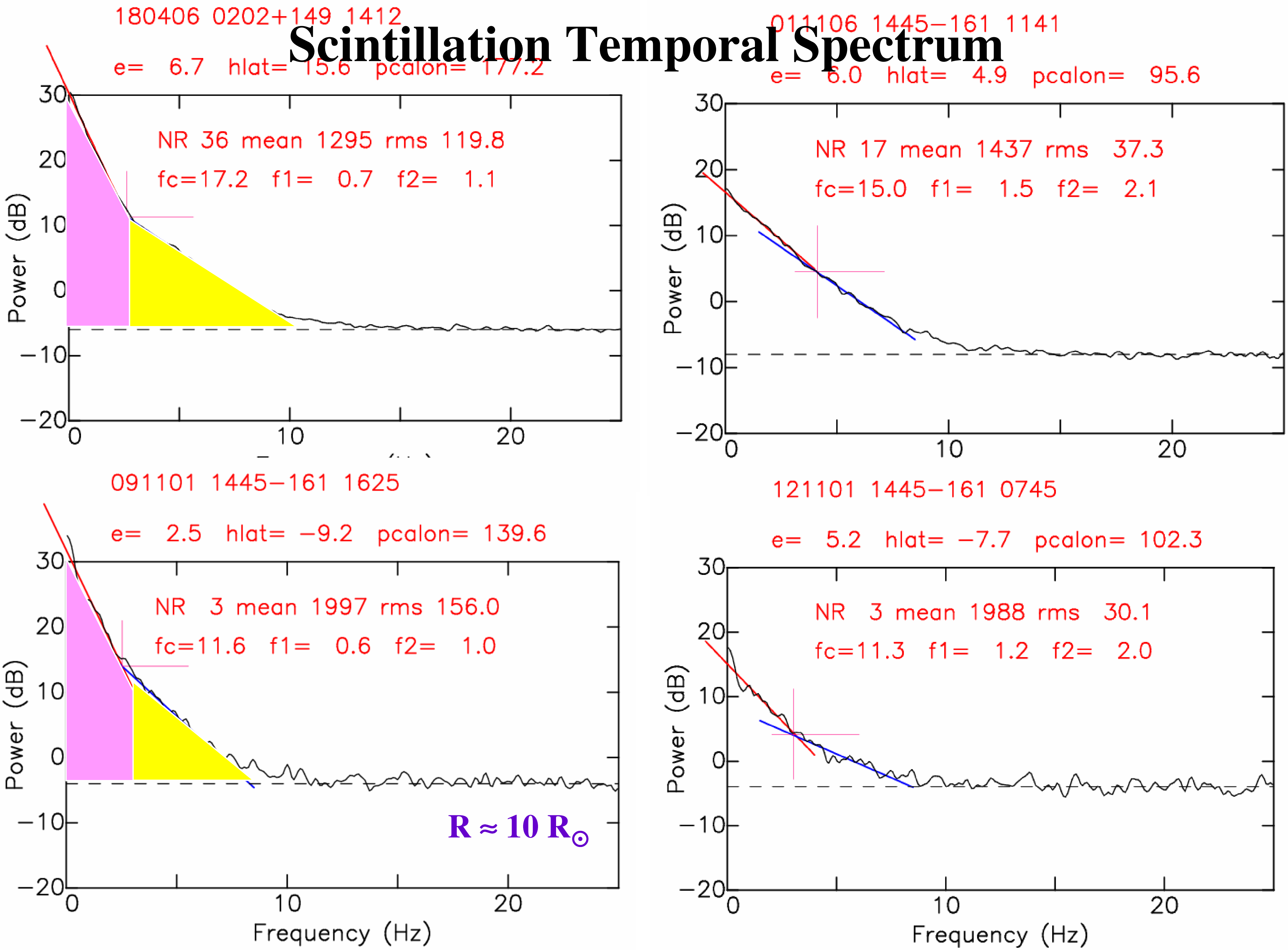
Solar wind turbulence at $R < 50 R_{\odot}$

- IPS on several compact radio sources have been observed in the heliocentric distance range 10 – 100 $R_{\odot}$

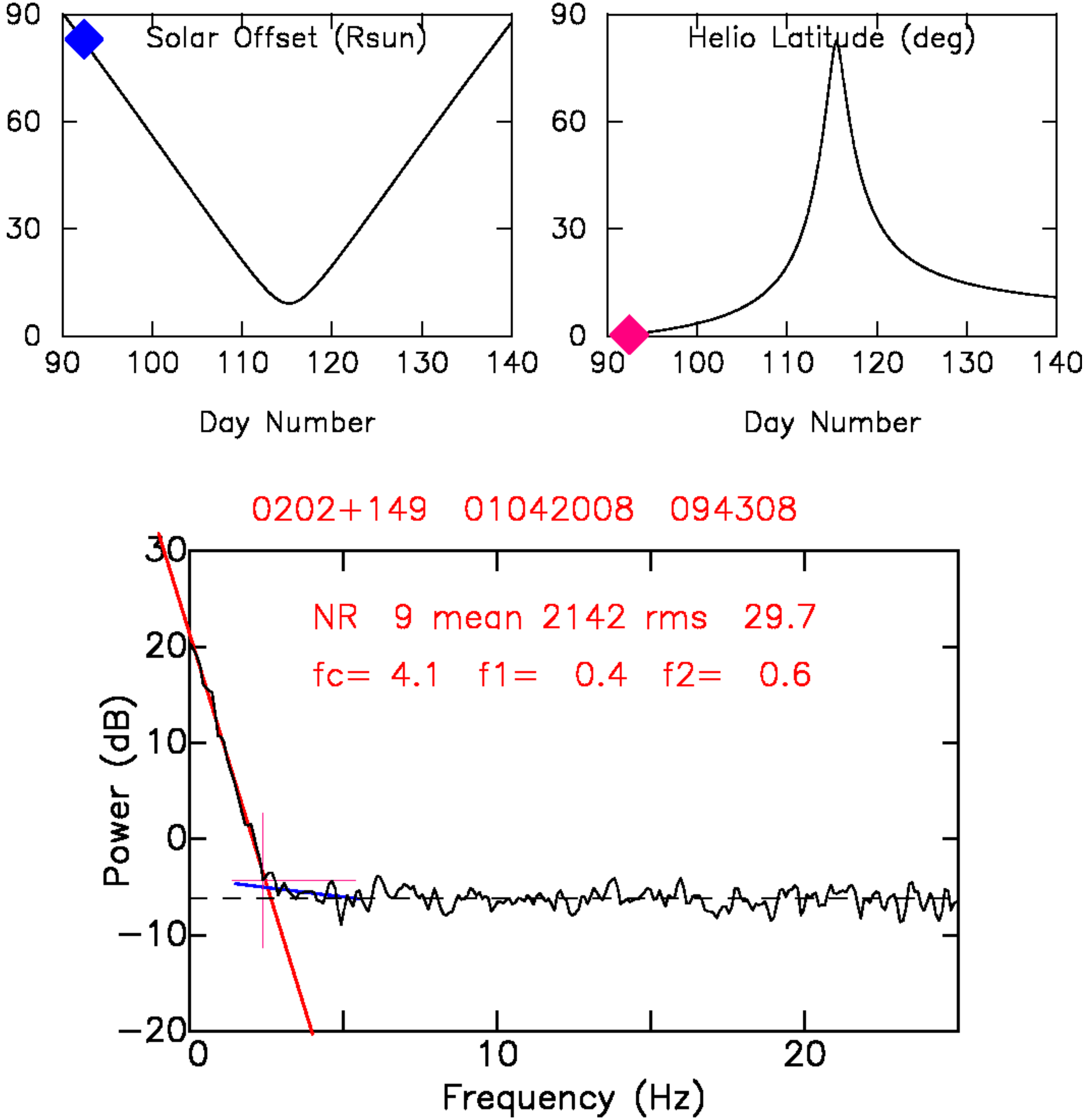
Scintillation Temporal Spectrum



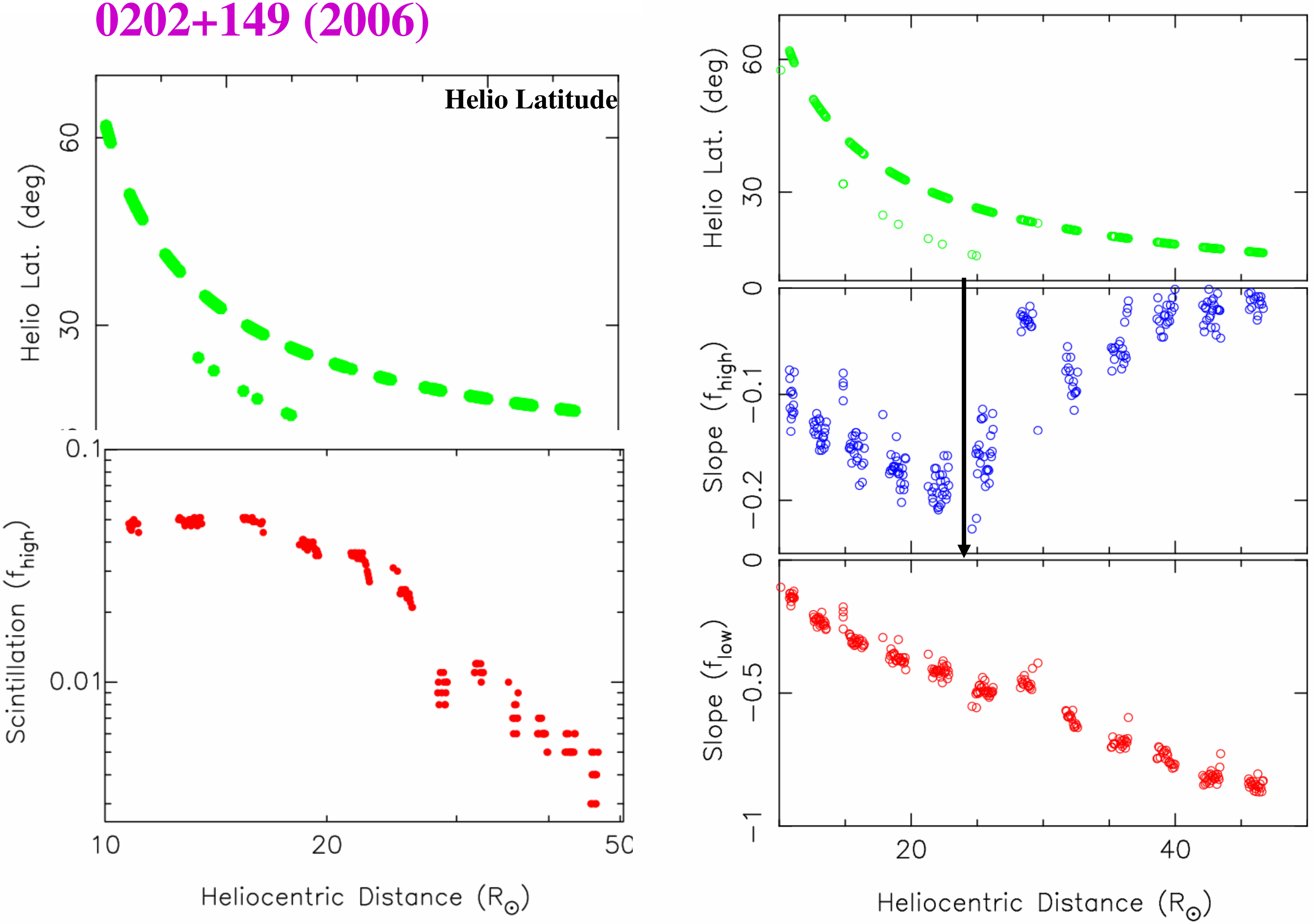
Scintillation Temporal Spectrum



Intensity fluctuations Spectra show evolution with heliocentric distance and latitude


Solar Offset (Rsun)
Helio Latitude (deg)
Day Number
Day Number
0202+149 01042008 094308
NR 9 mean 2142 rms 29.7
fc= 4.1 f1= 0.4 f2= 0.6
Power (dB)
Frequency (Hz)

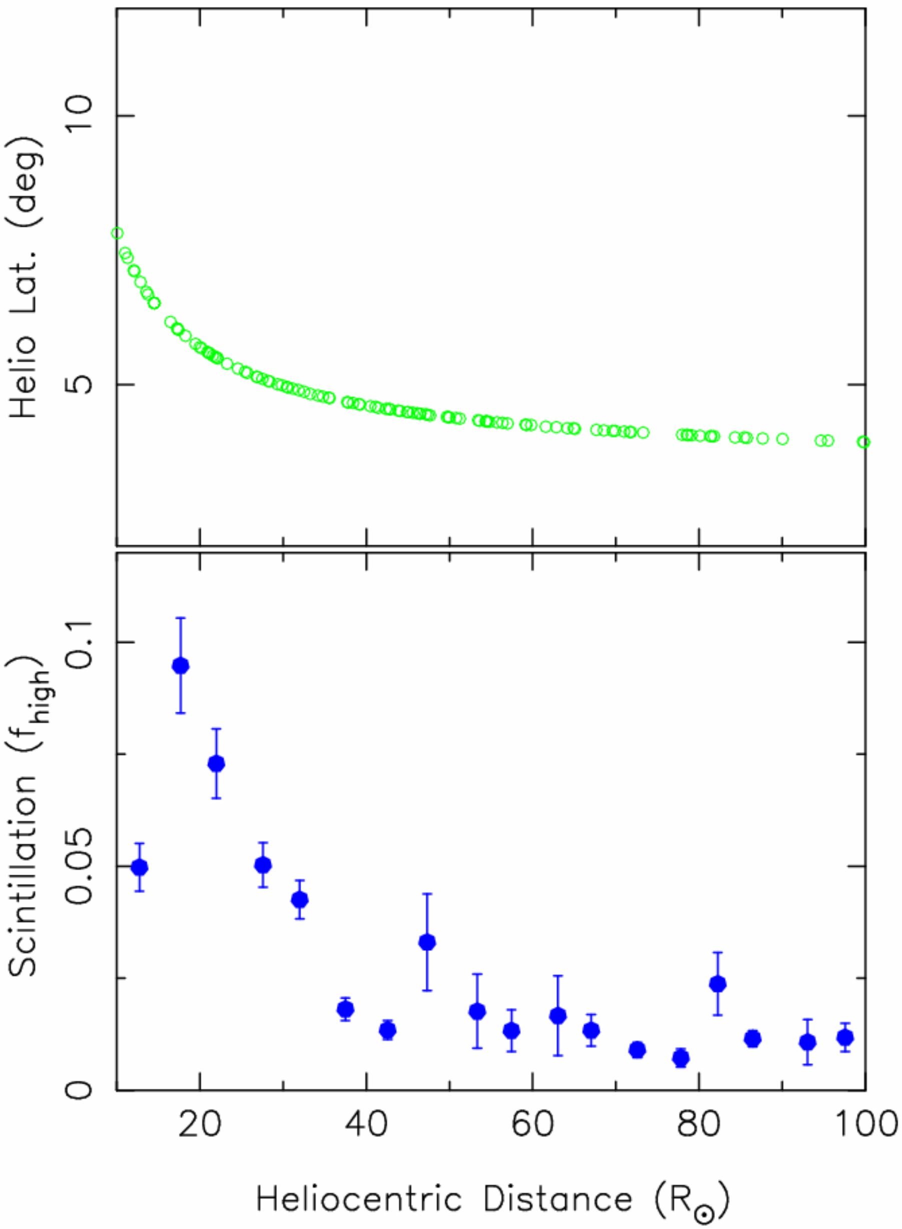
0202+149 (2006)

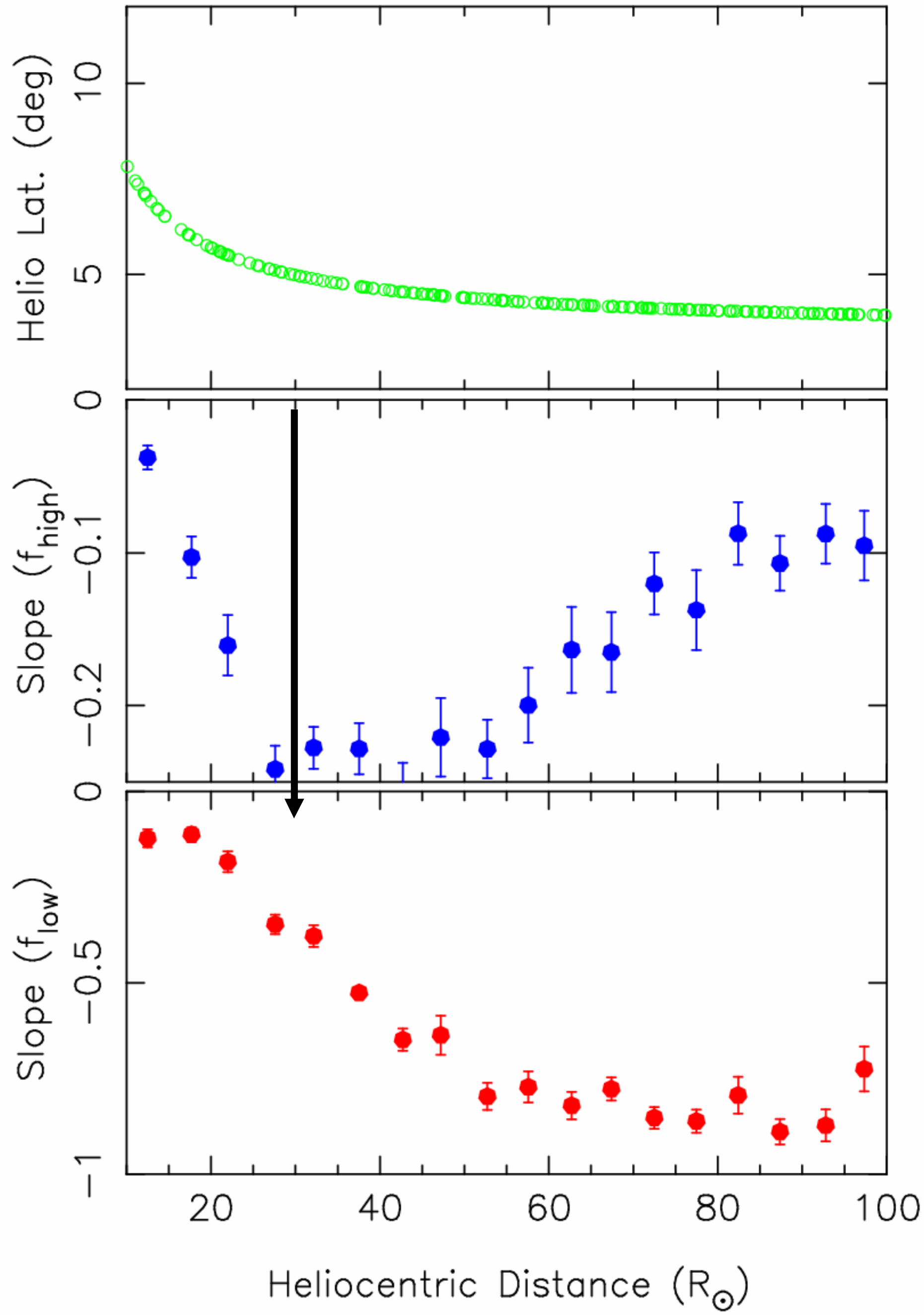


Turbulence Spectrum Evolution

- At R < 50 $R_\odot$
  - Low-frequency portion – flat to steep spectrum – tends toward a Kolmogorov-type spectrum at R >50 $R_\odot$
    - Contains most of the scintillation/turbulence power (~90%)
    - Corresponds to scales-size >50 km to Fresnel scale
    - Turbulence follows ~R^{-2} dependence
  - High-frequency part – steep to flat spectrum - turbulence power decreases and approaches a null value at R >25 $R_\odot$
    - Accounts for only <10% of total level of turbulence at R ~10 $R_\odot$
    - For typical solar wind velocity in the range 200 – 400 km/s, this part of the spectrum corresponds to spatial-scale size ~5 – 50 km
    - Turbulence falls off steeper than the above ~R^{-2} fall off

Radio Quasar 3C279 (2004 – 05)





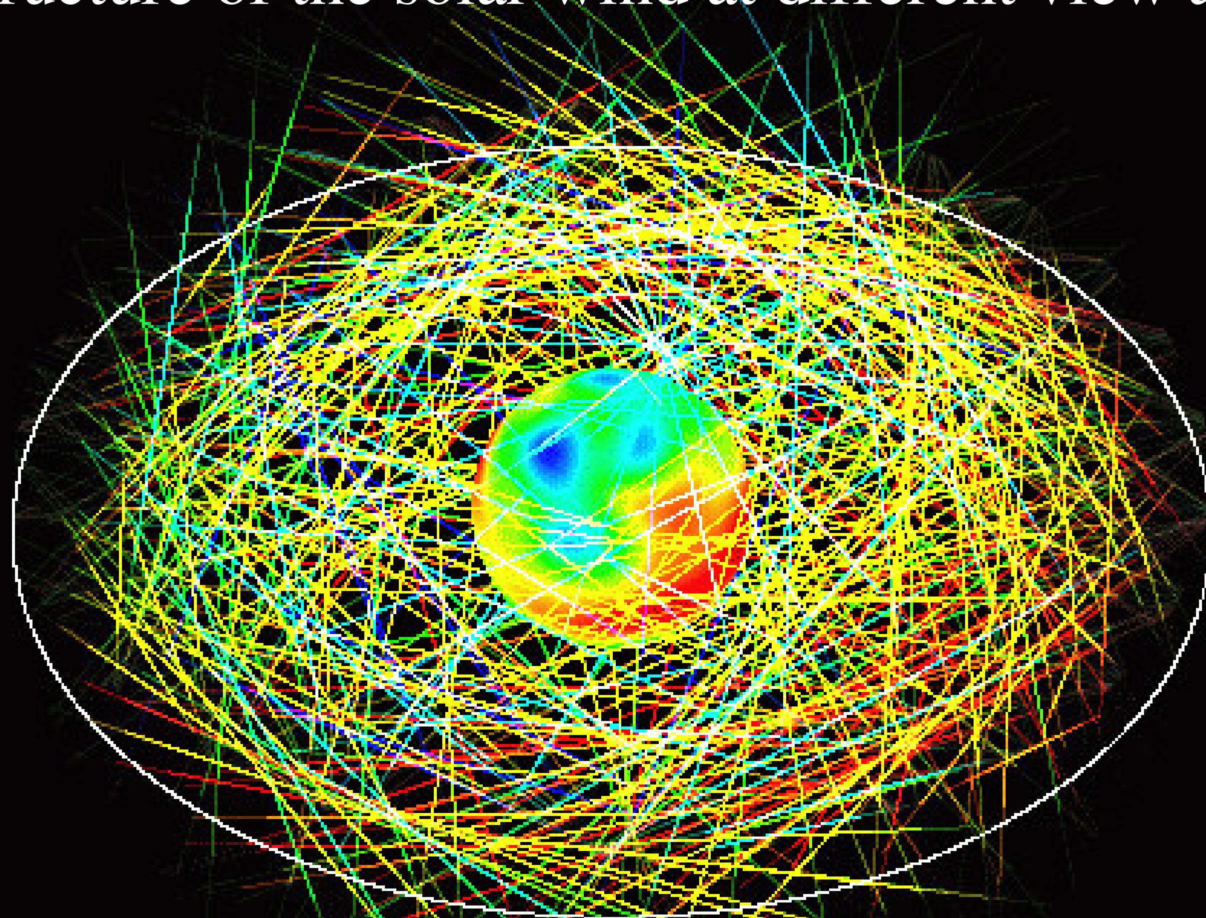
Conclusion

Broad turbulence spectra obtained from IPS measurements at $R<50\ R_{\odot}$ suggest obliquely propagating Alfven/ion cyclotron waves.

- **Inner-scale (or) cutoff-scale size – effect not seen**
  - **Turbulent cascade/WKB approximation inadequate to explain the broad spectrum – inner scale (or) spectral cutoff would limit the spectrum at high-frequency part.**
- **The spectral shape – two components**
  - **The shape and power of turbulence can be explained by a combined spectrum – power-law shape and presence of linear Alfven wave at small scales (dissipation associated with electron Landau damping and proton cyclotron damping).**
  - **These are consistent with other findings (angular broadening, …etc.)**

Thank You

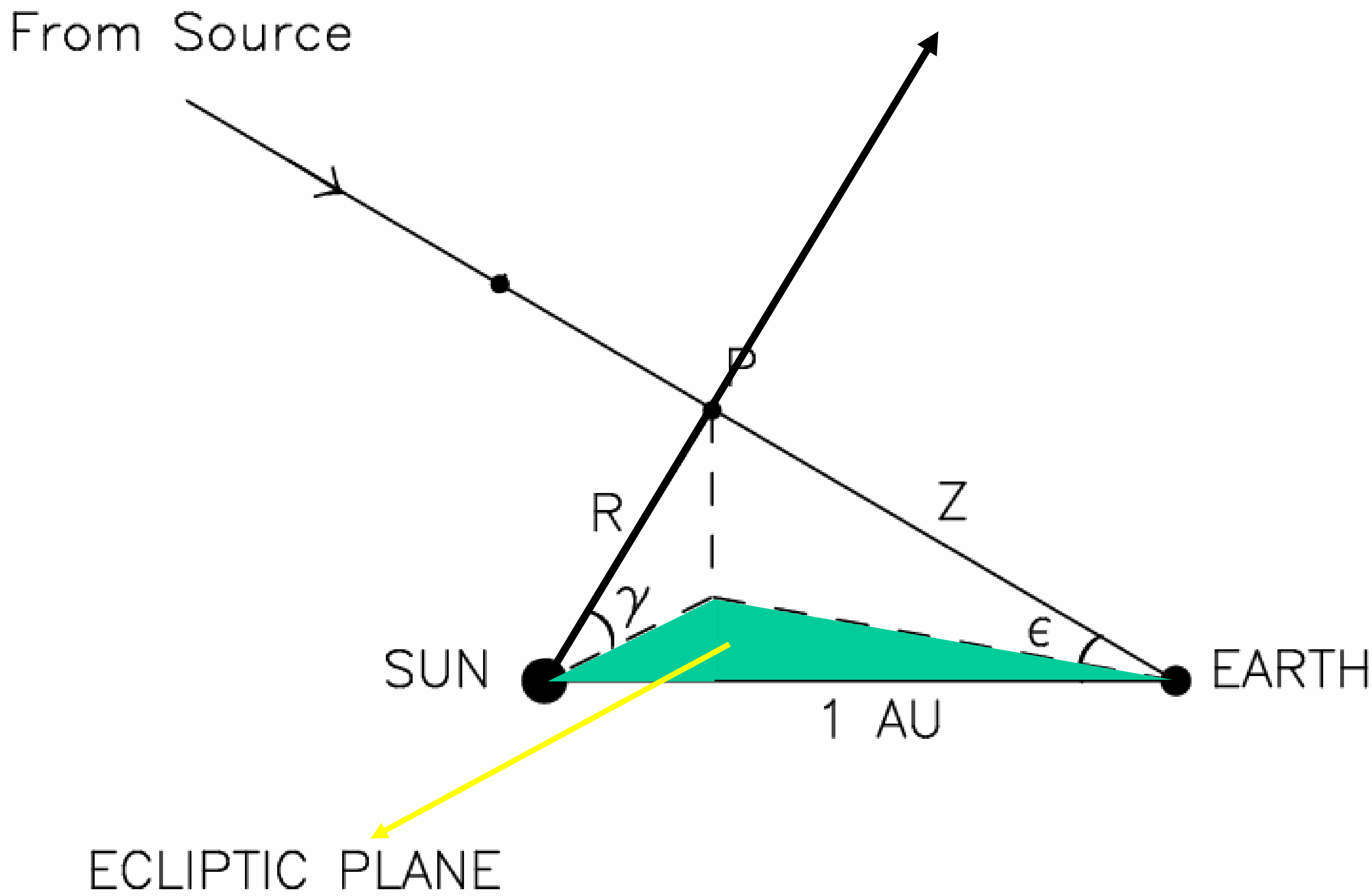
Solar rotation and radial outward flow of the solar wind provide the 3-d structure of the solar wind at different view angles



Computer Assisted Tomography analysis

can remove the line-of-sight integration imposed on the solar wind parameters also provides high spatial resolution

Interplanetary Scintillation Geometry



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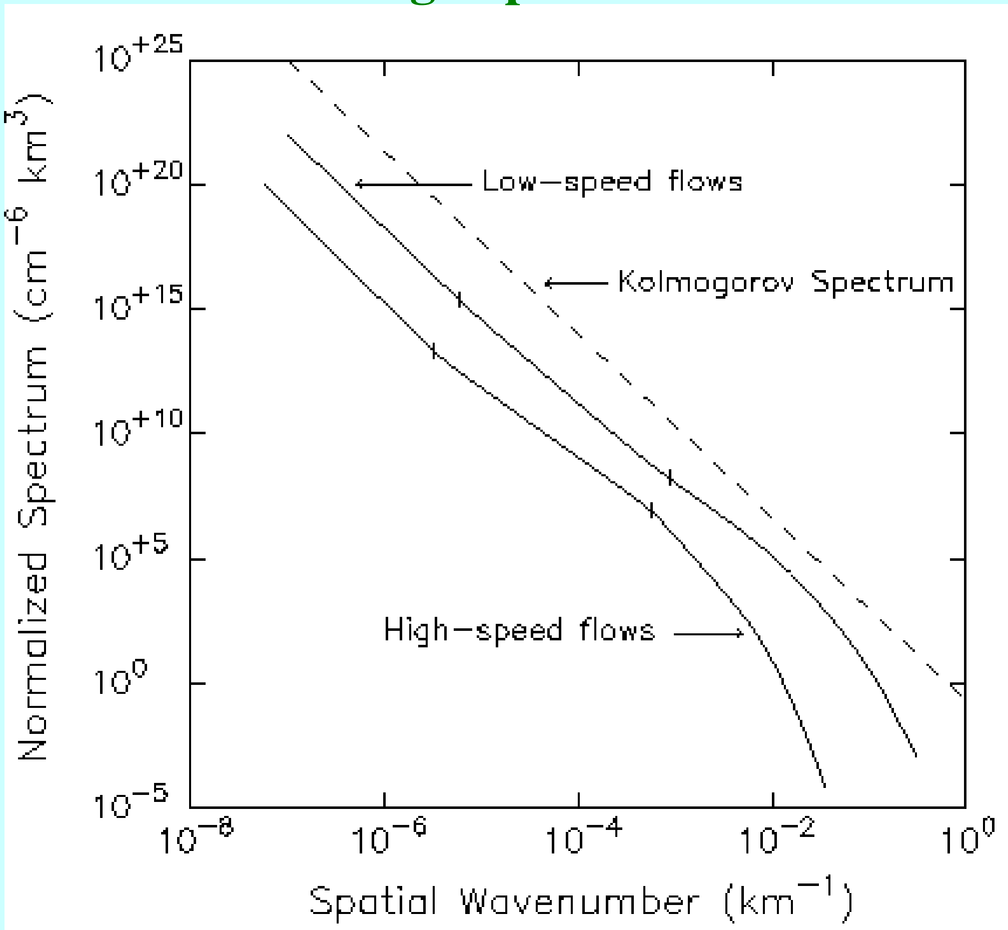

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$= N^{-1/2}$

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N Plasma density

Solar wind
Density turbulence spectrum

Density turbulence spectrum associated with propagating CME