Evolution of Turbulence Anisotropy in the Outer Heliosphere and Transport of Pickup-ion-associated Energy: Voyager 2 Observations

Xingyu Zhu[1], Jiansen He[1], Gary P. Zank[2,3], Daniel Verscharen[4], Ling-Ling Zhao[2,3], Die Duan[1], Rong Lin[1]

1 School of Earth and Space Sciences, Peking University, Beijing 100871, People's Republic of China. 2 Center for Space Plasma and Aeronomic Research (CSPAR), The University of Alabama in Huntsville, Huntsville, AL 35805, USA. 3 Department of Space Science, The University of Alabama in Huntsville, Huntsville, AL 35805, USA. 4 Mullard Space Science Laboratory, University College London, Dorking RH5 6NT, UK

This presentation participates in OSPP

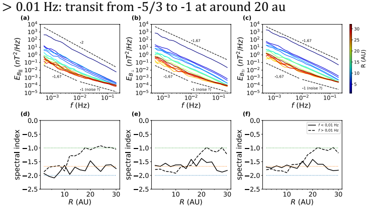
Outstanding Student & PhD candidate Presentation contest

abstract

We study the radial evolution of the inertial-range solar wind plasma turbulence and the turbulence anisotropy in the outer heliosphere. We use magnetic field measurements from *Voyager* 2 spacecraft in the range of heliocentric distance R from 1 au to 33 au. We find that the perpendicular and trace power spectral densities (PSDs) of the magnetic field $E_{B_\perp}$ and $E_{B_{Tr}}$, respectively) still follow a Kolmogorov-like spectrum until 33 au. $E_{B_\parallel}$ transits from a power law index of -2 to -5/3 as the distance goes from below $R < 10$ au to above $R > 10$ au. The PSD at frequencies 0.01 Hz< f <0.2 Hz gets flattened at $R > 20$ au, gradually approaching to a f^{-1} spectrum, probably due to instrument noise. The propagation angle distribution shows an interesting evolutionary feature. At 0.002 Hz $< f <$ 0.1 Hz, quasi-parallel propagation dominates in 1 au< R <10 au, with quasi-perpendicular propagation gradually emerging at $R > 5$ au . For $R >$ 7 au , oblique propagation becomes a primary component. At smaller frequencies of f <0.01 Hz , $E_{B_\perp}$ increases with propagation angle in 1 au< $R <$ 5 au, and in contrast decreases with propagation angle at $R > 5$ au due to the enhanced power level at propagation angles smaller than 20°. We suggest that such enhancement may derive from the injection of the wave energy from the pickup ion source into the background turbulent cascade, and the injected wave energy is transferred across scales without leaving bumps in $E_{B_\perp}$ or $E_{B_{Tr}}$.

radial evolution of power spectra density and spectral index of magnetic turbulence

- $f < 0.01$ Hz:
  - Spectral indexes for $E_{B_\perp}$ and $E_{B_{Tr}}$ are close to -5/3
  - Spectral index for $E_{B_\parallel}$: $R < 10$ au – between -2 and -5/3; $R > 10$ au – close to -5/3
- $f > 0.01$ Hz: transit from -5/3 to -1 at around 20 au



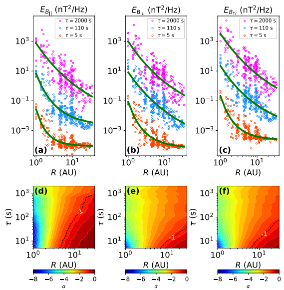
modelling the radial evolution of power spectral density at different scales

- Model for PSD evolution:

$$\log_{10} E_{B_i} = a_1 R^{-a_2} + a_3$$

$$E_{B_i} \sim R^{-\alpha}$$

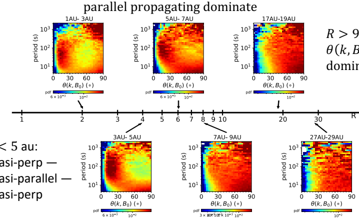
- $\tau = 2000$ s:
  - $R > 10$ au, decay of turbulent energy slows down
- $\tau = 110$ s:
  - The profiles of $E_{B_\perp}$ and $E_{B_{Tr}}$ are similar to larger scales
  - $E_{B_\parallel}$ decreases faster at $R < 5$ au while more slowly at $R >$ 5 au
- $\tau = 51$ s:
  - PSDs decrease faster at $R <$ 5 au while saturate at $R \sim 20$ au



radial evolution of the propagation angle distribution

5 au $< R <$ 7 au: more fluctuations of $\theta(k, B_0) > 30°$ but still quasi-parallel propagating dominate

$R > 9$ au: $\theta(k, B_0) > 30°$ dominates



$R < 5$ au: quasi-perp — quasi-parallel — quasi-perp

7 au $< R <$ 9 au: quasi-perpendicular propagating fluctuations dominate

average power spectra densities for different propagation angles

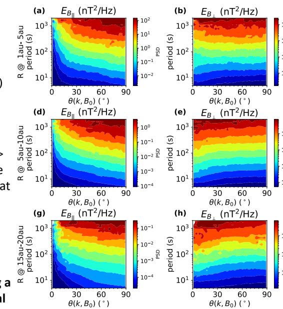
- 1au ~ 5au :
  - $\tau > 100$s :

  $E_{B_\perp}$ **increases** with $\theta(k, B_0)$
- 5au ~ 10au :
  - $\tau > 100$s :

  $E_{B_\perp}$ **decreases** with $\theta(k, B_0)$

- The change of power spectra anisotropy at $\tau >$ 100s is mainly due to the enhancement of power at $\theta(k, B_0) < 20°$

This result may imply the cascade of the turbulent energy associated with pickup ions without leaving a bump on the power spectral density



conclusion

- Evolution of the turbulence features in the outer heliosphere (1au-33au)

1. We propose a new model that describes the radial evolution of PSD.
2. The evolution of the propagation angle of the magnetic fluctuations is mainly between 5 au and 9 au, with a shift from quasi-parallel propagating fluctuations dominating to quasi-perpendicular propagating fluctuation dominating.
3. The turbulent energy excited by pickup ions can inject into the background solar wind turbulence. The pickup-ion-associated turbulent energy may cascade along the parallel direction with respect to the local mean magnetic field, without leaving a bump in the power spectrum.