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Turbulence Transport Modelling of the Temporal Outer Heliosphere

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Overview

Turbulence is a fundamental and ubiquitous process in the solar wind. The time-dependent turbulence transport equations describing the fluctuating magnetic energy density (E_b), correlation length (l), and solar wind temperature (T) are solved by introducing a variable solar wind convection speed, and time-dependent source terms and inner boundary conditions. The effect of solar cycle on solar wind turbulence is investigated along the trajectory of the Voyager 2 spacecraft. The turbulence transport equations are given by,

$$\frac{\partial E_b}{\partial t} + \mathbf{U}\cdot\nabla E_b + \frac{1}{2}\nabla\cdot\mathbf{U}E_b + 2\sigma_D M E_b = -\frac{E_b^{3/2}}{l} + S;$$

$$\frac{\partial l}{\partial t} + U\frac{\partial l}{\partial r} + \Gamma\frac{U}{r}l = \frac{E_b^{1/2}}{2} - \frac{l}{2E_b}S;$$

$$\frac{\partial T}{\partial t} + U\frac{\partial T}{\partial r} = -\frac{4}{3}\frac{T}{r}U + \frac{2}{3}\frac{m_p}{k_B}\frac{E_b^{3/2}}{l},$$

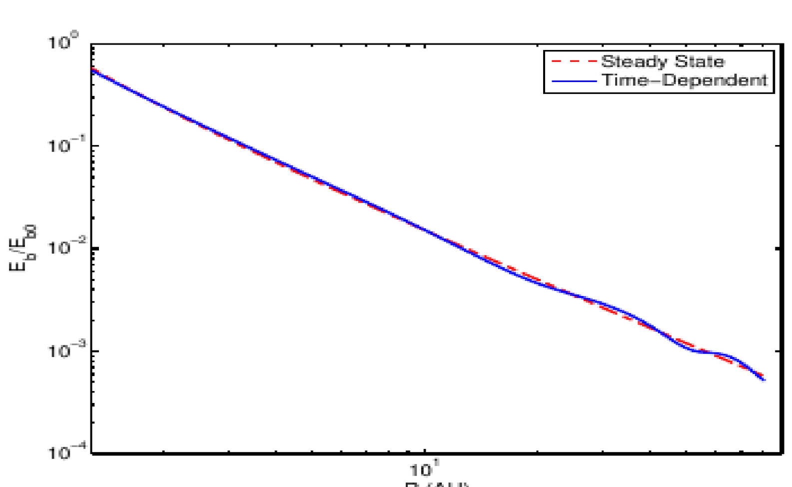


Fig:Normalized magnetic energy Density as a function of heliocentric distance (Undriven Model)

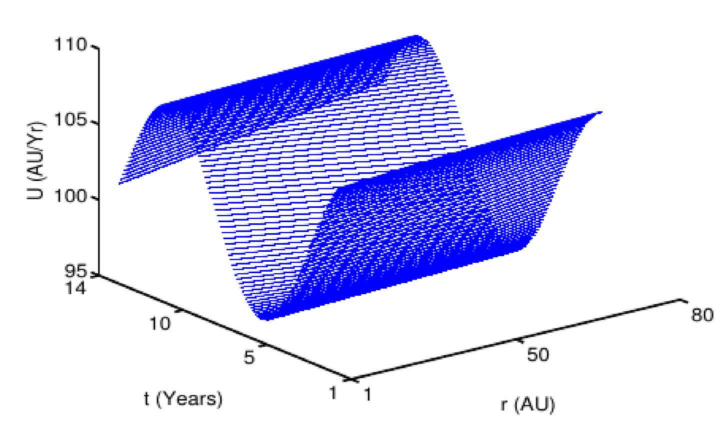


Fig: Time-dependent solar wind velocity

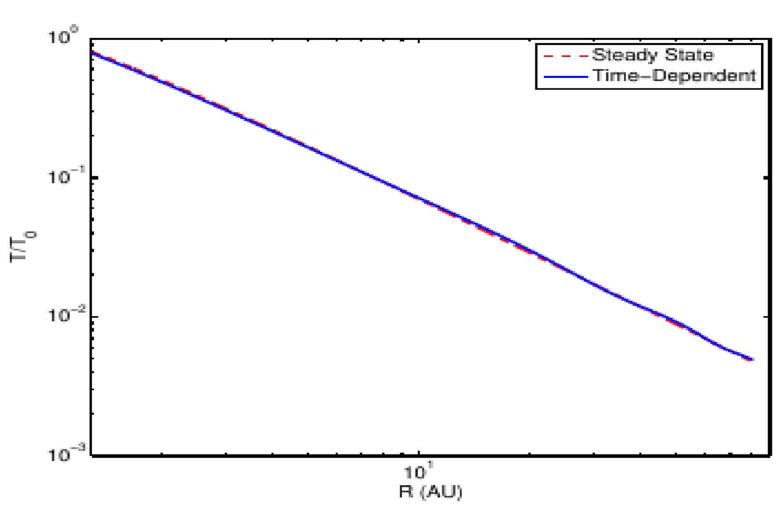


Fig: Normalized solar wind temperature as a function of heliocentric distance (Undriven Model)

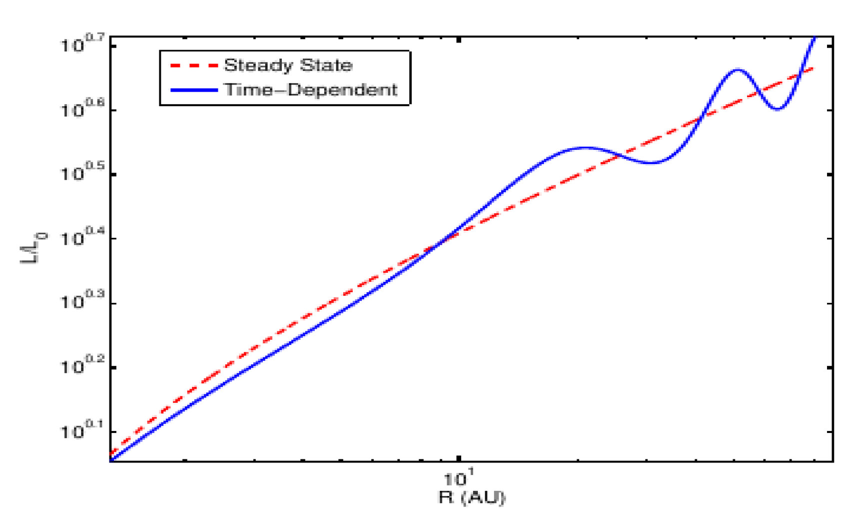


Fig:Normalized Correlation length as a function of heliocentric distance (Undriven Model)

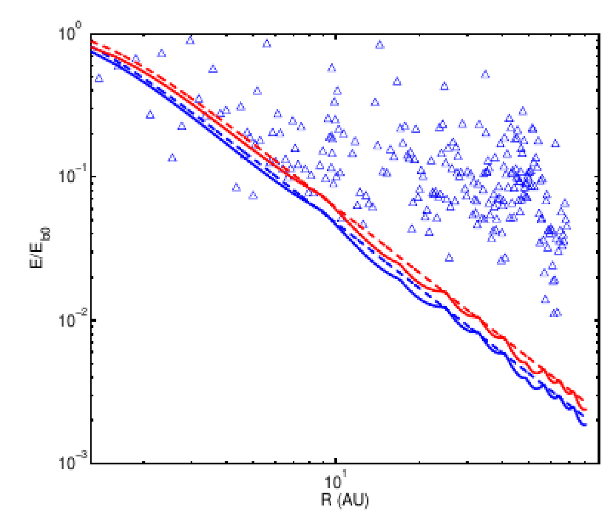
Impact

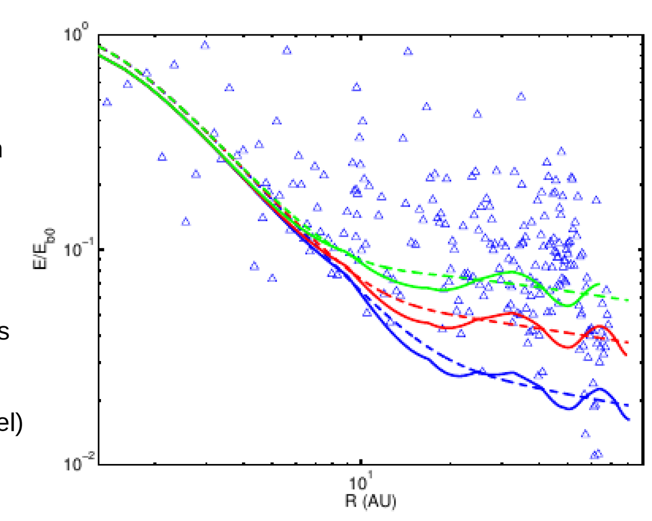
Understanding the transport of low-frequency magnetohydrodynamic turbulence in the solar wind has a critical impact on our understanding of almost all physical processes in the interplanetary medium. These include the extended heating of the solar wind, and the transport of cosmic rays. Previous work was restricted to steady-state models. However, the solar wind is intrinsically time-dependent, and its properties vary with solar cycle. Accordingly, we introduce and solve the turbulence transport equations in a temporal heliosphere.

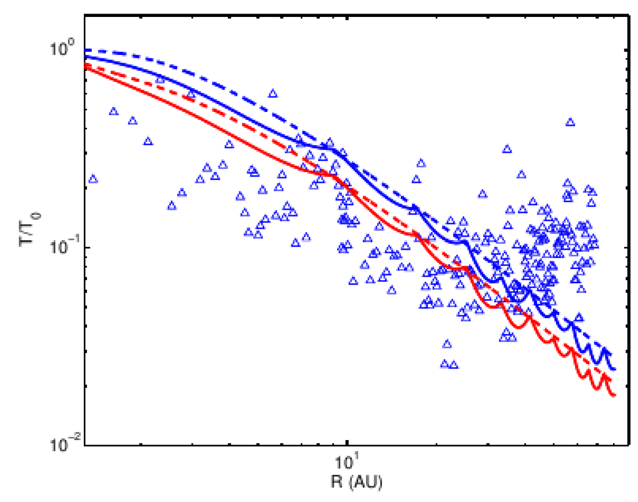
Key Findings

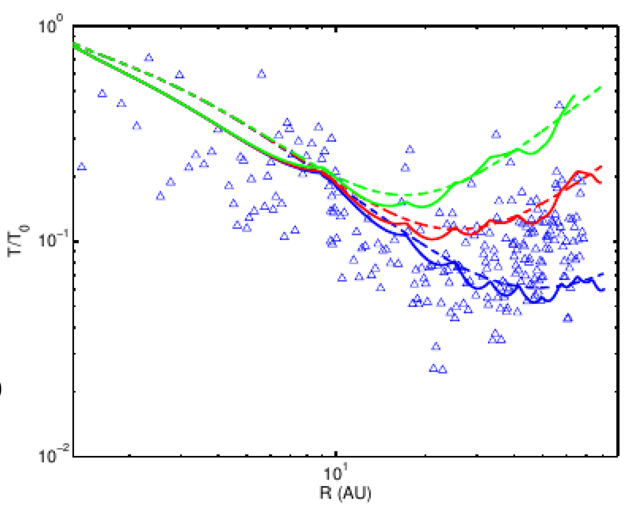
Besides the Sun, various sources (temporal) of turbulence are present in the solar wind. These include shock waves and streams due to the Sun, and the creation of interstellar pickup ions. The coupled equations are solved in the absence of sources (i.e. an undriven model) and with source terms (a separate stream-interaction source model and a pickup ion source model). We compare with Voyager 2 observations. Our results can be summarized as:

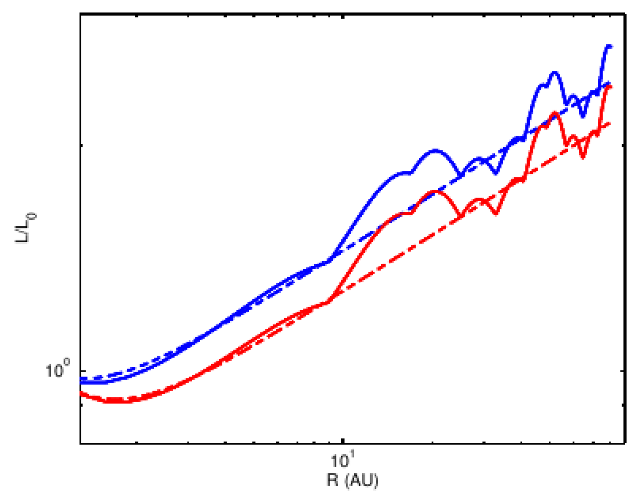
1) The turbulent magnetic energy, correlation, and temperature depend on solar cycle.
2) Driving by stream-shear is important in the inner heliosphere and pickup ion driving in the outer heliosphere.

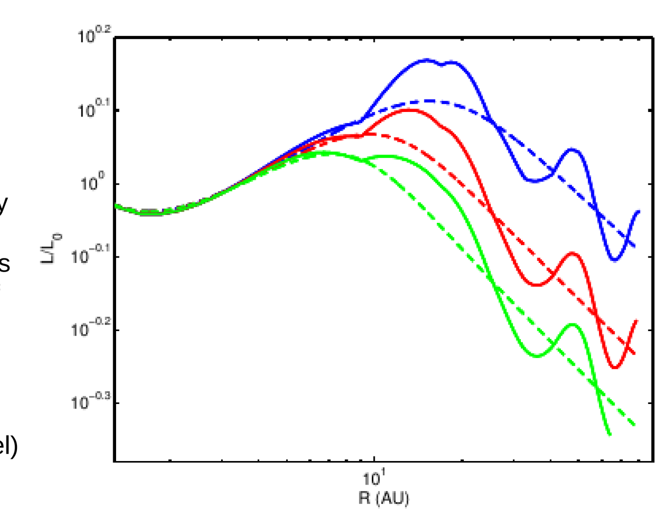

Comparison between normalized magnetic energy density with observations (Stream Interaction Driven Model)


Comparison between normalized magnetic energy density with observations (Stream Interaction & Pickup Ion Driven Model)


Comparison between Normalized Solar wind temperature with observations (Stream Interaction Driven Model)


Comparison between Normalized Solar wind temperature with observations (Stream Interaction & Pickup Ion Driven Model)


Normalized correlation length along the trajectory of the Voyager 2 as a function of heliocentric distance (Stream Interaction Driven Model)


Normalized correlation length along the trajectory of the Voyager 2 as a function of heliocentric distance (Stream Interaction and Pickup Ion Driven Model)

Explanation

Very energetic particles can affect satellites through single-particle events and latch-ups, and of course can be harmful to human health. Magnetic turbulence in the solar wind is directly responsible for controlling the propagation of these energetic particles. This work therefore has a considerable impact on our understanding of the particle radiation environment at the Earth.

Acknowledgements

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