A Comparison of Suprathermal Pickup Ion Tails with Solar Wind Conditions at 1AU

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INTRODUCTION:

Interstellar neutral atoms enter the heliosphere, become ionized, and begin to gyrate around the interplanetary magnetic field (IMF), forming the pickup ion (PUI) component of the solar wind. This species can be identified in situ with modern spacecraft instrumentation, and is important for heliospheric physics:

- PUIs can probe interactions between plasmas and fields
- PUIs are the seed population for anomalous cosmic rays (ACRs)
- PUIs change the solar wind, becoming important players in global heliospheric models
- PUIs are effective test particles for heliospheric acceleration processes
- Last but not least, PUIs tell us about their source, the local insterstellar medium (LISM)

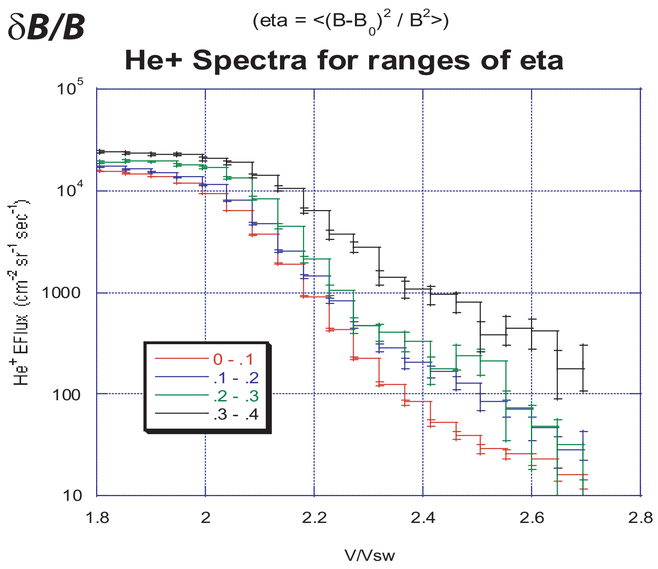
However, the use of PUIs as a diagnostic tool is limited by the large variations in their density and velocity distribution on a wide variety of time scales. To determine the interstellar source population, large time averaging is required. **It is an understanding of these variations in the PUI distribution that motivates this work.**

As the interstellar PUIs are convected outwards in the solar wind, they are subject to a number of complex transport processes. The interaction of the PUI distribution and ambient plasma waves has been discussed by many authors, and can act to create wave growth, pitch angle scattering, and statistical acceleration or velocity space diffusion. Large scale structures in the solar wind such as stream interaction regions, shocks, and other discontinuities, can accelerate the PUI distribution. The ubiquitous tails observed in PUI distributions have also been the subject of much discussion.

We present here in situ He+ measurements from SOHO CTOF taken in 1996, in an effort to determine the dominant transport effects creating suprathermal tails. We use both statistical analyses and case-study approaches. Schwadron et al [1] observed PUI tails near corotating interaction regions (CIRs) and compared tail strengths with the fluctuations of the magnetic field at Ulysses. The conclusion was that statistical acceleration by waves may be a stronger effect than the shock acceleration at the borders of the CIR. We have repeated this statistical analysis here for 1AU, using convected magnetic fields from WIND MFI. We also present PUI case studies, which show episodic acceleration on small space and time scales, comparing magnetic field wave activity with the PUI tails.

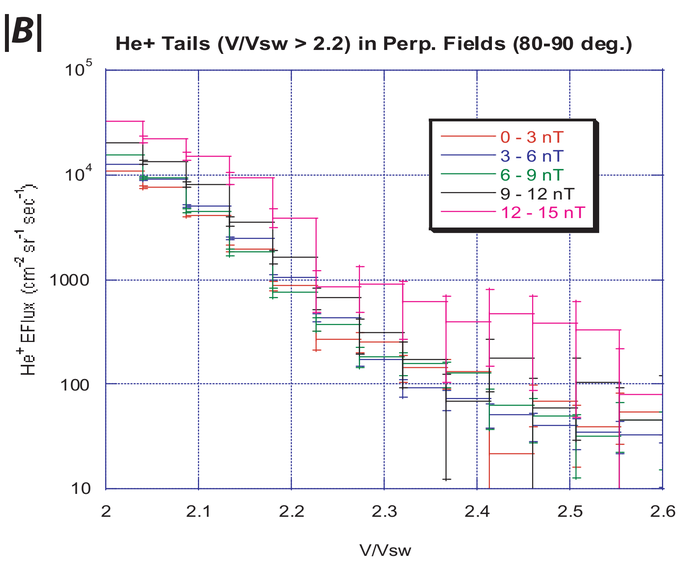
Interplanetary Parmeter Study of PUI Tail Formation

δB/B



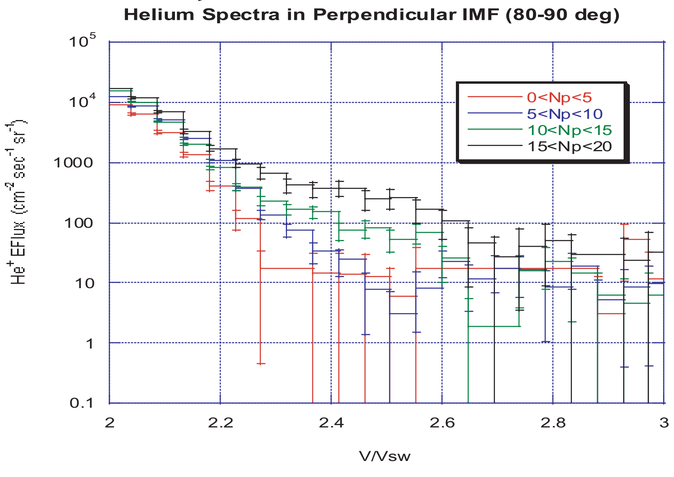
Here 15 minute averages were used as the individual |B| measurements. The parameter eta was calculated as a 2 hour sliding average, and the He+ spectra averaged for different ranges of eta. The PUI suprathermal tail spectra shown are averaged over time periods for which the eta parameter is as shown. Higher eta is indicative of stronger field fluctuations, but is influenced by both wave activity and IMF discontinuities, making the result more difficult to interpret. The stronger tails during periods of higher eta is consistent with the results of Schwadron et al [1]. Exceptions to the wave power and accelerated PUI correlation are observed as well (see below).

|B|



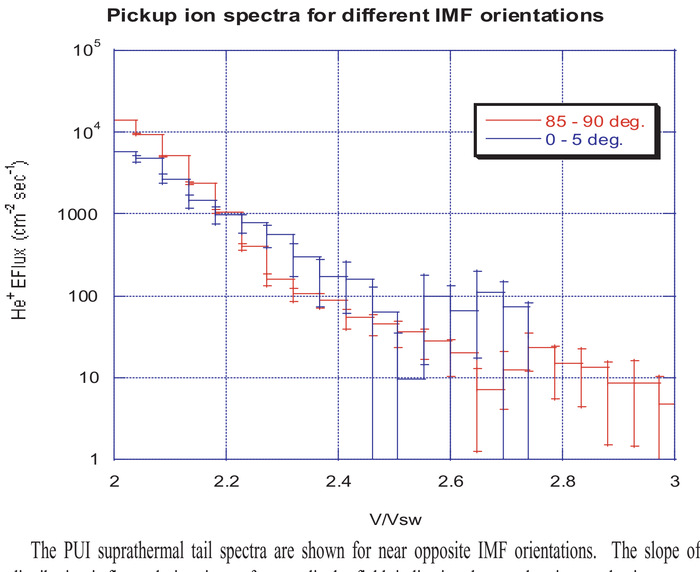
The PUI suprathermal tail spectra are shown for different ranges of IMF magnitude. The energy flux does show a correlation with the field, however the slope of the distribution looks unchanged for the different ranges of |B|. Acceleration mechanisms thus do not show a correlation with the field strength.

SW Density



The PUI suprathermal tail spectra are shown for different ranges of proton density. The density also shows a correlation with the pickup ion tails. Periods of higher solar wind density coincide with compression regions, which can form shocks, and interaction regions that are associated with MHD waves.

IMF Orientation

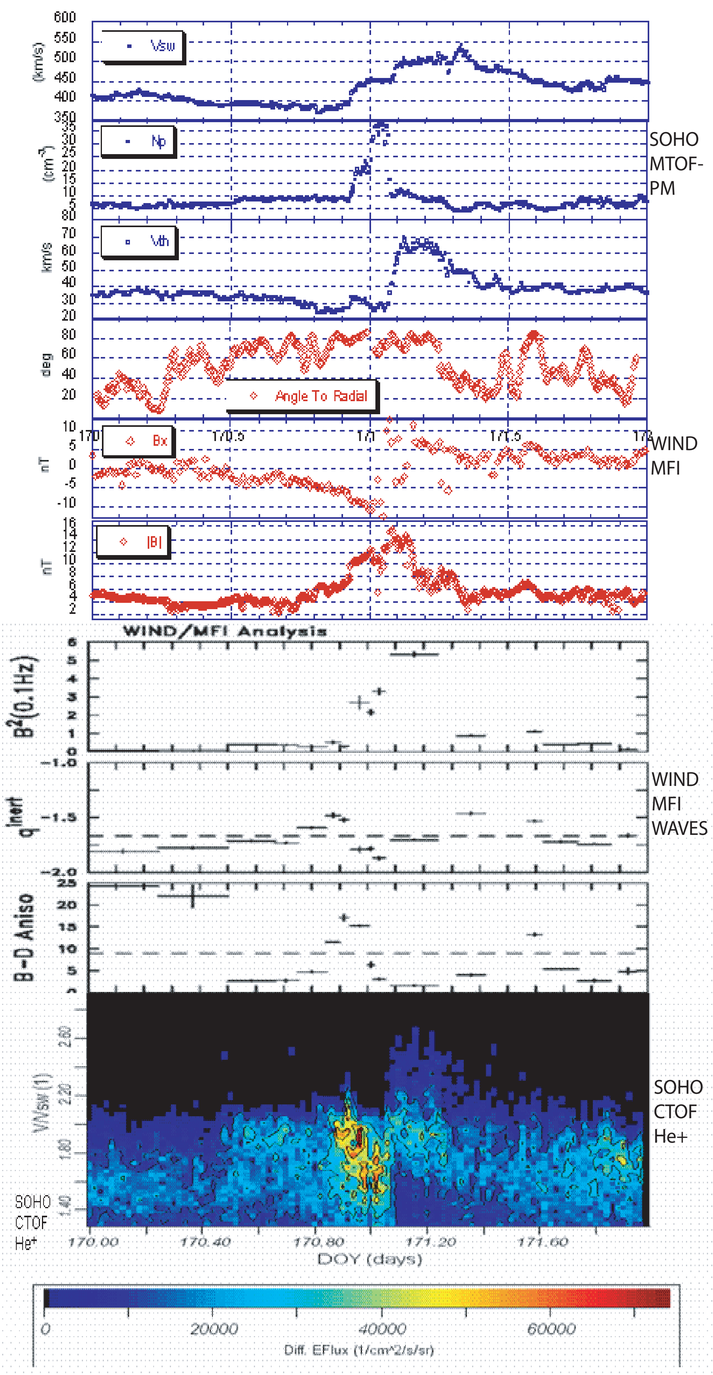


The PUI suprathermal tail spectra are shown for near opposite IMF orientations. The slope of the distribution is flatter during times of perpendicular field, indicating that acceleration mechanisms are more active during radial fields. Parallel fields could allow more radial diffusion of PUIs, from other acceleration sites. Also, radial fields could be indicative of sector boundaries in the solar wind and other compression sites.

Case Study of PUI Acceleration Events and IMF Waves

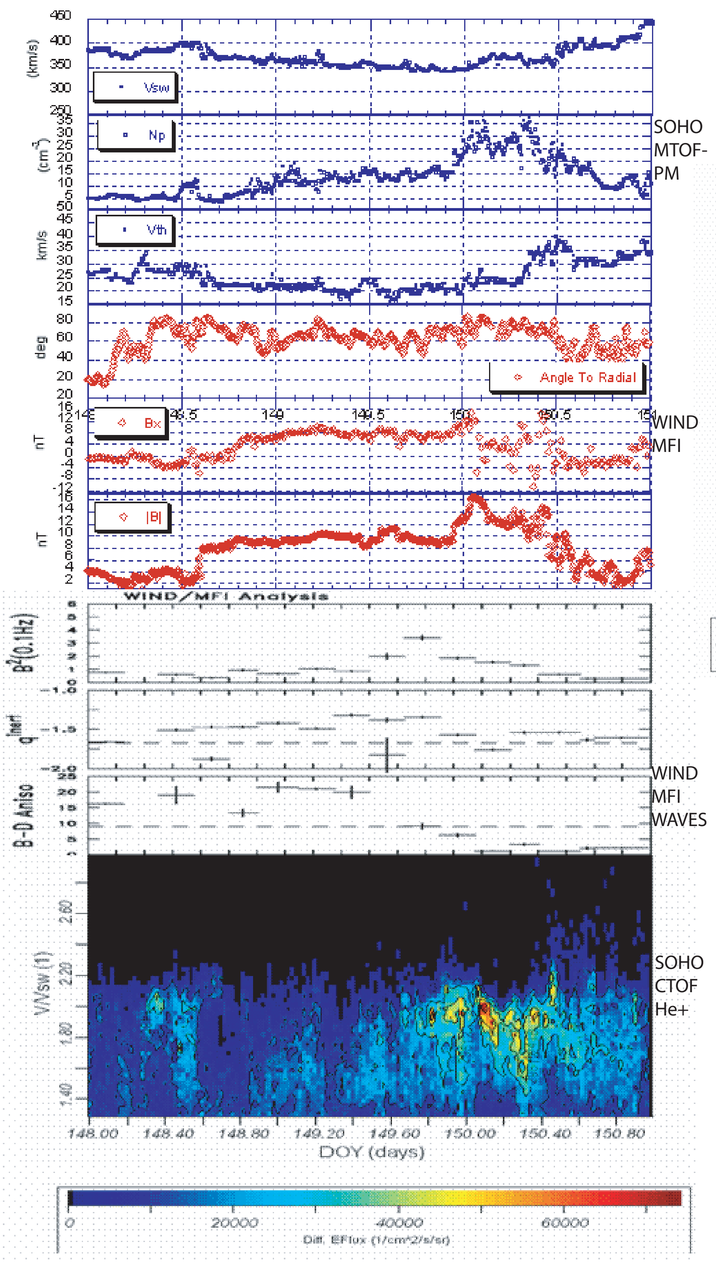
Three selected time periods are shown here with WIND data, MTOF-PM solar wind parameters, and the CTOF He+ as a color plot with V/Vsw on the vertical axis. In one strong compression event (below) can be seen a clear sector boundary, with faster wind running into slower wind compressing the protons and the PUIs, and a reversal in the radial component Bx. Note also the magnetic field discontinuity near the start of the compression and the associated spike in the PUIs. The PUIs show strong acceleration after the compression, in a region of higher wave power, consistent with a wave heating model [1]. However, a compressive acceleration mechanism [4] could play a role here as well.

Stream-stream interaction & compression DOY 170



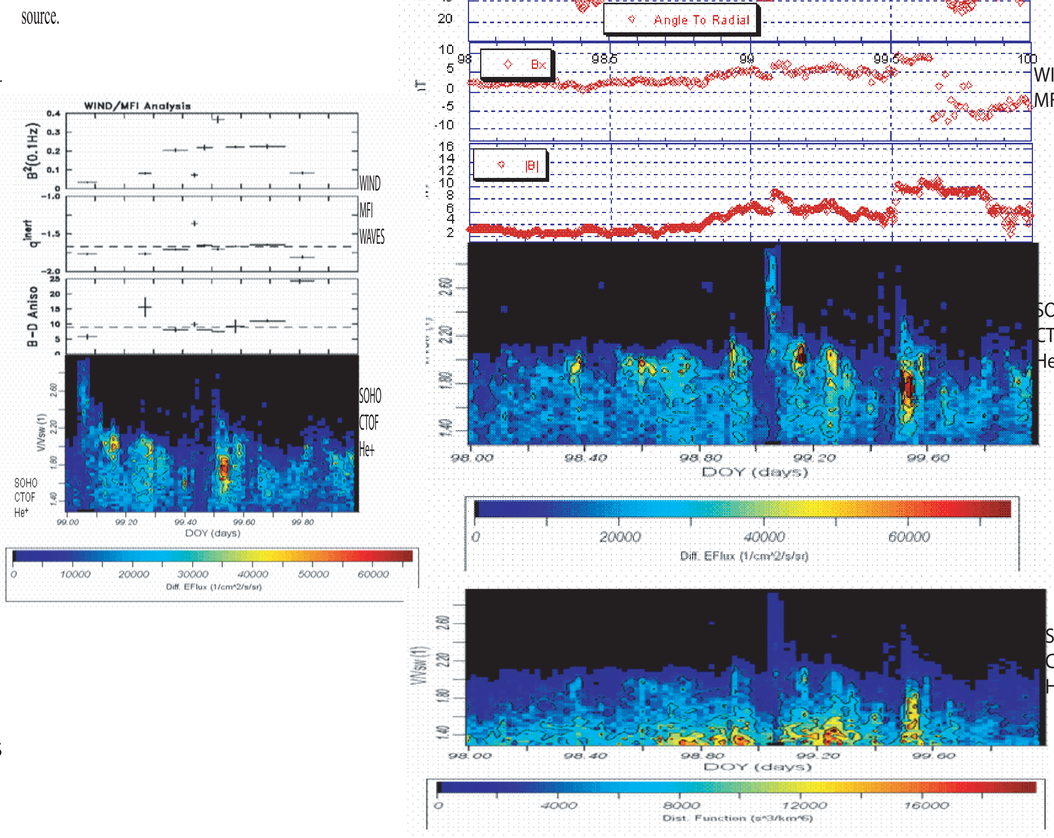
In the time period below a coronal mass ejection and associated magnetic cloud are visible in the IMF signature. Again the PUIs are compressed with the solar wind on the tail end of the cloud, when the solar wind increases somewhat. Some PUI acceleration is visible during the peak of the wave power, however the more striking area of PUI acceleration comes after the cloud has passed, and does not correspond with wave power, suggesting other sources of acceleration, perhaps elsewhere on the field line, or due to compressive acceleration [4].

CME and magnetic cloud DOY 149



Shown to the right are measurements taken in a time of slow solar wind, with small discontinuities visible in the solar wind density and the magnetic field. The PUIs show two marked regions of acceleration. Here the same PUI measurements are shown in two units (for comparison), the differential energy flux and the distribution function. The WIND MFI wave data (below) shows that the second acceleration event corresponds with high wave power, consistent with the wave heating model [1]. However, there is also a magnetic field discontinuity and compression of SW near this event as well. The first and slightly stronger acceleration event does not correspond to high wave power, pointing to a shock or compressional acceleration around the discontinuity [4] or possibly another unknown source.

Accelerated PUI events near DOY 99



CONCLUSIONS:

- Strongly enhanced PUI tails, indicative of acceleration processes, were found on time scales from less than 1hr to 12 hrs.
- PUI acceleration is statistically correlated with δB/B, radial IMF, and solar wind density.
- PUI acceleration was often correlated with higher wave power, consistent with [1], however exceptions were found.
- PUI acceleration can occur around IMF discontinuities and compression regions, consistent with [4], however exceptions were found.
- More work is needed to accurately model PUI acceleration in varied solar wind conditions!

Selected References:

1) *"Statistical acceleration of interstellar pick-up ions in co-rotating interaction regions"*, N.A. Schwadron, L. A. Fisk, G. Gloeckler, Geophysical Research Letters, Vol.23, No.21, pp 2871-2874, October 15, 1996

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5) *"Acceleration of interstellar pickup ions in the disturbed solar wind observed on Ulysses"*, G. Gloeckler et al, Journal of Geophysical Research, vol. 99, no. A9, p. 17637-17643, 1994

6) *"Interplantetary Pick-Up Ion Acceleration – A Study of Anisotropic Phase-Space Diffusion"*, S. Chalov and H. Fahr, Astrophysics and Space Science, v. 264, Issue 1/4, p. 509-525, 1998