RESEARCH SUMMARY

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My primary research area during my career thus far has been in cosmic rays physics. In particular, I have been studying the population of particles observed in interplanetary space with energies of a few times that of solar wind thermal particles. These so called suprathermal tail particles (STPs) are considered especially interesting as their omnidirectional distribution function form a power law spectra in velocity with a seemingly universal power law index of -5. These STPs are isotropic, have a composition similar to that of solar wind particles and appear to exist ubiquitously in the heliosphere. They are found in both the slow and fast slow wind, in quiet times and in the vicinity of shocks, and in the inner and outer heliosphere.

As an example of these tails existing in quiet times, consider the following data from the Advanced Composition Explorer (*ACE*) spacecraft. Figure 1 is the resulting spectra obtained by *ACE* over an 82 day period in 2009, a quiet-time of a deep solar minimum, using both the Solar Wind Ion Composition Spectrometer (*SWICS*) and the Ultra Low Energy Isotope Spectrometer (*ULEIS*) - the left panel at the highest and lowest particle densities and the right panel at various densities in between. At low speeds, $f(v) \propto v^{-5}$ spectra are clearly observed with little deviation. A more complicated spectra is seen at higher energies, possibly due to particles being accelerated elsewhere before being modulated while propagating to the spacecraft.

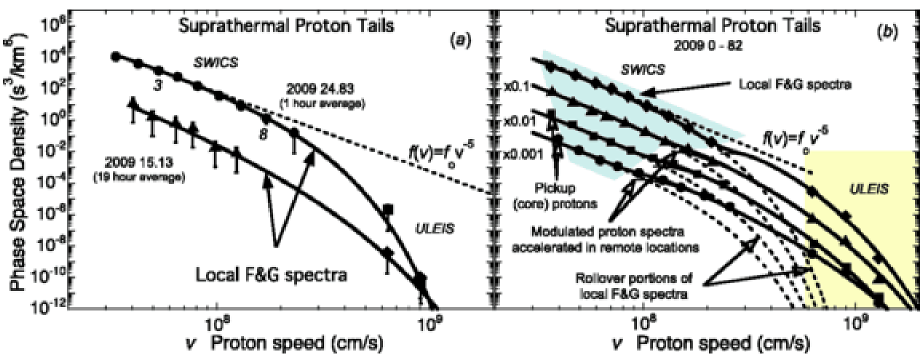

Figure 1: The resulting suprathermal proton spectra obtained for particular densities by *ACE* in 2009. In the left panel, the spectra is calculated at both the highest and lowest tail densities. In the right panel, the spectra from densities in between are shown. In both cases, at low energies, v^{-5} spectra are evident. At higher energies, more complicated spectra are observed, possibly due to particles being accelerated elsewhere.

Furthermore, as was previously mentioned, these spectra also exist in the presence of shocks. Figure 2 contain the observations made by *ACE* using *SWICS* over the entire year of 2001. This was a year of extremely disturbed conditions, with 61 shocks present in total. Even so, a power law index close to -5 is still consistently found throughout the year, indicating once again that this tail seem to be prevalent regardless of the particular environment that they are observed in.

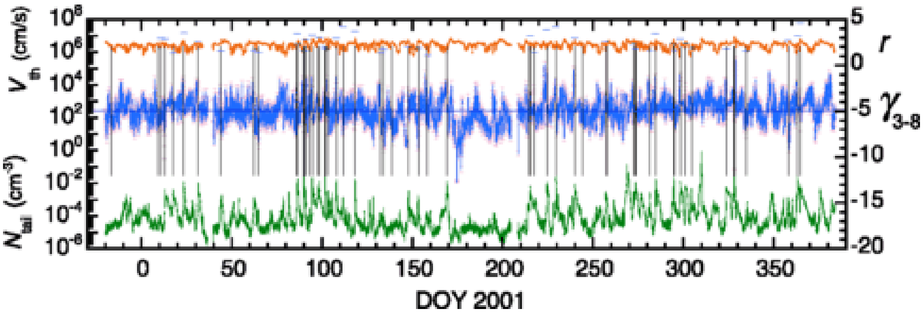

Figure 2: The solar wind and tail parameters obtained by *ACE* during the extreme disturbed conditions of 2001. Shown are the solar wind speed (red), the power law index (blue) and the proton tail density (green). A total of 61 shocks are present and represented by vertical lines. A common spectral index of -5 is still evident even in these conditions.

Currently, there are various possible theories as to how these particles are accelerated and why they take the particular power law shape that they do. For example, diffusive shock acceleration, the mechanism which is generally accepted to be behind the creation of galactic cosmic rays (GCRs), would appear to be a good candidate. It naturally leads to power law spectra which, in the simplest linear case, has a power law index depending only on the shock compression ratio r. The resulting spectra take the form $f(v) \propto v^{-\alpha}$, where $\alpha = 3r/(r-1)$. Therefore, a shock compression ratio of 2.5 is required to create the observed v^{-5} spectrum. However, it is not evident in the literature as to why a compression ratio of 2.5 should be favoured. Also, as Figure 1 shows, this v^{-5} spectrum is also observed during quiet times, where there are little to no shocks. Thus, diffusive shock acceleration is highly unlikely to be behind the creation of STPs.

Instead, we consider that the origin of the suprathermal tails could be of a stochastic nature. Various stochastic theories have been considered in the literature as possible explanations for the origin of these tail particles. One of the primary difficulties in any application of a stochastic theory is the treatment of spatial diffusion. In some instances, spatial diffusion is neglected or considered unimportant compared to other transport processes. In other models, spatial diffusion is treated in an atypical manner. For example, in a series of papers by Fisk and Gloeckler, a pump mechanism is developed, where tail particles gain their energy from a continuous "pumping" of energy from core particles. This approach naturally leads to the creation of v^{-5} spectra; however, it requires approximating spatial diffusion by a loss term of the form $-f/\tau_E$, where τ_E is the escape time from a compression region. The validity of this approximation has been discussed in the literature.

Recently, a new approach has been adopted by several authors, a so-called "pressure balance" condition. As particles stochastically accelerate in the presence of turbulence, their bulk pressure increases. As this turbulence is a finite source of energy and particle pressure, the process cannot continue indefinitely. However, if the increase in particle pressure is "balanced" by a source of pressure reduction, such as adiabatic deceleration, then momentum diffusion can be sustained. If we assume that underlying processes for the excitation and dissipation of plasma turbulence constrain the relationship between spatial and momentum diffusion in the presence of adiabatic losses, this condition allows us to determine both the momentum and spatial diffusion coefficients and therefore the particle spectrum.

This pressure balance condition between momentum diffusion and adiabatic deceleration has previously been applied in the presence of spatial diffusion in the inner heliosphere. This resulted in the creation of power law spectra with spectral indices of -5 at large momenta. However, these results cannot be applied in the outer heliosphere, where adiabatic cooling is considered negligible. Instead, the approach that I have taken is to apply this balance between momentum diffusion and *charge exchange losses*, which is considered an important process beyond the termination shock. For the first time, I have solved the resulting steady state transport equation under pressure balance in the presence of advection, spatial diffusion, momentum diffusion, adiabatic cooling, charge exchanges losses and injection from pickup ions for diffusion coefficients that have not previously been considered in the literature. This was done numerically using both Python and Matlab for sensible choices of the free parameters. I have demonstrated that, except for the unlikely case of very strong turbulence, v^{-5} spectra are created under many different circumstances - see Figure 3.

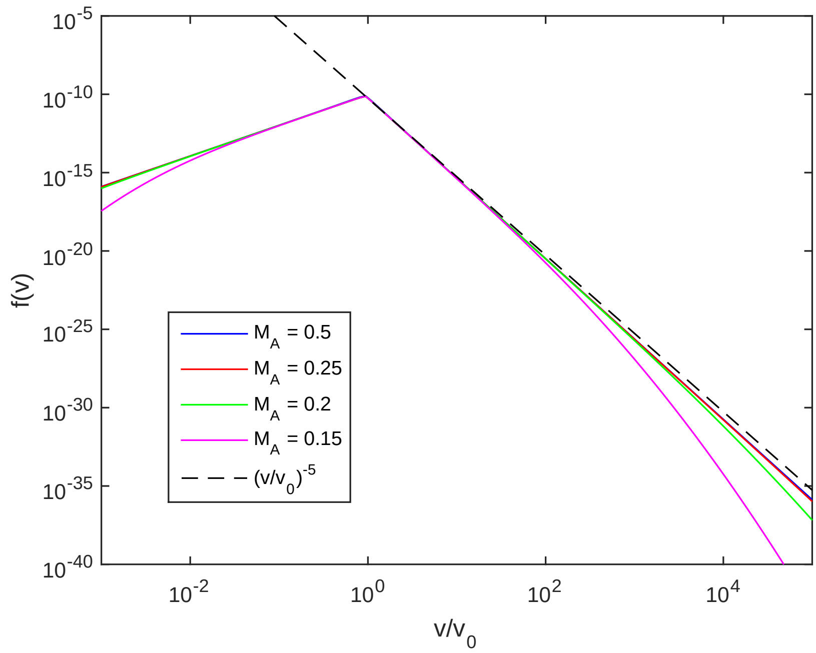

Figure 3: The steady state momentum spectra at 180 AU for four different choice of Mach number M_A. Also plotted is a $f(v) \propto v^{-5}$ spectrum for comparison. For all cases with $M_A > 0.5$, a v^{-5} spectrum is always obtained.