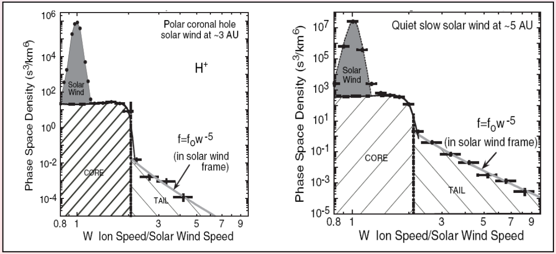
The ‘step feature’ of suprathermal ion distributions: A discriminator between acceleration processes?

H.-J. Fahr and H. Fichtner

Argelander Institut für Astronomie, Universität Bonn, Germany
Institut für Theoretische Physik IV, Ruhr-Universität Bochum, Germany



v^{-5}-tails

Fisk & Gloeckler [2007]

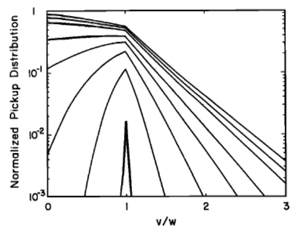
Outline

- Explanations and their problems
- Self-consistent velocity diffusion coefficient
- Simulation results
- Conclusion

Explanations and Problems

Explanations...

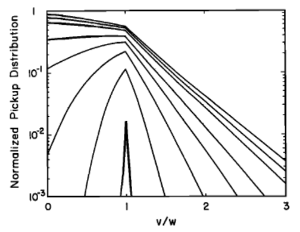
Velocity Diffusion & Cooling



Isenberg [1987]

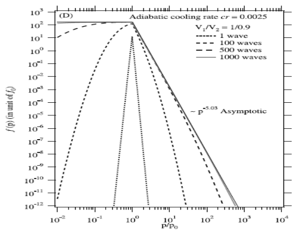
Explanations...

Velocity Diffusion & Cooling



Isenberg [1987]

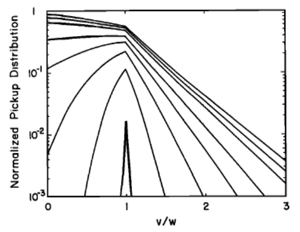
Compressional Turbulence



Zhang [2010]

Explanations...

Velocity Diffusion & Cooling



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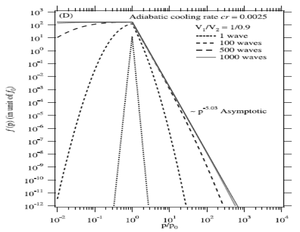

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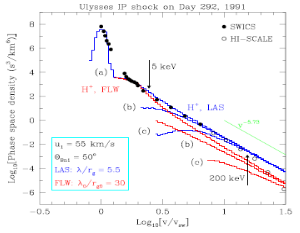
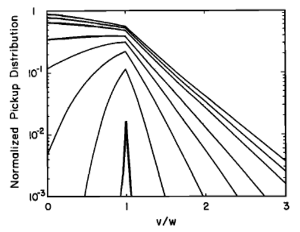
Shock Acceleration



Baring & Summerlin [2008]

Explanations...

Velocity Diffusion & Cooling



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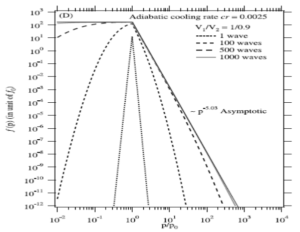

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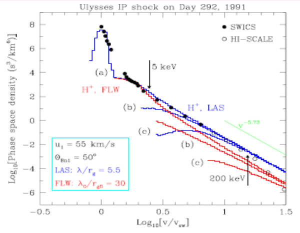
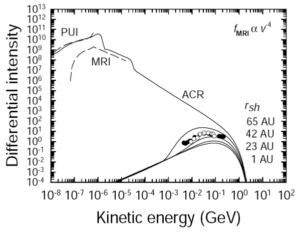


Baring & Summerlin [2008]

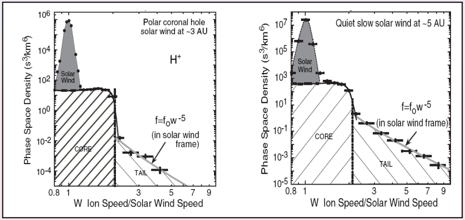
Shock Surfing / Mult. Refl.

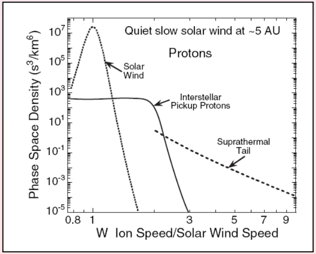


le Roux et al. [2001]

… and their problem(s)

It is not sufficient to derive the tails, also the general shape of the total distribution must be explained:





The ‘step feature’...

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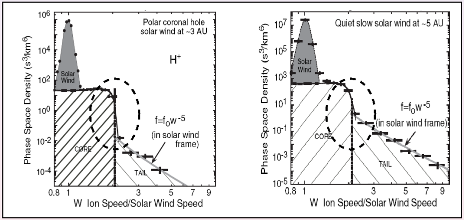
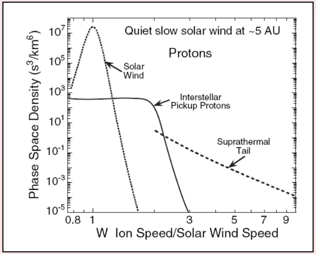
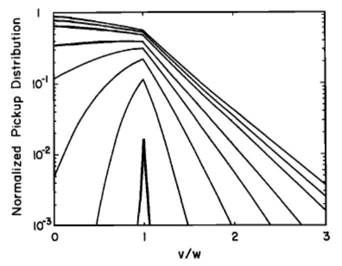




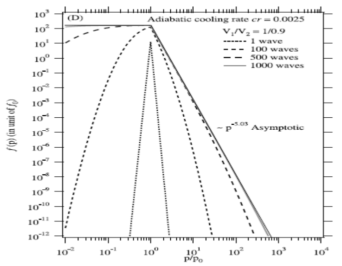
… has not been reproduced by all models

Alfvénic turbulence



Isenberg [1987]

compressive turbulence

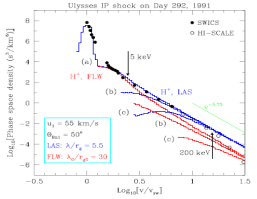


Zhang [2010]

$\longleftrightarrow$ **velocity diffusion fails…**

... but can by some

shock acceleration



Baring & Summerlin [2008]

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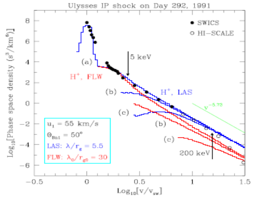
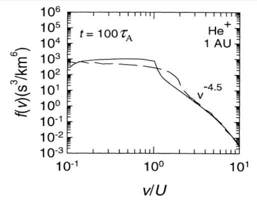


Baring & Summerlin [2008]

turbulent electric fields (2D turb.)



le Roux et al. [2001]

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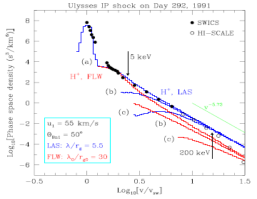

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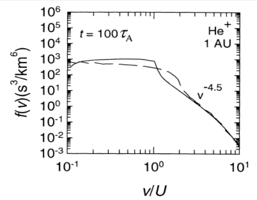
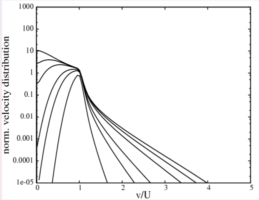


le Roux et al. [2001]

velocity diffusion threshold (?)



Fahr & Fichtner [2011b]

→ **Can velocity diffusion be ‘saved’?**

A Self-consistent Velocity Diffusion Coefficient

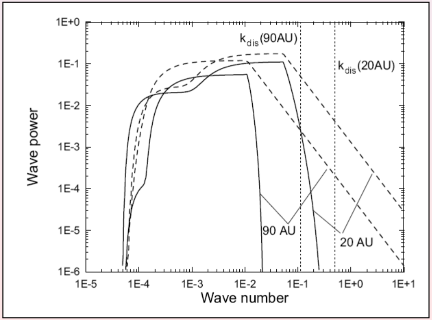
A self-consistent velocity diffusion coefficient

Coefficient used in *Bogdan et al. [1991]*, *le Roux & Ptuskin [1998]* and *Chalov et al. [2004]*:

$$D_{vv}(r,v) = \frac{2\pi^2 e^2}{m^2} \left(\frac{v_A}{c}\right)^2 \frac{1}{v} \int_{k_0}^{\infty} \left[1 - \left(\frac{k_0}{k}\right)^2\right] \frac{W(k)}{k}\, dk$$

with $W(k)$ according to *Chalov et al. [2004]*:

$\approx$ 'box-shaped'



A self-consistent velocity diffusion coefficient

$$D_{vv}(r,v) \approx D_0 \left(\frac{U}{v}\right) \int_{k_0}^{k_{max}} \left[1 - \left(\frac{k_0}{k}\right)^2\right] \frac{1}{k}\, dk$$

with $D_0 = (2\pi^2 e^2 v_A^2 W_0)/(m^2 c^2)$ and the solar wind speed U used for normalization. Upon introducing the dimensionless variable $x = k/k_0$ it follows that

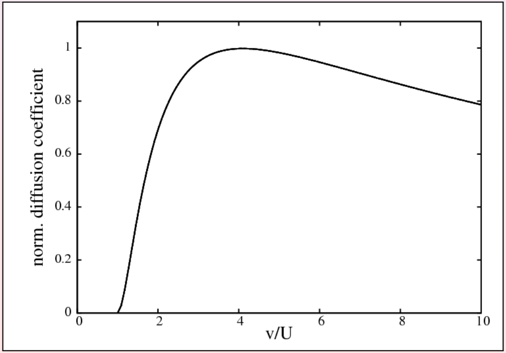
$$\begin{aligned} D_{vv}(r,v) &= D_0 \left(\frac{U}{v}\right) \int_1^{x_{max}} \left[1 - \frac{1}{x^2}\right] \frac{1}{x}\, dx \\ &= D_0 \left(\frac{U}{v}\right) \int_1^{x_{max}} \left[\frac{1}{x} - \frac{1}{x^3}\right] dx \\ &= D_0 \left(\frac{U}{v}\right) \left(\ln x_{max} + \frac{1}{2x_{max}^2} - \frac{1}{2}\right) \end{aligned}$$

A self-consistent velocity diffusion coefficient

With

$$x_{max} = \frac{k_{max}}{k_0} \approx \frac{\eta k_{inj,E}}{k_0} = \eta \left(\frac{\Omega_E}{U}\right)\left(\frac{v}{\Omega}\right) \approx \left(\frac{v}{U}\right)$$

and $\eta\Omega_E/\Omega \approx 1$ one obtains:



$\approx$ cut-off near $v/U \geq 1$

$\leftrightarrow$ diffusion threshold

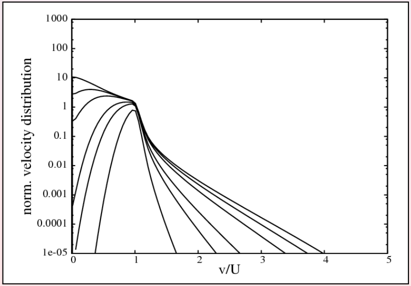
Numerical Simulation

Numerical simulation

Using the analytically approximated diffusion coefficient in

$$\frac{\partial f}{\partial t} = \frac{1}{v^2}\frac{\partial}{\partial v}\left(v^2 D_{vv}\frac{\partial f}{\partial v}\right) + \frac{3vU}{2r}\frac{\partial f}{\partial v} - U\frac{\partial f}{\partial r} + S$$

yields:



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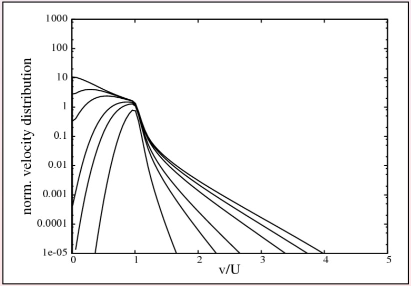

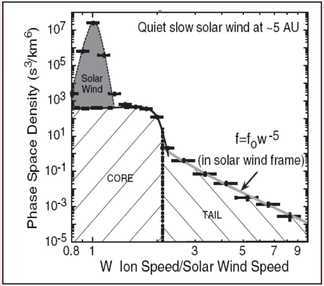

Conclusion

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- a velocity diffusion with a threshold – as resulting from self-consistent modelling – can explain not only the tail slopes but also the ‘step feature’ in the velocity distributions of suprathermal ions in the solar wind

$\Leftrightarrow$ standard theory still valid ☺

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⇔ standard theory still valid ☺

Remark:

Similarly shown for transit-time damping by Schwadron et al. [2010]: