Pitch-Angle Scattering of Interstellar Pickup He^+

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Newly ionized particles from the inflowing interstellar gas appear as a ring-beam in the solar wind plasma, depending on the angle between $\mathbf{V_{sw}}$ and **B**.

Distribution is then isotropized through resonant cyclotron interaction with ambient and self-generated waves.

The details of pickup ion isotropization in the solar wind are **still** not well understood.

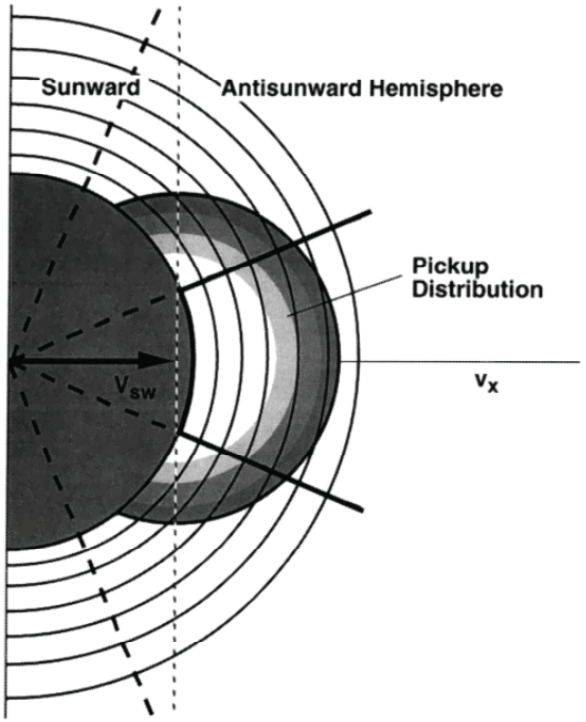
Resonant isotropization is thought to be rapid ($\sim 100/\Omega_i$), and this assumption is crucial to standard analysis of the observations:

- Pickup ions are difficult to observe
- "Anti-sunward" ions have the highest fluxes into a s/c instrument

  Anti-sunward sector yields:

  → More accurate energy spectra

  → Better time resolution



[Möbius et al. 98]

Isotropy allows anti-sunward densities to represent entire distribution independent of B-field angle.

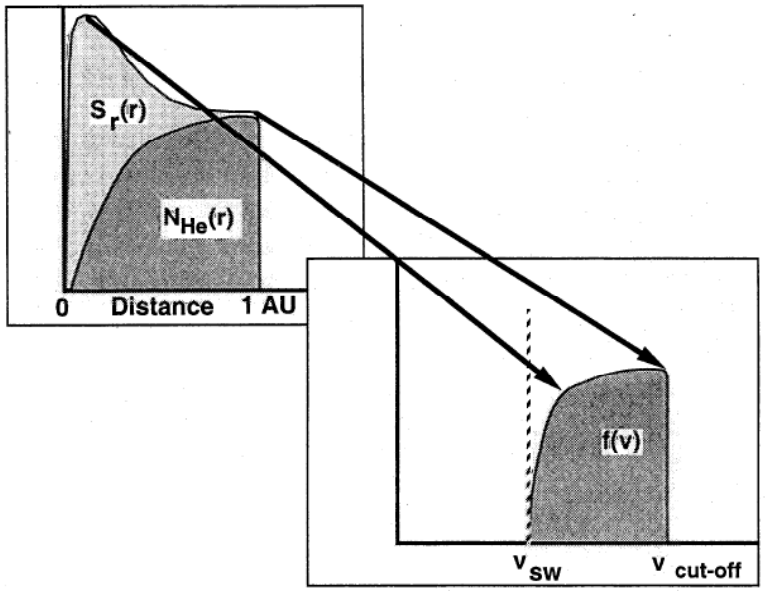
Isotropic distributions behave as ideal gas, with simple adiabatic deceleration in the expanding solar wind,

[Vasyliunas & Siscoe 76]

→ This allows a mapping in the energy spectrum between the observation point and the ionization point:

$$v/V_{sw} \sim (r_o/r_i)^{-2/3}$$

- Gives direct information on spatial distribution of neutrals, ionization rates, etc.



[Möbius et al. 95]

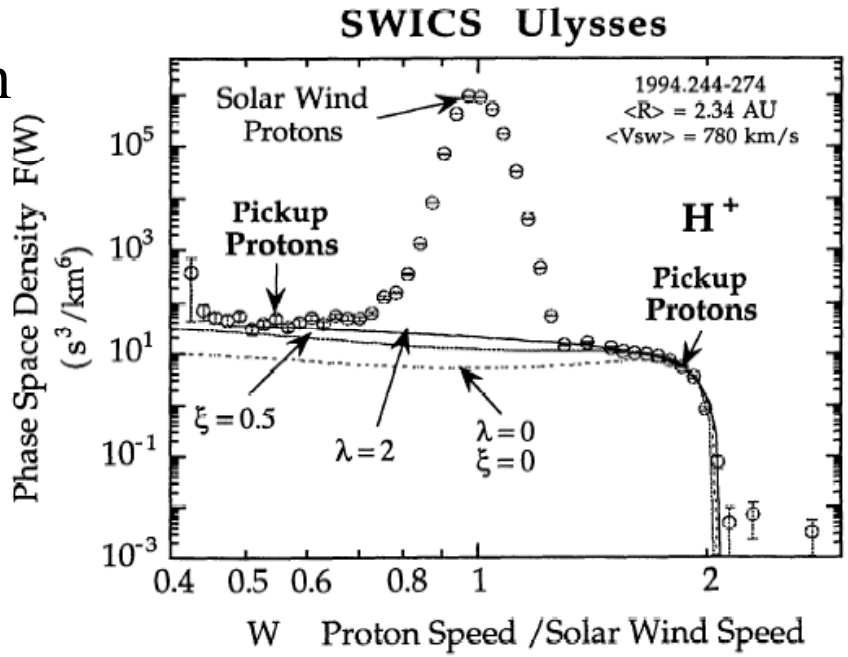
However,

→ **Interstellar pickup ions are not isotropic**

(or at least, isotropization is much slower than assumed)

- Ulysses pickup H^+ and He^+ are correlated [Gloeckler et al. 94]

- Ulysses long-time averages can measure sunward flux: [Gloeckler et al. 95]



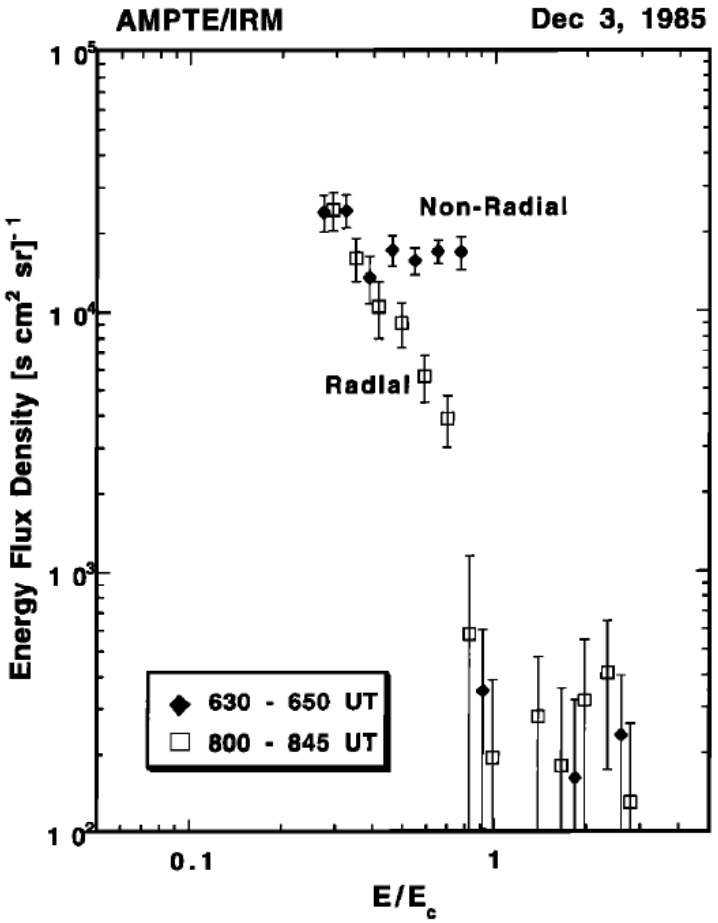
Further:

- On shorter time scales:

  anti-sunward fluxes decrease

  when field turns radial.

  [Möbius et al. 98]



- Even at 11 AU, observations at

  New Horizons indicate that

  pickup protons are highly anisotropic.

  [McComas et al. 10]

These observations suggested a

Hemispherical Model [Isenberg 97; Schwadron 98]

to describe the pitch-angle scattering:

- assume rapid scattering to isotropy

  except across $\mu = 0$.

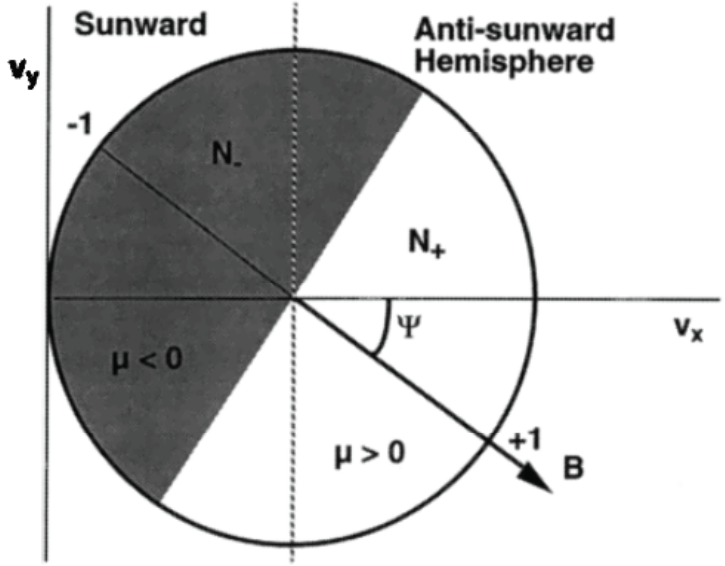
- idealization of "resonance gap" behavior

  expected for energetic protons.

- allows for simplification of

  transport equations, analogous to

  "two-stream" equations for cosmic rays.



But is this approximation a representation of the correct physics?

Most detailed observations of pickup ion distributions measure

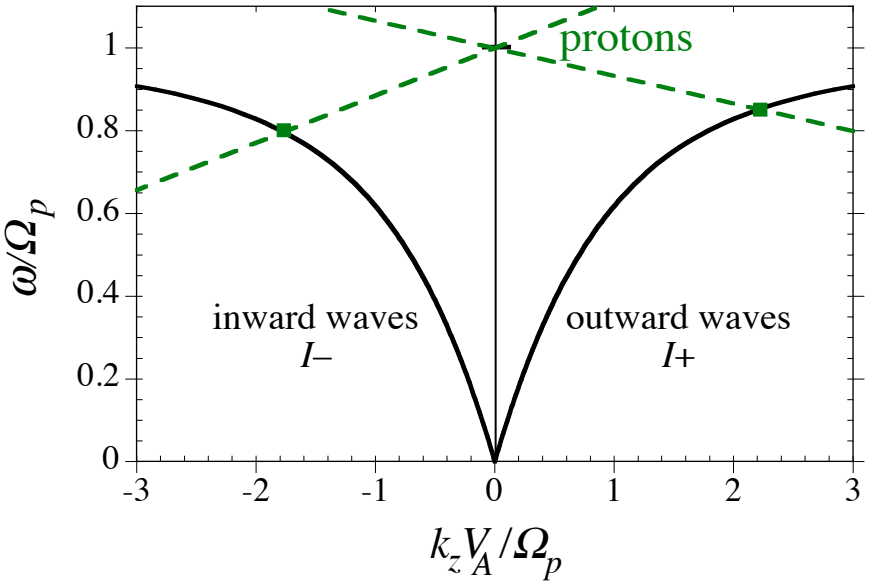
pickup He^+ at 1 AU.

but theoretically → Helium has **no resonance gap.**

Pitch-angle diffusion comes from cyclotron resonant wave scattering.

Resonance condition: $\omega(k) - k\, v_z = \Omega_i$

Doppler-shifted wave frequency = ion gyrofrequency

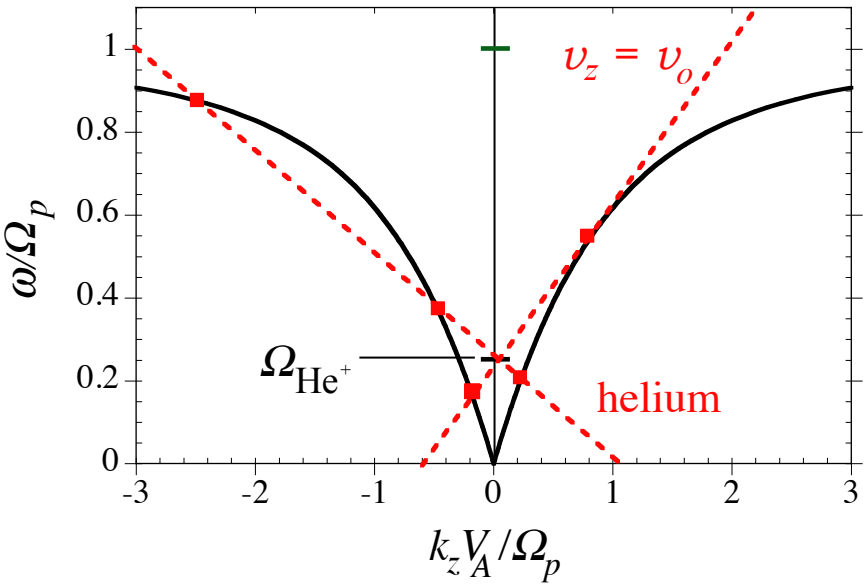


- Assume wave intensities $I_\pm \sim k^{-5/3}$

→ waves resonant with protons at $v_z \sim 0$ have $k >> 1$, so $I \to 0$.

"resonance gap"

Now, consider He^+:



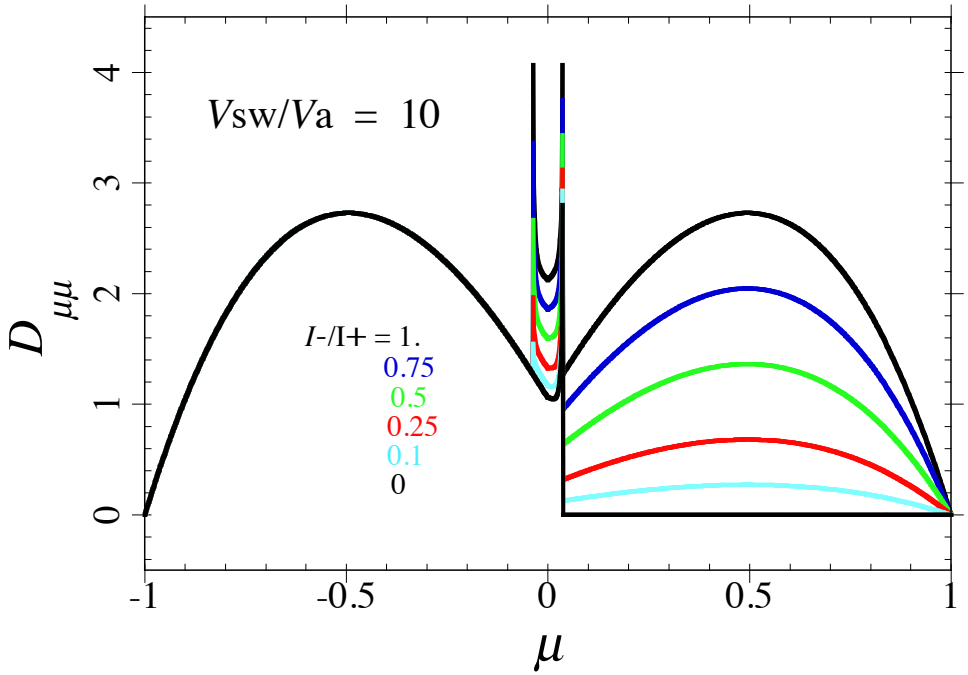
- resonant waves are strong
- multiple resonances

for $|v_z| < v_o$

→ He^+ scattering through $\mu = 0$ is enhanced.

Note that resonant waves in the solar wind are predominantly outward propagating:

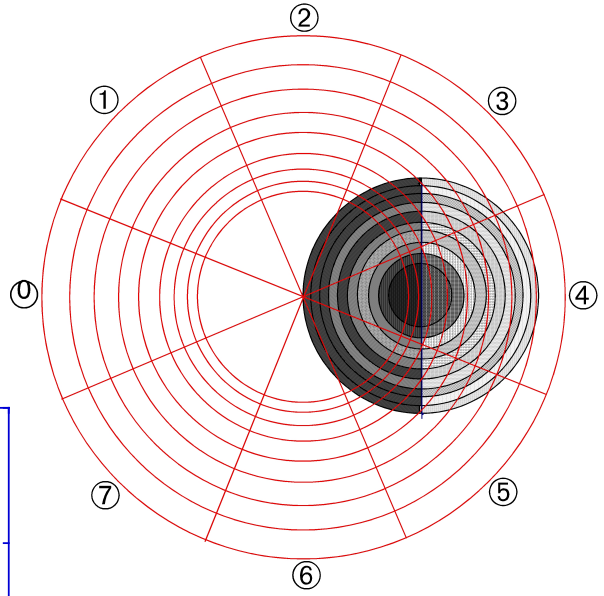
$I_+ > I_-$

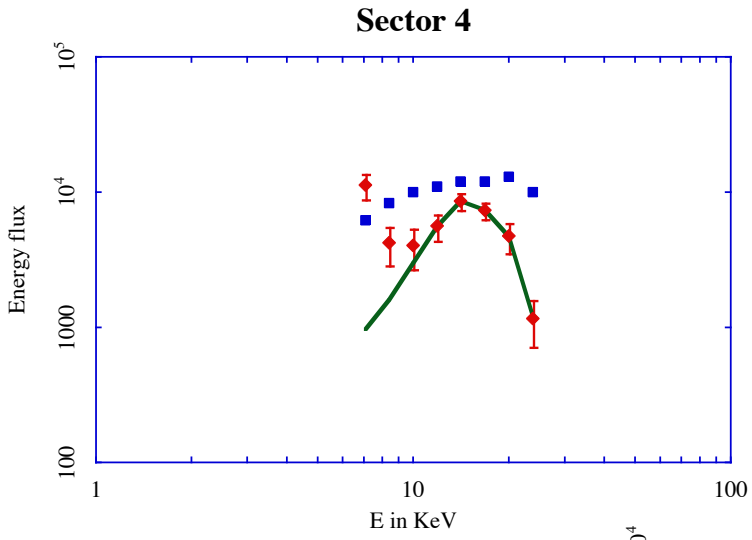


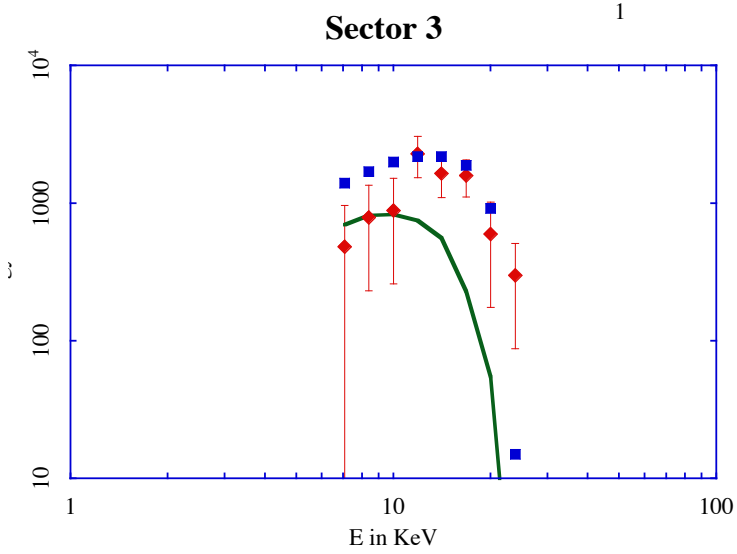
What do the observations say?

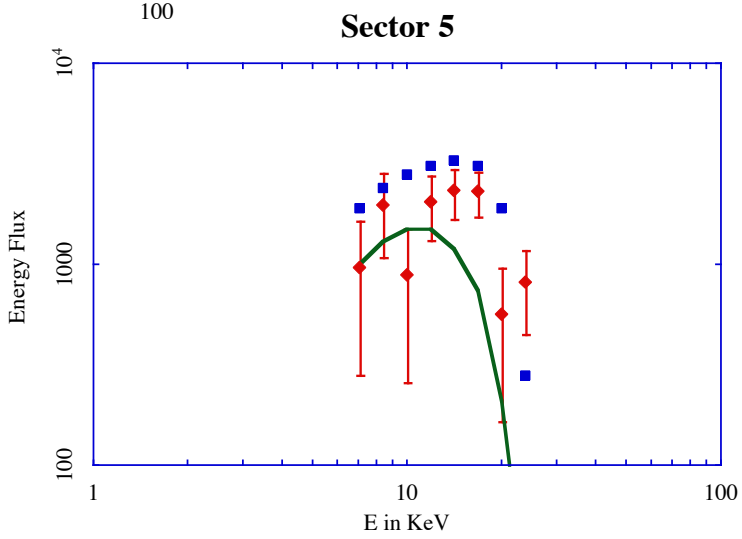
AMPTE/IRM, quasi-radial field

Nov 16, 1985 (0952-1053)

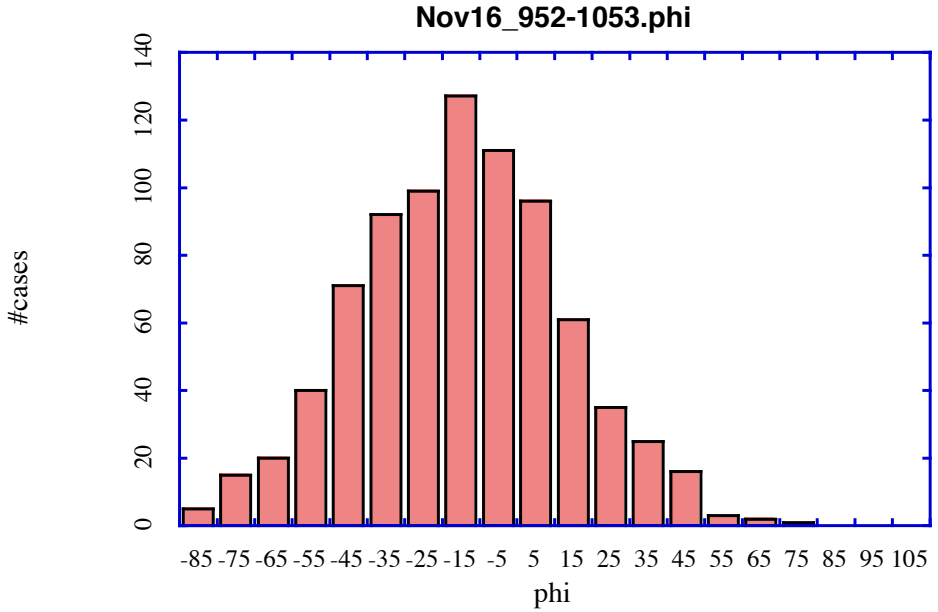








Seems to indicate gradual decrease of scattering
into the anti-sunward hemisphere,
rather than a barrier at $\mu = 0$.
Another possibility, though, is that the
B-field is waving back and forth,
spreading the higher sunward fluxes
into the anti-sunward directions.



AMPTE pickup ion
measurements are
integrated over ~ 1 hour.
We need the better time
resolution provided by
ACE and STEREO.

Conclusions

- Pickup ions in the solar wind are not isotropic.
- Pitch-angle scattering seems to be inhibited in the anti-sunward hemisphere, $v_z > 0$.
  - Could be due to a barrier at $\mu = 0$ (hemispherical assumption)
  - or reduced diffusion in sunward waves.
- We need to understand these details so we can unfold the observed distributions to obtain neutral densities, cooling rates, etc.
- Increased time resolution available from ACE and STEREO instruments (Messenger, too?) will be required to determine the pitch-angle scattering behavior.