Mechanisms of Heavy Ion Heating in the In Situ Solar Wind

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Tuesday PM
Wednesday AM
The first session (Tues) concentrated on

- describing the Kasper et al. [2013] observations of alpha/proton temperatures

- outlining the theoretical mechanisms which are being proposed to model this preferential heating:
  
  Isenberg & Vasquez - Fermi acceleration from multiple cyclotron resonances
  
  Chandran et al. - Stochastic heating due to nonlinear distortion of cyclotron motion
In the second session (Weds), we took up some additional aspects of ion heating in the solar wind, along with further discussion and explication of the two heating mechanisms.

Chadi Salem gave an invited report on last week’s “Solar Wind Heating, Acceleration & Transport” workshop. Brief reviews of some recent papers and a preview of interesting observations and modeling soon to be published:

- Hellinger et al., JGR 2013;
- Matteini et al., JGR 2013;
- Pulupa et al., JGR 2013
Michael Hahn described a new spectrographic technique for obtaining ion parallel and perpendicular temperatures, along with the non-thermal (wave) velocities in the low corona. Findings so far are consistent with earlier observations.

Paul Bellan outlined an analysis of relativistic pitch-angle scattering by a monochromatic circularly polarized wave.
Phil Isenberg returned to the problem of the cold dispersion relation in the I&V Fermi mechanism as used in Kasper et al. Dispersion in bi-Maxwellian plasmas gives unfavorable results, but Isenberg claimed that:

- Solar wind ion distributions heated by a turbulent cascade will **never** be bi-Max, since the strong damping is equivalent to rapid ion scattering away from the bi-Max shape.
- He presented a method for obtaining dispersion relations in non-bi-Max plasmas.
- Not yet known whether self-consistent ion distributions and wave dispersion will allow I&V mechanism to work on alphas.

Sofiane Bourouaine presented an analysis of the combined anisotropy and streaming instability in an alpha-proton plasma.

- Showed that the streaming threshold for anisotropic alphas can explain the observed radial decrease in $\delta v_{\alpha p}/V_A$. 
Tom Broiles described the capabilities of the Heavy Ion Sensor to be launched on Solar Orbiter, providing valuable new in situ data on ion composition, speeds and temperatures.

In all, this session represented an important first step toward understanding the new ion heating observations of Kasper et al., exploring and refining the theoretical modeling options.

When we return next year, we expect to have made considerable progress on these questions - and maybe even have some answers!
• Ben Maruca pointed out that alpha particles
(only heavy, non-minor SW species)
have a bi-modal
temperature distribution
which is not fully understood.

• T-ratios of 1 and 4 are perhaps expected, since
  collisions will push $T_\alpha/T_p \rightarrow 1$ and
  heating to equal thermal speeds gives $T_\alpha/T_p = 4$.

• But where do the $T_\alpha/T_p > 6$ cases come from?
Consider preferential heating model of Isenberg & Vasquez [2007]:

- Resonant cyclotron interaction can be preferential to heavy ions

- Simple dependences on $\beta$ and streaming speed of alphas yields predictions for three regions of parameter space.
Daniel Verscharen reviewing proposed theoretical mechanisms pointed out that the I&V mechanism assumed ion cyclotron dispersion in a cold plasma without significant alpha particles.

This mechanism also requires counter-propagating resonant waves.
• Also introduced an alternative mechanism from Chandran et al. [2010], which does not require high-frequency waves.

E-field fluctuations due to perpendicular turbulent cascade can disturb ion gyromotion enough to give stochastic perpendicular heating if

$$\varepsilon = \frac{\delta v_\rho}{v_\perp} = \frac{(\delta E_\perp) \rho}{B_0 v_\perp} \frac{c}{\rho}$$

is large enough ($\varepsilon \geq 0.2$)

This process yields a heating rate

$$Q_\perp = \frac{c_1 (\delta v_\rho)^3}{\rho} \exp \left( - \frac{c_2}{\varepsilon} \right)$$
These electric fields, originally derived in the plasma (proton) frame, can be transformed into the frame of a streaming particle to adapt this mechanism to the Kasper et al. data.

Transformation depends on normalized cross-helicity, $\sigma$, and $r_A = \text{value of fluctuating } \delta E/\delta B$, both at the ion gyroscale.

$$\chi = \frac{2}{r_A + 1} \left( r_A + \frac{v_{||}^2}{v_A^2} \right) - \frac{2\sigma v_{||}}{v_A}$$

Averaging over ion distributions, taking best fit parameter values:
• **Ben Chandran** followed with further description of his mech., along with explanations of the less satisfactory results from different parameter values.

• **Rob Wicks** described his preliminary attempts to test these two mechanisms in the data.

  So far, the results are **inconclusive** at best

  (and **inconsistent with both mechanisms** at worst).

• Throughout all the talks, there were useful suggestions and active discussion of interpretations, improvements and exciting projects for the coming year.

  Very valuable session, lots to do, and we continue on this morning!