Probing the Dependence of Charge Exchange on Solar Wind Velocity with Laboratory Experiments

Gabriele Betancourt-Martinez

December 5, 2012

Since the surprising discovery made in 1996 by Lisse et al., it has been known that comets are sources of X-rays. The cause was determined to be an interaction between the comet and the solar wind, but it was not until a year later that consensus was drawn on the exact emission process. Today, the accepted mechanism for the X-ray emission is charge exchange, or charge transfer. In this process, neutrals in the comet's coma, in particular molecules with O and H, exchange charge with the highly ionized heavy elements in the solar wind, primarily N^{5+} C^{5+}, and O^{6+}. As the recombined electrons cascade down to ground state, they emit X-rays. The relative intensity of the charge exchange emission lines is determined by the state-selective electron cross sections of the process, as well as the branching ratios of the final ion.

In their 2007 paper, Bodewits et al. analyzed eight X-ray spectra of comets observed with Chandra and determined fluxes and chemical abundances. They fit the spectral lines using a compilation of theoretical cross sections for collisions with atomic H, therefore assuming one-electron capture and a statistic triplet to singlet ratio of 3:1. As this compilation of cross-sections is velocity-dependent, the authors chose velocities of 300 km s^{-1} and 700 km s^{-1}. They found that the spectra varied to within a factor of 1.5 within this velocity range.

In reality, the solar wind is highly variable in speed and composition, with an average speed of about 450 km s^{-1} (about 1 keV nucleon^{-1}). Since the shape of the charge exchange spectrum is so dependent on velocity, it has been suggested that we use the shape of cometary spectra or spectra from other charge exchange processes elsewhere in the heliosphere as diagnostics of the solar wind. However, current theory and modeling assume statistical populations of excited states, which is only true for high collision energies. Even at the upper limit of solar wind collisional ion energy, about 3 keV nucleon^{-1}, it has been shown that populations are nonstatistical. Furthermore, in their interactions with the cometary coma, solar wind ions slow down significantly, with collision energies in the inner region of the coma reaching as low as 50 eV nucleon^{-1}. Efforts have been focused on predicting the high collision velocity limit, but theory and experimental data is lacking in this important low-velocity regime.

One way of characterizing the charge exchange flux is by measuring the hardness ratio, which is defined as the ratio of the flux in the n=3, 4, ... to n=1 transitions to the flux in the n=2 to n=1 transition. For He-like atoms, the n=2 to n=1 transition is taken as the sum of the forbidden, intercombination, and resonance lines. The hardness ratio is an clear indicator of charge exchange velocity dependence, as seen in figure 3 (here, figure 1) of Bodewits et al., 2007:

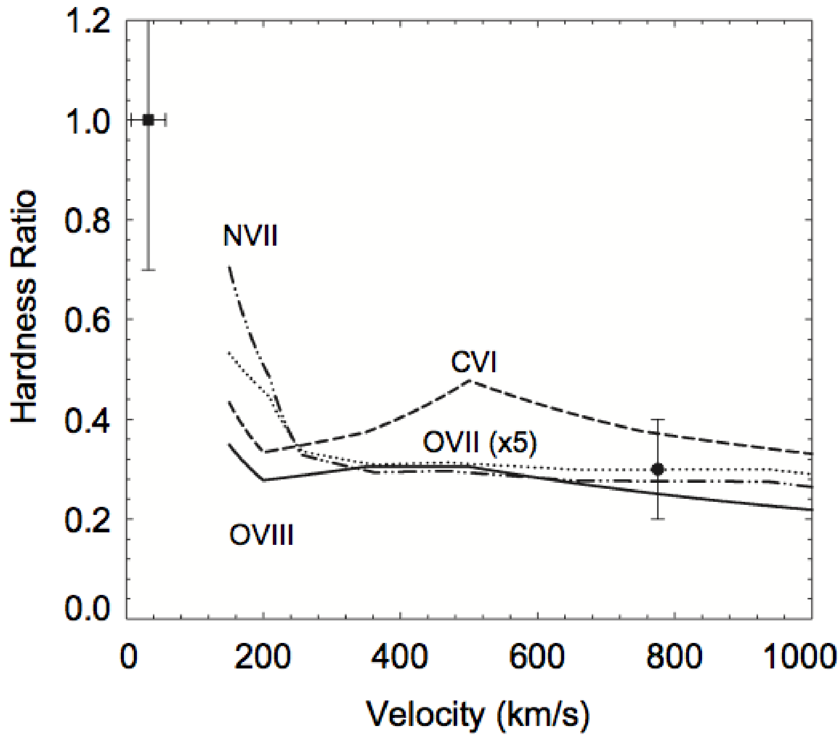

Figure 1: Velocity dependence of the hardness ratio of different solar wind ions. O VIII (solid line), O VII (dashed line) NVII (dashed line) and C VI (dash-dotted line). Also shown are two experimentally obtained hardness ratios by (Beiersdorfer et al. 2001) and (Greenwood et al. 2000) for O^{8+}colliding with CO_2 and H_2O, respectively.

In this work, we show that it is possible to fill in the gap in theory and corresponding experimental data by measuring the hardness ratio at various collision velocities using laboratories around the world. We use data from the Electron Beam Ion Trap facility at Lawrence Livermore National Lab to probe the low velocity (under 100 km s^{-1}) regime. We call on other accelerator facilities, such as the ion beam at the KVI in Groningen, Netherlands, to investigate this relation at high collision velocities and varied ion compositions. In this way, we can better constrain theory for the wide variety of realistic solar wind velocities.

References

[Beiersdorfer, D. et al. 2001, ApJ, 549, L147]

[Beiersdorfer, et al, 2003, Science, 300, 1558]

[Bodewits, Dennis 2007, Ph.D. Thesis]

[Bodewits, D. et al. 2007, A&A, 469, 1183]

[Cravens, T.E. 1997, Geophys. Res. Let, 24, 105]

[Greenwood, J.B. et al. 2000, ApJ, 533, L175]

[Lisse, C.M. et al. 1996, Science, 274, 205]

[Krasnopolsky, V. 1997, Icarus, 128, 368]

[Phaneuf, R. A., et al, 1999, Reports on Progress in Physics, 62, 1143]

[Snowden, S.L. et al. 2004, ApJ, 610, 1182]