Detecting X-ray emission from Cometary Atmospheres using the Suzaku X-ray Imaging Spectrometer

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Abstract

The Suzaku X-ray imaging spectrometer has been used to observe the X-ray emission from comets 73P/Schwassmann-Wachmann 3C and 8P/Tuttle. Comet 73P/Schwassmann-Wachmann 3C was observed during May and June of 2006, while it was near perihelion and passed within 0.1 AU of the Earth. Comet 8P/Tuttle was observed during January of 2008 when it was at its closest approach to the Earth at 0.25 AU, and again near perihelion at a distance of 0.5 Au from Earth. In the case of comet 73P/Schwassmann Wachmann 3C, the XIS spectra show line emission from highly charged oxygen and carbon ions as well as emission from what is most likely L-shell transitions from Mg, Si, and S ions. This line emission is caused by charge exchange recombination between solar wind ions and cometary neutrals, and can be used as a diagnostic of the solar wind. Here we present some of the results of the observation of the comet 73P/Schwassmann-Wachmann 3C.

Key words: Comets, Suzaku, X-ray, X-ray Imaging Spectrometer, Charge Exchange

X-ray emission from cometary atmospheres has been observed now for over a decade, and the dominant x-ray production mechanism is widely accepted to be charge exchange recombination (CEX) between solar wind ions and cometary neutrals. In this process a bound electron from the cometary neutral undergoes radiationless transfer to an excited state of the solar wind ion. The excited state then decays radiatively, emitting one or more photons in the process. The spectrum produced by CEX depends on the ion species, the neutral species, and the collision velocity between the two particles (Beiersdorfer 2001,Beiersdorfer 2003,Bodewits 2004, Bodewits 2006, Wargelin 2008). Thus, a CEX x-ray spectrum emitted from a comet is a powerful diagnostic of the solar wind ion abundance, the relative speed between the solar wind ion and the cometary neutral and the comet's neutral gas density and species distribution. It is thus possible to use the x-ray spectrum produced by a comet to remotely diagnose the composition and speed of the solar wind.

Comet 73P Schwassmann-Wachmann 3 was discovered in 1930 by F. C. A. Schwassmann and A. A. Wachmann, and has an orbital period of 5.5 years. Owing to the fact that it was faint and small, it was not identified again until 1979, when its optical magnitude was 12.5 at its closest approach to the Earth. It was not observed in 1985, but was observed in 1990 with an optical magnitude of 9. During its 1995 apparition, the brightness surprisingly went up several orders of magnitude as a result of the fact that the comet had broken into several smaller fragments. For its apparition in 2006, over 60 fragments were being tracked. The X-ray Imaging Spectrometer (XIS) on Suzaku observed fragment C on May 13 at its closest approach to Earth at a distance of 0.074 AU, and again at perihelion on June 8. During the June 8 observation, a solar flare occurred and the X-ray emission from the comet brightened as a result.

Figure 1 shows the X-ray spectrum measured during the June 8th observation, and also the fit to the spectrum. The data were fit using laboratory-measured charge exchange data from C V, C VI, N VI, N VII, and O VII. In addition, lines at 0.21,0.24,0.27, and 0.4 keV were also included to achieve a good fit. Many of these lines are likely produced by charge exchange onto L-shell ions of silicon, sulfur, and magnesium (see for example Frankel et al 2009 and Koutroupma et al 2010). One useful diagnostic of the speed of the solar wind ions is the hardness ratio. The hardness ratio is defined as the

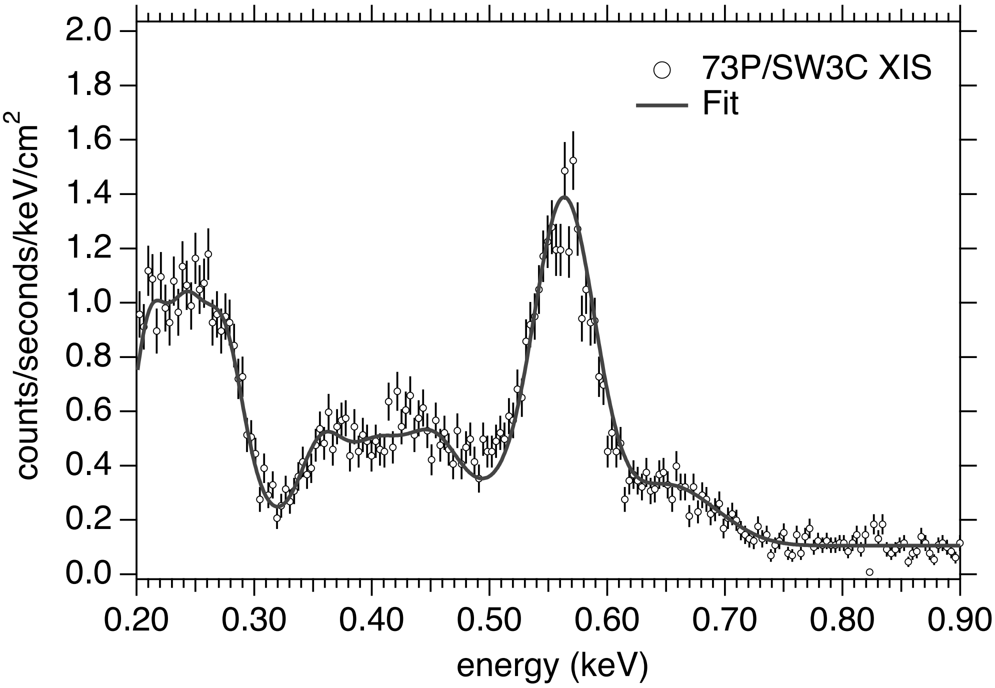

Fig. 1. X-ray spectrum measured by the back illuminated CCD of Suzaku's X-ray Imaging Spectrometer. This spectrum was measured on June 8th, 2006 when the comet was at perihelion. The data were fit using laboratory measured charge exchange spectra from C V & VI, N VI & N VII, and O VII. Additional lines at 0.21, 0.24, 0.27 and 0.4 keV are also included. The emission below 300 eV is most likely dominated by L-shell emission from S, Si, and Mg.

relative intensity of the $n > 3$ to 1 transitions relative to the $n = 2$ to 1 transitions. The larger the hardness ratio, the slower the speed of the solar wind ion relative to the cometary neutral (Beiersdorfer et al. 2001). Based on the hardness ratio measured from the hydrogenic C^{5+} Rydberg series, the velocity of the C^{6+} ions is $\sim$ 300 km/s, consistent with a slow solar wind. We also note that no hydrogenic O^{7+} was included in our fit, and thus no fully ionized O^{8+} was present in the solar wind during these observations. This result is consistent with measurements using the Solar Wind Ion Compositon Spectrometer (SWICS) on the Advanced Composition Explorer (ACE), which also showed that no O^{8+} was present in the solar wind during this observation.

In 2008, comet 8P/Tuttle was observed twice by the XIS. The first observation during the first week of January when the comet was at a distance of 0.26 AU from Earth, 1.1 AU from the Sun, and at a solar latitude of $\sim$ 1 degrees south, i.e., nearly in the ecliptic. During the second observation later in January when the the comet was 0.48 AU from the Earth, 1.0 AU from the Sun, and had a solar latitude of $\sim$ -20 degrees. The ACE sampled the solar wind during both observations. As a result, for the second observation, the solar wind was sampled simultaneously in the ecliptic (by ACE), and out of the ecliptic (by the X-ray emission from 8P/Tuttle).

In 2013, AstroH is planned to launch carrying a high resolution X-ray microcalorimeter array, the Soft X-ray Spectrometer (SXS). This instrument is expected to have a resolution of 7 eV across the 0.4 to 10 keV energy band and an effective area between 10 and 100 cm^2 between 0.4 and 1 keV. This instrument will make possible for the first time to resolve the X-ray spectral features from cometary atmospheres.

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