## Massachusetts Institute of Technology

Kavli Institute for Astrophysics and Space Center for Space

Research

Cambridge, MA 02139

April 11, 2006

To:XIS TeamFrom:Beverly LaMarr and Mark BautzSubject:Time variation of the spatial distribution of XIS contamination from atmospheric emission lines

## Summary

Following the ideas of Tsunemi-sensei, Anabuki-san, Bamba-san and others, we used the ratio of fluxes of characteristic emission lines from nitrogen and oxygen in the Earth's sunlit atmosphere to map the thickness of contaminant on the XIS1 optical blocking filter as a function of time during the *Suzaku* mission. Since the intrinsic fluxes of these lines vary with time in an unknown way, we can only constrain spatial variations in contaminant thickness, rather than the absolute thickness. Assuming that both the N and O lines illuminate the XIS1 field of view uniformly, thickness variations can be determined with a precision of  $\pm 100$ Å (for  $\rho_{contam} = 2.2$  gm cm<sup>-3</sup>), equivalent to a few per cent of the contaminant thickness, by integrating over spatial scales of about two arcminutes and timescales of four weeks.

The difference between the field-center thickness and field-edge thickness of the contaminant grows relatively rapidly during the first 3 months after the XIS door is opened, and then grows at a reduced, but roughly constant rate until the present. Although the time history of this difference is (nominally) insensitive to the rate of contaminant deposition, the early change in slope may signify the time at which the desorption rate at the edge of the filter saturates, as discussed by Mitsudasensei. If the deposition rate really has dropped significantly in recent times, the time history of the center-to-edge thickness difference might be expected to show another abrupt change in slope when the desorption rate at the filter edge again leaves the saturation regime. So far no such change in slope is observed.

This study is complementary to an analysis recently completed by Hayashida-san and others.

## Method and Assumptions

"Bright earth" data were accumulated<sup>1</sup> in 4 week intervals. A typical spectrum is shown in Figure 1. The characteristic emission lines of nitrogen (at 390 eV) and oxygen (at 525 eV) are evident. While bright earth spectra do vary significantly, these lines are always sufficiently bright that a 4-week integration produces of order 100,000 counts in each line.

We accumulated such bright-earth data over successive 4-week periods from the time of XIS door opening (13 August 2005) until the present. From each event list we extracted the pulse-height spectrum of g02346 events and fit gaussian profiles to the nitrogen and oxygen lines. The fit results were used to define a  $5\sigma$ -wide spectral band for each line. The bands are illustrated in Figure 1.

The total number of (g20346) events within each pulse-height band was then determined for circular annuli (in detector coordinates) centered on the geometrical center of the detector. The annuli have radial widths of 128 pixels (2.3 arcmin). The ratio of nitrogen-band to oxygen-band counts was then determined for each annulus. A sample radial profile of the ratio of counts in each band is shown in Figure 2.

<sup>&</sup>lt;sup>1</sup>Bright earth selection criteria: (DYE\_ELV.LT.-25).AND.(COR.LT.6).AND.(T\_SAA.GT.60)



XIS1BE9\_from20051020\_2308to20051024\_0146.evlist to XIS1BE12\_from20051107\_1324to20051111\_1950.evlist

Figure 1: Pulse-height spectrum (grades g02346) of bright earth data from XIS1. The K lines of nitrogen (390 eV) and oxygen (525 eV) each contain about 100,000 counts. Four weeks of bright earth data (weeks 9 - 12 after XIS door opening, between 2005 October 10 and November 7) were accumulated to produce tems are easily resolved in this case. No CTI corrections have been performed. Gaussian fits to the line, used to determine the pulse-height ranges over which the line counts are integrated, are shown. The pulse-height band limits ( $3\sigma$  "outboard" and  $2\sigma$  "inboard" of the line centroids) are indicated by the dashed vertical lines.

If we assume i) that the N:O line flux is uniform over the field of view for each integration period and ii) that the contamination is due entirely to an aziumuthally symmetric layer of carbon with density  $\rho = 2.2$  gm cm<sup>-3</sup>, then the difference in thickness of the carbon layer d(r) at two radii r and r\* is  $d(r) - d(r*) = 0.342 \mu m (R(r*) - R(r))$ , where R(r) = ln(N(r)/O(r)) and N(r) and O(r) are the counts in the nitrogen and oxygen bands, respectively, in the annulus at radius r.

Radial profiles of both the count rate ratio and the thickness difference  $d(r) - d(r^*)$  are shown for the various integration periods in Figure 3. Here we have defined  $d(r^*)$  from the counts detected at r > 512 pixels. Note that this center-to-edge thickness difference increases steadily through the mission.

The time dependence is illustrated more clearly in Figure 4, which shows the thickness difference between the central bin and the edges of the field of view  $d(r_0) - d(r^*)$  as a function of time.

## Discussion

Figure 3 shows that the N:O line ratio provides precise constraints on the spatial distribution of contaminant over the XIS1 field of view. If these results are coupled with measurements of the contaminant thickness at the center of the field of view derived from observations of calibration sources, they can be used to include the effects of the spatial variation of the contaminant in



Figure 2: Radial profile (black curve) of N:O line flux ratio for data shown in Fig. 1. Radius is measured from the center of the XIS1 detector. The red curve is just the black curve divided by the average line ratio for r > 512 pixels.

instrument response functions.

Strictly speaking this analysis cannot determine the cause of the non-uniformity of contaminant. One plausible model, however, is that the contaminant deposition rate is spatially uniform, and that the spatial variation results from differences in the desorption (or evaporation) rate caused by spatial variation in OBF temperature. Figure 4 can also be explained in this picture if we note, as Mitsuda has done, that the desorption rate grows with the contamination thickness until it saturates at a rate proportional to the equilibrium vapor pressure. It is at least plausible that this saturation occurs first at the edge of the filter, where the initial desorption rate is highest. The change of slope observed in Figure 4 at about 2005 Nov. 1 may indicate the time at which the desorption rate saturates in the center of the filter.

The most recent (2006 March 23-25) observation of the calibration source RXJ1856.5-3754 suggests that the thickness of the contaminant may actually have decreased since the preceding (2006 February) observation of E0102-72. Note that even if the deposition rate dropped to zero, one would not immediately expect a change in the slope in Figure 4. This is so because the thickness difference just measures the difference in desorption rates at the center and edge of the field of view. If the center of the filter is colder than the edge, the lower desorption rate at the center will cause the thickness difference to increase with time; that is, the contaminant thickness falls more slowly at the center than at the edge, so the difference continues to increase. Eventually, however, if there is no further deposition, the desorption rate at the edge will decrease (reaching zero when the



Figure 3: **TOP**: Radial profiles of N:O line flux ratio for various periods during the *Suzaku* mission. Each curve has been normalized (divided) by the average ratio at r > 512 pixels. **BOTTOM**: Implied carbon contaminant thickness (assuming contaminant density of 2.2 gm cm<sup>-3</sup>) in excess of the contaminant thickness at r > 512 pixels.

contaminant has all been removed there) and the the thickness difference must must then decrease. Figure 4 shows no such change in slope. The period covered by the final point on this graph ended 2006 March 19.



Figure 4: Time dependence of the excess contaminant thickness at the center of the XIS1 field of view. Contaminant is assumed to be pure carbon of density 2.2 gm cm<sup>-3</sup>. This graph shows the lowest-radius point on each curve in (the bottom panel of ) Figure 3 as a function of time.