**Supporting information**

**XMM-Newton Comparison**



SI Figure 1: Shows an adapted North pole projection of Jupiter with the Juno trajectory for Perijove 7 (black line with time increments) as produced by J. Connerney on (<http://lasp.colorado.edu/home/mop/missions/juno/trajectory-information/>) . The blue semi-transparent shape shows possible X-ray auroral ion emission regions from inspection of Chandra X-ray observations by Gladstone et al. (2002); Elsner et al. (2005); Branduardi Raymont et al. 2008; Kimura et al. 2016; Dunn et al. (2016;2017) and archival Chandra data from 2007 (Dunn et al. in prep a, b). The yellow spot indicates the most common location for X-ray auroral ion emissions – sometimes referred to as the X-ray hot spot. The grey contours indicate the locations of the Io footprint and UV main emission. The projection is on a 10° latitude by 30° longitude System III coordinate grid.

**

SI Figure 2: XMM-Newton EPIC-pn labelled image of Jupiter from 19:29 on July 10th to 09:38 on July 12th 2017.



SI Figure 3: 4-minute binned Jupiter Northern (blue) and Southern (Orange) X-ray auroral lightcurves from combined XMM-Newton EPIC-pn and MOS measurements between 19:40 on July 10th to 10:00 on July 11th 2017. The maroon arrow along the top indicates the time of the Juno perijove pass over the Northern aurora.

SI Fig 1. shows the Juno flight path over the North pole over the 10th and 11th of July 2017. We overlay on this an example of the X-ray auroral emission region taken from inspection of Chandra X-ray polar projections (e.g. Dunn et al. 2017), which provide higher spatial resolution than XMM-Newton (0.5’’ for Chandra’s High Resolution Camera vs 5’’ for XMM-Newton’s EPIC-pn). Only a short window (00:00 – 01:00 on July 11th 2017) of this flight was spent in the region from which the ion-produced X-ray aurora is normally observed to originate, when viewed from Earth (blue transparent shape).

SI Fig 2 shows an image of Jupiter from XMM-Newton’s EPIC-pn instrument from *19:29 on July 10th to 09:38 on July 12th 2017.*

SI Fig 3 shows the time variability of the X-ray aurora during the window relevant for this observation.

**Spectral Fitting Methods**

Spectra were extracted from oval regions centred on the Jovian North pole (from NASA JPL Horizons ephemeris data) with a latitudinal radius of 1/3 of the diameter of Jupiter’s total disk and longitudinal radius equal to that of the Jovian disk. The spectra were extracted and processed with the standard XMM-Newton SAS processes (calibration .ccf files produced; .rmf and .arf files generated and applied to reproduce the XMM response) and with the xspec software (e.g. see Branduardi-Raymont et al. 2004; 2007; Hui et al. 2010).

**Comparing Observed and Simulated Data**

To illustrate some of the different possible reasons that the simulated ion fluxes may not reproduce the non-oxygen spectrum, we tested a variety of other model fits. Here we demonstrate the different possible components of emission that combined with the CX+DE models could explain the observed emission, we show spectral fits to the first and second Northern auroral viewing intervals (19:29-21:30 on July 10th and 01:00-06:00 on July 11th (UT)) with CX+DE models and with these same models combined with fitted bremsstrahlung continua.

SI Fig.4 shows the simulated CX+DE model fluxes with a fitted bremsstrahlung component to represent a continuum that peaks at below 0.2 keV for 10 July 19:29-21:30. This additional bremsstrahlung component simulates a forest of sulphur lines with similar fluxes to the oxygen lines and produces a good fit to the spectrum (see main text Table 1.)

SI Fig 5 shows the simulated CX+DE model fluxes for 11 July 01:00-05:30, while SI Fig 6 shows this model with a bremsstrahlung component to model a high energy electron population, which contributes to the spectrum above 0.9 keV. We re-binned this spectrum to ensure a minimum of 5 counts per energy channel for comparison with the interval on 10 July. However, because the interval was more than twice as long, this provides additional counts and therefore higher energy resolution.

We note that to differentiate between underestimation from the model, time-varying precipitations and bremsstrahlung contributions, the methods presented here would need to be tested on a broader set of conjugate XMM-Newton-Juno observations, for which the XMM-Newton data has not yet been collected.





SI Figure 4: Similar layout to Figure 13 in the main text: a) model photon fluxes for the CX+DE model combined with a low energy (T ~0.05 keV) bremsstrahlung component to mimic a forest of sulphur lines, b) model convolved with XMM-Newton EPIC-pn instrument response and compared with observed Northern auroral spectrum from 10 July 2017 19:29-21:30.





SI Figure 5: Similar layout to Figure 13 in the main text: a) model photon fluxes for the CX+DE model b) model convolved with XMM-Newton EPIC-pn instrument response and compared with observed Northern auroral spectrum from 11 July 2017 01:00-05:30.





SI Figure 6: Similar layout to Figure 13 in the main text: a) model photon fluxes for the CX+DE model combined with a fitted bremsstrahlung continuum b) model convolved with XMM-Newton EPIC-pn instrument response and compared with observed Northern auroral spectrum from 11 July 2017 01:00-05:30.

**Comparing Different Auroral Zone Sizes**

To produce the photon fluxes shown here, it was necessary to assume a given emission region size in the X-ray auroral zone. XMM-Newton offers limited spatial resolution (e.g. SI Fig 2), so we relied on archival Chandra observations to estimate the size of an emission region during an interval of relatively dim X-ray aurora. Examples of time-binned polar projections can be found in Elsner et al. (2005) and Dunn et al. (2016). These suggest that the X-ray auroral zone covers a region of the order of 5° x 5° to 10° x 15° System III latitude-longitude, in a given few-minute window. Dunn et al. (2016) and Kimura et al. (2016) show that the size of the auroral zone can change from observation to observation. For the relatively dim intervals shown here, we found that the aurora was well-fitted by a 7.5° x 5° auroral zone. SI Figure 7 shows the photon fluxes produced by a 10° x 15° System III latitude-longitude region. We note that the resulting simulated oxygen emission is brighter than any Jovian auroral spectrum in the XMM-Newton archive, suggesting a limiting size for the X-ray auroral zone.

SI Figure 7: Similar layout to Figure 13 in the main text: a) model photon fluxes for the CX+DE model for a 10° x 15° System III latitude-longitude region b) model convolved with XMM-Newton EPIC-pn instrument response and compared with observed Northern auroral spectrum from 11 July 2017 01:00-05:30.