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# A spectral study of Jupiter's X-ray aurorae with XMM-Newton during a solar wind compression event detected by Juno

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## Abstract

This year marks the 40th anniversary since the first detection of Jupiter's X-ray aurorae by the Einstein Observatory [1]. Since then we have come to understand that there are two constituents to these emissions that are based on the energies of the photons. Soft X-rays with energies lower than 2 keV occur at high latitudes close to the poles and are due to charge exchange processes between precipitating ions and neutrals in the Jovian atmosphere. However, it is still unclear where these ions originate – are they from the solar wind, or are they from Io's volcanoes? Higher energy X-rays appear at lower latitudes and mostly coincide with the location of the main UV auroral oval. These transient emissions are produced by precipitating electrons [2].

XMM-Newton observed Jupiter on 19th June 2017 between 00:20-23:39 UTC. This is the first time that XMM-Newton was observing Jupiter whilst in-situ measurements of the planet's outer magnetosphere were being taken by Juno. Solar wind propagation models suggest that Jupiter's magnetosphere was experiencing a compression due to increased activity in the solar wind during this time, which was supported by data from Juno and by HST observations of the Jovian UV aurora. Spectra of the northern and southern X-ray aurorae were extracted and analyzed using the Atomic Charge Exchange model. We present results of our spectral fitting for the ion abundances responsible for the soft X-ray emissions that give us clues as to their origin.

## 1. Introduction

Jupiter's incredibly strong magnetic field produces a magnetosphere that carves out a cavity in the solar wind. Its exact size and shape depend on the conditions of the solar wind. The solar wind is a stream of plasma originating from the Sun's corona. It is usually divided into two categories: the fast and slow solar wind. The fast solar wind has a characteristic speed of ≈ 750 km $s^{-1}$ and has a composition close to that of the Sun's photosphere. On the other hand, the slow solar wind has a lower velocity of ≈ 400 km $s^{-1}$ and its composition is similar to the Sun's corona [3].

In addition, Io provides Jupiter with an internal plasma source: 400 volcanoes on this moon churn out 1 tonne of neutral sulfur and oxygen into Jupiter's magnetosphere per second that will later be ionized through collisions with other ions and neutrals.

The Jovian X-ray aurora is comprised of two distinct parts. A permanent emission of soft X-rays exists near the poles. The process responsible for this is charge exchange – an ion from the solar wind or from Io captures an electron from a neutral in Jupiter's atmosphere. This ion will eventually deexcite and release a photon. At the moment the split in contribution between the solar wind and Io is unknown. At the peripheral of this region is the main UV auroral oval where the hard X-ray emission also reside. This emission is due to precipitating electrons decelerating and releasing high energy X-rays through Bremsstrahlung radiation.

## 2. Method

The X-ray aurorae at both poles are fixed in Jupiter's frame, therefore, they are only visible during parts of Jupiter's rotation. The northern soft X-ray emissions tend to be brighter than in the south as seen in Fig. 1. XMM-Newton EPIC pn spectra were extracted during the periods of visibility: there were two for the northern aurora and three for the southern, giving a total of five spectra. The spectra were fitted in XSPEC using the Atomic Charge Exchange (ACX) and Bremsstrahlung models (Fig. 2). Two different ion populations were used for the ACX model. The first was magnetospheric in nature and consisted of S and O ions (Fig. 3a). The second comprised the ion abundances from the slow solar wind as measured by the Ulysses spacecraft [4] (Fig. 3b). This was to determine whether the ions responsible for the X-ray aurorae are from Io or from the solar wind.

## 3. Figures

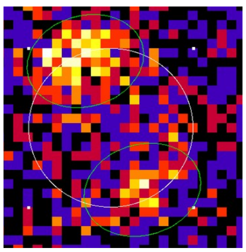

Figure 1: Jupiter as seen by the pn detector on XMM-Newton during 19th June 2017. The auroral regions are highlighted in green and the disk of the planet is in white. North is at the top.

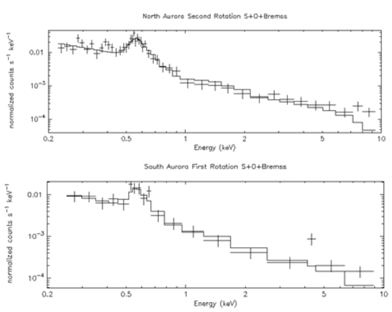


Figure 2: Examples of the north (top panel) and south (bottom panel) aurorae spectra (crosses); the histogram is the best fit.

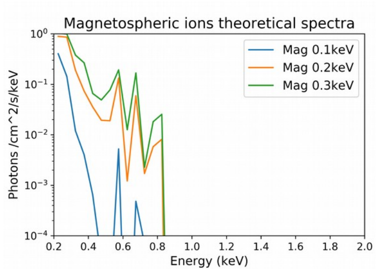


Figure 3a: Theoretical X-ray emission spectra of the magnetospheric (S and O) ions undergoing charge exchange at different temperatures.

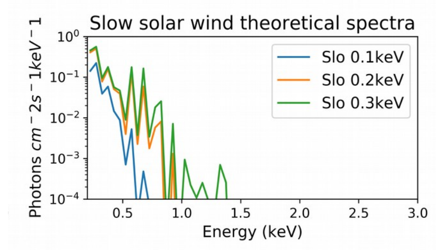


Figure 3b: Theoretical X-ray emission spectra of the slow solar wind undergoing charge exchange at different temperatures.

## 4. Summary and Conclusions

Our observation of Jupiter's X-ray aurorae occurred during a solar wind compression as shown by the solar wind propagation model and supported by measurements taken by Juno and the HST. A Bremsstrahlung continuum is a necessity to get good fits of the spectra and its contribution remained consistent for at least 20 hours. The contribution from the charge exchange process behaved independently to the Bremsstrahlung and fluctuated during the observation. The spectra for both poles were best fitted with a magnetospheric (S and O) instead of a solar wind ion population throughout the observation.

## References

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