Twenty-Two Simultaneous Chandra and Hubble Observations of Jupiter's X-ray and UV Aurorae

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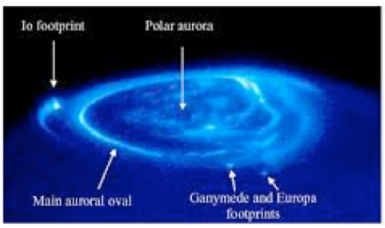
Abstract

Jupiter possesses the most powerful UV and X-ray aurora in the solar system. Previous work has shown that hard X-ray emission (photon energy > 2 keV), which is produced by precipitating electrons, coincides with the UV main auroral emission (Branduardi-Raymont et al. 2008). In contrast, soft X-ray emission (photon energy < 2 keV), which is produced by precipitating ions, coincides with UV aurora flares that occur polewards of the main emission (Elsner et al. 2005). The known connections between these two wavebands are based largely on a single simultaneous Chandra X-ray Observatory (CXO) observation and Hubble Space Telescope (HST) orbit from 24 February 2003. Here, we explore the 22 simultaneous HST and CXO Jupiter aurora observations taken between 2016 and 2019. By working with a group of school students, through the Orbyts research in schools programme, we identified intervals of shared UV and X-ray auroral morphology between the observations. We present the examples of shared morphologies that were identified and explore a variety of time cadences to note how the morphology varies with integration time. This exploration is critical for our potentially misleading characterisation of a coherent 'X-ray hot spot' (Gladstone et al. 2002; Dunn et al. 2017; Weigt et al. 2020). In fact, this supposed spot seems to be connected to several seemingly different UV auroral morphologies. We further note interesting observations from the sample and the persistent lack of X-rays and UV emissions from the 'dark polar region'.

1. Known Connections between Jupiter's X-ray and UV Aurora

Jupiter's UV aurora (Fig 1 top) and X-ray aurora (Fig 1 right) are known to be connected in 2 ways:

1. Hard X-ray emission (photon energy > 2 keV), which is produced by precipitating electrons, coincides with the UV main auroral emission (Branduardi-Raymont et al. 2008 – Fig.1 top left and right).
2. Soft X-ray emission (photon energy < 2 keV), produced by precipitating ions, coincides with UV aurora flares that occur polewards of the main emission in the 'polar aurora' (Elsner et al. 2005 – Fig 1).



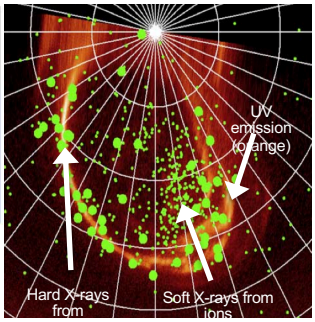
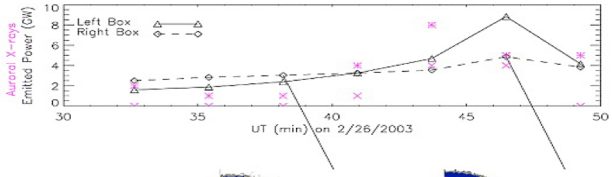
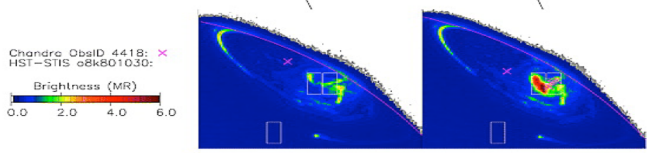


Fig. 1 (top left): *Labelled HST observation of Jupiter's UV aurora [Clark et al. 2004].* ***(top right):*** *Chandra X-ray image of Jupiter. Lower: Overlaid HST UV North Pole projection (orange) and CXO polar projection (green dots) [Branduardi-Raymont et al. 2008].* ***Bottom:*** *Overlaid HST UV (colour bar) and CXO observation of X-ray photons (purple crosses) from Jupiter*





2. New Simultaneous Observations

Since 2016, 22+ simultaneous CXO and HST observations have been acquired.

We created Python tools in Google Colaboratory that enabled school students to generate overlaid X-ray (white dots) and UV (blue-white-red colour bar) videos of Jupiter's aurora so that they could explore possible connections between the aurorae. The students produced 200+ slides of analysis like Fig. 2 (polar projections in the lower left and longitude-latitude map in the top right), presenting their analysis of morphological UV-X-ray connections.

For example, they note that the 'interior oval' (Fig. 2 yellow arrows), on the boundary of the UV swirl region, has persistent X-ray emission.

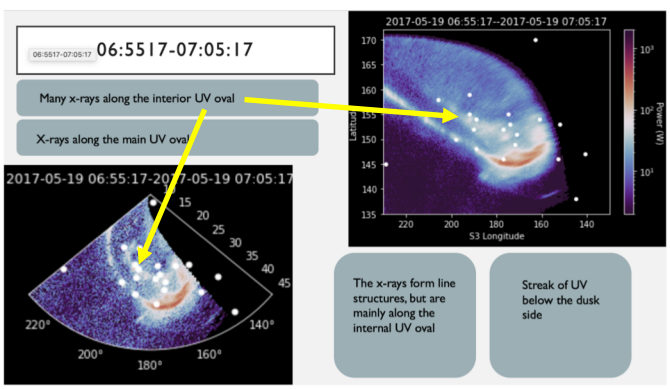


Fig. 2 (top): *Example slide produced by school student D. May from analysis of overlaid HST UV and CXO X-ray videos of Jupiter's aurora.*

3. Not a hot spot after all:

X-ray Flickering and Flaring emission in the UV Swirl and Active regions respectively

- Since 2002, Jupiter's X-ray aurora has been referred to as a hot spot (e.g. Gladstone et al. 2002; Dunn et al. 2017)
- Dunn et al. 2020 identified a non-flared soft X-ray auroral component in the time-series. Here we show that this 'flickering' emission is the X-ray equivalent of the UV swirl aurora. Therefore, Jupiter's X-ray 'hot spot' is at least 2 auroral emissions: flares from the UV active region and 'flickering' from the swirl region.

A clear example of this is shown on 16 July 2019, when throughout the 40 min observation the flickering emissions coincide with sporadic patches of emission in and along the boundary of the swirl region (Fig 3).

X-ray Flickering Coincident with the UV Swirl:

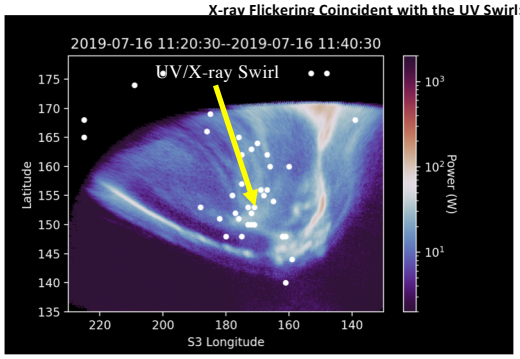


Figure 3: Overlaid X-ray (white dot) and UV (blue-white-red colour bar) S3 Longitude-Latitude map of Jupiter's Northern aurora

X-ray Pulses and UV Flares in the Active Region:

A short-lived flare also occurs on 16 July 2019, and coincides with a concentrated group of X-rays, spatially separate from the swirl. Fig 4. shows the flare, we also include with error bars in photon location (as white boxes), showing that Chandra's spatial resolution can distinguish between the 2 regions.

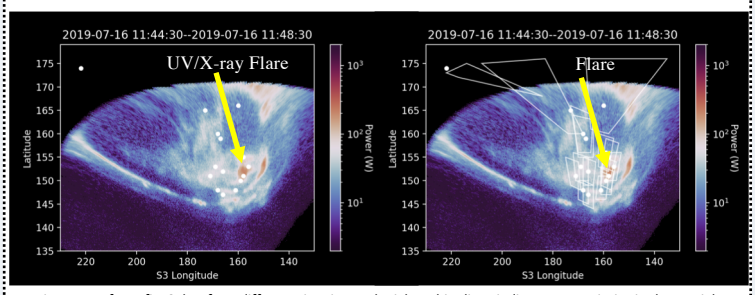


Figure 4: Left: As fig. 3, but for a different time interval. Right: white lines indicate uncertainties in the spatial location of the photons from Chandra's spatial resolution.

4. Further possible connections and relationships of note

Rare Lower Latitude Emissions: X-rays in the UV oval gap? X-ray Io Footprint? X-ray Injection Aurora?

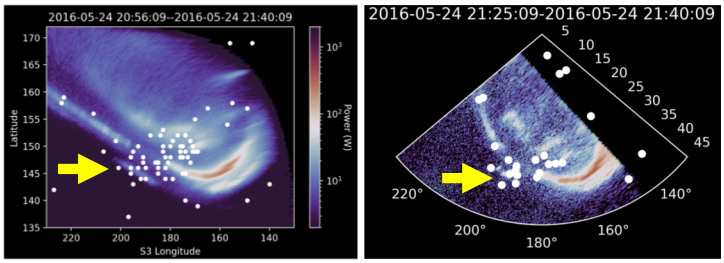


Figure 5: Left: As fig. 3, but for a 44-minute integration on 24 May 2016. Right: Polar projection of a 15-minute integration within this.

Persistent absence of UV and X-rays in the dark polar region

For all 22 observations analysed, there is a persistent absence of X-ray emission from the dark polar region (Fig. 6 yellow circle). There are also some very strange morphologies in the sample:

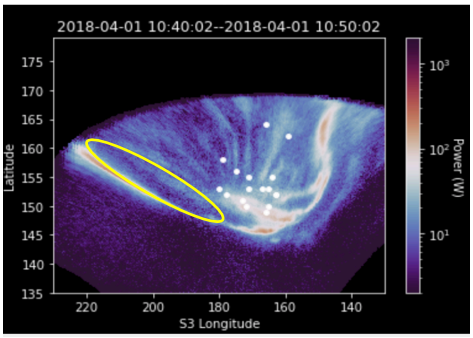


Fig. 6: UV and X-ray aurora map on 1 April 2018, showing a unique auroral morphological example from the 22 observation sample. Yellow circle highlights the UV 'dark polar region', which is also X-ray dark throughout all 22 observations.

We welcome collaborations on past and future planetary X-ray observations (w.dunn@ucl.ac.uk)..