Chandra observations of Jupiter's X-ray aurora during Juno upstream and apojove intervals

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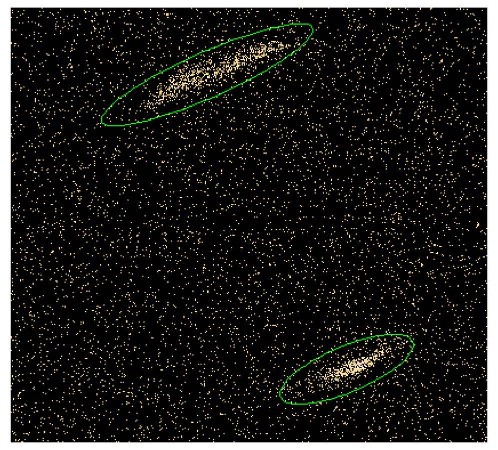
1. ABSTRACT

The Chandra space telescope has recently conducted a number of campaigns to observe Jupiter's X-ray aurora. The first set of campaigns took place in summer 2016 while the Juno spacecraft was upstream of the planet sampling the solar wind. The second set of campaigns took place in February, June and August 2017 at times when the Juno spacecraft was at apojove (expected close to the magnetopause). We report on these upstream and apojove campaigns including intensities and periodicities of auroral X-ray emissions. This new era of jovian X-ray astronomy means we have more data than ever before, long observing windows (up to 72 ks for this Chandra set), and successive observations relatively closely spaced in time. These features combine to allow us to pursue novel methods for examining periodicities in the X-ray emission. Our work will explore significance testing of emerging periodicities, and the search for coherence in X-ray pulsing over weeks and months, seeking to understand the robustness and regularity of previously reported hot spot X-ray emissions. The periods that emerge from our analysis will be compared against those which emerge from radio and UV wavelengths.

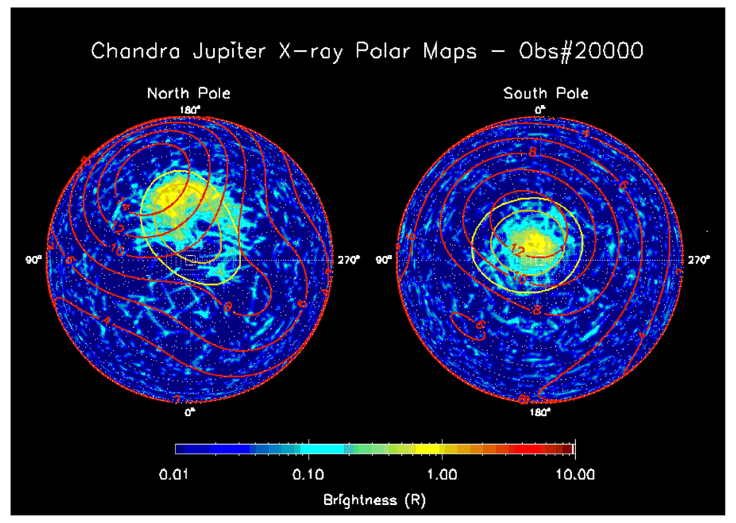
2. Dataset and analysis method

- Correction applied to raw Chandra image to account for motion of Jupiter across the FOV
- Manual extraction of northern and southern auroral zones (emission dominates background)
- Disk poorly defined during times of low solar X-ray flux
- Northern hot spot: longitude 155 to190 °, latitude 60 to 80° [after Gladstone et al., 2002]
- Southern hot spot: longitude 0 to 90°, latitude -90 to -70° [after Dunn et al., 2017]

1A



1B



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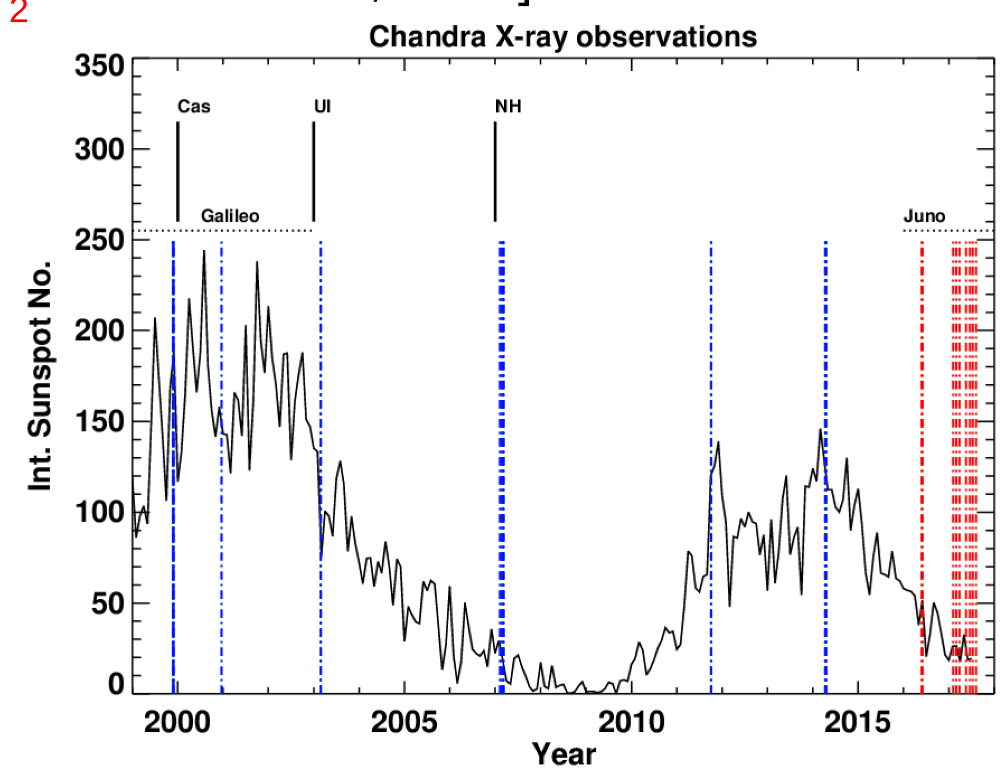

Figure 1: Feb 28th 2017 observation: 1A: Chandra data post-correction for Jupiter's motion. 1B: Polar maps for north and south with brightness in Rayleighs. Red contours = VIP4 model

Figure 2: Overview of X-ray observations of Jupiter from 1999-2018. Blue vertical lines show pre-Juno-era observations [statistical analysis, Jackman et al., in prep., 2017]. Red vertical lines are Juno-era observations. Flybys of Cassini, Ulysses, New Horizons plus Galileo and Juno orbital intervals marked.

3. Periodicities in auroral X-ray emissions

Previously reported periodicities in jovain X-rays: northern hot spot ~45 minutes [Gladstone et al., 2002], southern hot spot ~11 minutes [Dunn et al., 2017].

In the 24 pre-Juno era Chandra observations (Fig. 2), only 2 statistically significant periods found (~45 minutes and ~33 minutes in the north).

Figure 3: Light curve (A) from Chandra observation on June 18th 2017 from 18:39 – 22:29. 230 minutes of northern hot spot visibility. 191 photons. Lomb-Scargle analysis of unsmoothed, 60-second binned light curve data (B, C). Log-log plot (C) is intended to visually search for red noise (power law slope) which could mean that periods returned from Lomb analysis have slightly lower significance). Peak power = 13.6, 37-minute period. Monte Carlo analysis (D): initial light curve randomly shuffled, then Lomb analysis carried out. Process repeated 10,000 times. Histogram of maximum powers shown (plus cumulative distribution in red). The highest power associated with the real (unshuffled) data is at the 99.99th percentile (~a 7.7 sigma result assuming a normal distribution).

4. Case study with significant periodicity

- Statistically significant 37-minute quasi- period from northern hot spot on June 18th 2017 apojove observation.
- 1st of 2 hot spot visibility windows during 20-hour observation.

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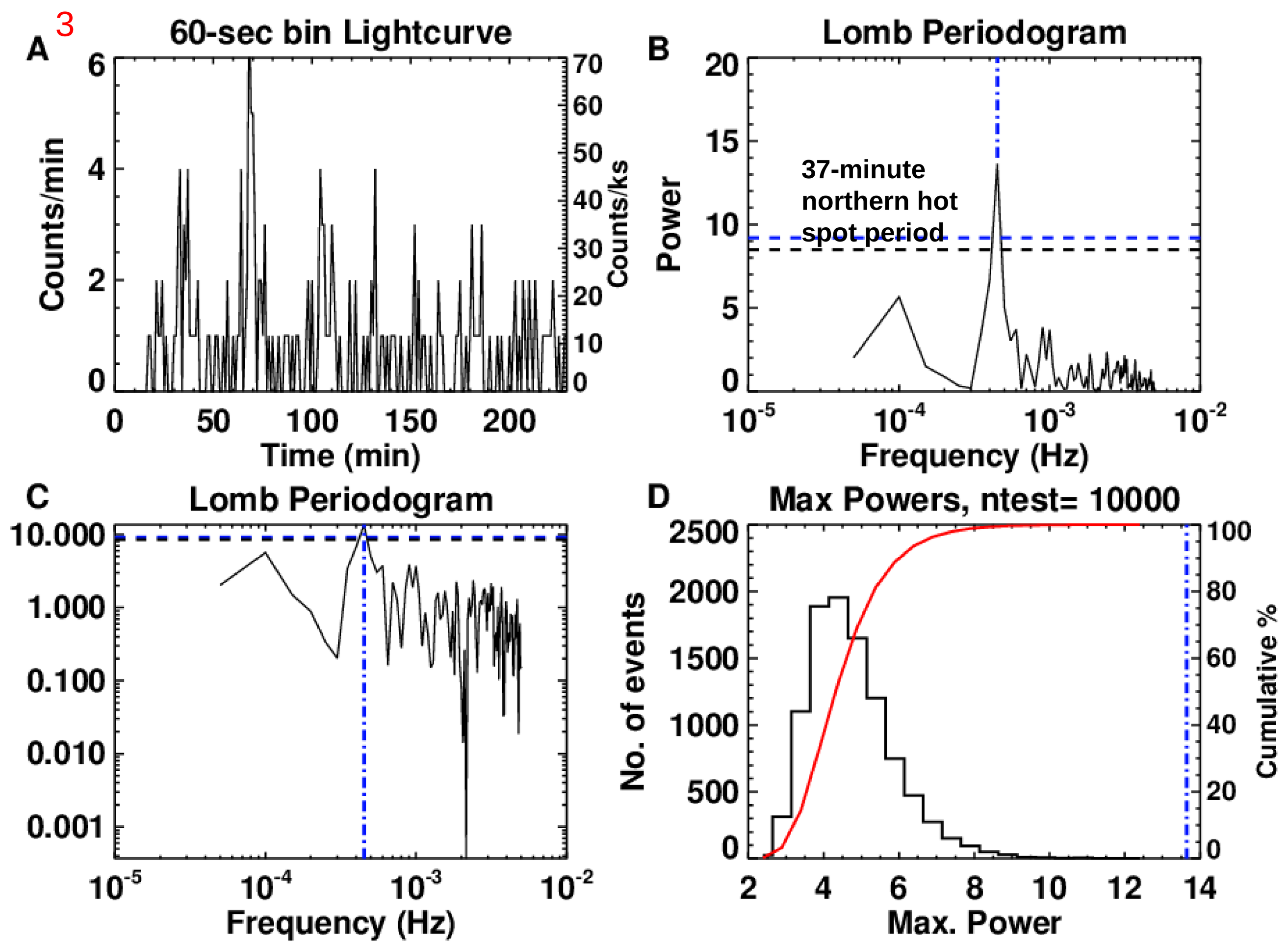

- 2nd, shorter hot spot visibility window (153 minutes) revealed 25-minute quasi-period (99th percentile, ~3.1 sigma).

5. Summary statistics

Analysis of 5 X-ray observation (2 Juno upstream, 3 Juno apojove):

- Periodic pulsing may be confined to a spatially limited hot spot region [June 1st 2016 southern hot spot (Dunn et al., 2017)]
- Orbit-to-orbit variability present in jovian X-rays [June 18th 2017]
- Northern photon counts consistently higher than south… Primarily visibility effect.
- Periodic pulsing is relatively rare… what light can this shed on possible drivers of jovian X-rays?

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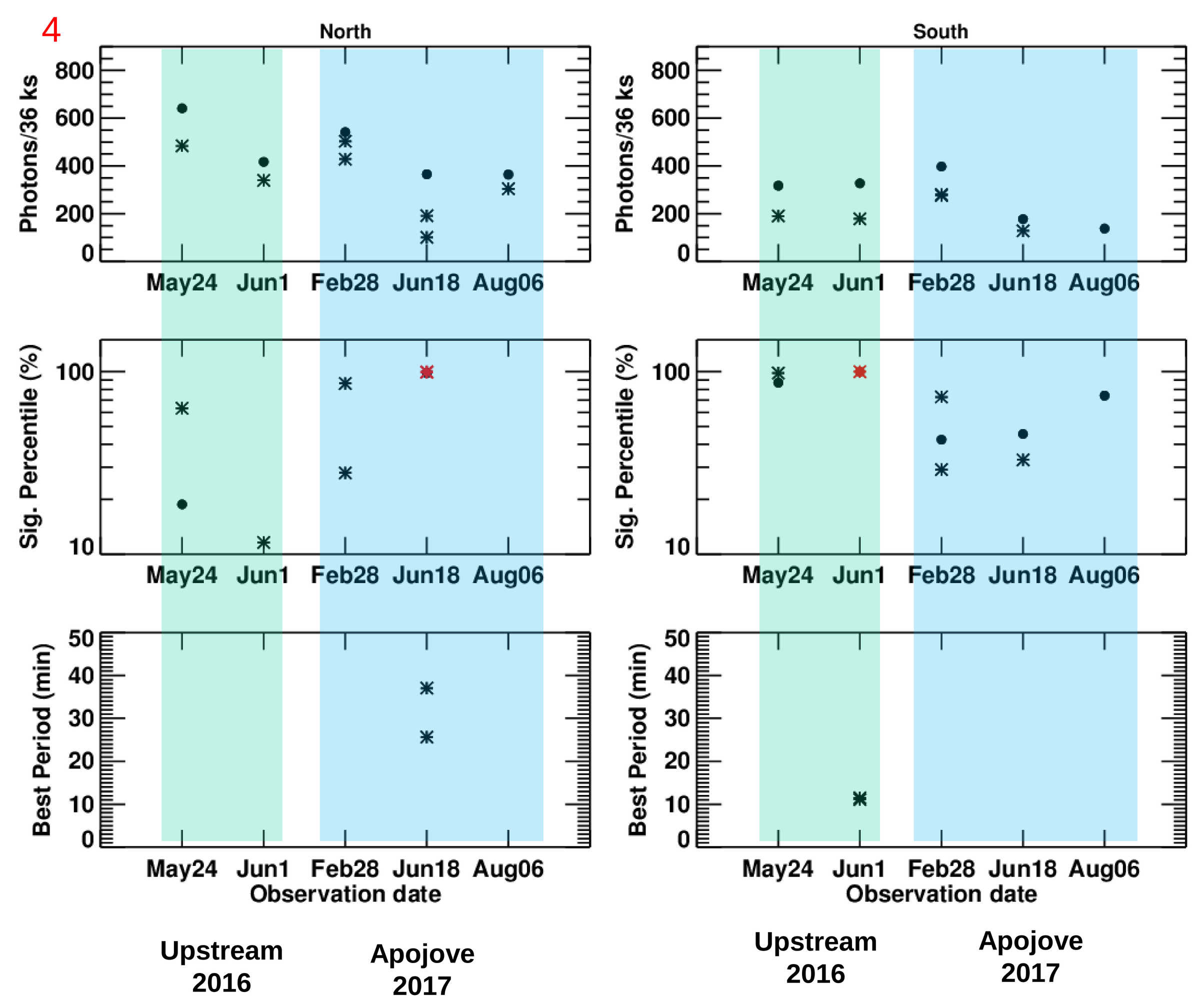

Figure 4: Summary figure of 2 upstream and 3 Juno apojove Chandra observations: (i) Total counts normalised to 1 Jupiter rotation, (ii) significance from Monte Carlo analysis, (iii) best period (shown for significant periods only). Circles = entire observation, Asterisks = N or S hot spot

Summary and Future Work

- Analysed Chandra data from 2 intervals with Juno upstream and 3 intervals with Juno at apojove
- June 18th 2017 apojove (2 Jupiter rotations) shows statistically significant northern hot spot quasi-periods of 37 and 25 minutes on consecutive planetary rotations. No significant pulsing in southern auroral X-rays during same observation. This is another example of the independent behaviour of northern and southern X-ray emissions [following Dunn et al., 2017 observation of ~11-minute period in south on June 1st 2016 while Juno was upstream],
- This poster + Statistical study of pre-Juno era Chandra observations (from 1999 – 2015, Jackman et al., in prep.) has also revealed rarity of statistically significant quasi-periods in X-ray emissions. Driver of emissions still an open question.
- Future: Examination of concurrent Juno data to compare to in situ conditions and unveil magnetospheric drivers. Possible scenarios: pulsed dayside reconnection (IMF B_Z), Kelvin-Helmholtz instability etc. [Dunn et al., 2016; Kimura et al., 2016]
- Future: Mapping of X-ray photons to magnetospheric source location. Explore proximity of X-ray sources to magnetopause [Vogt et al., 2015]

REFERENCES Dunn et al., 2016, JGR, doi 10.1002/2015JA021888; Dunn et al., Nature Astronomy, doi:10.1038/s41550-017-0262-6, 2017; Gladstone et al., 2002, Nature, doi 10.1038/4151000a; Kimura et al., 2016, JGR, doi: doi:10.1002/2015JA021893; Vogt et al. JGR, 2015, doi:10.1002/2014JA020729