HRC Update

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The most significant news of the past year from the HRC IPI team is the retirement of Jon Chappell. Jon's contributions to the success of the HRC instrument are well known to the *Chandra* scientists at SAO/CXC, MSFC, MIT, and PSU, but he is probably less well known to the broader *Chandra* users community. Jon began working on microchannel plate detectors in the 1980s at SAO and performed many of the early investigations on photocathodes, readout techniques, and degapping algorithms that were ultimately used on the flight instrument. He played a central role in the construction, testing, and calibration of the flight instrument in the 90s. After the launch of *Chandra*, Jon became the project scientist for the HRC IPI team, and was responsible for operations and monitoring its health and safety. His contributions to *Chandra* span more than 30 years, and his dedication and technical ability were appreciated by all who have worked with him. We wish him well in his future endeavors.

The HRC continues to operate smoothly after more than 15 yrs in orbit, with no significant anomalies. The HRC has been used for a wide range of scientific investigations over the past year. In this year's edition of the newsletter, we present results from an HRC observation of Jupiter taken in April 2014 as part of a large international campaign to study the Jovian aurora, inner magnetosphere, and Io plasma torus.

Early *Chandra* observations of Jupiter showed that the X-ray flux was dominated by two hot spots at the magnetic poles at latitudes poleward of the magnetic flux lines that map to Io (Gladstone et al. 2002, Elsner et al. 2003, Elsner et al. 2005). The primary X-ray emission process is charge exchange (CX) between neutrals in the Jovian atmosphere and energetic ions accelerated in an electric field parallel to the magnetic field (Cravens et al. 2003, Bunce et al. 2004). The origin of the ions responsible for the X-ray aurora is still an open question, and determining whether they originate from Io or the solar wind has important implications for our understanding about matter and energy transport in the magnetosphere, and the interaction between the magnetosphere and the solar wind. In the magnetic-dominated plasma of the inner magnetosphere, it is difficult to understand how ionized particles originating on Io could propagate to the outer magnetosphere perpendicular to the strong magnetic field. As an alternative, it was speculated that the ionized particles from the solar wind accelerate from large distances (> 30 R_J) to the X-ray hot spot.

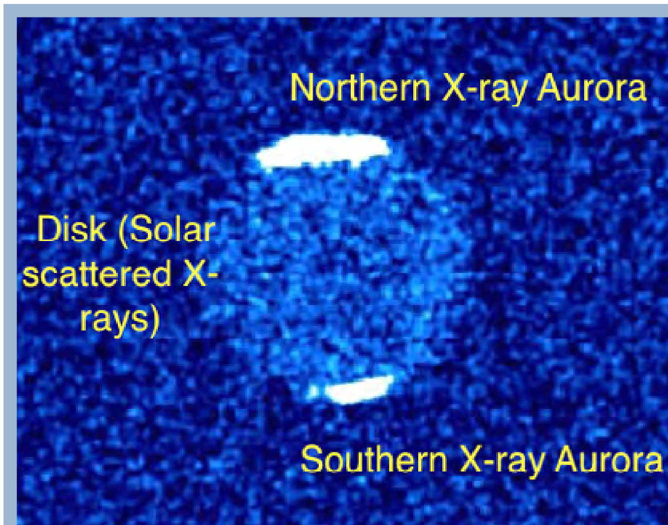

Fig. 1 — Chandra/HRC (240 ks observation time) X-ray image of Jupiter averaged over the system III rotation period. The auroral X-ray emission originates in small spots at the poles. They appear streaked in this image because of averaging over rotation. The X-ray emission from the disk is scattered X-rays from the Sun and unrelated to auroral processes.

In AO15, we proposed 6×40 ks *Chandra*/HRC observations of Jupiter coordinated with the Japanese EUV spectrometer Hisaki (an Earth-orbiting observatory studying CX emission from the gas giants and the exospheres of the terrestrial planets) over a two week period to investigate the relationship between the X-ray aurora, the electron aurora (Clarke et al. 2006), the Io plasma torus (IPT), and the solar wind. Two of these observations were made as part of the HRC GTO program (PI: S. S. Murray) and four were made as part of a GO program (PI: R. Kraft). Each observation spanned slightly more than one full system III rotation period[1]. A *Chandra*/HRC image of Jupiter made from the combined data of this observation is shown in Fig. 1.

To better constrain the origin of the ions responsible for the X-ray aurora, we projected the position of each of the X-ray photons of the northern aurora onto the system III coordinates, as shown in Fig. 2, with magnetic field contours derived from the VIPAL and Khurana model overlaid. All of the X-ray events originate in a small region near the magnetic pole. The field

[1] *The rotation period of the magnetic core of Jupiter.*

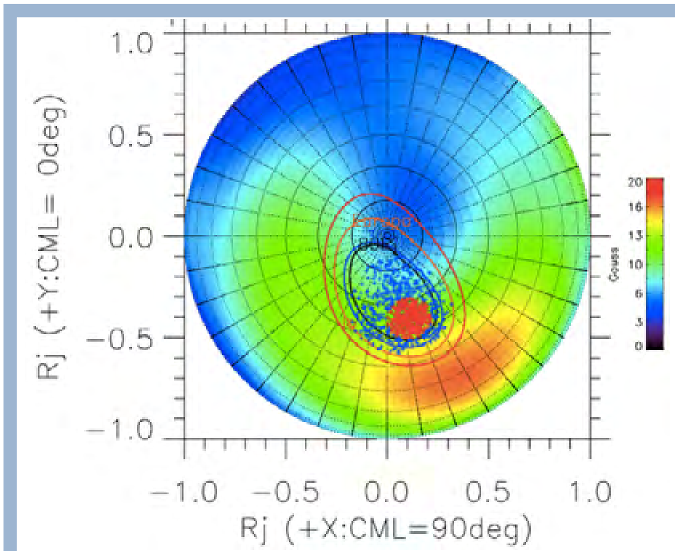

Fig. 2 — Polar plot of the X-ray location of the X-ray photons in the system III overplotted with the magnitude of the magnetic field strength. The X-ray photons are extracted from all 6 HRC datasets. The x axis directs to the central meridian longitude (CML) of 90°, and the y axis directs to the meridian plane of CML=0 deg. The red, orange, blue, and black lines represent latitudes from which magnetic field lines extend to radial distances at 6, 15, 30, and 80 R_J in the equatorial magnetosphere, respectively. Red points indicate the "core" region where photon density is high. Blue points indicate the "halo" region which surrounds the core region with a lower density of photons.

lines at these positions map either to the outer magnetosphere or are open to the solar wind. There are two distinct "groupings" of photons—a small region where the photon density is high we call the core (events shown in red), and a more diffuse region we term the halo. The halo region generally extends poleward of the core region, but there is a small region of diffuse emission that completely surrounds the core.

Using the VIPAL and Khurana models of the Jovian magnetic field, we map the apex points for the locations of each of the events. The apex point for each X-ray event is defined as the furthest distance in the magnetosphere that maps along the magnetic field to the position in the ionosphere where the X-ray photon was detected. The apex points generally lie in the equatorial plane, and given Jupiter's strong magnetic field it is reasonable to presume that the ions that are accelerated in the magnetosphere to create the X-ray aurora originate at or near the apex points. The distribution of apex points (for all 6 HRC observations) as a function of Jovian local time is shown in Fig. 3. Virtually all of the X-ray events that are on closed field lines map to the noon or dusk side of the magnetosphere. Additionally, many of the events from the core region map directly to the magnetopause, the thin region of plasma that separates the shocked Solar wind from the outer magnetosphere, whereas many of the events from the halo map to the the noon and dusk regions of the magnetosphere. Some of the events in both the core and halo are on open field lines and are not shown in Fig. 2. There is considerable day to day variation in the fraction of events in the core and halo, the fraction in the noon sector to the dusk sector, and the fraction in the magnetopause to those in the magnetosphere. Such a direct link to the magnetopause suggests that the ions originate in the region of tangled magnetic fields and matter where the magenotspheric plasma merges with the shock-heated solar wind. It is well known that in both the Earth's and Saturn's magnetosphere, strong Kelvin-Helmholtz instabilities are generated in the noon and dusk sectors of the magnetopause (Masters et al. 2012), although neither are sources of bright auroral X-ray emission. Results from this study, as well as a comparison of the *Chandra* and *Hisaki*/EUV light curves will be published in Kimura et al. (2015).

References

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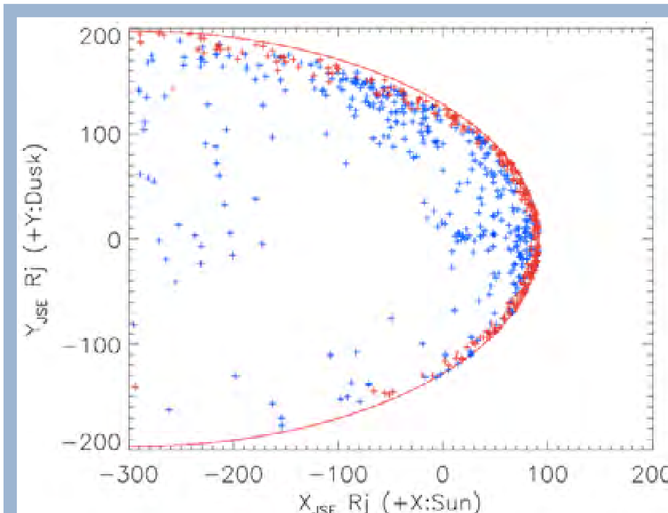

Fig. 3 — Local time distribution of the field line apex points corresponding to the X-ray source location. Apex points at the magnetic latitudes from -20° to +20° are selected. The red and blue crosses correspond to X-ray events in the core and halo regions (see Fig. 2), respectively. The approximate position of the magnetopause is shown by the red continuous curve.