Solar system X-rays: what we know and what we are looking for

G. Branduardi-Raymont
Mullard Space Science Laboratory
University College London, UK

... reporting work by K. Dennerl, C. Lisse, R. Gladstone, A.Bhardwaj, R. Elsner, H. Waite, T. Cravens, ...

The X-ray Universe, 16 – 19 June 2014
Dublin, Ireland
Mars disk and exosphere (halo): *XMM-Newton* RGS

- Fluorescent scattering of solar X-rays in CO$_2$ atmosphere
- Solar wind charge exchange (SWCX) in the exosphere

*Dennerl et al. 2006*
Soft X-rays (0.2 – 1 keV) from Jupiter’s aurorae

• Ionic Charge Exchange processes thought to lead to soft X-rays

• Ions first thought to originate in the inner magnetosphere (8–12R_J) but Chandra data point to origin at >30 R_J  

• What are the ion species (C or S) and thus their origin (solar wind / magnetosphere)?

• Recent XMM-Newton & Chandra spectra favour a magnetospheric origin  

• Relative roles?
Jupiter pulsating X-ray hot spot

~ 45 min periodicity in the X-ray flux

Chandra HRC-I
2000

Gladstone et al. 2002

X-ray: Chandra HRC
(Gladstone et al.)
UV: HST STIS (Clarke et al.)
Optical: HST (Beebe et al.)
Jupiter – *XMM-Newton*, 2003: EPIC

- OVII (0.55–0.60 keV)
- FeXVII (0.70–0.75, 0.80–0.85)
- 3–5 keV
- 5–10 keV

*B-R et al. 2007*
Jupiter – *XMM-Newton*, 2003: EPIC

Jupiter’s auroral and disk spectra

B-R et al. 2007
**Jupiter – Athena X-IFU simulation**

**XMM-Newton RGS – 210 ks**

**Athena X-IFU – 20 ks**

- Extended wavelength range
- 2 orders of magnitude higher effective area
- Non-dispersive spectroscopy
- Solar wind conditions from propagations from 1 AU, or JUICE!

*B-R et al. 2007*

*B-R et al. 2013*
Chandra ACIS reveals different spatial morphology of soft (< 2 keV, ion CX) and hard (> 2 keV, electron bremsstrahlung) X-ray events

→ CX X-ray events map far out from the planet

Simultaneous Hubble STIS images show > 2 keV events coincide with FUV auroral oval and bright features (FUV from excitation of atmospheric H₂ and H by 10 - 100 keV electrons)

→ Same energetic electrons responsible for both, UV and X-rays
Chandra ACIS polar projections in System III:

- **Red** 0.2 – 0.7 keV (CX)
- **Green** 0.7 – 1.5 keV (solar)
- **Blue** > 1.5 keV (brems.)

Dunn et al. in prep. (with help by R. Elsner)
X-rays from the Galilean satellites and the IPT

Io and Europa X-rays (*Chandra* ACIS) from energetic H, O and S ion impacts $\rightarrow$ fluorescence

Non-thermal electron bremsstr. + OVII em. from Io Plasma Torus

*Elsner et al. 2002*
On Saturn …

- Disk and polar cap X-ray emissions (unlike Jupiter) have similar coronal-type spectra

- Flux variability suggests X-ray emission is controlled by the Sun

- Fluorescent O-Kα line

- Scattering of solar X-rays on atomic oxygen in H₂O icy ring material

_Bhardwaj et al. 2005a_
3σ upper limits on auroral X-rays:

- 0.3 – 2.0 keV SWCX, 3 MW
- 2.0 – 8.0 keV bremsstrahlung, 23 MW

Caveat:
SW propagation uncertainty → CME arrival & possible auroral X-ray emission hard to correlate

B-R et al. 2013
The Earth’s X-ray aurorae

- PIXIE experiment on *Polar*: >2 keV electron bremsstrahlung
- *Chandra* HRC/DMSP F13 electron measurements: auroral electron bremsstrahlung and N & O line emission below 2 keV, very variable

**Apogee over North Pole**

*Ostgaard et al. 2001*

*Chandra Earth X-rays – January 24, 2004*

*Bhardwaj et al. 2006*
The Earth’s geocorona

- LTE of the ROSAT All Sky Survey ¼ keV background
- Time variable O emission lines on the dark side of the Moon
  Correlation with solar wind flux → SWCX in Earth’s geocorona
- Suzaku observations of the NEP: Increase in soft X-ray lines correlated with solar wind proton flux
- Systematic study with XMM-Newton
  Carter et al. 2008, 2010
- AXIOM concept mission: image Earth’s dayside magnetosphere in soft X-rays

Optical

XMM-Newton

Dennerl et al. 2003
Comet C/2000 WM1: combined RGS + EPIC pn spectrum

Dennerl et al., priv. comm.
Looking ahead ...

- *Chandra* and *XMM-Newton* combined have demonstrated the potential of planetary X-ray astronomy, establishing

  → planetary response (including Earth’s) to solar stimulation

  → CX as the process that provides global and remote X-ray diagnostics of astrophysical plasma interactions (also in ISM, stellar winds, galaxies, clusters)

- Observations at times of *enhanced solar activity* likely to return the most science

- Ultimate goal: X-ray observations *in-situ at the planets*, to provide necessary sensitivity and spatial/energy resolution and establish X-rays on a par with other wavebands!
Thank you!