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

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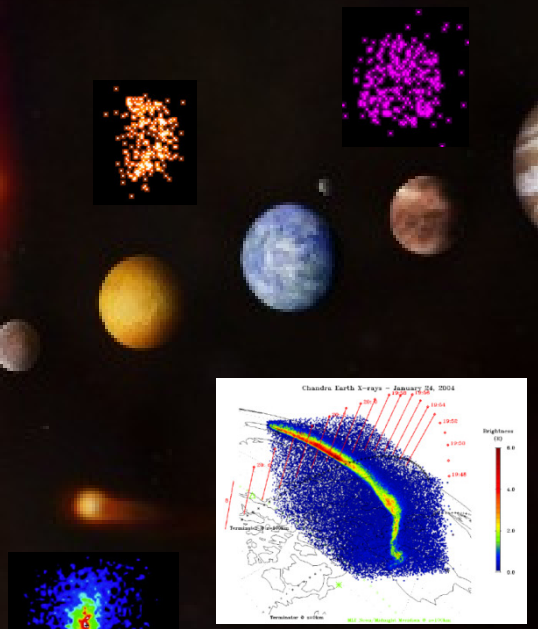
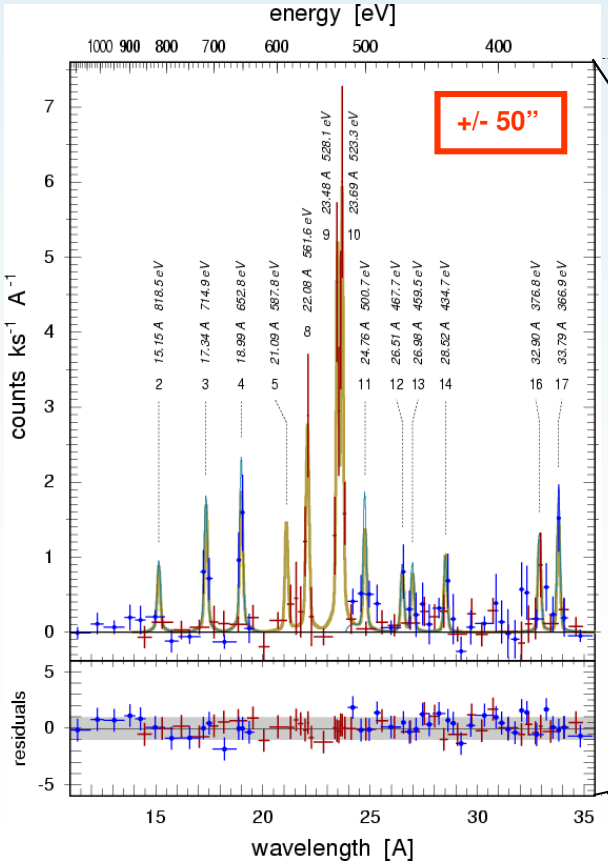


… reporting work by
K. Dennerl, C. Lisse, R. Gladstone,
A.Bhardwaj, R. Elsner, H. Waite, T. Cravens, …

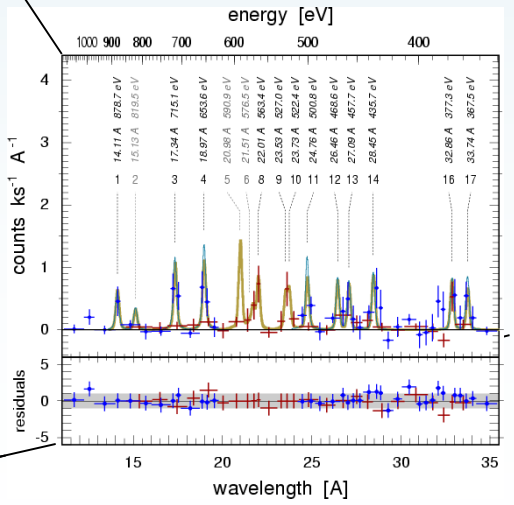
The X-ray Universe, 16 – 19 June 2014
Dublin, Ireland

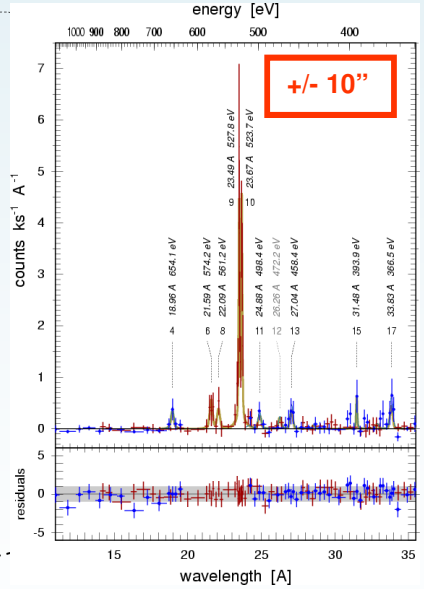
Mars disk and exosphere (halo): *XMM-Newton* RGS

- Fluorescent scattering of solar X-rays in CO_2 atmosphere
- Solar wind charge exchange (SWCX) in the exosphere

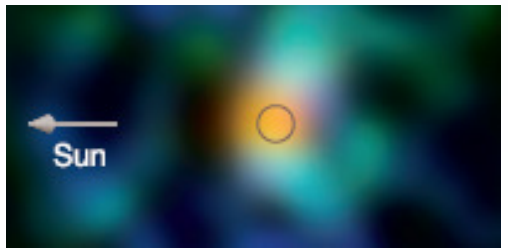


- 50” to - 15” and + 15” to + 50”



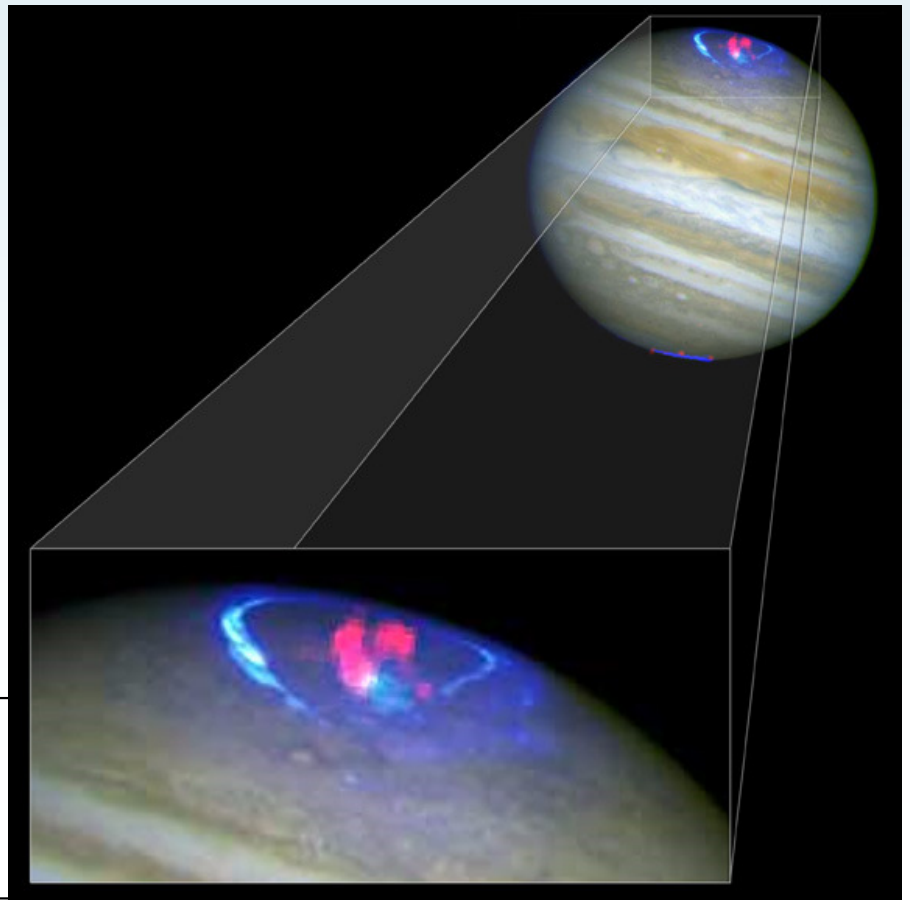


Dennerl et al. 2006



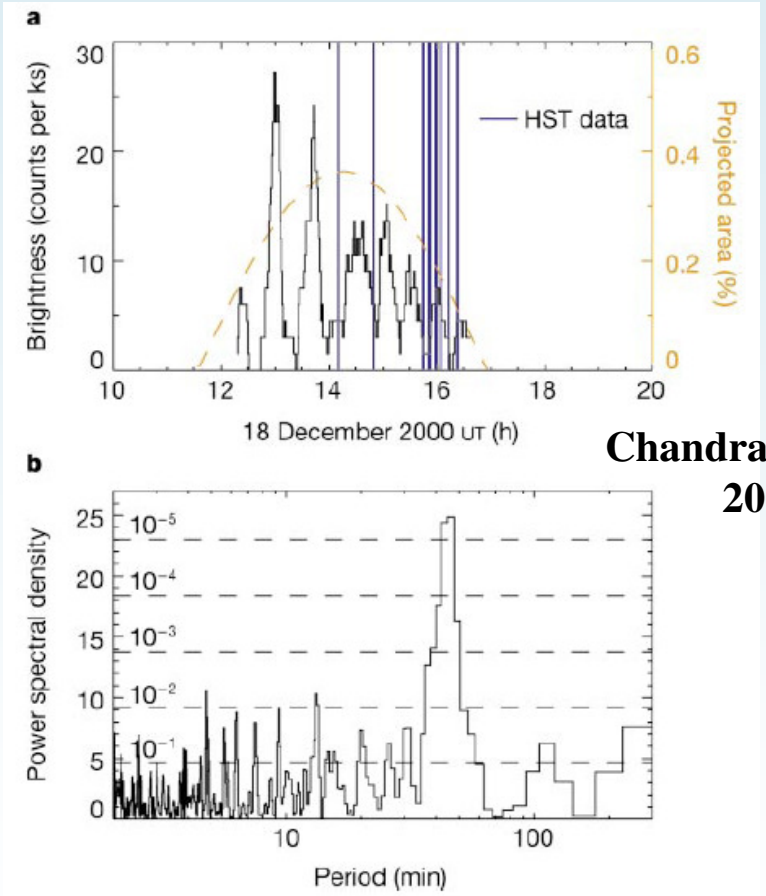
Soft X-rays (0.2 – 1 keV) from Jupiter's aurorae

- 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 ***Gladstone et al. 2002***
- What are the ion species (C or S) and thus their origin (solar wind / magnetosphere)?
- Recent *XMM-Newton* & *Chandra* spectra favour a magnetospheric origin ***B-R et al. 2007, Hui et al. 2010***
- Relative roles?



X-ray: Chandra HRC (*Gladstone et al.*)
UV: HST STIS (*Clarke et al.*)
Optical: HST (*Beebe et al.*)

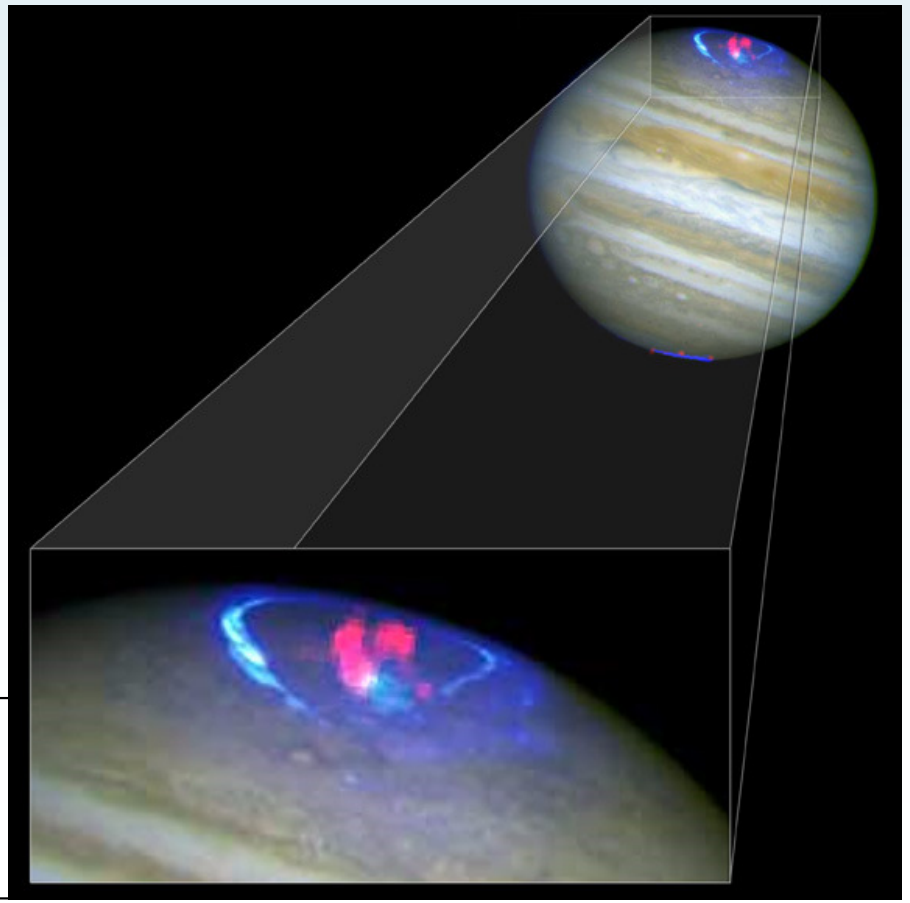
Jupiter pulsating X-ray hot spot



Gladstone et al. 2002

~ 45 min periodicity in the X-ray flux

Chandra HRC-I
2000



X-ray: Chandra HRC (*Gladstone et al.*)
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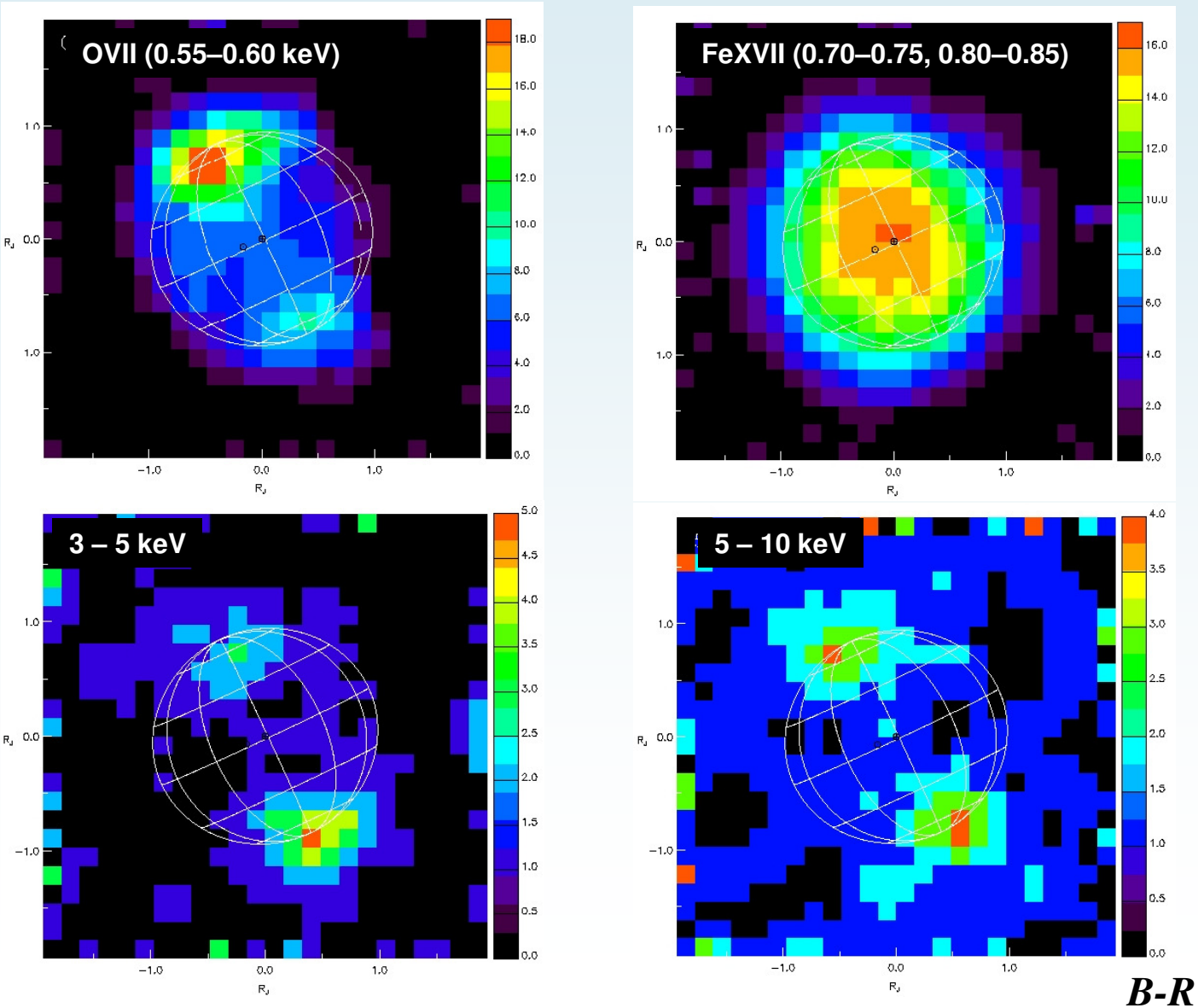
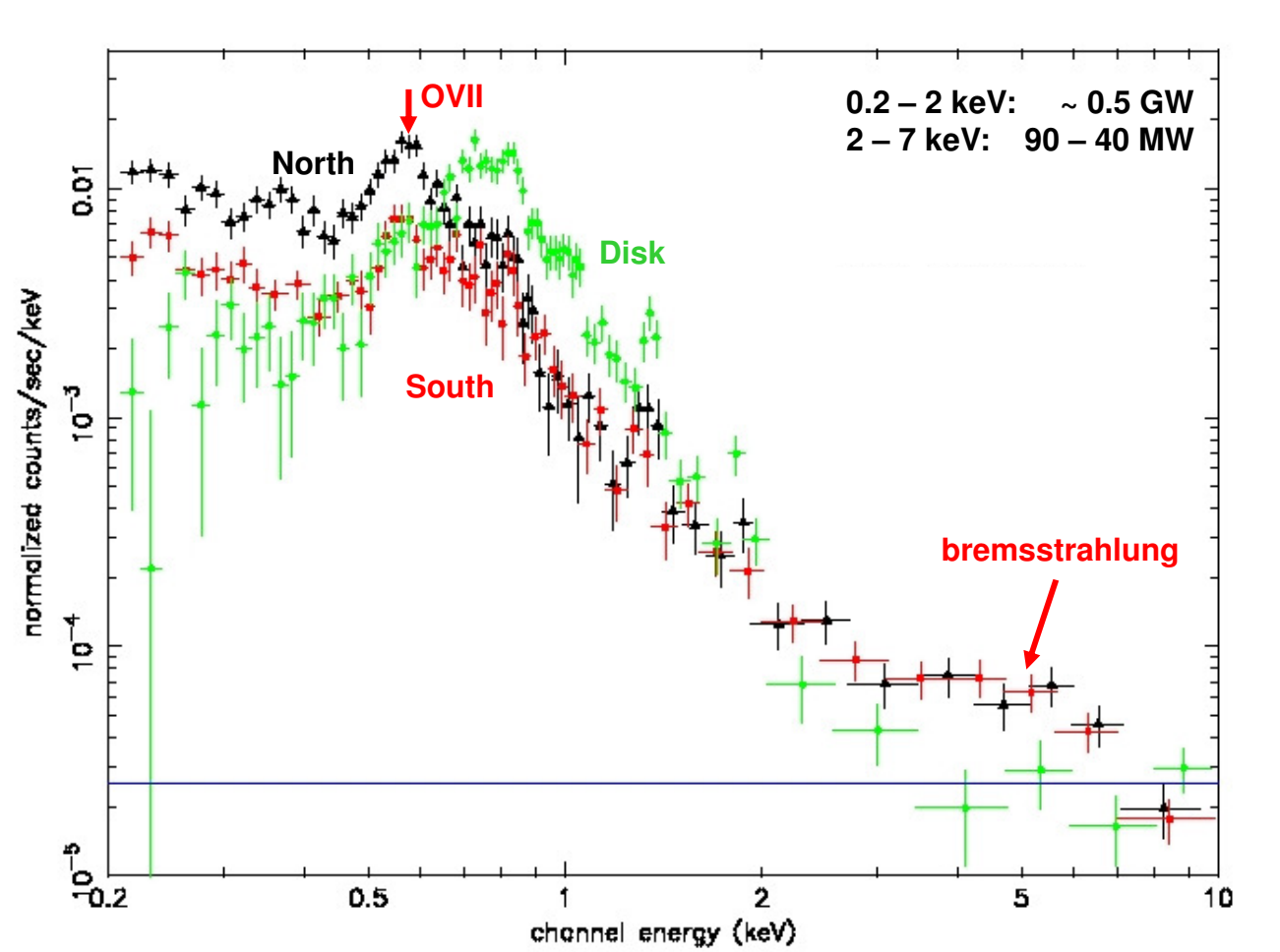
Jupiter – *XMM-Newton*, 2003: EPIC



B-R et al. 2007

Jupiter – *XMM-Newton*, 2003: EPIC

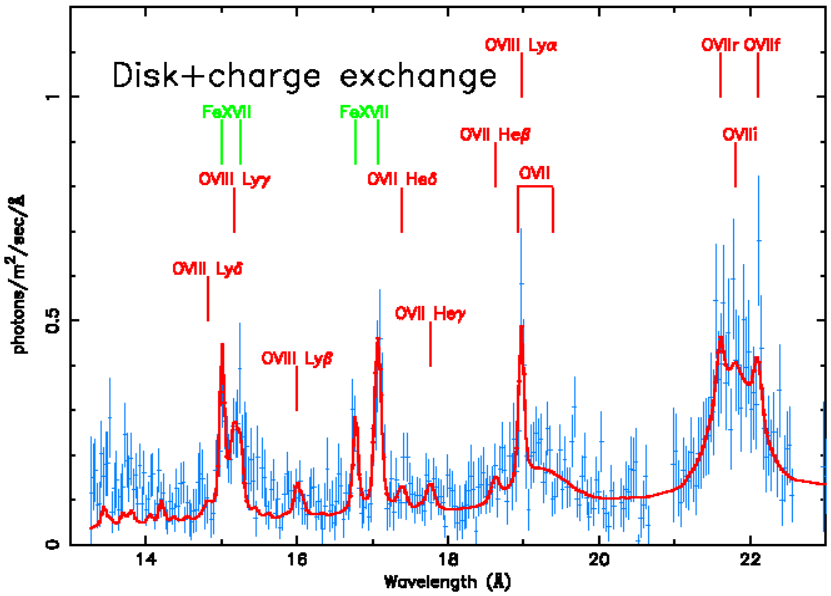
Jupiter's auroral and disk spectra



B-R et al. 2007

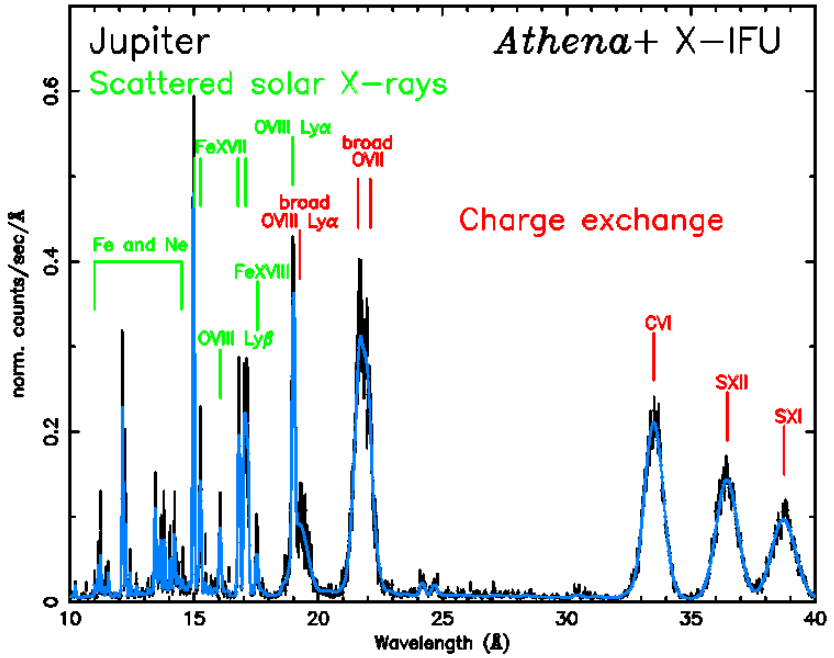
Jupiter – *Athena* X-IFU simulation

***XMM-Newton* RGS – 210 ks**



B-R et al. 2007

***Athena* X-IFU – 20 ks**



B-R et al. 2013

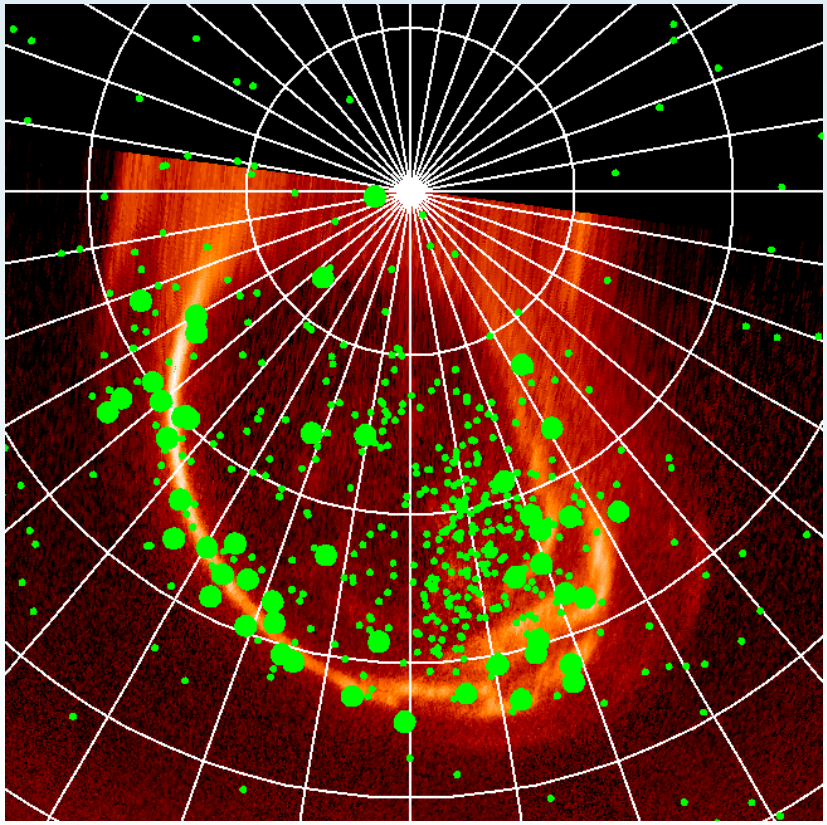
- **Extended wavelength range**
- **2 orders of magnitude higher effective area**
- **Non-dispersive spectroscopy**
- **Solar wind conditions from propagations from 1 AU, or JUICE!**

Jupiter – *Chandra* and *Hubble* STIS – 2003

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

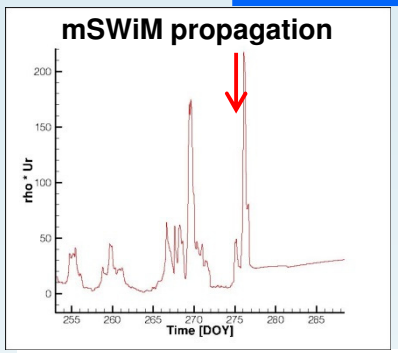
Simultaneous Hubble STIS images show > 2 keV events coincide with FUV auroral oval and bright features (FUV from excitation of atmospheric H_2 and H by 10 - 100 keV electrons)



B-R et al. 2008

→ Same energetic electrons responsible for both, UV and X-rays

Jupiter – *Chandra* TOO – Oct. 2011

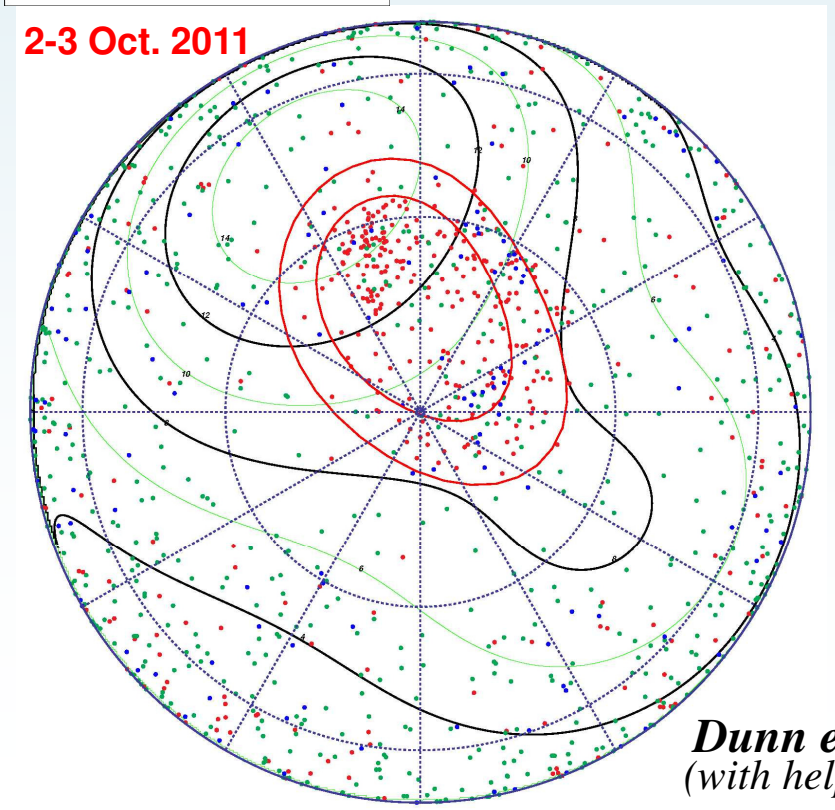


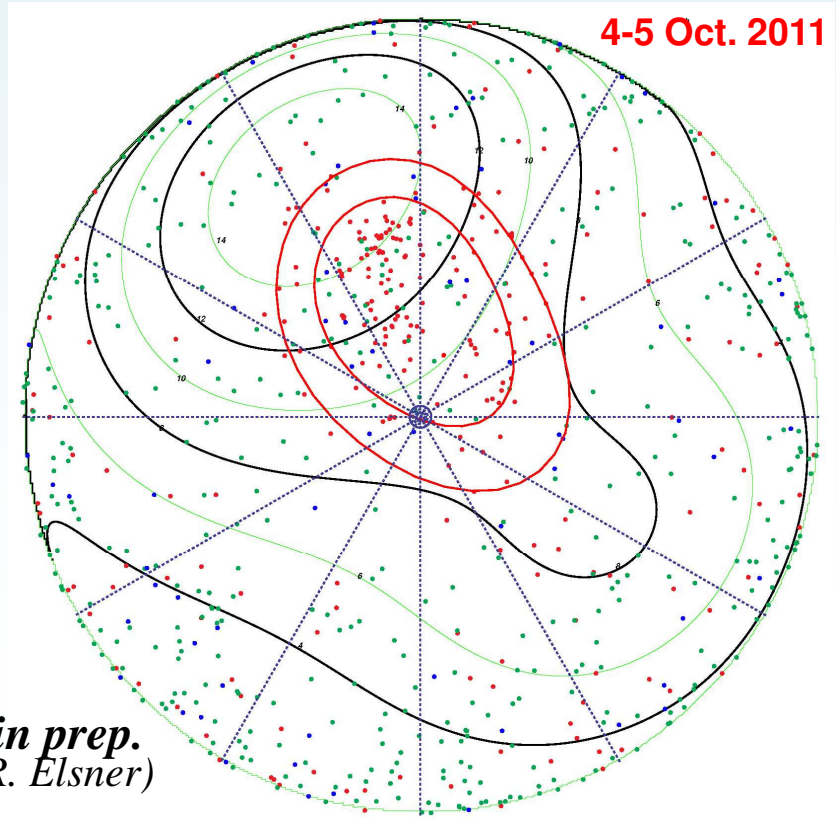
Chandra ACIS polar projections in System III:

Red 0.2 – 0.7 keV (CX)

Green 0.7 – 1.5 keV (solar)

Blue > 1.5 keV (bremss.)

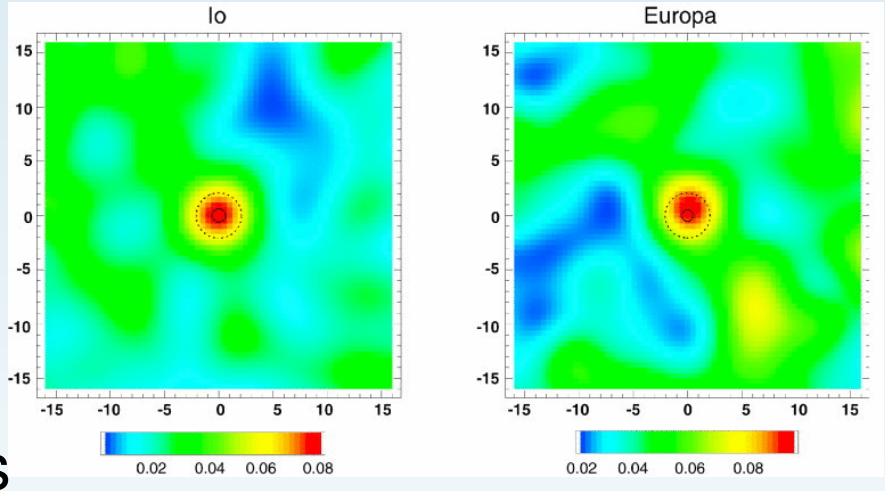




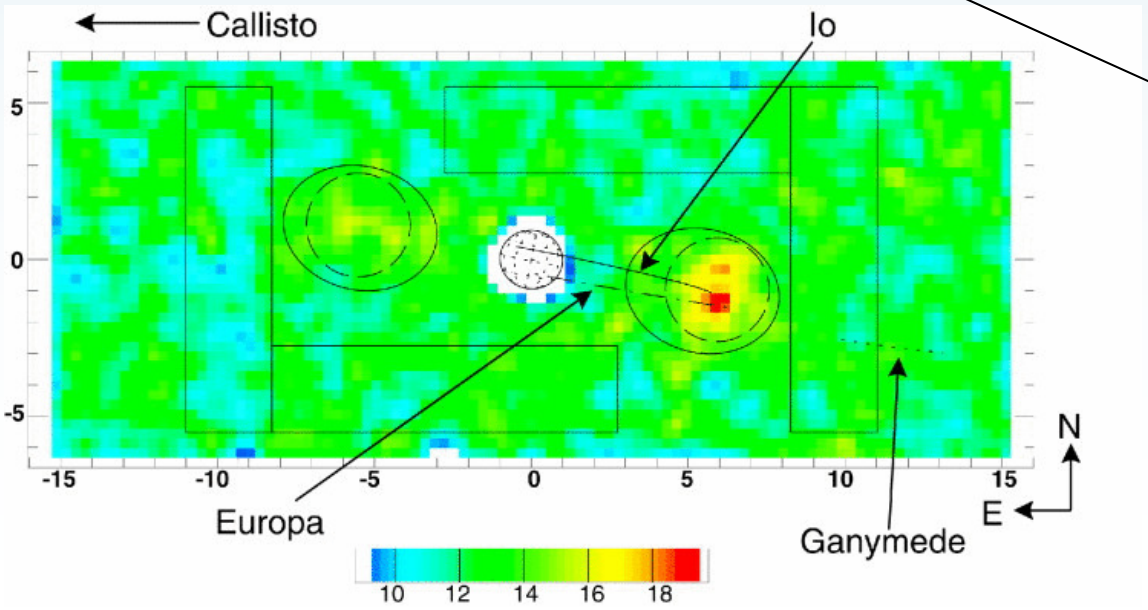
Dunn et al. in prep.
(with help by R. Elsner)

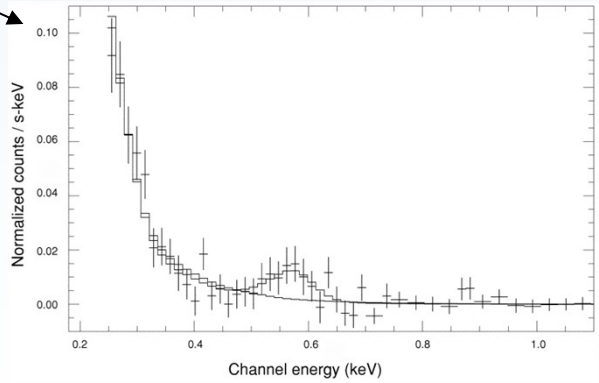
X-rays from the Galilean satellites and the IPT

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



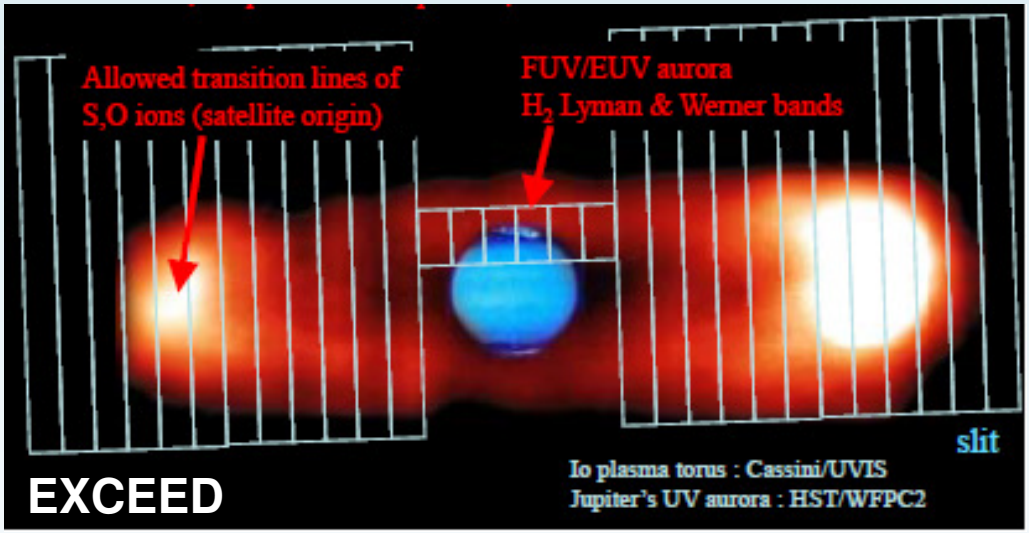
Non-thermal electron bremsstr.
+ OVII em. from Io Plasma Torus





Elsner et al. 2002

Hisaki / EXCEED + observing campaign



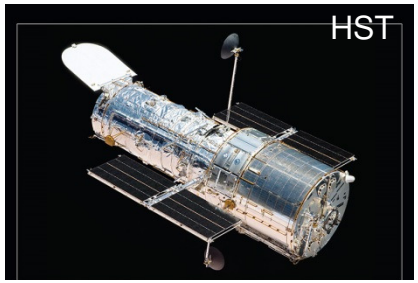
Tsuchiya et al. 2011

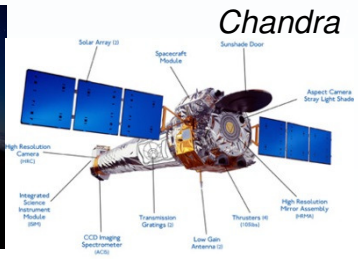
Nov. 2013 - Feb. 2014
HST (FUV)

1-14 Jan. 2014
HST (FUV)
Gemini & IRTF (IR)
Kitt Peak (Visible)

Feb.-March 2014
Subaru

9-20 April
Chandra/XMM-Newton
Suzaku
IRTF



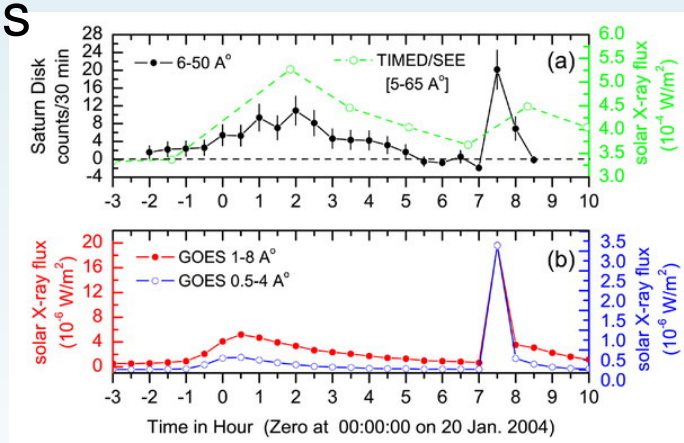


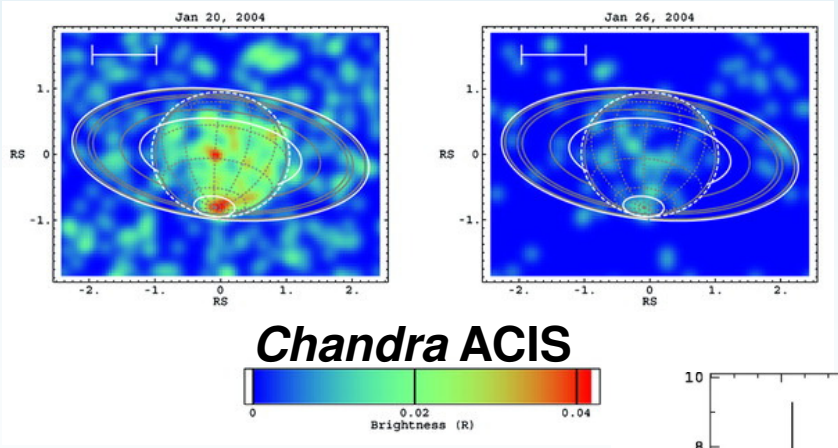
On Saturn …

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

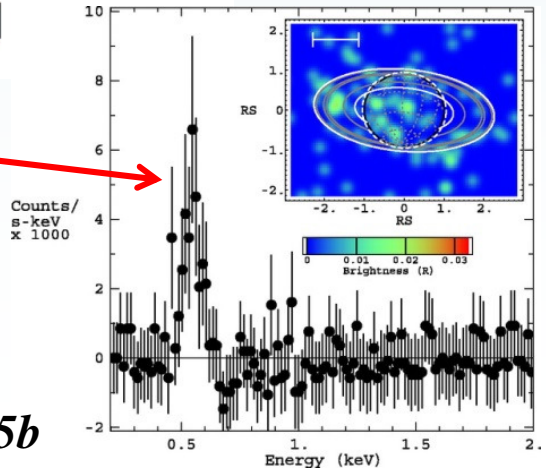
Bhardwaj et al. 2005a

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

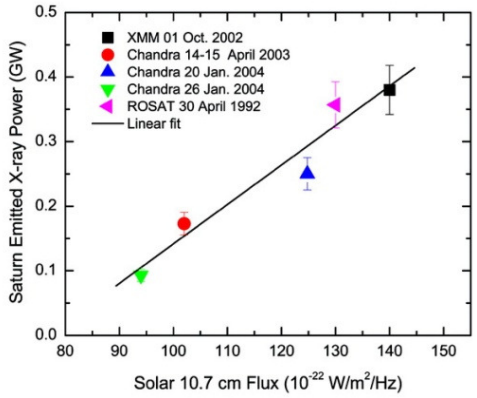




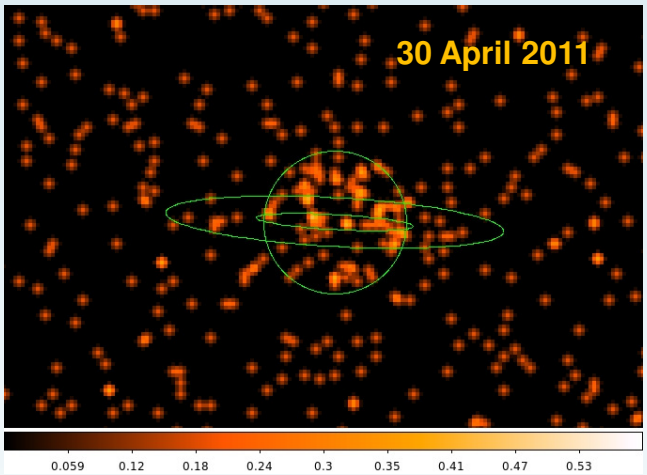
- Fluorescent O-Kα line
- Scattering of solar X-rays on atomic oxygen in H_2O icy ring material



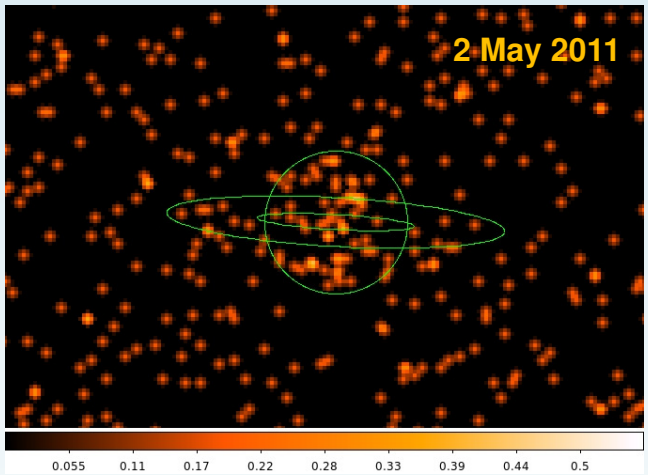
Bhardwaj et al. 2005b



Saturn – *Chandra* TOO – April-May 2011



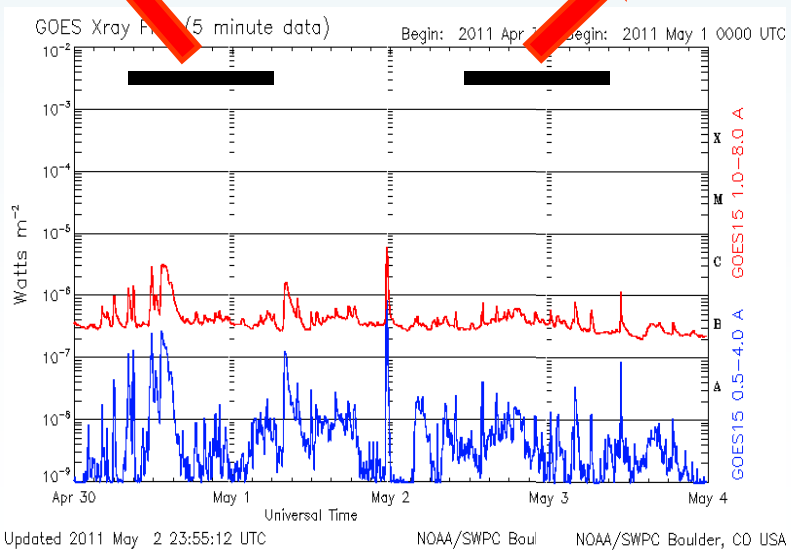
***Chandra* ACIS**



3σ upper limits on auroral X-rays:

0.3 – 2.0 keV SWCX, 3 MW

2.0 – 8.0 keV bremsstrahlung, 23 MW



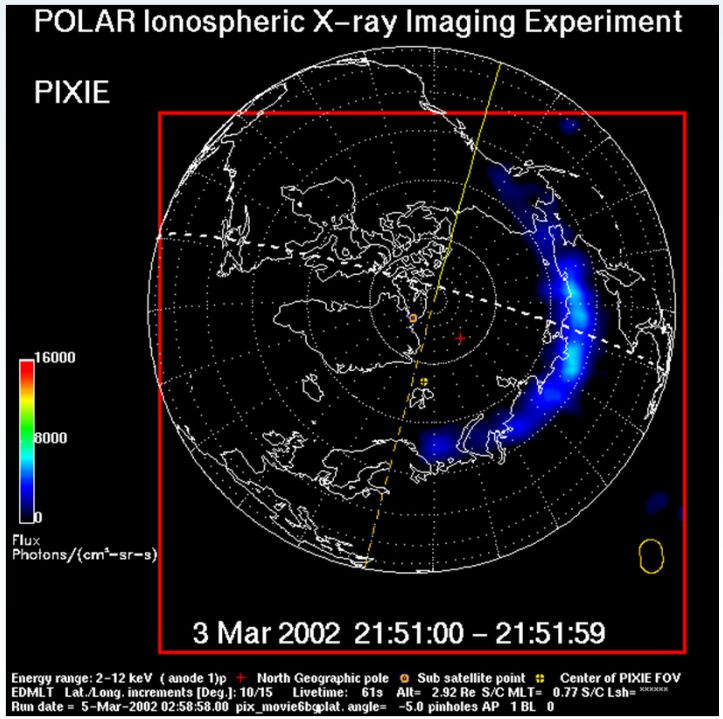
Caveat:
SW propagation uncertainty → CME arrival & possible auroral X-ray emission hard to correlate

B-R et al. 2013

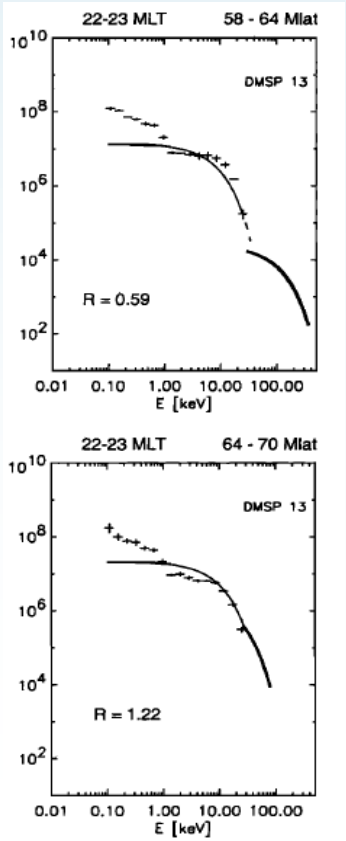
The Earth's X-ray aurorae

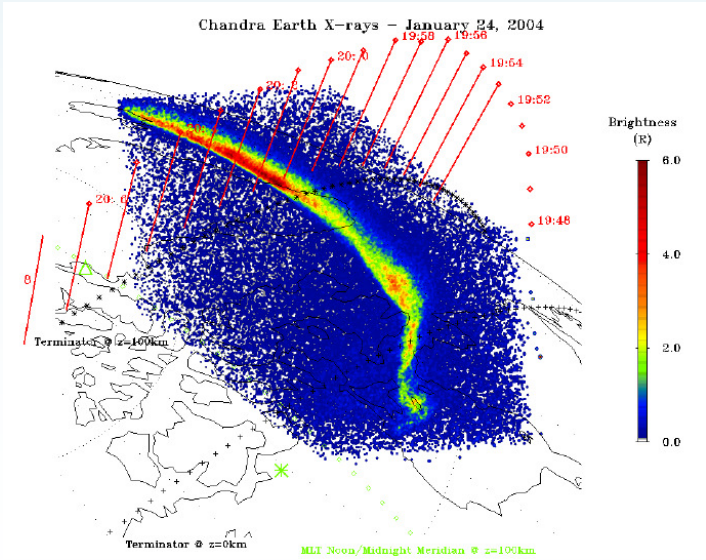
- PIXIE experiment on *Polar* : > 2 keV electron bremsstrahlung
- *Chandra* HRC/DMSP F13 electron measurements: auroral electron bremsstrahlung and N & O line emission below 2 keV, very variable

Apogee over North Pole



Ostgaard et al. 2001





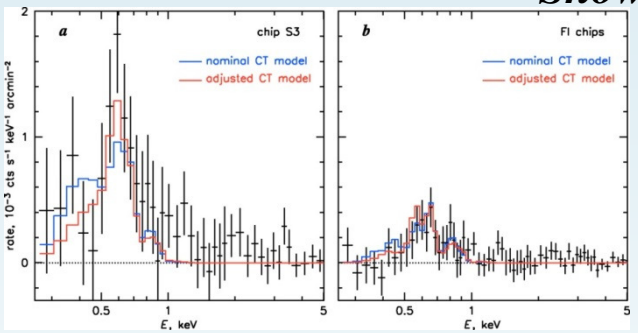
Bhardwaj et al. 2006

The Earth's geocorona

- LTE of the *ROSAT* All Sky Survey ¼ keV background

Snowden et al. 1995

- Time variable O emission lines on the dark side of the Moon

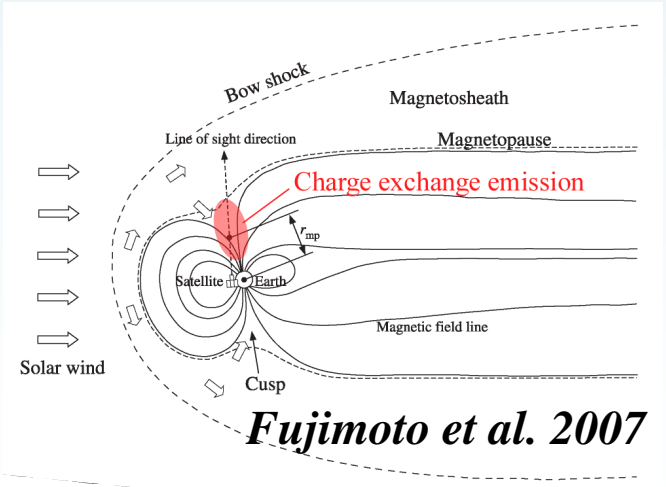


***Chandra* ACIS**

Wargelin et al. 2004

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



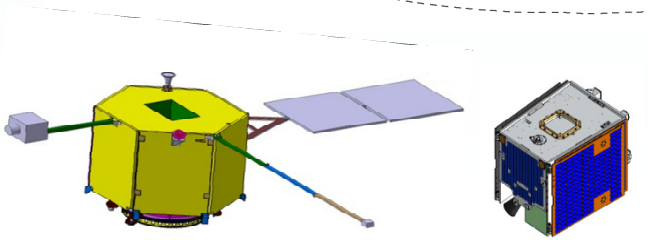
Fujimoto et al. 2007

- Systematic study with *XMM-Newton*

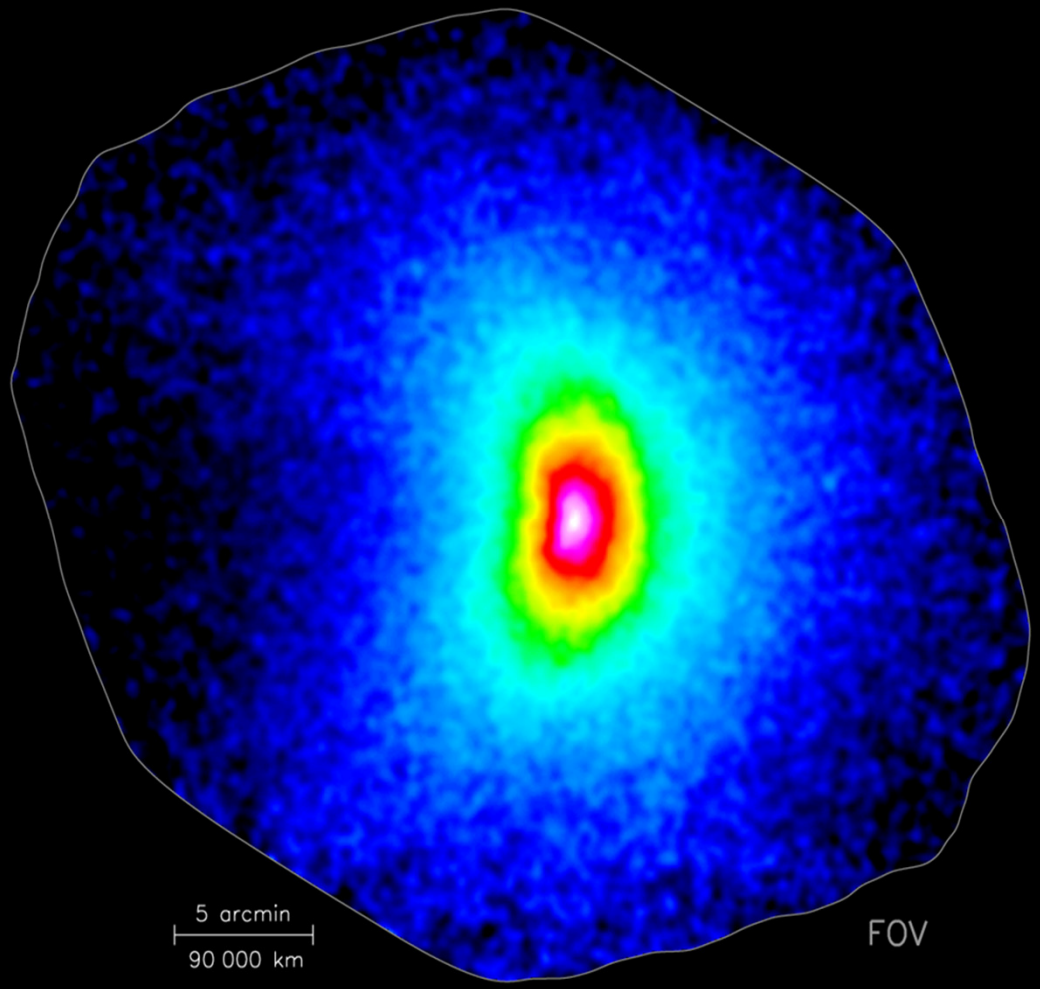
Carter et al. 2008, 2010

- *AXIOM* concept mission: image Earth's dayside magnetosphere in soft X-rays

B-R, Sembay et al. 2012



Comet C/2000 WM1, 2001 Dec. 13 – 14

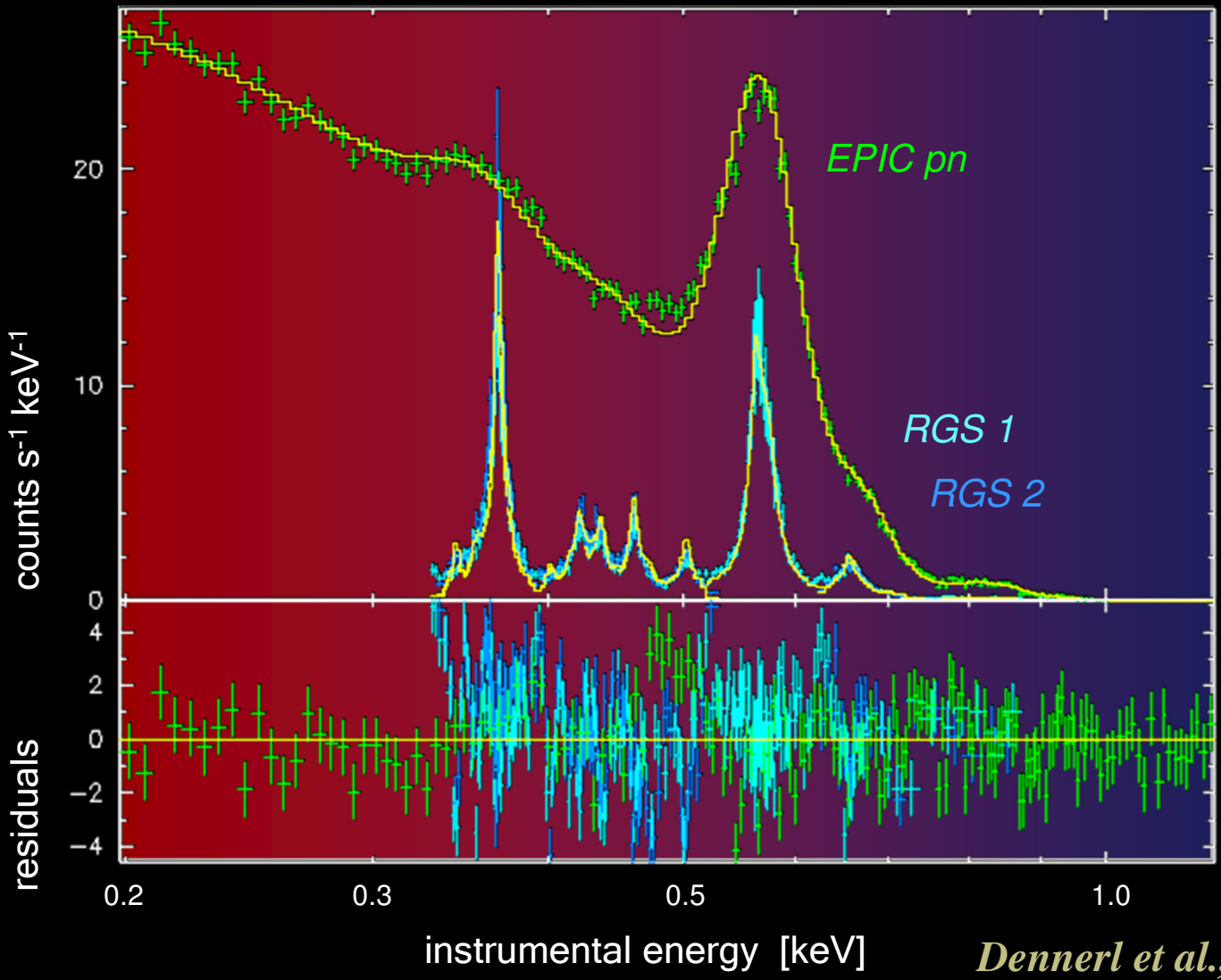


Optical

XMM-Newton

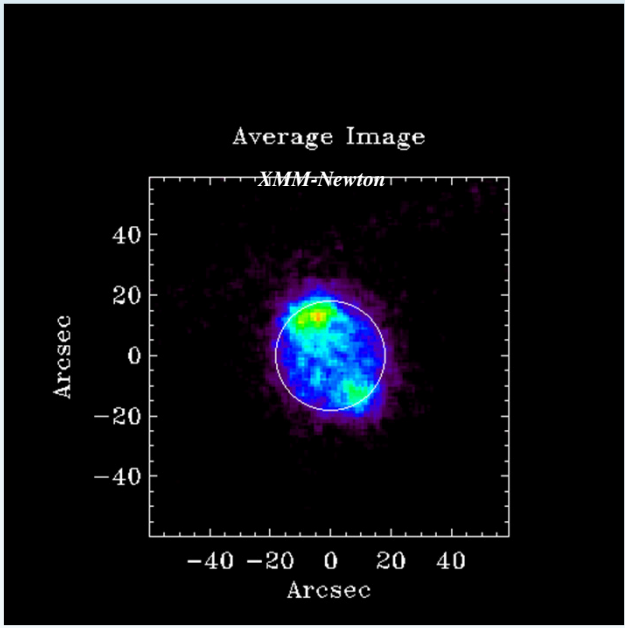
Dennerl et al. 2003

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

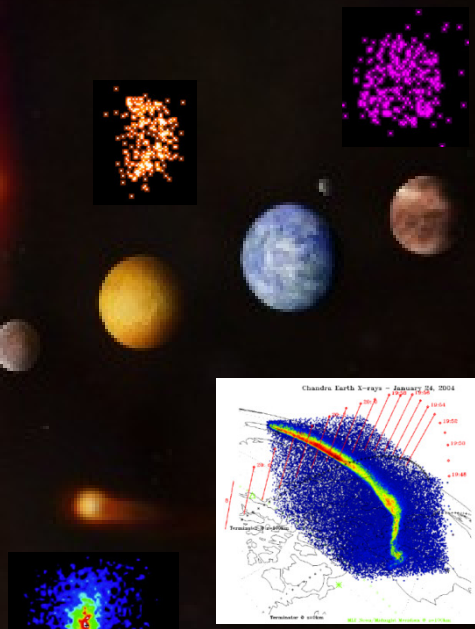
  → planetary response (including Earth's) to solar stimulation

  → 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!



The X-ray Universe 16 – 19 June 2014
Dublin, Ireland