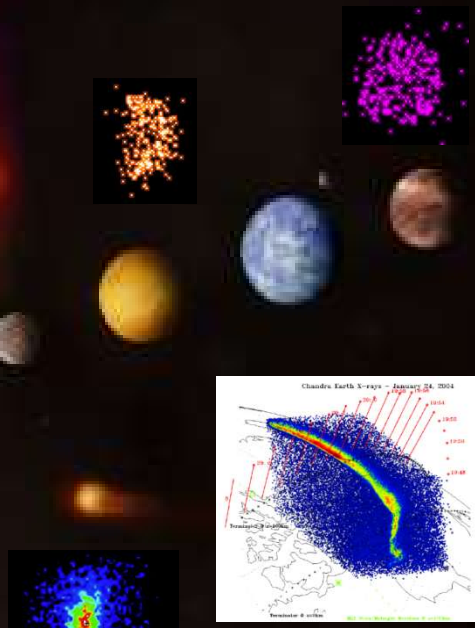
Solar system science possibilities at high spectral resolution

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



XCalibur 2019 workshop
Winchester, UK, 16 July 2019

X-ray astronomy workhorses since 1999

Exquisite spatial resolution,
CCD and grating spectroscopy
(optional)

Very large collecting area,
EPIC CCD spectroscopy and
RGS (simultaneous)

Probing solar system objects

- Global magnetospheric and auroral dynamics, mass and energy transport
- Solar wind – object interactions
- Planetary atmospheres
- Planet/satellite surface compositions

➔ **spectacular advances, in situ synergy**

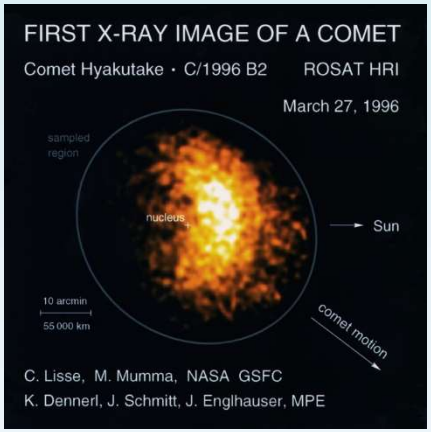
➔ **... and new questions!**

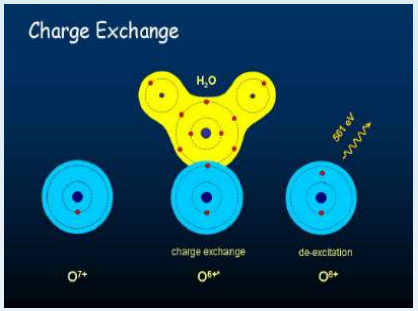
New scientific revolution enabled by future missions:
large effective area, very high spectral resolution, dispersive and not

X-ray emission mechanisms in the solar system

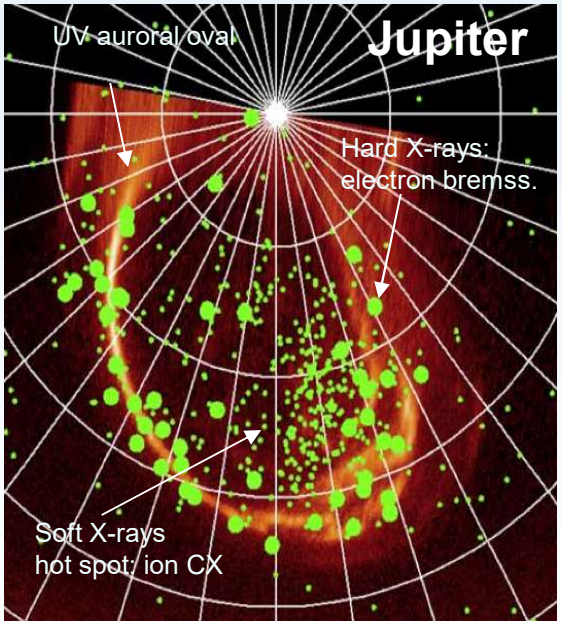
- **Charge eXchange**
- **Bremsstrahlung**
- **Elastic scattering**
- **Fluorescence**

} **of solar X-rays** (atmospheres and surfaces)

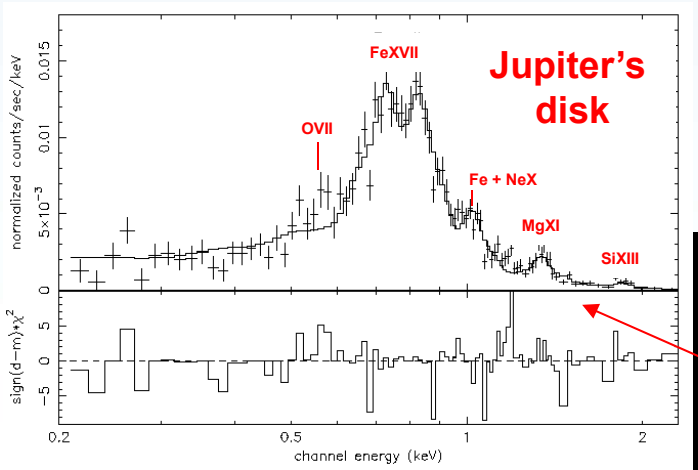




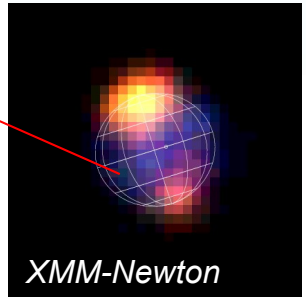
Dennerl 2009



B-R et al. 2008



B-R et al. 2007

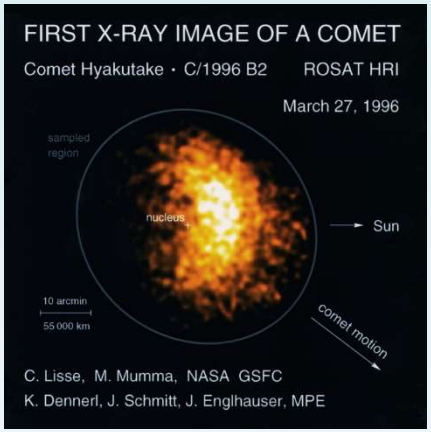


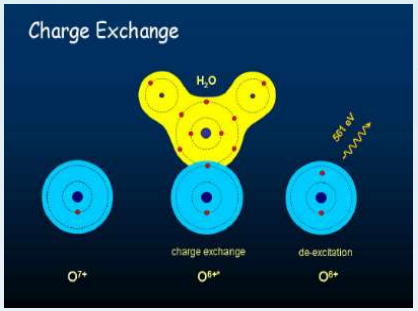
X-rays/UV probe current system
Ions origin: Io or solar wind?
Relative fractions?

X-ray emission mechanisms in the solar system

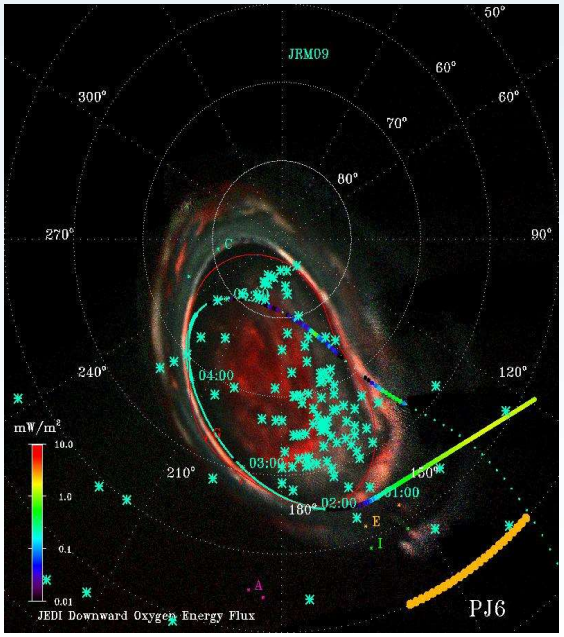
- **Charge eXchange**
- **Bremsstrahlung**
- **Elastic scattering**
- **Fluorescence**

} **of solar X-rays** (atmospheres and surfaces)

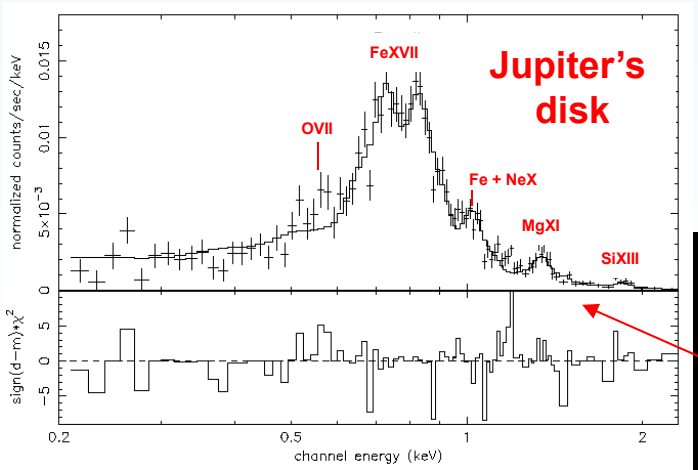




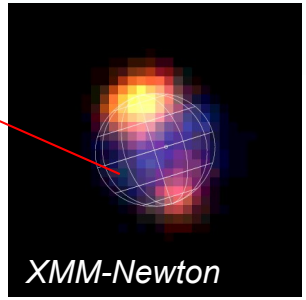
Dennerl 2009



Gladstone & Rymer, priv. comm.



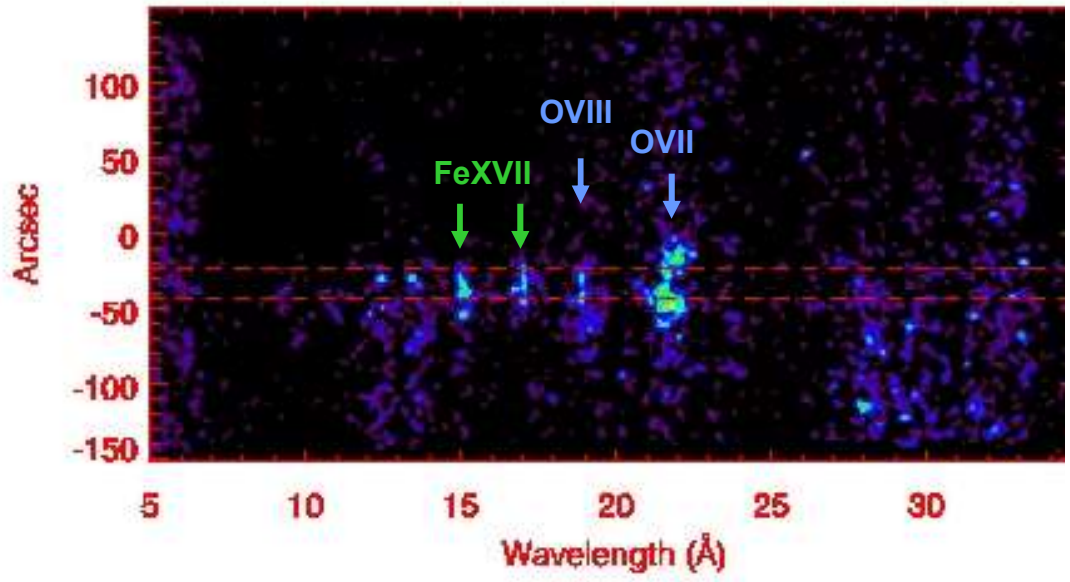
B-R et al. 2007

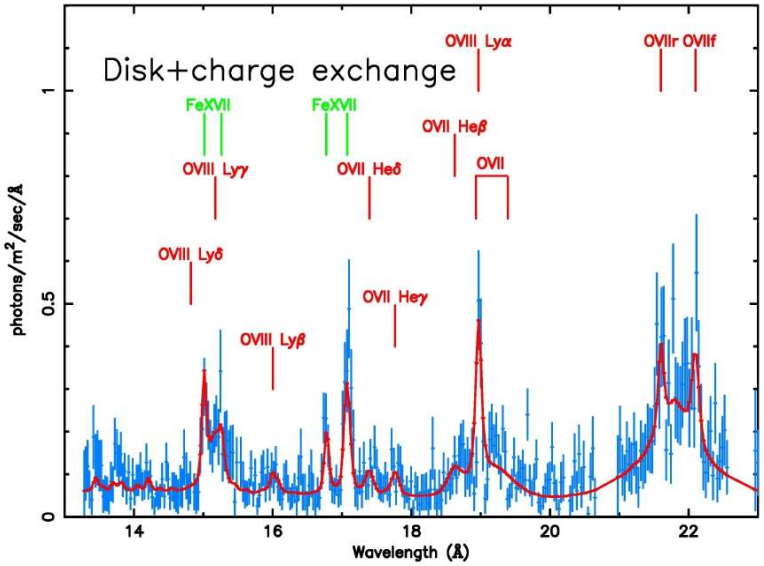


X-rays/UV probe current system
Ions origin: Io or solar wind?
Relative fractions?

Jupiter – *XMM-Newton* RGS

B-R et al. 2007



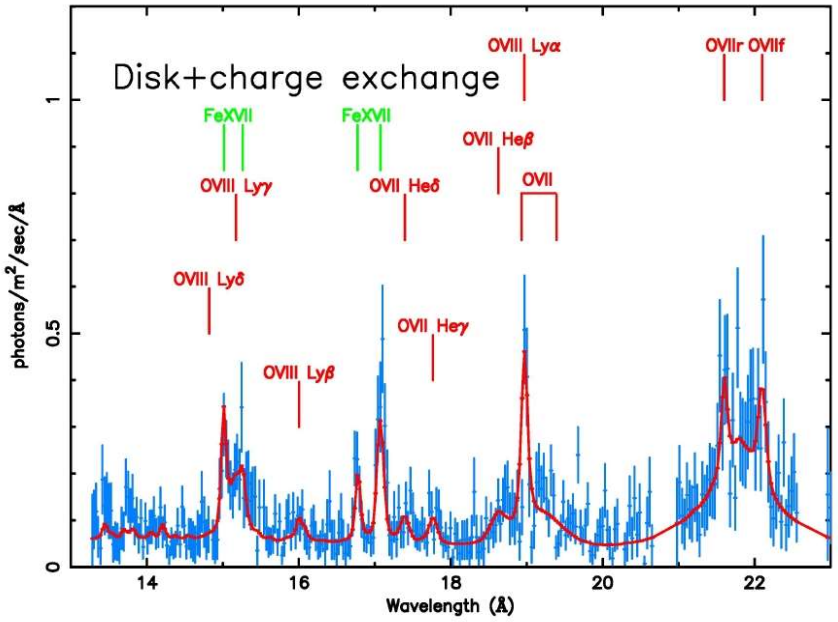


- RGS clearly resolves spectrally auroral CX from disk soft X-ray emission lines
- Width of OVII and OVIII lines corresponds to velocities of +/- 5000 km s^{-1} or energies of few MeV for O ions

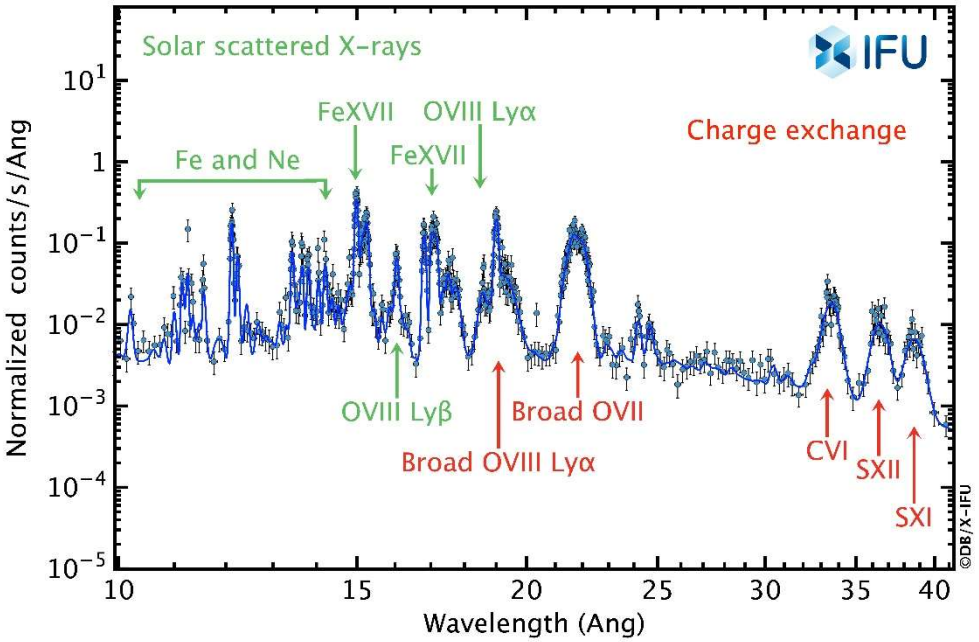
→ Probing the plasma dynamics ←→ In situ synergy

Jupiter – *Athena* X-IFU simulation

***XMM-Newton* RGS – 210 ks**



***Athena* X-IFU – 20 ks**

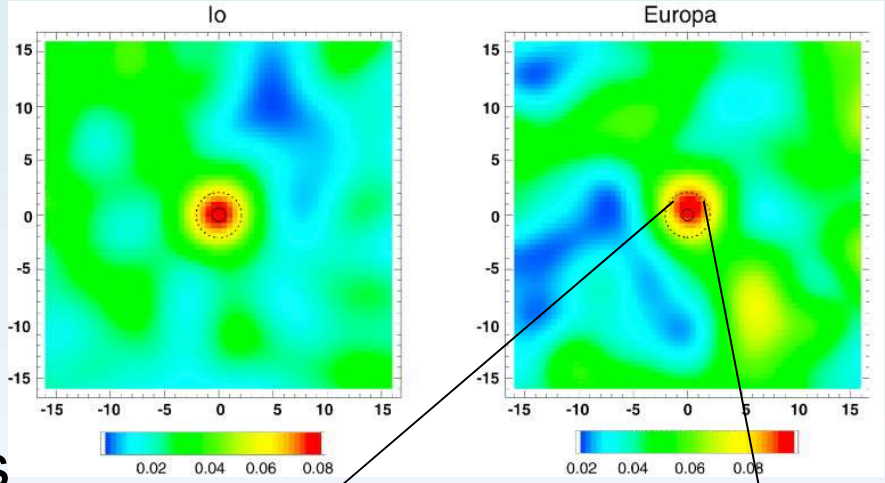


- Extended wavelength range
- 2 orders of magnitude higher effective area
- Non-dispersive spectroscopy

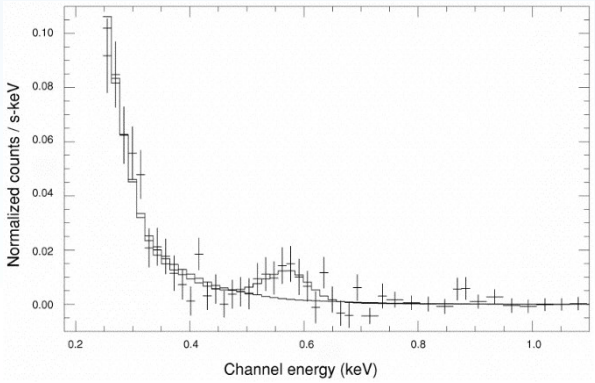
X-rays from the Galilean satellites and the IPT

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

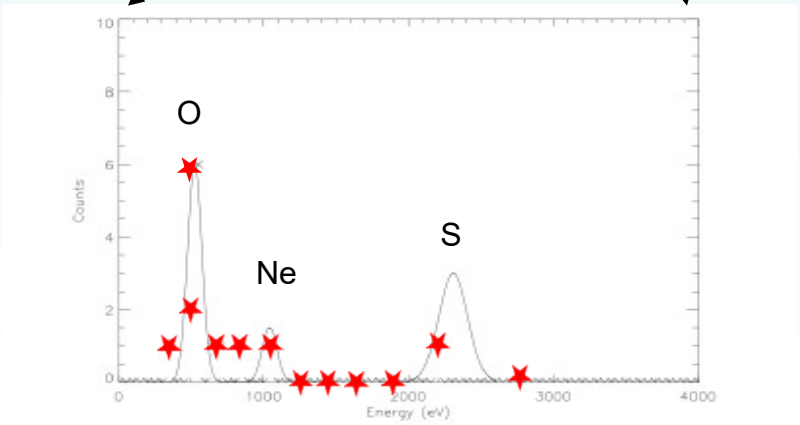
Non-thermal electron bremss.
+ OVII em. from Io Plasma Torus



Elsner et al. 2002



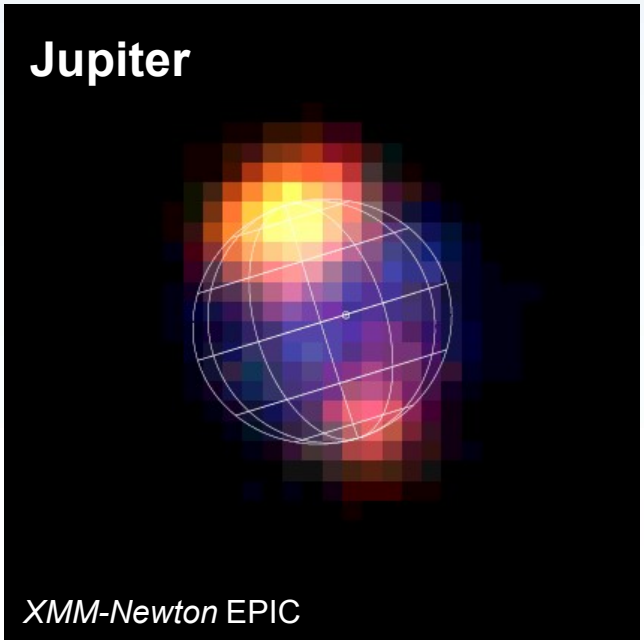
Elsner et al. 2002



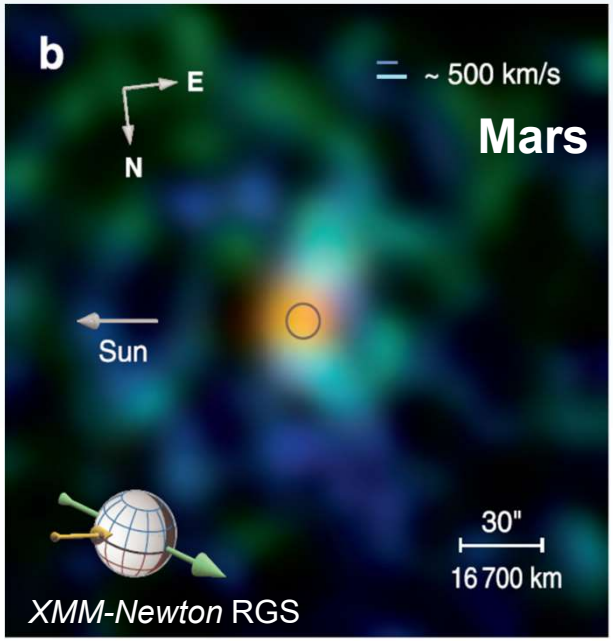
Nulsen et al. in review

How to separate spectral components …

- Jupiter's diameter 30-40", aurora ~ 10"
- Mars' disk ~14", exosphere out to 80"
- Targeting **~6" HEW angular resolution** for *ATHENA*
- There will be 'spill over' although less than in *XMM-Newton* EPIC (~16" HEW)
- **Small pixel size** for mapping small extended objects
- **Non dispersive spectral resolution** to separate components



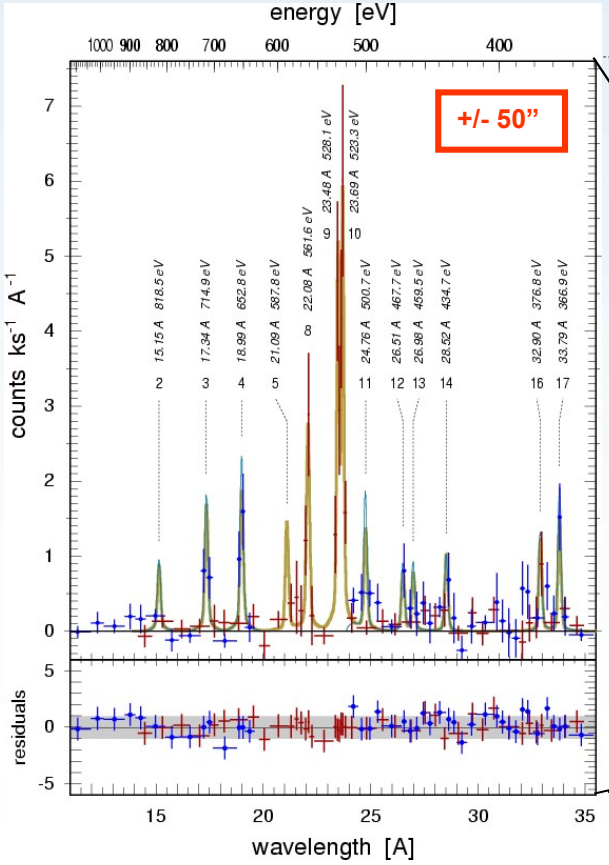
B-R et al. 2004

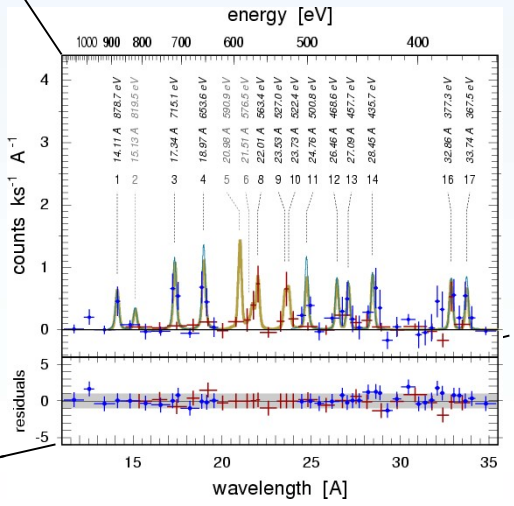


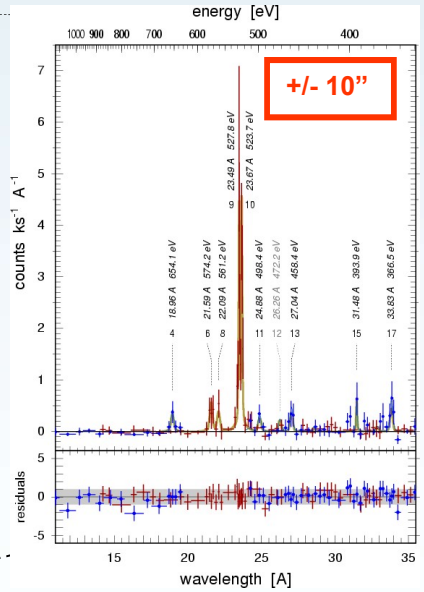
Dennerl et al. 2006

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

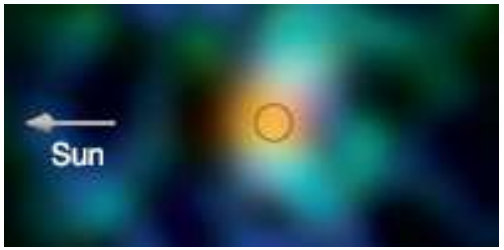
- Fluorescent scattering of solar X-rays in CO_2 atmosphere
- Solar wind charge exchange (SWCX) in the exosphere





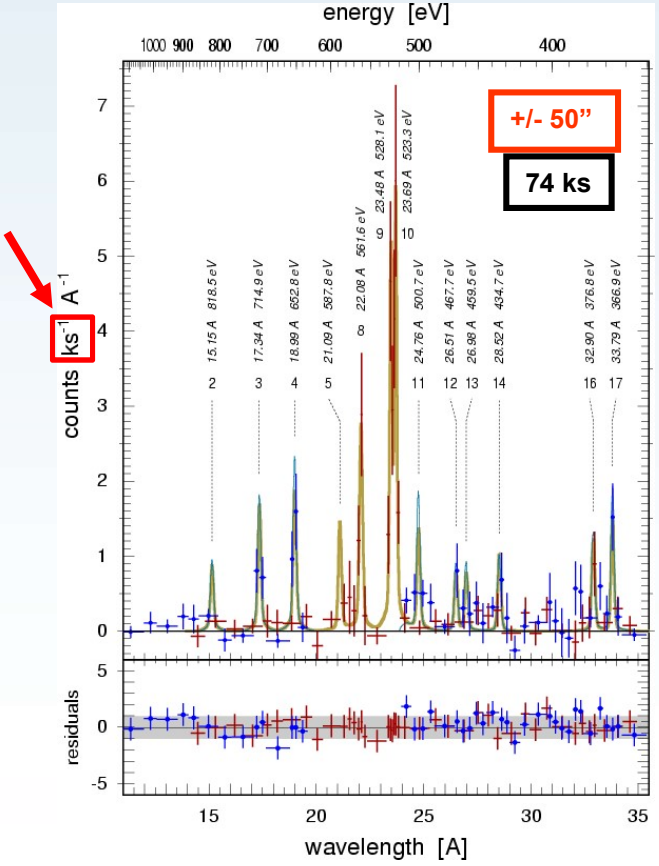


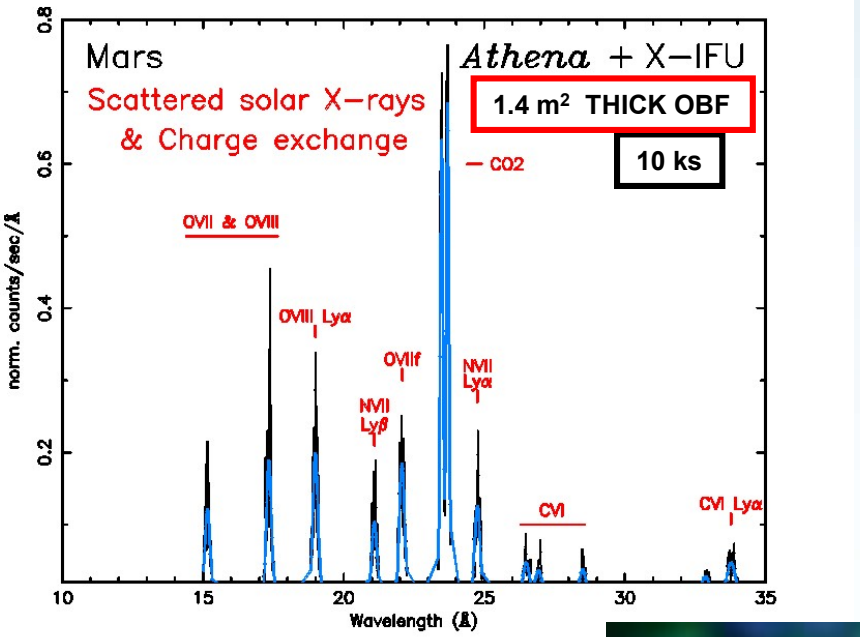
Dennerl et al. 2006

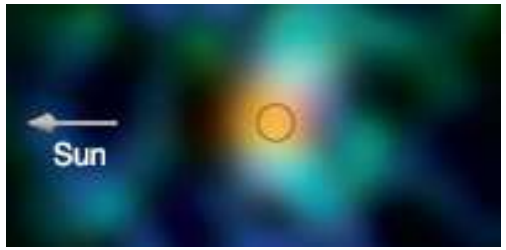


Mars disk and exosphere (halo): *Athena* X-IFU

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





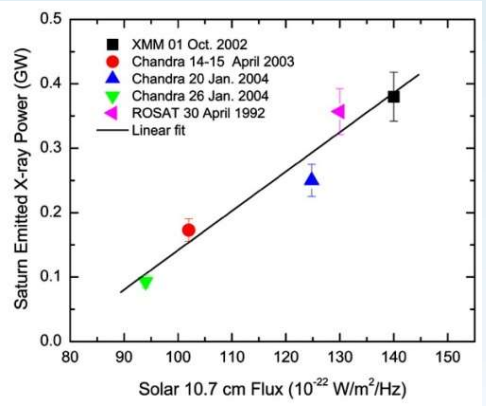


Dennerl et al. 2006

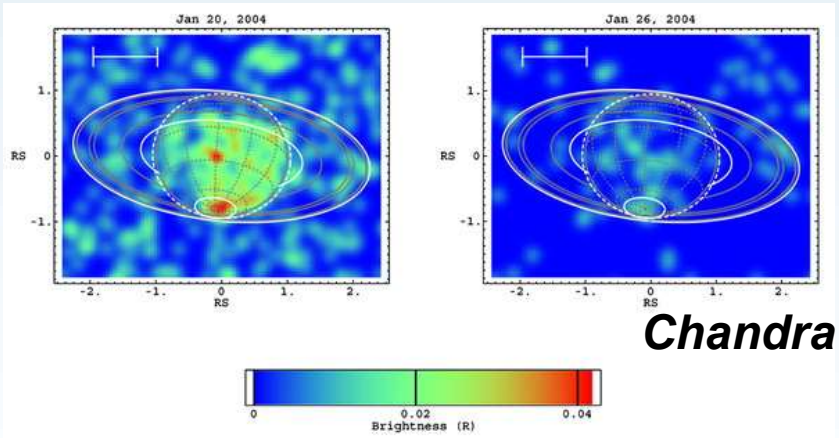
But Saturn …

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

Bhardwaj et al. 2005a

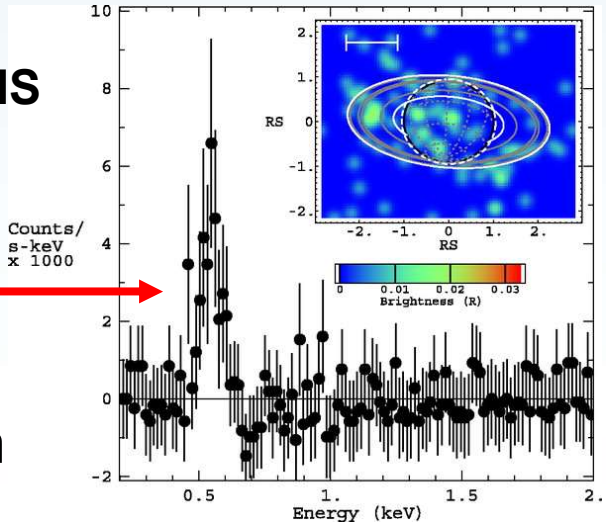


- Flux variability suggests X-ray emission is controlled by the Sun



***Chandra* ACIS**

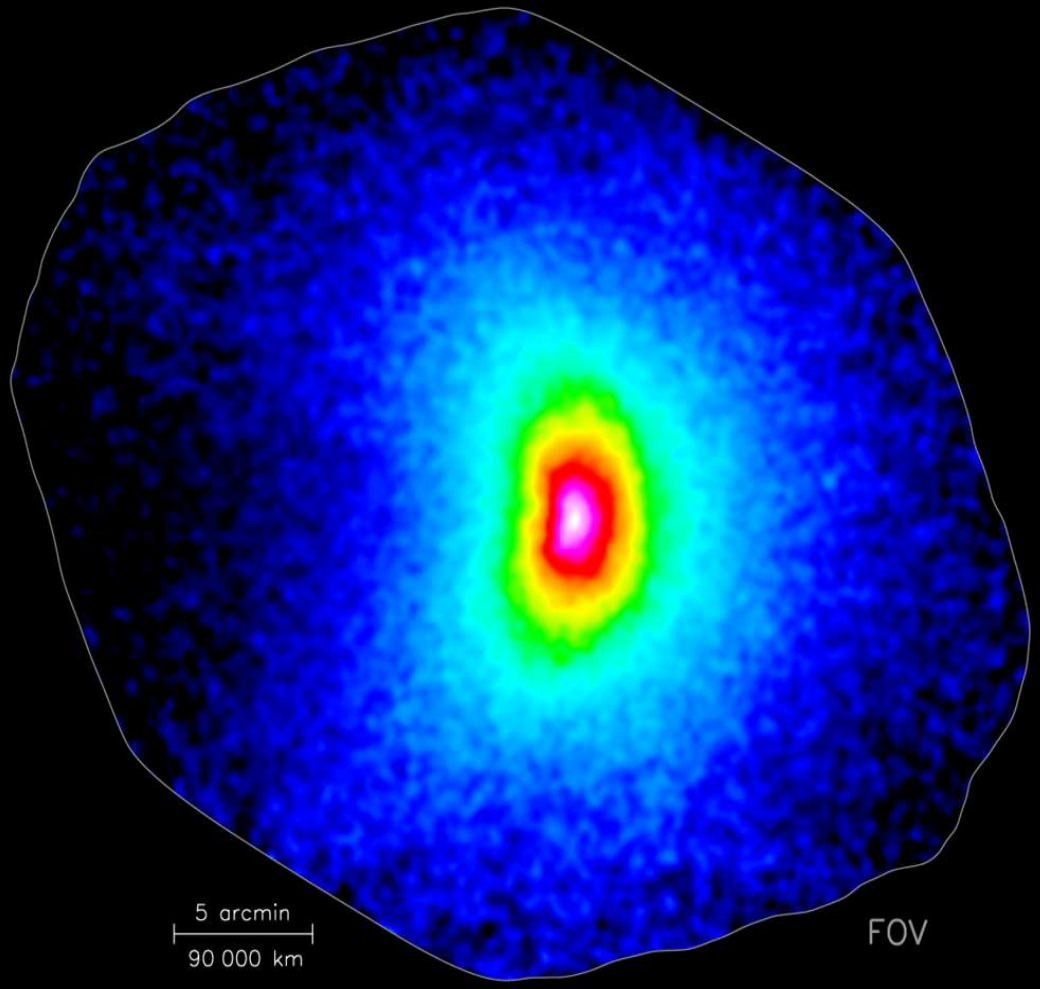
- **Rings**: 0.53 keV O-Kα fluorescent line (~1/3 of disk emission)



- Scattering of solar X-rays on atomic oxygen in H_2O icy ring material

Bhardwaj et al. 2005b

Comet C/2000 WM1, 2001 Dec. 13 – 14



Optical

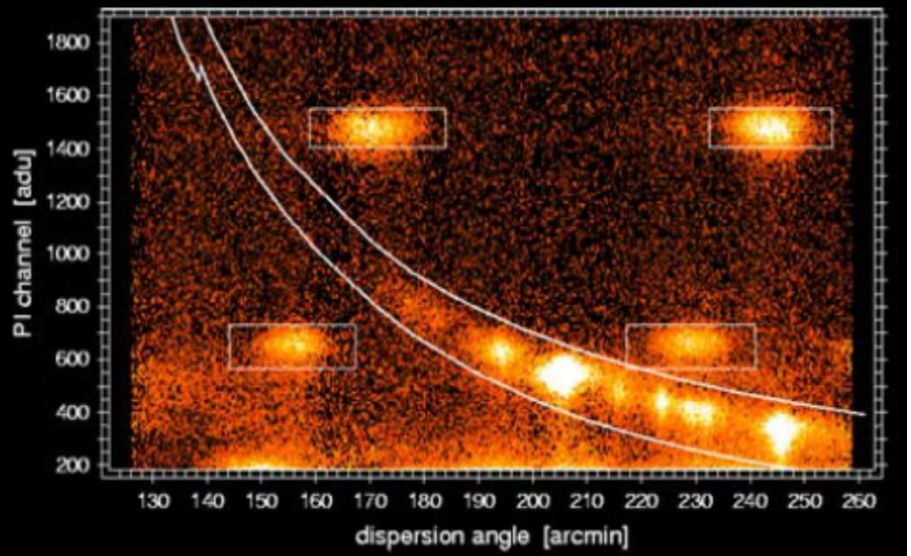
XMM-Newton

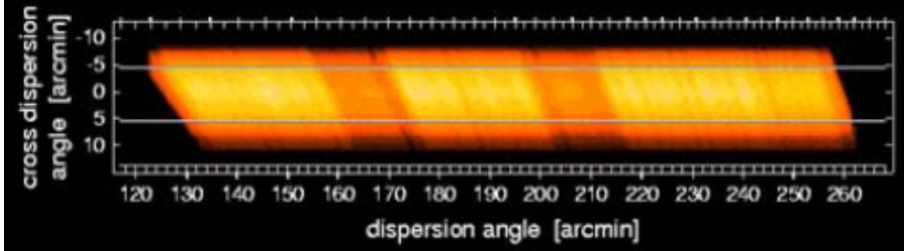
Dennerl et al. 2003

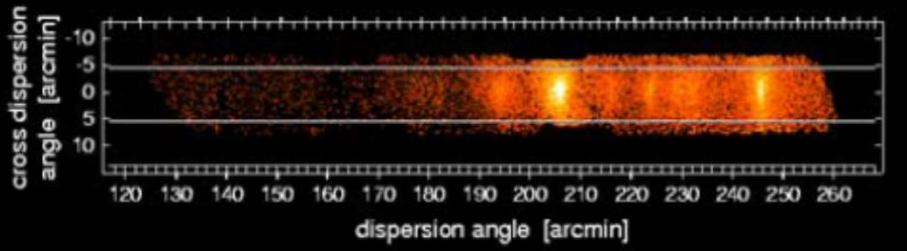
XMM-Newton observation of Comet C/2000 WM1

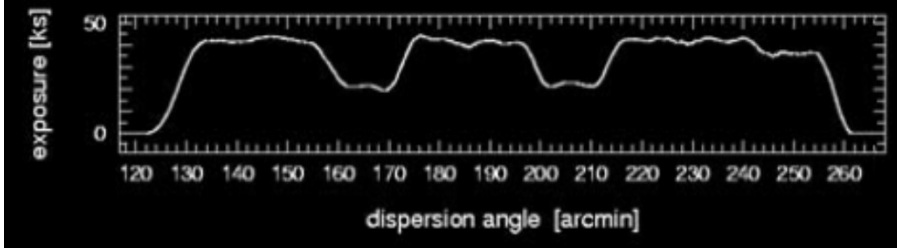
RGS 1+2 data

after transformation into comet reference frame



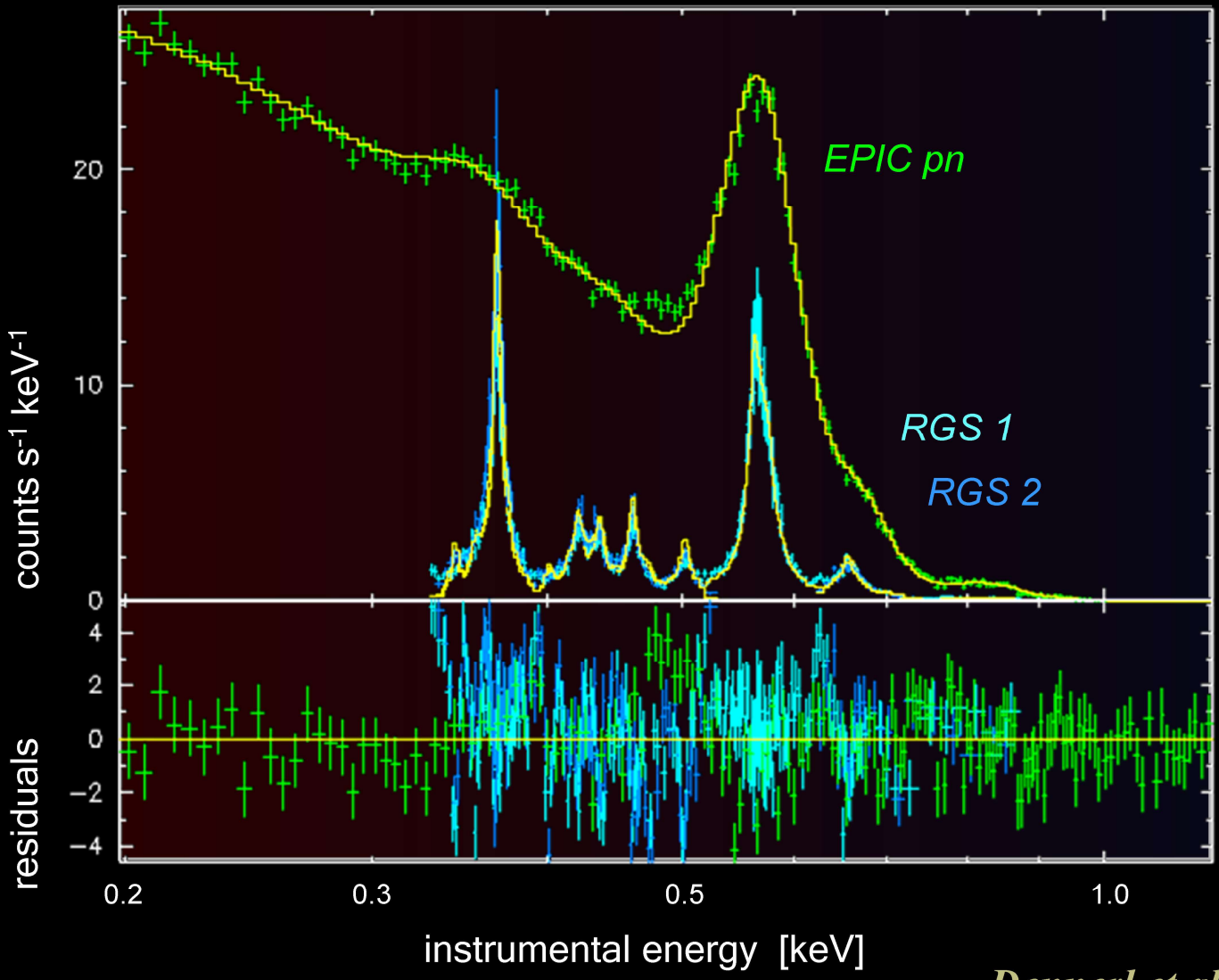




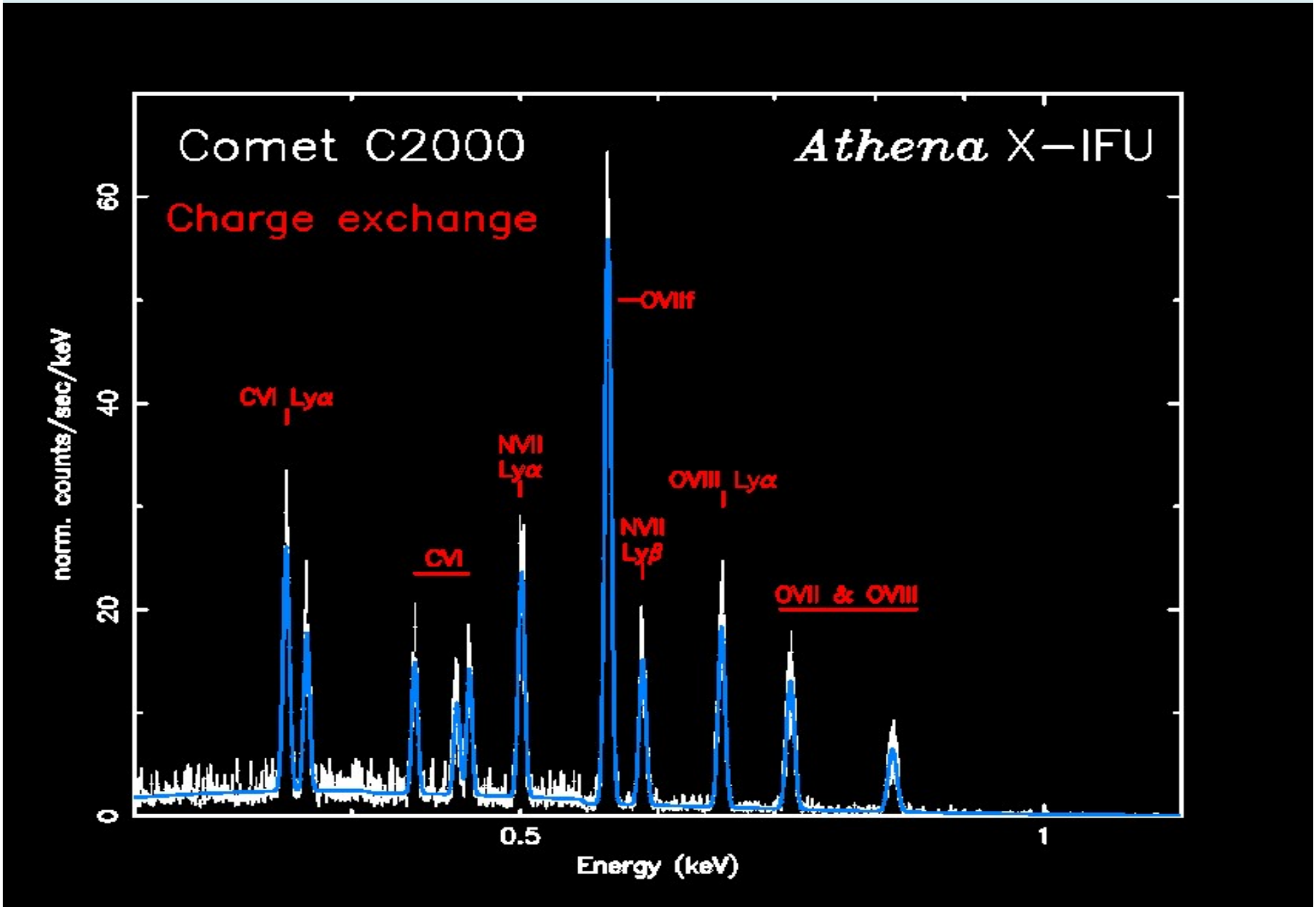


Dennerl et al., priv. comm.

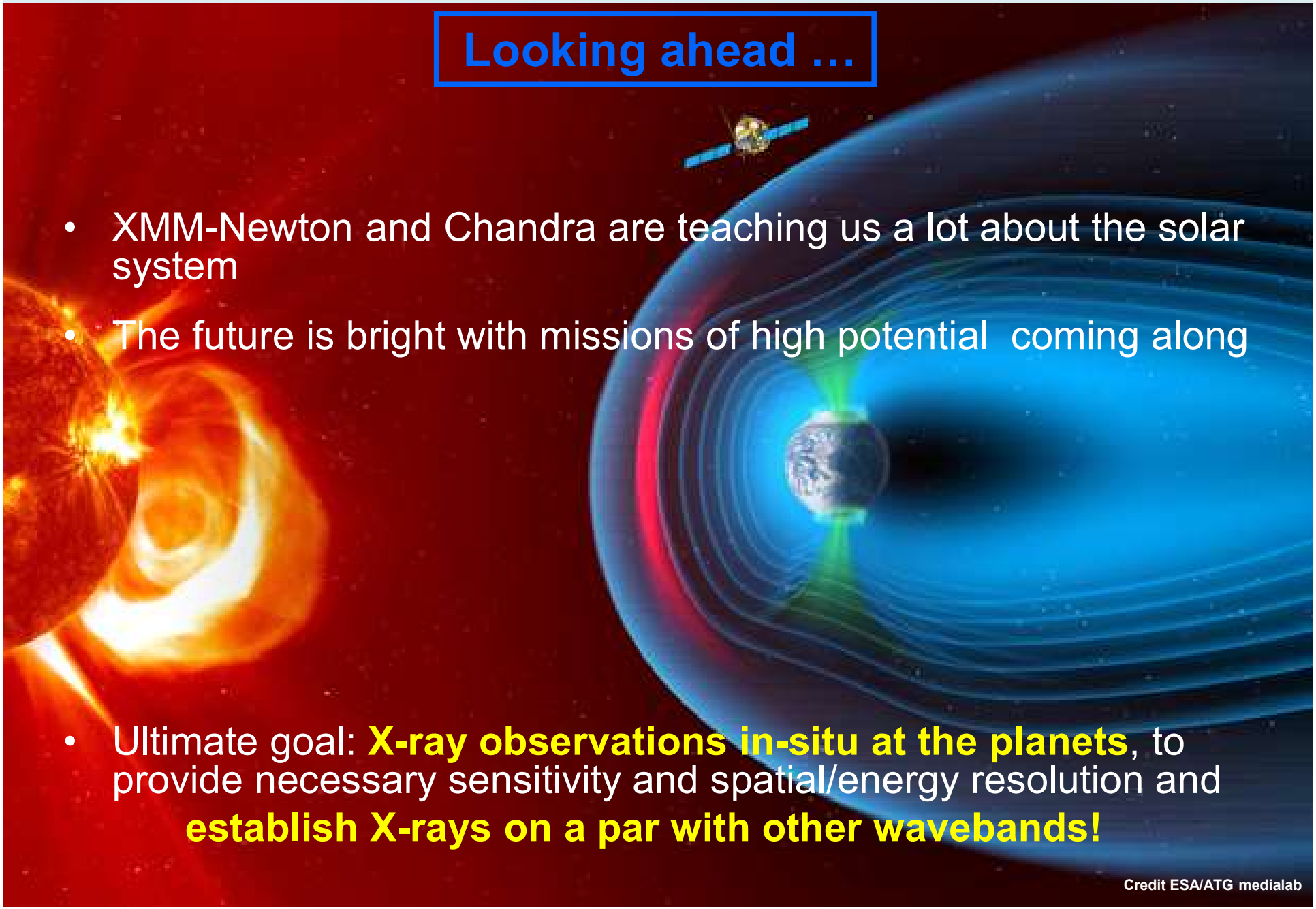
Comet C/2000 WM1: combined RGS + EPIC pn spectrum



Dennerl et al., priv. comm.


Comet C2000
Athena X-IFU
Charge exchange
CVI Lyα
NVII Lyα
CVI
OVIIf
NVII Lyβ
OVIII Lyα
OVII & OVIII
norm. counts/sec/keV
0
20
40
60
0.5
1
Energy (keV)

Looking ahead …

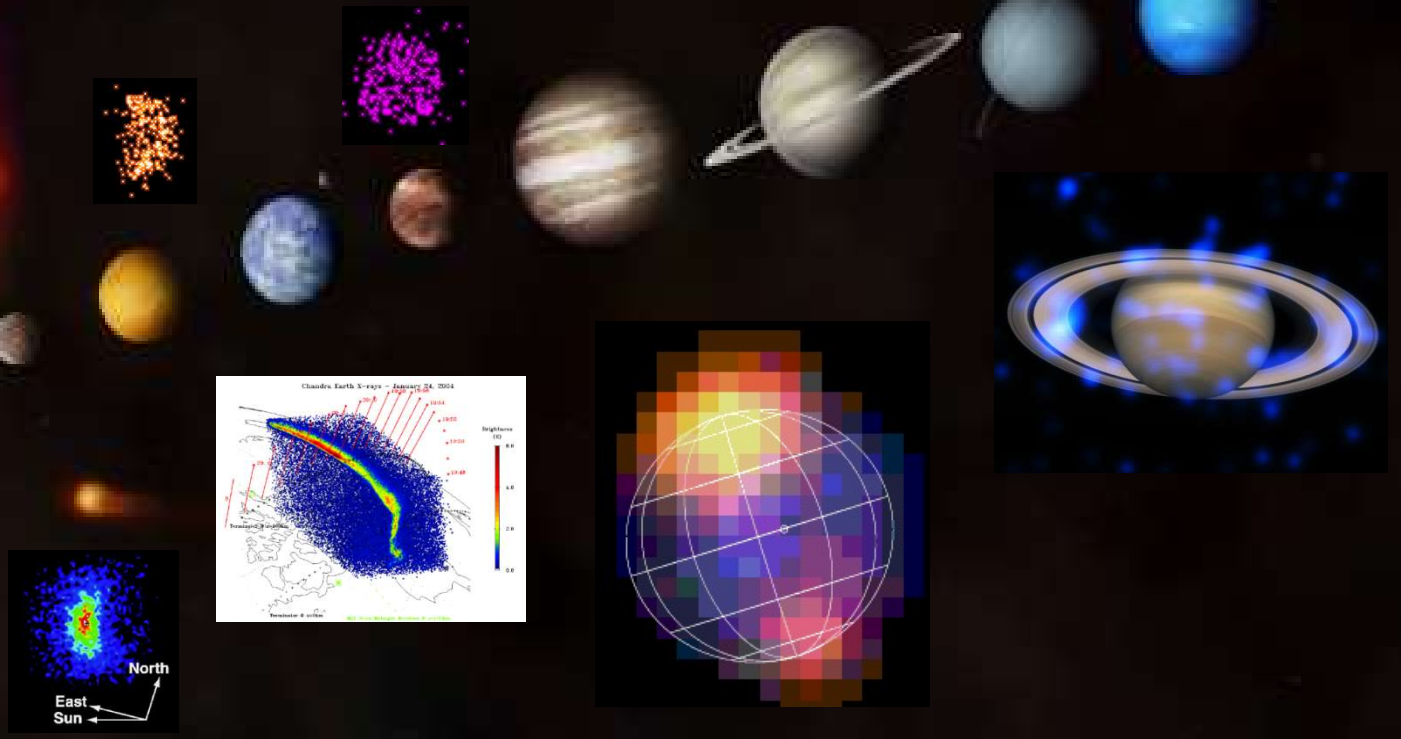


- XMM-Newton and Chandra are teaching us a lot about the solar system
- The future is bright with missions of high potential coming along
- Ultimate goal: **X-ray observations in-situ at the planets**, to provide necessary sensitivity and spatial/energy resolution and **establish X-rays on a par with other wavebands!**

Credit ESA/ATG medialab

UCL

Thank you!



XCalibur 2019 workshop
Winchester, UK, 16 July 2019