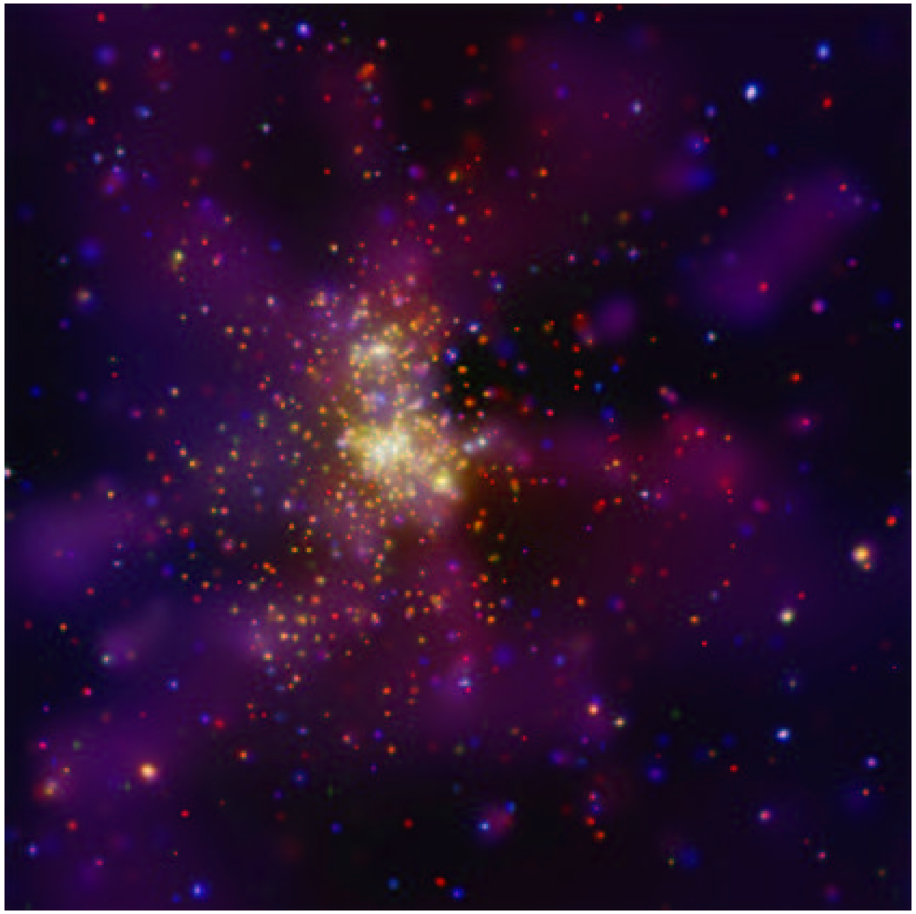
The X-Ray Universe

Potsdam University



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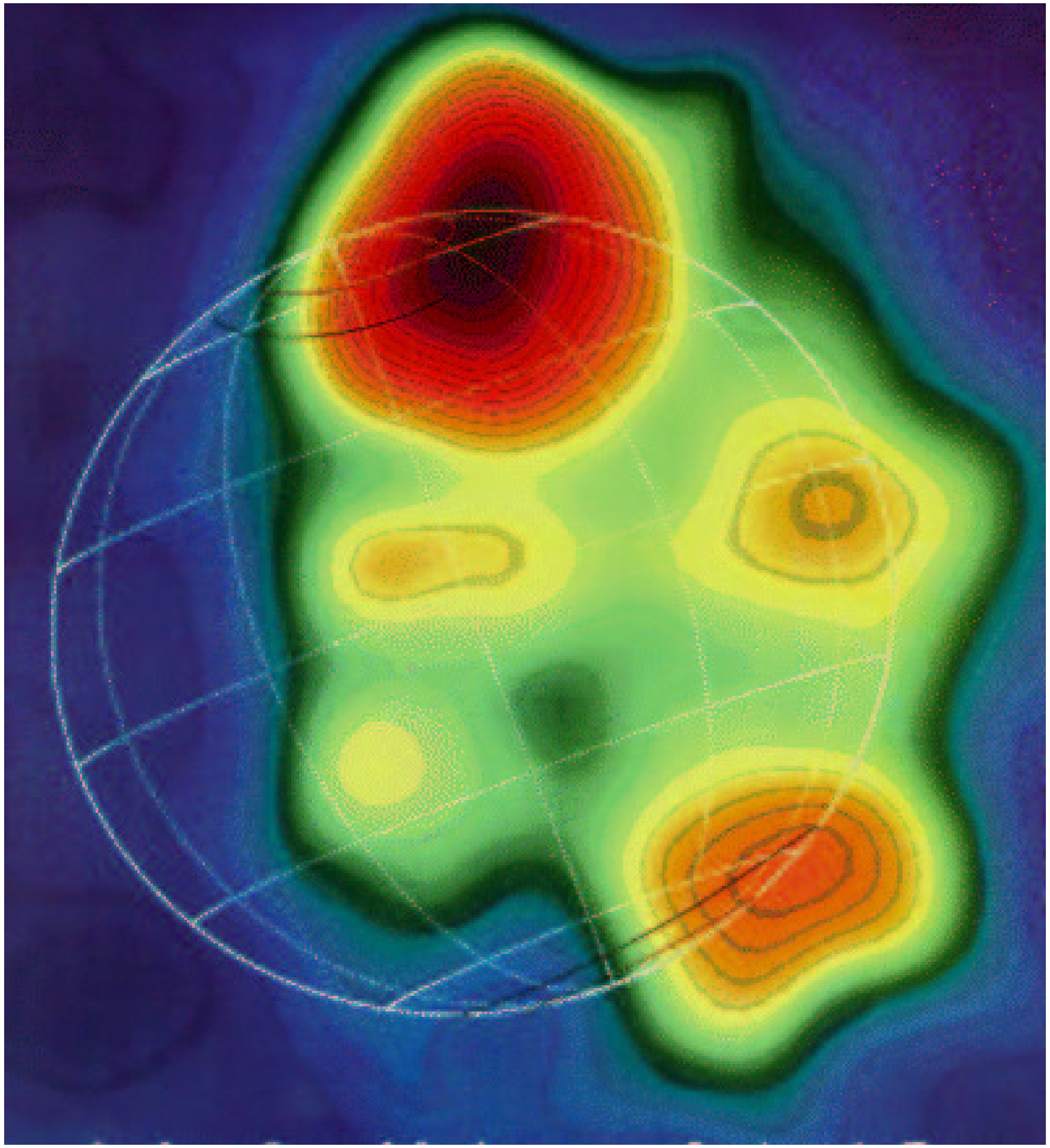
www.astro.physik.uni-potsdam.de/~lida/theormech.html

Chandra X-ray Observatory
Westerlund 2 - a young star cluster
d=2×10^4ly

IV. 35 Summary of Radiative Processes

- Blackbody: Neutron stars, WD
- CIE plasma: stellar coronae
- NEI: supernova remnants
- Bremsstrahlung: galaxy clusters
- Photoionized plasma: X-ray binaries
- Synchrotron: AGN jets
- Componisation: AGN, BH, galaxy clusters
- Charge Exchange: planetary systems

V. X-rays in Solar System

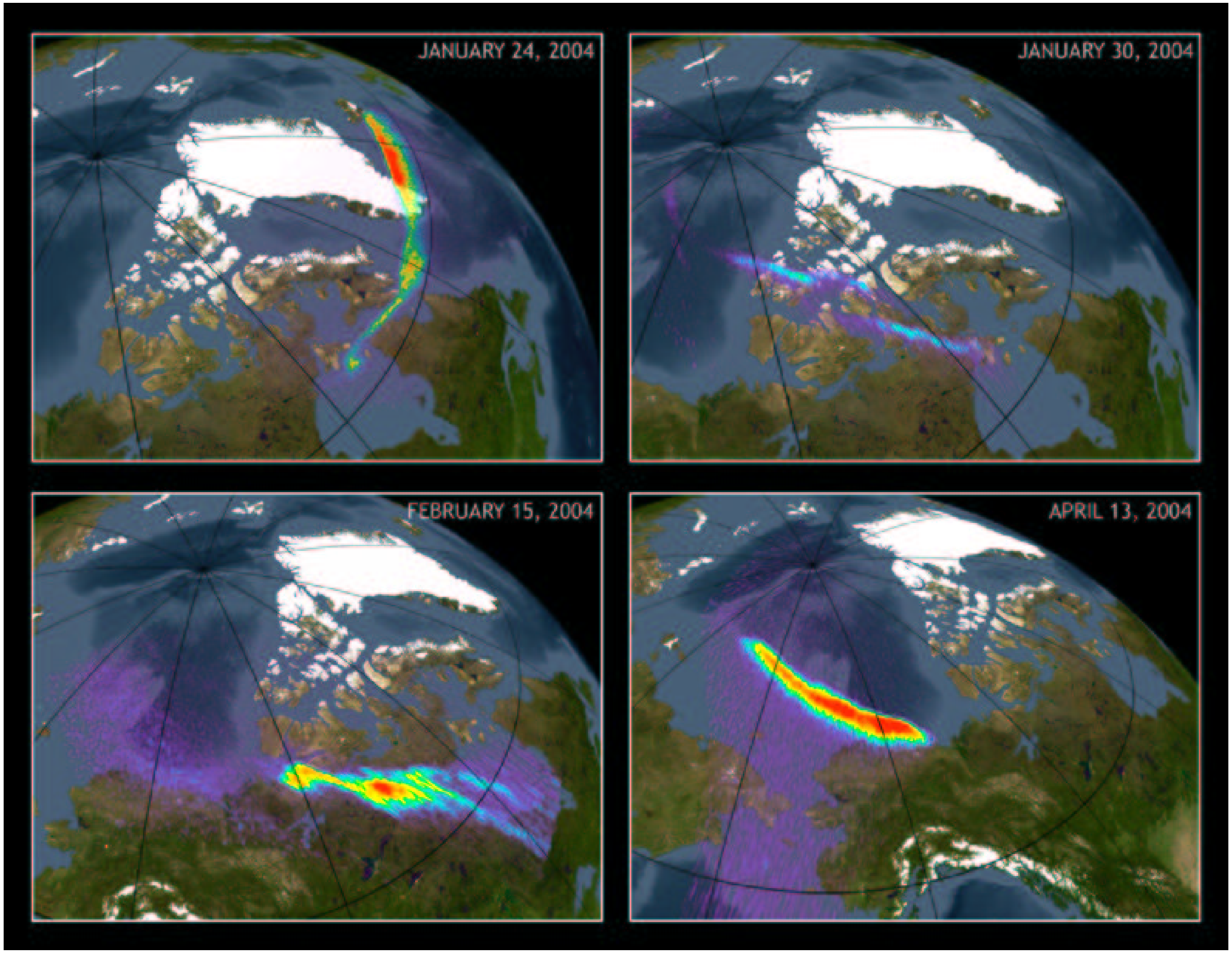


http://heasarc.gsfc.nasa.gov

High Resolution Imager (HRI) on the ROSAT

Impact of comet Shoemaker-Levy 9 in July, 1994 on Jupiter

V. 1. Aurorae: Earth, Saturn, Jupiter

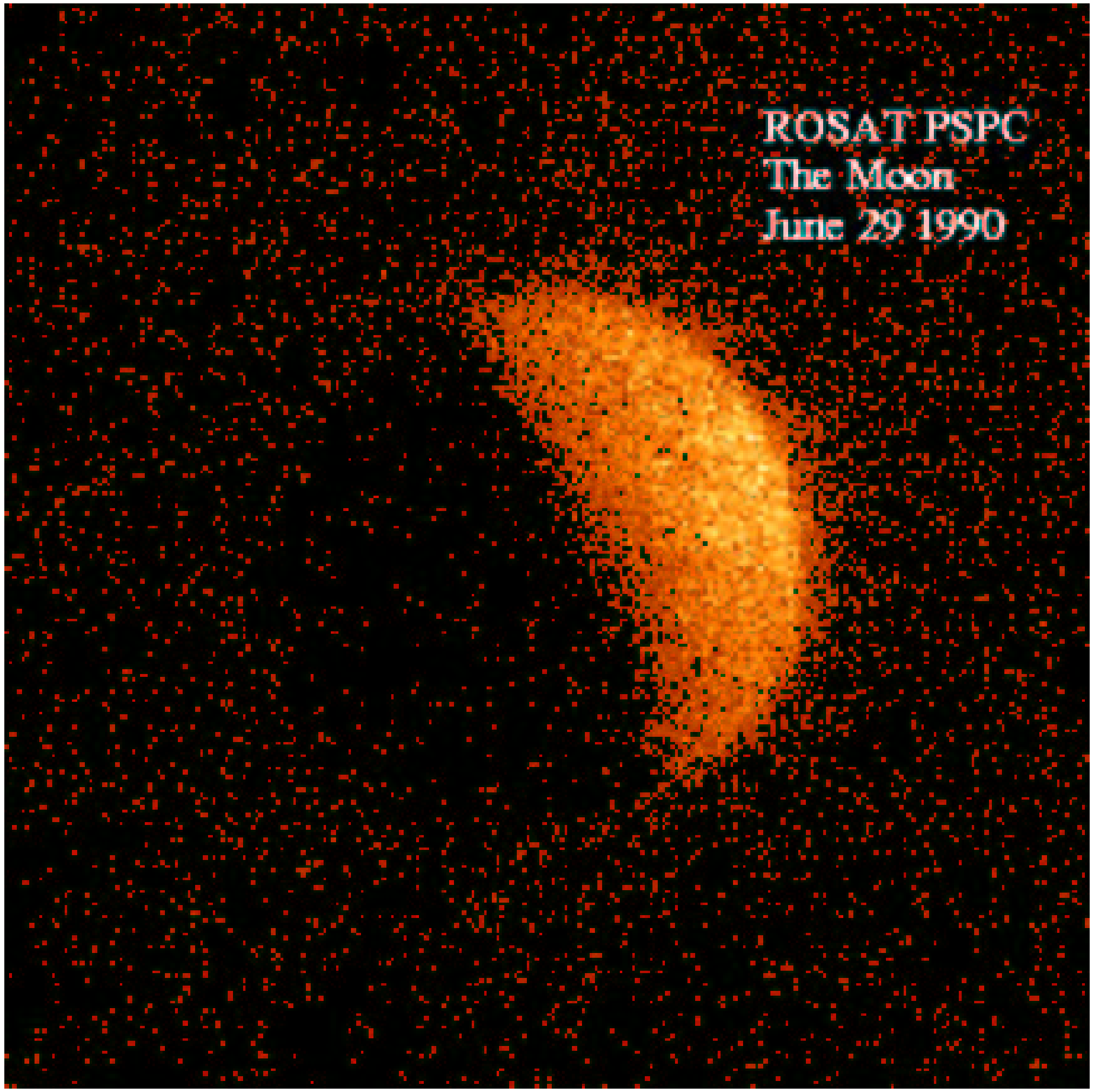


http://chandra.harvard.edu/photo/2005/earth/

Bremsstarhlung of solar wind particles in upper atmopshere.

Planetary magnetic field is required.

V. 2. A soft X-ray image of the Moon



Schmitt et al. 1991, Nature, 349, 583

Three components:

1.The Moon's bright side

Scattered solar X-rays:

Thompson scattering?

2.The Moon's dark side

A shadow in the diffuse background

Emission:

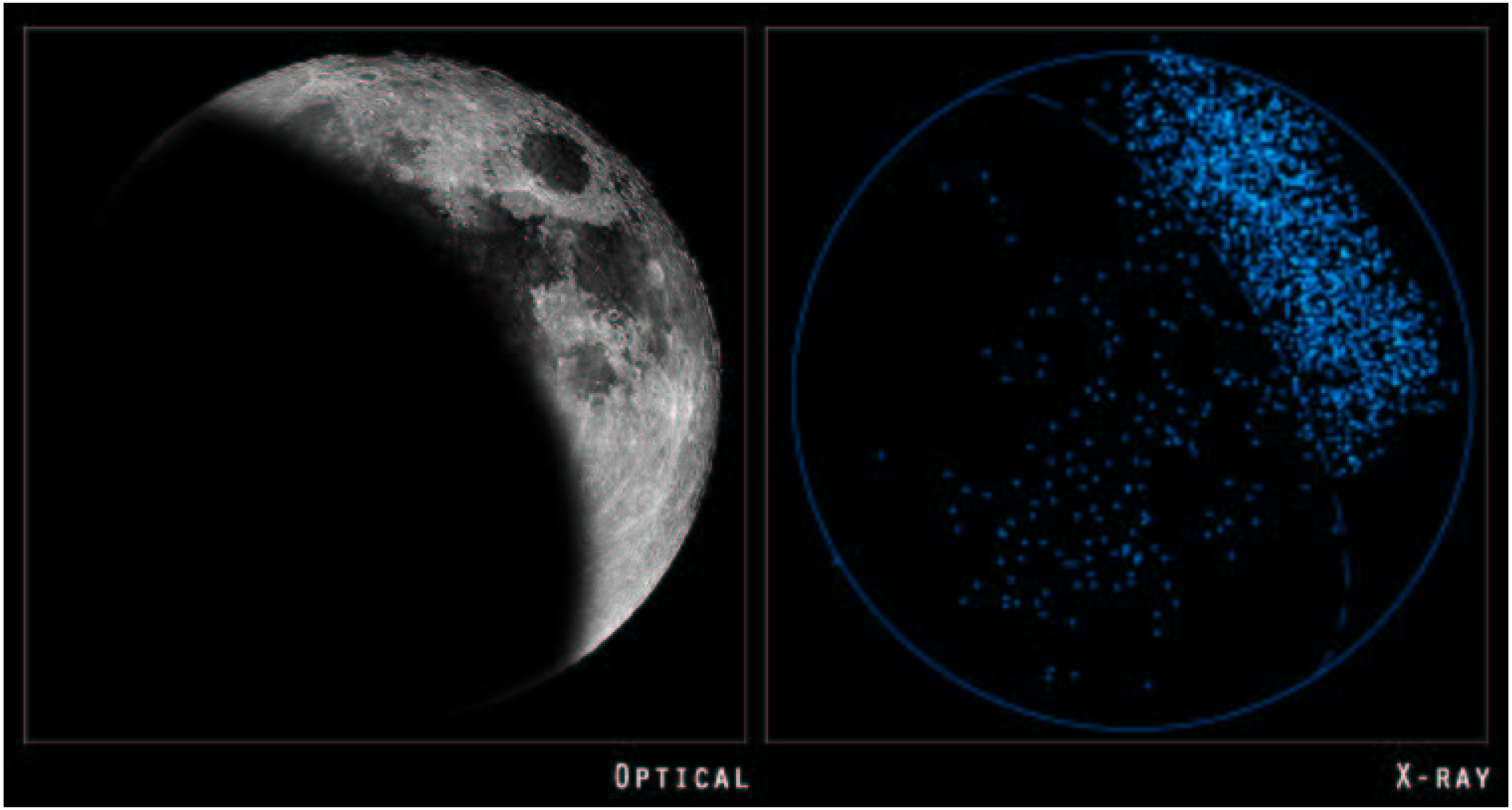
Bremsstrahlung of solar electrons?

3.The diffuse background

the cosmic X-ray background

$L_X = 7\times10^{11}$ erg/s

V. 3. Chandra image of the Moon



http://chandra.harvard.edu/photo/2003/moon/

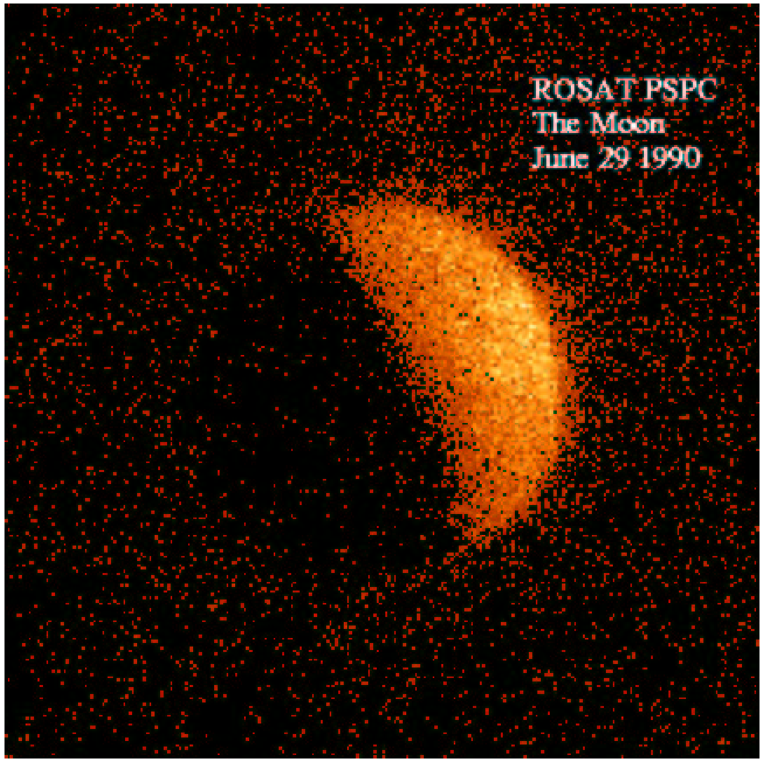
Reminder: Current theory of Moon origin: impact of a Mars-sized body 4.5 billion years ago

Chandra (0.2-12.0 keV)

high sensitivity, angular and spectral resolution

Spectra were obtained

V. 4. Bright side of the Moon



Schmitt et al. 1991, Nature, 349, 583

From Chandra measurments: (Wargelin et al. 2004)

1.The Moon’s bright side

Fluorescence

2.The Moon’s dark side

Charge exchange in geocorona

3.The diffuse background

the cosmic X-ray background

Fluorescence:

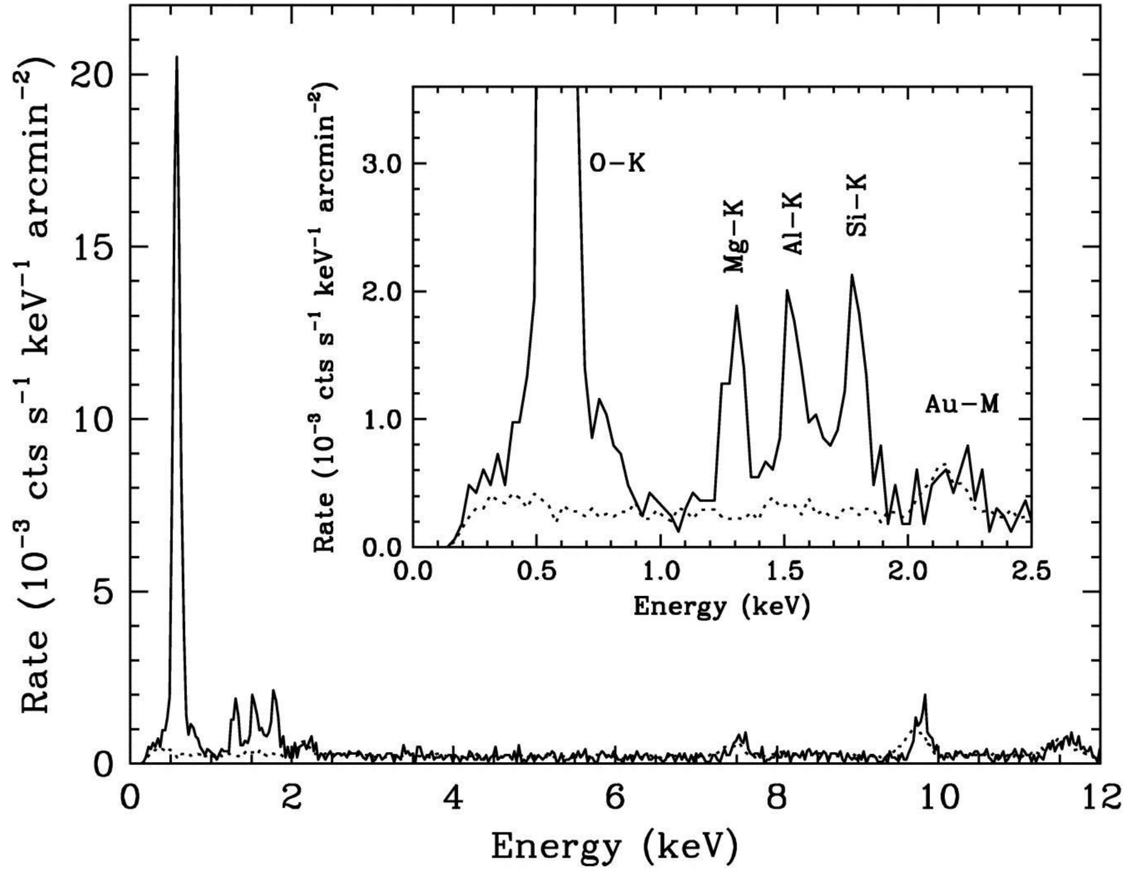
Photoexitation → line emission

Photon of longer wavelength is emitted

X-ray fluorescence: see applet

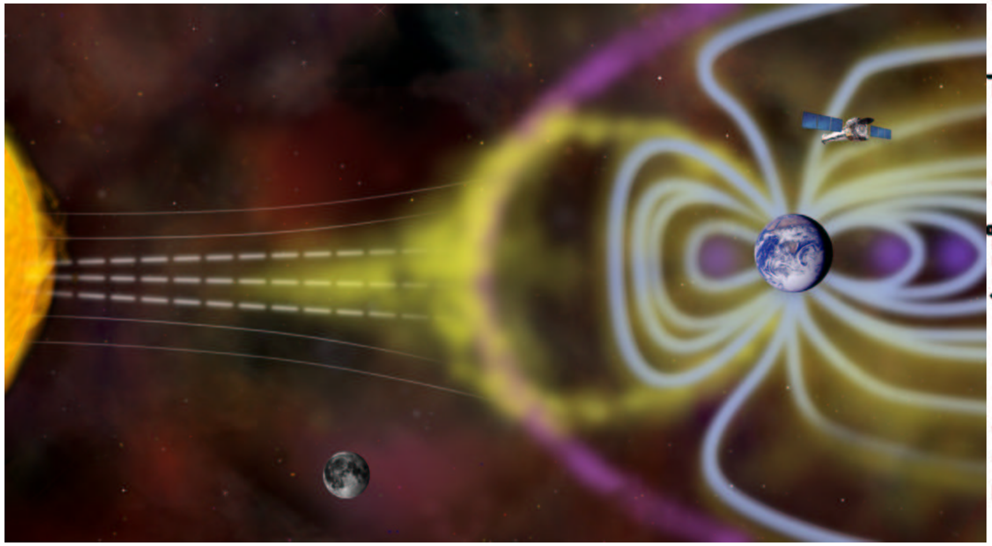
Moon: bombardment of surface by solar X-rays

Fluorescence Spectrum

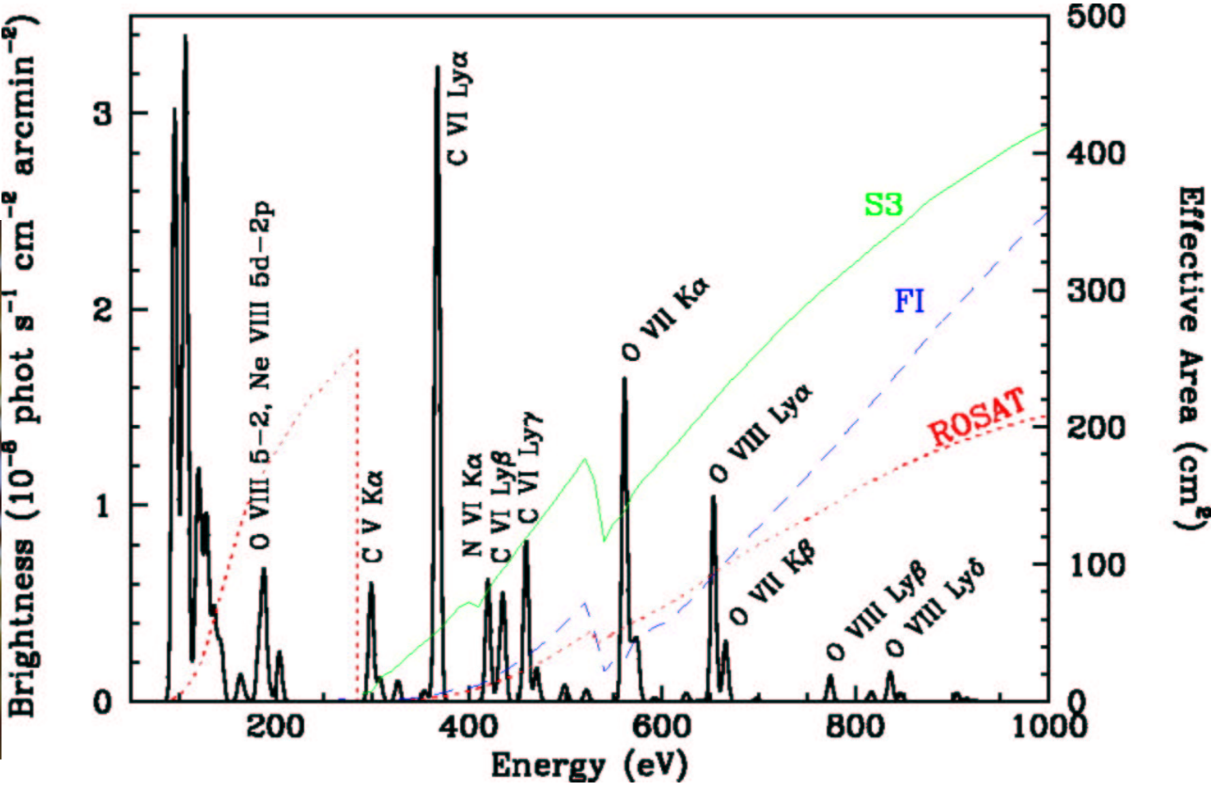


V. 5. Dark side of the Moon

Flux: 2x10^{-6} ph s^{-1} arcmin^{-2} cm^{-2}



http://chandra.harvard.edu/photo



The space craft just in geocorona:

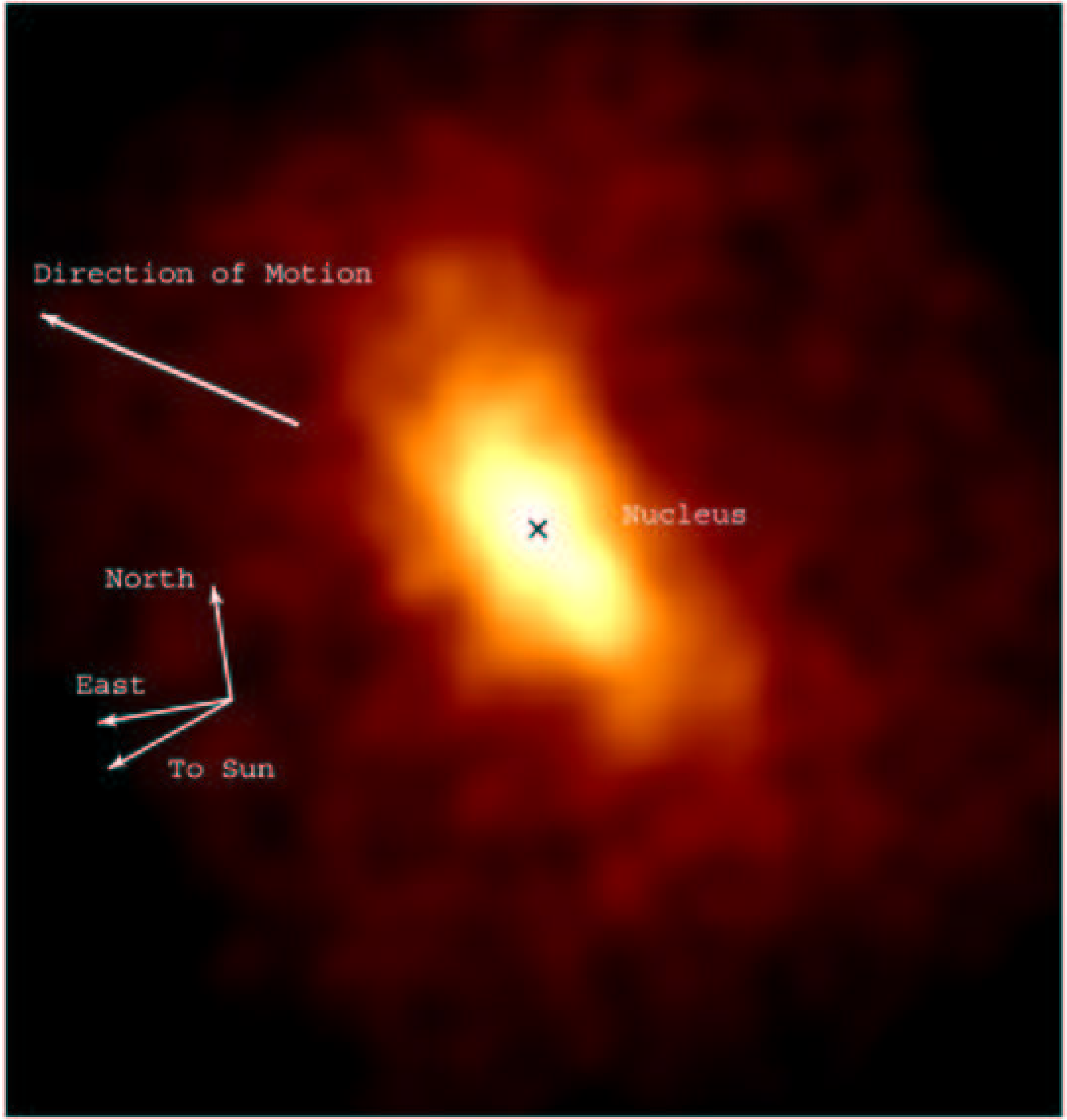
observes solar wind chrage exchange with neutral between Earth and Moon

$$A^{q+} + N \rightarrow A^{(q-1)+,*} + N^{-} \rightarrow A^{(q-1)+} + N^{-} + h\nu_{\mathrm{X}}$$

CT emissivity: $\epsilon_{\mathrm{il}} = v_{\mathrm{c}} n_{\mathrm{n}} n_{\mathrm{i}} y_{\mathrm{il}} \sigma_{\mathrm{i}}$ ph/s/cm^3

where v_{c} - is the collision velocity (solar wind velocity), n_{n} neutral species density, n_{i} is the relevant ion density, y_{il} the net line emission yield per CT-excited ion, and σ_{i} is the total CT cross section for ion i.

V. 6. More charge exchange: Comets



http://chandra.harvard.edu/photo/2000/c1999s4/

Comet C/1999 S4 (LINEAR)

Discoverd in 1999:

Lincoln Near Earth Asteroid Research

Closest approach in 2002

observed with Chandra

X-rays

from oxygen and nitrogen ions.

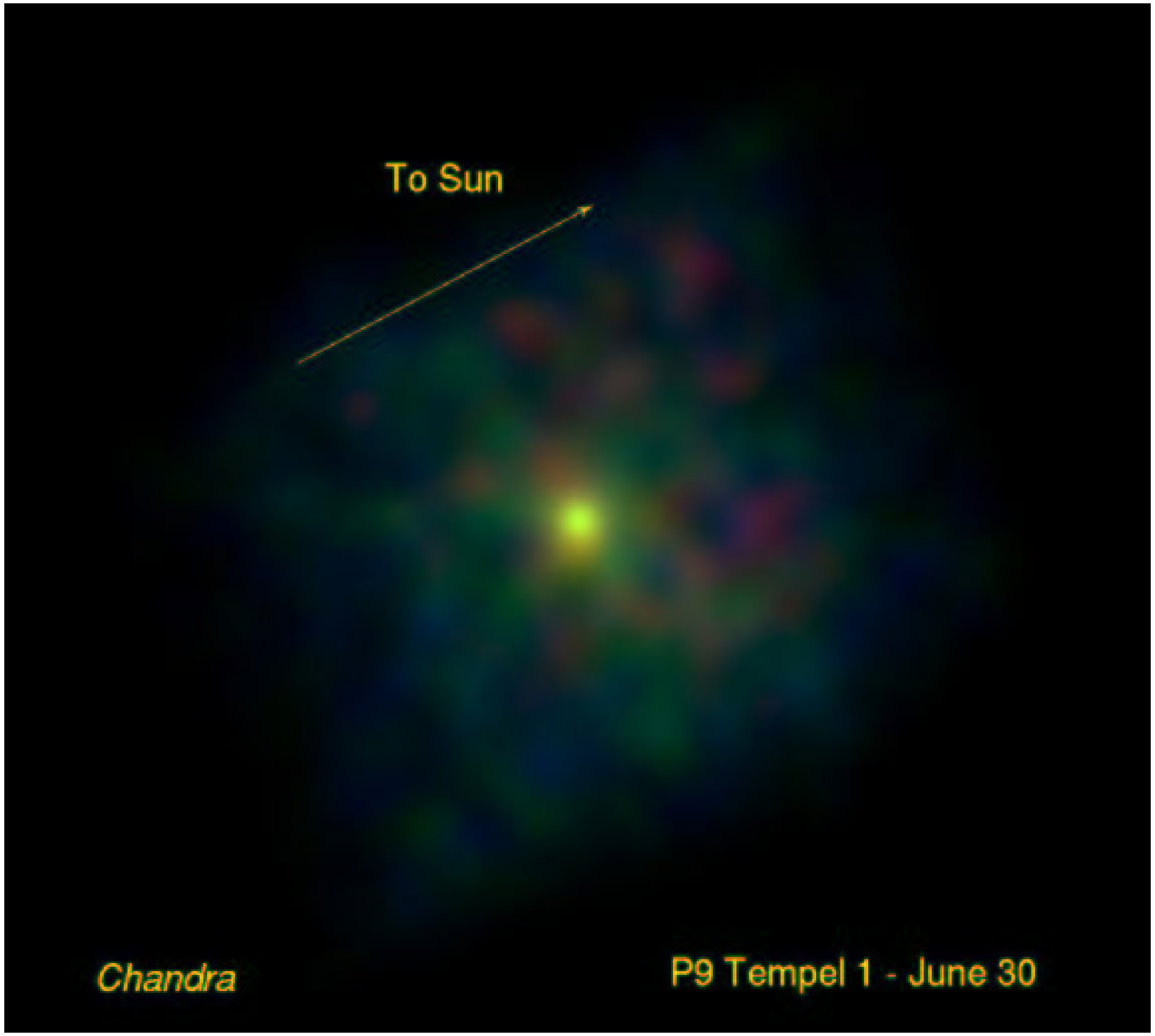
Charge exchange

with soalr wind particles

Chemistry of the solar wind,

and the structure of the comet’s

V. 7. More charge exchange: Comets



http://chandra.harvard.edu/photo/2005/dimpact/

Comet Tempel 1

Prior and after Deep Impact

(see annimation)

observed with Chandra

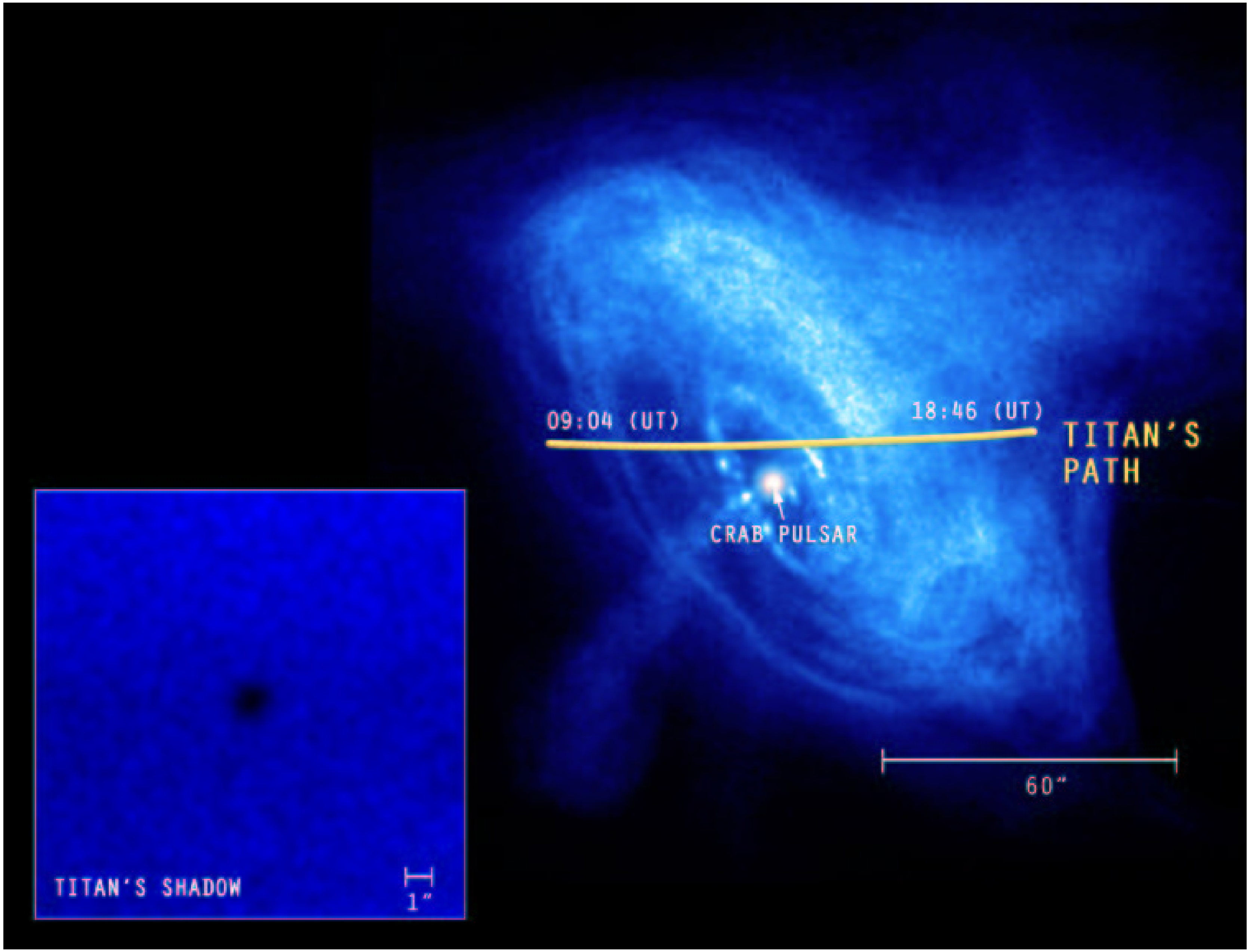
X-rays

from oxygen ions.

Charge exchange

with soalr wind particles

V. 8. Titan’s shadow

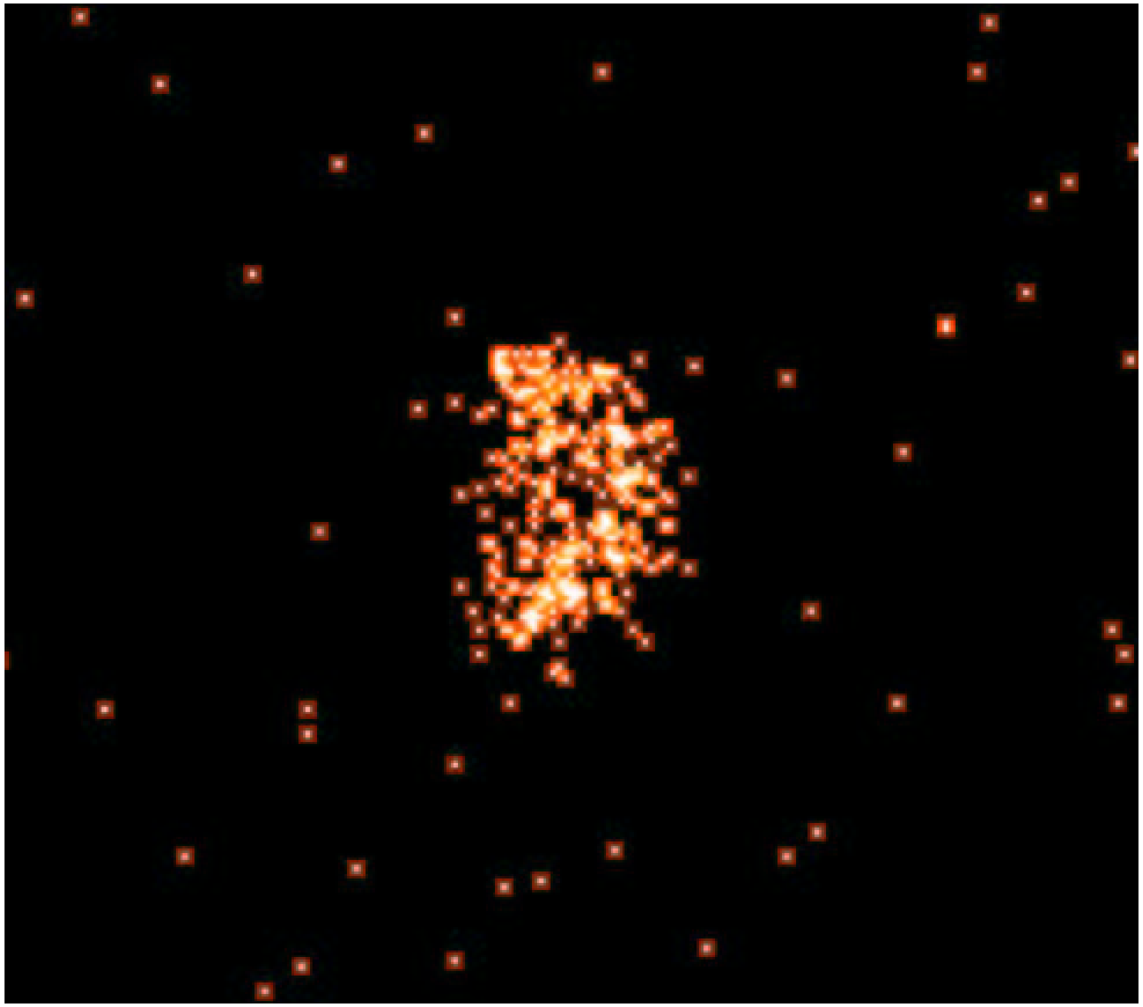


http://chandra.harvard.edu/photo/2004/titan/

Titan - Saturn’s largest moon: the only moon in Solar System with thick atmosphere

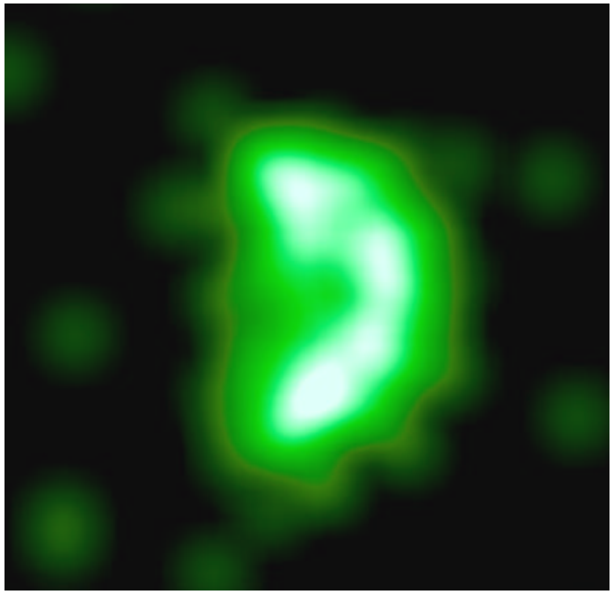
The duration of eclipse -- the extent of the atmosphere 880 km (see movie)

V. 9. Planets: Venus



Dennerl et al. 2002,AA 386, 319

$L_X / L_{opt} = 10^{-10}$



Adaptively smoothed

The Chandra data are fully consistent with fluorescent scattering (CNO) of solar X-rays in the Venus atmosphere up to height 110 km.

Different from the X-ray emission of comets, where the dominant process for the X-ray emission is charge exchange between highly charged heavy ions in the solar wind and cometary neutrals.

V. 10. Charge exchange vs. Fluorescence

Why CT is more important for comets? (Dennerl etal. 2004)

Because comets are more extended and less dence

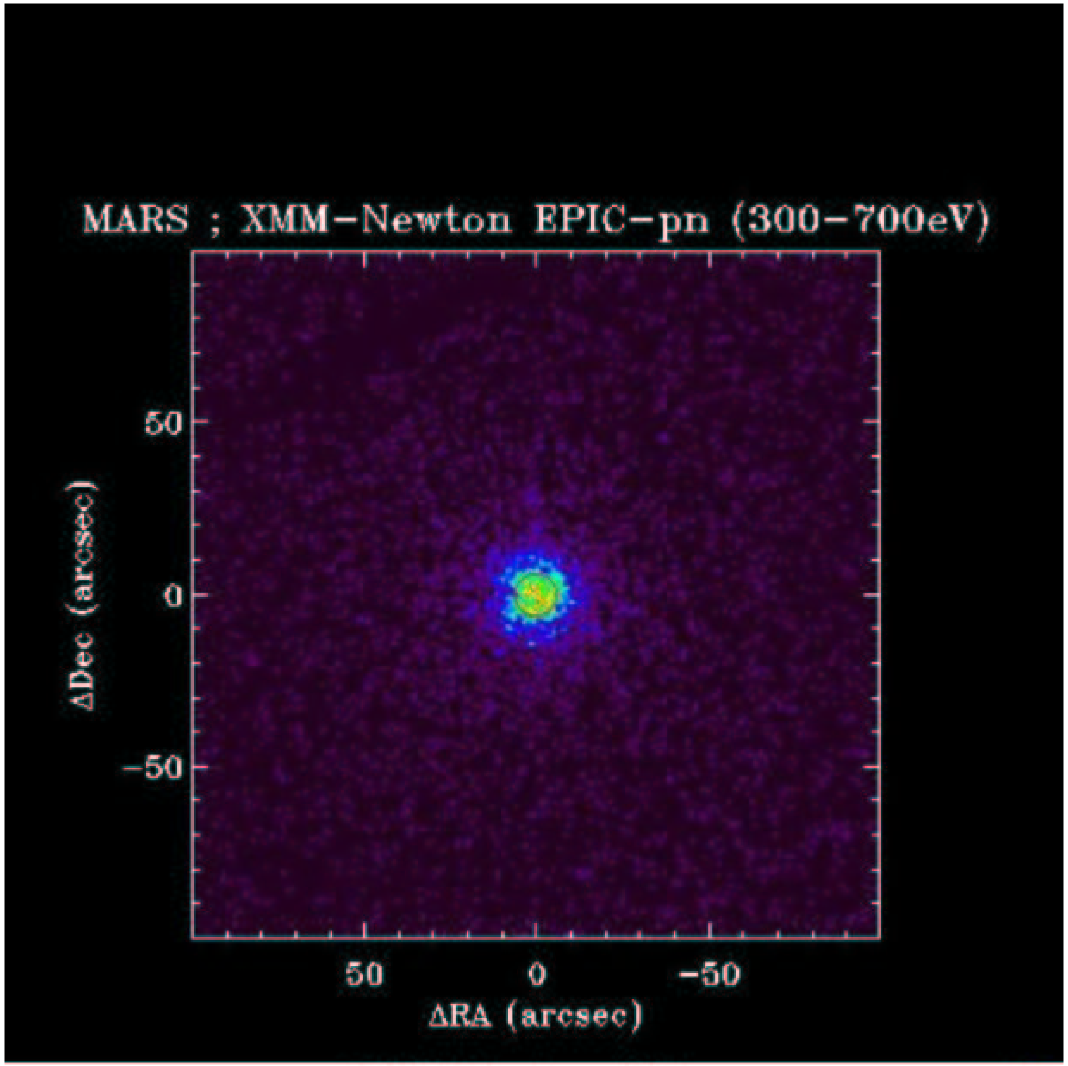
The cross sections for charge exchange typically > 10^{-15} cm^{-2} and are thus at least three orders of magnitude greater than for fluorescent emission, which are < 10^{-18} cm^{-2}

The gas in a comETARY coma is distributed over a much larger volume than in a planetary atmosphere. The particle density in a coma is too low and remains optically thin for X-rays, but it is high enough to provide a sufficient number of target electrons for charge exchange.

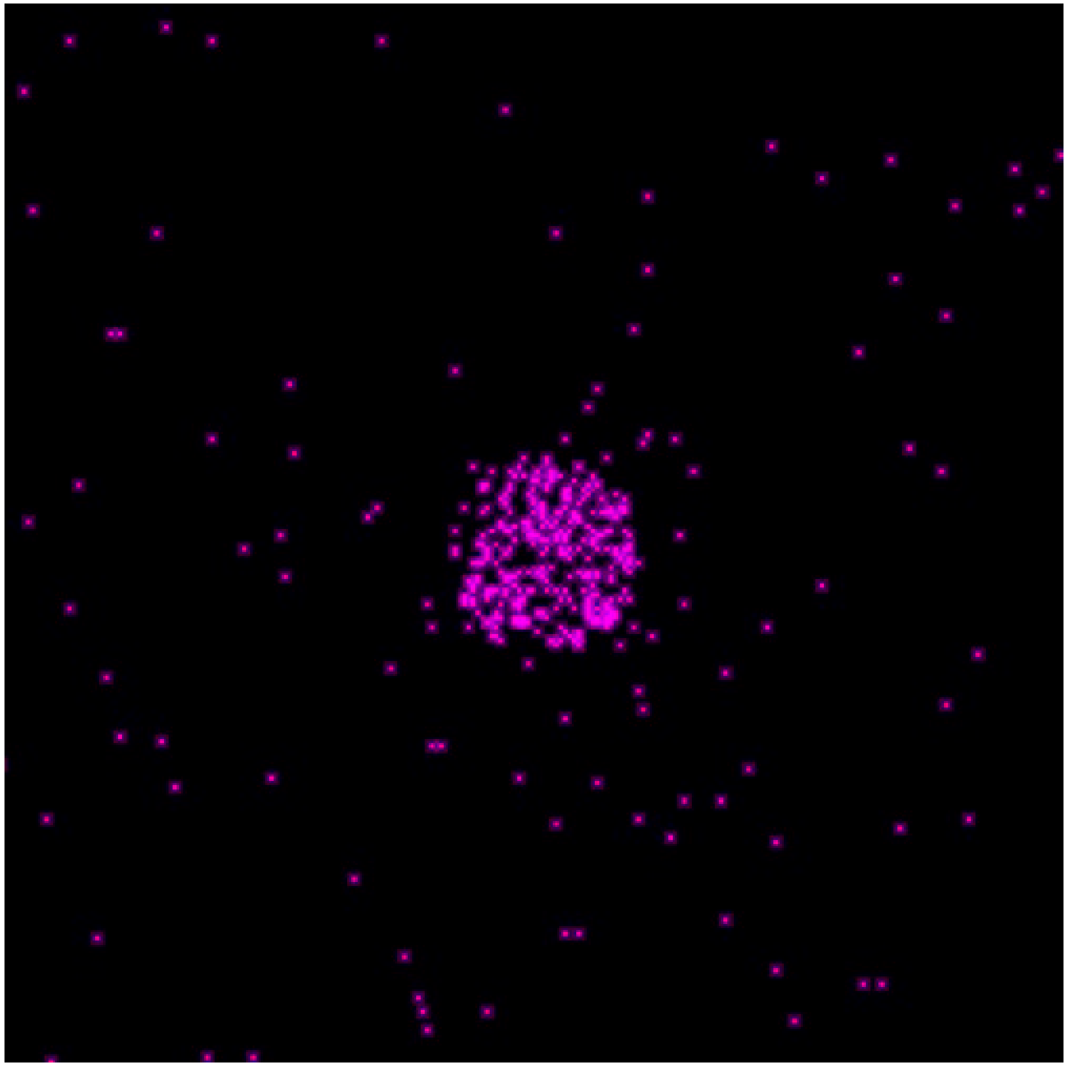
The atmosphere of Venus is so dense that it is optically thick. As the solar wind ions become discharged already in the outermost parts, only a tiny fraction of the atmospheric electrons can participate in the charge exchange process. The flux of incident solar wind ions is reduced by the presence of an ionosphere.

The X-ray area is < 1 arcminute in diameter in the case of Venus, the bright part of the cometary X-ray emission can extend > 10 arcminutes, thus increasing the total amount of charge exchange induced X-ray photons by two orders of magnitude or more.

V. 9. Planets: Mars



XMM-Newton image of Mars European Space Agency



NASA/CXC/MPE/K.Dennerl et al.

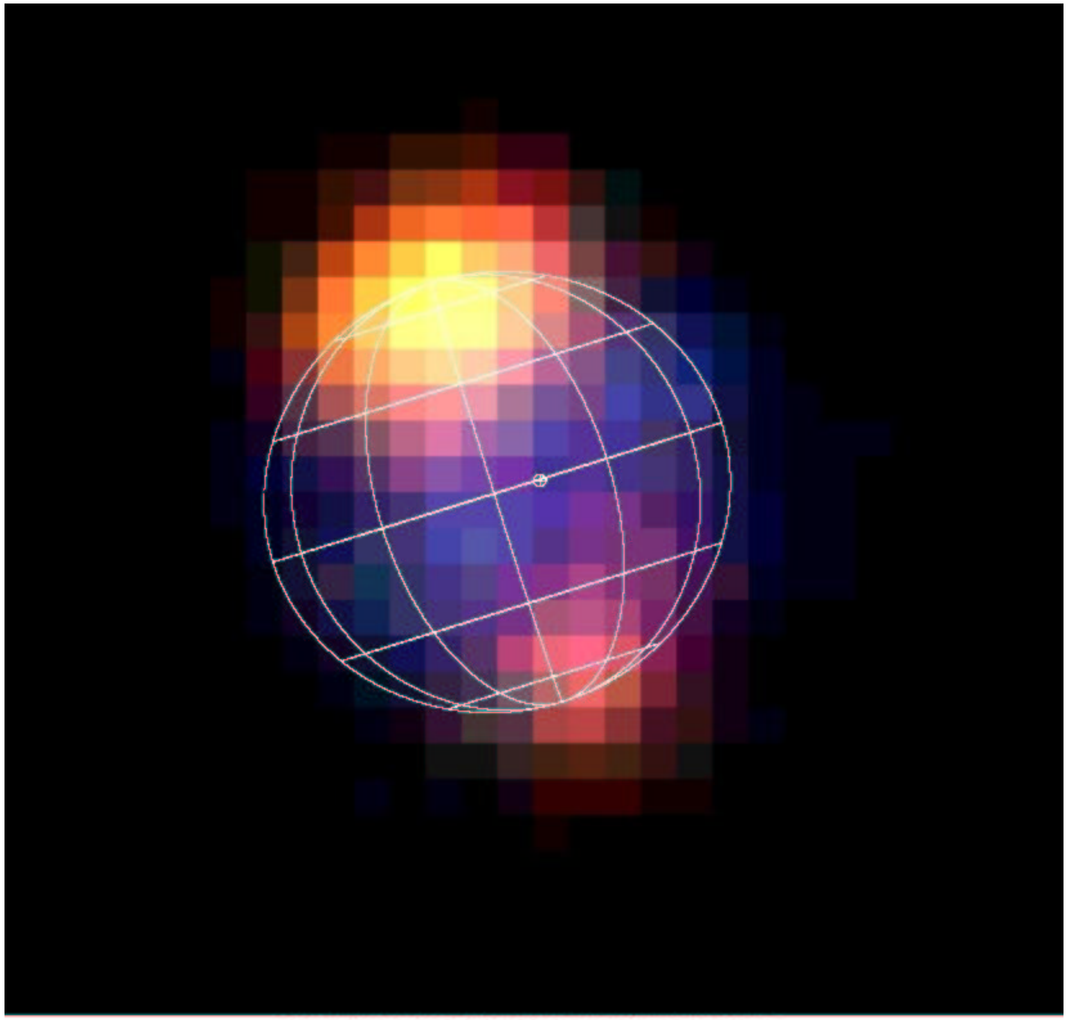
X-rays are produced by fluorescent radiation from oxygen atoms

At height 120km in Martian atmosphere

X-ray luminosity of 10 000 medical X-ray masines

Faint X-ray halo that extends out to 7 000 km above the surface charge exchange.

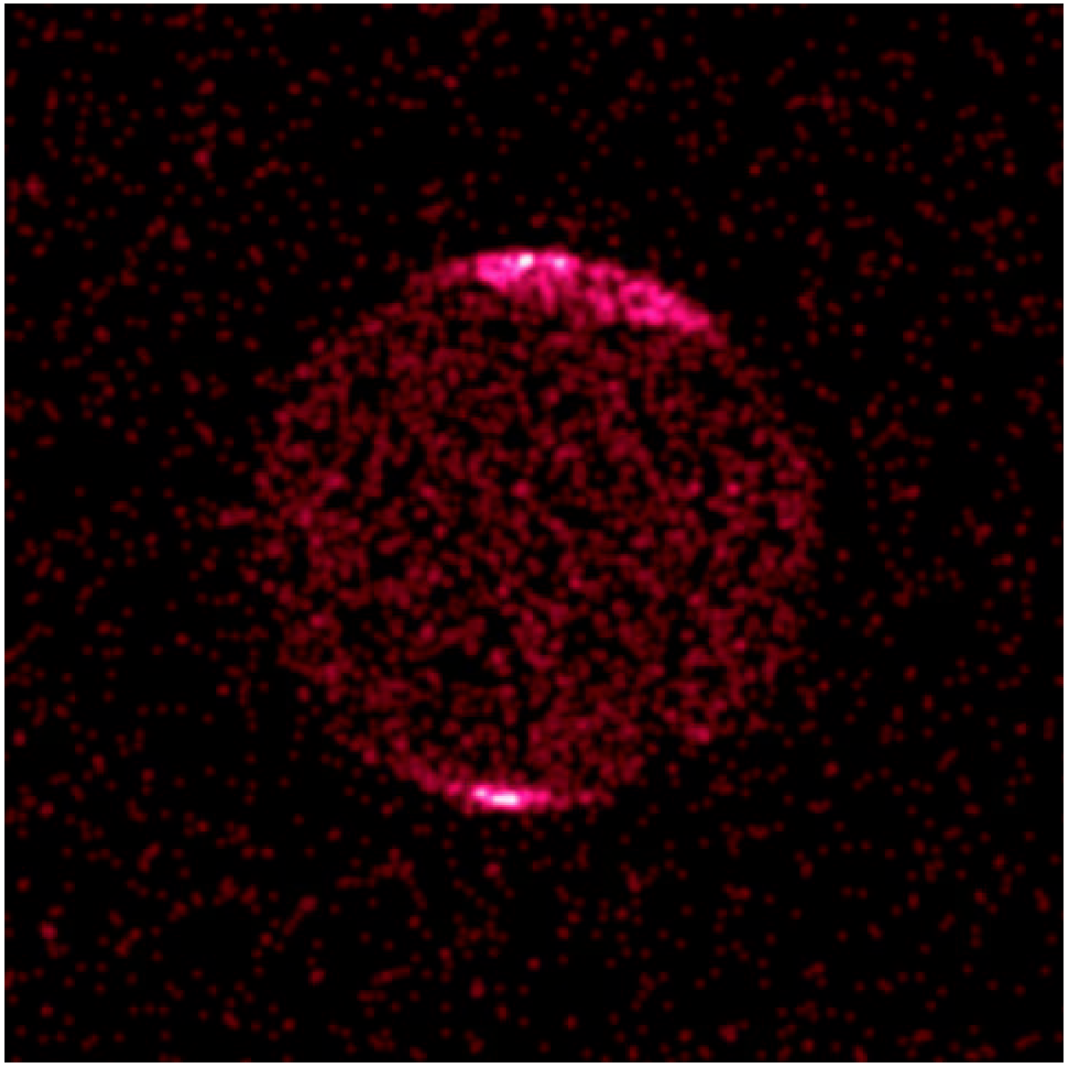
V. 10. Planets: Jupiter



Solar control on Jupiter's equatorial X-ray emissions

Image courtesy of Graziella Branduardi-Raymont

European Space Agency



NASA/CXC/SWRI/G.R.Gladstone et al.

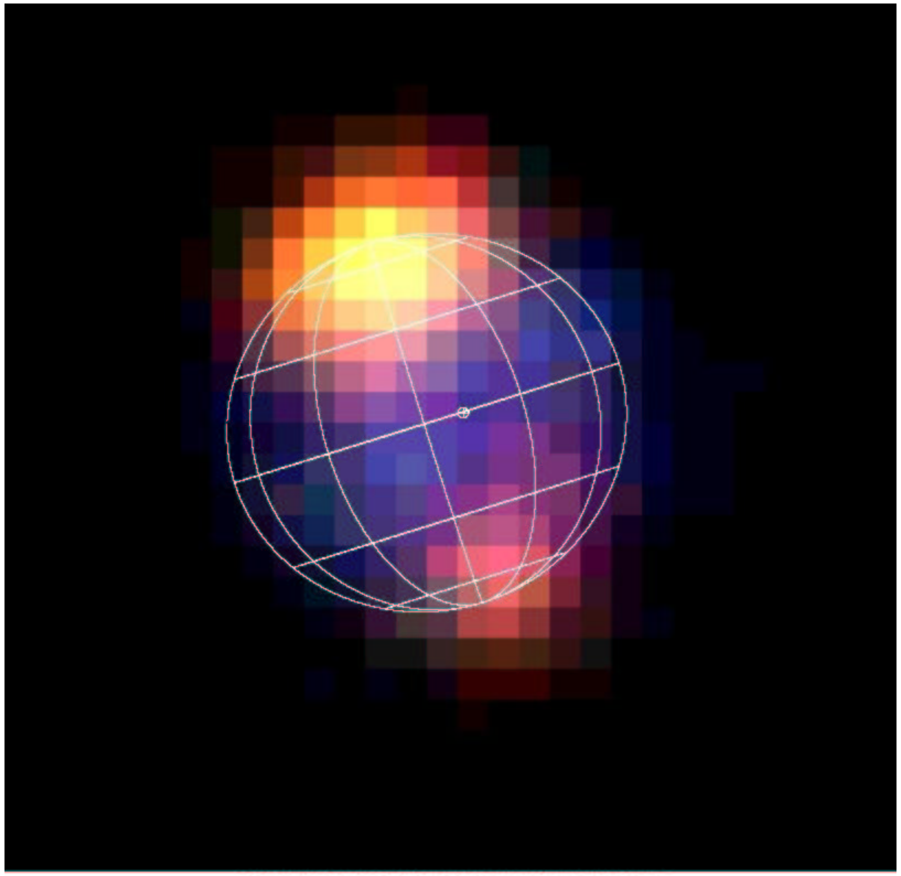
At least two components: Aurorae (harder X-rays) and disk emission (softer)

bremstrahlung + charge exchange. Are ions from Io or the solar wind?

Pulsating Hot spot in polar region P=45 min, nature is debated

Disk: scattering of X-rays: varies along with solar cicle

V. 10. Planets: Jupiter



Solar control on Jupiter's equatorial X-ray emissions

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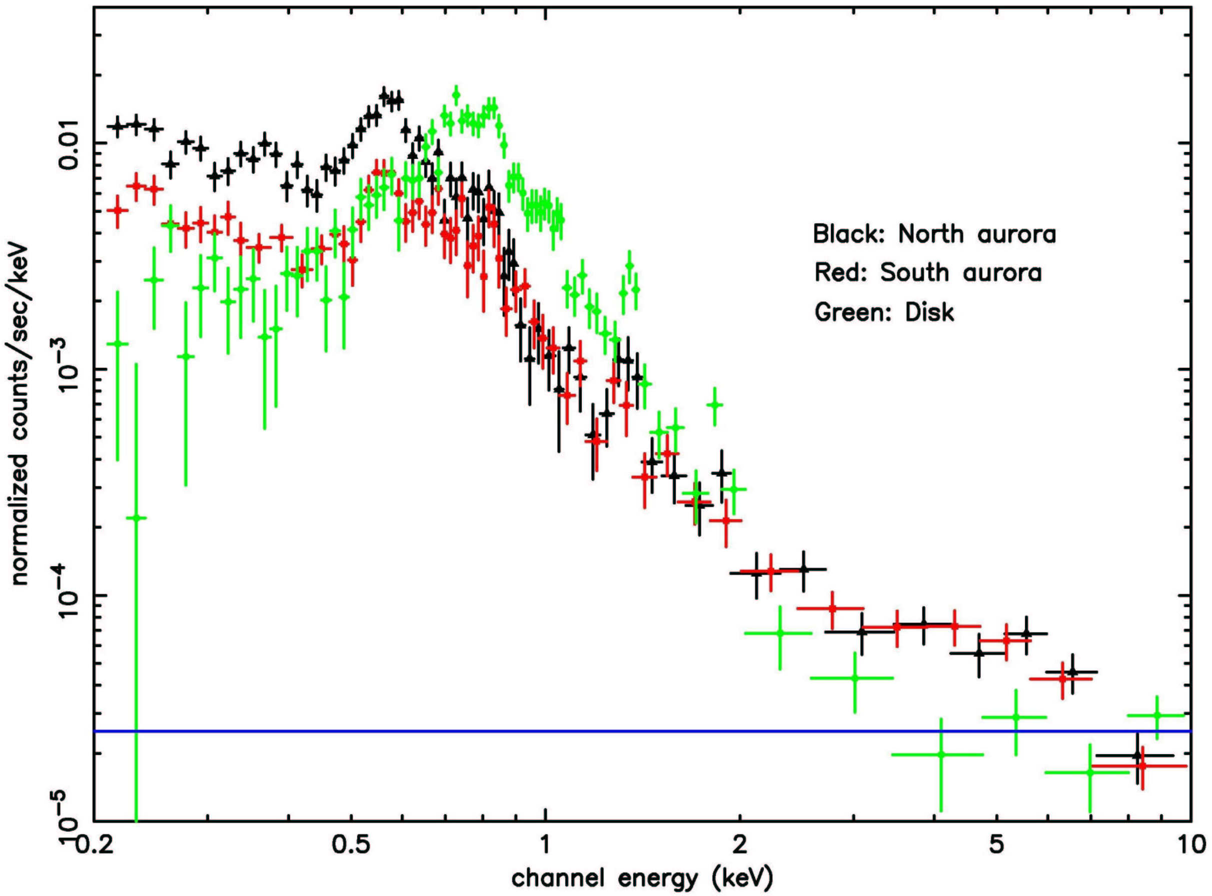


Image courtesy of Graziella Branduardi-Raymont

Image courtesy of Graziella Branduardi-Raymont (MSSL, UCL)

Jupiter's X-ray spectra

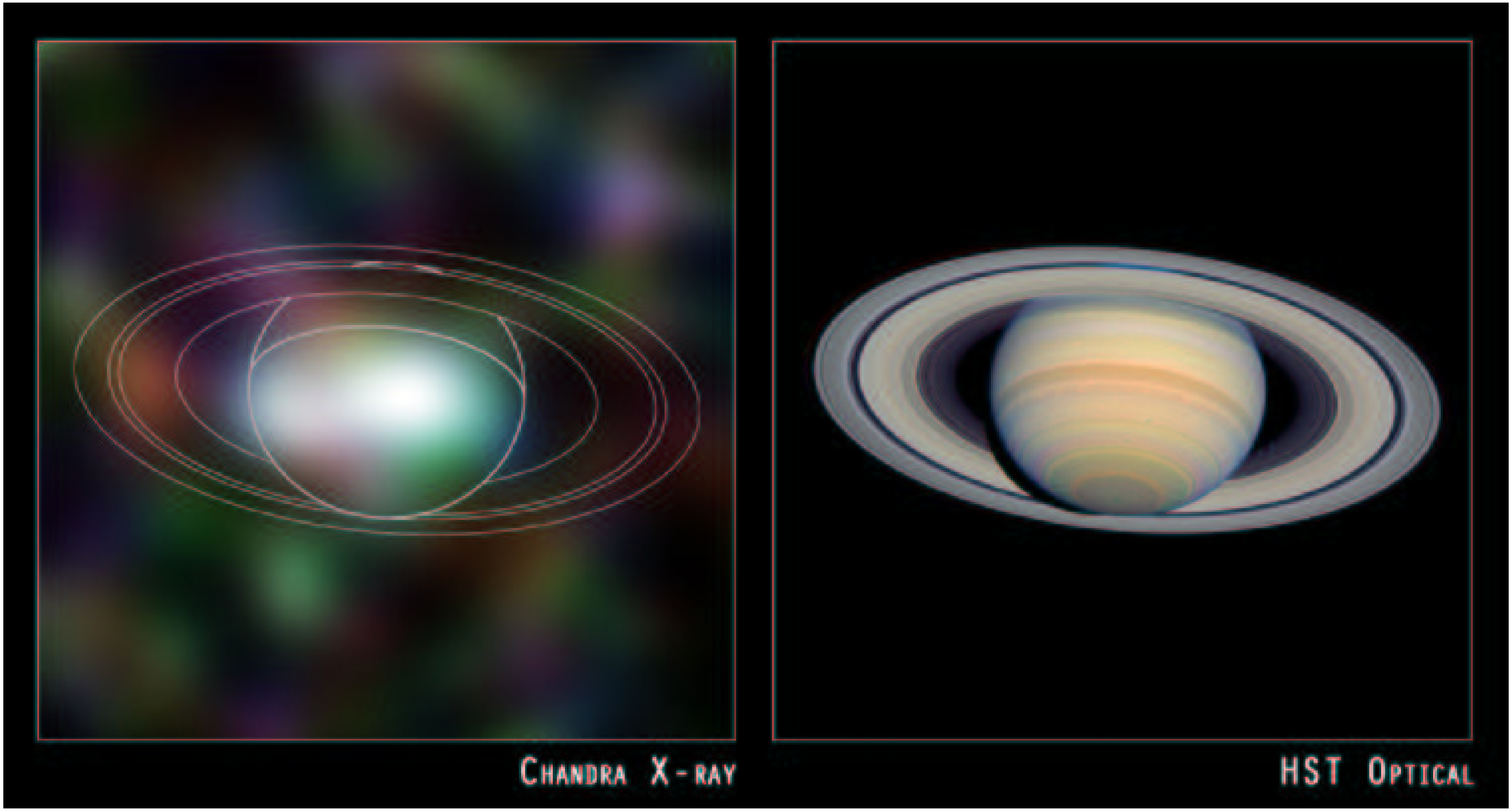
Combined EPIC-MOS and -pn spectra of the North (black) and South (red) aurorae, and of the low-latitude disk emission (green).

Aurorae: 1) CE by ions precipitating in Jupiter's magnetosphere (peaks around 0.5 - 0.6 keV), 2) high energy 'tail': bremsstrahlung electrons also precipitating in magnetosphere close to the poles.

Disk: scattering of solar X-rays in the upper atmosphere of the planet

V. 11. Planets: Saturn

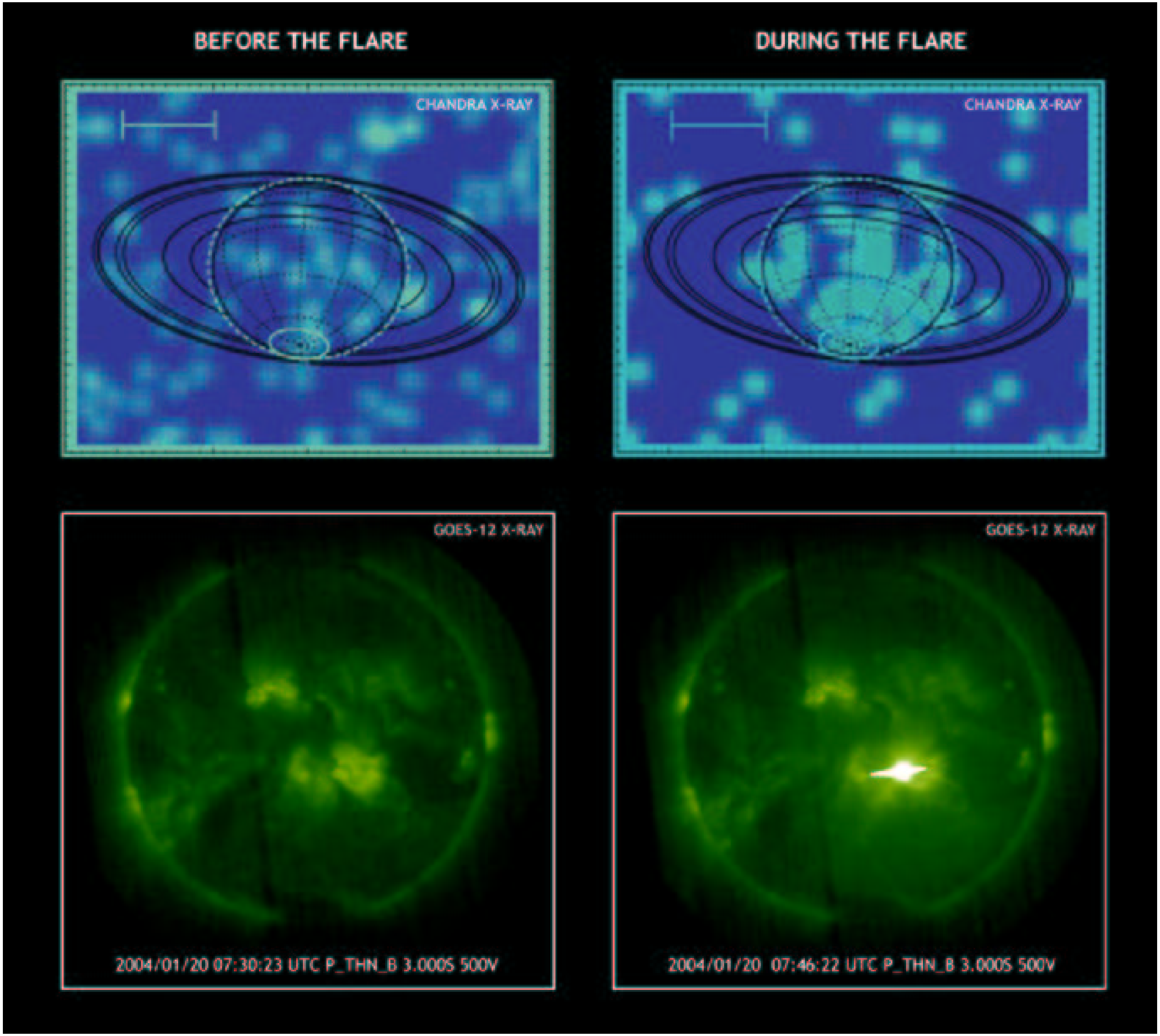
$L_X = 9 \times 10^{14}$ erg/s



NASA/U. Hamburg/J.Ness et al; Optical: NASA/STScI

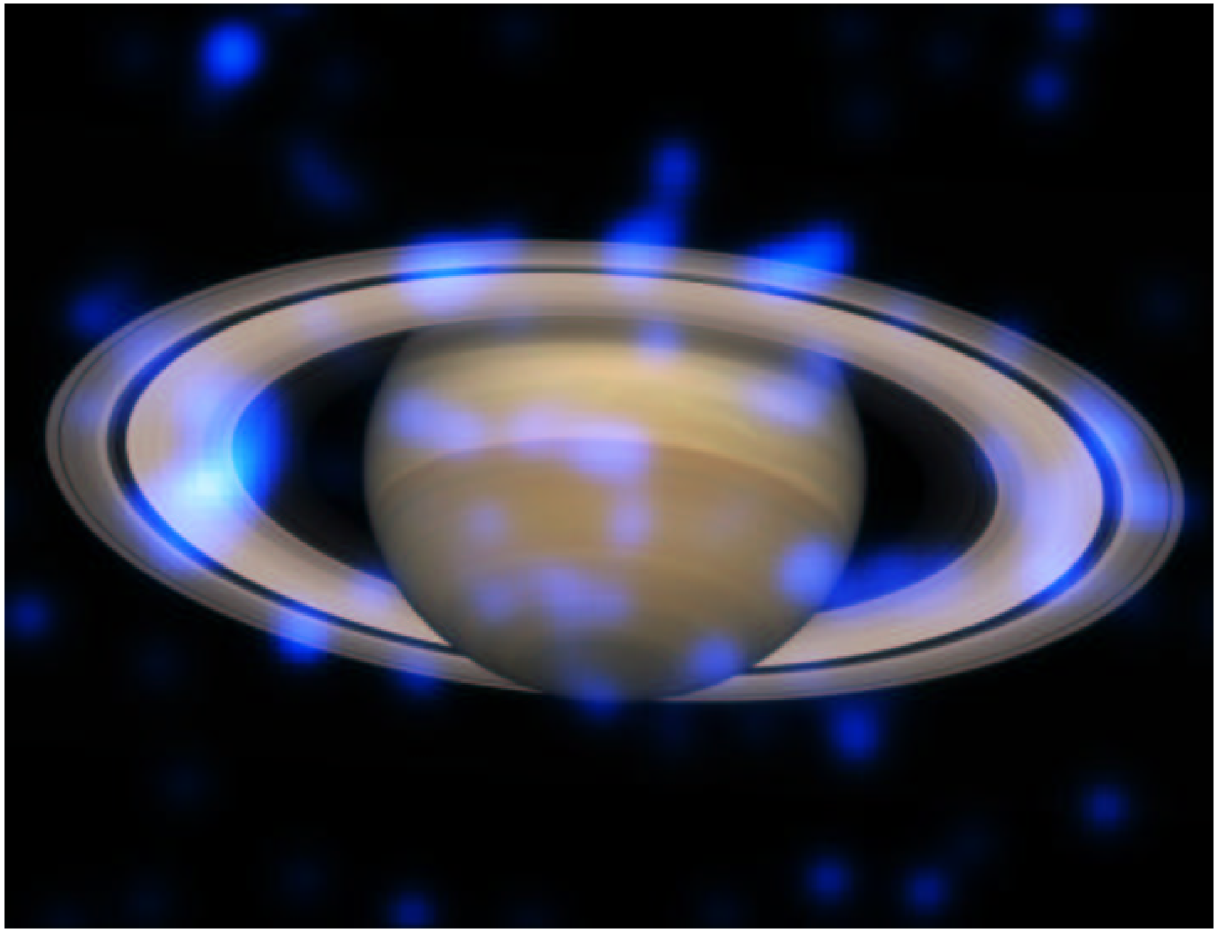
X-rays are concentrated near the equator (diffrent from Jupiter!)

Saturn’s X-rays are **not** because of fluorescence: compare X-ray spectra with Mars



Chandra X-ray: NASA/MSFC/CXC/A.Bhardwaj et al.; GOES-12 X-ray: NOAA/SEC

V. 12. Rings of Saturn sparkle in X-rays



NASA/MSFC/CXC/A.Bhardwaj et al.; Optical: NASA/ESA/STScI/AURA

Fluorescence caused by solar X-rays striking O atoms in H_2O icy rings.

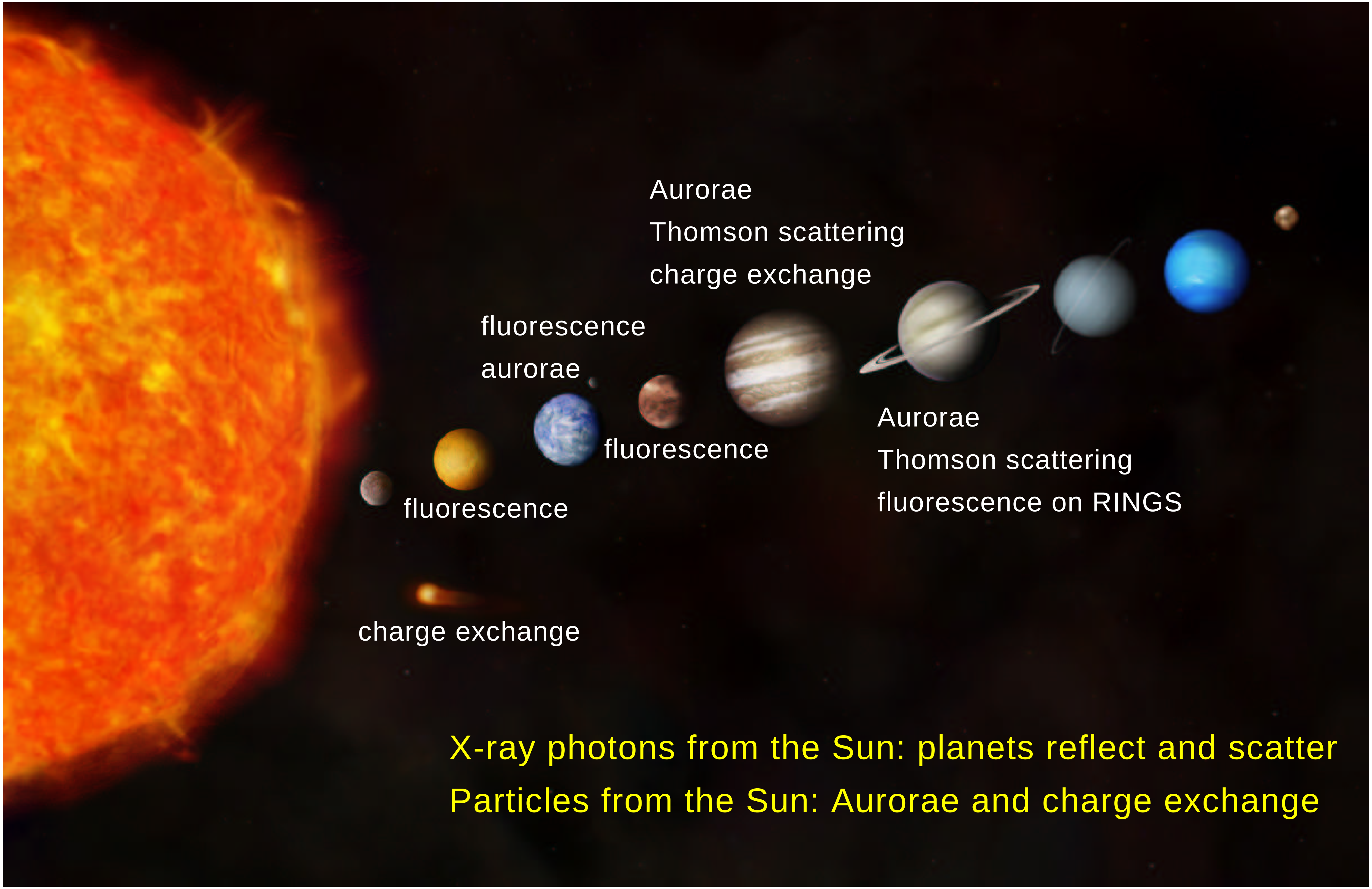
X-rays from B (inner) ring: 25,000 km wide and 40,000 km from the → surface

Concentration of X-rays on the morning side ? (left side) associated with spokes

Spokes: transient features clouds of fine ice that are lifted off the ring surface

Spokes are triggered by meteoroid impacts on the rings

V. 14. X-rays is solar system



Aurorae
Thomson scattering
charge exchange

fluorescence
aurorae

fluorescence

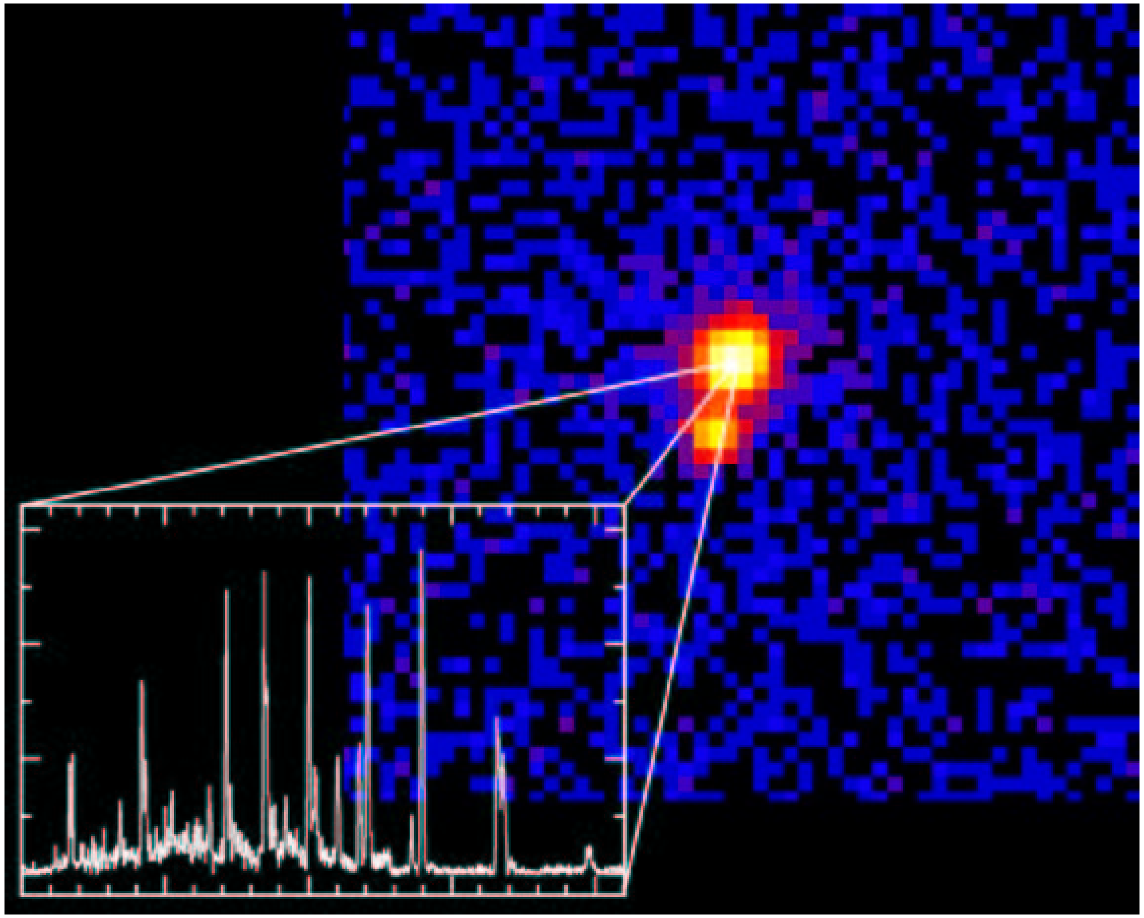
Aurorae
Thomson scattering
fluorescence on RINGS

fluorescence

charge exchange

X-ray photons from the Sun: planets reflect and scatter
Particles from the Sun: Aurorae and charge exchange

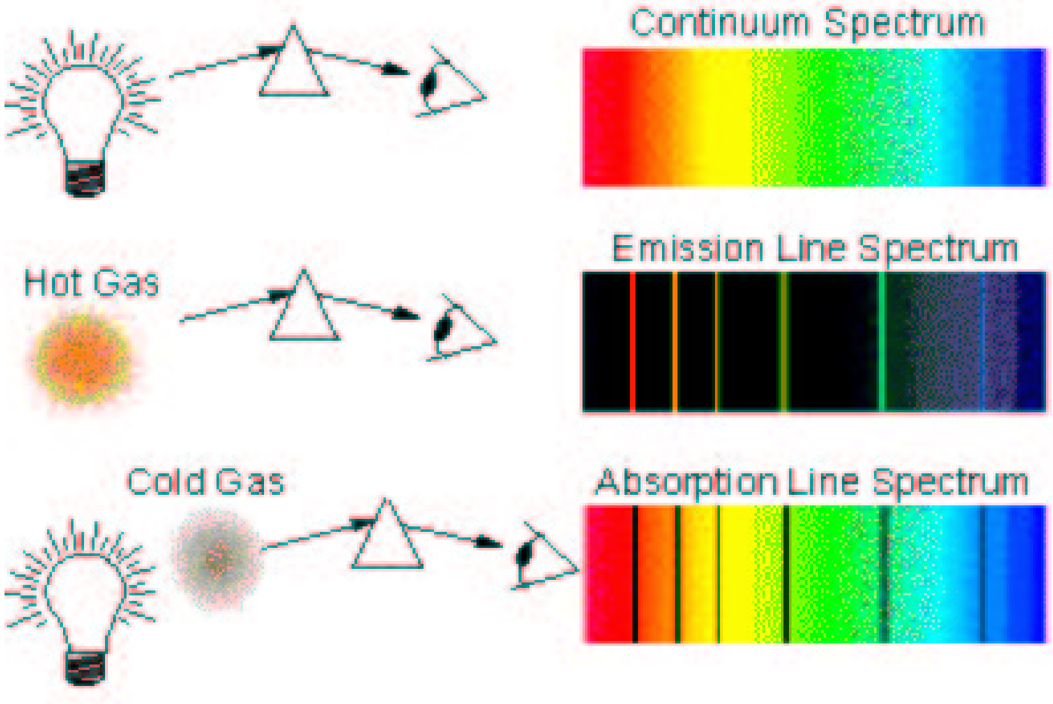
VI. X-rays from Normal Stars



NASA/EIT/W.Waldron, J.Cassinelli

Or not totaly abnormal

VI. 6. Brief reminder spectral classification



http://cass.ucsd.edu/public/tutorial/Stars.html

Wolf-Rayet (WR stars) hottest non-degenerate

Table 1: Stellar Spectral Classification

Sp	$T_{\rm eff}$	Hβ	Other Fetures	$M/M_\odot$	$R/R_\odot$	$R/R_\odot$	T(MS)
O	>33000	weak	He$^+$, mb. emission	>20	>10	90,000-800,000	10-1 Myr
B	10,500-30,000K	med.	HeI absorption	3-18	3.0-8	95-52,000	400-11 Myr
A	7,500-10,000K	strong	H lines	2-3	2-3 8-55	3Gyr - 440 Myr	
F	6,000-7,200 K	med.		1-2	1-1.5	2.0-7.0	7-3 Gy
G	5,500-6,000 K	weak, Ca+ H	K, Na ”D”	0.9-1	0.8-1	0.6-1.5	15-8 Gy
K	4,000-5,250 K	v. weak	a+, Fe, CH,CN	0.6-0.8	0.6-0.80	0.10-0.4	17 Gy
M	2,600-3,850 K	TiO, mol.		0.08-0.5	0.2-0.6	0.001-0.08	56 Gy
L			Brown dwarfs	<0.08			

VI. 6. Brief reminder stellar structure

Inner structure of stars is determined by:

Hydrostatic Equilibrium: $\frac{dP}{dr} = -\frac{GM(r)\rho}{r^2}$

Mass conservation: $\frac{dM(r)}{dr} = 4\pi r^2 \rho$

Energy conservation: $\frac{dL(r)}{dr} = 4\pi r^2 \rho \epsilon$

Energy transport:

By radiation: $\frac{dL(r)}{dr} \propto \frac{\kappa\rho}{T^3} \cdot \frac{L(r)}{4\pi r^2}$

By convection: $\frac{dL(r)}{dr} \propto \frac{T}{P}\frac{dP}{dr}$

Schwarzschild Criterion for convection: $\frac{dT}{dz} < \frac{g}{C_\mathrm{p}}$,

C_p - heat capacity