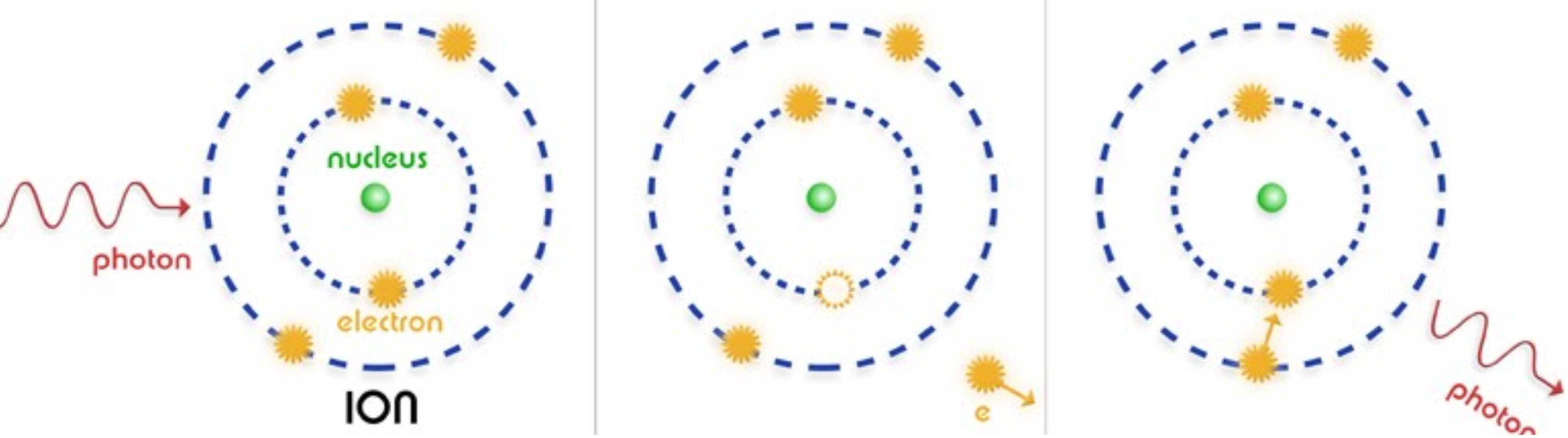
Lecture 09/27/2017

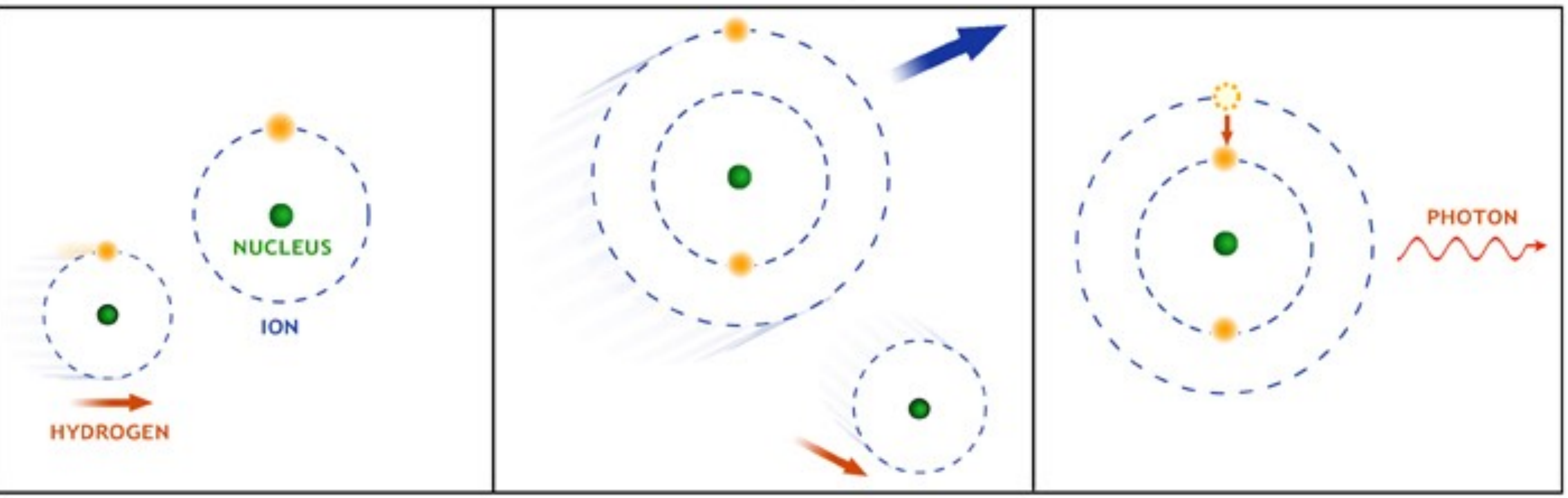
ASTRO 485

X-rays from the solar system

Reference: Dennerl et al., MPE
X-ray Universe 2017



Fluorescence line emission

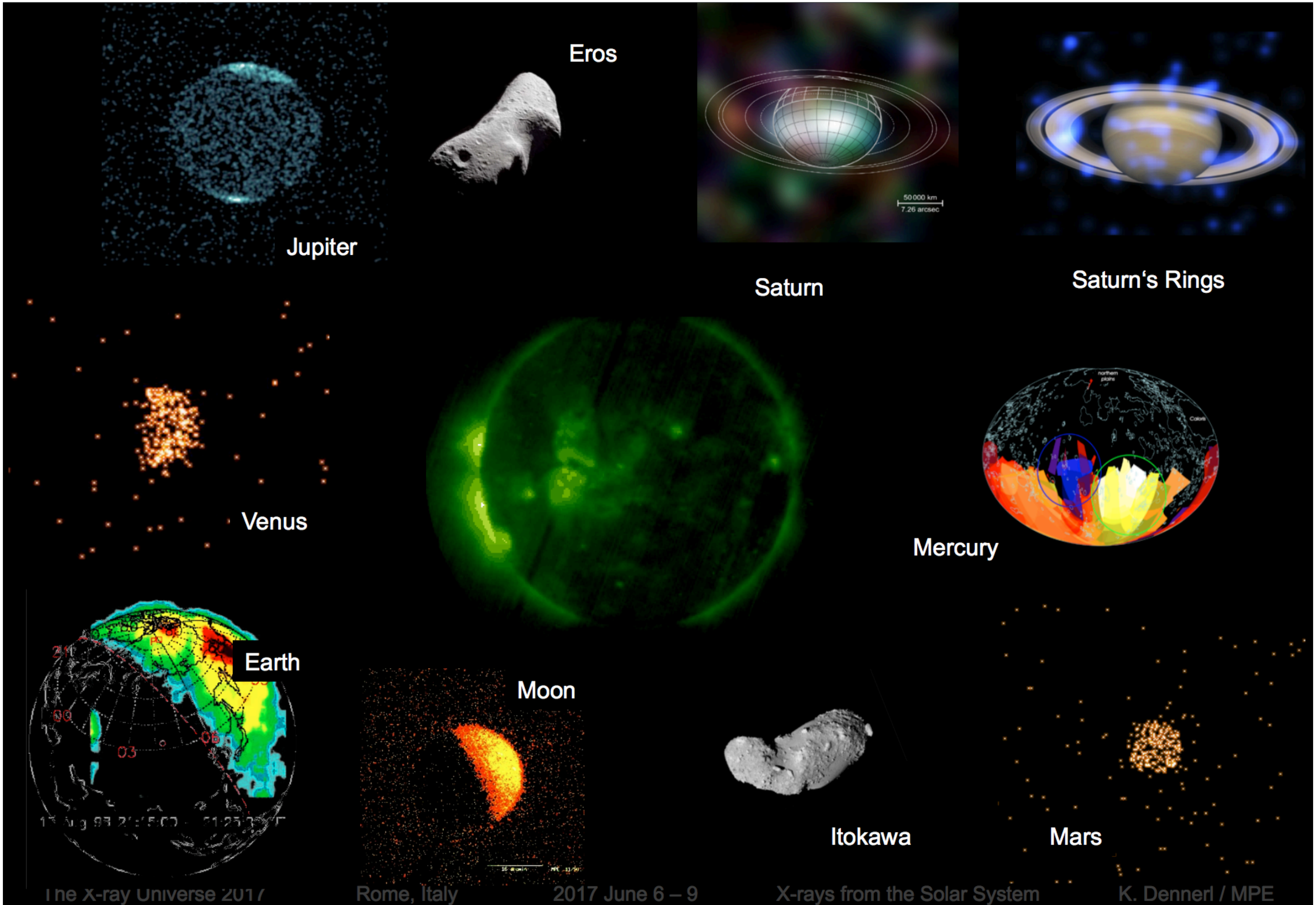


Charge exchange line emission

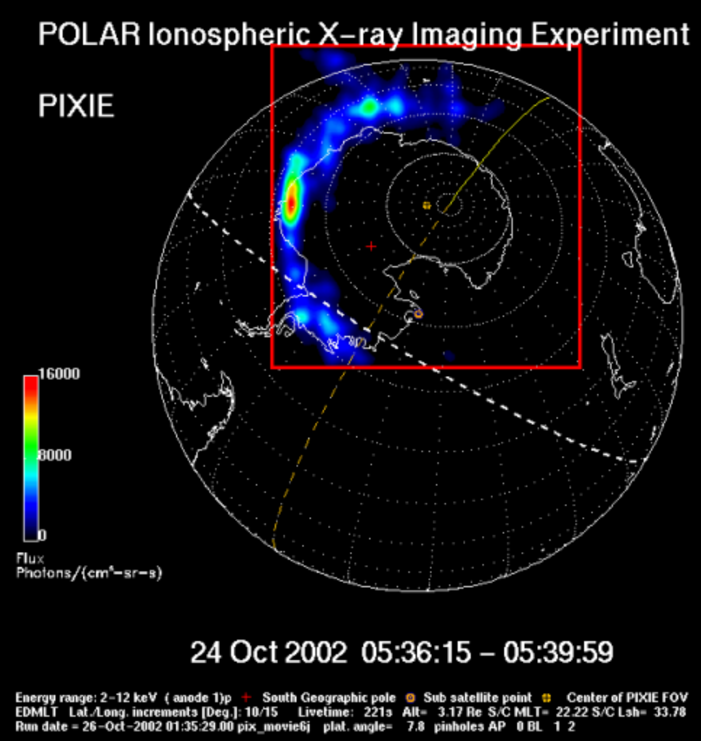
Solar X-ray photon (thermal) + scattering (for high density objects) — continuum

Bremsstrahlung (energetic electron / ion) — continuum

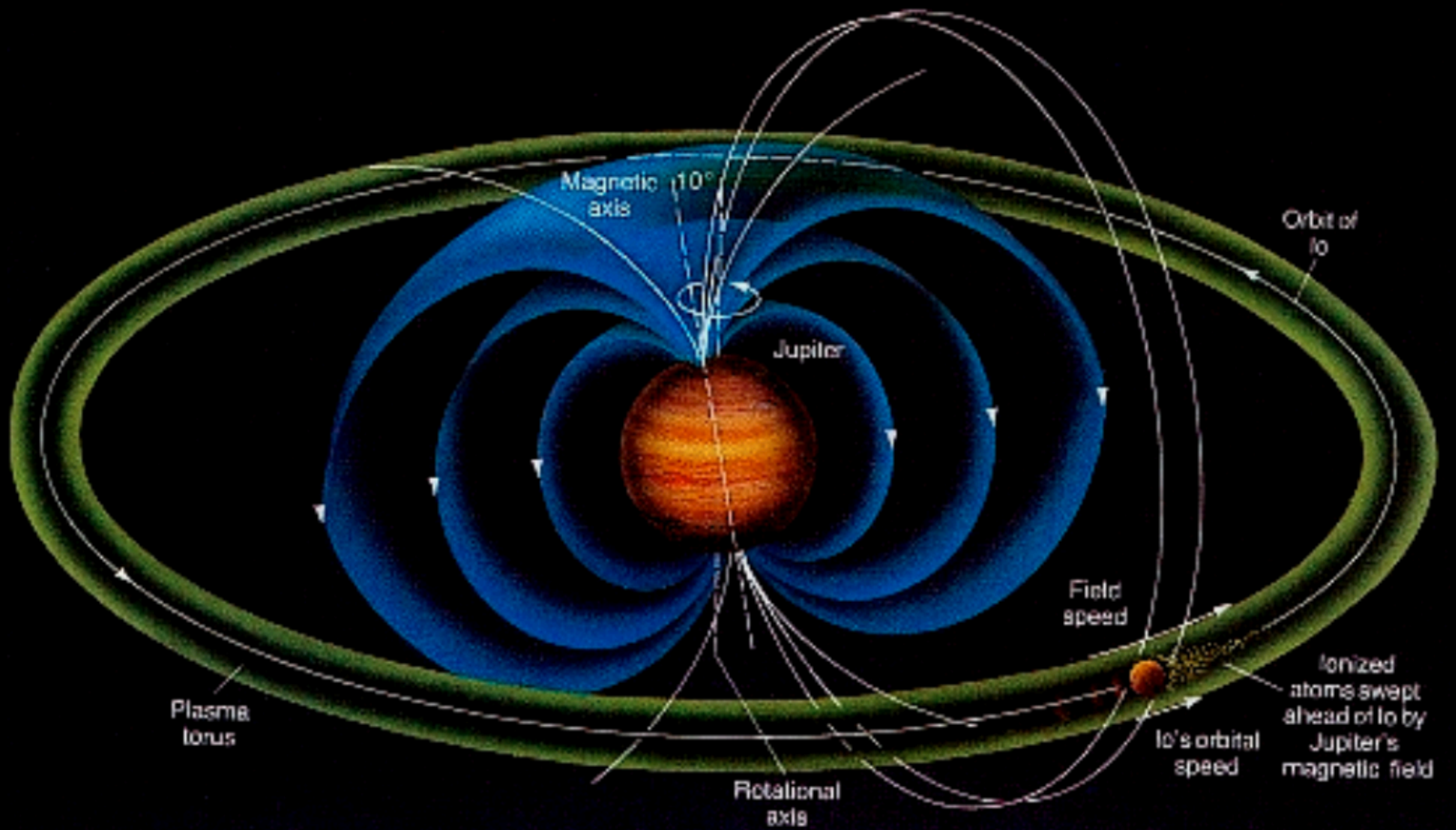
collisional ionization (energetic electron / ion) — line emission

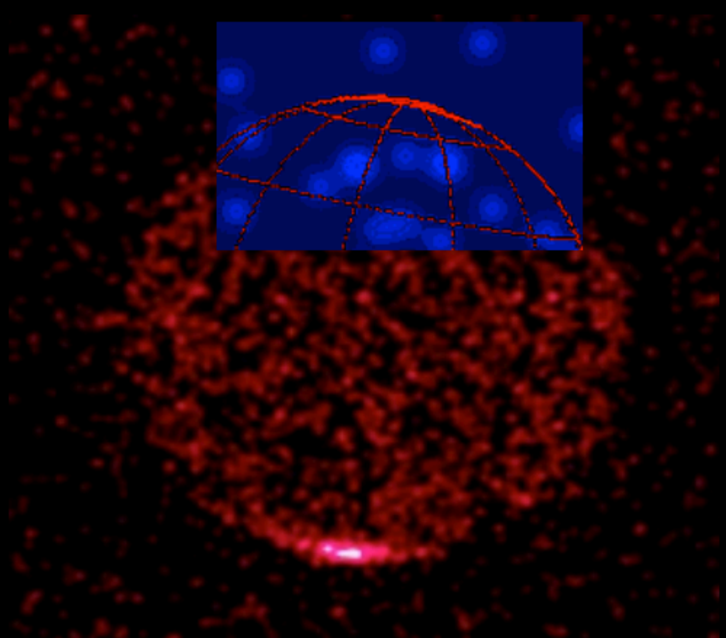


Scattered solar X-ray

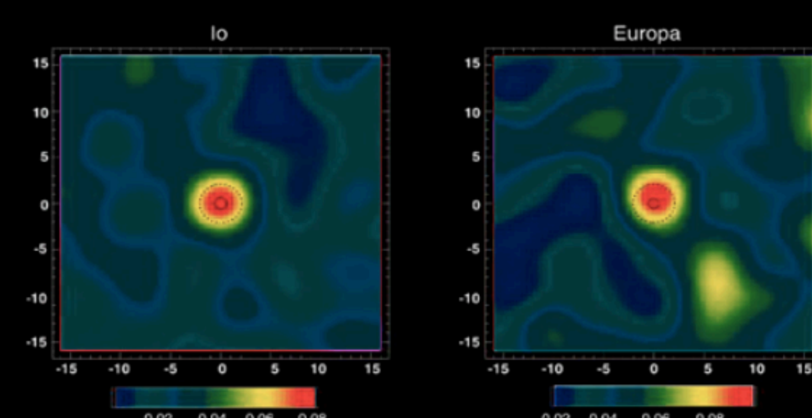


Earth

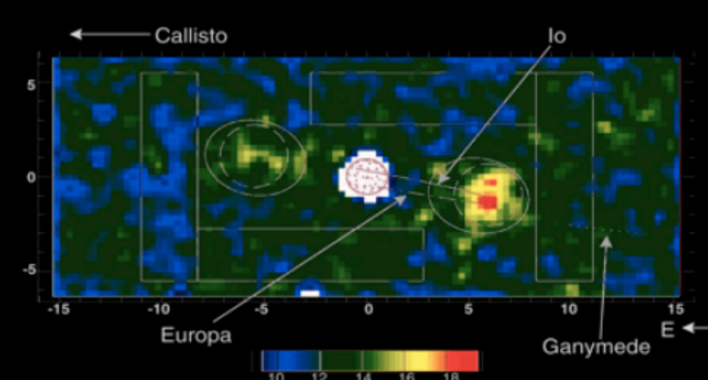




Jupiter



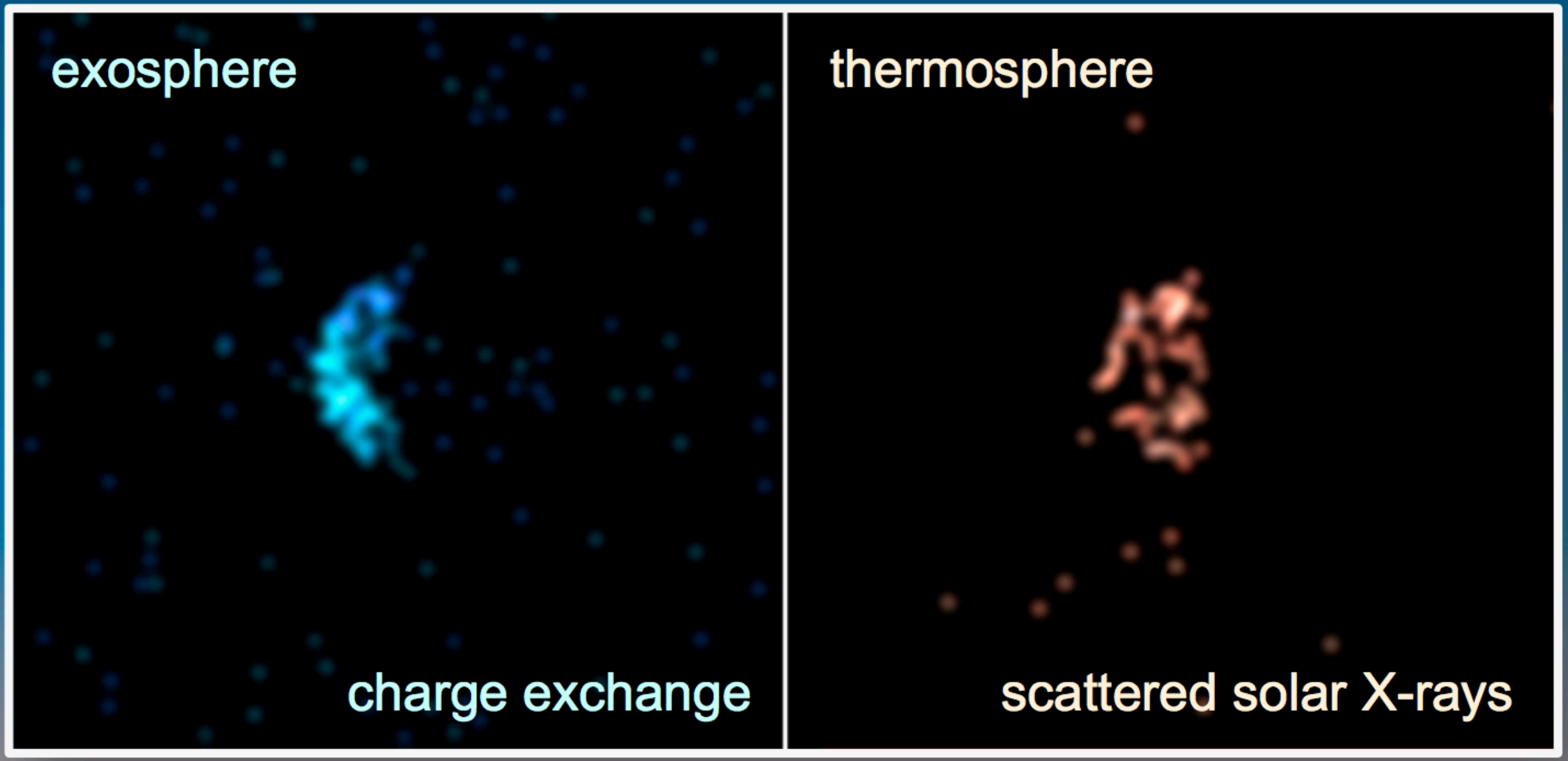
Io and Europa 2000



IPT 2000

energetic electrons / ions (perciptation)

Chandra/ACIS-I images of Venus



Dennerl et al. 2012

X-rays from the Solar System

Earth

History and context – before 1996

Journal of Geophysical Research Volume 64, No. 6 June, 1959

Auroral X-Rays, Cosmic Rays, and Related Phenomena during the Storm of February 10-11, 1958

J. R. Winckler, L. Peterson, R. Hoffman, and R. Arnoldy

School of Physics
University of Minnesota
Minneapolis, Minnesota

1959

Journal of Geophysical Research Vol. 73, No. 22, November 15, 1968

X-Ray Airglow in the Daytime Sky

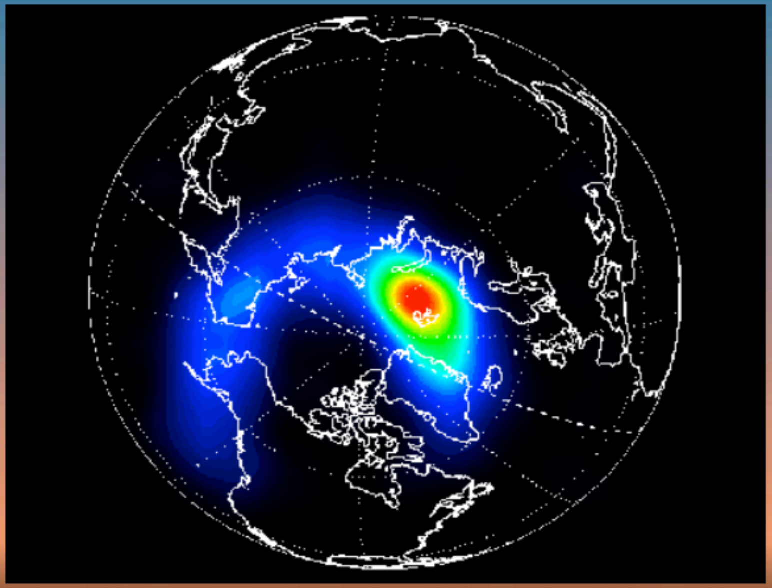
R. J. Grader, R. W. Hill, and F. D. Seward

University of California, Lawrence Radiation Laboratory
Livermore, California 94550

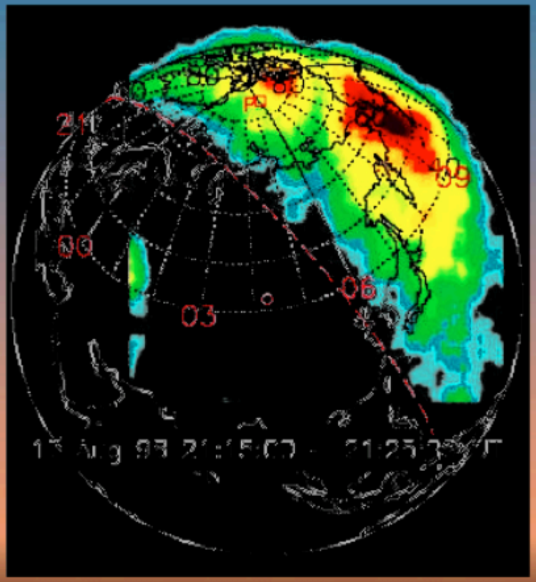
1968

Auroral X-ray bremsstrahlung has been observed from balloons and rockets since the 1960s and from spacecraft since the 1970s. Because of absorption of the low-energy X-rays propagating from the production altitude (~100 km) down to balloon altitudes (35-40 km), such measurements were limited to >20 keV X-rays.

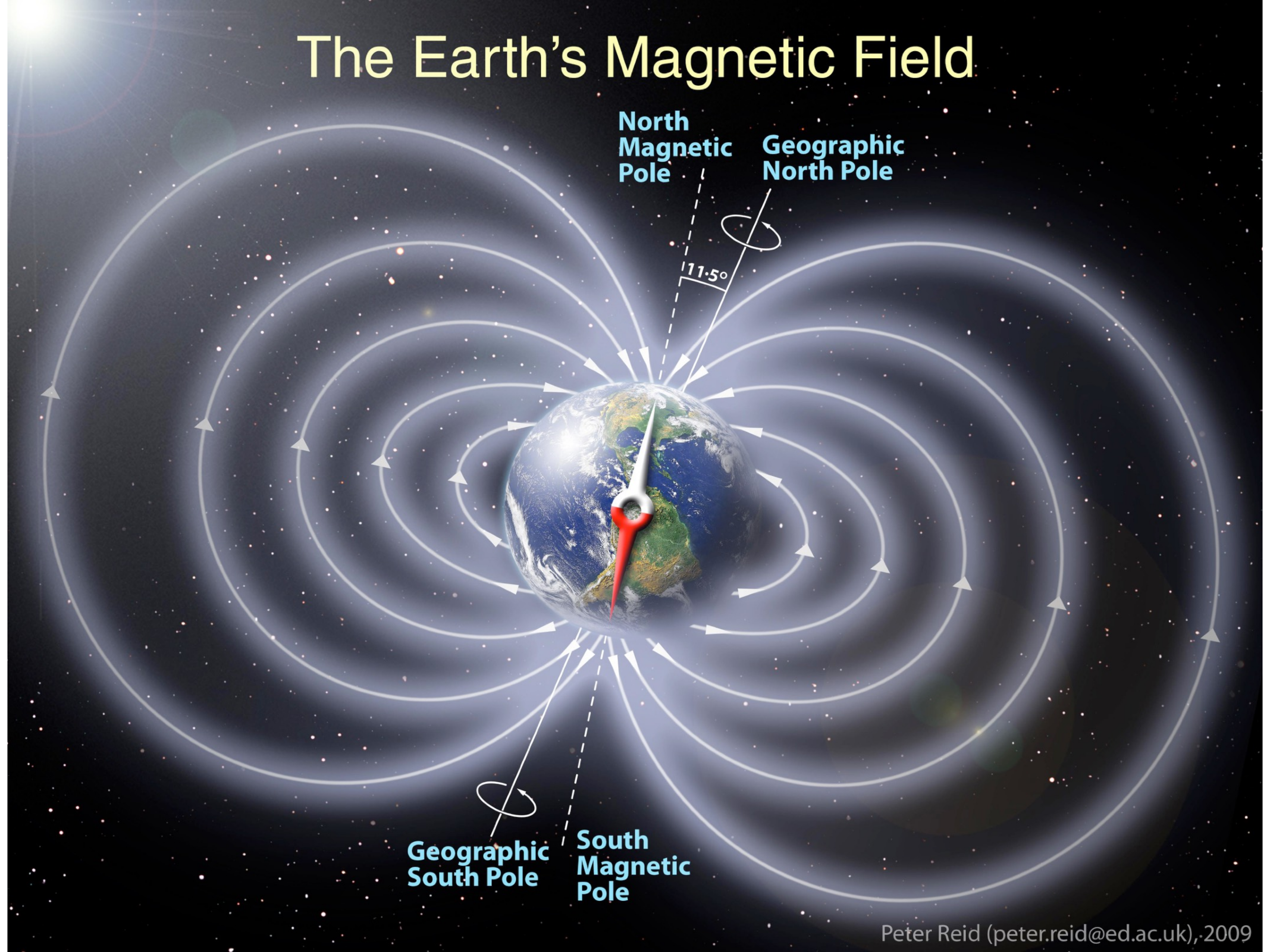
Fluorescent X-rays from the Earth were first indicated in 1967, when unexpectedly high background radiation was observed during a daytime stellar X-ray survey by a rocket.

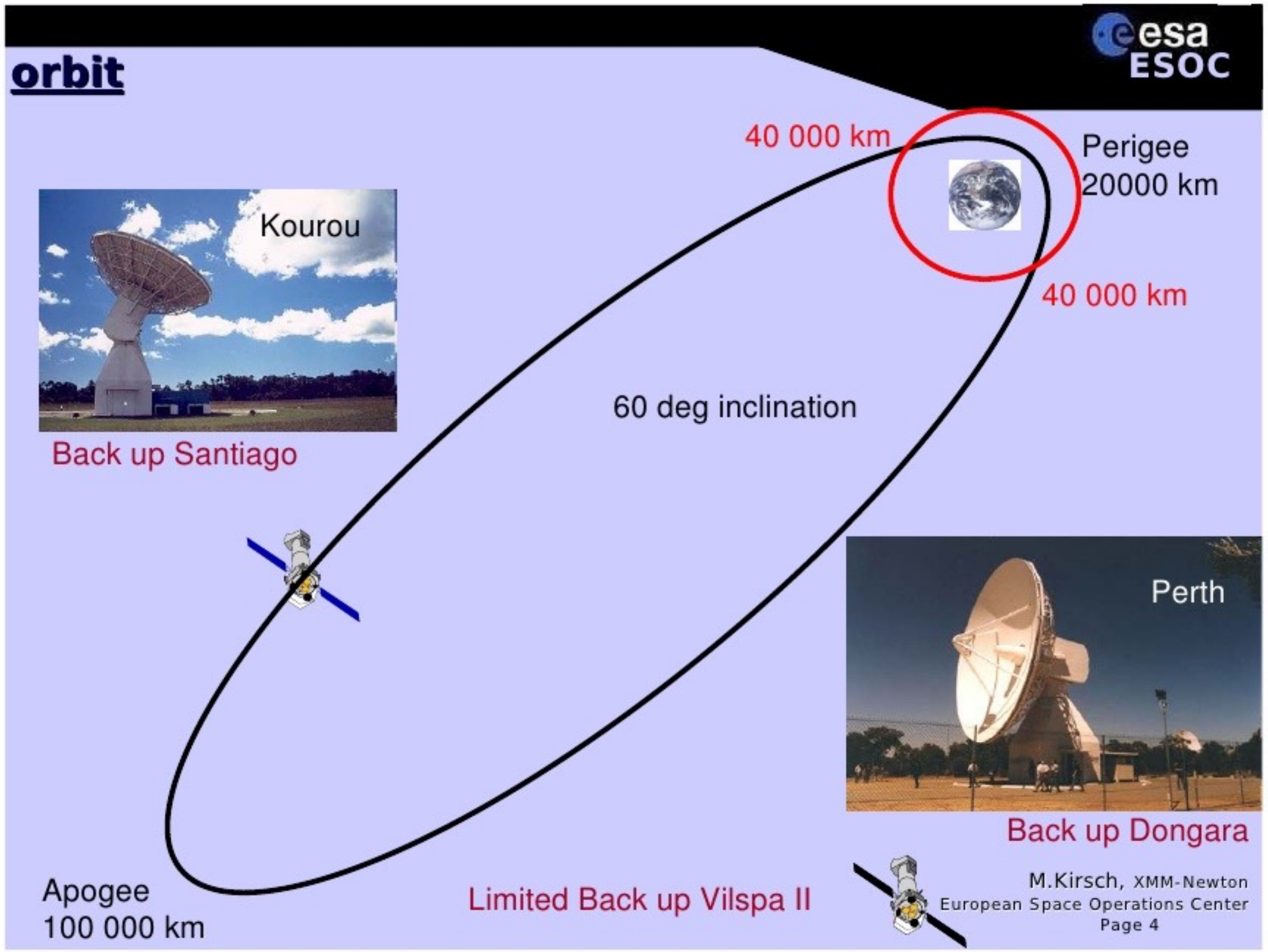


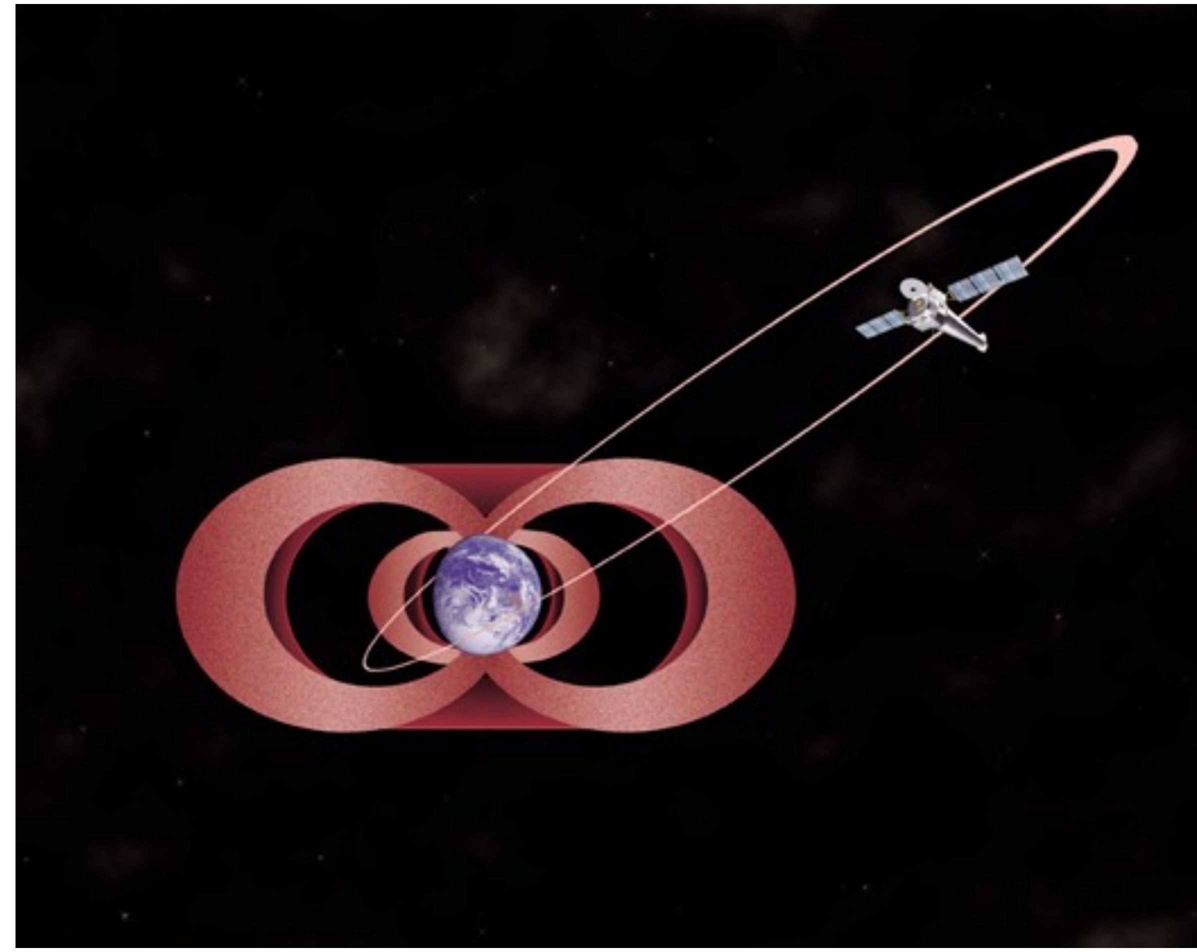
1996: first X-ray image of the Earth (PIXIE satellite)



1998: X-ray image of the Earth during a solar X-ray flare (PIXIE satellite)


The Earth's Magnetic Field
North Magnetic Pole
Geographic North Pole
11·5°
Geographic South Pole
South Magnetic Pole
Peter Reid (peter.reid@ed.ac.uk), 2009


esa
ESOC
orbit
40 000 km
Perigee
20000 km
Kourou
40 000 km
60 deg inclination
Back up Santiago
Perth
Back up Dongara
Apogee
100 000 km
Limited Back up Vilspa II
M.Kirsch, XMM-Newton
European Space Operations Center
Page 4

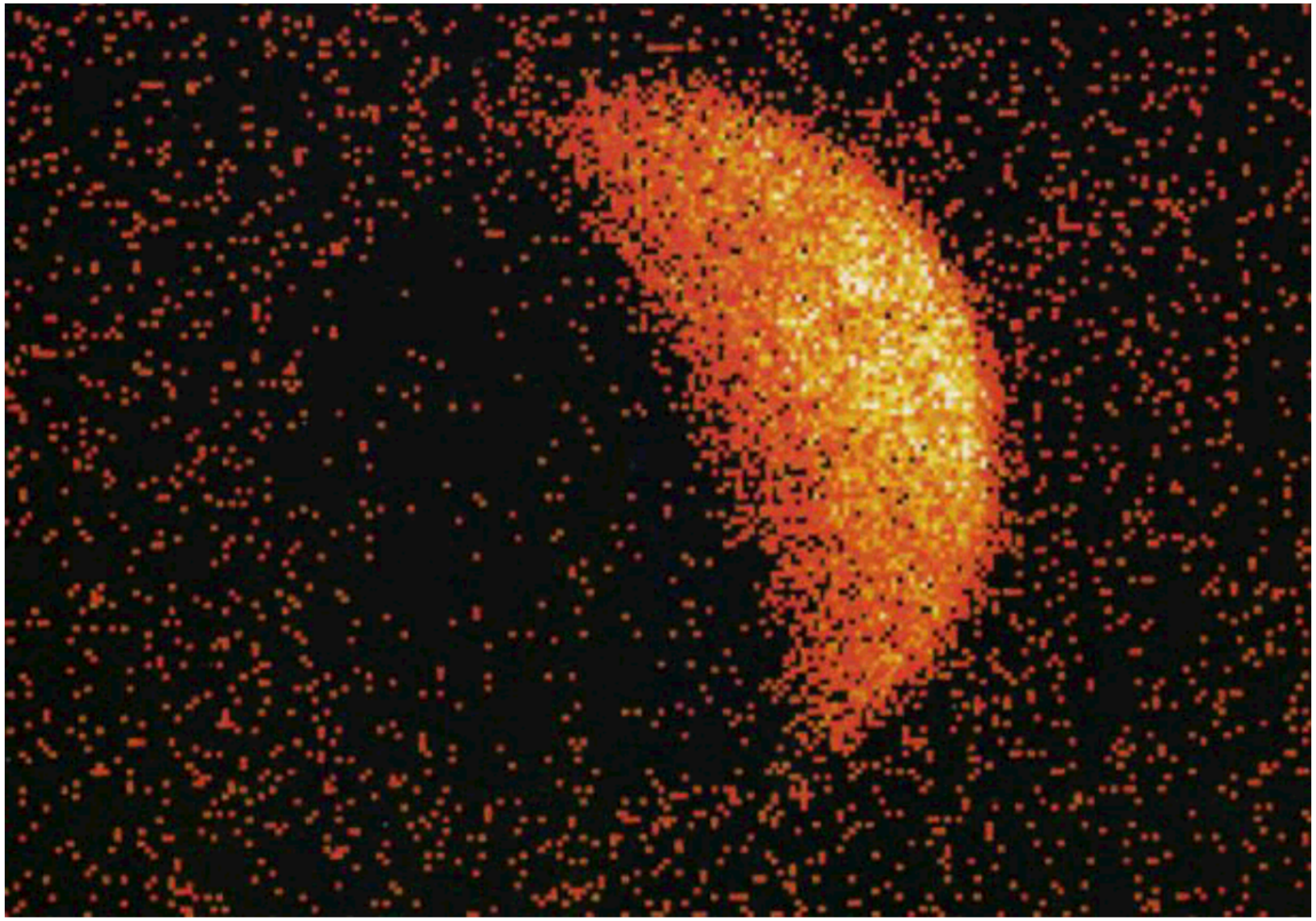


Earth

- Auroral particles — high energy electron “precipitate” along the magnetic field lines and high the Earth’s atmosphere.

- Solar scattered X-rays
  For 0.2— 1 keV scattering occurs at 100 — 120 km
  1—10 keV scattering occurs at 70—100 km

Moon



Moon

- Main source : scattered solar X-ray
- Dark side: bombardment of lunar surface by solar wind particles (e^-)
- X-rays can also be used for studying the lunar surface composition

X-rays from the Solar System

Jupiter

History and context – before 1996

Jupiter was detected in X-rays in 1979 with the Einstein satellite.

Metzger et al.: X Rays From Jupiter

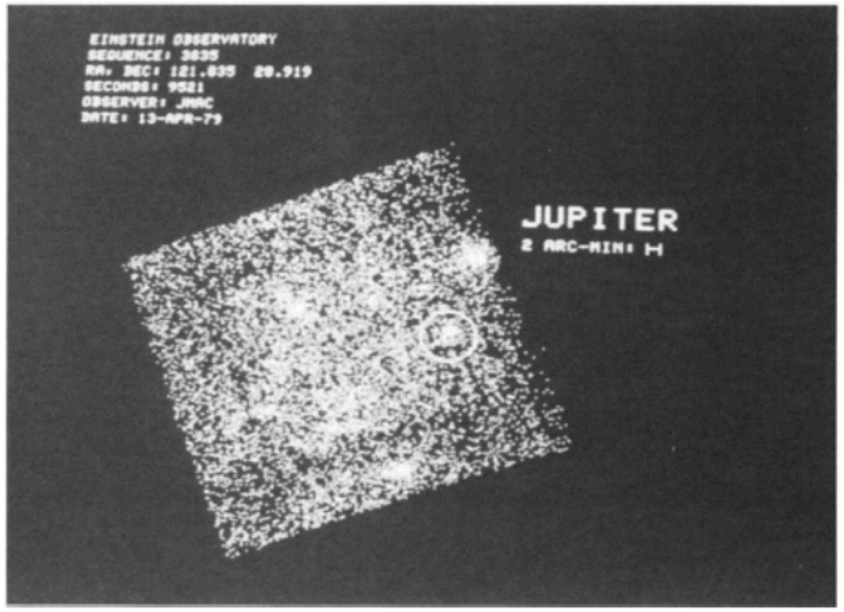


Plate 1. The first X ray image of a planetary body: Jupiter (circle) as seen by the Einstein Observatory satellite on April 13, 1979.

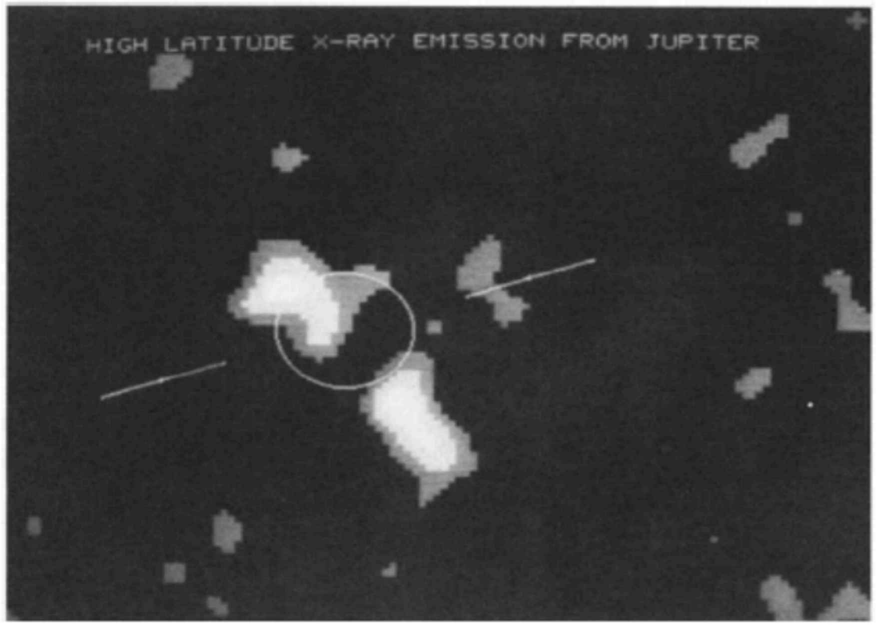


Plate 2. Intensity distribution of Jupiter's auroral X ray sources superimposed on an outline of the planetary disc. The measurement was made by the High Resolution Imager on the Einstein Observatory. The straight line corresponds to the equator. Motion of the planet is from right to left.

ROSAT 1992

WAITE ET AL.: ROSAT OBSERVATIONS OF THE JUPITER AURORA

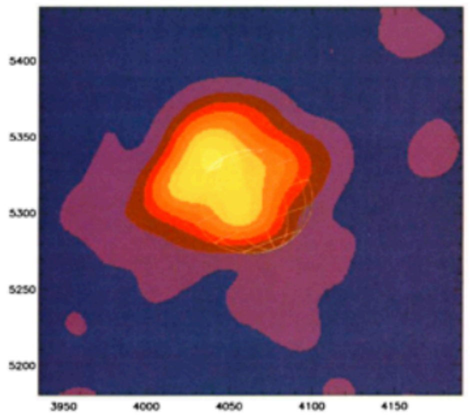
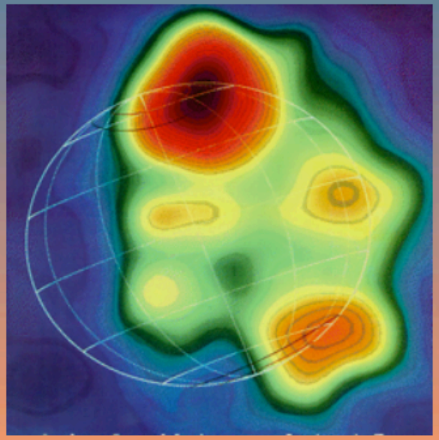


Plate 1. A Gaussian point spread filter (half width 7 arc sec) is used to construct this representation of the Röntgen satellite (ROSAT) HRI image with X ray intensity in pseudocolor. The image contains all the data acquired over the day-long observation and is therefore temporally and rotationally averaged. The position of Jupiter is indicated with the equator and a rough latitude-longitude coordinate system.



ROSAT 1994

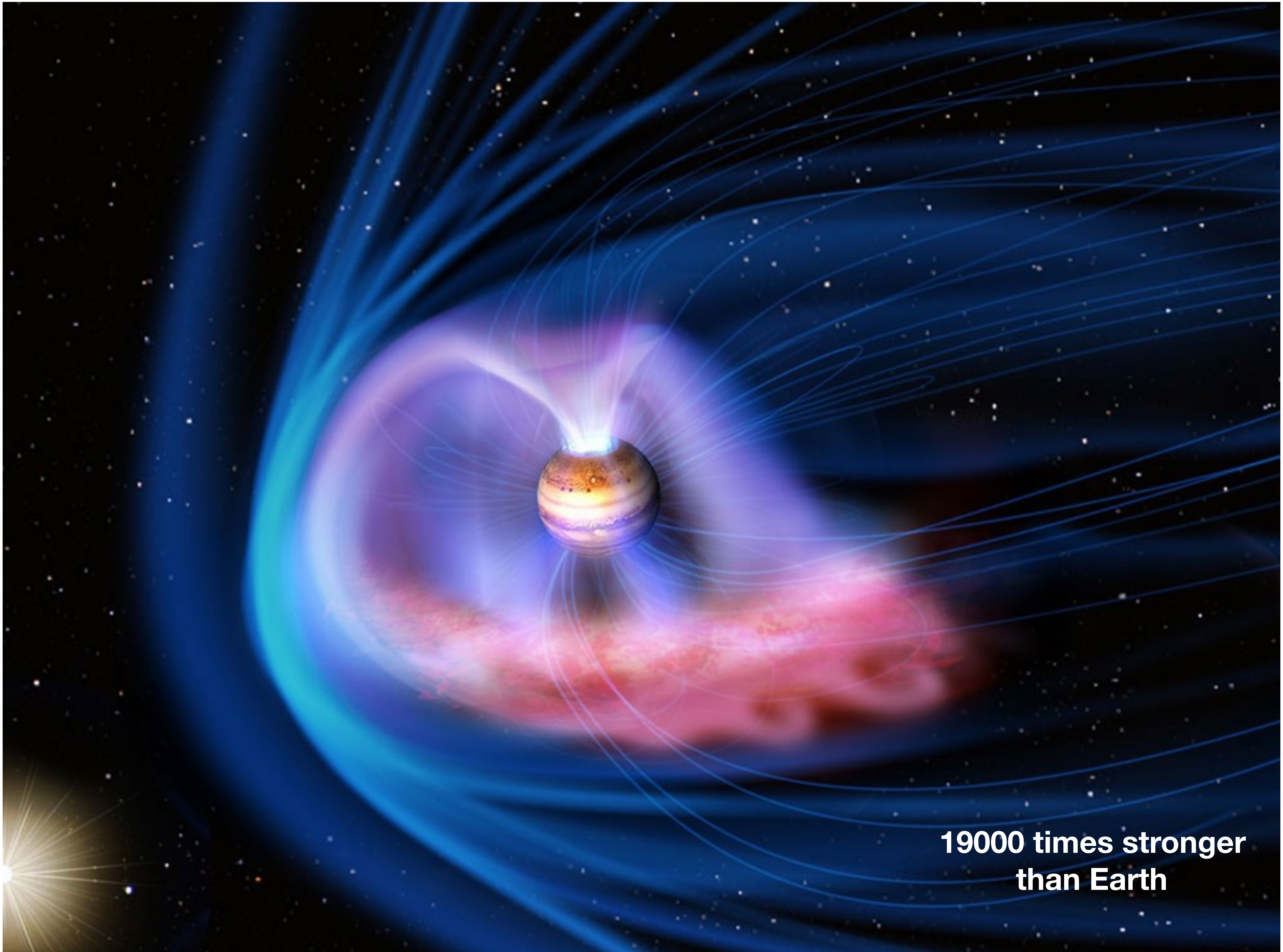
Jupiter

- Strong source of non-thermal radio emission

- The origin of Jupiter’s X-ray emission was not well-understood until Chandra/XMM

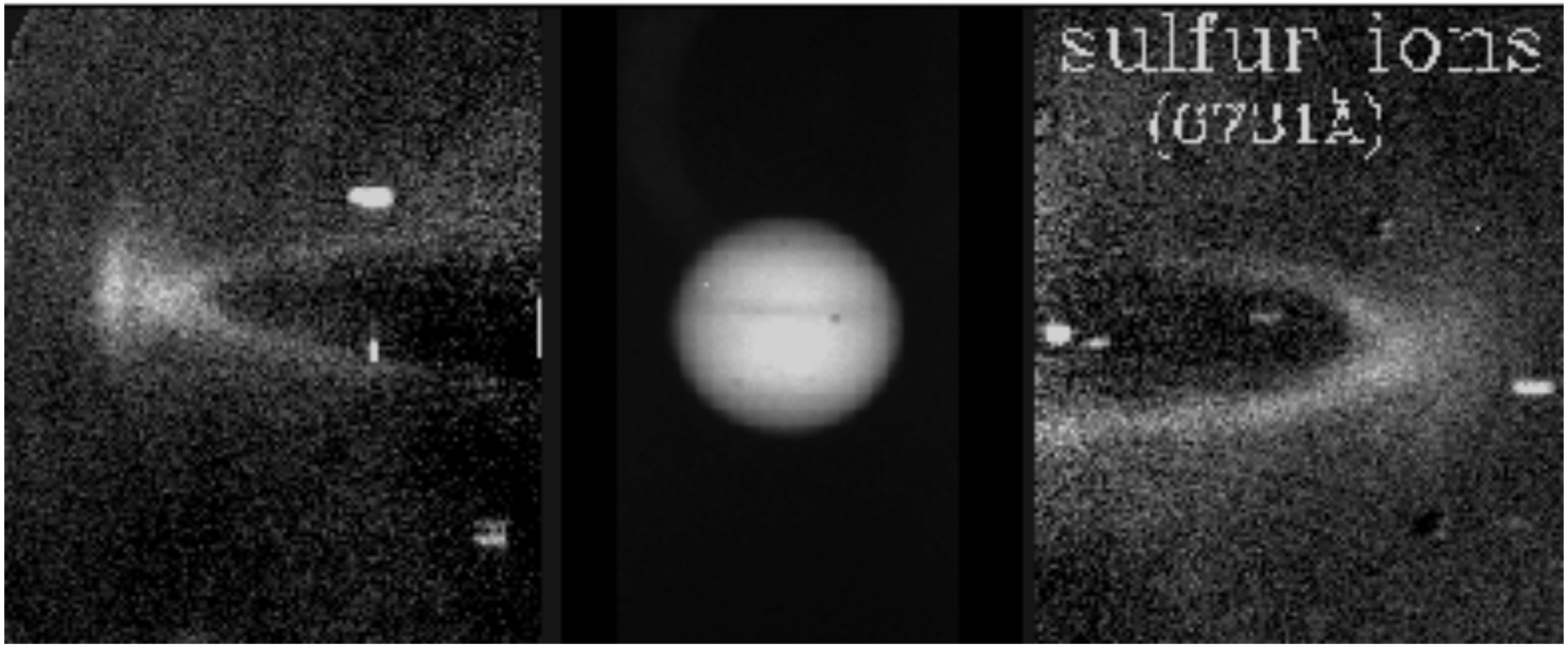
- Mostly soft X-ray emission (< 1keV)

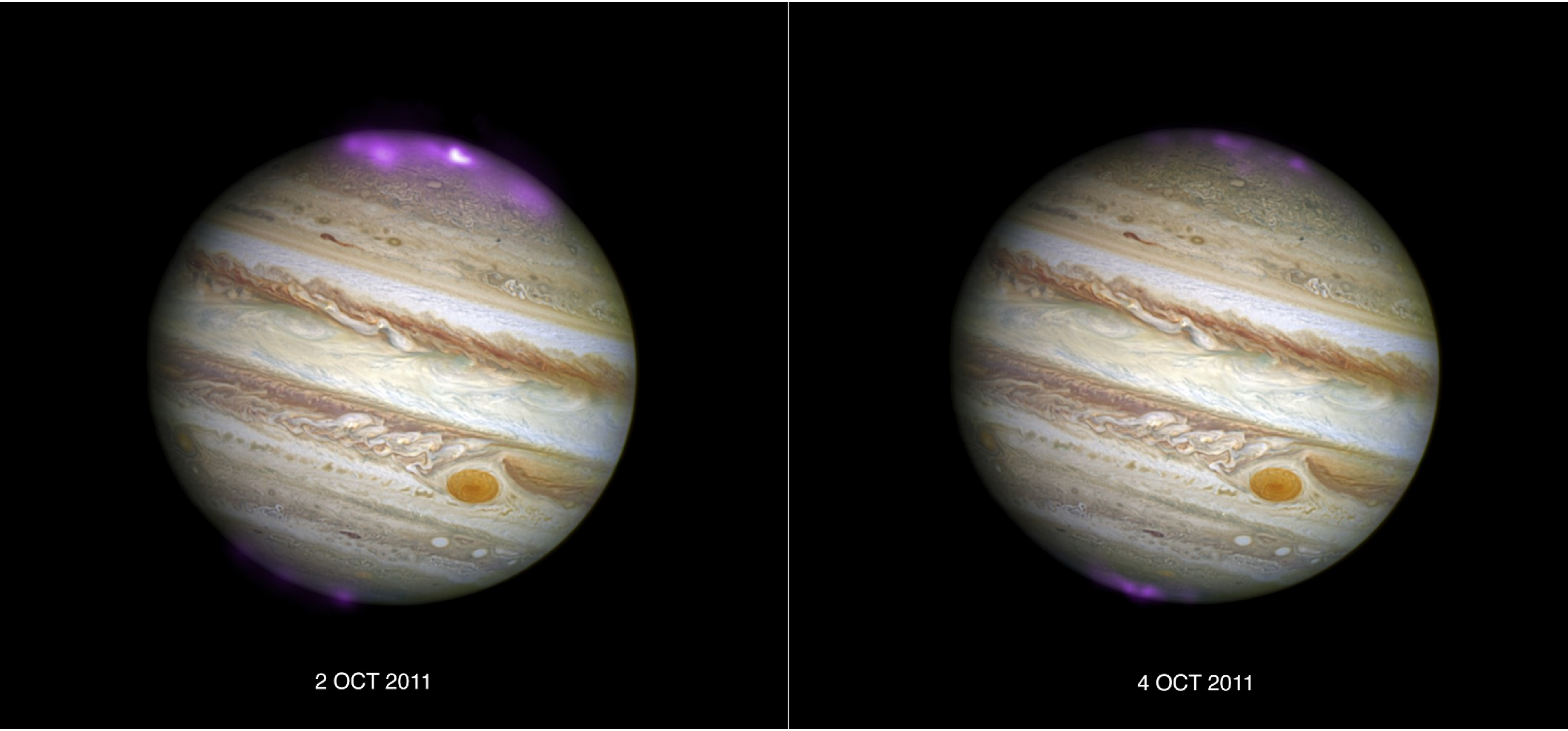
- Originally thought to be associated with IO

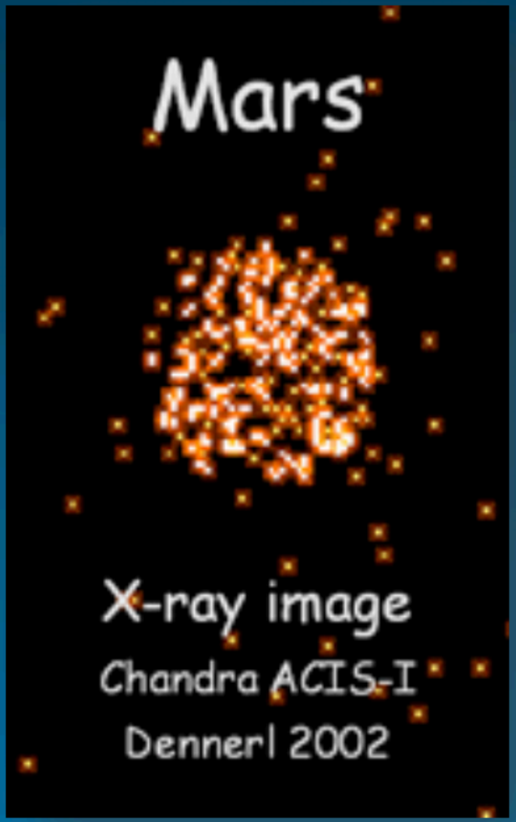

19000 times stronger
than Earth

IO

- Plasma torus




2 OCT 2011
4 OCT 2011



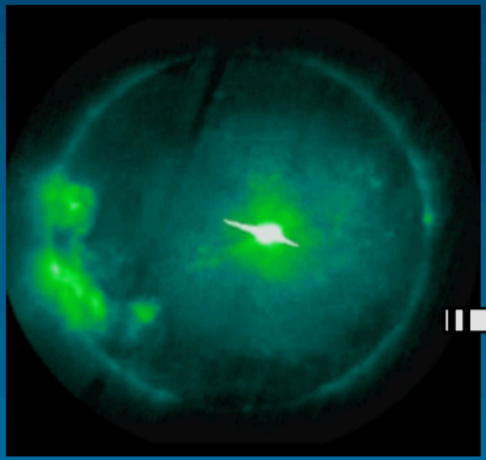
Venus & Mars:

One X-ray photon among ~10^{12} optical photons

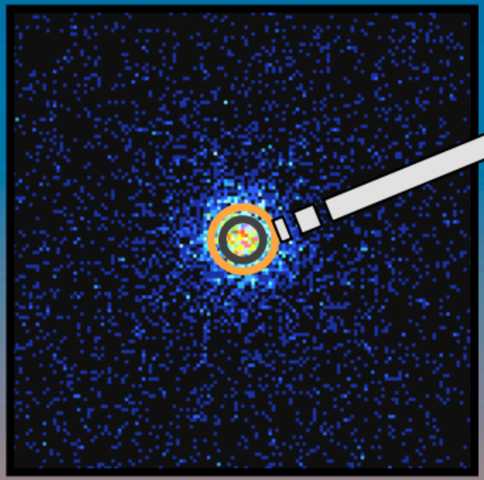
Saturn:

One X-ray photon every ~8 min
(Chandra ACIS-S, 2003)

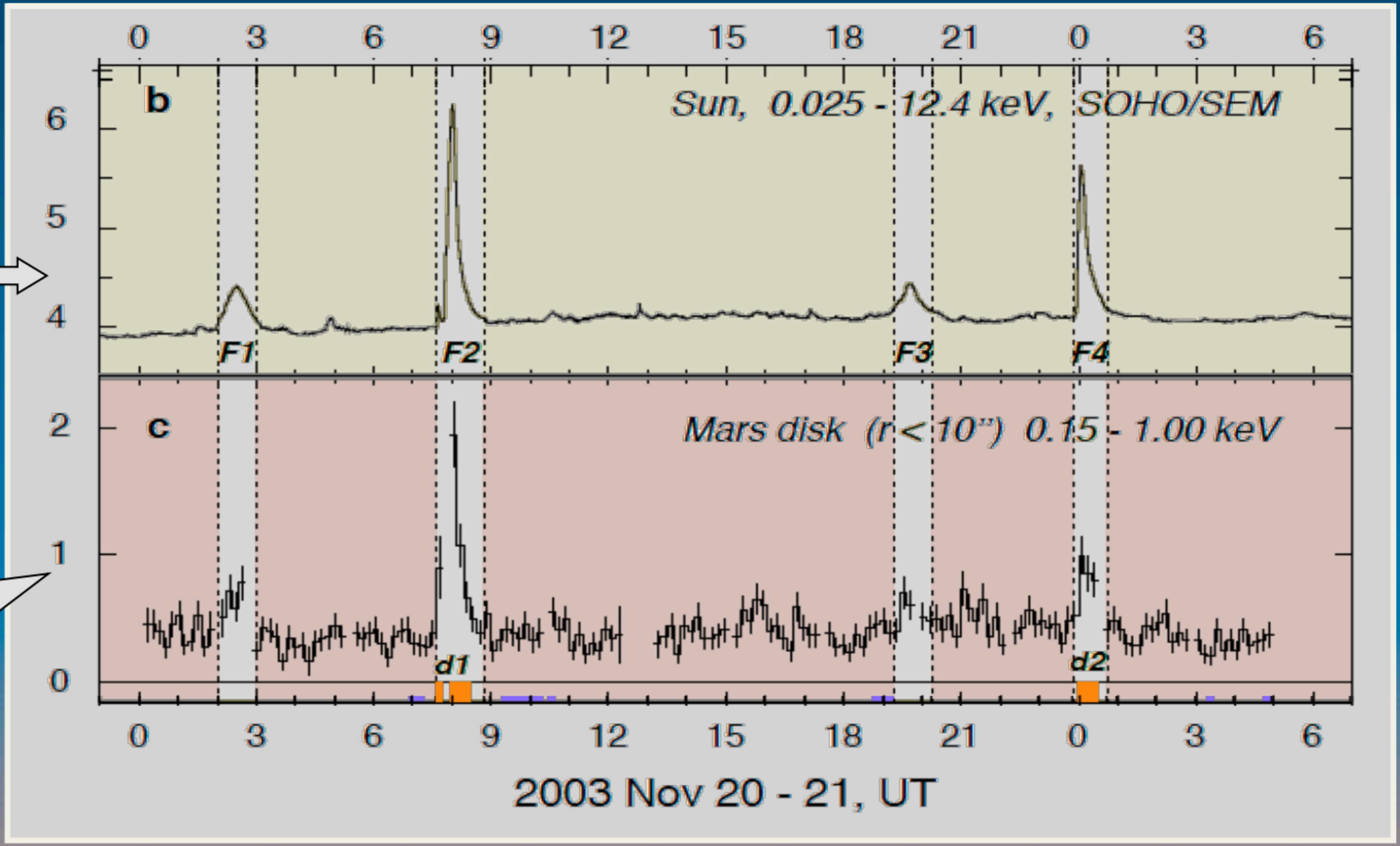
Mars illuminated by solar X-ray flares



Sonne

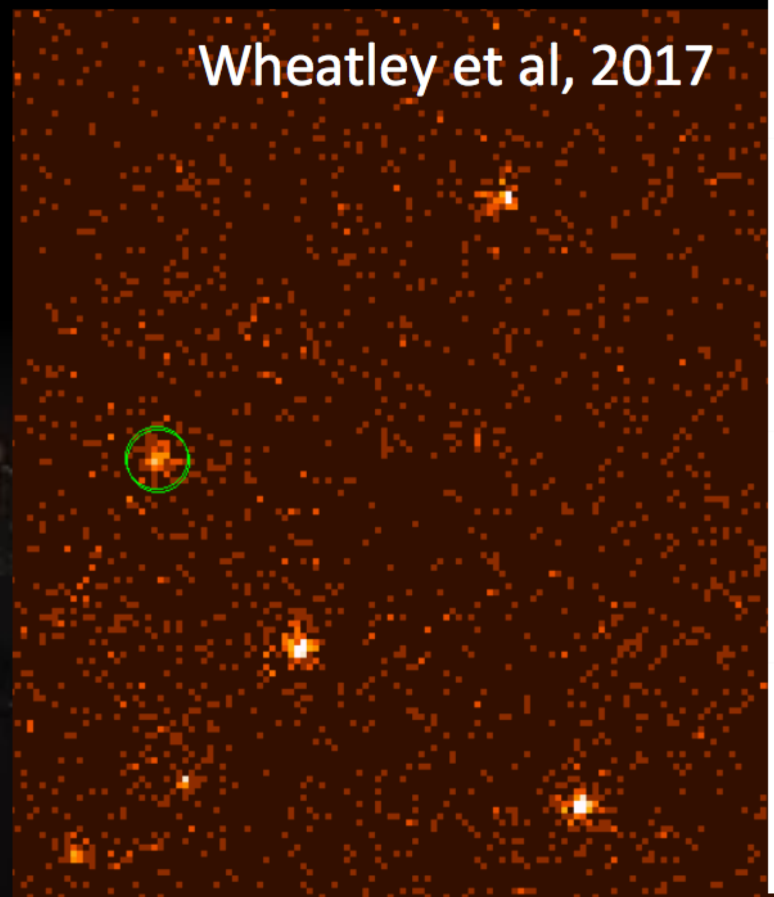


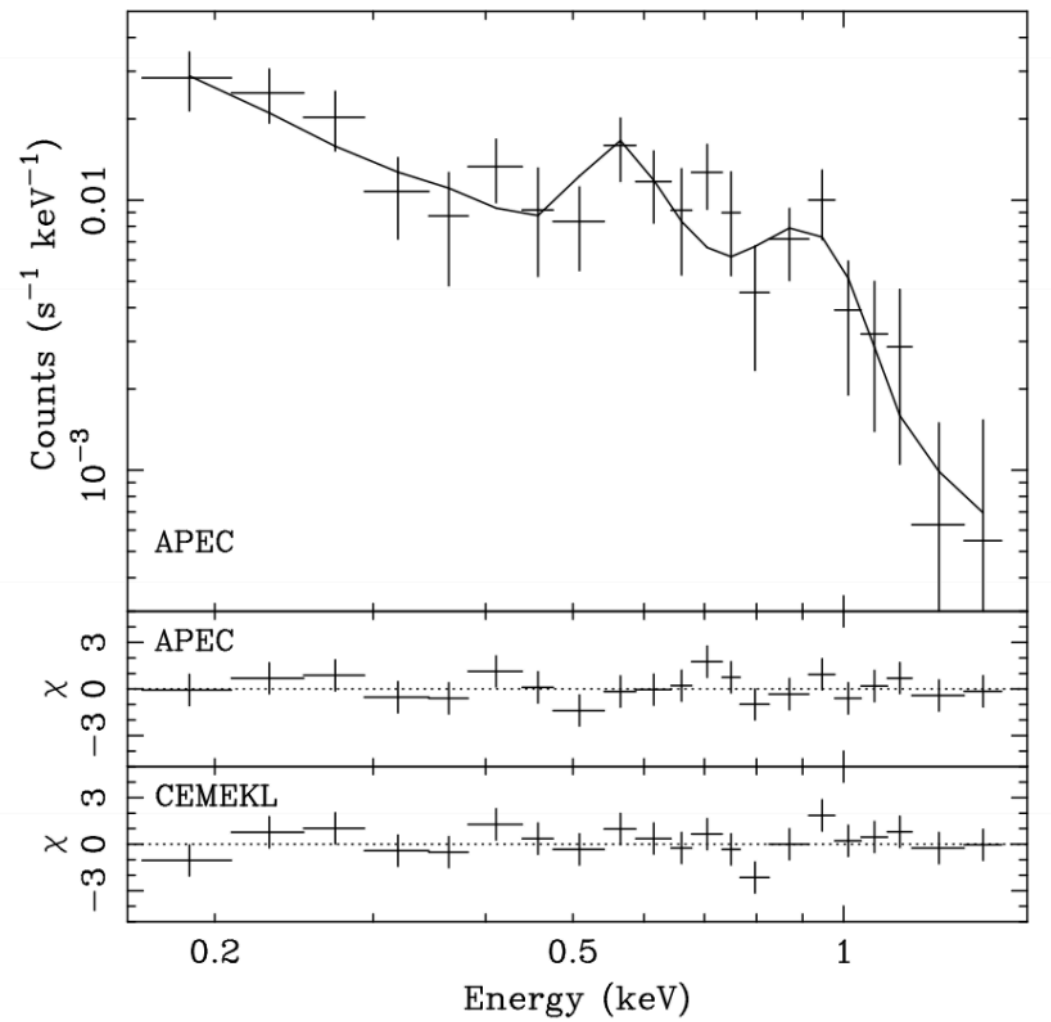
Mars



solar X-ray flares also observed from Jupiter and Saturn

TRAPPIST-1 in X-rays



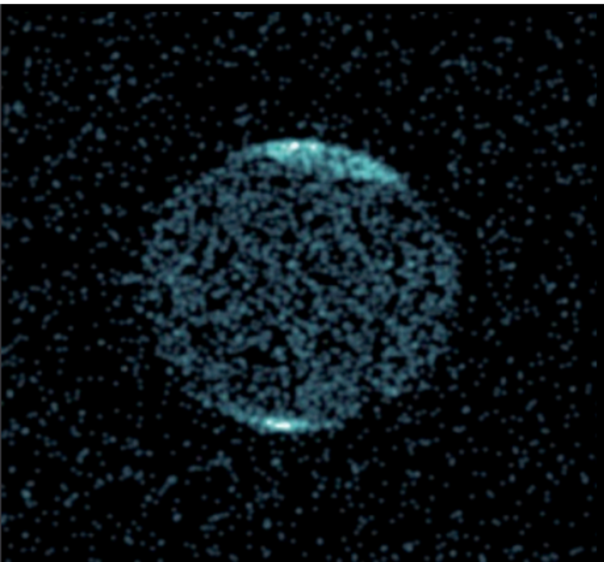


Strong XUV emission similar to quiet Sun despite L_{Bol} only 5×10^{-4} L_{sun}

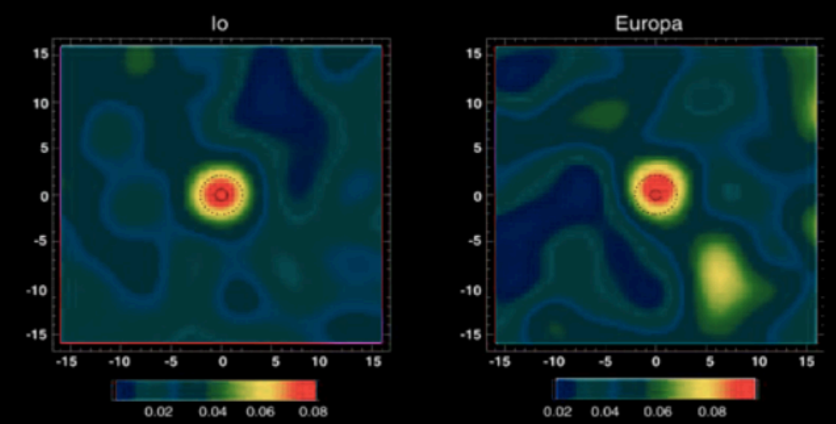
$L_X/L_{Bol} \sim 3 \times 10^{-4}$
XUV irradiation is 50x stronger than assumed by Bolmont et al 2016

Models of water loss for this XUV flux show inner planets desiccated during initial runaway greenhouse, while HZ planets may have lost less than 1 Earth ocean - Bolmont et al 2017

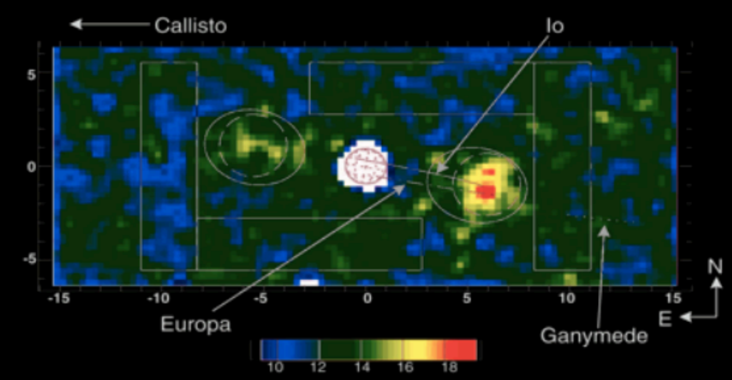
Possible that M dwarf HZ planets with thick primordial H/He can be rendered habitable by XUV evaporation - Owen & Mohanty 2016



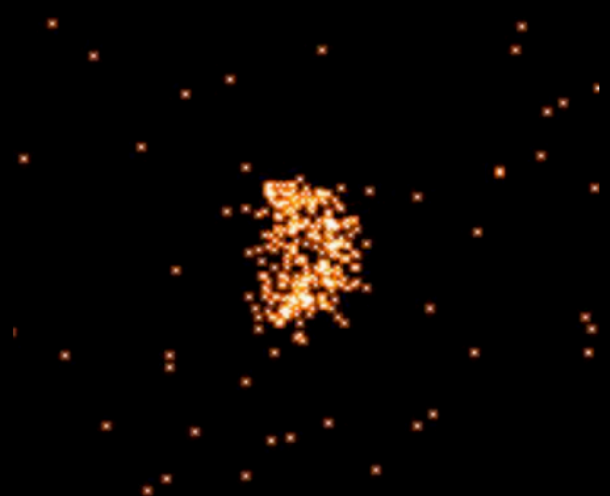
Jupiter 2000



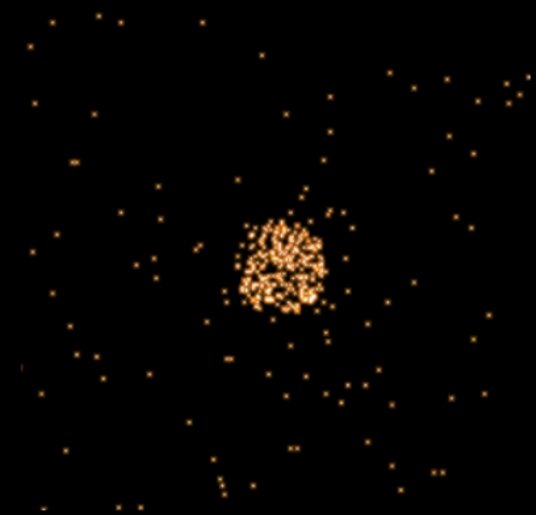
Io and Europa 2000



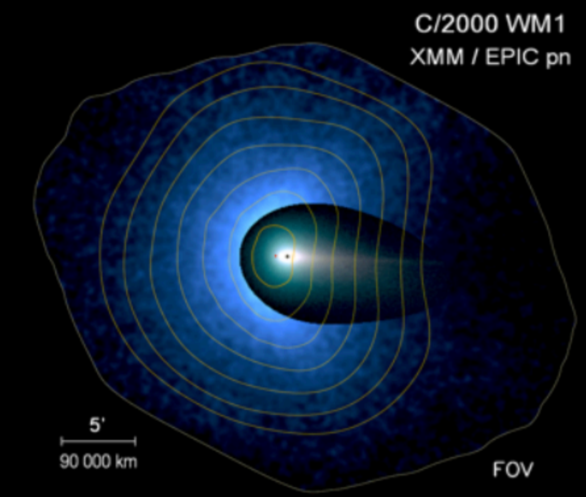
IPT 2000



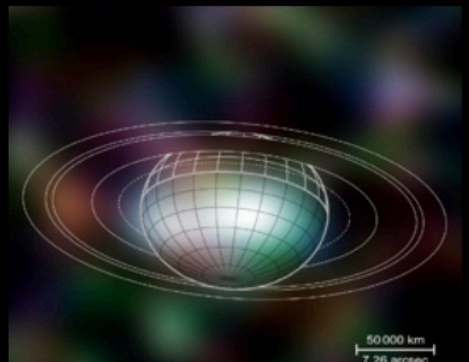
Venus 2001



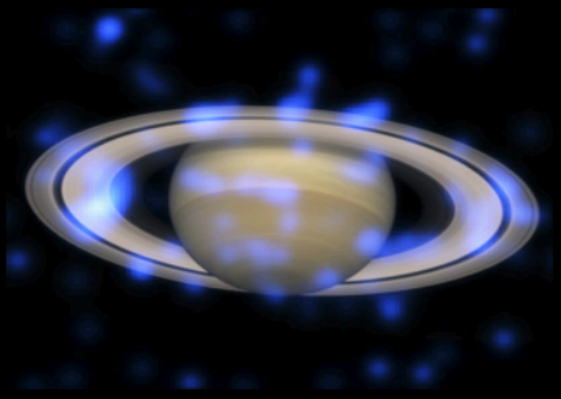
Mars 2001



Comet (one of many) 2001

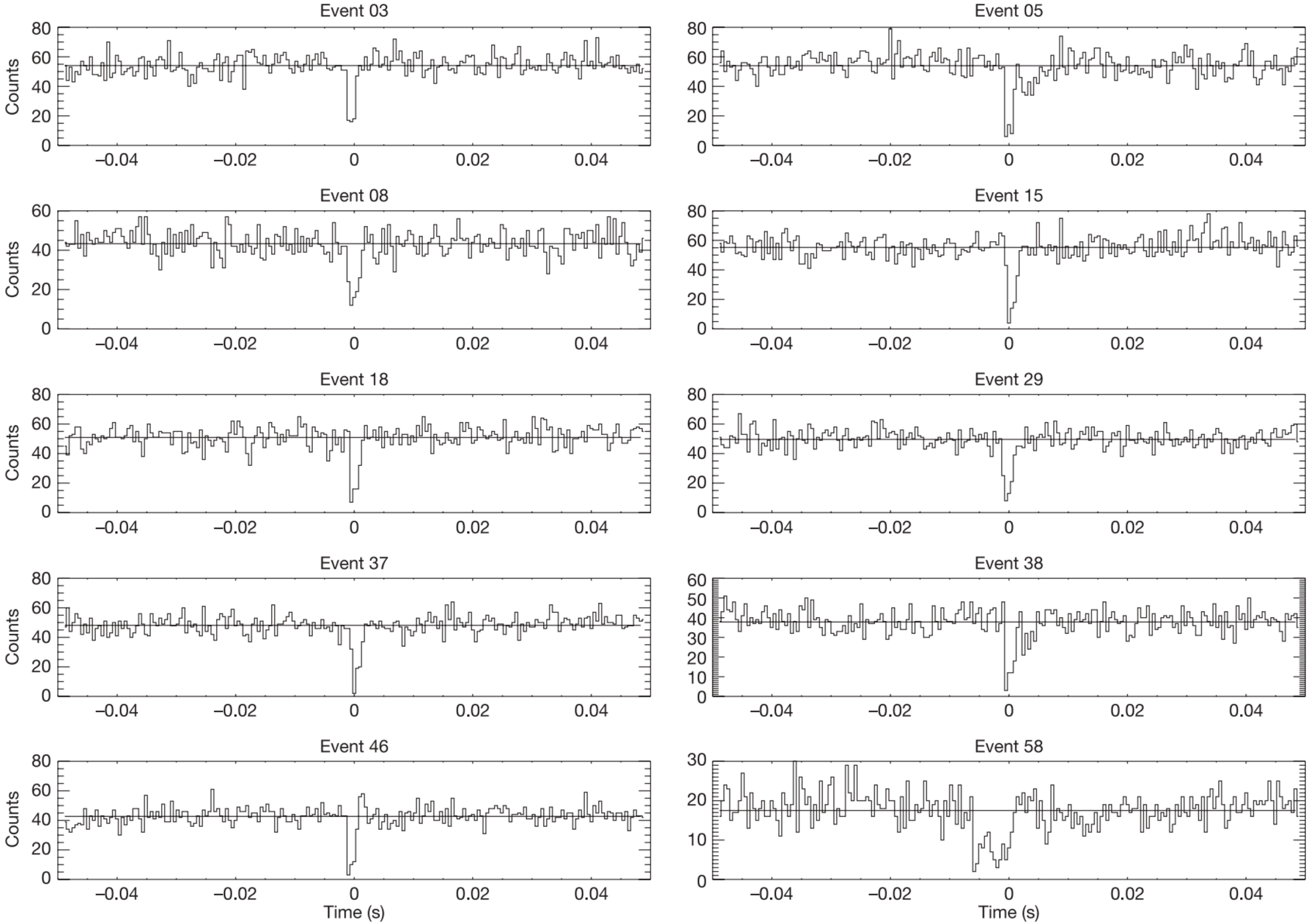


Saturn 2003



Saturn's Rings 2003

Titan 2003

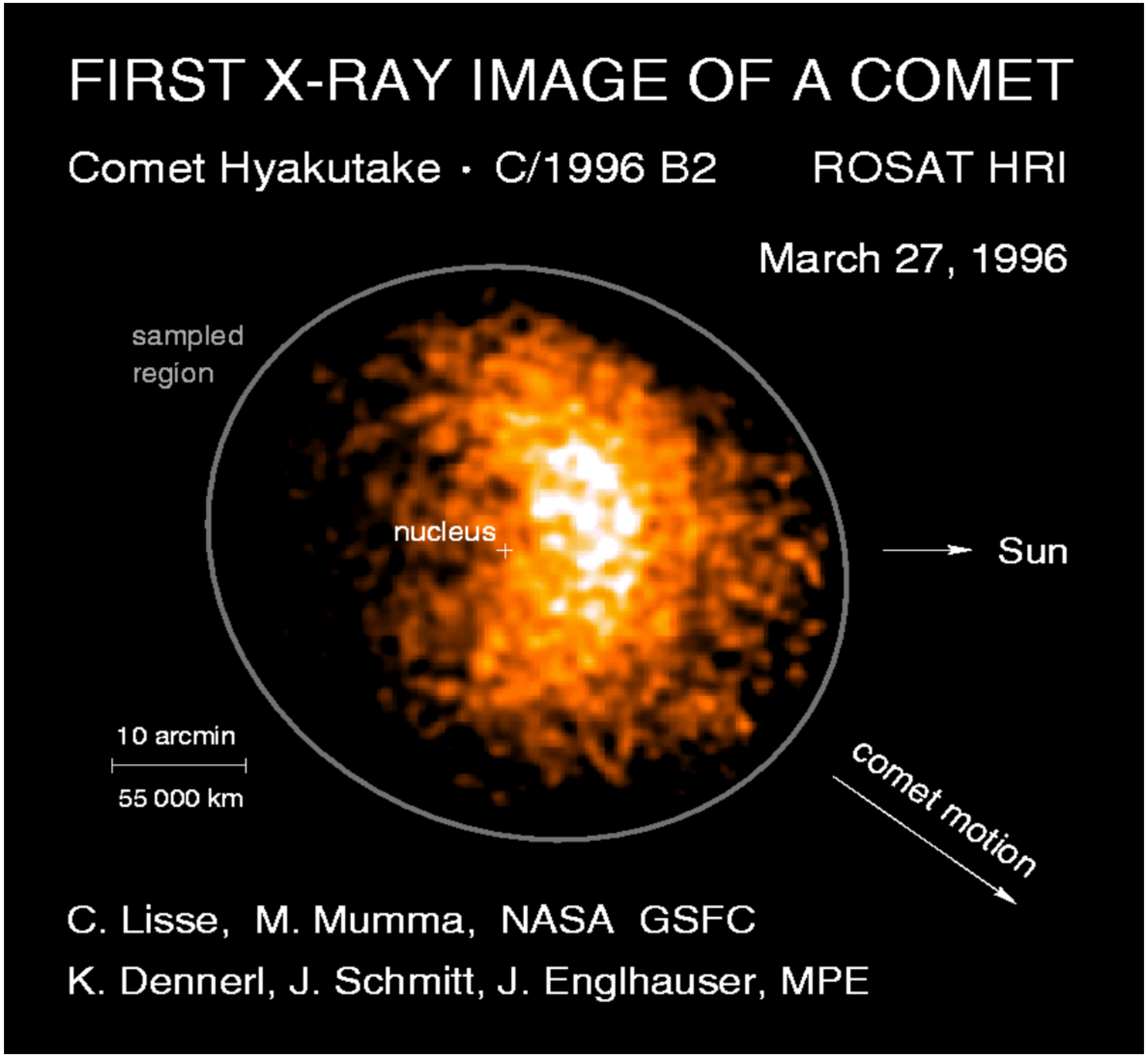


Search for TNO using X-ray

RXTE/PCA — Scorpius X-1 light curves

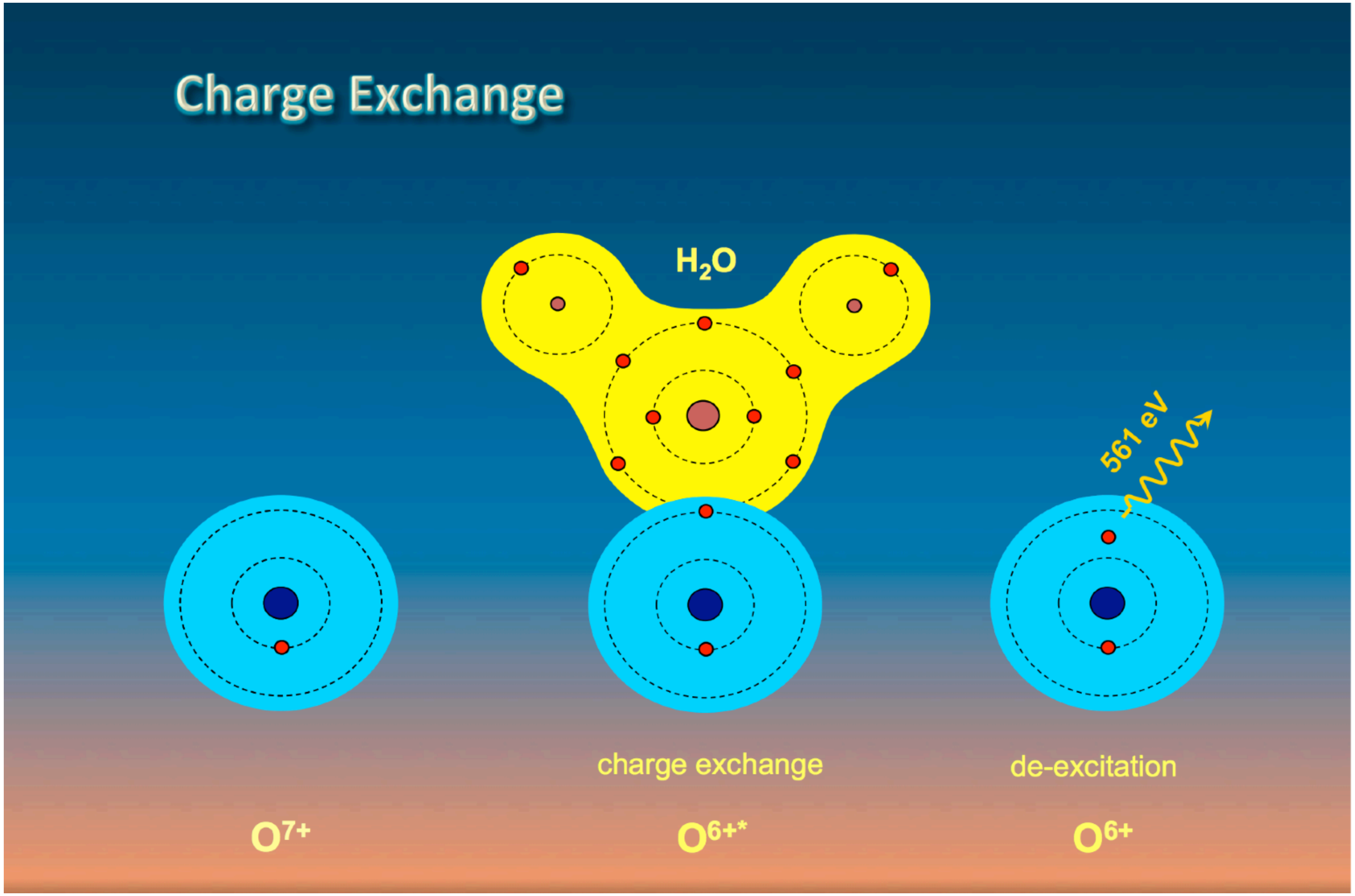
Chang et al. 2006

Comets



FIRST X-RAY IMAGE OF A COMET
Comet Hyakutake • C/1996 B2
ROSAT HRI
March 27, 1996
sampled region
nucleus
Sun
10 arcmin
55 000 km
comet motion
C. Lisse, M. Mumma, NASA GSFC
K. Dennerl, J. Schmitt, J. Englhauser, MPE

Charge exchange

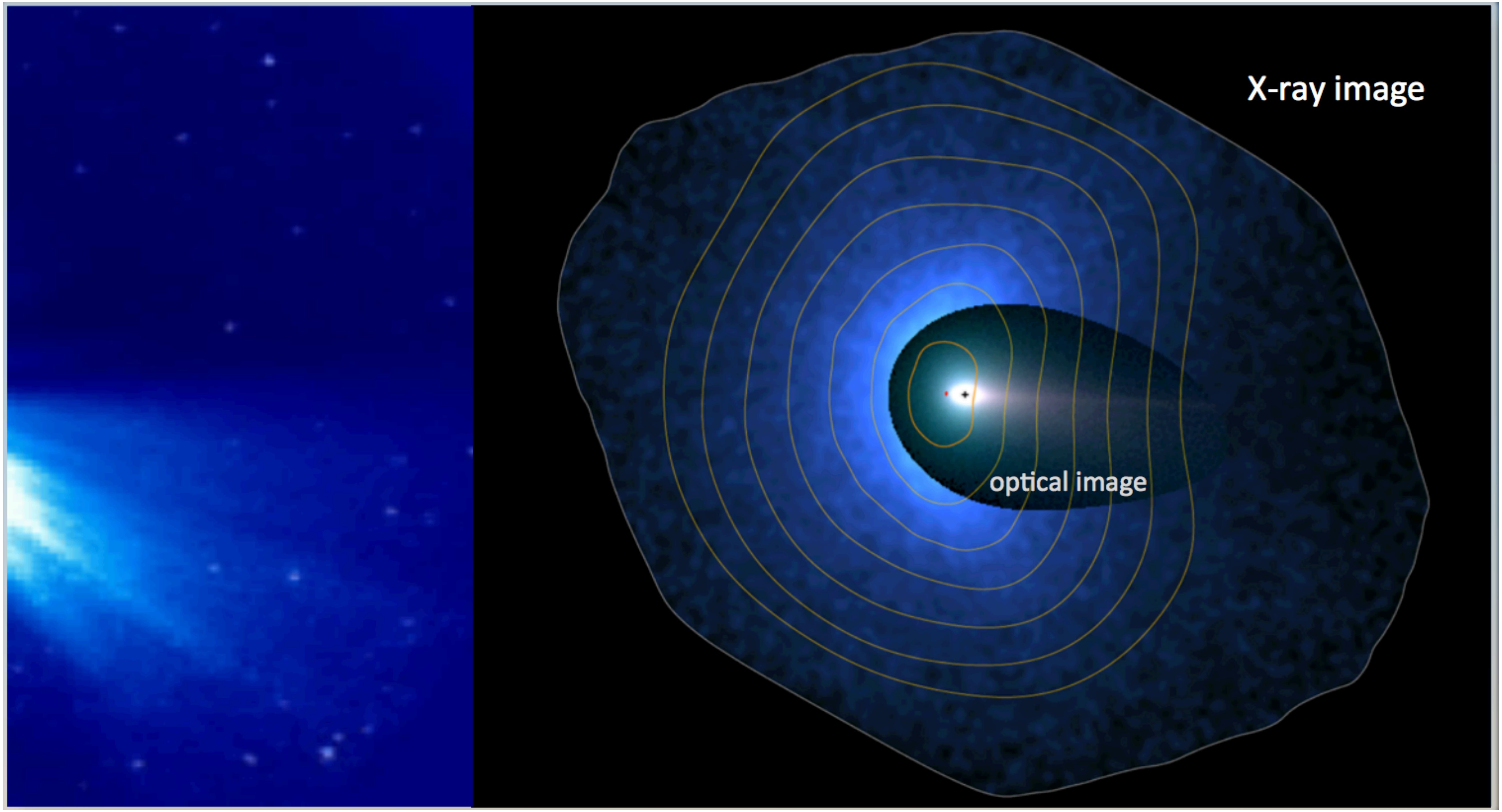


Solar wind heavy ion steals electron from cometary hydrogen atoms/molecules

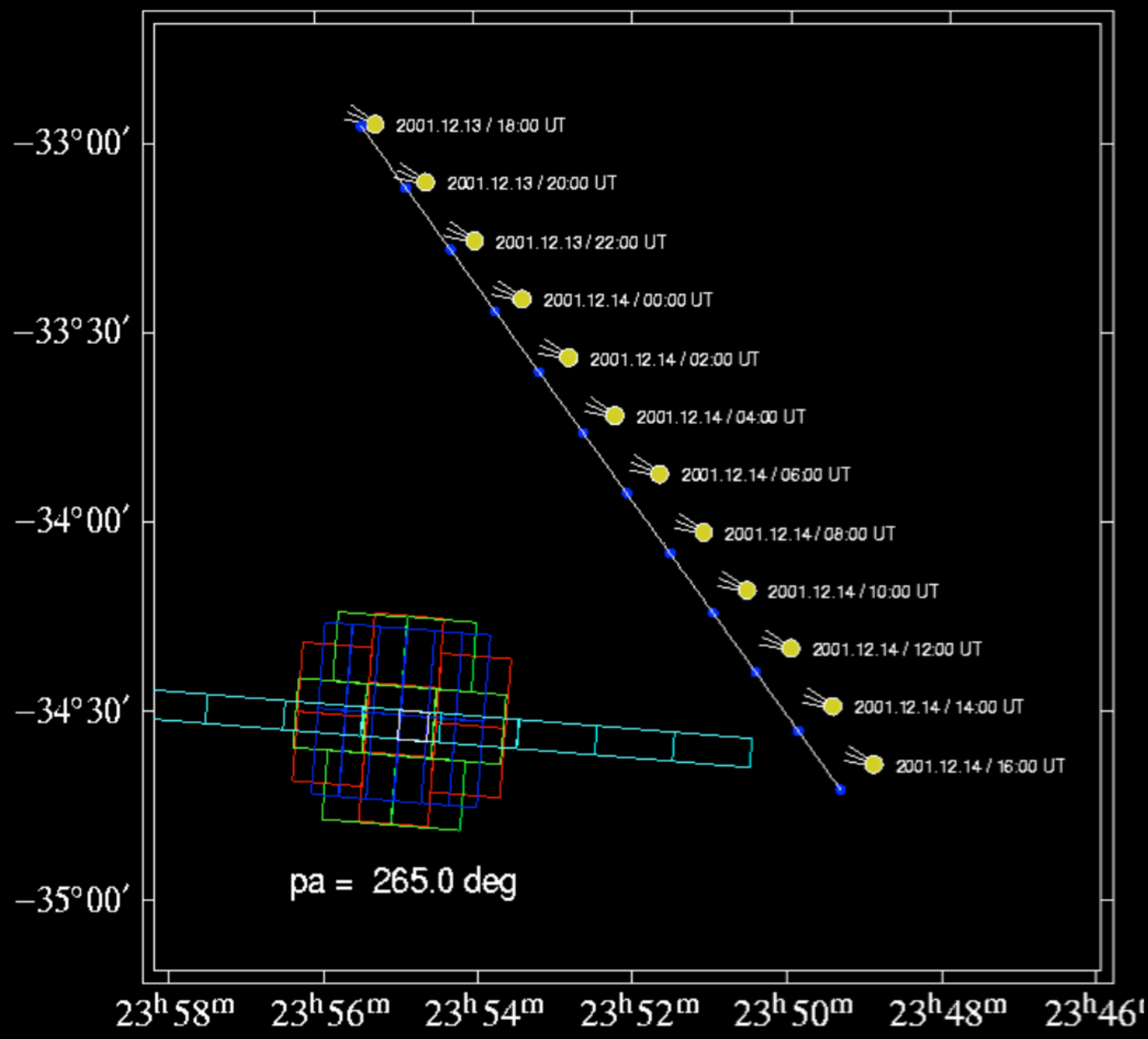
Charge exchange produce softer X-ray spectrum strongest : 561 eV H_2O or H_2 + O^{7+} —> O^{6+*} —> O^{6+}

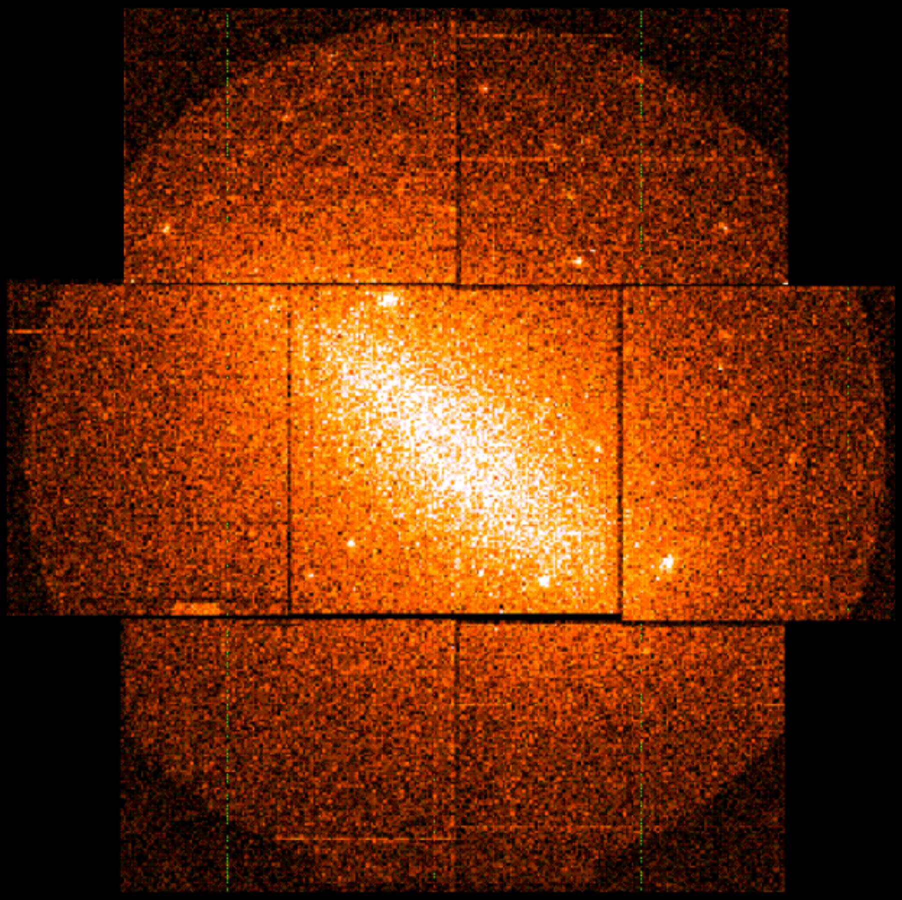
Comets

- X-rays emitted on sunward side of coma
- spatial extent 10^5 —10^6 km
- Intensity and morphology of X-ray emission changes over a few hours
- Very soft X-ray spectrum (charge exchange)
- L_X ~ 10^{16} erg/s (similar to Jupiter)


X-ray image
optical image

XMM-Newton observation of Comet C/2000 WM1: EPIC

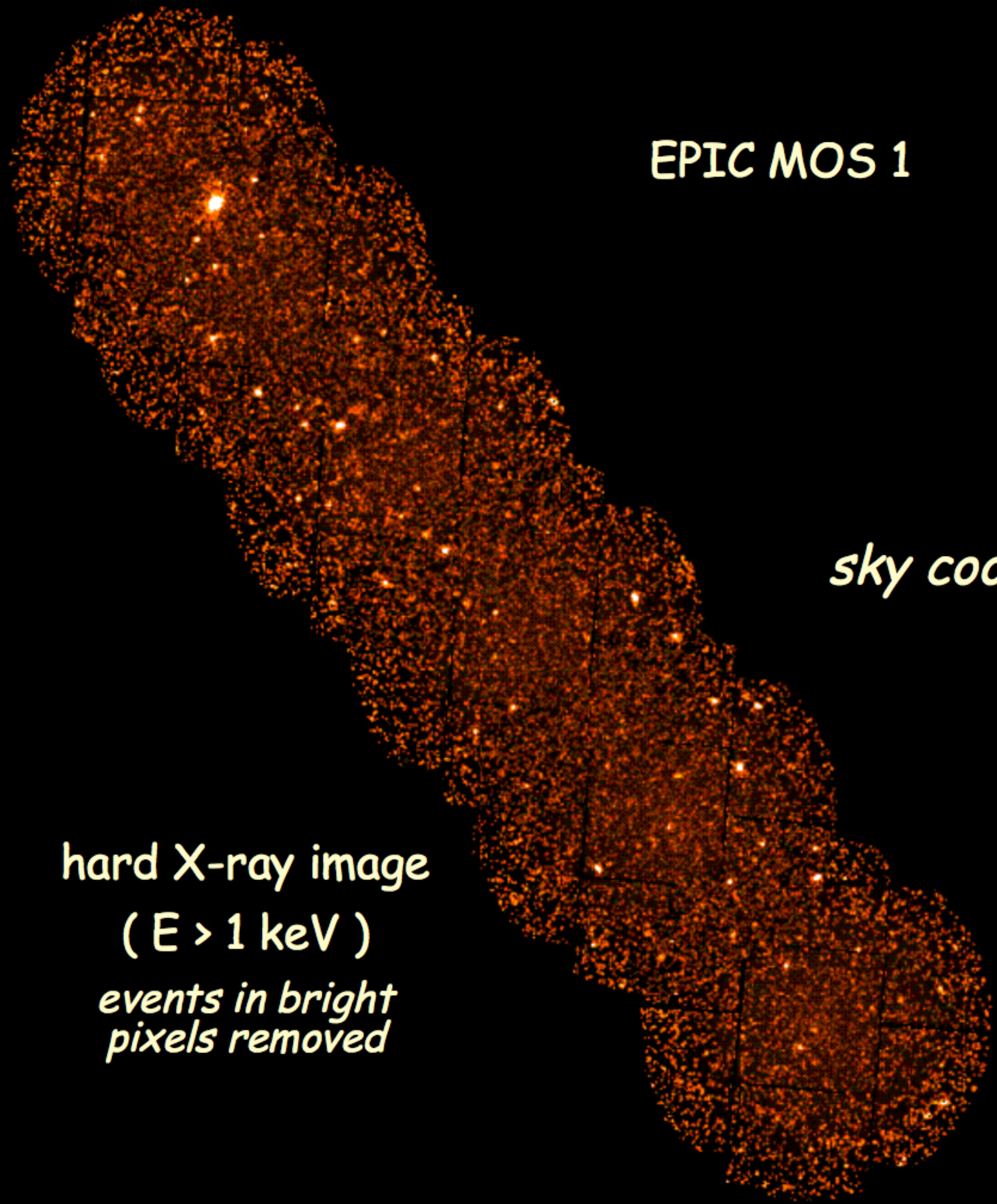




XMM-Newton observation of Comet C/2000 WM1: EPIC

EPIC MOS 1

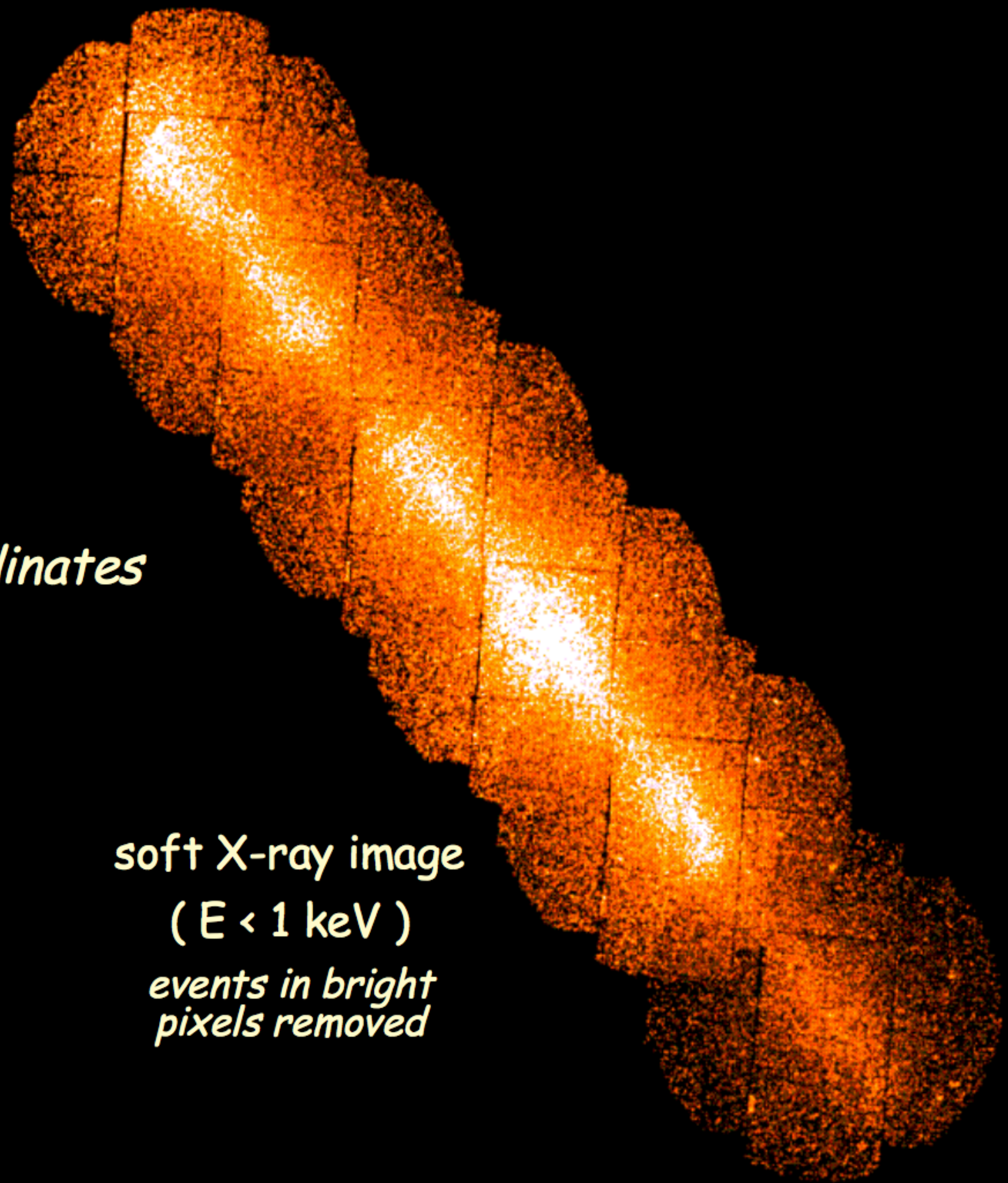
sky coordinates



hard X-ray image

(E > 1 keV)

events in bright pixels removed

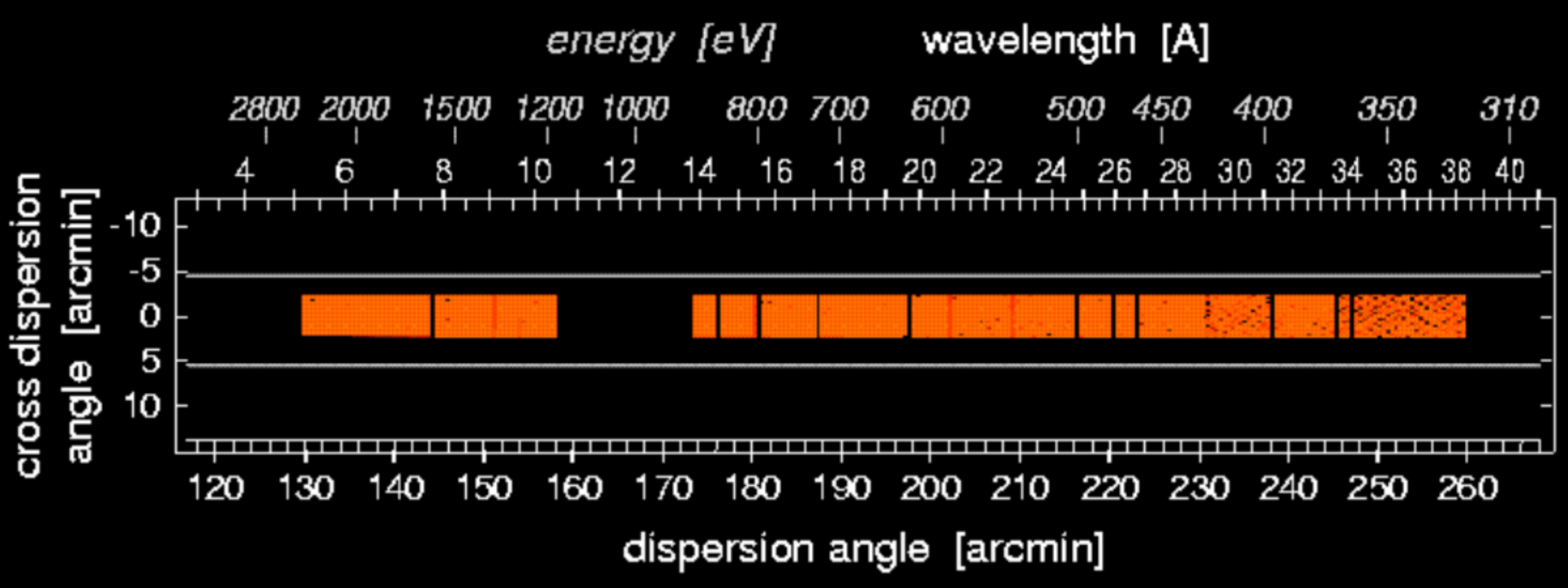


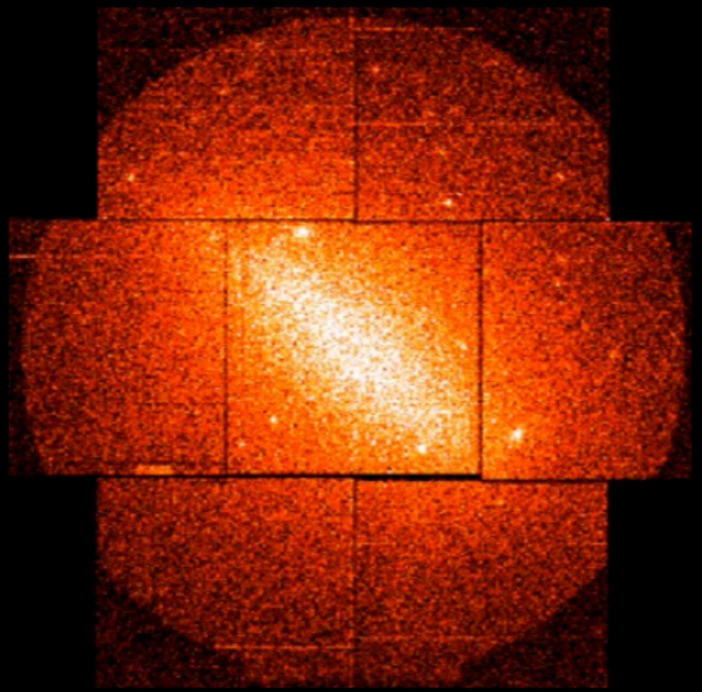
soft X-ray image

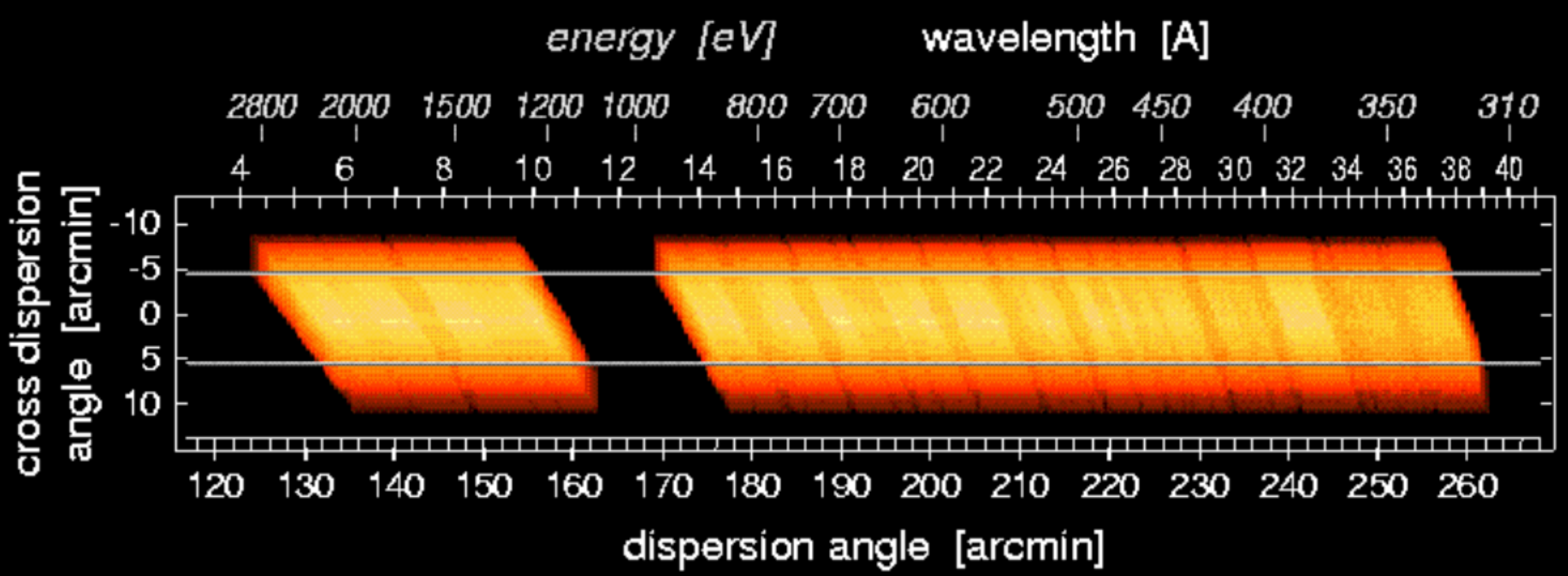
(E < 1 keV)

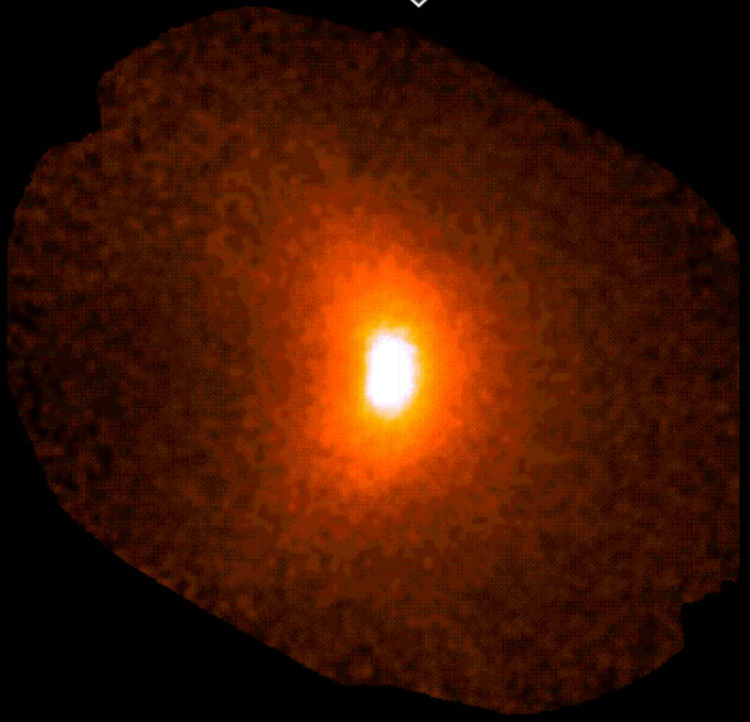
events in bright pixels removed

XMM-Newton observation of Comet C/2000 WM1: RGS

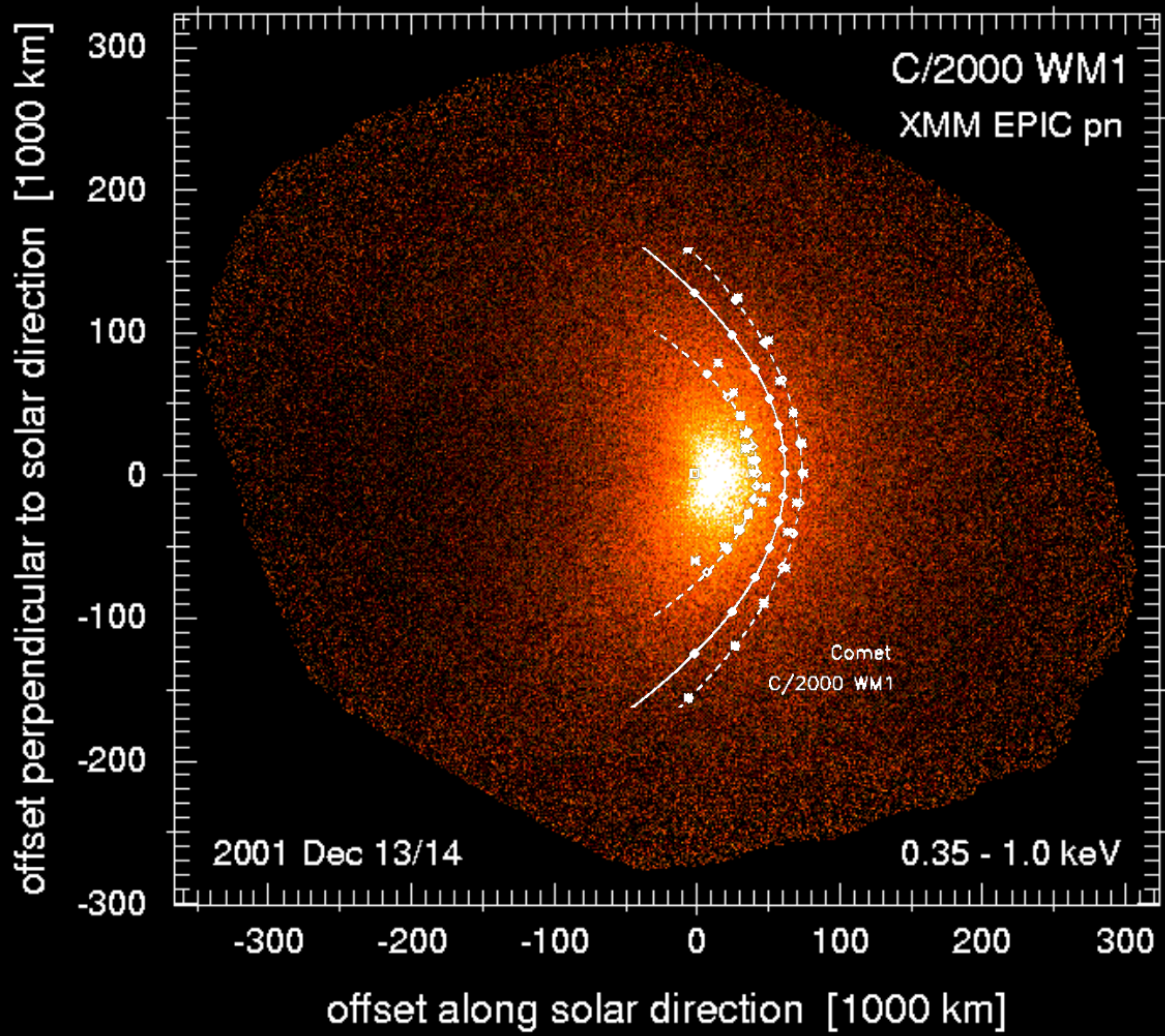


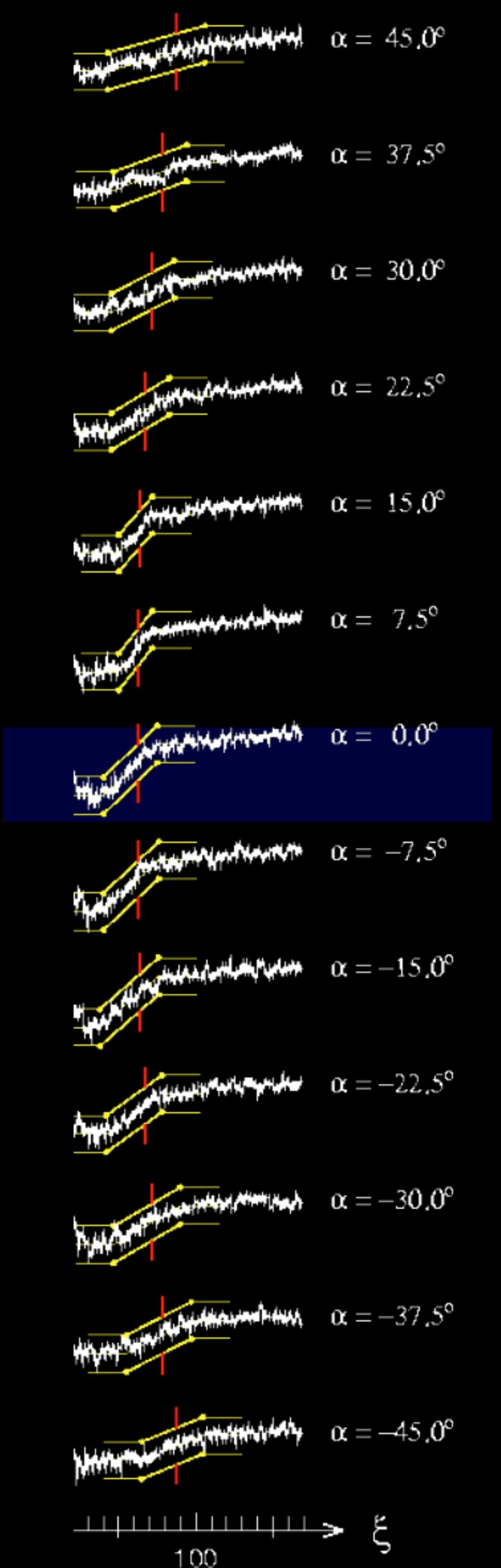






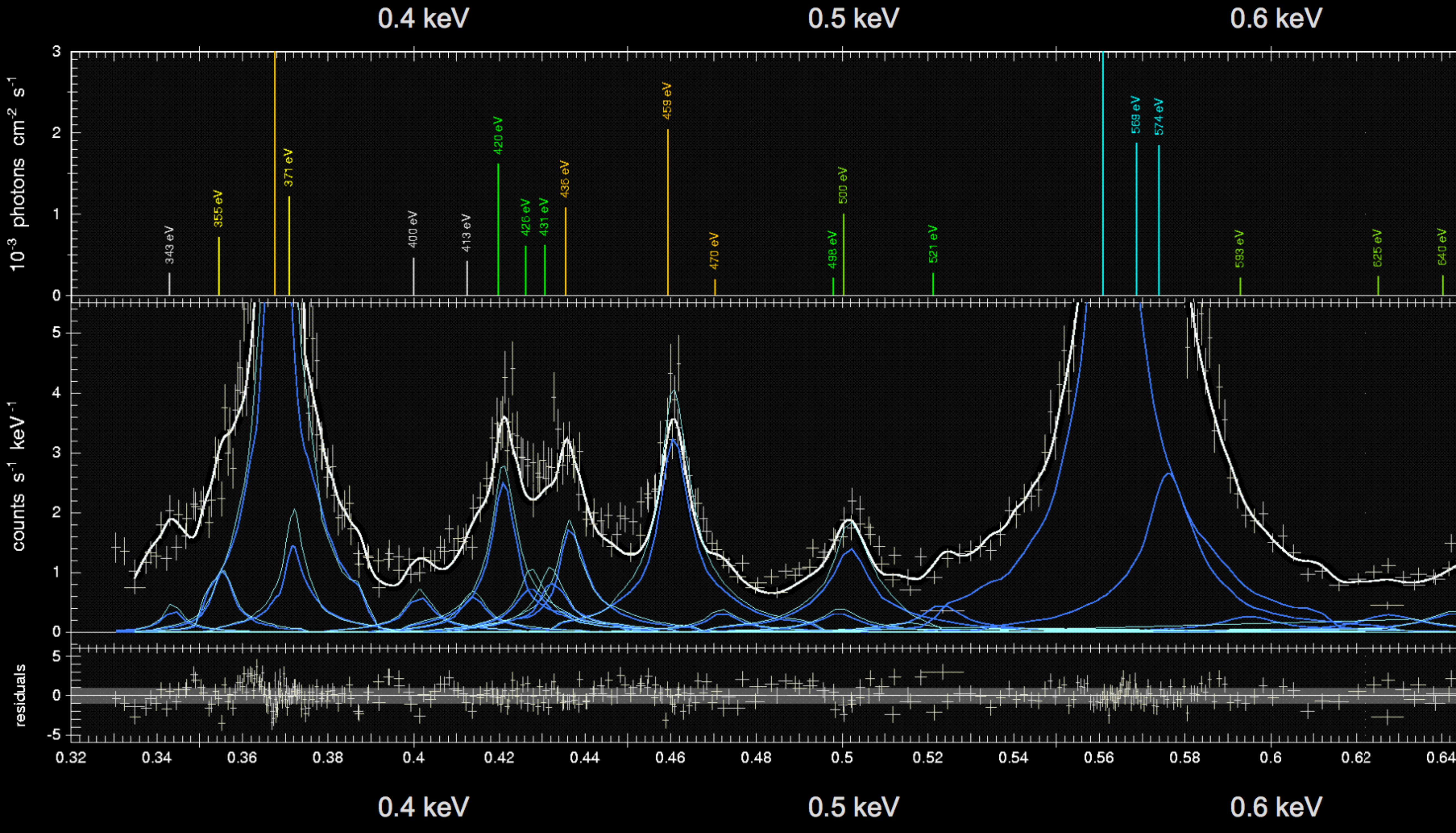
The bow shock of Comet C/2000 WM1





Wegmann and Dennerl 2005, A&A 430, L33-L36

Including the spatial extent into the spectral resolution

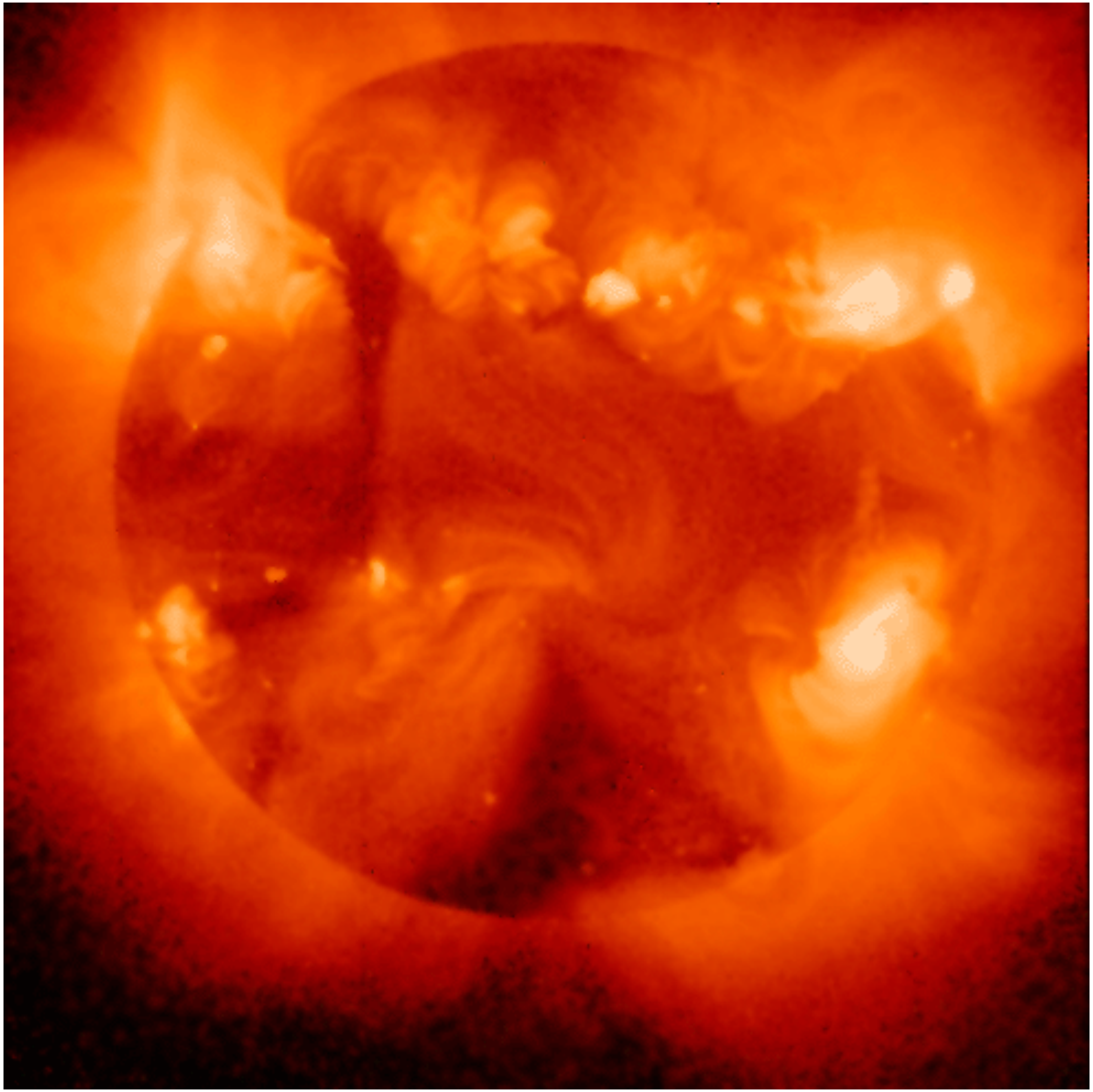


Sun

- Brightest X-ray source in the sky
- Not simple extension of thermal blackbody emission
- Quiescent $L_X \sim 10^{27}$ erg/s ($2.5 * 10^{-7}$) of its total luminosity
- But can increase by > 100 during flares
- Most of solar X-ray photons are from hot gas in solar corona with > 10^6 K

Coronal plasma

- Optically thin to their own emission
- low density (rare collisions) — ions are mostly in their ground states
- Not in thermal equilibrium
- Line emissions and bremsstrahlung



YOHKOH

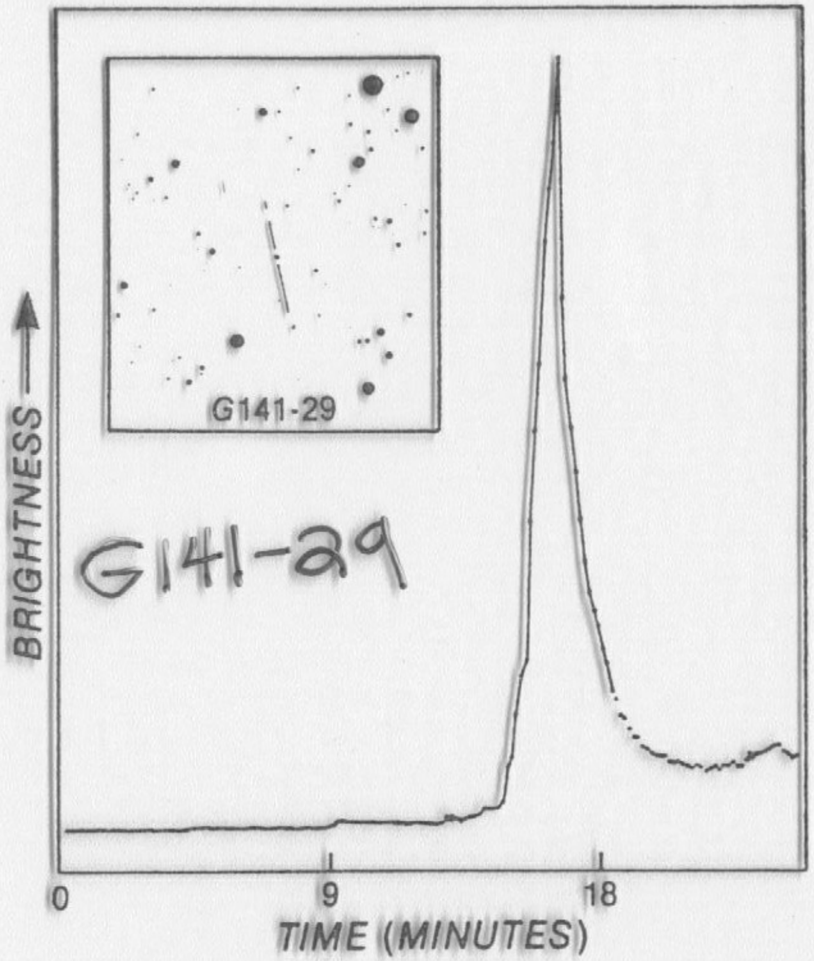
Sun

- How corona heating works
- How solar flares work
- Testbed for atomic physics, plasma / MHD codes

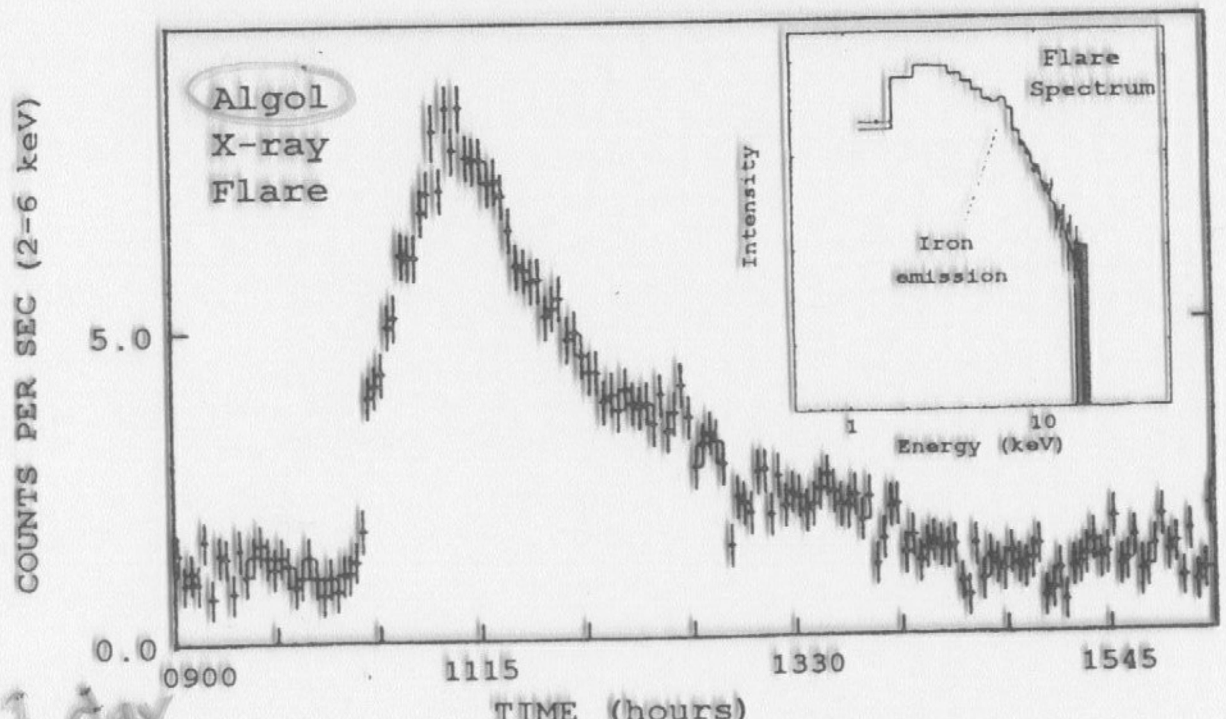
What we've learned from the Sun?

- Stars generally emit 10-7 to 10-3 of their total bolometric luminosity in X-ray
- Optical brightness is not a good predictor of X-ray brightness for stars — M stars are often more X-ray luminous than K stars, for example
- Wide range of luminosity for any particular spectral class
- Stellar X-ray emission might be strongly variable

Flares from Stars

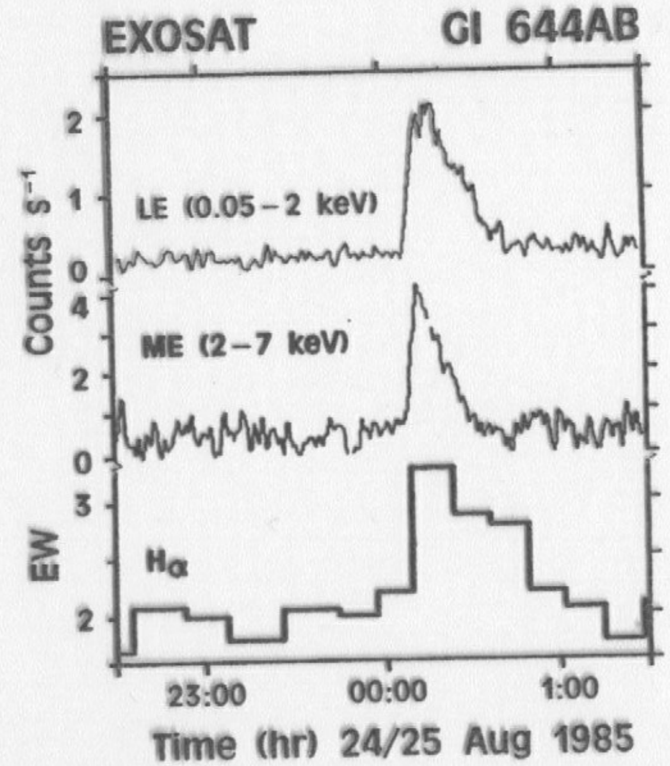


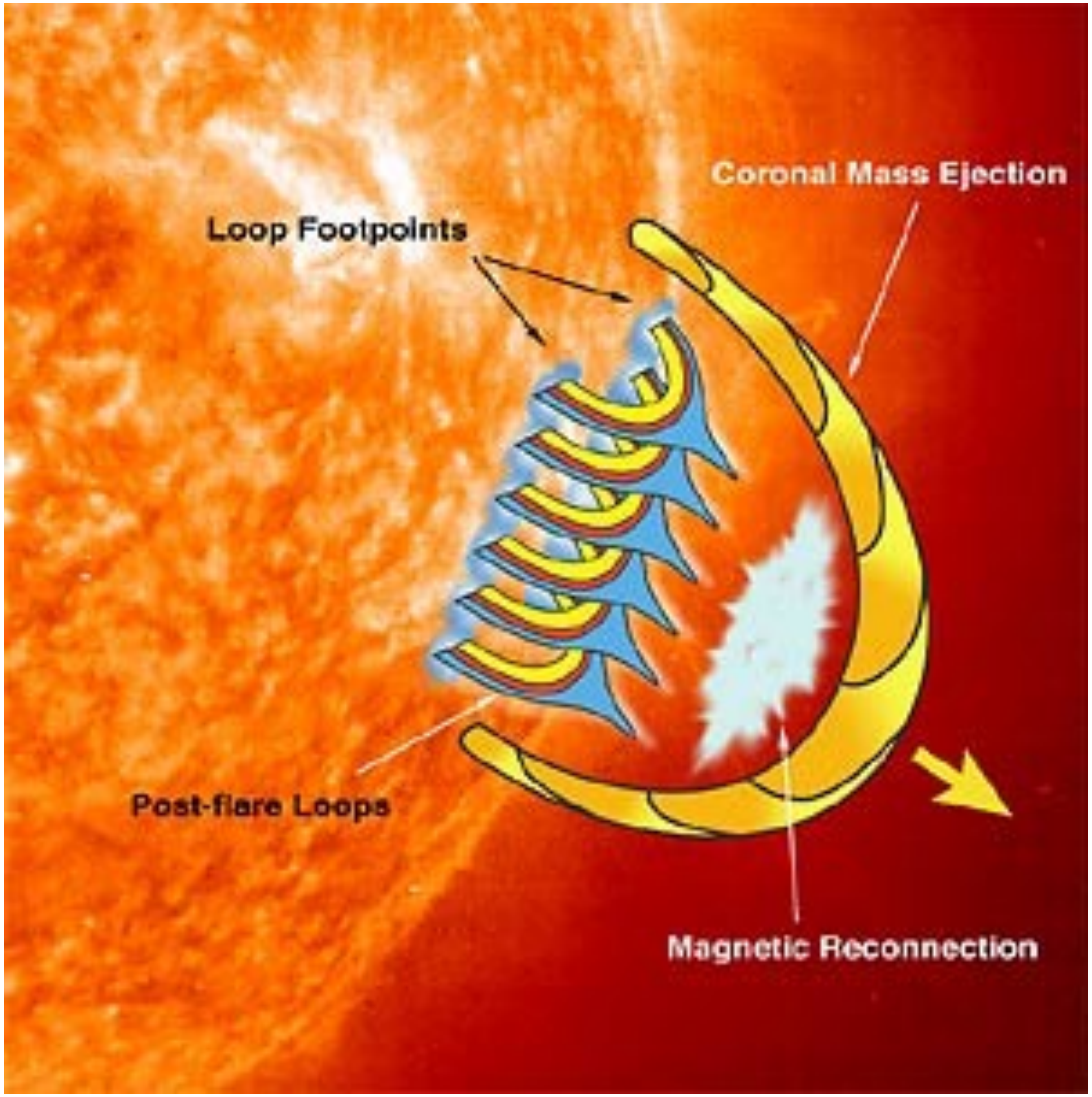
optical flare
13 th mag red star
can flare by factor ≈ 100 in 2 minutes

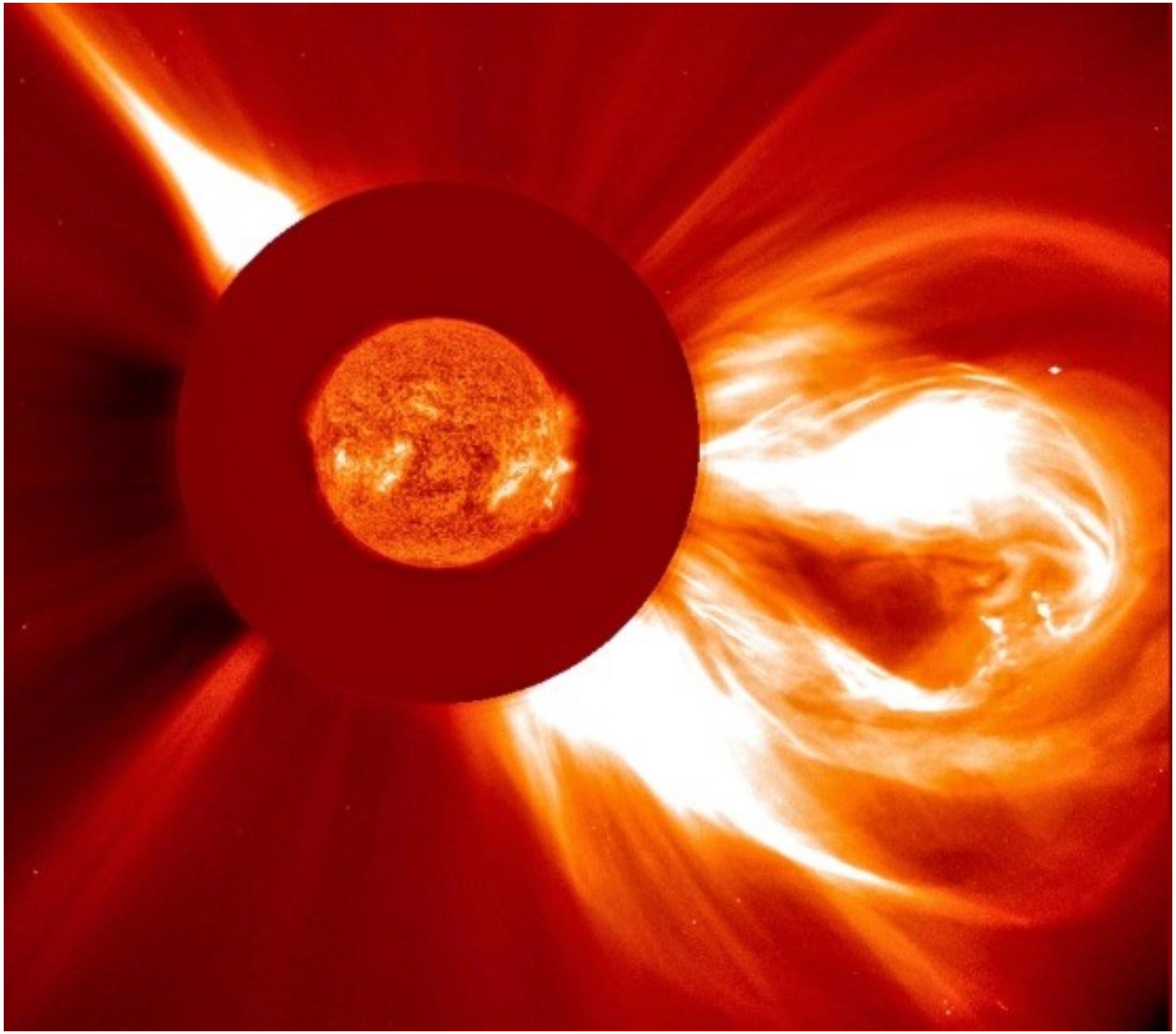


2.1 day
binary system, K subgiant flared

binary system with
2 M stars




Coronal Mass Ejection
Loop Footpoints
Post-flare Loops
Magnetic Reconnection



NuSTAR + SDO