X-ray Emission from the Saturn System

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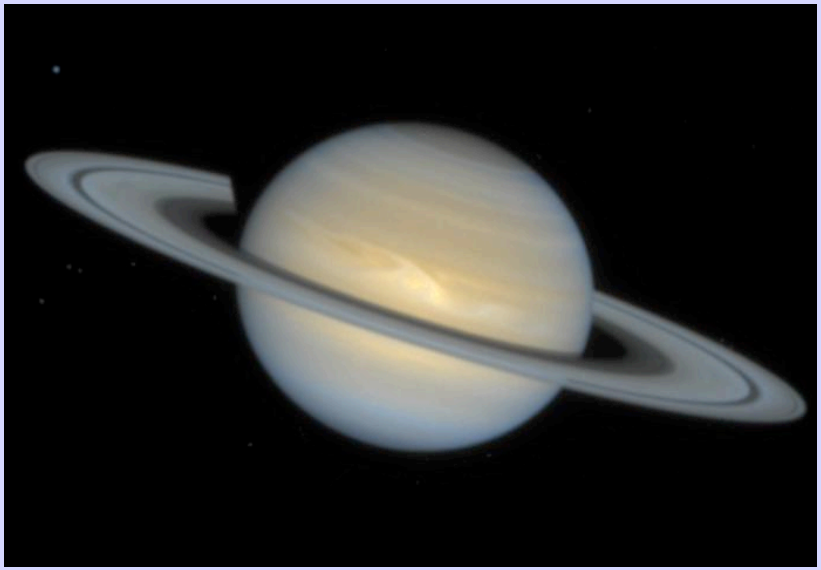


X-ray Observational History for the Saturn System

EINSTEIN IPC: Gilman et al. — **Ap. J (1986)**
3 hours on Dec 17, 1979 — 0.2-3.0 keV — no detection

ROSAT PSPC: Ness & Schmitt — **A&A (2000)**
1.48 hour on Apr 30, 1992 — 0.1-1.6 keV — marginal detection

XMM-Newton EPIC-pn: Ness, Schmitt & Robrade — **A&A (2004)**
6.67 hour on Oct 1, 2002 — 0.2-2.0 keV — detection & spectra

Chandra ACIS/grating: Mori et al. — **Ap. J. (2004)**
9.7 hours on Jan 5, 2003 — Titan occults Crab;

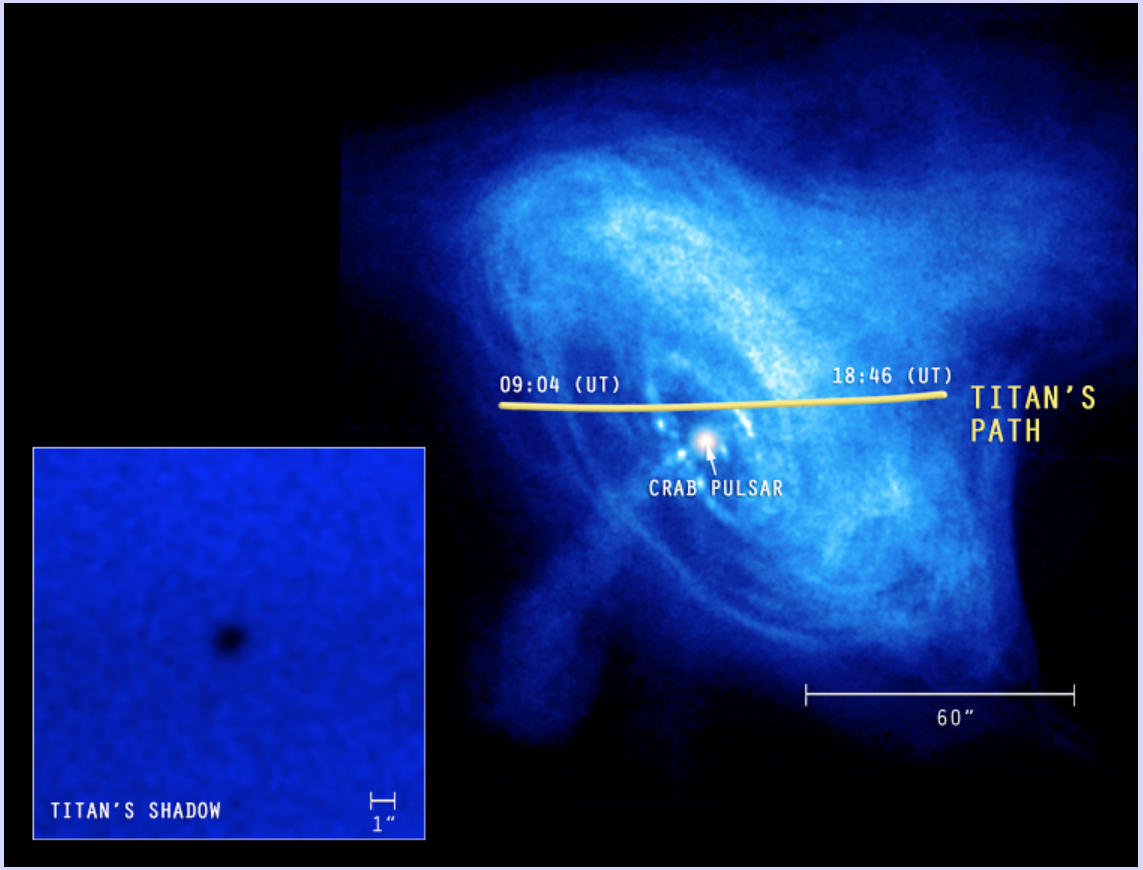
Chandra ACIS-S: Ness et al. — **A&A (2004)**
18.2 hours on Apr 14-15, 2003 — 0.2-2.0 keV — spectrum & spatial

Chandra ACIS-S: Bhardwaj et al. — **Ap. J. Lett. (2005a,b)**
10.4 hours on Jan 20, 2004 — 0.24-2.0 keV — spectrum, spatial,
10.1 hours on Jan 26-27, 2004 — 0.24-2.0 keV — flare, rings

XMM-Newton: Branduardi-Raymont et al.
~20 h on Apr 21-22 & on Oct 28-29, 2005 — 0.2-2.0 keV

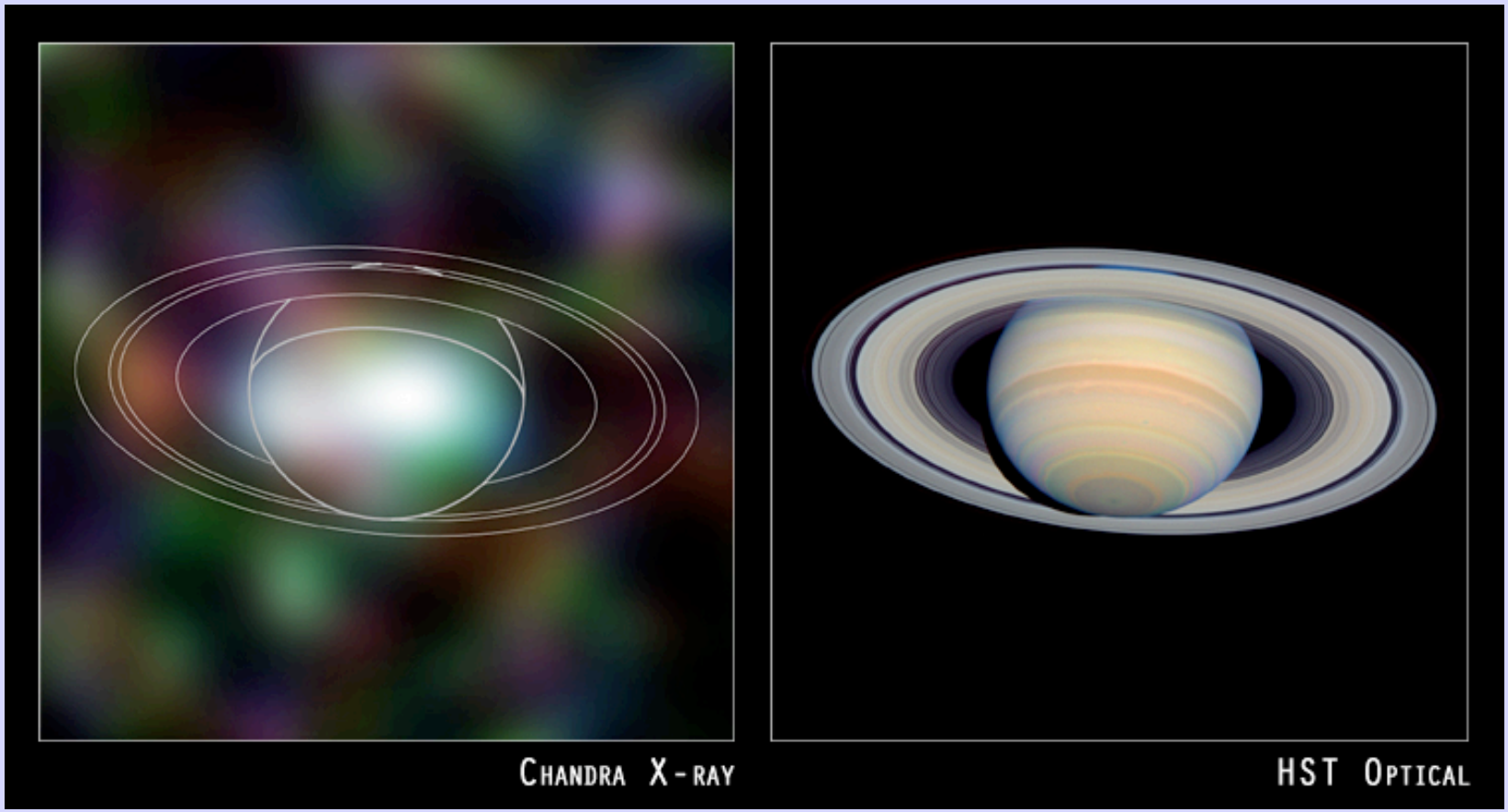
Titan's Occultation of the Crab Nebula

Mori et al. 2004, Ap. J., 607, 1065 measured extent of atmosphere from x-ray absorption consistent with or slightly larger than Voyager observations.



April 14-15, 2003 Chandra ACIS-S Observation of Saturn

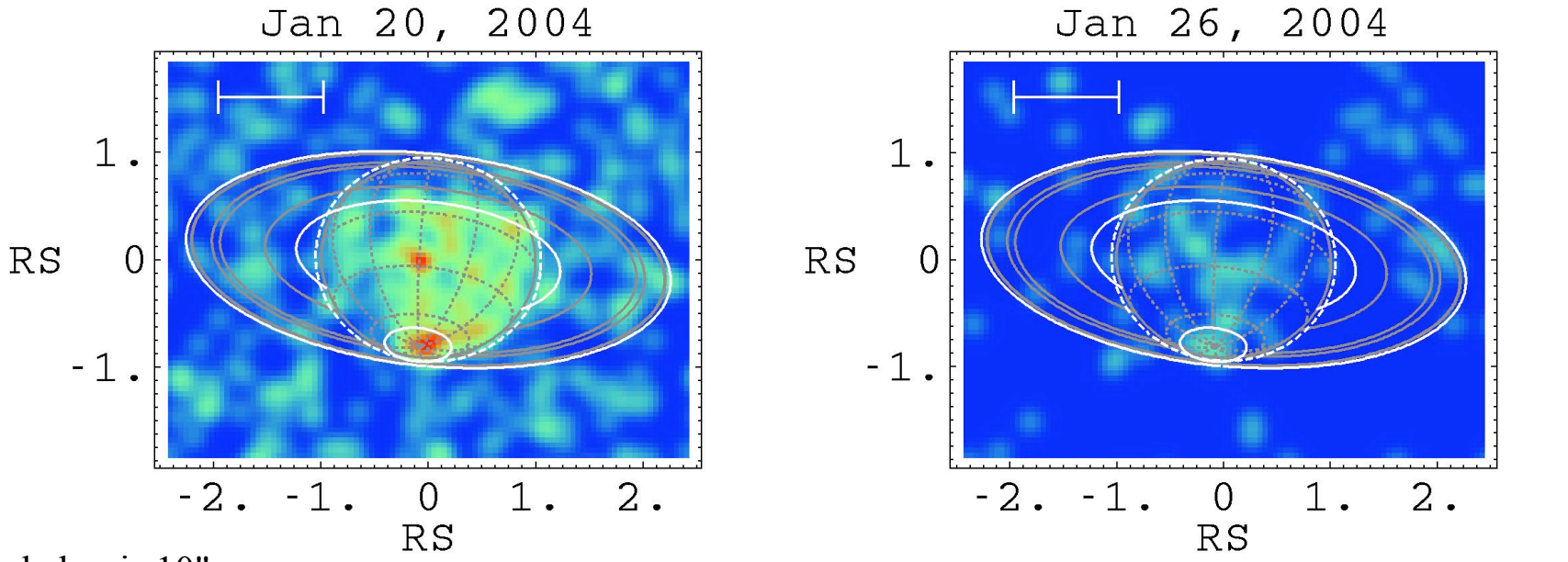
Ness et al. 2004, A&A, 418, 337 reported first unambiguous spatially and spectrally resolved x-ray observations of Saturn using Chandra ACIS-S. Spectrum consistent with solar.



Jan 20 & 26, 2004 Chandra ACIS-S Observations of Saturn

The two observations, only a week apart, look very different.

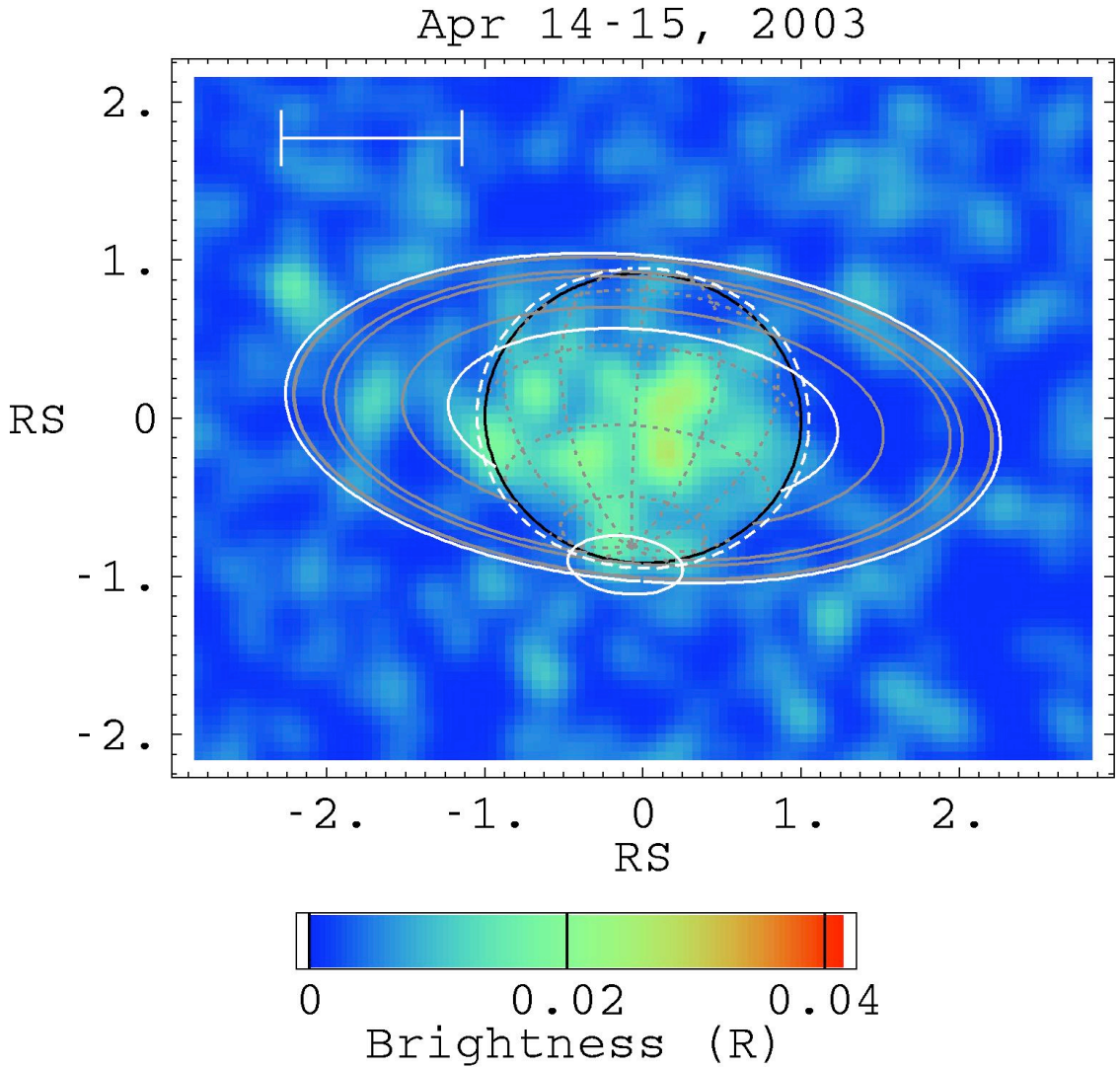
The 0.24-2.0 counts from the disk excluding the rings and south polar cap are 134 & 32 with 38.4 & 5.2 expected from background. The counts from the south polar cap region are 17 & 6 with 5.2 & 0.4 expected from background. The polar cap spectrum is consistent with the disk but not with Jupiter's auroral spectrum.



April 14-15, 2003 Chandra ACIS-S Observation of Saturn

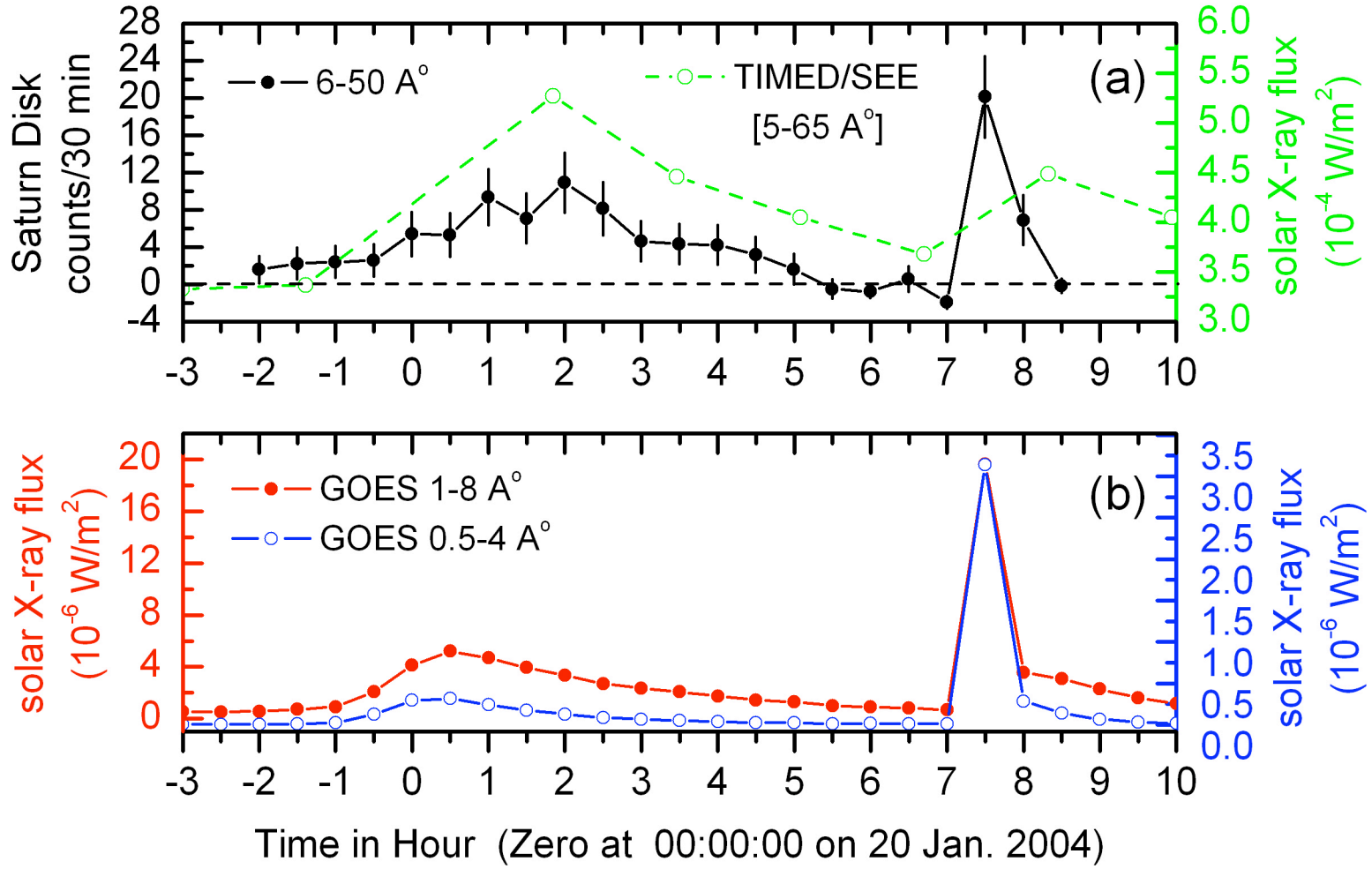
The earlier observation, plotted on same color scale, looks different from the other two.

Scale bar is 10"



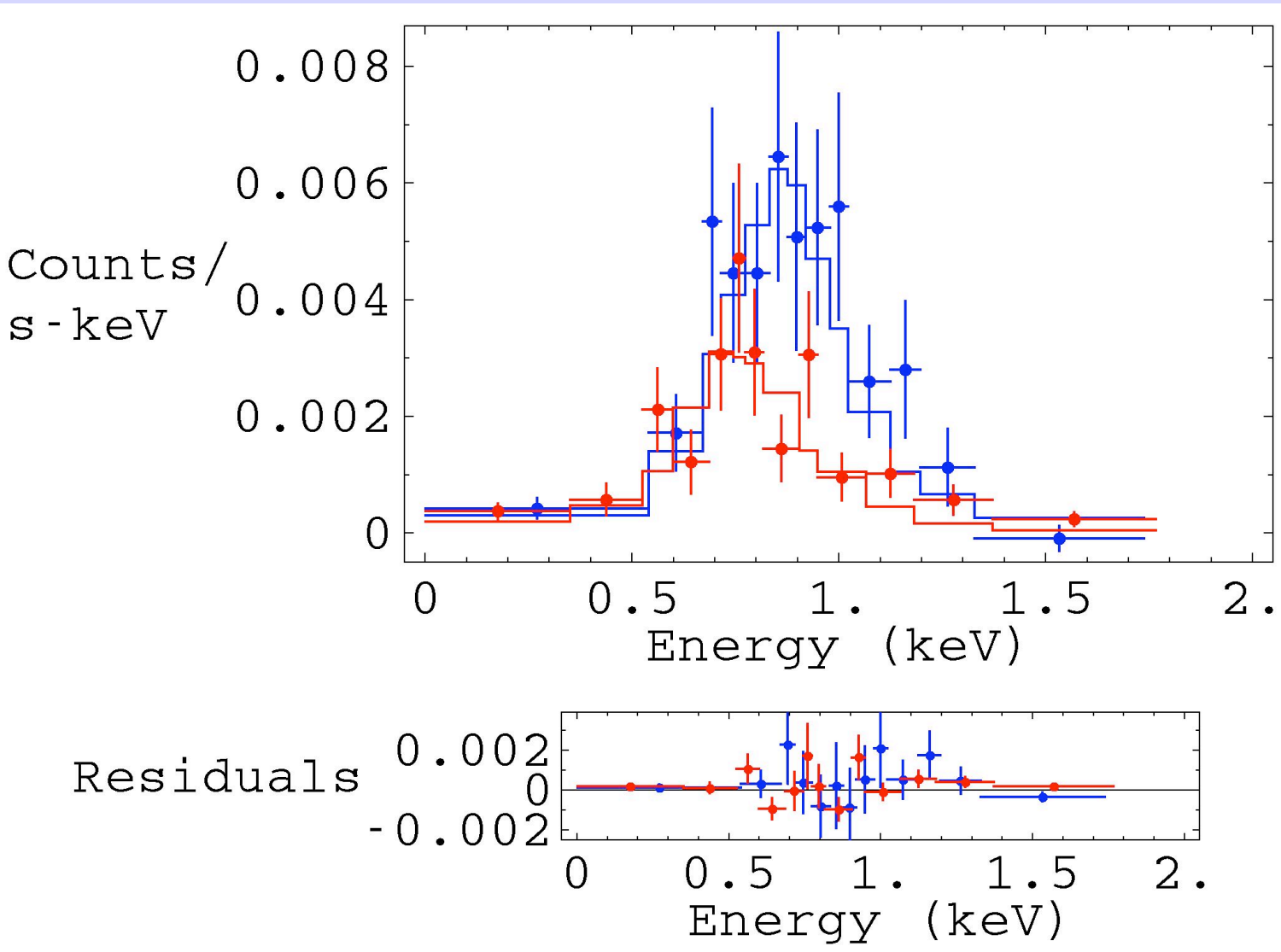
Saturn & Solar X-ray Time Histories on Jan 20, 2004

The background subtracted light curve on Jan 20, 2004, is not constant, and shows a flaring episode near the end of the exposure. When light travel time effects are included, this flare is coincident with an M6.1 solar flare from sunspot 10540 which lasted for ~36 min.



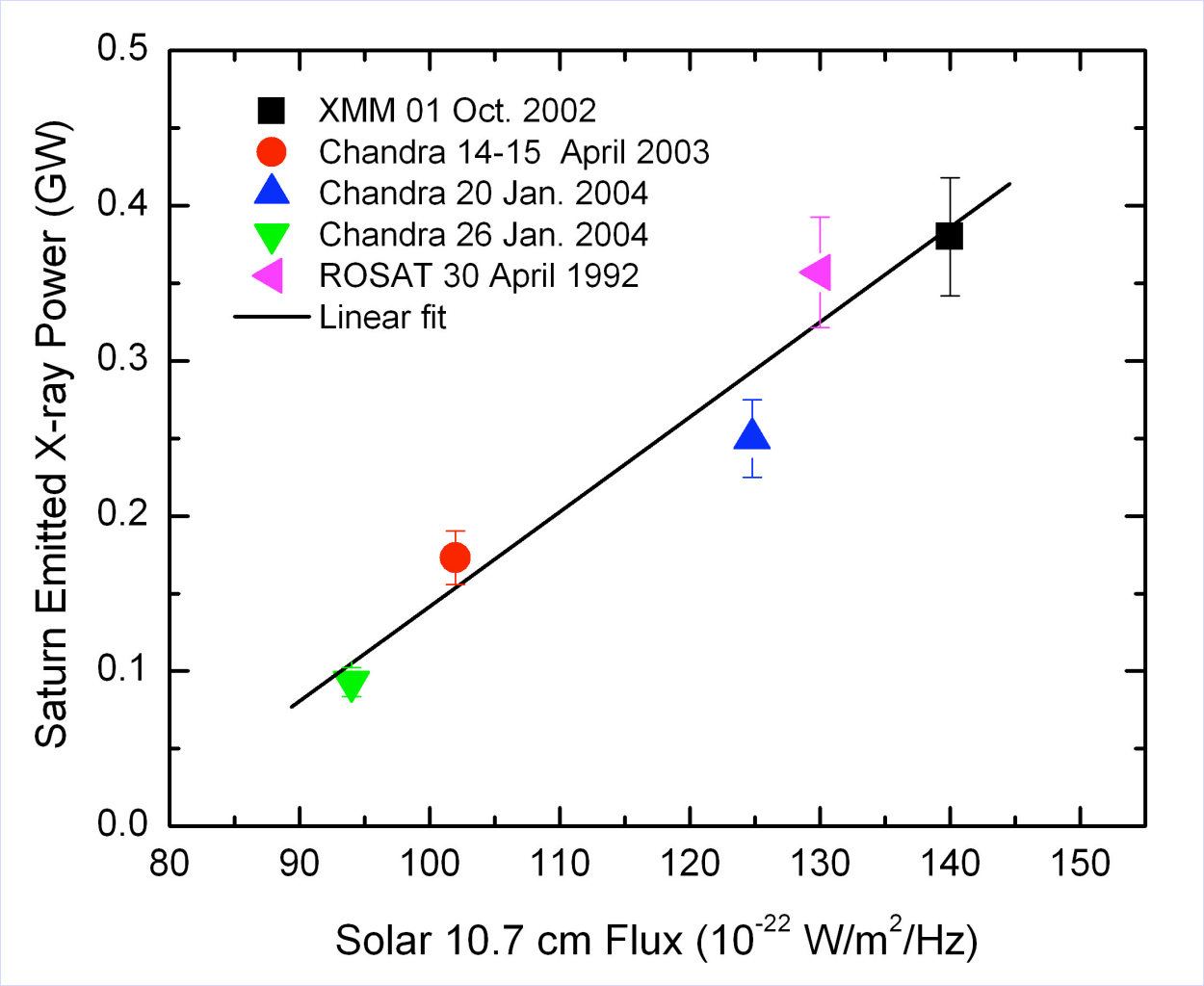
MEKAL Spectral Fits to Jan 20, 2004 & Apr 14-15, 2003 Data

The optically thin, thermal-equilibrium MEKAL model provides a good fit to the Jan 20, 2004, disk spectrum, but requires the addition of an O K line at 0.53 keV for the Apr 14-15, 2004, disk spectrum.



Correlation between X-ray Flux from Saturn & Solar Activity

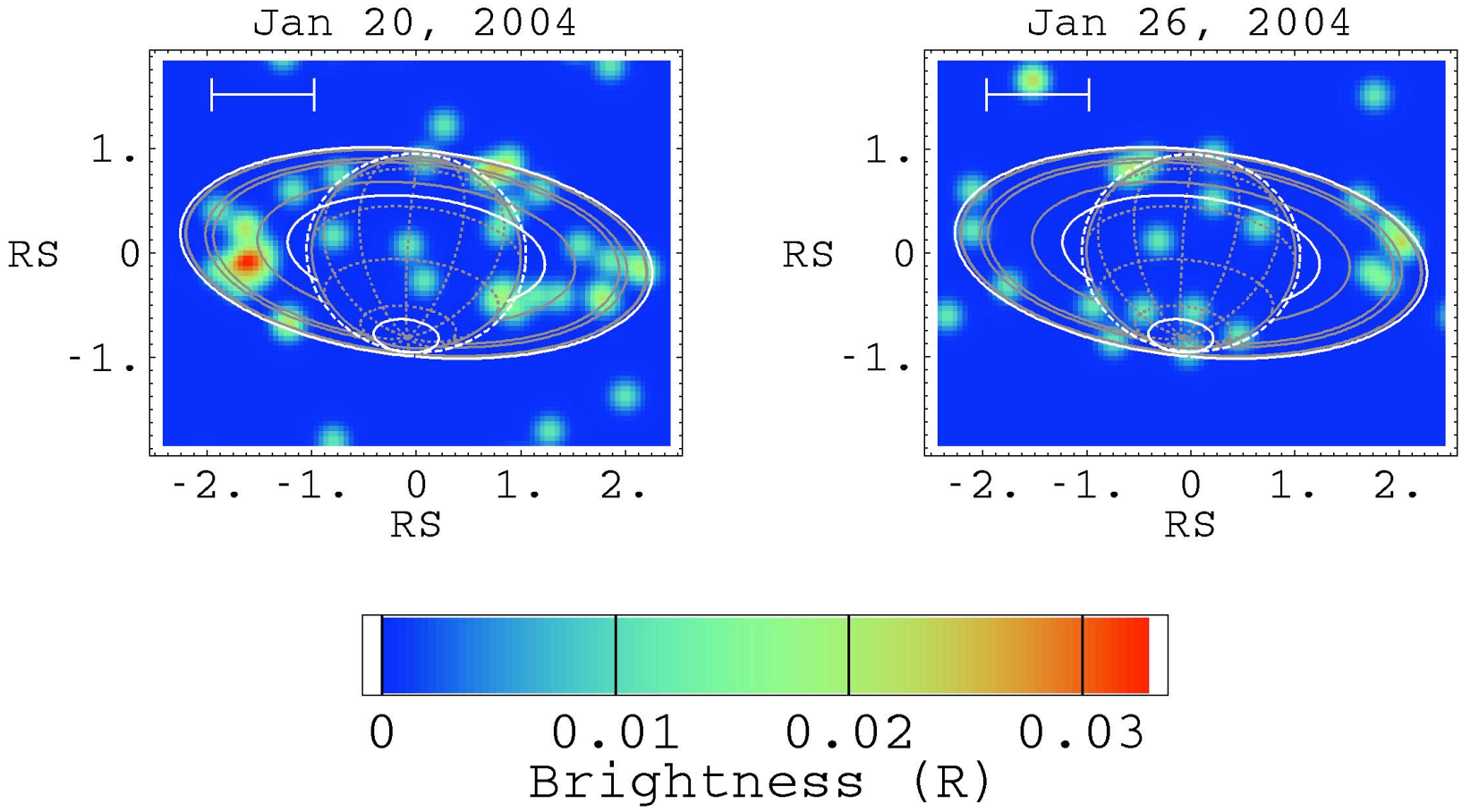
The 10.7 cm solar flux is used as a proxy for solar activity. The reported x-ray power from Saturn correlates very well with the 10.7 cm solar flux. The evidence points to x-rays from Saturn's disk resulting from scattering of and fluorescence due to solar x-ray emission incident on the disk.



Images of Saturn & Rings in the Energy Band 0.49-0.62

Ness et al. 2004 found a small but significant photon excess on side of the rings in the Apr 14-15, 2003, data.. The image for Jan 20, 2004, confined to the energy band 0.49-0.62 keV definitely shows emission from the rings with an apparent excess from the same side of the rings.

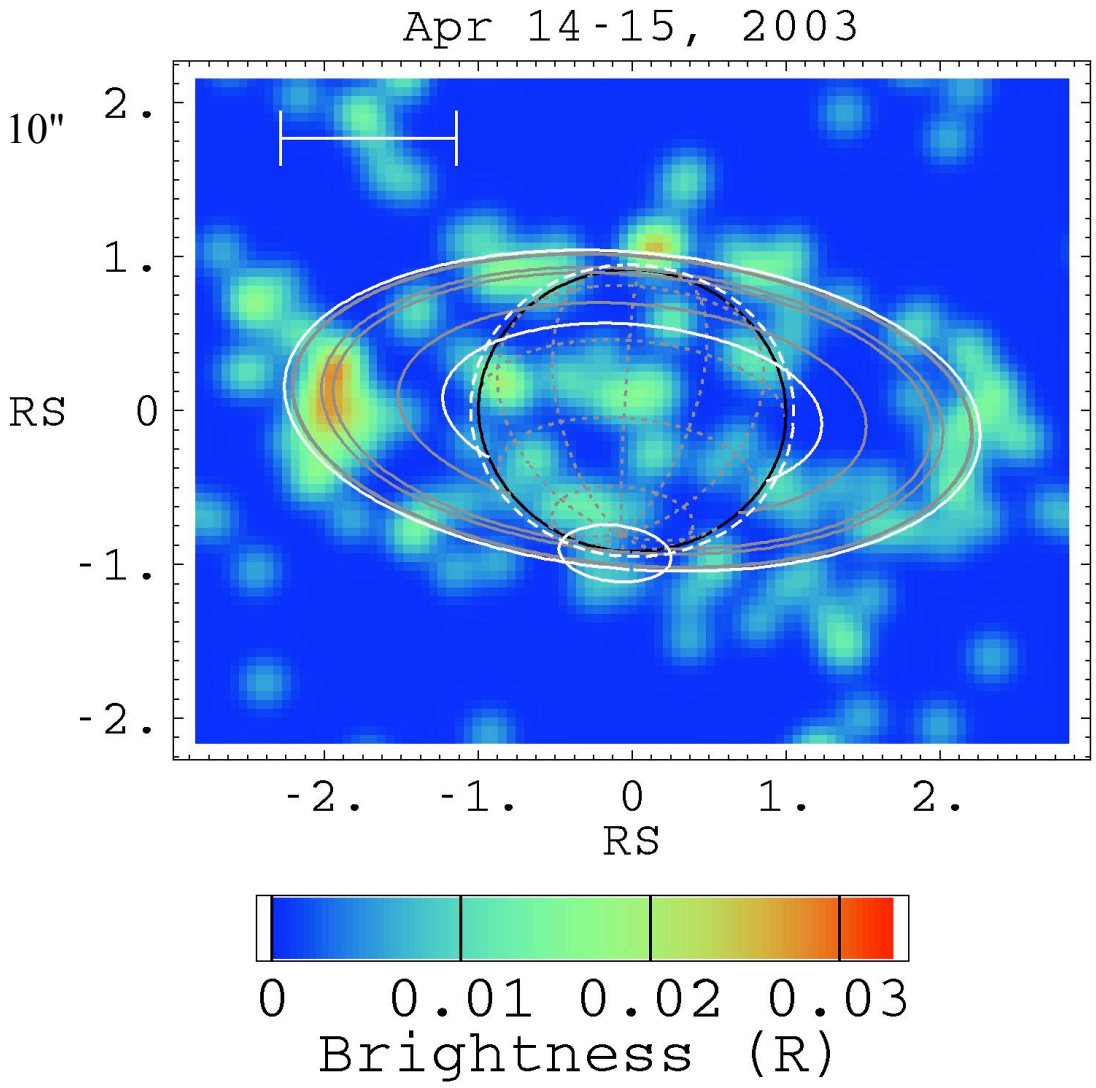
Spatial scale bar is 10"



Images of Saturn & Rings in the Energy Band 0.49-0.62 keV

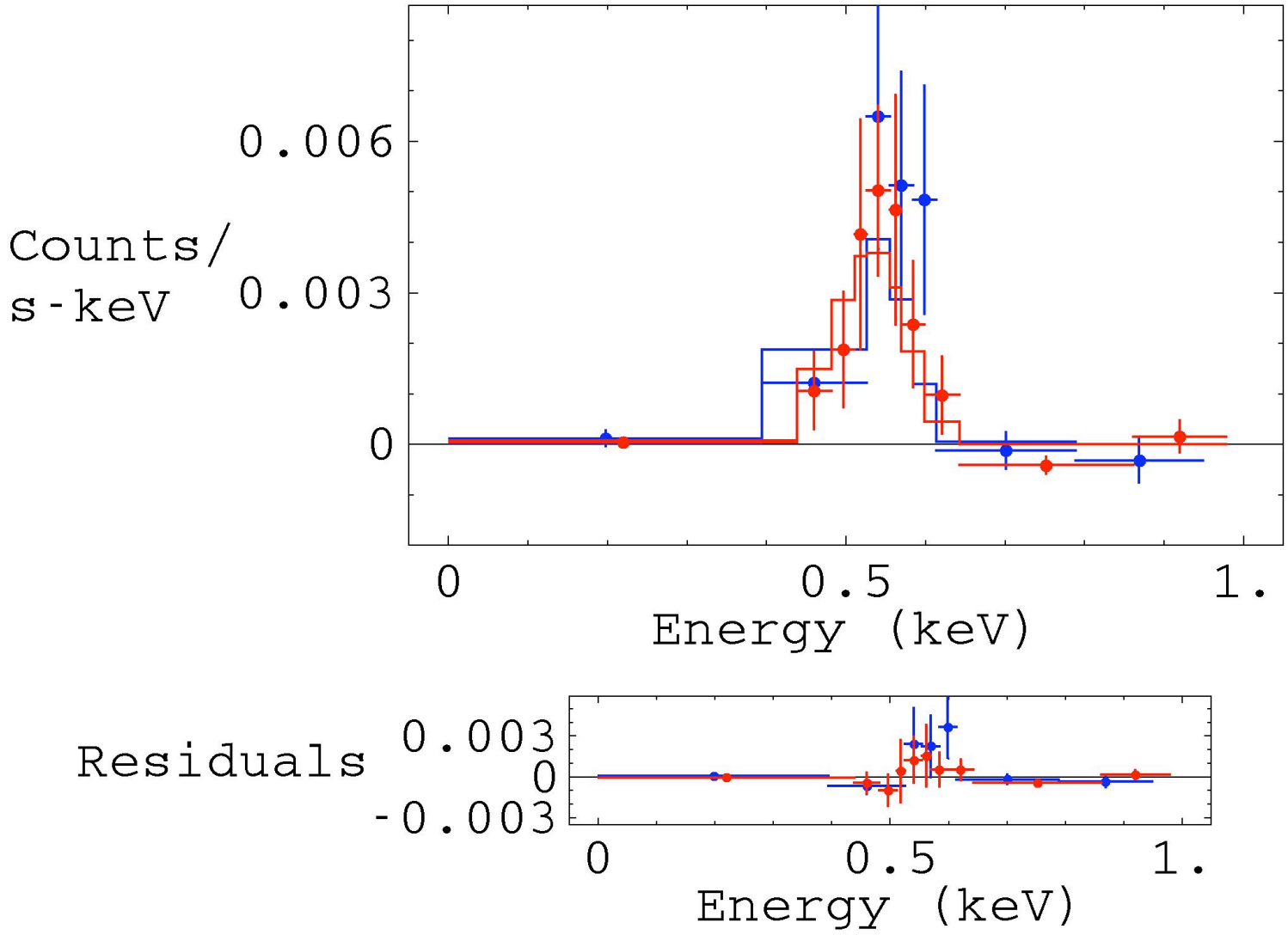
Here is the Apr 14-15, 2003, image in the 0.49-0.62 keV energy band. These images strongly suggest O K fluorescent line emission, consistent with the largely water ice composition of the rings.

Spatial scale bar is 10"



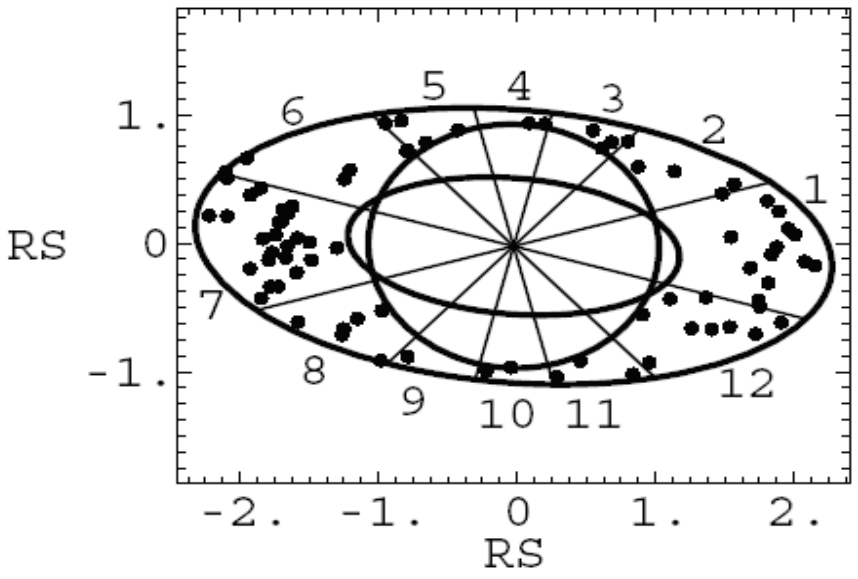
Line Fits to Jan 20, 2004 & Apr 14-15, 2003 Data Confined to Rings

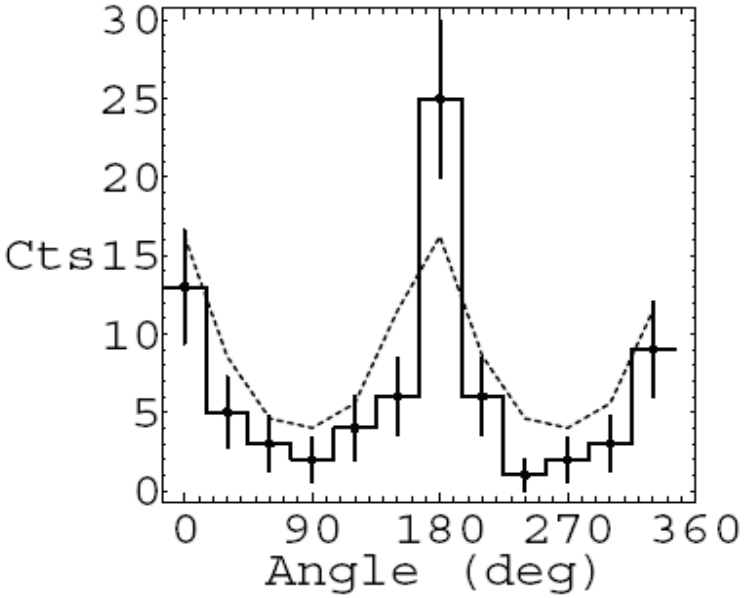
In fact, background subtracted spectra show no evidence for x-ray emission from the rings except in a line with center consistent with neutral O K fluorescence.



Asymmetry in Ring X-ray Emission ?

Combining the April 14-15, 2003, and Jan 20 & 26, 2004, exposures, the angular distribution of 0.49-0.62 events from the rings, taking into account the exposed projected area and excluding Saturn's planetary disk, provides suggestive but not overwhelming evidence for an East-West asymmetry. There are 13 events in sector 1 (West) and 22 in sector 7 (East). The probability of 22 expecting 13 is 0.002. The dotted curve on the right is proportional to the exposed projected area.





Summary

- X-rays from Saturn flared coincident with the arrival of solar x-rays from an M-class solar flare.

- X-ray spectra consistent with optically thin, thermal-equilibrium emission (but albedo effects not included --- see Cravens et al. 2005, J. Geophys. Res., submitted).

- Variability in Saturn's x-ray emission correlates well with the F10.7 cm flux proxy for solar activity.

- We find no evidence, at the present level of sensitity, for a south polar x-ray auroral.

- We conclude that the x-ray emission from Saturn's planetary disk is the result reprocessing of the incident solar flux in Saturn's atmosphere. This is also largely the case for Jupiter's low-mid-latitude x-ray emission, although the situation is complicated by Jupiter's very non-dipolar magnetic field and its dynamic and active magnetosphere.

- Saturn's rings shine in x-rays in the O K fluorescent line at ~0.53 keV.

- Fluorescent emission due to incident solar x-rays from O atoms in the H_2O icy ring material is the likely source for the ring x-ray emission.

- There possibly is an East-West asymmetry in the ring x-ray emission. If so, its origin is mysterious, as there should be no such asymmetry in the incident solar flux.