

IXO Science Panel

**Solar System, Planet Formation &
Evolution**

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IXO Science Panel

Solar System, Planet Formation & Evolution

Key question #1:

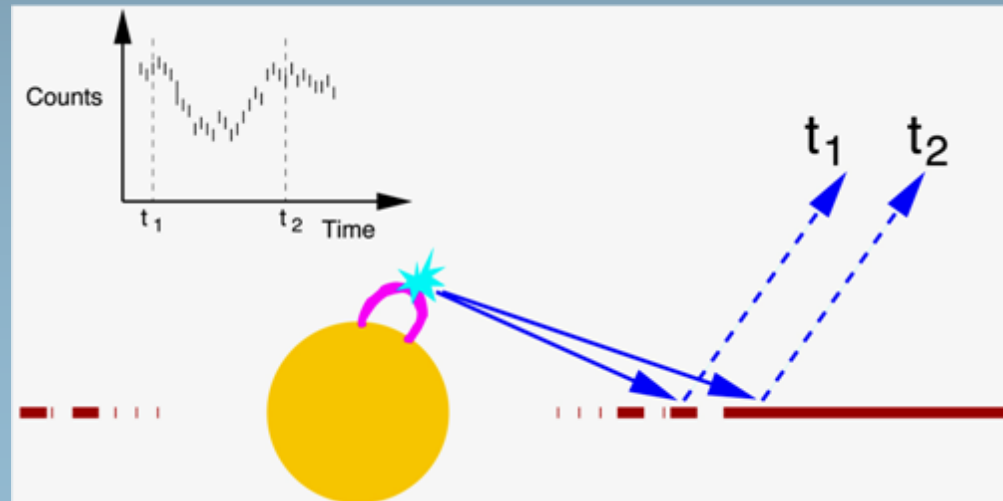
How do X-rays influence planet formation in protoplanetary disks?

X-rays from powerful magnetic reconnection flares are ubiquitous in pre-main sequence stars during the epoch of planet formation. If these stellar X-rays efficiently irradiate the protoplanetary disk, many effects on disk physics are expected (e.g., ionization-induced turbulence). Penetrating hard X-rays may regulate the 'dead zone' where dust settles to the midplane.

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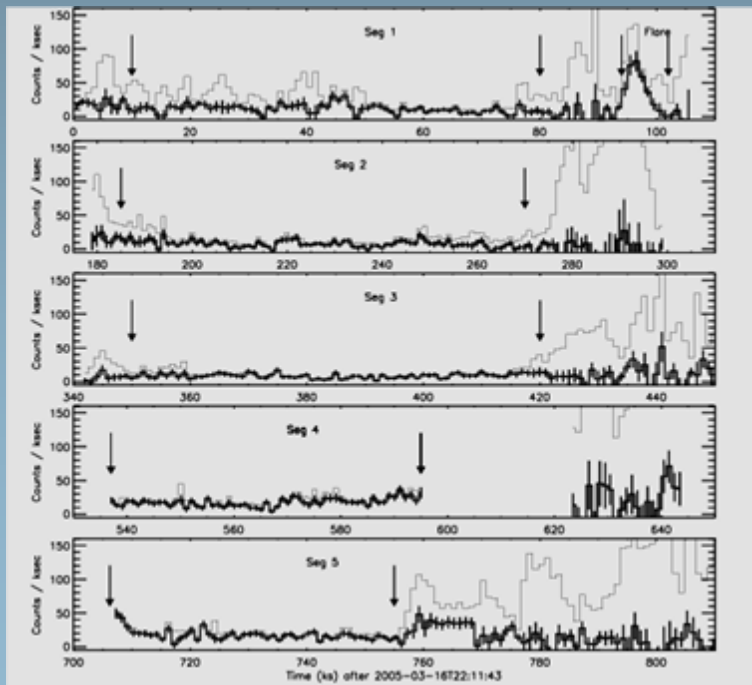
The fluorescent Fe 6.4 keV has been marginally detected in a few pre-main sequence systems. Con-X can measure the line in hundreds of nearby protostars and T Tauri stars with disks well-characterized in the infrared/submm band.

For a few bright X-ray flares, disk structure can be elucidated by reverberation mapping. This will reveal the disk structure as seen from the X-ray emitting loop on scales of $\sim 2-100$ AU.



Examples of pre-main sequence X-ray lightcurves

Chandra COUP, 13.2 days Wolk et al. 2005



XMM DROXO, 9 days Giardino et al. 2007

Chandra YLW 16A superflare, 1.2 days
Imanishi et al. 2001

Theoretical calculations of pre-main sequence magnetospheres

Open accreting field lines

Closed field loops

X-ray emission

QuickTime™ and a decompressor are needed to see this picture.

Jardine et al. 2006

Examples of magnetic accretion funnels

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Models of X-ray flare decays indicate that some arise from loops 5-20 stellar radii in size. These could efficiently illuminate the disk.

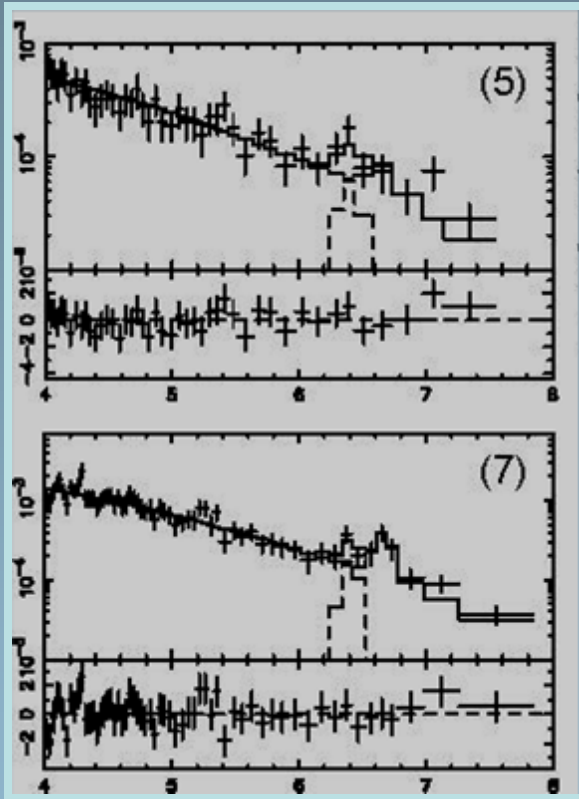
Favata et al. 2005,
Getman et al. 2008

Long et al. 2007, Romanova et al. 2008

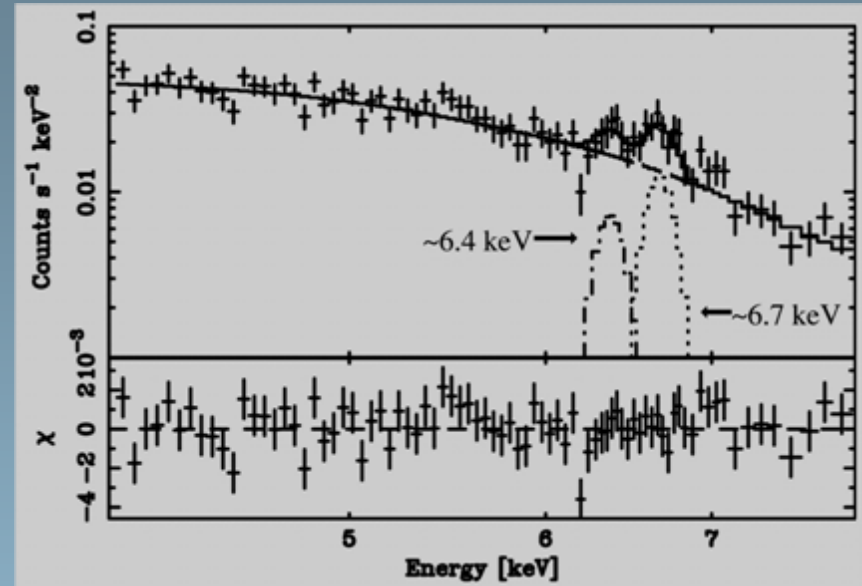
Iron fluorescent line

Cold disk reflects flare X-rays

COUP spectra

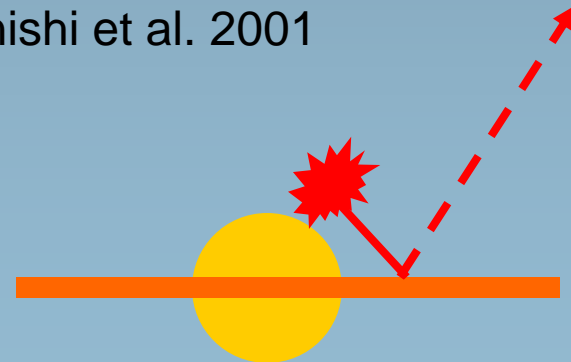


YLW 16A: protostar in Oph



Imanishi et al. 2001

Tsujimoto et al. 2005



X-ray ionization of the gaseous disk

PREDICTION

X-rays heat & ionize outer layers of disk.
 $J_{1/2} \rightarrow J_{3/2}$ [NeII] 12.81 μm line
predicted to be observable from 1-10 AU

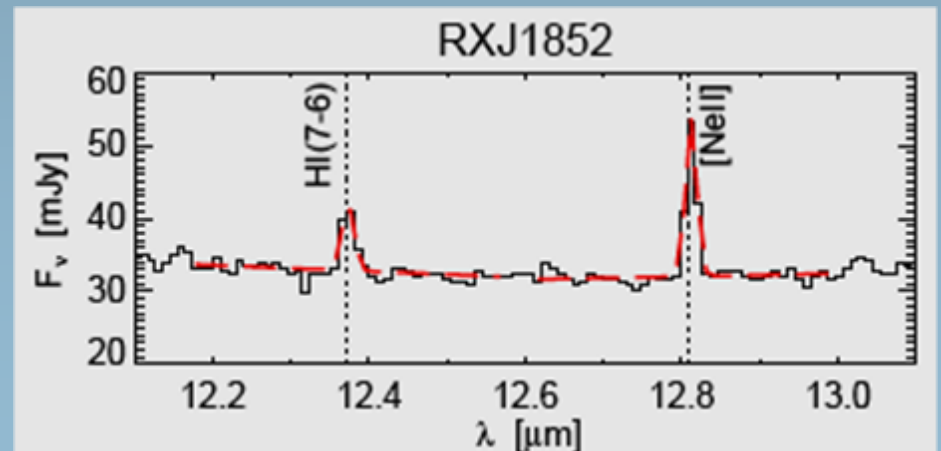
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Glassgold et al. 2007. Also Meijerink et al. 2008,
Gorti & Hollenbach 2008, Ercolano et al. 2008

DETECTION

Spitzer FEPS Legacy reports
[Ne II] line in 4 X-ray bright
T Tauri stars

Pascucci et al. 2007. Also Lahuis et al.
2007, Espaillat et al. 2007, Herczeg et
al. 2007



Plausible X-ray/flare effects on protoplanetary disks

- **PMS X-ray ionization will heat gas and change (organic) chemistry in disk outer layers**
- **PMS X-rays may be an important ionization source at the base of bipolar outflows**
- **X-ray ionization is likely to induce MRI turbulence affecting accretion, dust coagulation, migration, gaps**
- **Flare MeV protons may have produced some short-lived radio nuclides in meteoritic CAIs by spallation (^{10}Be , ^{21}Ne , ^{41}Ca , ...)**
- **Flare X-rays may have melted CAIs close to star and/or melted chondrules at Asteroid Belt**

(These issues are discussed in dozens of studies)

What can IXO learn about protoplanetary disks in 1 Ms?

A survey of the nearby Ophiuchus, Taurus, Perseus and Orion star forming clouds, IXO can detect fluorescent 6.4 keV in ~200 pre-main sequence stars. Their dust+gas disk properties would already be well-characterized by Spitzer, Herschel, JWST and ALMA. IXO would establish the importance of X-ray irradiation of disk physics & chemistry.

In a long exposure of the Ophiuchus cloud core (including YLW 16A), IXO is likely to detect several superflares with rise/fall in hours.

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Key question #2:

How does charge-exchange work in planetary atmospheres?

Soft X-ray emission from the interaction of solar wind and X-rays with neutral planetary atmospheres has been detected in comets and from the outer atmospheres of Venus, Mars, Jupiter & Saturn. The physical processes are still poorly understood because of inadequate signal and spectral resolution of current telescopes. Many charge-exchange lines are expected in the 0.3-1 keV band.

IXO will discriminate fluorescent and charge-exchange processes, produce movies of the Jovian aurorae, and map the unexpected Martian exosphere. Together with charge-exchange studies of comets, IXO will provide unique insights into the outer atmospheres of Solar System bodies and their interaction with solar phenomena.

Addresses NASA SMD science goals on heliospherics and charge-exchange

Jovian X-ray emission

Several spectral components with distinct spatial & temporal behaviors:

1. Soft charge-exchange lines of heavy solar wind ions (O, S, C)
2. Hard electron bremsstrahlung from solar wind particles
3. Scattering and fluorescence of hard and soft solar X-rays

QuickTime™ and a decompressor are needed to see this picture.

Jupiter viewed with XMM in four broad bands
Branduardi-Raymont et al. 2007

XMM grating
Spectra
highlighting
O charge
exchange lines

Branduardi-
Raymont et al.
2007

QuickTime™ and a
decompressor
are needed to see this picture.

Simulation of a 50 ks IXO spectrum based
on the XMM emission model showing a few of
the expected charge-exchange lines

Chandra spectra
of aurorae with
soft & hard
components

Branduardi-
Raymont et al.
2008

X-rays from Mars

The expected fluorescence of solar X-rays from inner Martian atmosphere

QuickTime™ and a decompressor are needed to see this picture.

Chandra, Dennerl 2002

The unexpected charge exchange emission from an exosphere at 2-8 radii.

Photoevaporation of the Martian atmosphere by solar UV/X-rays?

XMM, Dennerl et al. 2007

IXO SSPFE program

1. X-ray fluorescence in protoplanetary disks (0.4 Ms snapshot survey of Taurus, Perseus & Orion Clouds for X-ray irradiation effects; 0.5 Ms continuous exposure of Ophiuchus for reverberation mapping)
2. Charge-exchange physics in outer atmospheres of Jupiter (3 visits totaling 0.5 Ms) and Mars (3 visits totaling 0.3 Ms)
3. Comet studies (0.4 Ms), heliospheric emission (0.0 Ms, parasitic), evaporation of extrasolar planetary atmospheres (0.4 Ms)

Total program: 2.5 Ms