Planetary Science Advances with the International X-ray Observatory

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Introduction

Planets and their formation sites are far too cold to produce thermal X-rays. Nonetheless, they emit X-rays by unusual processes which provide astrophysical insights inaccessible at other wavelengths. Since 1983, X-rays have been detected from Jupiter, Saturn, Venus, Mars and many comets1,2. The principal emission mechanism is charge-exchange between solar wind ions and neutral atmospheric molecules. X-rays from magnetic flares have been seen in hundreds of pre-main sequence stars hosting protoplanetary disks3,4,5. X-ray irradiation and ionization of disks may play significant roles in planet formation processes6. X-ray diagnostics can provide unique inputs into conditions for planet habitability.

IXO’s combination of broad energy coverage, high sensitivity and spectral resolution will make qualitatively new advances in planetary science.

The IXO Planetary Key Projects

- Probing protoplanetary disks with the fluorescent iron line
- Elucidating the complex X-ray emission of Jupiter & Mars
  - Cometary charge exchange
  - Heliospheric charge exchange
  - Atmospheric evaporation of extrasolar planets

X-rays, protoplanetary disks and planet formation

All pre-main sequence stars produce magnetic flares far more powerful and frequent than older main sequence stars. A bright X-ray flare is shown above from a 1.2 day Chandra observation of protostar YLW 16A in the nearby Ophiuchus star forming cloud7. At peak emission, the flare shows $\log L_x \approx 32.1$ erg/s and $kT \approx 10$ keV plasma temperature.

Iron Kα emission lines are seen both from hydrogenic iron in the flare plasma at 6.7 keV and from neutral iron at 6.4 keV. This is interpreted as fluorescence off of the proto-planetary disk (diagram below). Evidence for efficient X-ray irradiation of disk outer layers includes the [NeII] 12.8 μm line8 and excited molecular rovibrational transitions.

The IXO Hard X-ray Telescope (blue line) can trace the emission out to 10-30 keV range where X-rays may penetrate into the disk midplane. This is critical for determining the extent of ionization-induced MHD turbulence (via the magneto-rotational instability) in the disk and the size of the ‘dead zone’. The diversity of planetary systems may depend in part on the early X-ray irradiation history of the disks.

1  Bhardwaj, Elsner et al. 2007, Plan. Space Sci.
2  Bhardwaj & Lisse 2007 in Encycl. of the Solar System
3  Feigelson & Montmerle, 1999, ARA&A
5  Feigelson et al., 2007, in Protostars & Planets V
9  Branduardi-Raymont et al. 2007, A&A

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Jupiter and Mars

Jupiter’s atmosphere shows spatially distinct, rapidly varying X-ray components from charge exchange of heavy solar wind ions, electron bremsstrahlung continuum, scattering and fluorescence of solar X-ray emission. The images above map two line tracers from XMM. IXO will produce superb spectra (including dozens of charge-exchange lines) and movies of each component during the planet’s 10-hr rotation and response to solar flare/CME events.

Mars shows fluorescent solar X-rays from the upper atmosphere and a halo of charge-exchange X-rays from a previously unknown exosphere out extending to ~8 Mars radii. The image here, derived from XMM observations, shows charge-exchange O+6-O+7 in blue, C+4-C+5 in green, and fluorescent lines in yellow10.

Study of the Martian exosphere with IXO may give crucial clues to the processes of atmospheric evaporation by stellar ultraviolet emission and winds, which may be a critical determinant of the habitability of terrestrial planets.