Solar System and Exoplanets

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on behalf of Topical Panel SW 3.1 : Solar System and Exoplanets

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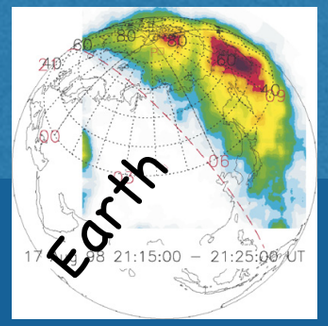
Introduction

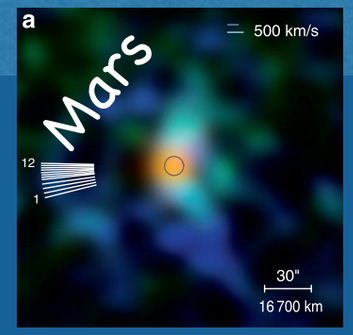
- In the last decade, X-ray studies of our solar system have been greatly advanced with XMM-Newton, Chandra and Suzaku

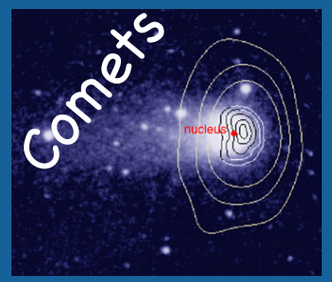
- The knowledge of our solar system is applicable to a variety of astrophysical themes such as charge exchange, particle acceleration and exoplanets

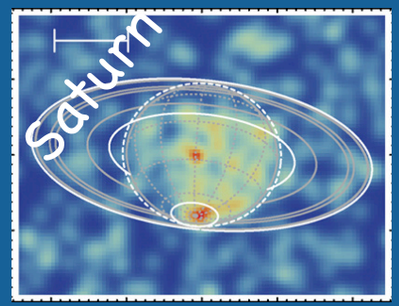
- Rapidly growing X-ray studies of exoplanets allow us to study planetary atmosphere and star-planet interaction

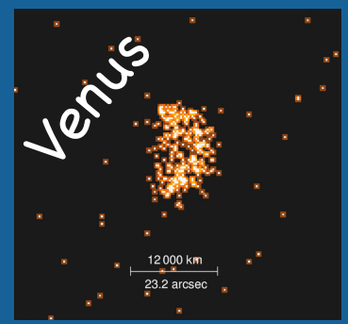
- Connected to the themes of ESA's cosmic vision "*How does the Solar System work ?*" and "*What are the conditions for planet formation and the emergence of life ?*"

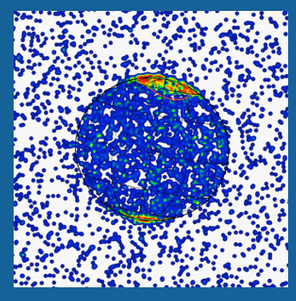




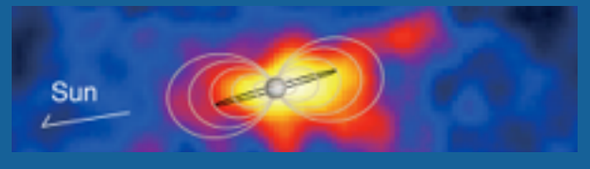


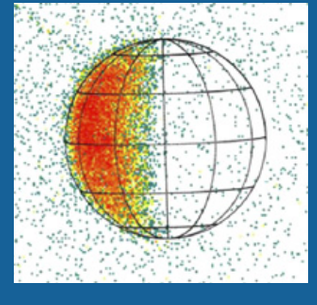


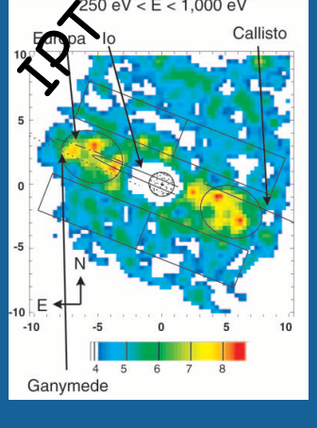


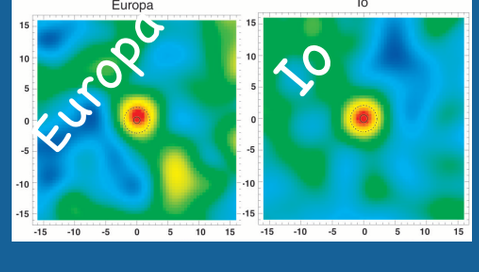


Jupiter's radiation belt





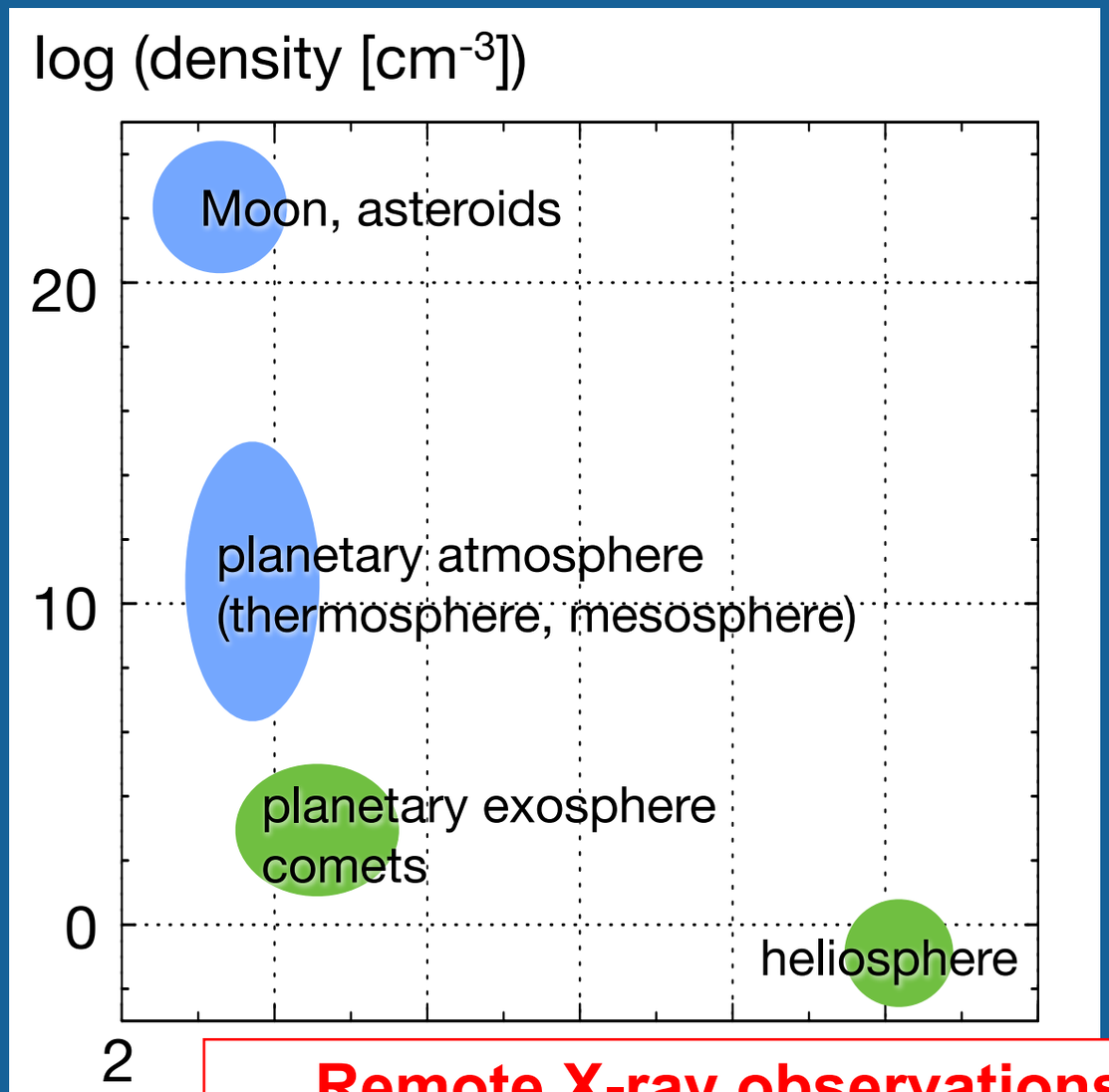




Bhardwaj+07, Dennerl+10, Ezoe+11

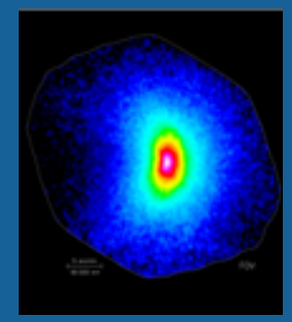
X-ray production mechanisms

- Mercury, Venus, Earth, Mars, Jupiter, Saturn, Moon, Io, Europa, Ganymede, Asteroids, Io Plasma Torus, Comets, Heliosphere, …



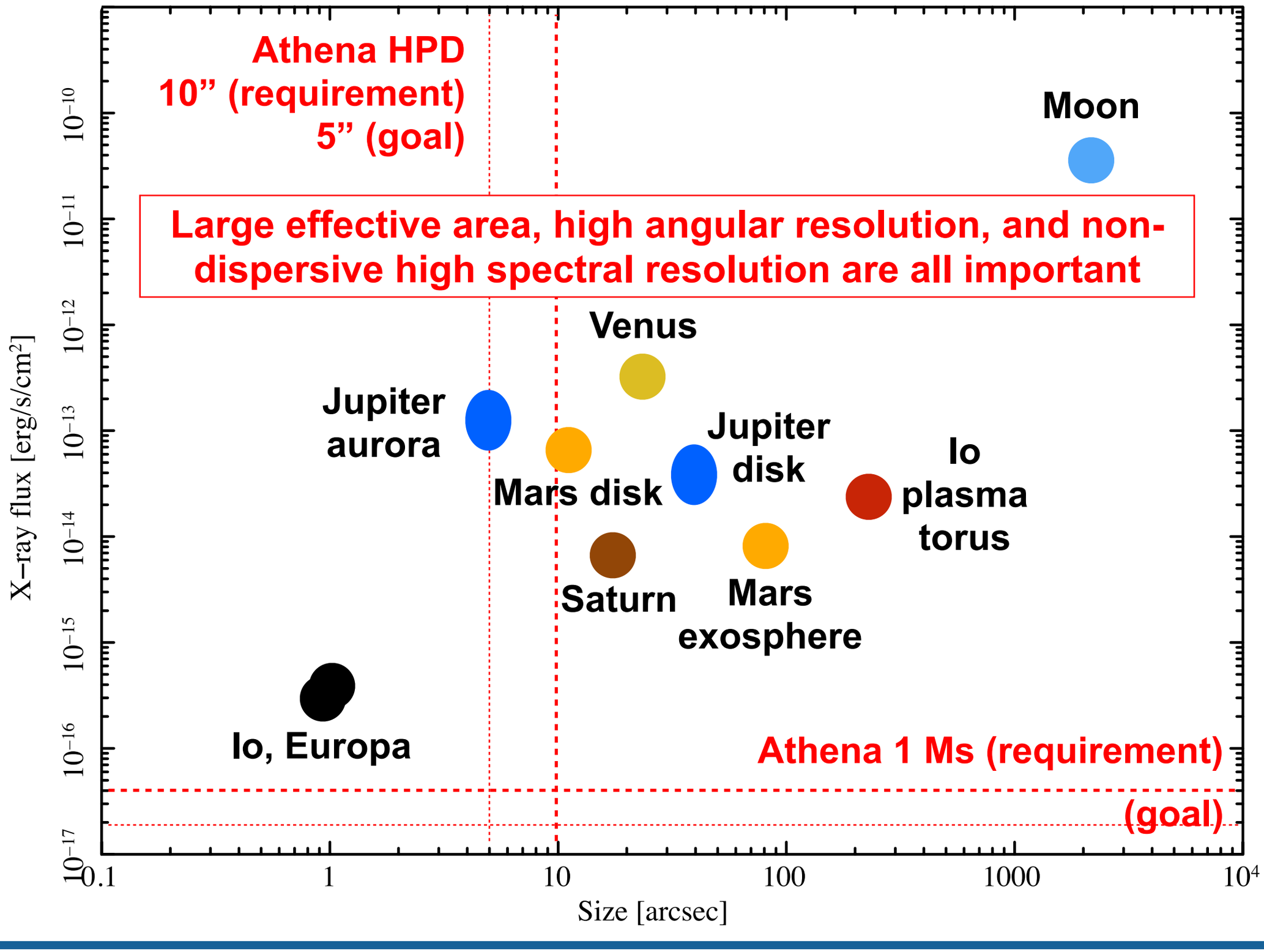
- Elastic and K-shell fluorescent scattering of solar X-rays
- Charge exchange (CX)
  e.g., $H + O^{7+} \rightarrow H^{+} + O^{6+} + h\nu$
  solar wind or magnetospheric ions
- Electron bremsstrahlung
- Electron/Ion collisions with line emission
- Electron inverse Compton scattering

Crevens+05



Remote X-ray observations are being established as new diagnostics of planetary atmospheres and magnetospheres

Typical angular size vs X-ray flux

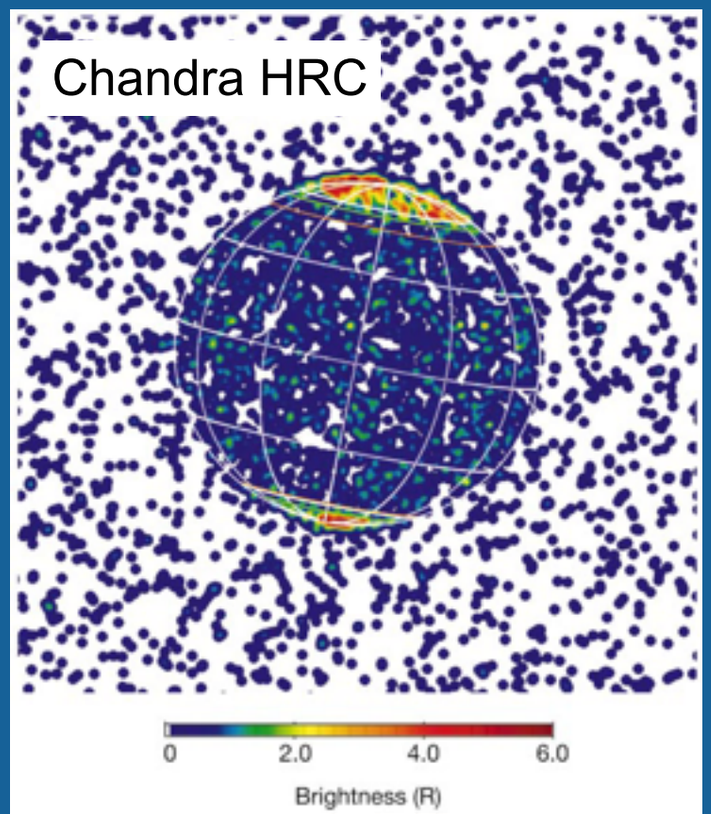


X-rays from Jupiter

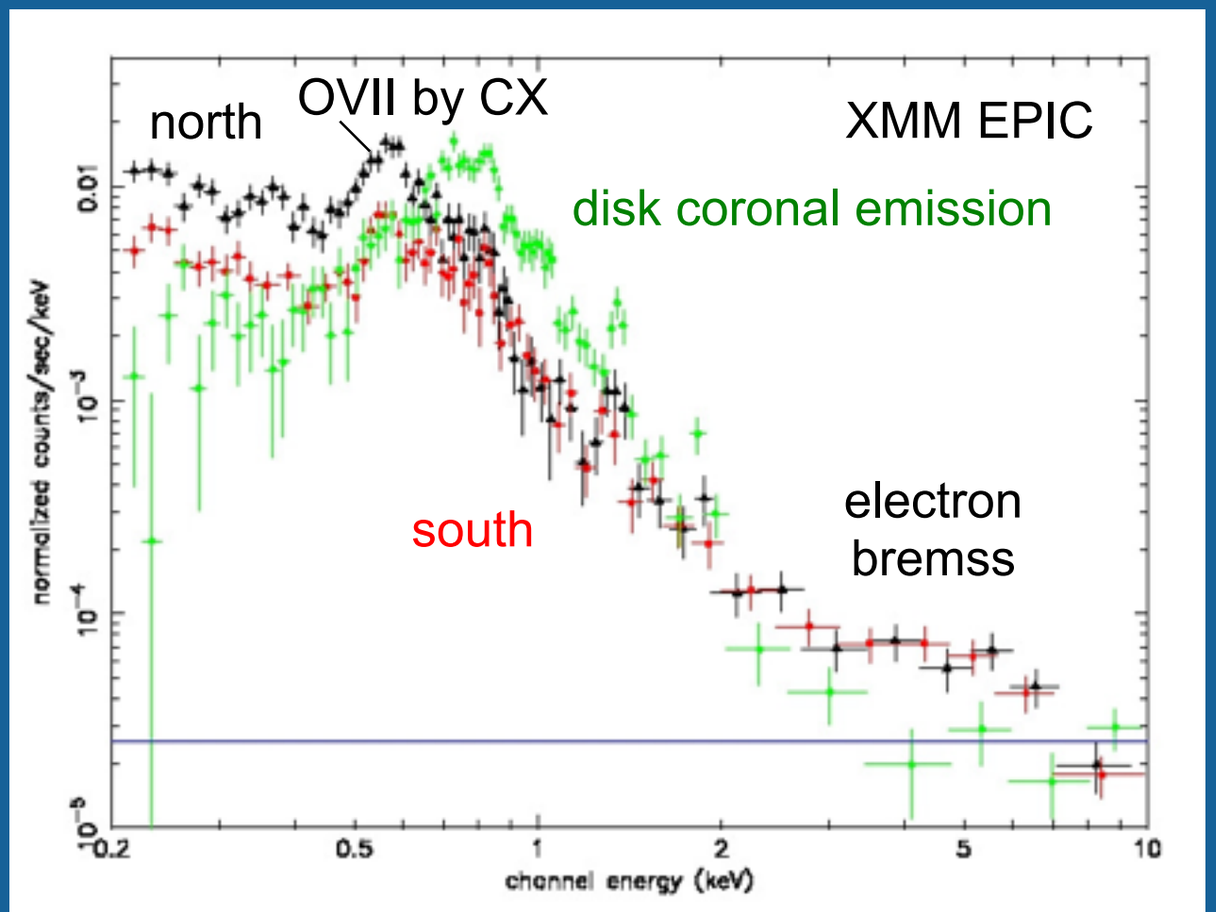
- First detection with Einstein
  → aurora by heavy ion precipitation & charge exchange ?

Metzger+83
Horanyi+88
Waite+88

- High angular resolution imaging & spectroscopy
  by Chandra and XMM
  → two components = aurora and disk (low & middle latitude)



Gladstone+02



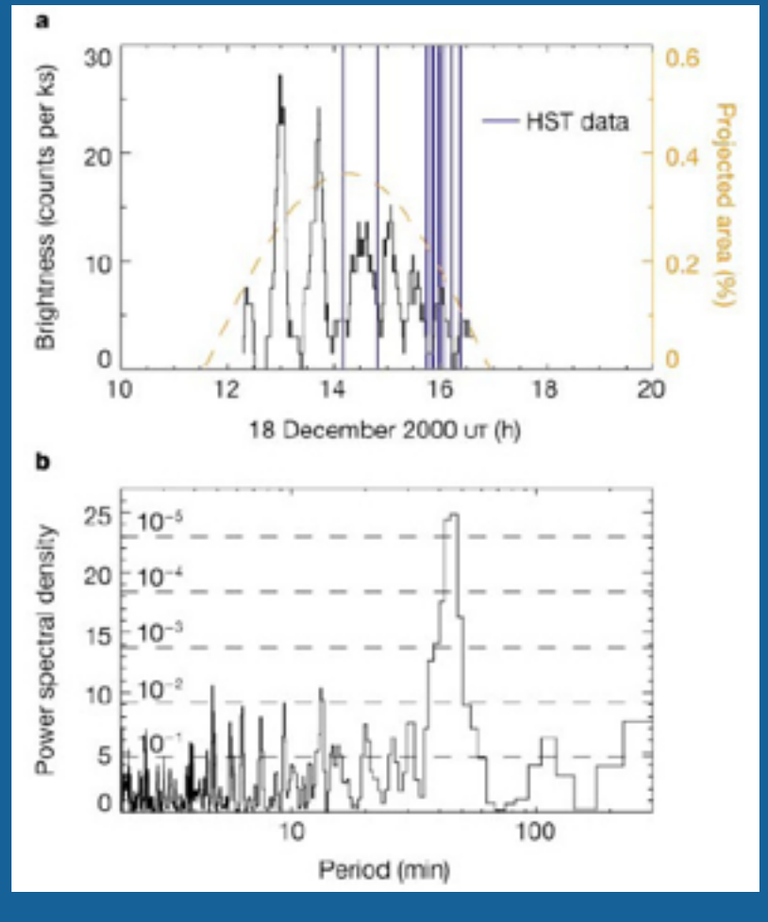
Branduardi-Raymont+07

Jupiter's aurora

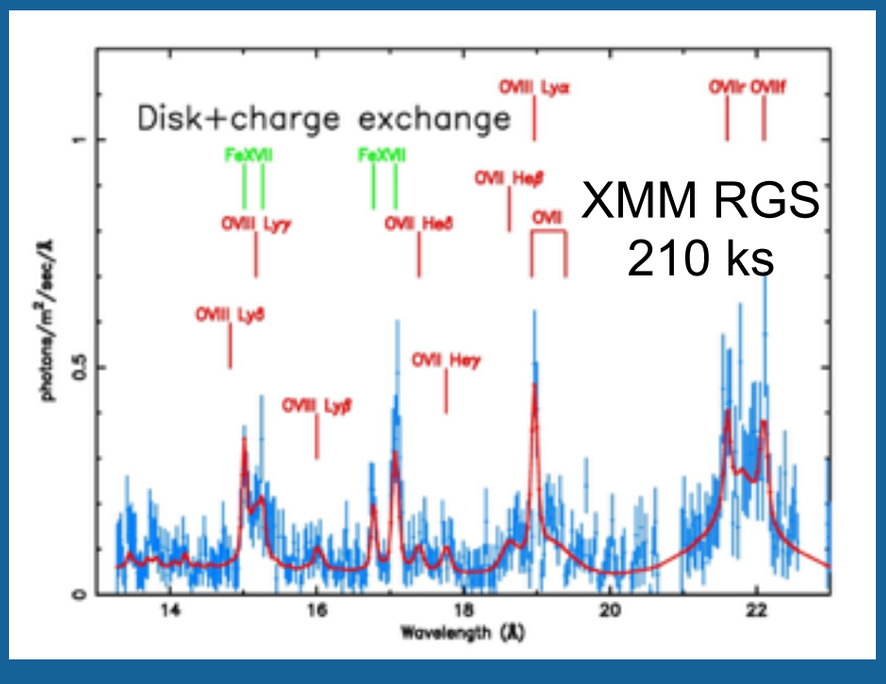
- Chandra detection of X-ray pulsation with a ~45 min period
  faster than the rotational period 10 hrs but similar to QP radio bursts
  -> Not detected in subsequent observations

- Broad OVII and OVIII components (+/- 5000 km/s) in XMM RGS spectrum
  corresponding to MeV/amu oxygen ions
  <-> electric field potential along magnetic field lines

Cravens+03
Bunce+04



Gladstone+02



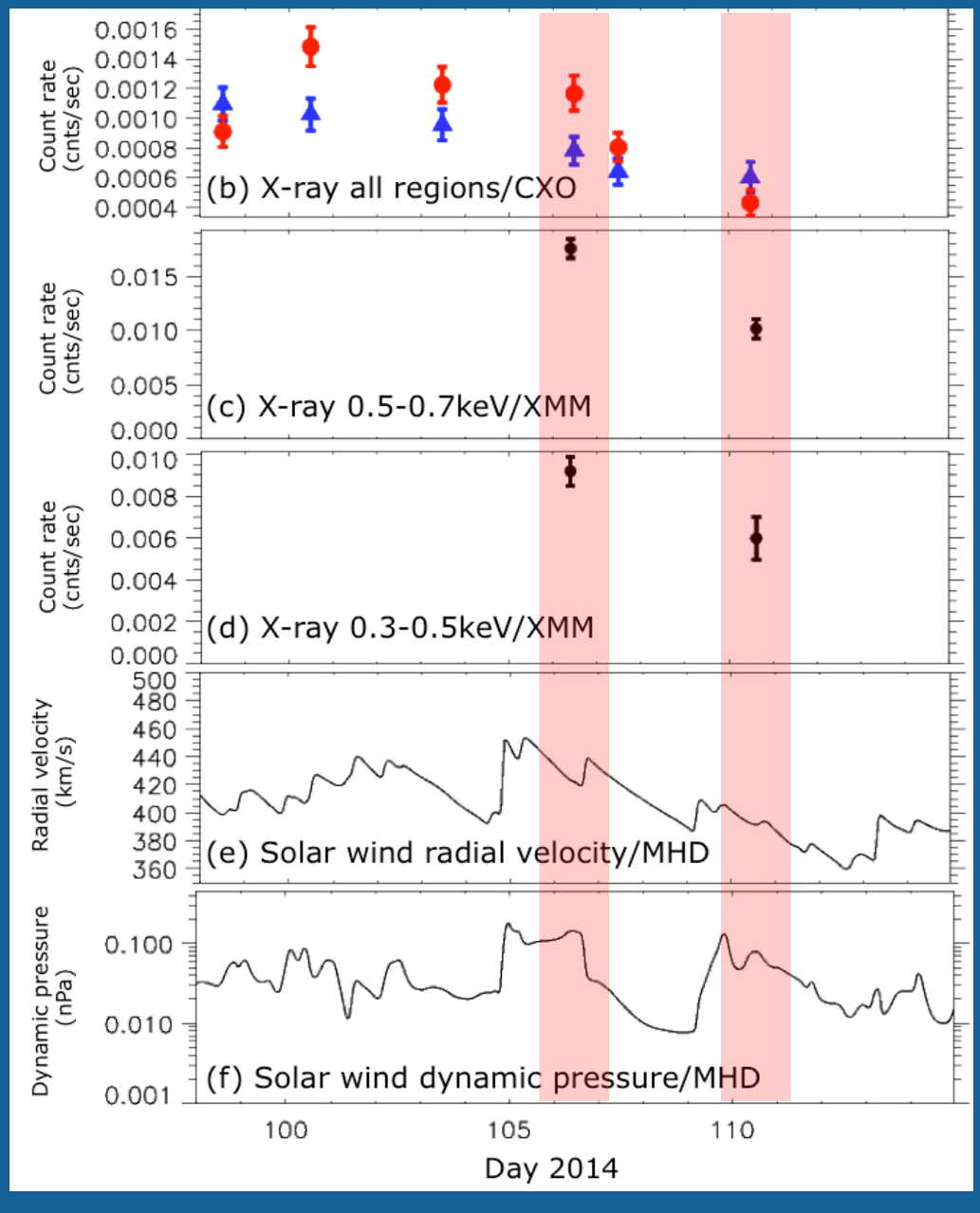
Branduardi-Raymont+07

Open questions

- Do solar wind conditions affect X-ray auroral emission ?
  - Correlation with solar wind radial velocity ?
- 45 min pulsation ? Why so rare ?
- What is the origin of ions ?
  solar wind or magnetospheric or both
  - Larger velocity shear at the boundary of magnetosphere can cause particle injection ?
  - XMM EPIC and Suzaku detected low energy line(s) : CVI (0.37 keV) or SXI, SXII (0.32, 0.34 keV) ?

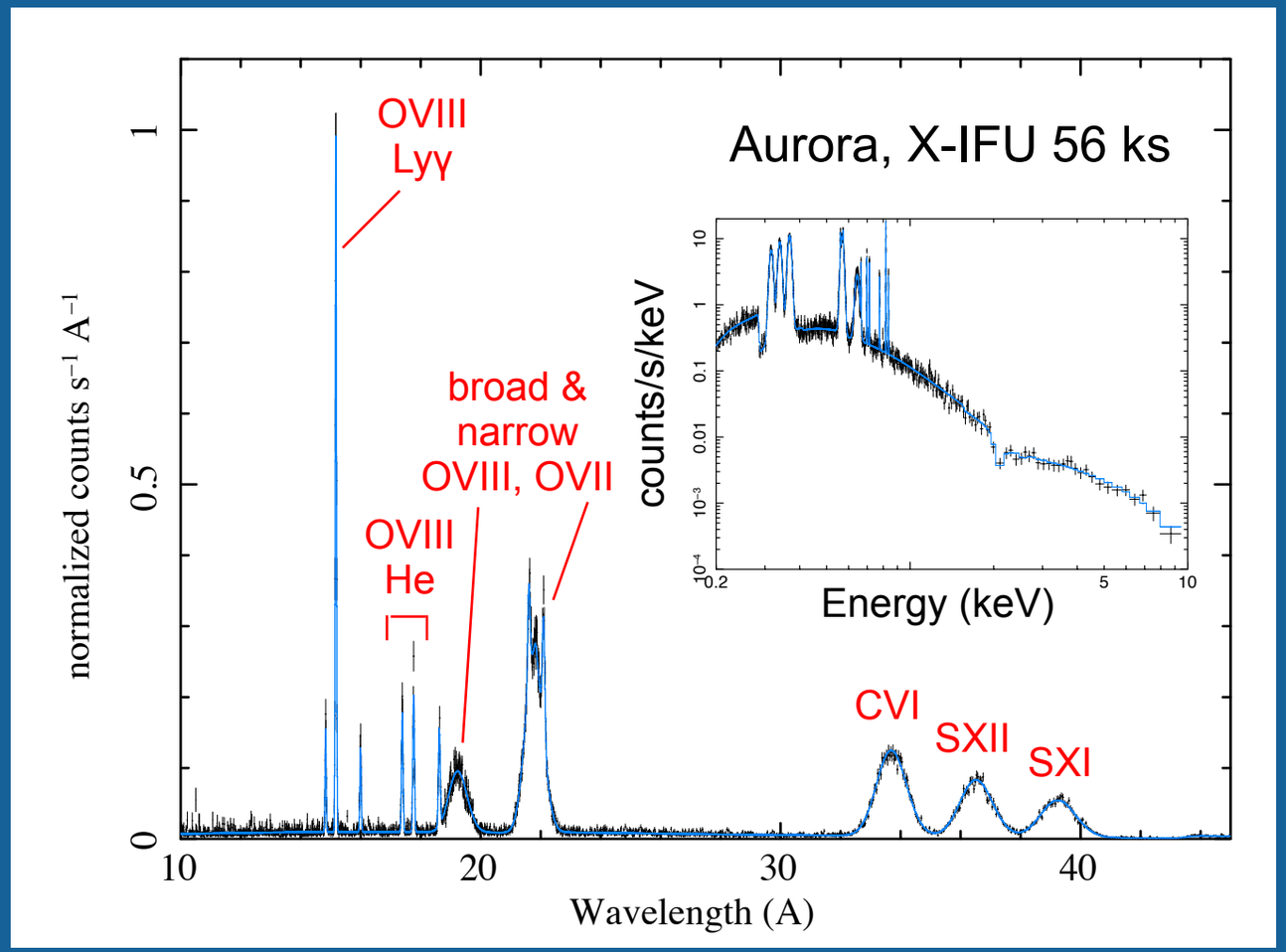
Branduardi-Raymont+07, Ezoe+10

Kimura+ JGR submitted

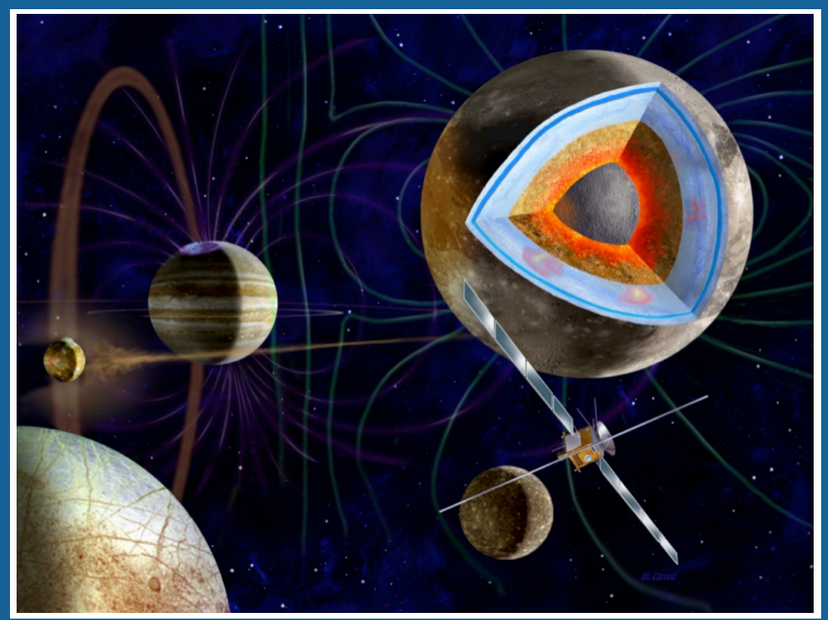


A way forward to Athena

- Athena X-IFU will reveal :
  (1) ion species, (2) velocity distributions of ions, (3) energy distribution of electrons and (4) their time variabilities



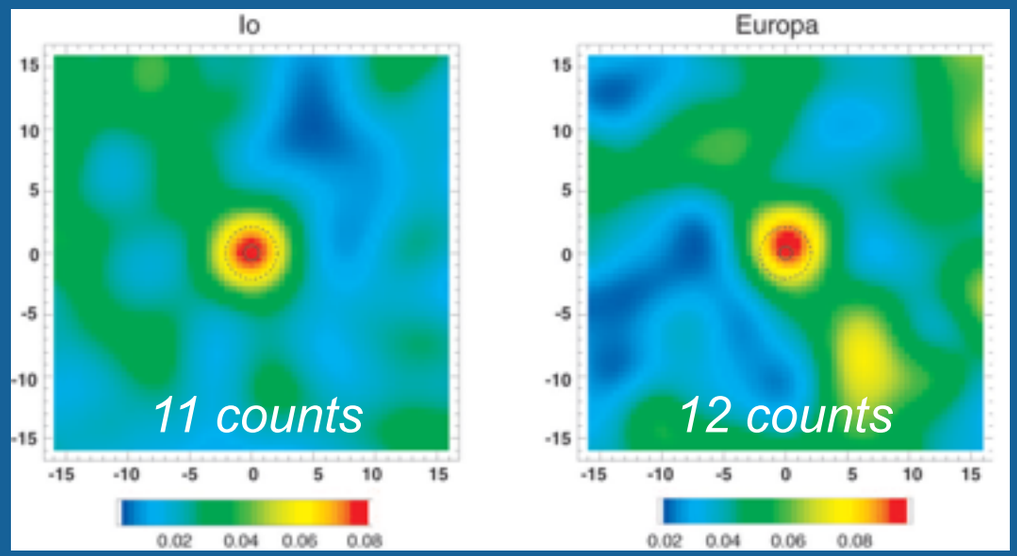
JUICE (2030 orbit insertion)
In-situ particle measurements
⇔ Global X-ray imaging spectroscopy



Athena will settle the long debate on the origin of ions and will test theories of particle transportation and acceleration in the Jupiter's m-sphere

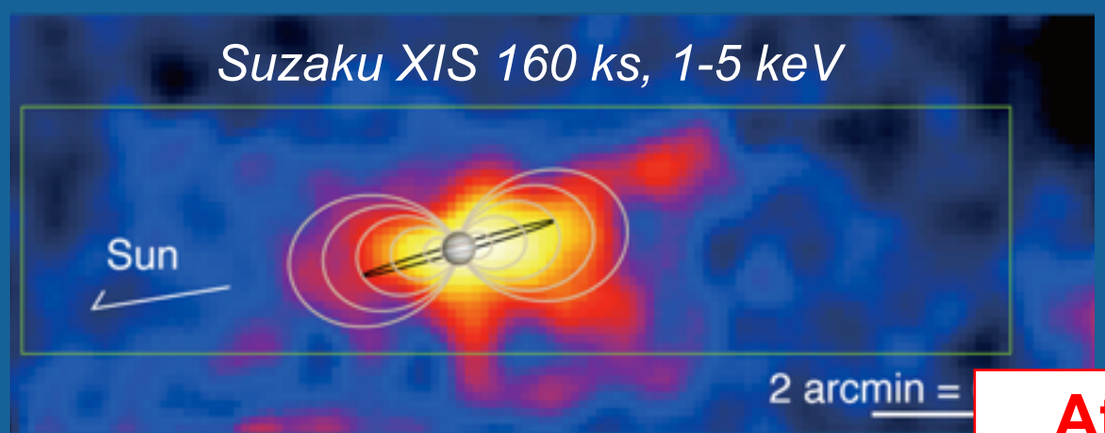
Galilean satellites, the IPT, radiation belts

- X-rays from Io and Europa :
  energetic ion impact on the surfaces → fluorescent lines ?

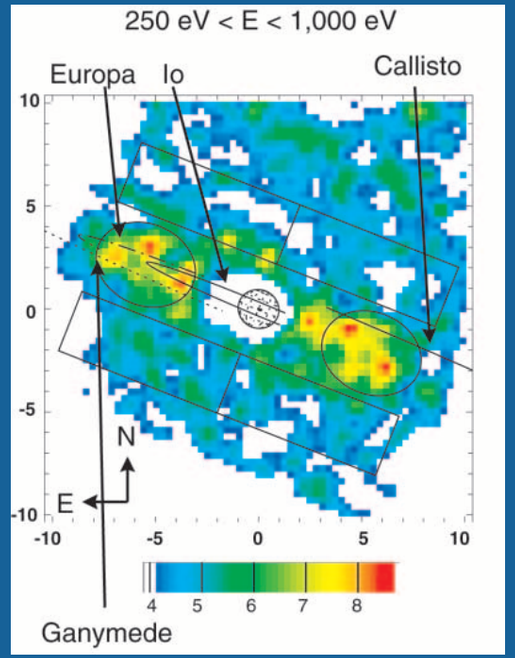


- The Io Plasma Torus :
  Soft continuum + OVII line

- Diffuse X-rays from radiation belts :
  Inverse Compton scattering by tens MeV electrons ? → PL



Ezoe+10



Chandra ACIS
86 ks
Elsner+06

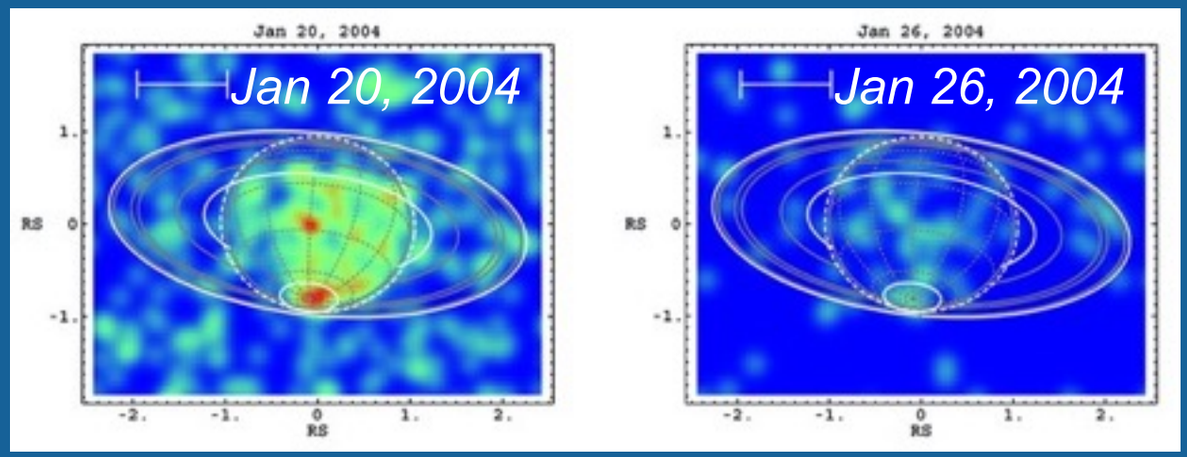
Athena can characterize their spectra and time variabilities

Saturn

Ness+04a,b
Bhardwaj+05a,b

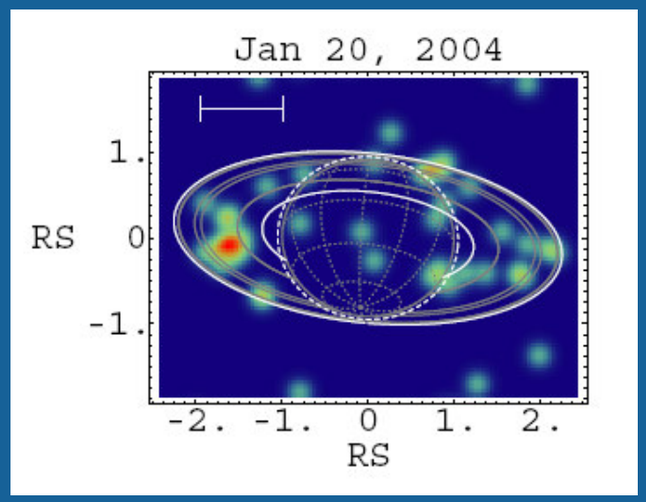
- Disk and polar X-rays show similar coronal spectra unlike Jupiter
- Good correlation b/w X-ray and solar 10.7 cm flux
  → scattering of solar X-rays
- Saturn's Ring :
  fluorescent scattering of solar X-rays on H_2O icy ring

Chandra ACIS, 37 ks, 36 ks

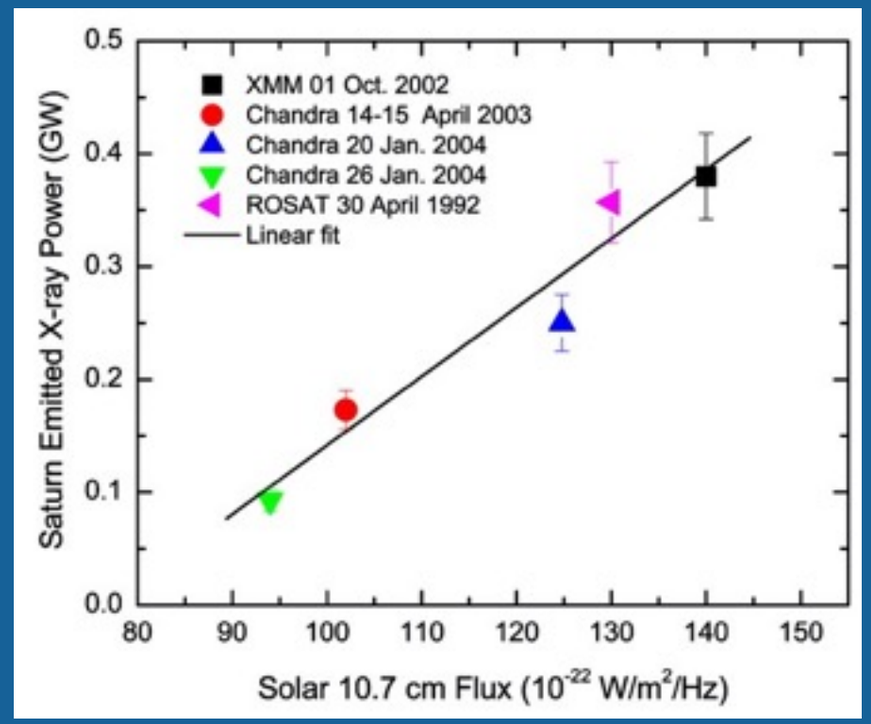


0.24-2 keV

Athena will push search for X-ray aurorae and understanding of X-rays from the ring to much greater depth



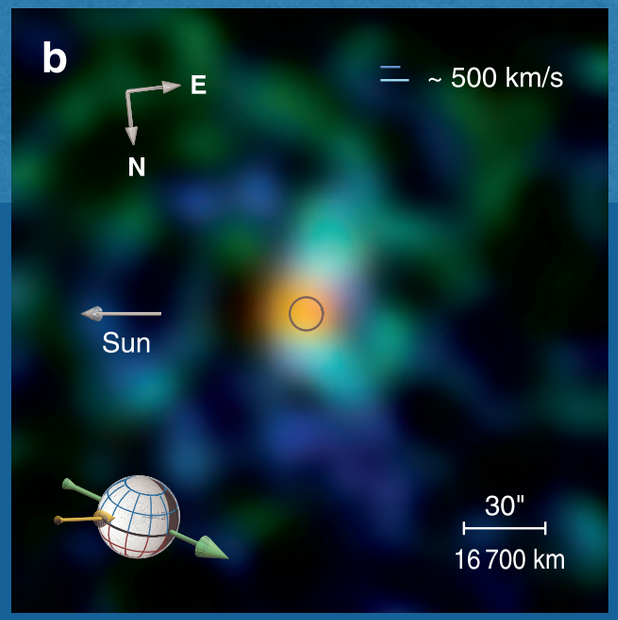
0.49-0.62 keV

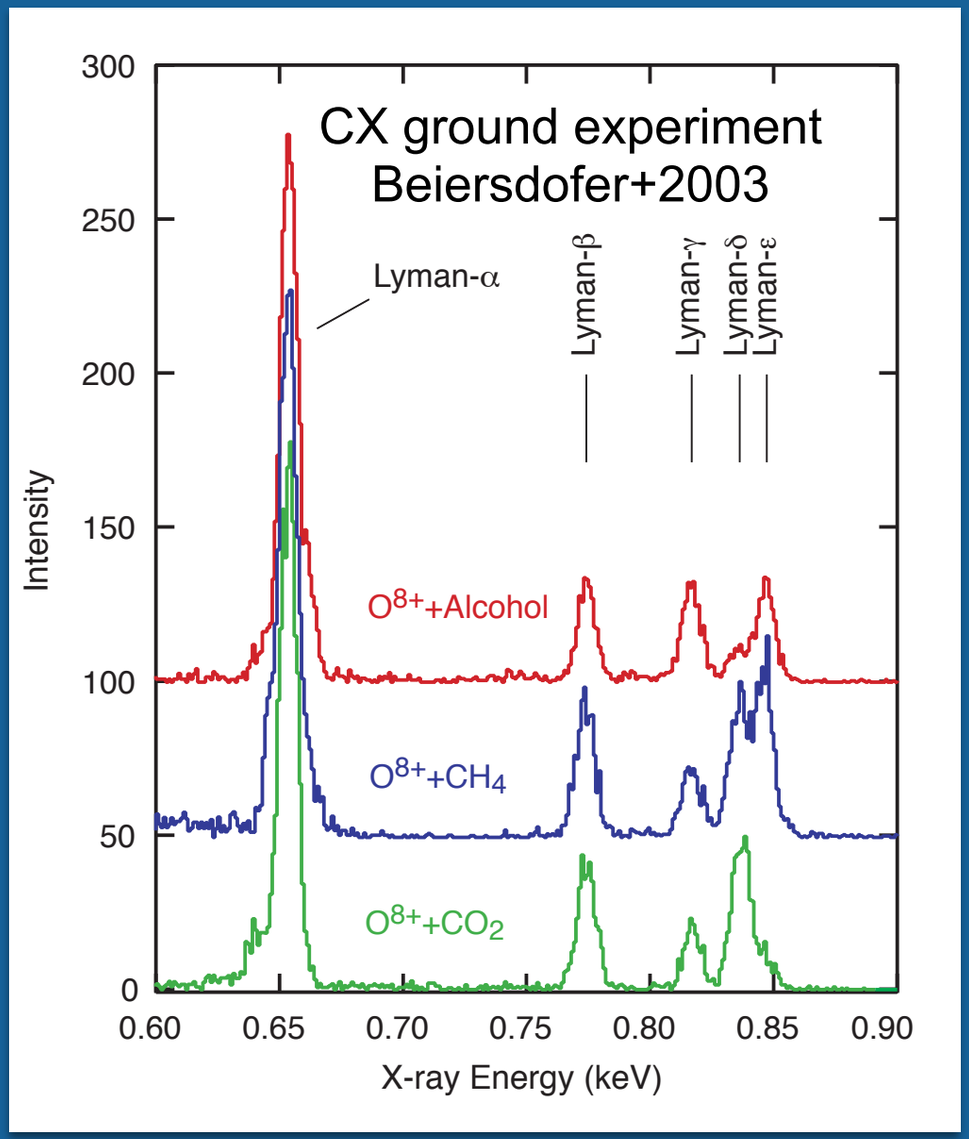


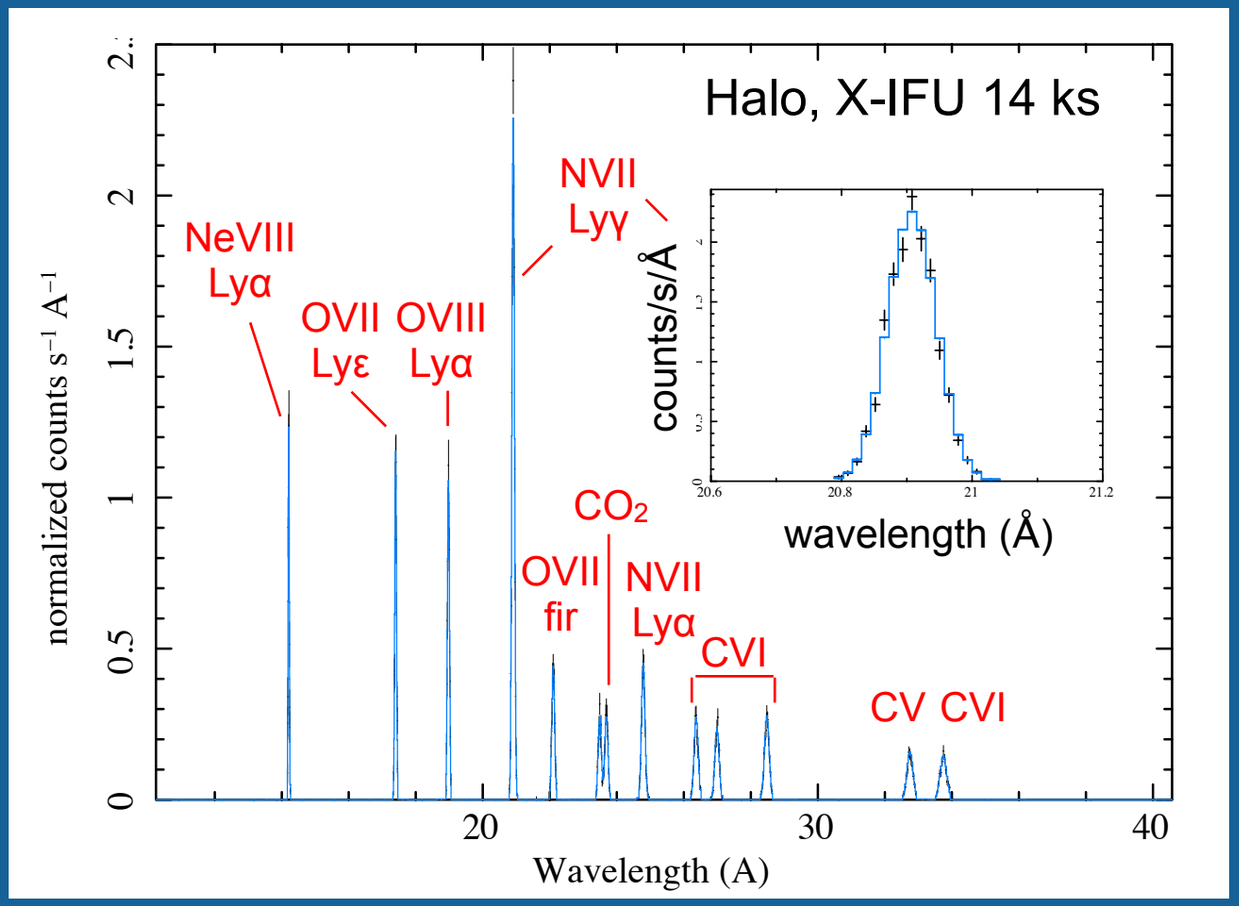
X-rays from Mars

Dennerl+06a, b
Ishikawa+11

- Disk by scattering of solar X-rays in its upper atmosphere and halo by CX in its exosphere



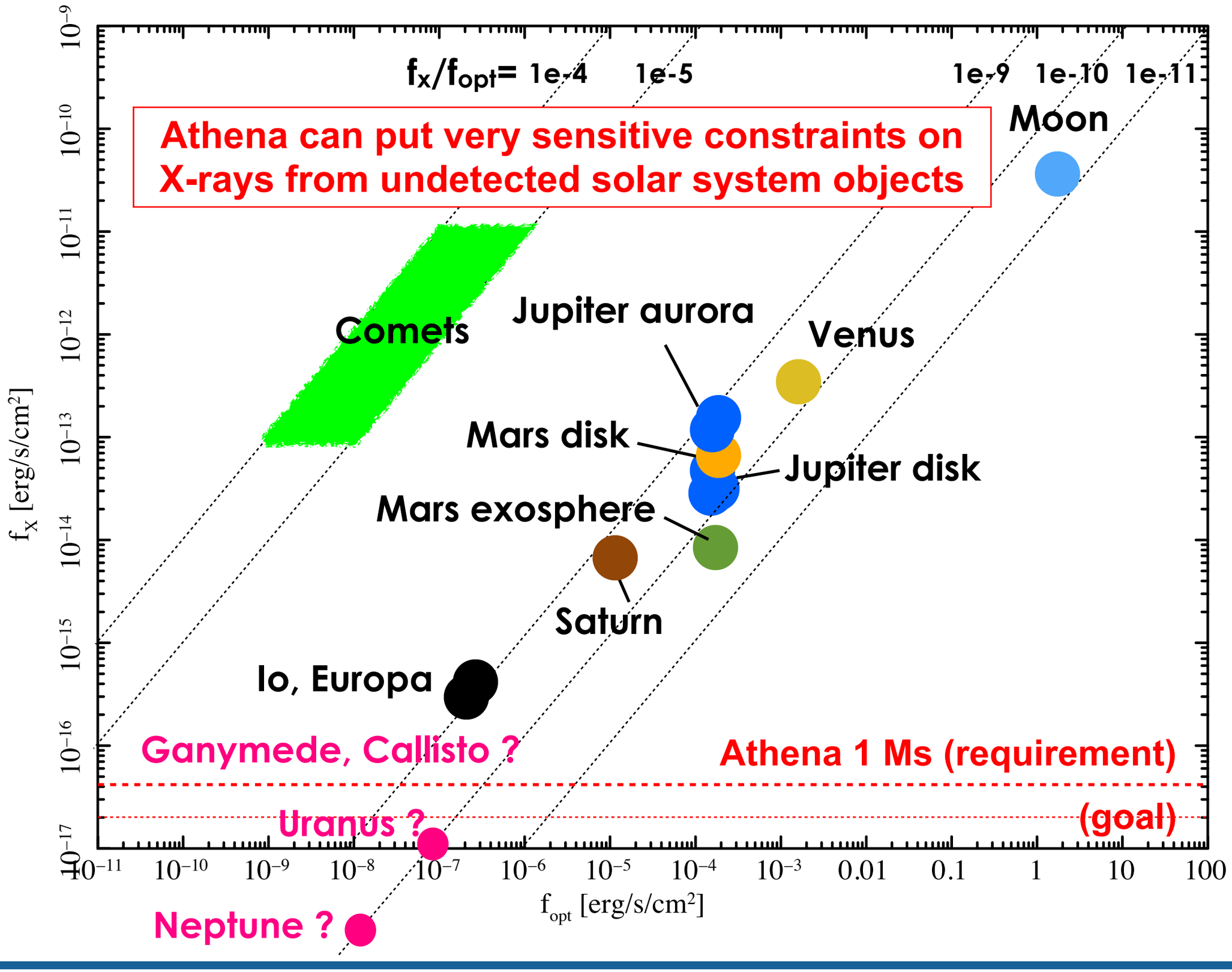




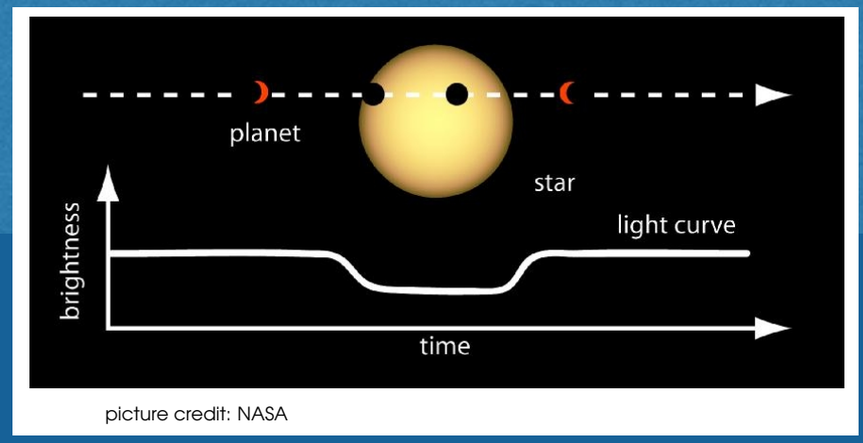
Athena will allow us to study chemical composition of ions and neutrals in the Martian exosphere and its atmospheric escape

New X-ray sources ?

Ezoe+11

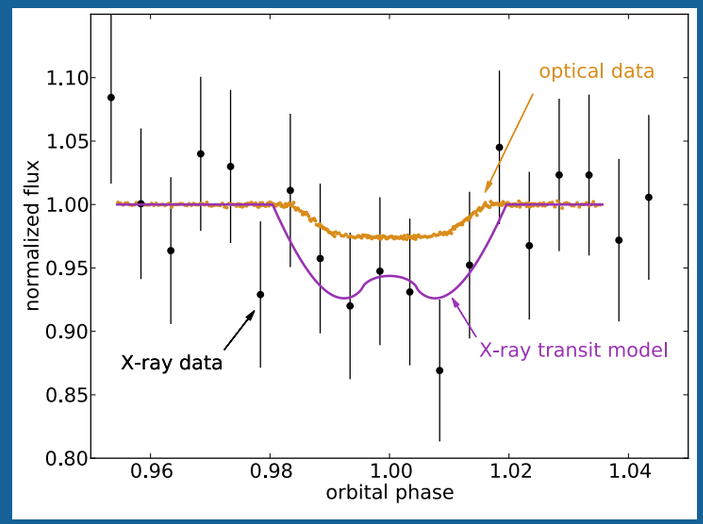


Exoplanets



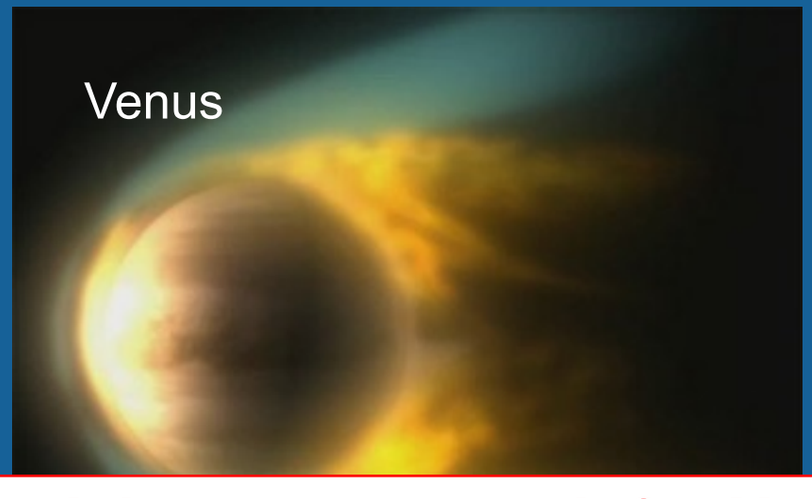
picture credit: NASA

- X-ray emission at young stages of a star will influence physical and chemical evolution of planetary atmospheres
  - X-ray transits → absorption by expanded atmosphere
  - Star planet interaction → magnetic interplay

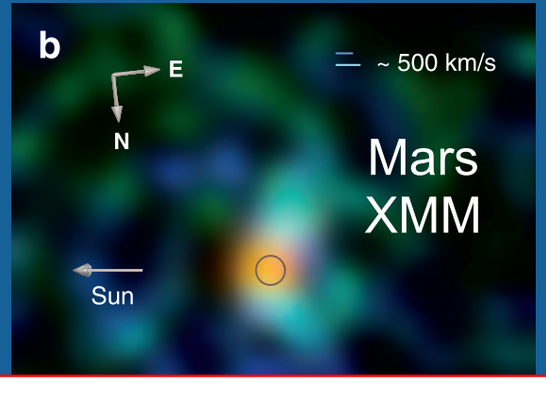


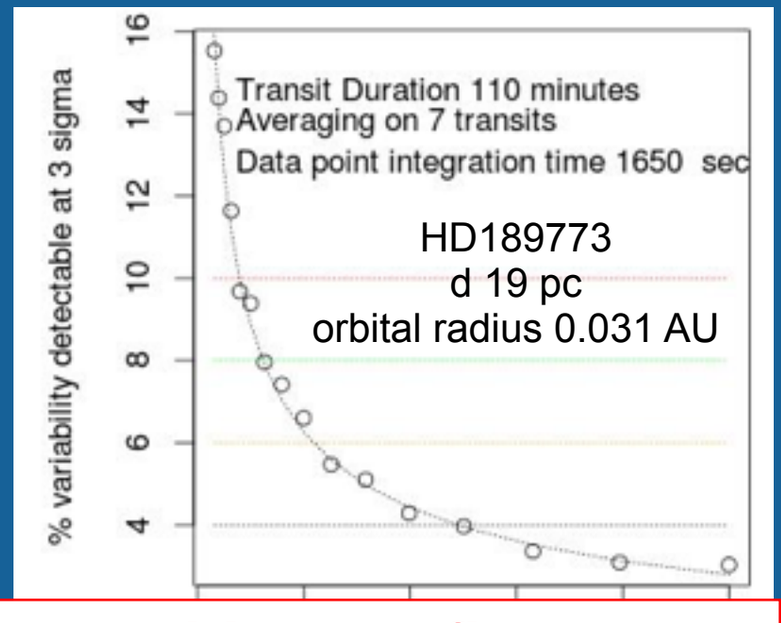
Poppenheiger+13

- Flare, stellar wind → atmospheric escape



Pilliteri+11
Lecavelier des Etangs+12

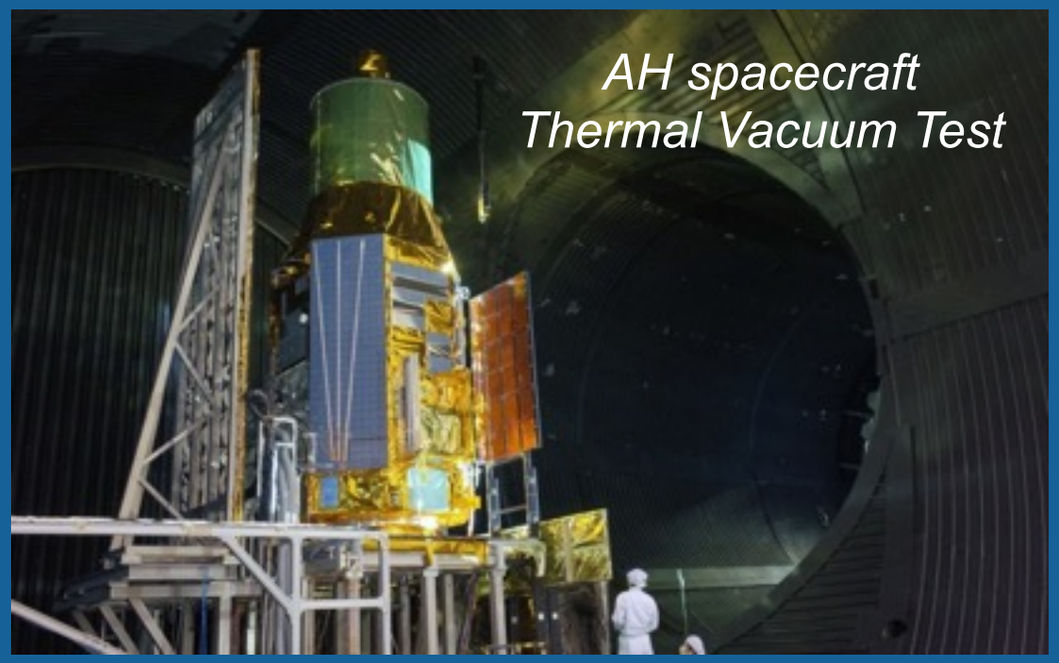


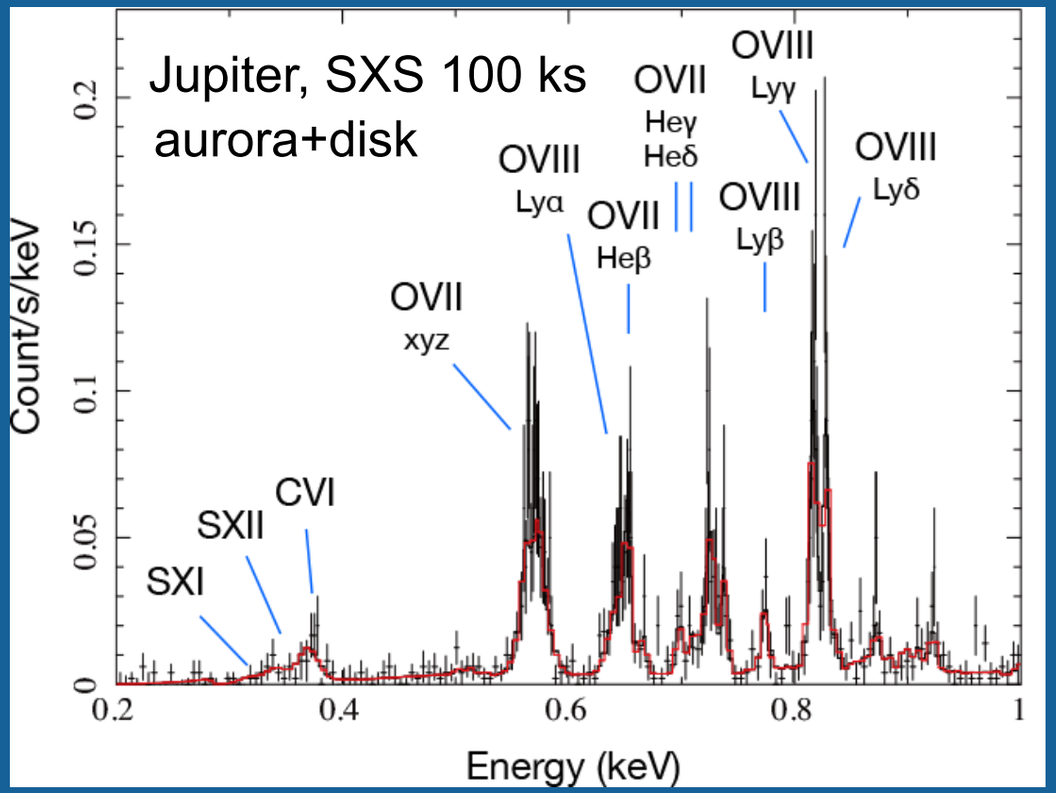


Athena can search for X-ray transits during planetary orbits, confirm star-planet interaction and search for spectral signatures

ASTRO-H Coming Soon

- ASTRO-H is the 6th Japanese X-ray astronomy satellite scheduled to be launched in 2016
- Now the spacecraft is on the vibration test
- Jupiter is a candidate for performance verification targets
- AH - Hisaki - JUNO campaign is planned





Ezoe+15

Summary

- Athena investigations of solar system and exoplanets will give us ever deeper insights in the complex working of planetary atmospheres and magnetospheres

- These studies will also provide a necessary step to understanding the details of CX and particle accelerations, and to applying them to wider contexts of Athena main science

- Including solar system and exoplanets as targets for Athena will add a new dimension to the mission's science and a dimension that is in itself one of the themes of ESA's cosmic vision

- *The authors are grateful to SOC and LOC for giving this opportunity and to SW team members for good discussions*