X-ray imaging of the magnetosphere

T. R. Sun[1], C. Wang[1], F. Wei[1], S. F. Sembay[2], J. A. Carter[2], S. Milan[2], A. M. Read[2], G. Branduardi-Raymont[3], J. Rae[3], H. Hietala[4], J. Eastwood[4] , W. Yuan[5], Z. X. Ling[5], M. Palmroth[6], D. G. Sibeck[7], M. Collier[7], B. Walsh[7]

[1]National Space Science Center, CAS, Beijing, China

[2]Department of Physics and Astronomy, University of Leicester, Leicester, UK

[3]Mullard Space Science Laboratory, University College London , UK

[4]Blackett Laboratory, Imperial College London, UK

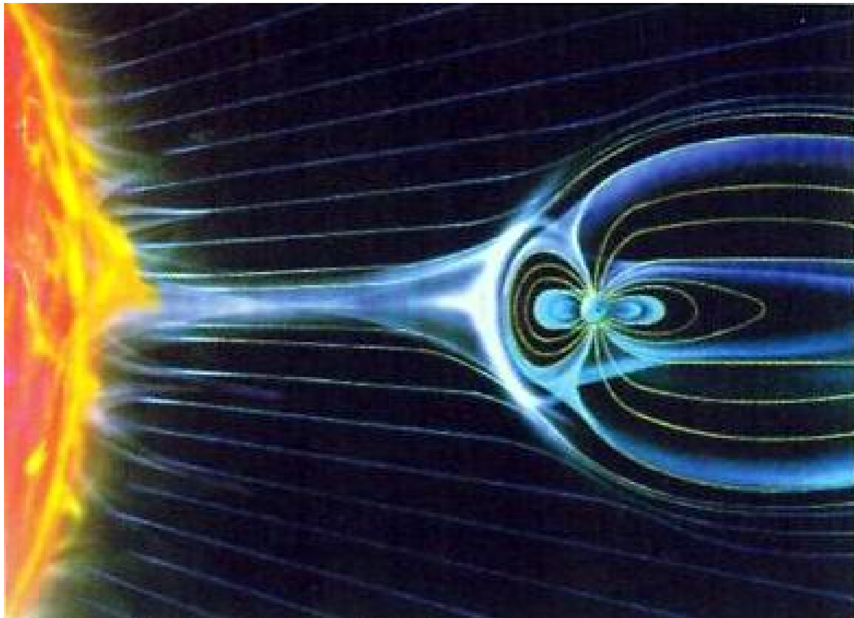
[5]National Astronomical Observatories, CAS, Beijing, China
[6]Finnish Meteorological Institute, Helsinki, Finland

[7]NASA Goddard Space Flight Center, Greenbelt, MD, USA

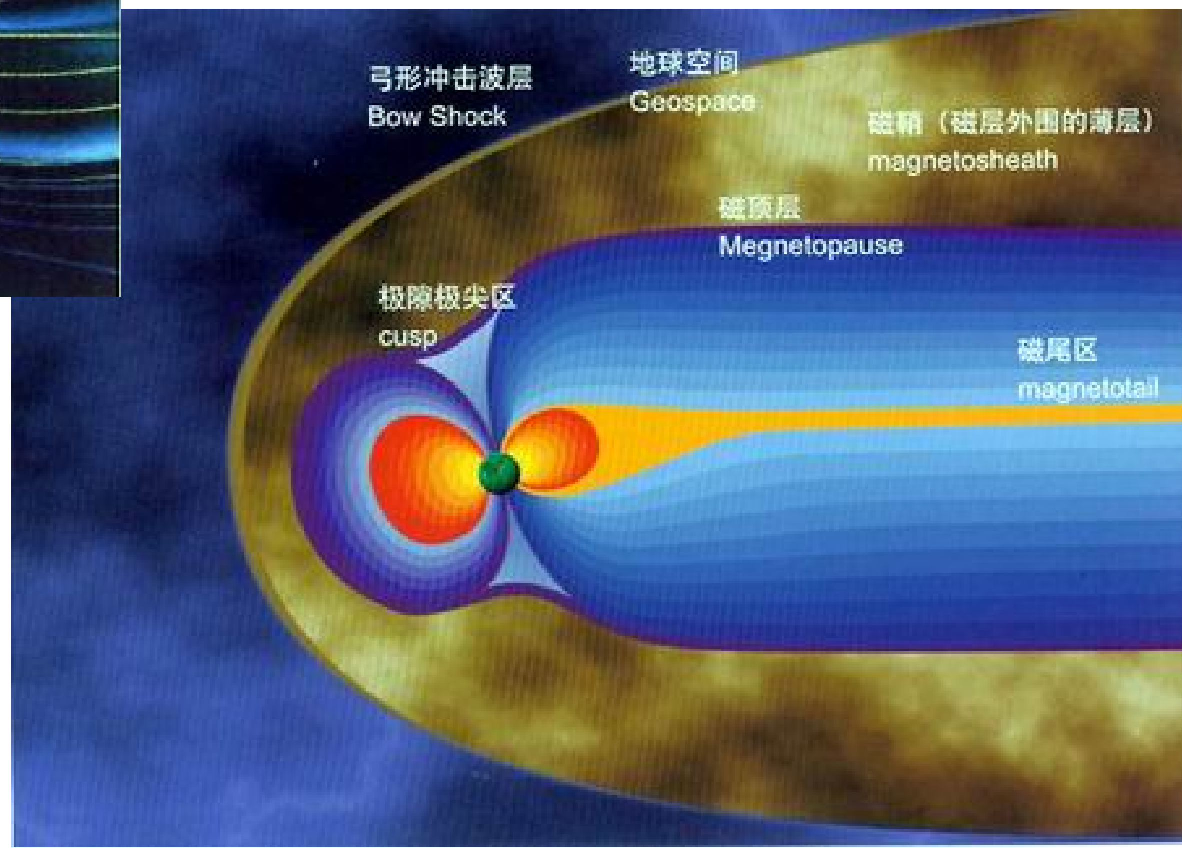
Email: trsun@spaceweather.ac.cn, cw@spaceweather.ac.cn

- Introduction
- Science objectives
- Mission concept and suggested payload
- Preliminary simulation results on X-ray imaging of the Kelvin-Helmholtz instability (KHI)
- Collaboration and heritage

1. Introduction



The magnetosphere:
protects the Earth from the Sun



Energy input is important:
Magnetic reconnection
Kelvin-Helmholtz instability (KHI)

In-situ observation

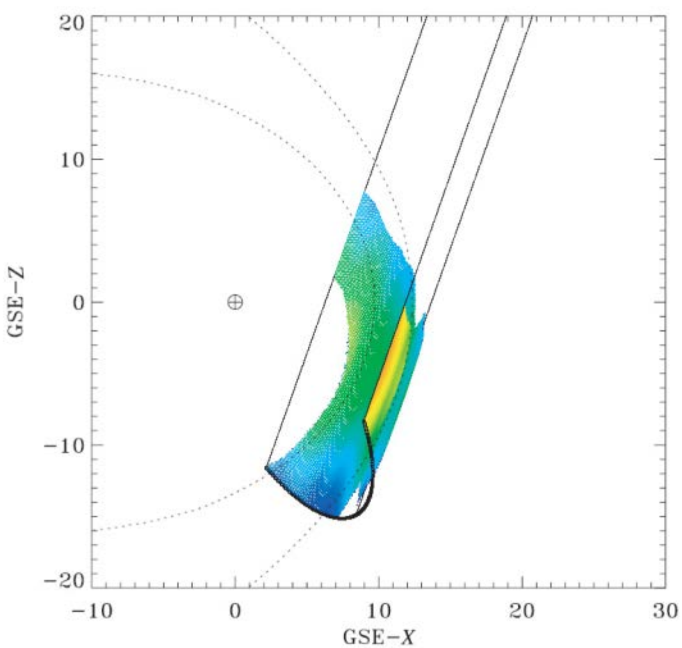
Remote sensing

- Mechanism of X-ray emission in geospace environment

solar wind charge exchange, SWCX

Heavy solar wind ions are responsible for the X-ray emissions.

X-ray emission from comets, planets, moon and the magnetosheath has been observed (Hyakutake Lisse96, Dennerl, Cravens…)



$$O^{7+} + H \rightarrow O^{6+*} + H^{+}$$

Hydrogen exosphere (geocoronal)

Snowden et al. 2009 Robertson et al., 2006
Branduardi-Raymont et al., 2012

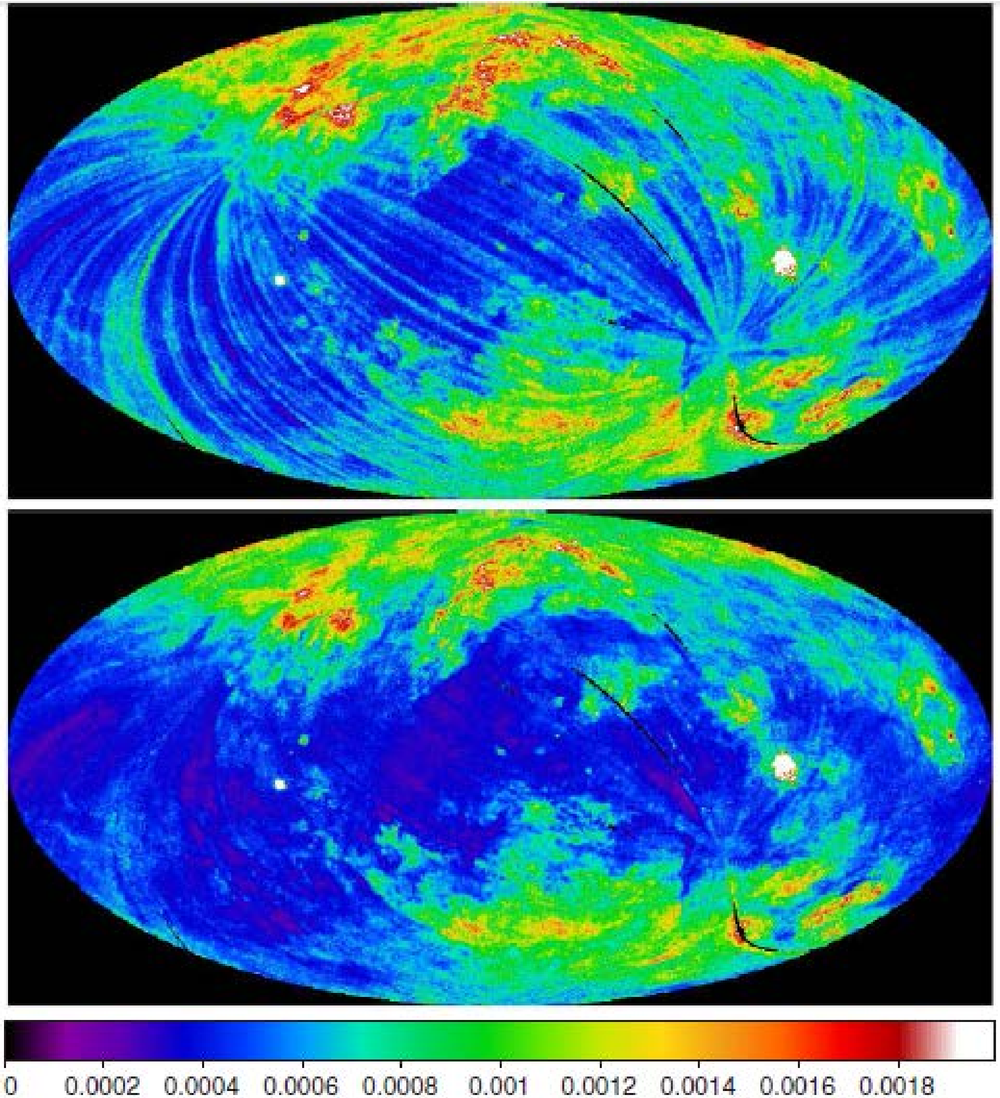


Figure 1. RASS maps of the $\frac{1}{4}$ keV diffuse background before (upper panel) and after (lower panel) removal of the LTEs. The color bar shows the X-ray intensity in units of counts s^{-1} $arcmin^{-2}$. The particle background (Snowden et al. 1992; Plucinsky et al. 1993) and the scattered solar X-ray background (Snowden & Freyberg 1993) have been subtracted in both maps. The maps are displayed in Aitoff–Hammer equal-area projections in Galactic coordinates with the Galactic center at the center and with Galactic longitude increasing to the left.

Snowden et al., 2009

- # Cusp

The cusps play a pivotal role in solar wind-magnetosphere coupling. Two key questions:

1.What controls the size, shape and boundary of the cusps?

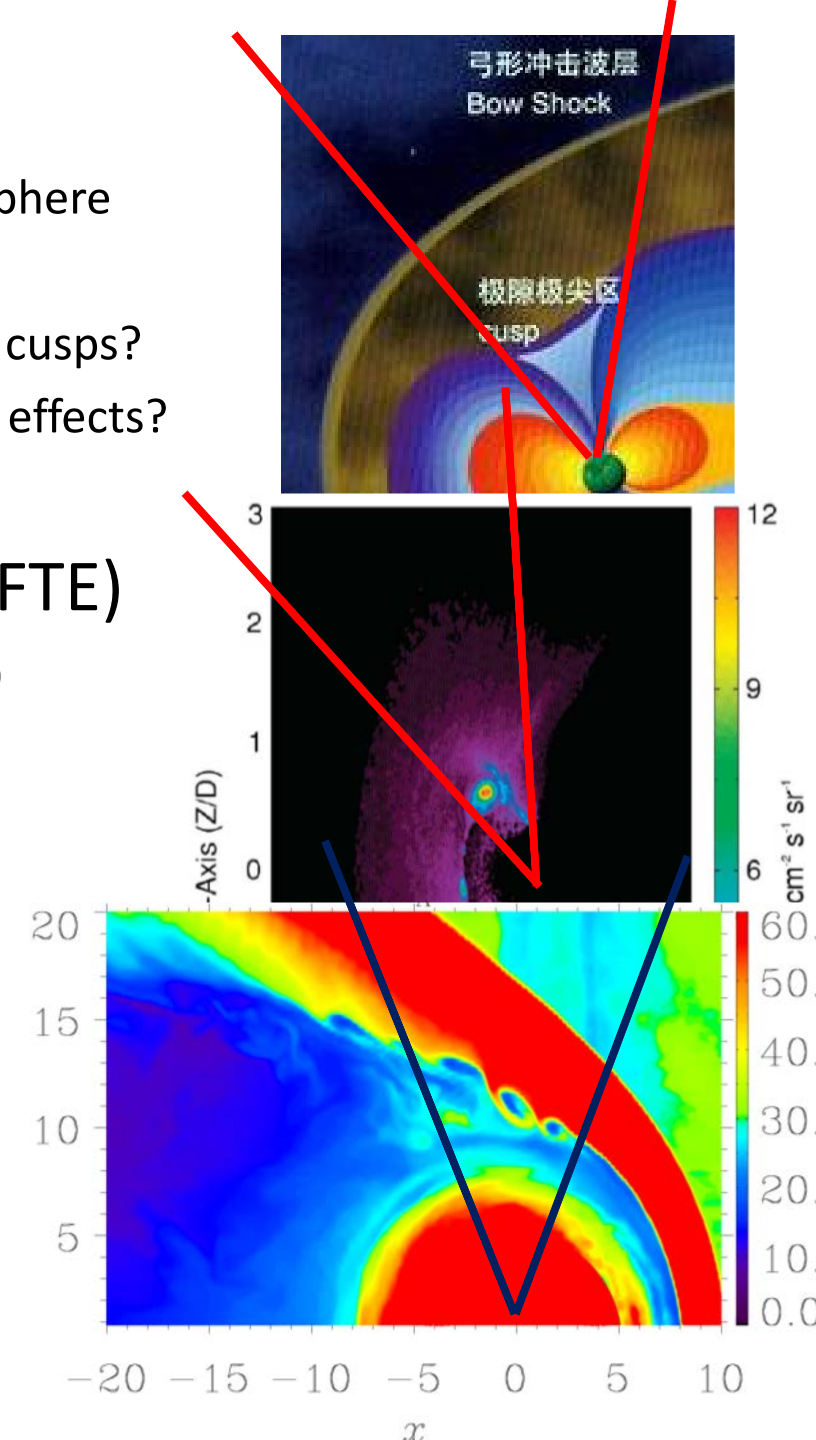
2.Is cusp structure dominated by spatial or temporal effects?

- # High latitude flux transfer event (FTE)

The basic features of magnetic reconnection (or FTE) and its dependence on solar wind conditions

- # Kelvin-Helmholtz instability (KHI) at the flank magnetopause

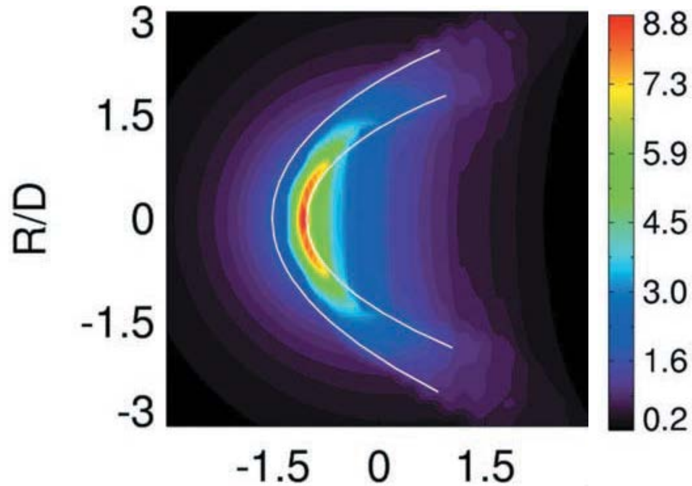
Evolution, period, spatial distribution of KHI and its dependence on solar wind conditions



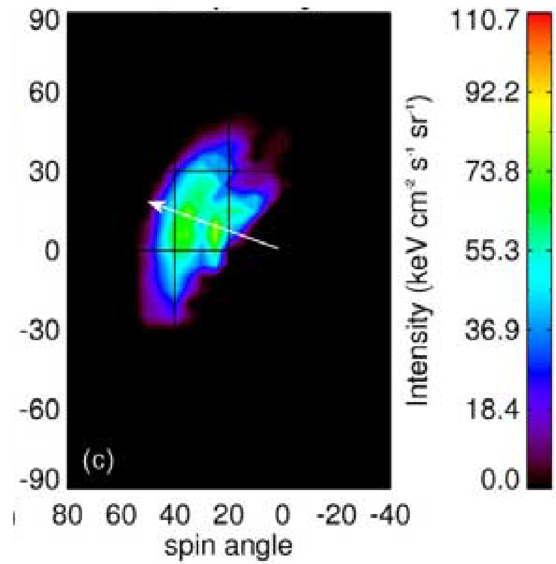
Eastwood et al., 2013; Branduardi-Raymont et al., 2012; Collier et al.,

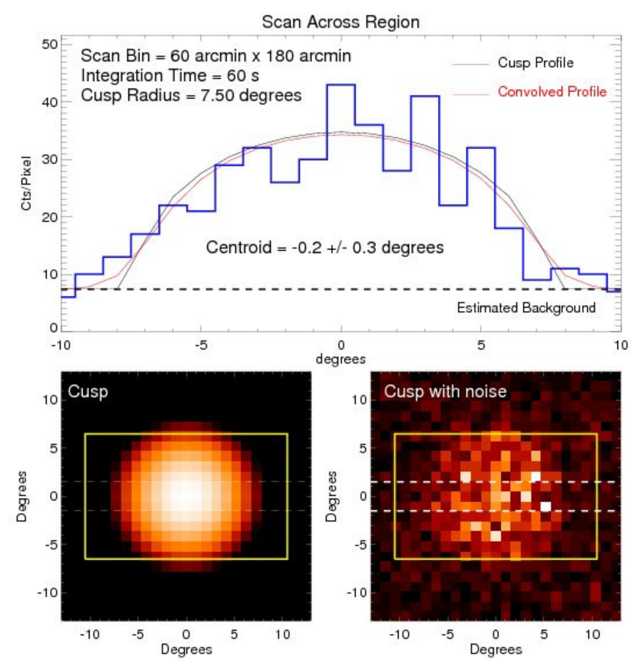
Simulation of X-ray intensity

Magnetosheath:

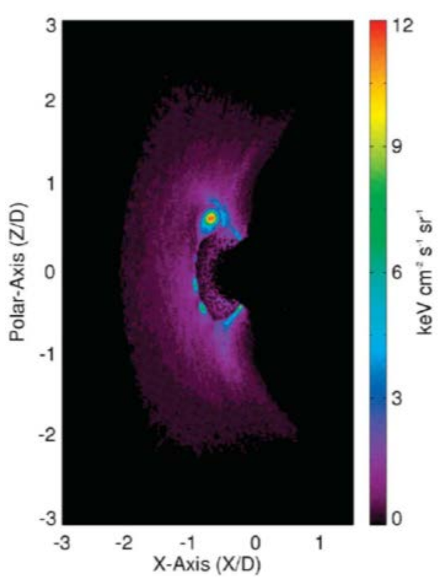


Cusp:





FTE:



Eastwood et al., 2013; Branduardi-Raymont et al., 2012; Collier et al., 2010; Robertson et al., 2006

Preliminary analyzed the requirement on exposure time and sensitivity:

region	Maximum X-ray ($keV \cdot cm^{-2} \cdot S^{-1} \cdot sr^{-1}$)	Exposure time (s)	Sensitivity limit ($keV \cdot cm^{-2} \cdot S^{-1} \cdot sr^{-1}$ with 60 S exposure time)
cusp	200	\	200
High latitude reconnection	12	60	12
KHI	2	60	2

Exposure time:
For cusp, there is no strict restriction on exposure time selection.
To resolve transient phenomena such as high latitude FTE and KHI, an exposure time of ~60 S is required.

Sensitivity limit:
RASS (60S):
10^{-10} $erg^{-1}S^{-1}cm^{-2}$ ~ 0.07 $keV^{-1}S^{-1}cm^{-2}$, may observe cusp/high latitude FTE/KHI

Eastwood et al., 2013; Branduardi-Raymont et al., 2012; Collier et al., 2010; Robertson et al., 2006

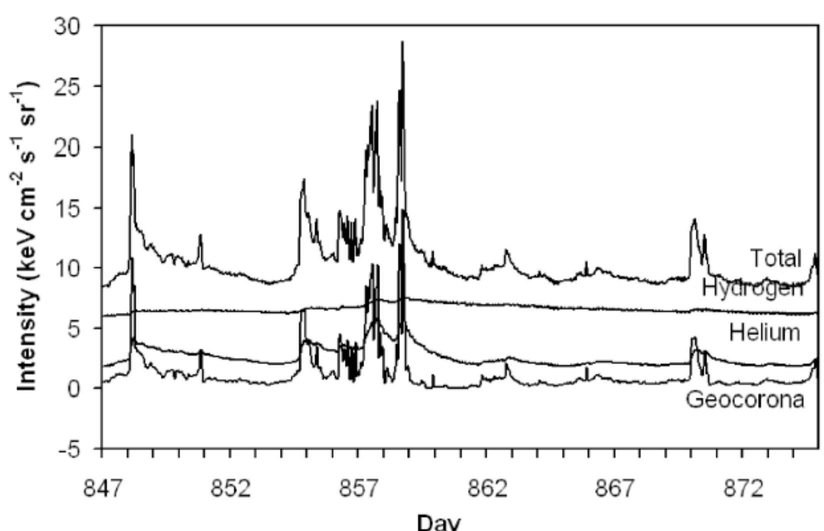
Interstellar diffusive X-ray analysis:

- A large fraction of the diffuse soft X-ray is produced in the inner heliosphere (especially druing times with large solar activity):

  [Robertson09]: ~ 50% of low latitude 3/4 keV emission is heliospheric

  [Cravens00]: emission observed from Earth is dominated by the inner heliosphere (within ≈ 10 AU)) and it is this region that contributes to the diffuse soft X-ray background. (outer heliosphere contributions: 25%)

- Even for periods when they do not dominate, charge exchange emissions in the geospace exhibit dramatic time variability compared to the other sources. And this could be used to 'filter out' the steady part of backgrounds.



Robertson and Cravens, 2003

2. Science objectives

- To provide global view of the magnetosphere for the first time
- To understand the overall interaction of the solar wind with the magnetosphere
- To investigate the response of the magnetosphere to solar wind disturbances

3. Mission concept and suggested payload

- Low-Earth Orbit (LEO)
- Supposed life time: 3 years
- Mass of the X-ray telescope: < 60 kg,
  spacecraft launch mass < 250kg

- Primary science payload:
  X-ray telescope making use of micropore optic (MPO) plates configured as a lobster-eye optic
  sensitive to X-rays in the energy range 0.2 to 4 keV
  a wide FOV of ~30° x 40°.

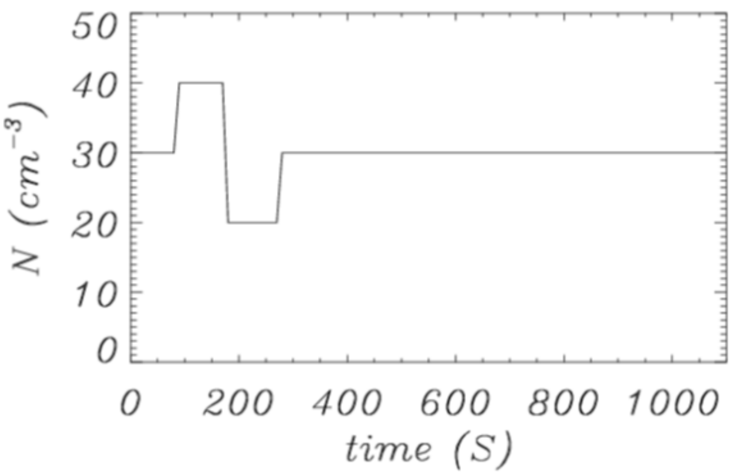
4. Preliminary simulation on KHI imaging

PPMLR-MHD code modeling the magnetosphere

$$P_{X-ray} = \alpha n_{sw} \langle g \rangle n_H \qquad keV \cdot cm^{-2} \cdot S^{-1} \cdot sr^{-1}$$

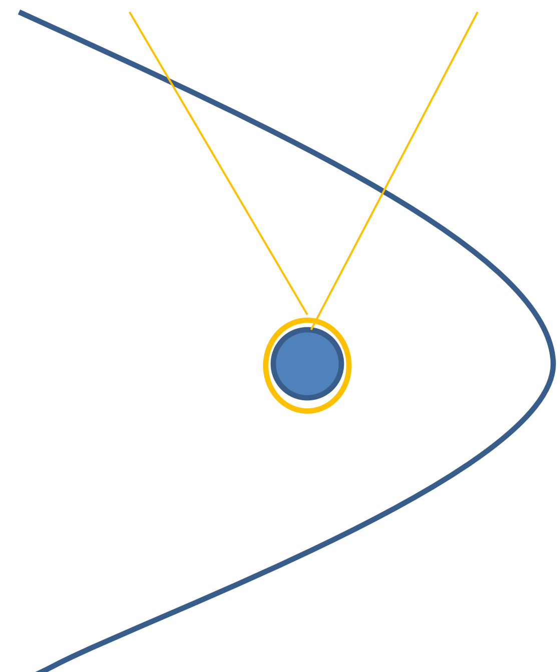
X-ray efficiency factor α; solar wind plasma number density N_{sw}; average total ion collision speed: <g>; Geocoronal neutral hydrogen n_H

Solar wind condition:



Vsw=400 km/s, Bz=2 nT, others: 0

Hu et al., 2007; Robertson et al., 2006



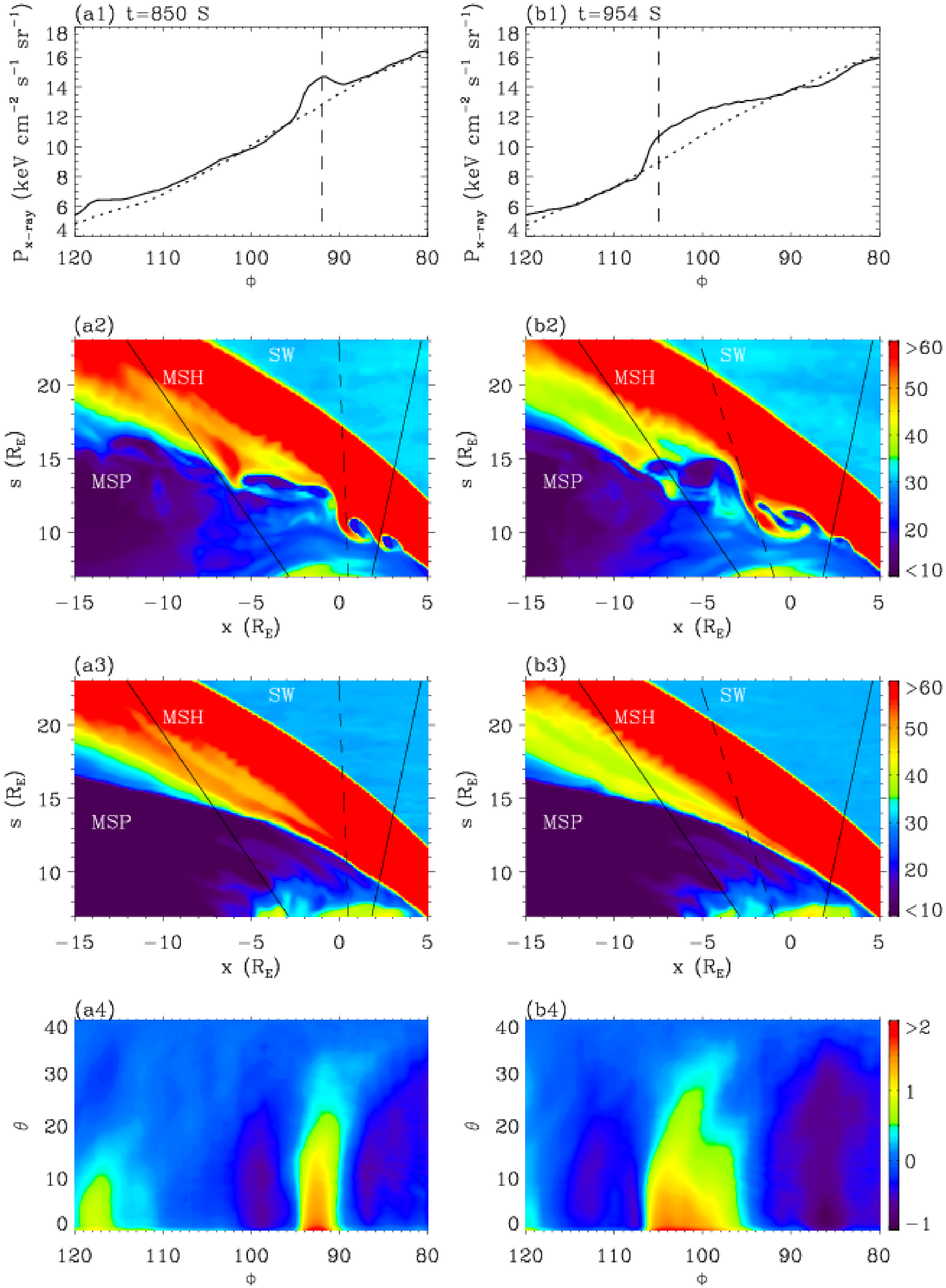
Solid/dashed line: X-ray emission on the equatorial plane/plane with θ=40° (latitude)

Density contour on the equatorial plane

Density contour on the plane with θ=40°

$$dP_x(\phi,\theta) = P_x(\phi,\theta) - P_x(\phi,\theta=40^\circ)$$

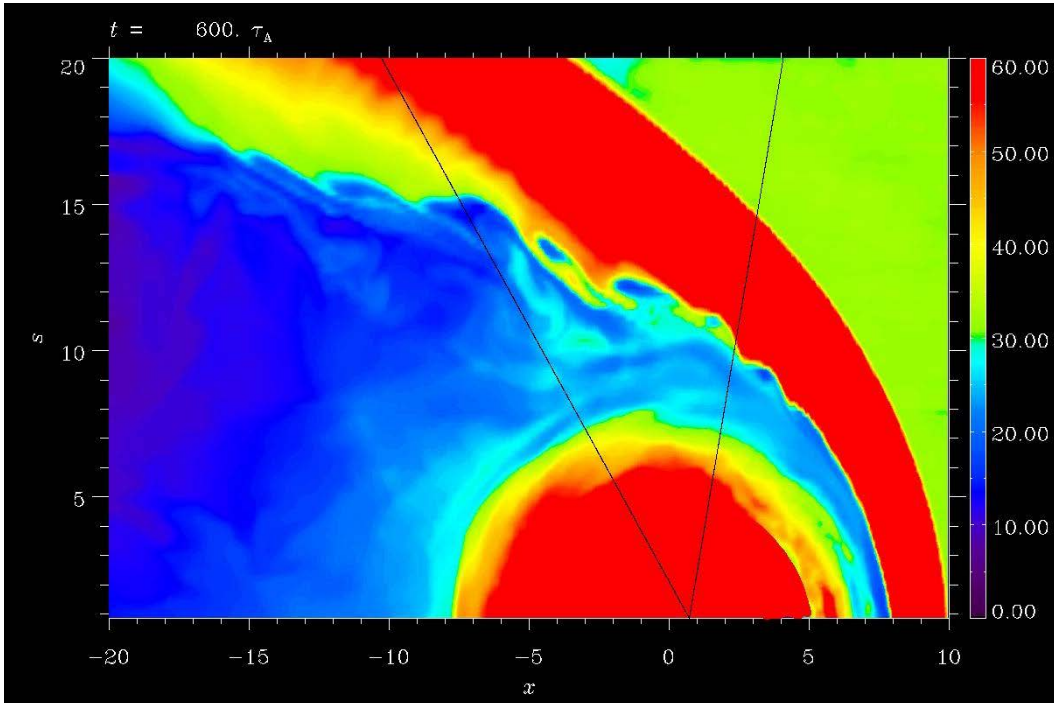
dPx contour in field of view



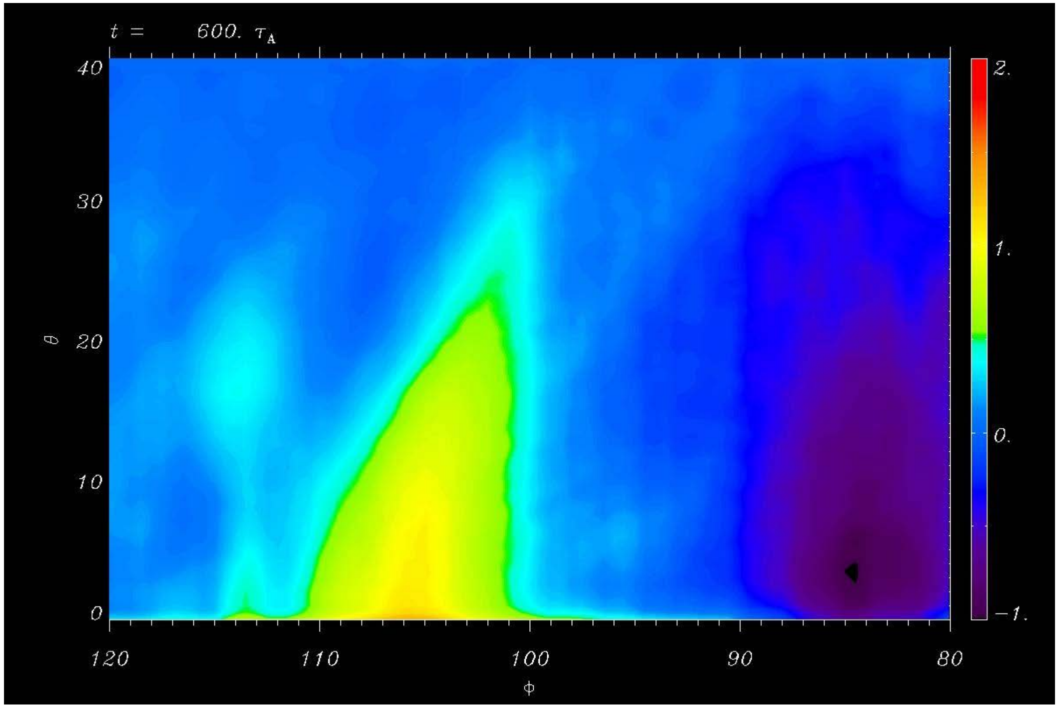
ϕ: Angle between view direction and the sun-earth line on the equatorial plane

θ: Angle between view direction and the equatorial plane

Density contour on the equatorial plane:



KHI information obtained from X-ray imaging:



After detailed analyses, we can investigate problems such as

- Does KH Vortex accelerates or decelerates to tail?
- Where does the maximum KHI occur?
- How far does KHI extend in the meridian plane?

-- HOW and WHERE do the solar wind particles and energies enter the magnetosphere and consequently affect the geospace environment.

(the place with most efficient plasma mixing or momentum transport in the magnetopause boundary layer)

5. Collaboration and heritage

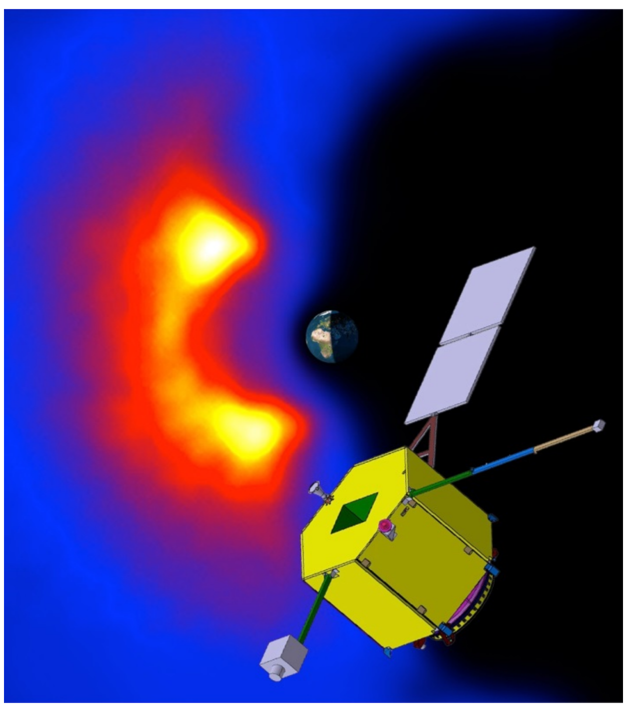
- AXIOM concept study has been carried out by Leicester University, the University College London and Imperial College London from UK, with possible participation of scientists from France and USA. Potential collaborations between ESA and CAS can range from payloads to science objectives and modelling.

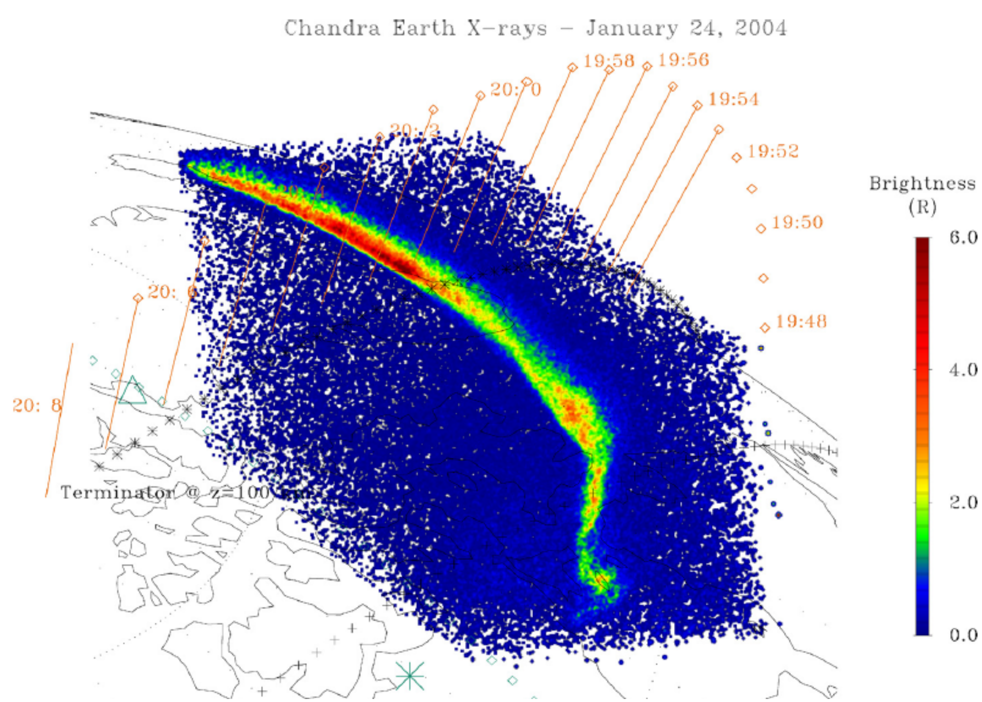
- X-ray detectors for astrophysical applications have been developed for decades. Key techniques are supported by CAS in collaboration with the Leicester University, which also participates in the design activity of the lobster eye optic onboard Einstein Probe.

Poster

AXIOM:

Advanced X-ray Imaging of the Magnetosphere





Chandra X-ray image of the Earth's ionosphere: auroral region (from [Bhardwaj et al., 2007])

Thank you for your attention!