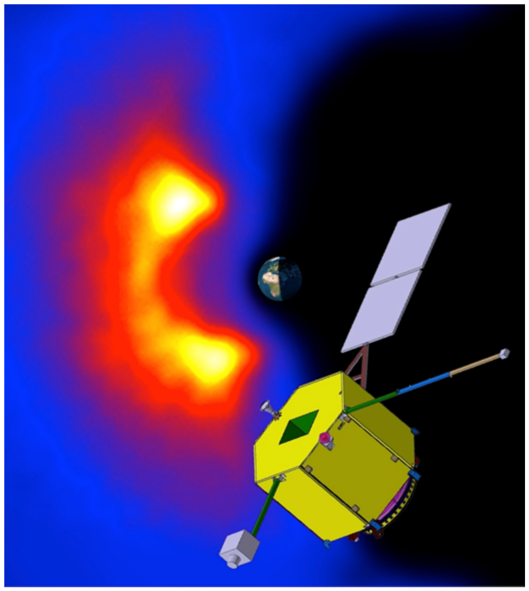
AXIOM-Jian: Science and Modelling

Advanced X-ray Imaging of the Magnetosphere/Cusp



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National Space Science Center, CAS

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Imperial College London   Finnish Meteorological Institute

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NASA GSFC

with the support of
Airbus Defence & Space Ltd

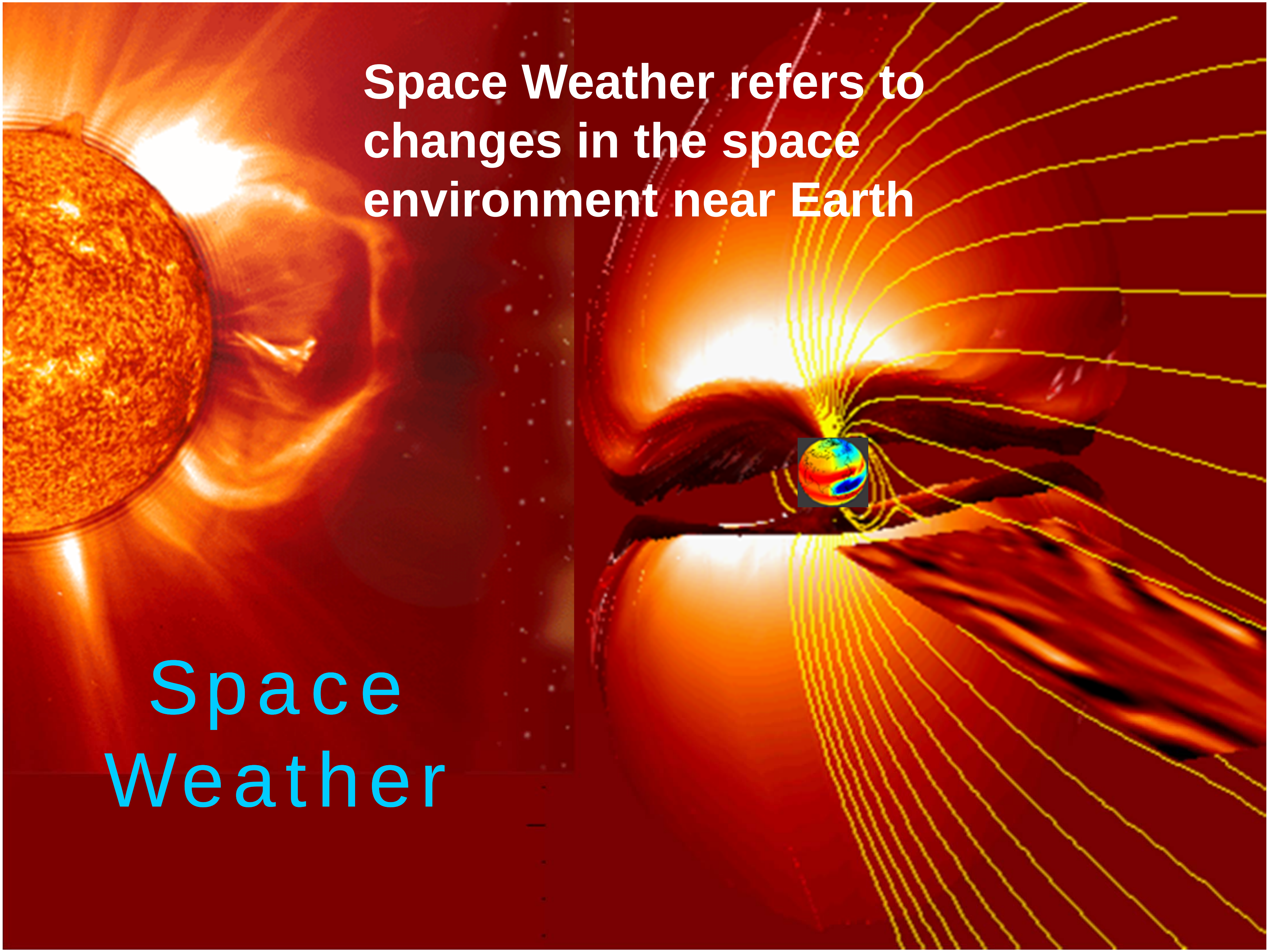
Outline

Part 1 : Science and Modelling

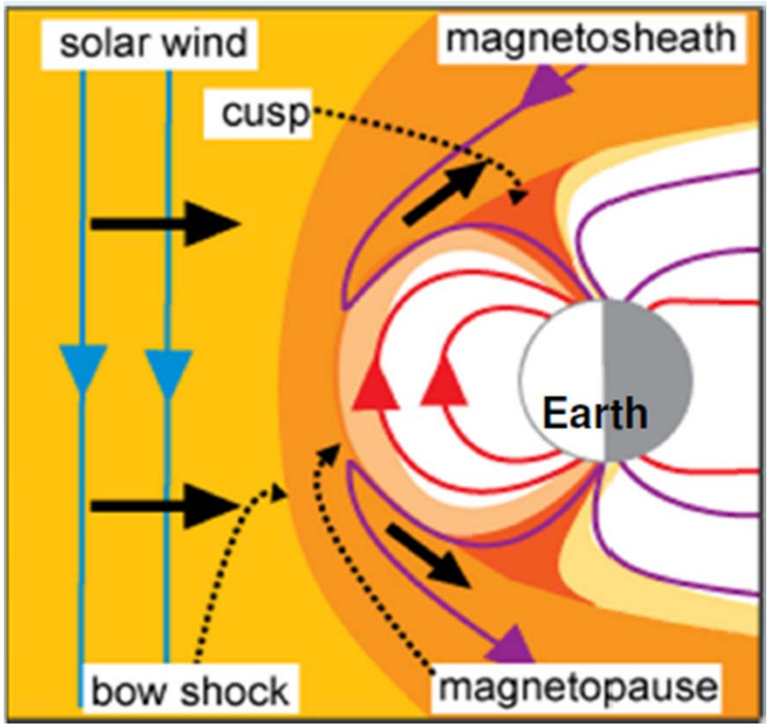
- Background: Magnetosphere
- Science Objectives
- X-ray Emissivity: Modelling Results

Part 2 : Payload and Mission Profile

- AXIOM-Jian Mission Profile
- Payload and Simulations
- Resources and Programmatics

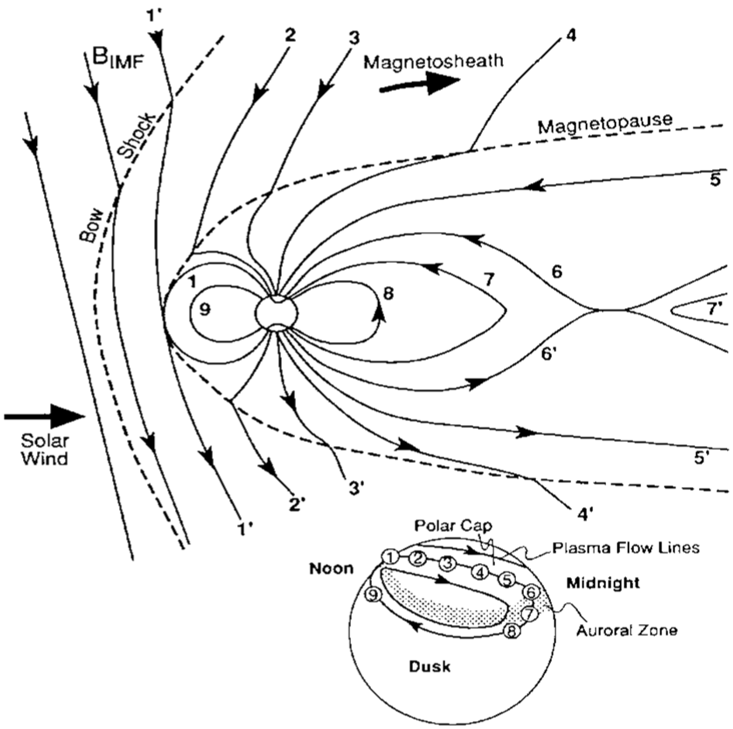

Space Weather refers to changes in the space environment near Earth
Space Weather

Magnetosphere



- Magnetosphere carves out a cavity in the solar wind (SW)
- SW compresses it on one side and stretches it on the other into a long tail
- SW is supersonic, a bow shock forms
- SW is slowed, compressed, heated and diverted into the magnetosheath
- This SW plasma interacts with the magnetopause and penetrates into the magnetosphere via the cusps

Why the Cusp Regions are Unique



- They provide direct access of the solar wind to Earth's ionosphere and upper atmosphere.
- Magnetic field lines within the cusps are believed to map to the entire magnetopause. Consequently, observations of the cusps afford an opportunity to monitor and understand the solar wind – magnetosphere – ionosphere coupling.

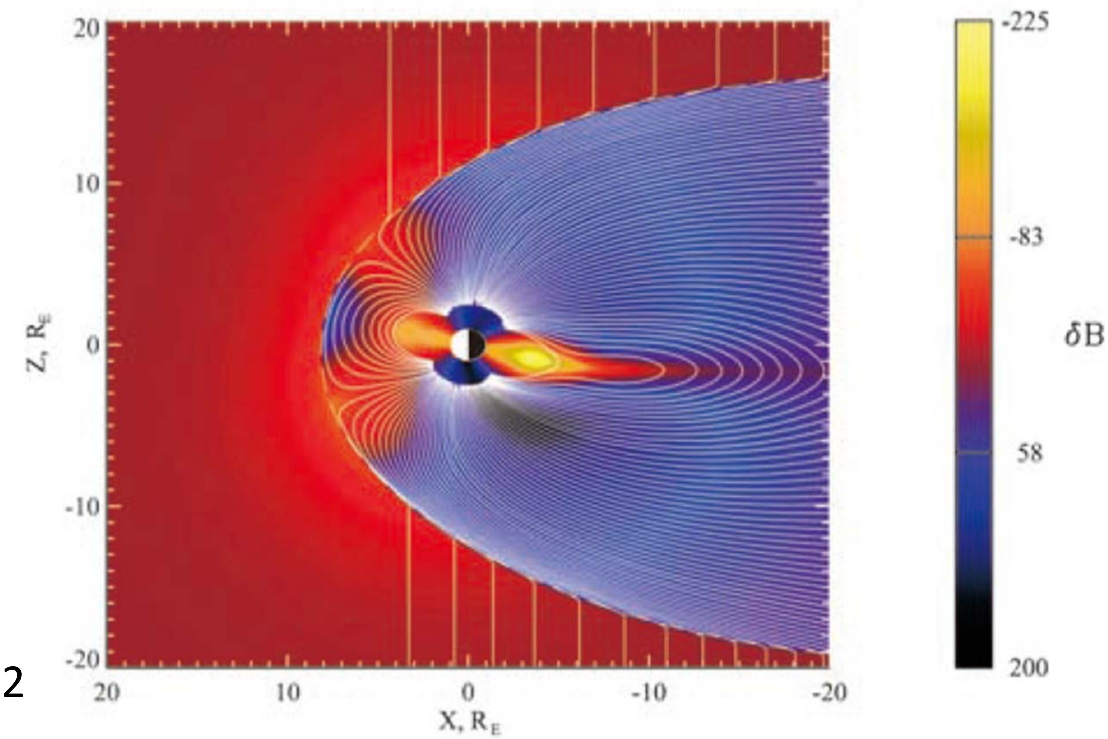
NSSC

What do we know already?

(1) Basic features of the magnetosphere

For instance: position of the magnetopause

Empirical model of the magnetopause:



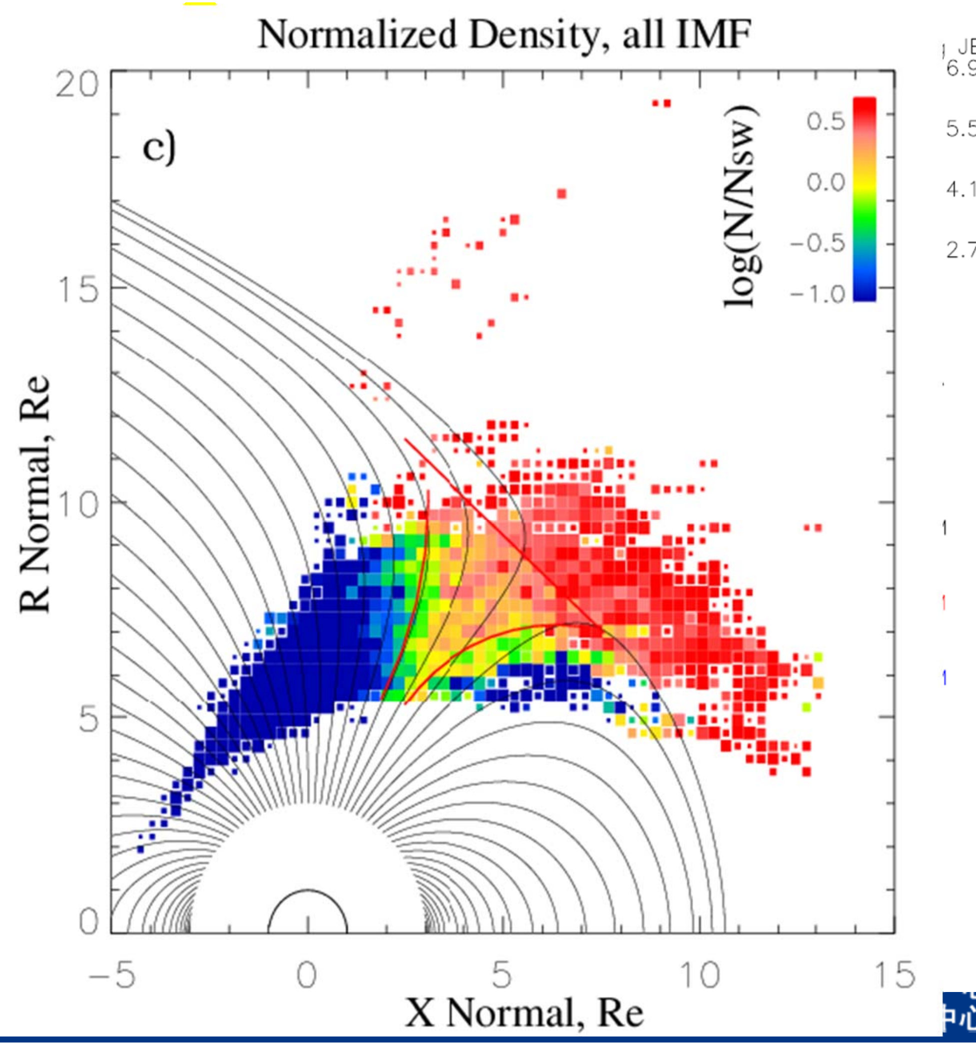
Tsyganenko, 2002

(2) Configurations of the magnetosphere

(Cusps, magneotail, plasmasphere, boundary layers…)

For instance: cusp

Statistical study of cusp plasma during plenty of crossings:

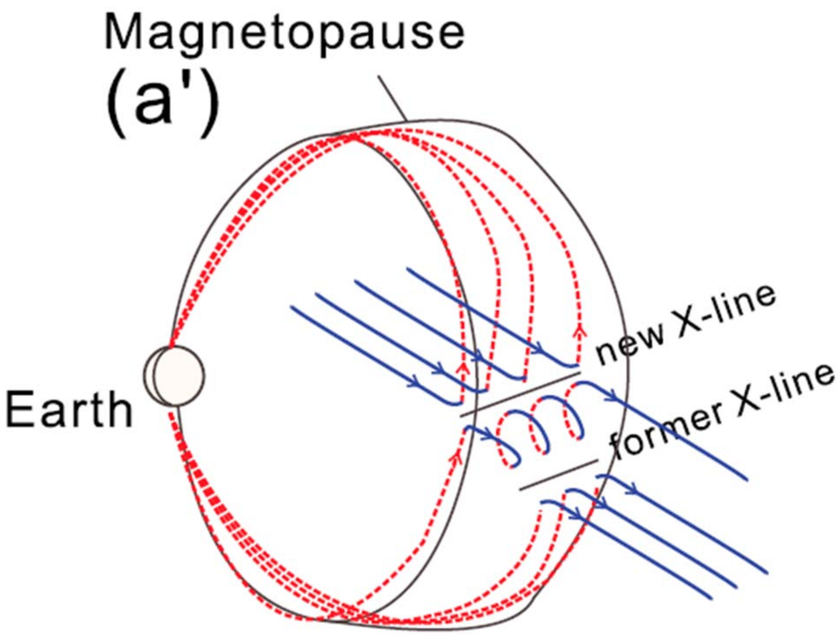


Argill et al. 2005

(3) Dynamics of the magnetosphere

(magnetic reconnection, instabilities, response to solar wind disturbances, and etc.)

Reconstruction:



The majority of the knowledge comes from in-situ measurements of the satellites passing by each specific region.

What are the limitations?

In situ measurements provide localized information about plasma, field and their dynamics.

However, they fail to provide the global view, large-scale configurations and overall evolutions of the magnetosphere.

Nssc

Limitations of the Observations

- A great deal of knowledge about the magnetospheric structure has come from mid- and low-altitude satellite observations such as those by DMSP, Viking, Cluster, DSP …
- However, even with multipoint in-situ measurements, considerable ambiguities and uncertainties remain.
  - ✓ We only know the size, shape and structure of the cusps in a statistical sense.
  - ✓ The overall structure is a complex combination of spatial and temporal variability that cannot be untangled.

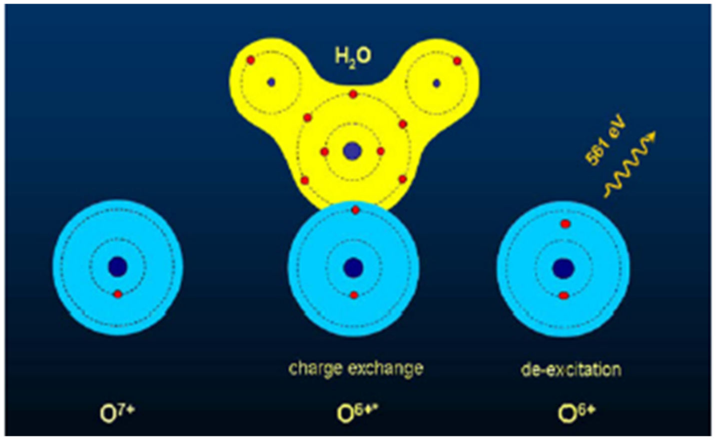
A novel approach to imaging

Solar Wind Charge Exchange (SWCX):

Heavy solar wind ions in collision with neutral target atoms (hydrogen) in the Earth's exosphere produce soft X-ray photons (0.1 – 2.5 keV)

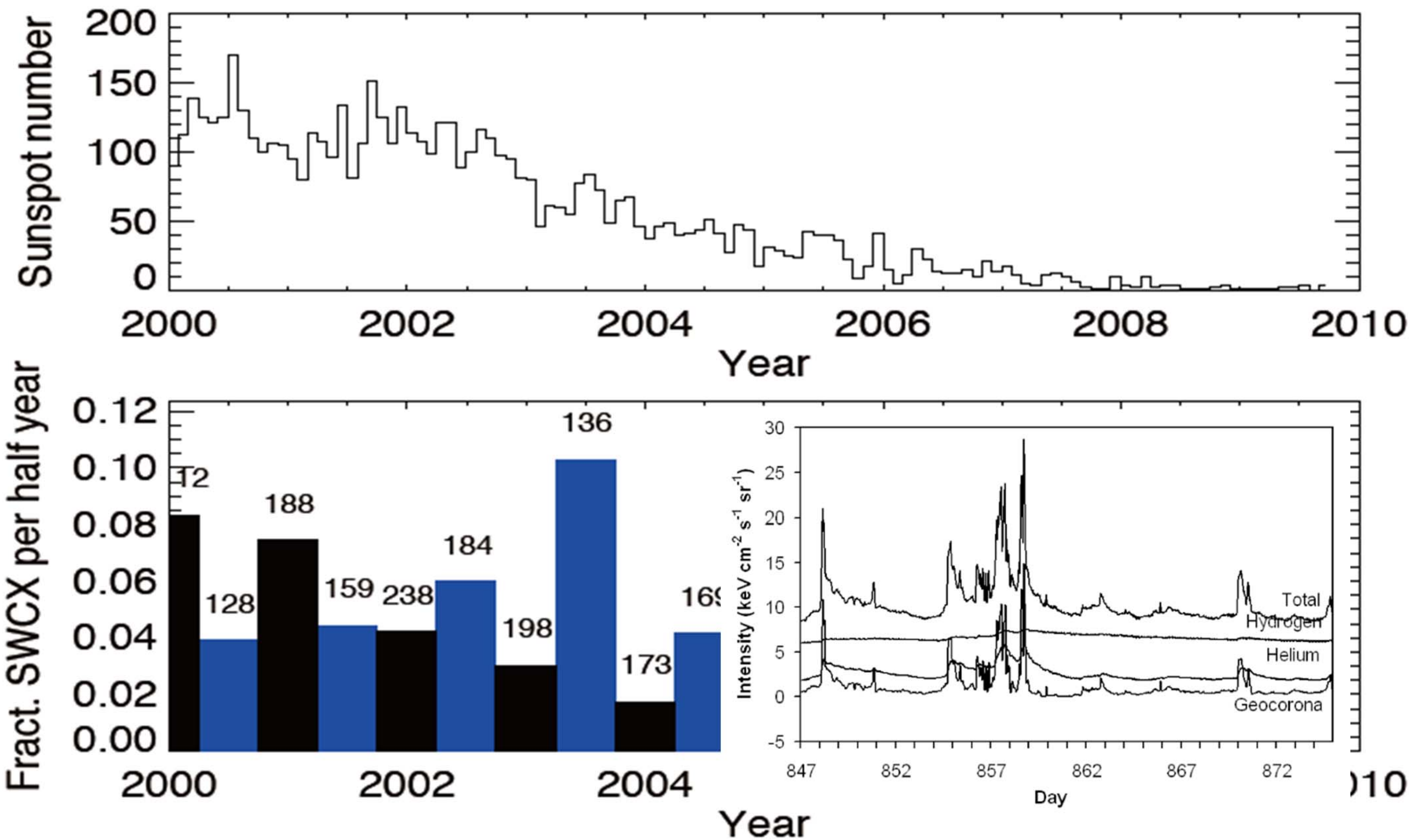
such as

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



Adapted from Dennerl. 2009

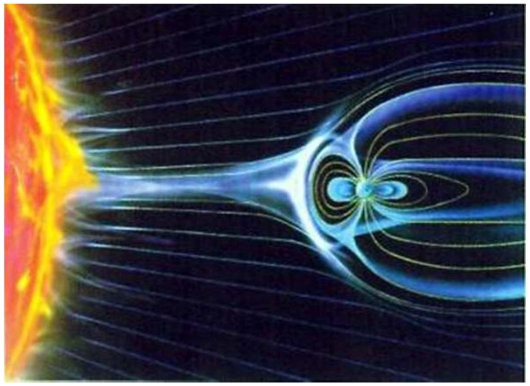
Noise from Astrophysics X-ray Missions



Science Objectives

(1) To provide global view of the magnetosphere for the first time

Since the innovative prediction of the magnetosphere in 1940, scientists have been studying this field for more than 70 years.



With AXIOM-Jian, we would actually **see** the magnetosphere for the first time, and further understand its global features.

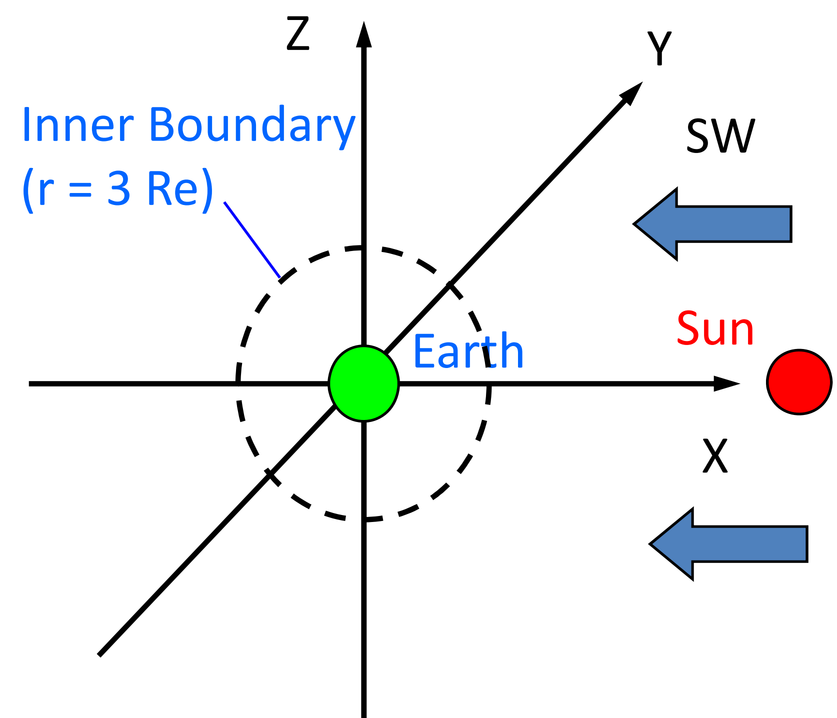
(2) To understand the overall interaction of the solar wind with the magnetosphere

Large scale dynamics are expected to be revealed by AXIOM-Jian: How are the solar wind energy, momentum, and plasma transported into the geospace environment through different regions of the magnetosphere, and further affect space weather? Especially in the cusp regions

(3) To investigate the response of the magnetosphere to solar wind disturbances

Through AXIOM-Jian, we will investigate the overall evolution of plasma and chain response of magnetosphere to solar wind disturbances, which is vital to the prediction of the possible damages to technological systems and even human life caused by solar activities in extreme cases.

3D MHD Model



$-300 \le x \le 30, -150 \le y, z \le 150\ R_E$

- Piecewise Parabolic Method (PPM) (Colella and Woodward [1984])
- MHD Extension of the Lagrangian version of the PPM [1995], Hu et al. [2005, 2007])
- High order spatial accuracy and low numerical dissipation

Two typical simulation cases:
Average solar wind flux: N=7 cm^{-3}, V=400 km/s
Storm time solar wind flux: N=20 cm^{-3}, V=600 km/s

X-ray intensity calculation

$$P_{X-ray} = \alpha n_{sw} \langle g \rangle n_H$$

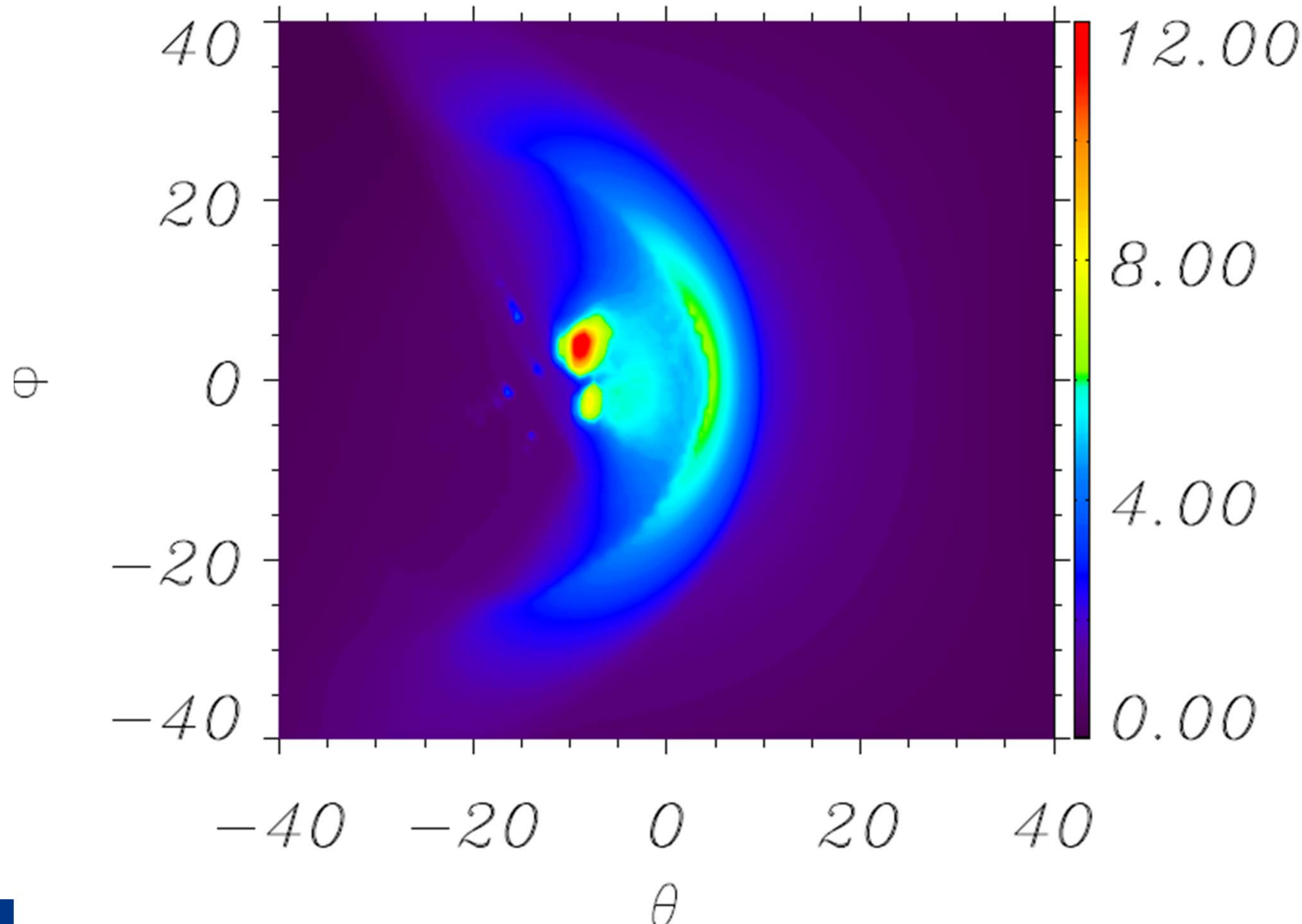
The X-ray efficiency factor $\alpha \sim 6*10^{-16} eV \cdot cm^2$

solar wind plasma number density n_{sw}

average total ion collision speed $<g>$

Geocoronal neutral hydrogen n_{H}

Integration along the line of sight $keV \cdot cm^{-2} \cdot S^{-1} \cdot sr^{-1}$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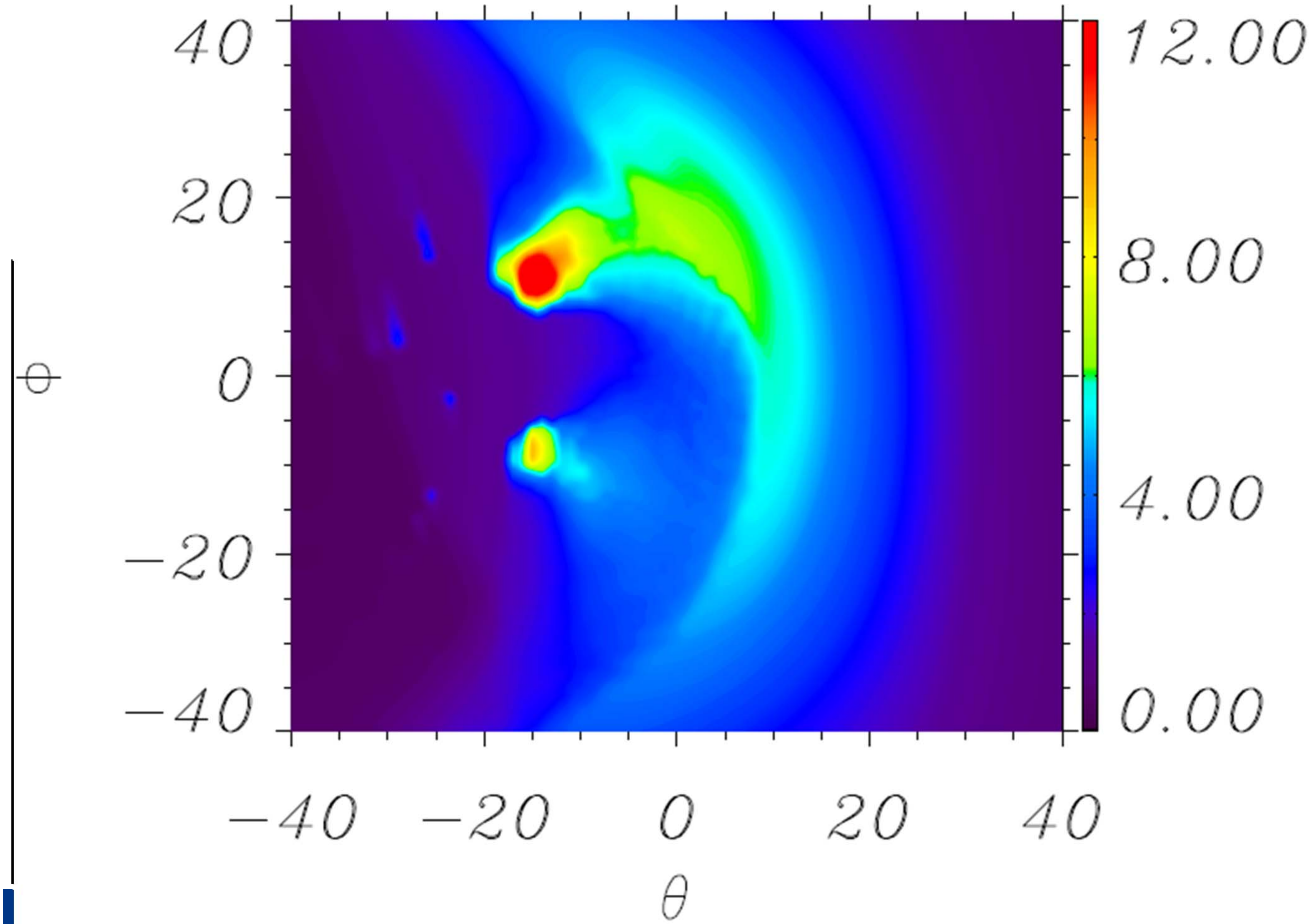
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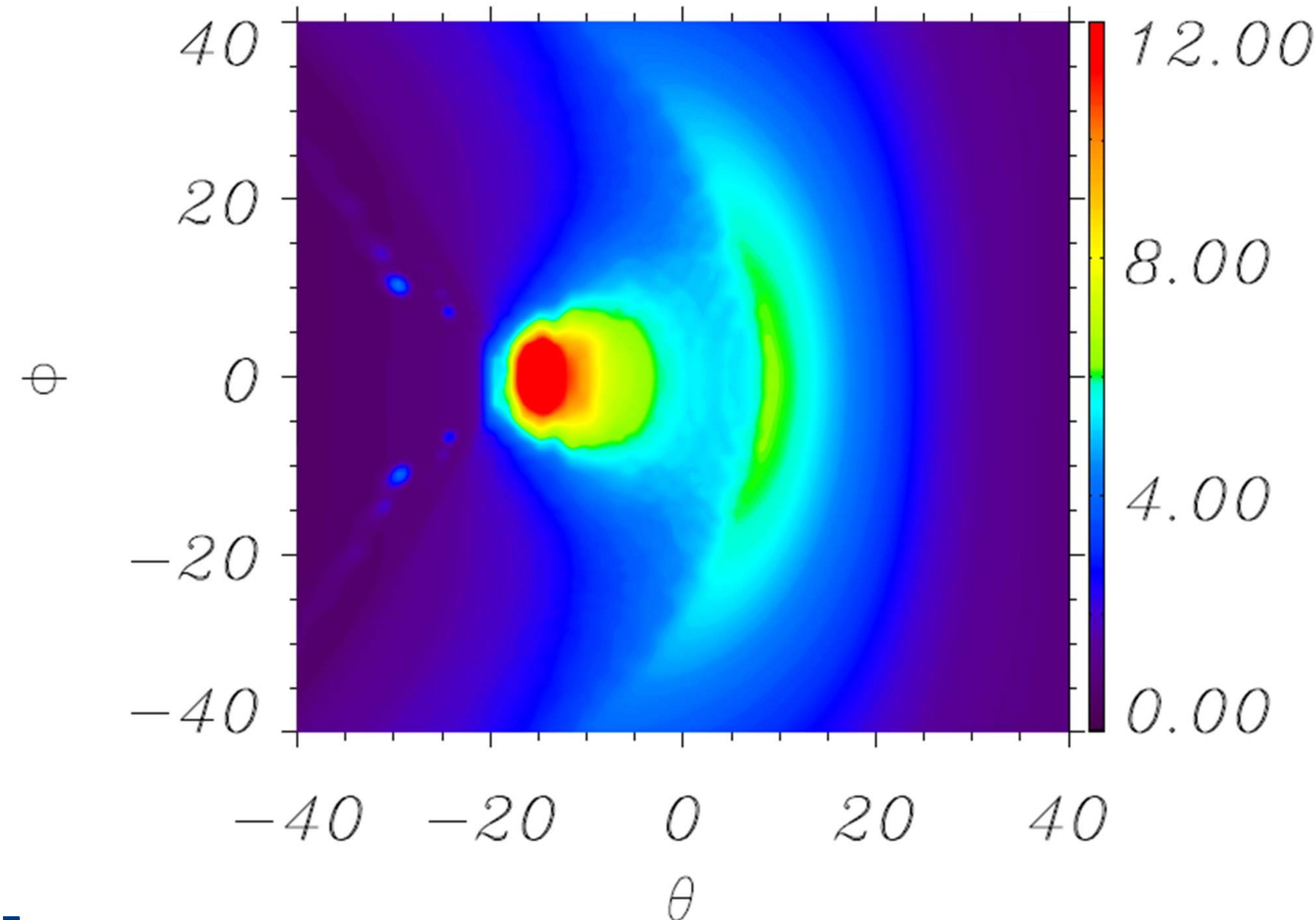
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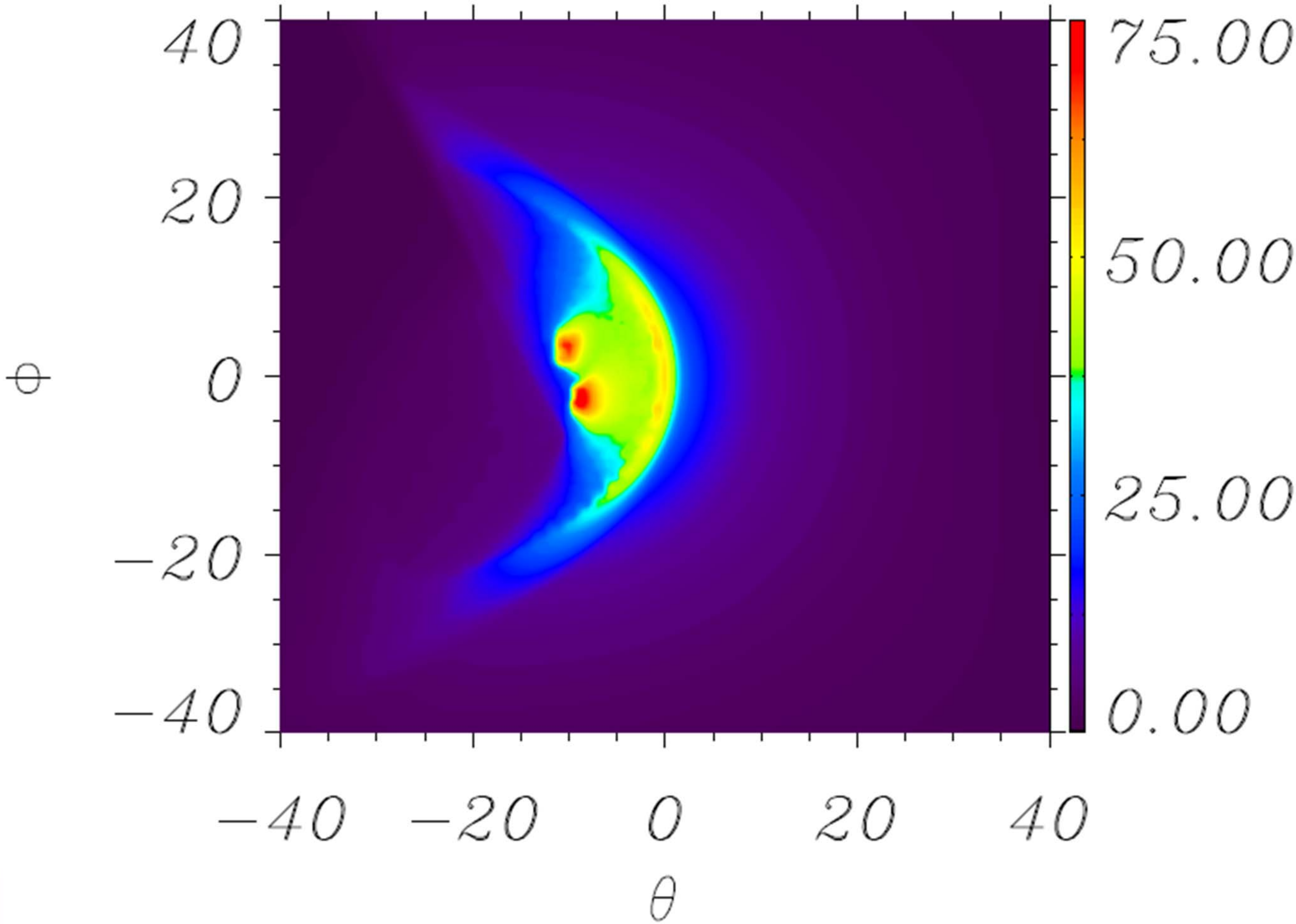

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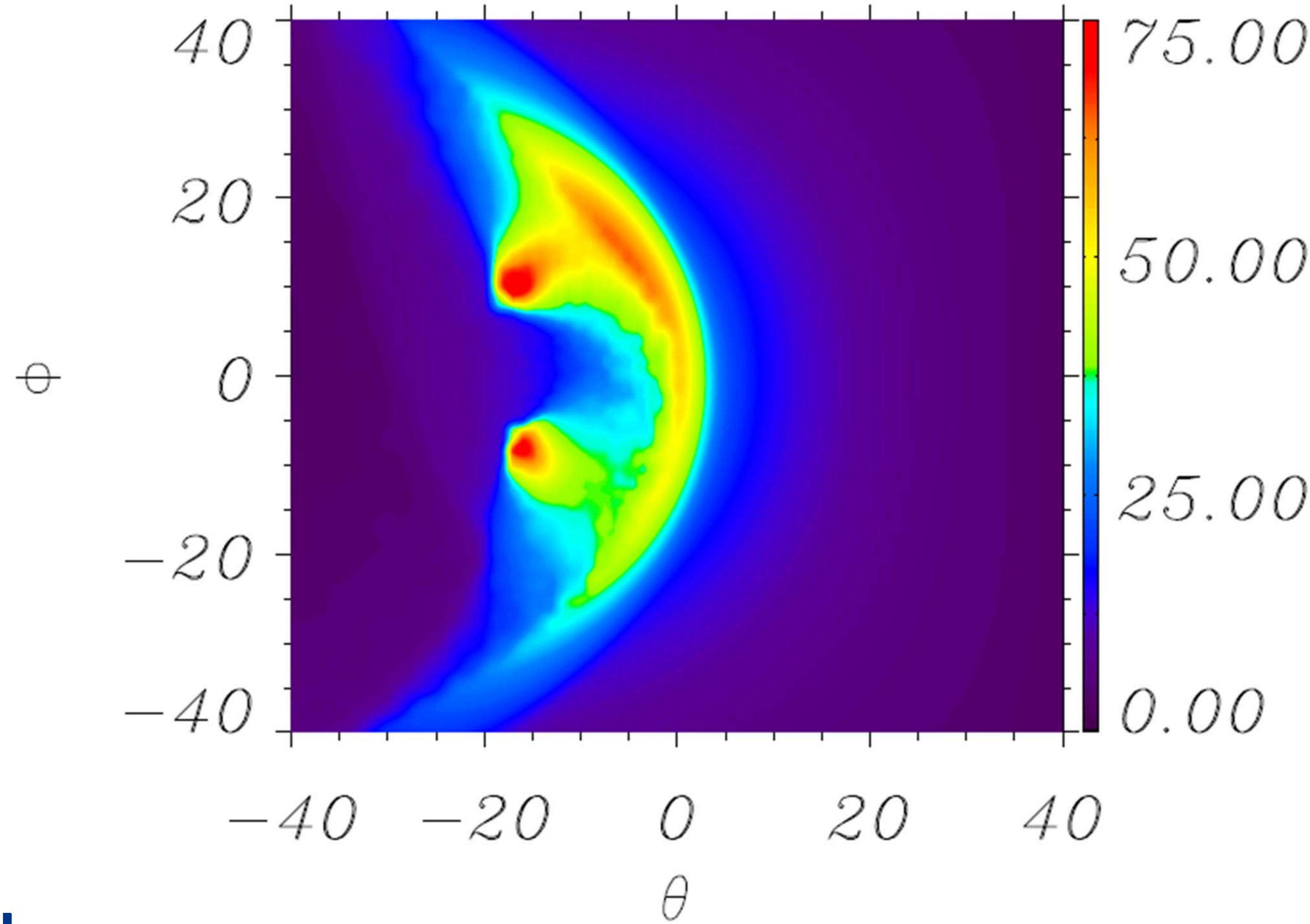

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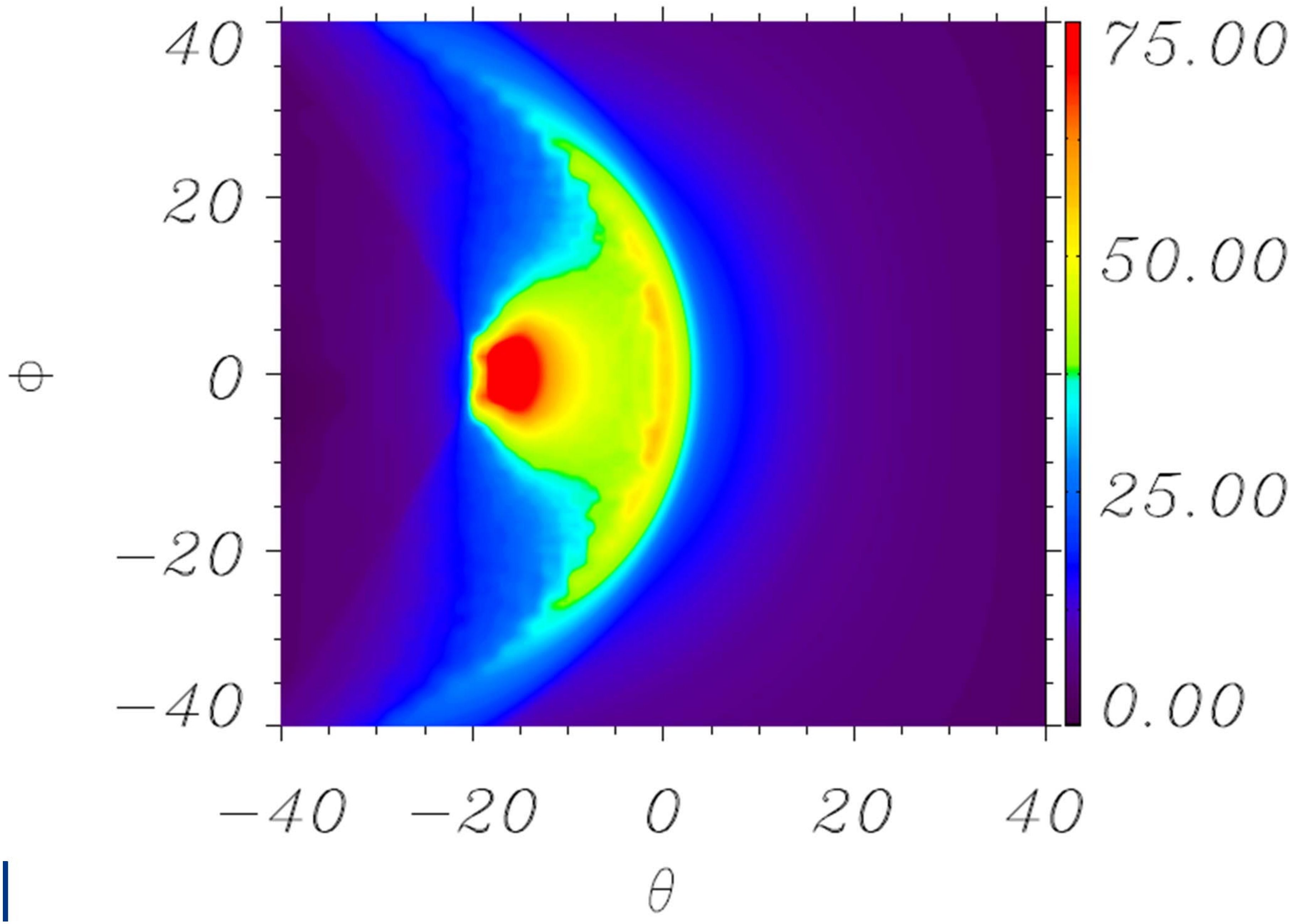

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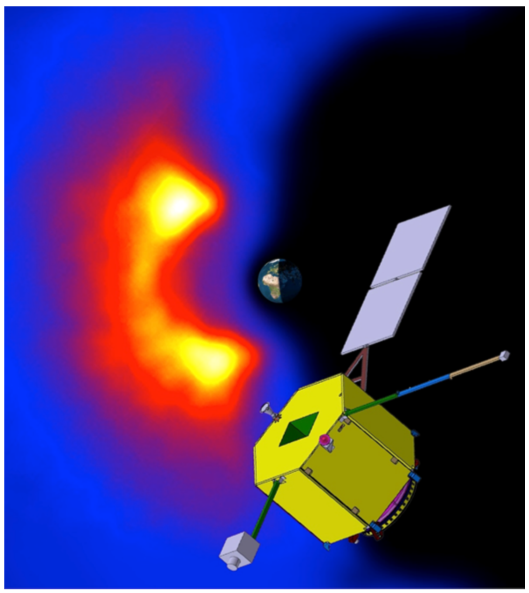
Realising Global Imaging

The Advanced X-ray Imaging of the Magnetosphere / Cusp (AXIOM-Jian) mission is a novel space project that will revolutionize magnetospheric physics by providing global views of the cusps and of the dynamic solar wind – magnetosphere interactions based on SWCX –X-ray emission using state-of-the-art detection techniques.

AXIOM-Jian: Payload & Mission Profile

Advanced X-ray Imaging of the Magnetosphere/Cusp



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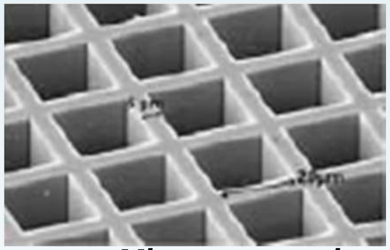
AXIOM-Jian mission profile

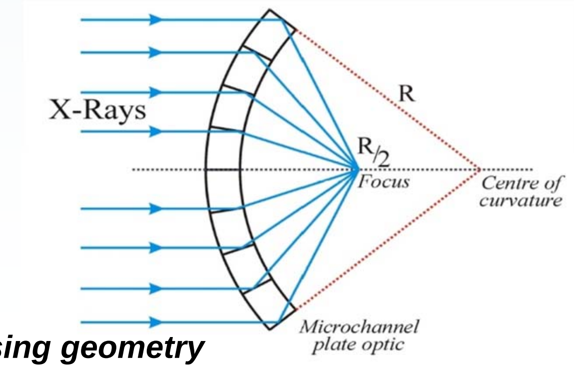
- Vantage point outside the magnetosphere
- Elliptical orbit, 35 R_E apogee, 63.4^o inclination
- Nominal mission lifetime 3 years
- Maximises viewing efficiency and scientific return
- Long March 2C/CTS launcher
- Core payload: X-ray WFI, plasma package, magnetometer
- Desirable for inclusion: FUV auroral imager

Core payload – X-ray WFI

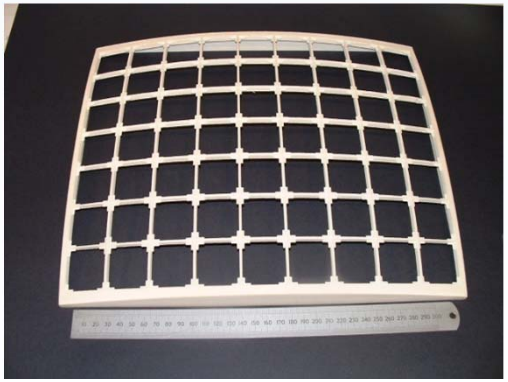
- **Wide Field Imager (WFI) will provide global X-ray imaging of the cusps and the day-side magnetosheath**
- **Wide FOV (30^o x 30^o baseline)**
- **Lobster-type optic, focal length 37.5 cm**
- **Angular resolution of 2.5 arcmin FWHM**
- **MCP detector, energy range 0.1 – 2.5 keV**
- **Baffle required**
- **TRL = 6 (BepiColombo)**



Micropore optic (Photonis)



Basic focusing geometry

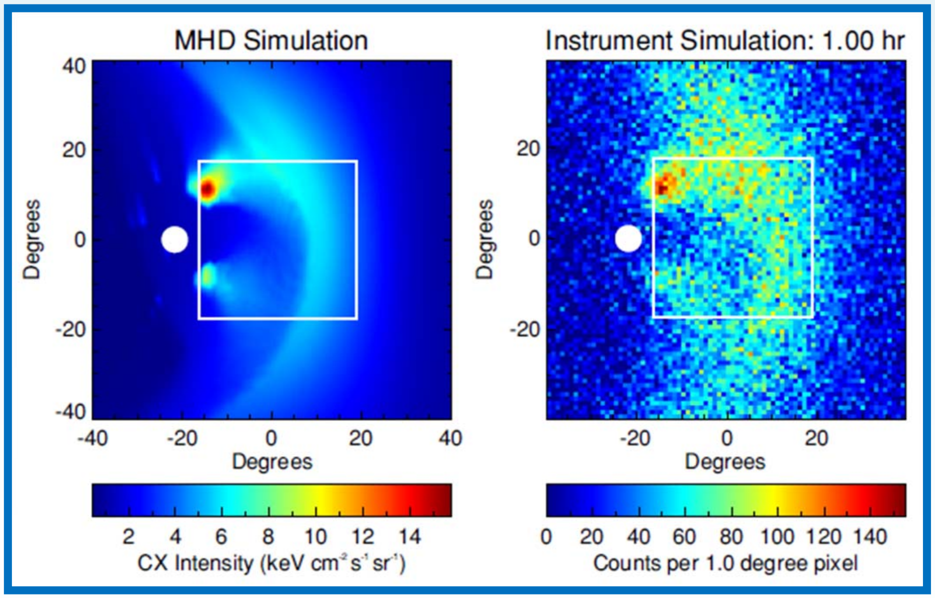


Frame holding individual MCP plates (Leicester Univ.)

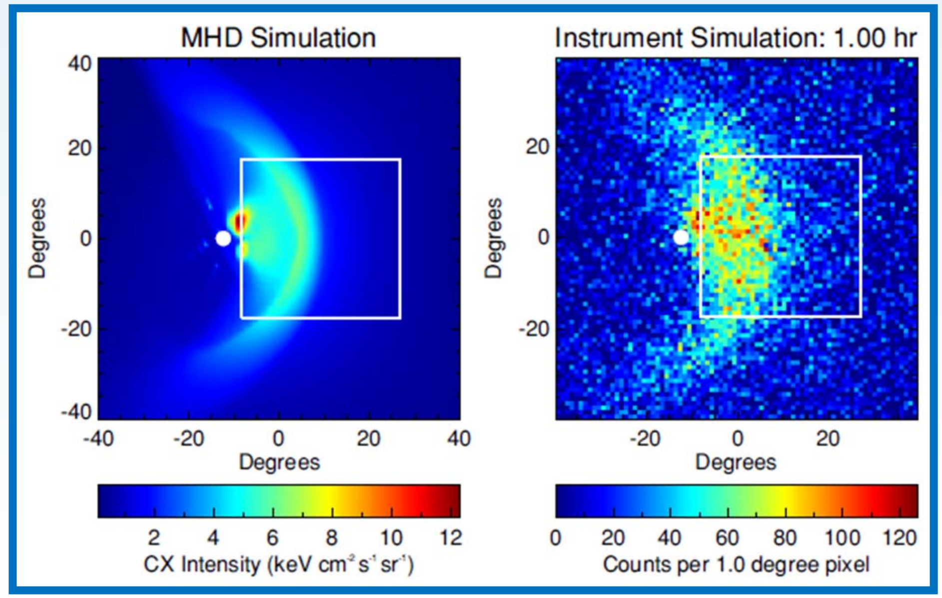
WFI simulated images

Average solar wind conditions

1 hr integration

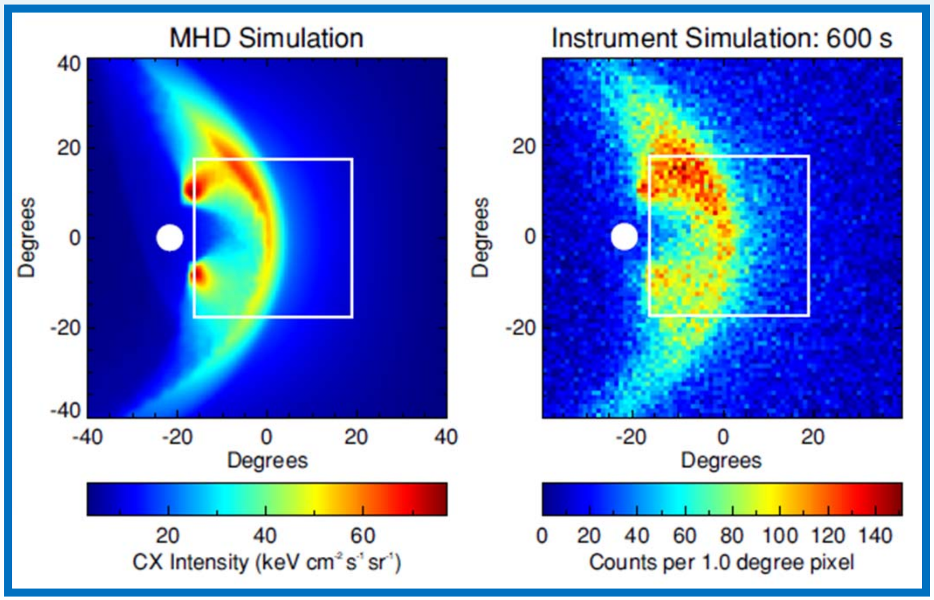


View from (3, -15, 12.5)R_E

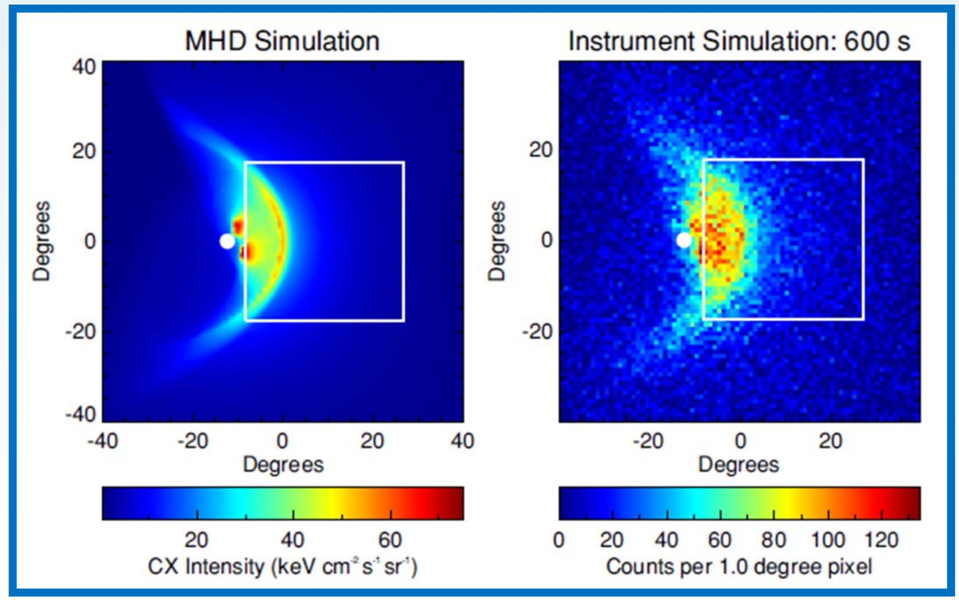


View from (6, -15, 31)R_E

WFI simulated images
Stormy solar wind conditions
10 min integration



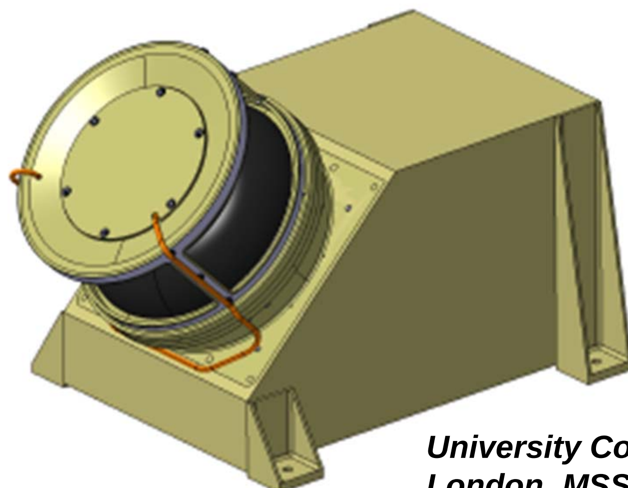
View from (3, -15, 12.5)R_E



View from (6, -15, 31)R_E

Core payload – Plasma package

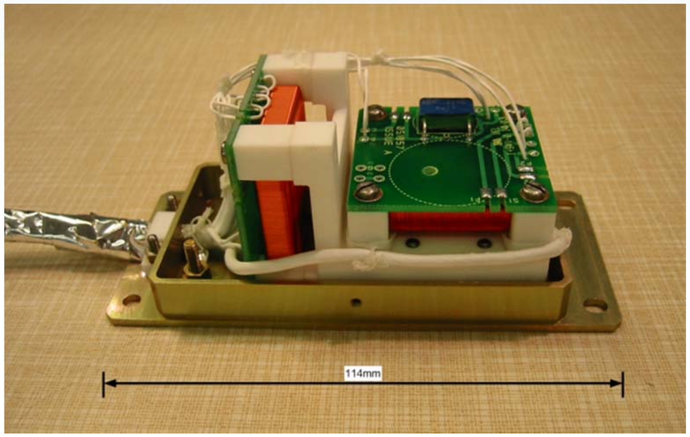
- Solar wind particle velocity established by top-hat electrostatic analyser: 3D ion distribution
- FOV 360º and +/-45º with deflector plates
- Mounted on the spacecraft body, continuous view of the incoming solar wind stream
- TRL = 6
  (Solar Orbiter heritage)



University College London, MSSL

Core payload – Magnetometer

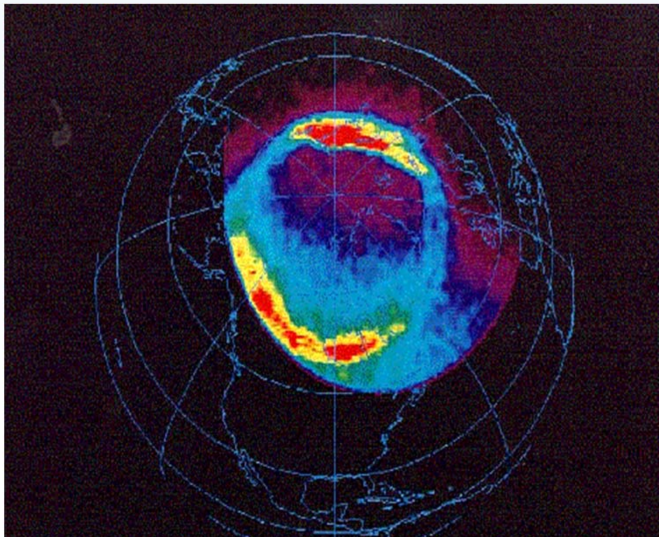
- Establish orientation and magnitude of solar wind magnetic field; detect interplanetary shocks and solar wind discontinuities
- Separate ambient field from spacecraft disturbances
- Spacecraft as magnetically clean as possible
- Dual redundant digital fluxgate magnetometer
- Two sensors, mounted on boom at different distances
- TRL > 6 (strong space heritage)



Fluxgate sensor (Imperial College London)

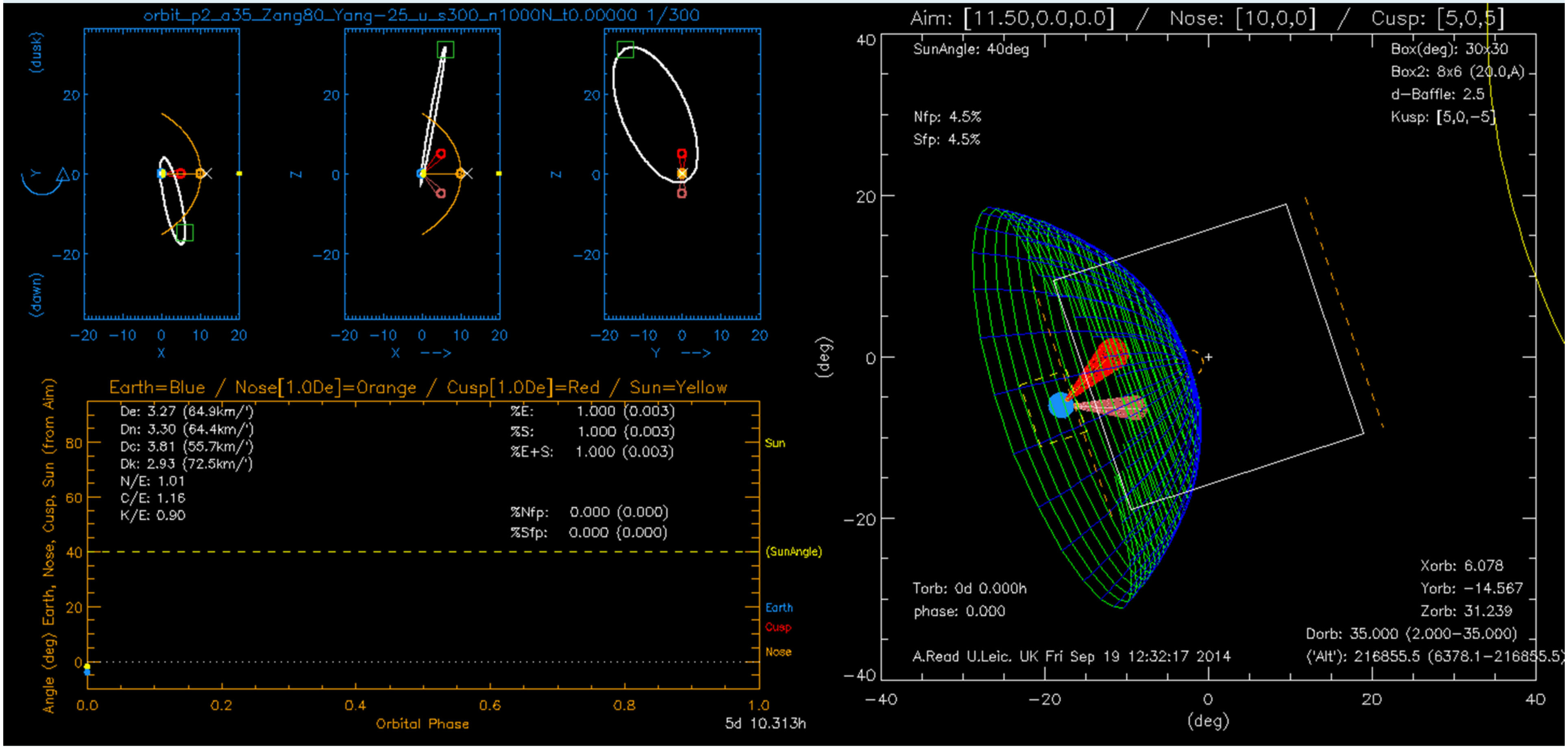
Auroral Imager (desirable)

- FUV auroral imager sets X-ray images into context, linking particle precipitation from magnetosheath with their ionospheric footprints
- Important additional science, within mass and power boundary conditions
- Telescope with intensified CCD
- 5^o x 5^o FOV, 140 – 190 nm band
- TRL ~ 6



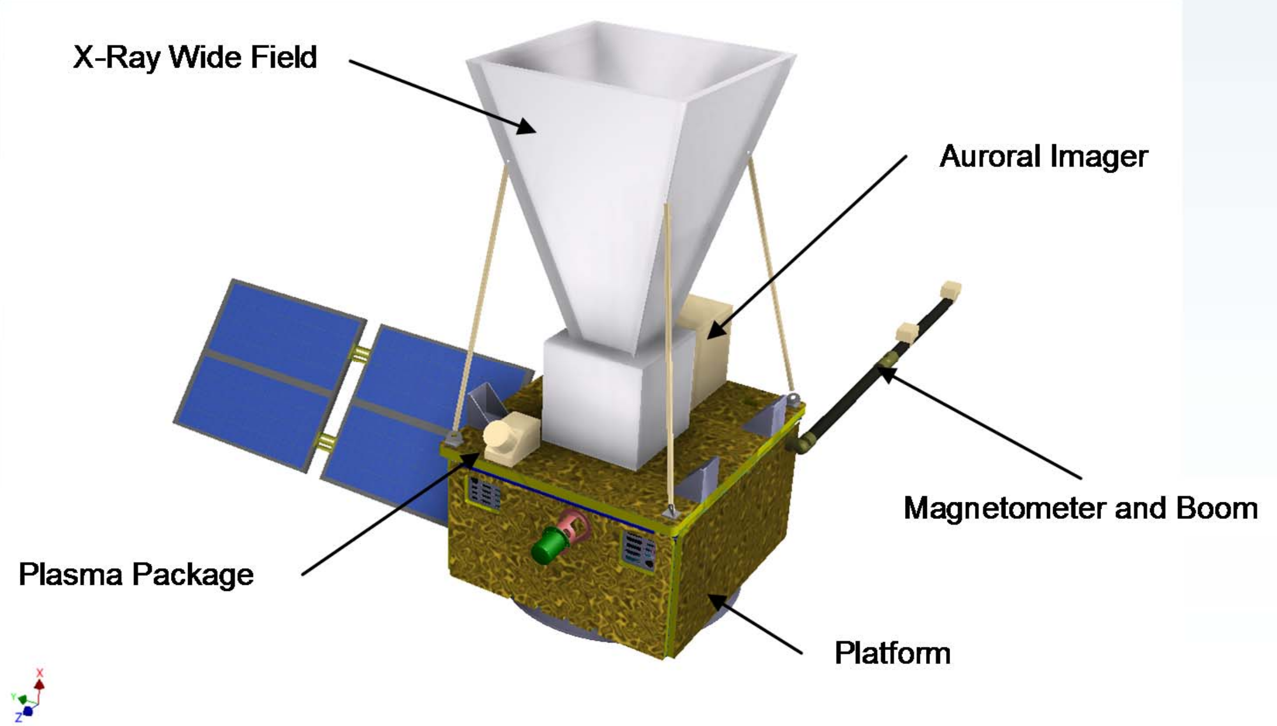
Polar UVI image of the Earth's aurora

Viewing efficiency simulations



Spacecraft platform

- Airbus Defence & Space: AstroBus Small platform under consideration
- Mass ~ 250 kg (including small propulsion module)
- TRL = 7-9 for subsystems



Resource requirements

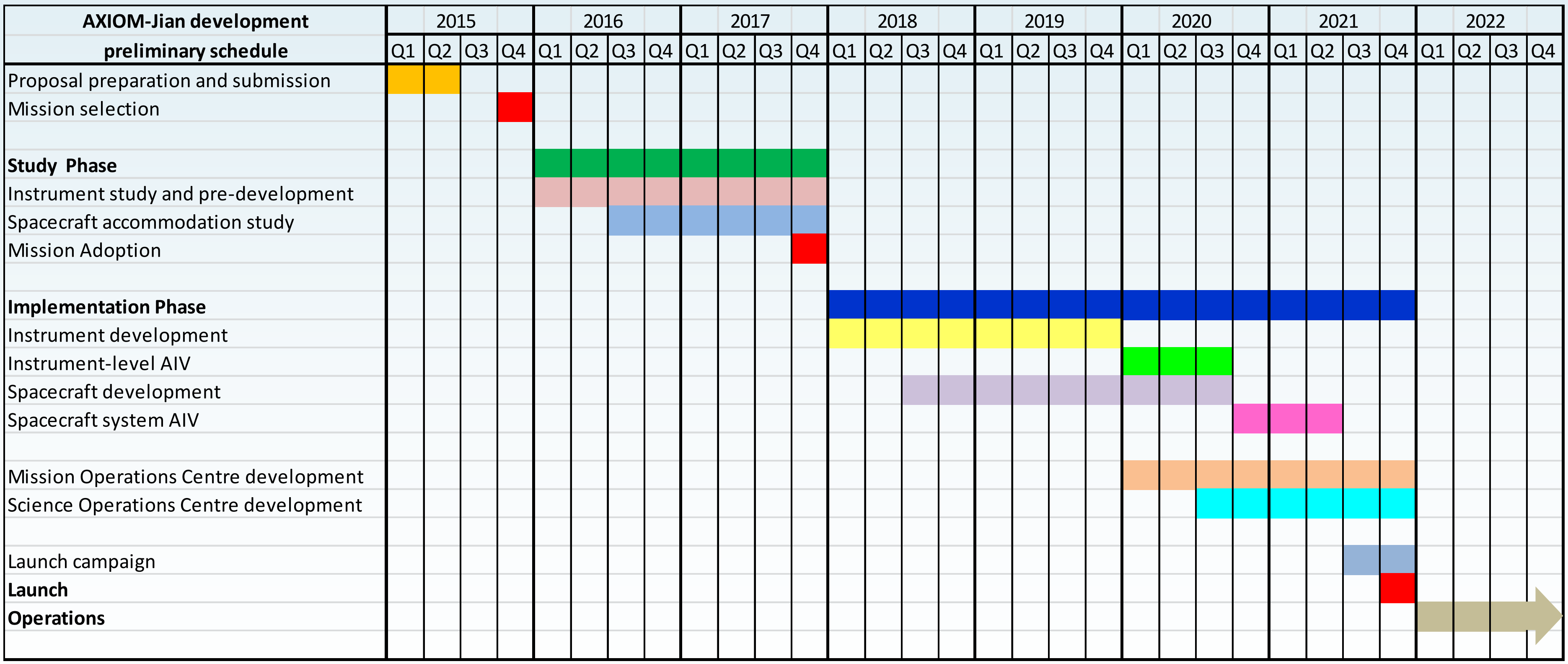
PAYLOAD / RESOURCES	X-ray Wide Field Imager (WFI)	Plasma package	Magnetometer	Auroral Imager	TOTAL required	Boundary conditions
FOV (deg)	30 x 30	360 & +/- 45		5 x 5		
Focal length	37.5 cm			20.4		
Dimensions (cm)	40 x 40 x 40 & 100 cm baffle	Sensor & DPU: 30 x 18 x 12	2 sensors, each 10 x 5 x 7 Electronics 16 x 16 x 10	35 x 24 x 30		
Mass (kg)	< 30 (20 without baffle)	2.5	3.5	< 10	< 46	< 60
Power (W)	12	6.5	3.5	< 11	< 33	< 65

Programmatics
Cooperation plan

- **ESA**: Platform, system engineering, system-level AIV, share of mission planning and operations
- **CAS**: Launcher procurement and launch campaign, participation in WFI and magnetometer, auroral imager, share of mission planning and operations
- **UK**: Design, development and testing of WFI, plasma package and magnetometer
- **USA, Finland**: Modelling tasks for WFI support

Programmatics

Schedule



Mission Operations and Science Operations Centres functions and locations to be shared between ESA states and China

Conclusion

- **AXIOM-Jian is a novel space mission which has a very high degree of technology readiness, is well within the imposed technical boundary conditions and is financially affordable**
- **AXIOM-Jian will lead to a better understanding of solar-terrestrial relationships on a global scale, hence will have a direct impact on our efforts to develop strategies to predict and mitigate space weather effects**