Imperial College London

AXIOM: Advanced X-Ray Imaging of the Earth's Magnetosphere

J. P. Eastwood[1], G. Branduardi-Raymont[2], S. F. Sembay[3], D. G. Sibeck[4], J. A. Carter[3], A. M. Read[3] and the AXIOM Collaboration[5]

1) *The Blackett Laboratory, Imperial College London, London SW7 2AZ, UK*
2) *Mullard Space Science Laboratory, University College London, Holmbury St. Mary, Dorking, Surrey, UK*
3) *Department of Physics and Astronomy, University of Leicester, Leicester, UK*
4) *Code 674, NASA Goddard Space Flight Center, Greenbelt, MD, USA*
5) *http://www.mssl.ucl.ac.uk/~gbr/AXIOM/index.html*

13 September 2013
Abstract EPSC2013-378
European Planetary Science Congress 2013, UCL, London, UK

Imperial College London

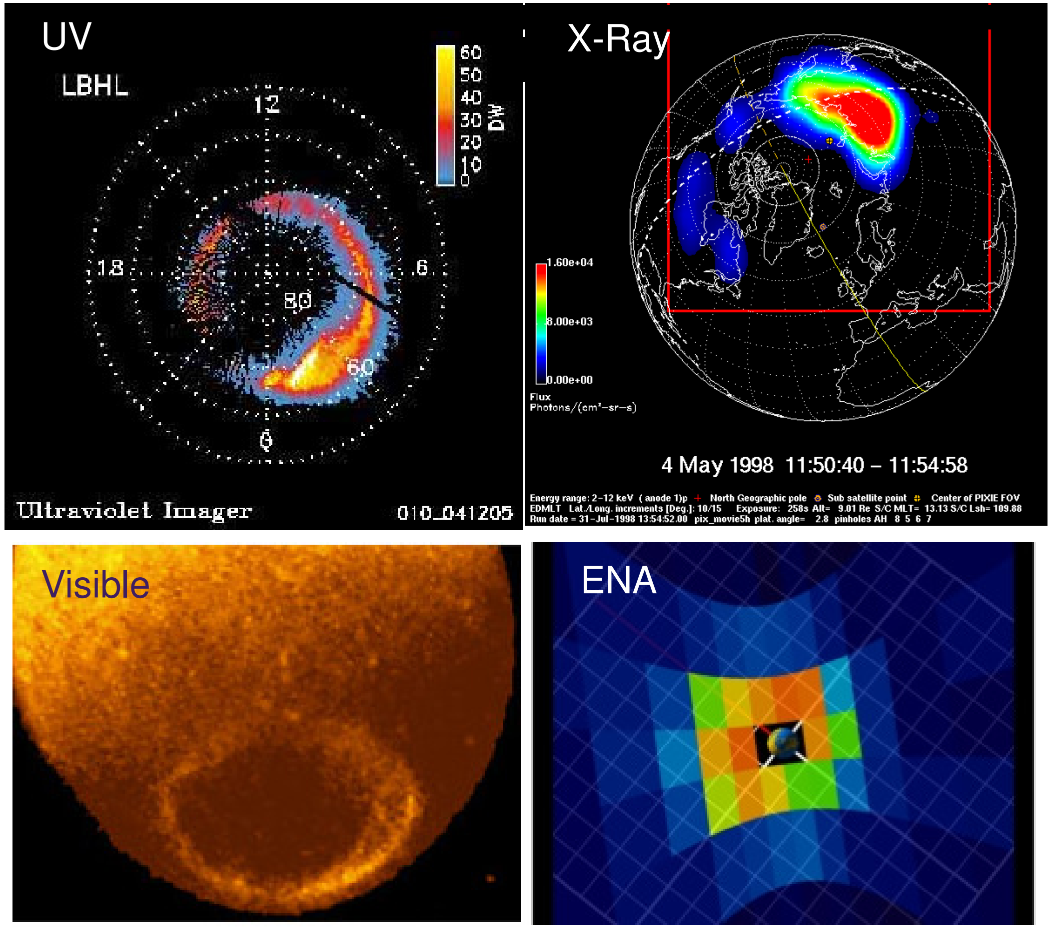
Summary (15 minute talk, inc. 3 minutes questions)

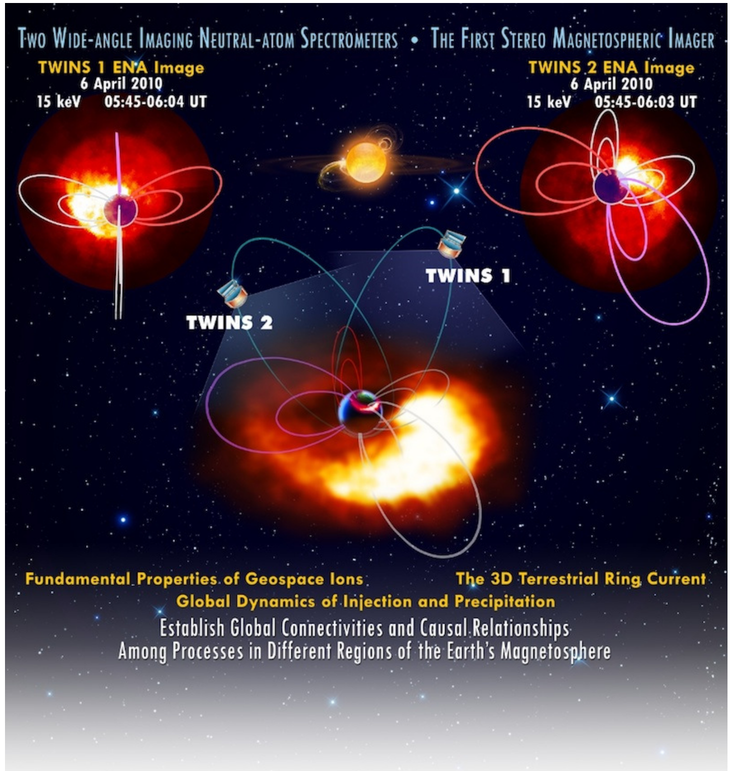
- Introduction
- Solar Wind Charge Exchange
- AXIOM
- AXIOM-C
- Conclusions

Introduction

- Plasma and magnetic field environments can be studied in two complementary ways:
  - **In situ measurement**: provides precise information about plasma behaviour, instabilities and dynamics.
  - **Remote measurement**: provides knowledge about global configurations and overall evolution.
- **To understand how planetary magnetospheres work, we need a combination of precise local information and the global picture.**
- Historically, magnetospheric physics has largely relied on in situ measurement.

Imaging the inner magnetosphere and aurora





http://www-spof.gsfc.nasa.gov/istp/polar/

http://twins.swri.edu/index.jsp

Imperial College London

Science questions: outer magnetospheric boundaries

- Magnetopause physics
  - How do upstream conditions control magnetopause location, size and shape, and magnetosheath thickness?
  - Under what conditions do transient boundary layers arise?

- Cusp physics
  - What are the size and shape of the cusps?
  - How do they move in response to SW changes?
  - Density, SW/magnetosphere coupling?

- Shock physics
  - What controls where the bow shock forms?
  - How does its thickness depend on the upstream conditions?

- Interaction of a Coronal Mass Ejection with the magnetosphere

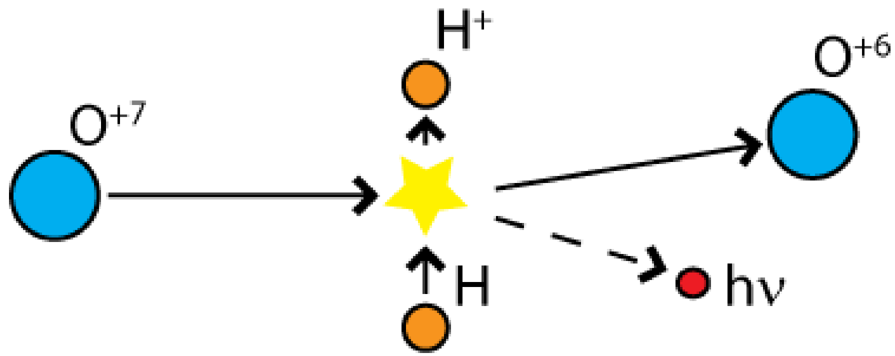
- All require global imaging for science closure

A novel approach to imaging

- Solar Wind Charge eXchange (SWCX) is expected where high charge state SW ions encounter neutrals, e.g. in the Earth's exosphere

- Observed at e.g. comet Hyakutake

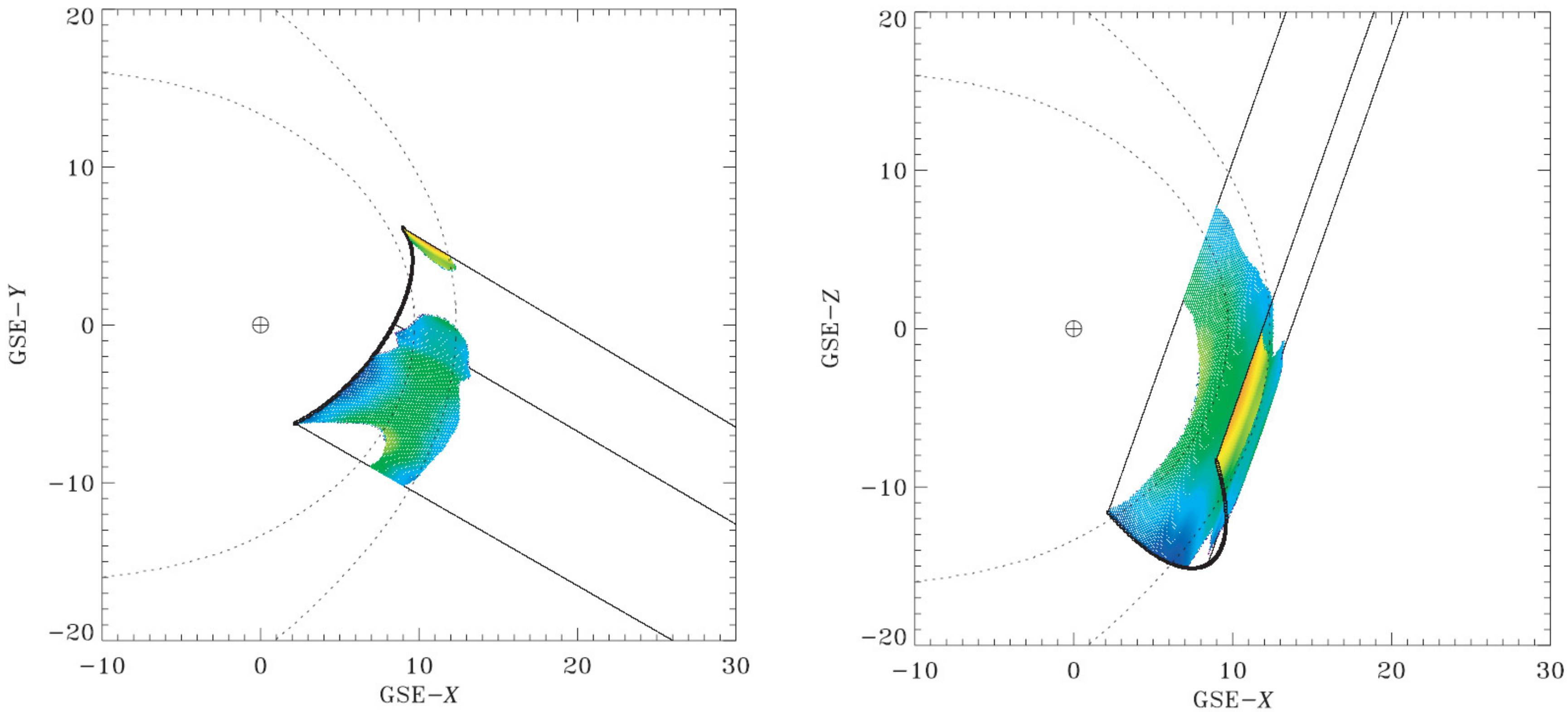
- Photon production rate P_X depends on
  - α : scale factor
  - n_{sw} : solar wind proton density
  - n_n : neutral density
  - <g> : relative velocity



$$P_X = \alpha n_{\mathrm{sw}} n_n \langle g \rangle \ \mathrm{eV\ cm^{-3}\ s^{-1}}$$

(Cravens, ApJ., 532, L153, 2000)

SWCX emission at Earth really exists (part 1)

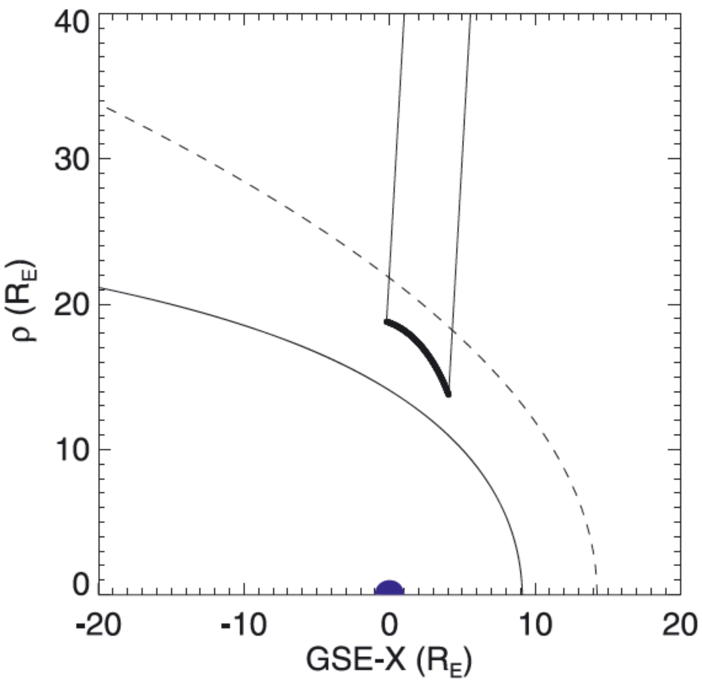


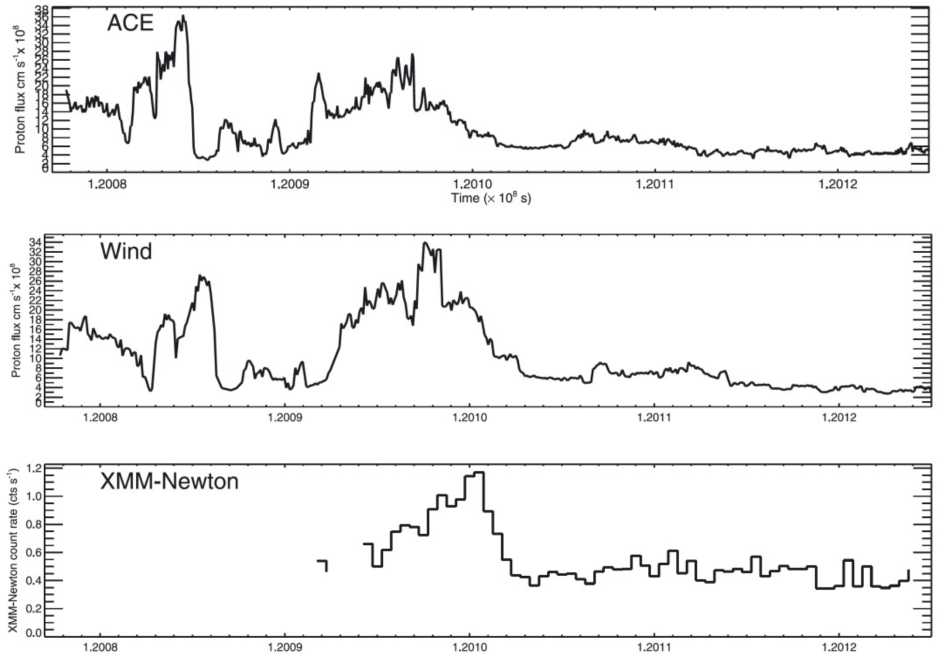
Solar wind charge exchange emission measured by Newton XMM

Colour shows emissivity $n_{sw}n_n\langle g\rangle$ (n_{sw} = solar wind density, n_n = neutral density, $\langle g\rangle$ relative velocity)

(Snowden et al. 2009)

SWCX emission at Earth really exists (part 2)





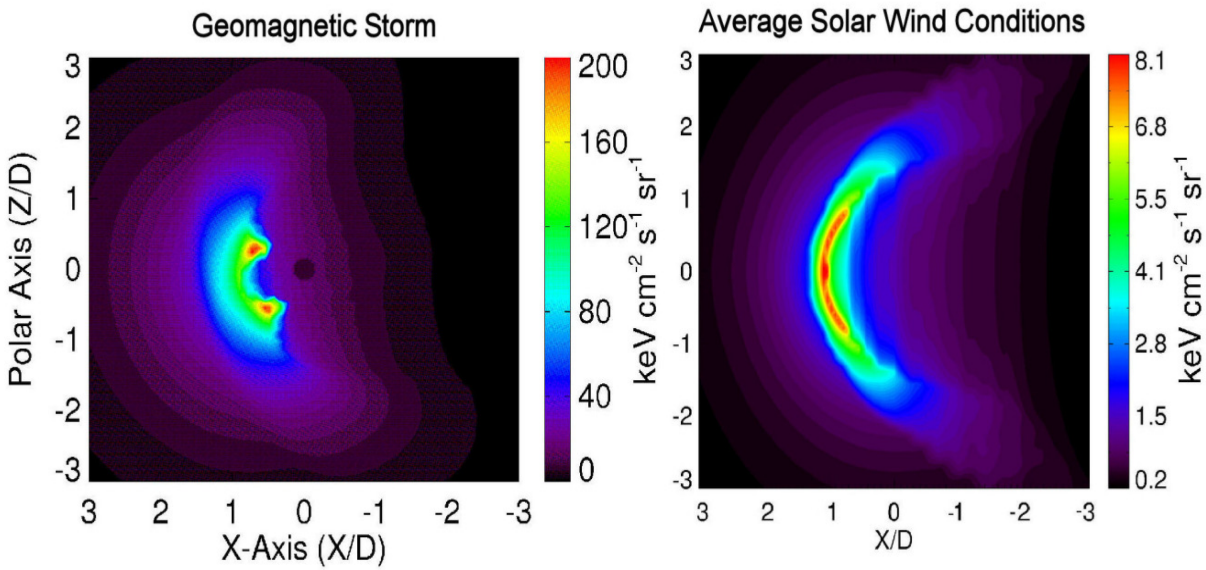
XMM trajectory from t = 1.2010×10^8 – 1.2012×10^8 s

A coronal mass ejection was observed by Newton XMM on 21 October 2001

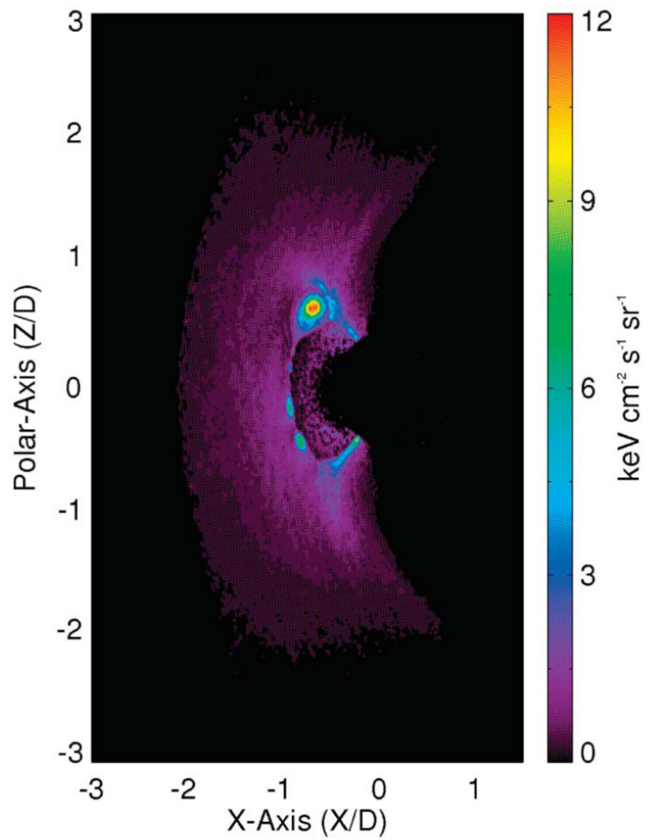
(Carter et al. 2010)

Simulated SWCX emission from around the Earth

- SWCX emission from the magnetosphere has been simulated (e.g. *Robertson and Cravens, GRL, 2003; Robertson et al. 2006*)



(*Robertson et al*. 2006)

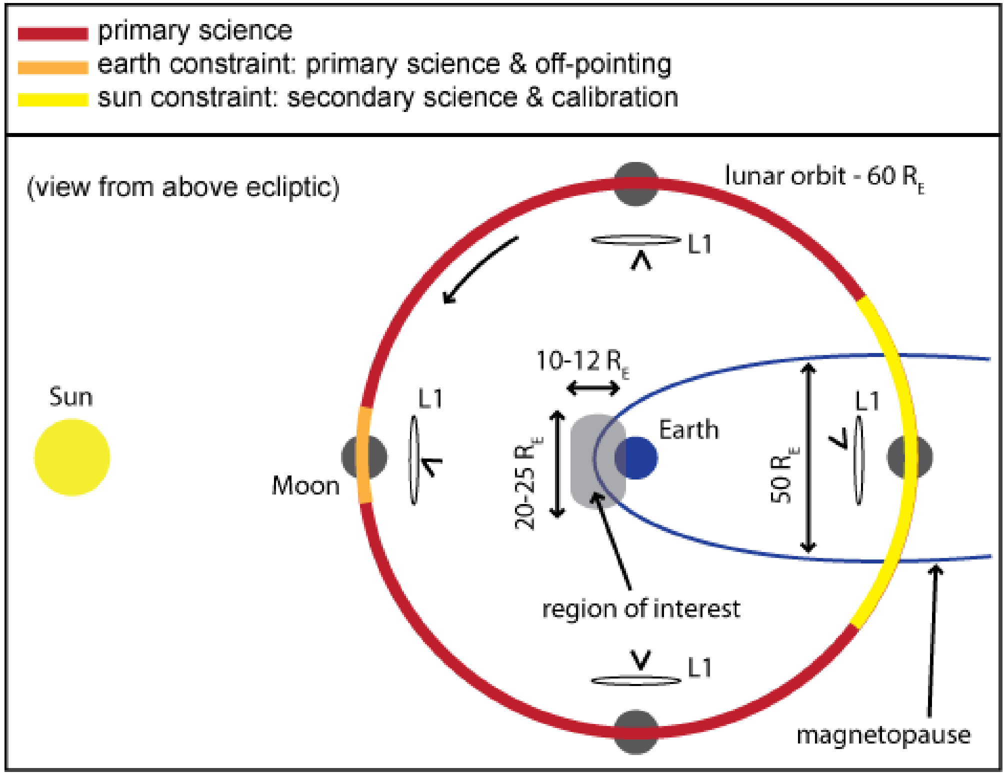


(Collier et al., EOS, 2010)

Imperial College London

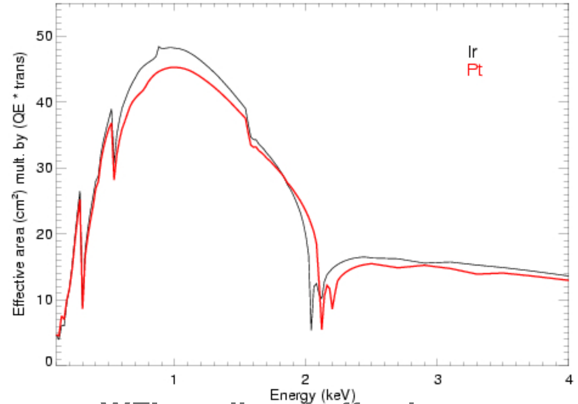
AXIOM: Advanced X-ray Imaging Of the Magnetosphere

- ESA M-Class mission proposal (2010)
- Payload
  - Wide FOV X-ray imager with spectroscopy
  - Compact plasma package
  - Magnetometer:
- Vega launch
  - Vantage point far out from Earth
  - Lissajous orbit at Earth - Moon L1 point (~50 R_E)



Branduardi-Raymont, Sembay, Eastwood et al., Exp Astron 33:403–443, 2012

AXIOM payload – X-ray WFI (Sembay, University of Leicester)



WFI predicted effective area

X-ray Wide Field Imager (WFI):

Wide FOV (10° x 15 °baseline)

Energy range 0.1 – 2.5 keV

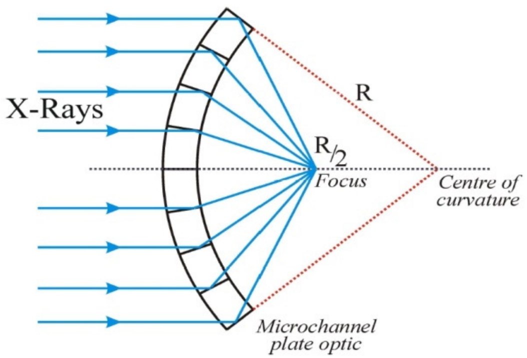
Energy resolution < 65 eV (FWHM) at 0.6 keV

Angular resolution of ~ 7 arcmin (0.1 R_E at 50 R_E)

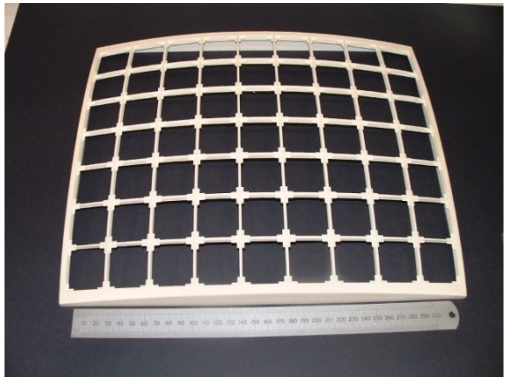
Time resolution of ~ 1 min

Grasp = effective area x FOV = 25x XMM at 0.6 keV

Achievable with MCP optics coupled with X-ray sensitive CCDs at focus



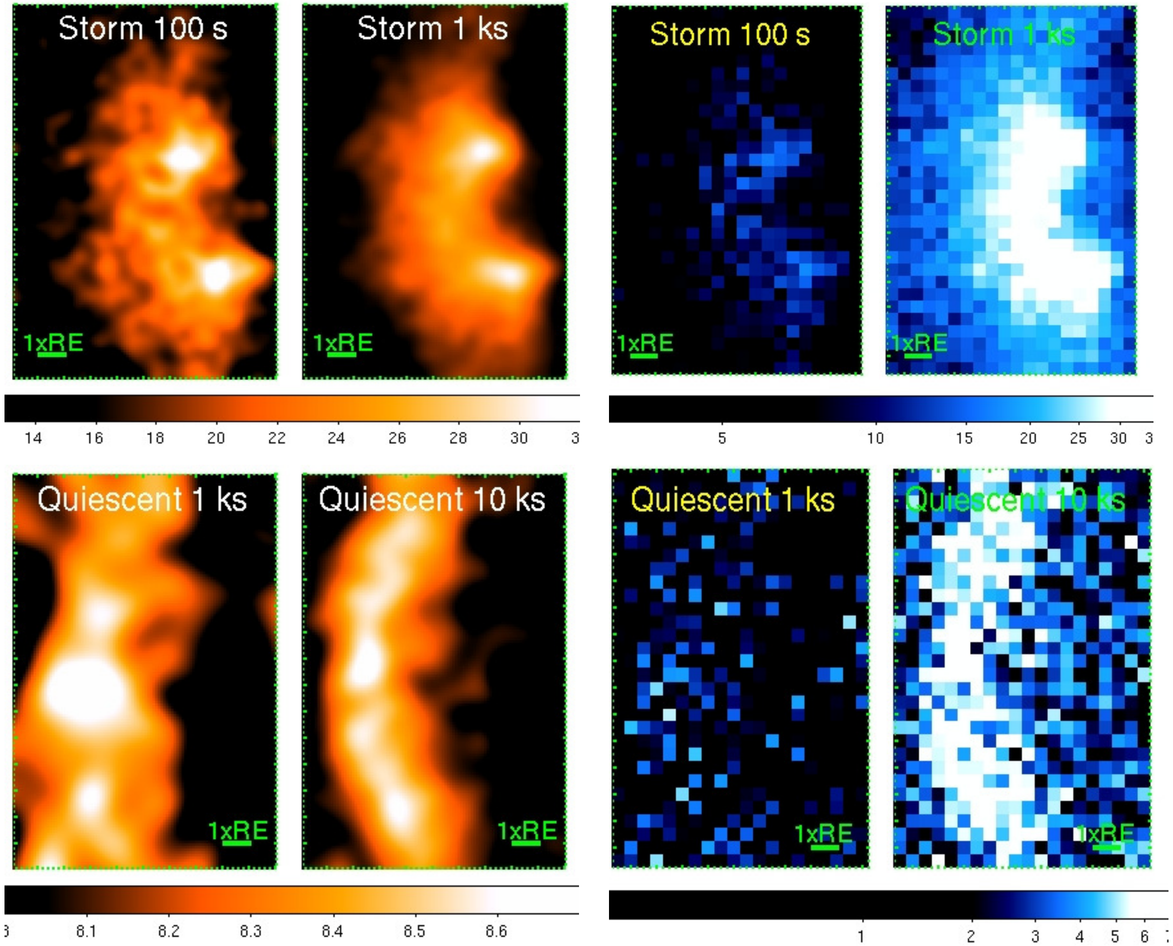
Basic focusing geometry



Frame holding individual MCP plates

Imperial College London

AXIOM WFI simulated images

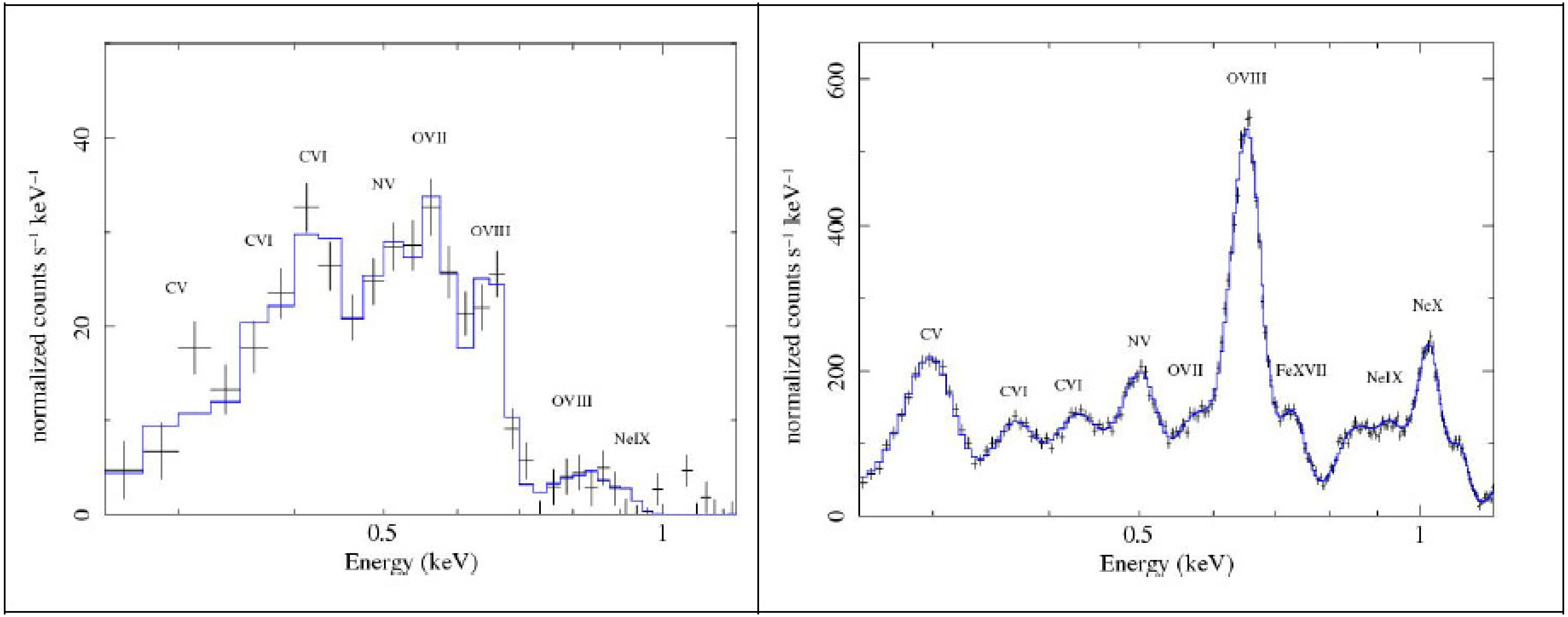


Simulated WFI images

Simulated WFI significance maps

http://www.star.le.ac.uk/~jac48/axiomsims/

AXIOM WFI spectral measurements



Simulated background-subtracted SWCX spectra

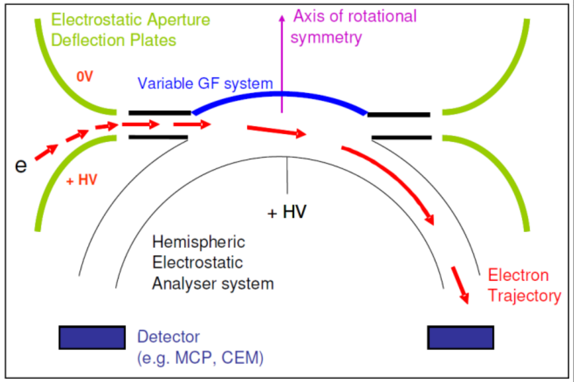
Left: quiescent solar wind

Right: during a coronal mass ejection

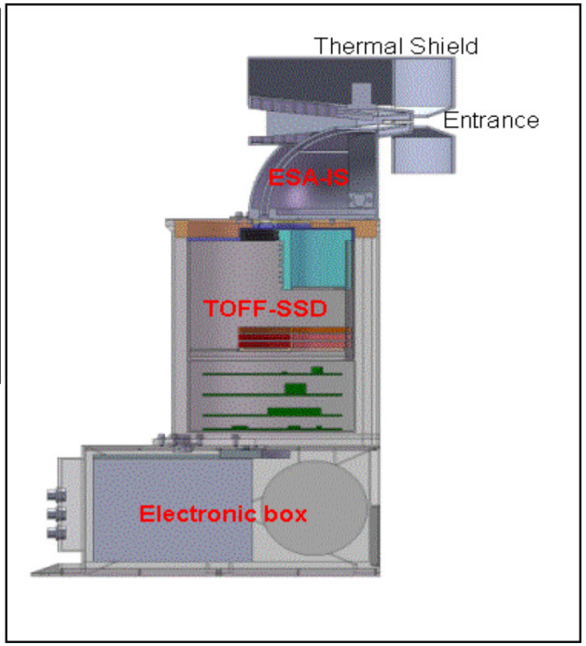
AXIOM in situ payload

Proton-Alpha Sensor (PAS): to measure the solar wind density and velocity.

Ion Composition Analyser (ICA): to measure properties of minor ions in the solar wind (2-56 amu/q).

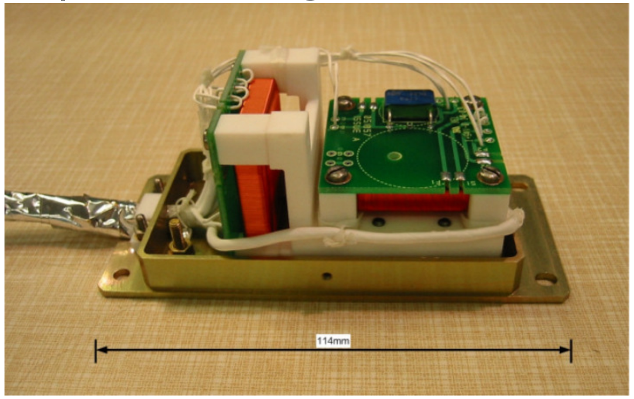


MSSL/UCL



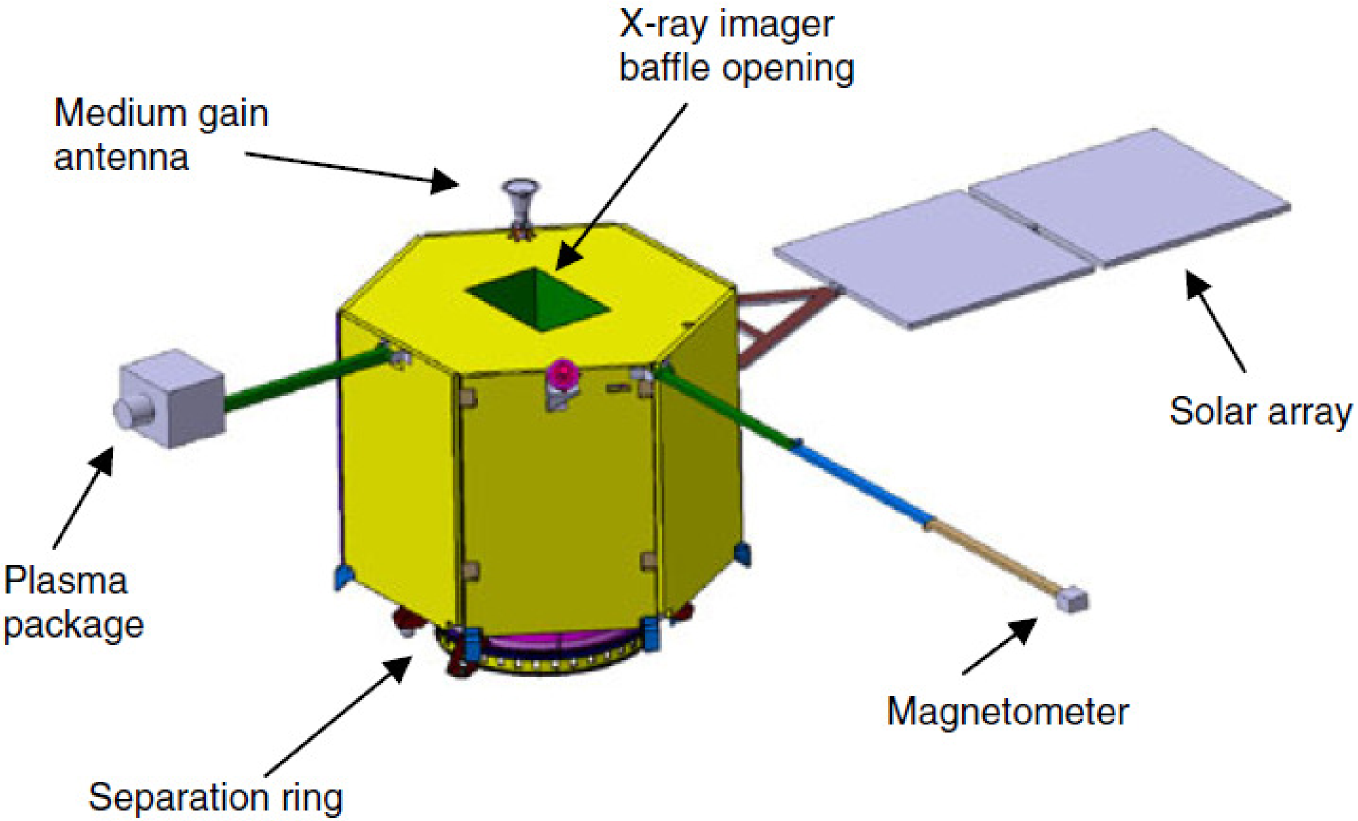
Flux-Gate Magnetometer (MAG): to measure the orientation and strength of the solar wind magnetic field, crucial for understanding the solar wind - magnetosphere interaction.

Imperial College London



Imperial College London

AXIOM satellite design



AXIOM lessons learned

Lessons learned from the M3 competition:

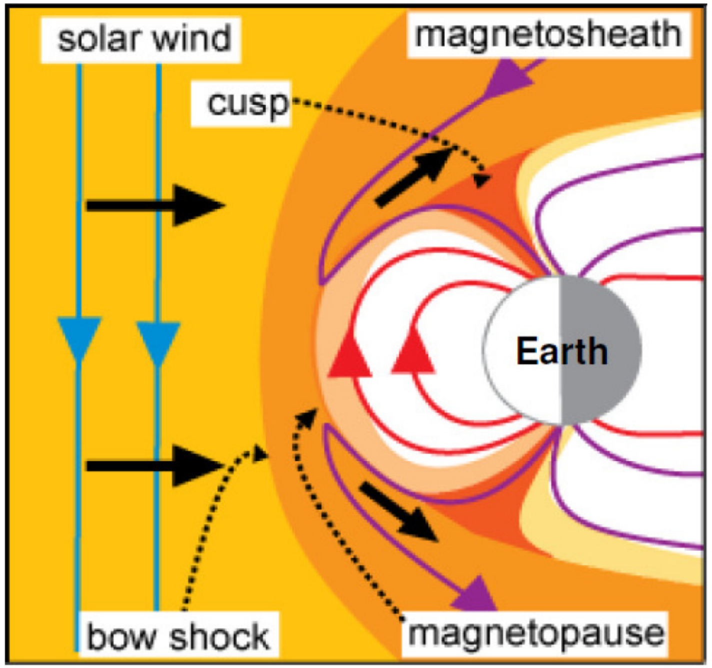
1. We tried to save ESA money, coming in well below the cost cap (250/470 M€), by flying a smaller satellite and using a Vega launcher
2. We should have used the full cost cap, and flown a larger imager (address questions regarding image accumulation time)
3. Science case was considered weaker because there were no in situ measurements coming from where the X-rays are generated
4. A larger pan-European team would have been considered an advantage

AXIOM-C: Advanced X-ray Imaging Of the Magnetosphere-Cusps

- ESA S-Class mission proposal (2012), targeted to focus on the magnetospheric cusps

- The cusps play a pivotal role in solar wind magnetosphere coupling. Two key questions:
  1. What controls the size and shape of the cusps and their boundaries?
  2. Is cusp structure dominated by spatial or temporal effects?

- Brightest regions of emission (easiest to image)



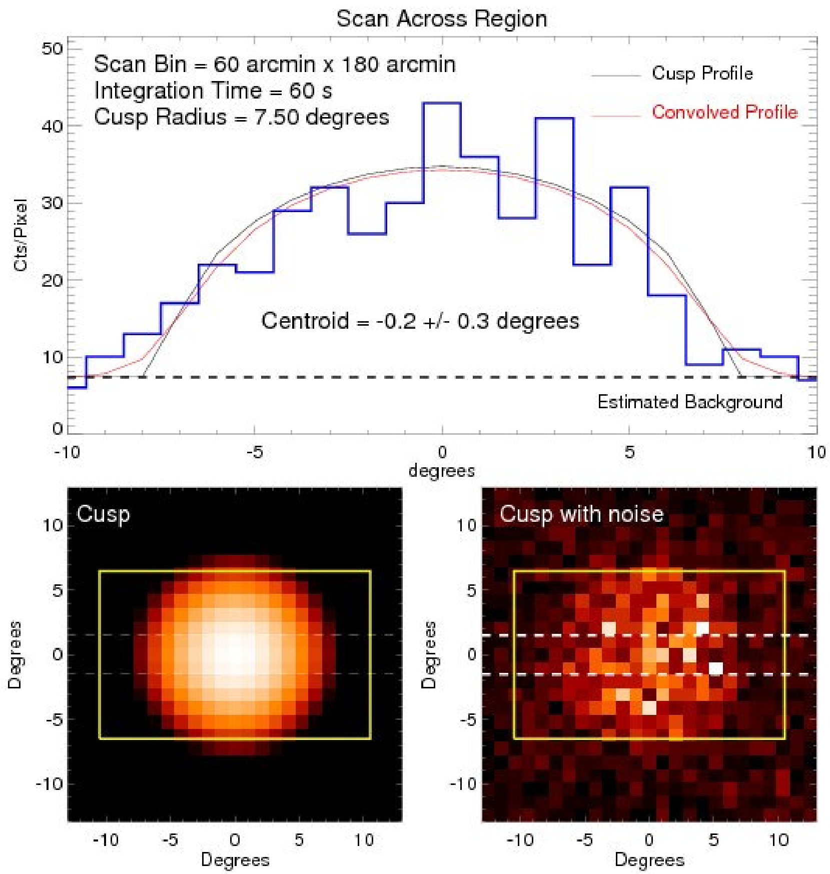
Imperial College London

AXIOM-C Mission profile

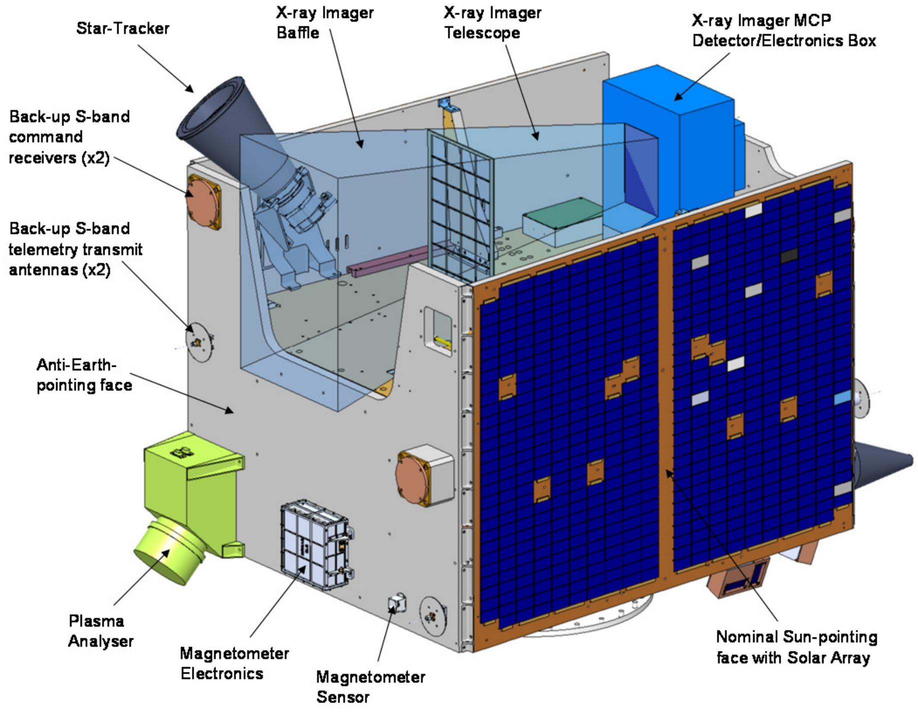
- Operate in LEO, where we ‘look out’ to cusps
  - Flying through/below cusps allows (quasi-)simultaneous in situ measurements
  - Link high altitude (AXIOM-C) with low altitude (ground observers) measurements
  - Gain remote + in situ knowledge
- Piggyback VEGA launch, Sun-synchronous, 650 km, 10:30 AN, circular orbit
- Instrumentation:
  - WFI: 21° x 13° FOV, 2.5 arcmin FWHM
  - Dual Electrostatic Sensor for Ions and Electrons (DESIE)
  - Magnetometer (MAG)
- Cost at completion ~ 50 M€ (everything including launch)

Imperial College London

AXIOM-C payload – X-ray WFI (Sembay, University of Leicester)



Simulated WFI observations of cusp-like structures for a 60 s integration



WFI accommodation in the AXIOM-C spacecraft

Spacecraft bus is SSTL-150

Imperial College London

Conclusions

- To fully understand how the magnetosphere works, we need global imaging.
- This can be achieved via Solar Wind Charge Exchange emission
- The AXIOM proposal used the Earth-Moon Lagrange points as a vantage point for observations
- The AXIOM-C proposal was designed to measure the cusps from LEO
- Next opportunity: ESA M4? (2014)