ESA F3 Mission Candidate: Magnetotail Dynamics Explorer

Poster Session I:
RAS MIST Meeting
November 2025

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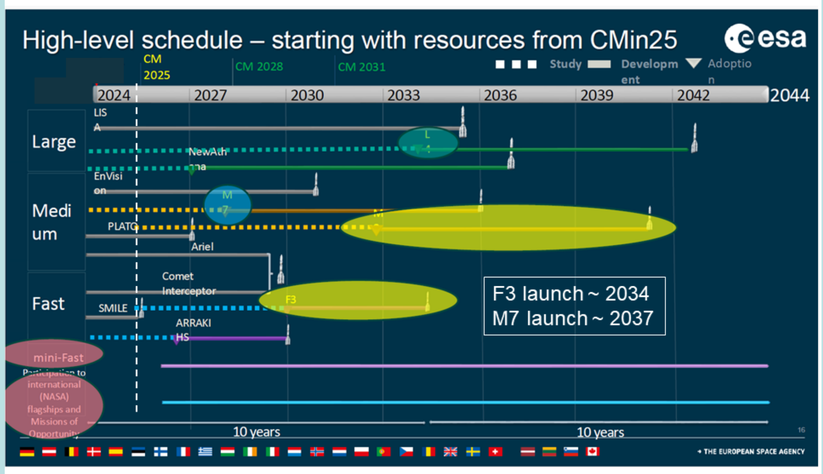
ESA Missions Call 2025: Programme Overview



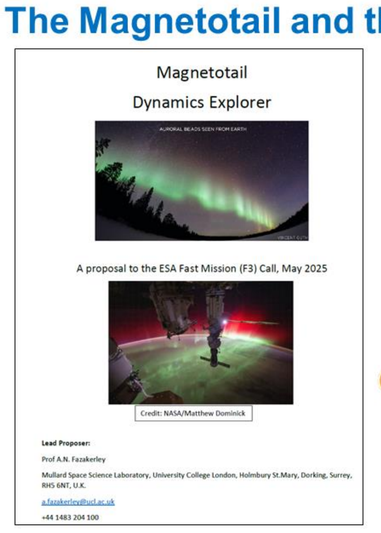
Credit ESA

call for a medium-size and a fast mission opportunity - 2025

SCHEDULE FOR THIS CALL AND IMPORTANT DATES

Activity	Date M-mission Call	Date F-mission Call
Briefing for the community	11 December 2024	
Release of Call	19 March 2025	
Step-1 proposal submission deadline	21 May 2025 – 12:00 (noon) CEST	
Step-1 proposal assessment	May - September 2025	
Step-1 proposer notification	**7 October 2025**	
M-class mission workshop (collective)	**29 October 2025 (morning) This will be an online workshop**	
M-class mission workshops (individual)	**29 October (afternoon); 30 October (all day) This will be an online workshop**	
F-class mission workshop #1 (collective)	**30 October (afternoon) This will be an online workshop**	
F-class mission workshops #1 (individual)	**30 October (afternoon); 31 October (all day) This will be an online workshop**	
Maturation Phase	Not applicable	November 2025 - mid-January 2026
F-class mission workshop #2	Not applicable	January 2026 (exact date TBD)
Step-2 proposal submission deadline	19 March 2026 by 12:00 (noon) CET	21 April 2026 by 12:00 (noon) CEST
Letters of Endorsement deadline	19 May 2026 by 12:00 (noon) CEST	16 June 2026 by 12:00 (noon) CEST
Proposal evaluation and scientific ranking	March - September 2026	April - October 2026
Selection of missions for study	November 2026 (up to 5 candidates)	November 2026 (1 candidate and 1 backup)

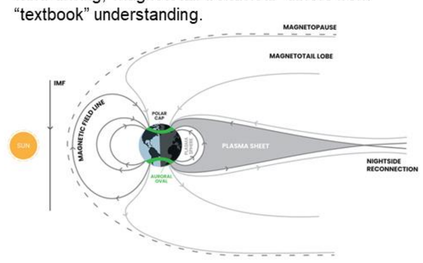
The Magnetotail and the Aurorae



The magnetotail is constantly changing in response to solar wind driving and internal instabilities.

The most common, yet still poorly understood, example is the magnetospheric substorm, which drives dramatic displays of the aurorae; also known as the northern and southern lights.

There is increasing awareness that during low solar wind driving, magnetotail behaviour differs from "textbook" understanding.



Decotte et al, JGR, 2023

MDE proposal is an evolution of the earlier BEADS proposal (ESA-CAS Call 2015) led by I.J. Rae and J. Cao, co-written by A Fazakerley

MDE Science Objectives

1: Why does a magnetospheric substorm start?

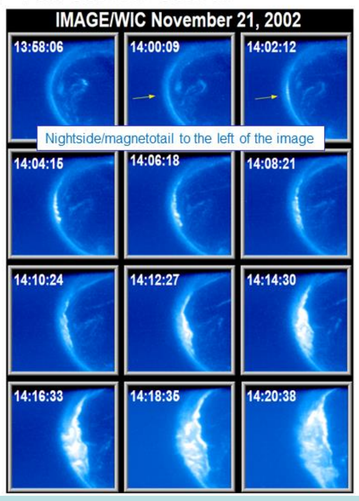
Substorm aurora onset and evolution

Measure development of "auroral beads", and corresponding particle and wave signatures on the field lines that see the "beads"

Determine their cause by comparison with competing models

Test hypothesis that "beads" map to inner edge of plasma sheet using isotropy boundary method.

Observations from 2.5 R_E altitude (most IMAGE observations are from 7 R_E altitude)



Onset arc develops "beads"

Structured "beads" grow

Substorm expansion begins

Henderson, Ann Geo, 2009

MDE Science Objectives

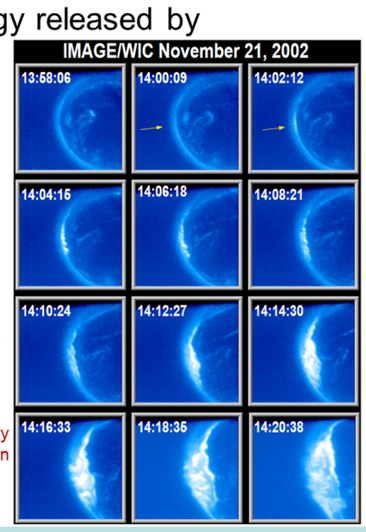
2: Where and how is the energy released by substorms dissipated?

Substorm energy dissipation

Auroral emissions only one part of energy dissipation in the ionosphere

Also need measurements of electromagnetic waves, plasma convection and charged particle precipitation along the spacecraft track as the substorm develops.

Evaluate relative importance of different contributions



Substorm expansion begins

Much energy dissipation in ionosphere

Henderson, Ann Geo, 2009

MDE Science Objectives

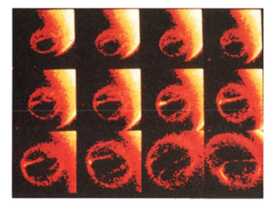
3: How closed can the magnetosphere become?

Investigate evolution of magnetosphere during prolonged northward IMF

What is the magnetotail configuration after prolonged northward IMF?

Do Cusp-Aligned Arcs indicate a nearly "closed" magnetosphere?

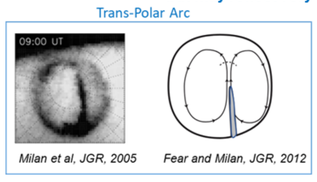
Are Trans-Polar Arcs due to closed flux trapped in the magnetotail, seen in the otherwise open polar cap?



Hones et al, JGR, 1989

Trans-polar Arcs and Cusp-Aligned Arcs seem similar, but may reflect very different magnetotail structures.

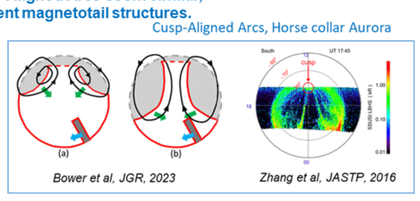
Trans-Polar Arc



Milan et al, JGR, 2005

Fear and Milan, JGR, 2012

Cusp-Aligned Arcs, Horse collar Aurora



Bower et al, JGR, 2023

Zhang et al, JASTP, 2016

MDE Mission Concept

Science orbit concept

Maximise number of observations of substorm onset using frequent overflights of substorm onset region magnetic footprint

Use a sun-synchronous orbit optimized for the mission

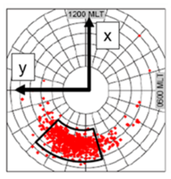
Example (un-optimised) orbit

- Circular orbit
- Inclination ~ 99°
- 894 km altitude
- Revs per day = 14
- Orbit period ~103 m

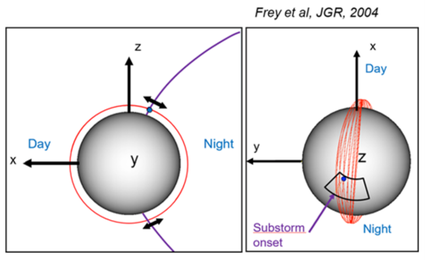
Expect ~2140 substorms per typical year.
Then MDE sees ~ 43 events/year

MDE may see > 70 events/year if launched ~2034/5 as planned, around Solar Maximum

Substorm onset is most probable for:
Magnetic LT 22:00-00:00 h
Magnetic latitude 63°- 70°



Frey et al, JGR, 2004



Solar Magnetic Coordinates

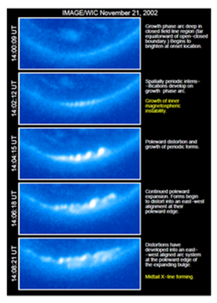
Newell et al, JGR, 2013

MDE Mission Concept

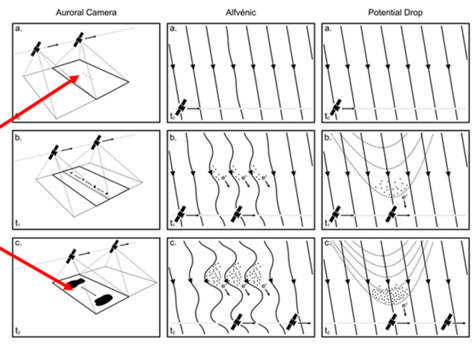
Requirement for 2 spacecraft

Why can't the mission be achieved with a single spacecraft?

A single spacecraft overflight of the auroral onset arc is too quick. Second spacecraft provides vital extended view.
Use ~ 200 km separation.



Henderson, Ann Geo, 2009



Credit BEADS proposal

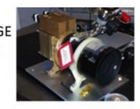
MDE Mission Concept

Payload

Experienced teams. Proven instruments.

Instrument	Measurement	Heritage	Team
FUVI	Auroral imager	IMAGE	CSL (Belgium) U Calgary (Canada) [Tbc French alternate]
MAG	d.c. magnetometer	BepiColombo, Comet Interceptor	IWF (Austria), TUB (Germany), Imperial (UK)
EFI *	Electric field	JUICE	IRF-U (Sweden)
EESA	Electron electrostatic analyser	Solar Orbiter SWA-EAS (one head not two)	MSSL (UK) [Tbc French partner]
EPE	Energetic particles	Elfin-EPD (Plasma Observatory EPE)	RAL Space (UK), UCLA (USA), U Kiel (Germany)
DPU	Data processing/ power supply/control	Vigil (Plasma Observatory)	CAS (Czech Republic)
IDPU	Data processing/ power supply/control	Comet Interceptor	CBK (Poland)

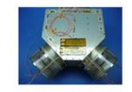
IMAGE -WIC => FUVI



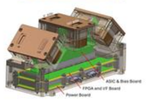
MAG

EFI

EESA



EPE



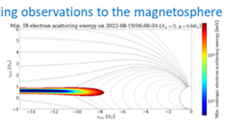
MDE Mission Concept

Testing models of substorm onset instability

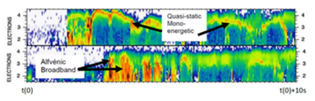
Example: Combined Payload contributions are vital for science closure for Objective 1

EPE: Connecting observations to the magnetosphere

Electron IB: Reveals transition between electron plasmasheet to outer radiation belt

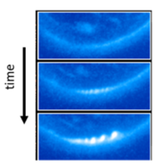


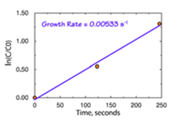
Wilkens et al. Arxiv Sept 2024



MAG/EFI: **Frequency** of electromagnetic waves

EESA: **Monoenergetic vs Alfvenic** electron energy spectra





FUVI: **Growth Rate** (of the "beads")

Instability	Reference	Frequency (mHz)	Growth Rate (s^{-1})	Spatial Scale (km)	Observable Test
Tearing	Coppi et al. [1966]	1-100	0.01	100-1000	Growth Rate
Drift kink/sausage	Zhu & Winglee [1996]	1-100	0.01	1-100	Growth Rate
Current driven Alfvénic	Perraut et al. [2000]	100s	1	1-100	Frequency
Lower-hybrid drift	Yoon et al. [1994]	1000s	1	1-100	Frequency/ Monoenergetic
Cross-field current instability	Lui et al. [1991]	20-30	0.1	100	Spatial Scale/ Monoenergetic
Shear-flow ballooning	Voronkov et al. [1997]	20-30	0.1	10	Spatial Scale/ Alfvénic
Kinetic ballooning	Horton et al. [2001]	20-30	0.1	10	Spatial Scale/ Monoenergetic

Table - Credit BEADS proposal

MDE Mission Concept

Spacecraft

Aim to use available spacecraft with minimal changes.

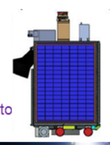
ESA boundary conditions; spacecraft < 500 kg

Commercial spacecraft in ~150 kg class may be suitable. Limited mass growth is possible within F-class boundary conditions

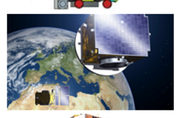
3 axis stabilized works best for imager, spinning helpful but not essential for particle instruments

Will need to be able to control inter-spacecraft distance and de-orbit.

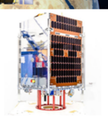
BEADS proposal (Proba family)
2 spacecraft with combined mass 300 kg
Was judged not to have adequately accounted for adding a propulsion system to control the separation of the spacecraft



ESA Proba-3
2 spacecraft, combined mass 550 kg
precision separation control thrusters
cost ~ £200 Meuro (~ F class)



SSTL Telesat LEO
Hydrazine propulsion for in-orbit raising and de-orbiting. 168 kg
(SSTL CARBSAR has electric propulsion)



NASA TRACERS spacecraft
Each < 200 kg. Spinners. Separation controlled.
Cost $170M

Summary and Next Steps

Magnetotail Dynamics Explorer

A focused, low cost mission designed to:

(i) Test models of magnetospheric substorm onset in the near magnetotail, addressing a very long-standing question

(ii) Find where and how magnetospheric substorm energy is dissipated in the ionosphere

(iii) Test models of magnetospheric reconfiguration under northern interplanetary magnetic field conditions

If selected, would launch ~ 2034

Inviting your support and participation

Please let us know if you are interested in joining the mission proposal team, or in more generally registering interest in the mission as a supporter.

Please contact me: a.fazakerley@ucl.ac.uk

Thank you for your interest.