Imperial College London

Development of a different range of **magnetometers** for space weather applications

P. Brown[1], C. Carr[1], J. P. Eastwood[1], H. Eshbaugh[1],T. Oddy[1], **C. Palla[1]**,
G. Berghofer[2], W. Magnes[2], B. Zabori[3], D. Nolbert[4], D. Milánkovich[5]

[1]Space and Atmospheric Physics, The Blackett Laboratory, Imperial College London, UK

[2]IWF Graz, Space Research Institute, Austria

[3]MTA-EK, Centre for Energy Research, Hungary

[4]Astronika, Poland

[5]C3S, Hungary

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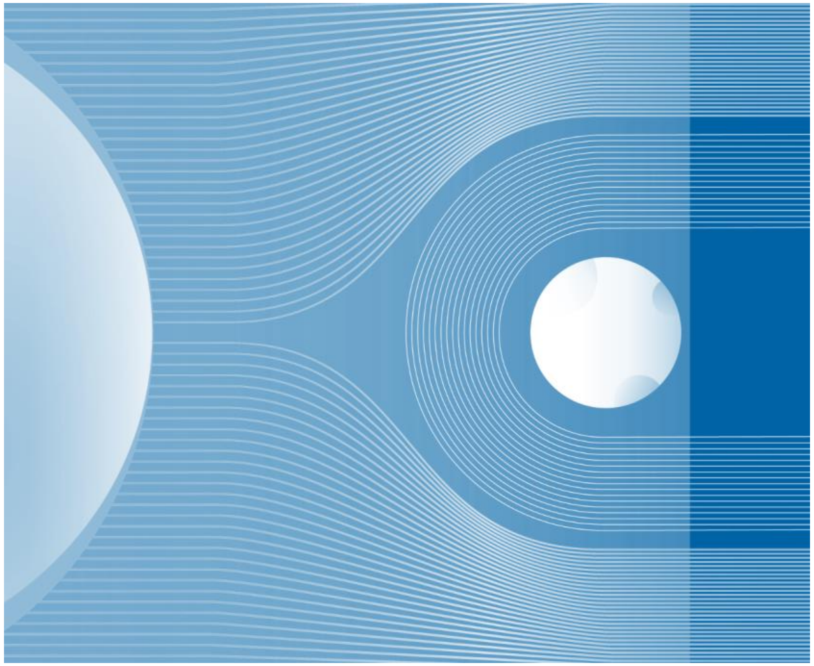
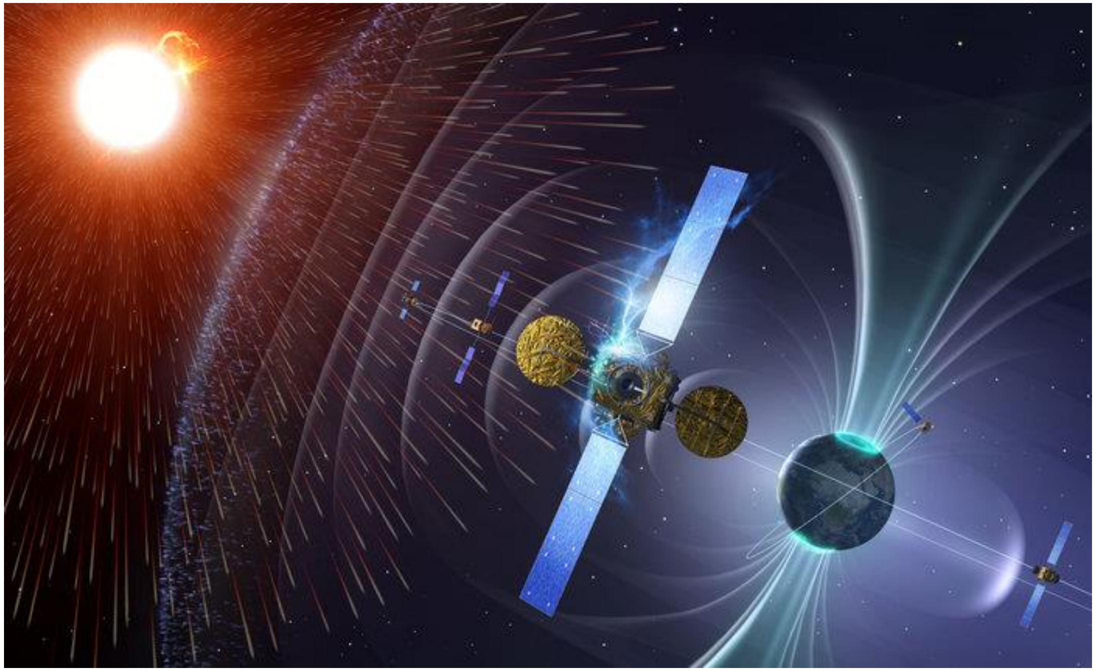


Background


Space Weather. Credit: ESA

Space Weather

Protecting infrastructure

Socio-economic impact

- Need for variety of in-situ measurements at many points simultaneously (analogous to weather stations on the ground)
- Space Safety and Security Programme → envisages heterogenous space-based system using dedicated platforms, hosted payloads, small satellites

Background

Magnetic field measurements

Why? Knowledge of strength and orientation is crucial to understanding and predicting space weather phenomena

How?

Fluxgate magnetometers

- Science missions heritage
- Stable, high precision measurements
- Reliability

Anisotropic magnetoresistive magnetometers

- When budgets are limited
- Fractioned observatories
- Solution for monitoring constellation missions

Where? on board

- Dedicated operational missions
- Science missions

- Small satellite platform
- CubeSats
- Hosted payload

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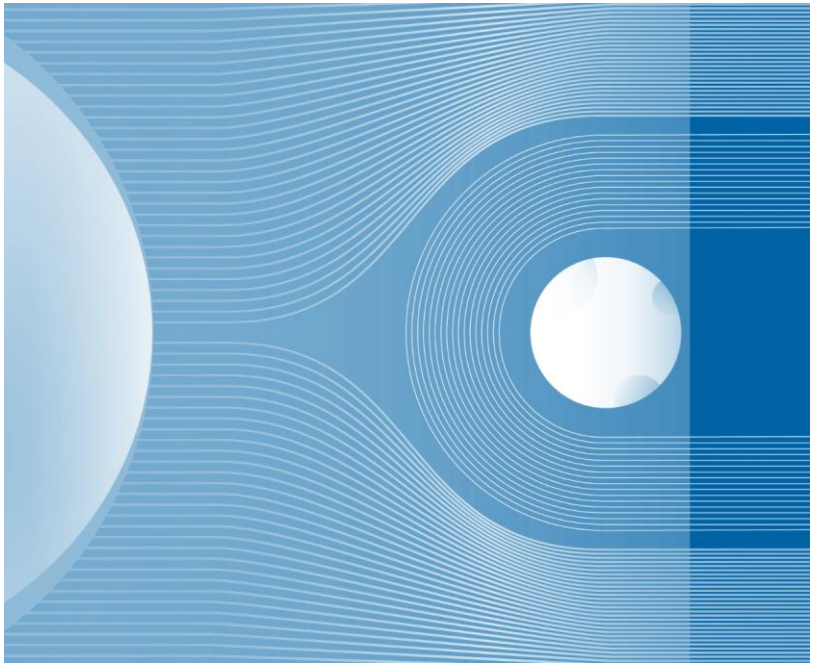
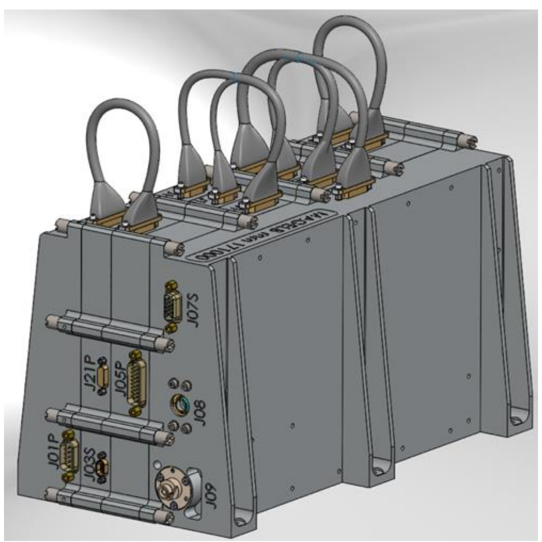


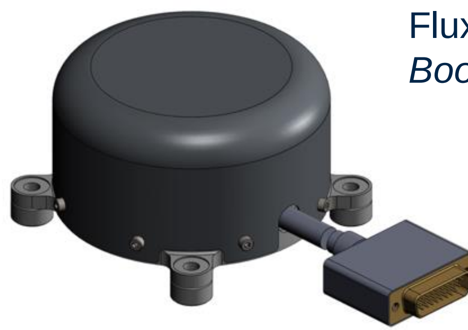
Fluxgate magnetometer
Overview

- Dual-sensor fluxgate magnetometer
  - ✓ *Critical measurement, no overlap*
- Heritage from JUICE, MMS and earlier
  - ✓ *CCSDS compliant SpaceWire interface*
- Meets or exceeds the measurement requirements
  - ✓ *Performance driven by spacecraft magnetic cleanliness*

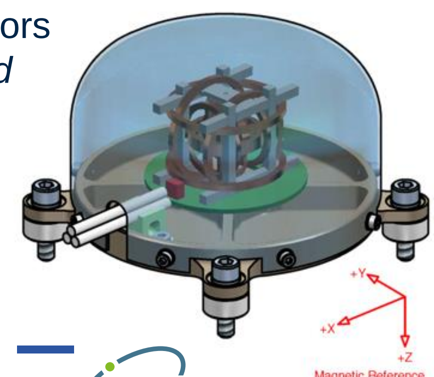
Main Features	
Mass (with margin)	5.8 kg
Power (with margin)	6.4 W
Sensor operating temperature	-70°C / +60°C
Operating range	± 256 nT
Digital resolution	8 pT
Noise	<10 pT/√Hz
Absolute accuracy	±0.5 nT



Electronics Box
Platform mounted



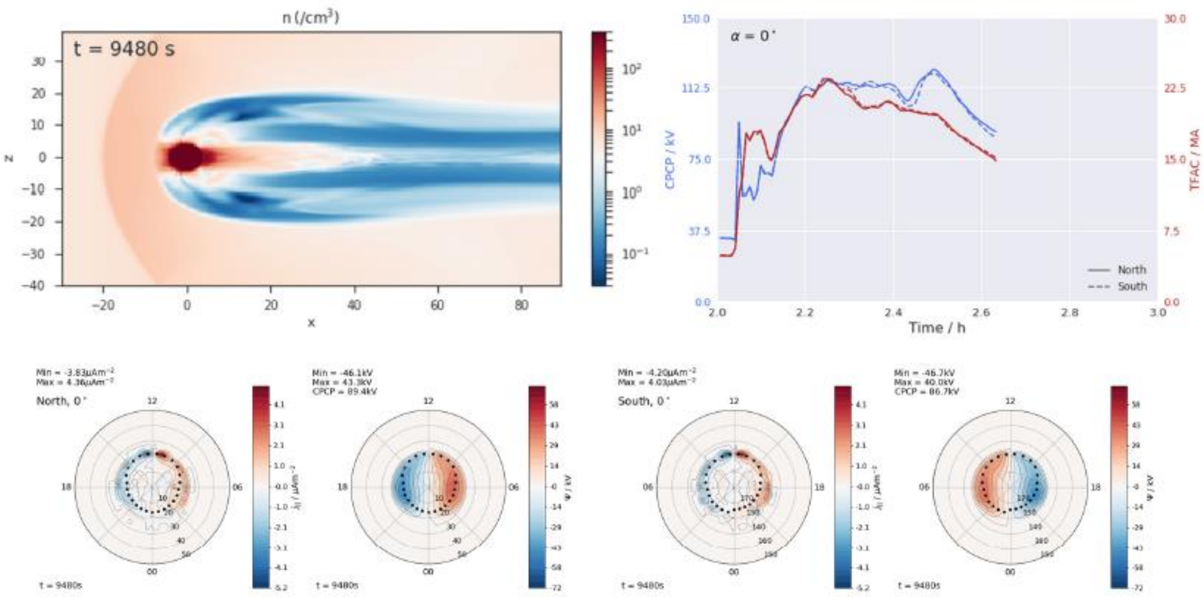
Fluxgate Sensors
Boom mounted



ÖAW IWF

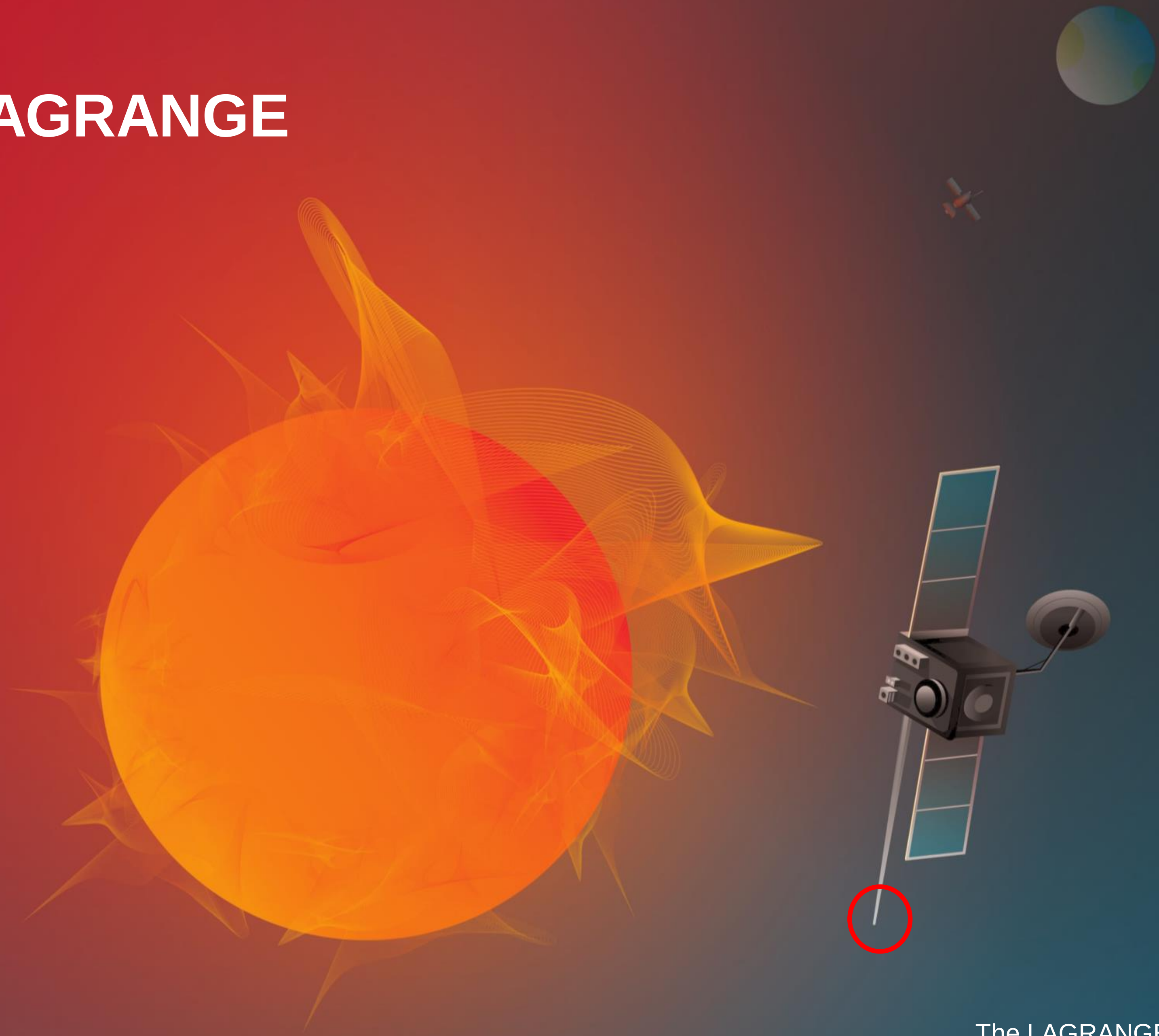
Fluxgate magnetometer
Knowing the magnetic field at L5 ?

- **Establishes the geoeffectiveness** of large-scale structures in solar wind (e.g. CME, stream interaction regions).
- **Allows mapping** of energetic particle propagation and connectivity of solar wind back to the corona.
- **Enables more accurate data assimilation**, crucial element of next generation solar wind and magnetosphere models.
- **Defines the geoeffectiveness of background solar wind** into which CMEs will propagate – to better understand CME sheath regions.



Forecasting SW effects using L5 data → Gorgon global magnetosphere-ionosphere modelling at Imperial College. Credit: J. Eggington, 2019 in prep.

LAGRANGE



The LAGRANGE mission, credit: ESA

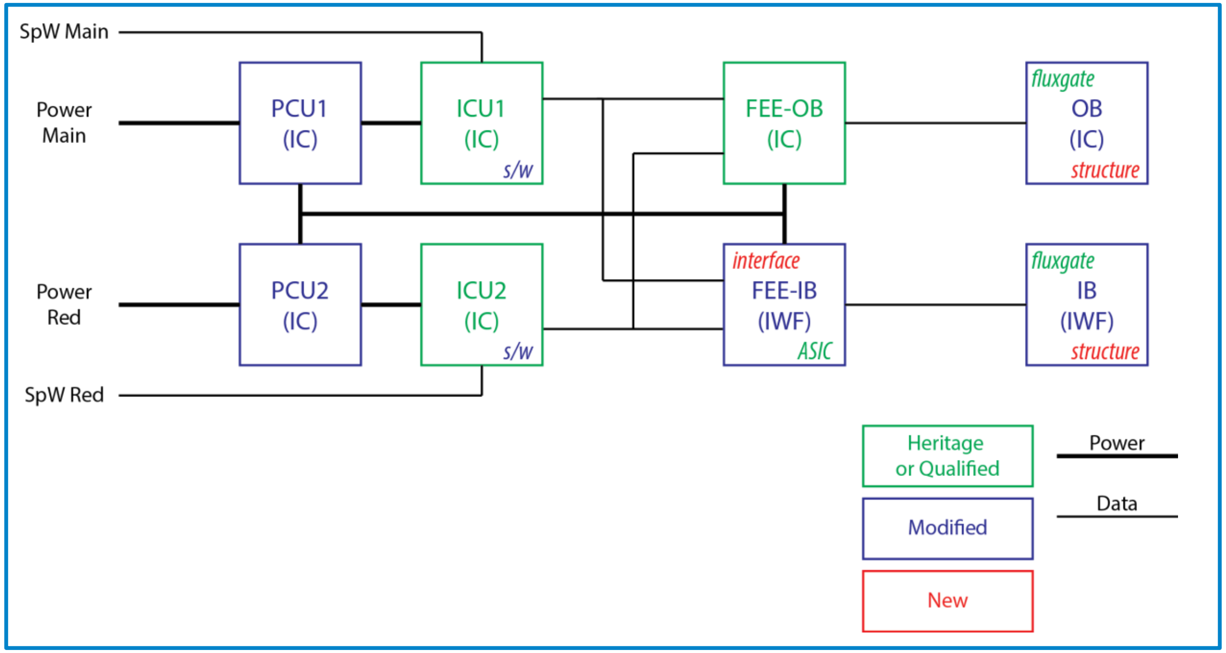
LAGRANGE

MAG Requirements

Observation
The MAG shall measure the 3 components of the interplanetary magnetic field (IMF) vector.
The MAG shall have a dynamic range for every component along negative and positive axis from 0.1 to at least 200 nT.
The MAG absolute accuracy shall be ±1 nT (±0.5 nT).
The MAG shall measure with a time resolution of 1 second.

Availability
The System shall make the measurements of MAG available with a latency < 13 min (9 min) [NB light travel time from L5 – Earth is 8 minutes].
During routine phase, the average availability of MAG due to planned outages shall be at least 99.96%

LAGRANGE
MAG Design development



Sensors:

- ✓ OB fluxgate: JUICE J-MAG with modification (Imperial College London)
- ✓ IB fluxgate: MMS with modification (ÖAW IWF)

PCU
JUICE J-MAG with modification

ICU
JUICE J-MAG

FEE
- OB: JUICE J-MAG
- IB: MMS with modification

LAGRANGE
MAG Design development

Space science	vs	Space weather

Strong heritage at instrument level for science missions:

- Relatively low risk and mature well understood designs can be tailored to Lagrange
- Very well-placed to deliver the required measurements

Different requirements:

- They are not *a priori* easier to meet
- Requires sufficiently clean magnetic environment
- Product Assurance requirements approach is different potentially requiring more analysis and paperwork compared to a science mission

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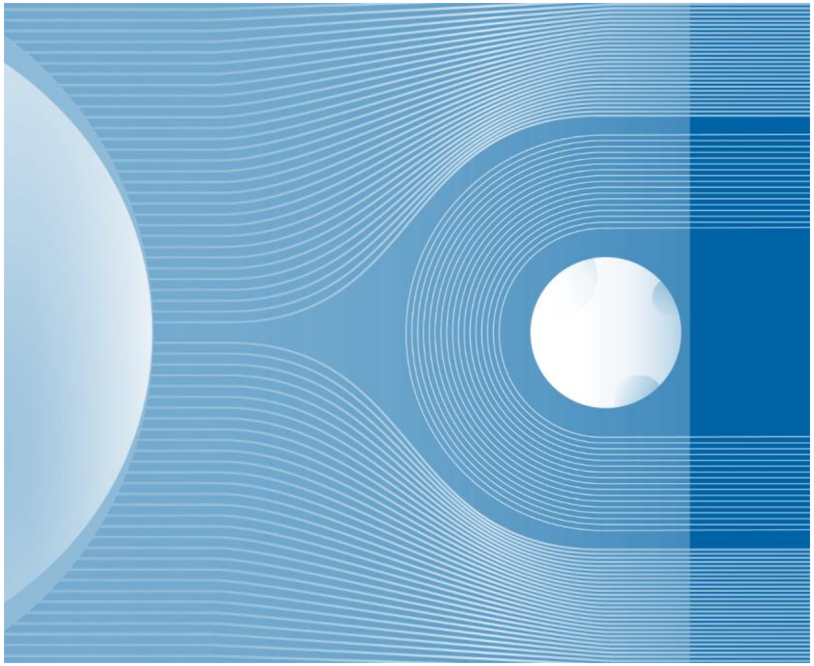


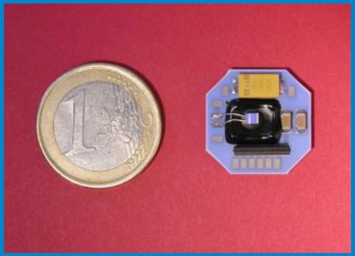
AMR magnetometer
Overview

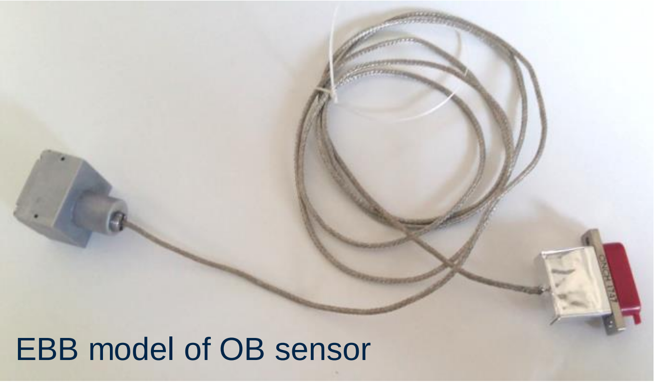
MAGnetometer from **I**mperial **C**ollege

- Anisotropic Magnetoresistive 3-axis DC sensors:
  - In-board (IB) sensor on PCB
  - Out-board (OB) sensor hybrid design
- Main sensor and control loop at **TRL 9**
- Technical development from heritage design

Main Features	
Volume	Electronics 90x90x1.8 mm^3 Sensor 21x21x11 mm^3
Mass	20 g (Sensor+harness) ~70 g (Electronics)
Power	<0.8 W (12V DC)
Range	± 60 000 nT
Sensitivity	2 nT (calibrated)
Cadence	1 vector/s 10 vectors/s

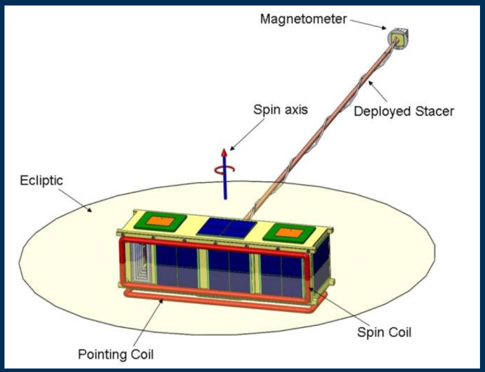
Main elements:
- Triad MR Honeywell sensors
- Gate driver for flipping pulses
- Non-magnetic capacitor
- Temperature sensor

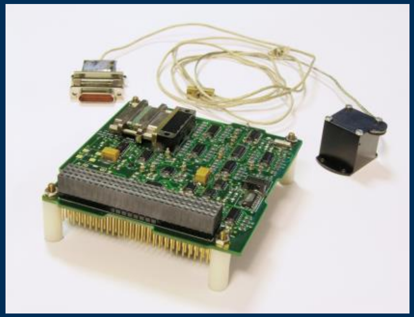



EBB model of OB sensor

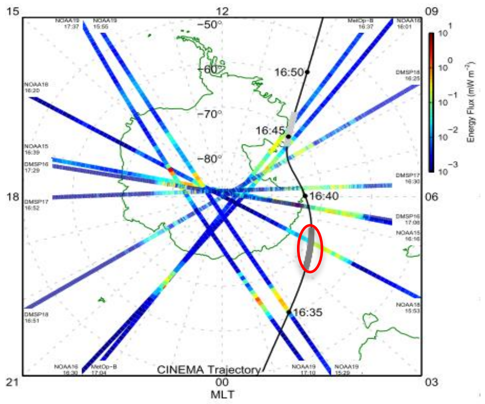
AMR magnetometer
Flight heritage

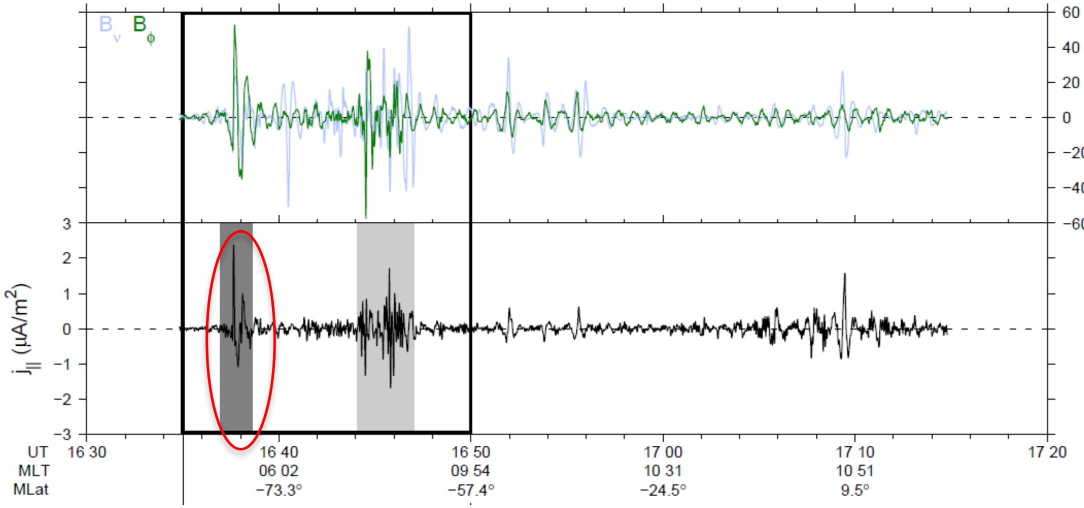
TRIO-CINEMA CubeSats
2012, 2013





- Detected transients of ~20-60 nT associated with FACs
- Consistent with POES and DMSP data



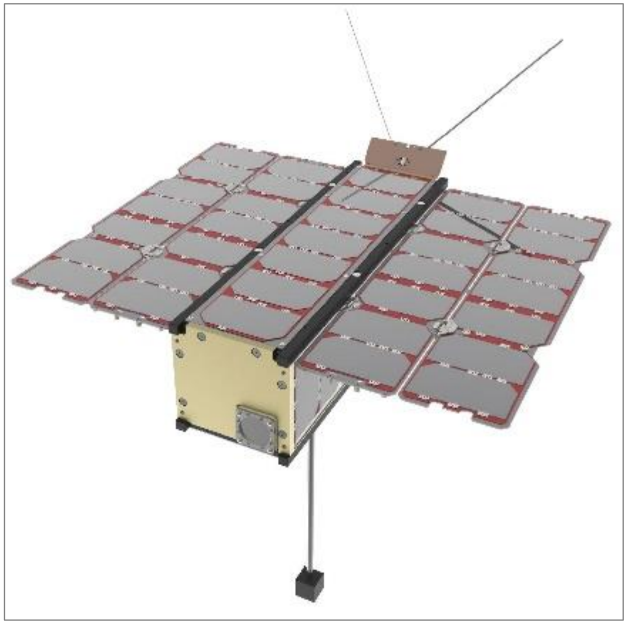


Archer et al., Ann. Geophys. 2015

RADCUBE

Mission overview

- 3U CubeSat
- esa funded, under IOD GSTP
- **MAGIC** magnetometer part of **RadMag**
- Launch planned in 2020
- LEO ~600 km
- Status: EQM building started



The RADCUBE CubeSat

Aim & Objectives

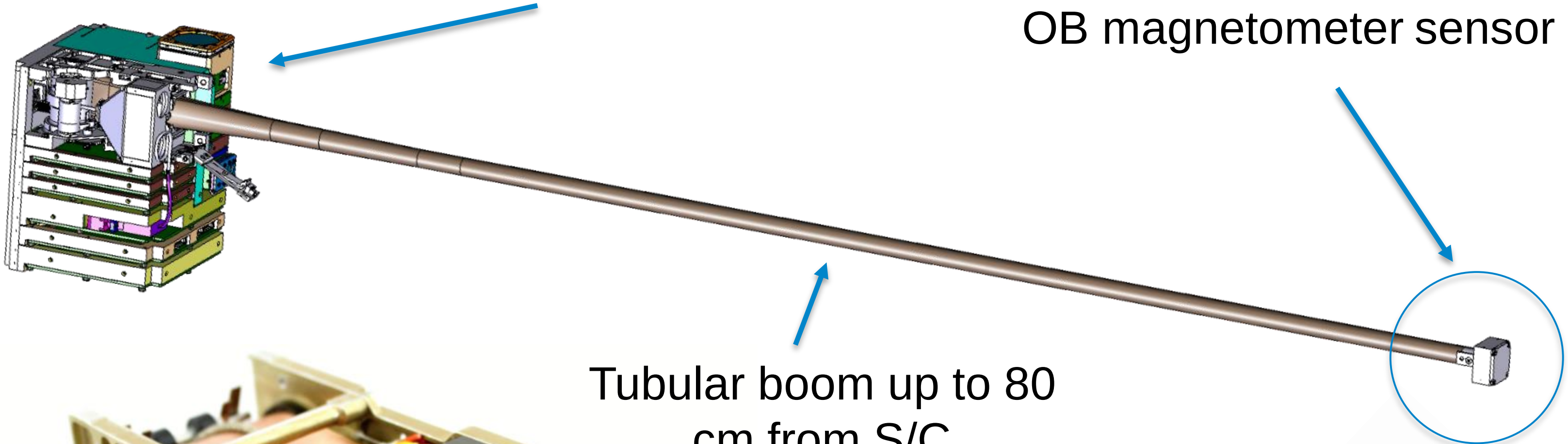
- Demonstrate miniaturised instrument technologies in LEO for **space weather** monitoring
- MAGIC goal: improve understanding of field aligned currents and ring current during geomagnetically disturbed conditions

RADCUBE

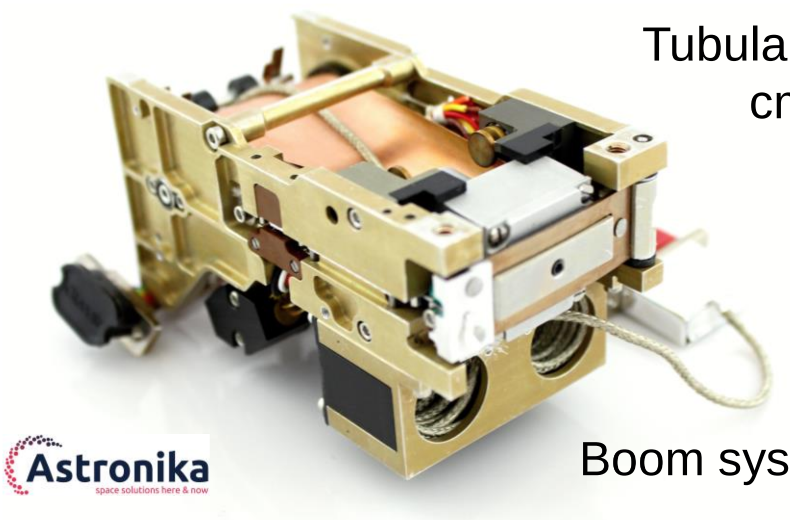
Boom system

RadMag payload

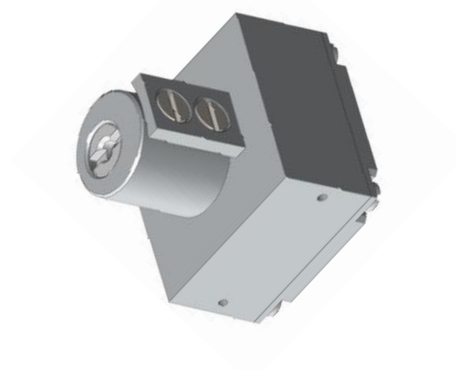
OB magnetometer sensor



Tubular boom up to 80 cm from S/C

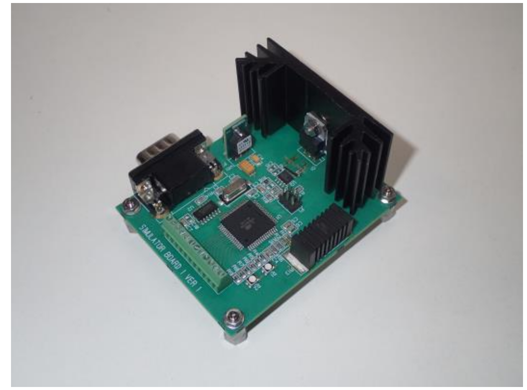


Boom system



MAGIC on RADCUBE
Electronic design

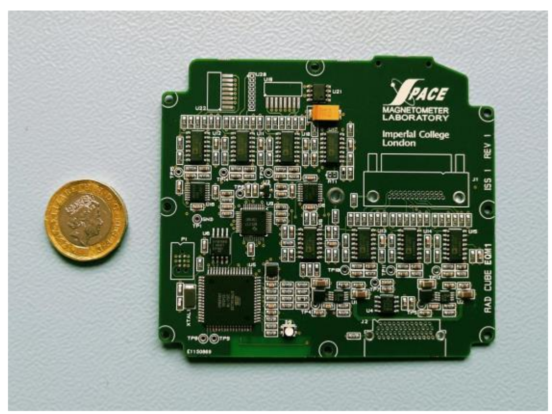
- ✓ **Inclusion of intelligence** via Atmel ATmega128 microprocessor:
  - enabling use of standard communications protocol to bus
  - flexibility in instrument management
- ✓ **Voltage conditioning** via the addition of buck converters



MAGIC Simulator

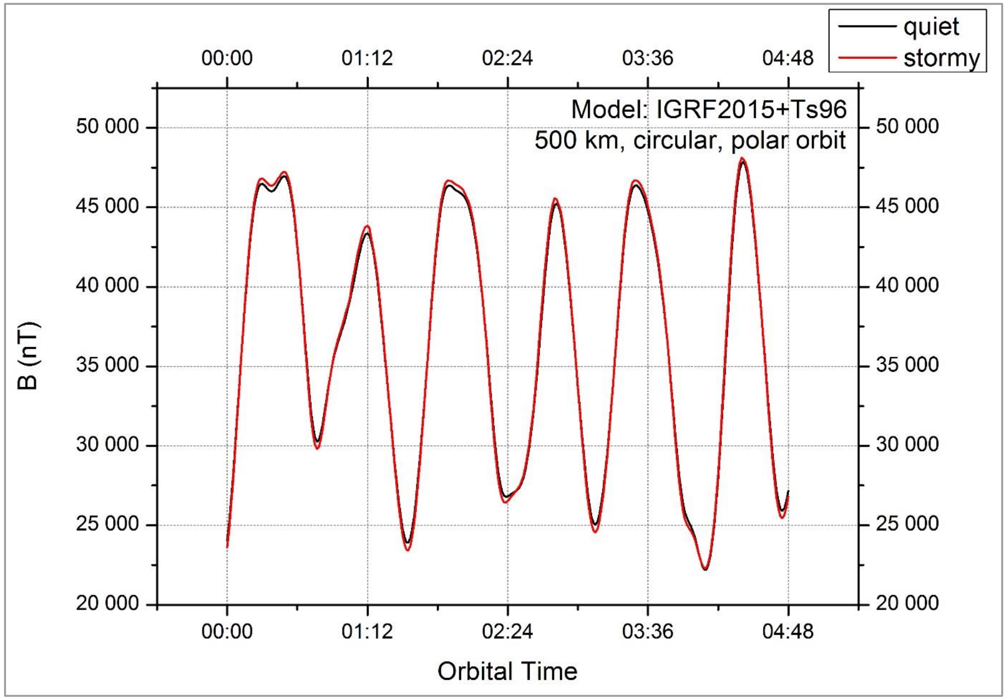
MAGIC Lab model with OB prototype

MAGIC EQM:
- Power electronics
- Microprocessor & digital circuitry
- ADC
- IB magnetometer & FEE (3 axes)
- OB FEE (3 axes)



MAGIC EQM

MAGIC on RADCUBE
Expected measurements



Magnetic field strength (1-min resolution data) for a few orbital periods for the LEO trajectory in the case of quiet and stormy conditions.

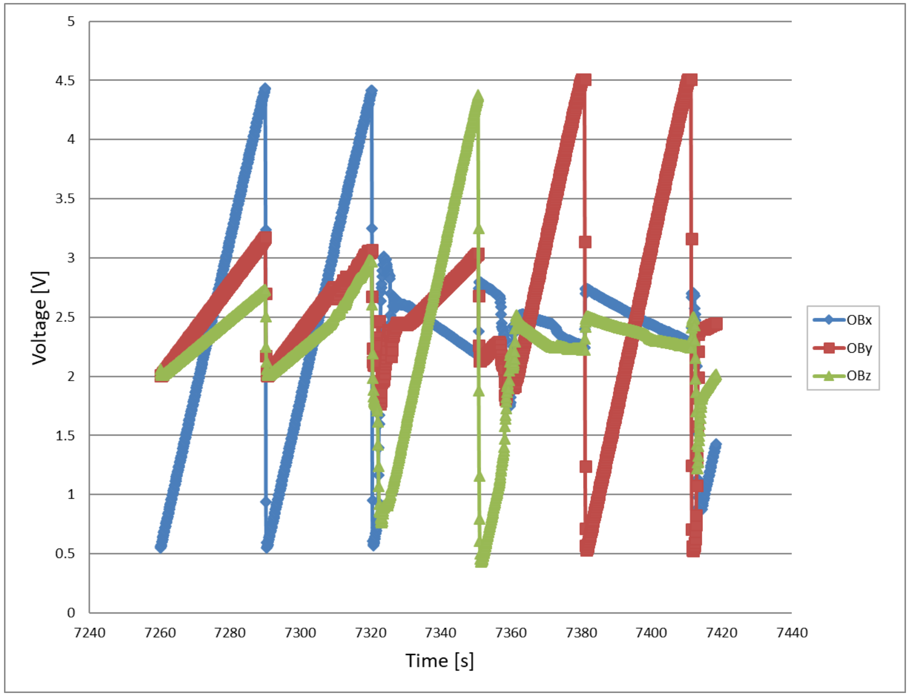
Study of magnetic field expected properties

Effects of a stormy geomagnetic environment:
0-2.5% changes in average magnetic field strength over spacecraft trajectory,
i.e.~**0-1200 nT** dynamic changes

Two different **levels** of field observations applicable:
1. Overall mapping
2. Field specific region localization, models validation, attitude

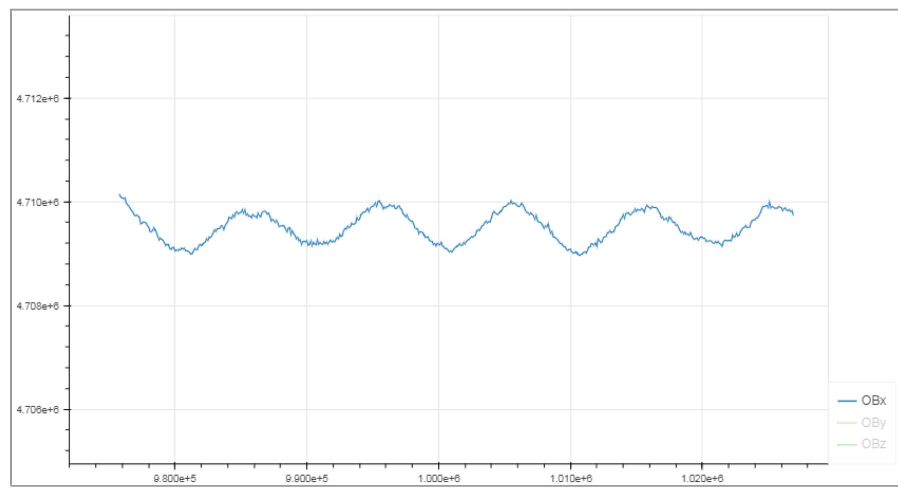
MAGIC on RADCUBE

Test measurements



OB prototype measurements ranging ±50000 nT

2.2 nT peak-to-peak 0.1 Hz field variation detected by OB prototype inside Mu-metal shield with solenoid applied field



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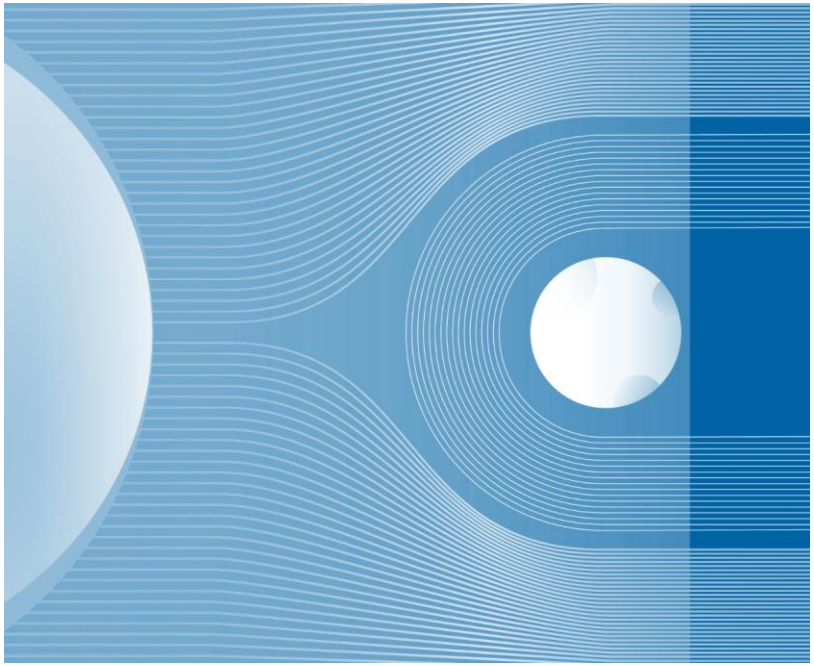

Conclusions

- In situ magnetic field measurements are mandatory on Lagrange for **operational** space weather purposes
- Lagrange magnetometer has extremely **high heritage** and well placed to deliver operational magnetic field measurements
- Future implementation as “**plug and play**” sensor on CubeSats, to be used either in a constellation configuration or as single hosted payload
- Payload for **space weather monitoring** in the context of ESA D3S monitoring concept.

+ Cooperation!

Dr. Chiara Palla
c.palla@imperial.ac.uk

SPACE MAGNETOMETER LABORATORY

UK SPACE AGENCY

Thanks for your attention!