Programme for Research-Development-Innovation on
Space Technology and Advanced Research – STAR

Cluster Flux Gate Magnetometer Daily Calibration TUNED

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D. Constantinescu

dragos@spacescience.ro

Institute for Space Sciences - INFLPR

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Project Information: Short Description

The task of the project is to perform the **daily in-flight calibration** for the Flux Gate Magnetometer (FGM) instruments onboard the four ESA Cluster satellites. The project takes advantage of the calibrated data to **investigate non-stationary processes** at the Earth's bowshock.

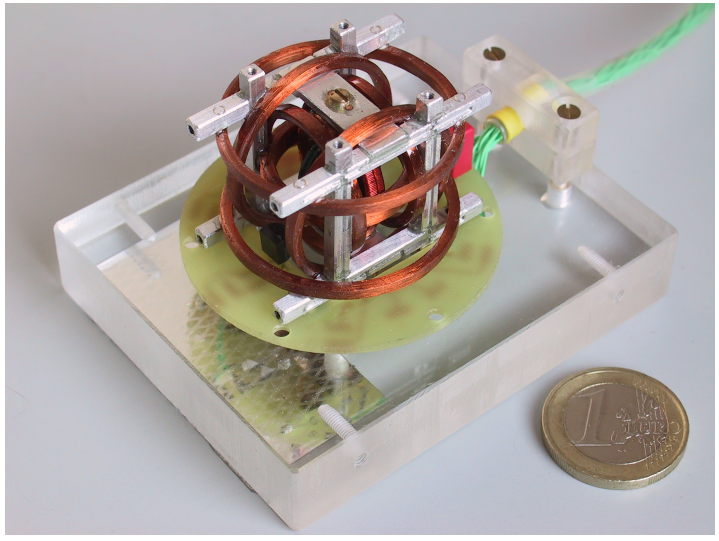
Cluster Spacecraft

- first ESA multi-spacecraft mission (launched in August 2000)
- mission extended to Dec 31 2018
- 11 field and particle instruments on each spacecraft
- multi-point measurements require careful calibration

FGM instruments $\rightarrow$

Project Information: Short Description - Instruments

- (inboard + outboard)×4
- very stable during the mission
- daily calibration is essential
- uses ranges (field magnitude)

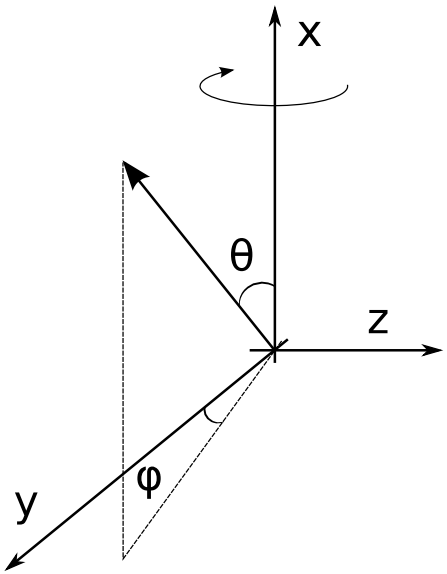


range	B_{max} (nT)	resolution (nT)	
2	64	1/128	
3	256	1/32	
4	1024	1/8	
5	4096	1/2	since 2006
6	16384	2	since 2008
7	65536	8	since 2009

Project Information: Short Description - Calibration

$$\begin{bmatrix} B'_x \\ B'_y \\ B'_z \end{bmatrix} = \mathcal{M} \cdot \begin{bmatrix} B_x \\ B_y \\ B_z \end{bmatrix} + \begin{bmatrix} O_x \\ O_y \\ O_z \end{bmatrix}$$

$$\mathcal{M} = \begin{bmatrix} G_x \sin\theta_x \cos\varphi_x & G_x \sin\theta_x \sin\varphi_x & G_x \cos\theta_x \\ G_y \sin\theta_y \cos\varphi_y & G_y \sin\theta_y \sin\varphi_y & G_y \cos\theta_y \\ G_z \sin\theta_z \cos\varphi_z & G_z \sin\theta_z \sin\varphi_z & G_z \cos\theta_z \end{bmatrix}$$



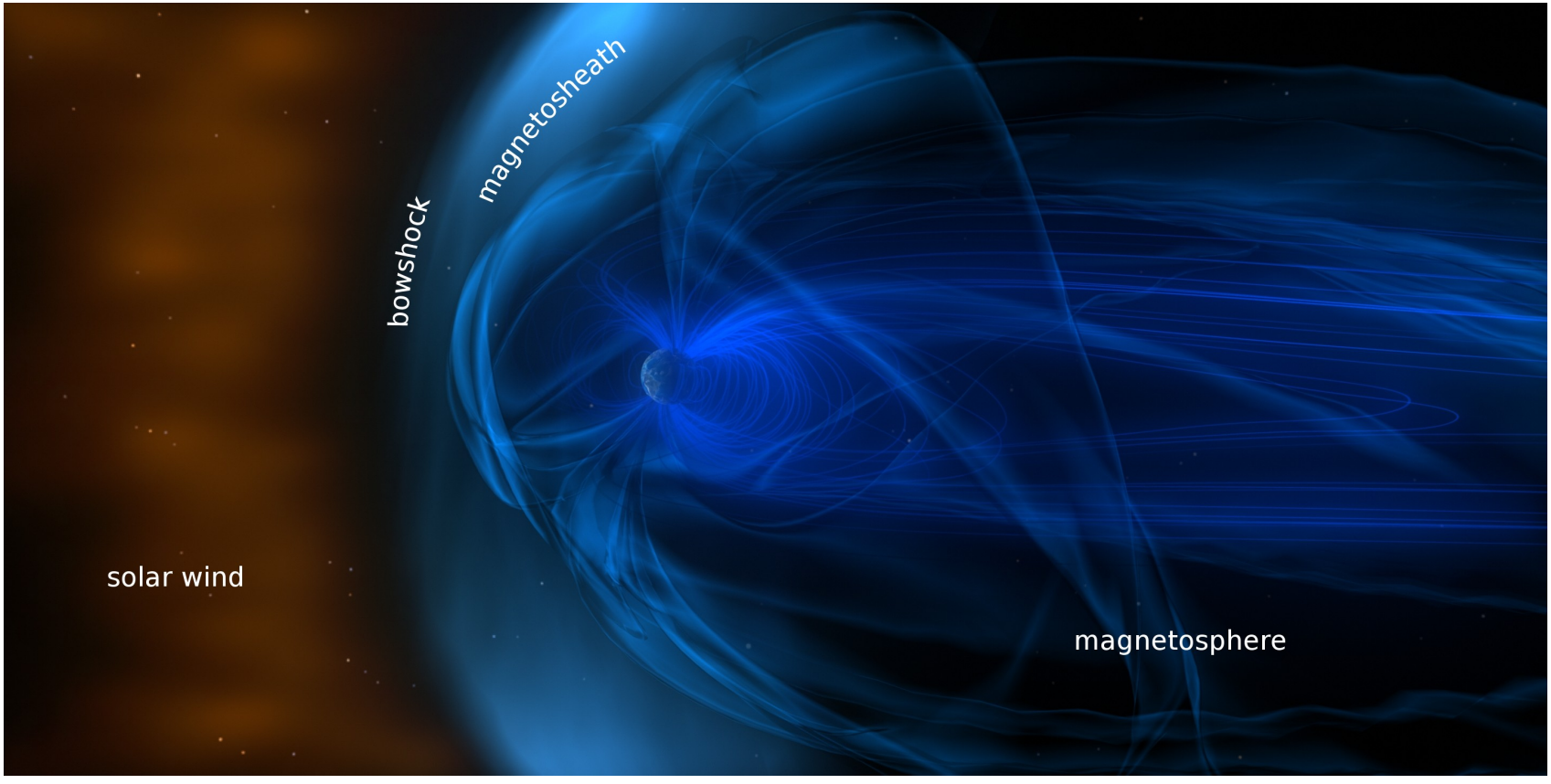
12 independent parameters for **each** range

- 3 elevation angles θ_i
- 3 azimuth angles φ_i
- 3 gains G_i
- 3 offsets O_i

in total: $4 \times 2 \times 6 \times 12 = 576$ **per day**

Project Information: Short Description - Bowshock

- fast supermagnetosonic shock
- the cross shock potential accelerates and scatters particles
- essential to the solar wind - magnetosphere interaction



Project Information: Objectives

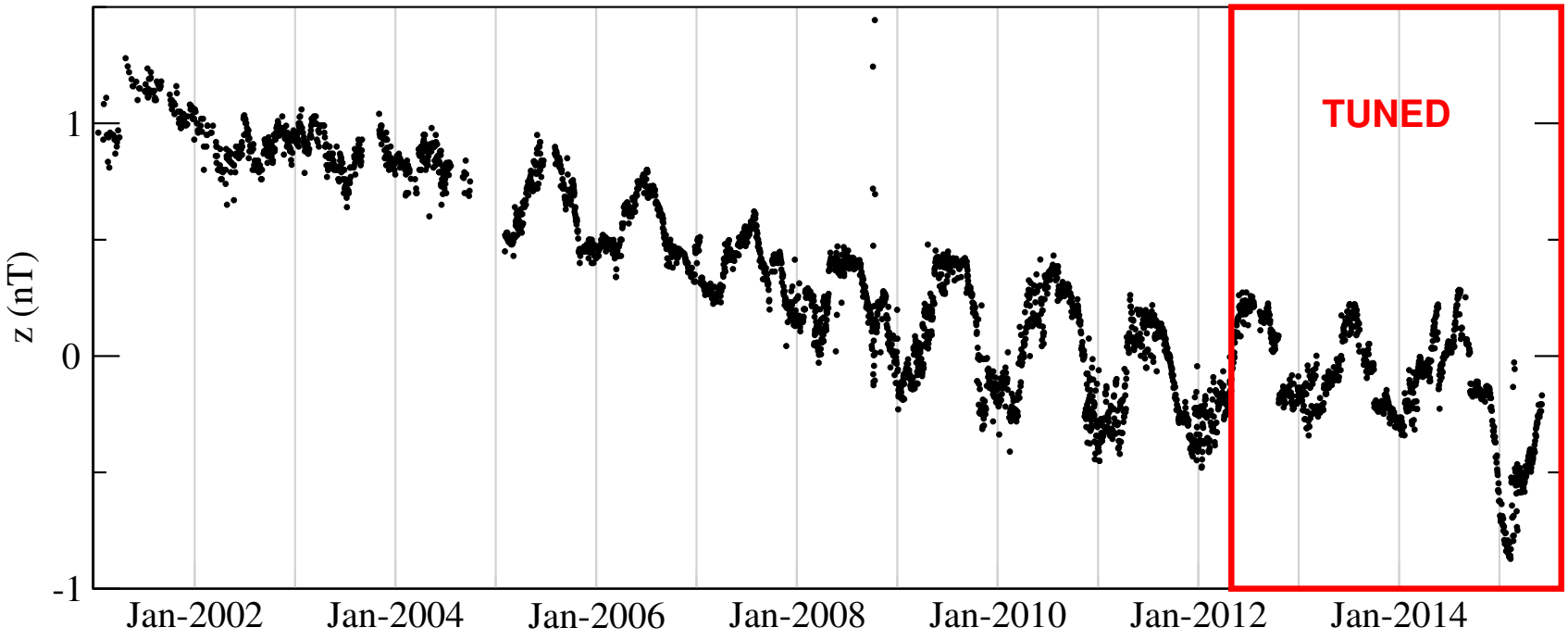
- In-flight calibration for the Cluster FGM
  - Develop a software package for automatic calibration
  - Perform the FGM daily calibration
  - Archive the calibration parameters
- Study of the non-stationary processes at the bowshock
  - Theoretical investigation of high Mach number shocks
  - Numerical modelling of the electron dynamics
  - Comparison results with Cluster measurements

Implementation Status: All objectives fulfilled

- Calibration package:
  - design: Finalised (2012)
  - development: Finalised (2013)
  - documentation: Finalised (2014)
  - start TRL: 1; achieved TRL: 9
- Daily calibration: Done (until August 2015)
- Bowshock investigation:
  - software tools preparation: Finalised (2013)
  - theoretical and numerical model of the CSP: Obtained (2014)
  - comparison with Cluster data: Done (2015)

Results: Daily calibration

Example: spacecraft z-offset for Cluster 1



- variation of less than 2 nT over the 15 years mission lifetime
- seasonal variations around 0.5 nT

Results: Bowshock investigation

- Theoretical investigation
  - new and better suited reference system for CSP evaluation
  - revised heating and acceleration mechanisms
- Numerical modelling
  - `em1D` Particle in Cell code optimised for 128 cores HPC Dell
  - model ran for various upstream conditions
- Model validation
  - model CSP compared with measured potential
  - electron heating and acceleration mechanisms validated

Contribution to STAR goals

- Increases the visibility of the participants in the scientific community
- Builds the expertise for future participation in hardware projects
- Strengthens the connection of the ISS with prestigious institutions
- Enhances the Romanian contribution to ESA
- Contributes to the identification of a research niche
- Helps the development of the national space research capacity
- Promotes the development of a highly qualified research team
- Enables high quality scientific results at international level

Contribution to ESA programmes

- Directly contributes to the ESA mission Cluster

Dissemination

- Cluster FGM daily calibration parameters database open to the Cluster principal investigators on the FTP server `ftp.geophys.nat.tu-bs.de/clusterg_data`
- TUNED helped the organisation of three FGM calibration workshops with international participation in Romania:
  - 17 – 23 March 2013
  - 14 – 21 May 2014
  - 14 – 18 September 2015
- Results of the TUNED project were presented at the Magnetometer Workshop, March 2014, Czech Republic
- Results of the bowshock investigation were published [Comișel et al, AnnGeo 2015]

Conclusions

- The TUNED project fulfilled all the proposed objectives
- TUNED brings a valuable contribution to the first ESA multi-spacecraft mission, Cluster
  - Calibration software package realised
  - Calibration done up to August 2015
- In depth bowshock investigation:
  - Theoretical study
  - Numerical model
  - Model validation through Cluster data comparison