INSTITUTE OF SOLAR-TERRESTRIAL PHYSICS
OF SIBERIAN BRANCH OF THE RUSSIAN ACADEMY OF SCIENCES

XVIII Baikal Young Scientists' International School on Fundamental Physics "Physical processes in space and near-Earth space"

Implementation of the frozen-in condition in magnetospheric disturbances: analysis of THEMIS-A data

Shubin D. A., Rubtsov A. V., Mager P. N., Klimushkin D. Yu.
Institute of Solar-Terrestrial Physics SB RAS

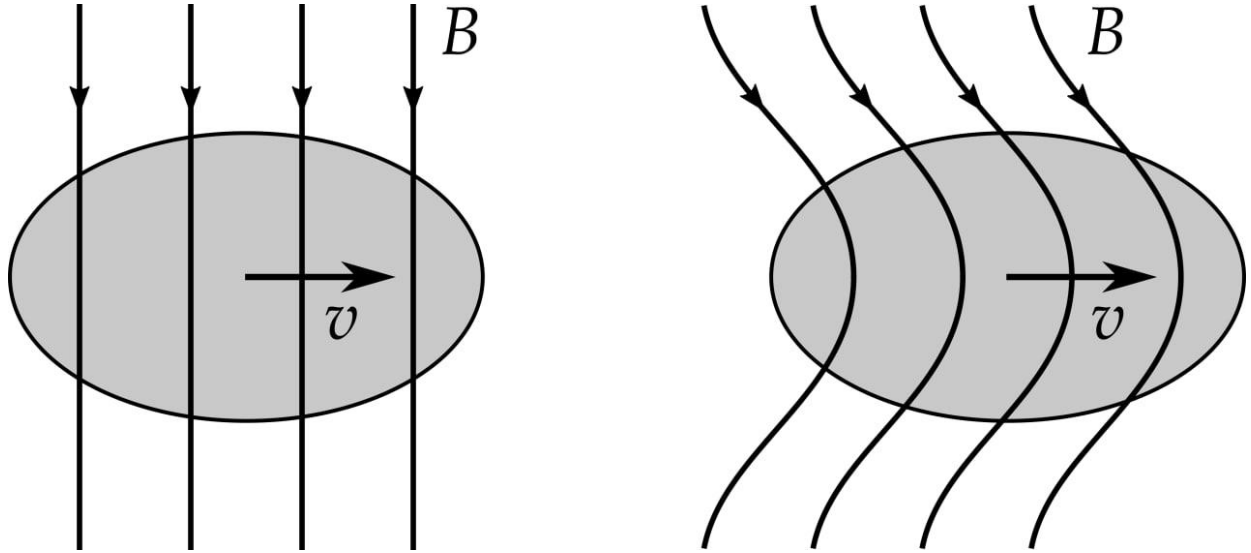
The study was supported by the Russian Science Foundation under Grant 22-77-10032.

Plasma FIC

Equation of the **frozen-in condition** (FIC) magnetic force lines into plasma:

$$\vec{E} = -\frac{1}{c}\left[\vec{v} \times \vec{B}\right],$$

where $\vec{E}$ – electric field, $\vec{v}$ – plasma bulk flow, $\vec{B}$ – magnetic field.



Changing the trajectory of magnetic field lines with plasma motion

Factors affecting the feasibility of the condition:

- Plasma inhomogeneity
- Plasma diffusion
- Turbulence
- The presence of electric currents

FIC usage

FIC plays a key role in equations of one-fluid MHD

Electrodynamics

$$\nabla \times \vec{B} = \frac{4\pi}{c}\vec{j}$$

$$\nabla \times \vec{E} = -\frac{1}{c}\frac{\partial \vec{B}}{\partial t}$$

Euler equation

$$\rho \frac{d\vec{v}}{dt} = -\nabla P + \frac{1}{c}\vec{j} \times \vec{B}$$

Hydrodynamics

$$\frac{\partial \rho}{\partial t} + \nabla \cdot (\rho \vec{v}) = 0$$

$$\frac{d}{dt} P \rho^{-\gamma} = 0$$

$$\boldsymbol{\vec{E} = -\frac{1}{c}\left[\vec{v} \times \vec{B}\right]}$$

It combines electro- and hydrodynamics

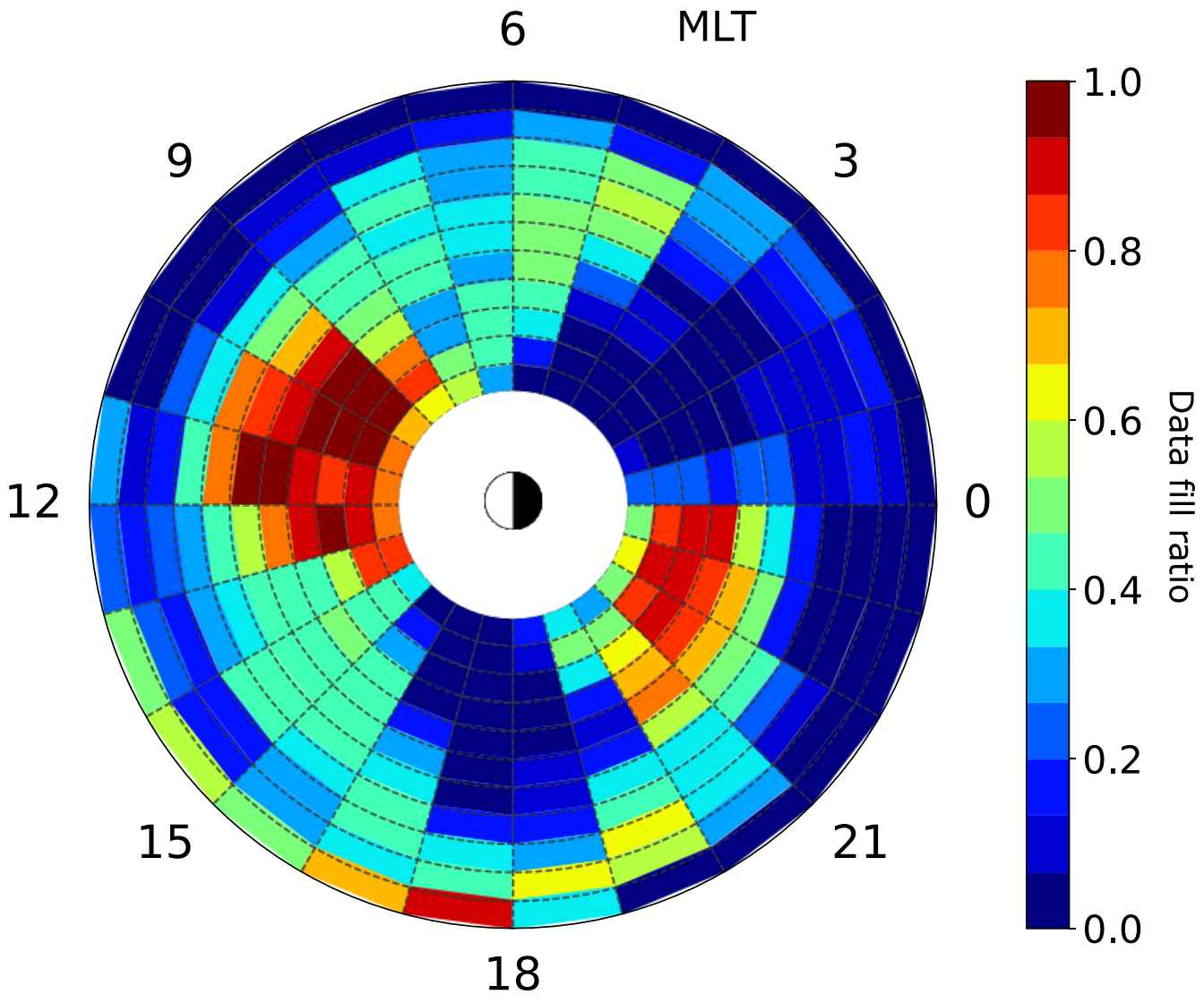
FIC in one-fluid MHD

- **The magnetosphere of the Earth**
- **The Solar Corona**
- **Magnetospheres of pulsars**
- **Solar and stellar wind**
- **The interstellar medium**
- **And other …**

To check the implementation of FIC, it is necessary to analyze data on the velocity of particles (protons), the magnetic field and the electric field, using satellite data.

What mission we may choose?

Data



Mission: THEMIS (probe A)

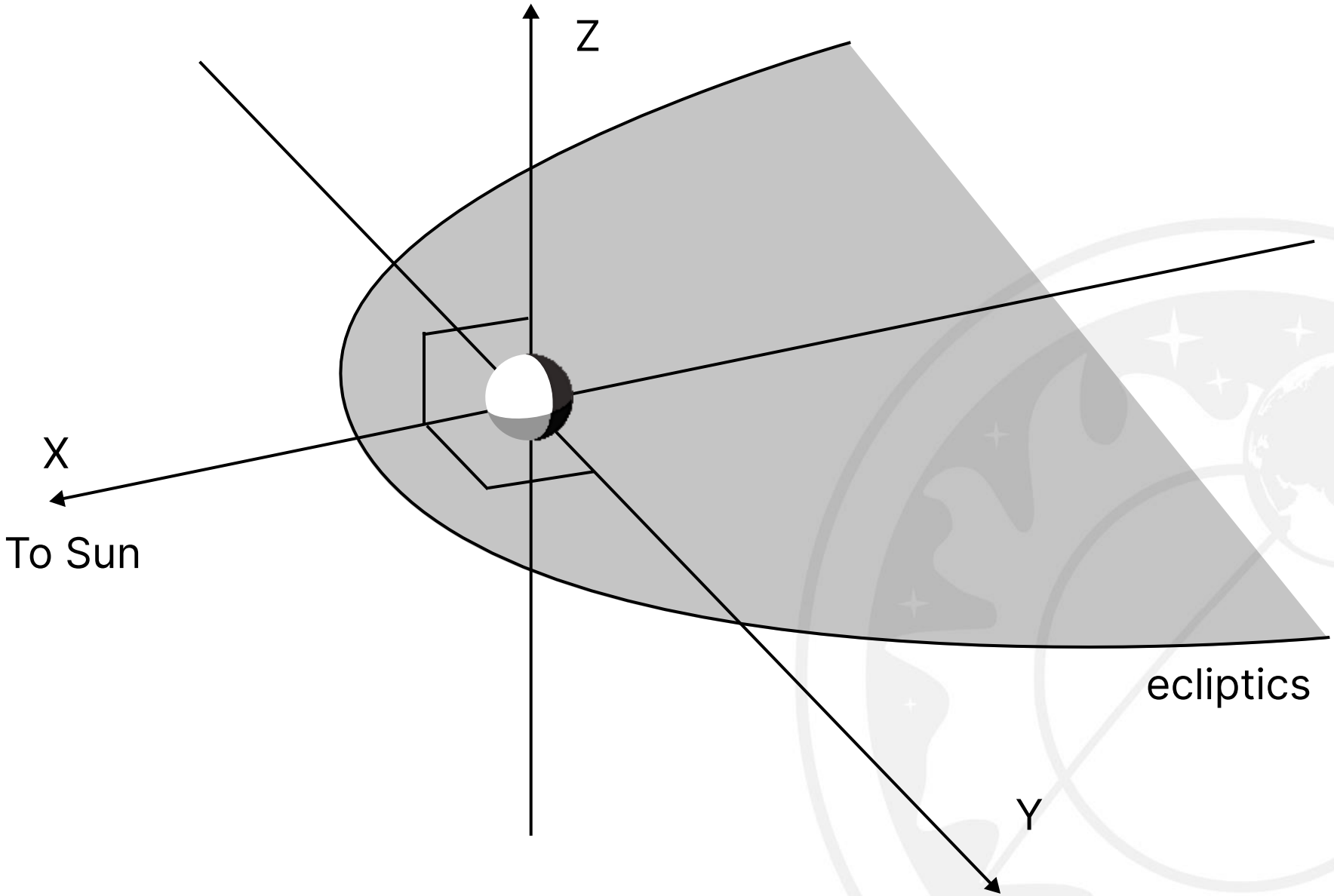
Observation period: Jun 2017 – Feb 2018

The distribution of data fill ratio on the L-MLT plane with cell-size $1\ R_E \times 1\ h$ and L in range 4-15 R_E for the observation period

The data was obtained using the service **CDAWeb**[1]

[1] Coordinated Data Analysis Web (CDAWeb) https://cdaweb.gsfc.nasa.gov/

GSE system

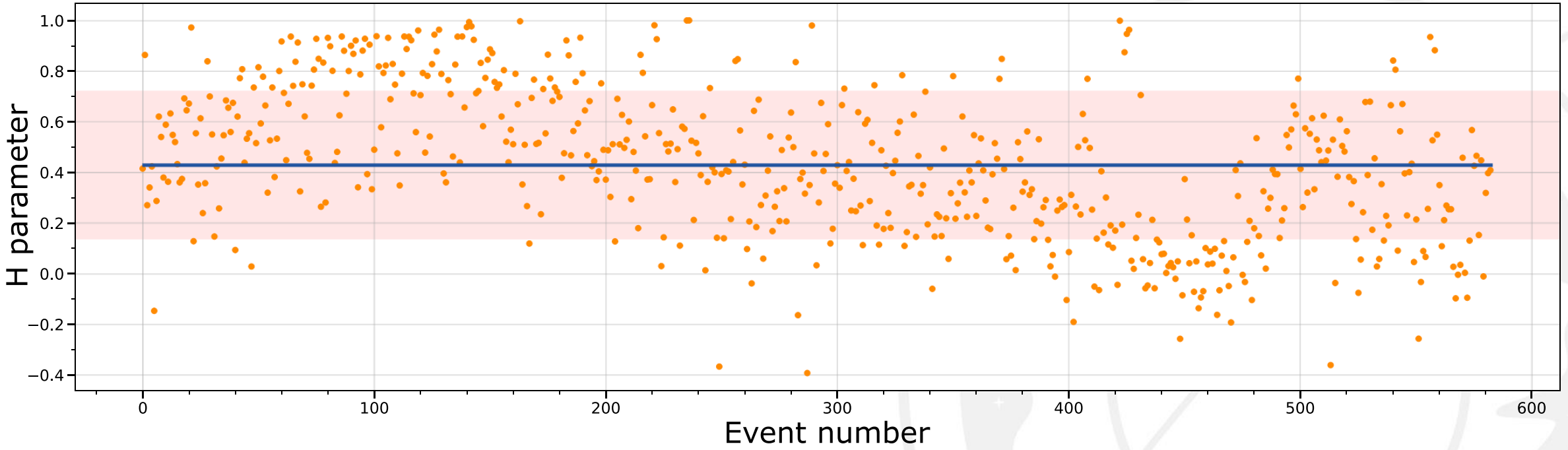


H-parameter

$$\mathbf{H} = \frac{\boldsymbol{E_n^2} - \boldsymbol{(v \times B)_n^2}}{\boldsymbol{E_n^2} + \boldsymbol{(v \times B)_n^2}}, \mathbf{n} \in (\boldsymbol{x}, \boldsymbol{y}, \boldsymbol{z})$$

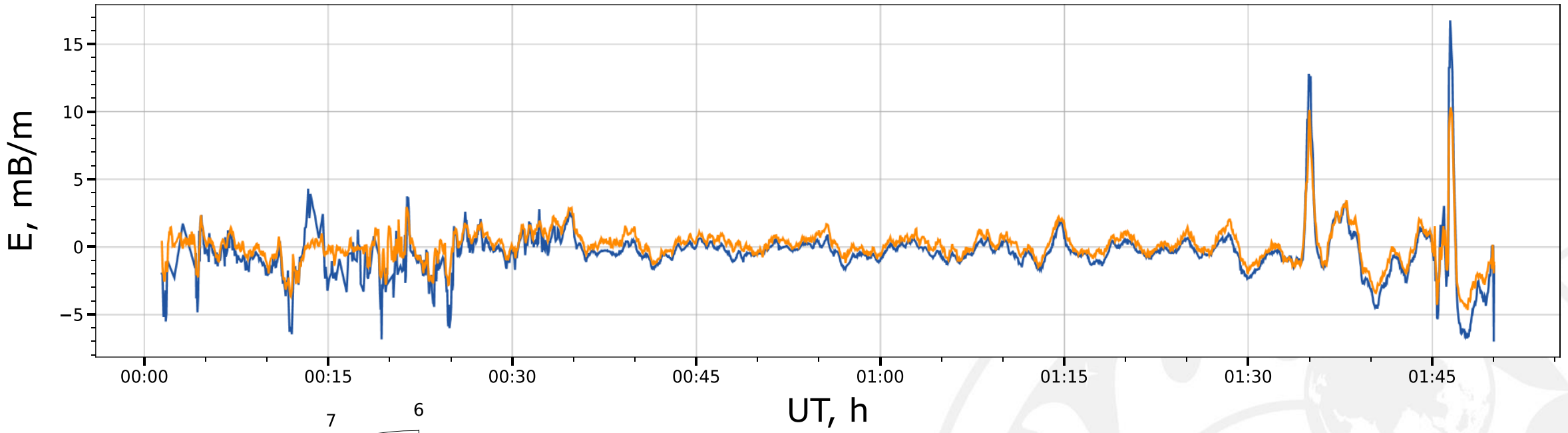
The range of valid values:

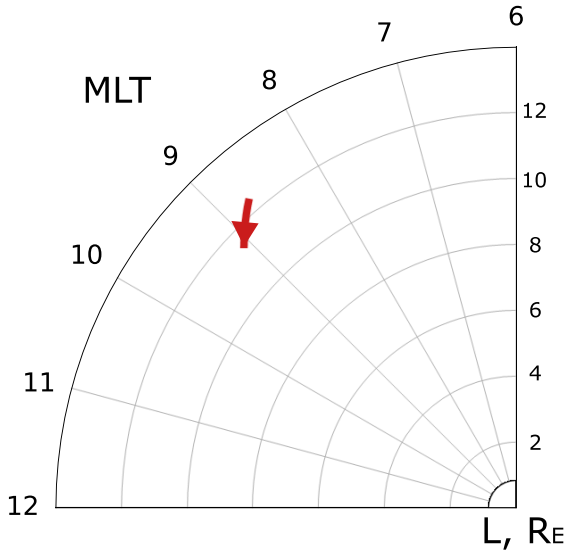
- $\mathrm{H} \sim 1: \rightarrow \mathrm{E} \gg \mathrm{v} \times \mathrm{B}$
- $\mathrm{H} \sim 0: \rightarrow \mathrm{E} \sim \mathrm{v} \times \mathrm{B}$
- $\mathrm{H} \sim -1: \rightarrow \mathrm{E} \ll \mathrm{v} \times \mathrm{B}$



The variation in parameter **H** over the study periods for *y-components*. The **blue** line represents $\boldsymbol{H_{avg}}$ **= 0.43**, and the area highlighted in **red** represents $\boldsymbol{H_{avg} \pm \sigma}$**.**

Examples

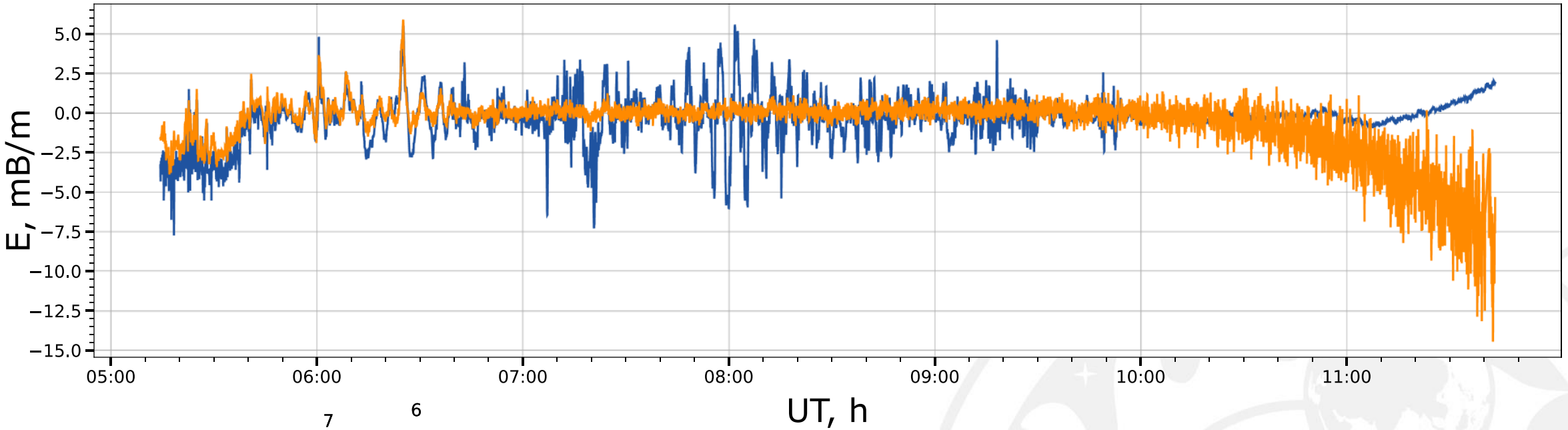


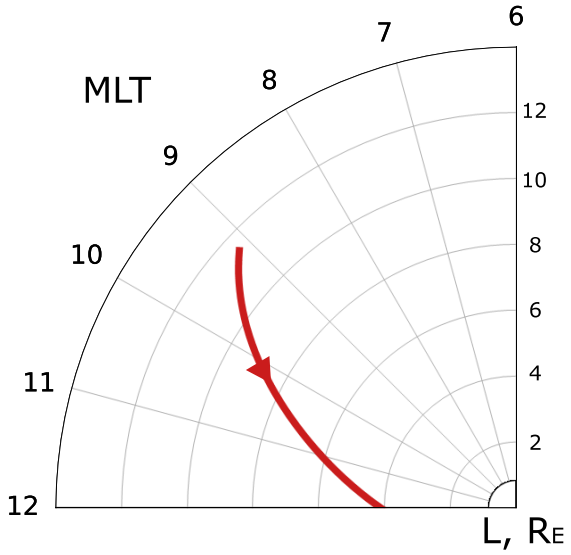


For the period from 00:01 to 01:50 28 October 2017, the dynamics of **the electric field (E_y)** and **the expression** $(-v \times B)_y$ are shown on the panel above.
The panel on the left shows the position and direction of the satellite during this period.

H-parameter for this period = $\mathbf{0.12}$

Examples

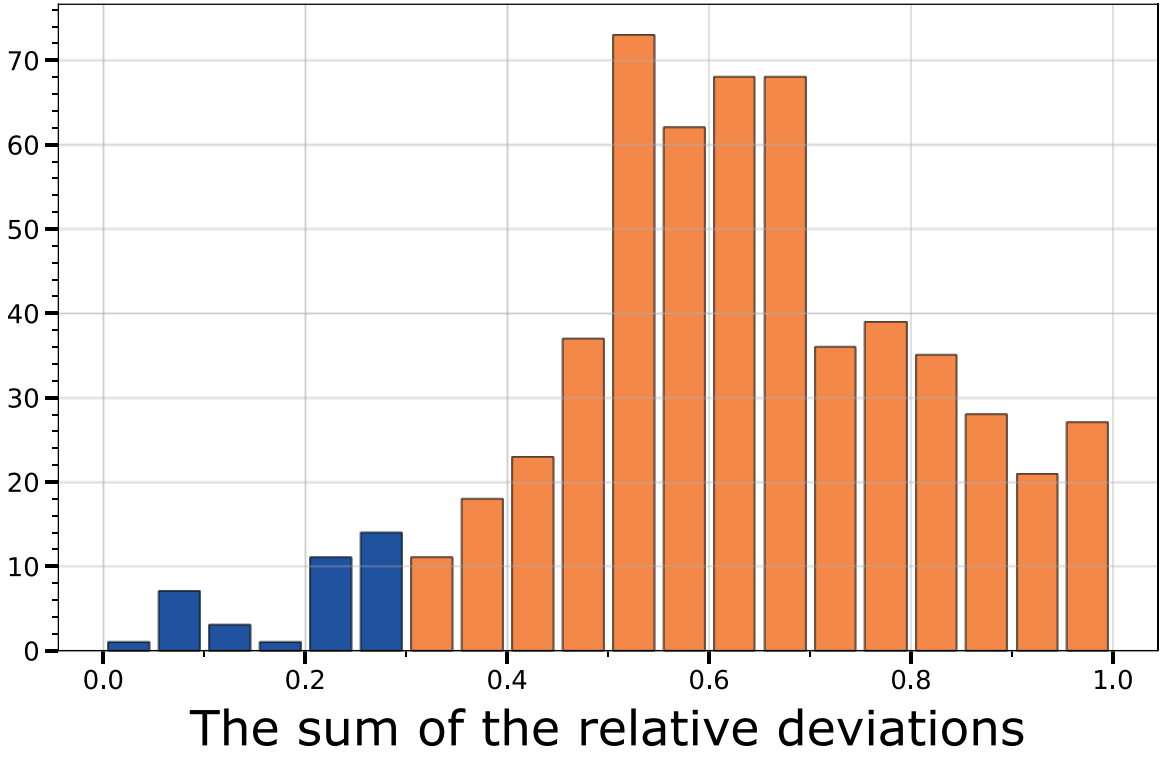


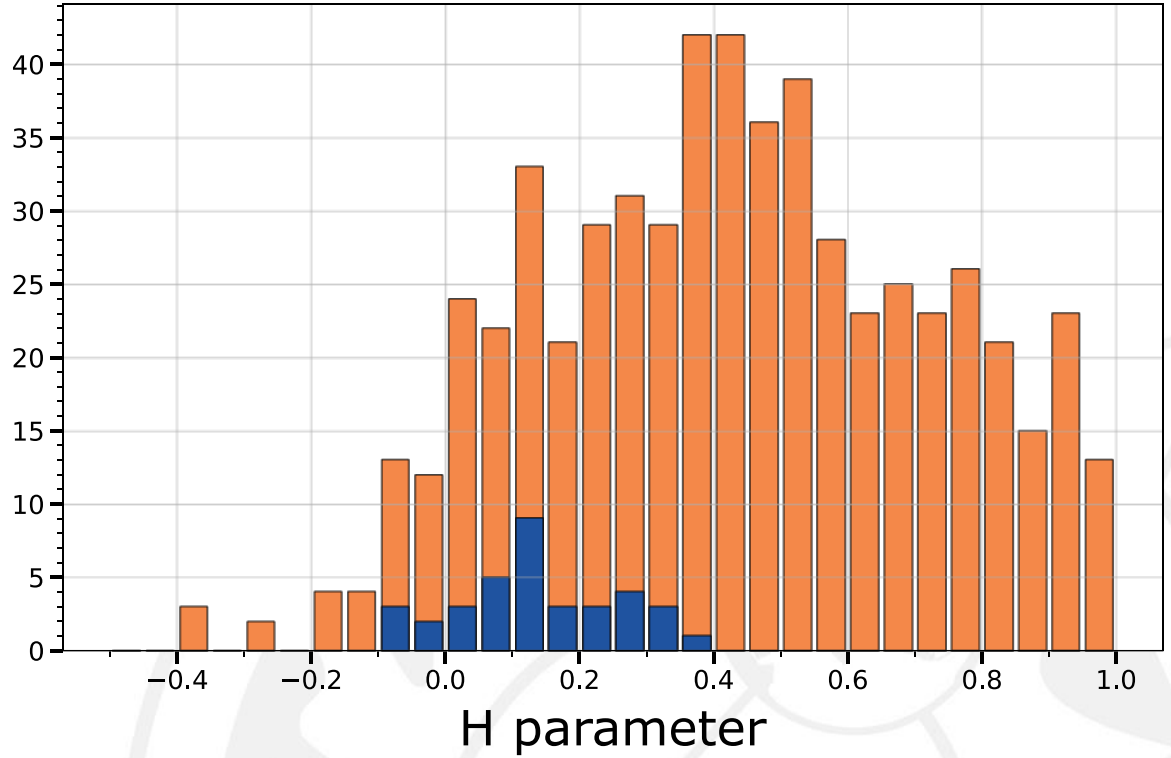


For the period from 05:14 to 11:43 29 October 2017, the dynamics of **the electric field (E_y)** and **the expression** $(-v \times B)_y$ are shown on the panel above.
The panel on the left shows the position and direction of the satellite during this period.

H-parameter for this period $= \mathbf{0.1}$

Deviation

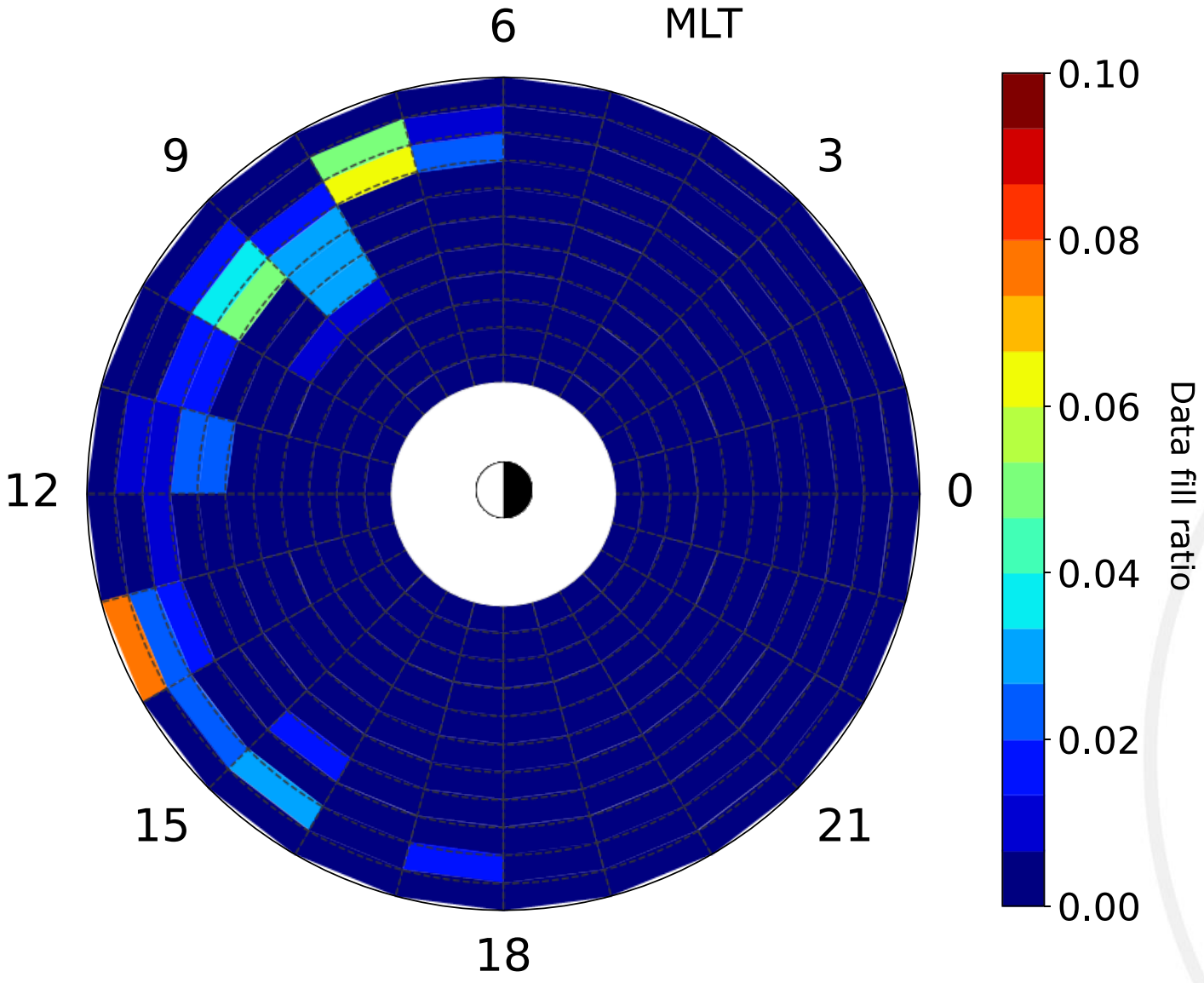




The left panel shows the distribution of the sum of relative deviations with a threshold value of 0.7. Sums that are less than 0.3 are highlighted in **blue.**

The right panel shows the distribution of the H-parameter. Those observed periods in which the sum of relative deviations was less than 0.3 are highlighted in **blue.**

FIC's data cover



The distribution of data fill ratio on the L-MLT plane with cell-size $1\ R_E \times 1\ h$ and L in range 4-15 R_E for data for which the FIC is fulfilled best.

Used parameters:

- $|H| \leq 0.15$
- Relative Deviation threshold (RD = 0.7)
- Sum of RD ≤ 0.3

Conclusion

- The data necessary to analyze the feasibility of the FIC for the THEMIS A satellite have been prepared.
- Parameters were introduced to assess the feasibility of the FIC, and their distribution was constructed based on the prepared data.
- It has been shown that, with the parameters used, the frozen-in condition is fulfilled mostly on the dayside of the magnetosphere.

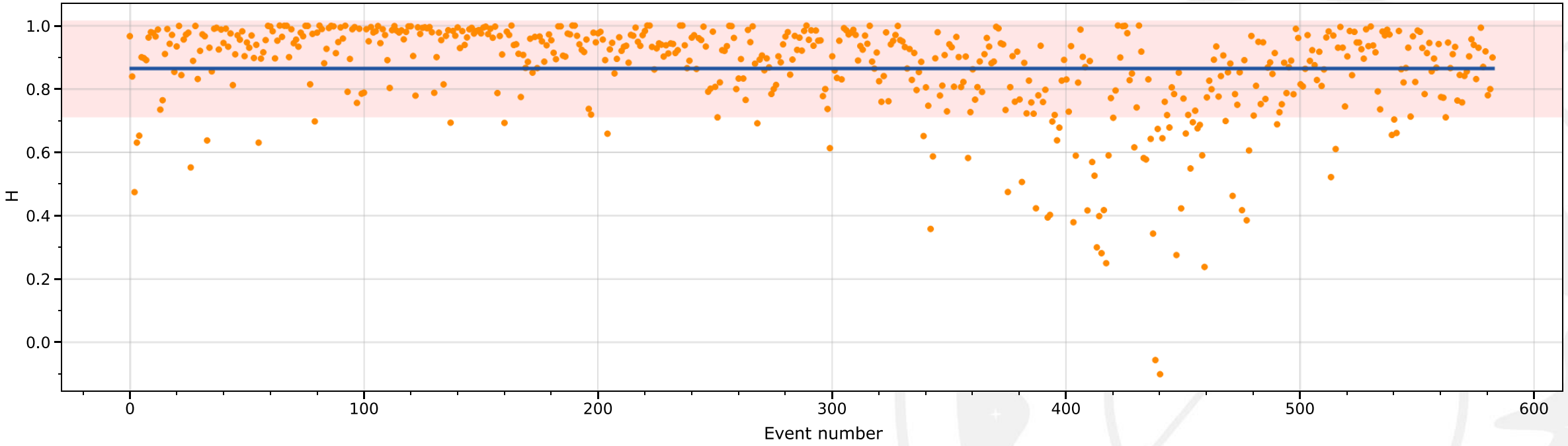
Thank you for your attention!

H-parameter, X-comp

$$\mathbf{H} = \frac{\boldsymbol{E_n^2} - \boldsymbol{(v \times B)_n^2}}{\boldsymbol{E_n^2} + \boldsymbol{(v \times B)_n^2}}, \mathbf{n} \in \boldsymbol{(x, y, z)}$$

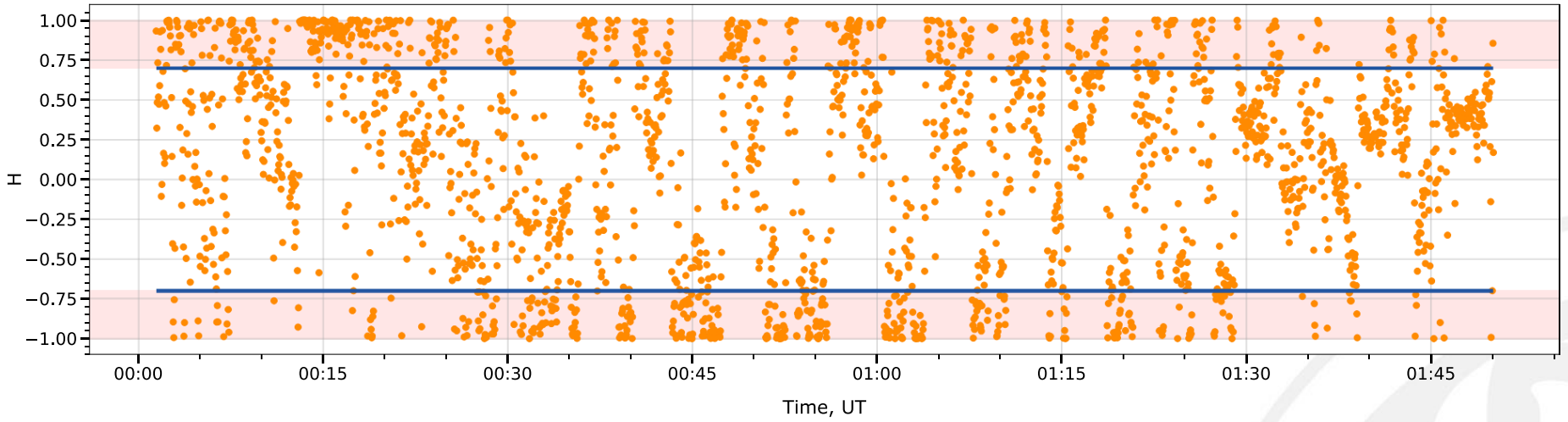
The range of valid values:

- $\mathrm{H} \sim 1: \rightarrow \mathrm{E} \gg \mathrm{v} \times \mathrm{B}$
- $\mathrm{H} \sim 0: \rightarrow \mathrm{E} \sim \mathrm{v} \times \mathrm{B}$
- $\mathrm{H} \sim -1: \rightarrow \mathrm{E} \ll \mathrm{v} \times \mathrm{B}$

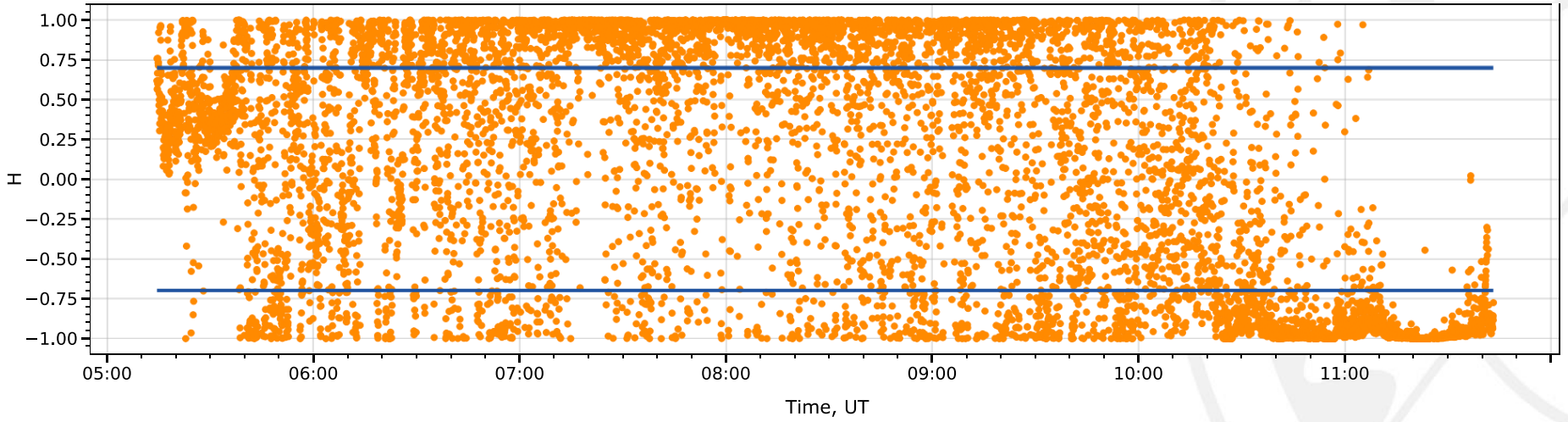


The variation in parameter **H** over the study periods for *x-components*. The **blue** line represents $\boldsymbol{H_{avg}}$ **= 0.86**, and the area highlighted in **red** represents $\boldsymbol{H_{avg} \pm \sigma}$**.**

Relative deviation



H = 0.12
URD = 0.24
LRD = 0.169
SRD = 0.409



H = 0.1
URD = 0.345
LRD = 0.27
SRD = 0.615