



# Measurement of lunar induced fields with KMAG onboard KPLO

Woojin Jo<sup>1</sup>, Ian Garrick-Bethell<sup>2</sup>, Ho Jin<sup>1</sup>, Shahab Fatemi<sup>3</sup>, Andrew R. Poppe<sup>4</sup>,  
Khan-Hyuk Kim<sup>1</sup> and Hyeonhu Park<sup>1</sup>

<sup>1</sup>*Kyung Hee University, South Korea*

<sup>2</sup>*University of California, Santa Cruz, USA*

<sup>3</sup>*Umea University, Sweden*

<sup>4</sup>*Space Sciences Laboratory, University of California, Berkeley, USA*

# Introduction

## The Moon's Farside interior structure is unknown

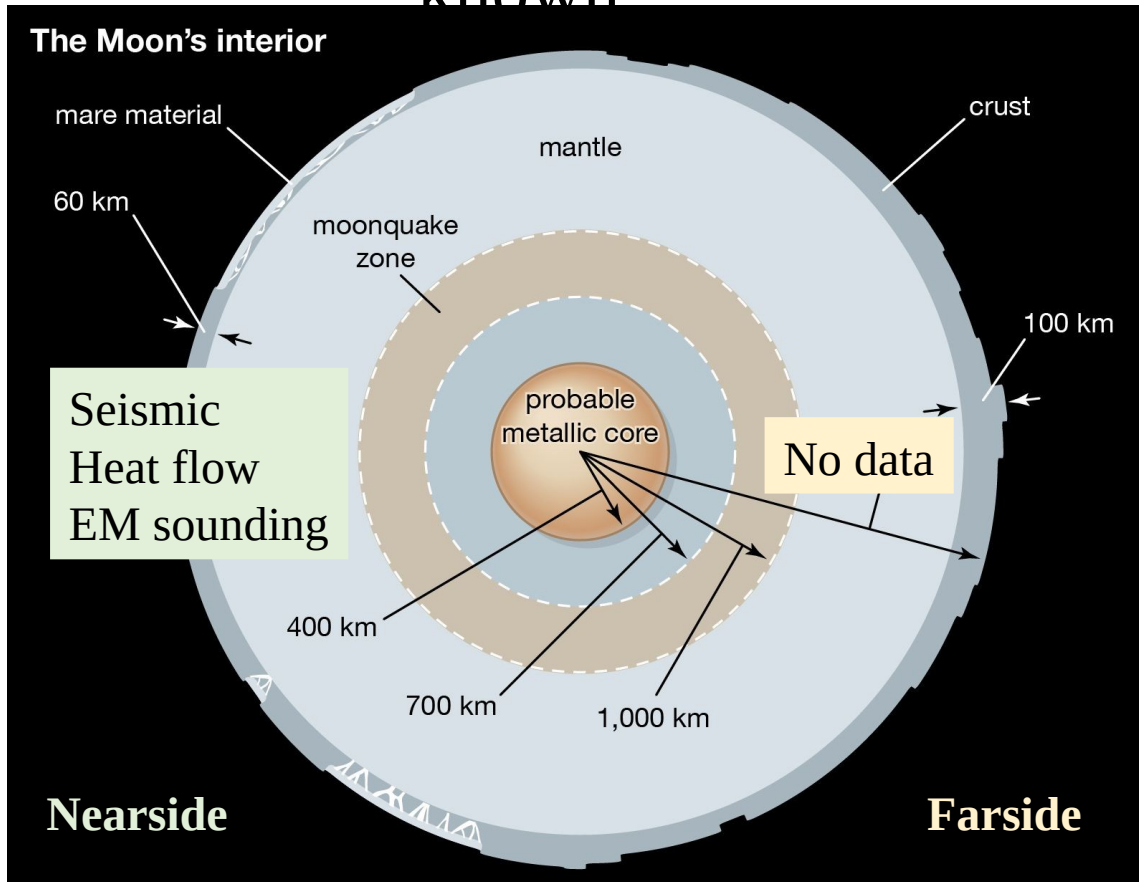


Image credit: Britannica

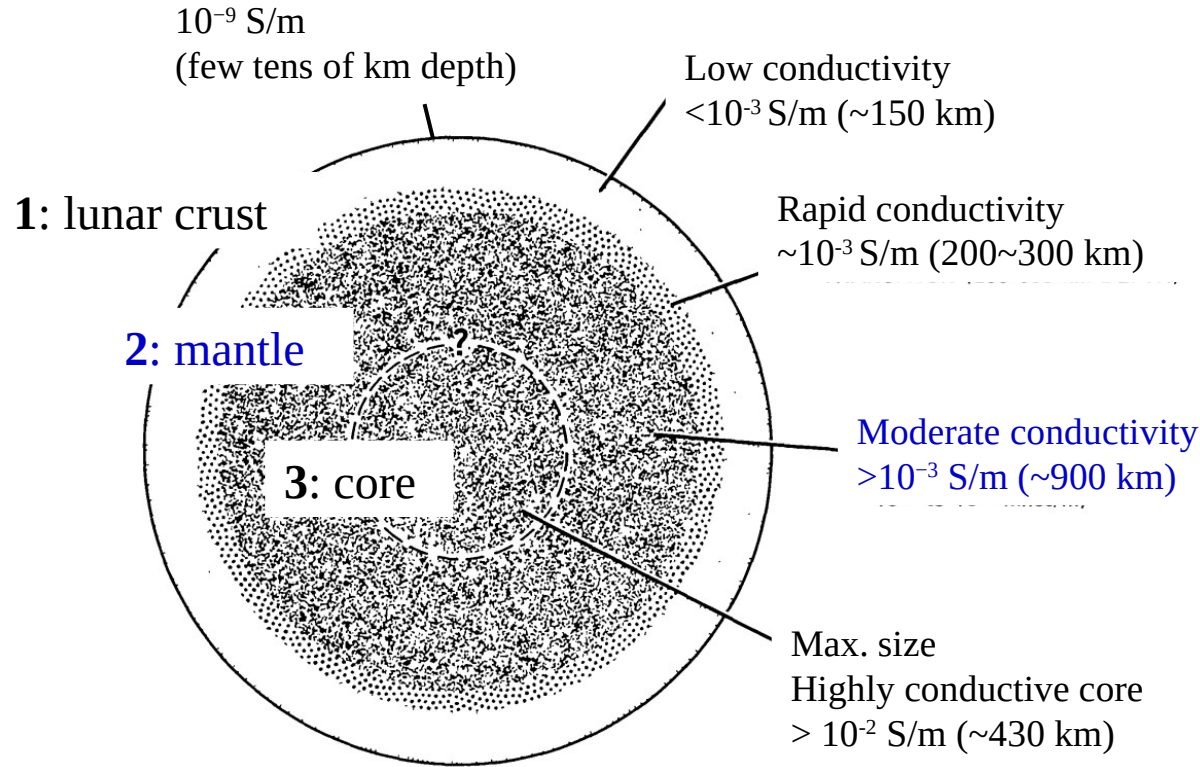
- No seismic data
- No heat flow data
- No electromagnetic sounding data
- Electromagnetic sounding
  - : information on temperature structure
  - ; dependence of conductivity on temperature (e.g Dyal and Parkin 1976)
- We present the farside electromagnetic sounding first time with an orbiting spacecraft.

# Previous study

## Faraday's law

$$\oint \mathbf{E} \cdot d\mathbf{l} = -\oint \frac{\partial \mathbf{B}}{\partial t} \cdot d\mathbf{A}$$

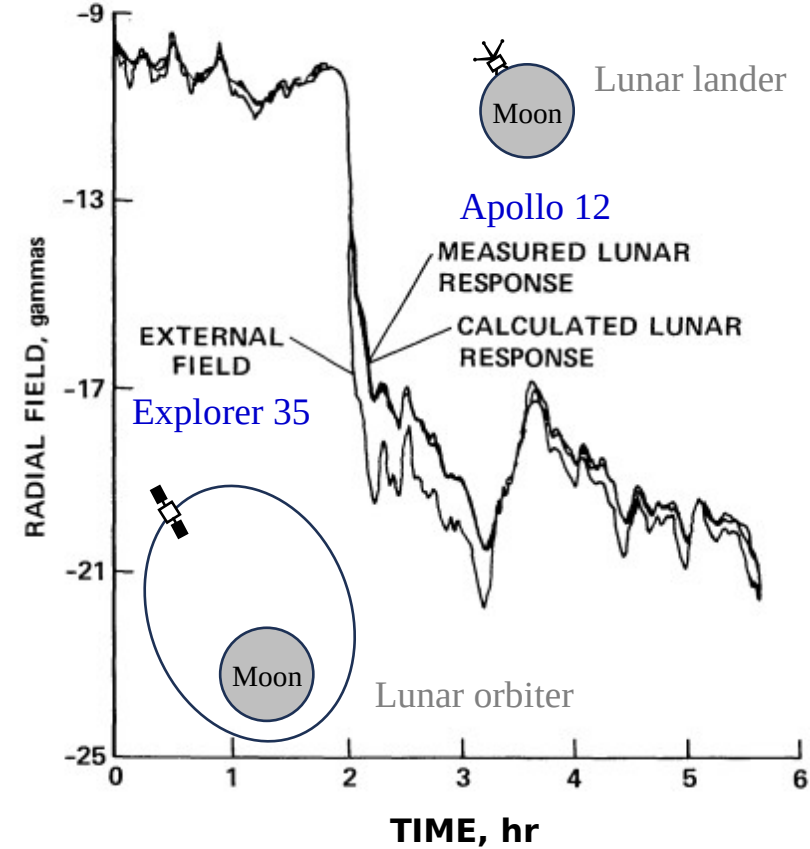
(Dyal and Parkin, 1971)



▲ Lunar interior structure (2: lunar mantle which acts as an electrical conductor)

Lunar induction by conducting lunar mantle in rapidly changing interplanetary magnetic field (IMF)

(Dyal et al., 1976)

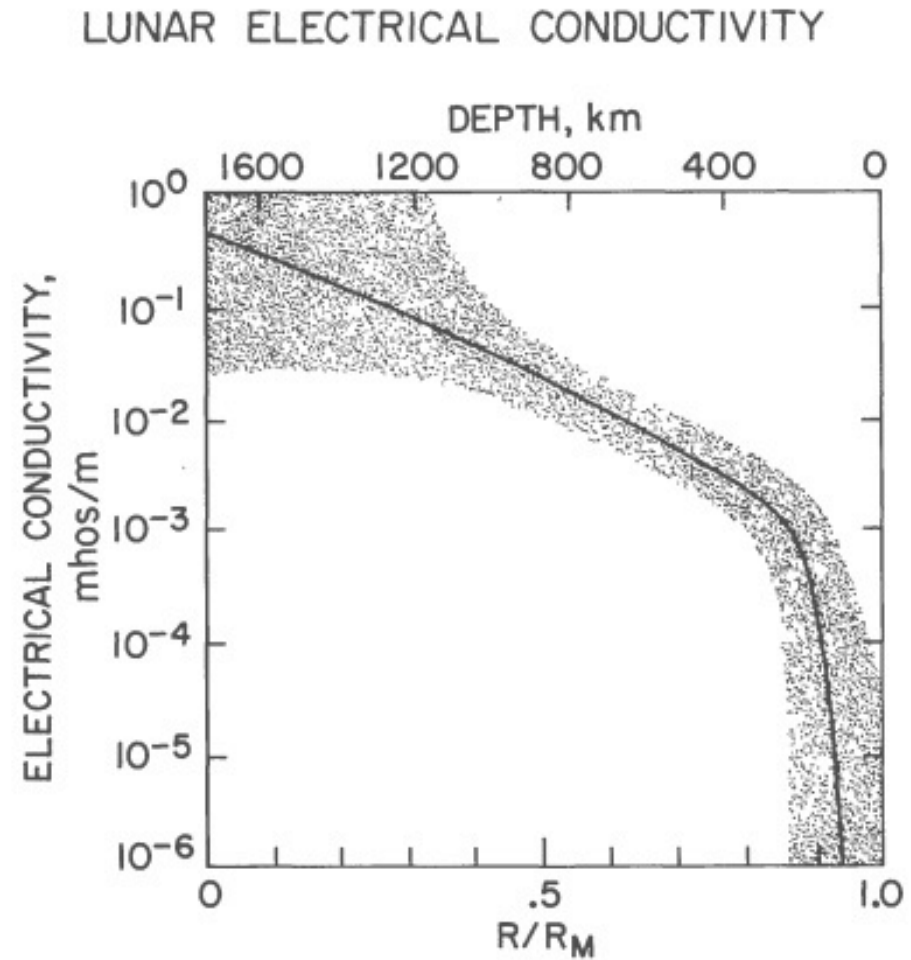


▲ Lunar radial responses measured by Apollo 12 and Explorer 35 and calculated from Explorer 35 measurements.

## Previous study

(Dyal et al., 1976)

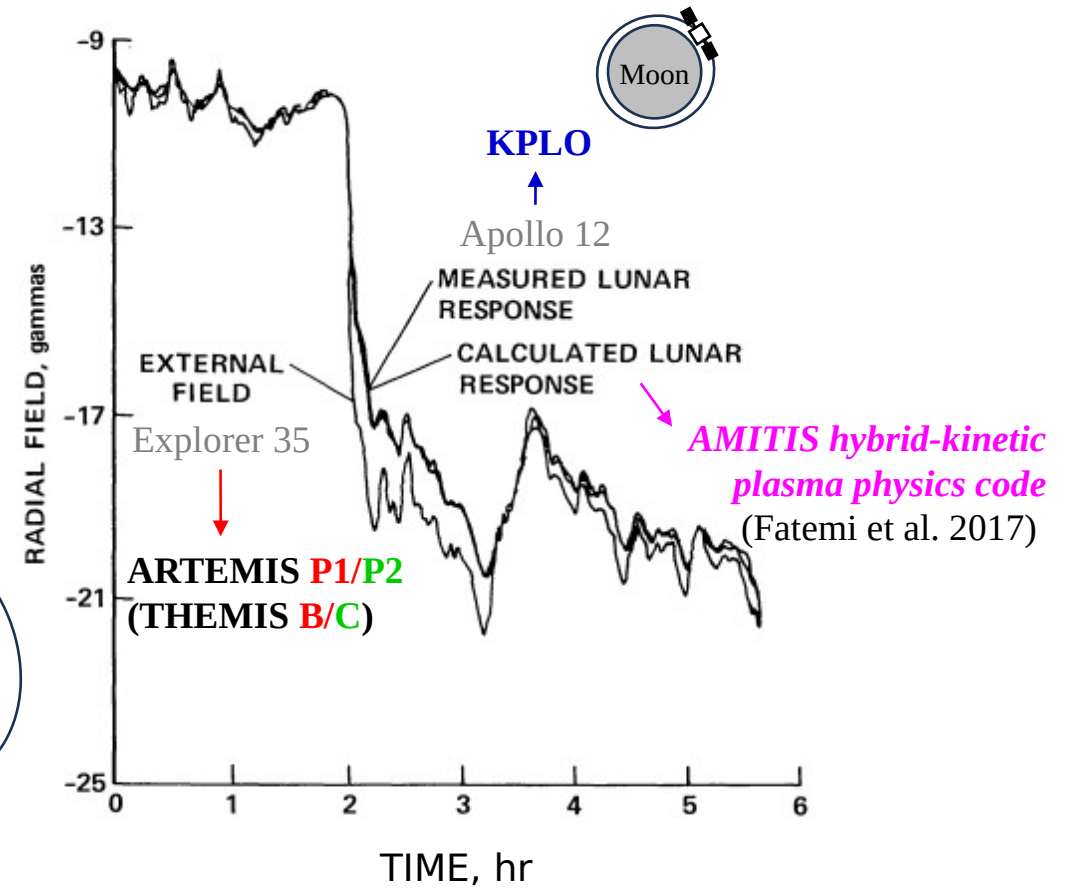
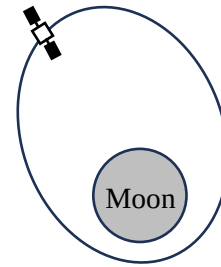
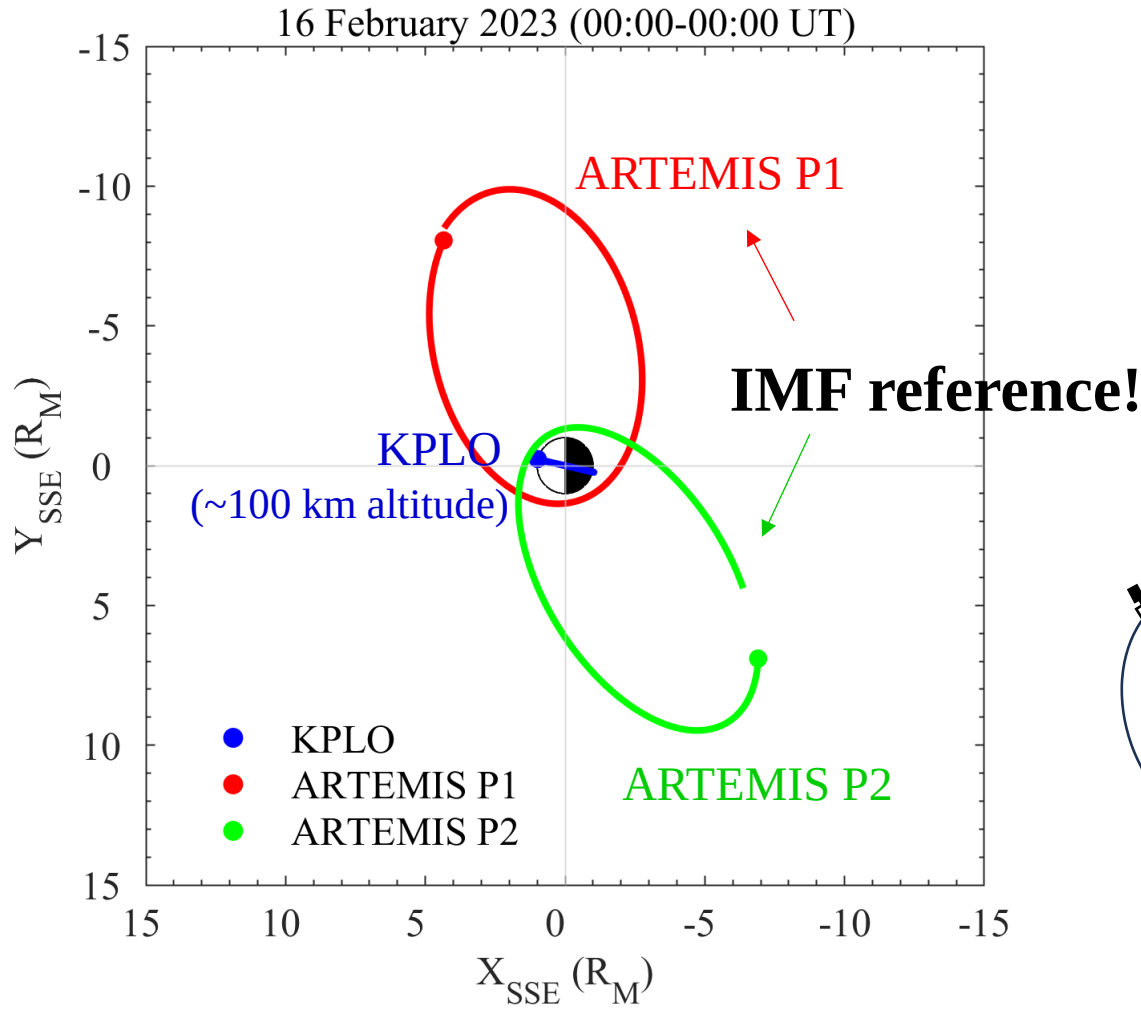
- Result on nearside (1976):
  - Best-fit  
: a resistive near-surface layer  
+ exponentially increasing conductivity
  - Consistent with increasing temperature with depth.



# This study



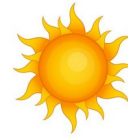
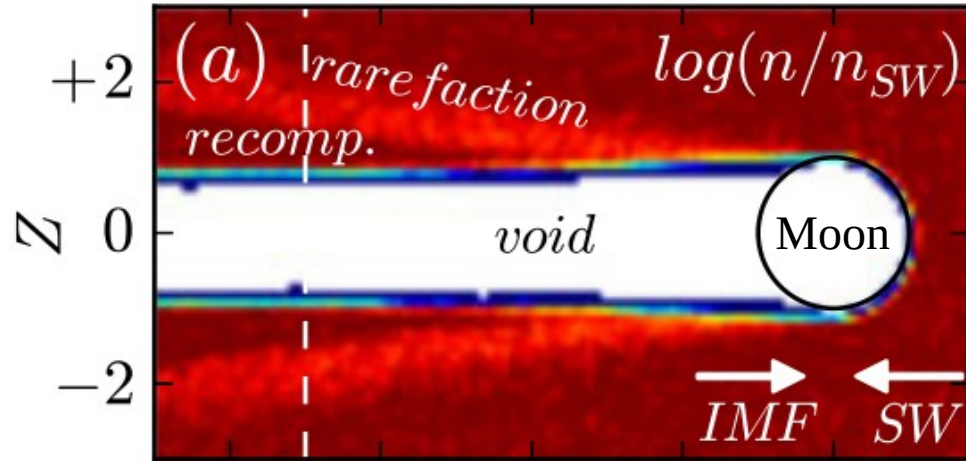
Compare KPLO observation with the IMF (ARTEMIS P1/P2) and AMITIS result!



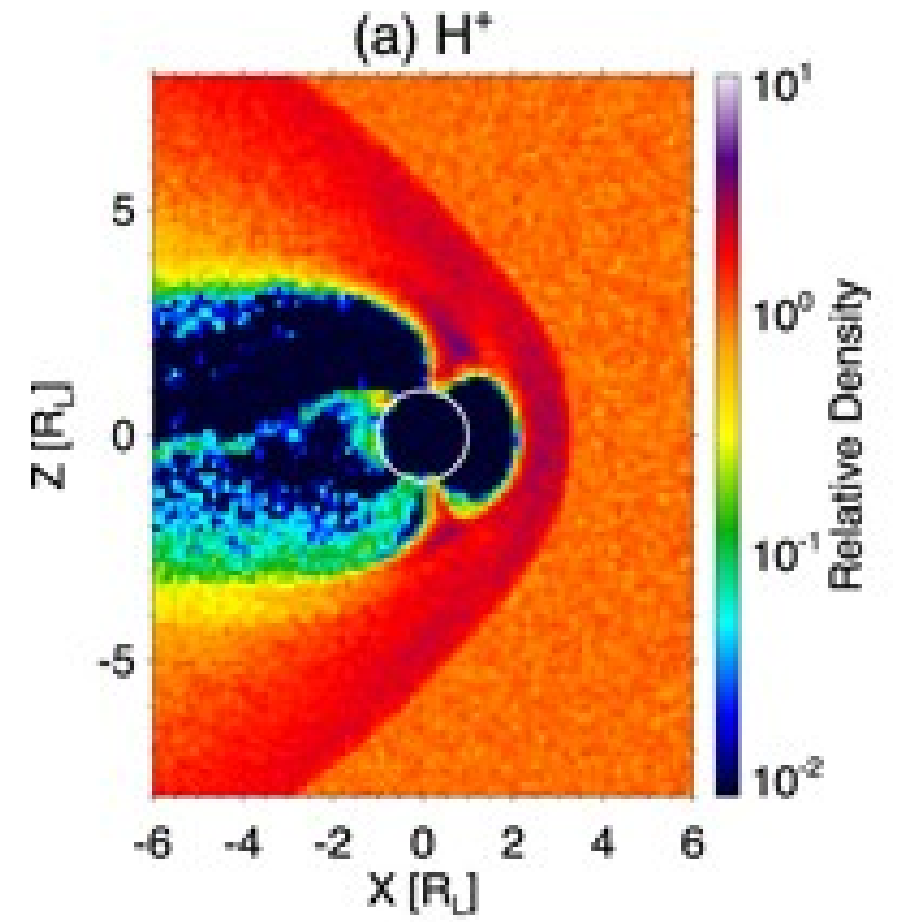
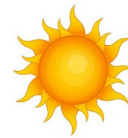
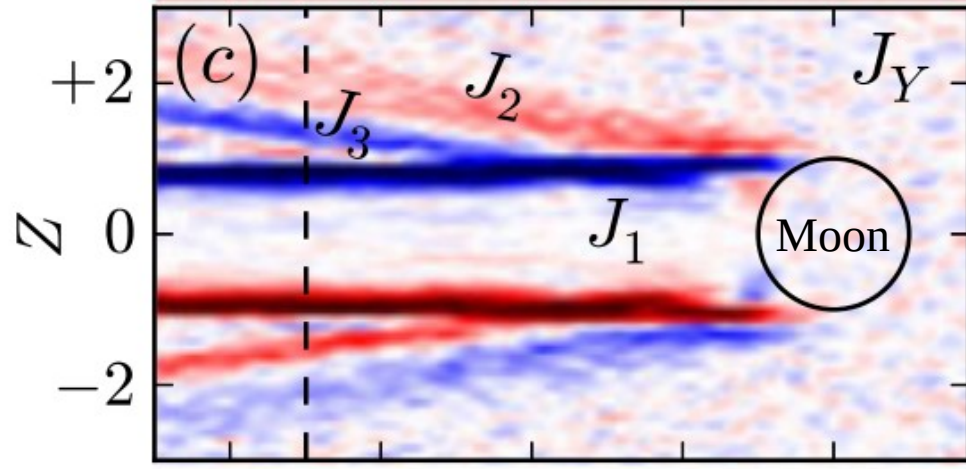
# This study

## Why AMITIS code?

Plasma density



Currents

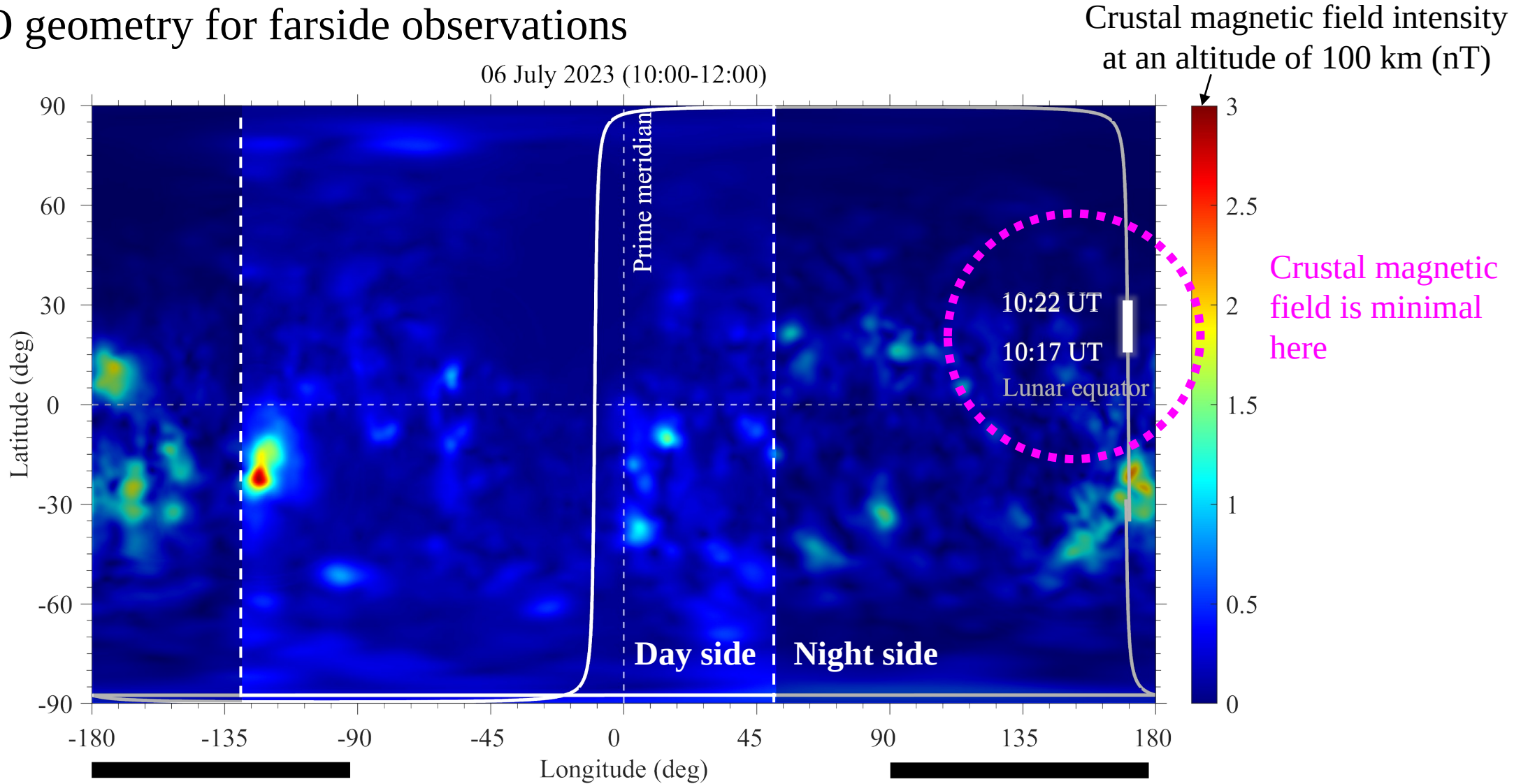


▲ Plasma effect slightly change the field in the lunar wake (Fatemi et al. 2013)

▲ AMITIS code (Poppe et al., 2021)

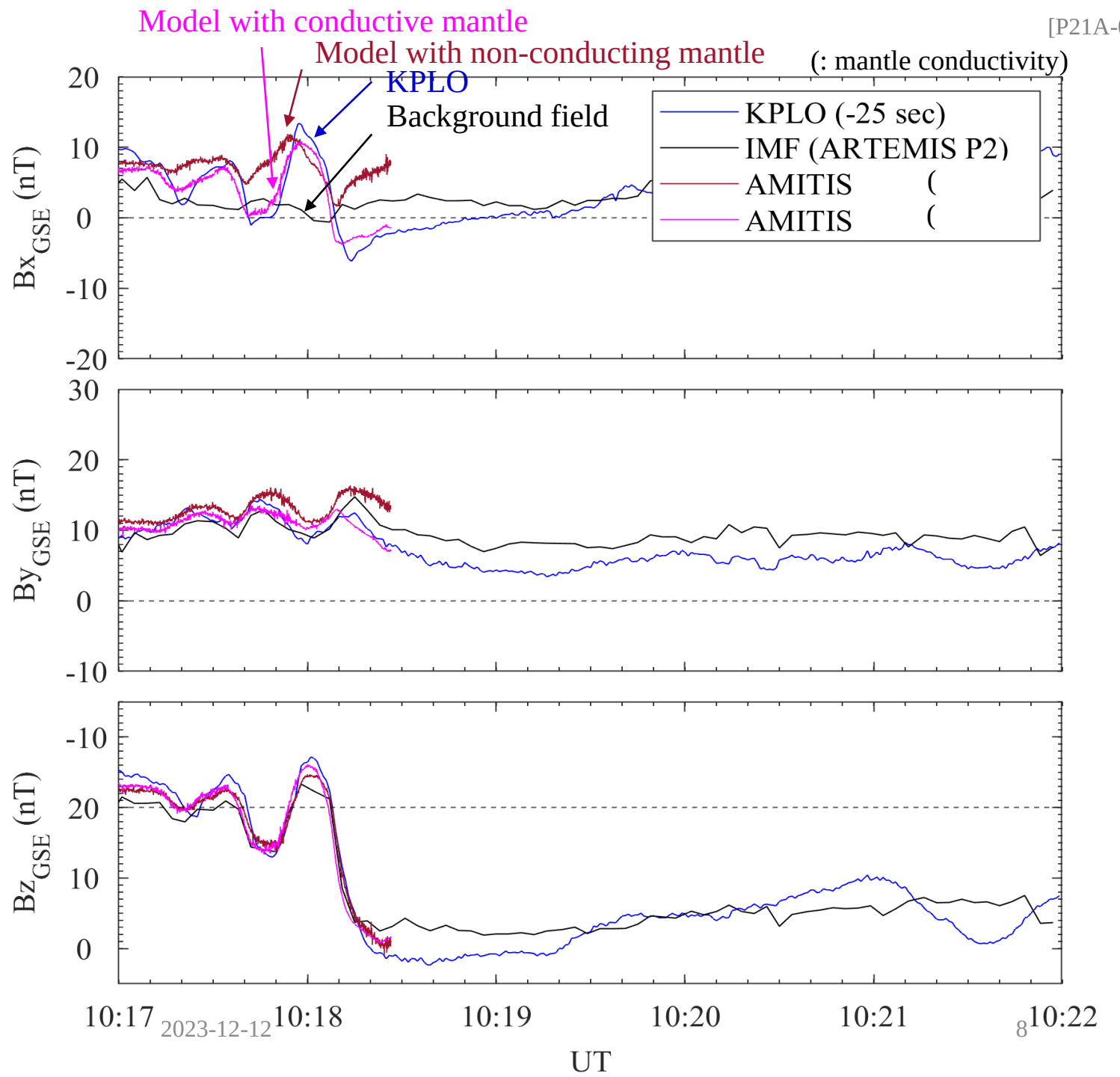
**This study:** July 6, 2023 10:18 UT

■ KPLO geometry for farside observations



## Results (1): July 6, 2023 10:18 UT

- The IMF changes mainly in the z-component, but a strong induced field is observed in the x-component.



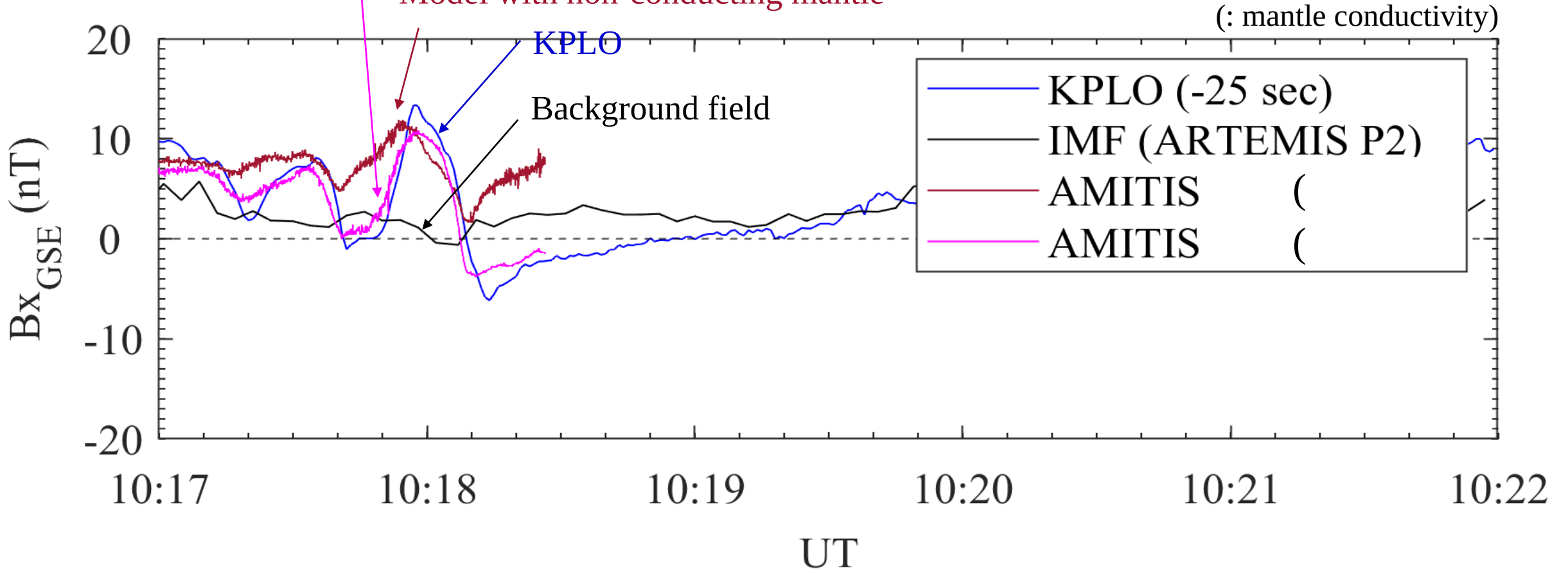


# Results (1): July 6, 2023 10:18 UT

- So far, the simulation results show that an **electrically conducting mantle** is required to explain the **KPLO observations**, particularly in the x-component.

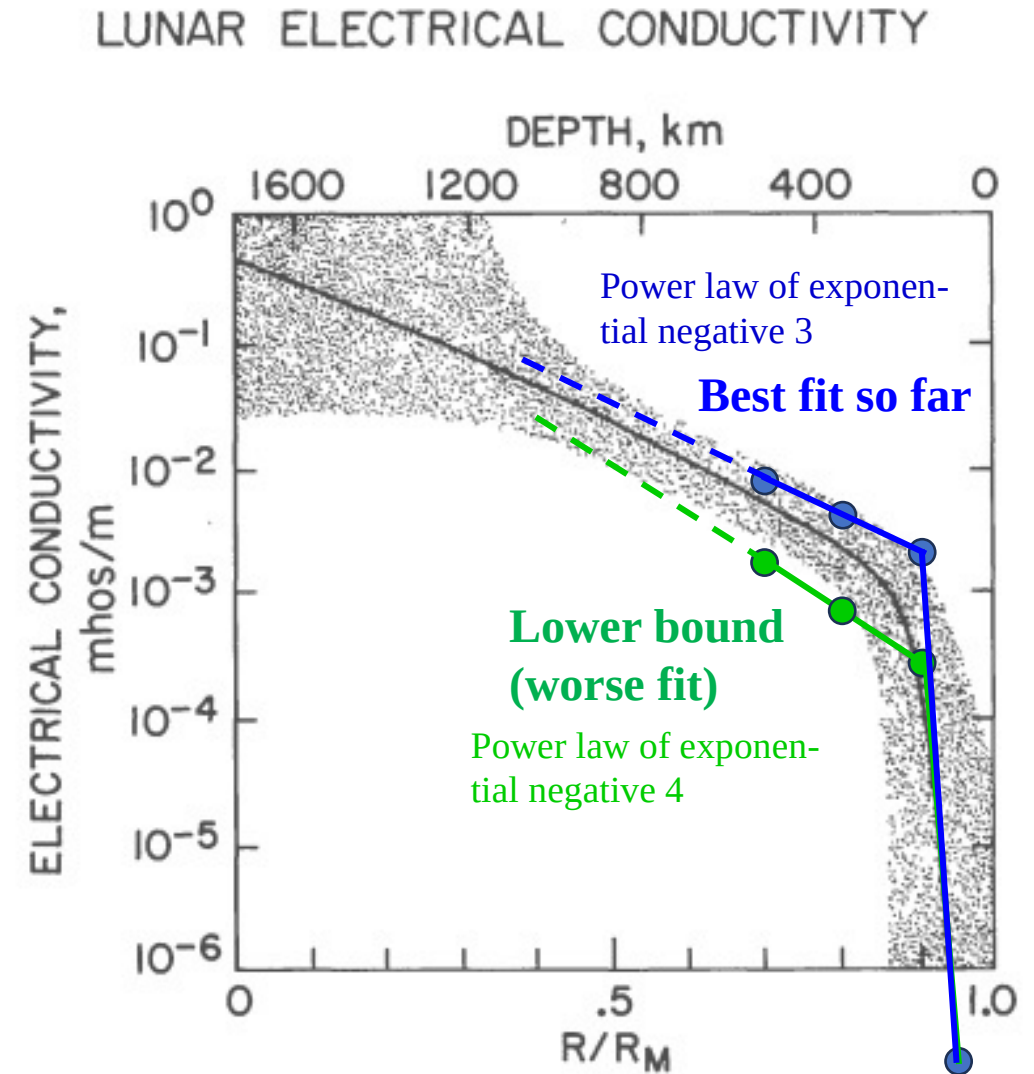
Model with conductive mantle

Model with non-conducting mantle



## Results (2): July 6, 2023 10:18 UT

- **Best model** (so far) is within Dyal and Parkin (1976) bounds for **nearside**.  
; Short duration of measurement limits sounding of deepest layers
- Expected **lower conductivity** on farside due to possible colder temperatures on farside.
- **Lower bound** (poorly fit model) is shown in green.
- Very preliminary results - more models running!





# Thank you

Woojin Jo

whdndls99@khu.ac.kr

*Kyung Hee University*

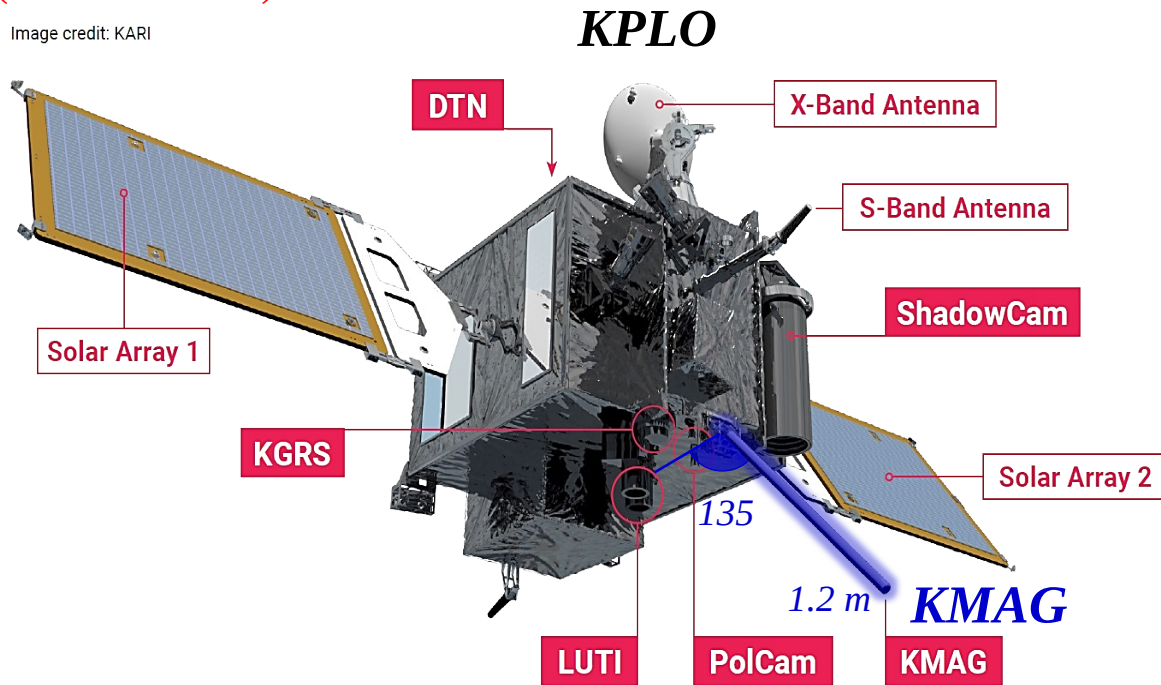
# Appendix A. KMAG

100% duty operation  
Missing data: 1.52%/yr

2022 08	2022 09	2022 10	2022 11	2022 12	2023 01	2023 02	2023 03	2023 04	2023 05	2023 06	2023 07	2023 08	2023 09	2023 10	2023 11	2023 12
Trans Lunar Cruise (TLC) phase				LOI phase		Nominal Mission phase										

Launch  
(2022.08.04 UTC)

Image credit: KARI



- Kplo Magnetometer (KMAG) [P11B-2718]

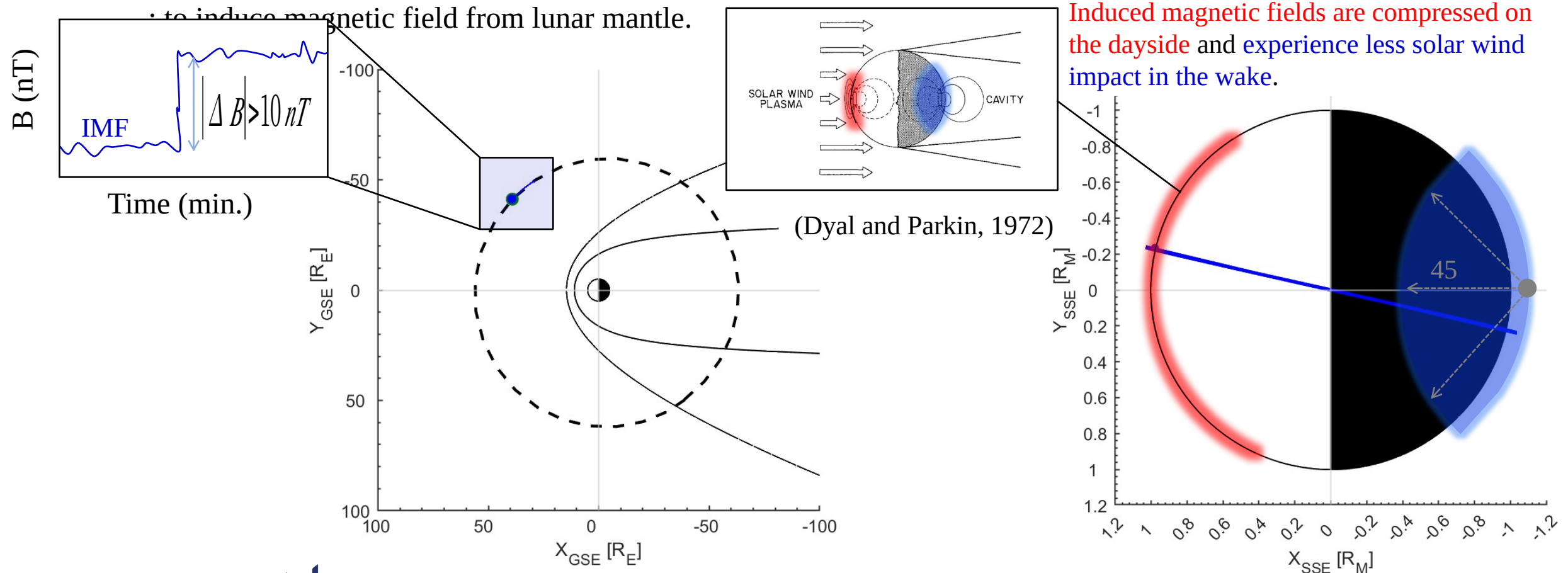
: Investigation of the magnetic field of the Moon and near-Moon space with three fluxgate magnetometer.

MAG properties	Contents
Measurement range	1000 nT
Resolution	< 0.2 nT at 10 Hz sampling rate
Mass	Total 3.5 kg
Operation	Duty: 100%

## Appendix B. Conditions for induction study

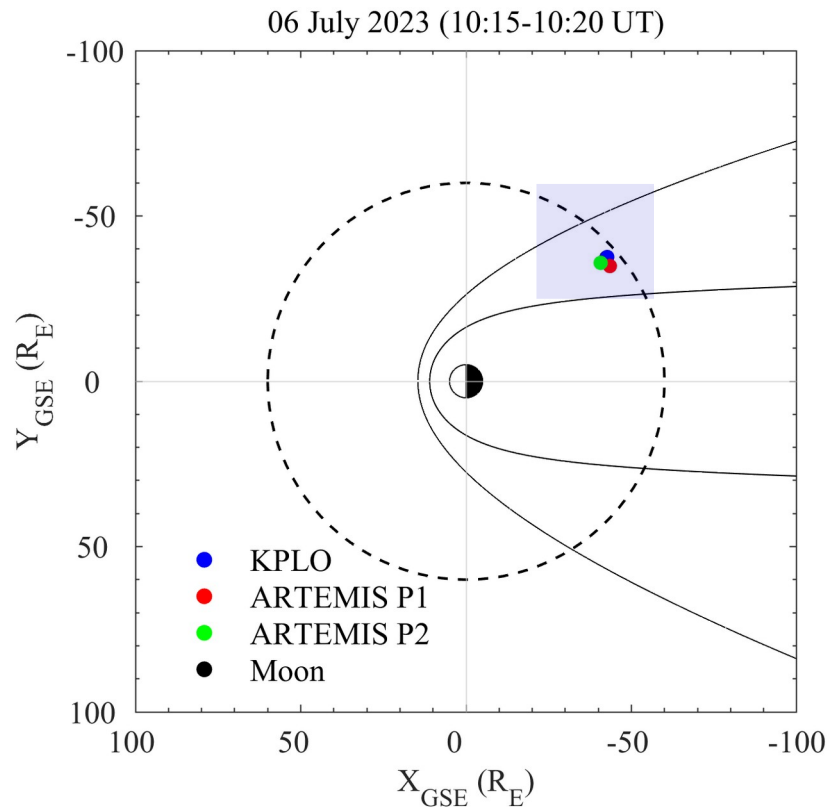
- 1) During **time-varying IMF** conditions (in **solar wind**)

- 2) KPLO is **within 45** of the deep **lunar wake** region ; to minimize plasma effects

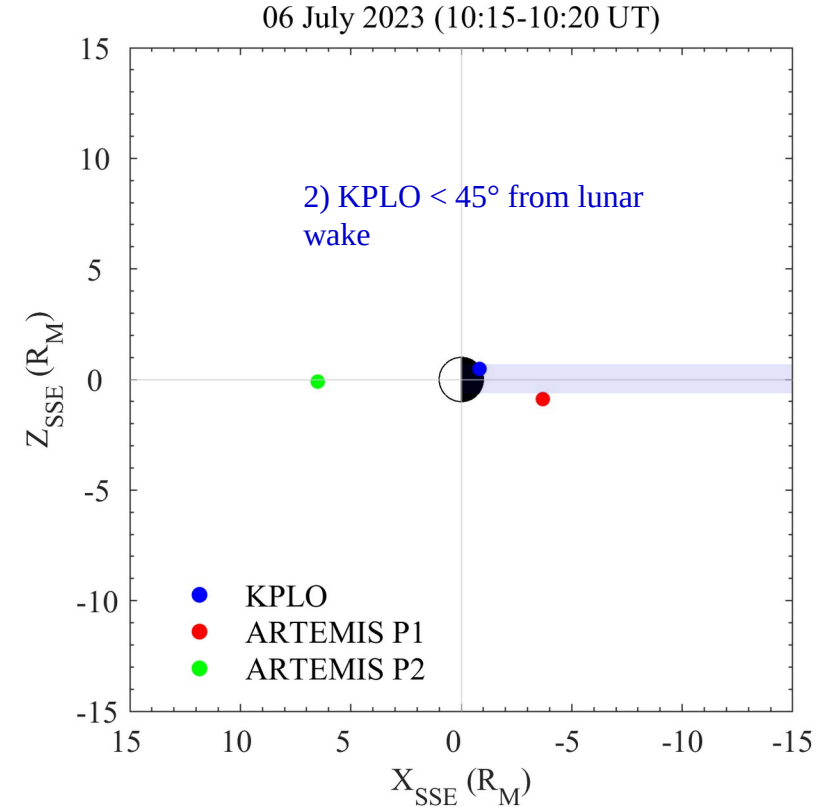
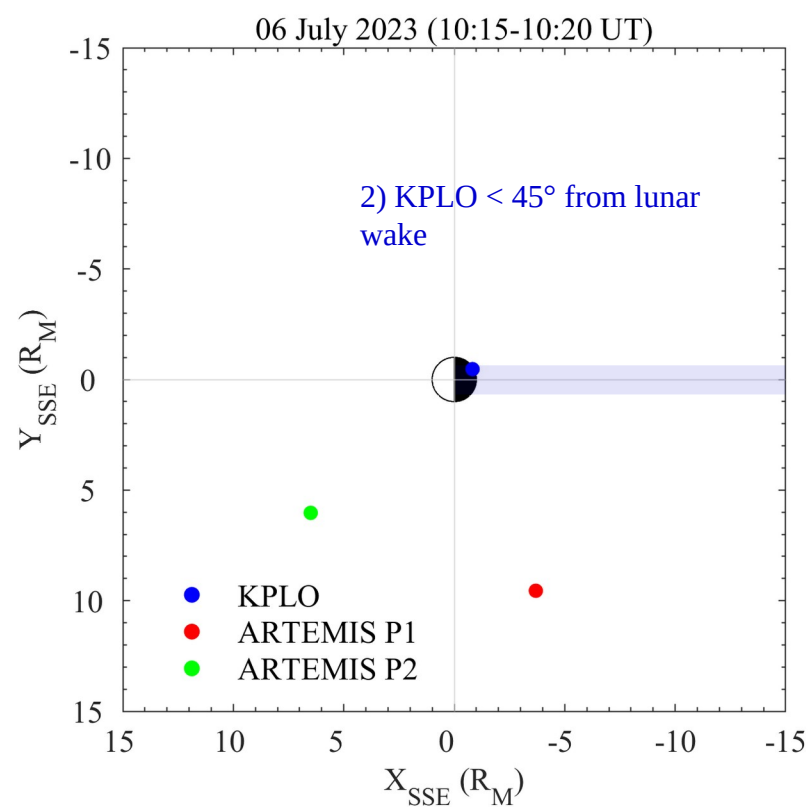


# Appendix C. Position on July 06, 2023 10:18

1) Time-varying IMF in solar wind  
; check with OMNI data

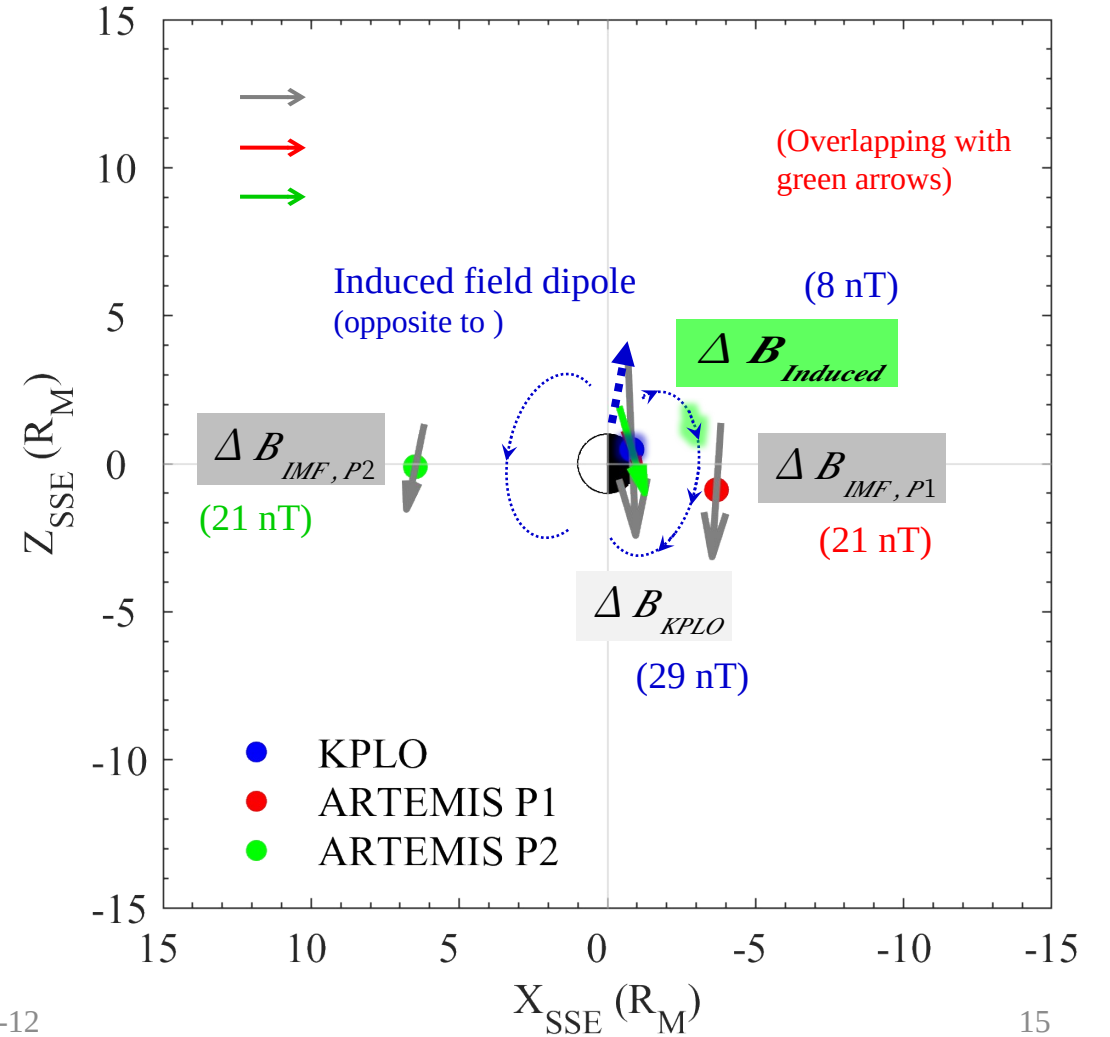
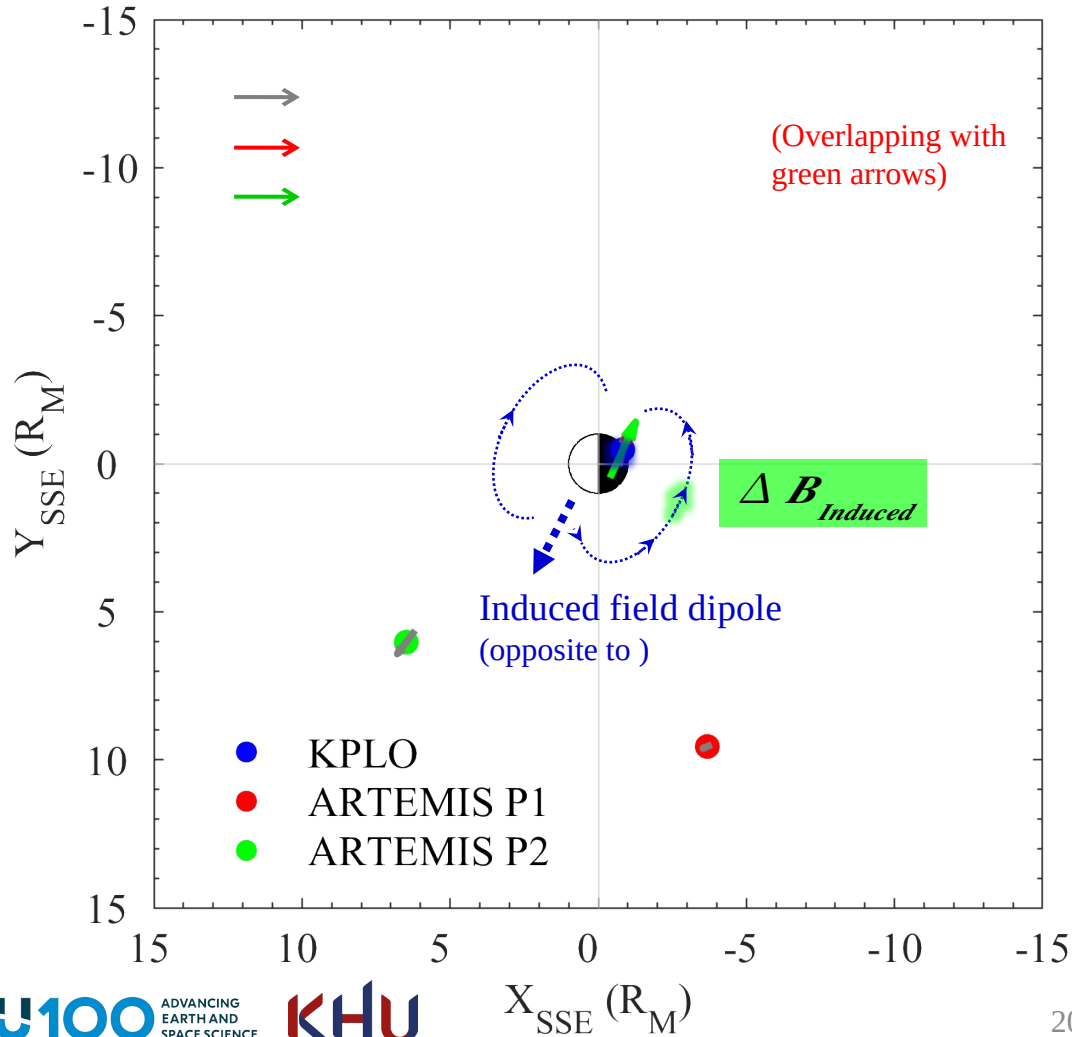


2) KPLO  $< 45^\circ$  from the deep lunar wake region



# Appendix D. Induced field measurement

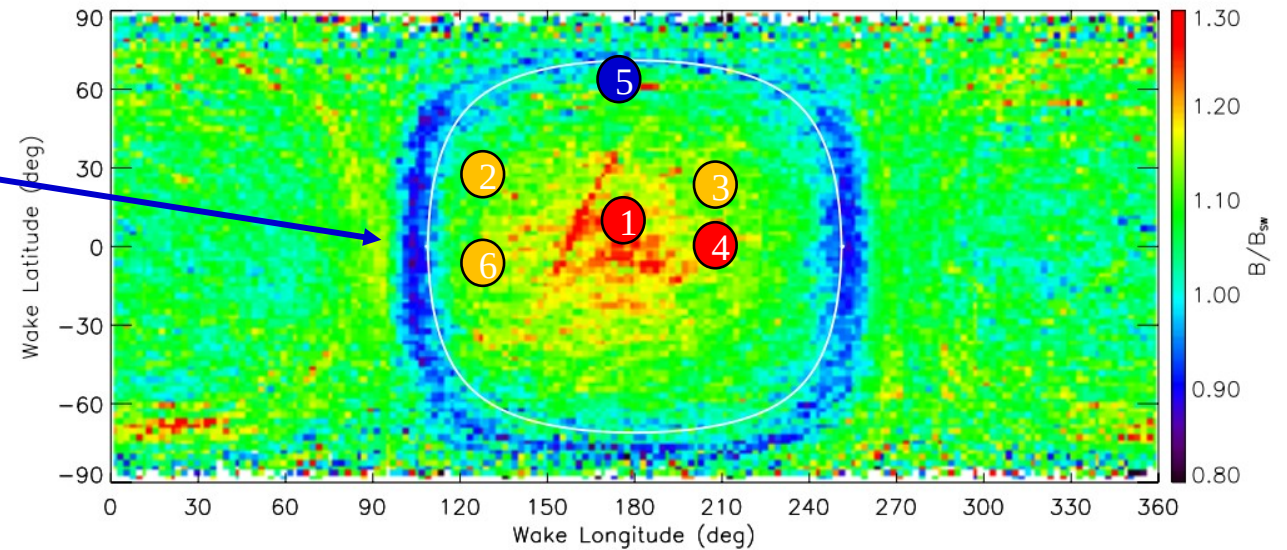
→ : mean vector (10:16-10:17 UT) before the transient field event (10:18 UT)  
→ : mean vector (10:19-10:20 UT) after the transient field event (10:18 UT)



## Appendix E. Lunar response measurement

- The **KPLO observations** are similar to the results of the **AMITIS model with mantle conductivity**.
- Based on a total of six cases of these events, the consistent ratio of **to** looks partially like **wake-field enhancements** (Halekas et al., 2005).
- This shows that KPLO is also observing the **wake field** well, and with greater similarity to the conductive mantle Moon AMITIS model, K MAG is observing the **lunar magnetic induction** together.

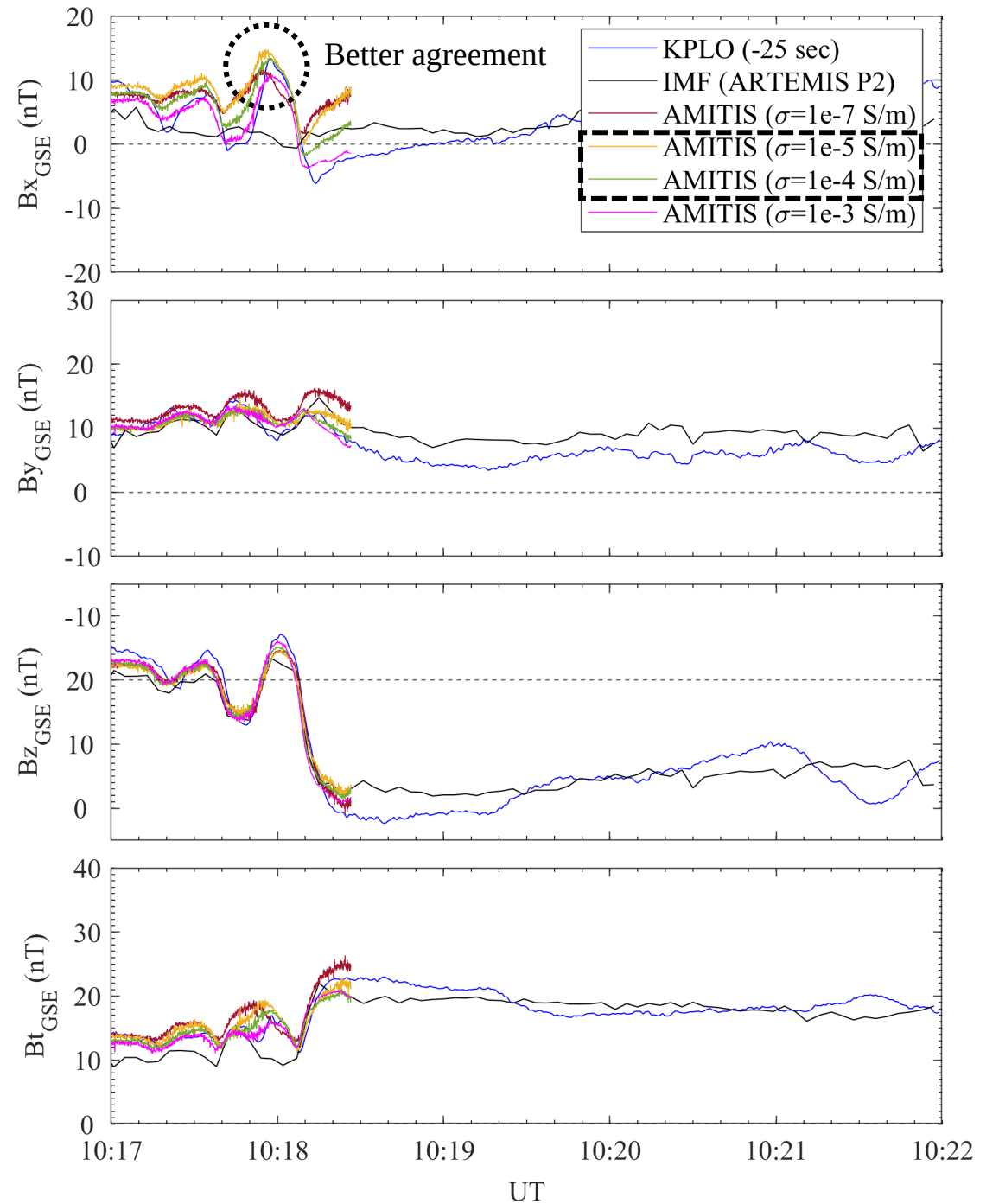
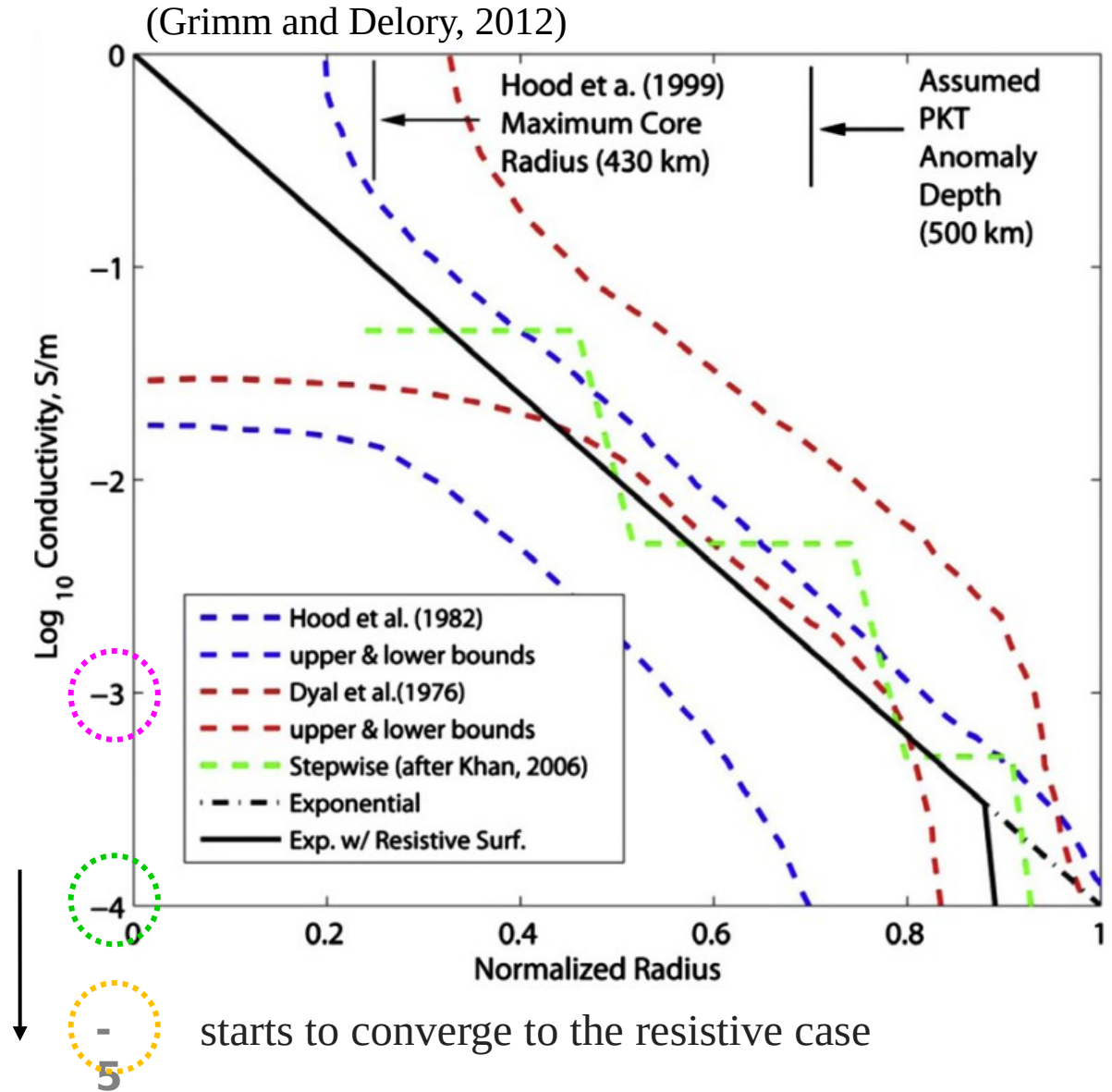
Index			Axis ratio ( $\lambda$ )
1	18	26	1.44
2	18	21	1.17
3	31	35	1.13
(July 06) 4	21	29	1.38
5	20	15	0.75
6	12	14	1.17



▲ Normalized LP magnetic field measurements from altitude of 85-115 km (Halekas et al., 2005)



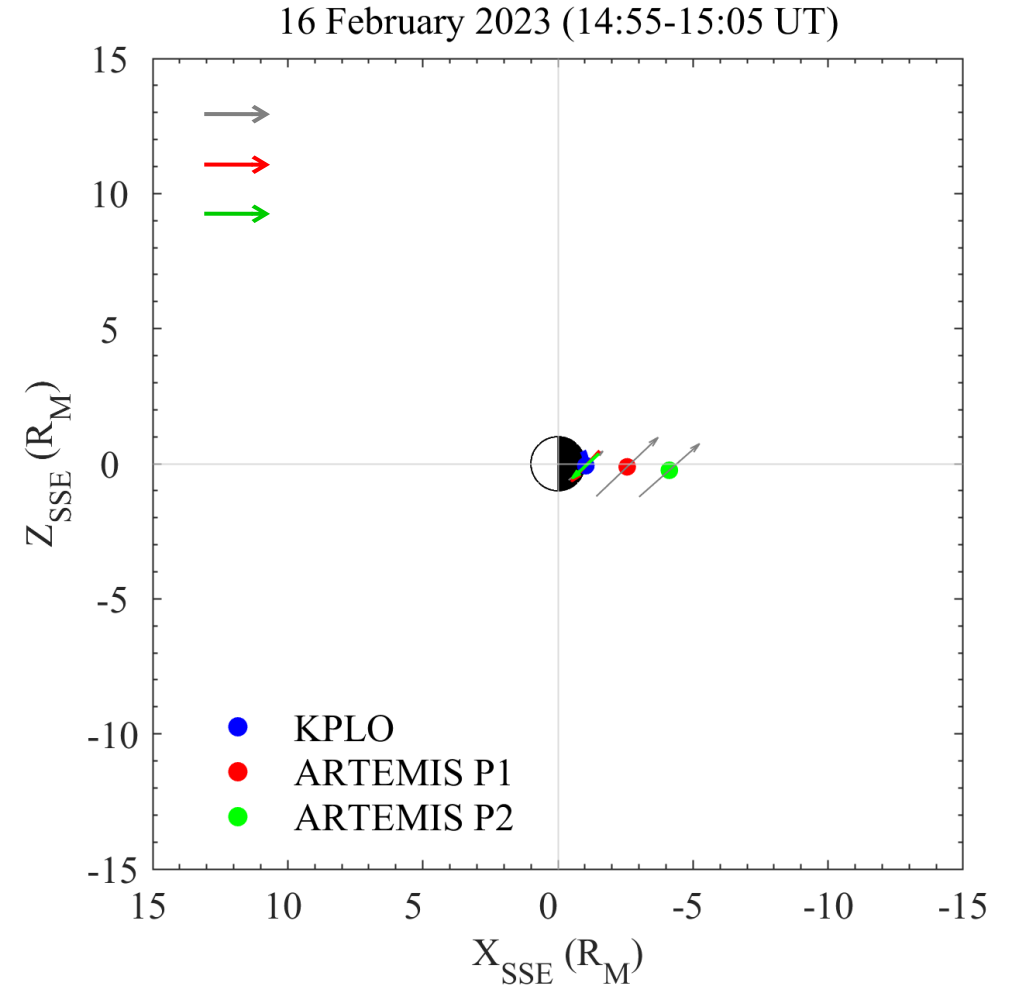
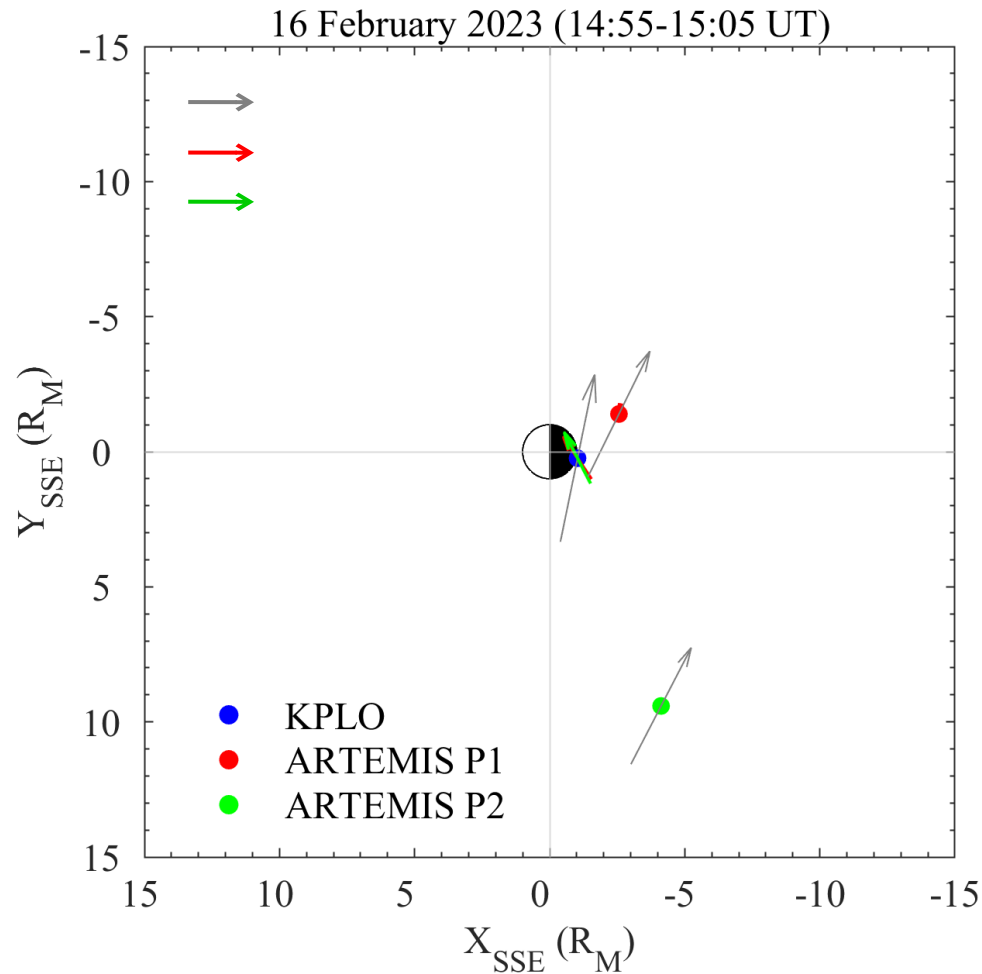
# Appendix F. Conductivity models



# Appendix G. Event cases

Candidate 1. Feb 16, 2023 14:58

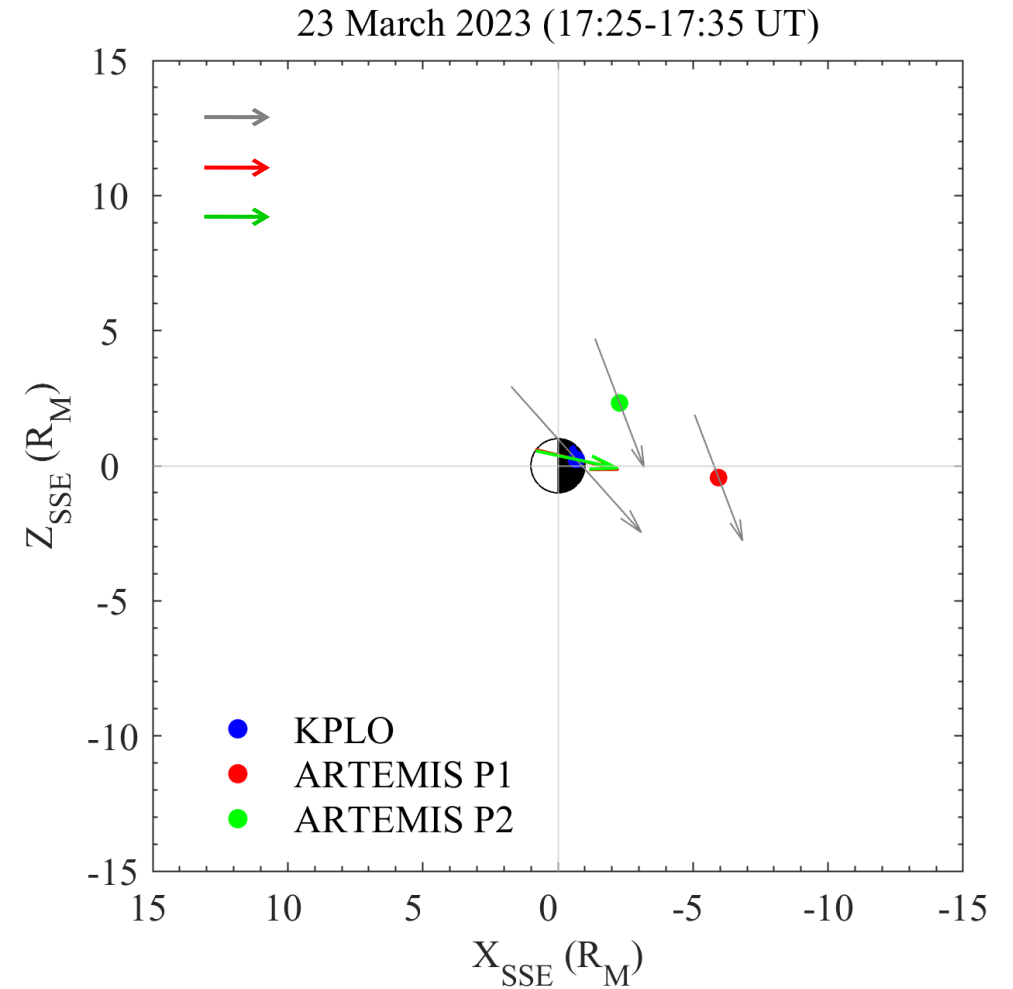
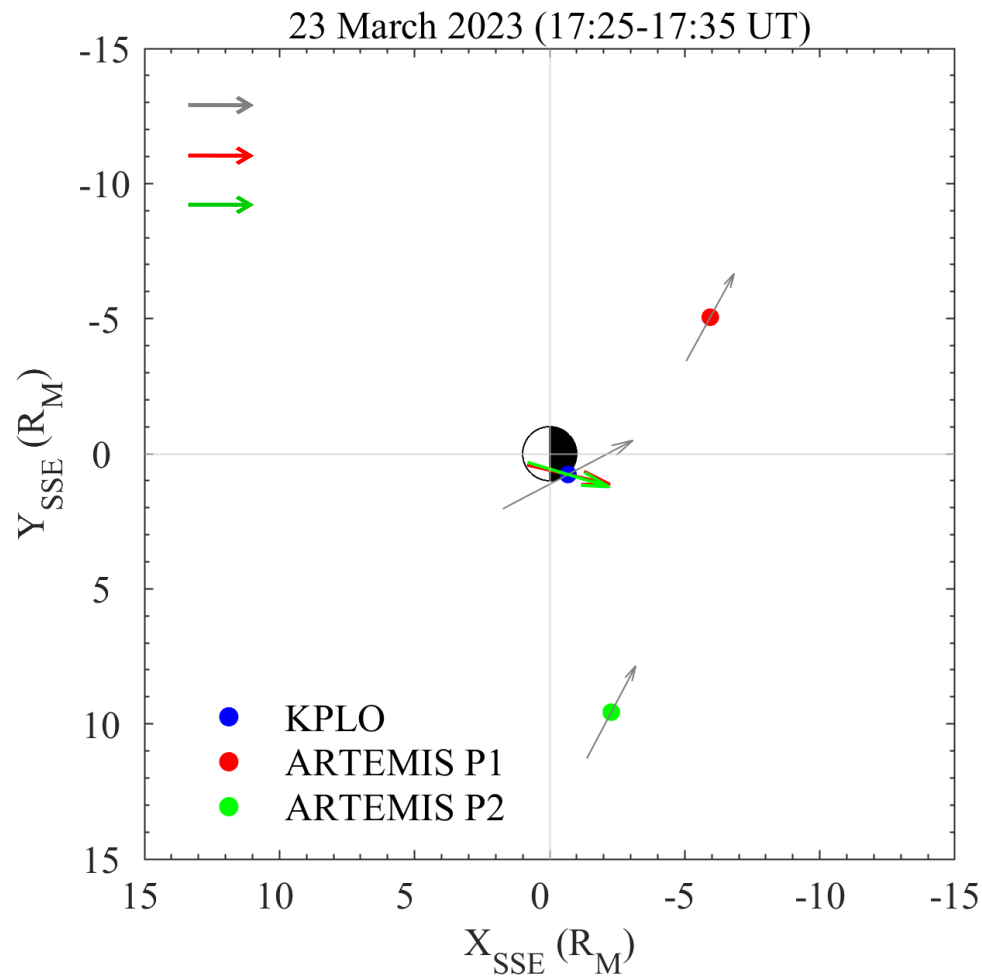
→ : mean vector before the transient field event  
→ : mean vector after the transient field event



# Appendix G. Event cases

Candidate 2. Mar 23, 2023 17:31

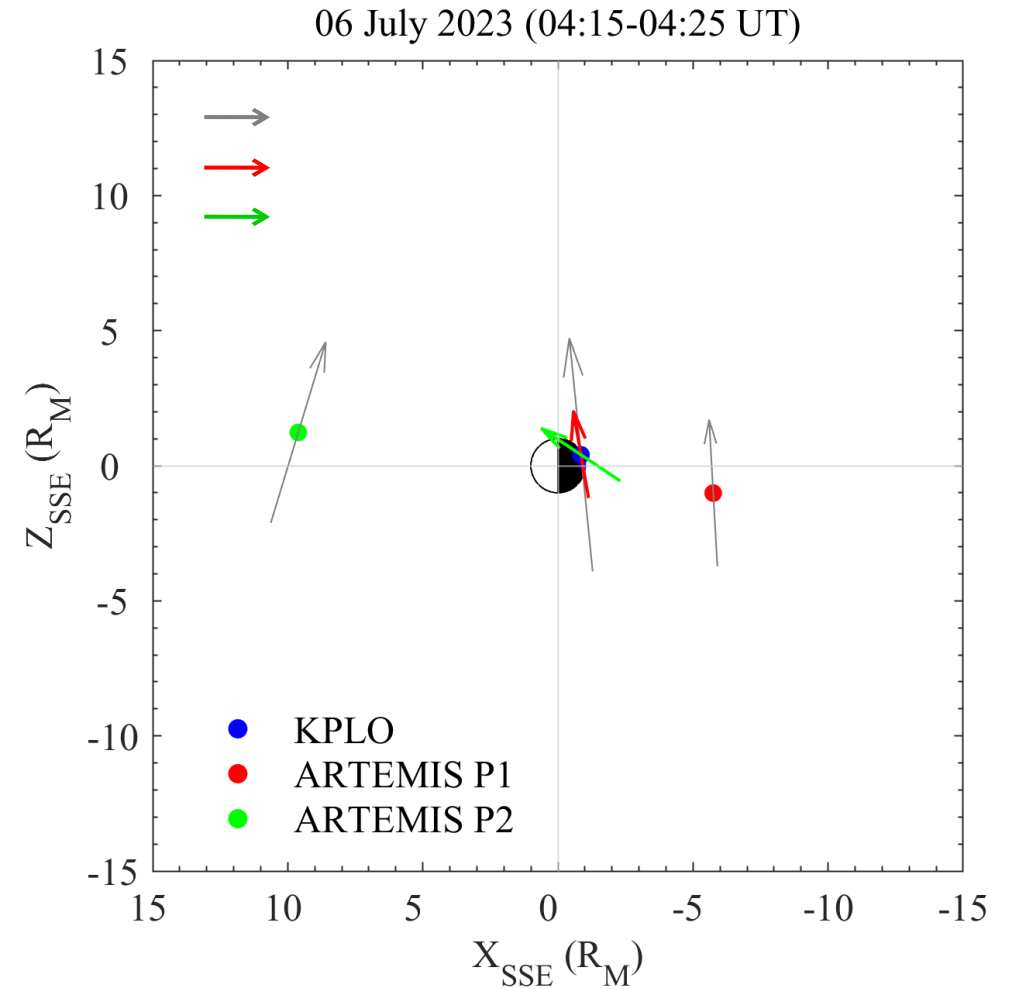
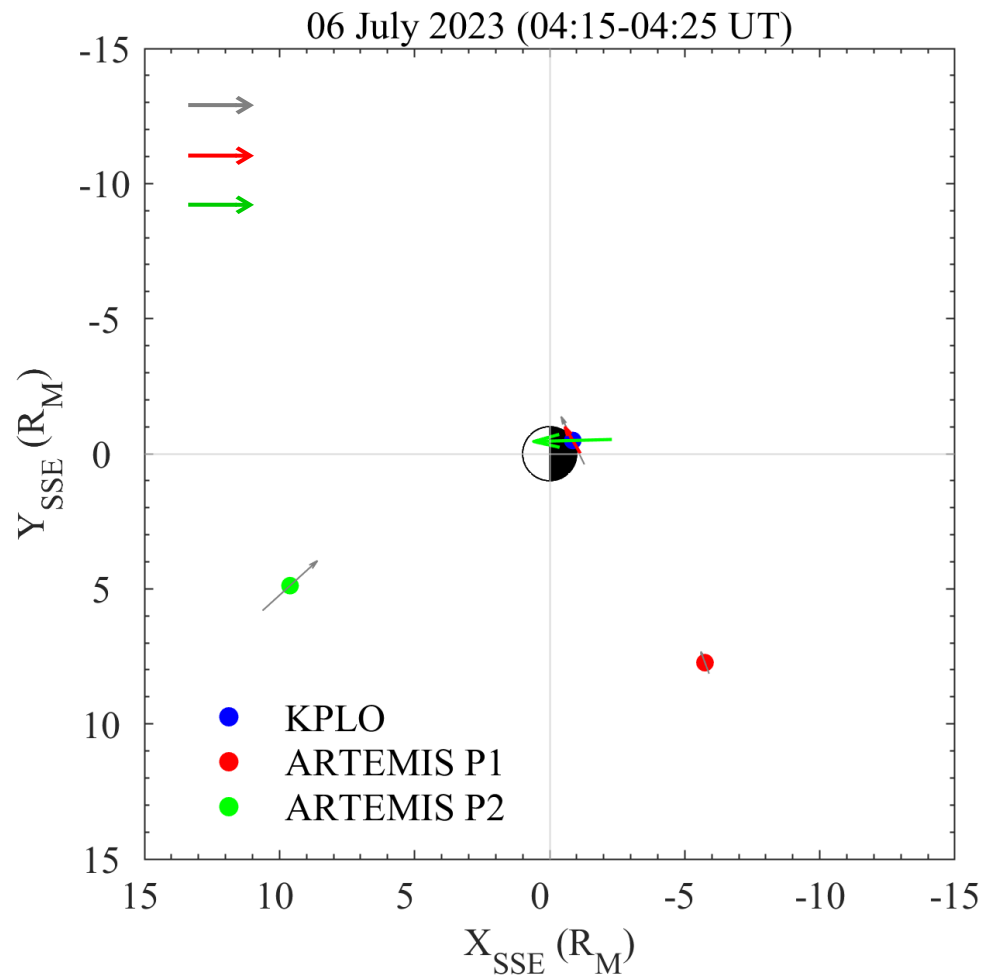
: mean vector before the transient field event  
: mean vector after the transient field event



# Appendix G. Event cases

Candidate 3. July 06, 2023 04:17

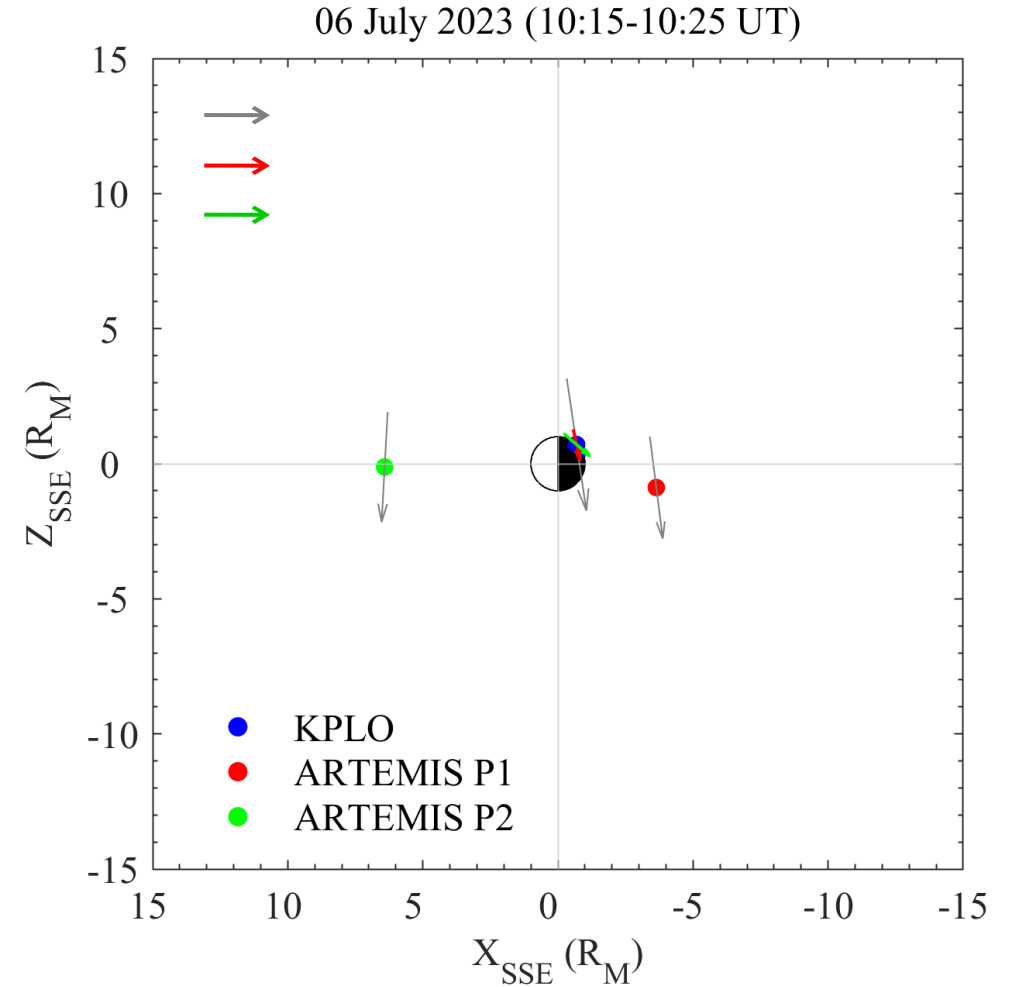
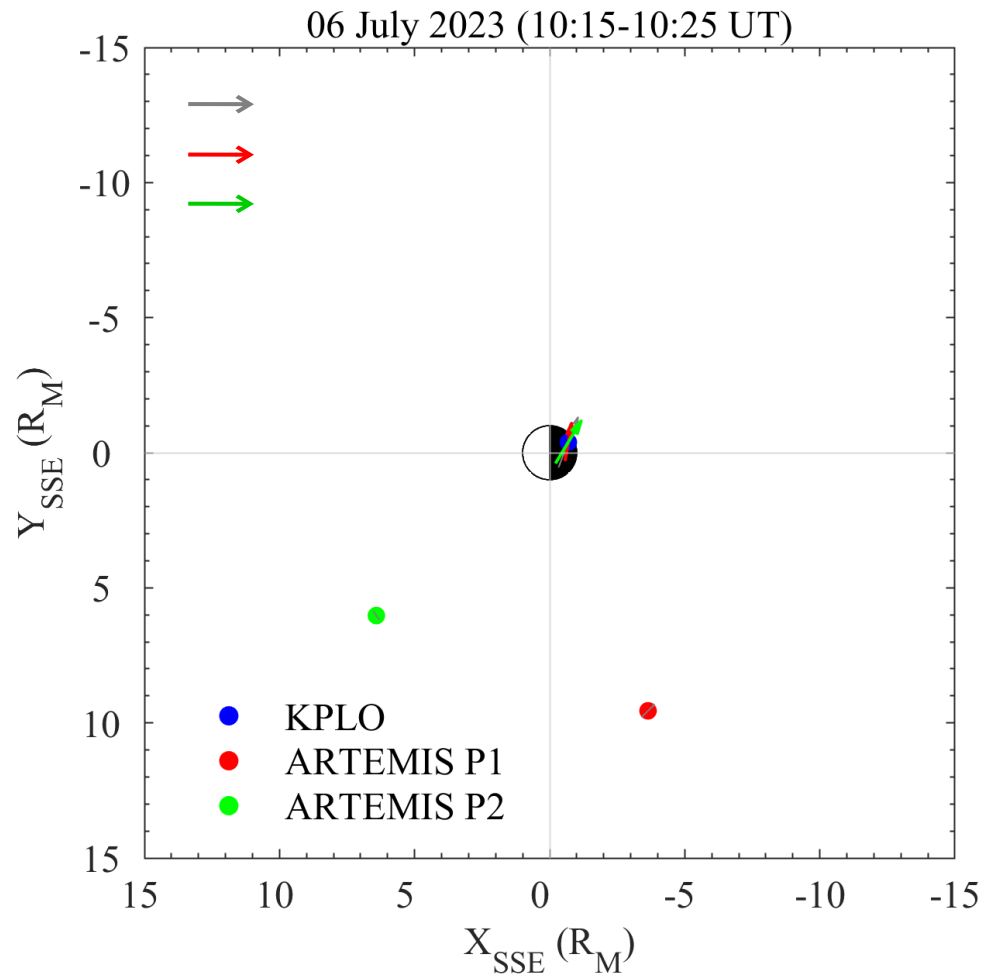
→ : mean vector before the transient field event  
→ : mean vector after the transient field event



# Appendix G. Event cases

Candidate 4. July 06, 2023 10:18

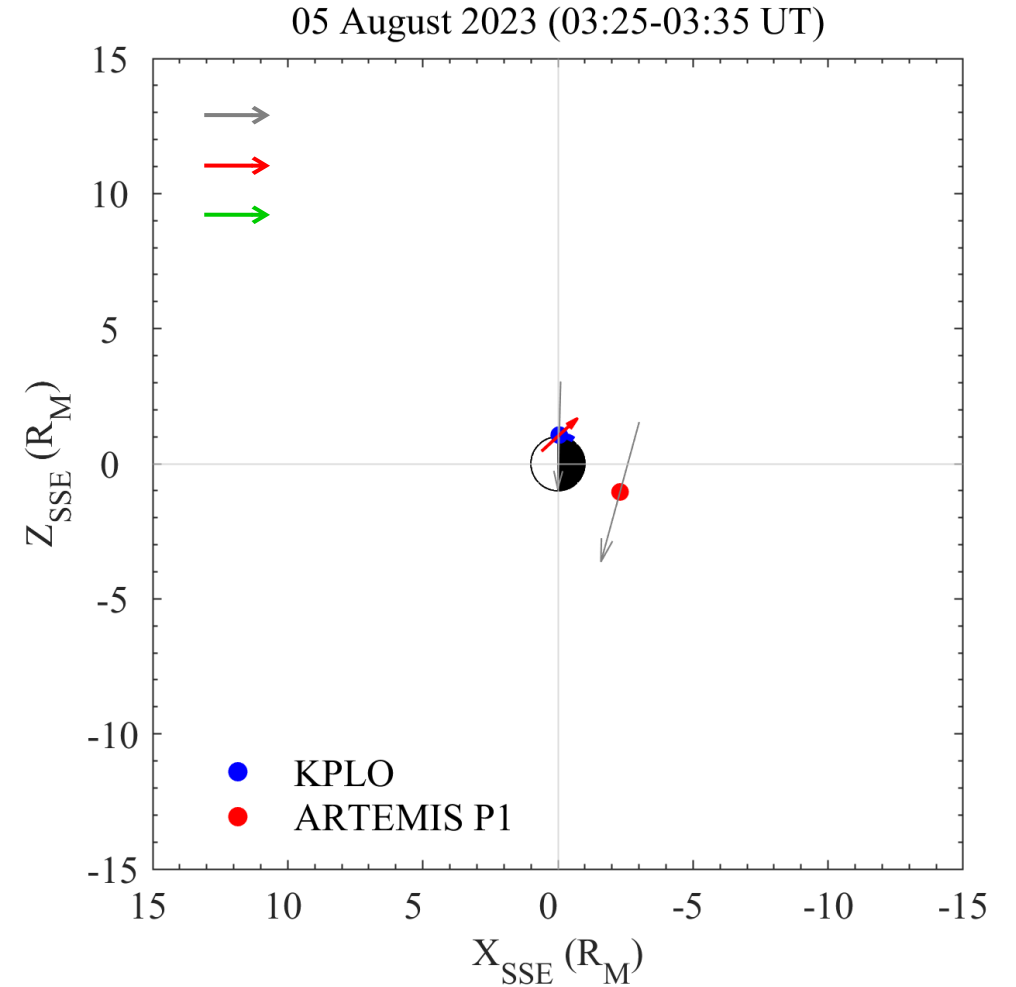
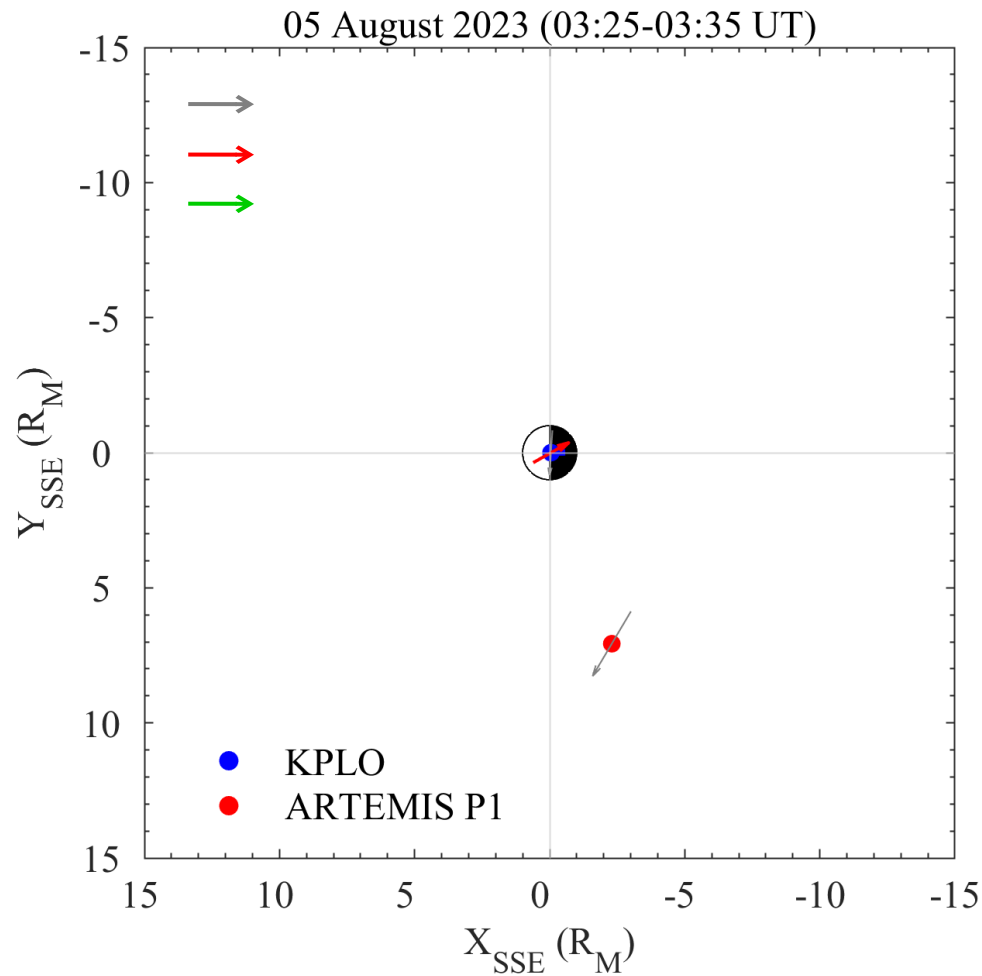
→ : mean vector before the transient field event  
→ : mean vector after the transient field event



# Appendix G. Event cases

Candidate 5. Aug 05, 2023 03:28

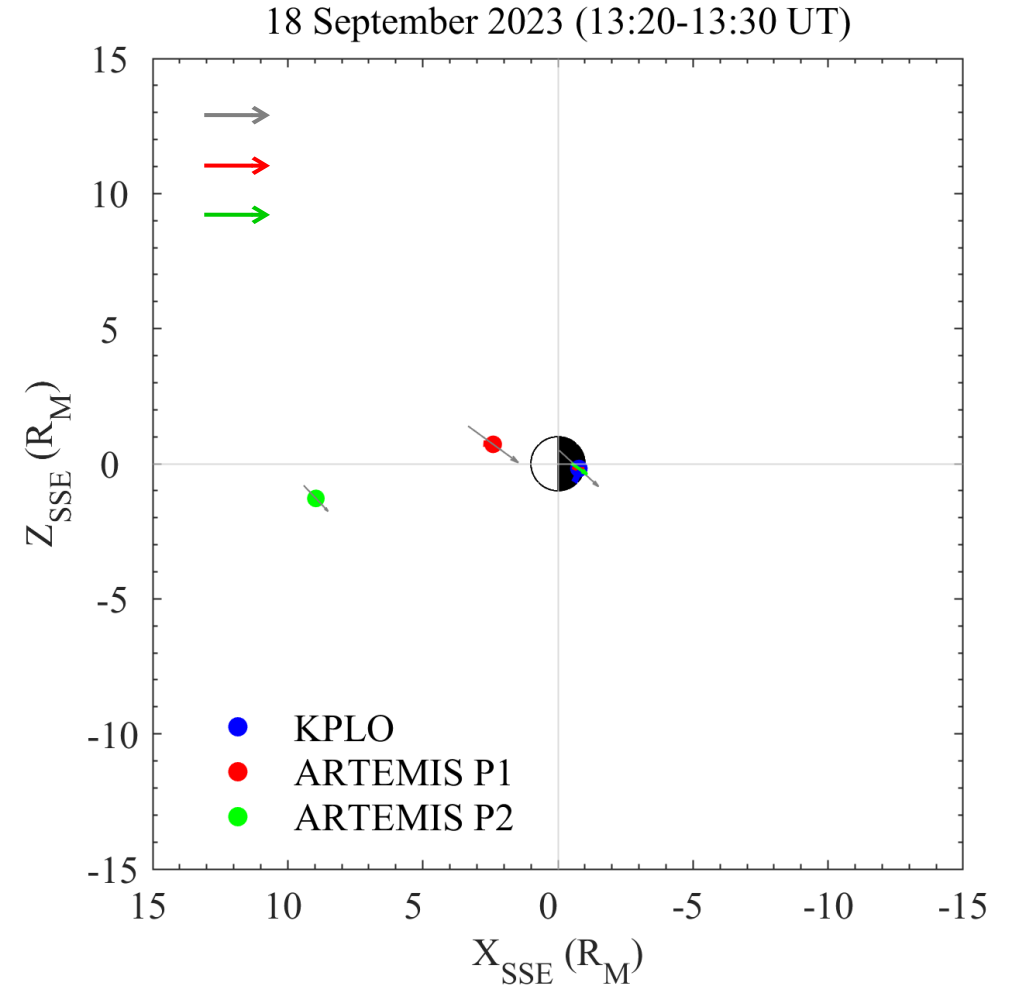
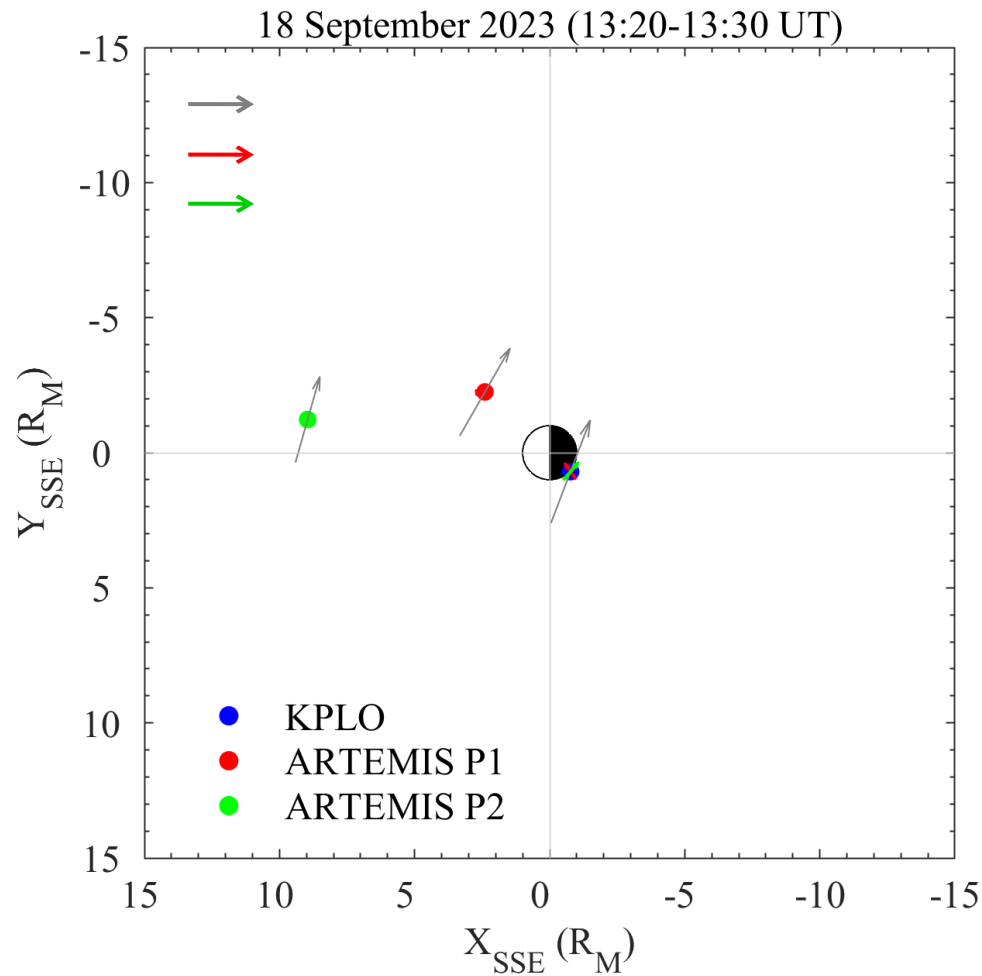
→ : mean vector before the transient field event  
→ : mean vector after the transient field event



# Appendix G. Event cases

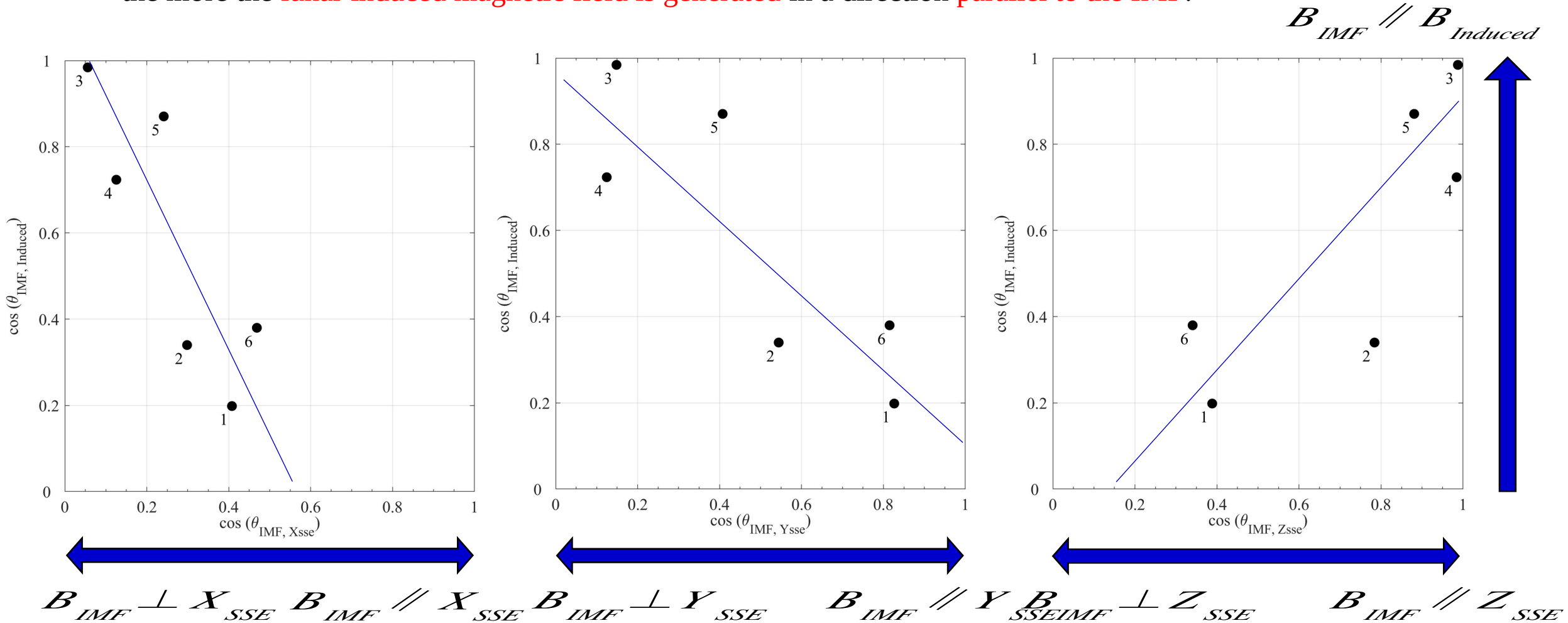
Candidate 6. Sep 18, 2023 13:27

→ : mean vector before the transient field event  
→ : mean vector after the transient field event



# Appendix H. Induced field direction analysis

- Based on the six events, the more parallel the IMF changes with the Z-axis in the SSE coordinates, the more the lunar induced magnetic field is generated in a direction parallel to the IMF.





## Appendix I. Results (2) make up

