PROBING THE INTERPLANETARY MAGNETIC FIELD WITH PLATFORM MAGNETOMETERS ON BOARD LISA PATHFINDER

Andrea Cesarini
Istituto Nazionale di Fisica Nucleare,
Sez. Firenze, Italy

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Abstract

LISA Pathfinder (LPF) was a European Space Agency (ESA) technology demonstrator of the Laser Interferometer Space Antenna (LISA). The LPF spacecraft (S/C) was orbiting around the Sun-Earth first Lagrangian libration point (L1), at about 1.5 millions of kilometers away from the Earth. The present study allowed to resolve the magnetic field (MF) generated on board (typically ~1 μT) from that of interplanetary origin (~1-25 nT) down to an overall statistical uncertainty of ~1.5 nT. The method described in this work may also apply to future LISA and LISA-like space interferometers. These missions represent natural multi-point observatories for probing both the interplanetary magnetic field (IMF) and high energy particles, thus providing precious clues on interplanetary physics and space weather science.

Content of the present document:

- The Space Environment and LISA(-like) gravitational wave observatories
- Lisa pathfinder (LPF) spacecraft: an `incidental' IMF sentinel in L1
- Platform magnetometer dataset inspection
- EM (wiring + electronics) and magnetic sources (AC+DC)
- Modeling, Analysis, Results and Conclusions
- EXTRA SLIDES providing further results and verifications

The Space Environment and LISA(-like) gravitational wave observatories

- This work has been carried out in the framework of the LISA Pathfinder (LPF) mission, the technology demonstrator of LISA and LISA-like future gravitational wave interferometer.

- Test Mass (TM) (non gravitational wave) spurious acceleration must be suppressed in order to achieve free-fall requirements. When TMs experience spurious accelerations, they should be carefully measured and/or estimated.

- The monitoring of the **space environment** becomes fundamental in order to guarantee the interferometer performances since plasma, interplanetary magnetic field and cosmic-rays interactions produces TM spurious accelerations in distinct frequency bands.

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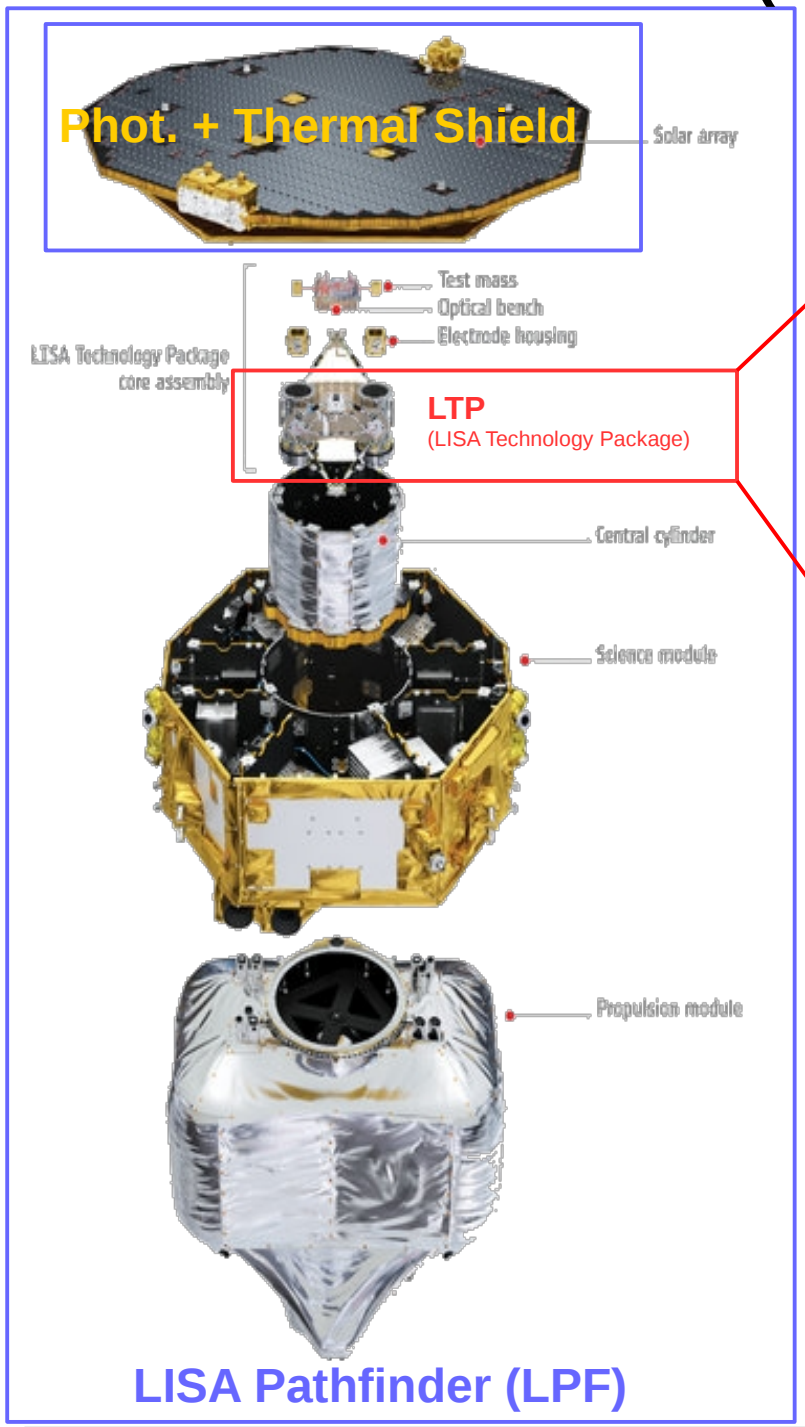
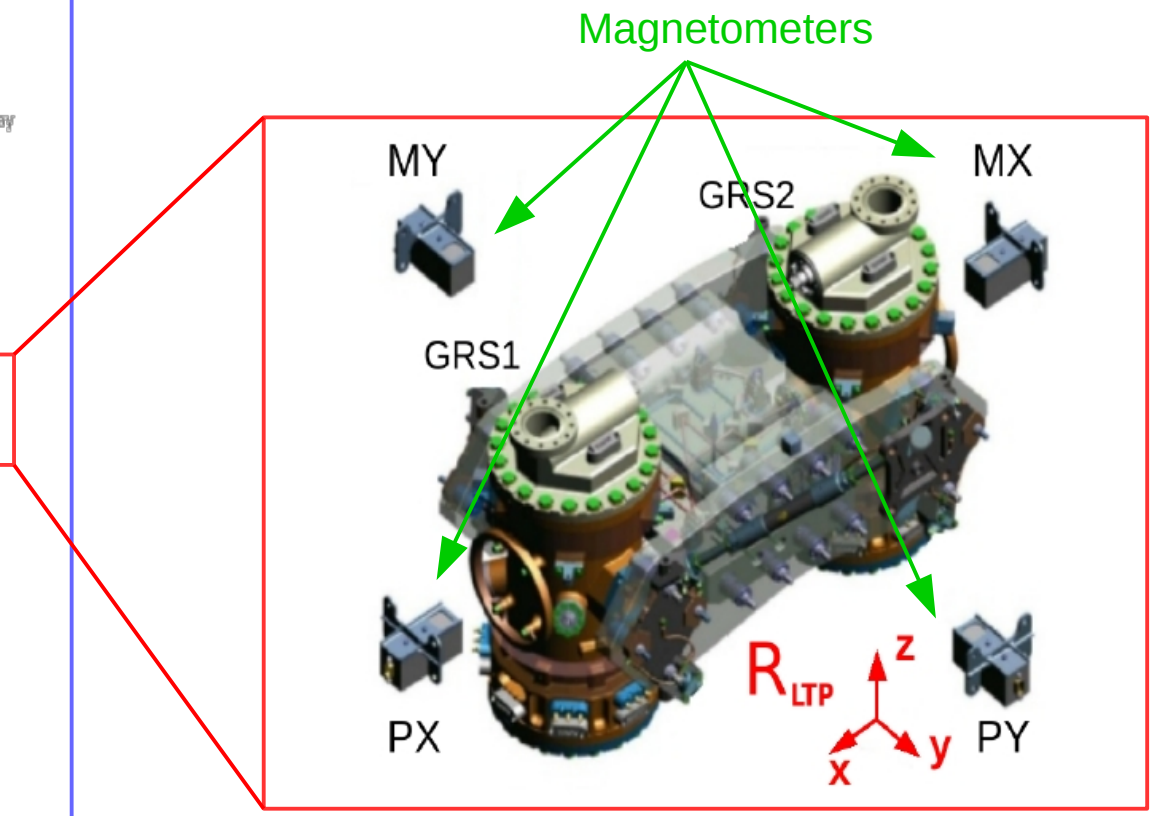
- The monitoring of the **space environment** becomes fundamental in order to guarantee the interferometer performances since plasma, interplanetary magnetic field and cosmic-rays interactions produces TM spurious accelerations in distinct frequency bands.

- Pre-mission estimations + LISA Pathfinder data analysis highlight that:
  - **Cosmic rays + SEPs** events induce charging noise and they become relevant between 10^-3 – 10^-4 Hz, see **Grimani's Talk, SPACEMON2020**)
  - **IMF** becomes relevant below 10^-5 Hz.

- However, a few aspects still needs to be further investigated: *e.g.* the passage of a magnetic structure as the ICME (Interplanetary Coronal Mass Ejection) which is able to produce an order of magnitude larger MF than the average IMF (roughly in the 10^-3 Hz - 10^-5 Hz frequency range).

Lisa Pathfinder (LPF) platform magnetometers





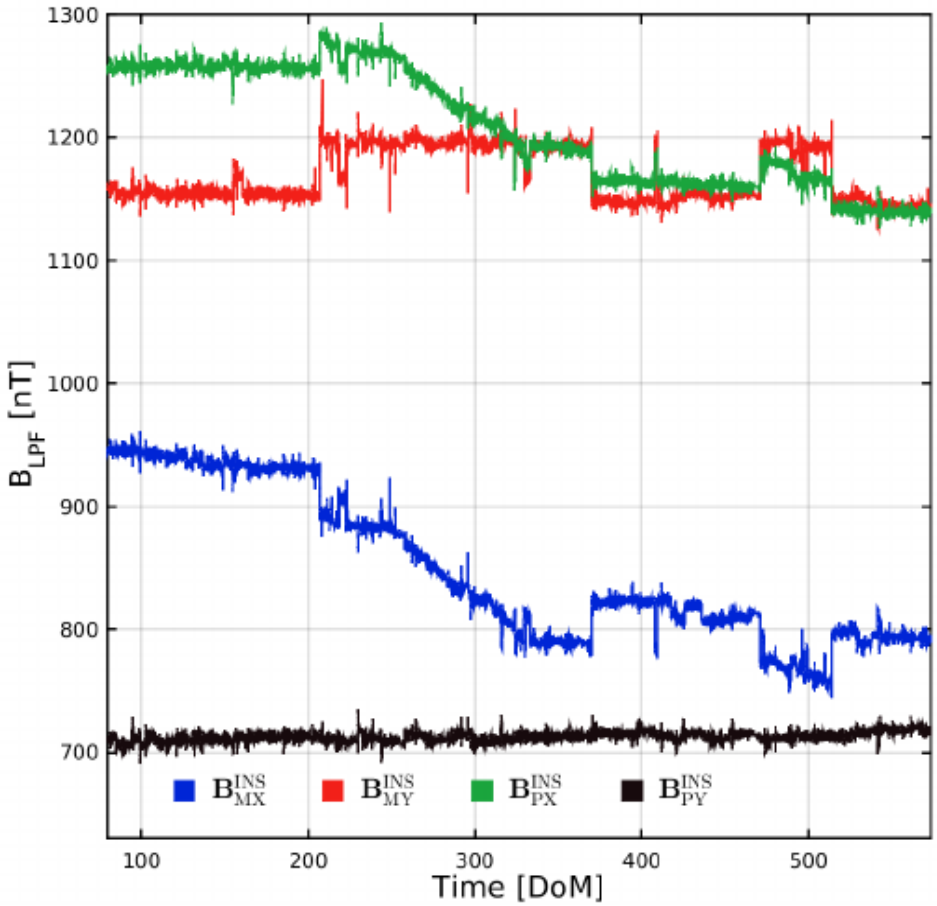
- **LPF Magnetometers** are placed at 1/3 of the way out from the S/C centre, MX and PX are placed at least ~18.85 cm from each of the proof test-masses (TMs).
- **Experimentally: ~50-300 nT** variation within the S/C (with 700-1200 nT disturbance trend).

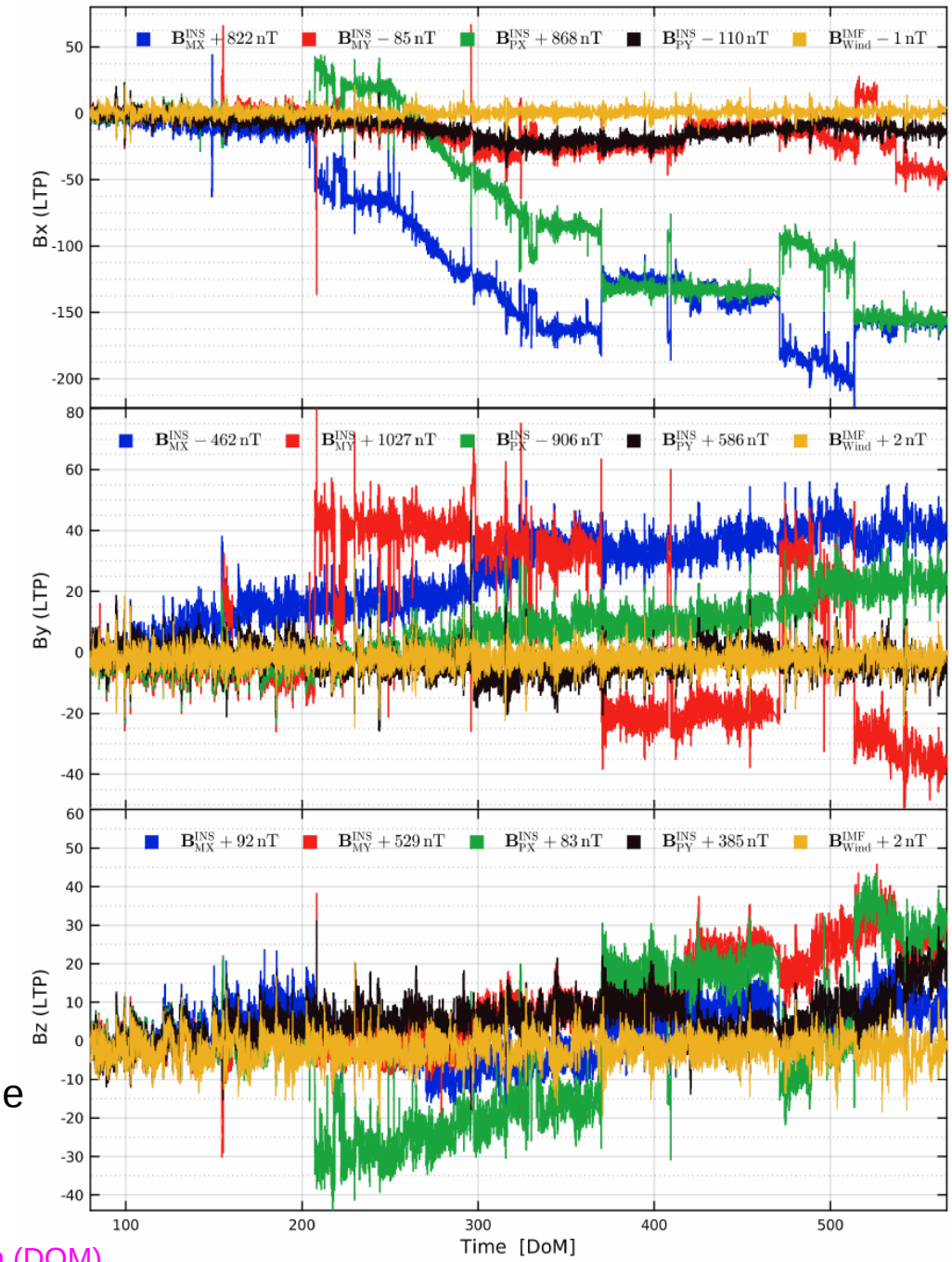
The MF noise originated on board is much larger than that of a dedicated IMF mission !!

Onboard magnetometer measurements

Onboard LPF MF measurements:

- Dominant intensity variations in the 1-25 nT range are mainly ascribable to the IMF
- The 0.1-1.2 μT disturbance must necessarily originate on board.



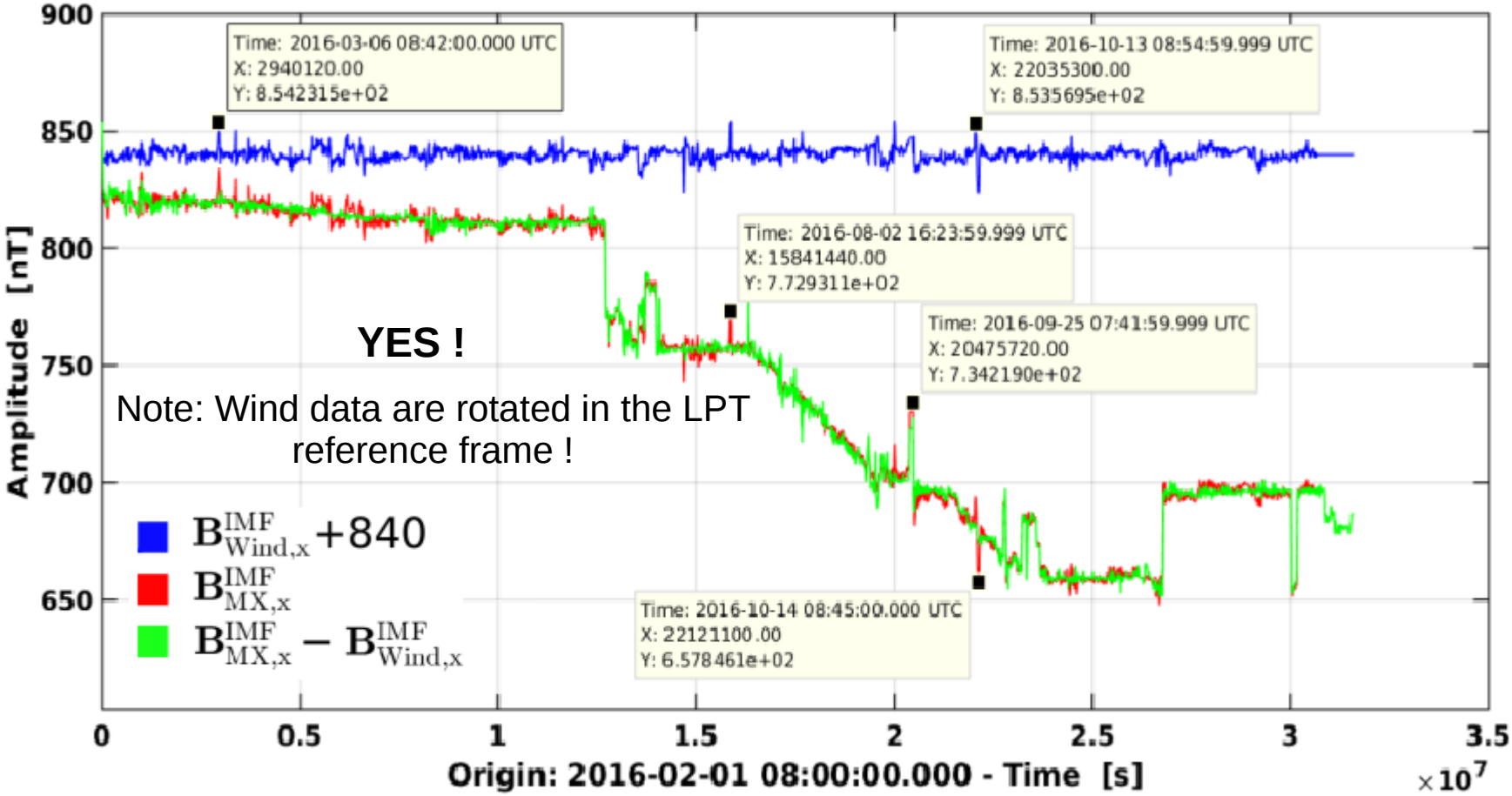


Measurements show many variability patters (with the partial exception of the PY magnetometer)

Note: The x-axis indicates the mission elapsed time in day-of-mission (DOM).

Are the LPF on-board magnetometers able to sense the IMF?

YES, LISA Pathfinder was an `incidental' IMF sentinel in L1



- Thus, taking advantage of platform magnetometers, LPF might become an "*incidental*" IMF sentinel !!

- We propose to build a S/C empirical model of the onboard generated MF to clean the measurements gathered from platform magnetometers.

Empirical MF S/C model

- Indeed,

$$\mathbf{B}_m^{\mathrm{MAG}}[t] = \mathbf{B}_m^{\mathrm{LPF}}[t] + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

$$= \boxed{\mathbf{B}_m^{\mathrm{EM}}[t]} + \mathbf{B}_m^{\mathrm{M}}[t] + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

Which is the impact on the electromagnetic field produced by wiring and electronics ?

$$\mathbf{B}_m^{\mathrm{EM}}[t] = \mathbf{B}_m^{\mathrm{EW}}[t] + \mathbf{B}_m^{\mathrm{ED}}[t]$$

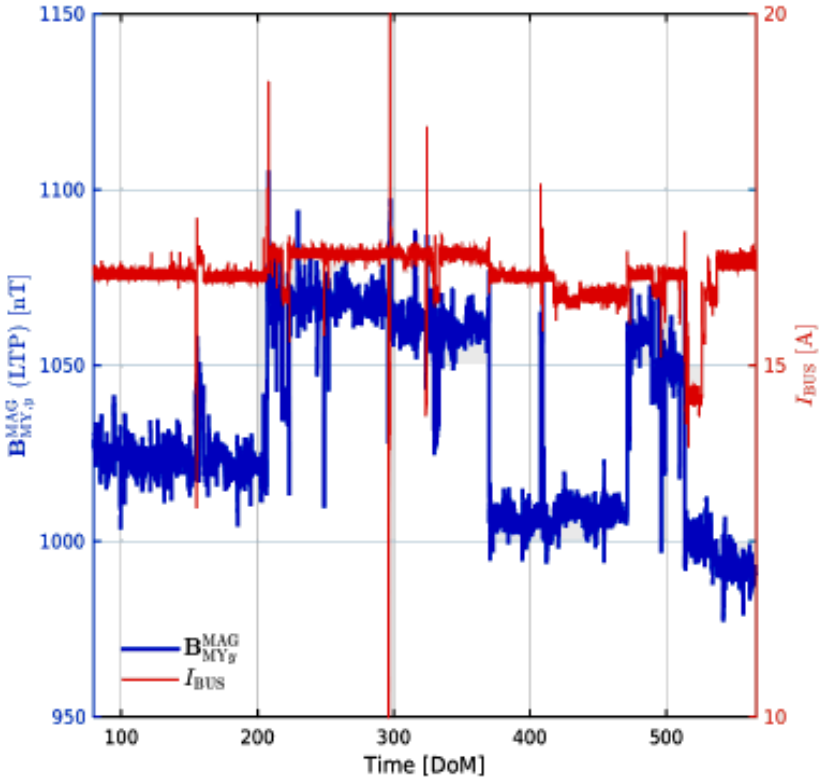
Wiring

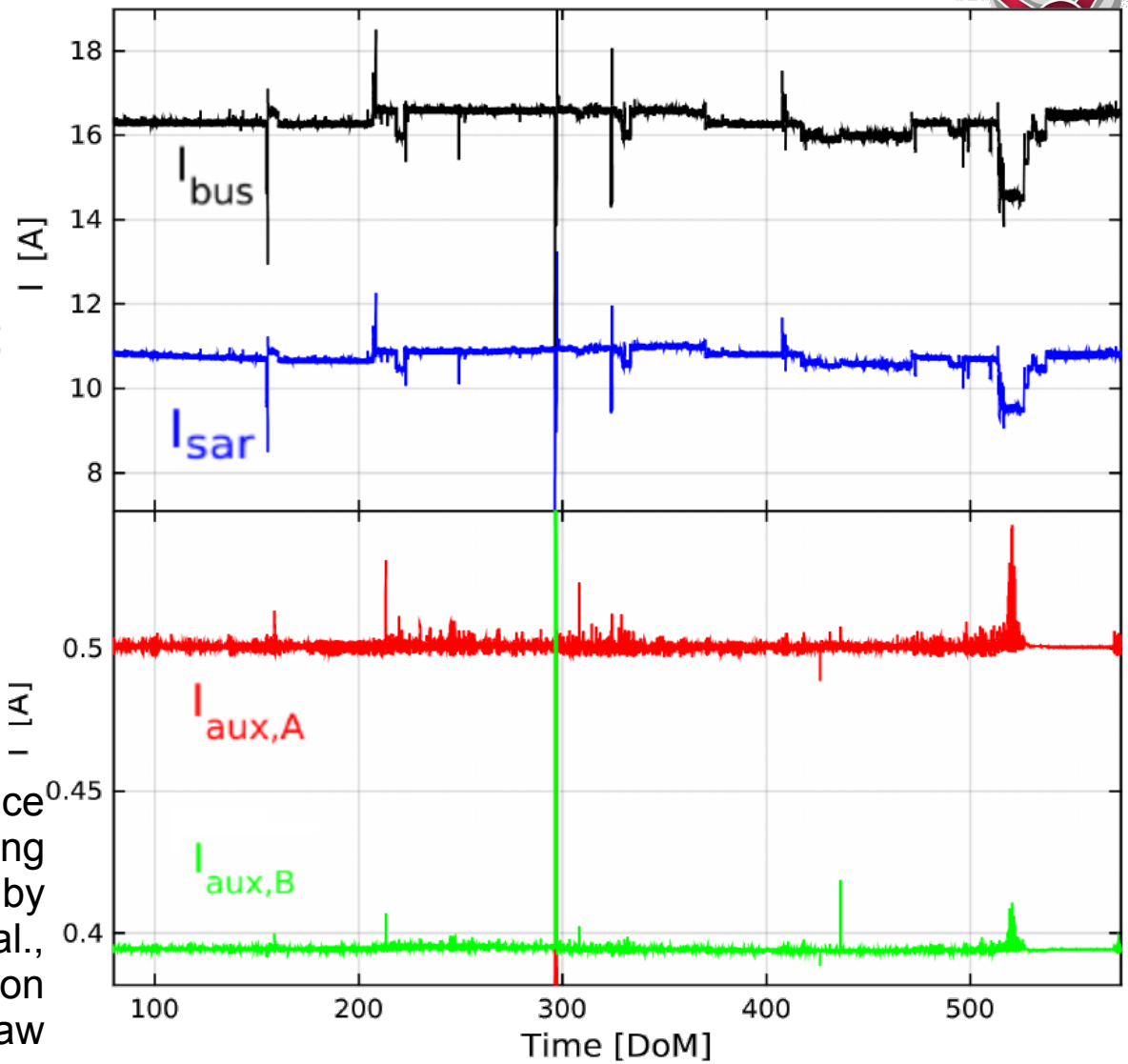
Electronics

?

Wiring

- Also the current bus (alongside the IMF) explains <u>mid- and short-timescale variations.</u>
- The onboard MF variations are well correlated with current main bus and solar array busses variations.





Electric currents carried by bus wires produce spurious MFs (see **left figure**). Considering the relevant currents (**right figure**) and by exploiting the superposition principle (Yu et al., 2013), it is possible to model the MF variation arising by wiring with the Biot-Savart law applied to each *j*-th current bus, with a proper parameterization, **am,j**.

Empirical MF S/C model - 2

- Indeed,

$$\mathbf{B}_m^{\mathrm{MAG}}[t] = \mathbf{B}_m^{\mathrm{LPF}}[t] + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

$$= \mathbf{B}_m^{\mathrm{EM}}[t] + \mathbf{B}_m^{\mathrm{M}}[t] + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

Which is the impact on the electromagnetic field produced by wiring and electronics ?

$$\mathbf{B}_m^{\mathrm{EM}}[t] = \mathbf{B}_m^{\mathrm{EW}}[t] + \mathbf{B}_m^{\mathrm{ED}}[t]$$

In the case of selecting 3 current buses

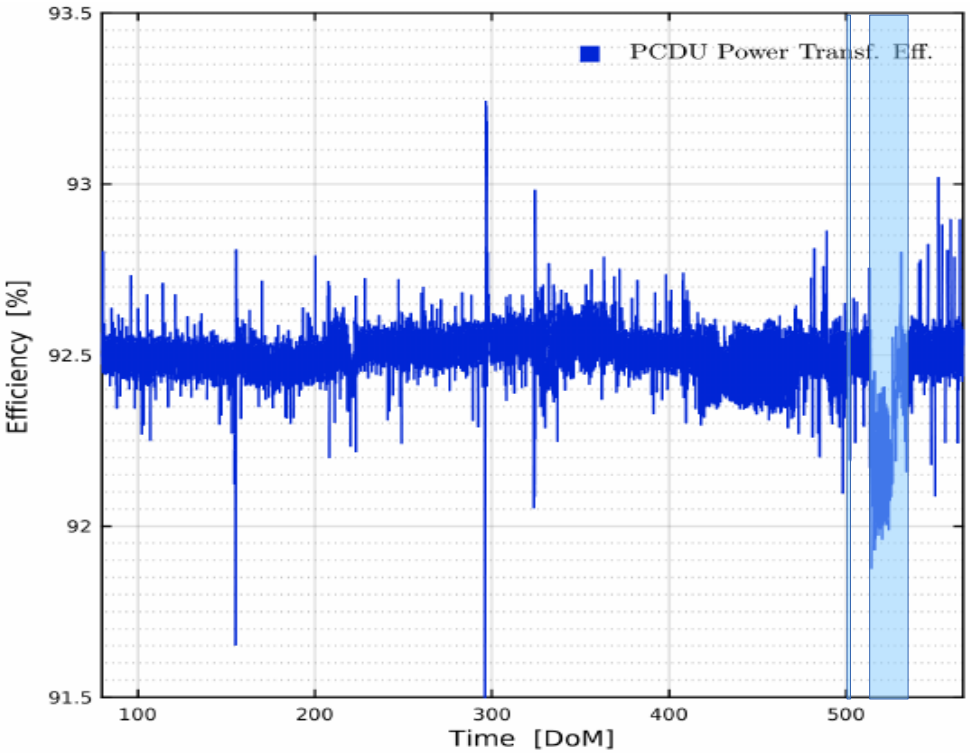
$$\mathbf{B}_m^{\mathrm{EW}}[t] = \sum_{j=1}^{3} \frac{\mu_0}{4\pi} \int_{C_j} \frac{I_j[t]}{r_{m,j}^2} d\mathbf{l}_j \times \mathbf{u}_{m,j} =$$

$$= \sum_{j=1}^{3} \int_{C_j} \frac{\mu_0}{4\pi} \frac{d\mathbf{l}_j \times \mathbf{u}_{m,j}}{r_{m,j}^2} I_j[t] =$$

$$= \boxed{\sum_{j=1}^{3} \mathbf{a}'_{m,j} I_j[t]}$$

$\mathbf{B}_m^{\mathrm{ED}}[t]$ ...

Power conversion efficiency and the electronics setup



Although the operation mode was changing during the mission, the voltage working point was very stable and the power conversion efficiency too.

$$\eta[t] = \frac{P_{\mathrm{OUT}}}{P_{\mathrm{IN}}} = \frac{I_{\mathrm{Bus}} V_{\mathrm{Bus}}}{(I_{\mathrm{SA}} + I_{\mathrm{DCH}} - I_{\mathrm{CH}}) V_{\mathrm{SA}}}$$

$$\begin{aligned} &\mathbf{B}_m^{\mathrm{EW}}[t] + \mathbf{B}_m^{\mathrm{ED}}[t] = \\ &= \sum_{j=1}^{3} \mathbf{a}'_{m,j}\, I_j[t] + \sum_{j=1}^{3} \mathbf{a}''_{m,j}\, I_j[t] = \\ &= \sum_{j=1}^{3} (\mathbf{a}'_{m,j} + \mathbf{a}''_{m,j})\, I_j[t] = \\ &= \sum_{j=1}^{3} \mathbf{a}_{m,j}\, I_j[t]\,. \end{aligned}$$

Timespan [Number]	Conf [Type]	Subs [ID]	Start Time [UTC]	Stop Time [UTC]	Duration [Days]
1	DFACS	1A	2016-02-20, 22:20	2016-05-04, 23:45	74
2	DFACS	1B	2016-05-11, 16:35	2016-06-27, 06:00	46
3	DRS	1A	2016-07-12, 09:55	2016-09-23, 00:05	72
4	DRS	1B	2016-09-26, 10:00	2016-10-21, 16:40	25
5	DFACS+	1A	2016-10-31, 16:35	2016-12-07, 03:35	36
6	DFACS+	1B	2016-12-08, 13:45	2017-01-13, 10:00	35
7	DFACS+	1C	2017-01-17, 06:30	2017-01-22, 23:45	5
8	DFACS+	2A	2017-01-25, 00:45	2017-02-01, 11:45	7
9	DFACS+	3	2017-02-02, 14:15	2017-02-10, 19:55	8
10	DFACS+	2B	2017-02-13, 17:35	2017-03-14, 06:00	28
11	DRS	2A	2017-03-18, 10:00	2017-04-05, 10:50	18
12	DRS	3	2017-04-05, 12:55	2017-04-12, 04:05	6
13	DRS	2B	2017-04-13, 02:15	2017-04-29, 07:30	16
14	DFACS+	4A	2017-04-30, 00:05	2017-05-23, 07:30	23
15	DFACS+	4B	2017-05-24, 20:25	2017-06-21, 20:00	27

Empirical MF S/C model - 3

- We propose to produce a S/C magnetic phenomenological model of the onboard generated MF to clean the measurements gathered from LPF platform magnetometers.

- Indeed,

$$\mathbf{B}_m^{\mathrm{MAG}}[t] = \mathbf{B}_m^{\mathrm{LPF}}[t] + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

$$= \mathbf{B}_m^{\mathrm{EM}}[t] + \boxed{\mathbf{B}_m^{\mathrm{M}}[t]} + \mathbf{B}_m^{\mathrm{IMF}}[t] + \mathbf{v}_m^c[t]$$

in the case of selecting 3 current buses + electronic devices for each timespan in which the power conversion efficiency is stable:

$$\mathbf{B}_m^{\mathrm{EW}}[t] + \mathbf{B}_m^{\mathrm{ED}}[t] =$$

$$= \sum_{j=1}^{3} \mathbf{a}'_{m,j}\, I_j[t] + \sum_{j=1}^{3} \mathbf{a}''_{m,j}\, I_j[t] =$$

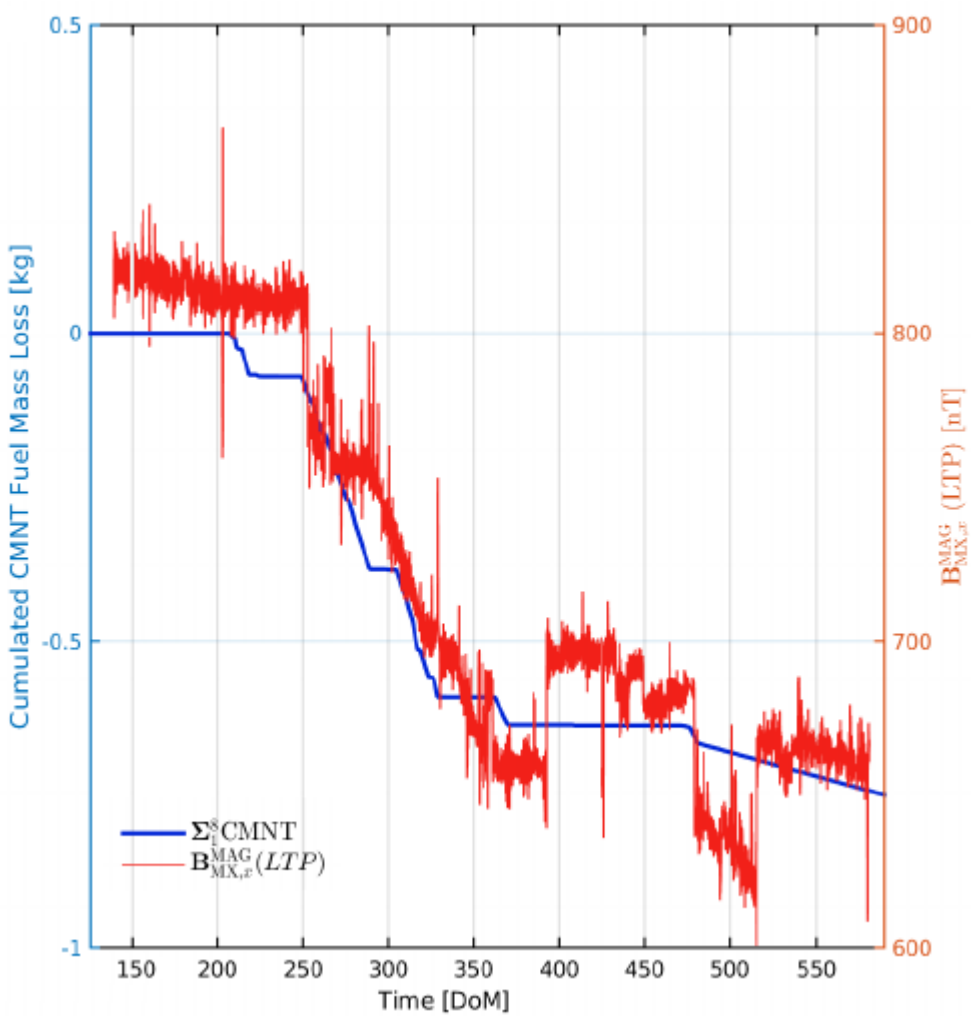
$$= \sum_{j=1}^{3} (\mathbf{a}'_{m,j} + \mathbf{a}''_{m,j})\, I_j[t] =$$

$$\boxed{\sum_{j=1}^{3} \mathbf{a}_{m,j}\, I_j[t]}.$$

$$\boxed{\mathbf{B}_m^{\mathrm{M}}[t] = \cancel{\mathbf{B}_m^{\mathrm{SC}}[t]} + \mathbf{B}_m^{\mathrm{CMNT}}[t]}$$

Insights on the mid- and long-term onboard magnetic field variations

- The long time-scale variation of the on-board MF seems to be related with the use of the Colloidal Micro-Newton Thrusters (CMNTs).



The correlation arises because the propellant was stored in a stack of four compressible bellows held with a spring connected to a moving assembly. The motion of as such eventually magnetized mechanical part would be able to justify the experienced MF variation

$$\mathbf{B}_m^{\mathrm{CMNT}}[t] = \mathbf{l}_m \; M[t]$$

Empirical MF S/C model - 4

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In the case of selecting 3 current buses + electronic devices for each timespan in which the power conversion efficiency is stable:

$$\mathbf{B}_m^{\mathrm{EW}}[t] + \mathbf{B}_m^{\mathrm{ED}}[t] =$$

$$= \sum_{j=1}^{3} \mathbf{a}'_{m,j}\, I_j[t] + \sum_{j=1}^{3} \mathbf{a}''_{m,j}\, I_j[t] =$$

$$= \sum_{j=1}^{3} (\mathbf{a}'_{m,j} + \mathbf{a}''_{m,j})\, I_j[t] =$$

$$\boxed{\sum_{j=1}^{3} \mathbf{a}_{m,j}\, I_j[t]}.$$

And finally

$$\boxed{\mathbf{B}_m^{\mathrm{M}}[t] = \cancel{\mathbf{B}_m^{\mathrm{SC}}[t]} + \boxed{\mathbf{B}_m^{\mathrm{CMNT}}[t]}}$$

with

$$\boxed{\mathbf{B}_m^{\mathrm{CMNT}}[t] = \mathbf{l}_m\, M[t]}$$

Interplanetary Magnetic Field (IMF) model

- Therefore, with the help of the equations already presented:

$$\mathbf{B}_m^{\mathrm{LTP}}[t] = \mathbf{B}_m^{\mathrm{EM}}[t] + \mathbf{B}_m^{\mathrm{M}}[t] = \sum_{i=1}^{3} \mathbf{B}_m^{\mathrm{BS}}[t] + \mathbf{B}_m^{\mathrm{CMNT}}[t] = \boxed{= \sum_{j=1}^{3} \mathbf{a}_{m,j}\, I_j[t] + \mathbf{l}_m\, \tilde{M}[f]}$$

$$? \; \mathbf{B}_m^{\mathrm{IMF}}[t] = \boxed{\mathbf{B}_m^{\mathrm{MAG}}[t]} - \boxed{\mathbf{B}_m^{\mathrm{LTP}}[t]} + \mathbf{v}_m^c[t] =$$

$$= \boxed{\mathbf{B}_m^{\mathrm{MAG}}[t]} - \boxed{\sum_{j=1}^{3} \mathbf{a}_{m,j}\, I_j[t] - \mathbf{l}_m\, M[t]} + \mathbf{v}_m^c[t]$$

Measurements!!

To be minimized !!

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Markov Chain Monte Carlo (MCMC) Fitting

Using the Markov Chain Monte Carlo (MCMC) algorithm provided by the LPF Data Analysis toolbox (which was developed specifically for the analysis of the LPF mission data), it allowed to sample the posterior distributions of the introduced model parameters.
Moreover, the least squares estimate adopted by the fitting algorithm is carried out in the frequency-domain . The parameters **am,j** and **lm** appearing in the equation below are estimated by minimizing the residue among the collected data and the model of the already introduced onboard generated MF as follows:

$$\tilde{\mathbf{B}}_m^{\mathrm{IMF}}[f] = \tilde{\mathbf{B}}_m^{\mathrm{MAG}}[f] - \sum_{j=1}^{3} \mathbf{a}_{m,j}\, \tilde{I}_j[f] - \mathbf{l}_m\, \tilde{M}[f] + \tilde{\mathbf{v}}_m^c[f]$$

assuming

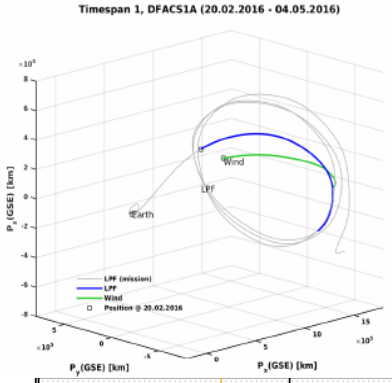
$$\theta_m = \left[\sum_{j=1}^{3} \mathbf{a}_{m,j}\, , \mathbf{l}_m \right]^T$$

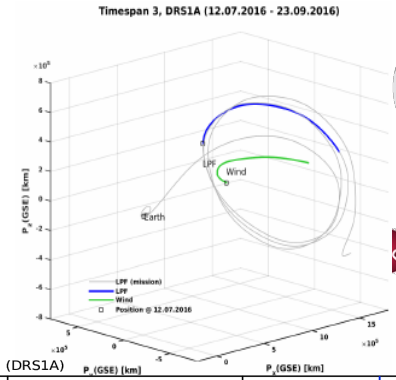
it is obtained

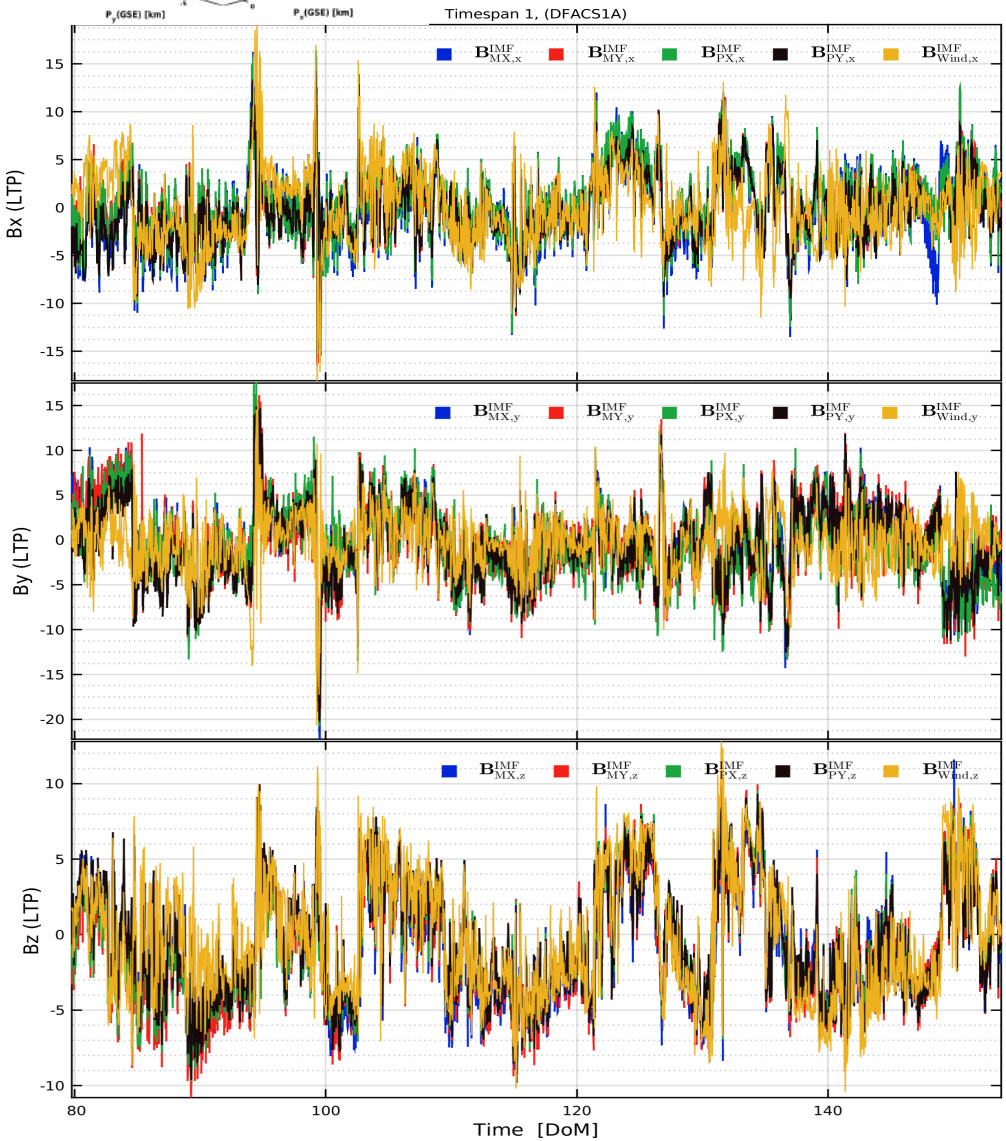
$$\hat{\theta}_m \simeq \arg\min_{\theta} \left| \tilde{\mathbf{B}}_m^{\mathrm{MAG}}[f] - \tilde{\mathbf{B}}_m^{\mathrm{LTP}}(\theta)[f] \right|$$

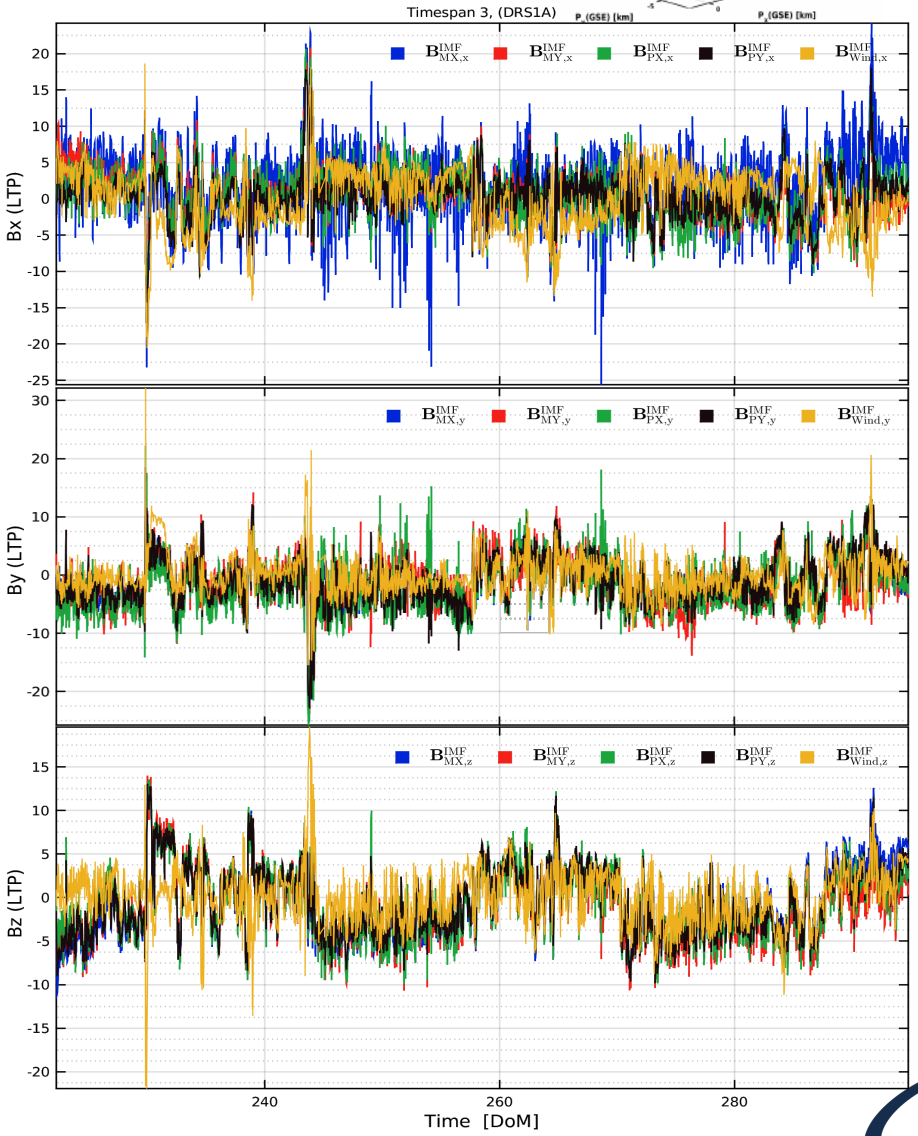
Results for TS1 and TS3

LPF vs Wind Timeseries comparison



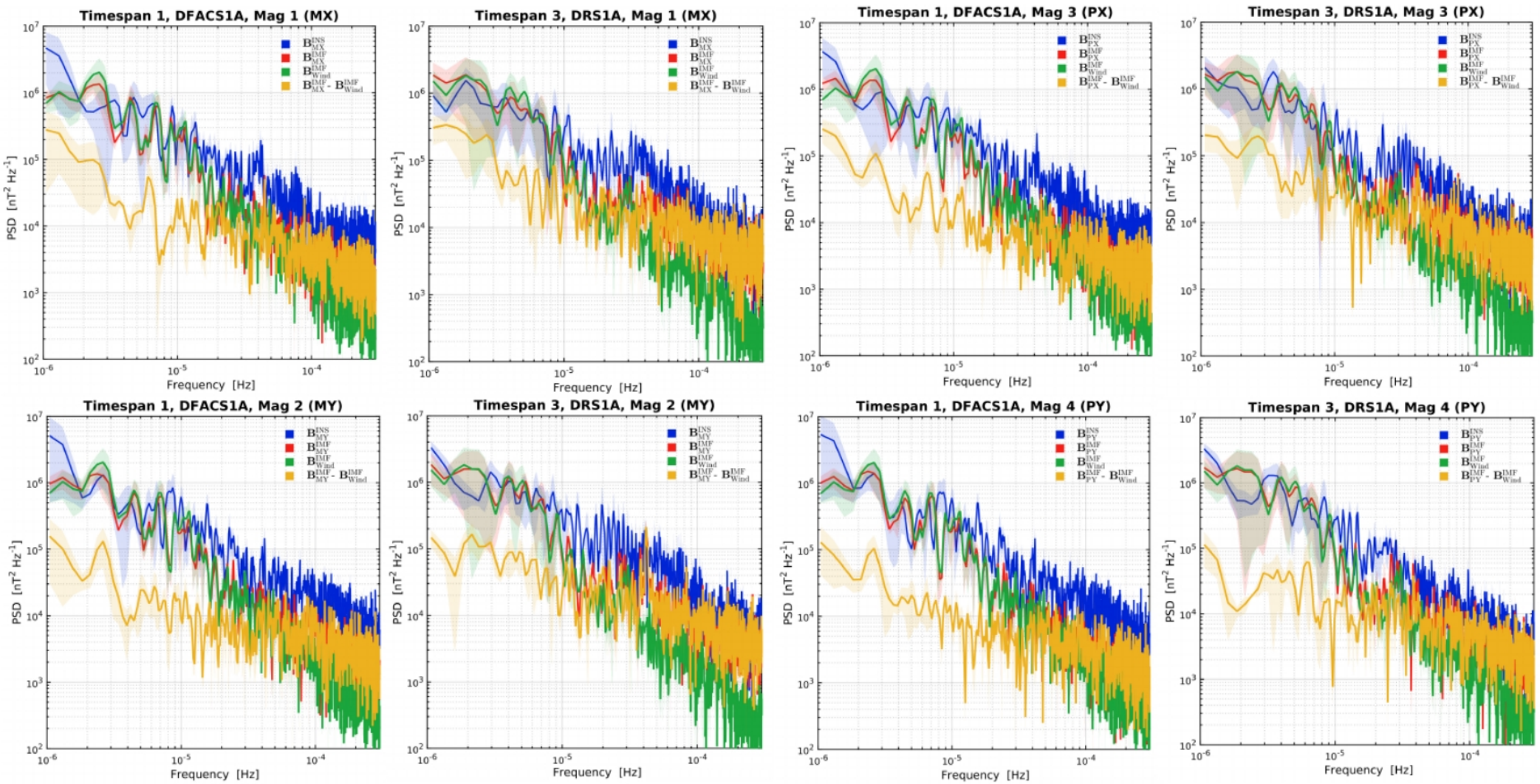






Results for TS1 and TS3

LPF vs Wind PSDs comparison



Probing the interplanetary magnetic field in L1 on board LISA Pathfinder with platform magnetometers

Space Environment Monitoring Workshop 2020 (SPACEMON2020), December 1-3, 2020, ESA/ESTEC, Andrea Cesarini

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Conclusions

- LPF onboard magnetometers are immersed in a strong magnetic field (~700-1200nT) considering IMF values in L1 (which are in the 1-25 nT range).
- The onboard generated MF varies at all timescales (short-, mid- and long-) and along all the 3-Cartesian axes.
- Identifiable and separable contributions originating by different onboard processes drive the MF variation in different frequency bands. As shown in this presentation, even within the short 10^-4 – 10^-6 Hz band, in the case of LPF there is the contribution of at least 4 processes !!
- In general, in order to systematically employ magnetometer platform measurements, an empirical MF noise model can be produced per each S/C design even when already in-flight (provided availability of the whole housekeeping dataset).
- **For the first time, we shown that it is possible to systematically separate the onboard generated MF from the IMF (with a residual around ~1-5 nT for the whole mission) and we tested our empirical approach against the Wind dataset.**
- **In the case of space-based gravitational wave interferometers, we shown that it is possible to effectively monitoring the space environment since having MAGs + PD on board the same S/C enables to infer the speed of the solar wind !!**
- **MOREOVER, these results enable LISA and LISA-like missions to trigger dedicated studies on**
    - **Space weather (science)**
    - **Interplanetary physics studies (science)**
    - **Advance in space science (engineering [HW + SW to reduce mission costs])**
    - **Further probing of S/C subsystems (engineering)**

Thanks

EXTRA

Overall Fit parameters (2)

MAG1 Coefficients	$\mathbf{a_1}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_2}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_3}$[nT nA^{-1}] *value* ± *Δerror* (%)
1 **DFACS1A** (74 days)	a_{1x} = −69.638 ± 5.87 (8%) a_{1y} = 75.271 ± 5.682 (7%) a_{1z} = 35.67 ± 7.591 (21%)	a_{2x} = 108.11 ± 8.062 (7%) a_{2y} = −126.72 ± 8.488 (7%) a_{2z} = −36.602 ± 10.36 (28%)	a_{3x} = 1997 ± 86.56 (4%) a_{3y} = −812.57 ± 67.51 (8%) a_{3z} = −240.66 ± 97.07 (40%)
2 **DFACS1B** (46 days)	a_{1x} = 82.426 ± 25.140 (30%) a_{1y} = 7.2615 ± 23.110 (↑) a_{1z} = 38.984 ± 23.420 (60%)	a_{2x} = −105.07 ± 37.760 (36%) a_{2y} = −29.167 ± 34.600 (↑) a_{2z} = −39.822 ± 35.510 (89%)	a_{3x} = 1496.0 ± 105.20 (7%) a_{3y} = −646.02 ± 115.30 (18%) a_{3z} = −39.822 ± 35.510 (37%)
3 **DRS1A** (72 days)	a_{1x} = 4.8856 ± 30.310 (54%) a_{1y} = −18.274 ± 36.110 (24%) a_{1z} = 20.202 ± 39.290 (58%)	a_{2x} = −82.799 ± 22.060 (27%) a_{2y} = 122.27 ± 28.240 (23%) a_{2z} = −54.139 ± 30.690 (57%)	a_{3x} = 3070.8 ± 40.540 (1%) a_{3y} = −1108.8 ± 65.880 (6%) a_{3z} = 233.42 ± 64.390 (28%)
4 **DRS1B** (25 days)	a_{1x} = −32.744 ± 27.290 (83%) a_{1y} = −1.6031 ± 35.570 (↑) a_{1z} = −19.424 ± 34.940 (↑)	a_{2x} = 65.133 ± 40.180 (62%) a_{2y} = −3.3094 ± 52.720 (↑) a_{2z} = 34.140 ± 52.270 (↑)	a_{3x} = 1508.8 ± 92.410 (6%) a_{3y} = −934.32 ± 133.00 (14%) a_{3z} = 125.07 ± 123.90 (99%)
5 **DRS1C** (36 days)	a_{1x} = −24.991 ± 16.24 (44%) a_{1y} = −25.892 ± 16.08 (41%) a_{1z} = −8.9309 ± 19.11 (↑)	a_{2x} = 52.380 ± 16.240 (31%) a_{2y} = 30.056 ± 16.080 (53%) a_{2z} = −8.9309 ± 19.110 (↑)	a_{3x} = 1515.8 ± 128.50 (7%) a_{3y} = −1100.3 ± 154.70 (13%) a_{3z} = 115.64 ± 191.20 (33%)
6 **DFACS + 1A** (35 days)	a_{1x} = 85.242 ± 29.72 (73%) a_{1y} = −90.134 ± 38.43 (68%) a_{1z} = 101.51 ± 33.29 (↑)	a_{2x} = −112.67 ± 43.88 (63%) a_{2y} = 122.14 ± 56.52 (84%) a_{2z} = −139.87 ± 48.79 (↑)	a_{3x} = 1495.8 ± 112.8 (8%) a_{3y} = −703.98 ± 158.4 (55%) a_{3z} = 53.146 ± 107.6 (↑)
7 **DFACS + 1B** (5 days)	a_{1x} = 76.122 ± 126.0 (↑) a_{1y} = 95.705 ± 127.2 (↑) a_{1z} = 119.98 ± 157.2 (↑)	a_{2x} = −72.945 ± 181.40 (↑) a_{2y} = −170.47 ± 182.20 (↑) a_{2z} = −199.97 ± 242.40 (↑)	a_{3x} = 907.77 ± 422.50 (46%) a_{3y} = −365.10 ± 528.10 (↑) a_{3z} = 817.58 ± 609.30 (74%)
8 **DFACS + 2A** (7 days)	a_{1x} = 5.1732 ± 89.69 (↑) a_{1y} = 67.885 ± 88.72 (↑) a_{1z} = −136.58 ± 54.55 (40%)	a_{2x} = −12.533 ± 134.3 (↑) a_{2y} = −96.026 ± 135.8 (↑) a_{2z} = 208.05 ± 83.21 (40%)	a_{3x} = 2010.9 ± 273.1 (14%) a_{3y} = −1234.4 ± 269.6 (22%) a_{3z} = 357.79 ± 258.7 (72%)
9 **DFACS + 3** (8 days)	a_{1x} = 51.294 ± 46.830 (91%) a_{1y} = 5.9103 ± 73.580 (↑) a_{1z} = −12.065 ± 52.000 (↑)	a_{2x} = −33.392 ± 70.270 (↑) a_{2y} = −27.734 ± 110.60 (↑) a_{2z} = 10.746 ± 76.860 (↑)	a_{3x} = 864.730 ± 160.60 (18%) a_{3y} = −575.060 ± 202.70 (35%) a_{3z} = 499.500 ± 203.80 (41%)
10 **DFACS + 2B** (28 days)	a_{1x} = 82.851 ± 19.86 (24%) a_{1y} = −15.713 ± 20.04 (↑) a_{1z} = −12.073 ± 18.03 (↑)	a_{2x} = −111.12 ± 29.49 (26%) a_{2y} = 25.985 ± 27.58 (↑) a_{2z} = 17.332 ± 25.66 (↑)	a_{3x} = 1633.8 ± 167.20 (10%) a_{3y} = −1128.0 ± 177.70 (16%) a_{3z} = 333.47 ± 161.90 (49%)
11 **DRS2A** (18 days)	a_{1x} = 28.399 ± 20.840 (73%) a_{1y} = 7.3786 ± 25.540 (↑) a_{1z} = 75.388 ± 27.570 (36%)	a_{2x} = −17.041 ± 44.76 (56%) a_{2y} = 45.33 ± 60.21 (↑) a_{2z} = −23.194 ± 52.23 (34%)	a_{3x} = 2801.4 ± 109.3 (5%) a_{3y} = −1282.2 ± 140.8 (13%) a_{3z} = 403.24 ± 141.6 (25%)
12 **DRS3** (6 days)	a_{1x} = −94.965 ± 93.17 (98%) a_{1y} = −50.879 ± 58.94 (↑) a_{1z} = −24.616 ± 39.8 (↑)	a_{2x} = 131.75 ± 129.3 (98%) a_{2y} = 53.842 ± 85.85 (↑) a_{2z} = 50.758 ± 59.38 (↑)	a_{3x} = 2262.7 ± 406.4 (18%) a_{3y} = −423.8 ± 250 (59%) a_{3z} = −62.446 ± 193.7 (↑)
13 **DRS2B** (16 days)	a_{1x} = 33.175 ± 45.62 (↑) a_{1y} = −18.262 ± 57.1 (↑) a_{1z} = 6.3719 ± 52.34 (↑)	a_{2x} = −87.068 ± 68.13 (78%) a_{2y} = 20.416 ± 85.12 (↑) a_{2z} = −23.83 ± 78.73 (↑)	a_{3x} = 2887.6 ± 110.6 (4%) a_{3y} = −852.84 ± 118.1 (14%) a_{3z} = 674.51 ± 138.1 (20%)
14 **DFACSA + 4A** (23 days)	a_{1x} = 165.32 ± 51.49 (31%) a_{1y} = 2.0824 ± 39.81 (↑) a_{1z} = −30.758 ± 77.58 (↑)	a_{2x} = −248.25 ± 79.95 (32%) a_{2y} = −4.3356 ± 61.87 (↑) a_{2z} = 46.789 ± 120.3 (↑)	a_{3x} = 1879.4 ± 46.96 (2%) a_{3y} = −1026.6 ± 47.91 (5%) a_{3z} = 310.83 ± 62.46 (20%)
15 **DFACS + 4B** (34 days)	a_{1x} = −82.878 ± 18.56 (22%) a_{1y} = −38.664 ± 21.89 (57%) a_{1z} = 11.451 ± 20.82 (↑)	a_{2x} = 119.62 ± 27.29 (23%) a_{2y} = 45.694 ± 31.81 (70%) a_{2z} = −13.911 ± 30.55 (↑)	a_{3x} = 2186.4 ± 111.5 (5%) a_{3y} = −691.63 ± 103.9 (15%) a_{3z} = 215.58 ± 93.29 (43%)

MAG3 Coefficients	$\mathbf{a_1}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_2}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_3}$[nT nA^{-1}] *value* ± *Δerror* (%)
1 **DFACS1A** (74 days)	a_{1x} = −3.1176 ± 6.227 (↑) a_{1y} = −5.4514 ± 5.838 (↑) a_{1z} = 0.95628 ± 8.062 (↑)	a_{2x} = 19.178 ± 8.408 (44%) a_{2y} = −6.3041 ± 8.213 (↑) a_{2z} = 1.4661 ± 11.14 (↑)	a_{3x} = 1801.2 ± 94.71 (5%) a_{3y} = −1902.3 ± 77.29 (4%) a_{3z} = 130.1 ± 99.98 (77%)
2 **DFACS1B** (46 days)	a_{1x} = 53.793 ± 21.44 (40%) a_{1y} = −12.053 ± 21.1 (↑) a_{1z} = 4.0753 ± 23.81 (↑)	a_{2x} = −51.481 ± 32.21 (63%) a_{2y} = −4.0582 ± 31.43 (↑) a_{2z} = −3.5945 ± 35.83 (↑)	a_{3x} = 1362.7 ± 112.6 (8%) a_{3y} = −1697 ± 110.5 (7%) a_{3z} = 137.71 ± 112.8 (82%)
3 **DRS1A** (72 days)	a_{1x} = 138.95 ± 16.72 (12%) a_{1y} = −53.545 ± 16.09 (30%) a_{1z} = −65.746 ± 19.62 (30%)	a_{2x} = −162.94 ± 24.75 (15%) a_{2y} = 80.523 ± 23.65 (29%) a_{2z} = 75.355 ± 29.04 (39%)	a_{3x} = 923.73 ± 58.23 (6%) a_{3y} = −2254.8 ± 59.73 (3%) a_{3z} = 822.46 ± 51.46 (6%)
4 **DRS1B** (25 days)	a_{1x} = 26.448 ± 37.3 (↑) a_{1y} = −42.131 ± 41.68 (99%) a_{1z} = −49.845 ± 48.01 (96%)	a_{2x} = 13.622 ± 56.79 (↑) a_{2y} = 22.742 ± 62.34 (↑) a_{2z} = 74.262 ± 72.11 (97%)	a_{3x} = 762.98 ± 108.8 (14%) a_{3y} = −1132.6 ± 119.9 (11%) a_{3z} = 180.32 ± 130.8 (73%)
5 **DRS1C** (36 days)	a_{1x} = 25.413 ± 13.24 (52%) a_{1y} = −63.98 ± 11.75 (18%) a_{1z} = −5.6464 ± 14.38 (↑)	a_{2x} = −6.1787 ± 20.12 (↑) a_{2y} = 73.251 ± 18.25 (25%) a_{2z} = 4.6297 ± 21.93 (↑)	a_{3x} = 1357.1 ± 123.9 (9%) a_{3y} = −1620 ± 110.6 (7%) a_{3z} = 252.56 ± 123.8 (49%)
6 **DFACS + 1A** (35 days)	a_{1x} = −8.849 ± 45.75 (↑) a_{1y} = −112.37 ± 51.39 (46%) a_{1z} = 1.8198 ± 38.61 (↑)	a_{2x} = 29.65 ± 66.45 (↑) a_{2y} = 135.58 ± 74.51 (55%) a_{2z} = 11.439 ± 56.01 (↑)	a_{3x} = 1711.8 ± 144.9 (8%) a_{3y} = −1350.7 ± 174.9 (13%) a_{3z} = −161.93 ± 131.5 (81%)
7 **DFACS + 1B** (5 days)	a_{1x} = 71.039 ± 114.4 (↑) a_{1y} = 9.2847 ± 129.3 (↑) a_{1z} = 181.78 ± 151.5 (83%)	a_{2x} = −67.792 ± 165.2 (↑) a_{2y} = −58.954 ± 191.4 (↑) a_{2z} = −301.62 ± 236.8 (79%)	a_{3x} = 1080 ± 423 (39%) a_{3y} = −1043.8 ± 569.4 (55%) a_{3z} = 988.79 ± 615.6 (62%)
8 **DFACS + 2A** (7 days)	a_{1x} = −62.744 ± 53.78 (86%) a_{1y} = −8.7753 ± 91.79 (↑) a_{1z} = −63.62 ± 70.09 (↑)	a_{2x} = 115.99 ± 78.14 (67%) a_{2y} = −1.9919 ± 137.5 (↑) a_{2z} = 93.231 ± 95.78 (↑)	a_{3x} = 1579.7 ± 410.3 (26%) a_{3y} = −1856.1 ± 387.6 (21%) a_{3z} = 290.19 ± 335.5 (↑)
9 **DFACS + 3** (8 days)	a_{1x} = 6.1123 ± 61.38 (↑) a_{1y} = −73.844 ± 49.6 (67%) a_{1z} = 34.629 ± 80.31 (↑)	a_{2x} = 39.381 ± 92.01 (↑) a_{2y} = 58.966 ± 76.12 (↑) a_{2z} = −74.749 ± 128.6 (↑)	a_{3x} = 860.54 ± 212.1 (25%) a_{3y} = −861.68 ± 225.9 (26%) a_{3z} = 833.53 ± 411.5 (49%)
10 **DFACS + 2B** (28 days)	a_{1x} = 27.995 ± 21.29 (76%) a_{1y} = 21.303 ± 19.04 (89%) a_{1z} = 8.9711 ± 18.2 (↑)	a_{2x} = −18.52 ± 30.97 (↑) a_{2y} = −36.566 ± 27.94 (76%) a_{2z} = −18.736 ± 25.76 (↑)	a_{3x} = 1516.7 ± 211 (14%) a_{3y} = −2148.5 ± 153.1 (7%) a_{3z} = 368.78 ± 156.3 (42%)
11 **DRS2A** (18 days)	a_{1x} = 90.565 ± 17.69 (20%) a_{1y} = 9.9868 ± 24.38 (↑) a_{1z} = 59.177 ± 26.04 (44%)	a_{2x} = −98.354 ± 26.04 (26%) a_{2y} = −28.168 ± 36.5 (↑) a_{2z} = −112.39 ± 38.82 (35%)	a_{3x} = 1187.3 ± 122.3 (10%) a_{3y} = −1897.3 ± 147.2 (8%) a_{3z} = 770.53 ± 127.4 (17%)
12 **DRS3** (6 days)	a_{1x} = −94.261 ± 81.37 (86%) a_{1y} = −131.41 ± 96.74 (74%) a_{1z} = −28.775 ± 81.93 (↑)	a_{2x} = 155.19 ± 116.8 (75%) a_{2y} = 180.55 ± 145.3 (80%) a_{2z} = 58.763 ± 122.3 (↑)	a_{3x} = 1911 ± 304.5 (16%) a_{3y} = −1716.8 ± 252.5 (15%) a_{3z} = −214.92 ± 219.8 (↑)
13 **DRS2B** (16 days)	a_{1x} = 38.061 ± 49.23 (↑) a_{1y} = −33.503 ± 46.57 (↑) a_{1z} = 14.814 ± 43.6 (↑)	a_{2x} = 7.7557 ± 73.23 (↑) a_{2y} = 42.162 ± 69.11 (↑) a_{2z} = −55.36 ± 64.88 (↑)	a_{3x} = 446.64 ± 124.8 (28%) a_{3y} = −1991.1 ± 118.9 (6%) a_{3z} = 1066.6 ± 139.2 (13%)
14 **DFACSA + 4A** (23 days)	a_{1x} = 116.79 ± 39.22 (34%) a_{1y} = −91.598 ± 31.64 (35%) a_{1z} = −169.95 ± 27.47 (16%)	a_{2x} = −167.54 ± 60.58 (36%) a_{2y} = 130.56 ± 48.77 (37%) a_{2z} = 257.39 ± 42.32 (16%)	a_{3x} = 1837.8 ± 35.58 (2%) a_{3y} = −1983.6 ± 36.67 (2%) a_{3z} = 308.94 ± 37.18 (12%)
15 **DFACS + 4B** (34 days)	a_{1x} = −49.838 ± 21.48 (43%) a_{1y} = −30.319 ± 24.84 (82%) a_{1z} = −4.512 ± 19.65 (↑)	a_{2x} = 74.053 ± 31.14 (42%) a_{2y} = 45.199 ± 36.52 (81%) a_{2z} = 2.8687 ± 28.89 (↑)	a_{3x} = 2178.7 ± 107.1 (5%) a_{3y} = −2201 ± 93.61 (4%) a_{3z} = 364.04 ± 90.65 (25%)

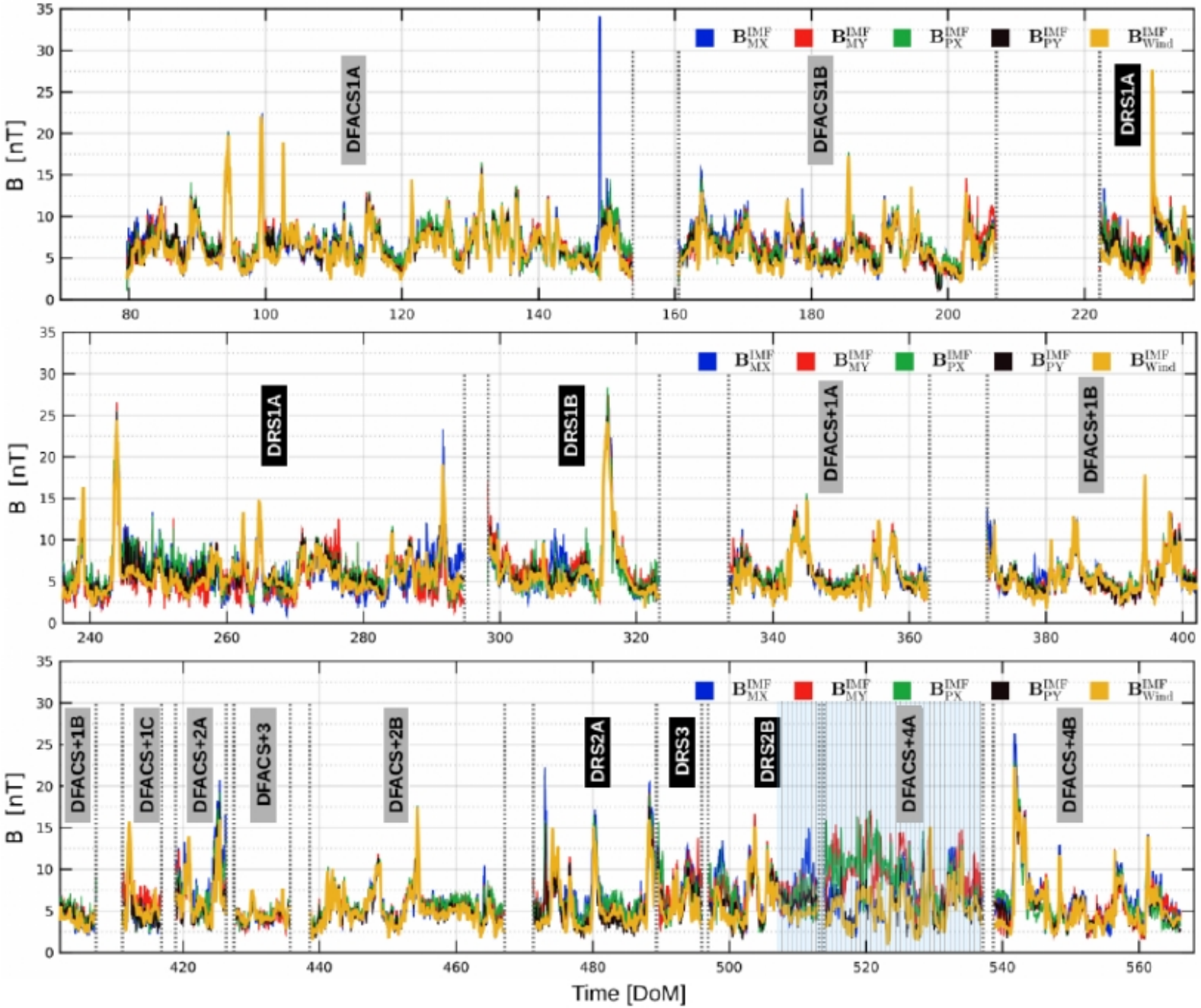
Overall Fit parameters (2)

MAG2 Coefficients	$\mathbf{a_1}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_2}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_3}$[nT nA^{-1}] *value* ± *Δerror* (%)
1 **DFACS1A** (74 days)	a_{1x} = −27.129 ± 6.16 (23%) a_{1y} = 5.7927 ± 6.295 (↑) a_{1z} = 0.087044 ± 8.191 (↑)	a_{2x} = 33.888 ± 7.991 (24%) a_{2y} = 10.771 ± 8.631 (80%) a_{2z} = 7.5306 ± 11.37 (↑)	a_{3x} = −22.472 ± 105.1 (↑) a_{3y} = 2061 ± 83.06 (4%) a_{3z} = 1130.4 ± 103.1 (9%)
2 **DFACS1B** (46 days)	a_{1x} = −25.453 ± 24.06 (95%) a_{1y} = 5.0095 ± 22.02 (↑) a_{1z} = 37.617 ± 23.91 (64%)	a_{2x} = 36.931 ± 36.09 (98%) a_{2y} = 24.928 ± 33.11 (↑) a_{2z} = −33.09 ± 36.11 (↑)	a_{3x} = −161.74 ± 118.2 (73%) a_{3y} = 1709.1 ± 102 (6%) a_{3z} = 682.95 ± 96 (14%)
3 **DRS1A** (72 days)	a_{1x} = −67.63 ± 18.97 (28%) a_{1y} = 234.55 ± 15.83 (7%) a_{1z} = 2.8847 ± 20.06 (↑)	a_{2x} = 76.132 ± 28 (37%) a_{2y} = −289.74 ± 23.36 (8%) a_{2z} = 8.4131 ± 29.67 (↑)	a_{3x} = 510.39 ± 68.48 (13%) a_{3y} = 826.46 ± 48.26 (6%) a_{3z} = 983.9 ± 66.45 (7%)
4 **DRS1B** (25 days)	a_{1x} = −38.263 ± 20.77 (54%) a_{1y} = 119.19 ± 22.43 (19%) a_{1z} = 121.53 ± 19.66 (16%)	a_{2x} = 51.024 ± 30.96 (61%) a_{2y} = −132.04 ± 33.65 (25%) a_{2z} = −159.2 ± 29.61 (19%)	a_{3x} = −51.628 ± 97.39 (↑) a_{3y} = 1303.1 ± 71.33 (5%) a_{3z} = 657.36 ± 91.85 (14%)
5 **DRS1C** (36 days)	a_{1x} = −16.353 ± 13.33 (82%) a_{1y} = −7.3601 ± 8.867 (↑) a_{1z} = 13.245 ± 15.51 (↑)	a_{2x} = 20.498 ± 19.93 (97%) a_{2y} = 39.336 ± 12.85 (33%) a_{2z} = −1.2351 ± 22.84 (↑)	a_{3x} = −108.42 ± 107.1 (99%) a_{3y} = 1849.2 ± 93.07 (5%) a_{3z} = 825.73 ± 112.3 (14%)
6 **DFACS + 1A** (35 days)	a_{1x} = −67.285 ± 45.61 (68%) a_{1y} = 56.6 ± 52.84 (93%) a_{1z} = 42.183 ± 37.25 (88%)	a_{2x} = 97.903 ± 67.19 (69%) a_{2y} = −54.875 ± 77.3 (↑) a_{2z} = −48.906 ± 54.97 (↑)	a_{3x} = −122.36 ± 149.4 (↑) a_{3y} = 1666.3 ± 154 (9%) a_{3z} = 963.16 ± 139.4 (14%)
7 **DFACS + 1B** (5 days)	a_{1x} = 110.26 ± 120.4 (↑) a_{1y} = 219.08 ± 101.5 (46%) a_{1z} = 65.443 ± 205 (↑)	a_{2x} = −148.53 ± 175.9 (↑) a_{2y} = −309.17 ± 139.3 (45%) a_{2z} = −92.683 ± 302.2 (↑)	a_{3x} = −698.52 ± 369.6 (53%) a_{3y} = 1916.6 ± 686.1 (36%) a_{3z} = 1197.2 ± 588.5 (49%)
8 **DFACS + 2A** (7 days)	a_{1x} = −31.001 ± 55.63 (↑) a_{1y} = −49.715 ± 47.47 (95%) a_{1z} = 62.627 ± 47.14 (75%)	a_{2x} = 22.502 ± 84.86 (↑) a_{2y} = 131.94 ± 65.08 (49%) a_{2z} = −90.509 ± 63.42 (70%)	a_{3x} = 473.71 ± 313.7 (66%) a_{3y} = 968.17 ± 474.8 (49%) a_{3z} = 1277.6 ± 280.7 (22%)
9 **DFACS + 3** (8 days)	a_{1x} = −57.465 ± 120.5 (↑) a_{1y} = 133.59 ± 68.67 (51%) a_{1z} = 9.4568 ± 58.23 (↑)	a_{2x} = 78.696 ± 182.8 (↑) a_{2y} = −150.27 ± 104.1 (69%) a_{2z} = 16.178 ± 87.34 (↑)	a_{3x} = 39.484 ± 274.4 (↑) a_{3y} = 1137 ± 184.7 (16%) a_{3z} = 574.73 ± 250.2 (44%)
10 **DFACS + 2B** (28 days)	a_{1x} = 20.668 ± 27.42 (↑) a_{1y} = 11.408 ± 17.82 (↑) a_{1z} = 5.1173 ± 19.29 (↑)	a_{2x} = −48.038 ± 36.57 (76%) a_{2y} = −2.566 ± 24.69 (↑) a_{2z} = −3.8521 ± 24.52 (↑)	a_{3x} = 269.72 ± 233.4 (87%) a_{3y} = 2108.7 ± 145.6 (7%) a_{3z} = 1282.8 ± 173.3 (14%)
11 **DRS2A** (18 days)	a_{1x} = 111.51 ± 25.62 (23%) a_{1y} = 22.143 ± 19.4 (88%) a_{1z} = 53.995 ± 27.81 (52%)	a_{2x} = −178.8 ± 39.36 (22%) a_{2y} = 26.769 ± 27.44 (↑) a_{2z} = −72.559 ± 42.41 (58%)	a_{3x} = 71.17 ± 151.7 (↑) a_{3y} = 985.34 ± 143.2 (15%) a_{3z} = 1117.7 ± 150.5 (13%)
12 **DRS3** (6 days)	a_{1x} = −124.99 ± 59.3 (47%) a_{1y} = −125.31 ± 34.66 (28%) a_{1z} = −73.599 ± 49.02 (67%)	a_{2x} = 170.06 ± 85.1 (50%) a_{2y} = 255.1 ± 50.82 (20%) a_{2z} = 107.2 ± 73.31 (68%)	a_{3x} = 357.74 ± 216.4 (60%) a_{3y} = 868.52 ± 163.2 (19%) a_{3z} = 1515.1 ± 186.7 (12%)
13 **DRS2B** (16 days)	a_{1x} = −8.9526 ± 55.52 (↑) a_{1y} = 92.42 ± 35.72 (39%) a_{1z} = 31.193 ± 43.44 (↑)	a_{2x} = −14.108 ± 81.55 (↑) a_{2y} = −62.659 ± 52.84 (84%) a_{2z} = −37.275 ± 63.87 (↑)	a_{3x} = 543.1 ± 140.9 (26%) a_{3y} = 491.84 ± 95.99 (20%) a_{3z} = 1116.2 ± 93.28 (8%)
14 **DFACSA + 4A** (23 days)	a_{1x} = 14.303 ± 43.04 (↑) a_{1y} = 146.29 ± 43.76 (30%) a_{1z} = −96.878 ± 23.44 (24%)	a_{2x} = −52.12 ± 66.43 (↑) a_{2y} = −212.46 ± 67.54 (32%) a_{2z} = 158.43 ± 35.77 (23%)	a_{3x} = 605.22 ± 39.42 (7%) a_{3y} = 2190.1 ± 38.11 (2%) a_{3z} = 1128.4 ± 32.22 (3%)
15 **DFACS + 4B** (34 days)	a_{1x} = −88.153 ± 21.32 (24%) a_{1y} = −55.687 ± 22.88 (41%) a_{1z} = −4.1108 ± 21.59 (↑)	a_{2x} = 119.04 ± 30.93 (26%) a_{2y} = 84.312 ± 33.45 (40%) a_{2z} = 3.3645 ± 31.68 (↑)	a_{3x} = 170.95 ± 113.5 (66%) a_{3y} = 2479.6 ± 109.2 (4%) a_{3z} = 1473.8 ± 107.8 (7%)

MAG4 Coefficients	$\mathbf{a_1}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_2}$[nT nA^{-1}] *value* ± *Δerror* (%)	$\mathbf{a_3}$[nT nA^{-1}] *value* ± *Δerror* (%)
1 **DFACS1A** (74 days)	a_{1x} = −54.458 ± 5.404 (10%) a_{1y} = 2.9634 ± 6.111 (↑) a_{1z} = 18.258 ± 7.104 (39%)	a_{2x} = 73.277 ± 7.057 (10%) a_{2y} = 2.3823 ± 8.5 (↑) a_{2z} = −22.134 ± 9.833 (44%)	a_{3x} = −31.626 ± 90.55 (↑) a_{3y} = 1298.1 ± 67.83 (5%) a_{3z} = 824.64 ± 87 (11%)
2 **DFACS1B** (46 days)	a_{1x} = 17.186 ± 19.96 (↑) a_{1y} = 59.977 ± 17.1 (29%) a_{1z} = 57.002 ± 16.99 (30%)	a_{2x} = −26.471 ± 29.74 (↑) a_{2y} = −71.498 ± 25.67 (36%) a_{2z} = −71.099 ± 25.47 (36%)	a_{3x} = −286.94 ± 95.87 (33%) a_{3y} = 945.23 ± 83.66 (9%) a_{3z} = 555.06 ± 79.4 (14%)
3 **DRS1A** (72 days)	a_{1x} = −96.087 ± 12.37 (13%) a_{1y} = 75.328 ± 10.54 (14%) a_{1z} = 64.095 ± 12.42 (19%)	a_{2x} = 142.9 ± 18.11 (13%) a_{2y} = −105.32 ± 15.5 (15%) a_{2z} = −83.25 ± 18.35 (22%)	a_{3x} = −185.71 ± 58.84 (32%) a_{3y} = 1212.6 ± 44.47 (4%) a_{3z} = 586.55 ± 53.54 (9%)
4 **DRS1B** (25 days)	a_{1x} = −78.115 ± 12.13 (16%) a_{1y} = 15.76 ± 13.9 (88%) a_{1z} = 82.293 ± 14.03 (17%)	a_{2x} = 117.37 ± 18.18 (15%) a_{2y} = −8.213 ± 20.57 (↑) a_{2z} = −109.74 ± 21.34 (19%)	a_{3x} = −253.8 ± 61.34 (24%) a_{3y} = 1018 ± 48.26 (5%) a_{3z} = 562.31 ± 55.02 (10%)
5 **DRS1C** (36 days)	a_{1x} = −67.337 ± 11.05 (16%) a_{1y} = −5.8703 ± 8.169 (↑) a_{1z} = −8.4035 ± 12.43 (↑)	a_{2x} = 97.762 ± 16.5 (17%) a_{2y} = 18.46 ± 11.99 (65%) a_{2z} = 15.367 ± 18.48 (↑)	a_{3x} = −163.8 ± 92.34 (56%) a_{3y} = 1191.2 ± 73.03 (6%) a_{3z} = 904.43 ± 78.05 (9%)
6 **DFACS + 1A** (35 days)	a_{1x} = −56.165 ± 36.31 (65%) a_{1y} = −93.076 ± 46.5 (50%) a_{1z} = 40.291 ± 29.72 (74%)	a_{2x} = 81.753 ± 53.9 (66%) a_{2y} = 146.35 ± 68.57 (47%) a_{2z} = −48.692 ± 44.03 (90%)	a_{3x} = −187.73 ± 128.8 (69%) a_{3y} = 1292.8 ± 130.3 (10%) a_{3z} = 654.25 ± 116.2 (18%)
7 **DFACS + 1B** (5 days)	a_{1x} = 73.045 ± 122.8 (↑) a_{1y} = 185.57 ± 106.4 (57%) a_{1z} = 55.162 ± 228.9 (↑)	a_{2x} = −96.251 ± 183.1 (↑) a_{2y} = −262.36 ± 152.9 (58%) a_{2z} = −95.248 ± 342.5 (↑)	a_{3x} = −638.83 ± 402.8 (63%) a_{3y} = 990.76 ± 604 (61%) a_{3z} = 1312.5 ± 491.5 (37%)
8 **DFACS + 2A** (7 days)	a_{1x} = −51.586 ± 50.33 (98%) a_{1y} = −15.235 ± 54.13 (↑) a_{1z} = 105.85 ± 46.22 (44%)	a_{2x} = 63.394 ± 77.4 (↑) a_{2y} = 61.896 ± 80.2 (↑) a_{2z} = −154.63 ± 64 (41%)	a_{3x} = 142.04 ± 320.2 (↑) a_{3y} = 422.22 ± 325.4 (77%) a_{3z} = 826.31 ± 250.8 (30%)
9 **DFACS + 3** (8 days)	a_{1x} = 2.8153 ± 86.49 (↑) a_{1y} = 48.65 ± 60.65 (↑) a_{1z} = 20.272 ± 43.21 (↑)	a_{2x} = −11.245 ± 131.5 (↑) a_{2y} = −55.095 ± 91 (↑) a_{2z} = −21.944 ± 63.04 (↑)	a_{3x} = −61.337 ± 204.8 (↑) a_{3y} = 988.84 ± 139.1 (14%) a_{3z} = 733.49 ± 202.7 (28%)
10 **DFACS + 2B** (28 days)	a_{1x} = 32.611 ± 22.47 (69%) a_{1y} = 22.639 ± 15.89 (70%) a_{1z} = 34.318 ± 17.06 (50%)	a_{2x} = −56.793 ± 31.4 (55%) a_{2y} = −24.653 ± 22.65 (92%) a_{2z} = −43.863 ± 22.42 (51%)	a_{3x} = −41.817 ± 192.7 (↑) a_{3y} = 1217.5 ± 118 (10%) a_{3z} = 748.26 ± 137.1 (18%)
11 **DRS2A** (18 days)	a_{1x} = 96.459 ± 18.92 (20%) a_{1y} = −38.638 ± 21.34 (55%) a_{1z} = 55.102 ± 22.73 (41%)	a_{2x} = −141.99 ± 29.62 (21%) a_{2y} = 83.804 ± 31.36 (37%) a_{2z} = −85.264 ± 34.24 (40%)	a_{3x} = −357.17 ± 106.3 (30%) a_{3y} = 781.95 ± 110.9 (14%) a_{3z} = 1007.9 ± 121.1 (12%)
12 **DRS3** (6 days)	a_{1x} = 40.299 ± 1.325 (3%) a_{1y} = −108.28 ± 6.415 (6%) a_{1z} = 89.856 ± 1.429 (2%)	a_{2x} = −50.772 ± 1.65 (3%) a_{2y} = 158.19 ± 9.048 (6%) a_{2z} = −119.23 ± 1.834 (2%)	a_{3x} = −501.32 ± 15.73 (3%) a_{3y} = 1644.4 ± 35.15 (2%) a_{3z} = 509.23 ± 25.72 (5%)
13 **DRS2B** (16 days)	a_{1x} = −3.6935 ± 34.61 (↑) a_{1y} = 72.988 ± 28.12 (39%) a_{1z} = 19.429 ± 28.62 (↑)	a_{2x} = 3.3834 ± 50.9 (↑) a_{2y} = −105.81 ± 41.54 (39%) a_{2z} = −22.777 ± 41.95 (↑)	a_{3x} = −166.51 ± 100.3 (60%) a_{3y} = 1324.9 ± 86.8 (7%) a_{3z} = 792.06 ± 82.73 (10%)
14 **DFACSA + 4A** (23 days)	a_{1x} = 76.536 ± 16.99 (22%) a_{1y} = 48.54 ± 16.82 (35%) a_{1z} = 74.005 ± 31.24 (42%)	a_{2x} = −118.98 ± 26.05 (22%) a_{2y} = −64.013 ± 25.79 (40%) a_{2z} = −107.86 ± 48.03 (45%)	a_{3x} = −178.76 ± 20.41 (11%) a_{3y} = 1206.7 ± 18 (1%) a_{3z} = 845.88 ± 23.66 (3%)
15 **DFACS + 4B** (34 days)	a_{1x} = −33.062 ± 22.2 (67%) a_{1y} = −40.015 ± 22.67 (57%) a_{1z} = 13.215 ± 19 (↑)	a_{2x} = 51.884 ± 32.33 (62%) a_{2y} = 57.616 ± 33.37 (58%) a_{2z} = −20.032 ± 27.64 (↑)	a_{3x} = −275.04 ± 110 (40%) a_{3y} = 1557.9 ± 98 (6%) a_{3z} = 1000.6 ± 90.71 (9%)

Overall LPF mission dataset

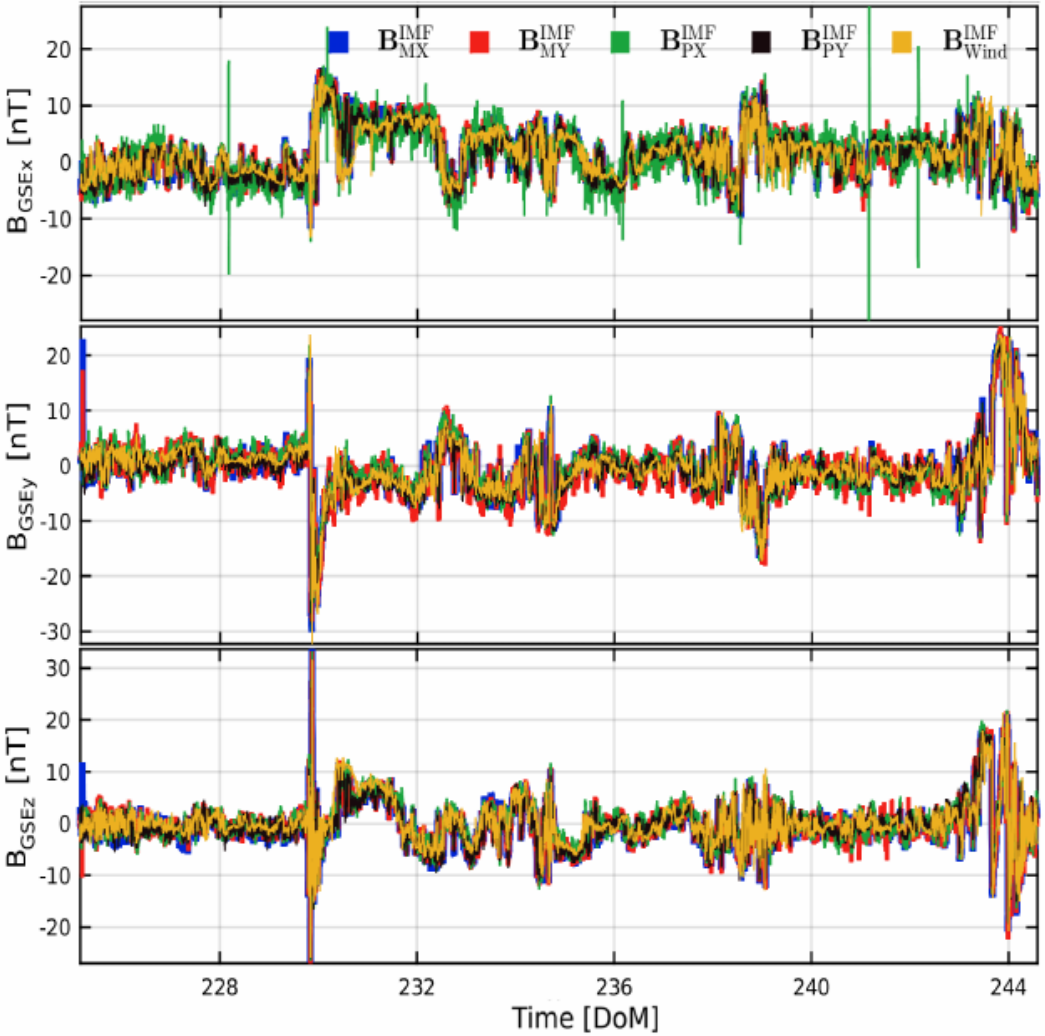
IMF timeseries obtained by processing the four LPF magnetometers compared with the IMF measurements gathered wby MFI Wind.



Note: DFACS+A4 is the “cooling down” period (vertical hatching). Time intervals are indicated in Table II.

The ICME during an ICME passage

- Time interval ranging from July 15 through August 4, 2016.
- Observations are shown with respect to the Global Solar Ecliptic (GSE) reference frame.
- The average distance between LPF and Wind S/C was limited below ~1.12 millions of kilometers.
- On these length scales the IMF was not expected to vary significantly.



Using a ICME passage as an independent verification

- The actual LPF IMF trend on the LPF orbit can be independently inferred (and verified) from Wind in situ observations during the passage of a magnetic cloud observed between August 2 and August 3, 2016.

- This event has been extensively studied in Benella et al. 2019 and 2020.

- In this case, LPF IMF data trend are estimated from the magnetic cloud configuration obtained by applying the Grad-Shafranov reconstruction technique to Wind S/C observations.

- The comparison between IMF components inferred from the GS reconstruction and LPF observations is shown in figure.

- LPF IMF (black line) and the IMF interpolation along the LPF orbit on the basis of the Grad-Shafranov reconstruction of the magnetic cloud (open blue circles). Each Cartesian LPF IMF component results from the average of the four inferred onoboard IMF timeseries.