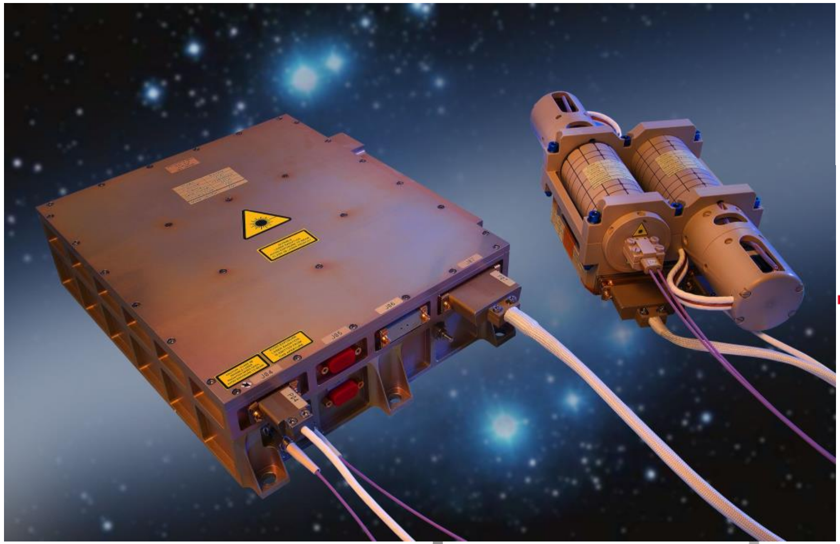

# DISTORTION EFFECTS ON ASM-V DATA: Preliminary analysis and correction perspectives

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1 Introduction

2 Potential distortion mechanism in ASM-V data

3 Foreseen in-orbit effect

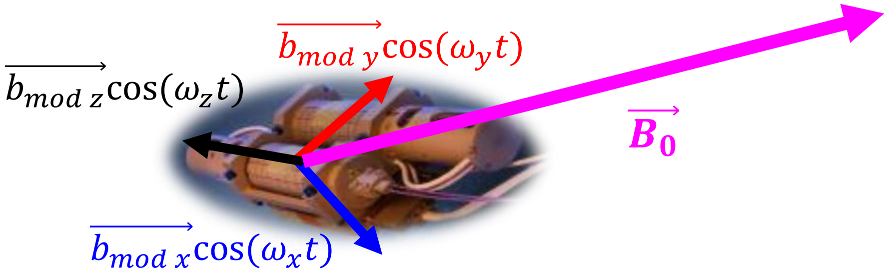
4 Preliminary on-ground characterizations

5 In-flight calibration issues

6 Way forward

# REMINDER OF ASM-V DATA RECONSTRUCTION PRINCIPLE

- **Vector modulations applied onto scalar field: 50 $nT_{peak}$ @ [8;11;13] Hz**




$$\left\|\overrightarrow{B_{tot}}(t)\right\| = \left\|\overrightarrow{B_0}(t) + \sum_{i=x,y,z} \overrightarrow{b_{mod\ i}}\cos(\omega_i t)\right\|$$

- **Scalar demodulation at modulations frequencies:**
  - Vector projections measured in the [-50;+50] nT range in the ASM vector coil frame
- **Reconstruction:**
  - Search for ASM-V orthogonality angles + vector coil transfer functions
  - Additional corrections:
    - Linear correction of 47 ppm/°C on the vector transfer functions (PEEK characteristics)
    - Mechanical imperfections due to stator/rotor architecture (n.l. corrections in $sin(\theta)$, $cos\ (\theta)$, and $cos\ (4\theta)$, where $\theta$ is the relative stator/rotor orientation)

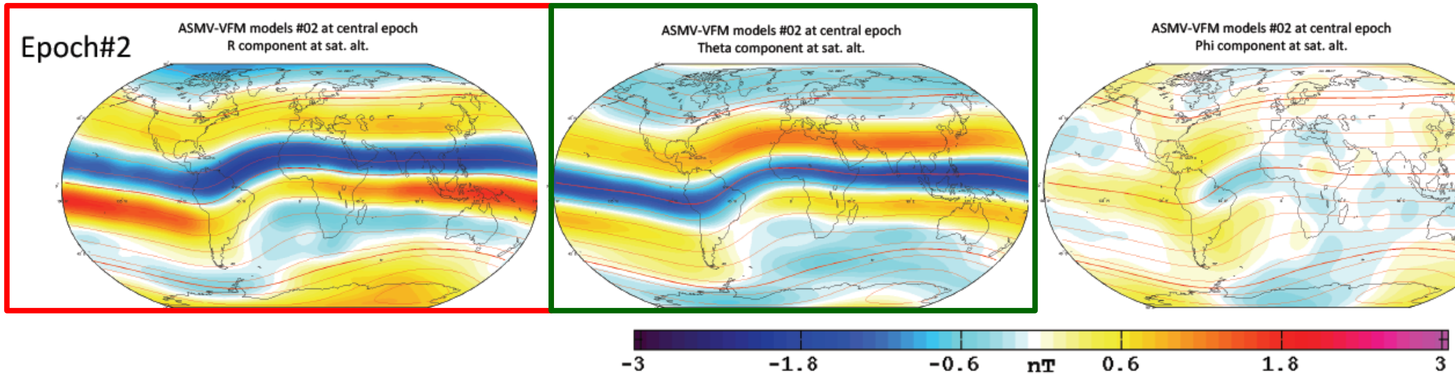
➡ **Reconstruction parameters are derived from scalar residual minimization (least squares algorithm) between $B_{0\ ASM}$ and $\left\|\overrightarrow{B_{vect\ ASM}}\right\|$**

# REMINDER OF THE OBSERVED VECTOR RESIDUAL

- **Cf previous presentations of P. Vigneron:**
  - Vector residual between ASM and VFM derived geomagnetic models

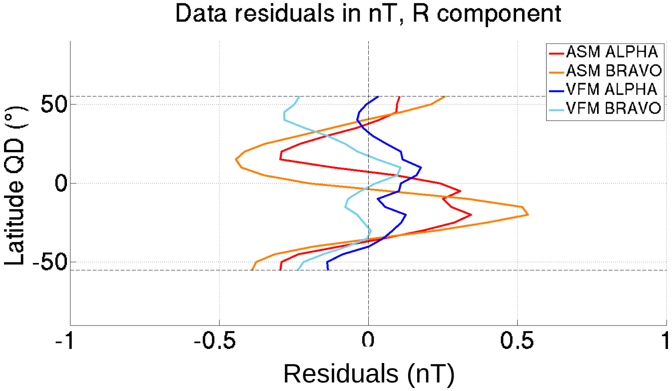
**~$B_Z$ ASM** | **~$B_X$ ASM** | **~$B_Y$ ASM**

**A clear signature**

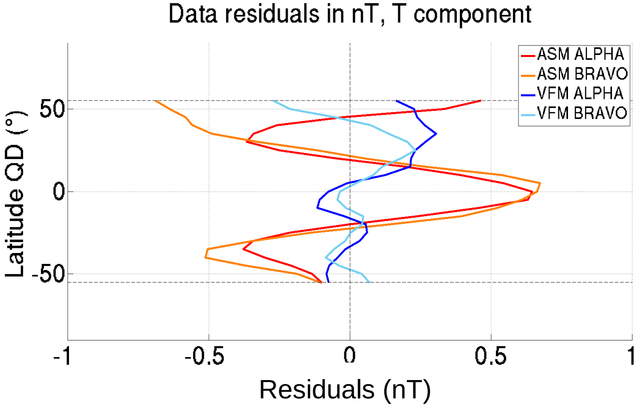



  - Vector residual between ASM-V data and derived ASM-V geomagnetic model

**Focus around magnetic equator**




**Antisymmetric signature around magnetic equator**




**Symmetric signature around magnetic equator**

# ASM-V DISTORTION EFFECTS CHARACTERISTICS

- **Effects affecting the vector measurements only**

  ➡ the distortion would affect the response of the {resonance-locked $^4$He atoms system} to the vector modulation amplitudes and frequencies, dissipating a part of the linear response into odd harmonics

- **Small effects**

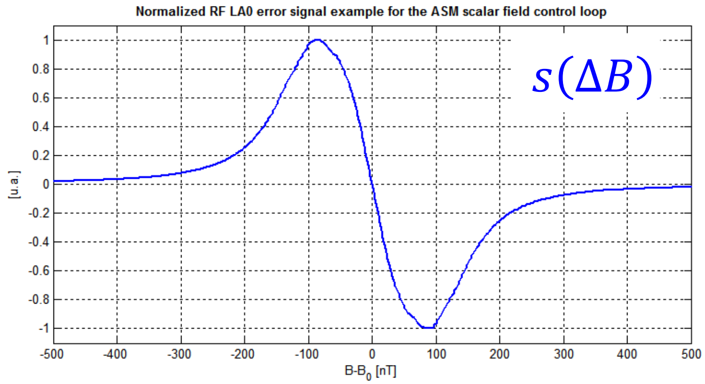
  ➡ a small scalar effect (pT range) is amplified into a not negligible vector one (nT range) due to the ASM vector reconstruction (amplification ratio $\frac{B_{0\ ASM}}{b_{mod}}$ of 300-1000 for any perturbation measured on vector projections)

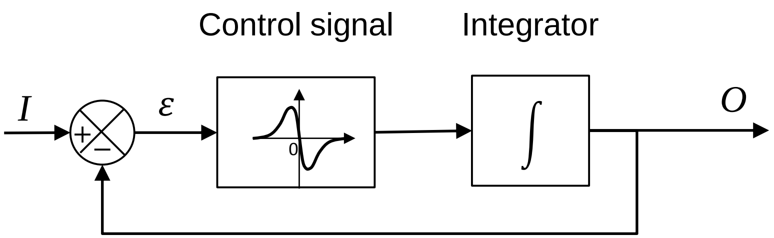
- **Field-orientation dependent in the instrument vector coils frame**

  ➡ consistent with the observations (cf. measurements vs model comparisons)

# POTENTIAL DISTORTION MECHANISM IN ASM VECTOR DATA

- **Scalar field control loop characteristics (RF frequency tracking):**
  - $B_{0\ ASM} = f_{RF} \times \gamma_{^4He}$ with $\gamma_{^4He}$ ~ 28. 024 kHz / µT
  - The control signal $s(\Delta B)$ used to drive the RF scalar frequency is symmetric but not purely linear

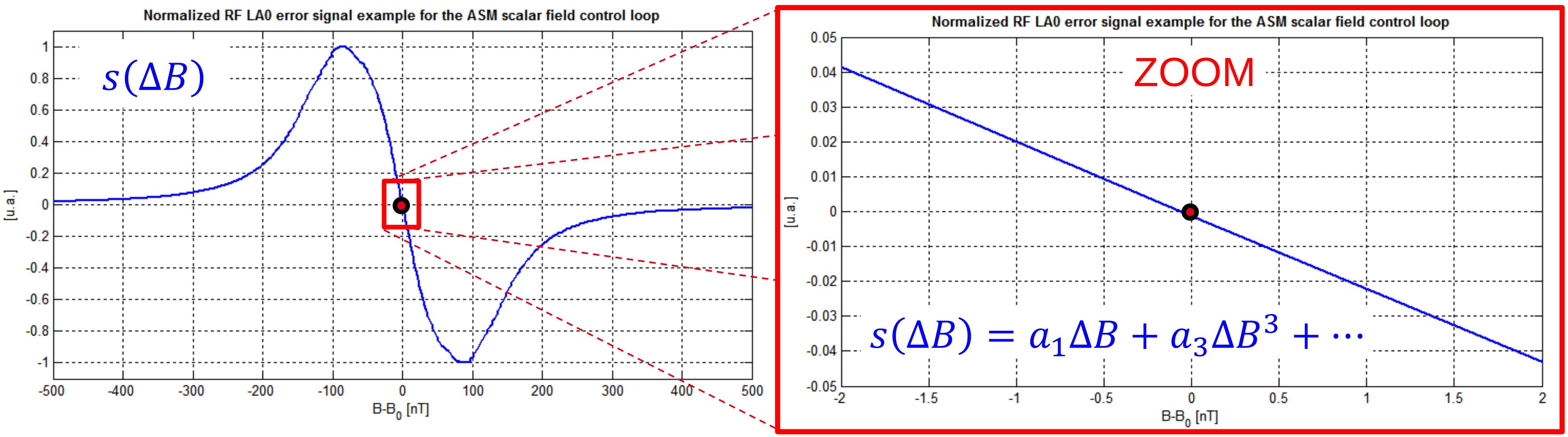



  - The RF control loop response $H(p) = O/I$ is ~1st order low-pass filter with $f_c$ ~ 300-400 Hz (depending on the $^4$He cell optical pumping characteristics + RF loop settings)
  - The control loop **error** response $G(p) = \frac{I-O}{I} = \varepsilon/I$ is ~1st order high-pass filter

# POTENTIAL DISTORTION MECHANISM IN ASM VECTOR DATA

- **The tracking of the vector modulation frequencies in the control loop experiences a delay that is translated into an extra-field excursion @ [8 ; 11 ; 13] Hz on the $s(\Delta B)$ curve:**
  - $\frac{\partial|\varepsilon|}{\partial f} \approx \frac{b_{mod}}{f_c} = \frac{50\ nT}{400\ Hz} = 0.13$ nT/Hz → [1 ; 1.4 ; 1.7] $nT_{peak}$ @ [8 ; 11 ; 13] Hz




- **A part of the fundamental signal @ [8, 11, 13 Hz] is translated into odd harmonics in the RF loop response due to non-linear characteristics of the control signal $s(\Delta B)$ (e.g. $cos^3x = \frac{3}{4}cos\ x + \frac{1}{4}cos3x$ )**

# FORESEEN AMPLITUDE EFFECT

- **With very simple hypothesis the principal harmonic attenuation $\Delta h_1$ on $h_1$ is given by:**
  - $\Delta h_1 = 3h_3$ where $h_3$ is the 3rd harmonic signal generated by the distortion of the fundamental $h_1$
  - $\frac{h_3}{h_1} = \frac{1}{4}\frac{a_3}{a_1}\left(\frac{f_{mod}}{f_C} b_{mod}\right)^2$ ➡ $\Delta h_1 = \frac{3}{4}\frac{a_3}{a_1}\left(\frac{f_{mod}}{f_C} b_{mod}\right)^2 \times h_1$

- **Precisely, $\Delta h_1$ would depend not on $b_{mod}$ but on $b_{mod}\cos(\overrightarrow{b_{mod}}|\overrightarrow{B_0})$**
  - $\Delta h_1 = \frac{3}{4}\frac{a_3}{a_1}\left(\frac{f_{mod}}{f_C}\right)^2 \times \left(b_{mod}\cos(\overrightarrow{b_{mod}}|\overrightarrow{B_0})\right)^{\mathbf{3}}$

- **With on-ground test characteristics on control loop signal, $\frac{a_3}{a_1}$ ~ 1.22 $10^{-4}$, $f_c$ ~300-400 Hz and $b_{mod}$ = 50 nT:**

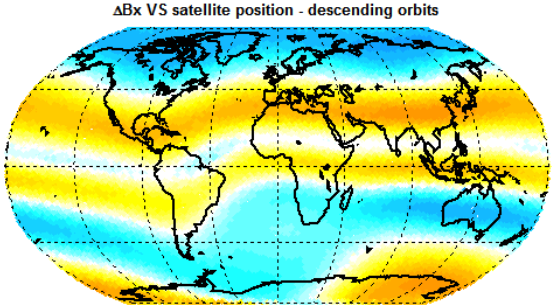
$\Delta h_1$ ~ [4-7; 8-15 ;11-20] pT @ [8 ;11; 13] Hz

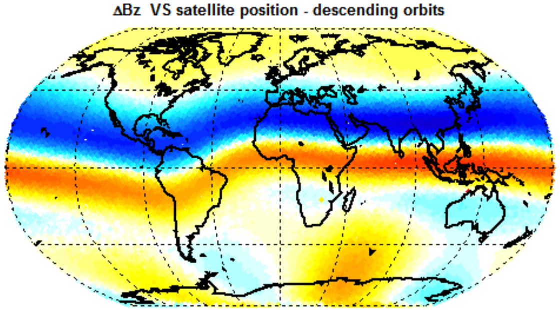
# FORESEEN IN-ORBIT AMPLITUDE EFFECT

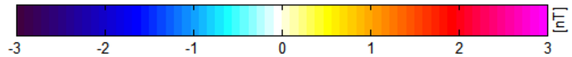
- Corresponding in-orbit vector signature (simulated)

**$\Delta B_X$ ASM** | **$\Delta B_Z$ ASM**

SIMULATED



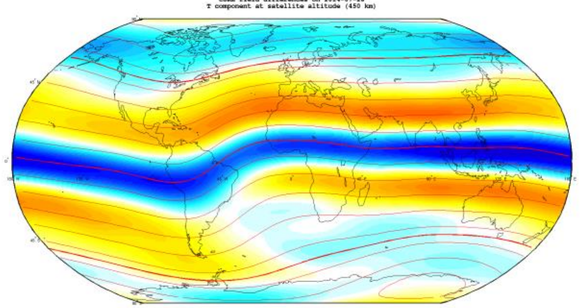



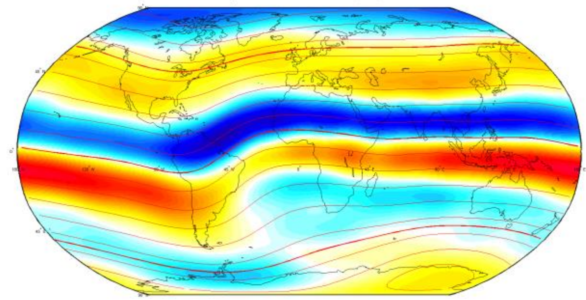




Antisymmetric signature around magnetic equator

Symmetric signature around magnetic equator

~OBSERVED (between models)

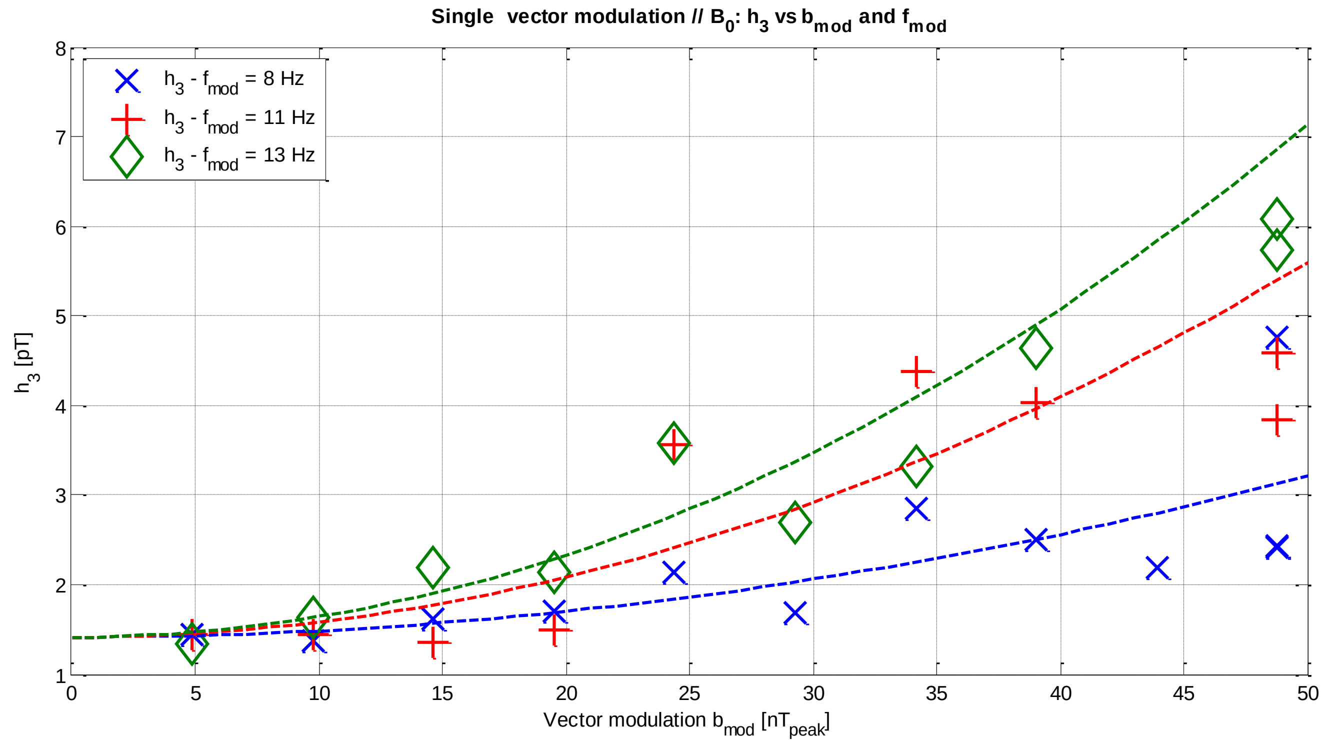



➡ The order of magnitude and the behavior of the simulated in-orbit effect is consistent with observations

# PRELIMINARY ON-GROUND CHARACTERIZATIONS

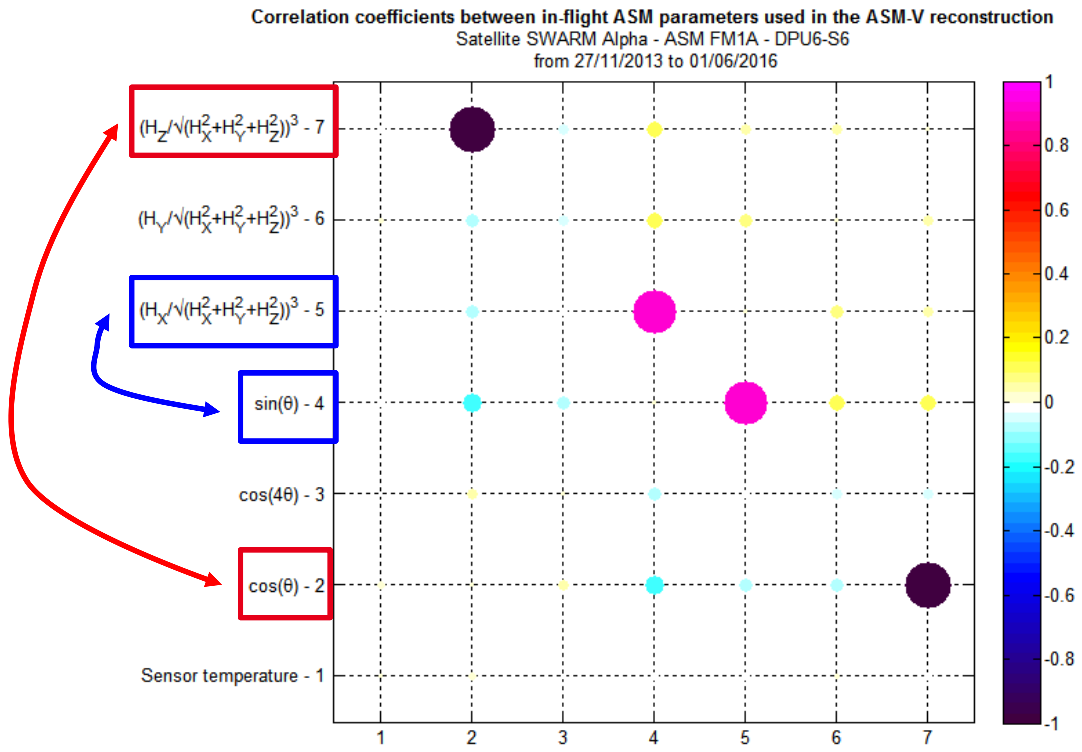
- **Monitoring of $h_3$ signal on ASM EQM in function of $f_{mod}$ & $b_{mod}$**
  - Single modulation operation
  - Worst case testing: $\vec{B}_0 \parallel \vec{b}_{mod}$




The measured (**<u>tiny</u>**) $h_3$ amplitudes are in the range of the expected values but there is no way to directly characterize $\Delta h_1$

# IN-FLIGHT CALIBRATION ISSUES

- **Cross-correlation with the evolution of other parameters**




➡ Distortions corrections compete with rotor/stator geometrical corrections

➡ The calibration process is currently not able to derive distortion parameters with enough accuracy

# WAY FORWARD

- **Comparison of respective operation conditions between on-ground instruments and in-flight ones**

- **Further testing to better understand the distortion parameters evolutions w.r.t:**
  - modulations amplitudes and frequencies
  - optical pumping characteristics and RF control loop settings

- **Testing of ASM-V updated reconstruction algorithm with fixed distortions parameters on short period**

- **Construction of updated ASM-V based geomagnetic model and comparison with old ones and VFM-based ones**
  - ➡ <u>Reminder:</u> ASM-V distortions are not the only source of difference between ASM-V and VFM based models (mechanical boom distortions, others errors, etc…)

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