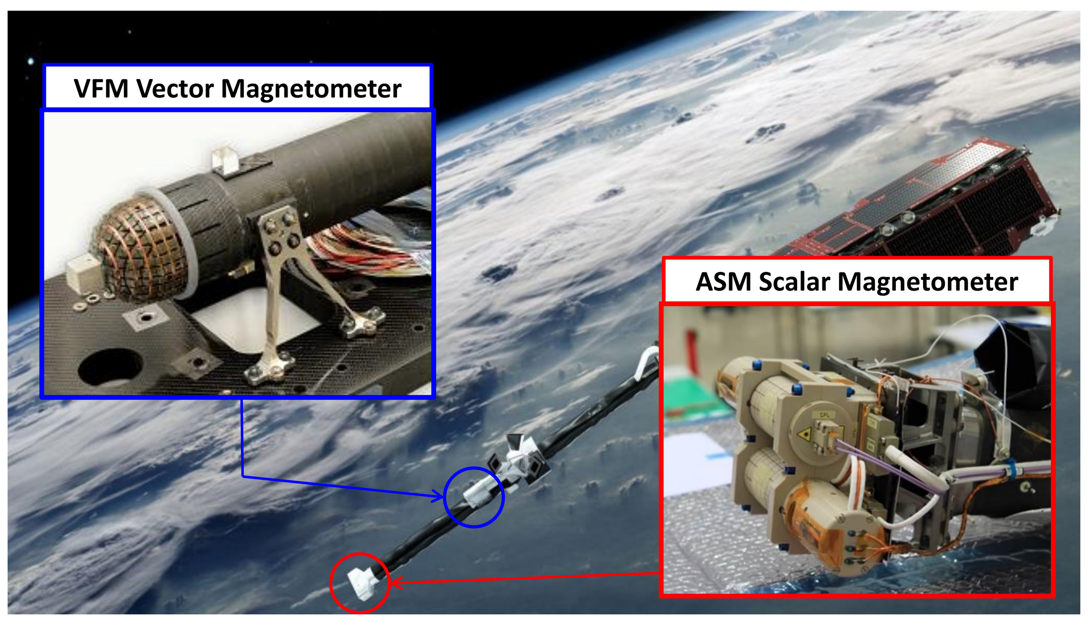
Review of the magnetic perturbation model of the Swarm Satellites

Peter Brauer[1], Lars Tøffner Clausen[1], Gauthier Hulot[2]

[1] Technical University of Denmark, Kgs. Lyngby, Denmark, [2] Institut de Physique du Globe de Paris, France.

Swarm Magnetometer package

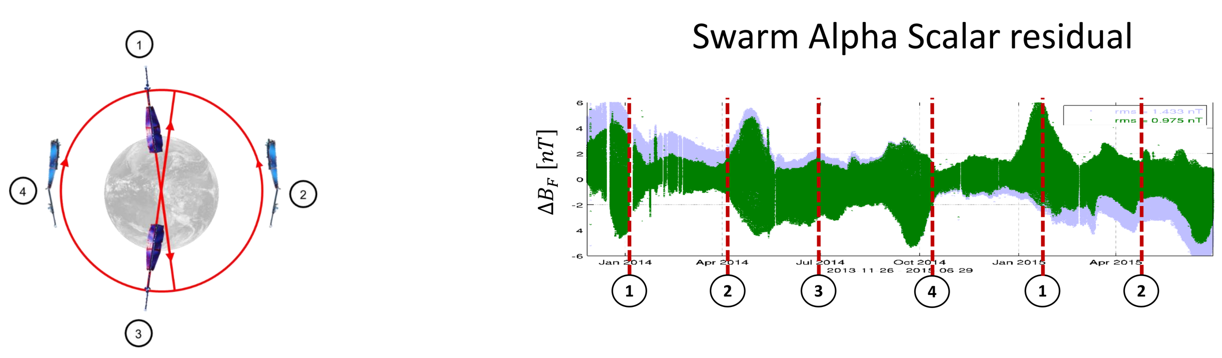
Each of the three Swarm satellites are equipped with a vector field magnetometer (VFM) and an absolute scalar magnetometer (ASM) to measure the magnetic field of the Earth. The scalar residual between the two instruments is used for in-flight calibration of the VFM instrument.



The planned in-flight calibration scheme was to adjust the sensitivities, offsets and orthogonality angles (9 parameters) of the VFM to minimize the scalar residual

Scalar Residual

During the commission period a large discrepancy between the measured scalar field from the two magnetometers was found.



The scalar residual was not understood until more than 1.5 years into the mission. The scalar residual had a local time dependency which indicated sun-induced perturbations on the magnetometers.

Disturbance Vector

In order to compensate for the perturbation the scalar residual needed to be transformed into a vector perturbation. A new in-flight calibration scheme was used to co-estimate an empirical disturbance vector together with calibration of the 9 VFM parameters.

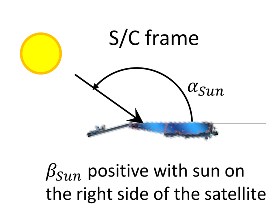
$$\begin{pmatrix} B_x \\ B_y \\ B_z \end{pmatrix} = \begin{pmatrix} s_x & s_x \cdot \cos a_{xy} & s_x \cdot \cos a_{xz} \\ 0 & s_y & s_y \cdot \cos a_{yz} \\ 0 & 0 & s_z \end{pmatrix} \cdot \begin{pmatrix} E_x - o_x \\ E_y - o_y \\ E_z - o_z \end{pmatrix} + \begin{pmatrix} dB_{sun,x} \\ dB_{sun,y} \\ dB_{sun,z} \end{pmatrix}$$

← Swarm Disturbance Vector

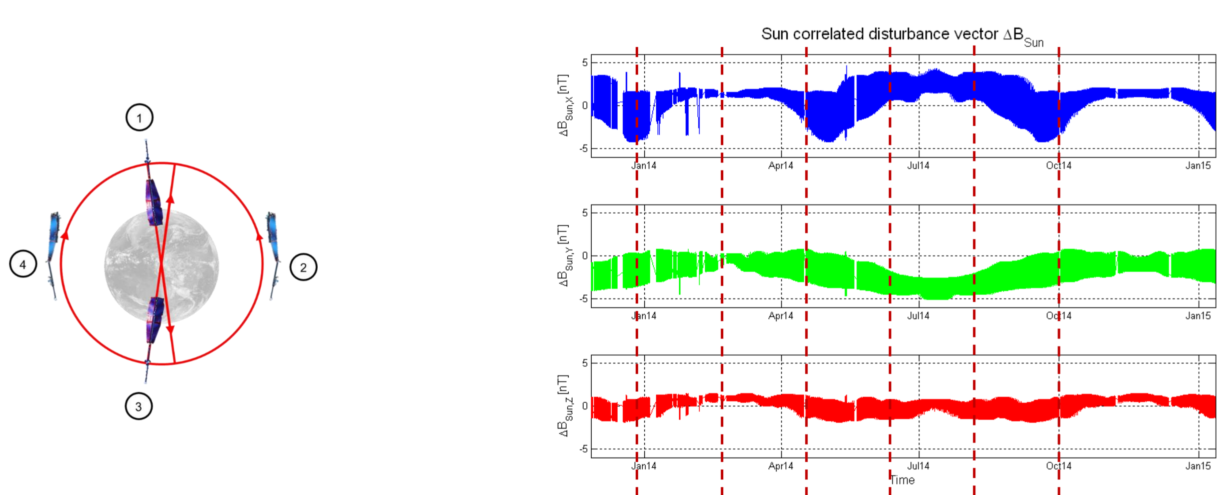
The empirical disturbance vector $\overrightarrow{dB}_{Sun}(\alpha_{Sun}, \beta_{Sun})$ describe an externally induced perturbation on the magnetometer sensor and varies with the sun impingement angle on the satellite.

The disturbance vector is modelled by a spherical harmonics model SHM with regards to the sun direction

$$\overrightarrow{dB}_{Sun}(\alpha_{Sun}, \beta_{Sun}) = \sum_{n=1}^{N} \sum_{m=1}^{n} \left(\vec{g}_n^m \cos m \cdot \alpha_{Sun} + \vec{h}_n^m \sin m \cdot \alpha_{Sun} \right) P_n^m(\cos \beta_{Sun})$$



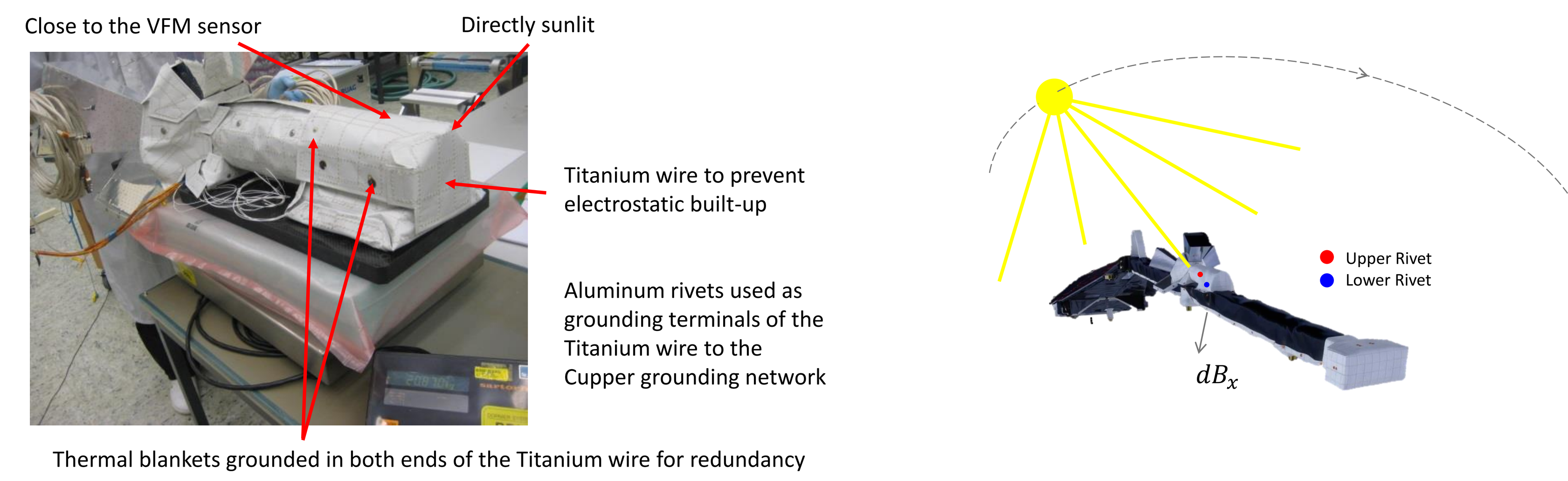
The model of each component of the disturbance vector consist of a SHM to degree and order 25 which limits the number of free parameters to ~200 pr. axis for each satellite



Although the uniqueness of the disturbance vector, as determined by least squares fitting, has been discussed, the method has turned out to be robust to predict physical disturbance phenomenon as discussed next.

Thermoelectric investigations

In May 2017 (three years after launch of the Swarm satellites) a thorough investigation was carried out to identify the root cause of the magnetic perturbation. The investigation was based on items near the VFM sensor that might be affected by thermoelectric currents generated by thermal gradients



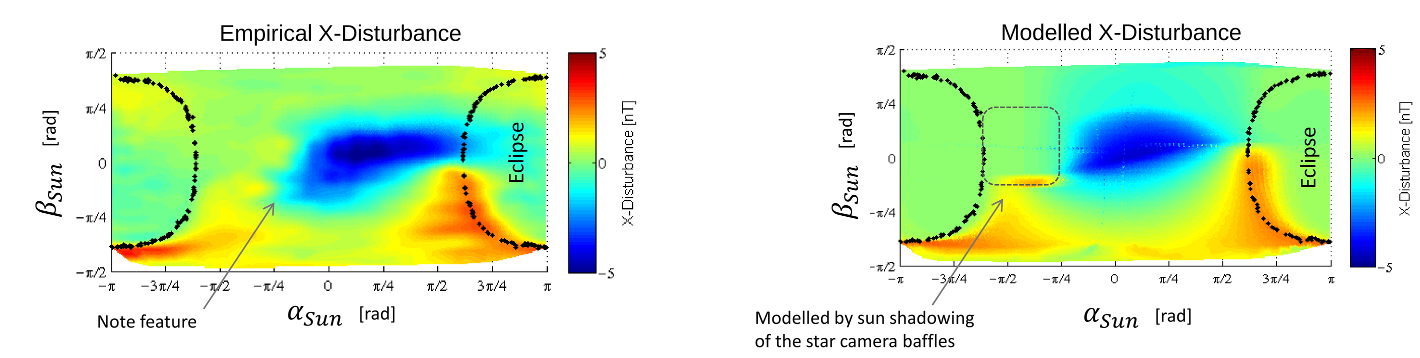
The design of the optical bench carrying the VFM sensor and the star cameras has gone through a magnetic cleanliness program and was expected to be clean of thermoelectric currents

It could, however, be demonstrated in laboratory measurements that a thermal gradient on the thermal MLI blanket of the VFM could cause a perturbation similar to the empirical disturbance vector. It turns out that a thermocouple circuit was formed between two grounding rivets on the VFM blanket – one branch from the aluminized MLI blanket and another from grounding copper wires with the two rivets being the thermocouple connection points.

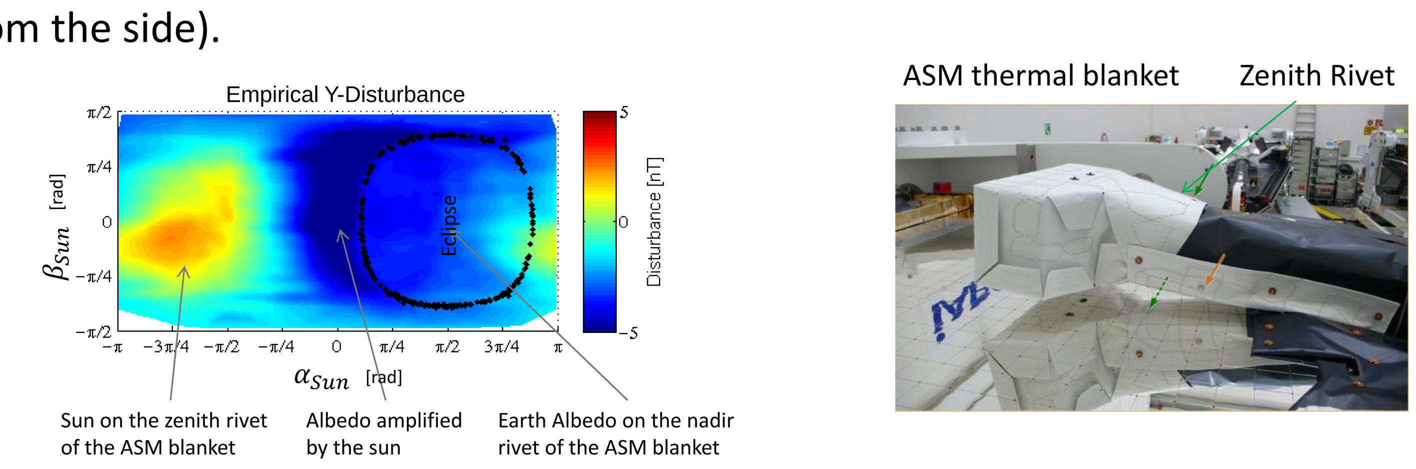
Physical Modelling

The laboratory confirmation of thermoelectric currents between the two rivers has been supplemented with physical modelling of the perturbation as the sun scans the two rivets on the thermal blanket. The model is based on energy balance between input power from the sun, power dissipation to deep space and internal power distribution of each rivet. This provides an estimated temperature of the rivets and herby a thermoelectric currents that result in a magnetic perturbation.

The plots below show a map of the x-axis disturbance for all directions of the sun experienced by the Swarm Alpha satellite (i.e. all local times).



The distribution of the x-axis disturbance is similar on all three Swarm satellites indicating similar perturbation mechanism. However, disturbance in the y-axis is somewhat different. On the y-axis the perturbation seem to be induced by the sun coming for above the satellite (not from the side).



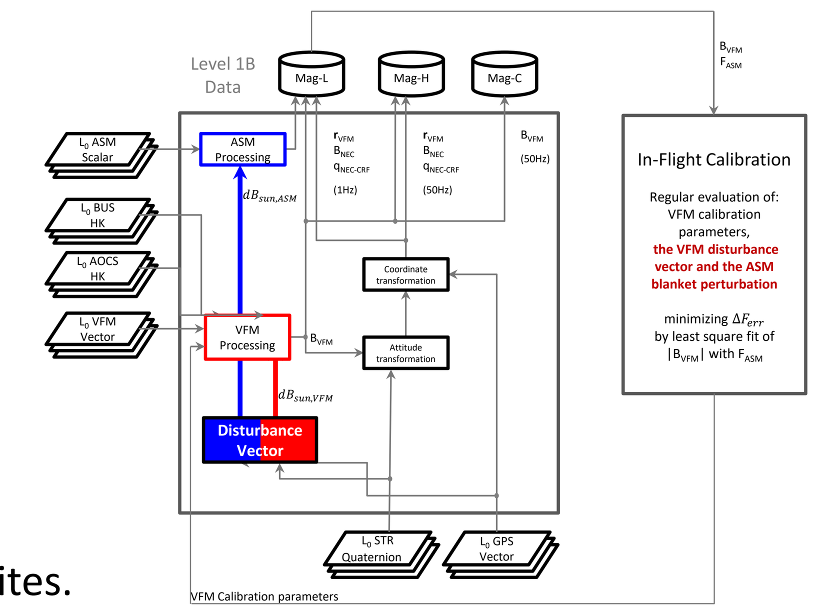
The ASM thermal blanket is designed similar to the VFM blanket but the rivets are placed up/down and the shape of the MLI blanket argues for a y-axis disturbance. The y-axis disturbance of the ASM has later been confirmed by intersatellite comparison of the ASM magnetometers on the two spacecraft's.

Level 1b processor

In order to achieve the scientific goals of the Swarm satellites, the magnetometer data is continuously compensated for by the disturbance vector in the level 1b processor.

The components of the disturbance vector is distributed among the VFM and ASM according to the physical model of the perturbation.

Due to distributed currents there are still features that can be allocated to thermoelectric currents in other blankets on the satellites.



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