2° Forum della Ricerca Sperimentale e Tecnologica

Disturbances Compensation in high accuracy spaceborne accelerometer using multi-sensors and machine learning approach

G.Fusco, F.Santoli, M. Lucente, C. Magnafico for ISA scientific team

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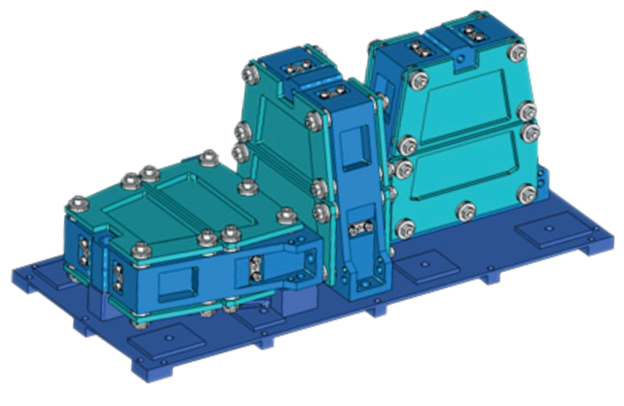
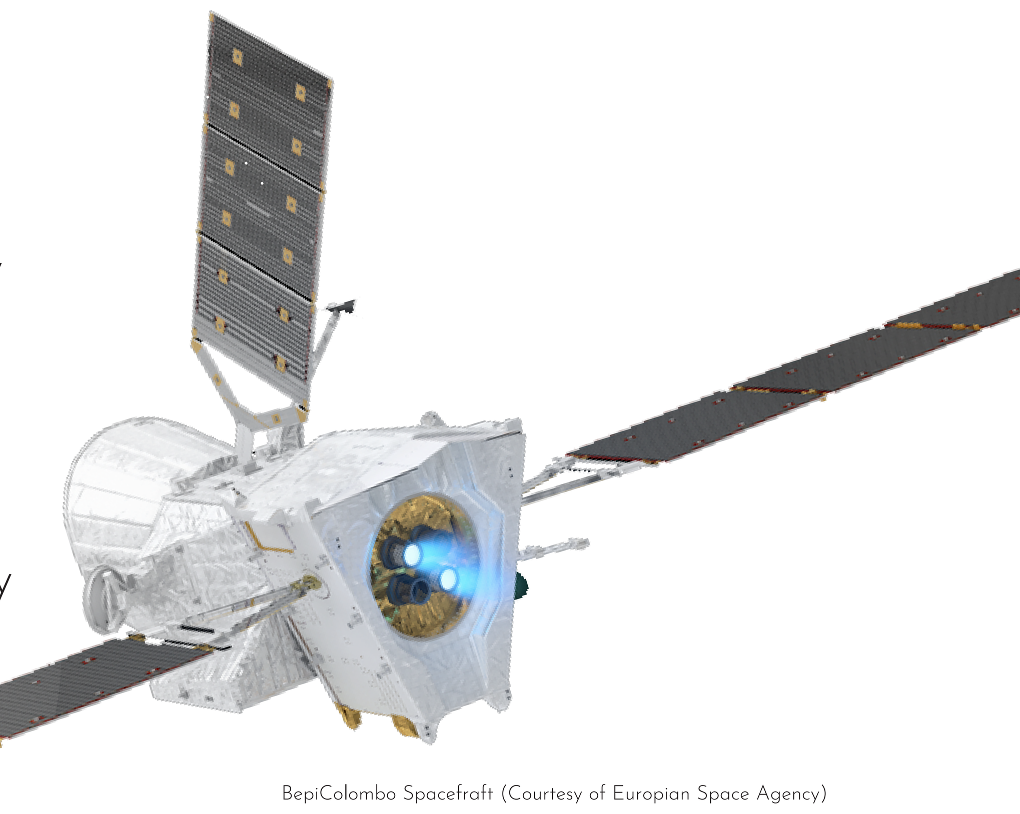
ISA accelerometer



ISA accelerometer - Sensing elements assembly

The first accelerometer in the interplanetary space to highlight gravity anomalies and relativistic effects.

Italian Spring Accelerometer (ISA) is a scientific payload of the European Space Agency's BepiColombo mission to Mercury. It aims to measure the Non Gravitational Perturbations acting on the MPO (Mercury Planetary Orbiter) spacecraft, allowing to consider it as a test-mass free falling in the planetary gravity field and hence disclosing the possibility to study the Mercury's interior, surface, and environment, as well as to perform tests of Einstein's General Relativity theory.

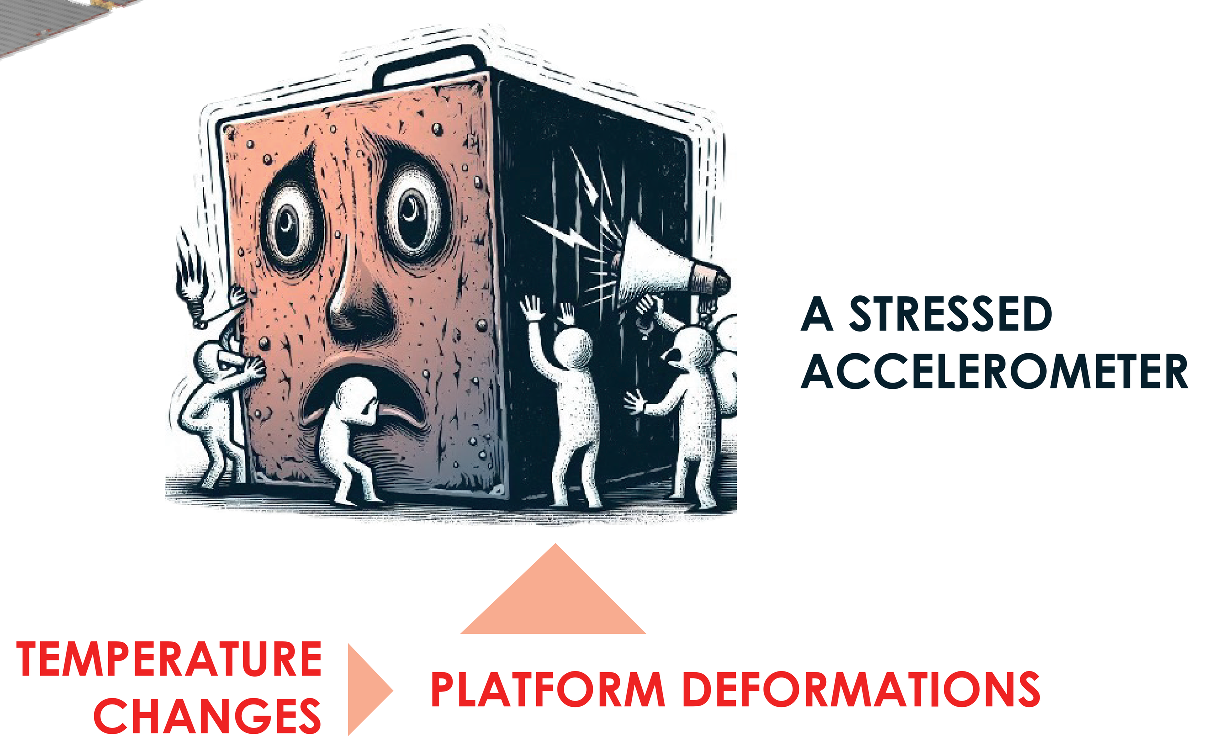


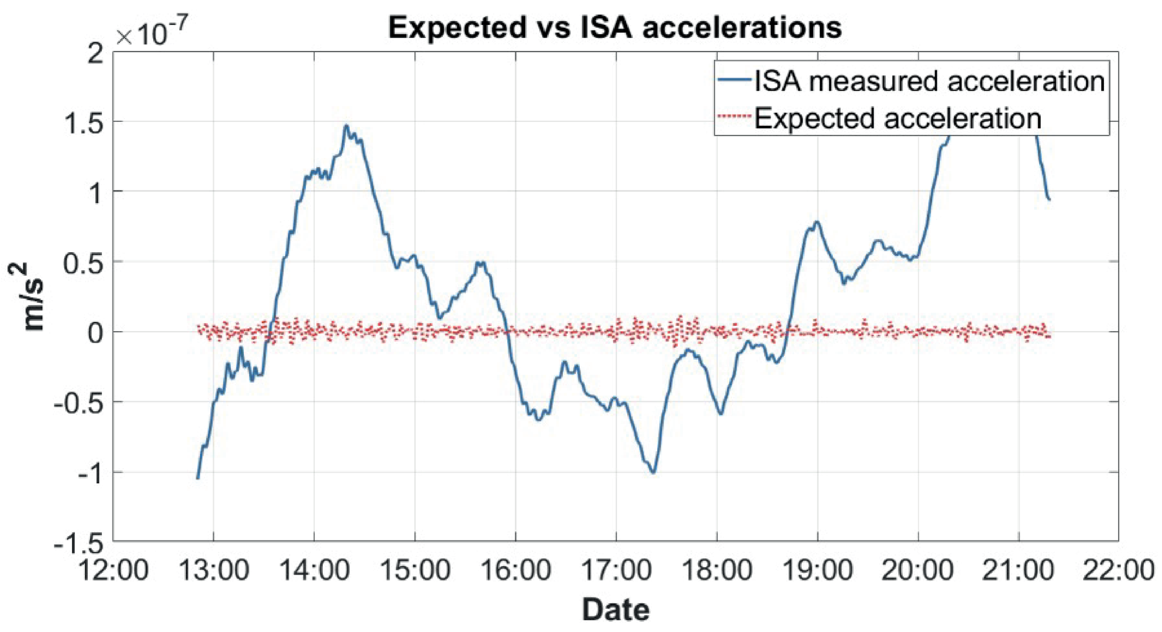
BepiColombo Spacefraft (Courtesy of Europian Space Agency)

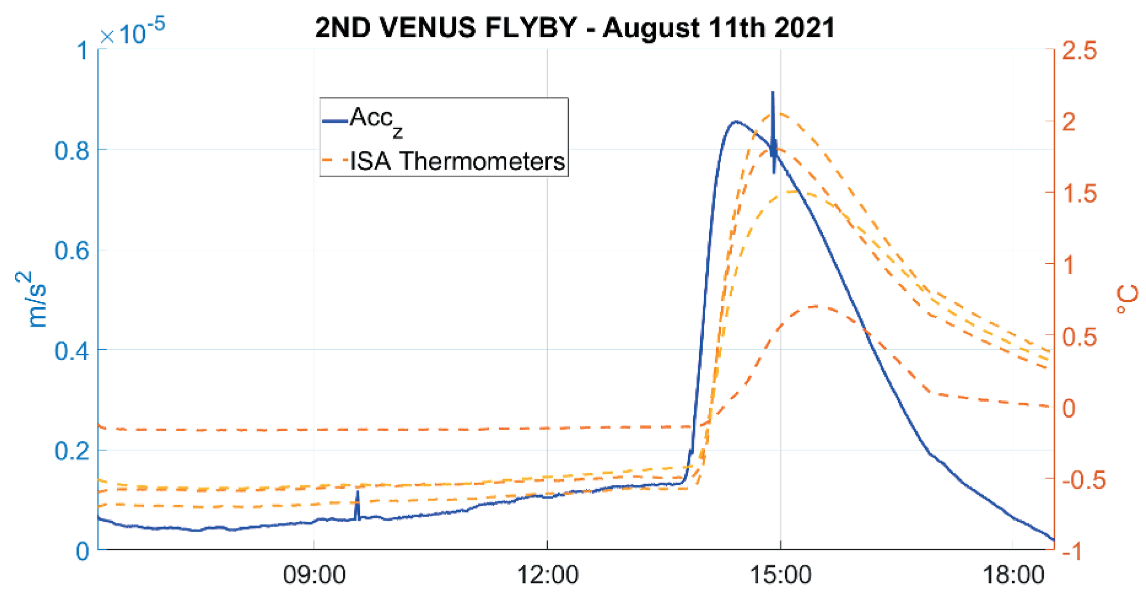
Thermoelastic disturbances

ISA sensitivity to the deformations of the spacecraft panel on which it is mounted on, is a limiting factor of the measurements accuracy, whose target is 10^{-8} m/s^2 .

The thermoelastic disturbance signal was found to be highly correlated with the spacecraft's temperature variations in the region around the plate where the accelerometer is mounted. Initially, the scientific team hypothesized that this signal was due to the instrument's thermal direct sensitivity to these temperature changes. However, after conducting further analysis, we ruled out this hypothesis. The temperature of the instrument remains stable, thanks to an efficient active thermal control system, while the temperature fluctuates around ISA and, more generally, inside the spacecraft. This indicates that the accelerometer is not directly sensitive to temperature changes, but rather to the thermoelastic deformations induced by these changes. Additionally, in several other phases of the cruise, the accelerometer signal precedes the temperature variations recorded by the thermometers close to ISA. This suggests that the source of the heating is located at some distance from the accelerometer.







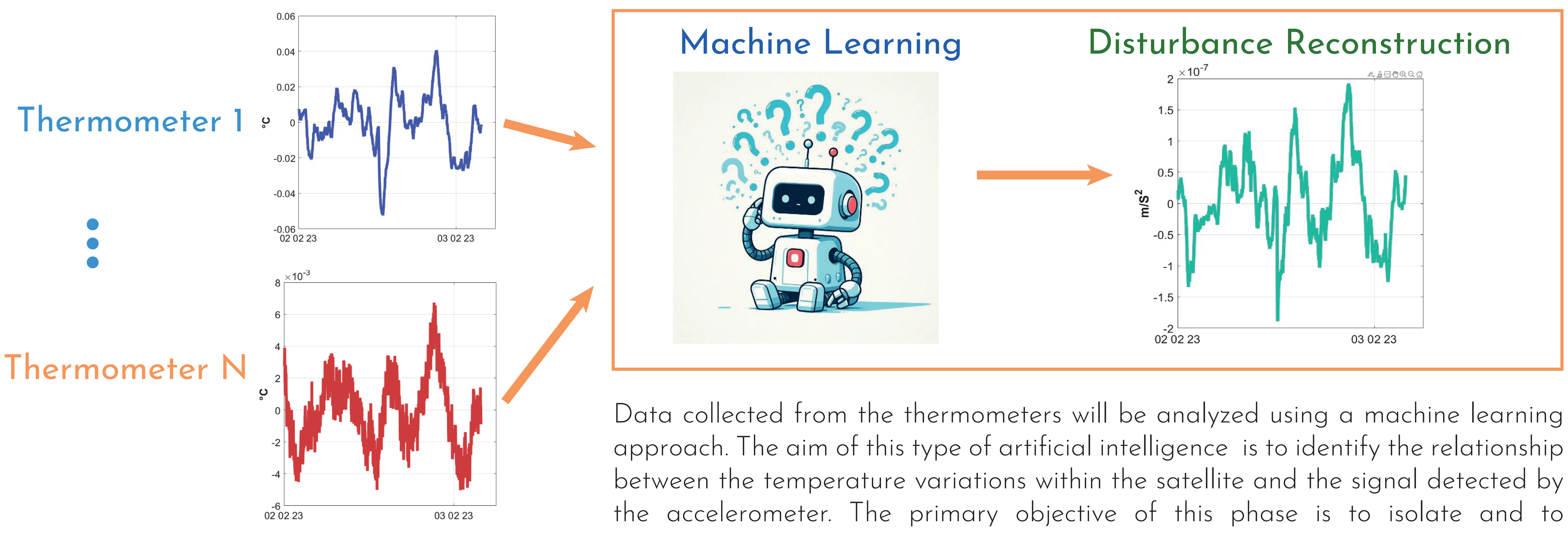
On the left, during the cruise phase of the mission to Mercury, an unexpected signal was detected. This period corresponds to a relatively quiet part of the journey. The red line represents the expected signal, which is nearly zero apart from some noise, while the blue line shows the acceleration measured by ISA along the z-axis.

On the right, during the 2nd Venus Flyby, the deformation signal of the platform, detected as an acceleration by ISA, is caused by an increase in temperature. However, the thermometers near ISA register this temperature rise only several minutes later, as heat diffuses more slowly compared to the thermoelastic response detected by the accelerometer.

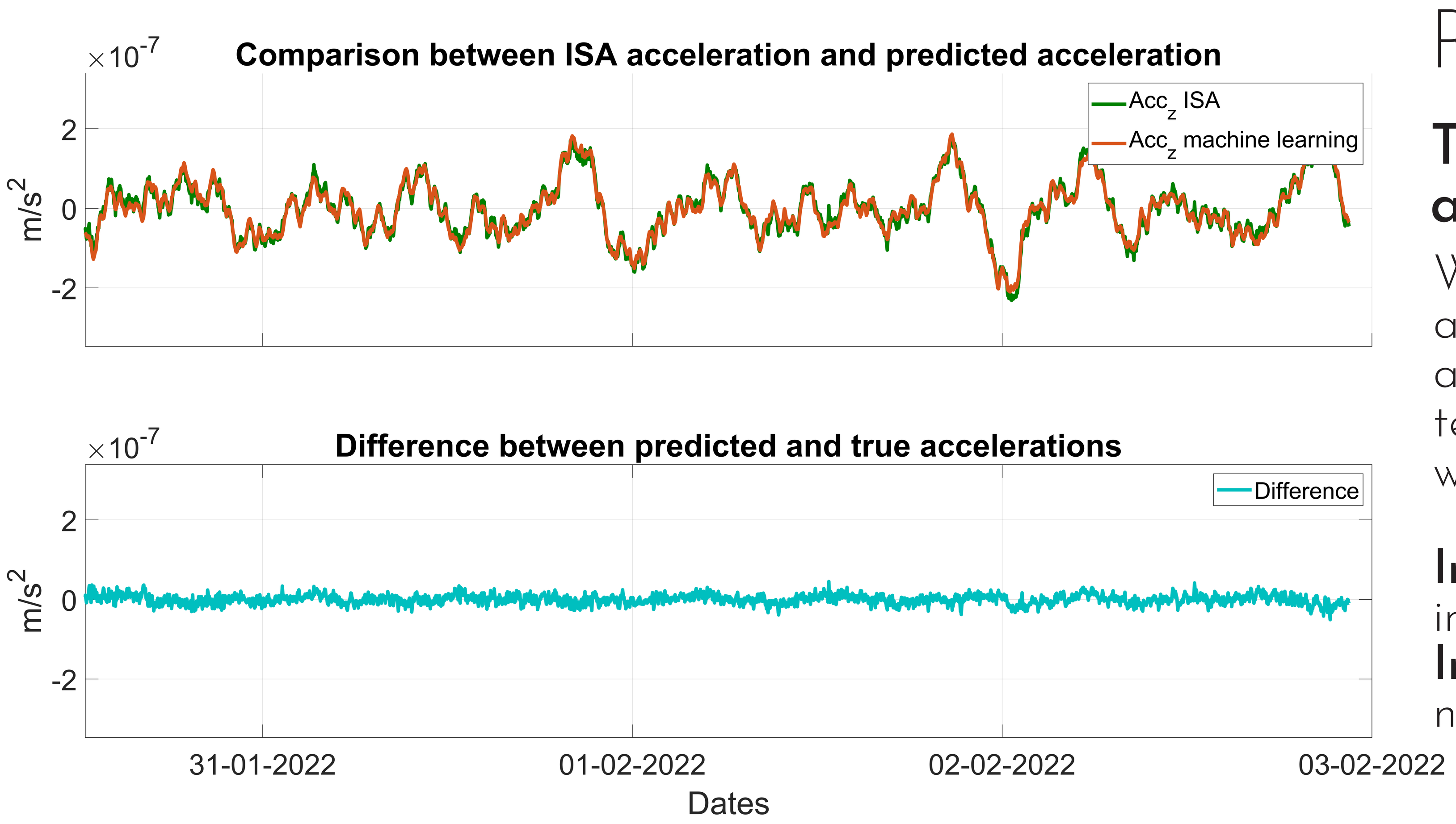
Machine Learning and Multisensor Approach

A new approach for a 'new' issue!

To tackle this challenge, we decided to employ a solution based on a multisensor system and a machine learning approach. As previously mentioned, thermoelastic deformations are influenced not only by temperature variations near the instrument but also by changes across the entire plate on which ISA is mounted. By thoroughly characterizing how temperature changes occur throughout the spacecraft, we can identify the regions that most significantly affect the ISA measurements. The technique is being developed during the mission's cruise towards Mercury, exploiting also the outcomes of the GAIN "Gravimetro Aereo INtelligente" project, which developed a similar methodology for airborne gravimetry.



Data collected from the thermometers will be analyzed using a machine learning approach. The aim of this type of artificial intelligence is to identify the relationship between the temperature variations within the satellite and the signal detected by the accelerometer. The primary objective of this phase is to isolate and to characterize the disturbances, so they can be removed from the total acceleration signal measured by ISA during the mission around Mercury.



Results and Conclusions

The results obtained so far are promising, indicating that the chosen approach may indeed be the right one to resolve the issue.

We have analyzed segments of the cruise phase of the mission, which are relatively quiet and free from other scientific signals. Our future objectives include the introduction of additional sensors, such as power meters, to gain a more precise mapping of internal temperature variations within the spacecraft. We also aim to test the model in periods where physical signals, not just disturbances, are present, such as during planetary flybys.

In the image on the top left, the actual accelerometric signal measured by ISA is shown in green, while the reconstructed signal from the artificial intelligence model is in orange. **In the image on the bottom left**, the difference demonstrates a good result, as the neural network successfully generates a signal very similar to the disturbance and removes it.

IAPS ISTITUTO DI ASTROFISICA E PLANETOLOGIA SPAZIALI

Contacts

Giacomo Fusco, PhD student, giacomo.fusco@inaf.it • Dr. Francesco Santoli, ISA PI, francesco.santoli@inaf.it • Carlo Lefevre, ISA operation manager, carlo.lefevre@inaf.it • Dr. Marco Lucente, ISA scientist, marco.lucente@inaf.it • Carmelo Magnafico, ISA data Handling and Archiving manager, carmelo.magnafico@inaf.it