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PIONEER ANOMALY AND SPACE ACCELEROMETER FOR GRAVITY TEST

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Abstract. The Pioneer 10 and 11 spacecraft are subject to an unexplained acceleration which has a constant value of $(8.741.33) \cdot 10^{-10}\mathrm{m} \cdot \mathrm{s}^{-2}$ and seems to be directed toward the sun. The hypotheses to explain this anomaly are either technical artifacts or new physics. This presentation deals with the unfolding of two aspects of my thesis: Doppler and telemetry data analysis with the objective to investigate the nature of the anomaly, and adapation of an ONERA accelerometer for a future mission in which the anomaly will be confirmed and more precisely measured. The presence of an accelerometer is mandatory for the identification of the anomaly's origin.

1 Introduction

The Pioneer 10 and 11 spacecraft were launched on March 2, 1972 and April 5, 1973. Their goal was to help us explore the solar system beyond Mars orbit with Pioneer 10 going to Jupiter and Pioneer 11 going to Saturn. After these two planetary rendezvous the two spacecraft followed trajectories to opposite ends of the solar system with roughly the same speed, which is now about 12 km/s. Furthermore, it is of note that Pioneer 10 and Pioneer 11 are identical in design. The Pioneer Anomaly refers to their deviations from the expected trajectories, as observed via Doppler radio signals (Anderson et al. 2002). The deviation is a constant sunward acceleration whose magnitude is $(8.74 \pm 1.33) \cdot 10^{-10}\mathrm{m} \cdot \mathrm{s}^{-2}$ for both spacecraft (fig. 1).

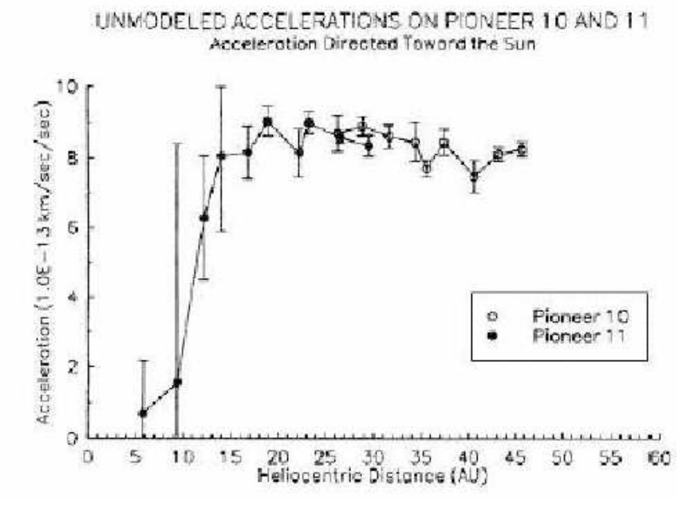

Fig. 1. Residual acceleration of Pioneer 10 and 11 (Anderson et al. 2002)

Hypotheses to explain this phenomenon are either on-board systematics or new physics; the three main attempt of explanation are:

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- RTG's (Radioisotope Thermoelectric Generators) asysmetric radiation,
- Modification of the gravity law (Jaekel and Reynaud 2005),
- Dark matter influence.

The different aspect of the thesis work will be detailed in this article. The first step is the analysis of the trajectory data, in order to confirm the existence of the anomaly with independant tools. The second step deals with the telemetry data, and the study of the more probable explanation for the anomaly, a residual thrust from the spacecraft itself; And finally, the future development of an ONERA accelerometer for the Pioneer anomaly measurement, will be discussed. /fig

2 Doppler data analysis

The data available for analysis are two ODFs (Orbit Data Files). These are two binary files (one for Pioneer 10 and one for Pioneer 11) which contain one especially interesting data type: the Doppler shift, that is to say the difference between the Doppler frequency received on the ground and the emitted frequency. This data will tell us about the movement of the spacecraft with respect to the Earth stations. The time span is between 1987 and 1998 for Pioneer 10 and between 1986 and 1990 for Pioneer 11. The general objective is to make an independant confirmation of the existence of the anomaly. The method to achieve this goal consists in the use of french software developped at the Observatoire de la Côte d'Azur in order to calculate the expected Doppler shift. Then this computed Doppler shift is compared to the observed one contained in the ODFs and the difference between the two will tell us whether or not there is an anomaly. The concern is that our model of the forces applied to the spacecraft and of the signal are accurate enough to be sure that the residual observed is actually an anomaly.

An interesting aspect of this independant analysis will be the possibility to include in our model current gravity theories which will enable us to test their ability to explain this phenomenon.

3 Telemetry data analysis

The second step of the thesis will deal with telemetry data. One of the main suggestion for the Pioneer anomaly is the differential change of the RTG's (fig. 2) radiant emissivity (Scheffer 2005 and Turyshev et al. 2006). One side of the RTG is always hit by the sun while the other side faces into any dust or gas. So, for instance, the first side could get bleached and become a slightly worse radiator. This degradation could result in asymetrics patterns of heat radiation away from the RTGs in the fore and aft directions along the spin axis, and therefore it could cause thrust in the right direction.

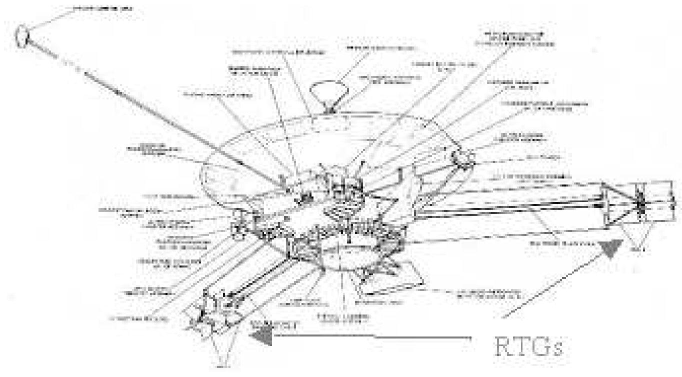

Fig. 2. Drawing of a Pioneer spacecraft

The RTGs had temperature sensors located at the root of one of the radiating fin. So, using the "fin root temperature" and the actual design information on the RTGs, the aim is to check if such a process could be at the origin of the anomalous acceleration.

4 Interest of an accelerometer

The confirmation of the existence of the Pioneer Anomaly implies the necessity to prepare a future mission dedicated to the study of this acceleration.

ONERA (Office National d'Etudes et de Recherches Aerospatiales) develops accelerometers whose properties are very interesting for the study of the nature of the acceleration.

An electrostatic accelerometer is composed of an electrode cage in which a proof mass (PM) is enclosed (fig. 3). The electrodes perform two functions. They permit capacitive sensing of the PM position and simultanously they apply the electrostatic forces necessary to maintain the mass at the center of the cage. The method to observe the acceleration undergone by the mass is to measure the force necessary to maintain it at the center. In this way an accelerometer will measure the difference in acceleration between the mass and the satellite that is to say the non gravitationnal acceleration.

Fig. 3. View of an accelerometer

Thanks to Doppler and/or range measurement the satellite trajectory is determined and compared to the output of the accelerometer, which is the non gravitationnal acceleration. As a result an estimation of the gravitational acceleration is obtained and compared to the gravity model and see if an error appears. Another possibility is to compare the output of the accelerometer to a model of non gravitationnal acceleration to see if an error occurs. Either way the accelerometer will indicate the nature, gravitationnal or not, of the anomalous acceleration, and therefore an accelerometer is mandatary to investigate the Pioneer Anomaly. Due to the size of the Pioneer Anomaly there are some constraints on the required performance of the accelerometer that will be used. The bias as well as the rms value of the resolution has to be inferior to $10^{-11}\mathrm{m}\cdot\mathrm{s}^{-2}$. Concerning the range, it will depend on the orbit considered.

Existing ONERA accelerometers involved in various missions such as GRACE or GOCE missions are good enough in terms of resolution, providing that the integration time is long enough (100 s for the GRACE accelerometer), but improvement has to be made for the bias. For the GRACE accelerometer there is a long term drift in the bias evolution whose magnitude is 20 $\mathrm{nm/s^2}$/year and there is a linear variation with respect to temperature whose magnitude is 3 $\mathrm{nm/s^2}$/year (fig. 4). Consequently the bias has to be reduced or calibrated.

The fact is there are many contributors to the bias: for instance wire stiffness or electrode surface dissimilarity. The sum of all contributions is theorically limited to a maximum $10^{-7}\mathrm{m}\cdot\mathrm{s}^{-2}$ for GOCE accelerometers. This is too much for Pioneer Anomaly observation and therefore the bias issue will have to be tackled. As it would be hard to nullify the bias the idea is rather to measure it accurately. Two methods are considered, both consisting in the rotation of the accelerometer axis with respect to satellite. In the first case there is a calibration with a periodic flip during phase measurement: In one position we measure the bias plus the non gravitationnal forces and in the other position we measure the bias minus the non gravitationnal forces.

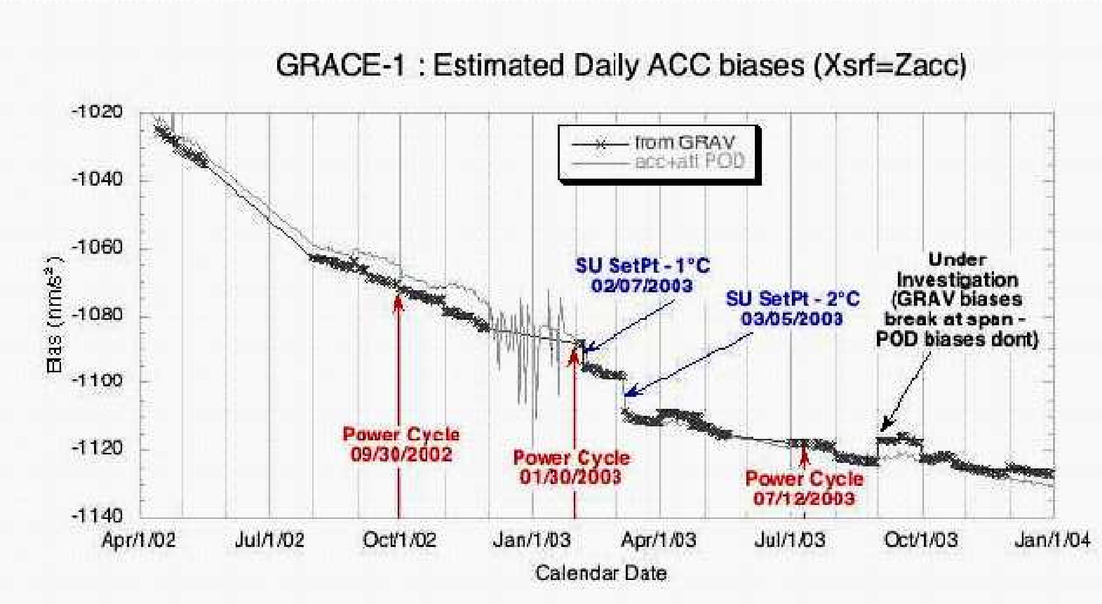

Fig. 4. GRACE: SuperSTAR Bias long-term evolution (Courtesy of UTCSR)

Then we can infer either the bias or the non gravitationnal forces. In the second case the signal is oscillated at a specific frequency so that the measure is not sensitive to the instrument bias.

5 Conclusion

The trajectory analysis is in progress and will be followed by a telemetry data analysis. A future mission appears necessary to reobserve the anomaly and characterize its nature. This necessitates to have an accelerometer on board. ONERA accelerometers have good proven performances, but with a large bias. Solutions to avoid the bias problem are currently being studied

Ackowledgments

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