CHAMP Scientific Payload and its Contribution to a Stable Attitude Control System

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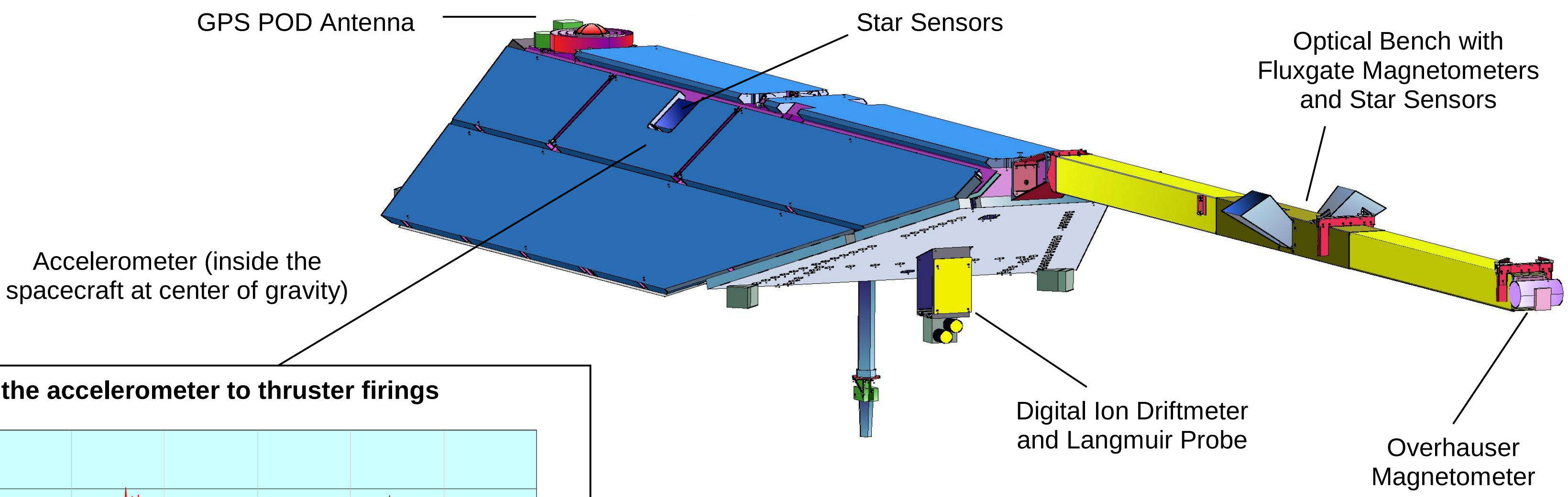
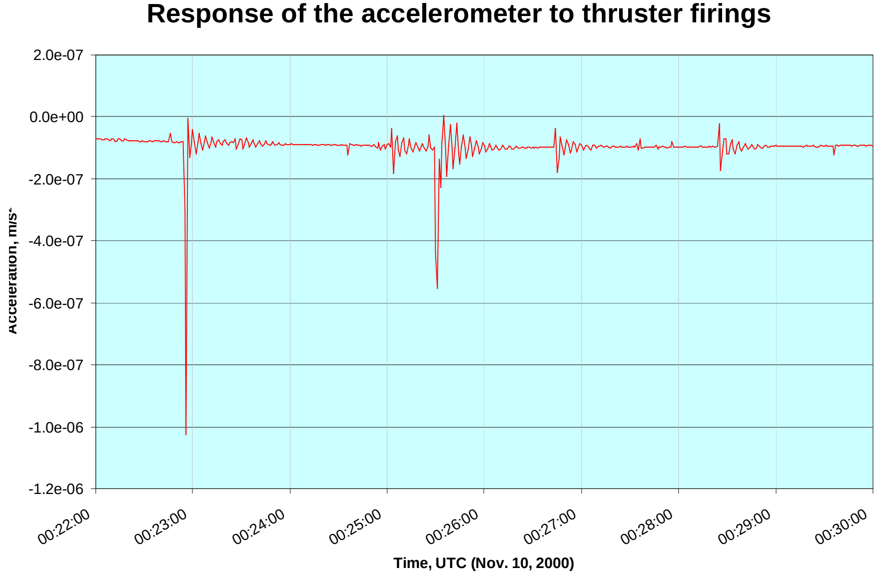
Introduction





Accelerometer measurements are affected by attitude thruster activation and subsequently triggered magnetometry boom oscillations which decay within a few tens of seconds. Here the orbit radial component is depicted. The maximum amplitude of the spikes (about 10^{-6} m/s²) exceeds the instrument resolution by nearly a factor of 1000. Such periods of thruster firings / boom oscillations have to be excluded from the science data processing, thus the number of thruster activations has to be kept at a minimum. The frequent thruster pulses in this example are due to a special attitude maneuver.

On July 15, 2000 the geoscientific satellite CHAMP has been launched into a near-polar, circular low earth orbit at 460 km altitude. Throughout its anticipated 5-year mission the altitude will decay to 300 km. This mission profile has been chosen to provide full global coverage and to resolve temporal variations.

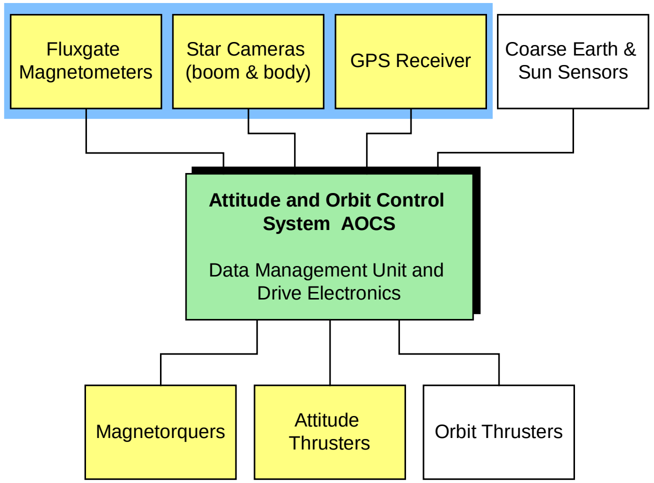
The CHAMP scientific payload is dedicated to recover the global gravity field, the magnetic field and to perform atmospheric sounding measurements. In addition to these scientific objectives the GPS receiver, star cameras and vector magnetometers are also used as input sensors for the attitude and orbit control system (AOCS).

In order to separate gravitational from non-gravitational orbit perturbations an accelerometer is flown on CHAMP. The non-gravitational perturbations include air drag, solar radiation pressure and attitude control actuator operation. Therefore an attitude control system is needed that sparsely performs thruster firing but predominantly uses magnetic torquing instead. The reason for this is that the latter produce significantly lower angular accelerations and no linear accelerations thus providing a quiet measurement platform.

While the Fluxgate Magnetometer delivers undisturbed input for magnetic torquing, outages of the GPS receiver and star cameras have occasionally affected the CHAMP AOCS performance.

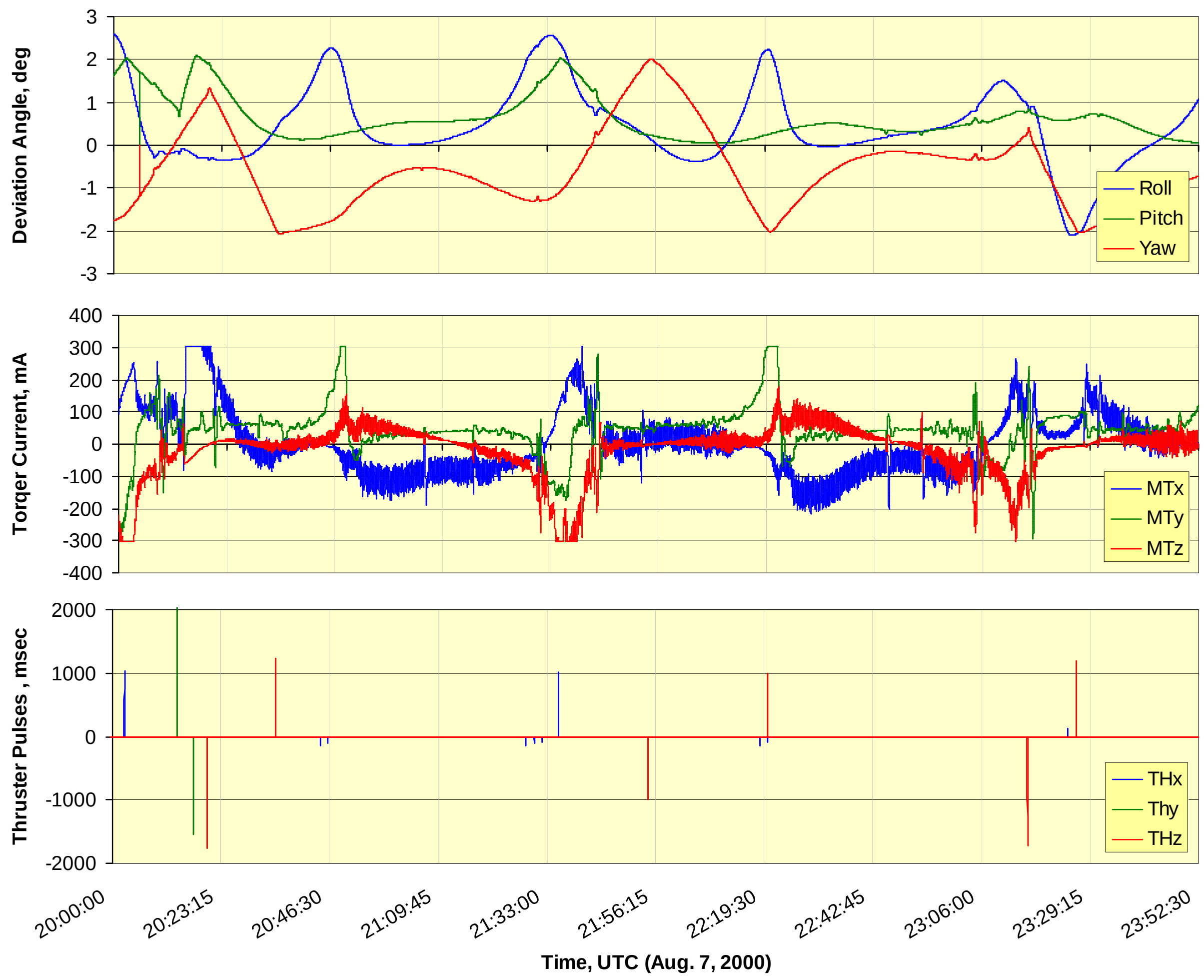
Attitude and Orbit Control System

The CHAMP satellite is kept in a three-axis stabilized earth-oriented attitude with the boom pointing in flight direction to ensure minimum air drag. The AOCS employs a cold gas propulsion system for attitude and orbit change maneuvers. A set of three magnetic torquers for pre-compensation of environmental disturbances supports the cold gas system. The payload instruments *Star Cameras*, *GPS Receiver* and *Fluxgate Magnetometer* are used as attitude sensors along with the Coarse Earth and Sun Sensors for the safe mode.



The accelerometer measures rotational and linear accelerations in the range of $\pm 10^{-4}$ m/s² with a resolution of $\pm 10^{-9}$ m/s². This led to demanding requirements in the spacecraft and AOCS design, e.g. positioning the accelerometer in the center of gravity, aligning thrusters to achieve force free torques and limit thruster activation to a few per orbit. Thruster firings disturb the accelerometer measurements thus mainly magnetic torquing is used for attitude control. Missing or false AOCS data input by the instruments leads to unnecessary thruster pulses.

Example of AOCS control activity

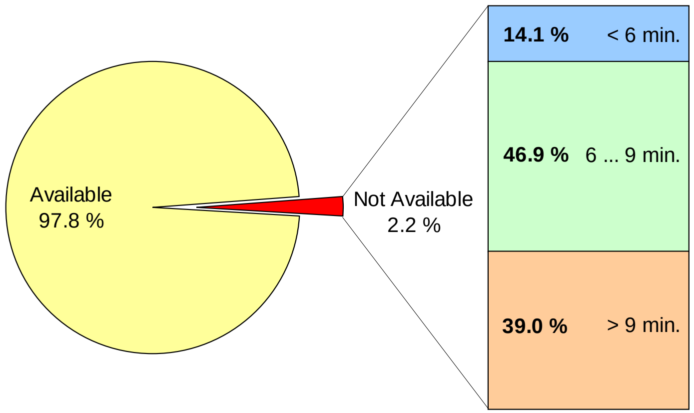


These plots over 2.5 orbits (each scale mark represents a quarter orbit, starting at a northbound equator pass at 20:00 UTC) show that the attitude is predominantly controlled by magnetic torquing and that regional patterns of attitude deviation angles and torquer activities exist. For example the roll axis can not be controlled by torquers over the equator (at 20:00, 20:46, 21:33 UTC etc.). If the deviation angles exceed 2° or the estimated rates are above 0.004 deg/sec the thrusters are activated. Unnecessary thruster firing occur due to false sensor input that lead to wrong rate estimates (e.g. 20:20 UTC).

GPS Receiver Effects

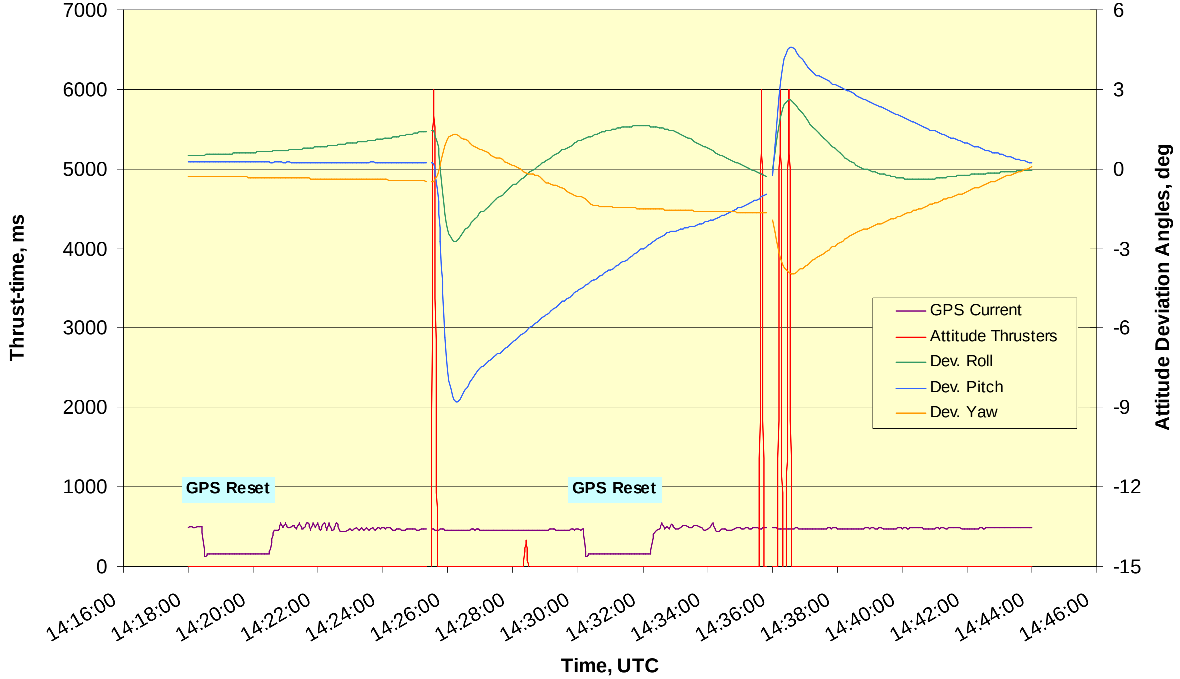
Apart from the scientific objectives like precise orbit determination and occultation measurements, the GPS TRSR-II space receiver forwards its navigation solution to the AOCS. These position and velocity data are required to provide the AOCS with the attitude reference direction (aligned with velocity vector) and are needed to calculate the actual attitude from the star sensor reading. During the first 3 months in orbit the CHAMP GPS receiver has experienced 4 software resets per day, but when navigation solutions are unavailable the AOCS propagates the orbit based on latest inputs from GPS. More harmful were false navigation solutions that led to wrong attitude deviations and caused thruster firings. The first shortcoming has been significantly reduced while the latter has been eliminated by a GPS software update on November 8, 2000.

GPS outages



The unavailability of GPS navigation solutions due to resets is 2.2% (statistics over 622 hours). This graph shows the distribution of those data gaps with respect to duration. The updated GPS software causes less resets but it requires the acquisition of 5 satellites in lock before the navigation solution will be forwarded to the AOCS. While the number of resets per day has decreased the overall time of data gaps is the same but the distribution has shifted to longer periods.

Reaction of the AOCS to a failed GPS position fix



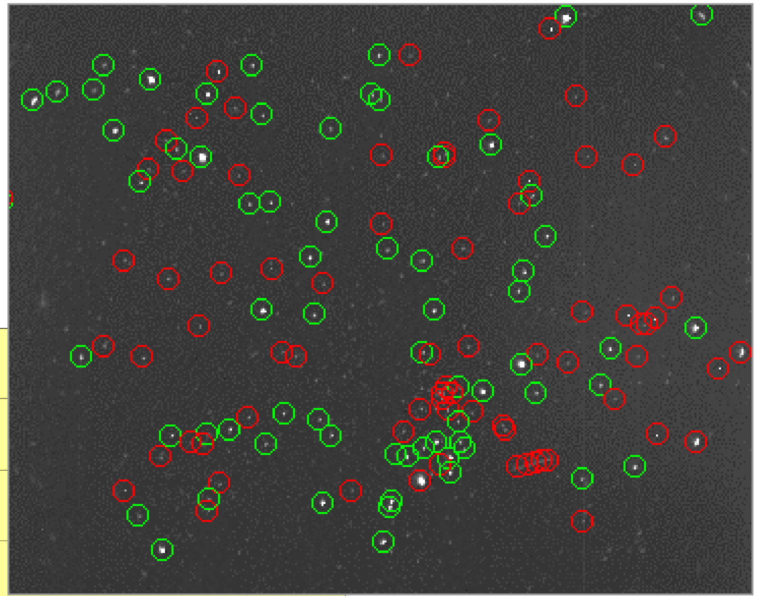
After a S/W reset, the GPS receiver performs an „open sky“ search for the navigation signals of the GPS constellation. The old S/W version started to output navigation solutions as soon as 4 satellites were in lock, but the quality check was insufficient. In case of a false solution, the AOCS on-board orbit propagator assumes a sudden change in the orbital position of the spacecraft and tries to steer the attitude according to this improper data. This causes excessive thruster firings and deviations from the nominal attitude.

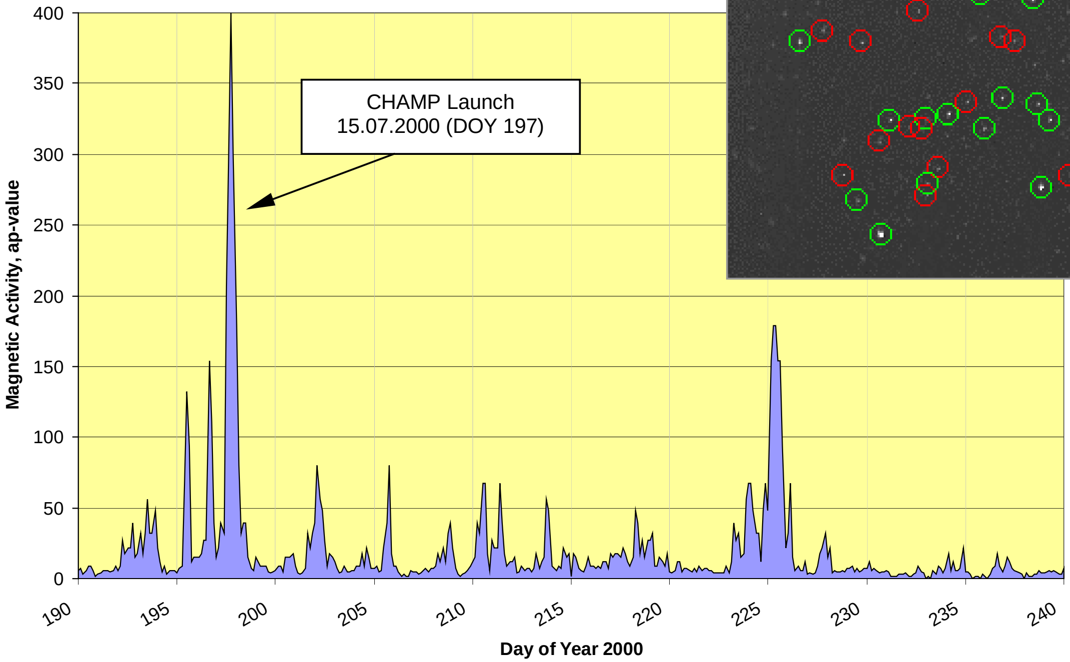
The GPS receiver clears the erroneous situation by a self-induced reset after a few minutes and produces good navigation data afterwards. The AOCS corrects for the improper attitude and brings CHAMP back into nominal orientation within short time. No more GPS-triggered attitude deviations have occurred since the software update.

Star Camera Effects

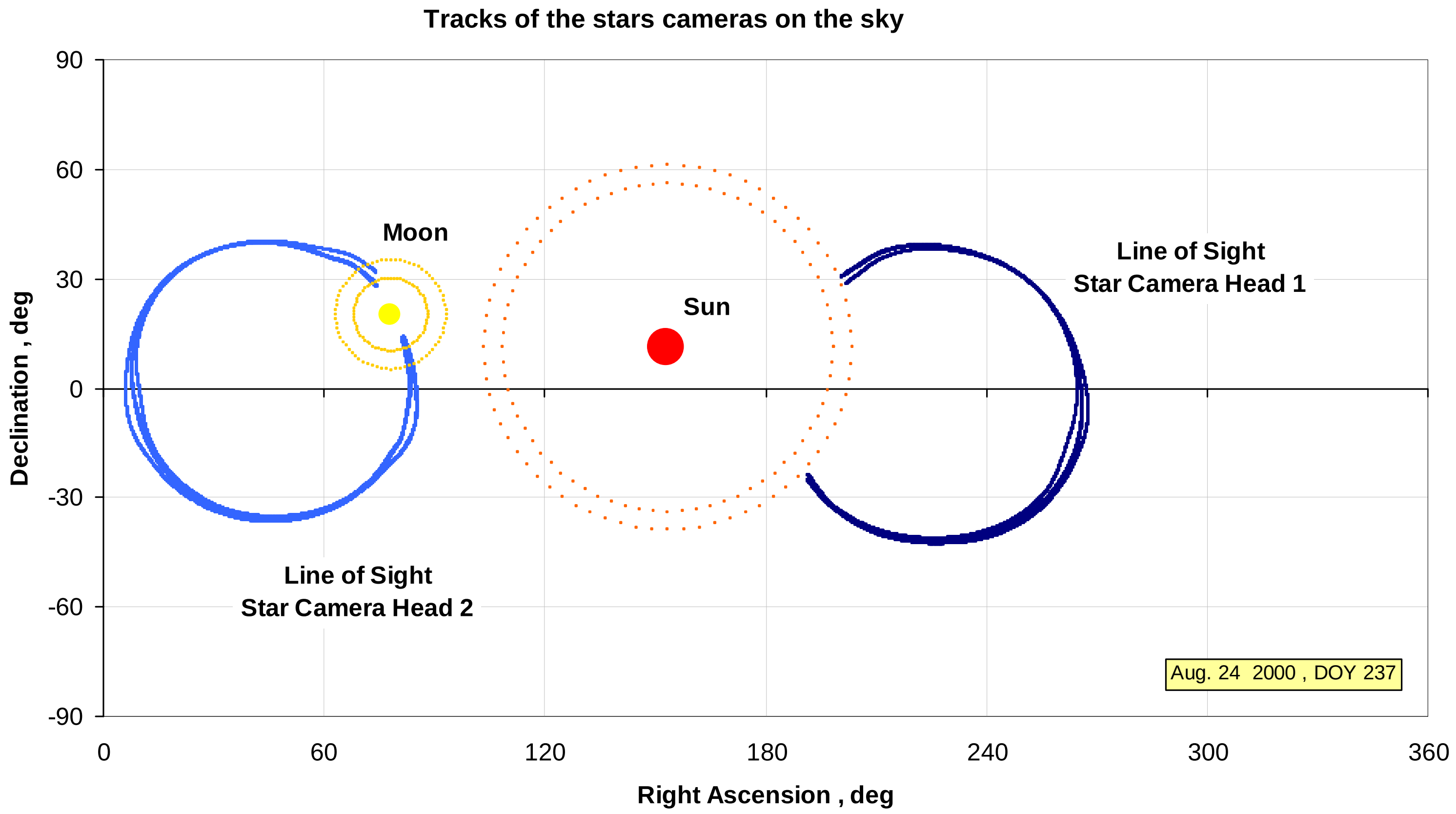
Two independent star camera systems are flown on CHAMP. Each operates two camera heads. They serve to determine the orientation in space of the body-mounted accelerometer sensor and the Fluxgate magnetometry assembly on the boom. These non-magnetic camera head units are flown for the first time in dual-head configuration and achieve an attitude resolution in the arcsecond range. The novelty of also using these dual-head star cameras for AOCS purposes required to investigate and adjust its interaction with the AOCS in flight.

Solar protons causing false stars on the star camera images





CHAMP was launched during an extremely severe magnetic storm on July 15, 2000. This has affected the ASC CCD chips as depicted in the first image of the ASC downloaded to ground. It shows the actual stars (green circles) and luminous non-stellar objects (red circles). Protons passing through the camera chip cause the many non-stellar objects. Nominally only a few proton impacts are expected, but due to the extreme geomagnetic storm the number is vastly increased. On this image 143 luminous objects were detected of which 71 are stars. Decreasing the sensitivity and installing a hotspot rejector has cured this problem.



Attitude data are not available when the sun or the moon are in the field of view. The line of sight in the celestial reference frame of two camera heads over several orbits is depicted. The AOCS uses only one of the 4 camera heads which is chosen according to its availability in a fixed order. The switch from one camera head to another, especially from body- to boom-mounted heads may cause thruster activation in case the transformation angles into the common reference system are not properly adjusted. Especially gracing incident sun light causes the frequent switching between camera heads. Software updates and angle adjustments have significantly reduced this effect.

Conclusion

The lessons learned during the CHAMP commissioning phase have led to improvements on the interaction between the scientific payload instruments and AOCS. The cold gas consumption has been considerably lowered by various adjustments and has reached the nominal value of 4g/day average. Because the cold gas is the life limiting resource a thorough analysis and good understanding of the behavior is the key to reach the planned 5 years in-orbit time.

Further software updates and functional parameter adjustments are planned and give a prospect on a enhanced robustness of the attitude and control system on CHAMP.