Asymmetric radiation pressure on LAGEOS

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Presentation to LW14, 2004 June 10, San Fernando, Spain by G. Appleby

Outline

- Analysis of the orbits of the LAGEOS satellites indicates that the radiation pressure on the satellites is not perfectly symmetrical. There is an unexplained force component along the spin axis. Corresponding acceleration ~10 $pms^{-2.}$ So need empirical 1-per-rev terms in POD.
- Previous work has suggested, for instance, an asymmetry in the reflectivity of the two hemispheres of LAGEOS (Scharroo, *et al*, 1991)
- A recent paper (Lucchesi, 2004) attempts to explain the asymmetry as being due to the germanium cube corners.
  - Each LAGEOS satellite carries 4 GE cubes – they are opaque to visible radiation, transparent to IR.
- We here refute the ***model*** used to reach this conclusion, explain our reasons and propose a different approach to the problem.

The Physical Problem

- LAGEOS is subjected to perturbing forces from incident radiation and from thermal radiation emitted by the satellite; incident radiation is both direct and Earth-reflected solar, plus thermal radiation from the Earth. The incident radiation is partially reflected from the satellite and partially absorbed.

- The energy absorbed by the satellite must be emitted as thermal radiation. The force due to the incident radiation is instantaneous. As long as the reflecting properties of the satellite are uniform there is no asymmetry

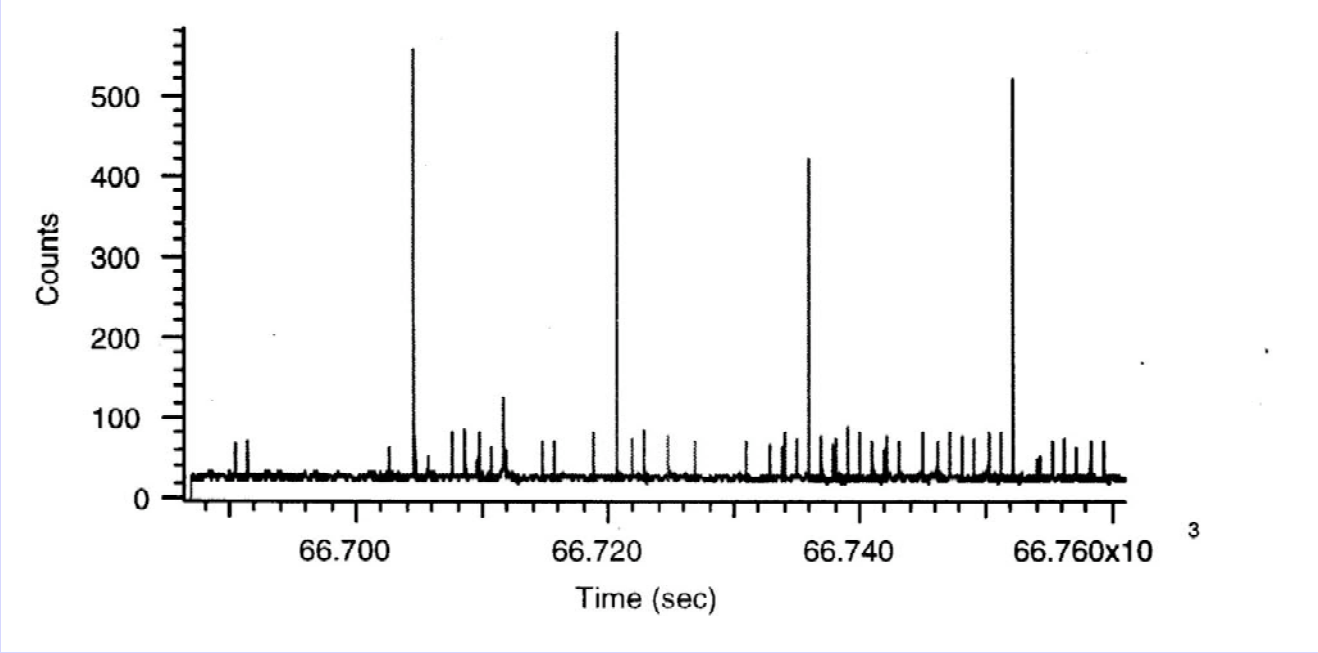
- But, reflection of thermal energy is not instantaneous, so thermal force will be in a different direction from incident radiation – effect depends on spin axis vector – different for LAGEOS-1 and -2.

- Since the optical and thermal parameters of the germanium cubes are different from the parameters of the optical cubes, they run at different temperatures and the pressure of the thermal radiation is different.

- **This results in an asymmetric thermal radiation pressure**.

GE cubes are good reflectors of sunlight

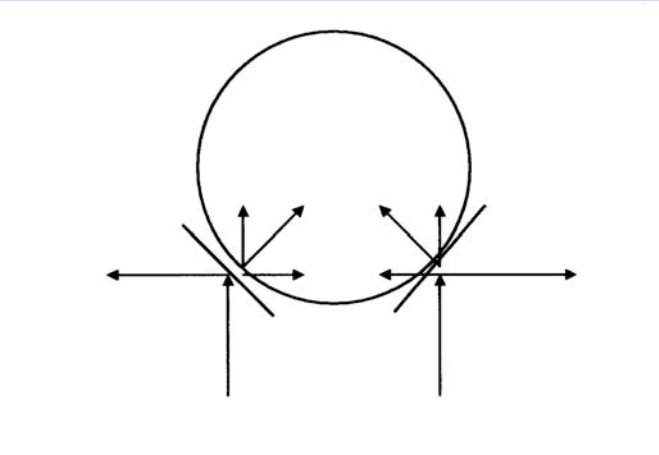
- By way of illustration, below is a photometric trace of a Solar flash set (Herstmonceux[1]) from LAGEOS-2 demonstrating that the Ge cubes are opaque to visible light – the bright flashes are from the front faces of the two Ge cubes in the ring, the fainter flashes from the silica cubes:



Asymmetry due to the germanium cube corners

- Lucchesi in his model assumes that the optical cubes cover the LAGEOS satellite uniformly and that there would be no asymmetry in the radiation pressure on a satellite with only optical cubes.

- The premise of the paper is that replacing 4 of the optical cubes with 4 germanium cubes results in an asymmetry in the radiation pressure on the satellite because the reflectivity of the germanium cubes with respect to solar radiation is different from the reflectivity of the optical cubes – illustrated below:



•Two mirrors on a spherical satellite which are at a 45 degree angle with respect to the incident solar radiation which is in the vertical direction.
•The mirrors have a reflectivity of 100 percent.
•The momentum transfer is perpendicular to the mirror in the direction of the center of the satellite for both mirrors – the horizontal components cancel and the net force on the satellite is in the vertical direction, parallel to the incident solar radiation – **this is symmetrical radiation pressure**.

•However, if say the right hand mirror is replaced by a different object, there will be a radiation pressure asymmetry which is proportional to the difference in force on the new object and the force on the mirror that was originally on the right side of the satellite.

Back to LAGEOS- Perturbation to the orbit

- So, if one replaces an optical cube corner on LAGEOS with a germanium cube corner, the effect is to subtract the force on the optical cube and add the (different) force on the germanium cube.

- One approach to determining the orbital perturbation caused by the germanium cube corners is the following:
- Do an orbital simulation with only optical cubes on the satellite, computing all the forces on the satellite due to incident radiation on the cube corners and the core, and the force due to thermal radiation from the core and the cube corners.
- Do the same again, replacing in the model 4 optical cubes with Ge ones.
- Compute the difference between the state vectors or orbital elements from the two simulations. This is the perturbation due to the germanium cube corners.

- We note that in the Lucchesi theoretical approach, the Ge cubes ‘replace’ black-body ‘cubes’, not at all close to the real situation.

Problem with our approach

- **There is no available model for computing the radiation pressure on an optical cube corner as a function of incidence angle** – for normal incidence there is no problem.
- What needs to be done:

- The satellite can be considered to consist of 4 parts:
- The optical cubes; germanium cubes; retaining rings; surface of the core
- To do a proper job, one needs time-dependent temperature of all, from which to calculate pressure of thermal radiation.

Recommendations

- As part of design study for CHAMP, commercial package ASAP was used to calculate the diffraction pattern of the cube corner with a single dihedral angle offset and a curved front face.
- I would suggest investigating whether some similar software could be used to develop a model of the radiation pressure on an optical cube corner.
- **Note:** It has been suggested by some authors that the reflecting properties of the core my not be uniform and this could account for the asymmetric reflectivity.
- However, it is unclear how one would determine if the core were not symmetric. Since the asymmetry in the radiation pressure on the optical cubes has not been computed, it seems premature to assume an asymmetry in the reflecting properties of the core.