Prosaic Explanation for the Anomalous Accelerations Seen in Distant Spacecraft

Anderson *et al.* [1] have recently reported the discovery of an apparent anomalous, weak, long-range acceleration in the Pioneer 10/11 and Ulysses spacecraft. I believe that this result can be explained, at least in part, by non-isotropic radiative cooling of the spacecraft electronics. The waste heat dissipated by the electronics is radiated from the spacecraft by passive surface radiators which are typically located on the antisolar side of the spacecraft.

Toward the ends of their missions, the Pioneer 10/11 spacecraft were drawing 80 W of electrical power [1] from their radioactive thermal generators (RTGs). Of this, 8 W was transmitted as rf power [1]. The essential electrical systems are located in a hexagonal hub beneath the high-gain antenna. The waste heat generated by the electronics is radiated through a series of louvered doors on the antisolar side of the spacecraft. Since the majority of the science instruments have been turned off, essentially all of the 72 W of internally dissipated electrical power is radiated from the louvered doors.

If the doors are closed, the radiation will be uncollimated and the 72 W of radiated power will generate an $a_P = 6.2 \times 10^{-8}$ cm s^{-2}. If the doors are fully open (an unlikely case) and the radiation fully collimated, the acceleration produced would be $a_P = 9.2 \times 10^{-8}$ cm s^{-2}. In fact, thermal design documents [2] indicate that the doors would have an opening angle of about 20° at 5 AU, which would result in an acceleration of $a_P = 3.2 \times 10^{-8}$ cm s^{-2} (note that the radiation would be highly collimated but directed at a large angle from the antisolar direction). Therefore, it appears that radiated waste heat can account for 40% or more of the reported anomalous acceleration of $a_P = 8.5 \times 10^{-8}$ cm s^{-2} [1]. A more detailed analysis of the Pioneer thermal design and power budget is underway and will be published elsewhere.

The Ulysses spacecraft keeps its rotation axis pointing approximately toward the Earth and within 25° of the Sun [3]. The waste heat from the electronics is radiated through a large, flat radiator panel on the antisolar side of the spacecraft. A power budget for the Ulysses spacecraft for January 1998 [3] indicates that Ulysses' systems are drawing 231 ± 3 W of electrical power. Of this, I calculate that the total power radiated through the spacecraft radiator on the antisolar side of Ulysses is (160 ± 21) W. The acceleration produced by this power is $a_P = (10.3 \pm 1.3) \times 10^{-8}$ cm s^{-2} which is consistent with the acceleration of $a_P = 12 \pm 3 \times 10^{-8}$ cm s^{-2} reported by Anderson *et al.* Since the radiator faces away from the Sun, the direction of this acceleration is toward the Sun.

For all of the missions, the essential electrical systems must remain powered at all times. Although the thermal power output of the RTGs is expected to decrease with time, the power drawn by the essential spacecraft electronics is nearly constant and, therefore, the acceleration imparted by the thermal radiation from the spacecraft radiators should also be constant with time. Most of the science experiments which have been powered off are located on the periphery of the spacecraft and are small enough that they radiate their power isotropically and do not employ a radiator system. Therefore, their waste heat has little effect on the net acceleration.

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