A possible explanation for the anomalous acceleration of Pioneer 10

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The reported anomalous acceleration of the Pioneer 10 spacecraft of $\sim -8.5 \times 10^{-10} \text{m.s}^{-2}$ (i.e. towards the sun) can be explained by a gravitational interaction on the S-band signals traveling between Pioneer 10 and the earth. The effect of this gravitational interaction is a frequency shift that is proportional to the distance and the square root of the density of the medium in which it travels. If changes in this frequency are interpreted as a Doppler shift the result is an apparent acceleration directed towards the sun. The gravitational interaction is caused by the focusing of the signal photons in curved space where in this case the curvature is related to the density of the interplanetary dust.

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I. INTRODUCTION

Precise tracking of the Pioneer 10/11, Galileo and Ulysses spacecraft have shown an anomalous constant acceleration for Pioneer 10 with a magnitude $\sim -8.5 \times 10^{-10} \text{m.s}^{-2}$. Additional analysis by the same team provide a new value for the acceleration ($-7.5 \pm 0.2) \times 10^{-10} \text{m.s}^{-2}$ (where the uncertainty is estimated from points in their Fig 1) and also reveal that there is an additional annual periodic component with a amplitude of $\sim 2 \times 10^{-10} \text{m.s}^{-2}$ directed towards the sun. The main method for monitoring the spacecraft is to measure the frequency shift of the signal returned by an active transponder. Any variation in this frequency shift that is not actually due to motion can be confused with a Doppler shift and would be attributed to anomalous velocities and accelerations.

This paper argues that there is an additional frequency shift in the spacecraft signal due to a gravitational interaction with the intervening material. Because the frequency shift is proportional to the distance to the spacecraft it can easily mimic an acceleration.

II. THE EXPLANATION FOR THE CONSTANT ACCELERATION

In previous papers it was argued that photons have a gravitational interaction. This claim is based on the premise that in curved space a bundle of geodesics is focused (the "focusing theorem", [6]) and as a consequence photons are also focused. This leads to an interaction in which low energy photons are emitted and the primary photon loses energy. The effect can be observed as a frequency shift in a signal that is a function of distance traveled and the density of the local medium. Although the cosmological consequences of such an interaction are profound, it also leads to predictions which can be tested locally, including the prediction that a frequency shift should be seen in the signals from spacecraft. For a signal passing through a medium with matter density $\rho$ the rate of change of frequency, $f$, with distance is

$$\frac{df}{dx} = -\left(\frac{8\pi G \rho}{c^2}\right)^{1/2} f.$$  \hspace{1cm} (1)

Note that although point masses may distort and deviate the geodesic bundle they do not focus it and so that there is no frequency shift predicted for signals passing near stars or planets. Since the effect is very small we can write it in effective velocity units as

$$\Delta v = -\sqrt{8\pi G \rho} \Delta x.$$ \hspace{1cm} (2)

Differentiating gives an apparent acceleration of $a = -\sqrt{8\pi G \rho} V$ where $V$ is the velocity of the spacecraft (or earth) and $\rho$ is the density at the current positions. It is not an average density over the path length. Using the observed anomalous acceleration of $-7.5 \times 10^{-10} \text{m.s}^{-2}$, and a Pioneer 10 velocity of 12.3 km.s$^{-1}$, the required density for the two-way path is $5.5 \times 10^{-19} \text{kg.m}^{-3}$. The only constituent of the interplanetary medium that approaches this density
is dust. One estimate \[8\] of the interplanetary dust density at 1 AU is \(1.3 \times 10^{-19} \text{kg.m}^{-3}\) and more recently Grün \[4]\ suggests a value of \(10^{-19} \text{kg.m}^{-3}\) which is consistent with his earlier estimate of \(9.6 \times 10^{-20} \text{kg.m}^{-3}\) \[10\]. Although the authors do not give uncertainties it is clear that the densities could be in error by a factor of two or more. The main difficulties are the paucity of information and that the observations do not span the complete range of grain sizes. Taking a density of \(10^{-19} \text{kg.m}^{-3}\) the computed (anomalous) acceleration is \(-3.4 \times 10^{-10} \text{m.s}^{-2}\), smaller by a factor of two than the observed anomalous acceleration. However the density is required at the distance of Pioneer 10 in 1998 of 72 AU in the plane of the ecliptic (ecliptic latitude of Pioneer 10 is 3°).

The meteroid experiment on-board Pioneer 10 measures the flux of grains with masses larger than \(10^{-10} \text{g}\). The results show that after it left the influence of Jupiter the flux \[11\] was essentially constant (in fact there may be a slight rise) out to a distance of 18 AU. It is thought that most of the grains are being continuously produced in the Kuiper belt. As their orbits evolve inwards due to Poynting-Robertson drag and planetary perturbations they achieve a roughly constant spatial density. Given the large uncertainties in both the observed density at 1 AU (due to the limitations of the detectors), and the extrapolation of the density to 72 AU, the conclusion is that interplanetary dust could provide the required density to explain the "anomalous acceleration" by a frequency shift due to the gravitational interaction.

### III. THE EXPLANATION FOR THE ANNUAL ACCELERATION

Figure 1B in \[8\] shows a time varying acceleration that has a period of one year and an amplitude that both fluctuates and decreases with time. (It may not be a valid decrease but be due to the solar cycle.) Their figure shows 50-day averages after the best-fit constant anomalous acceleration has been removed. For the years 1987 to 1993 where the curve is well defined the maxima occur at 0.94 ± 0.03 yr and the minima at 0.45 ± 0.03 yr. The amplitude changes from \(\sim 2.5 \times 10^{-10} \text{m.s}^{-2}\) in 1988 to \(\sim 1.5 \times 10^{-10} \text{m.s}^{-2}\) in 1992.

In principle the gravitational interaction can explain this acceleration but now the relevant velocity is not that of Pioneer 10 but the orbital velocity of the earth. Taking the earth’s velocity as \(30 \text{km.s}^{-1}\) and a dust density of \(10^{-19} \text{kg.m}^{-3}\) the predicted annual acceleration in 1989 has an amplitude of \(7.6 \times 10^{-10} \text{m.s}^{-2}\). Although this acceleration is a factor of three too large a more significant objection is that the predicted phase disagrees with the observations. With this model the maximum accelerations should occur when the earth has a maximum velocity relative to Pioneer 10, namely when it has maximum elongation as seen from the spacecraft. Since in 1989 Pioneer 10 had an ecliptic longitude of \(\sim 72^\circ\) these should occur at 0.17 yr and 0.68 yr. The discrepancy in phase of 97° ± 11° means that the gravitational interaction does not directly explain the annual variation. However since the gravitational interaction was not included in in the complex calculations used to compute the trajectory it is feasible that the effect has been compensated for by small adjustments to other parameters and all that is left is a distorted residual.

If mistakenly interpreted as a Doppler shift the annual component of the gravitational interaction is equivalent to an additional velocity of the earth (as seen by Pioneer 10) of 3.8 mm.s\(^{-1}\). For a circular orbit of the earth this is equivalent to a shift in the longitude of Pioneer 10 of 0.026 arcseconds. Thus if there is a gravitational interaction it could be masked by a small error in longitude. In practice the position of Pioneer 10 must be consistent with celestial mechanics and many other observations and it is unlikely that there would be complete compensation. The final analysis requires the inclusion of the gravitational interaction into the orbit calculations.

### IV. CONCLUSION

It has been argued that the gravitational interaction with a interplanetary dust density of \(10^{-19} \text{kg.m}^{-3}\) predicts an anomalous acceleration of Pioneer 10 at 72 AU of \(-3.4 \times 10^{-10} \text{m.s}^{-2}\) to be compared with the observed value of \((-7.5 \pm 0.2) \times 10^{-10} \text{m.s}^{-2}\). The largest uncertainty is in the estimate of the interplanetary dust density. Since the annual period in the gravitational interaction is easily masked by small shift in the longitude of Pioneer 10 its effects are unlikely to be observed. However the predicted magnitude is in the right range and the observed annual acceleration could be the residuals after a partial compensation.

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