Pioneer Anomaly Re-visited

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Abstract

This mysterious effect has been given considerable thought as to its nature. Some have thought that the effect is due to unknown spacecraft effects, such as gas leaks or anisotropic thermal radiation. Others hold out for some fundamental physics that might alter the theory of gravitation. Recently, a complete analysis of rediscovered spacecraft data provides a credible story for spacecraft engineering being the cause. However, more fundamental physics has not been absolutely ruled out. This paper will relook at the anomaly from a fundamental perspective by applying a recently published physical theory to the Pioneer anomaly, and will show that a new theory can explain the effect.

1 Introduction

The Pioneer 10 spacecraft was launched in 1972 followed by Pioneer 11 a little over a year later. These two spacecrafts are presently outside the solar system, each going in opposite directions. Both spacecraft have uncovered an unexplained phenomena described as an anomalous acceleration directed toward the sun, that has confounded all observers (Anderson, et al. 2002). Basically, observers have suggested two possible paths to explain the phenomena. Either there exists new physics, or events on the spacecraft related to design. More recently (Turyshev, et al.,2012) analyzing rediscovered data builds a credible case for an explanation due to events on board the spacecrafts, although this explanation does not absolutely rule out the case, at least in part, due to more fundamental physics involvement.

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The Pioneer spacecrafts were designed to measure the Doppler shift due to the relative motion of the spacecraft and the Earth. To accomplish this a reference signal is sent to the spacecraft that in turn transponder the signal back to Earth. When this signal is compared to the expected Doppler shift, an unexplained shift is observed that indicates there exists an unknown small acceleration pointing toward the sun. The actual test for Pioneer 10 began in 1987, after the spacecraft had encounter Jupiter and the solar wind had diminished to an acceptable level, and ran to 1998. Pioneer 11 had an on-board failure that limited its ability to provide Doppler data therefore this paper will not discuss Pioneer 11.

This paper will apply a newly introduced physical theory (Longo, 2016) to the anomalous Pioneer 10 phenomena. Leaving the possibility that at least part of the phenomena can be explained by the new physical theory. In these calculations no attempt will be made to obtain the ephemeral data or obtain and utilize the JPL codes. All spacecraft data was obtained from the Ecliptic pole view of the pioneer 10 and 11 trajectories, see Figure 3 in Anderson 2002, however the main features of the new theory will be applied.

2 Application of the Theory

The physical theory we will apply to the effect starts by assuming the General Relativity applies in the solar system and beyond. It will be assumed that the Schwarzschild solution is the proper solution. The solution can be embedded as a manifold in a higher dimension Euclidian space. At each point of the manifold, i.e., at every point in space-time, a tangent space can be constructed which not only collectively defines the manifold but is the background dependent space within which all theories other than General Relativity reside. All these theories are influenced by gravitation at the point of generation in space-time, and are modified by a scale factor that injects gravitation into these tangent space residing theories. See (Longo 2016) for the full details of the theory.

The key to this theory is the scale factor that is the ratio of the space-time length to the coordinate length and is given by

$$\sigma(R) = \frac{ds}{dR} = (1 - \frac{2GM}{c^2 R})^{-1/2}. \tag{1}$$

Where M is the mass of the sun and planets in kilograms and R is the radial distance from the sun to the position of the Pioneer 10 in meters. The scale factor at the Earth is the reference scale factor $\sigma(R_{earth}) = 1$ since all theories were developed and all constants measured on Earth. Therefore all the relevant constants have local gravity built in.

The test that fully defined the anomalous effect began in 1987 when the spacecraft was 40 AU from the sun., and ended in 1998 at a sun distance of 70.5 AU. To see the effect we must determine how the scale factor influences the received frequencies at the 1987 start point and subsequent point between the start and end point. Since this theory expects the return frequency to be modified at the spacecraft, unlike the original expectations, we must look at the one way signal travel to determine this change. There are many electronic systems aboard the Pioneer each of which could alter the frequency, however, since most are unknown to me, I will concentrate only on the final out put amplifier, the Traveling Wave Tube (TWT). The TWT device is designed to produce an interaction between an electron beam and an electromagnetic signal. This interaction extracts energy from the electron beam to amplify the electromagnetic signal. This interaction is well understood and described by an electromagnetic field theory (Chu, Jackson 1947).

We need only consider the TE mode of the electromagnetic field in the helix structure of the TWT and outside the electron beam to show how the frequency is affected. The only field we need to consider is the z-axis magnetic field H_z, since the other field components respond in a similar way to a frequency change. The field equation for this field is

$$\frac{1}{r}\frac{\partial}{\partial r}(r\frac{\partial H_z}{\partial r}) + (\gamma^2 + k^2)H_z = 0. \tag{2}$$

Where $k = 2\pi\nu/c$ and ν is the TWT output frequency[1], γ describes how the field varies along the z-axis and is involved with e-beam bunching that exchanges energy with the electromagnetic field. The new theory requires that the electromagnetic space variable r be replaced with $\sigma(R)r$ everywhere in the equation (2). This gives

$$\frac{\partial^2 H_z}{\partial r^2} + \frac{1}{r}\frac{\partial H_z}{\partial r} + \sigma(R)^2(\frac{2\pi\nu_{pr}}{c})^2 H_z = 0. \tag{3}$$

[1]Normally, $k = 2\pi/\lambda = 2\pi\nu/c$ when relating wavelength to frequency the 2π factor cancels, however in this application only frequency, sent back to Earth, is measured so the 2π in the conversion of angular frequency to frequency needs to be retained.

Where ν_{pr} is the one way Doppler shifted frequency received by the spacecraft. The new frequency $\nu_{pt} = 2\pi\sigma(R)\nu_{pr}$ is outputted to the antenna and sent to the earth.

Since the key effect is happening at the spacecraft we must consider the one-way transmission from the earth to the spacecraft where the frequency is alter and then sent back to earth[2]. First consider the signal sent to the spacecraft. The signal transmitted from earth, at the reference frequency ν_0 is Doppler shifted by the Earths motion and becomes ν_{ep}, given by

$$\nu_{ep} = \nu_0(1 - \frac{v_{earth}}{c}) \tag{4}$$

When received by the spacecraft it is Doppler shifted again and becomes to first order

$$\nu_{pr} = \nu_0(1 - \frac{\Delta v}{c}), \tag{5}$$

where $\Delta v = v_{earth} + v_{pioneer}$. While working its way through the onboard electronics its frequency is altered by the gravity at the position of the spacecraft. We have assumed that the only electronic item that alters the frequency is the TWT, so the frequency becomes

$$\nu_{pr} = 2\pi\sigma(R)\nu_0(1 - \frac{\Delta v}{c}). \tag{6}$$

The signal is sent to the antenna and transmitted, again acquiring an added Doppler shift

$$\nu_{pr} = 2\pi\sigma(R)\nu_0(1 - \frac{\Delta v + v_{pioneer}}{c}). \tag{7}$$

When received at the Earth it is Doppler shifted again due to the Earths motion, giving

$$\nu_{er} = 2\pi\sigma(R)\nu_0(1 - \frac{2\Delta v}{c}). \tag{8}$$

As the spacecraft progresses each measurement will give a different frequency due to the change in gravitational field as well as the Doppler shift.
When reaching its start point in 1987 the signal received by the Earth minus the modeled frequency $v_{modeled}$ is

[2]It is not necessary to consider the design shift in frequency to prevent incoming and outgoing signals from interfering. Since this known frequency shift is removed on analysis.

$$\nu_{rec}(R_0) = 2\pi\sigma(R_0)\nu_0(1 - \frac{2\Delta v}{c}) - \nu_{modeled}. \tag{9}$$

Where R_0 is the sun to pioneer radial distance of 40. AU. This now becomes the reference point for the test. As the spacecraft progresses toward the end point of 1998, $\sigma(R)$ changes as the spacecraft gets further from the sun and the gravitational field diminishes. With each new measurement we get

$$\nu_{rec}(R) = 2\pi\sigma(R)\nu_0(1 - \frac{2\Delta v}{c}) - \nu_{modeled}. \tag{10}$$

Given that the spacecraft velocity is a constant 12.8 km/s throughout the test period the modeled frequency $\nu_{modeled}$ defining the anomalous effect cancels, this gives

$$\nu_{obs} = 2\pi(\sigma(R) - \sigma(R_0))\nu_0(1 - \frac{2\Delta v}{c}). \tag{11}$$

Using the definition of σ in equation (1) we get to first order

$$\nu_{obs} = -2\pi\frac{GM}{c^2 R_0}(\frac{R - R_0}{R})\nu_0(1 - \frac{2\Delta v}{c}). \tag{12}$$

The final result gives the anomalous acceleration

$$a_p = c\frac{\nu_{obs}}{t}. \tag{13}$$

Since the frequency was determined at the spacecraft, only the one way path from the spacecraft to the Earth is counted thus the factor of 2 is not present in equation(13). In Table 1, the anomalous acceleration and other factors are determined for each year of the test. The published value of a_p is constant over the 11 year test with a value of $(8.74 \pm 1.33) \times 10^{-10}$ m/s^2 (Anderson, 2002). The value obtained with this theory is not constant but varies by a factor of 1.9 over the 11 years. This is not surprising considering that neither the ephemeral data or the orbit codes were used. If we take the average over the 11 years test we get $(7.63 \pm 1.59) \times 10^{-10}$ m/s^2 within the error of the published value. The rate of change of the frequency $\dot{f} = -\nu_0\frac{a_p}{c}$ (Wilhelm, 2011), taking the uplink frequency of 2.11 GHz we get, for the average value of a_p, $\dot{f} = 5.37 \times 10^{-9}$ Hz/s this compares to the published value of $\dot{f} = 5.99 \times 10^{-9}$ Hz/s (cf.Turyshev, 2006).

3 Conclusion

We have applied a new physical theory to the observed Pioneer anomaly and have found a respectable result for the anomalous acceleration. The new physical theory (Longo, 2016) was motivated by a philosophical concept of how humans make sense of the physical world. The result we have drawn is that the anomalous acceleration is a miss interpretation. These results suggest the correct interpretation is a shift in frequency caused by an electromagnetic interaction with gravity at the spacecraft. This interaction is not noticeable on Earth, since Earth is where all physical theories and pertinent constants are measured, therefore local gravity is incorporated into the measured constants. This result reopens the question as to the correct interpretation. Is it an engineering solution or a more fundamental solution, or perhaps a combination of both? Finally, I believe this new theory should be re-run using all the JPL tools, that were not available to the author.

4 References

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Table 1: The mass of the sun and planets is $M = 1.992 \times 10^{30} kg$ and $R_0 = 40\ AU$, the factor $2\pi \frac{GM}{cR_0}(1 - \frac{2\Delta v}{c}) = 0.465\ m/s$. The time, t was calculated by $DIST\ traveled\ in\ km/12.8\ km/s$. The acceleration a_p is negative and points toward the sun.

YEAR	DIST A.U. Traveled	t sec 10^8	Sun DIST A.U.	$(R-R_0)/R\ t$ $10^{-9}\ sec^{-1}$	a_p m/s^2 10^{-10}
1987	0	0	40	0	0
1988	2.712	0.317	43.2	2.340	10.89
1989	5.423	0.634	45.9	2.030	9.450
1990	8.135	0.951	48.8	1.896	8.828
1991	10.85	1.268	51.2	1.725	8.030
1992	13.56	1.550	54.3	1.699	7.911
1993	16.27	1.902	56.9	1.562	7.270
1994	18.98	2.219	59.6	1.482	6.899
1995	21.69	2.540	62.3	1.409	6.560
1996	24.41	2.850	65.0	1.350	6.283
1997	27.12	3.170	67.7	1.290	6.007
1998	29.83	3.490	70.5	1.240	5.772

Table 2: