Reconsideration of the Thermal Contribution to New Horizons Acceleration

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Abstract

A number of observations do not align with the hypothesis of anisotropic thermal radiation being the sole or predominant cause of the Pioneer Anomaly. Recent public release of Pioneer tracking data has enabled observation of peculiar temporal variation in the Pioneer anomaly, more aligned with a marked step change in the anomalous effect than a slow change consistent with the thermal radiation pressure mechanism. This paper considers thermal contributions to the Pioneer Anomaly and the New Horizons acceleration during hibernation periods. We conclude that there is a need for further detailed analysis, and call for the full public release of New Horizons tracking data (and detailed thermal models if possible), including from recent hibernation periods, so reported results can be extended and independently verified.

Keywords: Pioneer Anomaly, Thermal Radiation, New Horizons

Introduction

The Pioneer Anomaly[1,2] has been attributed to anisotropic thermal heat radiation by a number of authors, although support for such a hypothesis has less foundation than we would ideally need for a strong consensus scientific conclusion[3]. A number of secondary observations remain inconsistent with the postulated thermal mechanism. Large diurnal and annual fluctuations in Doppler residuals indicate modelling errors of a type yet to be fully determined. Evidence of an onset of the Pioneer Anomaly in the case of Pioneer 11 is entirely inconsistent with the thermal cause hypothesis. Within [4], Turyshev *et al.* argue on the basis of large error bounds obtained via their analysis, that there is no certainty to whether a Pioneer 11 onset effect is present. The same paper notes the appearance of significant transverse acceleration uncertainty in the early Pioneer 11 data set. These observations further suggest modelling errors of some yet-to-be-determined type.

A marked Pioneer 10 spin anomaly was also noted within the seminal Pioneer Anomaly paper[1]. The Pioneer 10 spin anomaly has remained an enigma to date, and doesn't appear to be resolved via consideration of thermal mechanisms. Thruster gas leak mechanisms would need to be extremely peculiar to provide the observed behaviour. A companion paper in these proceedings[5] considers whether there is reason to attribute the spin anomaly to an observation artefact due to unintended spacecraft subsystem interaction outside original design intent. We can conclude that an independent analysis of the spin, during the period of Imaging Photo Polarimeter spin determination, is justified and this work is awaiting NASA clearance of key engineering design documentation, including "PC-202"[6].

Doppler tracking data in NASA's Orbit Determination File (ODF) format covering the entire recovered Pioneer 10 and 11 data sets, has recently been made available to the public via NASA's Goddard Space Flight Center, Space Physics Data Facility (SPDF), thanks to considerable efforts by many, not least of which are Slava Turyshev and Viktor Toth. For Pioneer 10, the original data set used within [1] spanned from early 1987 through to mid-1995. Multiple papers, using largely independent analyses, have reproduced residual data plots parallel to that shown within Figure 8 of [1], where a clear linear Doppler trend is visible[7,8,9]. We provide yet another roughly parallel plot in Figure 1, below, using the recent SPDF public release of ODF data. The residual shown aligns with that produced by other authors, even with differences in the software processing, and some key distinctions in manoeuvre modelling (our 'conservative' manoeuvre modelling approach is outlined below).

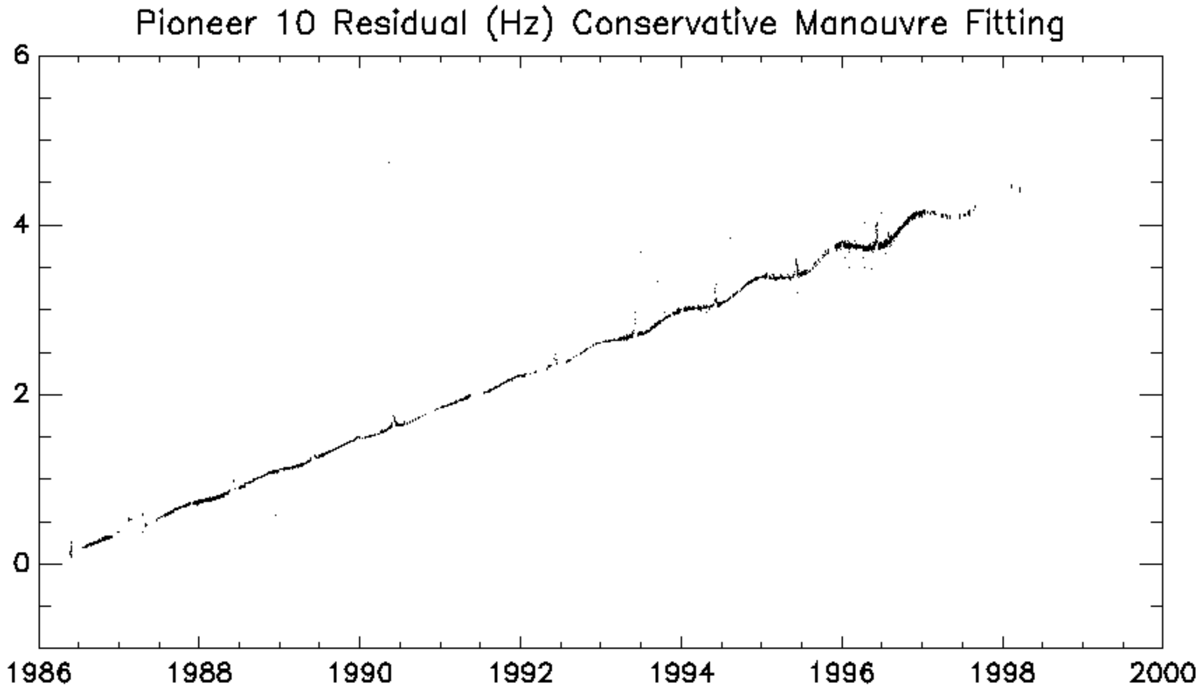

Figure 1. Pioneer 10 Residual for later years. Manoeuvre fitting in a conservative (not minimum MSE) single-axis impulse model.

While [4] considered the question of temporal variation of the Pioneer Anomaly over the extended Pioneer 10 and 11 data sets, a residual plot generated along the lines of Figure 8 of [1] was not provided. We are unaware of other work providing such a plot, and first presented the plot shown in Figure 2, below, at a recent conference[10].

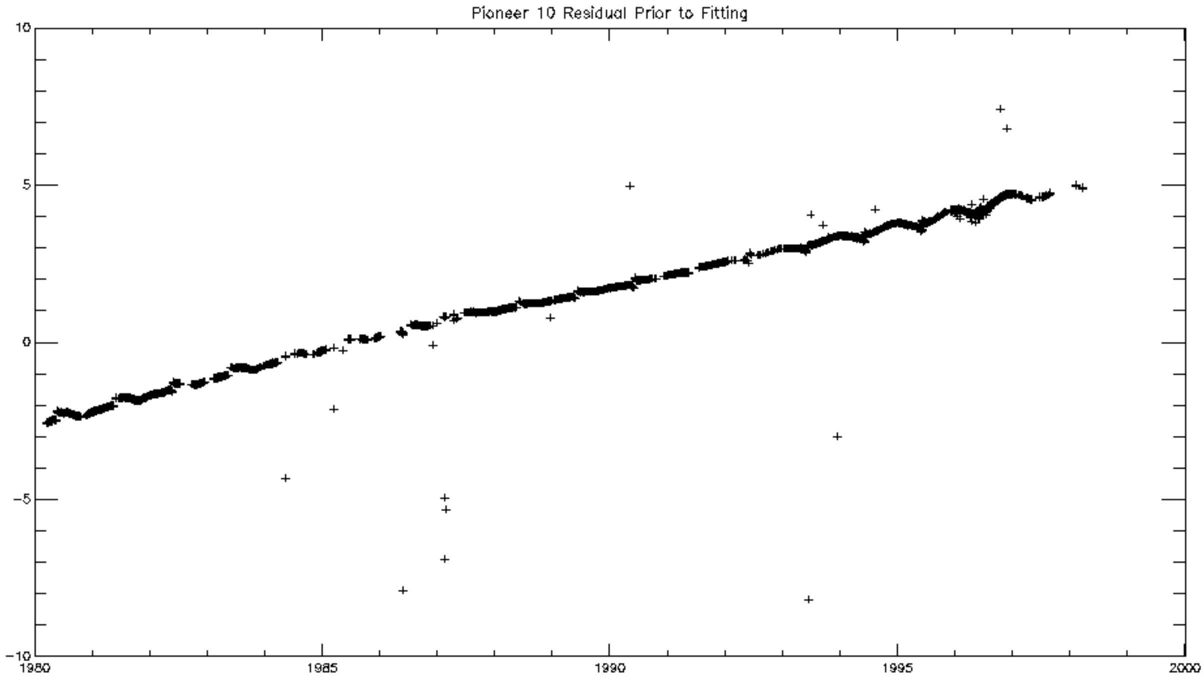

Figure 2. Pioneer 10 Residual for extended data arc, showing significant step change in behaviour.

Figure 2 shows a significant step change in character of the residual during ~1986. A step change of this nature appears entirely unexpected and counter to the temporal behaviour reported in [4]. Furthermore, it is exceedingly difficult to align any understanding of a significant step change with the hypothesis that the Pioneer Anomaly is largely or entirely of anisotropic thermal radiation origin. Naturally we must remain open to the possibility that the behaviour displayed in Figure 2 is caused by a software problem, and is not otherwise reflective of the physical reality of the Pioneer 10 Doppler tracking signal. However, a systematic analysis of the developed codebase has not yet revealed any hints of this being the case. Parameter fits to both the early data and the later data can independently achieve a zero-mean residual, but such fits differ markedly and result in a linear trend of the residual on the other side of the ~1986 epoch. Parameter fits using a single fixed value for the anomalous acceleration, spanning the ~1986 epoch, struggle to obtain a well-behaved zero-mean residual. Parameter fitting using a single step change in the anomalous acceleration are able to achieve good fits.

The larger slope of the of the earlier data displayed in Figure 2, aligns in a very loose sense with a reducing anomalous acceleration shown in Figure 1 within [4]. However, the gradual change in the anomalous acceleration parameter, as determined by [4], is seemingly at odds with the behaviour shown in Figure 2. We have attempted to extract values of the anomalous acceleration parameter corresponding to shorter data arcs, aligned with the approach in [4]. However, initial conditions and local minima problems quickly emerge with shorter data arcs. To date an acceptable outcome overcoming these limitations has not been achieved. The best conclusion we can make is that the nature of the anomalous acceleration appears better characterised by a step change than a gradual one.

It is not known if the approach taken in [4] has ultimately also been plagued by the curse of initial conditions and local minima. However, fitting a large number of parameters via minimum Mean-Square-Error (MSE) approaches is known as a problematic undertaking. Markwardt’s early analysis[7] showed that a zero-mean residual parameter fit could readily be obtained through parameterisation of manoeuvres only. Toth’s 2009 independent analysis[8] again included a similar manoeuvre-only parameter fit. The analysis presented here has been motivated by these prior results, and the knowledge that considerable structure remains in the Doppler residual after full parameterisation, to use a ‘conservative’ manoeuvre fitting approach. Manoeuvre impulse parameters are extracted to maximise continuity of the Doppler residual from pre to post manoeuvre, as opposed to minimisation of global MSE measures. This approach also minimises the number of parameters relevant to short data arc parameter extraction, as we are effectively left with an initial state vector (positions and velocities of the spacecraft in 3 dimensions) and parameters for the anomalous acceleration. Nonetheless, minimum MSE methods are confounded by the unmodelled nature of the residual over short intervals (significant diurnal and annual components).

The avoidance of ‘blind’ minimisation of MSE through the choice of our “conservative” manoeuvre modelling approach may explain the behaviour in Figure 2 appearing so readily when nothing similar has been reported by other studies on the extended data set. Certainly, manoeuvre parameters being free to vary as part of the core MSE minimisation parameter search would allow for an overall zero-mean residual, and removal of the anomalous acceleration parameter (linear modelling term) would largely produce a linear residual of the type seen in Figure 1.

The above observations question the foundation of support for a thermal origin for the Pioneer Anomaly. This paper attempts to revisit fundamental analyses relevant to the Pioneer spacecraft and New Horizons to determine if there is possibility that the thermal contribution has indeed been overestimated. Effectively we are looking to sanity check the anisotropic thermal radiation hypothesis.

Pioneer Thermal Contributions

A thermal contribution to the observed long-term Doppler residual trend, has effectively been considered since the Pioneer Anomaly was broadly published within [11]. Within [12], Anderson *et al.* respond to a comment by Katz, and clarify that basic calculations show that spherical radiation from the Radioisotope Thermoelectric Generators (RTGs) only amounts to approximately 1.5% of a nominal 2000W of thermal energy impinging on the spacecraft antenna rear surface. [12] further argues that the RTG radiation pattern is far from spherical, given the primarily cylindrical shape of the RTGs with large fins and insulated end caps.

Within [13] the Anderson *et al.* team respond to a comment by Murphy, clarifying the operation of the louver assemblies, and suggesting that radiation from the main-bus electrical systems is insufficient to explain the anomaly. Discussions of the non-isotropic radiation of heat from the Pioneer spacecraft has involved a large number of authors subsequently, with multiple efforts to create increasingly sophisticated analyses and thermal models. As reported in [3], a comprehensive finite-element thermal model of the Pioneer spacecraft was constructed by a collaborative effort between JPL (Jet Propulsion Laboratory) and the Applied Sciences Laboratory. Within [3] the thermal contribution is parametrised into contributions from the RTG (including reflected contributions from RTG radiation impinging on exterior spacecraft surfaces), and the effect of spacecraft electrical conversion back to thermal radiation. The thermal model is stated to provide a factor of 0.0104 for RTG heat converted to spin-axis acceleration-inducing radiation, and 0.406 for electrical power radiation. This is noted to amount to approximately 80% of the recoil force obtained by a minimum MSE analysis of the Doppler tracking data solving for these two parameters. An error analysis allowing a large contribution for RTG surface degradation uncertainty obtains overlapping error bars, and the paper concludes that there is hence support for the thermal origin hypothesis.

We can easily be sceptical of any anisotropic contribution from RTG surface coating degradation. Within [2], NASA's Thermal Control Surfaces experiment is discussed, where it is noted that up to a 5% change in solar absorptance is achieved, but no noticeable change in infrared emittance. Accepting this might lead to a conclusion that results within [3] indicate that anisotropic heat contributes up to 80% of the observed Pioneer Anomaly effect, but is incapable of explaining the entire effect. We would ideally like to see further investigation and independent review of the sophisticated thermal analysis performed within [3]. The complexity of this analysis is impressive, but such complexity has a consequence of many opportunities where small imperfections may translate to significant effects within the output. The numbers obtained for the efficiency factors in translating energy into acceleration-producing anisotropic radiation are at the extreme end of the range of what is delivered by less sophisticated analyses. Several authors have provided less complex analyses and reported smaller overall effects. The apparent step change in the anomalous acceleration reported above is motivation to re-examine in detail the Pioneer thermal contribution analyses. Unfortunately, this activity is far beyond the scope of the present paper. Our present conclusion can perhaps only be that the thermal contribution to the Pioneer Anomaly appears unlikely to explain the anomaly completely.

New Horizons Thermal Contributions

Observation of apparent small trajectory perturbations, such as the Pioneer Anomaly, has been clearly noted to require long tracking data arcs, free from large solar radiation pressure of the inner solar system, and with minimal disturbance from thruster operation. Both [11] and the later comprehensive paper, [1], included discussion of possible effects corresponding to the Pioneer Anomaly in data for Galileo and Ulysses. However, these spacecraft did not provide the same certainty obtained by the Pioneer spacecraft – hence the effect being known as the Pioneer Anomaly.

While there have been many calls for both dedicated missions and tailor-designed piggy-back missions to study the Pioneer Anomaly, none have been successful in achieving necessary support. The New Horizons spacecraft operates in long periods of 'hibernation' where spin stabilisation is used and minimal onboard activity occurs, providing an opportunity to search for unmodelled effects. Rogers, Flanigan, and Stanbridge[14] report on small accelerations acting on the spacecraft over long periods during the New Horizons flight to Pluto. Of course, the New Horizons spacecraft did not have a design objective of shedding light on the Pioneer Anomaly. A large RTG unit is physically mounted in close proximity to the main antenna, and we expect a significant acceleration contribution from anisotropic thermal radiation. [14] states that "*any near constant biases which remain can be reasonably attributed to the RTG*" when small modelling errors such as propellant leaks, Solar Radiation Pressure or gravitational models have been considered. Such a philosophy is entirely reasonable if we are convinced that there is no on-going reason to question if there is anything other than thermal contributions to the observed Pioneer Anomaly Doppler discrepancies. Discussions above might suggest we need to retain an open mind on the matter and consider that thermal contribution might not fully explain observations.

Rogers *et al.*[14] present data for New Horizons hibernation periods from early 2008 to mid-2013. A steady decline in the estimated acceleration parameters is reported (allowing for 'noise' in the measurements). The rate of decline appears consistent with the proportionate decline expected due to the Stefan-Boltzmann dependence on the fourth power of surface temperature and the data presented for RTG surface temperature obtained via telemetry from the spacecraft. There is a tantalizing hint of possible annual fluctuations in the acceleration values presented in [14], and it is hoped that release of additional data from the New Horizons team will enable analyses along these lines.

[14] also presents data for measured torques around the spacecraft Z axis during specific instances where the spacecraft is operating in 3-axis mode (as opposed to the spin-stabilised mode of hibernation). One torque measurement is obtained when the spacecraft is only 7.6 AU from the sun, and hence the effect of solar radiation pressure (SRP) has been considered. The spacecraft orientation during the measurement provides for an effective separation of any SRP contribution around other axes, leaving a robust measurement of the RTG-related torque. A later measurement in 2013 is provided for the spacecraft at significant distance from the sun. The reported result is a very similar torque determination. We might expect a difference in these observations aligned with the declining RTG surface temperature and the Stefan-Boltzmann fourth power of temperature. However, with only two independent measurements, the reality may simply lie in sources of measurement noise hiding such an effect. Ideally the New Horizons team will be able to release additional data which might aid the consideration of whether trends in the torque from the RTG aligns with changing surface temperatures as expected.

Turyshev and Toth[15] consider New Horizons thermal effects due to reflected heat from the RTG and electrical heat from the spacecraft body. We note that the effectiveness of the New Horizons Multi-Layer Insulation (MLI) is likely to be dominated by overlaps and stitches. Also, there are many areas such as thruster assemblies and spacecraft instrumentation where penetrations through insulation exist, and significant heat flow is effectively a design choice. Ultimately a detailed thermal analysis is needed. The New Horizons team has developed sophisticated thermal models to allow the spacecraft to be flown precisely. While [15] suggests a significant proportion of the spacecraft electrical power translates to acceleration-inducing radiation along the spin axis direction, it would informative to see detailed results from the extant thermal modelling.

Calculations for reflected heat from the RTG within [15] appear to omit the fact that only approximately 25% of the surface of the cylinder model used, would be effectively visible to the antenna (actual amount assuming the validity of the cylinder model is circa 50%, but the effect reduces by the angle between the thermal radiation direction and the surface normal). Reducing the contribution in [15] by this amount leads to an overall calculation for the New Horizons thermal acceleration as very close to the values later reported within [14]. Of course, these simplistic analyses ideally need to be augmented by far more sophisticated investigation.

Guerra *et al.*[16] turn their attention to a more sophisticated analysis, and conveniently obtain results for the thermal contribution which align very closely with the values previously reported in [14]. Ultimately extremely mature analyses are needed (using detailed thermal modelling) if there is to be reliable discrimination between thermal radiation components of the New Horizons acceleration, and any other anomalous effect. While we hope that the extant modelling might be applied to this purpose in the near future, of more direct interest is likely to be discovering whether annual or other fluctuations are also present in the New Horizons data. Searching for any step change in behaviour appears to be a worthwhile exercise given the Pioneer observations noted above.

Efforts to obtain public release of tracking data (or even release under NDA) for the New Horizons spacecraft appear to have not succeeded in reaching relevant decision makers to date. The benefits of independent confirmation of previously published results would appear significant. Extension of investigations, including recent New Horizons tracking data, and looking for any unmodelled step changes in observed accelerations, has merit considering the relative lack of conclusiveness for the thermal mechanism for the Pioneer Anomaly. We ask that the New Horizons team consider full publication of their tracking data. We trust that a positive outcome may occur, as the New Horizons team embrace the prospect of potential broader benefit from their engineering data. The New Horizons spacecraft is expected to remain operational and in contact with earth for several years yet. There is a possibility that prompt release of tracking/engineering data will allow analyses that suggest benefits to be obtained from future spacecraft activities after the Ultima Thule encounter data has been downloaded.

Conclusion

There are solid reasons to suggest that re-investigation of the thermal contribution to New Horizons acceleration should be considered. We call for full public disclosure of New Horizons tracking data so previous results can be independently confirmed and extended. Further investigation of more recent New Horizons hibernation tracking data is recommended. There may also be scope for additional tracking data to be obtained in the post-Ultima-Thule cruise phase. Any hint of unmodelled step-wise changes in measured accelerations would garner extreme interest.

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