The Pioneer anomaly and MOND: a possible explanation

Discussions of the anomalous Pioneer acceleration[1] and MOND[2] (Modification Of Newtonian Dynamics) have appeared in *TJ*. For the benefit of many *TJ* readers,[3] this letter introduces a paper written by L. Nottale that attempts to explain the Pioneer anomaly.[4]

The MOND effect is excellently explained by Dr Bill Worraker,[2] but some words concerning the Pioneer anomaly may be in order. Information on the famous Pioneer space-exploring robots, the first spacecraft to venture beyond the planets, can be found on the web.[5,6]

An anomaly has emerged in their trajectories. It's as though an acceleration of about 9 x 10^{-8} cm/s^2 has been unexpectedly added to the sun's gravitational pull. The probability that the anomaly is unexplainable by currently known physics is high, partly because so many different spacecrafts and trajectories are involved.[7]

Nottale's paper does not discuss MOND; however, I believe the Pioneer anomaly is the same as the MOND effect, and herewith, I refer to both as the Pioneer anomaly. To understand Nottale's explanation, let's review some General Relativity background.

Scientists since Newton have found the inertial frame of reference to be an extraordinarily useful mental tool for organizing our observations of Nature. In general, in no other reference frame do the laws of physics attain their simplest form. Newton's Laws of Motion both assume and define the inertial frame of reference.

Unfortunately, gravity makes an universal inertial reference frame for the whole universe impossible. By analogy, the idea of Euclidean space works very well for a rectangular room in a building. However, when the Euclidean space is extended far outside the building, the ground slopes down and away from the x and y plane of the frame (the floor of the room). Eventually, there is nothing underneath the 'floor' of the frame (figure 1). Euclidean geometry is often less helpful than spherical geometry for Earth-surface phenomena on scales far larger than that of the room.

Nothing 'straighter' than the light ray can be found, so light signals are useful in setting up an inertial frame of reference, such as light from 'distant stars', if electromagnetic phenomena obey the same laws of physics that mechanical phenomena obey (e.g. the trajectory of a baseball). This assumption is a principle of Special Relativity and also General Relativity.

However, we know, since Einstein, that gravity can bend light trajectories, so inertial frames of reference can only be used within small locations and small time intervals (small enough that the bending can be ignored). By analogy, we use Euclidean geometry on the surface of the spherical Earth only within small spatial and temporal intervals. General Relativity was invented partly to make non-inertial frames of reference useful for large-scale or rapid phenomena. A good example is the shape of hurricanes, with their swirls of clouds around an 'eye'. The inertial frame of reference has been used to explain the shape; however hurricanes are never at rest in any inertial frame of reference. Another good example of a non-inertial frame of reference is the rest frame of an accelerated observer.

Einstein and others had to labor to develop mathematical machinery that would make non-inertial frames useful (sometimes easier) to use, such as the rest frame of an observer 'sitting' on the event horizon of a black hole. A frame of reference in which the center of mass of the solar system and the 'distant stars' are all at rest can be found. However, for some phenomena it is 'not inertial enough', and the full mathematical machinery of General Relativity must be used to make it useful. According to Nottale, such is the Pioneer anomaly—that is, its discoverers do not understand fully how the solar frame failed to be inertial.

To understand the failure, let's go back and take a look at the modification Einstein made to his first cosmological model to keep it static. He started with the first definitive form of the field equations of General Relativity, which first appeared in public November 1915.[8] These equations show how spacetime (which became, in Einstein's stunning conception, a dynamic physical object) and the energy-matter content of the universe interact. Partly for simplicity he, at first, left out of the field equations some terms that contained the 'cosmological constant'. One might think of the 'cosmological constant' as governing the tension of spacetime. If the constant is positive, then spacetime tends to expand. That is why Einstein subsequently inserted these terms in his cosmological model—he wanted something to counteract the natural tendency for matter to gravitate together and collapse into a singularity. If the constant is negative, then spacetime tends to contract, in addition to the natural tendency for matter to gravitate together.

When Hubble announced that the universe was expanding, Einstein said that the insertion was the biggest blunder of his scientific career. (Theorists showed that Einstein's 'static' cosmos was unstable, so it was bound to expand or contract anyway.) However, the cosmological constant remains a part of the main stream understanding and experimentalists continue to try to measure it.

As Nottale notes, we may now have the first definitive measurement of the constant.[9] At any rate, we must consider the consequences of a positive value for it. Note that it does

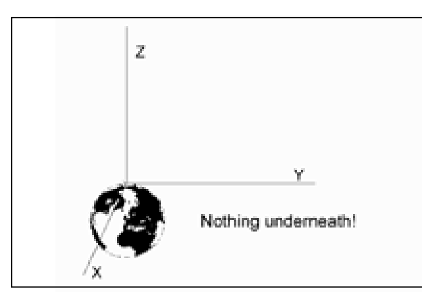

Figure 1. *Euclidean geometry is sometimes not good for the world. (Globe image from NASA website).*

not affect measurements made in any inertial frame of reference, provided that the frame is kept small enough and used briefly enough. However, it does impact the motions of all local inertial frames relative to the preferred rest frame of the Universe. The trajectories of the Pioneer crafts are monitored in a theoretical frame of reference that does not include the cosmological constant. Thus, Nottale writes, a part of the sunward acceleration appears as an anomaly.

Nottale notes that his prediction of the effect does not explain the whole anomaly and speculates that either better measurements may reduce the discrepancy or a new effect may be found in the anomaly. I think that he used the wrong cosmological model, namely the big bang model. Drs D.R. Humphreys and John Hartnett have criticized it in *TJ* already.[1,10] Instead, take the Klein model, which is the one that Humphreys uses in his white-hole cosmology,[11] insert the cosmological constant in the model, and then use it to re-derive Nottale's results.[12] A model could be built of the universe that might enable statistical analysis of MOND and Pioneer data and CMRB data to accomplish these desiderata:

- An explanation of the MOND effect in addition to the Pioneer anomaly.
- A determination that one of the two cosmological alternatives (FLRW a.k.a. big bang versus Humphreys' white-hole) fits the data better.
- Better estimates of the size and 'total mass' of the Universe.

However, I am not optimistic the data is that good. For one thing, we can't be sure the observable universe has all the matter and energy of the whole Universe. For another, our observations are not close to the edge of the observable universe. Still, such a possibility may someday become realizable.

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References

1. Humphreys, D.R., Humphreys' reply, *TJ* **17**(2):67–68, 2003.
2. Worraker, B., Bill Worraker Replies, *TJ* **17**(2):72–73, 2003.
3. Readers interested in General Relativity may take the references in endnote 2 in Ref 1, and follow them backwards until they find familiar reading. Then go forward.
4. Nottale, L., The Pioneer anomalous acceleration: a measurement of the cosmological constant at the scale of the solar system <theory.gsi.de/~vanhees/paper/astro-gr/pioneer-measurement-cosm-const-Nottale.pdf>, 25October 2003.
5. <www.nasm.si.edu/exhibitions/gal100/pioneer.html>, 28 November 2003.
6. <www.nasm.si.edu/research/ceps/rpif/outercraft.html>, 28 November 2003.
7. Anderson, J.D., Nieto, M.M. and Turyshev, S.G., A mission to test the Pioneer Anomaly, <www.arxiv.org/PS_cache/gr-qc/pdf/0205/0205059.pdf>, 28 November 2003.
8. Misner, C.W., Thorne, K.S. and Wheeler, J.A. *Gravitation*, W.H. Freeman, San Francisco, 1973; especially Chapter 17 and Section 17.7 'A Taste of the History of Einstein's Equation.'
9. See the first paragraph in ref. 4.
10. Hartnett, J., Cosmologists can't agree and are still in doubt, *TJ* **16**(3):21–26, 2002.
11. See the references in ref. 1.
12. Actually, instead of the Klein metric, I plan to use a specialization of the Lemaitre-Tolman-Bondi spherically symmetric dust metric. See <arxiv.org/PS_cache/gr-qc/pdf/9803/9803014.pdf >, 28 October 2003.