Hi this is Steve Nerlich from Cheap Astronomy www.cheapastro.com and this is *Anomalies.*

Strange things are happening to our spacecraft – well apparently. Something which is either just anomalous data – or an indication of some bizarre new physics has come back from spacecraft travelling in the outer edges of the solar system – as well as other spacecraft conducting planetary fly-bys. These anomalies have people suggesting causes ranging from dark matter to relativistic frame-dragging – but in the absence of more evidence, it's best just to consider them data anomalies.

What's commonly called the Pioneer anomaly relates to data received from Pioneers 10 and 11 which were launched in 1972 and 1973 respectively. Pioneer 10 did a fly-by of Jupiter in 1973 and then kept going towards the outer solar system – its last communication with Earth was in 2003 when it ran out of power. Pioneer 11 flew by Jupiter in 1974 and then Saturn in 1979 and had its last communication with Earth in 1995. Both spacecraft are on an escape trajectory from the solar system – though both have already been overtaken in terms of distance by the Voyagers 1 and 2, which were launched in 1977.

The data from both Pioneers suggest that while coasting outwards between 20 and 70 astronomical units from Earth, the craft weren't going quite as fast as they should have been. This has been argued to be an indication that the inverse square law for gravity is not maintained in the outer solar system – since the anticipated drag of gravity on the spacecraft seemed to be stronger than expected that far out from the Sun.

Various explanations for this – which don't require a bizarre new physics – are: 1) an equipment error producing erroneous data; 2) some kind of venting gas or even radiation pressure from the spacecrafts' electrical power generator, creating a slight thrust back towards the Sun; and 3) an electromagnetic drag due to the spacecraft carrying a slight electrical charge while passing through some kind of magnetic field.

To get some perspective here – the allegedly unaccountable drag back to the Sun equates to an acceleration of around 8 tenths of a nanometre per second squared – with error bars in the order of 20%, so a simple equipment error is a very plausible option.

More exotic suggestions of dark matter affecting the spacecraft seem unlikely as no such effects interfere with the normal rotation of planets – indeed the lack of any anomalous behaviour by the planets challenges the notion of needing a bizarre new physics to explain the spacecraft's behaviour, unless we are talking about a new physics that acts on 260 kg spacecraft but has no apparent effect on more massive objects.

There is some debate as to whether the Pioneer effect has been measured in other spacecraft which have travelled in the outer solar system. The effect is apparently present in data from Galileo – which went to Jupiter and the Ulysses spacecraft which achieved a polar orbit around the Sun via a gravitational assist manoeuvre past Jupiter. Apparently the use of attitude thrusters by the Voyagers created too many variables to compute whether or not they experienced a Pioneer effect.

With Cassini, now in orbit around Saturn, there might have been something, but its power source, or more accurately its radioisotopic thermoelectric generator, was hot enough that a

significant radiation pressure was expected anyway – and the main vector of that radiation could not be narrowed down to any particular direction.

So – it's all a bit inconclusive. One common factor does seem to be the use of radioisotopic thermoelectric generators – or RTGs – on all these spacecraft – as this is currently the only technology we have to effectively generate electric power in missions to the outer solar system, since there is not enough sunlight out there to make solar panels worthwhile.

Pioneer anomaly proponents have suggested the New Horizons spacecraft on its way to Pluto offers an excellent opportunity to test for the anomaly – though understandably the New Horizon's team seems more interested in making sure they get their spacecraft to Pluto.

And then there's what's become known as the fly-by anomaly – which is an allegedly unaccountable increase in velocity picked up by spacecraft passing close to a planet – generally for the purpose of a gravity assist manoeuvre. However, when I say a planet – it's actually only been measured for spacecraft flying by Earth – a not-insignificant detail that should already have you reaching for your skeptical goggles.

Various suggestions of there being a halo of dark matter around the planet or a loosely explained relativistic frame-dragging don't help to explain why it seems to just happen around Earth. Even Wikipedia makes an unnecessarily speculative statement about the flyby anomaly – with: *It is not known whether this phenomenon is related to the Pioneer anomaly* – which is really just another way of saying there is no reason to think this has anything to do with the Pioneer anomaly. In fact, the only obvious connection between the two issues is use of the word anomaly and some fairly unconvincing suggestions about dark matter.

To get some perspective on the flyby anomaly – we are talking about a velocity increase of up to 7mm/sec more than predicted – which is not a lot. But with the fly-by anomaly there are multiple instances of it being measured for different spacecraft – including Galileo, NEAR, Cassini, Rosetta and Messenger – enough to make it plausible that we are observing a real phenomenon.

However, there is a noticeable variance in the measured anomaly for different fly-bys – and there's even variance in the anomalous value for the same spacecraft which have done more than one Earth fly-by. The variance seems to arise from what trajectory the spacecraft follow as they approach and fly-by Earth.

So putting it all together – normal physics seems to work fine when we watch at a distance while a spacecraft flies by a different planet, but when a spacecraft flies by Earth (and noting that we are taking a measurement from Earth) we get an anomaly – at least under particular circumstances.

So, it is plausible to consider that maybe the problem here is that the predicted velocity change of the spacecraft were calculated without a full consideration of the physics of the situation. For example, we the observer on the ground, are in a frame of reference that is itself in rapid relative motion due to the Earth's rotation – trying to take measurements on a rapidly approaching and then receding object.

So rather than considering the measured velocities of the flown-by spacecraft are anomalous, it may just be that we got the maths wrong. There's discussion of relativistic time dilation and transverse Doppler effects which some physicists suggest could kind of explain everything here – and what's more they've done the maths.

A chance to revisit the fly-by issue is the November 2009 repeat flyby of the Rosetta spacecraft. It will take some weeks to crunch the numbers so you may be hearing about the outcome at about the same time this podcast is released. Either it will be a case of NASA remaining baffled or a congratulatory story of another test confirming some of the more complex implications of Einstein's theories of relativity.

So hey, how about that? A skeptical podcast. I wonder if it'll catch on.

Thanks for listening. This is Steve Nerlich from Cheap Astronomy, www.cheapastro.com. Cheap Astronomy offers an educational website where you can take cheap shots at wacky space theories. No ads, no profit, just good science. Bye.