Resolving Spacecraft Earth-Flyby Anomalies with Measured Light Speed Anisotropy

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Doppler shift observations of spacecraft, such as Galileo, NEAR, Cassini, Rosetta and MESSENGER in earth flybys, have all revealed unexplained speed 'anomalies' - that the doppler-shift determined speeds are inconsistent with expected speeds. Here it is shown that these speed anomalies are not real and are actually the result of using an incorrect relationship between the observed doppler shift and the speed of the spacecraft - a relationship based on the assumption that the speed of light is isotropic in all frames, *viz* invariant. Taking account of the repeatedly measured light-speed anisotropy the anomalies are resolved *ab initio*. The Pioneer 10/11 anomalies are discussed, but not resolved. The spacecraft observations demonstrate again that the speed of light is not invariant, and is isotropic only with respect to a dynamical 3-space. The existing doppler shift data also offers a resource to characterise a new form of gravitational waves, the dynamical 3-space turbulence, that has also been detected by other techniques.

1 Introduction

Planetary probe spacecraft (SC) have their speeds increased, in the heliocentric frame of reference, by a close flyby of the earth, and other planets. However in the earth frame of reference there should be no change in the asymptotic speeds, assuming the validity of Newtonian gravity, at least in these circumstances. However doppler shift observations of spacecraft, such as Galileo, NEAR, Cassini, Rosetta and MESSENGER in earth flybys, have all revealed unexplained speed 'anomalies' - that the doppler-shift determined speeds are inconsistent with expected speeds [1, 2, 3, 4, 5, 6]. Here it is shown that these speed anomalies are not real and are actually the result of using an incorrect relationship between the observed doppler shift and the speed of the spacecraft - a relationship based on the assumption that the speed of light is isotropic in all frames, *viz* invariant. Taking account of the repeatedly measured light-speed anisotropy the anomalies are resolved *ab initio.*

The speed of light anisotropy has been detected in at least 11 experiments [7, 8, 9, 10, 11, 12, 13, 14, 15, 16, 17], beginning with the Michelson-Morley 1887 experiment [7].

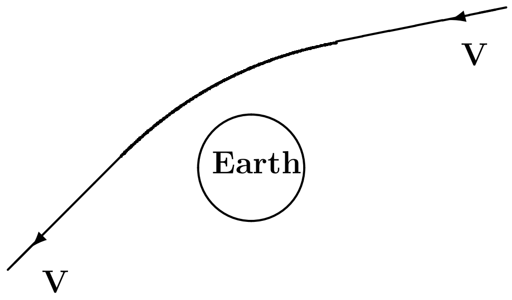

Figure 1: Spacecraft (SC) earth flyby trajectory, with initial and final asymptotic velocity **V**, differing only by direction. The doppler shift is determined from Fig.2 and (1). Assuming, as conventionally done, that the speed of light is invariant in converting measured doppler shifts to deduced speeds, leads to the so-called flyby anomaly, namely that the incoming and outgoing asymptotic speeds appear to be differ, by ΔV_∞. However this effect is yet another way to observe the 3-space velocity vector, as well as 3-space wave effects, with the speed of light being c and isotropic only wrt this structured and dynamical 3-space. The flyby anomalies demonstrate, yet again, that the invariance of the speed of light is merely a definitional aspect of the Einstein spacetime formalism, and is not based upon observations. A *neo*-Lorentzian 3-space *and* time formalism is more physically appropriate.

The interferometer observations and experimental techniques were first understood in 2002 when the Special Relativity effects and the presence of gas were used to calibrate the Michelson interferometer in gas-mode; in vacuum mode the Michelson interferometer cannot respond to light speed anisotropy [18, 19], as confirmed in vacuum resonant cavity experiments, a modern version of the vacuum-mode Michelson interferometer [20]. So far three different experimental techniques have given consistent results: gas-mode Michelson interferometers [7, 8, 9, 10, 11, 16], coaxial cable RF speed measurements [12, 13, 14], and optical-fiber Michelson interferometers [15, 17]. This light speed anisotropy reveals the existence of a dynamical 3-space, with the speed of light being invariant only wrt that 3-space, and non-isotropic according to observers in motion relative to that frame of reference - such a motion being conventionally known as "absolute motion", a notion thought to have been rendered inappropriate by the early experiments, particularly the Michelson-Morley experiment. However that experiment was never null - they reported a speed of at least 8km/s [7] using Newtonian physics for the calibration. A proper calibration of the Michelson-Morley apparatus gives a light speed anisotropy of at least 300km/s. The spacecraft doppler shift anomalies are shown herein to give another technique that may be used to measure the anisotropy of the speed of light, and give results very consistent with previous detections.

The numerous light speed anisotropy experiments have also revealed turbulence in the velocity of the 3-space relative to the earth. This turbulence amounts to the detection of sub-mHz gravitational waves - which are present in the Michelson and Morley 1887 data, as discussed in [21], and also present in the Miller data [8, 22] also using a gas-mode Michelson interferometer, and by Torr and Kolen [12], DeWitte [13] and Cahill [14] measuring RF speeds in coaxial cables, and by Cahill [15] and Cahill and Stokes [17] using an optical-fiber interferometer. The existing doppler shift data also offers a resource to characterise this new form of gravitational waves.

The repeated detection of the anisotropy of the speed of light is not in conflict with the results and consequences of Special Relativity (SR), although at face value it appears to be in conflict with Einstein's 1905 postulate that the speed of light is an invariant in vacuum. However this contradiction is more apparent than real, for one needs to realise that the space and time coordinates used in the standard SR Einstein formalism are constructed to make the speed of light invariant wrt those special coordinates. To achieve that observers in relative motion must then relate their space and time coordinates by a Lorentz transformation that mixes space and time coordinates - but this is only an artifact of this formalism. Of course in the SR formalism one of the frames of reference could have always been designated as the observable one. Such an ontologically real frame of reference, only in which the speed of light is isotropic, has been detected for over 120 years. The usual literal interpretation of the 1905 Einstein postulate, *viz* that "the speed of light in vacuum is invariant", is actually experimentally shown to be false.

There has been a long debate over whether the Lorentz 3-space *and* time interpretation or the Einstein spacetime interpretation of observed SR effects is preferable or indeed even experimentally distinguishable. What has been discovered in recent years is that a dynamical structured 3-space exists, so confirming the Lorentz interpretation of SR [22, 24, 25], and with fundamental implications for physics. This dynamical 3-space provides an explanation for the success of the SR Einstein formalism. It also provides a new account of gravity, which turns out to be a quantum effect [23], and of cosmology [21, 22, 26, 27], doing away with the need for dark matter and dark energy. So the discovery of the flyby anomaly links this effect to various phenomena in the emerging new physics.

2 Absolute Motion and Flyby Doppler Shifts

The motion of spacecraft relative to the earth are measured by observing the direction and doppler shift of the transponded RF transmissions. As shown herein this data gives another technique to determine the speed and direction of the dynamical 3-space as manifested as a light speed anisotropy. Up to now the repeated detection of the anisotropy of the speed of light has been ignored in analysing the doppler shift data, causing the long-standing anomalies in the analysis [1, 2, 3, 4, 5, 6]. In the earth frame of reference, see Fig.2, let the transmitted signal from earth have frequency f, then the corresponding outgoing wavelength is $\lambda_o = (c - v_i)/f$, where $v_i = v\cos(\theta_i)$. This signal is received by the SC to have period $T_c = \lambda_o/(c - v_i + V)$ or frequency $f_c = (c - v_i + V)/\lambda_o$. The signal is re-transmitted with the same frequency, and so has

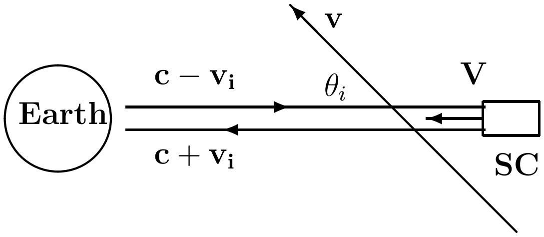

Figure 2: Asymptotic flyby configuration in Earth frame-of-reference, with spacecraft (SC) approaching Earth with velocity $\mathbf{V}$. The departing asymptotic velocity will have a different direction but the same speed, as no force other than conventional Newtonian gravity is assumed to be acting upon the SC. The Dynamical 3-space velocity is $\mathbf{v}(\mathbf{r}, t)$, which causes the outward EM beam to have speed $c - v_i$, and inward speed $c + v_i$, where $v_i = v\cos(\theta_i)$, with θ_i the angle between $\mathbf{v}$ and $\mathbf{V}$.

wavelength $\lambda_i = (c + v_i - V)/f_c$, and is detected at earth with frequency $f_i = (c + v_i)/\lambda_i$. Then overall we obtain

$$f_i = \frac{c + v_i}{c + v_i - V} . \frac{c - v_i + V}{c - v_i} f \tag{1}$$

Ignoring the projected 3-space velocity v_i, that is, assuming that the speed of light is invariant, we obtain instead

$$f_i = \frac{c + V}{c - V} f \tag{2}$$

The use of (2) instead of (1) is the origin of the putative anomalies. The doppler shift data is usually presented in the form of speed anomalies. Expanding (2) we obtain

$$\frac{\Delta f_i}{f} = \frac{f_i - f}{f} = \frac{2V_{i\infty}}{c} + .. \tag{3}$$

where $V_{i\infty}$ is defined as the incoming asymptotic speed deduced from (2), but incorrectly so. The asymptotic speeds $V_{i\infty}$ and, below, $V_{f\infty}$, are determined from the osculating hyperbolic trajectories [1]. Expanding (1) we obtain

$$V_{i\infty} \equiv \frac{\Delta f_i}{f} . \frac{c}{2} = \frac{f_i - f}{f} . \frac{c}{2} = \left(1 + \frac{v_i^2}{c^2}\right) V + ... \tag{4}$$

Similarly after the flyby we obtain

$$V_{f\infty} \equiv -\frac{\Delta f_f}{f} . \frac{c}{2} = -\frac{f_f - f}{f} . \frac{c}{2} = \left(1 + \frac{v_f^2}{c^2}\right) V + ... \tag{5}$$

and we see that the "asymptotic" speeds $V_{i\infty}$ and $V_{f\infty}$ must differ, as indeed first noted in the data by [3]. We then obtain the expression for the so-called flyby anomaly

$$\begin{aligned}\Delta V_{\infty} &= V_{f\infty} - V_{i\infty} = \frac{v_f^2 - v_i^2}{c^2} V + .. \\ &= \frac{v_f^2 - v_i^2}{c^2} V_{\infty} + ... \\ &= \frac{v^2}{c^2}(\cos(\theta_f)^2 - \cos(\theta_i)^2) V_{\infty} + .. \qquad (6)\end{aligned}$$

where $V \approx V_{\infty}$ to sufficient accuracy, where V_{∞} is the average of $V_{i\infty}$ and $V_{f\infty}$, The existing data on $\mathbf{v}$ permits *ab initio* predictions for ΔV_{∞}, and as well a separate least squares fit to the individual flybys permits the determination of the average speed and direction of the 3-space during each flyby. These results are all remarkably consistent with the data from the 11 previous laboratory experiments that studied $\mathbf{v}$. Note that whether the 3-space velocity is $+\mathbf{v}$ or $-\mathbf{v}$ is not material to the analysis herein, as the flyby effect is 2nd order in v.

3 Earth Flyby Data Analaysis

Eqn.(6) permits the speed anomaly to be predicted as the direction and speed v of the dynamical 3-space is known, as shown in Fig.3. The first determination of its direction was reported by Miller [8] in 1933, and based on extensive observations during 1925/1926 at Mt.Wilson, California, using a large gas-mode Michelson interferometer. These observations confirmed the previous non-null observations by Michelson and Miller [7] in 1887. The general characteristics of $\mathbf{v}(\mathbf{r}, t)$ are now known following the detailed analysis of the experiments noted above, namely its average speed, and removing the earth orbit effect, is some 420±30km/s, from direction right ascension= $\alpha_v = 5.5 \pm 2^{hr}$, declination=$\delta_v = 70 \pm 10$°S - the center point of the Miller data in Fig.3, together with large wave/turbulence effects. Miller's original calibration technique for the interferometer turned out to be invalid [22], and his speed of approximately 208km/s was recomputed to be 420 ±30km/s in [19, 22], and the value of 420km/s is used here as shown in Table 1. The direction of $\mathbf{v}$ varies throughout the year due to the earth-orbit effect and low frequency wave effects. A more recent determination of the direction was reported in [17] using an optical-fiber version of the Michelson interferometer, and shown also in Fig.3 by the trend line. Directions appropriate to the date of each flyby were approximately determined from Fig.3.

The SC data in Table 1 shows the values of V_{∞} and ΔV_{∞} after determining the osculating hyperbolic trajectory, as discussed in [1], as well as the right ascension and declination of the asymptotic SC velocity vectors $\mathbf{V}_{i\infty}$ and $\mathbf{V}_{f\infty}$. In computing the predicted speed 'anomaly' ΔV_{∞} using (6) it is only necessary to compute the angles

Parameter	GLL-I	GLL-II	NEAR	Cassini	Rosetta	M'GER
Date	Dec 8, 1990	Dec 8, 1992	Jan 23, 1998	Aug 18, 1999	Mar 4, 2005	Aug 2, 2005
V_∞ km/s	8.949	8.877	6.851	16.010	3,863	4.056
α_i deg	266.76	219.35	261.17	334.31	346.12	292.61
δ_i deg	-12.52	-34.26	-20.76	-12.92	-2.81	31.44
α_o deg	219.97	174.35	183.49	352.54	246.51	227.17
δ_o deg	-34.15	-4.87	-71.96	-20.7	-34.29	-31.92
α_v deg(hrs)	100(6.7)	100(6.7)	128(8.5)	47 (3.1)	119(7.9)	45 (3.0)
δ_v deg	-80	-80	-75	-77	-82	-88
v km/s	420	420	420	420	420	420
θ_i deg	87.2	61.0	79.9	73.4	92.6	122
θ_f deg	61.2	82.5	4.08	20.3	15.9	15.7
(O) ΔV_∞ mm/s	3.92±0.3	-4.6±1.0	13.46±0.01	-2±1	1.80±0.03	0.02±0.01
(P) ΔV_∞ mm/s	4.02±0.4	-3.79±0.7	12.06±0.2	-1.08±0.1	1.78±0.3	-0.28±0.8
v km/s (best fit)	439.9	436.2	451.1	449.3.	440.2	439.6

Table 1: Earth flyby parameters from [1] for spacecraft Galileo (GLL: flybys I and II), NEAR, Cassini, Rosetta and MESSENGER (M'GER). V_∞ is the osculating hyperbolic excess velocity, α and δ are the right ascension and declination of the incoming (i) and outgoing (o) osculating asymptotic velocity vectors, and (O) ΔV_∞ is the putative "excess speed" deduced by assuming that the speed of light is isotropic in modeling the doppler shifts, as in (3). The observed (O) ΔV_∞ values are after correcting, for atmospheric drag in the case of GLL-II, and thruster burn in the case of Cassini, from [1]. (P) ΔV_∞ is the predicted observed "excess speed", using (6), taking account of the known light speed anisotropy and its effect upon the doppler shifts, using α_v and δ_v as the right ascension and declination of the 3-space flow velocity, having speed v, which has been taken to be 420km/s in all cases. The ± values on (P) ΔV_∞ indicate changes caused by changing the declination by 5%. The angles θ_i and θ_f between the 3-space velocity and the asymptotic initial/final SV velocity V are also given. The observed doppler effect is in exceptional agreement with the predictions using (6) and the previously measured 3-space velocity. The last line shows the best-fit speed for each flyby, by varying magnitude, RA and Dec of $\mathbf{v}$, giving an average speed for all flybys of 443 ±20km/s, compared with 420±30km/s from the gas-mode Michelson interferometer Miller data [8, 22], and 418±30 km/s from the RF coaxial cable technique [14]. The fluctuations in these best fit speeds are attributed to wave effects. The flyby doppler shift is thus a new technique to accurately measure the dynamical 3-space velocity vector, albeit retrospectively from existing data.

θ_i and θ_f between the dynamical 3-space velocity vector and these SC incoming and outgoing asymptotic velocities, respectively, as we assume here that $|v| = 420$kms. So these predictions are essentially *ab initio* in that we are using 3-space velocities that are reasonably well known from laboratory experiments. The observed doppler effects are in exceptional agreement with the predictions using (6) and the previously measured 3-space velocity. Independently, a least-squares best-fit speed for each flyby, by varying magnitude, right ascension and declination of $\mathbf{v}$, gives the last line of Table.1. The average of these speeds for all flybys is 443 ±20km/s, compared with 420±30km/s from the gas-mode Michelson interferometer Miller data [8, 22], and 418±30 km/s from the RF coaxial cable technique. The variations in these best fit speeds from SC to SC are attributed to wave effects, discussed below. The flyby anomaly is thus a new technique to accurately measure the dynamical 3-space velocity vector, albeit retrospectively from existing data.

4 New Gravitational Waves

Light-speed anisotropy experiments have revealed that a dynamical 3-space exists, with the speed of light being c, in vacuum, only wrt to this space: observers in motion 'through' this 3-space detect that the speed of light is in general different from c, and is different in different directions. The dynamical equations for this 3-space are now known and involve a velocity field $\mathbf{v}(\mathbf{r}, t)$, but where only relative velocities are observable locally - the coordinates $\mathbf{r}$ are relative to a non-physical mathematical embedding space. These dynamical equations involve Newton's gravitational constant G and the fine structure constant α. The discovery of this dynamical 3-space then required a generalisation of the Maxwell, Schrödinger and Dirac equations. The wave effects already detected correspond to fluctuations in the 3-space velocity field $\mathbf{v}(\mathbf{r}, t)$, so they are really 3-space turbulence or wave effects. However they are better known, if somewhat inappropriately, as 'gravitational waves' or 'ripples' in 'spacetime'. Because the 3-space dynamics gives a deeper understanding of the spacetime formalism we now know that the metric of the induced spacetime, merely a mathematical construct having no ontological significance, is related to $\mathbf{v}(\mathbf{r}, t)$ according to [21, 22, 27]

$$ds^2 = dt^2 - (d\mathbf{r} - \mathbf{v}(\mathbf{r}, t)dt)^2/c^2 = g_{\mu\nu}dx^\mu dx^\nu \tag{7}$$

The gravitational acceleration of matter, a quantum effect, and of the structural patterns characterising the 3-space, are given by [21, 23]

$$\mathbf{g} = \frac{\partial \mathbf{v}}{\partial t} + (\mathbf{v}.\nabla)\mathbf{v} \tag{8}$$

and so fluctuations in $\mathbf{v}(\mathbf{r}, t)$ may or may not manifest as a gravitational force. The flyby technique assumes that the SC trajectories are not affected - only the light speed

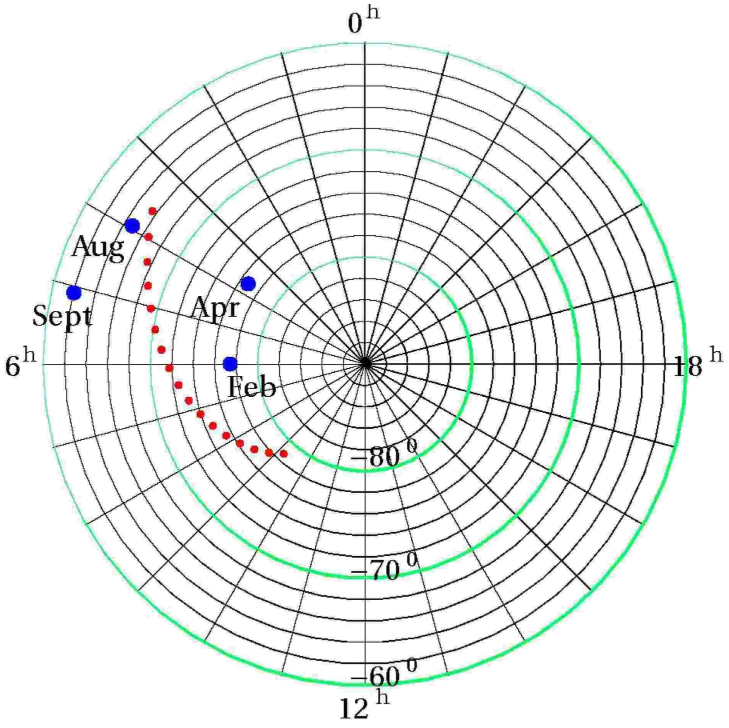

Figure 3: Southern celestial sphere with RA and Dec shown. The 4 blue points show the results from Miller gas-mode Michelson interferometer [8] for four months in 1925/1926. The sequence of red points show the daily averaged RA and Dec trend line as determined from the optical fiber interferometer data in [17] for every 5 days, beginning September 22, 2007. The day-to-day fluctuations away from the trend line show significant wave effects - not shown. From [17].

anisotropy is significant. The magnitude of this turbulence depends on the timing resolution of each particular experiment, and was characterised to be sub-mHz in frequency by Cahill and Stokes[14]. Here we have only used asymptotic osculating hyperbolic trajectory data from [1]. However data exists for the full flyby, and analysis of that data using the new doppler shift theory will permit the study and characterisation of the 3-space wave turbulence: essentially the flybys act as gravitational wave detectors. These gravitational waves are much larger than predicted by general relativity, and have different properties.

5 Pioneer10/11 Anomalies

The Pioneer 10//11 spacecraft have been exploring the outer solar system since 1972/73. The spacecraft have followed escape hyperbolic orbits near the plane of the ecliptic, after earlier planet flybys. The doppler shift data, using (2), have revealed an unexplained anomaly beyond 10 AU [28]. This manifests as an unmodelled increasing blue shift $\frac{d}{dt}(\frac{\Delta f}{f}) = (2.92 \pm 0.44) \times 10^{-18} s/s^2$, corresponding to an constant inward sun-directed acceleration of $a = \frac{dV}{dt} = (8.74{\pm}1.33){\times}10^{-8}$ cm/s^2, averaged from Pioneer 10 and Pioneer 11 data. However the doppler-shift data from these spacecraft has been interpreted using (2), instead of (1), in determining the speed, which in turn affects the distance data. Essentially this implies that the spacecraft are attributed with a speed that is too large by $\frac{v^2}{c^2}V_D$, where V_D is the speed determined using (2). This then implies that the spacecraft are actually closer to the sun by the distance $\frac{v^2}{c^2}R_D$, where R_D is the distance determined using (2). This will then result in a computed spurious inward acceleration, because the gravitational pull of the sun is actually larger than modelled, for distance R_D. However this correction to the doppler-shift analysis appears not to be large enough to explain the above mention acceleration anomaly. Nevertheless re-analysis of the Pioneer 10/11 data should be undertaken using (1).

6 Conclusions

The spacecraft earth flyby anomalies have been resolved. Rather than actual relative changes in the asymptotic inward and outward speeds, which would have perhaps required the invention of a new force, they are instead direct manifestations of the anisotropy of the speed of light, with the earth having a speed of some 440km/s relative to a dynamical 3-space, a result consistent with previous determinations using laboratory experiments, dating back to the Michelson-Morley 1887 experiment, as recently reanalysed [18, 19, 21]. However the flyby data also reveals, yet again, that the 3-space velocity fluctuates in direction and speed, and with results also consistent with laboratory experiments. Hence we see a remarkable concordance between three different laboratory techniques, and the newly recognised flyby technique. The existing flyby data can now be re-analysed to give a detailed charaterisation of these gravitational waves. The dynamical 3-space velocity effect also produces very small vorticity effects when passing the earth, and these are predicted to produce observable effects on the GP-B gyroscope precessions [29].

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