Frequency shift and Flyby anomalies

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ABSTRACT

A frequency shift is described that is derived from the difference of the kinetic energy of the particle and its gravitational potential. The frequency of photons emitted and the wave speed with an increase in the kinetic energy of the light source is decreased, and frequency of the observed photon is a combination of primary Doppler shift. The shift in gravitational frequency is due to the difference in heights, changes in the frequency of light emitted from its source, and changes in the speed of the wave and its wavelength during propagation. As an example, the flyby anomalies observed with ranging telemetry from certain spacecraft are analyzed in terms of the differences in the transverse Doppler shift and the delayed clock of the observer at infinity.

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INTRODUCTION

A previous study [1] involved representing energies (associated with gravitational mass, inertial mass, and Planck's constant) of different particle speeds as being equivalent to quanta ($Mc=\Delta m \Delta w=hf/c$). The mass in the energy-mass equivalence equation has two interpretations. Interpretation 1 is that energy and mass are not exactly the same; the energy of an object changes depending on velocity whereas the invariant mass does not change in any way. Interpretation 2 is that, apart from the constant c^2, energy and mass are exactly the same; the energy of a moving object is larger than that at rest. That is, when in motion, an object's relativistic mass is greater than when stationary. The majority of physicists have adopted Interpretation 1. We have here adopted Interpretation 2 with the equivalence principle of the momentum of light [2].

METHODOLOGY

The speed of a wave and the total energy of an object taken to be at rest in an inertial system [2] is

$$c=w_0=f_0\lambda_0,\ E_0=m_0cw_0. \tag{1}$$

The frequency shift and the primary Doppler shift by the difference in energy of the motion:

A state that has added the energy of motion from Eq. (1) is

$$w=(c^2-v^2)^{1/2},\ E=(c/w)E_0. \tag{2}$$

Energy of the photon emitted from the light source is

$$hf=(w/c)hf_0. \tag{3}$$

The light from the moving object is Doppler shifted along the line of sight as viewed from an observer,

$$f_D=f(1-v\cdot\cos\theta/c)=f_0w/(c-v\cdot\cos\theta), \tag{4}$$
$$\lambda_D=c/f_D=\lambda_0(c-v\cdot\cos\theta)/w. \tag{5}$$

The frequency of photons emitted and the wave speed with an increase in the kinetic energy of the light source is decreased, and frequency of the observed photon is a combination of primary Doppler shift.

Gravitational frequency shift by the difference of gravitational potential:

Consider a system whereby the state has lost gravitational potential energy. Then Eq. (1) becomes

$$w_L=(c^2-2GM/r)^{1/2},\ E_L=(w_L/c)E_0. \tag{6}$$

When represented as a quantum of energy, i.e., the photon, the energy is

$$hf_L=(w_L/c)hf_0. \tag{7}$$

Similarly, with a state that has increased its gravitational potential energy, Eq. (6) becomes

$$w_H=(c^2-2GM/[r+h])^{1/2},\ E_H=(w_H/c)E_0. \tag{8}$$

Hence, when represented as a photon, we have

$$hf_H=(w_H/c)hf_0. \tag{9}$$

Light emitted from the object but still at an altitude ($r+h$) undergoes a gravitational blue-shift when viewed by an observer at altitude r giving the wavelength criterion

$$\lambda_0>\lambda_L=w_L/f_H. \tag{10}$$

Light emitted from the object but still at an altitude (r) undergoes a gravitational red-shift as viewed by an observer at altitude $r+h$ giving the wavelength criterion

$$\lambda_0<\lambda_H=w_H/f_L. \tag{11}$$

The gravitational red (blue) shift resulting from the height difference ($r<r+h<\infty$) changes the frequency ($f_L<f_H<f_0$) of light emitted by the source, and changes the speed of the wave ($w_L<w_H<w_0$) and its wavelength ($\lambda_L<\lambda_0<\lambda_H$). These facts are supported by the following observations.

a) The difference in the advances of clocks is not related to the propagation of photons [3].
b) The photon does not change its speed of propagation by changing energy (frequency) [4].
c) A strong gravitational field delays the arrival time of photons passing through the field [5].

RESULTS AND DISCUSSION

In summary, the frequency shift in light from a source is caused by the difference in the gravitational potential as schematically depicted in Fig. 1. This frequency shift does not occur if the gravitational potential is the same. The relative motion produces only a primary Doppler shift.

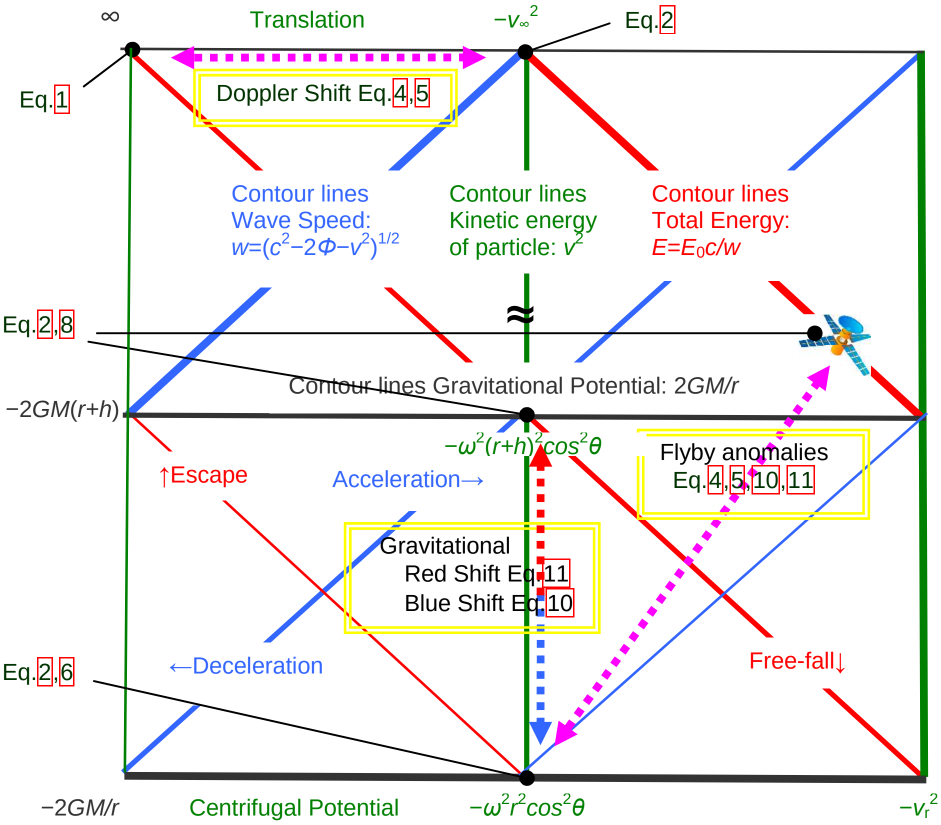

FIG.1. The frequency shift with the four independent contour lines for the kinetic energy of the particle (Y-axis), the gravitational potential (X-axis), the total energy (＼Clinoaxis) and the wave speed (／Clinoaxis).

For the flyby anomalies of spacecraft:

There is an unaccounted transverse Doppler effect—i.e., the red-shift of light from a source with zero radial and non-zero tangential velocity [6]. However, this cannot explain the similar anomaly in the range data [7]. For the transverse Doppler shift, we cannot distinguish the difference in the apparent or real speed at infinity of the spacecraft to offset the motion of the observer and the clock's time delay. The apparent speed from the low estimate ($v_\infty'^2=v\cdot v-2GM/r$) [8] in the free-fall of the spacecraft (Eqs. (2) and (8)) from infinity (Eq. (1)) appears as an apparent increment in speed. The real speed at infinity viewed from the observer in the delayed clock by centrifugal force potential (Eqs. (2) and (6)) is

$$v_\infty=(c/w)v_\infty'=v_\infty' c/(c^2-\omega^2r^2\cdot\cos^2\theta)^{1/2}. \tag{12}$$

The increment in speed at infinity obtained from the empirical formula appearing in [8], is

$$\Delta v_\infty=2v_\infty'(\cos\delta_i-\cos\delta_o)\omega r/c. \tag{13}$$

Table I shows results calculated from Eqs. (12) and (13) indicating that the range data of the fly-by anomalies is not correlated with the observed latitude. However, the angles for the incoming and outgoing directions of the spacecraft affect its real speed at infinity of the spacecraft during its fly-by (For incoming angle < outgoing angle, Galileo II and Cassini both decelerated). The data supports the relationship for which the frequency shift follows the four independent contour lines of Fig.1.

TABLE I. Comparison from the NASA Deep Space Network (DSN) view and the Equatorial view of empirical formula, The physical quantity was brought [8], ω: 7.292 115 $\times10^{-5}$ (rad/s) is the angular frequency of the Earth, r: 6,378 km is the Earth radius, v_∞ is the real speed at infinity of Eq. (12).

Quantity / Spacecraft	Galileo I	Galileo II	NEAR	Cassini	Rosetta-I	Messenger
Apparent speed at infinity: v_∞' (m/s)	8.949E+03	8.877E+03	6.851E+03	1.601E+04	3.863E+03	4.056E+03
Incoming: δ_i (deg)	-12.52	-34.26	-20.76	-12.92	-2.81	31.44
Outgoing: δ_o (deg)	-34.15	-4.87	-71.96	-4.99	-34.29	-31.92
Speed increment at infinity: Δv_∞ (m/s)	3.920E-03	-4.600E-03	1.346E-02	-2.000E-03	1.820E-03	2.000E-05
Ratio of flyby anomaly: $\Delta v_\infty/(2v_\infty'[\cos\delta_i - \cos\delta_o])$	1.473E-06	1.525E-06	1.571E-06	2.902E-06	1.365E-06	5.604E-07
Empirical formula: $\omega r/c$	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06
GOLDSTONE DSN: $(v_\infty^2 - v_\infty'^2)^{1/2}/(v_\infty \cdot \cos 35°)$	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06
MADRID DSN: $(v_\infty^2 - v_\infty'^2)^{1/2}/(v_\infty \cdot \cos 40°)$	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06	1.551E-06

CONCLUSION

This paper described a frequency shift that depends on the difference in the kinetic energy of the particle and the gravitational potential. If we do not use the absolute stationary system of coordinates, we lose all guarantee of having the same inertial system. However, it can be regarded as the same inertial system if no frequency shift occurs. Therefore, knowing the exact frequency shift of each phenomenon is important.

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