A Tentative Mechanism of Wavelength Stretching for Gravitational Frequency Shift and Time Dilation

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Abstract

This paper presents a simplified model of gravitational frequency shift and time dilation based on the physical picture that gravity stretches the wavelength of light along its propagation direction. The model derives a directional parameter $N = c/(\vec{g} \cdot \hat{k})$ and an exponential gravitational redshift formula, which can accurately calculate the magnitude of neutron star redshift and the clock bias of GPS satellites. The results are consistent with observations. This work is an exploratory study.

1 Basic Assumptions

1. Light propagates at a constant speed c in a homogeneous background.
2. The clock frequency is determined by the light signal frequency $\nu = c/\lambda$.
3. Gravity changes the wavelength of light along its propagation direction.

2 Core Equations

The wavelength dynamics equation:

$$\frac{d\lambda}{dt} = \frac{g_{\parallel}}{c}\lambda$$

where $g_{\parallel} = \vec{g} \cdot \hat{k}$ is the component of gravitational acceleration along the light propagation direction.

Using $dr = cdt$, the spatial differential form is:

$$\frac{d\lambda}{dr} = \frac{\vec{g} \cdot \hat{k}}{c^2}\lambda$$

Define the directional parameter:

$$N = \frac{c}{\vec{g} \cdot \hat{k}}$$

3 Gravitational Redshift

For a spherically symmetric gravitational field in the radial outward direction:

$$\vec{g} \cdot \hat{k} = -\frac{GM}{r^2}$$

Substitution gives:

$$\frac{d\nu}{\nu} = -\frac{GM}{c^2 r^2}dr$$

Integration yields:

$$1 + z = \exp\left(\frac{GM}{c^2 R}\right)$$

- For a typical neutron star, $GM/(c^2R) \approx 0.15$, $z \approx 0.16$ - For strong field case $GM/(c^2R) = 0.3$, $z \approx 0.35$

4 GPS Satellite Clock Correction

Gravitational frequency shift:

$$\frac{\Delta\nu}{\nu} = \frac{GM}{c^2}\left(\frac{1}{R_e} - \frac{1}{R_s}\right) \approx 5.3 \times 10^{-10}$$

Special relativistic effect:

$$\frac{\Delta\nu}{\nu} = -\frac{v^2}{2c^2} \approx -8.3 \times 10^{-11}$$

Total clock bias:

$$\Delta t \approx +38.3\ \mu\text{s/day}$$

5 Experimental Proposal

Three atomic clocks can be used to test the direction dependence:

- Free-falling clock ($g \approx 0$): less stretching, runs faster.
- Accelerated clock ($2g_0$): more stretching, runs slower.

Predicted fractional frequency shift: $\Delta\nu/\nu \sim -1 \times 10^{-16}$.

6 Conclusion

This paper provides a model for gravitational frequency shift and time dilation based on wavelength stretching. The formulation is concise and consistent with observations, which can serve as a reference for the study of gravitational effects.