Does the OPERA experiment reveal a systematic error in the satellite ephemeris of the Global Positioning System ?

Yves-Henri Sanejouand[A,B]

[A] Laboratoire U3B, UMR 6204 of CNRS, Faculté des Sciences, 2 rue de la Houssinière, 44322 Nantes Cedex 3, France.

[B] Email: Yves-Henri.Sanejouand@univ-nantes.fr

Abstract: When the difference between the speed of neutrinos measured in the OPERA experiment and the speed of light is assumed to be the error made on the GPS-based measurement of the distance between the source of neutrinos and the detector, the magnitude of this error is, within error bars, found to be equal to twice the ratio of the orbital velocity of the GPS satellites and the speed of light. So, it seems likely that the OPERA experiment, instead of revealing a new, unexpected and challenging aspect of the physics of neutrinos, has demonstrated that the Global Positioning System still suffers from a rather important error, which remained unoticed until now, probably as a consequence of its systematic nature.

Keywords: Speed-of-light – Neutrinos – OPERA – Distance measurement – GPS – Ephemeris.

Introduction

Recently, the time-of-flight of neutrinos going from CERN to the OPERA detector in Gran Sasso Laboratory was announced to be 58 ± 8 ns smaller than expected for light (Adam et al. 2011), that is, smaller than $\frac{d_{cgs}}{c_0}$, where c_0 is the speed of light in vacuum and where d_{cgs} is the distance between the source of neutrinos in CERN and the detector (about 730 km).

Given the pivotal role in modern physics of c_0 as a maximum possible speed of propagation of any signal, systematic effects that could explain this anomaly have to be investigated. Hereafter, it is shown that the magnitude of the anomaly suggests that systematic errors in the satellite ephemeris of the Global Positioning System (GPS) are likely to be responsible for the observed effect.

Result

The OPERA experiment is in essence extremely simple: a timespan, the time-of-flight of neutrinos, as well as a distance, namely, d_{cgs}, have to be measured accurately. While the former relies on highly accurate time measurements, using atomic clocks and well-mastered clock synchronization techniques, the later depends upon separate GPS measurements of the positions of the source and of the detector (Adam et al. 2011).

Although GPS accuracy also relies on highly accurate time measurements, those are used to obtain distances between a set of GPS satellites and a given GPS receiver. From such distances, the position of the receiver can be determined accurately if, and only if, the positions of the GPS satellites, more precisely, their ephemeris, is known with an accuracy high enough. Note that what is needed here is not only the distances between the satellites and a set of reference ground stations, but also their positions and their velocities with respect to a reference frame, whose center is nowadays chosen as being the center of mass of the Earth (Altamimi et al. 2007). For satellites above the Earth atmosphere, like GPS ones which are nearly 20,300 kms above mean-sea level (Dixon 1991), the most accurate way to obtain their distance from the Earth center of mass, r_{sat}, is through their orbital velocities, v_{sat}, which are measured by ground stations of the GPS control segment (Dana 1997). Indeed, to first order:

$$r_{sat} \approx \frac{GM}{v_{sat}^2} \tag{1}$$

where G is the gravitational constant and M the mass of the Earth, GM being known with a high accuracy.

Let us assume that v_{sat} is measured with a small, although systematic, error, δv_{sat}. For r_{sat}, according to (1), this would show up as an error, δr_{sat}, so that:

$$\frac{\delta r_{sat}}{r_{sat}} \approx -2\frac{\delta v_{sat}}{v_{sat}} \tag{2}$$

Since r_{sat} is used for determining all GPS-based positions, this error would also show up as an error in GPS-based distance measurements, like those performed within the frame of the OPERA experiment. Indeed, if the outcome of the OPERA experiment is interpreted as being a measure of the error, δd_{cgs}, done when estimating the distance between the source of neutrinos in CERN and the detector, using GPS-based positions, then (Adam et al. 2011):

$$\frac{\delta d_{cgs}}{d_{cgs}} = \frac{\delta r_{sat}}{r_{sat}} = 2.4 \pm 0.2\ 10^{-5} \tag{3}$$

With (2), this yields:

$$\frac{\delta v_{sat}}{v_{sat}} = -1.2 \pm 0.1\ 10^{-5}$$

Interestingly, since $r_{sat} \approx 26,600$ kms (Dixon 1991), according to (1), $v_{sat} \approx 3.9$ km.s^{-1}, that is:

$$\frac{v_{sat}}{c_0} \approx 1.3\ 10^{-5}$$

To summarize, as expected from (2) and (3):

$$\frac{\delta d_{cgs}}{d_{cgs}} \approx -2\frac{v_{sat}}{c_0}$$

Conclusion

When the difference between the speed of neutrinos measured in the OPERA experiment and the speed of light is interpreted as being a measure of the error made on the distance between the source of neutrinos and the detector, it is found that the magnitude of this error is, within error bars, equal to $2\frac{v_{sat}}{c_0}$, where v_{sat} is the orbital velocity of GPS satellites. Moreover, when this error is assumed to come from errors made on the measure of v_{sat}, the origin of the factor 2 becomes obvious.

So, it seems likely that the OPERA experiment, instead of revealing a new, unexpected and challenging aspect of the physics of neutrinos, has allowed to perform the first distance measurement over a rather long baseline (about 730 km), with an accuracy below 10^{-5} (better than 10 m), demonstrating *en passant* that the Global Positioning System still suffers from a rather important error, which remained unoticed until now, probably as a consequence of its systematic nature.

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