The 5^{th} IVS General Meeting Proceedings, 2008, p. 341-344

Measuring the Relativistic Parameter γ Using the Current Geodetic VLBI Data Set

Sébastien Lambert [1], *Christophe Le Poncin-Lafitte* [2]

[1] *Observatoire de Paris, Département SYRTE, France*

[2] *Lohrmann Observatory, Dresden Technical University, Germany*

Abstract. We used VLBI to measure the gravitational light deflection by Solar System bodies of radio waves emanating from distant compact radio sources. It is well known that this bending is characterized only by the post-Newtonian parameter γ within the standard parametrized post-Newtonian formalism, which is unity in General Relativity. Using a larger geodetic VLBI data set than in previous work, we studied the stability of the analysis and obtained $\gamma = 0.99995 \pm 0.00020$. We discussed also possible issues concerning systematic biases through an analysis of subgroups of data.

1. Light Deflection in General Relativity

Nowadays, relativity belongs to the toolbox of astronomers. As the gravitational field of the Solar System is not intense, it is however common to use the relativistic theories of gravitation in their asymptotic limit, namely the weak field approximation, to describe gravitational effects taking place in the Solar System. This can be done by the use of the parameterized post-Newtonian formalism enabling us to test all possible effects such as light deflection, time delay of light, or perihelion precession. This formalism has a dozen parameters, among them the very well-known β and γ. Experiments of light deflection are particularly sensitive to γ and VLBI is an important technique to study this effect when the light ray coming from quasars are grazing the Sun. This enables us to determine a value of the parameter γ, which is equal to unity in General Relativity (GR), and thus to constrain possible signatures of the scalar field in the Solar System.

If ϕ is the angle between the Sun and the source seen from the Earth, and b the impact parameter, the deflection angle is

$$\theta \approx (\gamma + 1)\frac{GM}{c^2 b}(1 + \cos\phi). \tag{1}$$

A grazing ray at the Sun's limb is deflected by 1.7″.

2. Close Approaches to the Sun

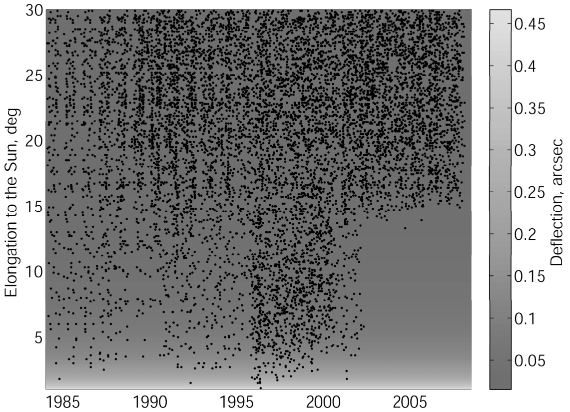

Figure 1. Observational history of the sources at less than 30° elongation to the Sun. The scale gives the deflection angle

Fig. 1 displays the observational history of the sources at less than 30° to the Sun in the 3762 24-hour geodetic sessions fully or partly processed in the upcoming analyses. The VLBI observing schedule included a number of radio sources that were observed at less than 15° to the Sun. As it is shown on Fig. 1, this number was quite uniform during 1984–1996, and then substantially increased during 1996–2002. Later, sources at less than 15° have no longer been observed, at least not in the permanent geodetic VLBI program whose data is released by the IVS. Fig. 1 naturally yields three time spans on which we propose to run the analyses: 1984–2007 (maximum number of data), 1996–2002 (higher density of close approaches), and 1984–2002 (compromise between density and number of data).

3. Analysis Strategies

Our analysis scheme is as follows.

1. Generate a base solution by a global inversion of all the data over 1984–2008. The radio source coordinates are estimated as global parameters and constrained by a no-net rotation (NNR) on the 247 stable sources [2] w.r.t. ICRF-Ext.2. The obtained celestial reference frame will be taken as a priori for all the other solutions. The station coordinates are estimated as global parameters with a NNR and no-net translation on 35 sites. Stations having non-linear motions are modeled by splines. EOP, rates, and nutation offsets are estimated as arc parameters.
2. Run two global solutions over 1984–2008, both with EOP and station coordinates as session parameters, γ as global parameter, and with (i)

source coordinates estimated as global parameters and constrained to stay within 10^{-8} rad around the a priori without any non rotation condition, (ii) source coordinates not estimated.

3. Run another two solutions over 1984–2008 in independent mode (i.e., no global parameter) where γ is obtained as time series and (i) source coordinates are estimated (same constraint as above), (ii) source coordinates are not estimated.
4. Repeat 2 for 1996–2002 and for 1984–2002.

In solutions 2–4, EOP, rates, nutation offsets, and station coordinates are estimated as session parameters. Troposphere zenith delay is estimated as a continuous piece-wise linear function at 20-min interval. Troposphere gradients are estimated as 8-hour East and North piece-wise functions at all stations except for a set of 110 stations. Elevation cut-off for radio sources is set to 5°. We used the Calc/Solve software package. Solution characteristics and γ estimates are gathered in the Table below.

Table 1. Characteristics of the solutions and estimated value of γ

	Number of sessions	Postfit rms delay, ps	γ		
			Sources estimated	Sources not estimated	Per session
1984–2008 (S1)	3762	34.3	1.00039 ±0.00016	1.00041 ±0.00015	1.00038 rms 0.0125
1996–2002 (S2)	753	32.6	0.99961 ±0.00022	0.99969 ±0.00021	0.99969 rms 0.0077
1984–2002 (S3)	2883	23.2	1.00015 ±0.00018	0.99995 ±0.00018	0.99990 rms 0.0125

4. Results and Discussion

All solutions are consistent with GR within $\sim 5\times10^{-4}$. From the solutions in independent mode, we estimate weighted averages of γ over the above three time spans (last column of the Table). They are in good agreement with the global estimates. Solution (S1) shows the highest departure to the unity and is discussed later. Global solution (S2) appears to have the lowest postfit rms delay. The estimates of γ (with or without estimating the radio source positions) are consistent with GR at 0.0002, which is the difference between the two estimates of γ. This value is slightly higher than the formal standard error and we will substitute it to the standard error. Moreover, the estimate of γ in the solution where the source coordinates are not estimated is expected to be more reliable since correlations between γ and source coordinates are cut. Our final reference value is $\gamma = 0.99995 \pm 0.00025$.

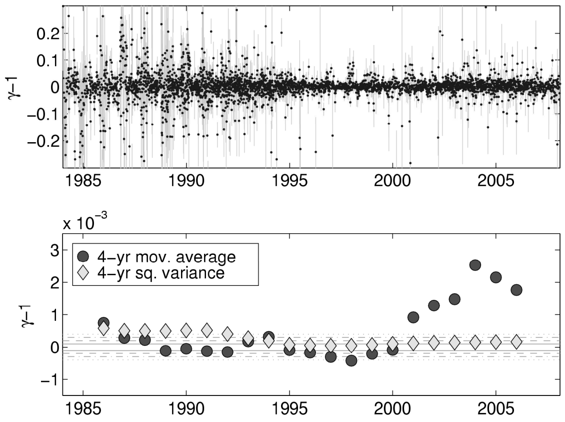

Figure 2. Solution per session for γ. Top: session estimates. Bottom: yearly values. Grey lines are spaced by 10^{-4} apart from zero

This value has to be compared to other recent estimates: Shapiro et al.[2] found 0.9998 ± 0.0004 by the analysis of VLBI delays over 1979–1999. Our study constitutes an independent check of their work and adds moreover the 1999–2002 observational period which is rich in close approaches below 10° to the sun. Bertotti et al. [1] derived from a spacecraft tracking time-delay experiment a value that is consistent with GR with an error of 0.00002. Although we are slightly better than [1, 2] have an error smaller than ours by a factor of ten.

Solution (S1) exhibits a significant systematic effect of $\sim 4 \times 10^{-4}$. It corresponds to a degradation of the estimates after 2002 showing up in Fig. 2, whose cause is not cleared up yet. Whether it is an effect of the lack of close approaches after 2002 or of the network, remains unclear at this stage of our research. Such a feature can be correlated with several changes appearing in the VLBI network organization after 2002. The year 2002 is also a key date: the entrance of the IVS R1/R4 parallel network leads to a smaller postfit rms for these sessions. Also, an examination of the baseline lengths shows that 12,000-km long baselines are extensively used after 2002 whereas they were only seldomly solicited before, resulting in a different relative geometry between the array and the sources.

References

[1] Bertotti, B., L. Iess, P. Tortora. Nature, 425, 374, 2003.

[2] Feissel-Vernier, M., C. Ma, A.-M. Gontier, et al. Astron. Astrophys., v. 452, 1107, 2006.

[3] Shapiro, S.S., J.L. Davis, D.E. Lebach, et al. Physical Review Letters, 92, 121101, 2004.