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AN ESTIMATE OF THE RELATIVISTIC PARAMETER γ USING VLBI

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Abstract. This paper presents estimates of the post-Newtonian parameter γ from the analysis of 24 years of radio delays recorded by the various geodetic VLBI observing campaigns and the current permanent geodetic VLBI network.

1 Light deflection and VLBI measurements

In the weak field approximation, gravitational effects in Solar System are described using the parameterized post-Newtonian formalism, that has a dozen parameters among which the very well-known β and γ. Experiments of light deflection are particularly sensitive to γ and VLBI is an important technique to measure this effect when light rays coming from quasars graze the Sun. If ϕ is the angle between the Sun and the source as seen from the Earth, and b the impact parameter, the deflection angle is $\theta \approx (\gamma + 1)(GM/c^2 b)(1 + \cos\phi)$, where $\gamma = 1$ in General Relativity (GR). A grazing ray at the Sun's limb is thus deflected by $1.7''$. The most recent attempt to measure γ by VLBI was done by Shapiro et al. (2004), using VLBI observations over 1979–1999. They found that γ is consistent with GR within 4×10^{-4}. Bertotti et al. (2005), found 2×10^{-5}, using Cassini spacecraft tracking time delays (this constitutes the current best determination).

A look at the observational history of extragalactic radio sources in the International VLBI Service for Geodesy and Astrometry (IVS) data base reveals that the VLBI observing schedule included a number of radio sources at less than 15° to the sun. 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. Note also that 1992–1999, that contains a number of close approaches, is a period of low solar activity.

In this work, we aim at estimating γ using the additional 1999-2008 time period with respect to Shapiro et al., and dropping the 1979–1984 period which contains observations with poor geometries and early recording systems. We also want to test several time spans that may be more reliable for this kind of experiment.

2 Data analysis and results

All the VLBI analyses are run using the IVS OPAR analysis center facilities (Gontier et al. 2006) at the SYRTE department of the Paris Observatory. In a first step, we build up a radio source coordinate (RSC) catalogue that will be taken as a priori catalogue for further analyses. This is realized in a single inversion of 3,852 ionosphere-calibrated dual-frequency diurnal VLBI sessions reparted over 1984–2008. In such an inversion, the RSC must be constrained in order to avoid any global rotation of the frame. After several tests, we choose to apply a no-net rotation constraint on the coordinates of 262 sources that were selected by Lambert & Gontier (2008). This set of sources was shown to provide a materialization of the celestial reference system more stable than previous ones (Ma et al. 1998; Feissel-Vernier et al. 2006). Thus, the obtained RSC catalogue is aligned to the International Celestial Reference Frame (Ma et al. 1998; Fey et al. 2004) within 20 μas. To avoid perturbation of the RSC estimates by any variable geophysical processes (e.g., unmodeled Earth orientation or seasonal deformation of the network geometry), all observing site coordinates and velocities are estimated over the full time span, together with session-wise Earth orientation parameters, antenna axis offsets, and troposphere gradients and zenith delay.

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In a second step, we launch inversions of the same VLBI sessions wherein (i) a mean value of γ is estimated over the full time span, and (ii) RSC are not globally constrained, but allowed to move within circles of 10^{-8} rad around the a priori position given by the a priori RSC catalogue previously set up. This second step is repeated for sessions within 1984–2002, and 1996–2002. Additionally, we also run similar a solution over the Shapiro et al.'s 1979–1999 time span for comparison purpose. (Nevertheless, the sessions used are not exactly the same, as well as the analysis strategy and the sofware package.) In all these solutions, station coordinates and Earth orientation parameters are estimated at each session, with appropriate loose constraints. Obtained values of γ are gathered in Table 1. The posfit rms delay that nears 27 ps means that the noise level is at the level of 250 μas in terms of angular positioning.

The solution over 1979–1999 confirms the results of Shapiro et al. with a slightly lower formal error that may originate from a different analysis strategy (e.g., constraints on radio source coordinates). The 1996–2002 solution obviously suffers from a small number of observations, bringing out less sources (with less observations) on which the adjustment of γ can be done. The solutions over 1984–2002 and 1984–2008 that include a large number number of sessions and delays both result in estimates of γ consistent with GR within 2×10^{-4}. The solution over 1984–2002, i.e., over the period that is both long and rich in close approaches, is the closest to the unity.

Table 1. Characteristics of the global solutions and estimates of γ.

	No. sessions	No. delays	No. sources	Postfit rms delay (ps)	γ
1984–2008	3,852	4,348,913	988	24.9	0.99986 ± 0.00015
1984–2002	3,040	2,857,624	781	27.0	0.99993 ± 0.00017
1996–2002	753	1,024,322	676	27.5	0.99940 ± 0.00022
1979–1999	2,598	2,115,509	723	27.4	0.99983 ± 0.00020

3 Conclusion

We show that the existing geodetic VLBI data can be used back to 1984 to get estimates of γ with a accuracy of 2×10^{-4}. The estimate of γ can even reach values close to 1 by 7×10^{-5} when using strictly the time span containing sessions with observations of sources at low elongations to the sun (less than 15°). The improvement with respect to the value of Shapiro et al. can be attributed to the extra three years of data (1999–2002) that are rich in close approaches, along with the improvement of the quality of the VLBI network and observations. Using the sessions after 2002, that no longer contains close approaches below 15°, makes the estimate of γ depart from the unity at the level of 1σ.

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