ON GENERAL RELATIVITY TESTS WITH THE VLBI

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ABSTRACT. Relativistic bending in the vicinity of a massive body is characterized only by the post-Newtonian parameter γ within the standard parameterized post-Newtonian formalism, which is unity in General Relativity. To estimate this parameter, we use very long baseline interferometry (VLBI) to measure the gravitational deflection of radio waves by Solar System bodies emitted by distant compact radio sources.

1. ESTIMATING THE PPN PARAMETERS FROM VLBI DELAYS

We recently published two papers (Lambert & Le Poncin-Lafitte 2009, hereafter LL09, and Lambert & Le Poncin-Lafitte 2011, designated as LL11) wherein we estimated the post-Newtonian parameter γ by analyzing group delays recorded by astrometric and geodetic very long baseline interferometry (VLBI) at 8 GHz.

In LL09, we analyzed geodetic VLBI observations recorded between 1979 and 2009 excluding VLBA and RDV sessions. We compared estimates of γ and errors obtained with various analysis schemes, including global estimations over several time spans and with various Sun elongation cut-off angles, and with analysis of radio source coordinate time series. We arrived at the conclusion that the relativistic parameter γ cannot be estimated at better than 2×10^{-4}. The main factor of limitation is the uncertainty in determining of (global or session-wise) radio source coordinates. A sum of various instrumental and modeling errors and analysis strategy defects, which cannot be decorrelated and corrected yet, is at the origin of the limiting noise.

2. A POSSIBLE IMPROVEMENT USING SPECIALLY DESIGNED SESSIONS

With respect to LL09, the latest paper included additional sessions of the IVS regular geodetic monitoring program (IVS rapid turn around sessions R1 and R4) in 2009–2010, as well as a relatively small number of additional sessions after 1994 used of the 10-station North American Very Long Baseline Array (VLBA). The observing configuration of the VLBA network allows one to image sources and determine highly accurate station and source positions (see, e.g., Petrov et al. 2009). The VLBA can be used either alone (these sessions will be referred to as VLBA sessions in the following) or together with additional overseas antennas (denoted by VLBA+ sessions in the following) that push baseline lengths to more than 10,000 km. The former category includes the VLBA Calibrator Survey (VCS) programs 1 to 6 (Beasley et al. 2002, Fomalont et al. 2003, Petrov et al. 2005, 2006, Kovalev et al. 2007, Petrov et al. 2008) that were scheduled between 1994 and 2007. They contain observations as close as 1.4° to the Sun, which are indicated as green, vertical bands in Figure 1. In the latter category, one finds the sessions known as RDV experiments using the VLBA plus up to ten additional geodetic stations located worldwide (in blue in Figure 1). It appears that VLBA+ sessions stopped observing at less than 15° from the Sun after 2002, like all other routine VLBI experiments. VLBA and VLBA+ sessions usually have a number of observations larger than 10,000 and a postfit rms delay in the range 5–30 ps.

The most complete solution in LL09 processed 5,055 sessions between 3 August 1979 and 30 August 2010, totaling more than 7.3 millions ionosphere-free group delay measurements at 8 GHz. The analysis configuration is detailed in the relevant paper. Including both VLBA+ and VLBA sessions in our analysis, we obtained $\gamma = 0.99992 \pm 0.00012$. Note that adding VLBA+ and VLBA sessions increases the number of delays by 30% and the number of sources by a factor of four. Our results show that the VLBA experiments, although scheduled sparsely, have a good potential for General Relativity tests.

Although we do not challenge the results of Bertotti et al. (2003) from Cassini spacecraft measurements

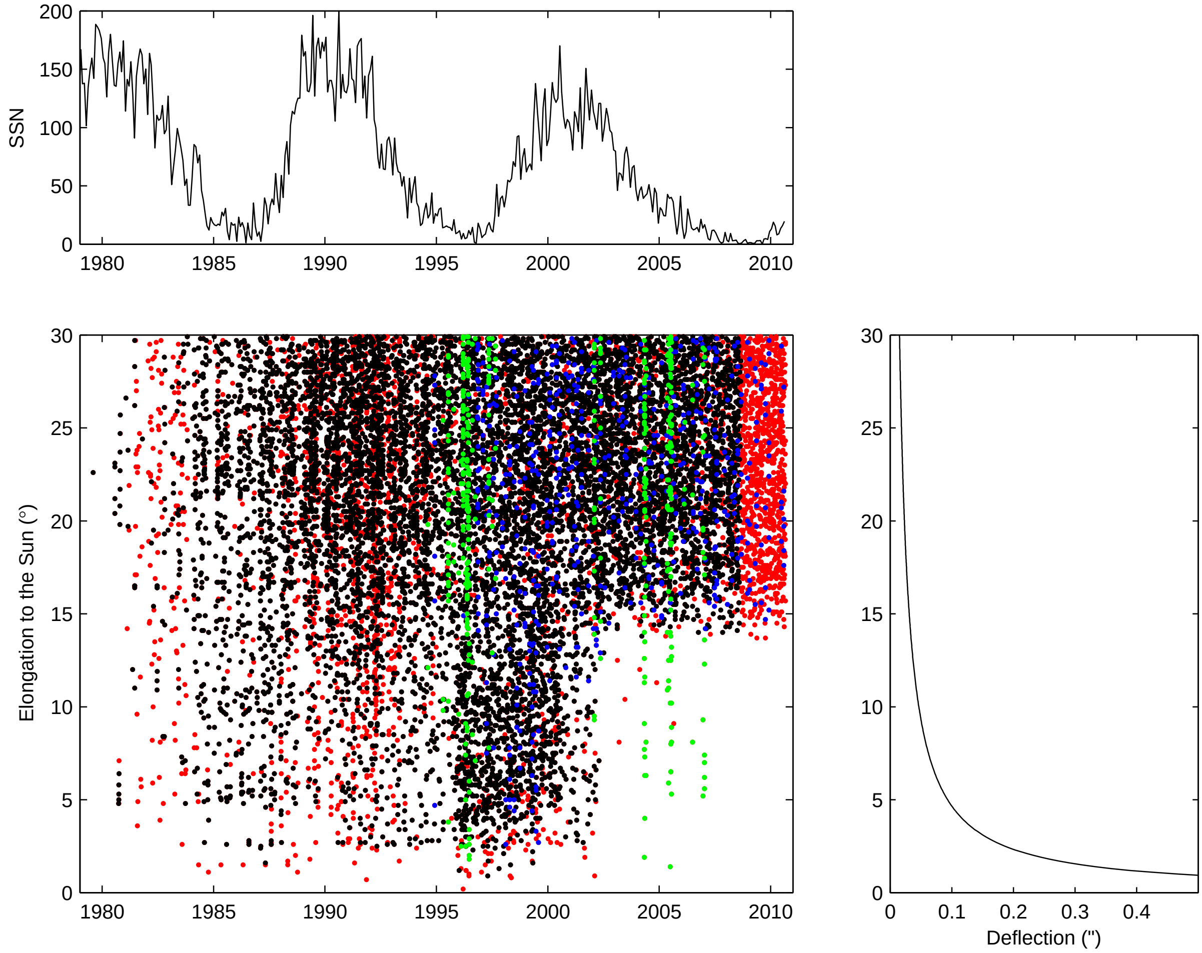

Figure 1: The main plot displays the observational history of the sources at less than 30° from the Sun (black: observations treated in LL09; red: additional observations of routine experiments not processed in LL09 excluding VLBA+ and VLBA; blue: VLBA+; green: VLBA). The upper plot gives the Sun spot number. The right plot displays the deflection angle predicted by General Relativity.

($\gamma = 1.00002 \pm 0.00002$), the results presented in this study are notable because they illustrate the capability of certain geodetic/astrometric VLBI networks and observing configurations to increase the sensitivity to γ. The VLBI observational data base provides a very flexible way to test General Relativity in the Solar System at the level of 10^{-4} thanks to the public availability of the data and the low CPU time taken by the solutions.

This data base is still increasing with new observations of very good quality thanks to a great, joint effort of worldwide radio astronomical observatories and space agencies. The upcoming VLBI 2010 will be designed in particular to reduce systematic errors, including possible source structure corrections thanks to faster antennas, larger networks, and higher data rates resulting in a *uv* coverage that is much better than in the current geodetic experiments (Petrachenko et al. 2008). This new VLBI network will likely lead to improved ground-based tests of General Relativity (Heinkelmann & Schuh 2010). We therefore encourage VLBI observing program committees to schedule observations of sources close to the Sun as in the VLBA calibrator survey sessions.

3. REFERENCES

Beasley, A. J., Gordon, D., Peck, A. B., et al. 2002, ApJSS, 141, 13

Bertotti, B., Iess, L., & Tortora, P. 2003, Nature, 425, 374
Fomalont, E. B., Petrov, L., MacMillan, D. S., et al. 2003, AJ, 126, 2562
Heinkelmann, R., & Schuh, H. 2010, In: S. A. Klioner et al. (Eds.), Proc. International Astronomical Union (IAU), 261, 286
Lambert, S. B., & Le Poncin-Lafitte, C. 2009, A&A, 499, 331
Lambert, S. B., & Le Poncin-Lafitte, C. 2011, A&A, 529, A70
Lambert, S. B., Dehant, V., & Gontier, A.-M. 2008, A&A, 481, 535
Petrachenko, W. T., Charlot, P., Collioud, A., et al. 2008, In: N. Capitaine (Ed.), Proc. Journées 2007 Systèmes de Référence Spatio-Temporels, Observatoire de Paris, France
Petrov, L., & Boy, J.-P. 2004, J. Geophys. Res., 109, 3405
Petrov, L., Kovalev, Y. Y., Fomalont, E. B., & Gordon, D. 2005, AJ, 129, 1163
Petrov, L., Kovalev, Y. Y., Fomalont, E. B., & Gordon, D. 2006, AJ, 131, 1872
Kovalev, Y. Y., Petrov, L., Fomalont, E. B., & Gordon, D. 2007, AJ, 133, 1236
Petrov, L., Kovalev, Y. Y., Fomalont, E. B., & Gordon, D. 2008, AJ, 136, 580
Petrov, L., Gordon, D., Gipson, J., et al. 2009, J. Geod., 83, 859