GRAVITATIONAL EFFECTS FROM A SERIES OF IVS R&D VLBI-SESSIONS WITH OBSERVATIONS CLOSE TO THE SUN

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ABSTRACT. In 2011 and 2012 the IVS observed twelve VLBI research and development (R&D) sessions that include successful observations as angularly close as 3.9° from the heliocenter. Among others, one purpose of these IVS-R&D sessions was to achieve an improvement in the determination of the PPN parameter γ. Besides, by analyzing this speciffic set of IVS sessions, it was for the first time possible to measure the dispersive effect of the Solar corona with VLBI (Soja et al., 2014). In this work we assess the formal error of the γ-parameter and the contributions of the various terms to the partial derivative of the γ-parameter. Furthermore, we investigate the size of the gravitational delays caused by: (i) Solar monopole field at rest and with approximately linear translation, (ii) rotation of the Solar monopole field, (iii) Solar gravitational field quadrupole expansion, and (iv) Solar higher order term.

1. COMPARISON OF GRAVITATIONAL DELAY MODELS

The current conventional gravitational delay model is based on the *Consensus* model (Eubanks, 1991) and specified by the current IERS Conventions (2010) (Petit & Luzum, 2010). It contains the first and higher order terms of the Solar monopole field at rest. Comments regarding the nomenclature and completeness of the current IERS Conventions: (i) The nomenclature of the unit vector in the direction of the radio source changes from $\vec{K}$ (eqs. 11.1, 11.2) to $\hat{K}$ (after eq. 11.2). (ii) The index used for the gravitating body changes from J (eqs. 11.1 till 11.7) to i (eq. 11.14), before index i was used for the individual antenna. (iii) It is not specified how the position of the gravitating body at the time of closest approach is to be numerically evaluated (e.g. interpolation or linear extrapolation). (iv) *"For observations made very close to the Sun, higher order relativistic time delay effects become increasingly important."* (Petit & Luzum, 2010). It is not specified what "very close to the Sun" numerically means.

The gravitational delay model in the Vienna VLBI Software VieVS (Böhm et al., 2012) equals the conventional model with two exceptions: (i) the time used for the iteration of the position of the gravitating body is different from the time of closest approach and (ii) the higher order term for the Sun is neglected. The time used for the evaluation of the closest approach considers the theoretical travel time from the gravitating body to the receiver. This is only a valid approximation if the gravitating body stays between the source and the baseline and the signal travels very close to the gravitating body. For all other cases the approximation is not valid. In particular it does not consider the case where the gravitating body is situated behind the baseline (as seen from the radio source).

The most complete gravitational delay model, derived by Klioner (1991) and reported in detail in Klioner & Kopejkin (1992), includes all additional terms of the 2PN metric. Compared to the conventional delay model it considers the delay caused by linear translation and rotation of the monopole field and by the expansion of the gravitational field to the quadrupole moment of the Sun. Furthermore, other expressions that are necessary for the derivation, such as the time of closest approach and the higher order term are given with precision higher than the two aforementioned models.

The maximum differences of the main term, the Solar gravitational monopole field at rest, when analysing the twelve IVS-R&D sessions (Soja et al., 2014), are at the level of $1 \cdot 10^{-3}$ ps. For the current precision of standard X/S VLBI group delay observables of about 20 ps the differences are negligible. For the minimum Solar elongation angles involved in the twelve IVS-R&D sessions of 3.9° the maximum absolute value of the higher order term reaches 0.14 ps and that of the quadrupole field term 0.06 ps. The other terms, the Solar translational and rotational terms, are negligible. For the analysis of the twelve

IVS-R&D sessions it follows that it is sufficient to work with one of the three models mentioned above. However, analysing other IVS sessions, where the Sun is situated in opposition and not in conjunction with the observed radio source, the deviations of the gravitational delay model of VieVS can exceed these values. The current minimum Solar elongation angle of IVS is 4°. For smaller elongations the higher order term and also the term due to the quadrupole expansion may become significant.

2. FORMAL ERROR AND PARTIAL DERIVATIVE OF THE γ-PARAMETER

In Heinkelmann & Schuh (2010) we first outlined that the partial derivative of the γ-parameter could be obtained considering the term of the gravitational delay of the Sun alone. For the twelve IVS R&D sessions under investigation we derived and considered the complete γ partial derivative that also involves the terms due to the Lorentz transformation, the Earth gravitational delay, the gravitational delays induced by the other planets and the Moon, and the contributions due to the extensions of the Solar gravitational delay as discussed in the first section. The average size of the contributions to the partial derivative are listed in Table 1. They are valid for the particular geometry of the twelve IVS-R&D sessions only.

The twelve IVS-R&D sessions that were designed to observe close to Sun aimed to improve the determination of the γ-parameter. We estimated two solutions: the first solution includes all observations of the IVS-R&D sessions and for the second solution we disregarded those observations within 15° Solar elongation. The formal error of γ estimated as a global parameter over the twelve sessions increased from 0.00076 to 0.00134 (almost double the size). The formal error when fixing station positions on their catalogue values increased from 0.00136 to 0.00239 if angularly close observations are excluded, indicating that the estimation of γ significantly depends on other parameters as well. Of course, a more reliable estimate of γ can be derived by including much more than twelve IVS sessions (Lambert & Le Poncin-Lafitte, 2009).

Solar monopole field at rest	1
Lorentz transformation	0.3
Earth gravitation	0.01
Planetary and Lunar gravitation	0.0005
Extended Solar gravitational terms	0.00001

Table 1: Mean size of the component's contribution to the γ partial derivative relative to the first component (Solar monopole field at rest).

3. REFERENCES

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