Preliminary results of the IVS gravity experiment grav01

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Abstract

Three IVS research and development experiments were observed in order to detect terms proportional to v^3/c^3 in gravitational delay caused by the Jupiter when it passed within $3'.7$ from the quasar 0839+187. Preliminary results of group delay analysis are presented. The estimate of parameter γ for gravitation delay in the Jovian gravitational field 1.2 ± 0.1 was determined.

1. Introduction

General relativity is not derived as a generalization of experimental facts, but based on a hypothesis that equations should be simple and beautiful. From one side it can be considered as a great merit of the theory which permitted to call it the most beautiful theory ever developed. Continuation of this merit is the that predictions of general relativity do not logically follow from experiments. Therefore, each time when the accuracy of the experiment is sufficient in order to try to determine the new effect predicted by the theory or a new term in a known effect, we have to check whether the theory agrees with the experiment, i.e. whether the simple and beautiful equations describe reality adequately.

2. Rational

On the class of metric theories of gravitation the expansion of the metric tensor over 1/c can be written [10] as

$$\begin{aligned} g_{00} &= -1 + 2\frac{U}{c^2} && + O(1/c^4) \\ g_{0i} &= -2\left(1+\gamma+\frac{\alpha_1}{4}\right)\frac{V}{c^3} && + O(1/c^5) \\ g_{ij} &= \delta_{ij}\left(1+2\gamma\frac{U}{c^2}\right) && + O(1/c^4) \end{aligned} \tag{1}$$

Parameters α_1 and γ are 0 and 1 respectively in general relativity, but may have different values in alternative metric theories of gravitation. Then, the gravitation VLBI delay is:

$$\tau_{gr} = (1+\gamma)\sum_a \frac{f m_a}{c^3}\left(1+\frac{1+\zeta}{c}\vec{\mathbf{v}}_a\vec{\mathbf{s}}\right)\ln\frac{|\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_a| + (\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_a)\vec{\mathbf{s}} - \frac{1}{c}\vec{\mathbf{s}}\times(\vec{\mathbf{v}}_a\times\vec{\mathbf{s}}))}{|\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_a| + (\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_a)\vec{\mathbf{s}} - \frac{1}{c}\vec{\mathbf{s}}\times(\vec{\mathbf{v}}_a\times\vec{\mathbf{s}}))} \tag{2}$$

where $\zeta = \dfrac{\alpha_1}{2+2\gamma}$, f — the universal gravity constant, m_a is a mass of the gravitating body, $\vec{v}_a$ — velocity of the a th body, $\vec{s}$ — source vector in the barycentric reference system, $\vec{x}_i$ — vector of the i th station in the geocentric reference system. Summing is done over all major planets, Sun and Moon. Detailed derivation of this expression for the case of general relativity can be found in found [3] and for general case in [10].

The second term in the brackets before logarithm and the third term in the numerator and denominator of the logarithm are proportional to v^3/c^3 and very small, except the cases when the source is close to the gravitating body. It can be easily shown that contribution of these terms to VLBI time delay is reciprocal to the third degree of the angular distance from a source to a gravitating body [4].

The part of the expression for VLBI time delay without terms of third order has been extensively tested. Analysis of the whole set of VLBI observations from 1979 to 2004 performed by the author gives $\gamma = 1.0004 \pm 0.0002$ when only Sun is taken into account in the expression 2. Here 0.0002 is the uncalled formal uncertainty.

Contribution of the terms proportional to v^3/c^3 has never been before detected experimentally. The interest to these terms arose recently as S. Kopeikin pointed out in a short paper [4] that "c" in the third term of the numerator and denominator of the logarithm corresponds to the speed of propagation of gravity. General relativity postulates that the speed of propagation of gravity is equal to the speed of propagation of light, but that statement has not been checked experimentally [9], [7]. This interpretation caused a fierce criticism of [1], [10] and [8] who presented arguments that that "c" is the speed of light, not gravity. Kopeikin analyzes arguments of his opponents in details and defends his position in lengthy papers [5], [6]. Regardless of theoretical interpretation of these terms, it is tempting to detect its contribution to VLBI path delay.

3. Event of 2002.09.08

Cursory analysis shows that the best circumstances of observation of the terms in gravitational delay proportional to v^3/c^3 is when the Jupiter or Saturn passes very close to a bright compact quasar. A. Kudryavtcev (personal communication, 2001) has found that on 2002.09.08 15h 56m 08.9s TAI the Jupiter passed within $3'.7$ from the quasar 0839+187 (fig. 2). There are two other quasars which were previously observed in geodetic experiments near 0839+187: 0836+182 and OJ287.

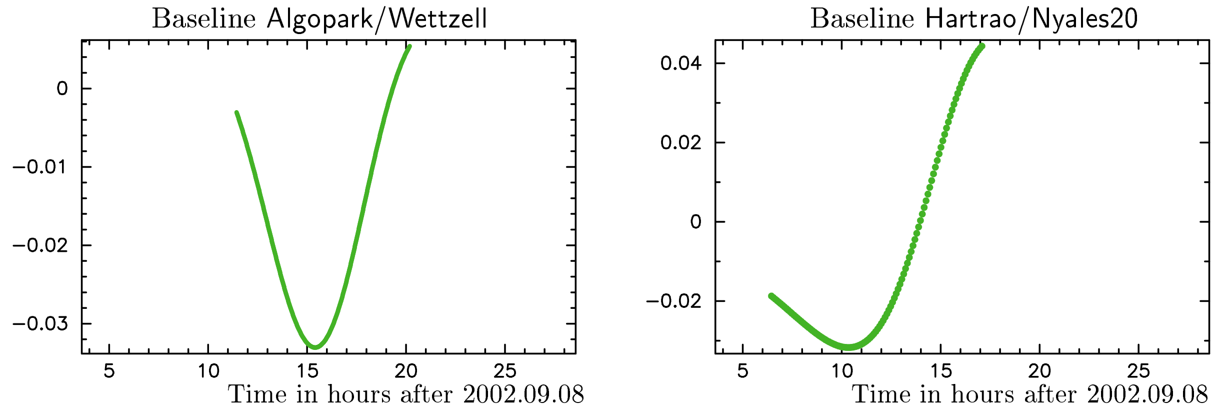
0839+187	flux 0.33Jy	min distance	$3'.7$
0836+182	flux 0.17Jy	min distance	$49'$
OJ287	flux 2.0Jy	min distance	$3^\circ 15'$

Simulation showed (figure 1) that the contribution of terms proportional to v^3/c^3 during that event can reach 7 psec when observed at the IVS network. Although precision of group delays is not sufficient in order to measure such an effect, but accuracy of differential phase should be sufficient for detection of this contribution provided phases can be successfully connected.

4. Design of the experiment

Three sources 0839+187, 0836+182, OJ287 were observed at Algopark, Gilcreek, Hartrao, Kokee, Medicina, Nyales20, Westford, Wettzell with 256 Msamples/sec bits rate at X/S bands. Experiment start time: 2002.09.08 06 UT. Duration: 24 hours. Every two hours 3–4 troposphere

Figure 1. Predicted contribution to fringe phase due to v^3/c^3 terms in phase turns



calibrators were observed during the experiment.

The purpose of the experiment was 1) to get group delays at X/S bands; 2) to get differential phases.

Scan length was taken long enough in order to get the signal to noise ratio at least 20 at baselines with weak antennas. In order to fit one tape pass, two observing sequences were used intermittently.

0836+182 — 0839+187 (840^s—250^s)

OJ287 — 0839+187 — OJ287 — 0839+187 — OJ287 — 0839+187 — OJ287 — 0839+187 (125^s—240^s—115^s—240^s—115^s—240^s—115^s—240^s)

The target sources were observed at all stations when they were above 10 degrees above the horizon.

Using similar schedule two other experiments were performed: on 2002.03.20 and 2002.08.28. The purpose of these experiments was to determine the noise level when the Jupiter was far away from 0839+187.

Quite independently, analogous experiment was performed at the network which included 10 VLBA stations and Effelsberg by E. Fomalont and S. Kopeikin [2].

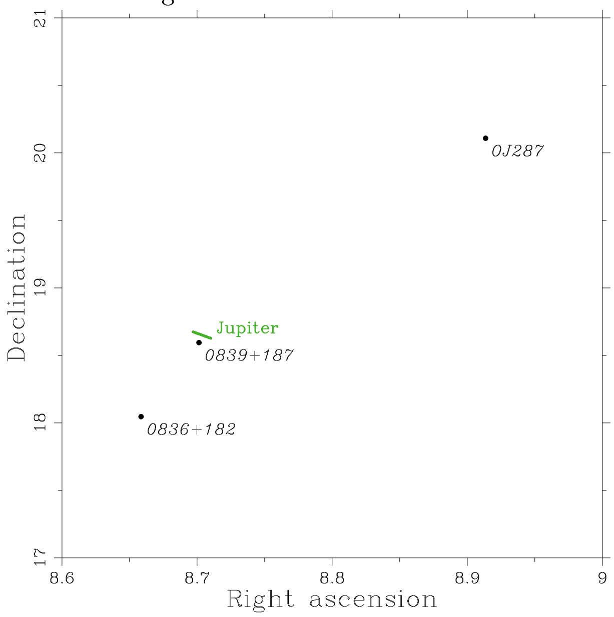
5. Analysis of group delays

The experiment was designed for getting precise group delays along with phase delays. Two solutions were performed.

In solution G1 gravitational time delay due to the Jupiter was not modeled. Parameter γ was considered as dependent on the gravitating body. Three VLBI sessions, 02MAR20XA, 02AUG28XA and 02SEP08XA were used for adjustment of $\gamma_{\rm J}$, as well as position of 0839+187, daily nutation offsets, clock function and troposphere path delay using least squares. The additive baseline-dependent noise was added to the weights in oder to keep the ratio of χ^2 to its mathematical expectation close to unity. Result of processing these three experiments: $\gamma_{\rm J} = 1.2 \pm 0.1$. Reported uncertainty is the unscaled 1-σ uncertainty.

In solution G2 terms proportional to v^3/c^3 were excluded from the expression for gravitational

Figure 2. Event of 2002.09.08



delay 2. The difference, denoted as ξ, is given by

$$\xi_3 = 2\frac{fm_{\rm J}}{c^3}\left[\left(1+\frac{\vec{\mathbf{v}}_{\rm J}\vec{\mathbf{s}}}{c}\right)\ln\frac{|\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_{\rm J}|+(\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_{\rm J})\vec{\mathbf{s}}-\frac{1}{c}\vec{\mathbf{s}}\times(\vec{\mathbf{v}}_{\rm J}\times\vec{\mathbf{s}})}{|\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_{\rm J}|+(\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_{\rm J})\vec{\mathbf{s}}-\frac{1}{c}\vec{\mathbf{s}}\times(\vec{\mathbf{v}}_{\rm J}\times\vec{\mathbf{s}})}-\ln\frac{|\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_{\rm J}|+(\vec{\mathbf{x}}_1-\vec{\mathbf{x}}_{\rm J})\vec{\mathbf{s}}}{|\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_{\rm J}|+(\vec{\mathbf{x}}_2-\vec{\mathbf{x}}_{\rm J})\vec{\mathbf{s}}}\right] \quad (3)$$

assuming $\gamma = 1$ as it follows from solution G1. The factor $A_3\xi_3$ was included in the estimation model and the unknown parameter of A_3 of the admittance of ξ_3 into time delay was estimated. In the case if expression 2 is precise, $\gamma = 1$, $\alpha_1 = 0$, observational noise is uncorrelated with ξ, the estimate of A_3 should be close to unity. Result of analysis of 02SEP08 session is $A_3 = 0.9 \pm 1.2$. This confirms prediction that the group delays are not precise enough in order to confirm or refute the presence of v^3/c^3 terms in expression 2.

6. Analysis of phase delays

This work is in progress.

7. Acknowledgment

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