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ABOUT RELATIVISTIC CLOSE APPROACHES BETWEEN JUPITER AND QUASARS IN THE PERSPECTIVE OF THE GAIA MISSION

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Abstract.
The recent improvements of ground and space observational techniques as well as the launch of specific space missions as Hipparcos has considerably increased the precisions of astrometric measurements. One of the most important goal still remaining to be done is the link between primary catalog ICRF (International Celestial Reference Frame) and the dynamical reference frame determined through the time coordinates and the trajectories of moving celestial bodies, as the Moon, the Sun and the planets. This link can be done through the close encounters between a planet (here Jupiter) and quasars. We focus preferentially on the period involving the future space mission GAIA, and also determine the corrections due to the relativistic deflection of light of the quasars around Jupiter. After defining the (α, δ) parallax effects between an Earth ground-based observational site and GAIA, we found a large number of close encounters. Then in order to understand the typical configurations of the close encounters above, we have selected examples involving the relativistic deflection of light as seen from the two observational sites (the Earth and GAIA). We conclude that these events deserve a great attention in the future in particular in the scope of a link between the dynamical reference system and the ICRF.

1 Introduction

To establish with optimal accuracy the link between a quasi-inertial reference frame in space, as the ICRF, and a frame to which the motion of celestial bodies is referred, as the dynamical ecliptic of J2000.0, represents one of the most challenging aim of modern astrometry.

Whereas the ICRF (International Celestial Reference Frame), constructed from S and X bands VLBI observations, represents the best quasi-inertial reference frame, its counterpart at optical wavelengths is given by the positions and the proper motions at J2000.0 of the Hipparcos stars. Recently, the maintenance of the Hipparcos link has been continued through huge projects as the USNO CCD Astrograph Catalog (UCAC) whose the goal is to achieve a large completeness of the final improved catalog whose the release is scheduled in 2007. Moreover several investigations were continued to use a substantial number of radio stars in order to link the optical frame to the ICRF (Boboltz et al.,2003, Fey et al.,2006). In this last paper, positions of 46 radio stars were obtained in the ICRF directly through phase referencing of the stars to nearby ICRF quasars. These positions were estimated to be accurate at the 10 mas level.

In addition to these improvements, it is now a well established fact that the quasars represent the most suitable objects giving a quasi-inertial direction in space. This basic premise was a the origin of the construction of the ICRF (International Celestial reference Frame) consisting in a set of 212 radio sources whose equatorial coordinates with respect to the mean equator of J2000.0 are considered as fixed. VLBI observations have shown that generally speaking, the quasars are so remote objects that despite their very large recession speed, their apparent proper motion is generally negligible. Only a rather small set of sources show significant displacement of their photocenter at radio wavelengths (Fey et al.,2004).

Our study is particularly well suited in the scope of the GAIA space astrometric mission. GAIA is planned as a survey mission and will make observations of roughly 1 billion objects. Among these objects we find a large proportion of all known extragalactic reference sources as quasars. As already remarked by several authors (see

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for instance Fey et al.,2004), if the projected astrometric accuracies for GAIA are realized, the GAIA astrometric grid will be serious competition for the radio realization of the ICRF. Therefore any close encounter phenomena between a planet and known quasars not only during, but also before and after the GAIA mission will deserve interest. Our choice for the planet Jupiter is motivated by several reasons that we enumerate below :

• Jupiter is by far the most massive of the nine planets of the solar system, and grazing close encounters between this planet and quasars, in addition to their fundamental astrometric interest, might lead to a significant and detectable relativistic effect, i.e. the deflection of the beam coming from the remote extra galactic object when its line of sight remains close to the limb of the planet. We will illustrate in this paper how large this effect can be in several occasions, and how it can significantly affect astrometric reductions at the level of several milliarcseconds. Moreover, second-order effects as the influence of Jupiter's quadripole moment J_2 and also J_4 might be detectable from an upcoming space mission as GAIA.

• The close approach between a quasar and Jupiter is automatically accompanied by a close approach with most of its satellites, whose most of them lie in the equatorial plane of the planet. As more than 40 satellites have been detected at total, this obviously increase the interest of the study, for differential astrometry between the large Galilean satellites as well as the much smaller point-like ones, and quasi-inertial objects as quasars looks precious in the goal of fitting ephemerides and contributing to the link between the dynamical system and the ICRF.

• An important study concerns the parallax effects : Jupiter will be a priority target for the GAIA space mission, in particular for the two above reasons, Then it is interesting to calculate precisely the parallax angle between the astrometric satellite and an Earth-based observer as seen from Jupiter (and reciprocally) both in a general situation as well as during close encounters between Jupiter and quasars. Remark that simultaneous observations or observations with very small observational time interval between the satellite and ground based telescopes might bring interesting comparisons in an astrometric point of view.

• We have no doubt that in the near future, the number of recorded quasars per field of view with very precise equatorial coordinates with respect to the ICRF will allow them to play exactly the same role as the present stars playing the role of astrometric standards, but with the great advantage that they do not present a priori significant proper motions at long time scales (one century). Therefore it is interesting to make a statistical estimation for a given planet (i.e. Jupiter) of close encounters with quasars, for a given interval of time, and with the up-dated dense quasar catalog (Véron-Cetty and Véron,2003).

2 Close approaches between Jupiter and quasars

2.1 Parallax effects

For differential studies it looks interesting to characterize close encounter events both from the Earth and from GAIA. In Fig.1 we represent for the time interval [2005-2010] the curves of the differences in arcseconds between the equatorial coordinates of Jupiter as seen from the two observational sites (GAIA and the Earth). As GAIA is moving along a Lissajous orbit with an osculating plane very close to the ecliptic, the differences $\Delta\delta$ are significantly smaller than the corresponding differences $\Delta\alpha$ in right ascension. As GAIA will be very closed to a Lagrange point the two signals are characterized by a sinusoid with period 1 year. The amplitudes reach respectively $\pm$900" and $\pm$350". These values are considerably larger than Jupiter's apparent diameter, which does not exceed roughly 50". This means that the cases for which the quasar subject to a close encounter is approaching the planet's limb above and beneath the planet according to the observer (on the Earth or from GAIA) might occur frequently, as well as the case for which a close encounter as viewed from the Earth corresponds to an occultation from GAIA or reciprocally.

2.2 Close encounters statistics

We have studied the number of close encounters for the time interval [2005-2010] as seen from the Earth with succesive intervals of 50" for d_{min} where d_{min} is the smallest angular distance during the close approach between Jupiter geocenter and the quasar. The number of quasars with respect each interval is quite stable, oscillating between 13 events (between 0" and 50") and 25 events (between 300" and 350").

We made a selection of the most interesting close encounters events between Jupiter and our set of quasars with the particular aim of showing a large deflection of light due to relativistic effect as modeled in the next

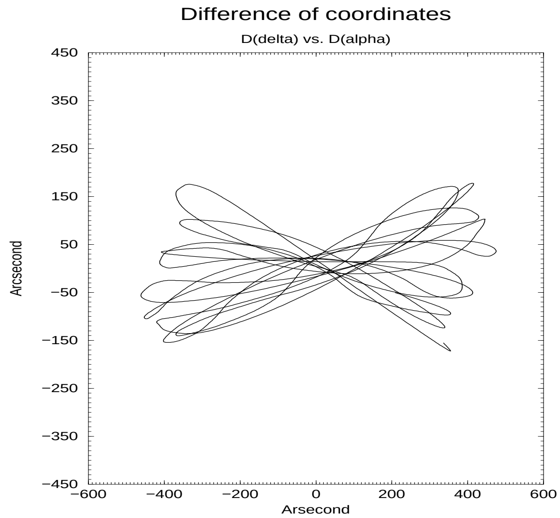

Fig. 1. Difference $\Delta\delta$ vs. $\Delta\alpha$ of Jupiter declination and right ascension as seen from the Earth and from GAIA

section. We found 23 encounters for which the angular distance between Jupiter's limb and the quasars goes below 5', (i.e. 300"), occurring in a rather small time interval between 2010.0 and 2012.5.

2.3 Relativistic deflection of light

At the mas and also sub-mas level, it is essential to take into account the relativistic deflection of light. For instance, Crosta & Mignard (2006) recently proposed the determination of the PPN parameter γ with GAIA in the frame of the GAREX project. One of the authors (Le Poncin-Lafitte et al., 2005) showed how to determine explicitly the deflection of light due to the coefficient J_n of Jupiter's potential, by the use of orthogonal polynomials, i.e. Legendre and Gegenbauer functions . But here, as in Crosta & Mignard (2006), we consider only the influence of the Jupiter mass on light propagation by applying the formula above to a quasar located at spatial infinity. By setting $\vec{n}_{obs}$ and $\vec{n}_{quasar}$ as the unit vectors along the directions Jupiter-observer and quasar-observer (without relativistic deflection) respectively, we can express the equation (**??**) in the following and rather simple manner:

$$\lambda = (\gamma + 1)\frac{GM_{Jupiter}}{c^2 r_c}\frac{n_{obs} - n_{quasar}}{\tan(\alpha/2)} \tag{2.1}$$

where α and r_c are defined by

$$\cos\alpha = \vec{n}_{quasar} \,.\, \vec{n}_{obs} \tag{2.2}$$

and

$$r_c = 2r_{obs}\cos\left(\frac{\alpha}{2}\right)\sin\left(\frac{\alpha}{2}\right) \ , \tag{2.3}$$

r_{obs} being the euclidean distance between Jupiter and the observer. We have simulated real close approaches cases using this last equation for the amplitude of the deflection of light.

2.4 Close encounter mapping

We have carried out the close encounters mappings including the relativistic light deflection curves As an example we chose the event shown at Fig. 2 at JJ2011.117, where the quasar is undergoing an occultation both from the Earth and from the astrometric satellite. Notice that the angular diameter of Jupiter (34".2) is rather small for this event because Jupiter's synodic configuration is far from the opposition. Fig.3 represents the deflection of light due to Jupiter's mass, which reaches about 0".016 at the grazing instant. Therefore such a deflection should be detected easily by the GAIA satellite.

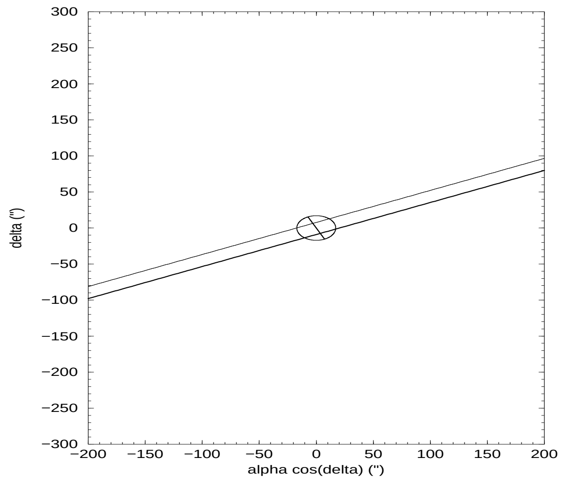

Fig. 2. Close approach between the quasar with coordinates $\alpha = 0^h 16^{mn} 30.7^{sec}$ and $\delta = 0°32'36"$, and Jupiter.

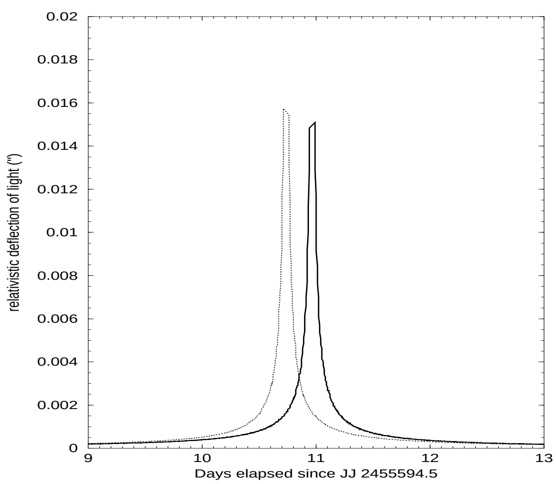

Fig. 3. Relativistic deflection of light of the quasar with coordinates $\alpha = 0^h 16^{mn} 30.7^{sec}$ and $\delta = 0°32'36"$, during the close approach with Jupiter

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