A Giant Step: from Milli- to Micro-arcsecond Astrometry
Proceedings IAU Symposium No. 248, 2007
W. J. Jin, I. Platais & M. A. C. Perryman, eds.

doi:10.1017/S1743921308019649

The restoration of the quadrupole light bending

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Abstract. The ESA astrometric mission Gaia will be able to put to test General Relativity thanks to differential astrometric measurements. The differential experiment, GAREX, implemented in the form of repeated Eddington-like measurement, aims at measuring the quadrupole light bending due to an oblate planet by comparing the evolution of relative distances in stellar fields in the vicinity of it. Simulations which utilize (i) selected fields extracted from the GSCII data base, (ii) a realistic error model as function of the star's magnitude and distance from Jupiter's edge, show the real best scenarios and how to improve the Gaia ability to detect this relativistic effect.

Keywords. astrometry, relativity, solar system: general, catalogs

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1. The GAia Relativistic EXperiment

The light deflection produced by an oblate planet on grazing photons (hereafter named the *q-effect*) was simulated for a Gaia-like mission for the first time in Crosta and Mignard (2006). This investigation was the first step of a wider project called GAia Relativistic EXperiment (GAREX), which aims at testing General Relativity (GR) with highly accurate astrometric differential measurements. The present study is more complicated than the case discussed in paper above (GAREX-I), based on a very crude Galaxy model, and taken as an "ideal experiment ". This tells us to what extent the q-effect is measurable once we deal with a more realistic observational scenario. The q-effect has been parameterized by introducing a new parameter ϵ, equal to one if GR predictions are true. This secondary deflection has a very specific pattern as a function of (i) the position of the star with respect to the oblate deflector and (ii) the orientation of its spin axis. After a set of Monte-Carlo runs, the results of GAREX-I showed that the q-effect is detectable within a 3-σ confidence level, but a single experiment on specific bright stars around Jupiter can do almost as well as a 5-year mission. Therefore, we designed a new GAREX experiment, GAREX-II, focused on single epochs of observations generated by using the GSCII data base, all along the mission life time and including realistic satellite observations of Jupiter. From the generated epochs we have selected the favorable ones, taking into account the astrometric accuracies deduced from the current error budget. The F-band magnitudes were chosen (Johnson R), since they are close to the Gaia's G-band magnitudes. Among the 8552 stellar fields investigated, we rejected those where the axis of Jupiter aligns approximately with the line of sight and we kept those with σ_ϵ below 0.5 in order to investigate more cases close to the reference value of GAREX-I.

GAREX-II has two major improvements. (i) The new sets of simulation utilize *real* star counts (ten thousand contiguous fields, 3-4 observations per day) from 2011 to 2020 using Jupiter ephemeris as observed from the Lissajous orbit of Gaia, in areas of about 0.5×0.5 square deg (approximately the size of the field of view of Gaia) and centered around the epoch equatorial coordinates of Jupiter. This choice assures a sufficiently fine sampling for searching the best candidate scenarios and, consequently, to place requirements on the initial phase of the scanning law in order to observe the selected fields as close as possible to the optimal epoch.

(ii) The model of astrometric errors as a function of magnitude is obtained from a simulation, taking into account the most relevant noise sources. However, the most important effect for bright magnitudes is CCD saturation. At magnitude 12 (13 in the selected Gaia configuration) the PSF starts to become saturated. For this reason part of the signal is lost, and the astrometric error increases with respect to the un-saturated case. Monte-Carlo simulations show that using an appropriate centroiding algorithm it is still possible to achieve good performances on partially saturated images. In this case the astrometric error can be described, as function of magnitude, by the following approximated formula $\sigma = 10^{g(F)}$. The function $g(F)$ will be published in a forthcoming paper (Crosta *et al.*). For a complete transit we have 9 independent measurements and the final error is divided by 3 times the square root of the mean number of observations per star. The background noise appears to be properly accounted by the expression *log f (F,r)*, where f is a complex function of the F magnitude and the angular distance from Jupiter's limb (r). The exact values provided by *log f* depend on several assumptions on the actual Gaia (stray-light, astrometric algorithm, and measurement process).

2. Results and open questions

GAREX-II proves the importance of having a real sky, as realized by the GSCII, to define the best epochs for the experiment. In fact, it appears that the best way to detect the quadrupole light bending effect is to choose optimal configuration during the mission operational life, confirming the statistical results already obtained in Crosta and Mignard: it is sufficient to select background fields which include a few bright stars close to Jupiter to produce the best results. If we include the background noise in the error model, the experiment is still possible, but not closer than about one Jupiter's radius.

Compared to the case without background, several good fields will be lost. For example, in 2011 the number of good cases decreases to four from an initial list of eleven. The experiment can be performed very early in the mission's lifetime and then repeated in 2012, 2013, and 2014. It means that *detecting the quadrupole light deflection of Jupiter as predicted by GR could be the first remarkable scientific result well before the end of the mission!*

Future work will take into account a further improved description of the observing scenario by including the details of the instrumental/technical effects (e.g., how to compare the two observations with/without Jupiter), and those associated with the stellar fields because of proper motions. The final task will be to apply the complete relativistic model, which includes all relevant relativistic effects at the level of Gaia's accuracy.

Last, but not least, the results of the experiment will contribute to checking the performance of the mission during its operational life time. The observation simulator assumes that the instrument is performing according to specifications. Degradation will be a big factor, therefore the good fields should be taken early into the mission.

References

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