Ground Based Optical Tracking of Gaia

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1. Introduction: What is GBOT and why is it needed?

Gaia's unprecedented ambitions regarding astrometric accuracy and precision require a level of knowledge of the position and velocity vector of the satellite itself not required in other satellite mission. Thus the usual methods of determining these quantities do not suffice and new approaches must be invoked. One of these is the Ground Based Optical Tracking (GBOT) campaign. There are two main reasons for these high precision needs:

1. Global astrometry is severely affected by aberration, caused by the finite nature of the speed of light. This is a large effect, which means that in order to correct for aberration in the precision regime of Gaia (i.e. a few microarcseconds), the motion of the detector and hence the satellite must be known to very great precision. The resulting tolerance in Gaia's velocity vector is 2.5 mm/s.

2. Apart from stars, Gaia will also measure faint Solar System objects. These are several orders of magnitude closer than even the closest stars, their distances being comparable to Earth's distance to the Sun. Errors in the baseline therefore have a far larger effect on the precision of the parallax of an asteroid than they have on stars, meaning that if Gaia is to measure sufficiently precise parallaxes to these objects, the 3D position of Gaia itself needs to be known to about 150 m.

Unfortunately the ranging of one radar-tracking station can only deliver 2000 m in position and 10 mm/s (75 m, 1 mm/s in radial direction). This means that additional measures need to be taken to ensure Gaia's aims. There are several approaches to accomplish this, one of them being GBOT.

GBOT will consist of a network of a small number of telescopes distributed worldwide, and is committed to deliver positions of Gaia on a daily basis. This network will consist of about half a dozen facilities. Although the aforementioned requirements translate to 20 mas/d and 30 mas on the sky, GBOT has committed itself to a precision of 10 mas/d in order to not exploit the complete error budget. Since all current reference catalogues are not precise enough to reach such a level of precision, GBOT's astrometry will initially have significantly higher errors, about 50 mas. Only after the first release of Gaia astrometry (which will be approximately 2 years after launch) we will be able to reach our aims, meaning that the analysis of all data obtained before will have to be repeated using Gaia as reference catalog in order to meet the requirements.

2. GBOT Requirements and Challenges

One of the first steps in the preparation of GBOT was the establishment of a set of minimum requirements on instrumentation. Given the probable faintness of Gaia and also the fact that most comparison stars will be at the faint end of the Gaia catalogue, participating telescopes should not be smaller than about 1 m. A well matched pixel scale is mandated, to allow a good sampling of the PSF. Given that mean ambient conditions in different sites can be quite different from each other, we decided on a minimum pixel scale of 0.3 x median seeing conditions. We also need to set a lower limit of 5' x 5' on the field of view, since we need a certain number of background stars in order to perform the astrometric reduction.

Apart from these hard constraints concerning the telescope/instrument, we also need to know the geographic coordinates of a telescope and whether a facility can observe and deliver on a daily basis. In the end, we intend to work with 3-6 observatories on both hemispheres. Ideal would be robotic telescopes, since they only need to be programmed with the target coordinates and they will conduct the observations autonomously. Telescopes with dedicated observing programs are a second possibility, as are telescopes operated in queue mode and remote controlled appliances. All of these usually ensure regular observations and a dependable stream of data.

As a compromise between depth and minimizing the differential colour refraction (DCR), we chose Cousins-*R* or similar passbands for our observations. While *I*-band-like filters are much less affected by DCR, this advantage is more than offset by the much higher background level resulting in significantly lower S/N and depth. The nature of Gaia as a moving object sets limitations on the exposure times. Typically it moves about 1 degrees per day, translating to 40 mas/s. This sets an upper limit on the exposure time of 30 – 120 seconds somewhat depending on seeing, pixel scale and centroiding method. Therefore usually more than one image should be taken, we aim at sequences of about 10 exposures. These will be summed up, so that the S/N of the background stars – most of them presumably fainter than the Gaia satellite itself (the limit of Gaia astrometry, thus the faint limit of our reference stars is 20 mag) is optimized. Our group has been investigating various methods of centroiding and also guiding during the observations. This is described in more detail in the contribution by Andrei et al. elsewhere in these proceedings.

Another, still mostly open question is the brightness of Gaia which we will only know for certain once Gaia is in L2. However we have to make assumptions, especially to choose the right aperture range for our partner telescopes. Gaia is in principle shaped like a hat, with the "brim" pointing towards us but inclined by 45°. This means that the bulk of sun light will be reflected 90° away from Earth, i.e. the observers. We thus have to rely on diffuse reflection, caused by imperfections, wrinkles in the Kapton material of which most of the surface of Gaia is made, or reflection of structures, solar panels, etc. How large this amount of light is, remains unknown. However we were able to get some part of the answer by observing other space craft in the L2 region, especially WMAP, which was an object with a rather similar layout as Gaia, just with an inclination angle of 22.5° and half the diameter, and the current Planck mission – however its shape is completely different. Both spacecraft turn out to be faint, but bright enough to make GBOT feasible with the modest telescopes we plan to use. WMAP was of about 18-19 mag in *R*-magnitude, Planck is somewhat brighter, i.e. about 17-18.5 mag. Both satellites show a considerable amount of brightness variation. Given the size of these two satellites compared with the overall larger size of Gaia we assume that Gaia will be at about *R*=17 – 18 mag. Keeping our estimate on the conservative side, we consider Gaia for our preparations to be at *R*=18 mag, keeping in mind all the uncertainties, which could lead to quite substantial deviations from this value in both directions, not to mention intrinsic variability.

Collecting data from a network of different telescopes means having to cope with non-uniform data. FITS header keywords will be different, some data will come detrended others not. In order to accommodate for this, we are developing a data reduction pipeline and a database system. This is also necessary to keep the time demand of daily routine a low as possible – after all these operations need to be done on about every day for five or more years! Furthermore, all reductions will need to be repeated, after the first data release of Gaia (see the introduction of this paper). The pipeline is at this point already working, and reductions within our test observing program have been carried out, resulting in precisions of better than 50 mas even with the current reference catalogs, see. Fig. 1

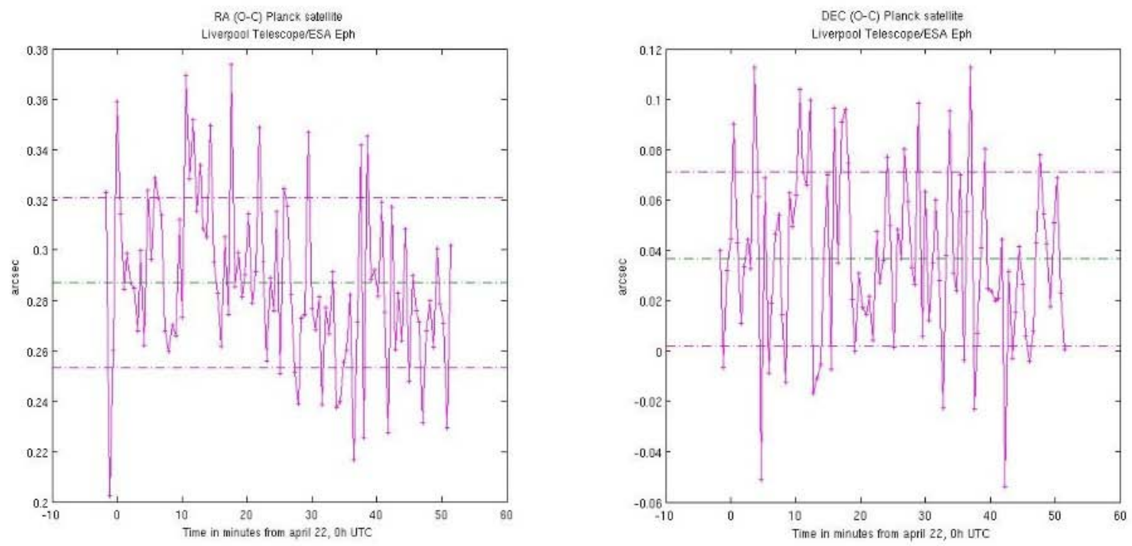

Fig. 1 – Set of observations of the Planck satellite obtained with the 2 m Liverpool telescope with RATCAM reduced with the GBOT pipeline. Shown are the O-C (i.e observation vs. Ephemeris) residuals versus time. The R.M.S. Error in both coordinates is about 35 mas. UCAC2 (Zacharias et al. 2002) was used as reference catalog.

In order to establish the best possible observational methods, intensive tests had to be carried out. For this we used data taken mainly at the 1.06 m Pic du Midi telescope, the 1.23 m at Observatoire de Haute-Provence, and the 2.2 m telescope at ESO's La Silla observatory with its WFI mosaic detector (since mosaiced detectors present additional complications and residual effects on the field mapping, we restrict ourselves to one chip of a mosaic). The main work horse however became the 2 m Liverpool telescope located on Roque de los Muchachos (La Palma), since it fits to our nominal requirements in an almost ideal way.

Once we enter the operational phase, we will make weekly deliveries to ESOC, which will mainly be used for the derivation of geocentric ephemerides which are then in return relayed to GBOT. We will then convert them to topocentric ephemerides for each observing site and supply our partners with these. Data will be delivered to GBOT on a daily basis, fed into the database system and analyzed. A schematic view of the structure of GBOT is shown on fig. 2.

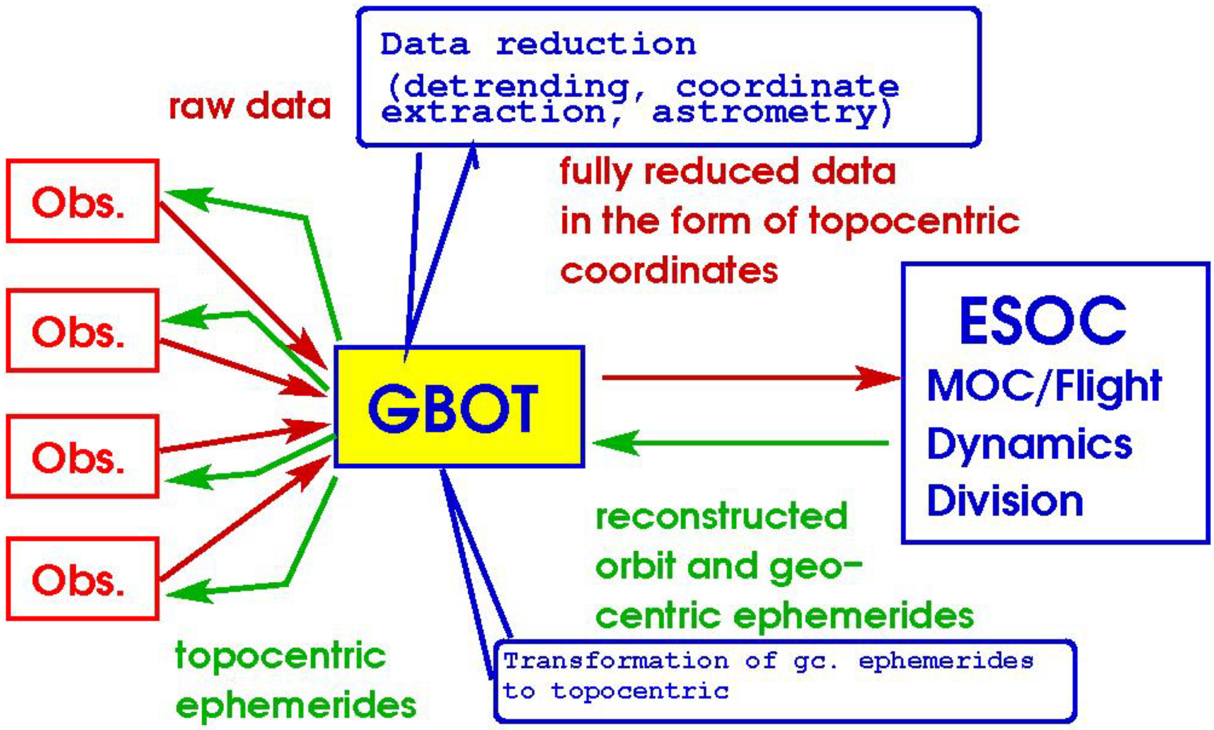

Fig. 2 – Schematic view of the GBOT in relation to its outside connections, i.e. the data recipient, ESOC MOC/Flight dynamics Division, and our data suppliers, namely GBOT's partner observatories.

3. Contact informations for institutions willing to help GBOT

Readers who have access or own a telescope which fulfills our constraints (see Sect. 2), can contact the GBOT group under the following email address: gbot@ari.uni-heidelberg.de or maltmann@ari.uni-heidelberg.de giving us information about your facility. We will then contact you back in order to arrange for a test campaign to evaluate your facility for our purposes.

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References

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