SYRTE and PARSEC Contribution for the GBOT/GAIA Moving Target Astrometry

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Introduction

GAIA will measure to unprecedent precision positions, movements, and parallaxes, by the superposition of two fields apart by 174deg, taken from the L2 Earth-Sun, about 1.5 million km from the ground. To achieve the aimed precision for stars, and particularly for solar system bodies, the instantaneous position and speed of the satellite must be known respectively to 150m and 2.5 mm/s. This translates to the GBOT (Ground Base Optical Tracking) requirement to deliver quasi-daily positions of the satellite at the accuracy of 10mas relatively to the GAIA´s reference frame itself (Altmann et al., 2010, this proceeding). The challenge increases because the satellite will probably be dimmer than R 17th magnitude and will be moving on average at 30mas/s, and switching hemispheres between summer and winter. We will present the strategies worked out for the satellite centroid´s determination, including tracking mode, binning, super-gaussian fit, blind co-addition of images; as well as the astrometric reduction open code designed to cope with this variety of conditions. We will show applications of these resources to observations of the satellites WMAP and PLANCK, and to fast asteroids. All these topics, on the other hand, make for an exchange of experiences and ensuing of scientific programs with other groups targeting fast, dim objects prior and during the GAIA mission.

1. Goals and feasibility

The main issues of the campaigns aiming to emulate the observation conditions of the GAIA satellite are speed, magnitude, and their variations. For the observational band there were two main a priori choices, between V-band or clear against the near infrared. In the first case maximum light is gathered, but atmospheric extinction and chromatic refraction are also large. On the near infrared atmospheric extinction is less important but the satellite and the reference stars are dimmer, demanding longer exposures. A compromise on the R-band, which is readily available from all envisaged observatories, favors also the closeness to GAIA's band. In particular the early studies made with WMAP have shown the important magnitude modulation brought by the satellite´s spin.

Here, we focus on the other important issue, which concerns the astrometric pipeline, given the precision required and movement of the target. All this considered, observations are being taken of satellites within the Lagrange zone L2 (WMAP and PLANCK), and asteroids with large tangential motion (mostly double or suspected, in order to mimic the satellite spin).

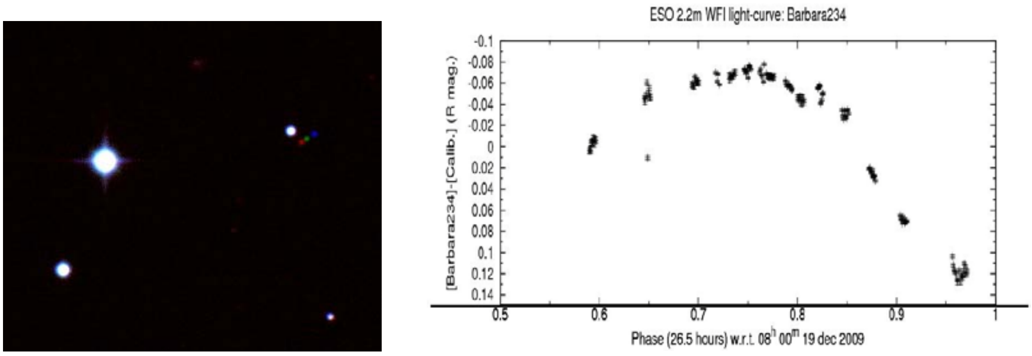

Fig. 1 – On the left the very first images of the test campaigns, taken of the WMAP satellite on April 5th, 2008. On the right light curve of double asteroid Barbara234, taken on December 19th, 2009, and which is part of a larger campaign for this object. Both observations were made at the ESO2.2m/WFI telescope, in Chile.

2. Astrometric handling

The astrometric pipeline is preceded by a database, which rectifies headers´ inconsistencies and makes the images available for reduction. Specific routines are being developed for the GAIA´s case. The first step is the recognizing of objects, using variable thresholds and local boundaries of search and adjustment. The routine can deal with crowded fields as well as with fields affected by Moon´s illumination gradient. In particular, it is able to recognize GAIA either as an elongated or particularly dim object. The derivation with the equatorial coordinates can use pre-existing catalogs of earlier version of the GAIA catalog itself.

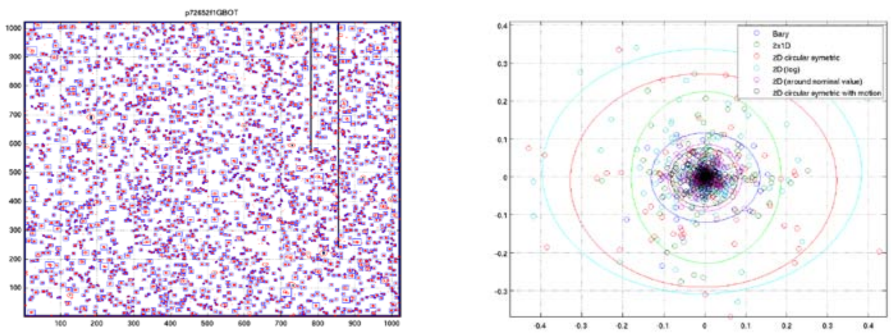

Fig. 2 – On the left an example of object recognition in a dense field and wildly different magnitudes. On the right the improving on the centroid determination of a moving object from a barycentric fit (outer circle) to a fitting through a bi-dimensional Gaussian plus a displacement term (inner circle).

3. Blind co-addition

The Moving Gaussian approach (Fig. 3) describes to mathematical exactness the displacement of the GAIA satellite or, for instance, of an asteroid. To tackle the problem of the intrinsic faintness of the object, another approach is proposed, which we term as Blind Co-addition. It borrows from the standard co-addition procedures used to pile up images, enhancing the signal to noise ratio of faint objects without worsening the centroid´s determination.

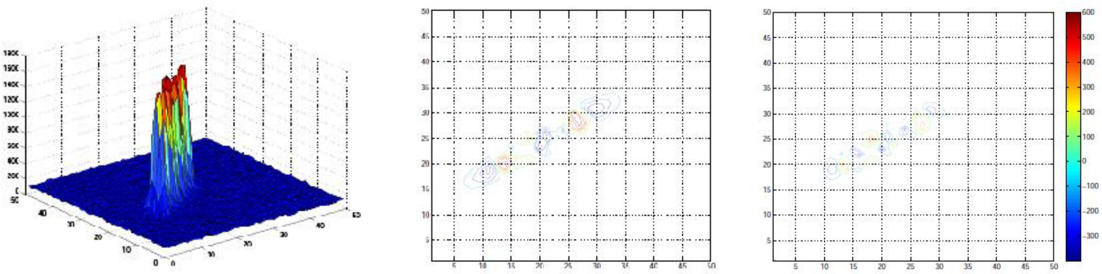

Fig. 3 – For the simulated moving object appearing on the left, the middle figure shows the residuals for a fitting by a bi-dimensional Gaussian, while the left figure shows the much smaller residuals resulting from the fitting by the Moving Gaussian procedure developed for the GAIA (and asteroids) case.

The distinctive feature of the blind co-addition when applied to enhance a moving target is that it cannot no longer rely on the reference of the bright stars positions, since the target position is varying with respect to them. Thus, the piling up of the target images relies on the constancy of its underlying distribution of incoming photons. In practice, though the PSF shape is disrupted, the barycenter of the illuminated region around the object would remain the same. The blind co-addition procedure entails taking short images, so that a large number of references stars are still well sampled and for which the centroid can be determined to derive the required astrometric precision, orientation and scale. At the same time the moving target remains effectively circular.

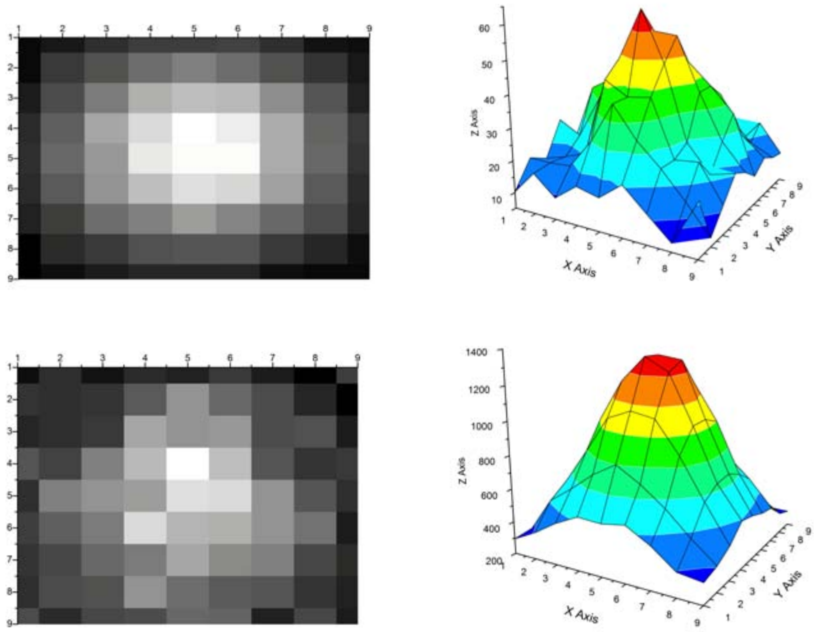

Fig. 4 – Principle of the Blind Co-addition. From an actual observation of WMAP, with 12sec exposition, at the ESO 2.2m/WFI, on the top panel it is seen the local region (left) and reconstructed photon distribution (right). On the lower panel are the corresponding compound region and photon distribution of the co-addition of 20 frames.

The first step of the blind co-addition procedure is to take several frames, preferably in a fast sequence, up to theoretically being able to reach the signal to noise ratio goal. Next a region around the moving object is cropped centered on the ephemeris position. For each frame the orientation and pixel scale are obtained by the astrometry of the well imaged stars. The ensemble of orientation and pixel scales values (in practice much alike) are used to normalize all of the target´s regions coming from the several frames. If the target motion is not linear, the regions orientation is also compensated for. Then in each region the barycenter of the illuminated portion is calculated. All regions are now co-added by the barycenter, at the nominal precision aimed at, and a bi-dimensional Gaussian is adjusted to the resulting distribution. The centroid is de-convoluted towards the orientation and scale of each frame, so that the original region is replaced by the compound one, but particular to the original frame instead of common to all of them. In this way one independent measurement is extracted for each frame. The independent measurements can finally be averaged, either using the ephemeris speed if it can be taken as correct for the total time range, or leaving a correction to the ephemeris speed as unknown.

4. Results and Conclusion

A series of observations of PLANCK was conducted at the 2m. Liverpool Robotic Telescope, at La Palma, from 10th to 18th August 2010. The integration time was 20sec and a sequence of 10 measurements was made daily. On these conditions, namely, brighter probe, longer integration time, and limited number of daily observations, the blind co-addition still improved the correction to the ephemeris. Relatively to a local frame of 2MASS stars, on the best observation night the error on R.A. went to 46mas and the DEC. error went to 58mas, respectively a reduction of 8mas and 2mas in comparison with the average of individual reductions. On the worst night, however, the same comparison shows an improvement on R.A. by 35mas but a worsening on DEC. by 24mas.

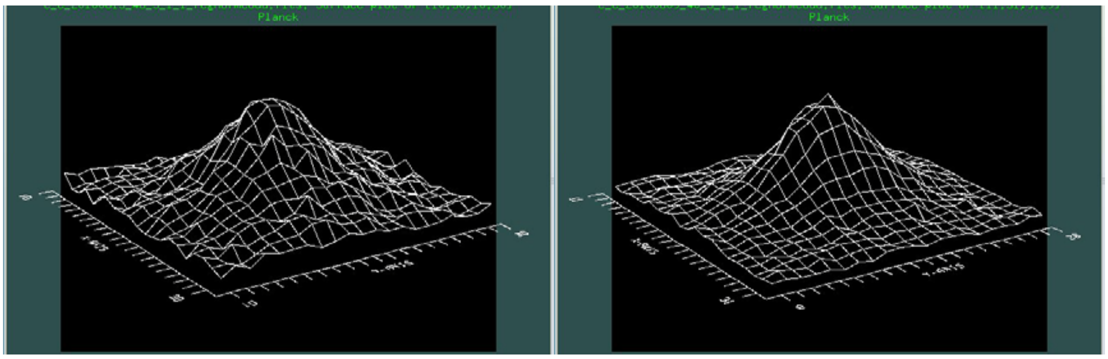

Fig. 5 – Compound images of PLANCK taken at the 2m LT at La Palma, for series of 10 exposures of 20sec. On the left the night of best seeing is depicted, and on the right that one of worst seeing. Though nominally the error on the centroid is nearly the same (1mas), on the worst night there was no net improvement upon the results from the average of standard astrometric reductions.

Both the Moving Gaussian and the Blind Co-addition offer a substantial improvement for the determination of the centroid of the GAIA satellite during its mission. Their utilization in the astrometric pipeline used by the GBOT/GAIA will hence depend of the actual satellite brightness, and variation, during the mission, as well of observational conditions, like seeing, number and length of exposures. The series of tests using PLANCK and selected asteroids will continue to improve the present procedures.