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THE GAIA-GBOT EXPERIMENT

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RESUMEN

Con el objetivo de asegurar la máxima capacidad de medida de Gaia, se ha implementado -desde el comienzo de la misión- un programa diario de observaciones del satélite utilizando telescopios en tierra, denominado "Ground Based Optical Tracking (GBOT)". El requisito de tener una calidad astrométrica de 20 mas o mejor en el posicionamiento de Gaia, y el hecho de que el satélite es débil (magnitud 21 en banda roja) y se mueve relativamente rápido (0.04 $''$/s), nos ha llevado a analizar de manera muy rigurosa la precisión astrométrica que es factible obtener a partir de observaciones CCD para objetos móviles débiles.

ABSTRACT

To ensure the full capabilities of Gaia's measurements, a programme of daily observations with Earth-based telescopes of the satellite itself - called *Ground Based Optical Tracking (GBOT)* - was implemented since the beginning of the Gaia mission. The constraint of 20 mas on the tracking astrometric quality and the fact that Gaia is a faint and relatively fast moving target (its magnitude in a red passband is around 21 mag and its apparent speed around 0.04$''$/s), lead us to rigorously analyse the astrometric precision obtainable for CCD observations of faint moving objects.

Key Words: astrometry — methods: data analysis — methods: observational — methods: statistical — minor planets, asteroids: general — techniques: image processing

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1. INTRODUCTION

ESA's Gaia astrometric satellite mission provides high quality absolute astrometry for more than 1 billion celestial objects, i.e., positions, proper motions and parallaxes for every object brighter than 20.7th magnitude. This data will revolutionize our understanding of the Milky Way, and therefore of galaxies in general. Additionally it will make significant contributions to several other fields of astrophysics, from the foundations of basic physics, small solar system objects, exoplanets to cosmology.

To achieve its aim in terms of astrometric precision, standard procedures for satellite tracking (i.e. the radiometric methods) are not sufficient either for correcting the aberration effects for the stars with the best measurements or for precisely measuring the parallaxes of solar system objects. To add a stronger observational constraint for the positioning of Gaia in the tangential plane, Delta-DOR measurements have been added by ESA. However this technique, requiring two antennae operating simultaneously, is expensive and frequently unmanageable due to the limited number of antennae in charge of tracking all space missions.

For that reason, a supplementary tracking method based on ground based CCD images of the Gaia satellite itself was devised, and has been in operation since the start of the Gaia mission.

2. THE GAIA-GBOT EXPERIMENT

The aim of the Gaia-GBOT project is to observe the Gaia satellite every day during the full mission with CCD cameras of 2m-class telescopes to provide daily topocentric astrometric positions of the satellite in the ICRF with an error smaller than 20 mas. The GBOT observations are carried out mainly with the VLT Survey Telescope (ESO's VST) on Cerro Paranal in Chile and the Liverpool Telescope (LT) on the Canary Island of La Palma. Schematically, the Gaia-GBOT operating procedure consists of the following steps: 1) The Flight Dynamical Centre of ESA provides us with weekly deliveries of updated geocentric ephemerides of Gaia. 2) The GBOT group uses these to compute topocentric ephemerides and provide field of view maps of Gaia for each telescope location. 3) The telescope teams use them daily to track the Gaia satellite and to take a set of 10 to 20 images. 4) Then, every day, the GBOT group retrieves the latest observations,

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reduces them, and puts all the data and results in a dedicated database for easy access and future re-reduction. 5) Finally, every month, the GBOT group sends all of the measured positions of Gaia to the Flight Dynamical Centre for a future improvement of the Gaia ephemeris. GBOT activities and operating details are given in Altmann et al. (2014).

3. REDUCTION AND ESTIMATOR FOR THE ASTROMETRIC PRECISION OF MOVING OBJECTS

Concerning the reduction part of the GBOT images, Fortran software called the *GBOT astrometric reduction pipeline* has been developed to perform accurate astrometry of moving objects such as satellites, space debris, meteors, NEOs or other asteroids observed with CCD sensors. In particular, this tool is specifically adapted to deal with trailed PSFs on the CCD plane and to provide accurate estimators for the astrometric precision of these objects. More details concerning GBOT reduction software can be found in the paper by Bouquillon et al. (2014).

It should be noted that the calibration of the GBOT images requires a reference star catalogue with an accuracy equal to or better than that required for positioning the Gaia satellite itself. Currently, this accuracy is only available with the *first data release of Gaia catalogue* (*Gaia-DR1*) (see for instance Figure 3 in the contribution of M. Altmann to these conference proceedings which shows a comparison of two reductions of 21 GBOT data sets performed with PPMXL and Gaia-DR1 respectively).

A significant effort has also been made to characterize the ultimate limit for the astrometric precision of moving objects observed with CCD sensors. In particular, the Cramér-Rao lower bound (*CRLB* here after) has been used to estimate the precision limit for the PSF center when drifting in the CCD-frame. This work extends earlier studies dealing with one-dimensional detectors and stationary sources (Mendez et al. 2013 & 2014) to the case of standard two-dimensional CCD sensors, and then, to moving sources. In Figure 1 the CRLB has been plotted as a function of the pixel size of the CCD sensor for a stationary source and a drifting source for three different values of the image FWHM. The CRLB expressions for moving sources along with the results of this study have been accepted for publication (Bouquillon et al. 2017).

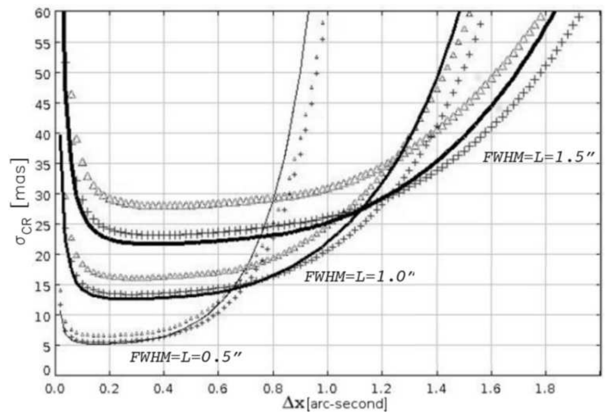

Fig. 1. The square root of CRLB in mas as a function of the instrumental pixel size Δx for sources observed with a CCD sensor. We assume a background flux per pixel of 4000 e^{-}/FWHM$^{2} \times \Delta x^{2}$ and a source total flux of 6000 e^{-}. The solid lines (thin, normal and bold) are computed for a stationary circularly symmetric Gaussian PSF with FWHM of 0.5, 1.0, and 1.5″ respectively. The + and triangle symbols correspond to the CRLB along the direction normal and parallel respectively to the drifting motion, where the drift parameter L is equal to 0.95×FWHM and L is the product of the exposure time and the speed of the source in the CCD frame.

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