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Improvement of positional accuracy of Solar system bodies ground-based observations with CCD-imaging of close approaches of them with Gaia stars

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Abstract. Current release of the Gaia mission provides representation of a new reference frame on an unprecedent level of accuracy. This astrometric catalogue is practically free of systematic errors with respect to astrometric ground-based observations. First applications Gaia DR1 and Gaia DR2 as a reference in an analysis of CCD-observations of asteroids and planetary satellites demonstrated small decrease of formal positional errors. The basic reasons are unaccounted systematic effects of telescope projection and offsets caused by atmospheric dispersion. As a result, positional error of the Solar system bodies‘ observations performed with the “Saturn” 1-m telescope at Pulkovo Observatory ($F/D = 4$) is in the range of 20 – 80 mas. A frame-to-frame astrometric transformation gives the error level less than 5 – 30 mas. One of possible ways to transfer subpixel accuracy to the final positions of the Solar system bodies are observations of close approaches of satellites or asteroids to the Gaia stars. The main idea is that systematic displacements caused by atmospheric effects and telescope optics that occur in close approaches (< 10 arcsec) are the same for asteroids and the Gaia stars. This makes it possible to significantly improve the quality of ground-based astrometry of the Solar system bodies, taking into account the fairly dense distribution of Gaia stars across the celestial sphere.

Key words: Solar system bodies – close approaches – astrometry

1. Introduction

Tidal evolution of planetary satellites‘ orbits and motion of asteroids in unstable resonances require the accuracy of astrometry of a 10 mas level. Traditional ground-based observations and processing technique mainly give us 50 - 100 mas. Improvement of the accuracy may be done with observations of the well known sort of events - close approaches of Solar system bodies to Gaia stars (Kopal, 1959). Gaia astrometry has provided us with dense and high precision realization of the reference frame to solve the mentioned task.

2. Observational program and technique of data analysis

Our objects of interest are planetary satellites and selected asteroids.

Planetary satellites:Jupiter: Europe, Ganymede, Callisto, Himalia, Elara, Pasiphae, Carme; Saturn: Mimas, Saturn-Enceladus, Tethys, Dione, Rhea, Titan, Hyperion, Iapetus, Phoebe, Janus, Epimetheus, Helene, Telesto, Calypso, Atlas, Prometheus, Pandora, Pan; Uranus: Ariel, Umbriel, Titania, Oberon; Neptune: Triton, Nereid.

Selected asteroids: Venus: 33342 1998 WT24, 322756 2001 CK32, 417217 2005 YS; Earth: 164207 2004 GU9, 419624 2010 SO16, 459872 2014 EK24, 439898 2000 TG2, 439908 2000 XH47, 449097 2012 UT68; Mars: 5261 Eureka, 121514 1999 UJ7, 311999 2007 NS2, 385250 2001 DH47, 391595 2007 UR2, 16834 1997 WU22, 83982 Crantor, 101429 1998 VF31, 154020 2002 CA10, 261938 2006 OB5, 359170 2009 CN5, 387505 1998 KN3, 439898 2000 TG2, 439908 2000 XH47, 449097 2012 UT68; Neptune: 309239 2007 RW10, 385571 Otrera, 385695 2005 TO74, 310071 2010 KR59, 316179 2010 EN65.

A simulated sum of exposures taken according to a scheme of such appulse observations of a typical asteroid is seen in the left panel of figure 1.

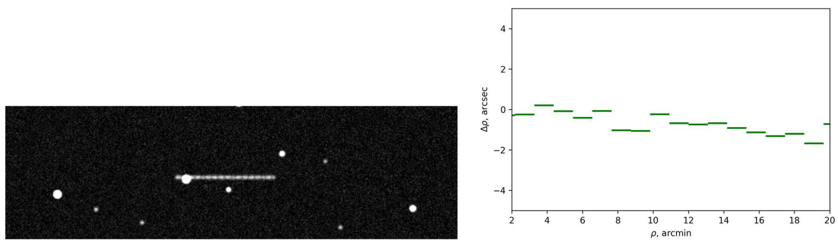

Figure 1. Left panel: Simulation of images taken during a close approach. Right panel: An analysis of several images taken with the Saturn 1-meter telescope (Pulkovo Observatory).

A shapelet decomposition was used for the celestial object image fitting. The efficiency of shapelet decomposition technique is demonstrated in many applications (i.e. Khovrichev et al., 2018).

A standard astrometric reduction of these images with Gaia DR2 as an astrometric calibrator has been done. As a result, residuals for angular distances between stars of each pair in the image were calculated. The right panel of figure 1 shows how the residuals depend on the value of angular distance. As we see, they systematically change with angular distance. This demonstrates advantage of astrometry of close approaches of asteroids to Gaia stars against traditional procedures of determination asteroids coordinates (Morgado et al., 2016).

The procedure of processing of the image taken for the case of close approaches of asteroids to Gaia stars is similar to the method of astrometry of binary stars (Buchheim, 2008).

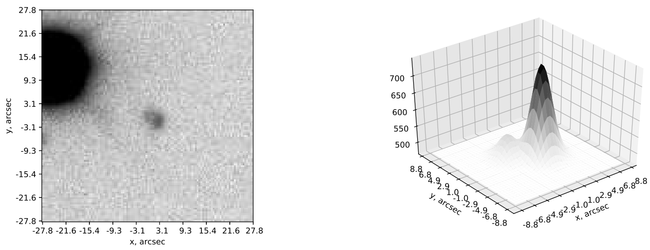

Figure 2. A close approach of U4 Oberon to Gaia2574476038004764800 at 2018-09-23T22:23:32.100 taken with the Saturn1m telescope of Pulkovo Observatory

An part of the CCD-frame taken during the close approach of U4 Oberon to the Gaia star($G = 14.964$) is shown in the left panel of figure 2. The right panel of this figure provides the results of the shapelet decomposition. The ρ value is 3.090 arcsec at the central moment. As a result, the positional accuracy of 10 mas was achieved.

3. Conclusions

The results of simulations and testing observations of appulses performed with the Pulkovo Observatory 'Saturn' 1m telescope demonstrates the high potential of the method considered. Presented technique (observations of appulses and shapelet decompositions) allows us to improve the positional accuracy of ground-based observations of Solar system bodies with small telescopes up to 5-10 mas. Appulse-based orbits of the objects of interest will be calculated as soon as necessary quantity of observations have been performed.

References

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