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Astrometry of three near Earth asteroids with the Lijiang 2.4 m telescope *

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Abstract Under the framework of observational campaigns organized by the GAIA Follow Up Network for Solar System Objects, three near Earth asteroids, 367943 Duende, 99942 Apophis and 2013 TV135, were observed with the Lijiang 2.4 m telescope administered by Yunnan Observatories. The software package PRISM was used to calibrate the CCD fields and measure the positions of 99942 Apophis and 2013 TV135, and our own software was used for 367943 Duende. A comparison of the results show that the ephemerides of INPOP10a and JPL are consistent for 99942 Apophis and 2013 TV135, however, they are quite inconsistent for 367943 Duende. Moreover, we have found that differences between the mean values in the ephemerides of INPOP10a and JPL are about $72''$ and $-199''$ in right ascension and declination respectively for 367943 Duende. Moreover, the ephemeris published by JPL is reliable in terms of the mean observed-minus-calculated ($O-C$) residuals in right ascension and declination of about $2.72''$ and $1.49''$ respectively.

Key words: astrometry — near Earth objects — astrometric observation — ephemerides

1 INTRODUCTION

Near Earth objects can cross the orbit of Earth and approach Earth very closely, for example, the smallest distance of approach for the near Earth asteroid 367943 Duende (hereafter called Duende), also known as 2012 DA14 (Wlodarczyk 2012), was only 27 700 km from the surface of Earth (closer than satellites in geosynchronous orbit) at 19:25 on 2013 February 15 as calculated by researchers at the Jet Propulsion Laboratory (JPL). It is essential to study and make a precise orbit model for near Earth objects to accurately predict their positions. Now the process of monitoring and predicting the trajectories of near Earth objects is becoming an international campaign.

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The Gaia probe (Lindegren et al. 2008; Jordan 2008; Prusti 2011), a satellite that scans and tracks changes in celestial objects, was launched on 2013 December 19. Long term ground-based tracking observations are necessary for confirming new moving objects or improving the orbits of some ones previously detected by Gaia. The goal of the Gaia Follow Up Network for Solar System Objects (Gaia-FUN-SSO) is to coordinate such observational campaigns (Thuillot 2011).

As part of pre-launch training programs organized by the Gaia-FUN-SSO program, three near Earth asteroids, Dudende, 99942 Apophis (hereafter called Apophis) and 2013 TV135, were observed during 2013, with the Lijiang 2.4 m telescope administered by Yunnan Observatories. This paper will describe observational information about these three near Earth asteroids and compare the results with several current ephemerides.

In this paper, Section 2 shows the detailed observational information about these three near Earth asteroids, Section 3 describes the methods used to measure the positions of near Earth asteroids and compares the results with several current ephemerides and Section 4 gives the discussion.

2 ASTROMETRIC OBSERVATIONS

Our observations were carried out with the Yunnan Faint Object Spectrograph and Camera (YFOSC) instrument and the Princeton Instruments VersArray 1300B camera (PICCD) attached to the Lijiang 2.4 m telescope of Yunnan Observatories. The sizes and effective fields of view of YFOSC and PICCD are 2148 $\times$ 2200 pixels, 10.1×10.4 square arcmin and 1340 $\times$ 1300 pixels, 4.8×4.7 square arcmin respectively. More detailed information can be found in the papers of Bai & Liu (2011) and Fan et al. (2013).

Table 1 shows the specifications of both instruments, where "F-length" means the focal length of the system and "FOV" indicates the field of view.

Table 1 Specifications of the Two Cameras Attached to the Lijiang 2.4 m Telescope of Yunnan Observatories

Camera	F-length	CCD FOV	Size of Pixel	Size of CCD	size/pixel
YFOSC	9840 mm	$10.1' \times 10.4'$	13.5 μm×13.5 μm	2148×2200	$0.283''$
PICCD	19200 mm	$4.8' \times 4.7'$	20.0 μm×20.0 μm	1340×1300	$0.215''$

On 2013 February 15, the near Earth asteroid Duende was observed with the YFOSC instrument attached to the Lijiiang 2.4 m telescope of Yunnan Observatories, and no filter was used during the observations. Each exposure was 1 s long and it took almost 12 s to transfer each frame from the camera to a computer. Before and after its closest approach to Earth, Duende moved very fast and its highest velocity reached almost one arcmin per second. Because of its quick motion, only 23 frames were acquired.

The near Earth asteroid Apophis, which has been identified as a potential hazard in the future (Bancelin et al. 2012; Souchay et al. 2014), was also observed on 2013 February 18-March 2, with the YFOSC instrument of the Lijiang 2.4 m telescope. Over six observational nights, a total of 90 frames were recorded.

The near Earth asteroid 2013 TV135, which was discovered on 2013 October 12 by the Crimean Astrophysical Observatory, was observed with the PICCD and YOFSC instruments attached to the Lijiang 2.4 m telescope over seven nights from 2013 October 31 to December 6, and 204 frames were collected.

Detailed information about these three near Earth asteroids is listed in Table 2, where "N" and "R" indicate no filter and the Johnson R filter respectively was used during the observations.

Table 2 Observational Information about the Near Earth Asteroids Duende, Apophis and 2013 TV135

NEA	Date	Exposure (s)	Filter	Camera
Duende	Feb. 15	1	N	YFOSC
Apophis	Feb. 18	120	N	YFOSC
	25	120	N	YFOSC
	26	120	N	YFOSC
	27	120	N	YFOSC
	Mar. 01	120	N	YFOSC
	02	120	N	YFOSC
2013 TV135	Oct. 31	60	N	PICCD
	Nov. 01	50	N	PICCD
	Nov. 02	50	R	PICCD
	Dec. 04	120	R	YFOSC
	Dec. 06	120	R	YFOSC
	Dec. 09	180	R	YFOSC
	Dec. 10	180	R	YFOSC

Table 3 Mean and Standard Deviation (StdDev) Values of $(O-C)$ Residuals for the Near Earth Asteroid Duende

Ephemerides	Mean $(O-C)$		StdDev $(O-C)$	
	RA (arcsec)	DEC (arcsec)	RA (arcsec)	DEC (arcsec)
INPOP10a	74.44310	–197.54389	21.61420	96.36600
JPL	2.71566	1.49123	0.59428	7.03829

3 MEASUREMENTS AND COMPARISON

3.1 Measurements

The observations of Apophis and 2013 TV35 were reduced and the positions were measured with the software PRISM, a professional astronomical software package for conducting astronomical observations and image processing. This approach was recommended by the committee advising the Gaia-FUN-SSO project so that astrometric results can be compared between different observing programs. A model with six constants and the UCAC4 catalogue (Zacharias et al. 2013) were chosen to calibrate the CCD fields.

As introduced above, the exposure of Duende was only one second in duration which resulted in the reference stars in the observed frames not being bright enough to make the measurement with the PRISM software package, so we calculated the positions of Duende with our own program, that included the process of calibrating the CCD fields and applying the centering algorithm, the correction due to annual aberration and diurnal aberration. During the measurements, a model with six constants and the UCAC4 catalogue were utilized.

3.2 Comparison

The observed positions of the near Earth asteroids Duende, Apophis and 2013 TV135 were compared to both the ephemeris of INPOP10a (Fienga et al. 2011) calculated by the Institut de mécanique céleste et de calcul des éphémérides (IMCCE), and the JPL ephemeris. The results show that the mean values of $O-C$ residuals in right ascension (RA) and declination (DEC) for Duende are almost

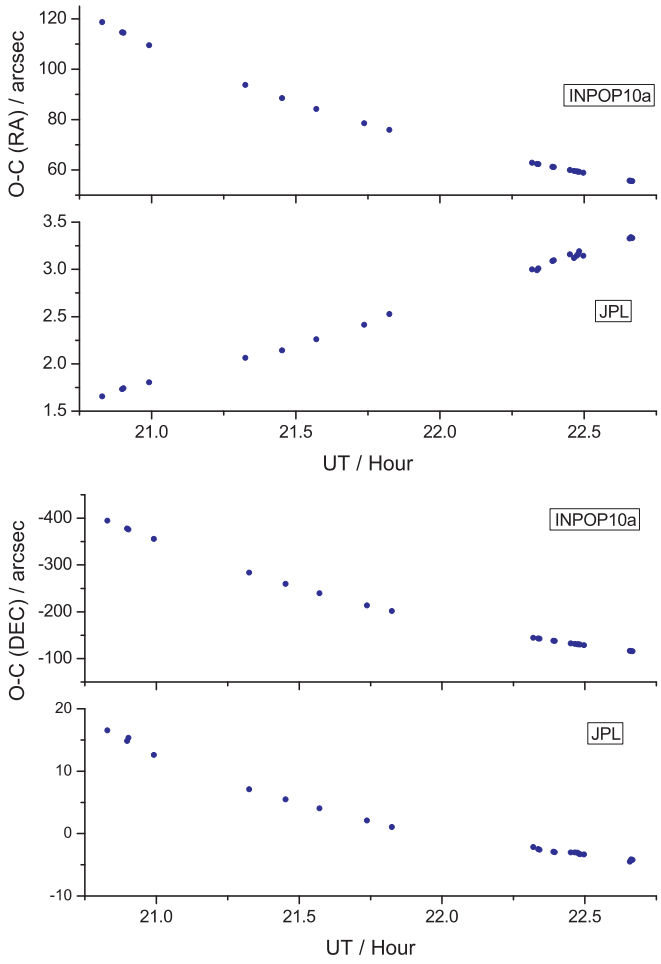

Fig. 1 The $O - C$ residuals of the near Earth asteroid Duende in RA (*top*) and DEC (*bottom*) compared to the ephemerides of INPOP10a and JPL.

$75''$ and $-198''$ different compared with the ephemeris of INPOP10a; however, the differences are $2.72''$ and $1.49''$ compared with the ephemeris of JPL, as shown in the second and third columns of Table 3. The fourth and fifth columns of Table 3 list the standard deviations of RA and DEC for $O - C$ residuals of Duende.

Figure 1 displays the $O - C$ residuals of Duende with different ephemerides, along with the UT time in hours.

As shown in Tables 4 and 5, the ephemerides of INPOP10a and JPL are consistent for the near Earth asteroids of Apophis and 2013 TV135. The mean values of $O - C$ residuals are about 1.9 mas and 2.8 mas for Apophis; they are 26 mas and 290 mas for 2013 TV135 with respect to the ephemeris INPOP10a and about 3.3 mas and –5.6 mas for Apophis; they are 33 mas and 350 mas for 2013 TV135 compared to the ephemeris given by JPL. Figures 2 and 3 display the $O - C$ residuals of Apophis and 2013 TV135 for each observational night.

Table 4 Mean and StdDev Values of $(O-C)$ Residuals for the Near Earth Asteroid Apophis

Ephemerides	Mean $(O-C)$		StdDev $(O-C)$	
	RA (mas)	DEC (mas)	RA (arcsec)	DEC (arcsec)
INPOP10a	1.900	2.830	0.00501	0.13453
JPL	3.330	–5.610	0.00501	0.13469

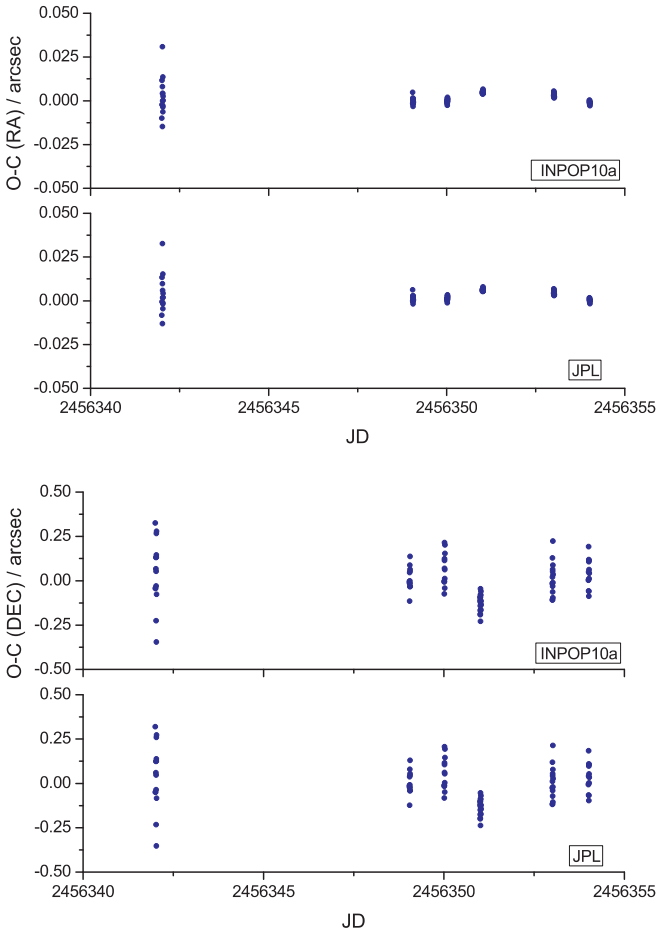

Fig. 2 The $O-C$ residuals of the near Earth asteroid Apophis in RA (*top*) and DEC (*bottom*) compared to the ephemerides of INPOP10a and JPL.

4 DISCUSSION

The orbital calculation of a near Earth object is usually inaccurate when it approaches Earth too closely (the case for Duende), or when the amount of astrometric data is not enough (the case for 2013 TV135). As displayed in Table 6 and Figure 4, the difference between the ephemerides of

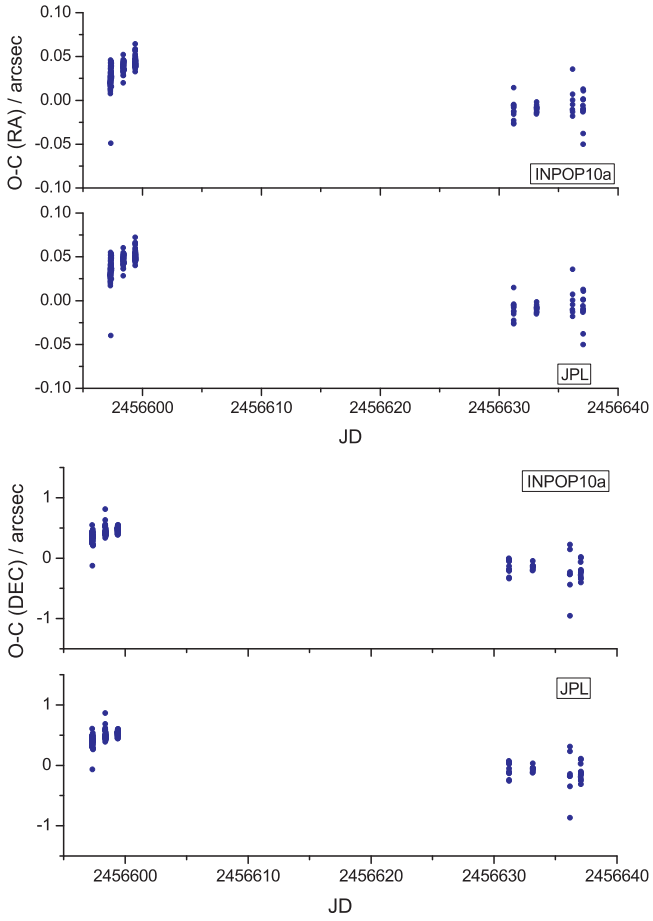

Fig. 3 The $O - C$ residuals of the near Earth asteroid 2013 TV135 in RA (*top*) and DEC (*bottom*) compared to the ephemerides of INPOP10a and JPL.

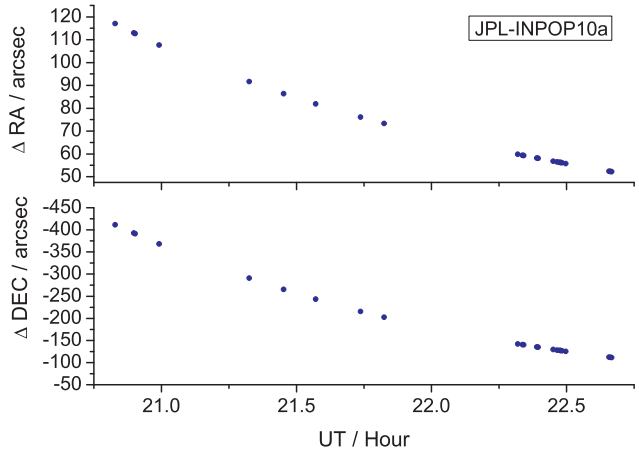

Fig. 4 Residuals of JPL-minus-INPOP10a ephemerides for the near Earth asteroid Duende.

Table 5 Mean and StdDev values of $(O - C)$ Residuals for the Near Earth Asteroid 2013 TV135

Ephemerides	Mean $(O - C)$		StdDev $(O - C)$	
	RA (arcsec)	DEC (arcsec)	RA (arcsec)	DEC (arcsec)
INPOP10a	0.02582	0.28790	0.02152	0.26514
JPL	0.03263	0.34932	0.02413	0.25487

Table 6 Mean and StdDev Values of JPL-minus-INPOP10a Ephemerides Residuals for the Near Earth Asteroid Duende

Ephemerides	Mean ($''$)		StdDev ($''$)	
	RA	DEC	RA	DEC
JPL−INPOP10a	71.72749	–199.03512	22.19941	103.39296

INPOP10a and JPL is very large for Duende, which decreases with a farther distance from Earth. For the newly discovered near Earth asteroid 2013 TV135, more accurate astrometric data are necessary to study its dynamics. It would be advantageous if astrometric data about near Earth asteroids obtained from different sites could be collected to better study their motion. For this goal, our astrometric data have been sent to the administrators of the Gaia-FUN-SSO project.

A large telescope is very helpful for acquiring accurate astrometric data of faint near Earth objects, and long term observations are necessary to determine their orbits. The astrometric observations of the near Earth asteroids Duende, Apophis and 2013 TV35 were organized by the Gaia-FUN-SSO project, which has the goal of making follow-up observations of near-Earth objects identified by Gaia. Observations of these three near Earth asteroids by the Lijiang 2.4 m telescope demonstrate the advantage of accurate astrometric observation, especially for astrometry of faint near Earth objects.

As introduced in the papers of Peng (2011); Peng et al. (2012) and Zhang et al. (2012), geometric distortion (GD) occurs during astrometric observations made with the Lijiang 2.4 m telescope of Yunnan observatories. As a next step, we will take the effect of GD into account during our work to derive more accurate astrometric data about near Earth objects.

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References

Bai, J., & Liu, Z. 2011, in Proceedings of Gaia Follow-up Network for Solar System Objects: Gaia FUN-SSO Workshop Proceedings, 63

Bancelin, D., Colas, F., Thuillot, W., Hestroffer, D., & Assafin, M. 2012, A&A, 544, A15

Fan, Y.-F., Zhang, X.-L., & Peng, Q.-Y. 2013, in Proceedings of GAIA-FUN-SSO 2012: Second'Gaia Follow-up Network for Solar System Objects: Gaia FUN-SSO Workshop Proceedings, 87

Fienga, A., Laskar, J., Kuchynka, P., et al. 2011, Celestial Mechanics and Dynamical Astronomy, 111, 363

Jordan, S. 2008, Astronomische Nachrichten, 329, 875

Lindegren, L., Babusiaux, C., Bailer-Jones, C., et al. 2008, in IAU Symposium, 248, eds. W. J. Jin, I. Platais, & M. A. C. Perryman, 217

Peng, Q. 2011, Scientia Sinica Physica, Mechanica & Astronomica, 41, 1126

Peng, Q. Y., Vienne, A., Zhang, Q. F., et al. 2012, AJ, 144, 170
Prusti, T. 2011, in Proceedings of Gaia Follow-up Network for Solar System Objects: Gaia FUN-SSO Workshop Proceedings, 11
Souchay, J., Souami, D., Lhotka, C., Puente, V., & Folgueira, M. 2014, A&A, 563, A24
Thuillot, W. 2011, in Proceedings of Gaia Follow-up Network for Solar System Objects: Gaia FUN-SSO Workshop Proceedings, 55
Wlodarczyk, I. 2012, MNRAS, 427, 1175
Zacharias, N., Finch, C. T., Girard, T. M., et al. 2013, AJ, 145, 44
Zhang, Q.-F., Peng, Q.-Y., & Zhu, Z. 2012, RAA (Research in Astronomy and Astrophysics), 12, 1451