THE IMPROVEMENT OF THE PLUTO ORBIT USING ADDITIONAL NEW DATA

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ABSTRACT. Observational series of the Pluto dwarf planet have started since 1913. At this moment observations have covered only a third of the Pluto orbit, therefore, the Pluto orbital elements are defined with insufficient accuracy. A growing number of observations leads to the improvement of the accuracy of the orbit determination. The database of the Pluto's observations was expanded with the help of about 350 observations during 1930–1996 obtained at the Pulkovo Observatory, and about 5500 observations (1995–2013) including occultation data from Brazilian colleagues obtained at the European Southern Observatory and the Pico dos Dias Observatory, and the new analyzed 469 historical photographic observations archived at Lowell Observatory. The new cross-platform software ERA-8 has been developed in IAA RAS and has been used for implementation of all mathematical procedures for constructing Pluto orbit. The modern ephemerides (EPM2011, EPM2013, DE430, DE432, INPOP13c) are chosen for comparison of the ephemeris positions: equatorial coordinates and heliocentric distance. The main result of the work – construction of ephemerides EPM2014a is a significant improvement of the Pluto's orbit using additional observations.

1. INTRODUCTION

Prof. George Krasinsky and his group started the development of The Ephemerides of Planets and the Moon (EPM) since 1974, firstly in the Institute of Theoretical Astronomy, then in the Institute of Applied Astronomy of the Russian Academy of Science (IAA RAS). The most complete version of that time, designated EPM87, was created in 1987 (Krasinsky et al., 1993). Its parameters were fit to a wide variety of observational data for the time span XVIII–XX centuries. EPM ephemerides were computed using the program package ERA-7 (ERA: Ephemeris Research in Astronomy) (Krasinsky & Vasilyev, 1997). Pluto ephemerides presented in this paper, was based on the improvement of only Pluto orbit using additional new observations. The corresponding ephemerides are called EPM2014a.

The Pluto was discovered in 1930 (Tombaugh, 1946), but its observational series are available from 1913 due to finding of the Pluto image on old photographic plates. Therefore, only one third part of the Pluto orbit has been covered with observations. As a result, its positions and velocities are known far worse than for other big planets of the Solar system (Pitjeva & Pitjev, 2014). Observational data recently obtained (Assafin et al., 2010; Khrutskaya et al., 2013; Buie & Folkner, 2015; Folkner, 2014; Folkner et al., 2014; Benedetti-Rossi et al., 2014) present a valuable information for making the new ephemeris.

2. THE SURVEY OF THE NEW DATA

The new observations can be divided into two groups represented in Table 1. Figure 1 shows both groups of observations: the photographic plates are on the left plot and the CCD data are on the right plot. The multicolor dots of plots in Fig. 1 mark residuals of the three sorts of photographic plates from Table 1. The CCD observations of Pluto in Table 1 was started from 1995 and are presented on the right side of Fig. 1. All the data were calculated using the ephemerides EPM2014a. The CCD data are far better than photographic ones, but, unfortunately, they cover a very short arc of Pluto orbit.

3. THE CONSTRUCTION OF THE EPHEMERIDES EPM2014A

The modern ephemerides EPM2013 was used as a zero approximation to make the EPM2014a. Only the Pluto orbit was improved for the EPM2014a. The new cross-platform software ERA-8 (Pavlov &

name of observatory	type of data	N observations	time span
digitized Pulkovo (Khrutskaya et al., 2013)		63	1930–1960
USNO/Lowell (Buie & Folkner, 2015)	photographic plates	469	1931–1951
review Pulkovo (Rylkov et al., 1995)		193	1930–1992
Pico dos Dias (PDO) (Benedetti-Rossi et al., 2014)		5489	1995–2011
USNO/Flagstaff (Folkner et al., 2014)	CCD	1197	1995–2013
Table Mountain (TMO) (Folkner, 2014)		695	2001–2013
ESO/La Serena (Assafin et al., 2010)		11	2005–2008

Table 1: Description of the new observations.

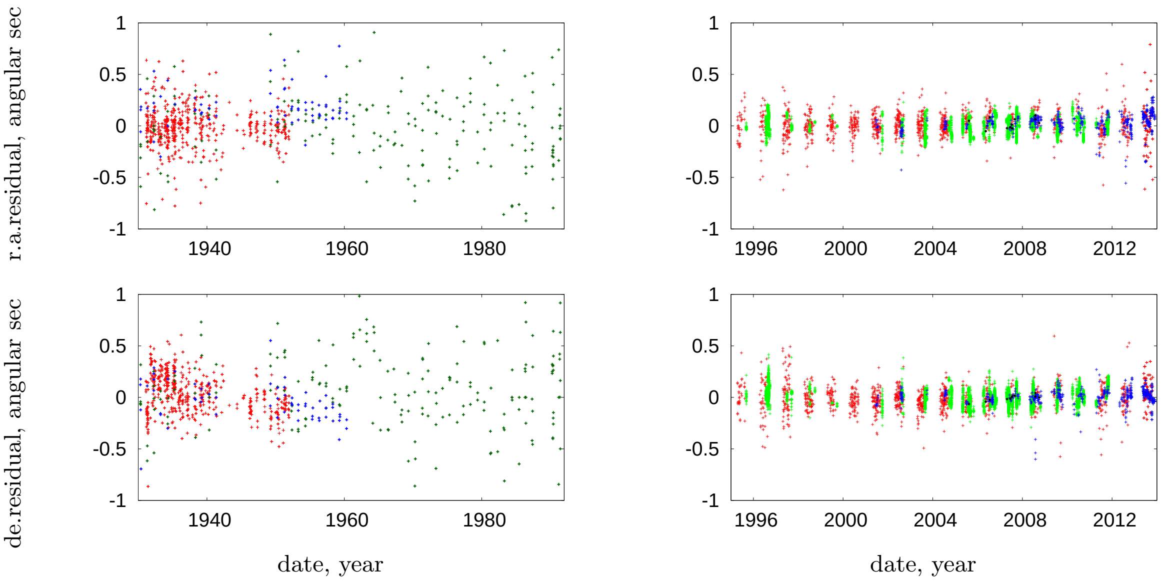

Figure 1: Residuals in right ascension (the upper panel) and declination (the bottom panel) of photographic plates (on the left side): digitized Pulkovo of blue color, USNO/Lowell of red color and review of Pulkovo of green color and CCD observations (on the right side): the PDO of green color, the USNO/Flagstaff of red color and the TMO of blue color, the ESO/La Serena of black color.

	element	EPM2014a	of the EPM2013	of the EPM2014a
1	a	39.713 a.u.	1316.116 km	563.306 km
2	$\sin i \cos \Omega$	0.285	0.816 mas	0.865 mas
3	$\sin i \sin \Omega$	0.276	4.516 mas	3.312 mas
4	$e \cos \pi$	-0.170	27.453 mas	12.900 mas
5	$e \sin \pi$	-0.187	21.417 mas	8.384 mas
6	l	-2.435	13.299 mas	4.870 mas

Table 2: Lagrangian elements.

Skripnichnko, 2014) has been used for implementation of all mathematical procedures of process for constructing Pluto orbit. The six elements of the orbit were derived from this solution. The observations from Table 2 cover only one third part of the Pluto orbit, therefore the standard deviations of the six elements are larger than for the same elements of other planets of the Solar system (Pitjeva & Pitjev, 2014). One of the results, the Lagrangian elements are computed with the EPM2014a for the epoch of 2446600.5 JD, are shown in Table 2. The standard deviations for the elements of the EPM2014a are better than for the EPM2013 (Pitjeva & Pitjev, 2014).

4. THE RESULT OF THE COMPARISON WITH MODERN EPHEMERIDES

Figure 2 illustrates positions differences between independent orbit estimates of EPM2014a ephemeris and EPM2011 and EPM2013 on the left side, as well as differences of orbit estimates for the A test ephemeris and DE430, and for the B test ephemeris and DE432 as a function of time on the right side.

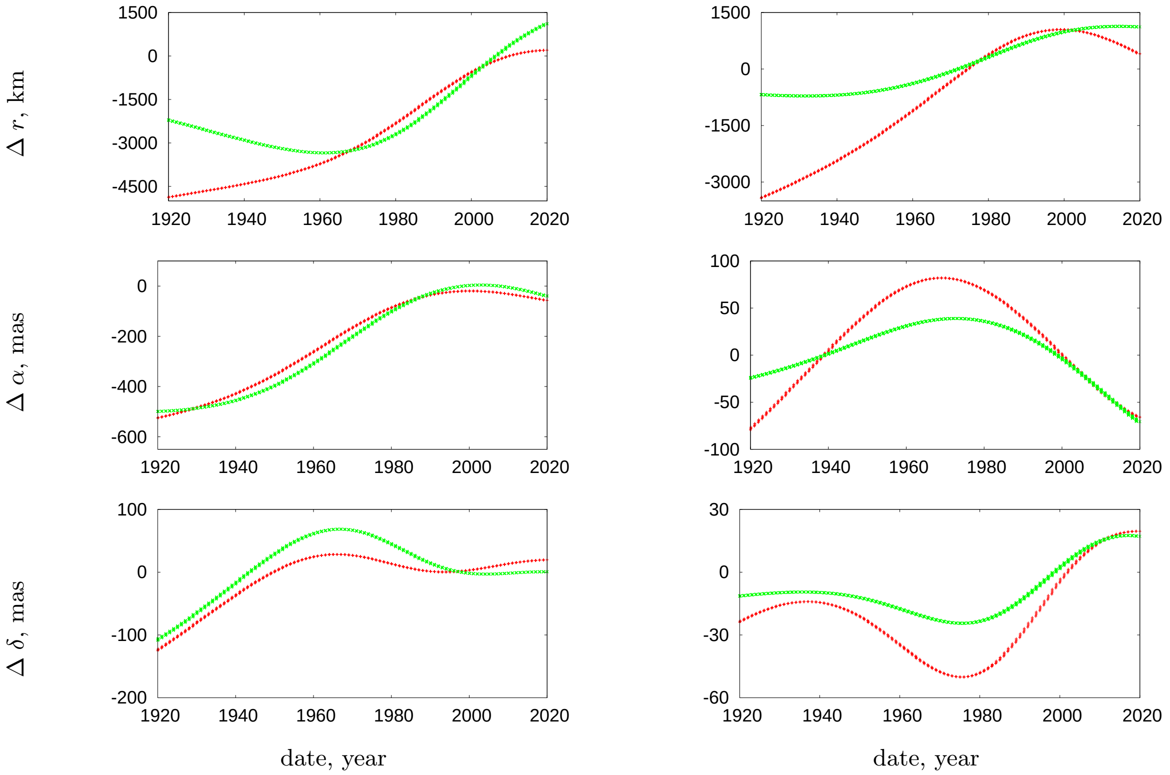

Figure 2: The upper panel is the heliocentric distance in kilometers, the middle panel is right ascension and the bottom — declination differences in milliarcseconds. The left side presents comparison of EPM2014a ephemerides to EPM2011 of red line and to EPM2013 of green line. The right side presents comparison of the A test ephemeris to DE430 of red line and the B test ephemeris to DE432 of green line.

The calculation of differences between equatorial coordinates and radius vectors is a suitable procedure for comparison of ephemerides. The comparison was carried out for several different ephemerides discussed below. At first, the EPM2014a ephemeris was taken, where the full set of Pluto available observations was used. Two test ephemerides were also constructed. The test ephemeris A used for fitting the same set Pluto observations as DE430 including Pulkovo photographic observations and data from the following observatories: the TMO, the PDO, the USNO/Flagstaff. The test ephemeris B used for fitting the same set Pluto observations as DE432, i.e. in addition to observations for the test ephemeris A, the Lowell observations were added.

And finally, the comparison of ephemeris the EPM2014a with modern ephemerides INPOP13c (Fienga et al., 2014) and DE432 is represented in Fig. 3. There are a lot of reasons for existing difference, for example, different data arrays and their weight data, the process of improvement and estimated parameters.

5. CONCLUSION

The data array observations were expanded with the new data up to about 10 thousand observations. The increasing accuracy ephemerides with the addition of new data was demonstrated, particularly, the improvement of ephemerides appears in residual observations. The EPM2014a corresponds to the modern ephemerides EPM2011, EPM2013, DE430, especially, is close to DE432.

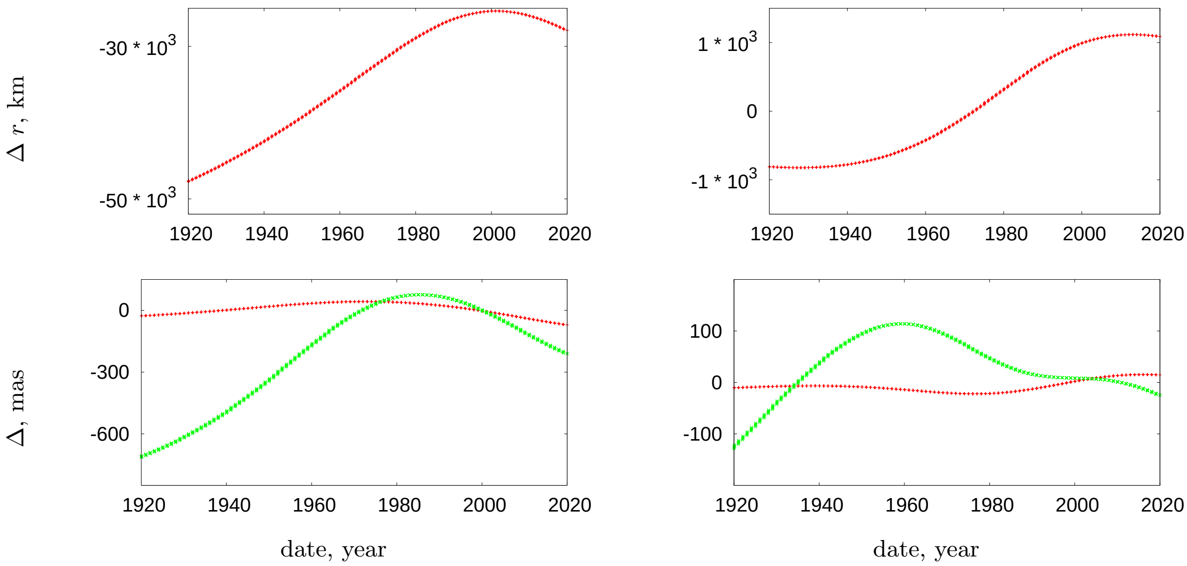

Figure 3: The upper panel is the heliocentric distance in kilometers for difference between EPM2014a and INPOP13c on the left side and DE432 on the right side, the bottom panel left to right is right ascension and declination differences in milliarcsecond and presents comparison of the EPM2014a to DE432 of red line and to INPOP13c of green line.

6. REFERENCES

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