ANALYTICAL REPRESENTATION OF PLUTO MODERN EPHEMERIS

S.M. KUDRYAVTSEV, N.S. KUDRYAVTSEVA
Sternberg Astronomical Institute of Moscow State University
13, Universitetsky Pr., Moscow, 119992, RUSSIA
e-mail: ksm@sai.msu.ru, natkud@rambler.ru

ABSTRACT. A high-accurate analytical representation of the latest JPL's numerical ephemeris of Pluto, DE421 (Folkner et al. 2008), by Fourier series is obtained. The maximum difference between barycentric positions of Pluto given by the new analytical series and the numerical ephemeris over 1900–2050 (the entire time interval covered by DE421) is 1.3 km. To get Pluto heliocentric positions, a development of heliocentric coordinates of the Solar system barycenter to Poisson series is made. The heliocentric positions of the barycenter given by the new analytical series and by DE421 numerical ephemeris differ by less than 5 km over 1900–2050.

1. INTRODUCTION

An accurate ephemeris of Pluto is of a great interest now because of the NEW HORIZONS mission recently launched to that dwarf planet. The spacecraft should reach Pluto in 2015, and by anticipating that encounter, the Pluto ephemeris is essentially updated in recent JPL's planetary ephemerides; the latest and most accurate of them is DE421 (Folkner et al. 2008). It is important to note, that all modern ephemerides of Pluto are numerical ones. There is also a number of analytical series representing Pluto coordinates (Goffin et al. 1986; Chapront & Francou 1995, 1996; Simon 2004); their advantage over the numerical ephemerides is an essential compactness. However, all the available analytical series are adjusted to now outdated numerical ephemerides of Pluto that differ from its modern ephemerides by several thousand km (Folkner et al. 2007). Therefore, the task of obtaining the new analytical series for Pluto coordinates that accurately approximate the latest Pluto ephemeris is an actual one.

2. DEVELOPMENT OF PLUTO COORDINATES TO ANALYTICAL SERIES

To obtain new analytical series for barycentric coordinates of Pluto we used a method by Chapront & Vu (1984). Following their approach, Pluto coordinates are first calculated over at least one orbital period of this dwarf planet with a small sampling step. In our study we used the latest JPL's numerical planetary ephemeris DE421 as a source of Pluto coordinates. As an approximating analytical function, the method suggests a Fourier series with the frequencies being successive multiples of the main frequency of Pluto's motion ν plus a constant term and a term proportional to time t:

$$X(t) = X_0^c + X_0^s t + \sum_{k=1}^{N} (X_k^c \cos k\nu t + X_k^s \sin k\nu t) \qquad (1)$$

The amplitudes $X_0^c, X_0^s, \ldots, X_N^c, X_N^s$ are found with help of the least-mean-square algorithm. This form of expansion by us is used to represent rectangular barycentric ICRF coordinates of Pluto: X, Y and Z.

However, the method is only effective when the expansion is made over a time interval not shorter than the Pluto's orbital period. It is equal to about 248 years, but DE421 ephemeris only covers 150 years (1900–2050). Thus DE421 by us has been preliminary expanded over the time interval 1850–2150 with help of ERA software (Krasinsky & Vasilyev 1997).

Table 1 presents the main characteristics of the new development of the rectangular barycentric ICRF coordinates of Pluto to series of form [1]. The comparison of the new analytical series with DE421 numerical ephemeris is done over 1900–2050, the entire time interval covered by the ephemeris. The complete set of numerical values for all the coefficients of the expansion [1] for rectangular barycentric coordinates of Pluto can be found at http://lnfm1.sai.msu.ru/neb/ksm/pluto/pluto_ssb.zip. The archive also includes a relevant Fortran subroutine for calculation of Pluto barycentric coordinates.

Coordinate	Number of Fourier terms	Maximum error of approximation
X	153	0.83 km
Y	153	0.96 km
Z	153	0.41 km

Table 1: Analytical approximation of DE421 barycentric coordinates of Pluto over 1900–2050.

Coordinate	Number of Poisson terms	Maximum error of approximation
X	128	4.17 km
Y	129	4.12 km
Z	130	1.36 km

Table 2: Analytical approximation of DE421 heliocentric coordinates of the SSB over 1900–2050.

To get Pluto positions relative to the Sun, a development of heliocentric coordinates of the Solar system barycenter (SSB) to Poisson series is additionally made. For that we used the expansion method by Kudryavtsev (2007). The development is made over 1000AD–3000AD; as a source of the SSB heliocentric coordinates we used the latest long-term JPL's ephemeris DE406 (Standish 1998). According to the method, the development is directly done to Poisson series, where both amplitudes and frequencies of the series' terms are high-degree time polynomials. This allows one to make the expansion over long-term intervals, and therefore the series' terms of close frequencies can be better separated.

Table 2 presents the main characteristics of our development of the rectangular heliocentric ICRF coordinates of the SSB to Poisson series. All coefficients of the Poisson series for the SSB coordinates and a relevant Fortran subroutine can be found at http://lnfm1.sai.msu.ru/neb/ksm/ssb/ssb_sun.zip.

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