JET PROPULSION LABORATORY

INTEROFFICE MEMORANDUM

343-04-008

4 November 2004

TO: Distribution

FROM: E. M. Standish

SUBJECT: The Ephemeris of Pluto : DE413

Abstract

The JPL Planetary Ephemeris, DE413, has been created expressly for an updated ephemeris of Pluto, in view of the upcoming possible occultation of a star by Pluto's satellite, Charon, on 11 July 2005 around 03:39 UT.

1 Introduction

On July 11, 2005, Pluto's satellite, Charon, is expected to occult the 15^{th} magnitude star, UCAC2 26257135. The positions of both the star and Charon are critical for this event, for the diameter of Charon, about 1200 km, is only 0."055 on the sky. As such, the optimim observing site is heavily dependent upon the positional accuracies.

CCD observations of the Pluto-Charon system from a number of observatories over the past year have been collected and added to the existing data set. This set, along with the rest of the ephemeris data have been fit, resulting in the creation of a new ephemeris, DE413.

In order to assess the accuracy of the ephemeris of Pluto on DE413, plots of Pluto residuals are shown, statistics of the residuals for the past 10 oppositions are given, and the ephemeris of Pluto on DE413 is compared with the previous ephemerides, DE200, DE405, DE409, and DE411.

2 The Measurements

CCD observations now provide the majority of the ephemeris measurements of the outer planets. In comparison to previous optical transit timings and photographic astrometry, CCD measurements are inherently more accurate. In addition, they are now reduced with reference catalogs (Tycho2, UCAC2) which are based directly upon the ICRF (International Celestial Reference Frame). This frame, inertial for practical purposes, is the reference frame for all the major facets of spacecraft navigation: the planetary and lunar ephemerides, the earth orientation parameters (eop), and interplanetary spacecraft navigation. The concern for frame-ties no longer exists.

For Pluto, three observatories have contributed CCD observations over the past decade: Bordeaux Observatory, 1995–97; Table Mountain Observatory, 2001–2004; and the US Naval Observatory, Flagstaff, 1995–2004. The observations have been collected up through 2004 October 1 and therefore include the 2004 opposition of Pluto.

The fitting of DE413 to the CCD observations, as well as to the rest of the standard ephemeris observational data, provides an improved ephemeris for the planets, in particular here, for Pluto.

3 The Improved Ephemeris of Pluto

The new DE413 ephemeris for Pluto may be assessed in two different ways: analyses of the DE413 CCD residuals and comparisons of DE413 with previous ephemerides.

3.1 The Observational Residuals

The residuals of the CCD observations of Pluto, fit with DE413, are shown in Figs.1a–1d, giving the residuals from each observatory and a combined plot, in both right ascension and in declination.

Table 1 gives the means and standard deviations of the residuals for each opposition and for each observatory. The single observation statistics for Bordeaux and for Table Mountain are exceptional – usually under $< 0.''1$. While the statistics are somewhat poorer for USNOFS, the number of observations and the continued reliability of that program are highly valued. The slightly lesser accuracy is directly attributable to the small size of the telescope (8") used up until the present time. The transition to the new 51" telescope in the near future is certain to provide increased accuracy for the USNO Flagstaff observations.

Some scatter is seen among the opposition means in Table 1, much of which comes from errors in the reference catalog: the motion of Pluto can not produce such irregularity over the course of just a few years. The scatter of the Bordeaux and Table Mountain means is a direct result of the small number of observations, especially for the last two years when the TMO observations were taken on only one night in 2003 and only one night in 2004. Thus, the same reference stars were used for each and the scatter reflects the few-star statistics of the reference catalog. For the Flagstaff observations, the scatter of the means is much reduced by the higher number of observations.

3.2 Comparisons with Previous Ephemerides

Figs.2a-3b show comparisons of the DE413 ephemeris of Pluto with those of the previous ephemerides, DE200 (created in 1979), DE405 (1995), DE409 (2003), and DE411 (2004). DE200 was not fit to any Pluto observations; its ephemeris for Pluto should not be used at all. DE405 was fit to photographic astrometric data, 1914-89, and some early 1995 CCD observations; DE409 was fit through the Pluto opposition of 2002; and DE411, through the Pluto opposition of 2003. (The data set for DE413 includes the 2004 opposition.)

For July next year, the past three ephemerides differ from DE413 in (right ascension, declination) by (-0.''030, -0.''040) for DE405, by (-0.''050, +0.''020) for DE409, and by (+0.''005, +0.''030) for DE411. These differences are comparable to the size of Charon itself. They show, in part, the difficulty of extrapolating the ephemeris of Pluto. They are also a result of having previously solved for reference-frame corrections, applied to the earlier CCD observations. Since the more recent CCD observations are given w.r.t. catalogs based directly upon the ICRF, the reference frame rotation parameters are no longer necessary.

4 Conclusions

The two methods used in assessing the uncertainty of the Pluto ephemeris on DE413 are pretty consistent with each other.

- The USNO opposition means over the past few years seem to be settled down, assuming that there are no significant *global* systematic errors in the reference catalog over the relevant fields of the past few years. The scatter between the means is usually less than 0.''020.
- The four most recent ephemerides for Pluto differ among each other significantly, being as large as 0.''040 or so. However, with the more recent data for DE413 and with no more need for frame ties, it should be assumed that the ephemeris for DE413 is an improvement over its predecessors.

Thus, a realistic uncertainty of the ephemeris of Pluto on DE413 should be $\pm 0.''020$ or even less.

Distribution

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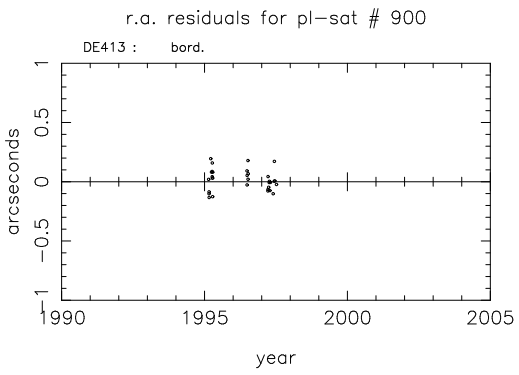
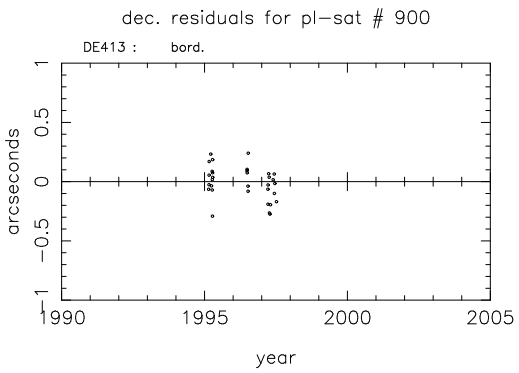
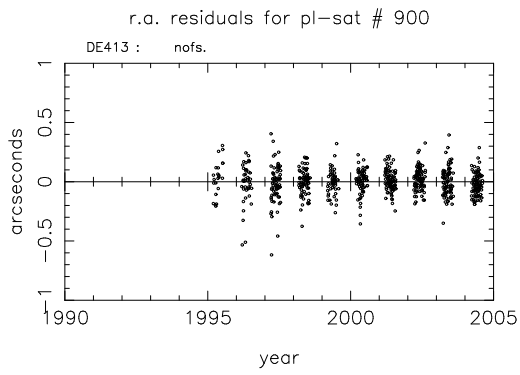
Table 1. Opposition means and uncertainties of CCD Pluto observations, taken by various observatories over the past decade.

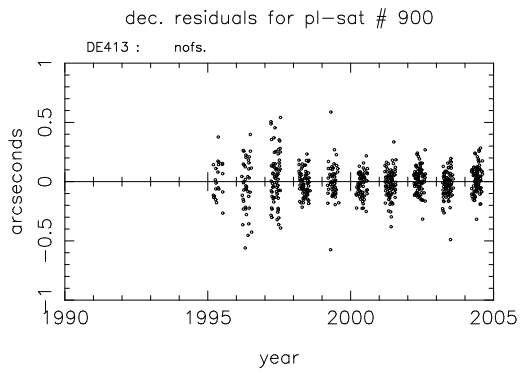
nr	time-span	$\overline{\nu_\alpha}$	σ_α	$\frac{\sigma_\alpha}{\sqrt{n}}$	$\overline{\nu_\delta}$	σ_δ	$\frac{\sigma_\delta}{\sqrt{n}}$
Bordeaux-Floirac							
13	1995.142-1995.284	0.022	0.101	0.028	0.029	0.130	0.036
6	1996.486-1996.527	0.064	0.064	0.026	0.065	0.104	0.043
12	1997.217-1997.460	-0.012	0.069	0.020	-0.079	0.119	0.034
Table Mountain Observatory, Wrightwood							
8	2001.374-2001.412	0.046	0.026	0.009	-0.043	0.041	0.014
24	2002.472-2002.548	-0.051	0.099	0.020	0.062	0.073	0.015
2	2003.643-2003.643	0.028	0.013	0.010	0.145	0.019	0.014
3	2004.410-2004.410	-0.101	0.009	0.005	-0.173	0.016	0.009
U.S. Naval Observatory, Flagstaff							
22	1995.195-1995.525	0.032	0.145	0.031	0.015	0.150	0.032
41	1996.192-1996.533	-0.014	0.166	0.026	-0.035	0.218	0.034
71	1997.210-1997.546	-0.018	0.159	0.019	0.032	0.213	0.025
71	1998.188-1998.578	-0.001	0.110	0.013	-0.017	0.105	0.012
52	1999.195-1999.580	-0.005	0.102	0.014	0.004	0.152	0.021
66	2000.189-2000.585	0.006	0.102	0.013	-0.027	0.100	0.012
82	2001.197-2001.582	0.010	0.089	0.010	-0.018	0.118	0.013
89	2002.212-2002.614	0.026	0.093	0.010	0.018	0.102	0.011
84	2003.214-2003.589	0.000	0.117	0.013	-0.027	0.109	0.012
89	2004.227-2004.610	-0.021	0.093	0.010	0.019	0.112	0.012



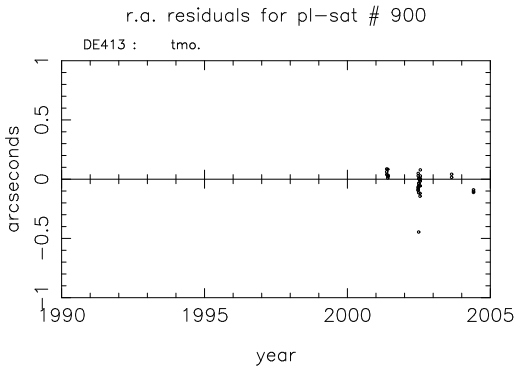


Bordeaux Observatory





USNO Flagstaff Station



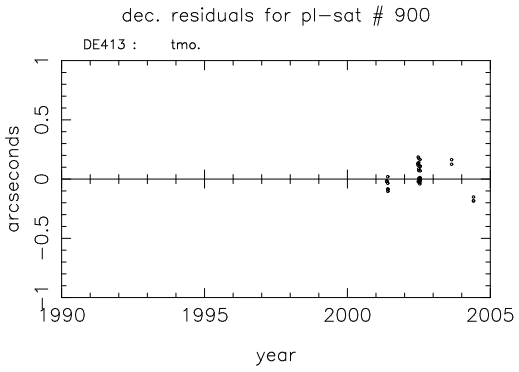
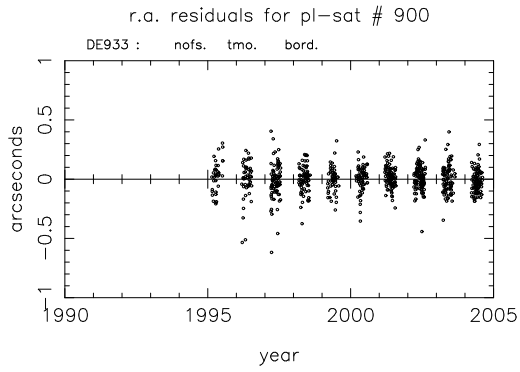
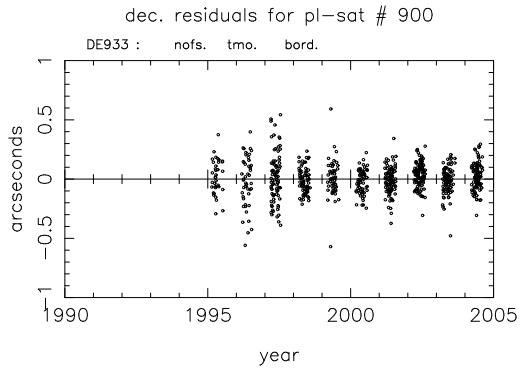


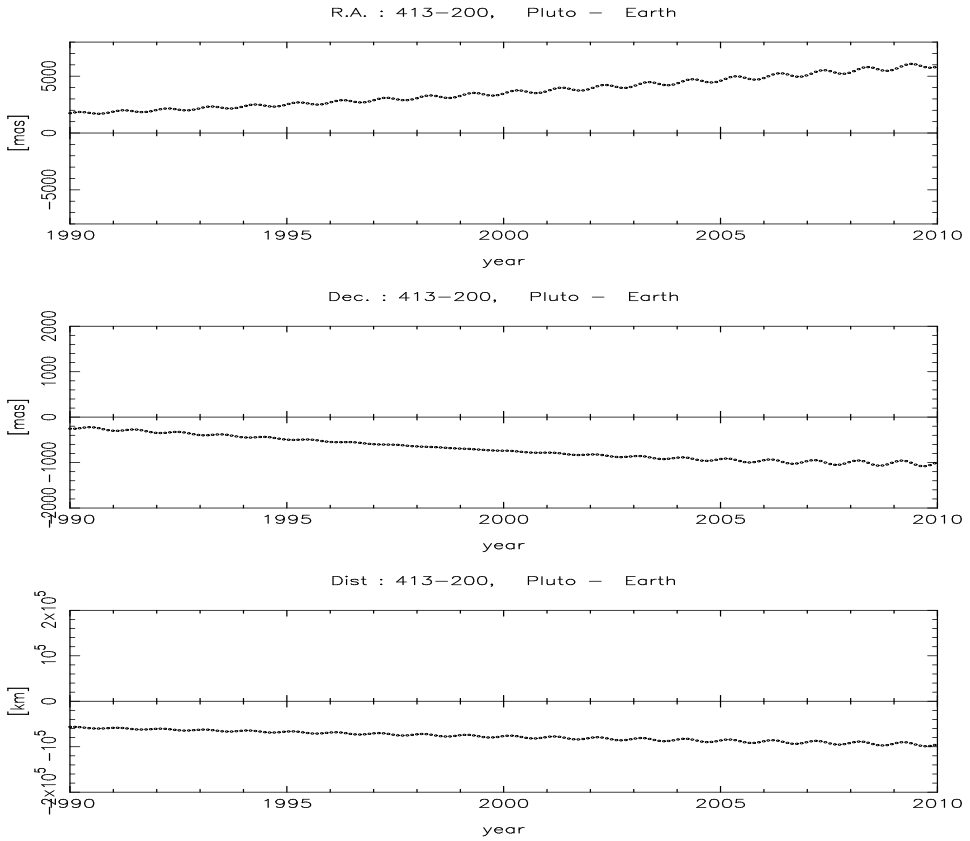
Table Mountain Observatory



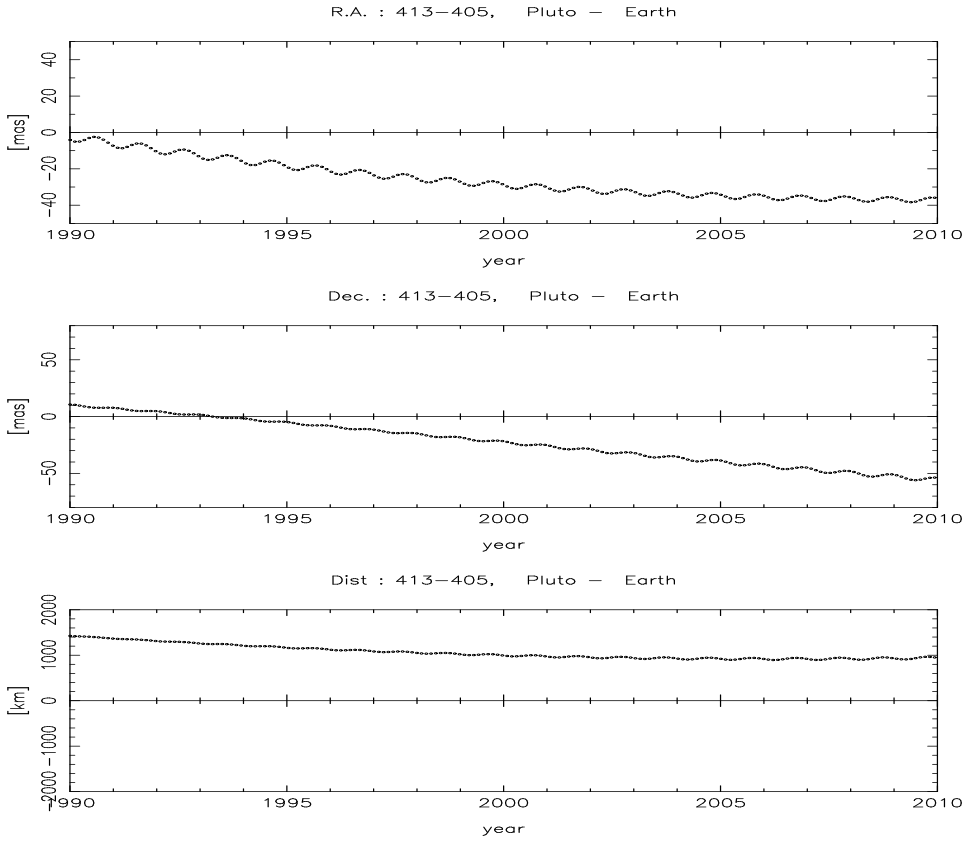


Combined

Figure 1: CCD Residuals of the Pluto-Charon system.

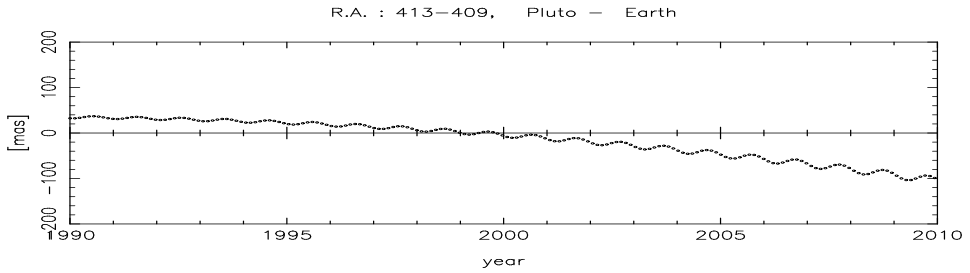


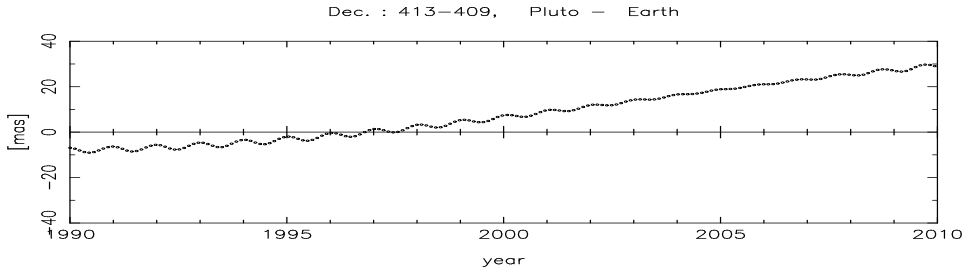
DE413 - DE200

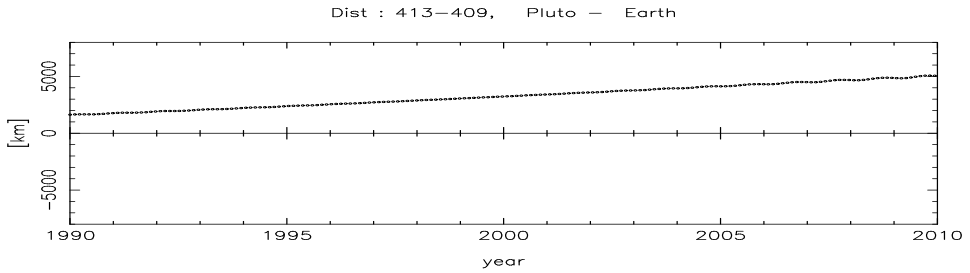


DE413 - DE405

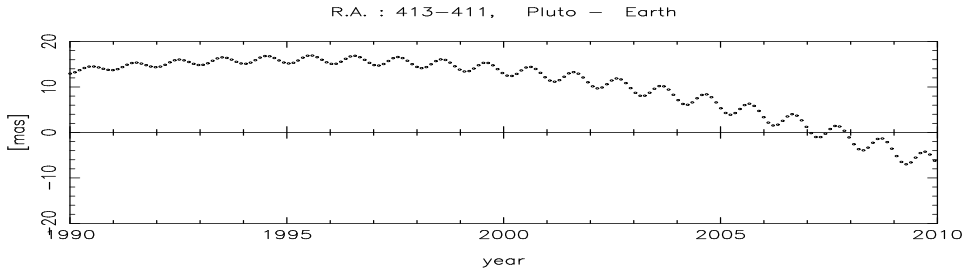
Figure 2: Differences in right ascension and declination.

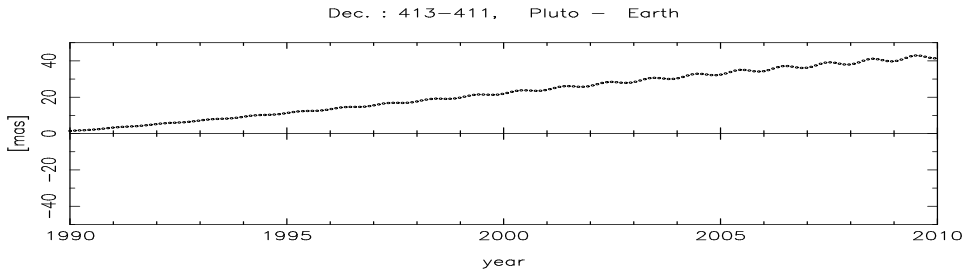


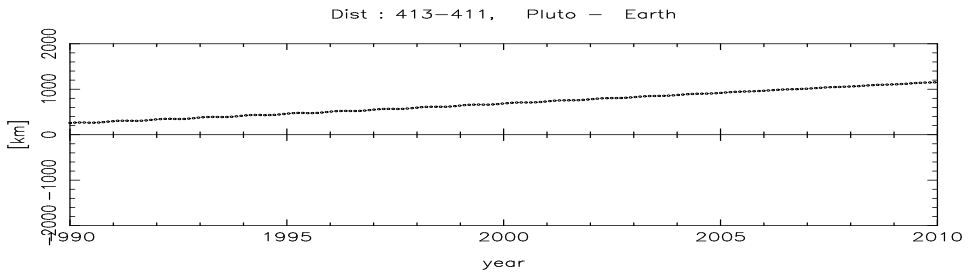




DE413 - DE409







DE413 - DE411

Figure 3: Differences in right ascension and declination.