JET PROPULSION LABORATORY INTEROFFICE MEMORANDUM

IOM 392R-15-018

23 December 2015

To: Distribution

From: Ryan Park, William Folkner, and Robert Jacobson

Subject: The planetary ephemeris DE434

1. Introduction

The planetary ephemeris DE434 was created in November 2015 to support the Juno navigation team for operating Juno in the Jupiter environment, including the Jupiter orbit insertion schedule in mid-2016. This delivery is essentially an update of the planetary ephemeris DE430 [*Folkner et al., 2014*]. The main difference in the Jupiter orbit from DE430 is due to the re-processing of data from six spacecraft flybys of Jupiter and the addition of data from the New Horizons flyby of Jupiter, which were delivered by R. Jacobson as a part of the latest Jupiter satellite ephemeris reconstruction. The change in the Jupiter orbit is consistent with the uncertainty delivered for the New Horizons project. An updated Jupiter covariance is described in a separate memo.

2. Jupiter Data Update and Improvements

The data used to estimate the orbit of Jupiter is summarized in Table 1. Radio tracking of spacecraft that passed close to Jupiter en route to the outer planets was used to estimate a position of Jupiter at the time of closest approach. These reconstructed position estimates are the most accurate data used for Jupiter. In addition to the spacecraft encounters, ground-based astrometric observations of Jupiter and its major satellites are used in the ephemeris estimation.

Table 1: Primary measurements for Jupiter ephemeris.

Class	Type	Observatory/ Spacecraft	Span	Number
Spacecraft	R.A., Dec., Range	Pioneer 10	1973-DEC-04	1, 1, 1
Spacecraft	R.A., Dec., Range	Pioneer 11	1974-DEC-03	1, 1, 1
Spacecraft	R.A., Dec., Range	Voyager 1	1979-MAR-05	1, 1, 1
Spacecraft	R.A., Dec., Range	Voyager 2	1979-JUL-09	1, 1, 1
Spacecraft	R.A., Dec., Range	Ulysses	1992-FEB-08	1, 1, 1
Spacecraft	R.A., Dec., Range	Cassini	2000-DEC-30	1, 1, 1
Spacecraft	R.A., Dec., Range	New Horizons	2007-FEB-28	1, 1, 1
Spacecraft	VLBI	Galileo	1996-1997	22
Astrometric	CCD (R.A., Dec.)	Flagstaff	1998-2012	3144, 3147
Astrometric	CCD (R.A., Dec.)	Nikolaev	1962-1998	1293, 1293
Astrometric	Transit (R.A., Dec.)	La Palma	1986-1997	658, 658
Astrometric	Transit (R.A., Dec.)	Tokyo	1986-1988	97, 97
Astrometric	Transit (R.A., Dec.)	Washington	1914-1994	1743, 1667

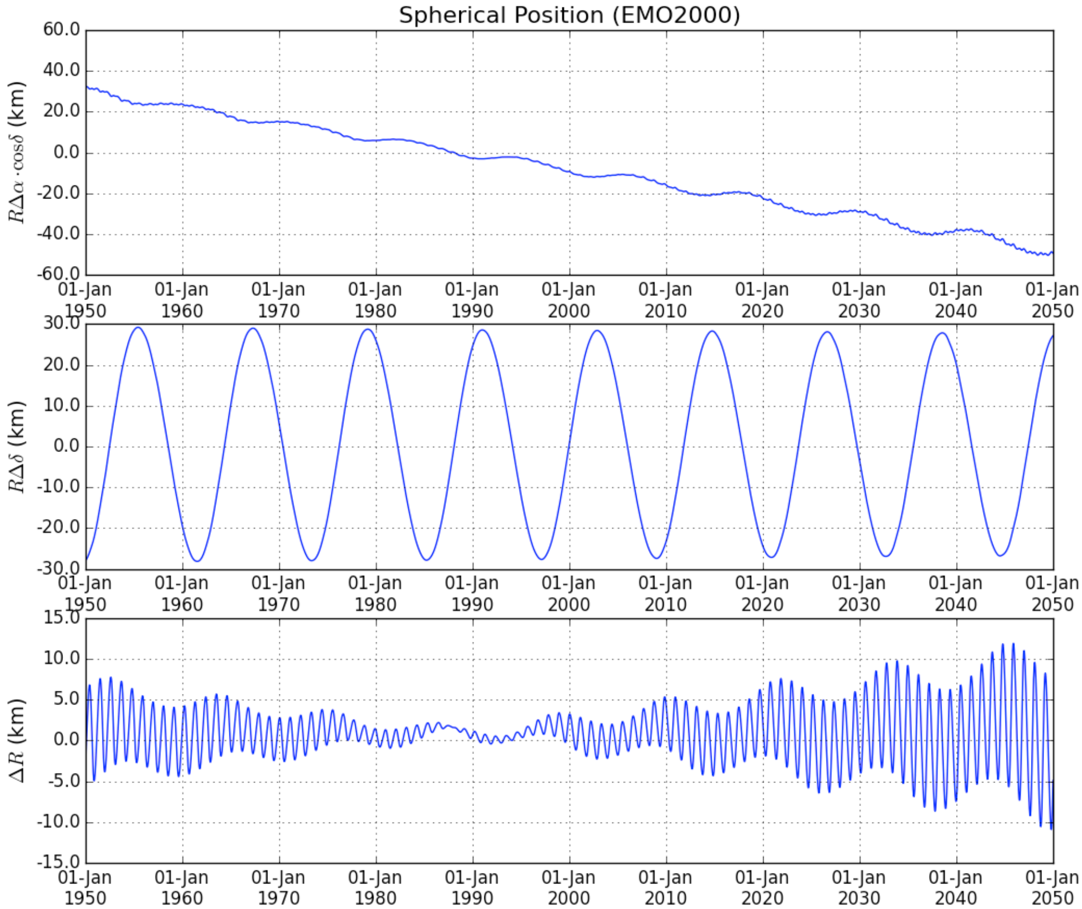

Figure 1: The difference between DE 430 and DE 434 in the EMO2000 frame for Jupiter barycenter relative to Earth.

Because of the failure of the high-gain antenna, the Galileo spacecraft did not provide range measurements during its orbital phase. VLBI measurement of Galileo were made, but with reduced accuracy compared with other spacecraft, particularly Ulysses, Cassini, and New Horizons.

Figure 1 shows the difference of position of Jupiter relative to Earth between DE434 and DE430. This difference is consistent with the estimated uncertainty. The estimated uncertainty in the Jupiter ephemeris of DE434 is presented in the companion report [*Park, 2015*].

The estimated orbit of Jupiter for DE434 differs from the previous estimate in DE430 primarily due to updates in the spacecraft flybys of Jupiter and the addition of the New Horizons flyby. For DE430 the Jupiter position estimates for the flybys of Pioneer, 10, Pioneer 11, Voyager 1, Voyager 2, and Cassini were derived during the development of the JUP230 satellite ephemeris. For DE434 the estimated positions of at times of these spacecraft flyby plus the New Horizons flyby were updated during development of the JUP310 satellite ephemeris. Figures 2-4 show the residuals of the JUP230 flyby positions and the JUP310 flyby positions relative to DE434. The biggest differences are the change in estimated declination, and declination accuracy, of the Cassini flyby and the addition of the New Horizons flyby. The Ulysses, Cassini, and New Horizons flyby all included range and high-accuracy VLBI (ΔDOR) data and, for the JUP310 development, the best accuracies. These three flybys now dominate the estimate of the Jupiter's orbit, which is consistent (within 2 sigma) with the earlier flybys, and the other observations of Jupiter (primarily ground-based astrometric measurements).

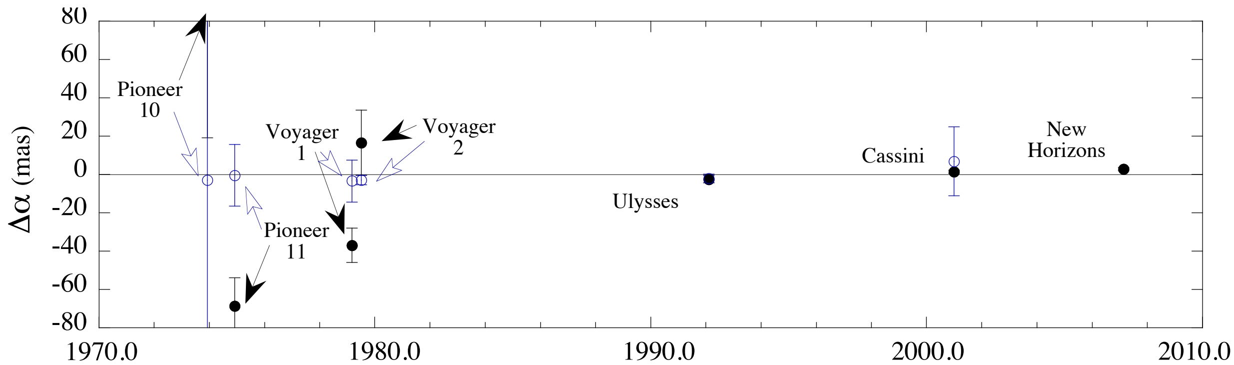

Figure 2. Residuals of right ascension of Jupiter relative to DE434 based on reconstruction of spacecraft flybys. In black are the residuals for the most recent reconstructed orbits developed for the JUP310 satellite ephemeris and used for DE434. In blue are the residuals for the previous reconstructed orbits for the satellite ephemeris JUP230 and used for DE430.

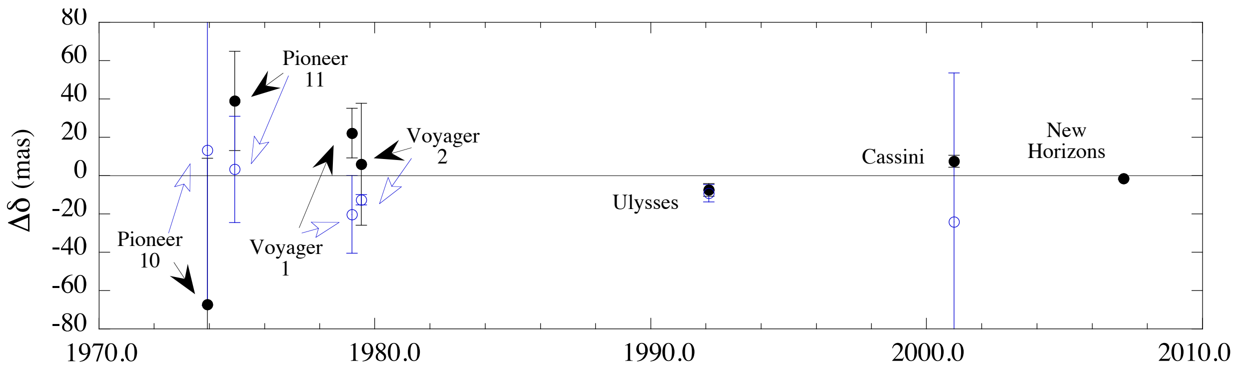

Figure 3. Residuals of declination of Jupiter relative to DE434 based on reconstruction of spacecraft flybys. In black are the residuals for the most recent reconstructed orbits developed for the JUP310 satellite ephemeris and used for DE434. In blue are the residuals for the previous reconstructed orbits for the satellite ephemeris JUP230 and used for DE430.

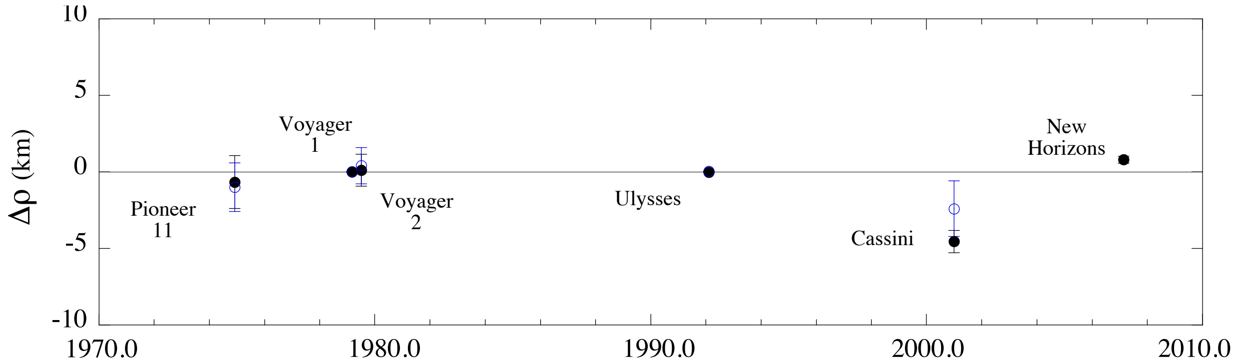

Figure 4. Residuals of range from Earth to Jupiter relative to DE434 based on reconstruction of spacecraft flybys. In black are the residuals for the most recent reconstructed orbits developed for the JUP310 satellite ephemeris and used for DE434. In blue are the residuals for the previous reconstructed orbits for the satellite ephemeris JUP230 and used for DE430.

References

W.M. Folkner, J.G. Williams, D.H. Boggs, R.S. Park, and P. Kuchynka, The planetary and lunar ephemerides DE430 and DE431, *IPN Progress Report*, 42-196, February 15, 2014.

R.S. Park and W.M. Folkner, Uncertainty in the orbit of Jupiter for Juno planning, *JPL Interoffice Memorandum*, IOM 392R-15-019, December 23, 2015.

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