Comparision of "Old" and "New" Concepts: Future JPL Ephemerides

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Abstract: Future planetary and lunar ephemerides from JPL will not reflect the recent IAU Conventions regarding TCB. The ephemerides will continue to be released in the same relativistic coordinate time, "T_{eph}", as before. They may be easily converted by the user into SI units.
The new IAU changes regarding earth orientation do not affect the ephemerides directly; they enter the ephemeris creation process only through the reduction of the observational data to which the ephemerides are fit. For the planetary observations, the change is far below even the most accurate measurements (1-2 m); for the LLR data, a rough equivalent of the change has already been in place for a number of years, and conversion to the IAU formulation is unlikely in the near future.
The accuracy of the planetary ephemerides is 1 km or better for all relative angles and distances between any of the 4 inner planets; the orientation of the inner planet system onto the ICRF is accurate to about 0."001. Over time, however, the accuracy deteriorates due to the perturbations of many asteroids whose masses are not well known. For this reason, the ephemerides require constant maintenance using the latest high accuracy observations.

1 The Time Argument of the Ephemerides

The JPL ephemerides have never used either ET or TDB, as they were defined by the IAU. Instead, the time argument used in the JPL ephemerides since the mid-1960's, "T_{eph}", is a true relativistic coordinate time. As shown by the author (1998), the latest IAU-defined time, "TCB", is rigorously equivalent to T_{eph}, differing by only a rate and an offset. Thus, it is a simple matter to convert from the T_{eph} units provided by the JPL ephemerides into SI units using TCB; this involves simply the scale factor, $(1 - L_B) = d(T_{eph})/d(TCB)$, applied to the time (independent argument of the ephemerides), the distances, and the GM values.

Contrary to what has been said in the literature, a conversion to TCB would not allow an increase in accuracy for the JPL ephemerides. One can show that working in T_{eph} is equivalent to working in TCB; the resultant ephemerides would be equivalent.

There has been an immense amount of sophisticated and detailed software produced over the past number of decades throughout the astronomical community and within the aerospace industry. A conversion to TCB would involve unacceptable cost and unavoidable risk while providing no improvement in accuracy.

2 New Earth Orientation Formulation

For the planetary ephemerides, the most accurate observational data are at the 1-2 *m* level. This limit applies to the best ranging measurements – those taken with dual-frequency, calibrated transponders aboard a landed or an orbiting spacecraft. The uncertainties come from the non-constancy of the interplanetary medium, from the imprecisions in the calibrations of the transponders, and, in the case of an orbiter, from the uncertainties of the orbit itself. The IAU improvements to the earth orientation procedures are below the level of $0.''001$; this is equivalent to 3 *cm* on the earth’s surface, an amount which is negligible for planetary ranging observations.

For the reduction of LLR observations, the deficiencies in the existing (1976, 1980) IAU earth orientation procedures are important, and, in fact, have been known for many years. Consequently, the JPL reductions of LLR data have used a modified EOP formulation for increased accuracy. There are no plans at present to adopt the recent IAU formulation.

3 Accuracy Level of the Ephemerides

For the four inner planets, the ephemerides are dominated by two types of data: 1) ranging measurements, whether radar reflections from a planetary surface or return signals from a transponder aboard a landed or orbiting spacecraft, and 2) ΔVLBI measurements of an orbiting or landed spacecraft w.r.t. the ICRF catalogue. The ranging measurements, taken over various parts of the planets’ orbits, provide all relative angles and distances between the earth and the other three innermost planets, thus locking the whole system together. The ranging measurements also provide accurate mean motions of the planets w.r.t. inertial space. The only feature not provided by the ranging measurements is the orientation of the whole system with respect to some exteroir reference frame. That feature is provided by ΔVLBI measurements which tie the system onto the background ICRF.

Even with such accurate observational data, the planetary motions show rather large uncertainties, for the planets are perturbed by the presence of many asteroids whose masses are quite poorly known. Furthermore, it’s not possible to solve for the asteroid masses, other than for the biggest few, because there are too many of them for the data to support such an effort. As shown by Williams (1984) and by Standish and Fienga (2002), the ephemerides of the inner planets, especially Mars, will deteriorate over time. Attempts to fit all of the observational data result in effectively smoothing over the perturbations during the intervals connecting the observations. The result is that the ephemerides have uncertainties at the 1-2 *km* level over the span of the observations and growing at the rate of a few *km*/decade outside that span.

A great deal of effort has been applied in order to represent the asteroid perturbations as well as possible. Studies of the estimations of masses of the most relevant 300 or so asteroids have been made by Fienga (2001) and by Krasinsky *et al.* (2001); Krasinsky *et al.* (2002) have also modeled a ring to represent the perturbations from the remaining thousands of small asteroids.

For Jupiter, a number of spacecraft observations exist, allowing Jupiter’s ephemeris to be known better than about 100 *km* ($0.''02$). For the outermost four planets, the only observations are optical; correspondingly, those ephemerides are accurate to only about $0.''1$ - $0.''2$.

4 Future JPL Ephemerides

There is a choice to be made in creating ephemerides; the choice involves mainly the ephemeris of Mars and is due to the uncertainties imposed by the perturbations of the asteroids.

- One may fit all of the observations as well as possible, thereby smoothing out the perturbations and creating an ephemeris which is as accurate as possible over extended periods of time.
- One may concentrate on fitting only the most recent observations so that the ephemeris into the near future (a year or two) is as accurate as possible, but thereby sacrificing the accuracy of the long-term ephemeris.

For future JPL planetary ephemerides, the intention is to make available to the general public the former type of ephemerides (such as DE405) and to create the latter type for navigational purposes and for specific scientific studies.

Certainly, any improvement in our knowledge of asteroid masses in general will provide a corresponding improvement in the computed dynamics of the planetary motions.

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References

Fienga, A.G., private communication, (2001)

Krasinsky, G.A., Pitjeva, E.V., Vasilyev, M.V., Yagudina, E.I., *Russian Academy of Sciences / Institute of Applied Astronomy*, "Estimating Masses of Asteroids", **139** (2001)

Krasinsky, G.A., Pitjeva, E.V., Vasilyev, M.V., Yagudina, E.I., *Astron. Astrophys.*, "Hidden mass in the asteroid belt", to appear (2002)

Standish, E.M., *Astron. Astrophys.*, "Time Scales in the JPL and CfA Ephemerides", **336**, 381-384 (1998)

Standish, E.M. and Fienga, A.G., *Astron. Astrophys.*, "Accuracy limit of modern ephemerides imposed by the uncertainties in asteroid masses", Astronomy and Astrophysics, **384**, 322-328 (2002)

Williams, J.G., *Icarus*, "Determining Asteroid Masses from Perturbations on Mars", **57**, 1-13 (1984)