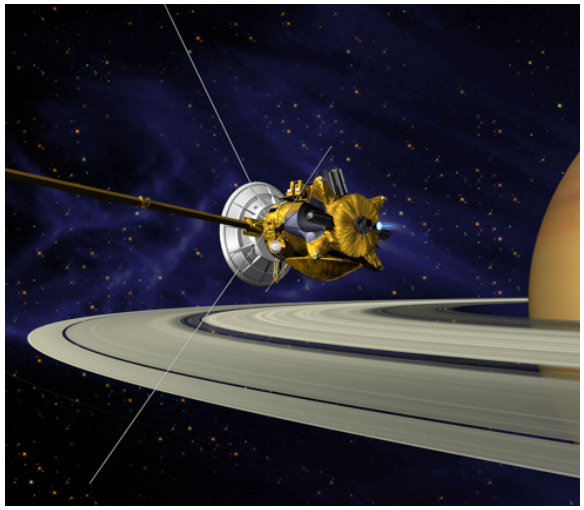
Improving the Planetary Ephemeris with VLBA Astrometry: Transitioning from Cassini to Juno

D. L. Jones (SSI)

W. M. Folkner, R. A Jacobson, C. S. Jacobs (JPL)

J. Romney, V. Dhawan, E. Fomalont (NRAO)



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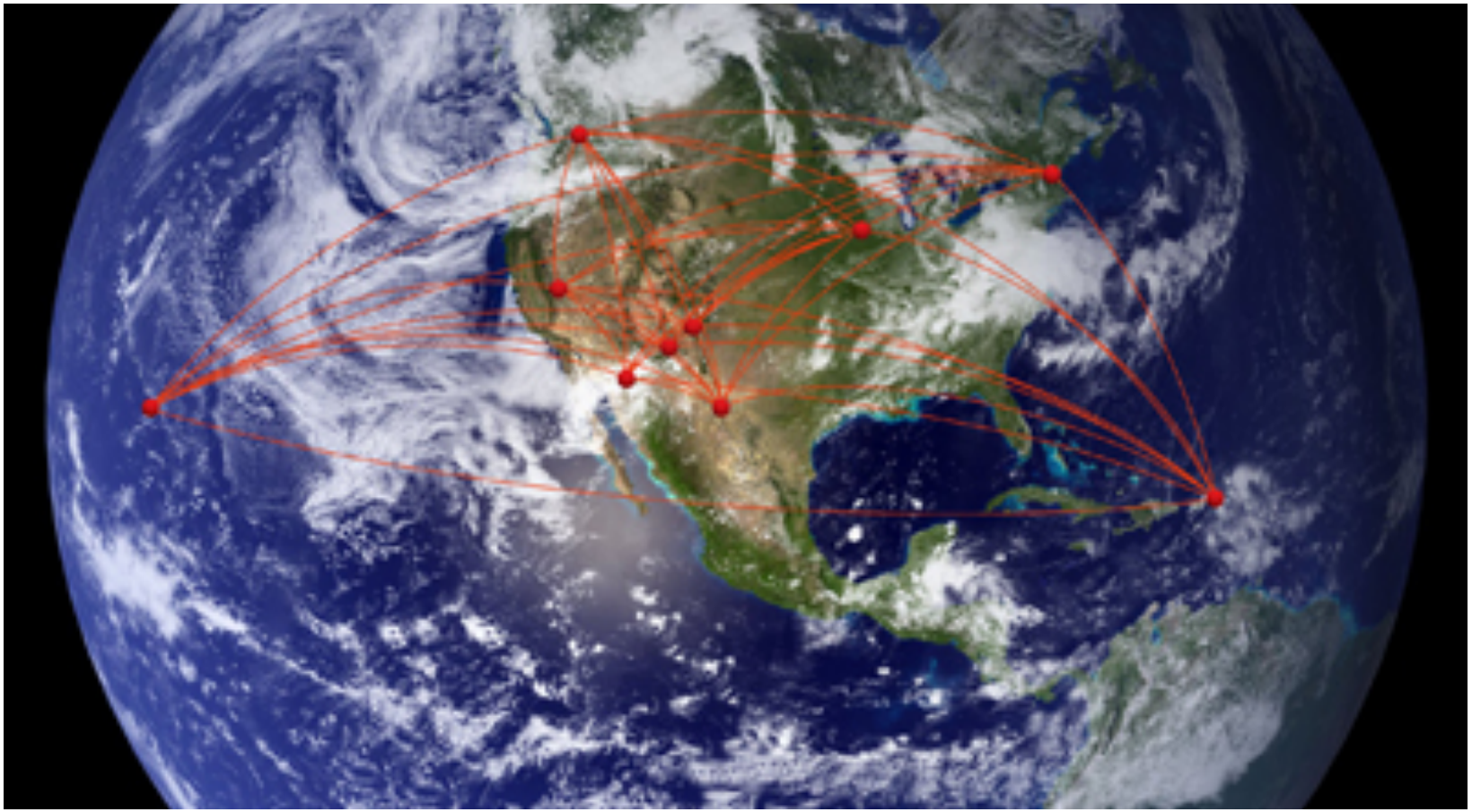
Planetary Ephemeris

- Used for dynamical studies of the solar system, tests of general relativity, prediction of occultations and eclipses, pulsar timing, and interplanetary spacecraft navigation.
- Inner planets are tied together to a few meters in current ephemeris through radar and range tracking of multiple missions including orbiters and landers.
- Inner planet orbit orientations known to 0.25 mas from VLBI of Mars orbiters relative to ICRF
- Outer planets not as well tied to inner solar system, or to each other. (Jupiter orbit known to about ~20 mas)
- Cassini was the first outer planet mission to provide high accuracy, long term position measurements for Saturn
- Juno will be the first outer planet mission to provide high accuracy, long term position measurements for Jupiter.

Very Long Baseline Array



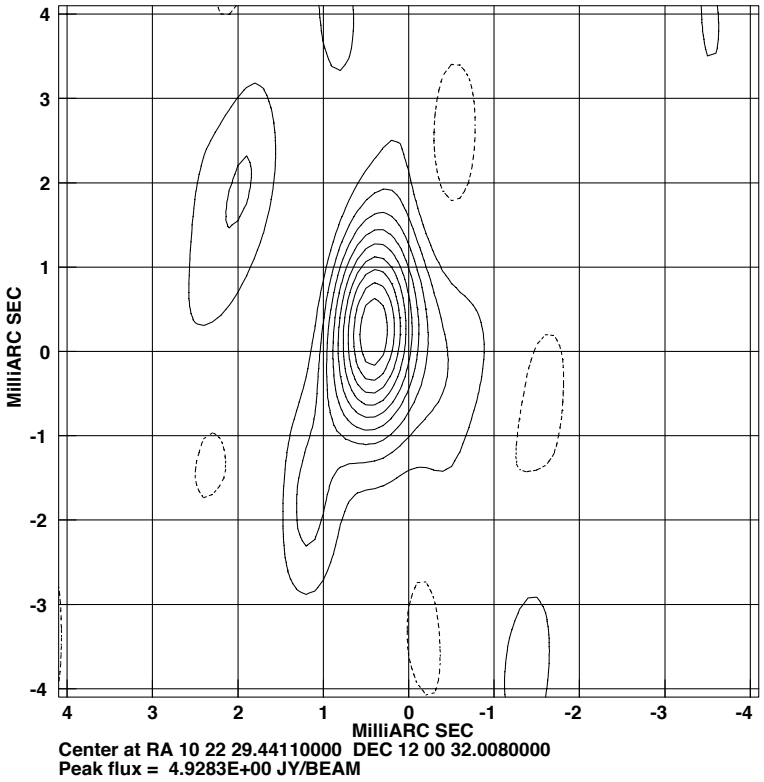
Good baseline range, good stability, good calibration, good coverage of ecliptic declinations

Phase Referenced Astrometry

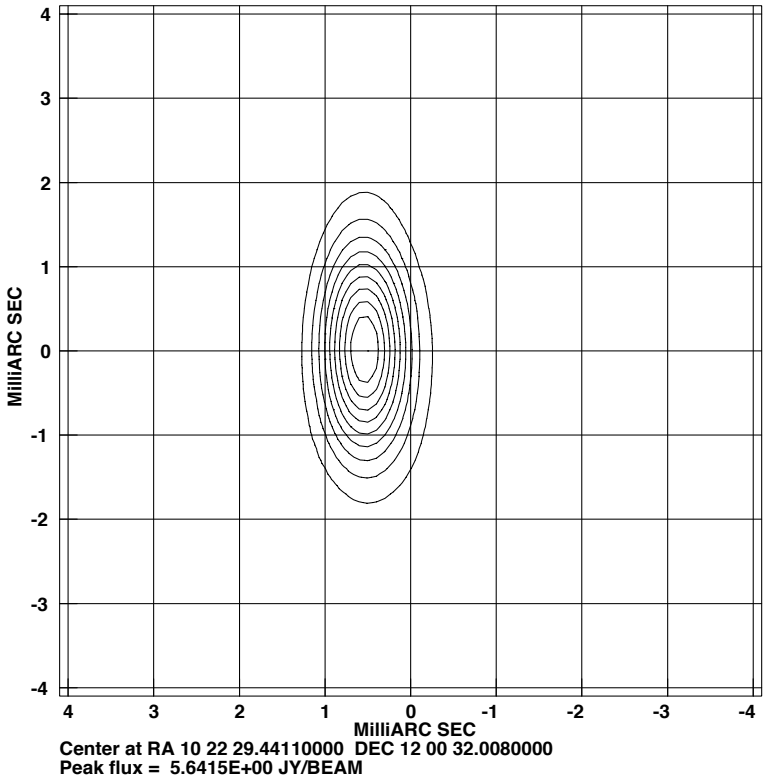
Source switching time < time scale of typical systematic errors

- Phase differencing reduces model delay errors by 1/(sep)
- Troposphere delays and souce position offsets are the main error sources in residual phase differences at X-band
- Unmodeled troposphere delay error between close sources ~ 1 ps (1λ at 8.4GHz = 120 ps)
- Best relative position accuracies are < 0.05 mas
- Our goal is ~ 0.2 mas (dominated by error in link to ICRF)

Phase-Referenced Imaging

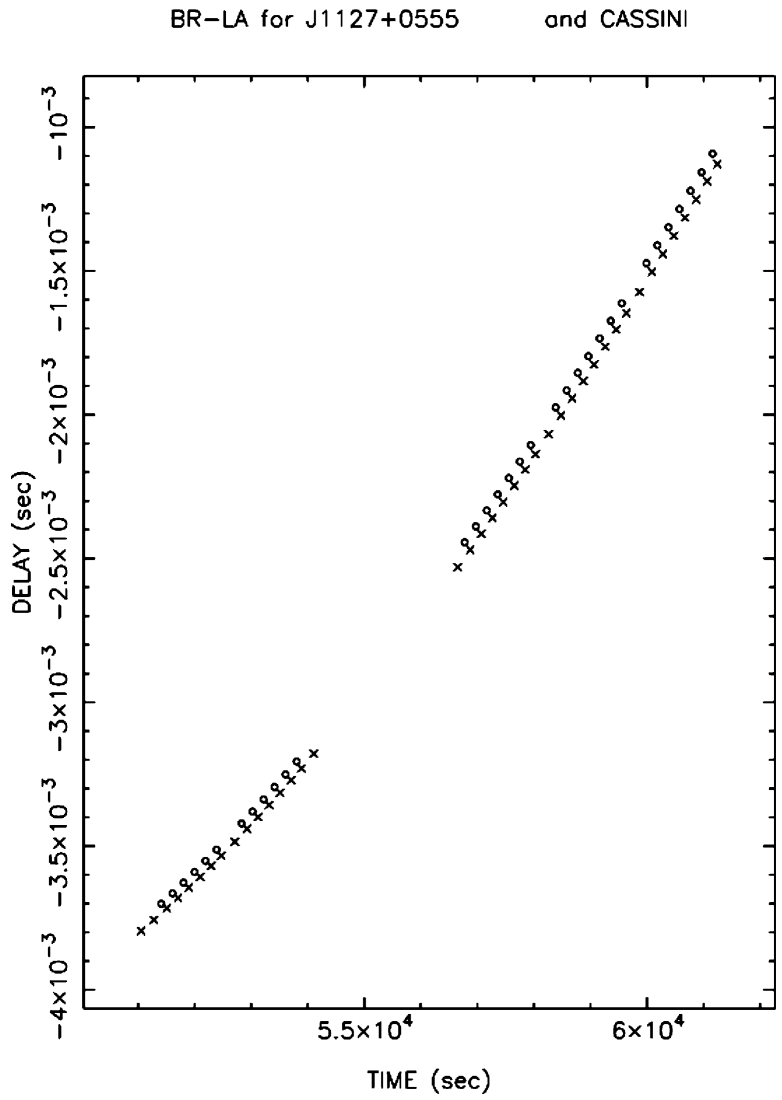


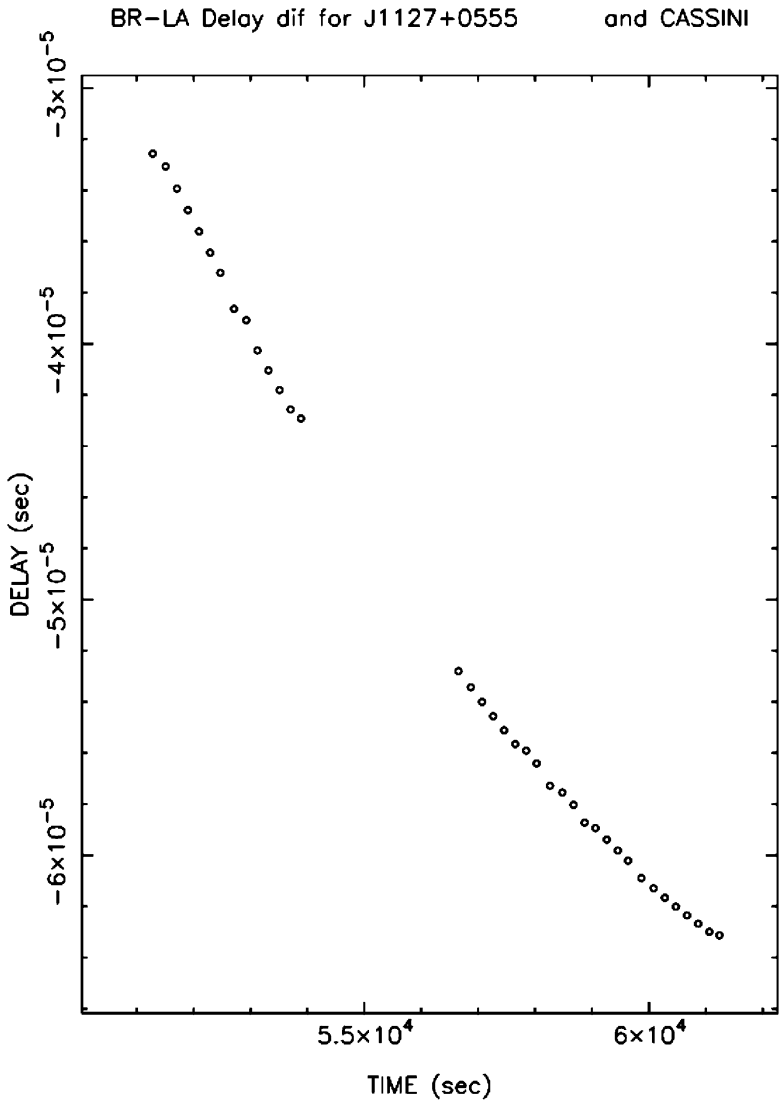
Peak flux density 4.9 Jy



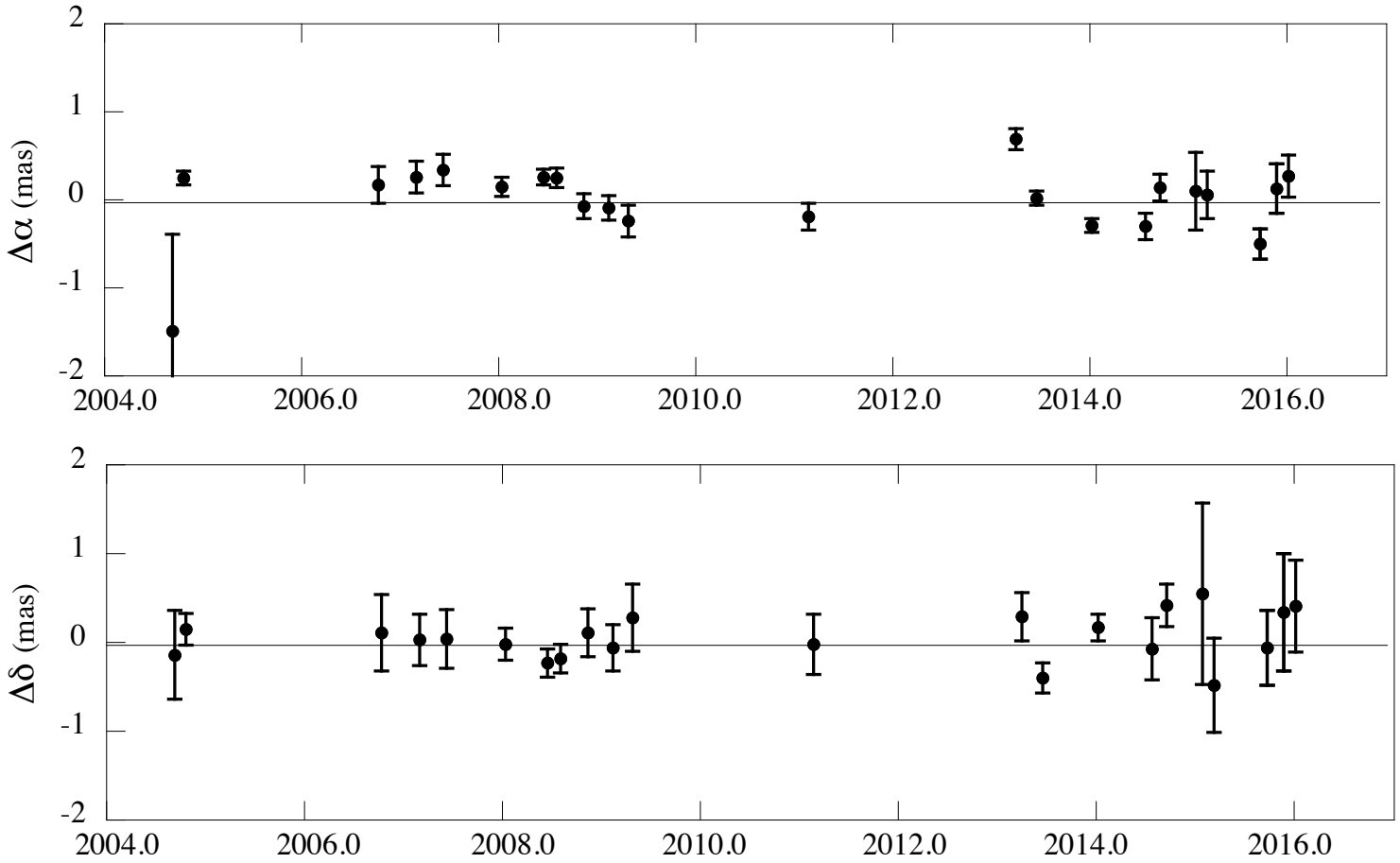
Peak flux density 5.6 Jy

Baseline Total Delays



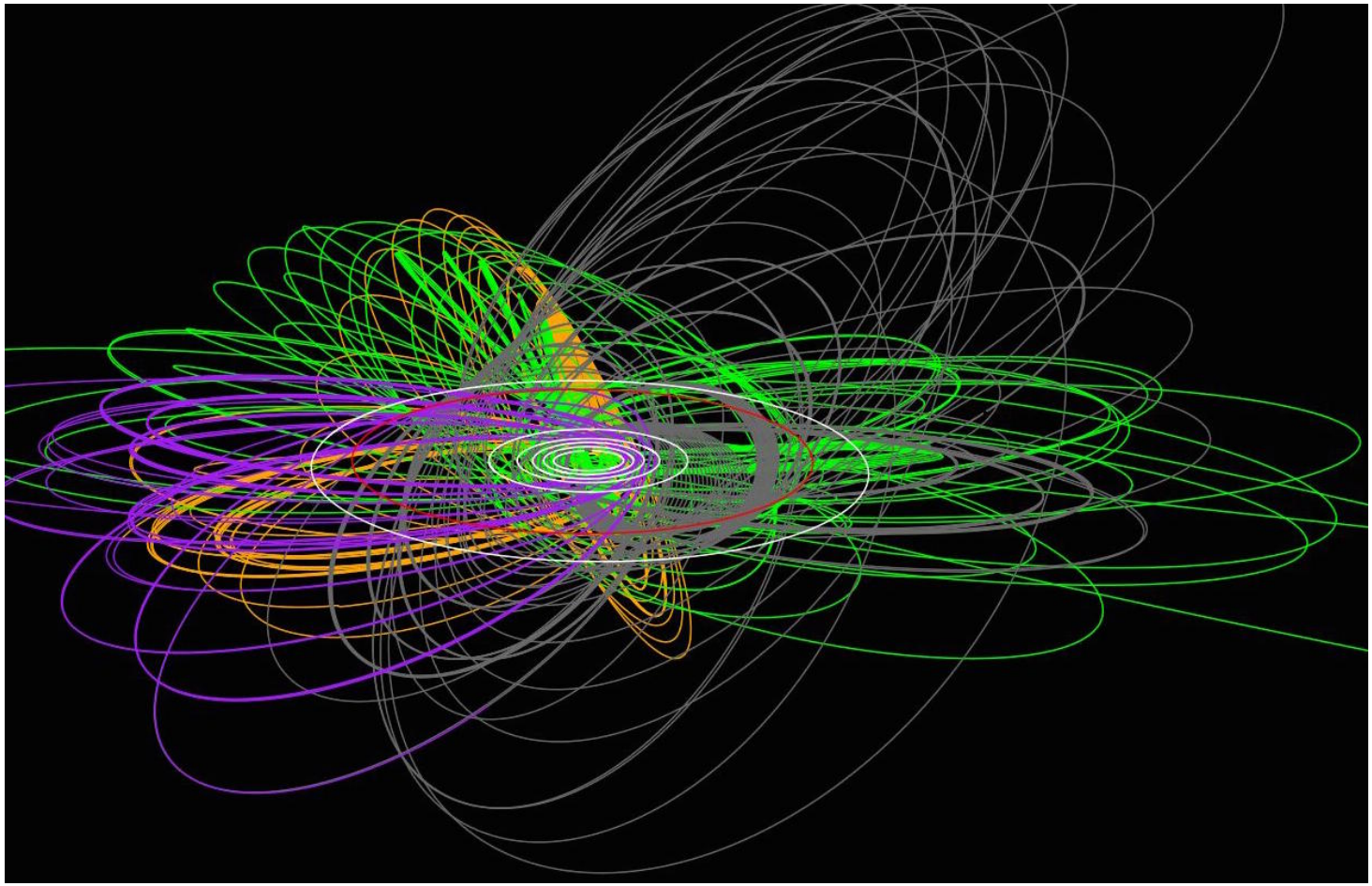


Cassini VLBA Data



- VLBA observations determine Saturn orbit plane to ~ 0.25 mas.
- Uncertainty limited by position of phase reference sources.
  - Improving with follow-up quasar observations.

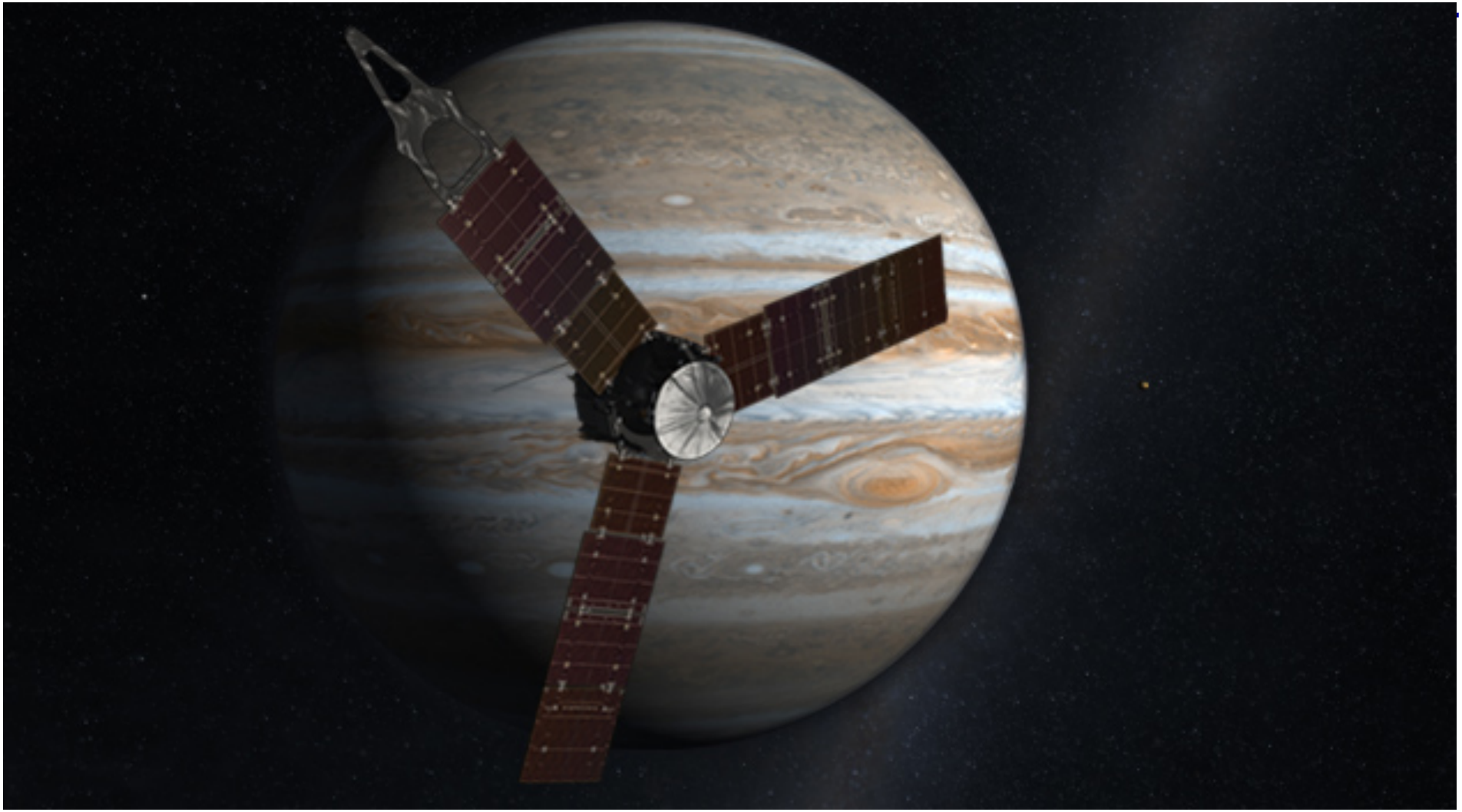
Cassini Orbit Determination



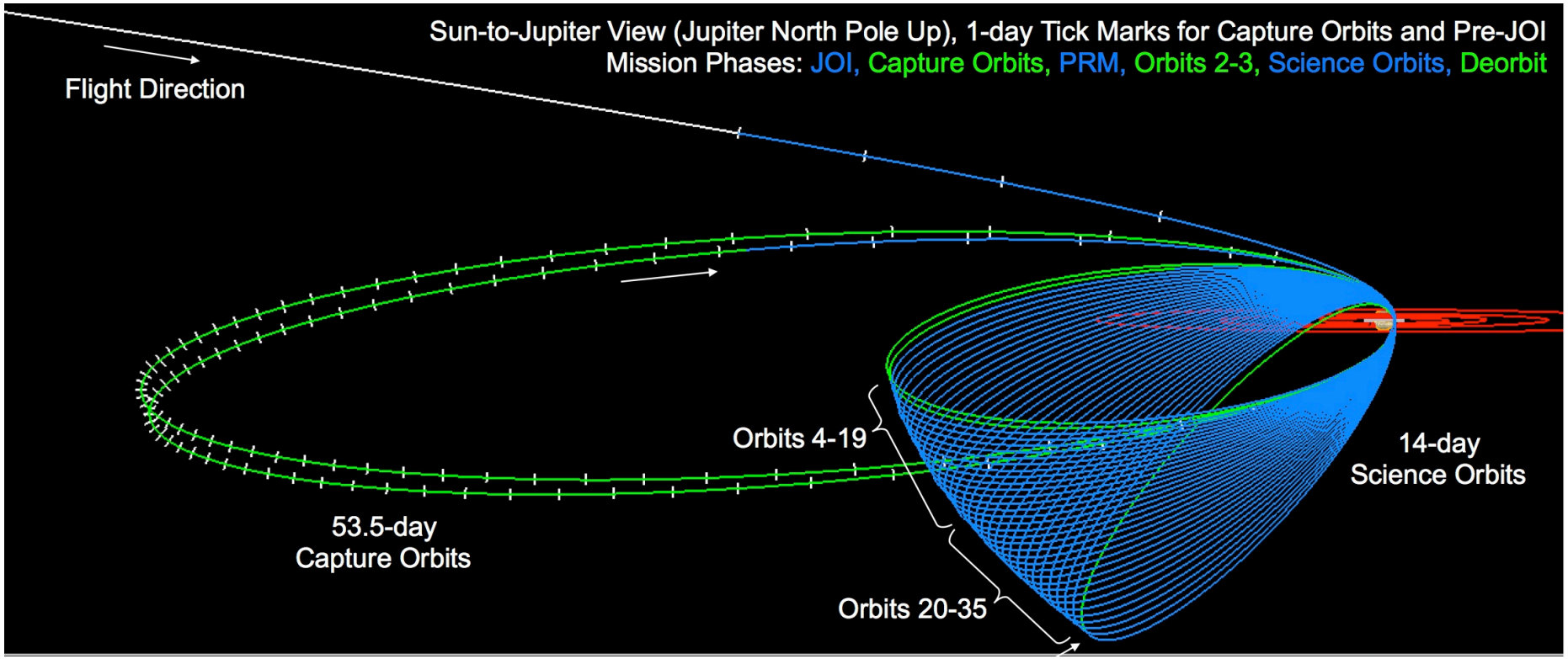
Unlike inner planet orbits, Cassini orbit period is much longer than one day.

Most orbits include multiple maneuvers and one or more satellite flybys.

(Figure provided by W. M. Folkner, JPL)



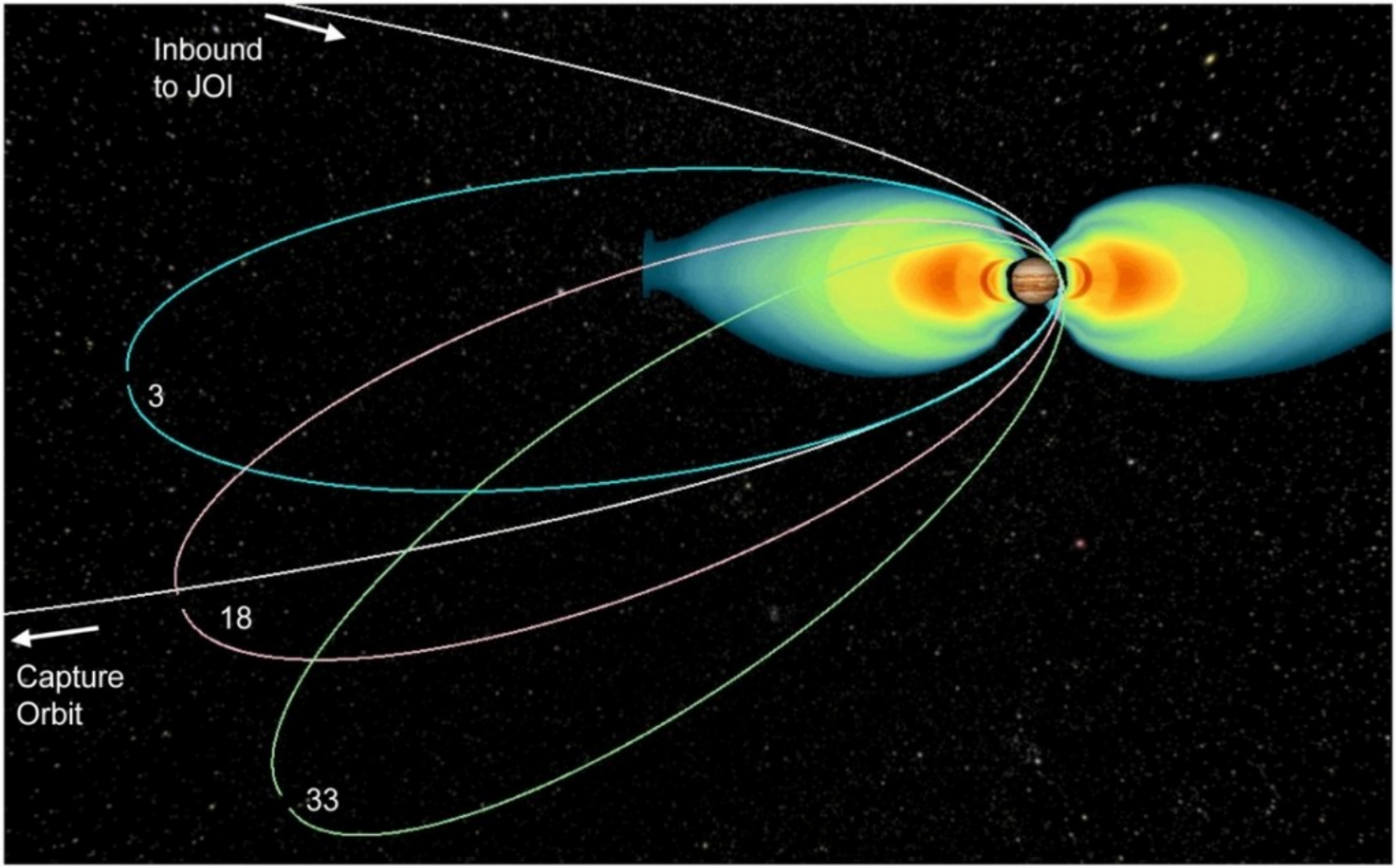
Juno Orbit 2016-2018



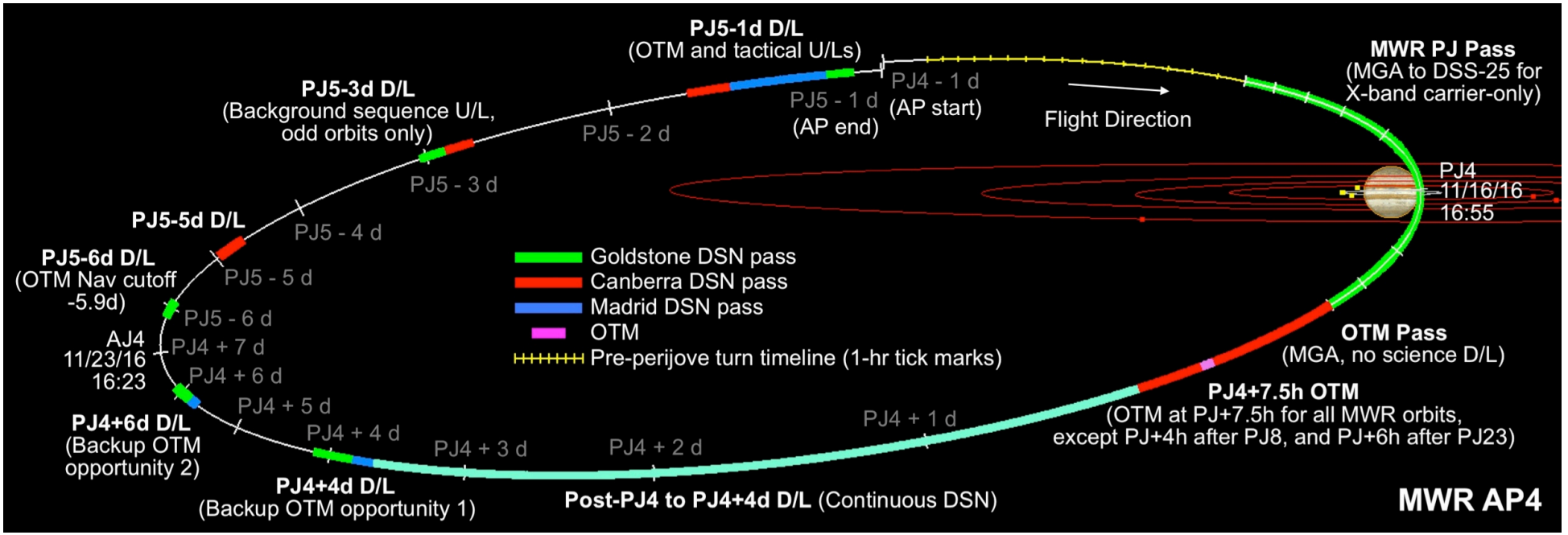
- Jupiter orbit insertion 5 July 2016.
- Low altitude flyby every orbit; Doppler will provide good orbit.
- Initial mission duration covered less than ¼ of Jupiter orbit.
- Longer orbit period extends range of Jupiter orbit longitudes covered.

(Figure provided by W. M. Folkner, JPL)

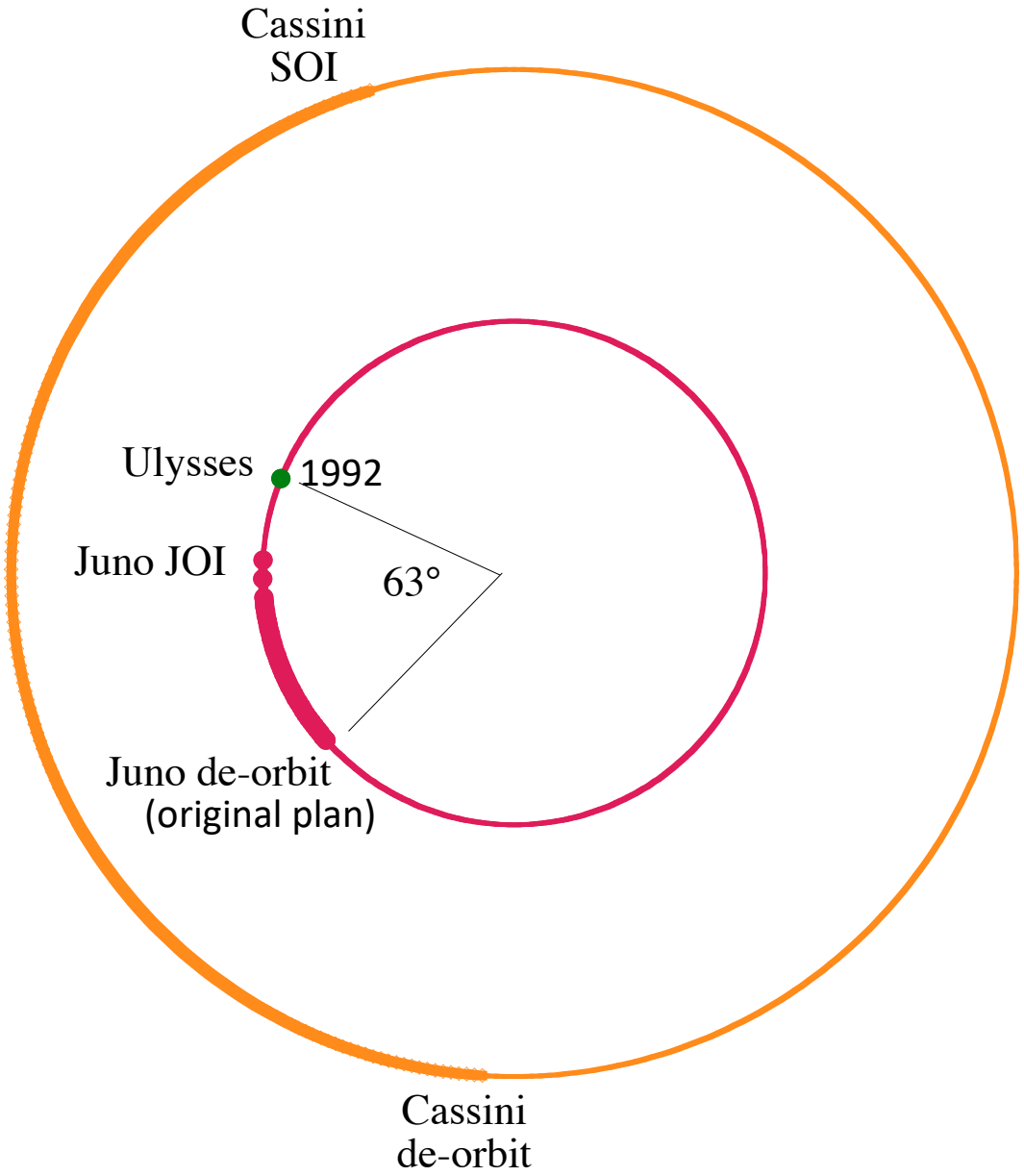
Orbit Design to Minimize Radiation Exposure



Juno DSN Tracking Plan

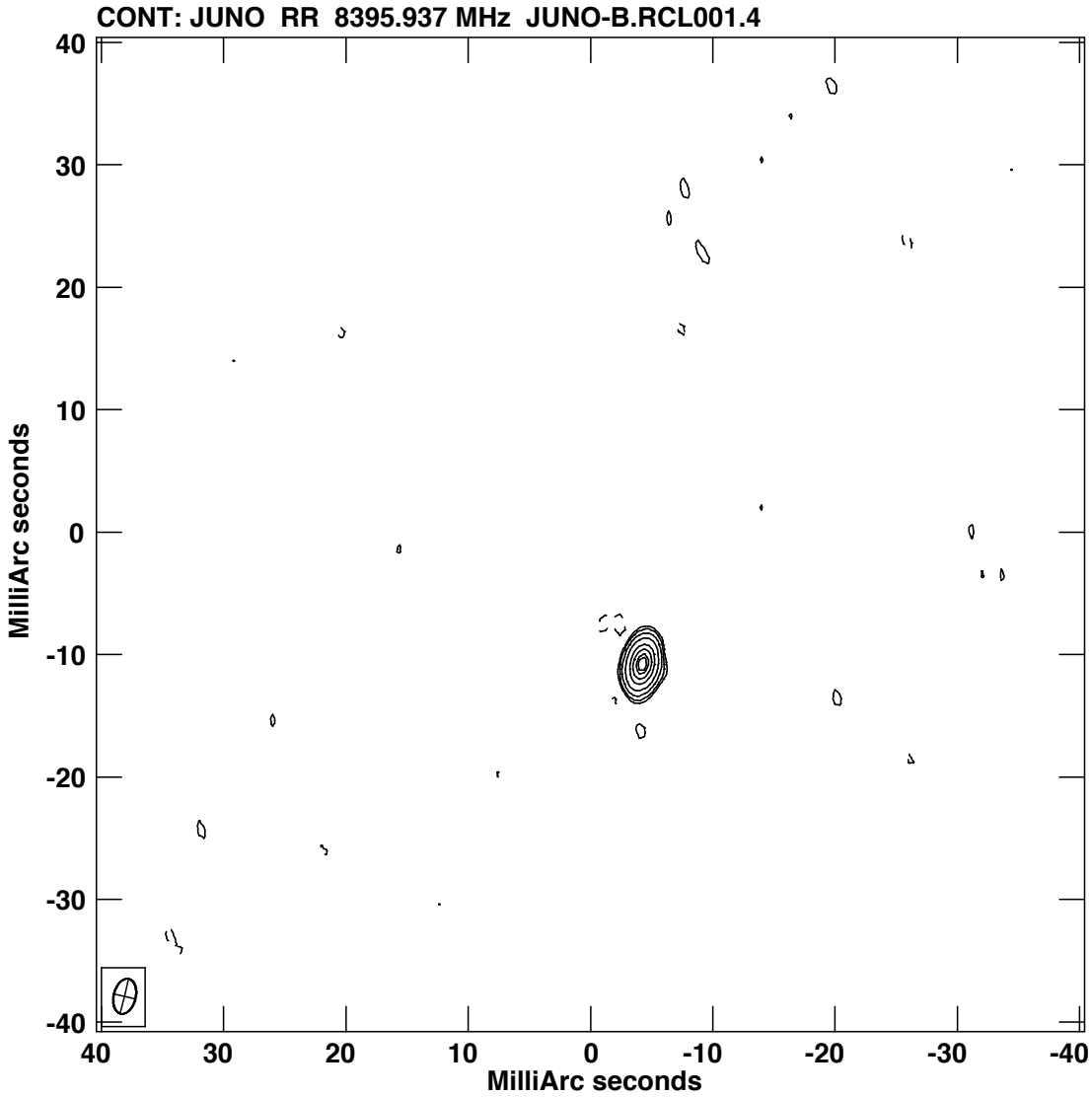


Ecliptic longitude coverage

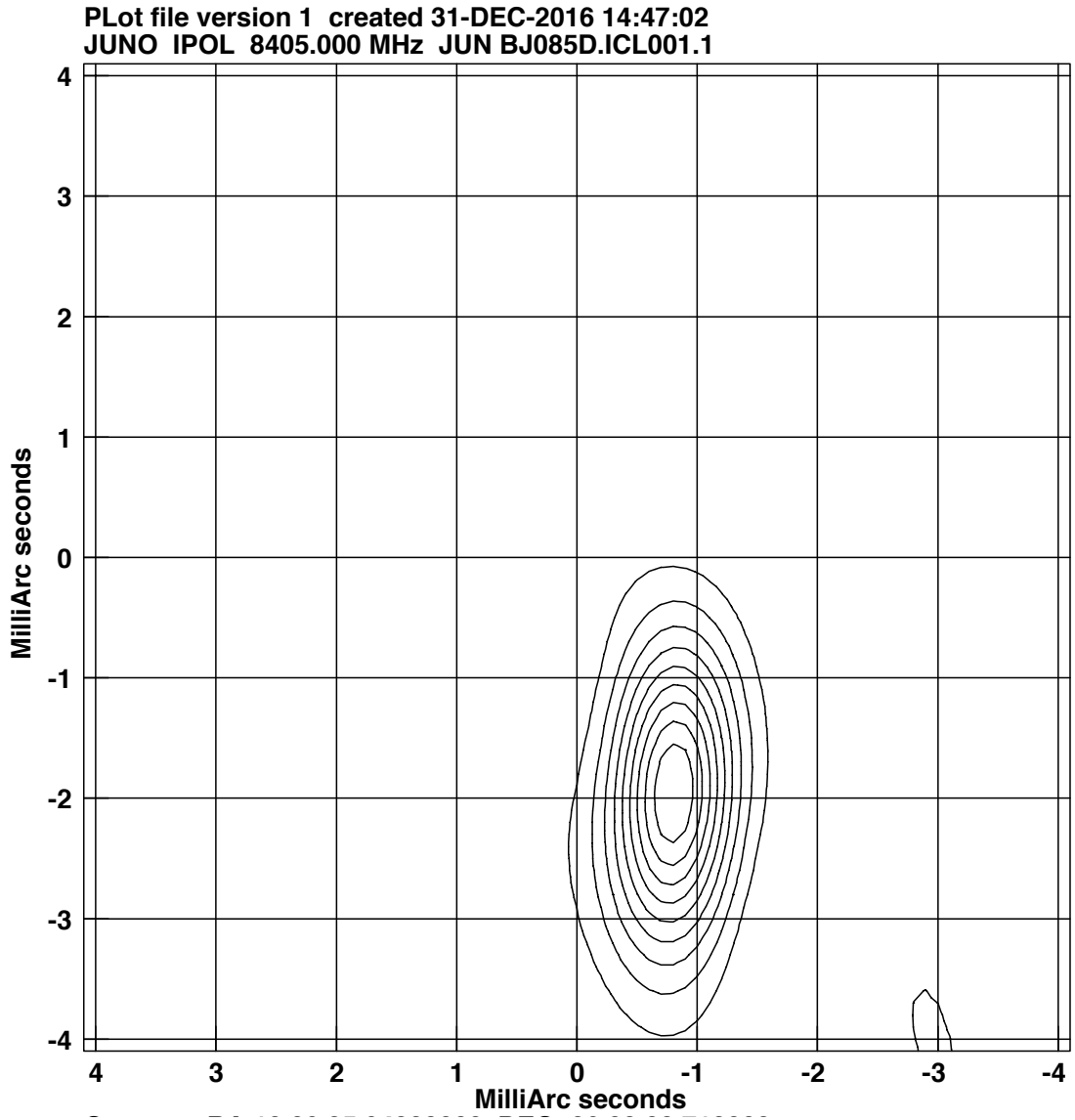


(Figure provided by
W. M. Folkner, JPL)

VLBA Observation of Juno during Cruise



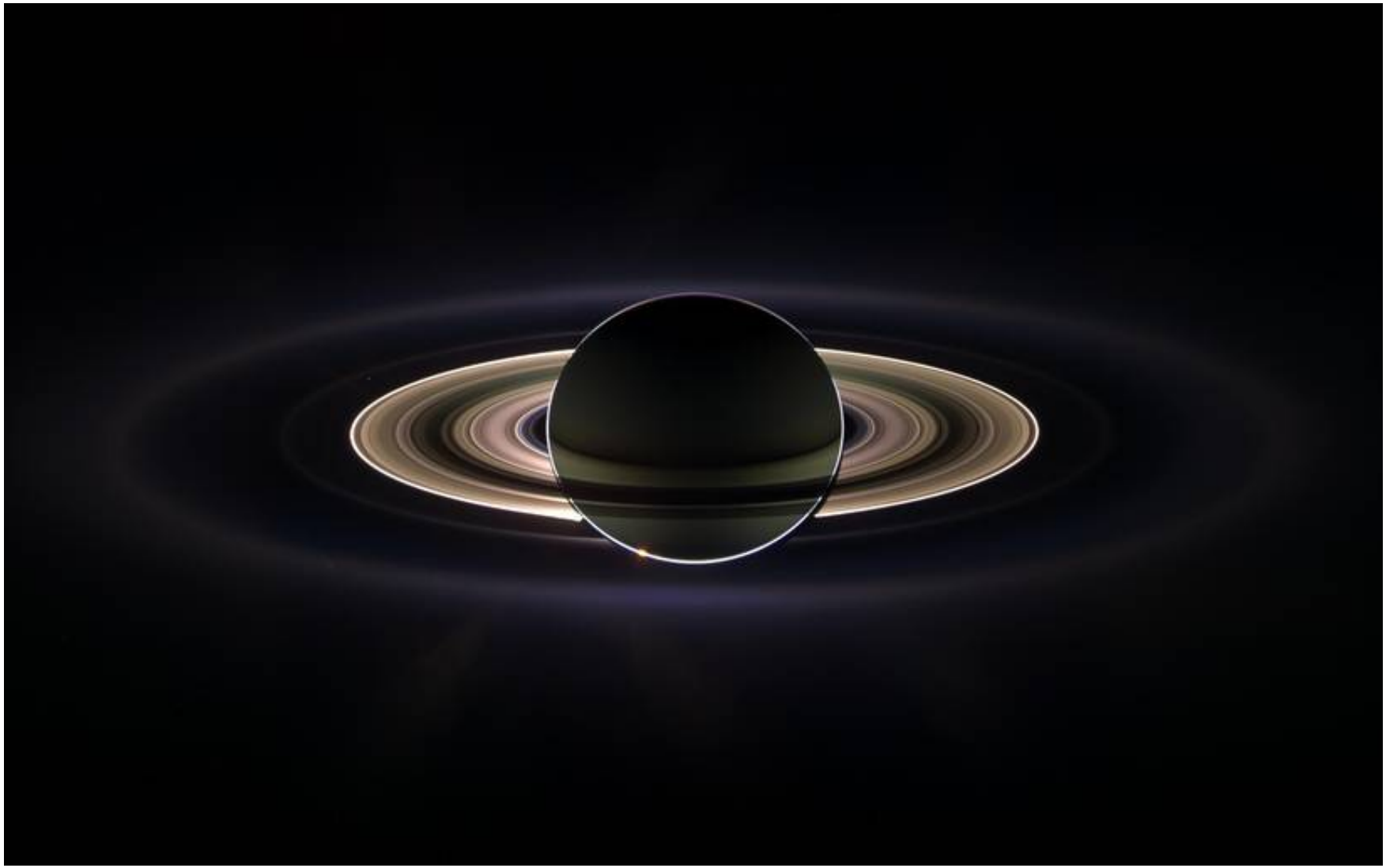
VLBA Observation of Juno during PJ3



Summary

- VLBA astrometry of spacecraft orbiting other planets provides the highest accuracy link to the ICRF
- Improved planetary orbits reduce mission delta-V (and fuel) requirements, allow extended mission duration
- Troposphere delay calibration remains challenging
- Continuing VLBI observations of reference sources are providing ever increasing position accuracies
- This technique is applicable to all future interplanetary missions, but long-duration orbiters will provide the greatest improvement in the accuracy of the planetary ephemeris

Cassini view of Saturn backlit by Sun



Reference Source Structure