JPL planetary ephemerides
Accuracy and implications for pulsar timing

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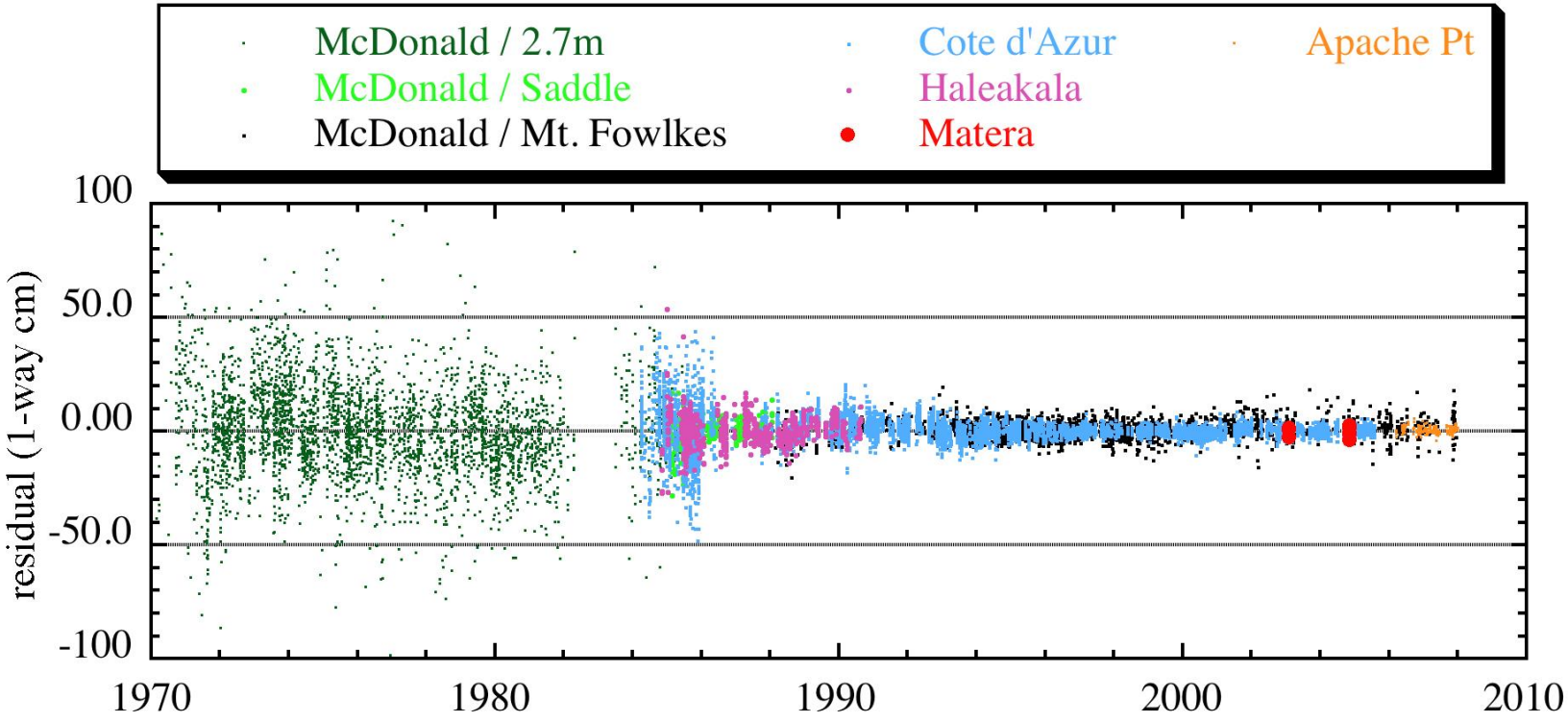
Outline

- Data used for planetary ephemerides
  - Ranging
  - VLBI
- Stability and accuracy of Earth orbit w.r.t Sun.
- Solar System Barycenter
  - Definition
  - Changes in Uranus and Neptune
- Changes and accuracy of Earth w.r.t. SSBC

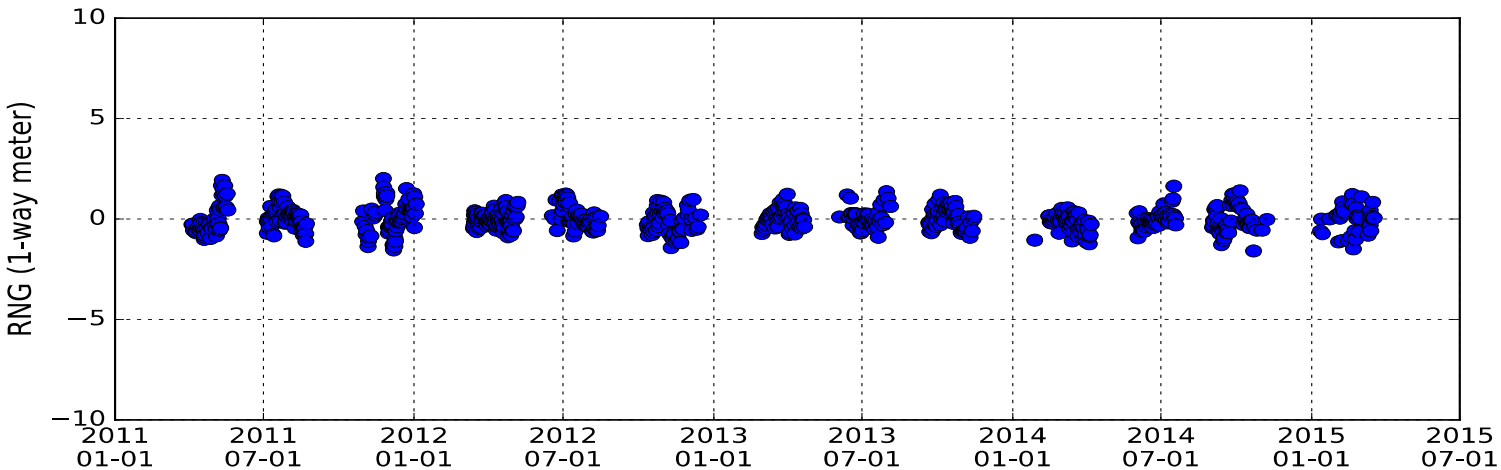
Lunar Laser Ranging

- LLR data from several observatories to 4 retroreflectors
  - Accuracy improvement due to laser technology advance
  - Currently limited by retroreflector array distribution and lunar model
    - Strong correlation of semi-major axis and Earth+Moon GM

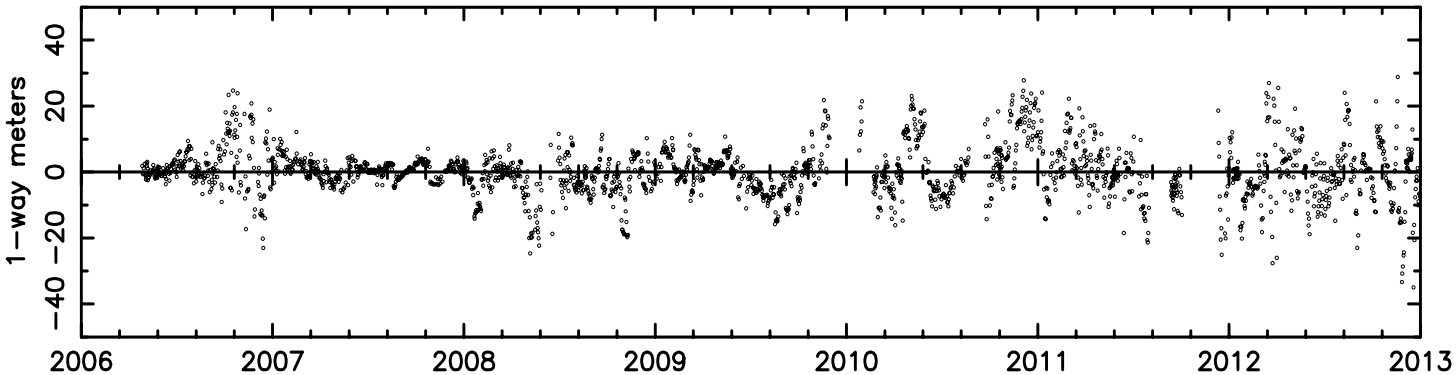


Mercury and Venus Data

MESSENGER Range at Mercury

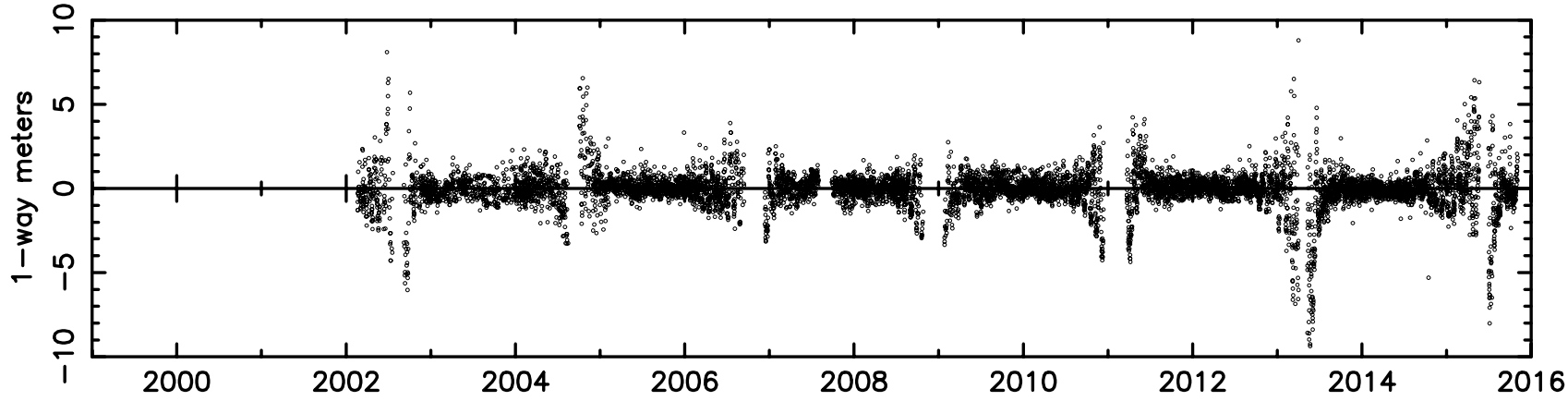


Venus Express Range

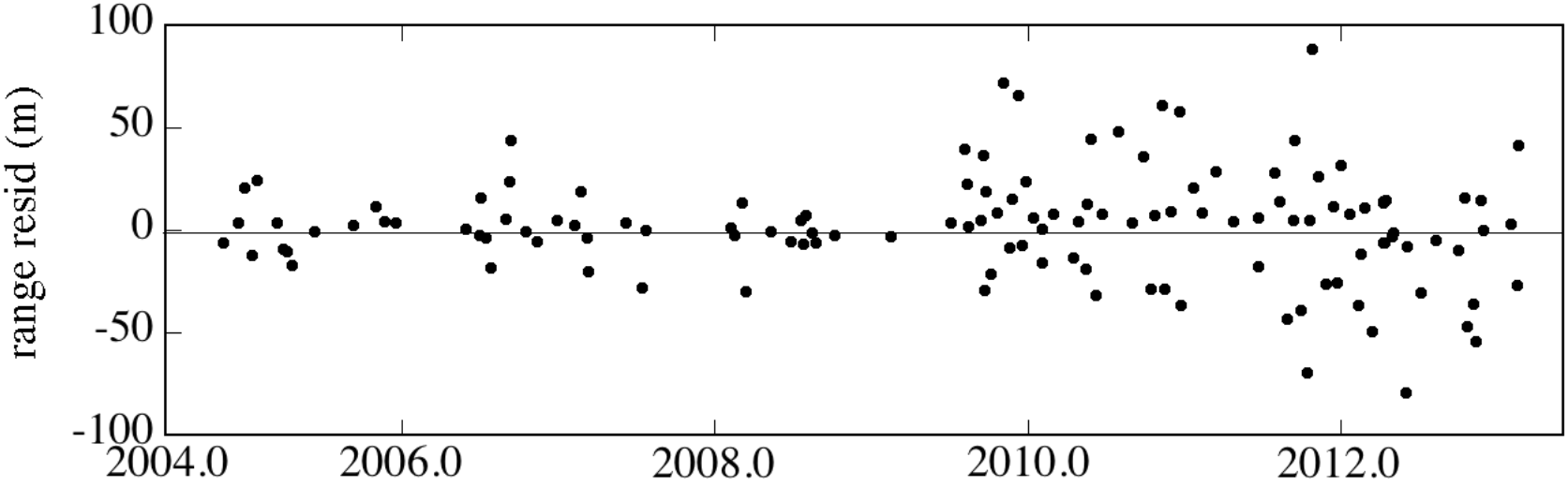


Mars & Saturn Range

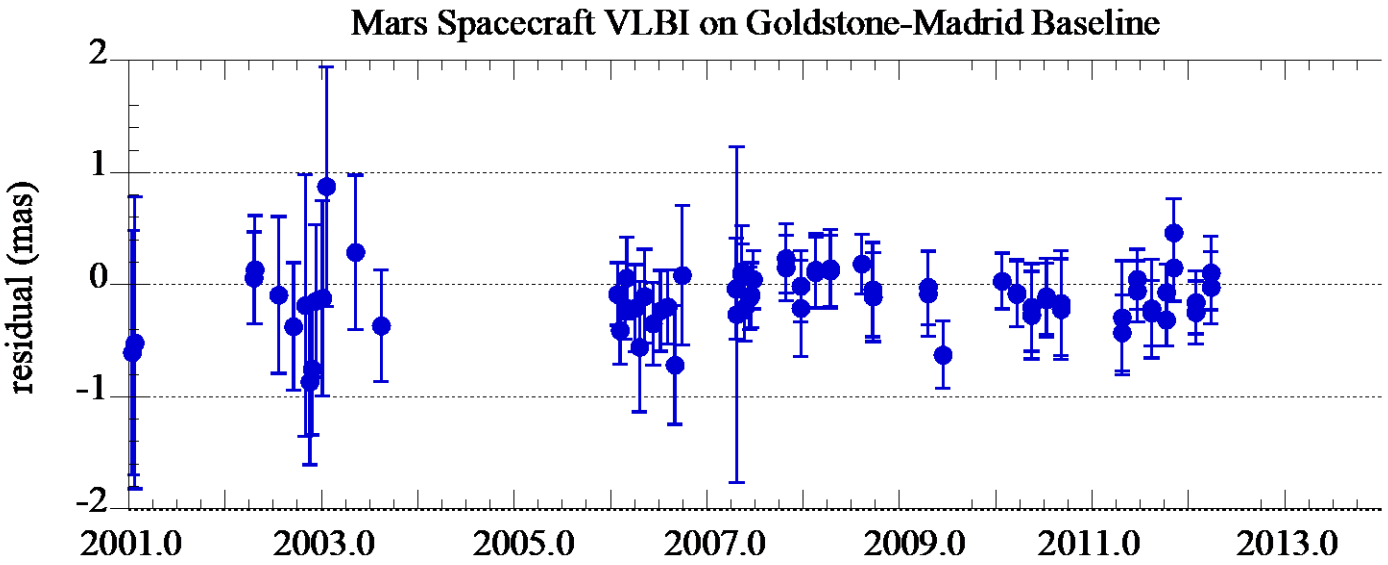
Mars Odyssey Range

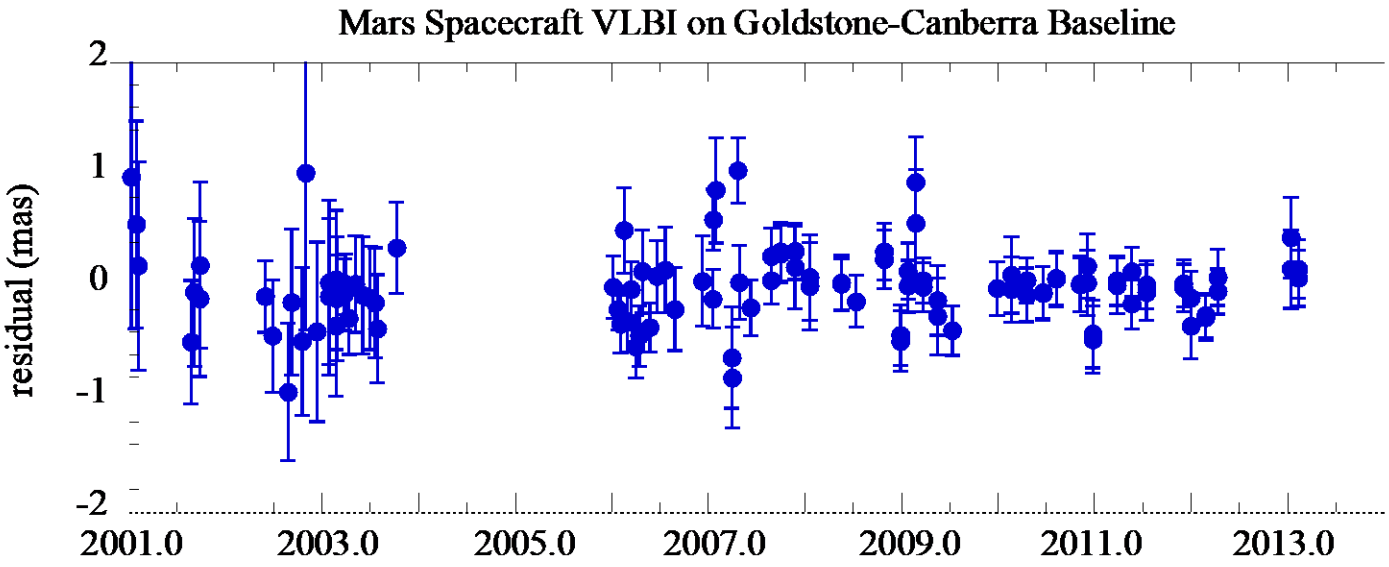


Cassini Range at Saturn



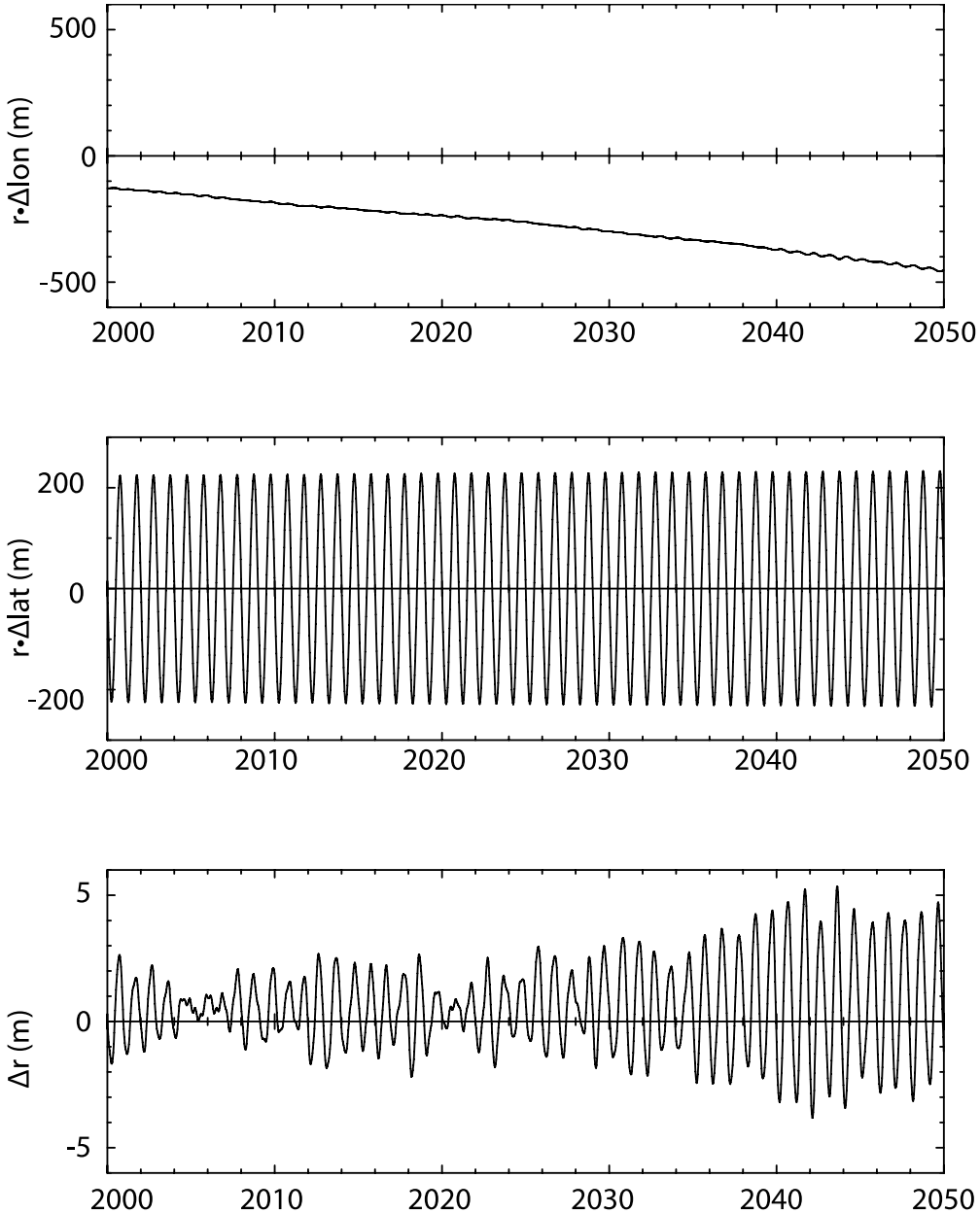
Mars VLBI Data





Earth relative to Sun, DE421 – DE430

- Earth-Sun distance stable to ~5 meters.
- Change in ecliptic longitude at 2000.0 and variation in latitude reflect VLBI accuracy.
  - ~1.5e8km*1.5 nrad
- Drift in longitude reflects change in mean Earth-Sun distance.



Solar System Barycenter

- Solar system center of mass is defined by invariant quantity under EIH equations of motion:

$$\vec{R} = \left(\sum_j m_j^* \vec{r}_j\right) \Big/ \left(\sum_j m_j^*\right)$$

$$m_j^* = GM_j \left[1 + \frac{v_j^2}{2c^2} - \frac{1}{2c^2} \sum_{k \neq k} GM_k / r_{jk}\right]$$

- Because tidal effects are not included, this is not quite invariant
  - Difference is ~1 mm/century
- Barycenter shift ~100 km with dwarf planets (e.g. Sedna)

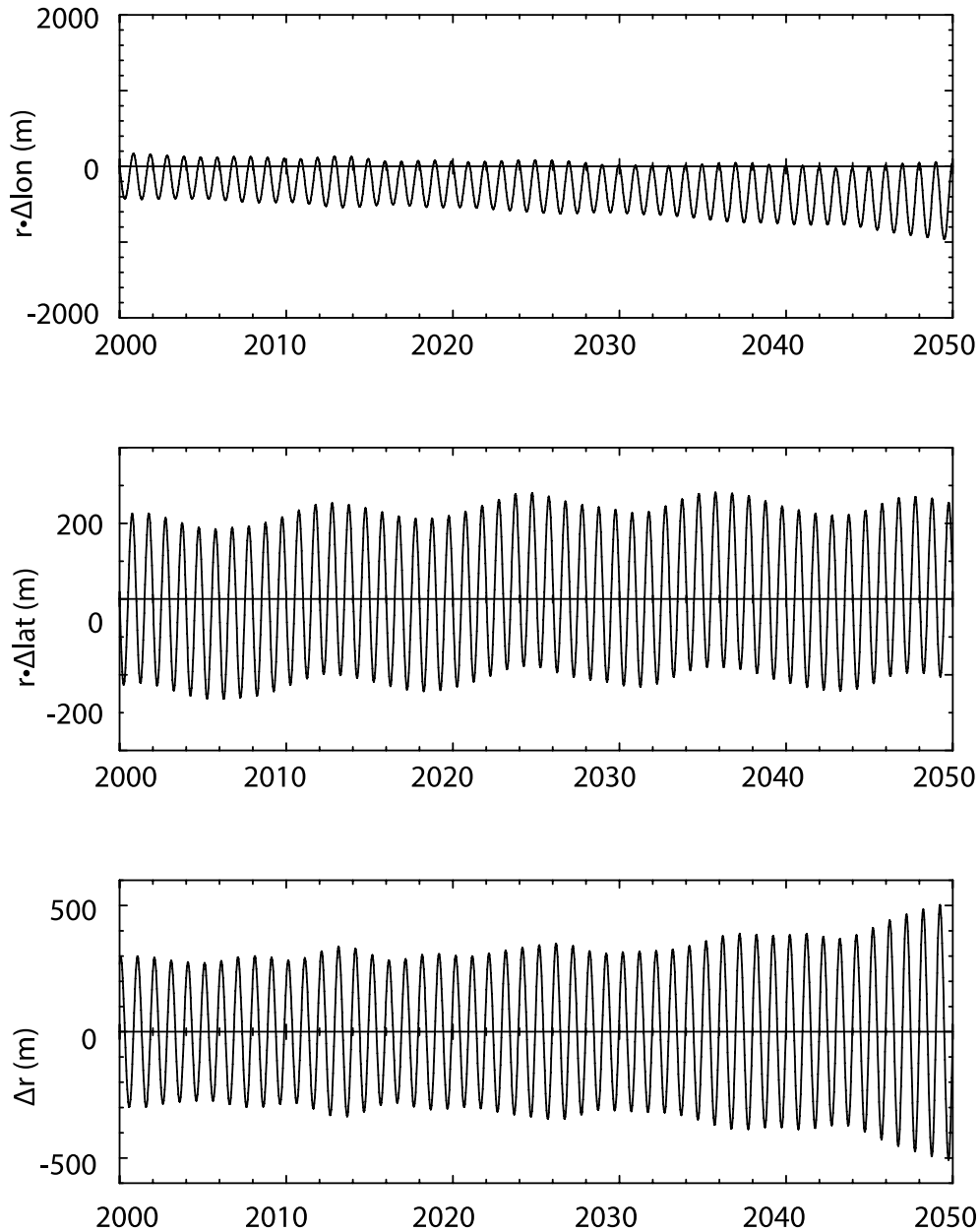
- Recent changes in barycenter mainly due to Uranus and Neptune

Uranus and Neptune Mass Changes

- DE421, 2008
  - GM7 = 5794548.6, GM8 = 6836534.9
- Jacobson, 2009, AJ, 137:4322-4329,
  - GM8 = 6836527.1 +/- 10.0 km^3/s^2
- DE430, 2013
  - GM7 = 5794548.6, GM8 = 6836527.1
- Jacobson, 2014, AJ, 148:76
  - GM7 = 5794556.4 +/- 4.3 km^3/s^2
- DE436, 2016
  - GM7 = 5794556.4, GM8 = 6836527.1

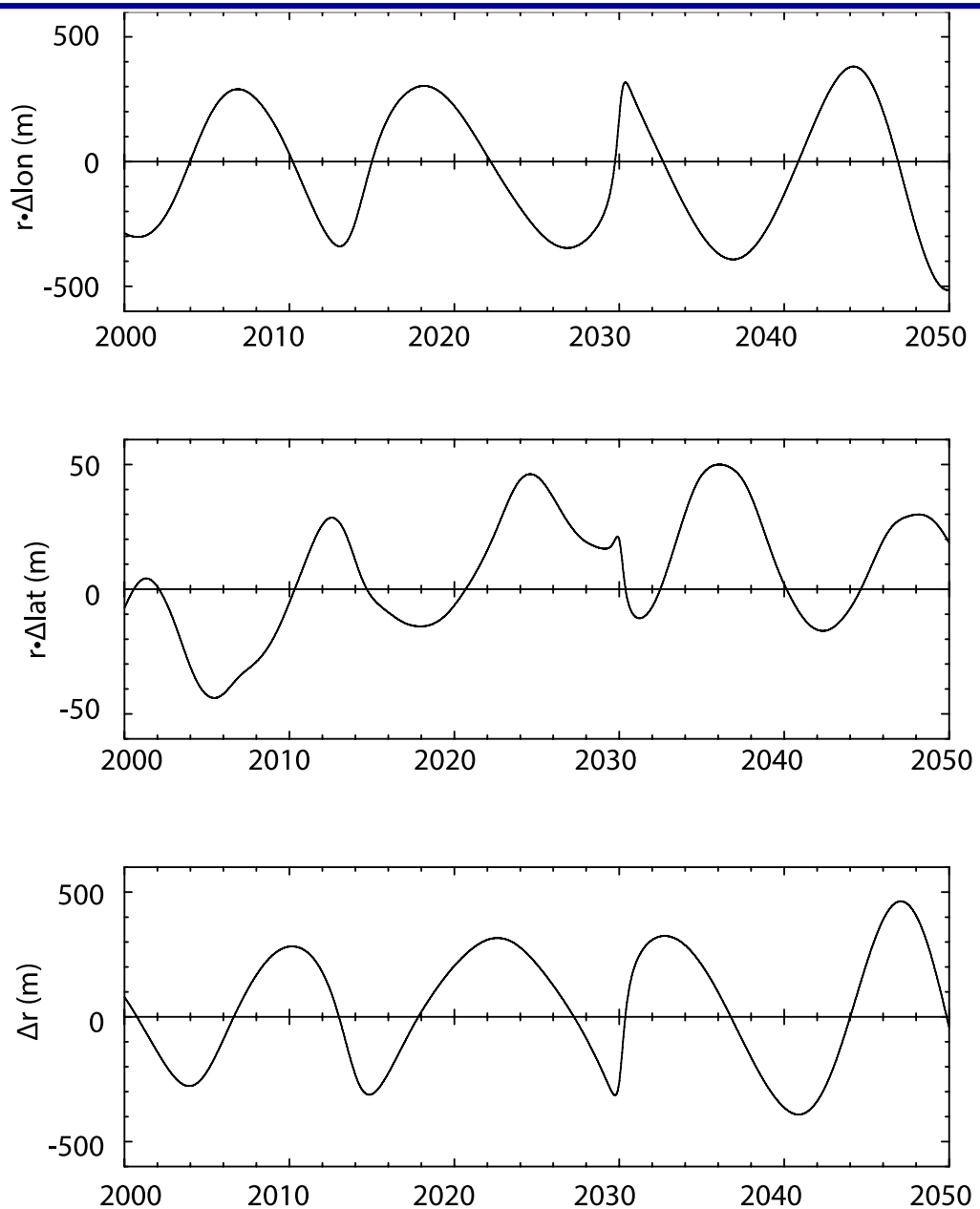
Earth w.r.t SSBC, DE421-DE430

- Change in distance of Earth w.r.t SSBC not understood.
- Related to change in orbit of Sun with respect to SSBC.



Sun w.r.t SSBC, DE421-DE430

- Change in orbit of Sun mostly in ecliptic plane.
- Quasi-periodic at Jupiter orbit period.
- Larger change than expected given change in Jupiter orbit and Jupiter/Sun mass ratio.



What's Next?

- Juno mission expected to give accurate range to Juno from 2016 to 2021.
  - May result in more stable Jupiter-Sun distance like Earth-Sun.
  - May then give more stable Sun orbit.
- Can be tested in 1-2 months making simulated data.

- Other ideas?

Acknowledgement

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