Can Planetary SLR Measure the Expansion of the Solar System?

David E Smith
Maria T Zuber, Antonio Genova

Massachusetts Institute of Technology
Cambridge, MA USA

20th International Workshop on Laser Ranging
Helmholtz Center, Potsdam

Oct 9-16, 2016

- Although never observed or proven, it has been suggested the gravitational constant, *G*, could change over time.

- The best and latest estimate of the change in *G* is:
  (*Gdot*/*G*) = (-0.6 ± 1.1) x 10^{-12} (Zhu et al., *ApJ, 809*, 41, 2015) from a 21-year timing study of a pulsar binary, and is consistent with zero .

- A very early estimate by van Flandern (*ApJ, 248,* 813-816, 1981) arrived at:
  (*Gdot*/*G*) = (-6.4 ± 2.2) x 10^{-11} from lunar occultation, lunar laser ranging, and planetary radar.

- A change in *G* affects everything in the universe, but within the solar system we also governed by the distribution of mass, particularly the mass of the Sun.

- The estimated change in solar mass (*M*) from the conversion of H to He is:

  $(\dot{M}/M) = -0.07 \times 10^{-12}$/year

  (see Stanford and Cornell solar websites).

- In addition, there is a loss of solar mass due to the solar wind, estimated to be:

  $(\dot{M}/M) = -0.02 \times 10^{-12}$/year, leading to a total of:

  $\sim -0.1 \times 10^{-12}$/ year

  assuming the rate of loss is constant over the rest of the life of the sun.

- Interestingly, all estimates suggest a decrease in *GM* of the sun over time.
- But the estimates range for 6×10^{-11} to 1×10^{-13} /year.
- Planetary ranging may be able to place an upper bound on these numbers by measuring the changes in distance between planets.

So What is the Effect of a Change in *GM* of the Sun on the Positions of the Planets?

- Assume the present understanding and knowledge of the positions of the planets.

- Assume that there could be a change in the *GM* of the sun of -$1x10^{-12}$ per year.

- Then resulting change on the position of the planets is given, approximately, in the following charts (by Antonio Genova).

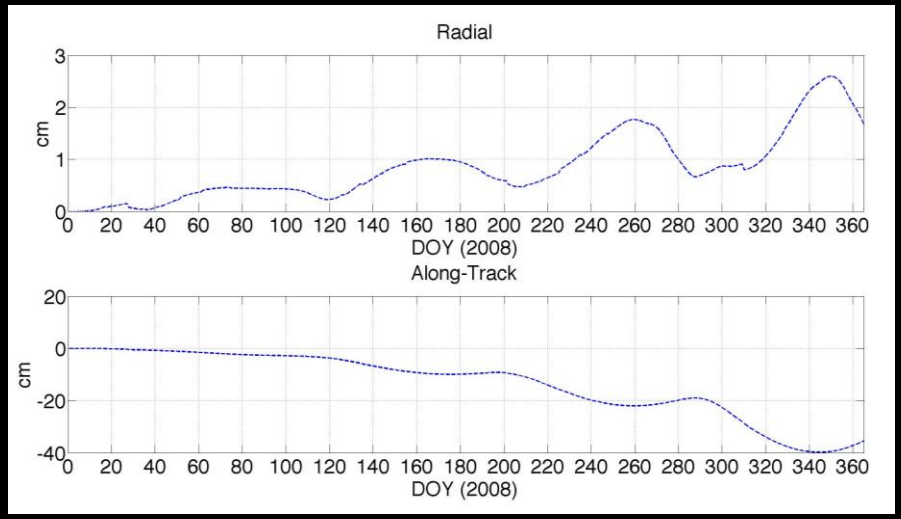
- It is not just a scaling of the solar system, but also of the velocity of the planets because angular momentum is conserved during the change of GM.

($150x10^{6}$ km x 10^{-12} = 1.5 x 10^{-4} km = 15 cm/year)

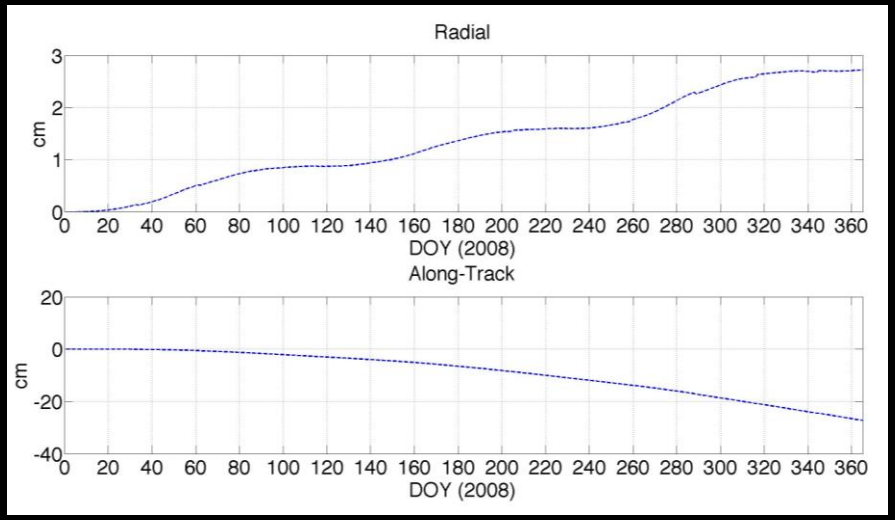
The following calculations are approximate.

Changes in the orbits of the planets are not intuitive

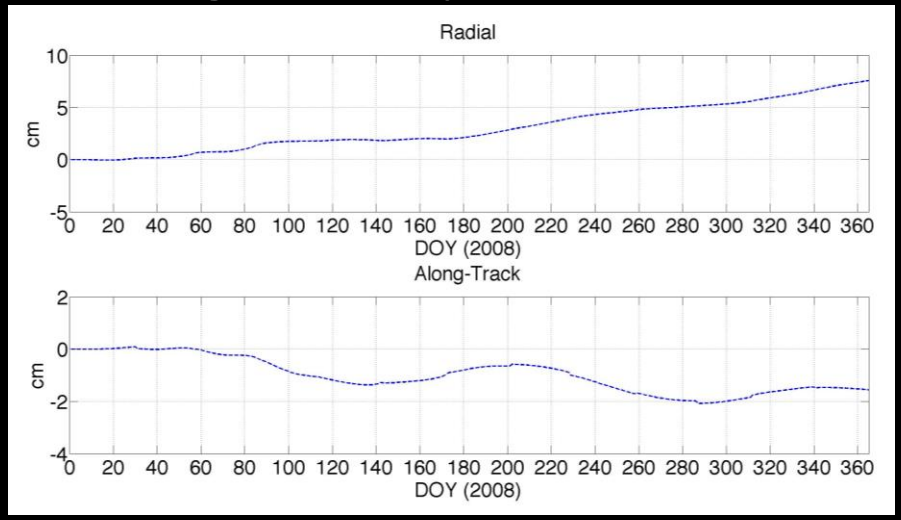
Change in the position of Mercury



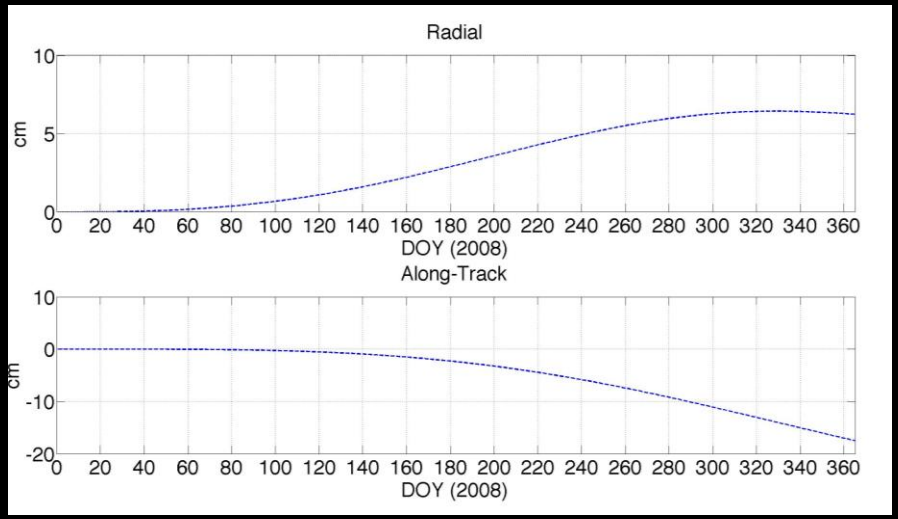
Change in the position of Venus



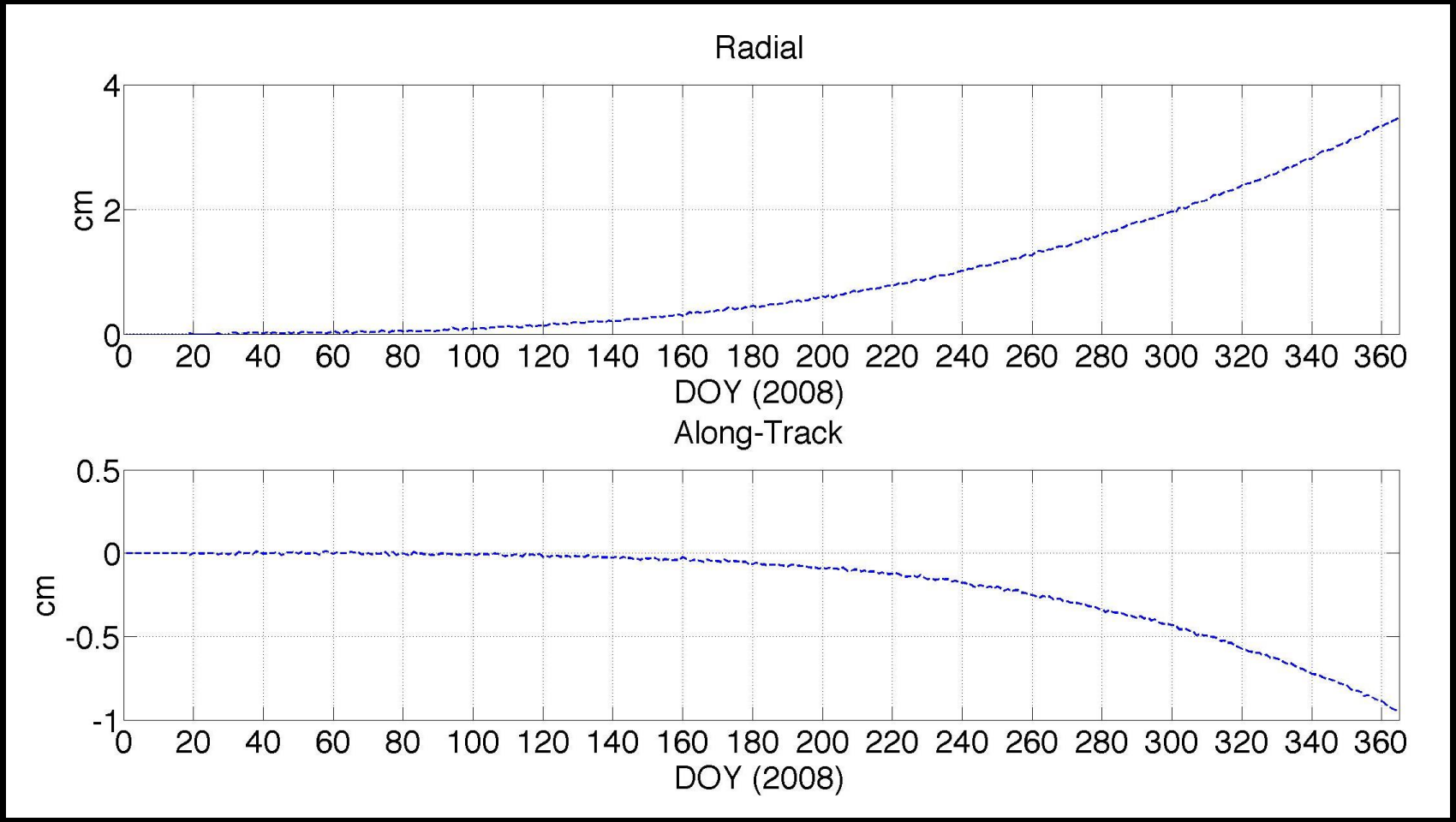
Change in the position of Earth



Change in the position of Mars

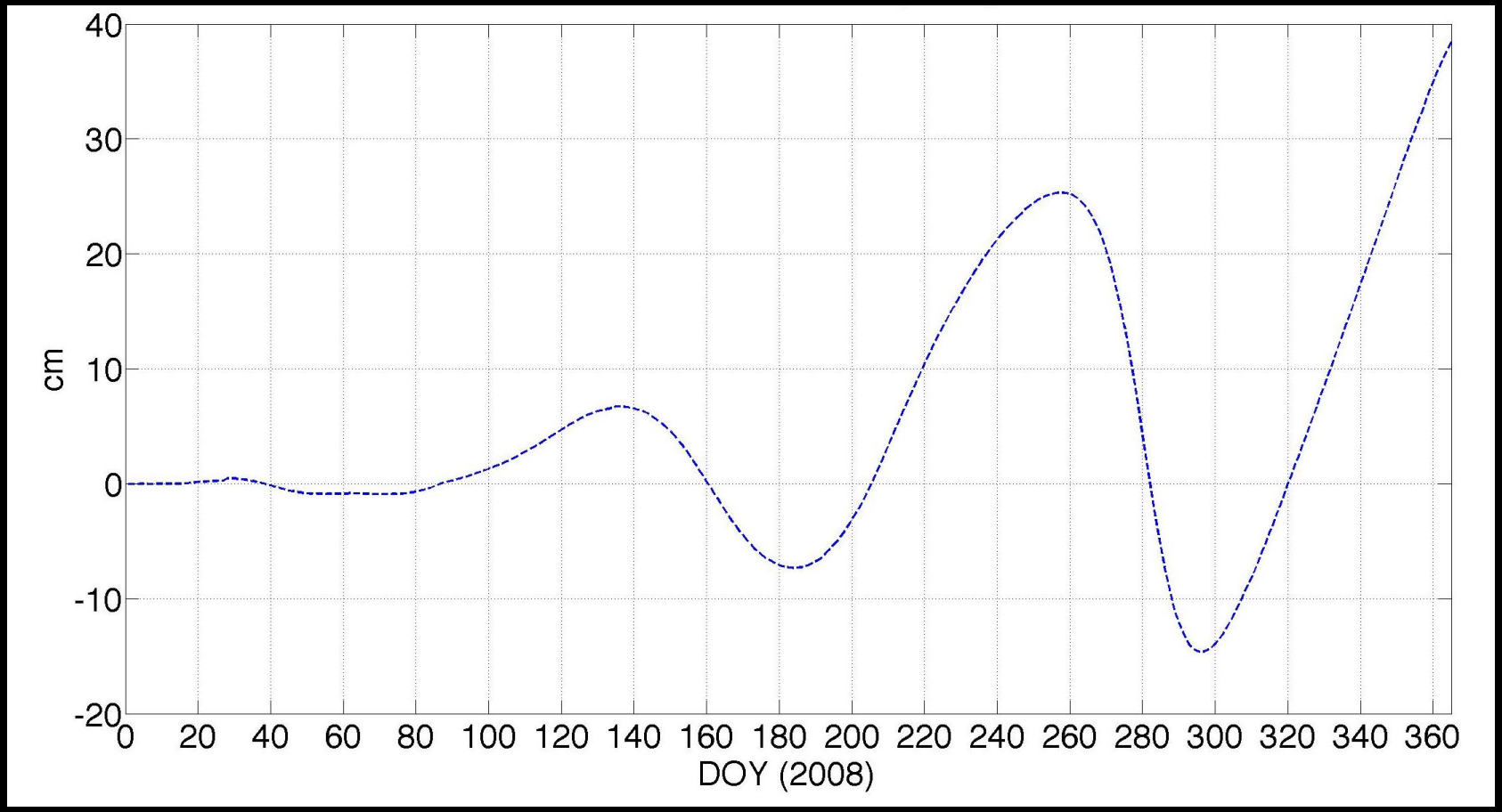


Change in the position of Jupiter



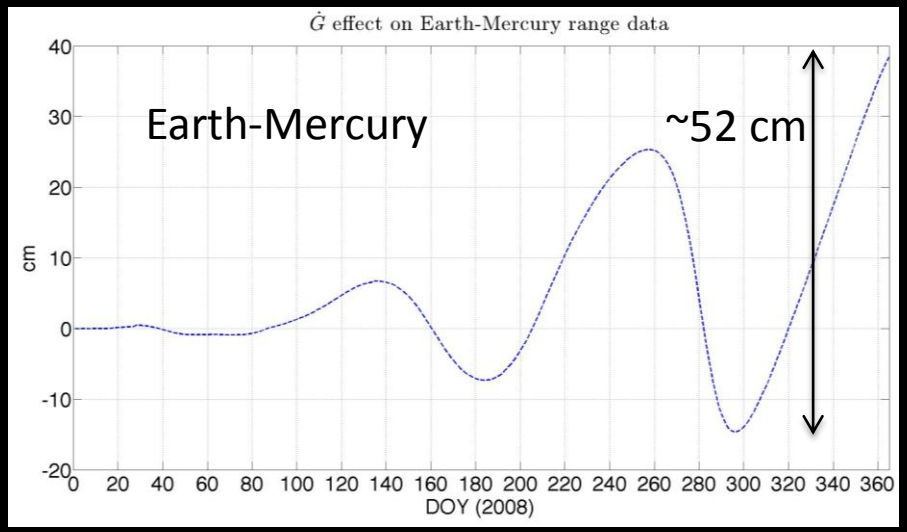
The general pattern for all planets is for the effects to grow with time (not surprisingly), modulated by the orbital period.

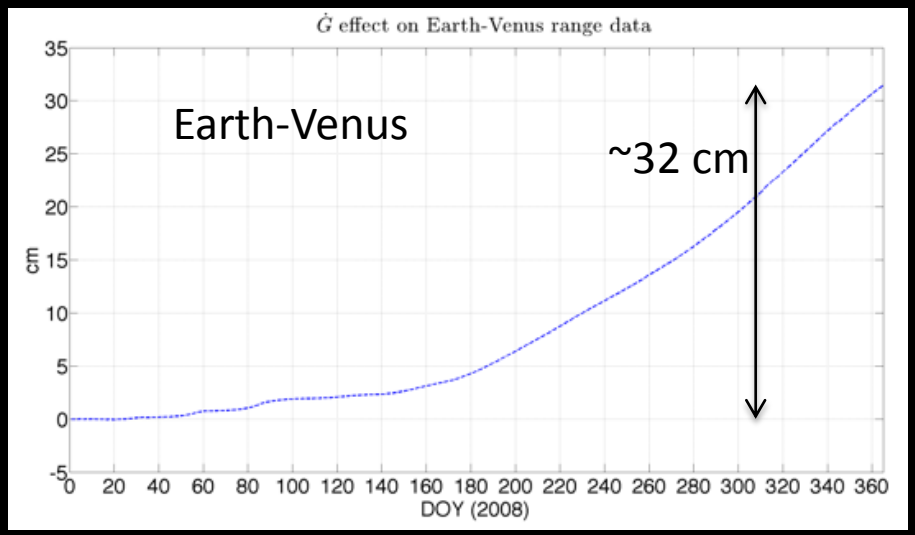
But, from Earth, the distance of Mercury …….

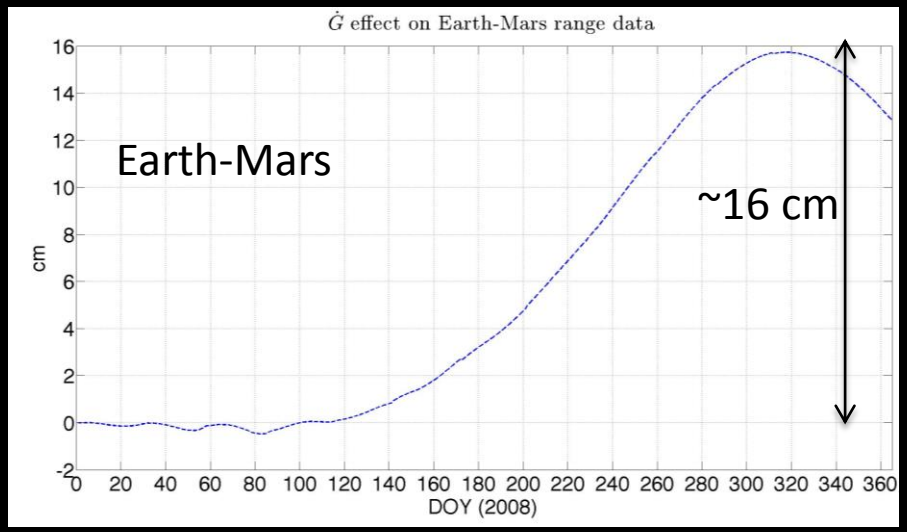


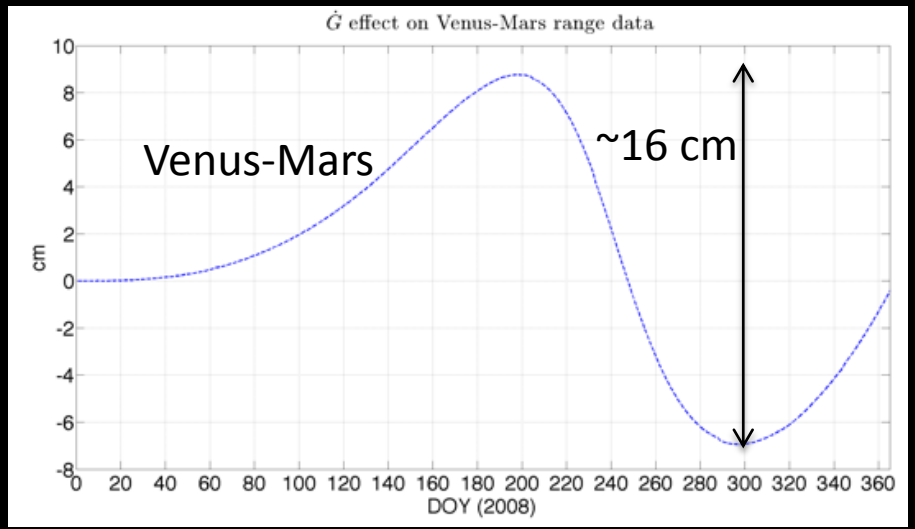
An oscillation that grows with time and reaches ~40 cm in 2008.

Over a few years we could see the effect of a change in GM (2008)



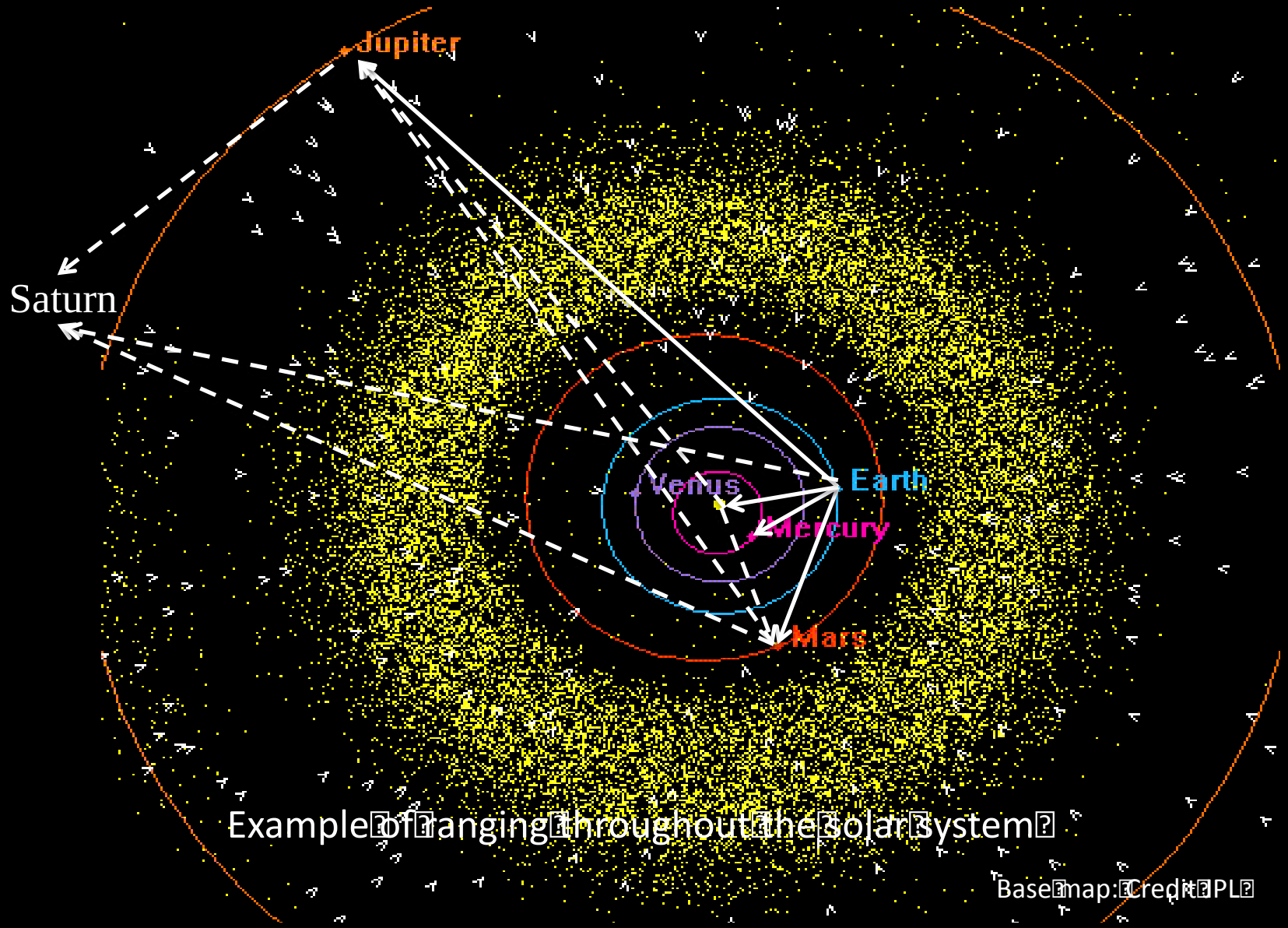






.....is the solar system expanding?

Examples of Inter-Planetary Ranging

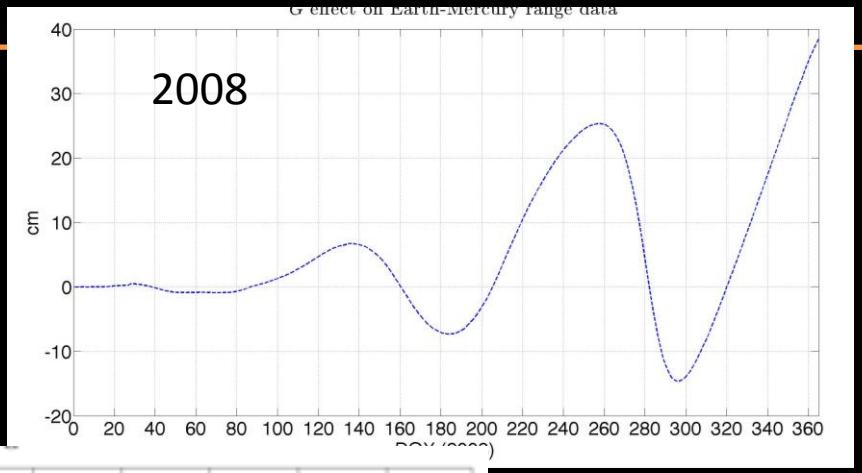


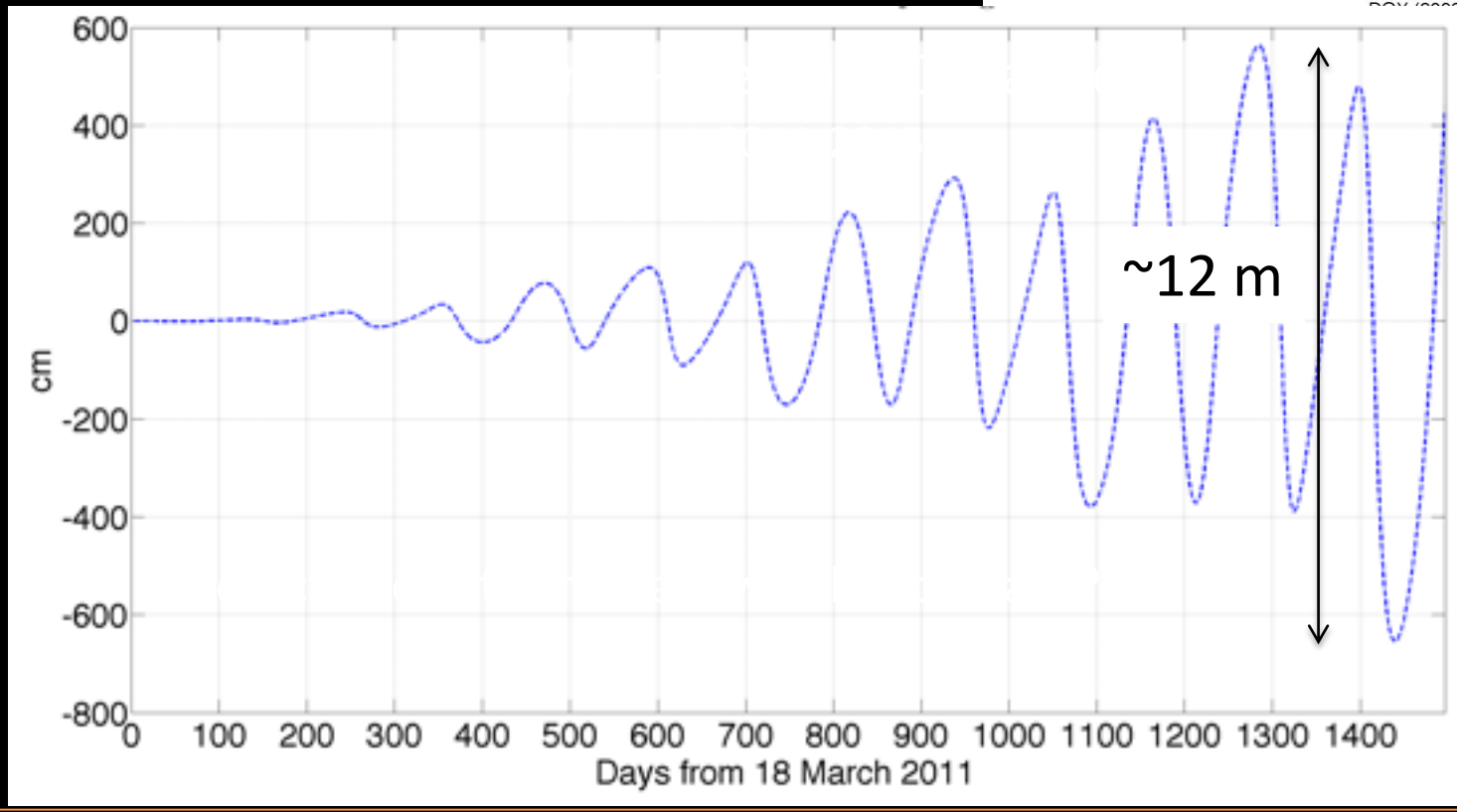
Example of ranging throughout the solar system

Base map: Credit: PL

We already have some microwave data…….

During the 4-years of MESSENGER in orbit at Mercury





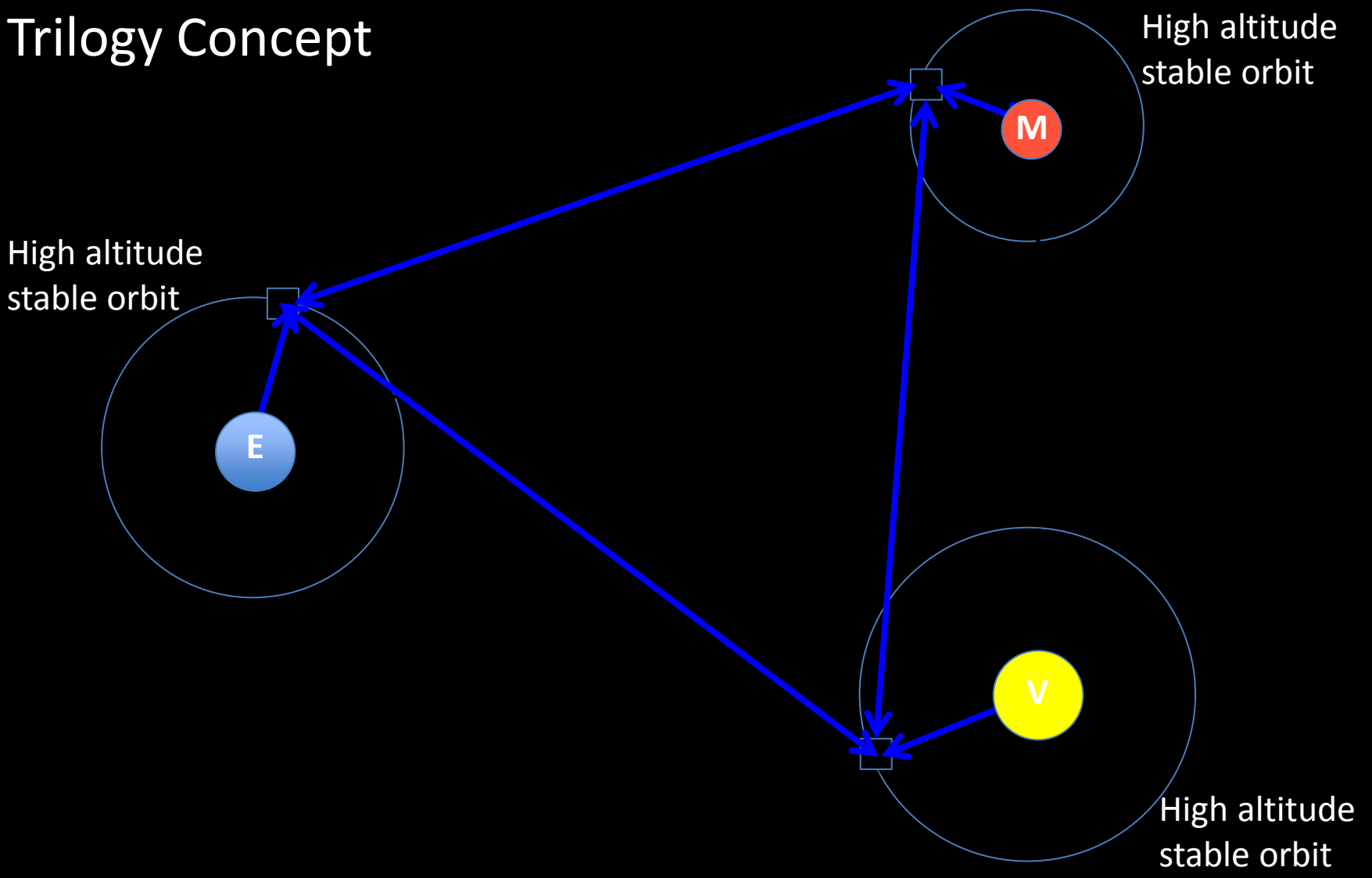
And B-C may get several more years of data in a different decade.

How would we measure the distances between planets?

- So far, all planetary distance measurements have been Earth-centric, ie. they are one way from Earth (except for a few LOLA LR measurements from LRO at the Moon). We need measurements in a closed loop "triangle" between planets.
- Measurements are probably best made from spacecraft orbiting the planets rather than from landers (planet's rotation, power constraints of landers, etc)
- The laser transponder approach is probably a requirement; (microwave systems need large antennas for AU scales.
- We do not need mm accuracy measurements, cm level would be adequate.

Example: Earth – Mars – Venus

Trilogy Concept



Conclusions

- The required measurements of interplanetary ranges are small, but measureable.

- Experiments on MGS, MESSENGER, and LRO have provided evidence that we know how to make the measurements.

- We already have in our possession some relevant measurements, that would be useful for a proof-of-concept study.

- If there is the possibility of measuring a change in the solar *GM*, shouldn't the SLR community be the ones to do it?

Question

At the end of the presentation the following question was asked:

How long will it take to detect *GM-dot* to 10^{-14}/year?

Answer:
We estimate 3 to 5 years. But a full simulation should be conducted since separation of some correlated parameters may require a longer period.

END