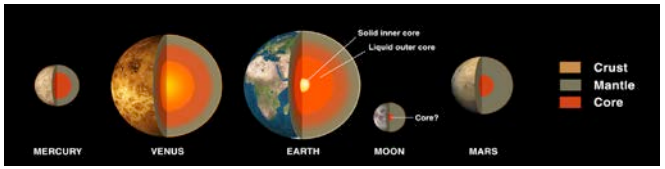
AGU FALL MEETING
San Francisco | 14 – 18 December 2015

Enabling Planetary Geodesy With the Deep Space Network



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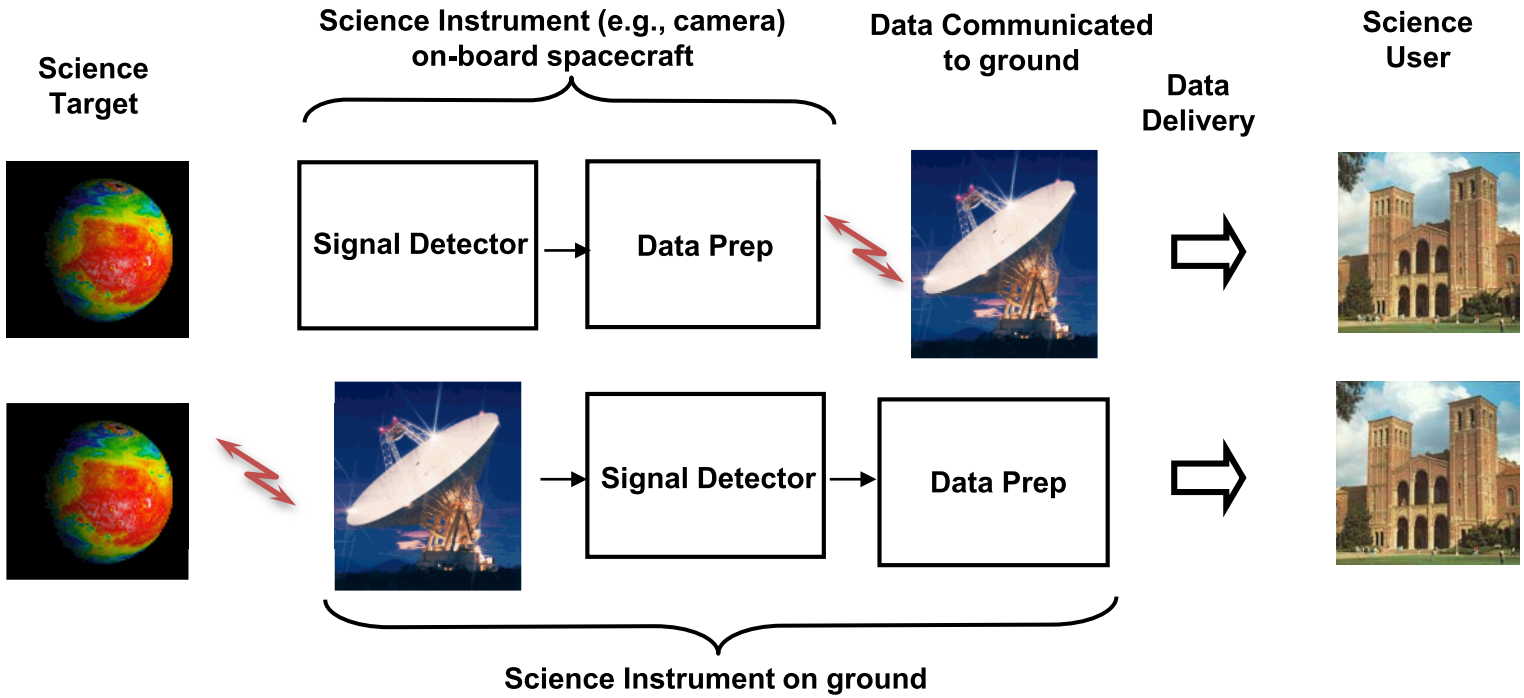
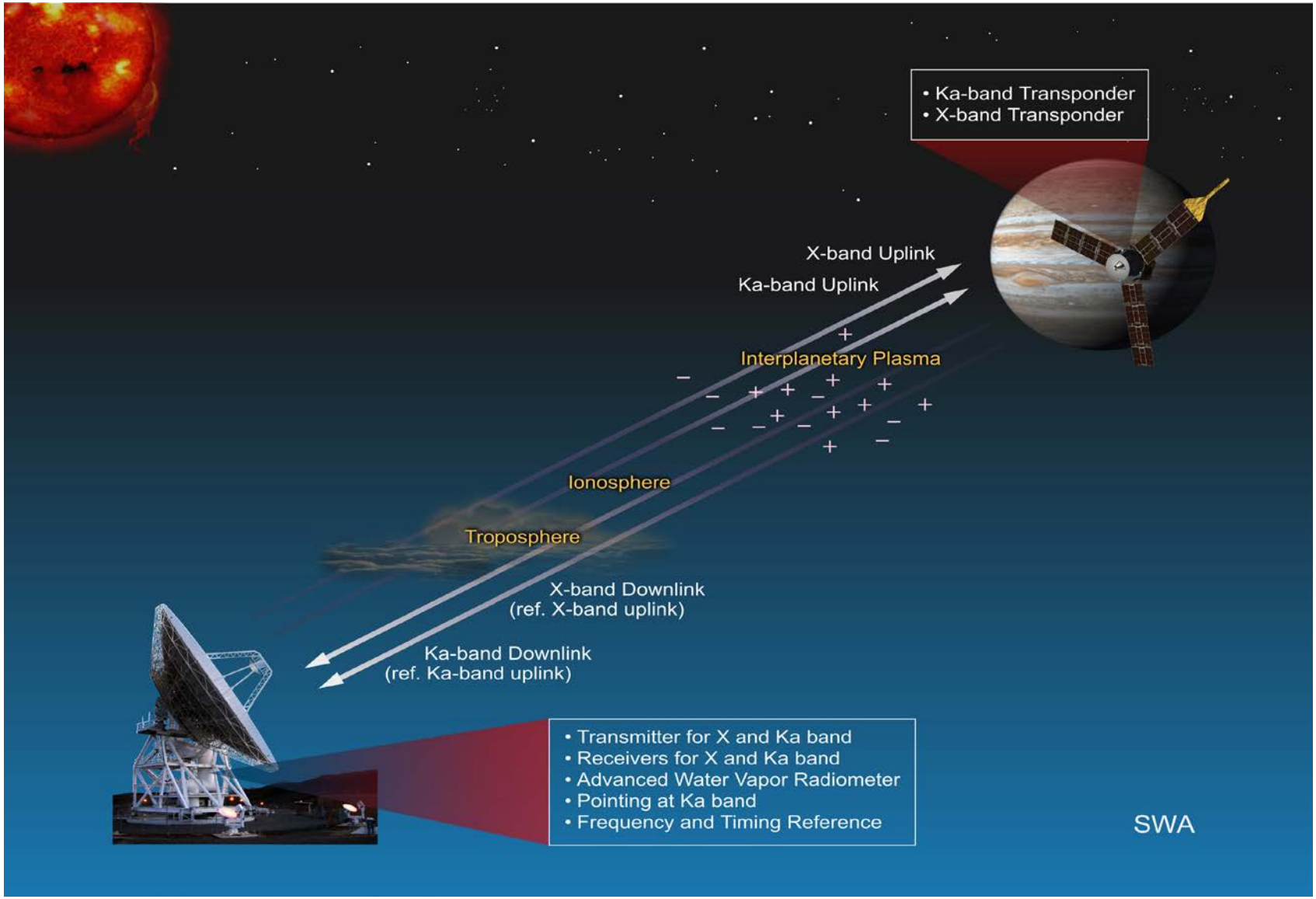
Deep Space Network

- DSN is a large global infrastructure and national investment
- Started 52 years ago for spacecraft communications
- Proved to be world-class instrument for science research
- Intentionally instrumented for planetary geodesy research
- Contributed to numerous discoveries

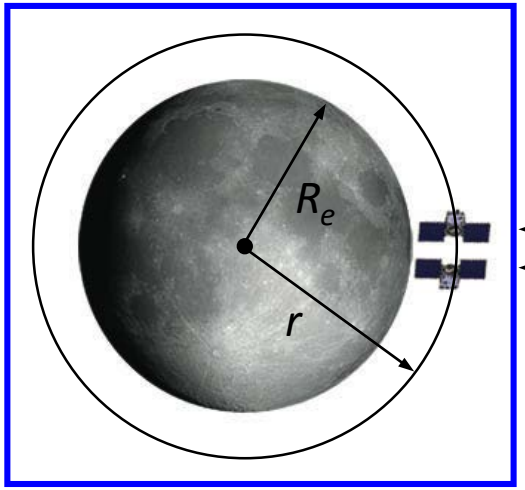
Analogy of DSN as a Science Instrument



Radio Science: Largest Planetary Instrument in Solar System



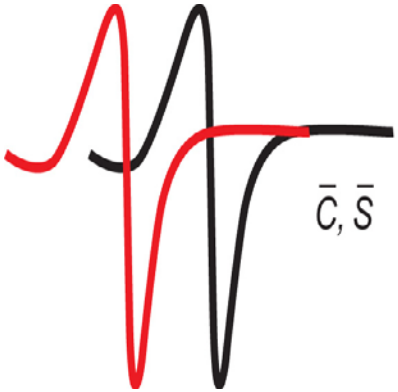
Gravity Field from Tracking Data



Deep Space Network (DSN)

lat: ø,
long: λ

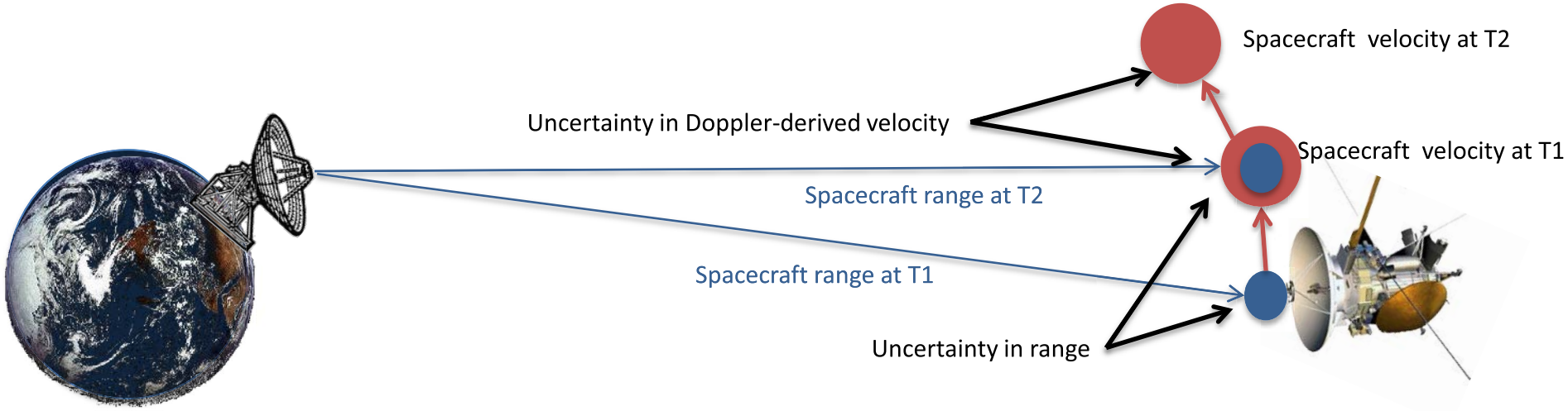
Spacecraft tracking (Doppler) enables global estimation of planet's gravitational potential and tidal parameters



$$U(r,\phi,\lambda) = \frac{GM}{r}\sum_{n=0}^{180}\sum_{m=0}^{n}\left(\frac{R_e}{r}\right)^n \bar{P}_{nm}(\sin\phi)\left[\bar{C}_{nm}\cos(m\lambda) + \bar{S}_{nm}\sin(m\lambda)\right]$$

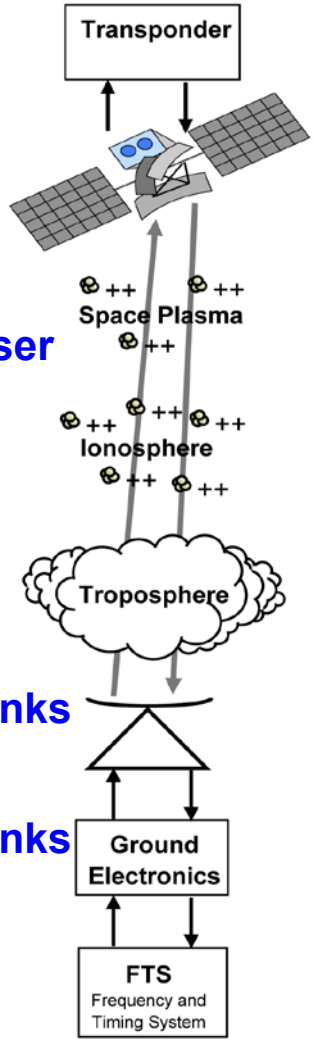
Range and Range-Rate Observables

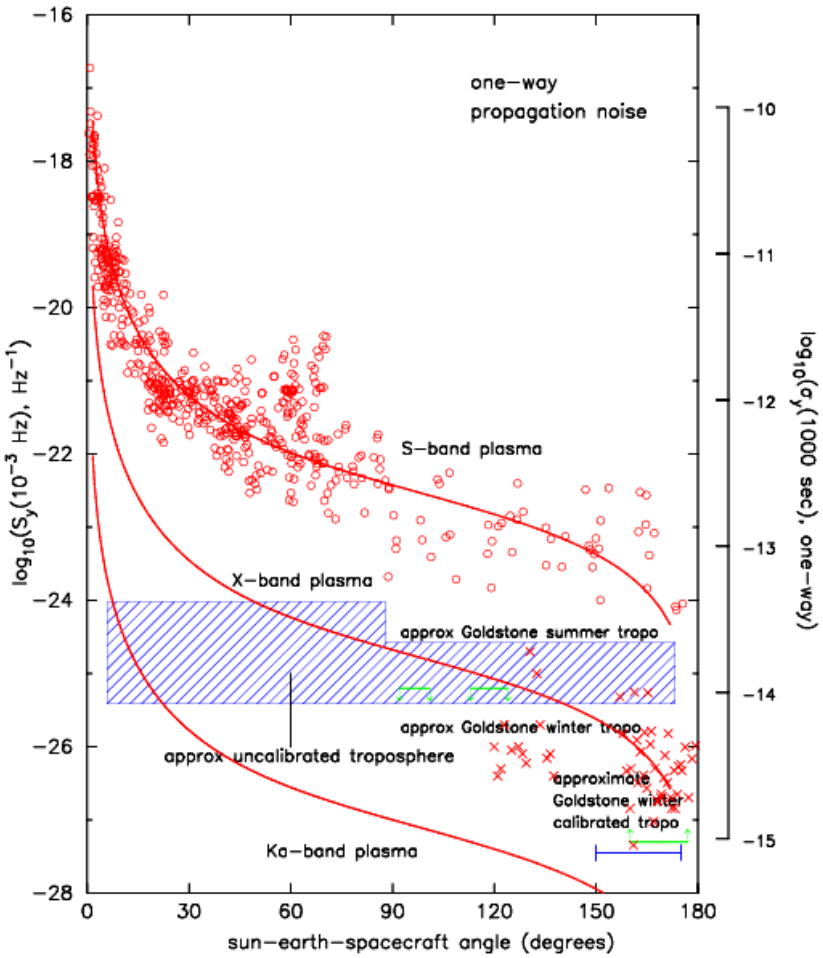
- DSN receivers always measure Doppler shift in frequency due to spacecraft Doppler
- Range & Doppler measurements reduce each other's uncertainty
- Current range accuracy ~1 meter (X-band)
- Current range rate ~0.03 mm/s (X-band) under good conditions
  - Order of magnitude better at Ka-band after full calibrations



Noise Sources in DSN Geodesy Data

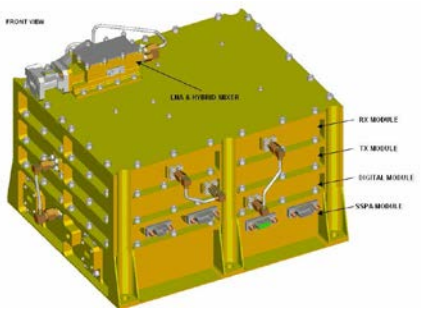
1. Instrumental: random errors
   - Phase fluctuations in link
   - Electronic components
   - Un-modeled motion
   - Frequency standard
     - DSN atomic clock/maser
   - Antenna mechanical
     - Optimized. Room for improvement
2. Propagation:
   - Solar Wind
     - Calibrated with dual links
   - Ionosphere
     - Calibrated with dual links
   - Troposphere
     - Calibrated with water vapor radiometer
3. Systematic errors





Gravity Science Instrument

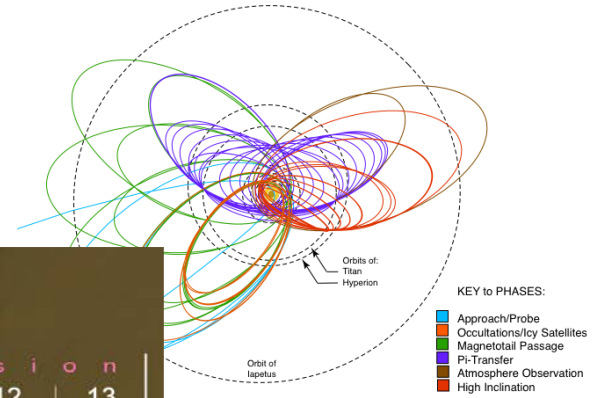
DSN Station 25 at Goldstone, 34 meter diameter

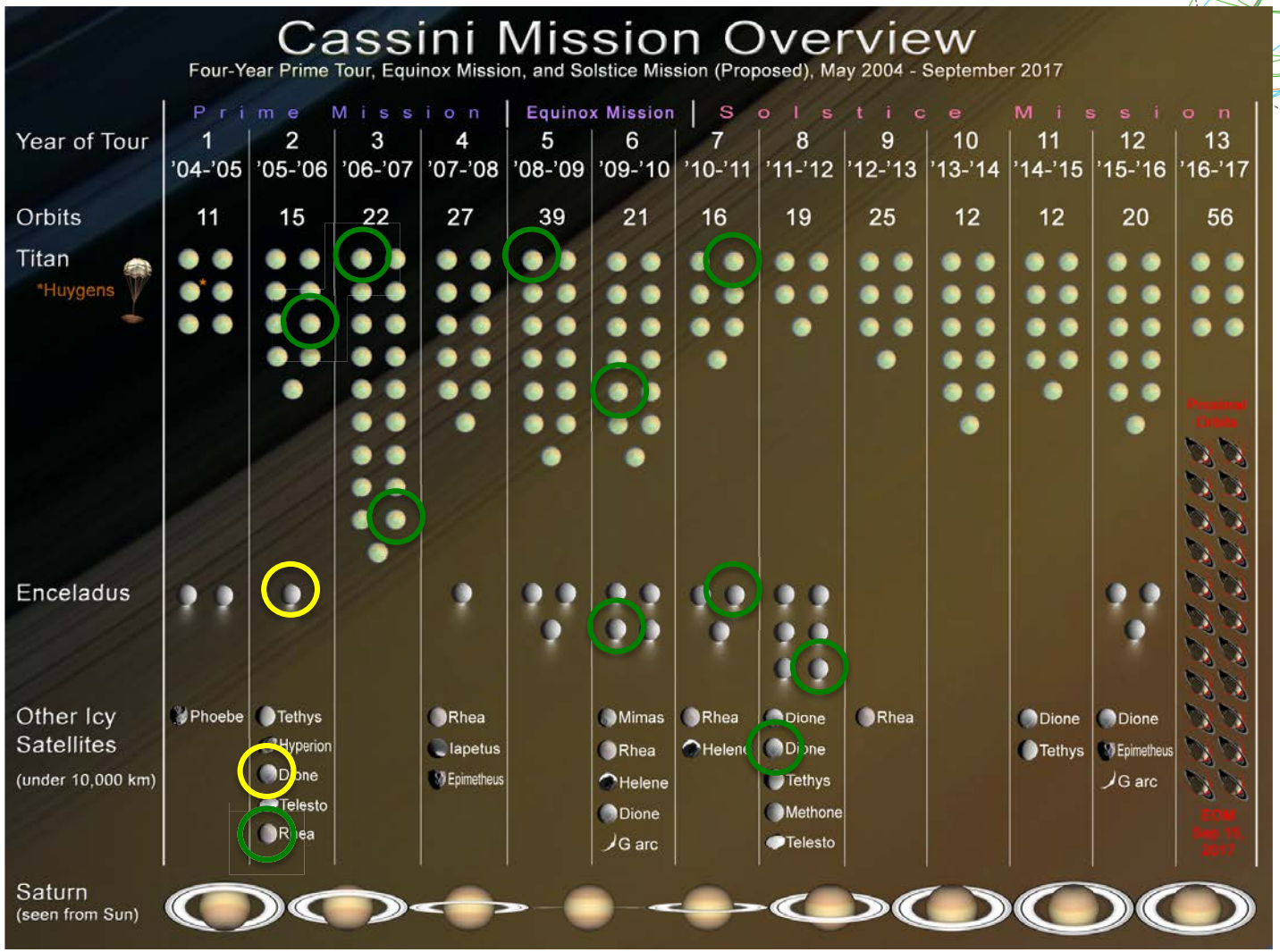


Typical spacecraft transponder turns around signal from DSN preserving phase stability

DSN Advanced Water Vapor Radiometer at DSS-25 calibrates Earth's troposphere

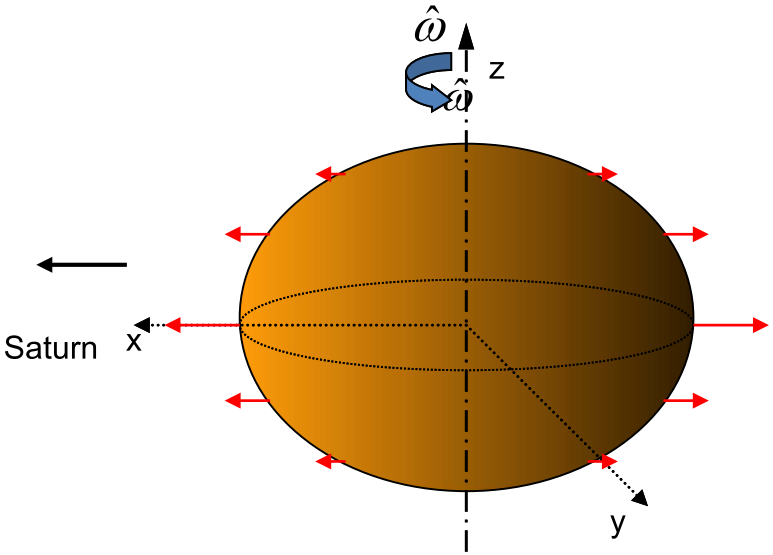
CASSINI MISSION SATELLITE TOUR



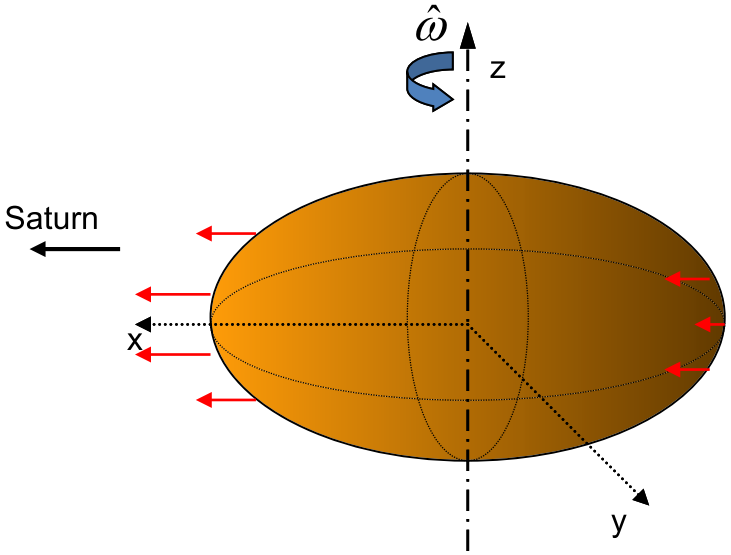


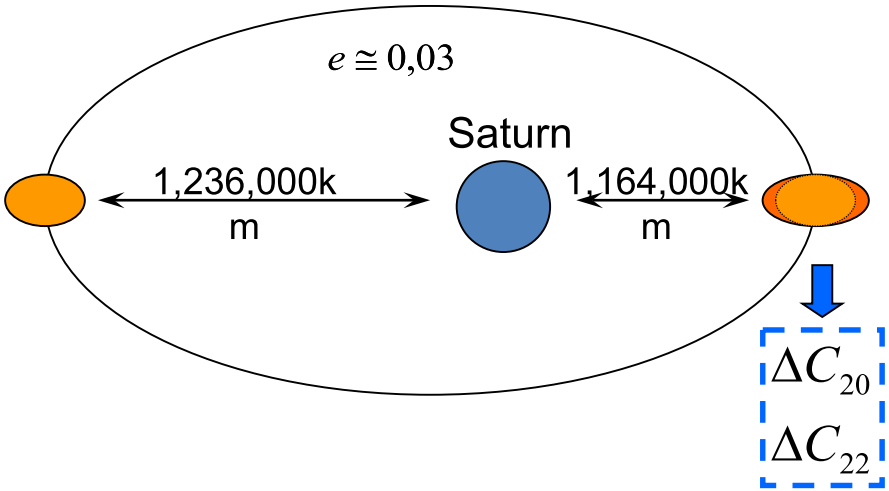
Elastic Deformations of Titan

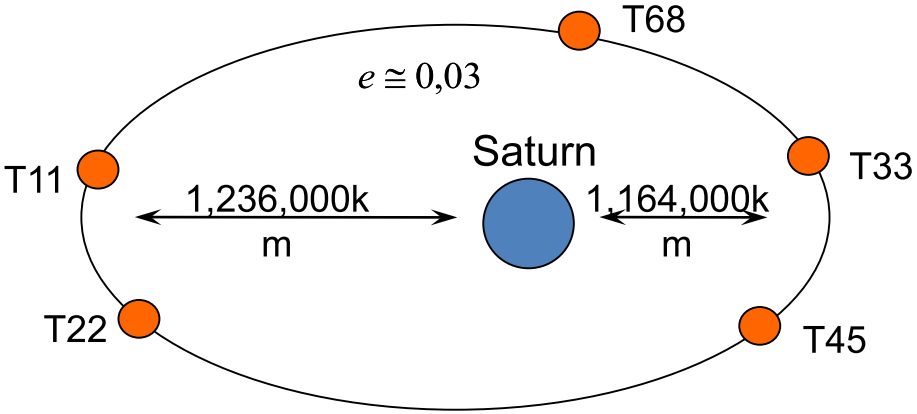
Centrifugal deformation



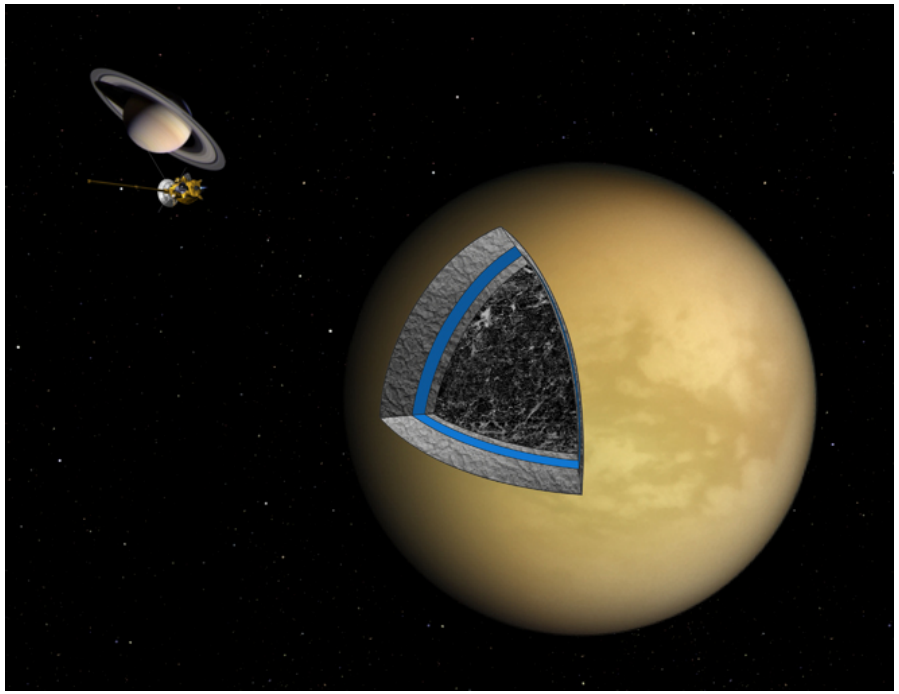
Tidal deformation



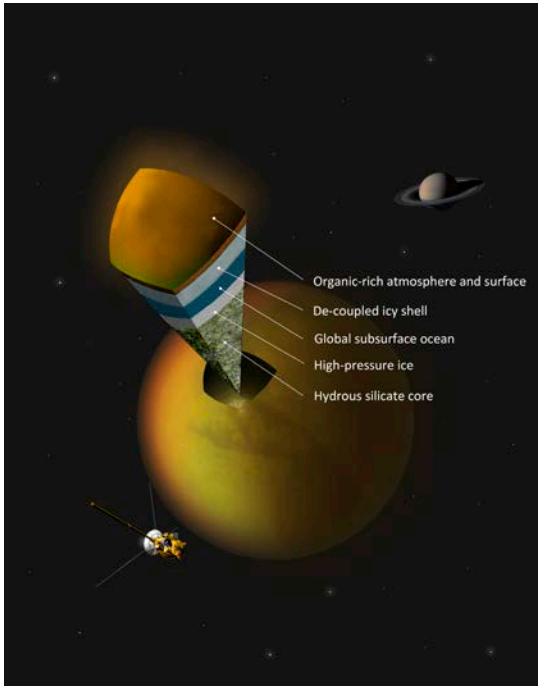




Titan's MOI: Geophysical Implications

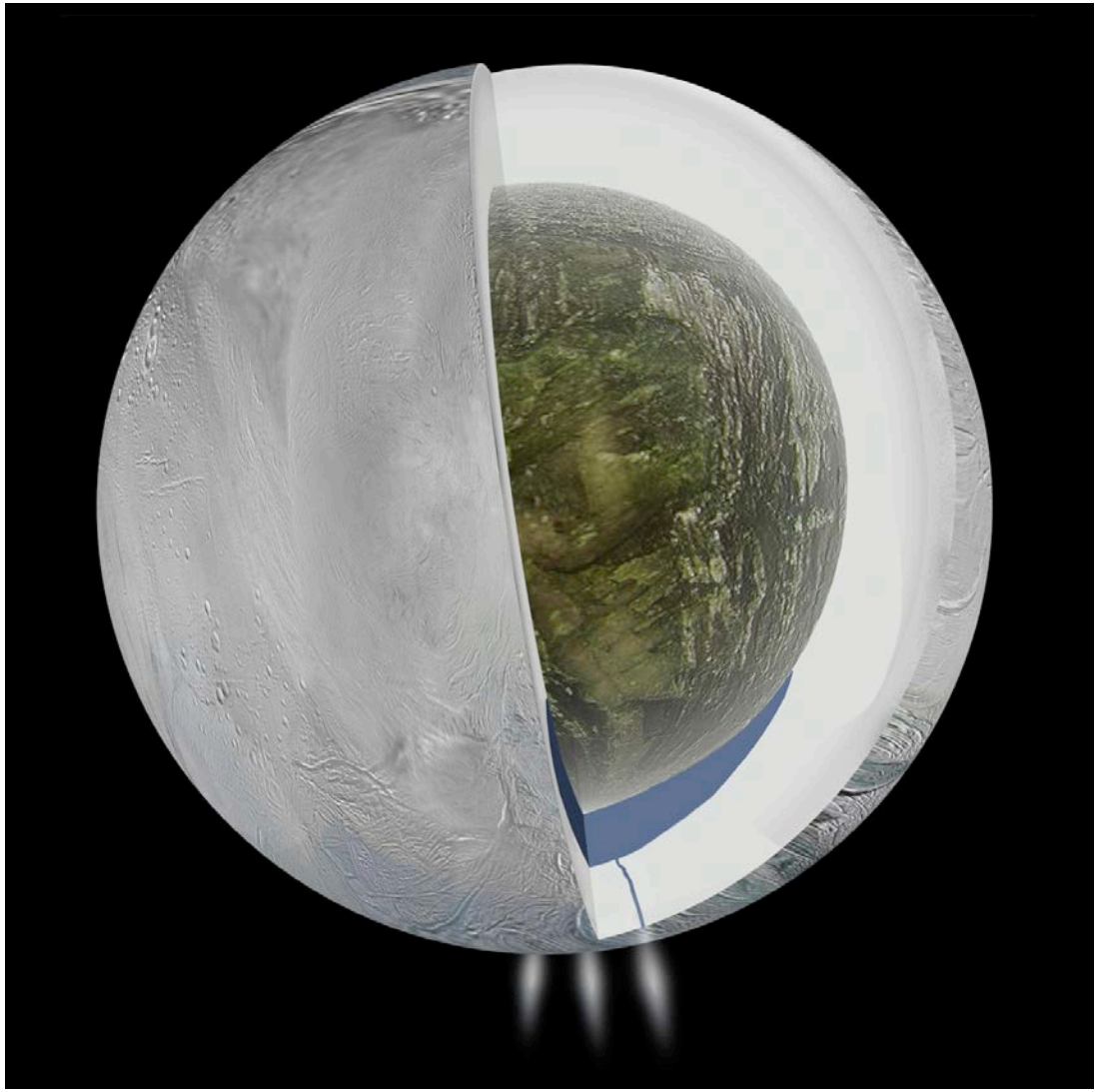


Iess et al, 2012



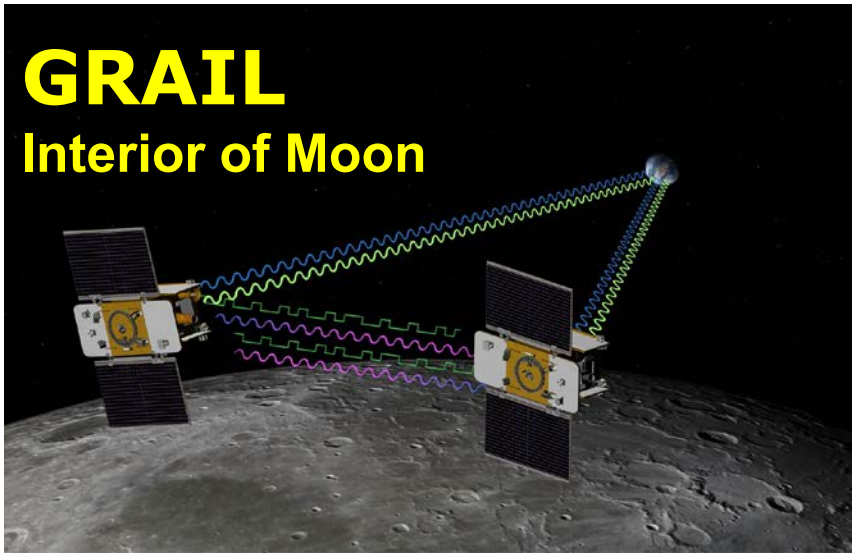
In a simple, two layer model with an outer shell made by pure ice provides a core radius and density of 2050–2100 km and 2550–2600 kg/m^3.

Cassini-DSN Plumbs the Depths of Enceladus Sea

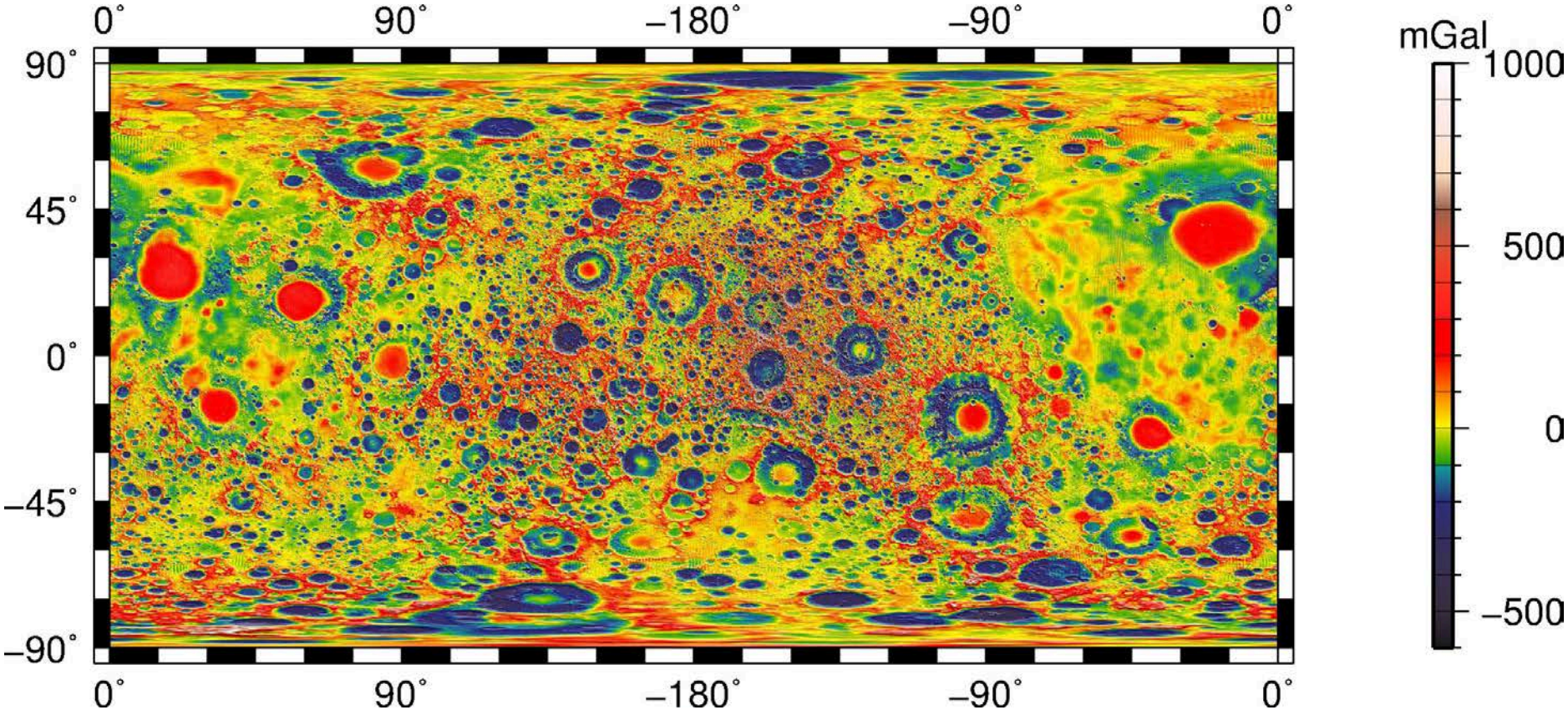


- ***Cassini*** **previously sampled jets of water spewing from south pole**
- **DSN-*Cassini* radio science measurements confirm sub-surface ocean**
- **Another possible habitat in the solar system?**

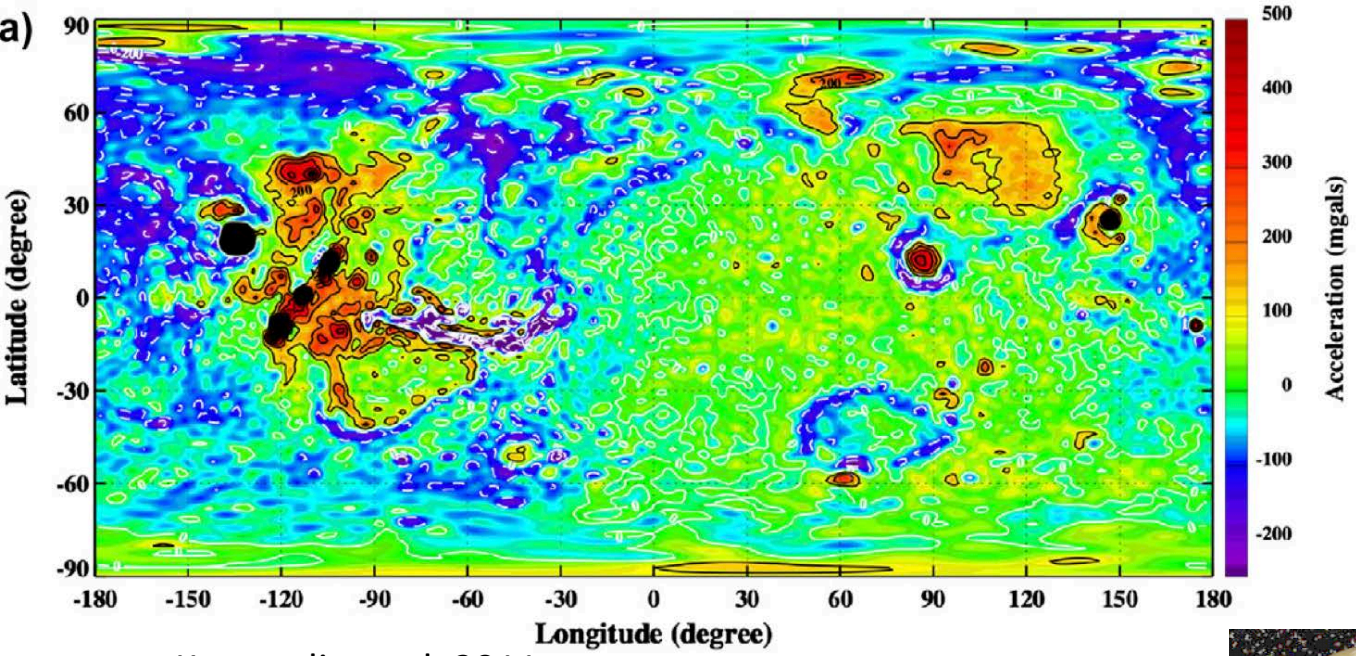
Iess et al, 2014



Current gravitational field solution up to degree and order 1500, and higher in progress

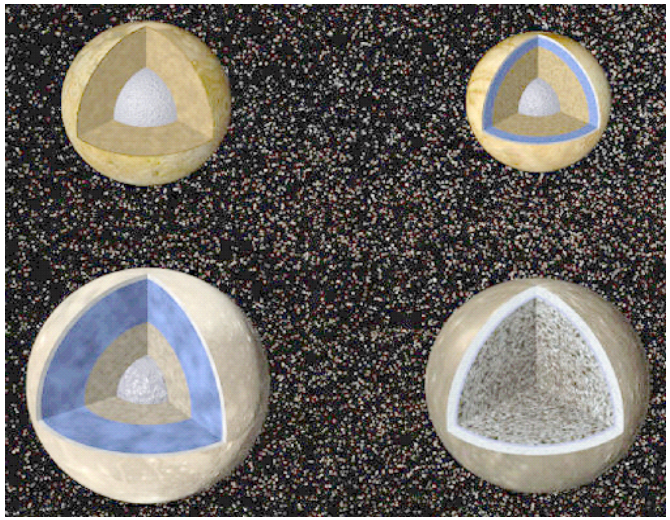


Mars Gravity Field

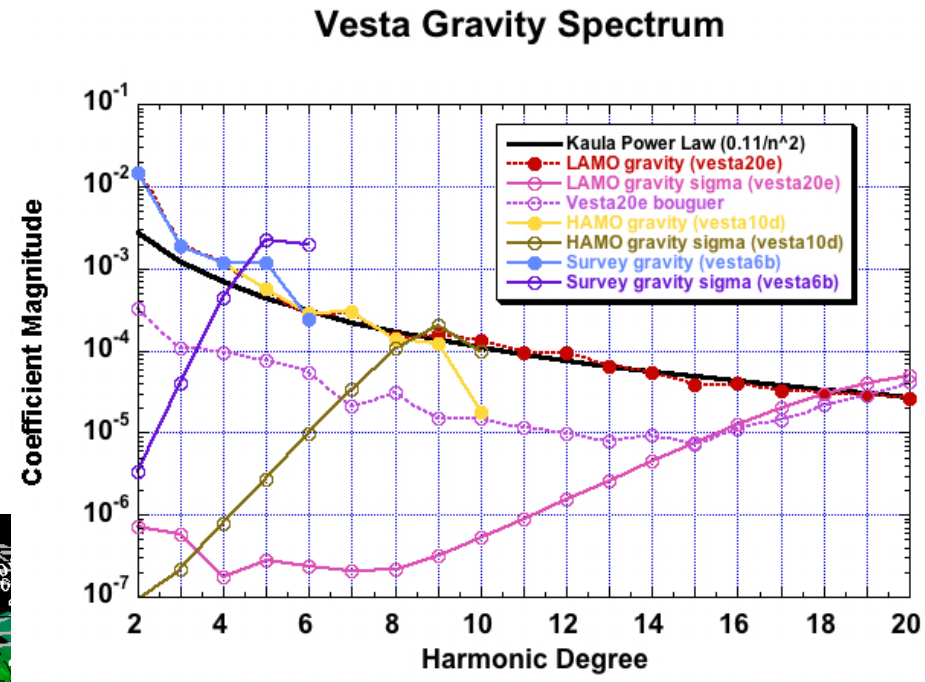


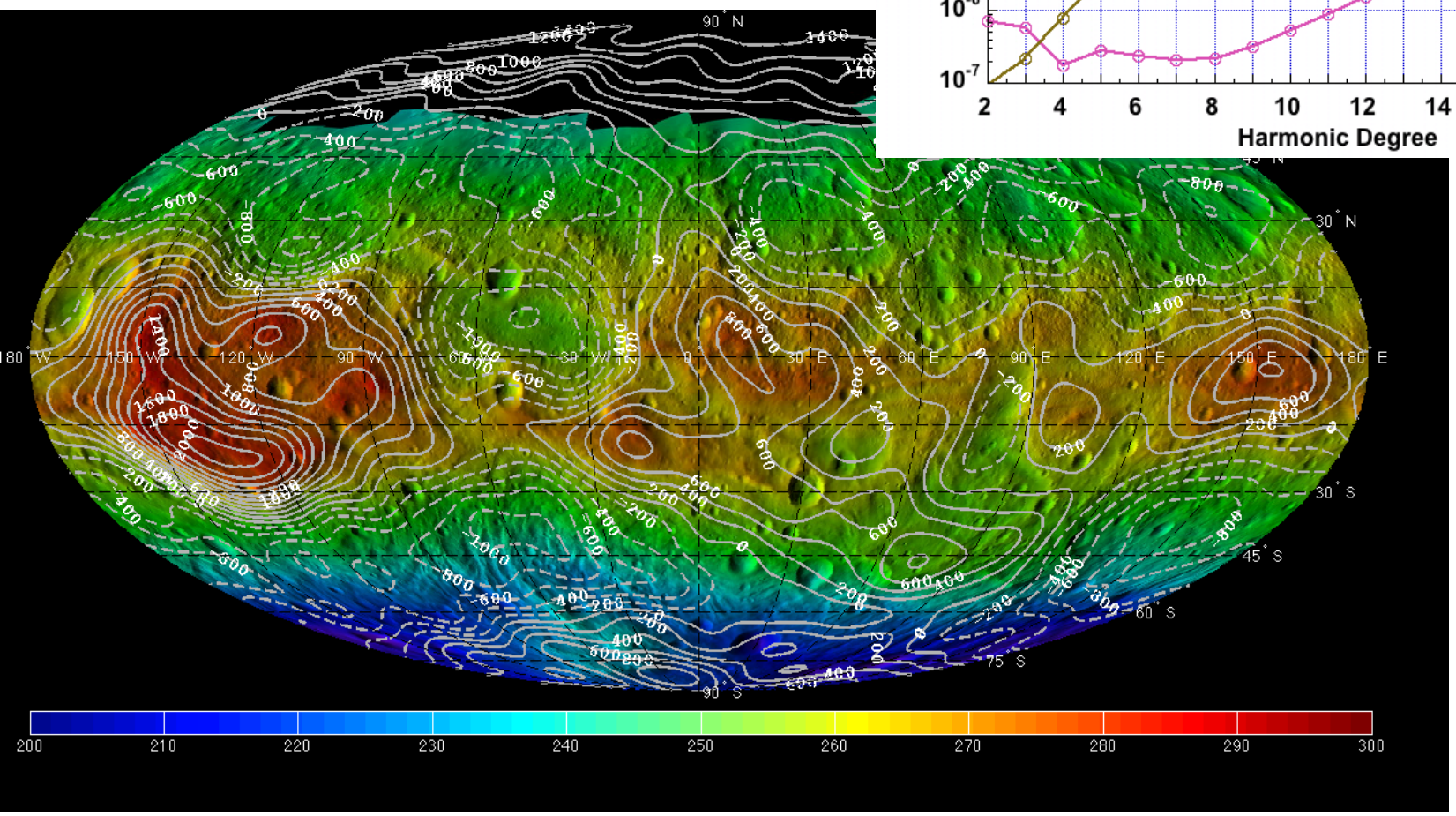
Konopoliv et al, 2011

Interior Models of Galilean Satellites from magnetometer and gravity



Vesta surface gravity

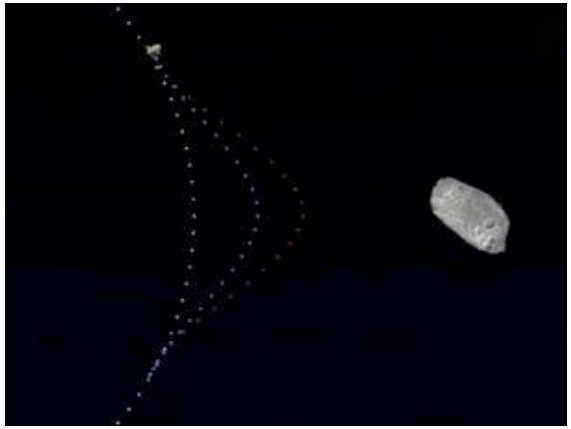


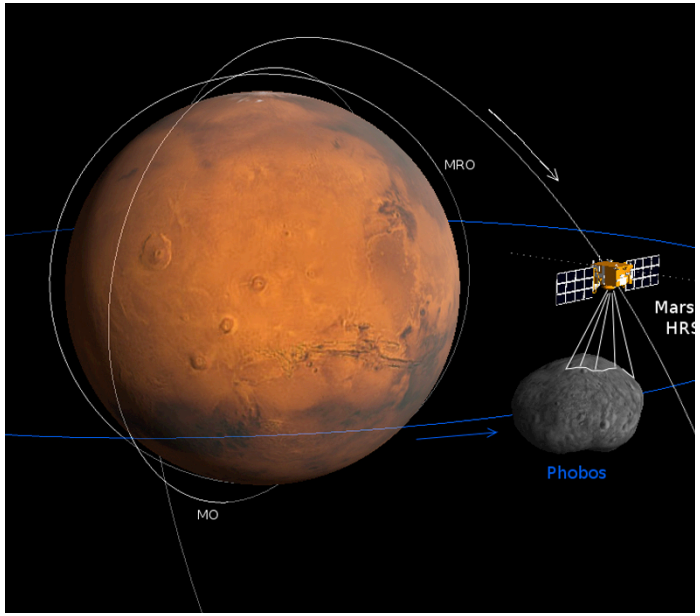


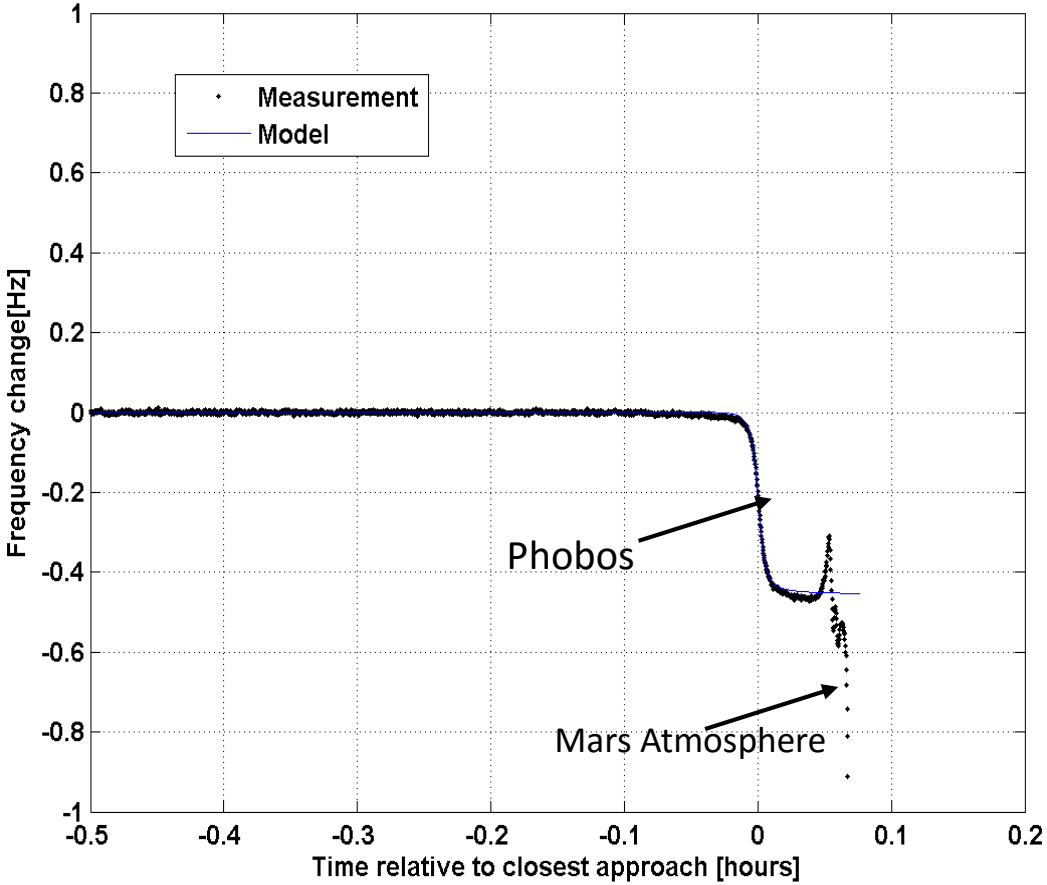
Mass of Phobos with Mars Express & DSN

- **Determine mass and bulk density**

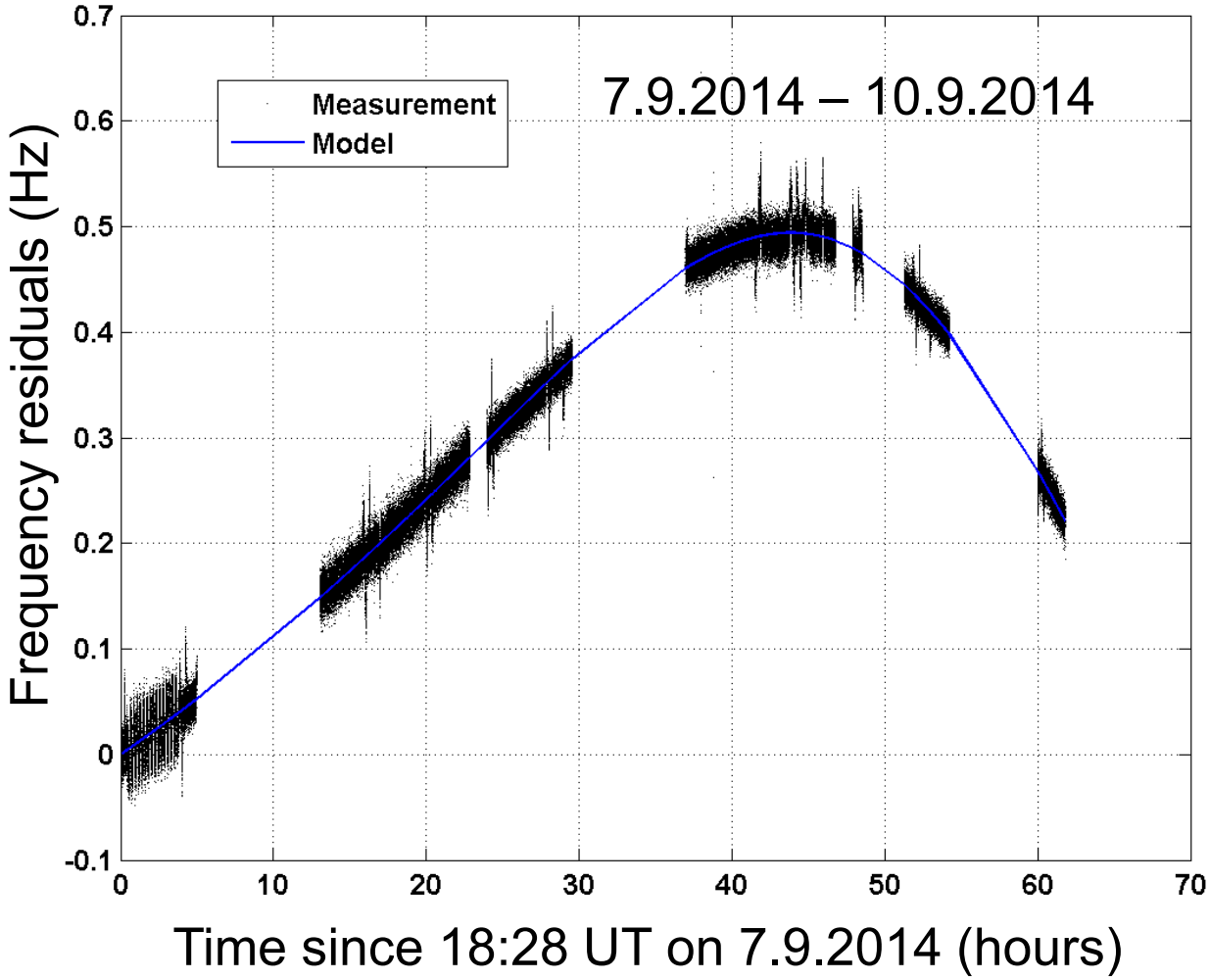
$$\rho_{bulk} = 1862 \pm 20 \text{ kg/m}^3$$







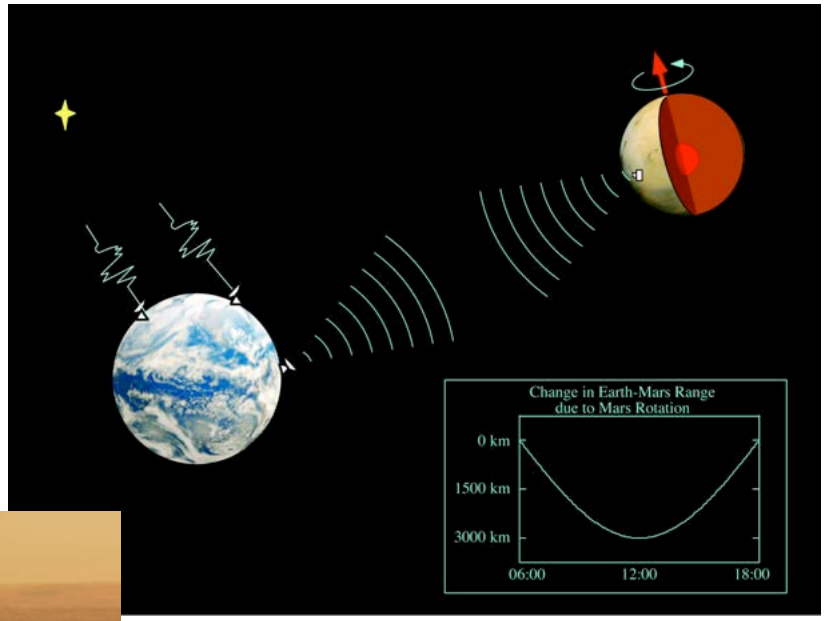
Rosetta‘s Comet nucleus mass determination
(September 2014, 30 km bound orbit)

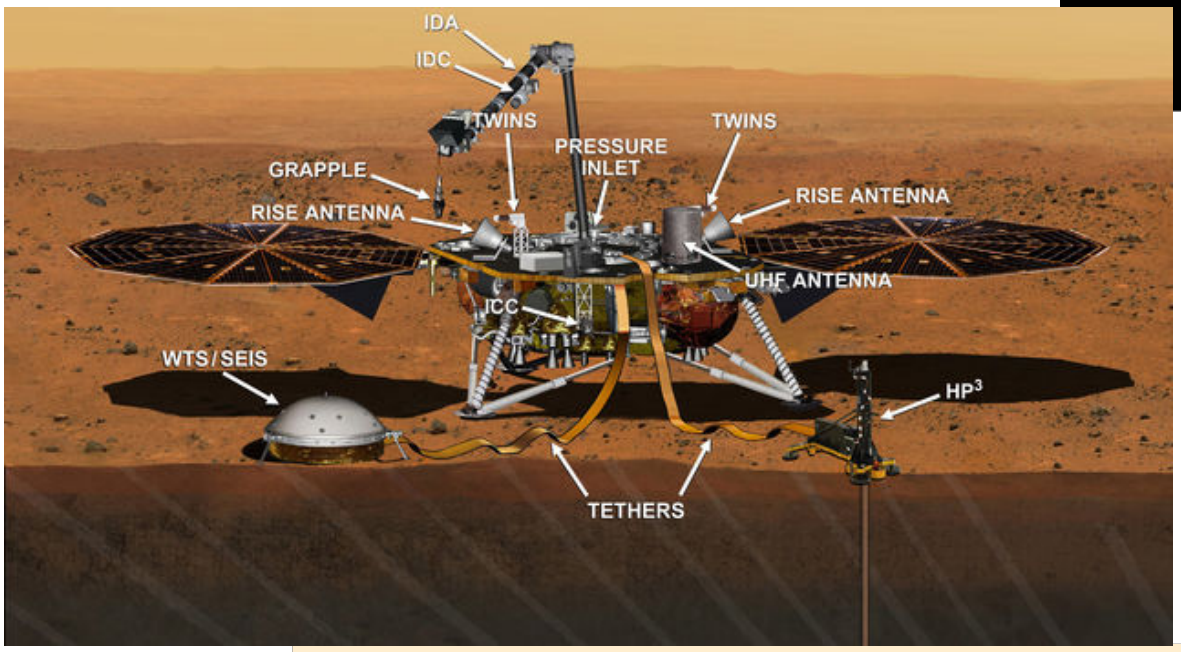


Upcoming Future Experiments

InSIGHT

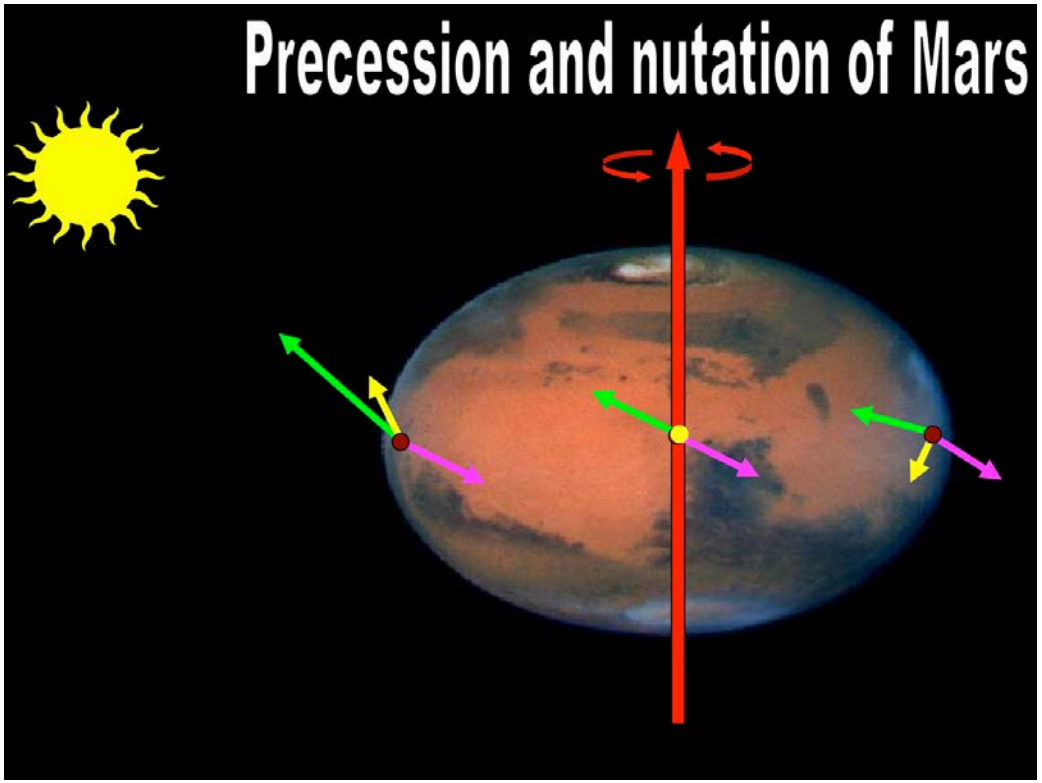
RISE: Rotation & Interior Structure Experiment





Two-way X-band links from DSN referenced to H maser

Understand the formation and evolution of terrestrial planets through investigation of the interior structure and processes of Mars.

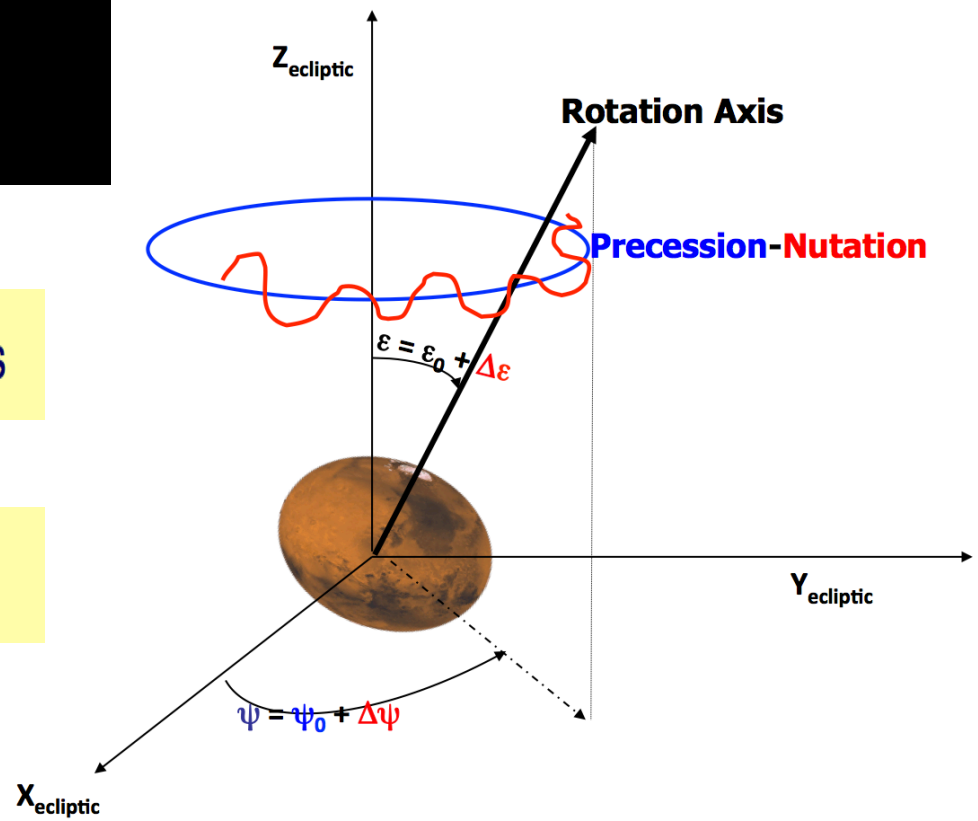


Earth

Precession = 50".406445 / y → 25711.163 years

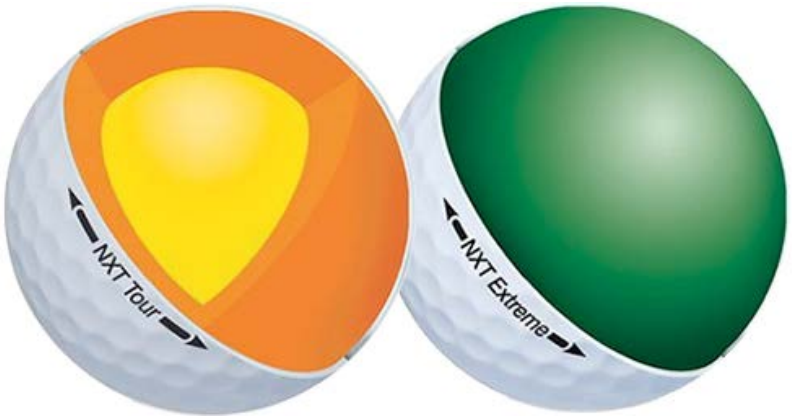
Mars

Precession = 7".594 / y → 171 000 years

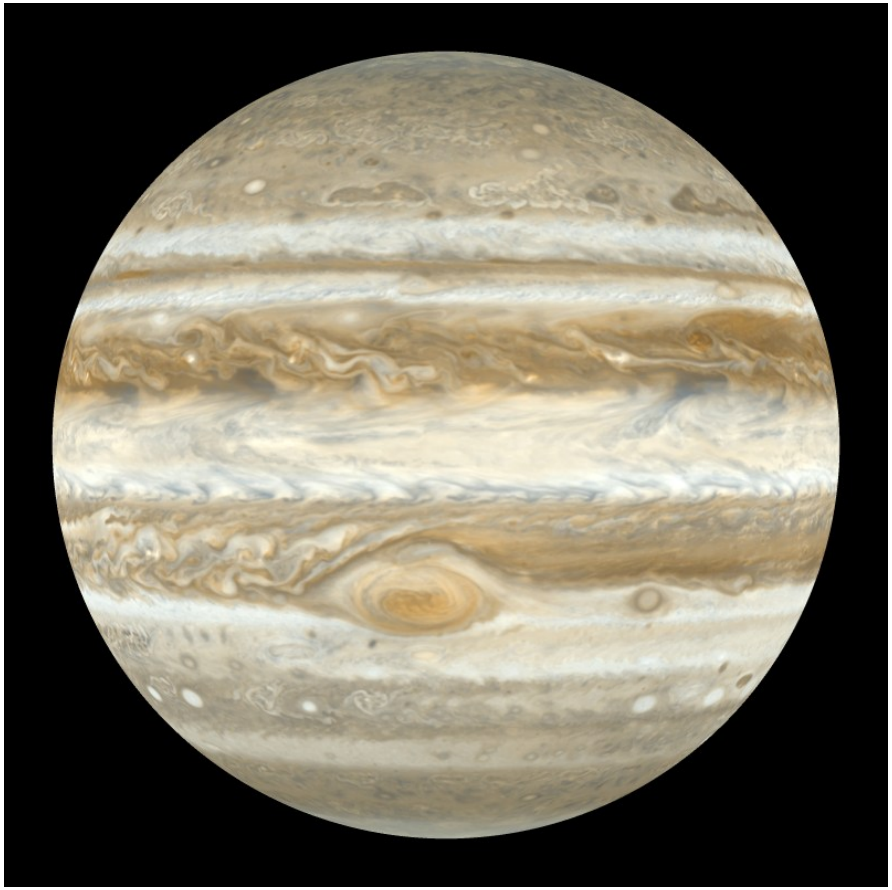


Juno Gravity Science Goals

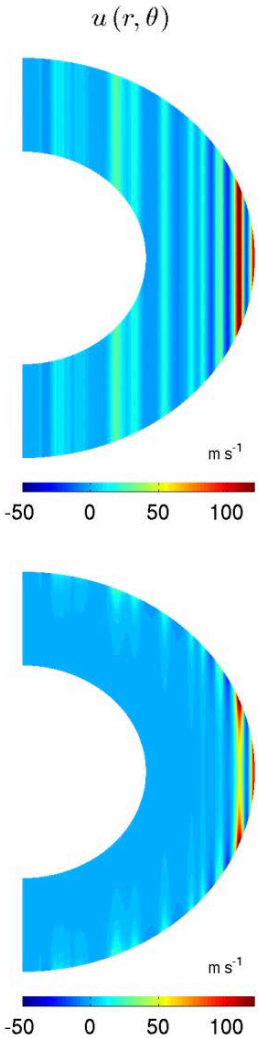
- Juno Gravity Science goals are generally to learn about the interior mass distribution of Jupiter.
- However, the surface gravity field does not determine a unique interior.
  - All golf balls have the same external gravity but different interiors.
- Specific Gravity Science measurements include;
  - Precession – change in direction of Jupiter spin axis from solar torque
  - Deep Zonal Flow – motion of gas on series of concentric cylinders
  - Tidal response – change in mass distribution due to position of Io



Concentric Cylinder Model

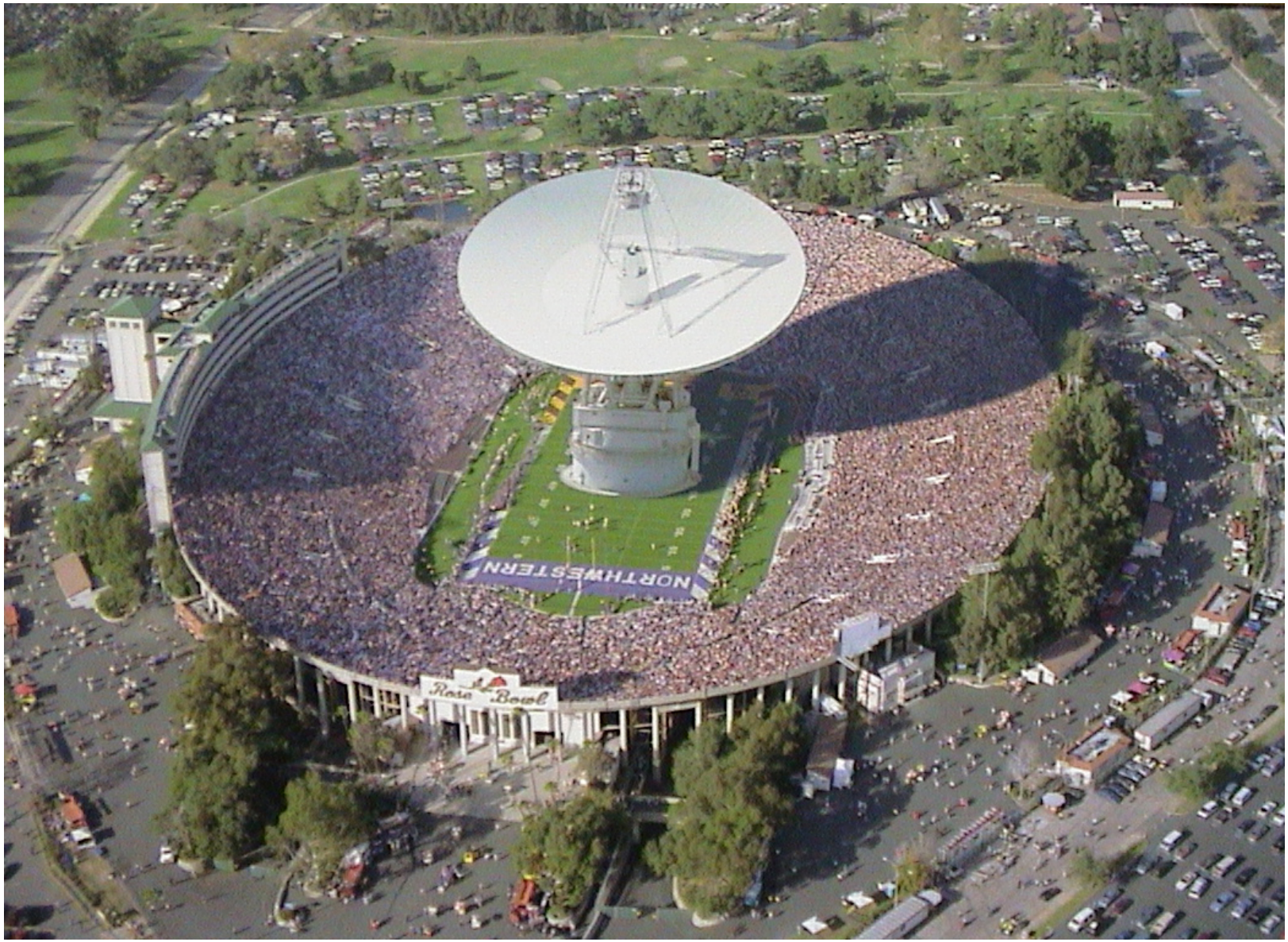


NASA/Cassini



Y Kaspi et al.
GRL 37,
L01204
2010

Advanced Planetary Geodesy

- BepiColombo Mercury Orbiter Radioscience Experiment (MORE) + Italian Spring Accelerometer (ISA) will provide the most advanced planetary geodesy measurements ever carried out.
- Key advancement is provided by the use of Ka/Ka radio link both for Doppler and range (Cassini's test of general relativity and Juno gravity investigation based on Doppler only).
- BepiColombo's advanced tracking system will be used for improved spacecraft navigation.
- JUICE's 3GM experiment is a follow on of MORE. It will provide the first in-depth geodesy of an icy satellite (Ganymede, full 10x10 gravity field).
- BepiColombo and JUICE will put ESA at the forefront of the investigation of planetary interiors, a most important goal for future missions.

Any Questions?