The influence of a fluid core and a solid inner core on the Cassini sate of Mercury

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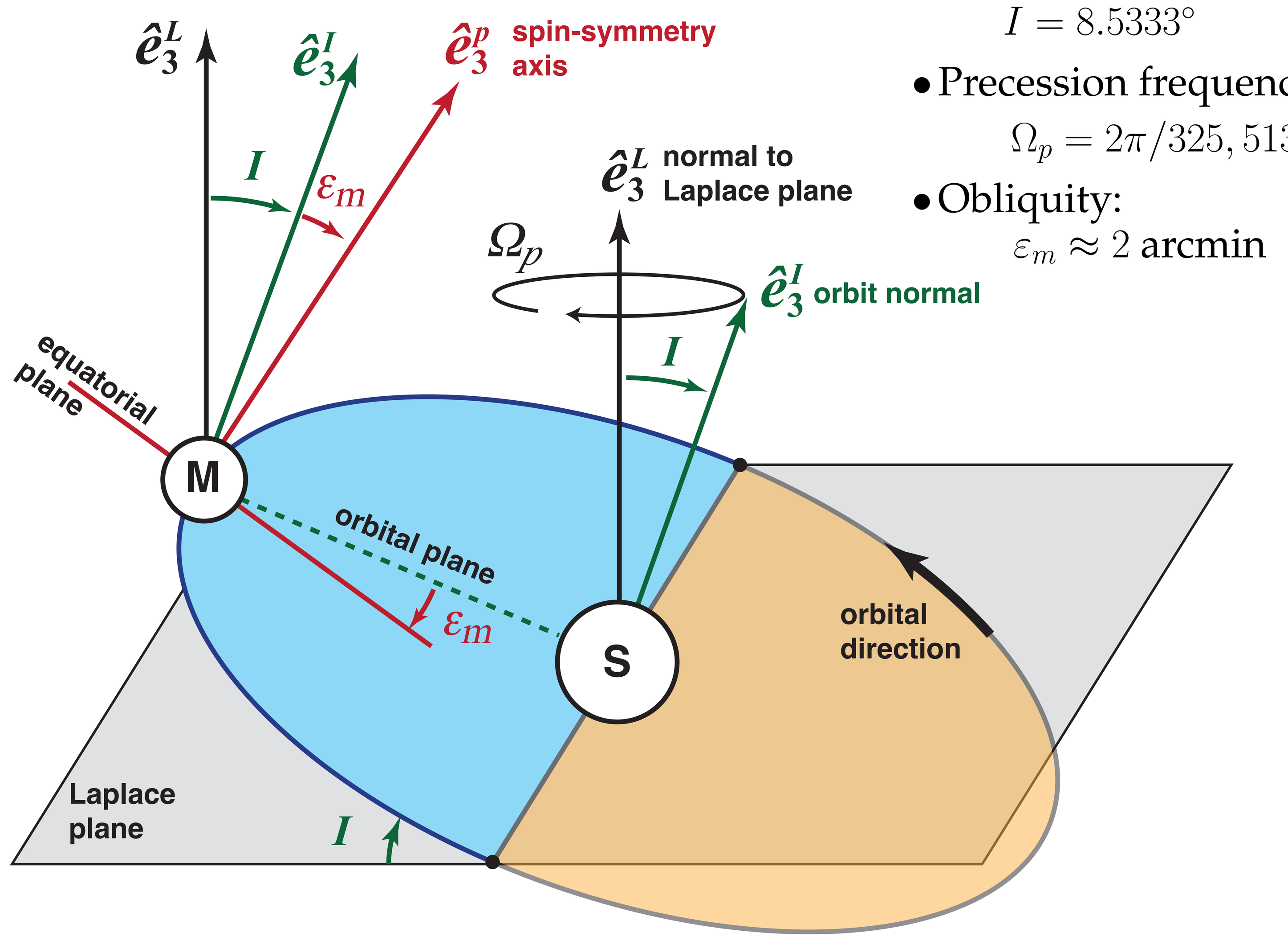
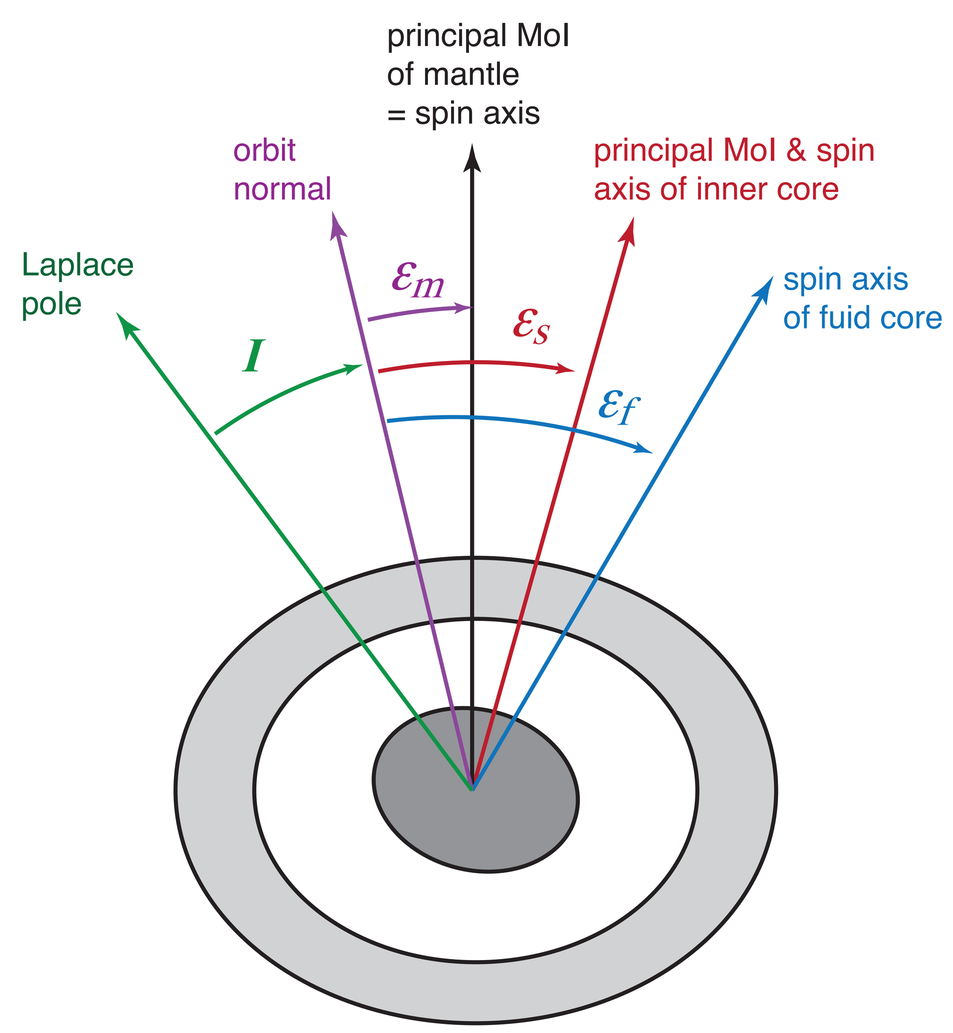
1. Mercury's Cassini state

- Orbit normal & spin-symmetry axis are coplanar with, and precess about, the normal to the Laplace plane



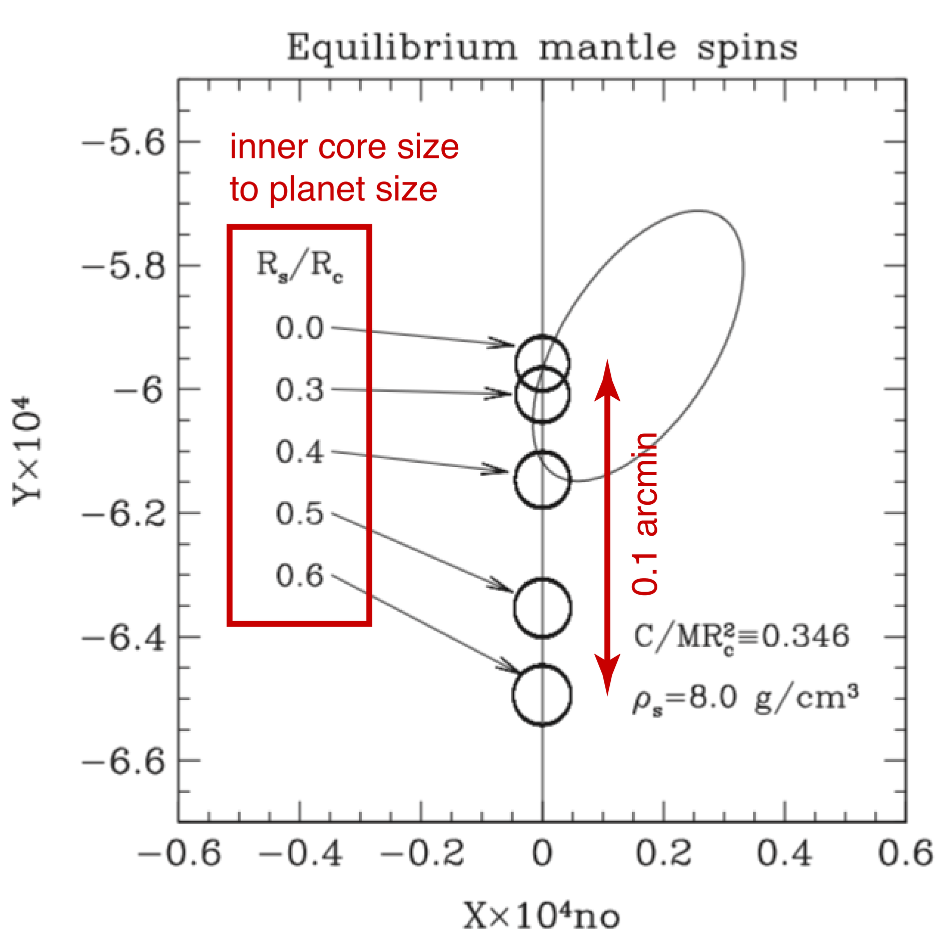
- Orbit inclination: $I = 8.5333°$
- Precession frequency: $\Omega_p = 2\pi/325,513\,\mathrm{yr}^{-1}$
- Obliquity: $\varepsilon_m \approx 2$ arcmin

- How is the Cassini state modified by a fluid core and a solid core?
- How does it change the resulting mantle obliquity ε_m?

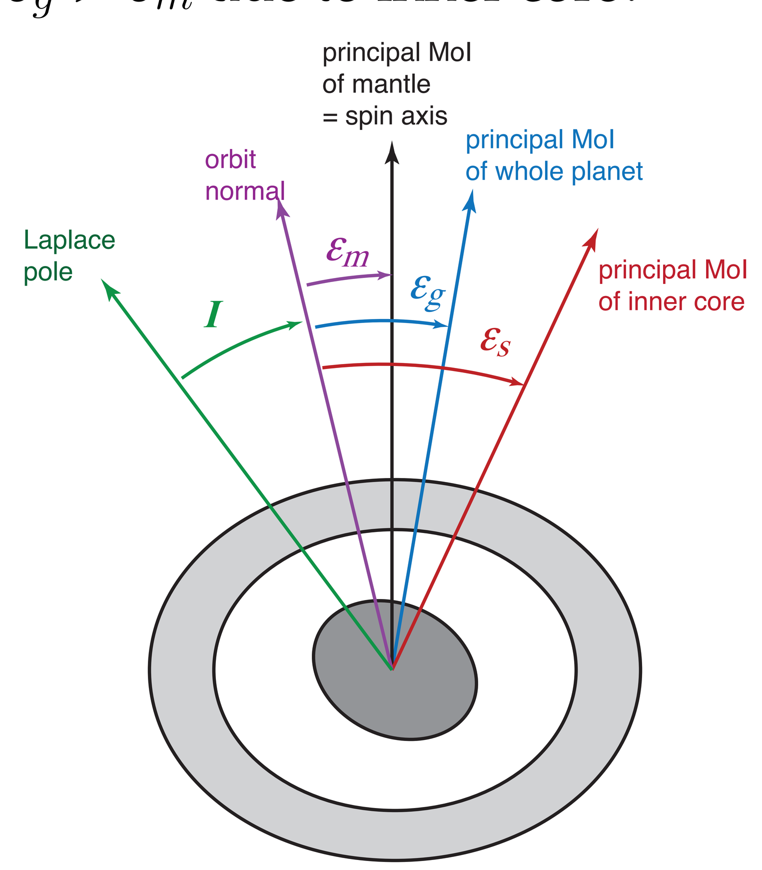


2. Motivations

- Peale et al. (Icarus, 2016): large inner core can increase ε_m by ~ 0.1 arcmin



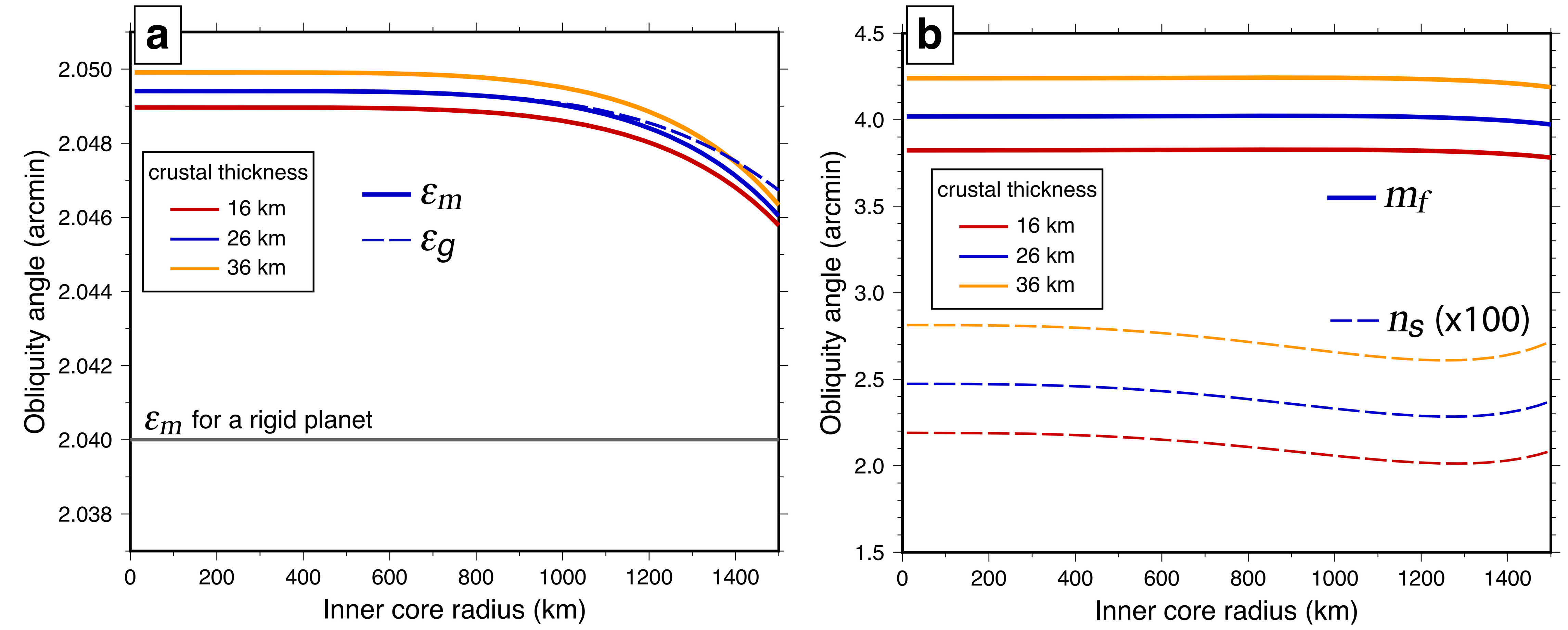
- Genova et al. (GRL, 2019): Obliquity of gravity field $\varepsilon_g = 1.968 \pm 0.027$ arcmin different than $\varepsilon_m = 2.04 \pm 0.08$ arcmin [e.g. Margot et al, JGR 2012]
- $\varepsilon_g > \varepsilon_m$ due to inner core?



3. Method

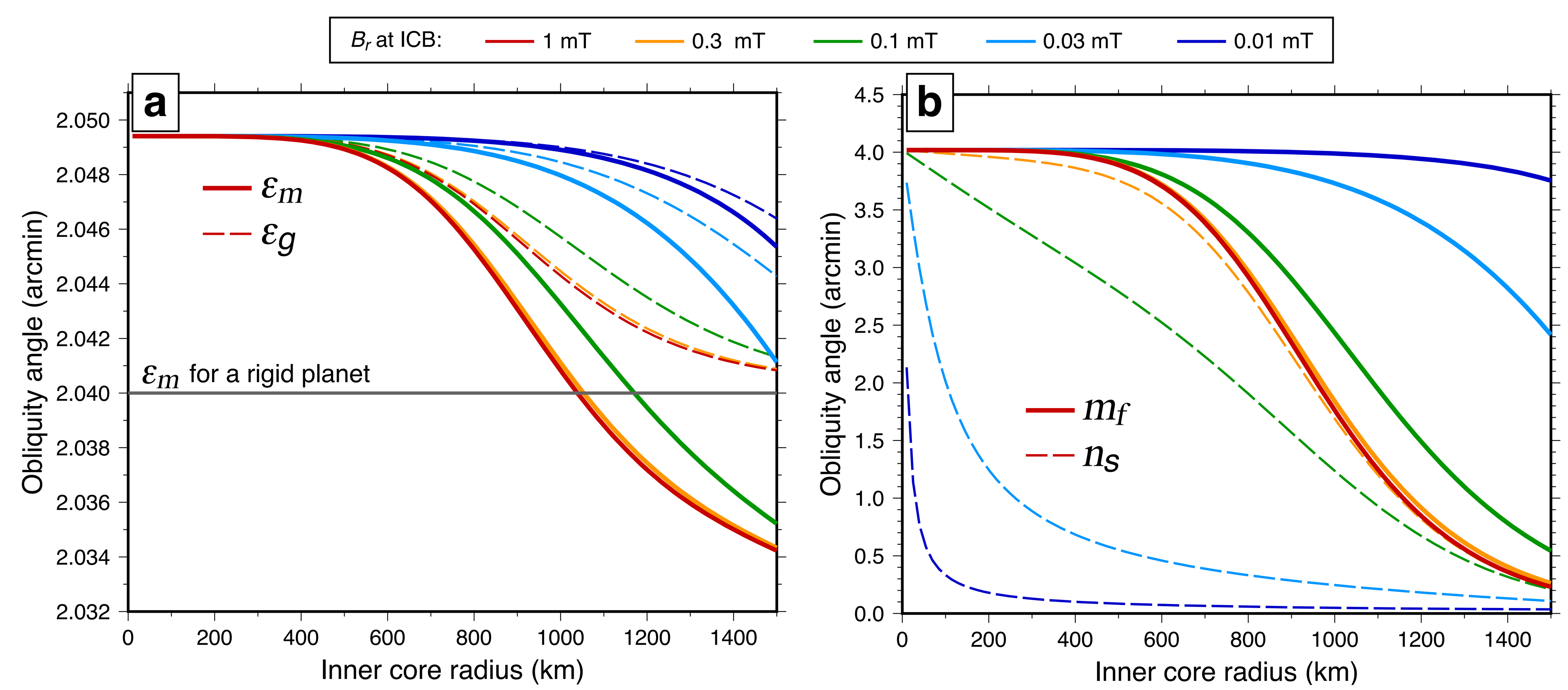
- We adapt model of internal coupling developed to study Earth's forced nutations by Matthews et al. (JGR, 1991). For details, see: Dumberry, JGR 2021 https://doi.org/10.1029/2020JE006621
- The model includes
  - Gravitational torque (external and internal)
  - Pressure torques at ICB and CMB
  - viscous and electromagnetic torques at ICB and CMB

4. Results: Inertial and gravitational coupling



- Fluid core offset (m_f) ≈ 4 arcmin, inner core offset (n_s) ≈ 0.025 arcmin. (both wrt mantle)
- Max difference in ε_m wrt rigid planet = 0.01 arcmin. Max difference $\varepsilon_g - \varepsilon_m = +0.001$ arcmin.

5. Results: Inertial, gravitational and EM coupling



- For Br at ICB > 0.3 mT, fluid and solid cores are locked into a co-precession.
- Difference in ε_m wrt rigid planet = +0.01 to -0.006 arcmin.
- Difference $\varepsilon_g - \varepsilon_m = +0.007$ arcmin for a large inner core.

7. Implications

- Larger inner core implies a *decrease* in ε_m. The larger the inner core is, the more Mercury precesses as a rigid body.
- At present-day level of errors (0.03-0.08 arcmin), the measured obliquities of the mantle and gravity field should
  - coincide and
  - cannot be distinguished from that of a rigid planet.
- Measurements of the obliquity from BepiColumbo (error < 0.008 arcmin) may allow us to identify an offset compared to that of a rigid planet, and thus provide further constraints on Mercury's interior.