The interior structure of Mercury constrained by geodesy data and new experimental data about iron-rich alloys

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Geodesy data

- Margot et al. 2012
  Obliquity: 2.04 ± 0.08 arcmin ⇒ MOI=0.345 ± 0.014 (4%)
  Libration amplitude: 38.5 ±1.6 arcsec (4%)

- Stark et al. 2015
  Obliquity: 2.03 ± 0.09 arcmin ⇒ MOI=0.345 ± 0.014 (4%)
  Libration amplitude: 38.9 ±1.3 arcsec (3%)

- Verma et al. 2016
  Tidal Love number: k_2=0.46 ± 0.02 (4%)

Pole right ascension and declination from moving surface features

- Genova et al. 2019
  Obliquity: 1.97 ± 0.009 arcmin ⇒ MOI=0.333 ± 0.0015 (0.5%)
  Libration amplitude: 40.0 ± 8.7 arcsec (20%)
  Tidal Love number: k_2=0.57 ± 0.03 (5.2%)

- Konopliv et al. 2020
  Obliquity: 1.99 ± 0.12 arcmin ⇒ MOI=0.337 ± 0.02 (~6%)
  Tidal Love number: k_2=0.53 ± 0.03 (5.6%)

Pole right ascension and declination from MESSENGER orbit

MOI ↓ and k_2 ↑

core radius ↓ **core radius ↑**

New thermodynamic model for liquid-Fe alloys

JGR Planets

RESEARCH ARTICLE
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Pressure and Composition Effects on Sound Velocity and Density of Core-Forming Liquids: Implication to Core Compositions of Terrestrial Planets

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Key Points:
- The sound velocity and density of liquid Fe-Ni-S (17 and 30 at% S) and Fe-Ni-Si (29 and 38 at% Si) were measured up to 14 GPa
- Based on the obtained elastic properties, estimated S contents in

- based on measured densities (up to 5 GPa) and acoustic sound velocities (up to 14 GPa) of liquid ($Fe_{73}Ni_{10}S_{17}$, $Fe_{60}Ni_{10}S_{30}$), liquid ($Fe_{61}Ni_{10}Si_{29}$, $Fe_{52}Ni_{10}Si_{38}$), and liquid Fe eos
- predicted low and high pressure elastic properties are in good agreement with previously measured low pressure and high pressure data (up to 60GPa)

⇒ **thermodynamic model valid for the whole (x,p,T) range of Mercury's liquid core**

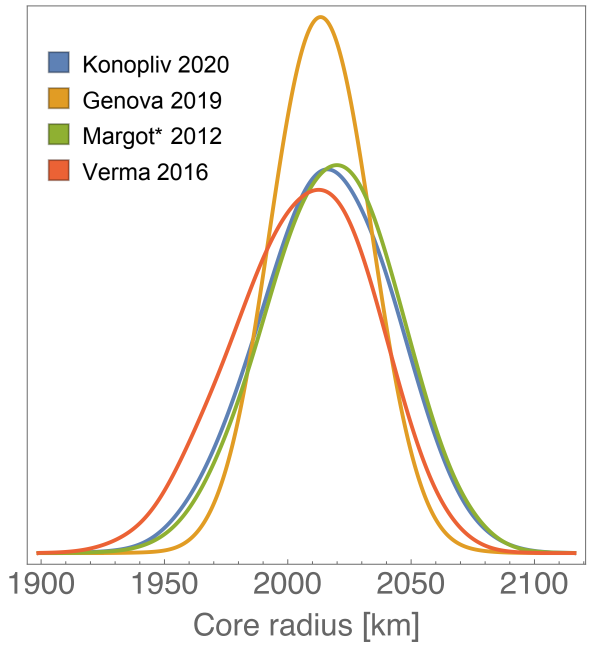
Prior assumptions, modeling, and data

- crust: density [2700, 3100]kg/m^3 and thickness [15,120]km
- mantle elastic properties compatible with forsterite-enstatite mixture
- inner core radius and light element fraction in agreement with liquidus; assume Si concentration in liquid below eutectic composition (because of unknown liquidus at those compositions); core radius prior [1800, 2200]km
- prior core-mantle boundary temperature between eutectic temperature and (optimistic) mantle solidus
- libration amplitude calculated by taking into account gravitational core-mantle coupling and mantle induced core density stratification (Dumberry et al., 2013)
- geodesy data: 88 day libration amplitude Margot et al. 2012+obliquity+ k_2
  1) Konopliv 2020, **2**) Genova 2019, **3**) Margot 2012 (with k_2 from Konopliv 2020),
  4) Verma 2016 (with obliquity from Margot 2012)

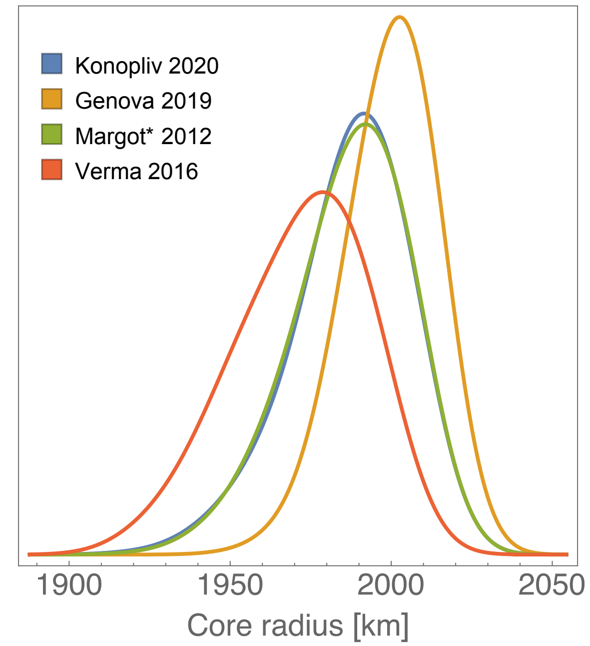
Results: Core radius

Fe-S

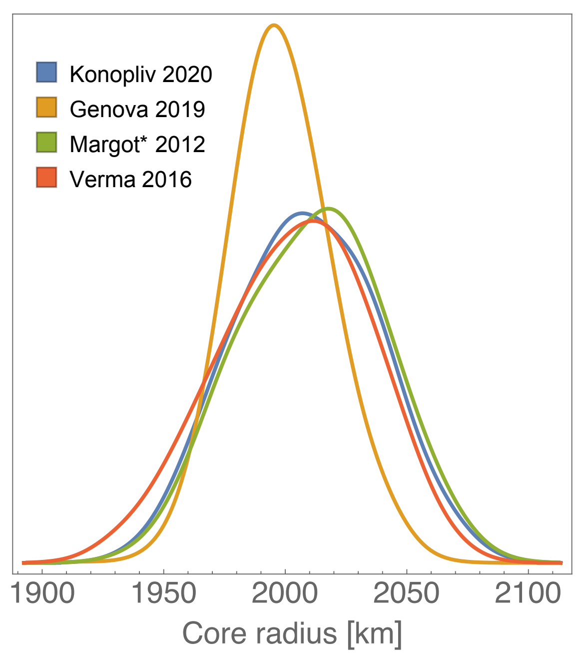
Liquid core models

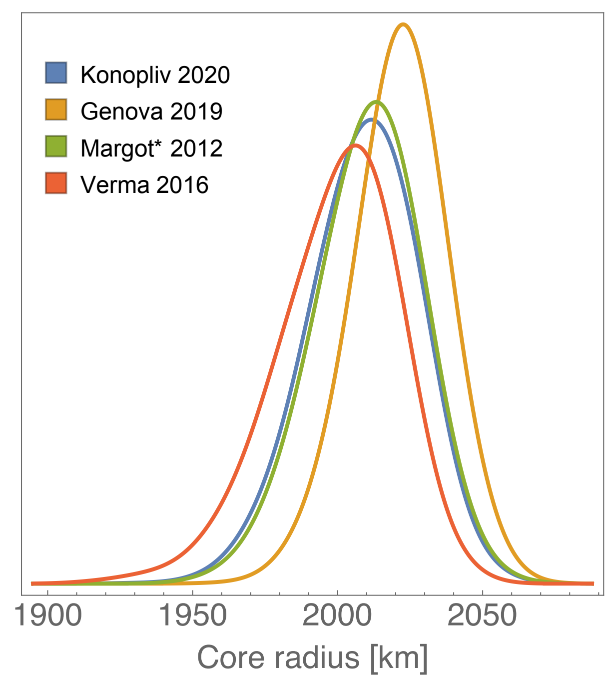


Inner core models



Fe-Si





Liquid core models Fe-S

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	2016_{26}	2013_{17}	2017_{25}	2008_{27}
x_S [wt%]$_{1\sigma}$	3.8-7.4	3.9-5.9	3.9-7.5	3.5-7.4

Inner core models Fe-S

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	1987_{16}	2000_{11}	1987_{16}	1972_{20}
x_S [wt%]$_{1\sigma}$	3.5-5.8	4.4-6.0	3.5-5.8	2.4-5.6

Liquid core models Fe-Si

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	2008_{29}	1998_{19}	2011_{29}	2003_{31}
x_{Si} [wt%]$_{1\sigma}$	6.4-12.7	6.4-10.0	6.6-12.8	6.0-12.8

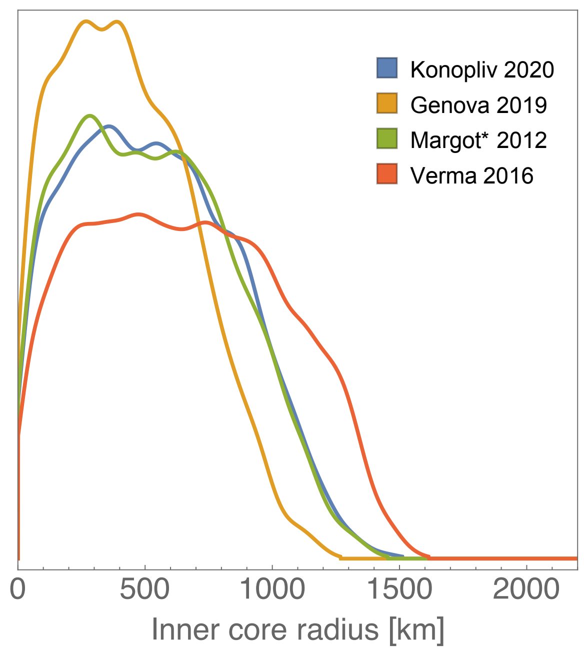
Inner core models Fe-Si

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	2009_{17}	2021_{14}	2010_{14}	1999_{20}
x_{Si} [wt%]$_{1\sigma}$	11.2-15.0	12.2-15.2	11.4-15.0	10.6-15.1

- Fe-Si models require more light elements since Fe-Si alloys are denser than Fe-S alloys
- core radius at 1σ : 1952-2043 km
- core radius mostly driven by k_2 value

Results: Inner core radius

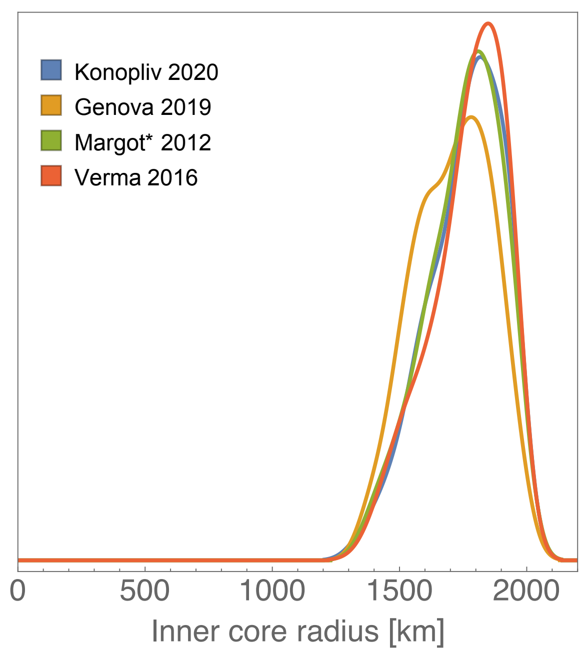
Fe-S



Inner core models Fe-S

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	1987_{16}	2000_{11}	1987_{16}	1972_{20}
r_{icb} [km]$_{3\sigma}$	0-1380	0-1174	0-1347	0-1495

Fe-Si

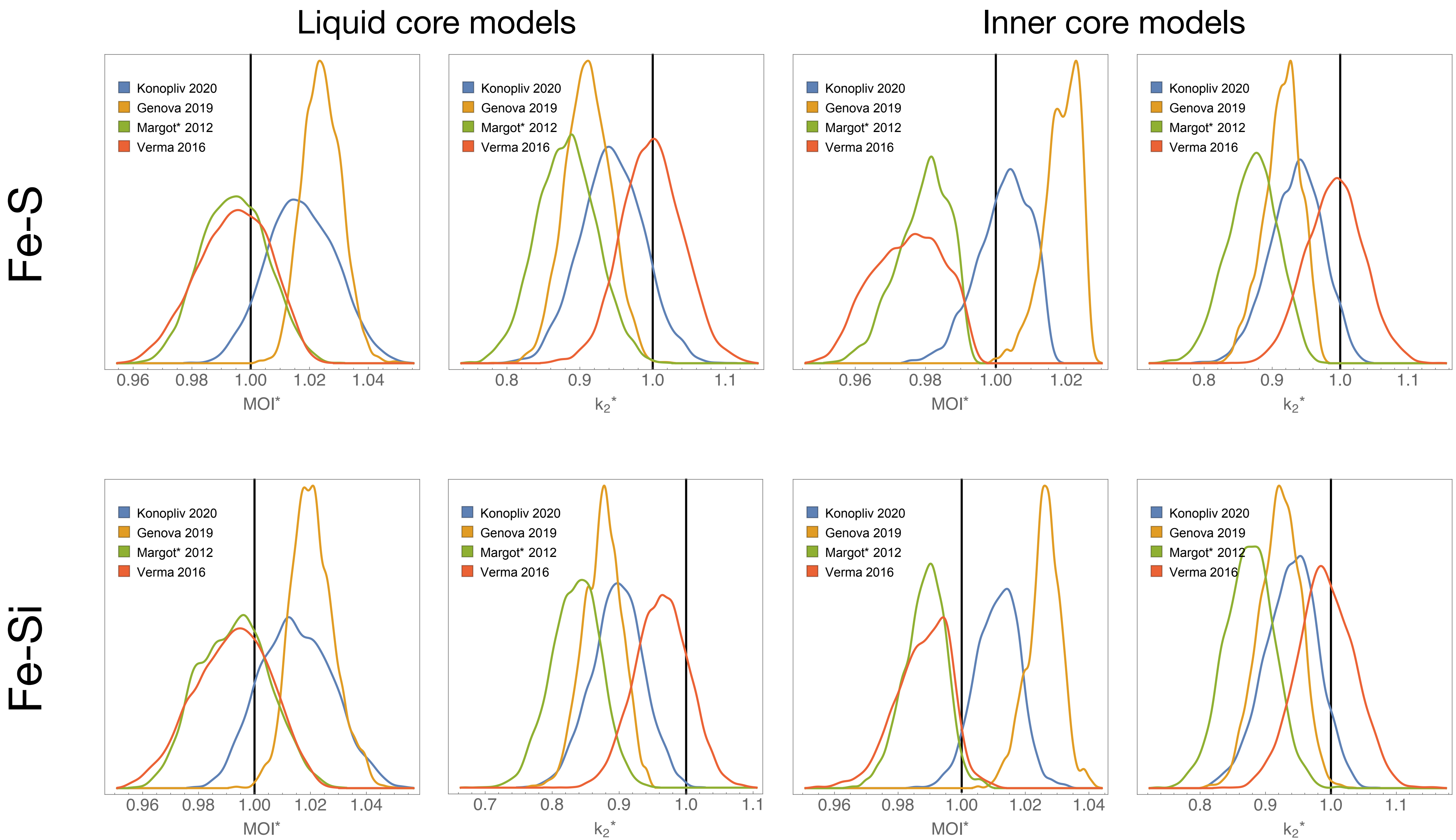


Inner core models Fe-Si

	Konopliv	Genova	Margot	Verma
r_{cmb} [km]$_{1\sigma}$	2009_{17}	2021_{14}	2010_{14}	1999_{20}
r_{icb} [km]$_{3\sigma}$	1306-2003	1346-2007	1345-2002	1345-2002

- inner core radius at 3σ: **Fe-S** : 0-1495 km and **Fe-Si**: 1306-2007 km
- expect to loose inner core radius constraint with Fe-S-Si models!

Results: Model fit



Score: Liquid core models

	Konopliv	Genova	Margot	Verma
MOI	0/0	-/-	+/+	+/+
k_2	0/0	-/-	-/-	+/+

Score: Inner core models

	Konopliv	Genova	Margot	Verma
MOI	+/0	-/-	-/0	-/0
k_2	0/0	-/-	-/-	+/+

likelihood: + high, 0 moderate, - marginal

Conclusions

- models with and without inner core agree with geodesy data but liquid Fe-Si models require somewhat unlikely high present-day core temperatures

- core radius ~$[1952,2043]_{1\sigma}$ km

- inner core radius: **Fe-S:** ~$[0,1500]_{3\sigma}$ km and **Fe-Si:**~$[1300,2010]_{3\sigma}$ km
⇒expect to loose inner core constraint for Fe-S-Si models

- high likelihood for models with MOI-k_2 from Margot 2012-Verma 2016 and significantly lower likelihood with MOI-k_2 from Genova 2019

- not used constraints:
- without a growing inner core past and present dynamo cannot be explained
- 7km radial contraction of Mercury requires a relative small inner core and limited amount of core cooling
- magnetospheric induced currents require a core radius of 2066±22km
(Wardinski 2019)