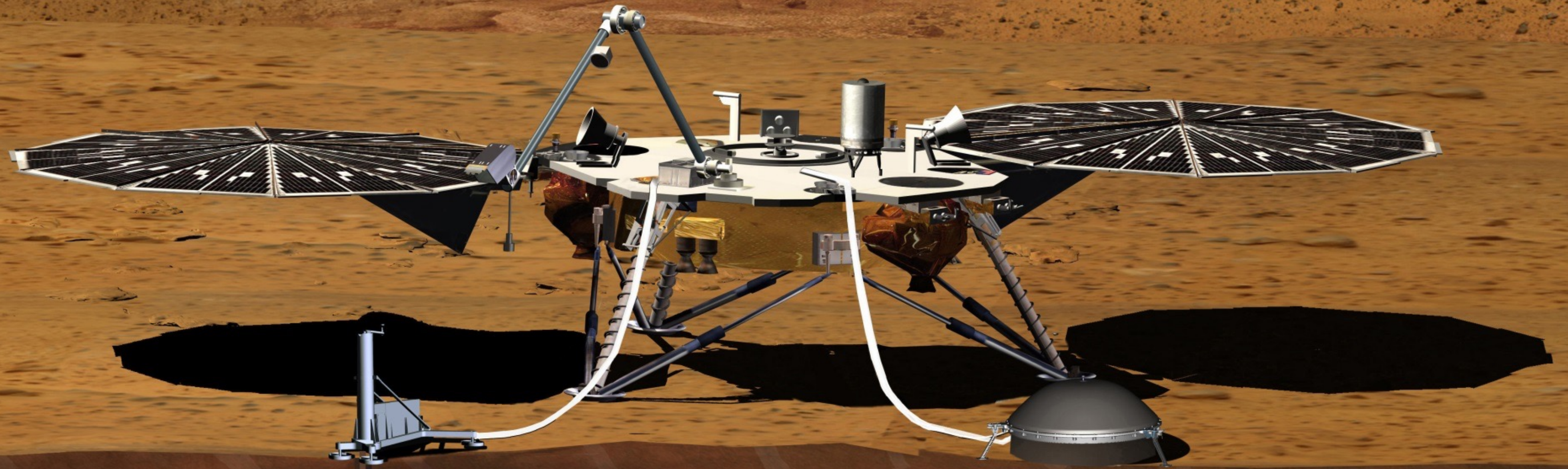


The Crust of Mars



Mark Wieczorek

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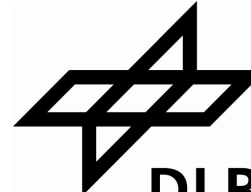


InSight

JPL



cnes



DLR

ETH

LOCKHEED MARTIN

MPS

ISAE



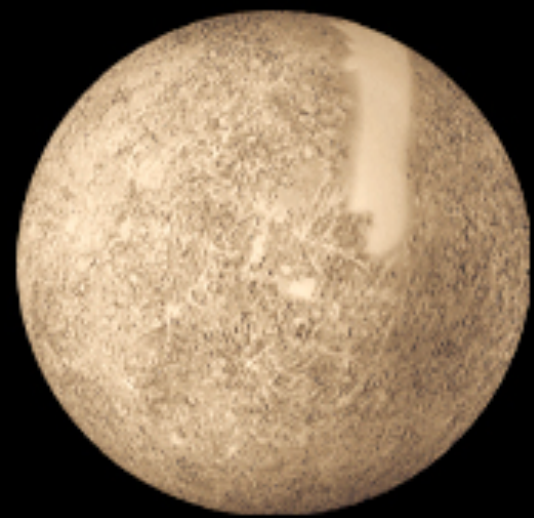
Imperial College
London



CAB

Comparative Planetology

Mercury



Ancient crust,
active dynamo

Venus



Young volcanically
active surface

Earth



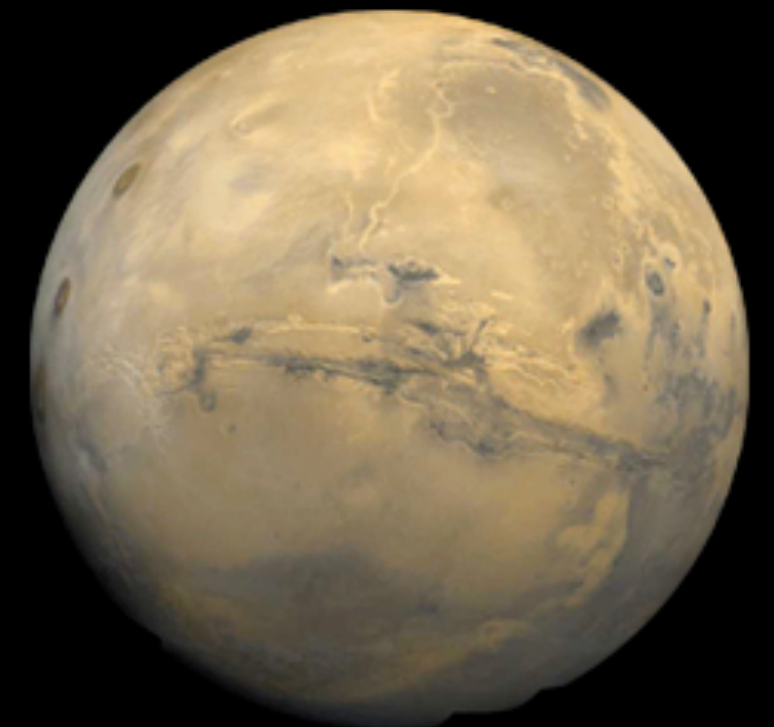
Dynamo,
plate tectonics

Moon



Ancient crust,
impact craters

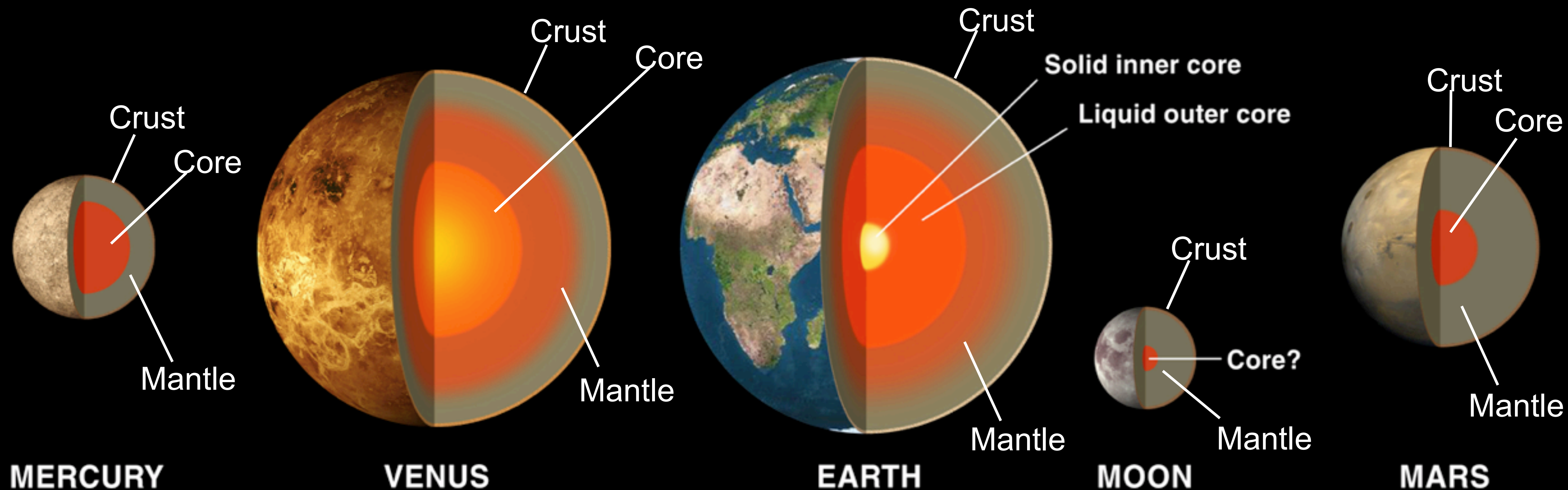
Mars



Single long-
lived plume

Why are the planets so different?

Is crust formation on Mars more similar to Earth, Venus, Mercury or the Moon?



no seismic data

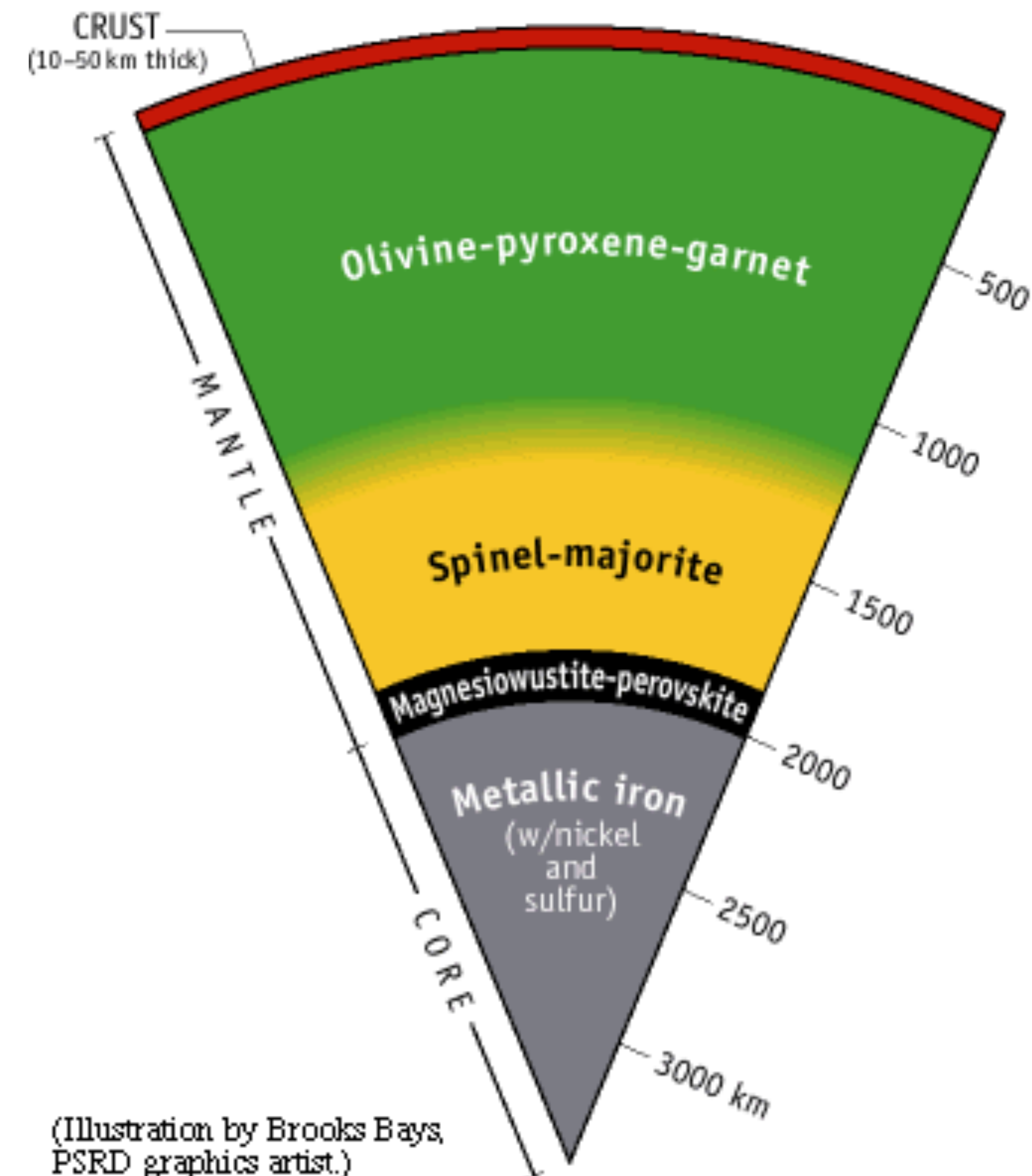
no seismic data

$T_{\text{crust}} = 35 \text{ km}$
silicate vol.% ~2%

$T_{\text{crust}} = 34\text{-}43 \text{ km}$
silicate vol.% ~6-7%

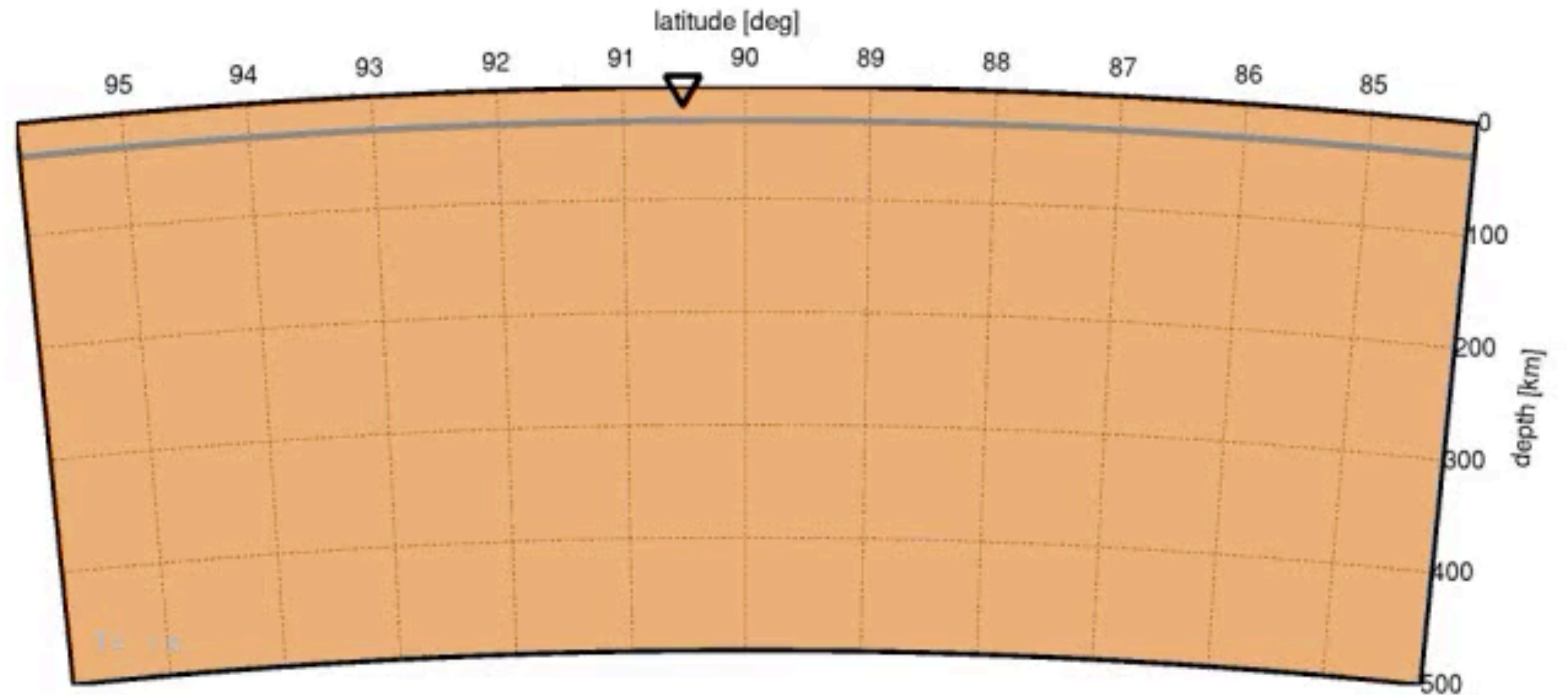
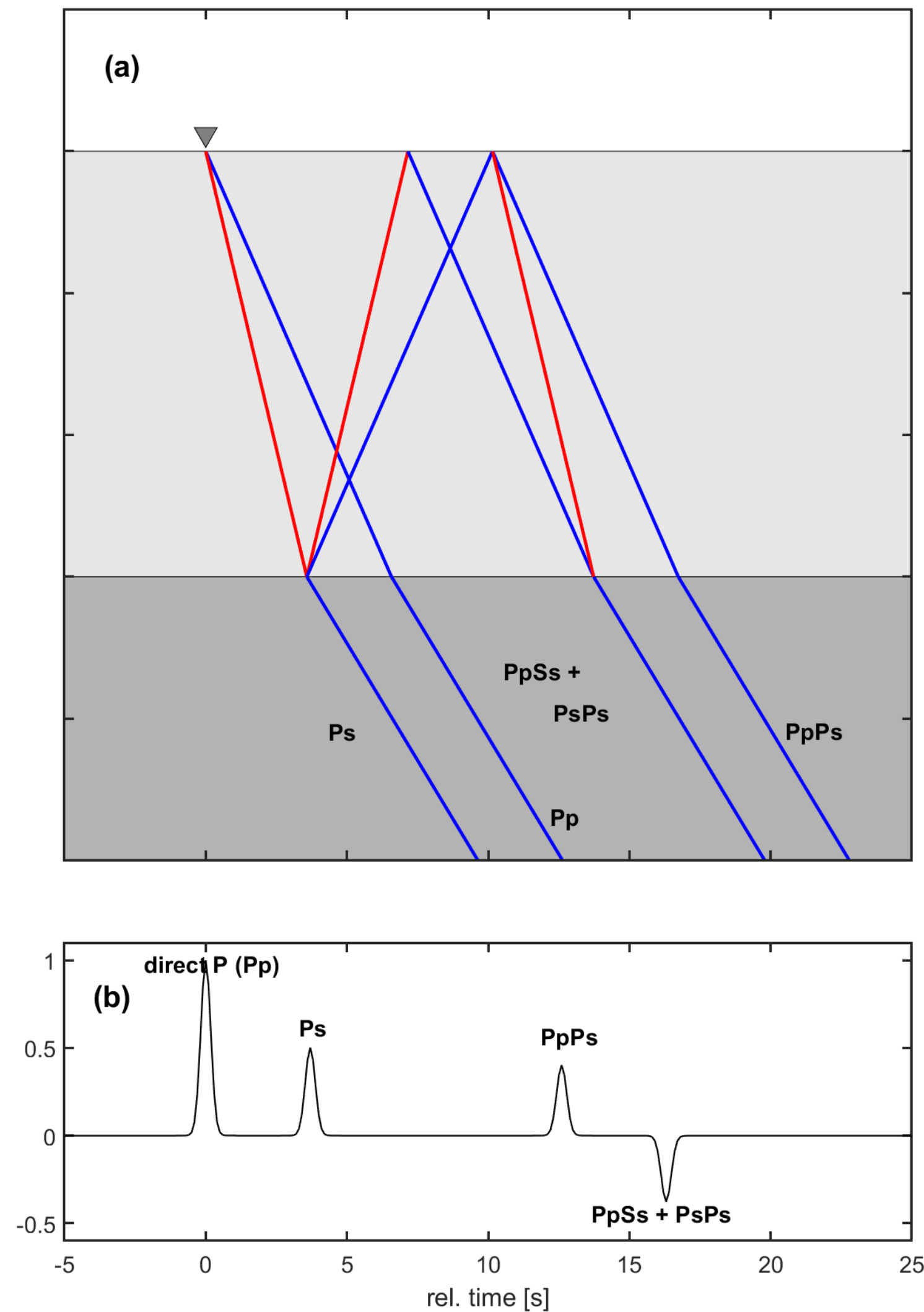
InSight!

Questions related to the crust



- **How did the crust form?** Volcanism? Plate tectonics? Magma ocean crystallization?
- **How thick is the crust of Mars?** The crust is enriched in elements like aluminum, and if you want to estimate the bulk composition of Mars, you need to know the thickness of the crust.
- **How does the thickness of the crust vary from place to place?** Did impact craters excavate through the crust and into the mantle?
- **How much heat is produced in the crust and mantle?** The radioactive elements Thorium, Uranium and Potassium are highly concentrated in the crust. The distribution of heat producing elements affects the thermal and volcanic evolution of the planet.

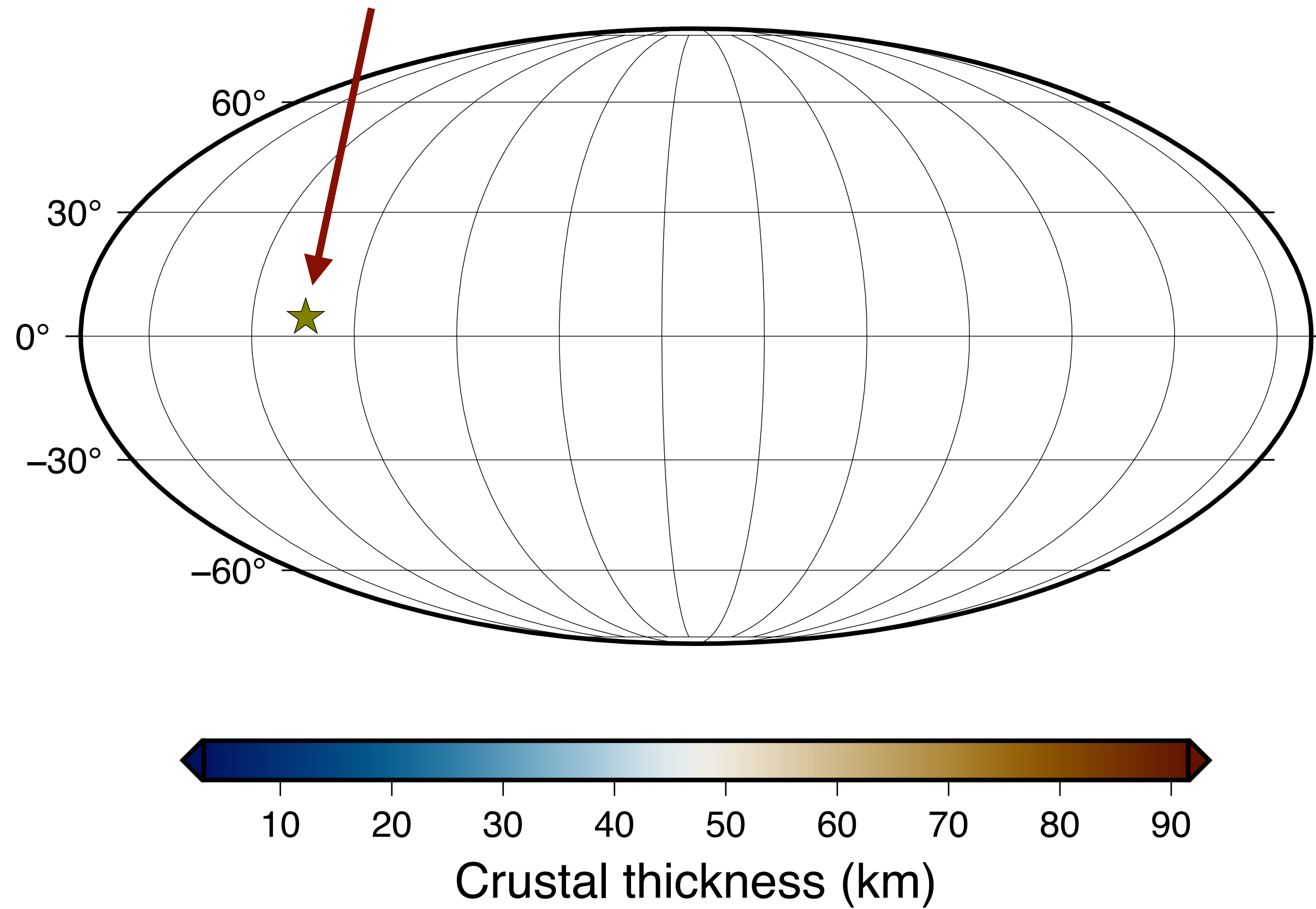
Crustal thickness from seismology



Seismic waves get converted from $P \Leftrightarrow S$ waves when they encounter the crust-mantle interface. The arrival times of these secondary phases are related to the thickness of the crust.

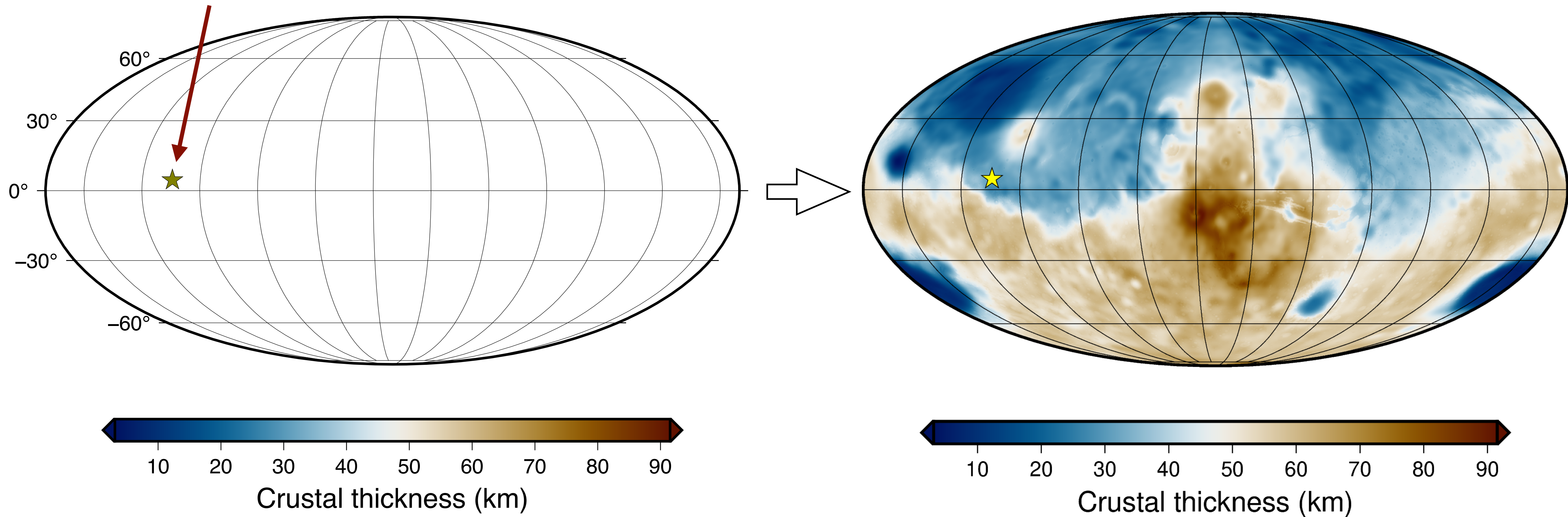
InSight will give us the crustal thickness beneath the landing site...

InSight Landing Site



...but we would like to have a global crustal thickness map!

InSight Landing Site



Gravity and topography data can help us extrapolate this single measurement globally.

The gravity field of the planet depends on crustal thickness

Newton's law of gravitation

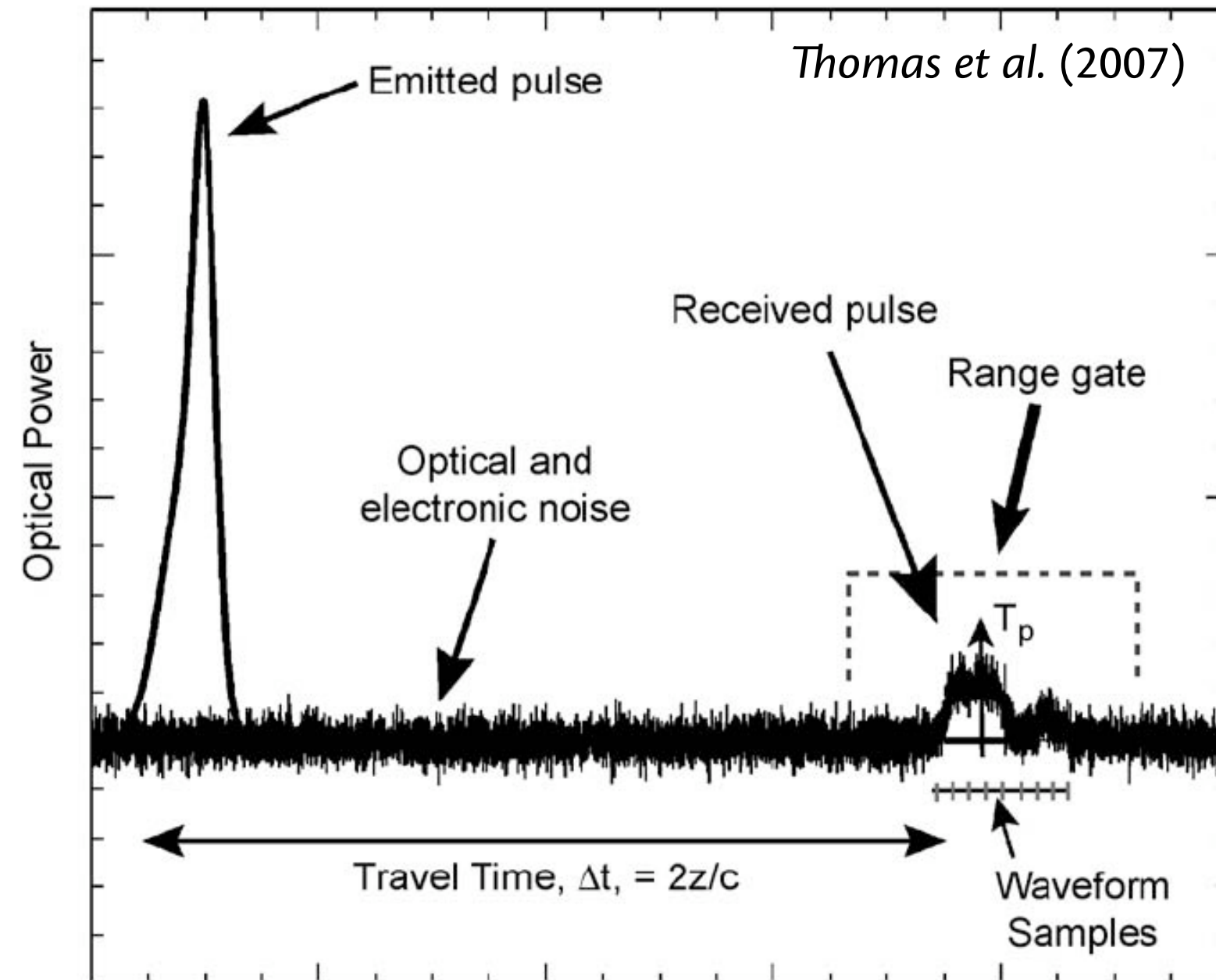
$$F(\mathbf{r}) = Gm \sum_i \frac{\rho(r_i) \Delta V_i}{|\mathbf{r} - \mathbf{r}_i|^2} \left(\frac{\mathbf{r} - \mathbf{r}_i}{|\mathbf{r} - \mathbf{r}_i|} \right)$$

Schematic cross-section of the crust of Mars



- The gravitational force acting on an orbiting satellite of mass m depends upon the density distribution of the planet.
- The largest gravitational signal comes from surface topography (mountains and canyons).
- The second largest contribution to the gravity field comes from “topography” along the crust-mantle interface.

How to measure topography: Altimetry



- The distance from the spacecraft to the surface is determined by measuring the travel time of a reflected laser (or radar) pulse.
- The radius of the surface is determined by knowledge of the spacecraft's position in orbit.
- Example parameters for the Mars Orbiter Laser Altimeter (MOLA) on the mission Mars Global Surveyor:

Range Precision: ~ 37 cm

Absolute Vertical Resolution: <10 m (determined by orbit precision)

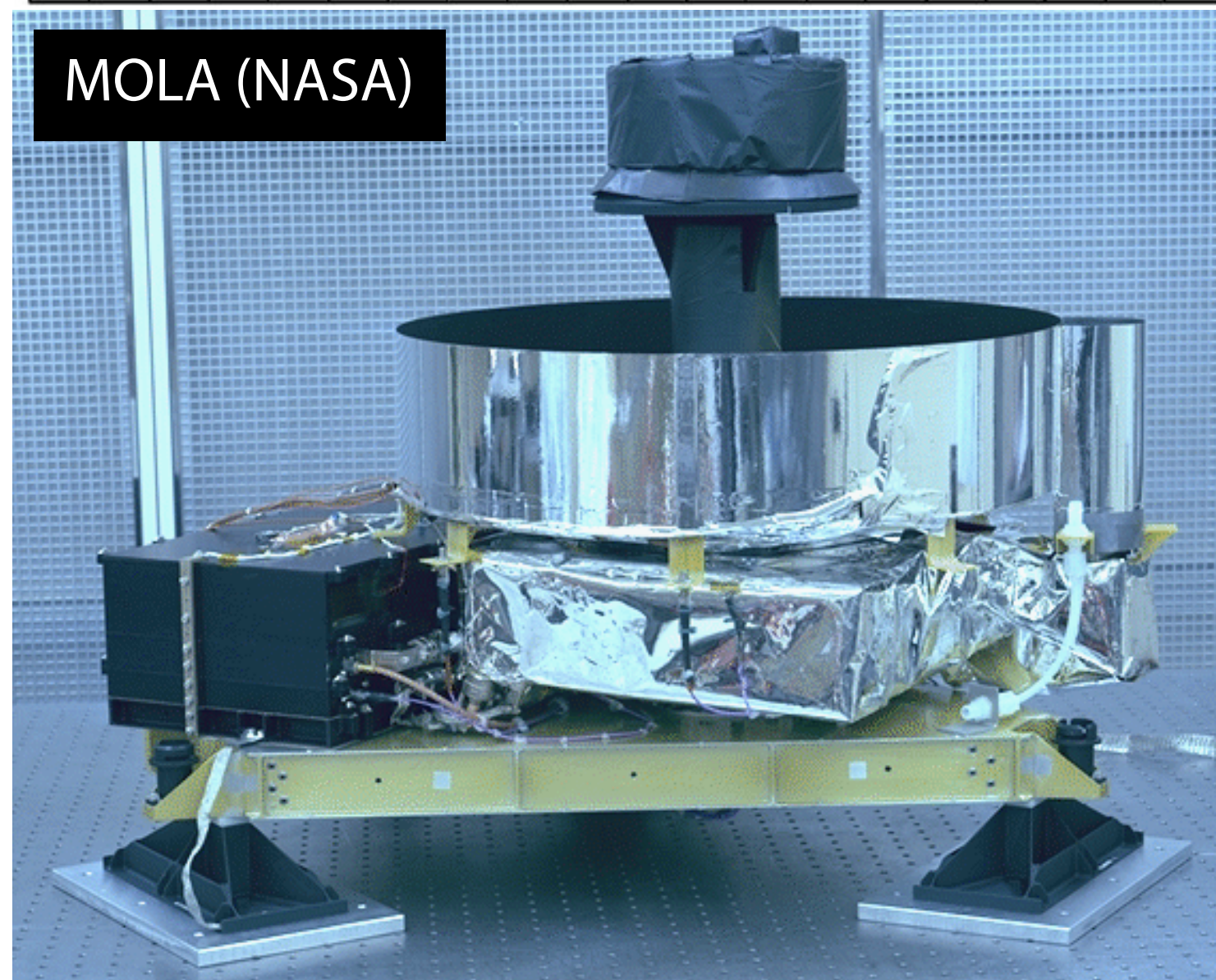
Total number of Shots: ~640 Million

Surface Spot Size: 130 m

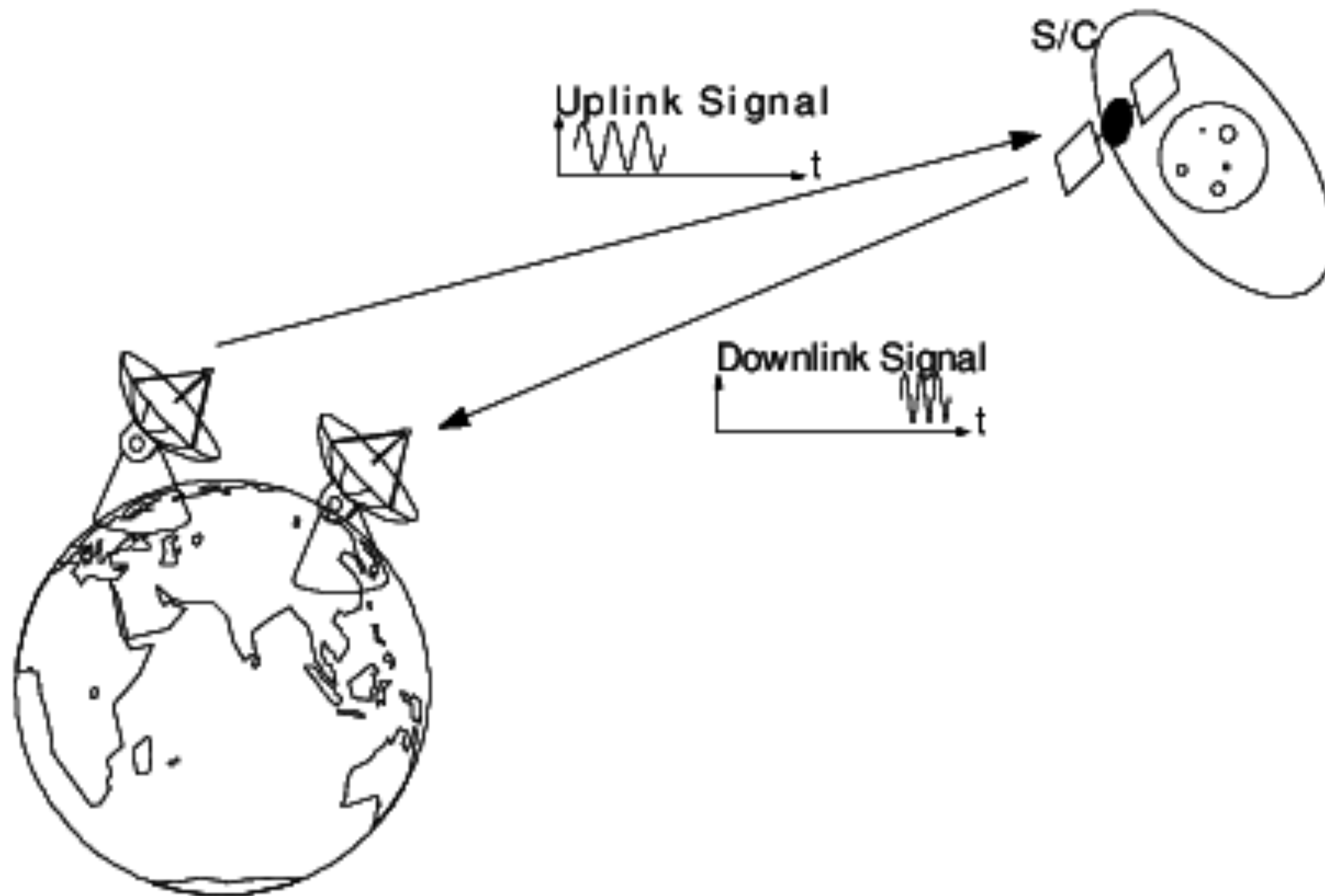
Along Track Shot Spacing: ~330 m

Cross-Track Spacing: ~1-30 km (equator)

MOLA (NASA)

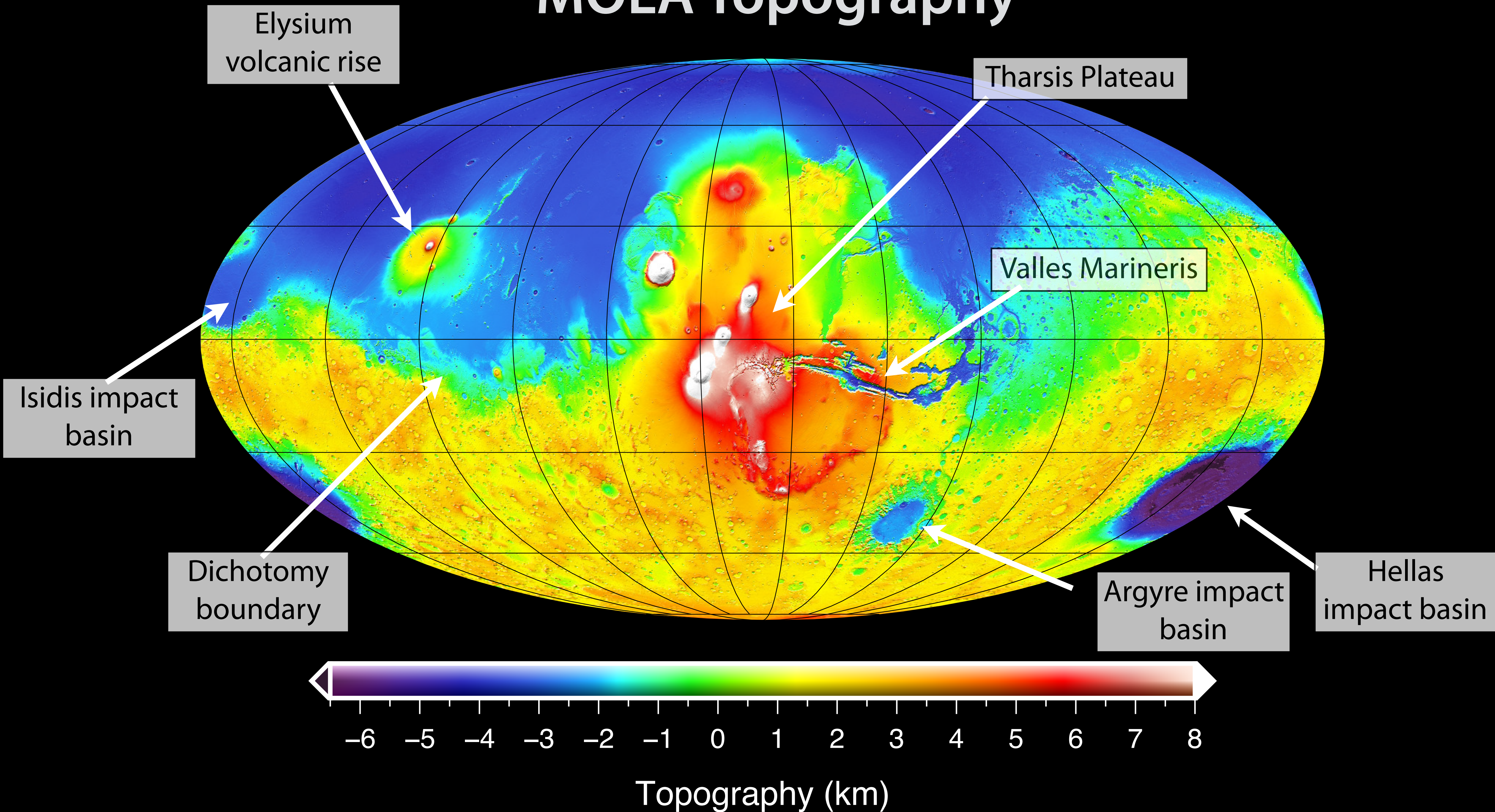


How to measure gravity

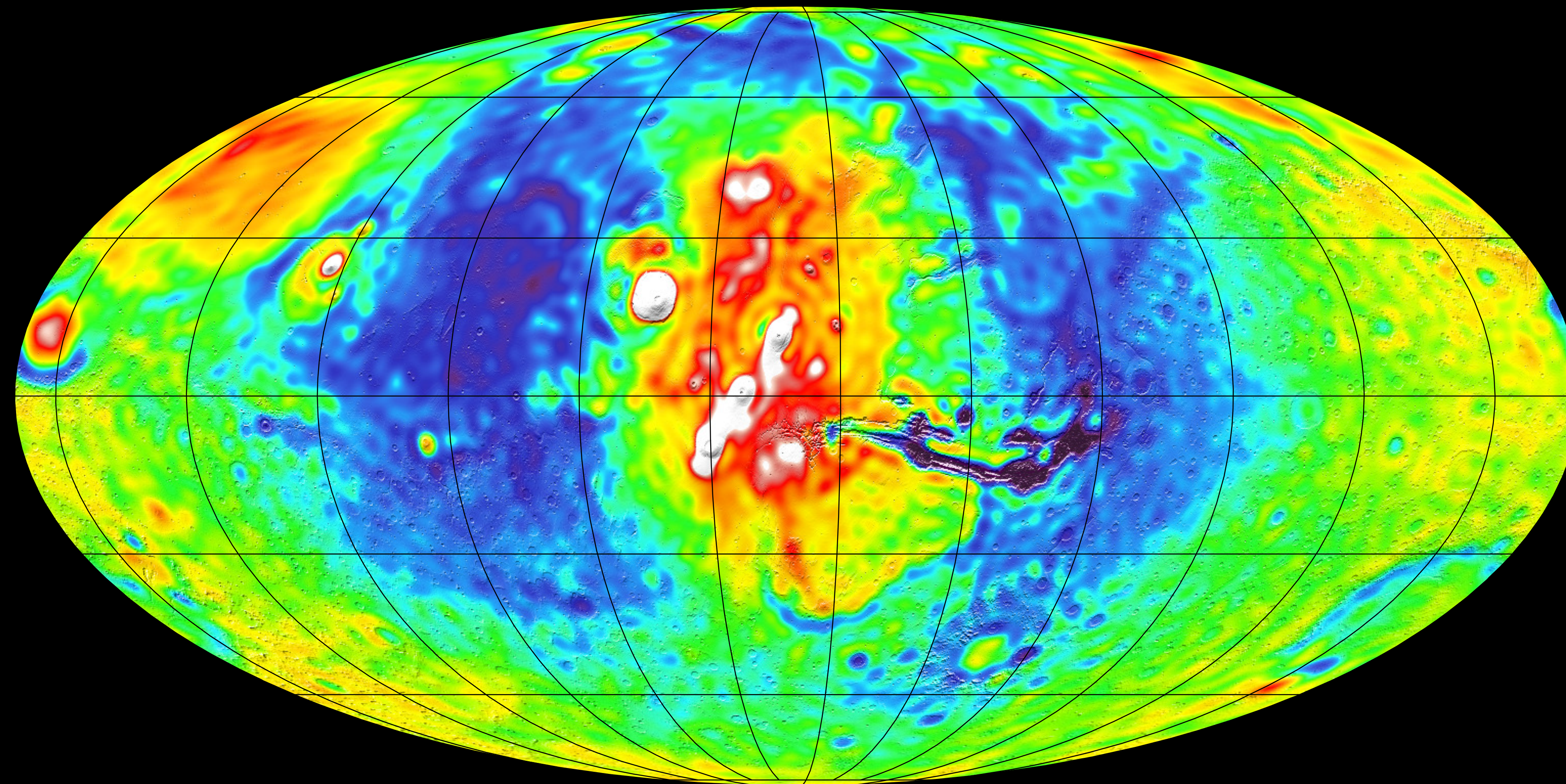


1. The distance to the satellite is measured by the time-of-flight of the radio signal.
2. The line-of-sight velocity is determined by the doppler shift of the radio signal.
3. Gravitational anomalies from the planet perturb the orbit of the orbiting satellite, which are seen in the doppler data.

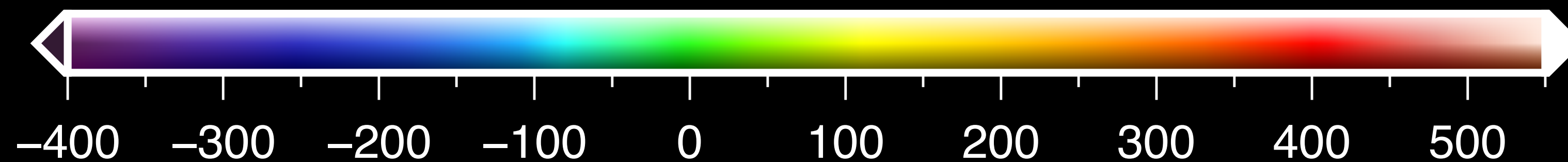
MOLA Topography



Gravity



- Volcanoes have high elevations and large positive gravitational anomalies.
- The Isidis impact basin has a topographic low with a large positive anomaly (i.e., “mascon structure”)



Total Gravity Anomaly (mGal)

Parameters that go into a crustal thickness model

Model Parameters	Certitude
Gravity and topography	Pretty good / Great
Mantle and core density profile	Good (upper mantle density is most important)
Relief of density interfaces in mantle and core	Good enough
Crustal thickness at InSight landing site	Working on it! Best estimates are either 30 or 45 km.
Bulk density of the crust	Poorly known
Lateral variations in crustal density	Poorly known

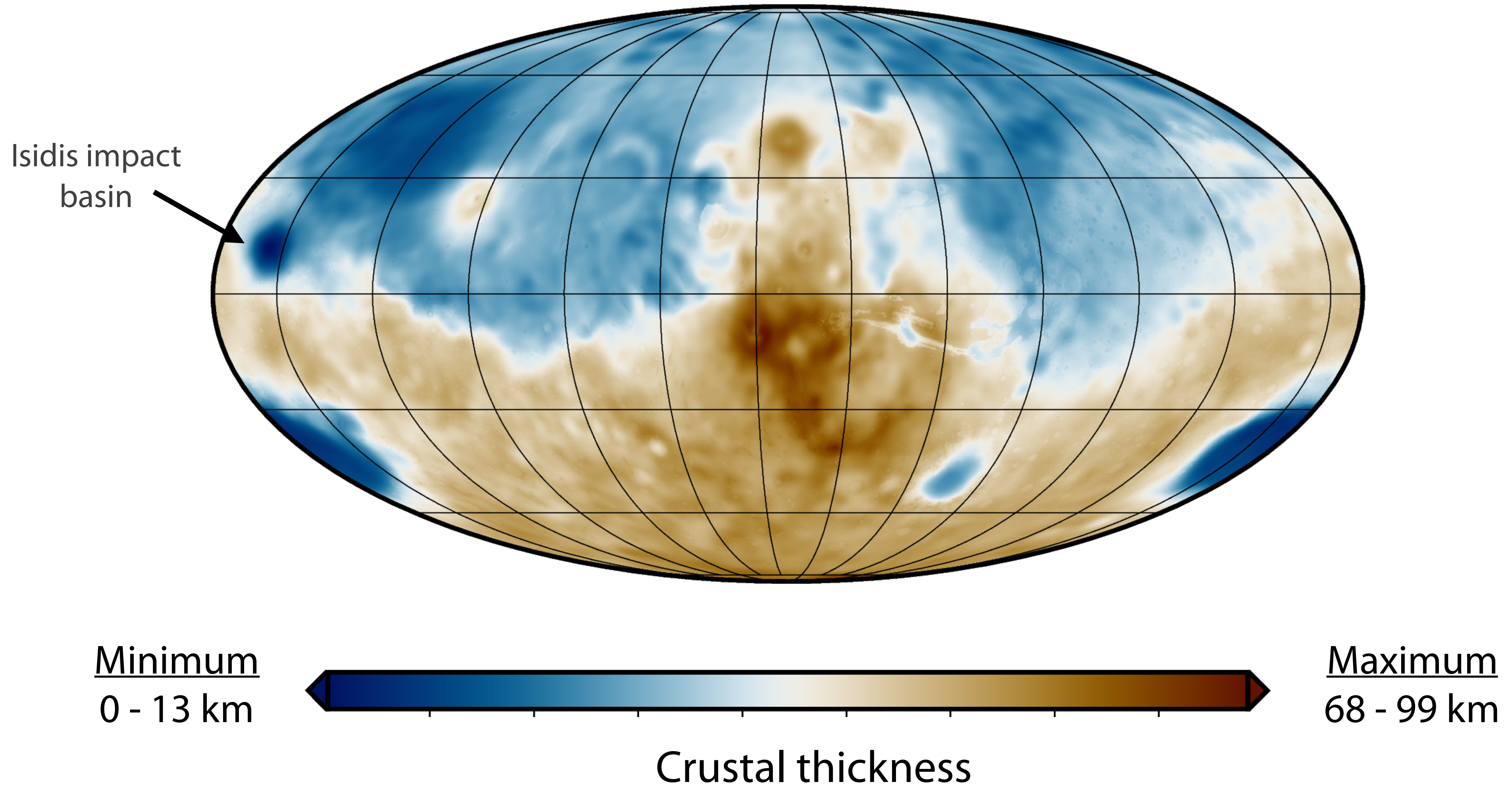
The simplest possible model of the martian crust



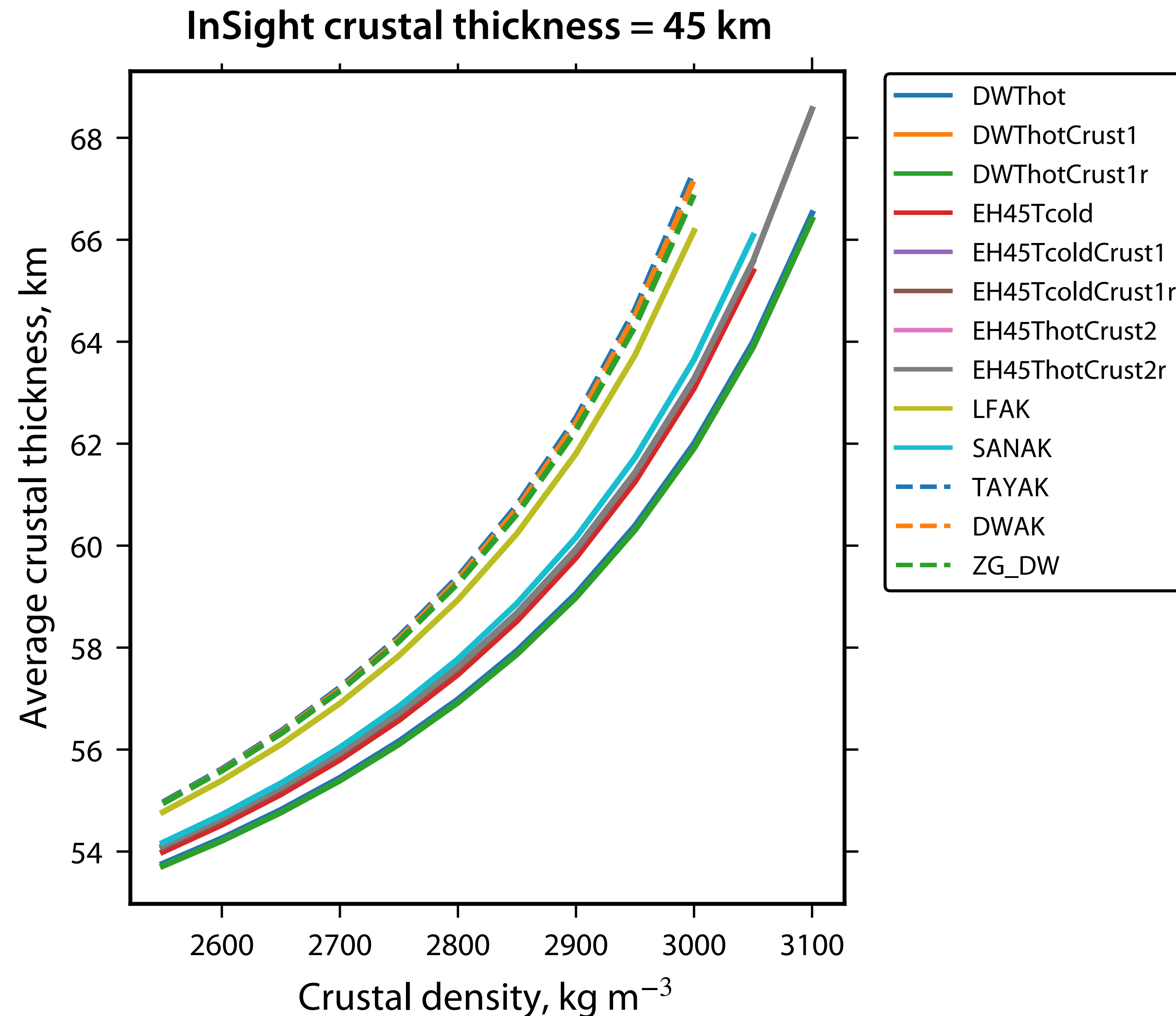
Assume that the density of the crust is everywhere the same:

The observed gravity field is equal to the gravity from the surface topography and crustal thickness variations. If we know the density of the crust, we can invert for the thickness of the crust.

The assumed crustal density affects only the colorbar!



Constant density crust



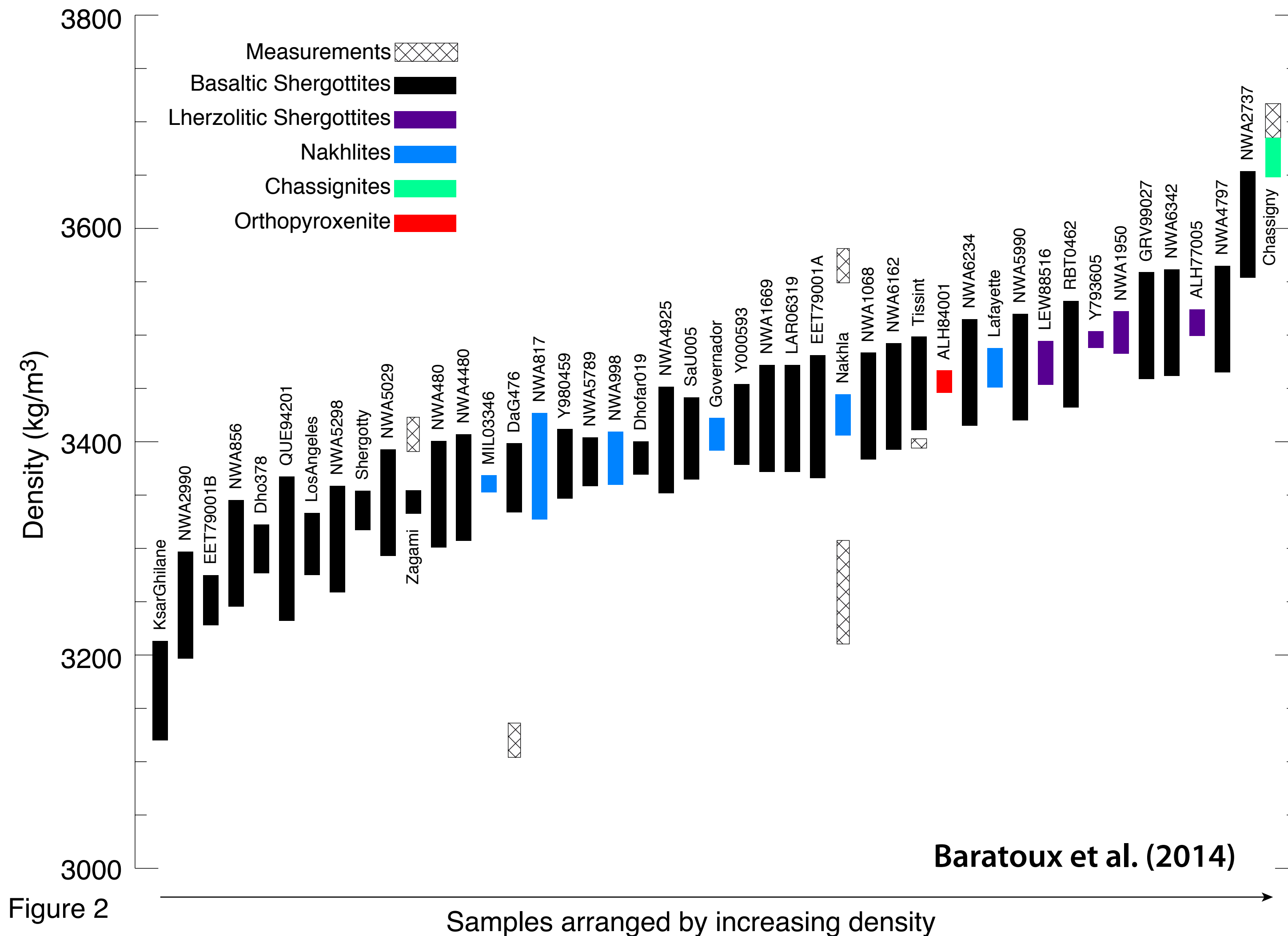
As you increase the density of the crust:

- the maximum crustal thickness increases,
- the average crustal thickness increases,
- the minimum crustal thickness decreases.

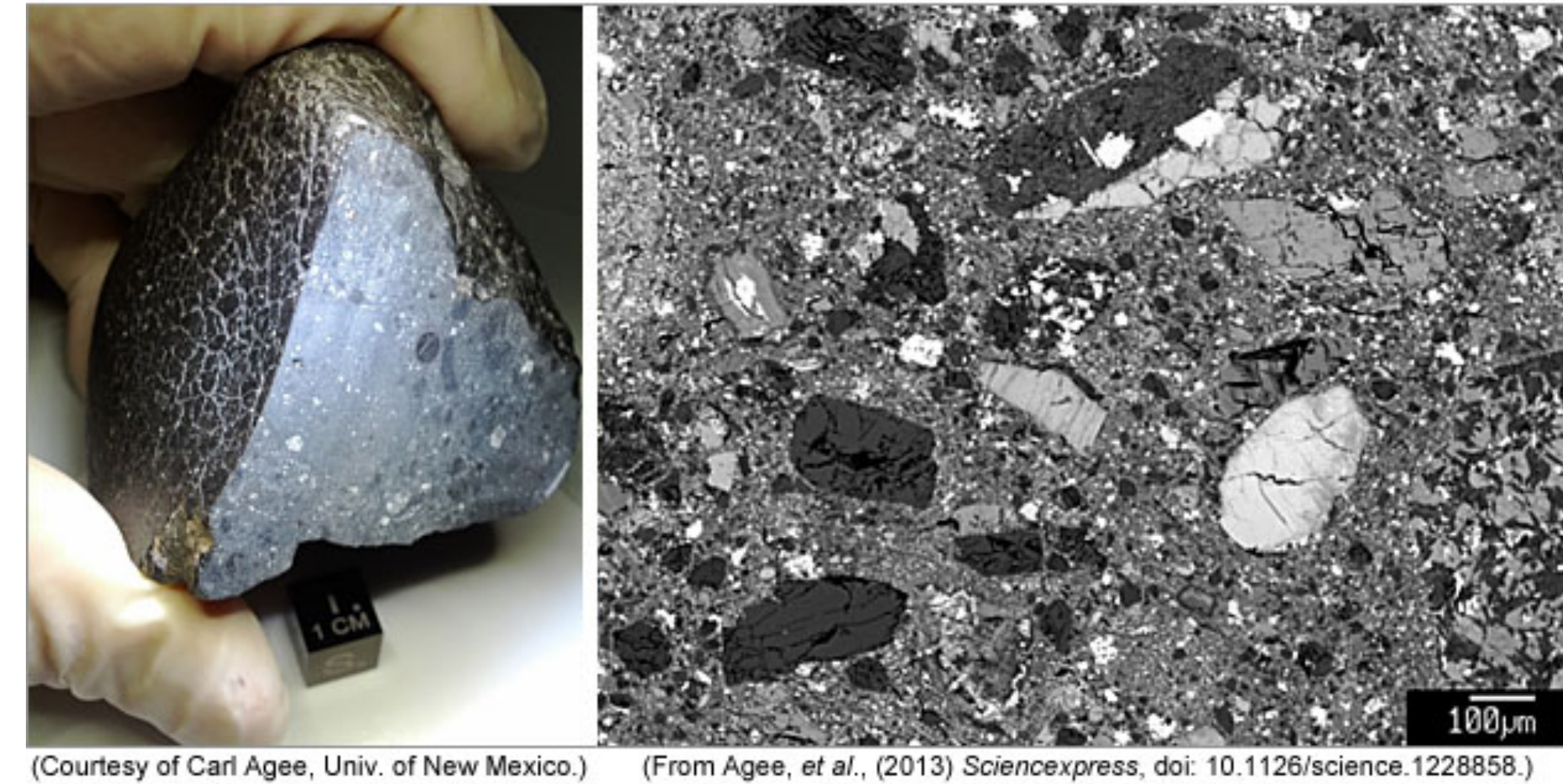
At a certain point, the minimum crustal thickness becomes 0 km, and it is no longer possible to increase the density further. This provides us with a maximum allowable crustal density.

For a 45 km thickness, the density must be less than 3100 kg m^{-3} , the average crustal thickness lies between 54 and 68 km, and the maximum crustal thickness is 160 km.

What do Martian meteorites tell us about the crustal density?



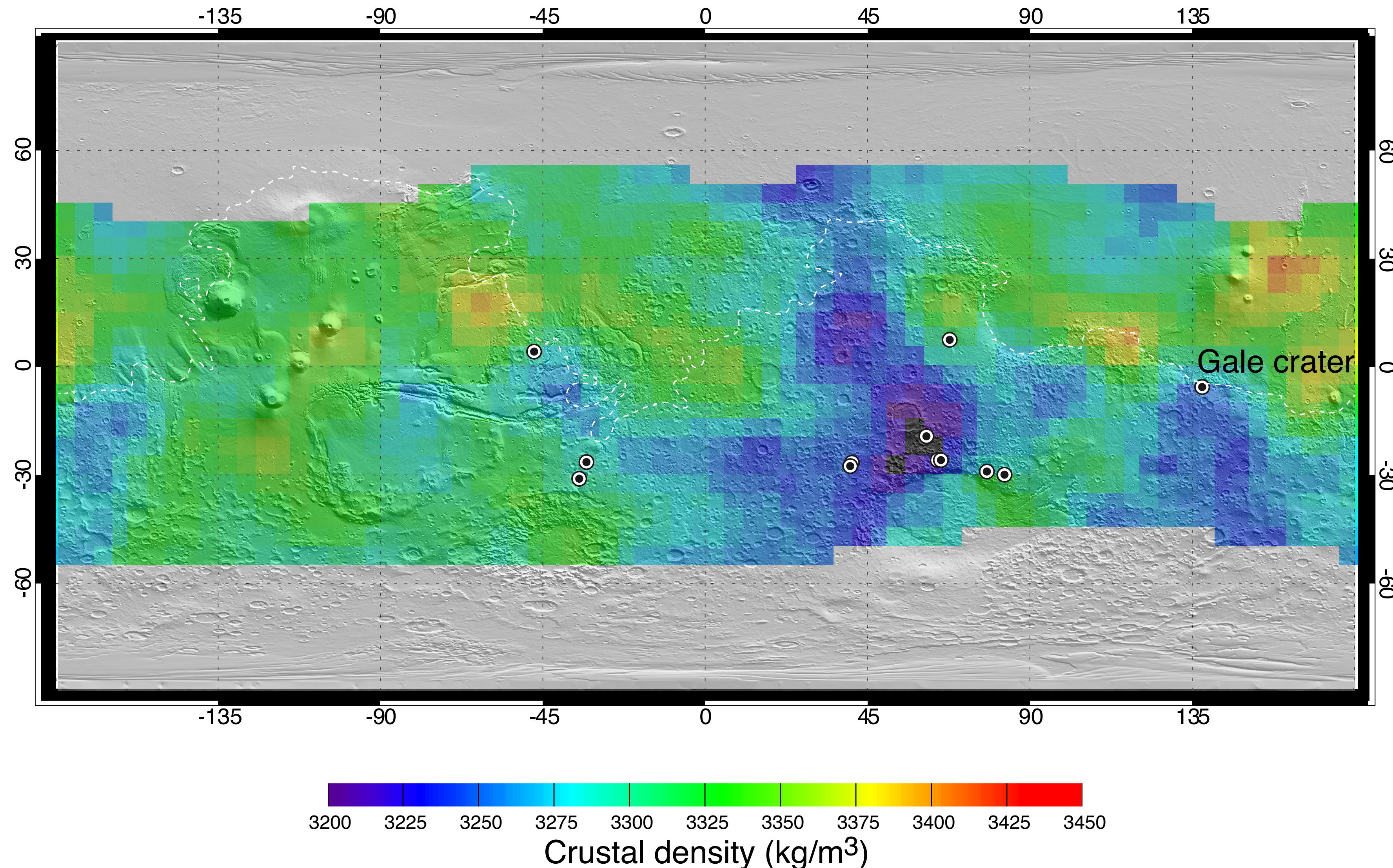
Martian Meteorite: Northwest Africa 7034



Martian meteorites are “basaltic” in composition, but they contain more iron (FeO) than basalts on Earth.

The Martian meteorites have a similar density as basalts collected on the Moon, but they are much denser than basalts we find on Earth (3300 kg m^{-3} vs 2900 kg m^{-3}).

Compositional data collected from orbit imply that the surface composition is similar to the martian meteorites



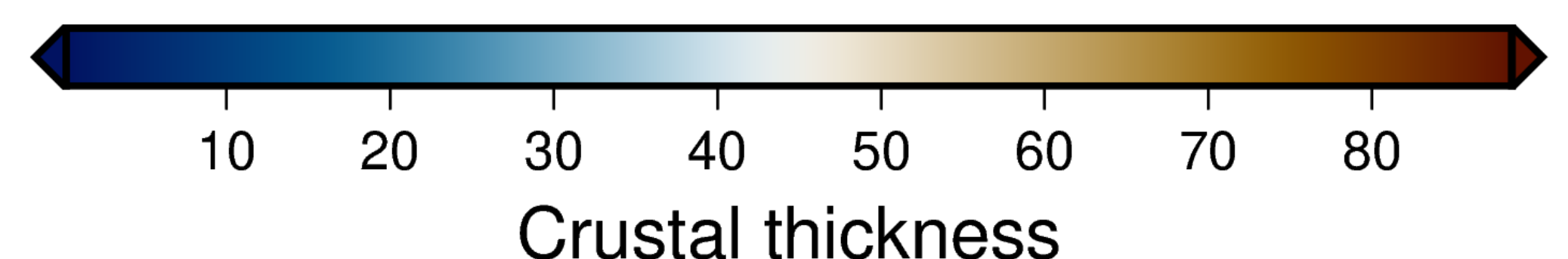
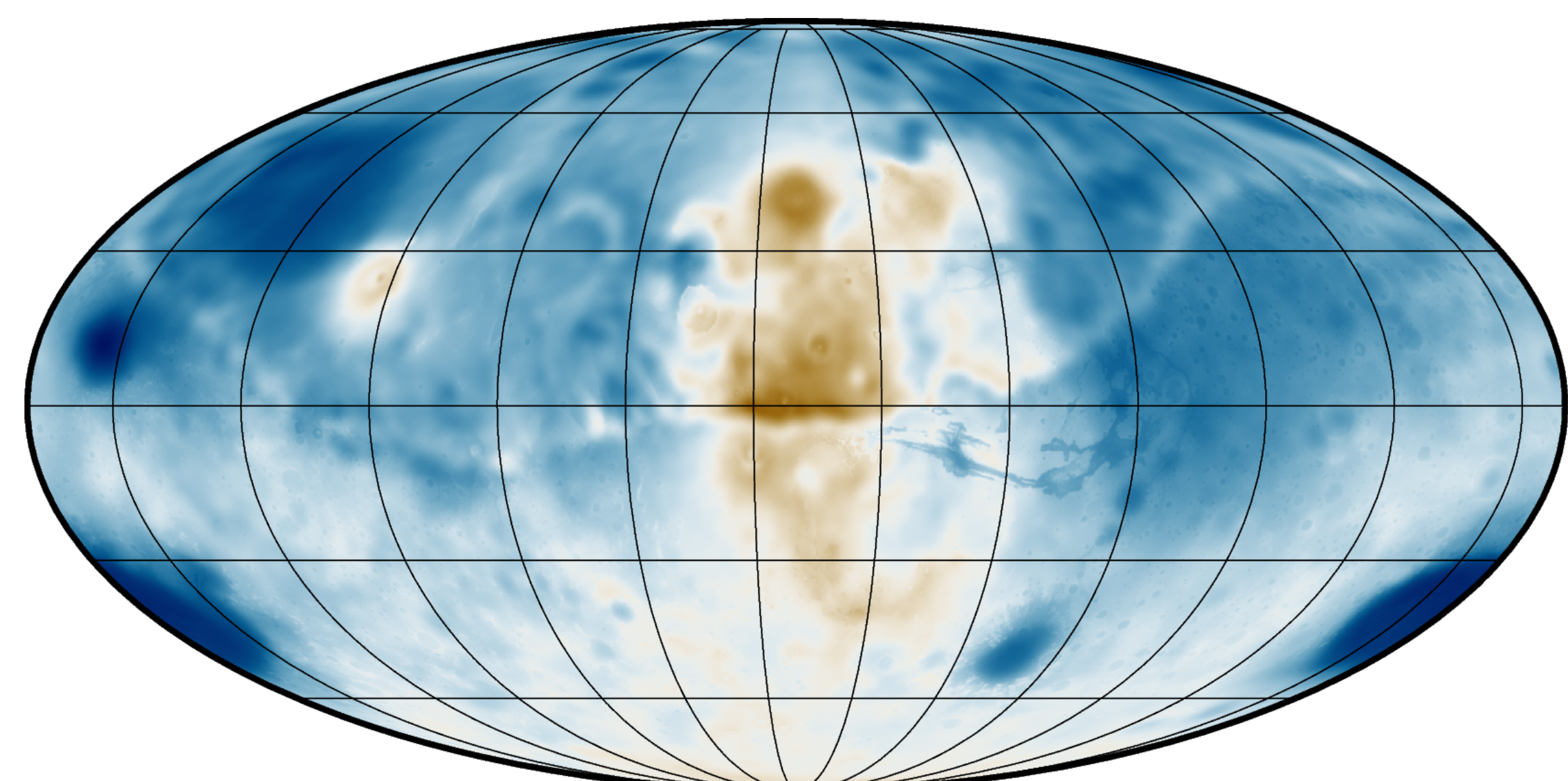
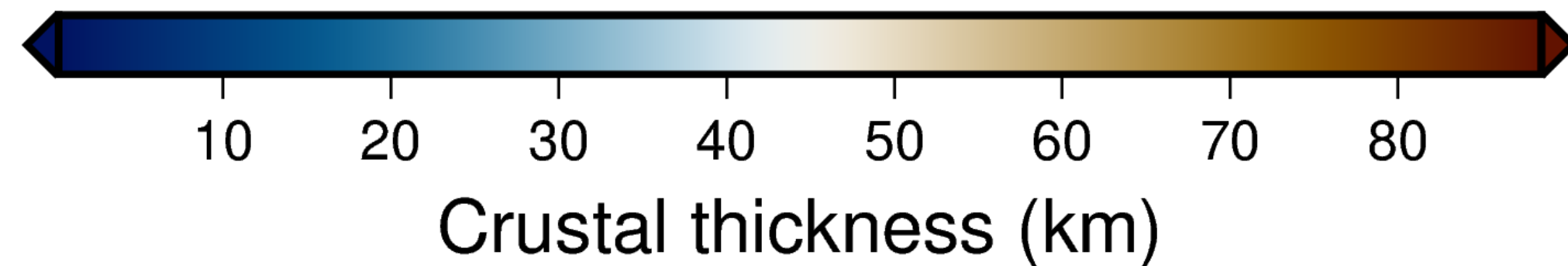
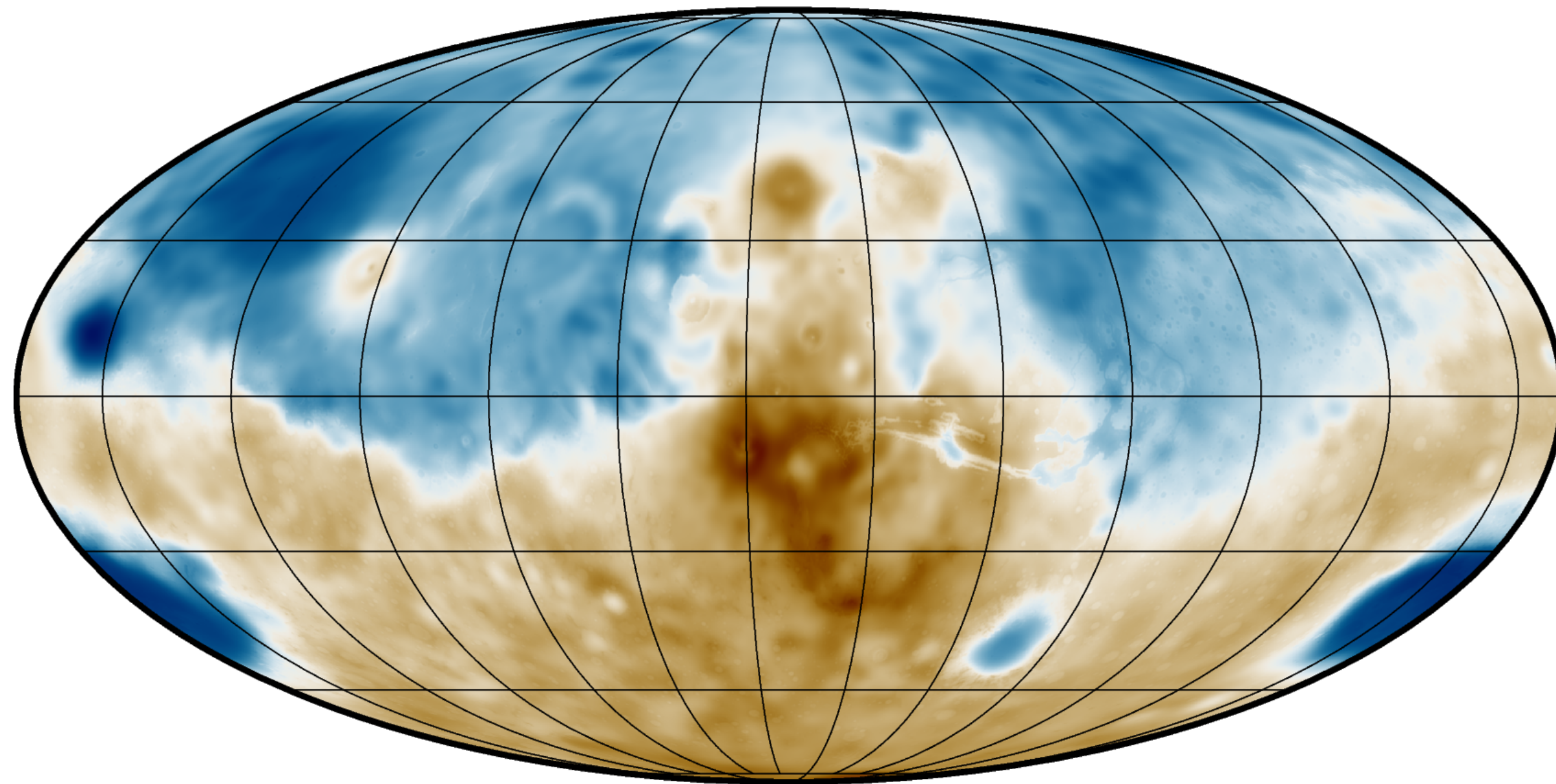
The composition of the surface (as seen by orbital gamma-ray spectroscopy data) is basaltic, and has an intrinsic grain density of $\sim 3350 \text{ kg m}^{-3}$ (Baratoux et al. 2014).

How to reconcile the density constraints

Global crustal thickness models require a density less than 3100 kg m^{-3} , whereas compositional data and Martian meteorites imply a density of about 3350 kg m^{-3} .

1. **The crust could contain about 10% porosity.** This would be similar to what is observed for the Moon, where impact craters have fractured the deep crust. Rocks within the Chicxulub impact crater on Earth have a similar porosity.
2. **The composition of the near surface materials on Mars might not be representative of the underlying crust!** The basaltic materials might be thin ($\sim 1 \text{ km}$ thick) and overlie a more “felsic” (granitic) crust.

We are investigating more complicated density structures of the crust



Conclusions

- 1. We don't know the average thickness of the crust of Mars.**
- 2. We don't know the average composition and density of the crust.**
- 3. We don't know the abundances of heat producing elements in the crust and mantle.**
- 4. Preliminary results suggest that the crust of Mars might have about 10% porosity resulting from impact fracturing of the crust, or the deep crust has a different composition than the surface.**
- 5. Data from InSight should help us resolve these questions!**