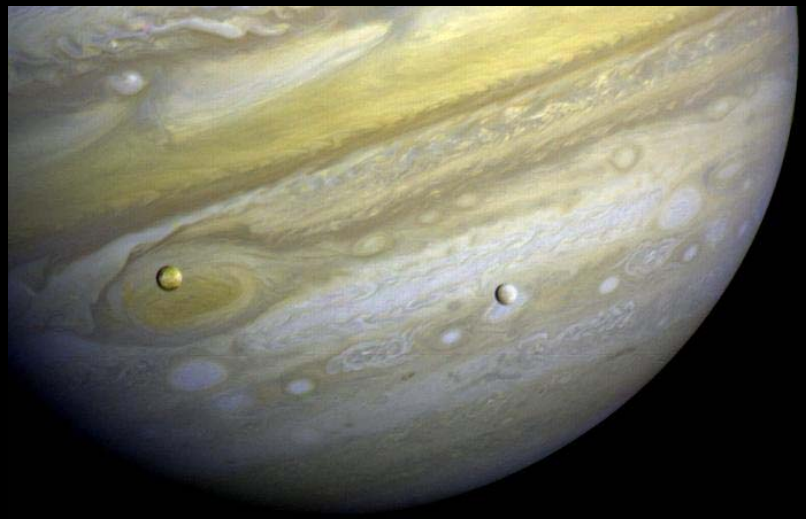

Tidal Deformation and the Interior Structure of Europa

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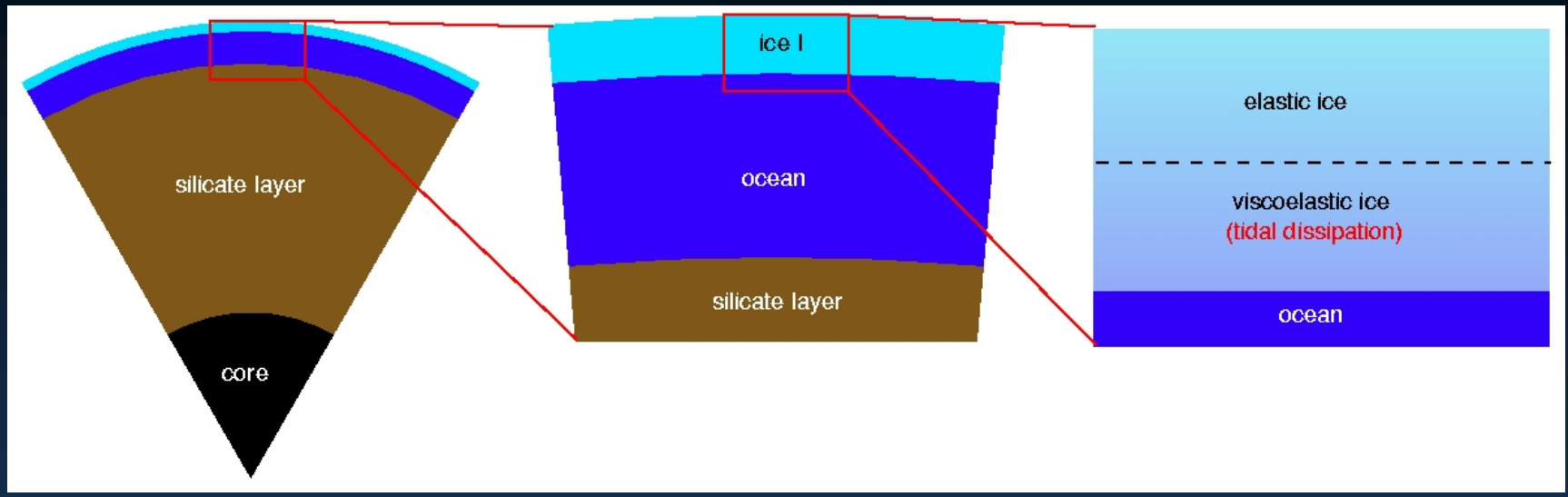
Europa Lander: Science Goals and Experiments

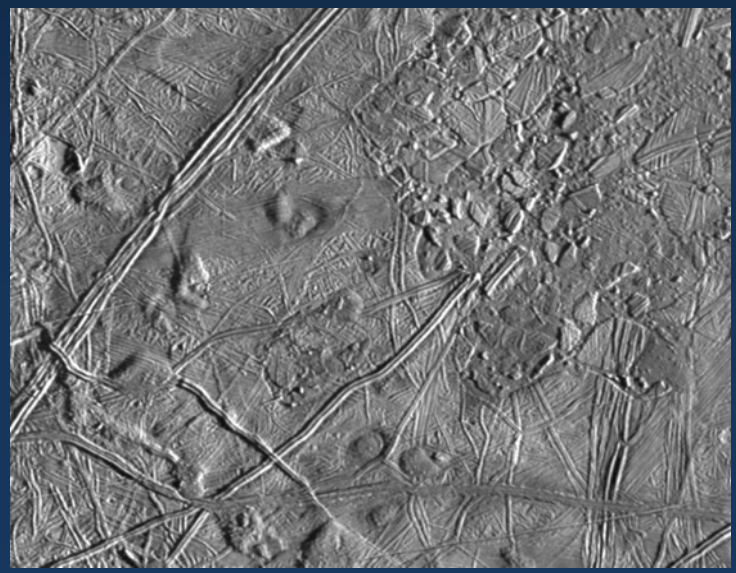
Introduction



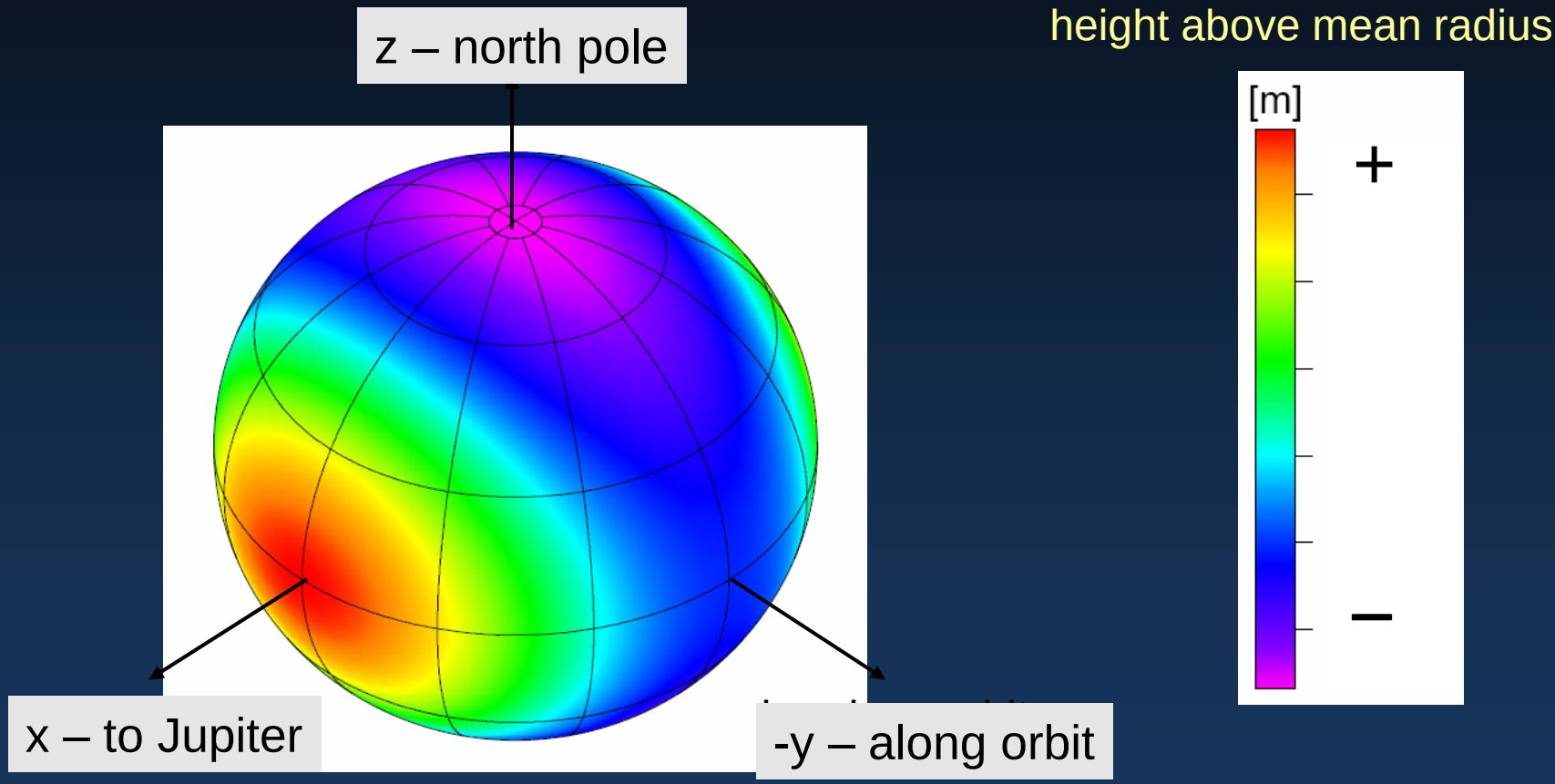
Europa's complex surface is the consequence of physical processes in the ice shell and in the deep interior.

Tidal heating and tidal deformation is an important factor for these processes.

Tidal deformation induces pressure changes and therefore may drive currents in the ocean.



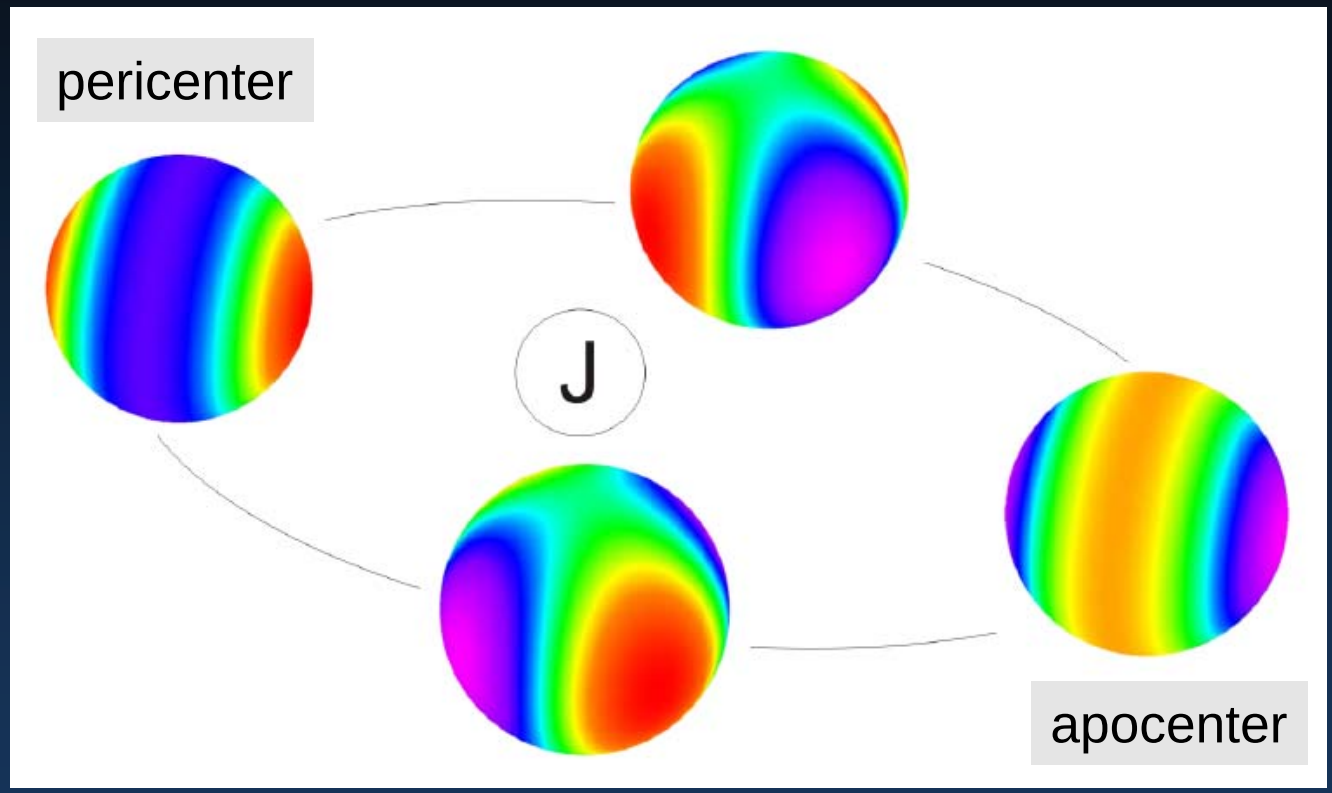
Ellipsoidal Shape (static tides and rotation)



- related to moment of inertia if hydrostaticity is assumed
- determined by J_2 and C_{22} coefficients

Dynamical Tides

Tidal Potential



- Time-variable radial & librational tide.
- Periodic deformation on the time-scale of the orbital period (3.55 days)

Solid Body Tide Love Numbers

- Measures for tidally-induced global distortion of a solid planet or satellite
  - h_n … radial displacement
  - k_n … potential variation
  - l_n … tangential displacement
- complex numbers (amplitude, phase) depending on the interior structure (density profile), tidally-effective rheology, and period of tidal forcing.

n … degree of spherical harmonic representation of tidal potential

Detecting Oceans from Orbit

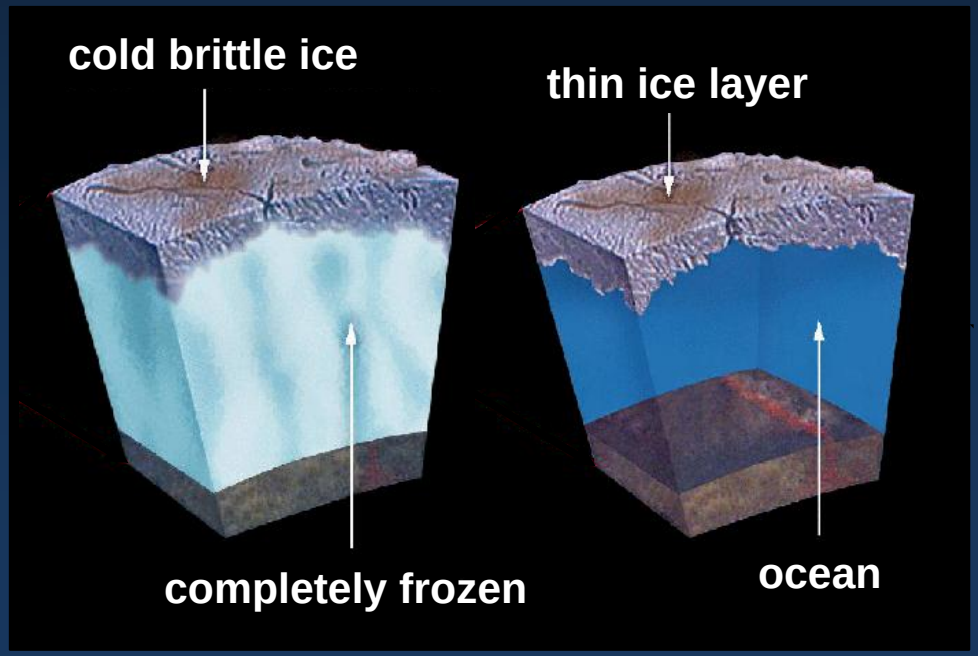
	maximum amplitude	h_2	k_2
Europa	~ 20 – 30 m (~60 cm)	~1.16 – 1.26 (~0.03)	~0.1 – 0.3 (~0.01)
Ganymede	~ 3 – 4 m (~20 cm)	~1.0 – 1.5 (~0.2)	~0.5 (~0.08)
Callisto	~ 2 – 3 m (~10 cm)	~0.9 – 1.5 (~0.2)	~0.3 (~0.08)

in red: without ocean

reference: Moore and Schubert 2000, 2003

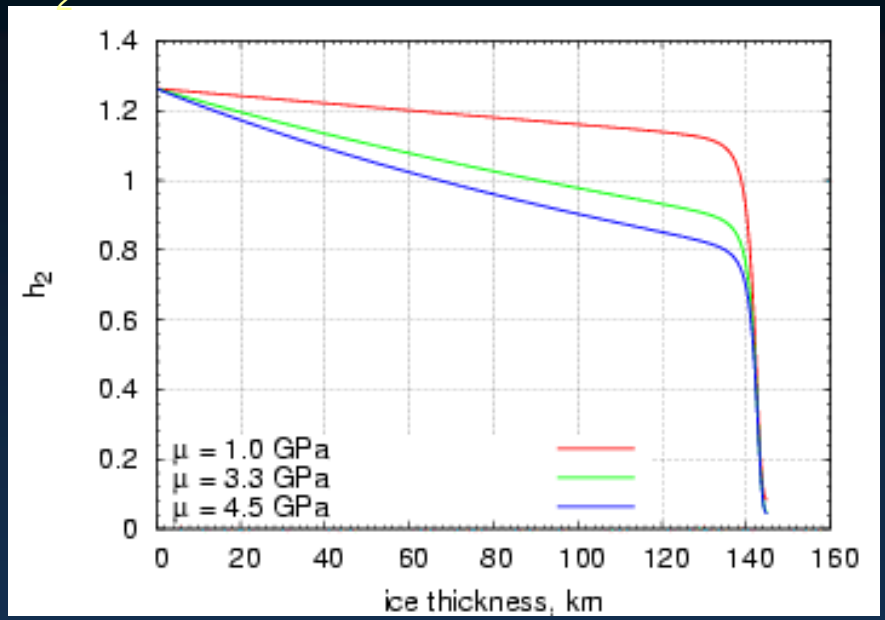
Determined by Doppler Tracking and Laser Altimetry.

Additional constraints come from radar sounding and the magnetic response of the ocean.
This allows for the determination of the ice shell thickness.



Europa's Response to Tidal Forcing

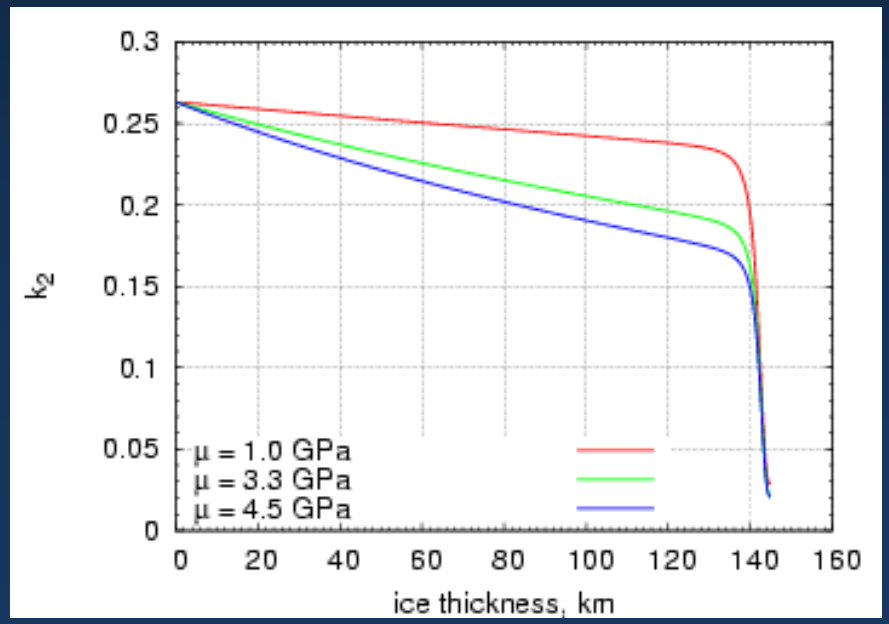
h_2



Elastic response of the ice shell.

Radial displacement h_2, and tidal potential k_2.

k_2



The signal will clearly show if there is an ocean present in Europa.

There is a dependence of h_2 on ice thickness and on rheological properties of the ice shell.

Additional constraints from radar and the induced magnetic field will additionally constrain the ice thickness.

Tidal Distortion Measured at the Surface

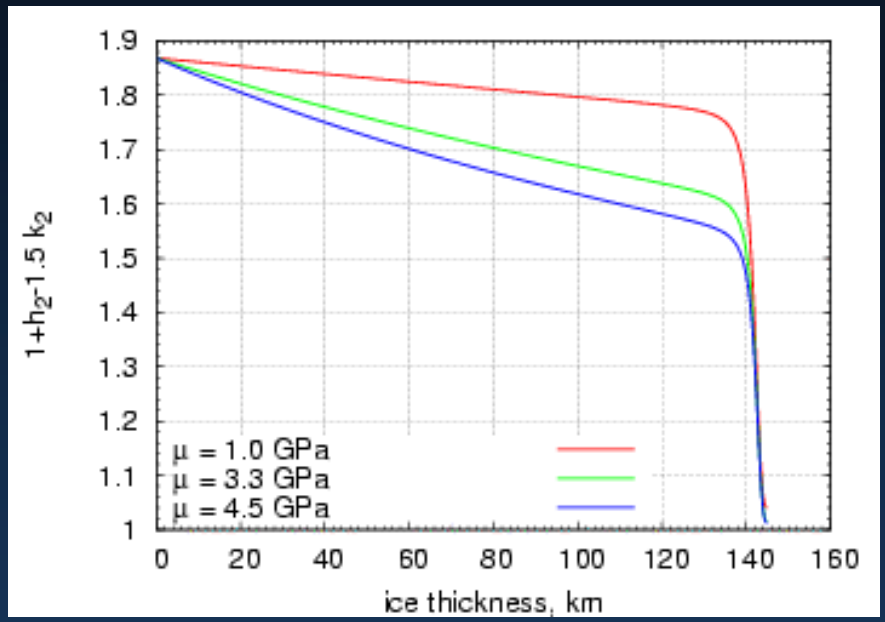
Combinations of body tide Love numbers h_n, k_n, l_n are measured.

- Astronomical latitude changes (star-field observations with a lander camera)
  - latitude factor = $1 + k_n - l_n$
- Gravity changes due to the displacement of mass (gravimeter)
  - gravimeter factor = $1 + 2/n\ h_n - (n + 1)/n\ k_n$
- Tilt changes (tiltmeter)
  - diminishing factor = $1 + k_n - h_n$
- Linear-, area-, volume strain changes (strainmeter)
  - strain factor = $2\ h_n - n\ (n + 1)\ l_n$

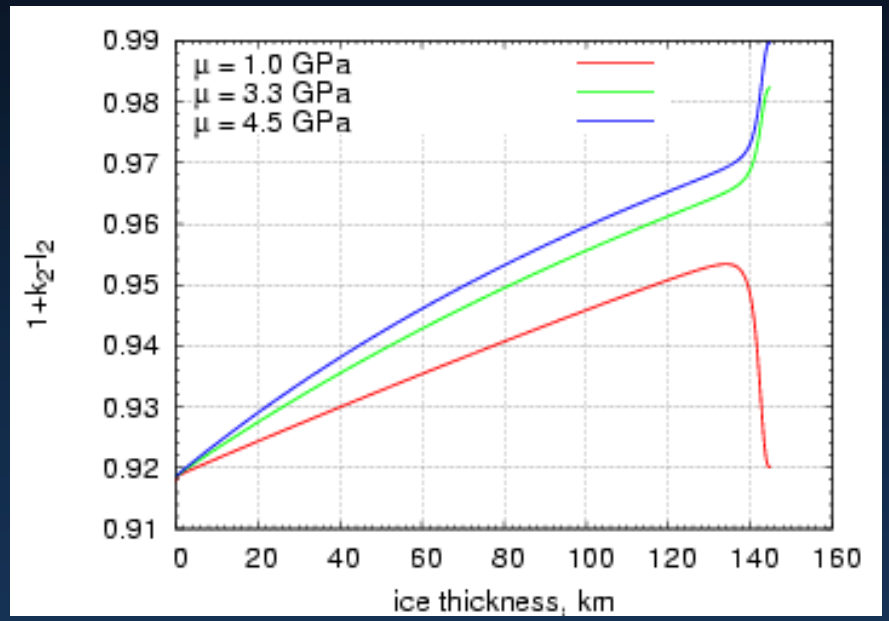
n … degree of spherical harmonic representation of tidal potential

Measurements at the Surface

Gravimetric factor



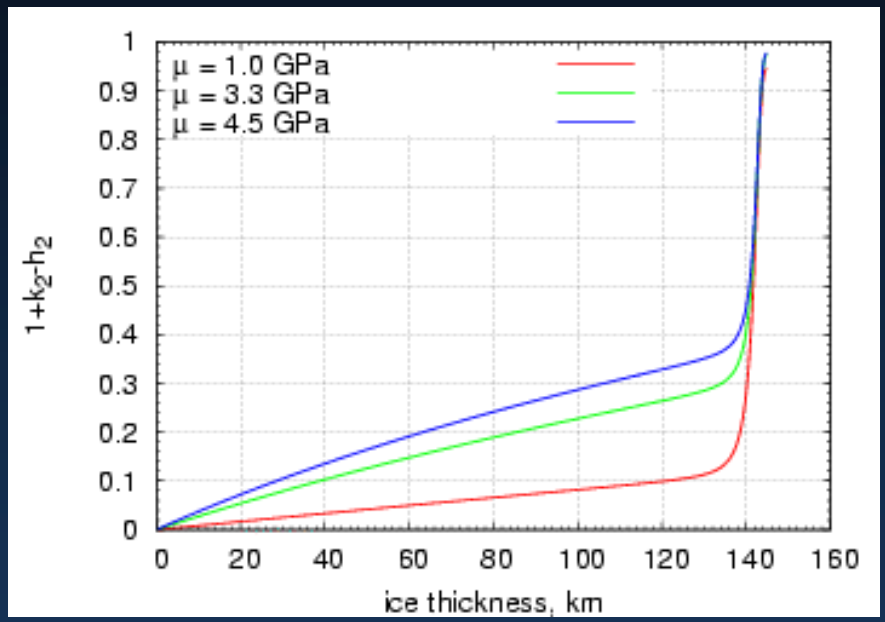
Latitudinal factor



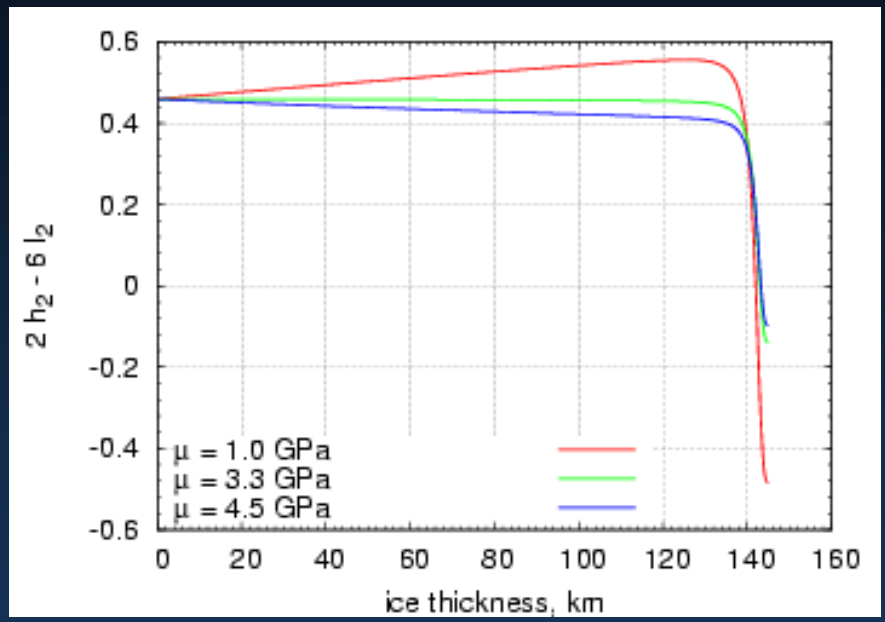
Additional equations to determine the tidal response, independent from the determination from orbit, are provided by measuring linear combinations of h,k and l directly at the surface.
The rigidity or other rheological properties and the ice thickness can be better constrained.

Measurements at the Surface

Deminishing factor



Strain factor



Additional equations to determine the tidal response, independent from the determination from orbit, are provided by measuring linear combinations of h,k and l directly at the surface.
The rigidity or other rheological properties and the ice thickness can be better constrained.

Measurements at the Surface

- ***Lander Camera***
  - changes of latitude by monitoring star-fields.
- ***Gravimeter/Long-period Seismometer***
  - changes of gravitational acceleration using test masses suspended on metal or quartz springs.
- ***Tiltmeter***
  - changes of surface tilting using vertical and horizontal pendulum.
- ***Strainmeter/Horizontal Extensiometer***

changes of relative distances (N-S, E-W-components), length standards provided by invar wires, quartz rods and laser beams.

These are standard methods to measure solid-body tides on Earth.

Summary

Measuring the tidal distortion at Europa's surface

- ... linear combinations of the Love numbers h, k, and l can be obtained.
- ... is complementary to the determination of h_2 and k_2 from orbit.
- ... can further constrain the ice thickness and/or the rheological properties of the ice shell.
- ... have the advantage of a fixed location (=> no integration times) during the tidal cycle.

Recommended instruments: Gravimeter (long-period seismometer); camera observations of star-field; tiltmeter, strain-meter.

Summary

Advantages: Single station sufficient, tidal excitation-/source functions well known, time series analysis standard methods.

At Europa: large tidal amplitudes, no surface loads (atmosphere, surface oceans)

Disadvantages: Instrument drift (3.55-day tidal cycle), temperature variations, coupling to surface, tectonics;

harsh radiation environment (short life-time); at least one tidal cycle (3.55 days) should be covered

The possible improvement of constrainig the thickness and other properties of Europa's ice shell has to be assessed in further studies.