Geophysics and planetary science

From mathematical modeling to space observations

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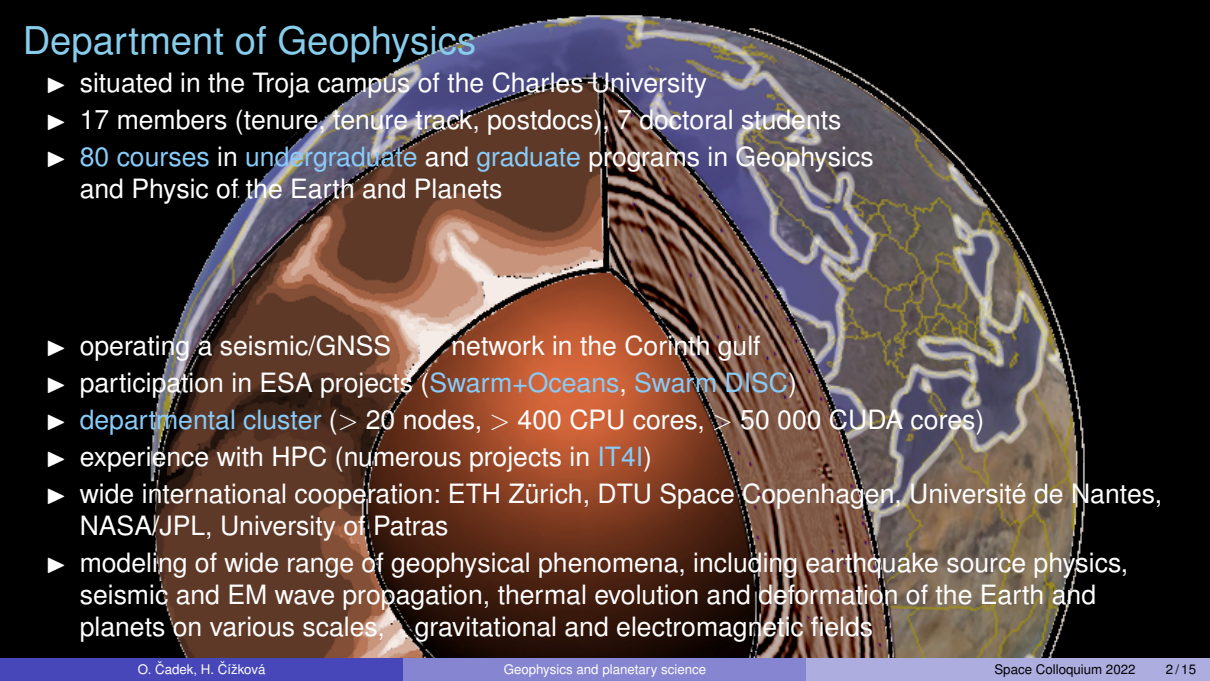
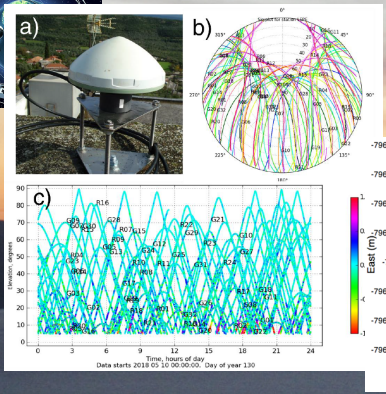
Department of Geophysics

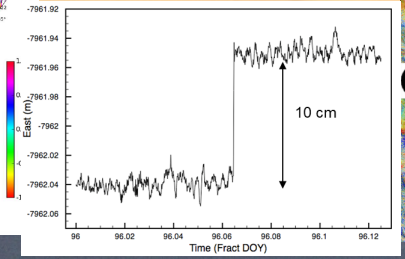
- situated in the Troja campus of the Charles University
- 17 members (tenure, tenure track, postdocs), 7 doctoral students
- 80 courses in undergraduate and graduate programs in Geophysics and Physic of the Earth and Planets

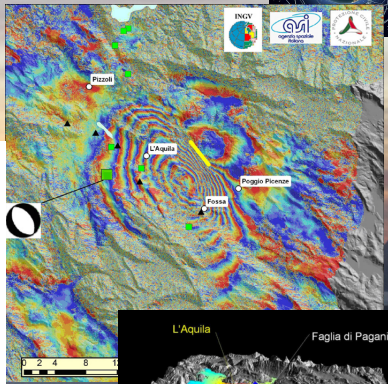


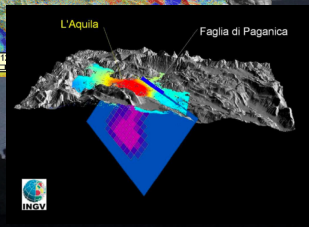
- operating a seismic/GNSS network in the Corinth gulf
- participation in ESA projects (Swarm+Oceans, Swarm DISC)
- departmental cluster ($>$ 20 nodes, $>$ 400 CPU cores, $>$ 50 000 CUDA cores)
- experience with HPC (numerous projects in IT4I)
- wide international cooperation: ETH Zürich, DTU Space Copenhagen, Université de Nantes, NASA/JPL, University of Patras
- modeling of wide range of geophysical phenomena, including earthquake source physics, seismic and EM wave propagation, thermal evolution and deformation of the Earth and planets on various scales, gravitational and electromagnetic fields

GNSS and InSAR data in seismic source inversions





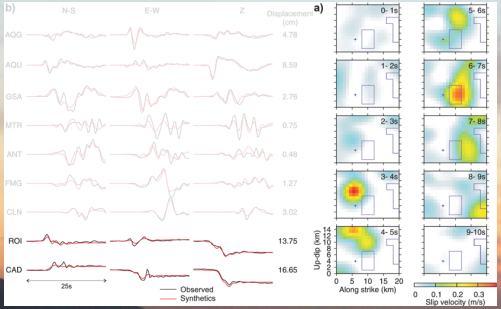




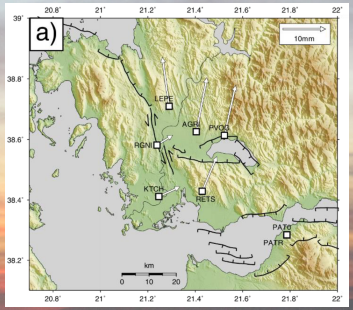
(Lyros et al., 2021)

- Measurement of displacement due to long-term tectonic deformation and earthquake fault rupture (static and time series)
- Mitigation of seismic hazard in earthquake prone areas

GNSS and InSAR data in seismic source inversions



(Gallovič et al. 2015)

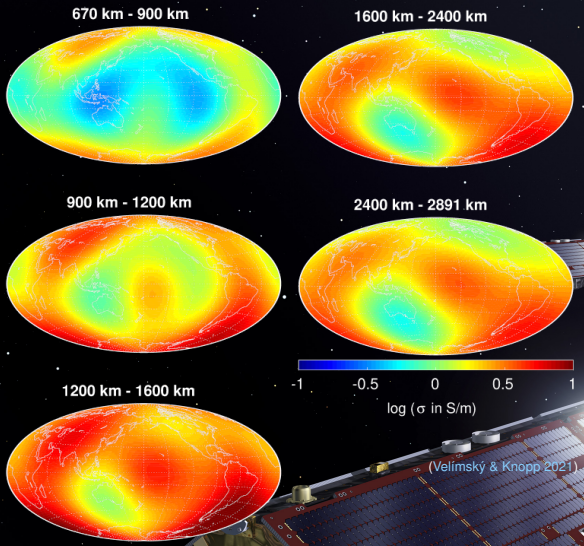


(Lyros et al., 2021)

- Present state
  - PPGNet: Prague-Patras GNSS network
  - Only GNSS static and waveforms interpreted by kinematic earthquake source inversions
- TODO
  - Inference of dynamic source models based on fault constitutive (friction) law (based on method introduced by Gallovič et al., 2019a, 2019b, for seismic data)
  - Stabilization of inverse modeling, Bayesian methods, error estimates
  - Worldwide applications (not limited to Corinth Gulf)

Satellite observations of geomagnetic field

Electrical conductivity of the Earth's deep mantle



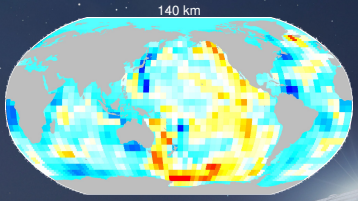
- time variations of geomagnetic fields on hourly to monthly scales induce EM response in the conductive Earth's mantle
- the response depends on (3-D) distribution of electrical conductivity
- inversion of dedicated (CHAMP, Swarm) satellite missions and data from platform magnetometers (CryoSat-2)

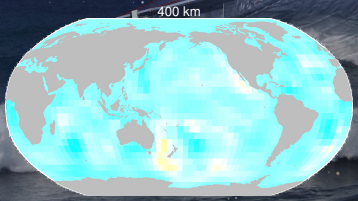
TODO

- new satellite data will become available with significantly improved local time coverage (Macao, NanoMagSat, reprocessing of Grace, Grace-FO)
- interpretation in terms of thermochemical state of the mantle (Bayesian methods)

Satellite observations of geomagnetic field

Tidally induced magnetic field and upper mantle conductivity





(Šachl *et al.*, 2022)

- the energy source for EM sounding is the interaction of tidally driven ocean flows with the main field
- sensitive to electrical conductivity in the sub-oceanic upper mantle

TODO

- new satellite data will become available with significantly improved local time coverage (Macao, NanoMagSat, reprocessing of Grace, Grace-FO)
- interpretation in terms of thermochemical state of the mantle (Bayesian methods)
- joint multi-source inversion

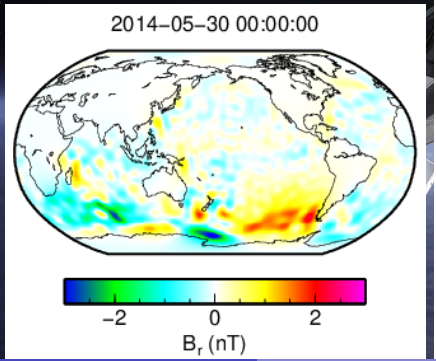
Satellite observations of geomagnetic field

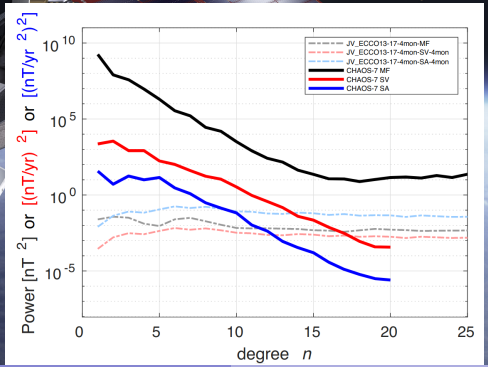
Magnetic signatures of the global ocean circulation

- wind- and temperature-driven ocean circulation induces secondary magnetic field
- weak field on the surface but much stronger at ocean depths (Velímský *et al.* 2018)
- time variability observable by seafloor cables (Velímský *et al.* 2021)

TODO

- can we detect it in magnetic Swarm data?
- can we monitor long-term variability of ocean currents by satellite magnetic measurements?





Inductive response of the icy moons in the solar system

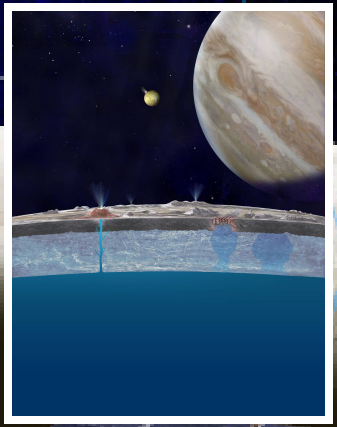


Image credit: NASA/JPL-Caltech

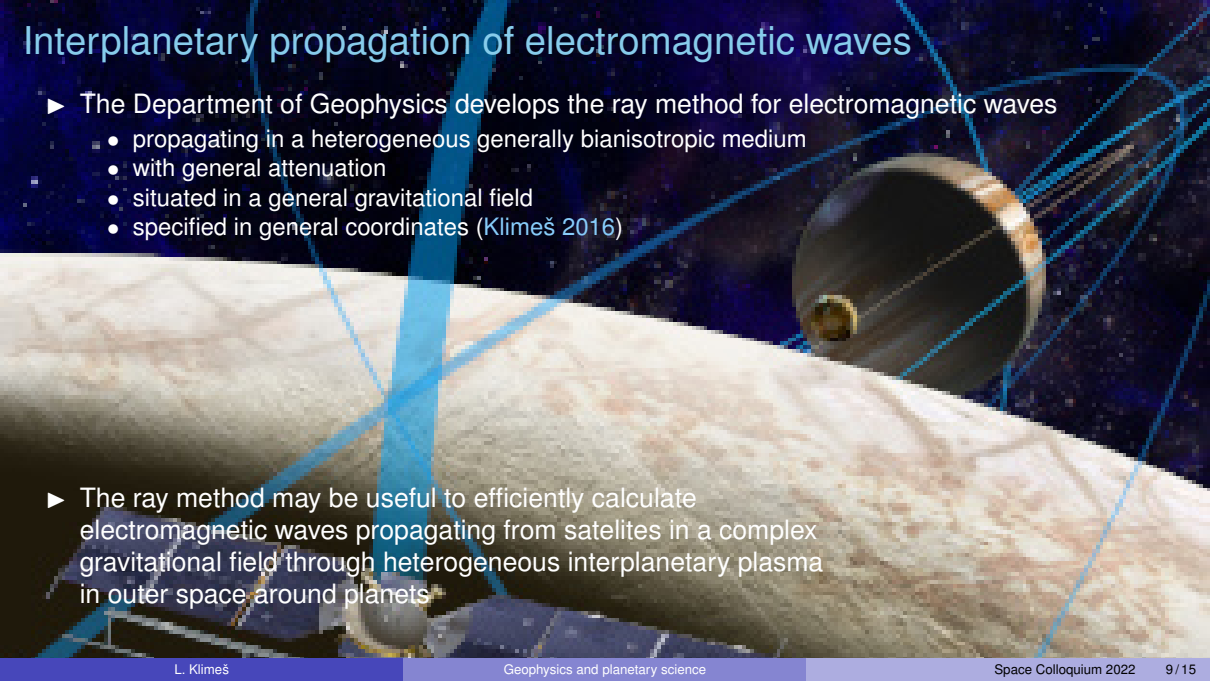
- the EM methods have played a crucial role in interpreting Galileo mission results and in detecting the subsurface oceans on Europa, Callisto and Ganymede
- their potential has not yet been fully explored

TODO

- simulation studies for future JUICE and Europa Clipper missions
- detectability of subsurface melt in Io and Europa
- motional induction in the subsurface ocean of Europa: detectability of ocean flows

Interplanetary propagation of electromagnetic waves

- The Department of Geophysics develops the ray method for electromagnetic waves
  - propagating in a heterogeneous generally bianisotropic medium
  - with general attenuation
  - situated in a general gravitational field
  - specified in general coordinates (Klimeš 2016)



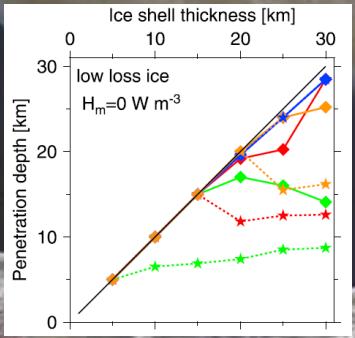
- The ray method may be useful to efficiently calculate electromagnetic waves propagating from satelites in a complex gravitational field through heterogeneous interplanetary plasma in outer space around planets

Giant planets' satellites

Radar sounding: Example of Europa

- radar waves interact with dielectric contrast structures → **detectable radar return**
- scattering losses likely negligible, **attenuation** in warm ice strongly reduces penetration

- study of radar attenuation for a range of thermal structures of Europa's ice shell
- deepest signal penetration through cold downwellings
- direct ocean detection for shells of up to 15 km
- shallow brines detectable for all plausible shells



Kalousová *et al.* (2017)

TODO

- investigate radar performance at Enceladus

Giant planets' satellites

Tidal sounding: Example of Enceladus

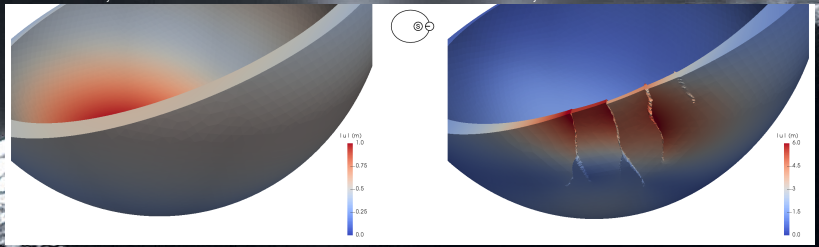
- Tidal deformation during one orbit, impact of variable ice shell thickness and faults (Souček et al., 2016, 2019; Běhounková et al., 2017), including effects of friction along faults (Pleiner Sládková et al., 2021).
- Prediction of detectability by future missions for variables measured from a distance and from a surface (Vance et al., 2021, Marusiak et al., 2021).

TODO

- Deformation and stress signatures on different time scales.
- Conditions for faults initiation.

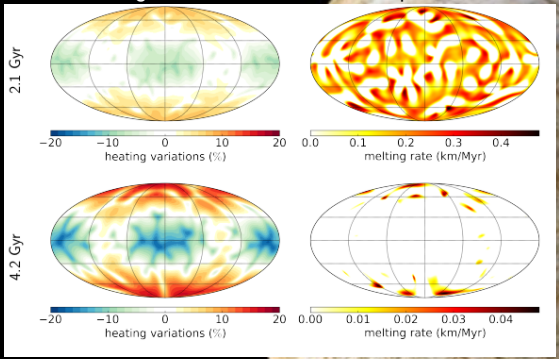
no faults, uniform shell thickness

faults, variable shell thickness



Giant planets' satellites

Long-term evolution: Example of Europa



- Silicate melt can be produced during most of Europa's history due to the limited efficiency of internal cooling and the presence of radiogenic heating and tidal dissipation, supporting habitability potential (Běhounková et al., 2021).
- Identifying detectable signatures of recent volcanic activity: detection of long-wavelength variations of gravity field and H_2 , CH_4 and other gas species by Europa Clipper.

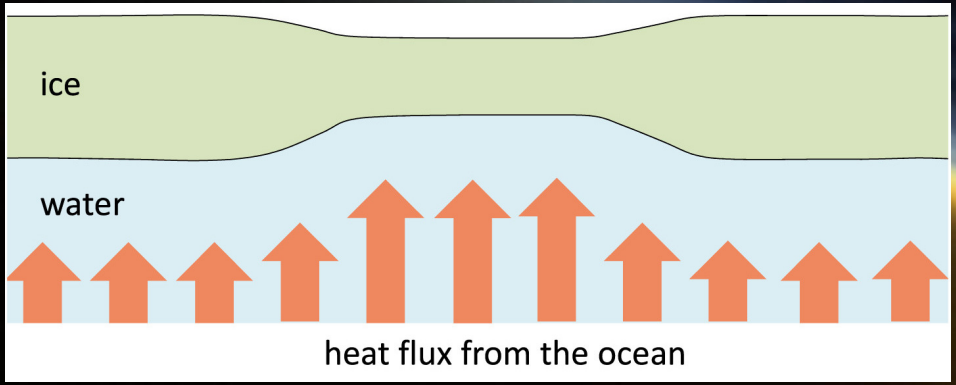
TODO

- Towards a more realistic treatment of melt for evolutionary models.
- Coupled thermal-orbital evolution.

Giant planets' satellites

Heat flux from Titan's ocean and surface topography

- heat flux from the subsurface ocean anti-correlates with long-wavelength topography
- thinning of the ice layer due to melting; ice layer in conductive regime (Kvorka & Čadek, 2022)



TODO

- implementation of more complex physics and chemistry of the subsurface oceans: presence and advection of salts, multi-phase flows,...

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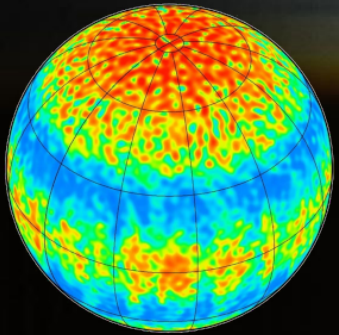
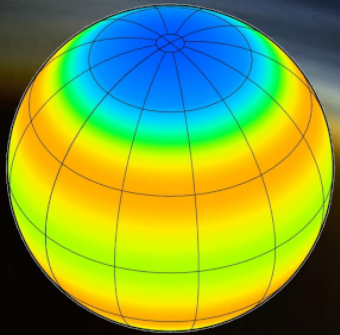


numerical prediction of the heat flux



observed long-wavelength zonal topography

TODO

- implementation of more complex physics and chemistry of the subsurface oceans: presence and advection of salts, multi-phase flows,...

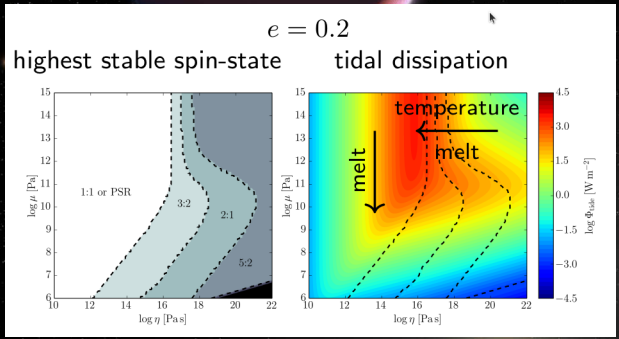
Extrasolar planets

Long-term evolution

- Better constrain the conditions on terrestrial extrasolar worlds through understanding the complex relationship between the internal dynamics and the likely measurable quantities.
- Complex feedback among internal, rotational, and orbital evolution through tides (Walterová and Běhounková, 2020).

TODO

- More realistic internal evolutionary models with melt.
- Planet-planet interaction and tides, planets around binary stars.



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