# HP2C/PASC community network "Solid Earth Dynamics"

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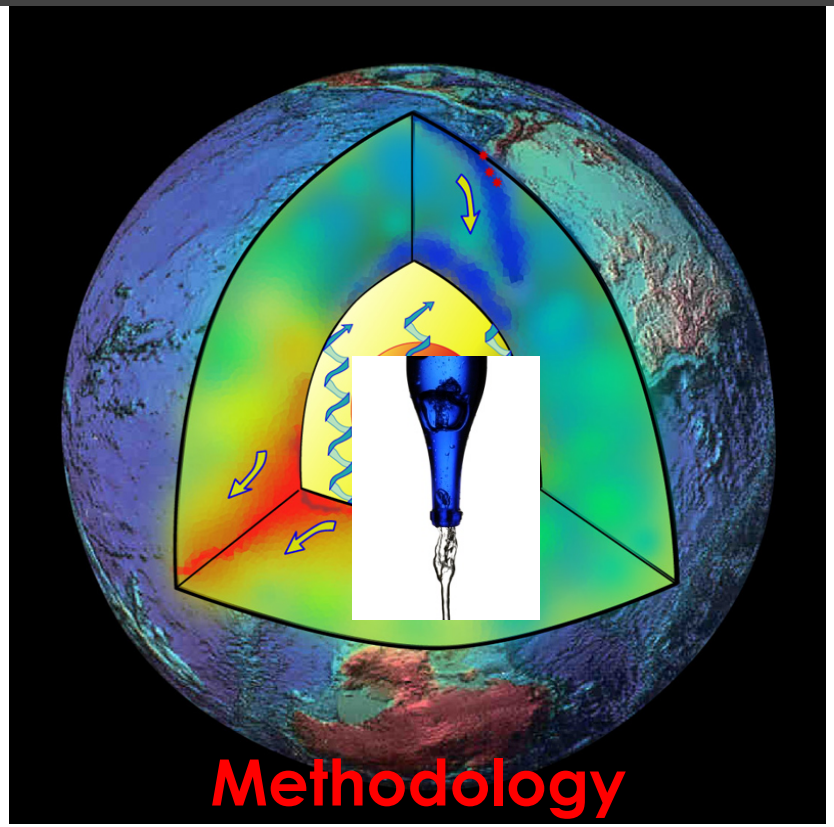
# Scientific goals & challenges

*Improve multidisciplinary understanding of Earth's interior*

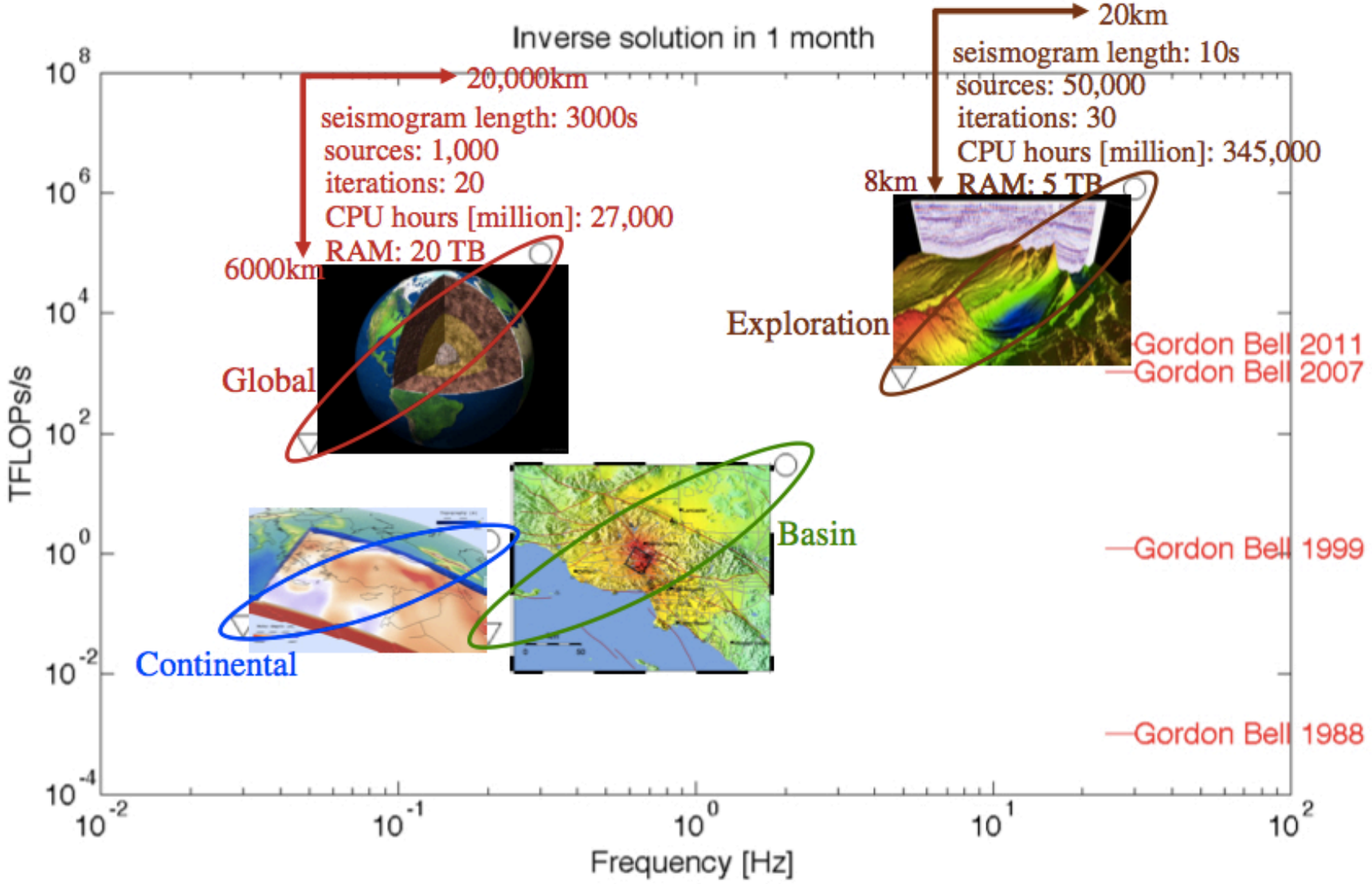


- structure
- dynamics
- magnetism
- resources
- seismic hazard

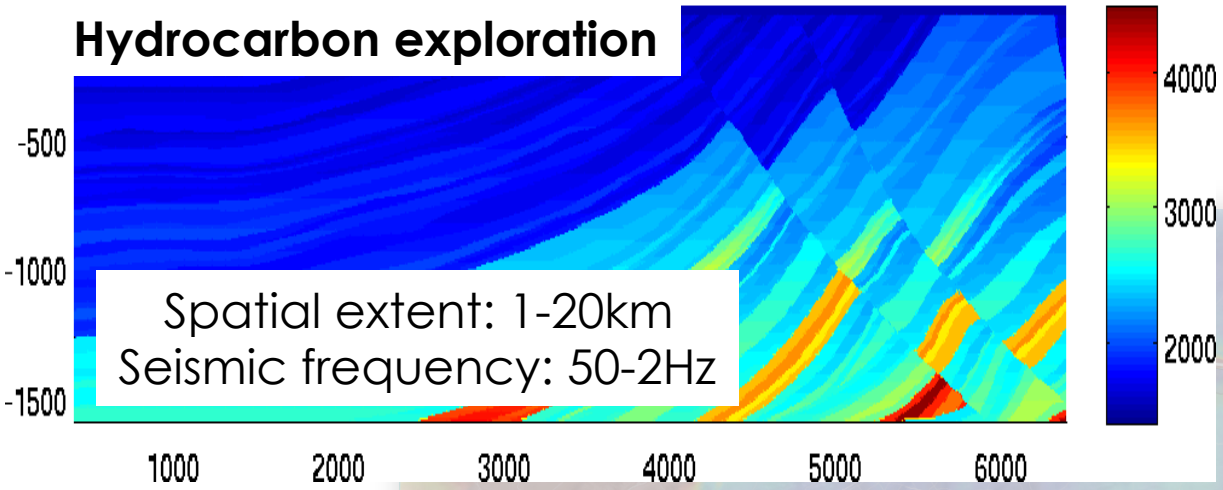
**Methodology**

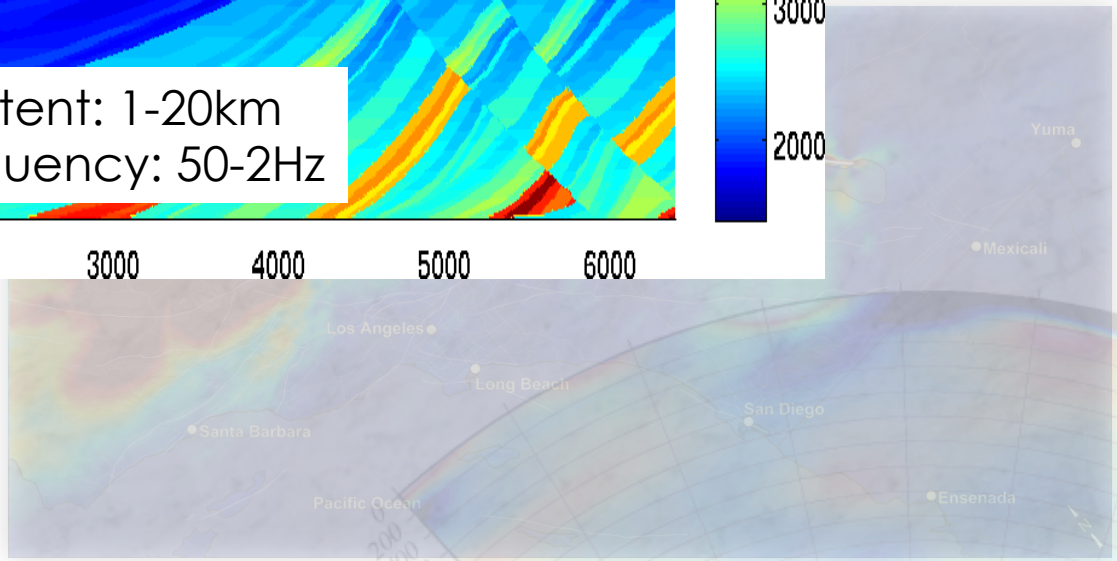
Physics-based *forward* modelling of multi-scale Earth processes
Wave propagation, fluid dynamics, magnetohydrodynamics
Large number of degrees of freedom (~$10^{11}$)
Ill-posed, non-unique *inverse* modeling
Experimentally unverifiable
HPC

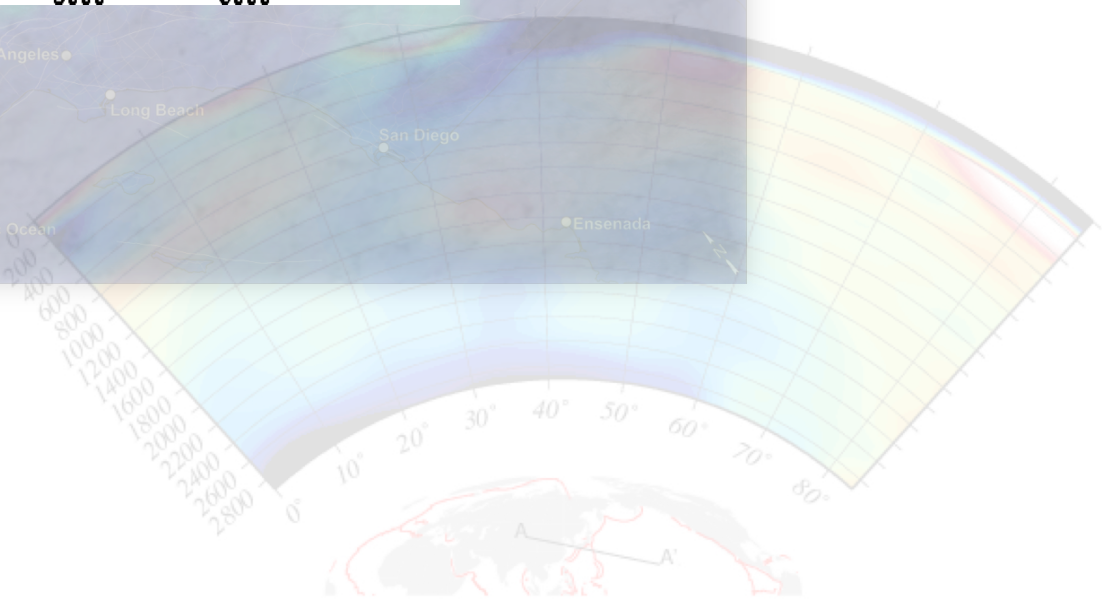
# Computational cost - seismology



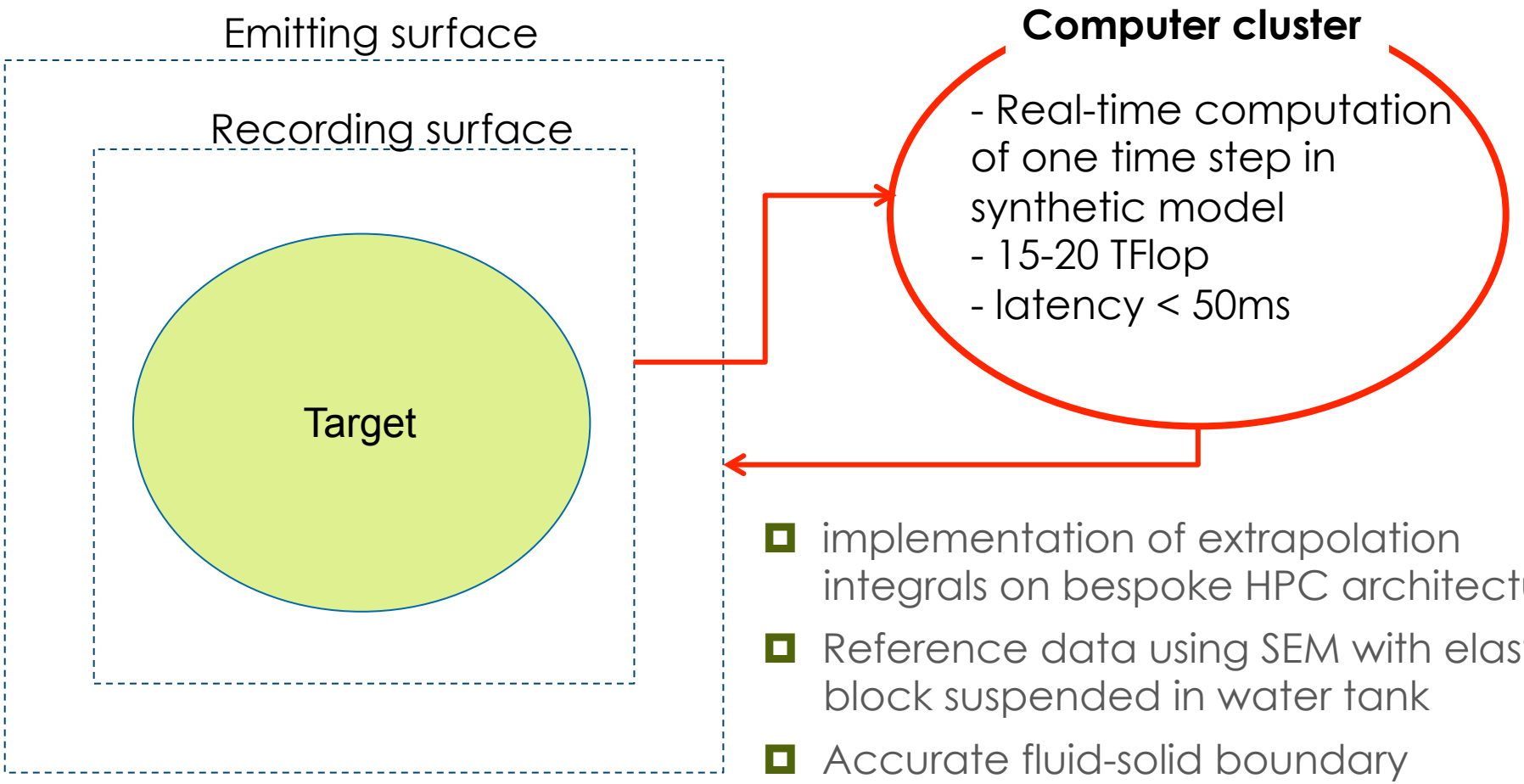
# Scales of interest: 10km



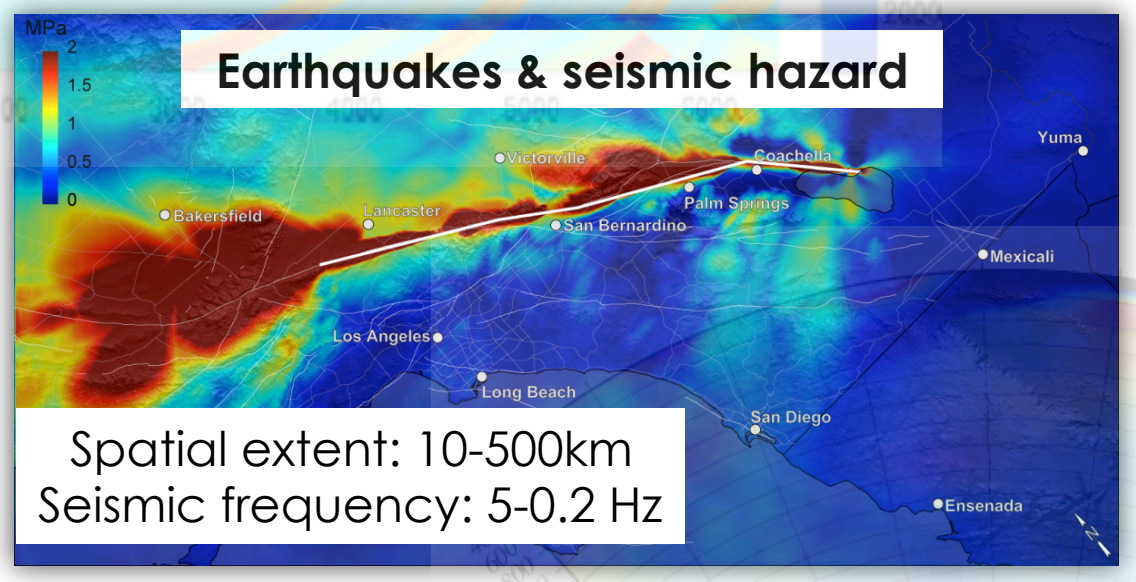



# Wave propagation laboratory (Robertsson)




- implementation of extrapolation integrals on bespoke HPC architectures
- Reference data using SEM with elastic block suspended in water tank
- Accurate fluid-solid boundary
- source points all around block surface
- Optimization of 3D elastic FD code

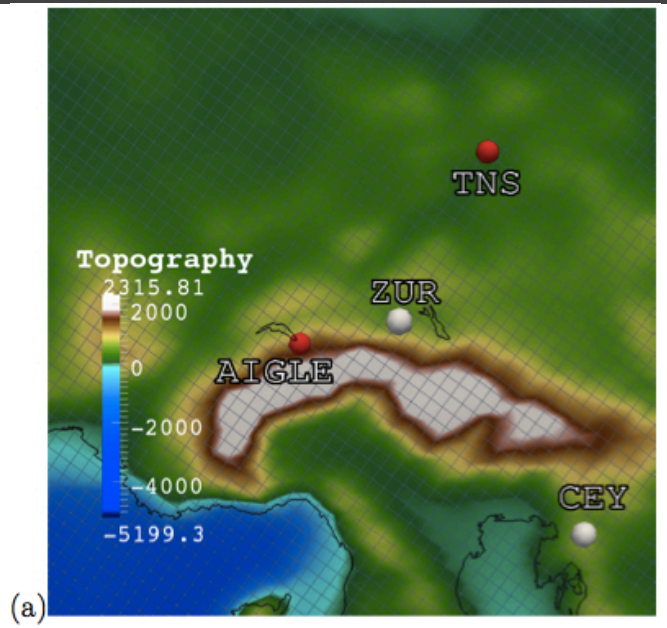
# Scales of interest: 100km



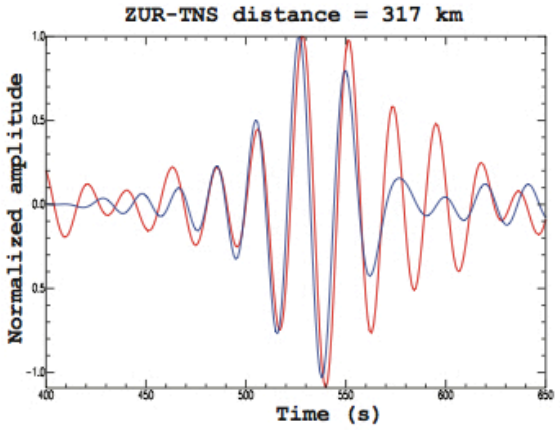

Spatial extent: 10-500km
Seismic frequency: 5-0.2 Hz

# Earthquake rupture & crustal structure (Giardini)

Multi-frequency dynamic rupture
on non-planar fault (Tohoku)
*(Galvez et al., to be submitted, 2012)*




(a)

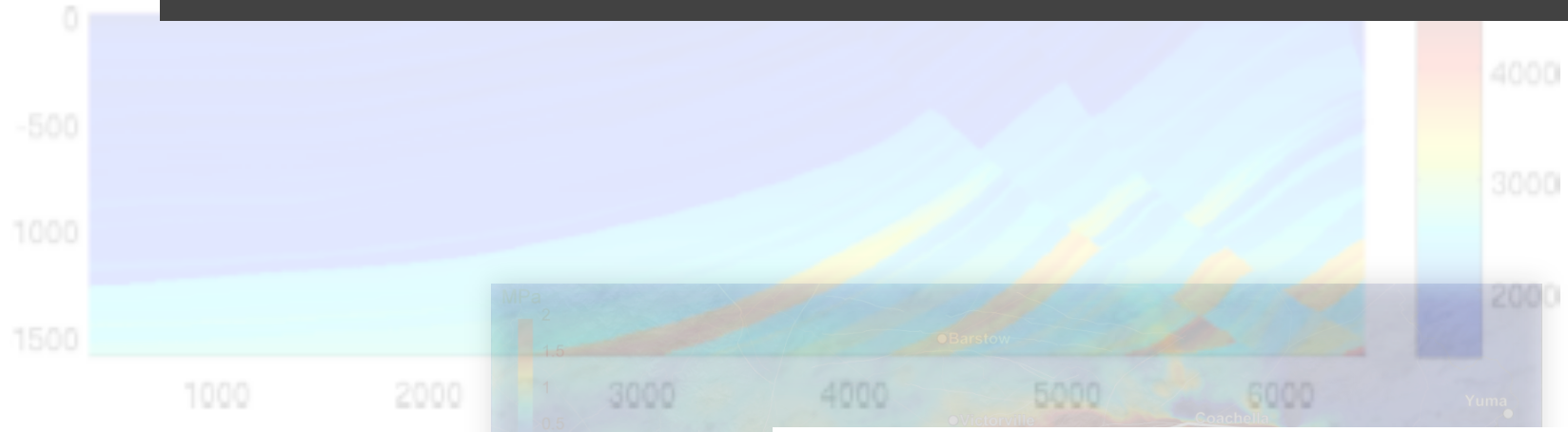



(c)

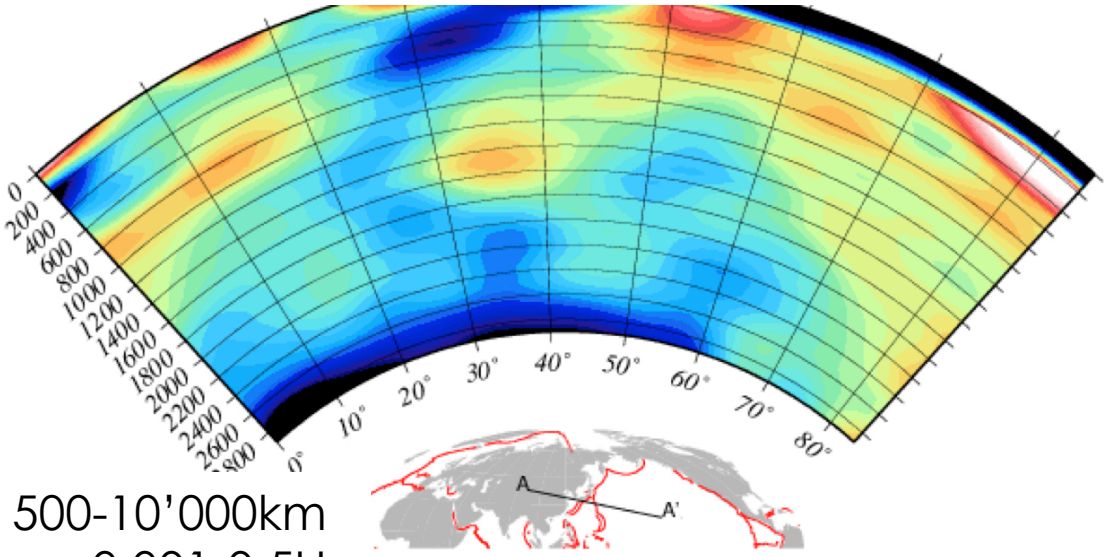
Tomography with ocean-generated "noise"
*(Basini et al., accepted, G-cubed, 2012)*

(all work done with SPECFEM3D)

# Scales of interest: 1000km




**Tectonics & global Earth dynamics**

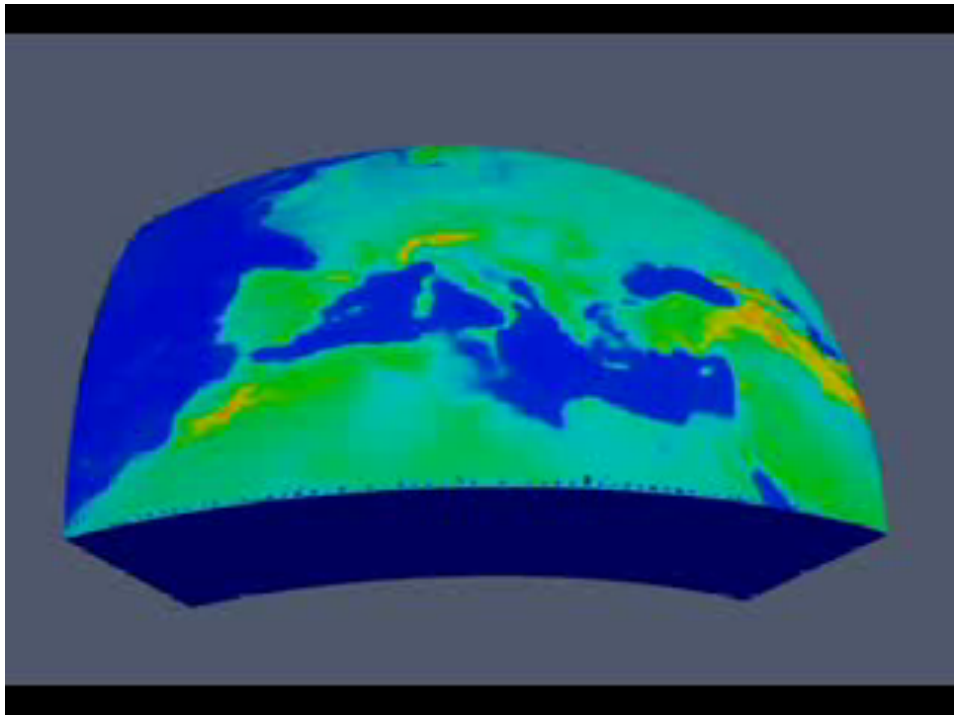



Spatial extent: 500-10'000km
Seismic frequency: 0.001-0.5Hz

# Petaquake (HP2C; Schenk, Giardini)

- ✓ Cuda version of SPECFEM3D for realistic setups, scalable up to 900 GPUs
- ✓ Stencil autotuning of seismic FD code AWP (seismic hazard analysis)
- ✓ Noise tomography with adjoint methods (European/Alpine scale)
- ✓ Gradient schemes for nonlinear seismic inversion

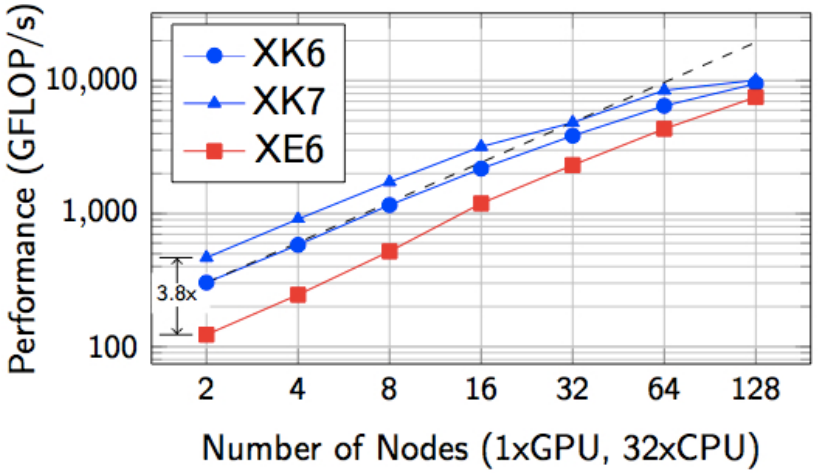
U.S. DEPARTMENT OF ENERGY INCITE LEADERSHIP COMPUTING



19 Mio elements ($6 \times 10^9$ dof) on 896 GPUs
sustained 135 TFLOP/s (Titan, Oakridge)
*(Rietmann et al., Supercomputing '12)*

## Spectral-element code SPECFEM3D

- ➢ highly scalable
- ➢ Gordon Bell prize 2003
- ➢ accommodates all relevant physics
- ➢ used by several hundred groups

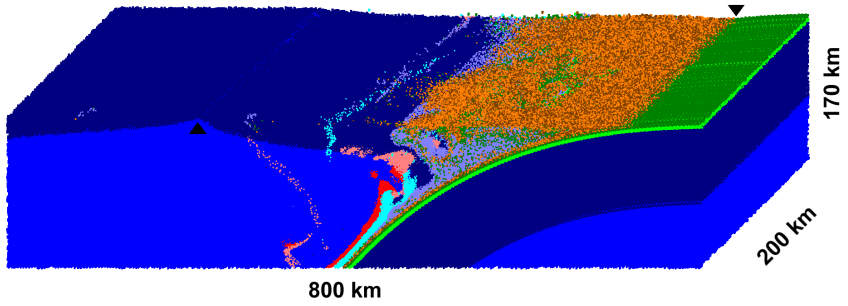


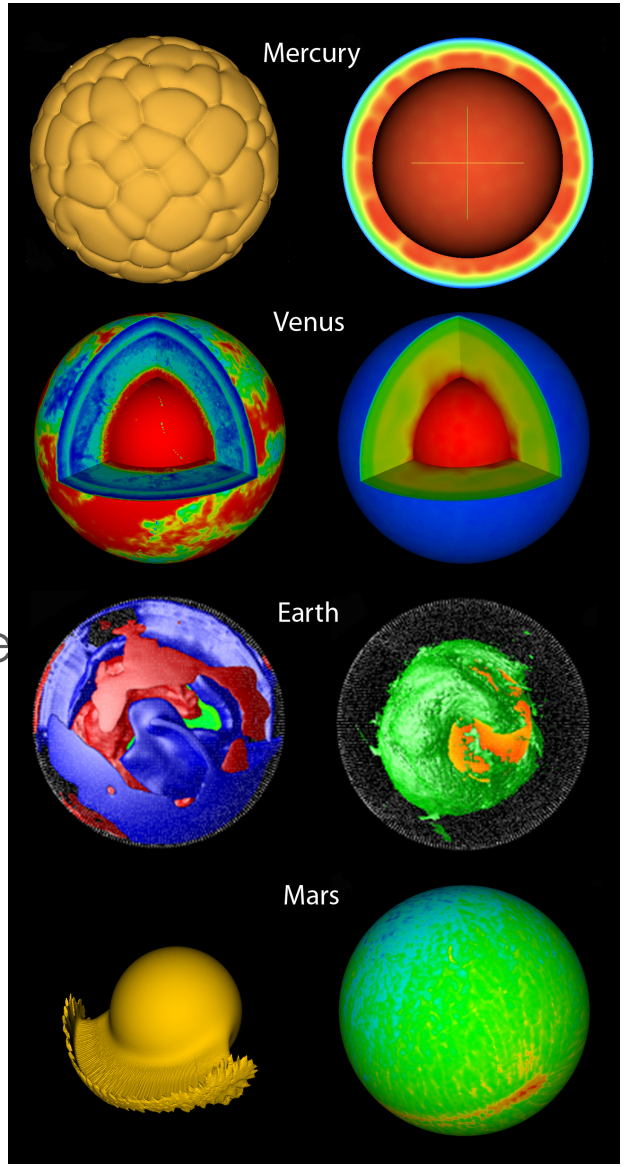
# Geophysical Fluid Dynamics (Tackley)


*Simulating the dynamics of the solid Earth and planets (mantle, lithosphere, crust, formation, evolution)*

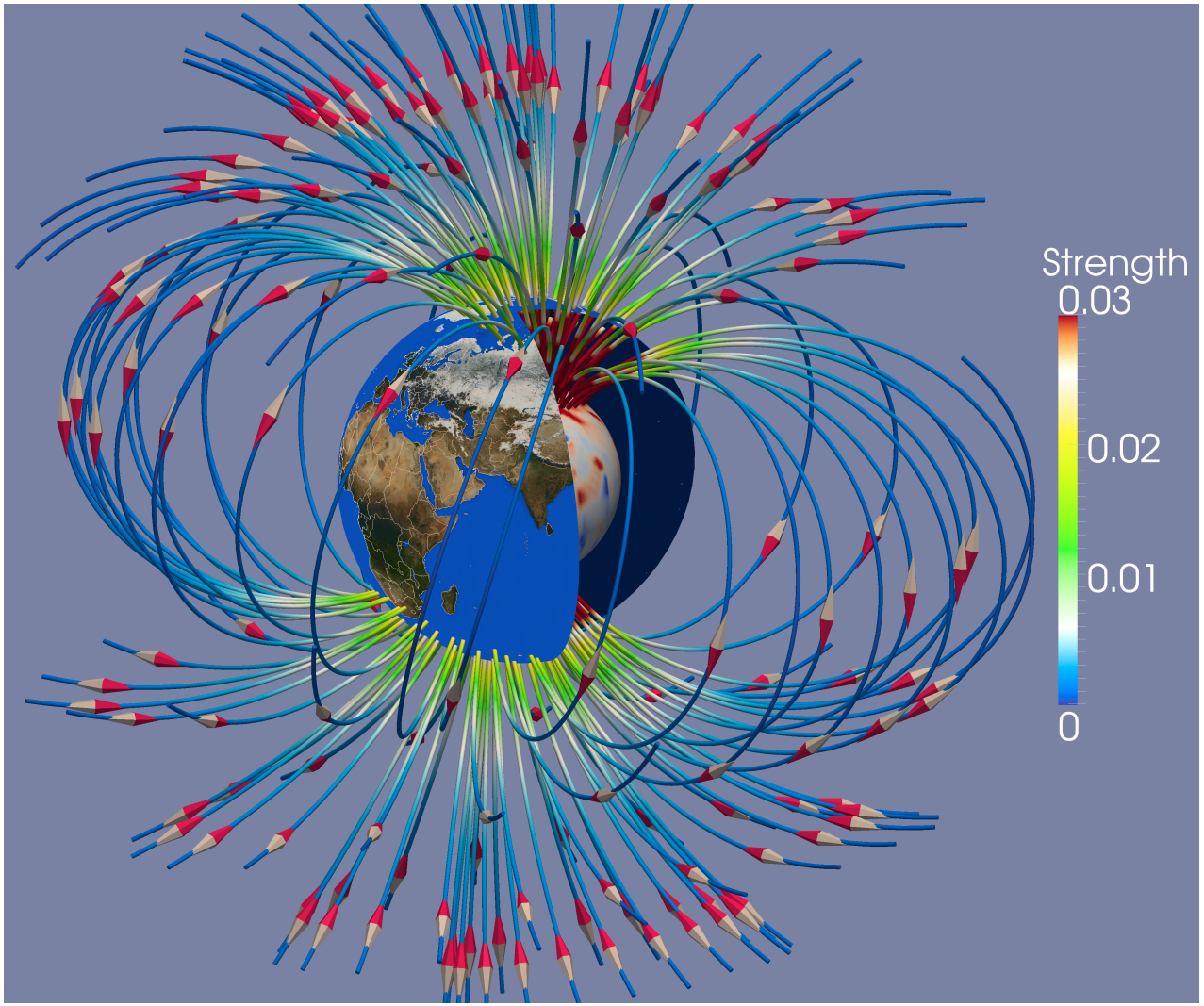
## Challenges

- Large domain (billions of cells needed)
- Complex rheology (visco-elasto-plastic; nonlinear)
- Viscosity contrast: 10-20 orders of magnitude
- Compositional variations
- Partial melting; melt migration



# Planetary magnetic fields (Jackson)



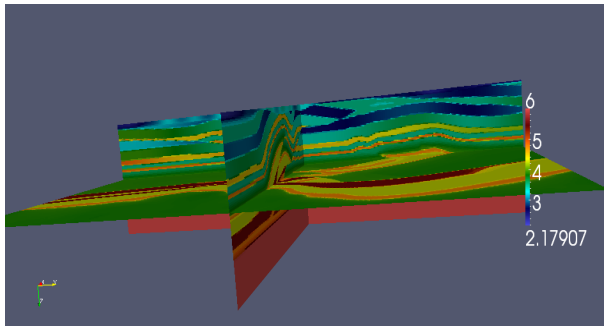

- 3-D Resolution: typically $(256)^3$ on up to 1200 processors
- Mixed FD-spectral methods
- PDEs are very stiff
- Need new time schemes
- Need fast spherical harmonic and polynomial transforms

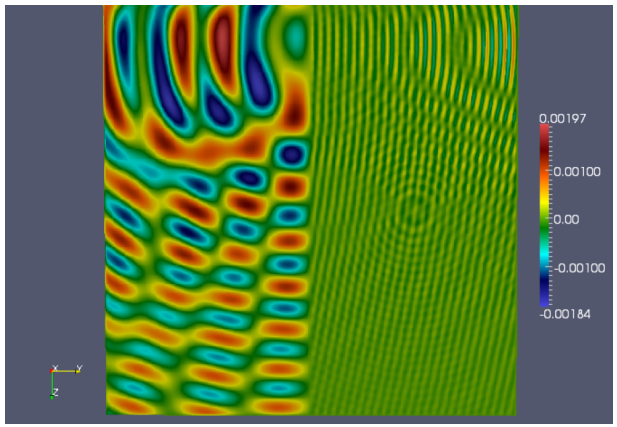
Challenge: drop Ekman number to reach asymptotic regime – not yet reached

# Advanced Computing Laboratory (Schenk)

- Fast parallel solution of heterogeneous 3D time-harmonic **wave** equations
- 3D Helmholtz: Simplest time-harmonic wave equation (acoustic waves)

Source: D. Giardini (ETHZ)




**WP Software**
P2P **-** Prototype implementation of a moving-PML preconditioner for large 3D Helmholtz equation

**WP Computational Algorithms**
PML · parallel sweeping preconditioning · seismic imaging · fault tolerance · communication avoiding computations

**WP Exascale Programming**
Cray Cascade System (CSCS) · IBM Blue Gene Q (Argonne), Titan (ORNL)

# Communal projects

- Knowledge transfer
  - GPU modeling (magnetic geodynamo)
  - FD stencil auto-tuning (geodynamics & wave laboratory)
  - Common algorithmic kernels (derivatives, I/O, time stepping)
- Synergies with CoCoNet: Algorithmic kernels (stencils, GPU, I/O)
- Workshops, code dissemination, co-design
- Efficient handling of massive I/O; 3D in-situ visualization
- Algorithmic improvements (e.g. local time-stepping)
- Grand-challenge Earth imaging
  - A 3D seismic model for Switzerland with uncertainty estimation
  - Tomography coupled with mantle dynamics, Materials network?