Low-Frequency Seismology

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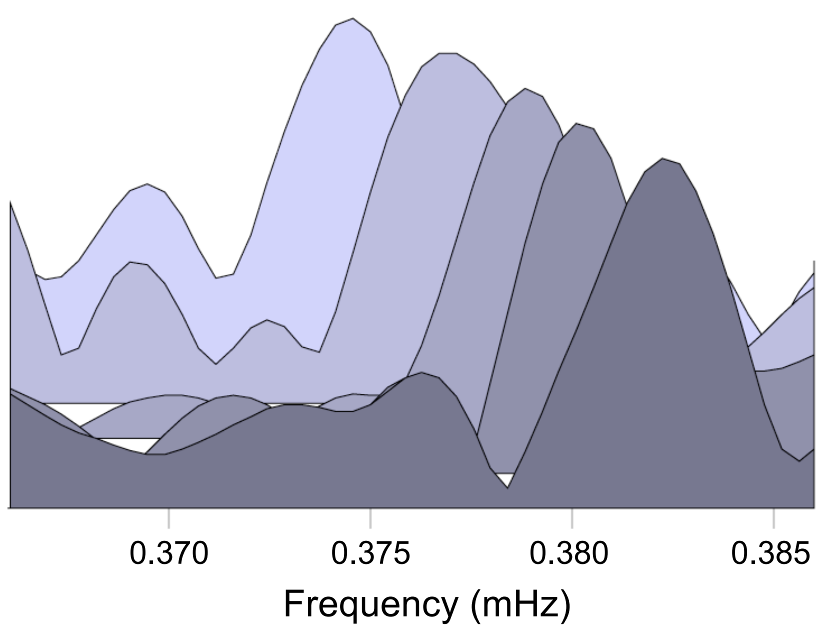
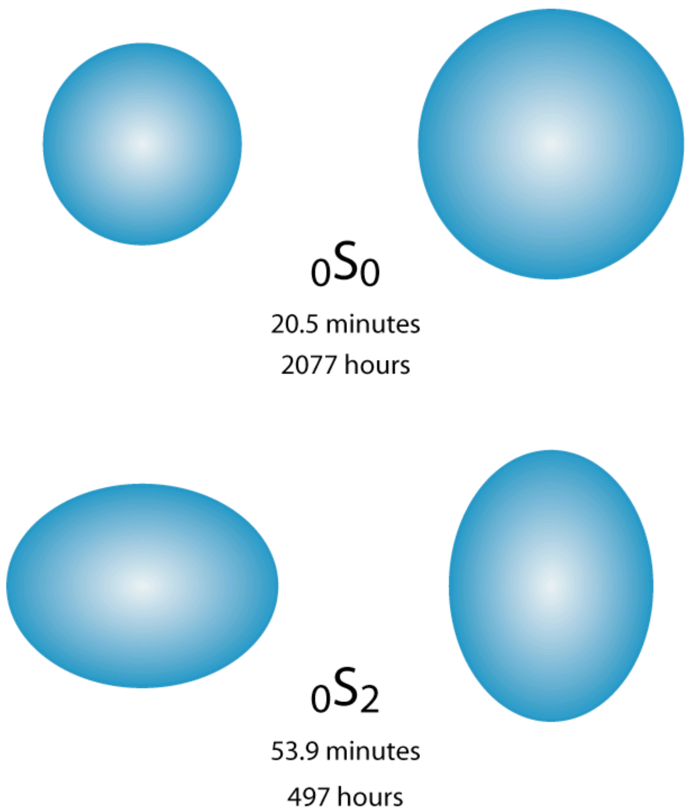
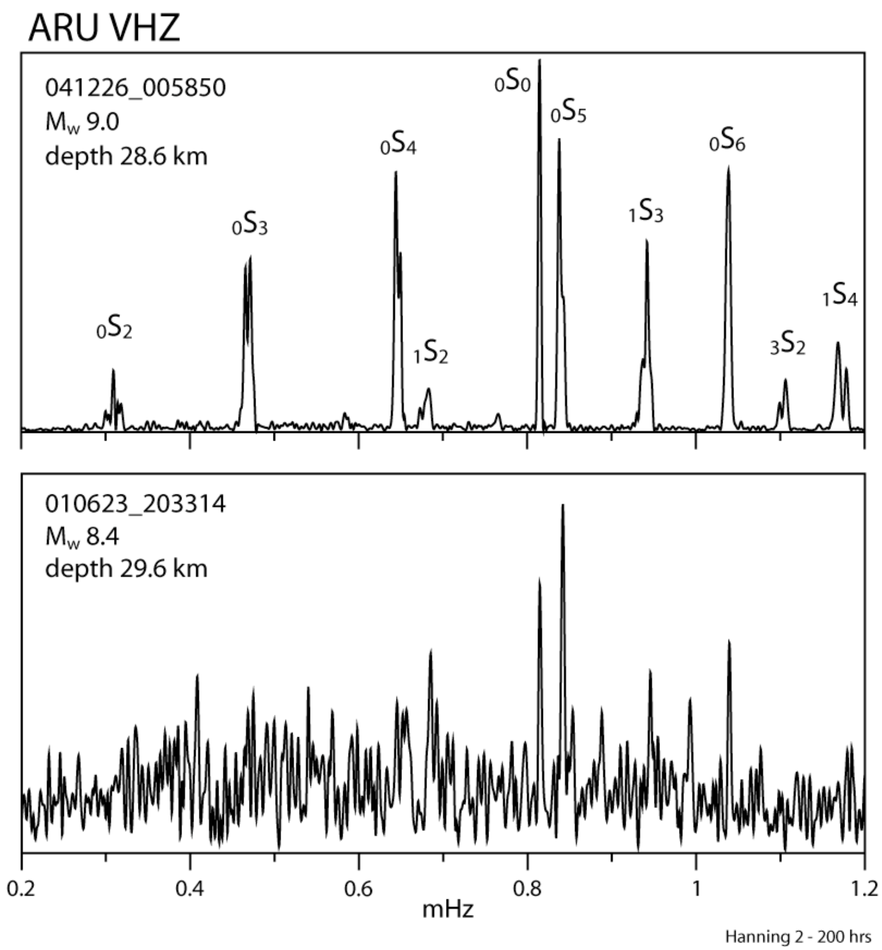


Outline

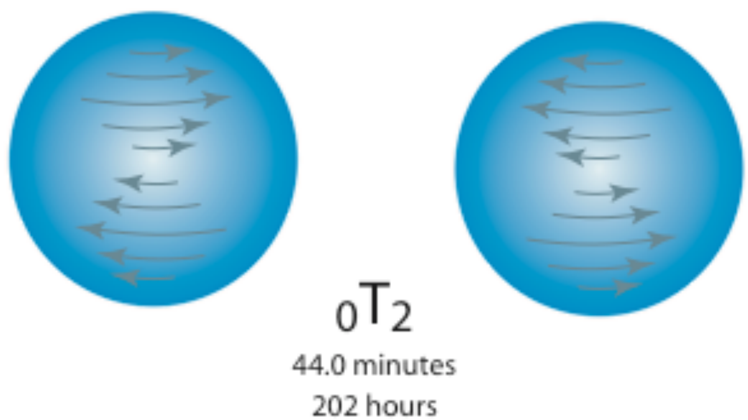
- brief review of free oscillations
- some examples of mode studies
- lower frequencies?
- summary

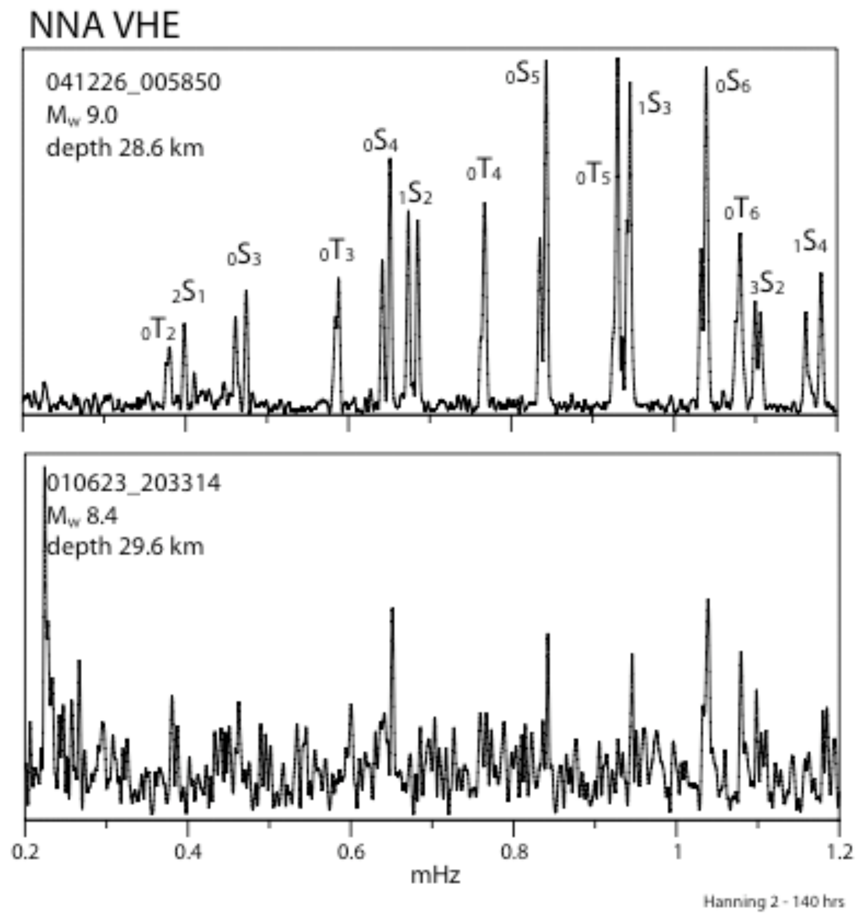
Earth's Free Oscillations (Spheroidal Mode)



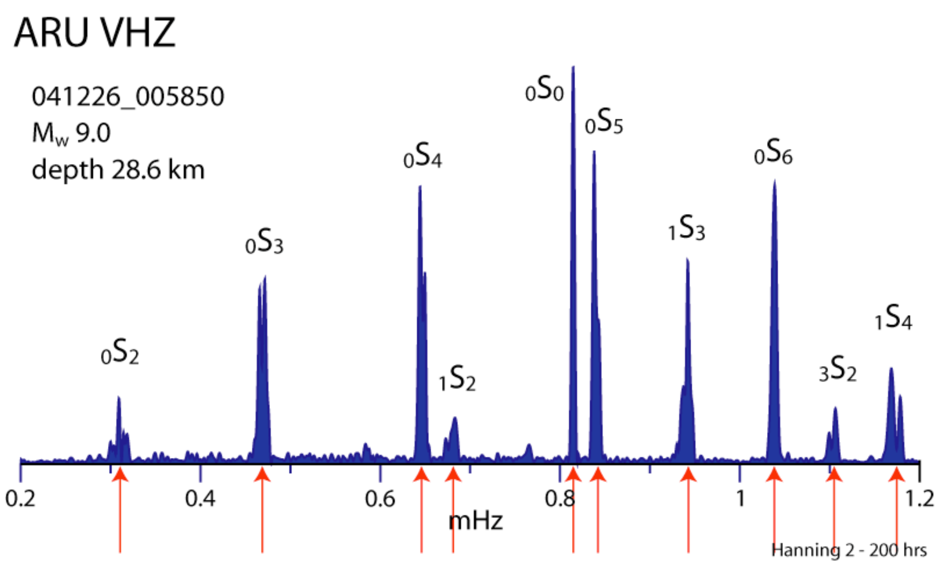


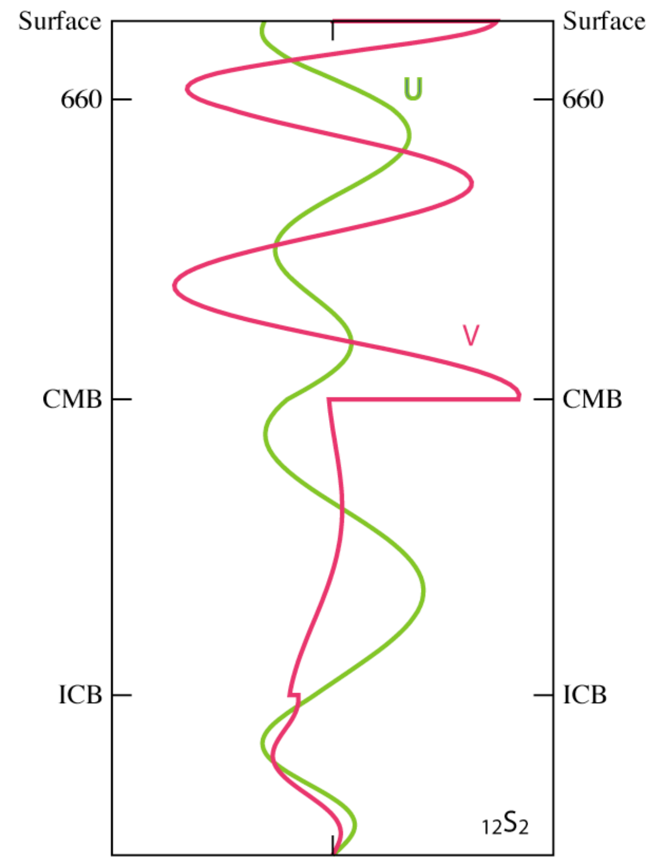
Earth's Free Oscillations (Toroidal Mode)





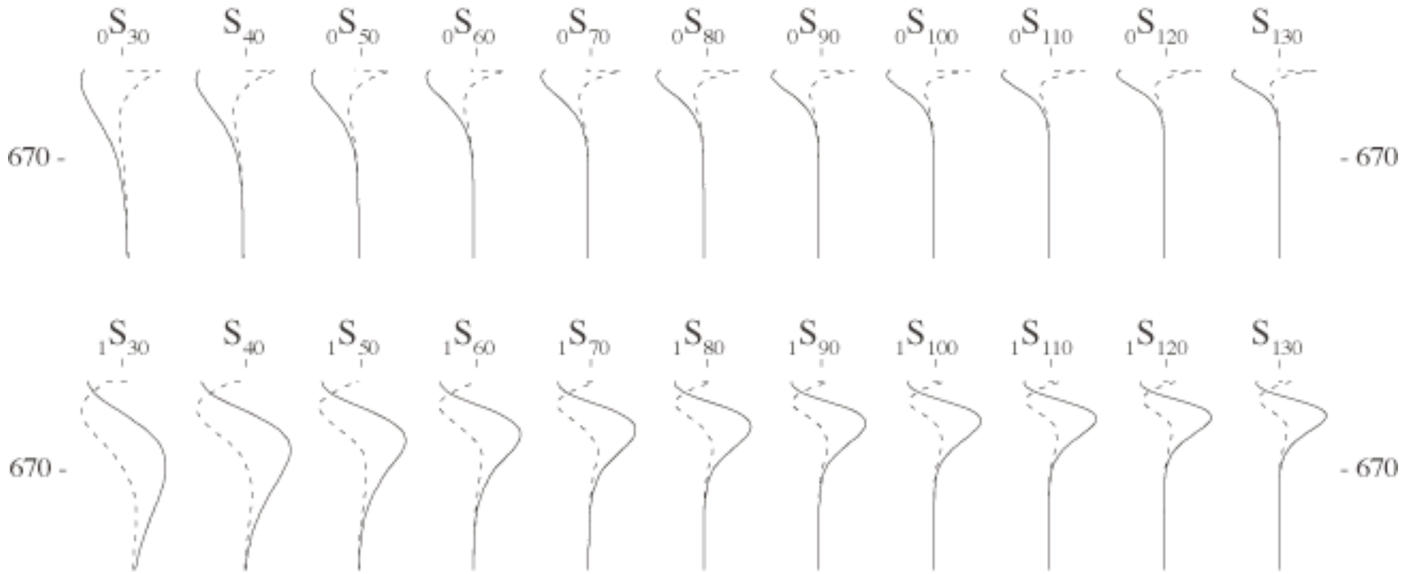
Normal-Mode Central Frequency



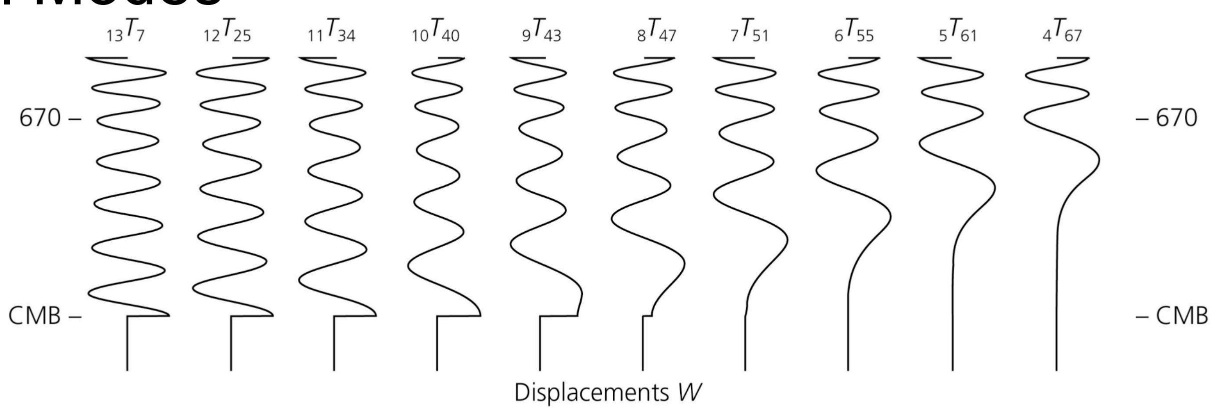


Eigenfunctions

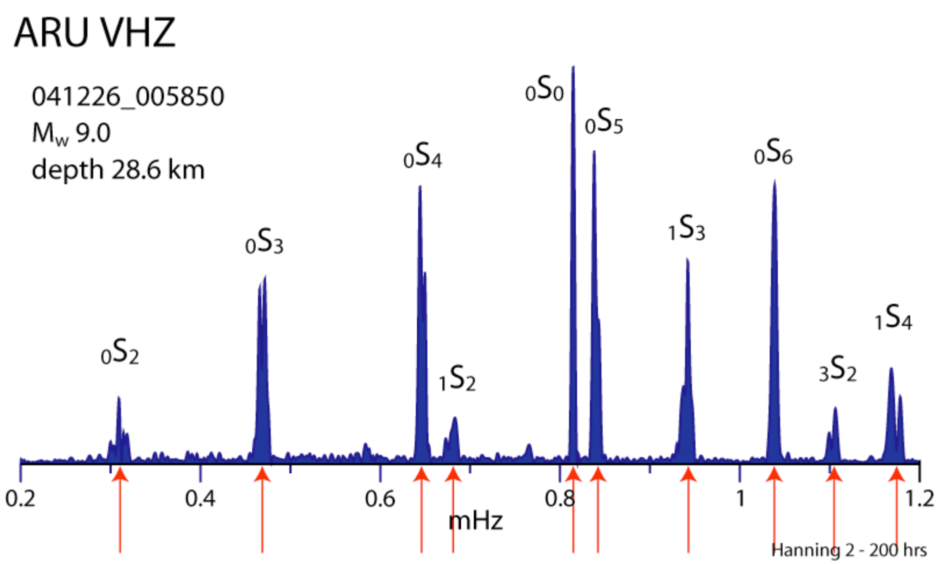
Spherical Modes

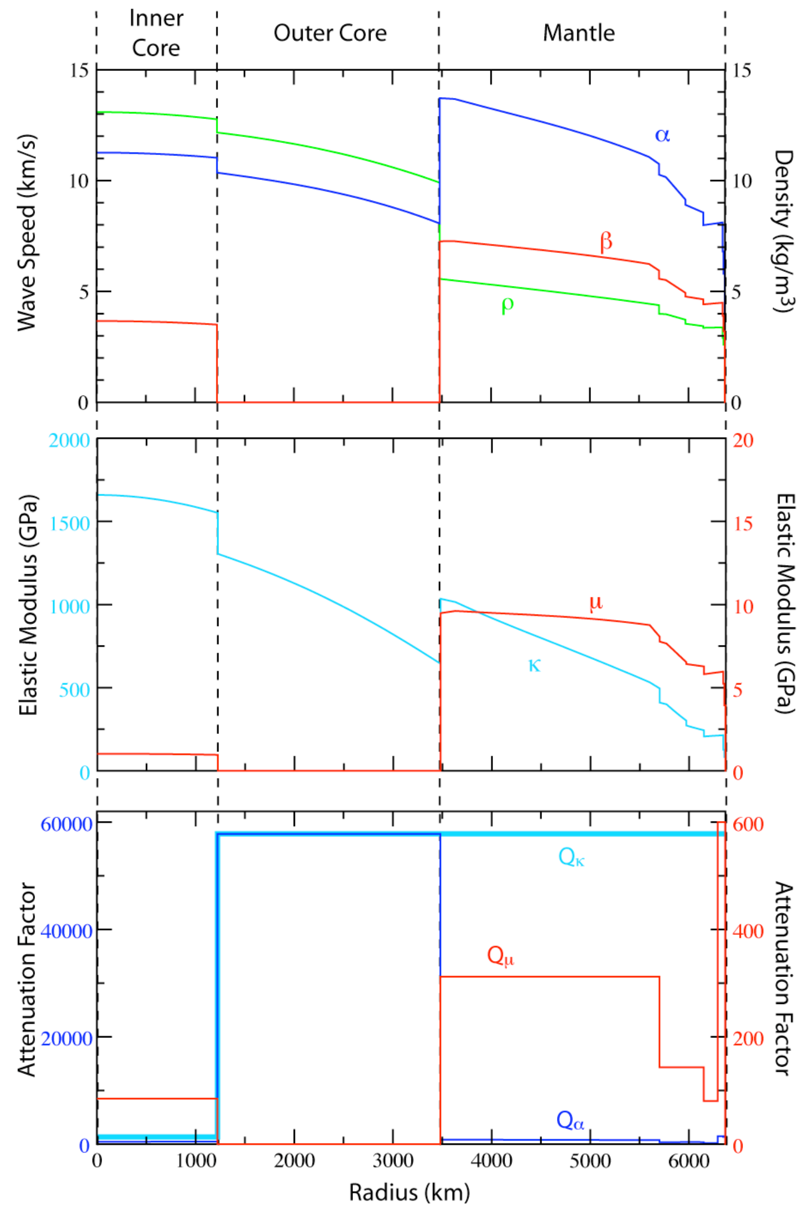


Toroidal Modes



Normal-Mode Central Frequency





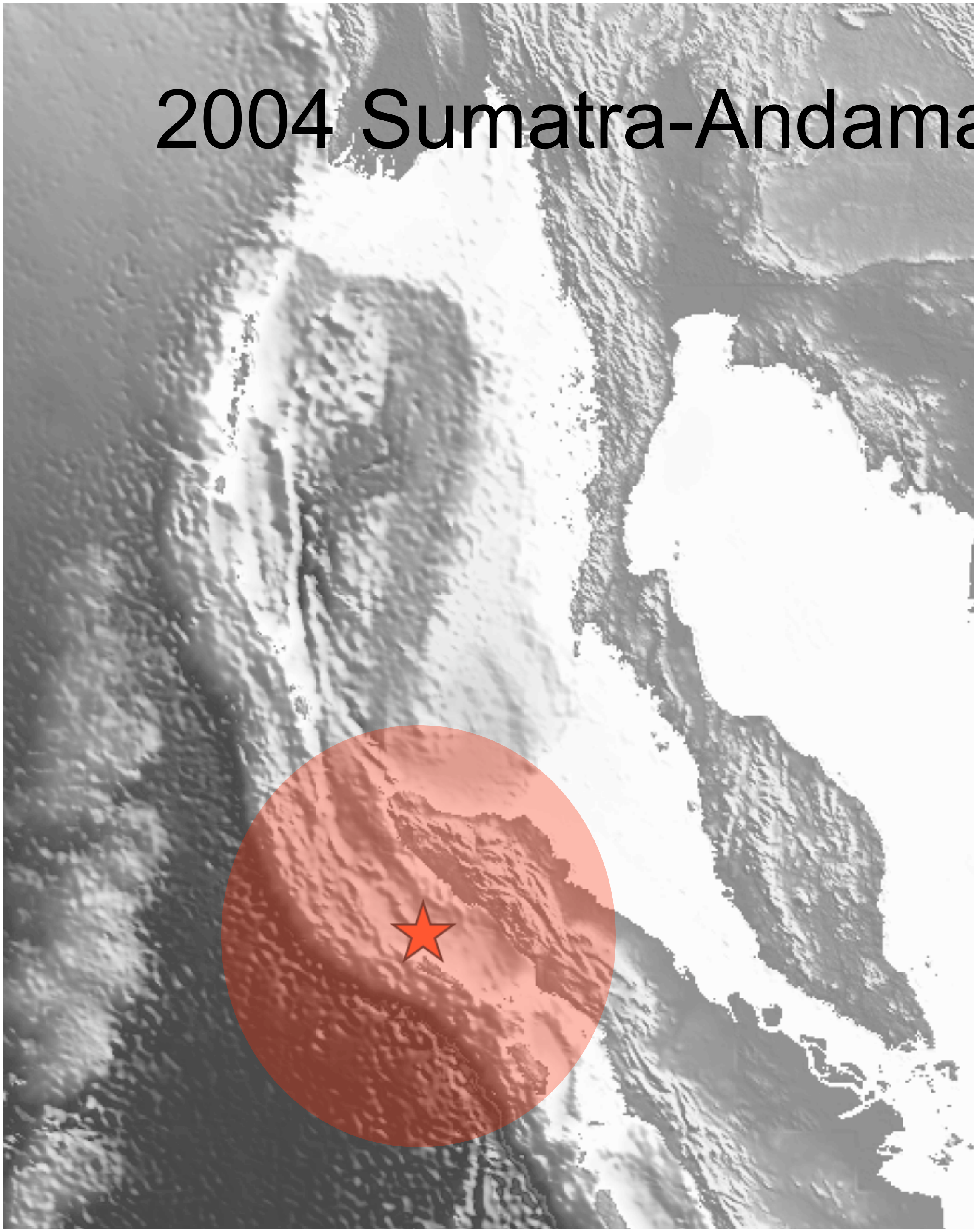
Normal-Mode Studies

1. Large Earthquakes

2. Incessant Hum

3. Internal Structure

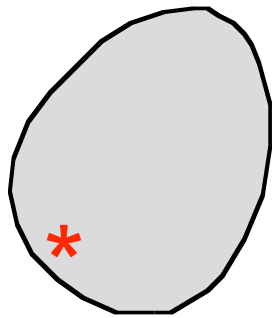
2004 Sumatra-Andaman Earthquake



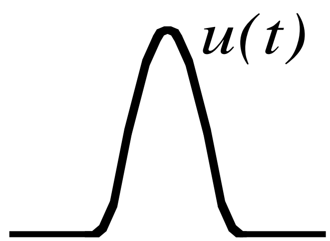
Magnitude

0:11	PTWC	Mwp 8.0
0:17	NEIC	Mb 6.2
0:40	NEIC	Mw 8.2
0:45	PTWC	Mwp 8.5
1:15	NEIC	Ms 8.5
2:05	Harvard	Mw 8.9
19:03	Harvard	Mw 9.0

Small and Large Earthquakes

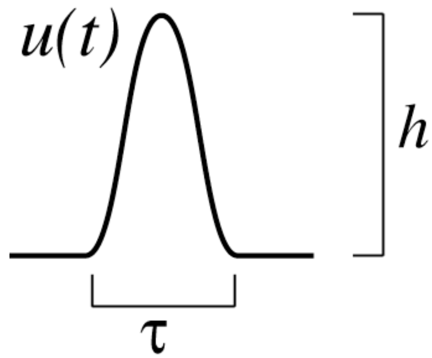


A = area



Modified from Prieto et al. (2003)

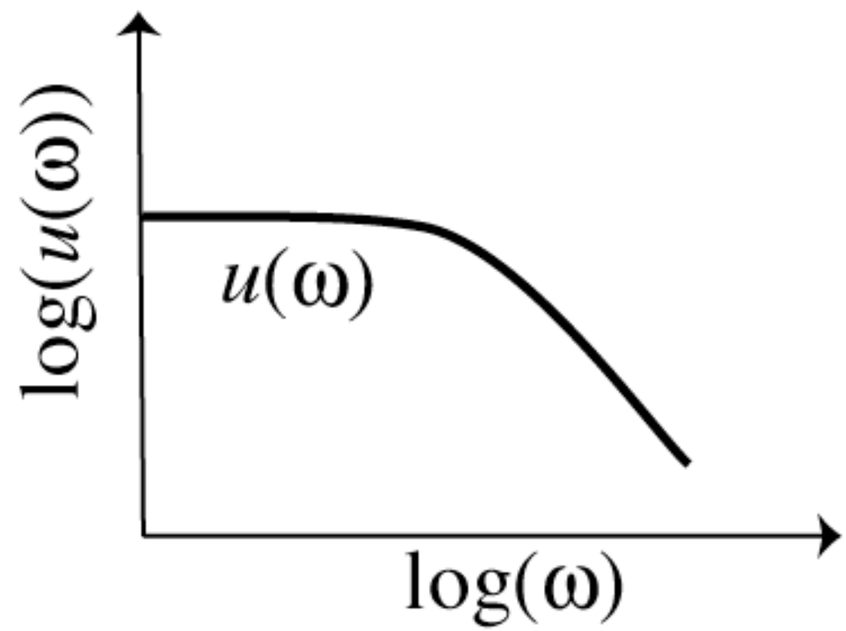
Earthquake Size and Frequency Content



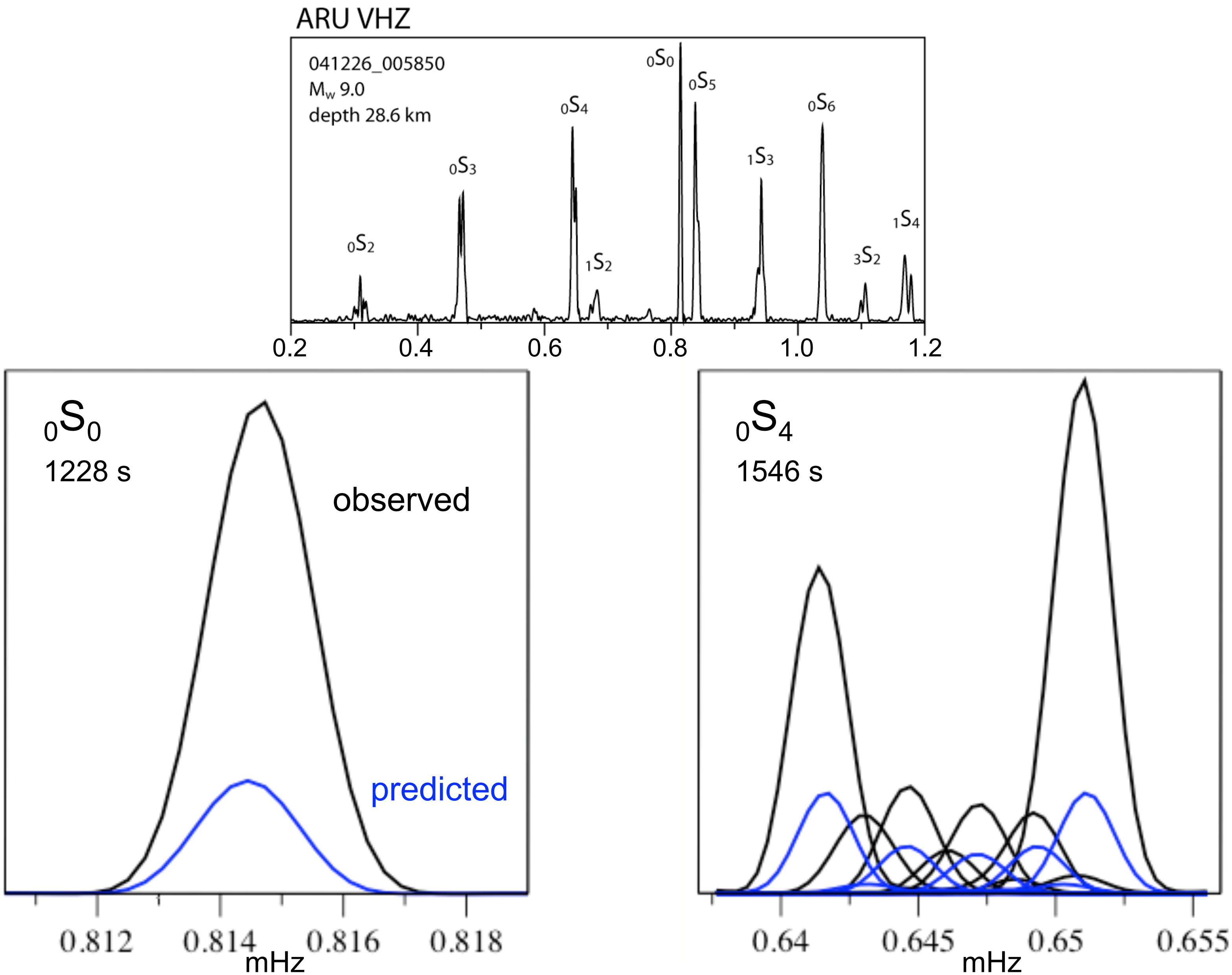
Modified from Prieto et al. (2003)

Estimated Magnitude and Frequency

0:00 earthquake started
0:15 mb = 6.2 (body waves)
1:15 Ms = 8.5 (surface waves)
6:12 Mw = 8.9 (surface waves)
20:40 Mw = 9.0 (surface waves)

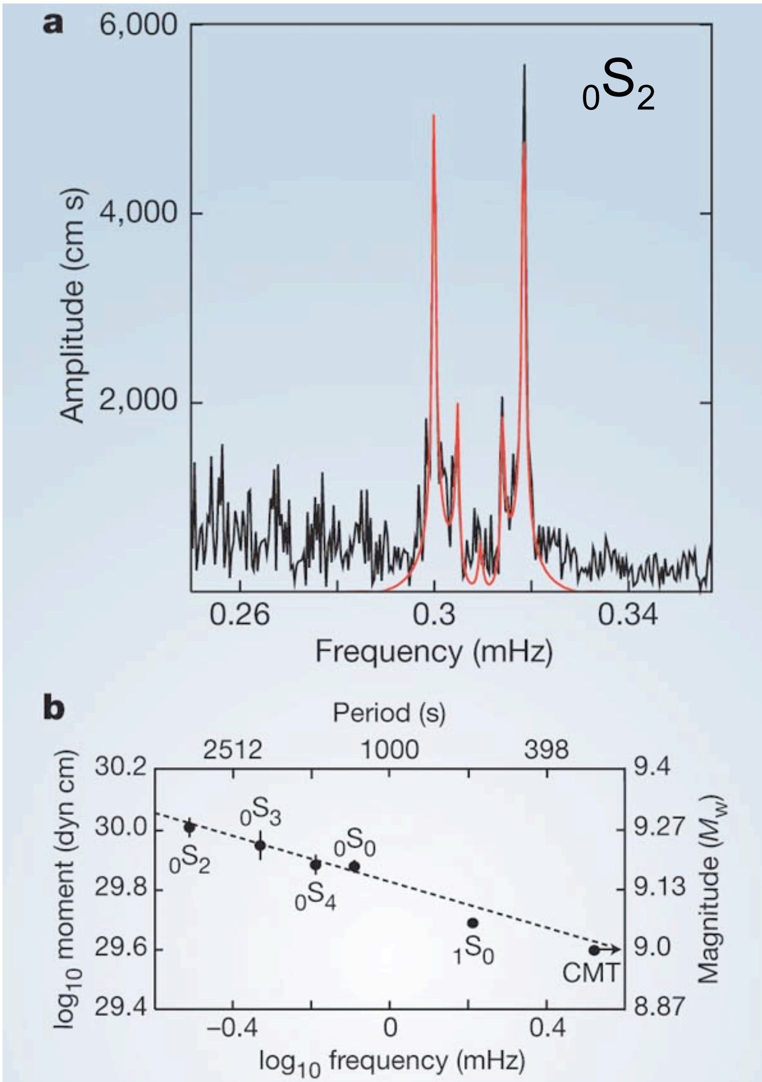


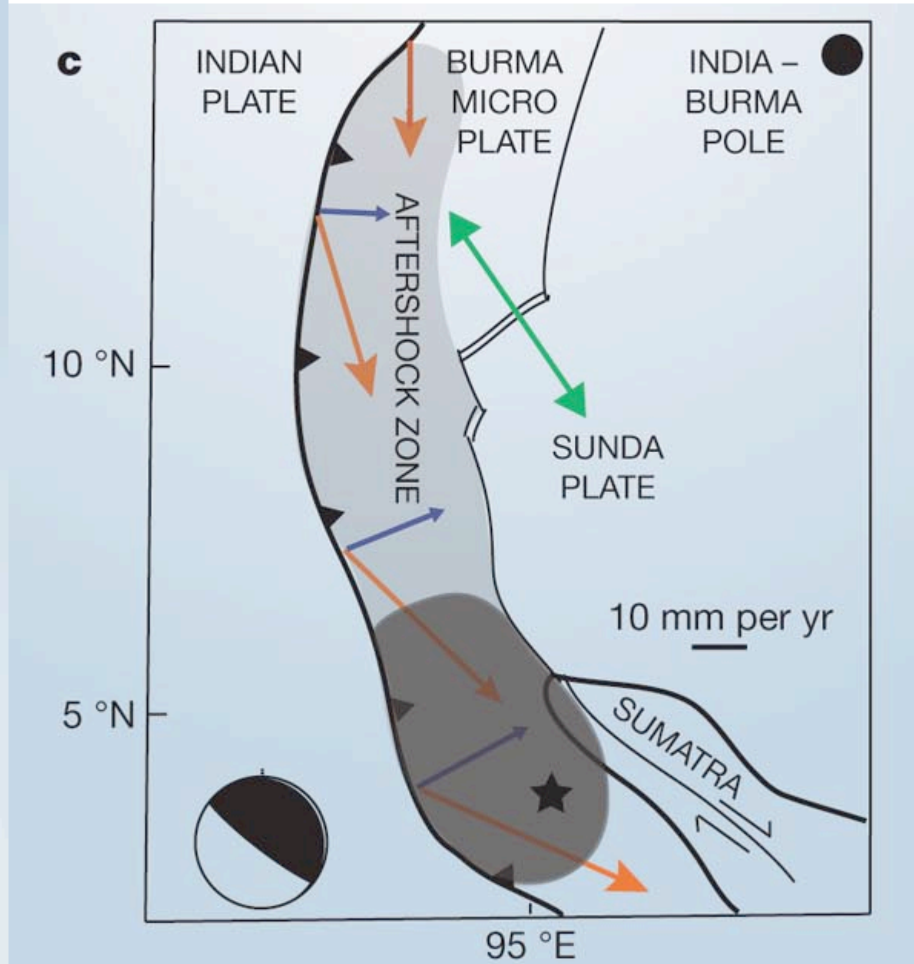
Fit to Normal-Mode Data



Receiver strips, prediction using Harvard CMT solution

Normal-Mode Analysis for Earthquake





Stein & Okal (2005)

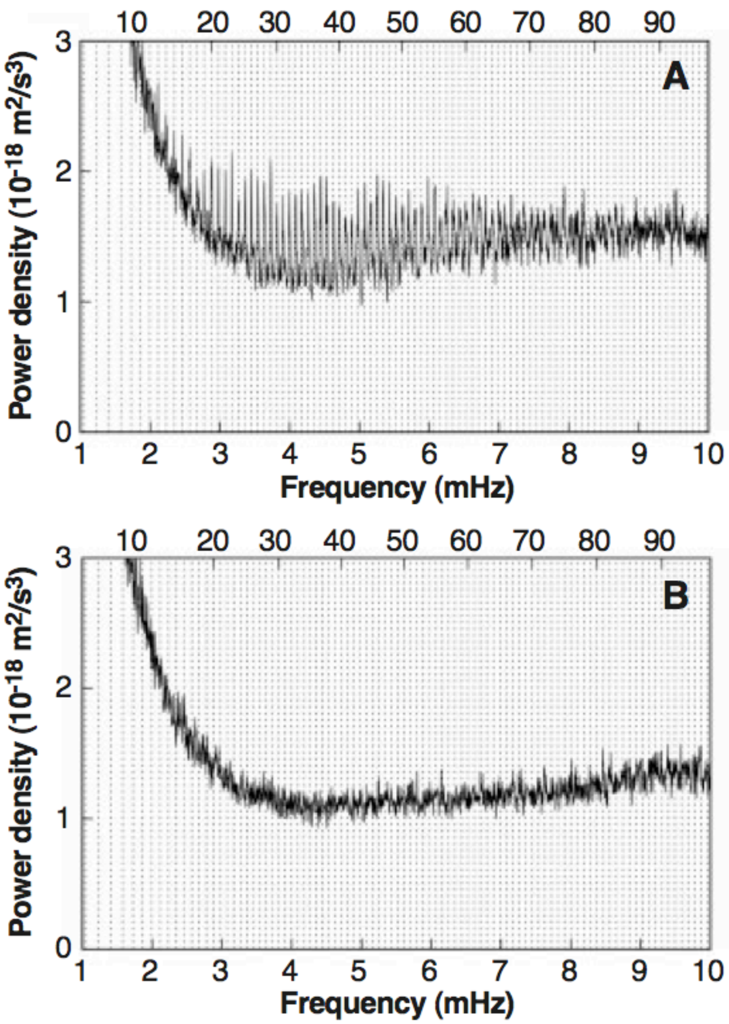
Normal-Mode Studies

1. Large Earthquakes

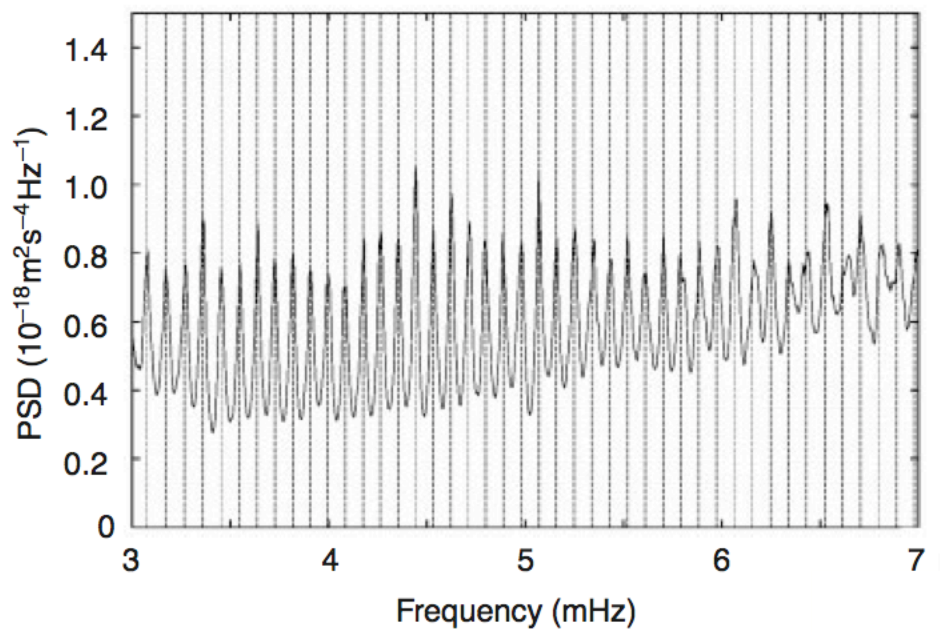
2. Incessant Hum

3. Internal Structure

Hum of the Earth



Kobayashi & Nishida (1998)

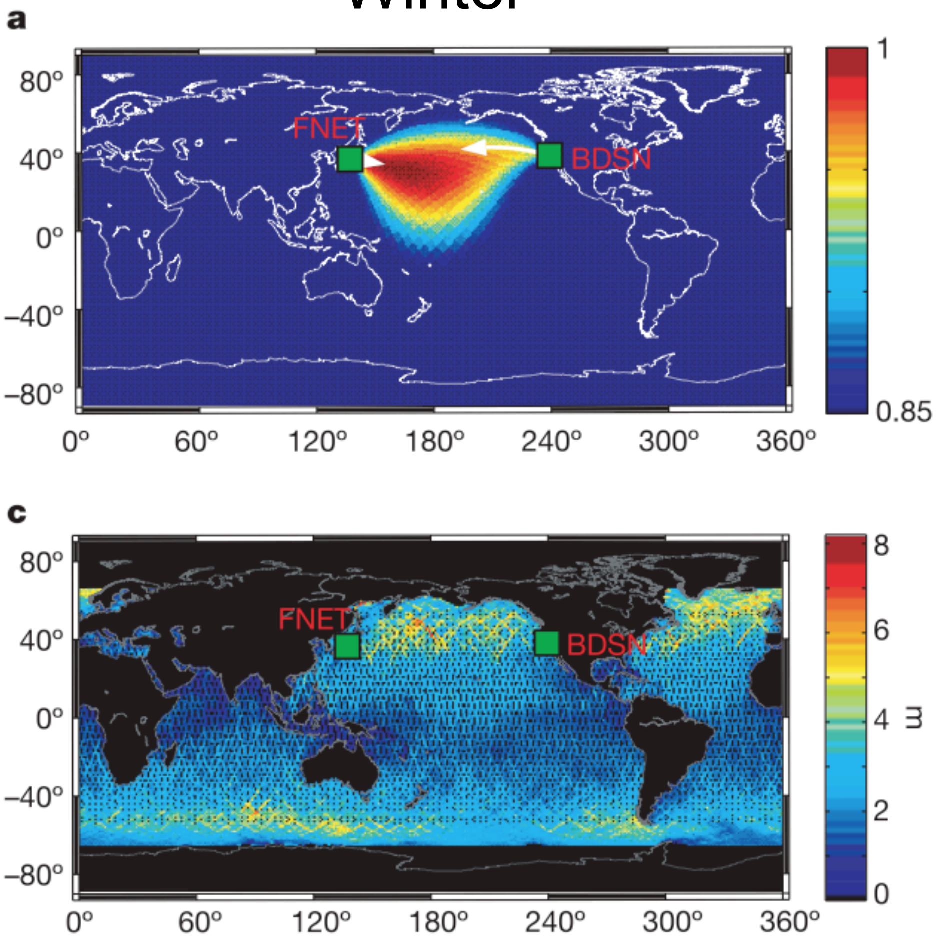


- not from small earthquakes
- not from “slow” earthquakes

Suda et al. (1998)

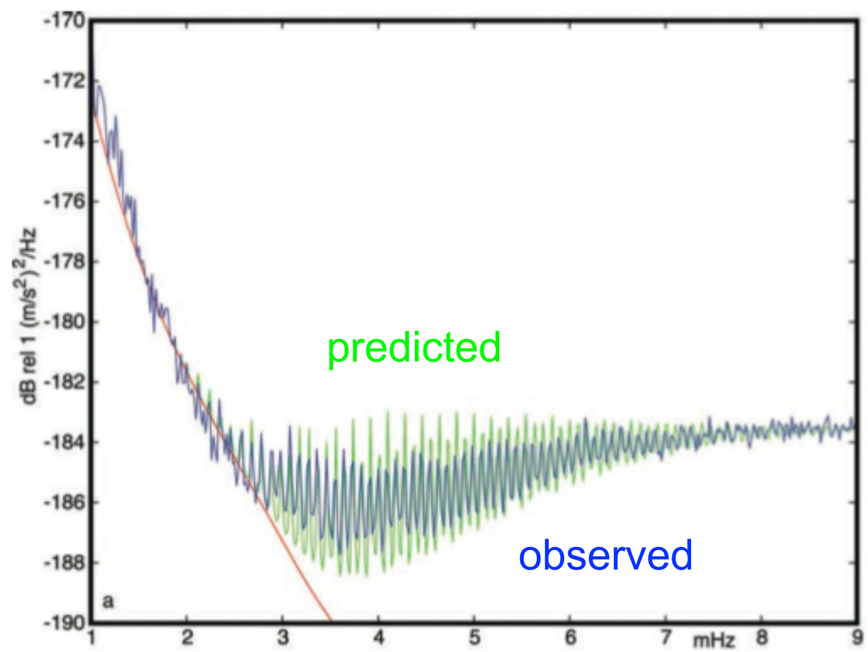
Source of the Hum?

Winter



Rhie & Romanowicz (2004)

Webb (2008)



➔ non-linear interaction of ocean waves with seafloor (continental shelves & deep ocean basins)

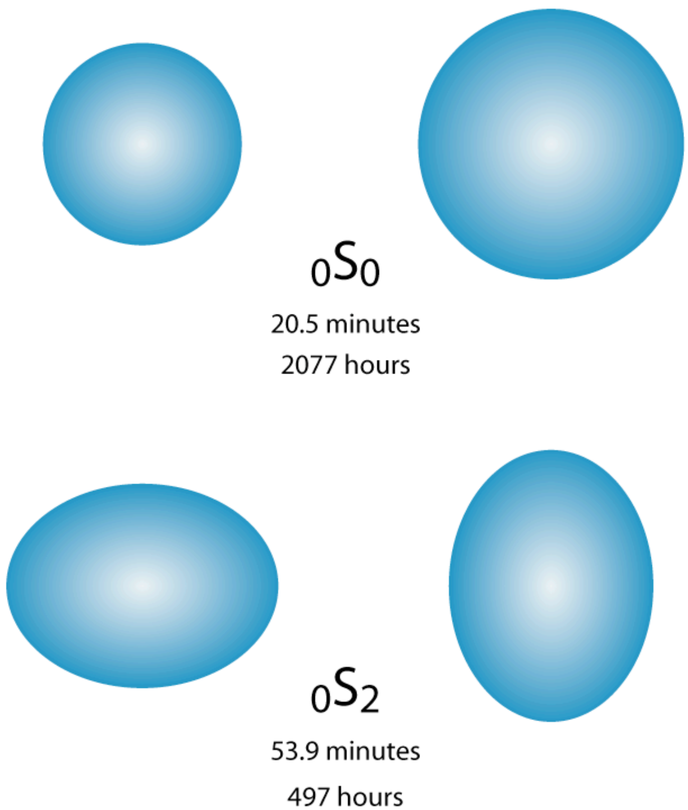
Normal-Mode Studies

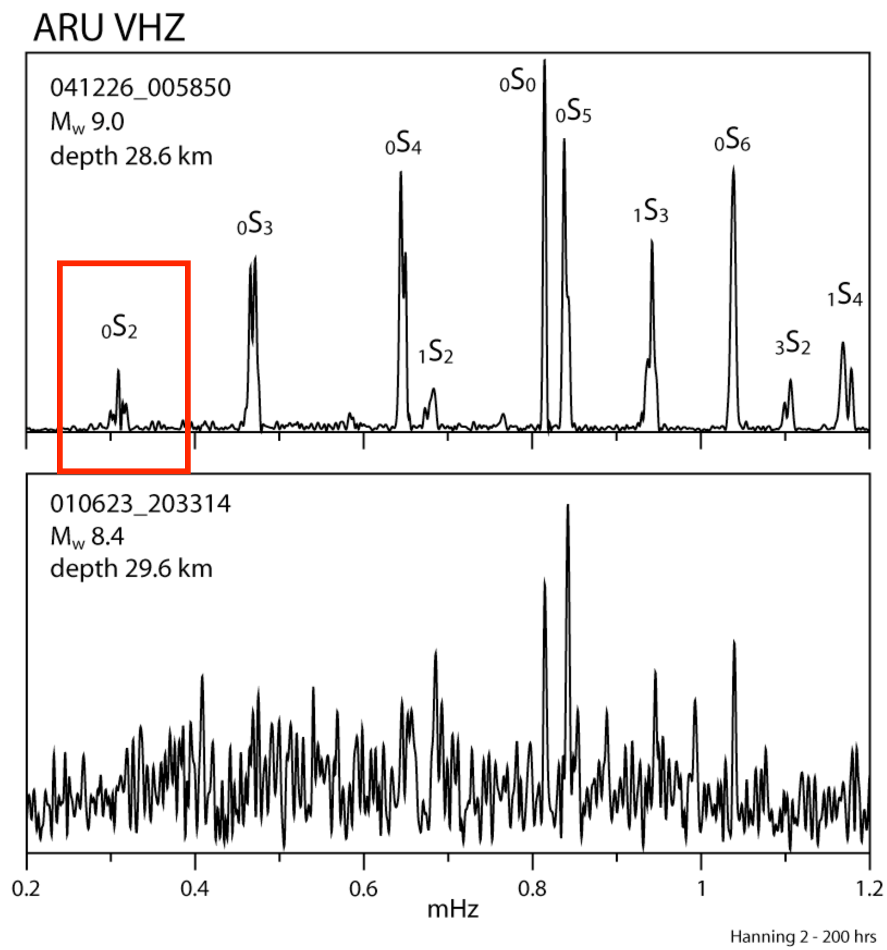
1. Large Earthquakes

2. Incessant Hum

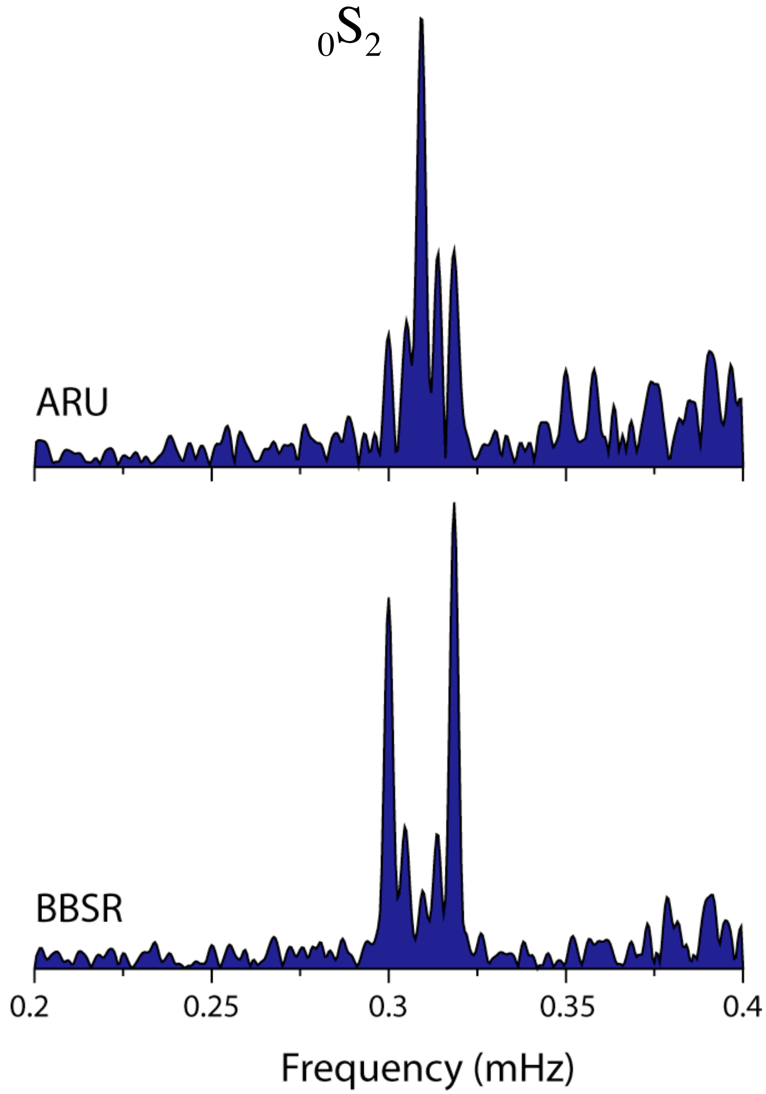
3. Internal Structure

Earth's Free Oscillations (Spheroidal Mode)





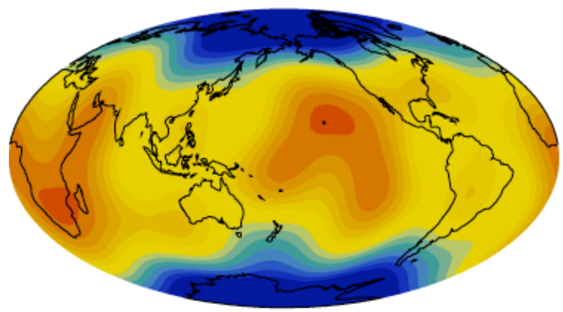
Mode Splitting



- rotation
- ellipticity
- lateral variations

Splitting Function

Observed Splitting Function ($_6S_3$)

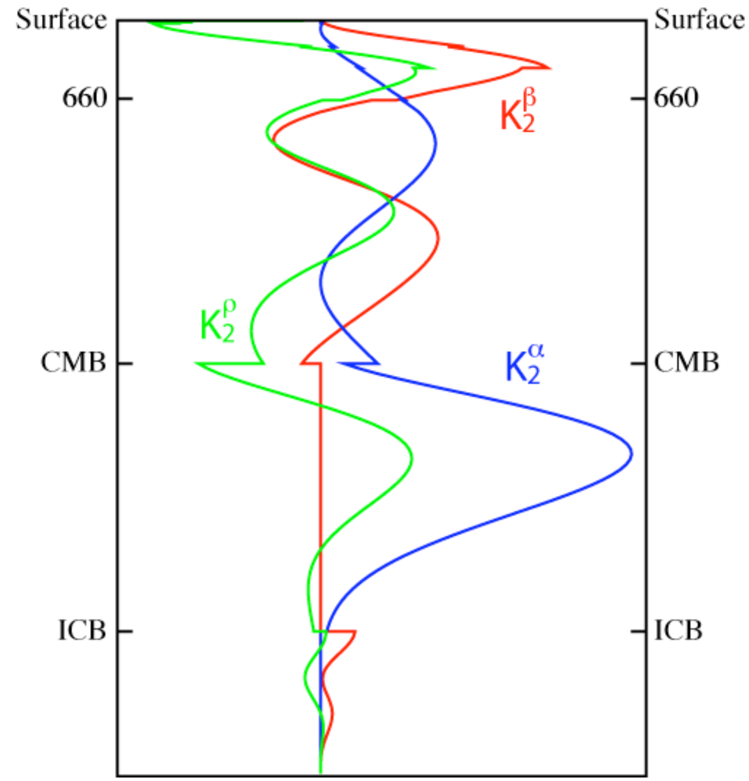


$$\sigma(\theta,\phi) = \sum_{s,t} c_{st}\, Y_{st}(\theta,\phi)$$

Splitting Function

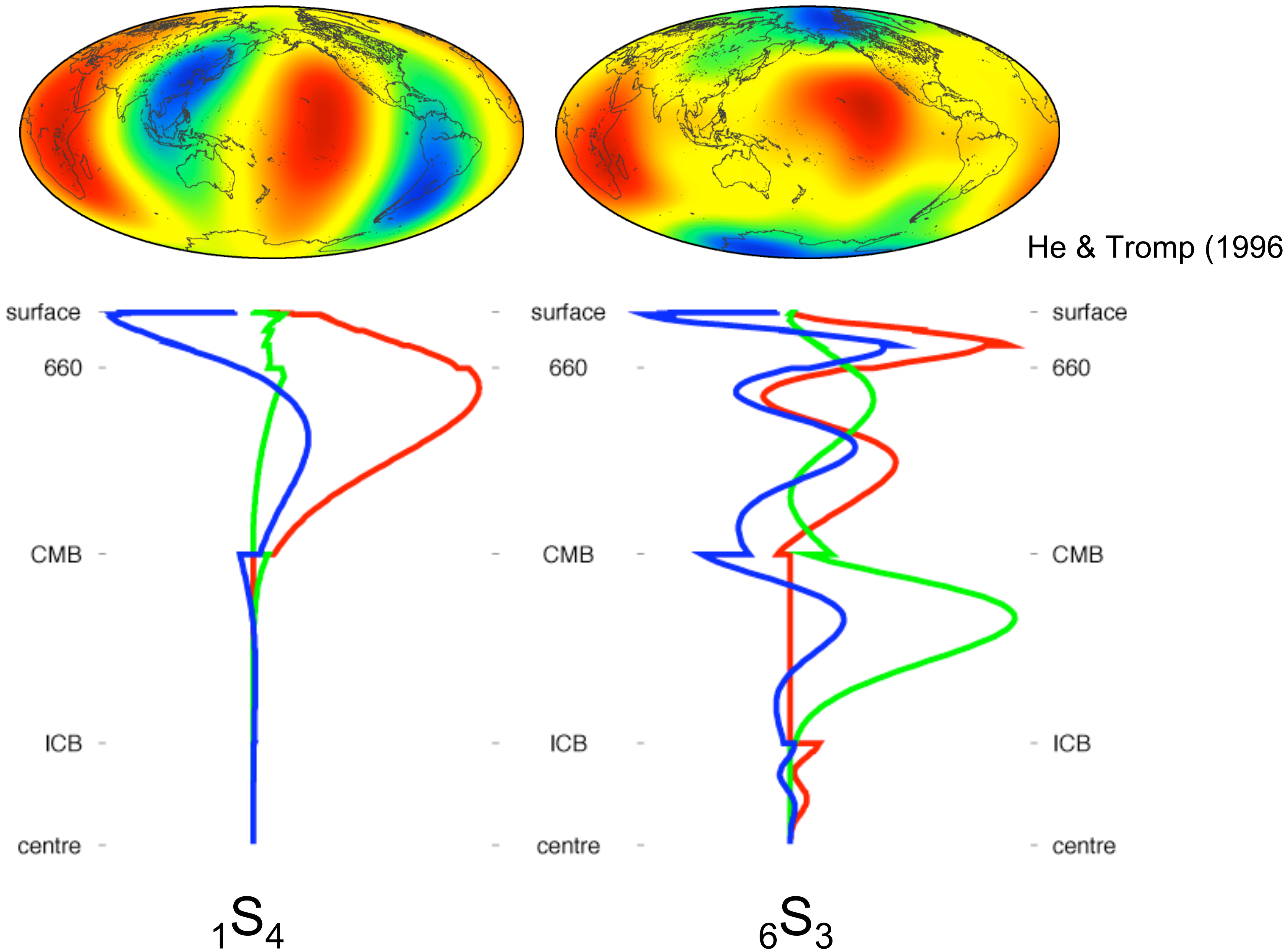
Spherical Harmonics

Sensitivity Kernel ($_6S_3$)

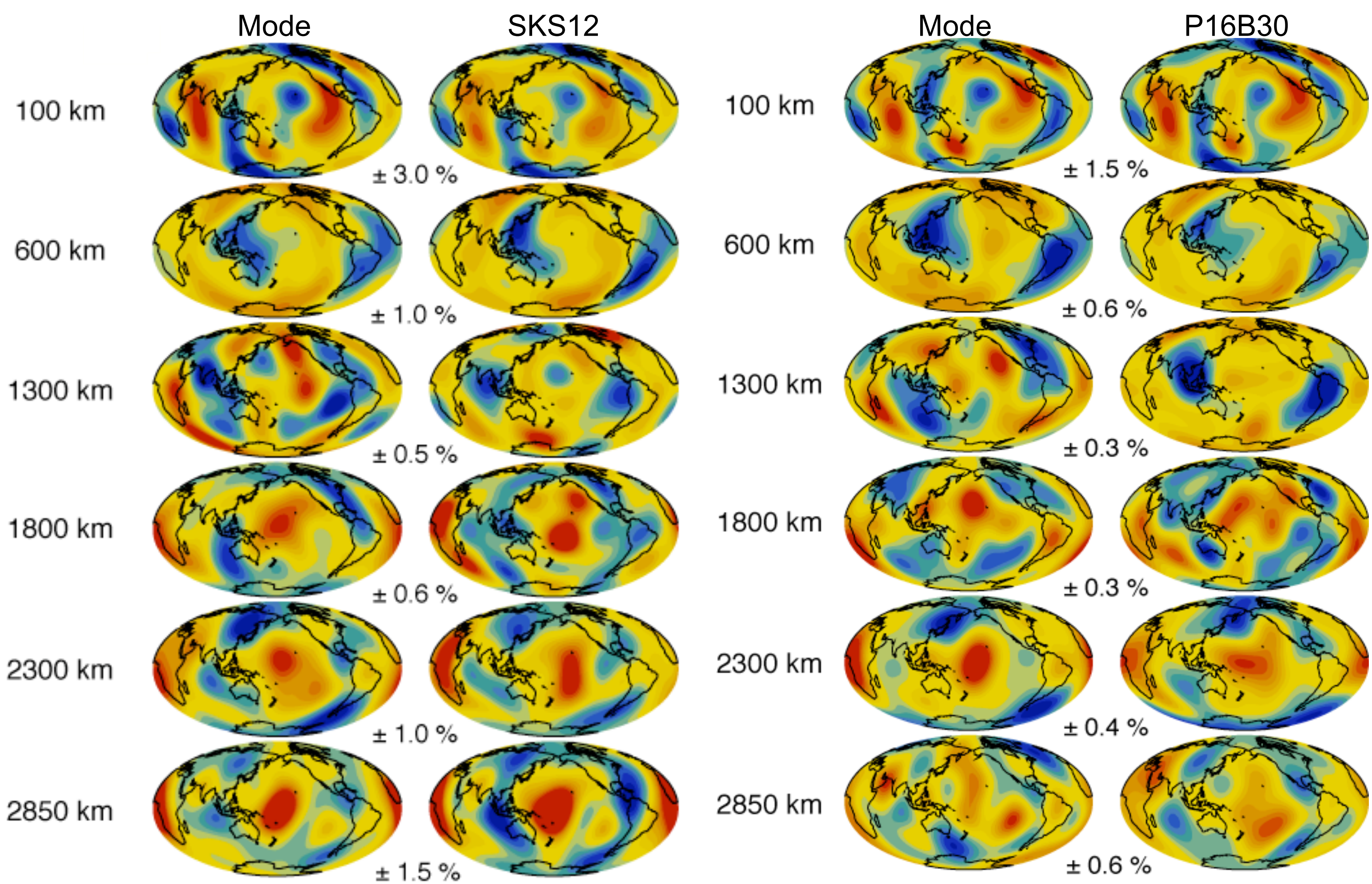


$$c_{st} = \int_0^a \left[K_s^\beta(r)\,\delta\beta_{st}(r) + K_s^\alpha(r)\,\delta\alpha_{st}(r) + K_s^\rho(r)\,\delta\rho_{st}(r) \right] dr$$

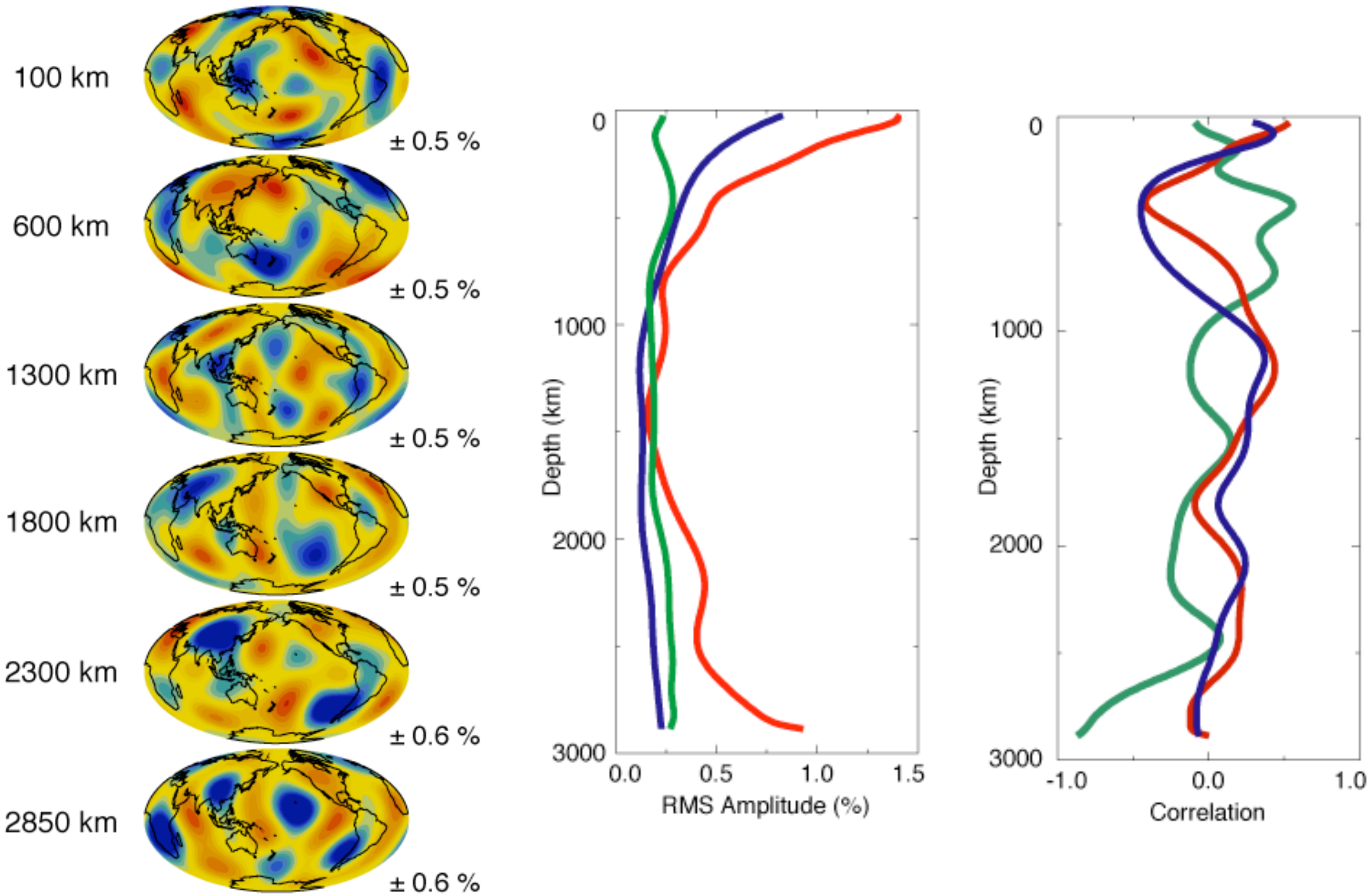
Normal Mode Splitting



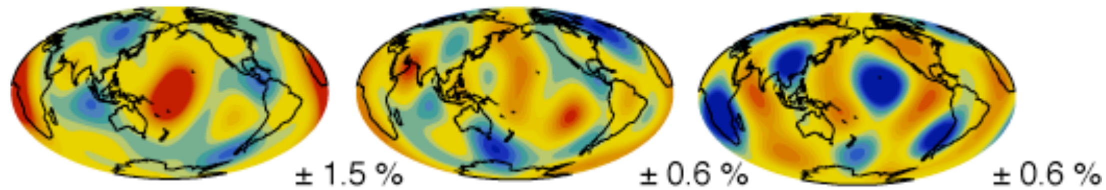
Mantle Seismic Wave Speed Models



Mantle Density Model



Structure Near the Core-Mantle Boundary

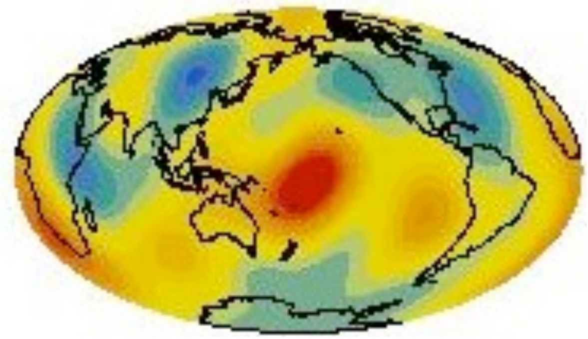


- strong anti-correlation ➔ small amplitude Vp
- density decorrelation (regional anti-correlation)

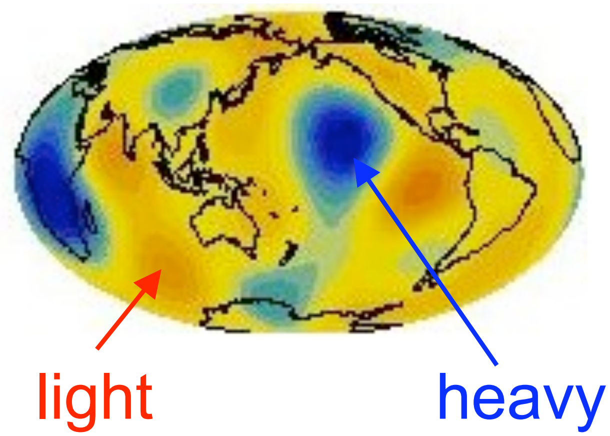
Implications for Mantle Dynamics?

Near Core-Mantle Boundary

Wave Speed (~Temperature)

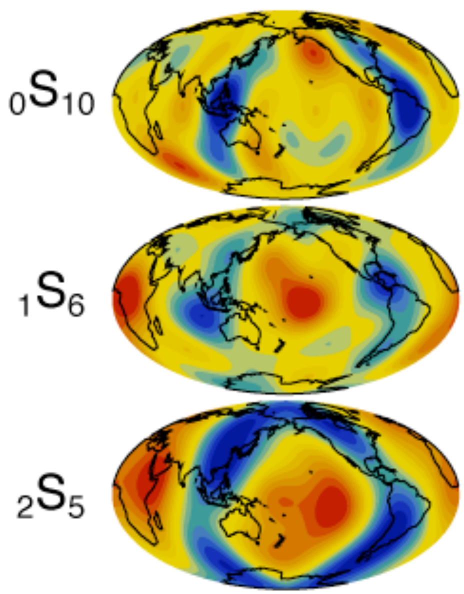


Density



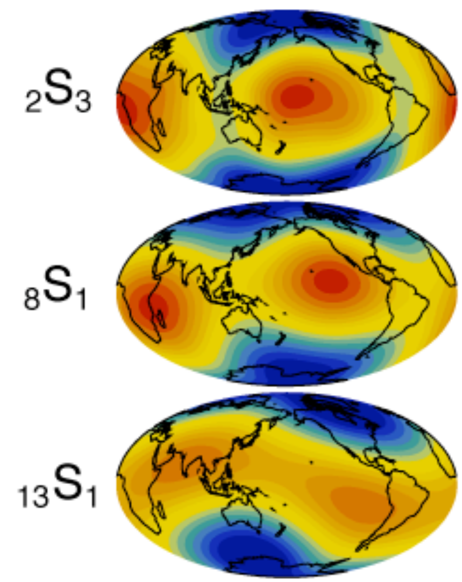
Comparison of Splitting Functions

Mantle Modes



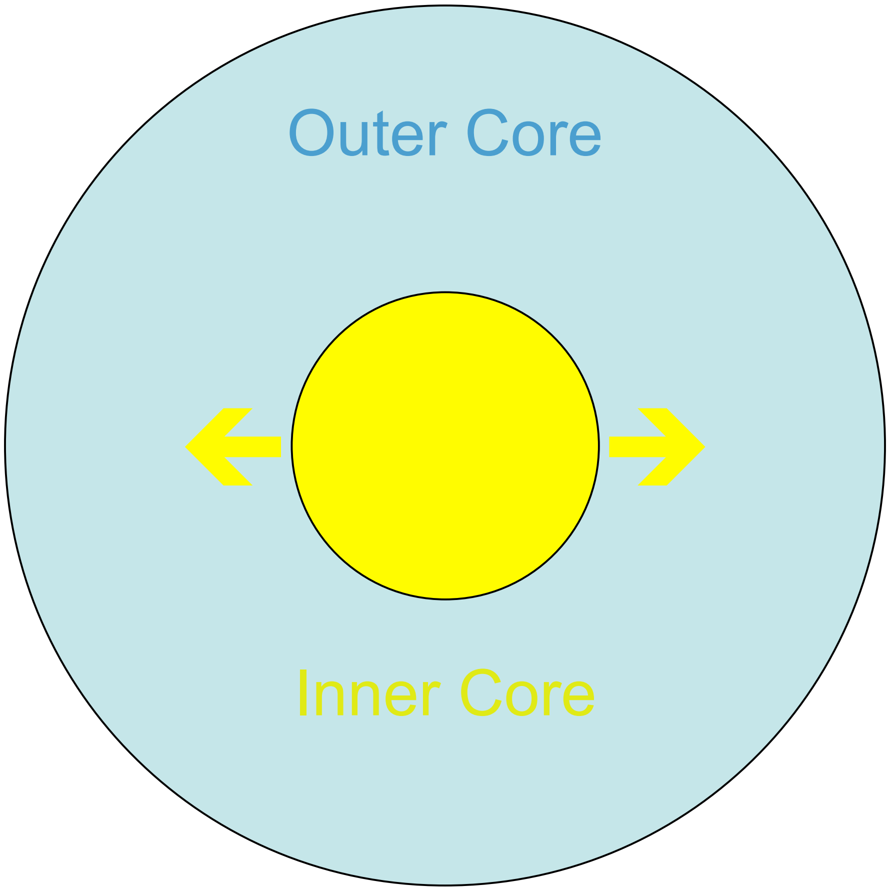
➔ 3D Models of S & P wave speeds and density

Inner-Core Modes



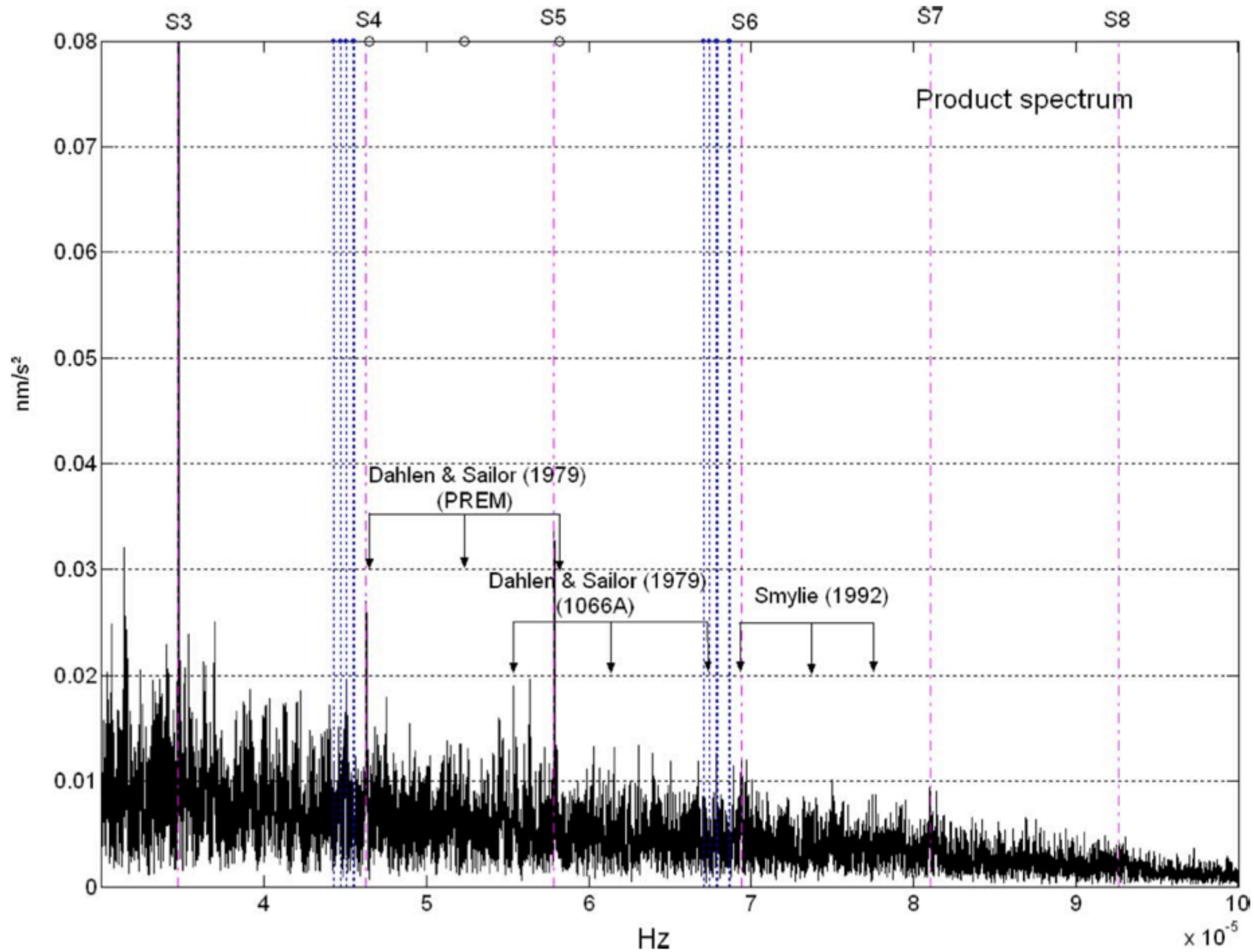
➔ ~ 2% anisotropy

Slichter Mode



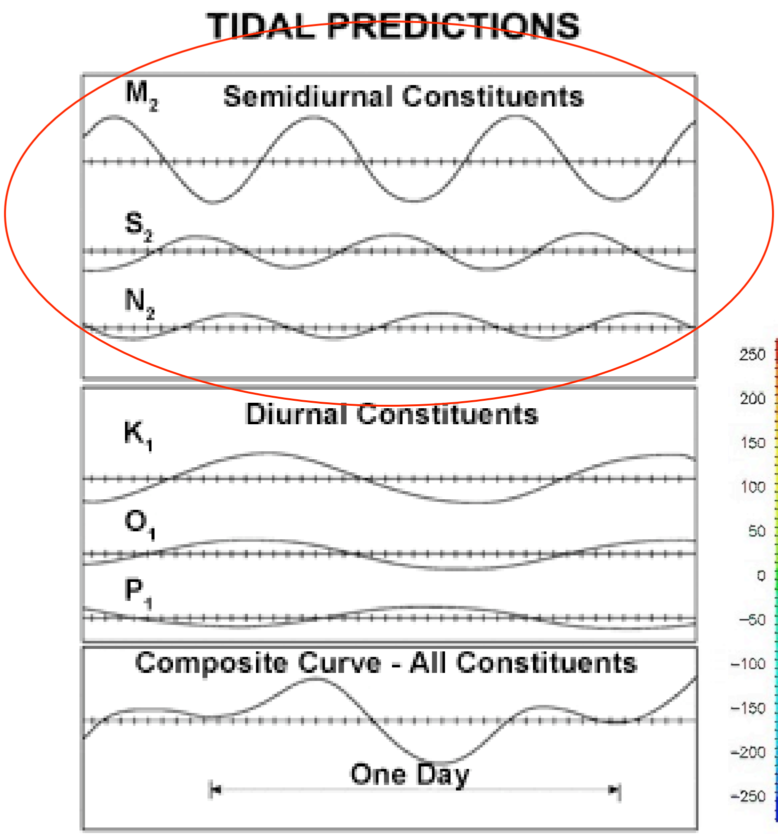
- translational inner core mode
- T = 325 min ~ 5.5 hours
- superconducting gravimeter
- sensitive to viscosity of the liquid outer core

Slichter Mode

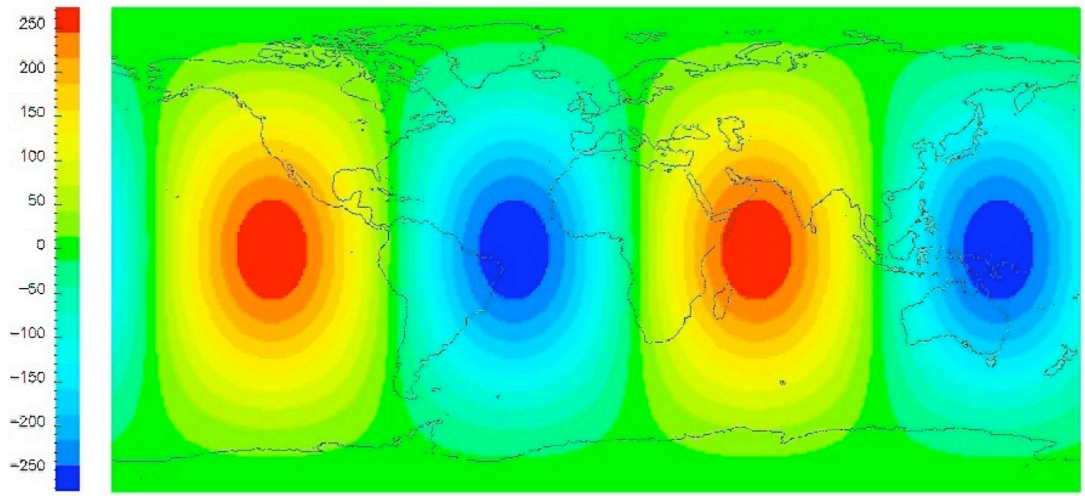


Rosat et al. (2003)

Forced Oscillation: Body Tide

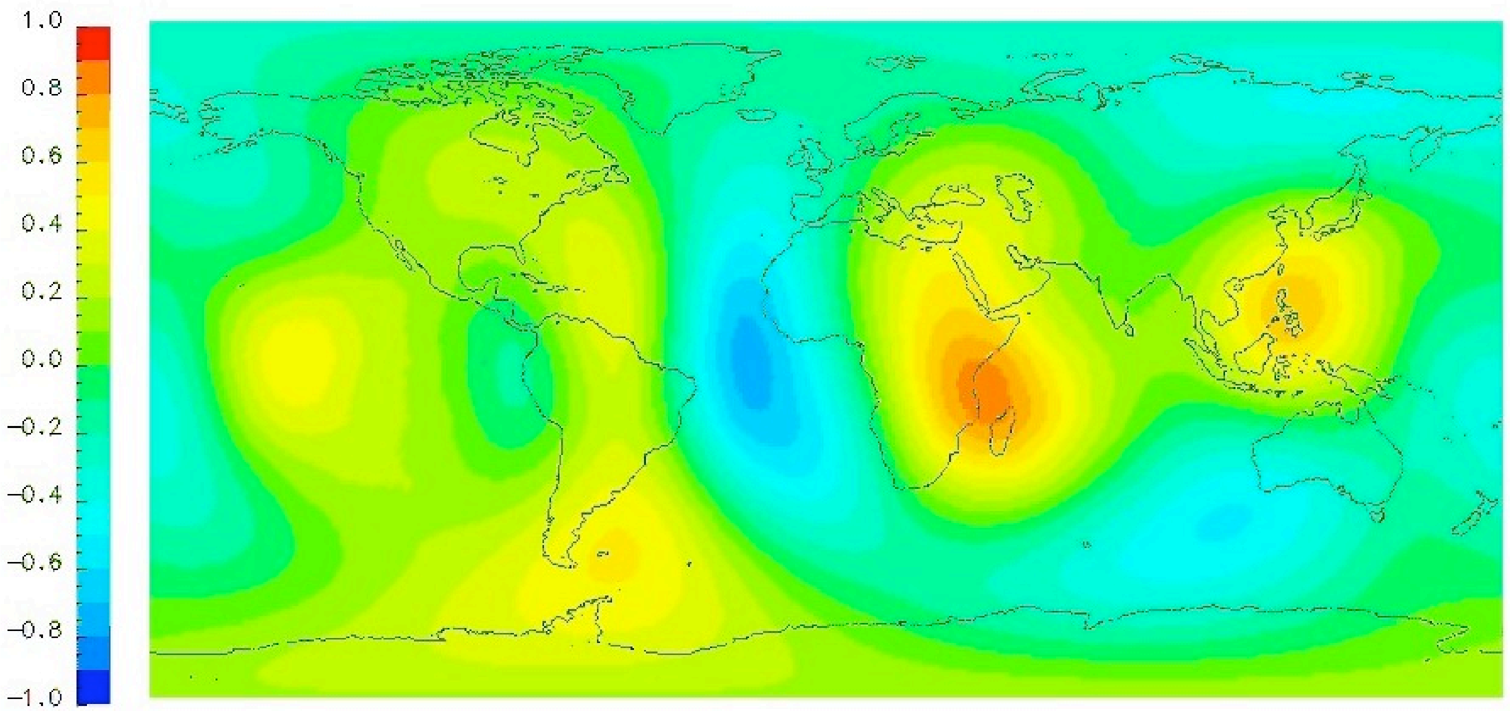


Radial Displacement

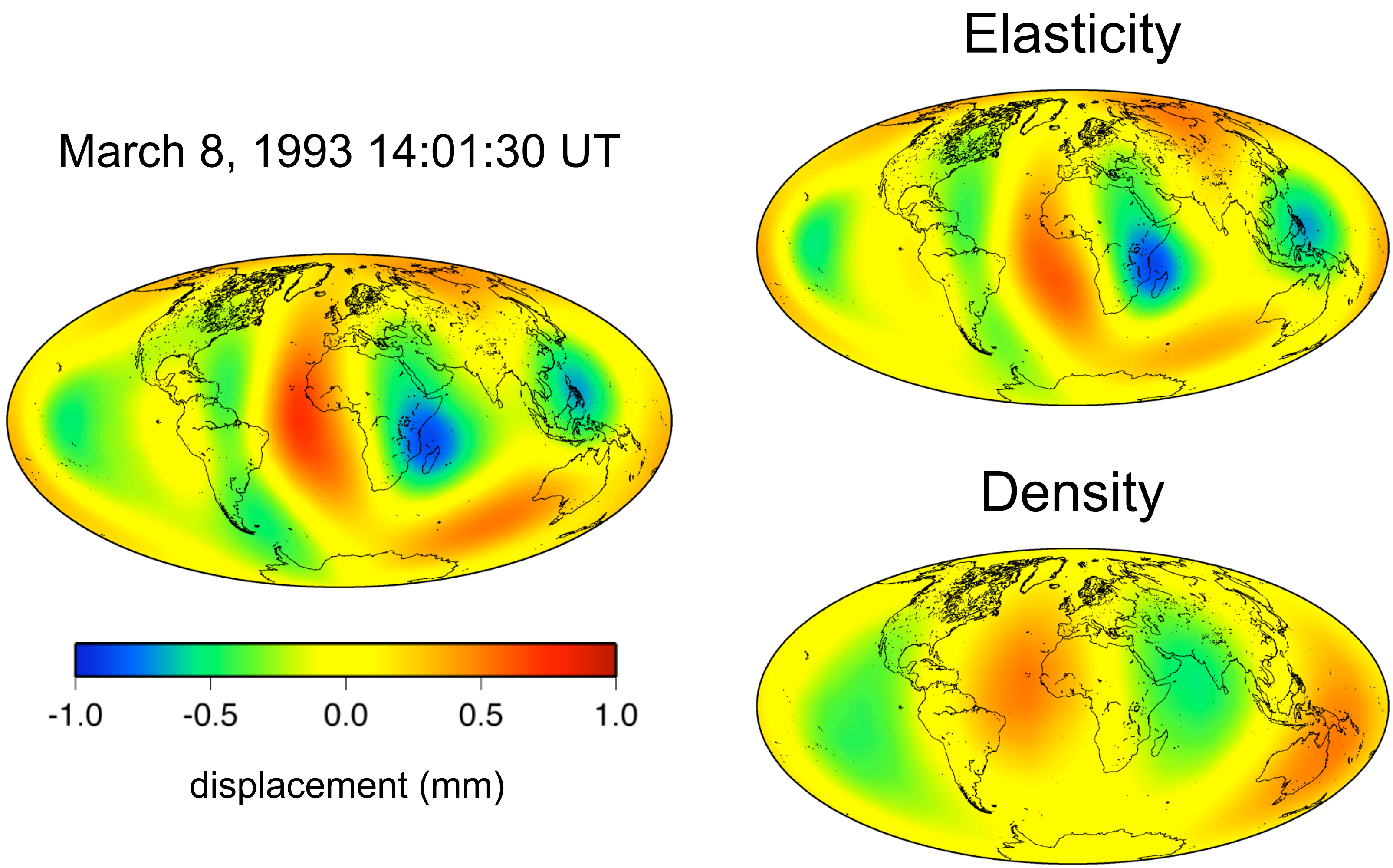


Body Tide Perturbation from 3-D Earth Model

Residual Radial Displacement



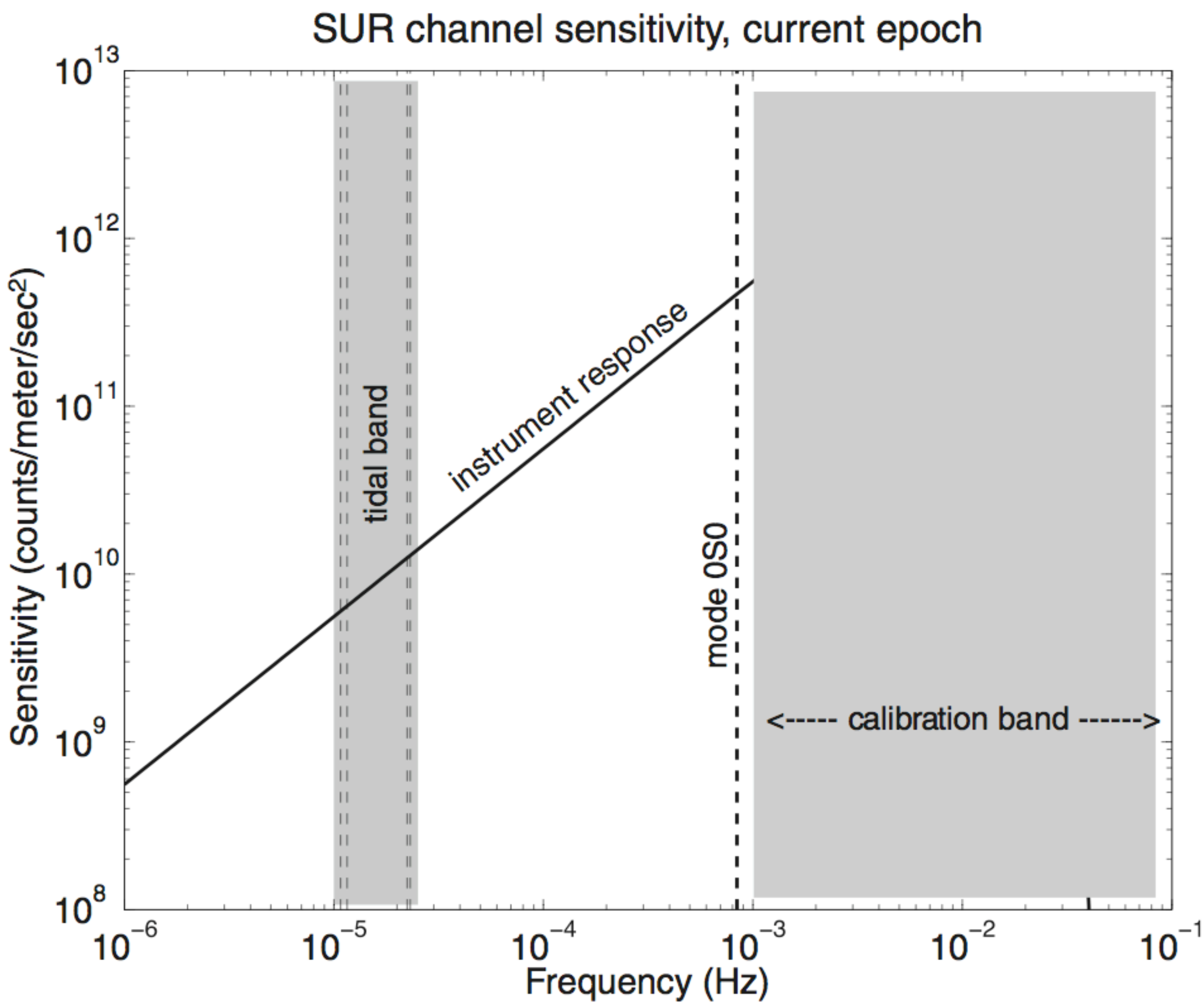
Residual Radial Displacement



Effects due to Three-Dimensional Structure

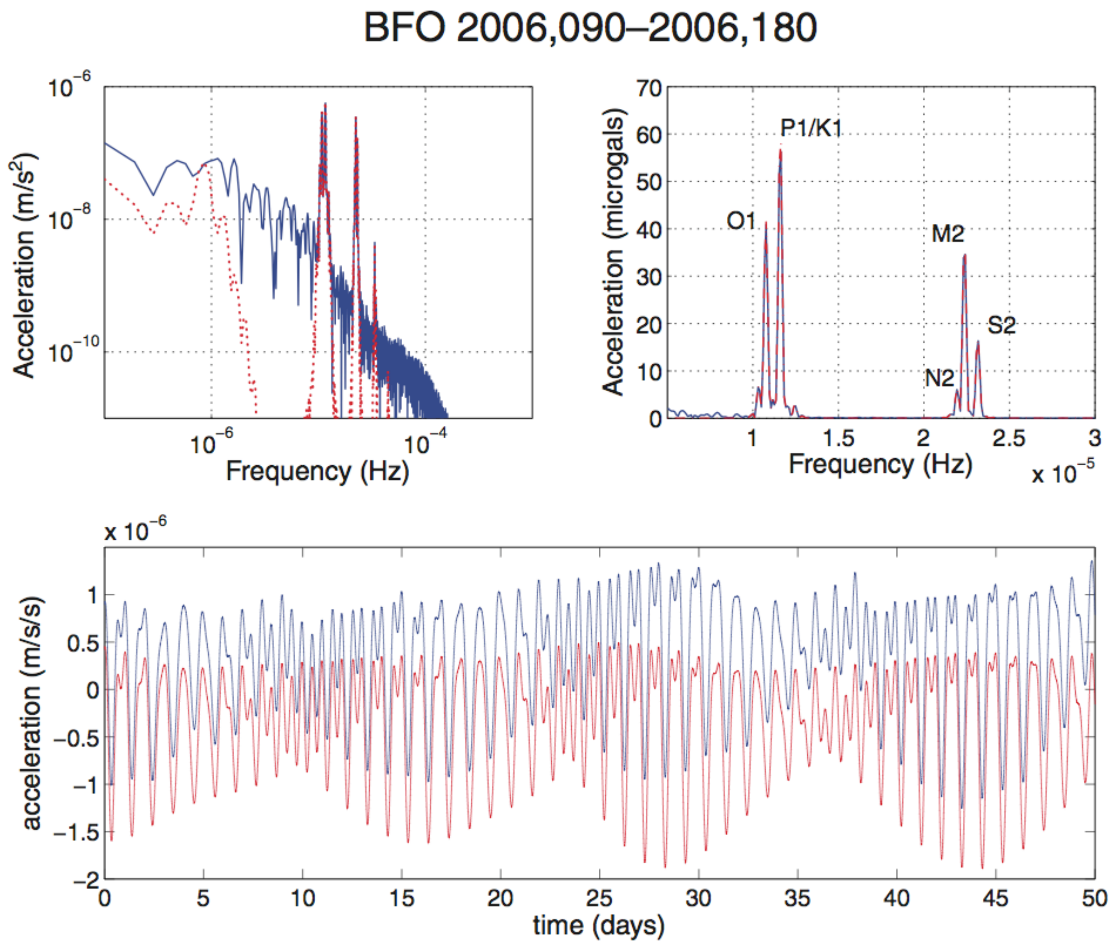
Tide		Scripps	SPRD6
Semi-Diurnal 03/08/1993 14:01:30 UT	gravity (μgal)	±0.16	±0.19
	radial disp.(mm)	±0.88	±0.91
Diurnal 12/12/2004 14:15:00 UT	gravity (μgal)	±0.14	±0.16
	radial disp.(mm)	-0.96/+0.95	-1.04/+1.05
Long-Period 03/08/1993 06:00:00 UT	gravity (μgal)	-0.02/+0.04	-0.03/+0.05
	radial disp.(mm)	-0.25/+0.20	-0.28/+0.17

Instrument Calibration at Lowest Frequencies



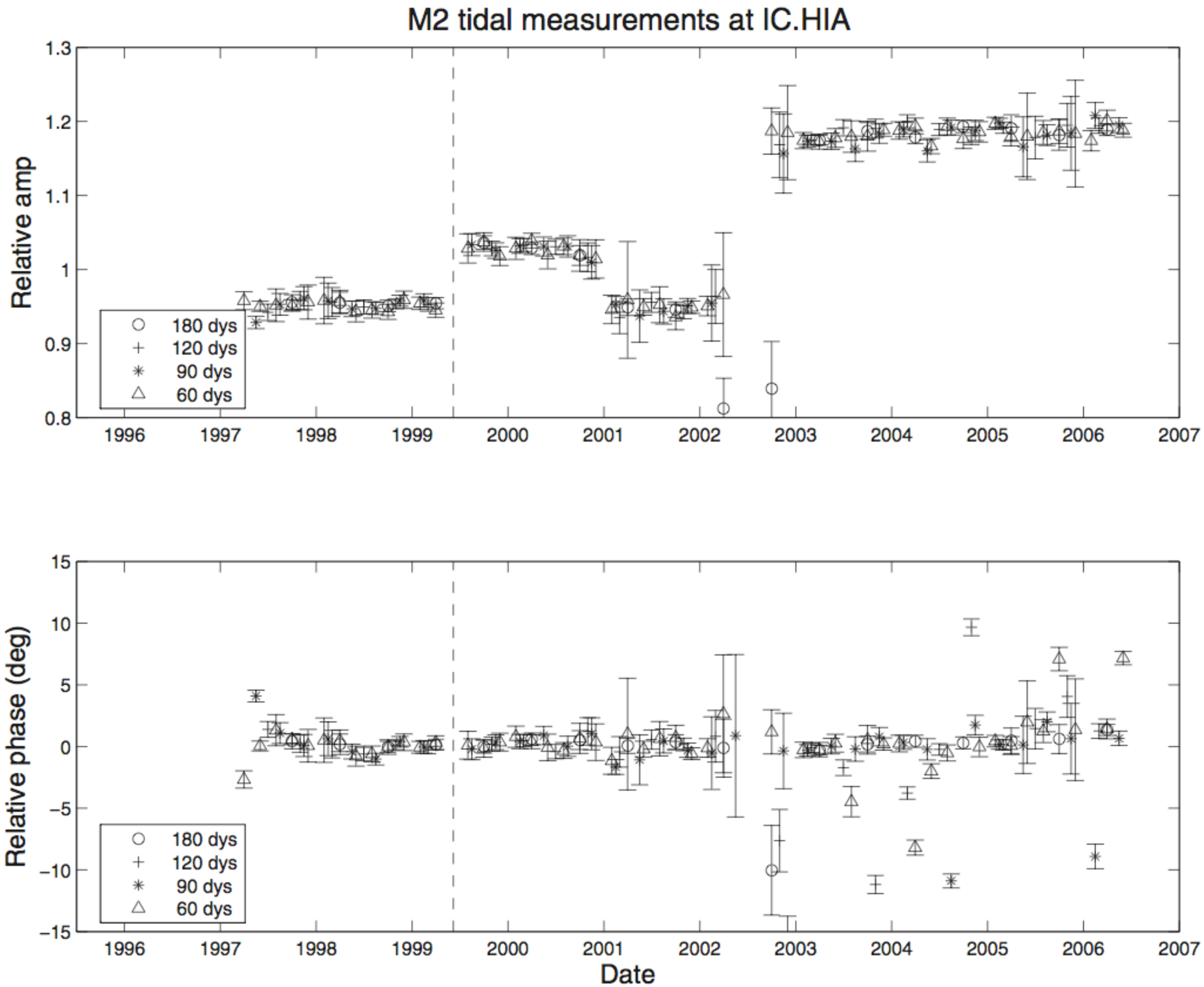
Davis & Berger (2007)

Comparison with Tide



Davis & Berger (2007)

Comparison with Tide



Davis & Berger (2007)

Comparison with Mode

$_0S_0$

predicted spectra using receiver function

observed spectra

➔ difference most likely from instrument response

Davis et al. (2005)

Summary

• normal-mode data are sensitive to processes of the Earth from earthquakes to surface processes and to internal structure

• normal-mode data are complementary to body wave data

• constraints on intriguing parameters from observation/analysis of lower frequency features