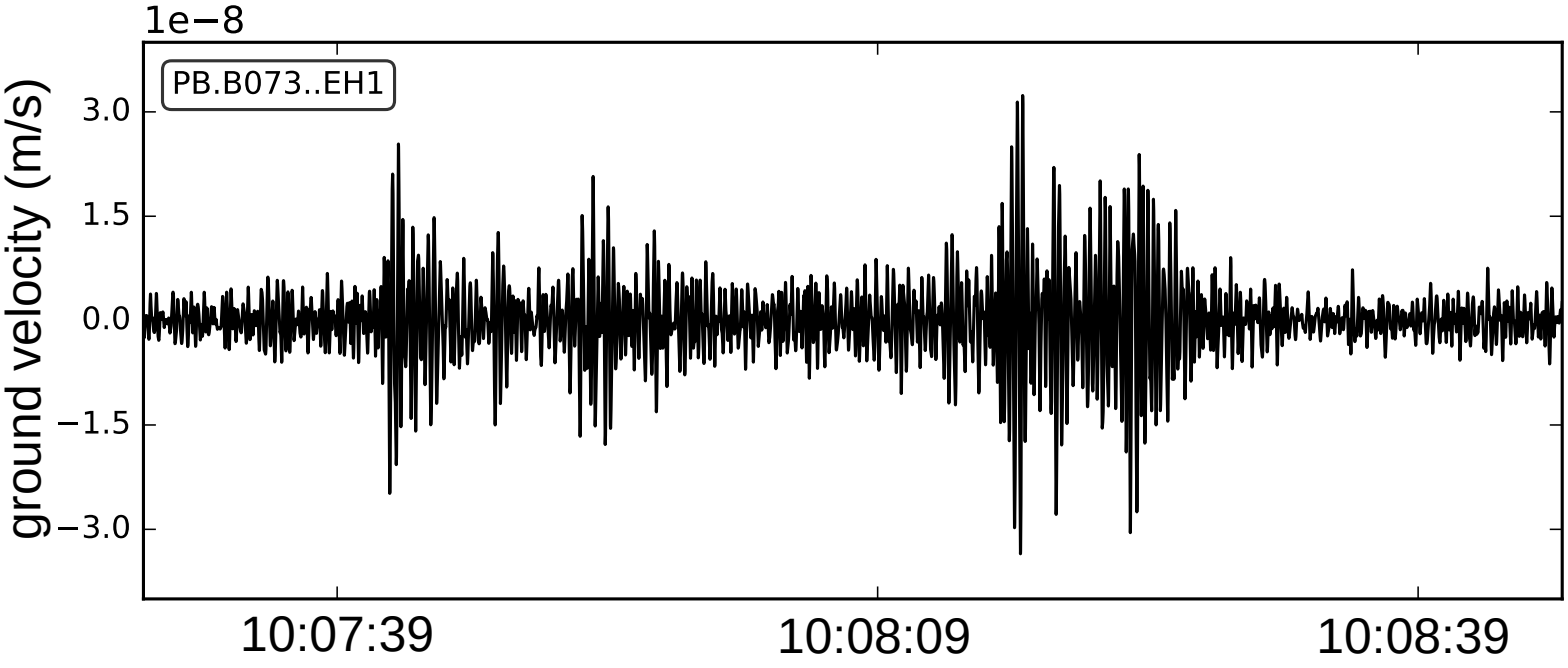
# Estimating the rupture extent of low frequency earthquakes near Parkfield, CA

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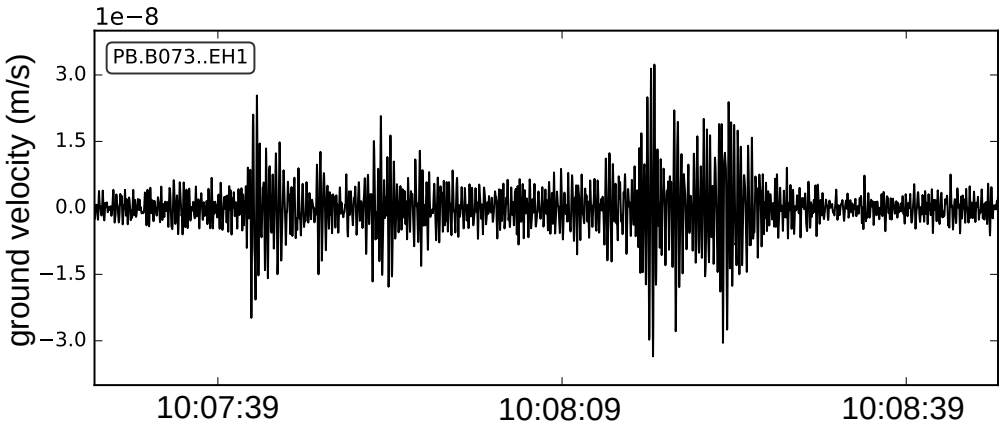
Amanda Thomas (Oregon), Pablo Ampuero (Caltech)

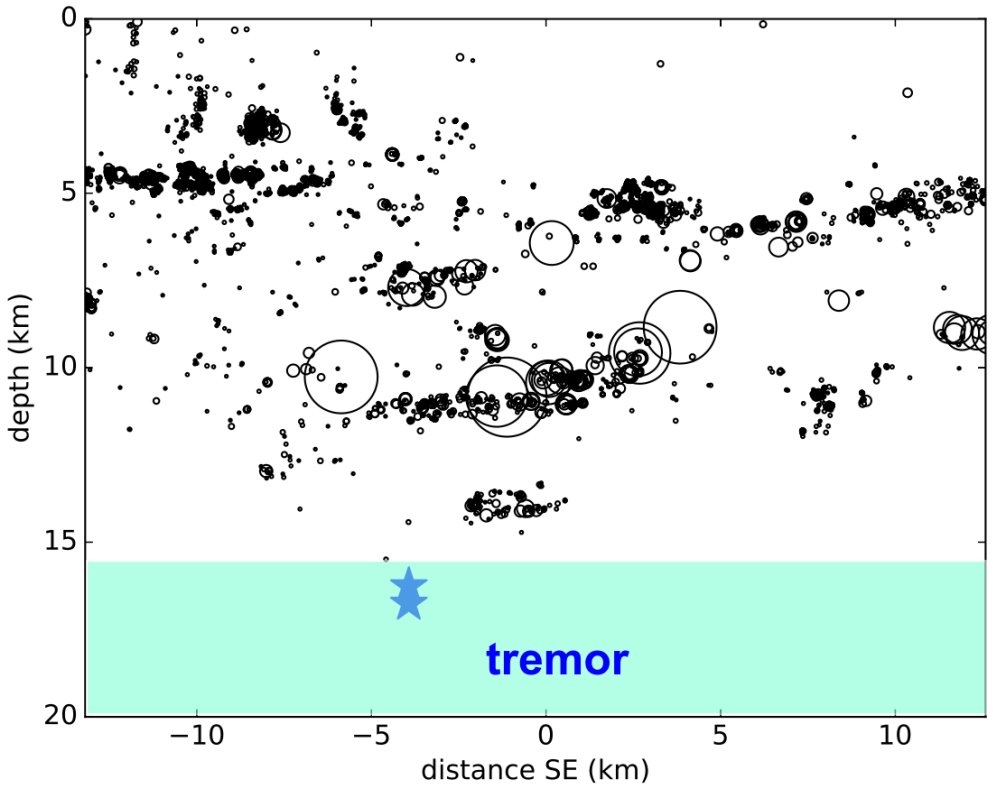
6 April 2017

# Tremor

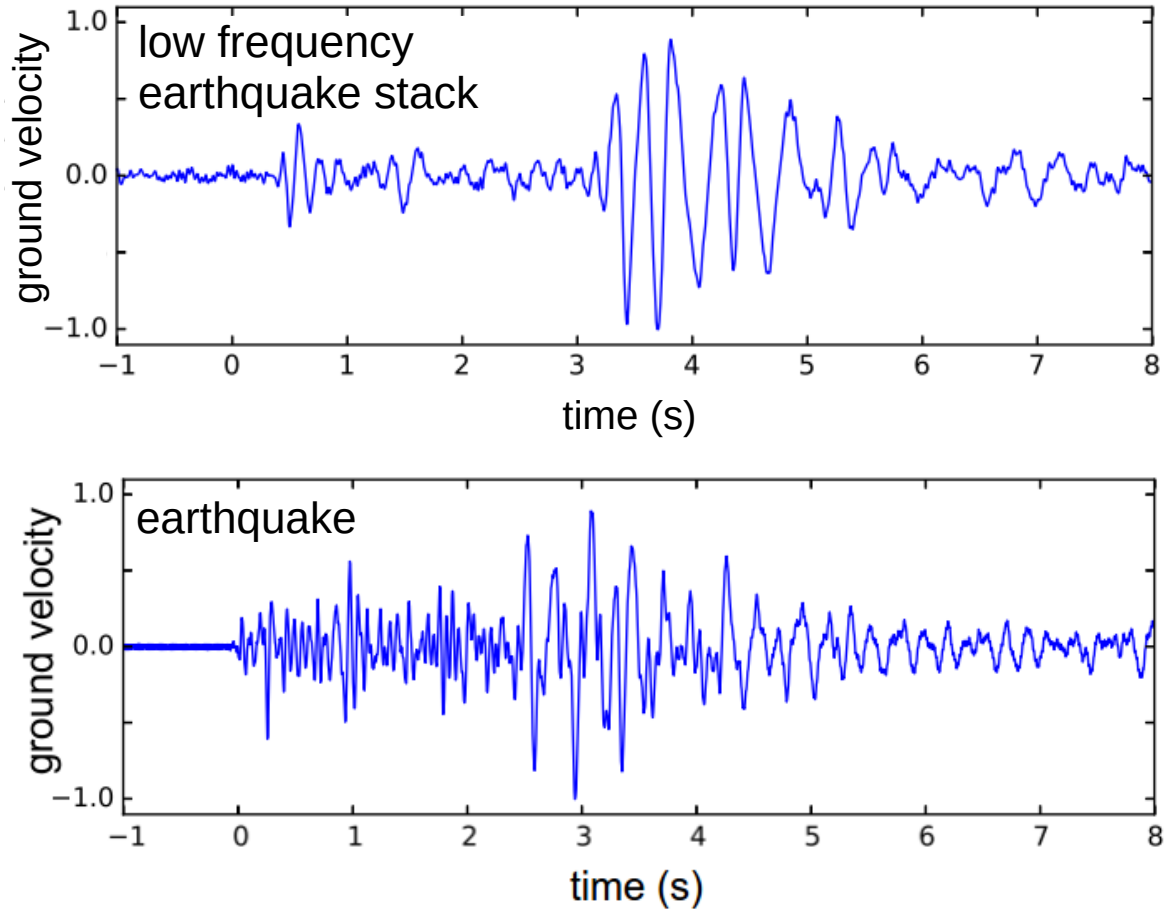



- Many small earthquakes
- On the plate interface below the seismogenic zone
- **Low-frequency: most energy in 1-10 Hz band**

⇒ Constituent earthquakes have long durations?



# Low frequency earthquakes have long durations. Why?




0.5 seconds in Cascadia (Bostock et al., 2015)
0.2 seconds near Parkfield (Thomas et. al., 2016)

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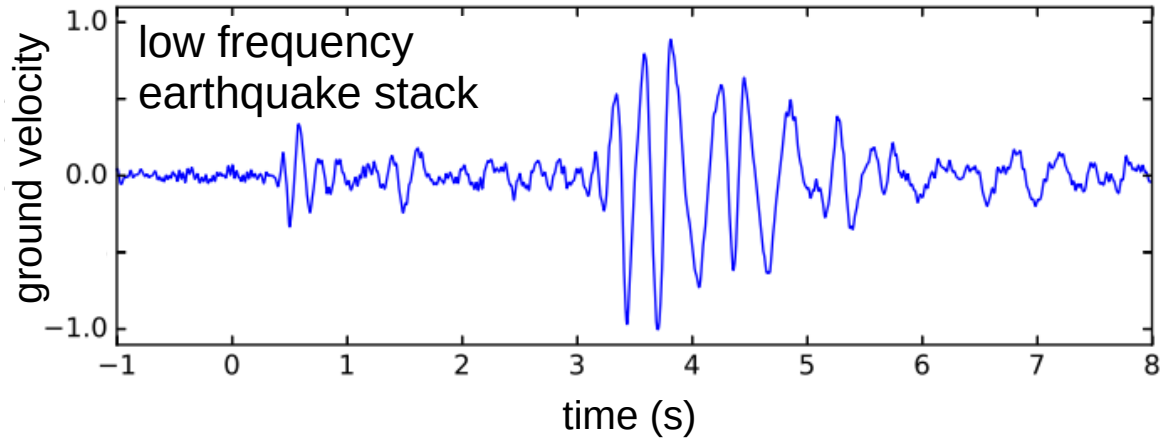


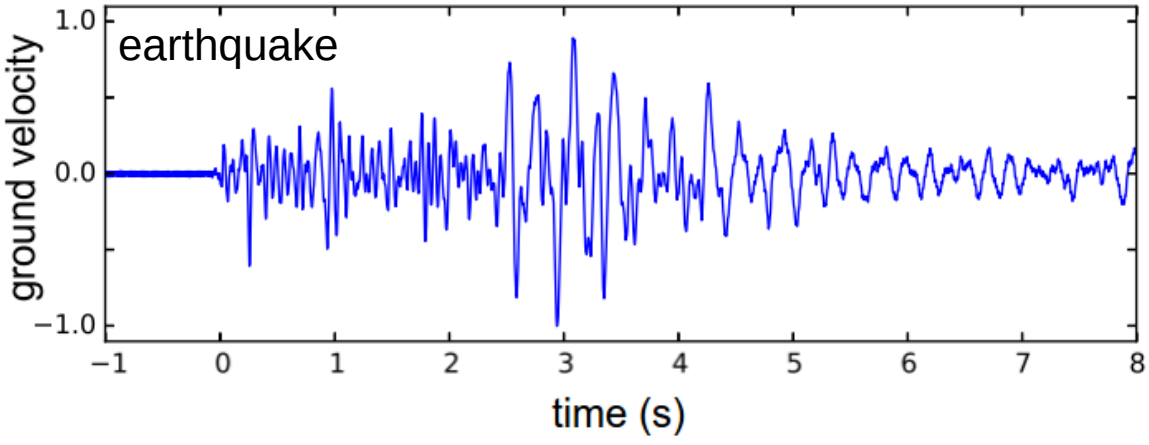


They're spatially big, with durations

$$\approx \frac{\text{earthquake radius}}{0.8 \times \text{shear wave speed}}$$

$\rightarrow$ 1200 m diameters

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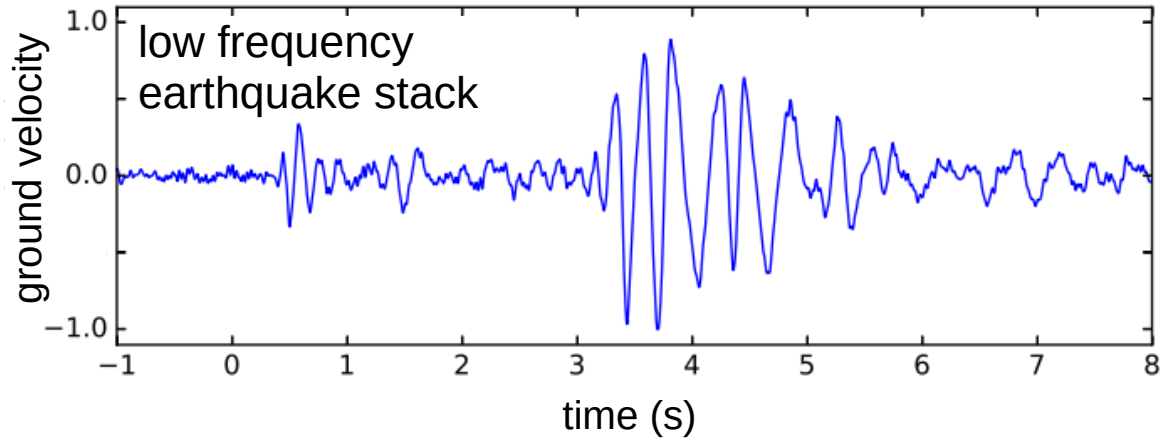


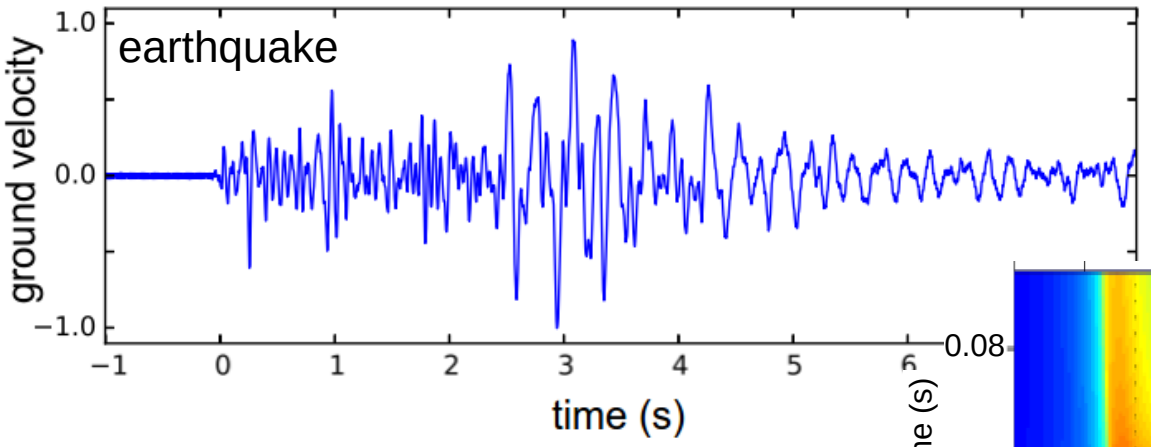


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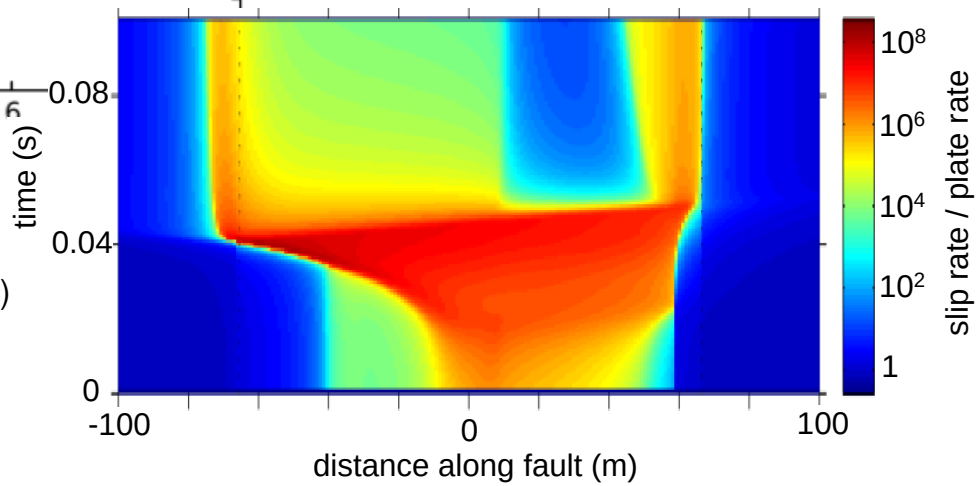
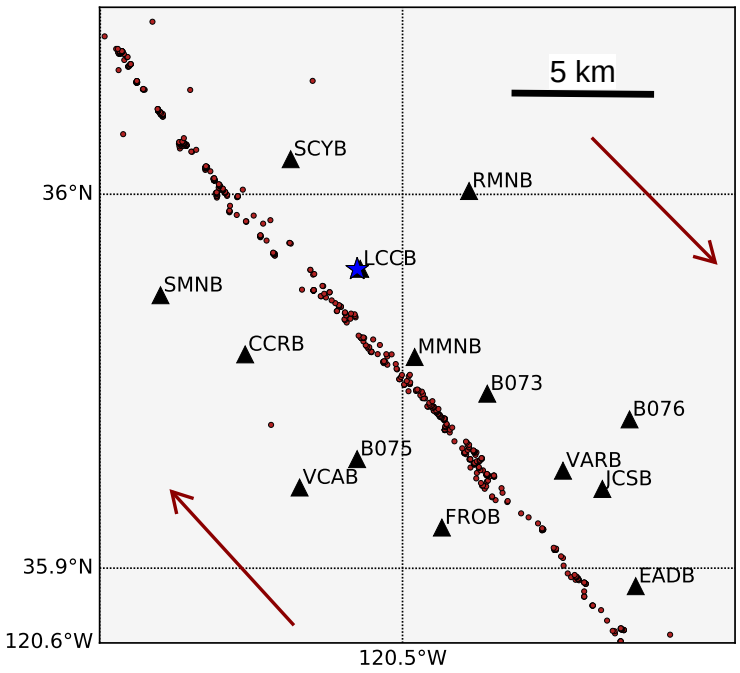
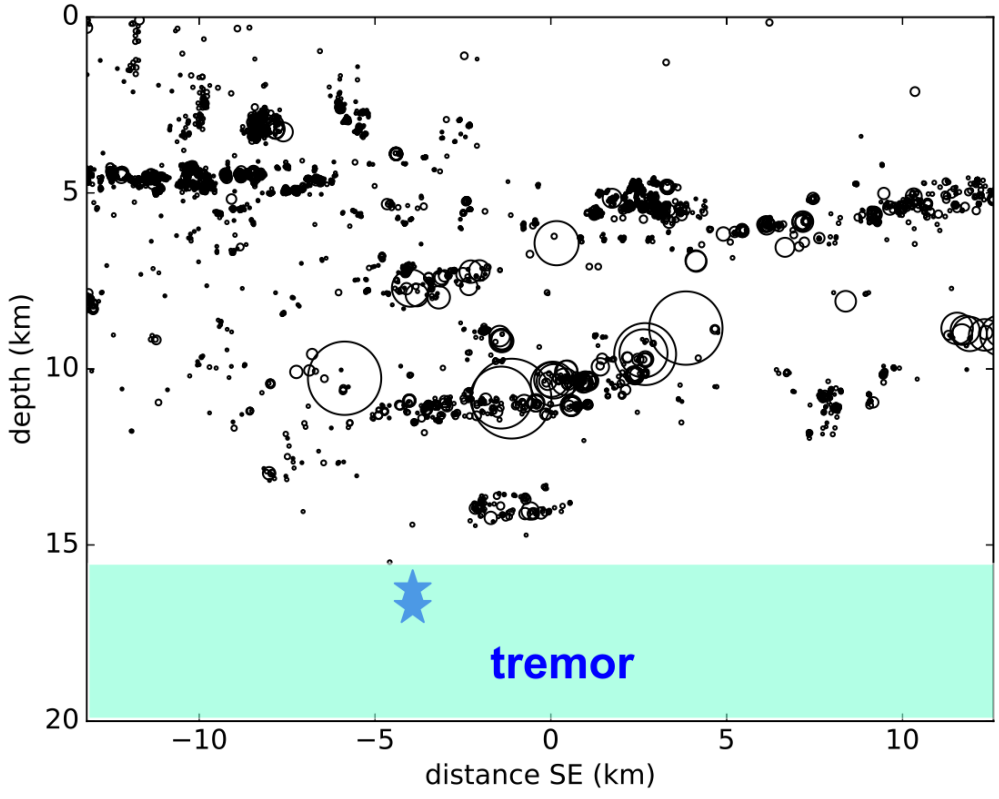
Or LFEs have different rupture dynamics?



# LFE families near Parkfield, CA

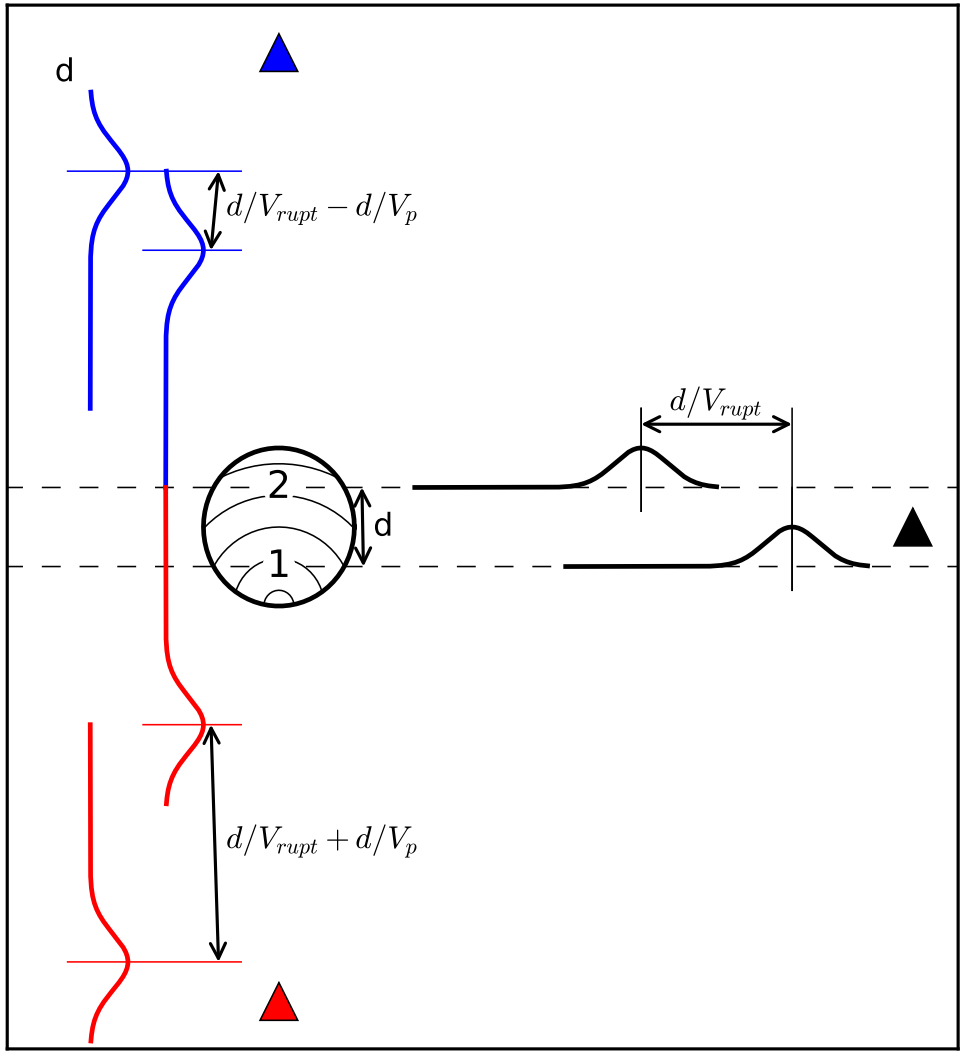



- 4000 and 8000 detections in the catalog of Shelly et al, 2009
- HRSN and PBO borehole data, 2006-2016

Do these LFEs have diameters $>$ 1 km, as suggested by 0.2-s durations?

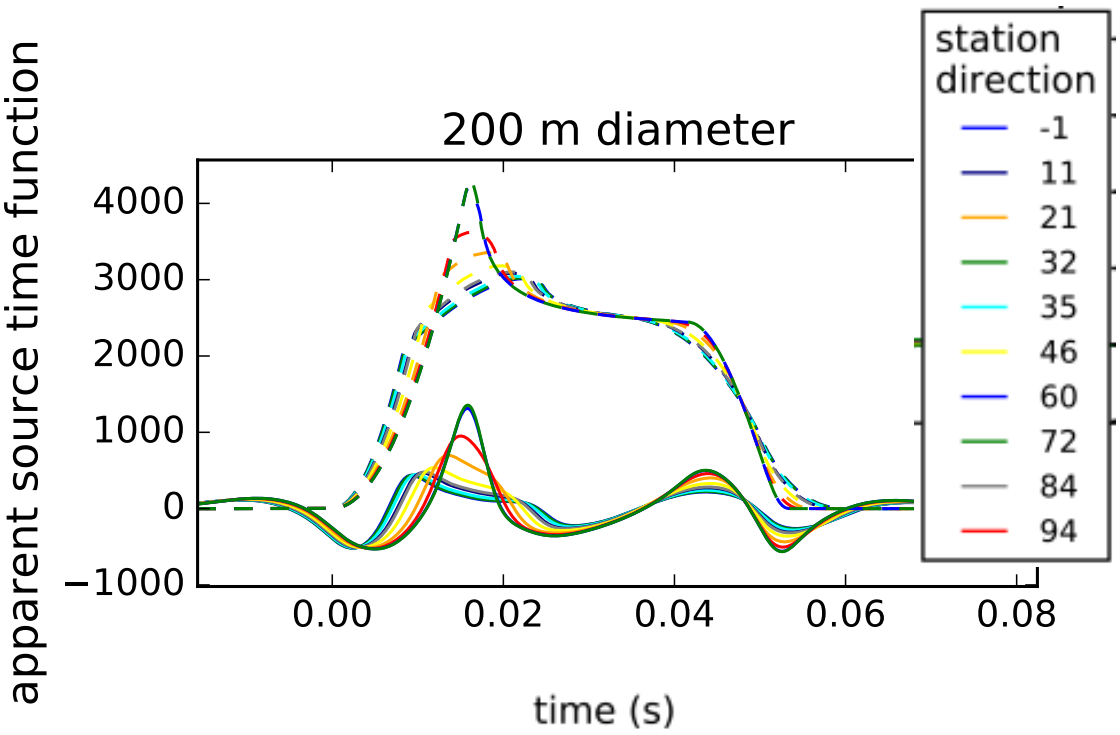
- Want to use variation in travel time within the source region to estimate the LFEs' spatial extents




Apparent stfs are

- Similar at periods longer than the travel time across the earthquake
- Different at shorter periods

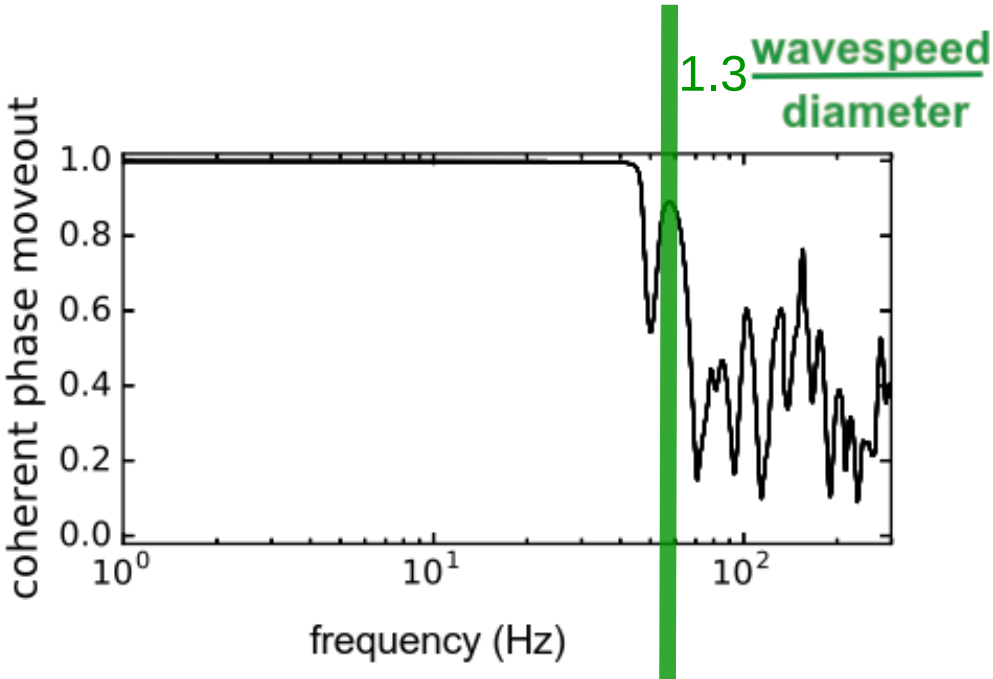
# Synthetic apparent source time functions




- Similar at periods longer than the travel time across the earthquake
- Different at shorter periods

Measure phase similarity:

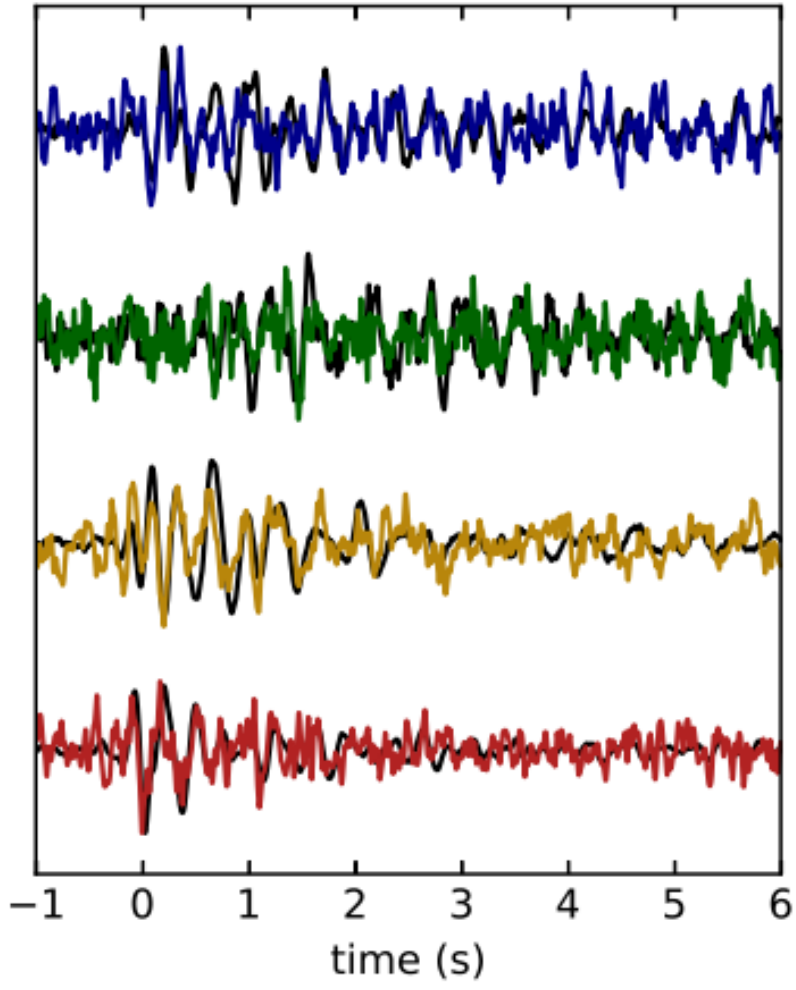
$$R = \frac{1}{N} \sum_{\text{stations}} \frac{\hat{s}_a}{|\hat{s}_a|}$$



# Empirical Green's function phase removal

Expect apparent stfs ($s_{tk}$ and $s_{ik}$) to vary among stations
when wavelength $<$ rupture diameter.

But we only have the observations: $d_{tk} = s_{tk} * g_k$ and $d_{ik} = s_{ik} * g_k$



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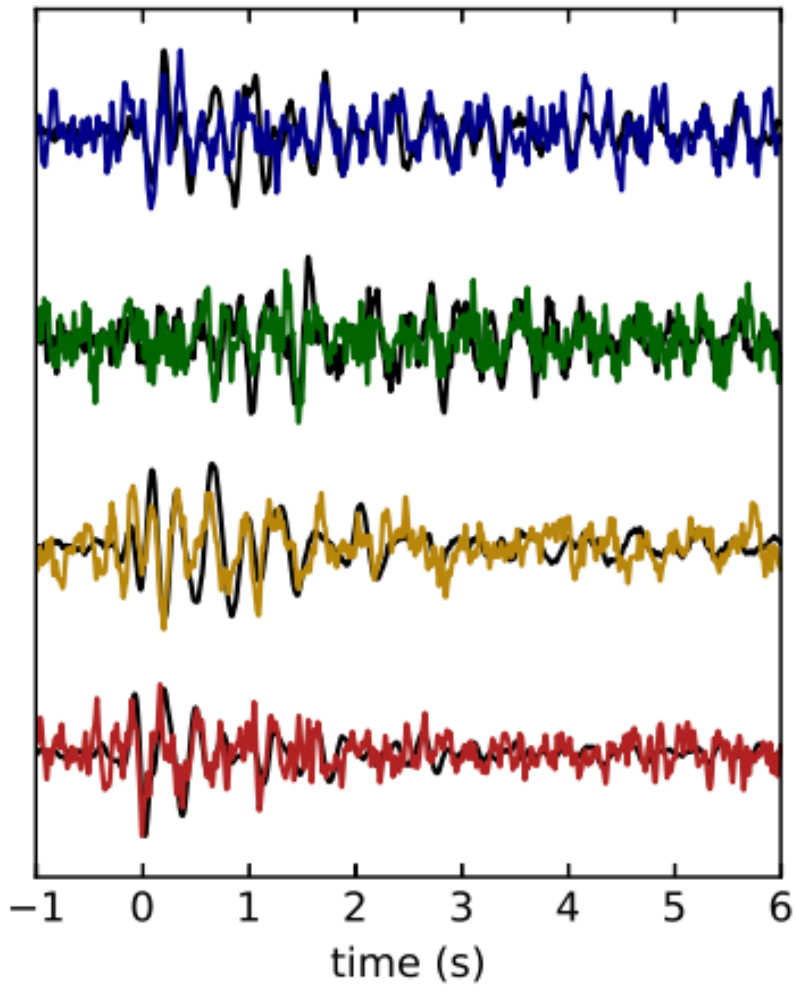

# Removing the Green's functions' phases

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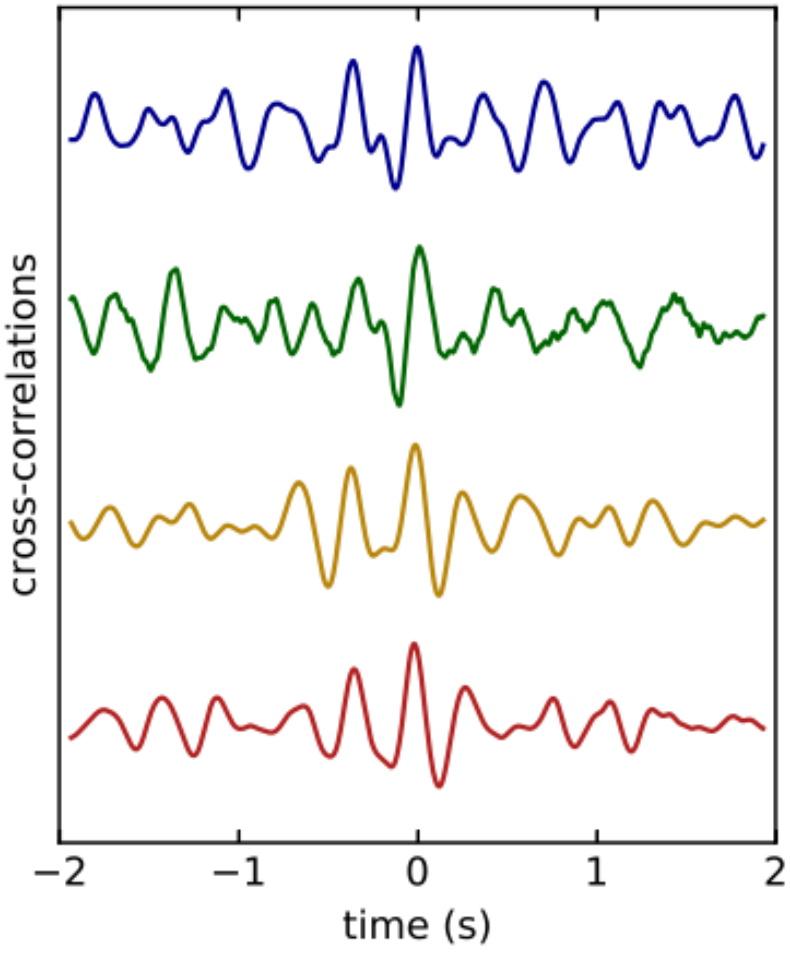
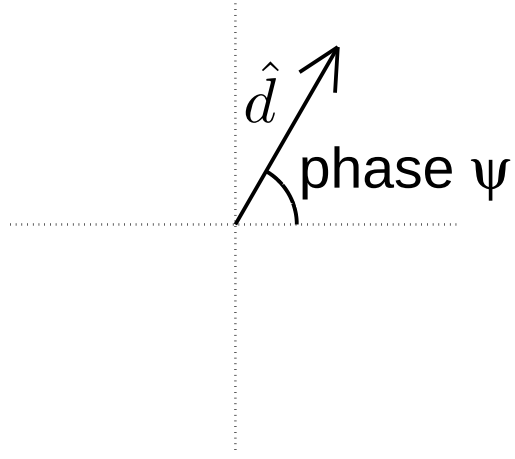



Cross-correlate at each station

$$\hat{x}_k = \hat{d}_{ik}\hat{d}^*_{tk}$$

$$= \underbrace{\hat{s}_{ik}\hat{s}^*_{tk}}_{\text{same across stations?}} \quad \overbrace{\hat{g}_k\hat{g}^*_k}^{\text{zero phase}}$$



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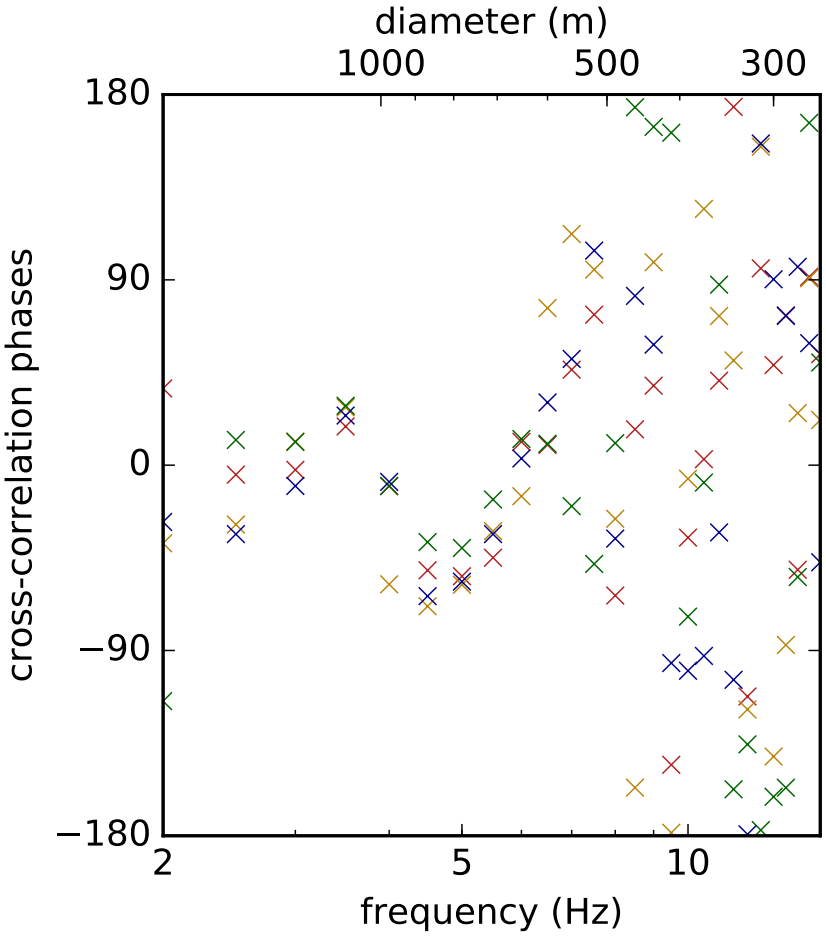


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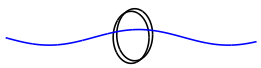
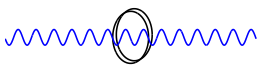
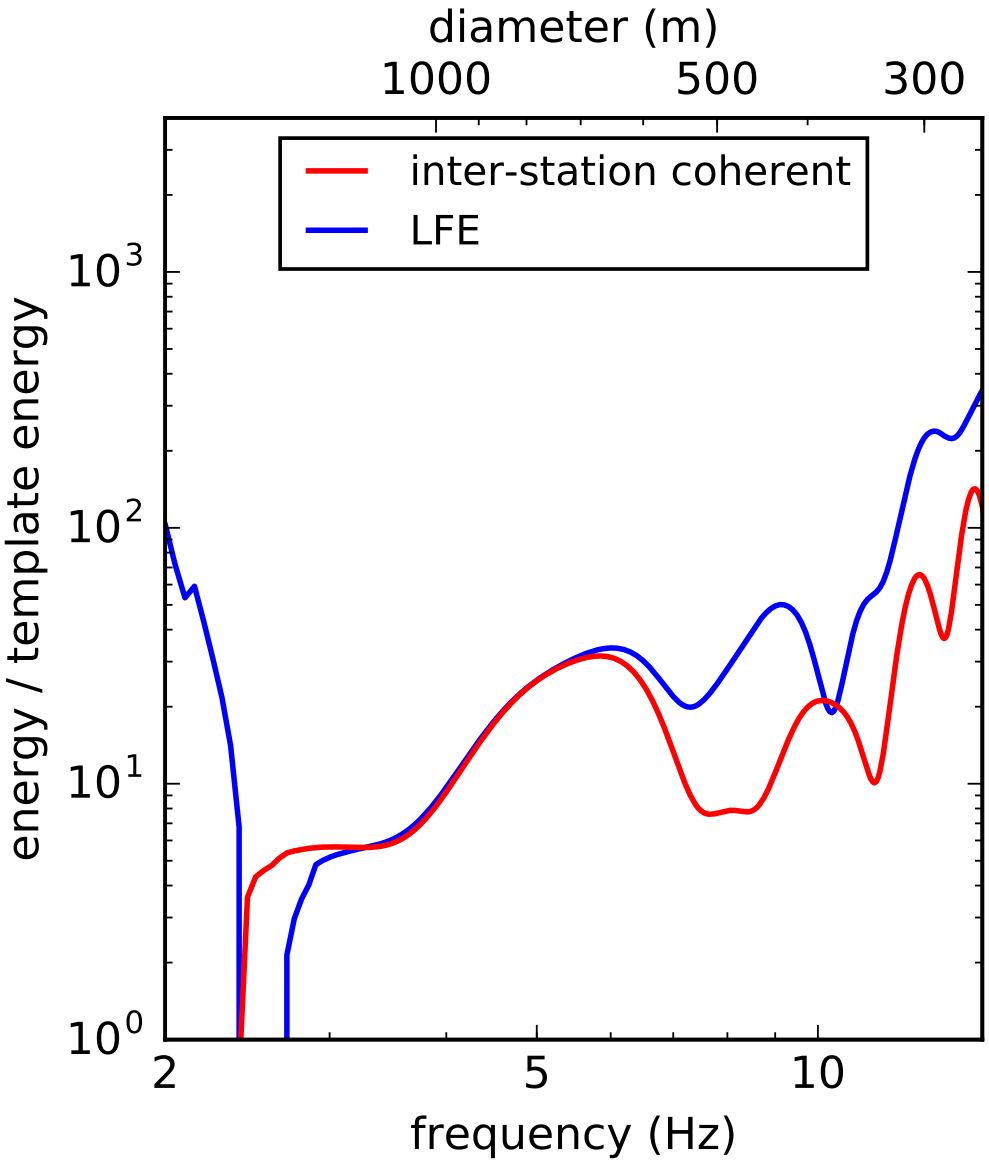
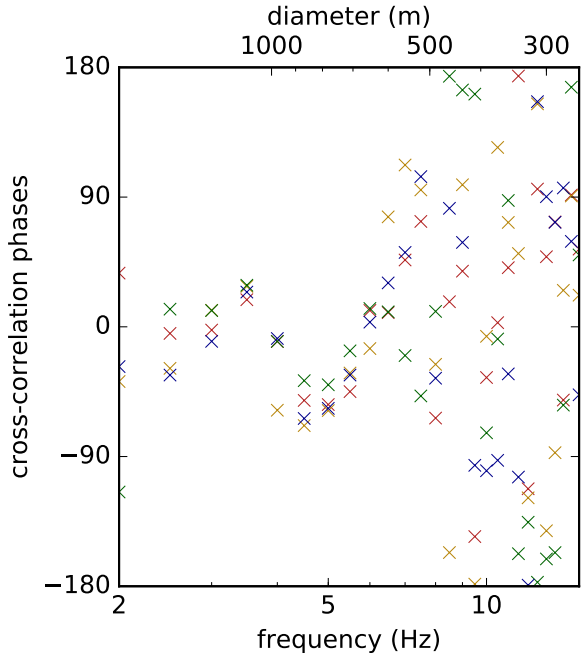
- when $x_k$ phases are the same, wavelength is larger than LFE





# Template-normalized LFE energies




- total LFE energy: observed minus noise
- LFE energy coherent across stations:

$$E_c = \frac{\hat{x}_k \hat{x}_l^*}{|\hat{d}_{tk} \hat{d}_{tl}|^2}$$

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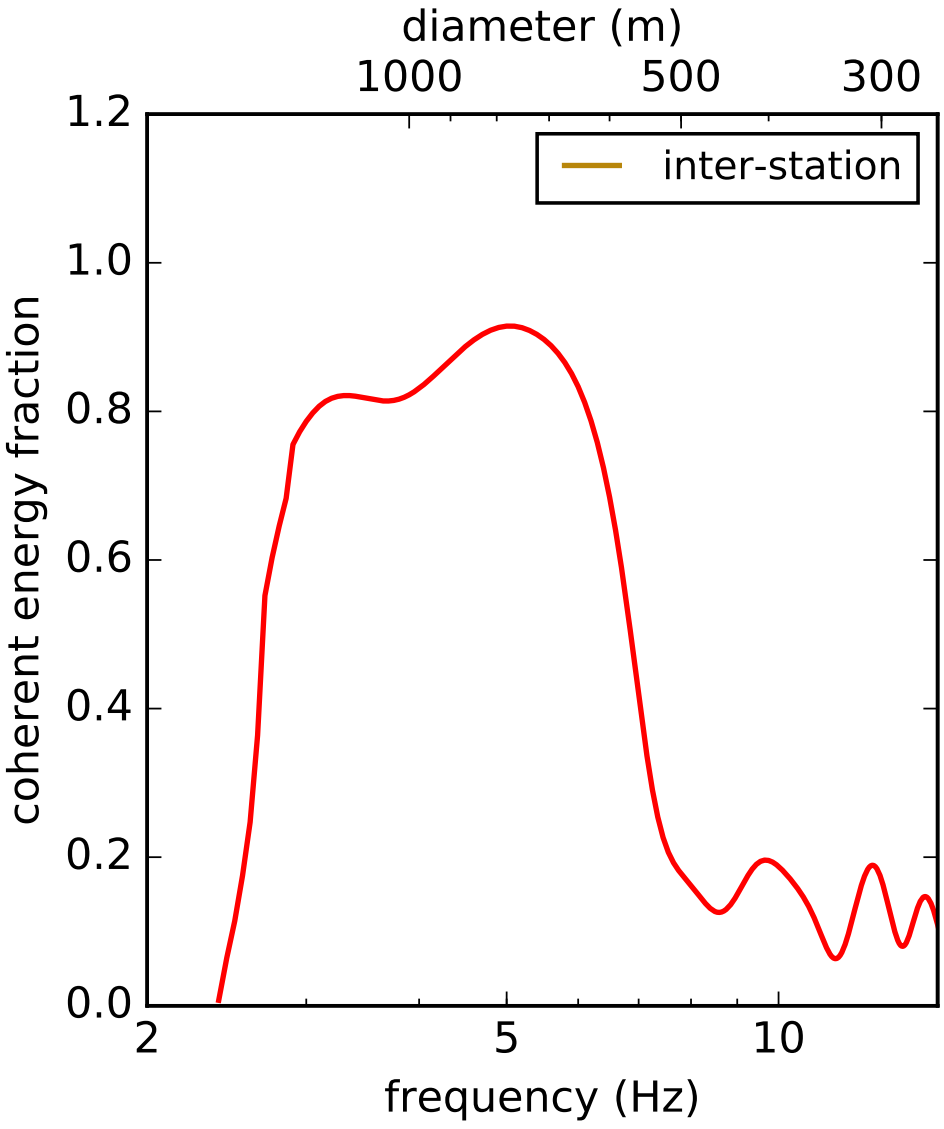


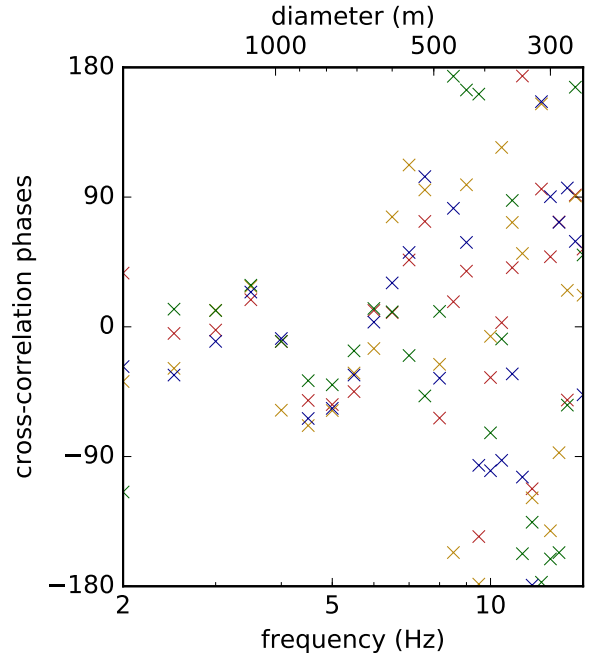


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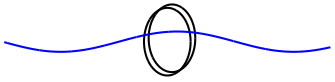
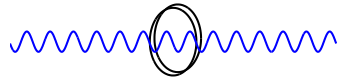
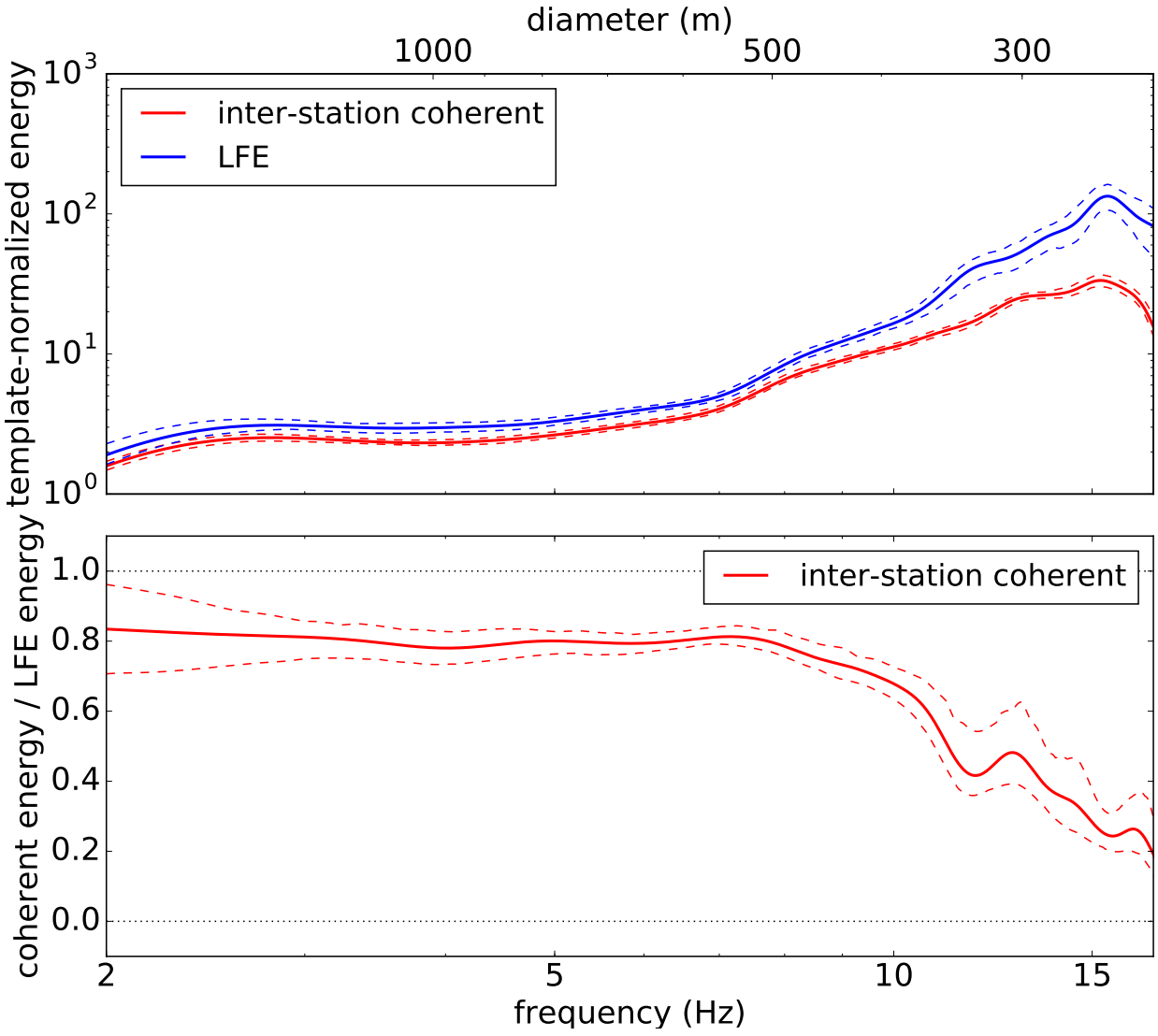


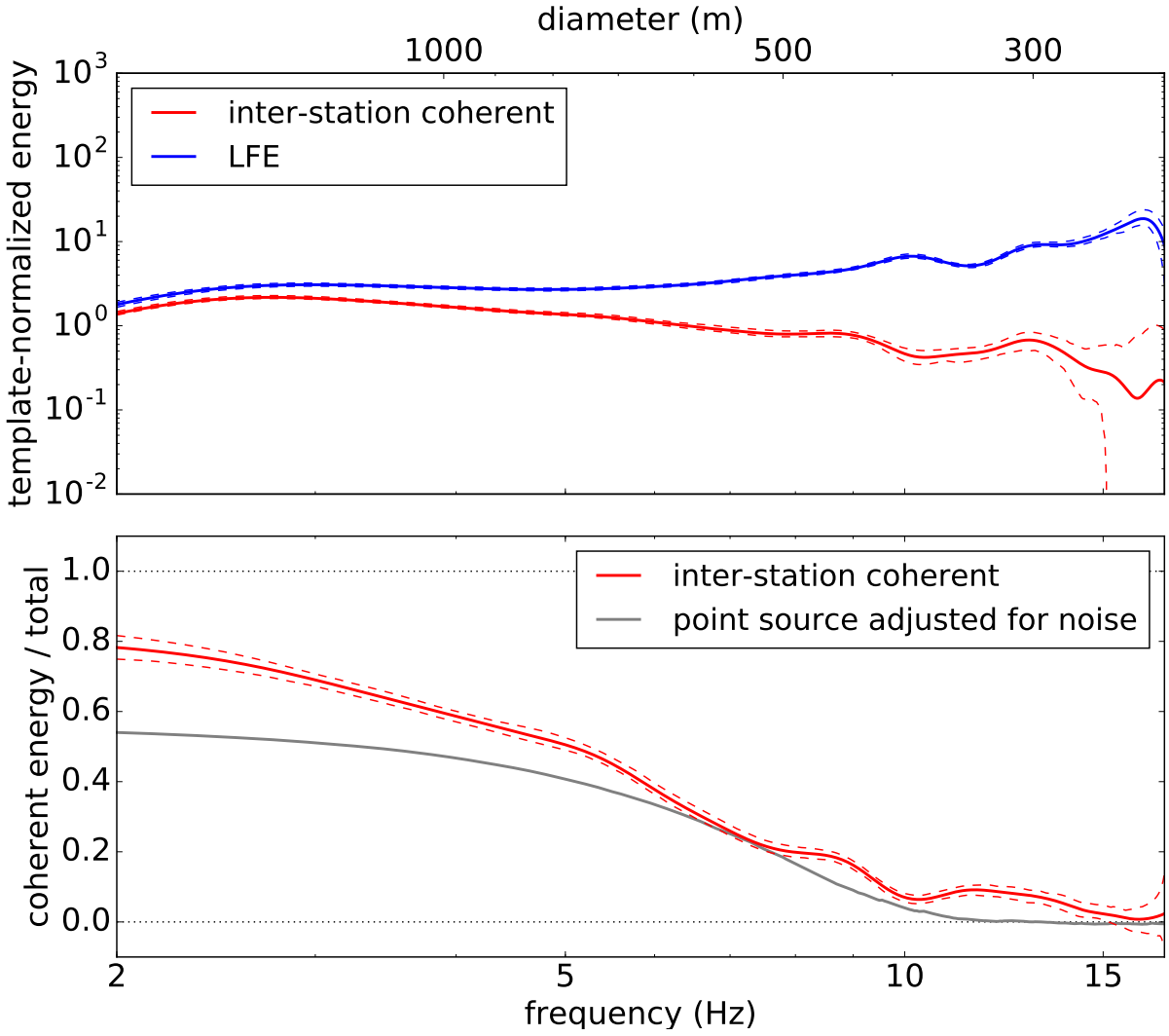


# Averaging over 2600 LFEs: Family 37140



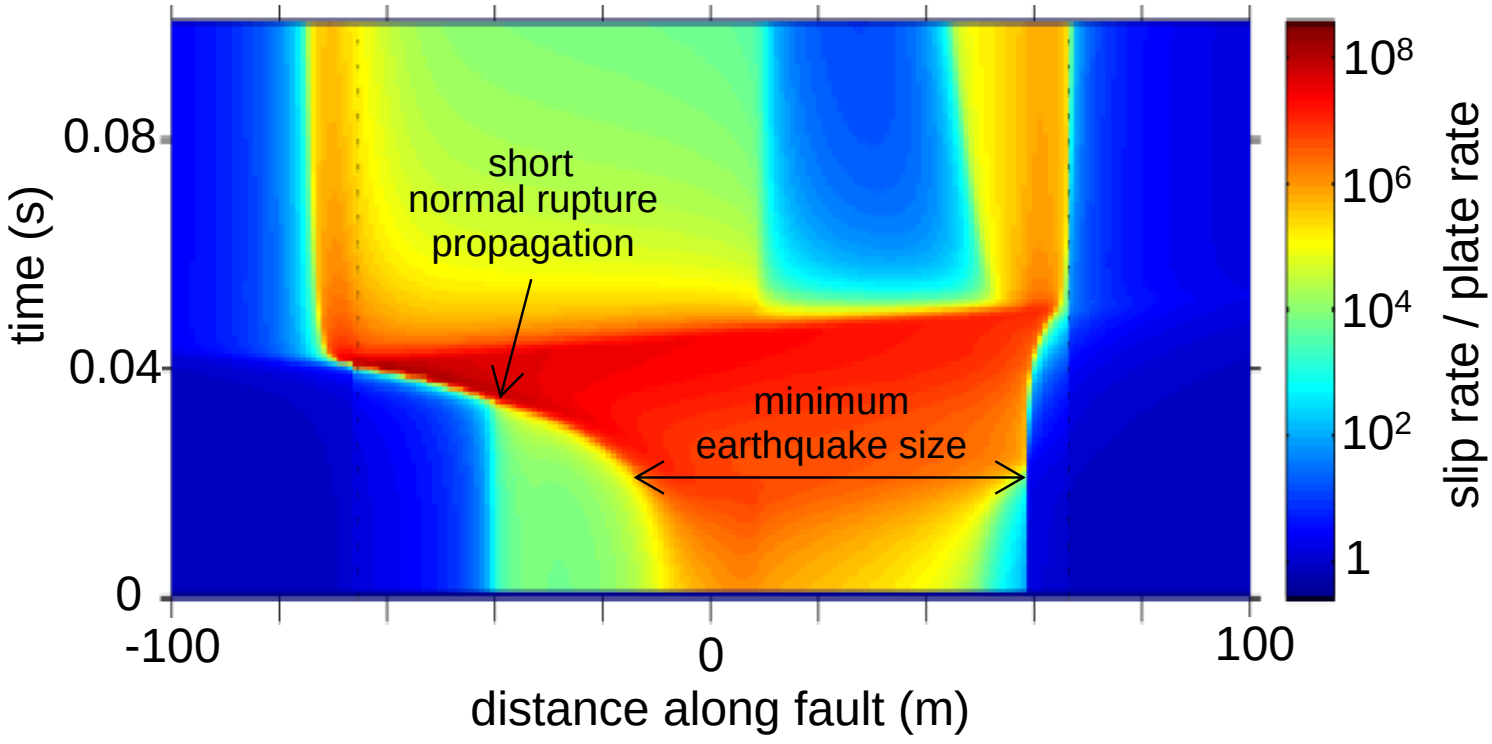

- Coherent fraction high out to 10 Hz ⇒ Diameter around **300 - 400 m**
- Factor 3-4 smaller than 1.2 km expected for 3 km/s rupture velocity

# Averaging over 3800 LFEs: Family 37102



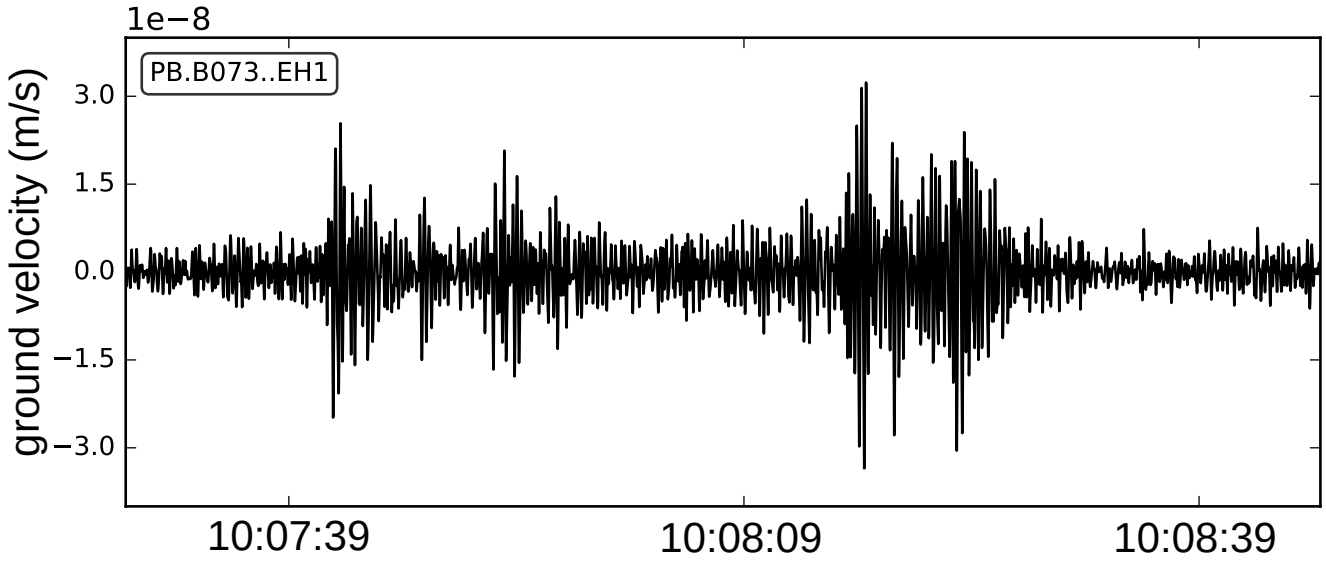

- Coherent fraction high out to $>$ 5 Hz $\Rightarrow$ Diameter $<$ **700 m**
- Decoherence could be due to timing, tapering, nearby LFEs
- Factor $>$ 2 smaller than 1200 m expected for 3 km/s rupture velocity

# So why are the rupture durations long?




- Long rise time from nucleation?
- Slow propagation?
- Complex rupture patterns?
- Attenuation?

# Conclusions




- Low-frequency nature of tremor does not arise because the asperities are big.
- High inter-station coherence out to $\approx$10 Hz implies average diameters $<$ 400 m and $<$ 700 m
- Rupture extents are a factor of $>$2-4 smaller than expected for 0.2-s durations and near-shear-wave rupture velocities
- Suggest different rupture dynamics or a role for attenuation