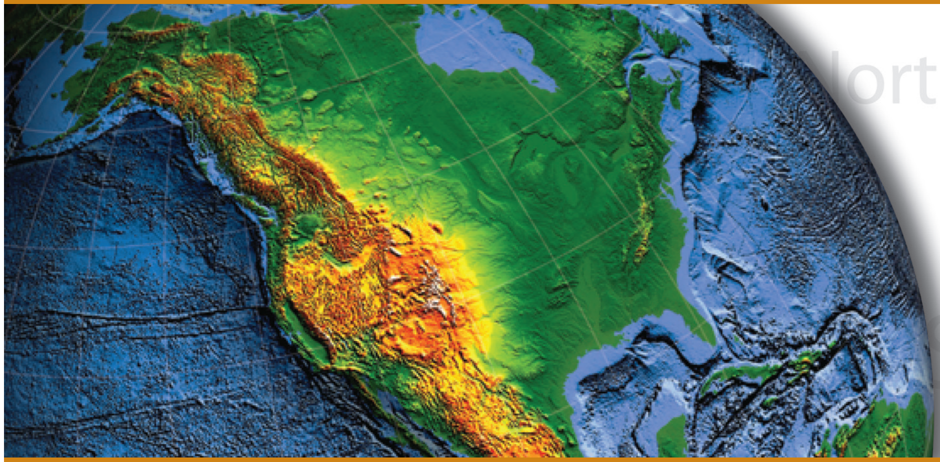
1. A few words about EarthScope and USArray
2. Surface-wave studies of the crust and mantle
3. Tomography using noise and Aki’s method
4. Remarkable images of US crust (and basins)!

earth
scope



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Unlocking the Secrets of the North America
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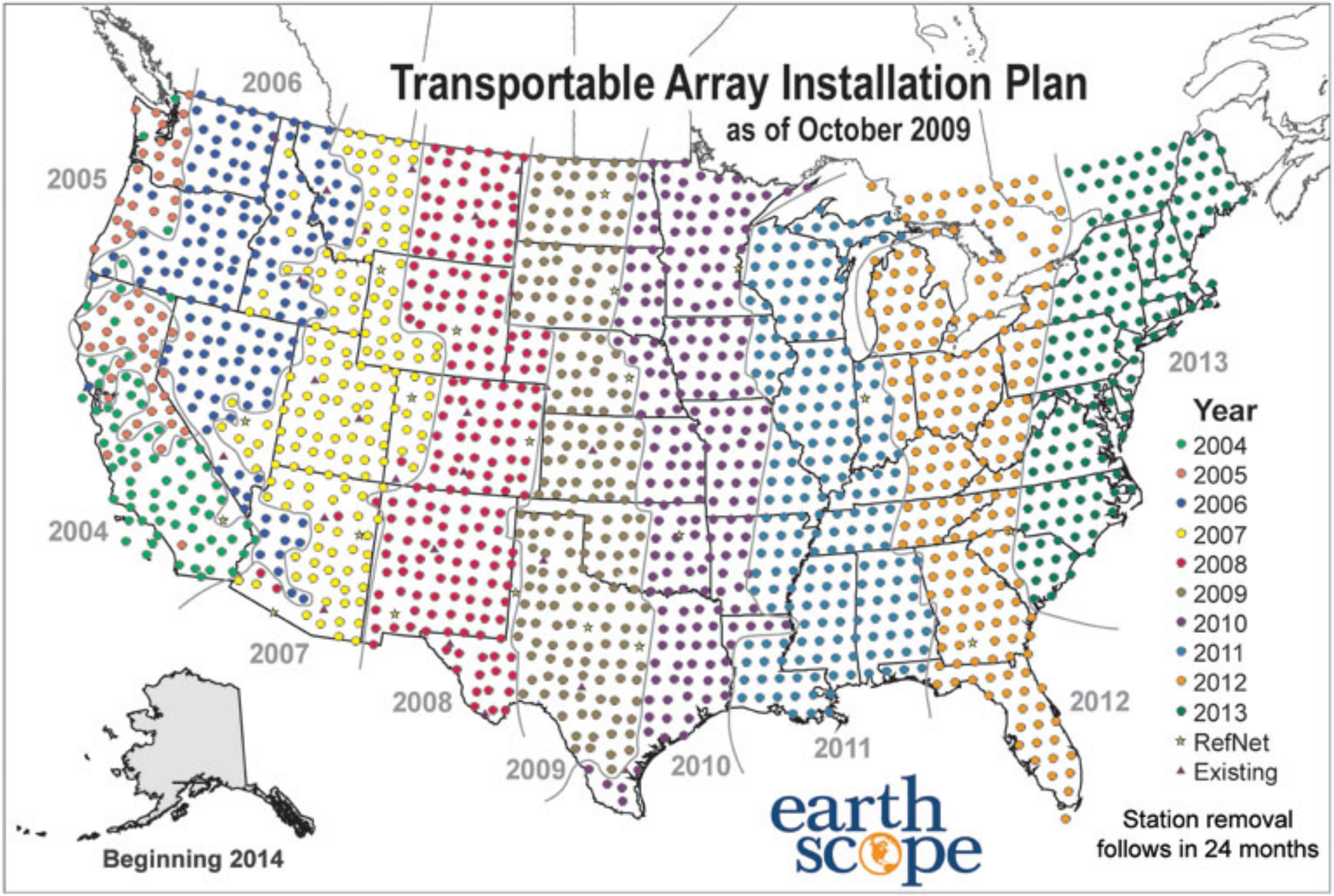
Unlocking the Secrets of the North American Continent

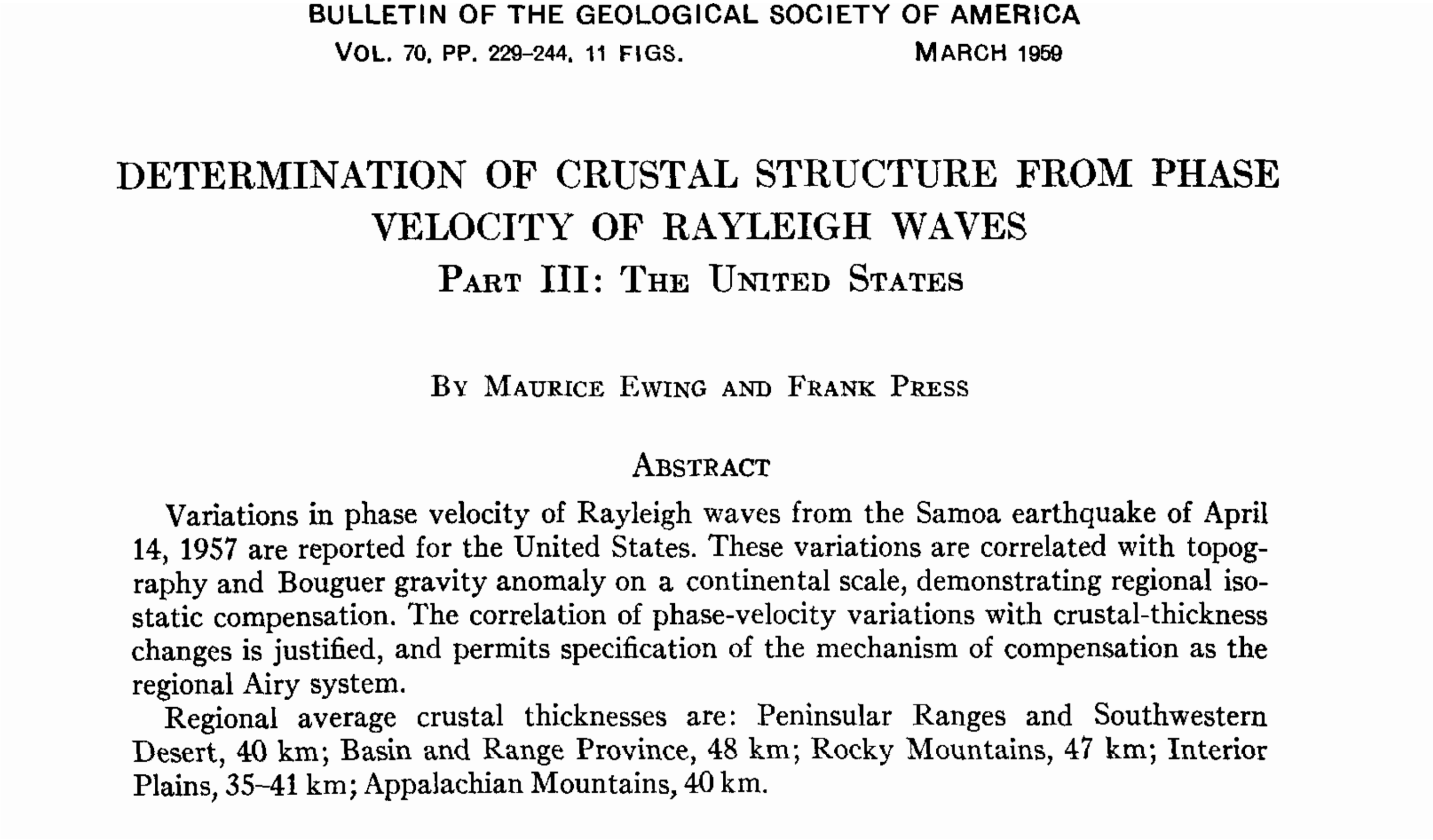
An EarthScope Science Plan for 2010–2020



Transportable Array Installation Plan

as of October 2009

The speed of surface waves (Love and Rayleigh) depend on the shallow structure of the Earth



BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 70, PP. 229–244, 11 FIGS. MARCH 1959

DETERMINATION OF CRUSTAL STRUCTURE FROM PHASE VELOCITY OF RAYLEIGH WAVES

PART III: THE UNITED STATES

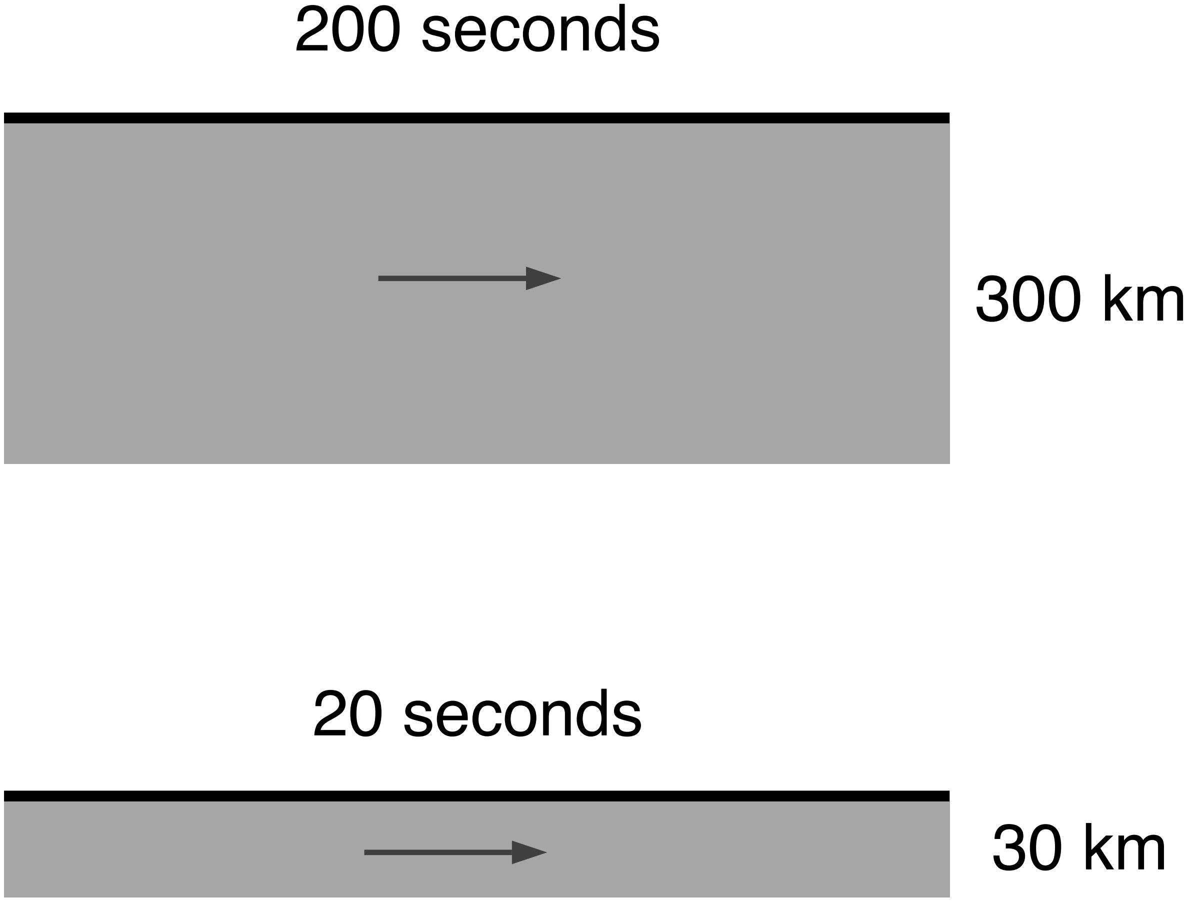
BY MAURICE EWING AND FRANK PRESS

ABSTRACT

Variations in phase velocity of Rayleigh waves from the Samoa earthquake of April 14, 1957 are reported for the United States. These variations are correlated with topography and Bouguer gravity anomaly on a continental scale, demonstrating regional isostatic compensation. The correlation of phase-velocity variations with crustal-thickness changes is justified, and permits specification of the mechanism of compensation as the regional Airy system.

Regional average crustal thicknesses are: Peninsular Ranges and Southwestern Desert, 40 km; Basin and Range Province, 48 km; Rocky Mountains, 47 km; Interior Plains, 35–41 km; Appalachian Mountains, 40 km.

Sensitivity of surface wave velocities to elastic stucture at depth



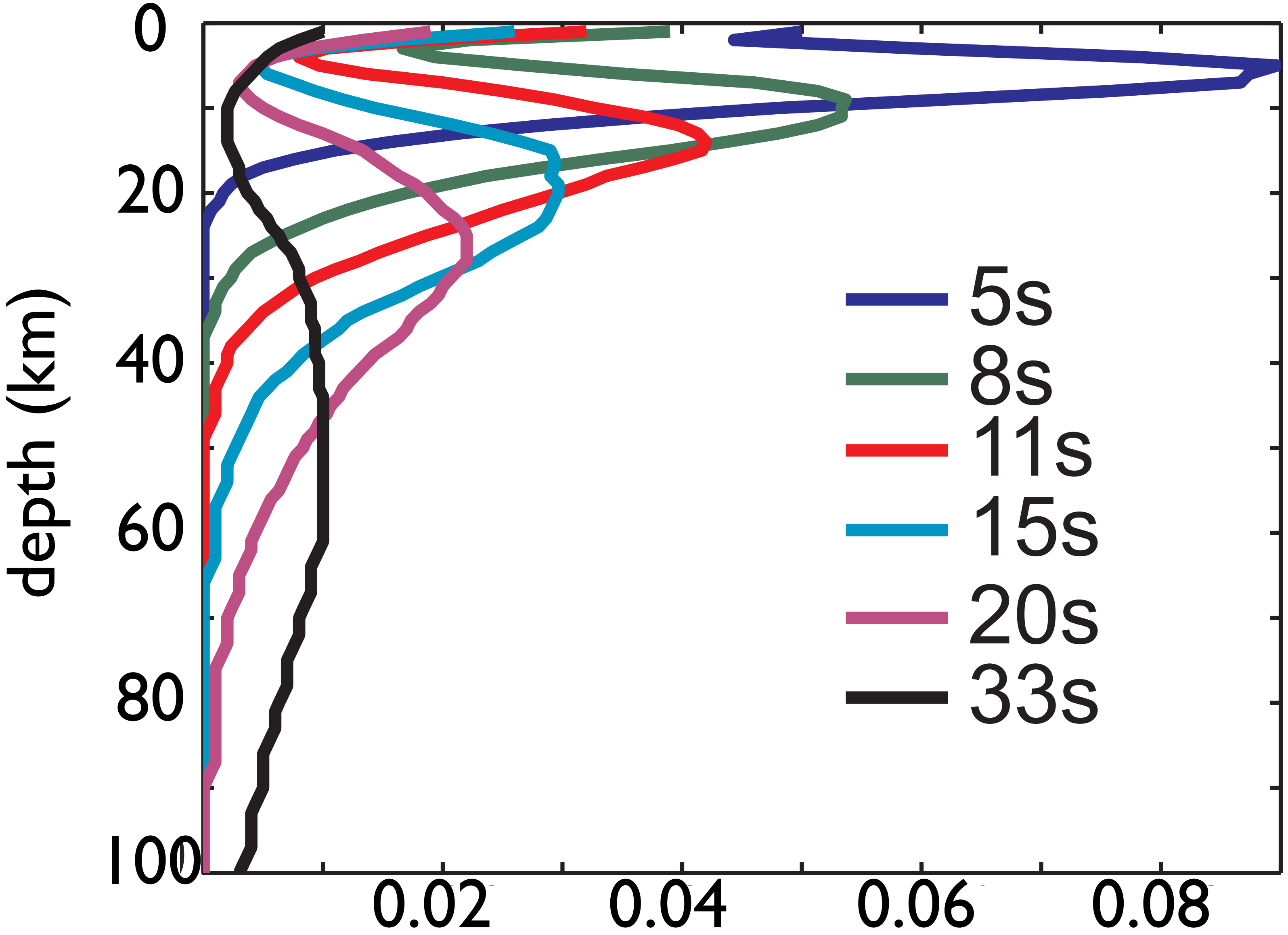
200 seconds

300 km

20 seconds

30 km

Rayleigh wave sensitivity to Vs



Requirements for high-resolution (~50 km) surface-wave tomography:

1. short paths to resolve small structures
2. short periods (5 < T < 25 sec) to resolve shallow (crustal) structure
3. evenly distributed sources (earthquakes) to create a tomographic image

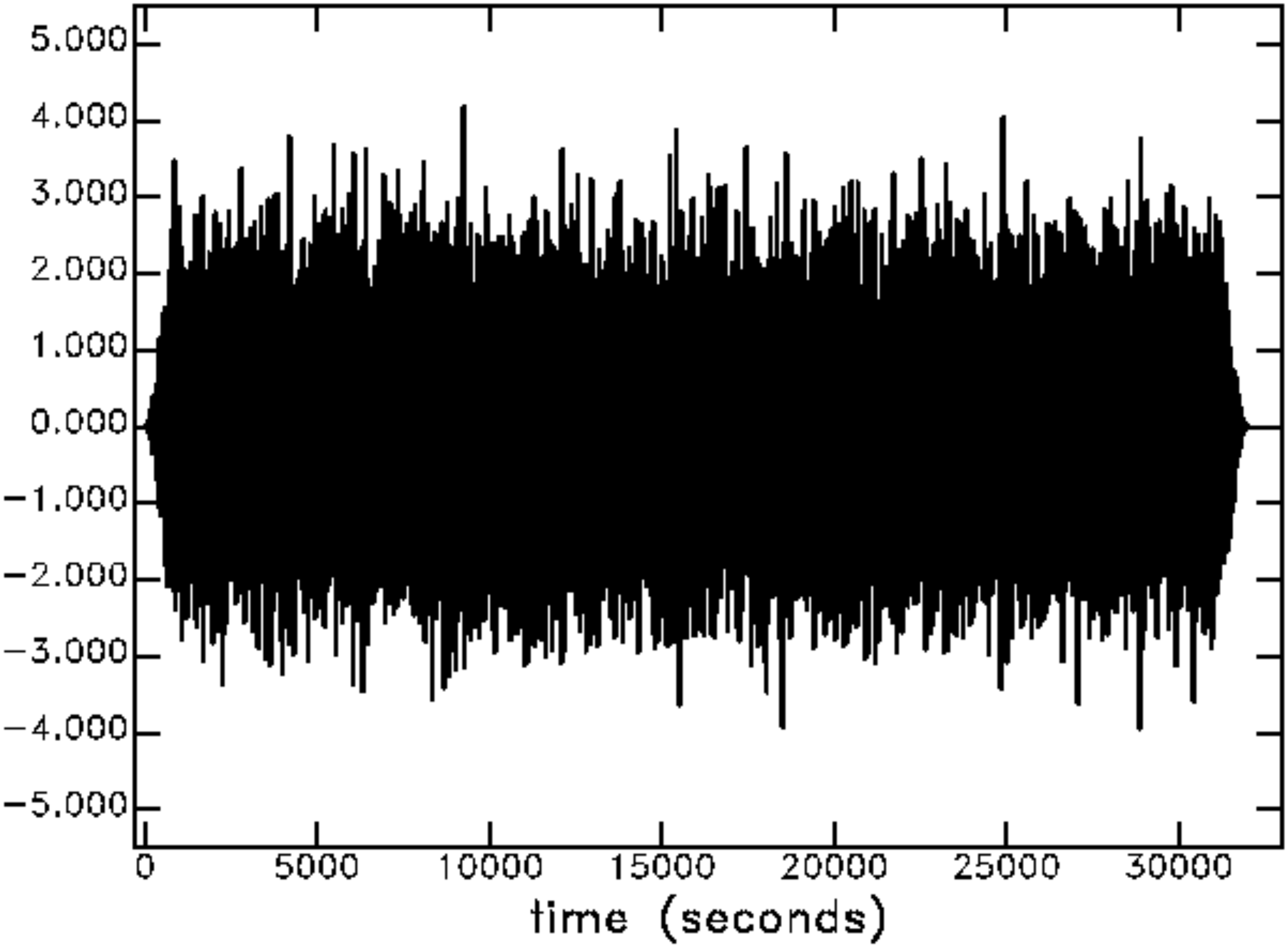
These are not met by traditional earthquake-based techniques

Proposition:

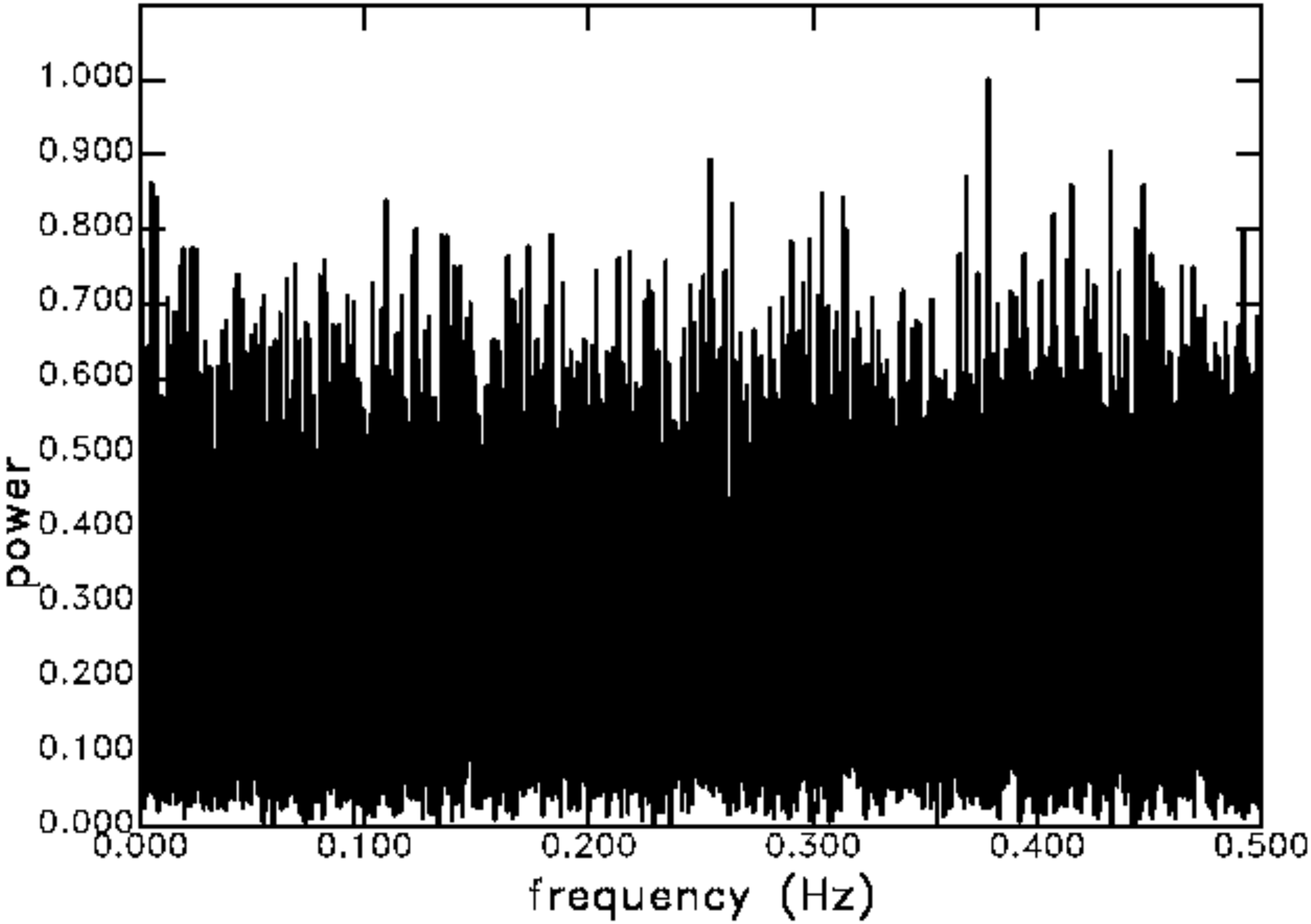
The cross correlation of background seismic noise recorded at two stations provides information about the propagation speed (the phase velocity) of surface waves between the two stations.

Explored by many, e.g., Aki, Campillo, Cox, Lobkis, Ritzwoller, Sabra, Shapiro, Snieder and many others, also in other fields

Gaussian white noise, 1 Hz sampling

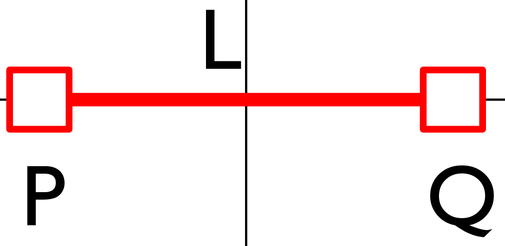


Gaussian white noise spectrum



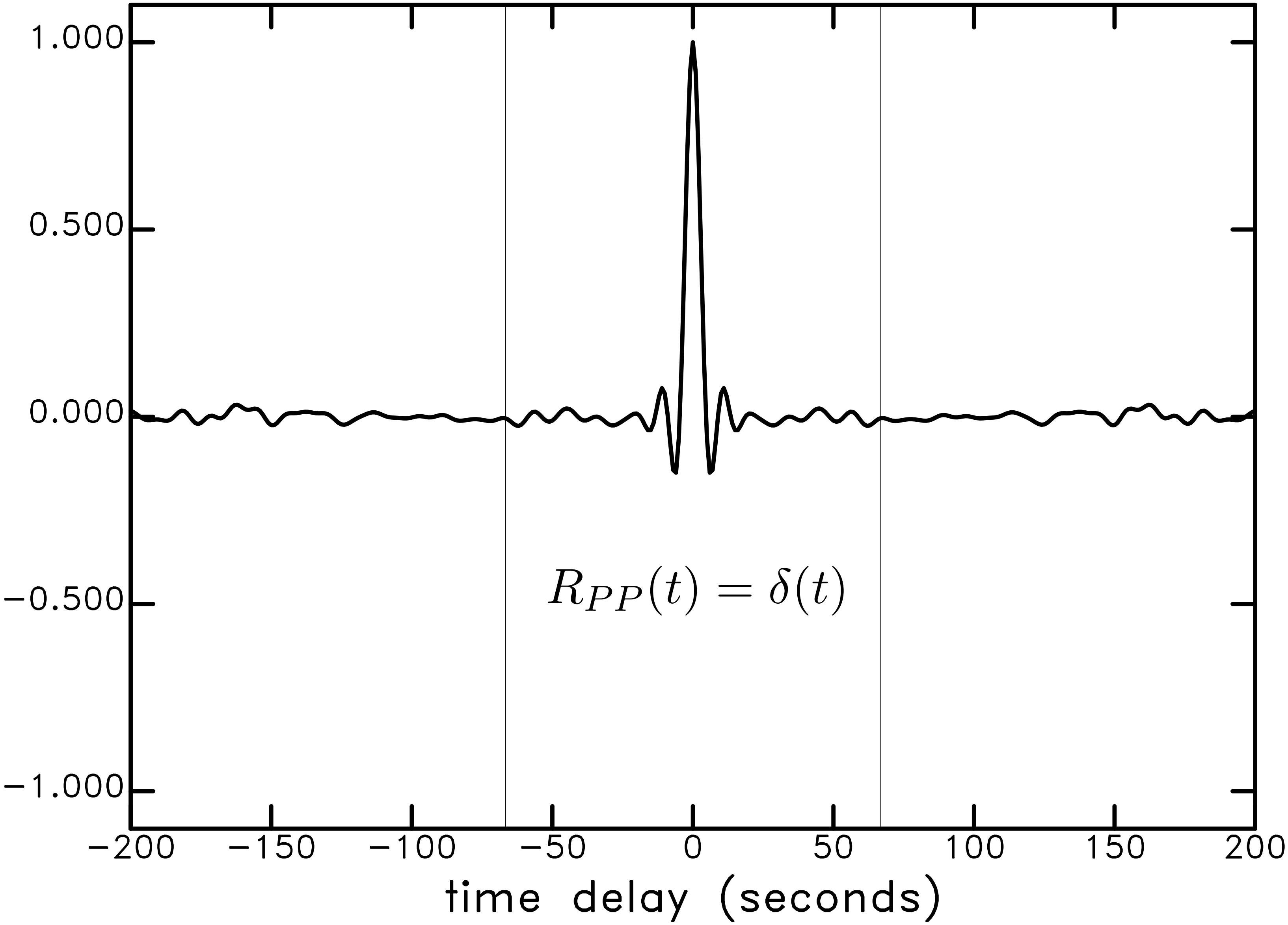
Two stations, P and Q, separated by L km

What is the cross correlation of noise signals recorded at P and Q?



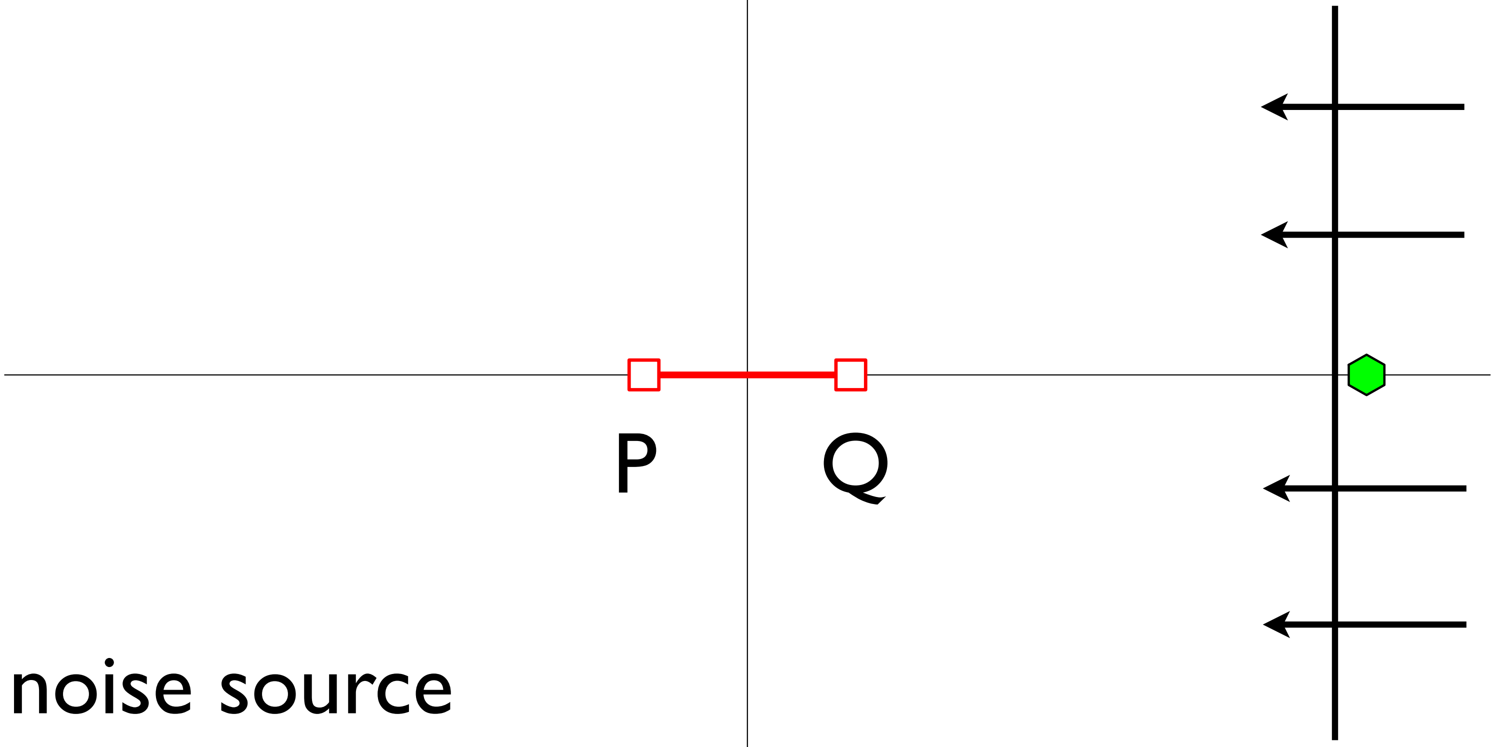
$$R_{PQ}(\tau) = \frac{1}{T}\int_0^T s_P(t)s_Q(t+\tau)dt$$

Auto-correlation function of noise



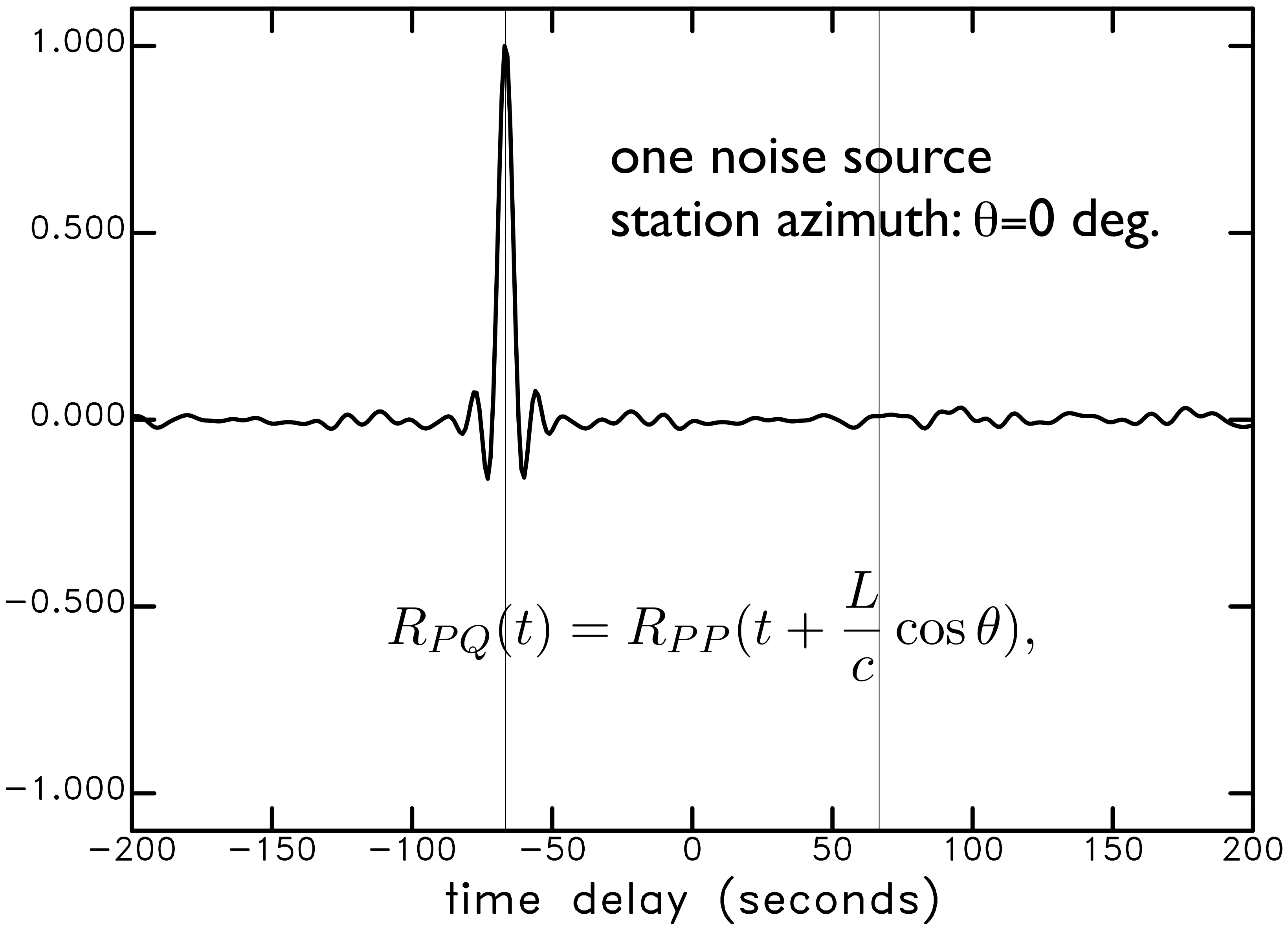
distance: L=200 km
speed: c=3 km/s

Plane wave of noise incident on two stations, P and Q



one noise source
station azimuth: $\theta=0$ deg.

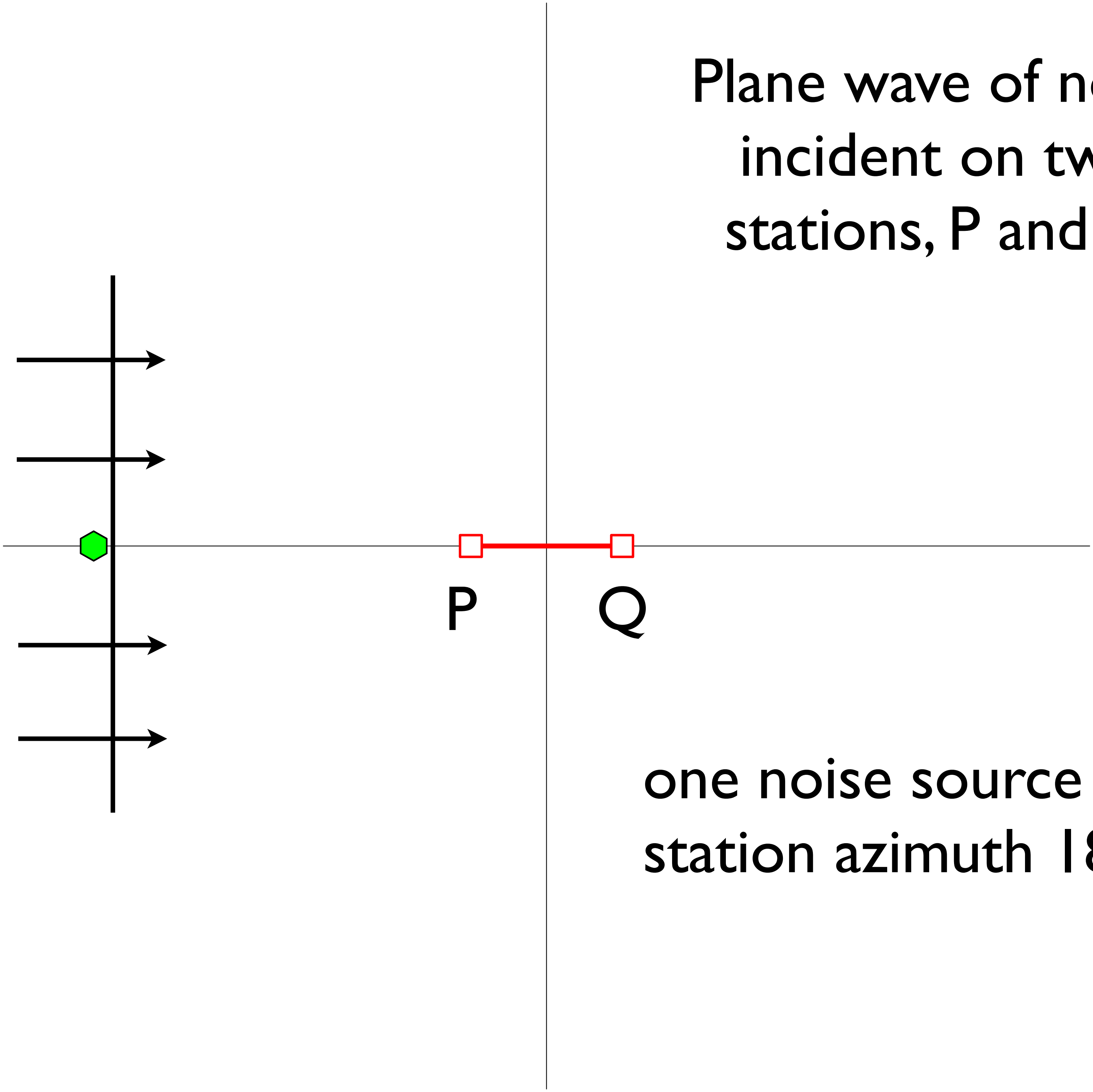
Cross-correlation function, P and Q



one noise source
station azimuth: θ=0 deg.

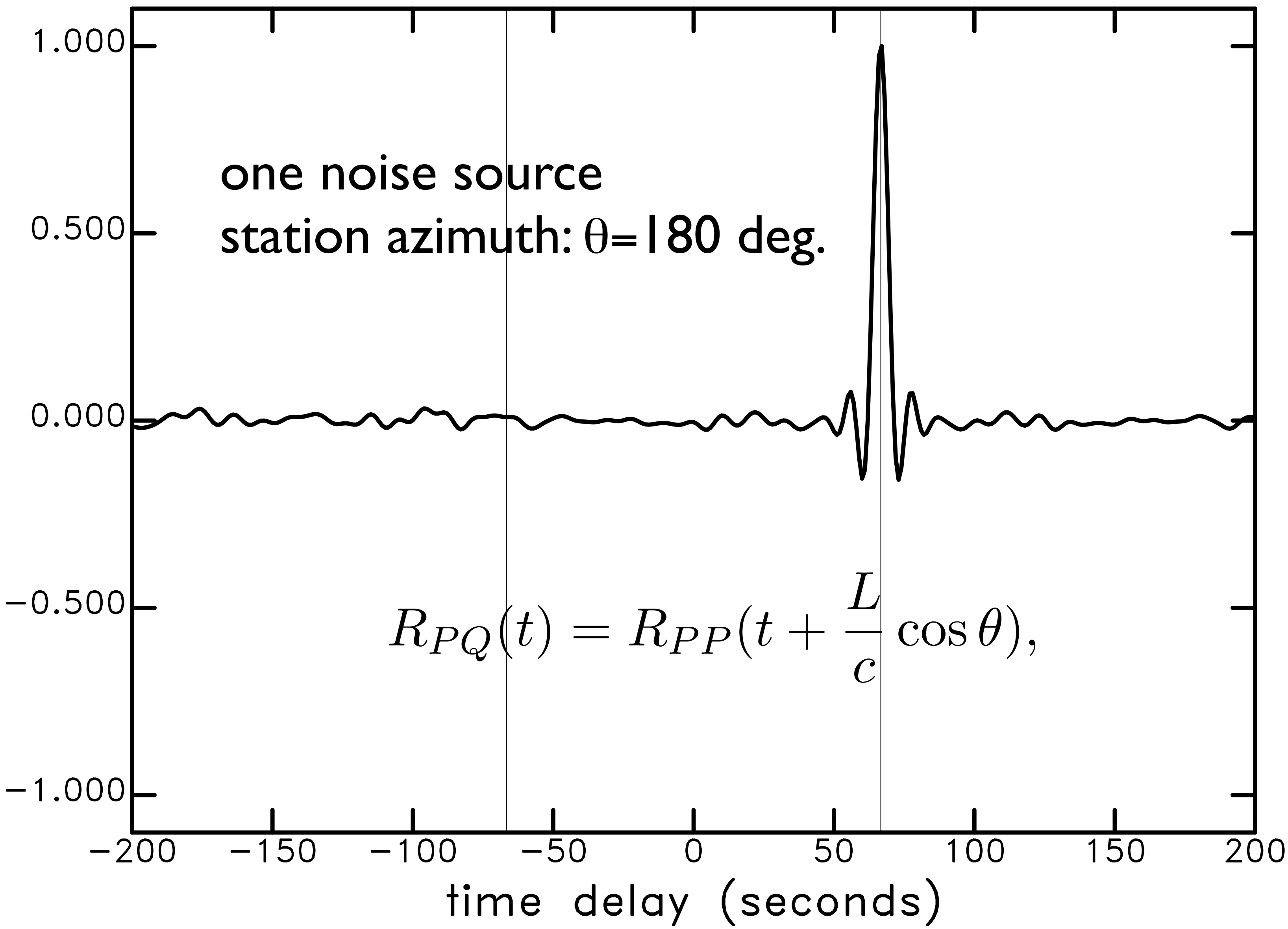
$$R_{PQ}(t) = R_{PP}(t + \frac{L}{c}\cos\theta),$$

Plane wave of noise incident on two stations, P and Q



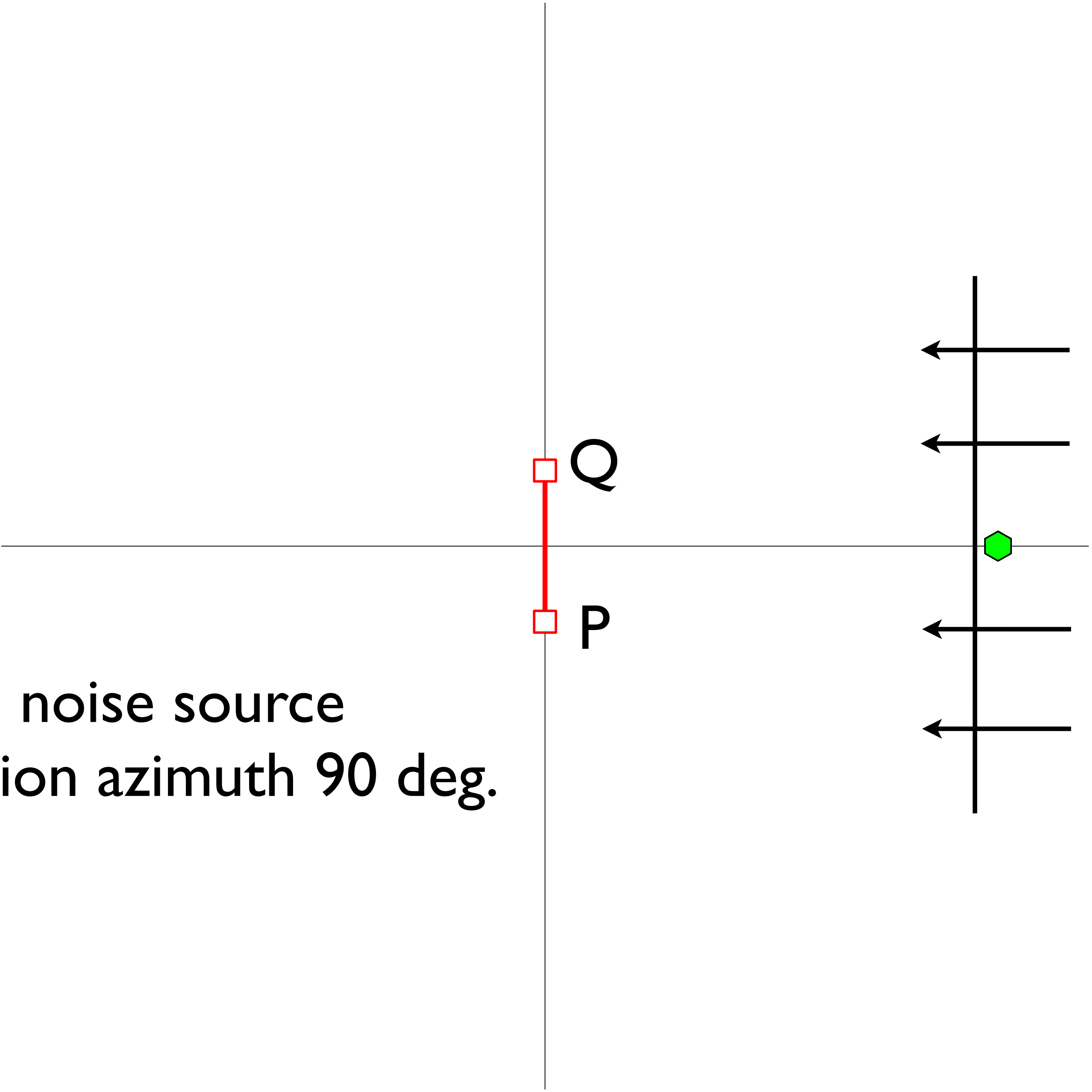
one noise source
station azimuth 180 deg.

Cross-correlation function, P and Q



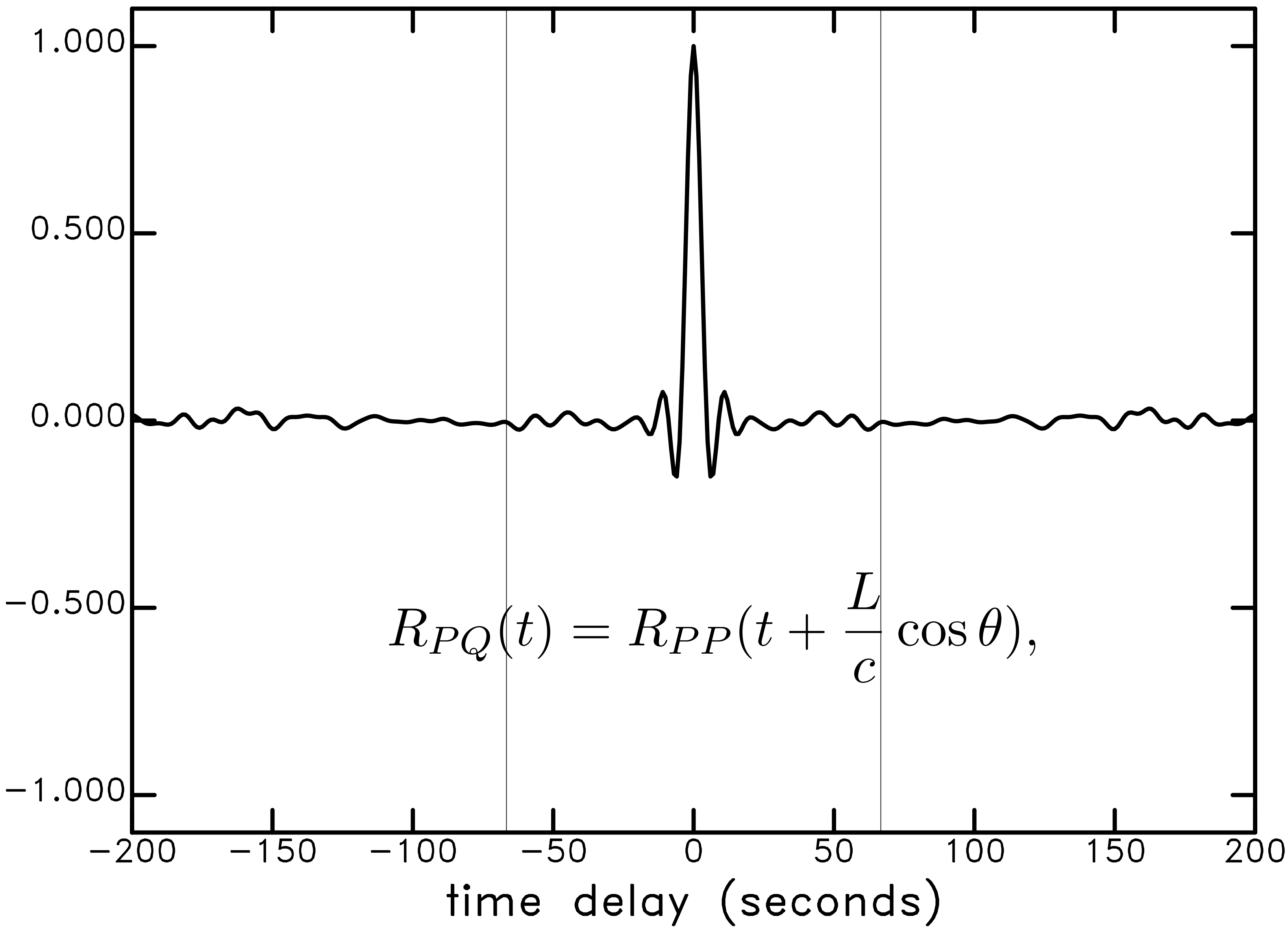
one noise source
station azimuth: θ=180 deg.

$$R_{PQ}(t) = R_{PP}(t + \frac{L}{c}\cos\theta),$$

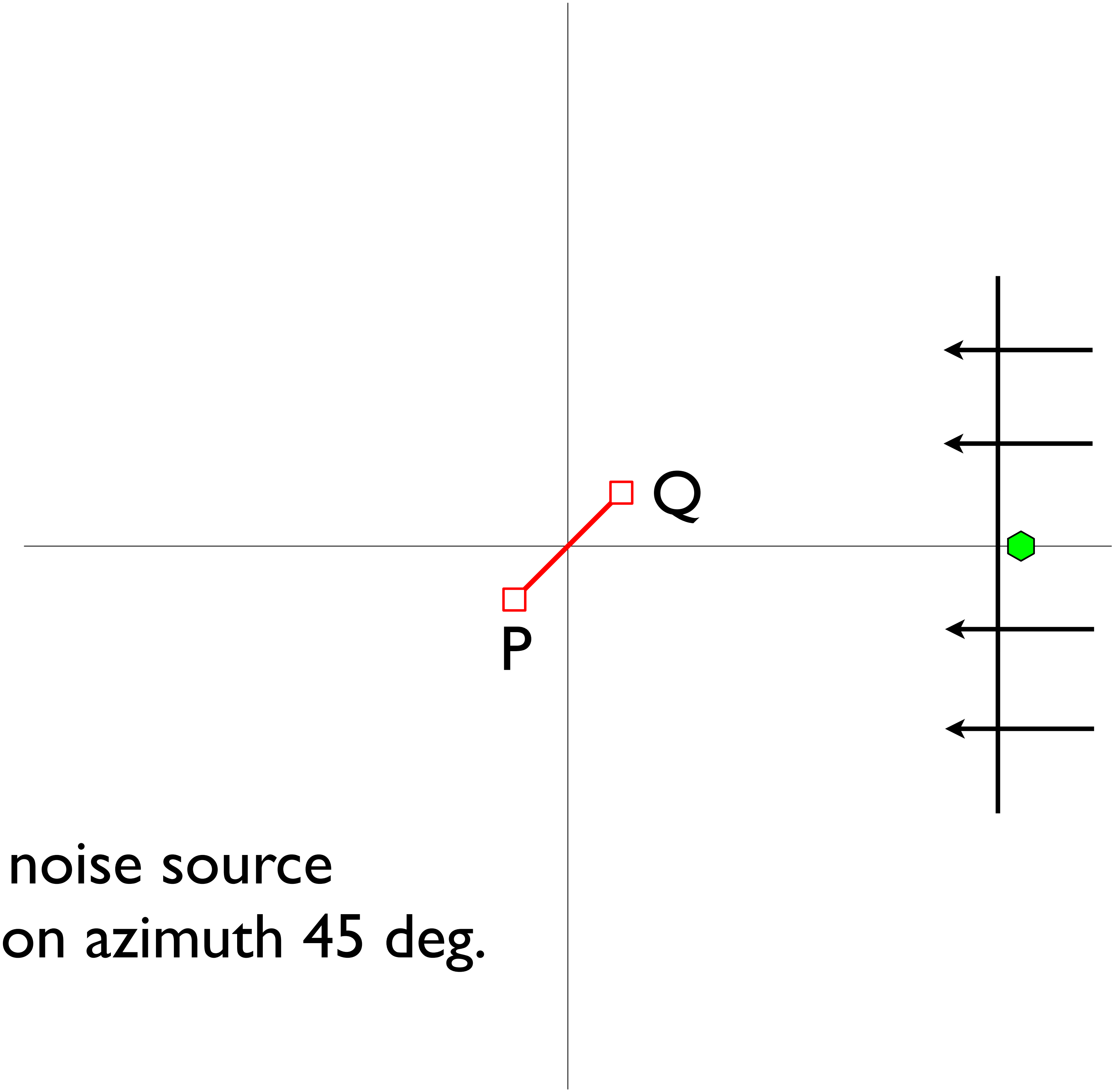


one noise source
station azimuth 90 deg.

Cross-correlation function, P and Q

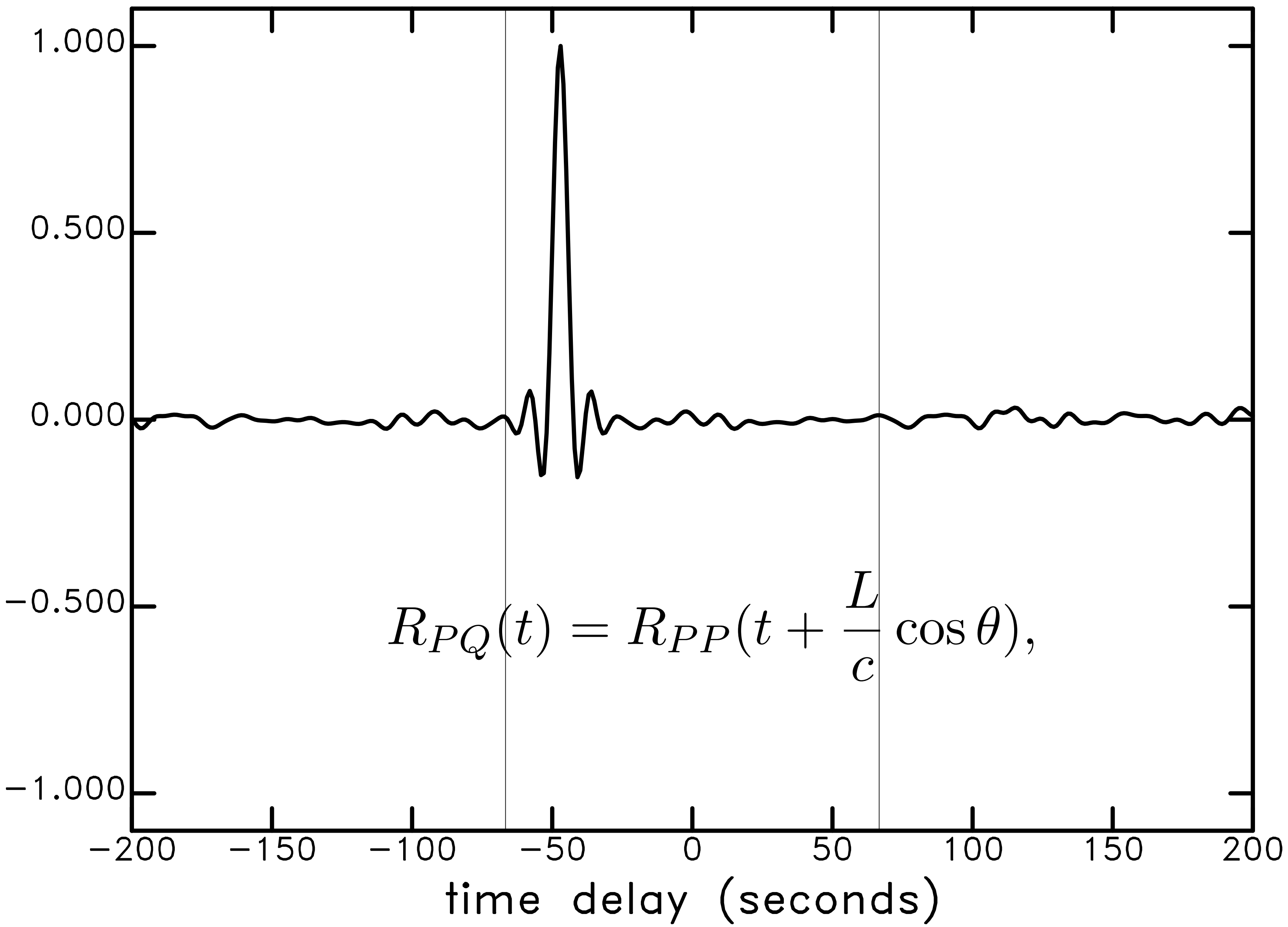


$$R_{PQ}(t) = R_{PP}(t + \frac{L}{c}\cos\theta),$$

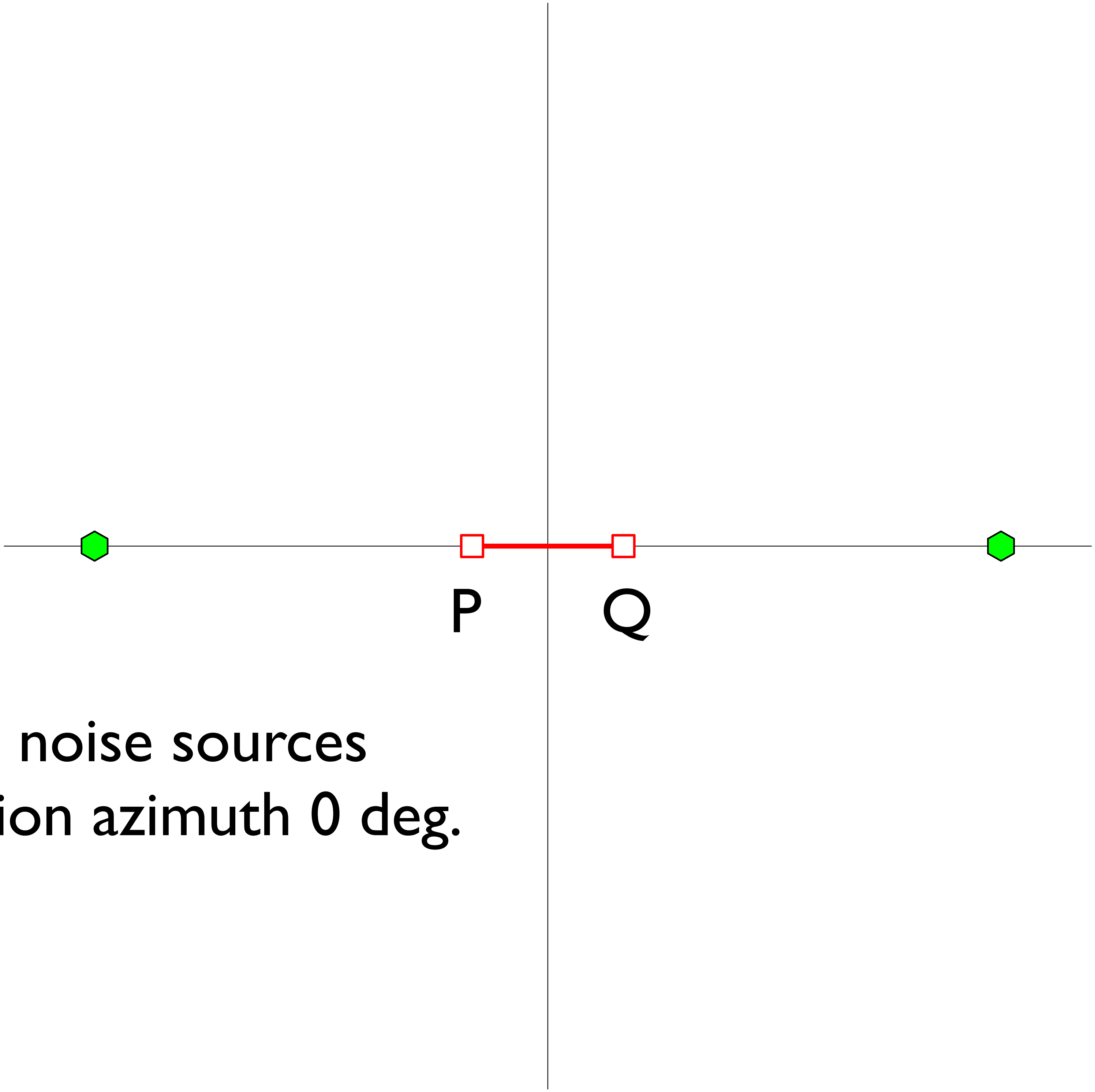


one noise source
station azimuth 45 deg.

Cross-correlation function, P and Q

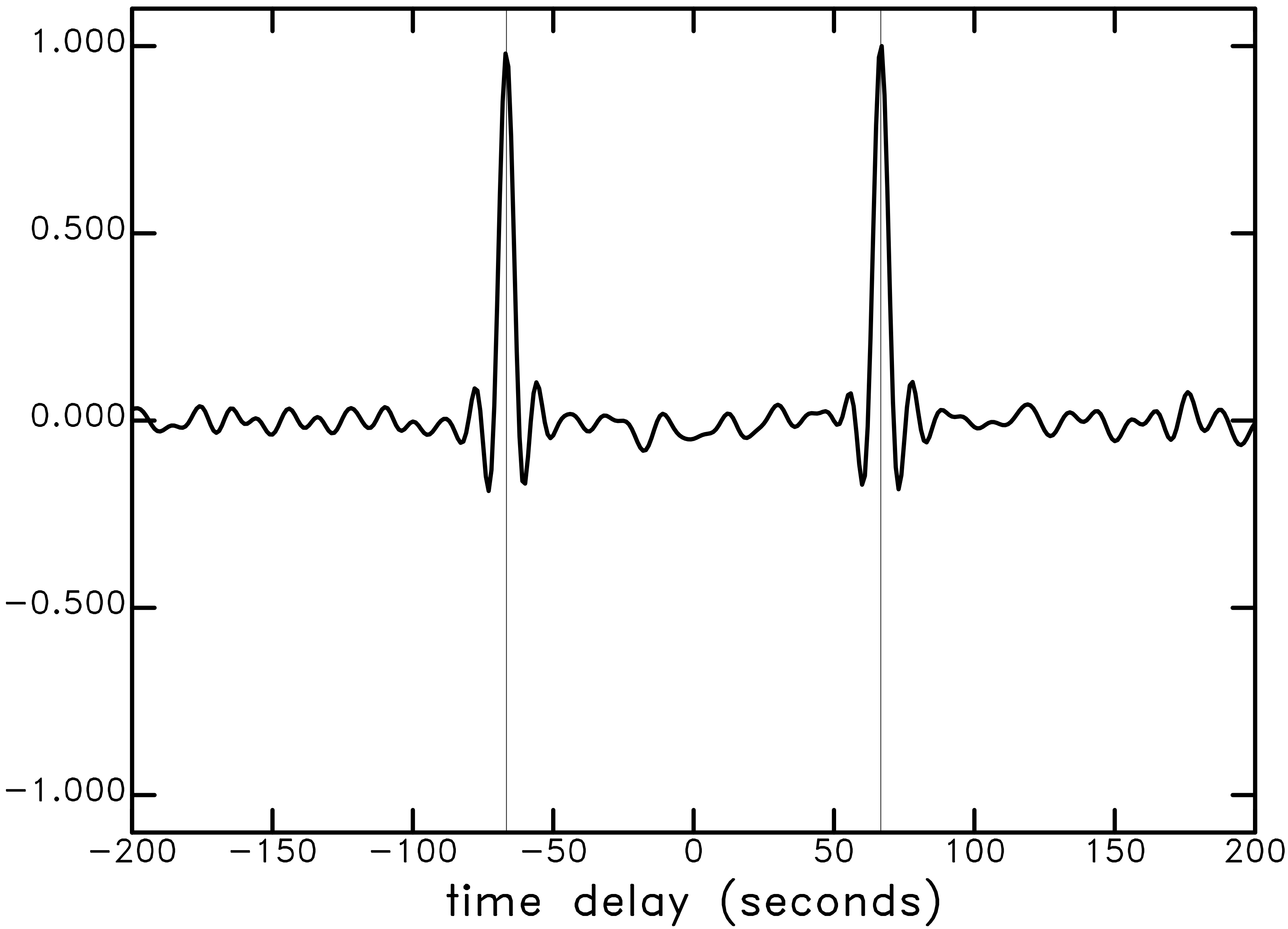


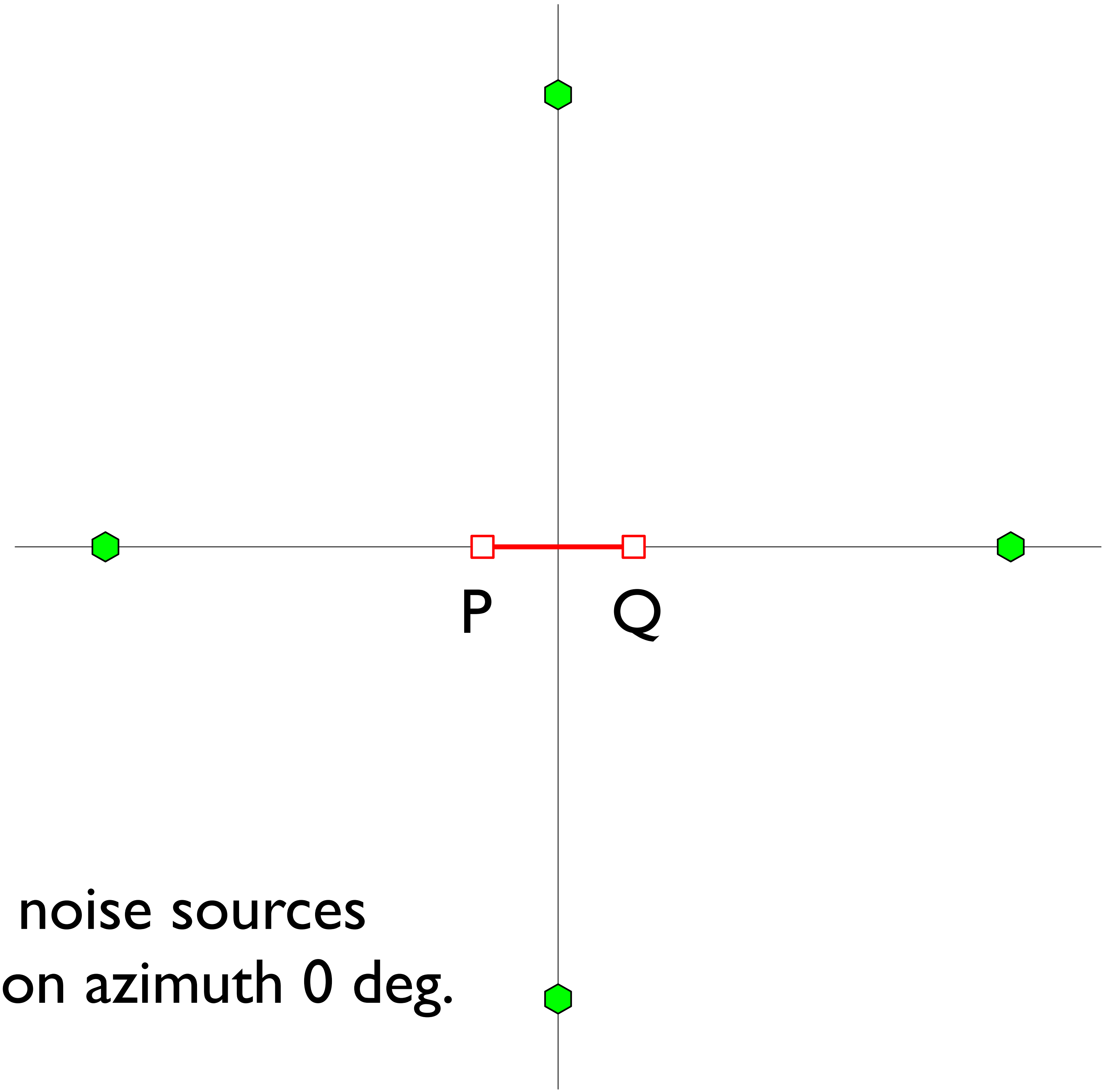
$$R_{PQ}(t) = R_{PP}(t + \frac{L}{c}\cos\theta),$$



two noise sources
station azimuth 0 deg.

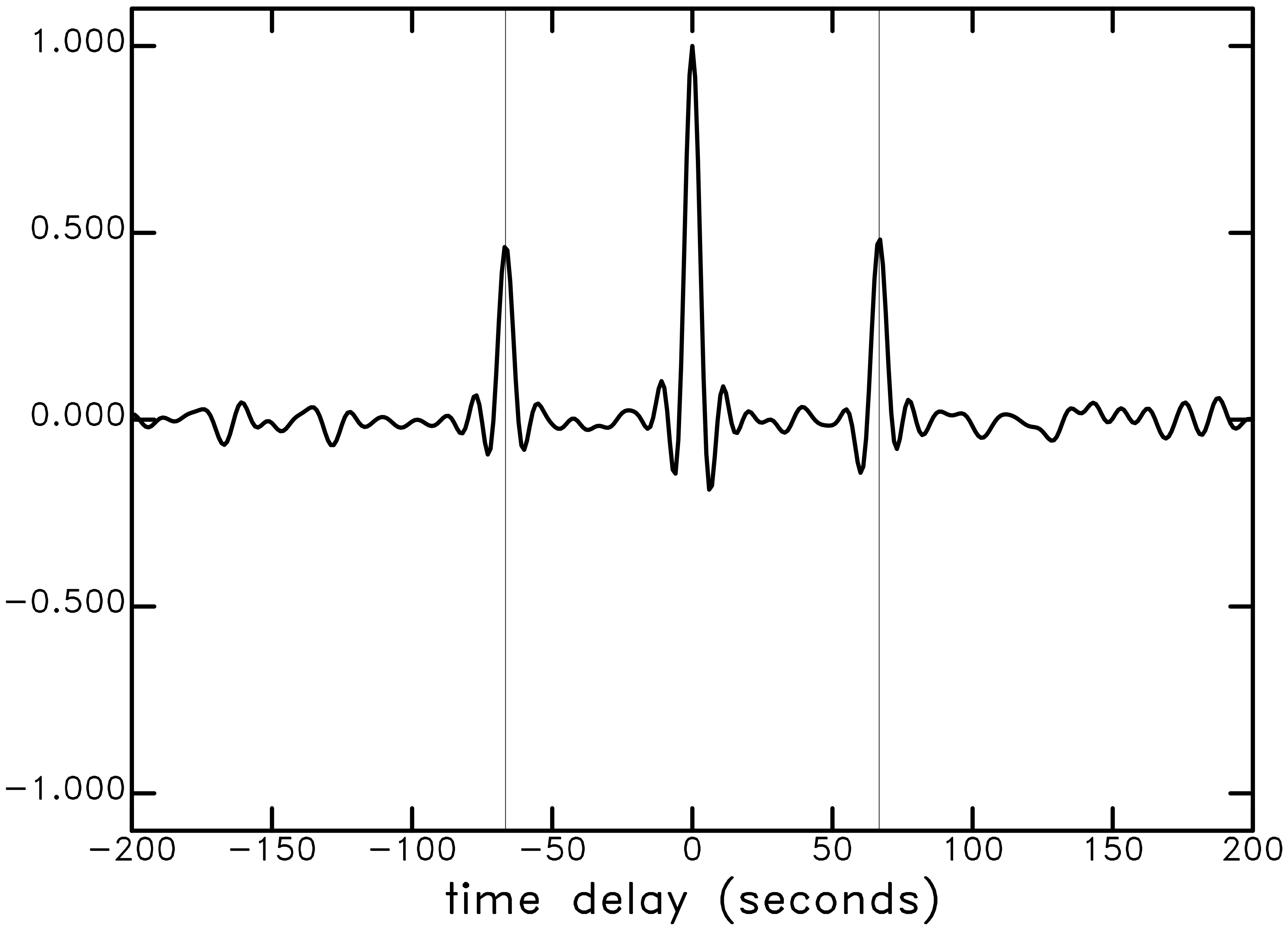
Cross-correlation function, P and Q



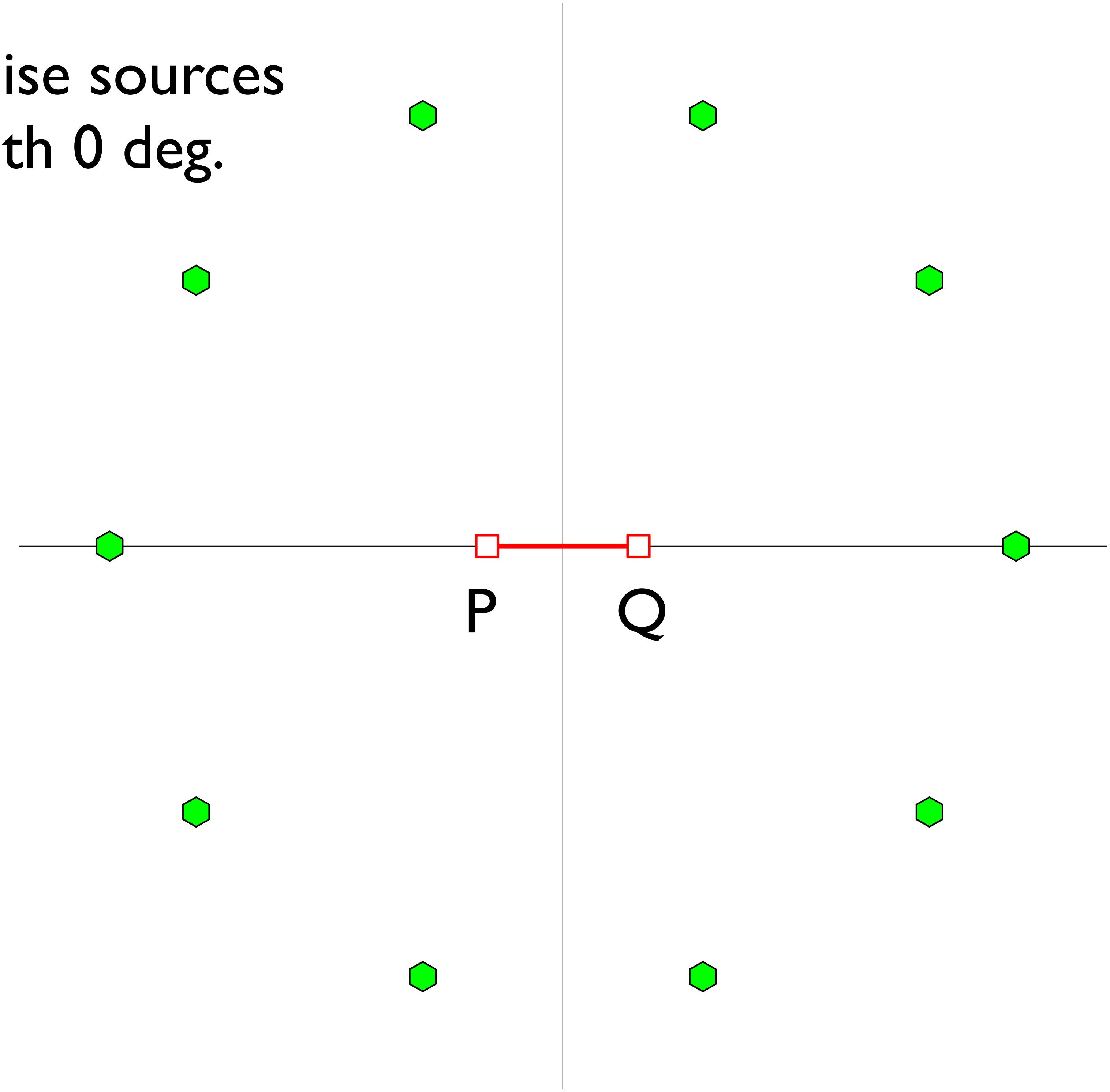


four noise sources
station azimuth 0 deg.

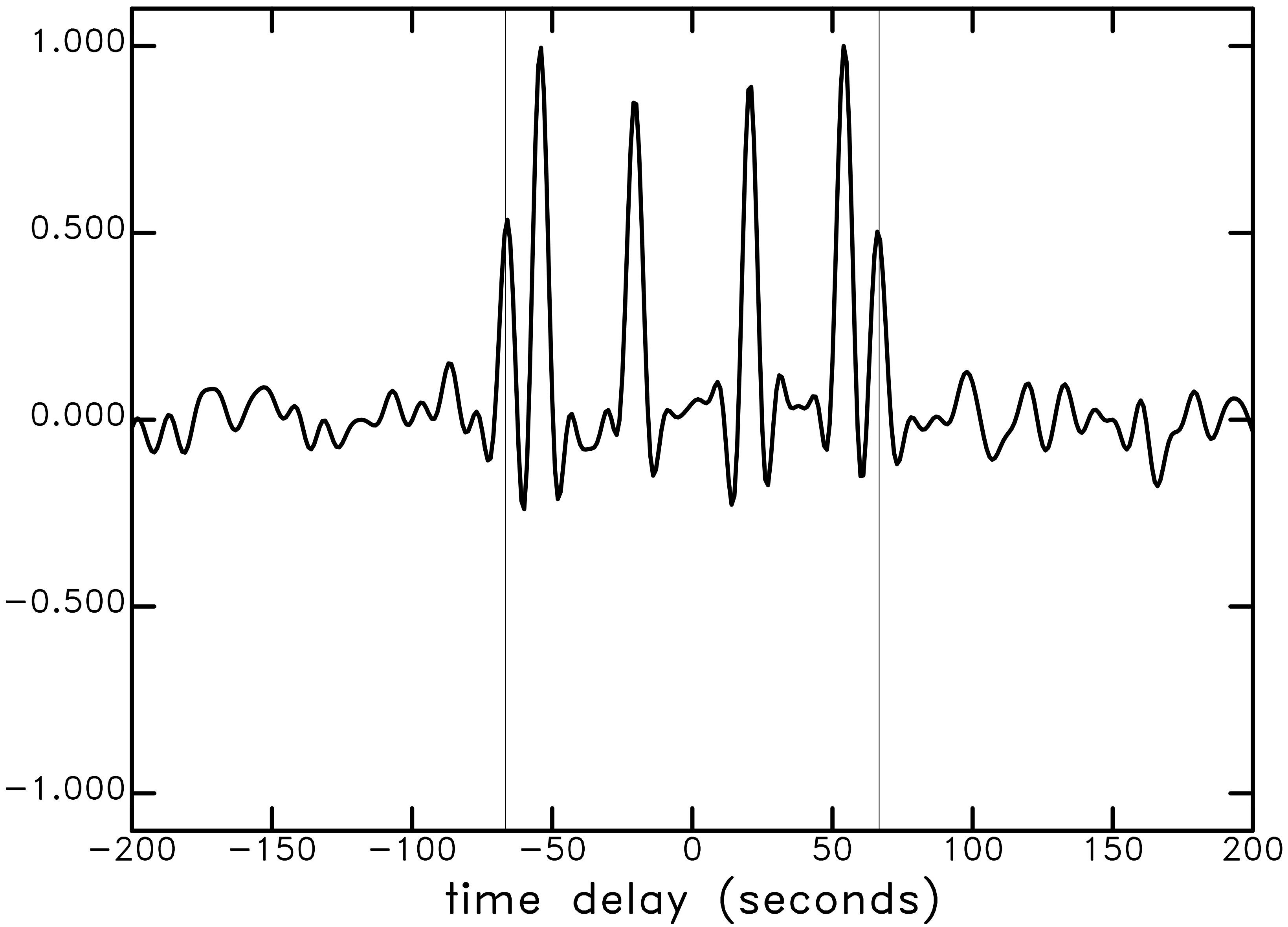
Cross-correlation function, P and Q



10 noise sources
azimuth 0 deg.

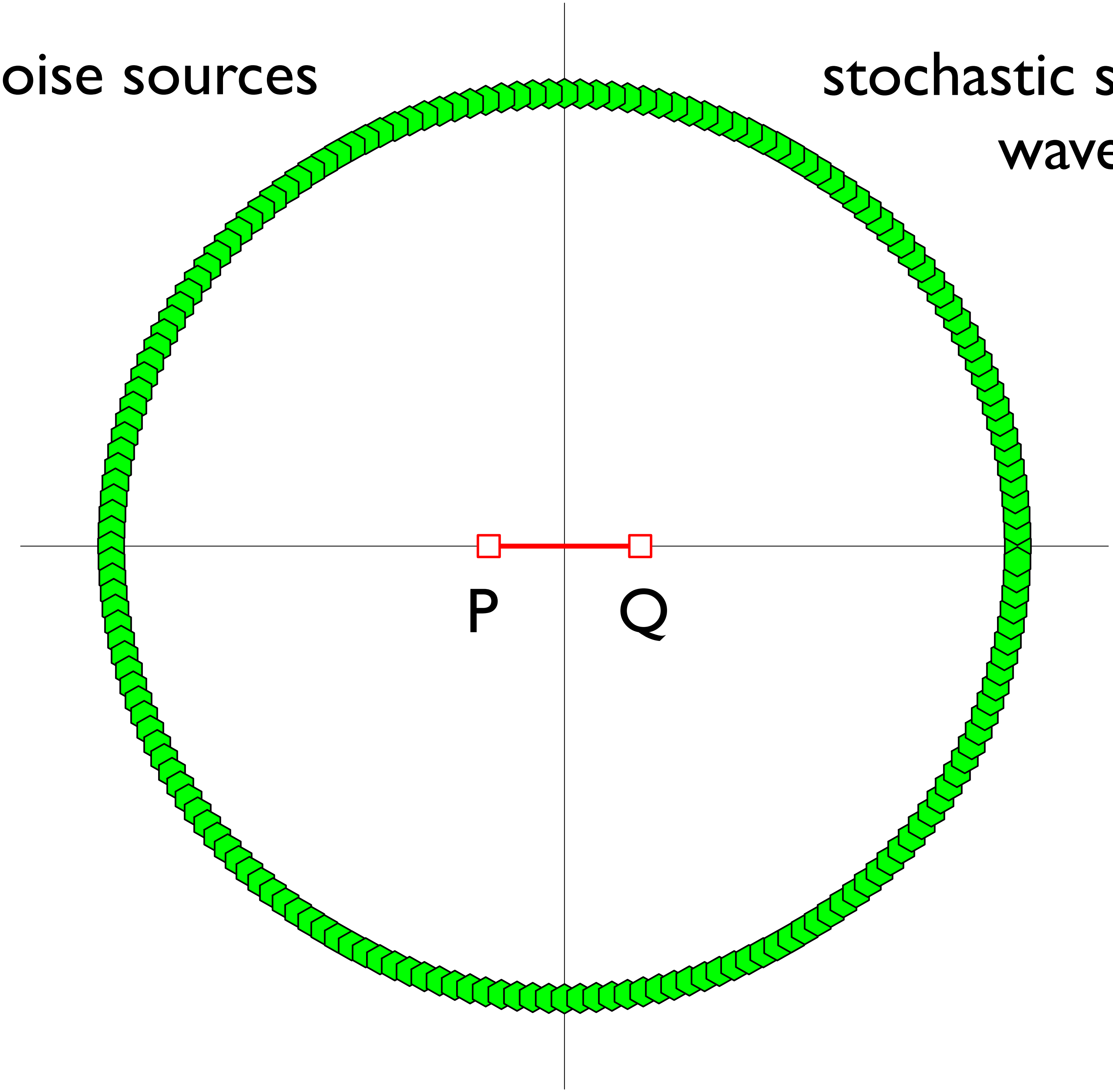


Cross-correlation function, P and Q

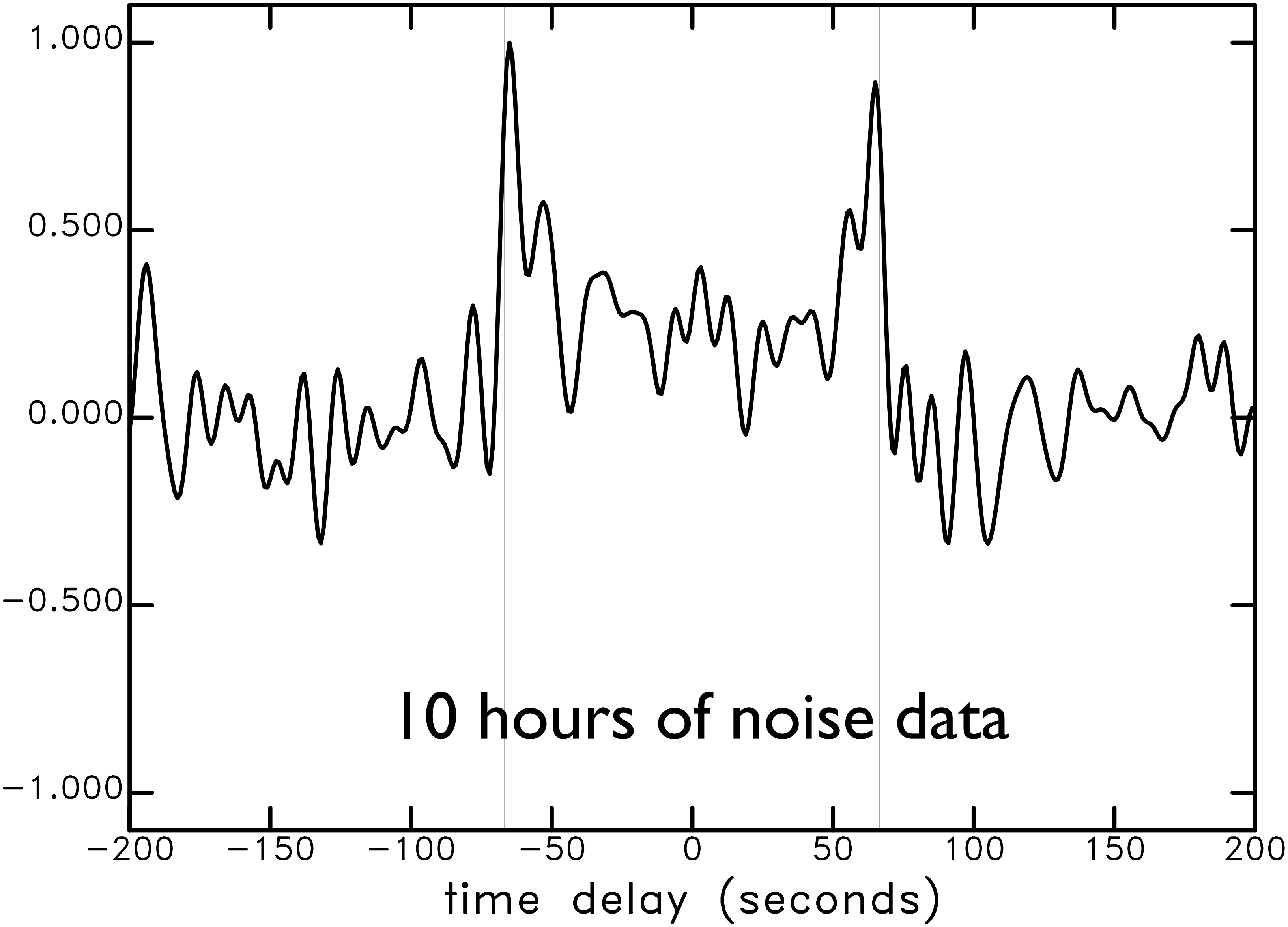


180 noise sources

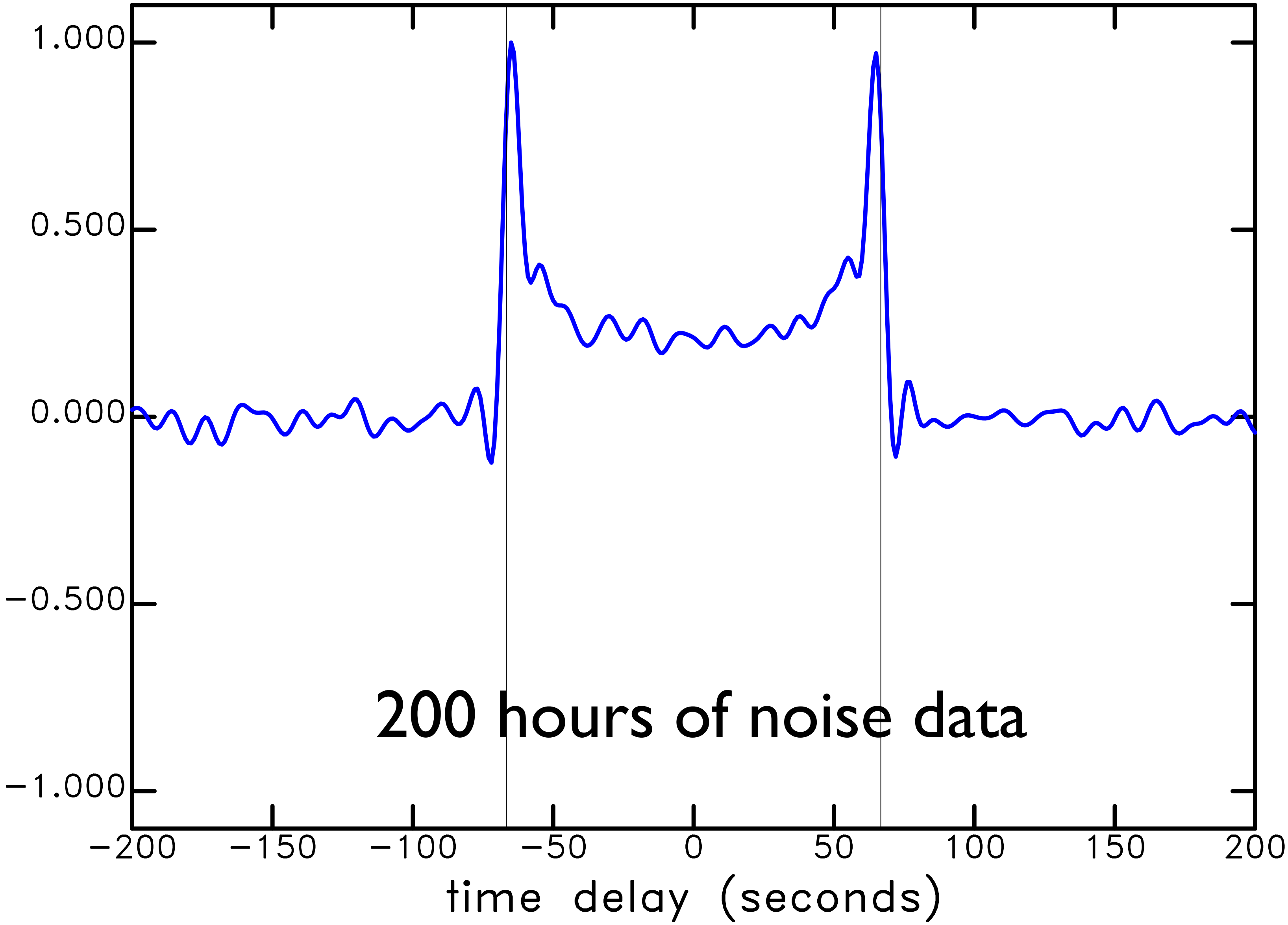
stochastic surface waves



Cross-correlation function, P and Q

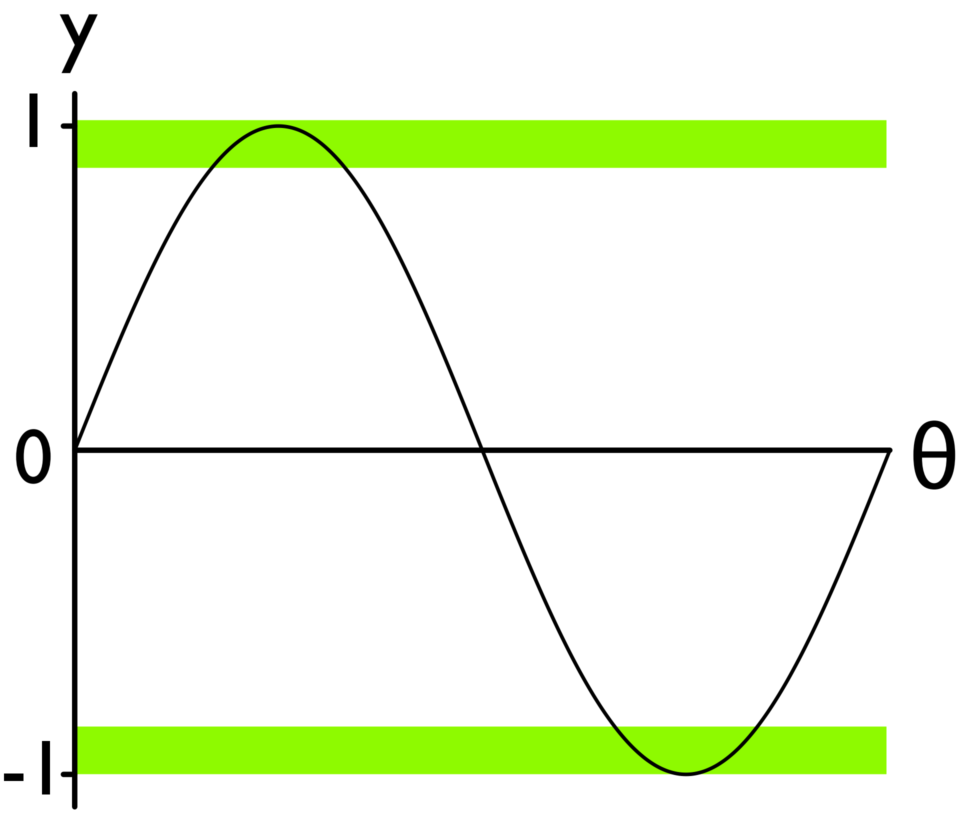


Cross-correlation function, P and Q

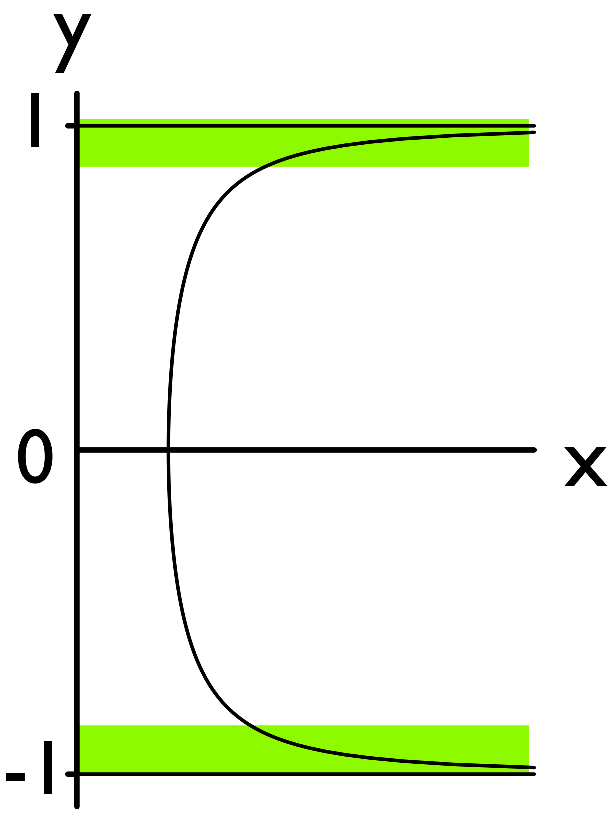


200 hours of noise data

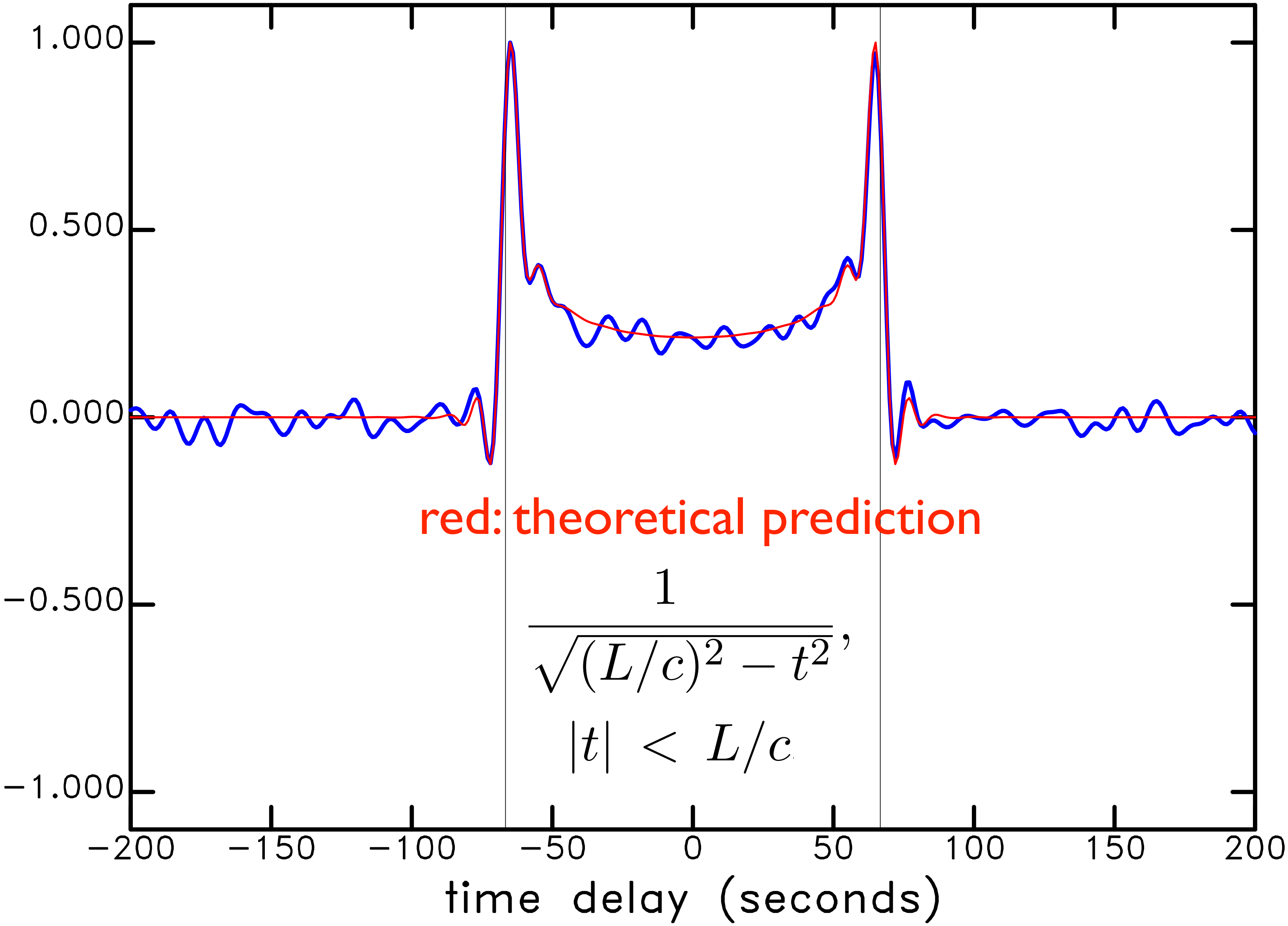
sine function
y=sin(θ)



pdf of sine function
x=p(y)



Cross-correlation function, P and Q



red: theoretical prediction

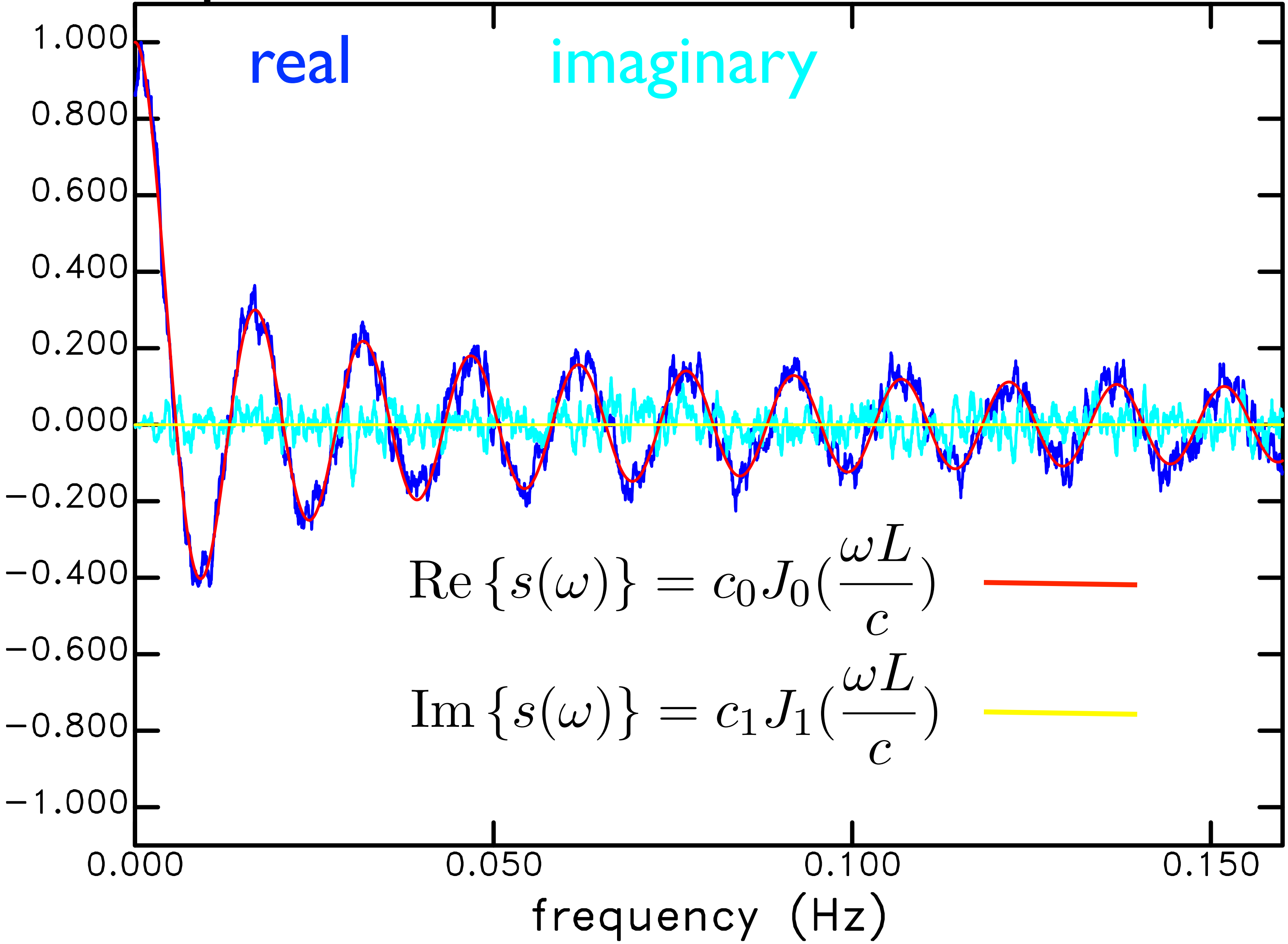
$$\frac{1}{\sqrt{(L/c)^2 - t^2}},$$

$$|t| < L/c$$

What about the Fourier transform?

$$\frac{1}{\sqrt{(L/c)^2 - t^2}} \longrightarrow J_0(\frac{\omega L}{c})$$

Spectrum of cross-correlation function

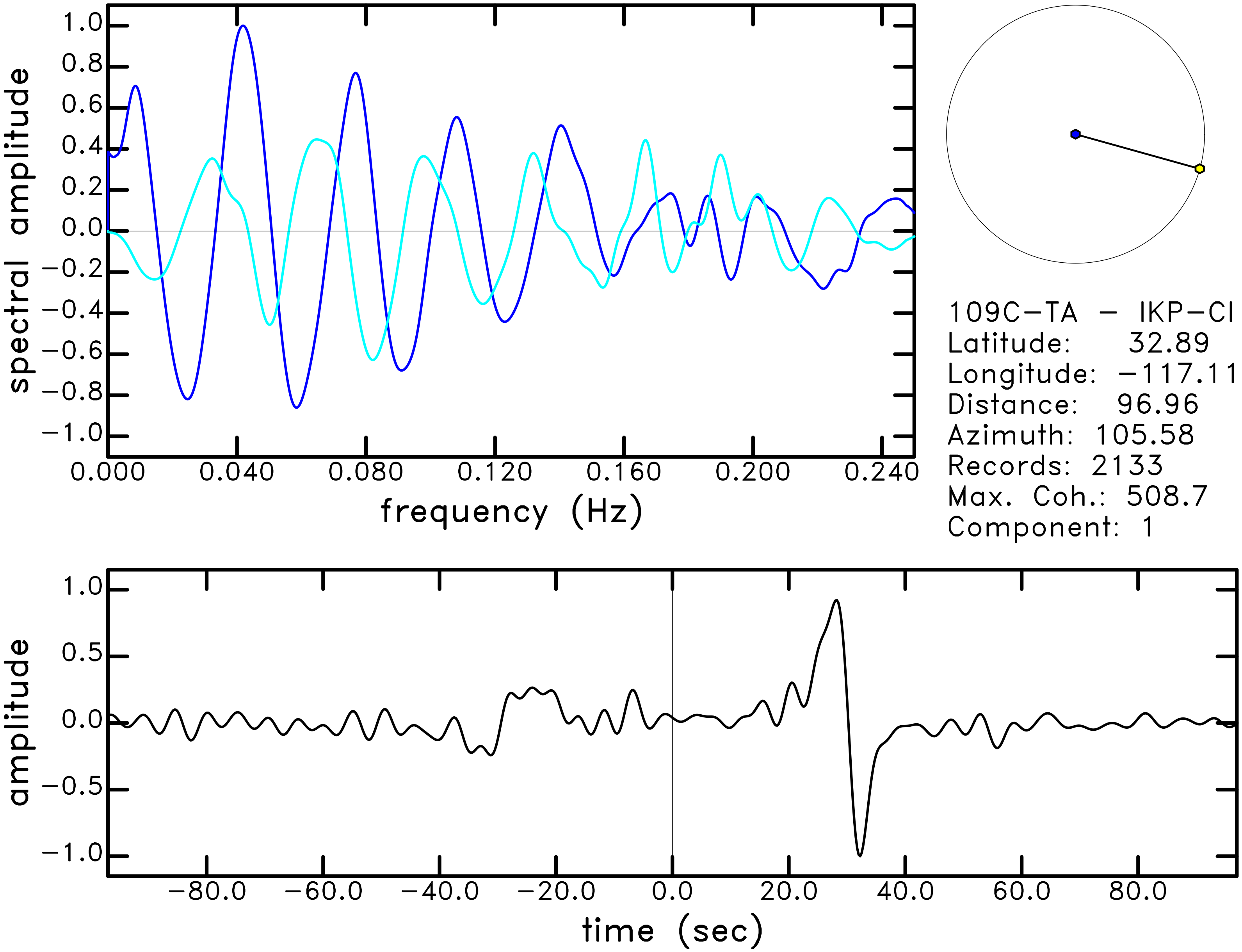


$$\overline{\rho}(r, \omega_0) = J_0\left(\frac{\omega_0}{c(\omega_0)} r\right)$$

"This formula clearly indicates that if one measures $\overline{\rho}(r, \omega_0)$ for a certain r and for various ω_0's, he can obtain the function $c(\omega_0)$, i.e., the dispersion curve of the wave for the corresponding range of frequency ω_0".

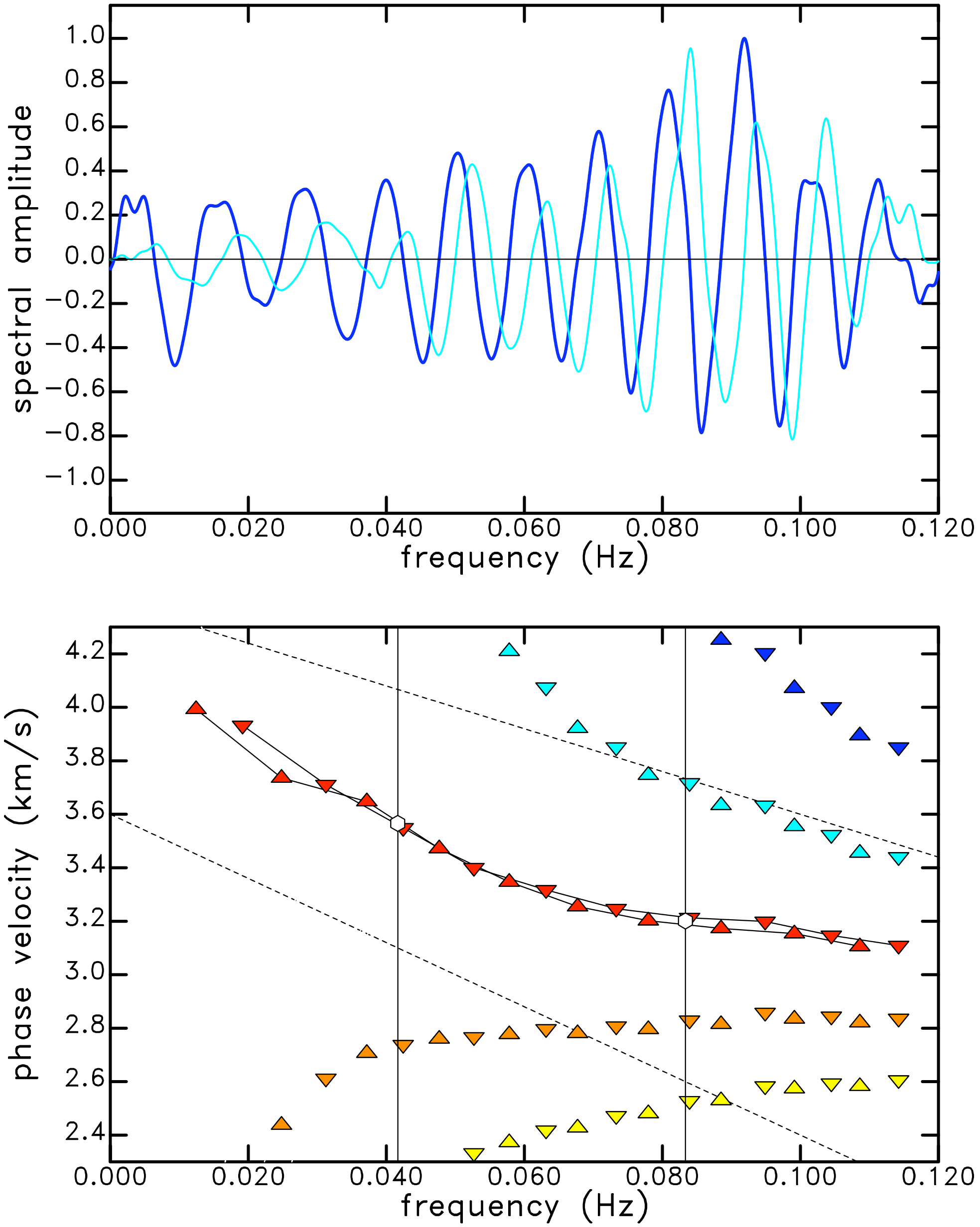
Aki, 1957

Real data



109C−TA − IKP−CI
Latitude: 32.89
Longitude: −117.11
Distance: 96.96
Azimuth: 105.58
Records: 2133
Max. Coh.: 508.7
Component: 1

Matching zero crossings for dispersion



D07A-B04A

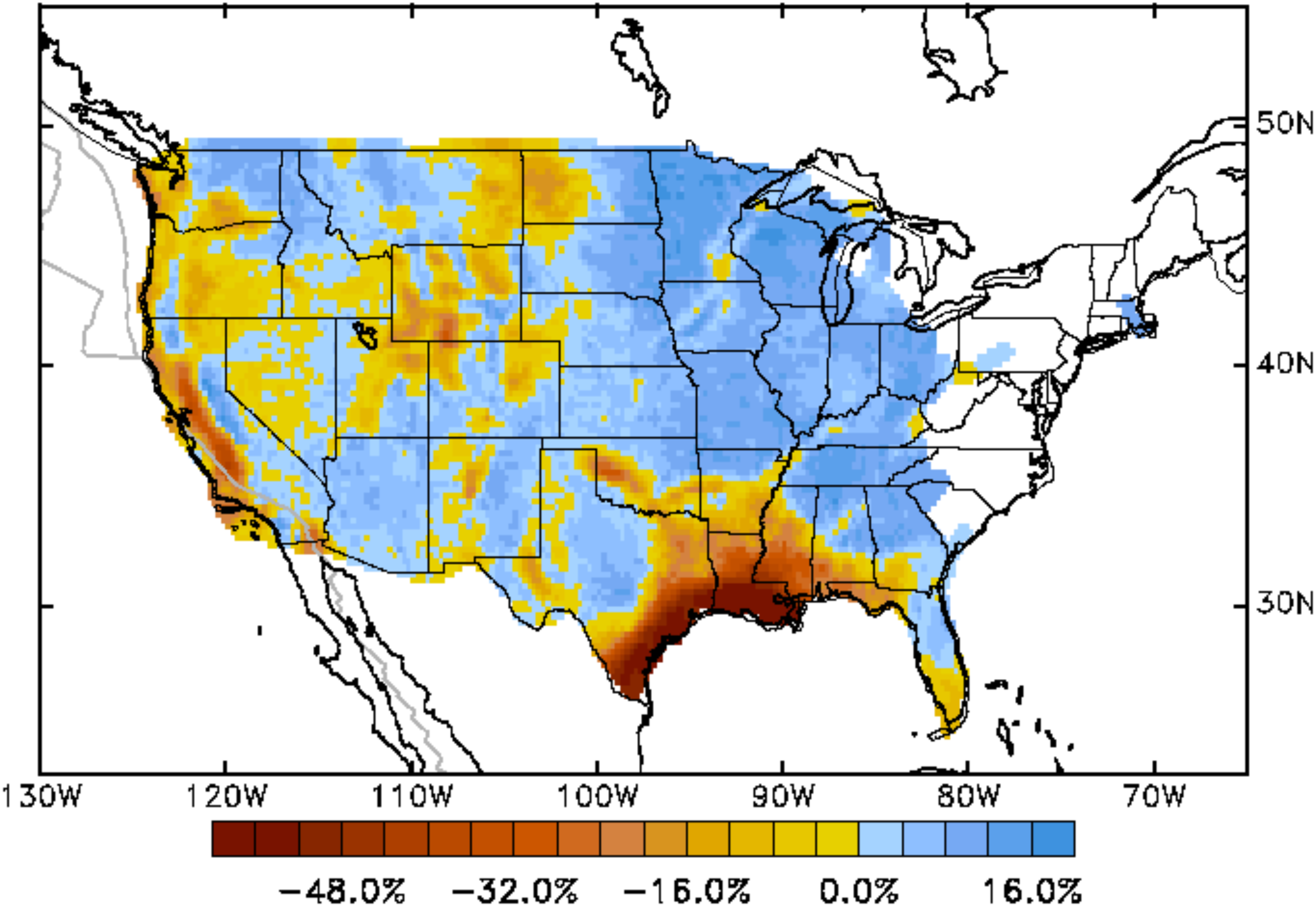
282 km

$$c(\omega_n) = \frac{\omega_n r}{z_n}$$

Recipe for tomographic success:

1. Correlate continuous recorded signals at all pairs of USArray stations in 4-h windows (note - this is a big calculation)
2. Stack all correlation functions for each pair
3. Determine zero crossings of stacked cross-correlation spectra
4. Determine phase velocities using Aki's formula
5. Invert phase-velocity observations to determine phase-velocity maps

R005.1212 t bo.pix



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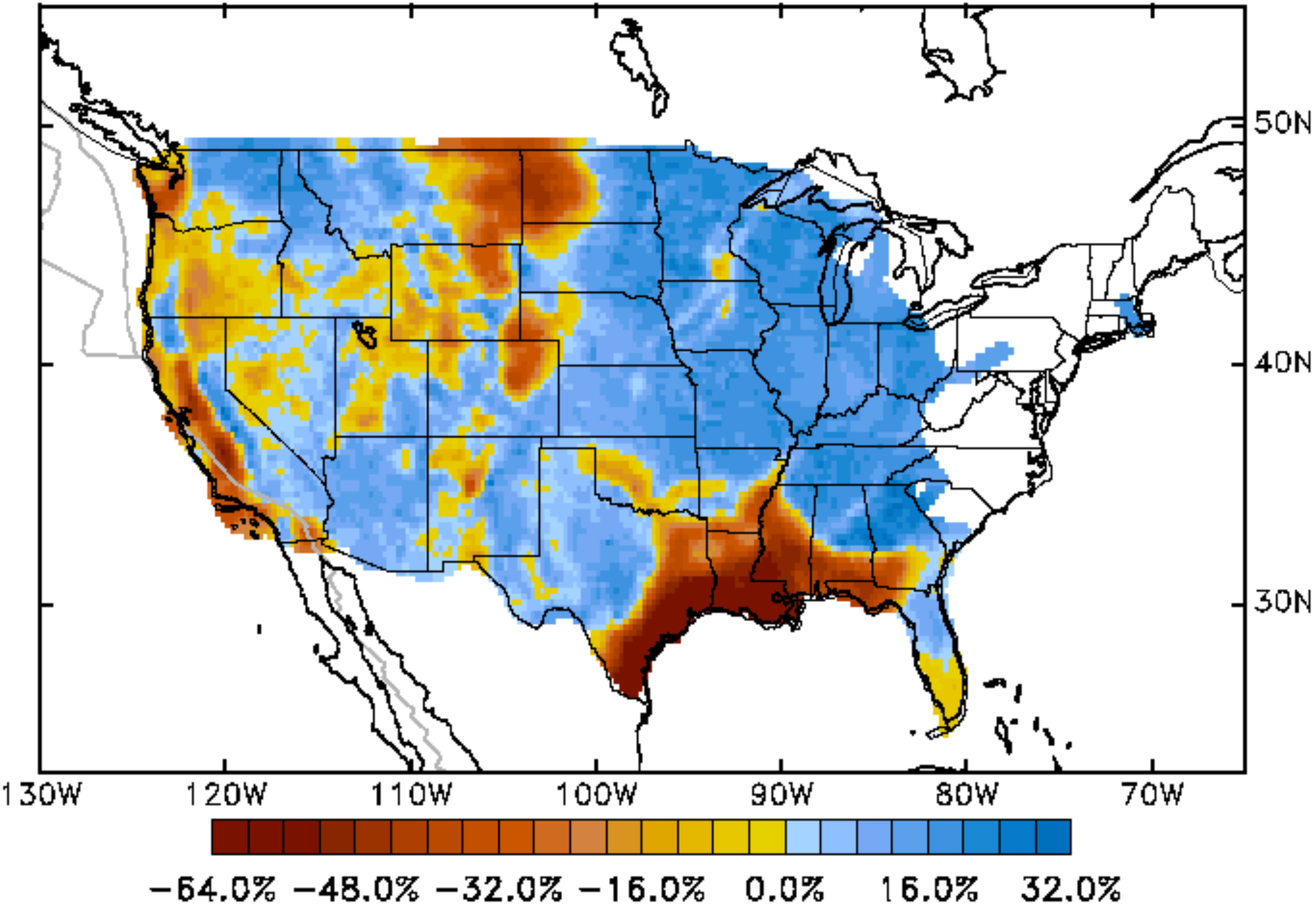
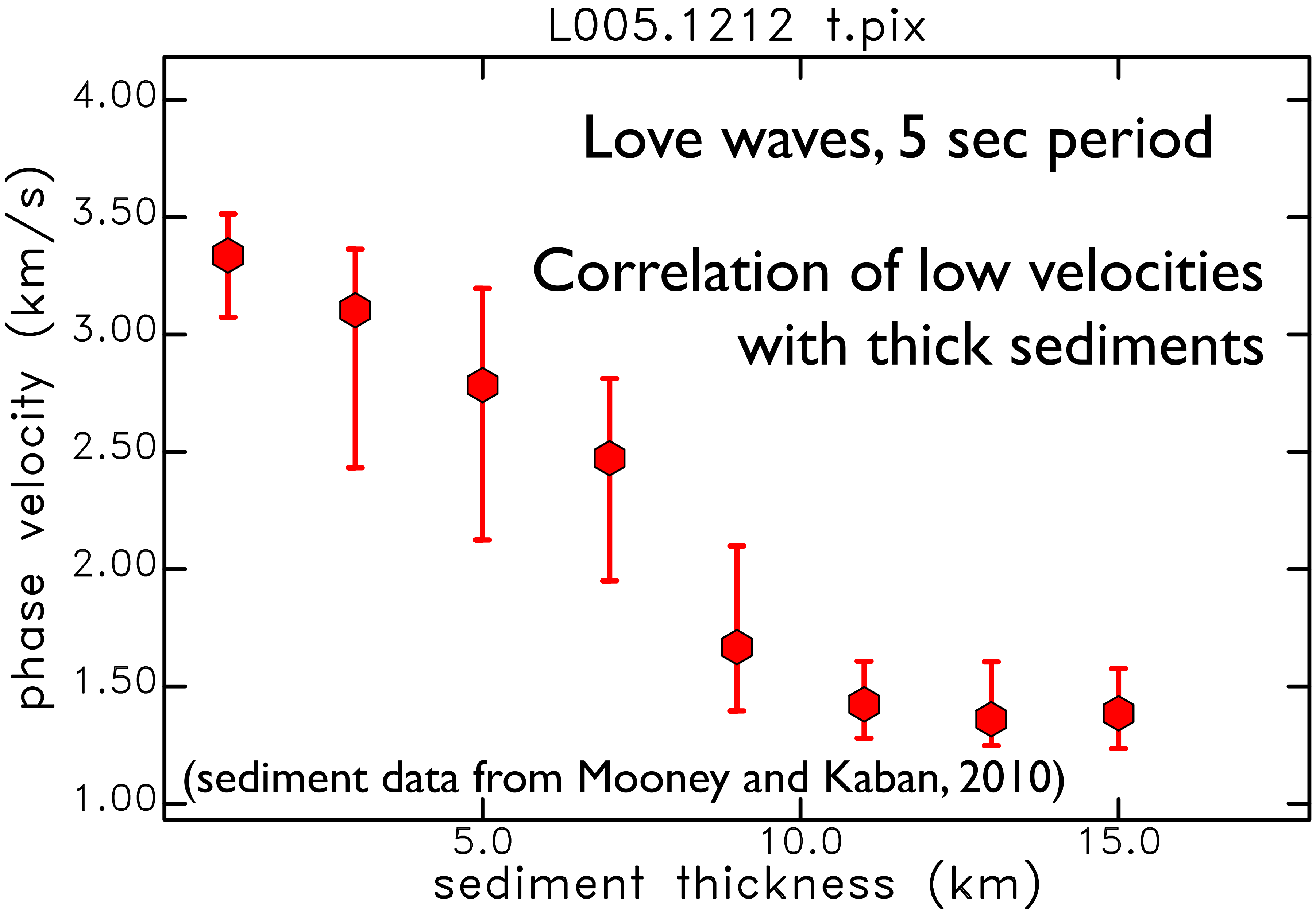


What are we looking at?

Elastic structure of the crust

Including strong signals of slow sediments



Love waves, 5 sec period

Correlation of low velocities with thick sediments

(sediment data from Mooney and Kaban, 2010)

1. The Transportable Array of USArray allows spatially uniform mapping of surface-wave dispersion across the US using noise tomography

2. Aki's spectral approach works well for automation

3. Extremely slow Love and Rayleigh velocities along the Gulf coast (and in other areas) are not matched by current models of the crust

4. Very low VS is needed (high VP/VS ratio) to explain the signals from the basins