What changes when we use ambient noise recorded by fiber optics?

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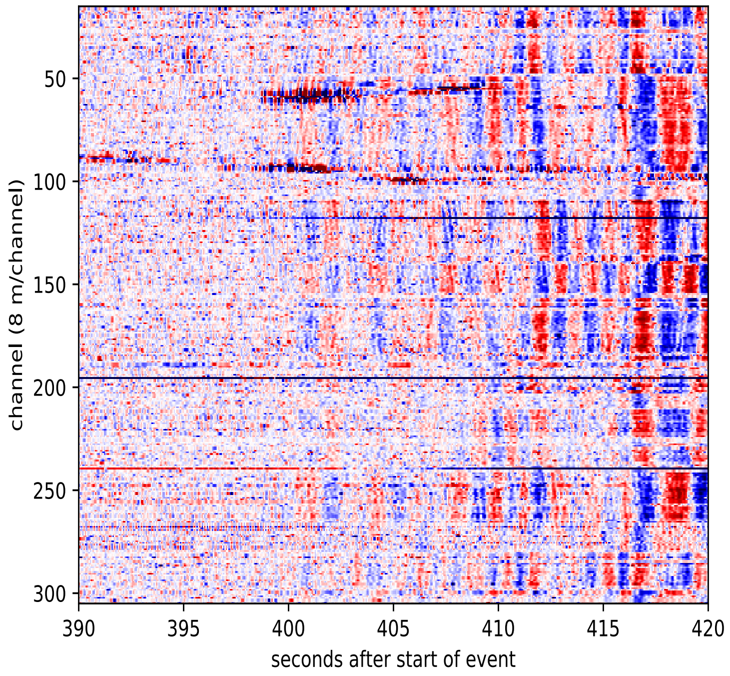
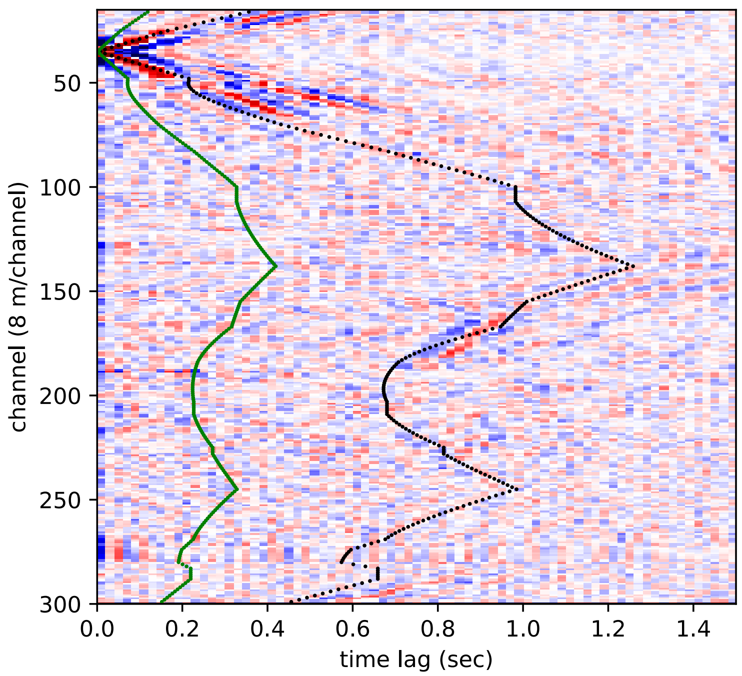


Part 1: If an array passively records a particular source, how should it look on different parts of the array?



Part 2: For any pair of receivers in the array, what should their cross-correlations look like?

Examples of Passively Recording Fiber Optic Arrays

Richmond Field
Station (LBL/CRREL)

Fairbanks Permafrost
Thaw Study (LBL/CRREL)

Stanford Fiber Optic
Seismic Observatory

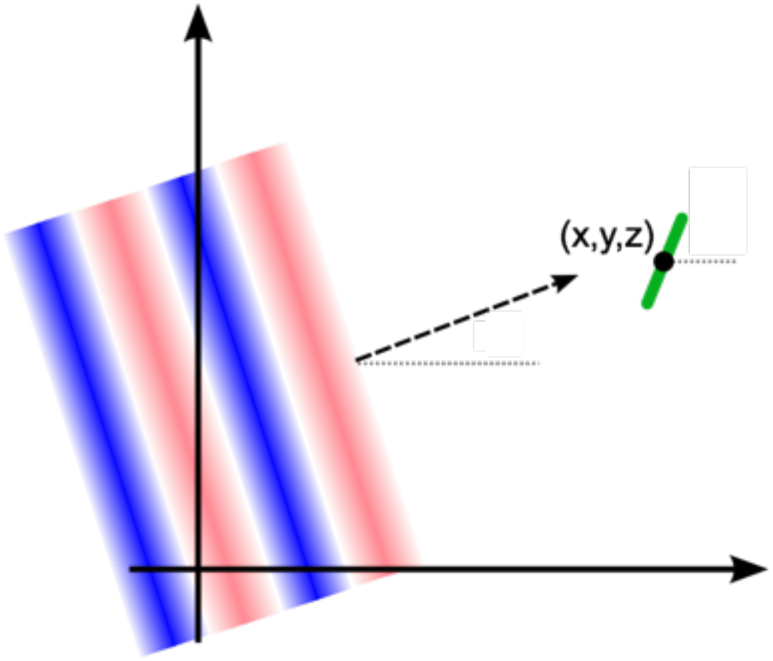
Penn State
FORESEE Array

DAS Records Fiber’s Axial Component of Strain Tensor

DAS = Distributed
Acoustic Sensing

Longitudinal:
P-waves, Rayleigh waves

Transverse:
S-waves, Love waves



Geophone/Seismometer:

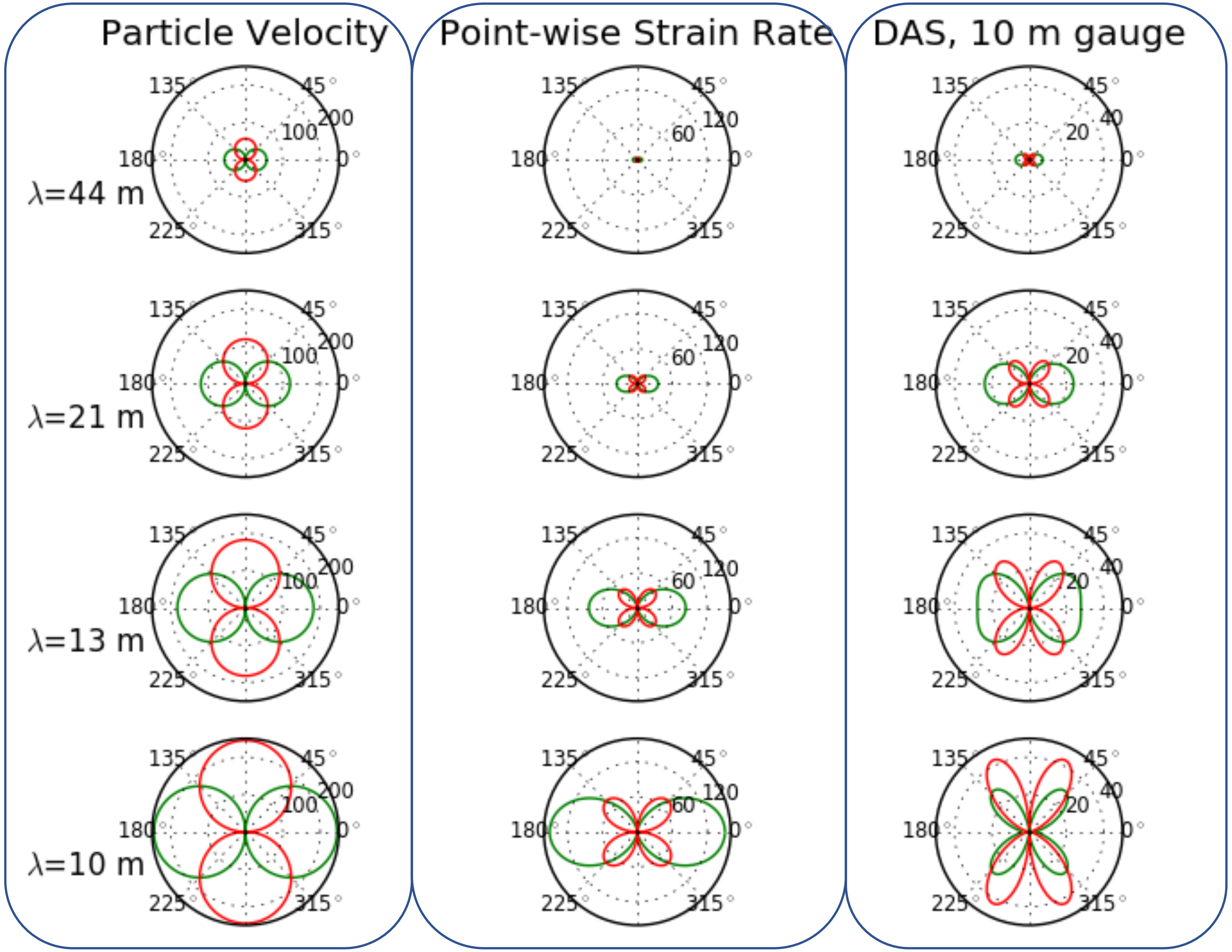
$$u_\theta = \cos(\theta) u_x + \sin(\theta) u_y$$

$$\epsilon_\theta = \cos^2(\theta)\frac{\partial u_x}{\partial x} + \cos(\theta)\sin(\theta)\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right) + \sin^2(\theta)\frac{\partial u_y}{\partial y}$$

$$\Sigma_\theta(x, y, z, t) = \begin{bmatrix} \cos(\theta) & \sin(\theta) & 0 \\ -\sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \frac{\partial u_x}{\partial x} & \frac{1}{2}\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right) & \frac{1}{2}\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right) \\ \frac{1}{2}\left(\frac{\partial u_x}{\partial y} + \frac{\partial u_y}{\partial x}\right) & \frac{\partial u_y}{\partial y} & \frac{1}{2}\left(\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}\right) \\ \frac{1}{2}\left(\frac{\partial u_x}{\partial z} + \frac{\partial u_z}{\partial x}\right) & \frac{1}{2}\left(\frac{\partial u_y}{\partial z} + \frac{\partial u_z}{\partial y}\right) & \frac{\partial u_z}{\partial z} \end{bmatrix} \begin{bmatrix} \cos(\theta) & -\sin(\theta) & 0 \\ \sin(\theta) & \cos(\theta) & 0 \\ 0 & 0 & 1 \end{bmatrix}$$

Detected Signal Comparison

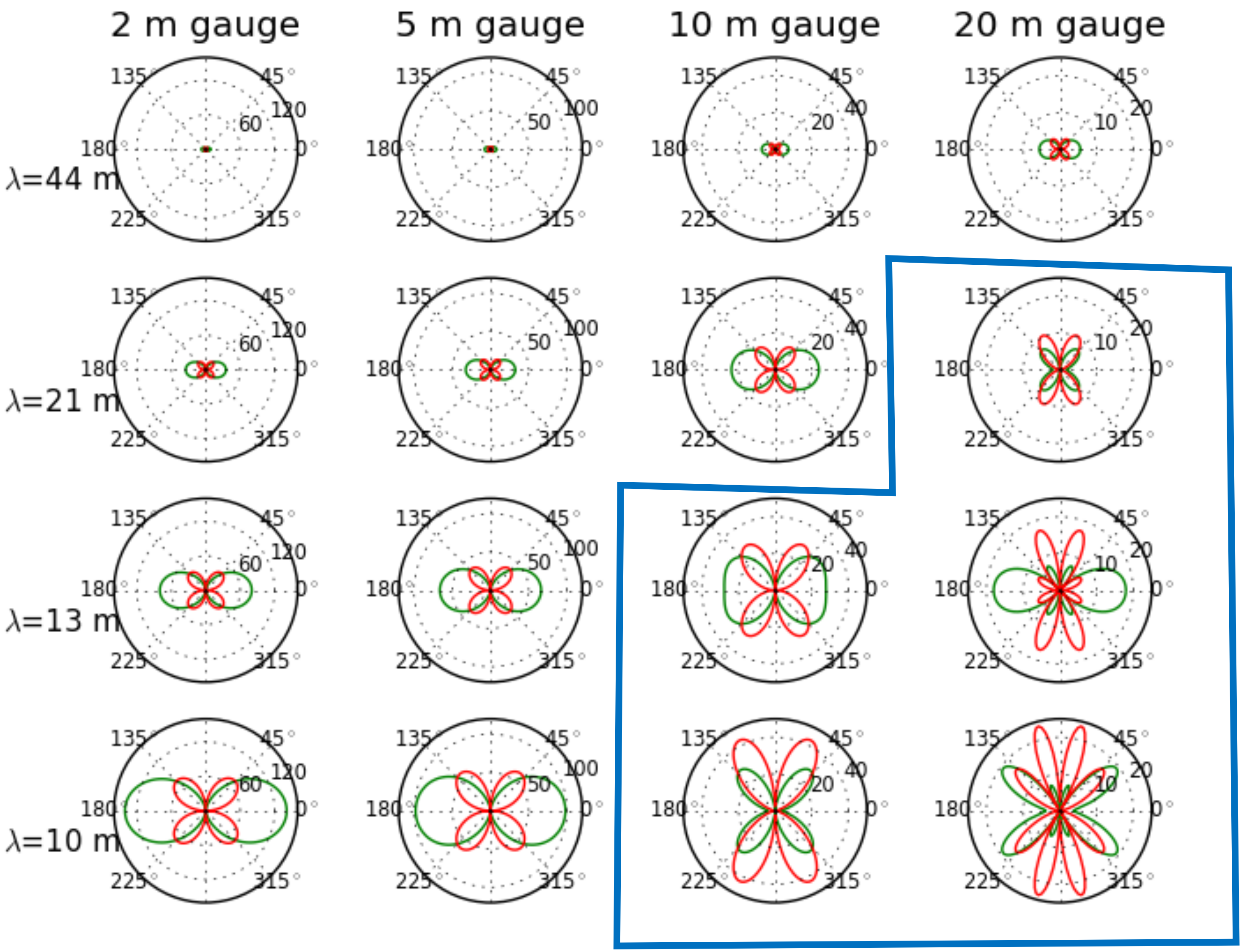
Rayleigh and Love Waves



Note:
Sensors oriented
along 0 degrees

Detected Signal Comparison: Gauge Effect

Rayleigh and Love Waves

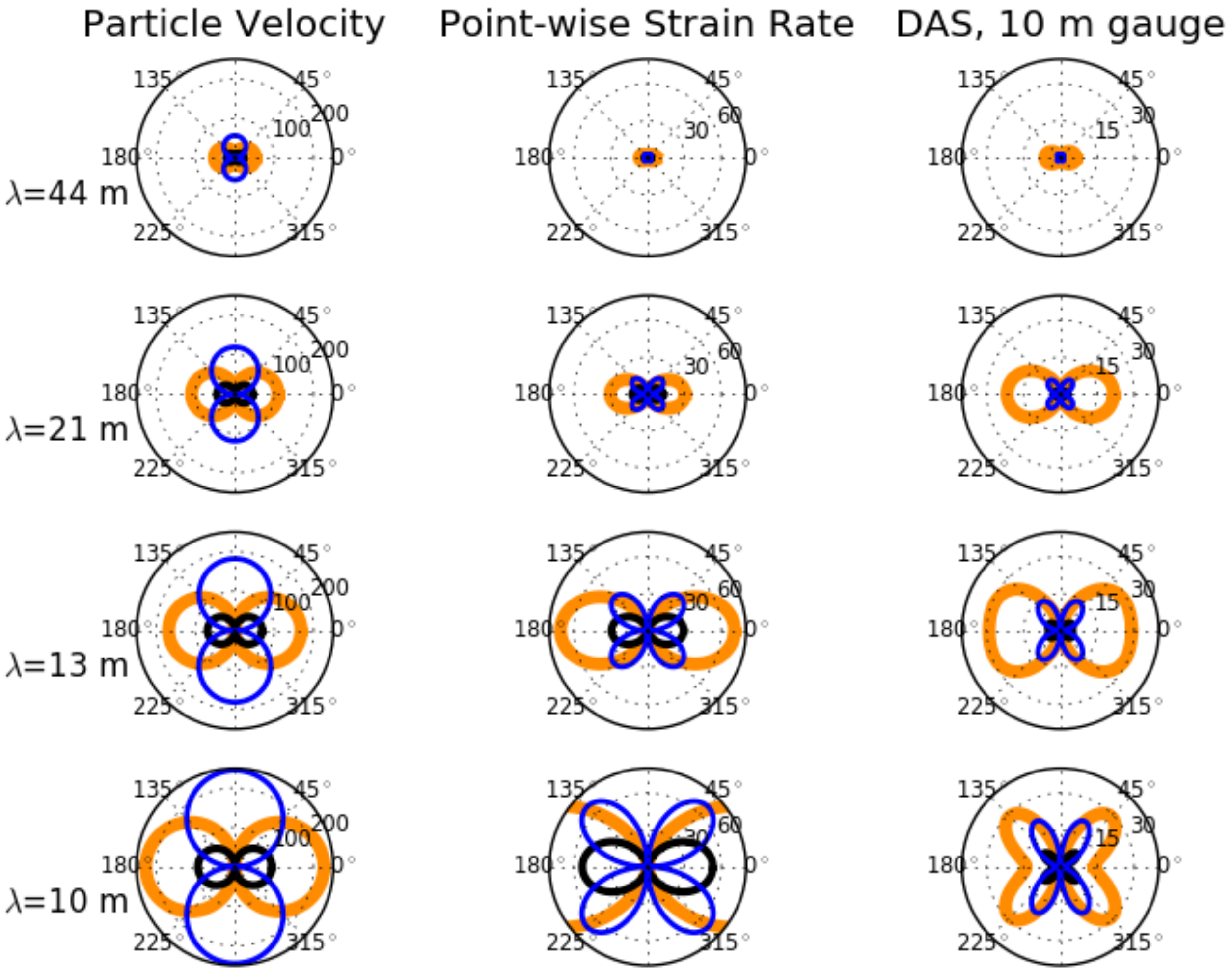


if wavelength too small relative to gauge length

Note:
Sensors oriented along 0 degrees

Detected Signal Comparison

P, SV and SH Waves

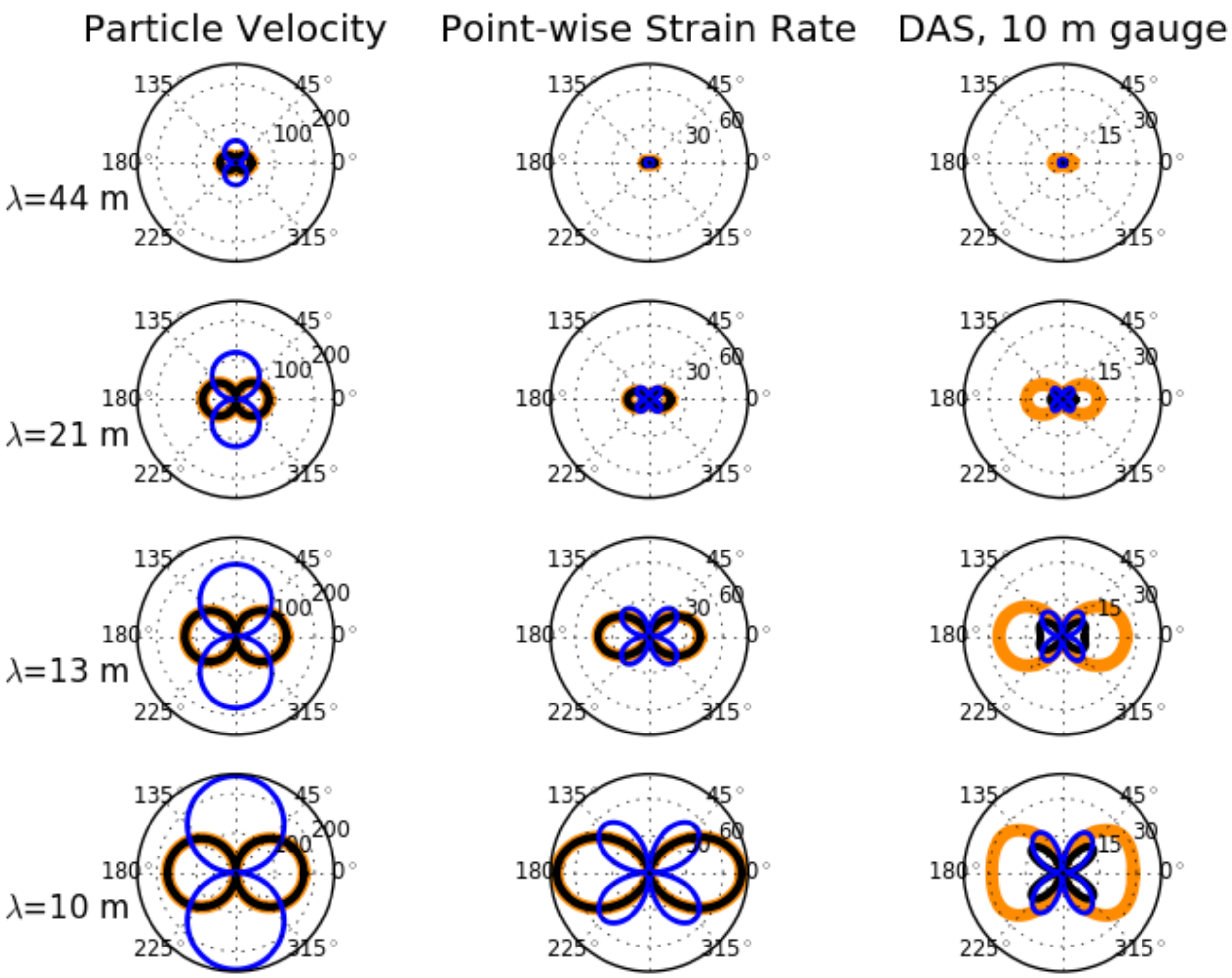


Note:
Sensors oriented along 0 degrees horizontal

Wave's vertical angle of incidence 22.5 degrees

Detected Signal Comparison

P, SV and SH Waves

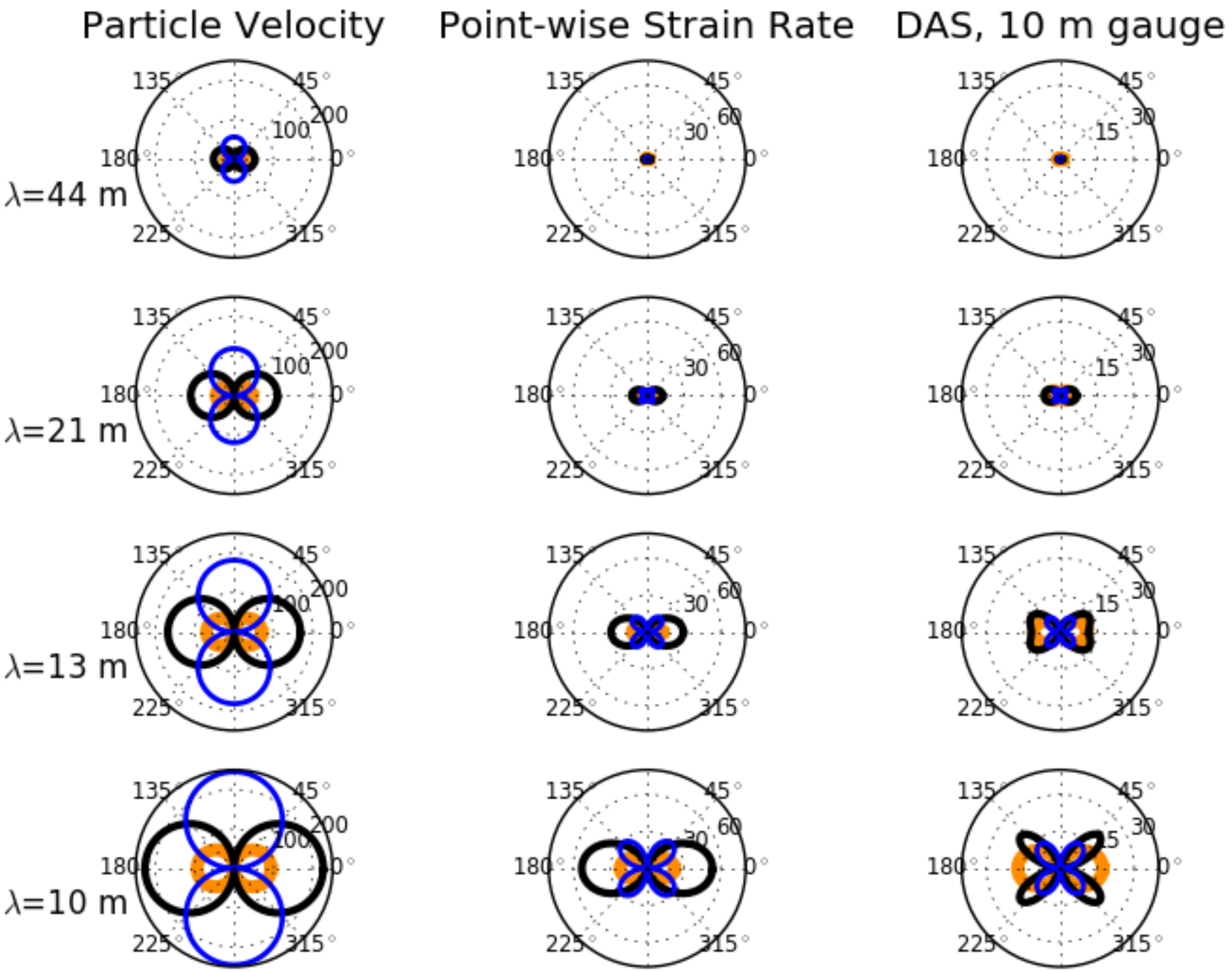


Note:
Sensors oriented along 0 degrees horizontal

Wave's vertical angle of incidence 45 degrees

Detected Signal Comparison

P, SV and SH Waves

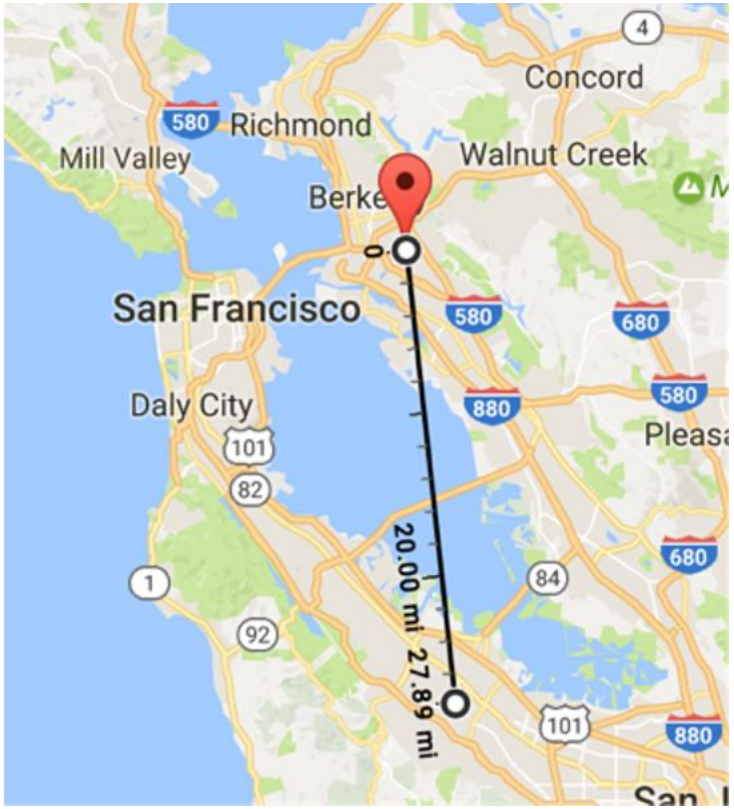


Note:
Sensors oriented along 0 degrees horizontal

Wave's vertical angle of incidence 67.5 degrees

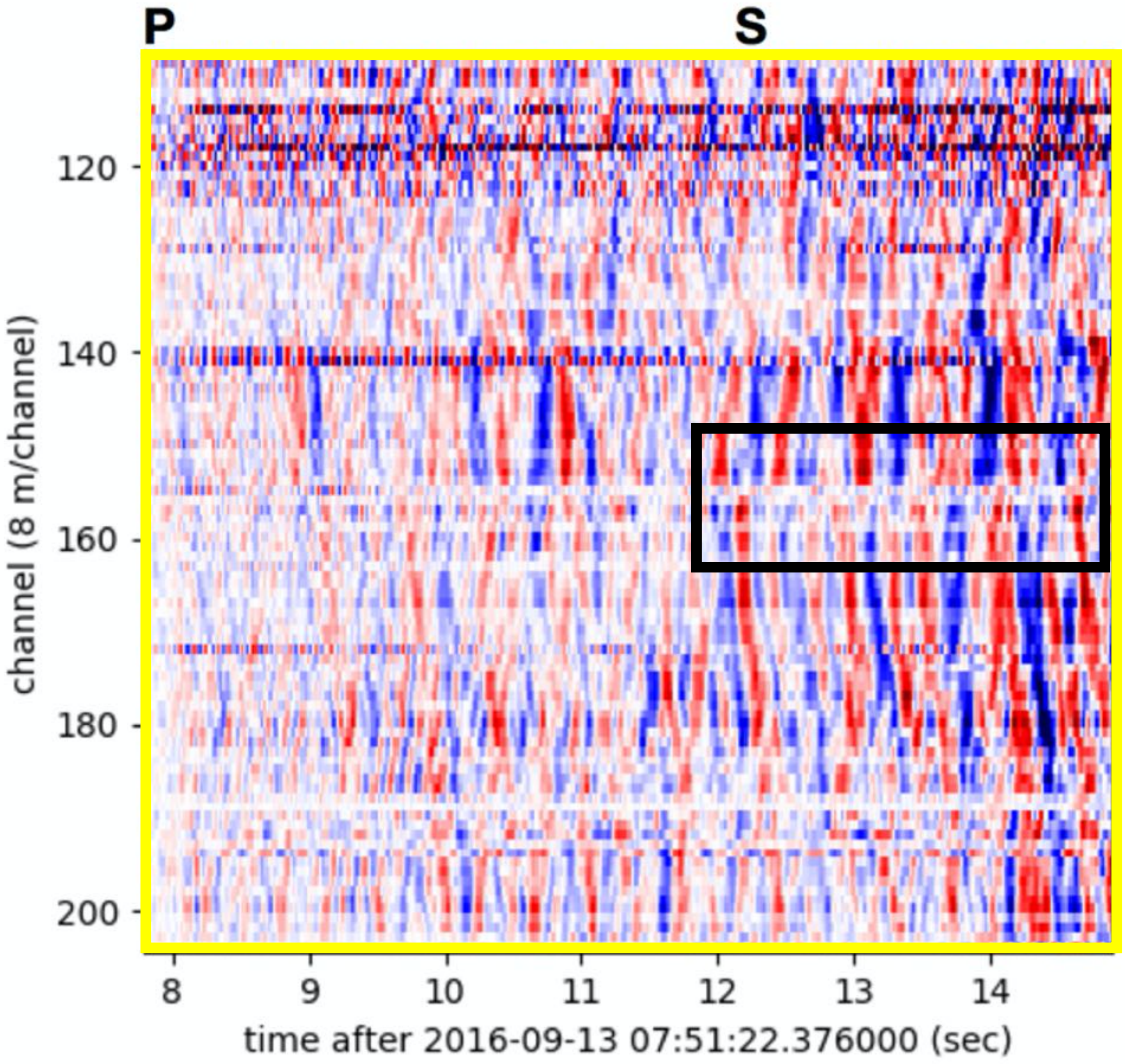
Nearby Earthquake Example

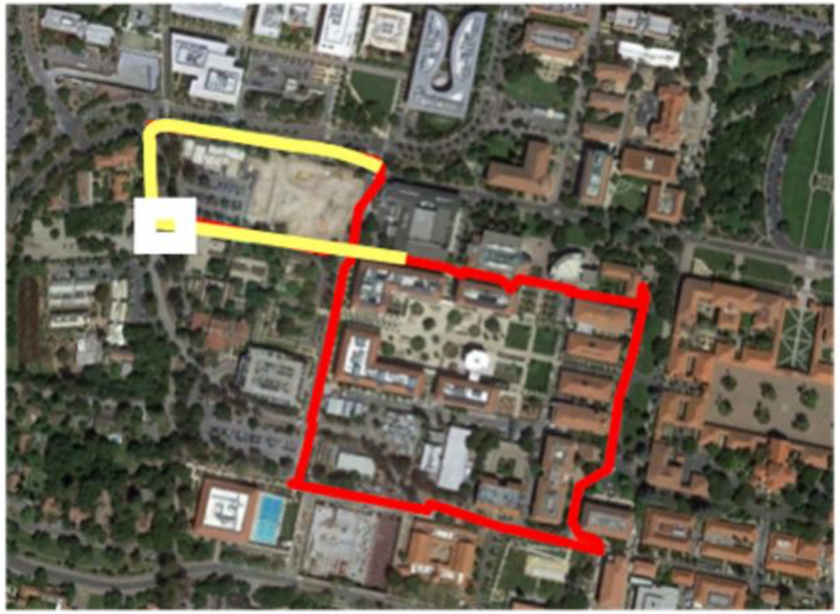
Magnitude 3.5 earthquake
Piedmont, CA



Recorded on the Stanford Fiber Optic Seismic Observatory

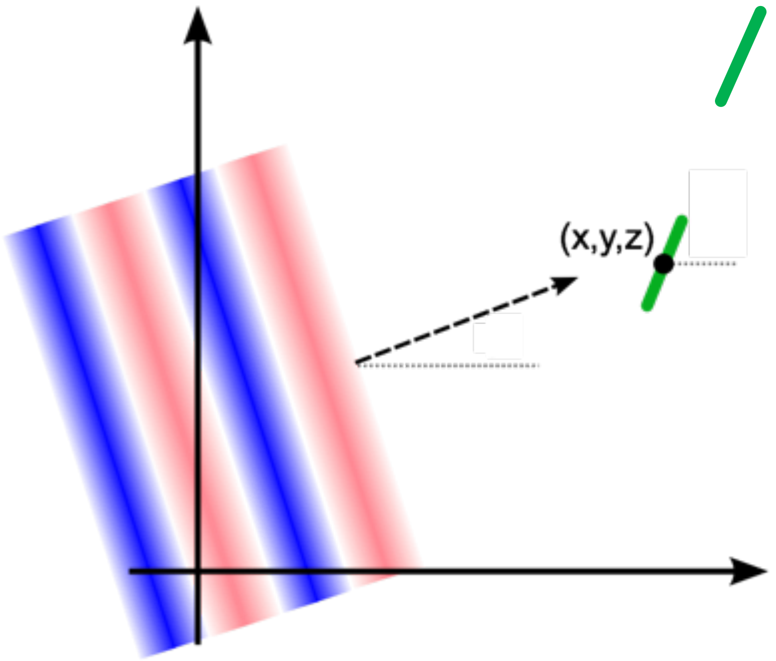
S-wave Polarity Switches at Corners

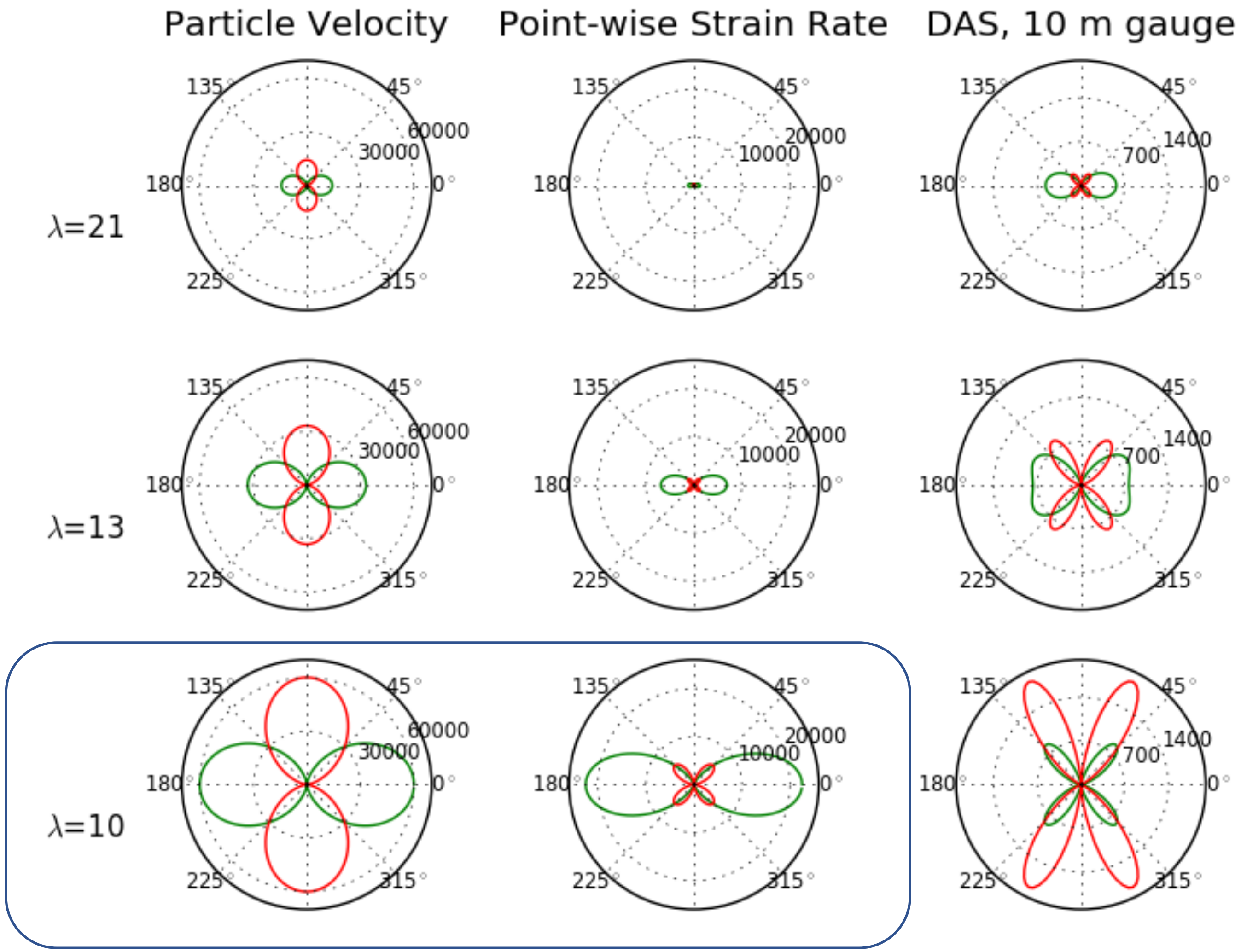




Radial-Radial Cross-correlation Sensitivity

Rayleigh and Love Waves

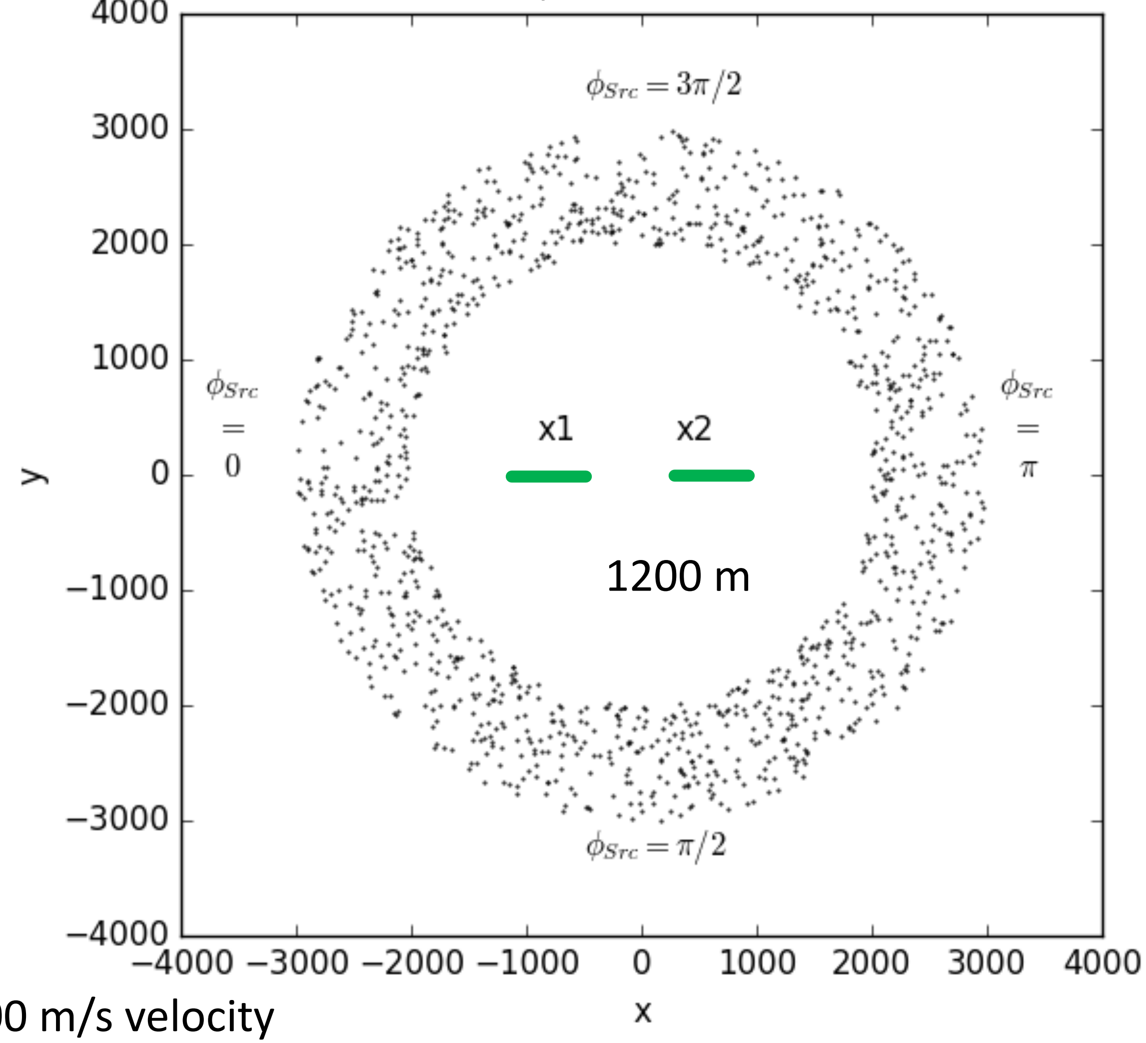


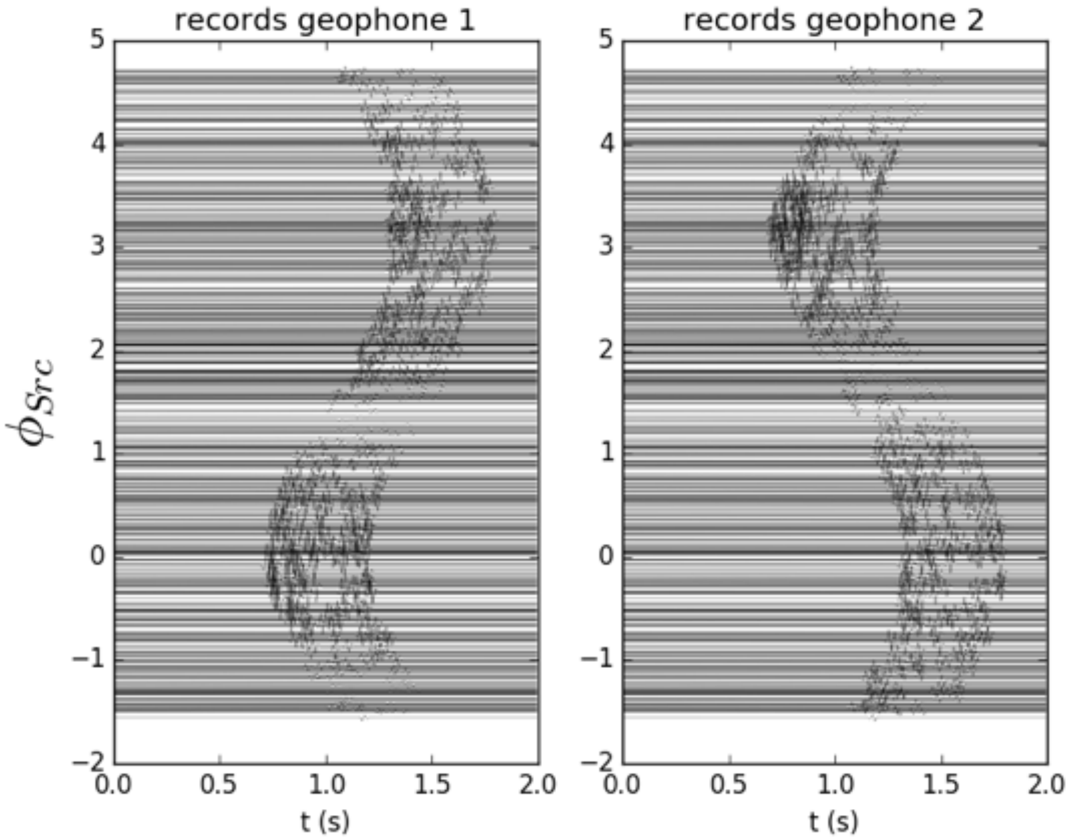


Simple Synthetic: Random Sources Around Sensors

based on Wapenaar et al, 2010

Sources randomly in 2000-3000 m radius

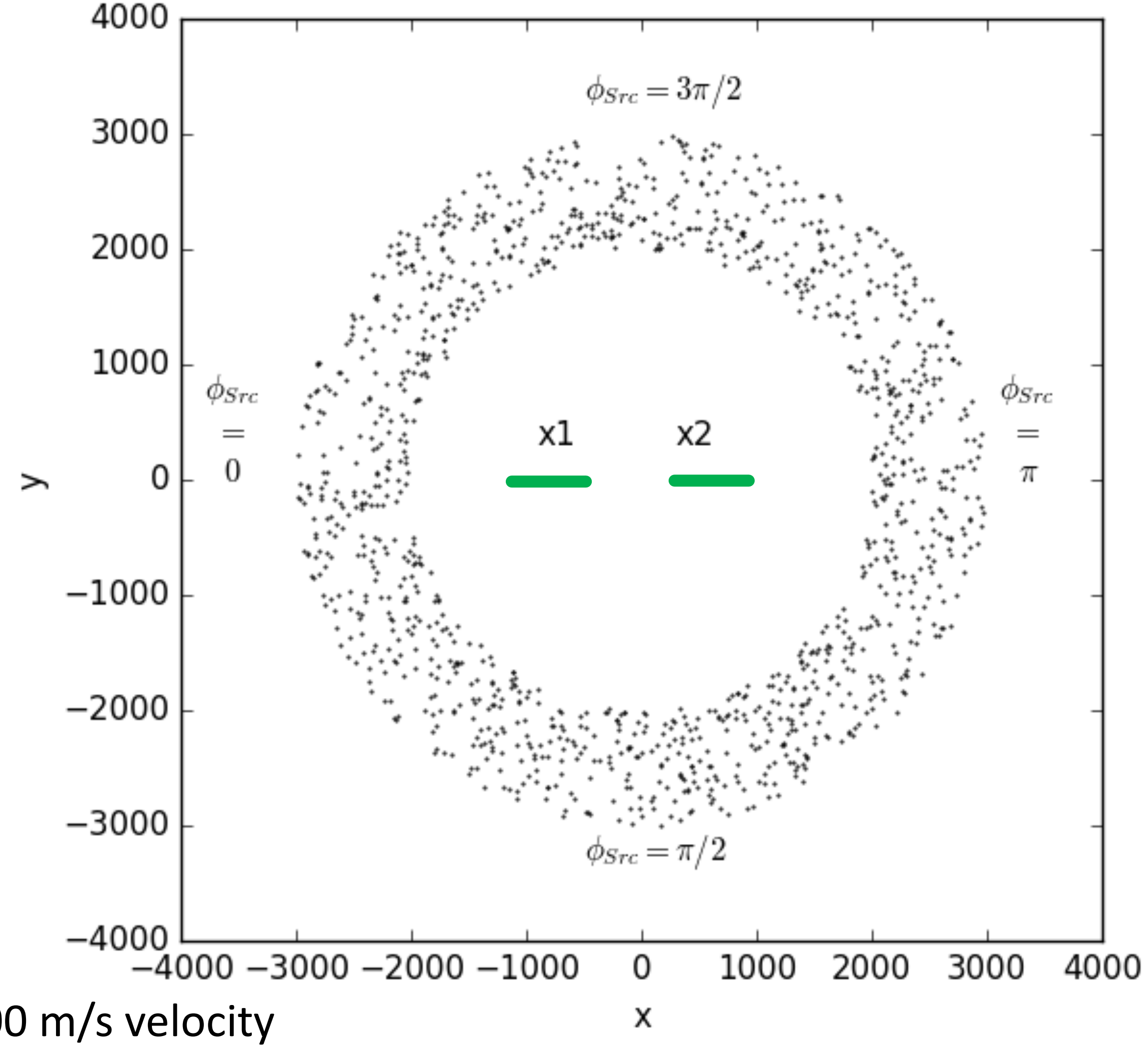


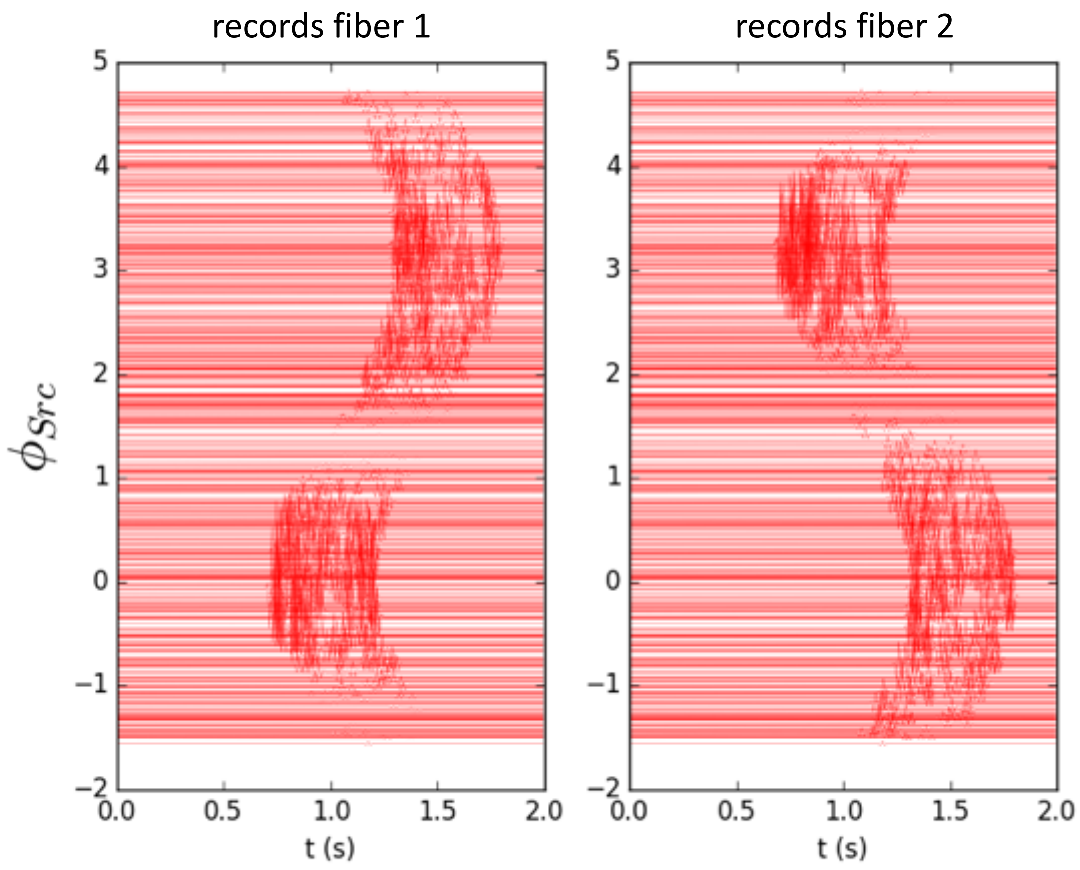


2000 m/s velocity

Simple Synthetic: Random Sources Around Sensors

based on Wapenaar et al, 2010





2000 m/s velocity

Simple Synthetic: Random Sources Around Sensors

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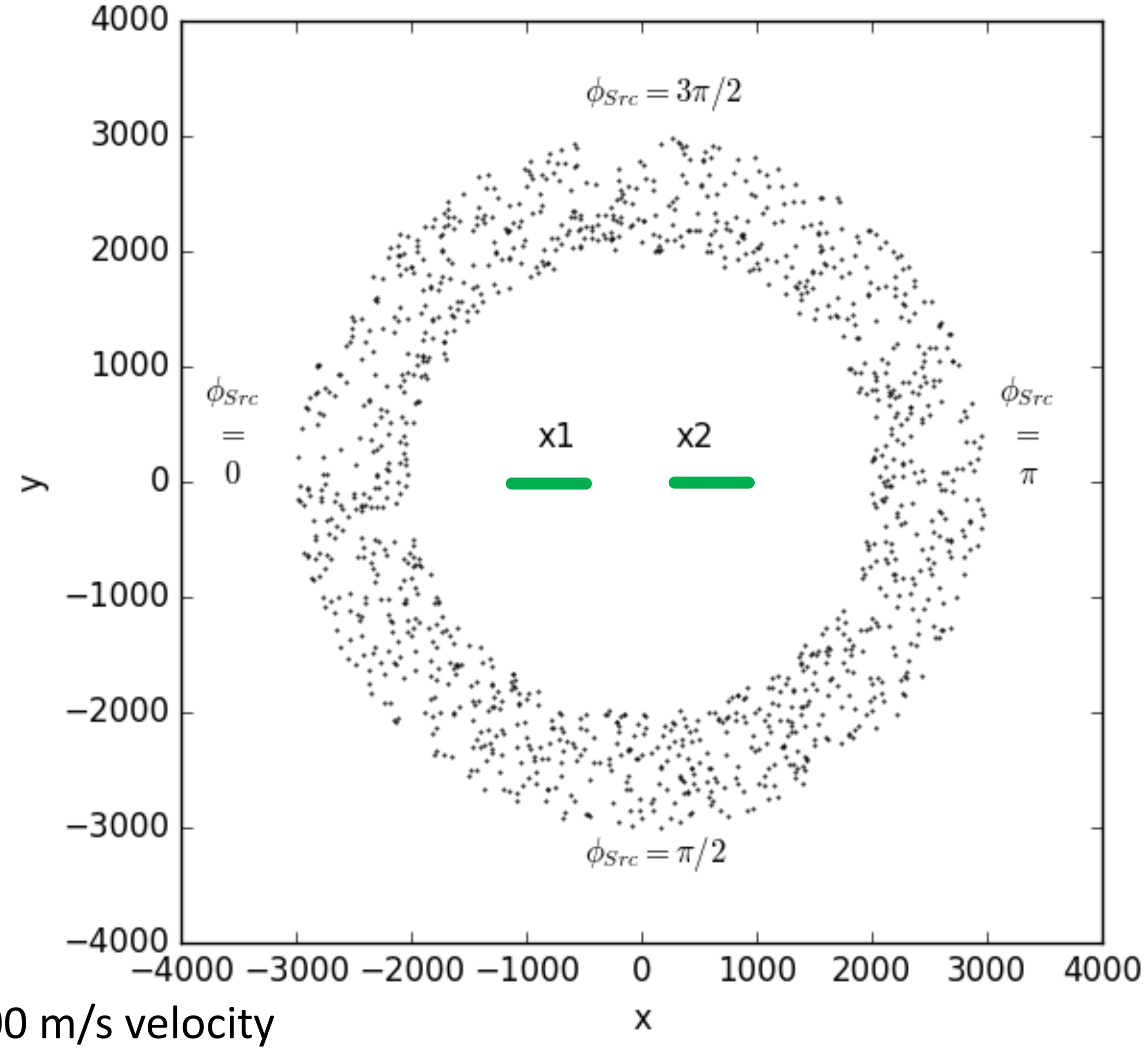

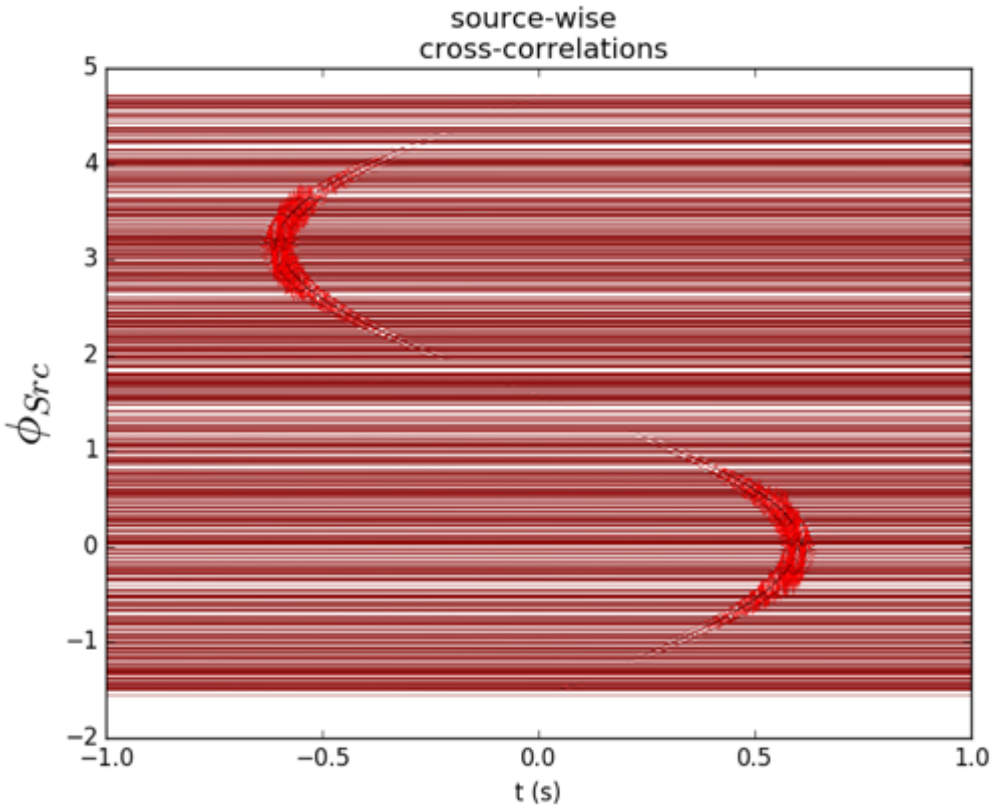

2000 m/s velocity

Simple Synthetic: Random Sources Around Sensors

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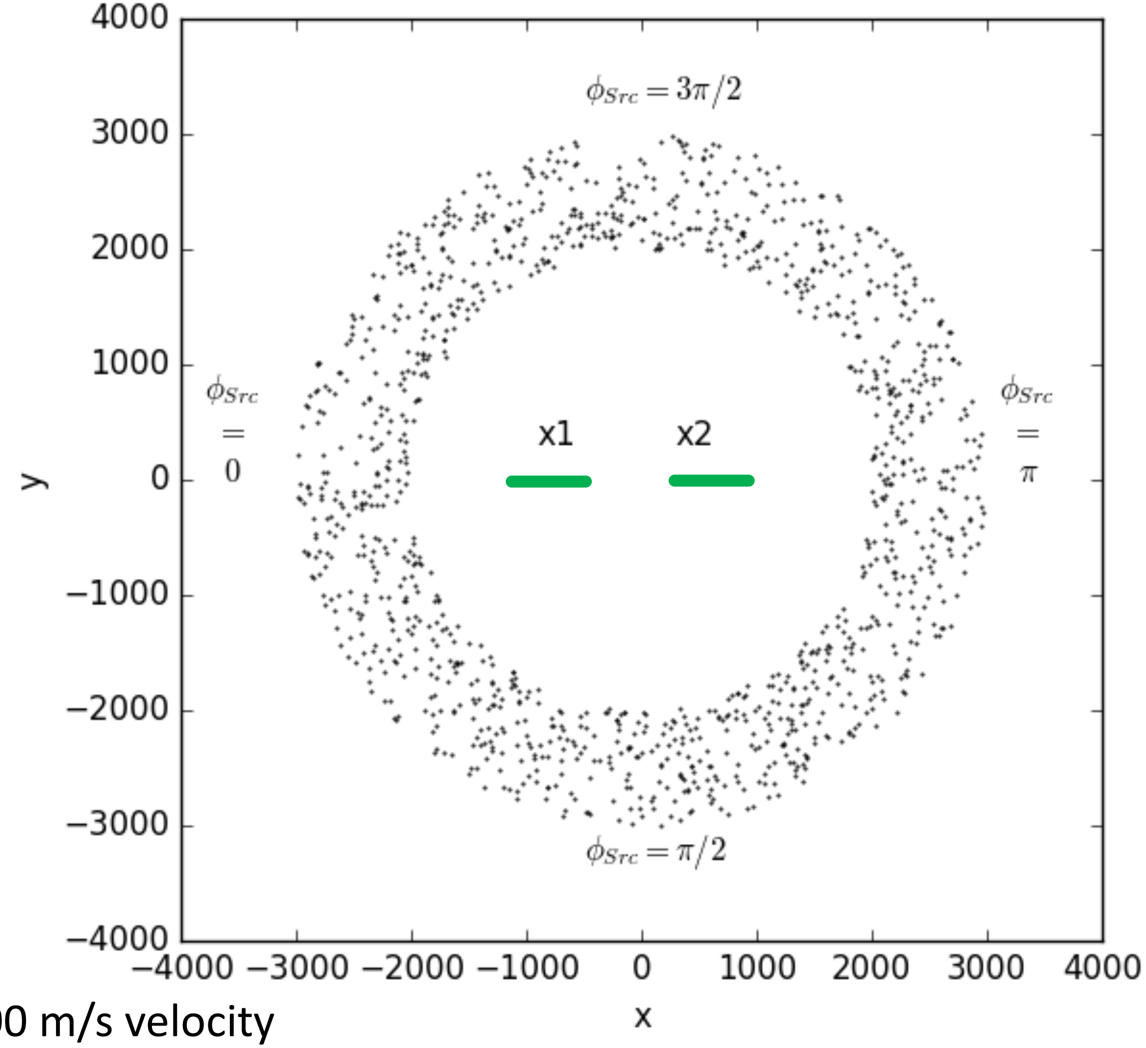
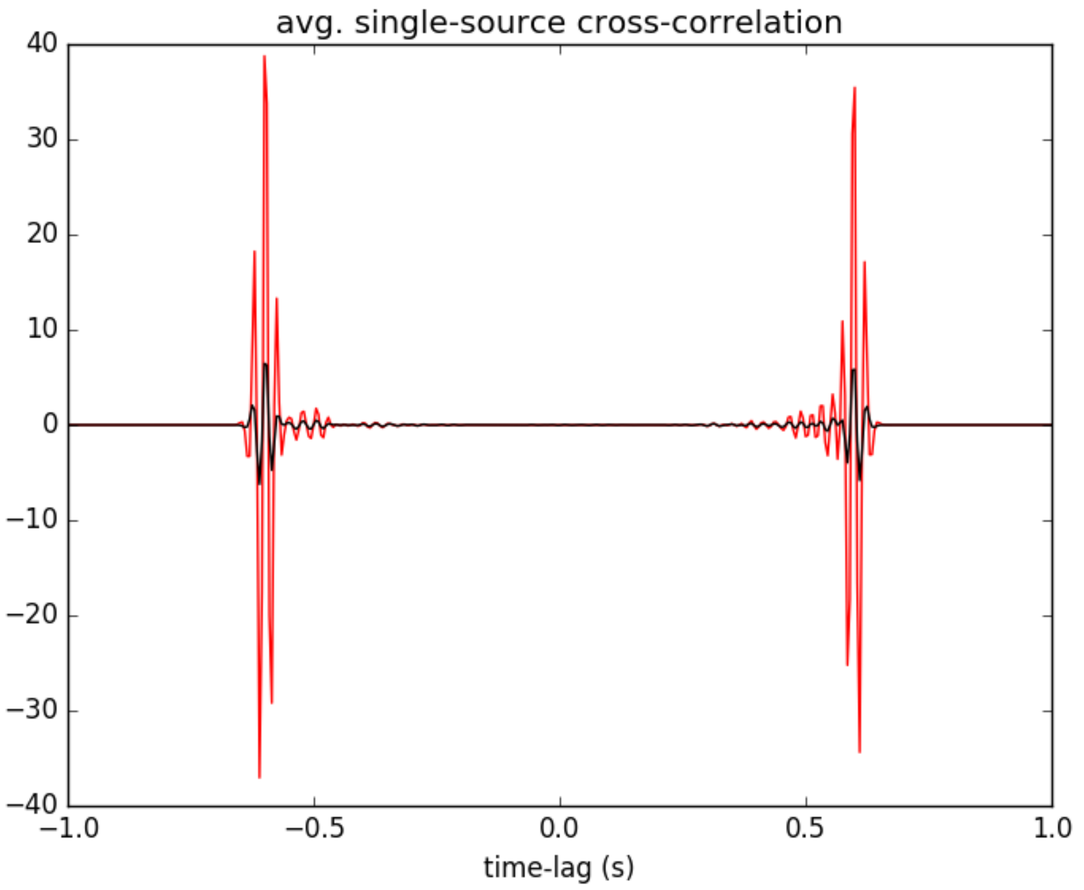
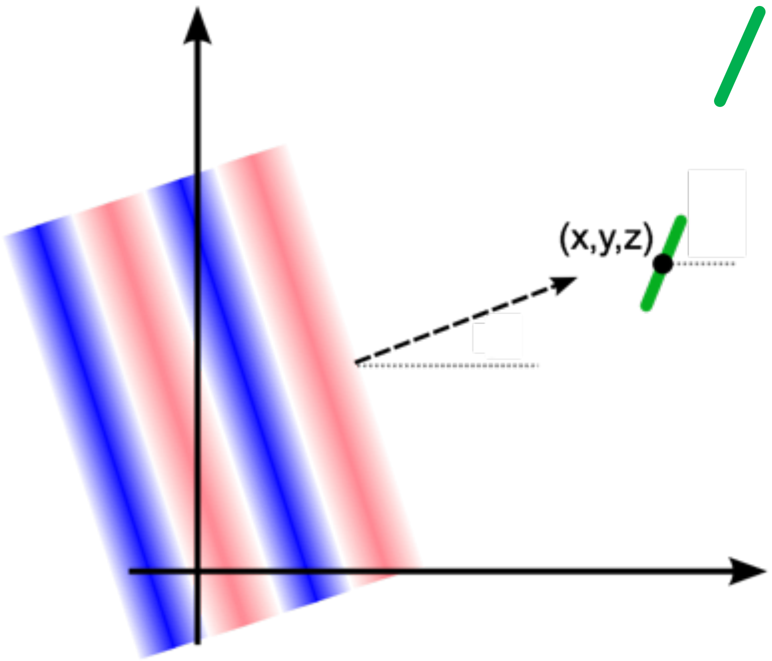




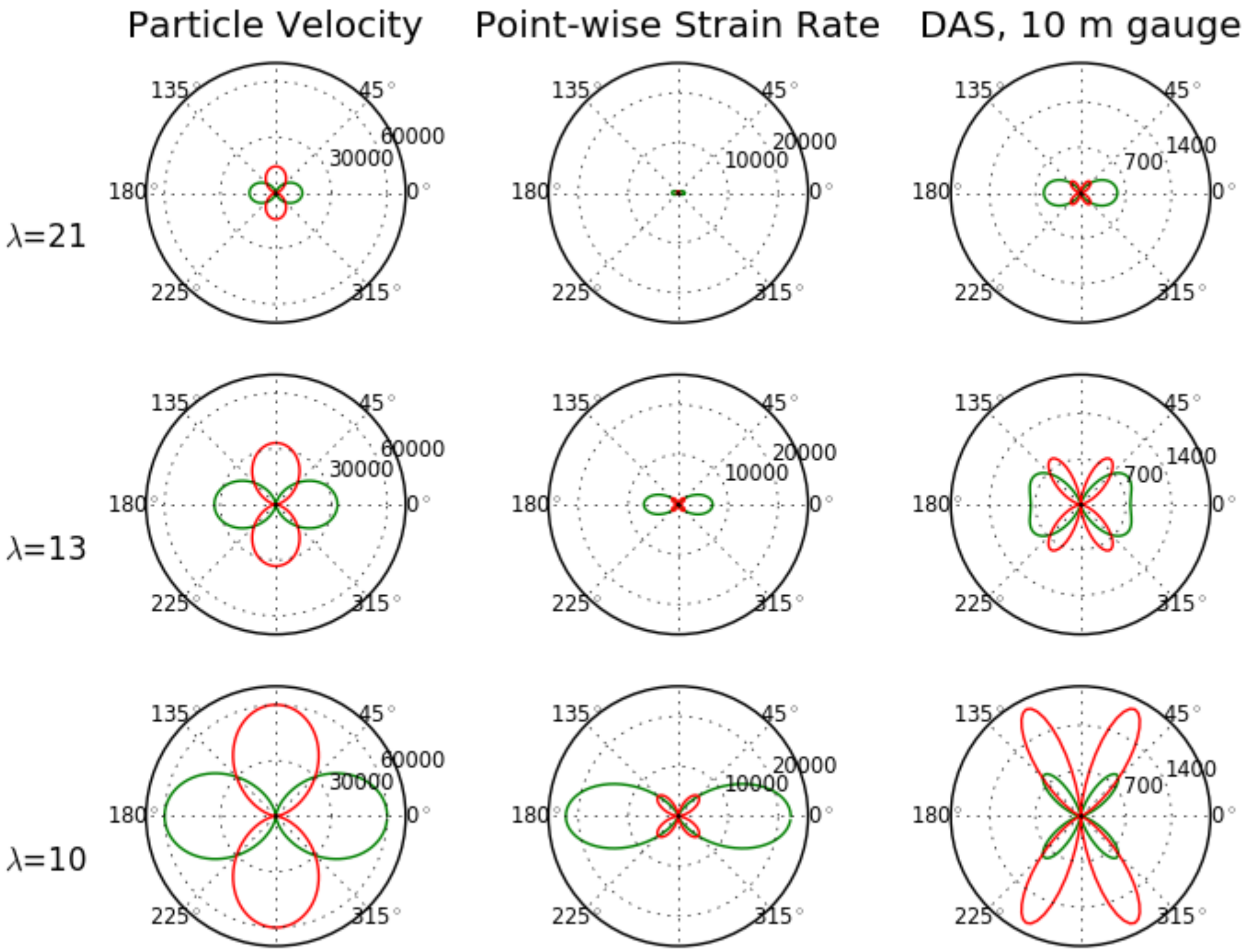
2000 m/s velocity

Fiber, geophone

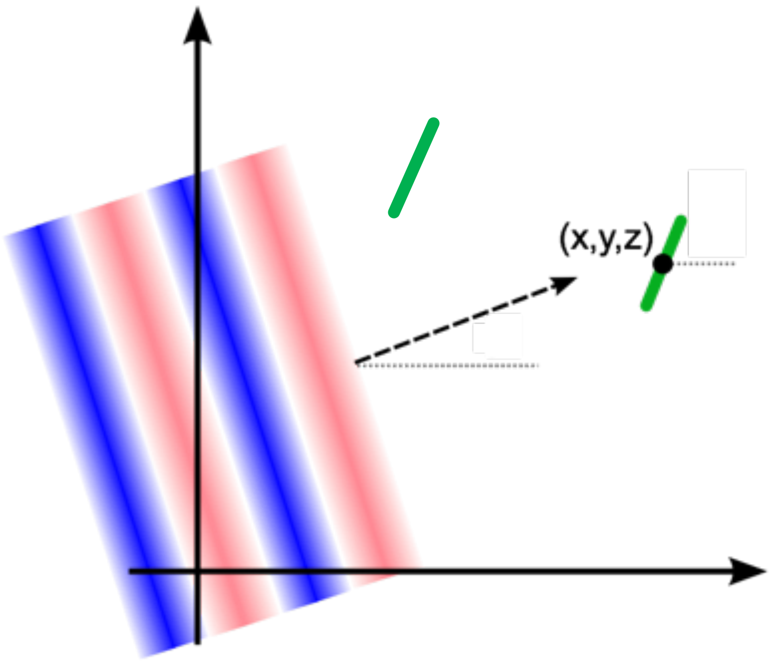
Radial-Radial Cross-correlation Sensitivity



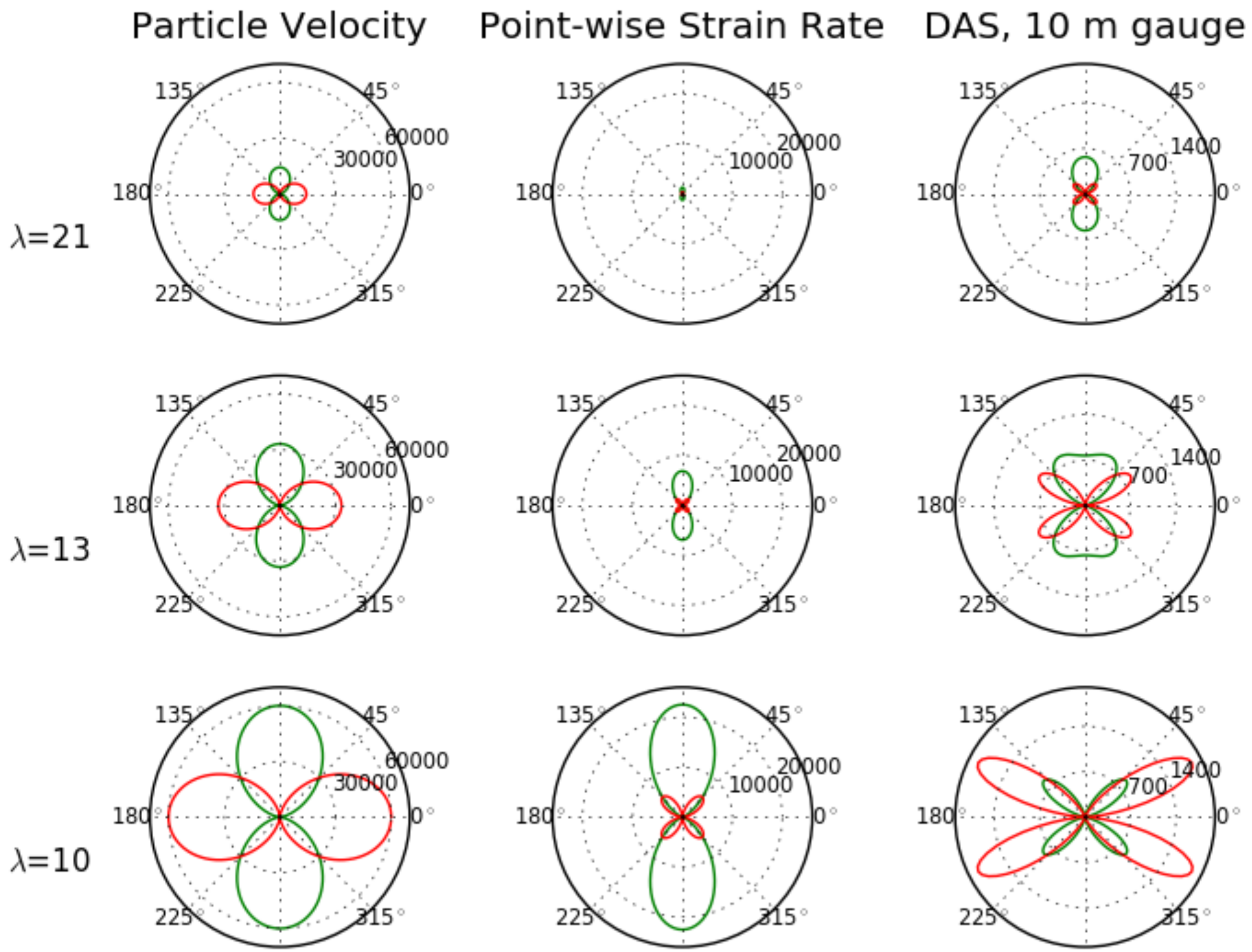
Rayleigh and Love Waves



Transverse-Transverse Cross-correlation Sensitivity

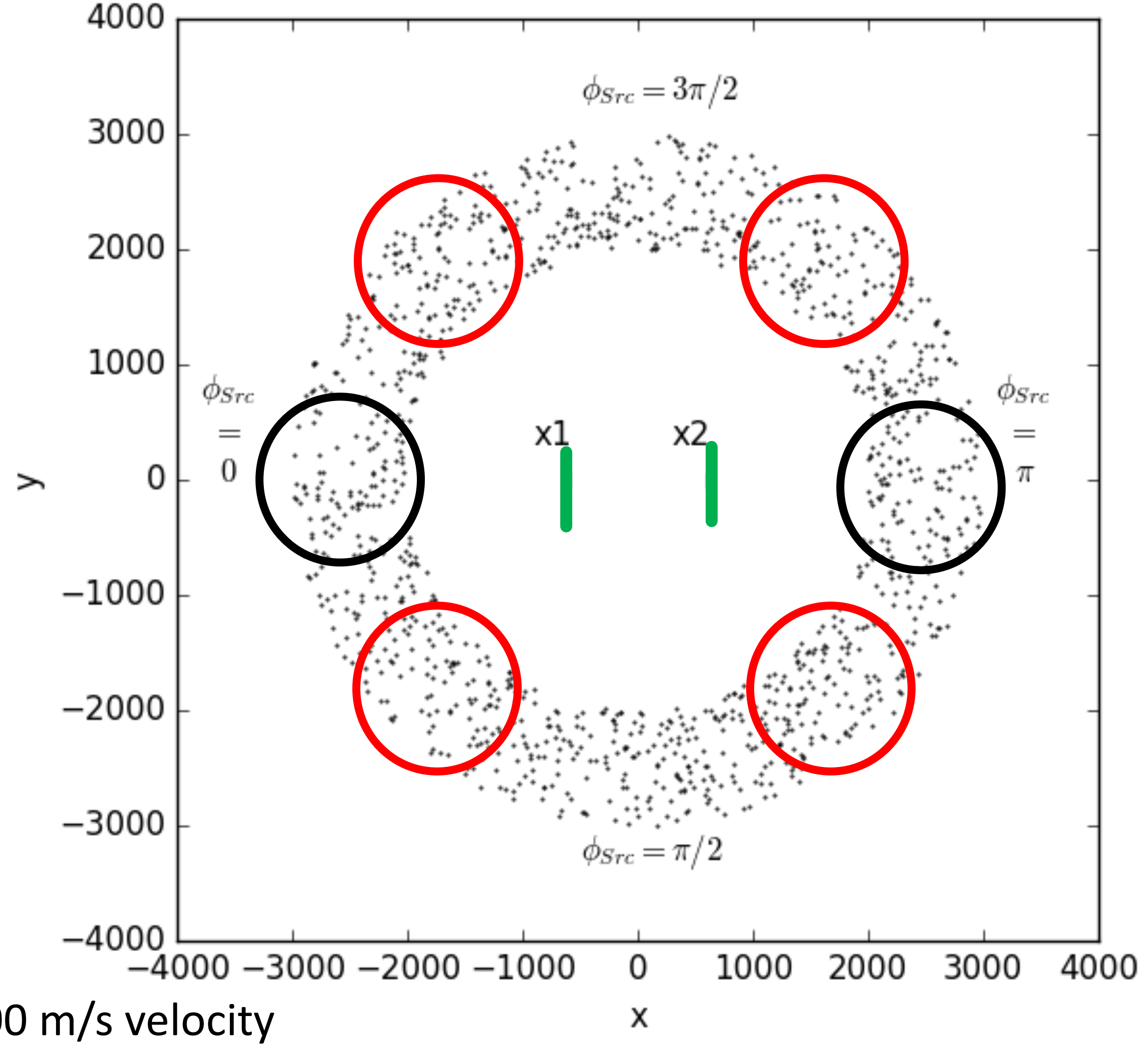


Rayleigh and Love Waves

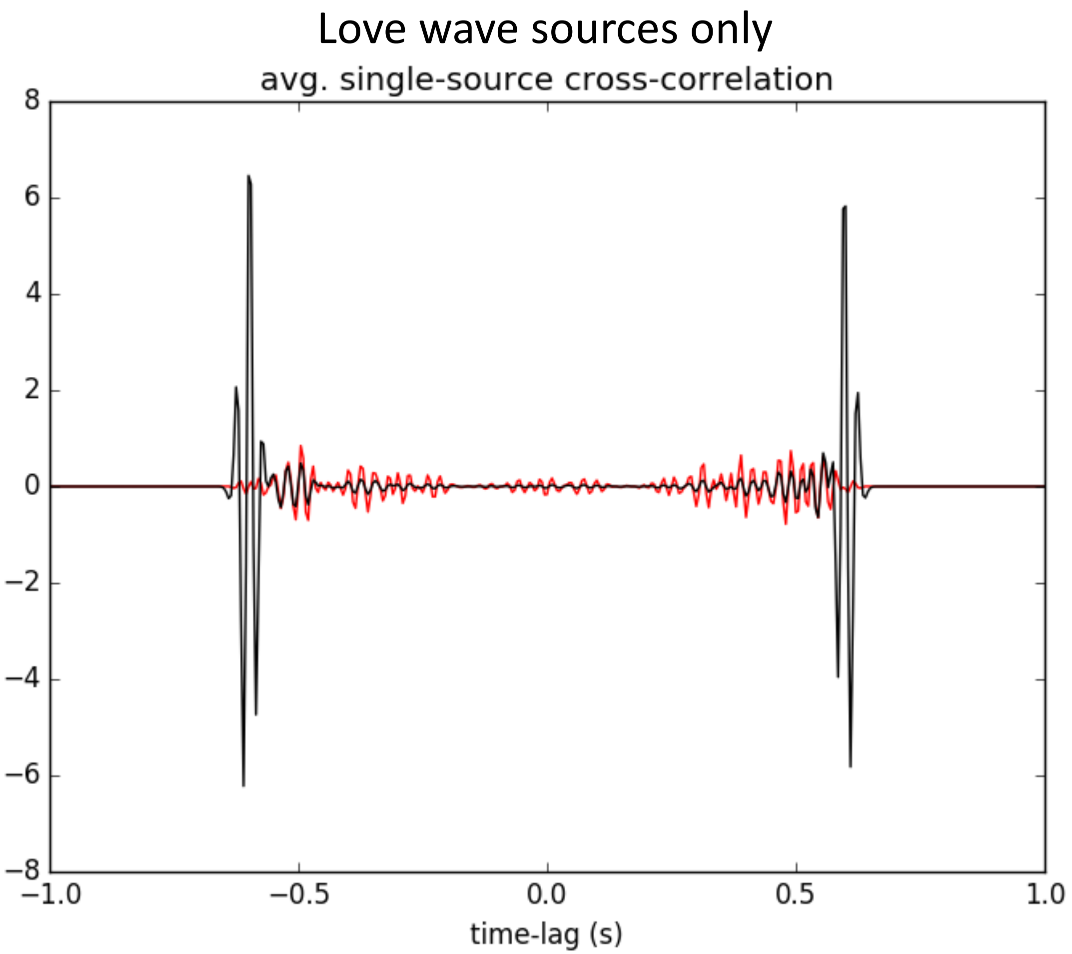


Simple Synthetic: Random Love Wave Sources Around Sensors

based on Wapenaar et al, 2010



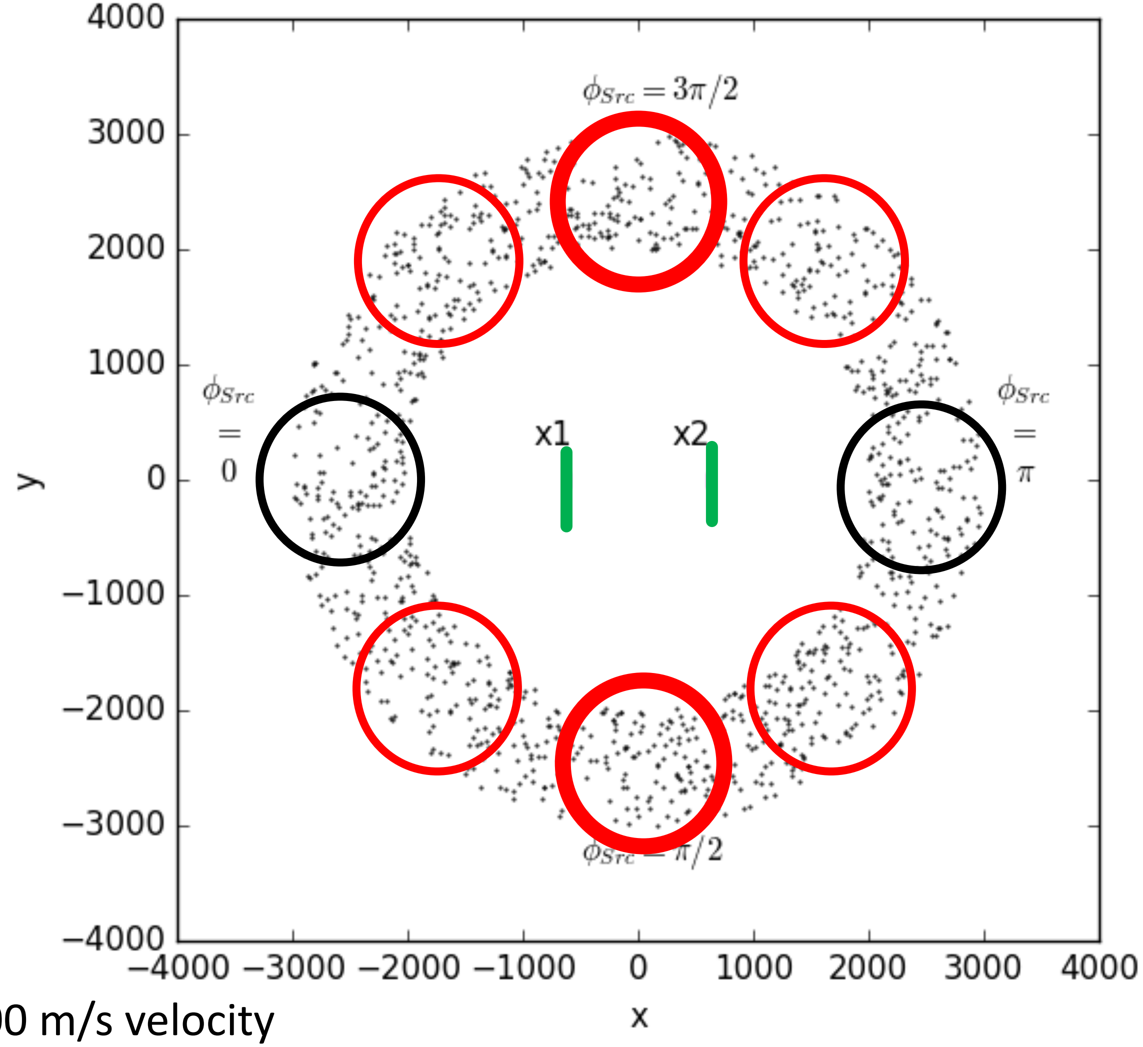
2000 m/s velocity



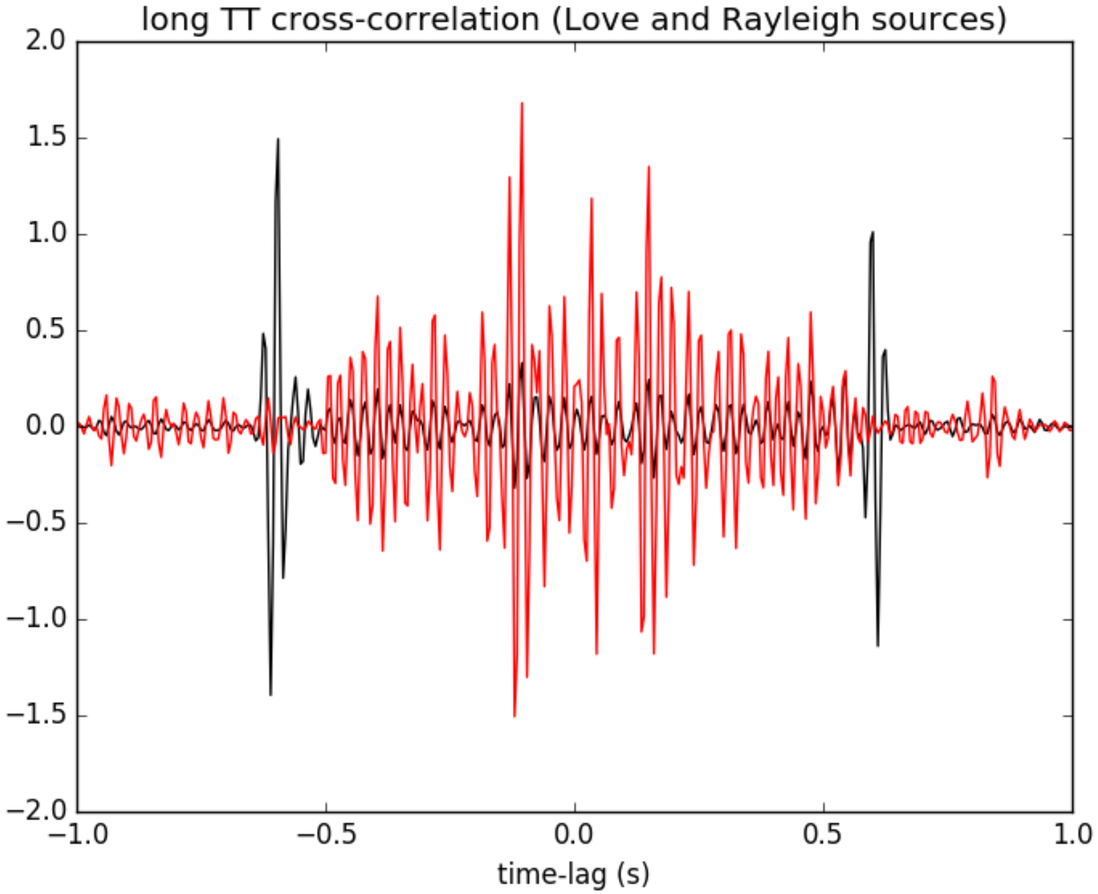
Fiber, geophone

Simple Synthetic: Random Sources Around Sensors

based on Wapenaar et al, 2010



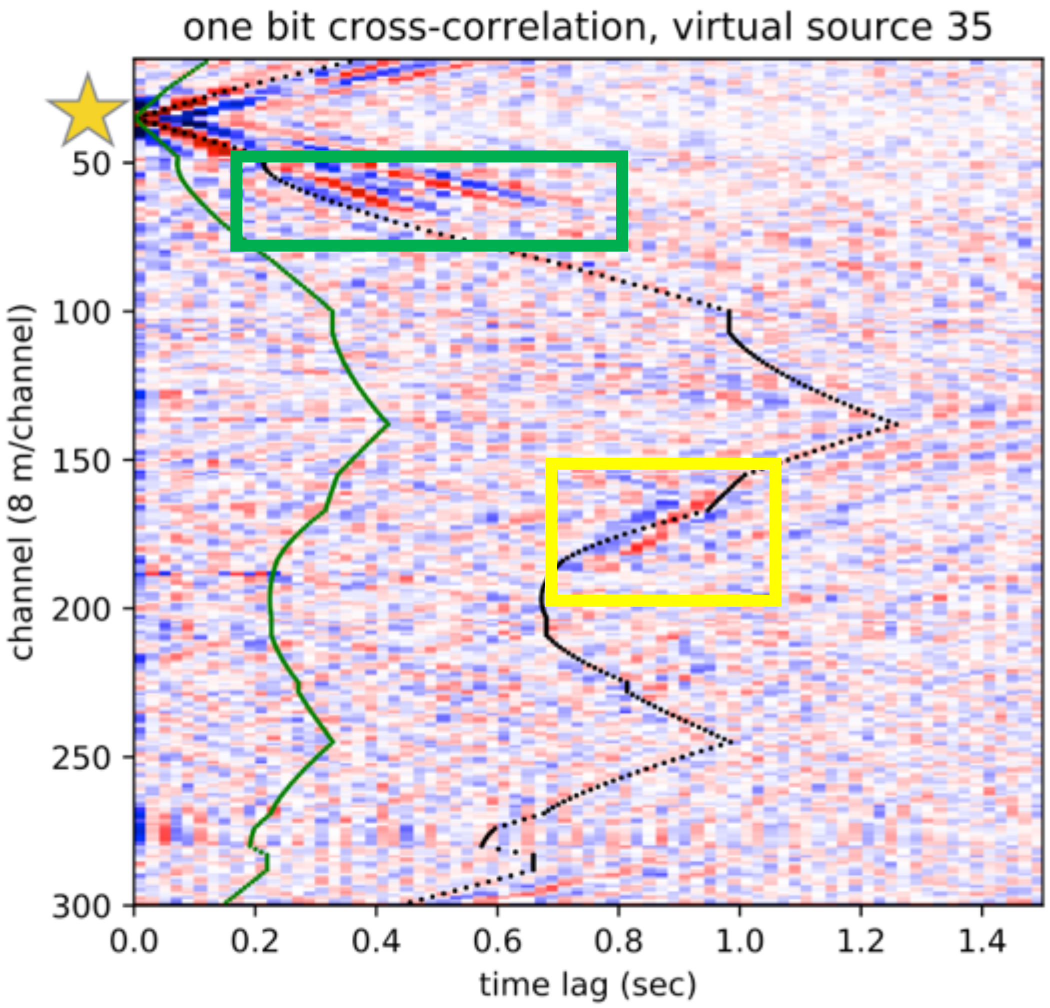
2000 m/s velocity

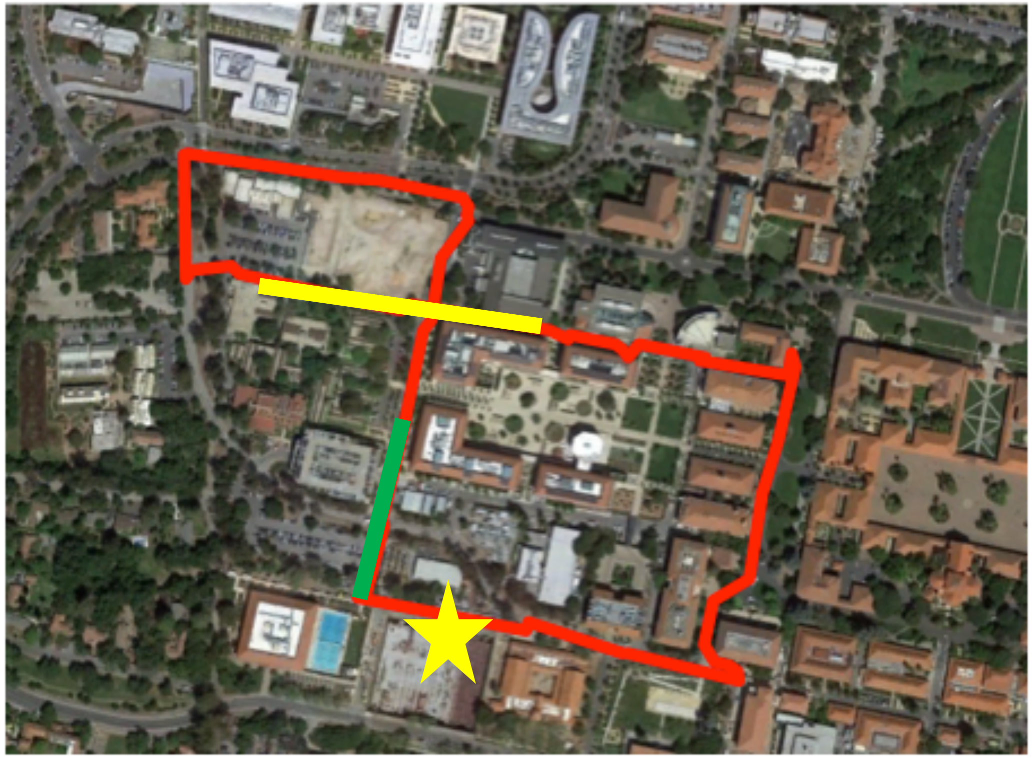


Fiber, geophone

How this affects real data: we get signals along Parallel lines, but not at the closest offsets

400 m/s
1200 m

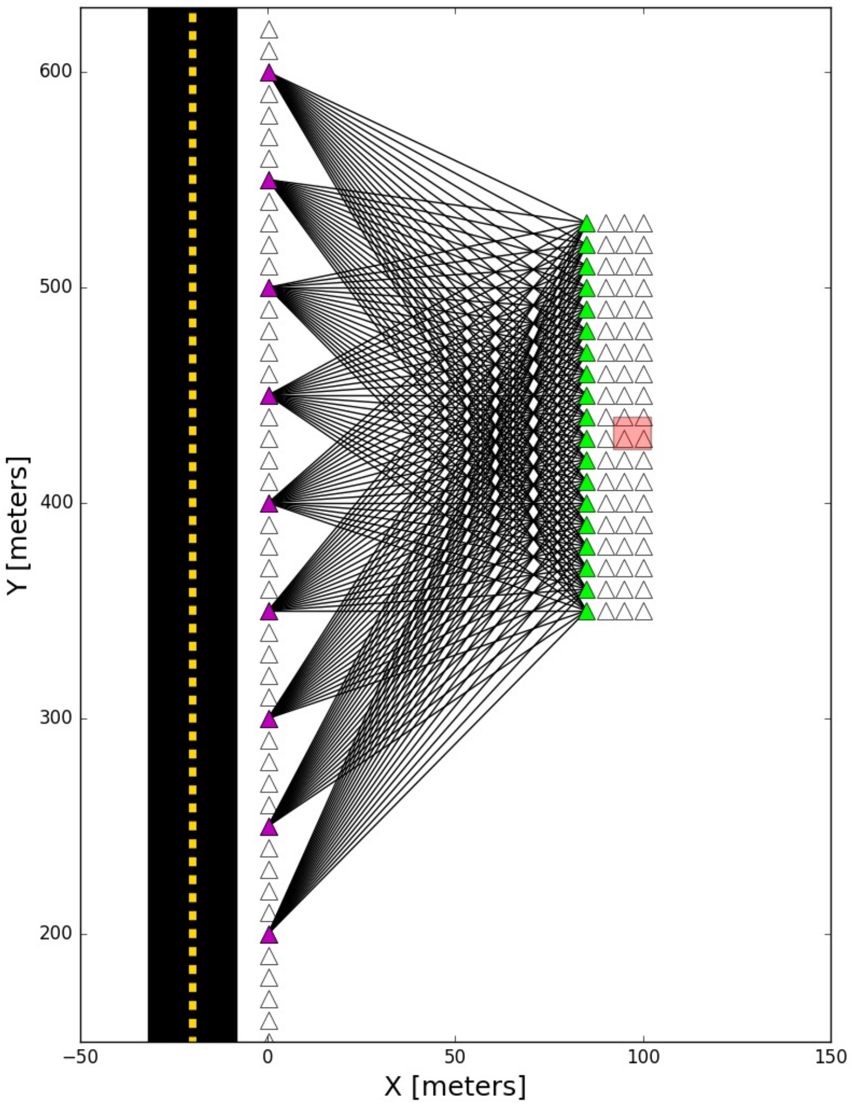


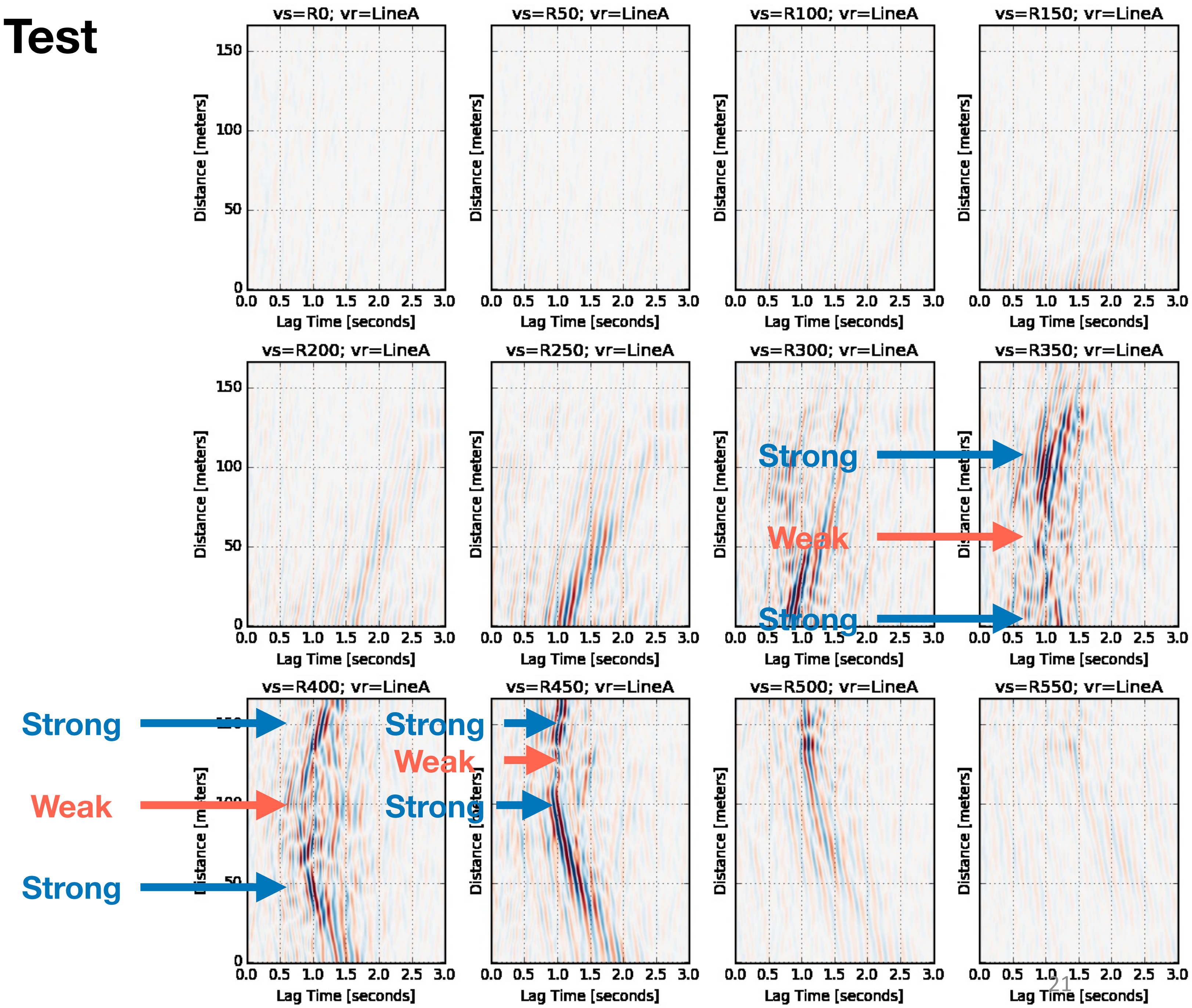


E.R. Martin and B.L. Biondi, “Ambient noise interferometry across two-dimensional DAS arrays,” 2017, SEG Ann. Mtg. Expanded Abstracts, 2642-2646.

Effects at Fairbanks Thaw Test

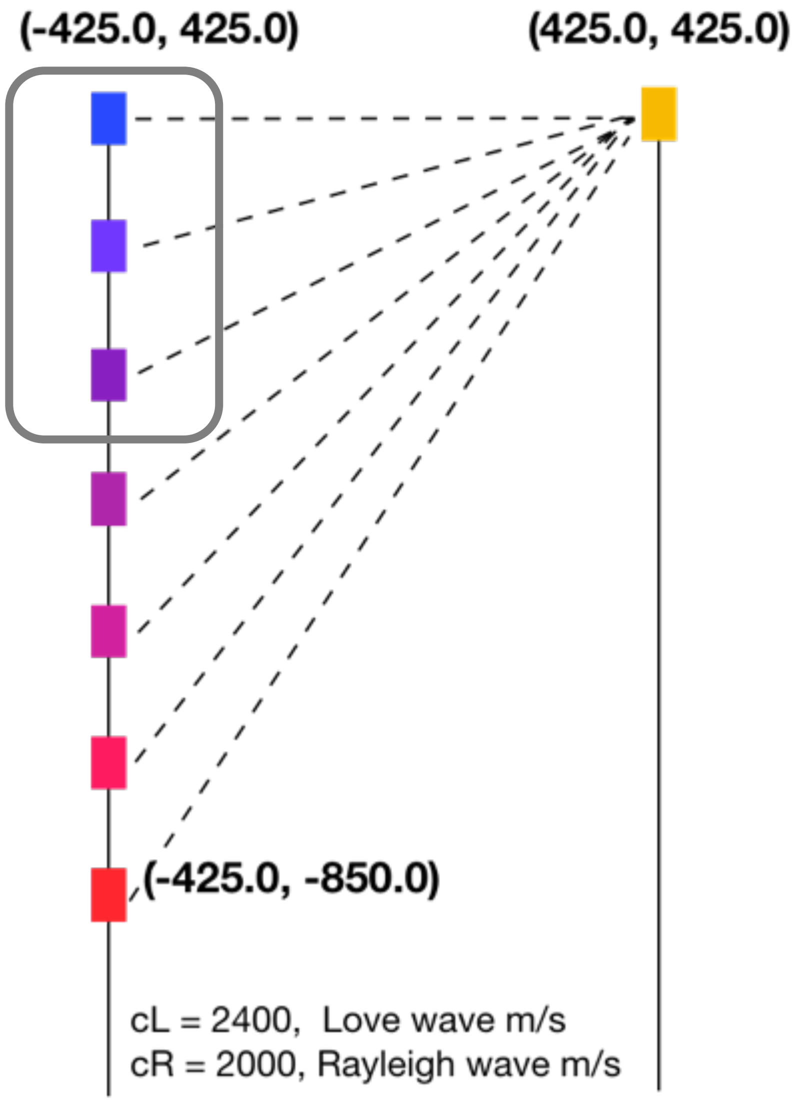
slide % Nate Lindsey

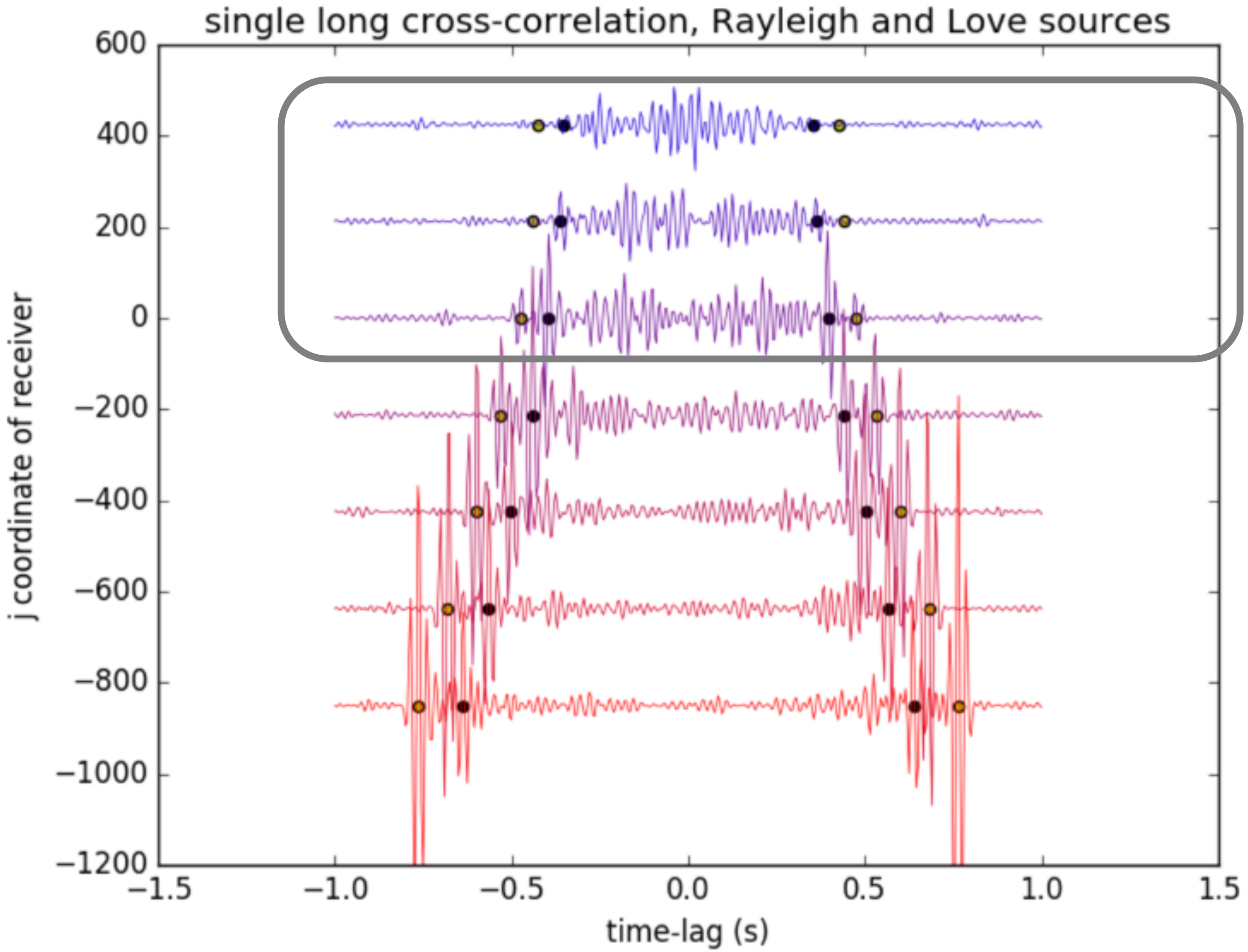




Lindsey et al., 2018 Fall AGU Meeting

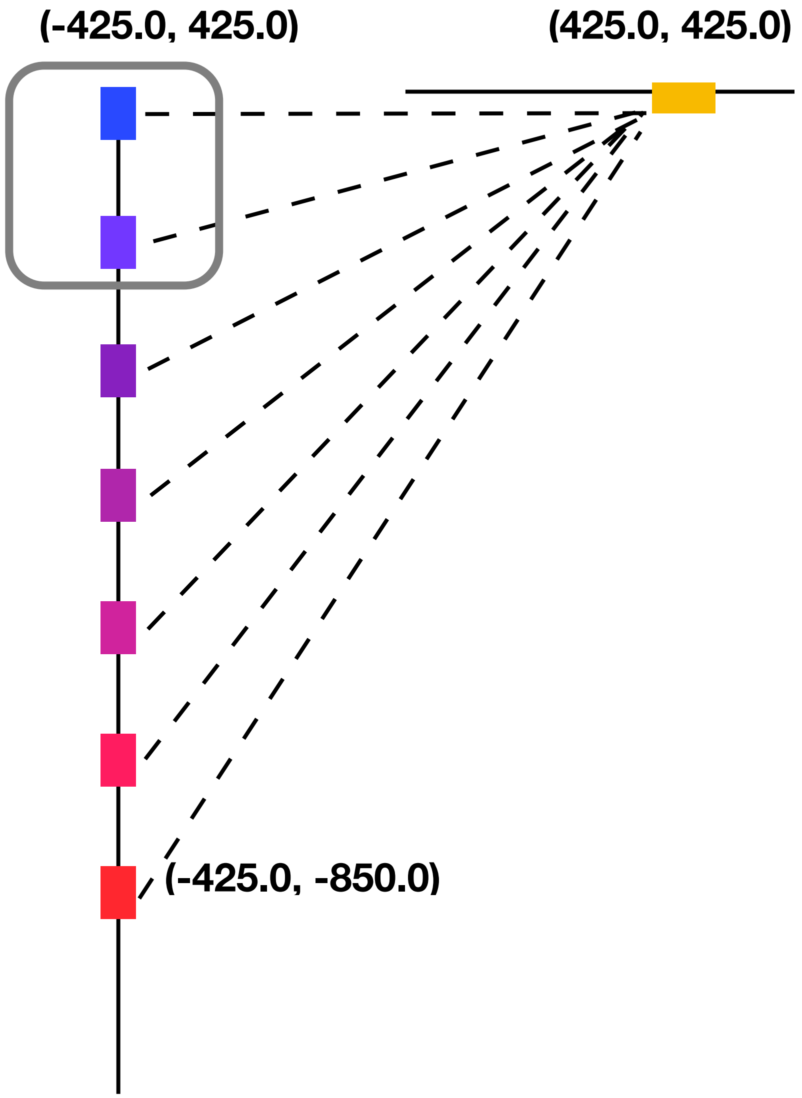
Most (not all) parallel channel pairs are useful

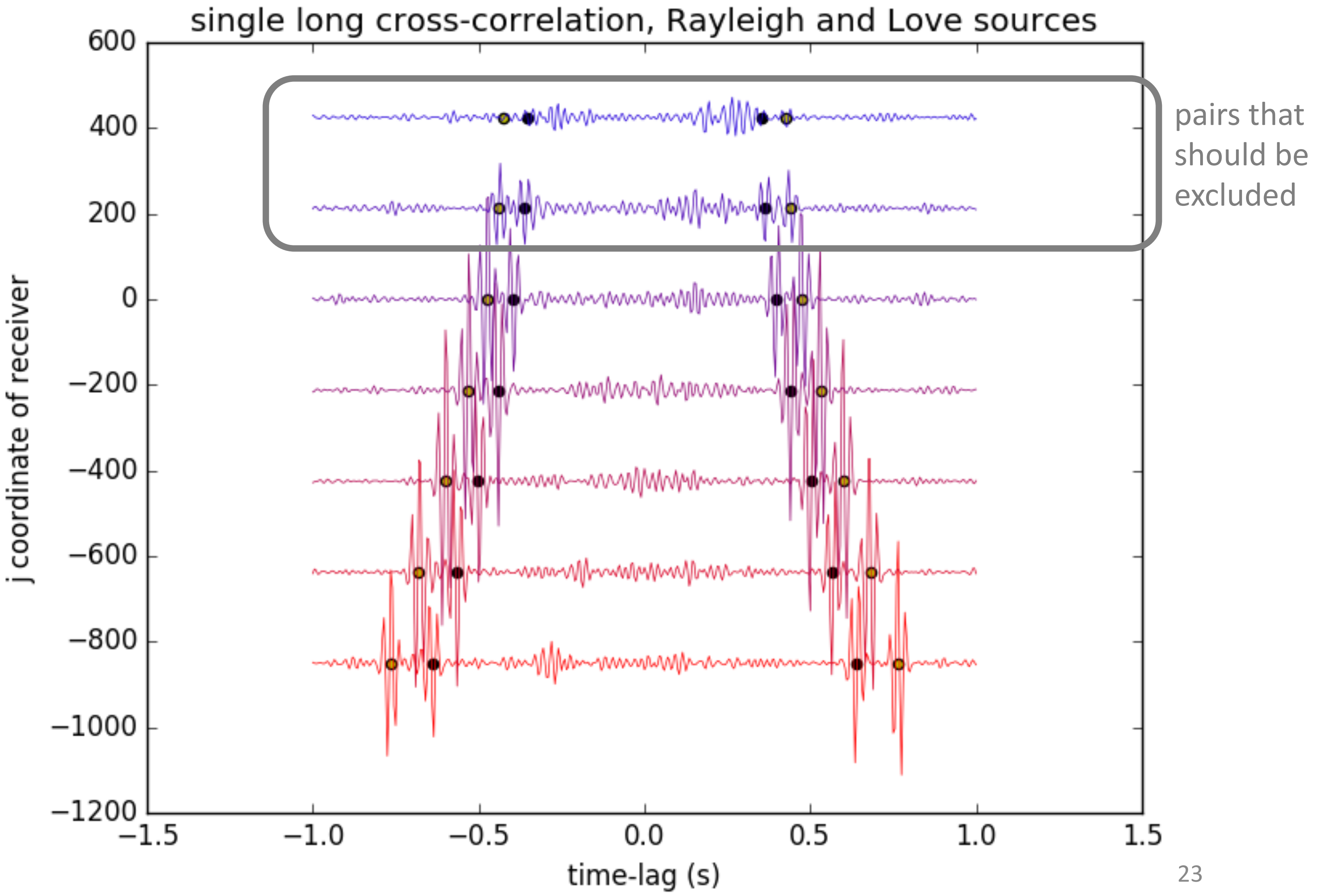




pairs that should be excluded

More orthogonal channel pairs are useful





Acknowledgements

Reference:

E Martin, N Lindsey, J Ajo-Franklin, B Biondi, "Introduction to Interferometry of Fiber Optic Strain Measurements,"

Preprint on EarthArXiv at https://eartharxiv.org/s2tjd/

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OptaSense (Standford Fiber Optic Seismic Observatory)
Silixa (Penn State FORESEE, Fairbanks Permafrost, Richmond Field Station)

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Collaborators: Patrick Fox, Andy Nyblade, David Stensrud
Penn State IT
Virginia Tech Advanced Research Computing