Exploiting the potential of urban DAS grids: Ambient-noise imaging using joint Rayleigh & Love waves

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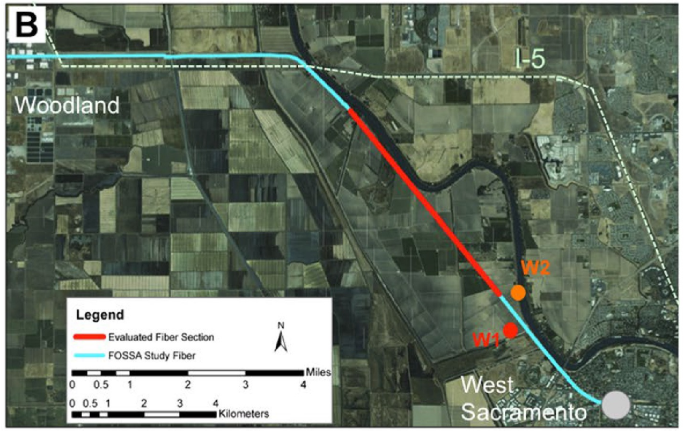
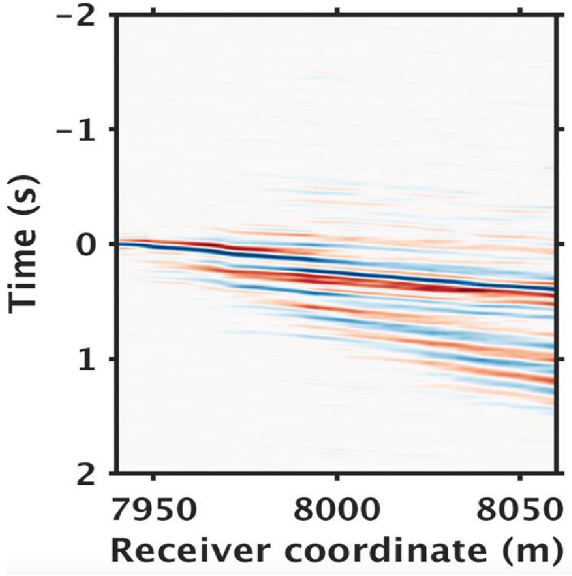
DAS ambient noise imaging: Example workflow

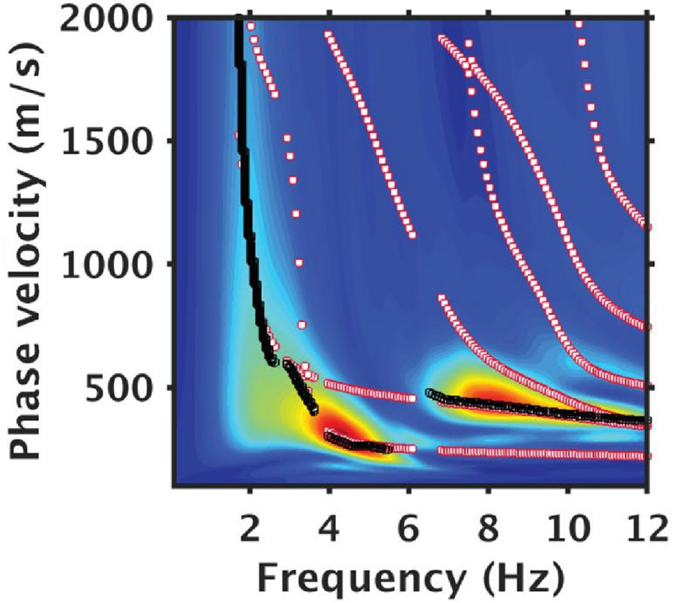
(Ajo-Franklin et al. 2019)



Linear DAS fiber segment

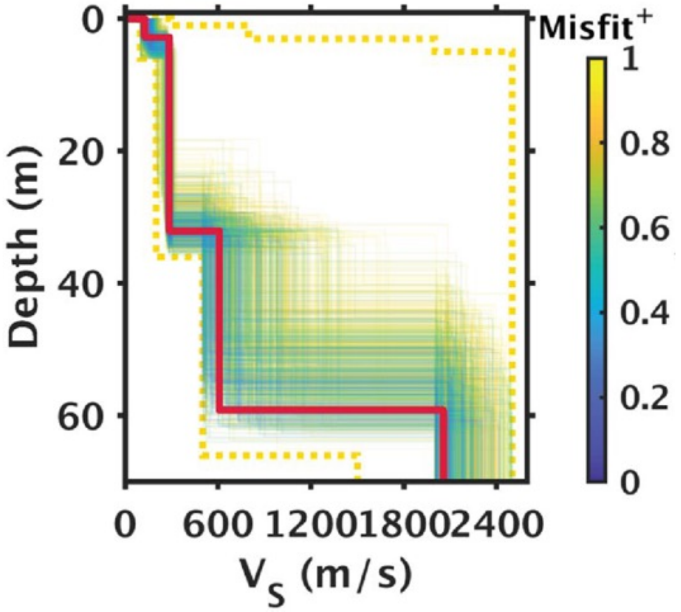
Cross-correlation (Green's function)





Rayleigh phase velocity dispersion

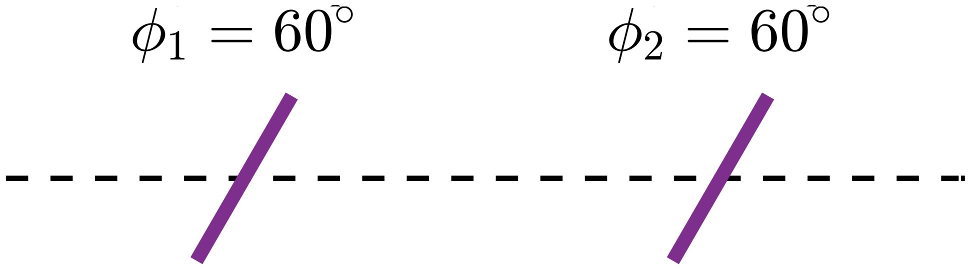
1D subsurface shear velocity



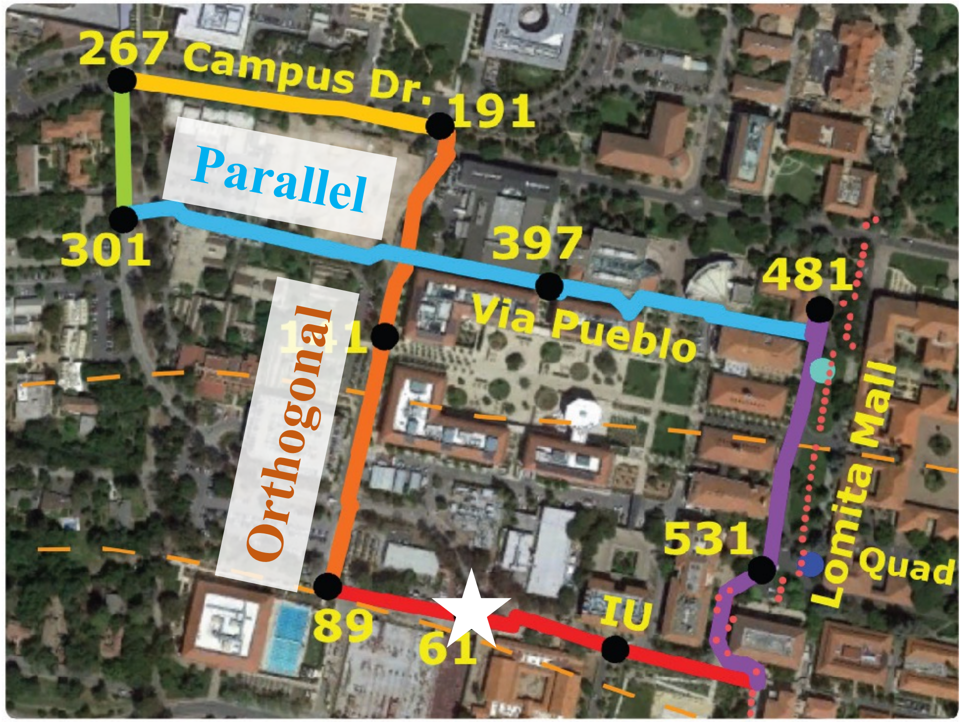
Angular response of DAS ambient-noise cross-correlation

Rayleigh: $A_R = \cos^2\phi_1 \cos^2\phi_2 \in [0, 1]$

Love: $A_L = \frac{1}{4}\sin 2\phi_1 \sin 2\phi_2 \in [-0.25, 0.25]$

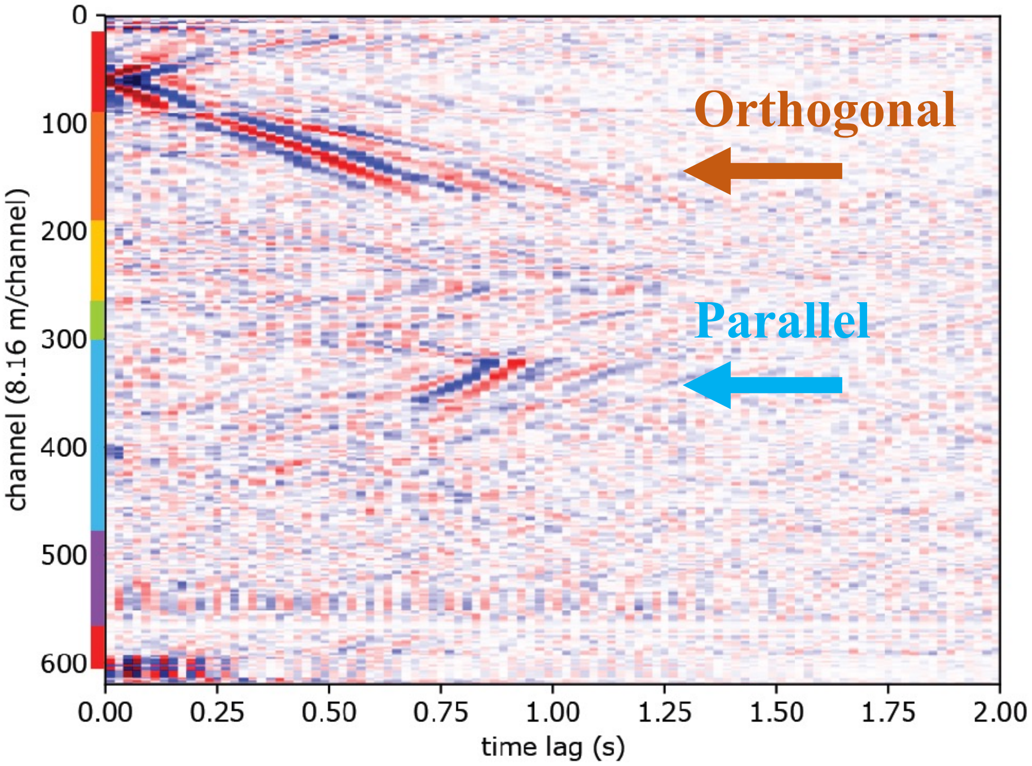


Exploiting the potential of 2D array geometry



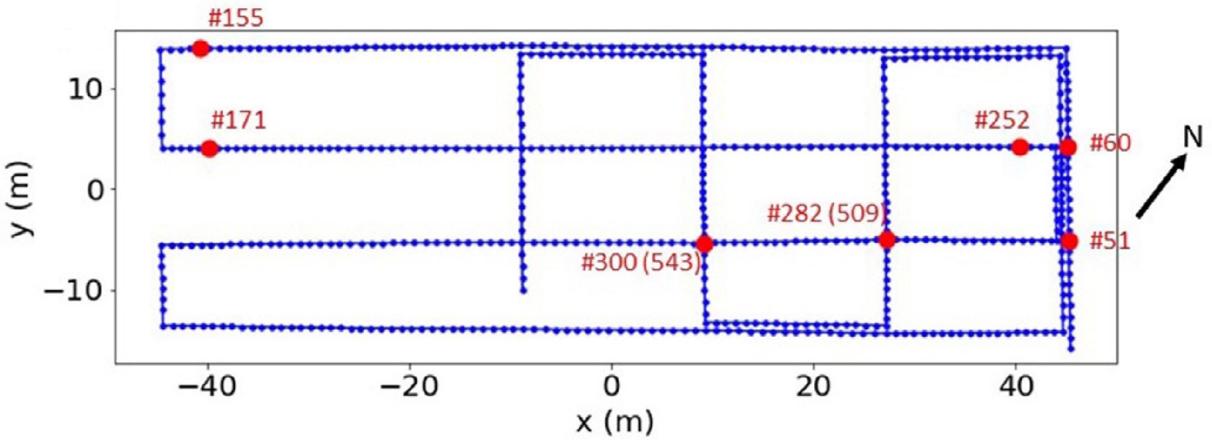
Stanford Campus

(Martin et al. 2017)



Likely both Rayleigh & Love

Exploiting the potential of 2D array geometry



Colorado School of Mines Campus

(Luo et al. 2020)

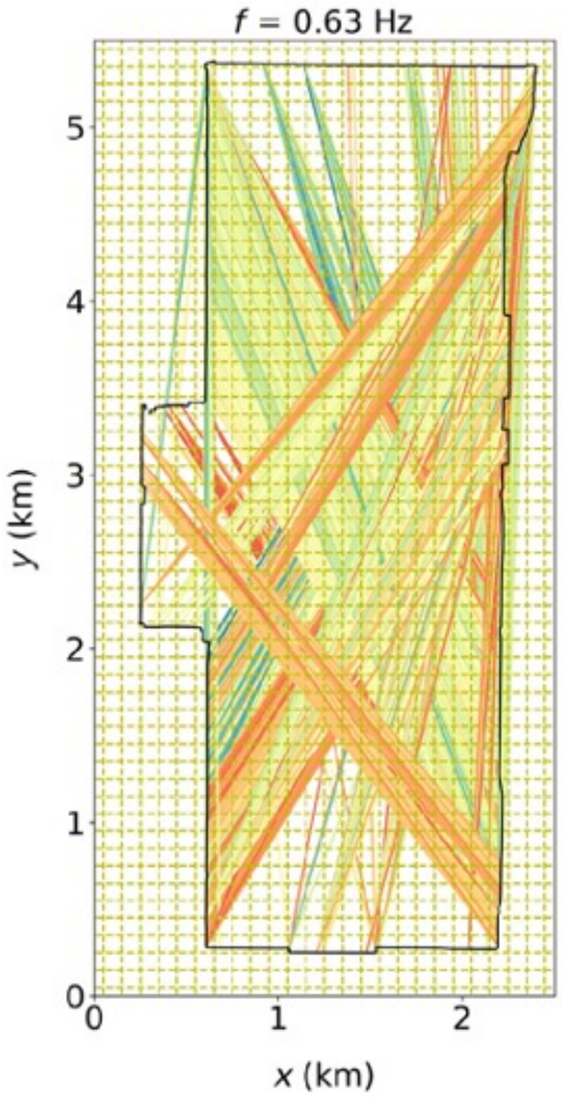
- Extract Love waves from earthquake records
- Still use Rayleigh waves from noise interferometry on one single line

Oxnard, California

(Fang et al. 2022)

Dominant Rayleigh (0.5 - 1 Hz)

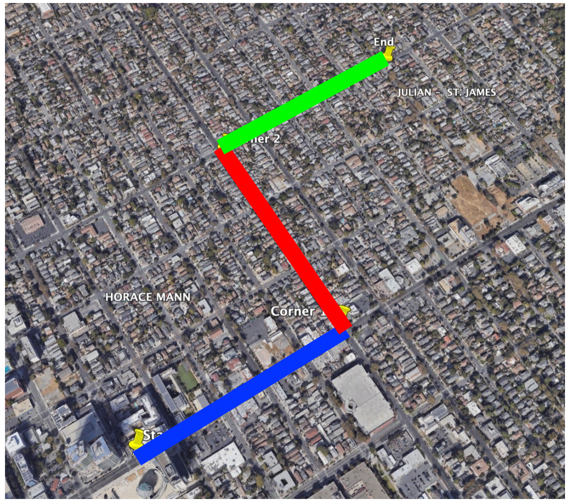
Rayleigh group velocity map

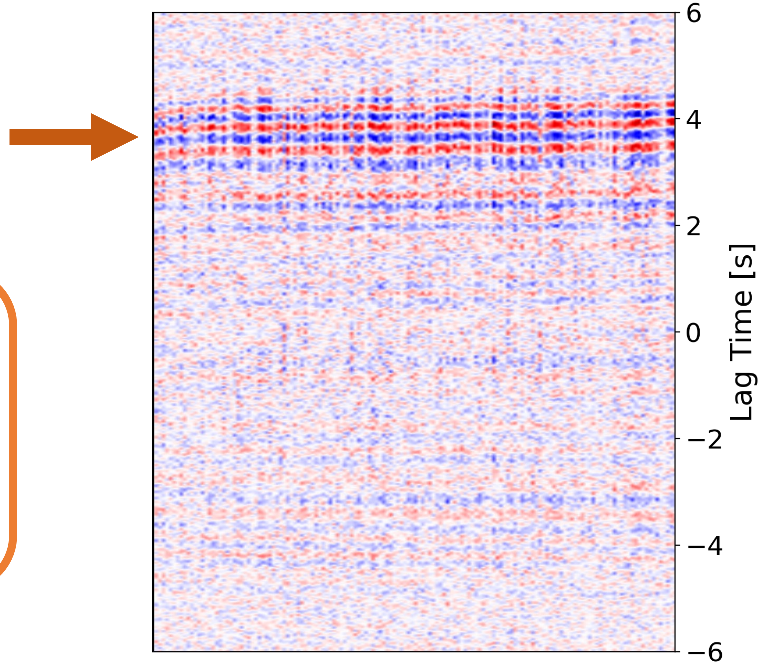


Love?

Our study

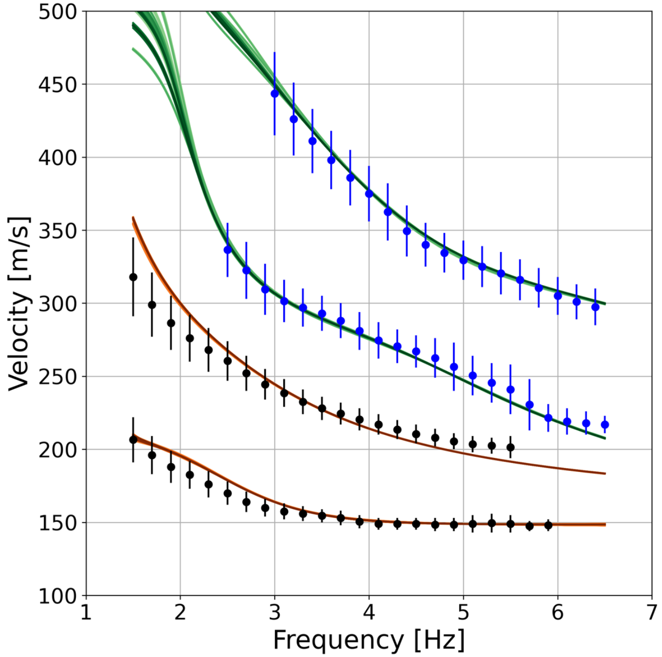
(Ji et al. 2023, submitted)





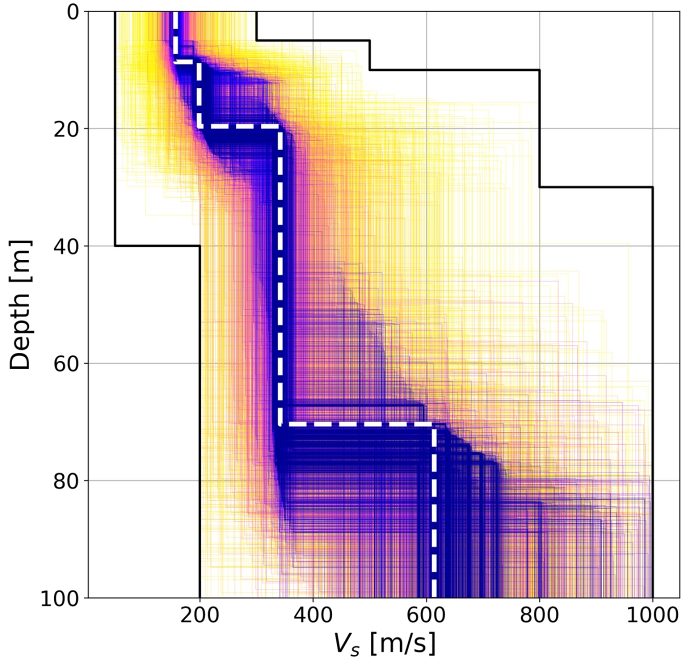
Orthogonal DAS segments in San Jose

Love signals in cross-correlation

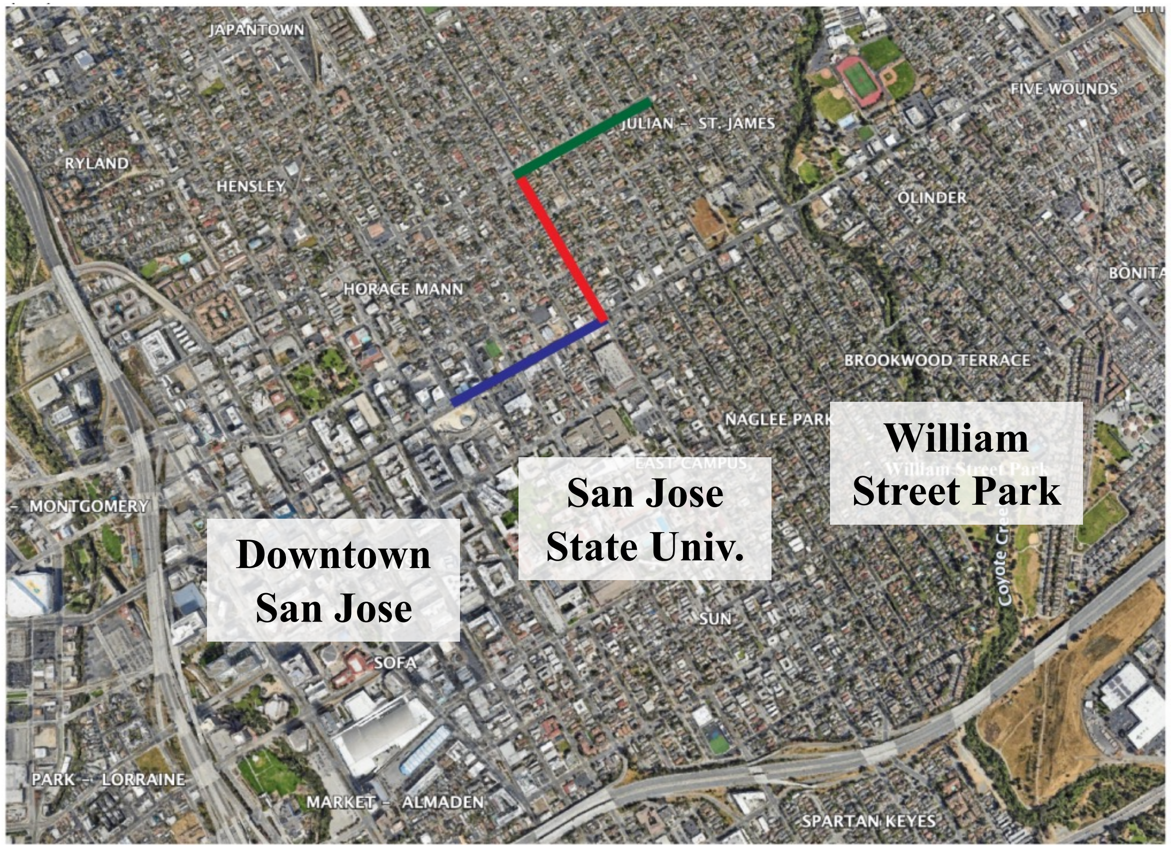


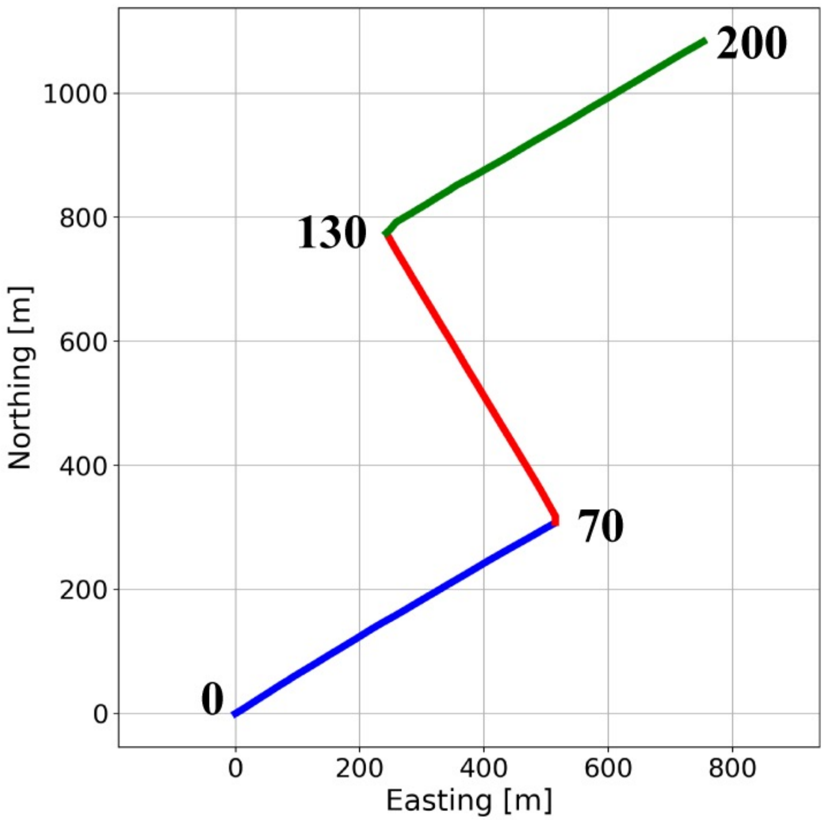
Rayleigh & Love phase & group (~ 1 - 6 Hz)

1D subsurface shear velocity



DAS array configuration



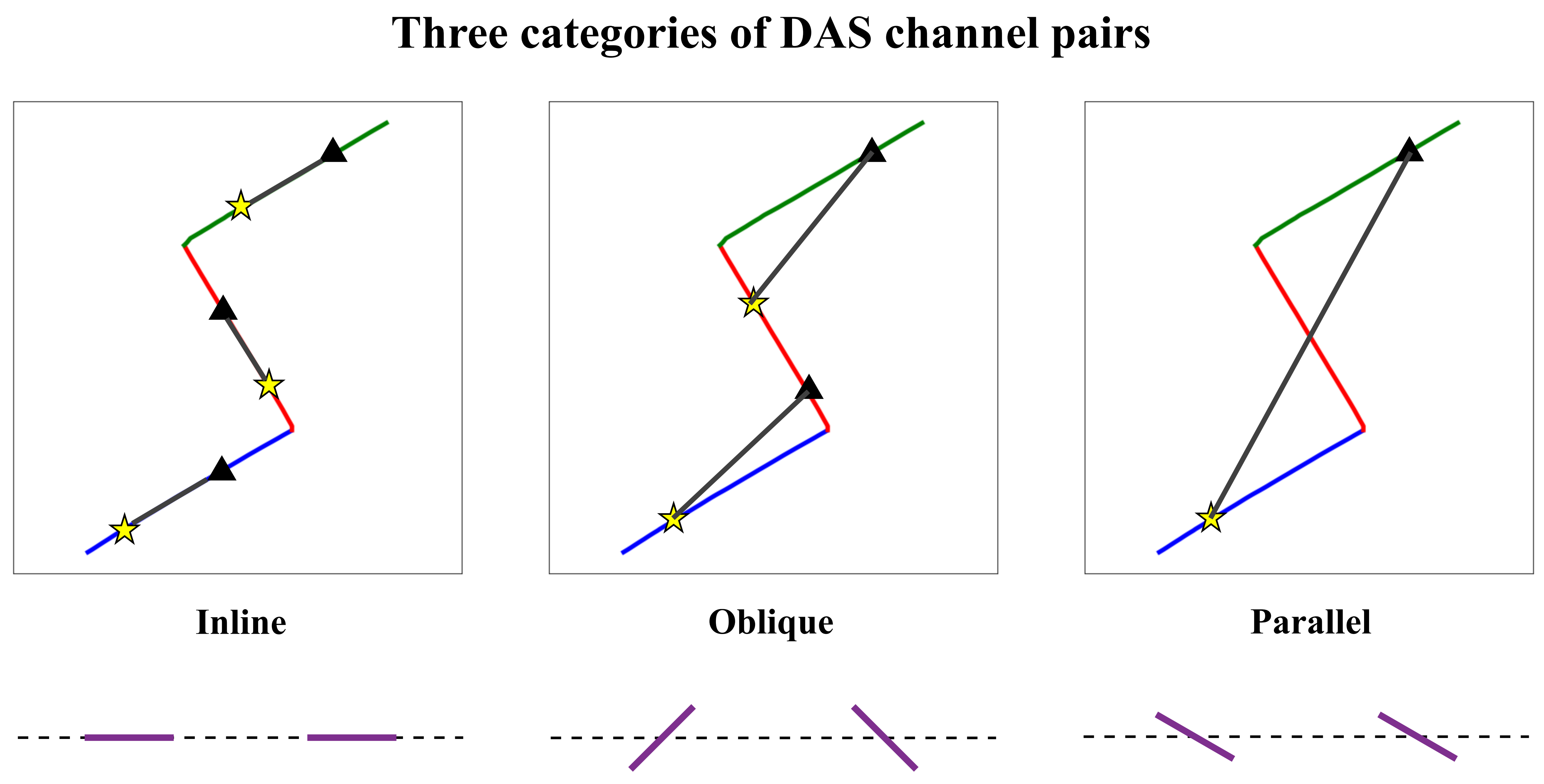


DAS noise records: 3 days in June 2021

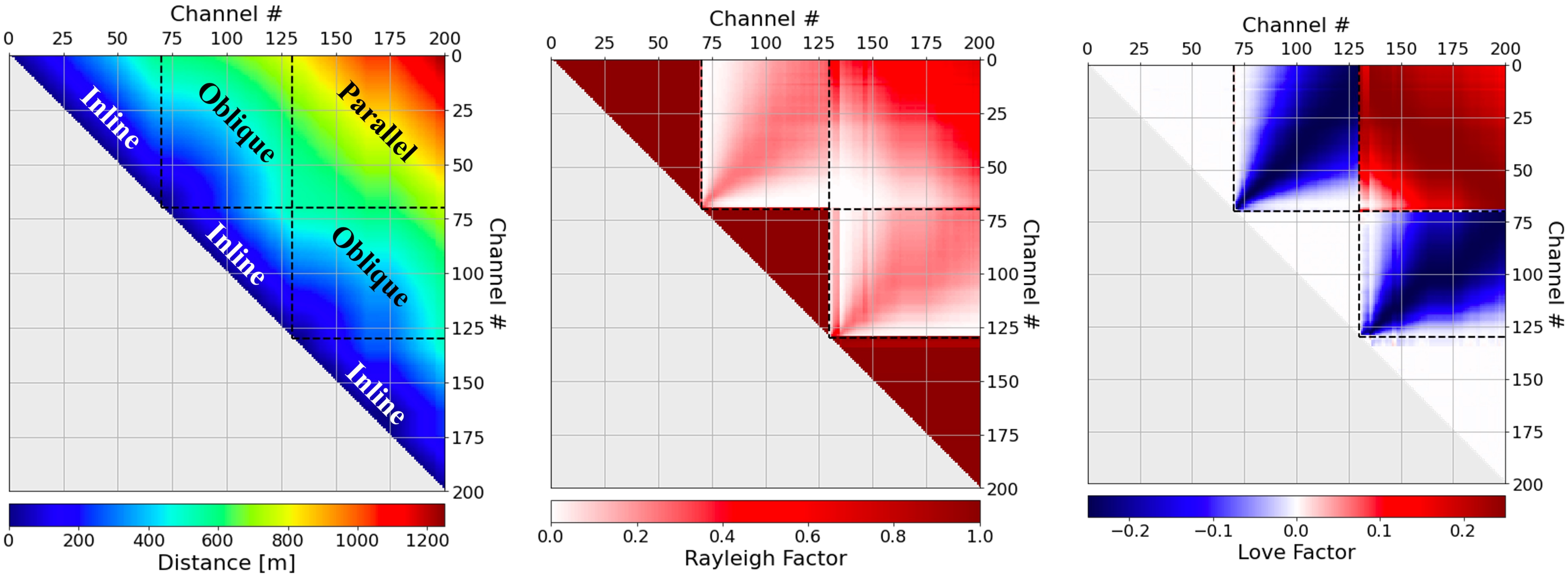
Cross-correlation data: 50 Hz

Gauge length: 10 m

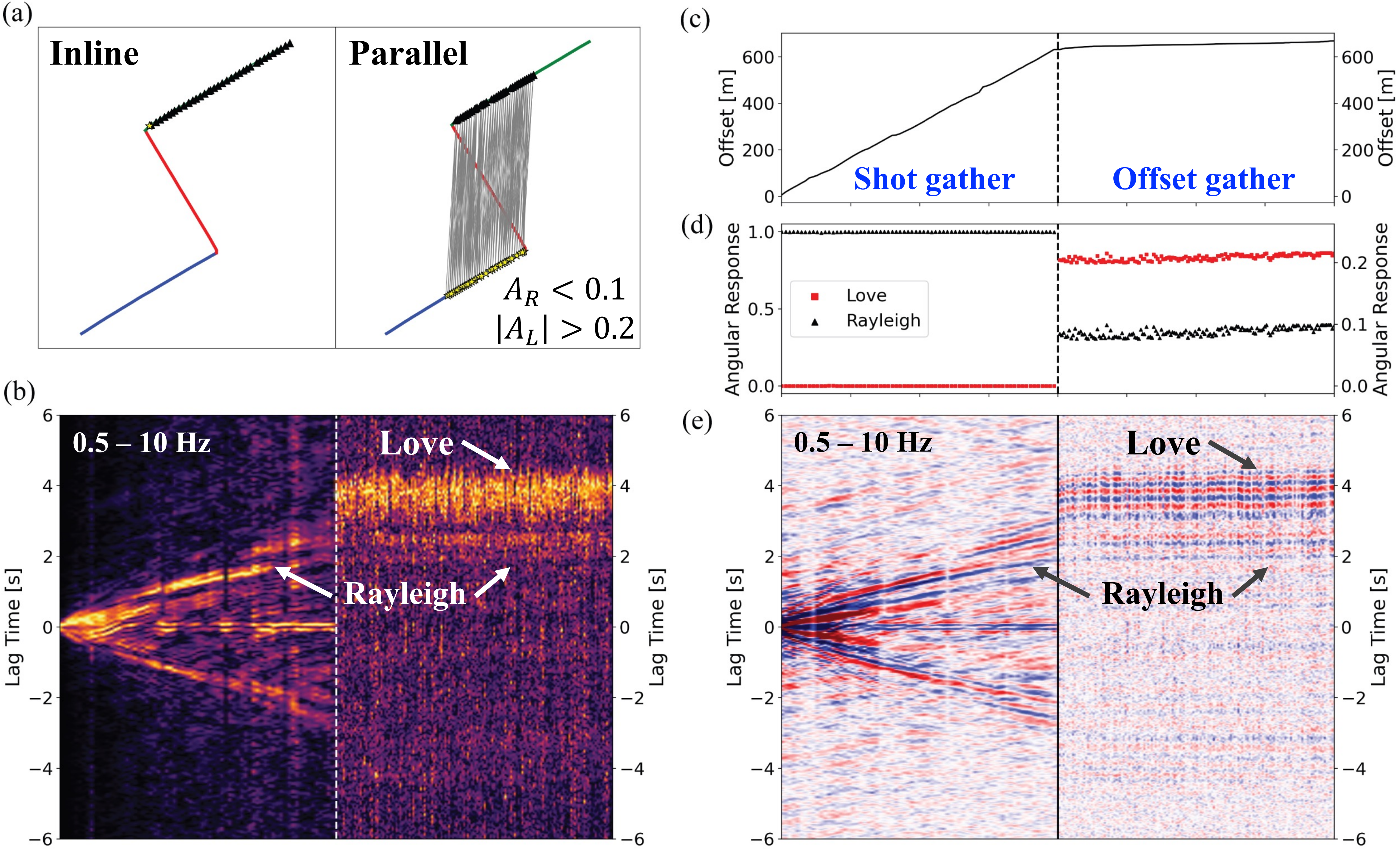
Channel spacing: ~ 10 m


Three categories of DAS channel pairs
Inline
Oblique
Parallel

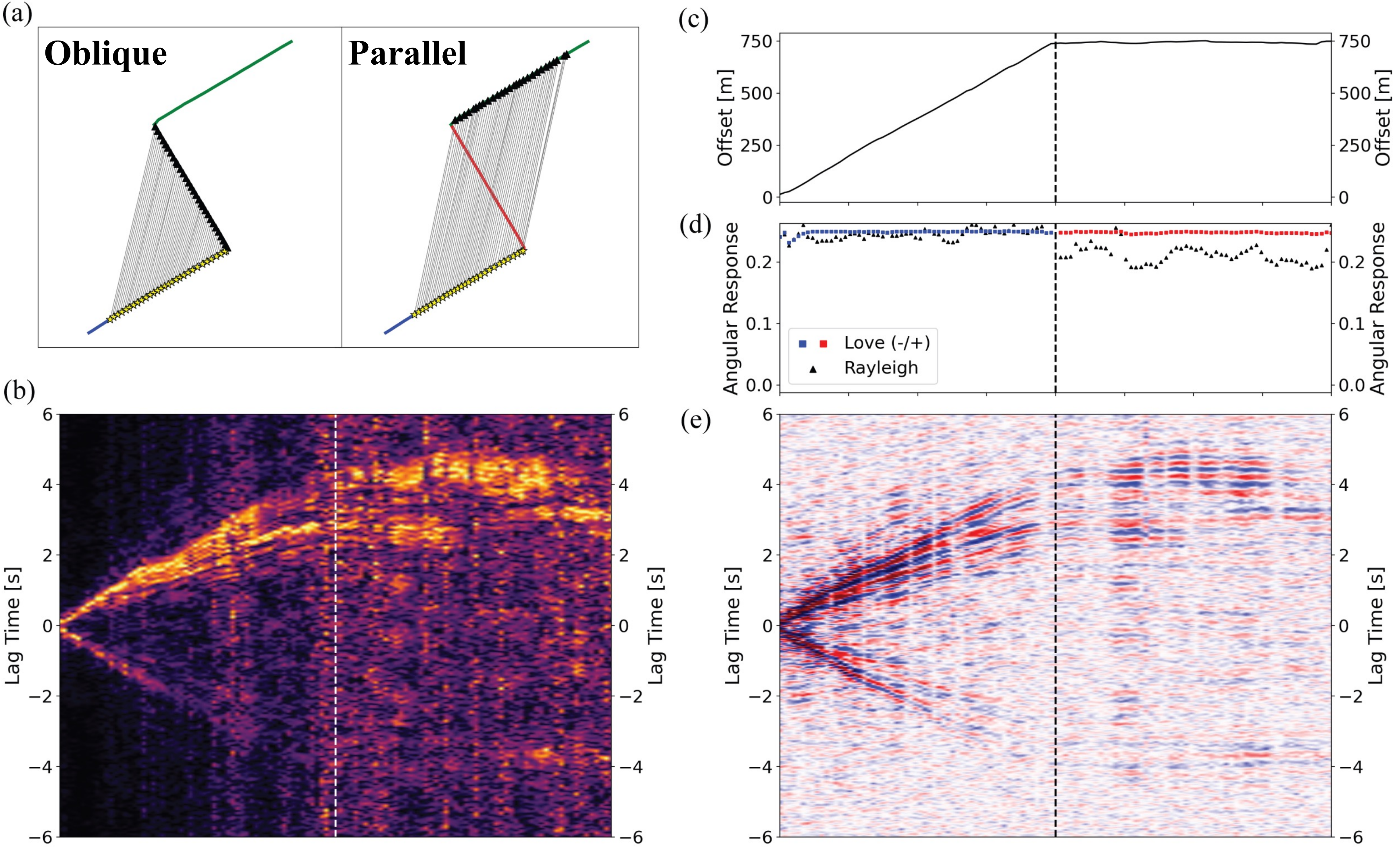
Offset and theoretical response



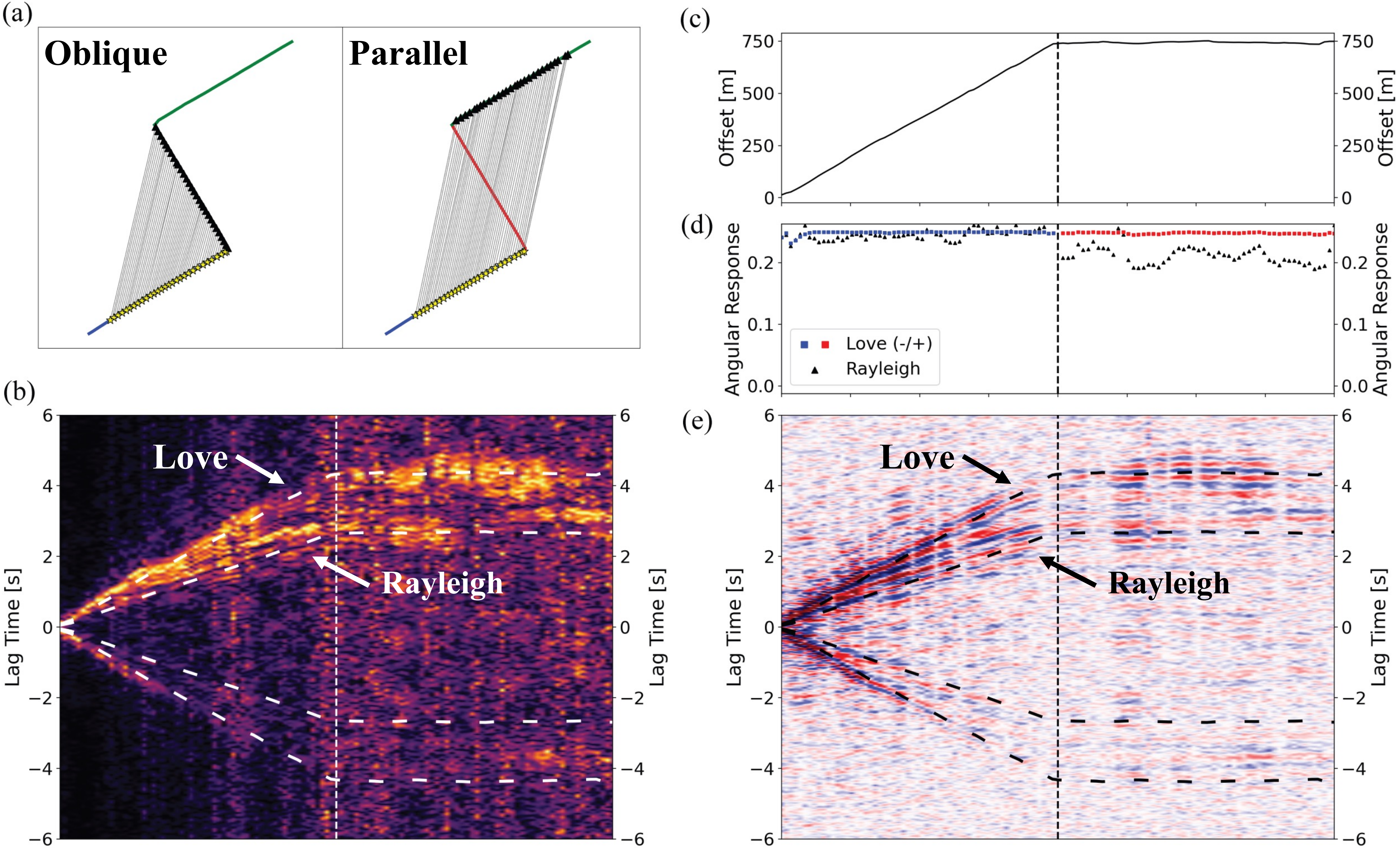
Three categories of channel pairs: **Inline, oblique, parallel**



(a)
Inline
Parallel
$A_R < 0.1$
$|A_L| > 0.2$
(b)
0.5 – 10 Hz
Love
Rayleigh
Lag Time [s]
(c)
Offset [m]
Shot gather
Offset gather
(d)
Angular Response
Love
Rayleigh
(e)
0.5 – 10 Hz
Love
Rayleigh
Lag Time [s]



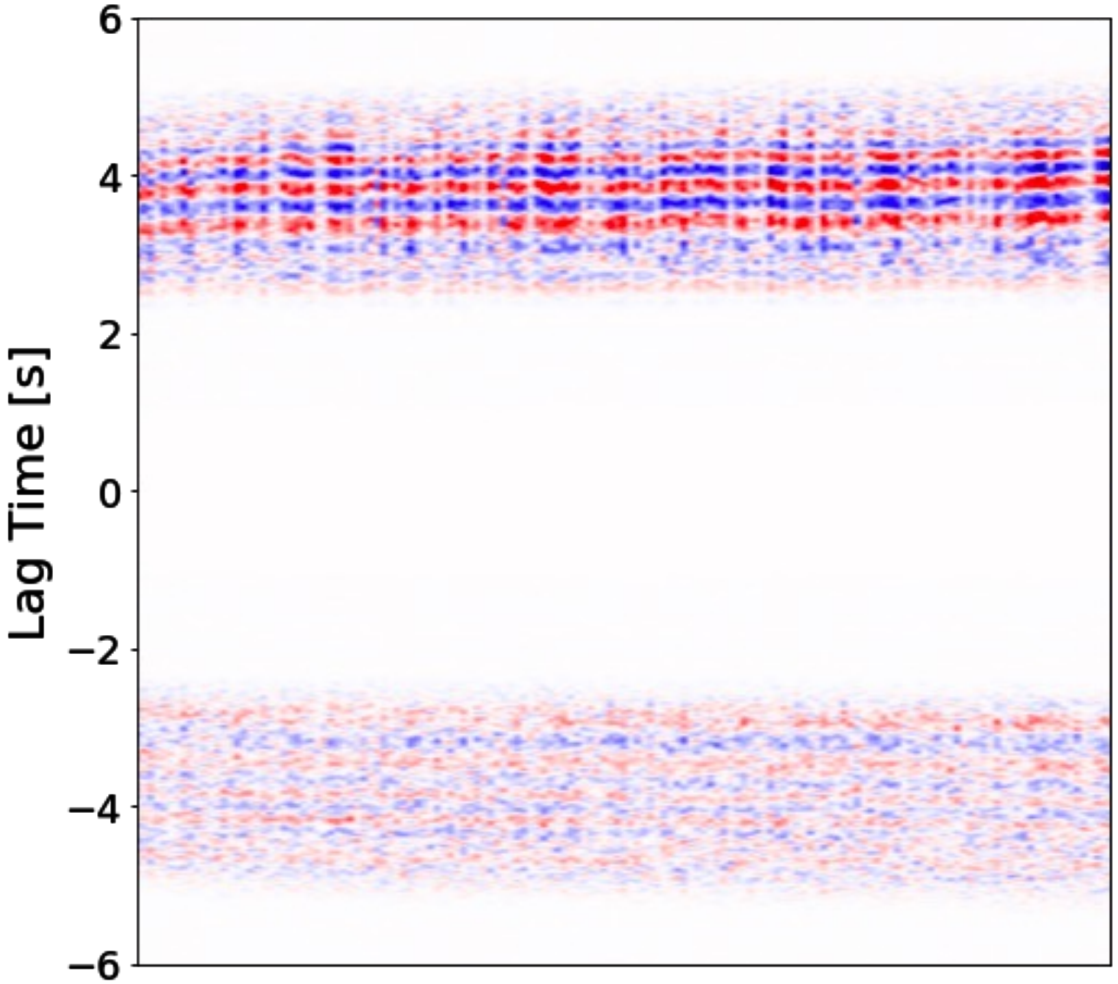
(a)
Oblique
Parallel
(b)
Lag Time [s]
(c)
Offset [m]
(d)
Angular Response
Love (-/+)
Rayleigh
(e)
Lag Time [s]



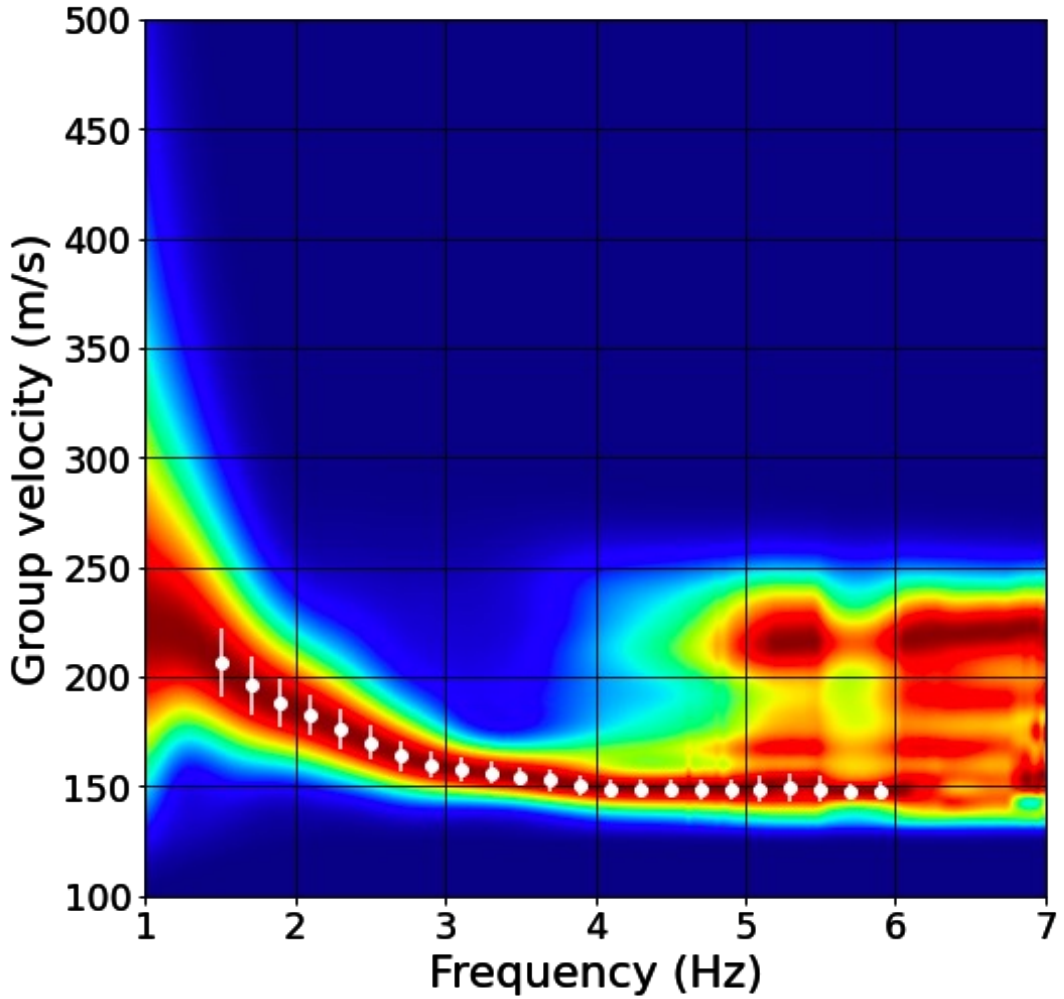
(a)
Oblique
Parallel
(b)
Love
Rayleigh
Lag Time [s]
6
4
2
0
−2
−4
−6
(c)
Offset [m]
750
500
250
0
(d)
Angular Response
0.2
0.1
0.0
Love (-/+)
Rayleigh
(e)
Love
Rayleigh
Lag Time [s]

Love wave dispersion, Group velocity

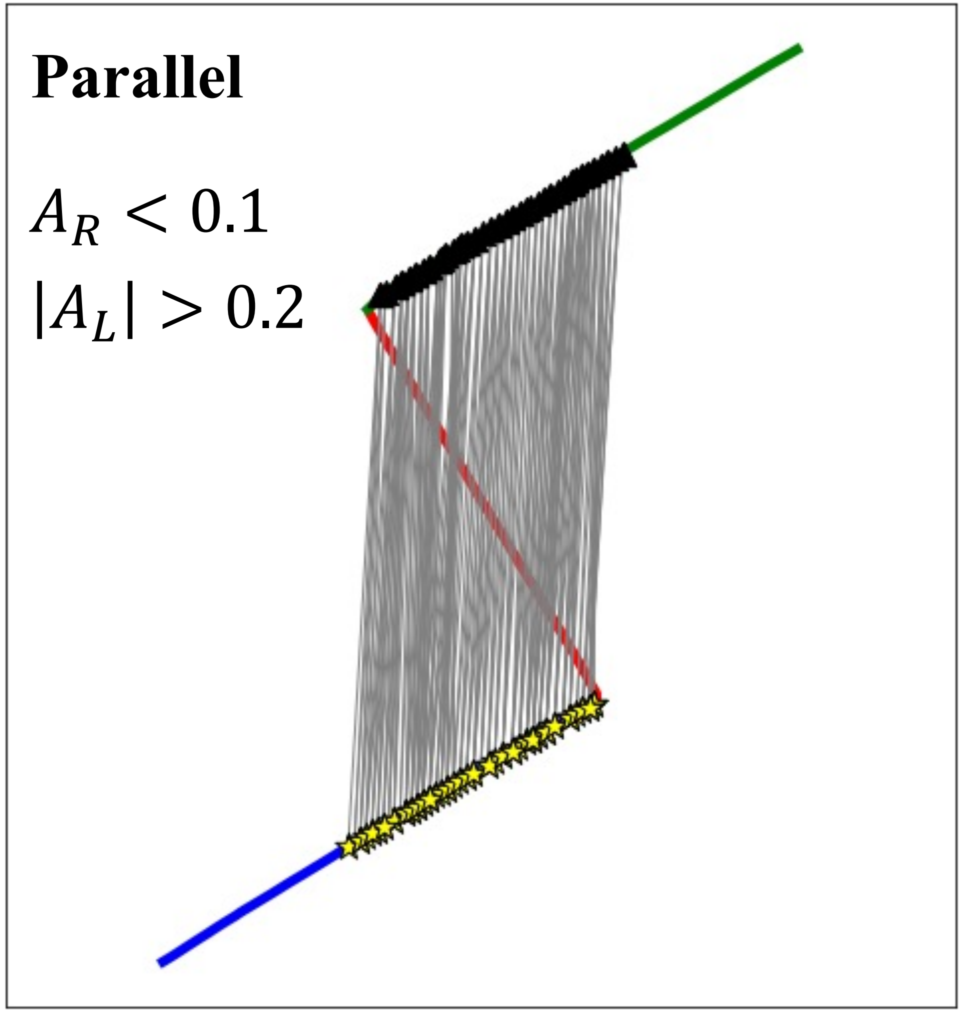
Windowed profile

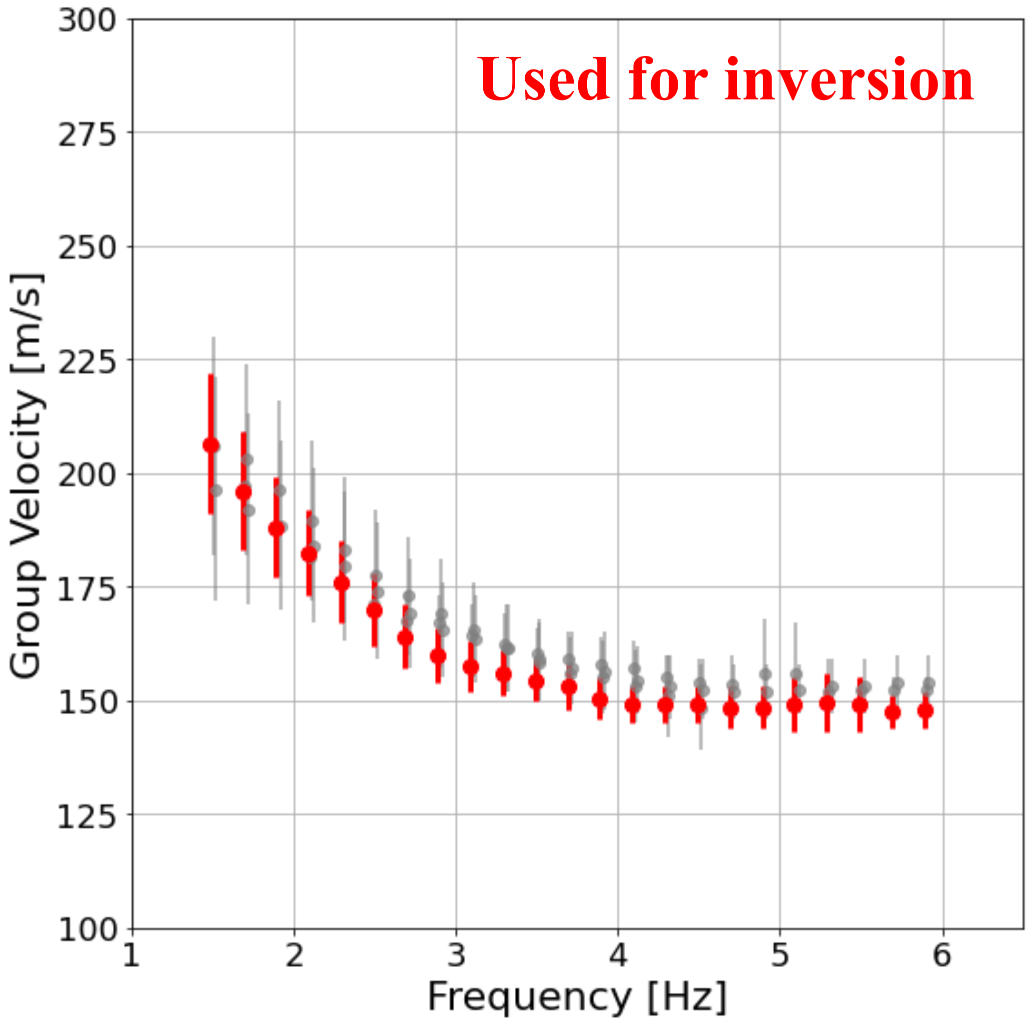


Stacked over all traces

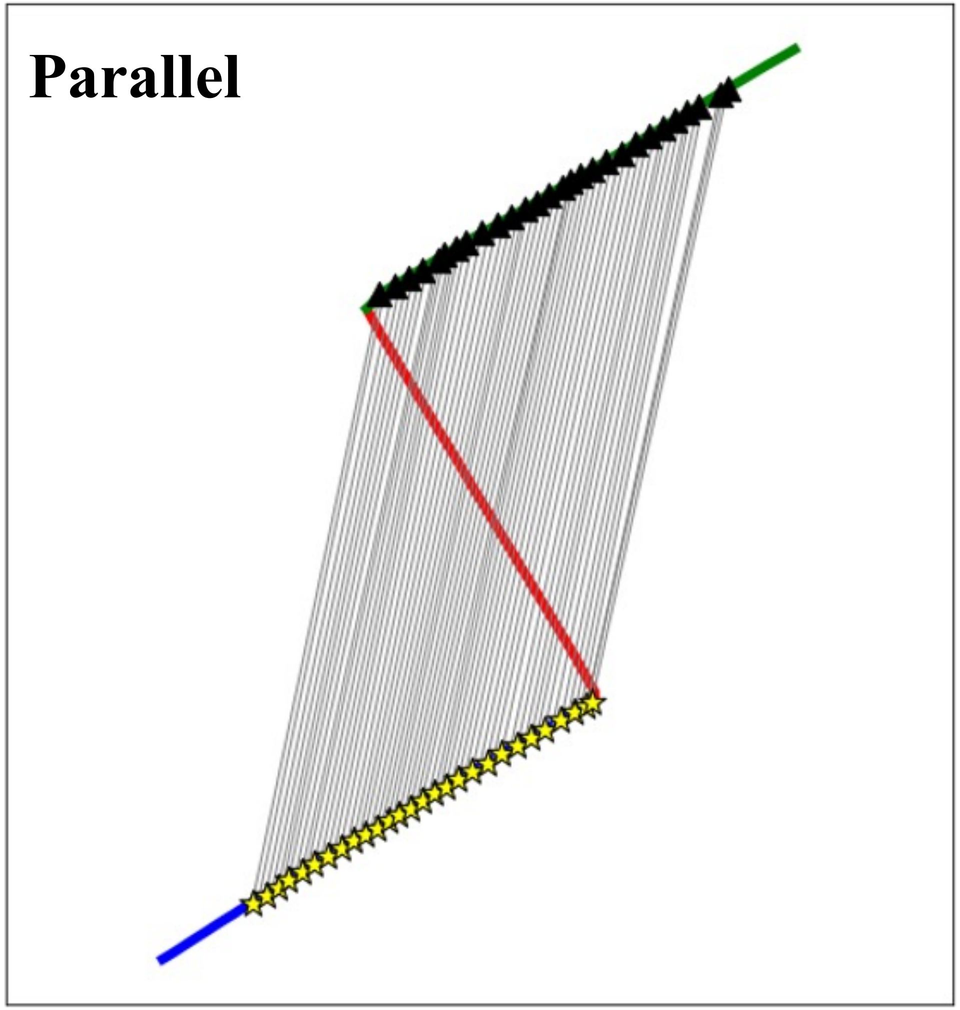


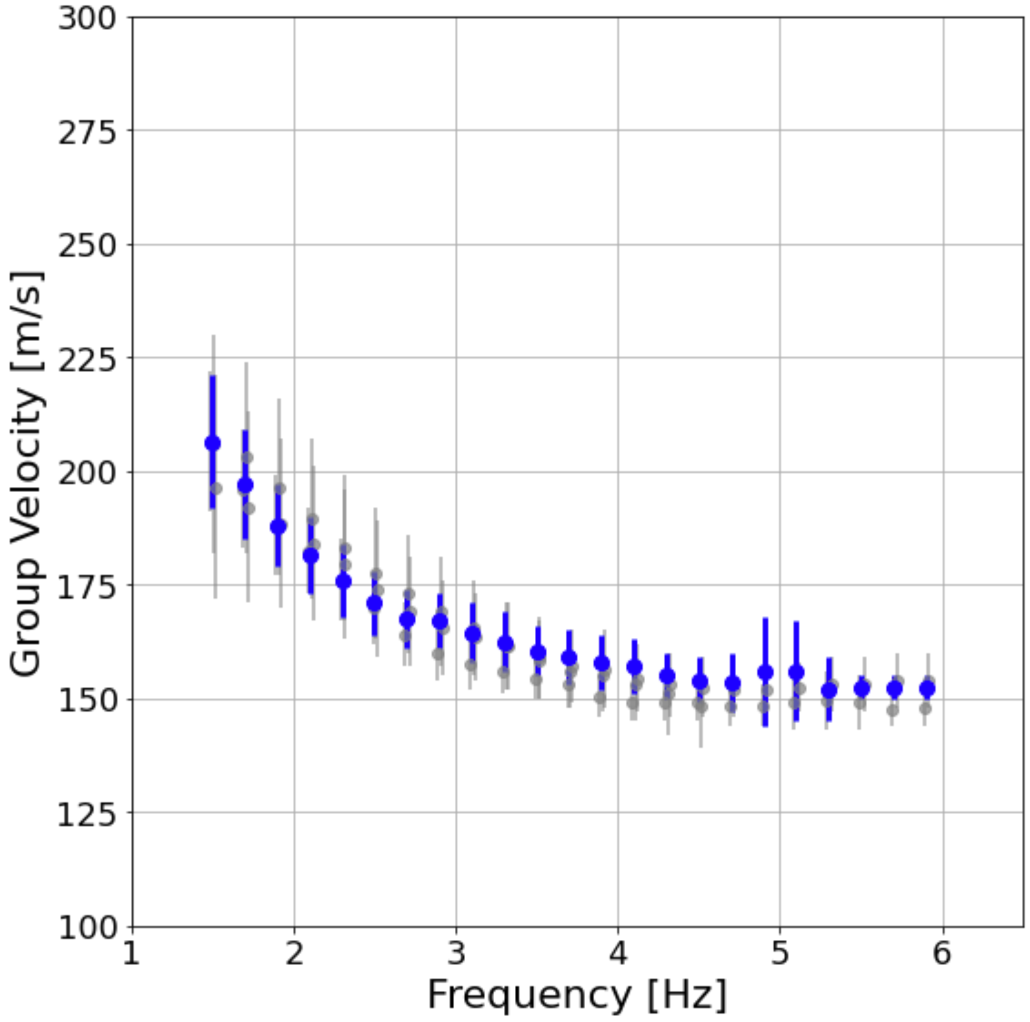
Reliable Love wave detection



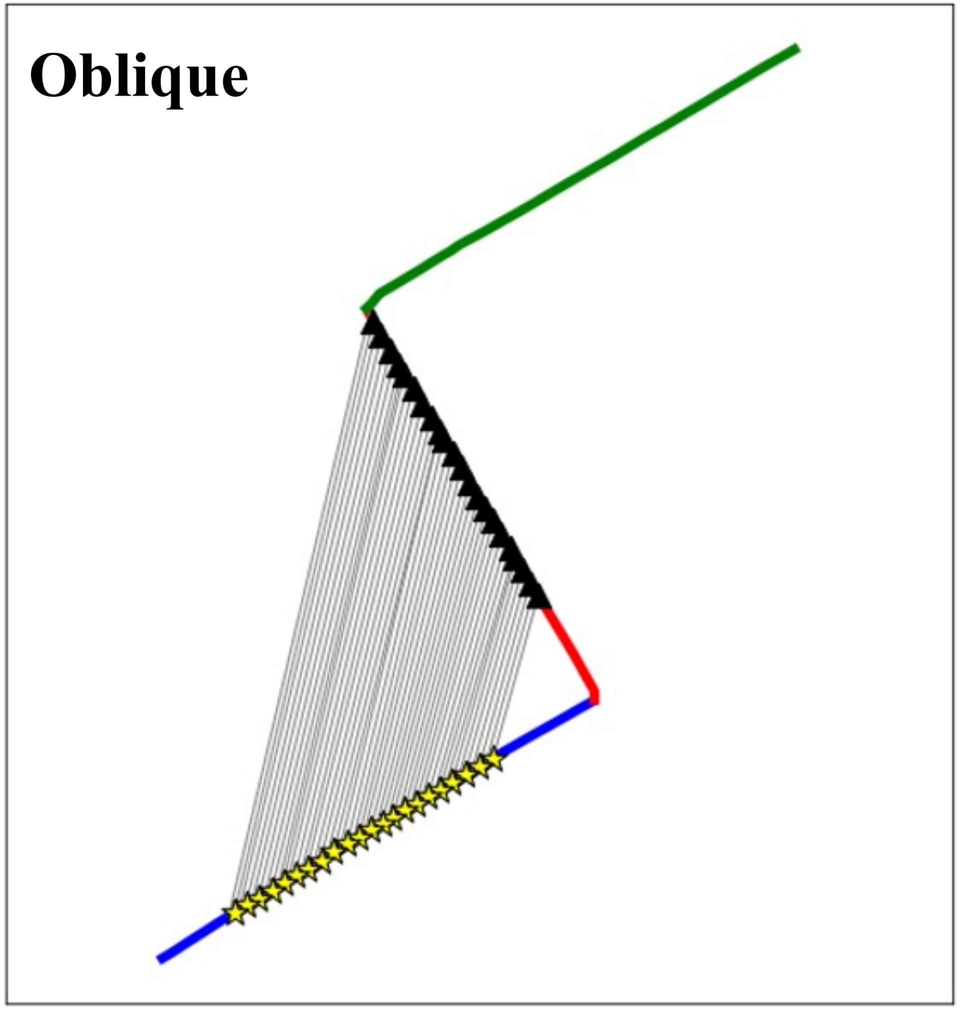


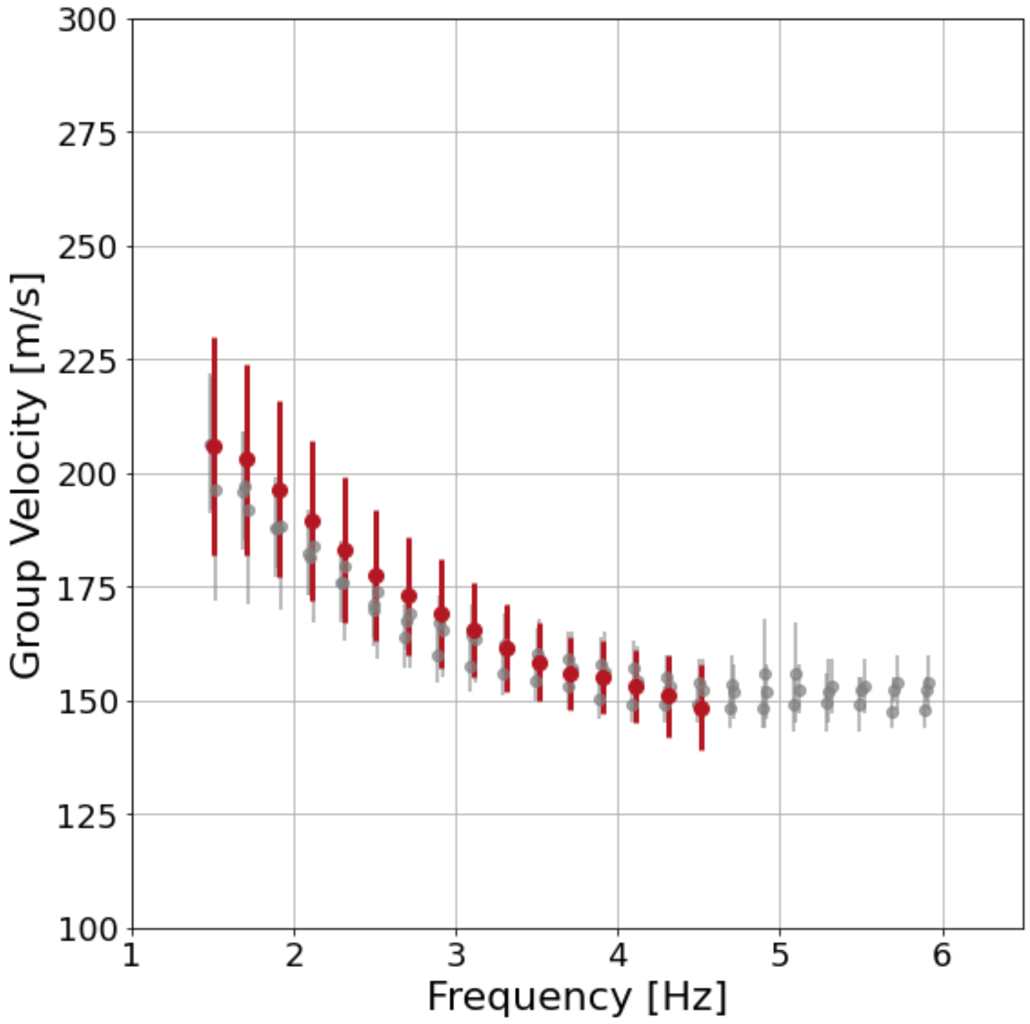
Reliable Love wave detection



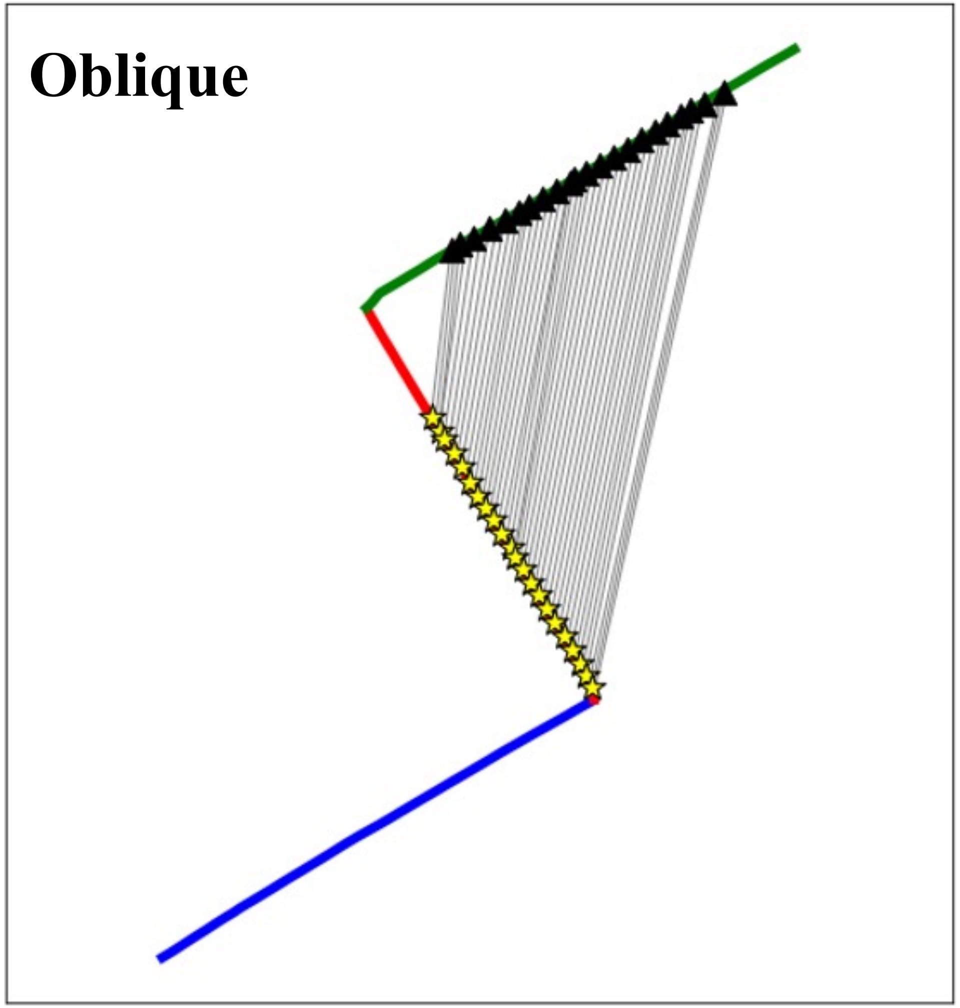


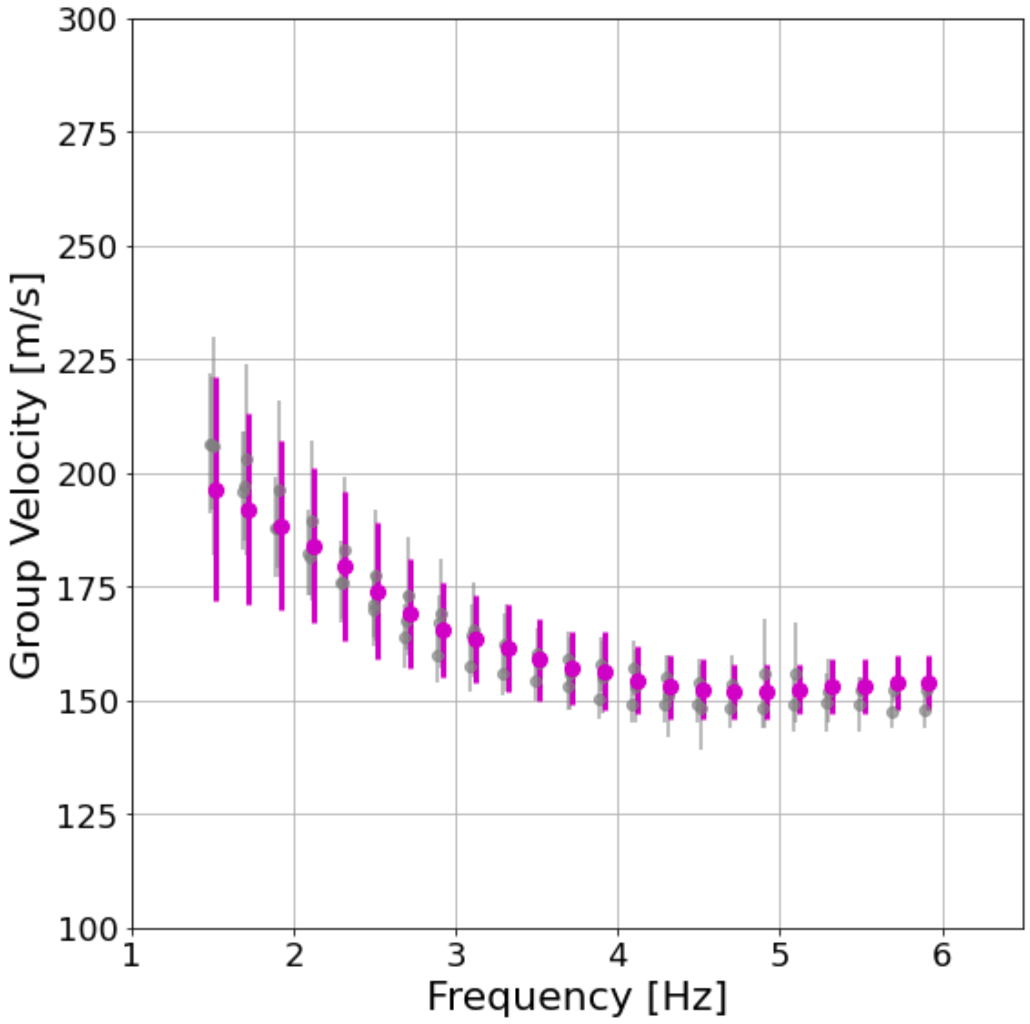
Reliable Love wave detection





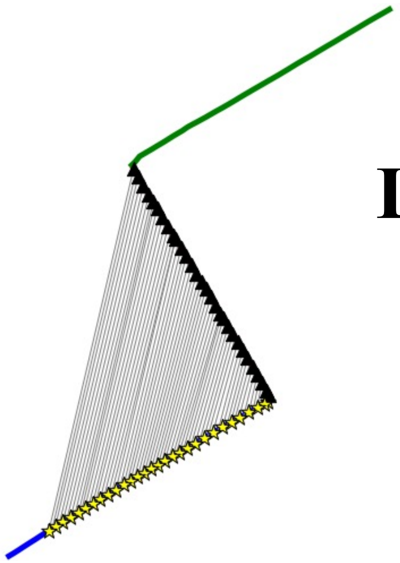
Reliable Love wave detection

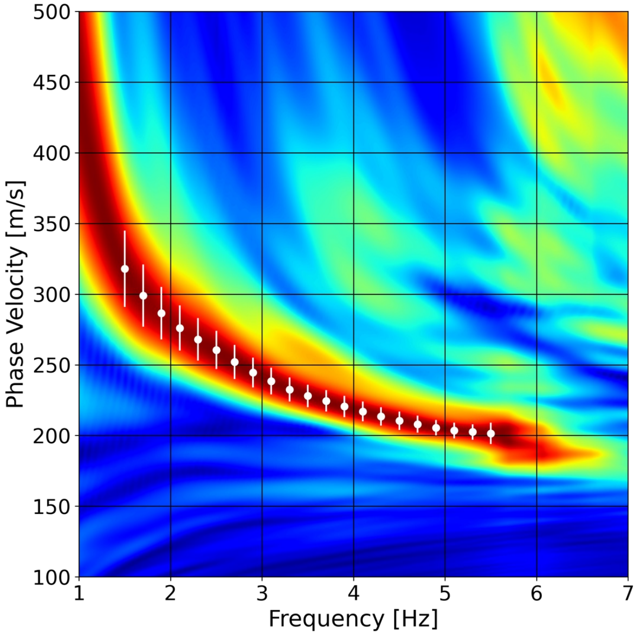




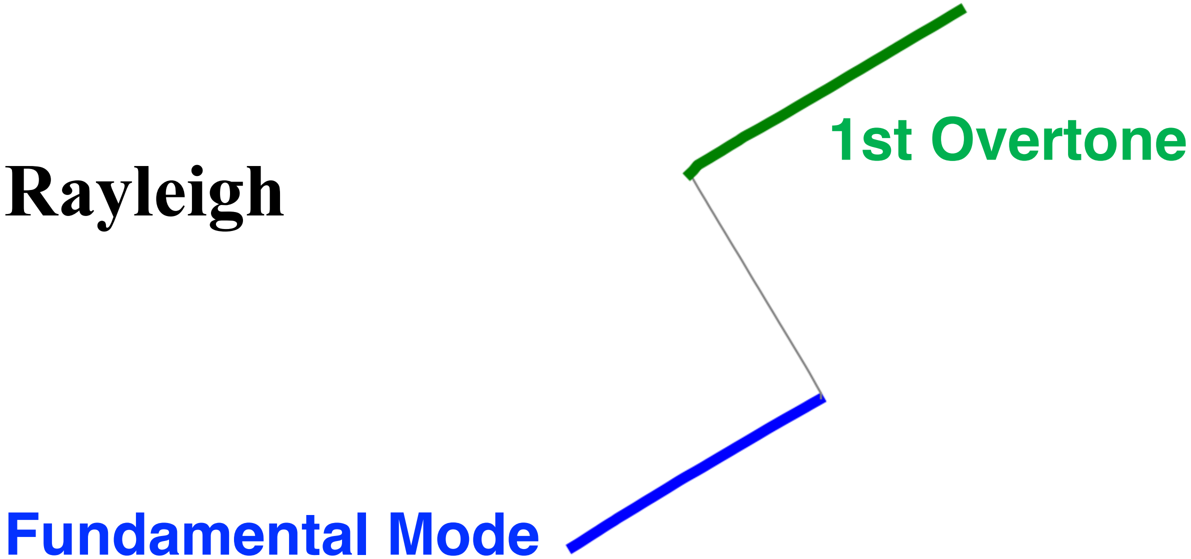
Phase velocity dispersion

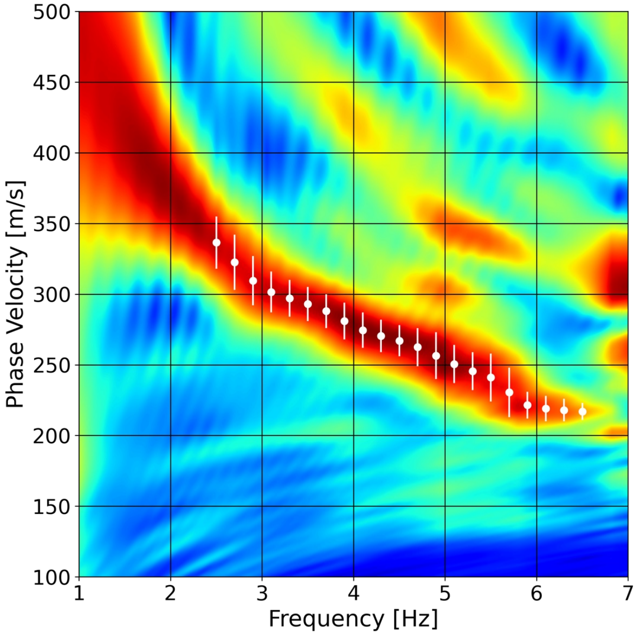
Love

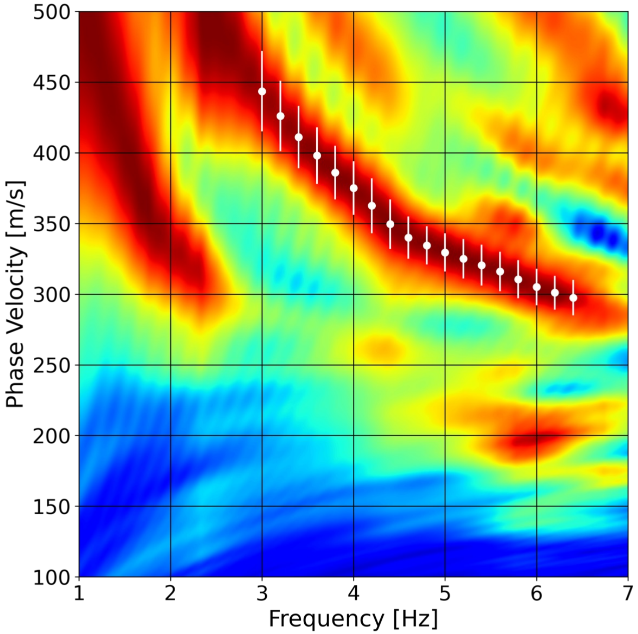




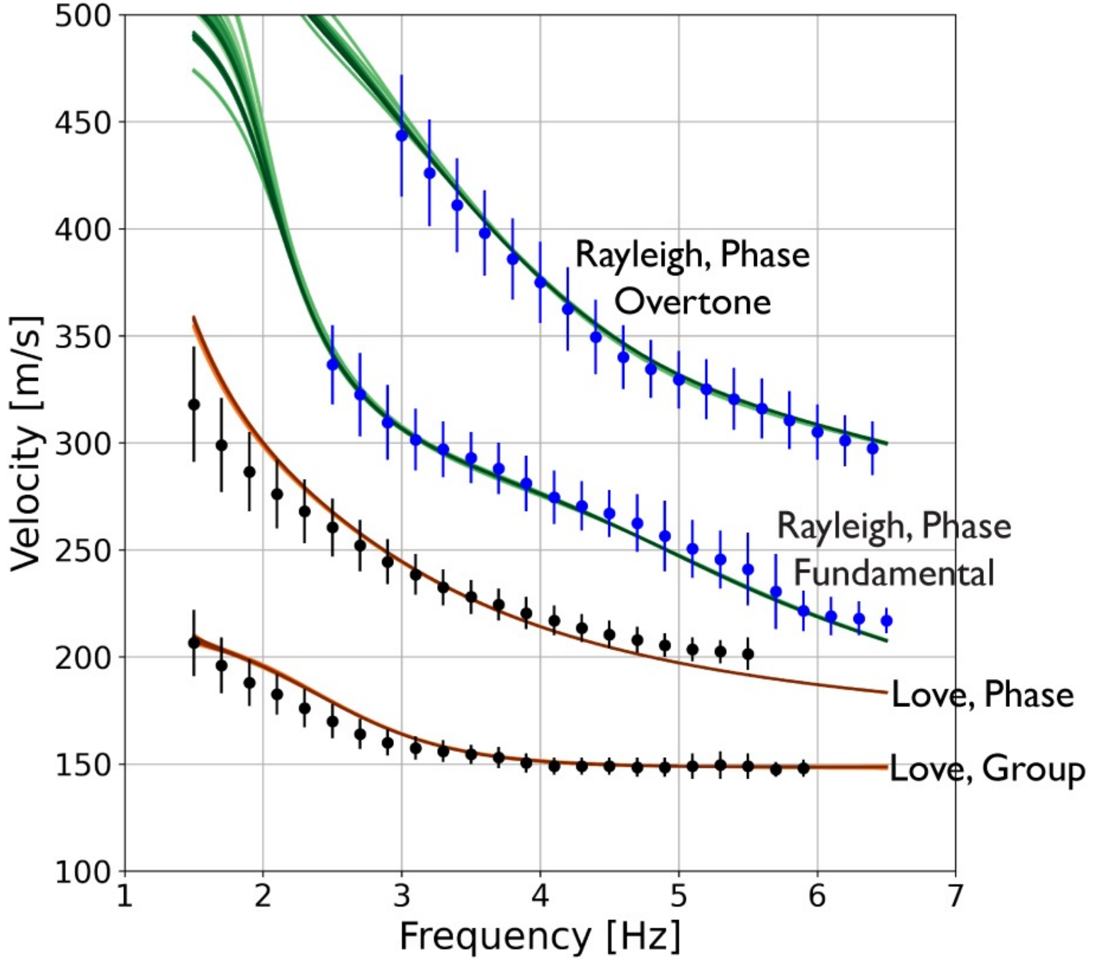
Rayleigh

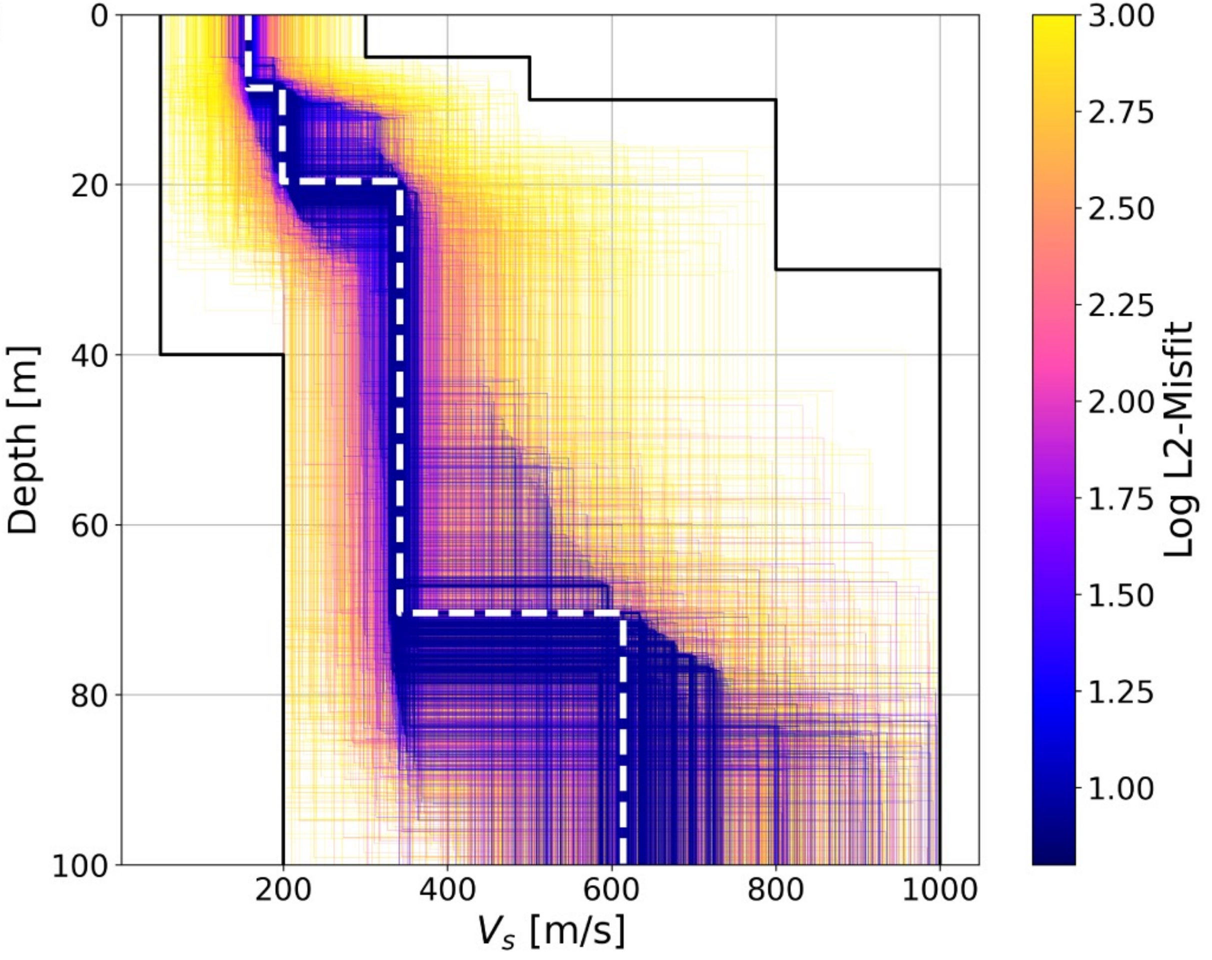






Inversion results





Fit 4 dispersion curves simultaneously

Sensitive to top ~ 100 m structures

Particle swarm optimization (Luu et al. 2018)

1,250,000 test models, 4-layer

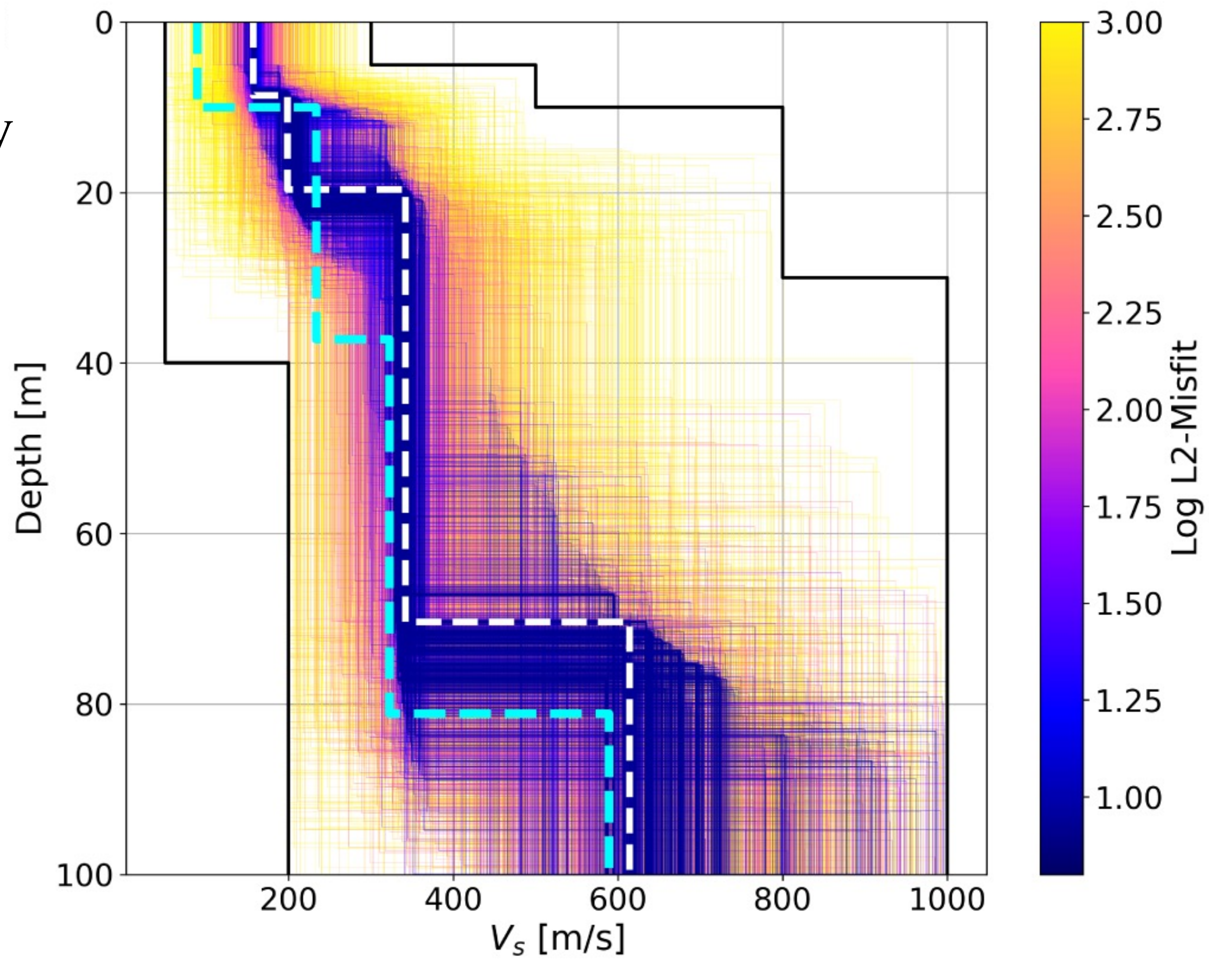
Inversion results

Similar with model from Hayashi and Burns (2020) for William Street Park, ~2 km away from DAS array

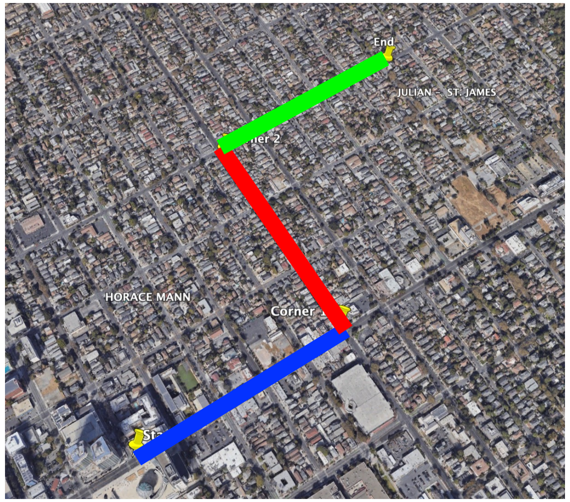
They use Rayleigh dispersion and H/V ratio

High Poisson's ratio (> 0.4) for top ~ 80 m

→ saturated Holocene alluvial sections (Wentworth and Tinsley, 2005)

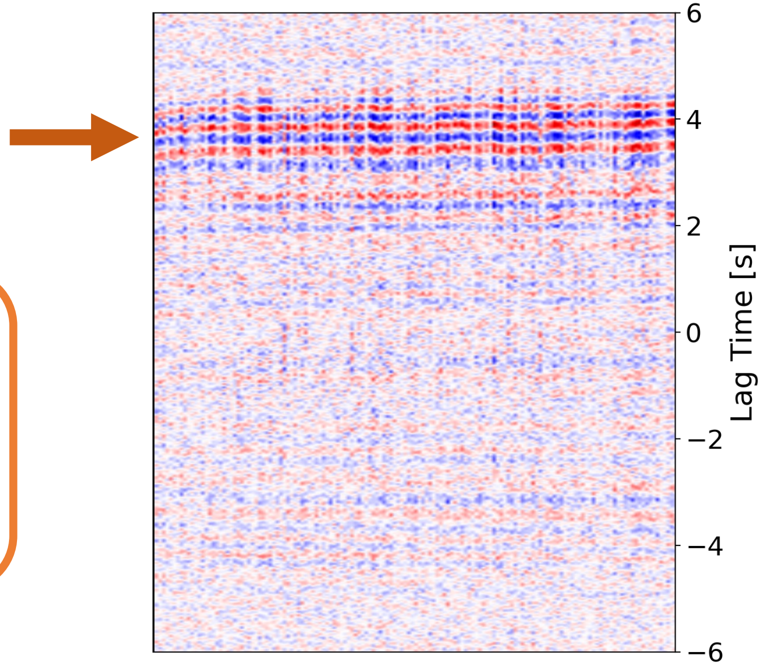


Summary



Orthogonal DAS segments in San Jose

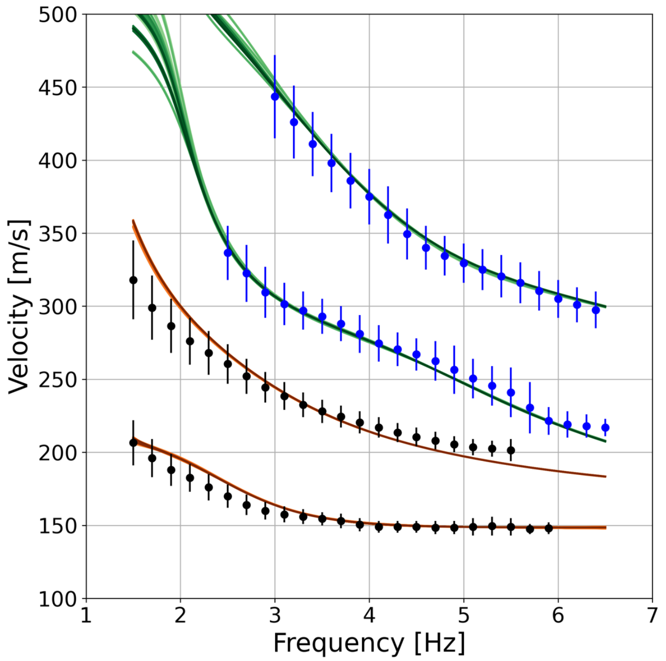
Love signals in cross-correlation



- ✓ Represent DAS grid in urban environment
- ✓ Take advantage of 2D geometry

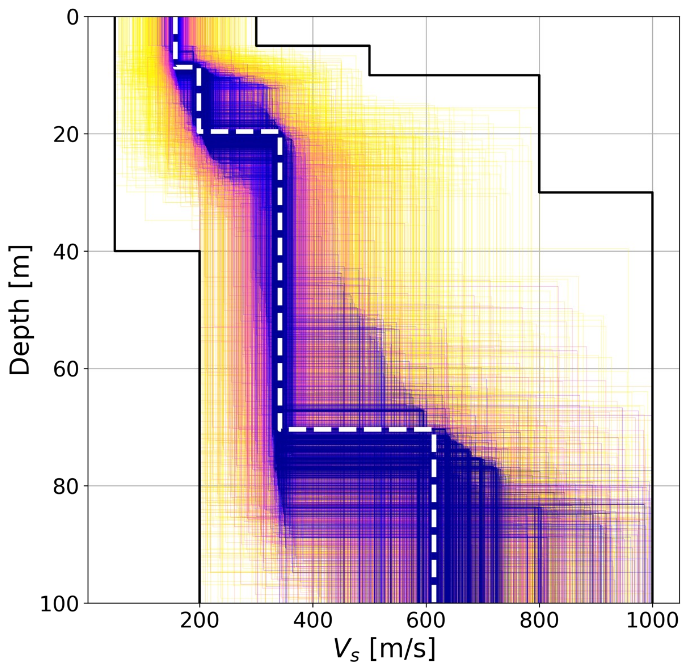
- ✓ Guided by theoretical DAS angular response
- ✓ Consistent Love wave signals from parallel, oblique channel pairs
- ✓ Traffic noise, scattering from Rayleigh to Love

Summary



Rayleigh & Love
phase & group
(~ 1 - 6 Hz)

1D subsurface
shear velocity



- ✓ Reliable dispersion maps from 3 days of noise record
- ✓ Accommodate both virtual source gathers and common offset gathers
- ✓ Better fit and more stable inversion than using either Rayleigh or Love only
- ✓ Consistent with local geology and results from other methods

Continuous monitoring of shallow subsurface in urban areas

Acknowledgements

City of San Jose by providing us access to the urban fiber network

OptaSense Inc. for help with the organization of DAS data from San Jose

Stanford Sustainability Initiative, UPS Foundation Endowment Fund and Stanford Exploration Project for financial support

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