



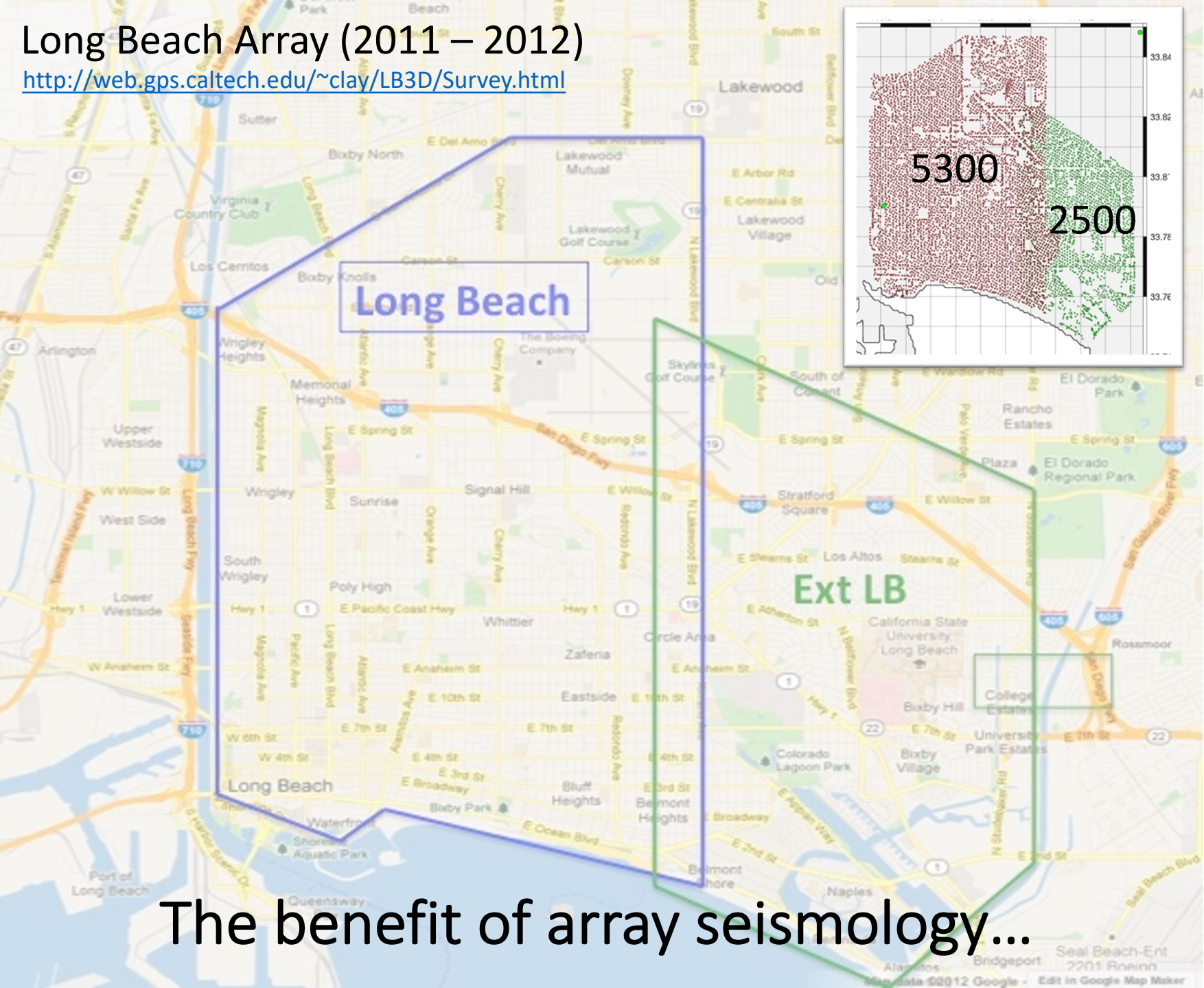
City-scale dark fiber DAS measurements of infrastructure use during the COVID-19 pandemic

Nathaniel Lindsey¹, Siyuan Yuan¹, Ariel Lellouch¹, Lucia Gualtieri¹, Thomas Lecocq², Biondo Biondi¹

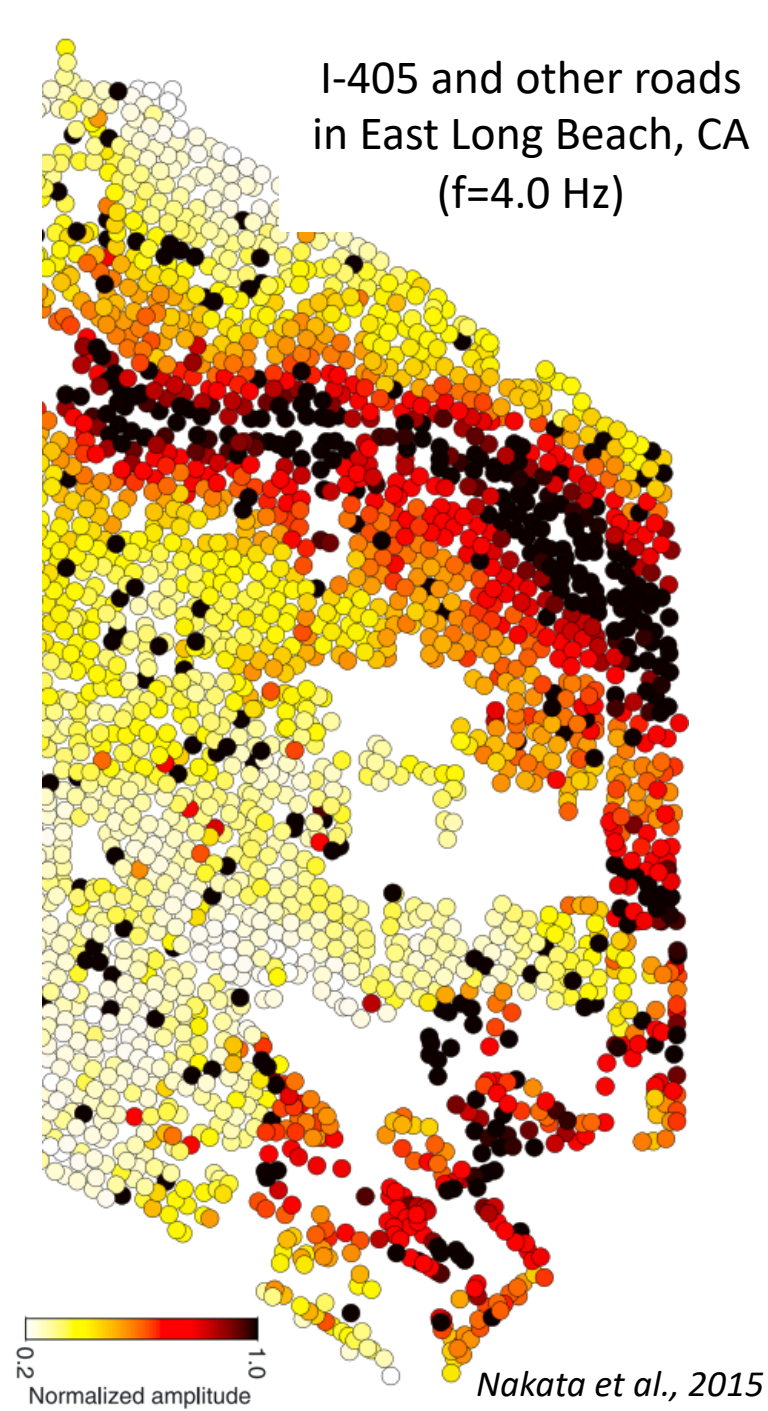
1. Stanford University, 2. Royal Observatory of Belgium

Long Beach Array (2011 – 2012)

<http://web.gps.caltech.edu/~clay/LB3D/Survey.html>



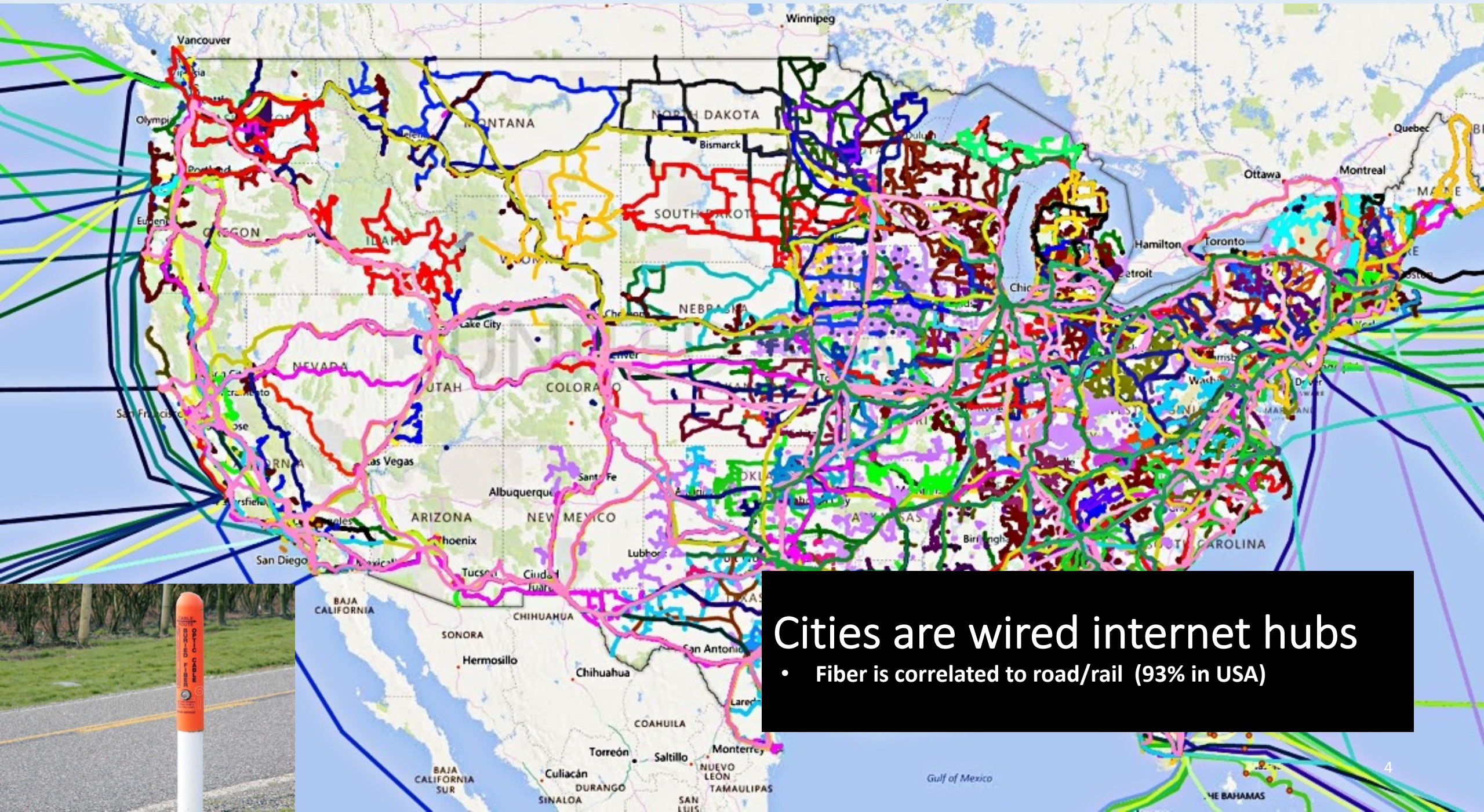
I-405 and other roads
in East Long Beach, CA
($f=4.0$ Hz)



The benefit of array seismology...

Nakata et al., 2015

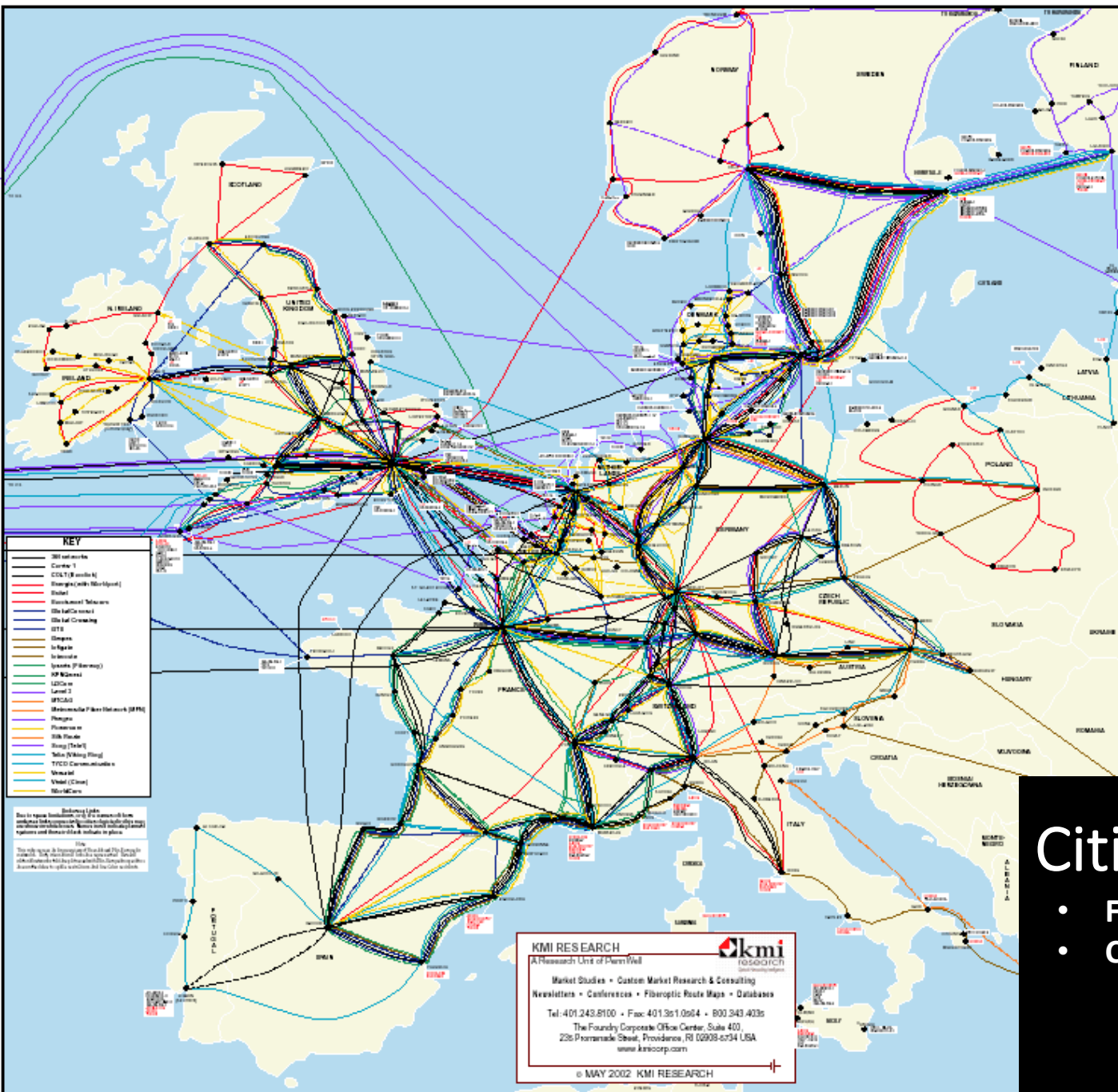
Cities are wired internet hubs



Cities are wired internet hubs

- Fiber is correlated to road/rail (93% in USA)





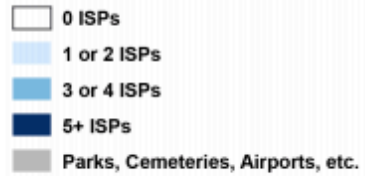
Cities are wired internet hubs

- **Fiber is correlated to road/rail (93% in USA)**
- **CenturyLink owns 5.6 Gm of fiber, adding 1.9 Gm in 70 cities**

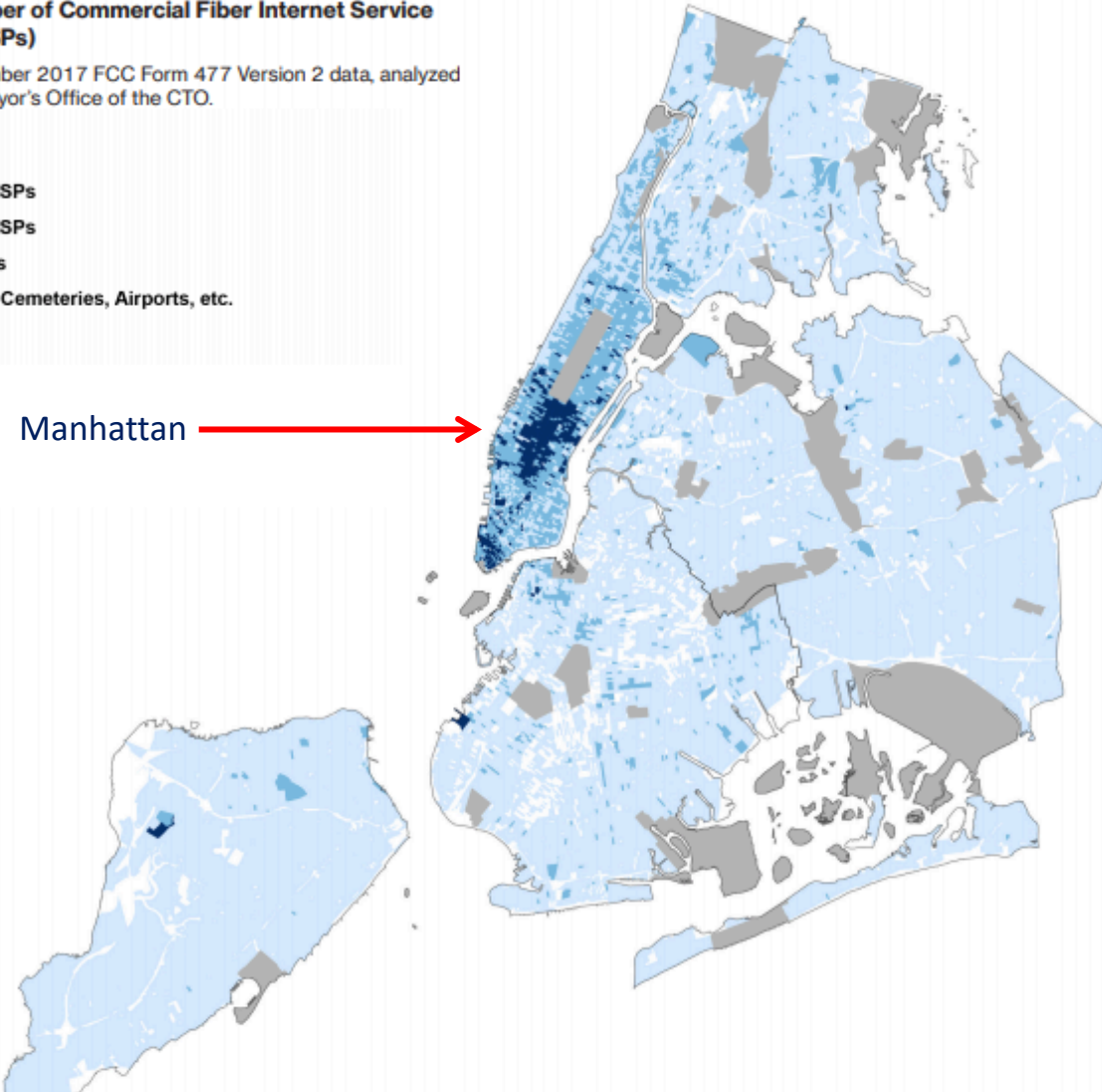
NYC Internet Master Plan Jan 2020

Map 2: Number of Commercial Fiber Internet Service Providers (ISPs)

Source: December 2017 FCC Form 477 Version 2 data, analyzed by the NYC Mayor's Office of the CTO.



Manhattan



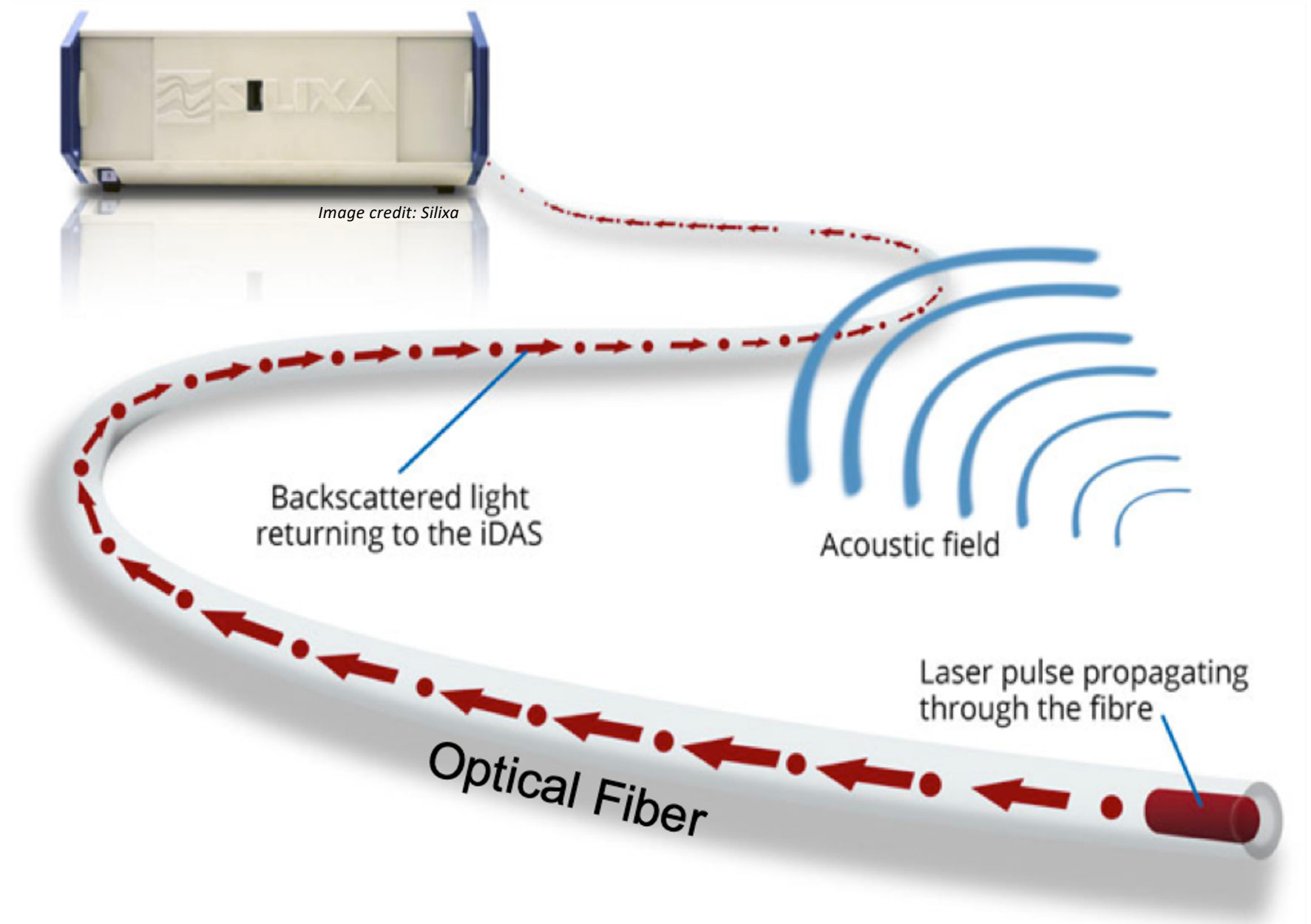
https://tech.cityofnewyork.us/wp-content/uploads/2020/01/NYC_IMP_1.7.20_FINAL-2.pdf

Cities are wired internet hubs

- Fiber is correlated to road/rail (93% in USA)
- CenturyLink owns 5.6 Gm of fiber, adding 1.9 Gm in 70 cities
- Many cities have 3-5 ISPs per block

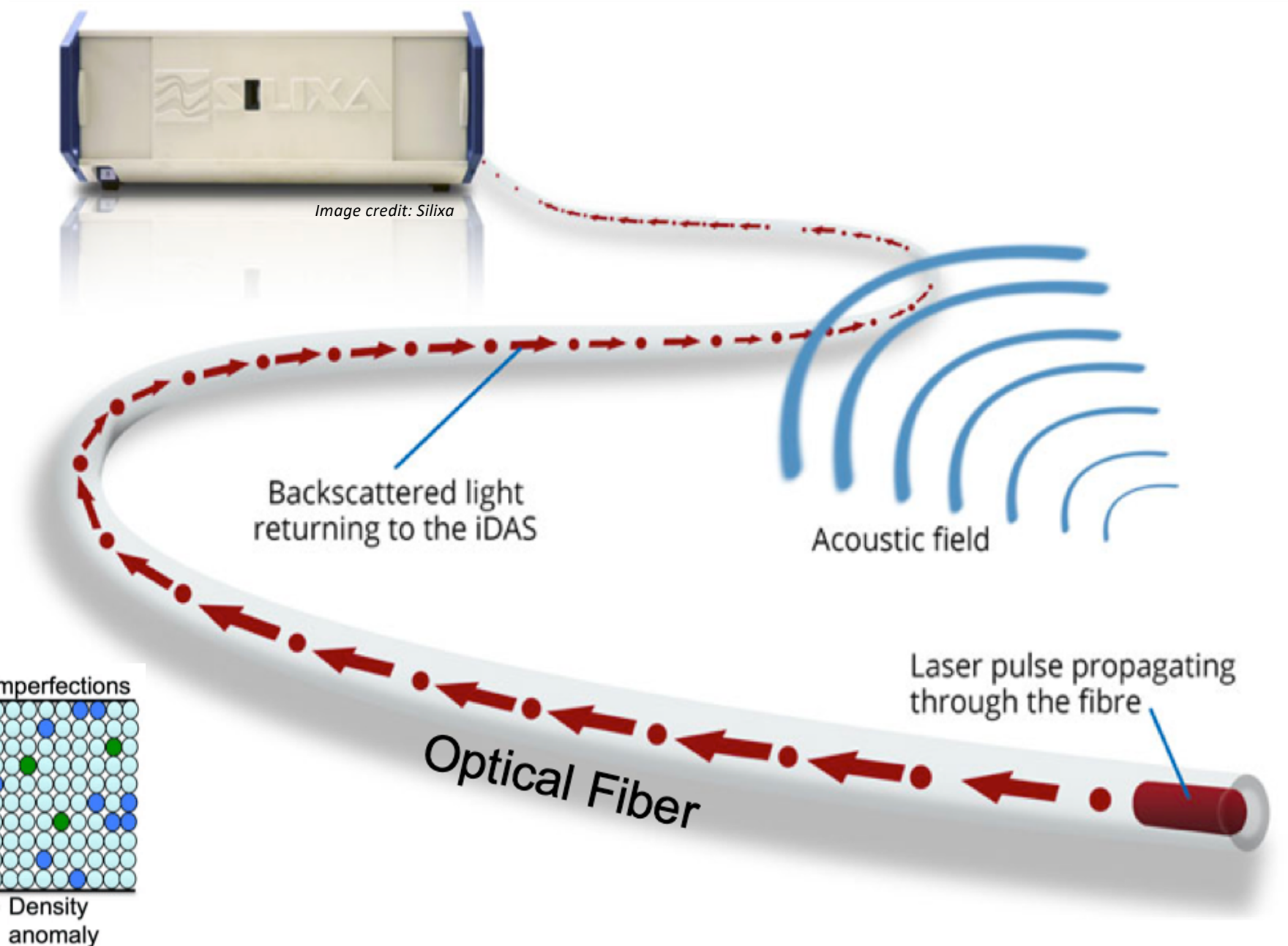
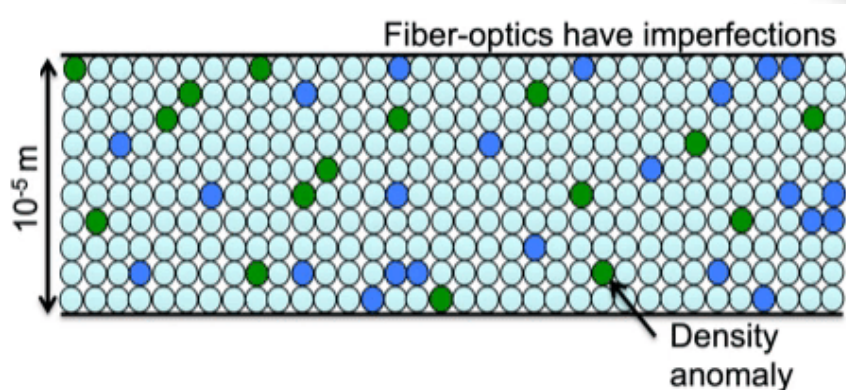
Cities are wired internet hubs
What if we could use this for geophysics?

Distributed Acoustic Sensing



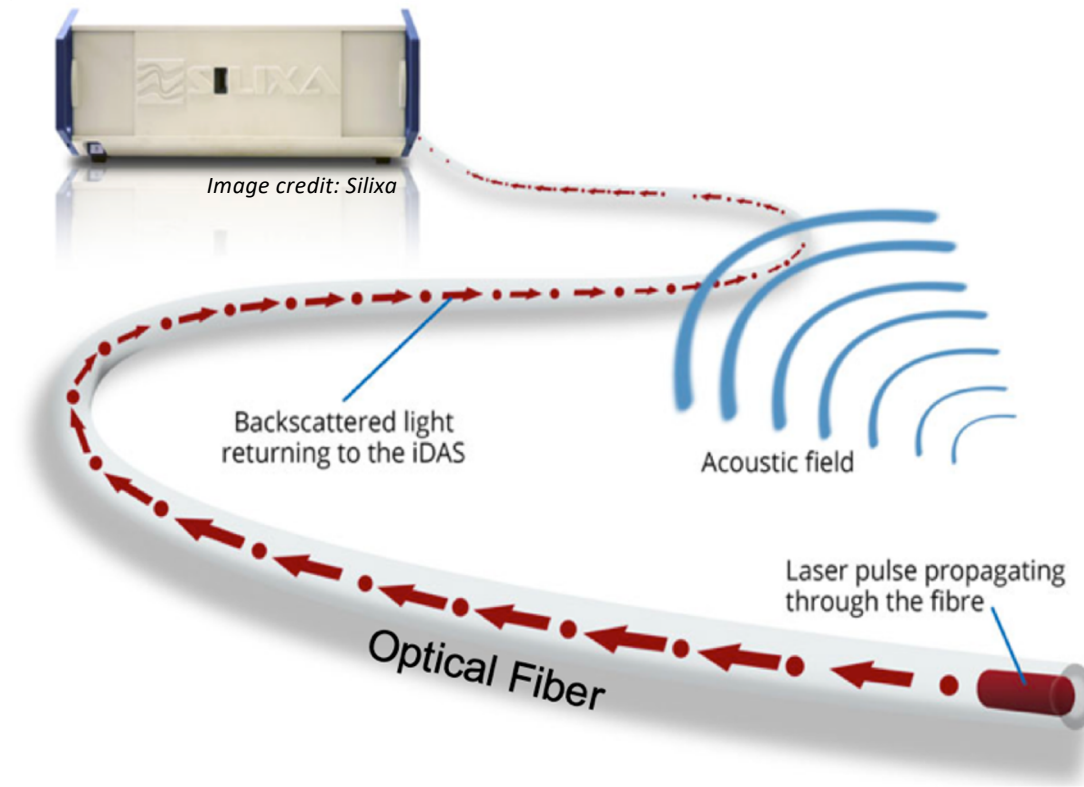
Distributed Acoustic Sensing

turns a fiber-optic cable
into a massive 1C
seismic array
(of strain-rate sensors).



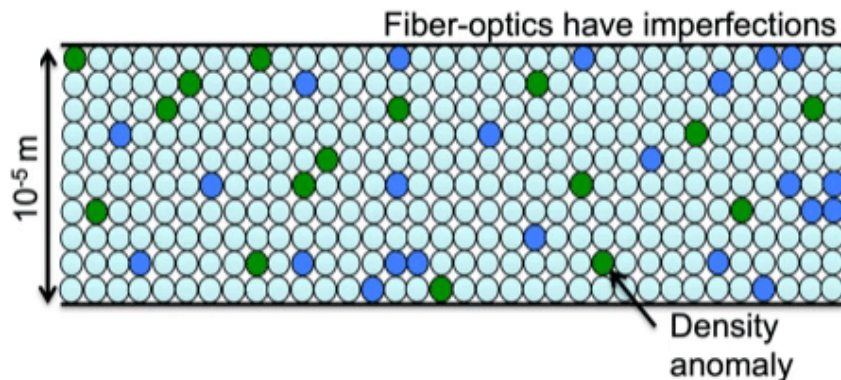
Distributed Acoustic Sensing

turns a fiber-optic cable
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Some Common Recording Parameters:

Laser pulse width $\sim 10 - 40$ ns
Spatial sampling (L_G) ~ 10 m
Maximum aperture ~ 30 km (standard fiber)
Laser pulse rate (t^{-1}) $\sim 10 - 100$ kHz
Digital sampling $\sim 100 - 1000$ Hz
Data flowrate $\sim 0.01 - 10$ TB/day



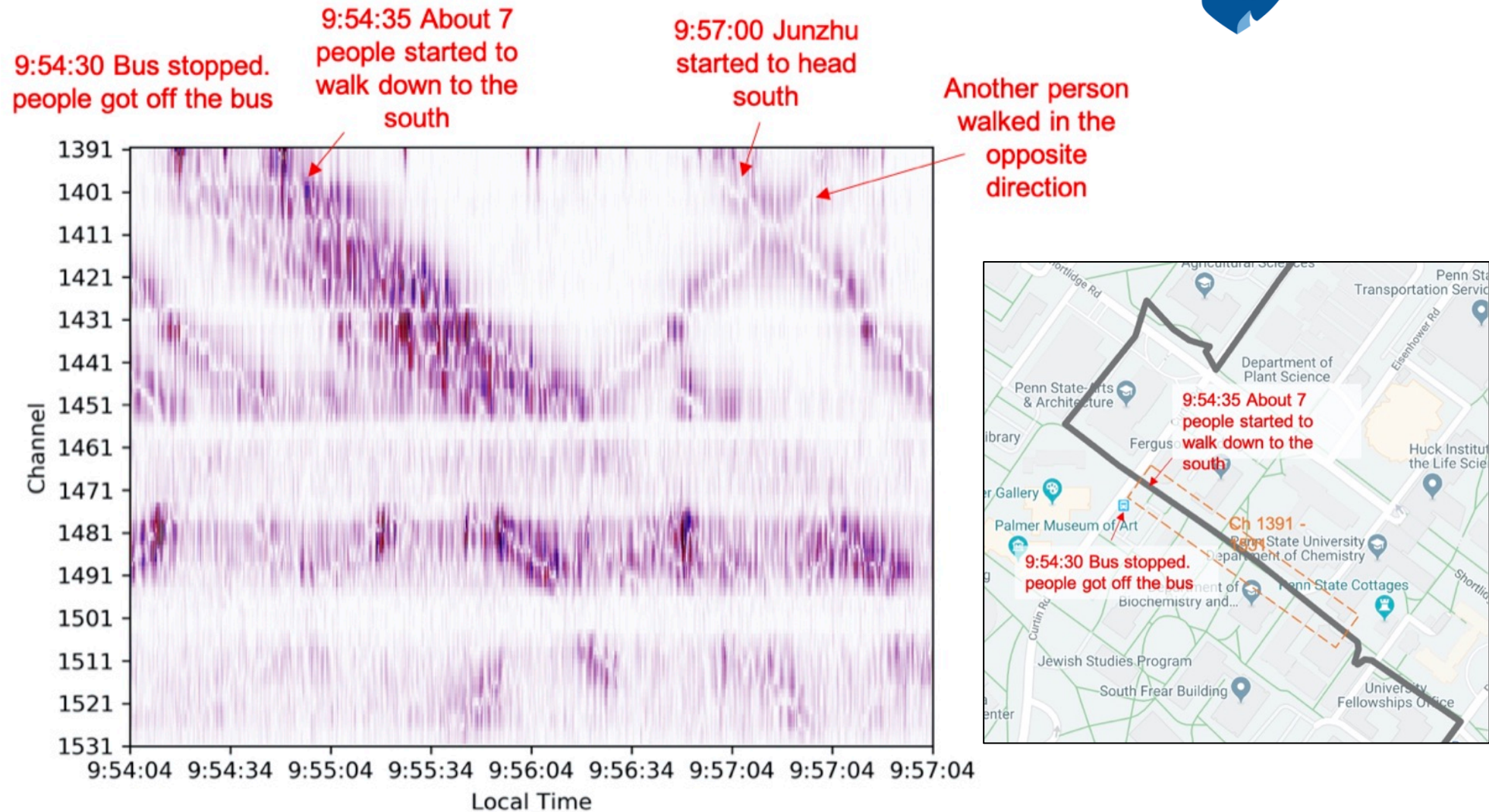
$$\epsilon_{xx}(t, x_j) = \frac{\lambda}{4\pi n L_G \zeta} \Delta\Phi = \frac{1550 \cdot 10^{-9} \text{ (m)}}{4\pi \cdot 1.445 \cdot 10 \text{ (m)} \cdot 0.735} \Delta\Phi = 11.6 \cdot 10^{-9} \cdot \Delta\Phi \text{ (rad)}$$



Lindsey, N.J., Rademacher, H. and Ajo-Franklin, J.B., 2020.
On the broadband instrument response of fiber-optic DAS arrays.
Journal of Geophysical Research: Solid Earth, 125(2), p.e2019JB018145.

Footstep detection with DAS

Jakkampudi, Shen, Li, Dev, Martin, Zhu (*The Leading Edge*, accepted)

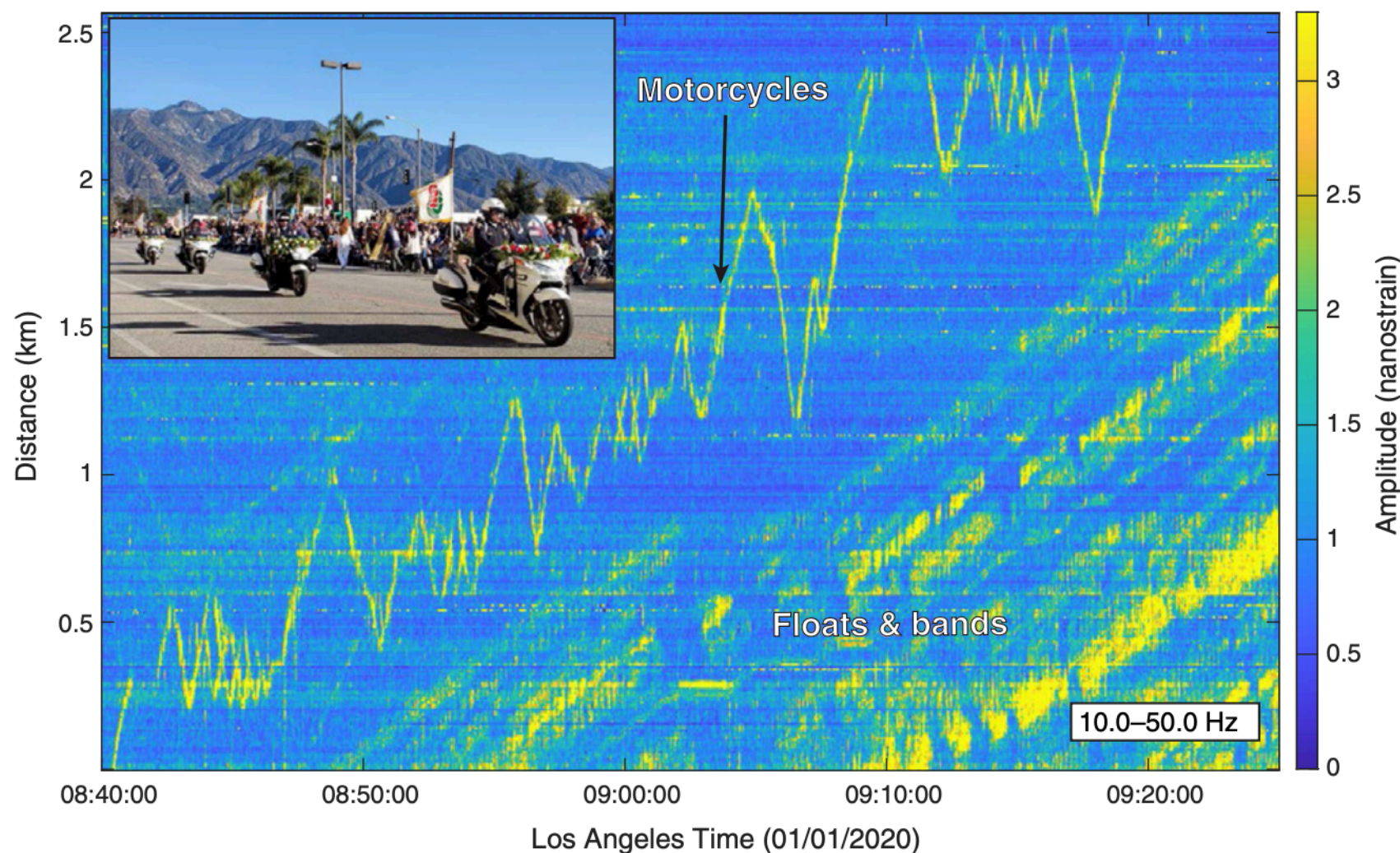




Caltech

Rose Parade observed with DAS

Wang, Williams, Karrenbach, Gonzalez Herraes, Martins, Zhan (*Seismo. Res. Letters*, in press)

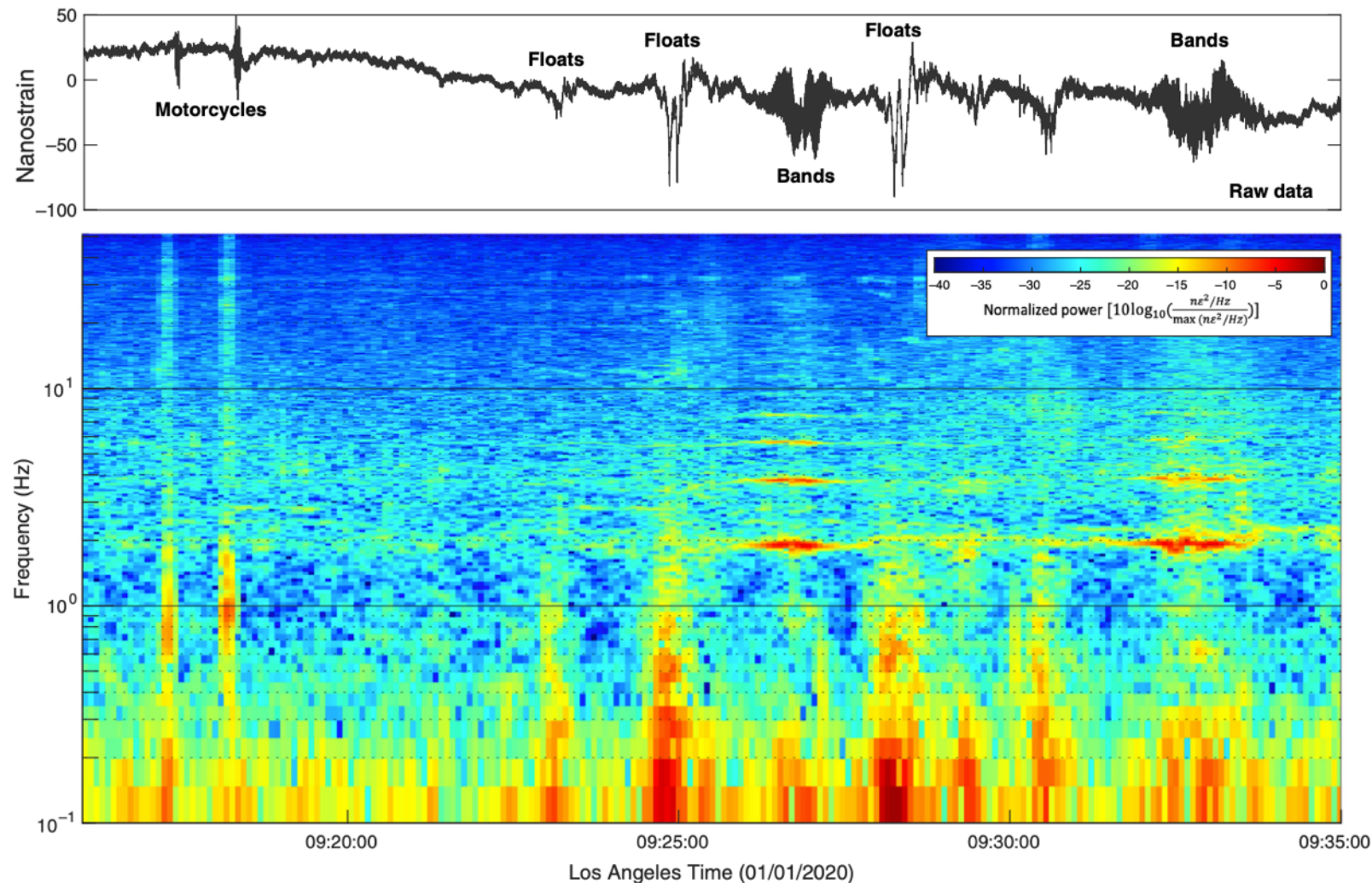




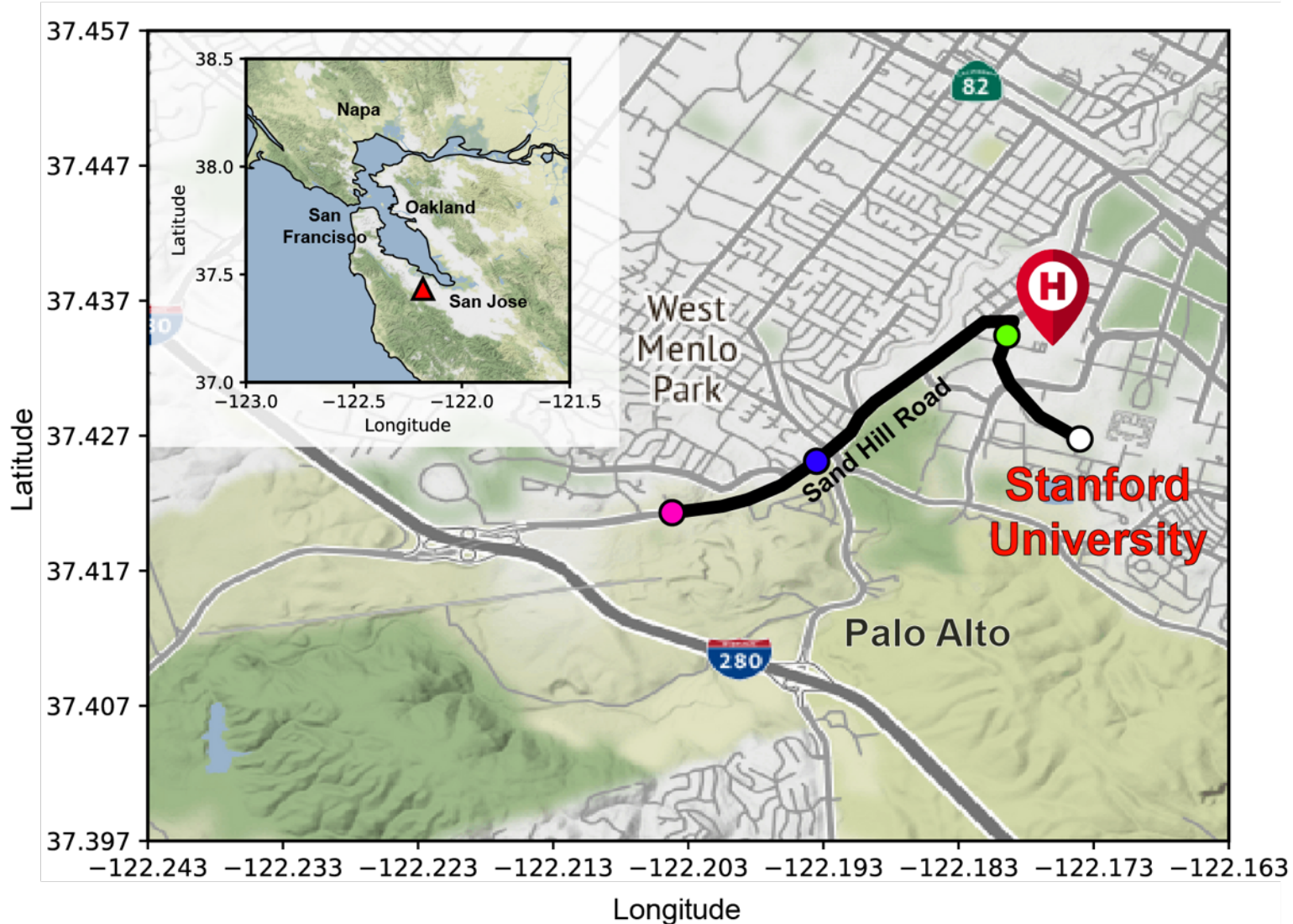
Caltech

Rose Parade observed with DAS

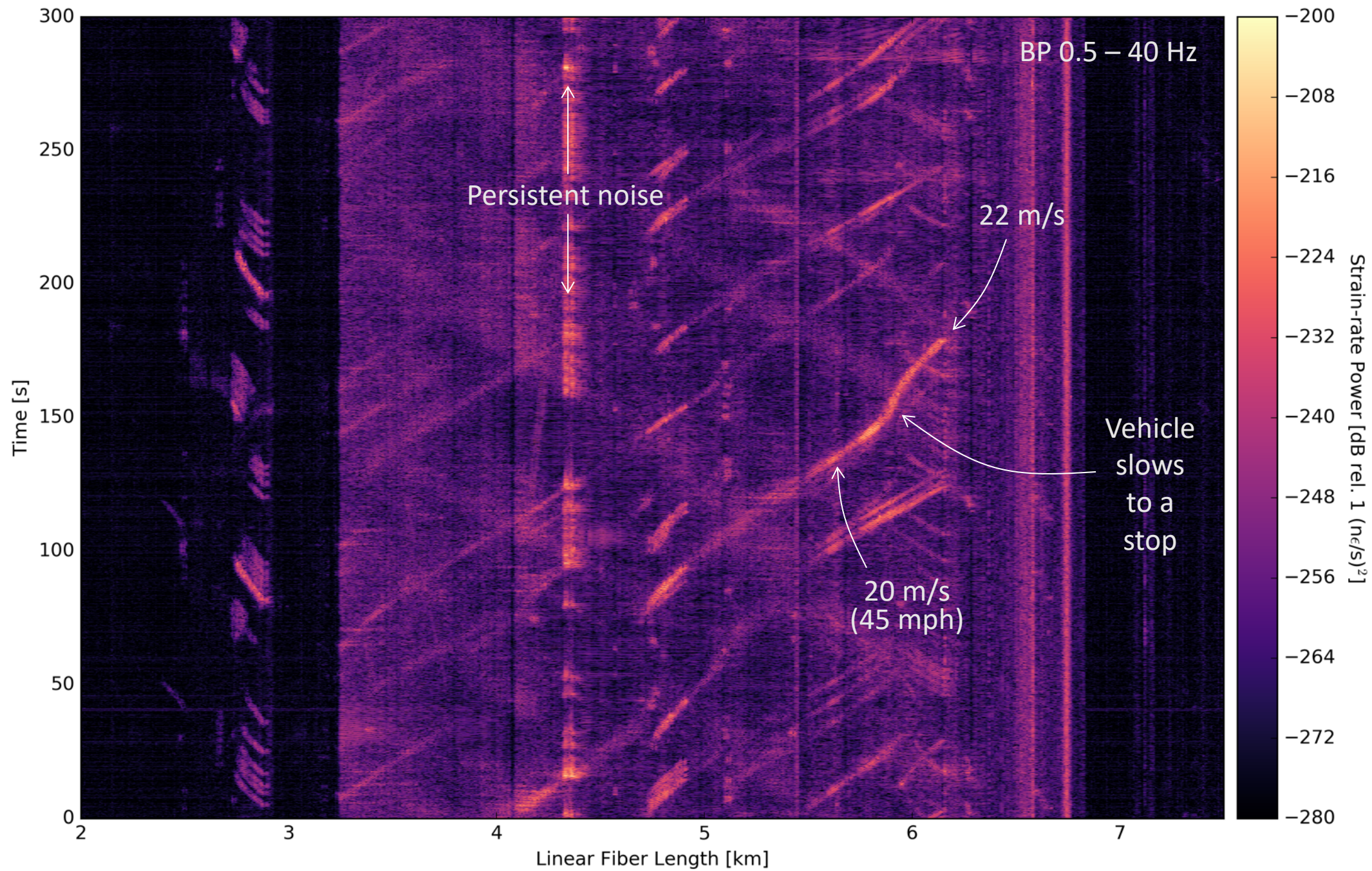
Wang, Williams, Karrenbach, Gonzalez Herraiez, Martins, Zhan (*Seismo. Res. Letters*, in press)



Stanford DAS-2 Experiment

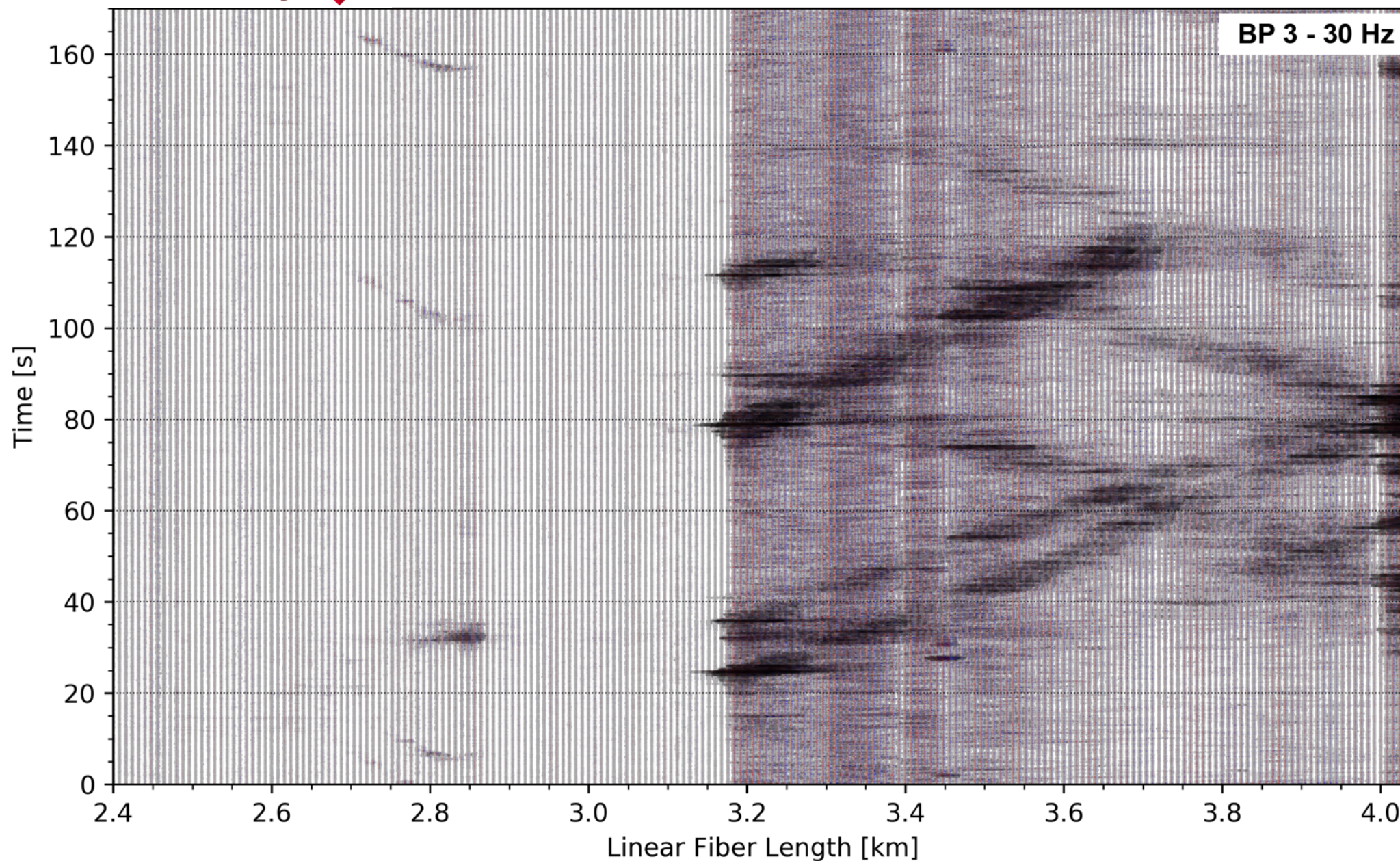


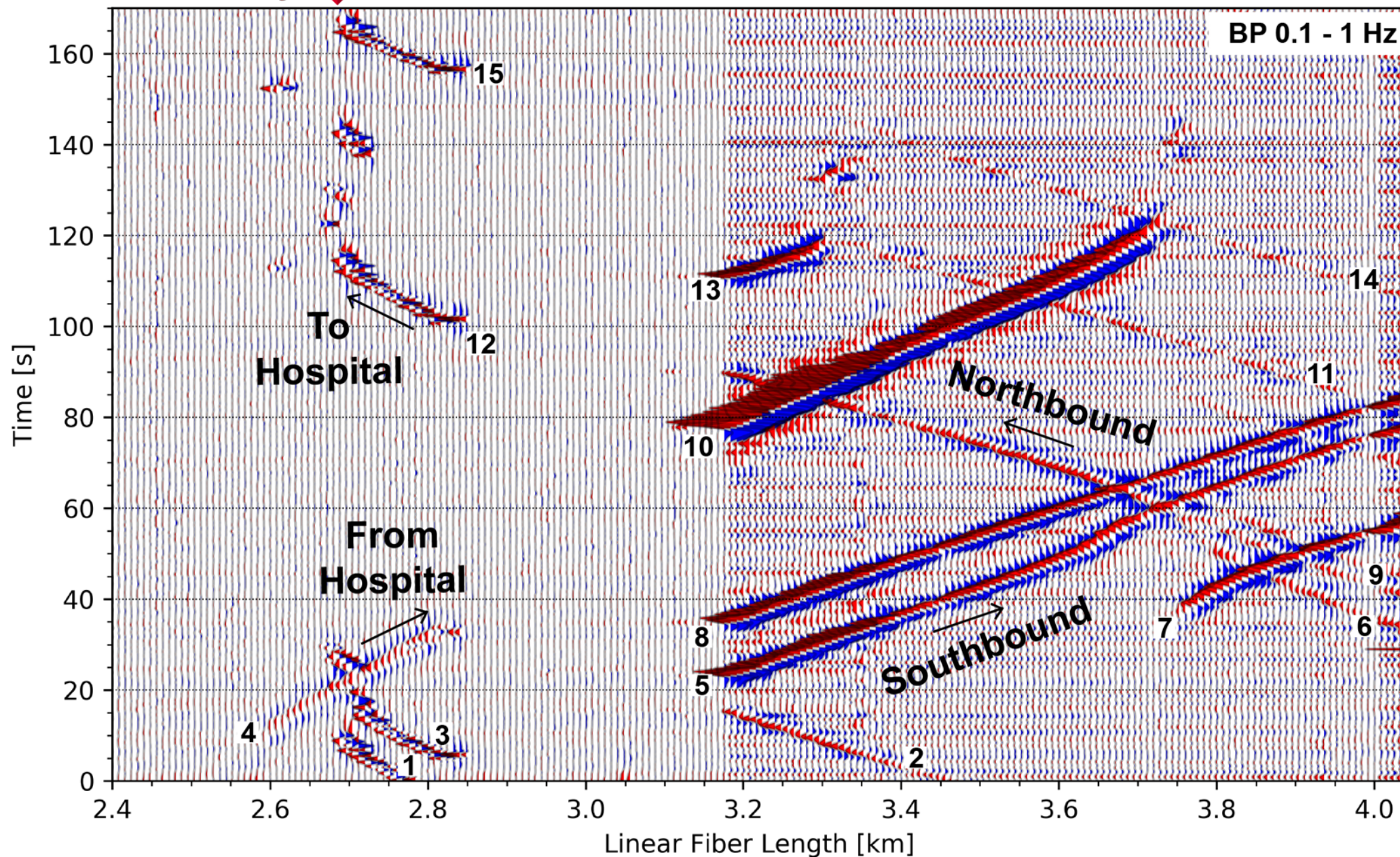
- Optasense ODH3
- Telecommunication FO
- Array = 1250 channels
- Channel spacing = 8.16 m
- Gauge length = 20 m
- Sampling rate = 250 sps
- 108 GB/day from Dec-10-2019



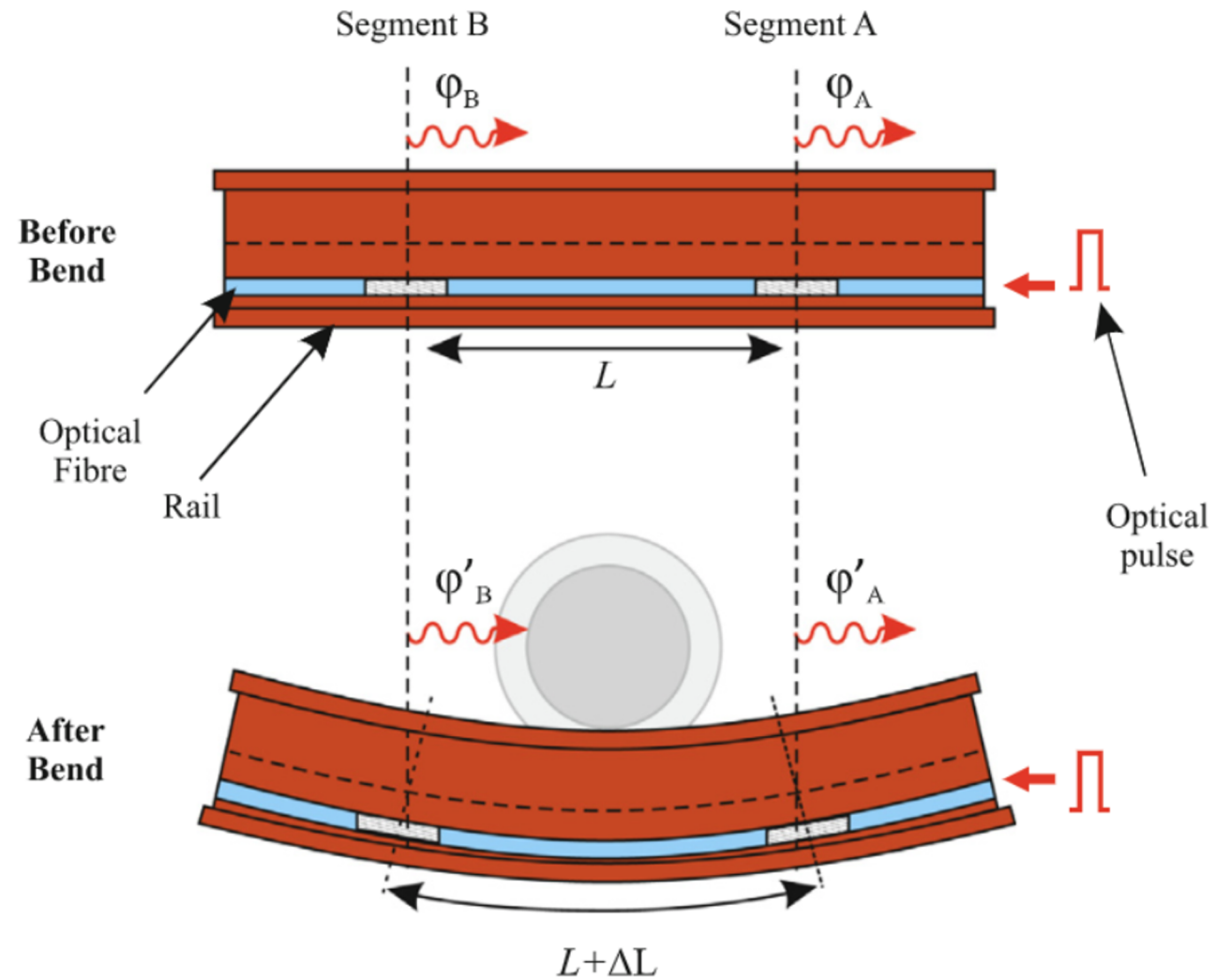


BP 3 - 30 Hz

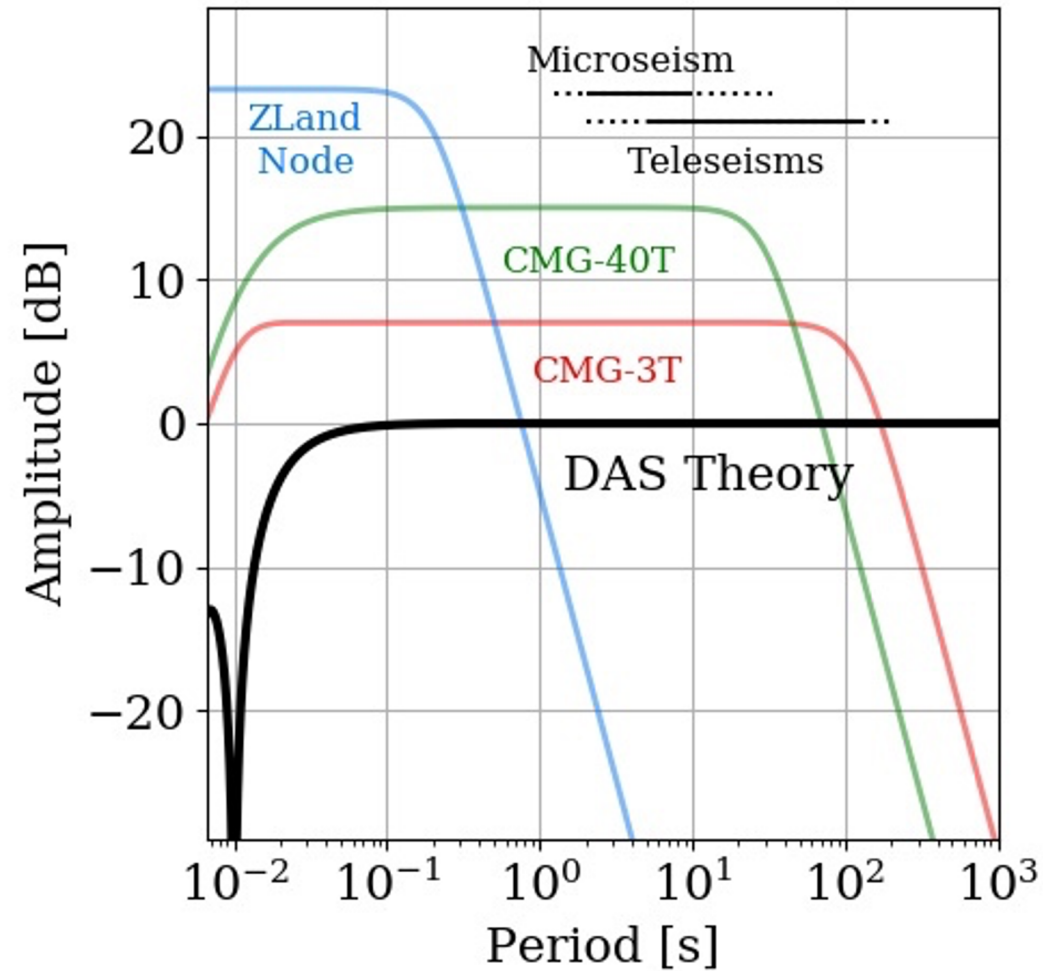




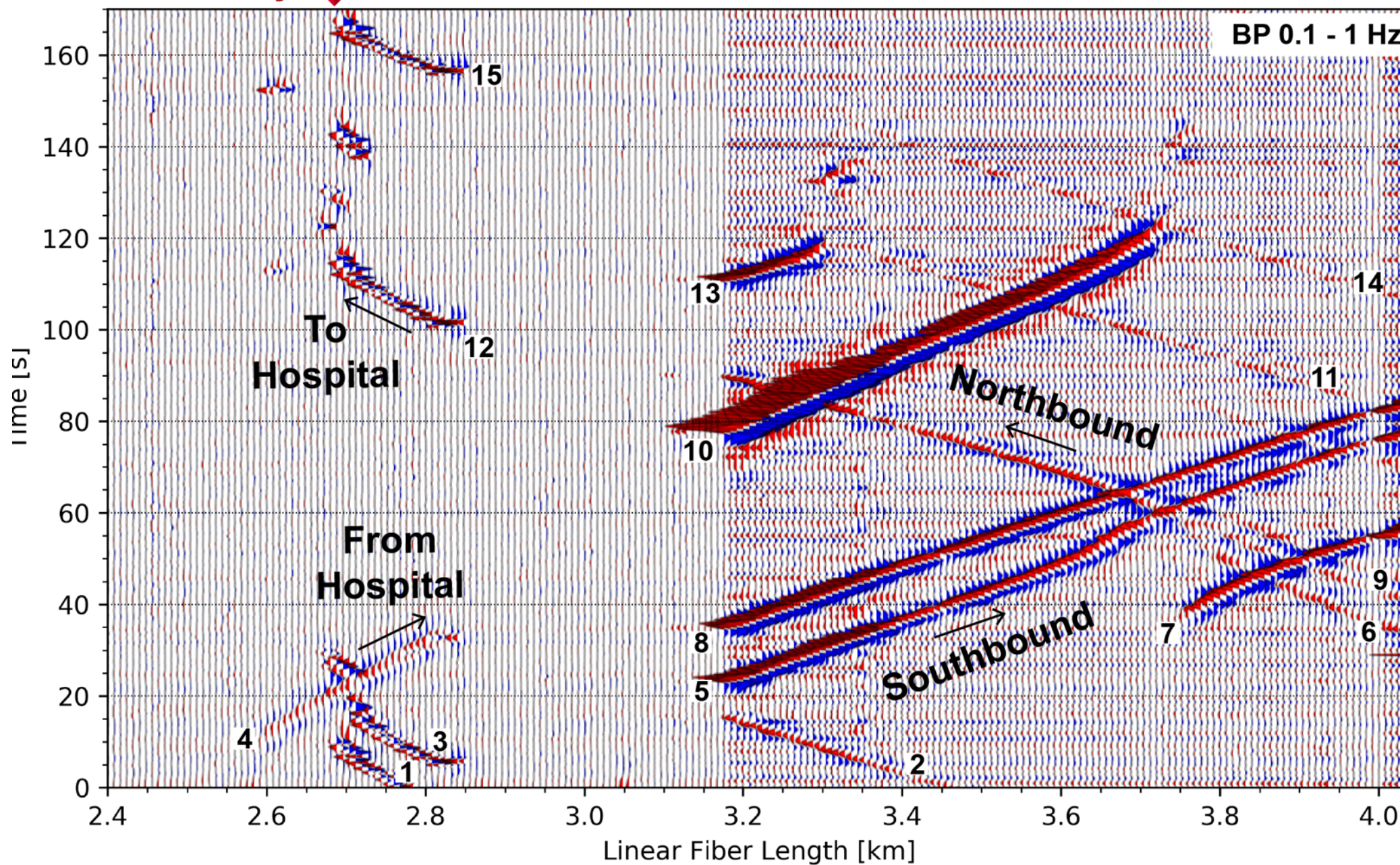
DAS observations



DAS observations



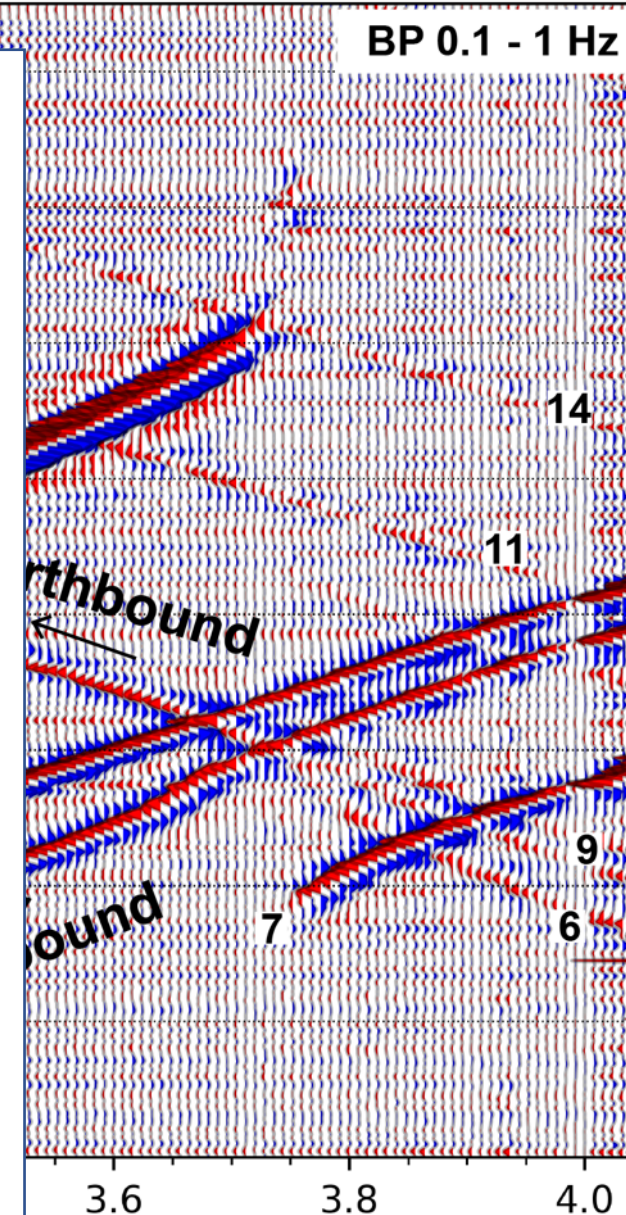
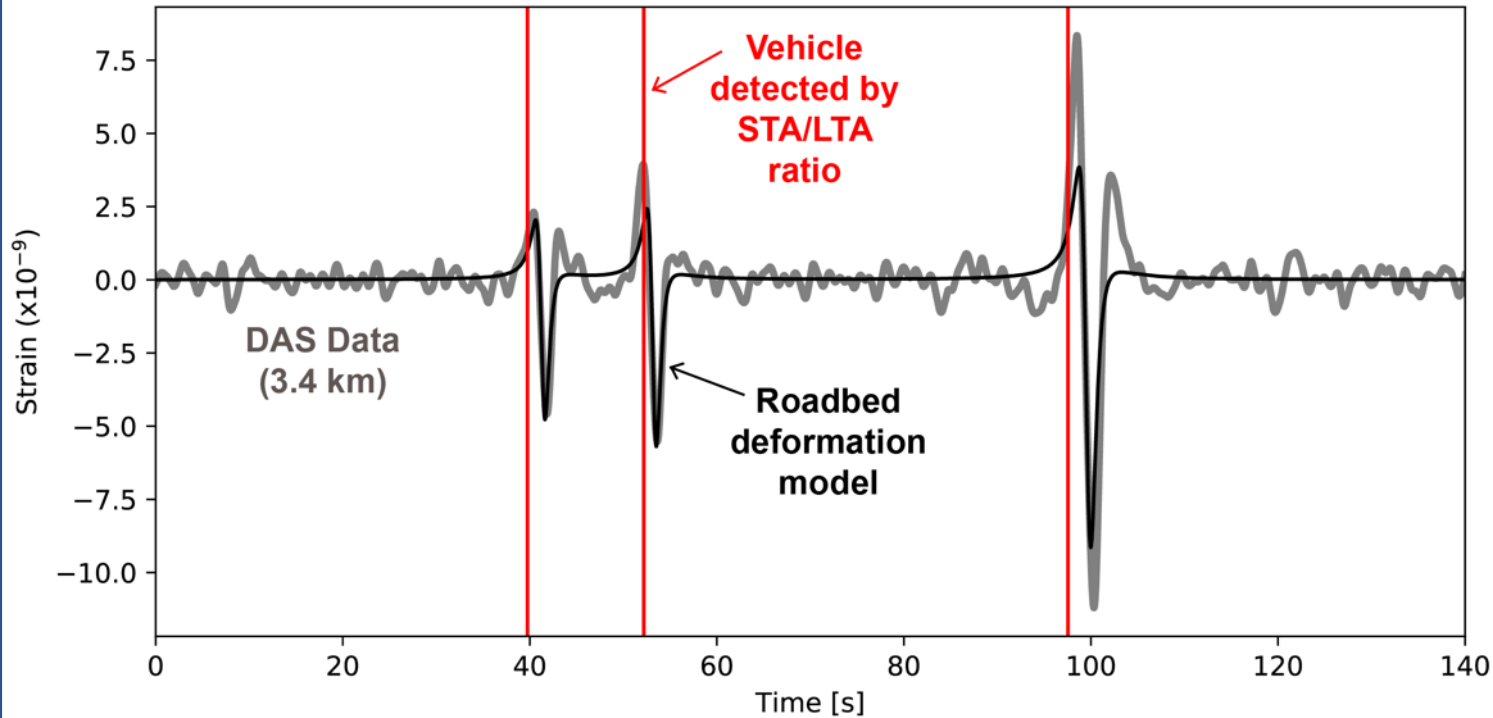
Broadband DAS records on the order of 10^{-8} strain due to vehicle loading/unloading that would be missed by geophones.



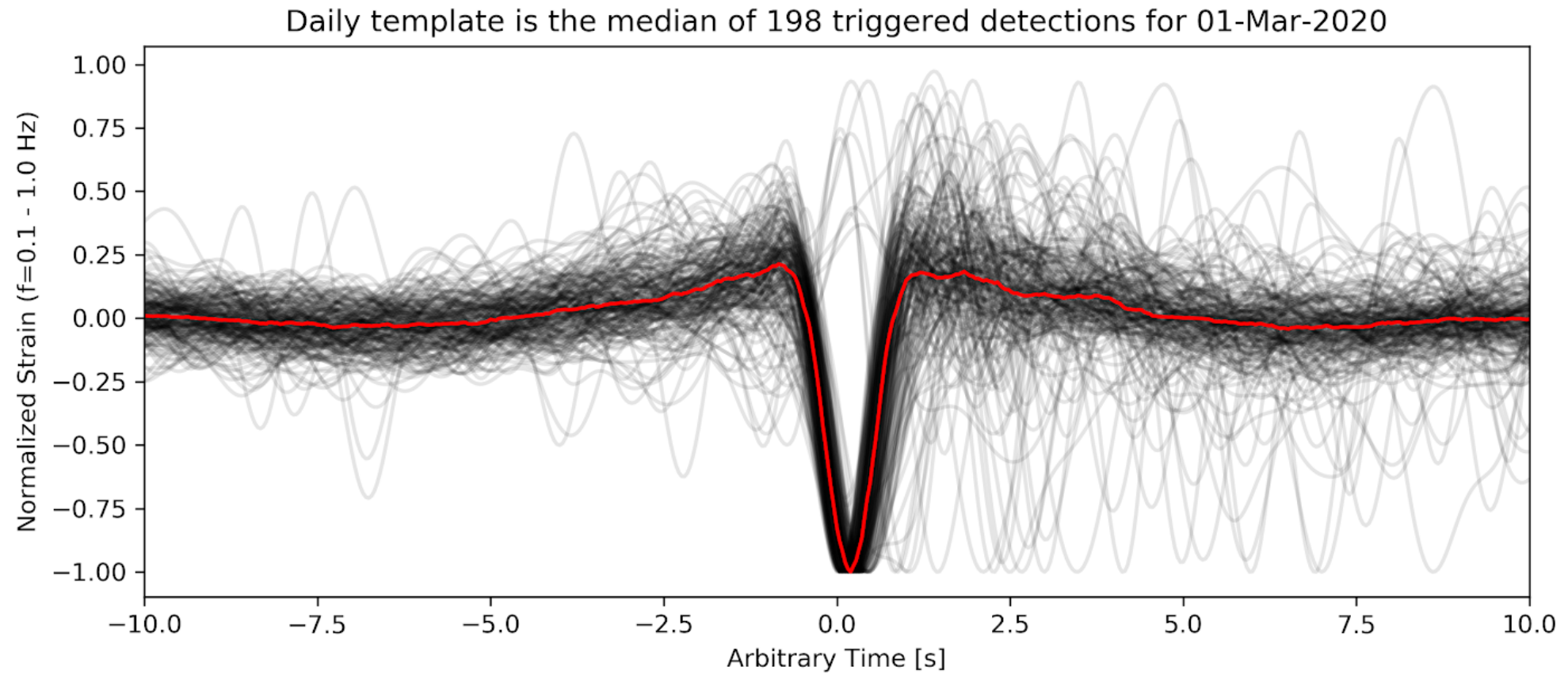
Horizontal strain due to static point load (Boussinesq approximation)

$$u_x(x) = \frac{F}{4\pi\rho v_p^2} \frac{2\nu - 2}{2\nu - 1} \left(\frac{zx}{r^3} - \frac{x}{r^2 + zr} + \frac{2xv}{r^2 + zr} \right); \quad \varepsilon_x = \frac{\Delta u_x}{G}$$

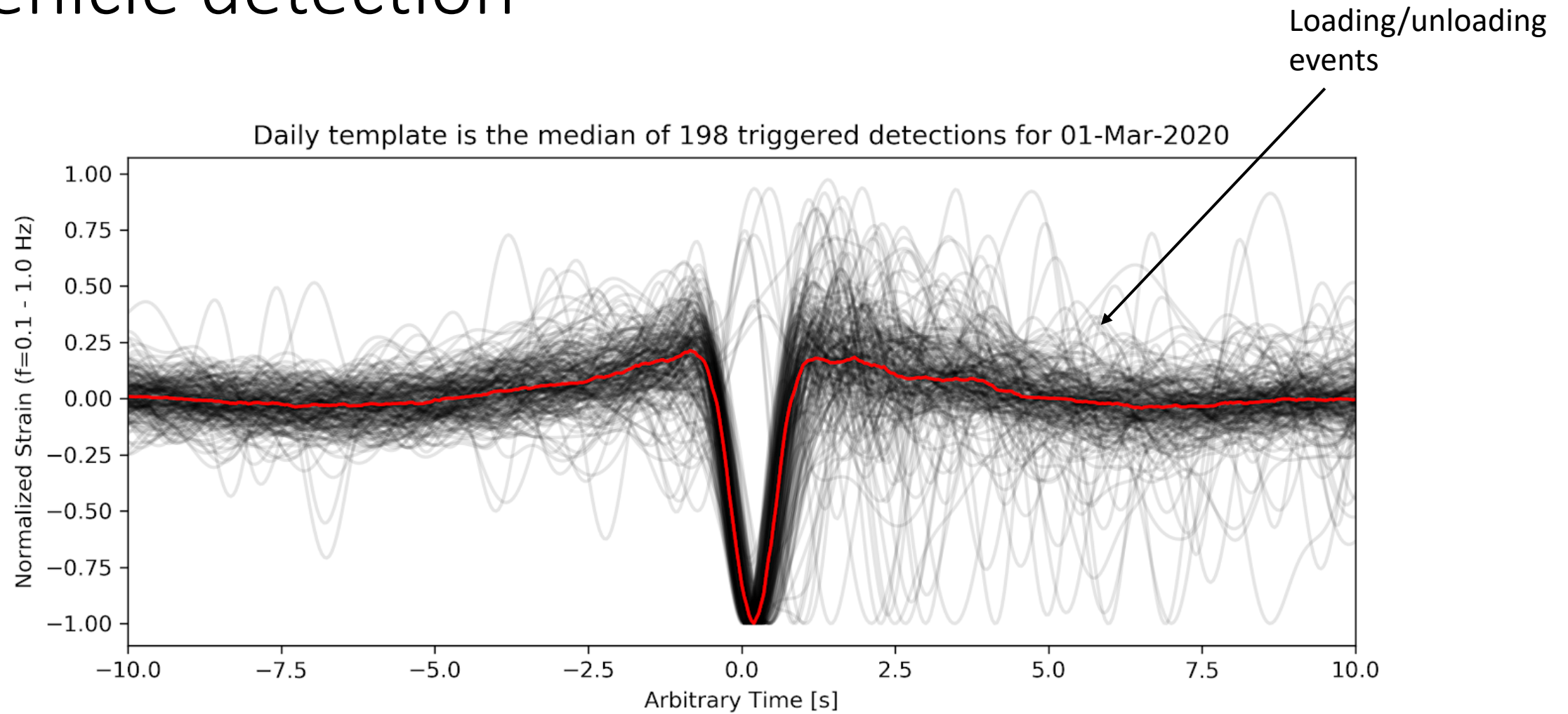
Detection of Vehicles on DAS using Roadbed Deformation Signals



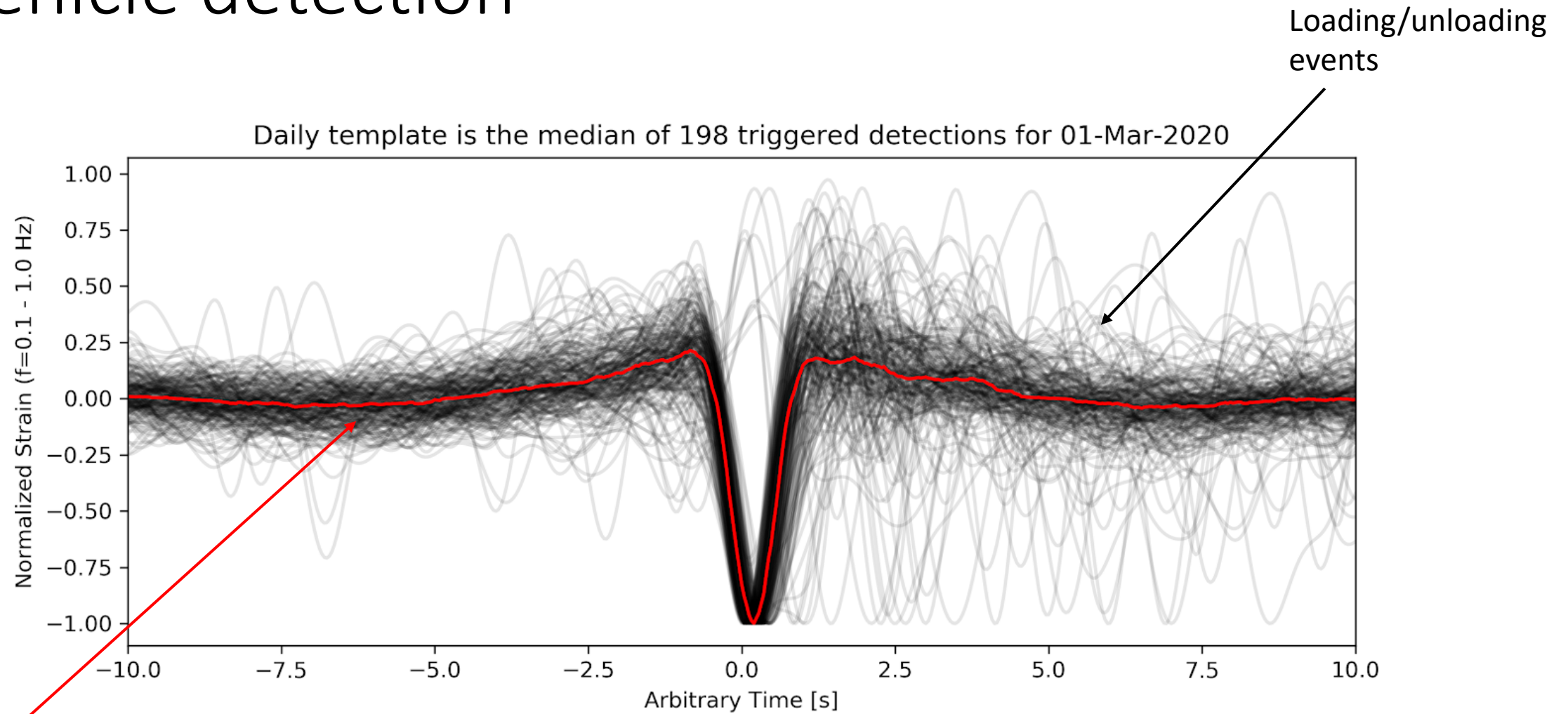
Vehicle detection



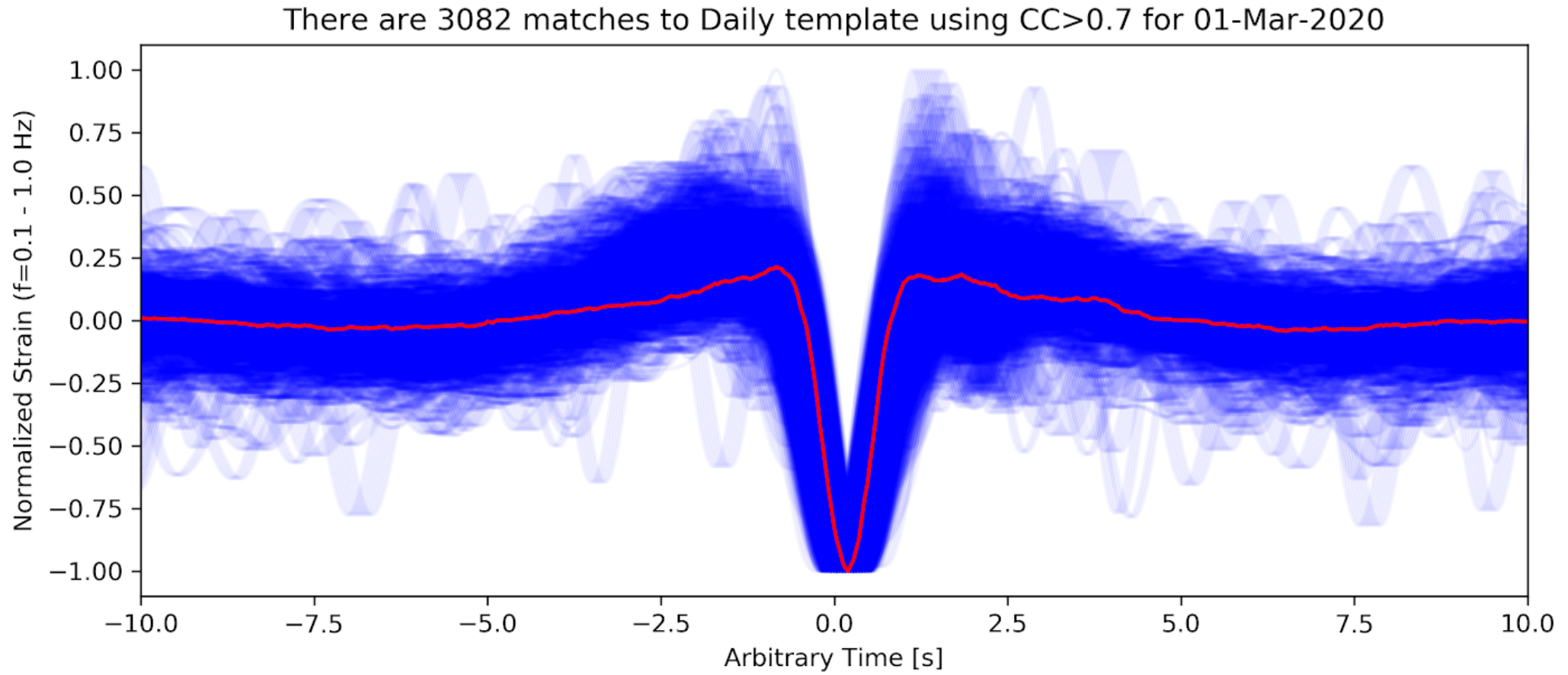
Vehicle detection



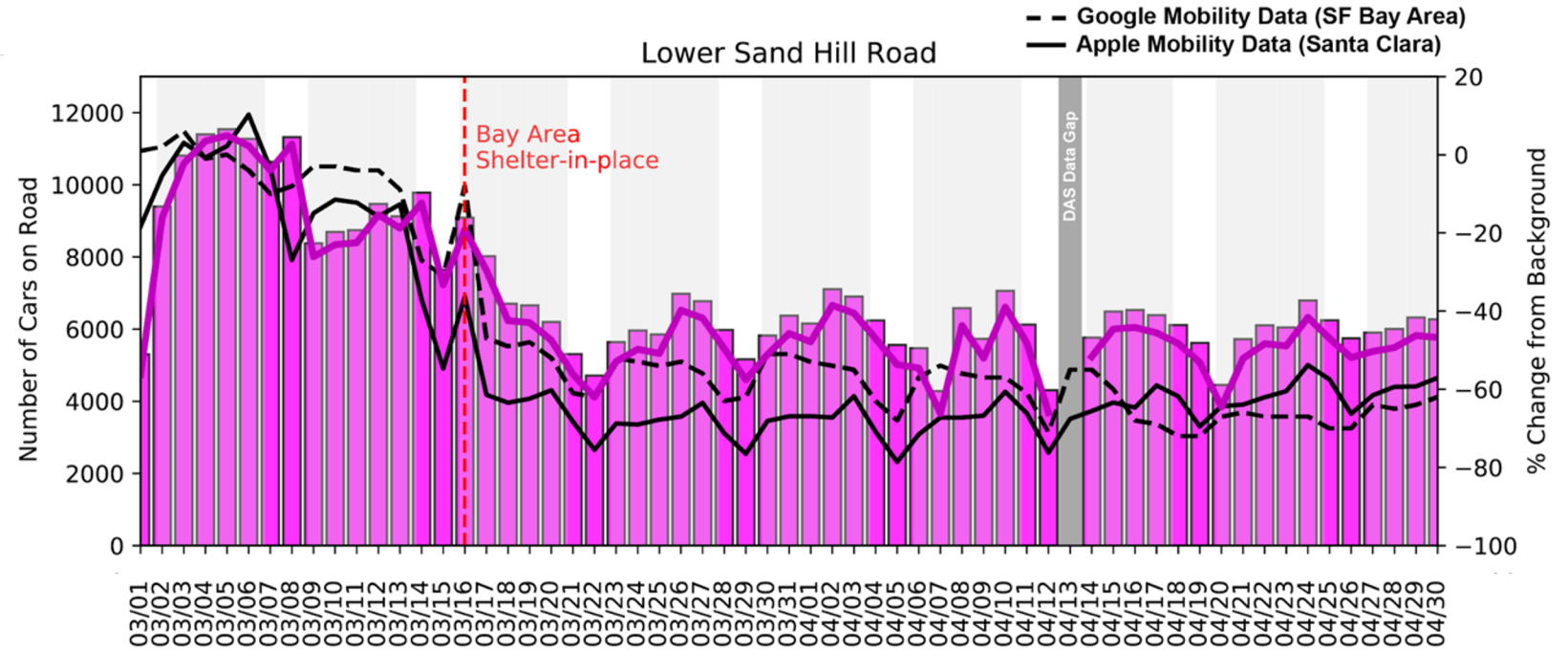
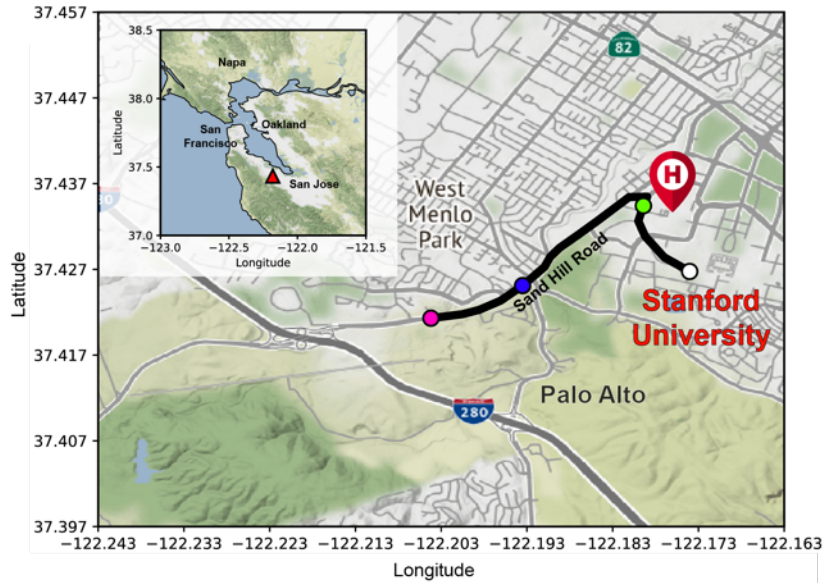
Vehicle detection



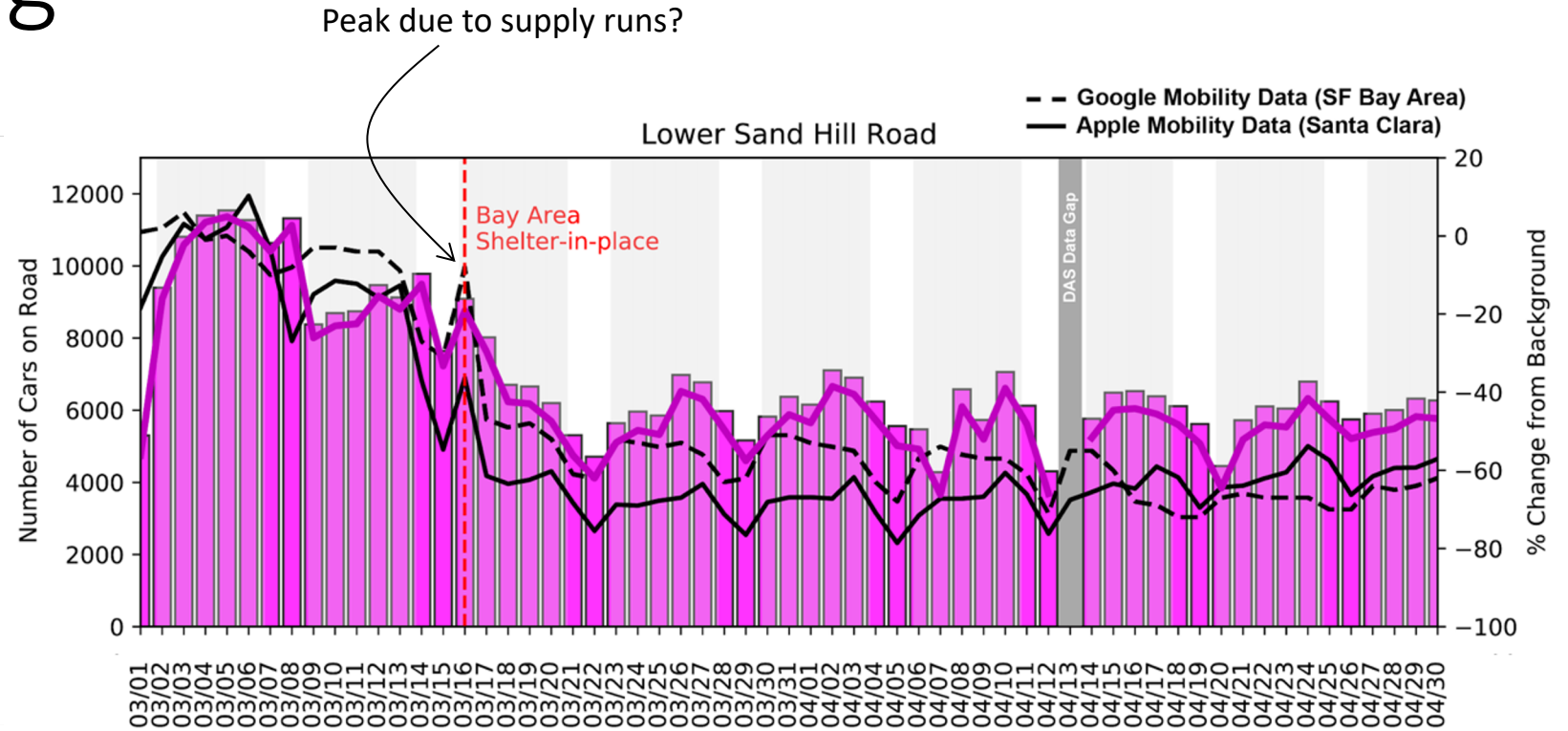
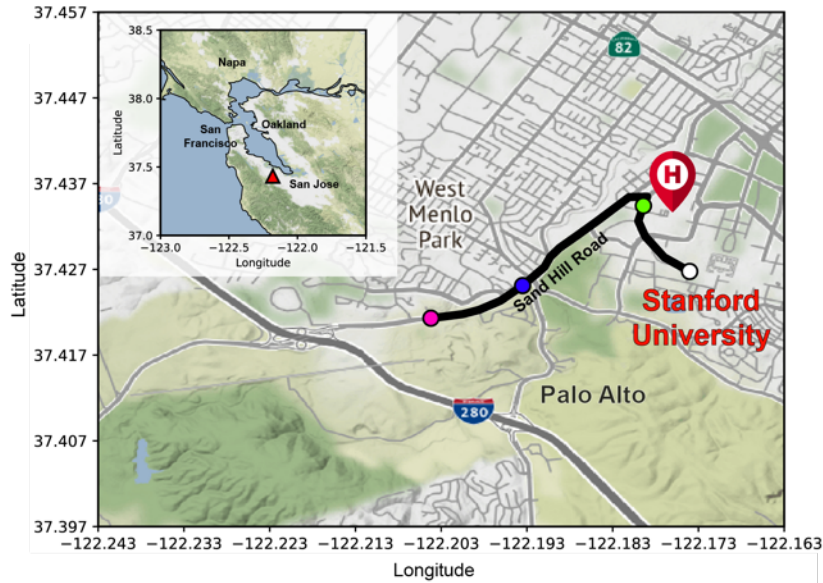
Vehicle detection



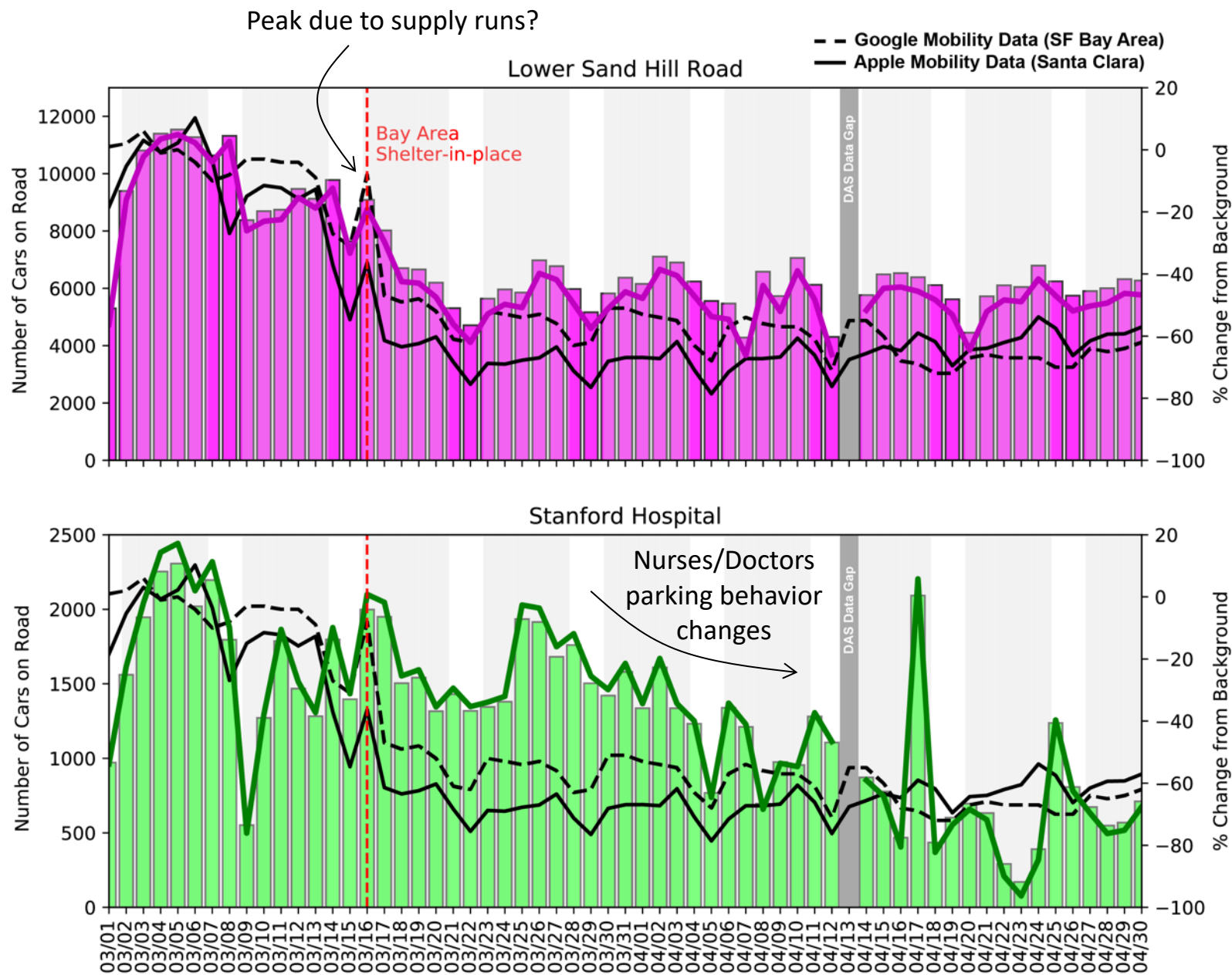
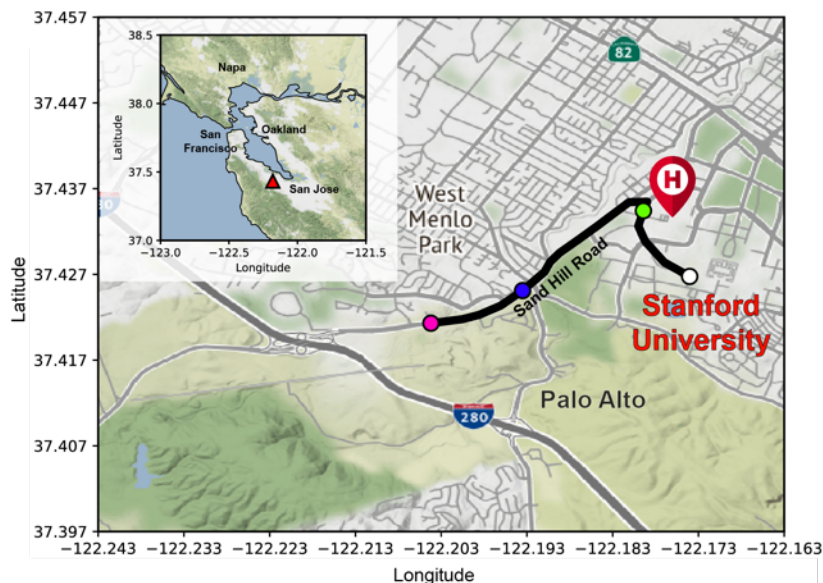
Vehicle counting



Vehicle counting

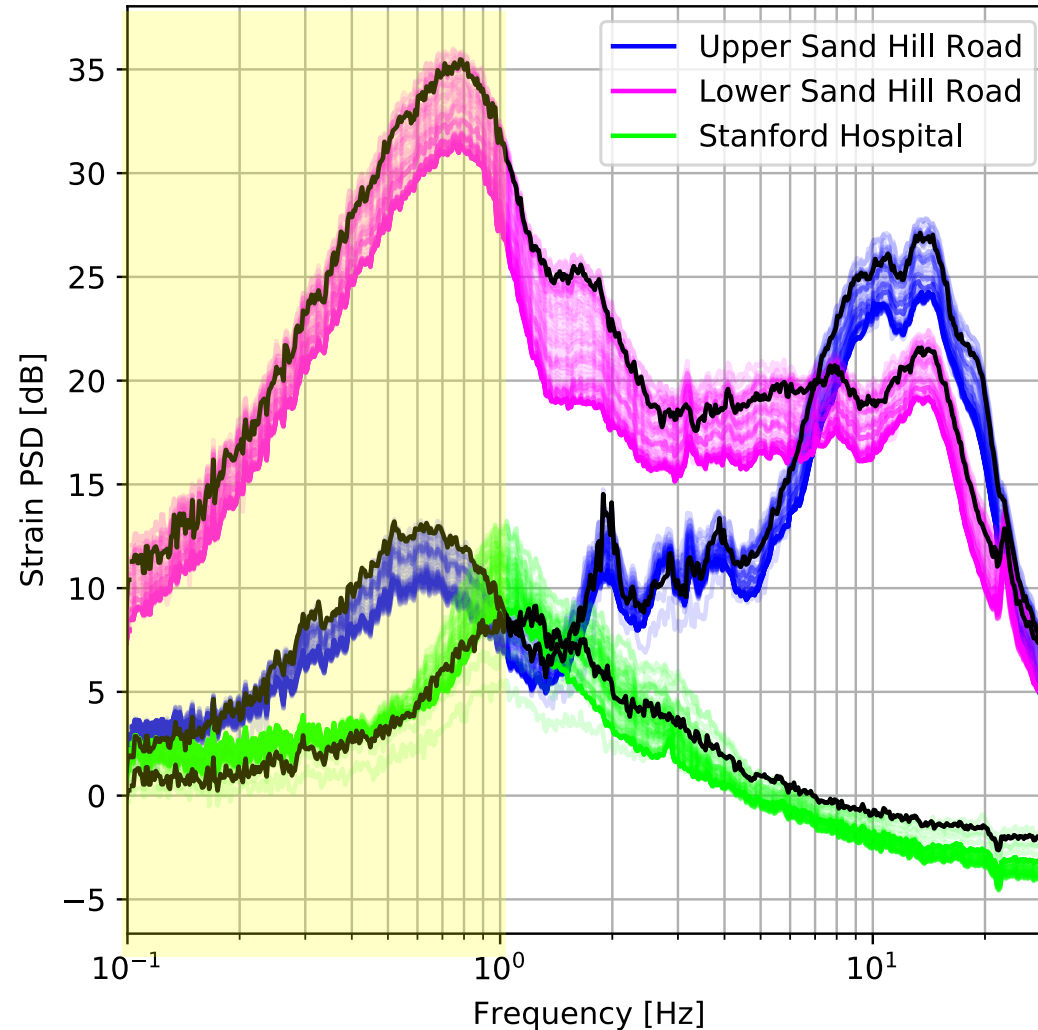
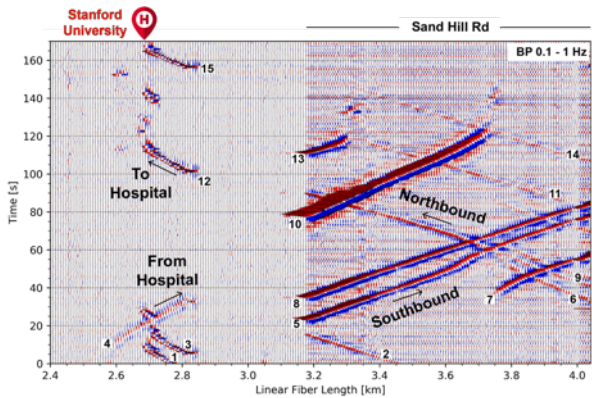


Vehicle counting

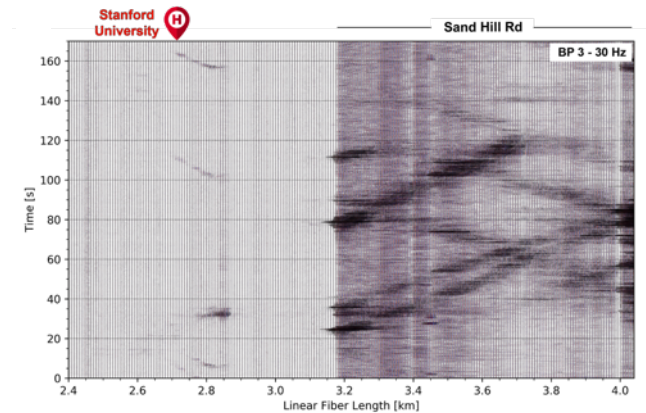


Connecting Geodetic and Seismic Observables

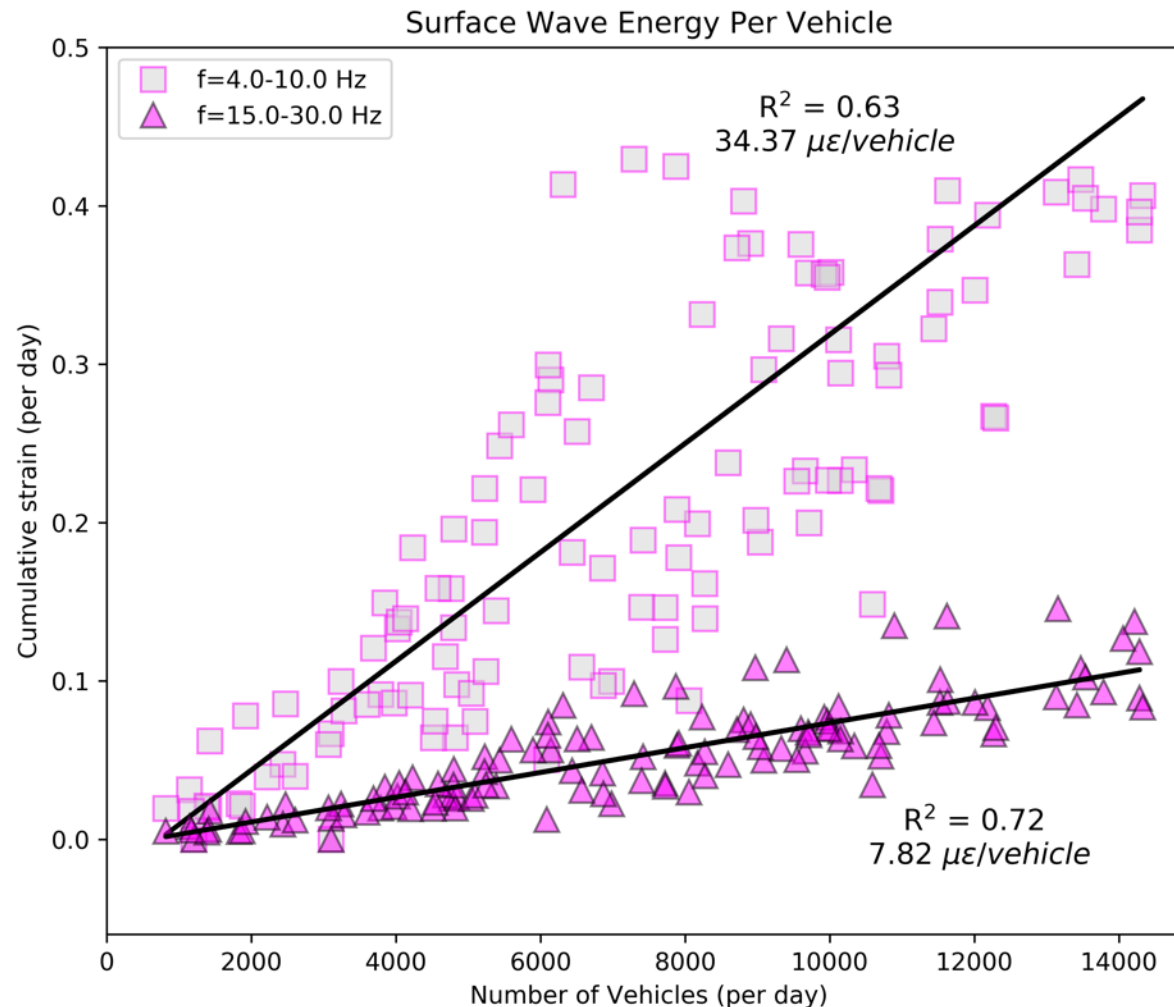
Geodetic roadbed deformation



Dynamic surface waves



Connecting Geodetic and Seismic Observables



- Linear relationship between strain and vehicle count
- Do parameters hold in other areas?

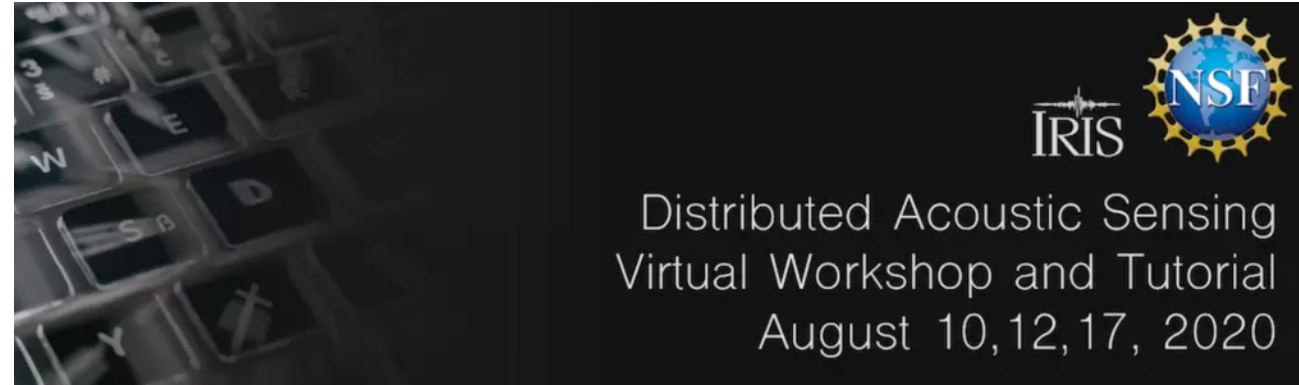
Summary of Findings

- Fiber beneath urban areas enables vehicle counting
- Business traffic reduced 50% immediately
- Hospital traffic changed more slowly
- Linear relationship between strain and vehicle count

Thank you for listening!



Learn more about fiber sensing:



https://www.iris.edu/hq/event/2020_DAS_Workshop

https://www.iris.edu/hq/initiatives/das_rcn

Watch a tutorial on DAS:

<https://www.njlindsey.com/>

Read the paper:



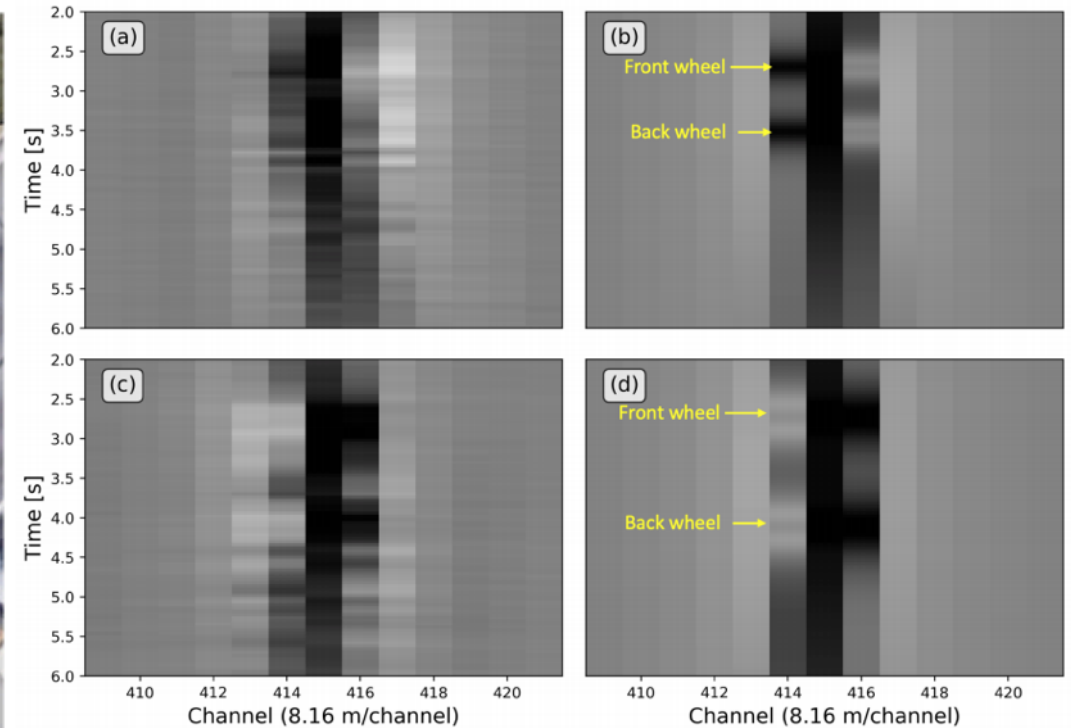
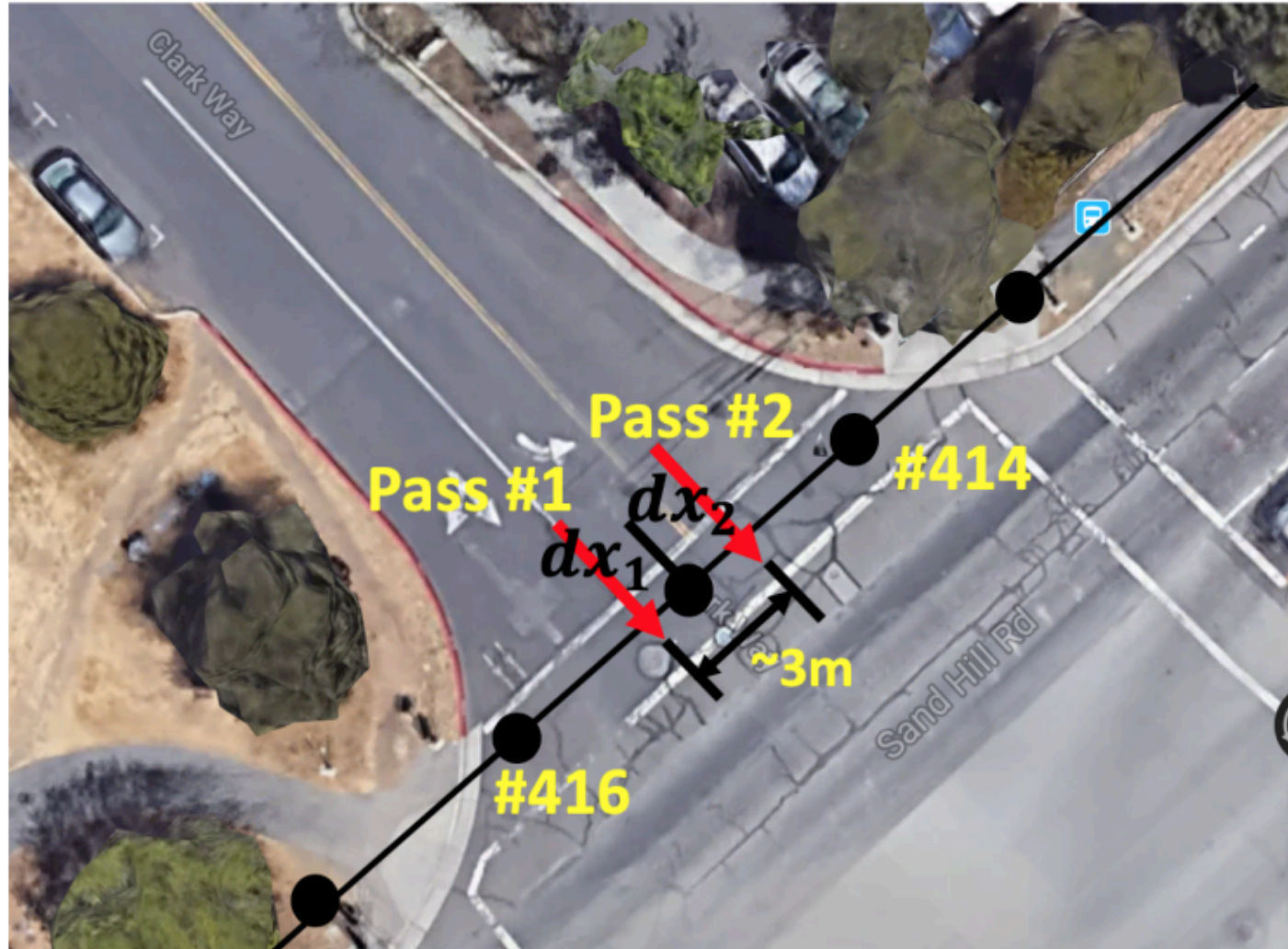
Lindsey, N.J., Yuan, S., Lellouch, A., Gualtieri, L., Lecocq, T. and Biondi, B., 2020. City-scale dark fiber DAS measurements of infrastructure use during the COVID-19 pandemic. *arXiv preprint arXiv:2005.04861*.

Contact me:

nlindsey@stanford.edu

Supplement

Stanford DAS-2 Experiment Roadbed Testing



Yuan et al., 2020 (*The Leading Edge*, submitted)
<https://arxiv.org/pdf/2006.01360.pdf>