Imaging wavefields using interferometry

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motivation $\rightarrow$ method $\rightarrow$ theory $\rightarrow$ sensitivity

How can we image time traces of wavefields from passive source observations?

motivation

Goal and challenges

We ultimately want to image material properties using wave energy.

Sometimes actively generating a wavefield is not an option.

Some others, there are already many wavefields propagating through our zone of interest.

How do we use these wavefields?

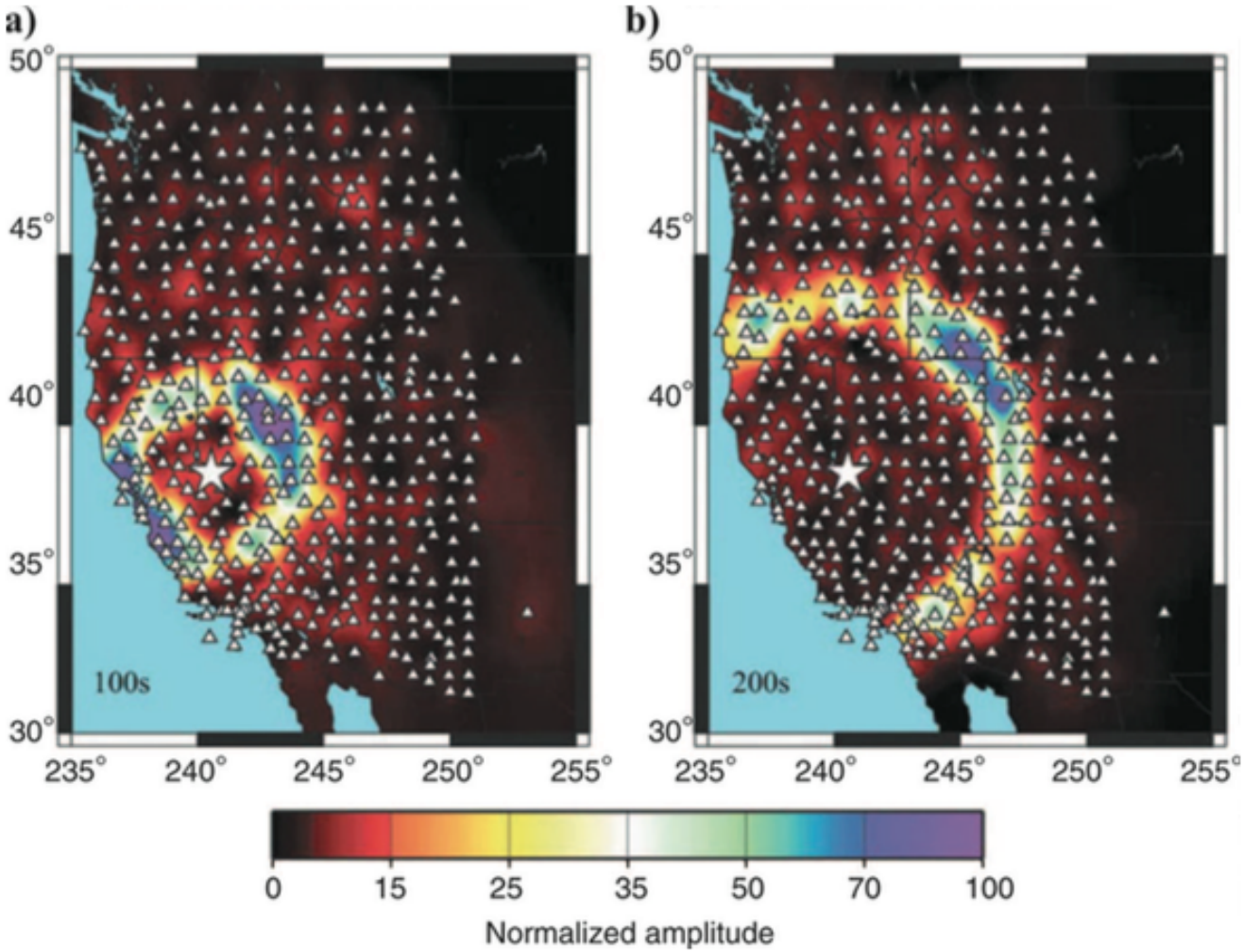
Listen

The idea is to,

- listen to echoes of wavefields generated by many sources,
- correct these records of echoes,
- image material properties using the corrected echoes.

... so, reorganize many energy responses into a coherent response.

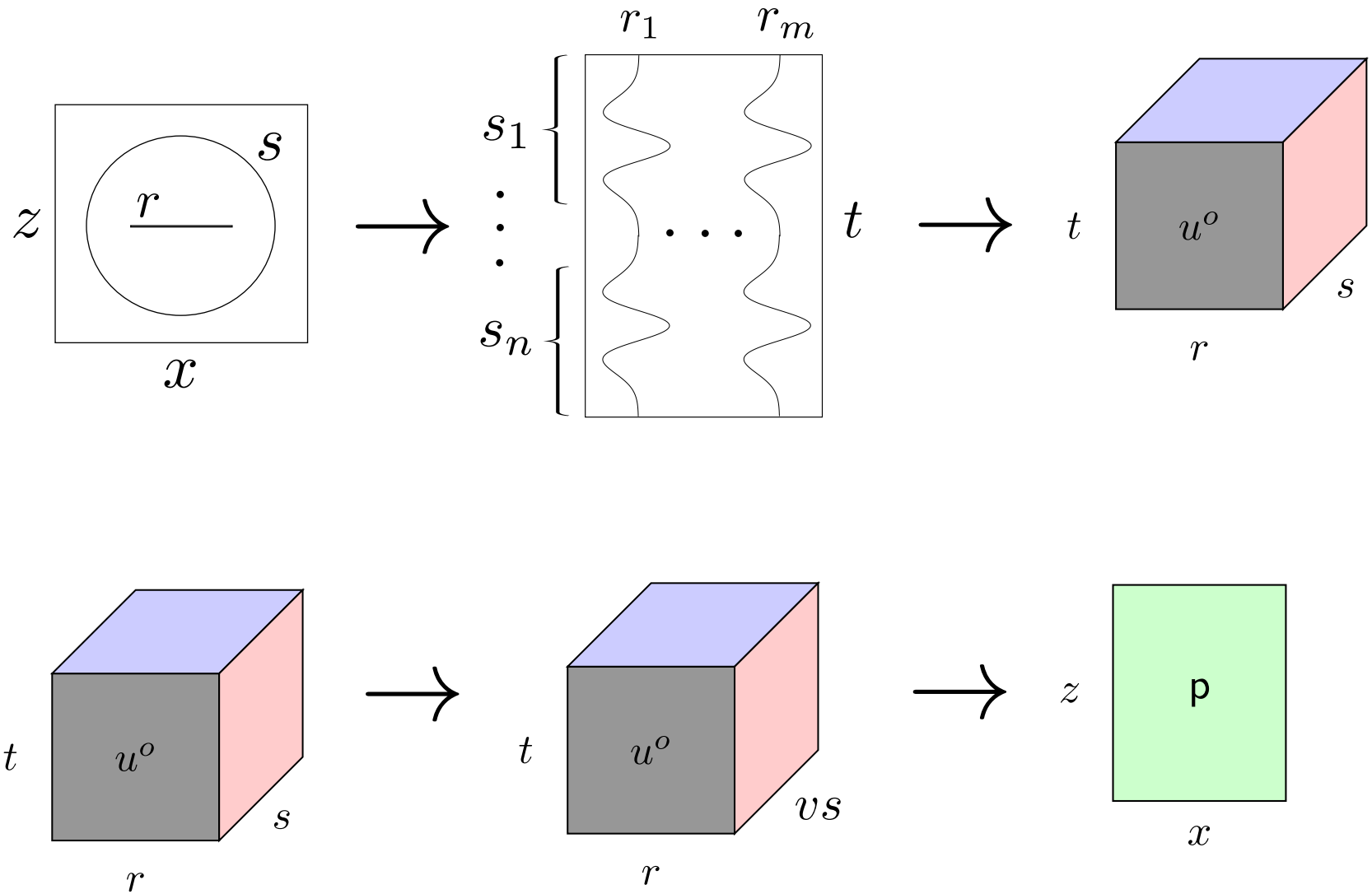
Imaging a wavefield in real life



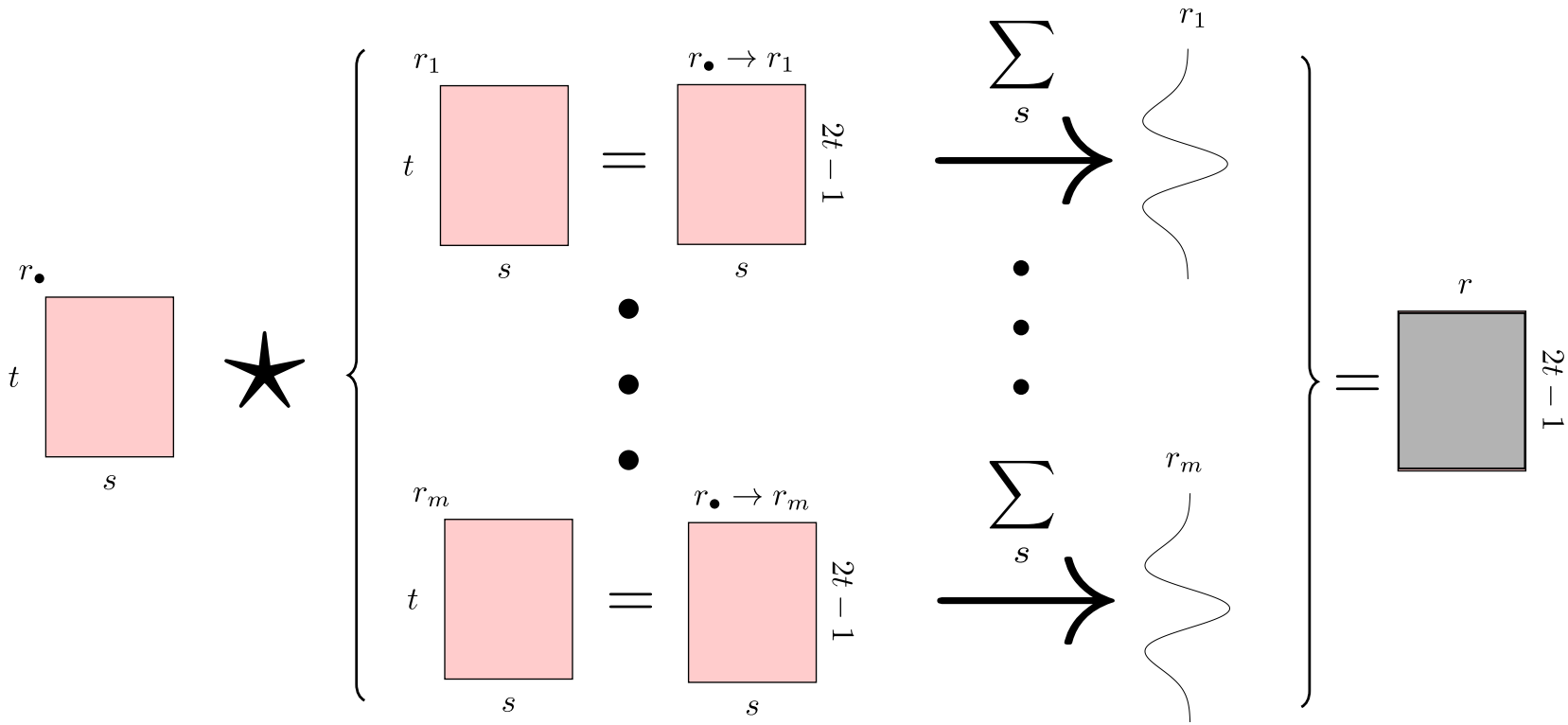
Lin et al.

method

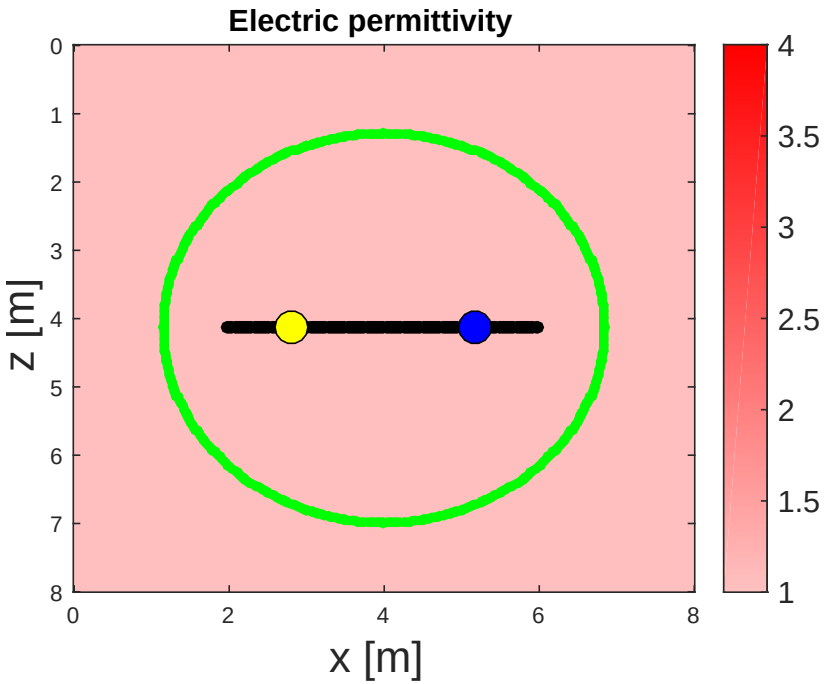
Best case scenario

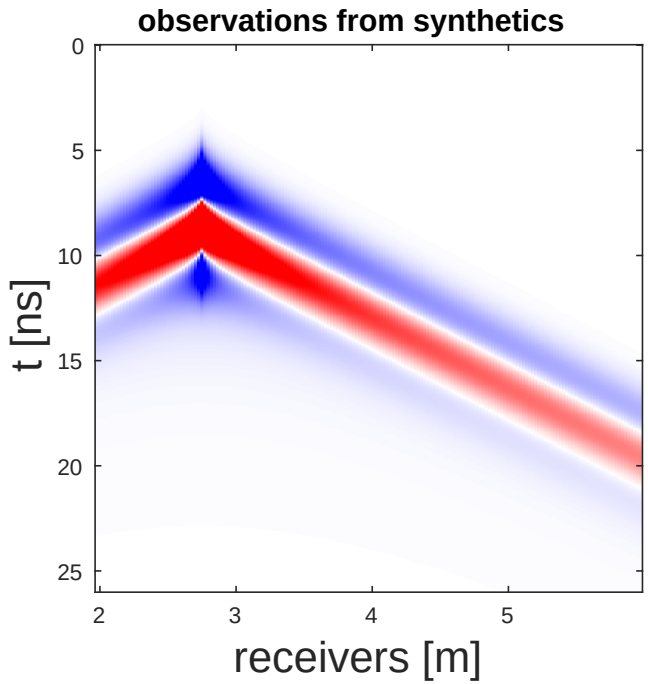


Pseudo-code


$r_\bullet$
t
s
$\star$
r_1
t
s
$=$
$r_\bullet \to r_1$
$2t-1$
s
r_m
t
s
$=$
$r_\bullet \to r_m$
$2t-1$
s
$\sum_s$
r_1
$\sum_s$
r_m
$=$
r
$2t-1$

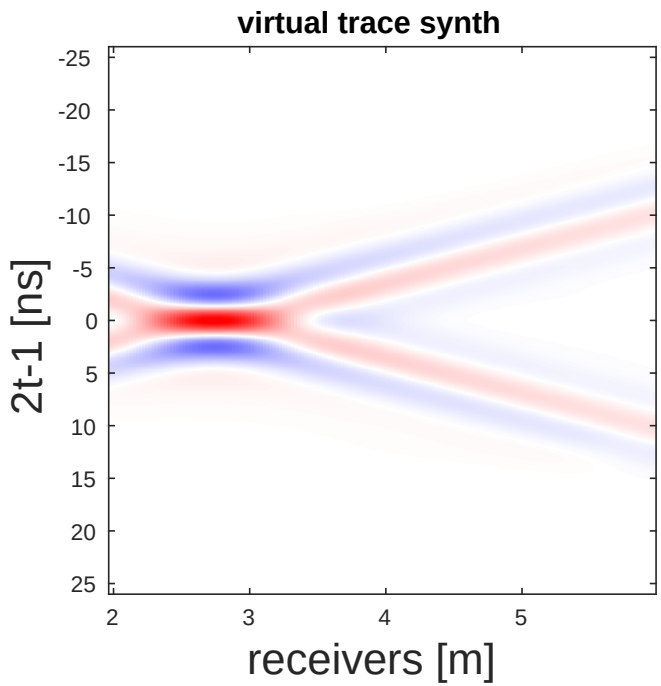
Example - setup

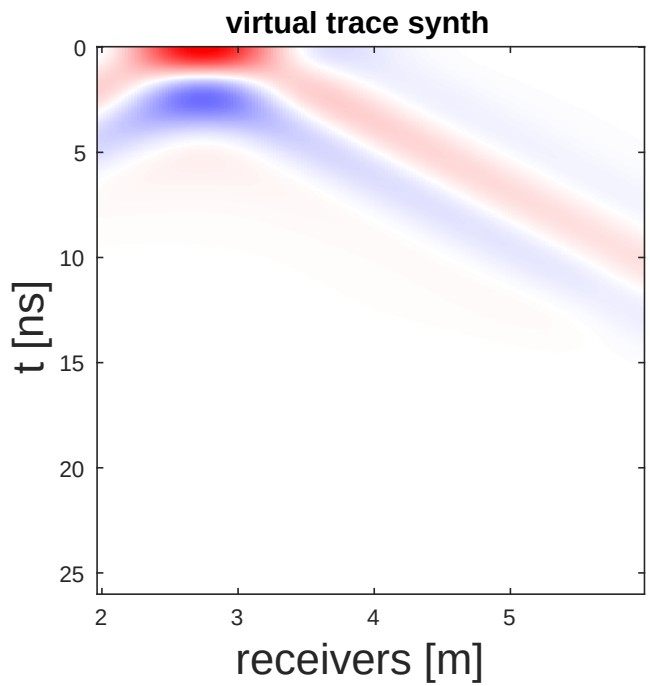




Example - stacking

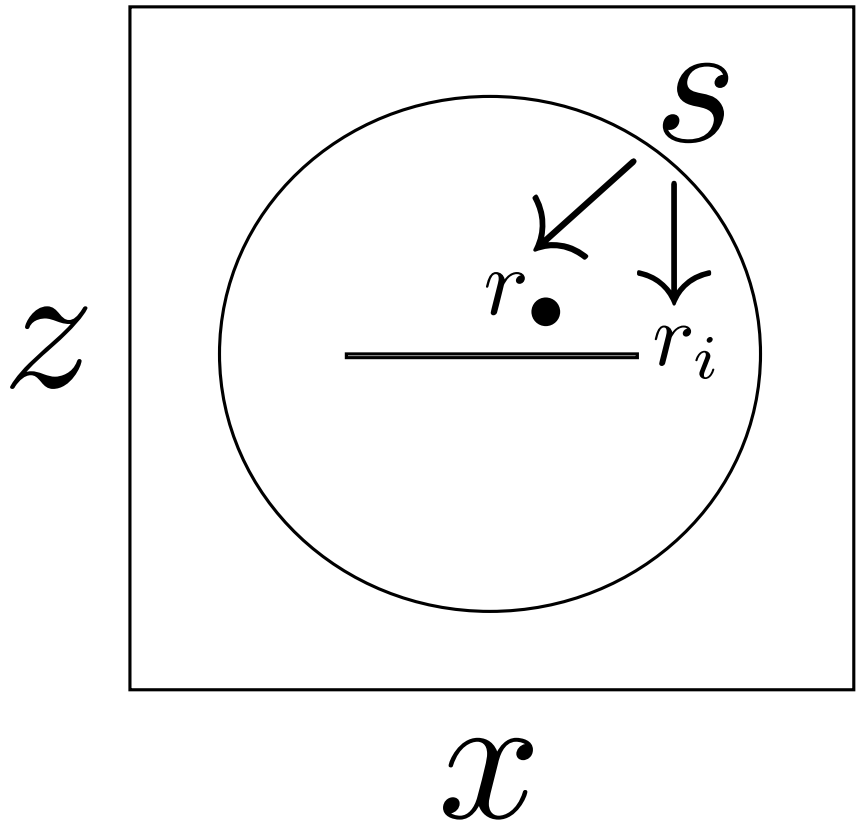
Example - virtual shot gather





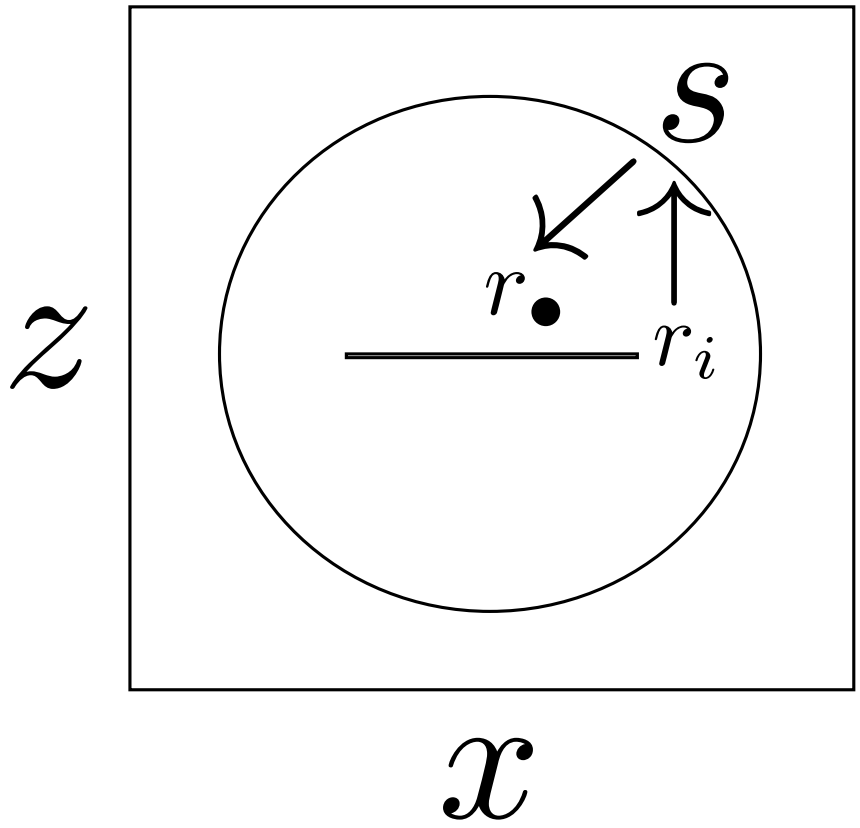
theory

Behind the stage



$$\int_\Gamma g(r_\bullet, s) \star g(r_i, s)\, \mathrm{d}\Gamma \quad \propto \quad g(r_i, r_\bullet, -t) + g(r_i, r_\bullet, t)$$

Source-receiver duality



$$\int_\Gamma g(r_\bullet, s) * g(s, r_i)\, \mathrm{d}\Gamma \;\propto\; g(r_i, r_\bullet, -t) + g(r_i, r_\bullet, t)$$

Full *traceform* inversion

Recall the FWI scheme,

$$\int_0^T u(T-t)\, q(t)\, \mathrm{d}t = \nabla_\sigma \mathsf{E},$$

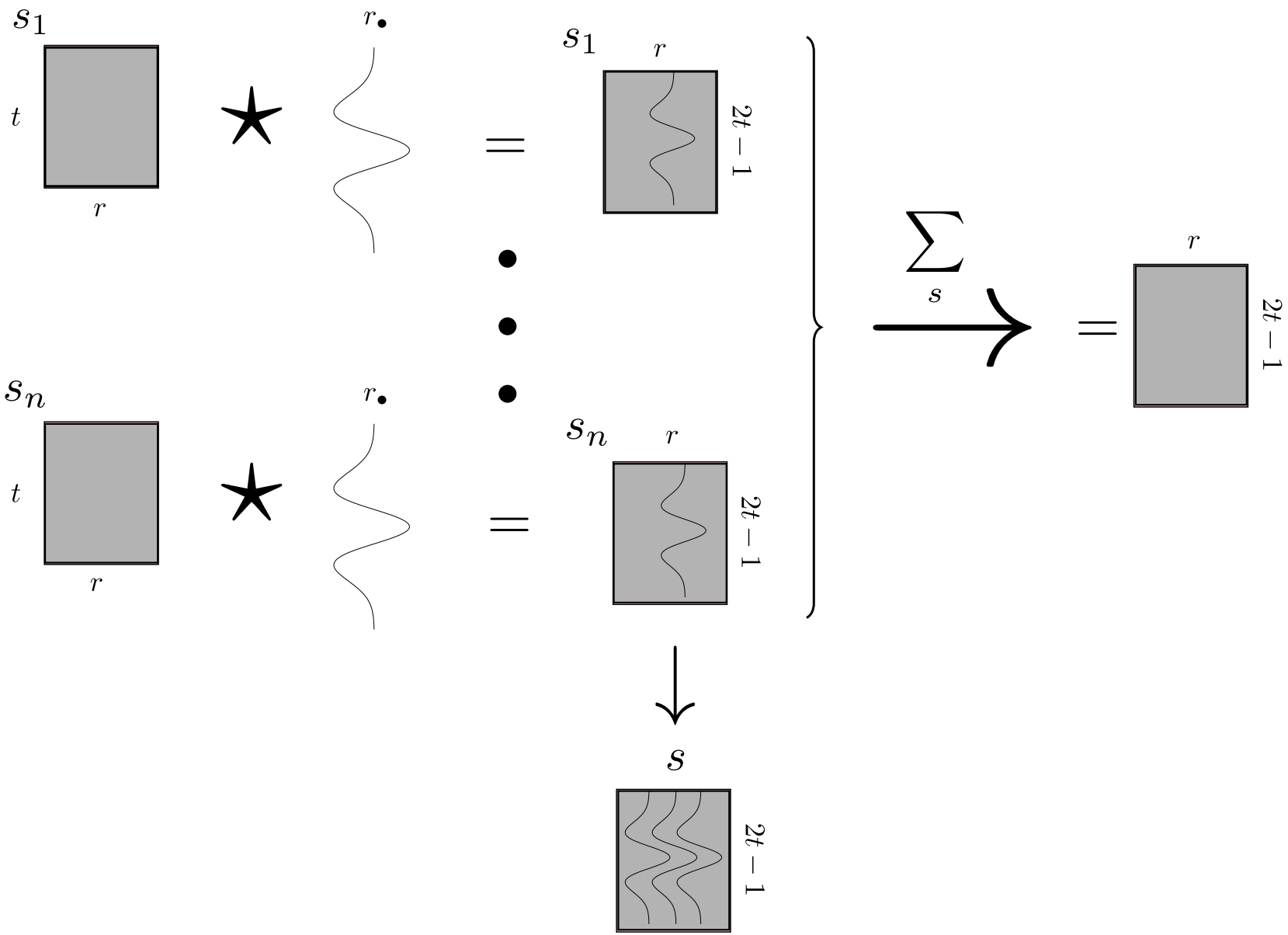
where q is the forward back-propagation of errors and u is our generated wavefield.

Now, think of s as the spatial boundary, $r_\bullet$ as our source location, and the rest of receivers r_i as our receivers in our FWI scheme.

We have,

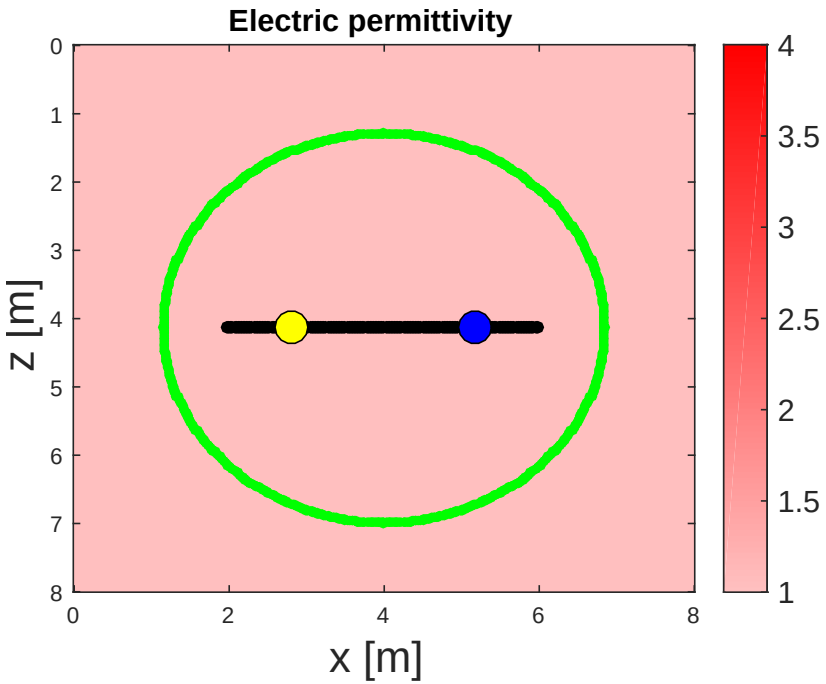
$$\int_\Gamma \underbrace{g(r_\bullet, s)}_{u(T-t)} * \underbrace{g(s, r_i)}_{q(t)}\, \mathrm{d}\Gamma \quad \propto \quad g(r_i, r_\bullet, -t) + g(r_i, r_\bullet, t).$$

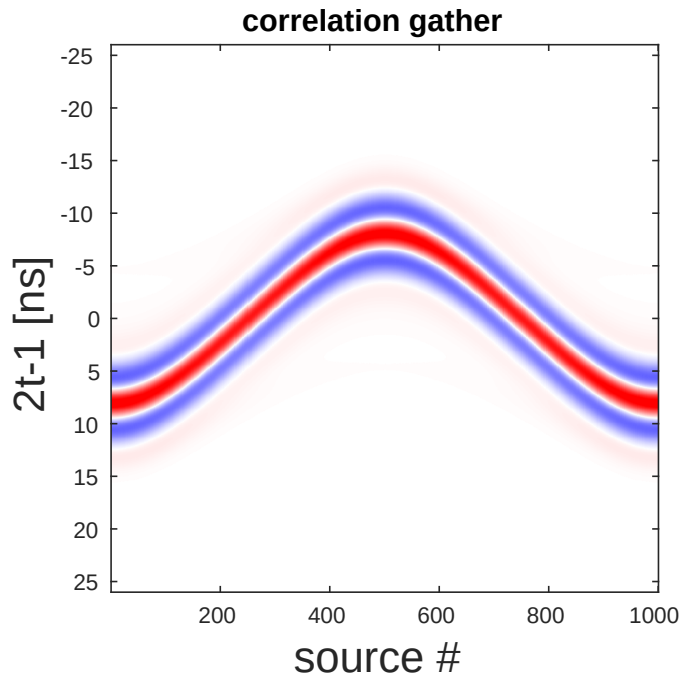
Pseudo-code of implementation



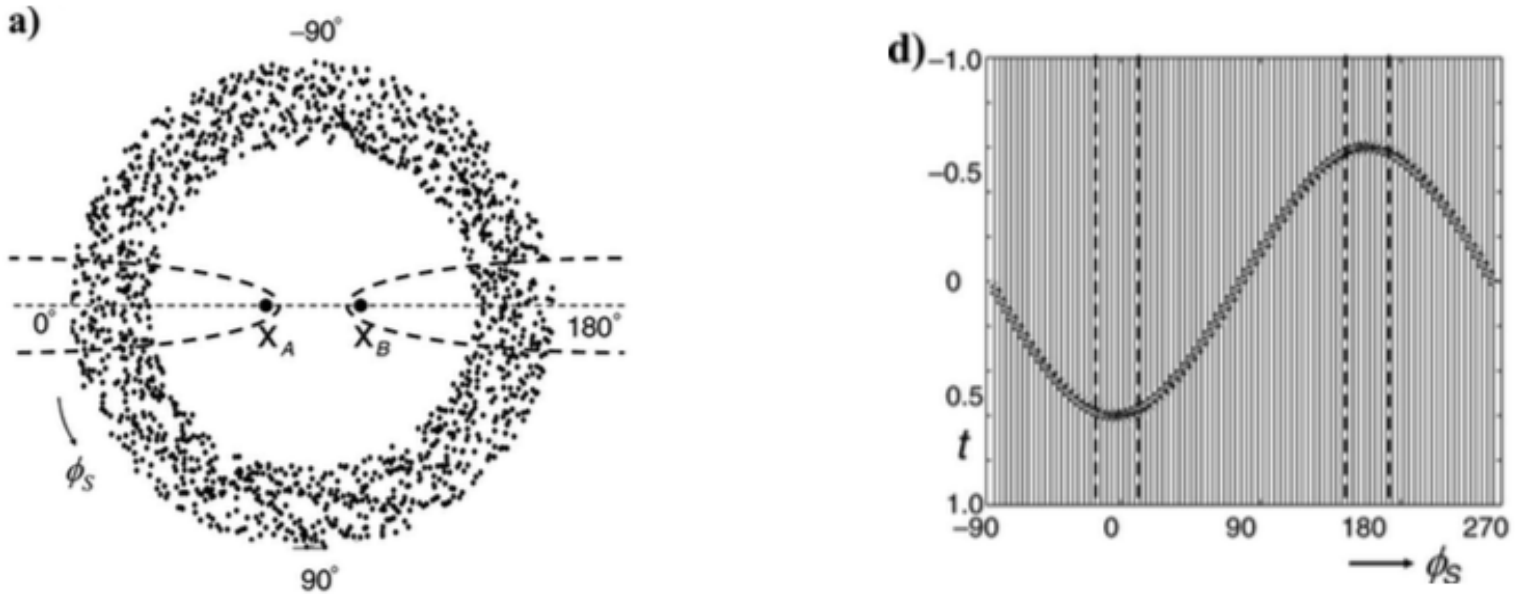
sensitivity

Correlation gather





Fresnel zones and curvature of s

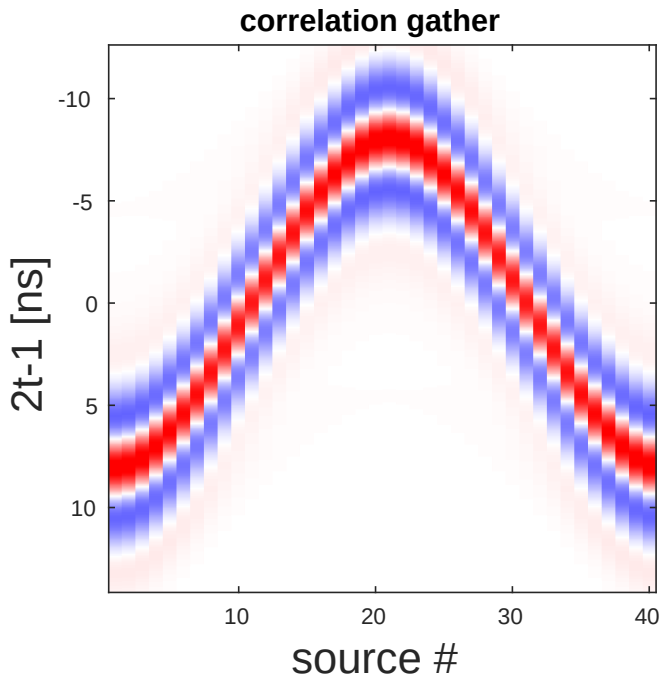


- Sources parallel to the line segment $X_A - X_B$ give extrema in the correlation gather.
- The closer X_A and X_B are to s, the more they feel its curvature, the narrower the Fresnel zone.

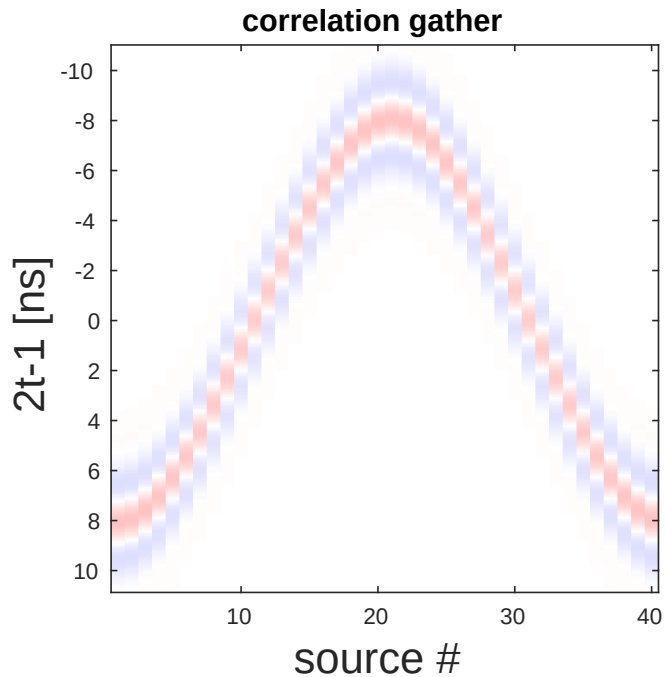
Wapenaar et al.

Fresnel zones and ω

600 [MHz]

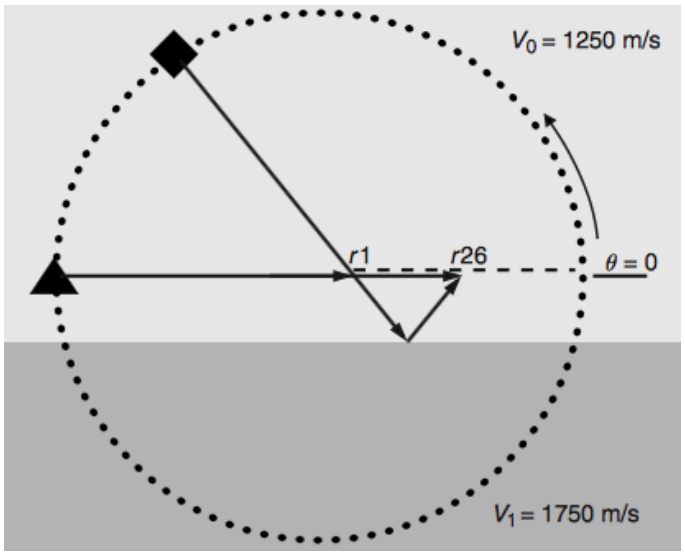


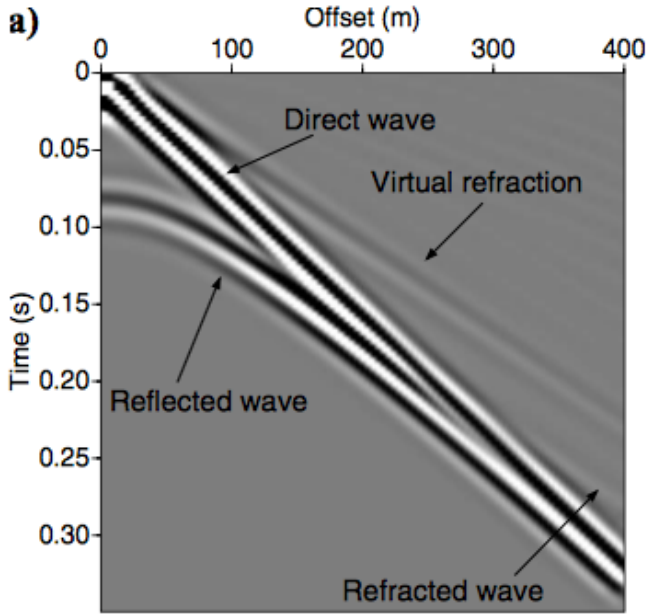
1000 [MHz]



Known issues

- Heterogeneous media gives rise to spurious events in virtual shot gathers.





- Optimal (s, r) geometry is not always ensured.

- How to crop original (r, t) gather into (r, s, t) cube?

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