

Seismic interferometry and beyond

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ROSE meeting
Trondheim

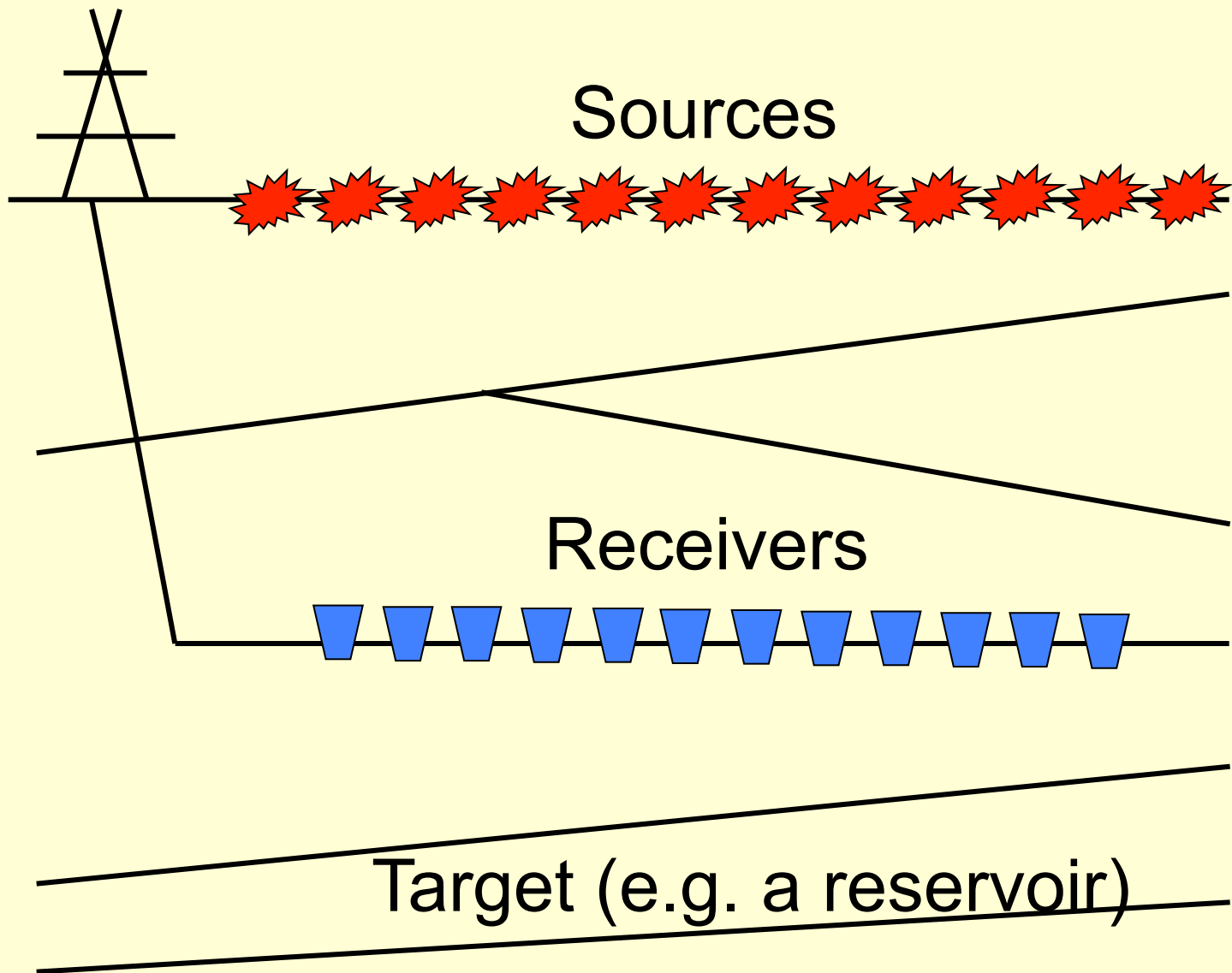
April 23, 2013

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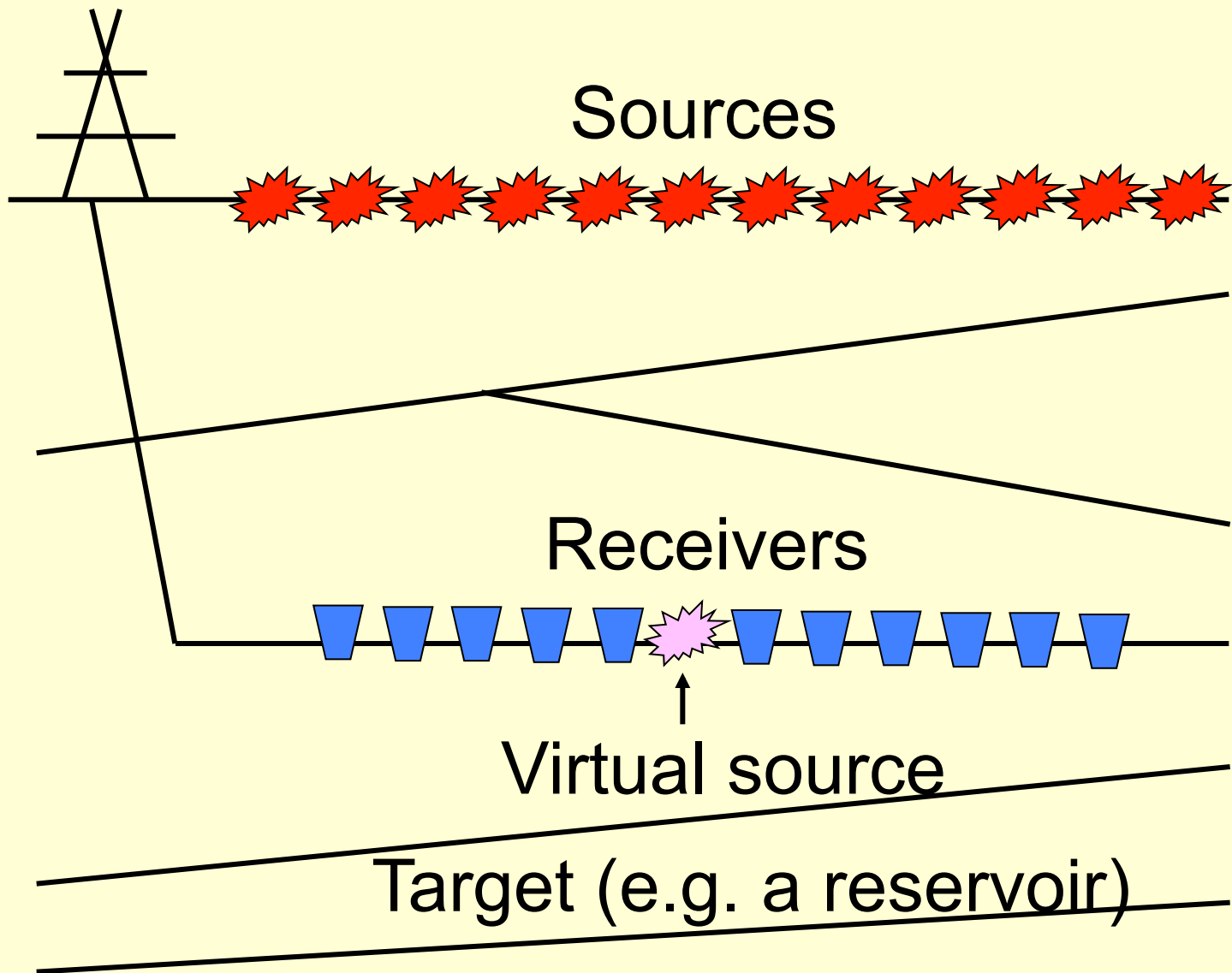
- Introduction
- Creating a virtual source from reflection data
- Imaging scheme, accounting for internal multiples
- Conclusions

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Seismic interferometry



Seismic interferometry

Noise autocorrelation
Claerbout, 1968

Time-reversed acoustics
Fink et al, 1990' s

Fluctuation-dissipation
Rytov, 1956

Interferometric imaging
Schuster et al., 2001

Virtual source
Calvert & Bakulin, 2004

Thermal noise correlation
Weaver & Lobkis, 2001

3D passive seismic
Delft, 2002

Surface wave retrieval
Campillo et al., 2003

Seismic interferometry: obtaining new responses by cross-correlation
(passive and active)

Borehole imaging etc

Reservoir monitoring

Ultrasonic imaging

Salt-flank imaging

Passive seismic imaging

Regional tomographic imaging

Civil engineering

CSEM imaging

Surface wave suppression

Crustal reflection imaging

Passive GPR

Volcano monitoring

Passive ocean acoustics

Atmospheric infrasound imaging

Medical imaging

Global-scale interferometry

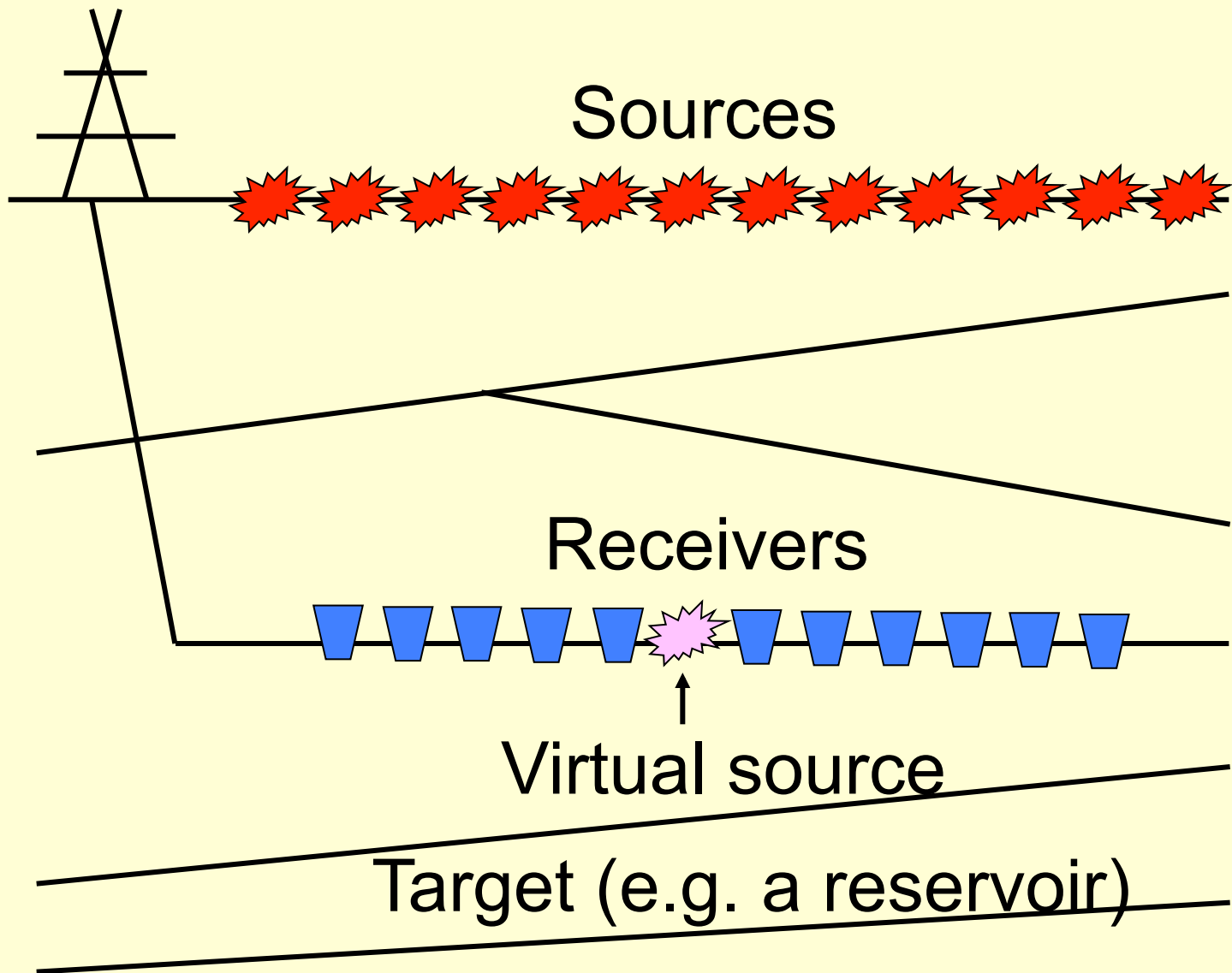
Seismoelectric imaging

Improved modeling/inversion

Lunar imaging

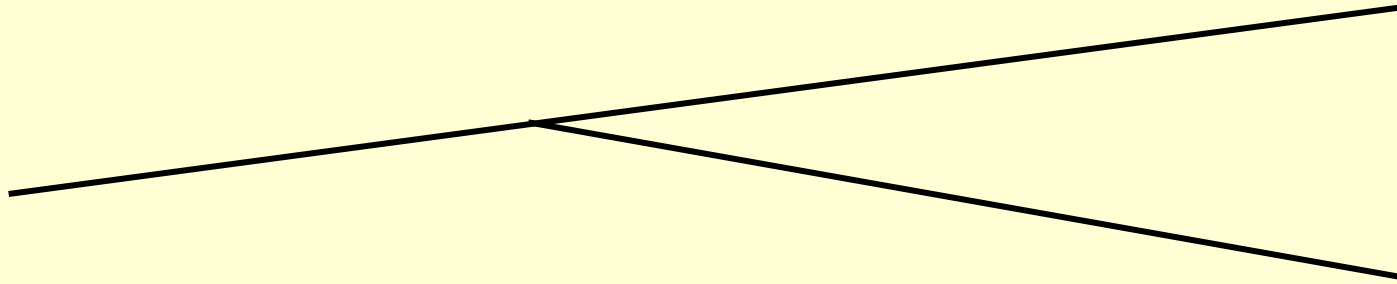
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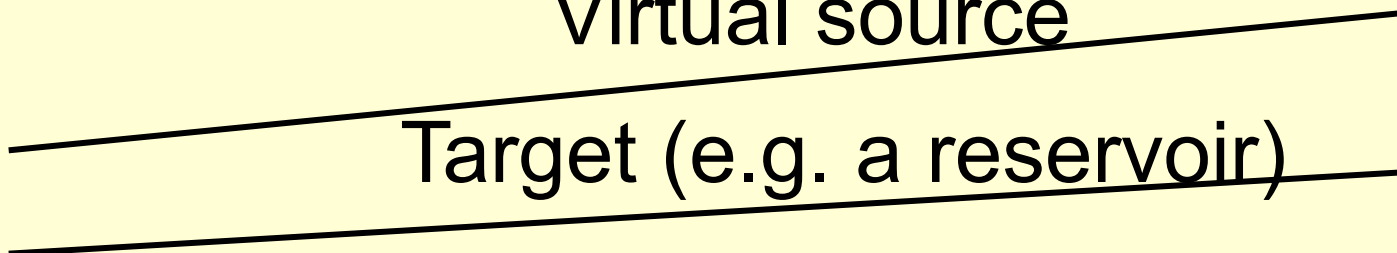
Seismic interferometry

Sources and receivers



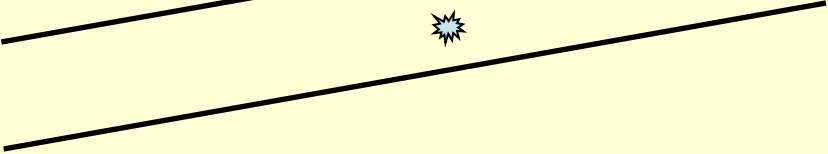
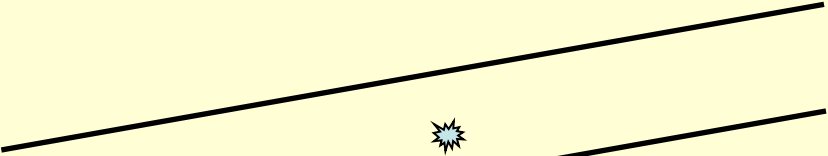
Virtual source

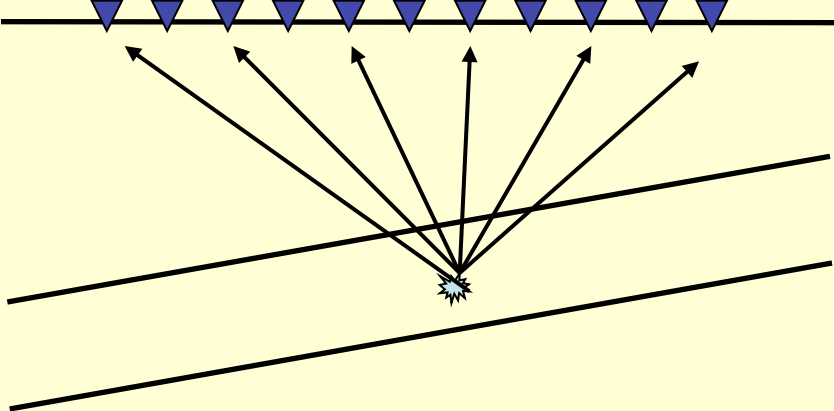
Target (e.g. a reservoir)

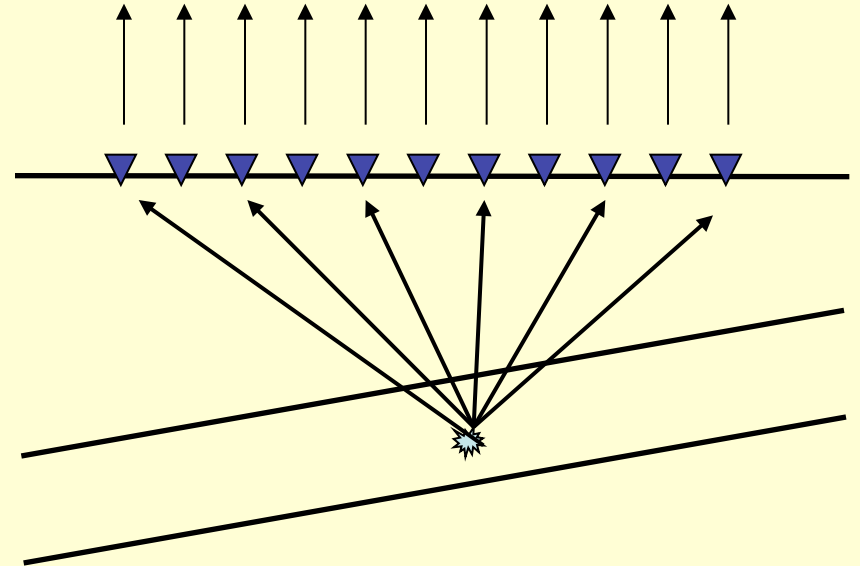
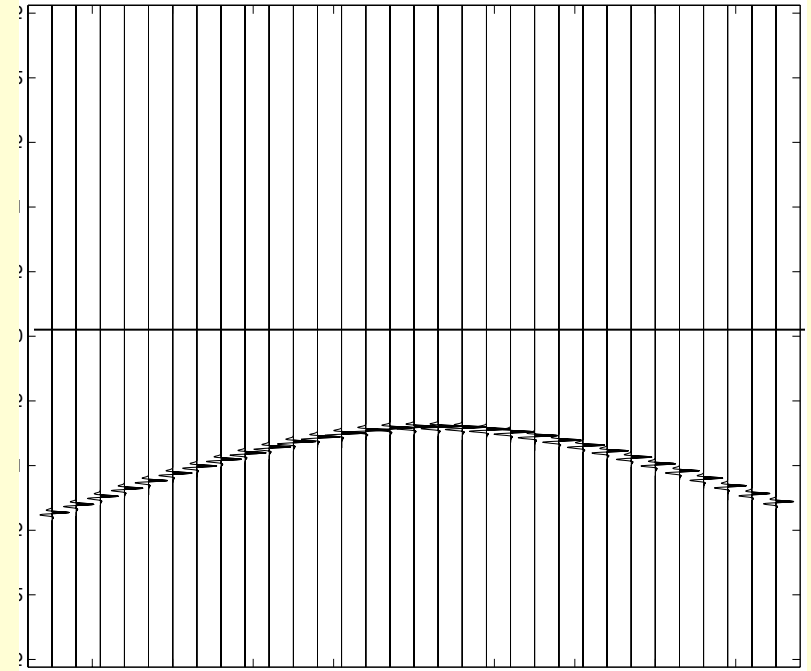


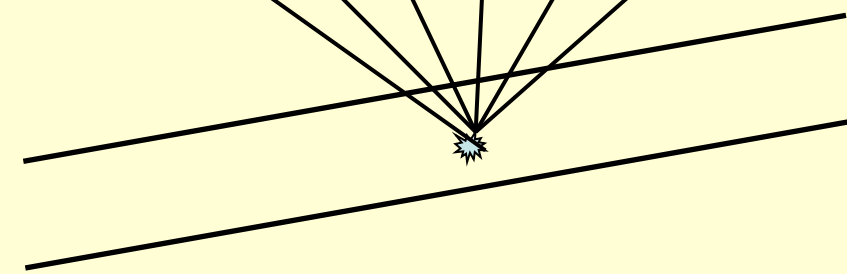
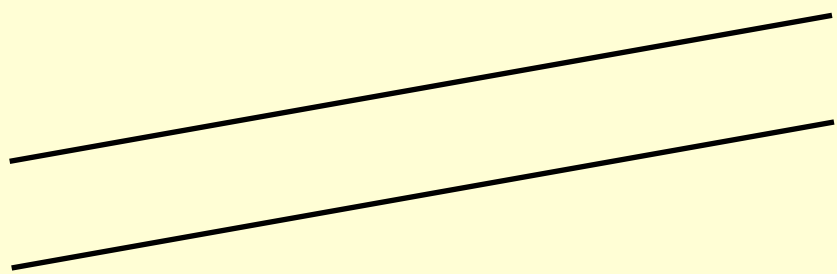
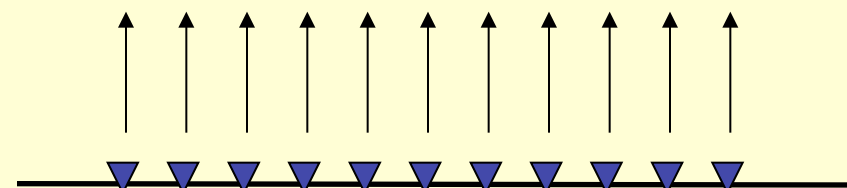
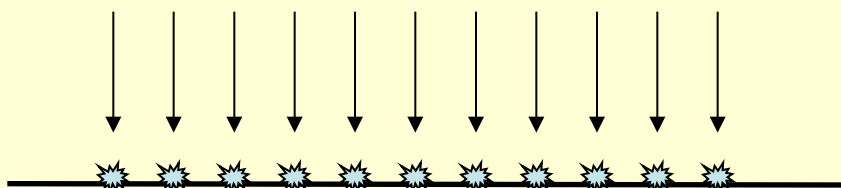
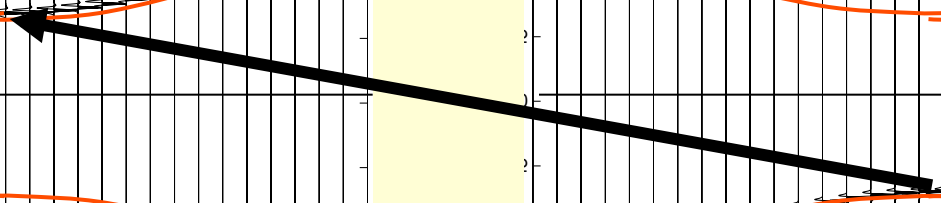
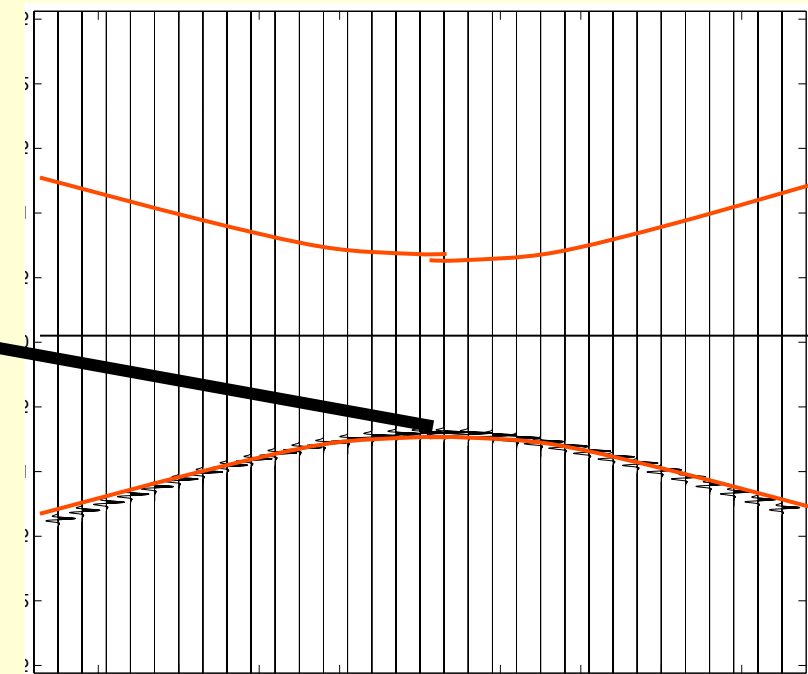
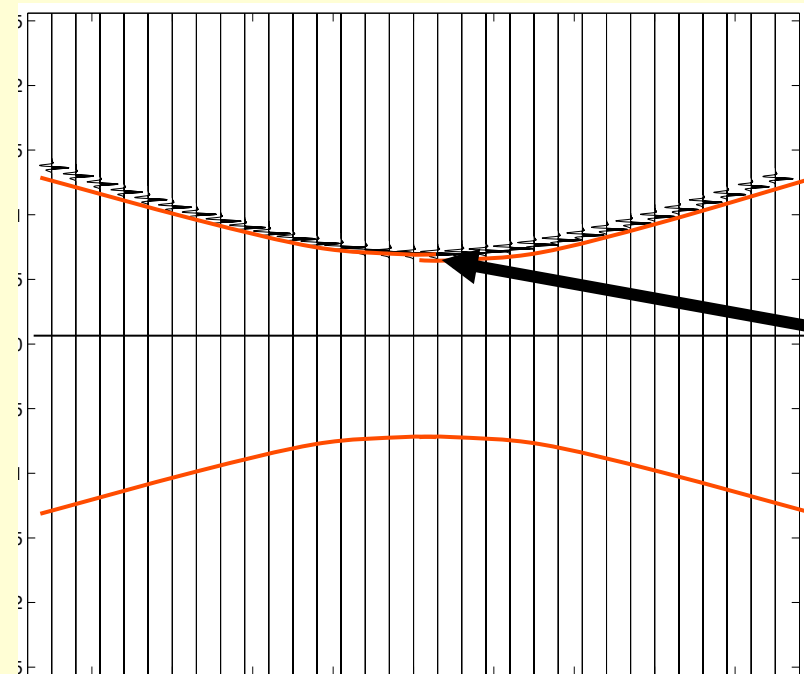
Beyond seismic interferometry

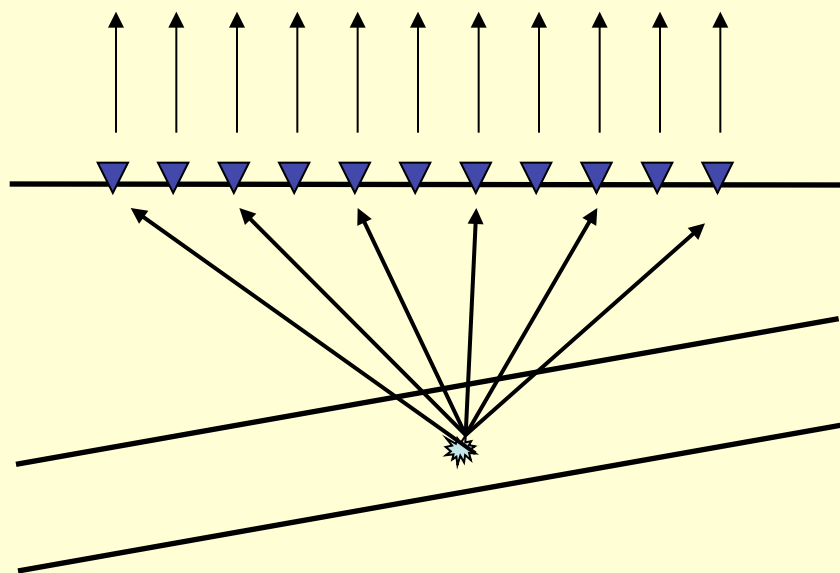
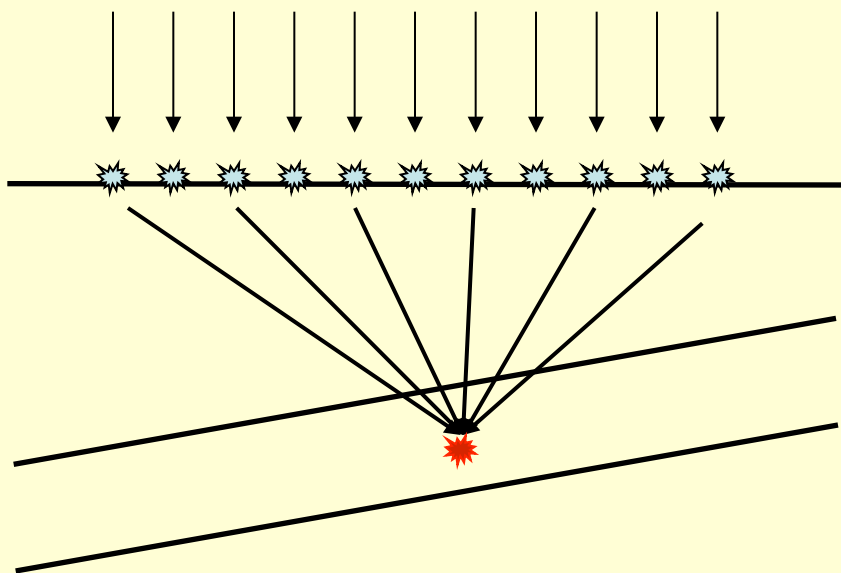
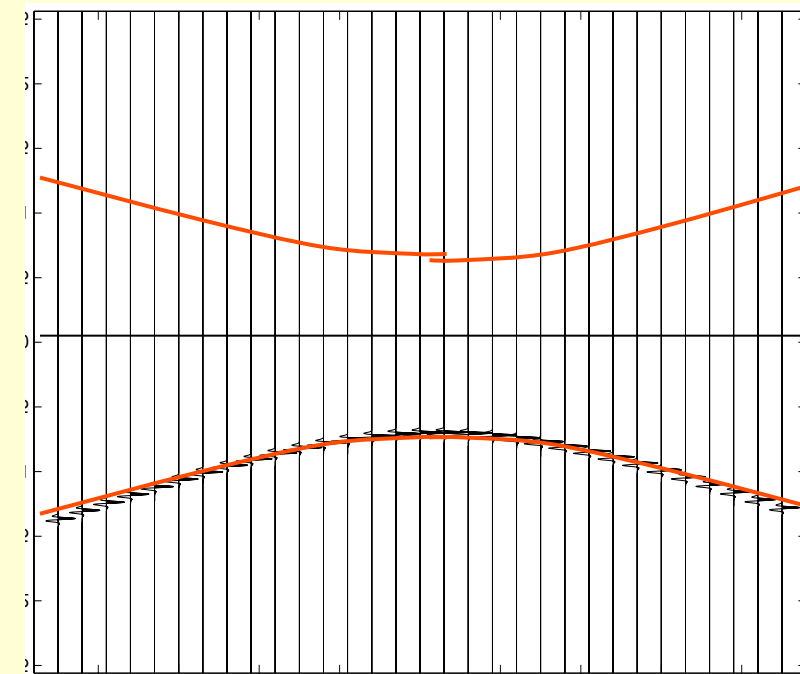
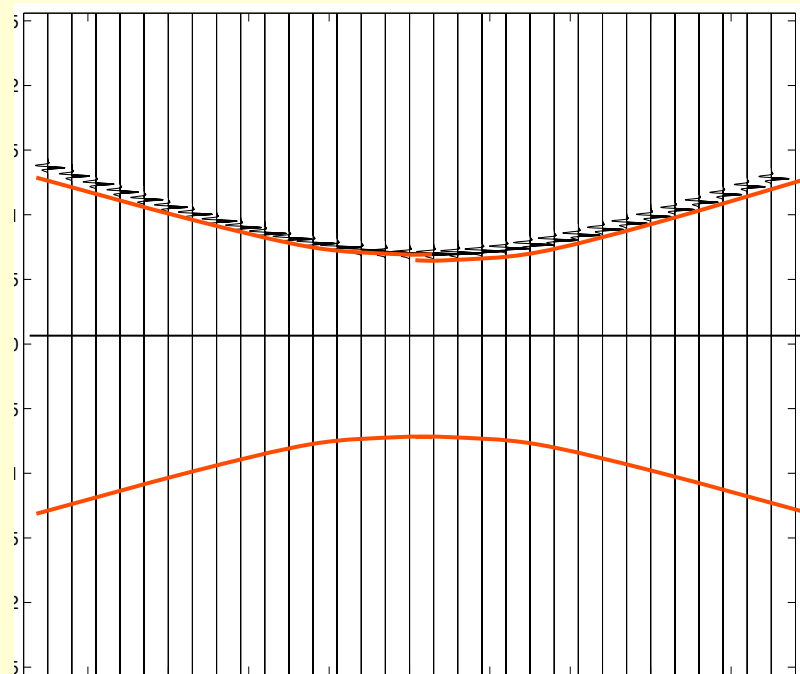
- Broggini and Snieder, 2012, Connection of scattering principles: a visual and mathematical tour. *European Journal of Physics*, 33, 593-613.
- Broggini, Snieder and Wapenaar, 2012, Focusing the wavefield inside an unknown 1D medium: Beyond seismic interferometry. *Geophysics*, 77, A25-A28.
- Wapenaar, Broggini and Snieder, 2012, Creating a virtual source inside a medium from reflection data: heuristic derivation and stationary-phase analysis. *Geophysical Journal International*, 190, 1020-1024.
- Wapenaar, Broggini, Slob and Snieder, 2013, Three-Dimensional single-sided Marchenko inverse scattering, data-driven focusing, Green's function retrieval, and their mutual relations. *Physical Review Letters*, 110, 084301.

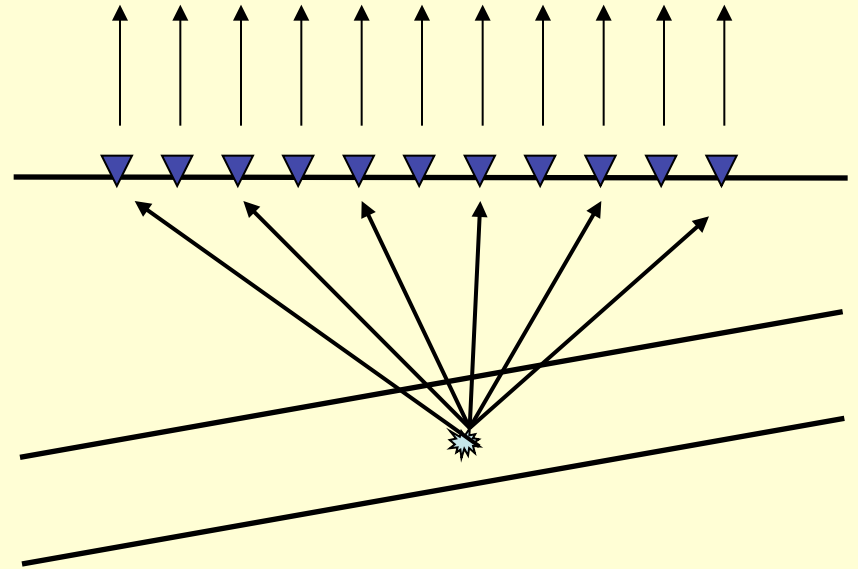
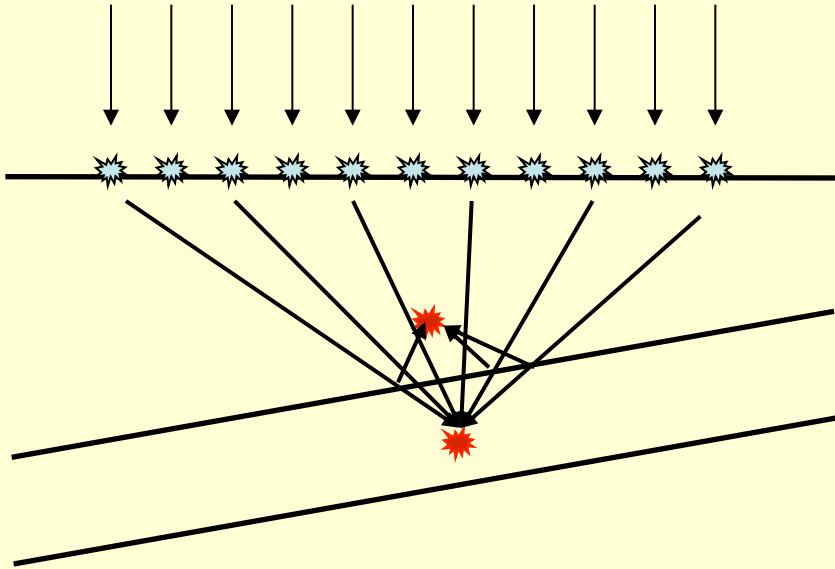
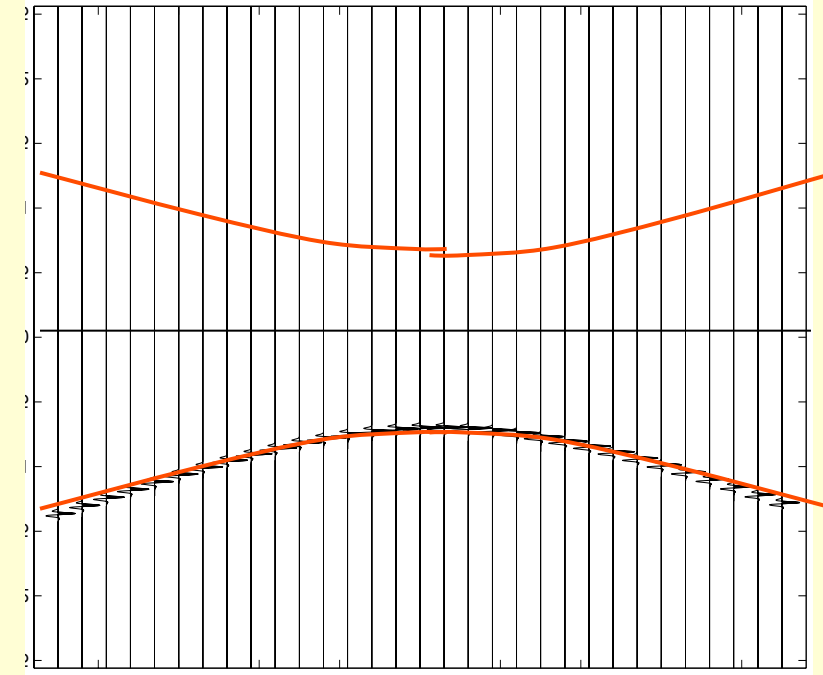
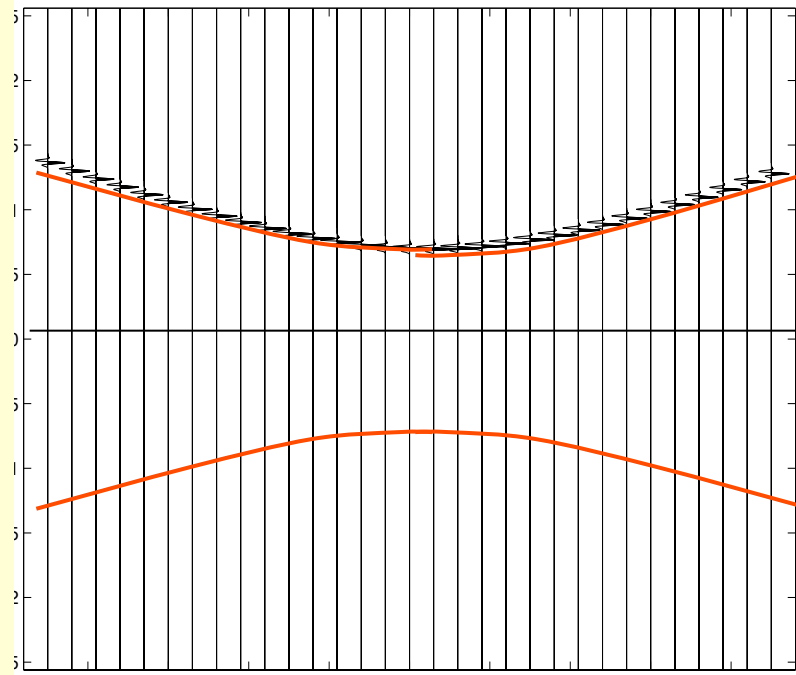


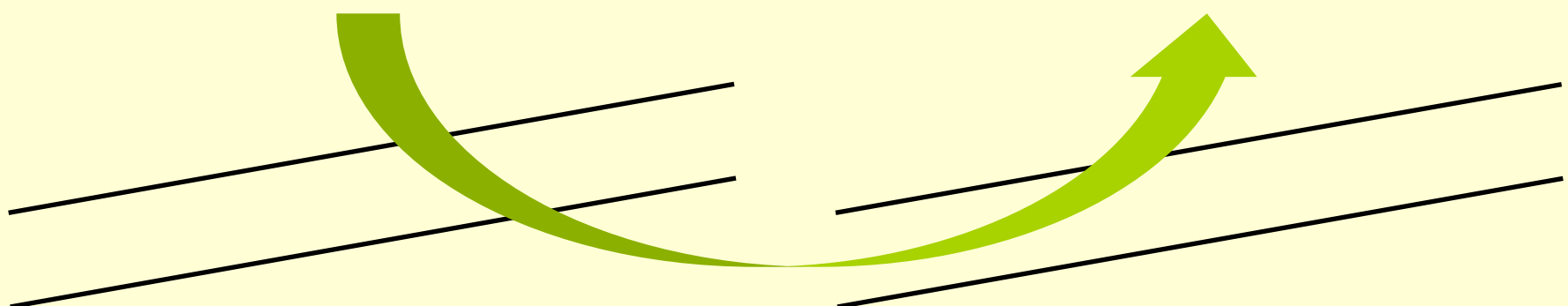
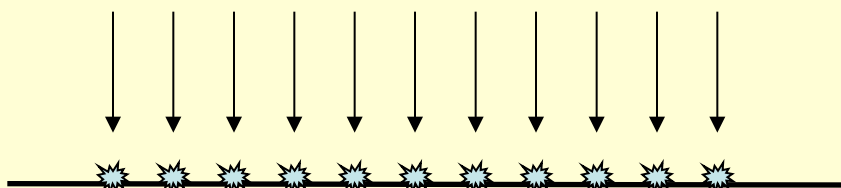
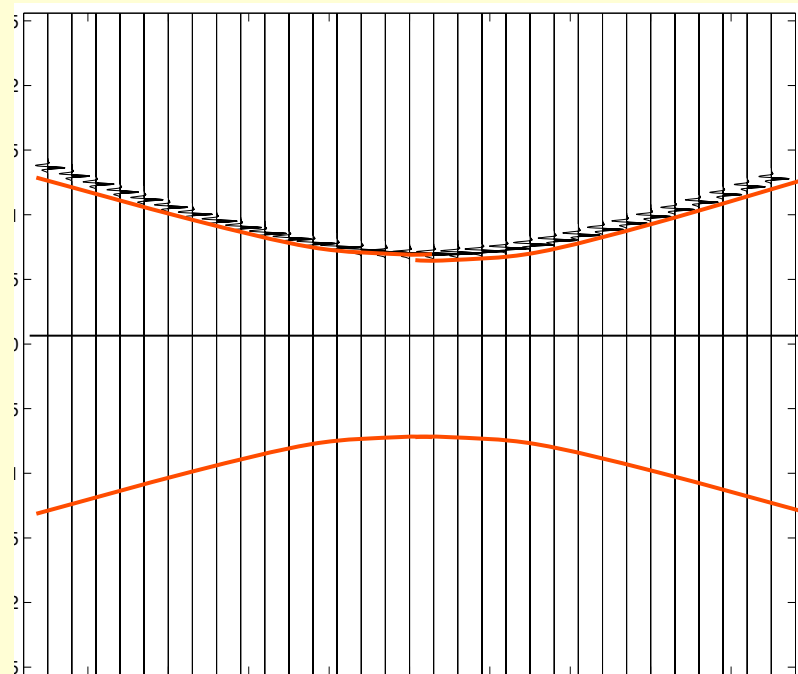




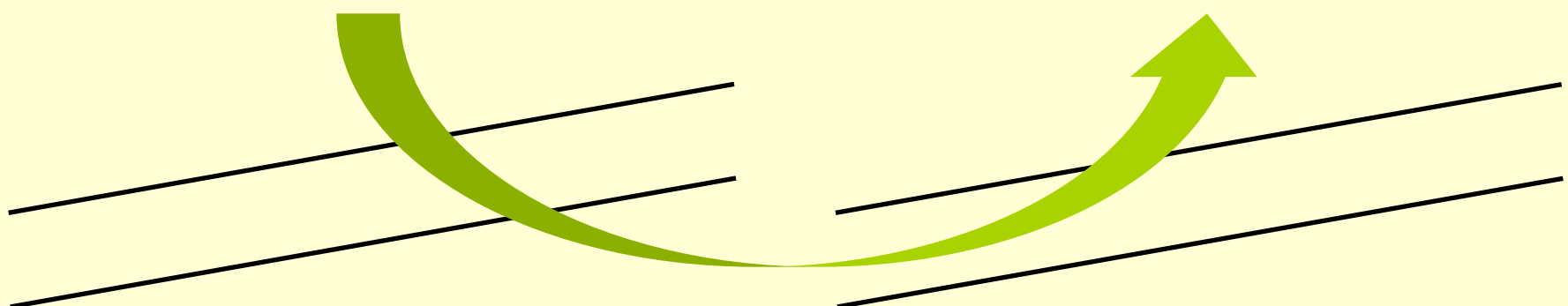
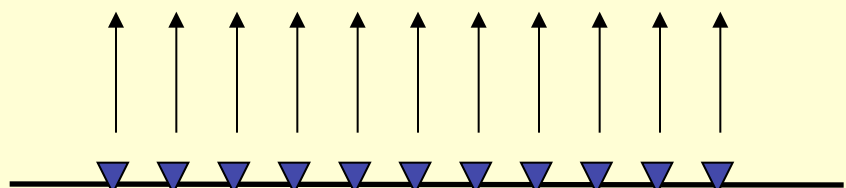
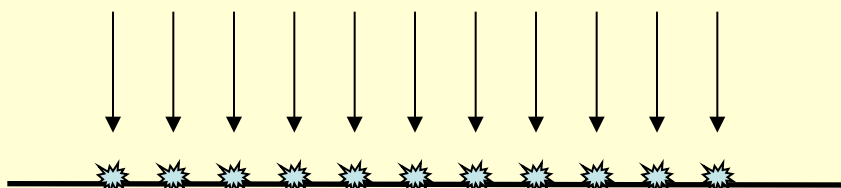
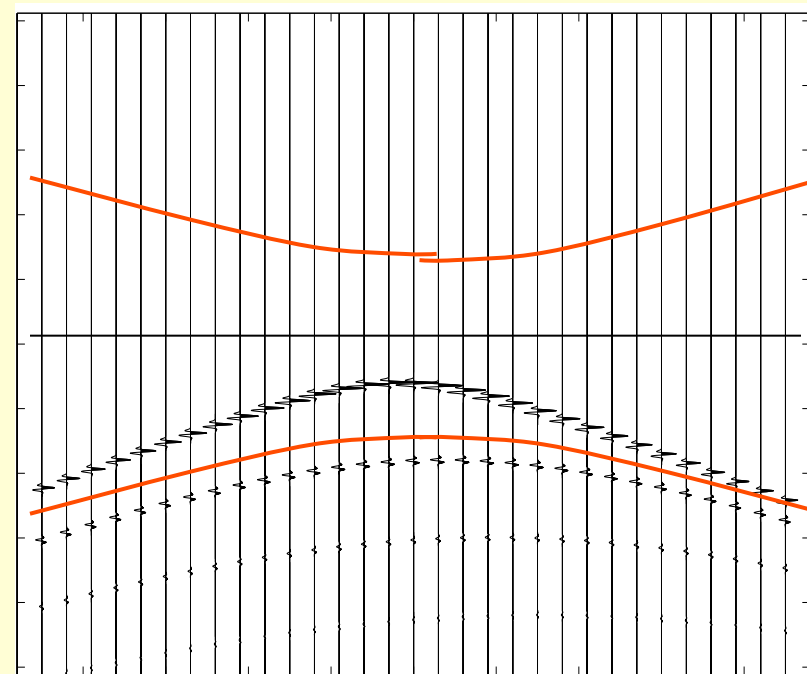
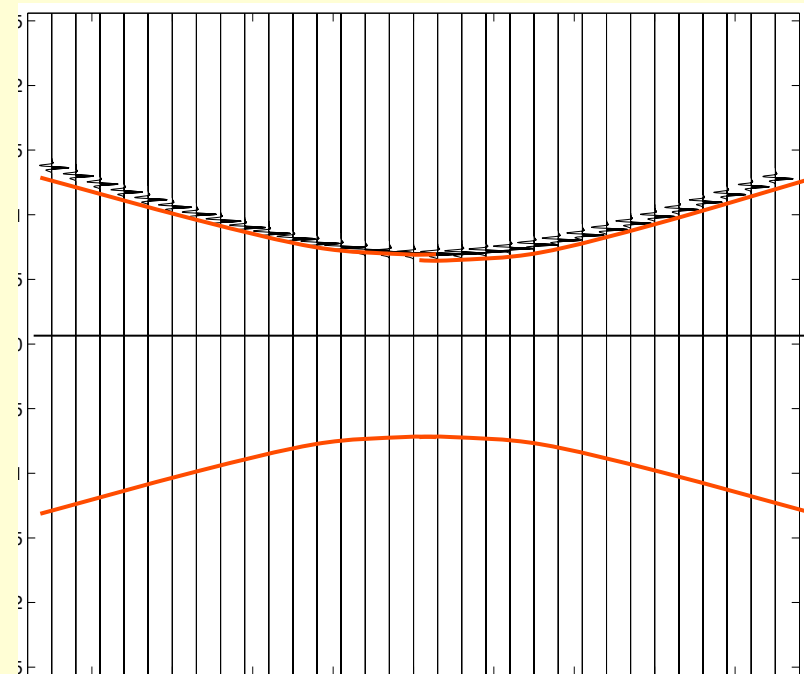




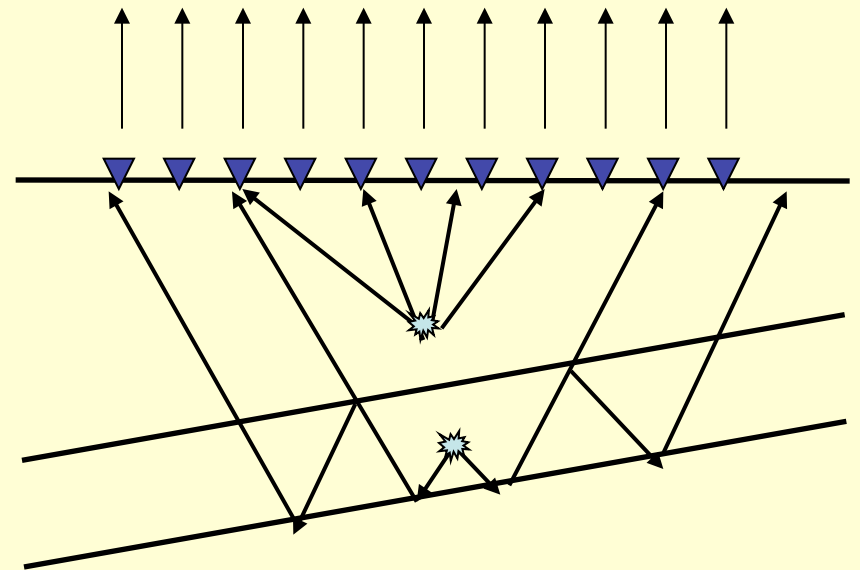
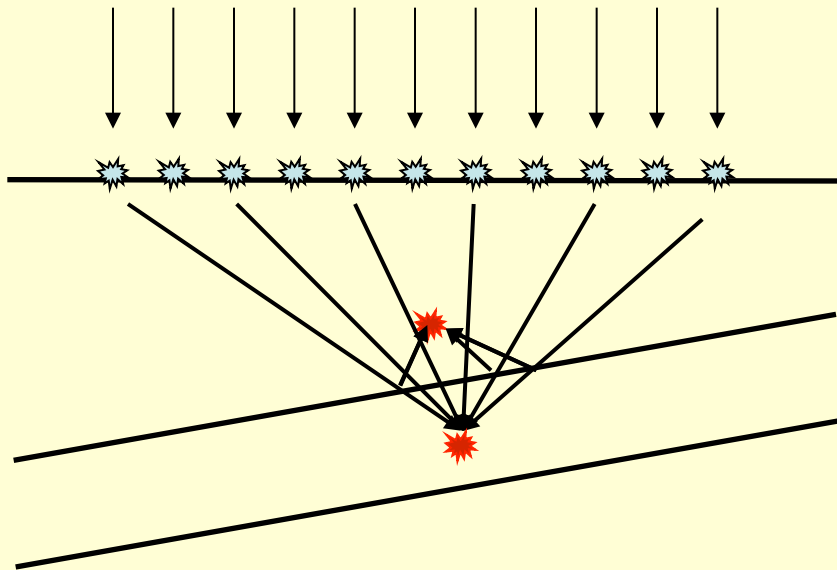
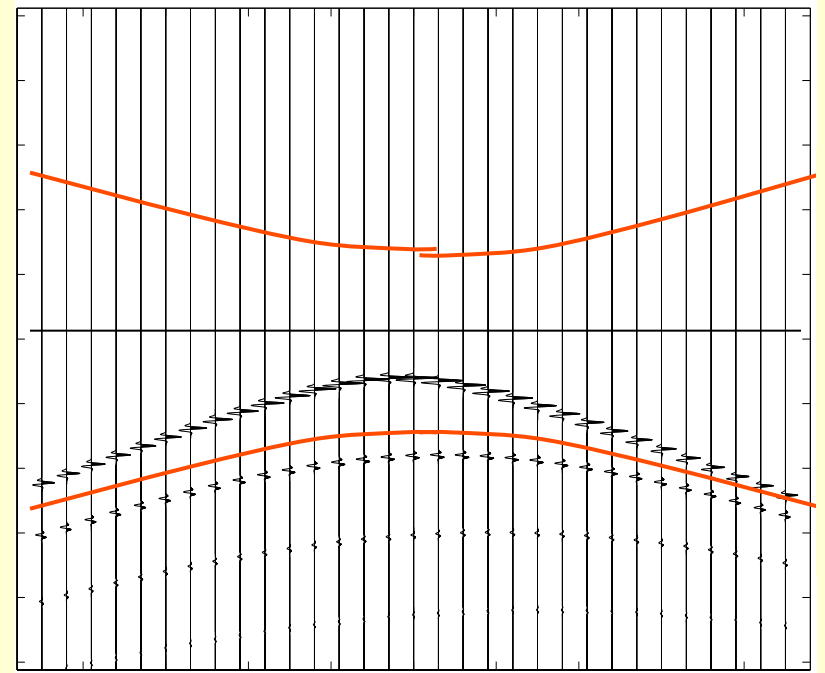
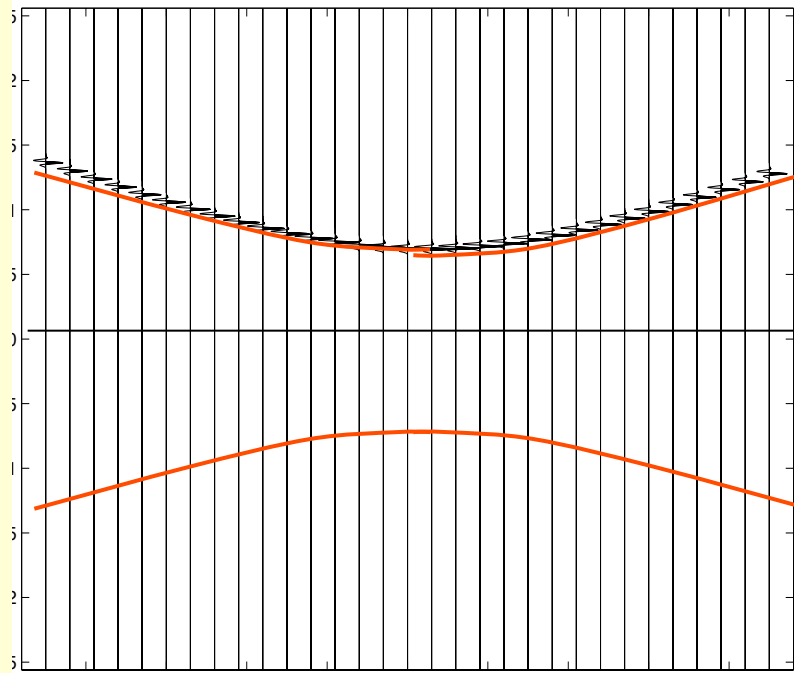


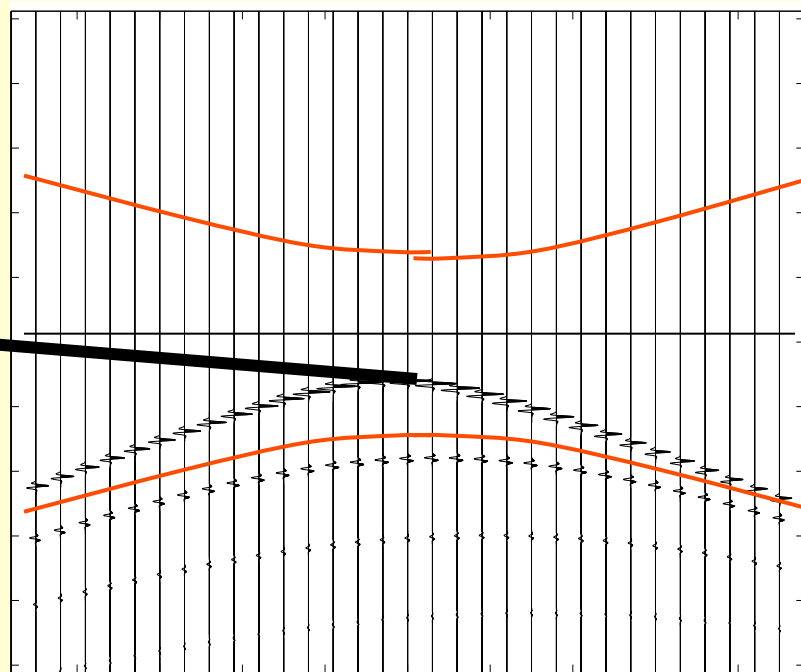
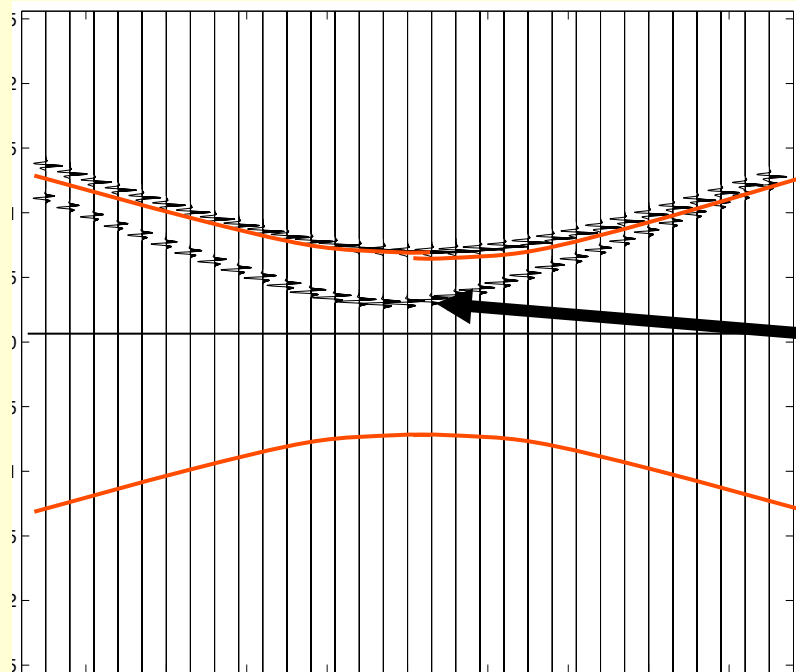


Convolve with reflection response and sum over all sources

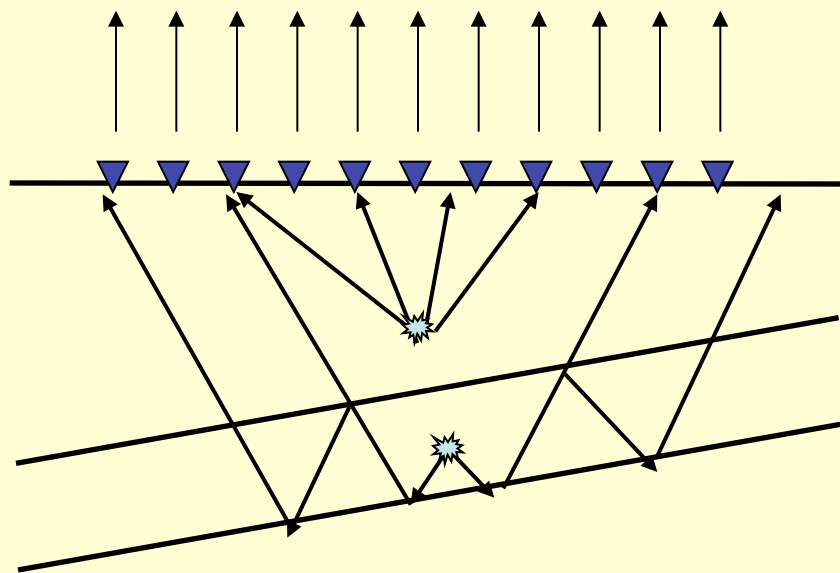
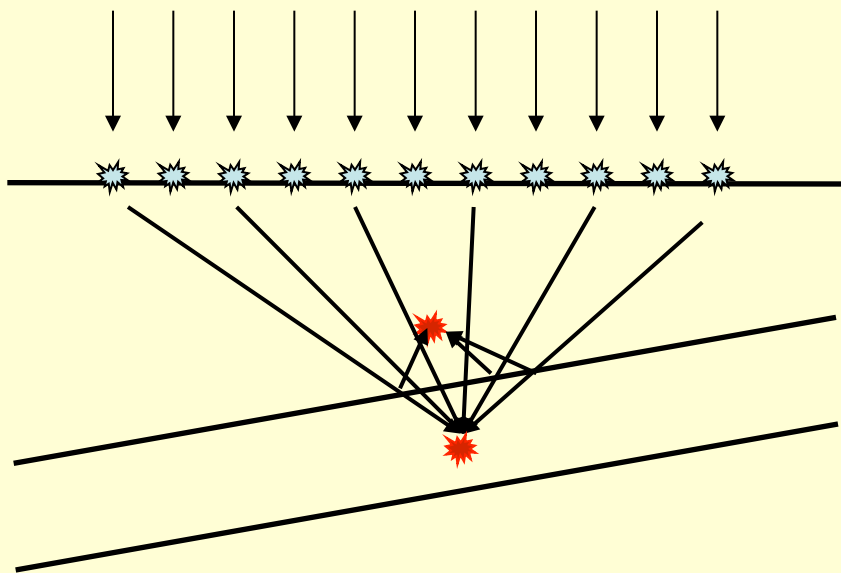


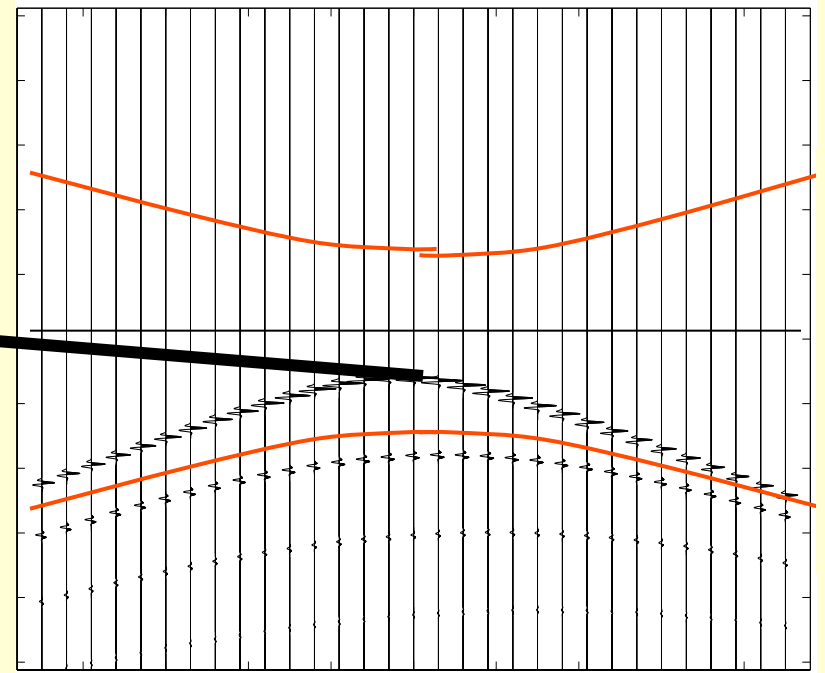
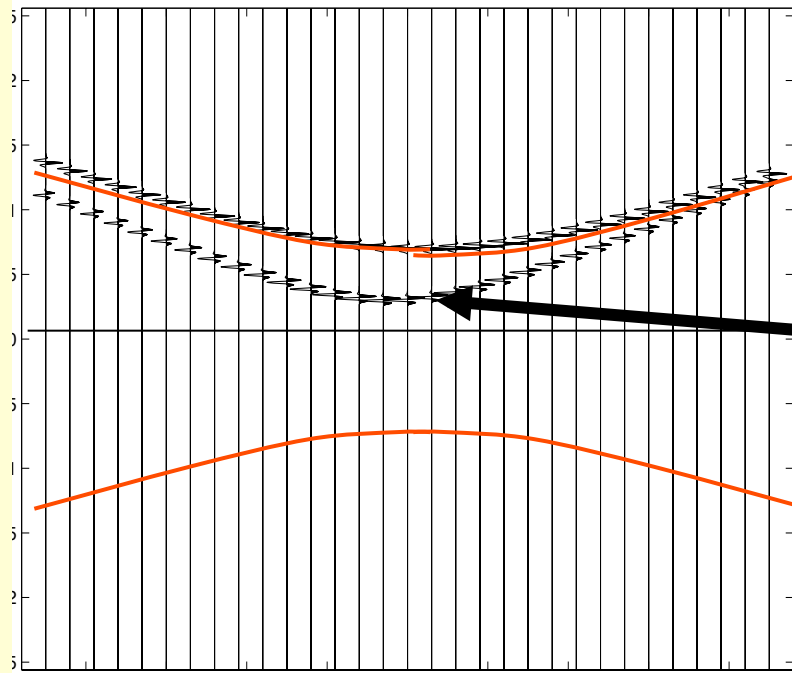
Convolve with reflection response and sum over all sources



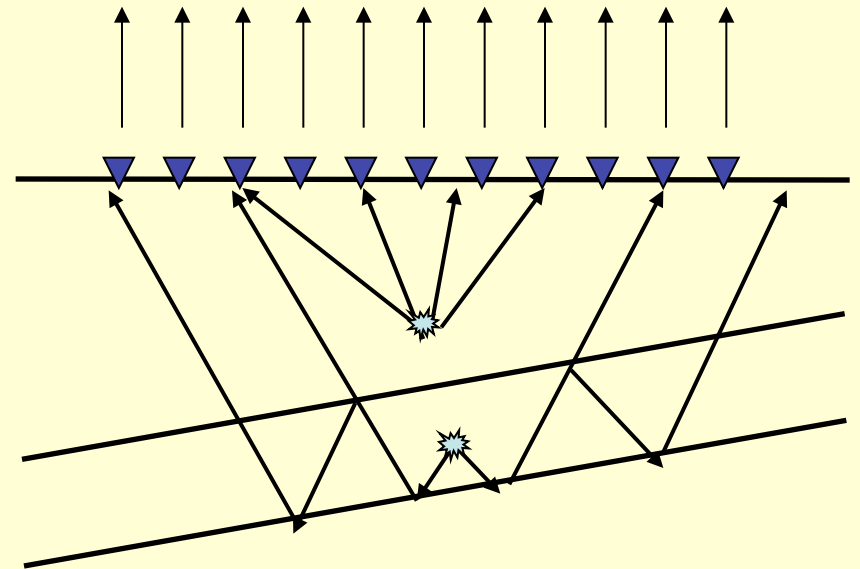
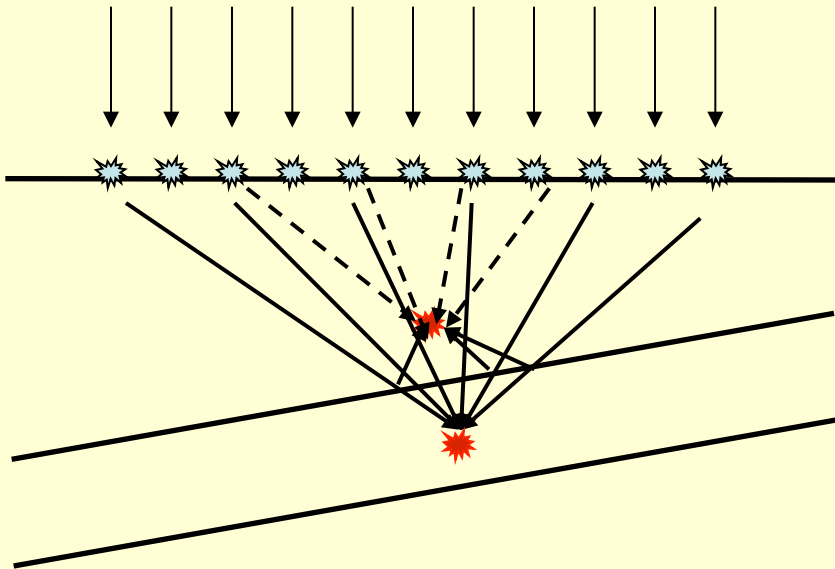


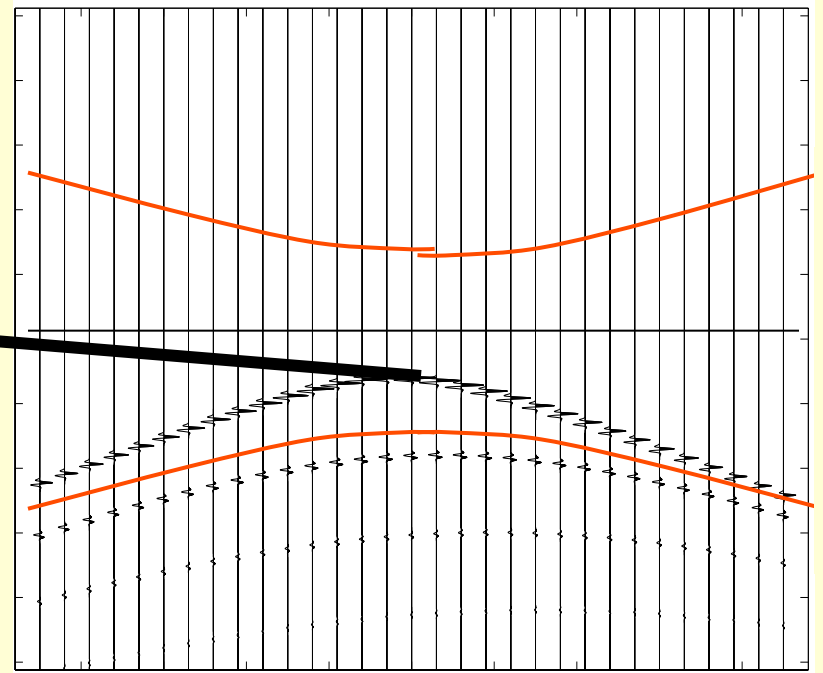
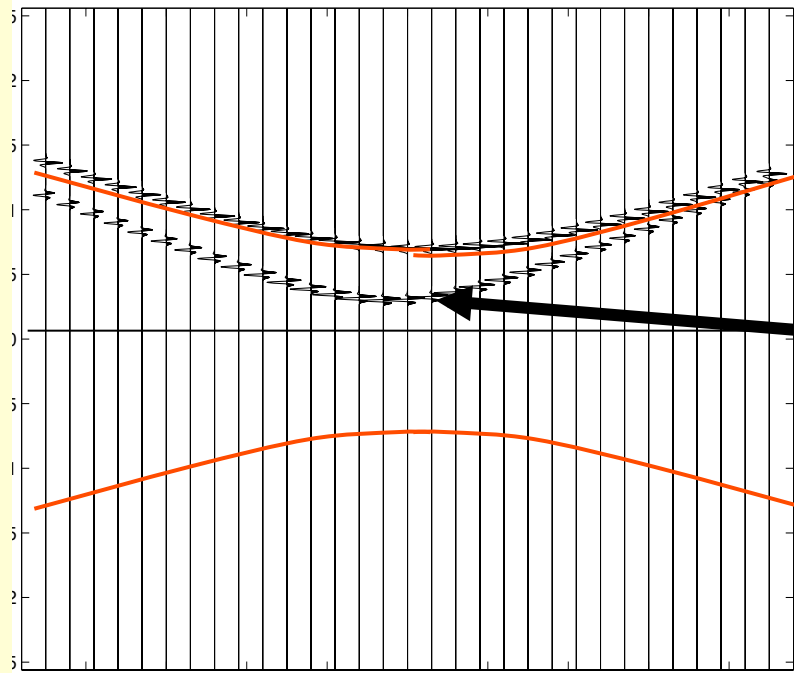
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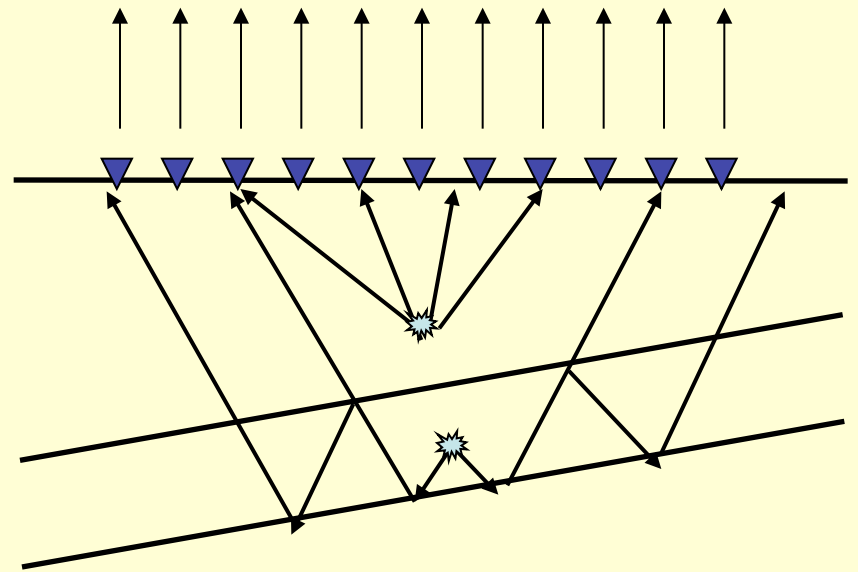
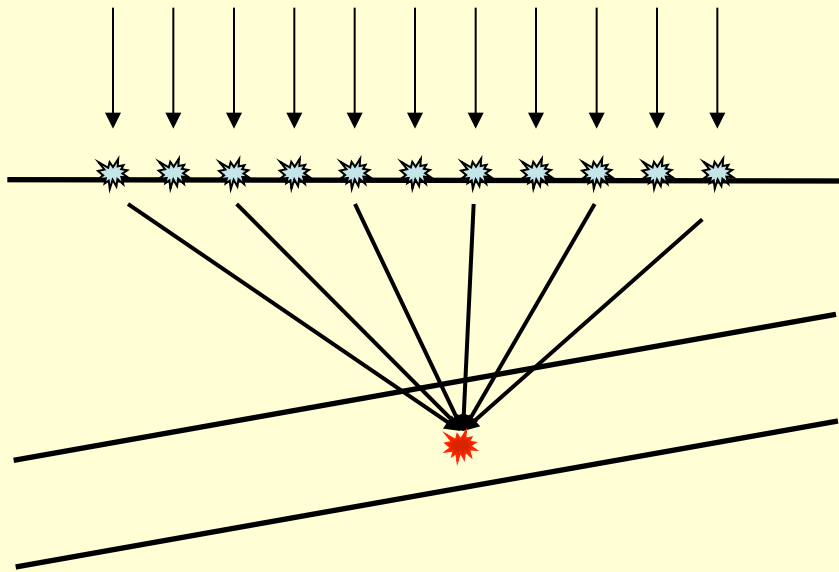


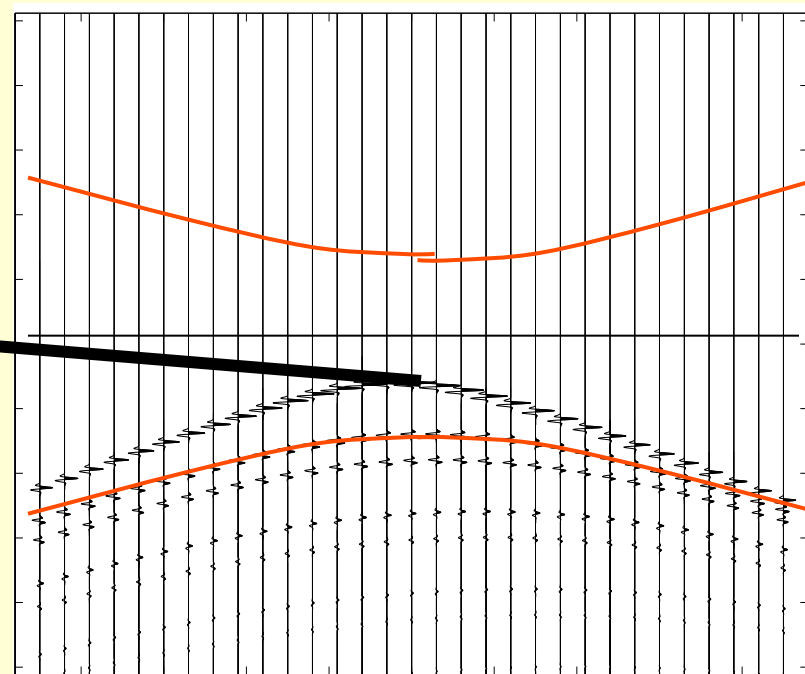
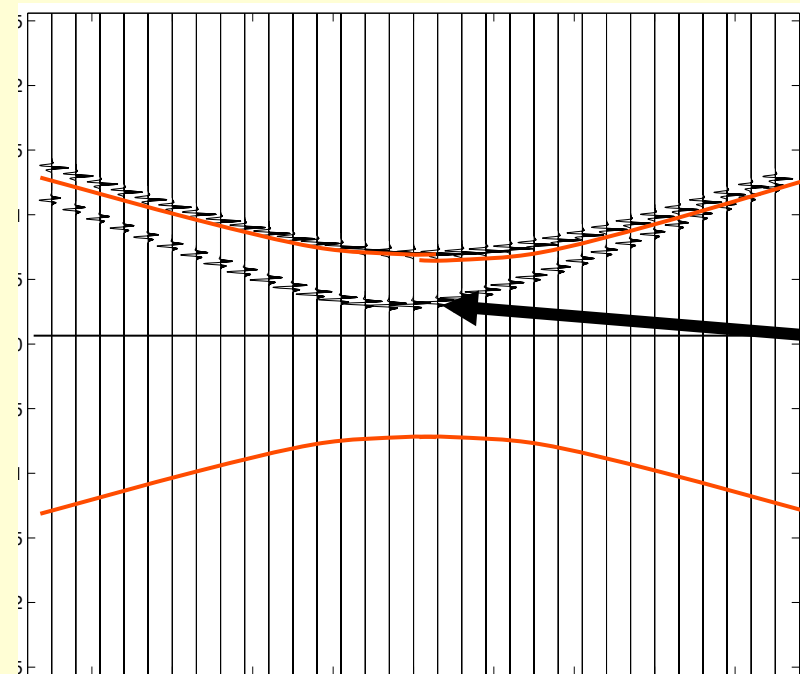
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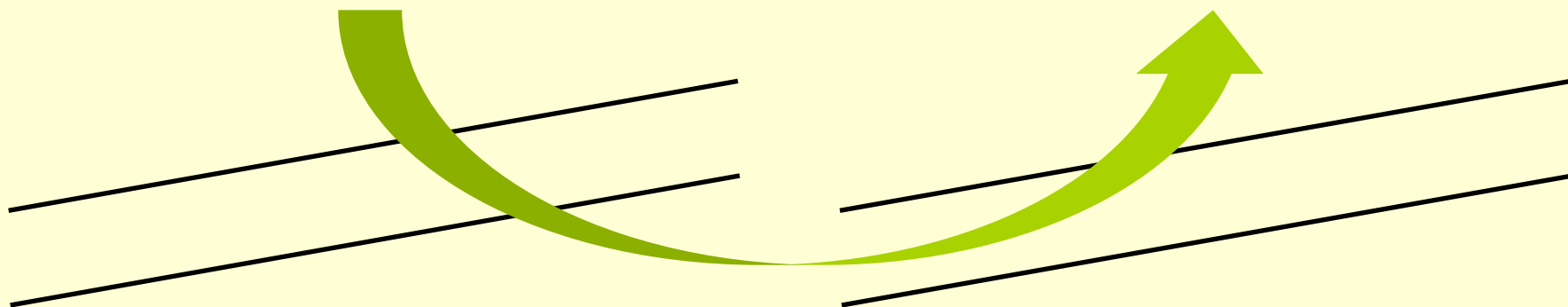
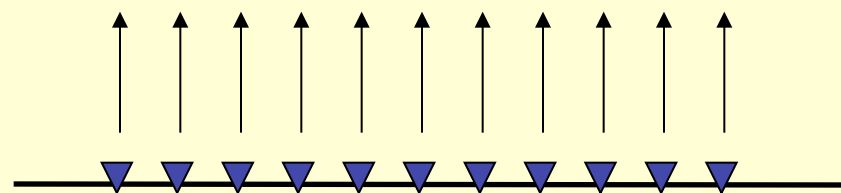
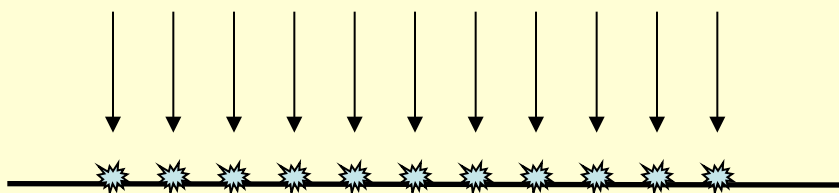


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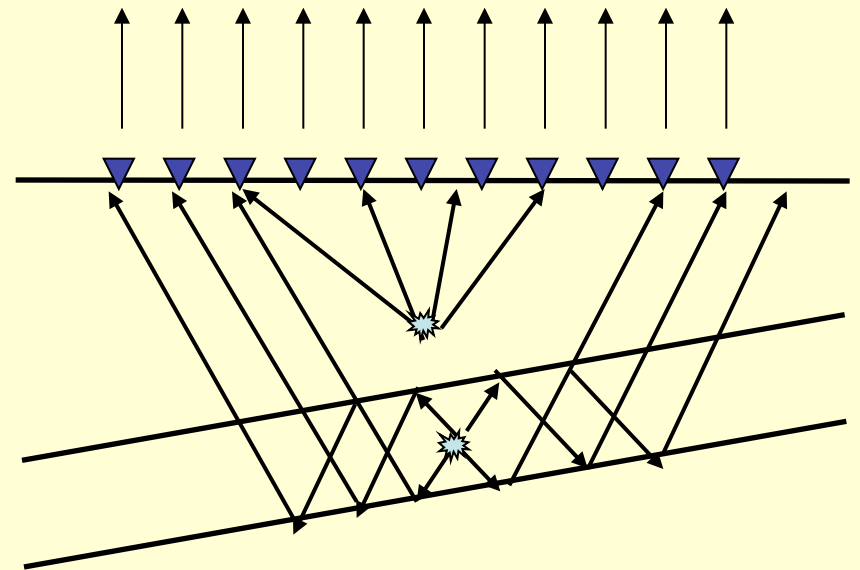
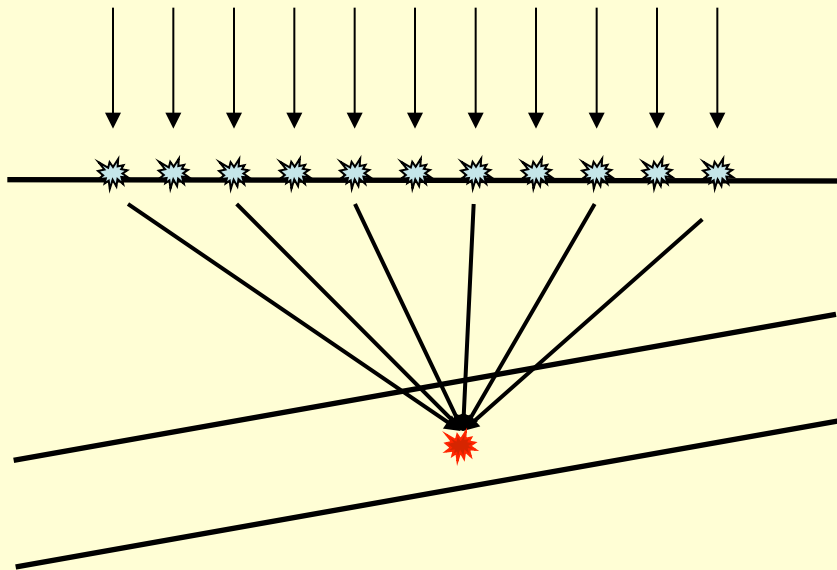
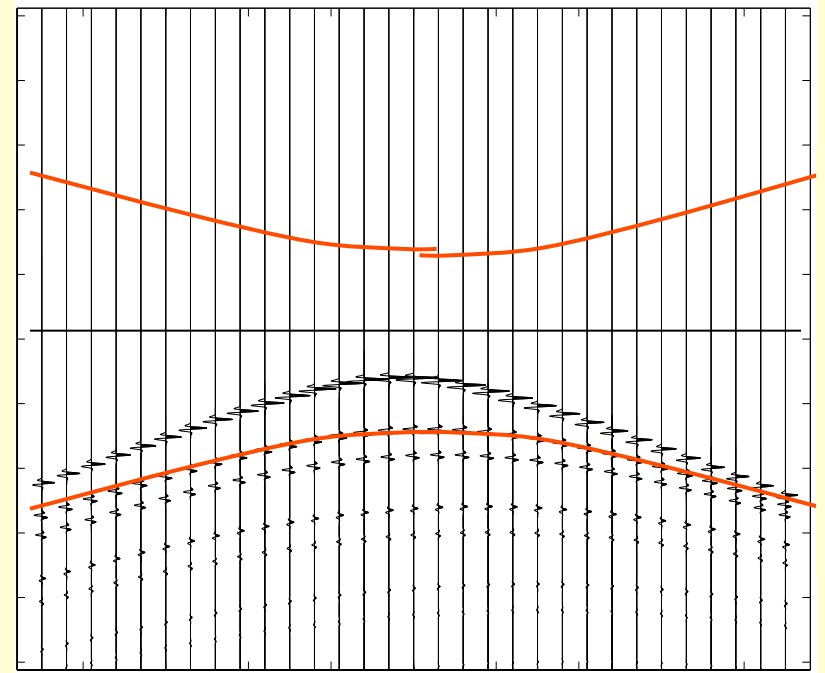
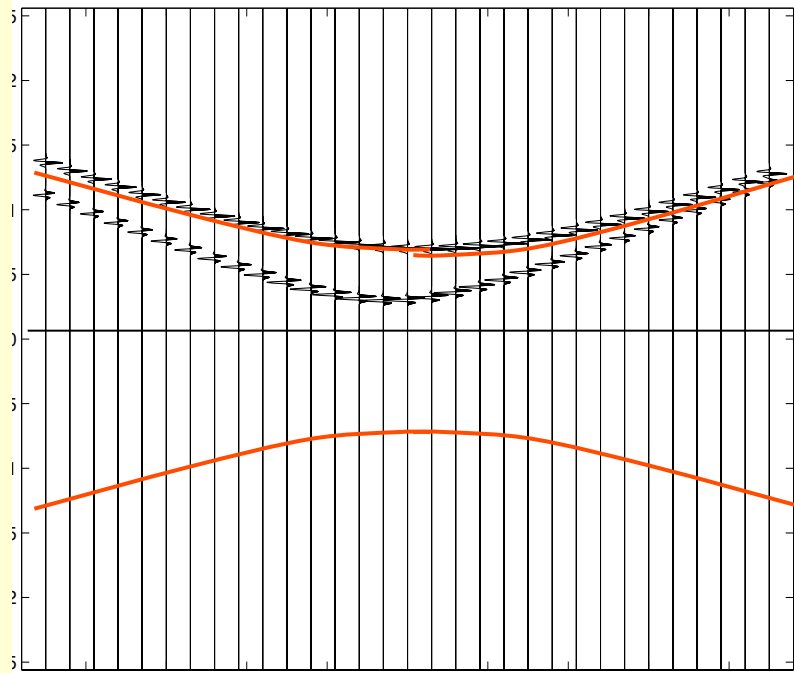




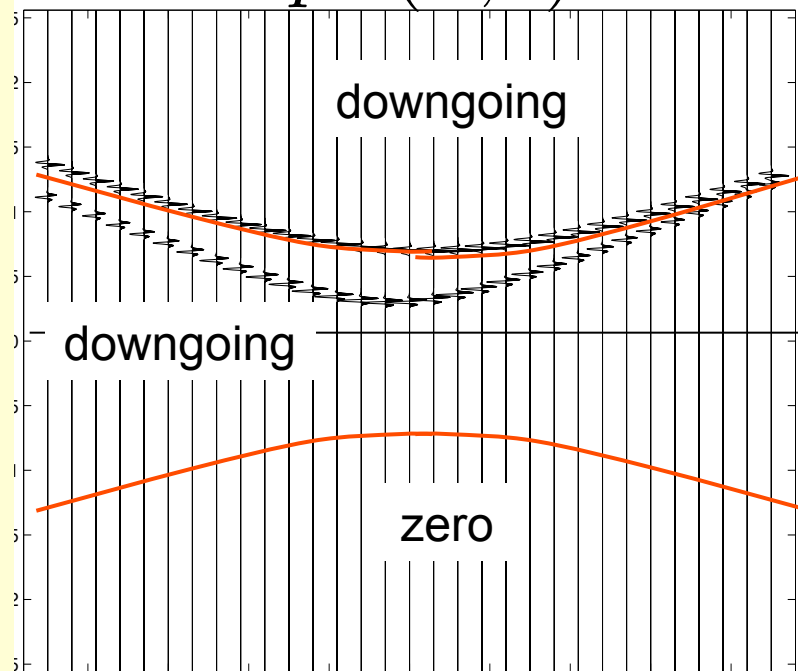
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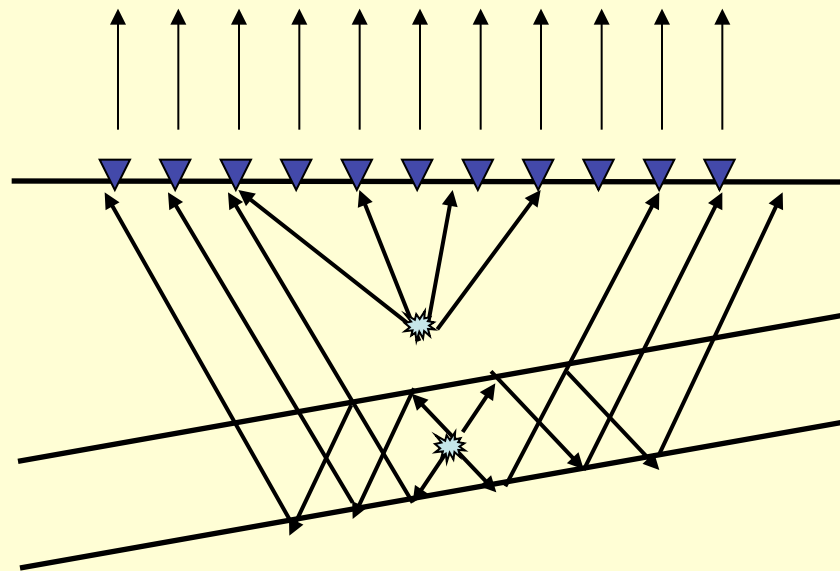
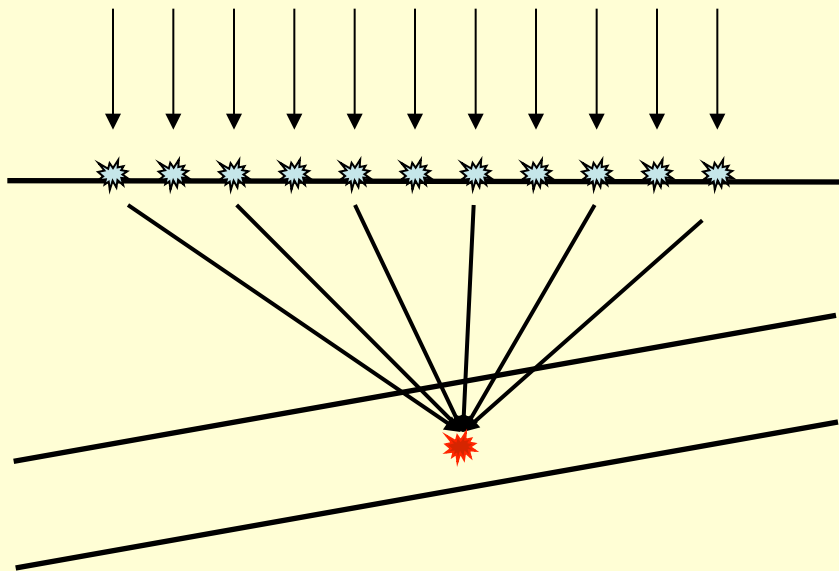
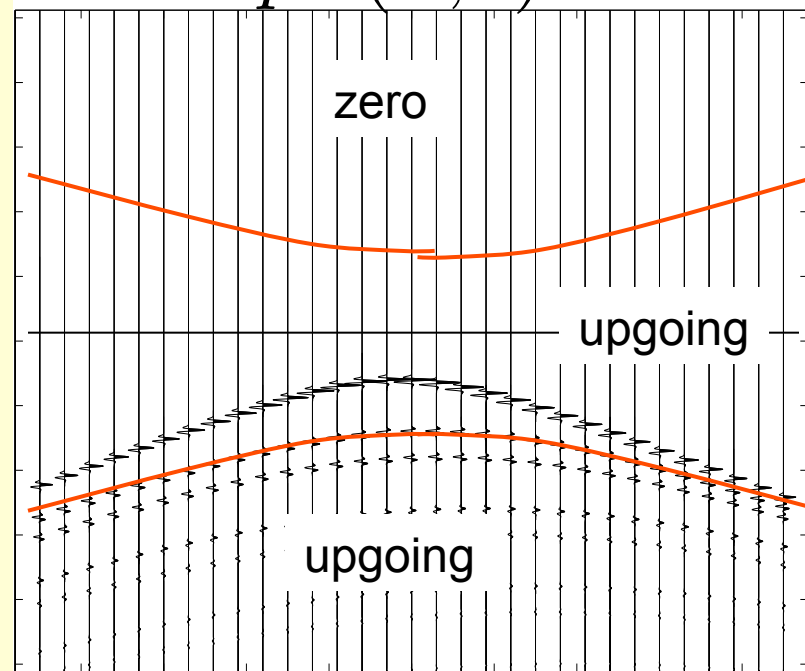
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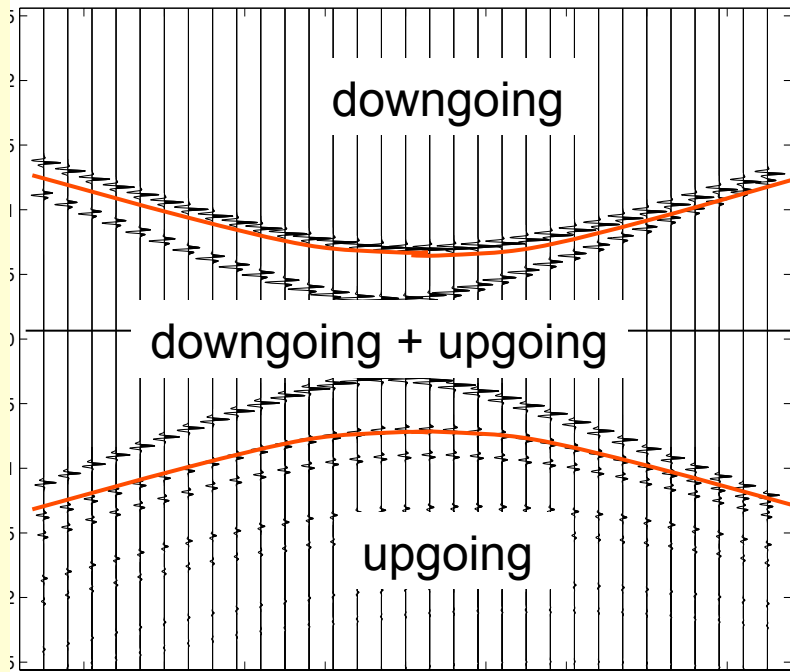


$$p^+(\mathbf{x}, t)$$



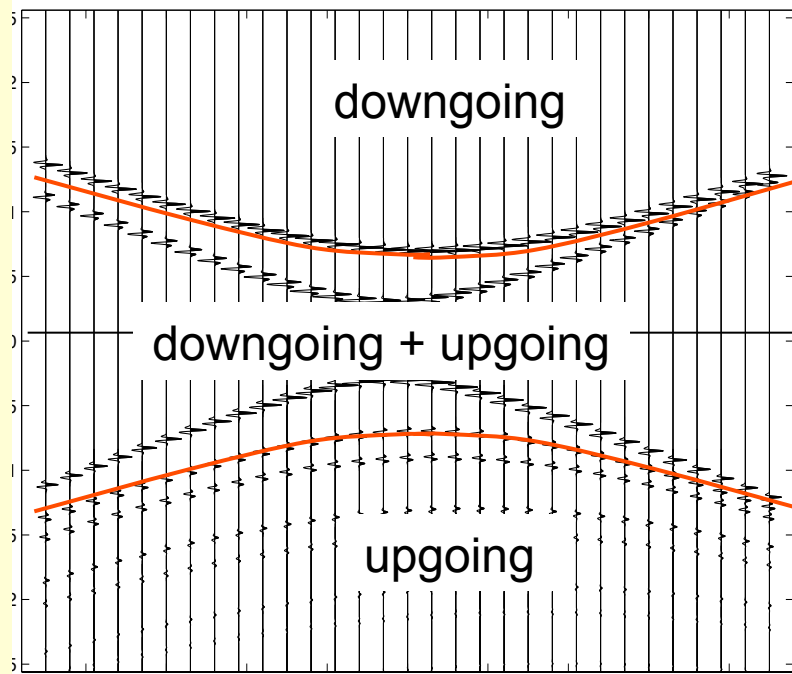
$$p^-(\mathbf{x}, t)$$



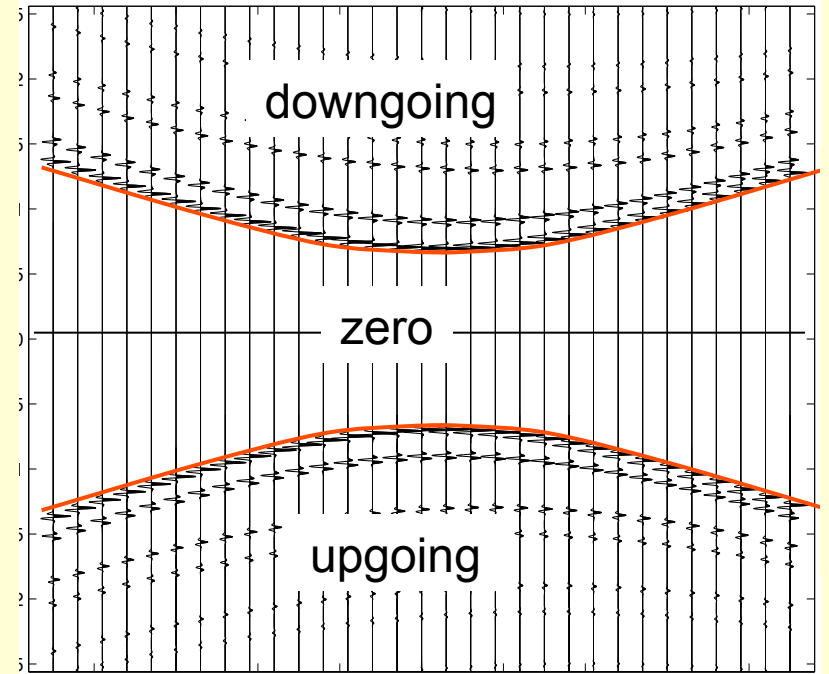


Superposition

$$p(\mathbf{x}, t) = p^+(\mathbf{x}, t) + p^-(\mathbf{x}, t)$$



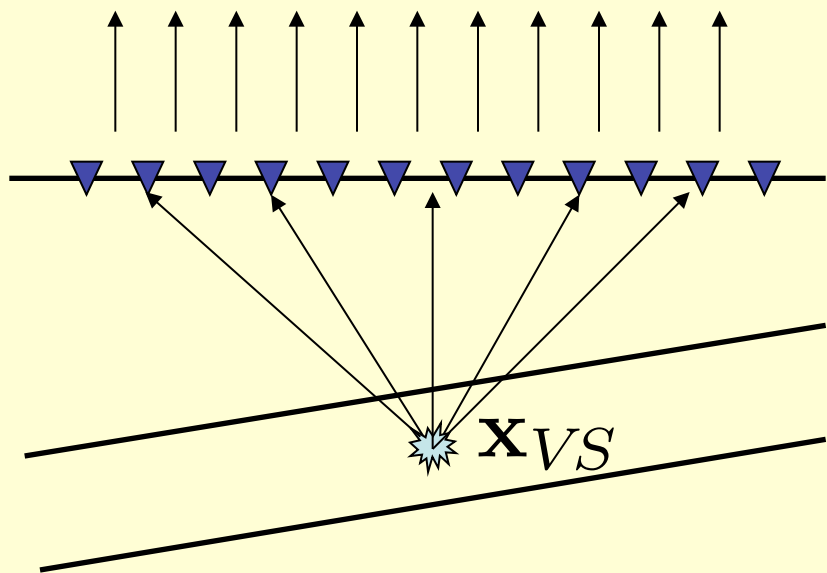
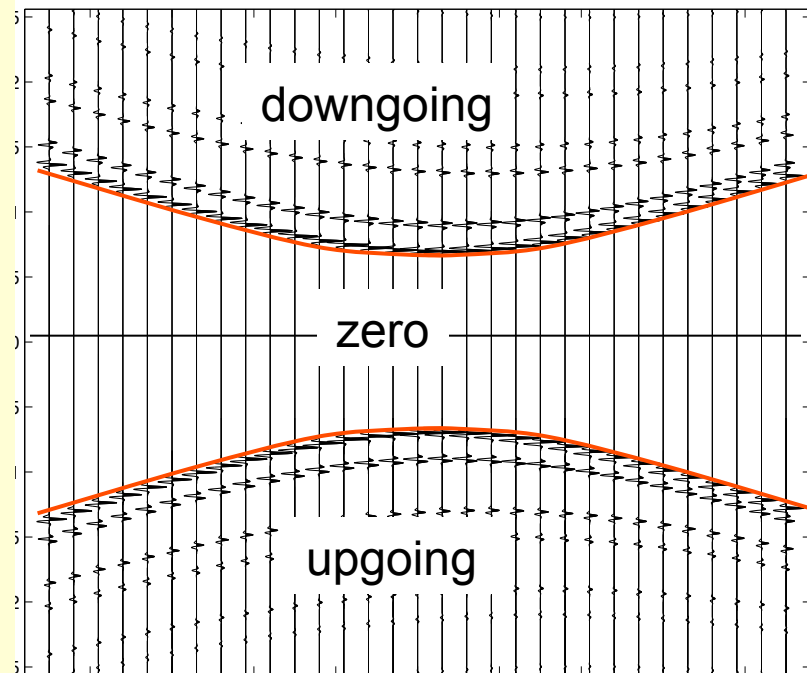
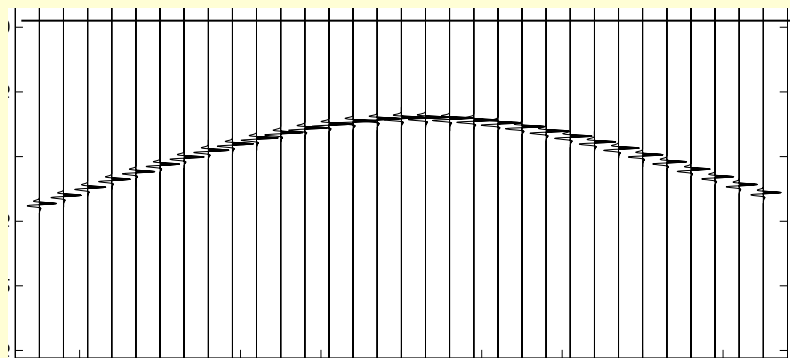
Superposition



Add time-reversed field

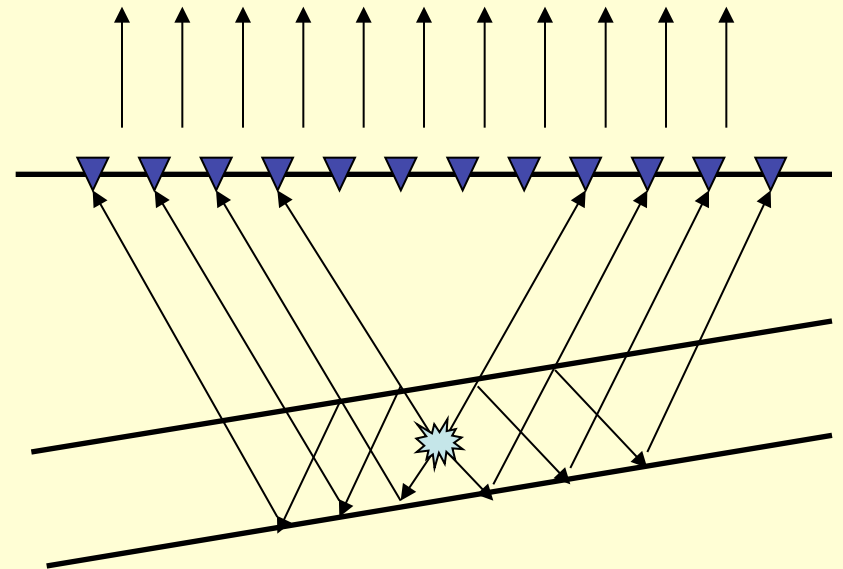
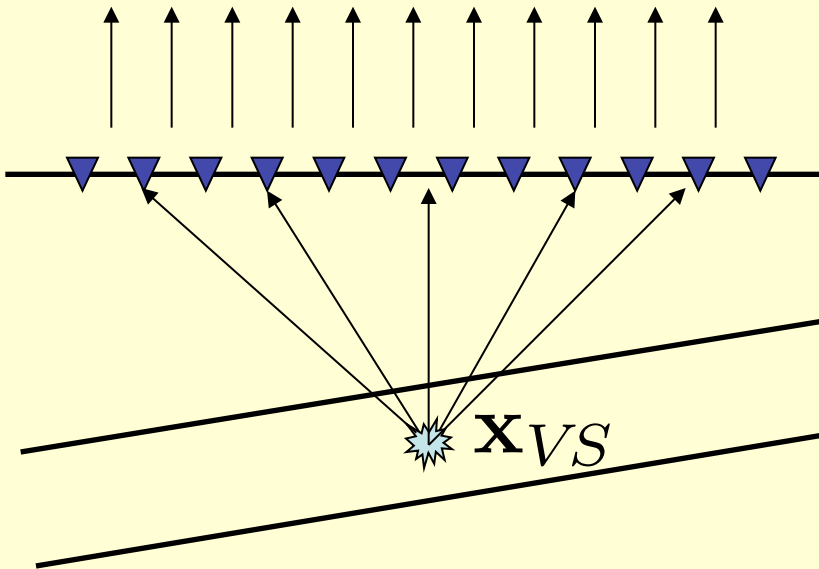
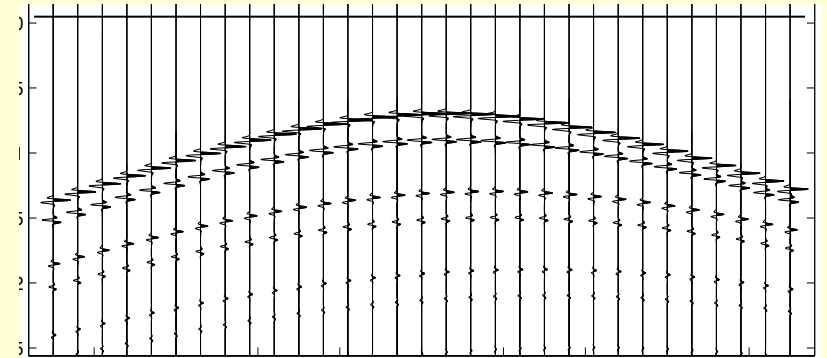
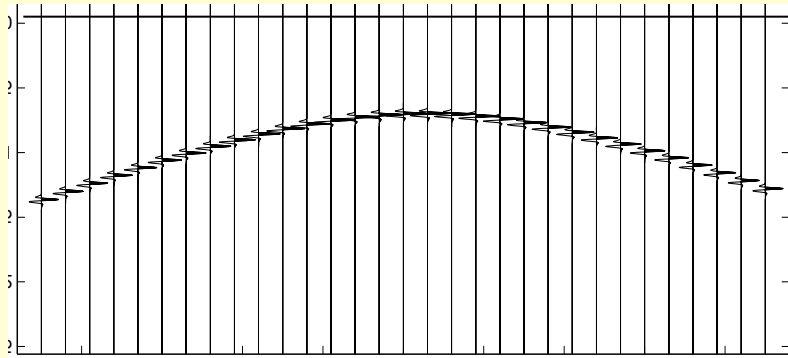
$$p(\mathbf{x}, t) = p^+(\mathbf{x}, t) + p^-(\mathbf{x}, t)$$

$$p(\mathbf{x}, t) + p(\mathbf{x}, -t)$$



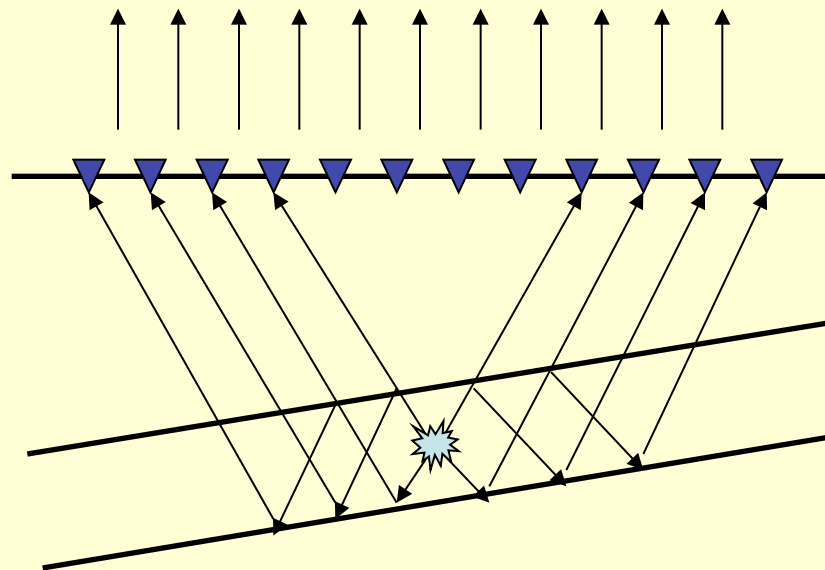
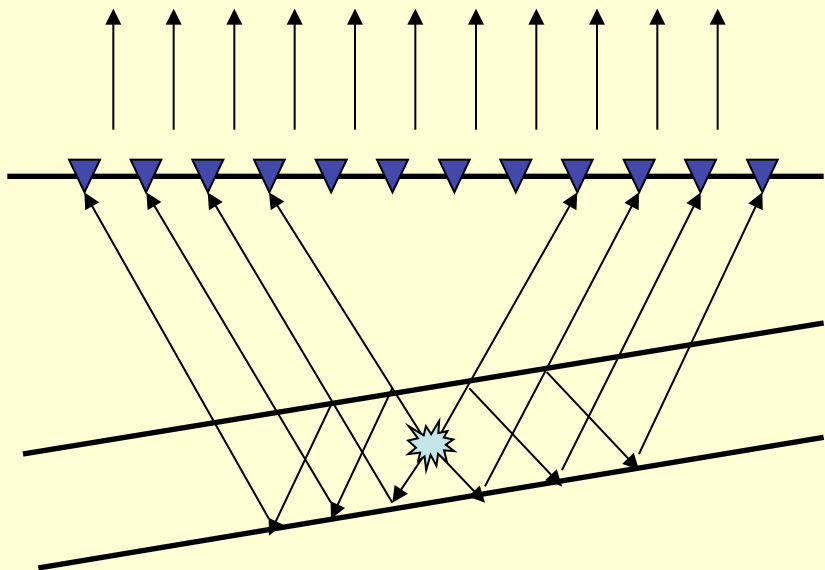
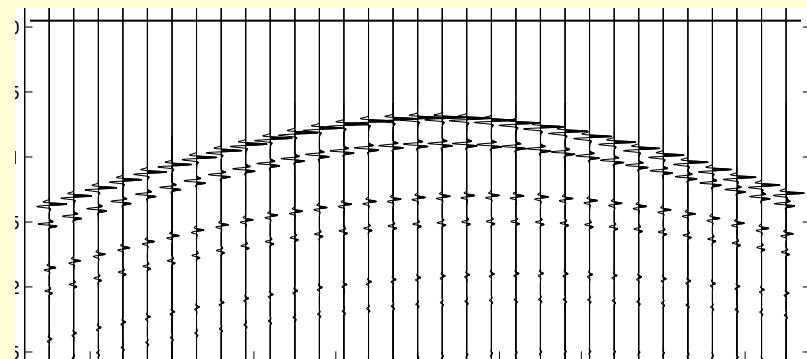
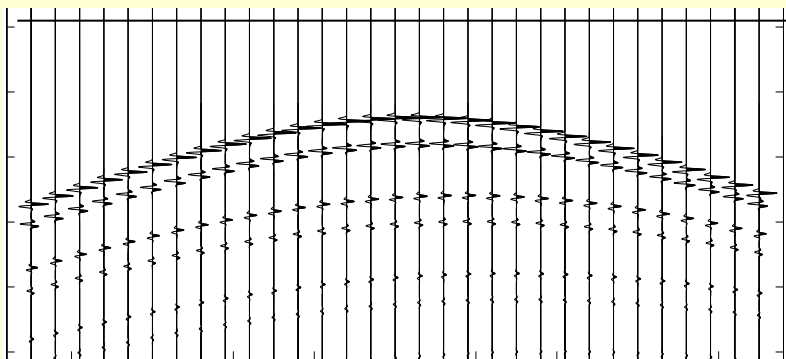
$$p(\mathbf{x}, t) + p(\mathbf{x}, -t)$$

$$G(\mathbf{x}, \mathbf{x}_{VS}, t) * s(t)$$



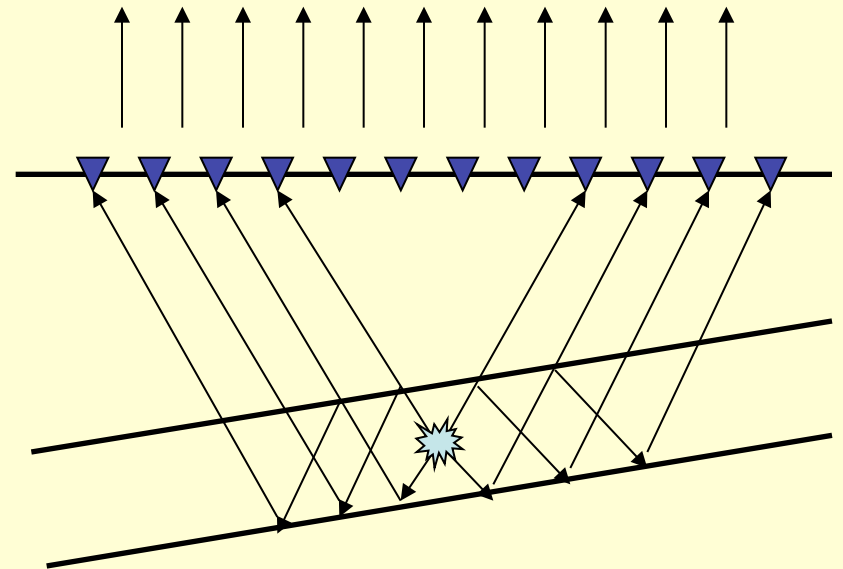
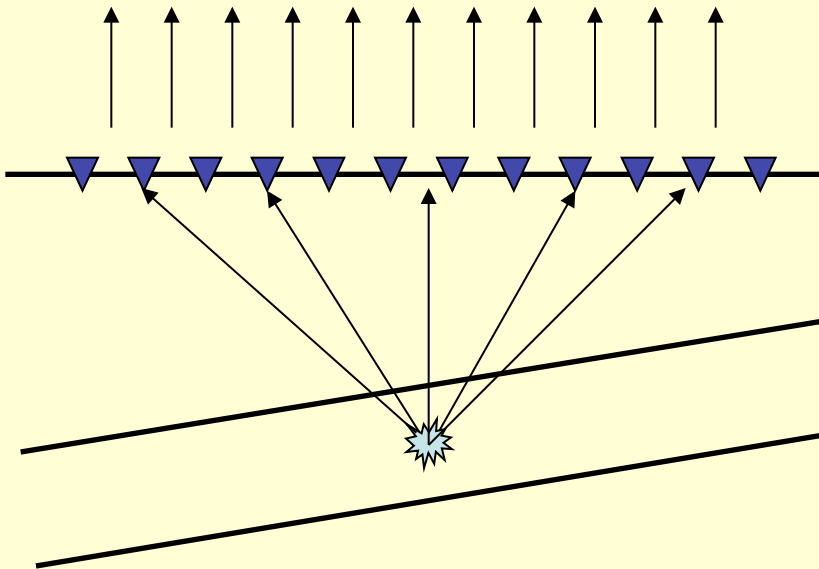
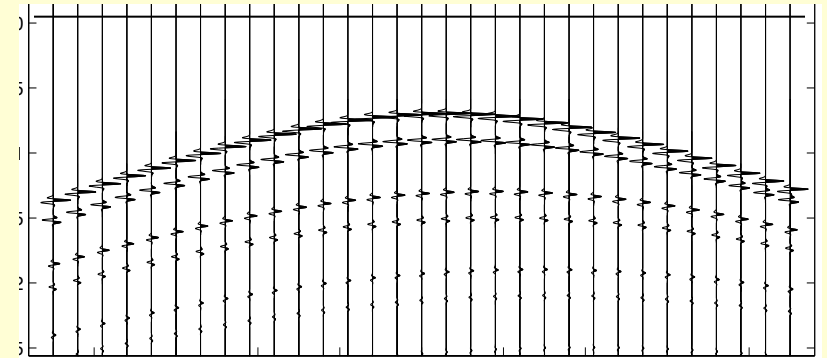
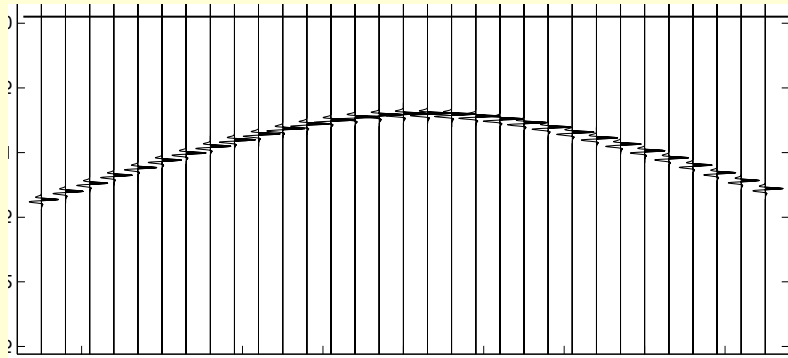
Directly modeled response

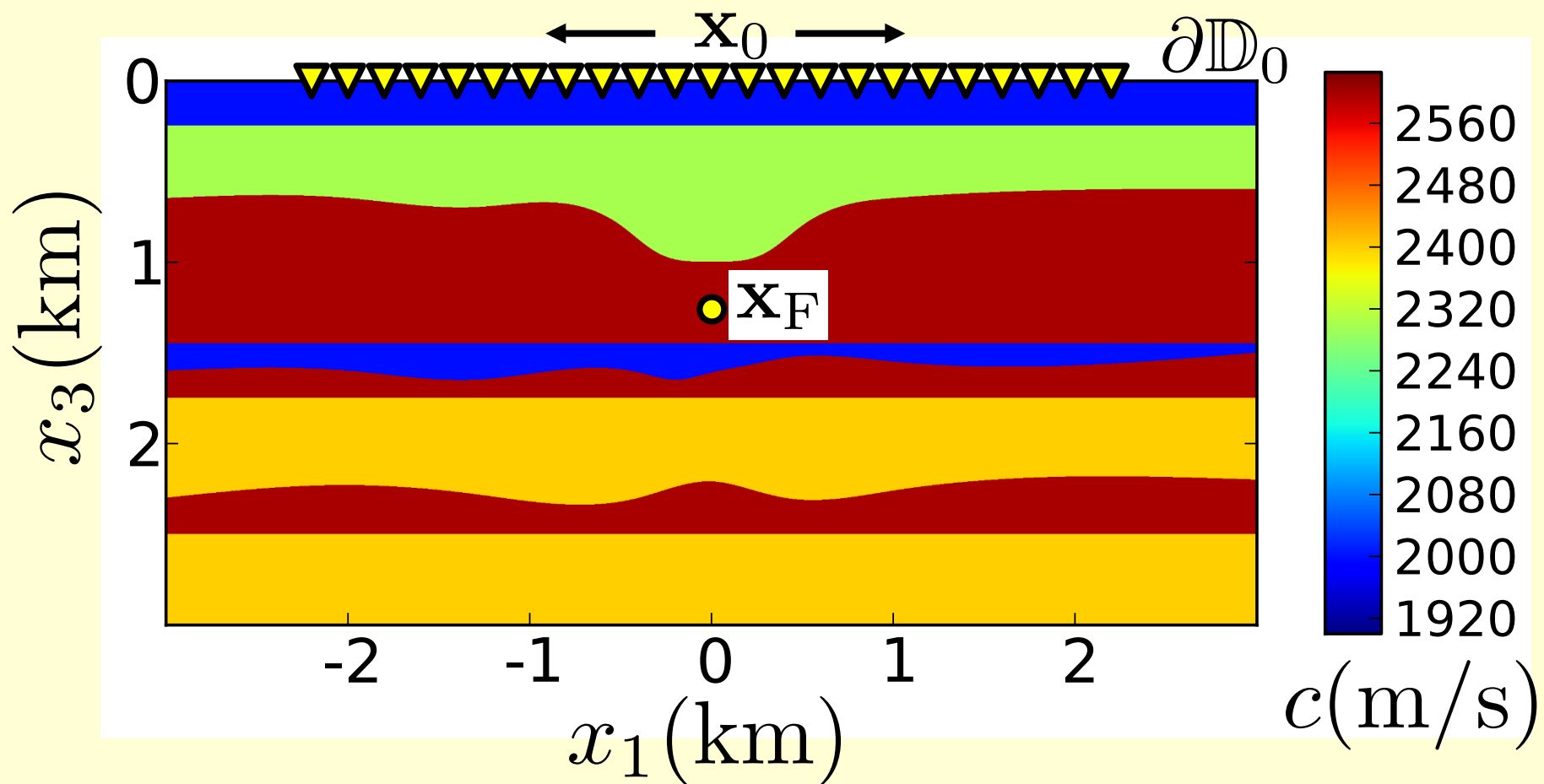
$$G(\mathbf{x}, \mathbf{x}_{VS}, t) * s(t)$$

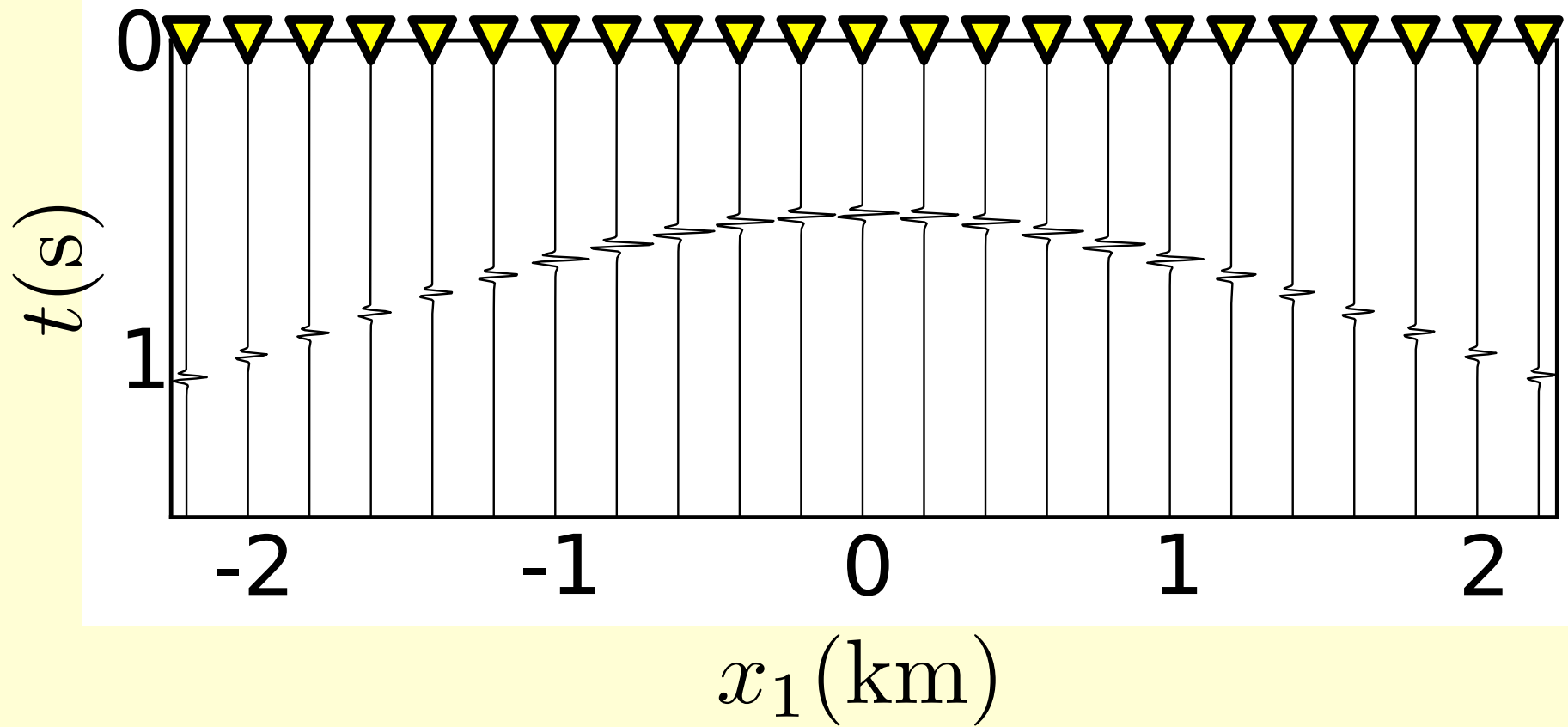


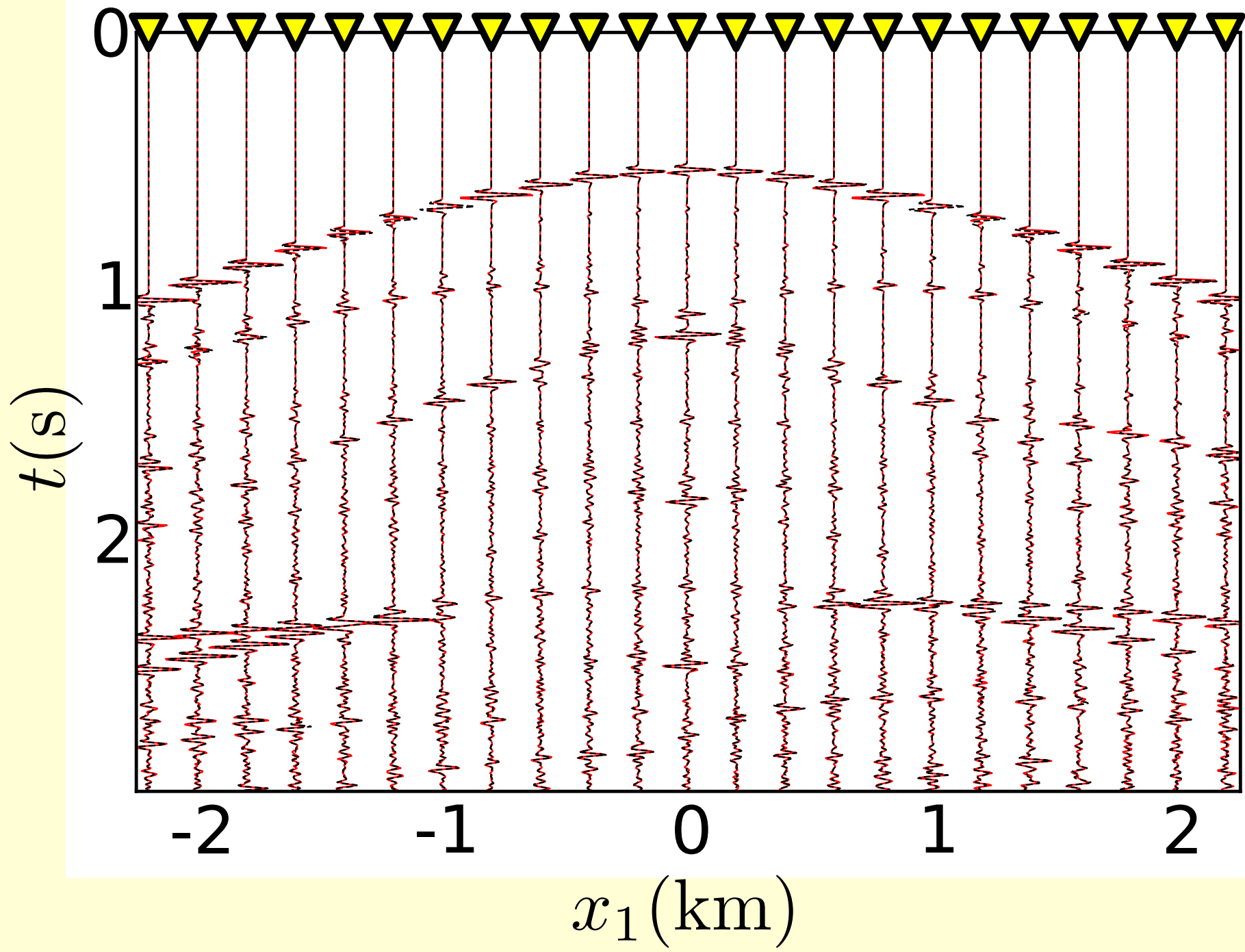
Summary:

Measured reflection response at surface,
plus estimate of primary virtual source response,
gives full virtual-source response



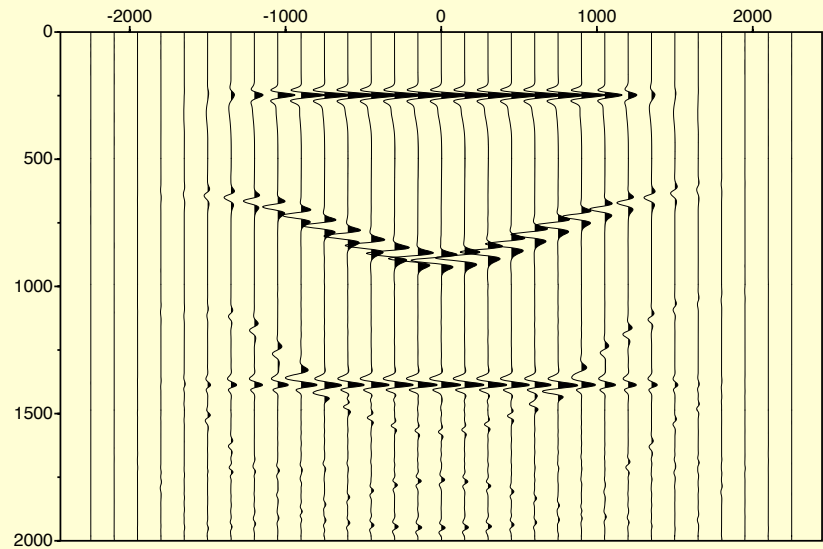
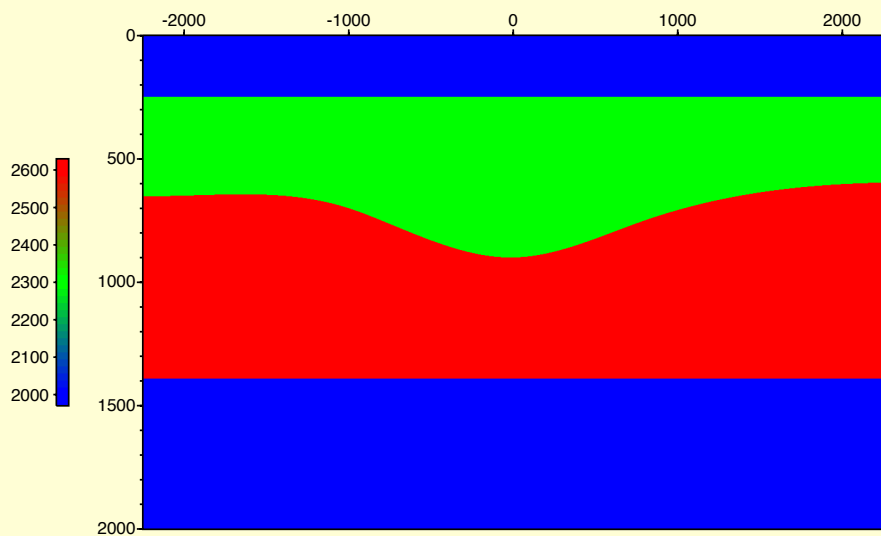




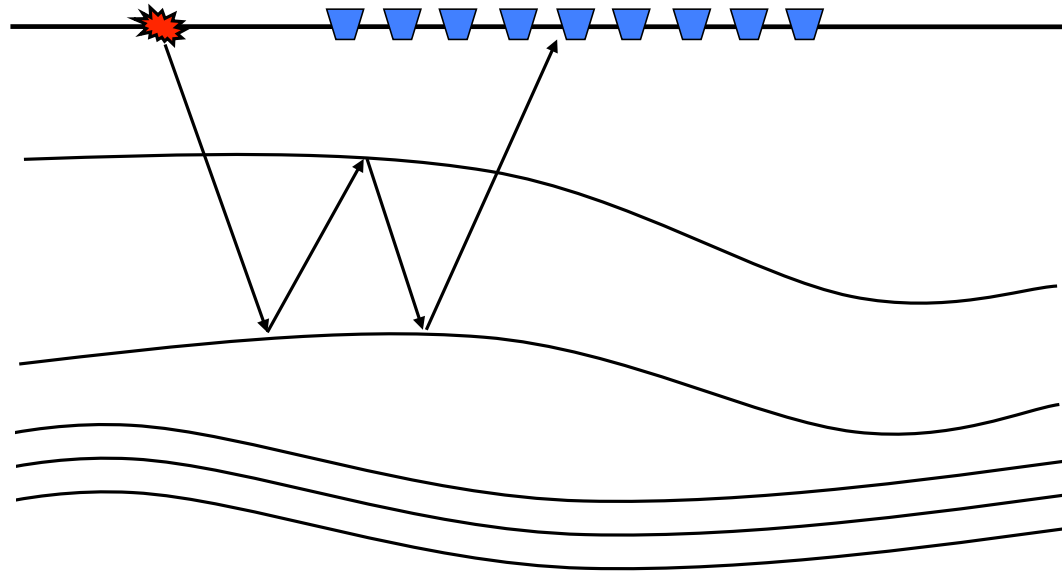


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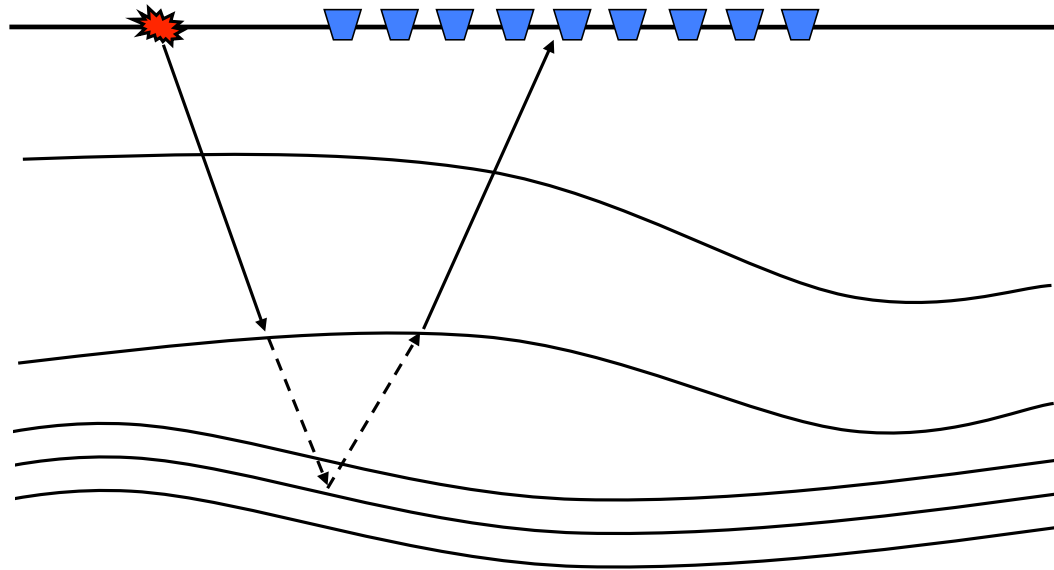
- Introduction
- Creating a virtual source from reflection data
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- Conclusions



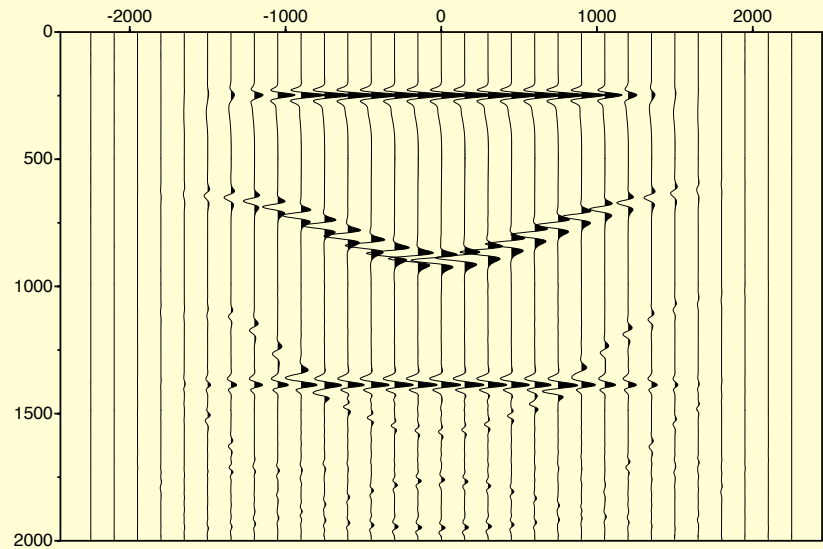
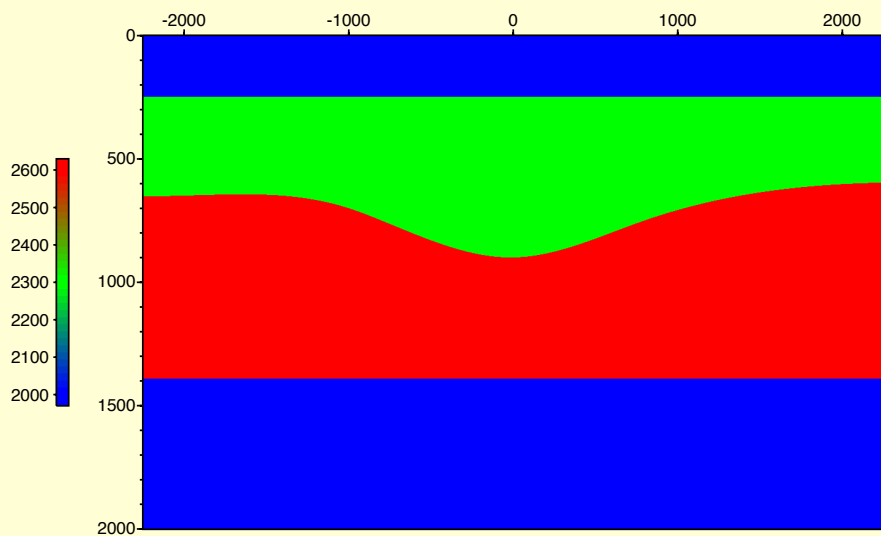
Standard imaging



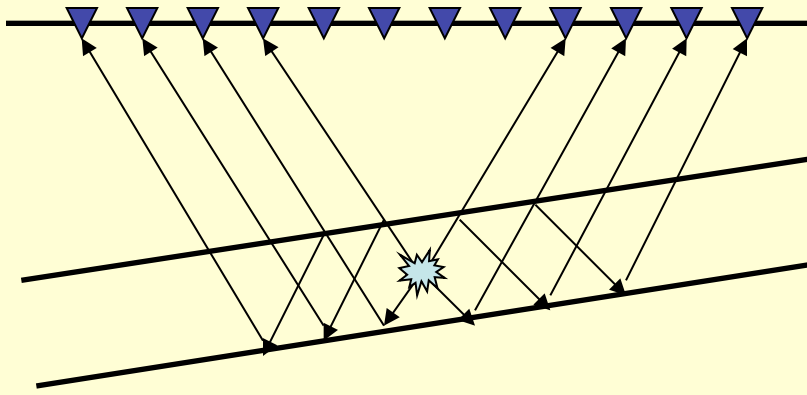
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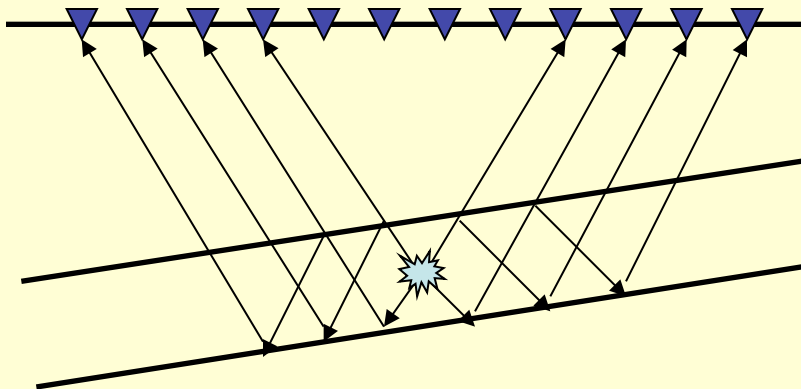


Standard imaging

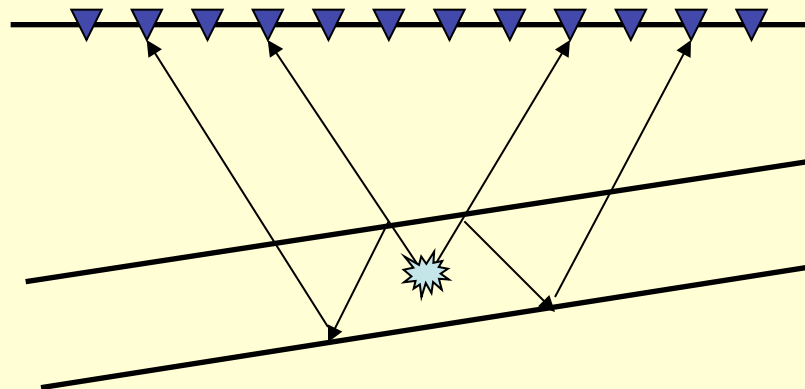
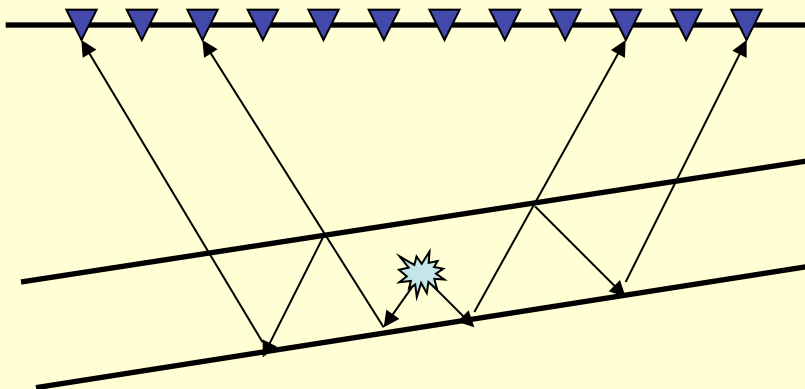
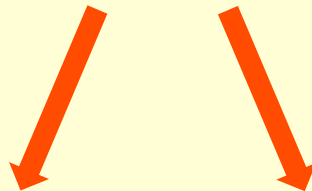


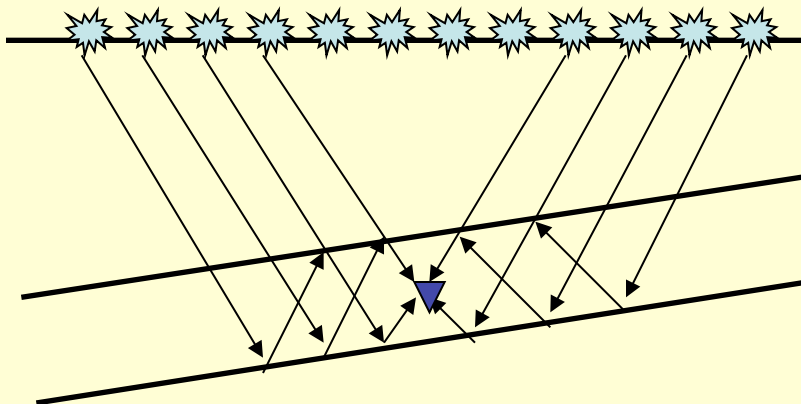
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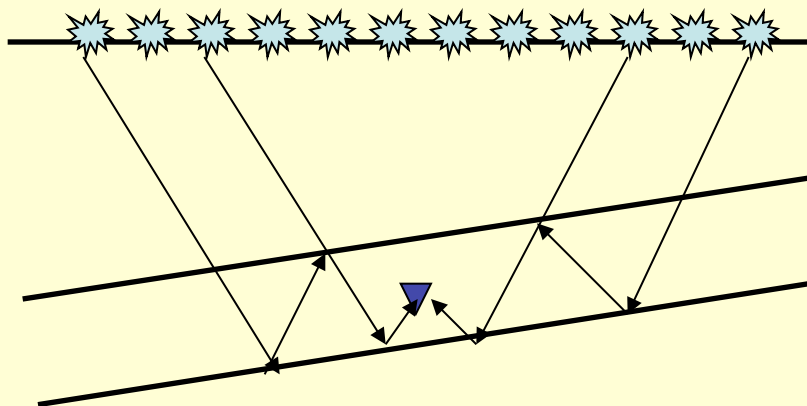
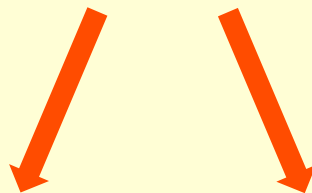


decomposition

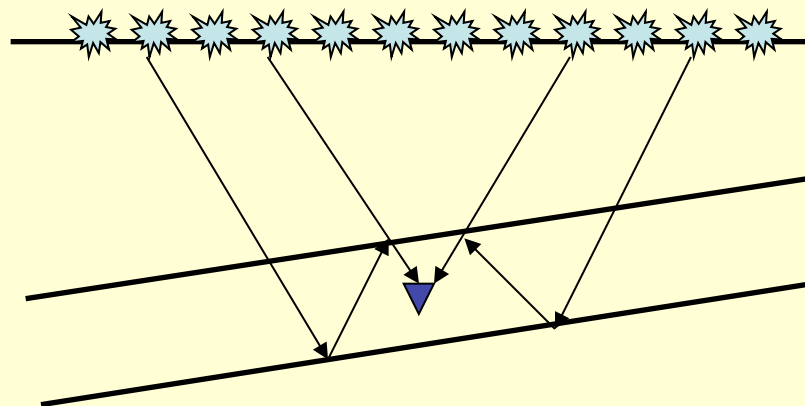




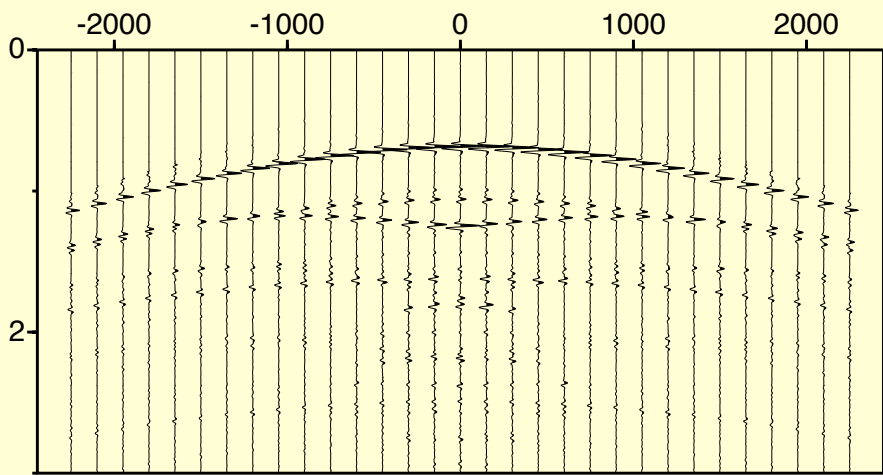
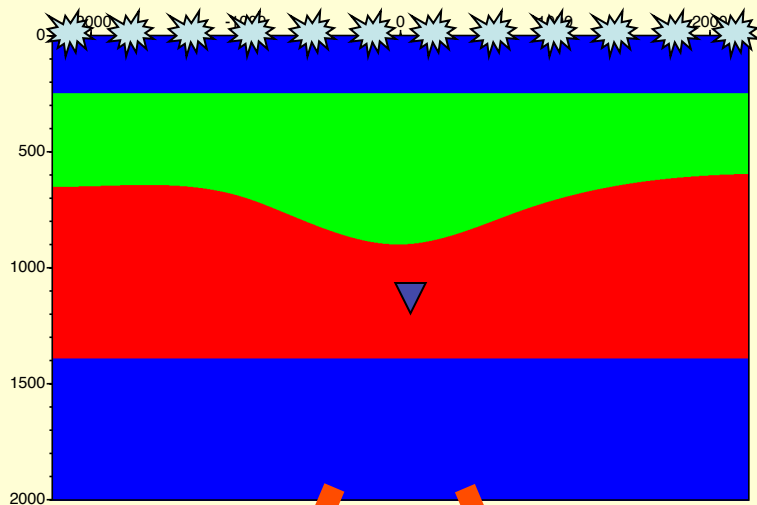
decomposition
+ reciprocity



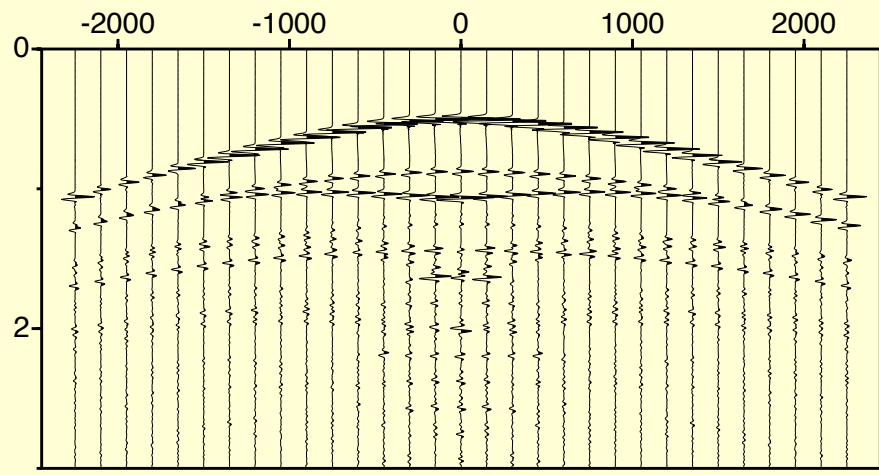
$$G^{-}(\mathbf{x}, \mathbf{x}_S, t) * s(t)$$



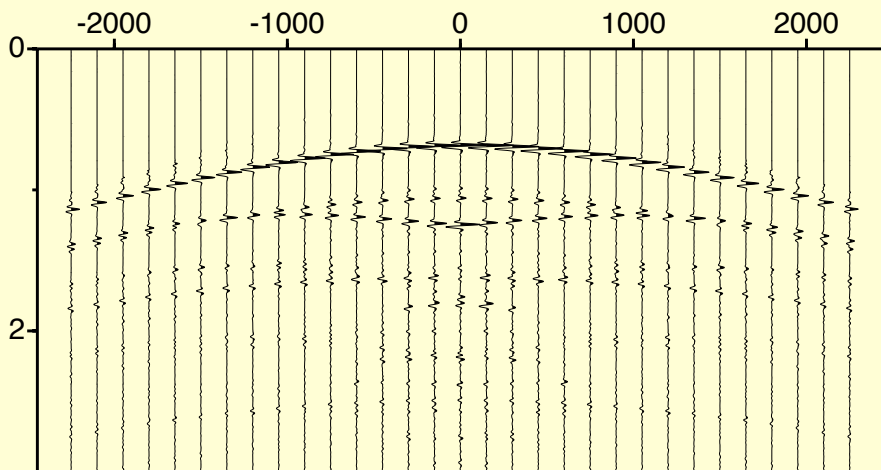
$$G^{+}(\mathbf{x}, \mathbf{x}_S, t) * s(t)$$



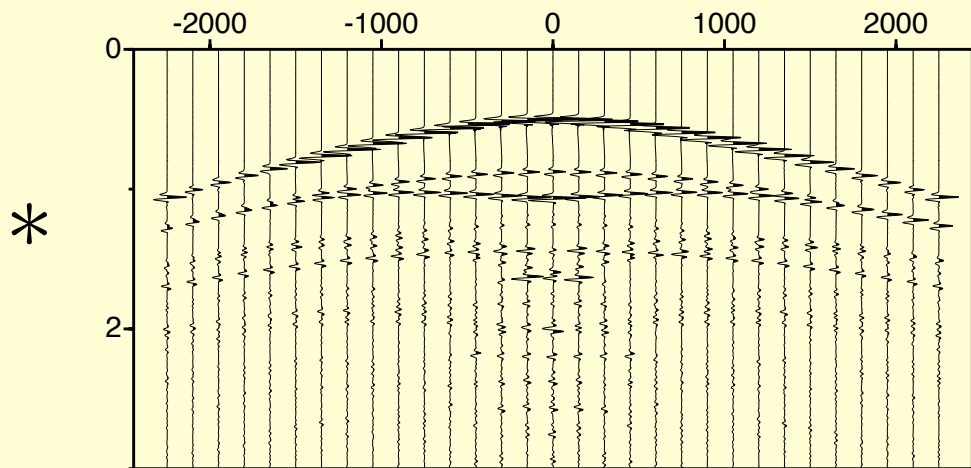
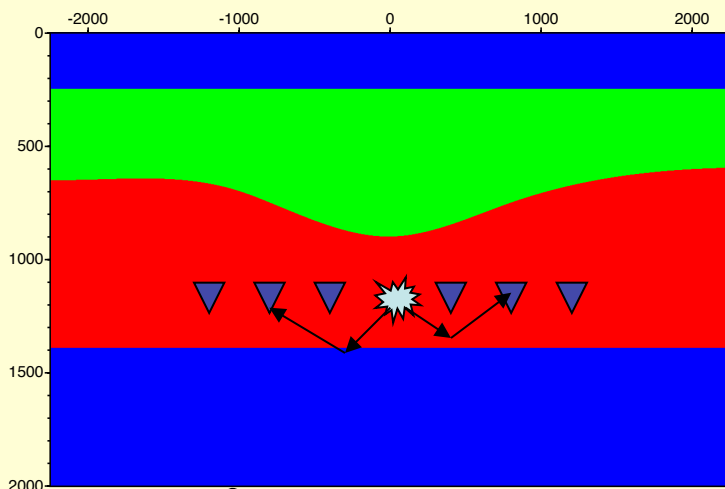
$$G^{-}(\mathbf{x}, \mathbf{x}_S, t) * s(t)$$



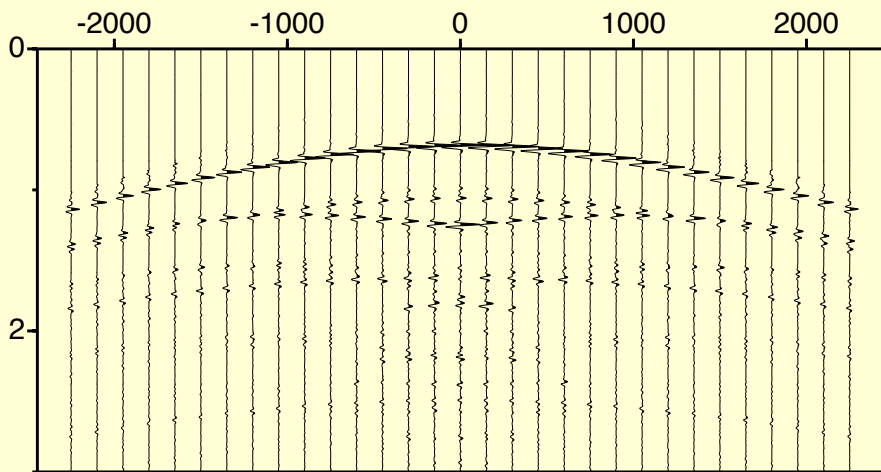
$$G^{+}(\mathbf{x}, \mathbf{x}_S, t) * s(t)$$



$$G^{-}(\mathbf{x}_R, \mathbf{x}_S, t) * s(t) =$$



$$\int R(\mathbf{x}_R, \mathbf{x}', t) * G^{+}(\mathbf{x}', \mathbf{x}_S, t) * s(t) d\mathbf{x}'$$

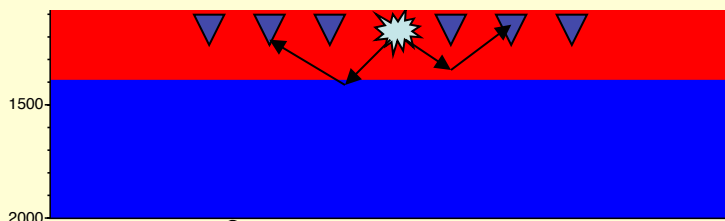


Resolve

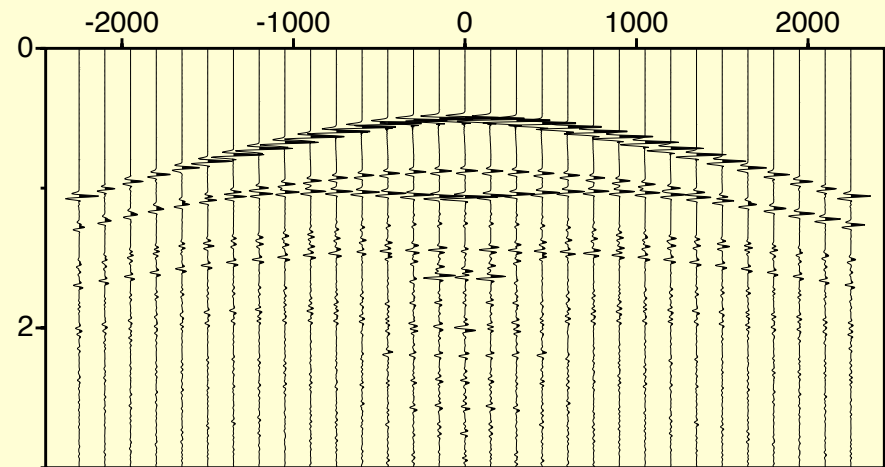
$$R(\mathbf{x}_R, \mathbf{x}', t)$$

by MDD, etc.....

$$G^-(\mathbf{x}_R, \mathbf{x}_S, t) * s(t) =$$

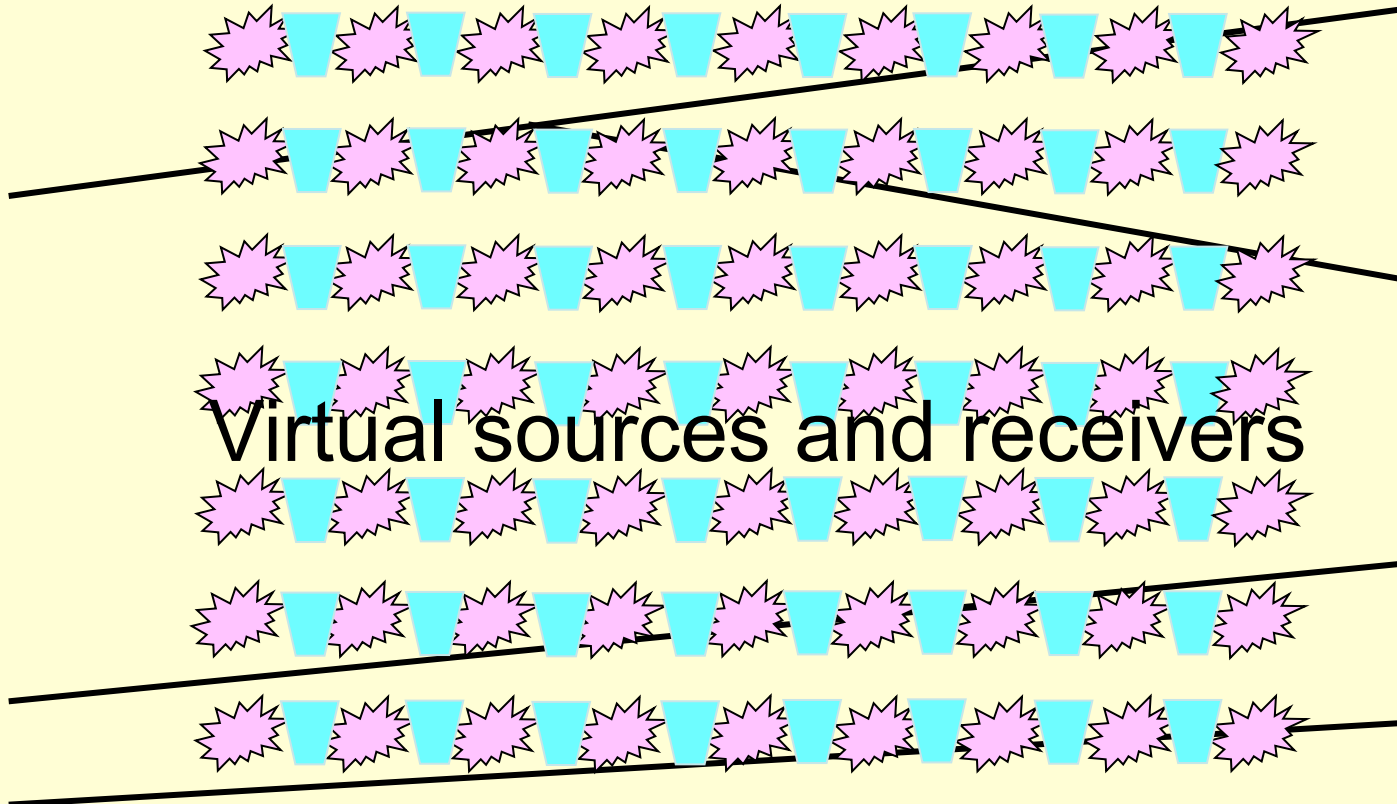
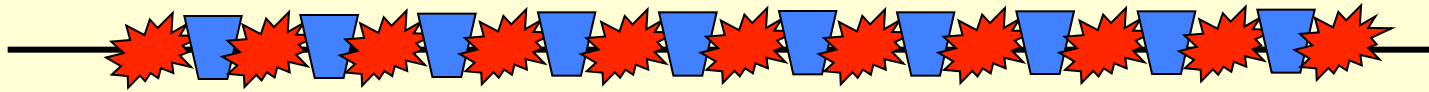


*



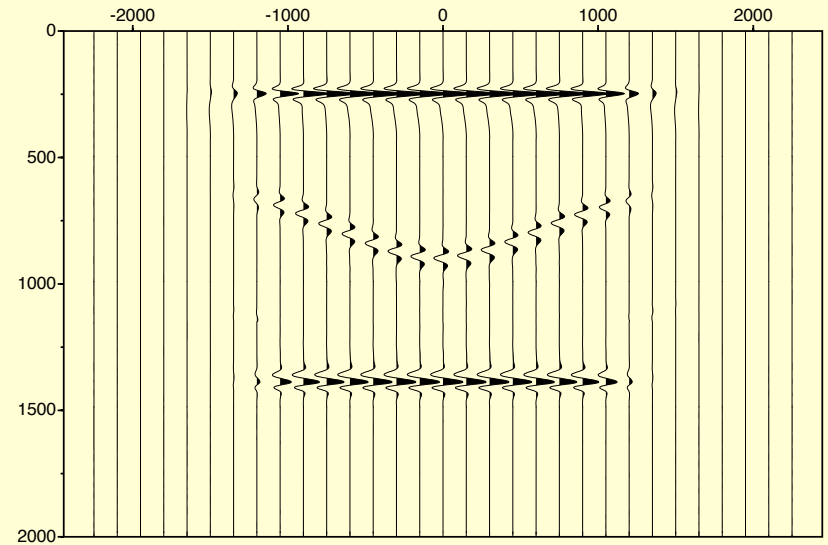
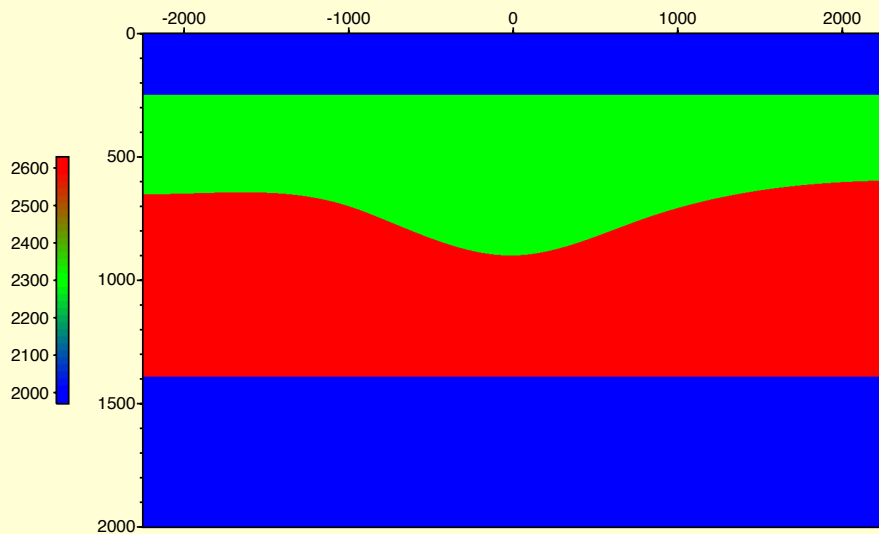
$$\int R(\mathbf{x}_R, \mathbf{x}', t) * G^+(\mathbf{x}', \mathbf{x}_S, t) * s(t) d\mathbf{x}'$$

Sources and receivers

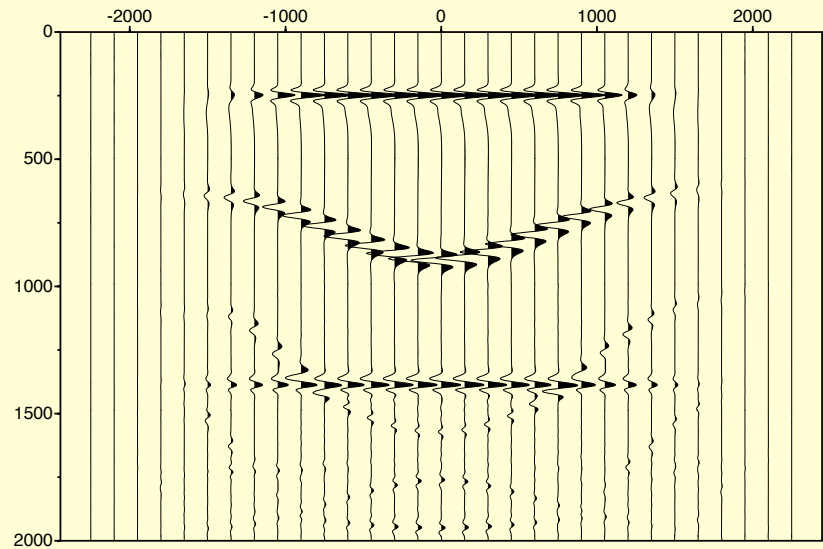
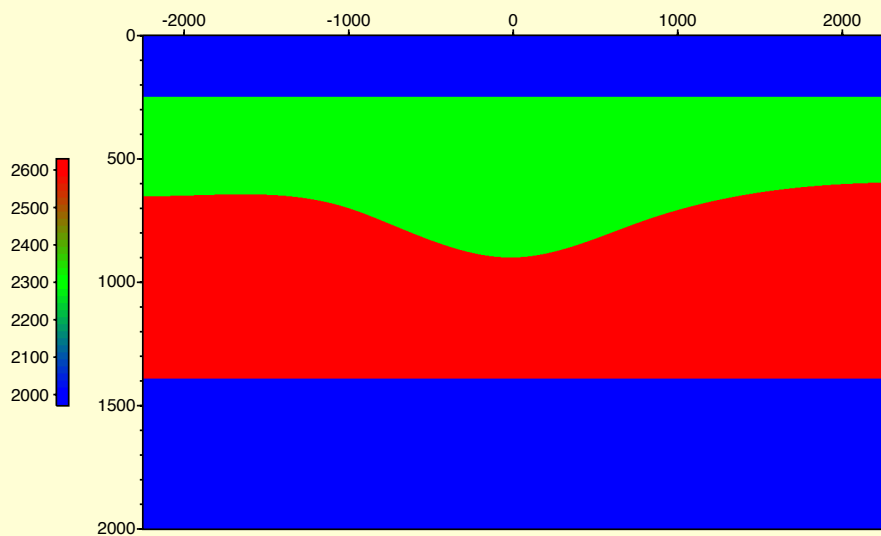


Virtual sources and receivers

Data-driven redatuming



Data-driven redatuming + imaging



Standard imaging

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- **Seismic interferometry:**
 - Creating virtual source responses by crosscorrelating responses at different receivers.
 - The virtual source is located at the position of a receiver.
 - No medium information is required.

Conclusions

- **Seismic interferometry:**
 - Creating virtual source responses by crosscorrelating responses at different receivers.
 - The virtual source is located at the position of a receiver.
 - No medium information is required.
- **Beyond seismic interferometry:**
 - The virtual source can be positioned anywhere (no physical receivers required at virtual source position).
 - No detailed medium information required (a macro model suffices).
 - Leads to new imaging method, accounting for internal multiples.