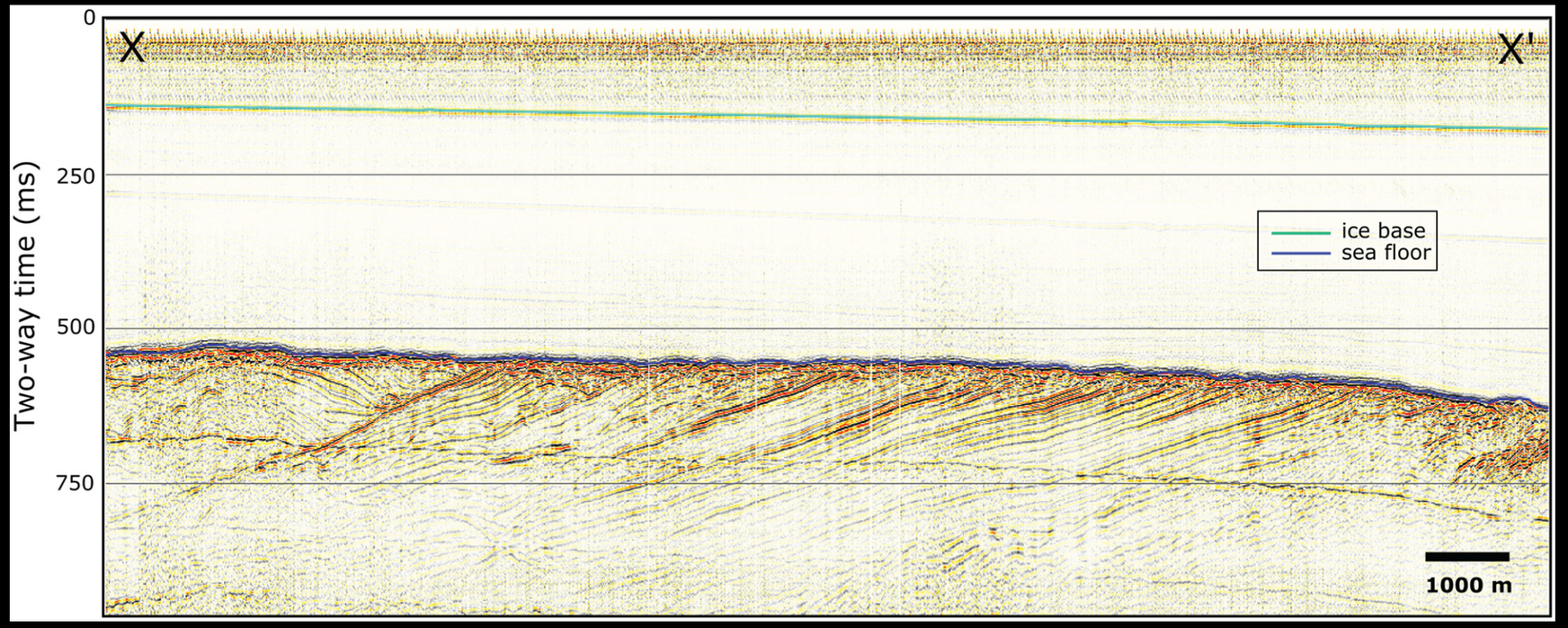
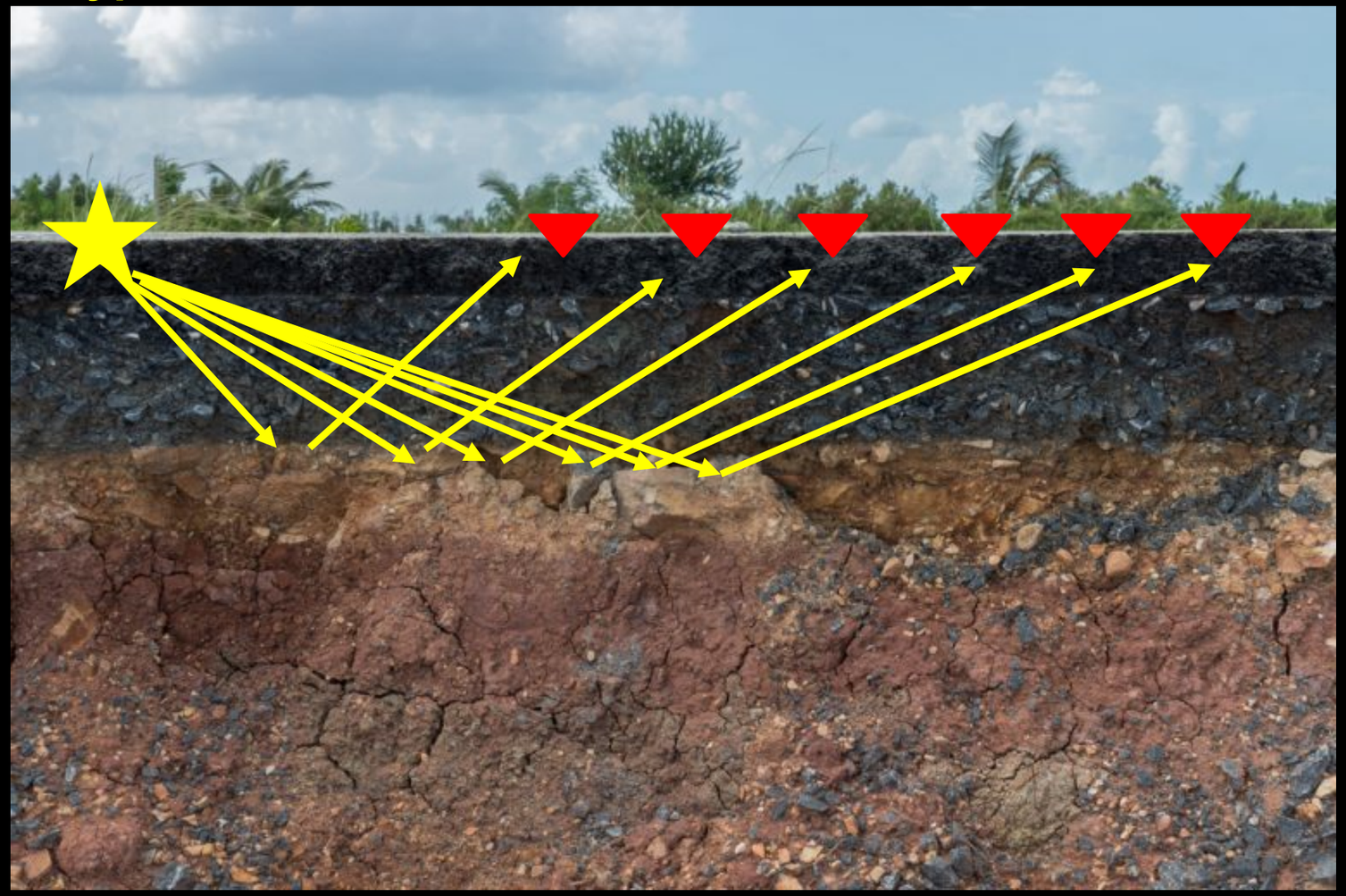
- Principles of Reflection Seismics
- Interval Velocities
- Basic (very basic) imaging principles

Smith et al., GRL, 2020

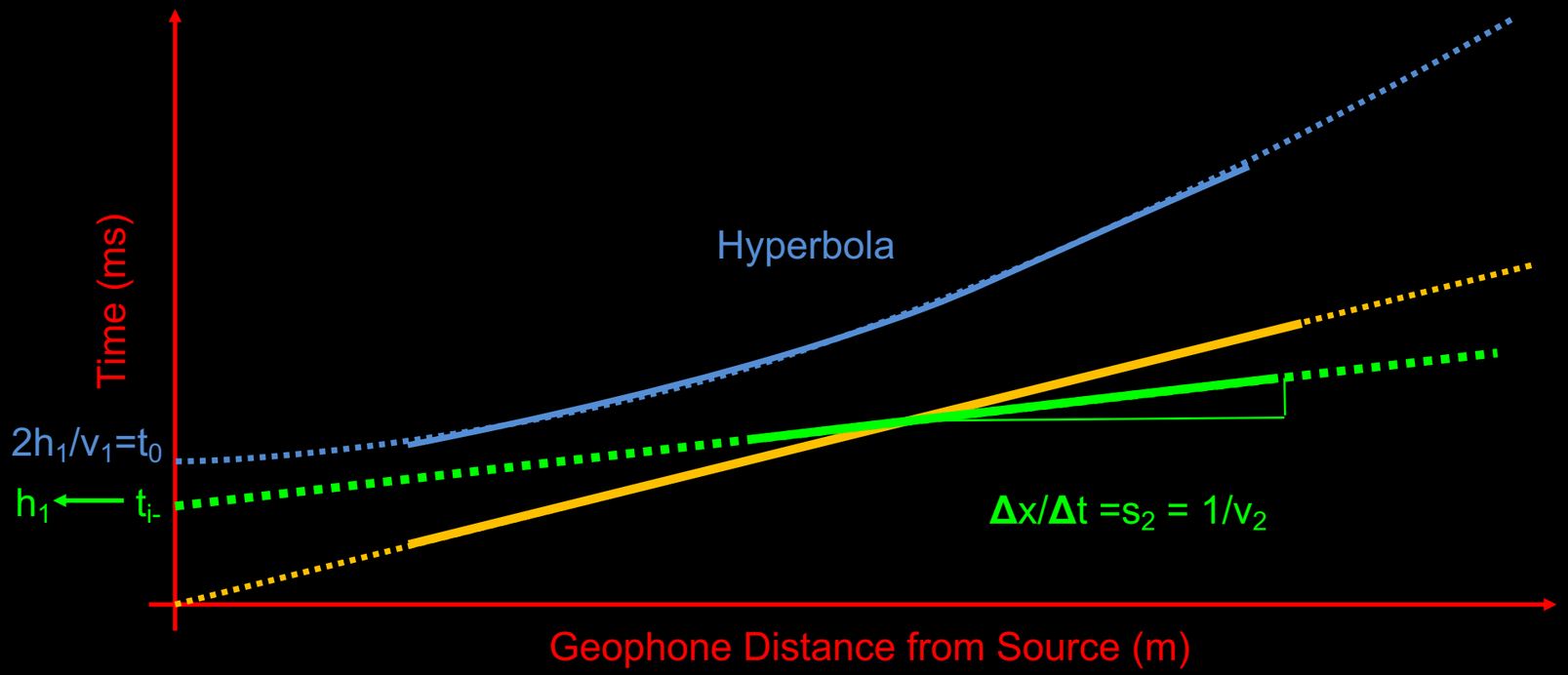


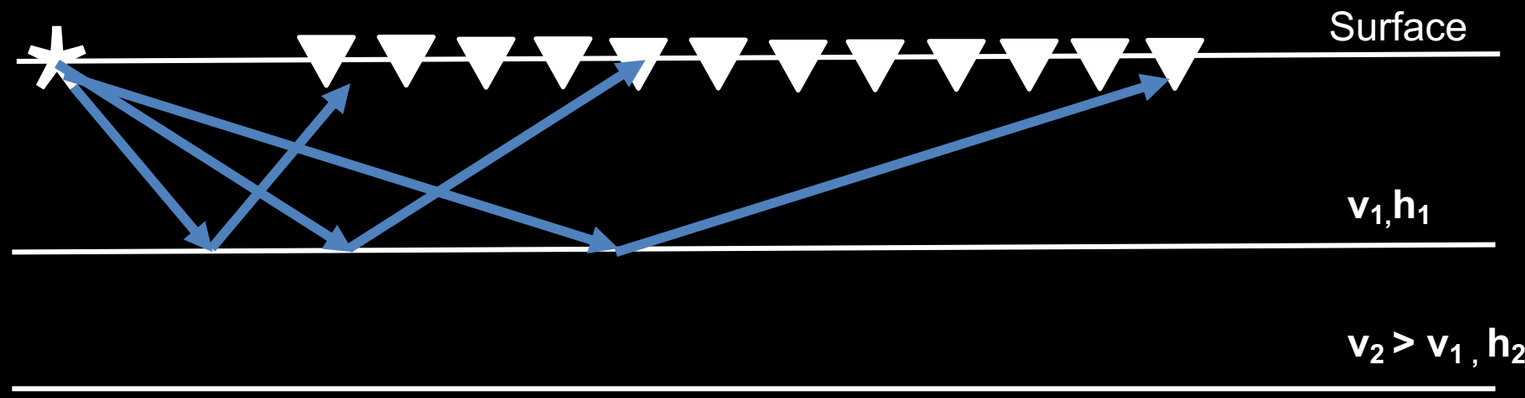
- Refraction seismics doesn’t “image” the subsurface per se. It would be very hard, e.g., to find point targets etc.
- Reflection seismics can do this for you, but it takes a number of processing steps which can be delicate at times.
- We will try to get a peak into what is done.

Raypath for reflections

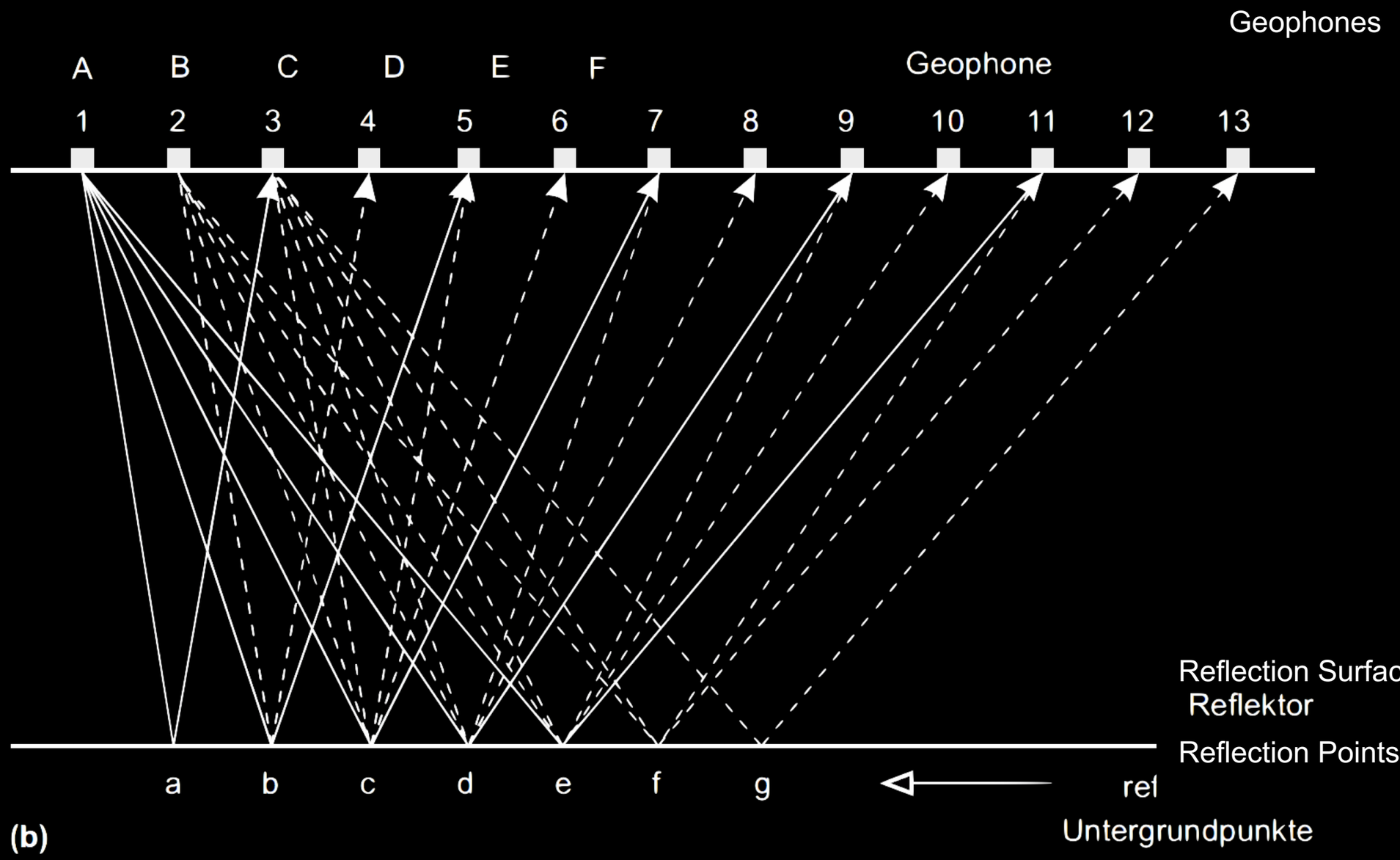


Credit:Rory Arnold (EarthWork.com)

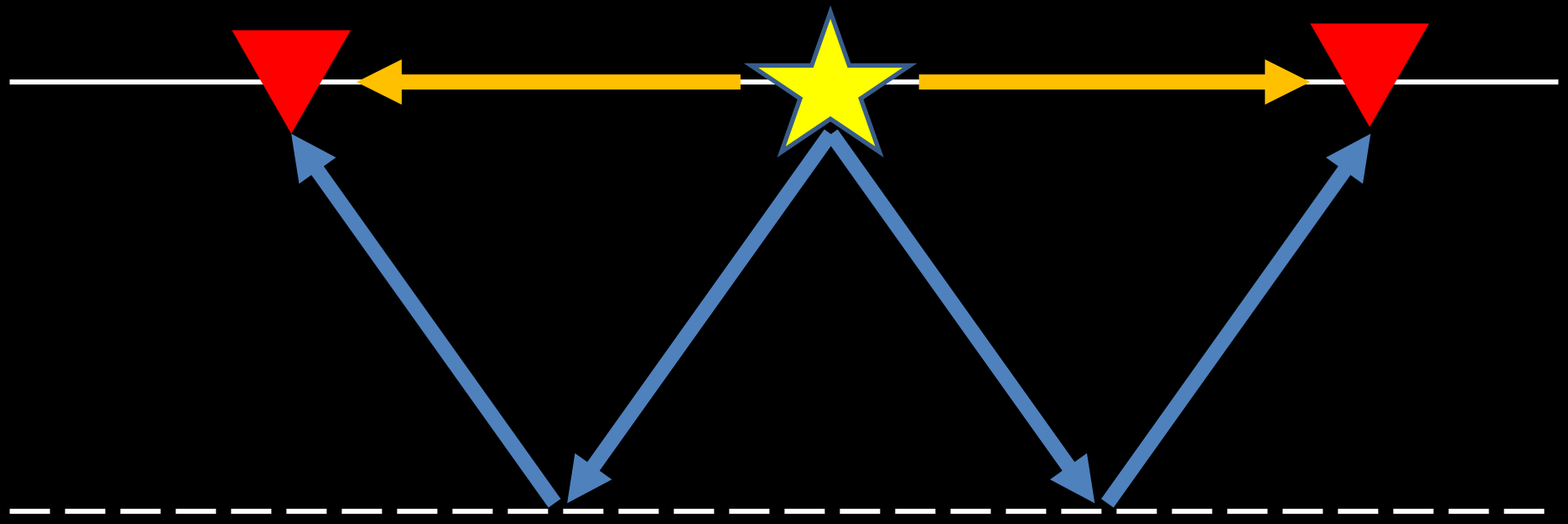

Time (ms)
Hyperbola
$2h_1/v_1=t_0$
$h_1 \leftarrow t_{i-}$
$\Delta x/\Delta t = s_2 = 1/v_2$
Geophone Distance from Source (m)

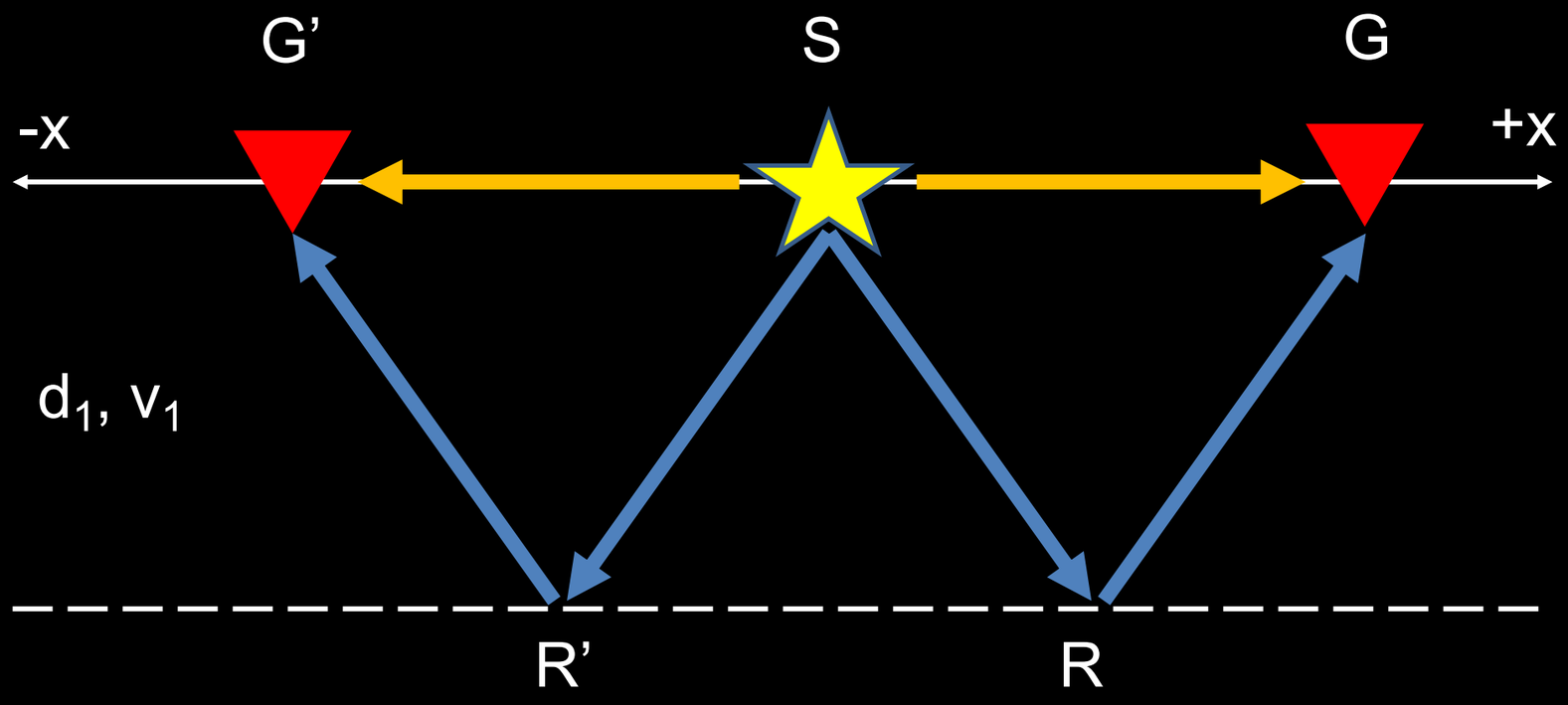

Surface
v_1, h_1
$v_2 > v_1, h_2$

Reflection geometries for multiple shots



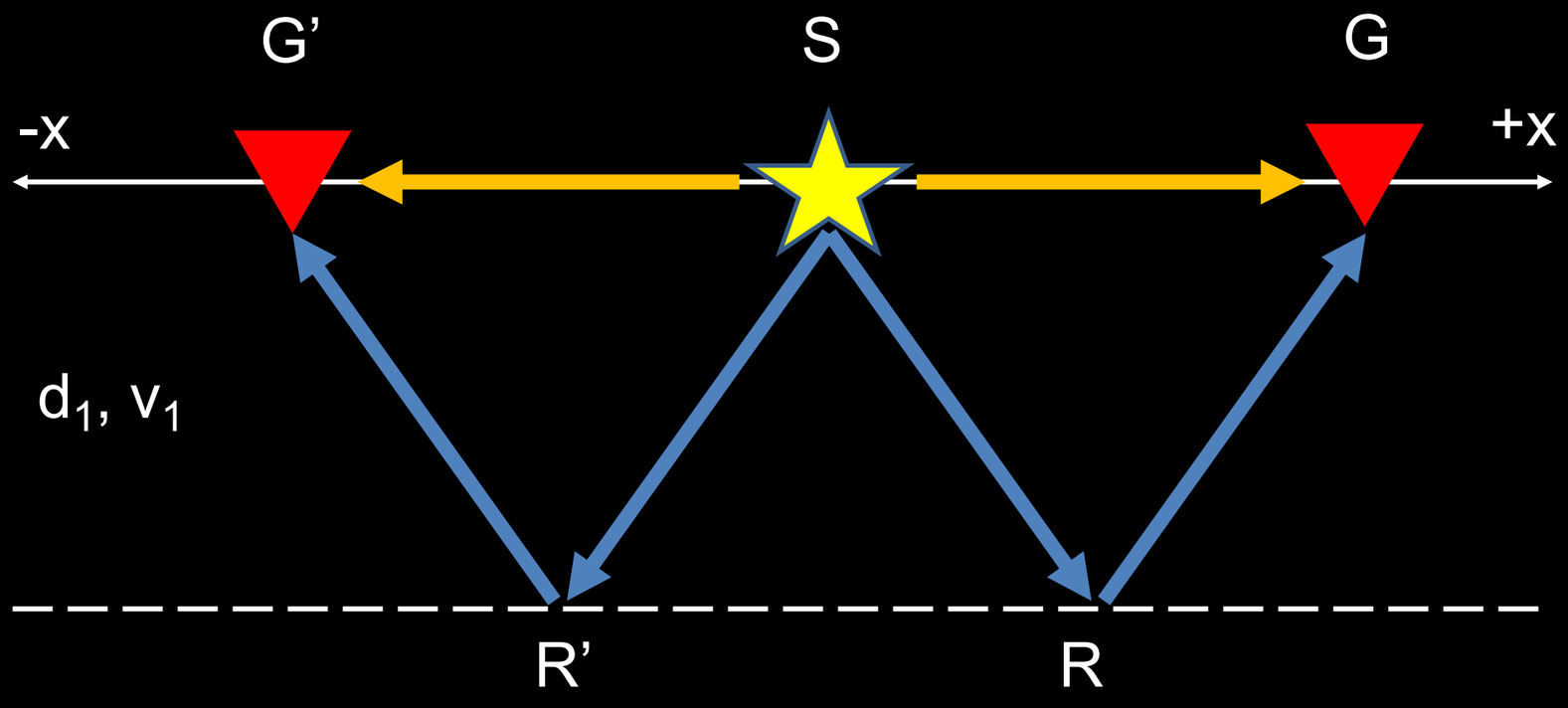
- What are expected signatures in a single shot gather?
- What is the traveltime of reflections?

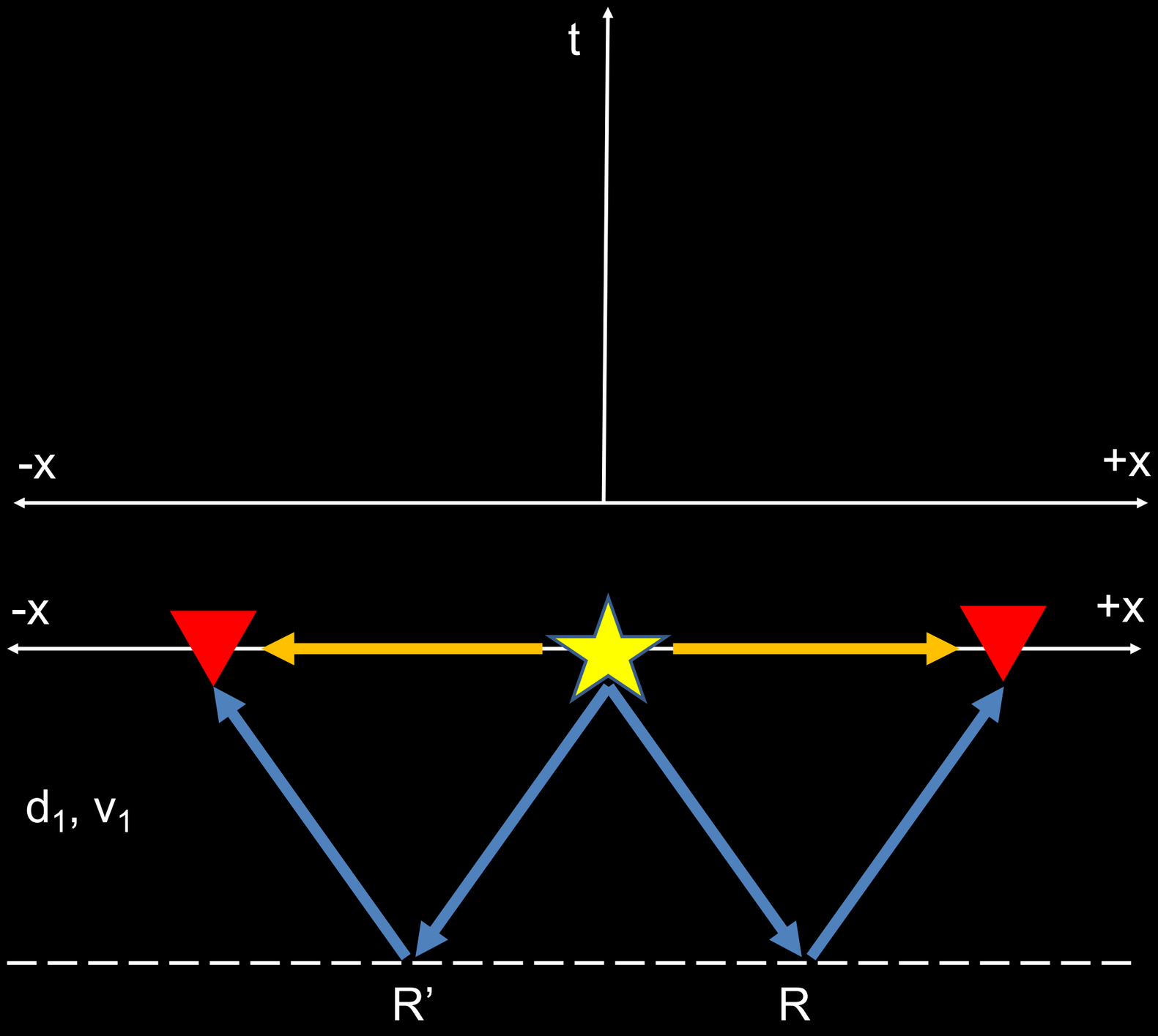



G'
S
G
-x
+x
d_1, v_1
R'
R

$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

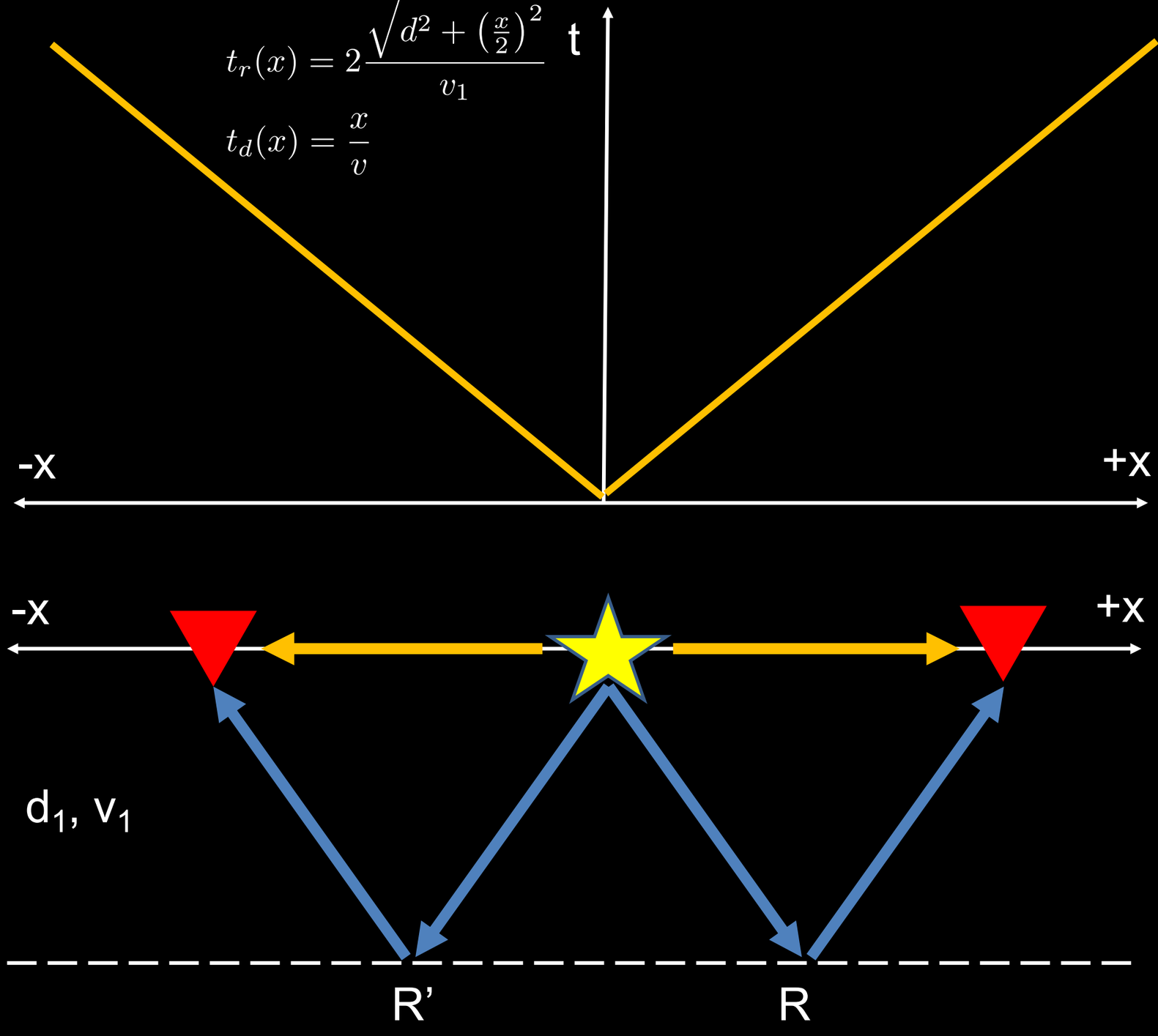
$$t_d(x) = \frac{x}{v}$$




t
-x
+x
-x
+x
d_1, v_1
R'
R

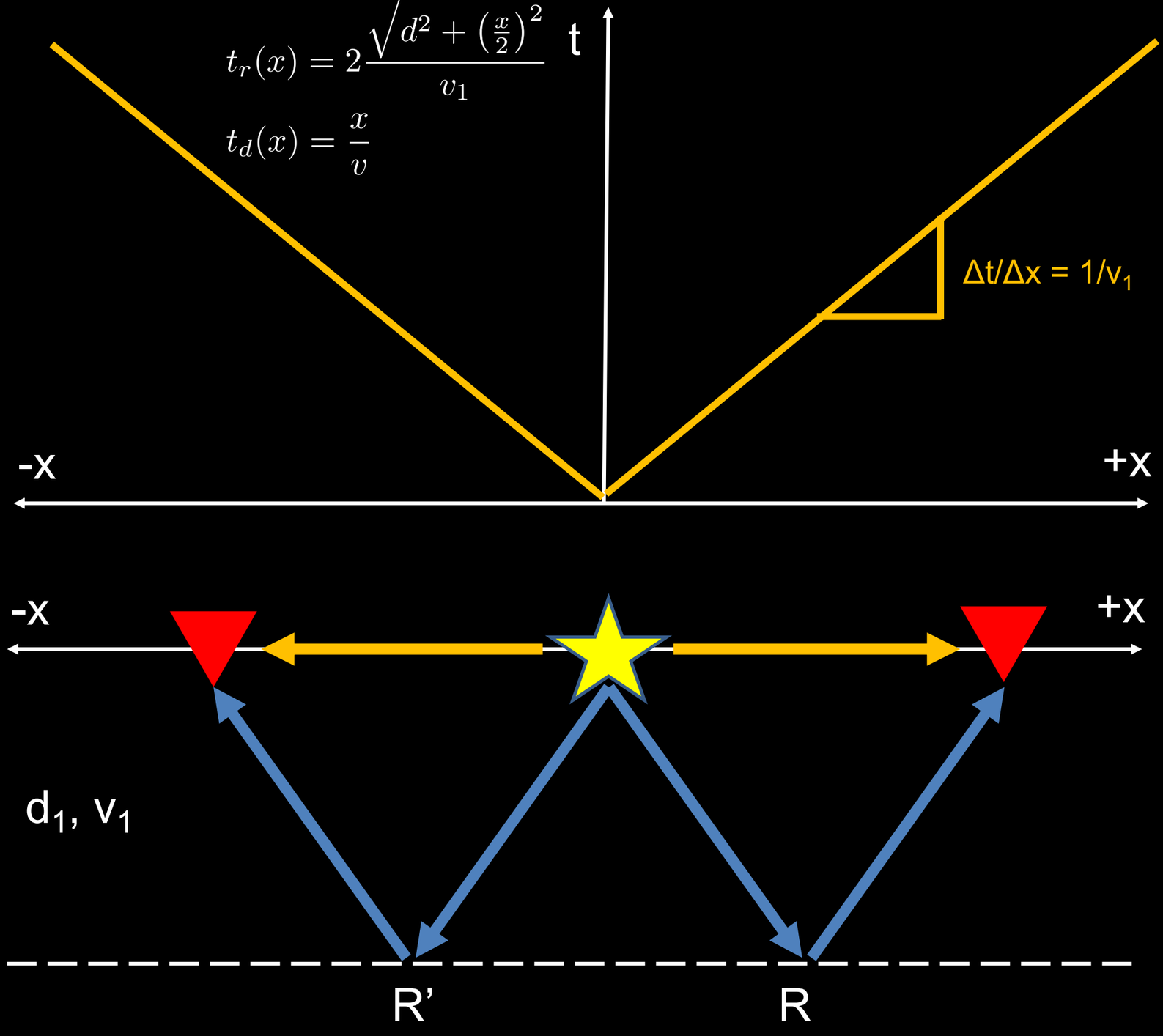
$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

$$t_d(x) = \frac{x}{v}$$



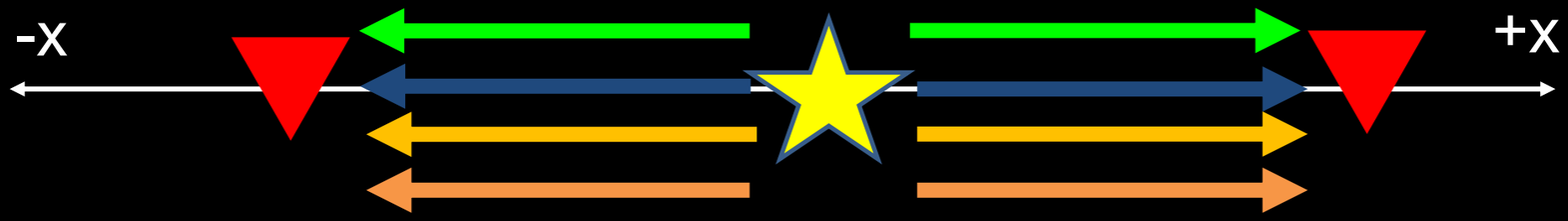
$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

$$t_d(x) = \frac{x}{v}$$



Direct Waves

Direct Air Wave
Direct Surface Wave (at boundary)
Direct s-wave (in body)
Direct p wave (in body)



d_1, v_1

R’ R

Direct Waves

Slow

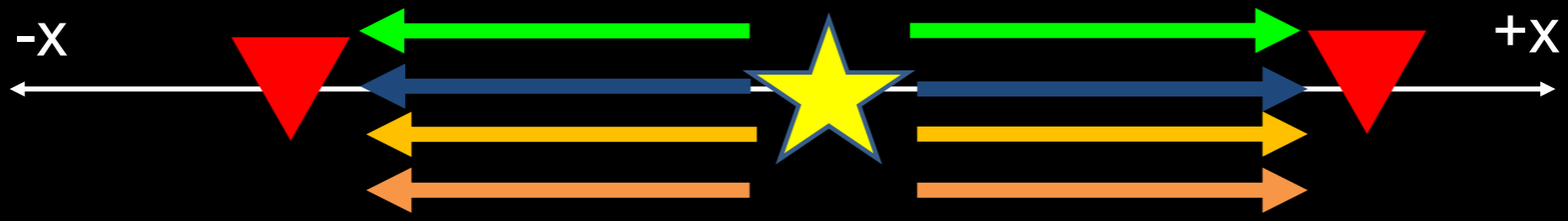
Fast

Direct Air Wave

Direct Surface Wave (at boundary)

Direct s-wave (in body)

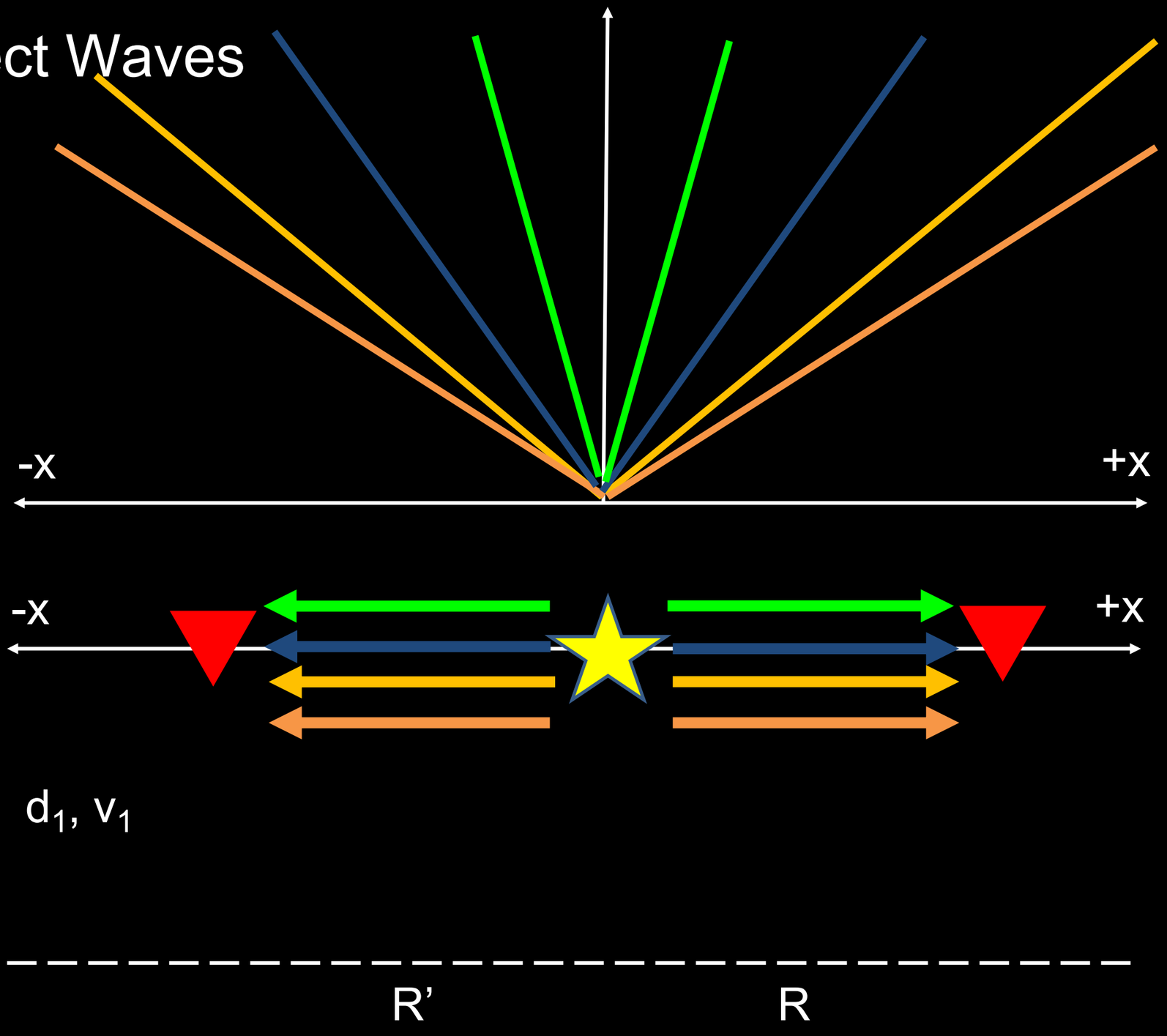
Direct p wave (in body)



d_1, v_1

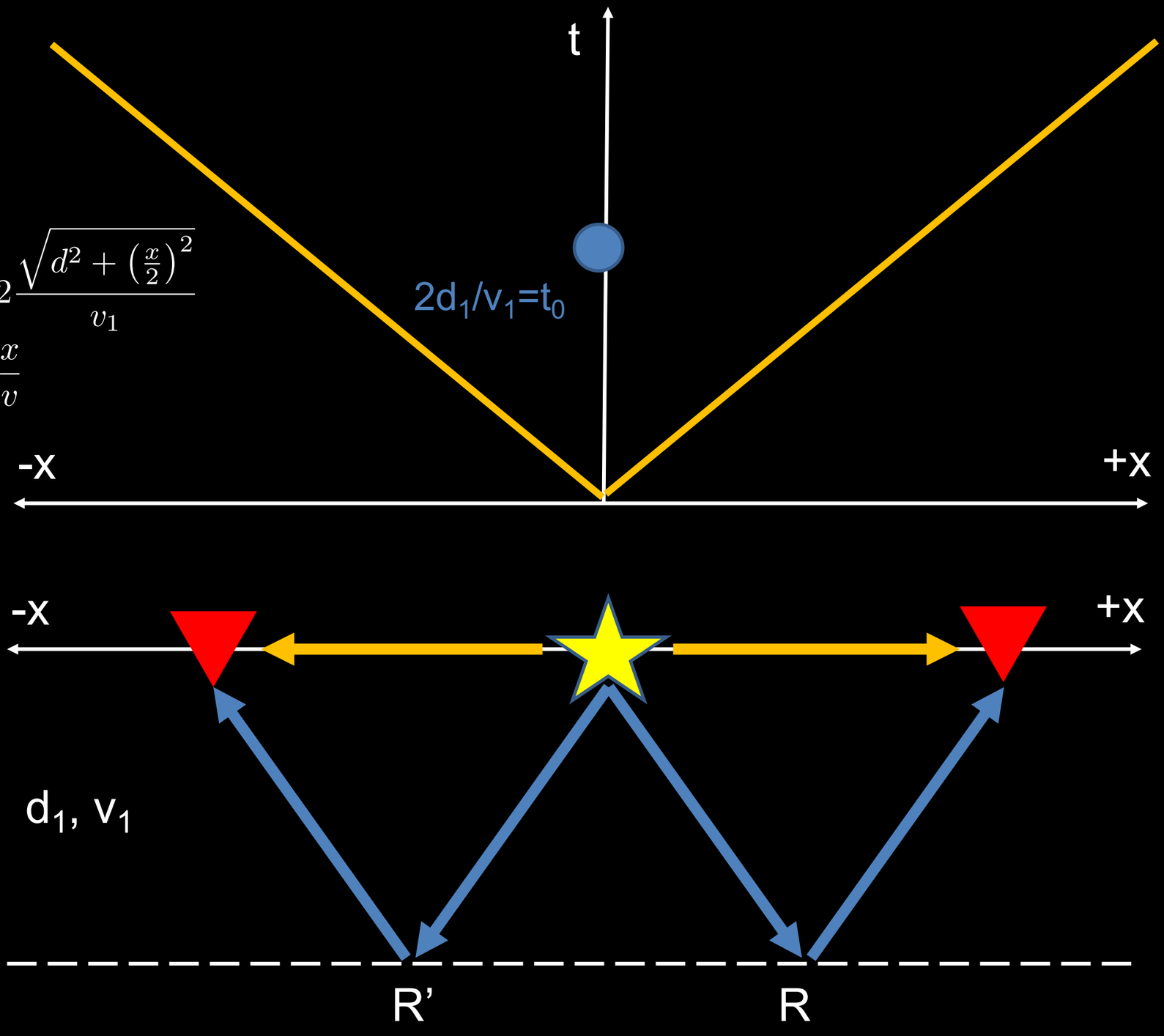
R’ R

Direct Waves



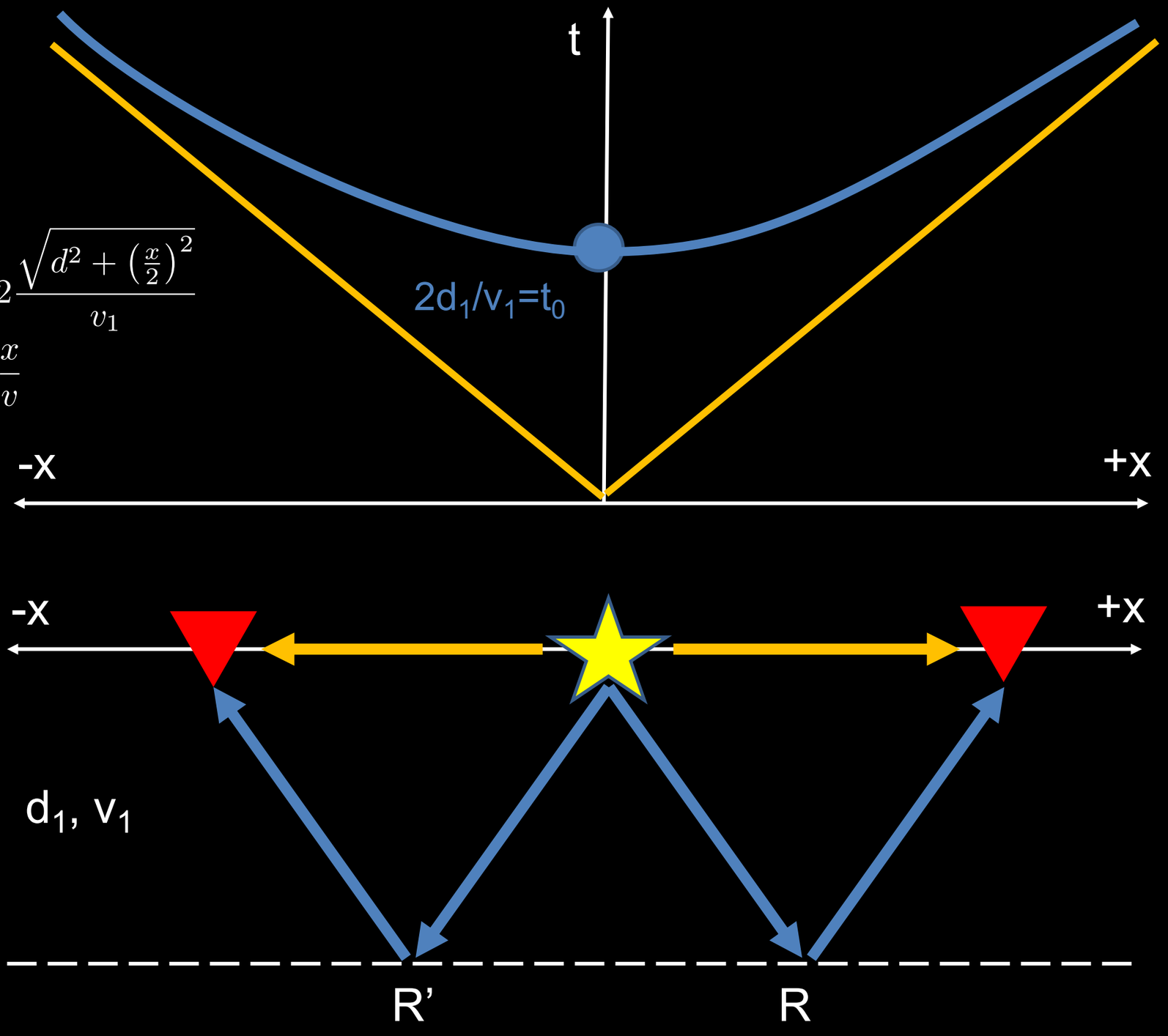
$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

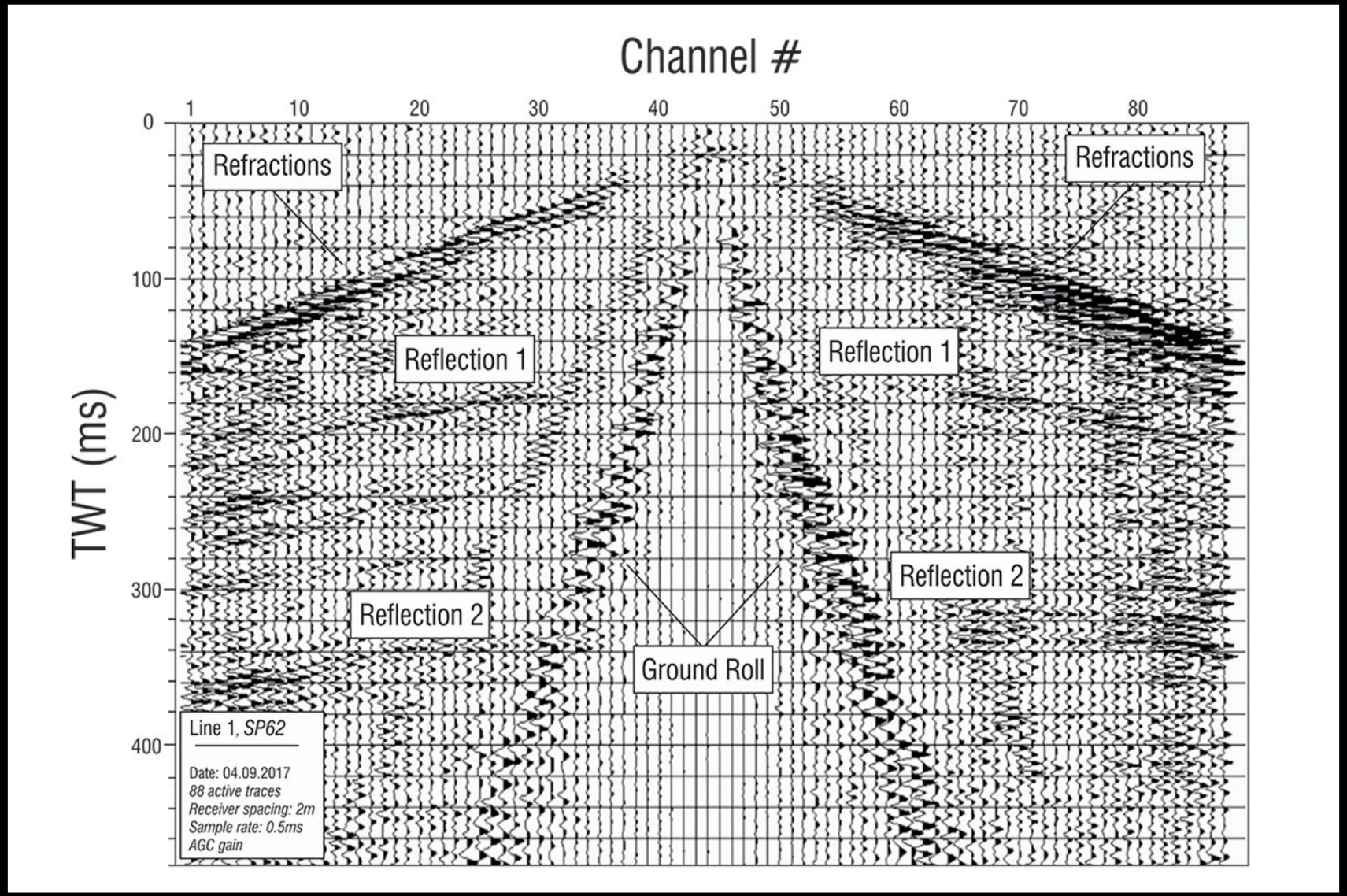
$$t_d(x) = \frac{x}{v}$$



$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

$$t_d(x) = \frac{x}{v}$$

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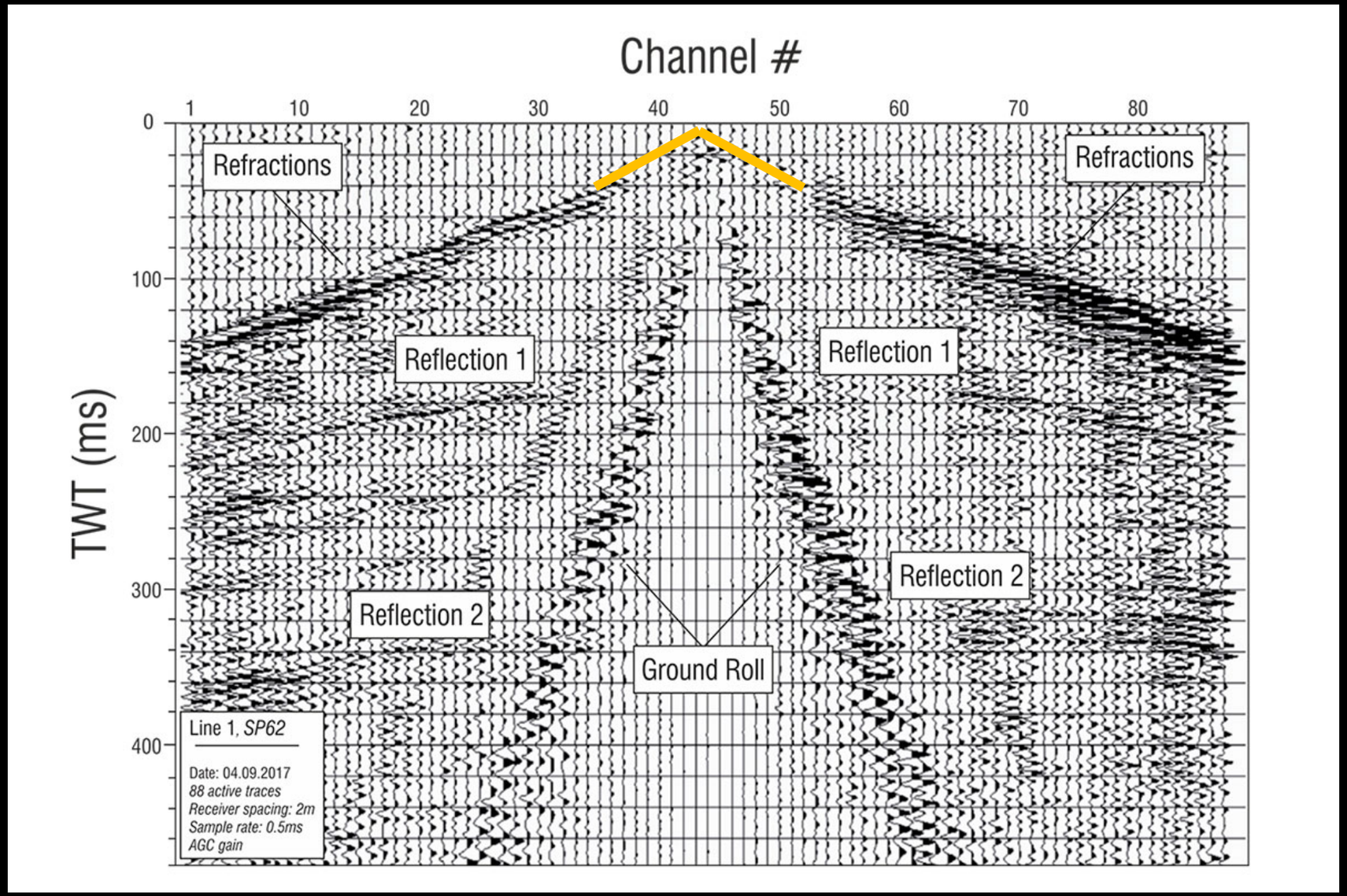
TWT (ms)
Refractions
Refractions
Reflection 1
Reflection 1
Reflection 2
Reflection 2
Ground Roll
Line 1, SP62
Date: 04.09.2017
88 active traces
Receiver spacing: 2m
Sample rate: 0.5ms
AGC gain


Direct p (body)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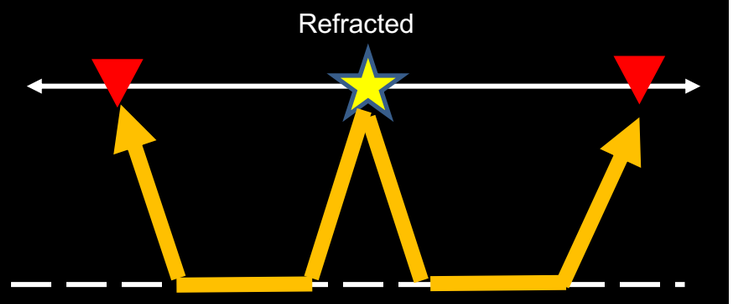
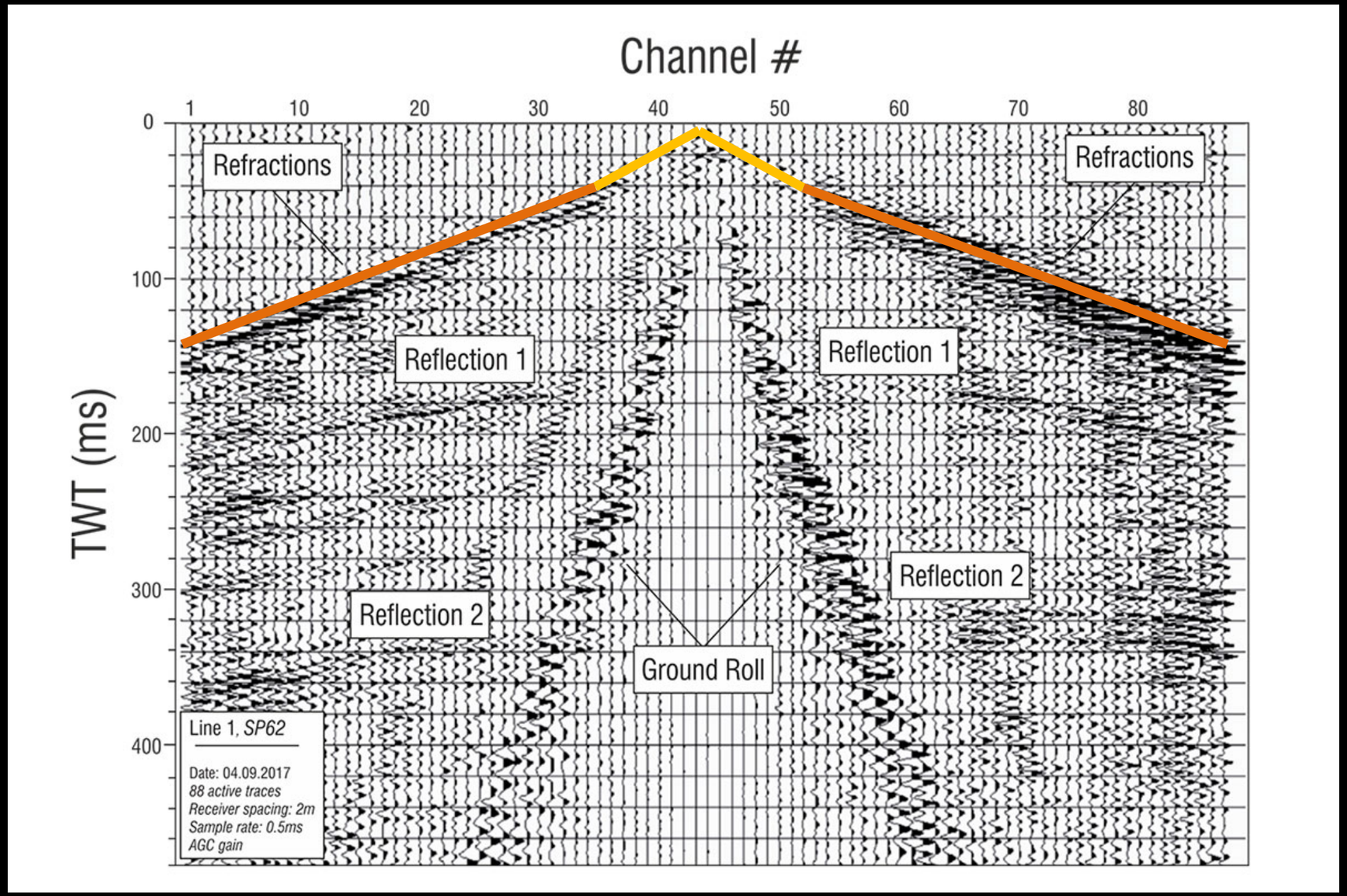

Refracted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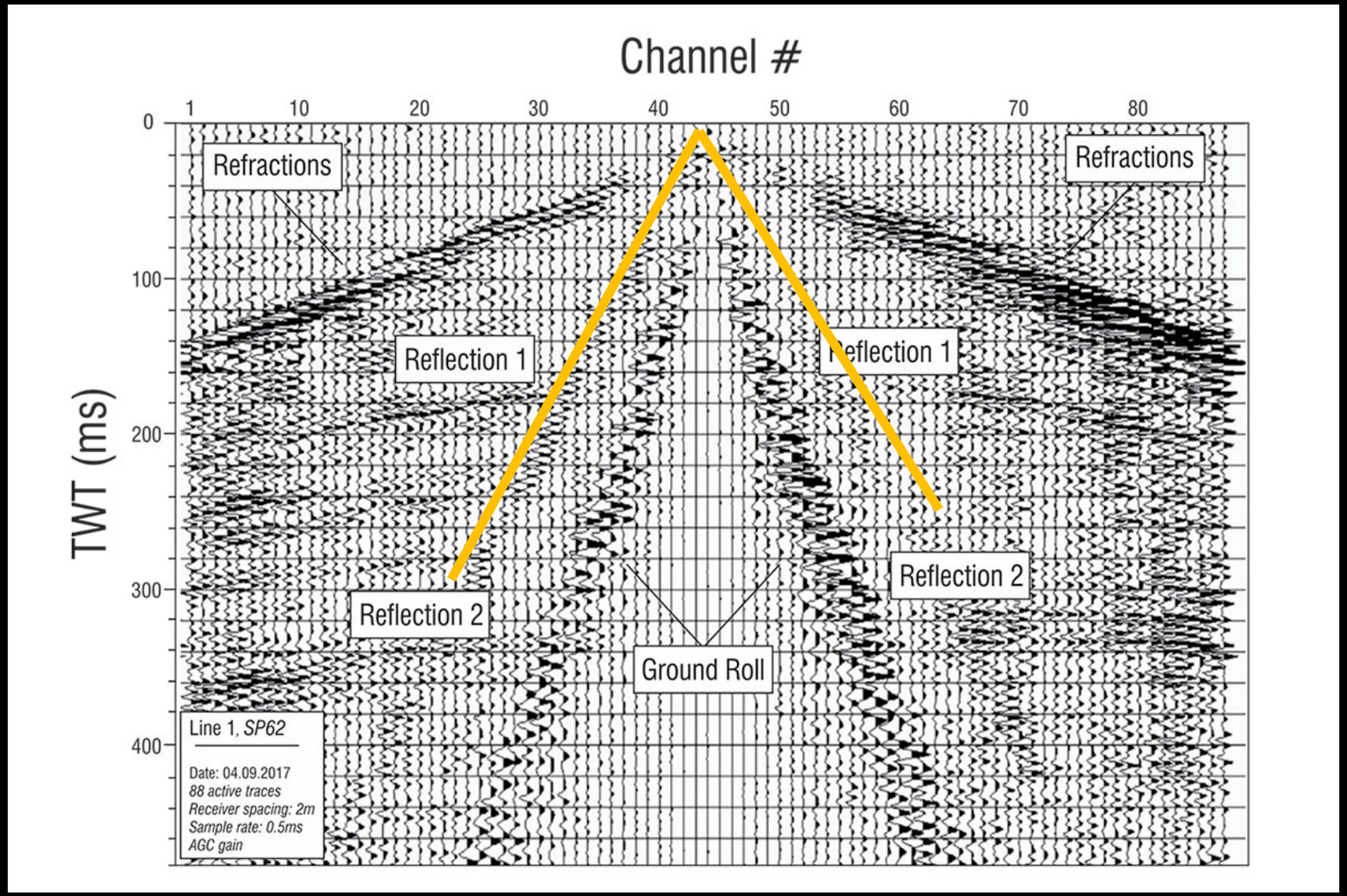
Direct s (body)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Reflection 2
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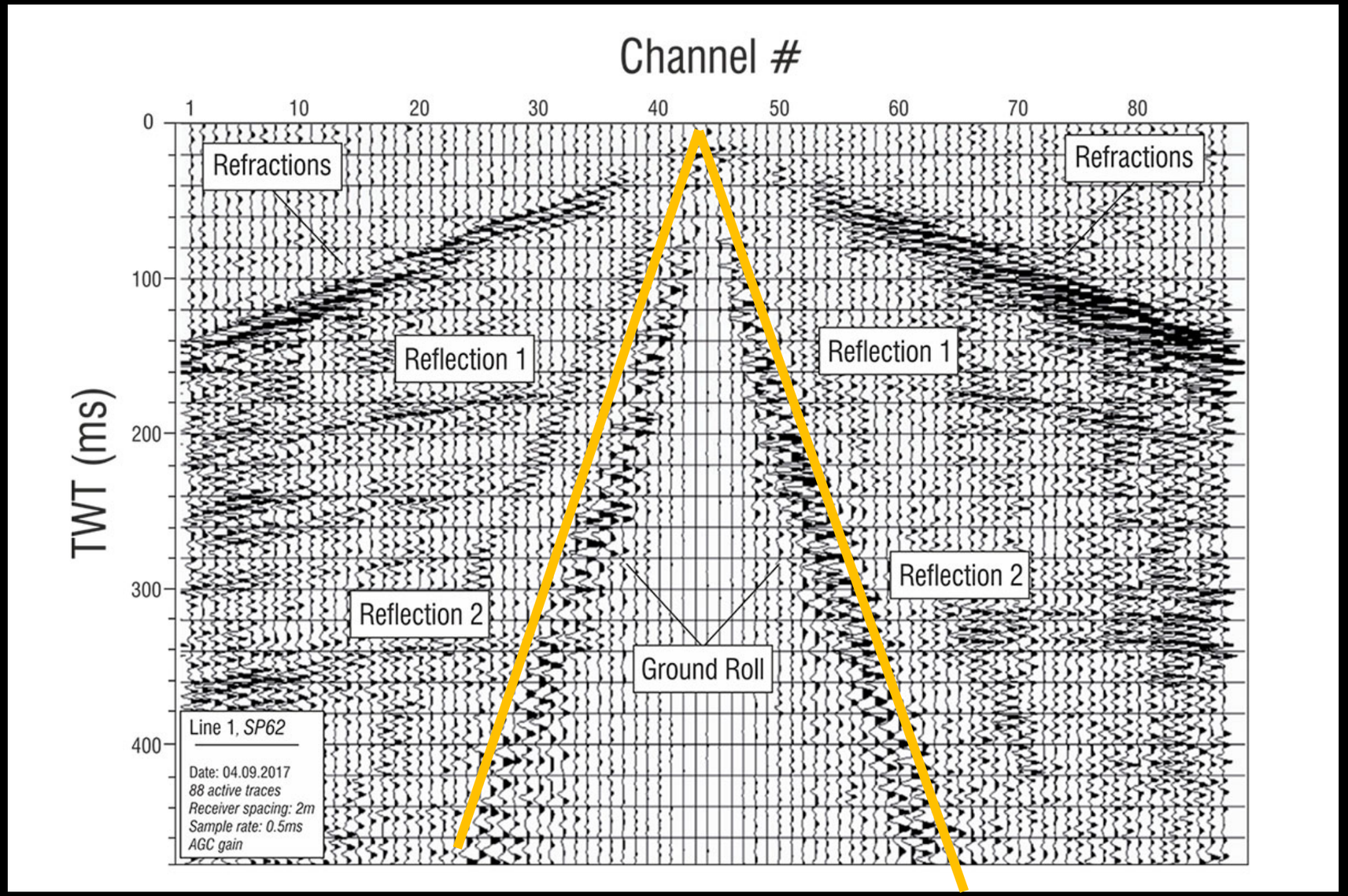
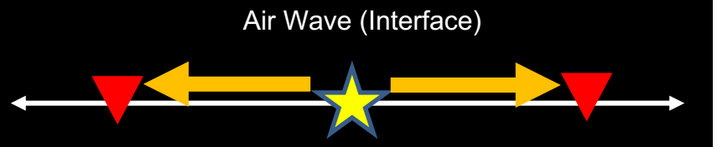
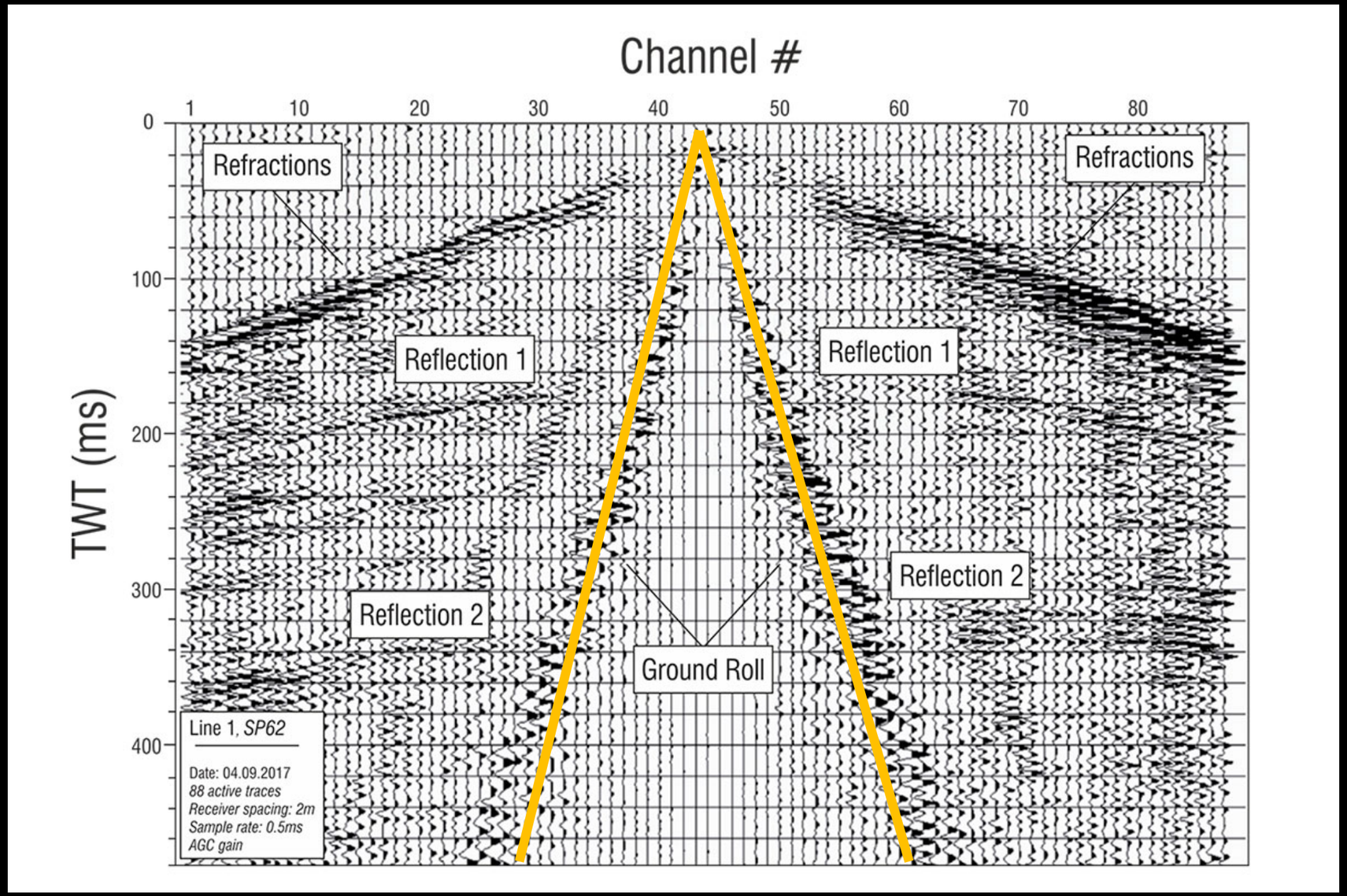
Surface Wave (Interface)




Air Wave (Interface)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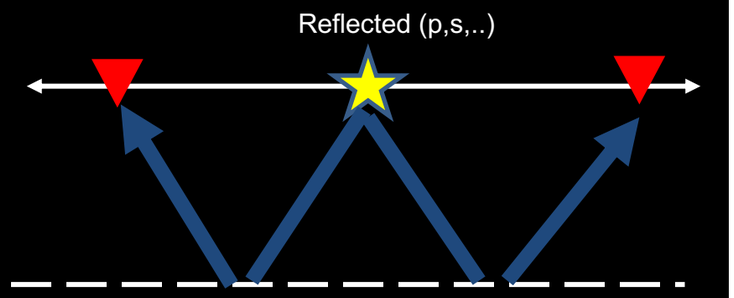
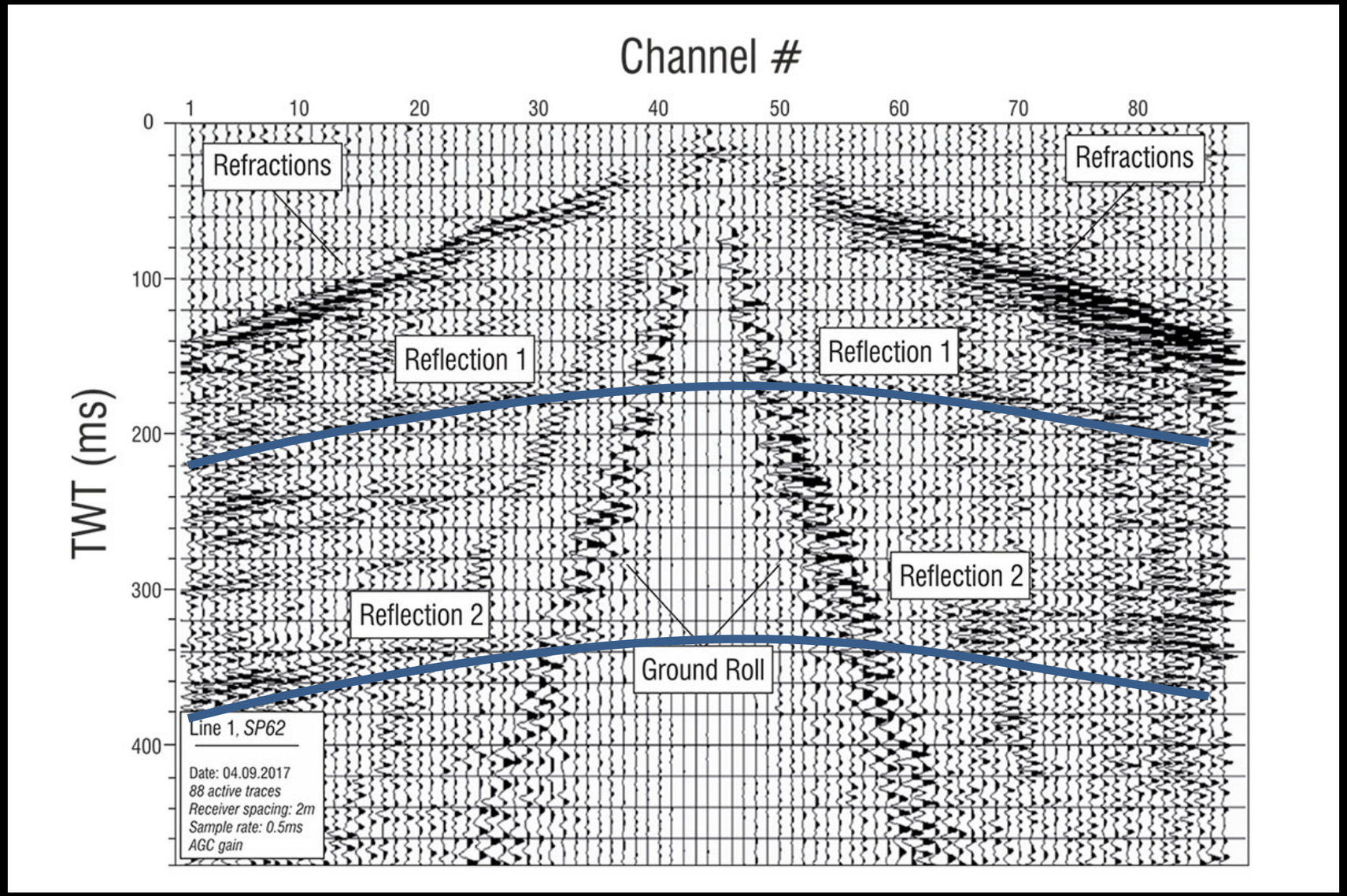

Reflected (p,s,..)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AGC gain

t^{2--} x^2 method

- How to determine velocities from a shot gather ?
- How to most efficiently combine different shot gathers ?

t^{2--} x^2 method

$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

t^{2}-- x^{2} method

$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

$$t_r(x)^2 = \frac{4}{v_1^2}(d^2 + \frac{x^2}{4})$$

Alternatively: t^2-x^2 method

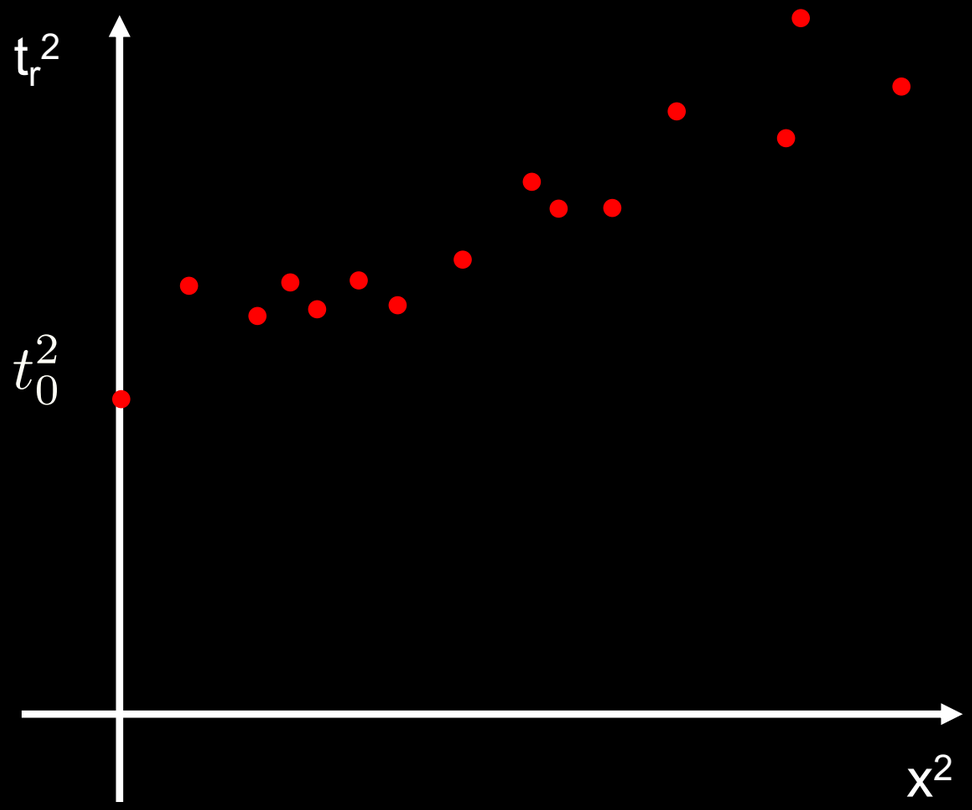
$$t_r(x) = 2\frac{\sqrt{d^2 + \left(\frac{x}{2}\right)^2}}{v_1}$$

$$t_r(x)^2 = \frac{4}{v_1^2}(d^2 + \frac{x^2}{4})$$

$$= \frac{1}{v_1^2}x^2 + t_0^2$$

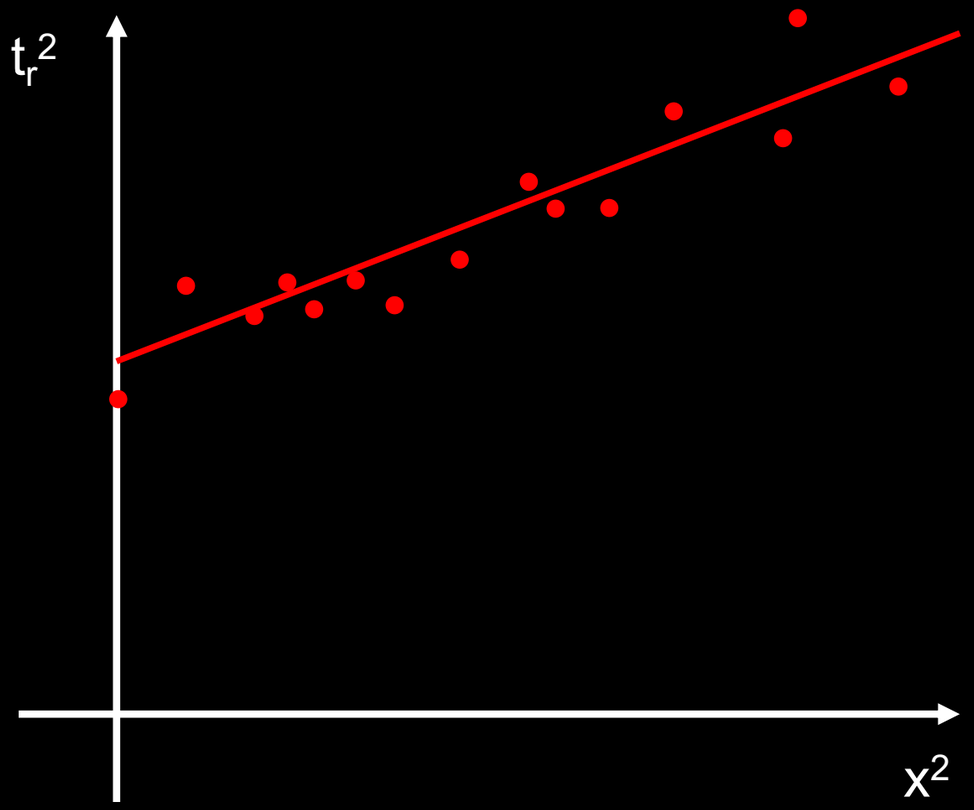
t^{2--} x^2 method

$$t_r(x)^2 = \frac{1}{v_1^2}x^2 + t_0^2$$



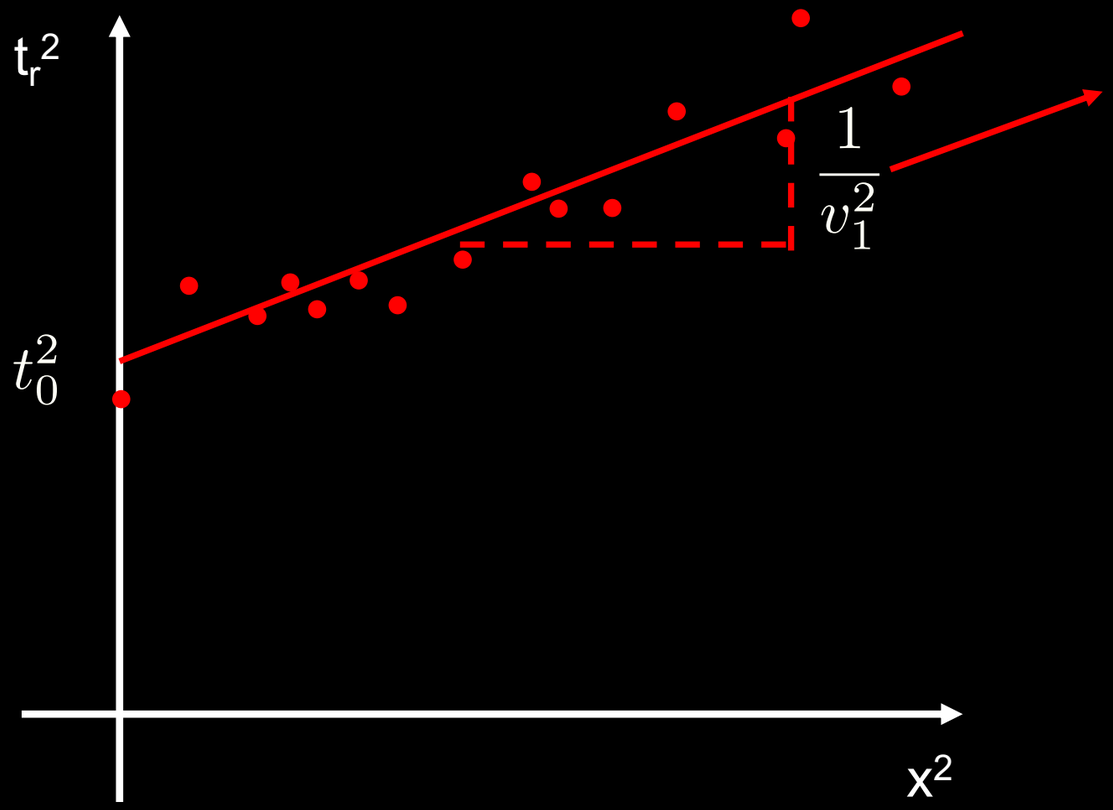
t^{2--} x^2 method

$$t_r(x)^2 = \frac{1}{v_1^2}x^2 + t_0^2$$

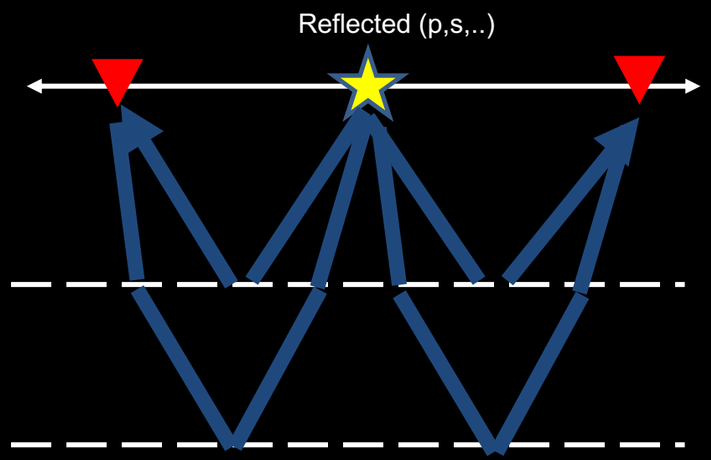


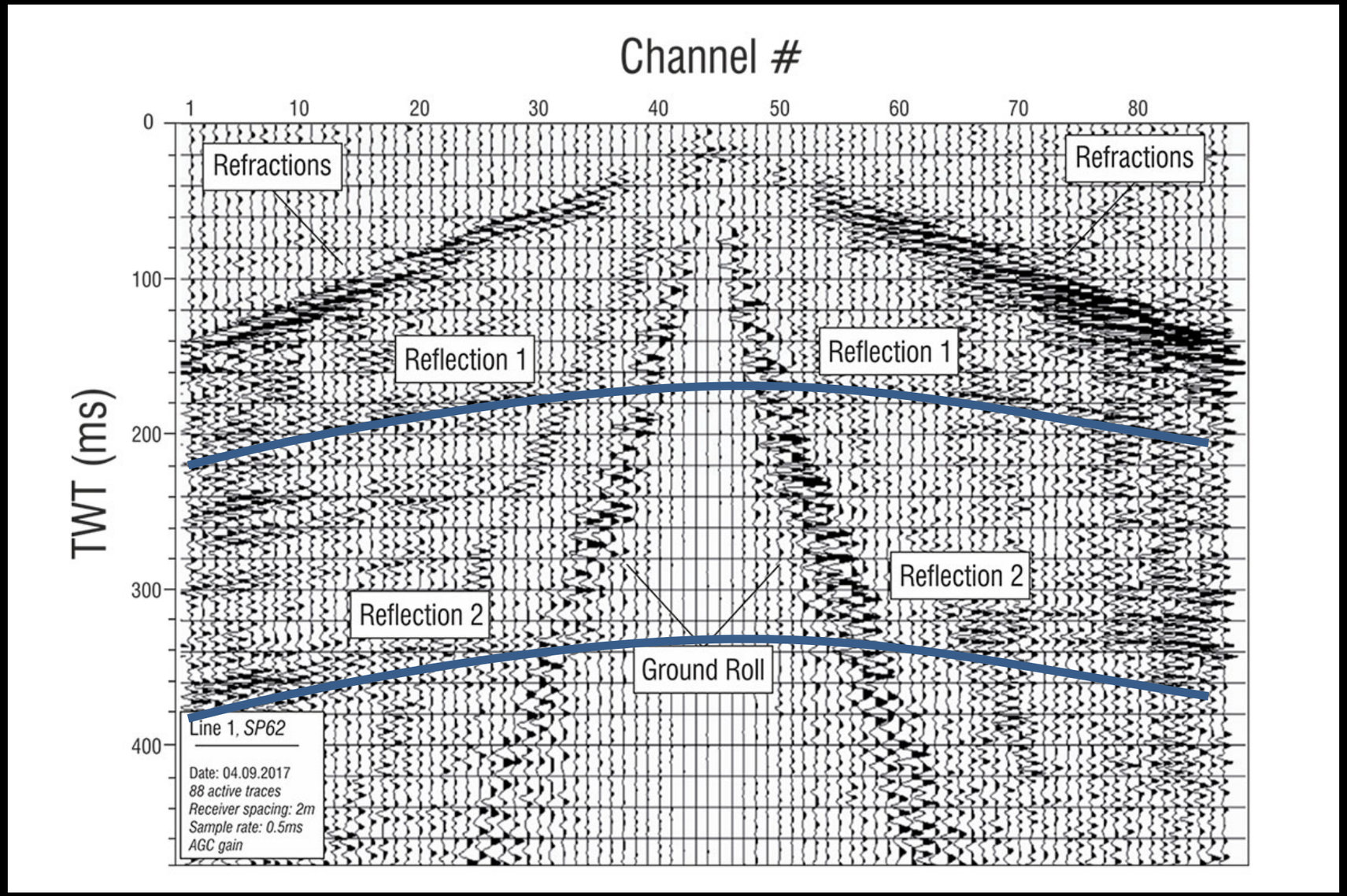
t^{2--} x^2 method

$$t_r(x)^2 = \frac{1}{v_1^2}x^2 + t_0^2$$



- What about multiple layers ?


Reflected (p,s,..)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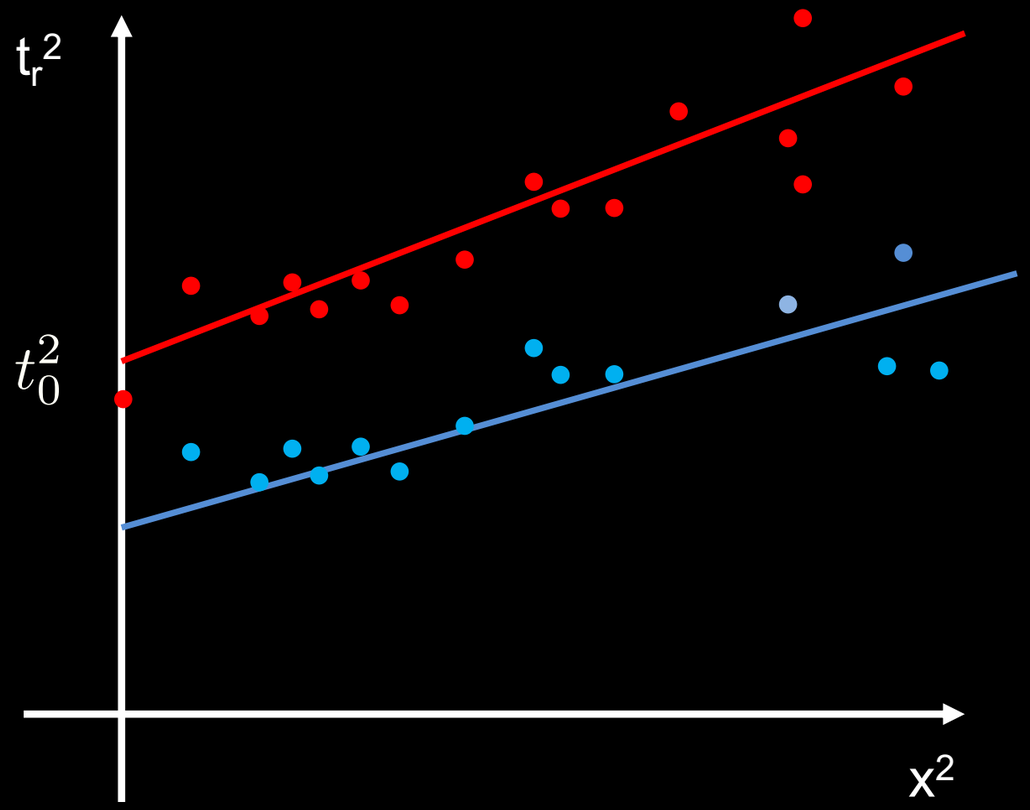
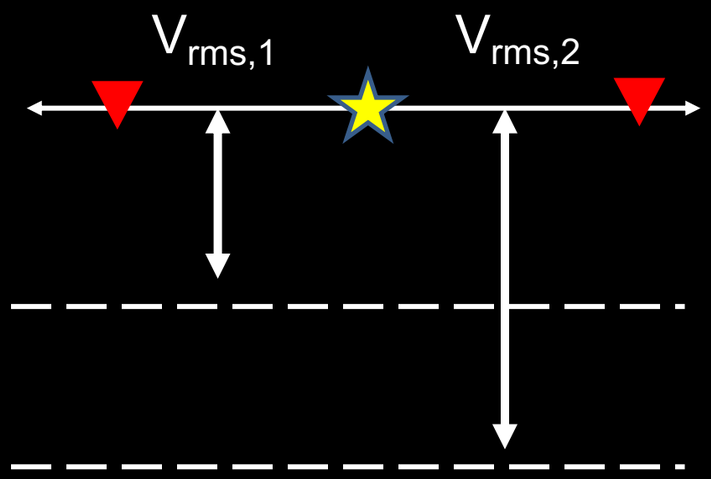
t^{2--} x^2 method

$$t_r(x)^2 = \frac{1}{v_1^2}x^2 + t_0^2$$

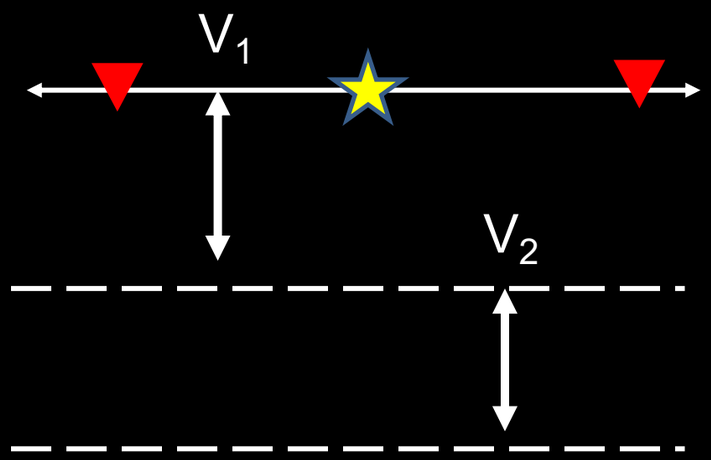


- This works for near-nadir incidence



RMS Velocities

- Methods mentioned above deliver average velocities from the surface to the reflector.



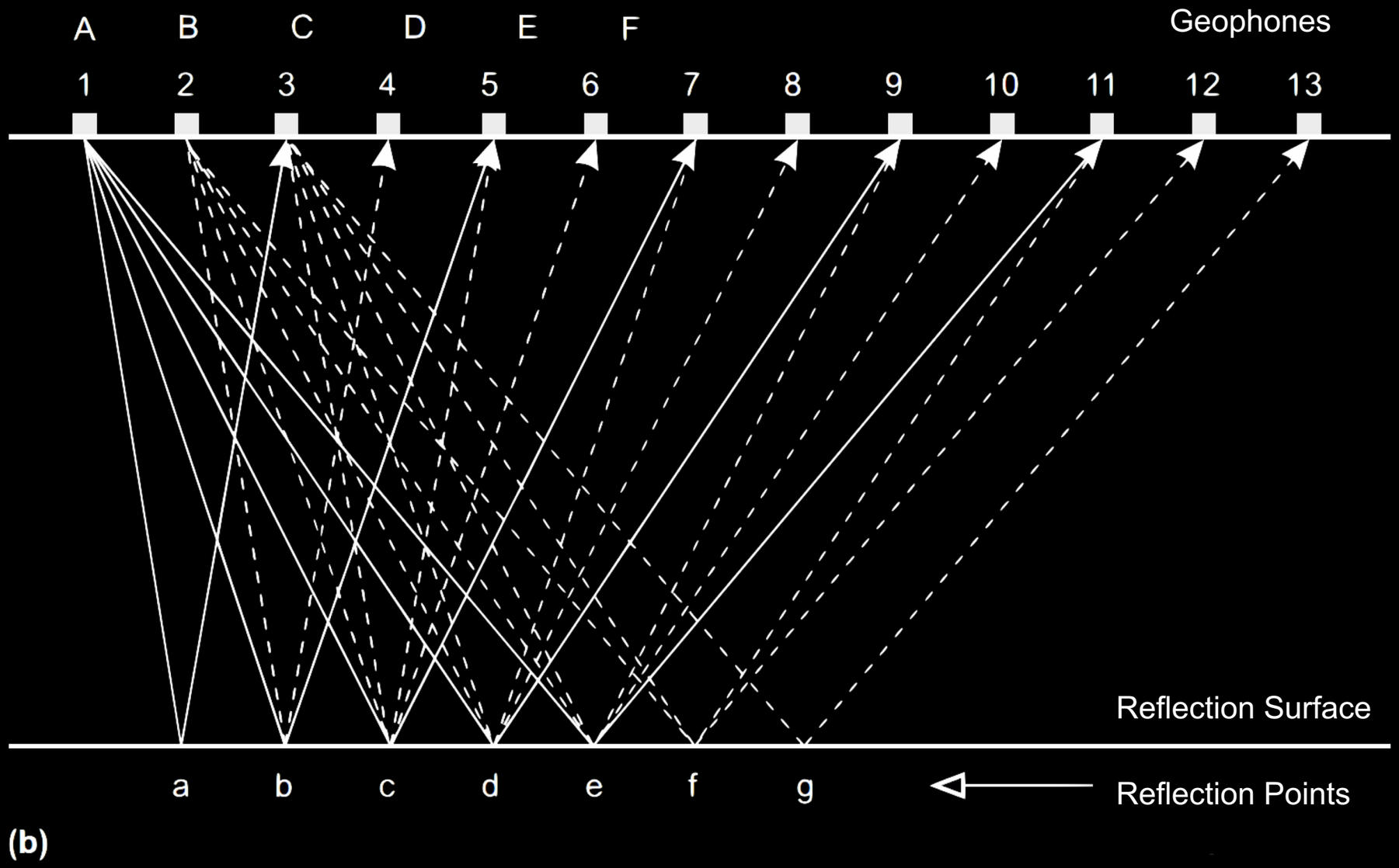
Interval Velocities

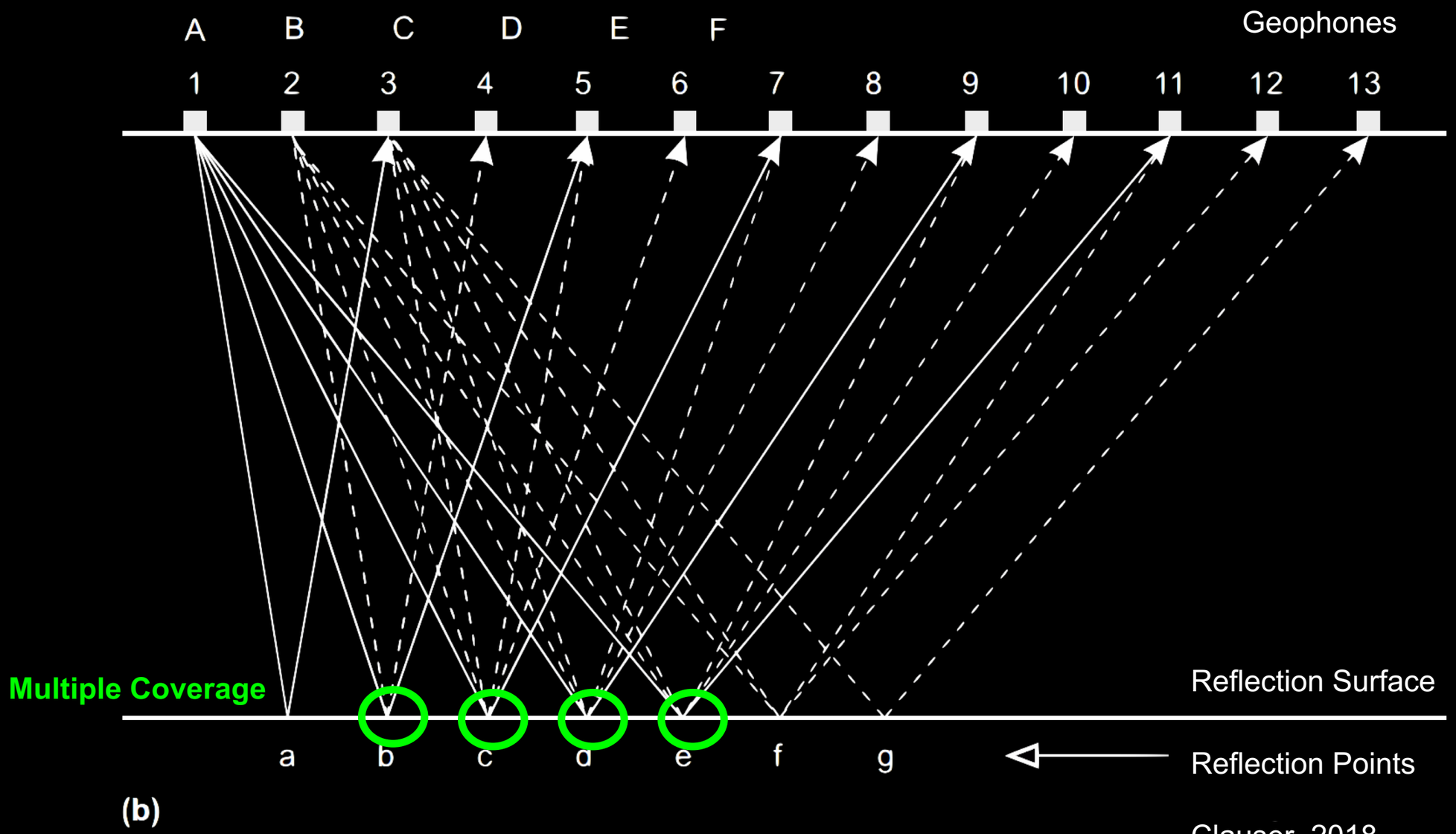
- Interval velocities can be obtained in a top-to-bottom approach (Dix Inversion)

EBERHARD KARLS
UNIVERSITÄT
TÜBINGEN

R. Drews: Introduction to Geophysics

Shot Gather and CMP Gather

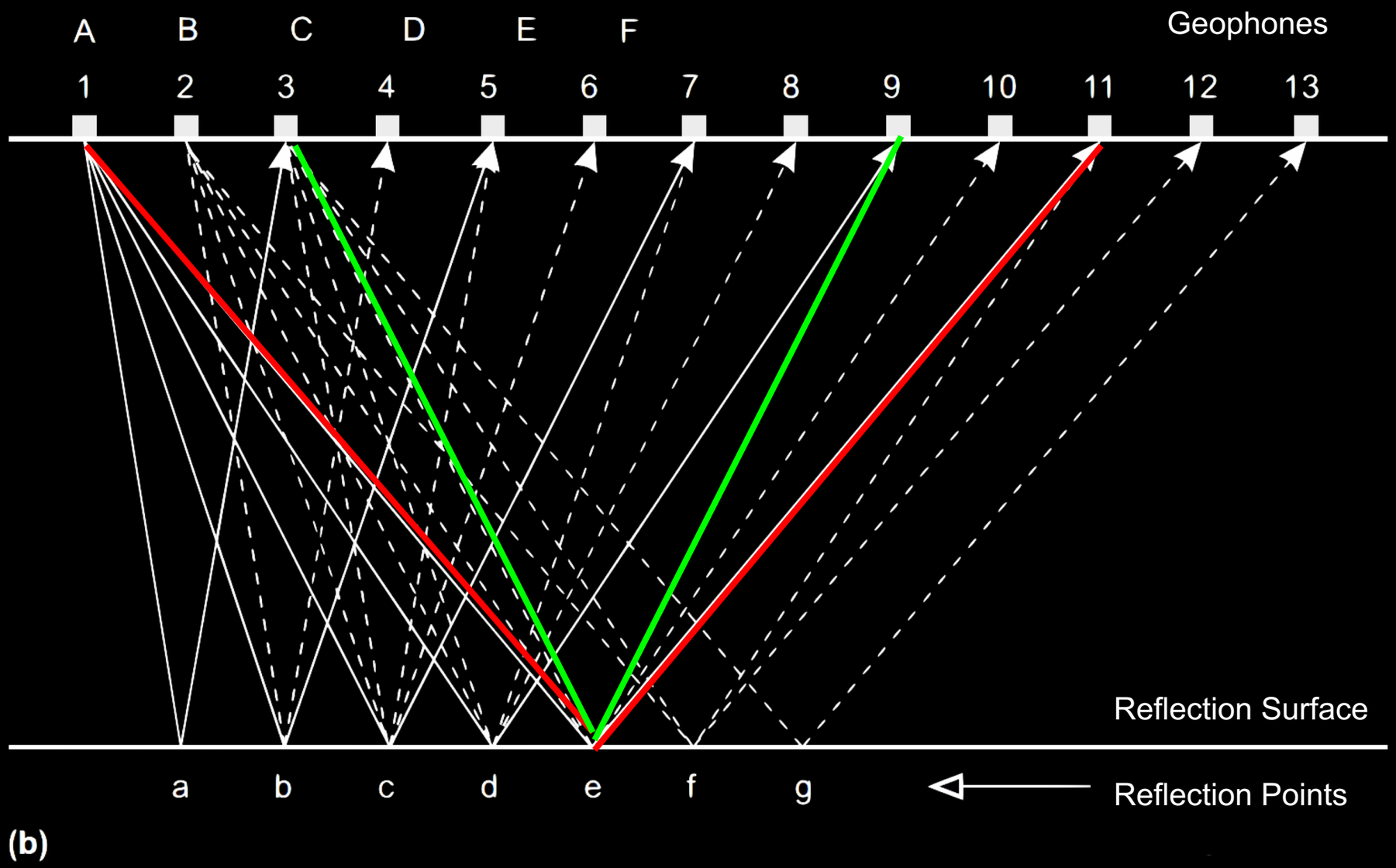




(b)

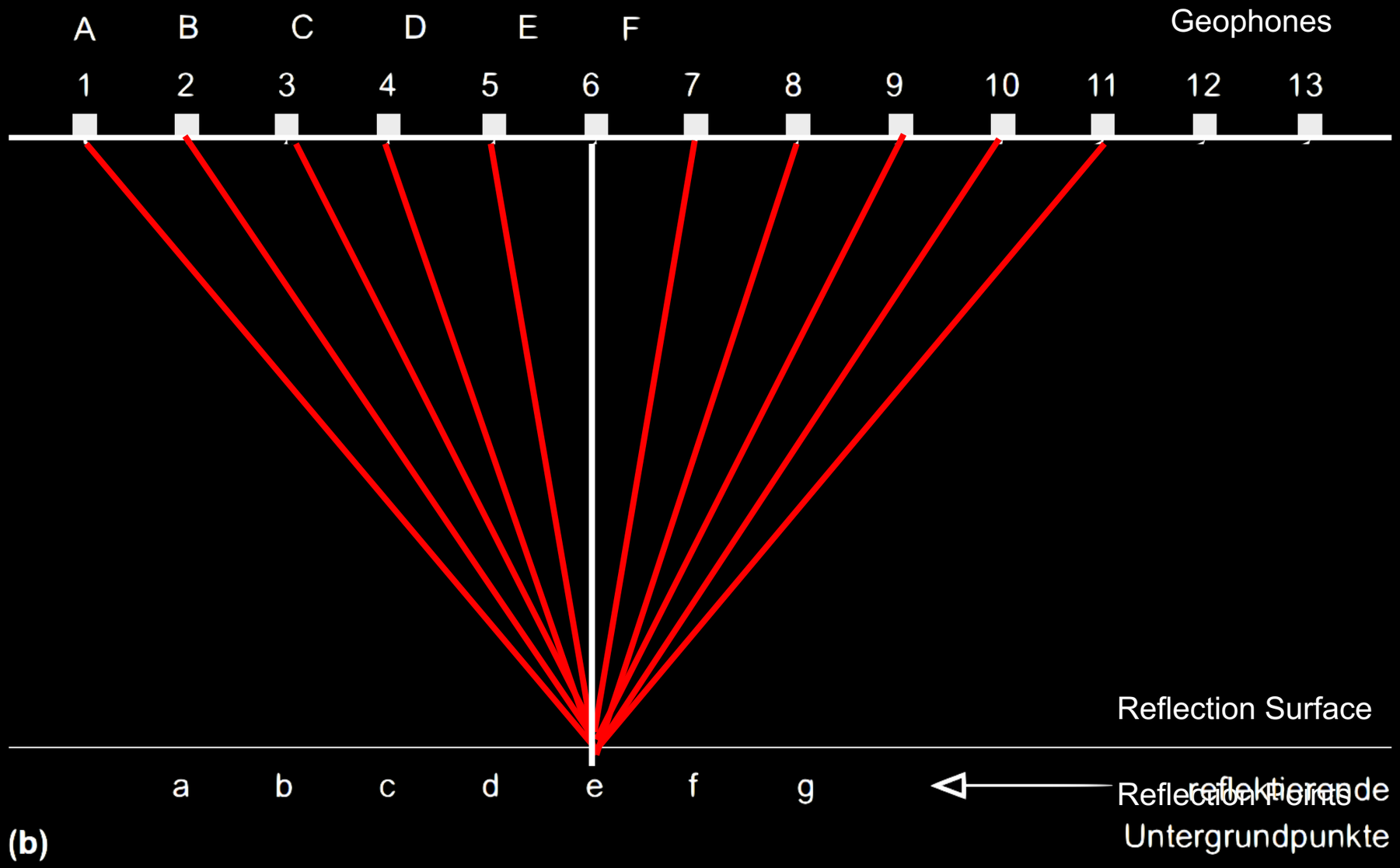
Clauser, 2018

Shot Gather to CMP Gather

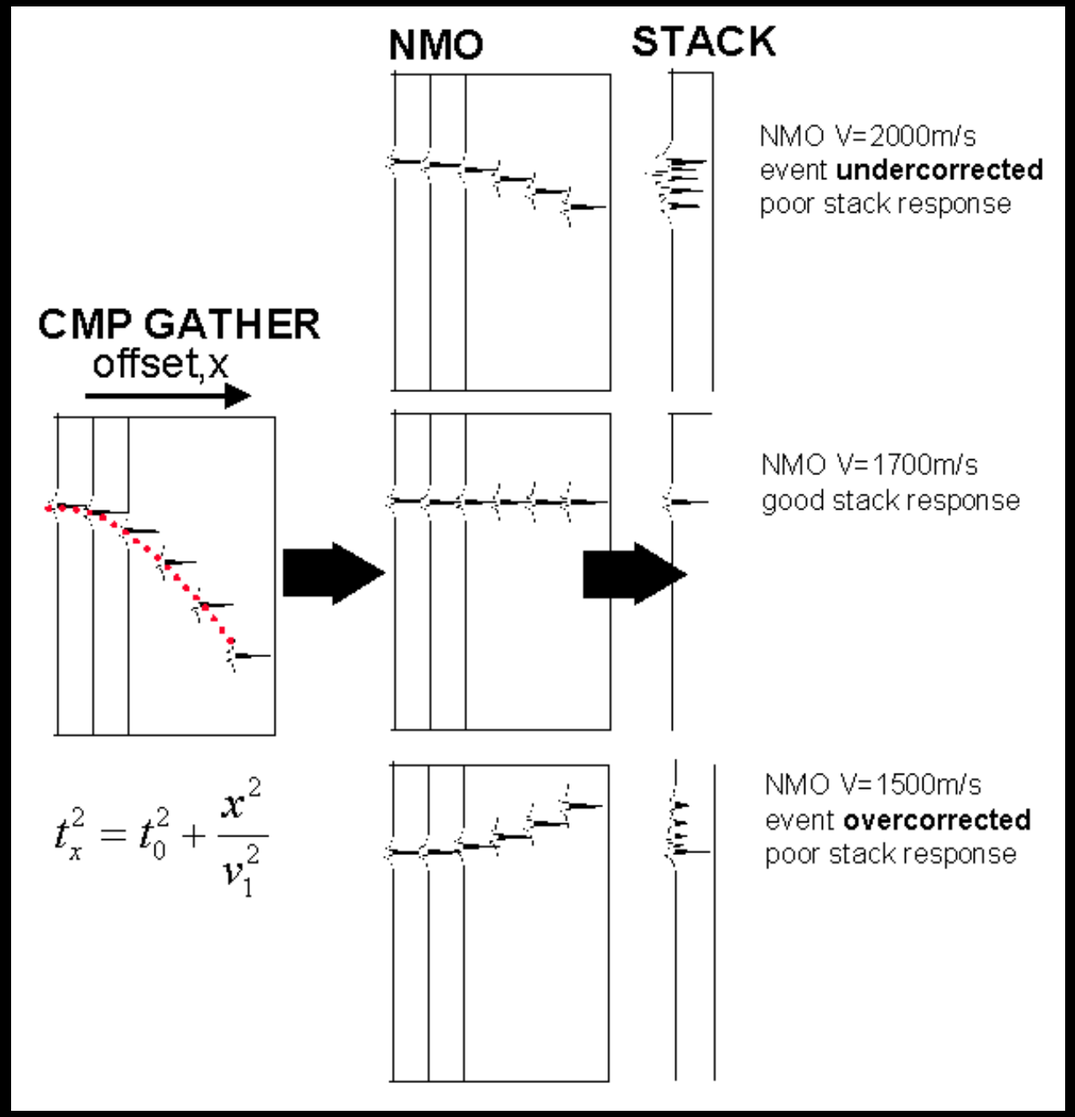


(b)

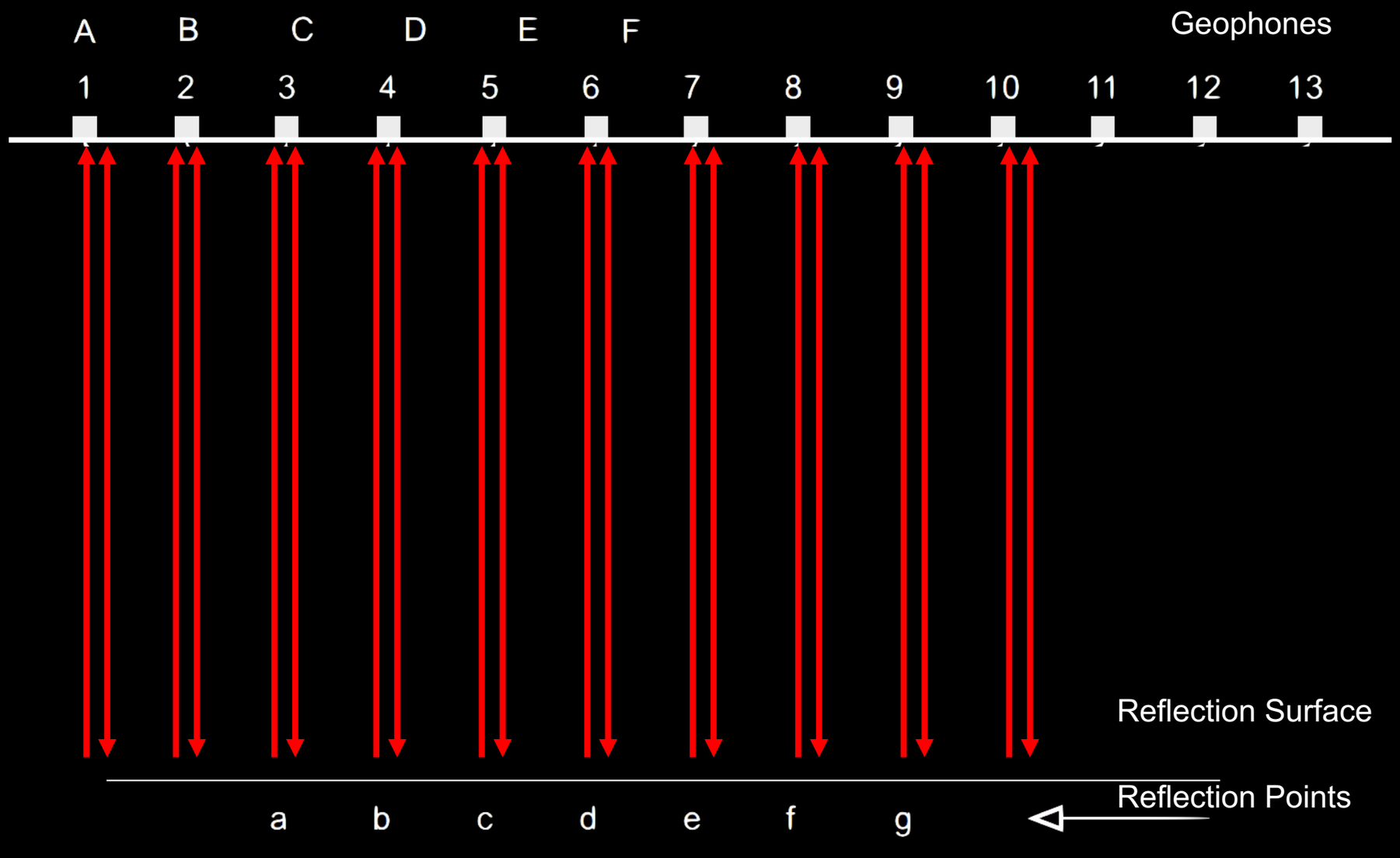
Shot Gather to CMP Gather



- NMO stacking in CMP gather

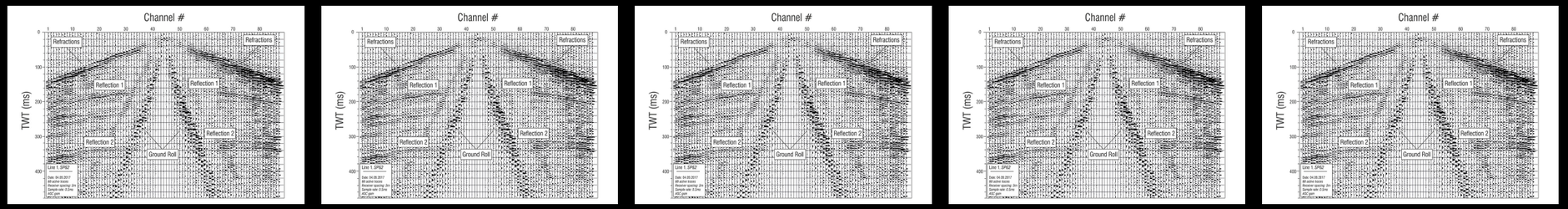


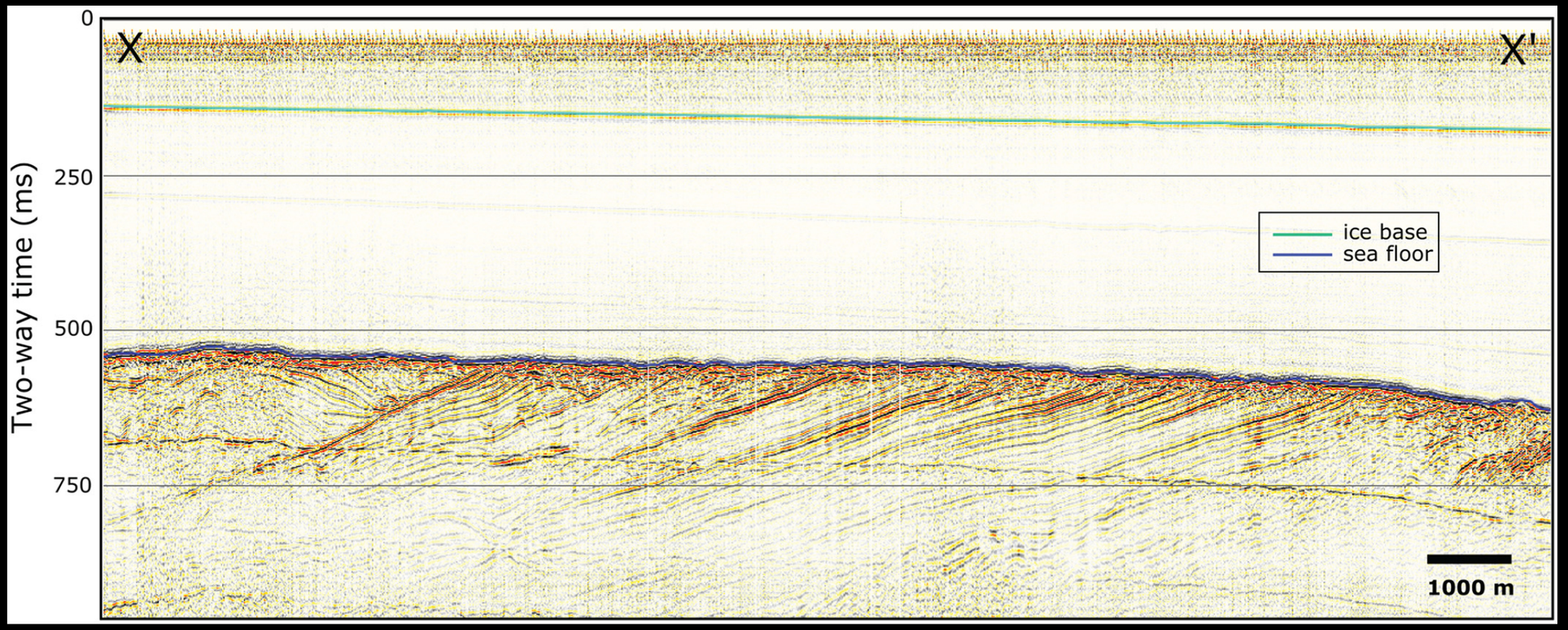
Zero Offset Gather



The stacking enables to combine everything into quasi vertical raypaths

Shot gather, CMP sorting, NMO correction, stacking

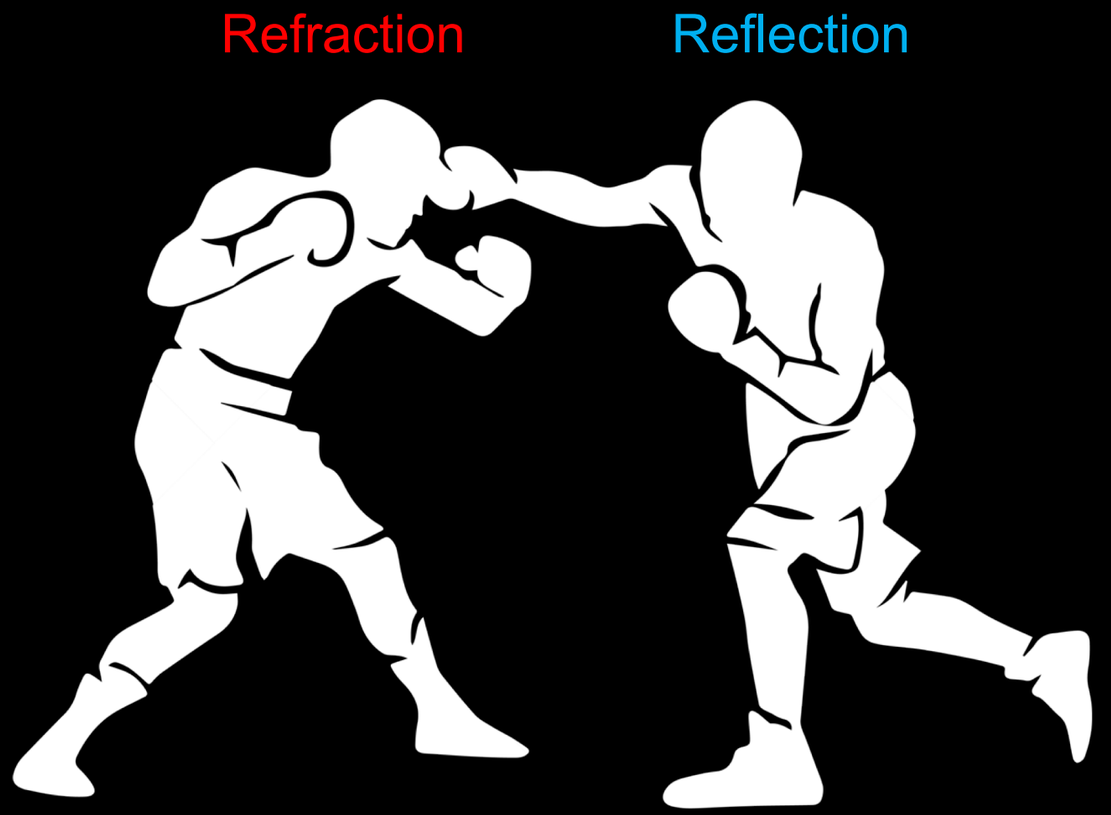




Source: Smith et al., GRL, 2020

- The zero offset gather provides and “image” of the subsurface. But it is important to realize that this “image” does in general not correspond to the true geometry of the sub-surface. Why?

- Because so far we have done everything with horizontal reflectors. Off-angle point targets or dipping interfaces will have a different appearance in (unmigrated) reflection datasets.



[academic use]

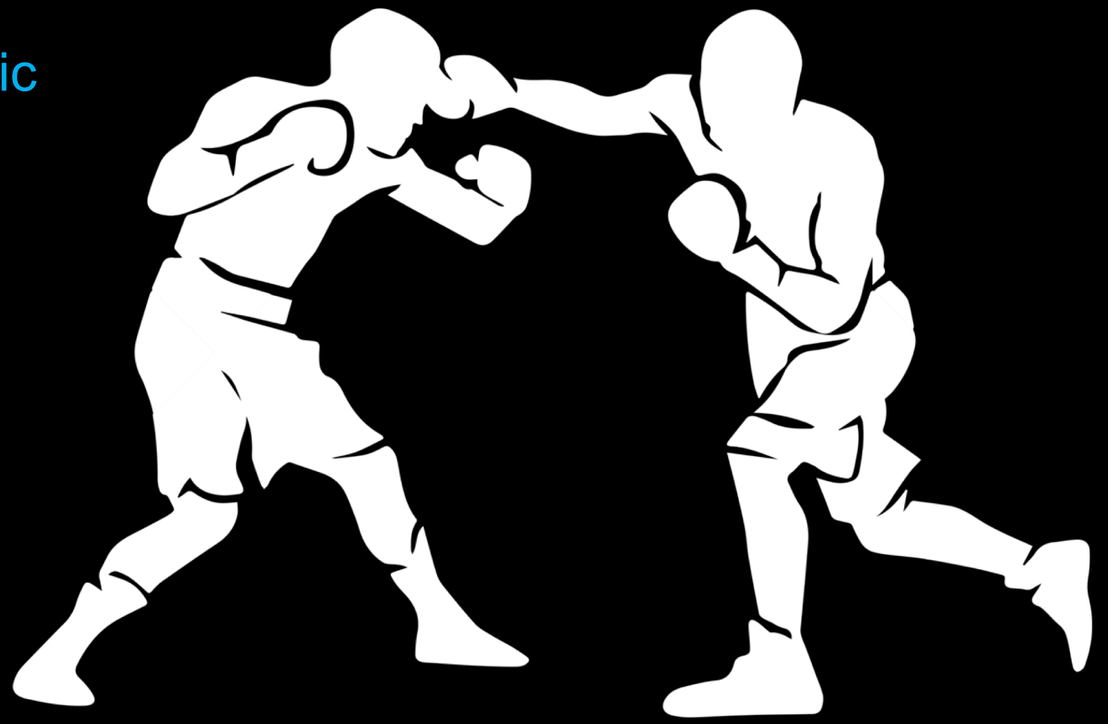
+ No need for critical angles

+ No need for increasing seismic velocities with depth

+ Better suited for deep exploration

+ Less restrictions on sub-surface geometry

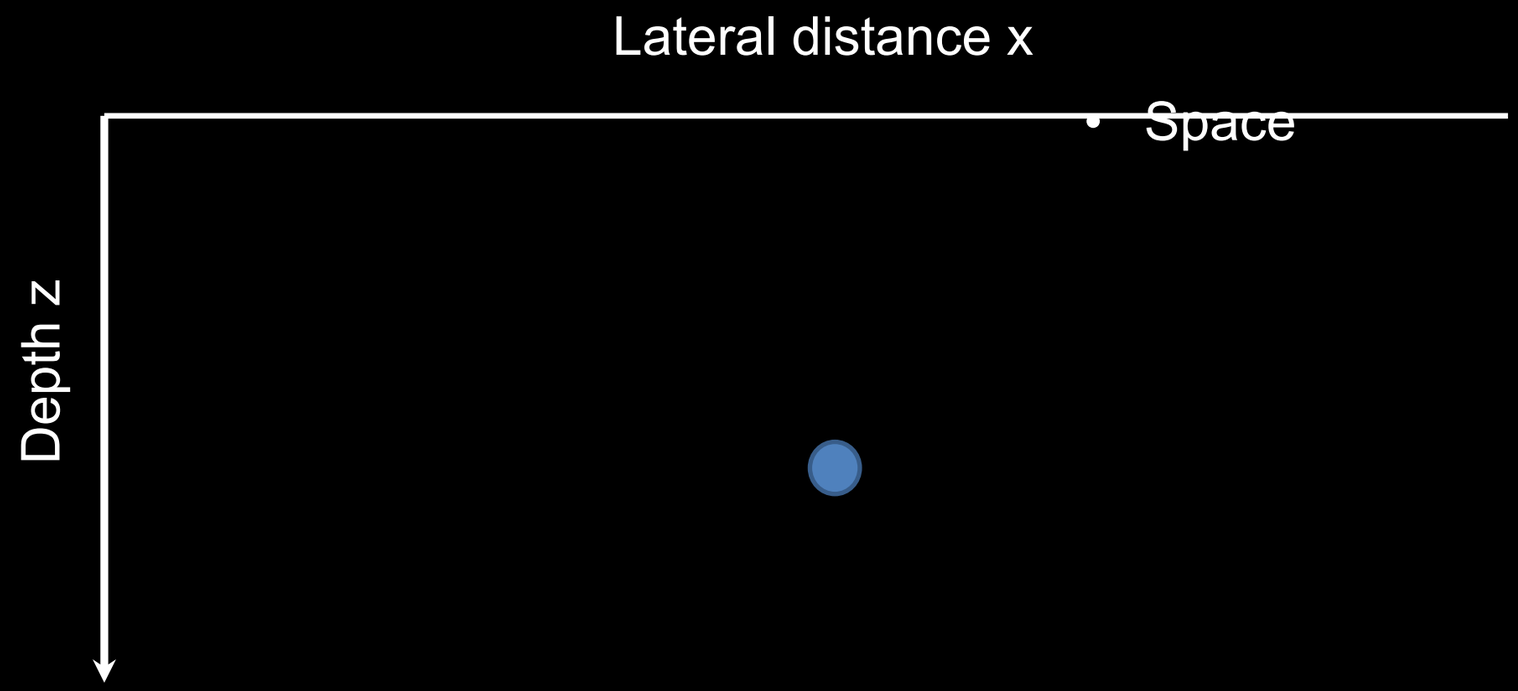
Refraction Reflection



[academic use]

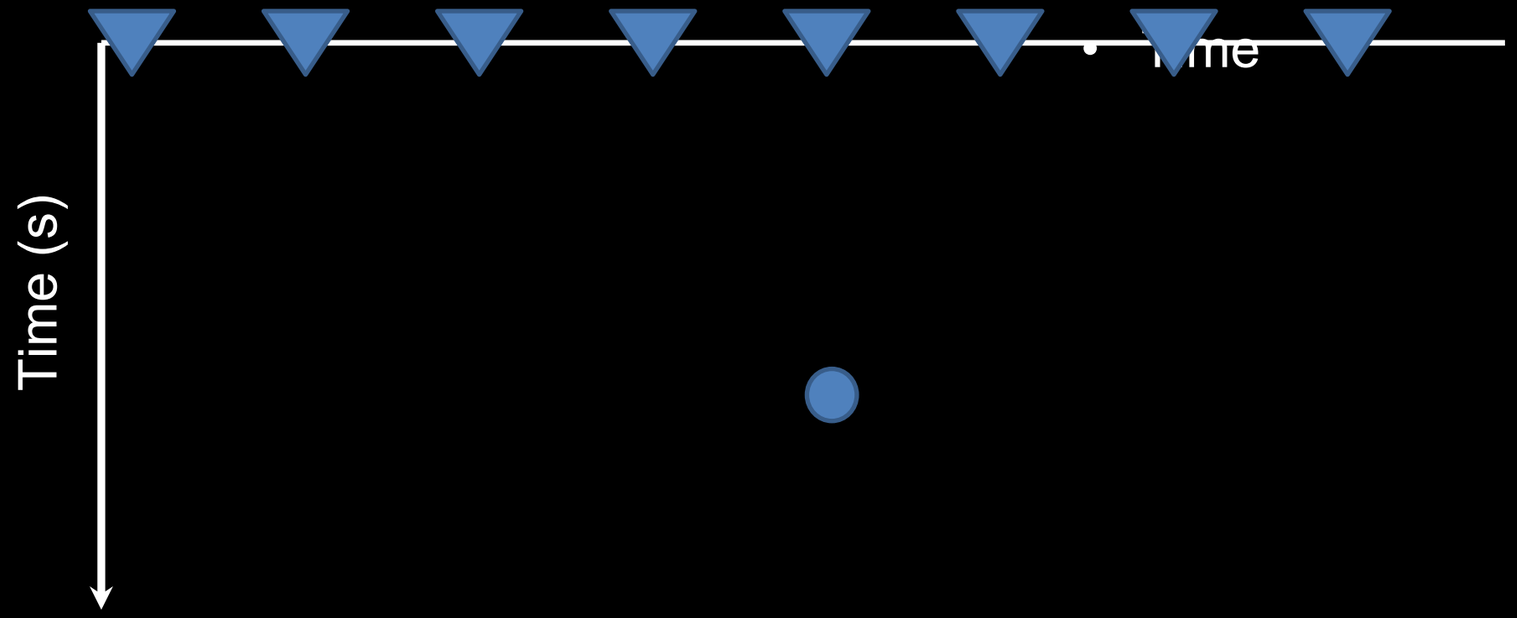
- Migration: What is it and why do we need it in reflection data (seismics or ground-penetrating radar) ?

Kirchhoff Migration



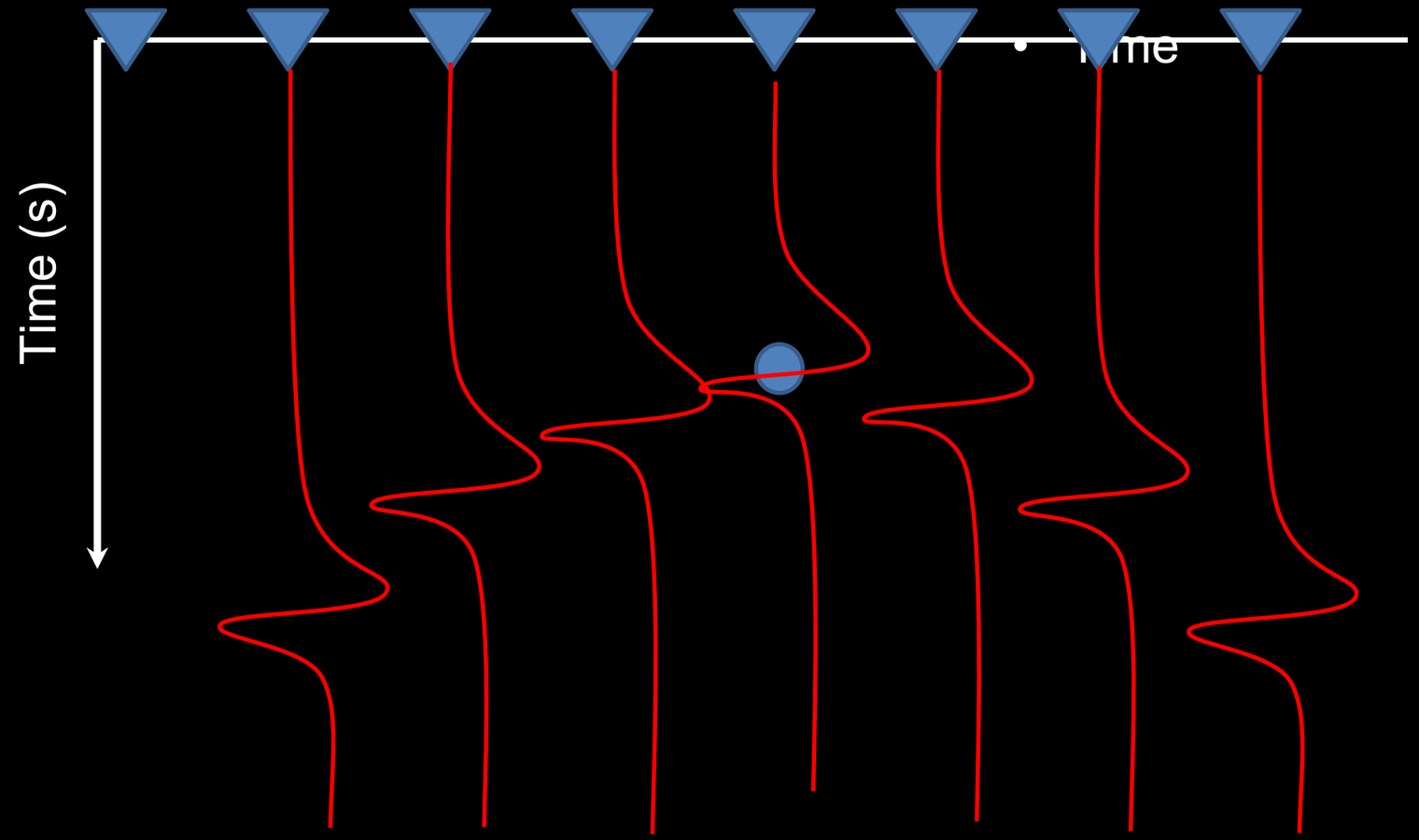
Lateral distance x

Kirchhoff Migrtaion Yilmaz 1987



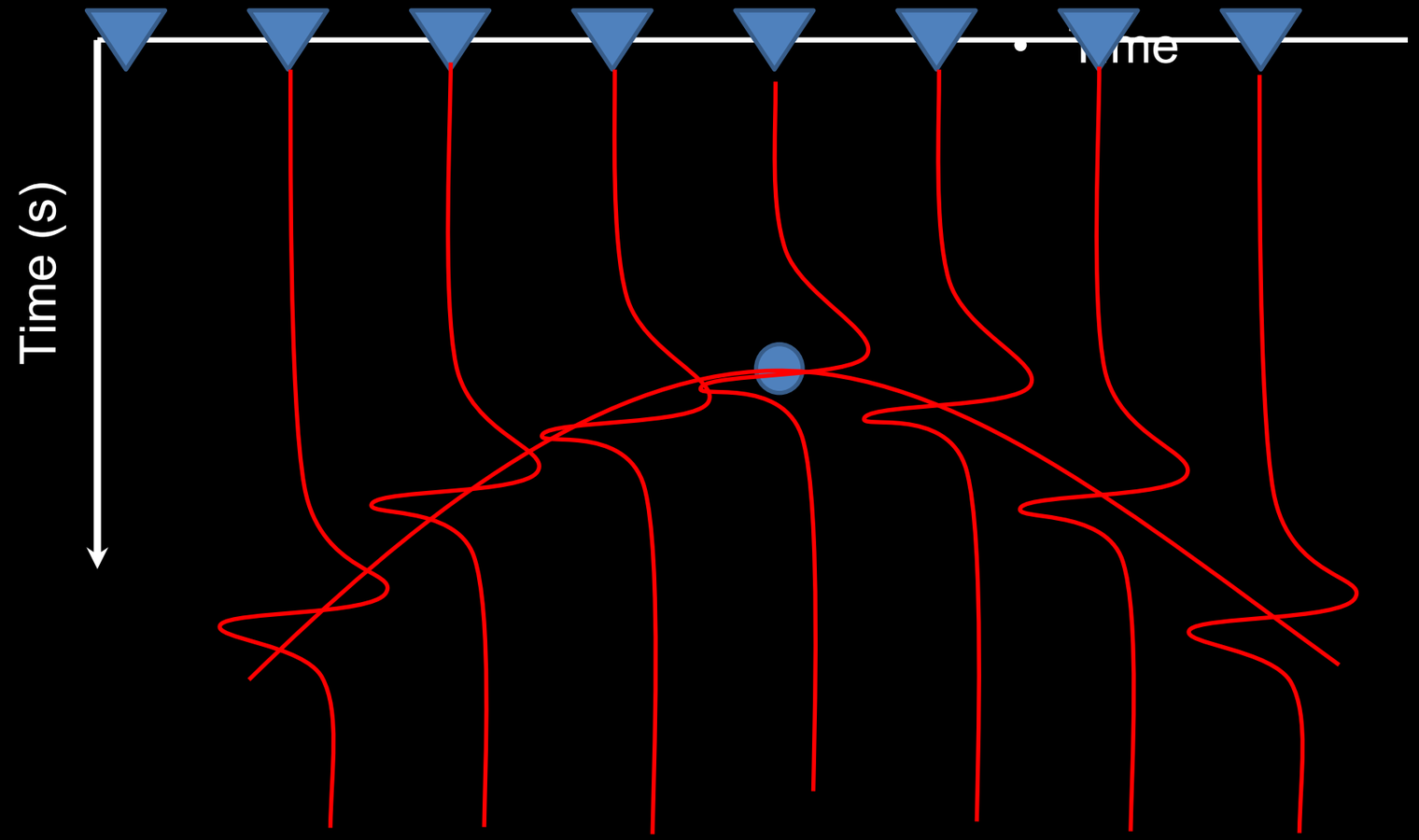
Lateral distance x

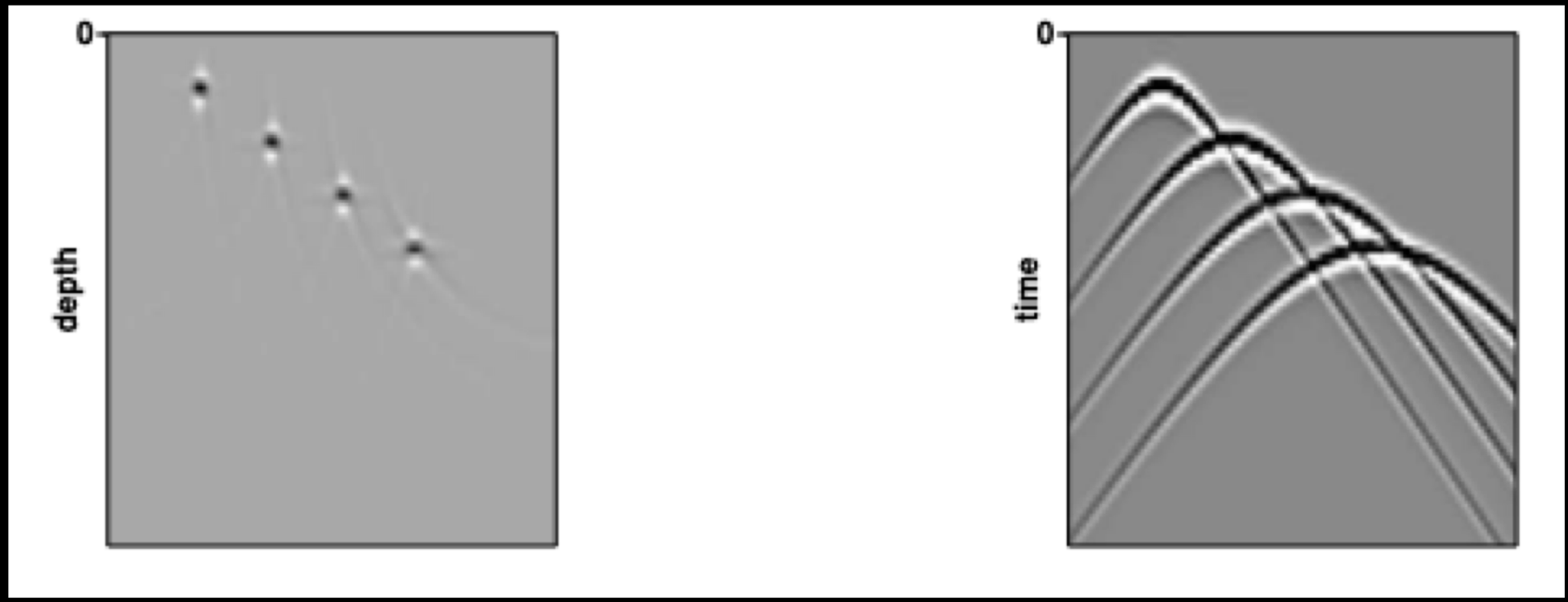
Kirchhoff Migrtaion Yilmaz 1987



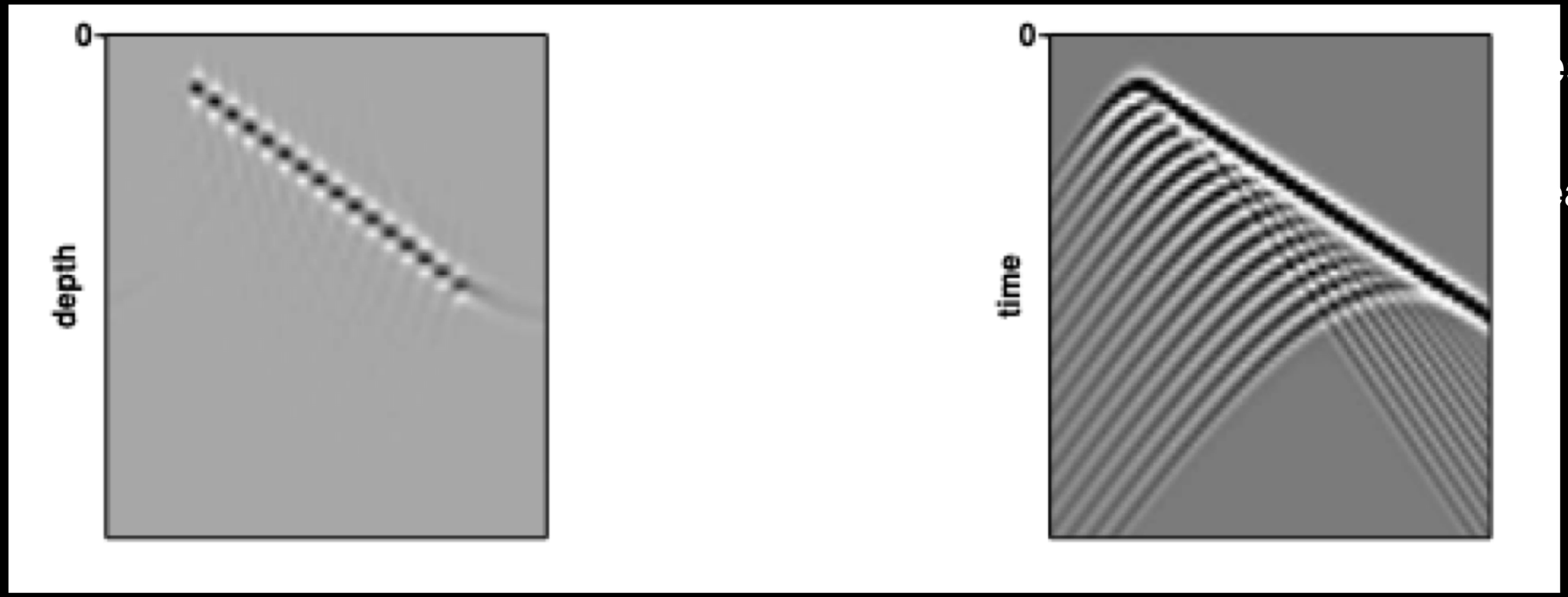
Lateral distance x

Kirchhoff Migrtaion Yilmaz 1987





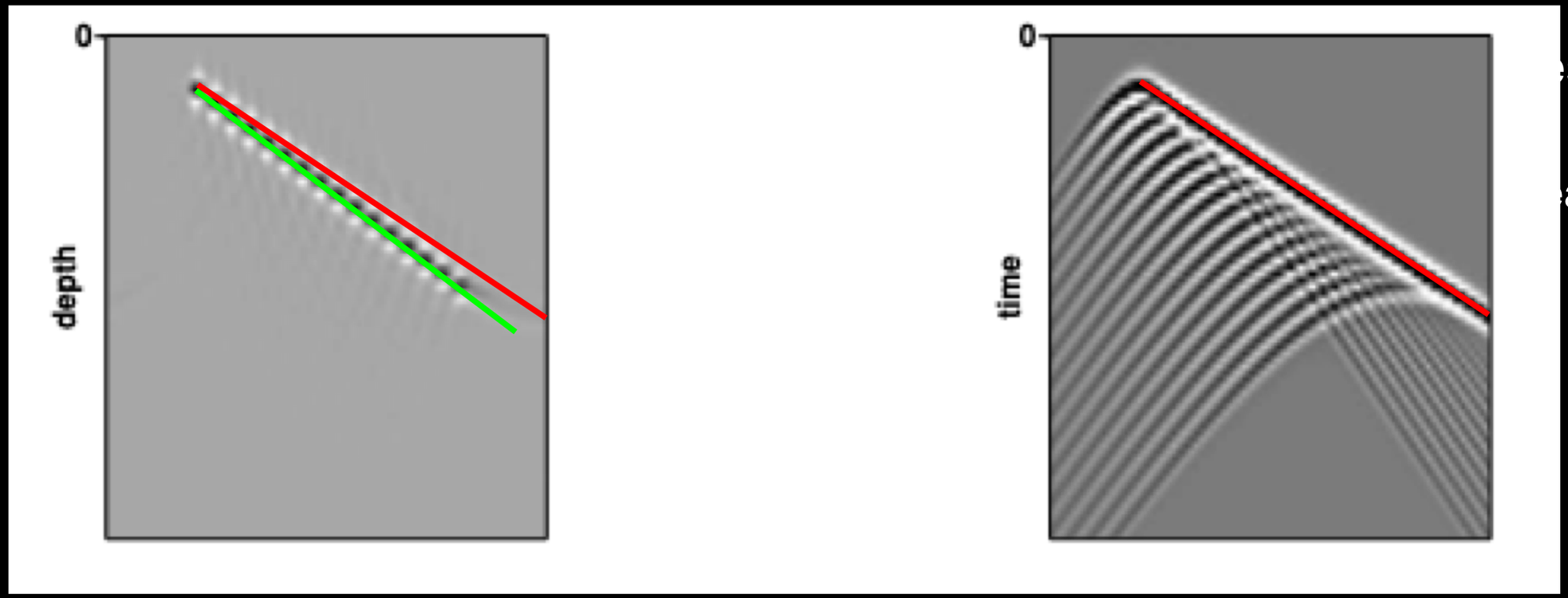
- Real World (left) vs. seismic/radar world (right)



essing)

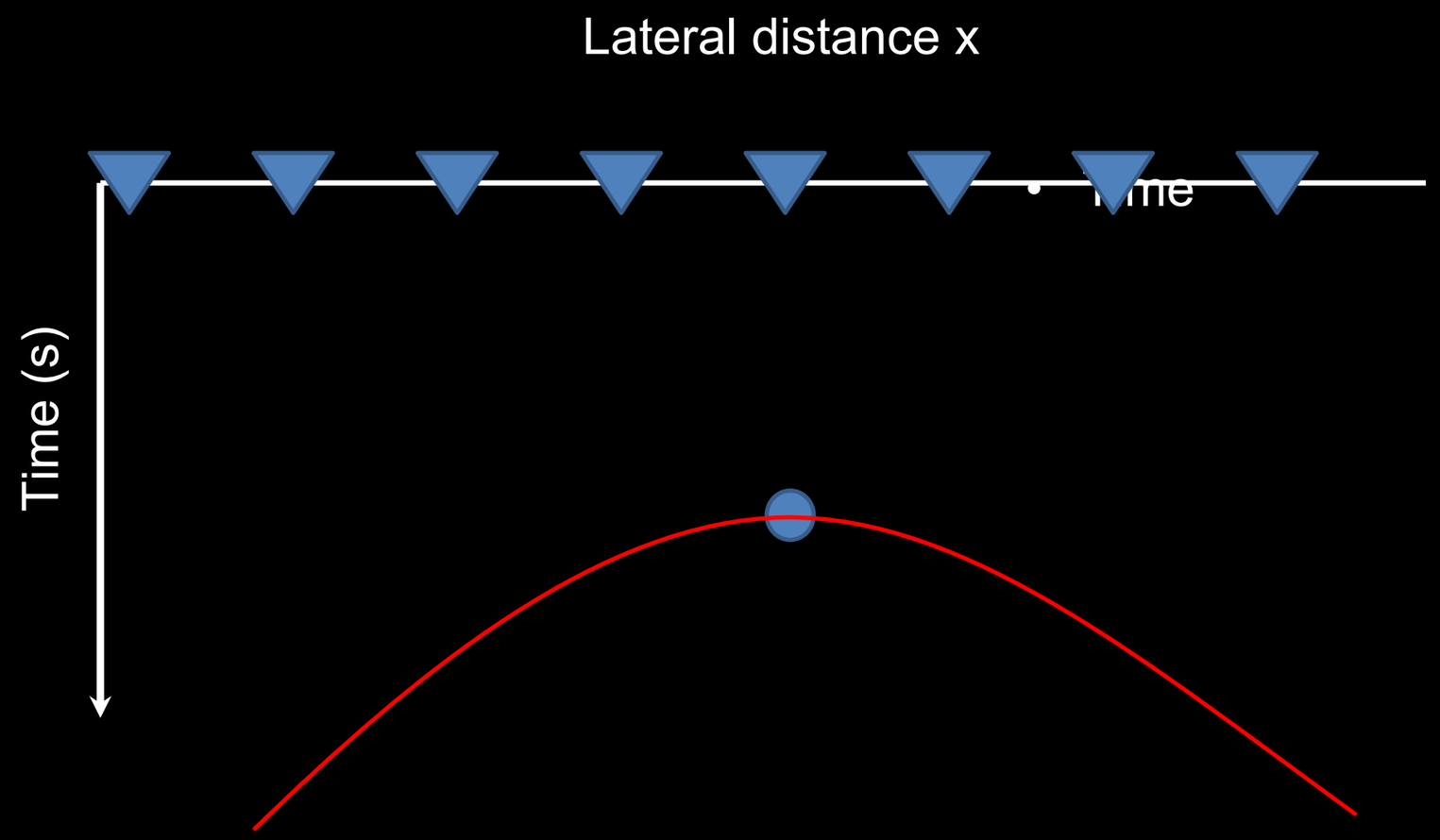
ear

- Real World (left) vs. seismic/radar world (right)

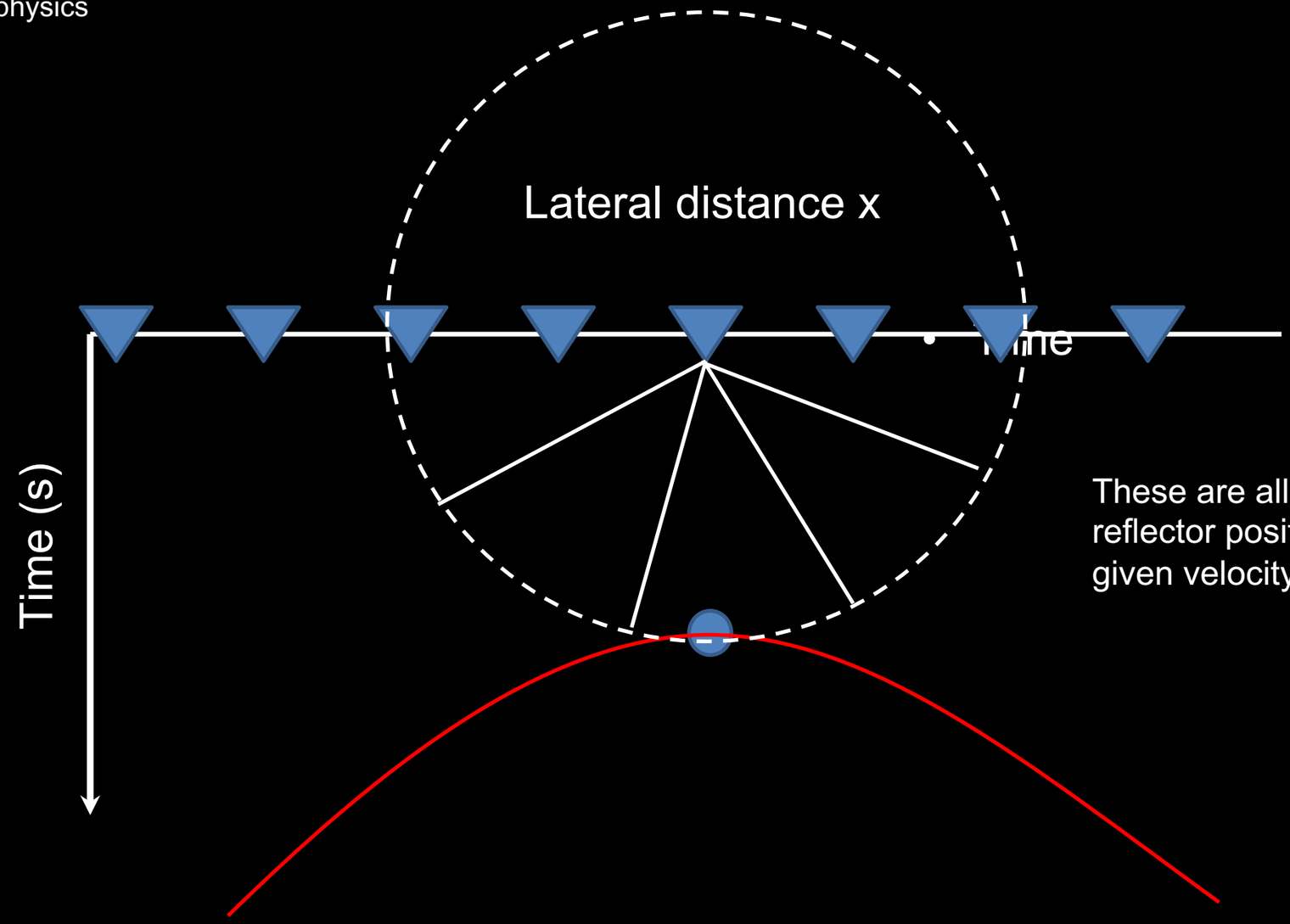


Slopes in common offset sections appear gentler than the slope of the corresponding reflection interface.

Kirchhoff Migration

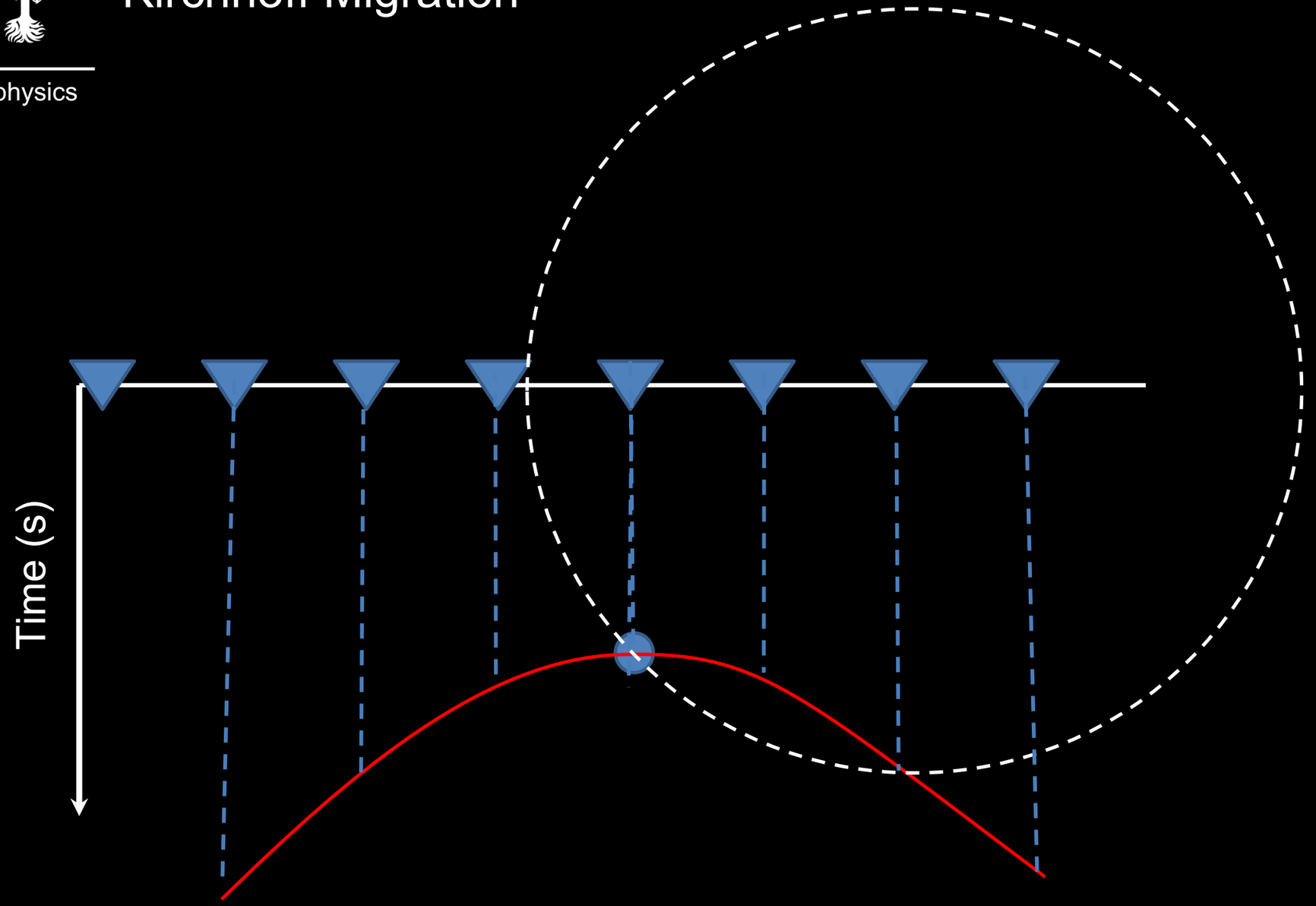


Kirchhoff Migration

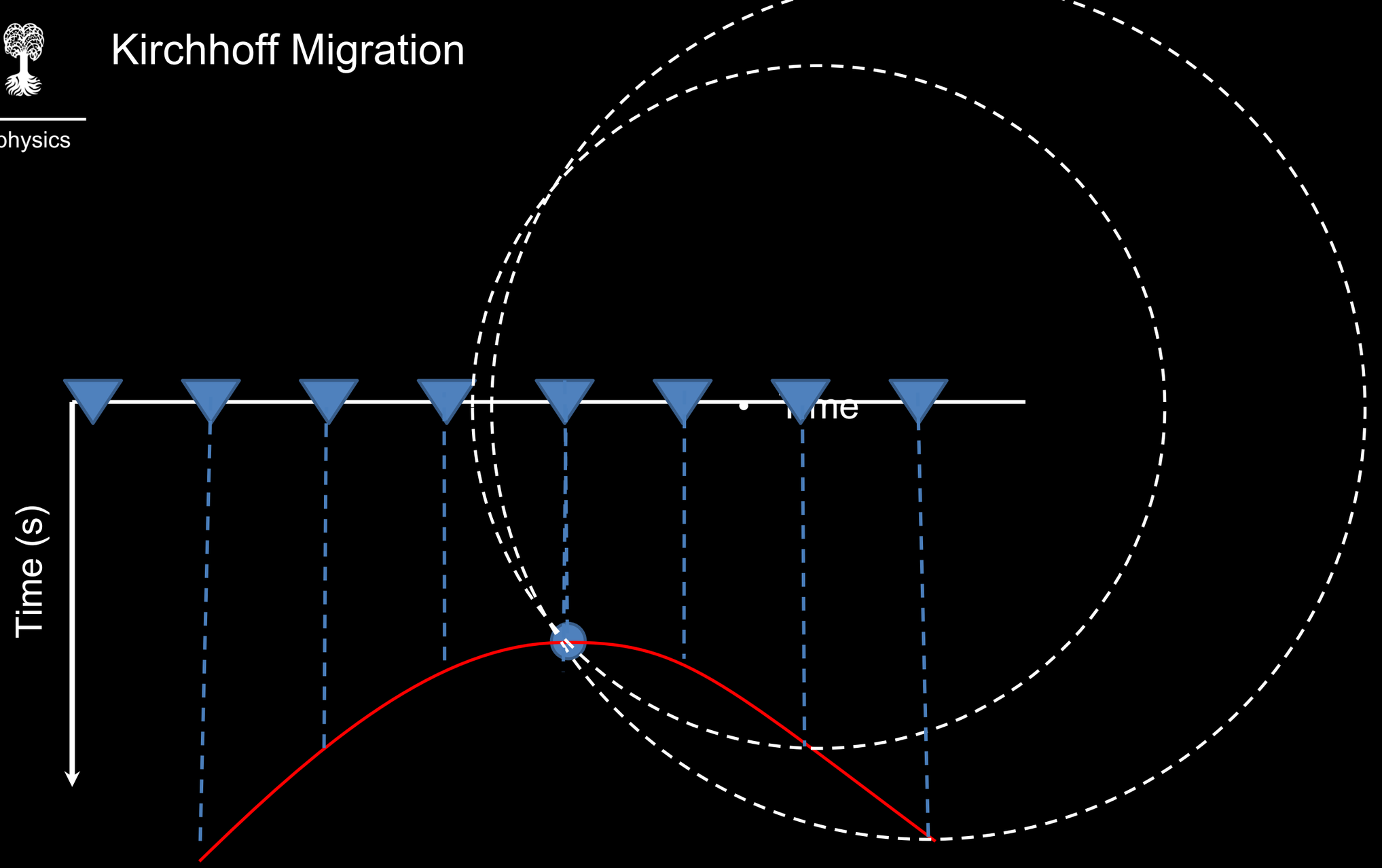


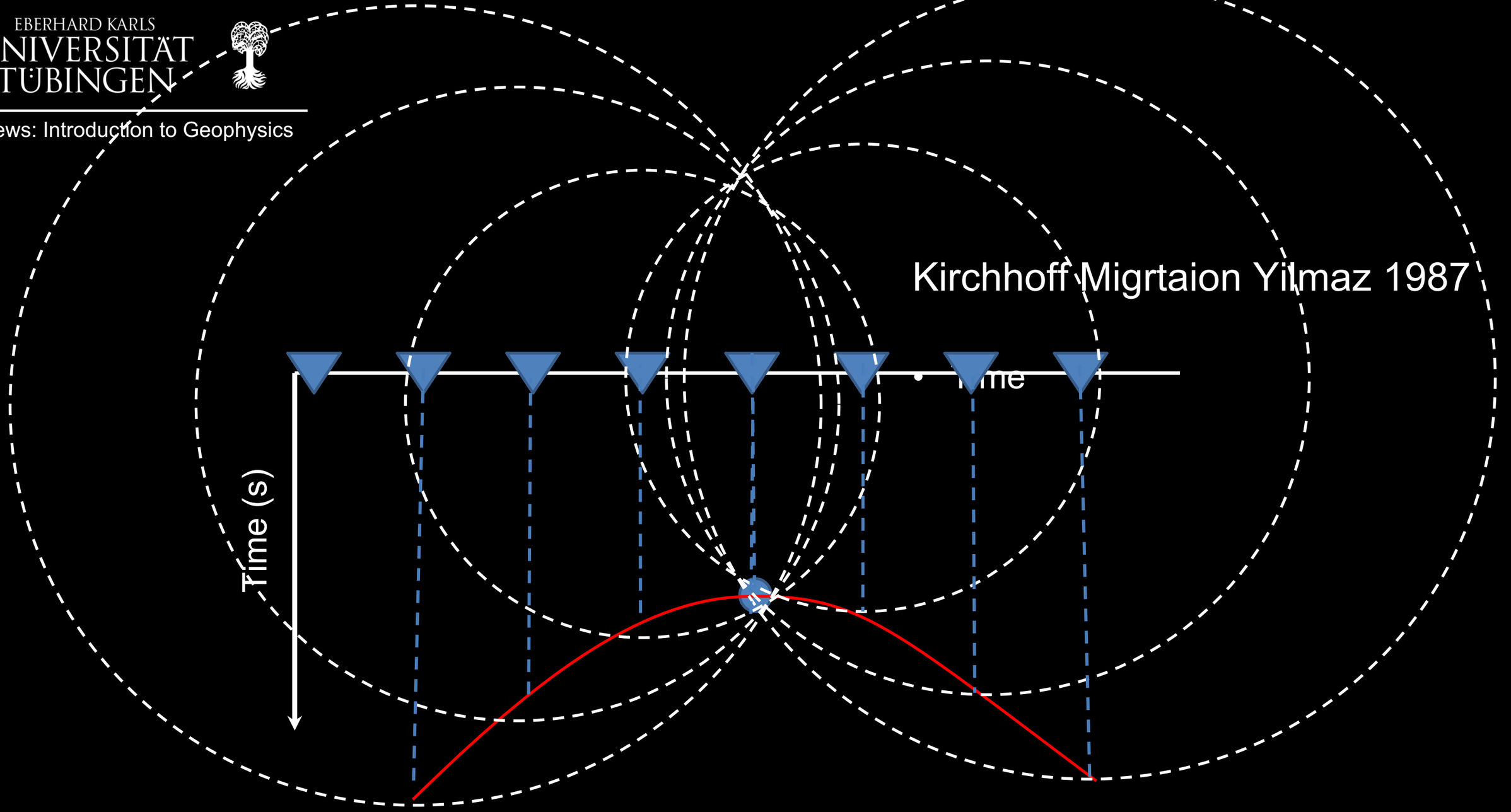
These are all possible reflector positions (for a given velocity)

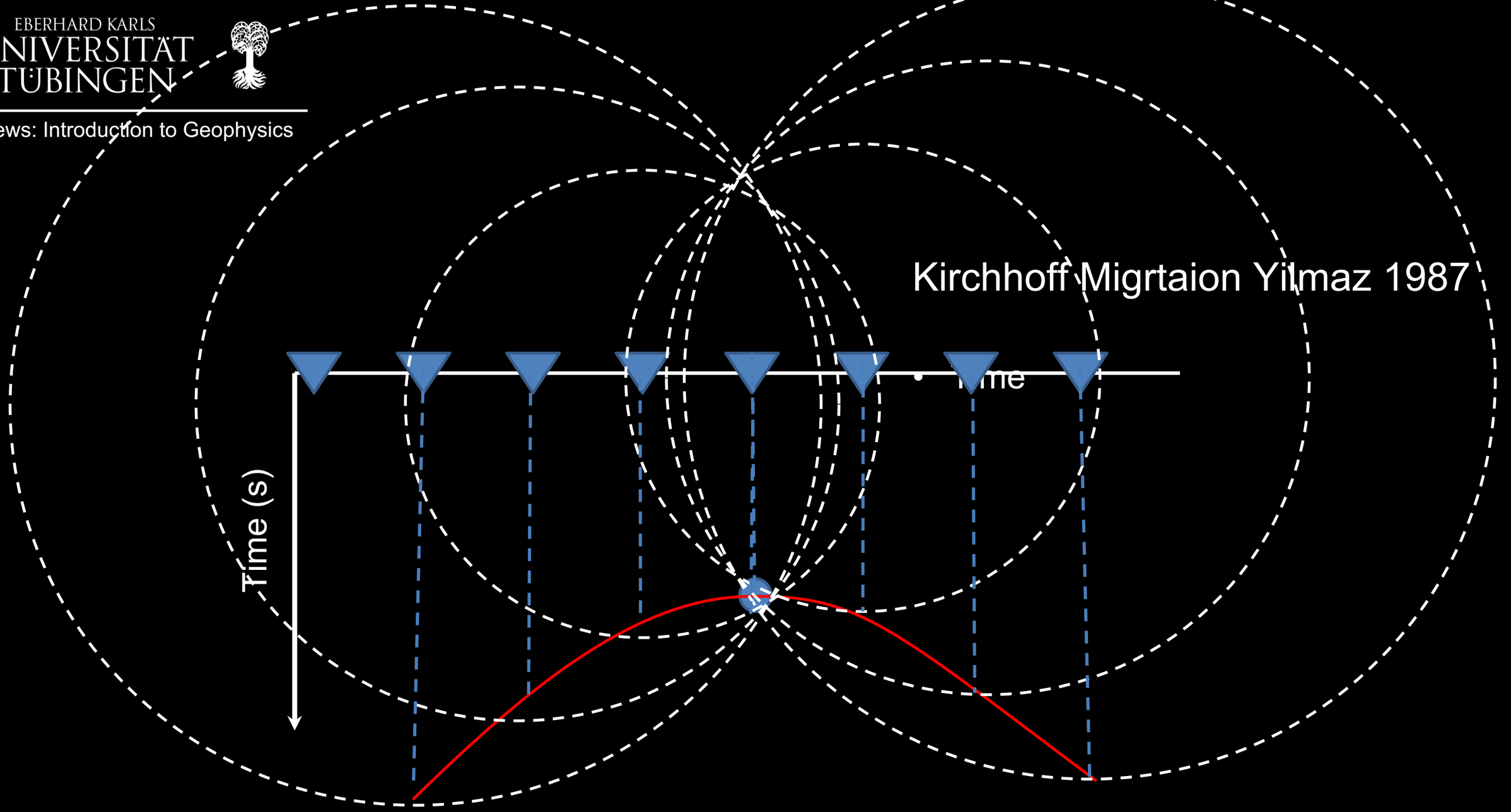
Kirchhoff Migration



Kirchhoff Migration

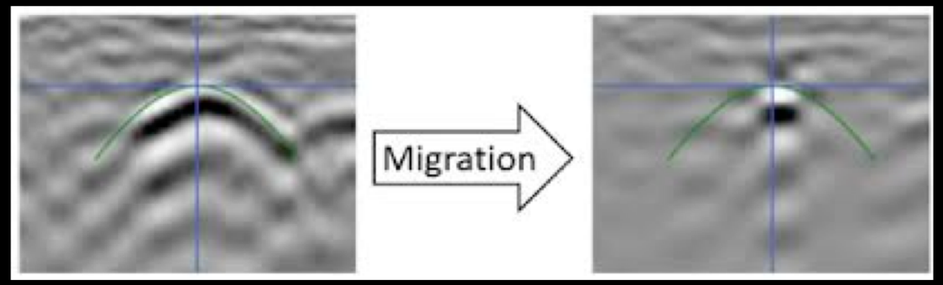


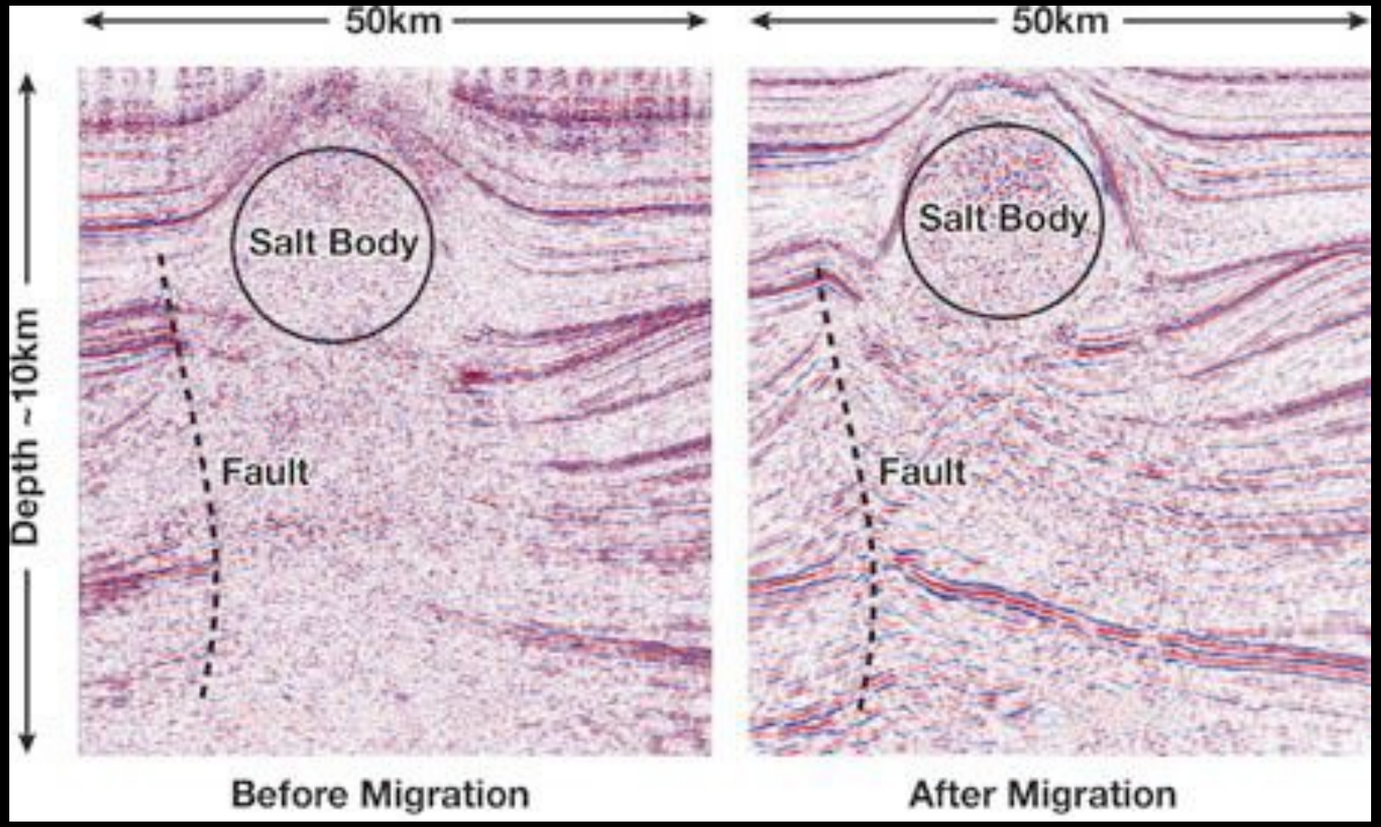

Kirchhoff Migrtaion Yilmaz 1987
Time
Time (s)

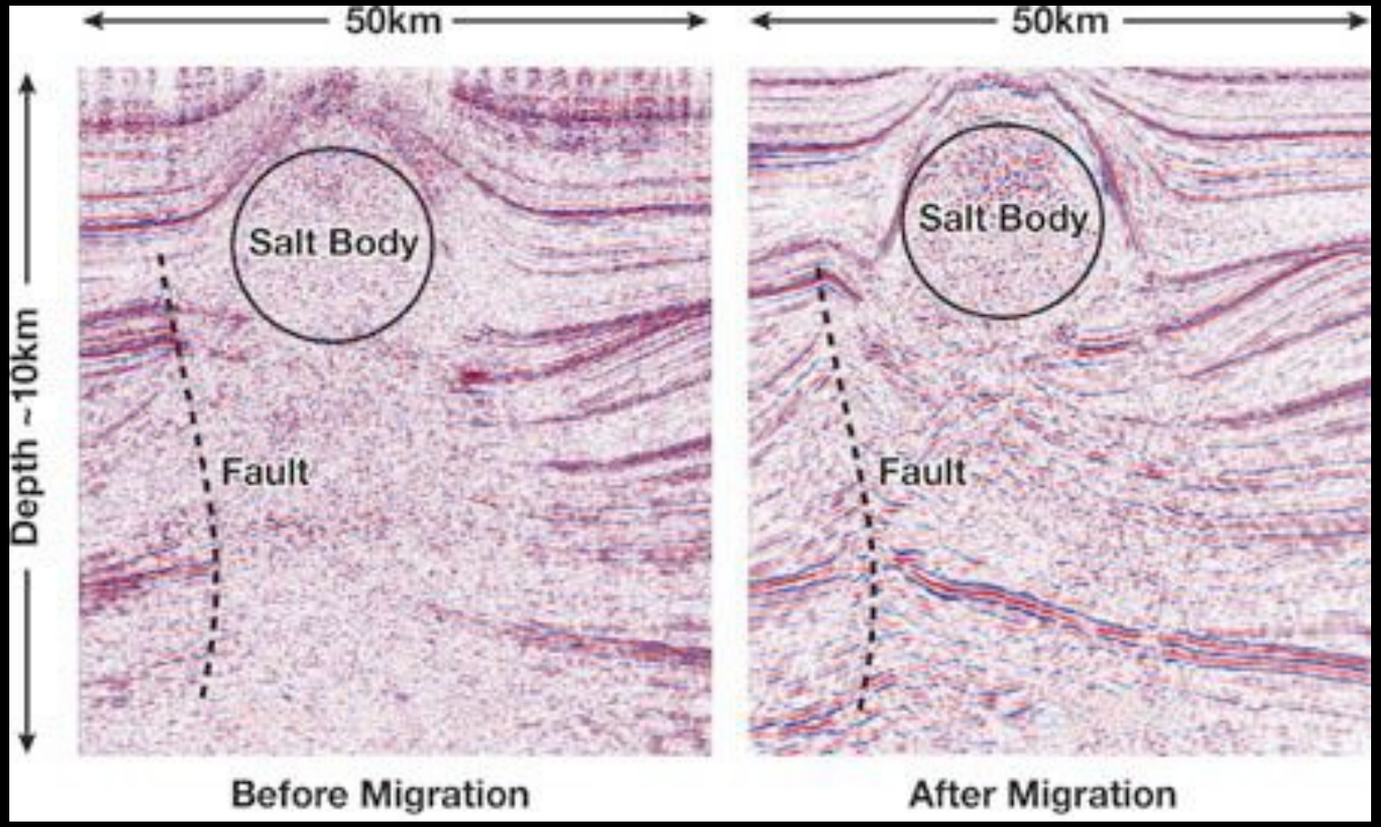

Kirchhoff Migrtaion Yilmaz 1987
Time
Time (s)

Kirchoff migration is a simple geometric way to migrate common-offset data for known velocities.

It focuses diffraction hyperbolas into points and also results in correct layer dips.




50km
50km
Salt Body
Salt Body
Fault
Fault
Depth ~10km
Before Migration
After Migration


50km
50km
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Salt Body
Fault
Fault
Depth ~10km
Before Migration
After Migration