Seismic interferometry

Kees Wapenaar

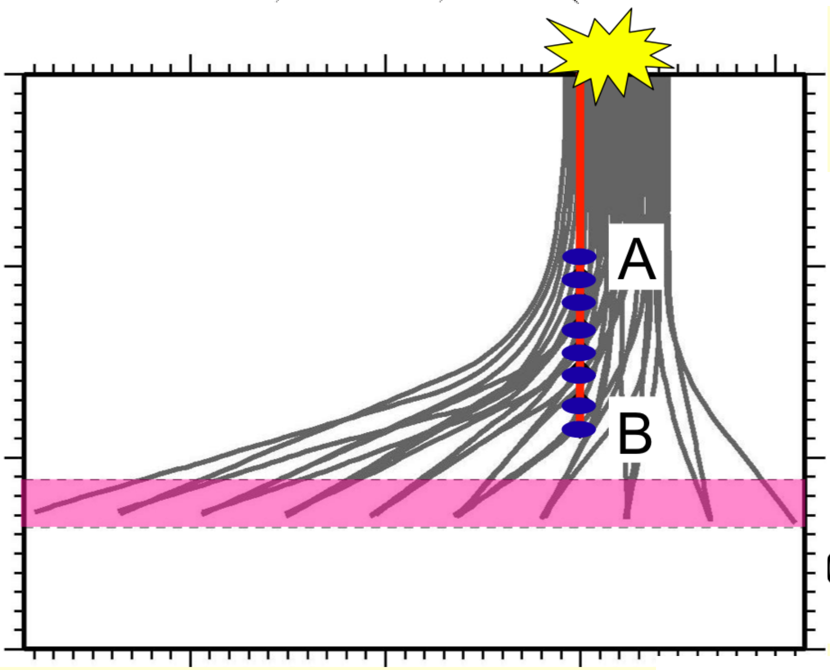
with many contributions from:

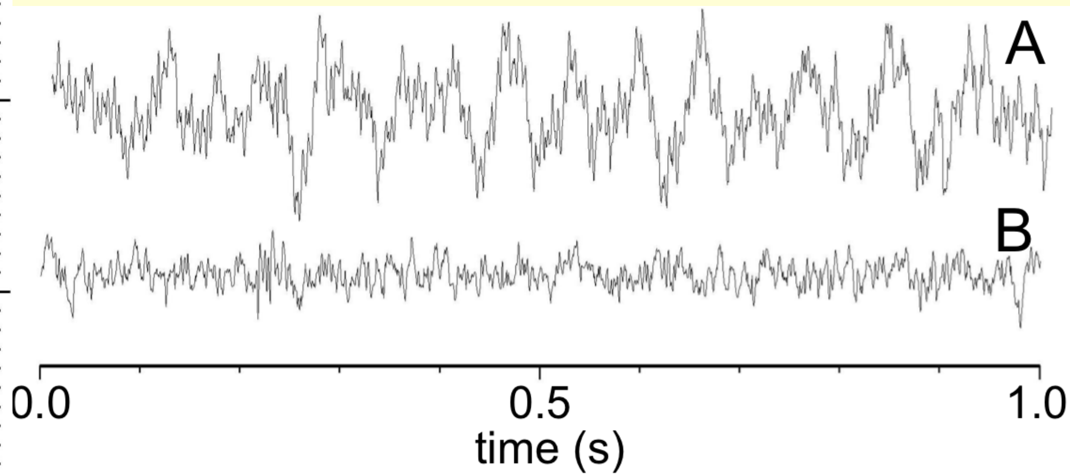
Deyan Draganov, Joost van der Neut, Elmer Ruigrok,
Evert Slob, Juerg Hunzicker, Jan Thorbecke, Roel Snieder,
Xander Campman, Arie Verdel

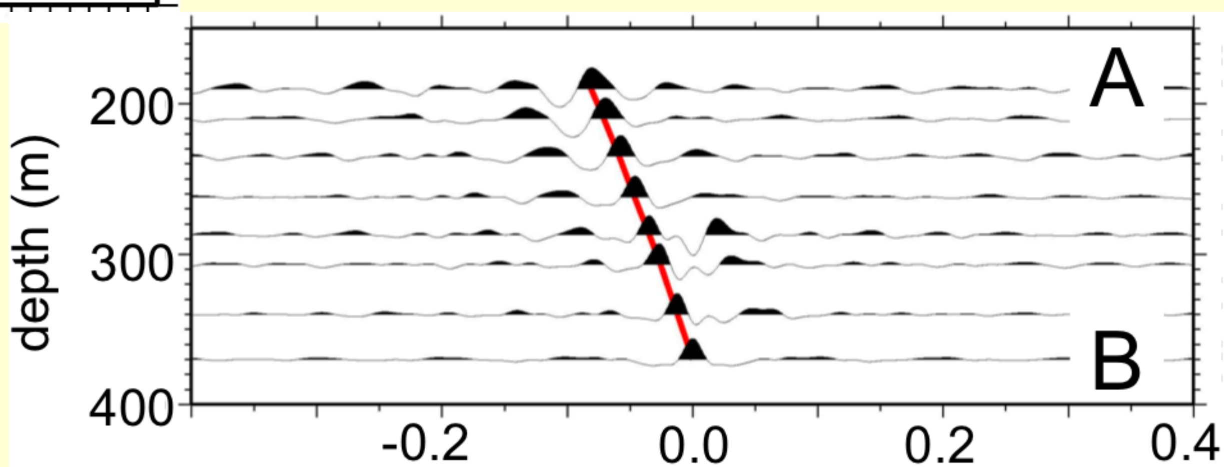
Application of seismic interferometry to extract P- and S-wave propagation and observation of shear-wave splitting from noise data at Cold Lake, Alberta, Canada

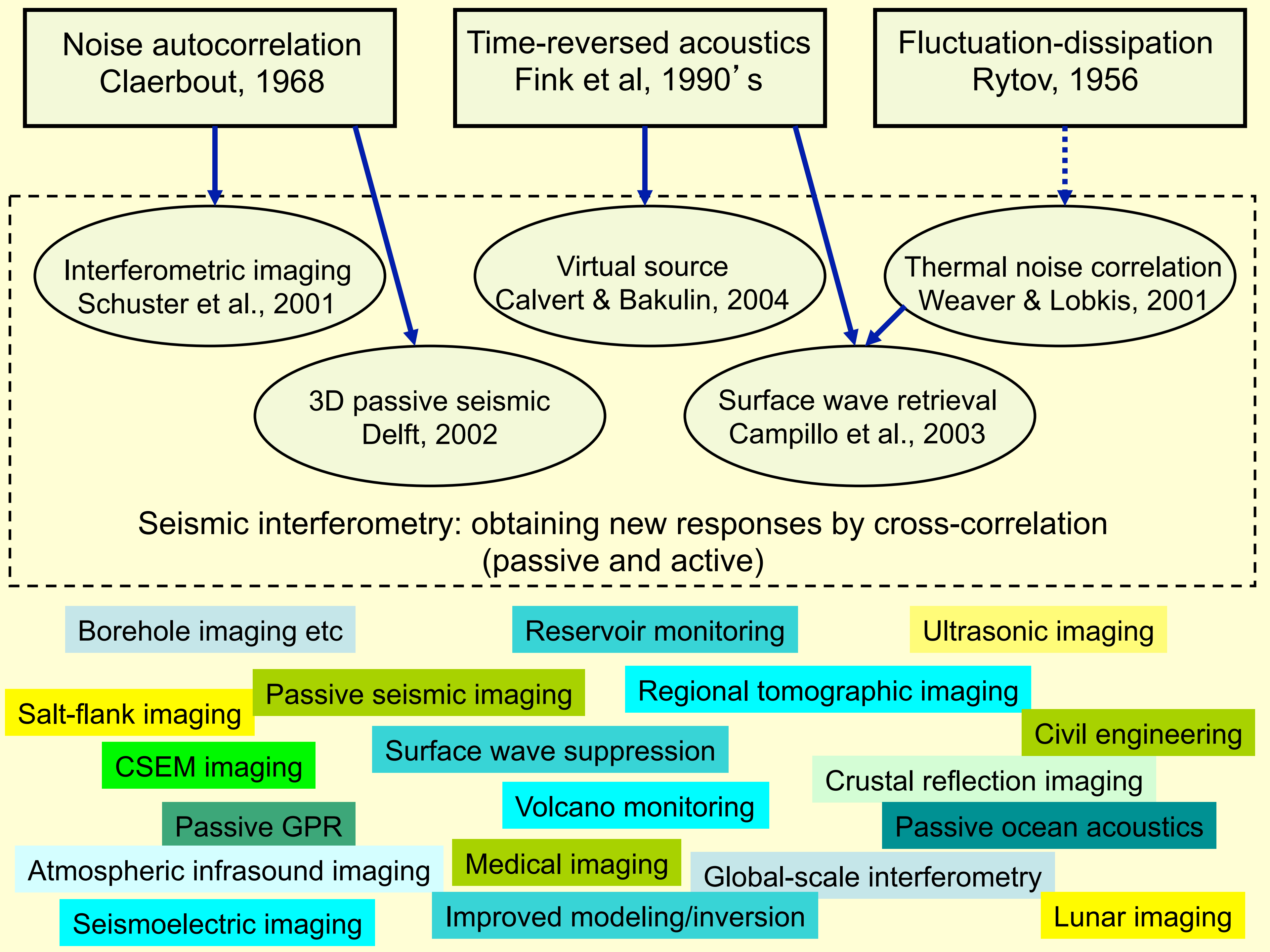
Masatoshi Miyazawa[1], Roel Snieder[1], and Anupama Venkataraman[2]

GEOPHYSICS, VOL. 73, NO. 4 (JULY-AUGUST 2008); P. D35–D40, 6 FIGS.





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Passive seismic imaging
Regional tomographic imaging
Salt-flank imaging
Civil engineering
Surface wave suppression
CSEM imaging
Crustal reflection imaging
Volcano monitoring
Passive GPR
Passive ocean acoustics
Atmospheric infrasound imaging
Medical imaging
Global-scale interferometry
Seismoelectric imaging
Improved modeling/inversion
Lunar imaging

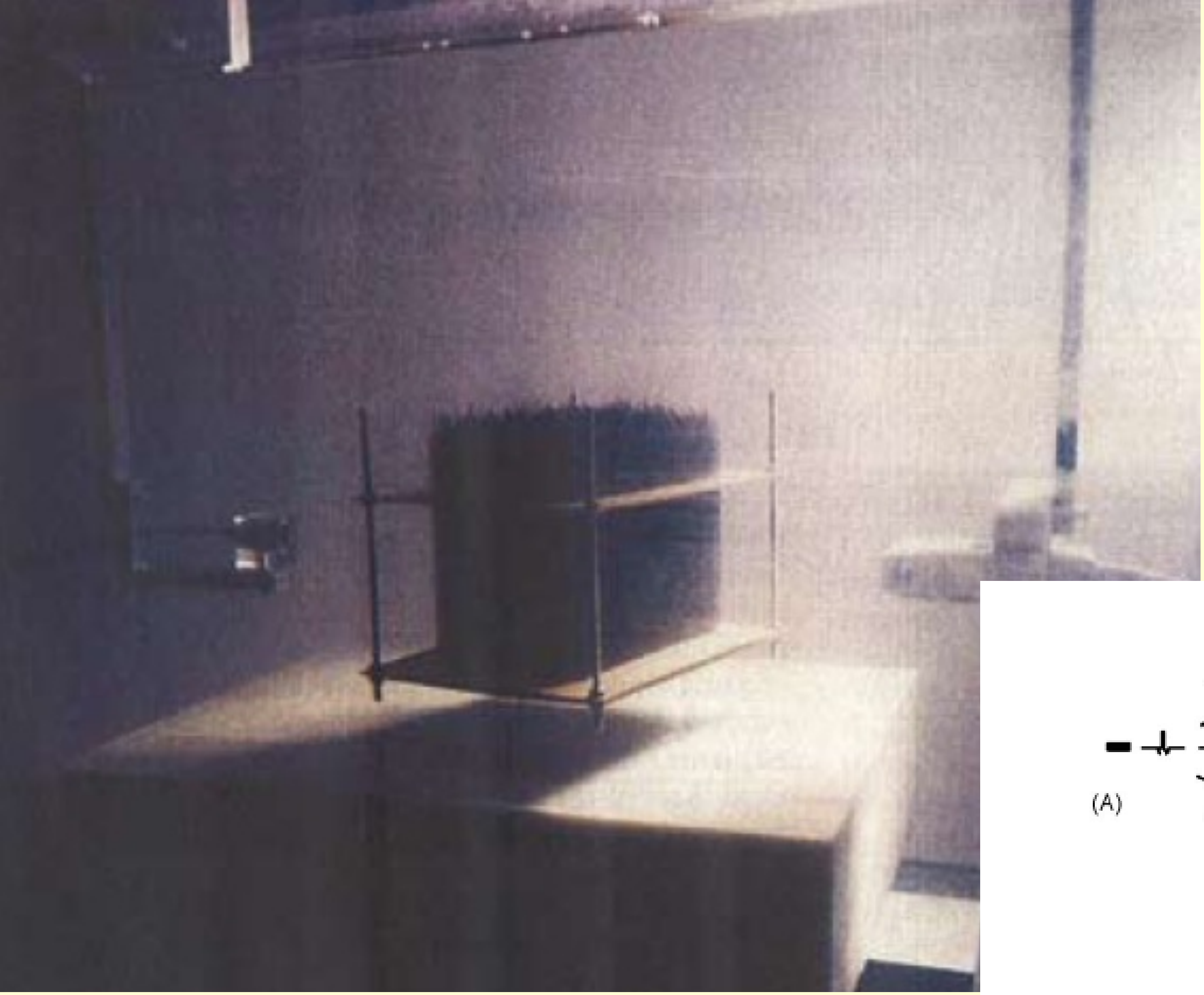
Time-reversed acoustics
Fink et al, 1990's

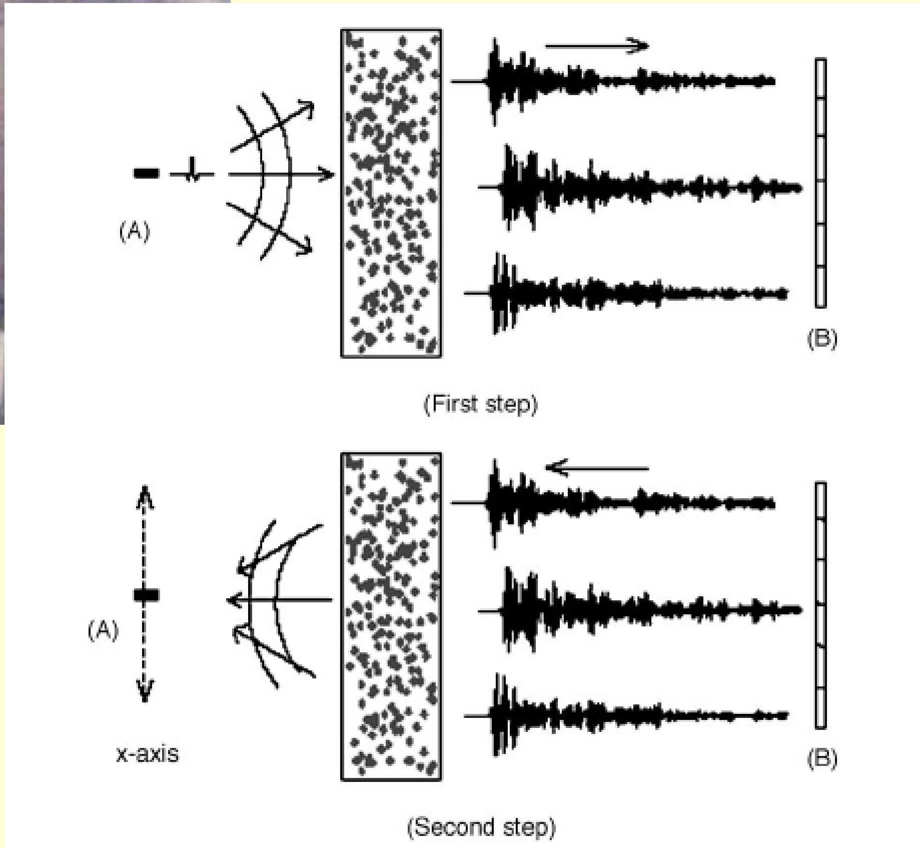
Time Reversed Acoustics

Nowadays we can intercept a spreading sound wave, time-reverse it and send it back to the source. That should greatly enhance our ability to locate gallstones and submarines.

Mathias Fink

March 1997 Physics Today





(A)
(B)
(First step)
(A)
x-axis
(B)
(Second step)

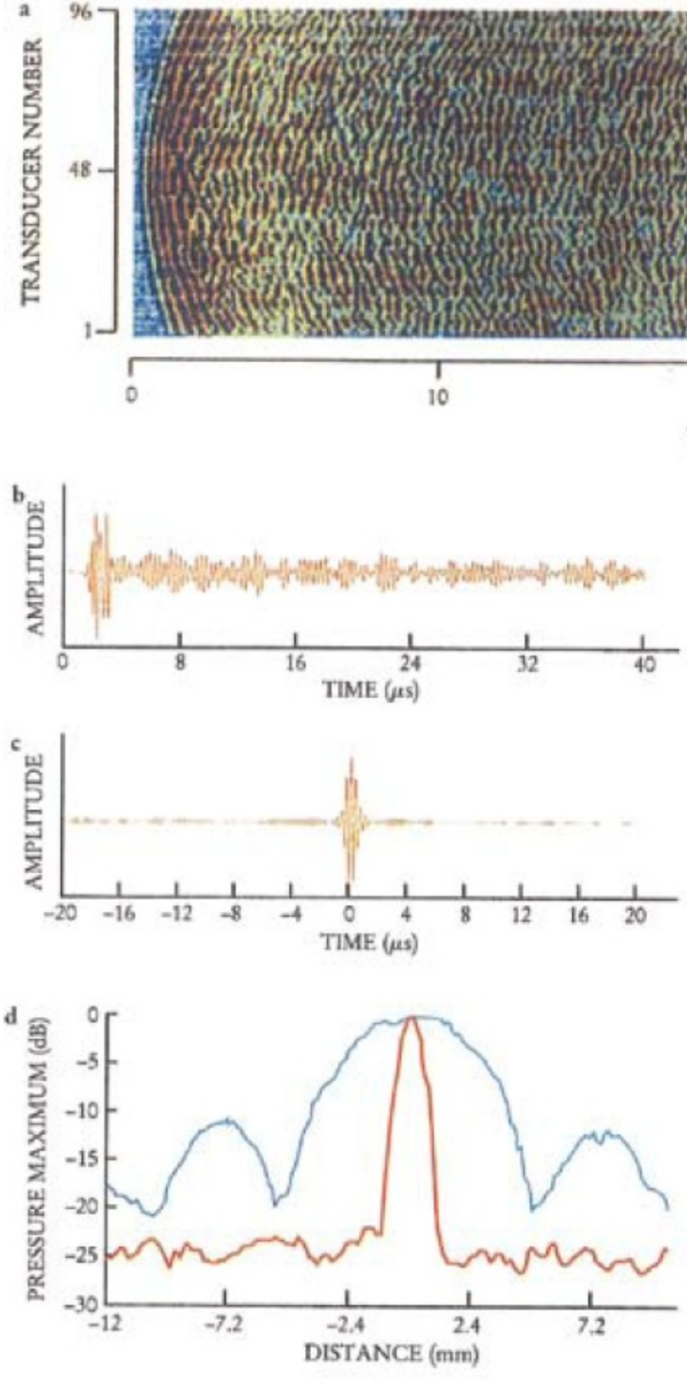
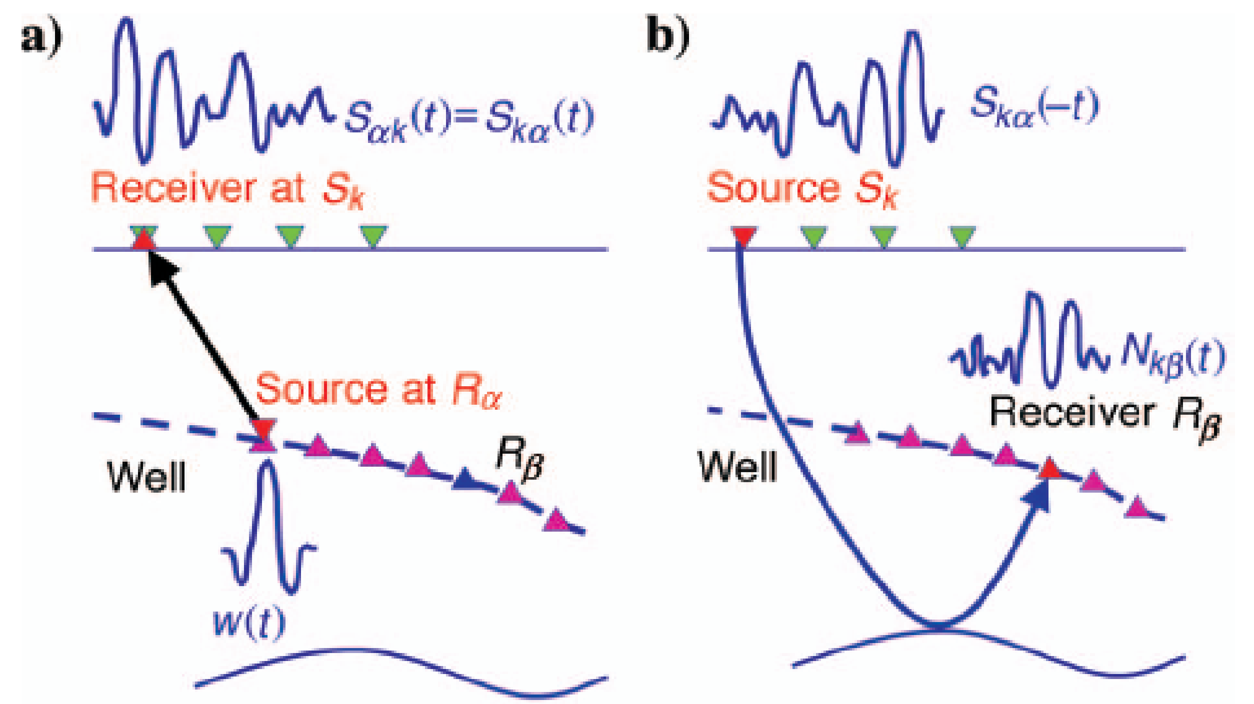


FIGURE 2. WAVEFRONTS recorded in the apparatus shown in figure 1. **a:** Wavefront recorded by the 96-element transducer mirror array after the initial microsecond ultrasonic pulse has passed through the forest of scattering rods. Color indicates acoustic amplitude. Each horizontal line is a temporal echograph of the signal received by one of the transducer elements. **b:** The acoustic signal recorded by an individual transducer of the mirror array. After the first (ballistic) wavefront arrives, one sees the much longer train of interference between the many scattered wave components. **c:** The returning time-reversed wave measured at the initial source position shows strong temporal recompression. The distention due to multiple scattering, as seen in **b**, has been largely squeezed out. **d:** Spatial recompression of the time-reversed wave is measured by scanning with a hydrophone in the plane of the initial source. Paradoxically, better focusing is seen in the multiscattering medium (red curve) than when all the scattering rods are removed (blue curve). (Adapted from ref. 5.)

GEOPHYSICS, VOL. 71, NO. 4 (JULY-AUGUST 2006); P. SI139–SI150, 25 FIGS.

The virtual source method: Theory and case study

Andrey Bakulin[1] and Rodney Calvert[1]



GEOPHYSICS, VOL. 71, NO. 4 (JULY-AUGUST 2006); P. SI139–SI150, 25 FIGS.

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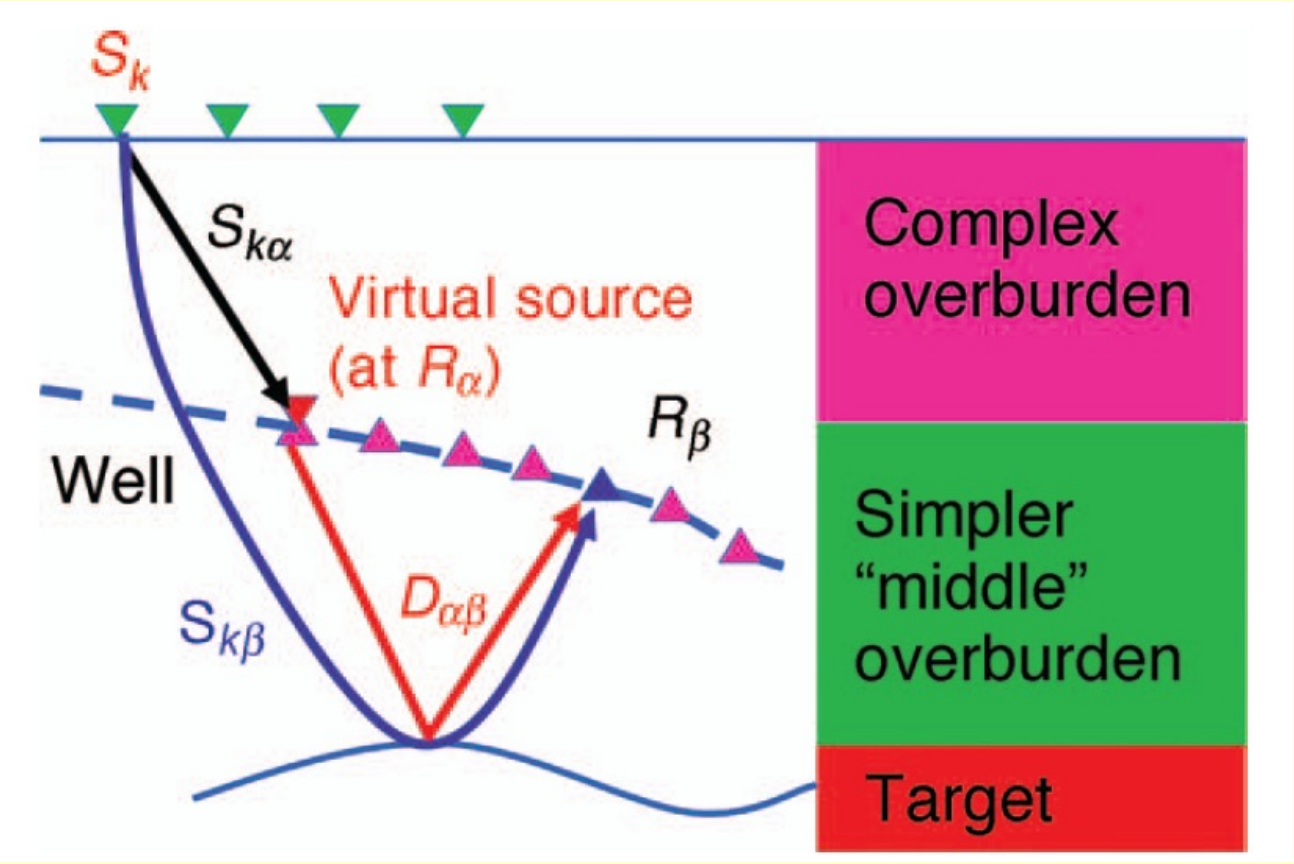
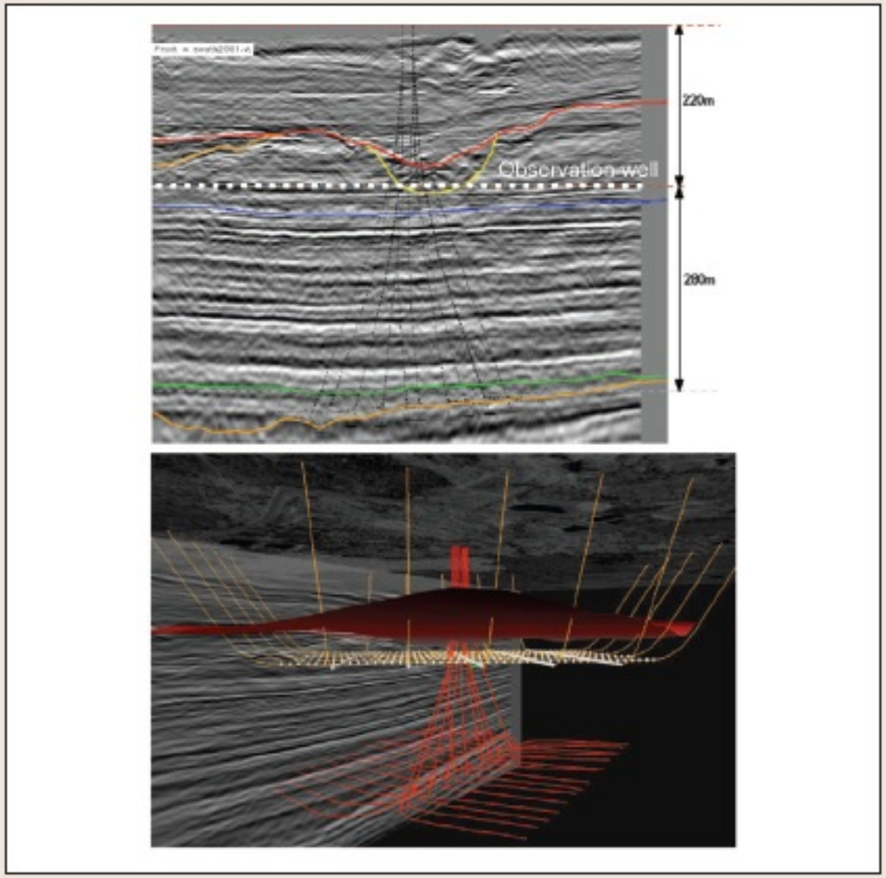
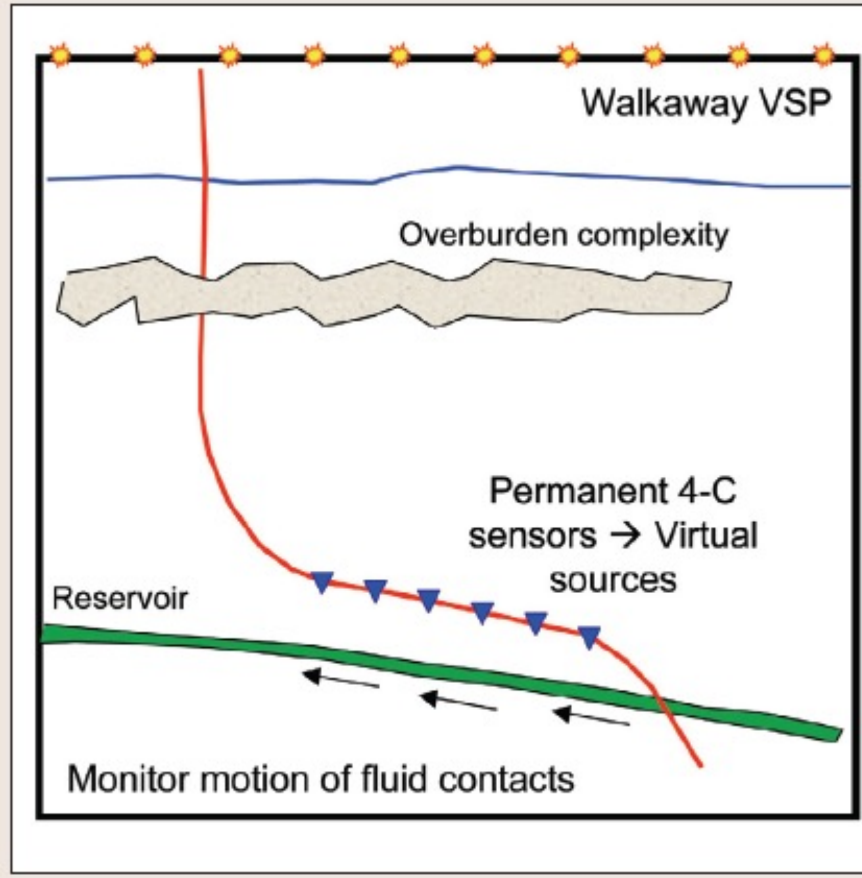


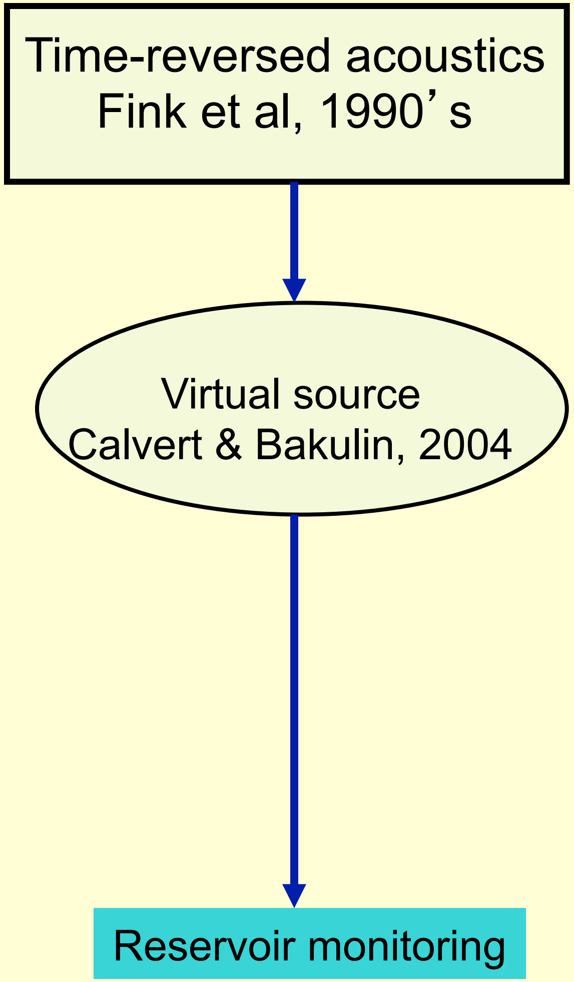
Virtual source applications to imaging and reservoir monitoring

A. BAKULIN, A. MATEEVA, K. MEHTA, P. JORGENSEN, J. FERRANDIS, I. SINHA HERHOLD, and J. LOPEZ, Shell International Exploration & Production, Houston, USA





THE LEADING EDGE JUNE 2007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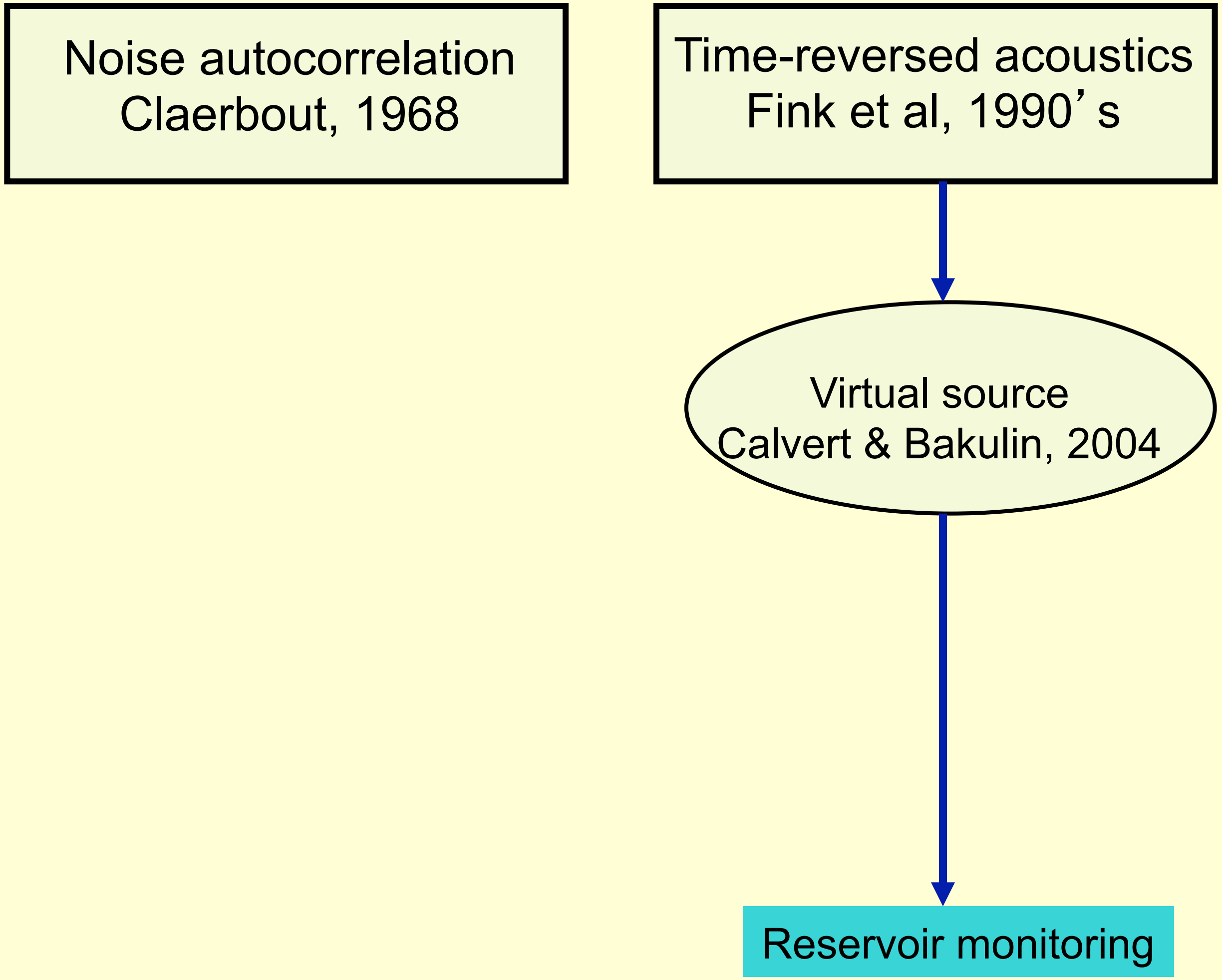
Reservoir monitoring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GEOPHYSICS, VOL. 33, NO. 2 (APRIL, 1968), P. 264–269, 3 FIGS.

SYNTHESIS OF A LAYERED MEDIUM FROM ITS ACOUSTIC TRANSMISSION RESPONSE†

JON F. CLAERBOUT*

A direct (noniterative) method is presented to determine an acoustic layered medium from the seismogram due to a time-limited plane wave incident from the lower halfspace. It is shown that one side of the autocorrelation of the seismogram due to an impulsive source at depth is the seismogram due to an impulsive source on the surface. This transforms the problem to the acoustic reflections problem as solved by Kunetz. Both the deep source time function and the layering can be determined from a surface seismogram.

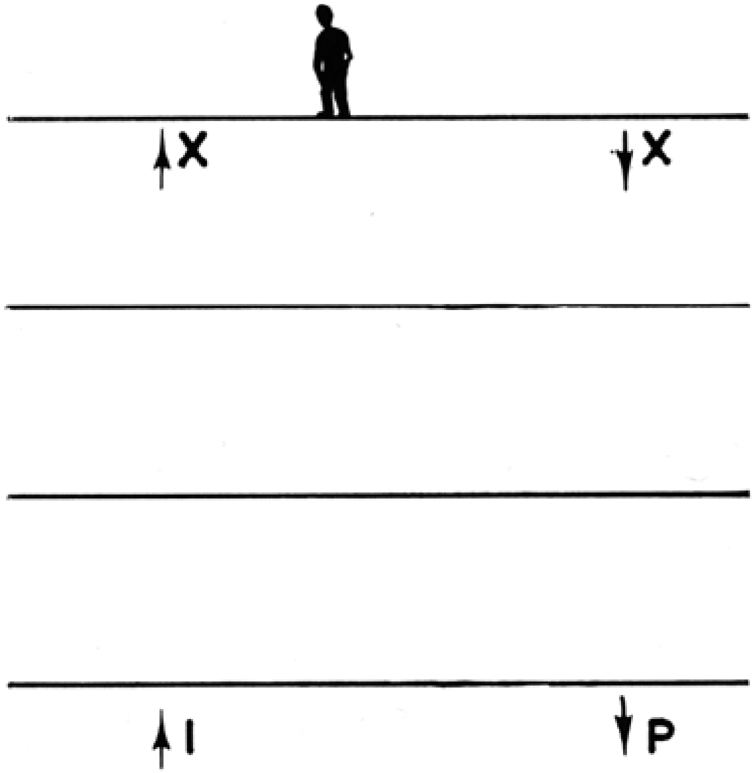


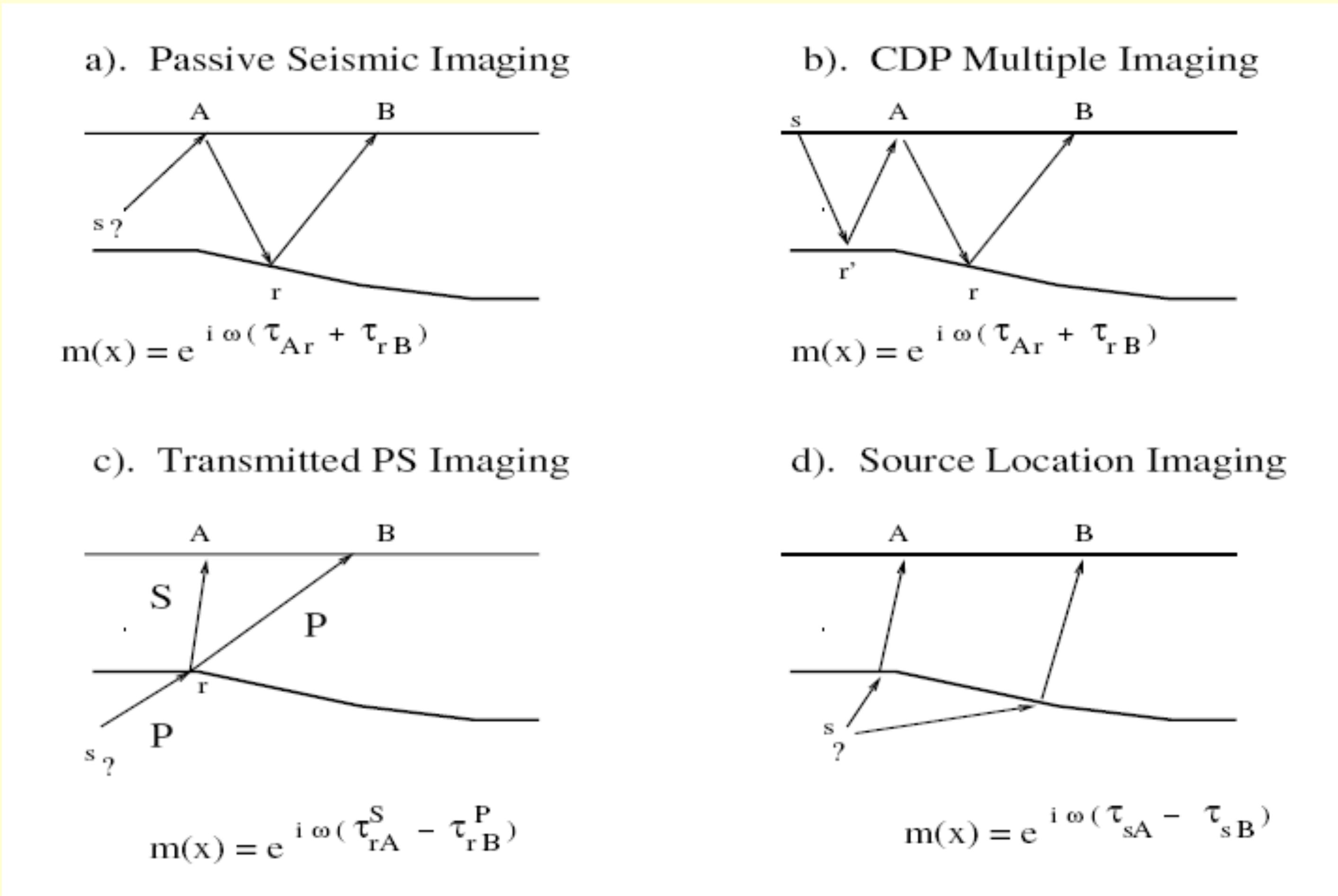
FIG. 3. Incident, observed, and reflected waves in the transmission problem.

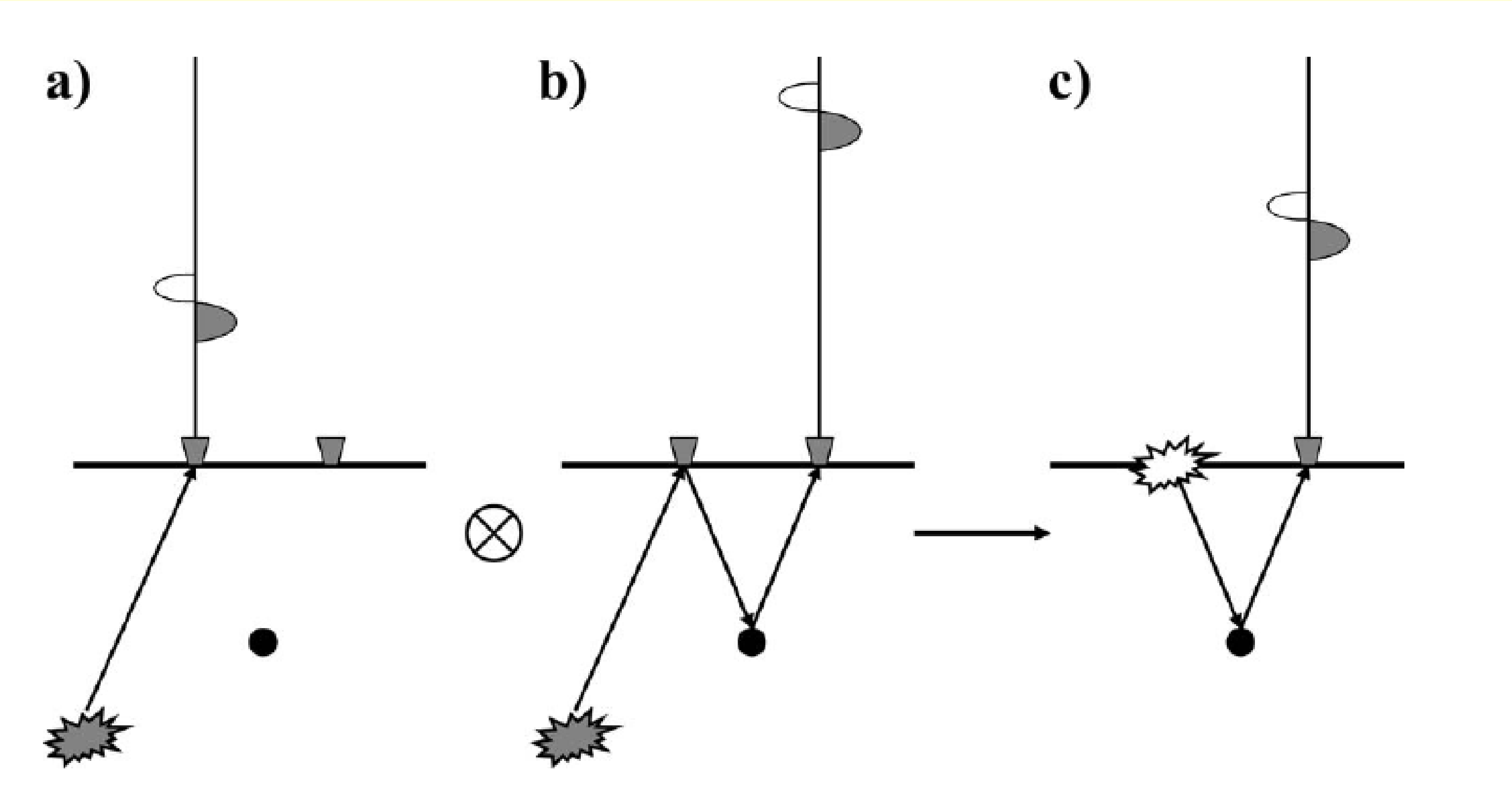
$$(1 + R(1/z) + R(z)) = \frac{1}{\prod \det} X(z)X(1/z) \quad (22)$$

This shows the important result: *The reflection seismogram from a surface source and a surface receiver is one side of the autocorrelation of the seismogram from a source at depth and the same receiver.*

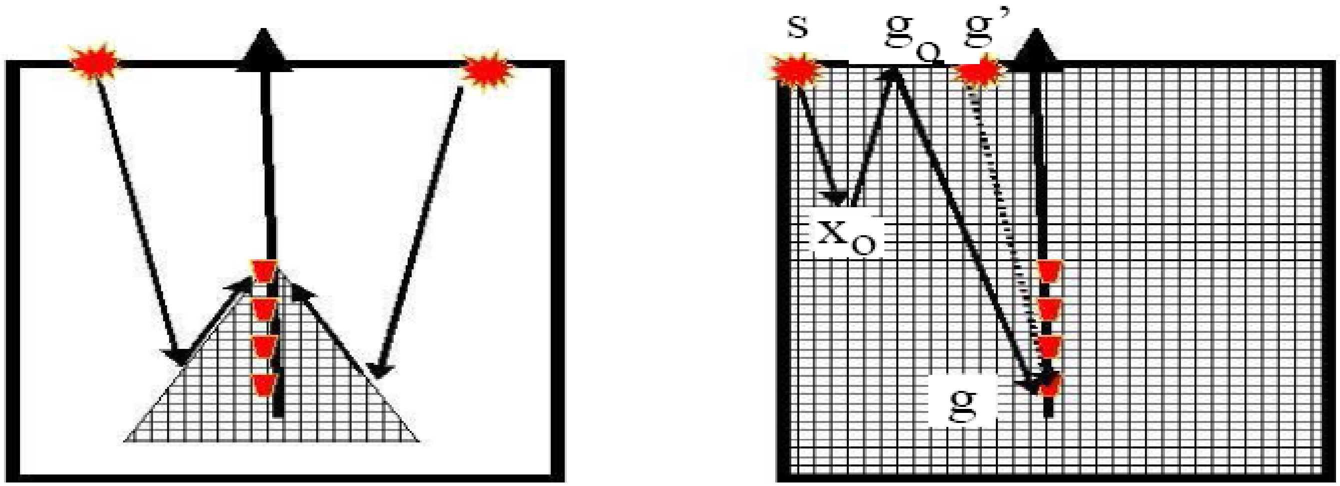
A-032 THEORY OF DAYLIGHT/INTERFEROMETRIC IMAGING: TUTORIAL

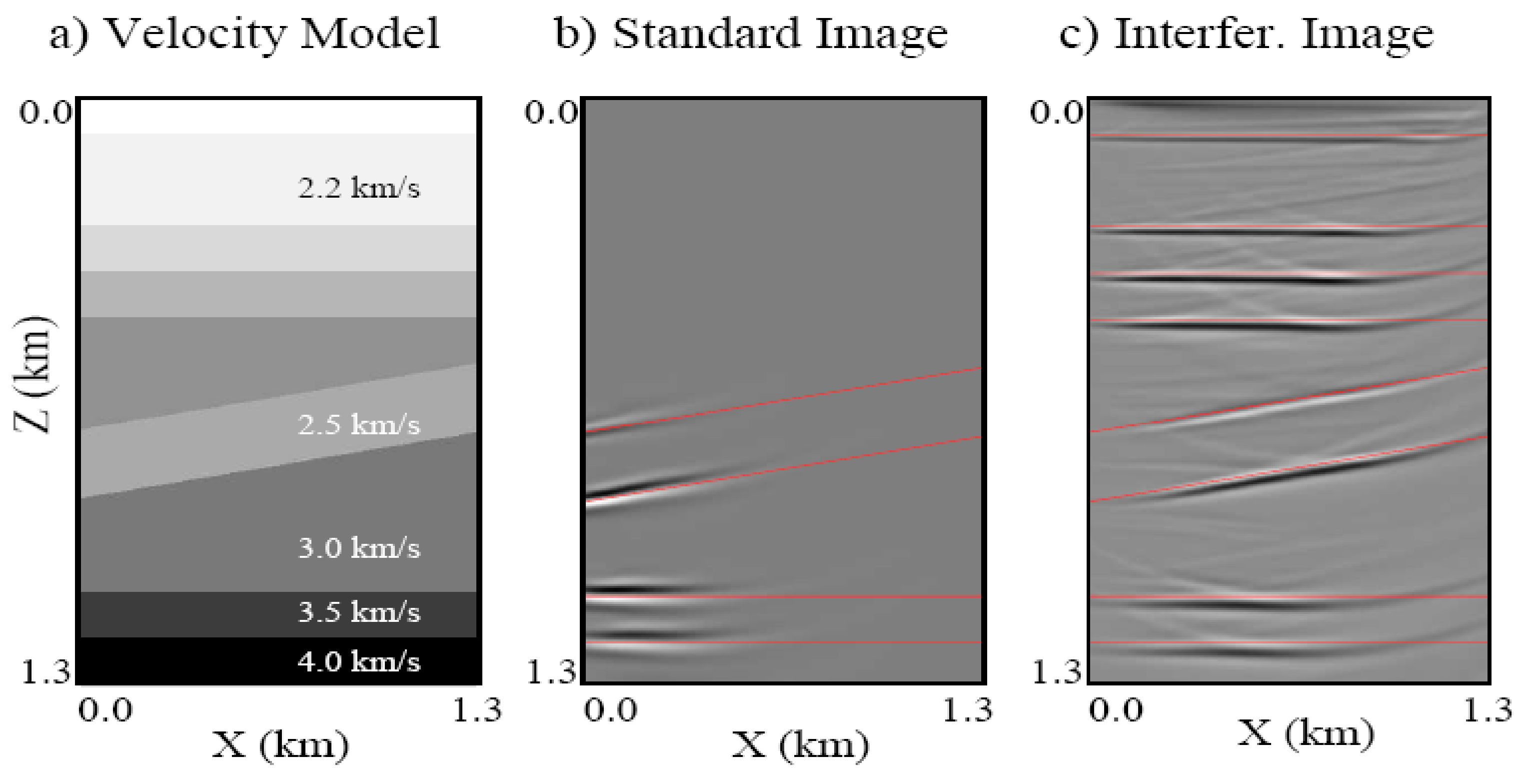
GERARD T. SCHUSTER
University of Utah, Salt Lake City, Utah 84112 U.S.A



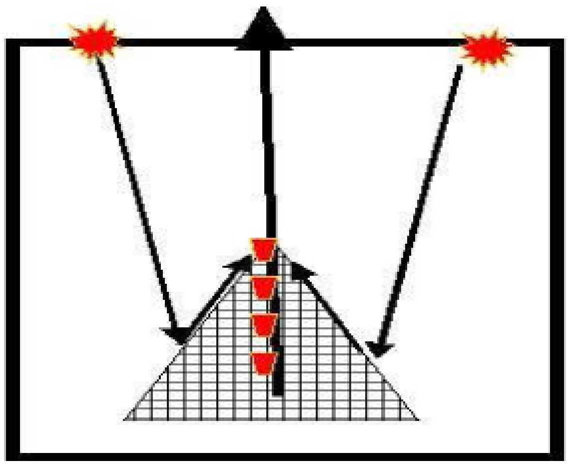

a)
b)
c)

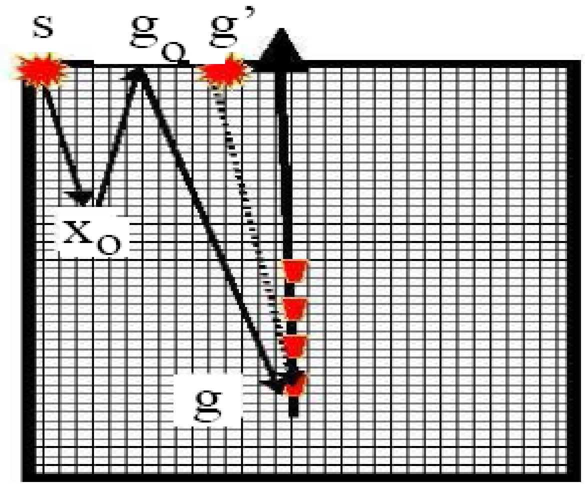
Primary vs Ghost Migration Illumination

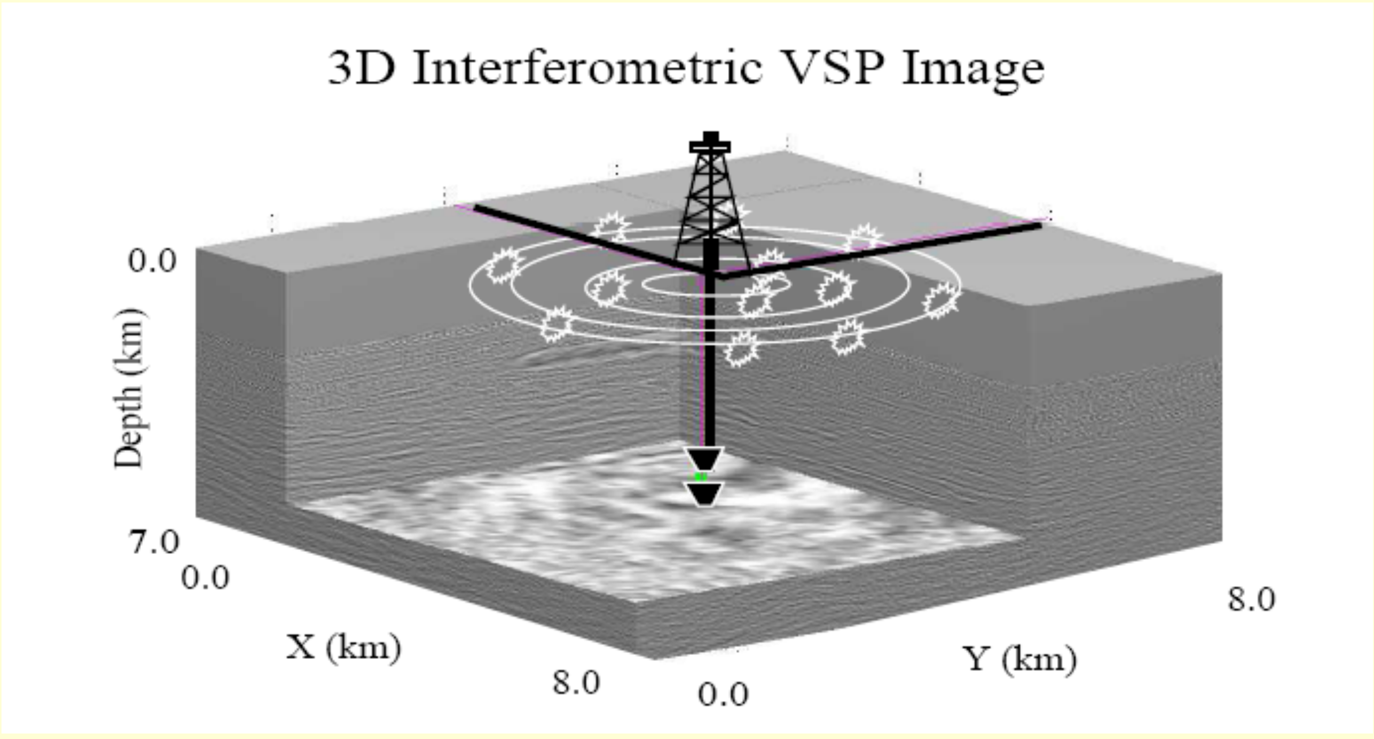


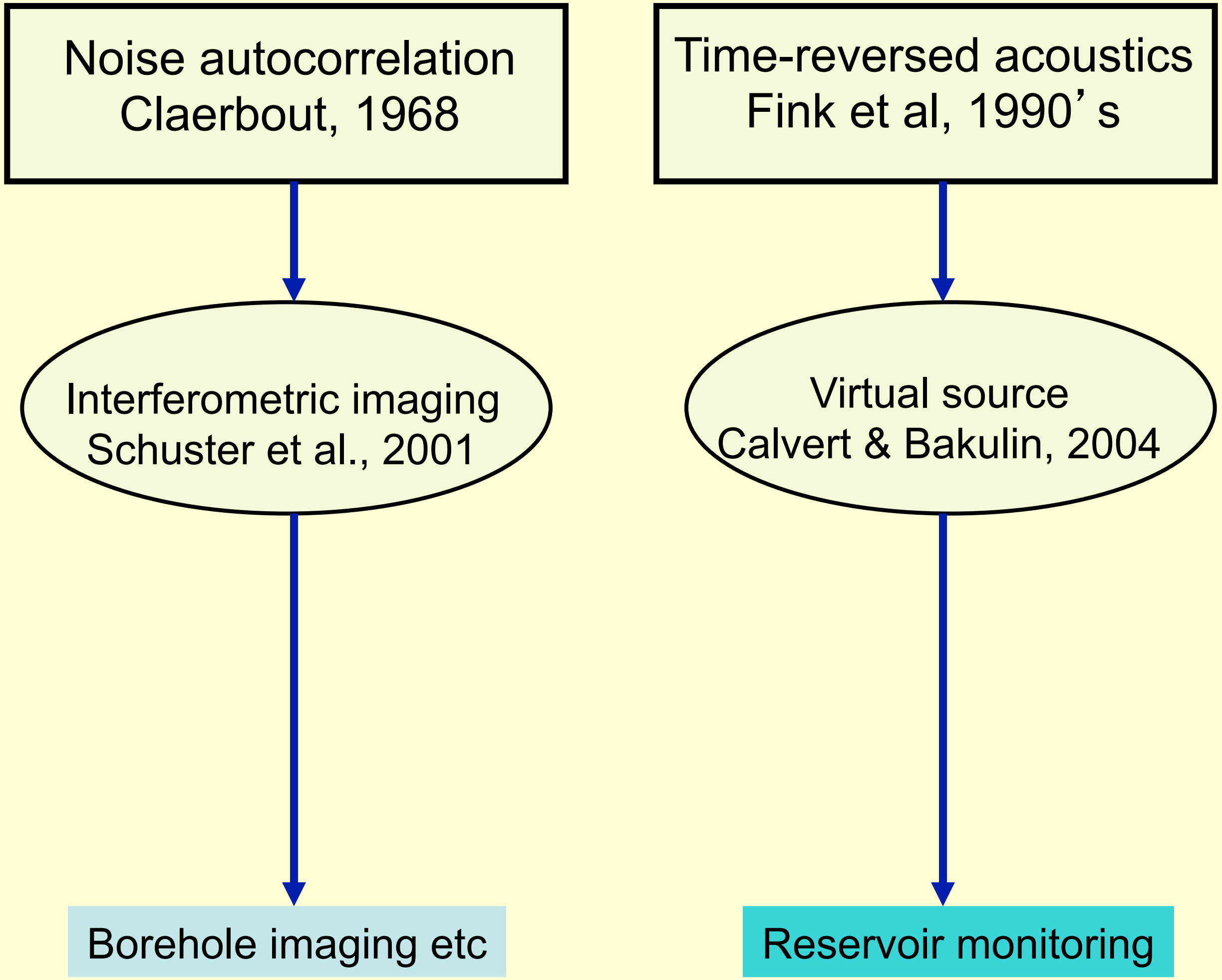


Primary vs Ghost Migration Illumination





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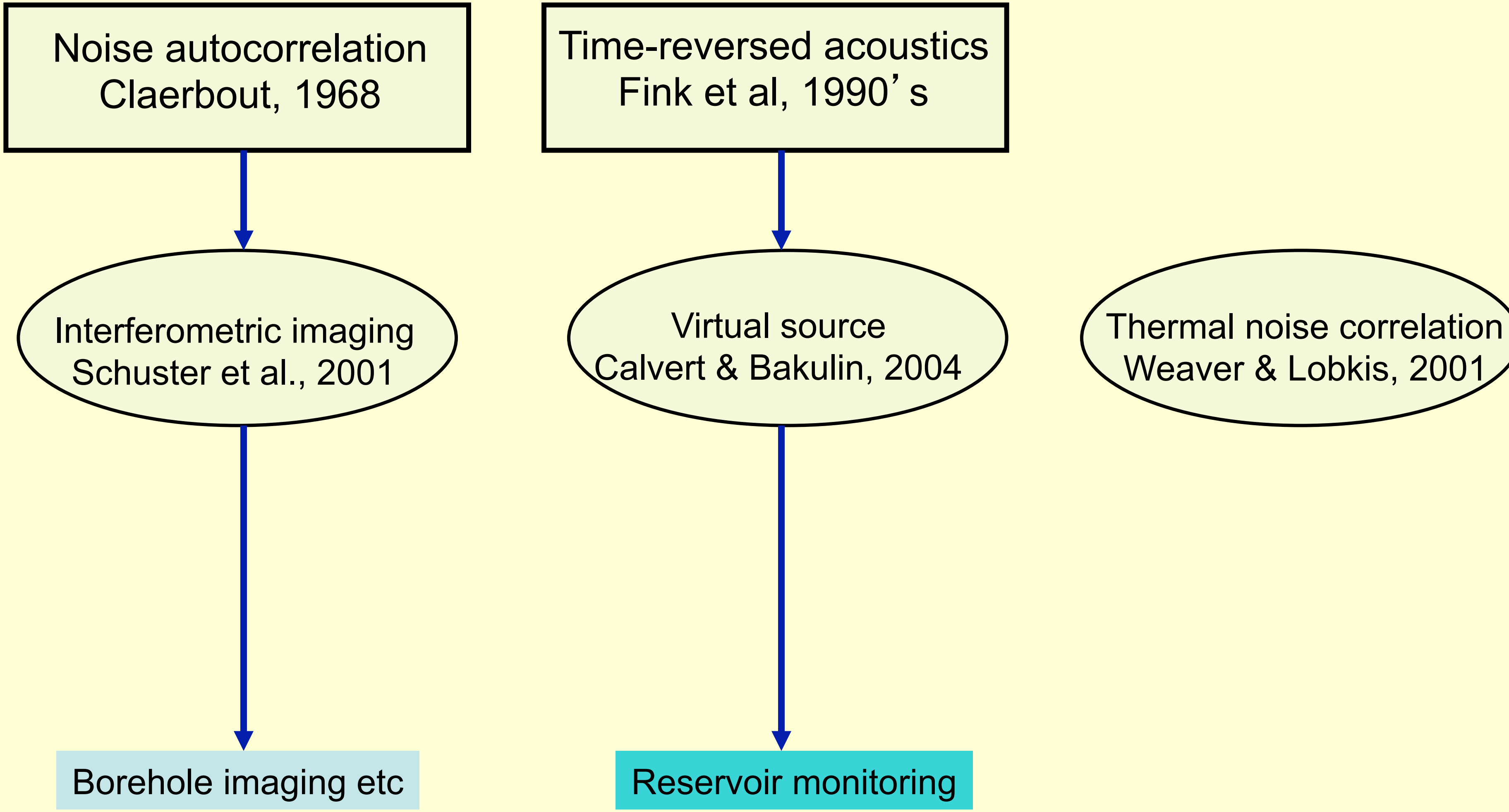
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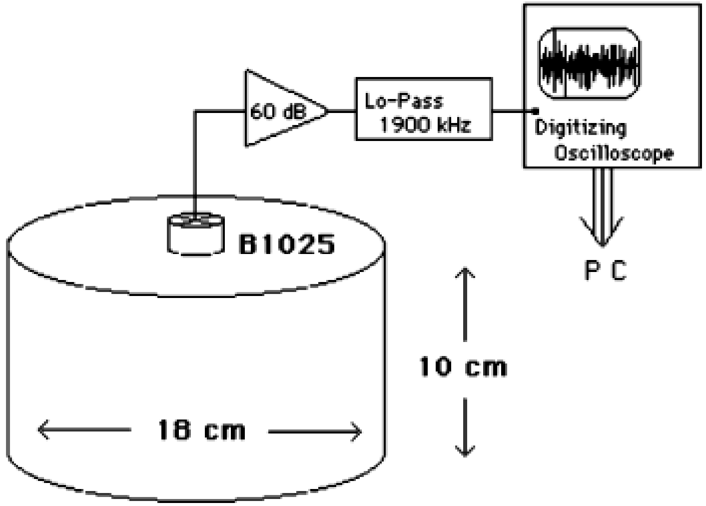
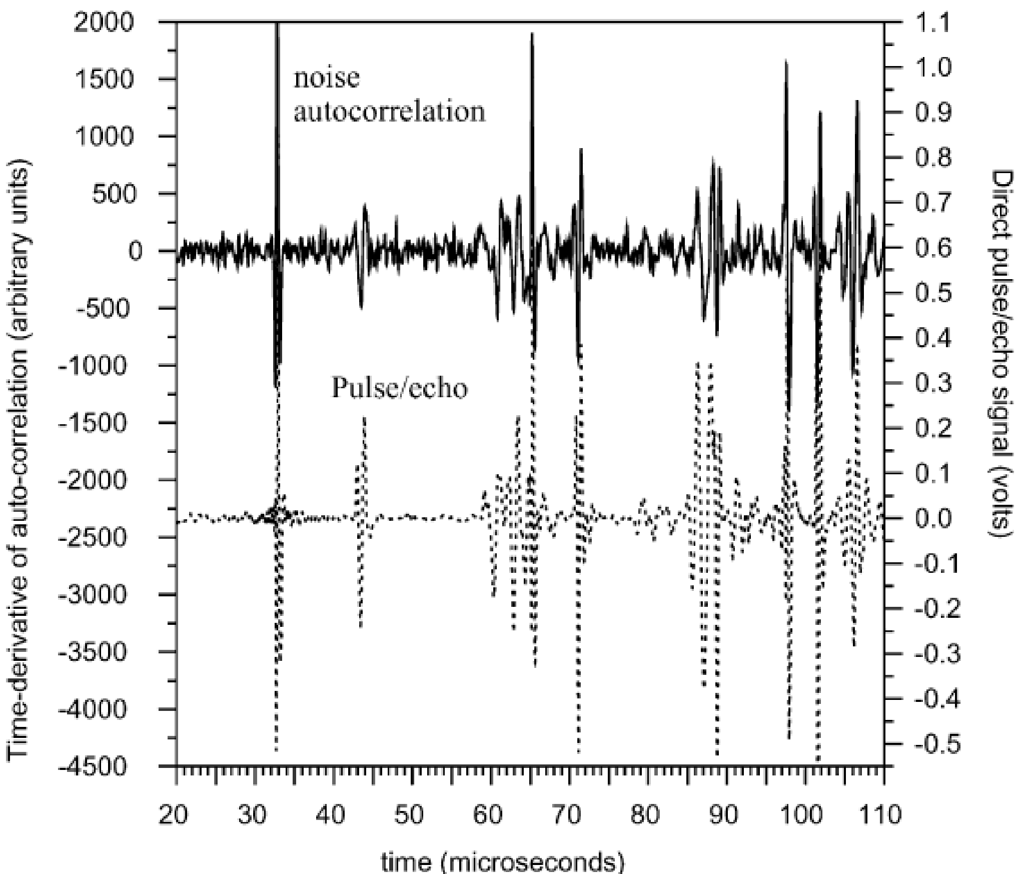
Reservoir monitoring

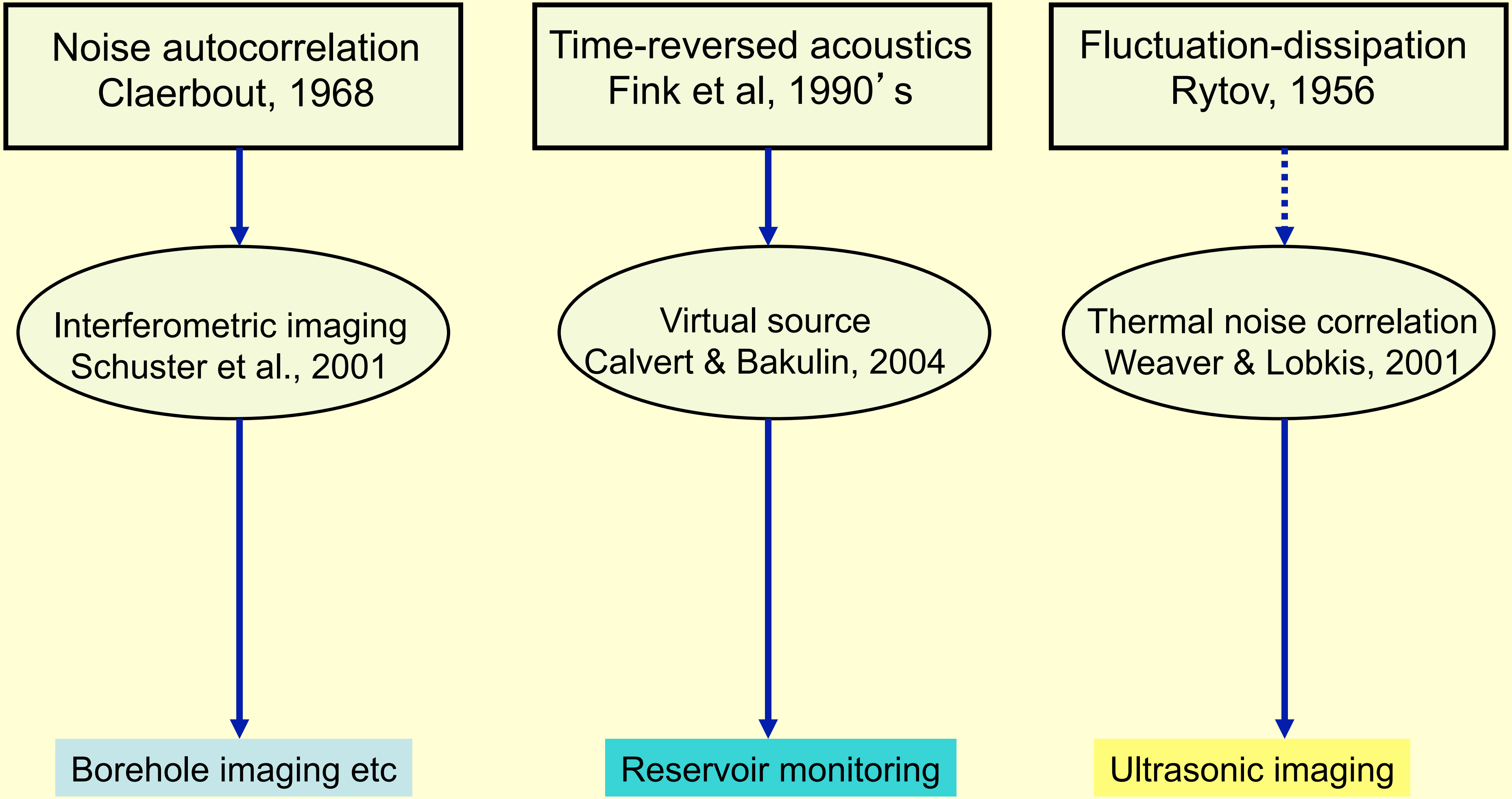
On the emergence of the Green's function in the correlations of a diffuse field: pulse-echo using thermal phonons

Richard Weaver *, Oleg Lobkis



Ultrasonics 40 (2002) 435–439

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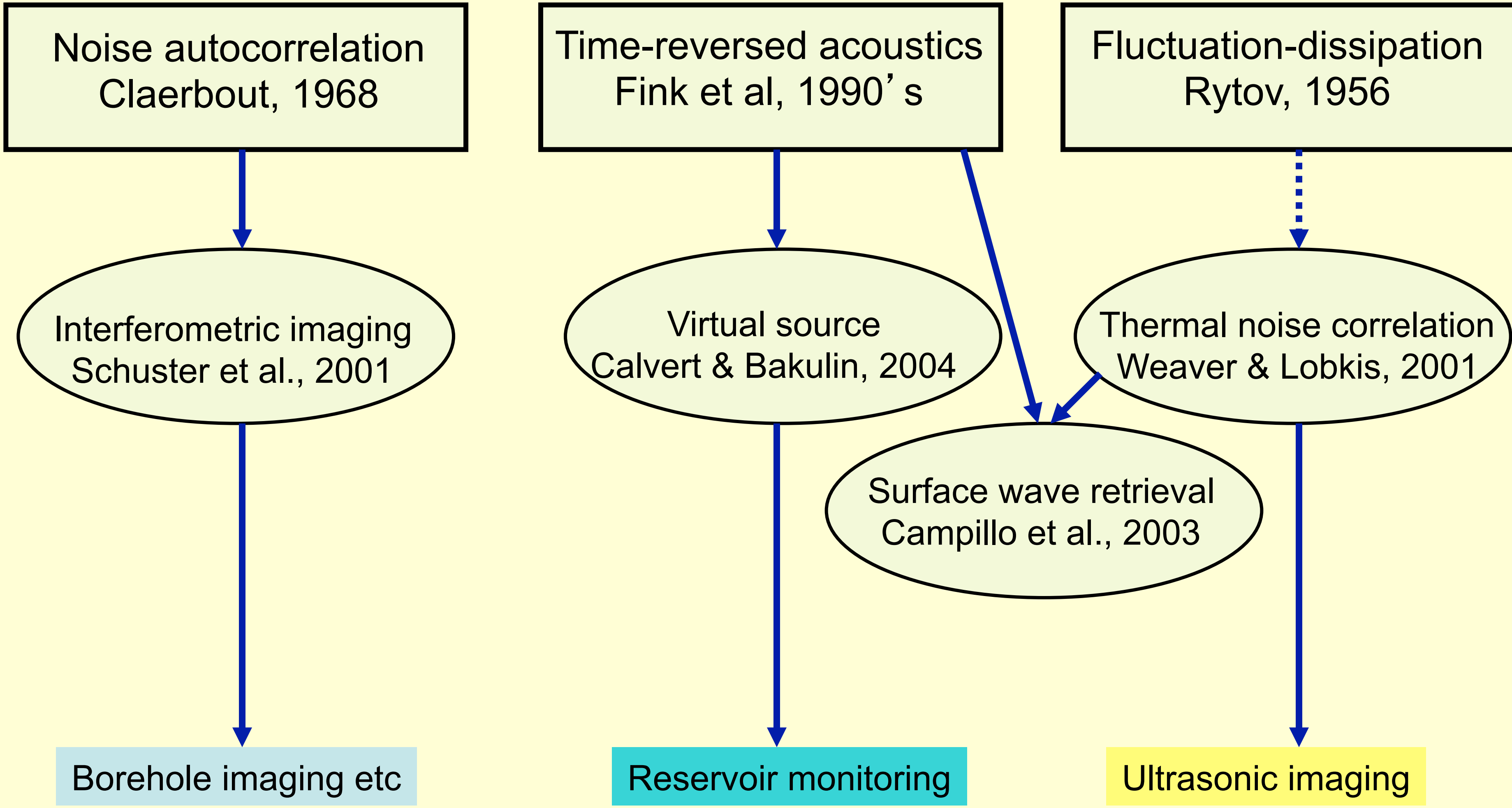

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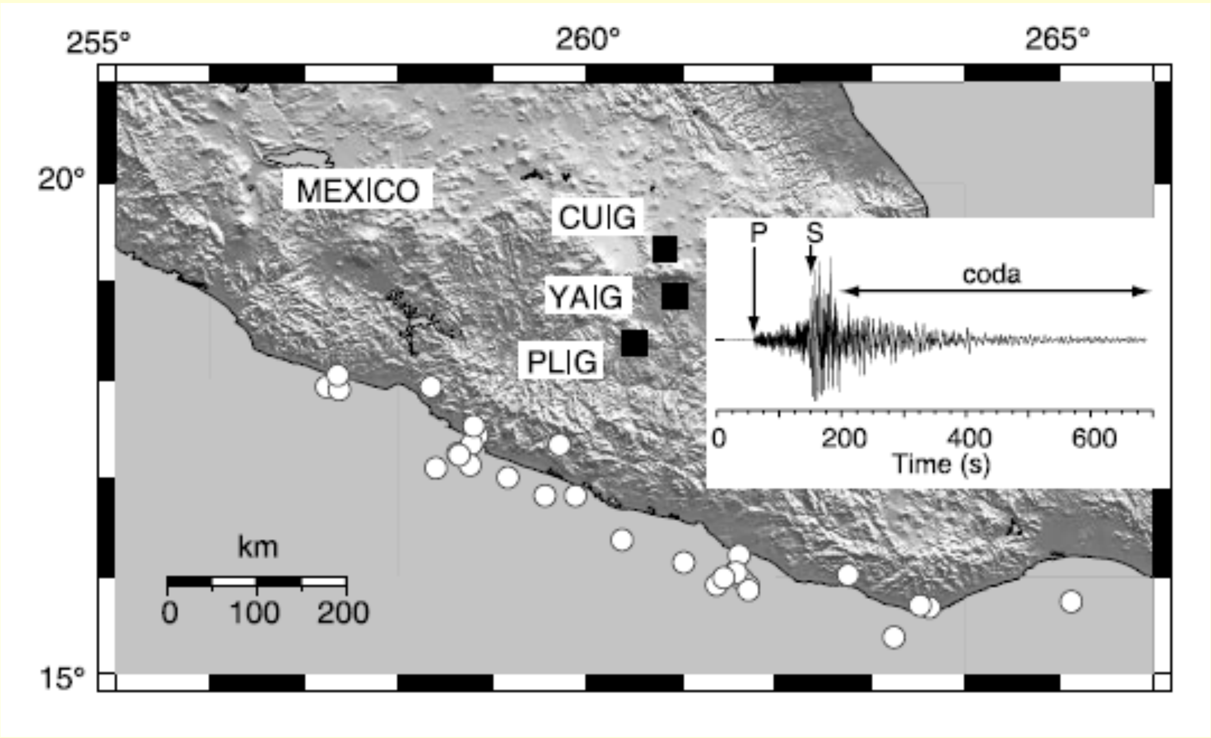
SCIENCE VOL 299 24 JANUARY 2003

Long-Range Correlations in the Diffuse Seismic Coda

Michel Campillo* and Anne Paul



High-Resolution Surface-Wave Tomography from Ambient Seismic Noise

Nikolai M. Shapiro,[1*] Michel Campillo,[2] Laurent Stehly,[2] Michael H. Ritzwoller[1]

SCIENCE VOL 307 11 MARCH 2005

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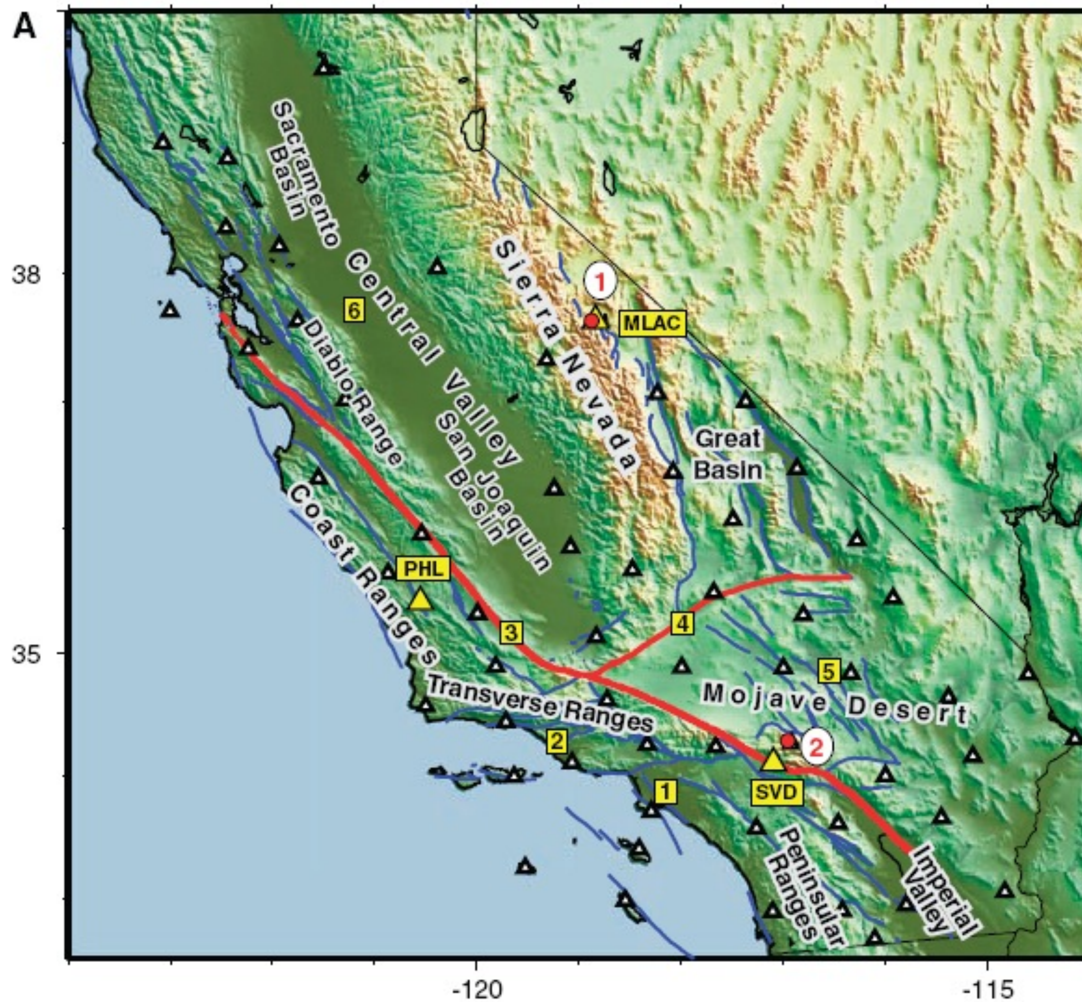

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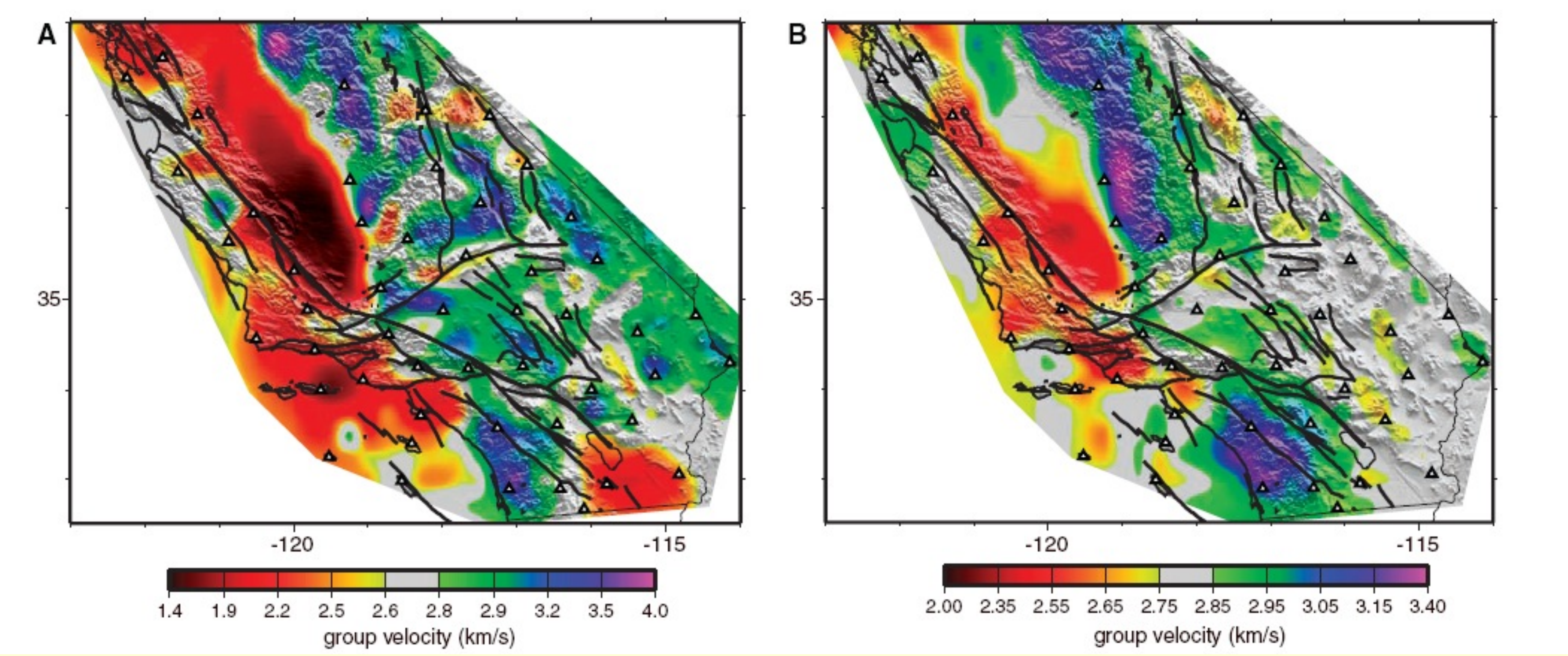
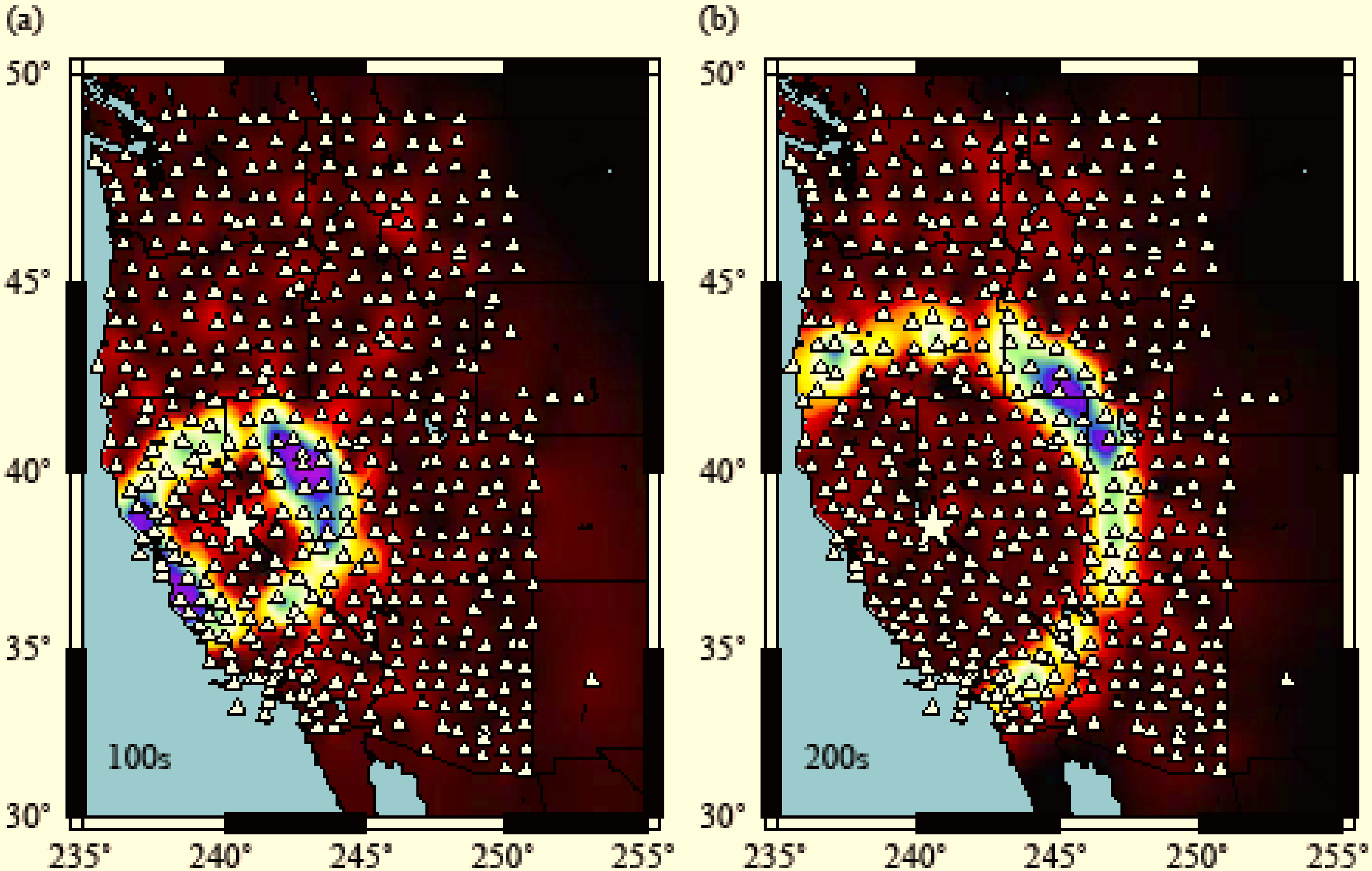
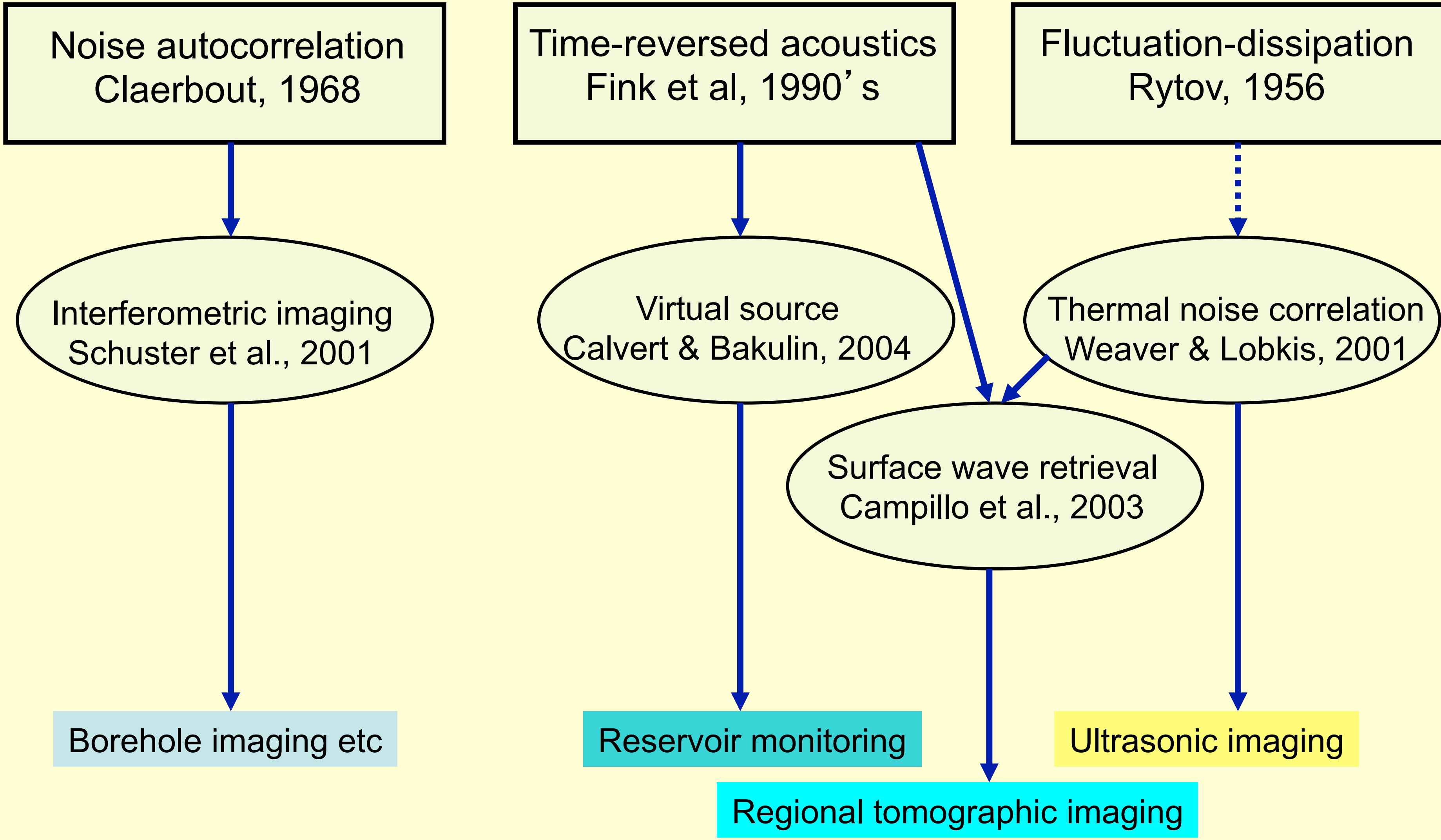


Eikonal tomography: surface wave tomography by phase front tracking across a regional broad-band seismic array

Fan-Chi Lin,[1] Michael H. Ritzwoller[1] and Roel Snieder[2]

Geophys. J. Int. (2009) **177,** 1091–1110

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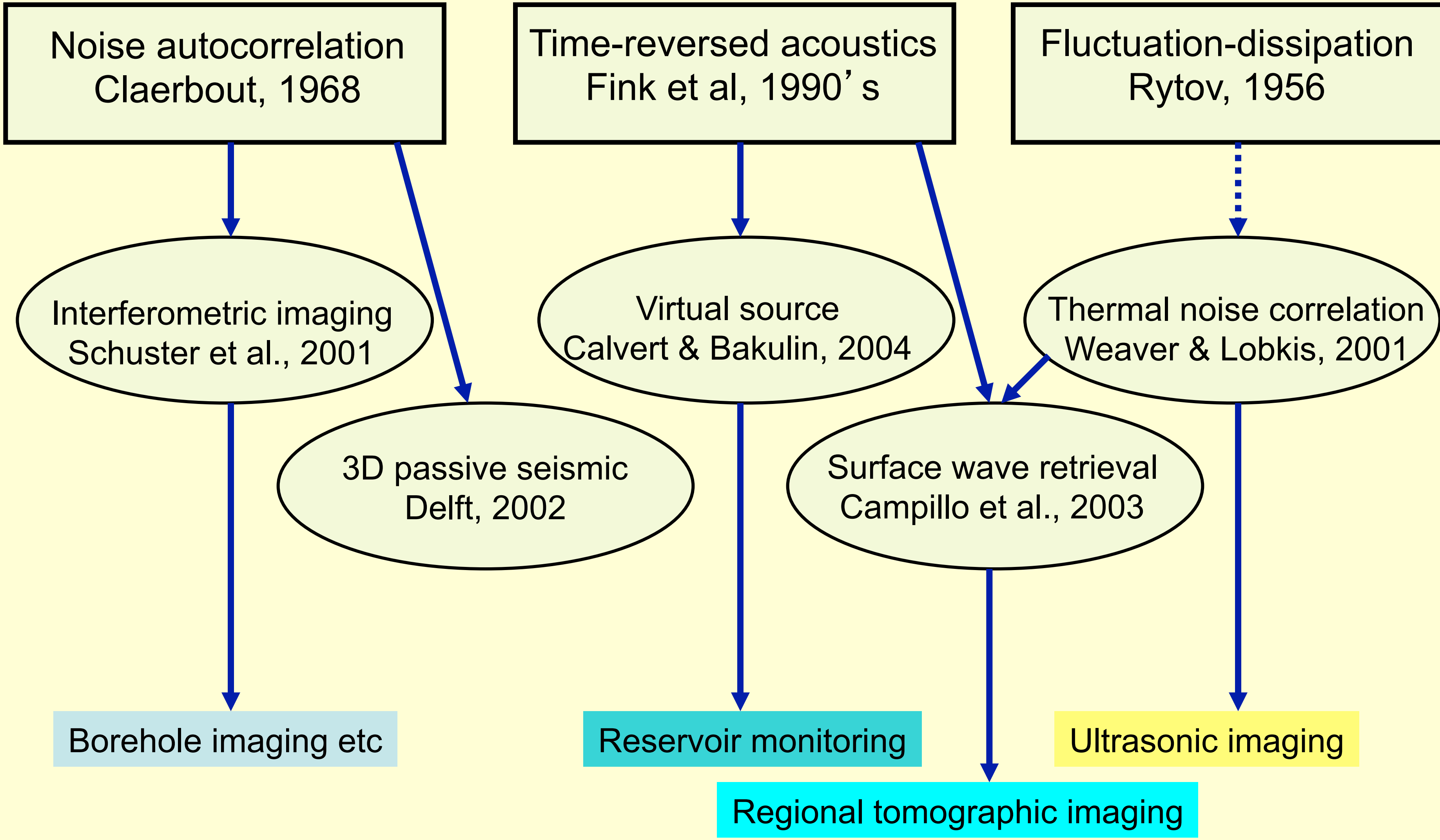
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GEOPHYSICS, VOL. 33, NO. 2 (APRIL, 1968), P. 264–269, 3 FIGS.

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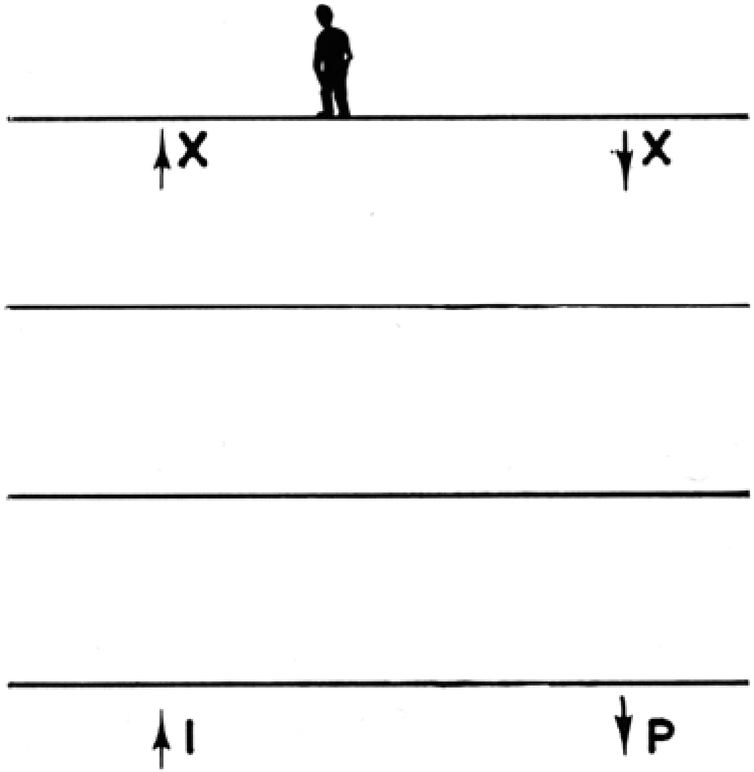

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GEOPHYSICS, VOL. 33, NO. 2 (APRIL, 1968), P. 264–269, 3 FIGS.

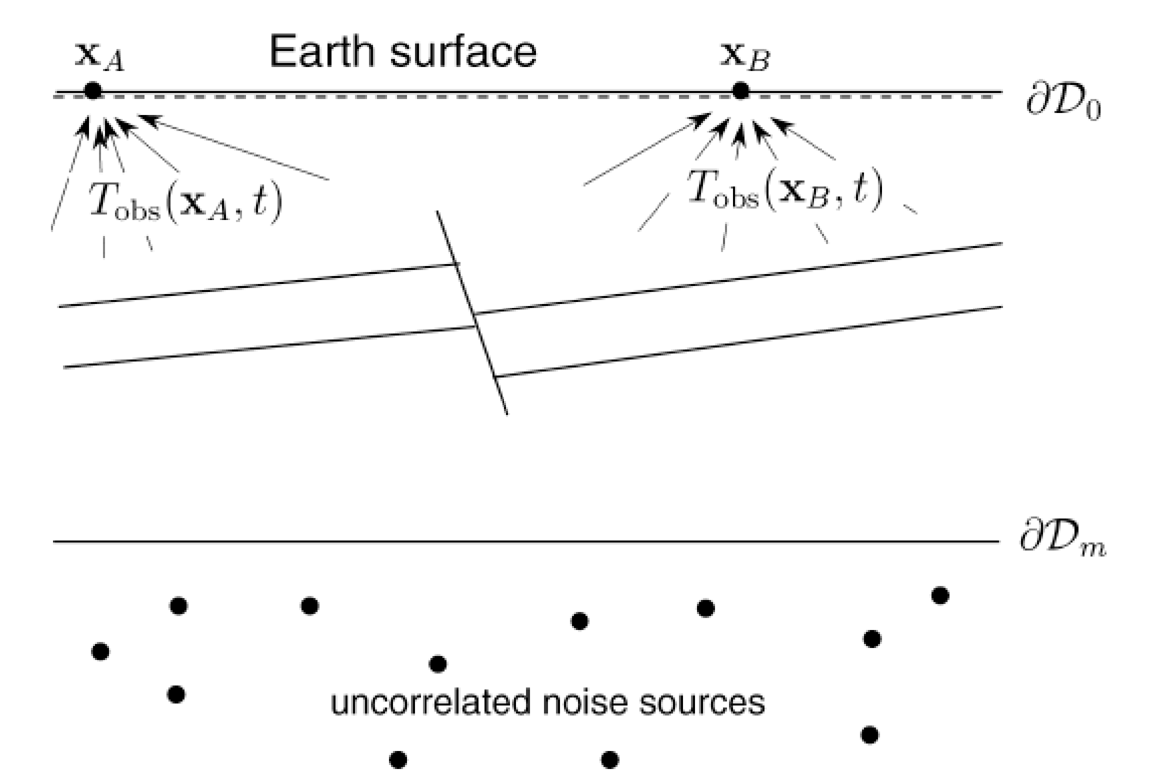
SYNTHESIS OF A LAYERED MEDIUM FROM ITS ACOUSTIC TRANSMISSION RESPONSE†

JON F. CLAERBOUT*

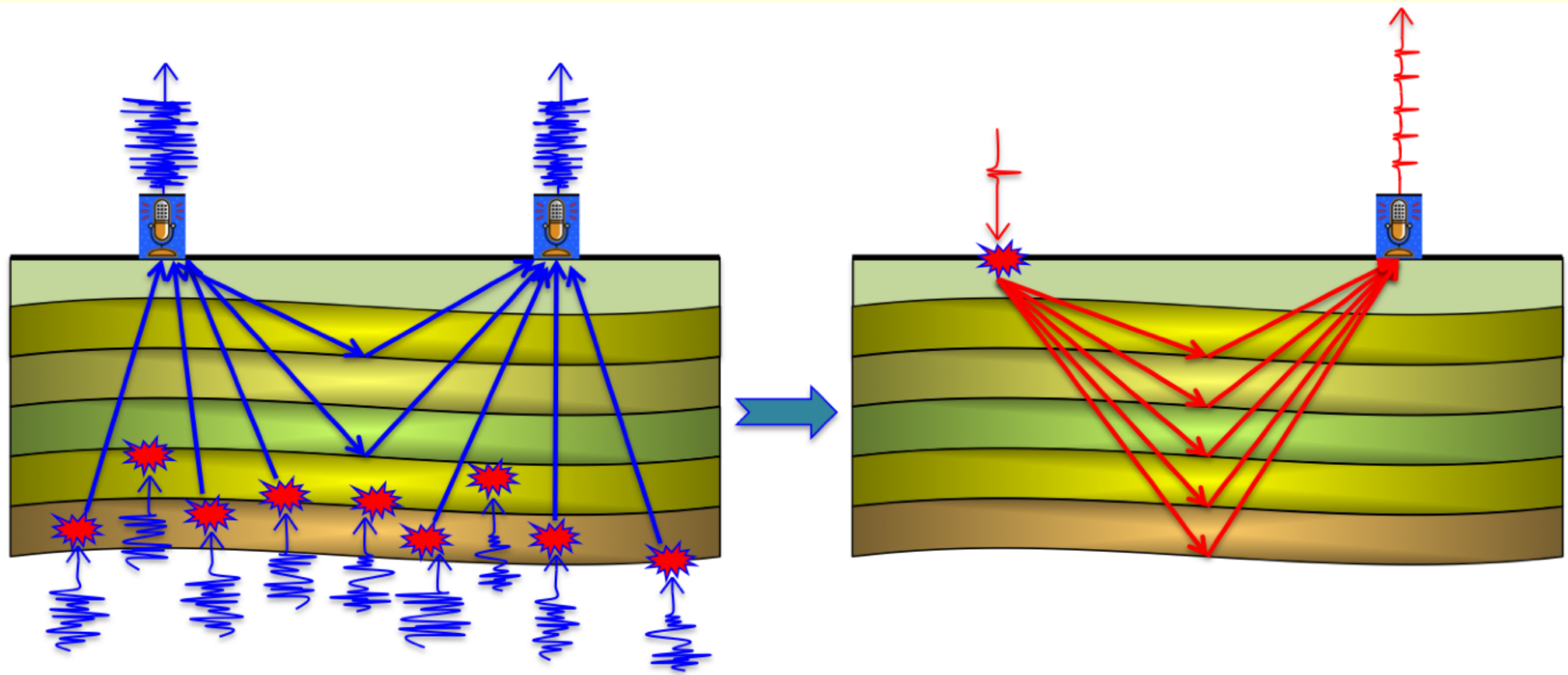
GEOPHYSICS, VOL. 68, NO. 5 (SEPTEMBER-OCTOBER 2003); P. 1756–1759, 3 FIGS.

Synthesis of an inhomogeneous medium from its acoustic transmission response

Kees Wapenaar*



$$R(\mathbf{x}_A, \mathbf{x}_B, t) + R(\mathbf{x}_A, \mathbf{x}_B, -t) = \delta(\mathbf{x}_{H,A} - \mathbf{x}_{H,B})\delta(t) - T_{\rm obs}(\mathbf{x}_A, -t) * T_{\rm obs}(\mathbf{x}_B, t) \qquad (16)$$



GEOPHYSICS, VOL. 74, NO. 5 (SEPTEMBER-OCTOBER 2009); P. A63–A67, 5 FIGS.
10.1190/1.3193529

Reflection images from ambient seismic noise

Deyan Draganov[1], Xander Campman[2], Jan Thorbecke[1], Arie Verdel[2], and Kees Wapenaar[1]

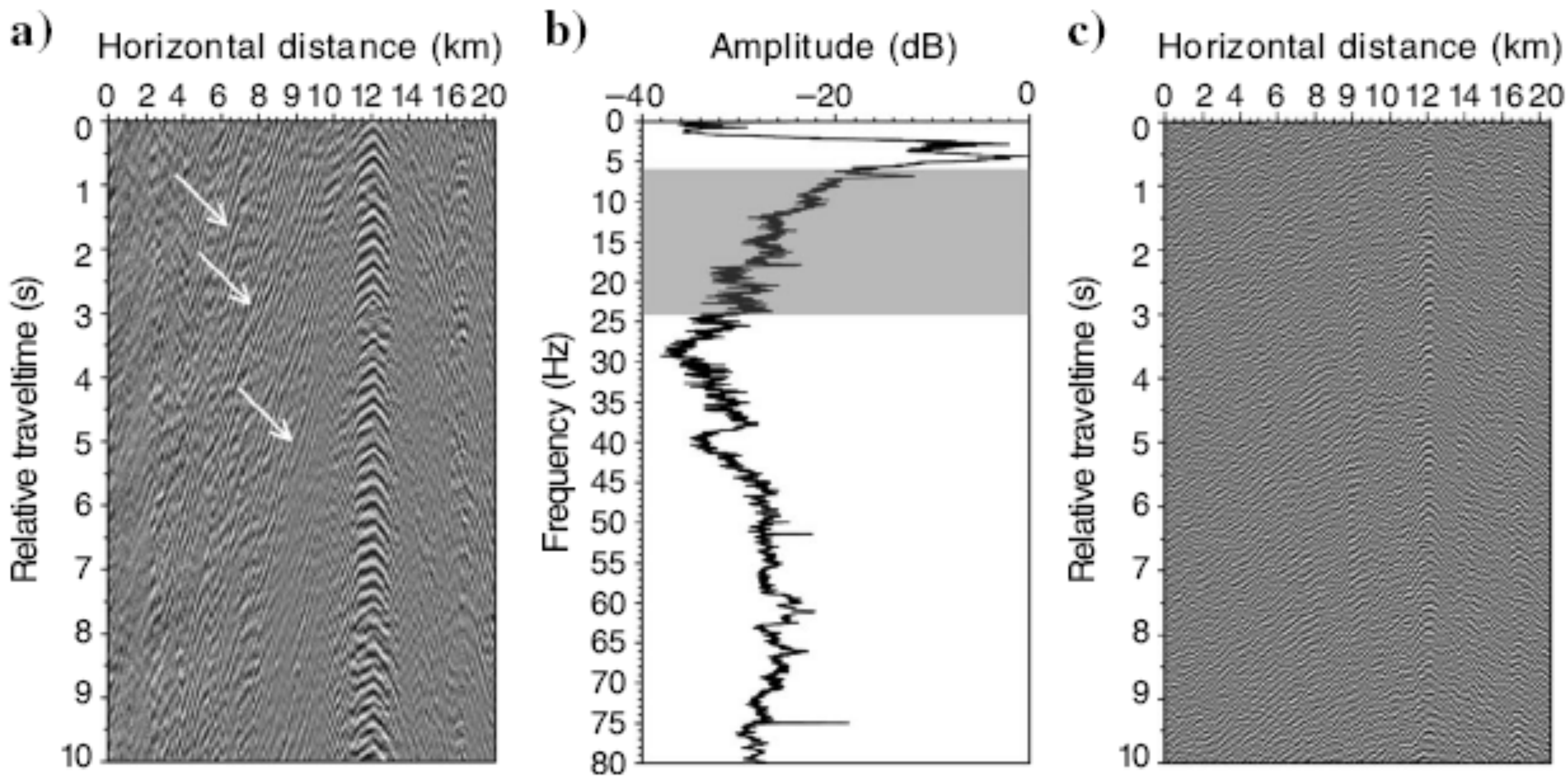


Figure 2. (a) First 10 s from an arbitrary ambient-noise record. The white pointers indicate surface waves. (b) Amplitude spectrum of the panel in (a) after summing over all traces. (c) The panel in (a) after frequency-wavenumber and band-pass filtering.

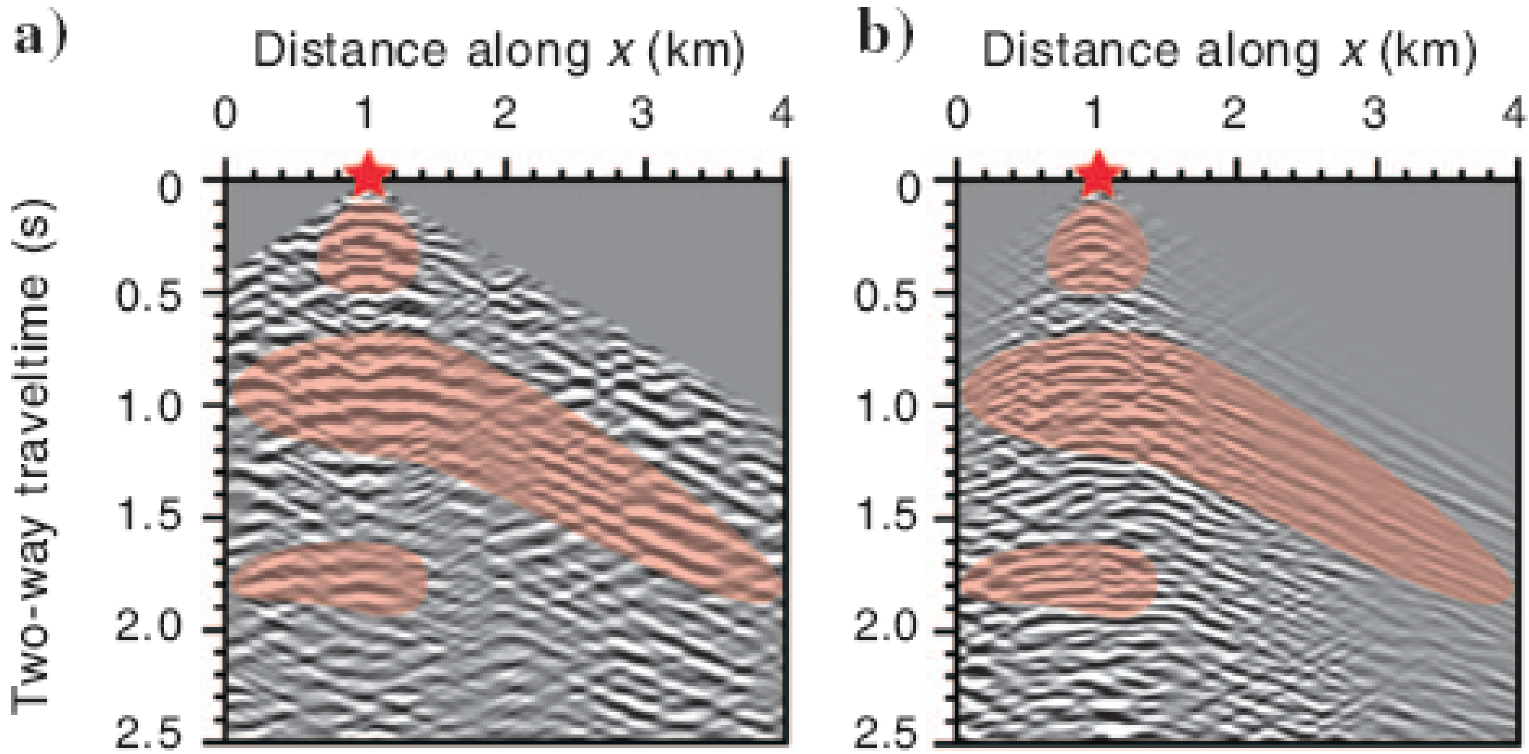


Figure 3. (a) Retrieved common-shot gather from the ambient noise. (b) Active-source common-shot gather recorded at the same location. The red stars indicate the positions of the virtual and real sources. Sections with coinciding events are highlighted in transparent red. Events at times earlier than the direct-wave arrival have been muted.

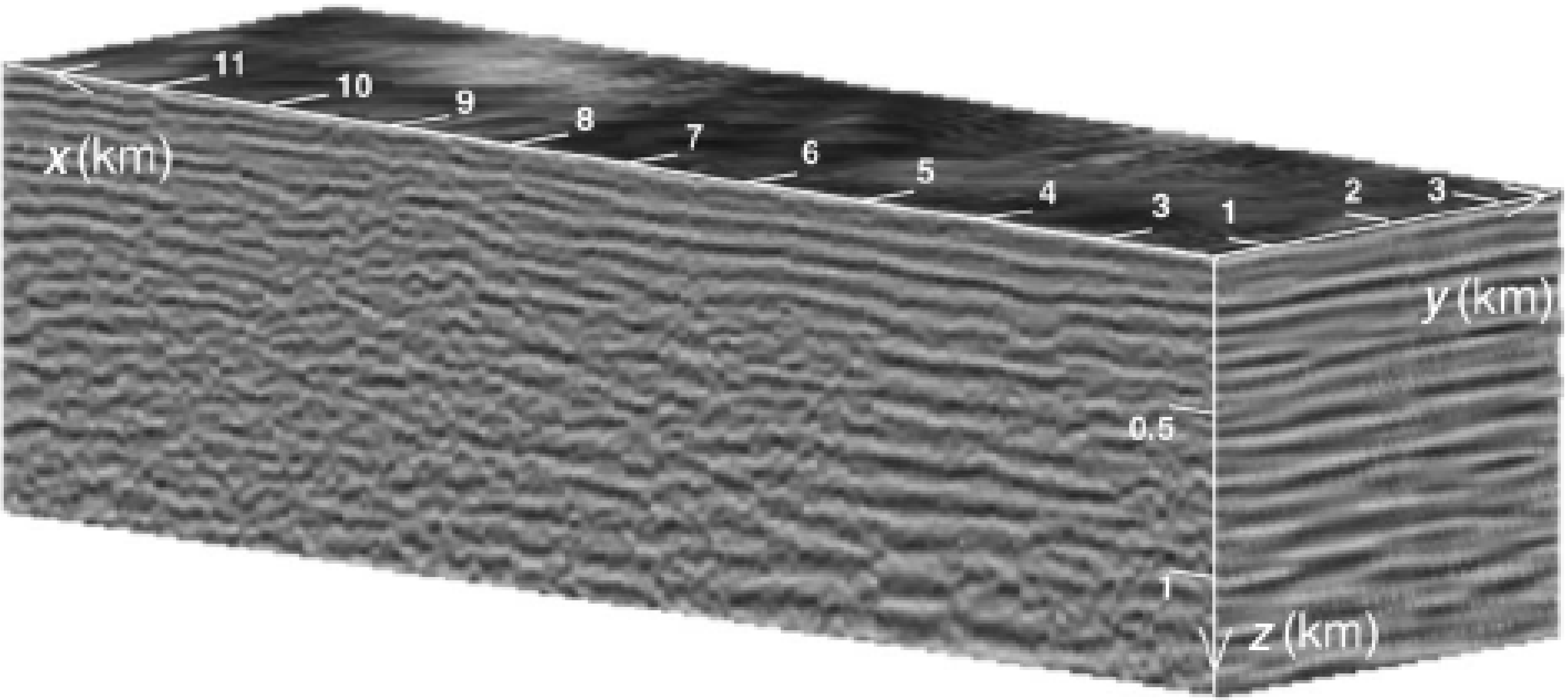
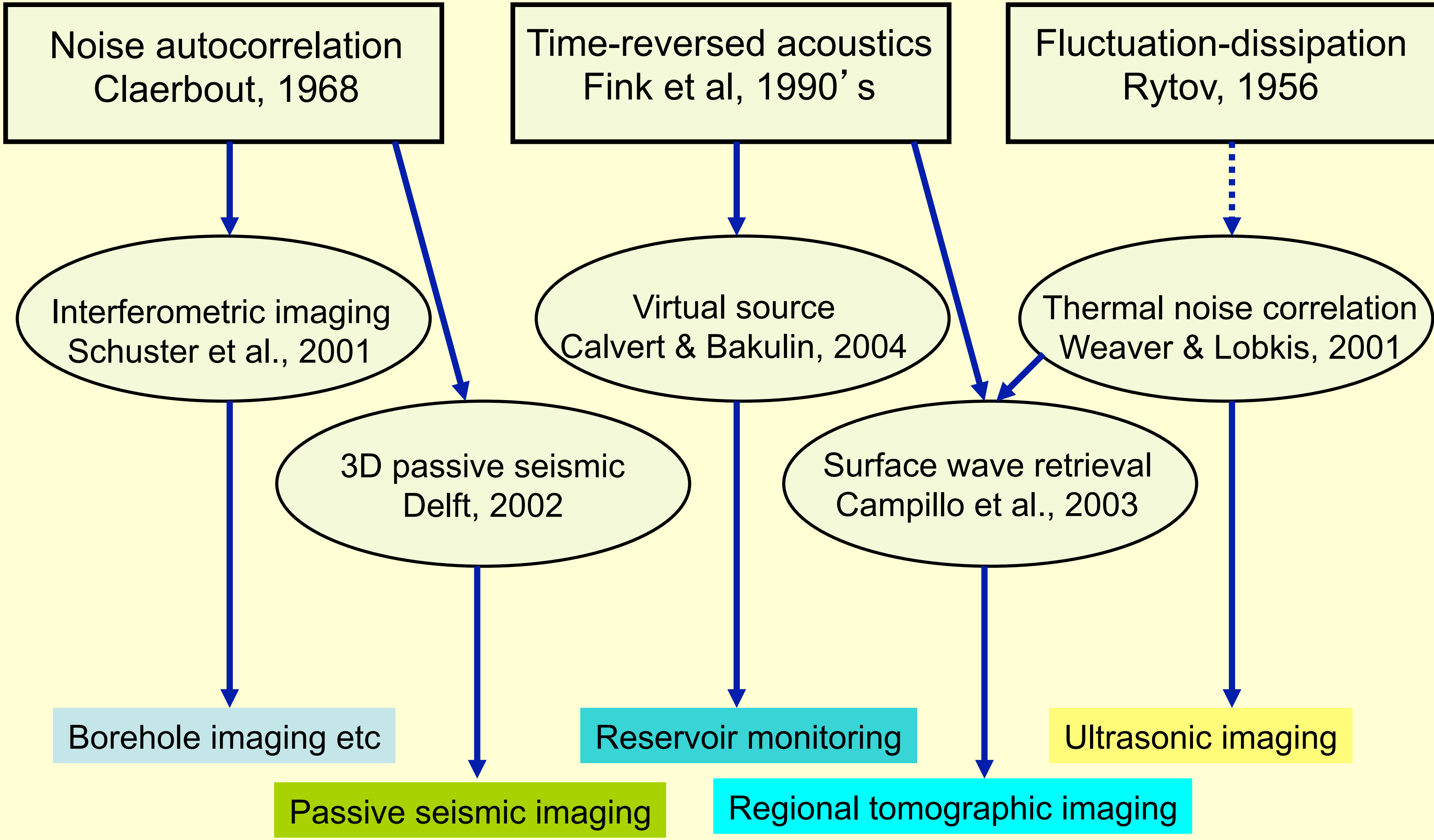


Figure 5. A pseudo-3D image giving an impression of the subsurface below the survey lines. The pseudo-3D image from Figure 5 played along the y-axis starting from line L1. Figure enhanced online. [DOI: http://dx.doi.org/10.1190/1.3193529.1]



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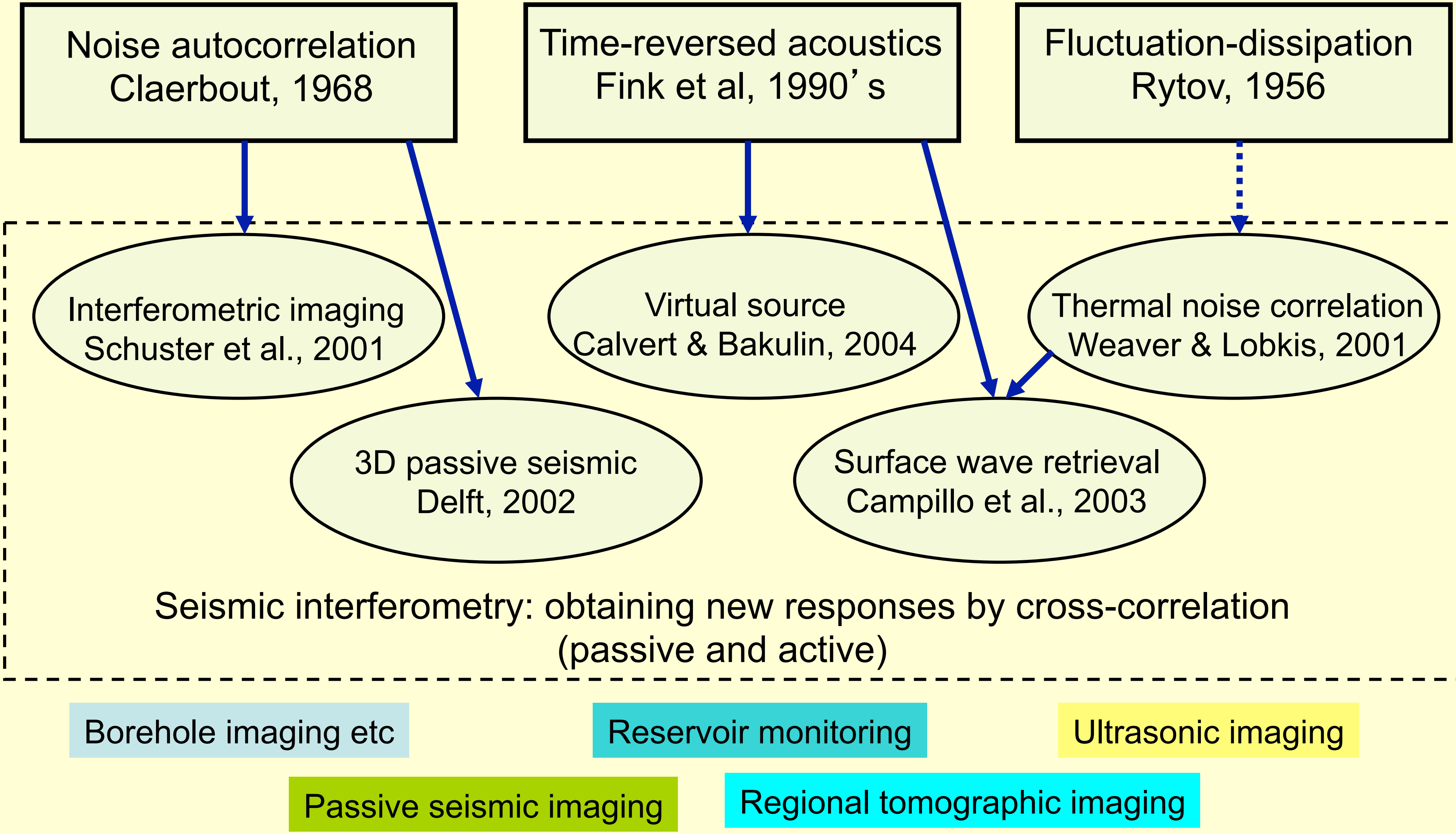
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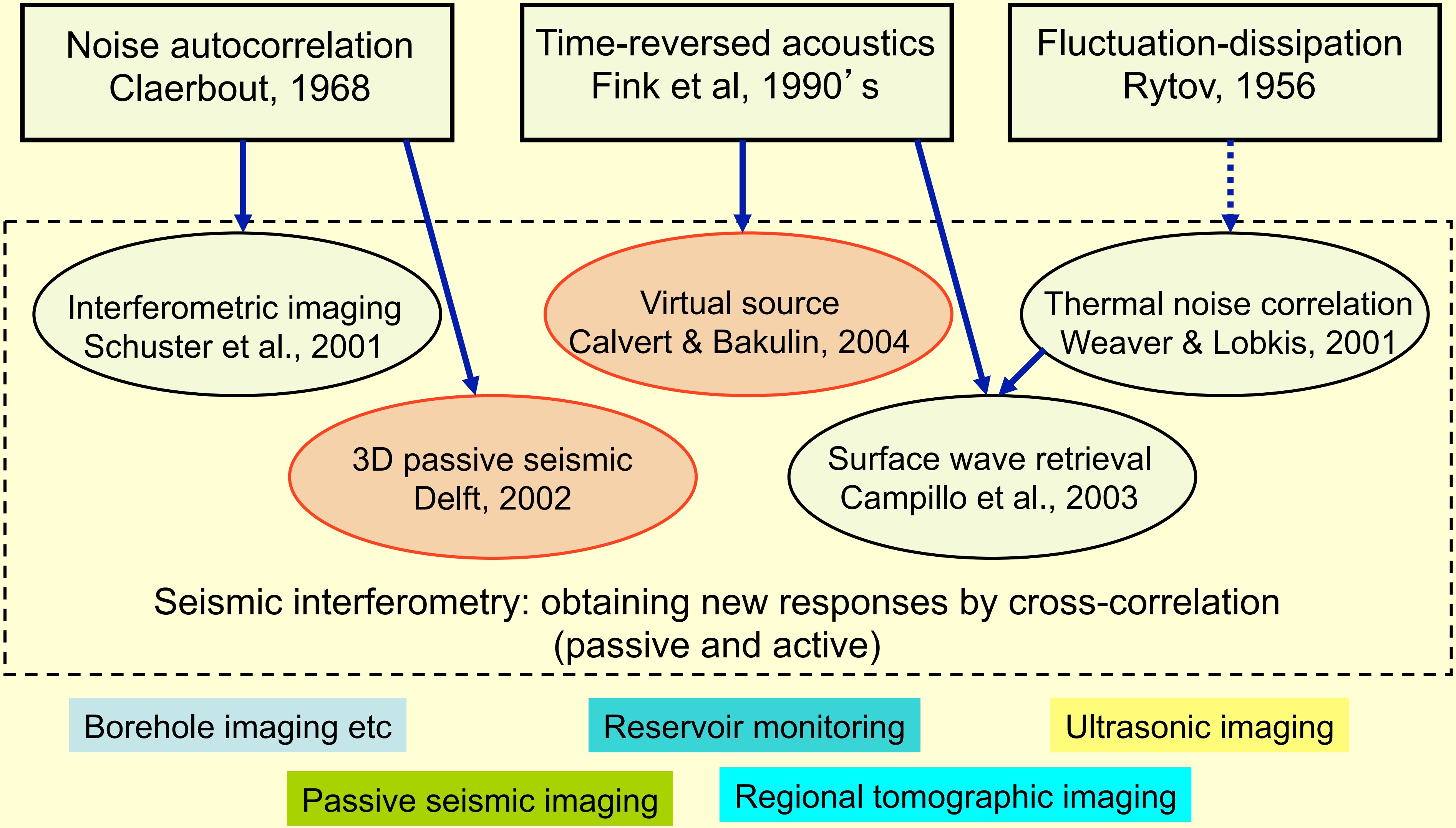
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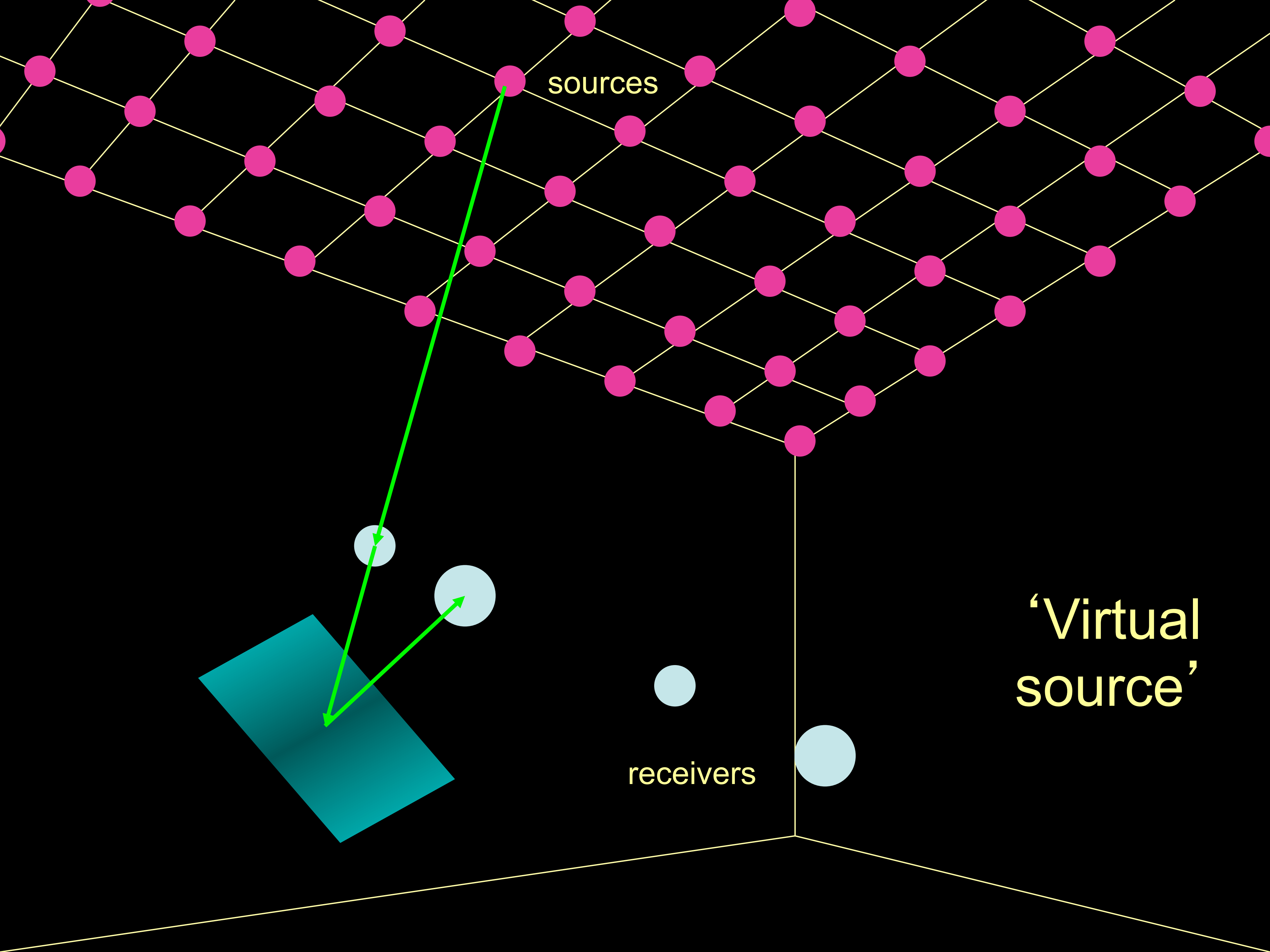
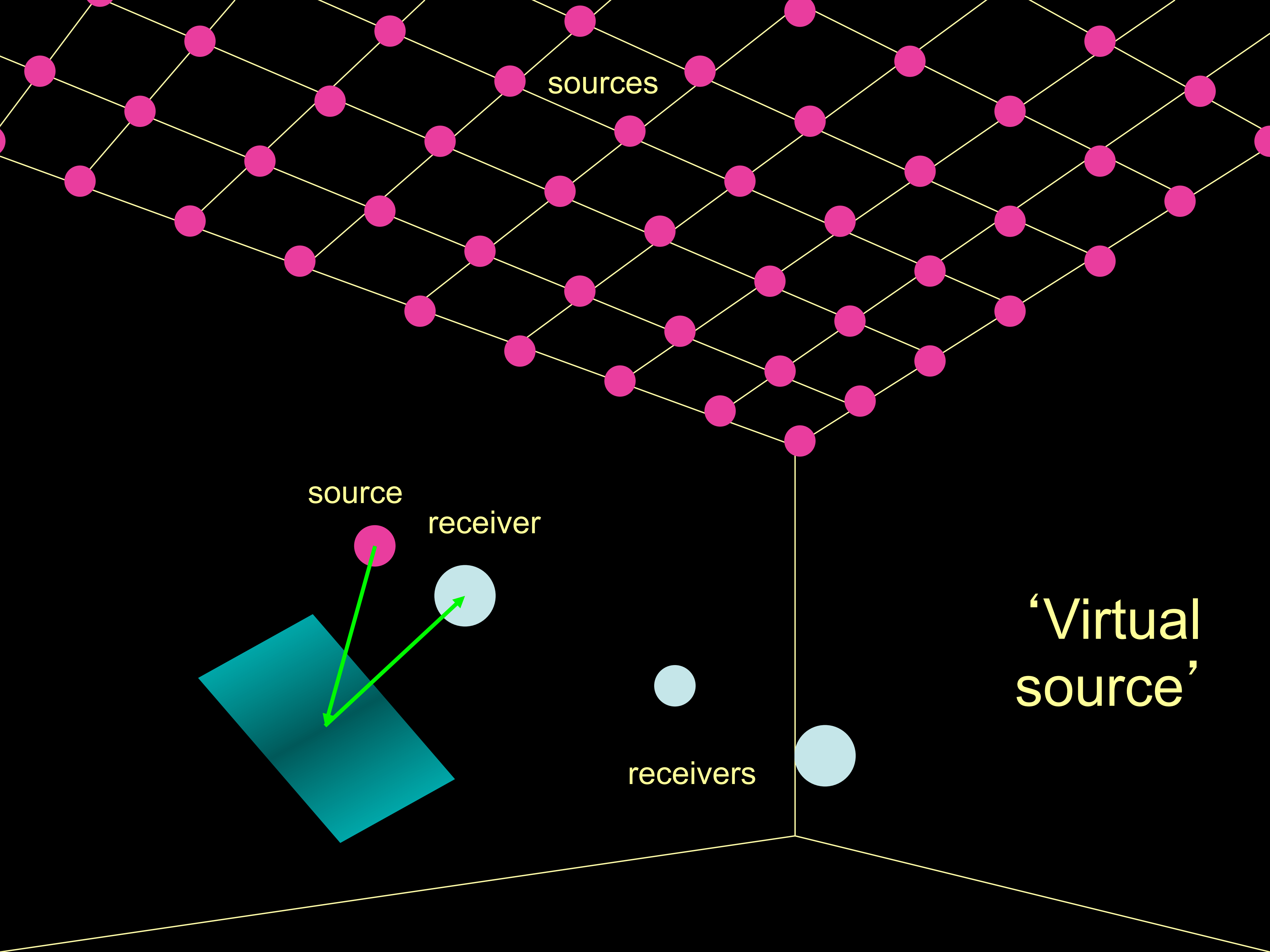
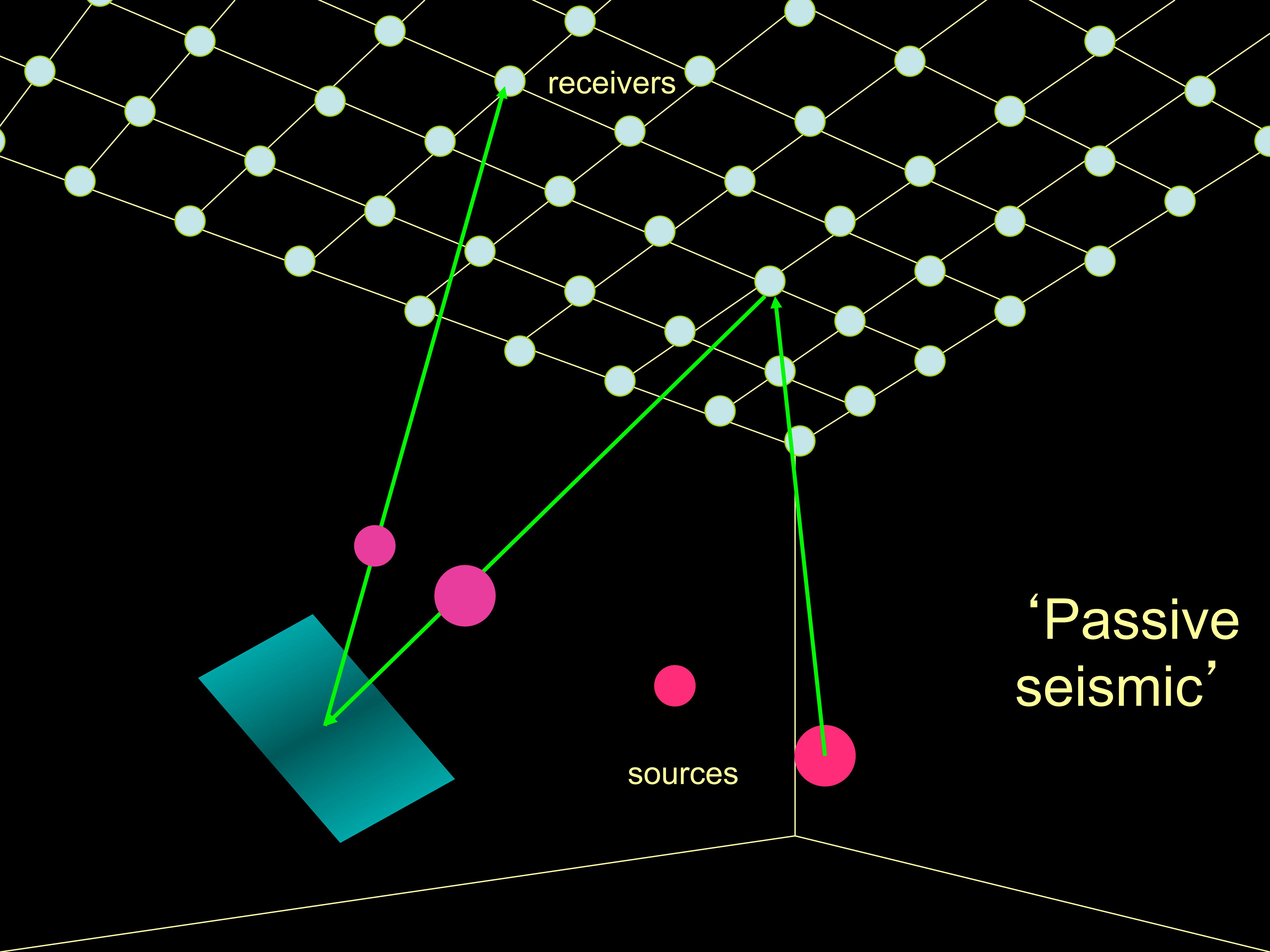
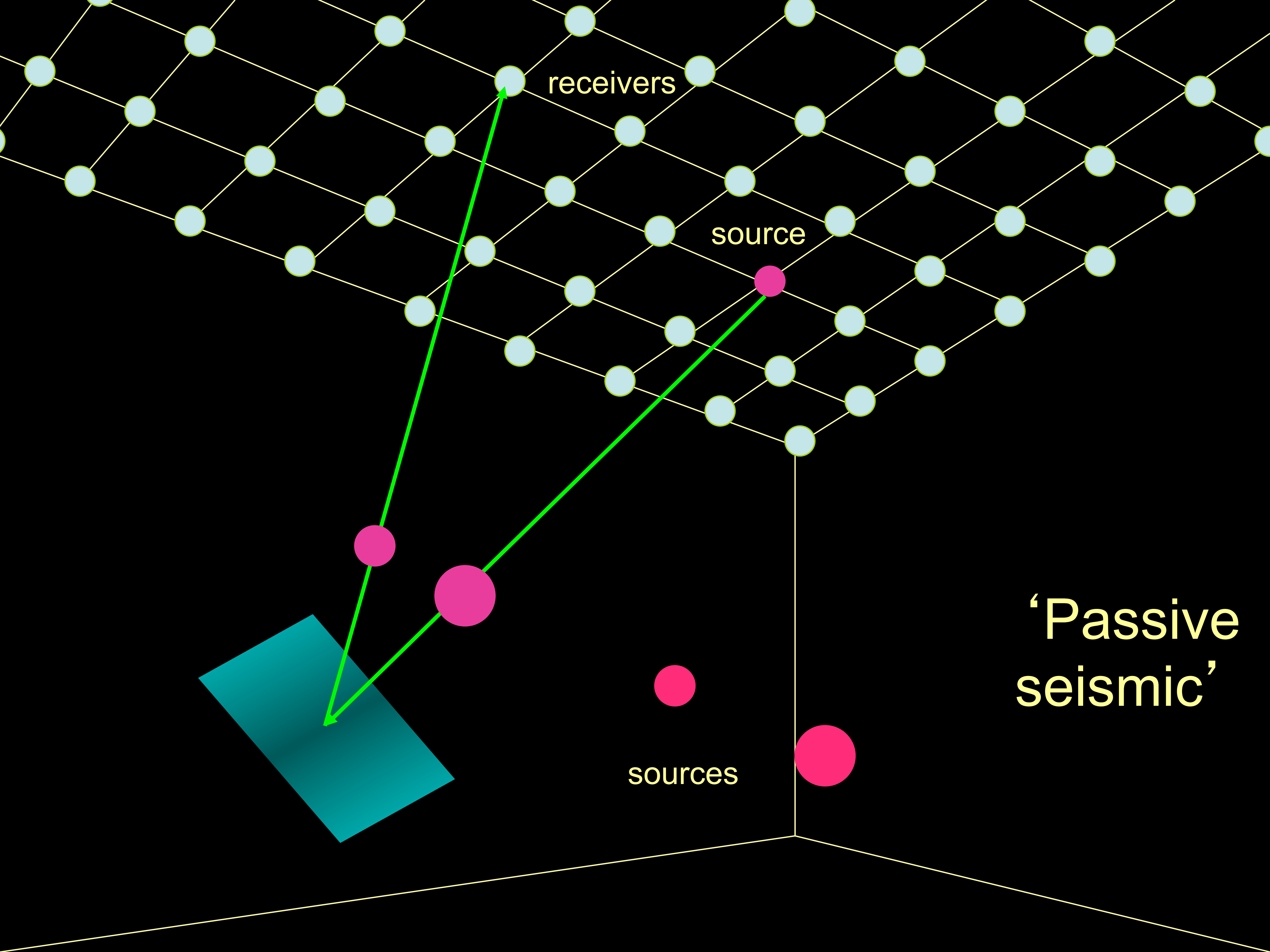
Passive seismic imaging
Regional tomographic imaging

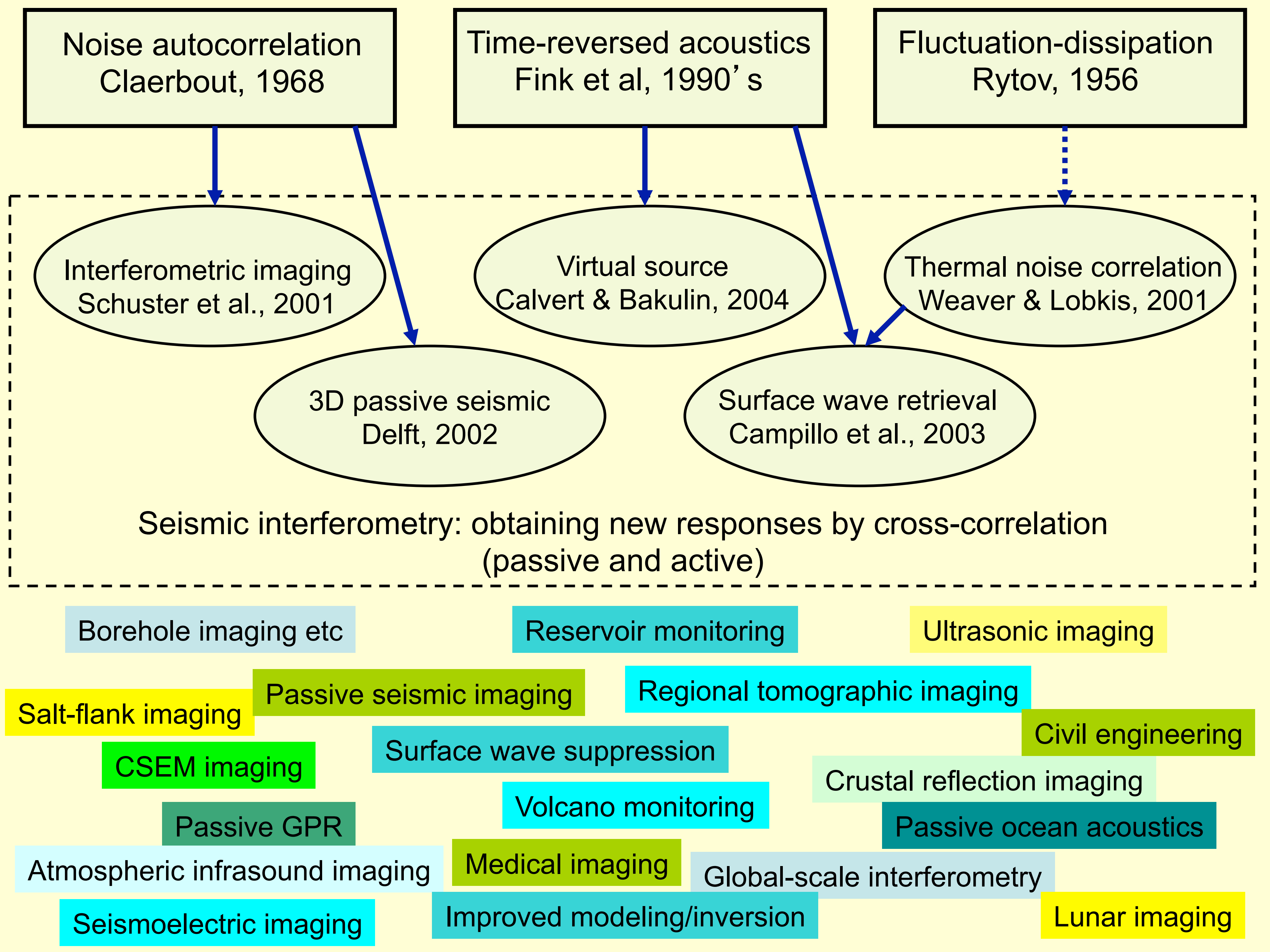


sources
receivers
'Virtual
source'


sources
source
receiver
receivers
'Virtual source'


receivers
sources
‘Passive seismic’


receivers
source
sources
‘Passive
seismic’


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
Volcano monitoring
Passive GPR
Passive ocean acoustics
Atmospheric infrasound imaging
Medical imaging
Global-scale interferometry
Seismoelectric imaging
Improved modeling/inversion
Lunar imaging

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Tutorial on seismic interferometry: Part 1 — Basic principles and applications

Tutorial on seismic interferometry: Part 2 — Underlying theory and new advances