ROSE
Rock Seismic Research Project

S-waves in acoustic transversely isotropic media with a tilted symmetry axis

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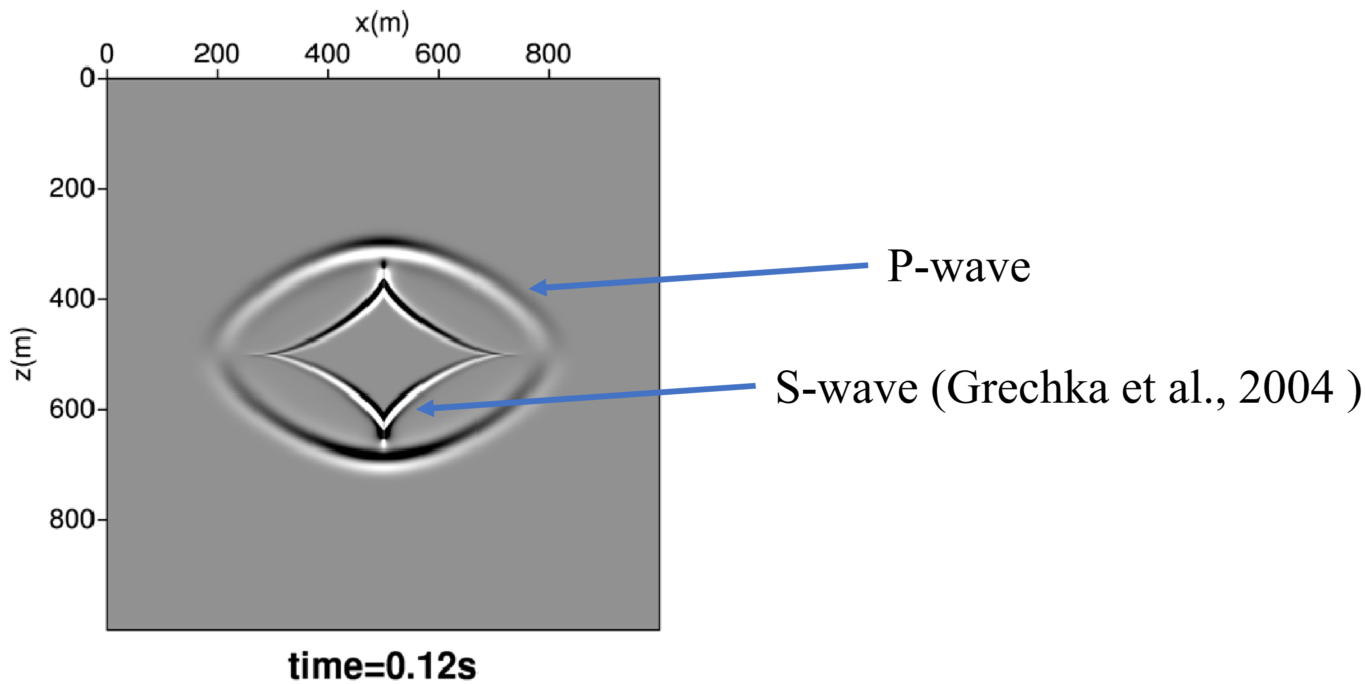
Outline

- An overview of the acoustic anisotropic media
- Slowness surface
- Traveltime functions
- S-wave in multi-layered acoustic TTI media
- Reflected waves and converted waves
- Conclusion

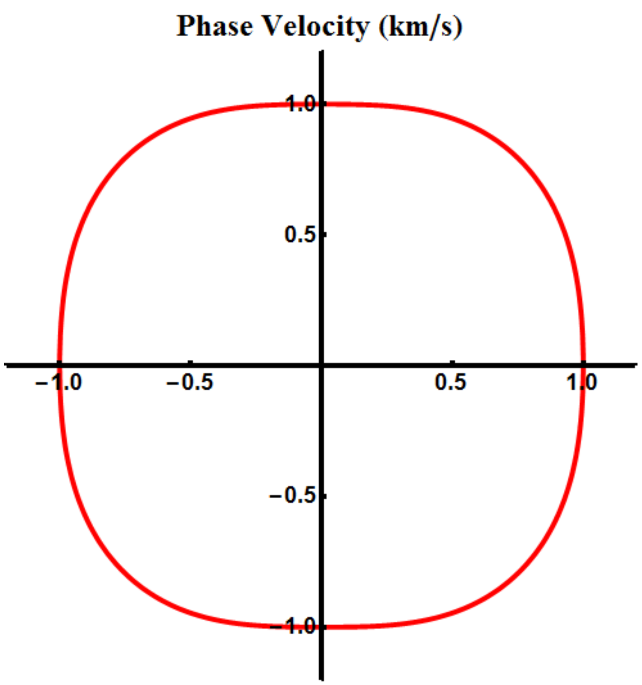
An overview of the acoustic anisotropic media

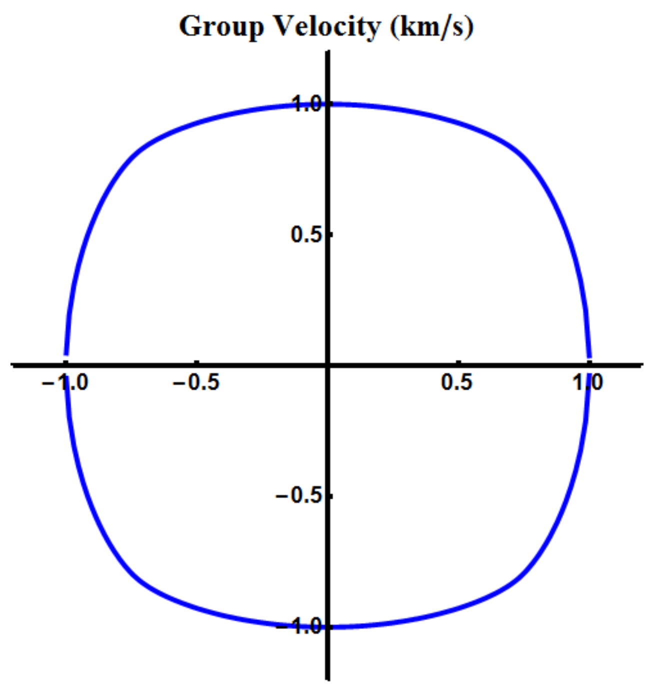
The acoustic VTI medium was firstly proposed by setting the $v_{S0} = 0$ (Alkhalifah, 1998).



An overview of the acoustic anisotropic media

SV-wave in elastic VTI media

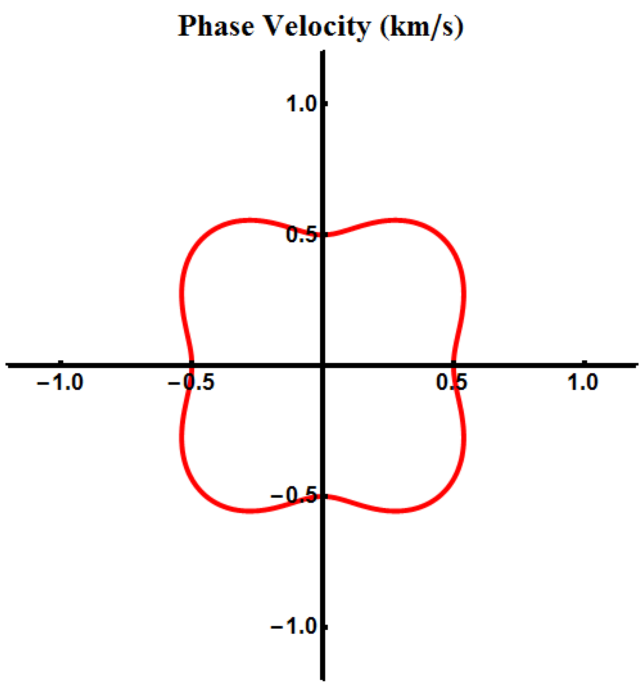


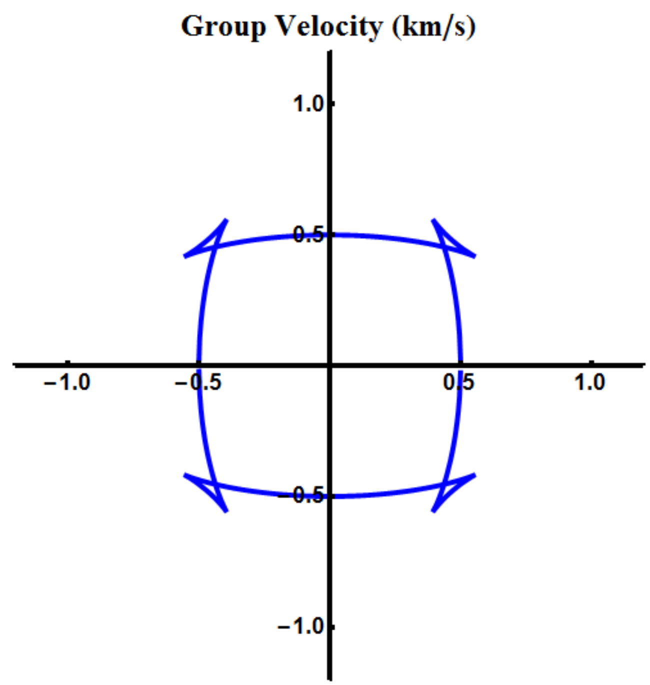


$v_{S0} = 1.0$ km/s

An overview of the acoustic anisotropic media

SV-wave in elastic VTI media



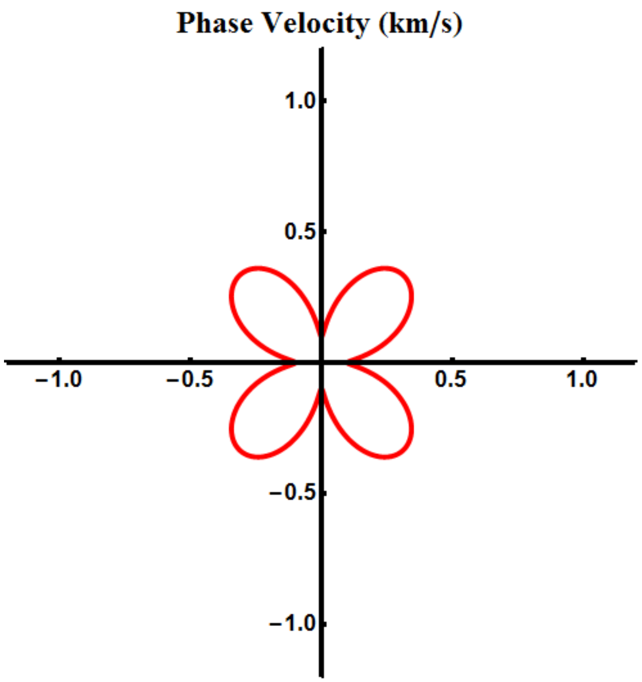


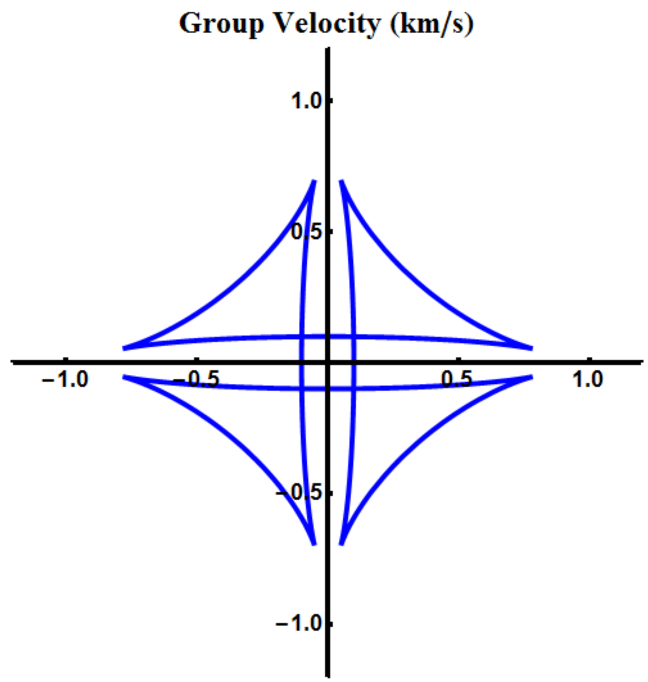
$v_{S0} = 0.5$ km/s

off-axis triplication

An overview of the acoustic anisotropic media

SV-wave in elastic VTI media



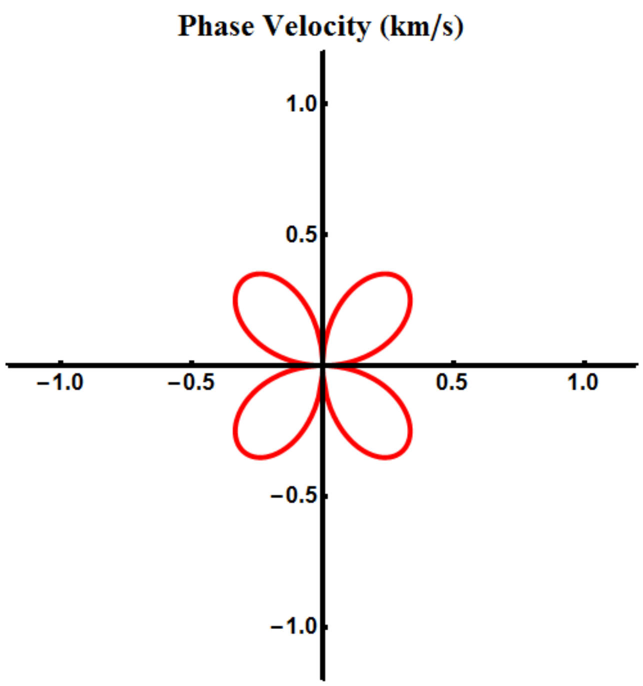


$v_{S0} = 0.1$ km/s

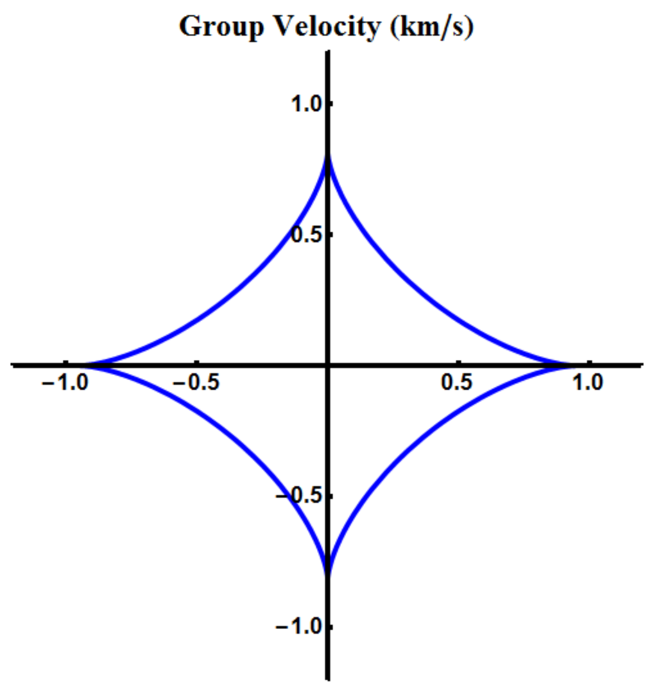
off-axis triplication

An overview of the acoustic anisotropic media

S-wave in acoustic VTI media



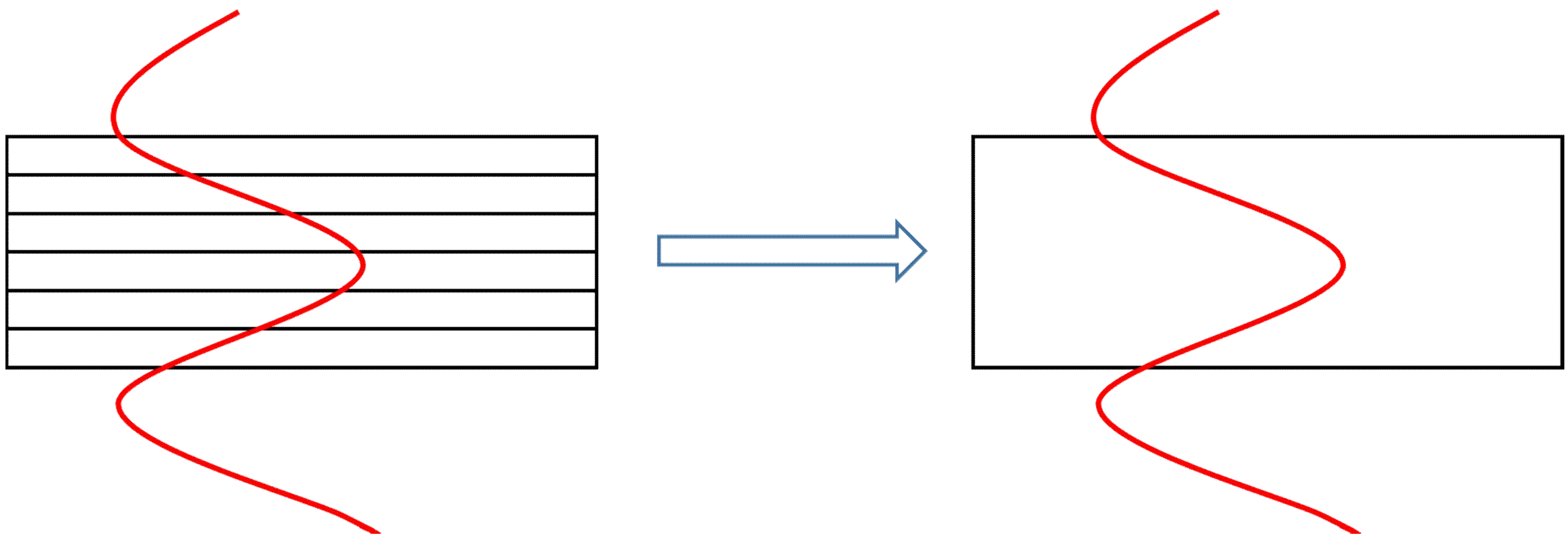
$v_{S0} = 0.0 \text{ km/s}$



off-axis triplication

An overview of the acoustic anisotropic media

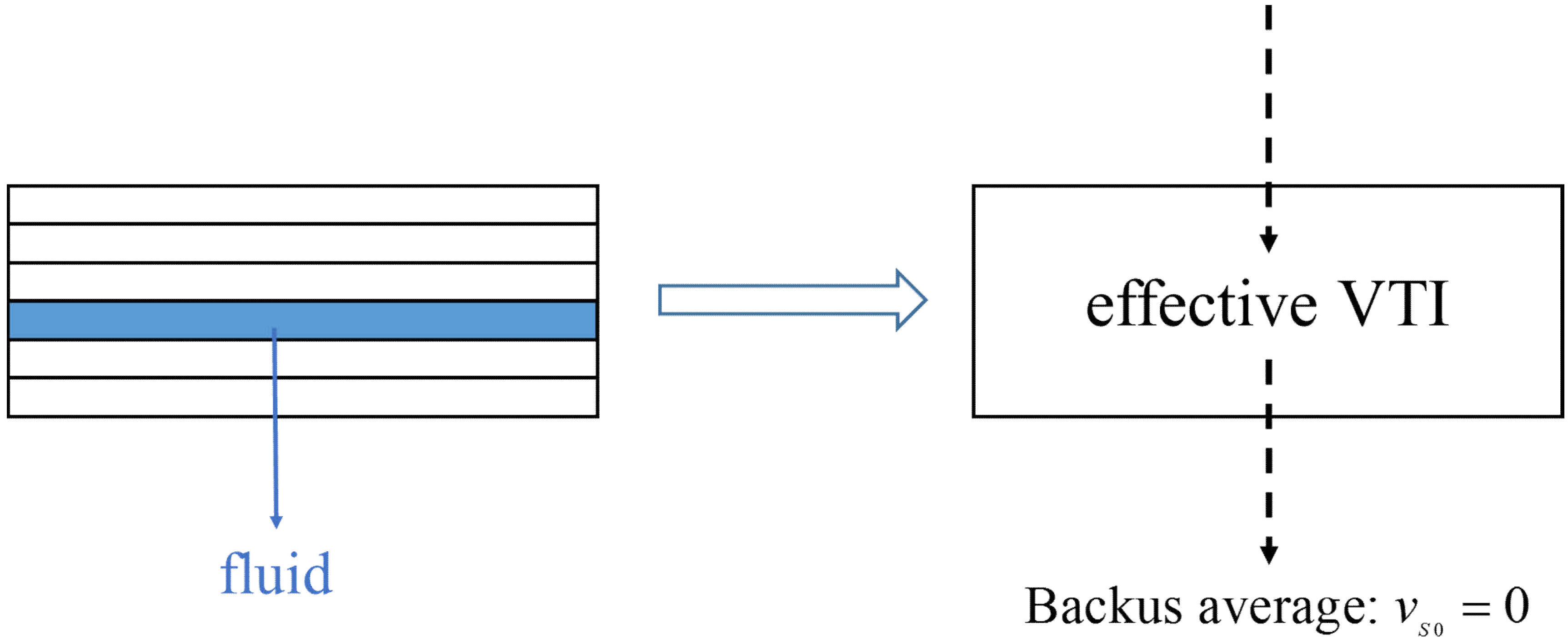
Acoustic VTI media can also be practical from the upscaling point of view (Grechka et al., 2004).



thin isotropic/VTI layers　　　effective VTI

long wave equivalent medium theory (Backus, 1962)

An overview of the acoustic anisotropic media



The acoustic TI media can be obtained by:

- manually setting the $v_{S0} = 0$
- equivalent media from the upscaling point of view

Anomalously low S-wave velocity (10-50m/s) was observed in unconsolidated ocean-bottom sediments (Ayres and Theilen, 1999).

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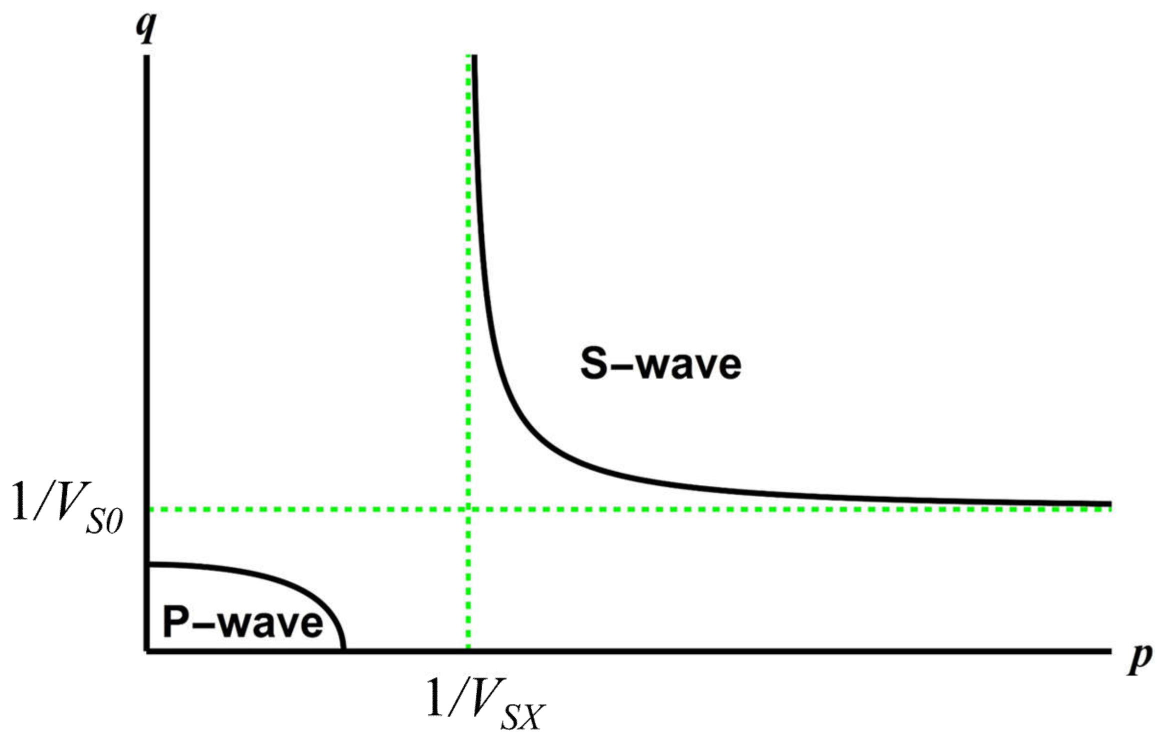
Slowness surface

For the acoustic VTI medium, the slowness surface is (Alkhalifah, 1998)

$$q = \frac{1}{v_{P0}}\sqrt{\frac{(1+2\eta)v_{Pn}^2 p^2 - 1}{2\eta v_{Pn}^2 p^2 - 1}}$$

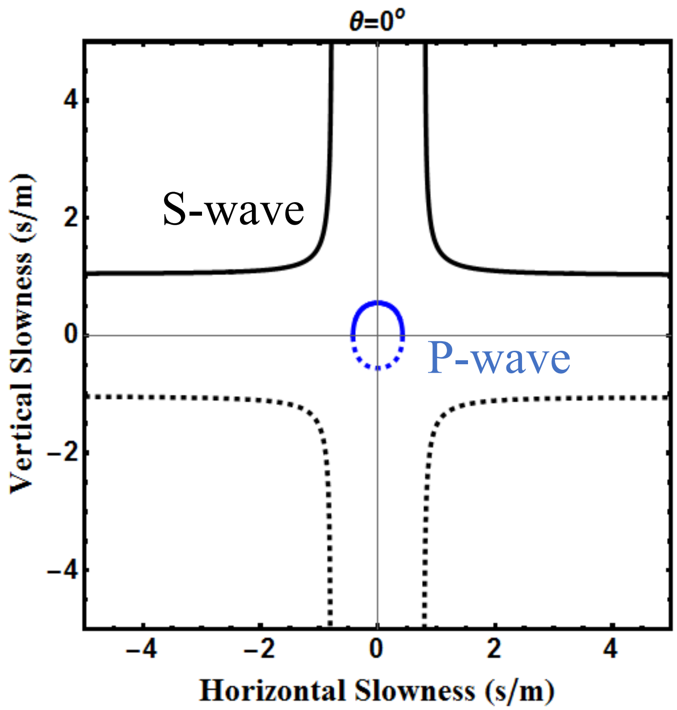


Slowness mapping from VTI to TTI

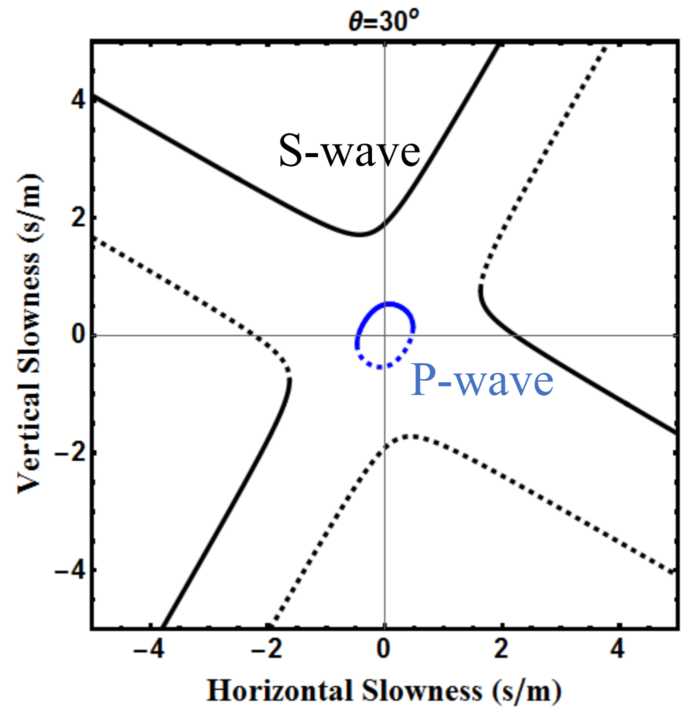
$$\begin{bmatrix} p_n \\ q_n \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\begin{bmatrix} p \\ q \end{bmatrix}$$

TTI VTI

Slowness surface



Acoustic VTI



Acoustic TTI

Solid: Downwards wave

Dashed: Upwards wave

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Traveltime functions

Slowness surface in acoustic VTI

Traveltime in acoustic VTI

Mapping (Stovas and Alkhalifah, 2013)

Traveltime in acoustic TTI

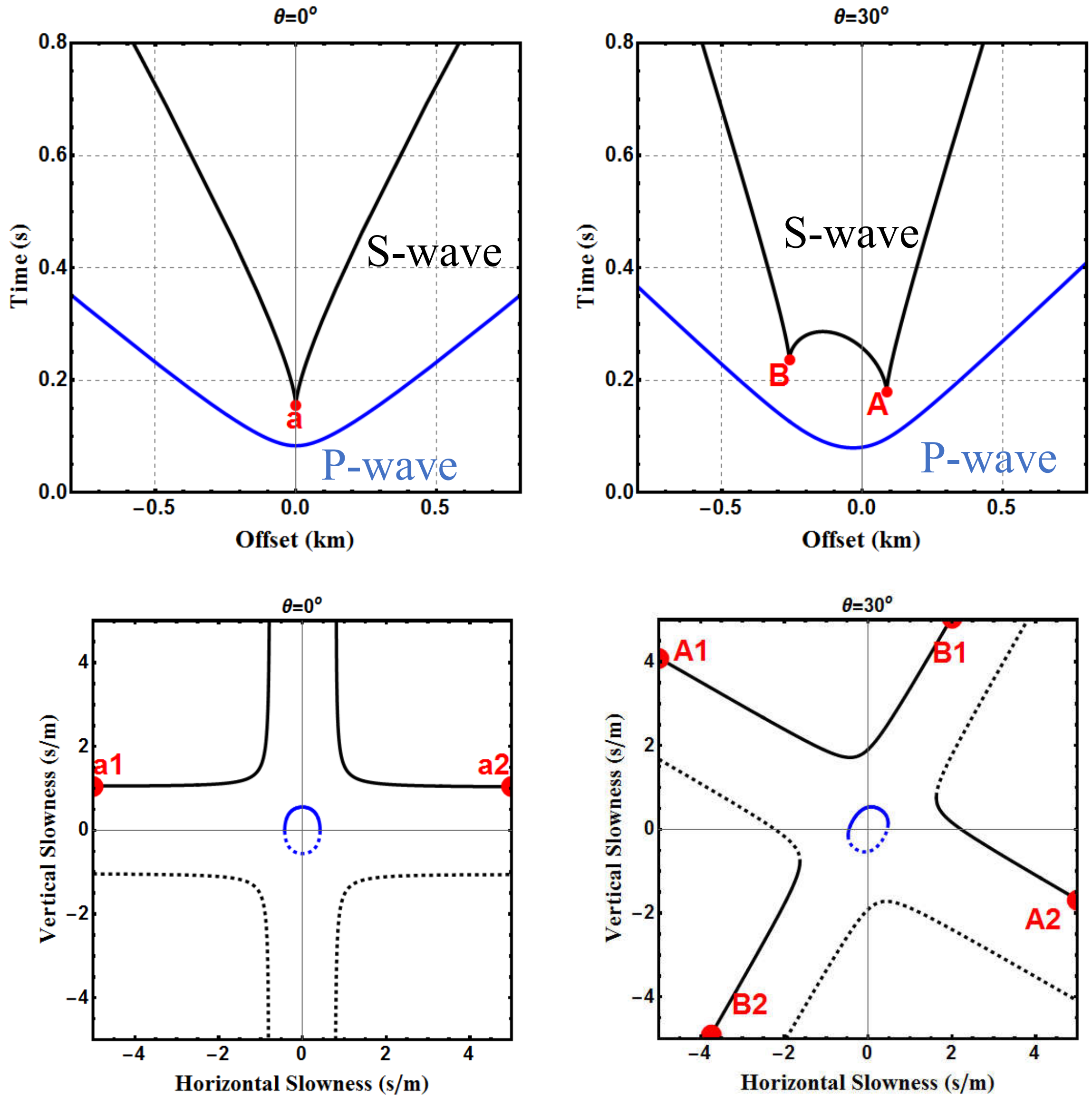
Traveltime functions

Acoustic VTI

Acoustic TTI

traveltime

slowness surface



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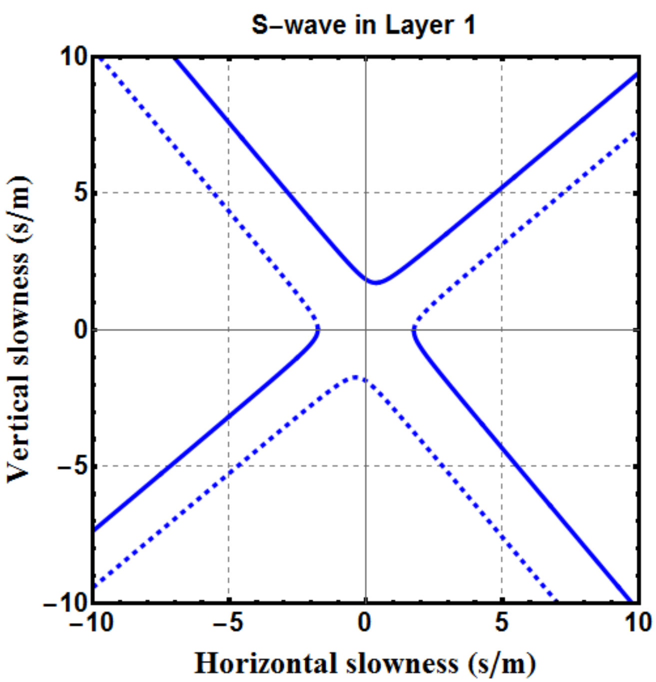
S-wave in multi-layered acoustic TTI media

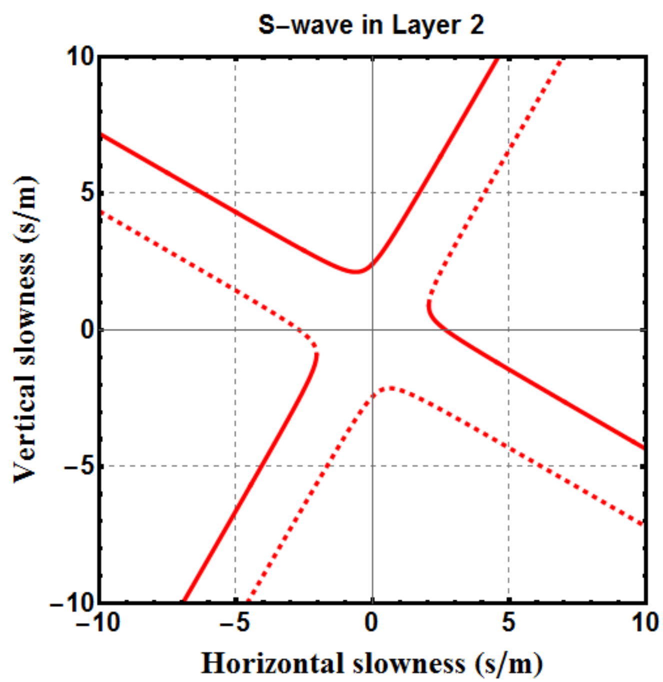
The effective slowness surface in multi-layered media is defined as:

$$q_n(p_n)_{eff} = \frac{\sum_i q_{n,i}(p_n) z_i}{\sum_i z_i}$$

Two-layered acoustic TTI model:



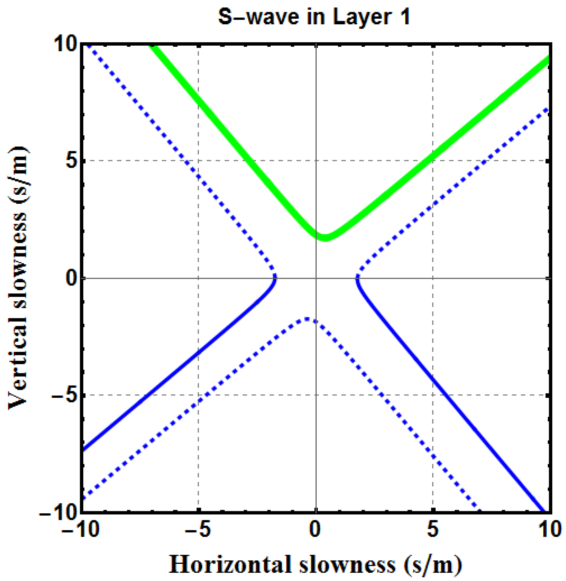
Blue: layer 1



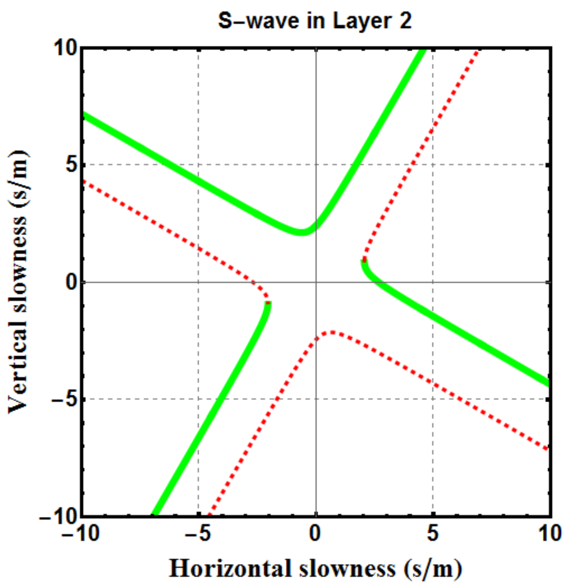
Red: layer 2

S-wave in multi-layered acoustic TTI media

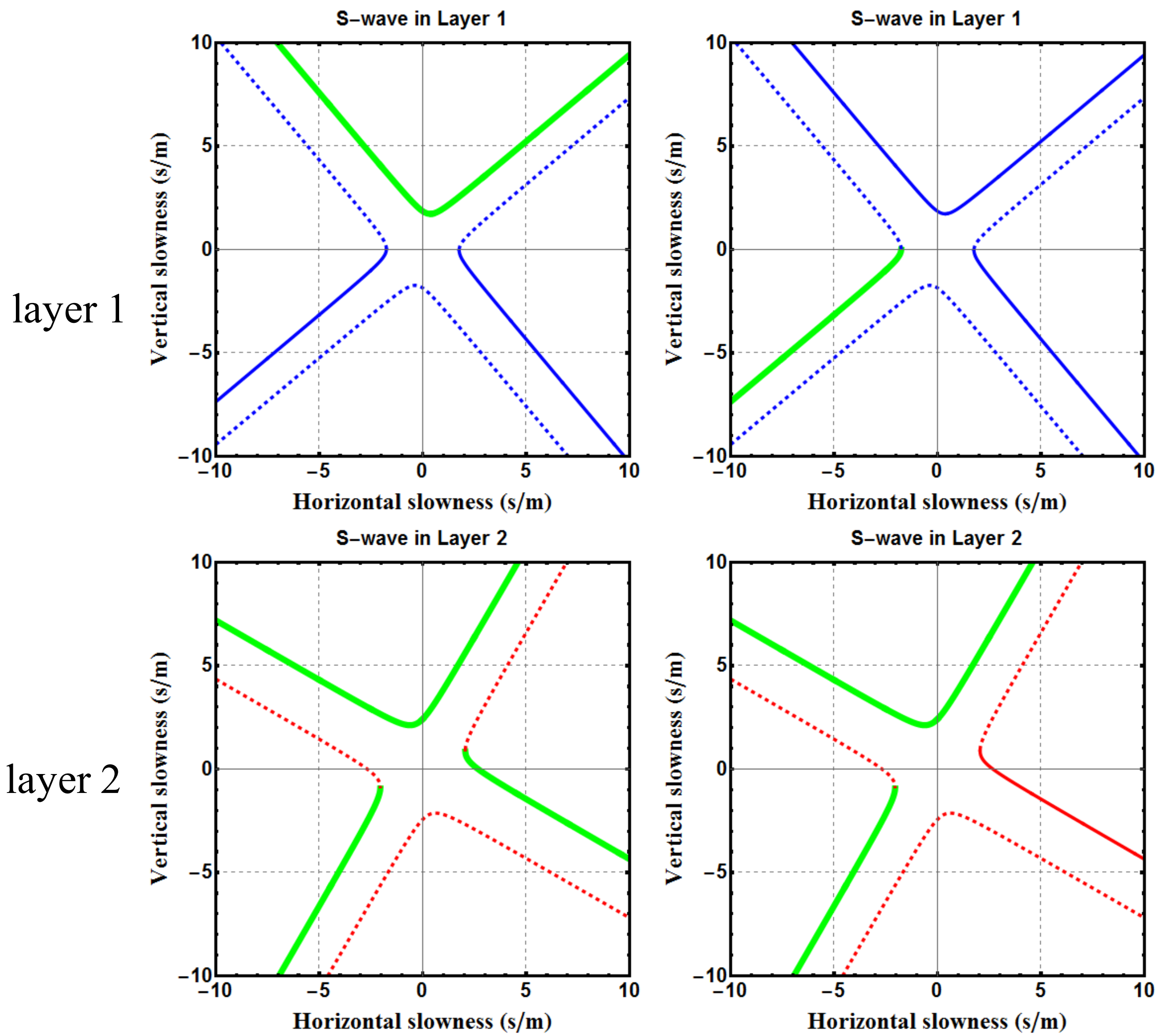
layer 1



layer 2



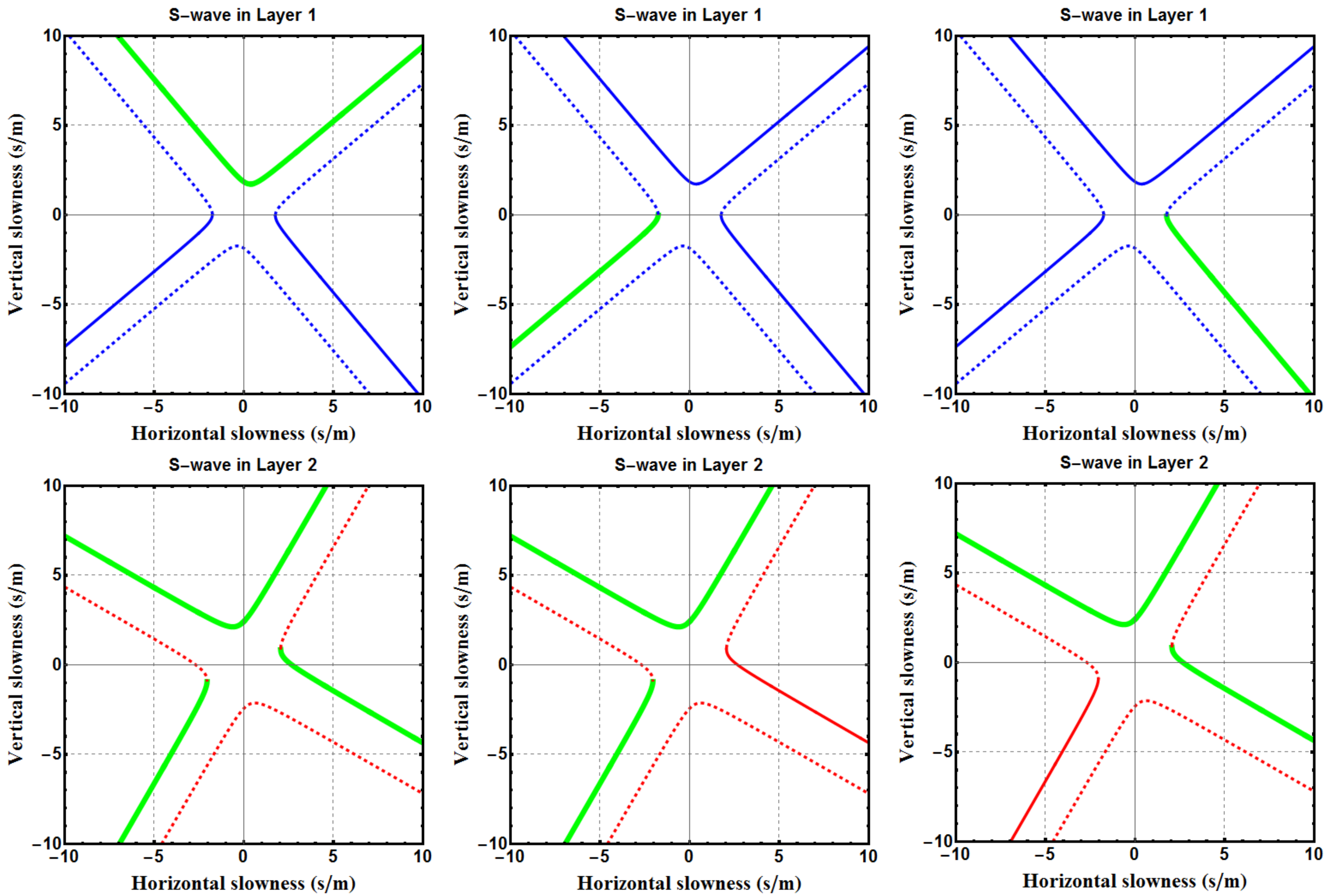
S-wave in multi-layered acoustic TTI media



S-wave in multi-layered acoustic TTI media

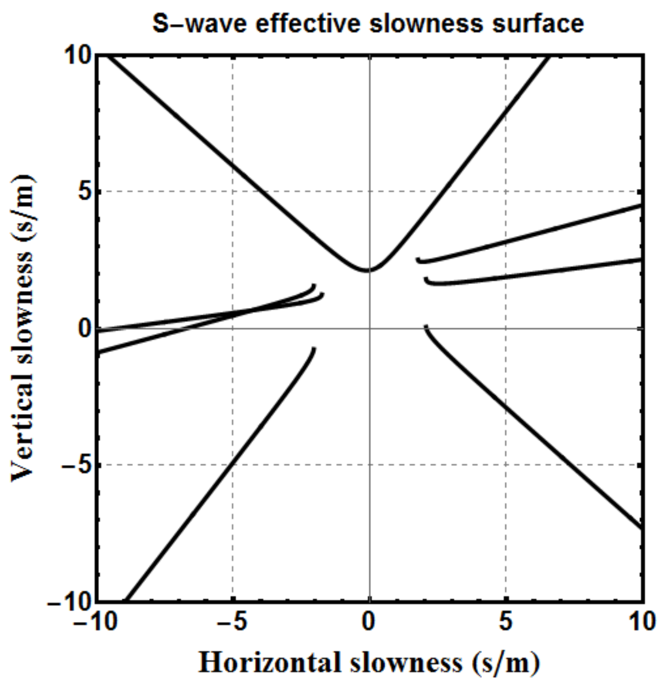
layer 1

layer 2

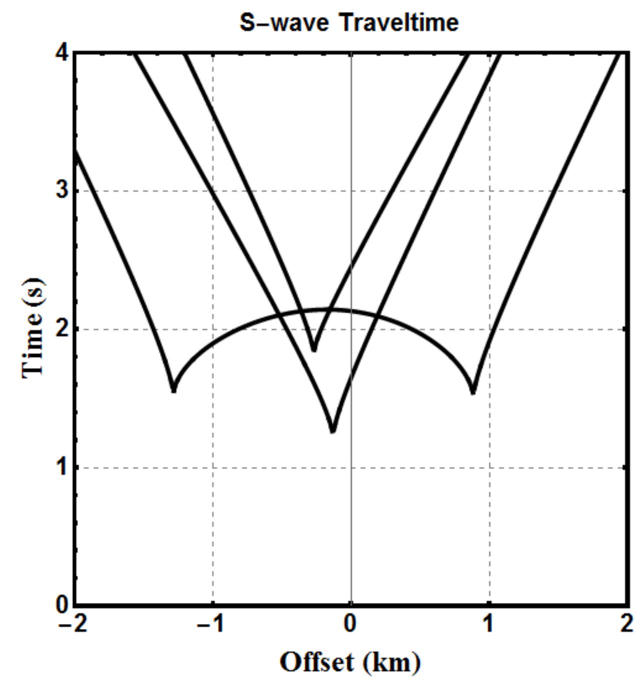


S-wave in multi-layered acoustic TTI media

Effective slowness surface



Traveltime



S-wave in multi-layered acoustic TTI media

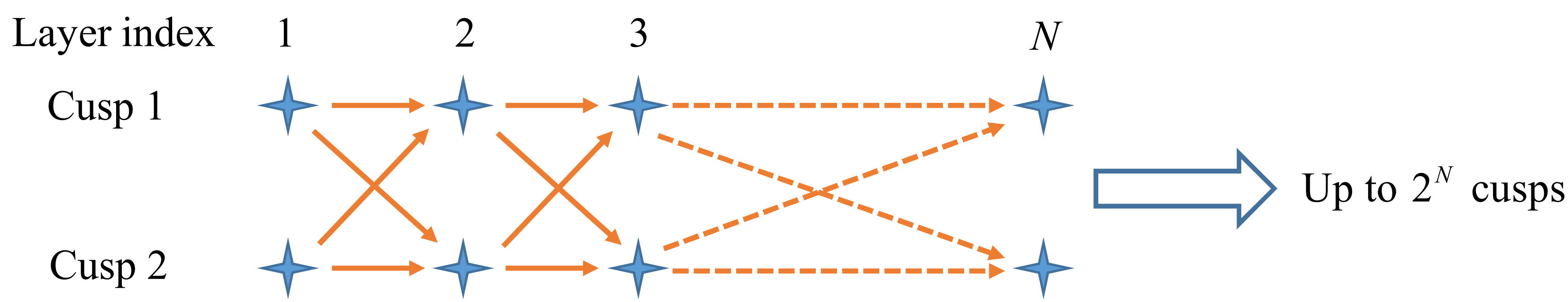
For a model composed of N acoustic TTI layers and M acoustic VTI layers ($M > 0$), the downward (or upward) S-wave has:

Maximum number of effective slowness surface branches : 2^{N+1}

Maximum values of the traveltime-offset functions: 2^N

Maximum number of cusps: 2^N

The cusp points offset and traveltime can be obtained by accumulating the counterparts for either cusp in every layer



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Reflected waves

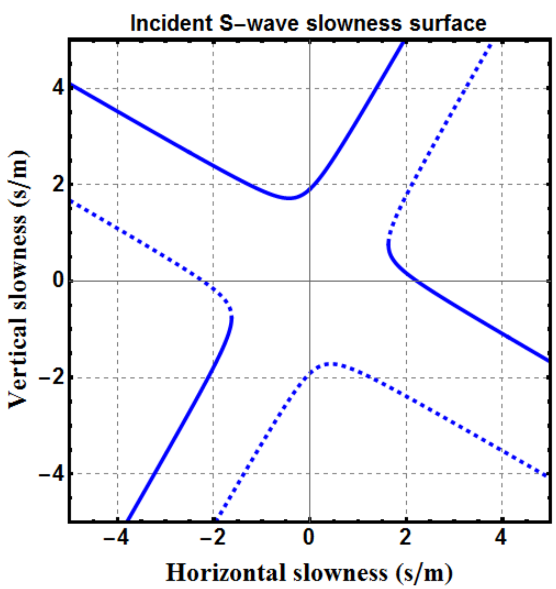
In VTI media $\quad q_{\text{Inc}}(p) = q_{\text{Ref}}(p)$

In TTI media $\quad q_{\text{Inc}}(p_n,\theta) \neq q_{\text{Ref}}(p_n,\theta)$

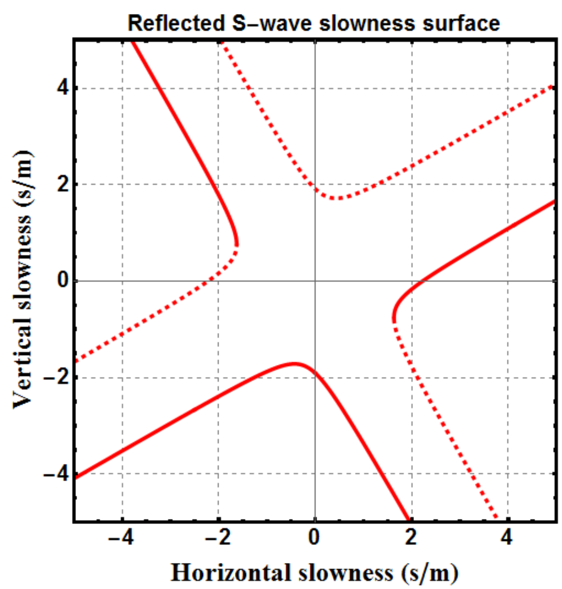
The two-way S-wave in acoustic TTI media is given by: $q_n^{SS}(p_n)_{eff} = \dfrac{q_{\text{Inc}}(p_n,\theta) + q_{\text{Ref}}(p_n,\theta)}{2}$

A homogeneous acoustic TTI model

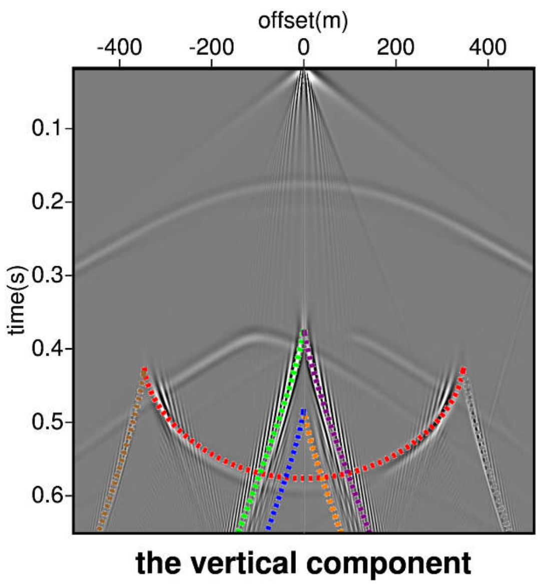
Incident wave



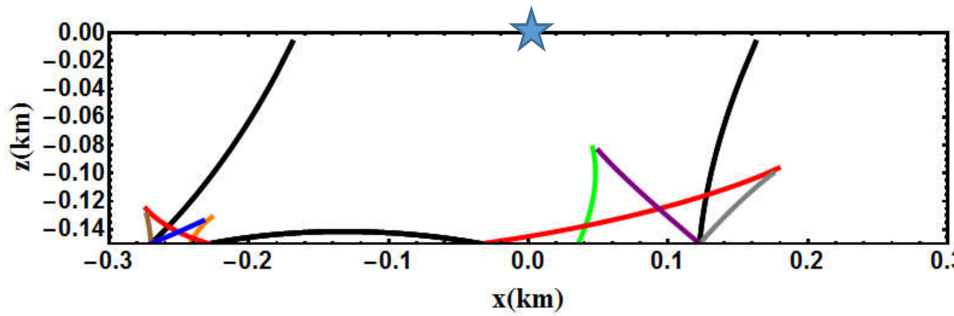
Reflected wave



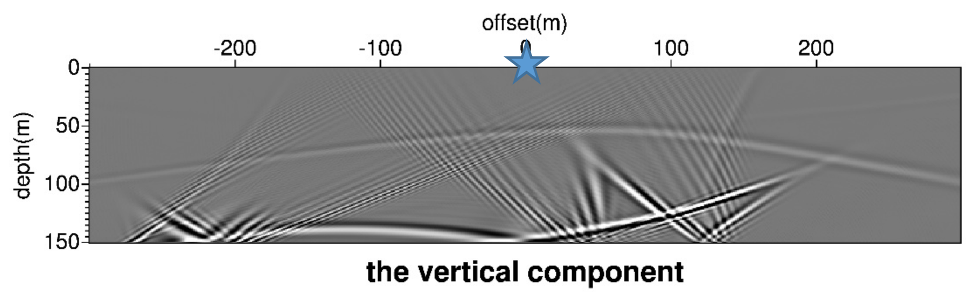
Reflected waves



Source



0.28s



Converted waves

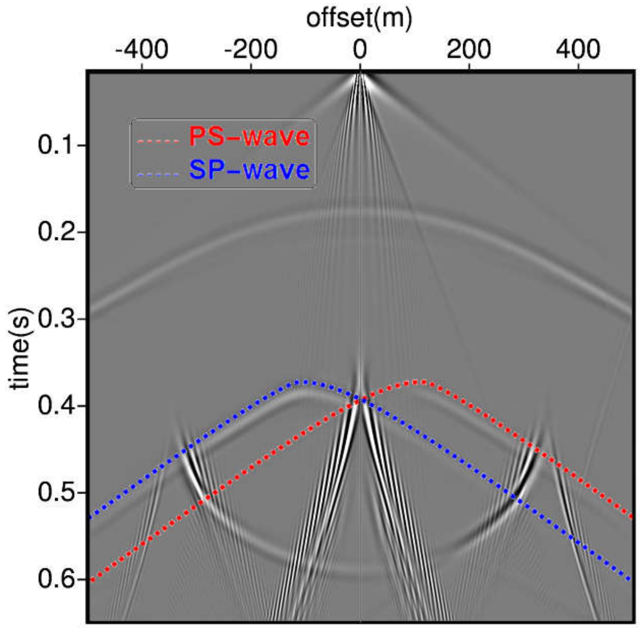
In acoustic VTI media: No converted waves

In acousticTTI media: $\begin{cases} q^{P}_{n,Down}(\theta) \neq q^{P}_{n,Up}(\theta) \\ q^{S}_{n,Down}(\theta) \neq q^{S}_{n,Up}(\theta) \end{cases} \Rightarrow \bar{q}^{PS}_{n}(\theta) \neq \bar{q}^{SP}_{n}(\theta)$

The converted waves slowness surface in acoustic TTI:

$$\bar{q}^{PS}_{n}(\theta) = \frac{q^{P}_{n,Down}(\theta) + q^{S}_{n,Up}(\theta)}{2}$$

$$\bar{q}^{SP}_{n}(\theta) = \frac{q^{S}_{n,Down}(\theta) + q^{P}_{n,Up}(\theta)}{2}.$$



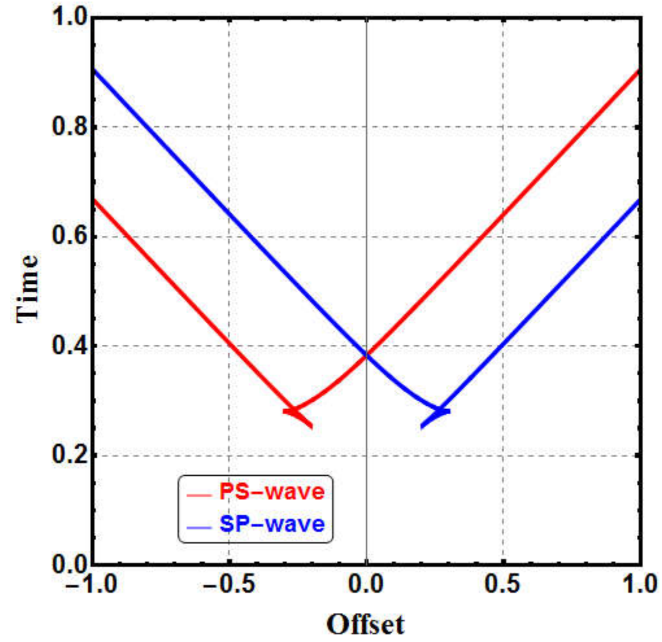
the vertical component

Converted waves

S-wave: Triplications

P-wave: No Triplications

Converted waves: May have triplications



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Conclusion

- Mapping S-wave slowness surface and traveltime from acoustic VTI to acoustic TTI media.
- S-wave (downwards or upwards) slowness surface in homogeneous acoustic TTI media has three branches.
- S-wave moveout function has two cusp points in homogeneous acoustic TTI media. The cusps number can be up to 2^N in N acoustic TTI layers.
- The two-way S-wave traveltime function is multi-valued.
- The converted waves moveout function may have triplications.

Thanks for the financial support by Rose project

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Thanks for your attention