Effects of attenuation and anisotropy on AVO and FWI sensitivities

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Outline

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  - Model parameterization
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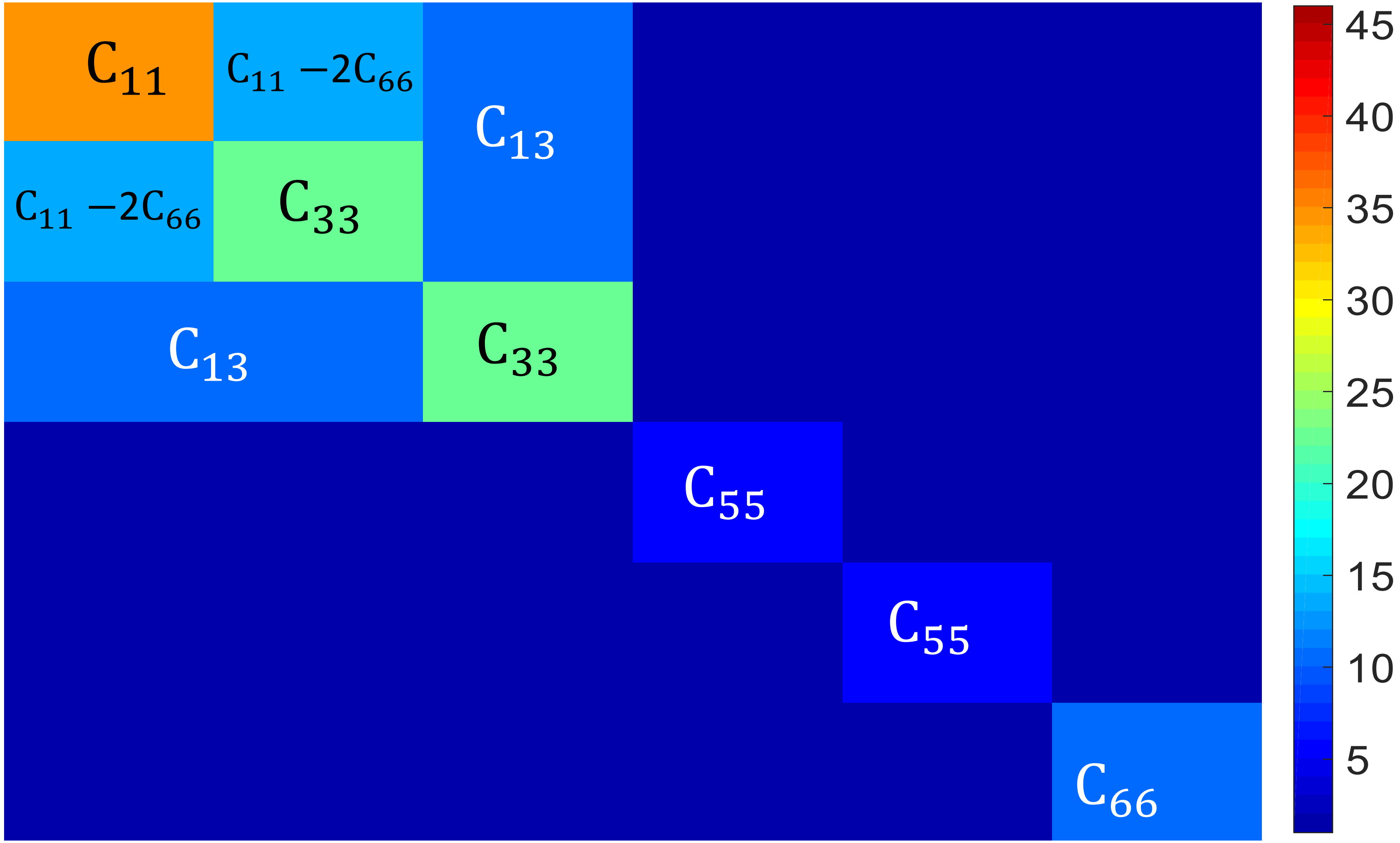
- Scattering potentials and AVO equations
- Numerical examples: FWI sensitivities
- Conclusion

Introduction and motivation

- Study the effects of both attenuation and anisotropy on linearized reflection coefficients
- Taking into account the inhomogeneity of the incident wave on the AVO equations
- Choosing a suitable set of parameters to describe the model and designing an effective inversion strategy
- Establish a framework for viscoelastic full wave form inversion

Viscoelastic VTI media: stiffness tensor



Viscoelastic anisotropic

$$C_{kl} = C^R_{kl} + iC^I_{kl}$$

$$C_{kl} = C^R_{kl}\left(1 + iQ^{-1}_{kl}\right)$$

$$Q^{-1}_{kl} = \frac{C^R_{kl}}{C^I_{kl}}$$

Viscoelastic VTI media: model parameterization

Model 1

c_{11}^{R}	c_{11}^{I}
c_{13}^{R}	c_{13}^{I}
c_{33}^{R}	c_{33}^{I}
c_{55}^{R}	c_{55}^{I}
c_{66}^{R}	c_{66}^{I}

Model 2

c_{11}^{R}	Q_{11}
c_{13}^{R}	Q_{13}
c_{33}^{R}	Q_{33}
c_{55}^{R}	Q_{55}
c_{66}^{R}	Q_{66}

Model 3

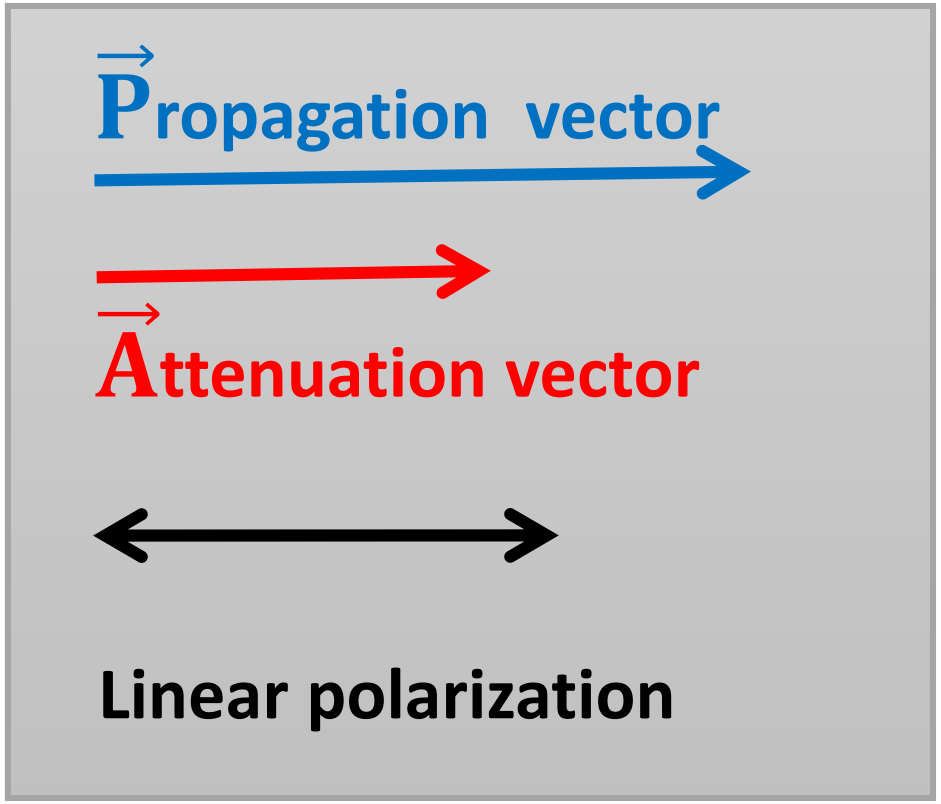
V_P	Q_P
V_S	Q_S
ε	ε_Q
δ	δ_Q
γ	γ_Q

Thomsen, 1983

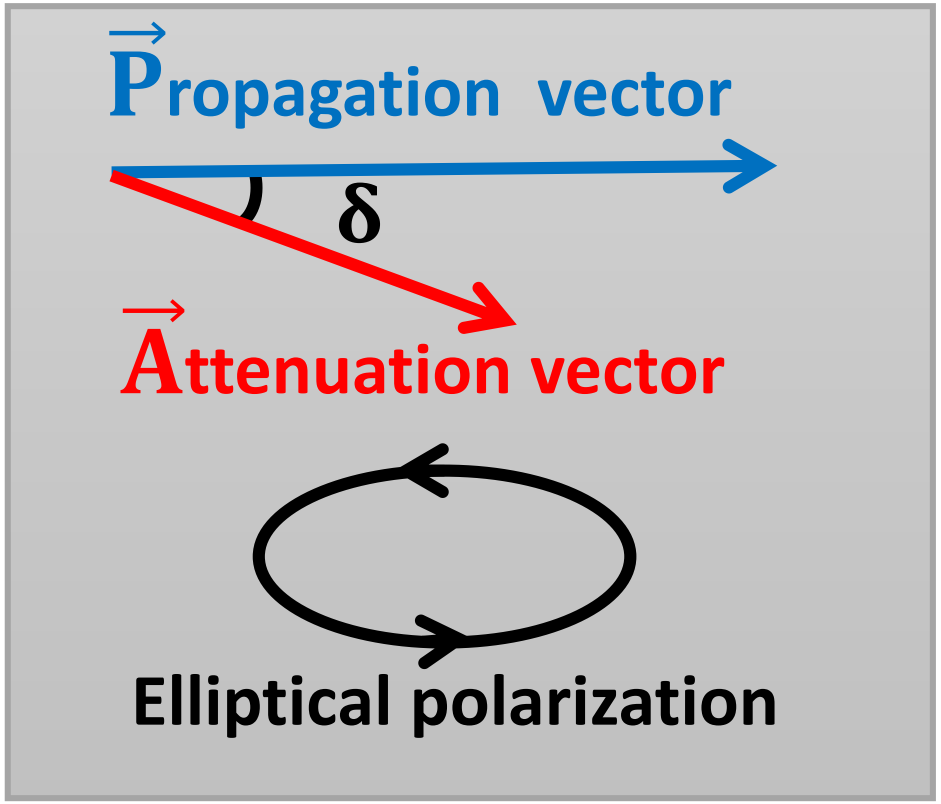
Yaping & Tsvankin 2006

Viscoelastic VTI media: viscoelastic waves

Homogenous wave

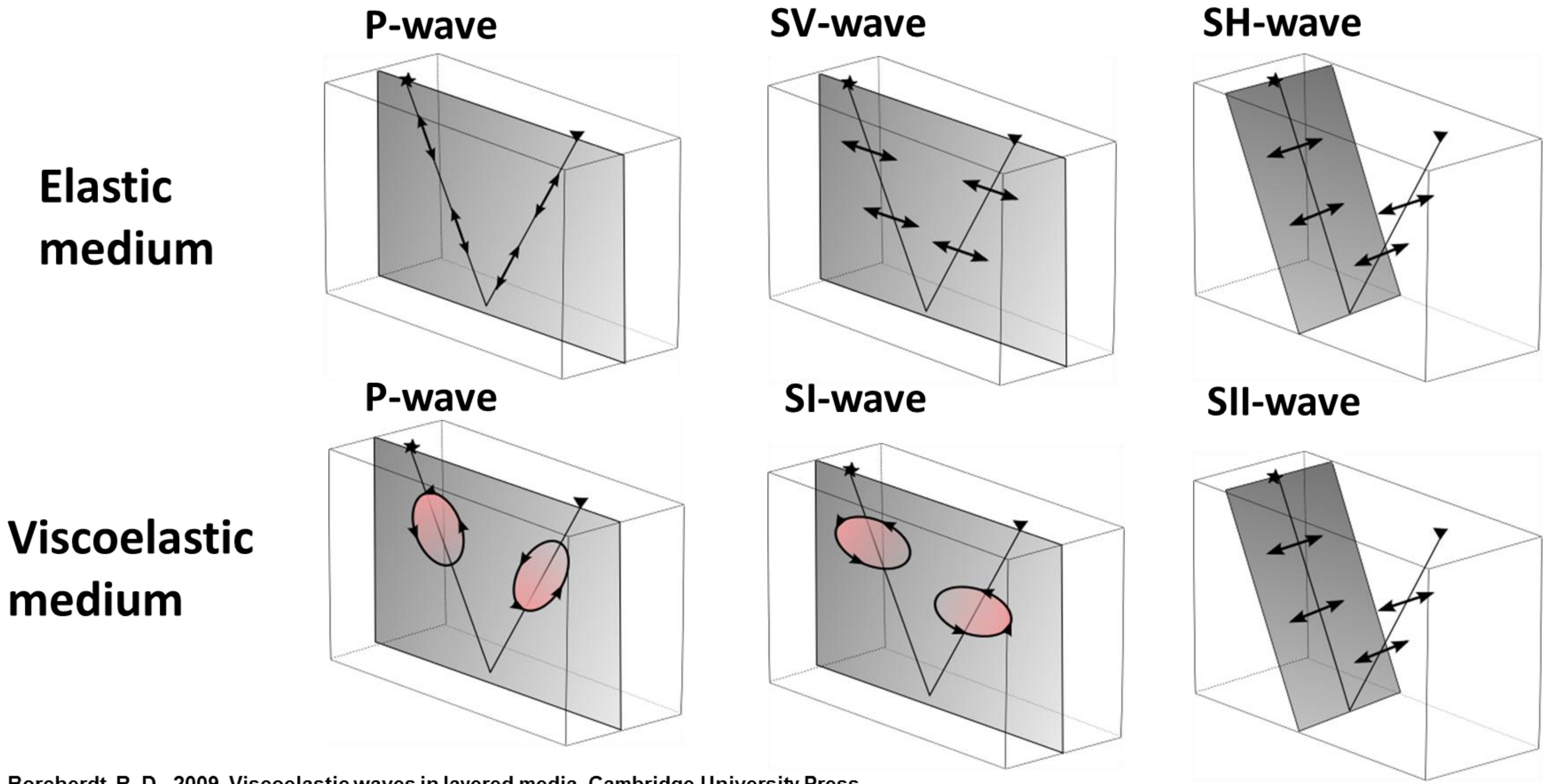


Inhomogeneous wave



Borcherdt, 2009

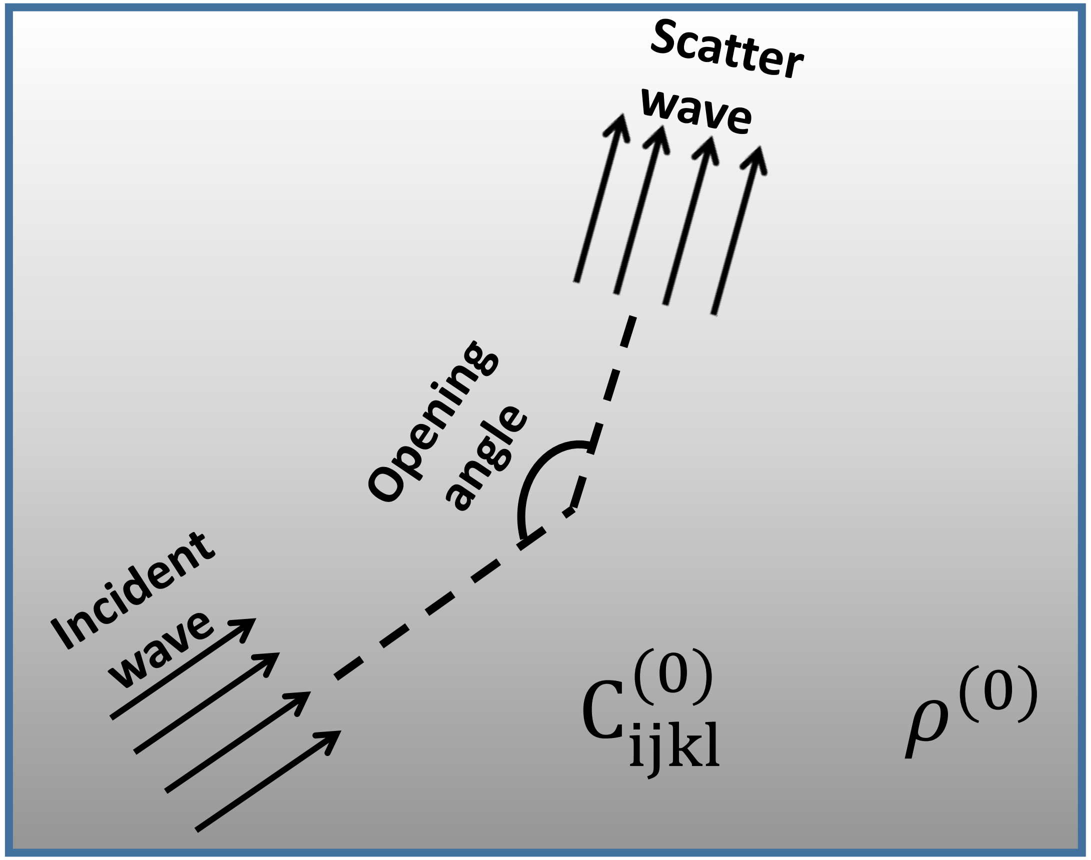
Viscoelastic VTI media: viscoelastic waves



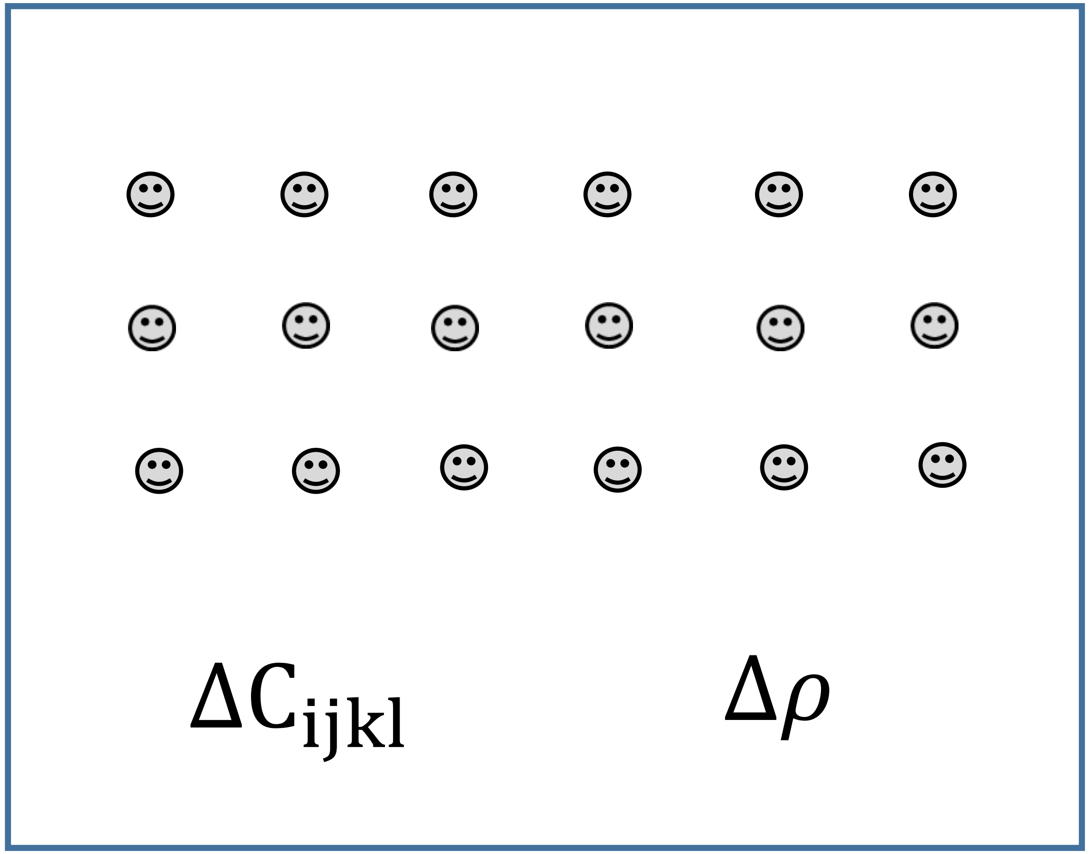
Borcherdt, R. D., 2009. Viscoelastic waves in layered media, Cambridge University Press

Born approximation

Reference medium



Perturbations



Volume scattering vs low contrast reflection

Volume scattering(Born approximation)

Elastic parameters: ρ_0, V_{P0}, V_{S0}

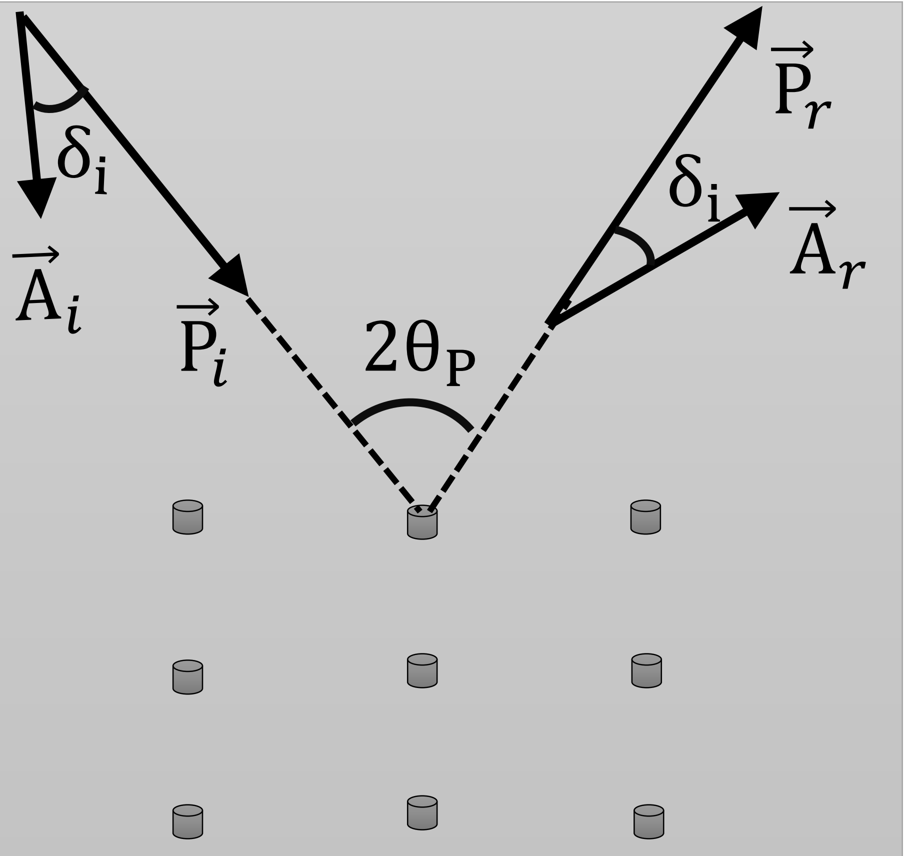
Viscoelastic parameters: Q_{P0}, Q_{S0}

Elastic perturbations: $\Delta\rho$, ΔV_P, ΔV_S

Anisotropic perturbations: $\Delta\varepsilon$, $\Delta\delta$, $\Delta\gamma$

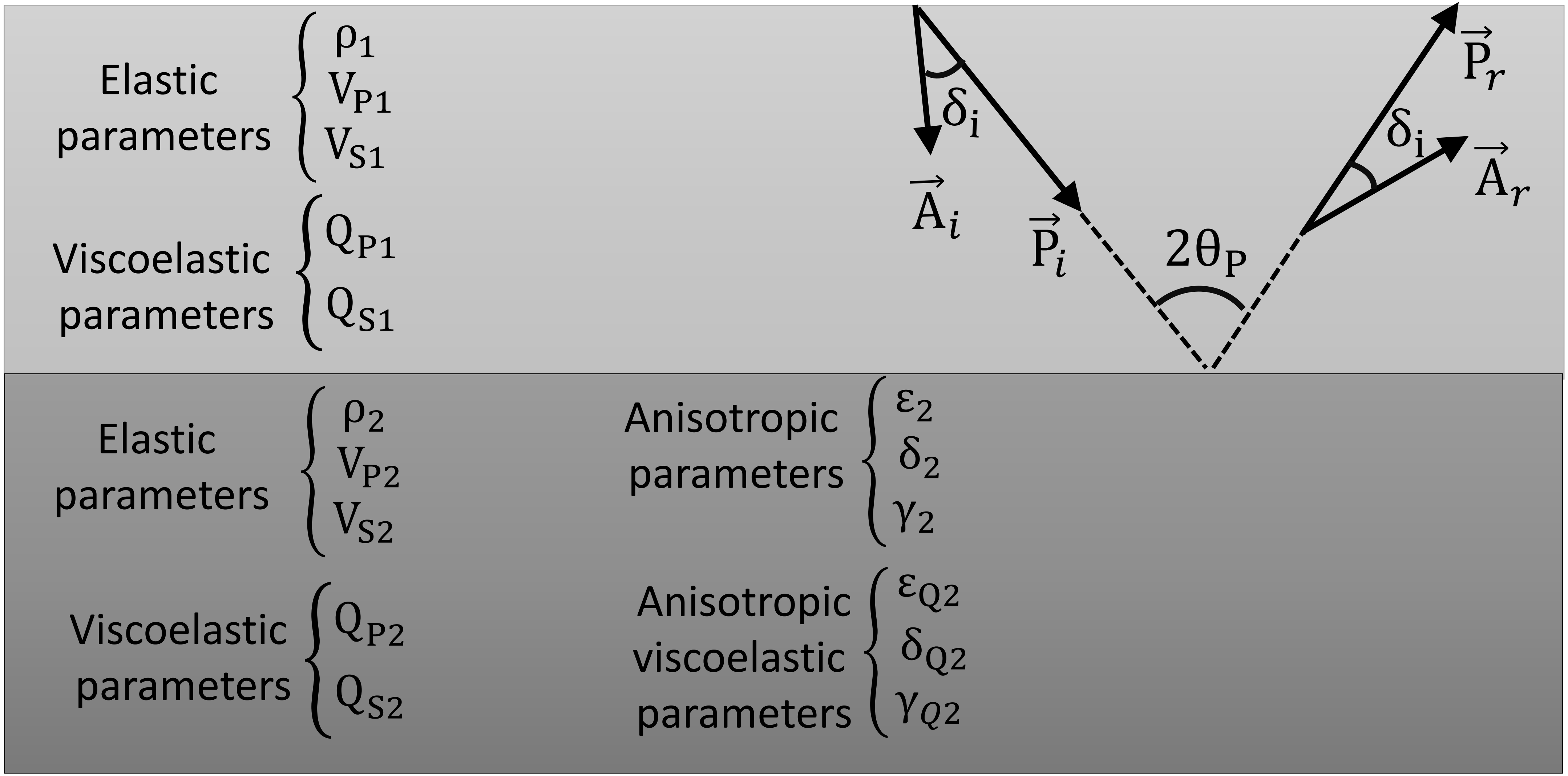
Viscoelastic perturbations: ΔQ_P, ΔQ_S

Anisotropic viscoelastic perturbations: $\Delta\varepsilon_Q$, $\Delta\delta_Q$, $\Delta\gamma_Q$



Volume scattering vs low contrast reflection

Low contrast reflection(Zoeppritz equation)



Scattering patterns and AVO equations

- **Isotropic Elastic (IE):** sensitive to the changes in density P-and S-wave velocity. This terms is the scattering potential for scattering of seismic wave in an isotropic elastic reference media (Aki & Richards).

- **Anisotropic Elastic (AE):** sensitive to the changes in Thomsen parameters. (IE+AE)-term is the scattering potential for scattering of elastic wave in an anisotropic-elastic reference medium (Thomsen 1986; Rüger, 1997; Shaw & Sen, 2004).

- **Isotropic Viscoelastic (IV):** sensitive to the changes in density, P-and S-wave velocities and P- and S-wave quality factors. (IE+IV)-term is the scattering potential for scattering of viscoelastic wave in an isotropic viscoelastic reference media (Moradi & Inannen, 2015).

- **Anisotropic Viscoelastic (AV):** sensitive to the changes in Q-dependent Thomsen parameters. In the case that media is either isotropic or elastic this term is zero.

Scattering patterns and AVO equations

$$[S]=\begin{bmatrix} \boxed{PP} & 0 & PSI \\ 0 & SIISII & 0 \\ SIP & 0 & SISI \end{bmatrix}$$

Viscoelastic VTI model

Viscoelastic Orthorhombic

Scattering patterns and AVO equations

$$[\mathrm{PP}] = [\mathrm{PP}]_{\mathrm{IE}} + [\mathrm{PP}]_{\mathrm{AE}} + i\,[\mathrm{PP}]_{\mathrm{IV}} + i\,[\mathrm{PP}]_{\mathrm{AV}}$$

Isotropic Elastic

$$[\mathrm{PP}]_{\mathrm{IE}} = [\mathrm{PP}]_{\mathrm{IE}}^{\rho}\frac{\Delta\rho}{\rho} + [\mathrm{PP}]_{\mathrm{IE}}^{\mathrm{V_P}}\frac{\Delta V_P}{V_P} + [\mathrm{PP}]_{\mathrm{IE}}^{\mathrm{V_S}}\frac{\Delta V_{\mathrm{S}}}{V_{\mathrm{S}}}$$

Anisotropic Elastic

$$[\mathrm{PP}]_{\mathrm{AE}} = [\mathrm{PP}]_{\mathrm{AE}}^{\varepsilon}\Delta\varepsilon + [\mathrm{PP}]_{\mathrm{AE}}^{\delta}\Delta\delta$$

Isotropic Viscoelastic

$$[\mathrm{PP}]_{\mathrm{IV}} = [\mathrm{PP}]_{\mathrm{IV}}^{\rho}\frac{\Delta\rho}{\rho} + [\mathrm{PP}]_{\mathrm{IV}}^{\mathrm{V_S}}\frac{\Delta V_{\mathrm{S}}}{V_{\mathrm{S}}} + [\mathrm{PP}]_{\mathrm{IV}}^{\mathrm{Q_P}}\frac{\Delta Q_{\mathrm{P}}}{Q_{\mathrm{P}}} + [\mathrm{PP}]_{\mathrm{IV}}^{\mathrm{Q_S}}\frac{\Delta Q_{\mathrm{S}}}{Q_{\mathrm{S}}}$$

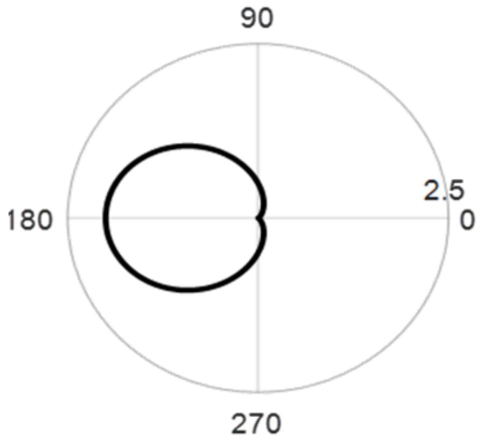
Anisotropic Viscoelastic

$$[\mathrm{PP}]_{\mathrm{AV}} = [\mathrm{PP}]_{\mathrm{AV}}^{\varepsilon}\Delta\varepsilon + [\mathrm{PP}]_{\mathrm{AV}}^{\delta}\Delta\delta + [\mathrm{PP}]_{\mathrm{AV}}^{\varepsilon_{\mathrm{Q}}}\Delta\varepsilon_{\mathrm{Q}} + [\mathrm{PP}]_{\mathrm{AV}}^{\delta_{\mathrm{Q}}}\Delta\delta_{\mathrm{Q}}$$

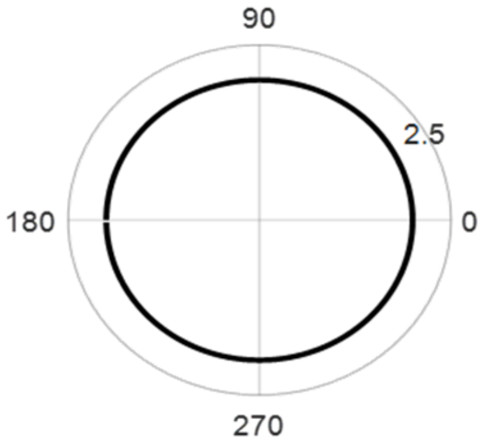
Scattering patterns and AVO equations

Isotropic Elastic

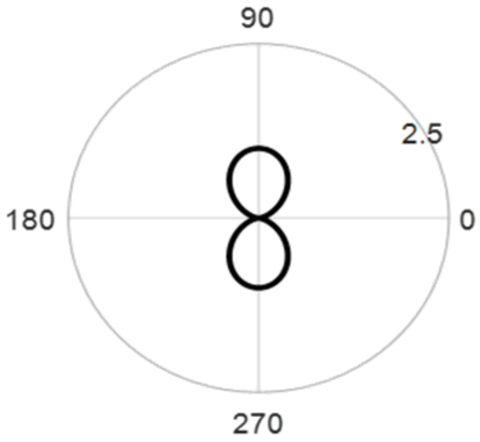
$[\mathbf{PP}]^{\rho}_{\mathbf{IE}}$



$[\mathbf{PP}]^{\mathbf{Vp}}_{\mathbf{IE}}$

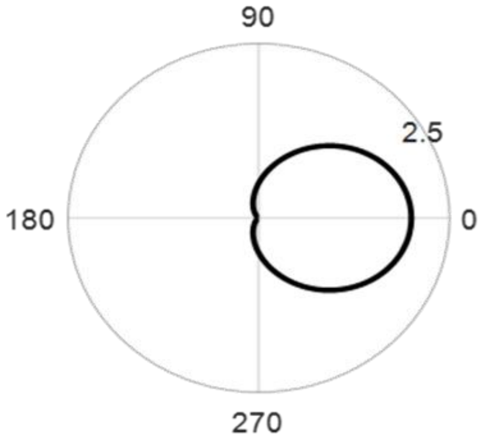


$[\mathbf{PP}]^{\mathbf{Vs}}_{\mathbf{IE}}$

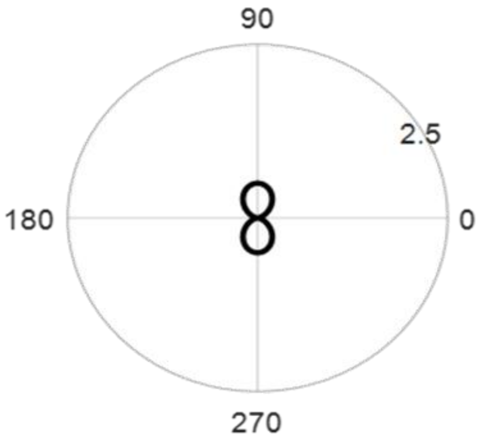


Anisotropic Elastic

$[\mathbf{PP}]^{\epsilon}_{\mathbf{AE}}$



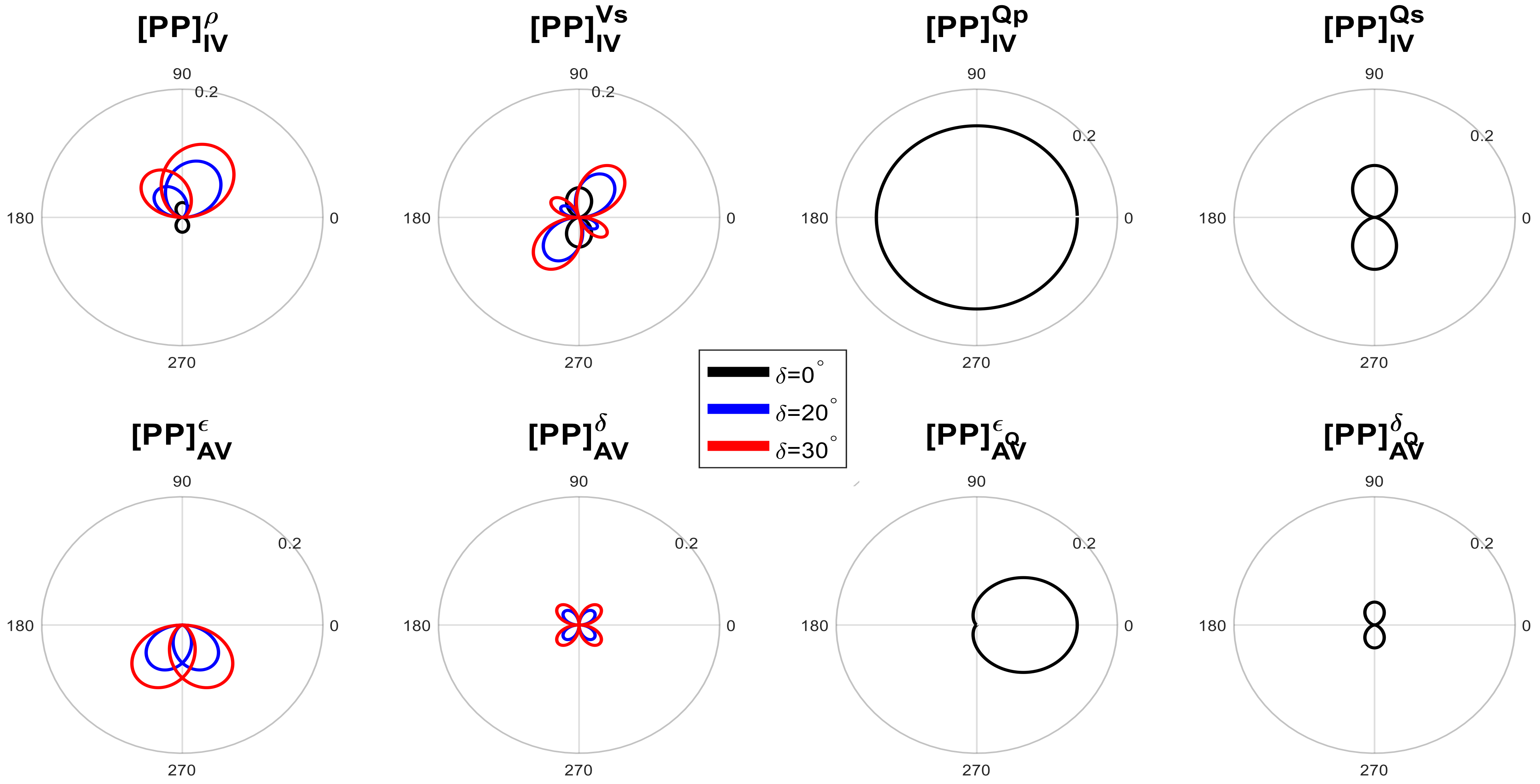
$[\mathbf{PP}]^{\delta}_{\mathbf{AE}}$



Scattering patterns and AVO equations

Isotropic Viscoelastic

Anisotropic Viscoelastic



Scattering patterns and AVO equations

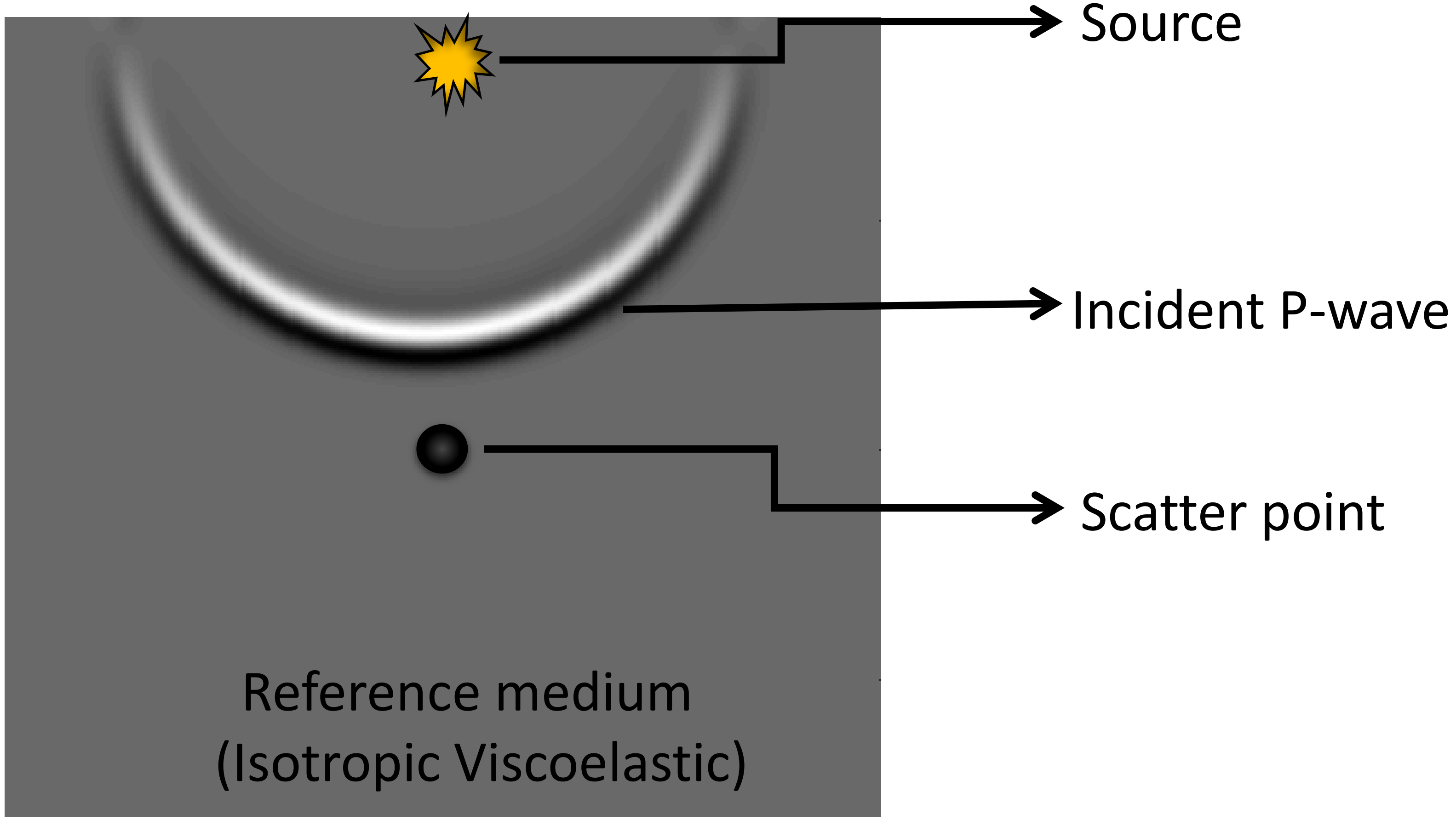
$$R_{PP} = \hat{A}_{PP} + \hat{B}_{PP}\sin^2\theta_P + \hat{C}_{PP}\sin^2\theta_P\tan^2\theta_P$$

$$\hat{A}_{PP} = \frac{1}{2}\left(\frac{\Delta\rho}{\rho} + \frac{\Delta V_P}{V_P}\right) - \frac{i}{4}Q_{P0}^{-1}\frac{\Delta Q_{P0}}{Q_{P0}}$$

$$\hat{C}_{PP} = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} + \Delta\varepsilon\right] - \frac{i}{4}Q_{P0}^{-1}\frac{\Delta Q_P}{Q_P} + \frac{i}{4}Q_{P0}^{-1}\Delta\varepsilon_Q$$

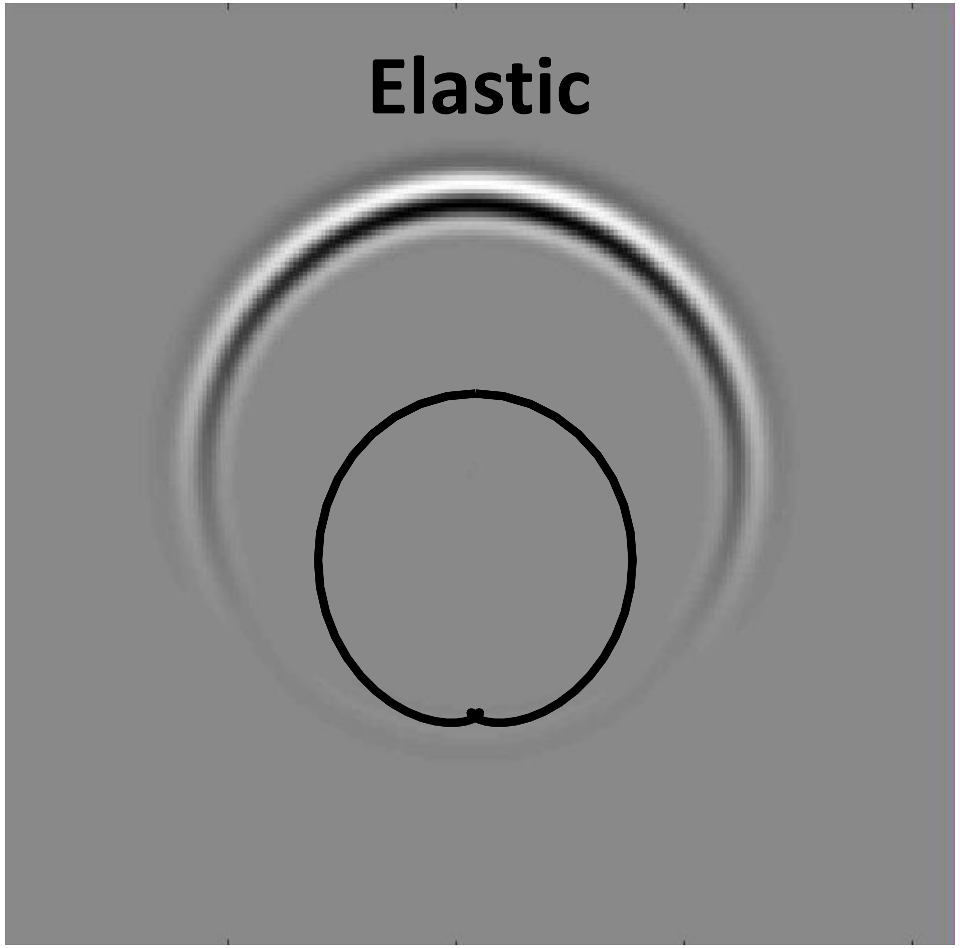
$$\hat{B}_{PP} = \frac{1}{2}\left[\frac{\Delta V_P}{V_P} - 4V_{SP}^2\left(\frac{\Delta\rho}{\rho} + 2\frac{\Delta V_S}{V_S}\right) + \Delta\delta\right] - i\left[\frac{1}{4}Q_{P0}^{-1}\frac{\Delta Q_P}{Q_P} - 2V_{SP}^2 Q_{S0}^{-1}\frac{\Delta Q_S}{Q_S}\right]$$
$$- i\left[2V_{SP}^2(Q_{S0}^{-1} - Q_{P0}^{-1})\left(\frac{\Delta\rho}{\rho} + 2\frac{\Delta V_S}{V_S}\right) - \frac{1}{4}Q_{P0}^{-1}\Delta\delta_Q\right]$$

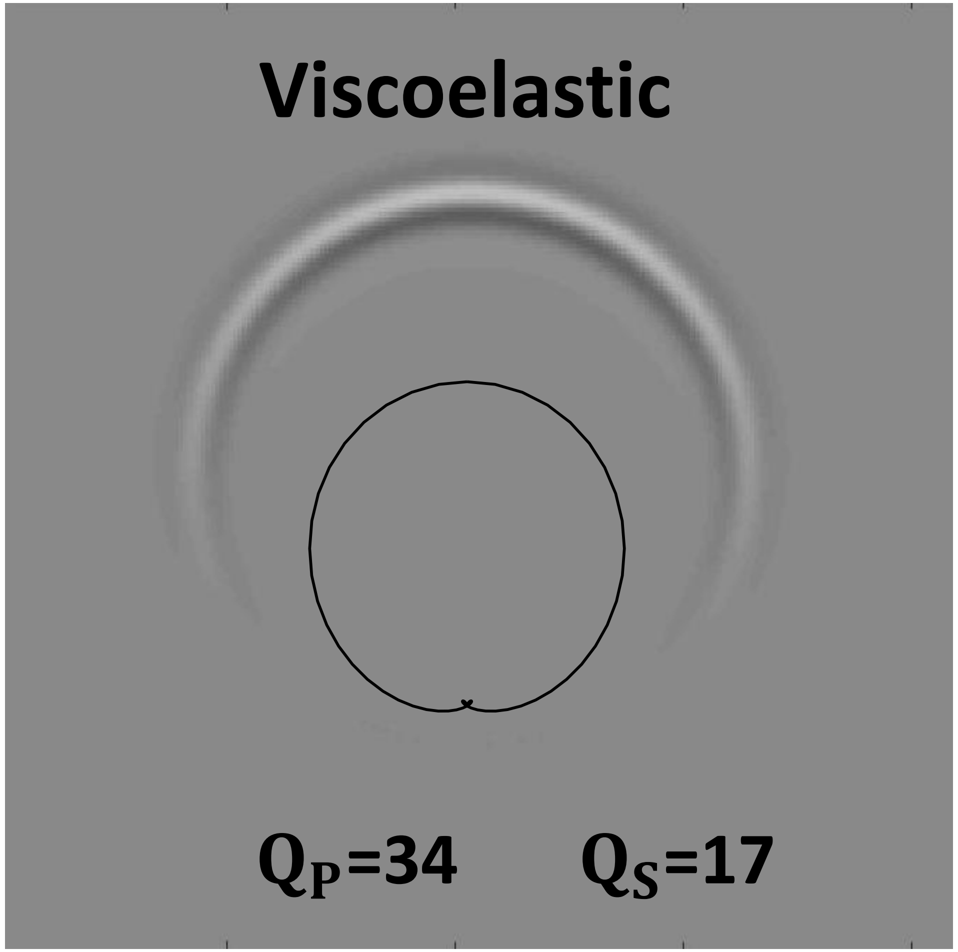
Numerical examples: FWI sensitivities



Numerical examples: FWI sensitivities

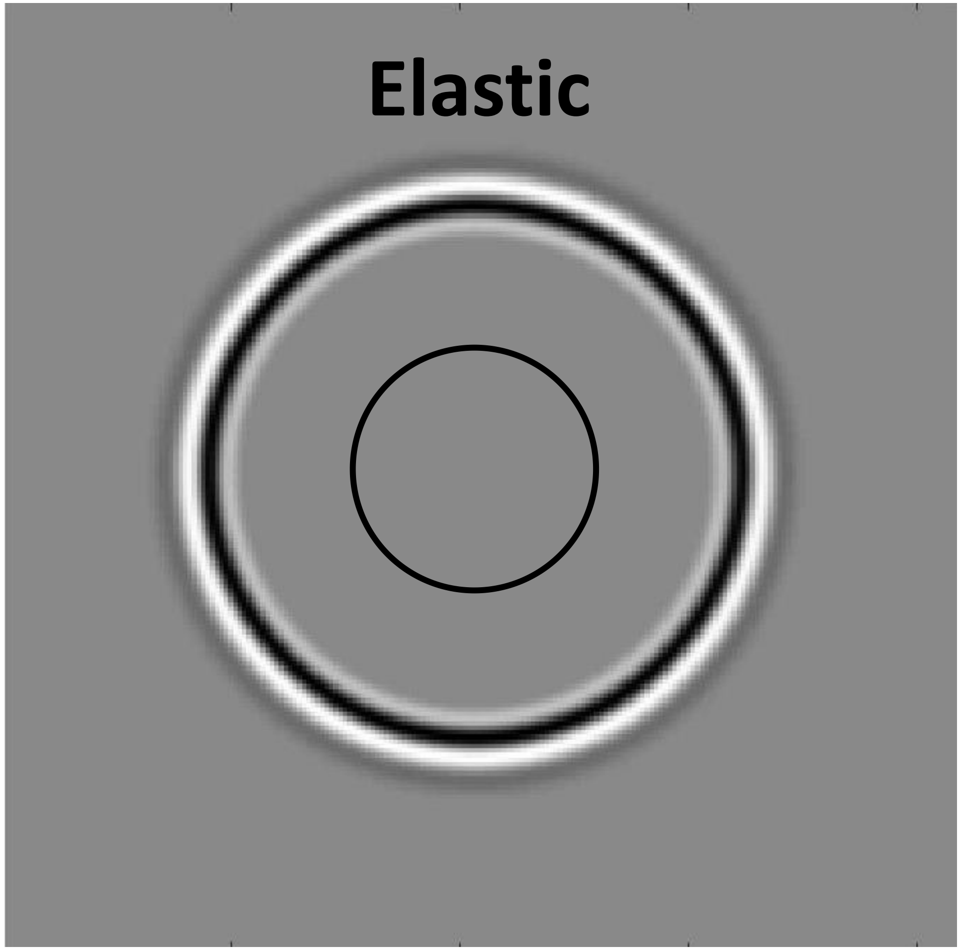
PP-wave(density scatter point)

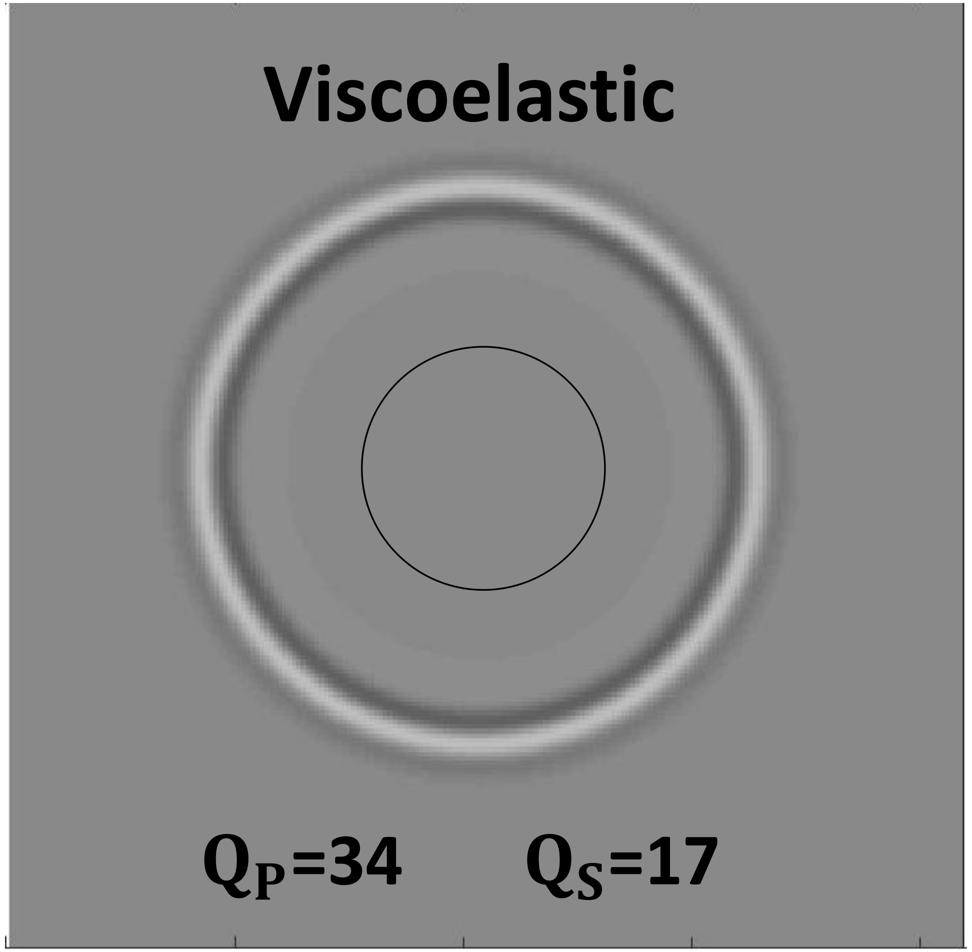




Numerical examples: FWI sensitivities

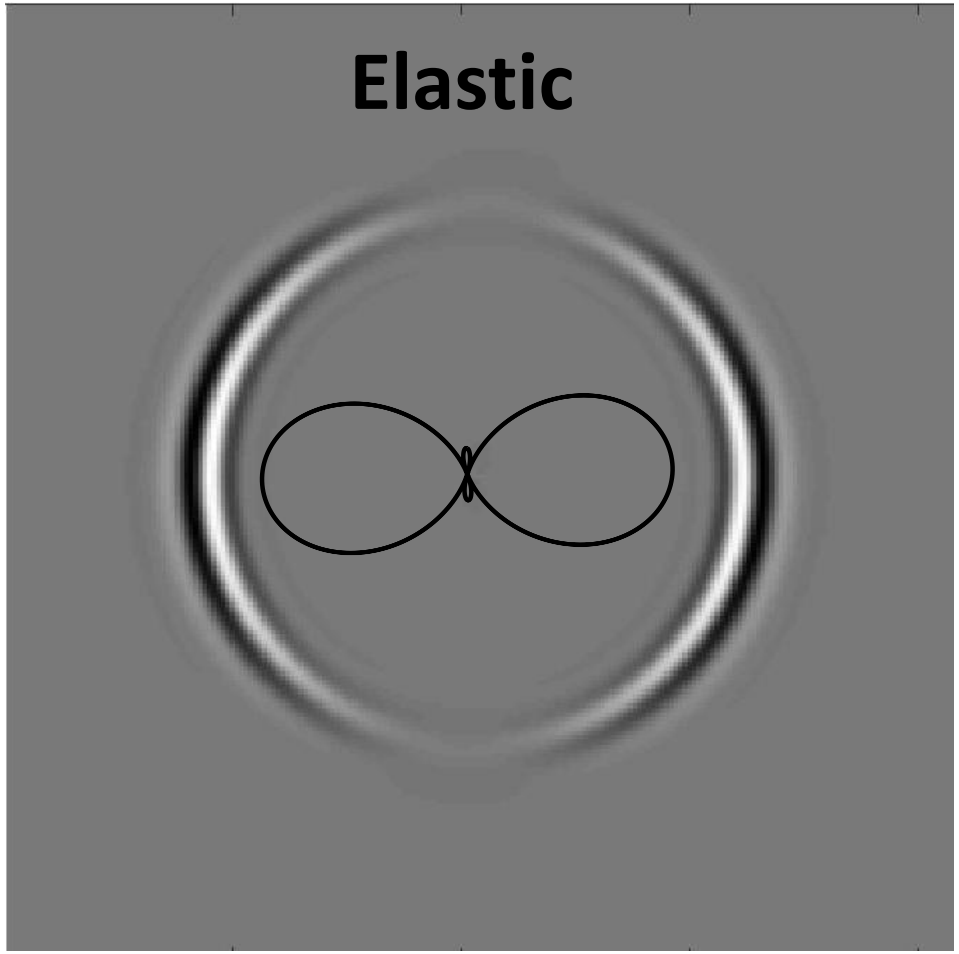
PP-wave(P-wave velocity scatter point)

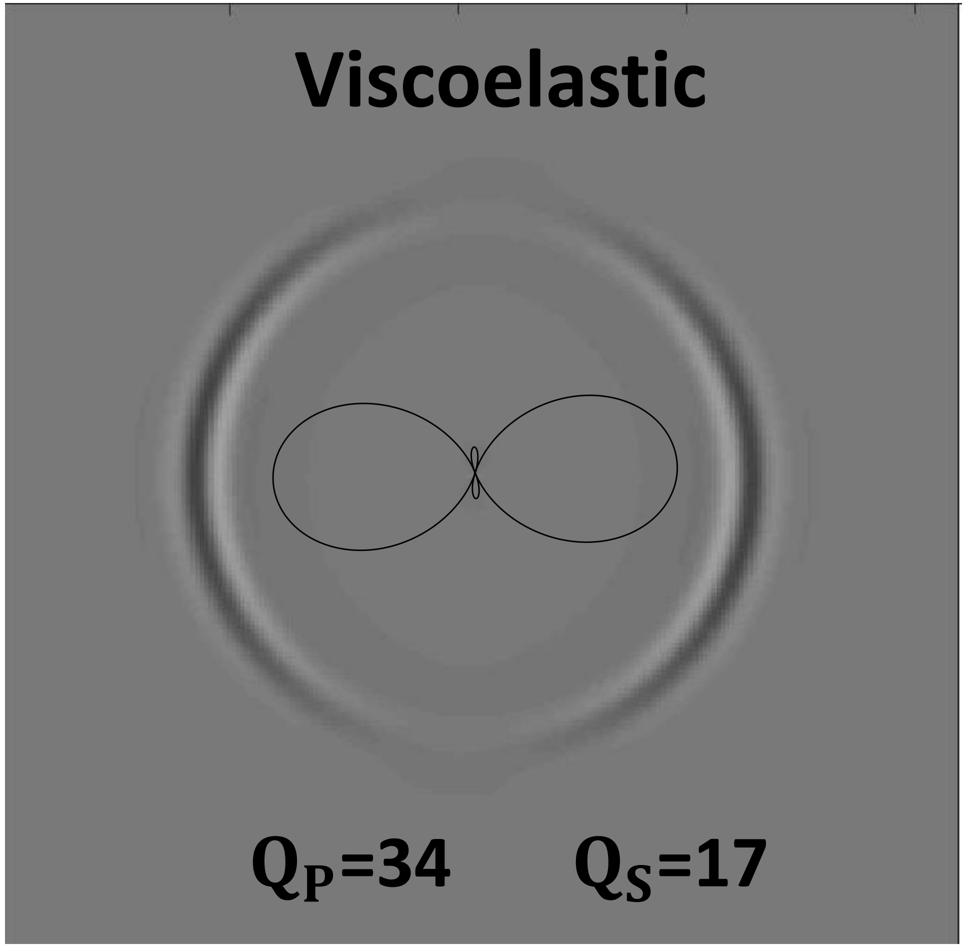




Numerical examples: FWI sensitivities

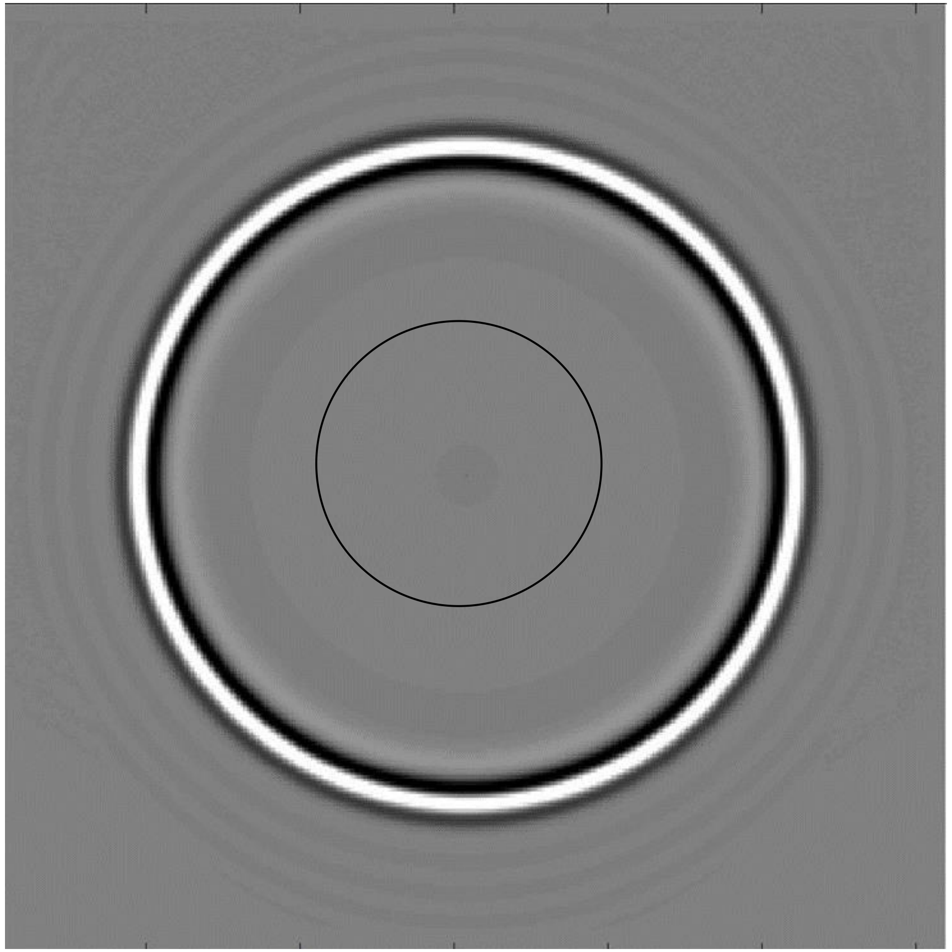
PP-wave(S-wave velocity scatter point)



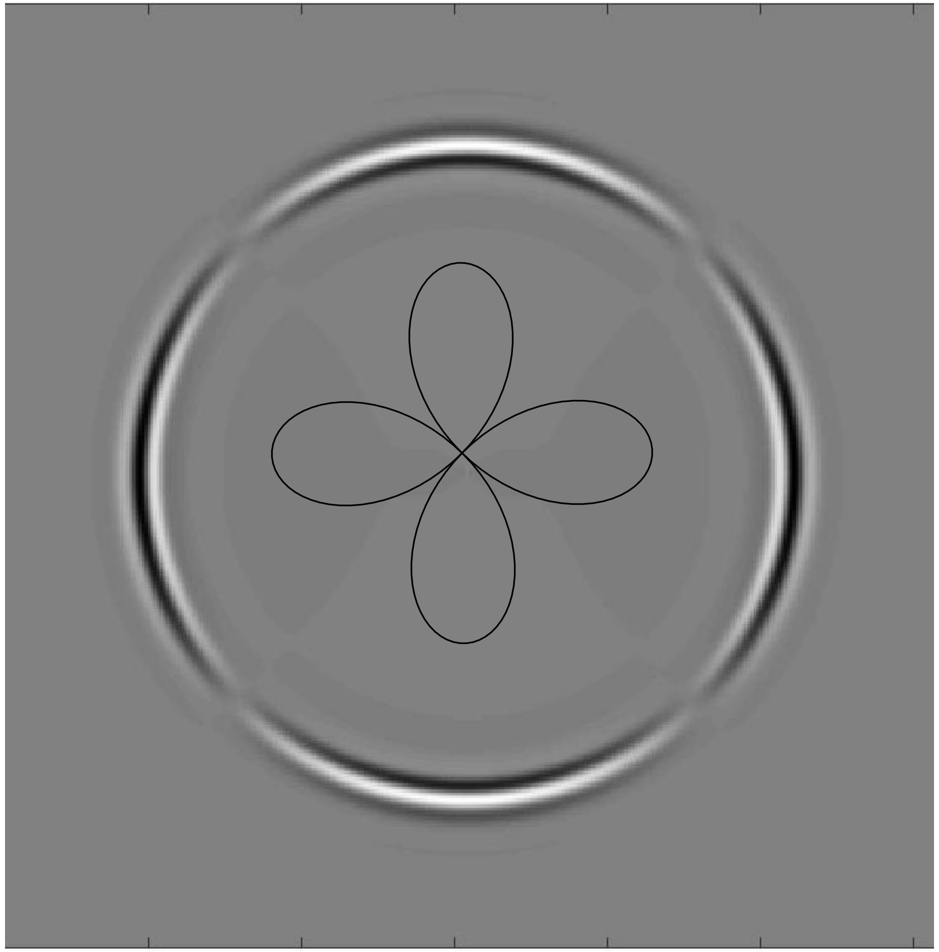


Numerical examples: FWI sensitivities

PP-wave(Qp scatter point)



PP-wave(Qs scatter point)



Summary and conclusion

- Scattering potentials and linearized reflection confidents are derived in anisotropic viscoelastic media
- Inhomogeneity of the wave does not have any influence on the reflection coefficient for vertically incident waves.
- The consistency of our theoretical/scattering treatment with the numerical results obtained is a significant step towards the development of several processing and inversion applications for data with nonneglible P and S wave attenuation and anisotropy.

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Thank you