ROSE meeting

ROSE
Rock Seismic Research Project

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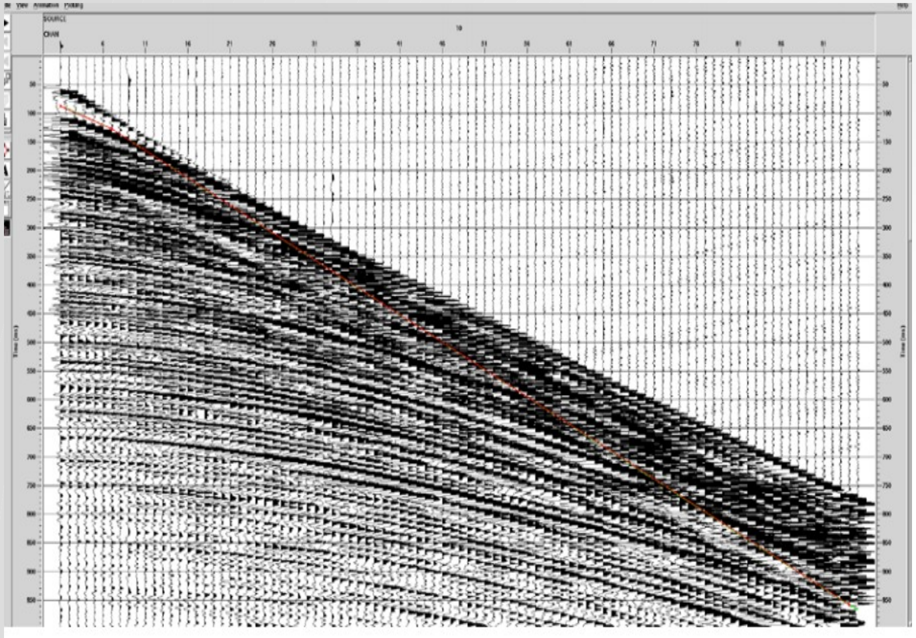
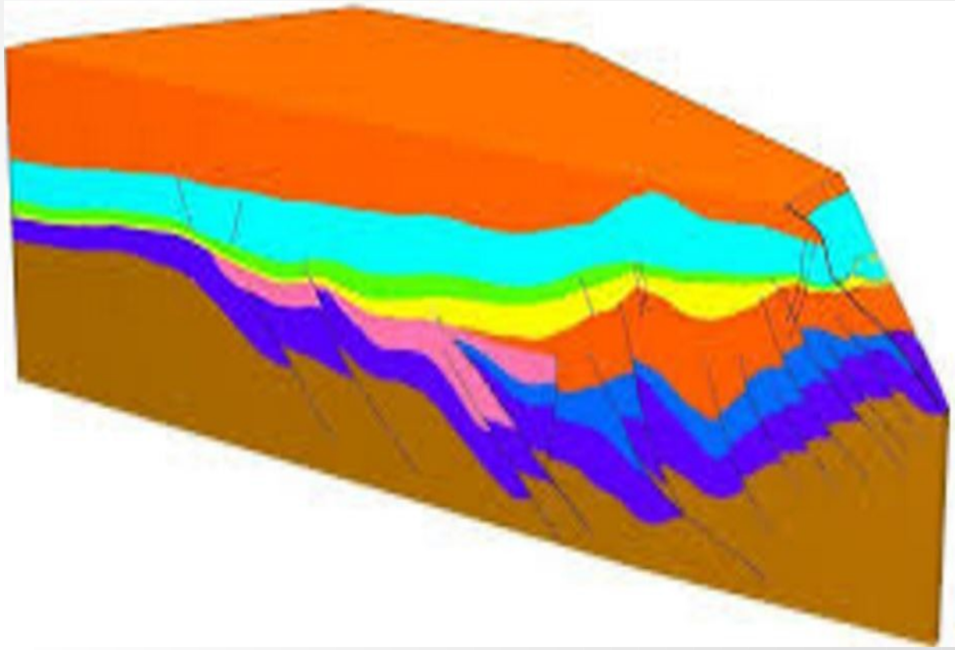
27-30th.04.2015, Trondheim





Seismic data

$T(m,h)$

Curvature, Anisotropy & Heterogeneity

Reflector & model

R, z_0

δ, η, V

Estimation of anisotropy parameters from CRS approximation

Objectives:

1. Distinguish curvature and anisotropy from CRS approximation

2. Investigate the effect from anisotropy and inhomogeneity to CRS attributes and model parameters

3. Estimation of anisotropy and model parameters

Outline

- 1 The CRS operator for a circular reflector in isotropic medium

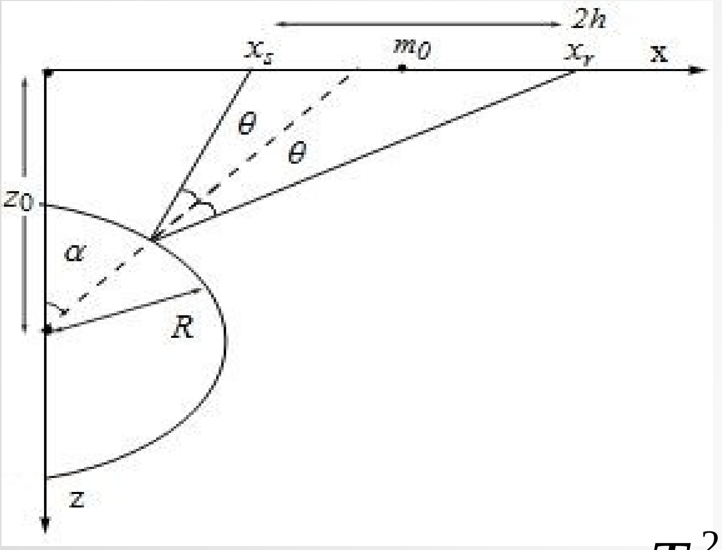
  2 Extend for more complicated media

  3 Numerical examples & sensitivity analysis

  4 Curvature and anisotropy estimation

  5 Conclusions

CRS approximation

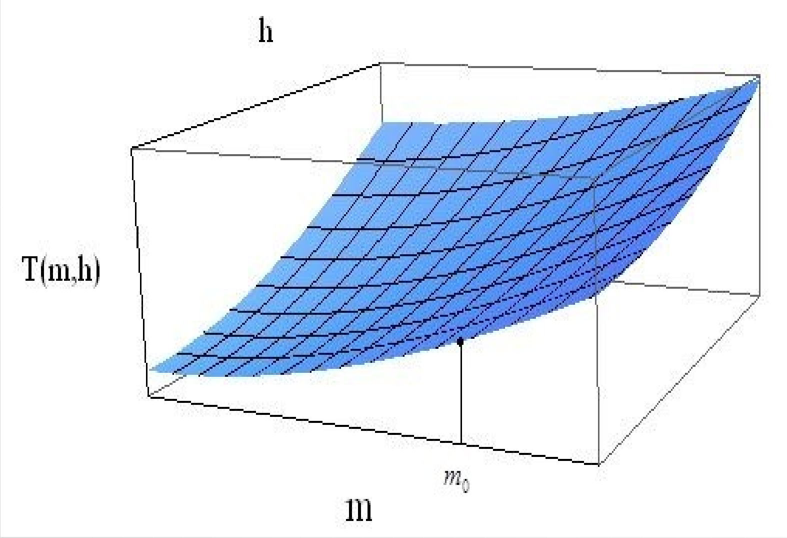


$$m = \frac{x_r + x_s}{2},$$

$$h = \frac{x_r - x_s}{2},$$

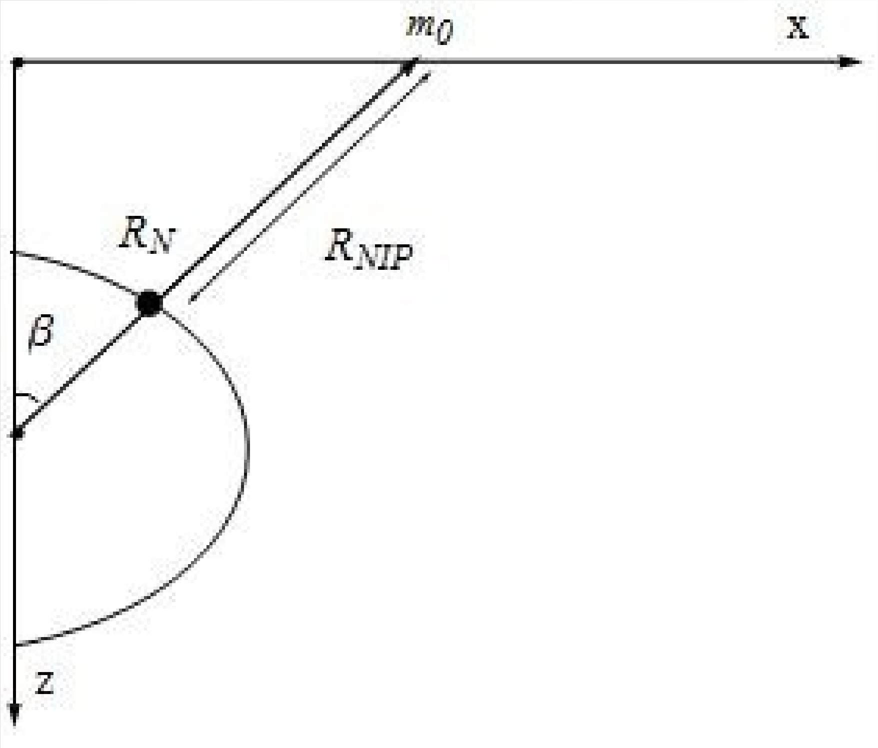
$$T = T_1 + T_2 = \frac{(z_0 - R\cos\alpha)}{V\cos(\alpha - \theta)} + \frac{(z_0 - R\cos\alpha)}{V\cos(\alpha + \theta)}$$

$$T_{CRS}^2(\Delta m, h) = A_0 + A_1\Delta m + A_2\Delta m^2 + B_2 h^2.$$



$$A_0, A_1, A_2, B_2 \text{ -- } (R, z_0, V, m_0)$$

Inversion of CRS attributes



$$A_0 = \frac{4R_{NIP}^2}{V^2}, \; A_1 = \frac{8R_{NIP}\sin\beta}{V^2},$$

$$A_2 = \frac{4(R_{NIP}\cos^2\beta + R_N\sin^2\beta)}{V^2 R_N}, \; B_2 = \frac{4\cos^2\beta}{V^2}.$$

⇓

$$\hat{R}_{NIP}, \; \hat{R}_N, \; \sin\hat{\beta},$$

⇓

$$\hat{R}, \; \hat{V}, \; \hat{z}_0.$$

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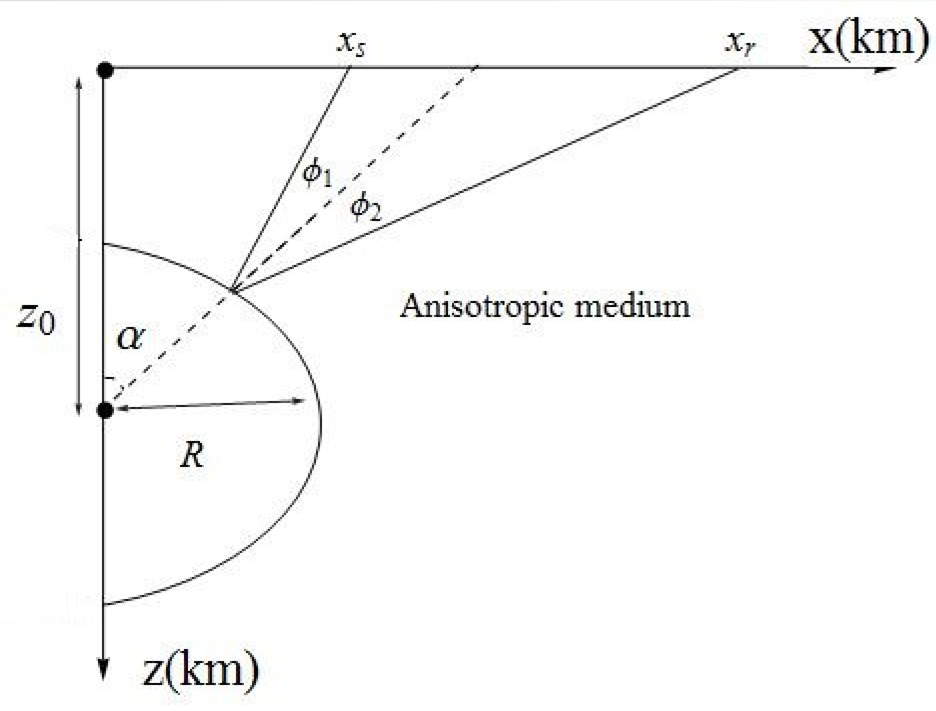
Extension for anisotropic media



For geometrical relation

$$m = \frac{x_r + x_s}{2}, h = \frac{x_r - x_s}{2}.$$

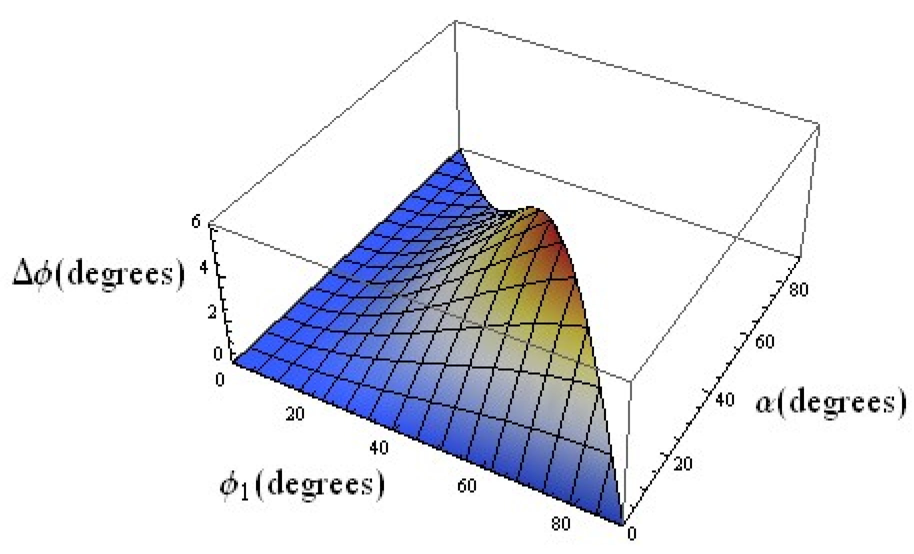
For group velocity

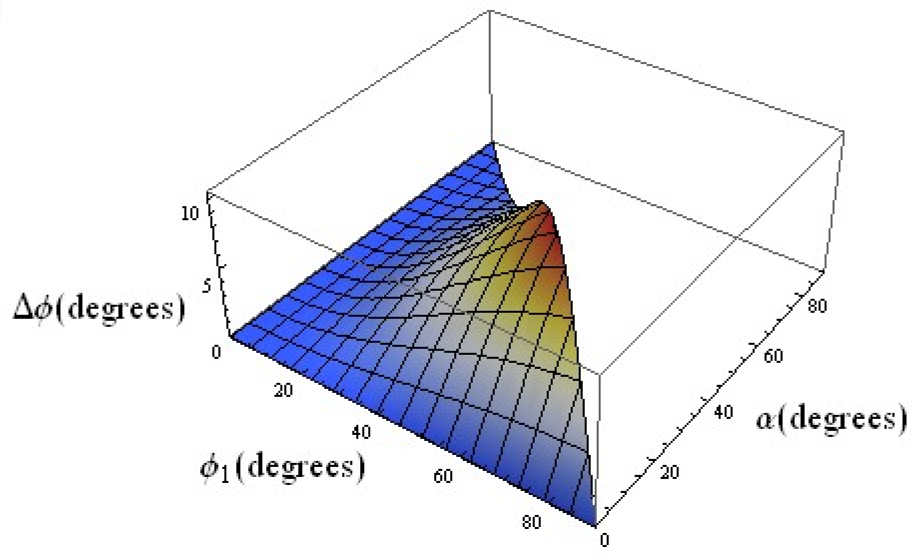
$$V_1 = V(\alpha - \phi_1), \quad V_2 = V(\alpha + \phi_2)$$

For traveltime

$$T = \frac{(z_0 - R\cos\alpha)}{\cos(\alpha - \phi_1)} \frac{1}{V(\alpha - \phi_1)} + \frac{(z_0 - R\cos\alpha)}{\cos(\alpha + \phi_2)} \frac{1}{V(\alpha + \phi_2)}.$$

EI medium





$\delta = 0.1$

$\delta = 0.2$

$$T = \frac{(z_0 - R\cos\alpha)}{\cos(\alpha - \theta)} \frac{1}{V(\alpha - \theta)} + \frac{(z_0 - R\cos\alpha)}{\cos(\alpha + \theta)} \frac{1}{V(\alpha + \theta)}.$$

GMA group velocity

$$\frac{1}{V(\phi)^2} = \frac{\cos^2\phi}{V_0^2} + \frac{\sin^2\phi}{V_N^2} + \frac{A\sin^2\phi\tan^2\phi}{V_N^4\left(\frac{1}{V_0^2} + \frac{B\tan^2\phi}{V_N^2} + \sqrt{\frac{1}{V_0^4} + \frac{2B\tan^2\phi}{V_0^2V_N^2} + \frac{C\tan^4\phi}{V_N^4}}\right)},$$

(Fomel and Stovas, 2010)

Effective anisotropy

1 Homogeneous anisotropic media

- Elliptical isotropic model (EI)
- Transversely isotropic model with vertical symmetry axis (VTI)

2 Heterogeneous isotropic media

- Two layered isotropic model (2LI)

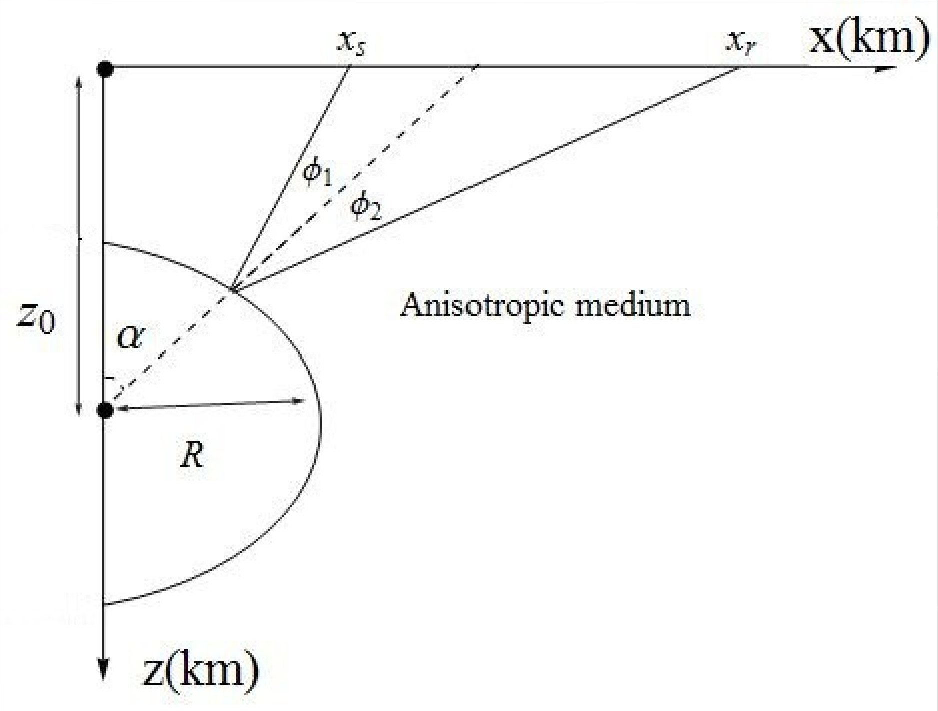
$$\frac{1}{V(\phi)^2}=\frac{\cos^2\phi}{V_0^2}+\frac{\sin^2\phi}{V_N^2}+\frac{A\sin^2\phi\tan^2\phi}{V_N^4\left(\frac{1}{V_0^2}+\frac{B\tan^2\phi}{V_N^2}+\sqrt{\frac{1}{V_0^4}+\frac{2B\tan^2\phi}{V_0^2V_N^2}+\frac{C\tan^4\phi}{V_N^4}}\right)},$$

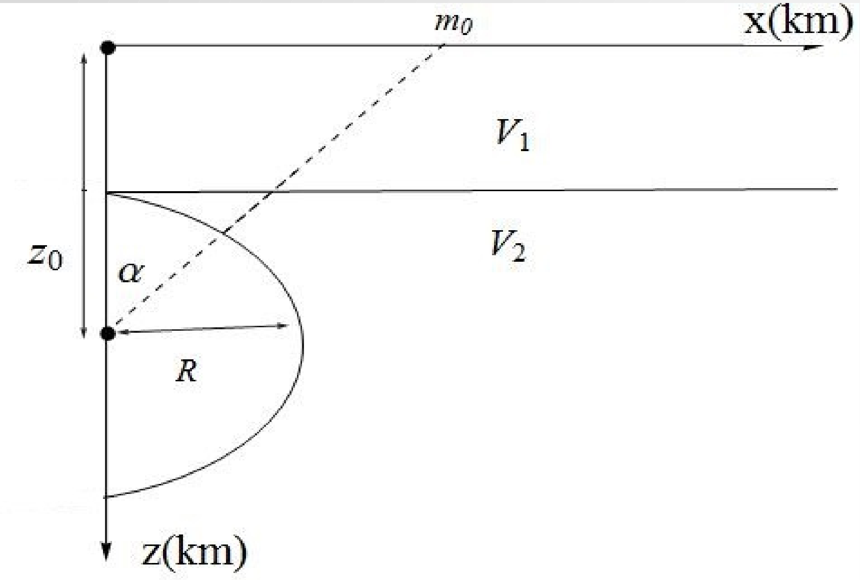
EI model:

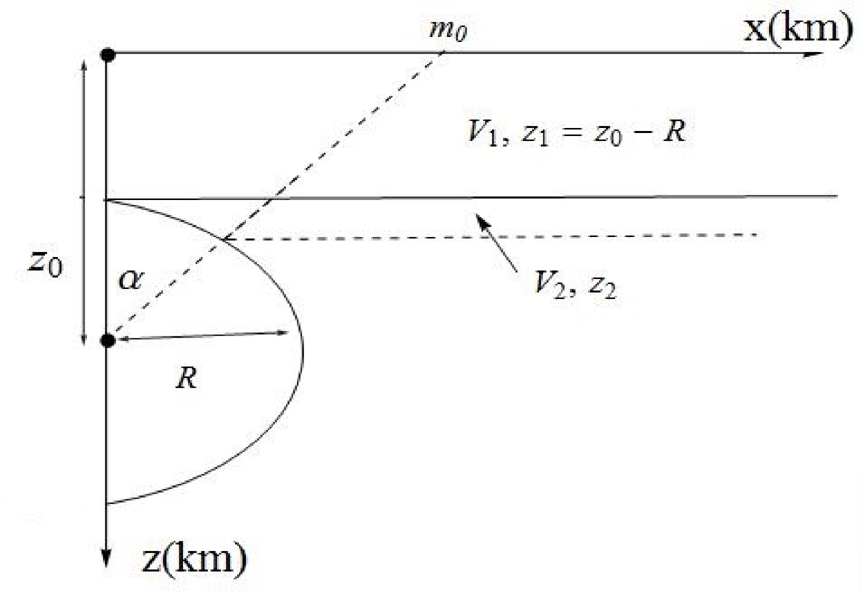
$$A=0.$$

VTI model:

$$A=-4\eta,\quad B=\frac{1+8\eta+8\eta^2}{1+2\eta},\quad C=\frac{1}{(1+2\eta)^2}.$$







2LI model:

$$\gamma = \frac{V_2}{V_1} \qquad \varepsilon = \frac{z_2}{z_1} = \frac{R - R\cos\alpha}{z_0 - R}$$

$$V_0 = V_1 \frac{1+\varepsilon}{1+\dfrac{\varepsilon}{\gamma}},$$

$$V_N = V_1 \sqrt{\frac{1+\varepsilon\gamma}{1+\dfrac{\varepsilon}{\gamma}}},$$

$$A = -\frac{\varepsilon(\gamma^2-1)^2}{2\gamma(1+\varepsilon\gamma)^2},$$

$$B = \frac{(\gamma^2-1)(1+\dfrac{\varepsilon}{\gamma})}{2(1+\varepsilon\gamma)^2},$$

$$C = 0.$$

Group velocity comparison

Reflector : $R = 1\,\text{km}$

$z_0 = 2\,\text{km}$

ISO : $V_0 = 2\,\text{km/s}$

EI : $V_N = V_0\sqrt{1+2\delta}$

$\delta = 0.1$

VTI $\eta = 0.2$

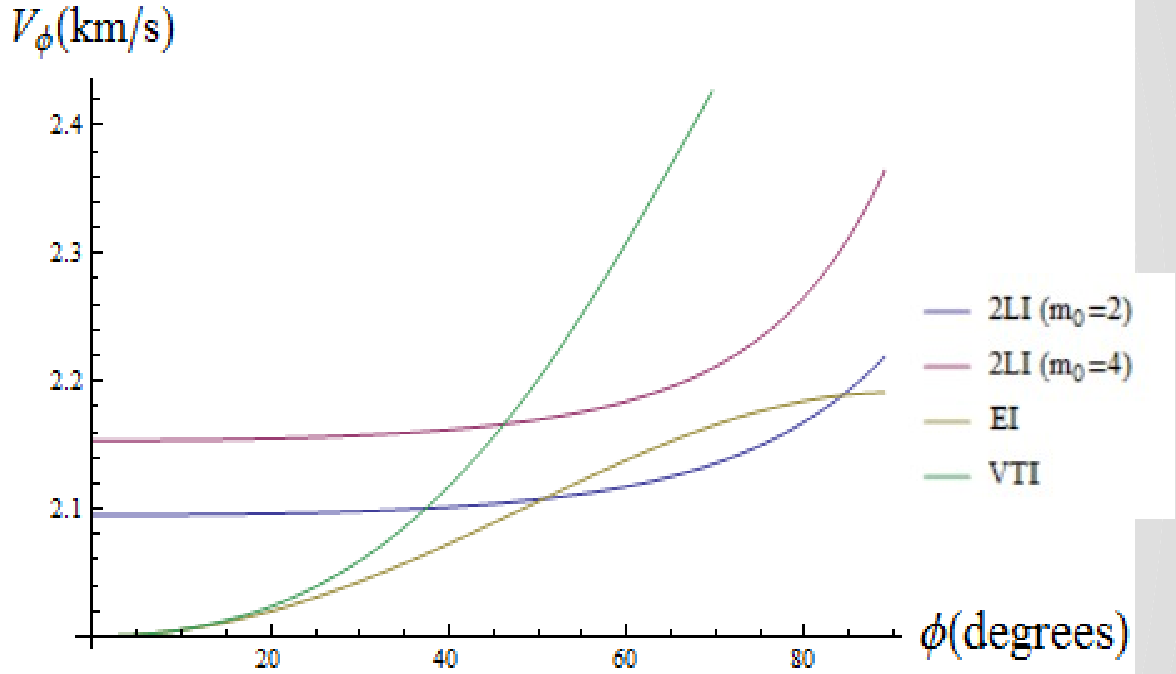
2LI : $V_1 = 2\,\text{km/s}$

$V_2 = 2.5\,\text{km/s}$

$m_0 = 2\,\text{km}$

$m_0 = 4\,\text{km}$

$\gamma = 1.25 \quad \varepsilon_1 \approx 0.29 \quad \varepsilon_2 \approx 0.55$



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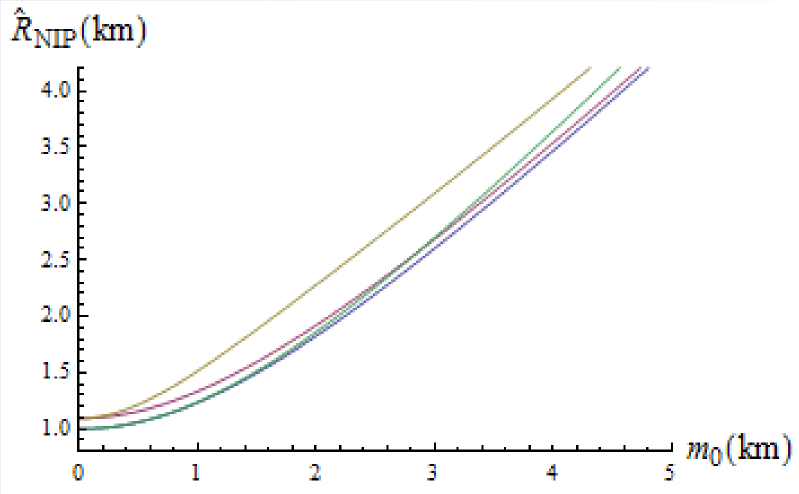
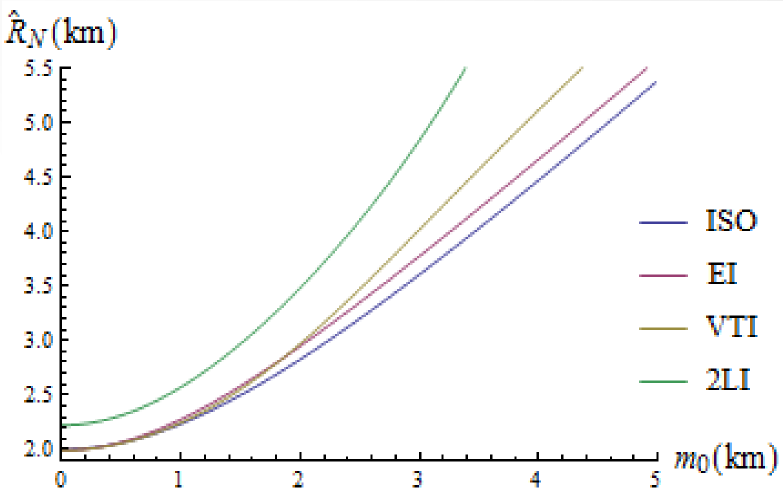
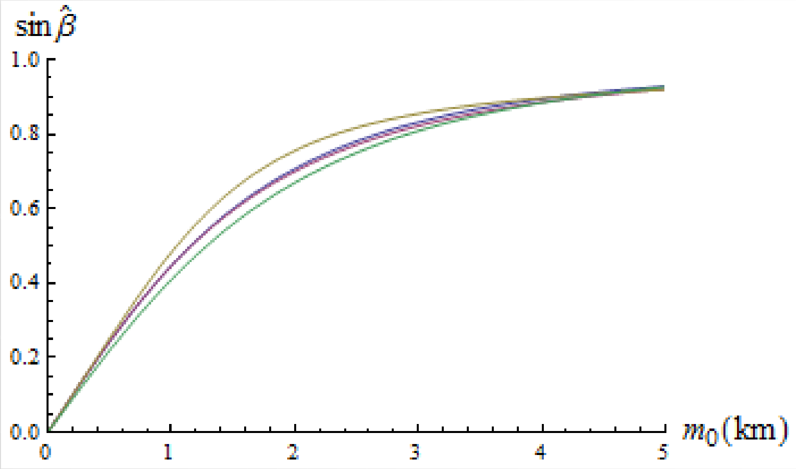
Numerical examples –CRS attributes

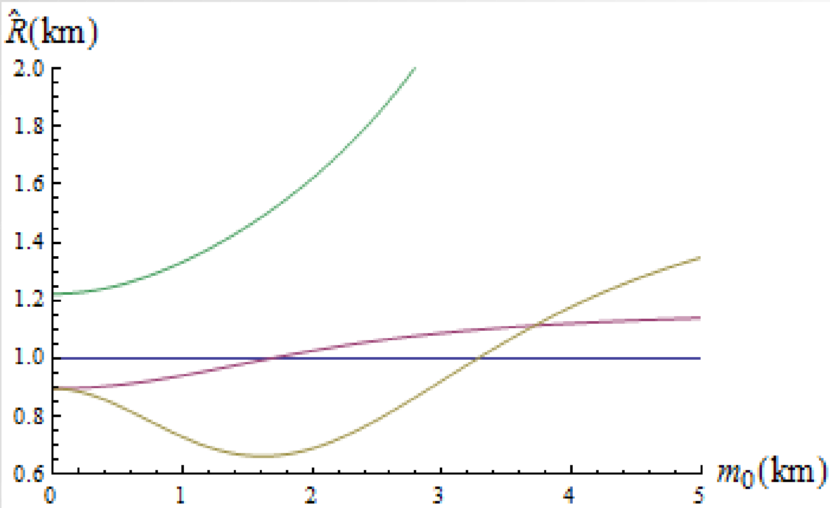


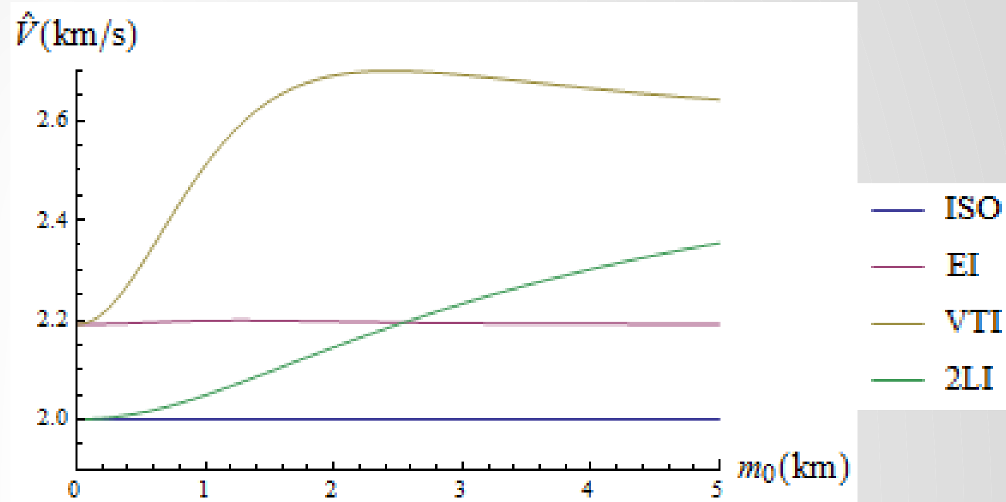


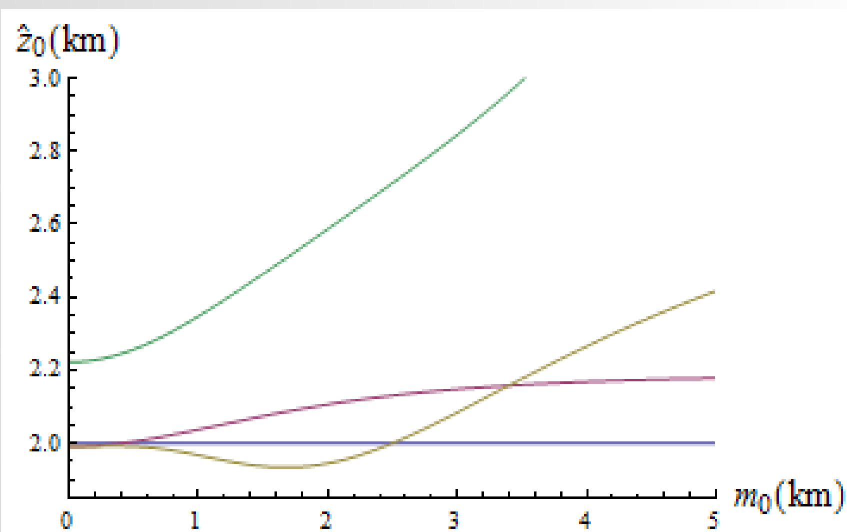


The plots of CRS attributes versus m0. The ISO, EI, VTI and 2LI cases are shown by blue, red, yellow and green colours, respectively.

Numerical examples –model parameters





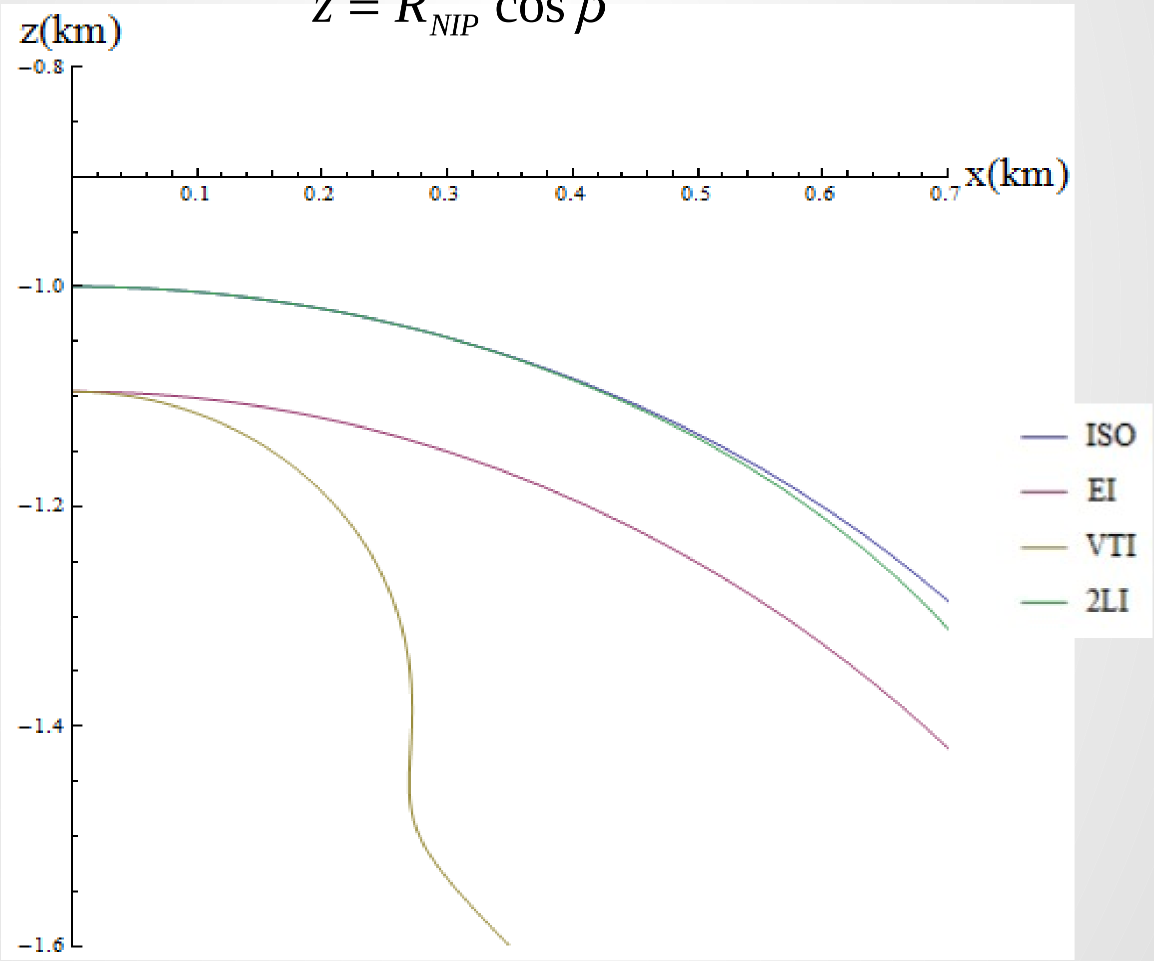


The plots of model parameters versus m0. The ISO, EI, VTI and 2LI cases are shown by blue, red, yellow and green colours, respectively.

Reconstructed reflector

$$\hat{x} = m_0 - \hat{R}_{NIP} \sin \hat{\beta}$$

$$\hat{z} = \hat{R}_{NIP} \cos \hat{\beta}$$



Linearization

CRS attributes

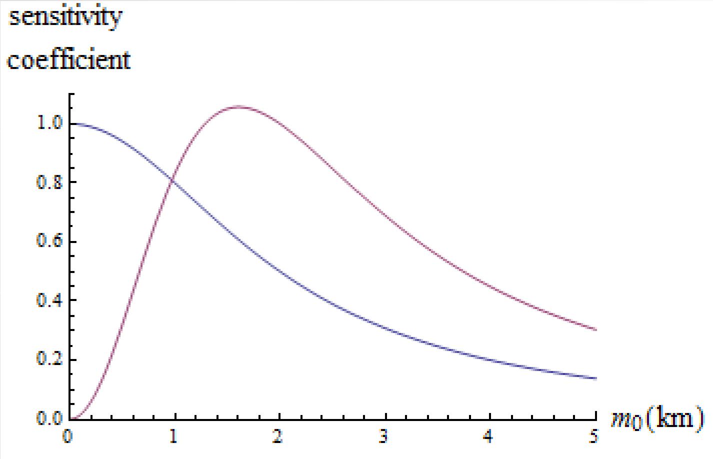
$$\hat{R}_{NIP} = R_{NIP}(1 + a_1\delta + a_2\eta),$$
$$\hat{R}_N = R_N(1 + b_1\delta + b_2\eta),$$
$$\sin\hat{\beta} = \sin\beta(1 + c_1\delta + c_2\eta).$$

Model parameters

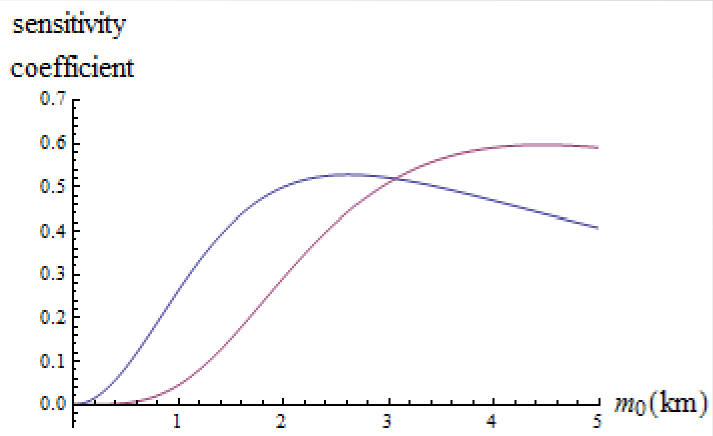
$$\hat{R} = R(1 + d_1\delta + d_2\eta),$$
$$\hat{V} = V_0(1 + e_1\delta + e_2\eta),$$
$$\hat{z}_0 = z_0(1 + f_1\delta + f_2\eta).$$

Sensitivity analysis

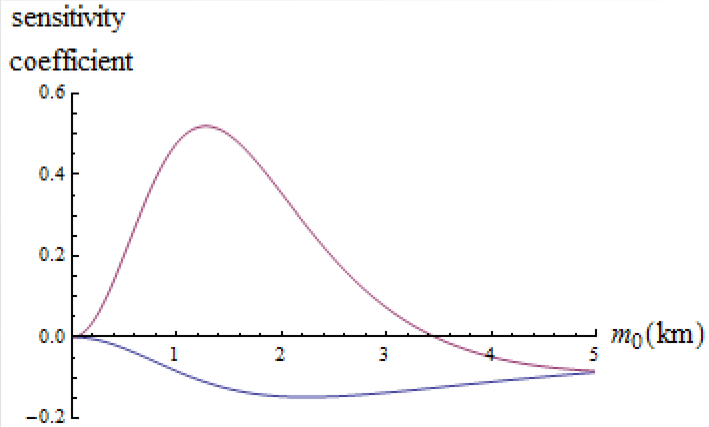
R_{NIP}



R_N



$\sin\beta$

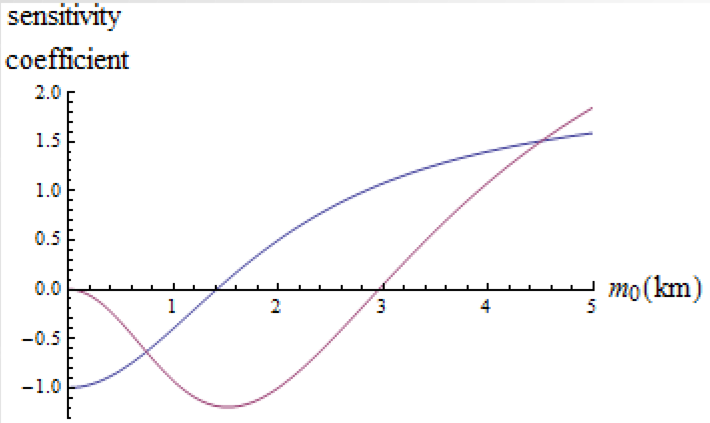


$\delta - blue$

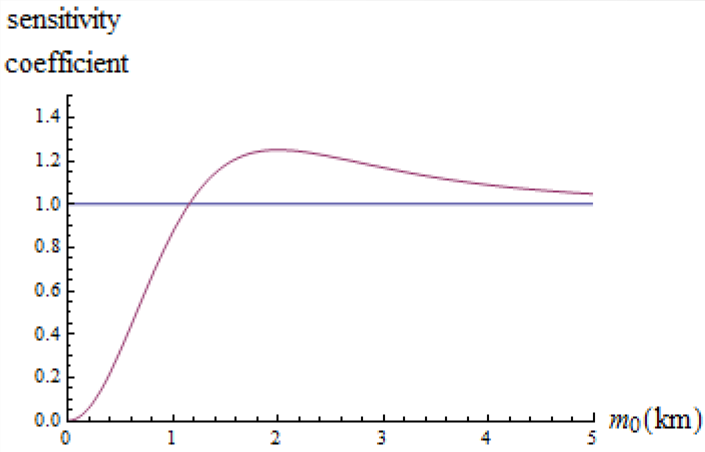
$\eta - red$

Sensitivity analysis

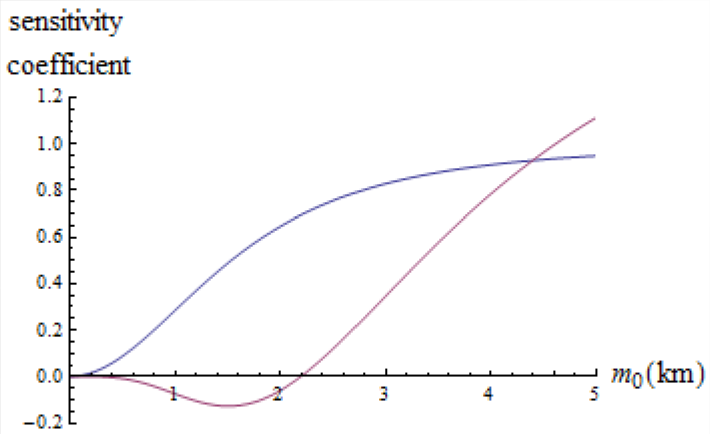
R



V



z_0



$\delta - blue$

$\eta - red$

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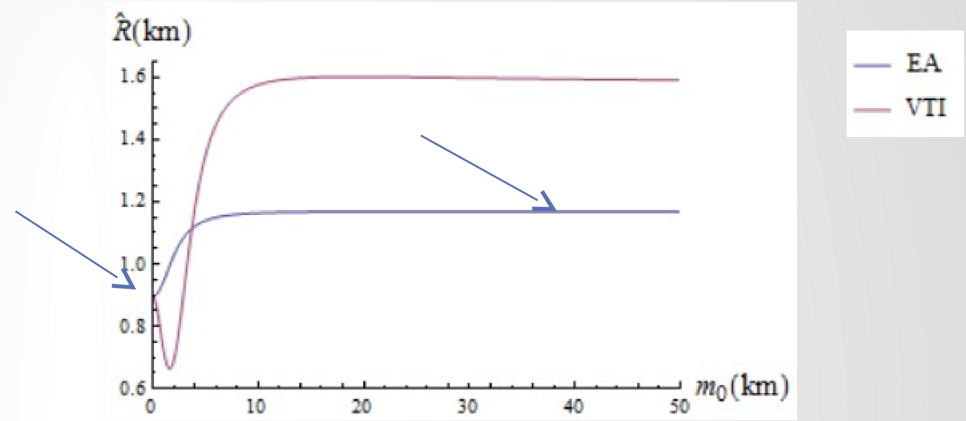
Estimation

$$\hat{R}^{(0)} = \hat{R}(m_0 = 0)$$

$$\hat{R}^{(\infty)} = \hat{R}(m_0 \to \infty)$$

$$\hat{z}_0^{(0)} = \hat{z}_0(m_0 = 0)$$

$$\hat{z}_0^{(\infty)} = \hat{z}_0(m_0 \to \infty)$$



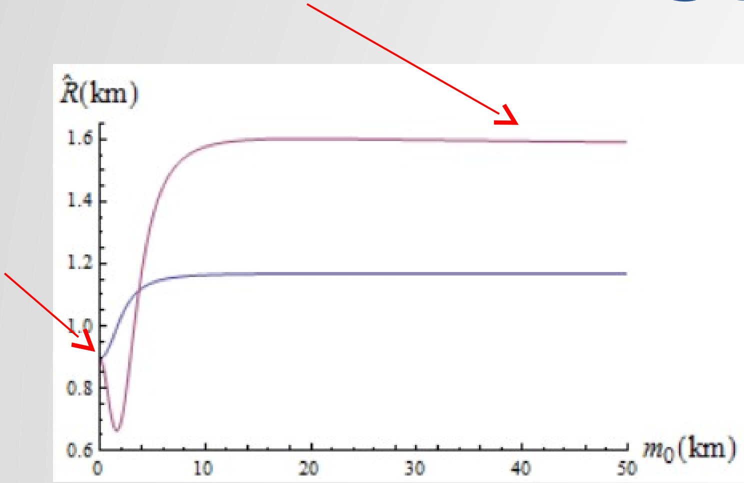
For EI model

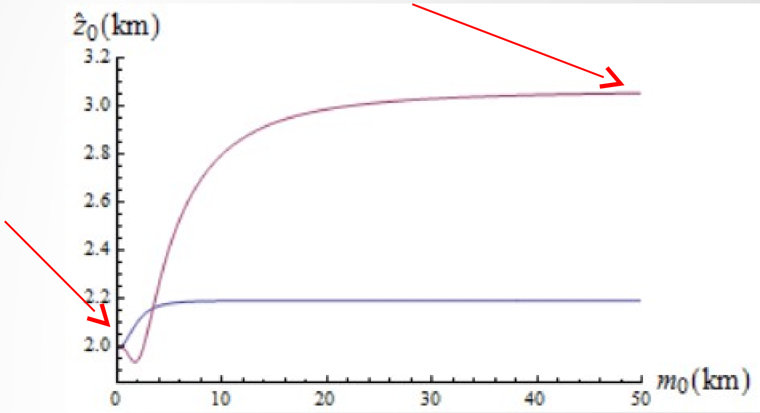
$$\hat{R}^{(0)} = \lim_{m_0 \to 0} \hat{R} = R\left(\frac{z_0 + 2R\delta - 2z_0\delta}{z_0 + 2R\delta}\right)\sqrt{1+2\delta} \approx R(1-\delta),$$

$$\hat{R}^{(\infty)} = \lim_{m_0 \to \infty} \hat{R} = R\frac{1+4\delta}{1+2\delta} \approx R(1+2\delta).$$

$$\Rightarrow \quad \tilde{R} = \frac{2\hat{R}^{(0)} + \hat{R}^{(\infty)}}{3}, \quad \tilde{\delta} = \frac{\hat{R}^{(\infty)} - \hat{R}^{(0)}}{2\hat{R}^{(0)} + \hat{R}^{(\infty)}}.$$

Estimation





For VTI model

$$\hat{R}^{(0)} = \lim_{m_0 \to 0} \hat{R} = R\left(\frac{z_0 + 2R\delta - 2z_0\delta}{z_0 + 2R\delta}\right)\sqrt{1+2\delta} \approx R(1-\delta),$$

$$\hat{R}^{(\infty)} = \lim_{m_0 \to \infty} \hat{R} = R\left(2 - \frac{1}{(1+2\delta)(1+2\eta)^2}\right) \approx R(1+2\delta+4\eta),$$

$$\hat{z}_0^{(0)} = \lim_{m_0 \to 0} \hat{z}_0 = \frac{z_0^2\sqrt{1+2\delta}}{z_0 + 2R\delta} \approx z_0(1+\delta) - 2R\delta,$$

$$\hat{z}_0^{(\infty)} = \lim_{m_0 \to \infty} \hat{z}_0 = z_0\sqrt{1+2\delta}(1+2\eta) \approx z_0(1+\delta+2\eta).$$

$\Rightarrow$ $\tilde{R},\ \tilde{z}_0, \tilde{\delta}, \tilde{\eta}$

Estimation test

$m_0 = 0\,\text{km}$ $\quad m_0 = 5\,\text{km}$

$\hat{R}^{(0)} = 0.896\,\text{km}$

$\hat{R}^{(\infty)} = 1.348\,\text{km}$

$\hat{z}_0^{(0)} = 1.992\,\text{km}$

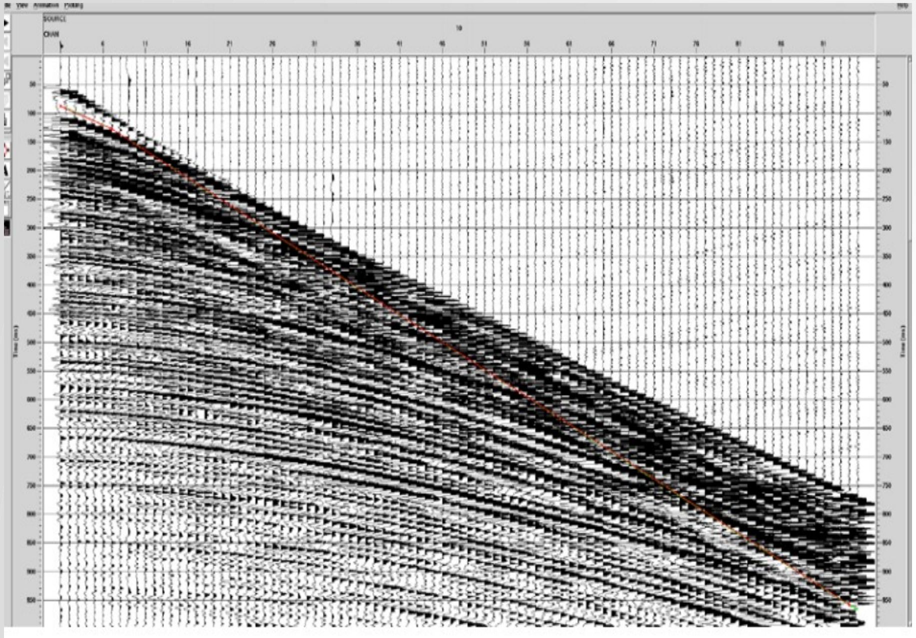
$\hat{z}_0^{(\infty)} = 2.417\,\text{km}$

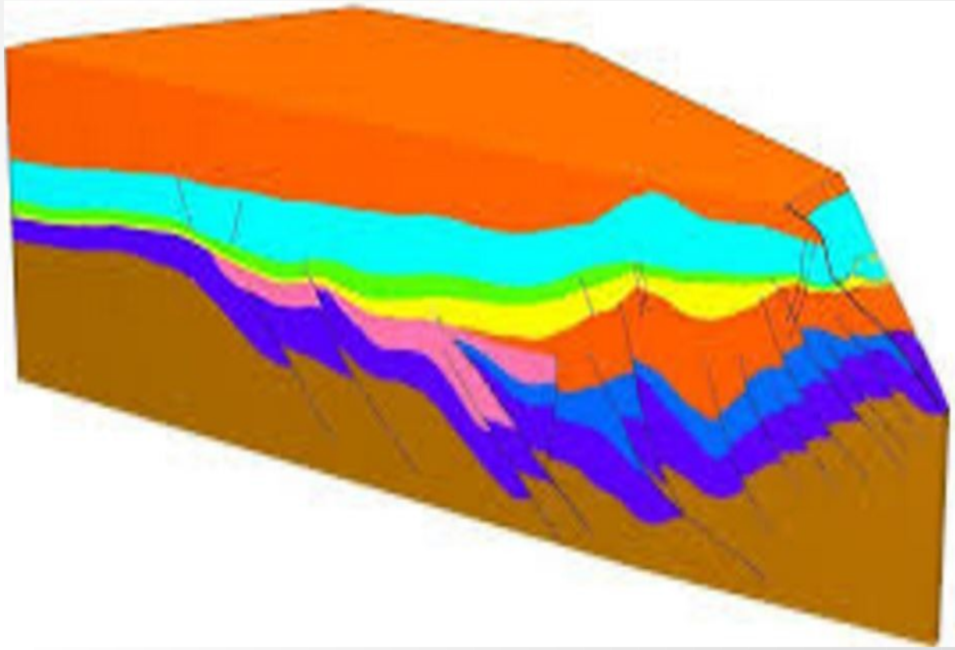
$R = 0.941\,\text{km}$

$z_0 = 1.987\,\text{km}$

$\delta = 0.048$

$\eta = 0.084$





Seismic data → Reflector & model

$T(m,h)$

R, z_0, V

δ, η

Step 1. $T(\Delta m, h)$ ---data

Step 2. A_0, A_1, A_2, B_2 --- $(\frac{\partial T^2}{\partial \Delta m}), (\frac{\partial^2 T^2}{\partial \Delta^2 m}), (\frac{\partial^2 T^2}{\partial h^2})$,CRS approximation

Step 3. $\hat{R}^{(0)} = \hat{R}(m_0 = 0)$ ---isotropic inversion from CRS approximation

$\hat{R}^{(\infty)} = \hat{R}(m_0 \to \infty)$

$\hat{z}_0^{(0)} = \hat{z}_0(m_0 = 0)$

$\hat{z}_0^{(\infty)} = \hat{z}_0(m_0 \to \infty)$

Step 4. $\tilde{R},\ \tilde{z}_0, \tilde{\delta}, \tilde{\eta}$ ---analysis sensitivity

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Conclusions

1 Investigate the effect of effective anisotropy (anisotropy & heterogeneity) on CRS attributes and the estimated model parameters.

2 Propose a method to estimate the strutural and anisotropy parameters by using CRS approximation from a circular reflector.

References

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End

Thanks for attention!