There's nonlinear, and then there's nonlinear…

Priddis pulse probe data and large contrast AVO in the lab

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Outline

Two different kinds of nonlinearity

Nonlinearity type I:

- **Priddis pulse probe experiment - early results (with G. Margrave, M. Bertram & CREWES)**

Nonlinearity type II:

- **Large contrast AVO in the lab (with F. Mahmoudian)**

Two different types of nonlinearity

$$\left[\nabla^2 - \frac{1}{c^2(\mathbf{r})}\frac{\partial^2}{\partial t^2}\right] P(\mathbf{r},t) = f(\mathbf{r},t)$$

Two different types of nonlinearity

$$\begin{aligned} \mathcal{L}P_1 &= f_1 \\ \mathcal{L}P_2 &= f_2 \end{aligned} \quad \rightarrow \mathcal{L}(P_1 + P_2) = f_1 + f_2$$

$$\left[\nabla^2 - \frac{1}{c^2(\mathbf{r})}\frac{\partial^2}{\partial t^2}\right] P(\mathbf{r}, t) = f(\mathbf{r}, t)$$

…absent explicit linearization (e.g., Innanen CREWES 2010),

Type I $\quad \mathcal{L}(P_1 + P_2) \neq f_1 + f_2$

Two different types of nonlinearity

Even given a linear wave equation

$P = P\left[c(\mathbf{r})\right]$ **is nonlinear**

$$\left[\nabla^2 - \frac{1}{c^2(\mathbf{r})}\frac{\partial^2}{\partial t^2}\right]P(\mathbf{r},t) = f(\mathbf{r},t)$$

Type II $R = \frac{c_1 - c_0}{c_1 + c_0} = \frac{1}{4}(\delta c) + \frac{1}{8}(\delta c)^2 + \ldots$

Nonlinearity Type I:

The Priddis pulse-probe experiment

Type I: Priddis pulse-probe

Wave nonlinearity

- acoustic medical imaging
- physical modeling
- theory

Seismic nonlinearity

- Zhukov et al., 2007 (TLE)
- Margrave et al., 2008 (CREWES)
- Campman et al., 2012 (EAGE)

Type I: Priddis pulse-probe

CREWES Field Experiment July 2012

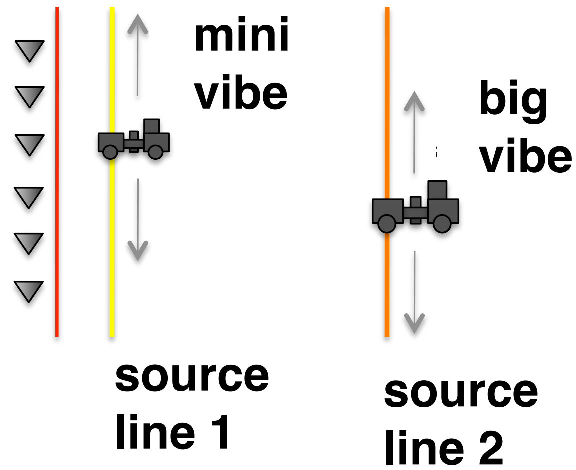
Objectives

- Autoseis & array tests
- Dynamite charge size
- "Pulse probe" revisited

Partners

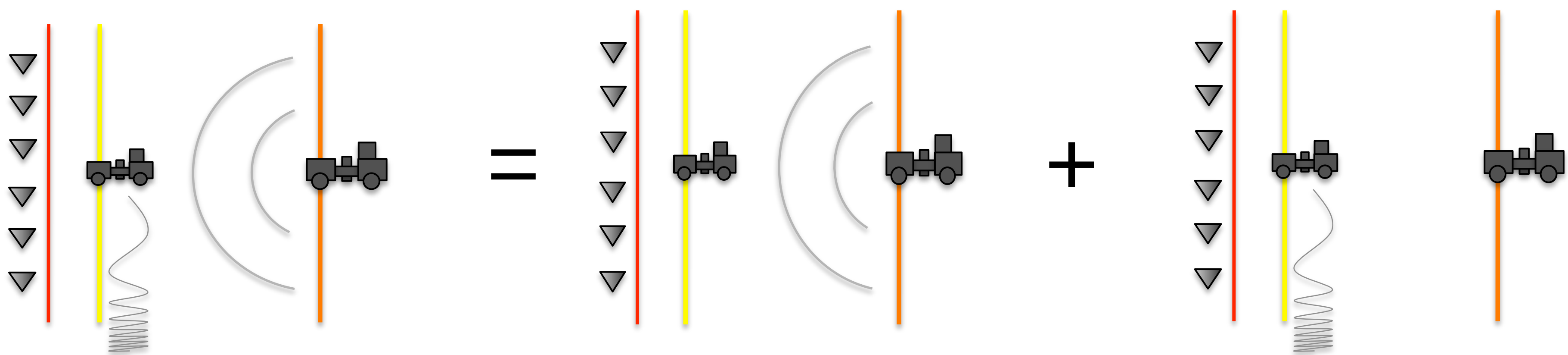
- Global Geophysical
- Geokinetics
- Outsource
- INOVA

Type I: Priddis pulse-probe



Type I: Priddis pulse-probe

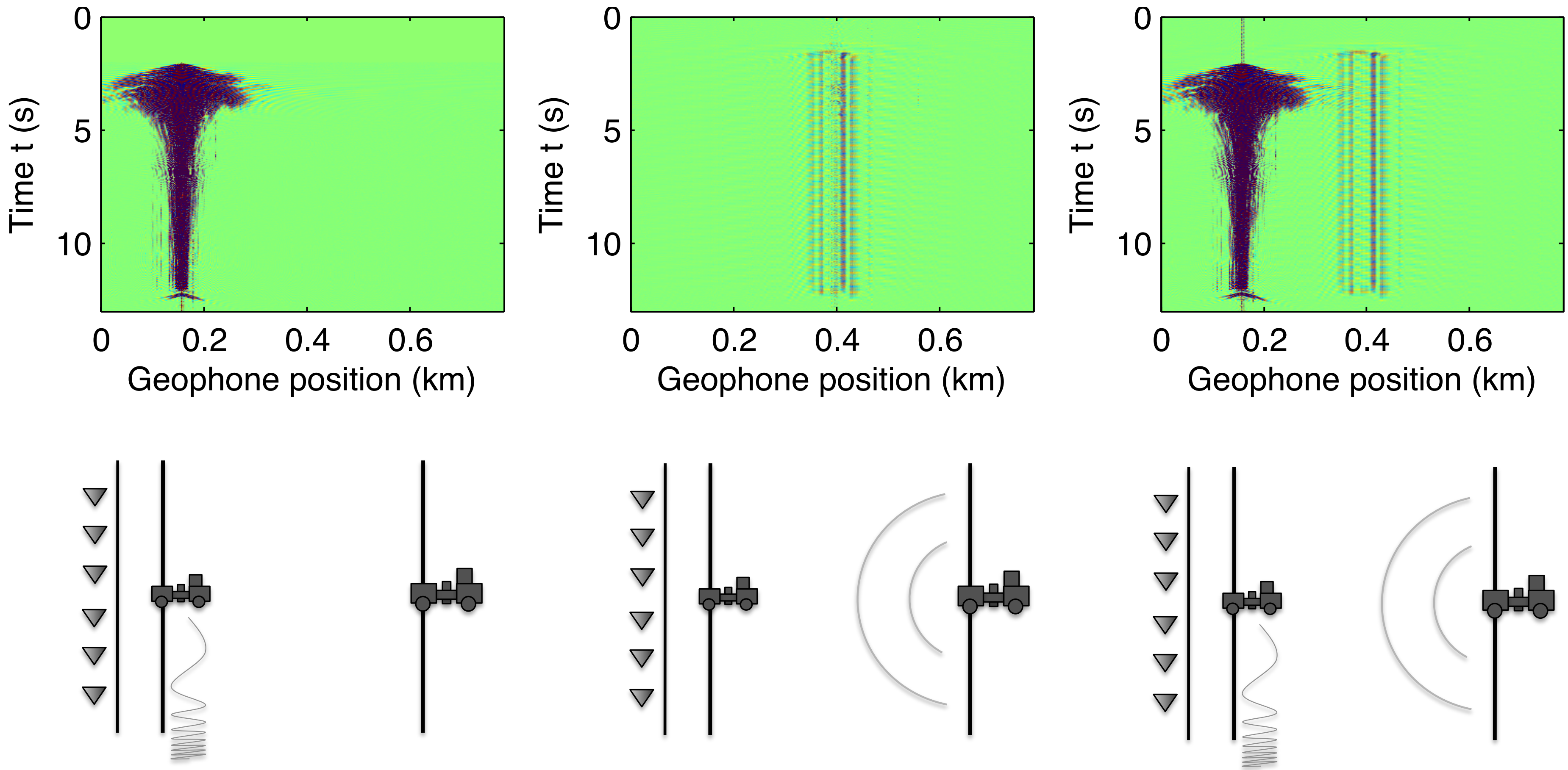
Superposition



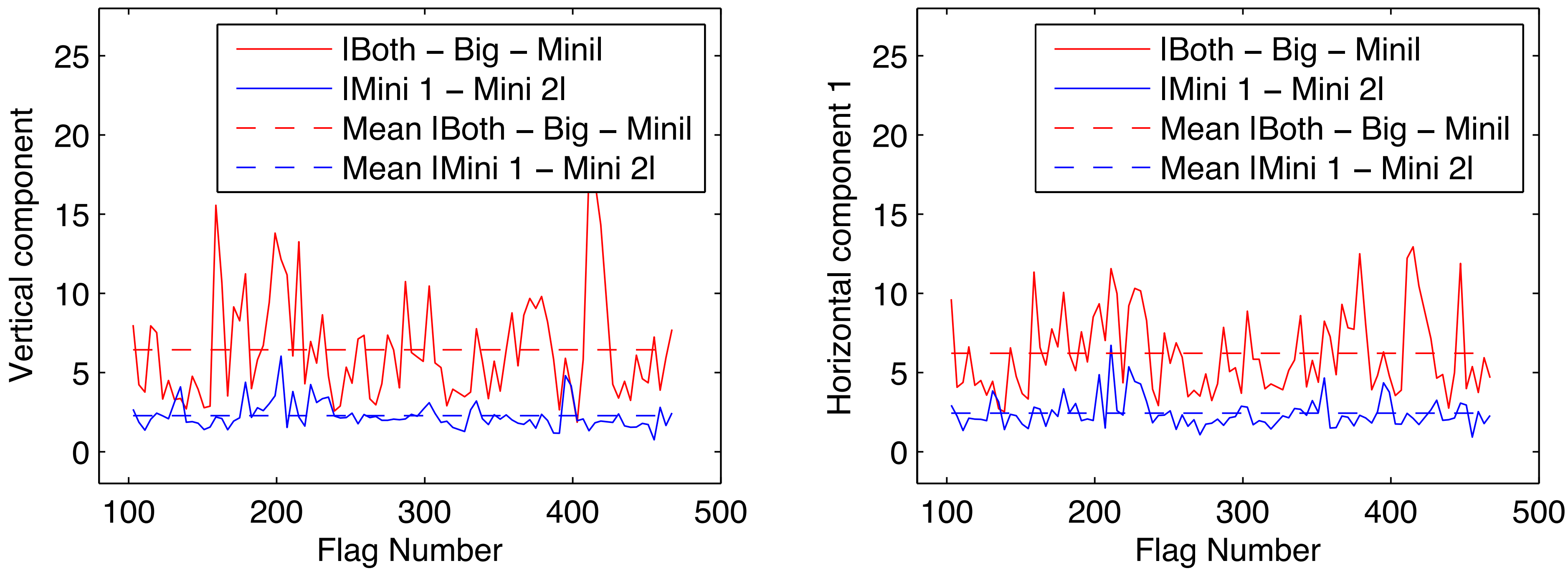
Both = Big (fixed 25 Hz) + Mini (linear sweep)

Type I: Priddis pulse-probe

Mini only **Big only** **Both**



Type I: Priddis pulse-probe



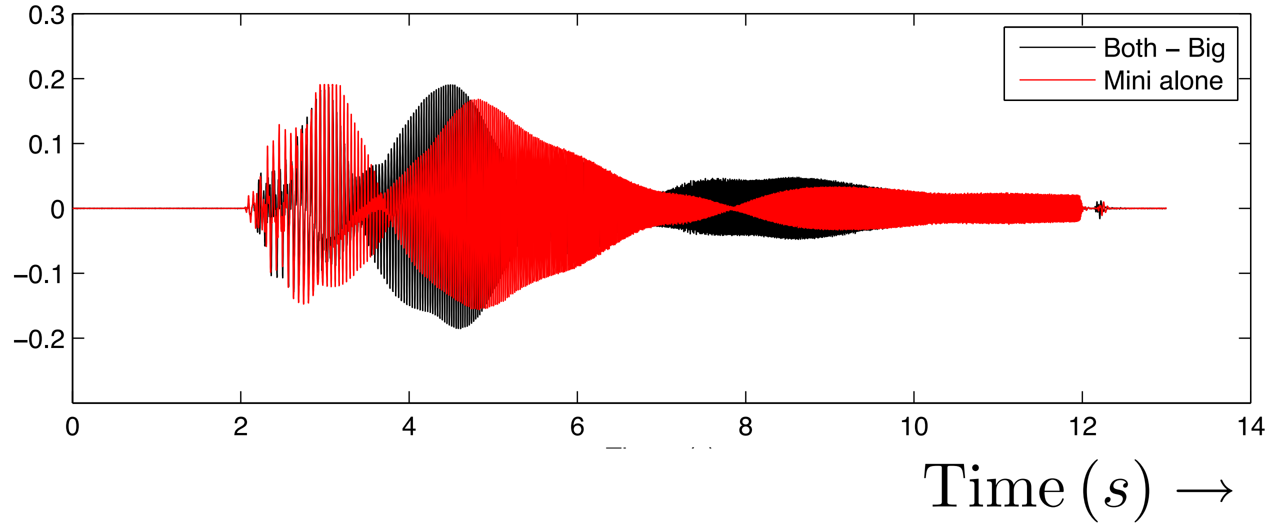
Superposition

Both – Big – Mini = 0

Type I: Priddis pulse-probe

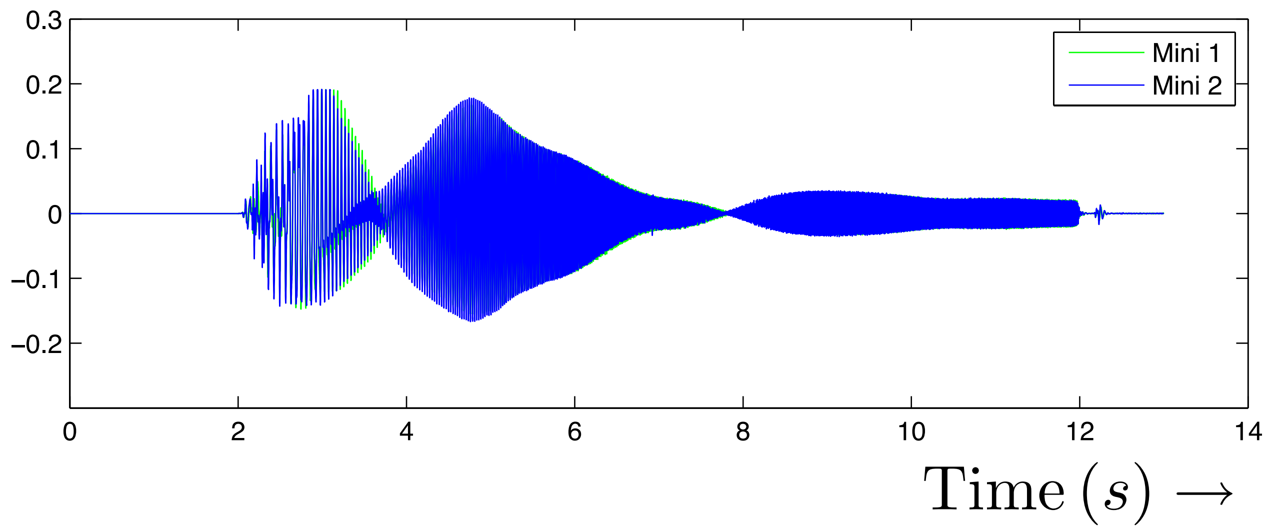
Mini alone

Both - Big



Mini 1

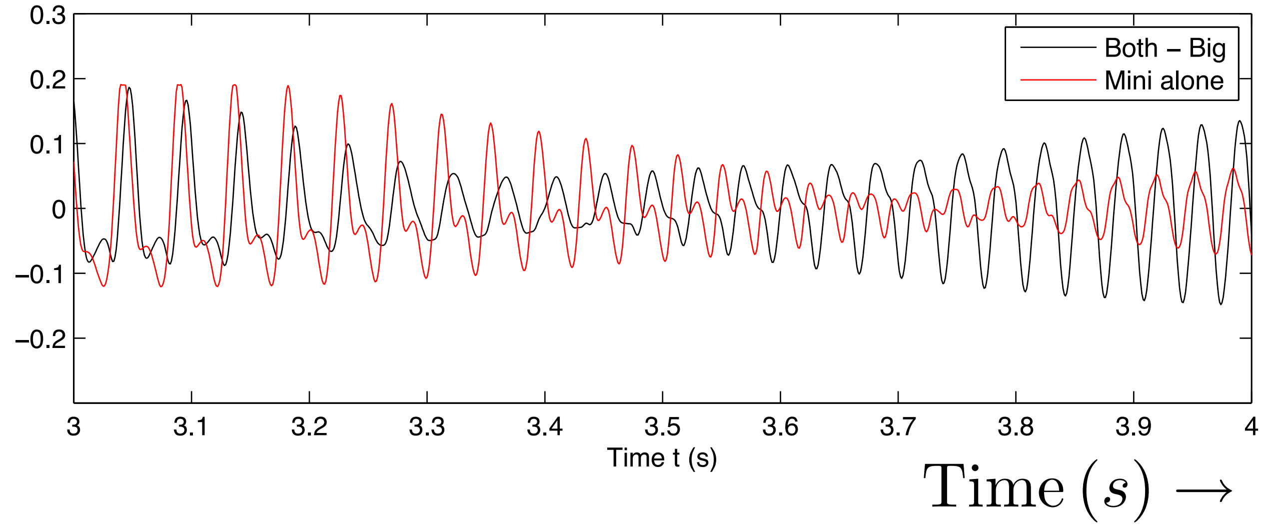
Mini 2



Type I: Priddis pulse-probe

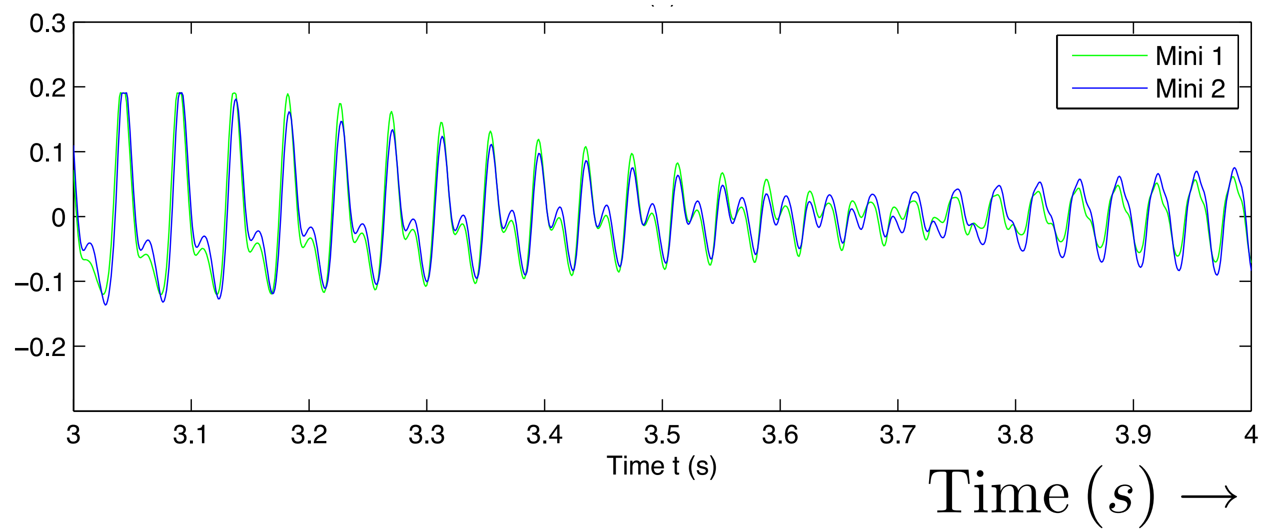
Mini alone

Both - Big

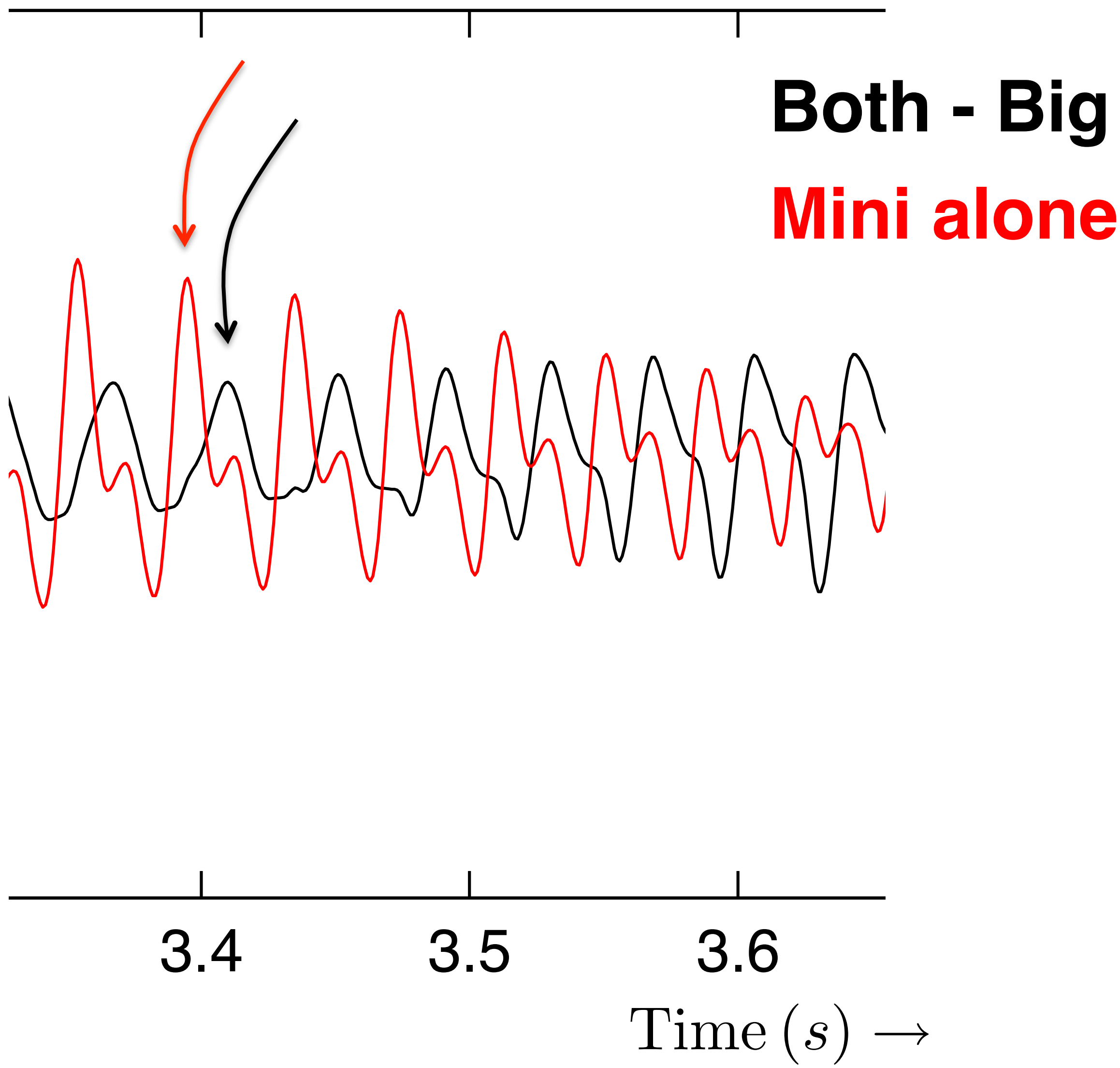


Mini 1

Mini 2



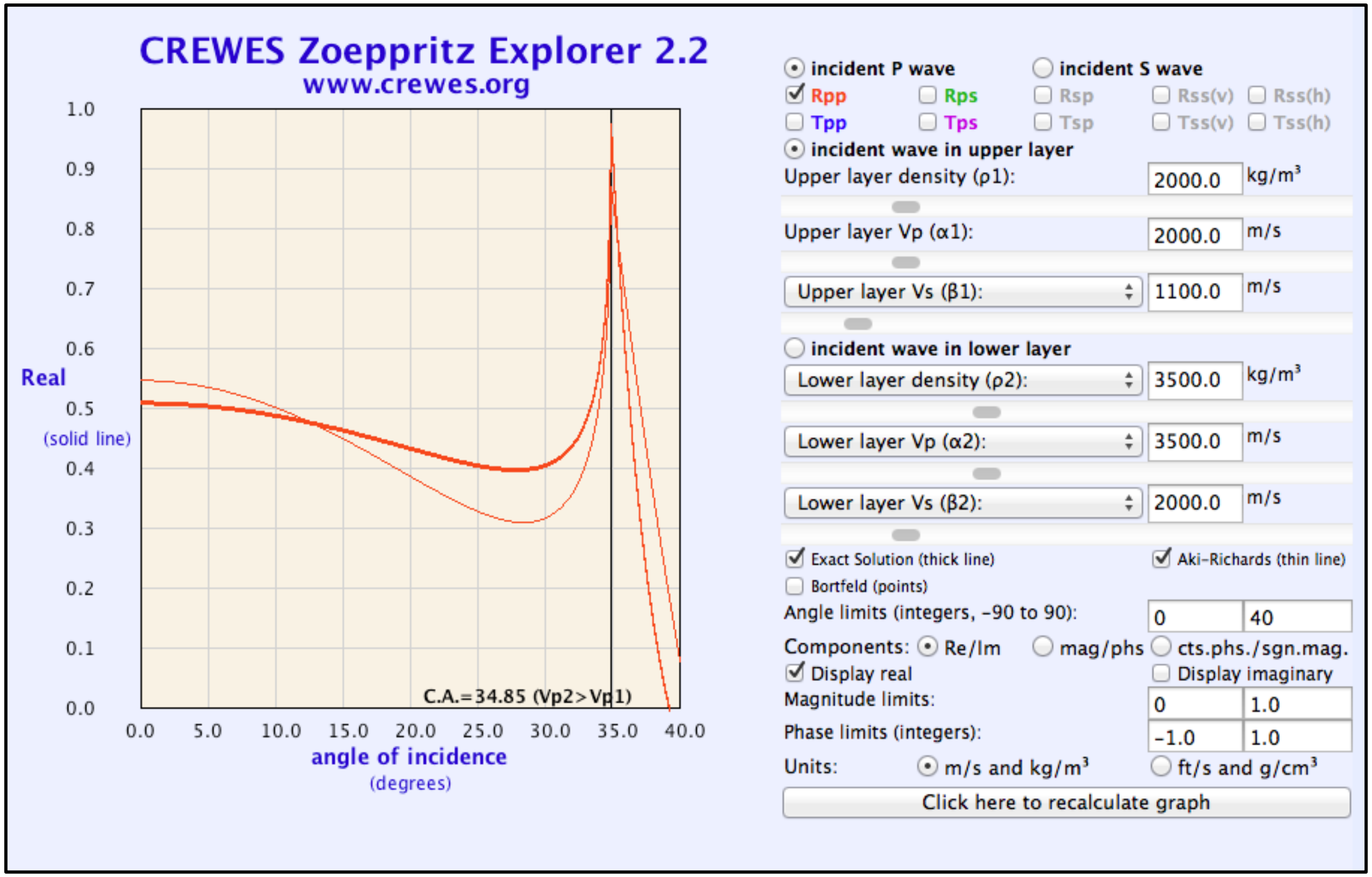
Type I: Priddis pulse-probe



Nonlinearity Type II:

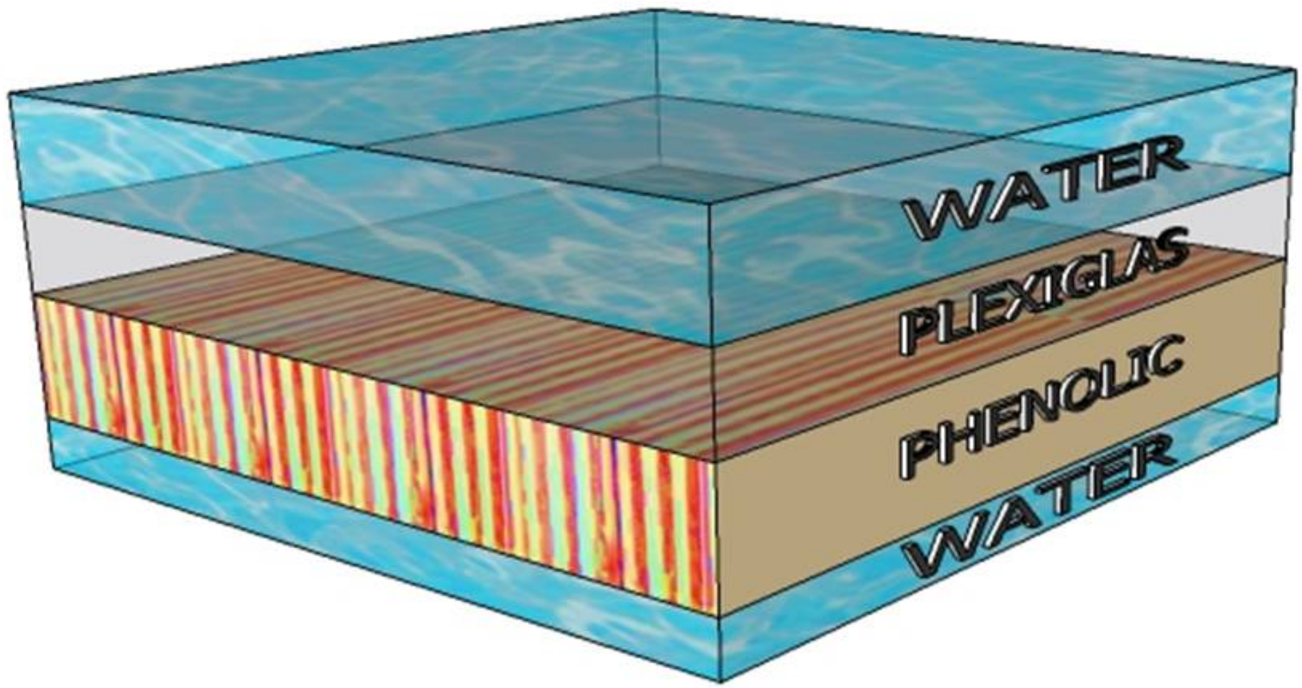
Large contrast AVO in the lab

Type II: large contrast AVO



V_P contrast $\approx 55\%$ V_S contrast $\approx 58\%$ ρ contrast $\approx 55\%$

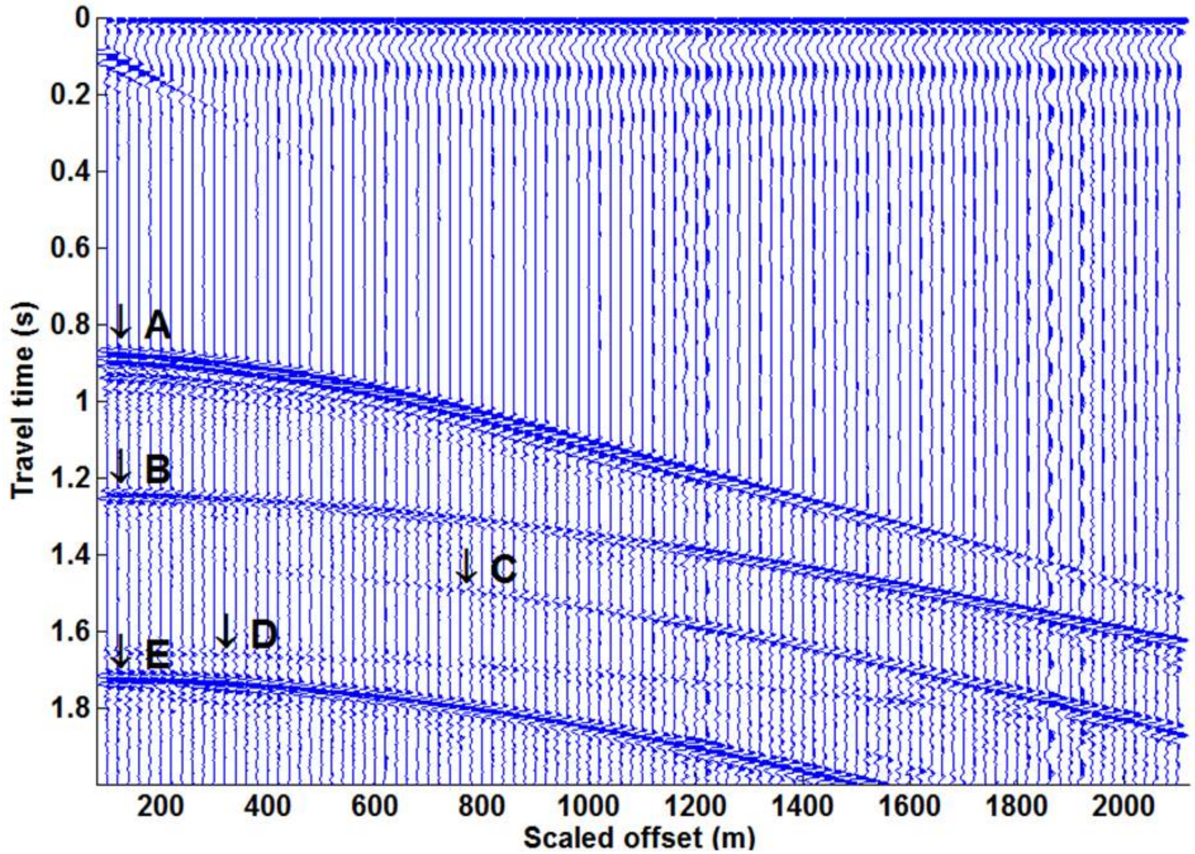
Type II: large contrast AVO



Physical model designed to study anisotropic AVAZ

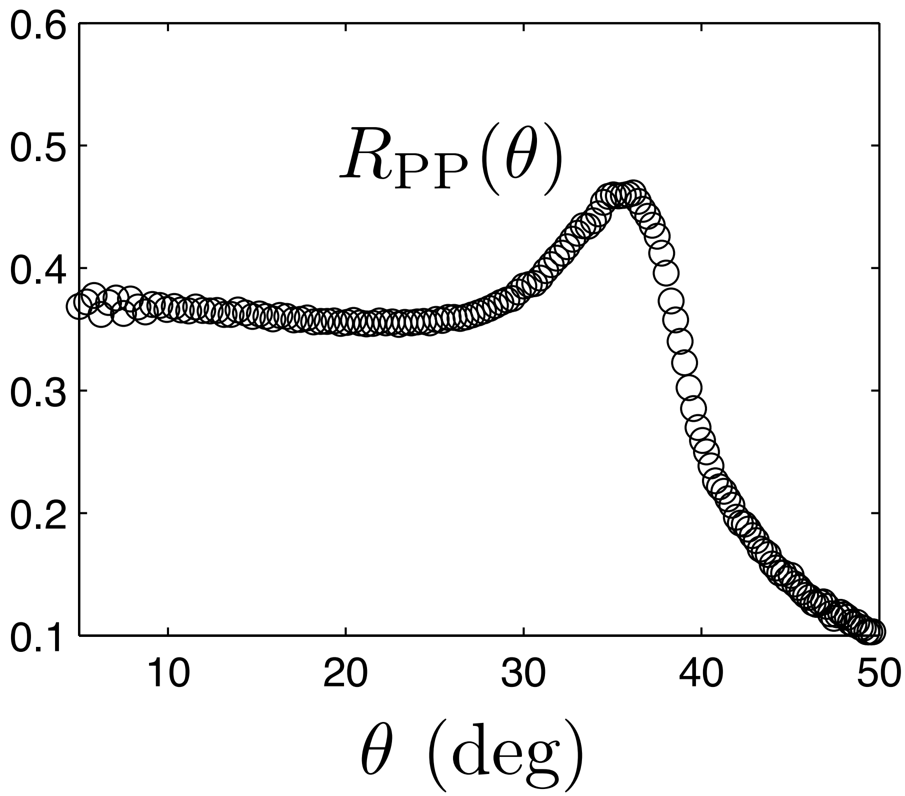
See also Mahmoudian et al., CREWES 2012

Type II: large contrast AVO

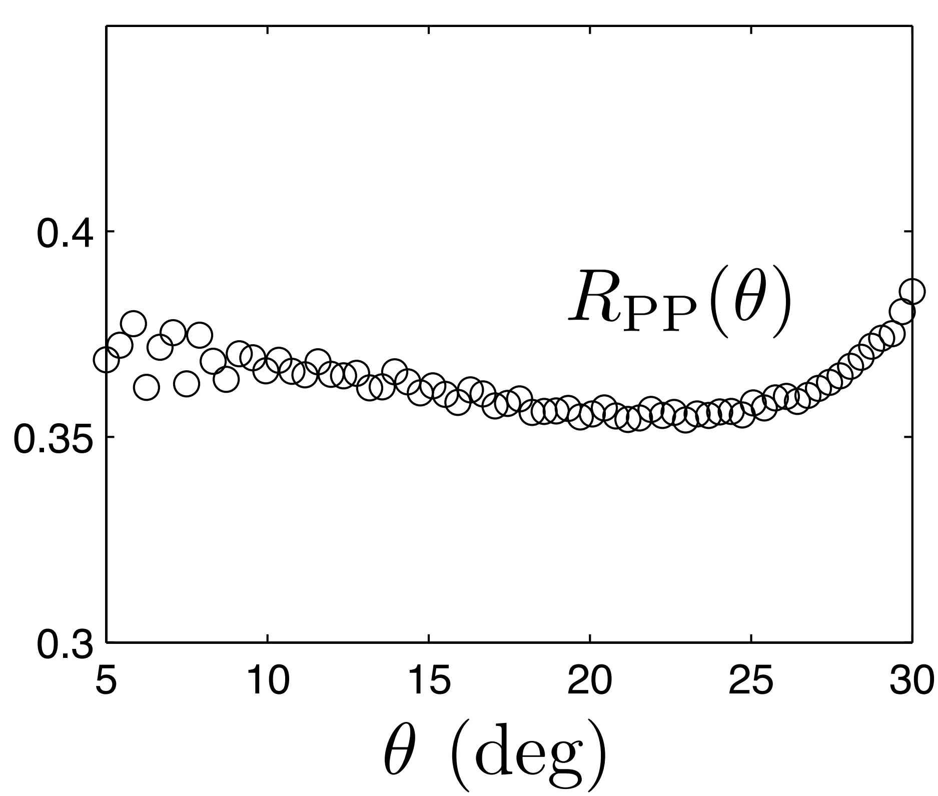


Consider reflection (A) – water-plexiglas boundary

Type II: large contrast AVO



Full angle range

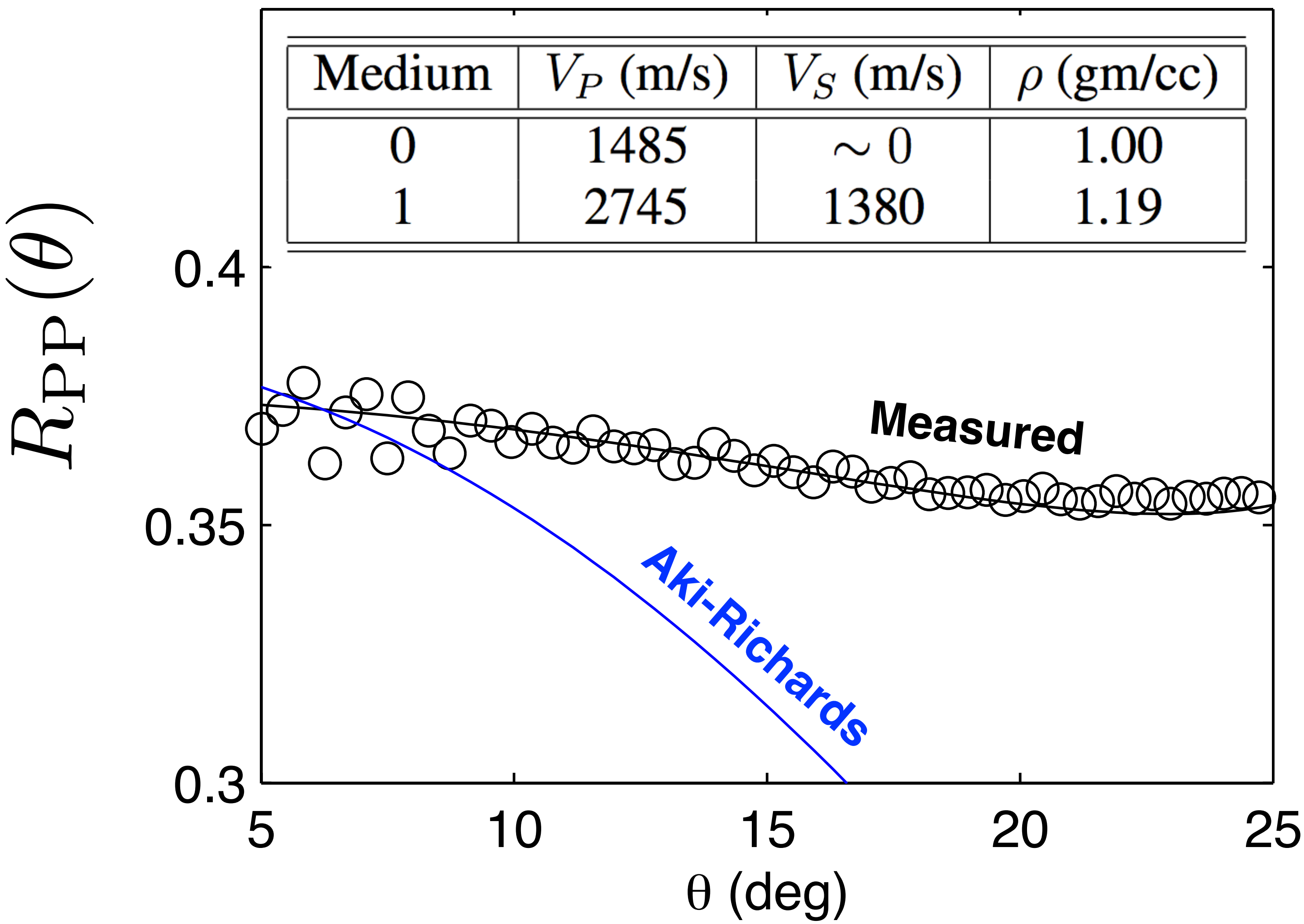


Low angles

See also Mahmoudian et al., CREWES 2012

Type II: large contrast AVO

Medium	V_P (m/s)	V_S (m/s)	ρ (gm/cc)
0	1485	~ 0	1.00
1	2745	1380	1.19



Type II: large contrast AVO

1st order ~ Aki-Richards

$$R_{\mathrm{PP}}(\theta) = R_{\mathrm{PP}}^{(1)}(\theta) + R_{\mathrm{PP}}^{(2)}(\theta) + R_{\mathrm{PP}}^{(3)}(\theta) + \ldots,$$

$$R_{\mathrm{PP}}^{(1)}(\theta) = \frac{1}{2}\left(1 - 3\sin^2\theta\right)\frac{\Delta V_P}{V_P} + 2\sin^2\theta\frac{\Delta V_S}{V_S} + \frac{1}{2}\frac{\Delta\rho}{\rho}$$

Type II: large contrast AVO

2nd order – no zero offset contribution

$$R_{\text{PP}}(\theta) = R_{\text{PP}}^{(1)}(\theta) + R_{\text{PP}}^{(2)}(\theta) + R_{\text{PP}}^{(3)}(\theta) + \ldots,$$

$$R_{\text{PP}}^{(2)}(\theta) = \frac{3}{2}\sin^2\theta\left(\frac{\Delta V_P}{V_P}\right)^2 - 6\sin^2\theta\left(\frac{\Delta V_P}{V_P}\right)\left(\frac{\Delta V_S}{V_S}\right) + 5\sin^2\theta\left(\frac{\Delta V_S}{V_S}\right)^2$$

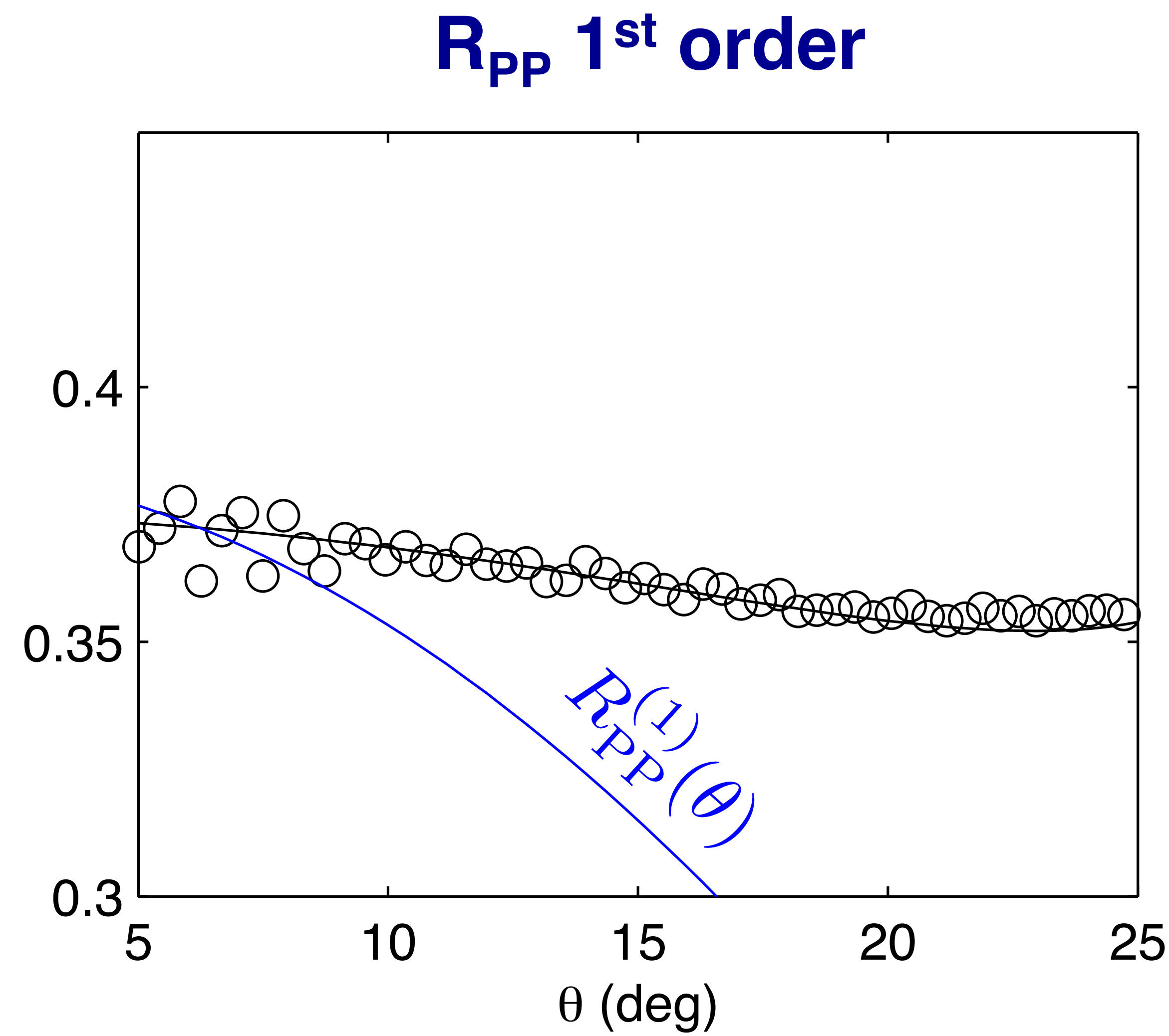
Type II: large contrast AVO

3rd order

$$R_{\mathrm{PP}}(\theta) = R^{(1)}_{\mathrm{PP}}(\theta) + R^{(2)}_{\mathrm{PP}}(\theta) + R^{(3)}_{\mathrm{PP}}(\theta) + \ldots,$$

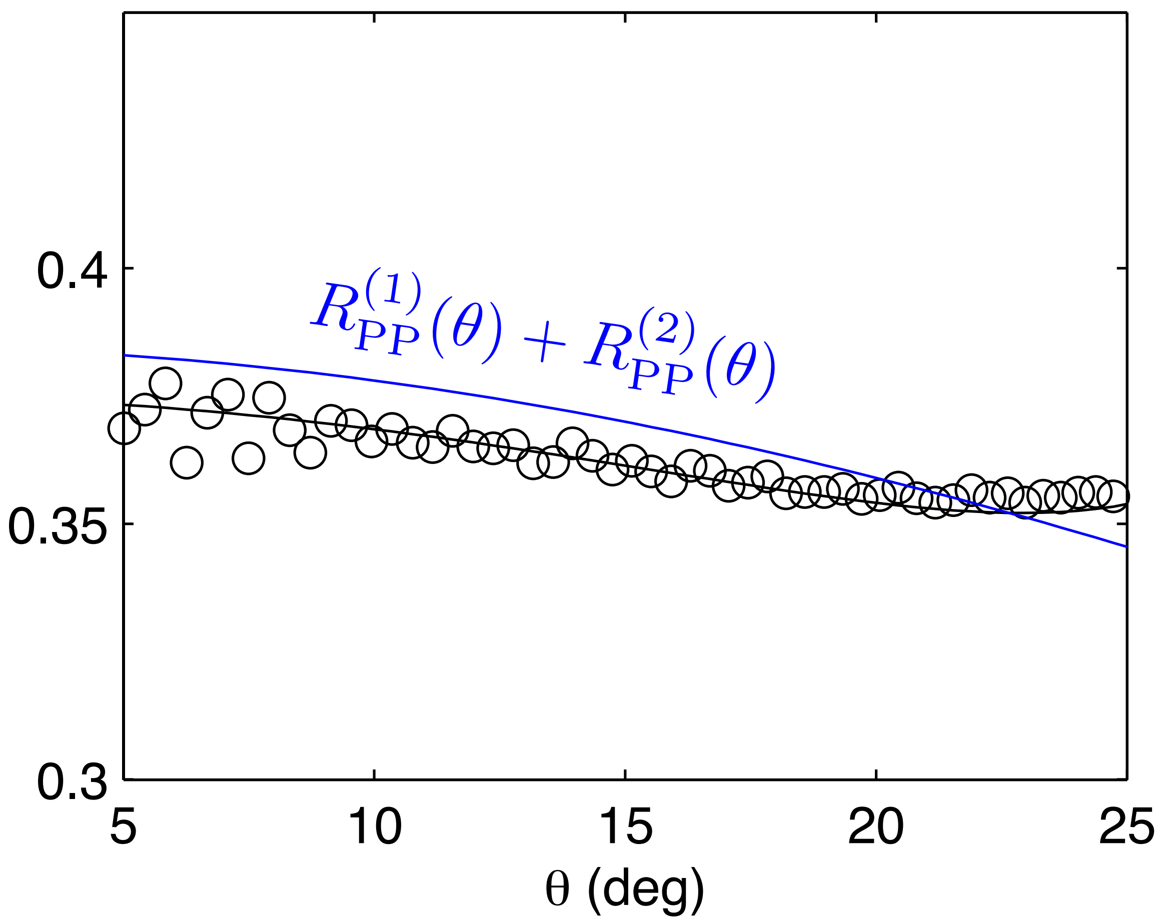
$$\begin{aligned} R^{(3)}_{\mathrm{PP}}(\theta) = & -\frac{1}{8}\left(\frac{\Delta V_P}{V_P}\right)^2\left(\frac{\Delta\rho}{\rho}\right) - \frac{1}{8}\left(\frac{\Delta\rho}{\rho}\right)^2\left(\frac{\Delta V_P}{V_P}\right) \\ & + \left[\frac{13}{2}\left(\frac{\Delta V_S}{V_S}\right)^3 + \frac{1}{4}\left(\frac{\Delta V_P}{V_P}\right)^3 + \frac{3}{8}\left(\frac{\Delta V_P}{V_P}\right)\left(\frac{\Delta\rho}{\rho}\right)^2 \right. \\ & \left. + \text{ four terms } - \left(\frac{\Delta V_P}{V_P}\right)\left(\frac{\Delta V_S}{V_S}\right)\left(\frac{\Delta\rho}{\rho}\right)\right]\sin^2\theta \end{aligned}$$

Type II: large contrast AVO



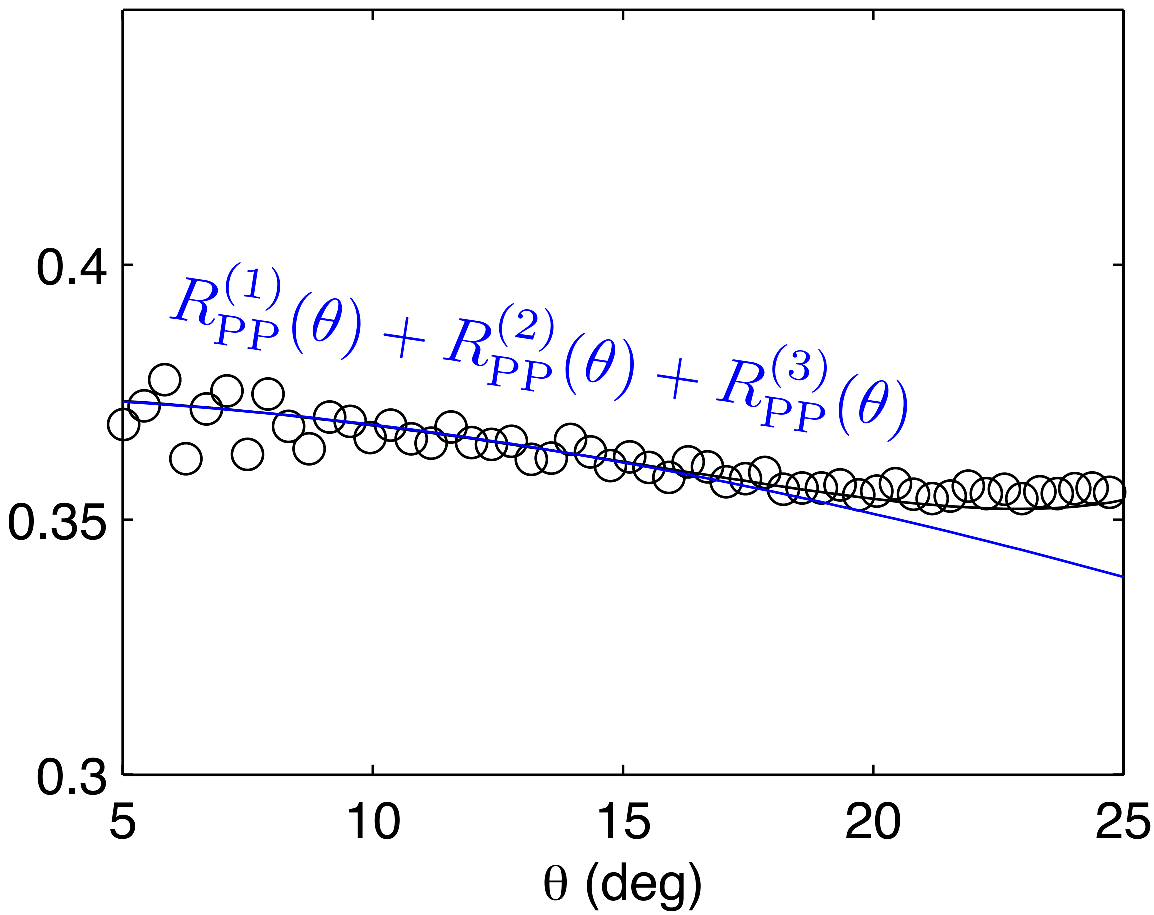
Type II: large contrast AVO

R_{PP} 2nd order



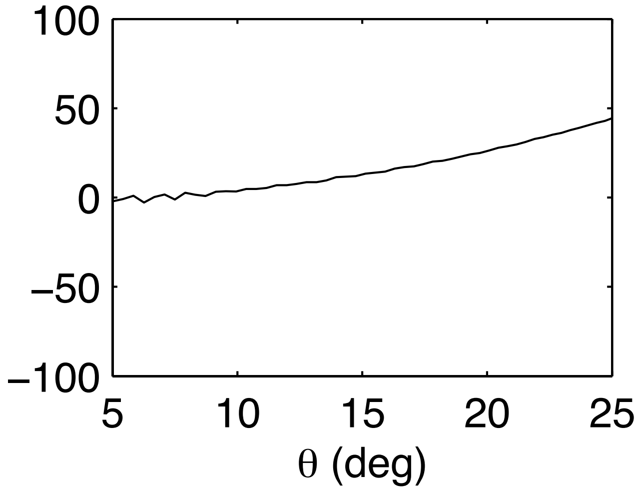
Type II: large contrast AVO

R_{PP} 3rd order



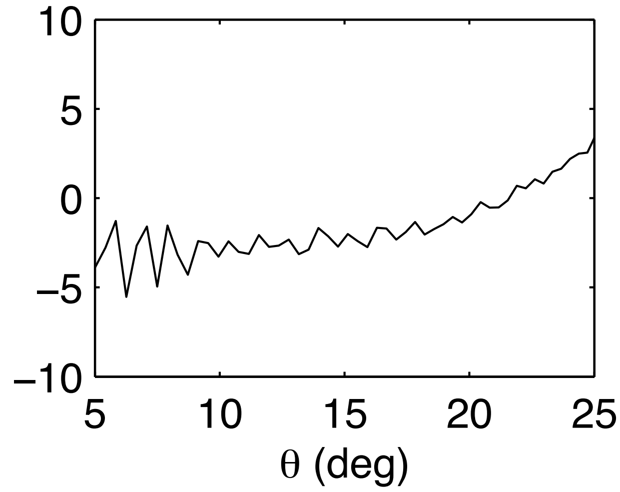
Type II: large contrast AVO

% Error 1st order



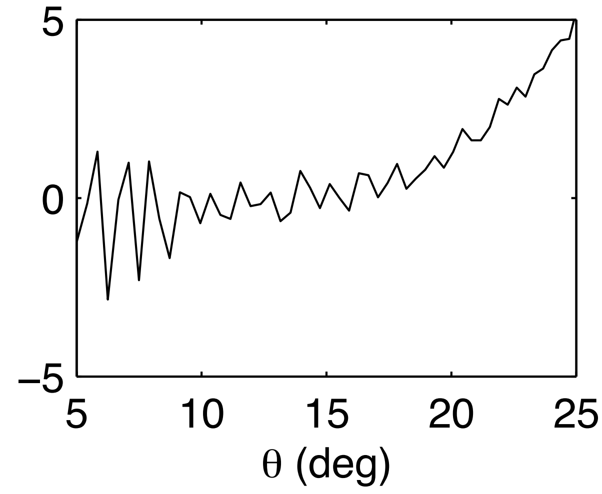
Error Significant

% Error 2nd order



Trend Corrected

% Error 3rd order



Magnitudes Corrected

Conclusions

Two types of NL – 1 definitely, 1 possibly present in exploration-monitoring seismology

Priddis pulse probe – does a "background" seismic wave field change seismic responses?

Unconfirmed (vibe feedback vs. NL)

Uses? Target differentiation

Nonlinear AVO in the lab – interpretable approximations for large contrast targets

Acknowledgments

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CRSNG

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