Error estimates of elastic tensor components in stress-dependent VTI media

Kyle Spikes

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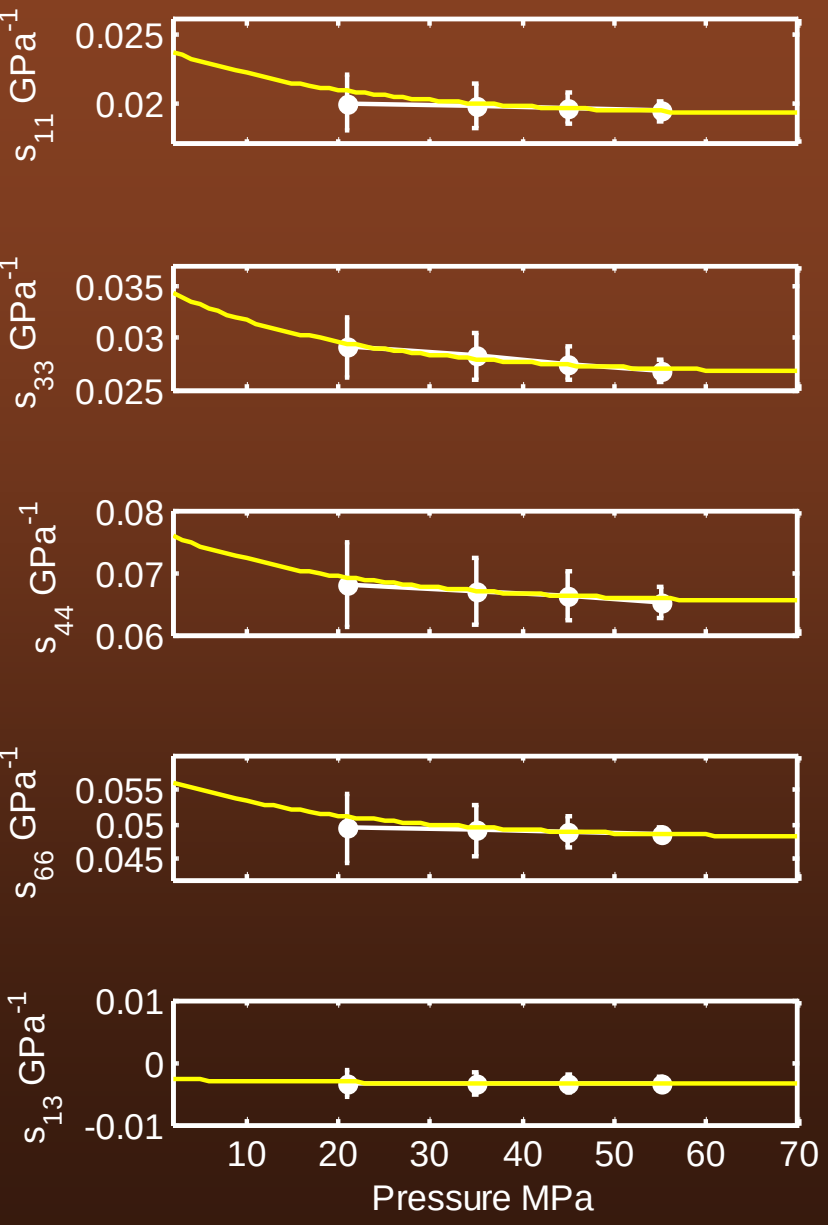
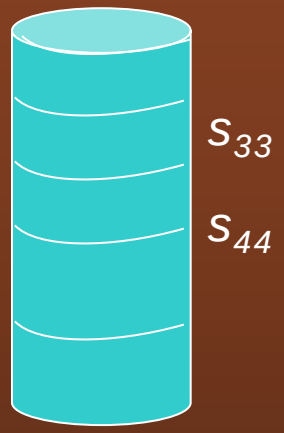
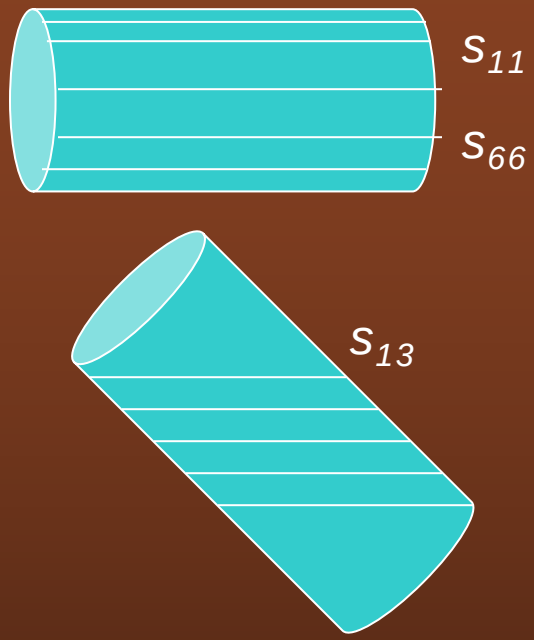
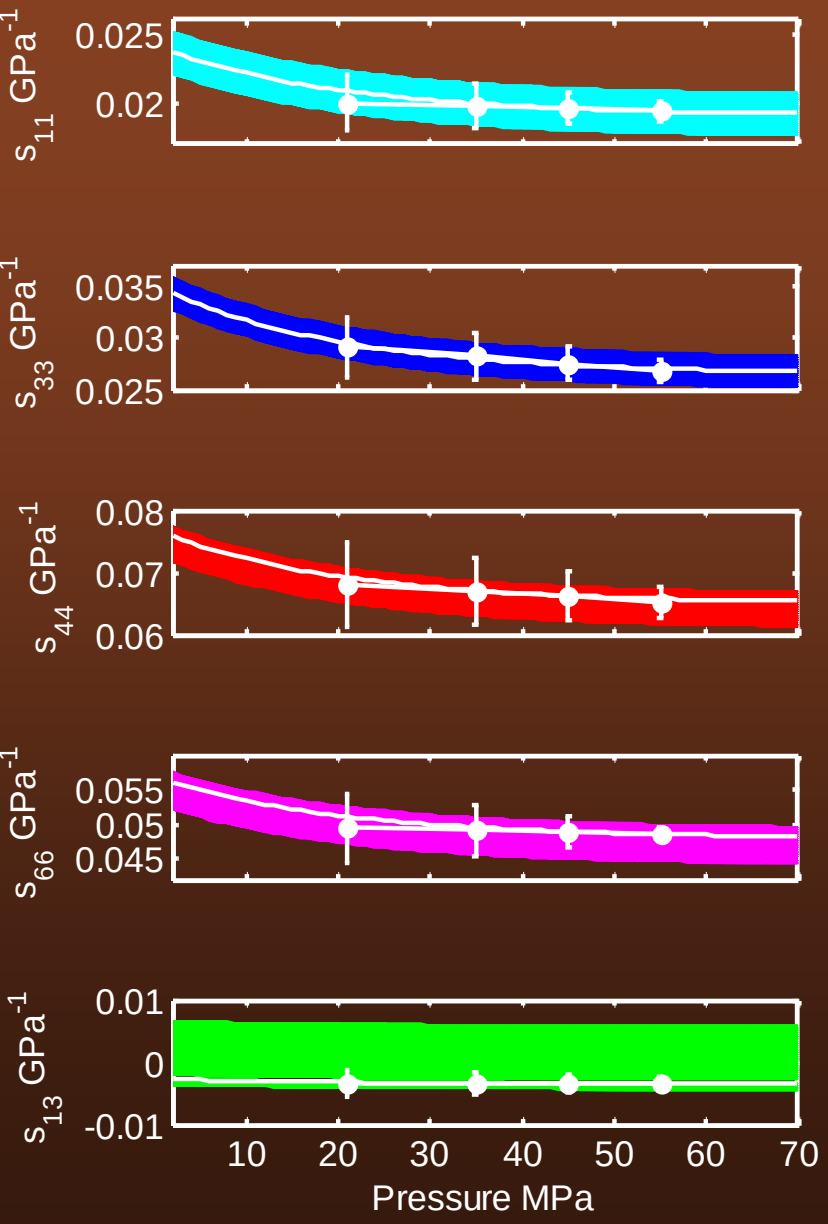
Motivation

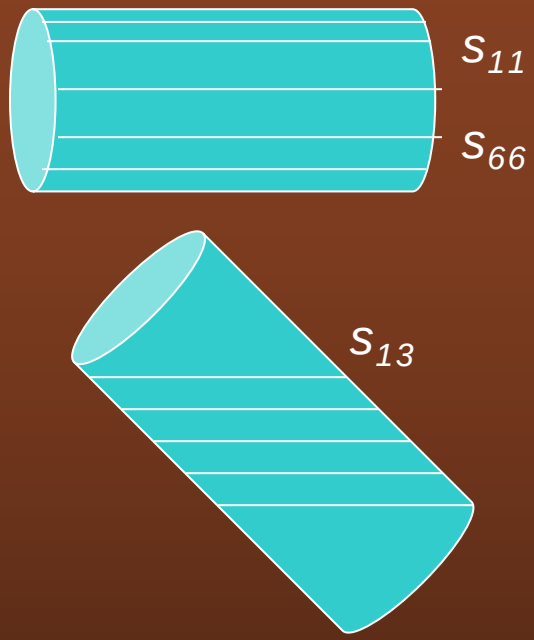

s_{11} GPa^{-1}
0.025
0.02
s_{33} GPa^{-1}
0.035
0.03
0.025
s_{44} GPa^{-1}
0.08
0.07
0.06
s_{66} GPa^{-1}
0.055
0.05
0.045
s_{13} GPa^{-1}
0.01
0
-0.01
10
20
30
40
50
60
70
Pressure MPa


S_{33}
S_{44}


S_{11}
S_{66}
S_{13}

Motivation



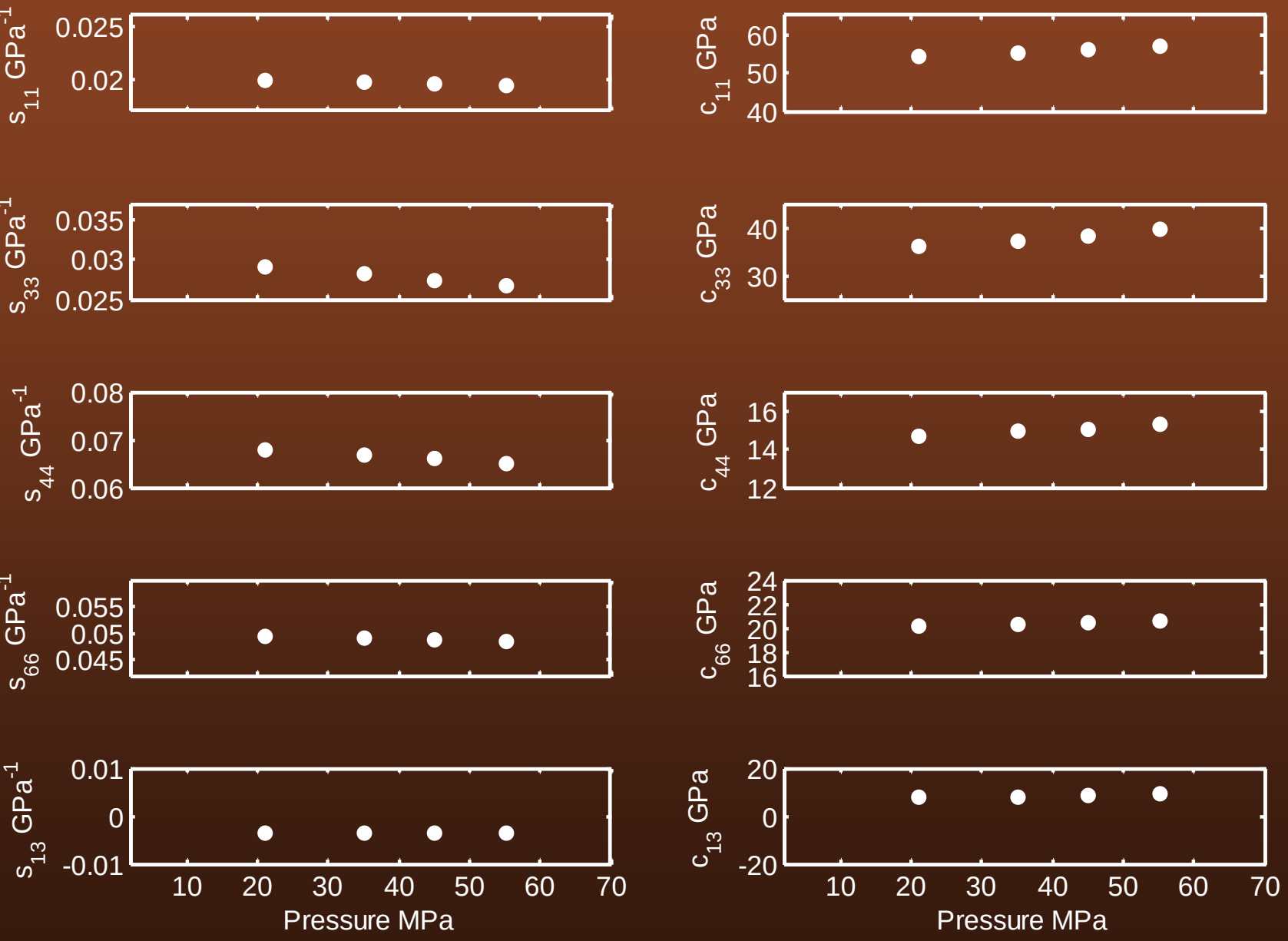


Account for measurement and model errors

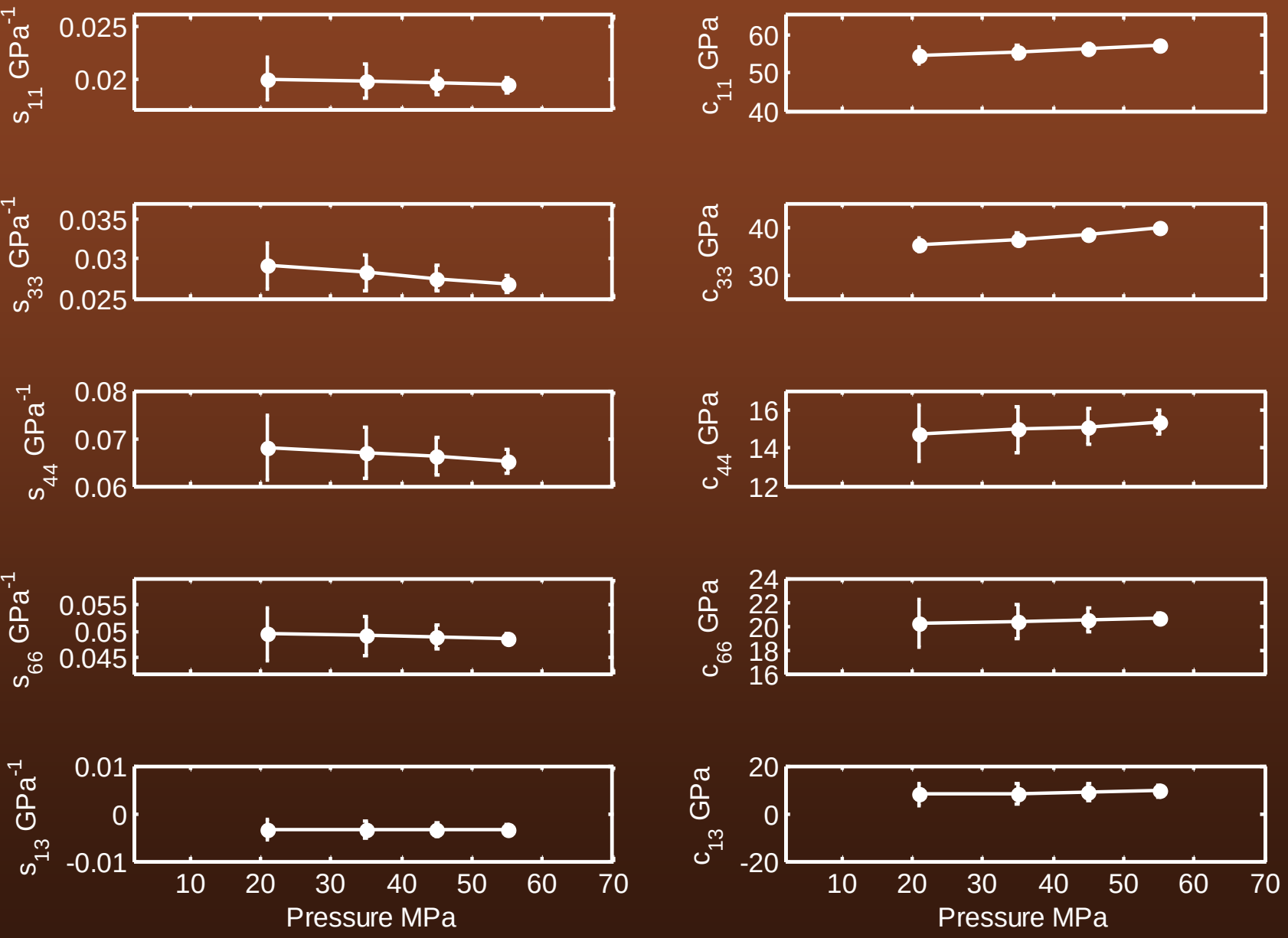
Provide insight into viable ranges of anisotropy

Constraint anisotropic seismic imaging and inversion schemes

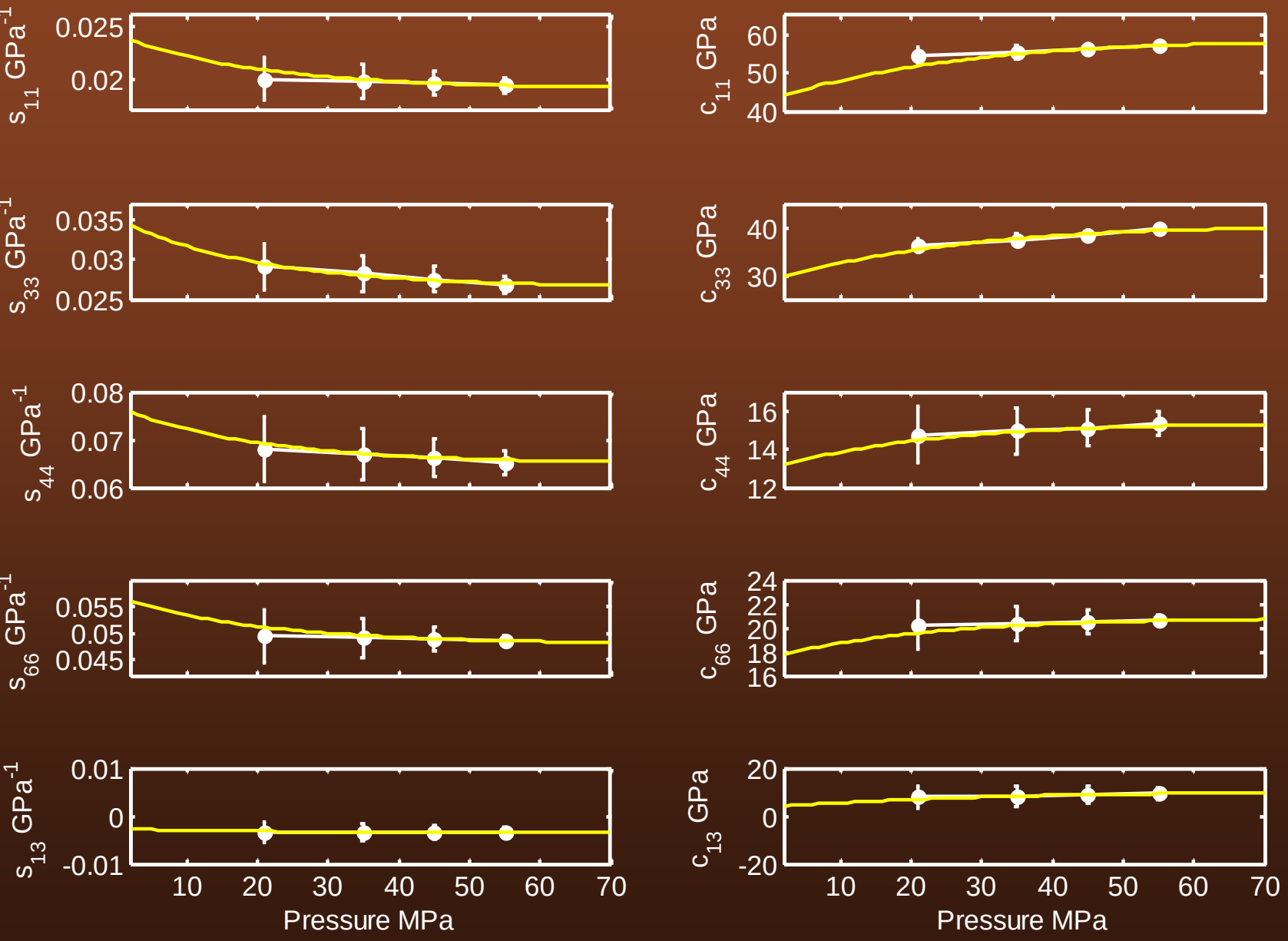
Dataset


s_{11} GPa^{-1}
0.025
0.02
c_{11} GPa
60
50
40
s_{33} GPa^{-1}
0.035
0.03
0.025
c_{33} GPa
40
30
s_{44} GPa^{-1}
0.08
0.07
0.06
c_{44} GPa
16
14
12
s_{66} GPa^{-1}
0.055
0.05
0.045
c_{66} GPa
24
22
20
18
16
s_{13} GPa^{-1}
0.01
0
-0.01
c_{13} GPa
20
0
-20
10 20 30 40 50 60 70
Pressure MPa
10 20 30 40 50 60 70
Pressure MPa

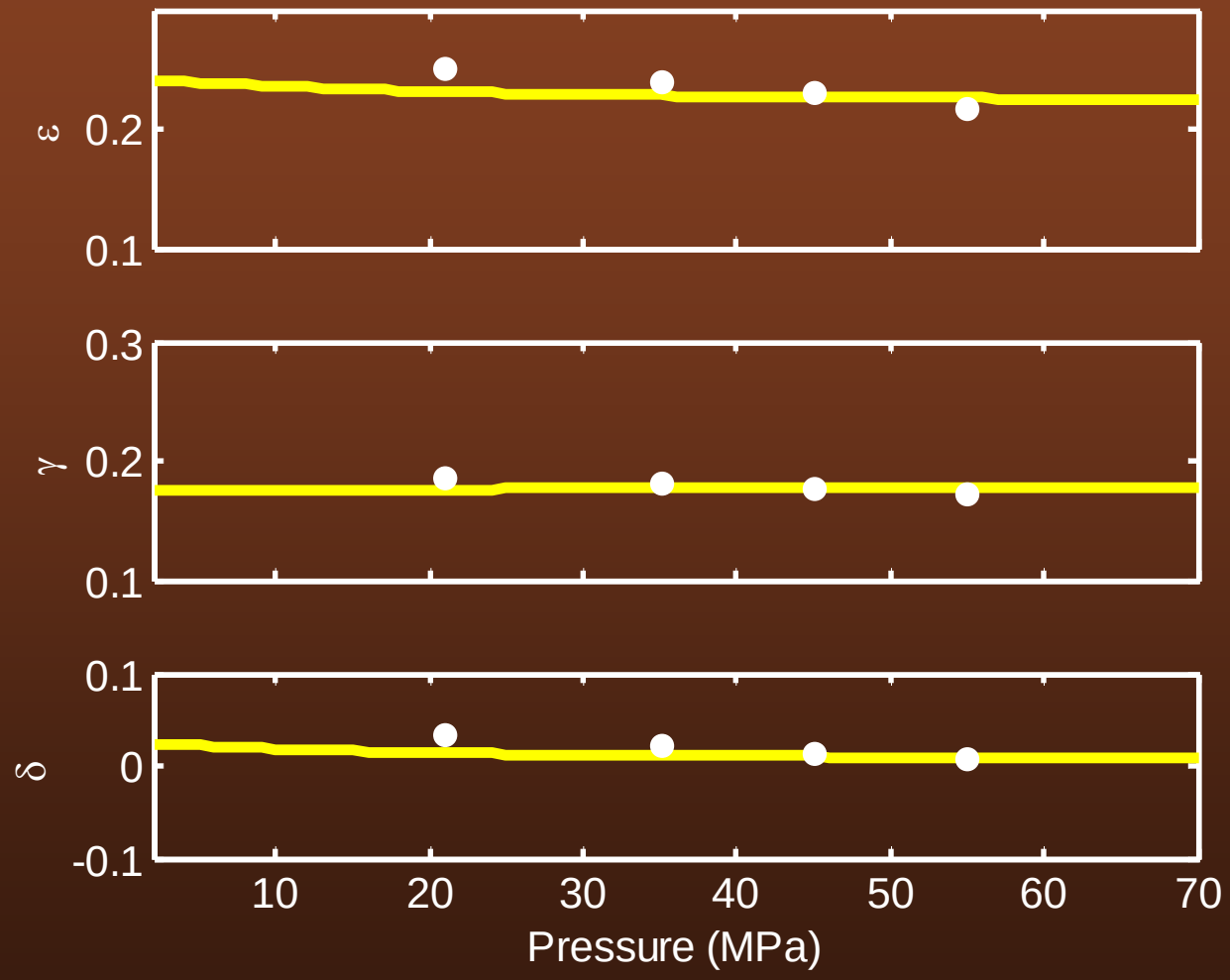
Dataset and error bars



Dataset, error bars, and the original model



Anisotropy data and original model



Pervukhina model

$$\Delta S_{11} = S_{11} - S_{11}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 4\eta + 21B + 3B\eta)$$

$$\Delta S_{33} = S_{33} - S_{33}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 6\eta + 21B + 15B\eta)$$

$$\Delta S_{44} = S_{44} - S_{44}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(42 + 16\eta + 28B + 12B\eta)$$

$$\Delta S_{66} = S_{66} - S_{66}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(42 + 10\eta + 28B + 4B\eta)$$

$$\Delta S_{13} = S_{13} - S_{13}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(7B + 3B\eta - 7 - 3\eta)$$

$B = B_N / B_T$. P = Pressure

$s_n = \dfrac{N_0 A^0}{4\pi(1+\eta/3)}$, (specific surface area of cracks per unit volume)

η: Anisotropic crack orientation parameter

P_c: Characteristic pressure where compliant cracks are closed

Rock physics model: effective compliances

$$\Delta S_{11} = S_{11} - S_{11}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 4\eta + 21B + 3B\eta)$$

$$\Delta S_{33} = S_{33} - S_{33}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 6\eta + 21B + 15B\eta)$$

$$\Delta S_{44} = S_{44} - S_{44}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(42 + 16\eta + 28B + 12B\eta)$$

$$\Delta S_{66} = S_{66} - S_{66}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(42 + 10\eta + 28B + 4B\eta)$$

$$\Delta S_{13} = S_{13} - S_{13}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(7B + 3B\eta - 7 - 3\eta)$$

Model from Pervukhina et al., 2011 (Geophysics)

Rock physics model: excess compliances

$$\Delta S_{11} = S_{11} - S_{11}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 4\eta + 21B + 3B\eta)$$

$$\Delta S_{33} = S_{33} - S_{33}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 6\eta + 21B + 15B\eta)$$

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$$\Delta S_{13} = S_{13} - S_{13}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(7B + 3B\eta - 7 - 3\eta)$$

Model from Pervukhina et al., 2011 (Geophysics)

Rock physics model: high-pressure compliances

$$\Delta S_{11} = S_{11} - S_{11}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 4\eta + 21B + 3B\eta)$$

$$\Delta S_{33} = S_{33} - S_{33}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(14 + 6\eta + 21B + 15B\eta)$$

$$\Delta S_{44} = S_{44} - S_{44}^0 = \frac{s_n B_T \exp(-P/P_c)}{105}(42 + 16\eta + 28B + 12B\eta)$$

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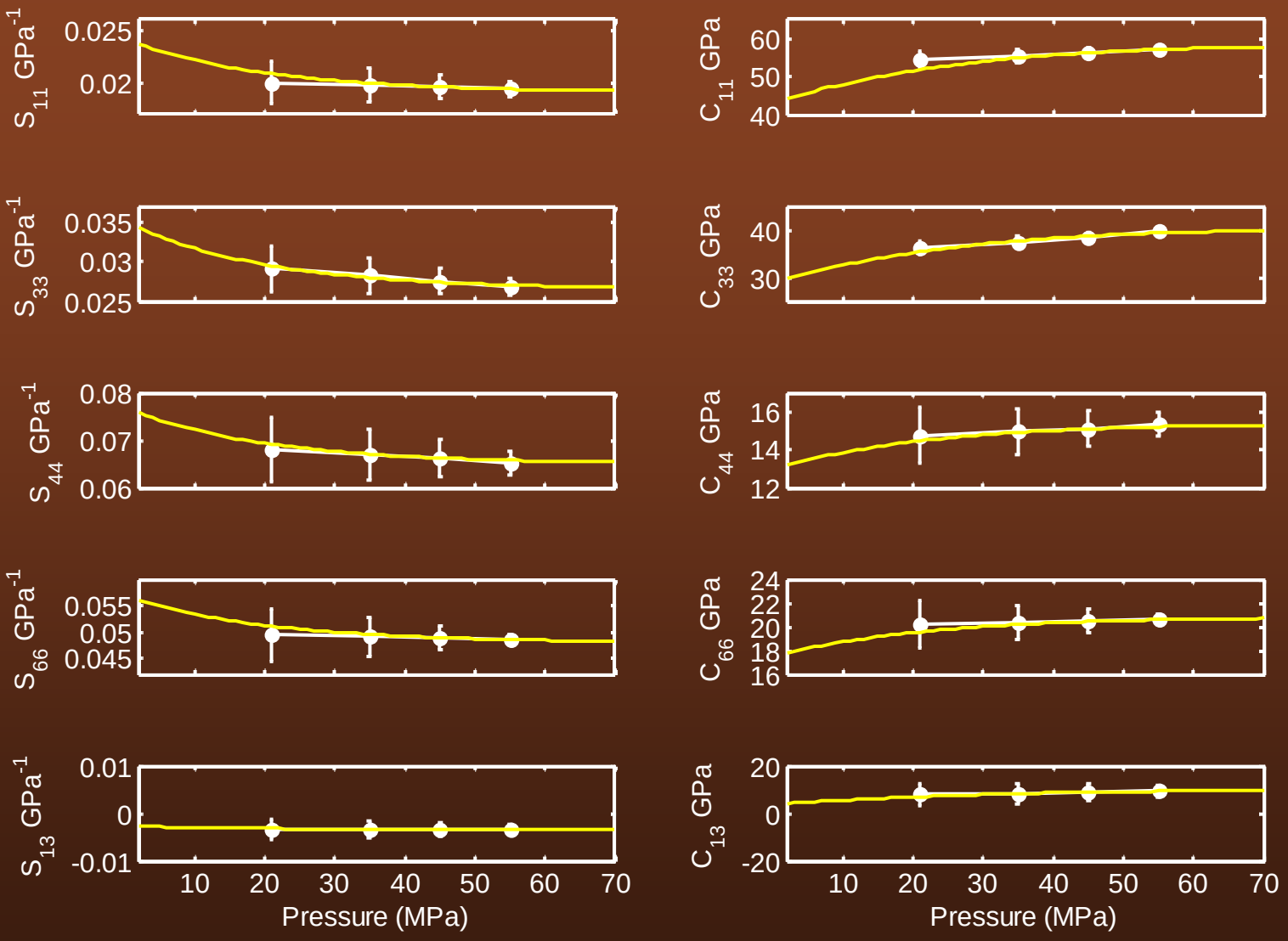
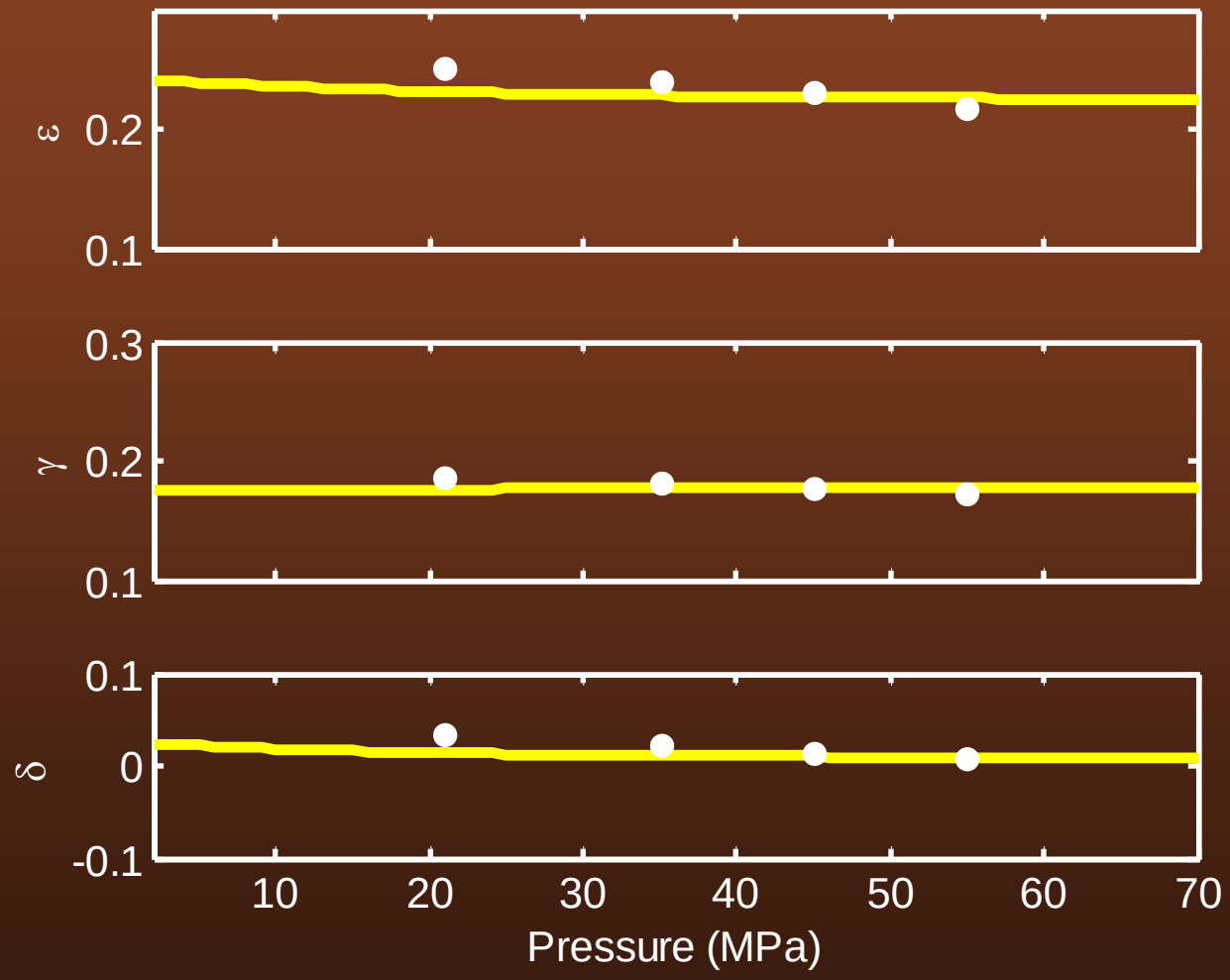
Model from Pervukhina et al., 2011 (Geophysics)

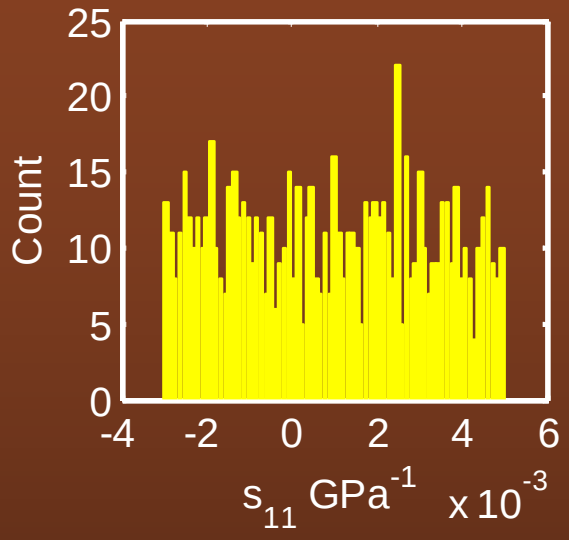
Dataset, errorbars, and the original model

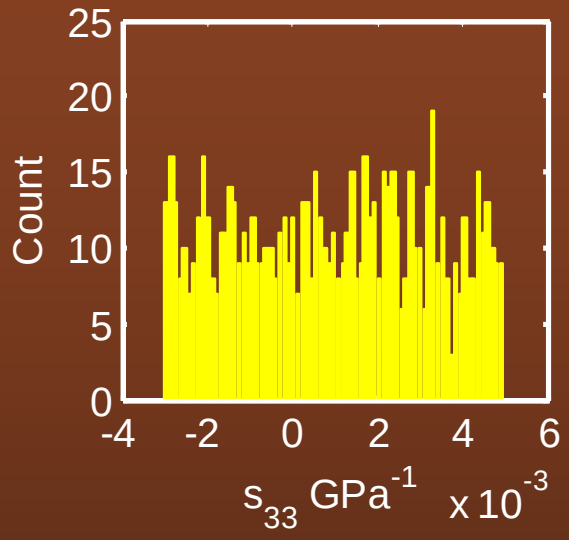


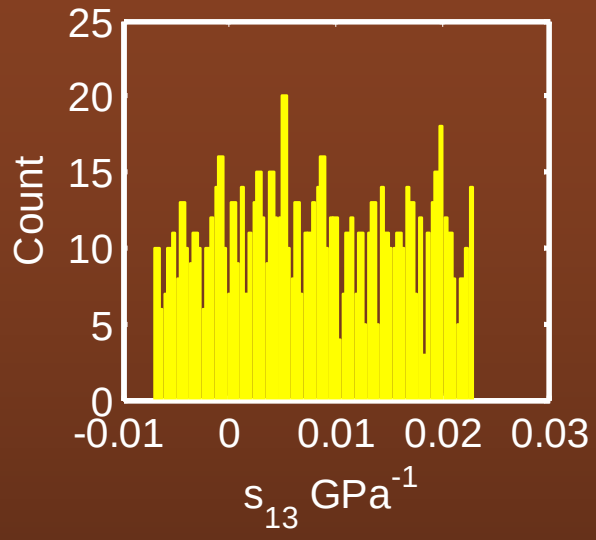
Anisotropy parameters and models

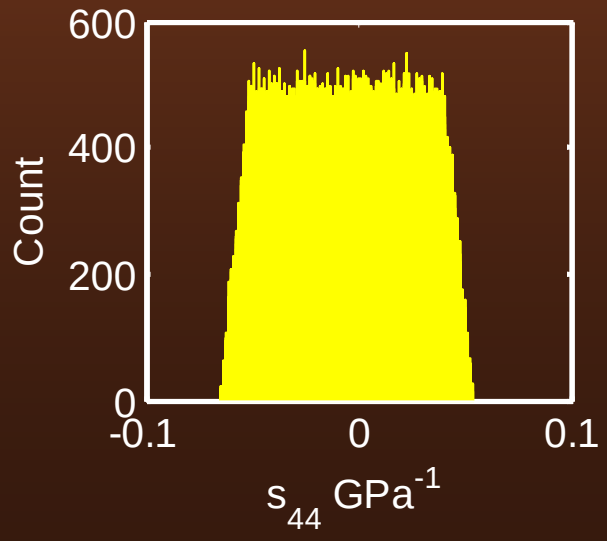


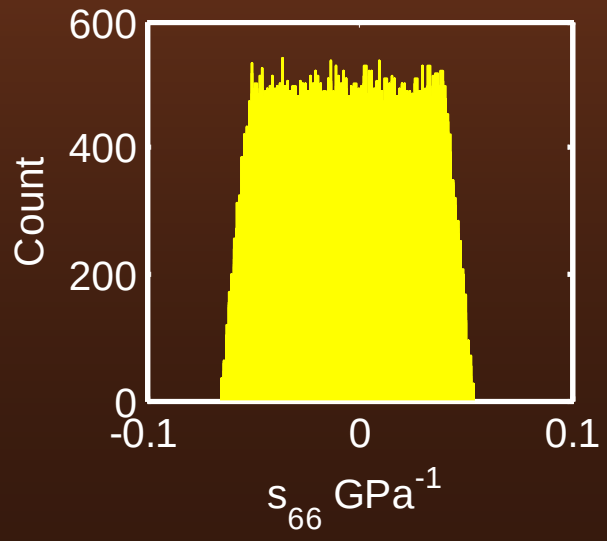
Prior distributions



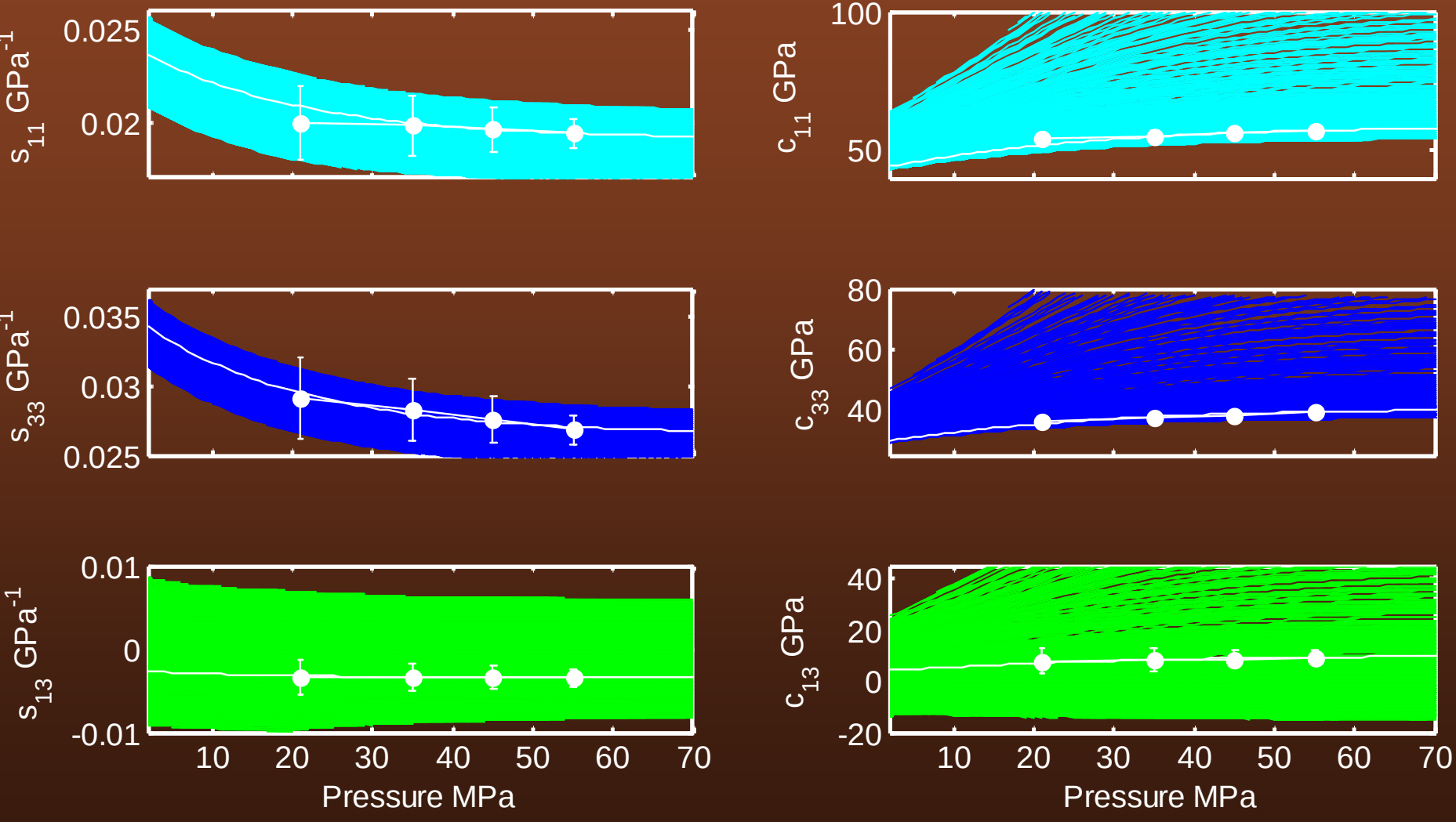








Models with all slopes



Strain energy requirements

$$c_{44} \geq 0$$

$$c_{11} > |c_{12}|$$

$$(c_{11} + c_{12})c_{33} \geq 2_{13}^{2}$$

$$(c_{13} + c_{44}) > 0$$

Anisotropy parameters and relative values

$$\delta \geq \frac{1}{2}\left(1-\frac{c_{44}}{c_{33}}\right)$$

$$\delta \leq \frac{2}{c_{33}/c_{44}-1}$$

$$\varepsilon > \delta$$

$$\varepsilon - \delta \geq 0$$

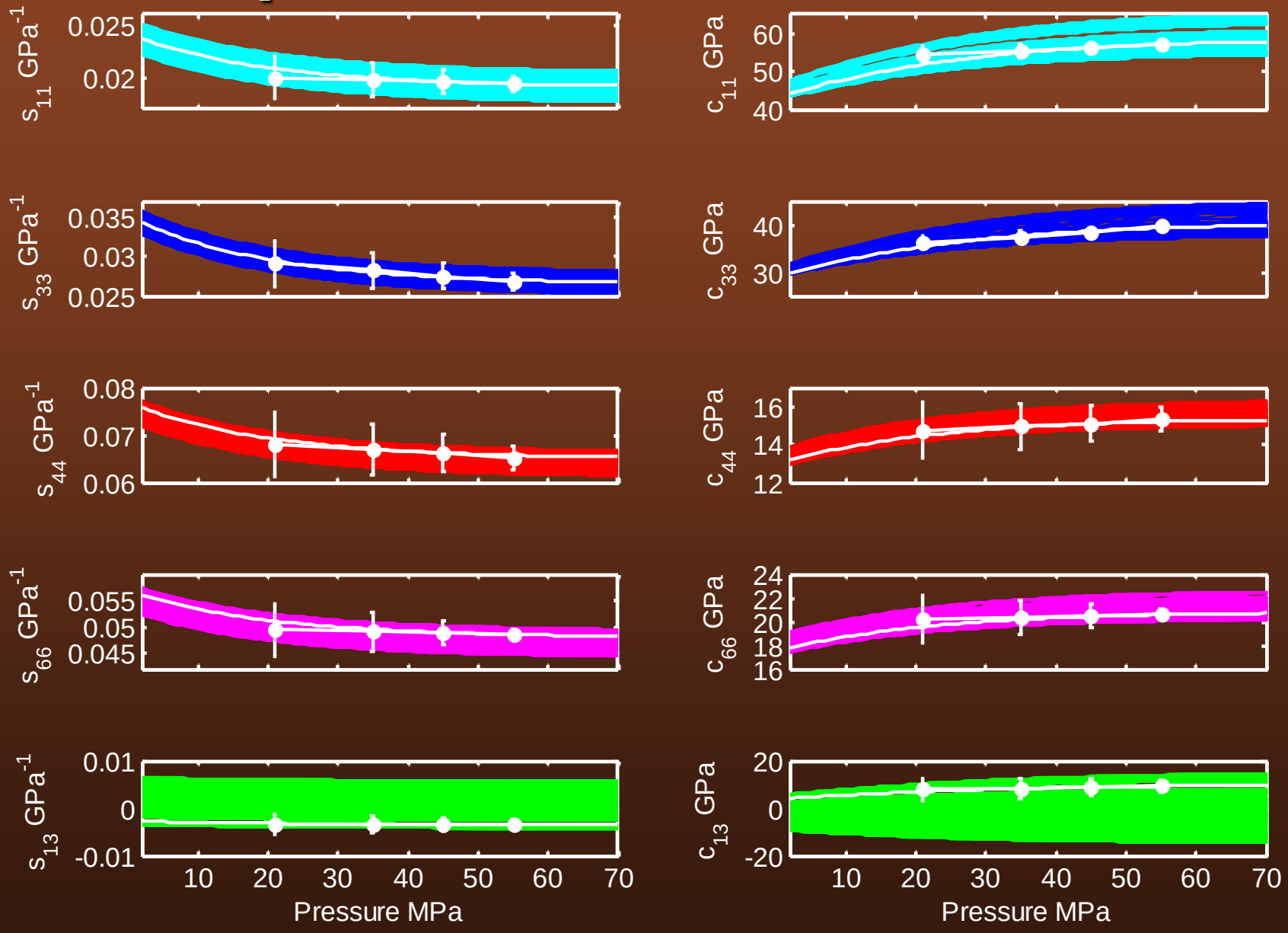
$$\gamma \geq 0$$

$$\varepsilon = \frac{c_{11}-c_{33}}{2c_{33}}$$

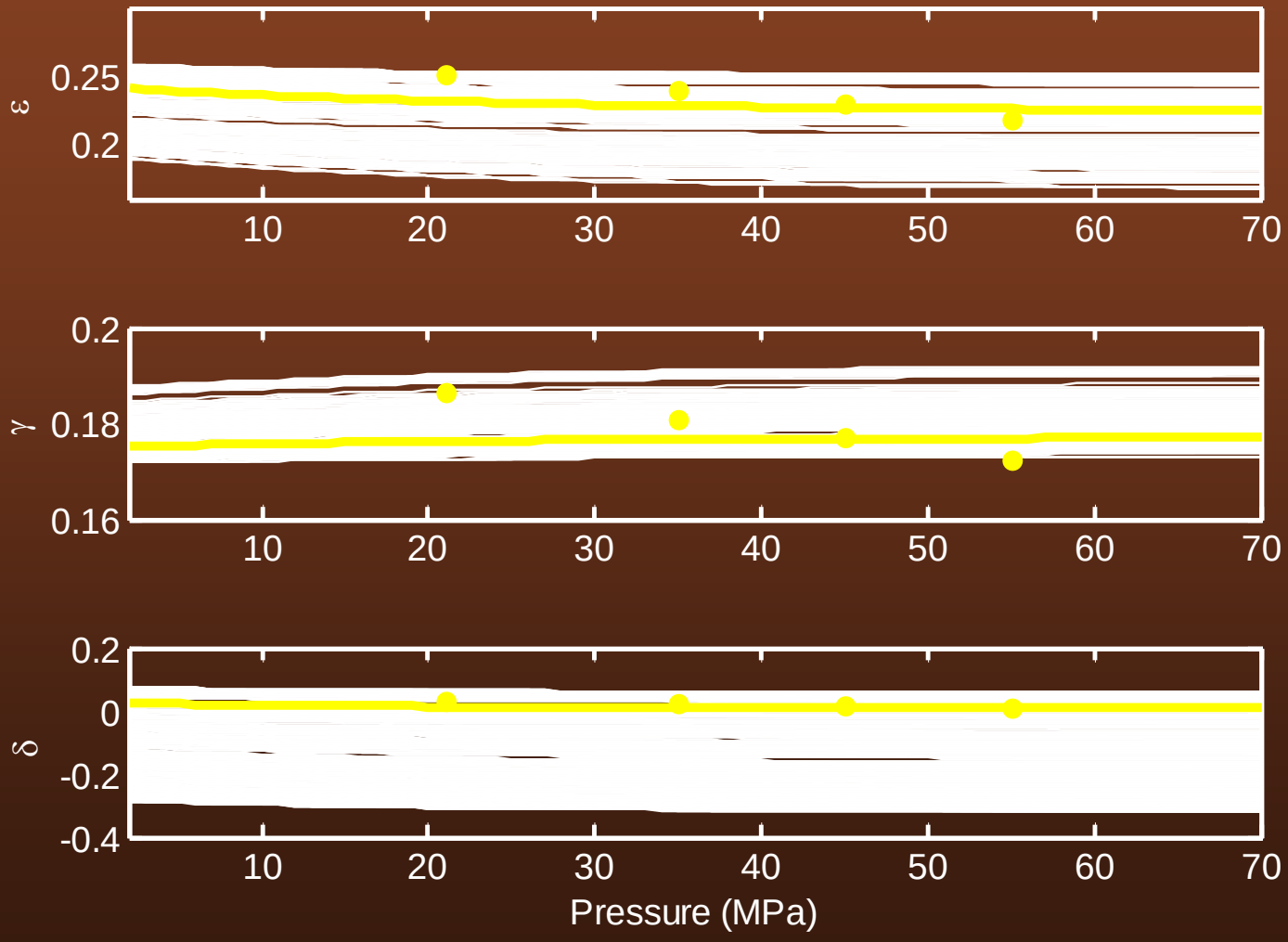
$$\gamma = \frac{c_{66}-c_{44}}{2c_{44}}$$

$$\delta = \frac{(c_{13}+c_{44})^2-(c_{33}+c_{44})^2}{2c_{33}(c_{33}-c_{44})}$$

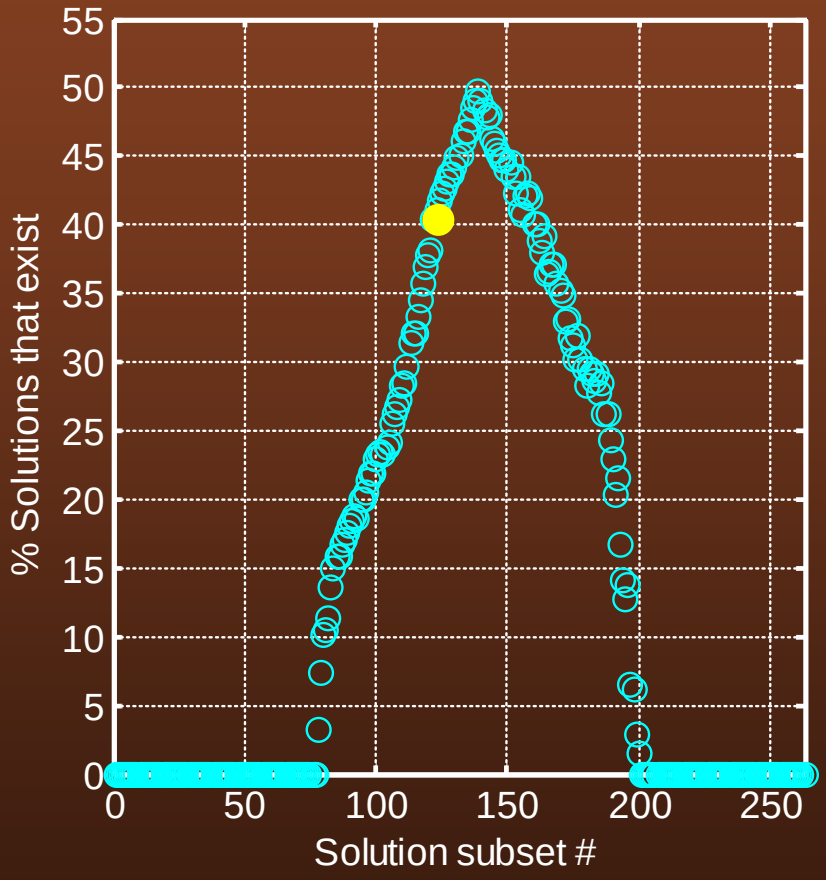
Compliance and stiffness models

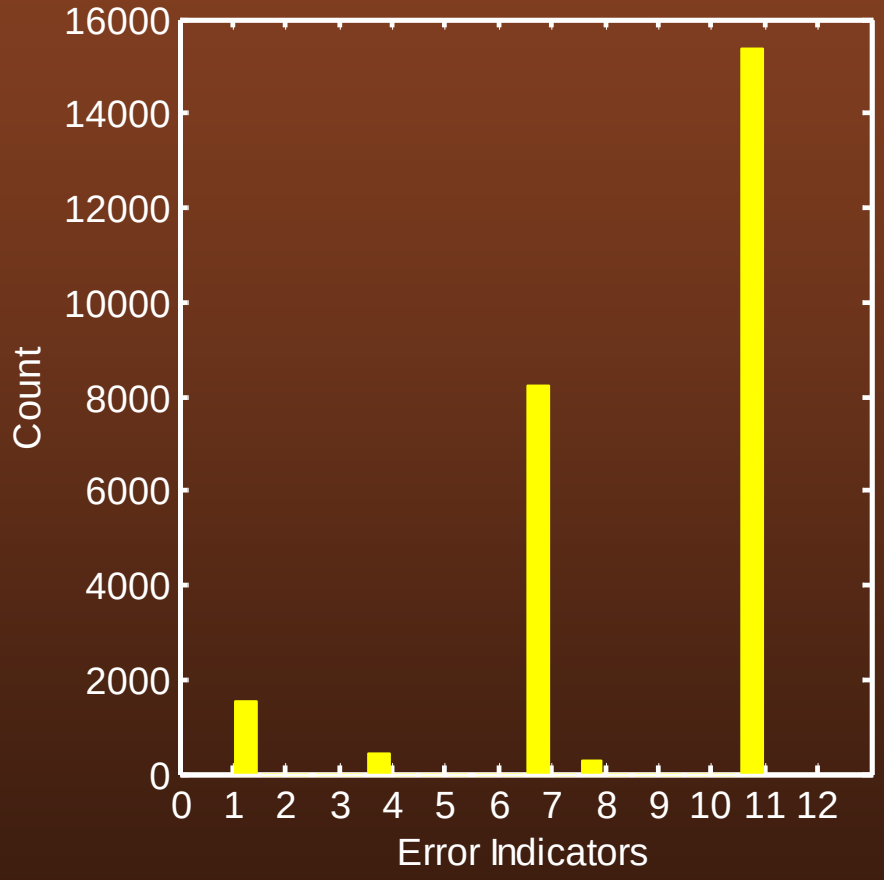


Anisotropy parameter models

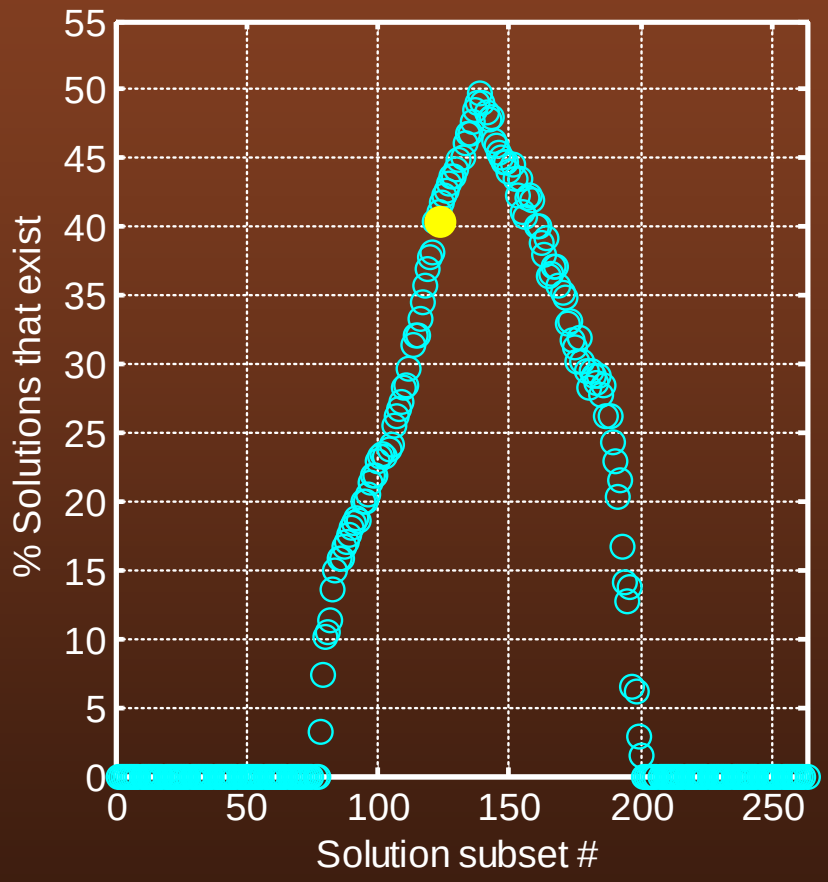


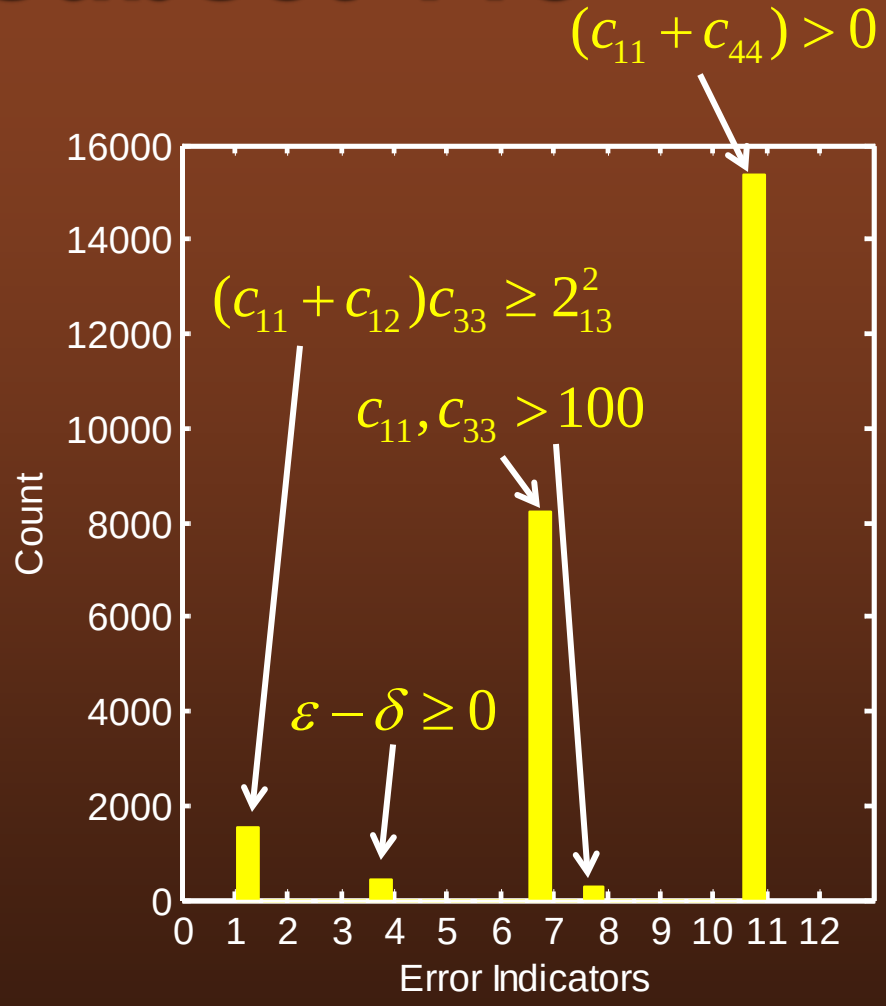
Solution subset 118



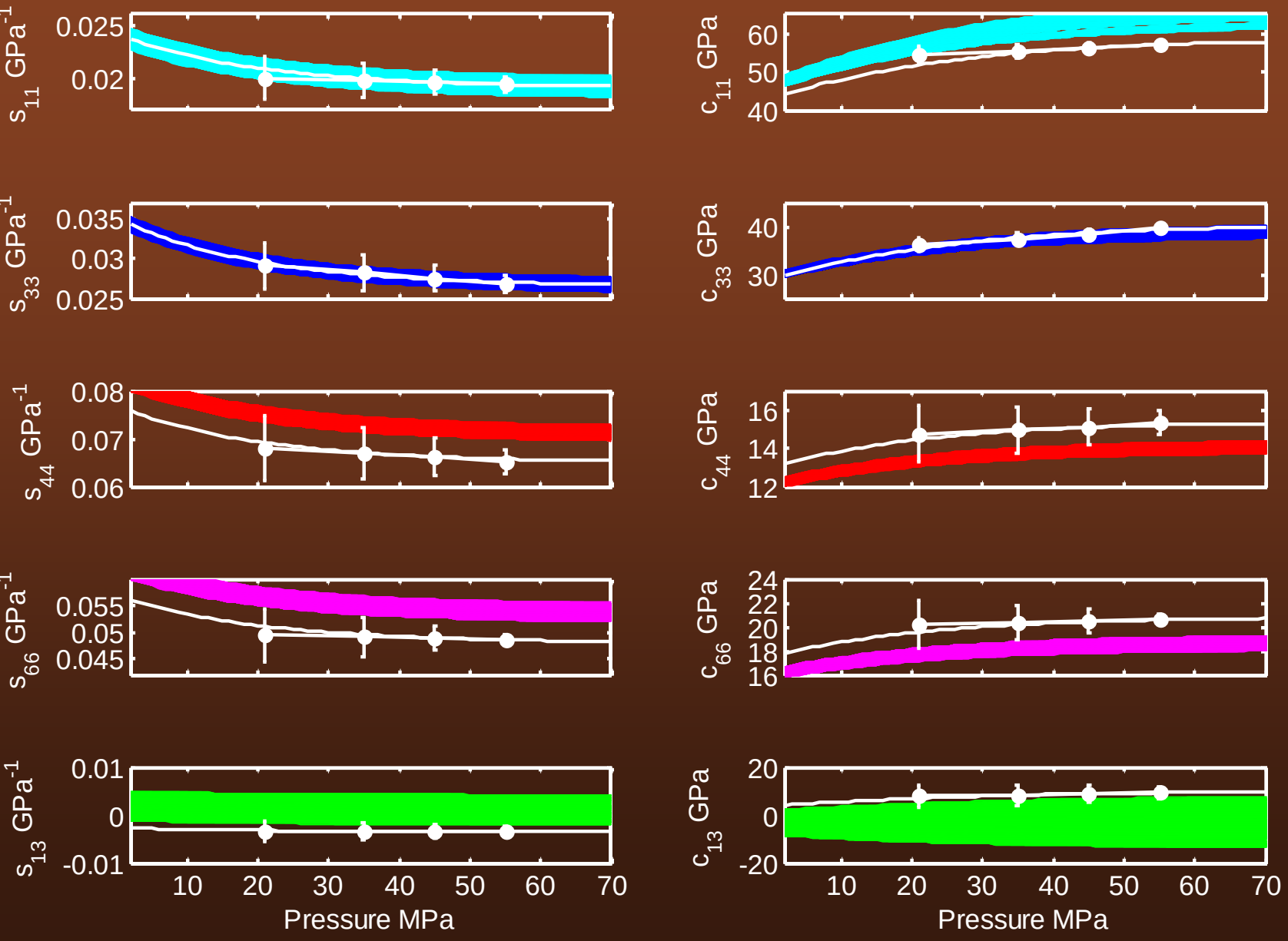


Solution subset 118

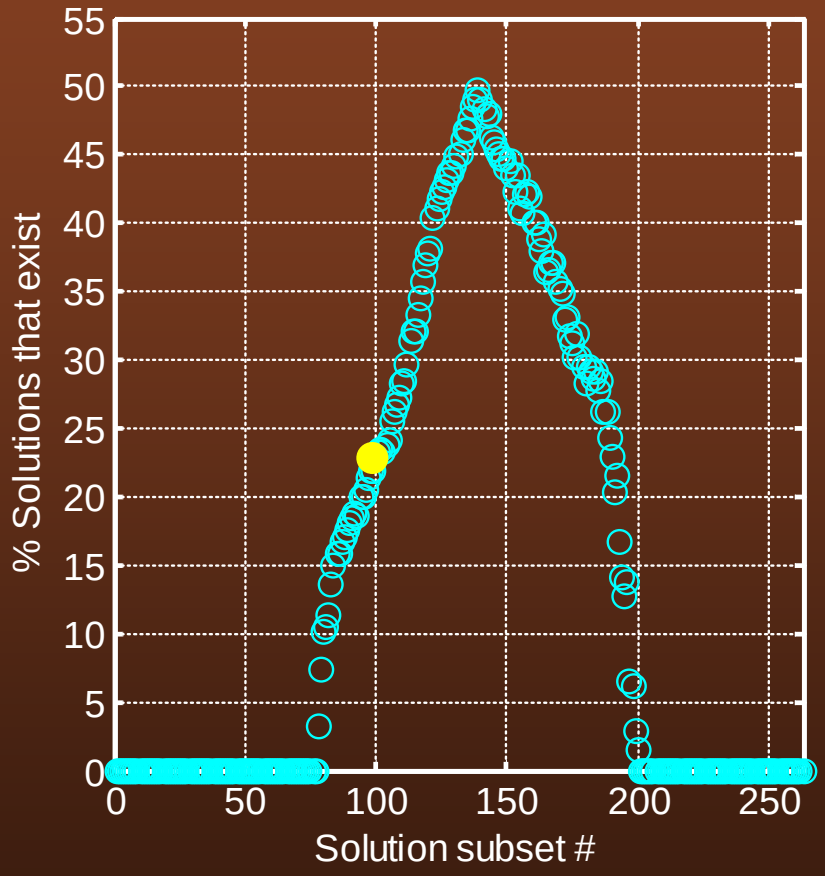


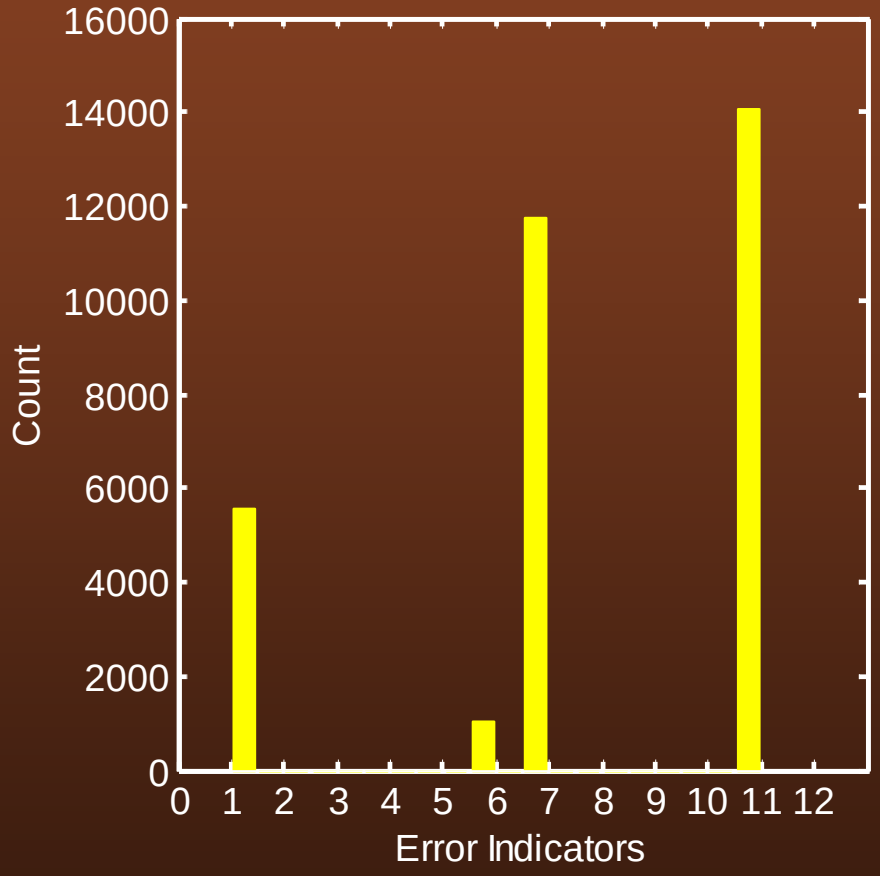


Solution subset 100

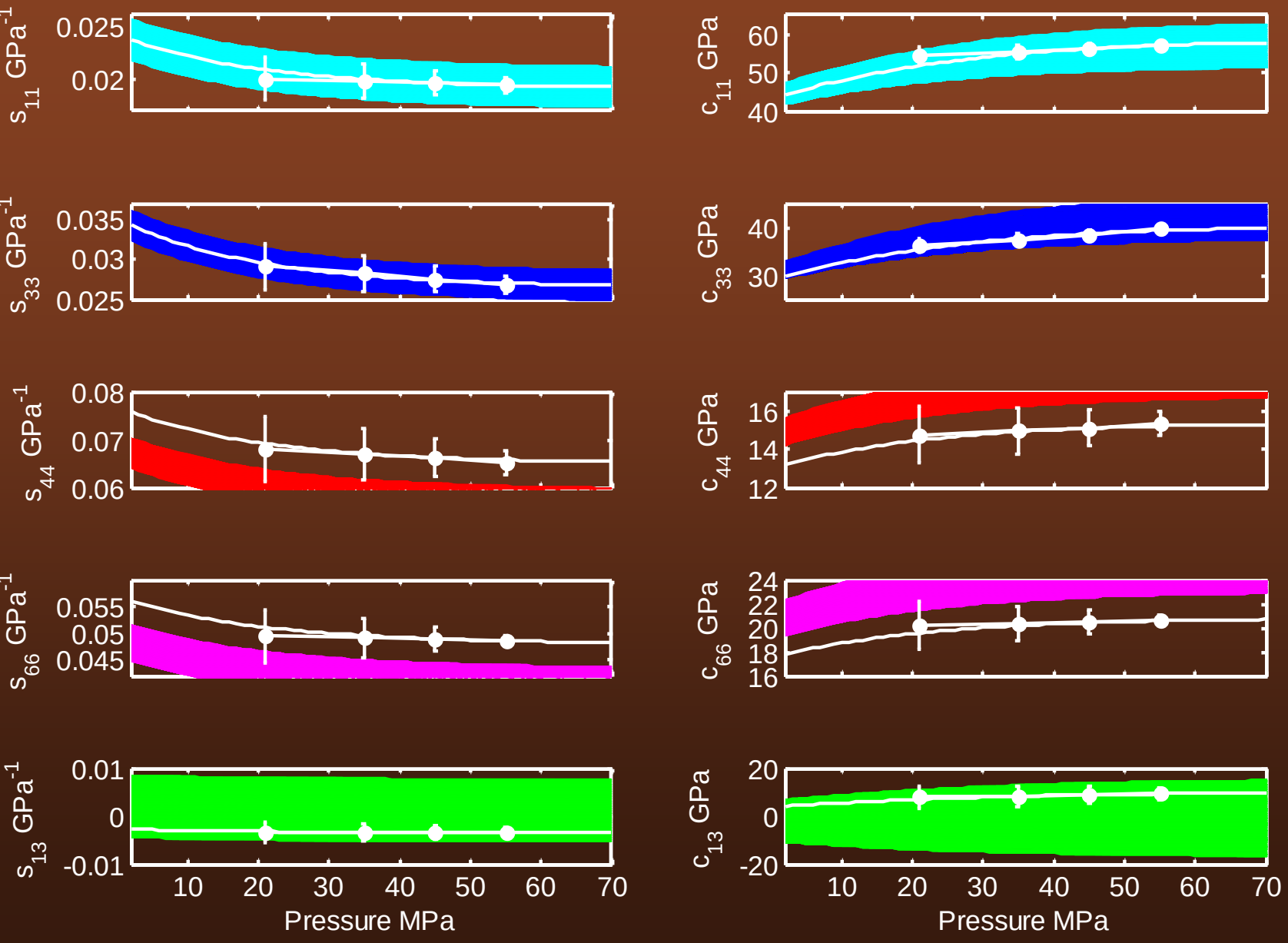


Solution subset 100

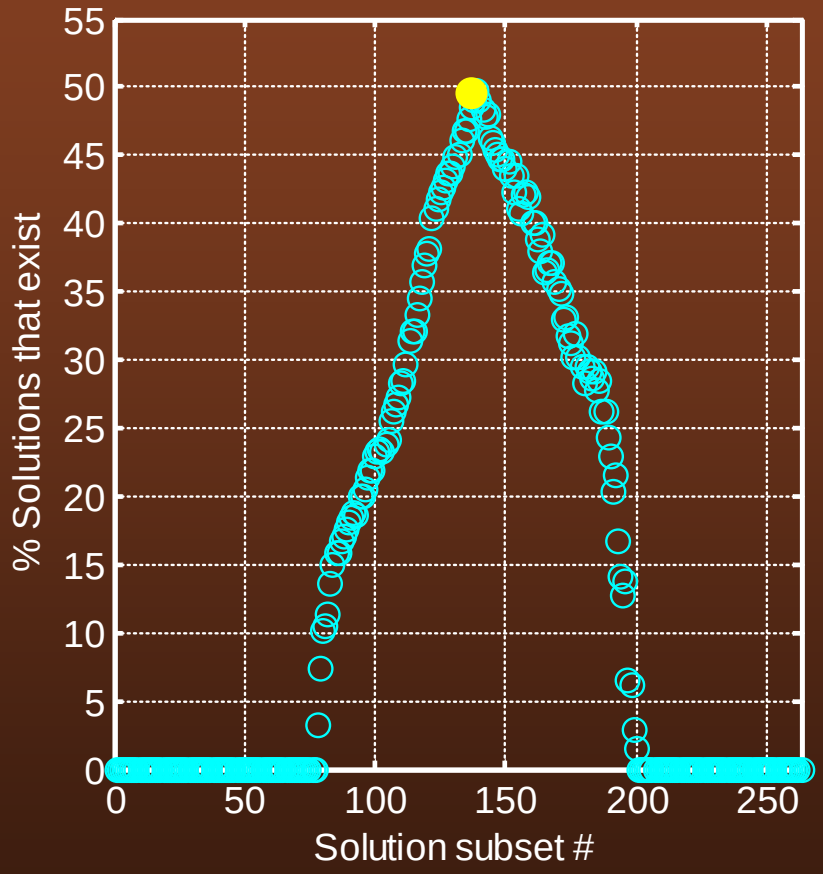


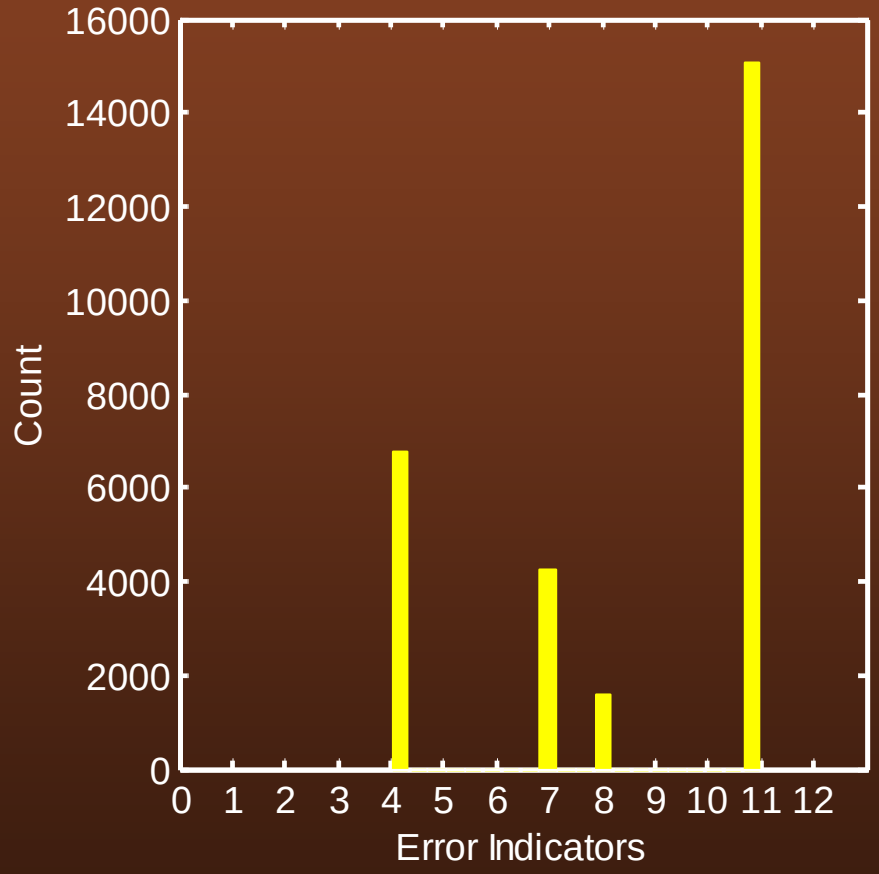


Solution subset 135



Solution subset 135





Discussion

Data clearly shows anisotropic behavior.

In most cases, 11 and 33 terms match better than 44, 66, and 13 terms.

Do the S-wave measurements inherently more uncertain?

Are these samples truly homogeneous VTI?

Error assessment suggests inhomogeneities at the MHz frequency range might be detectable.

Conclusions

Account for measurement and model errors

Provide insight into viable ranges of anisotropy

Constrain anisotropic seismic imaging and inversion schemes

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