Discriminating between fractures and fabrics in a highly anisotropic shale using shear-wave splitting

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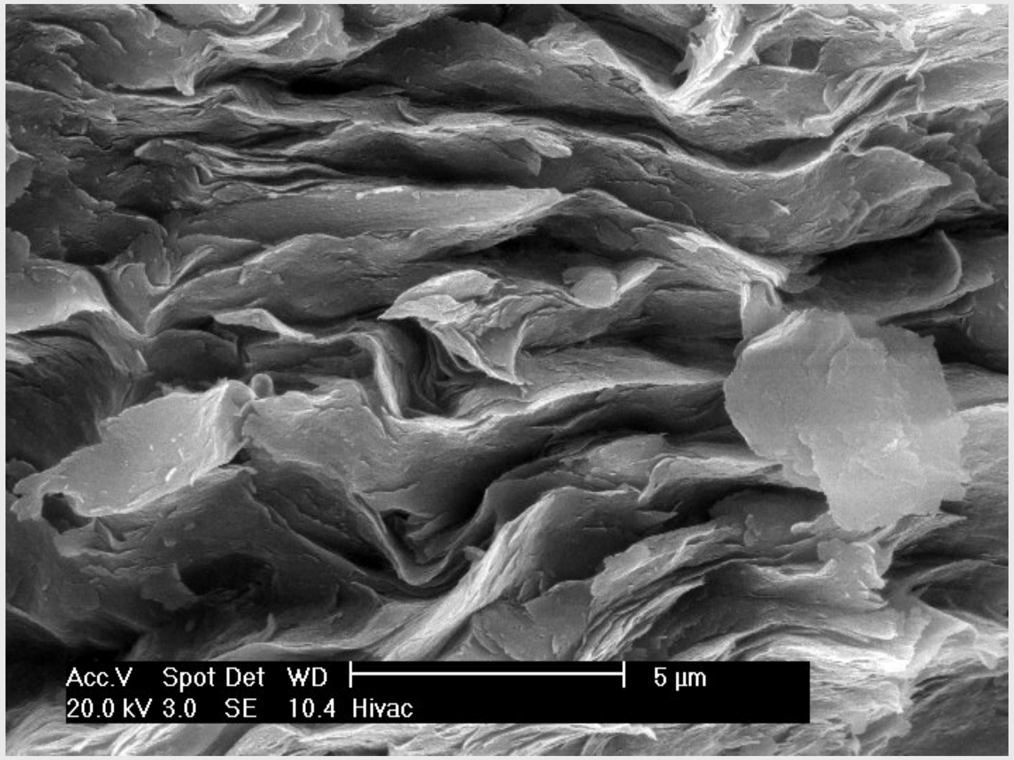
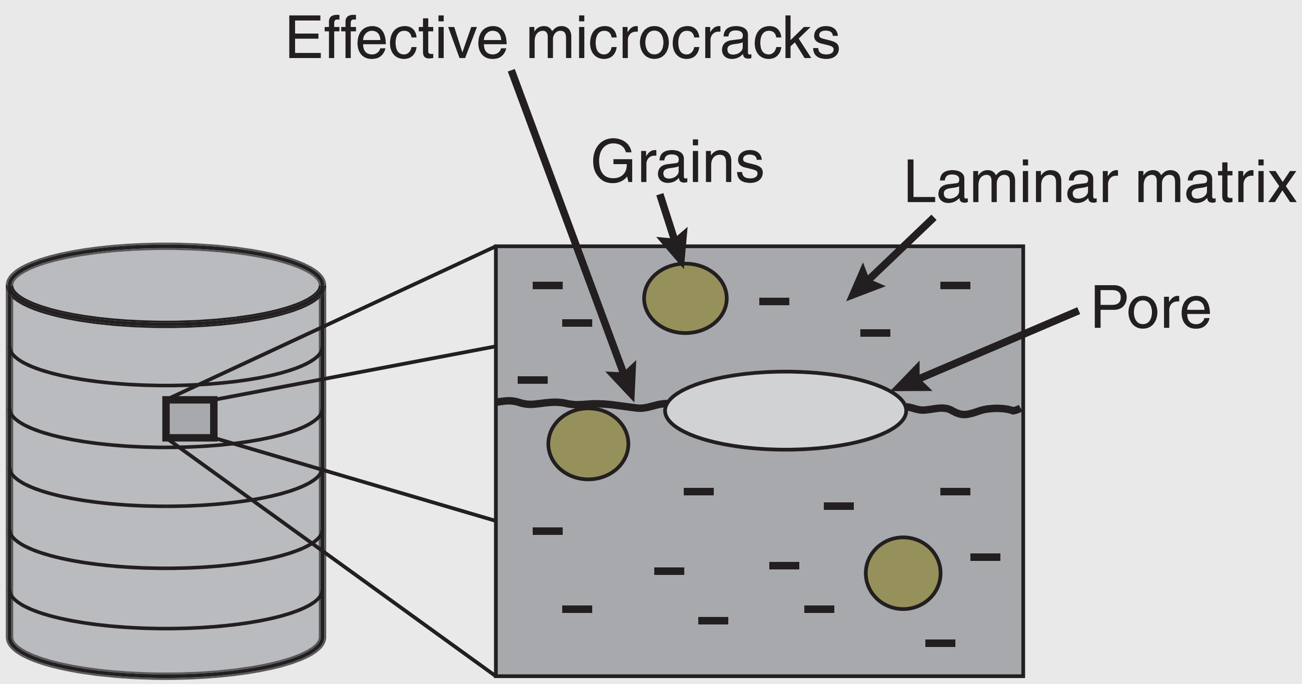
Shale Texture

Shales possess an intrinsic microstructure – high degree of crystal preferred orientation (e.g., Kaarsberg, 1959; Vernik and Nur, 1992; Valcke et al., 2006; Kanitpanyacharoen et al., 2011)

Observable effect on seismic wave propagation in shales





Allan et al (2016)

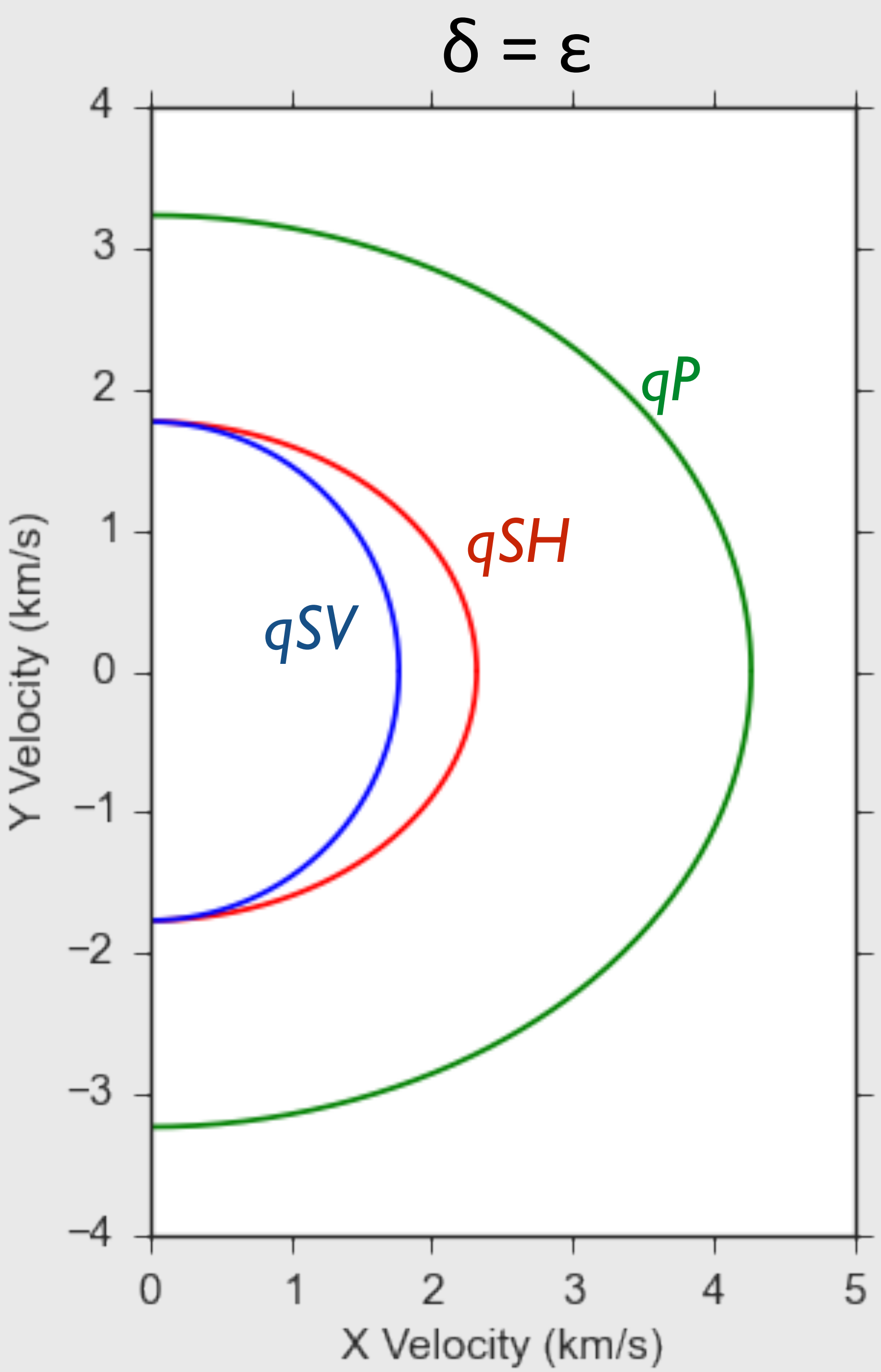
Shale Seismic Anisotropy

Commonly known as vertical transverse isotropy (VTI)

Thomsen (1986) parameters – ε, γ, δ – provide simple description of VTI anisotropy

Effects:

- Shear-wave splitting
- Shear wave sheets cross
- Shear wave triplications



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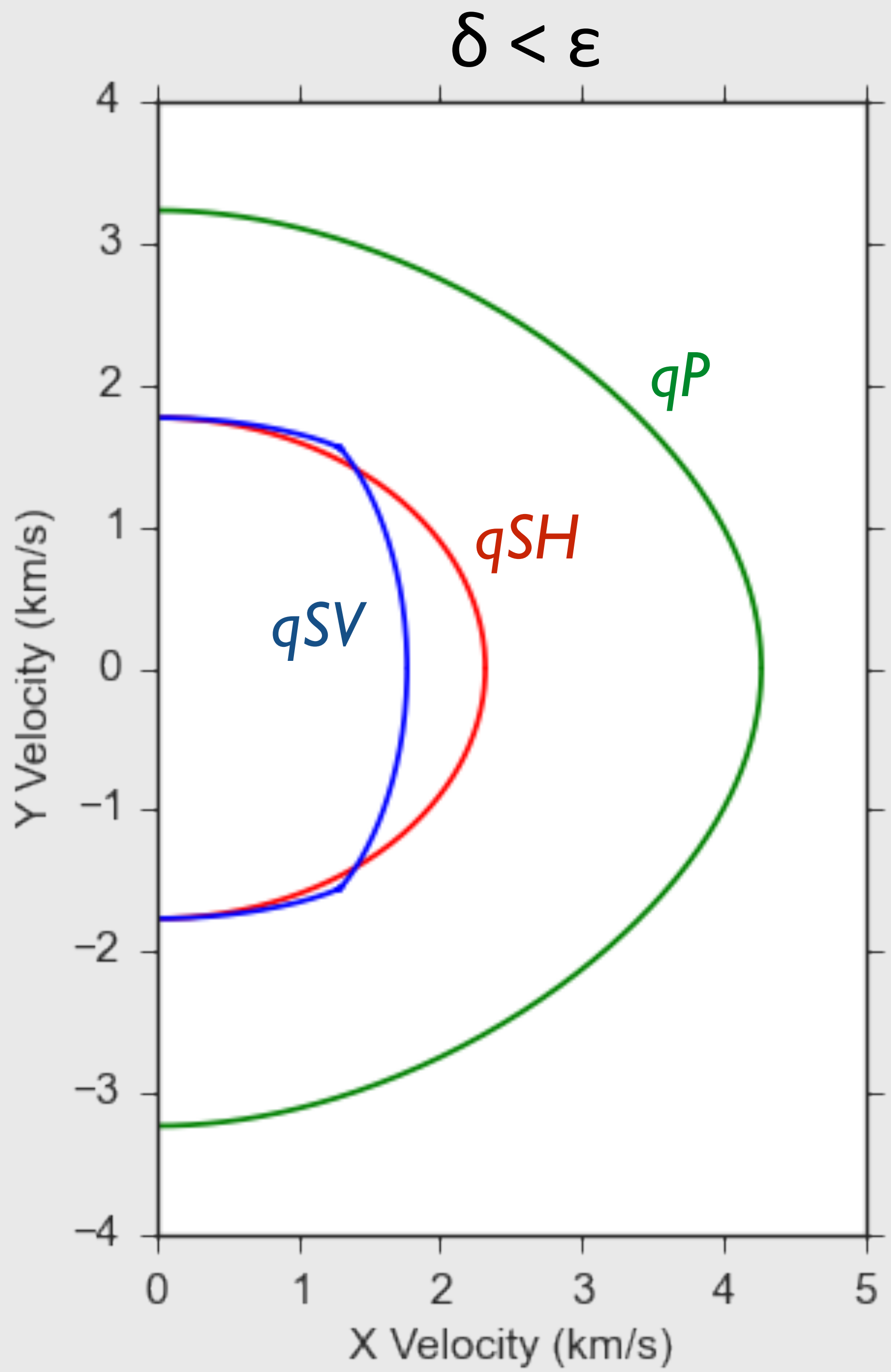

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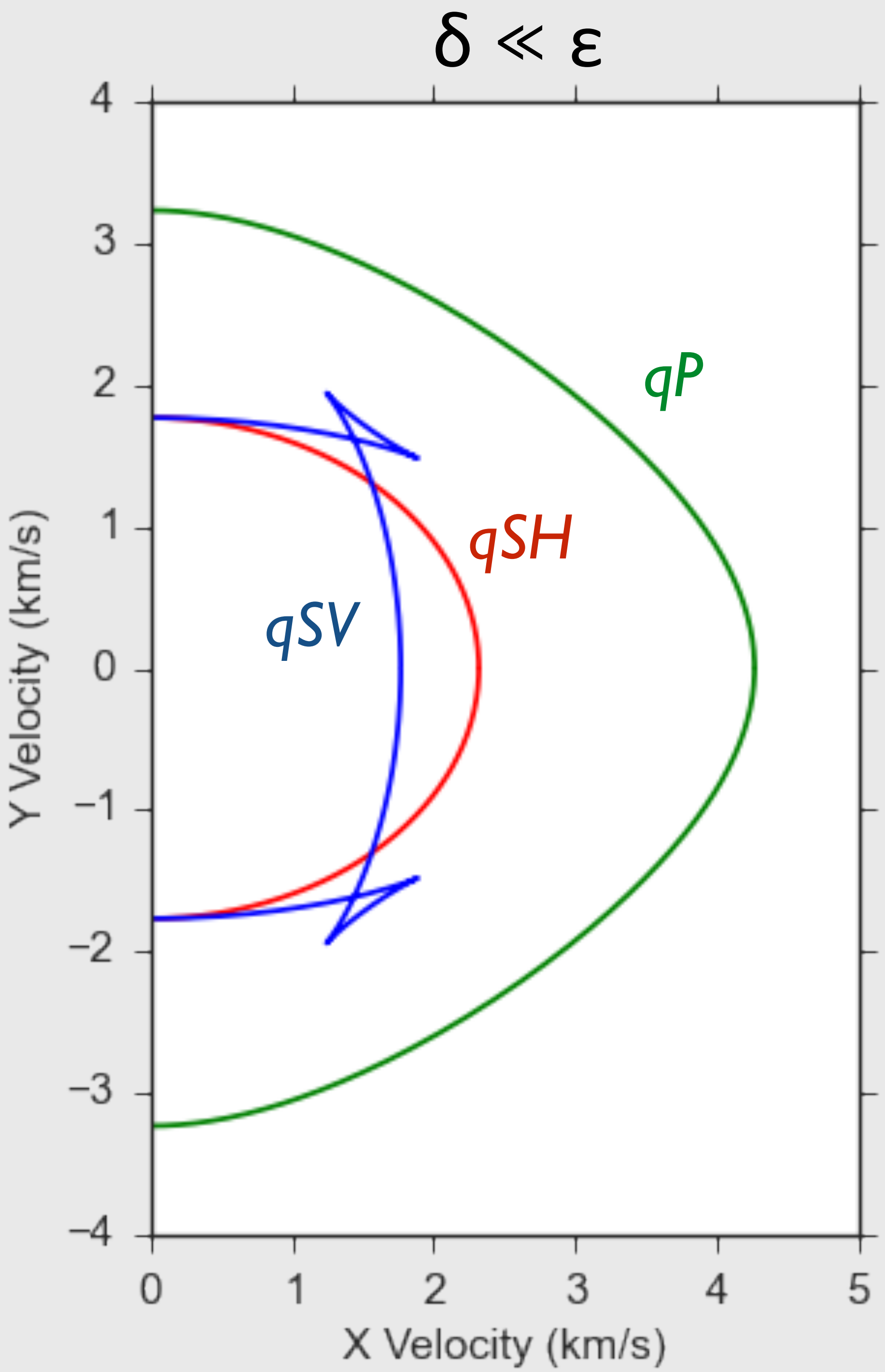
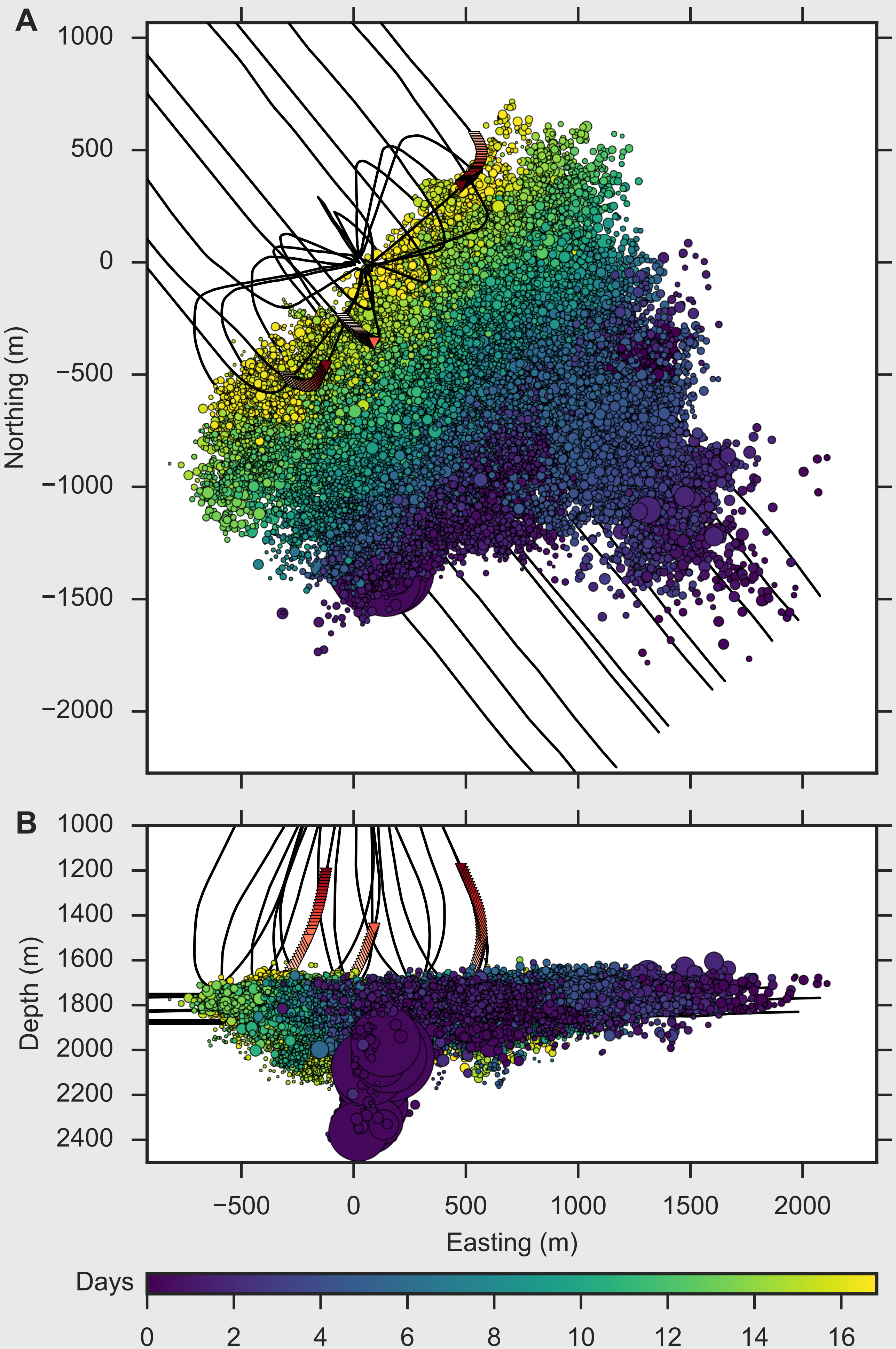
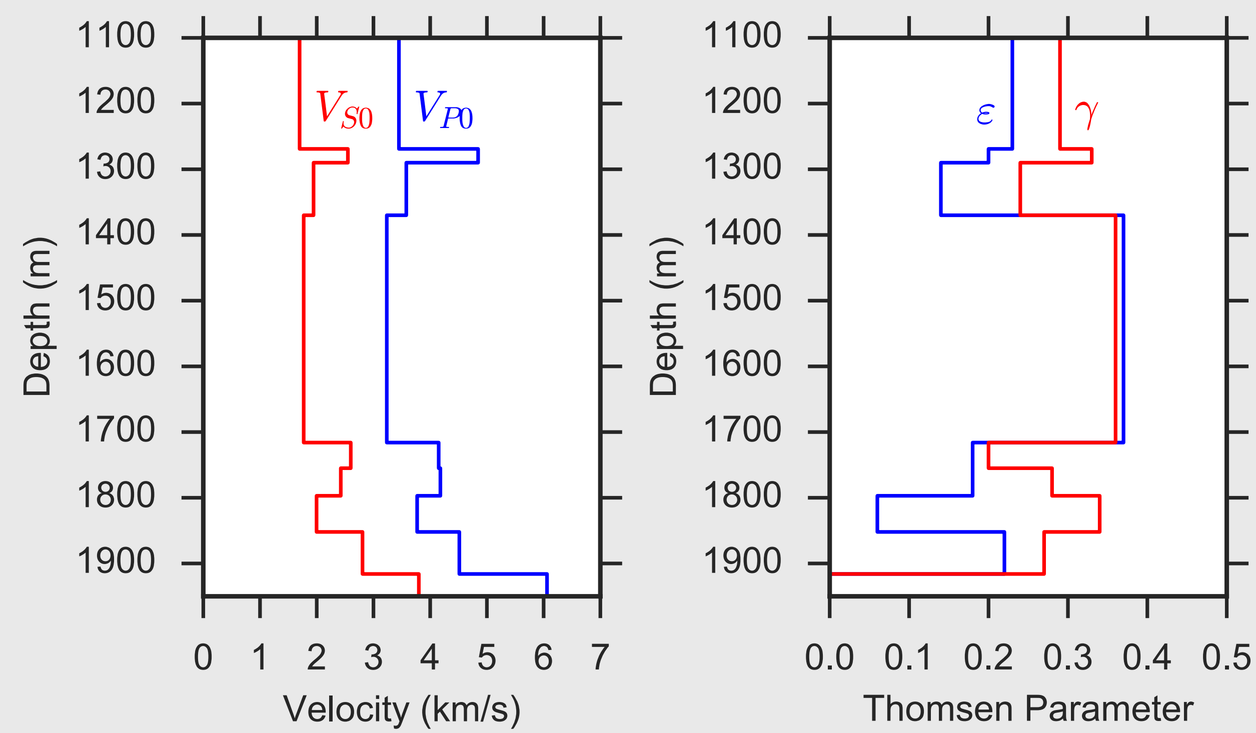


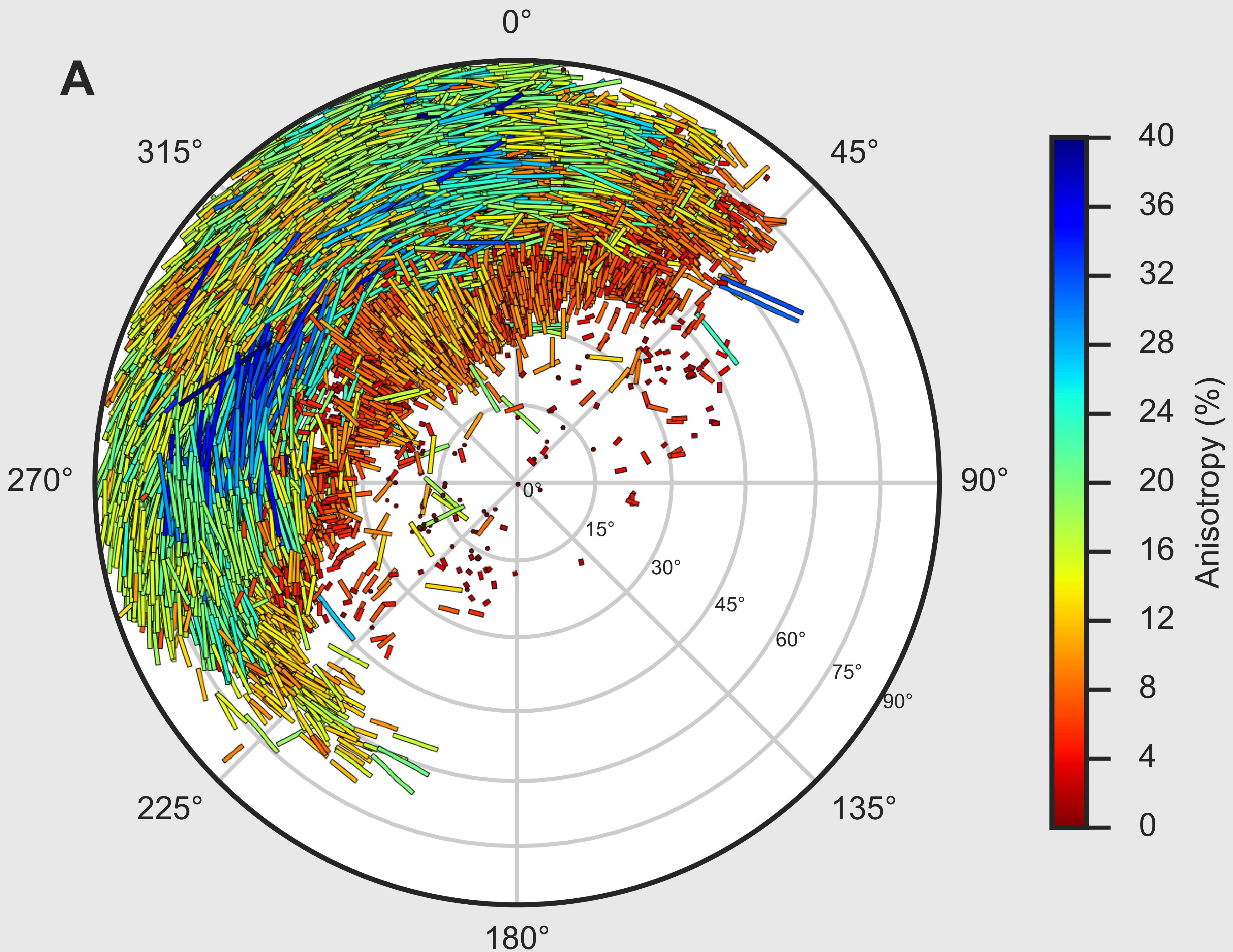
Microseismic dataset



- 92,571 events from 119 stages along 10 horizontal wells
- Recorded by 96 3C geophones in three downhole arrays
- 1D velocity model built assuming elliptical anisotropy
  - Provides estimates of ε and γ
  - Geophones located primarily in thick, strongly anisotropic layer above target layers



Shear-wave splitting results



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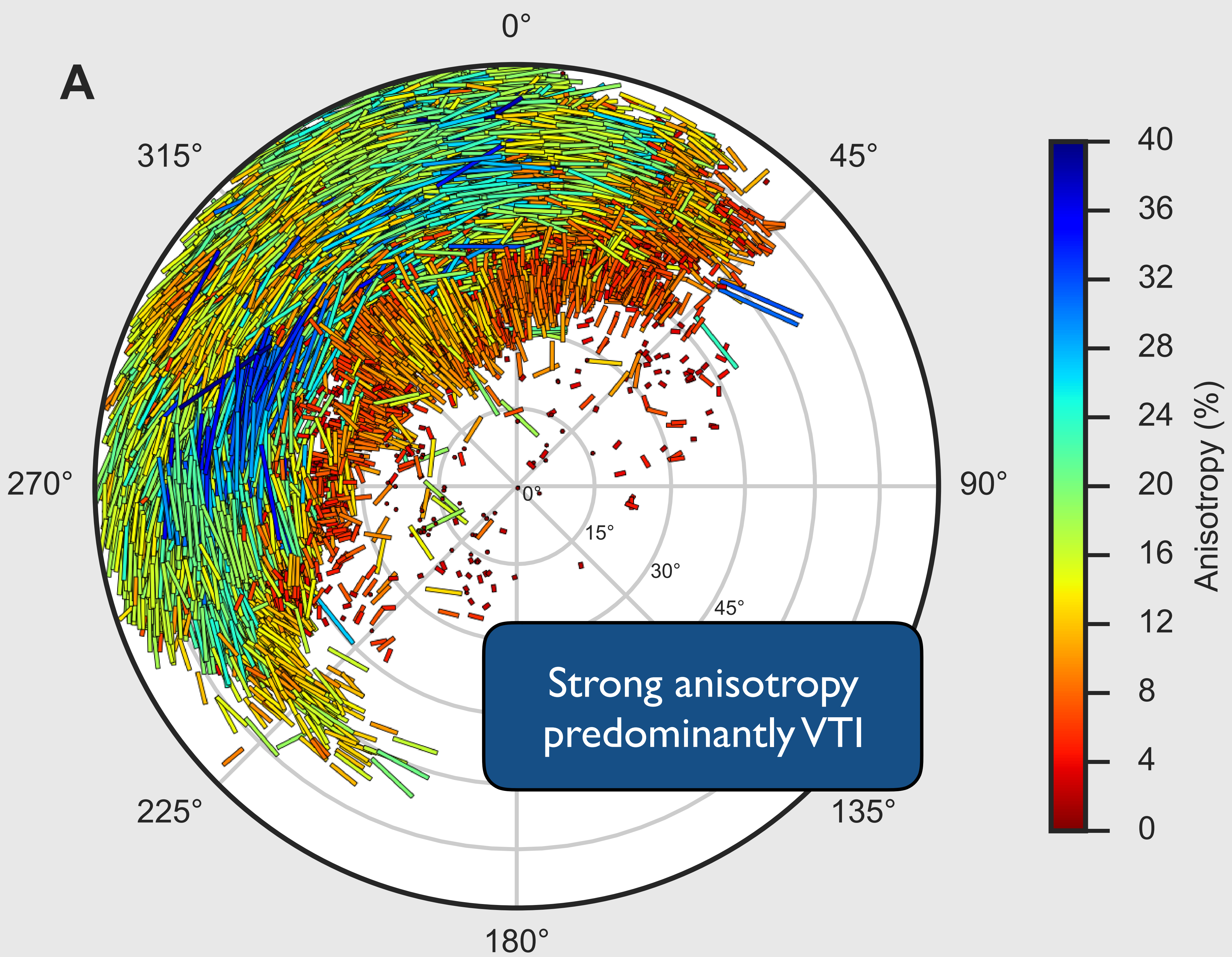
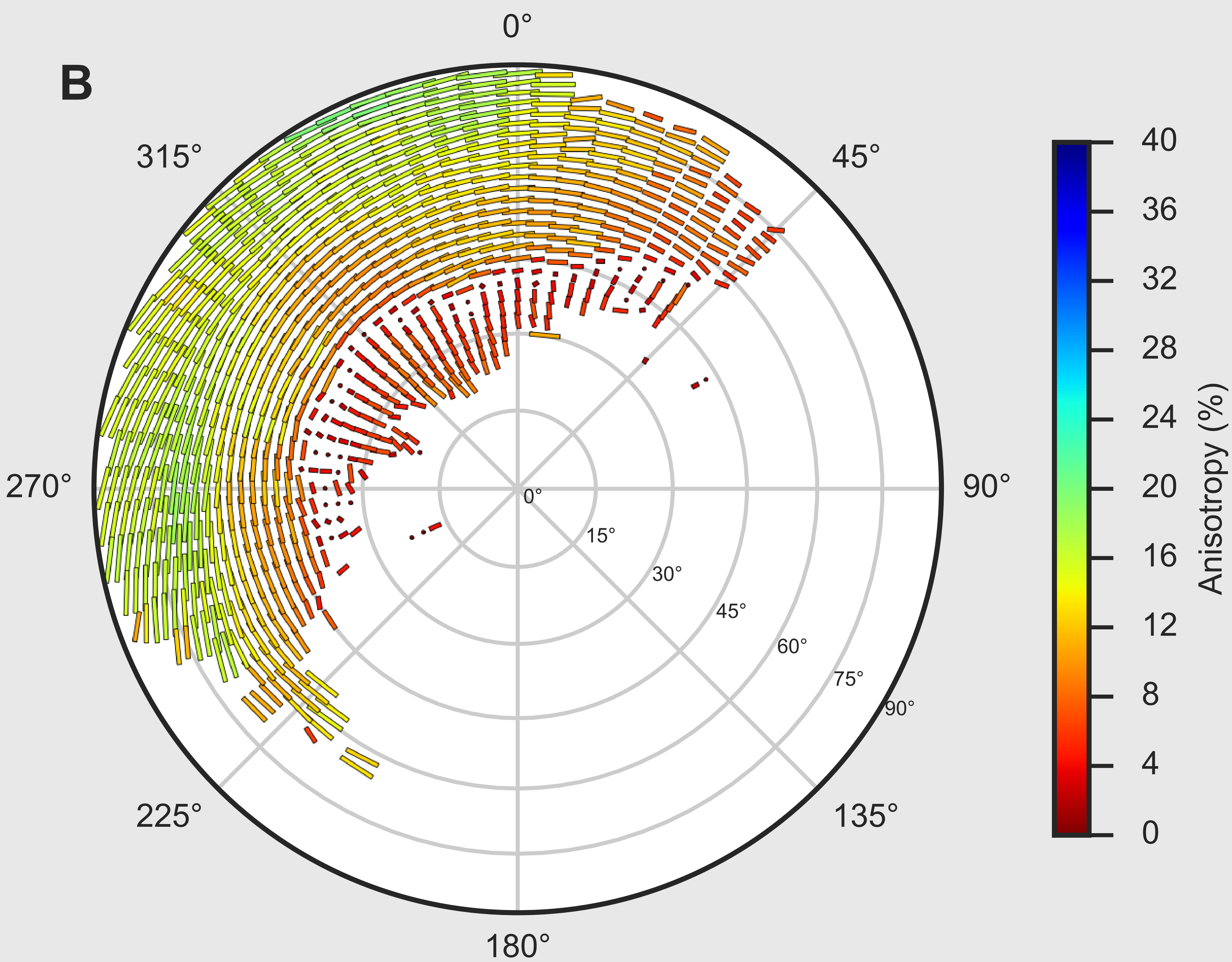


Smoothed splitting results



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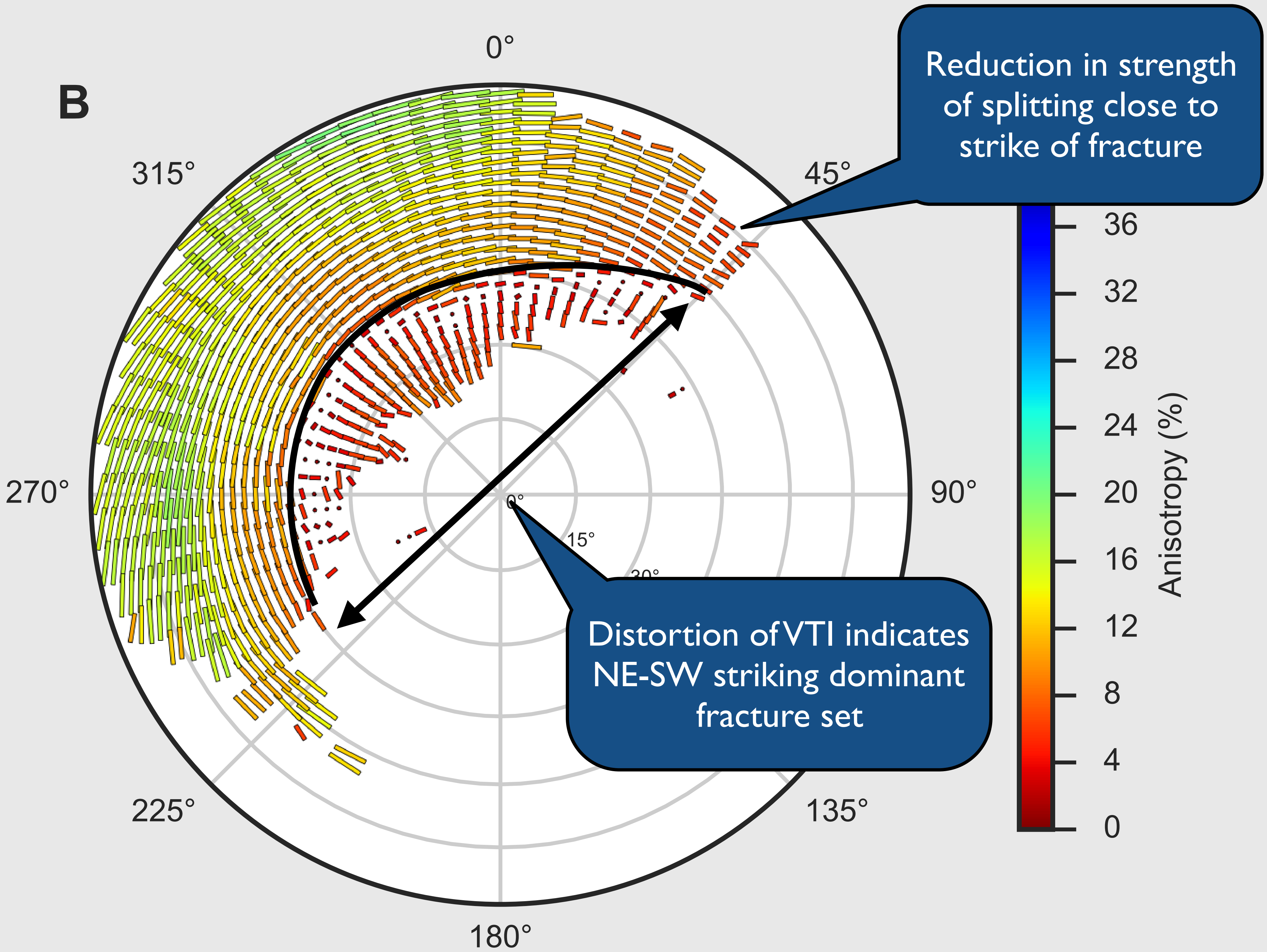
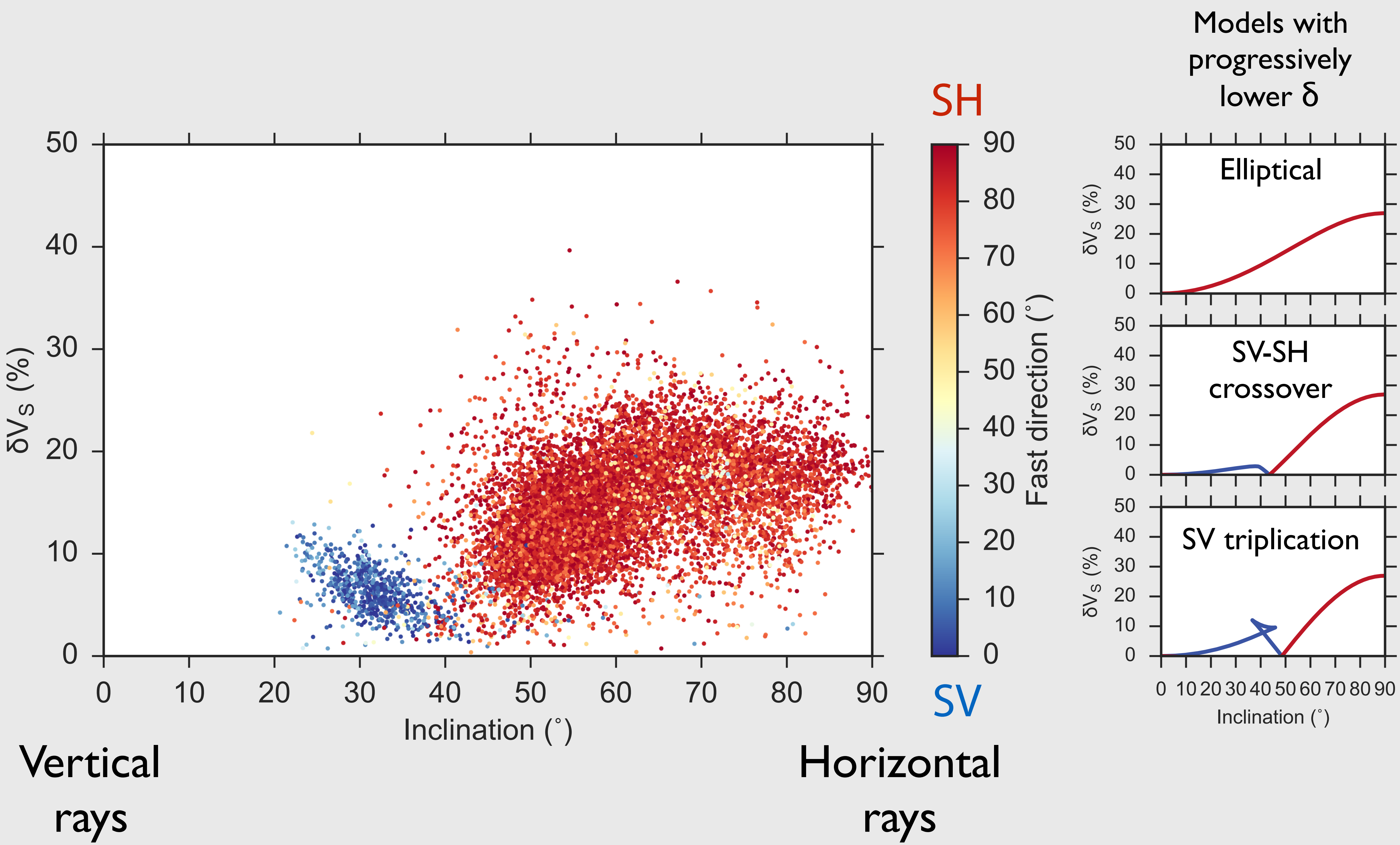


Shear-wave Splitting Results and Modelled Thomsen Parameters



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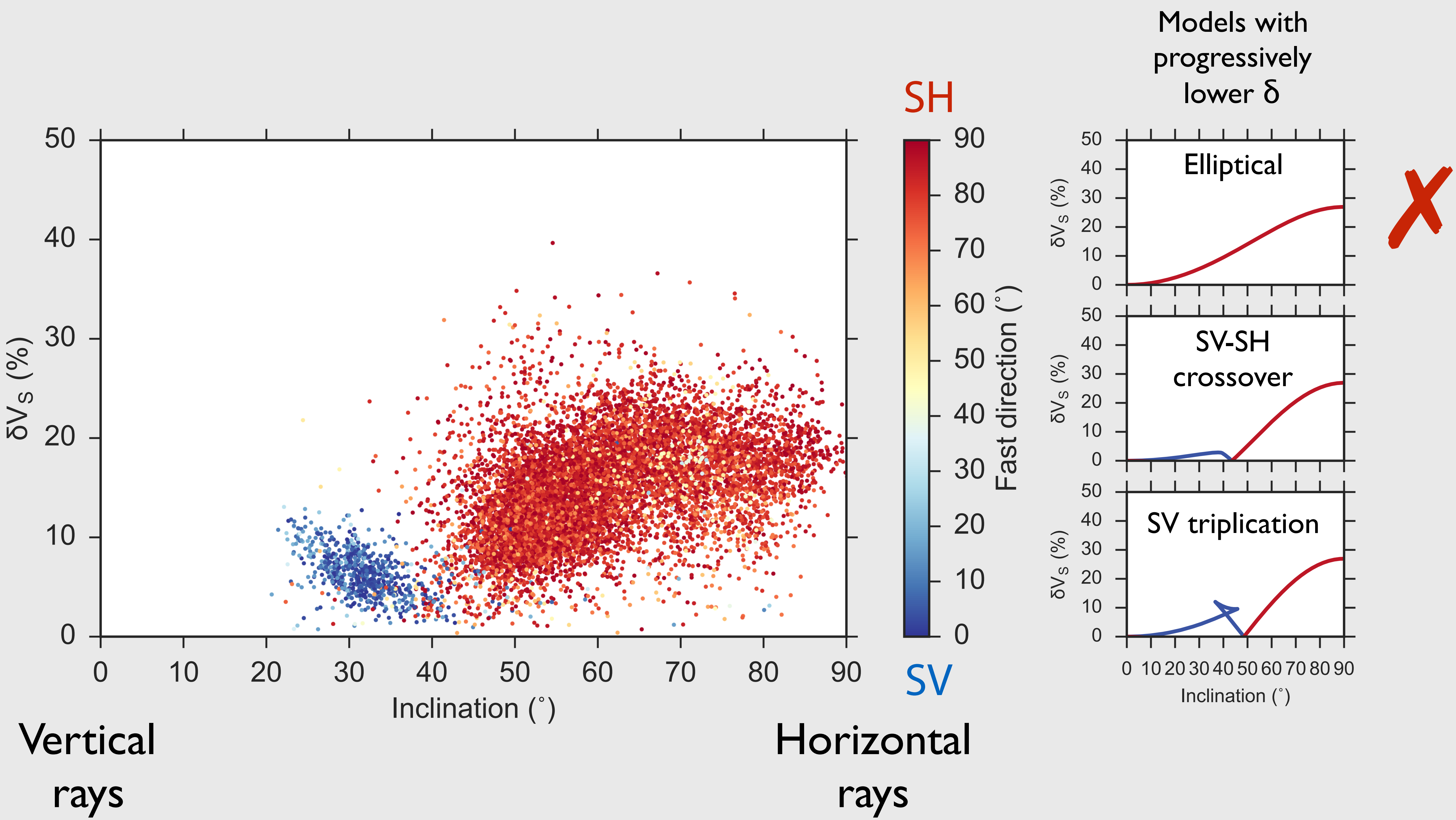

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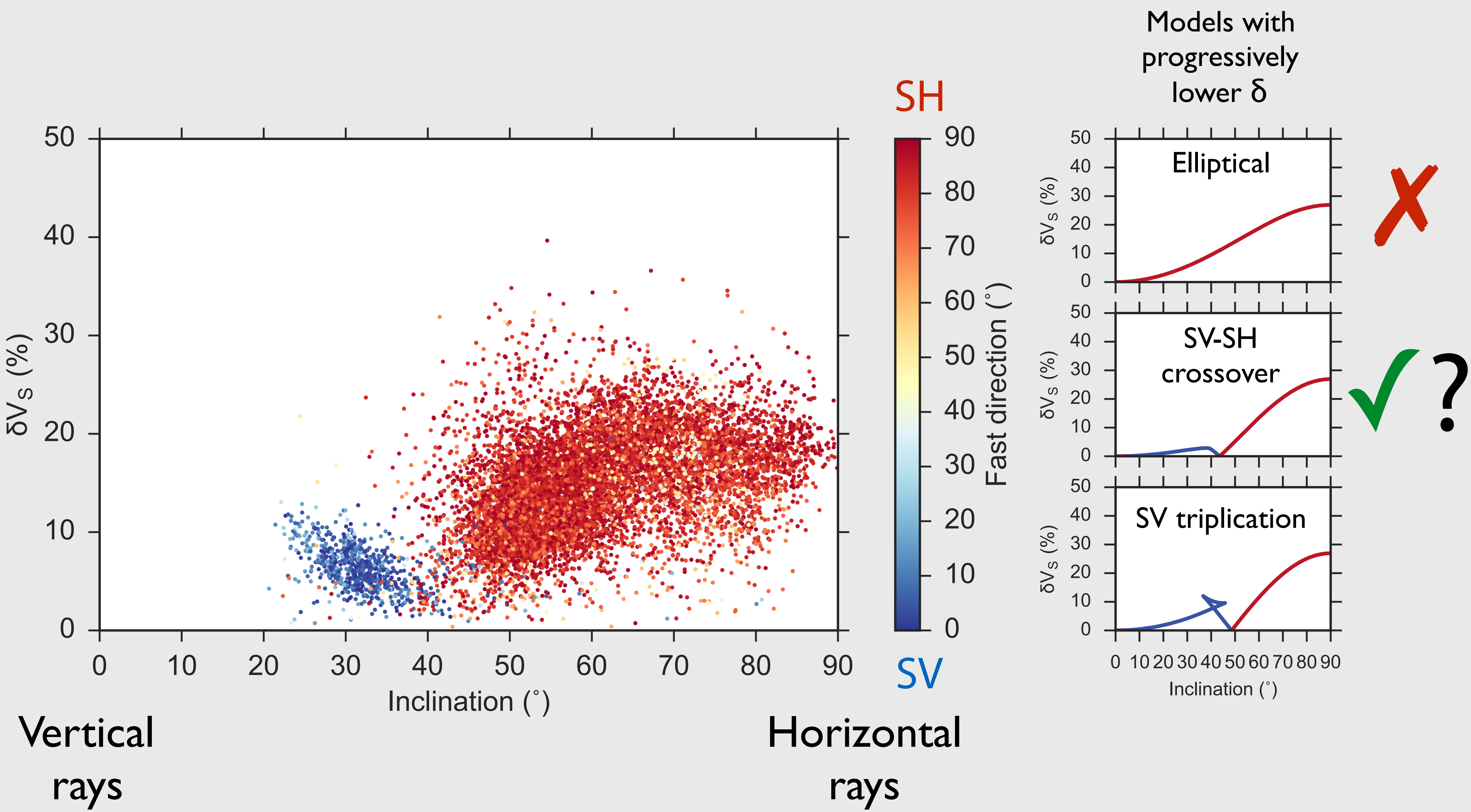

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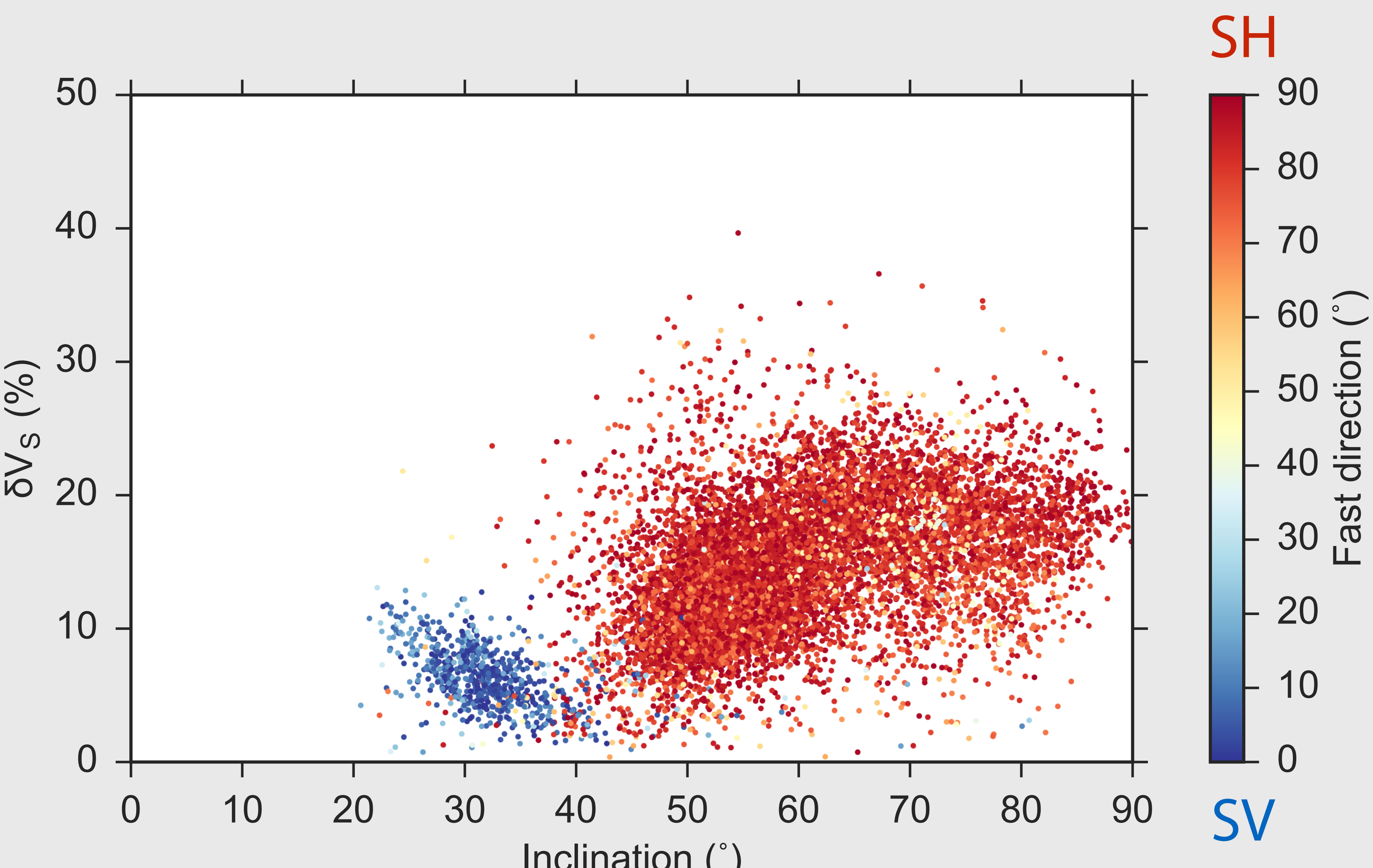
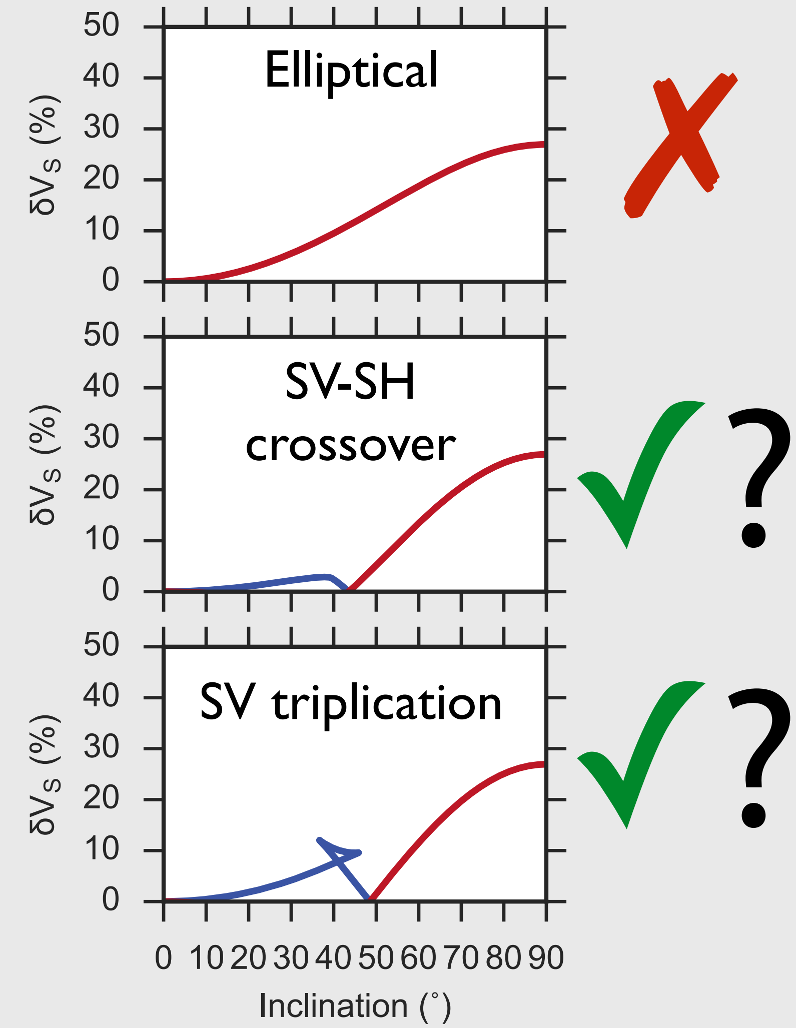


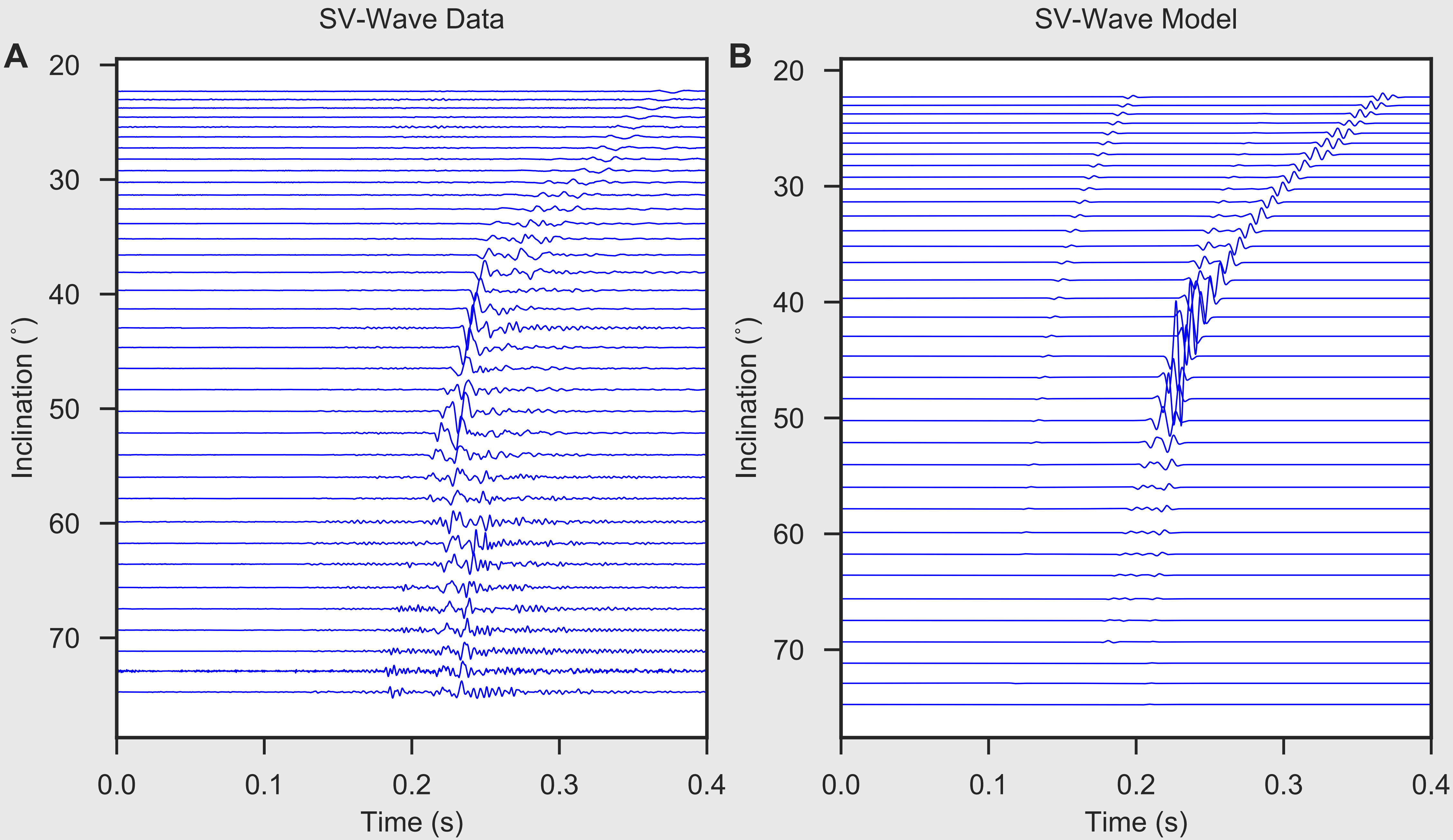
Models with progressively lower δ



Vertical rays

Horizontal rays

SV Synthetics
Maslov asymptotic theory



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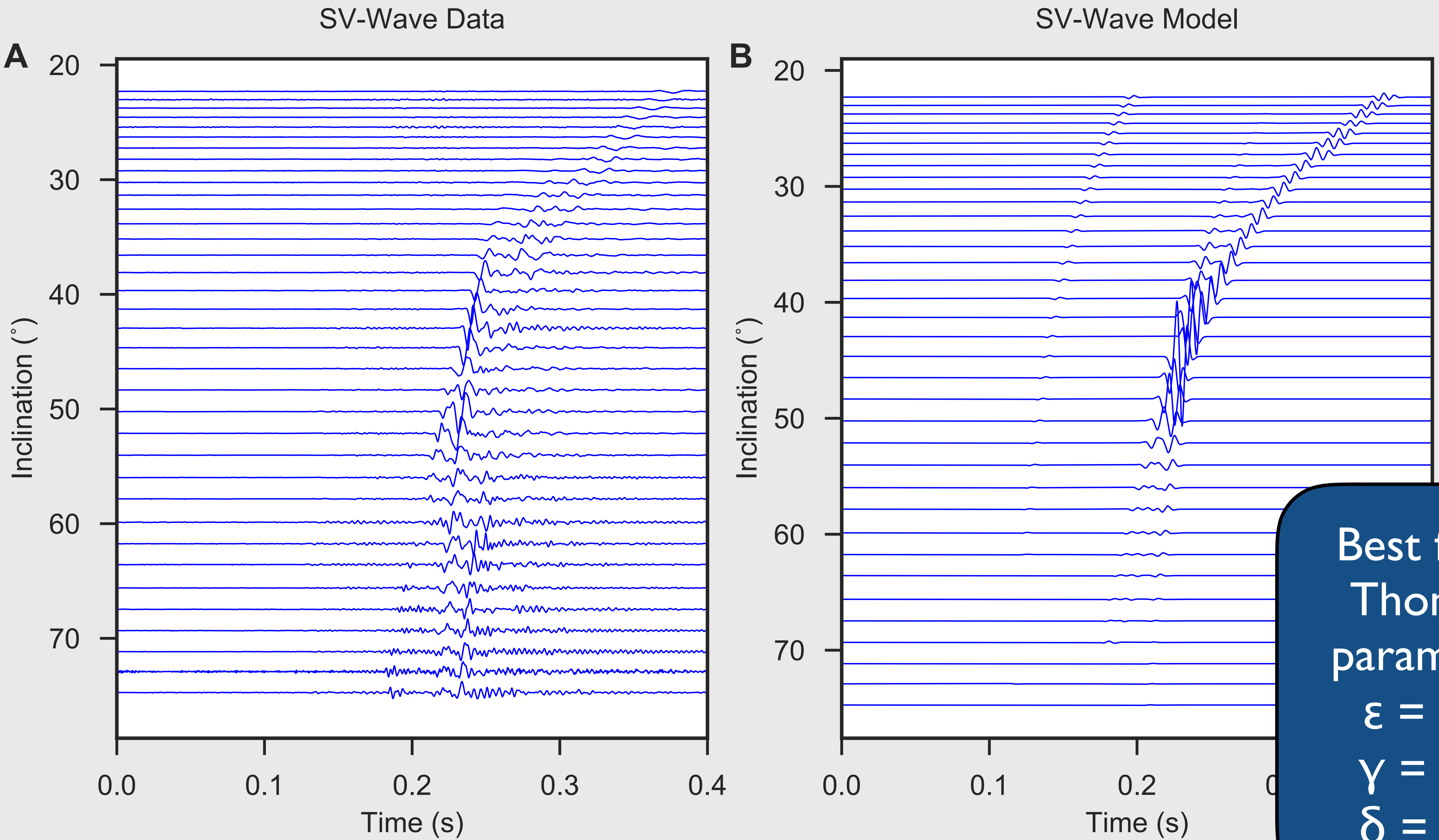

Best fitting Thomsen parameters
ε = 0.33
γ = 0.46
δ = 0.01

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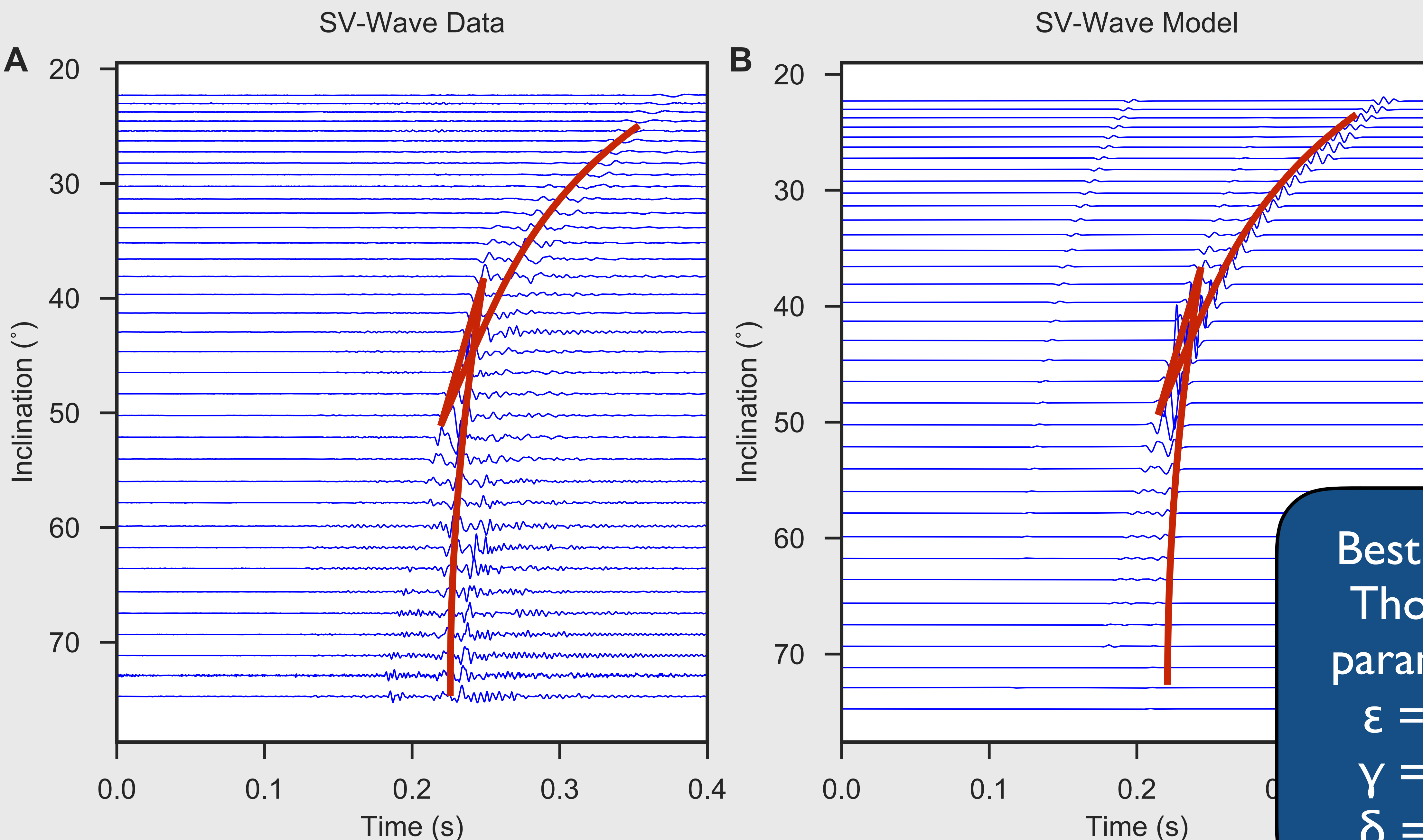

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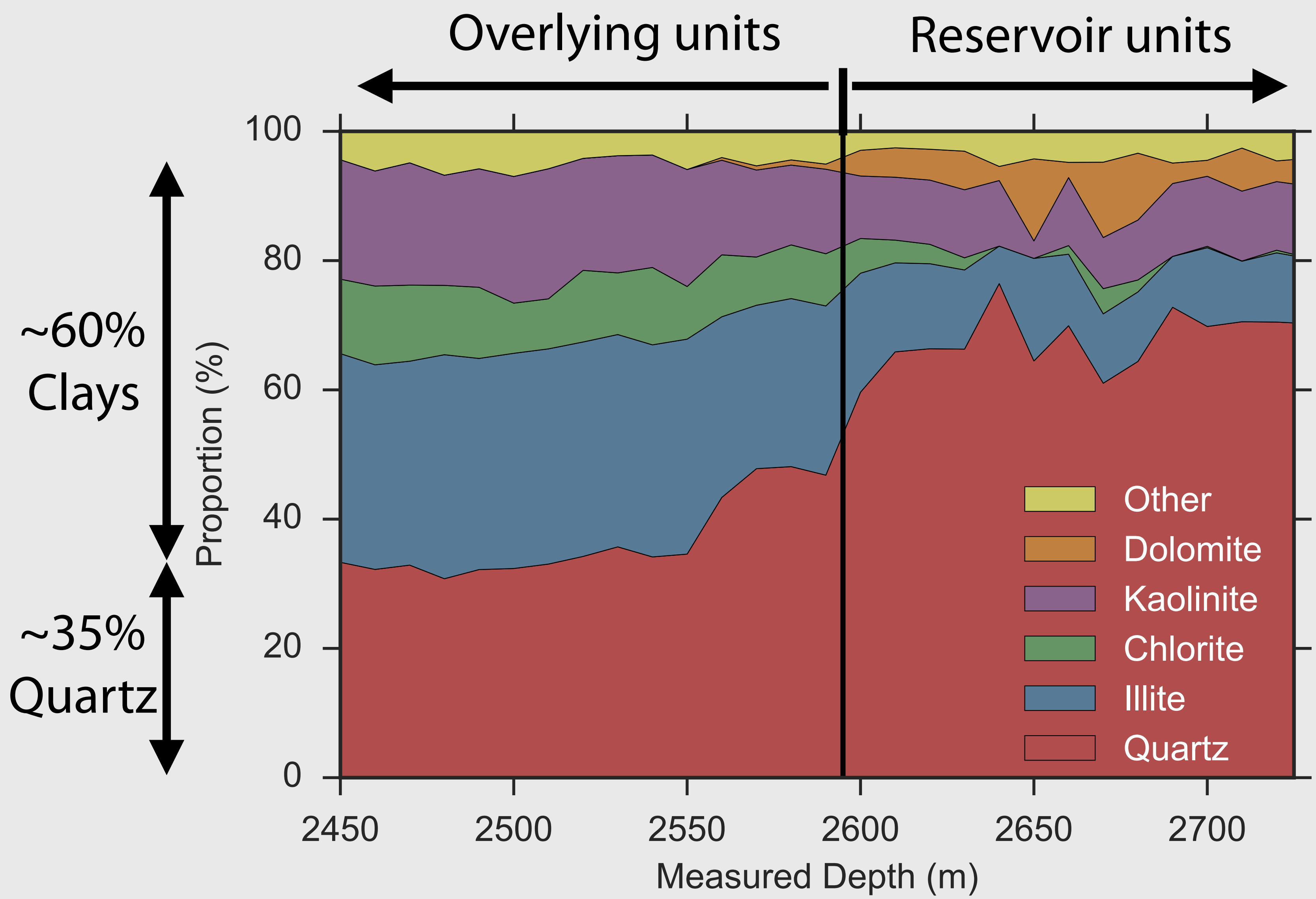
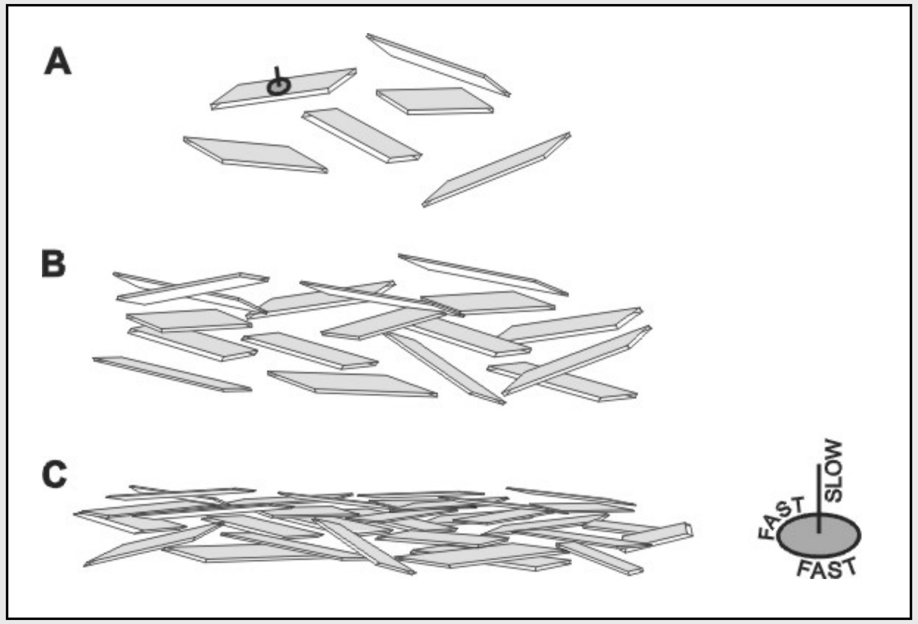
Sources of anisotropy: Mineralogy





- Most geophones are in the overlying clay rich layers
- Preferred alignment of clay minerals can produce anisotropy

Anisotropy due to clay platelet alignment

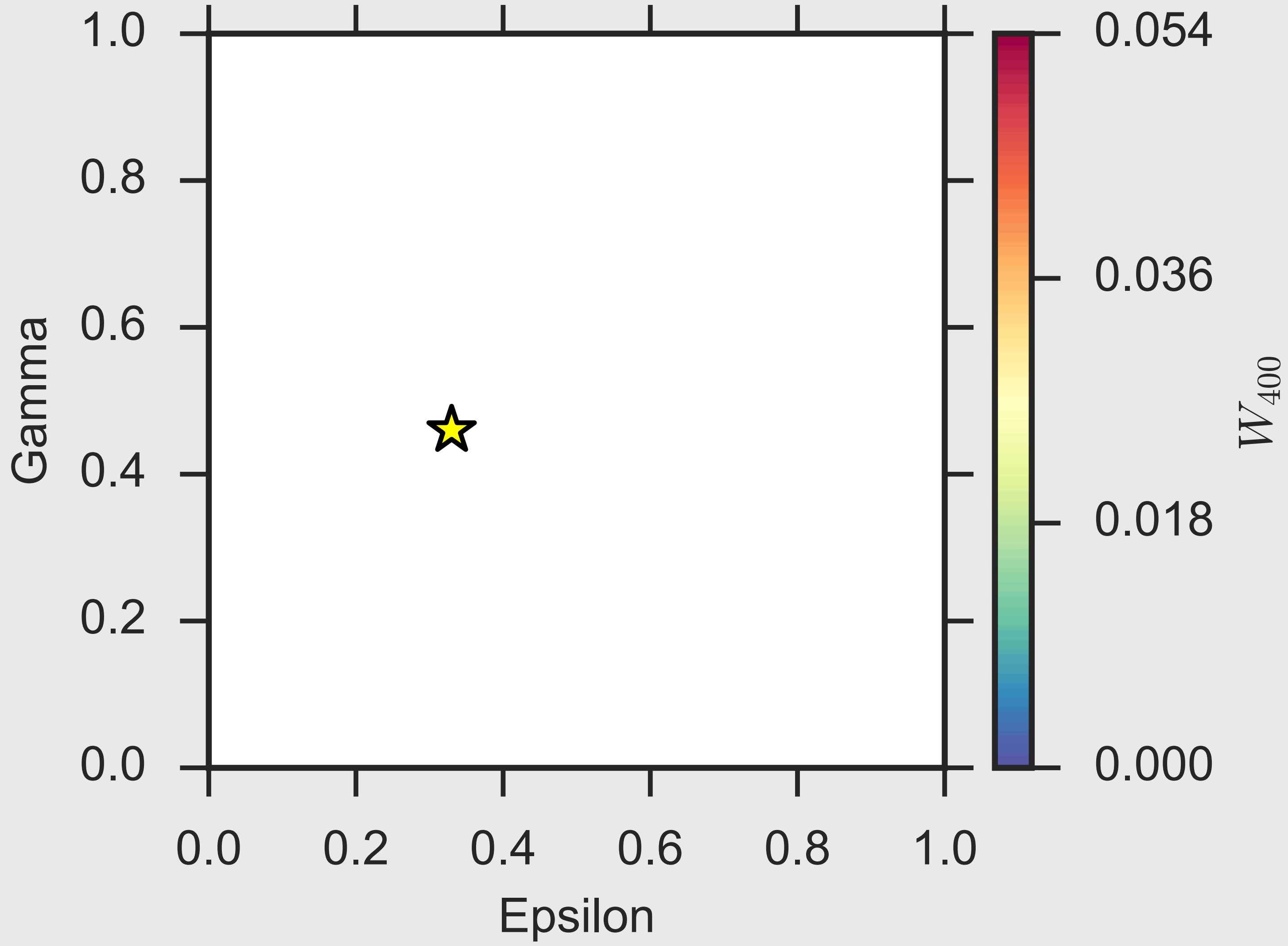
- Theoretical model of Sayers (2005)
- ODF described by two coefficients: W_{200} (contours) and W_{400} (colour)
- Assumptions:
  - VTI rock and TI clay platelets
  - Quartz randomly oriented (isotropic)

Composition

60% clay: 60% illite, 13% chlorite, 27% kaolinite

40% quartz

(Katahara, 1996)



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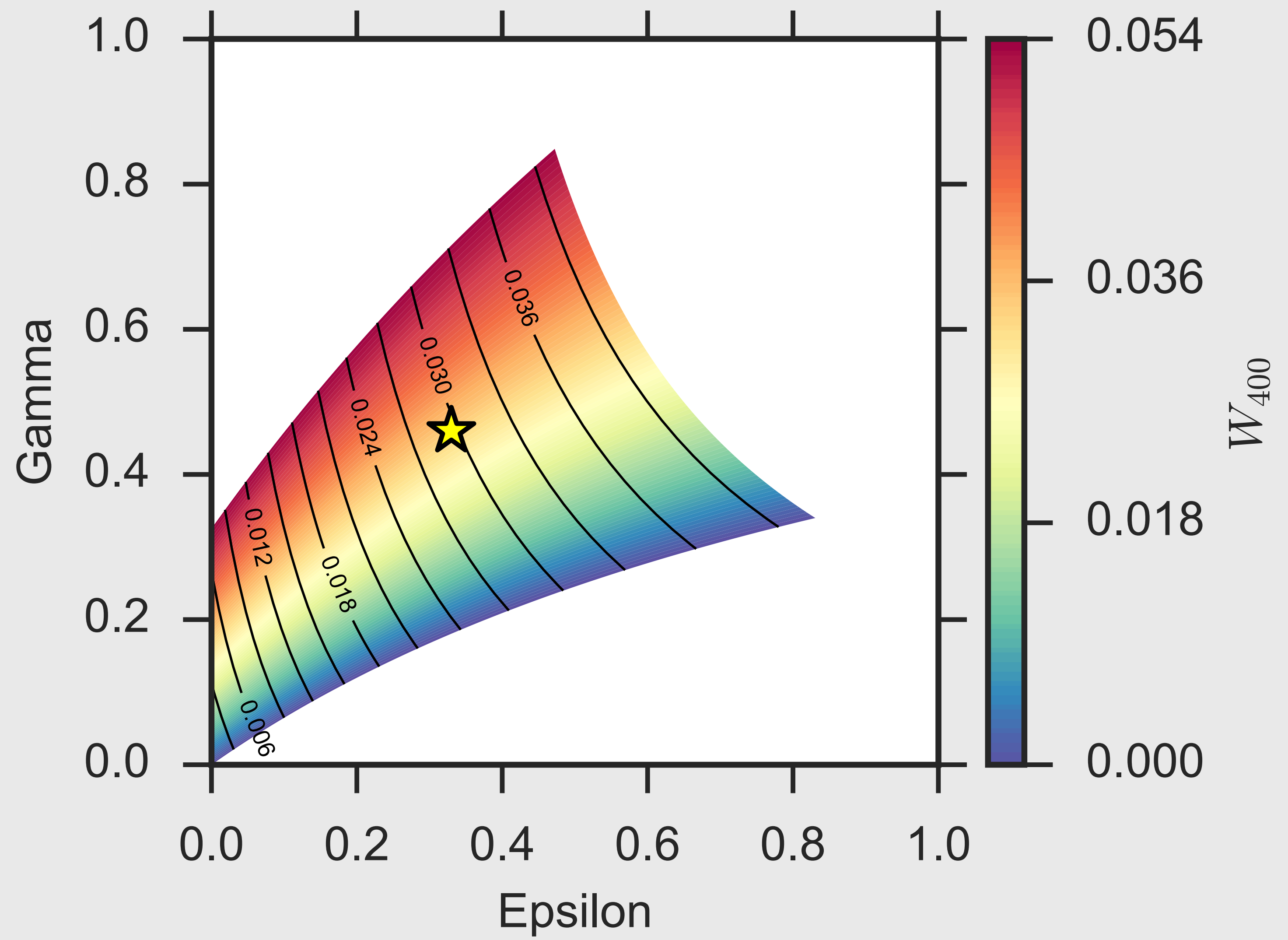

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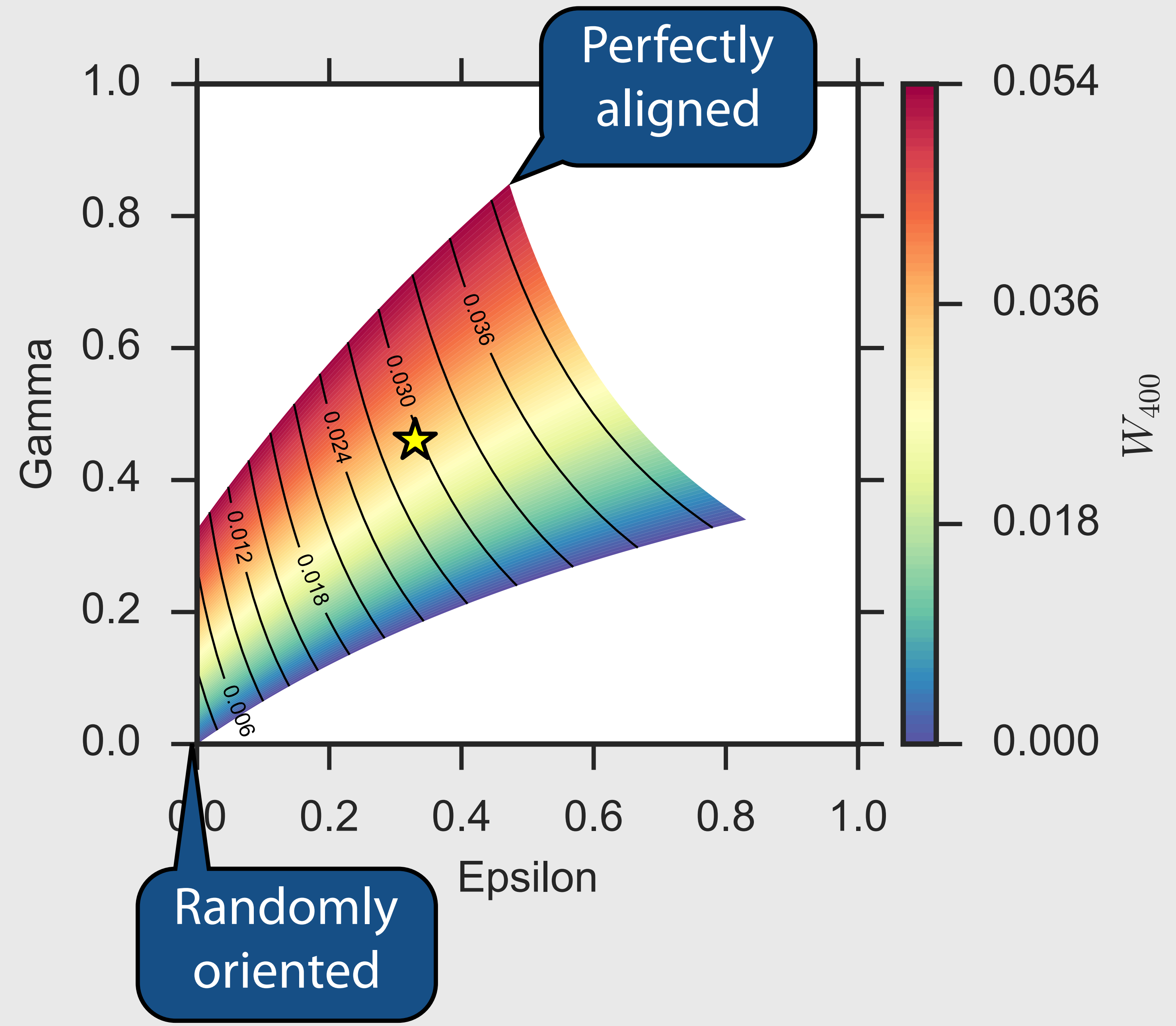

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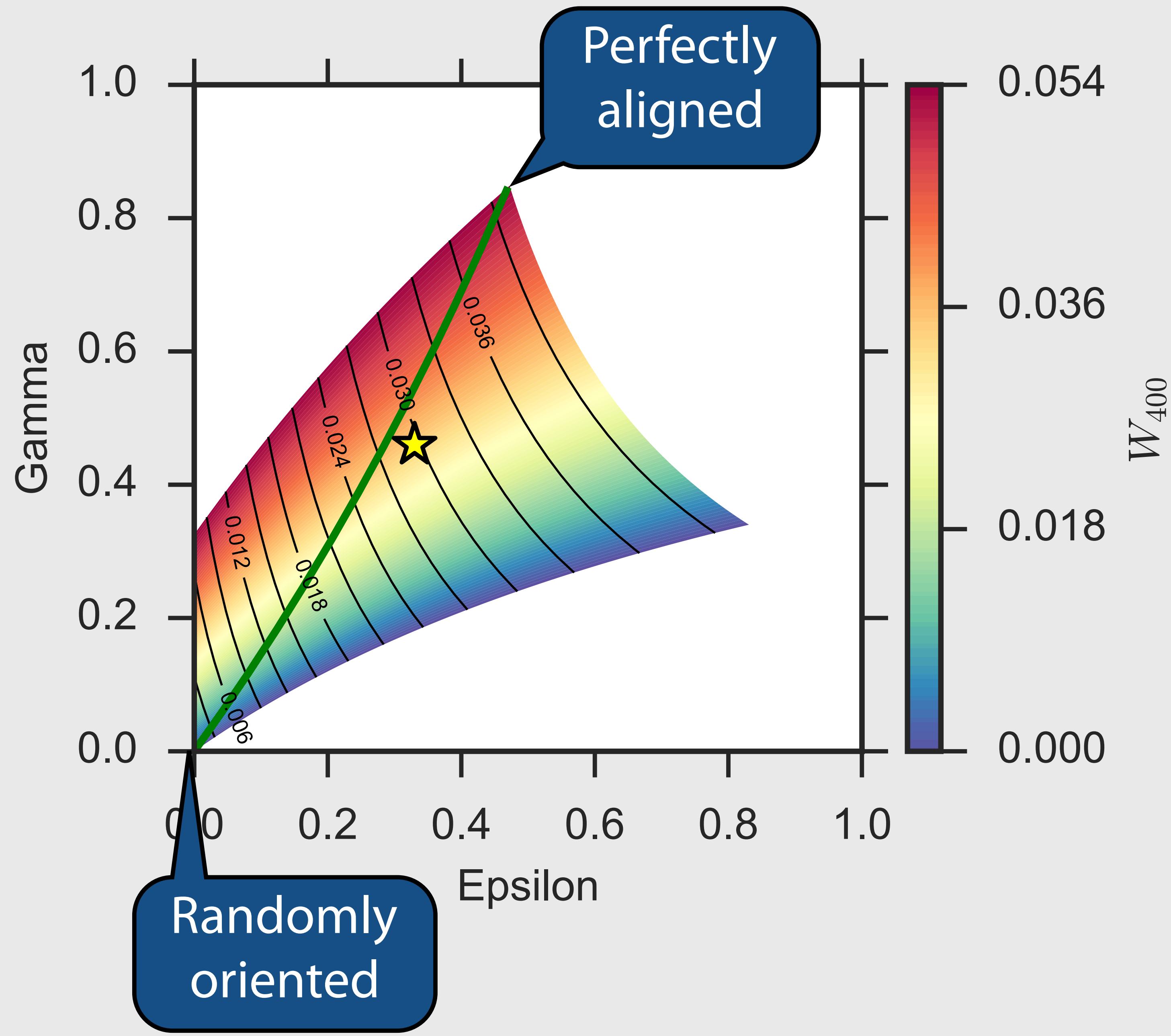

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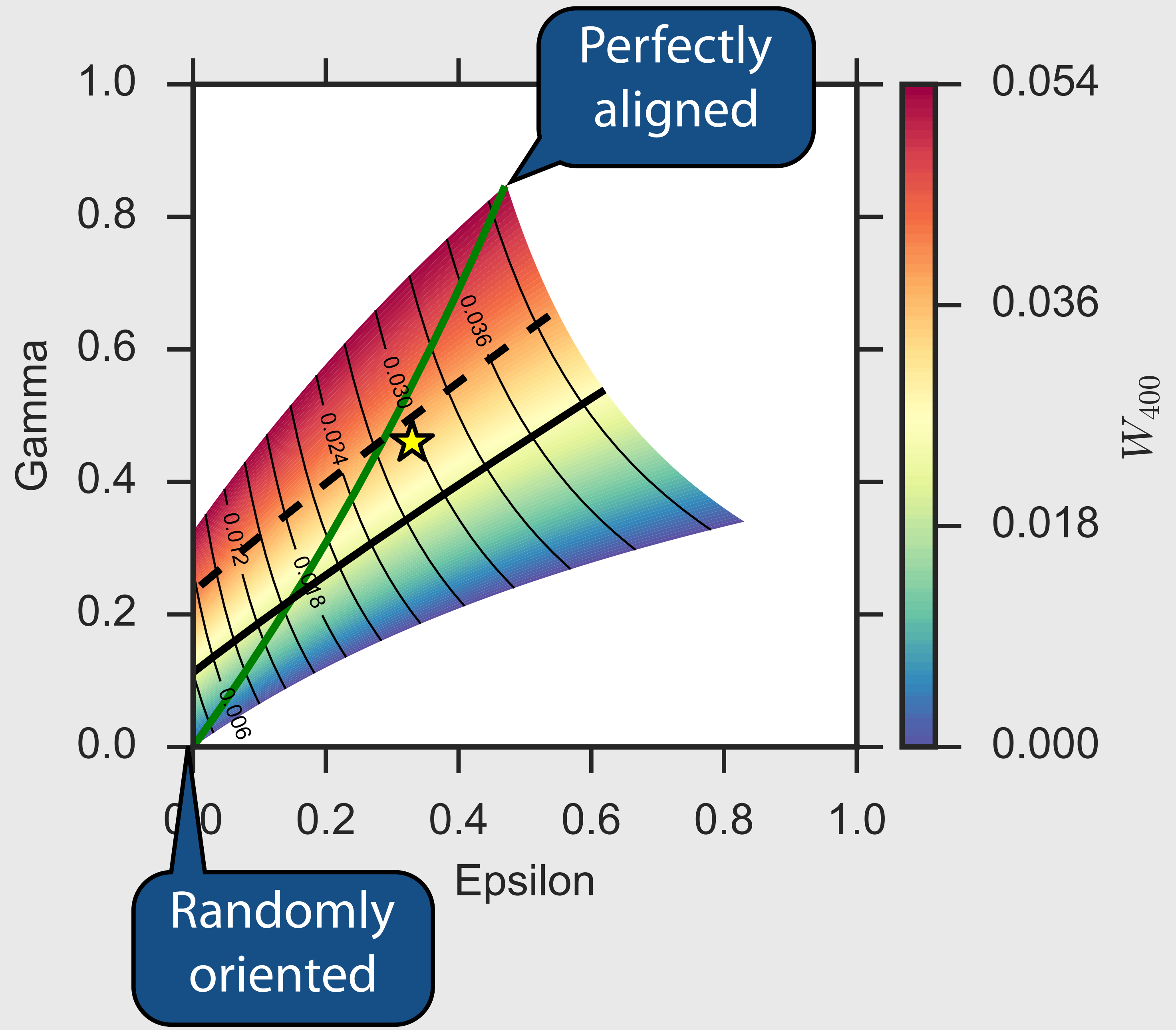

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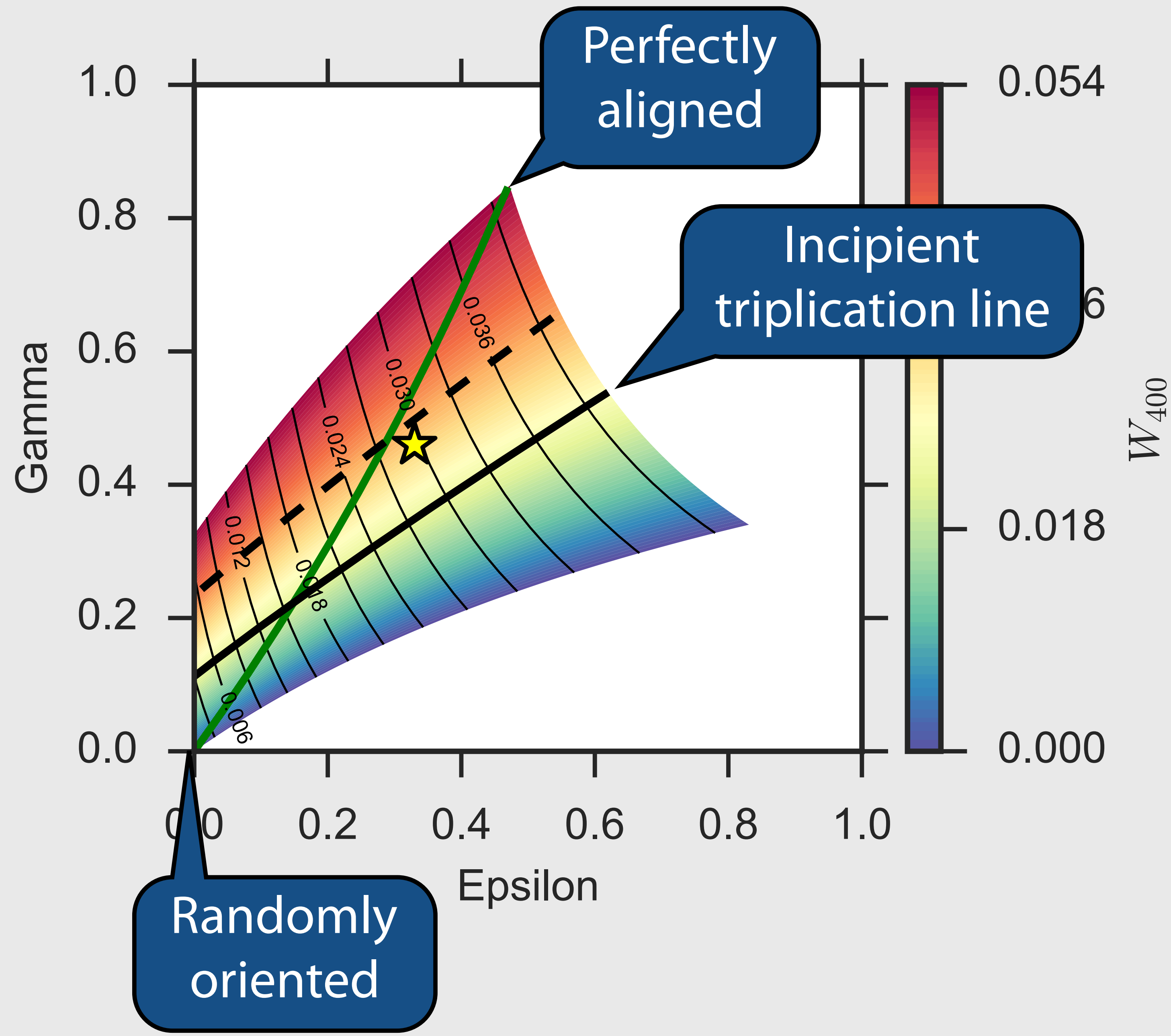
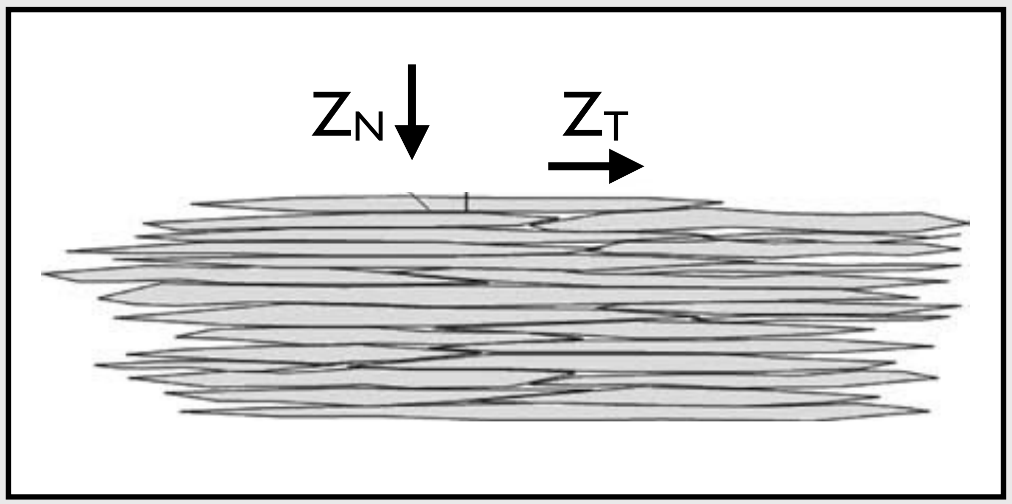
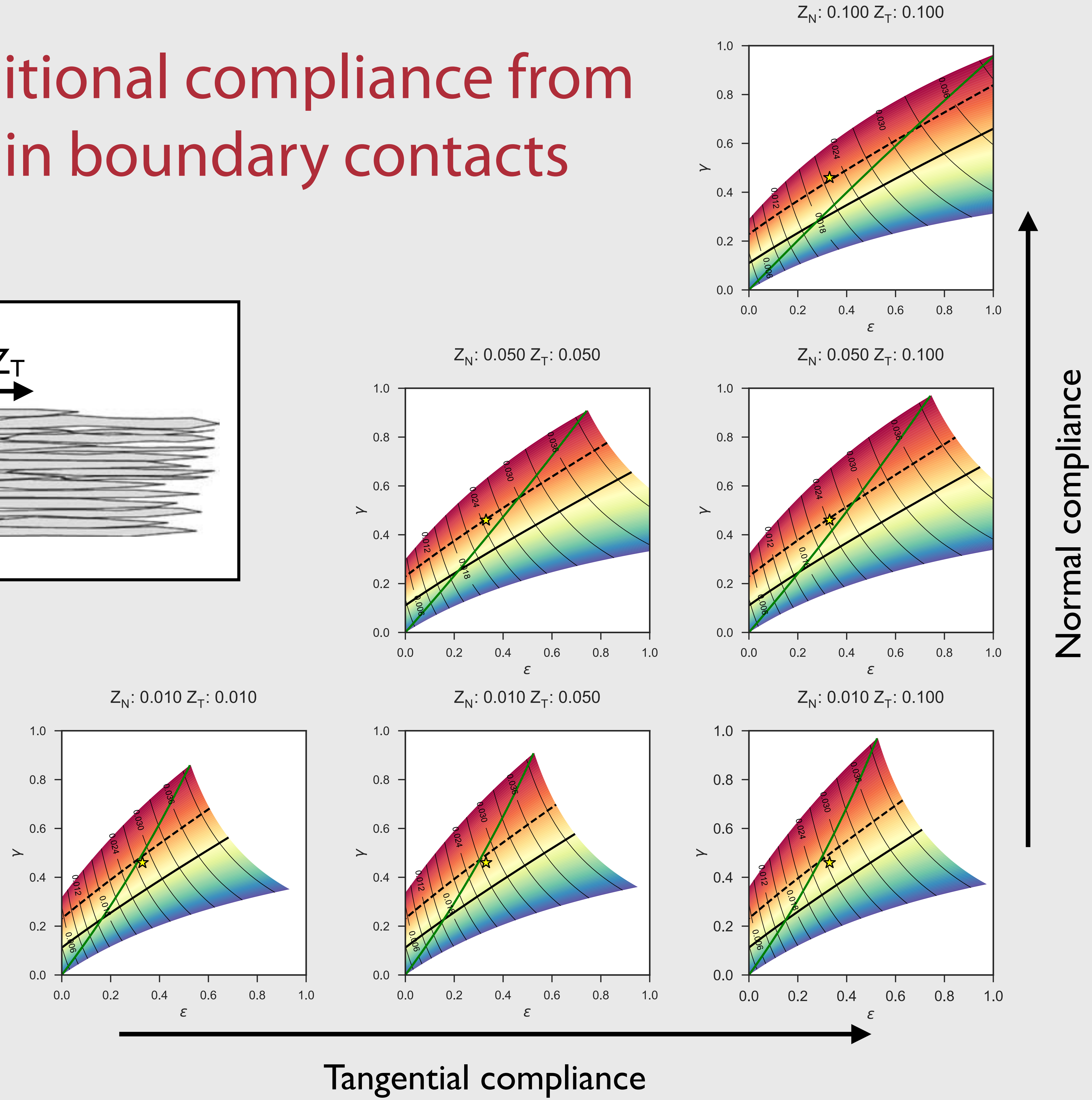


Effect of additional compliance from cracks/grain boundary contacts





Grain boundaries must have low normal compliance

Conclusions

- Estimated SWS from microseismic events in a shale reservoir and interpreted anisotropy in terms of fabric and fractures
- Strong VTI anisotropy with evidence for:
  - Overprint of NE striking fracture induced anisotropy
  - SH-SV wavefront crossover
  - SV wavefront folding (triplication)
- Aligned phyllosilicates can explain magnitude of anisotropy
- Horizontal micro-cracks or grain boundaries must have low normal compliance
- Future work: obtain a sample of shale to better quantify mineralogy and texture

Acknowledgments

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