Understanding the role of fractures in hydraulic stimulation from anisotropic attenuation measurements of microseismic waveforms

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Summary

- Attenuation is anisotropic and sensitive to fracture properties
- An increase in anisotropic attenuation was measured during hydraulic fracturing at Cotton Valley
- Interpreted as an increase in fracture density
- We will look at the link between attenuation and shear-wave splitting

Cotton Valley Dataset

We used data from the Carthage Cotton Valley hydraulic injection experiment in East Texas - a widely studied dataset, and hence an excellent example for developing a novel technique (Rutledge et al., 2004 and Wuestefeld et al., 2011). Rutledge et al. (2004) located 888 events (Fig. 1), and calculated moment tensors.

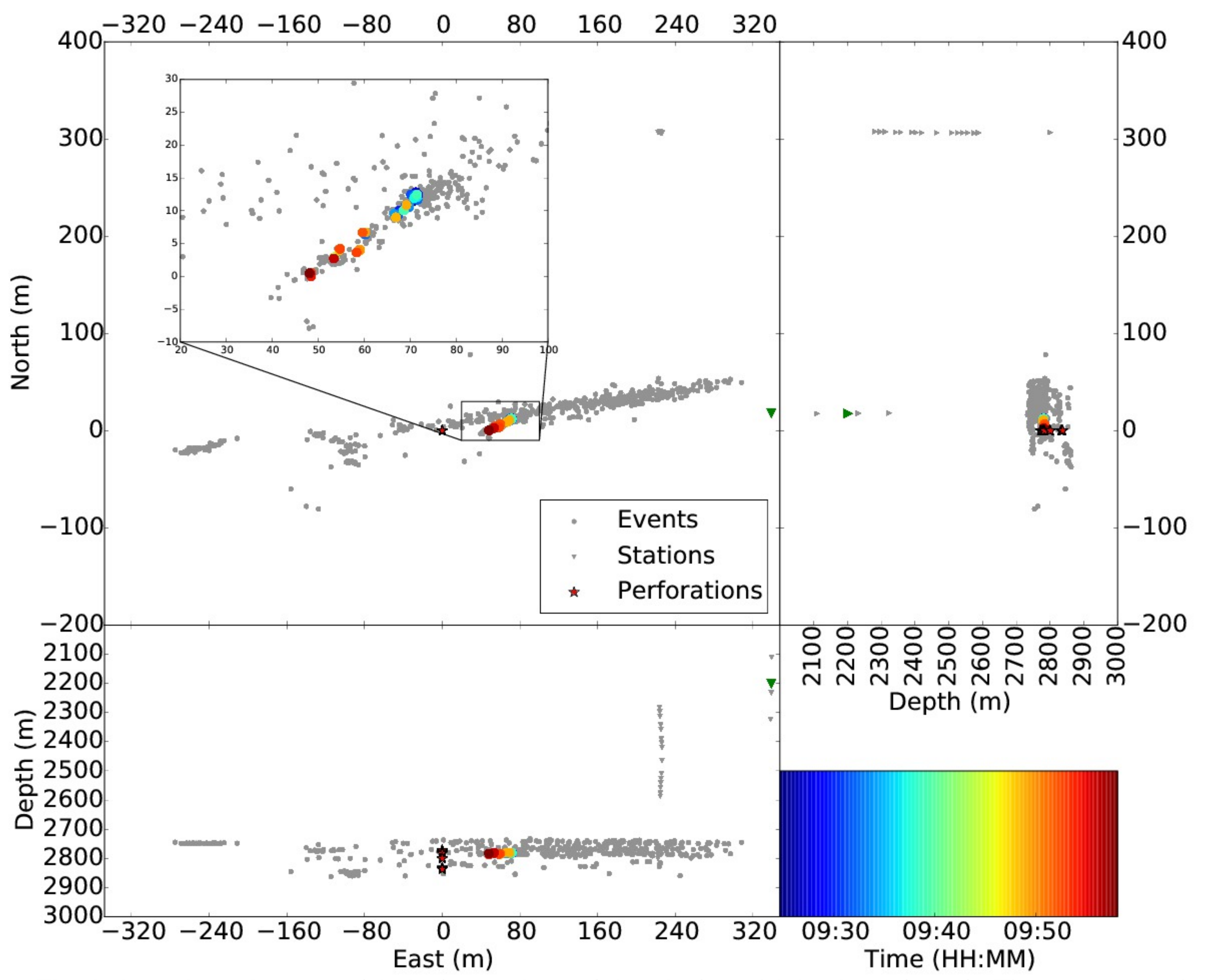

Fig 1. Location of events (circles), receivers (triangles) and injections (stars). The events and receivers used in this study (coloured).

Log-Spectral-Ratio Method

Δt* is the differential attenuation and travel time between two waveforms.

$$ln(\frac{A_1}{A_2}) = ln\frac{A_{s1}G}{A_{s2}G} + f\frac{\Delta t^*}{2\pi}$$

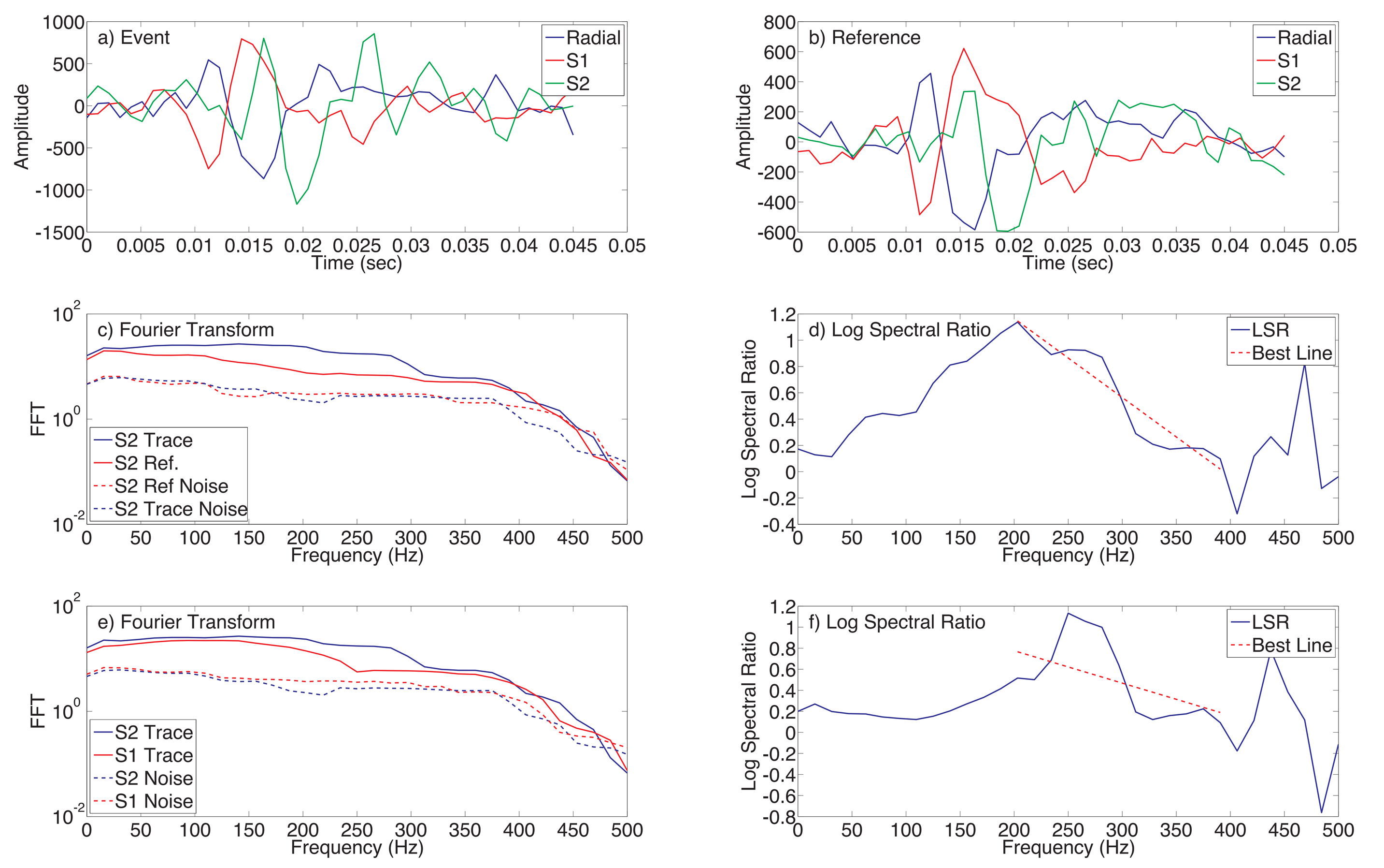

Fig 2. Windows, FFTs and LSR for our waveforms. We use the clustering approach of Kelly et al., (2011) and the attenuation anisotropy approach of Carter and Kendall (2006).

Squirt Flow Modelling

- Is the most likely cause of attenuation (Toksoz and Johnston, 1981)
- Used the model by Chapman (2002)
- Most sensitive to fracture density (Fig. 3) for rock, fluid and fracture properties similar to Cotton Valley
- Attenuation was only sensitive to the S2 (the slow wave polarised perpendicular to the fractures)

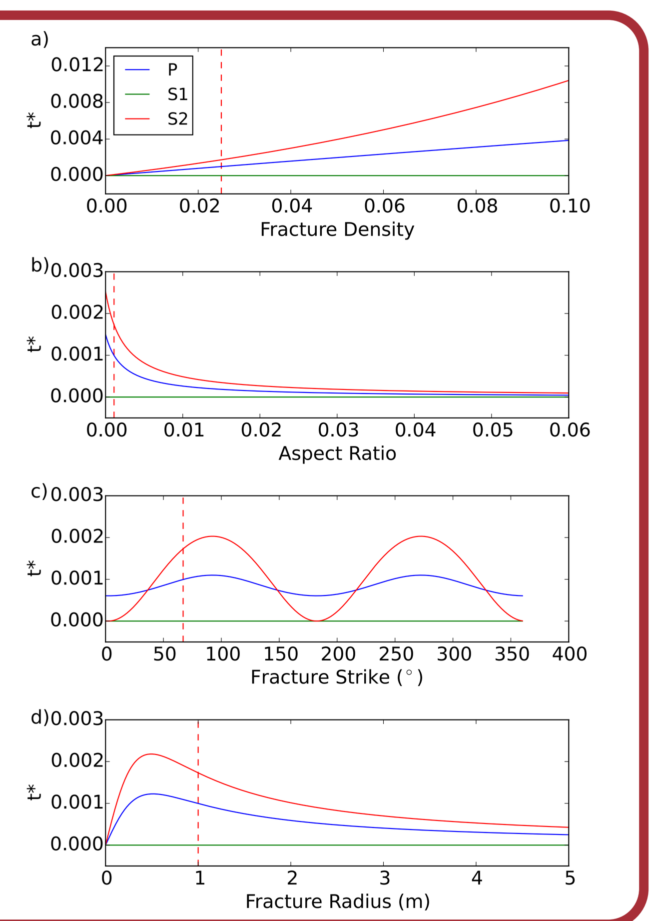

Fig 3. Changes in t due to changes in fracture properties according to a squirt flow model (Chapman 2003)*

Shear-wave splitting

Cotton Valley has velocity anisotropy shown by shear-wave splitting measurements of Wuestefeld et al. (2011). For the injection period, the anisotropy increased with time, which was interpreted, using the inversion approach of Verdon et al. (2009), as an increase in fracture density (Fig. 4). The fracture strike did not change with time.

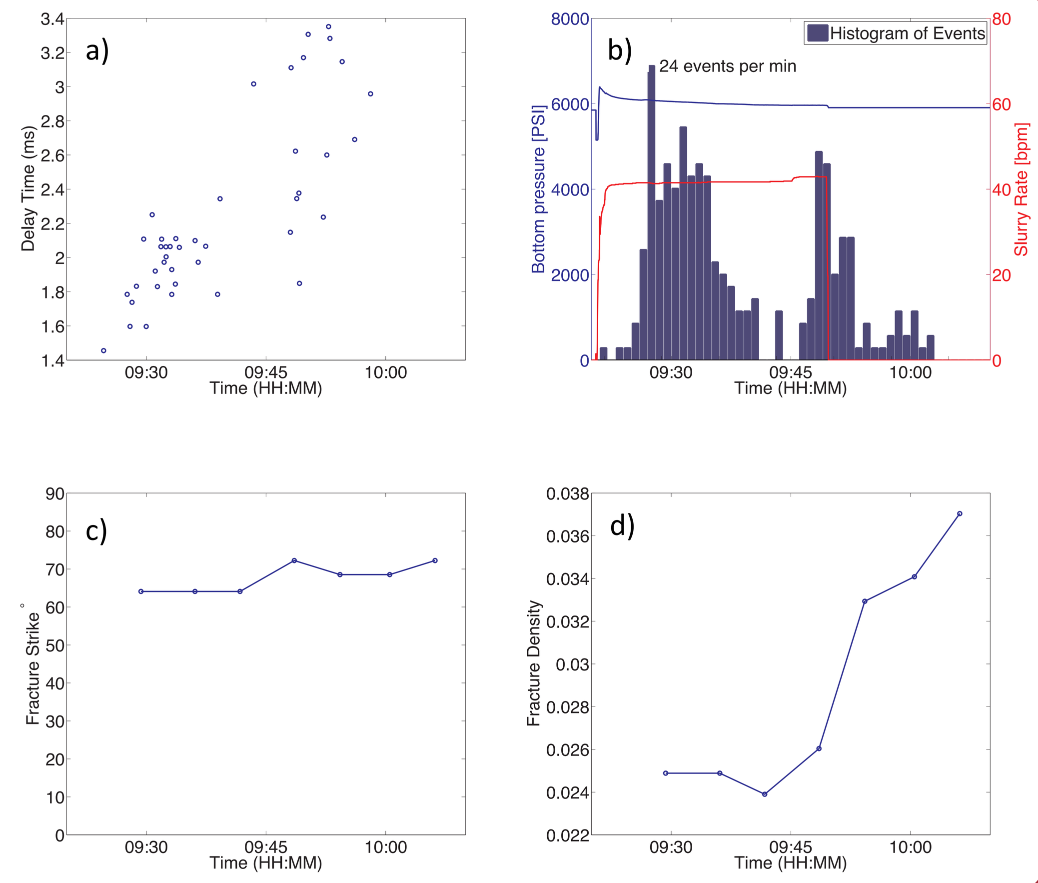

Fig 4. (a) Delay time from shear-wave splitting measurements increasing with time. (b) Histogram of the number of events along with bottom pressure and slurry rate of the injection. (c) Fracture strike and (d) fracture density derived from the inversion of splitting measurements. Fracture density shows an increase over the time interval.

Attenuation Anisotropy Results

- Attenuation measurements from a cluster of events (Fig. 5)
- Uses one event as a reference, and Δt* between each event is measured for both S1 and S2
- Attenuation increases for S2, but not for S1
- Much larger than any travel time effects

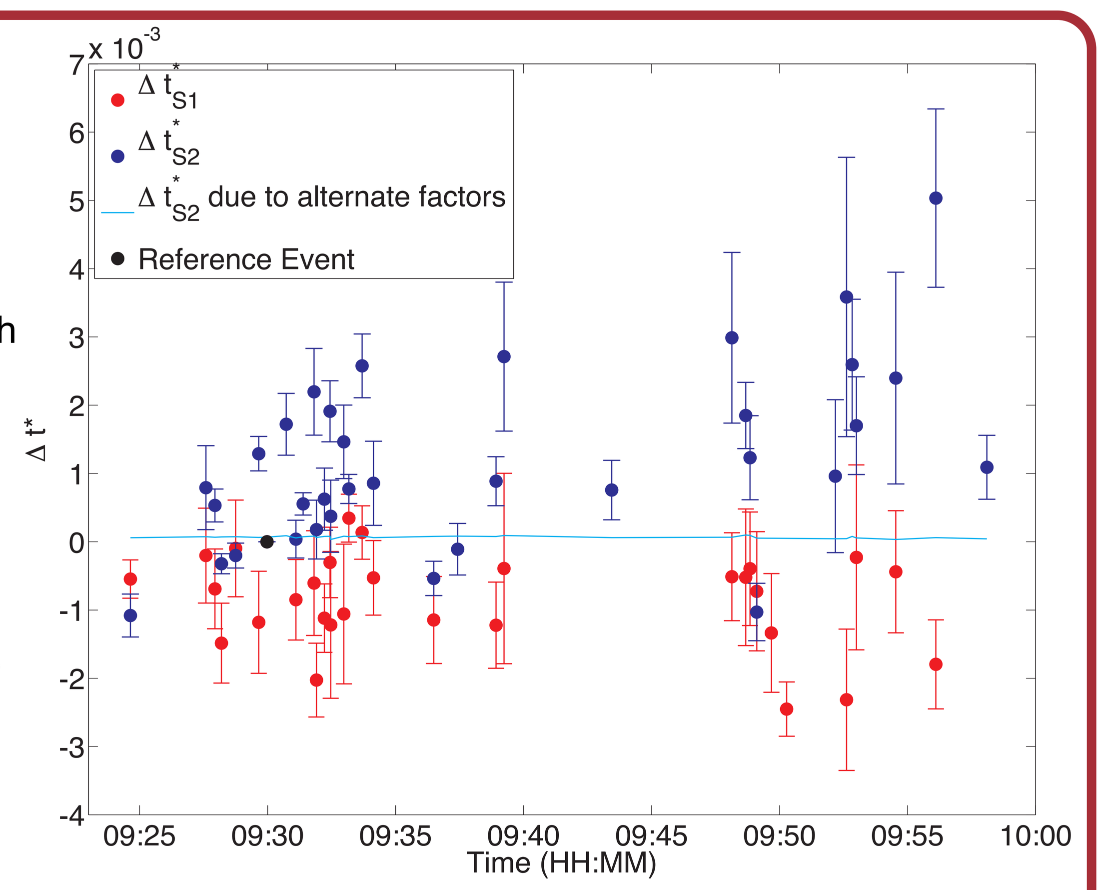

Fig 5. Increase in Δt of 6 x 10^{-3} sec with time for the S2 phase compared to much smaller changes in the S1 phase. Any change in Δt* not due to attenuation (in green), is an order of magnitude smaller than the measurements.*

- S1 used as a reference event. and compared to S2 for each event (Fig. 6)
- Anisotropy attenuation increases with time
- Less change than the previous measurement (Fig. ??)

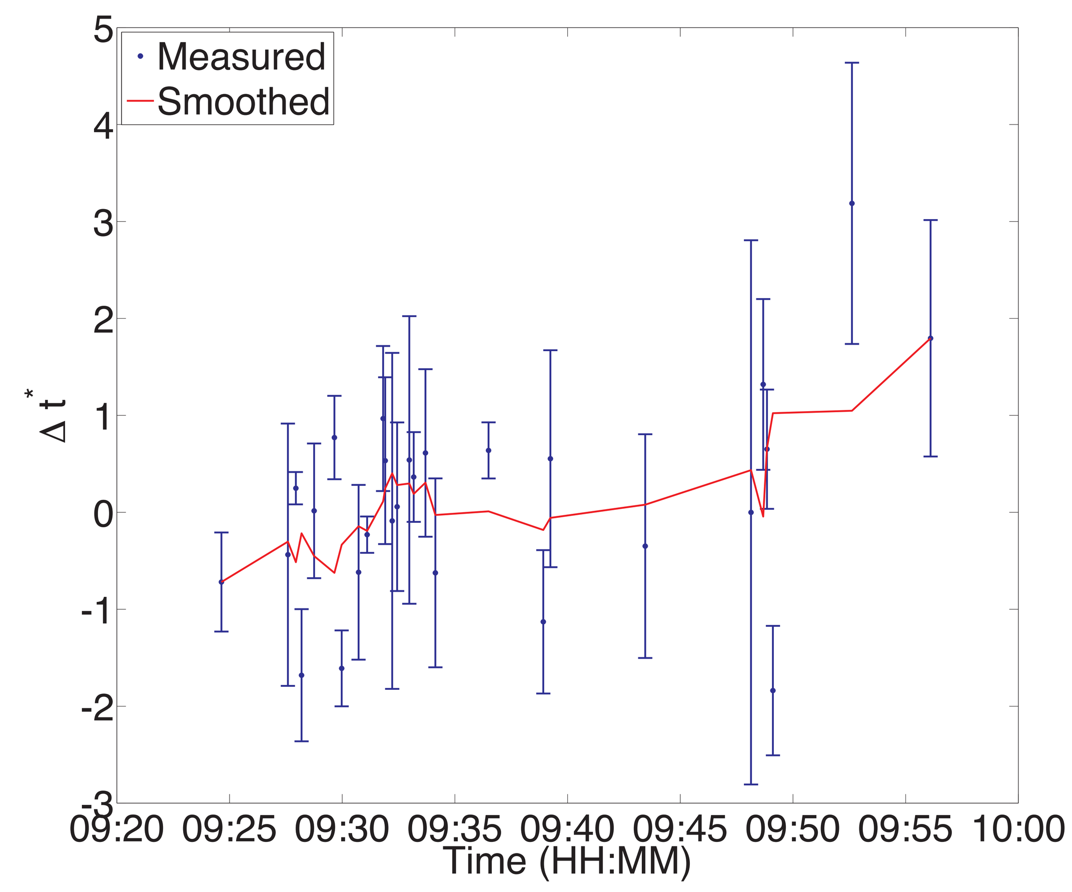

Fig 6. Comparing the S2 phase to the S1 phase using the log-spectral-ratio leads to an increase in Δt of 4 x 10^{-3} sec over the same time period.*

- Inverting the S2 attenuation measurements from Fig. 5 for fracture density using the model of Chapman (2002)
- Increase in fracture density with time
- Measured a larger increase than from shear wave splitting

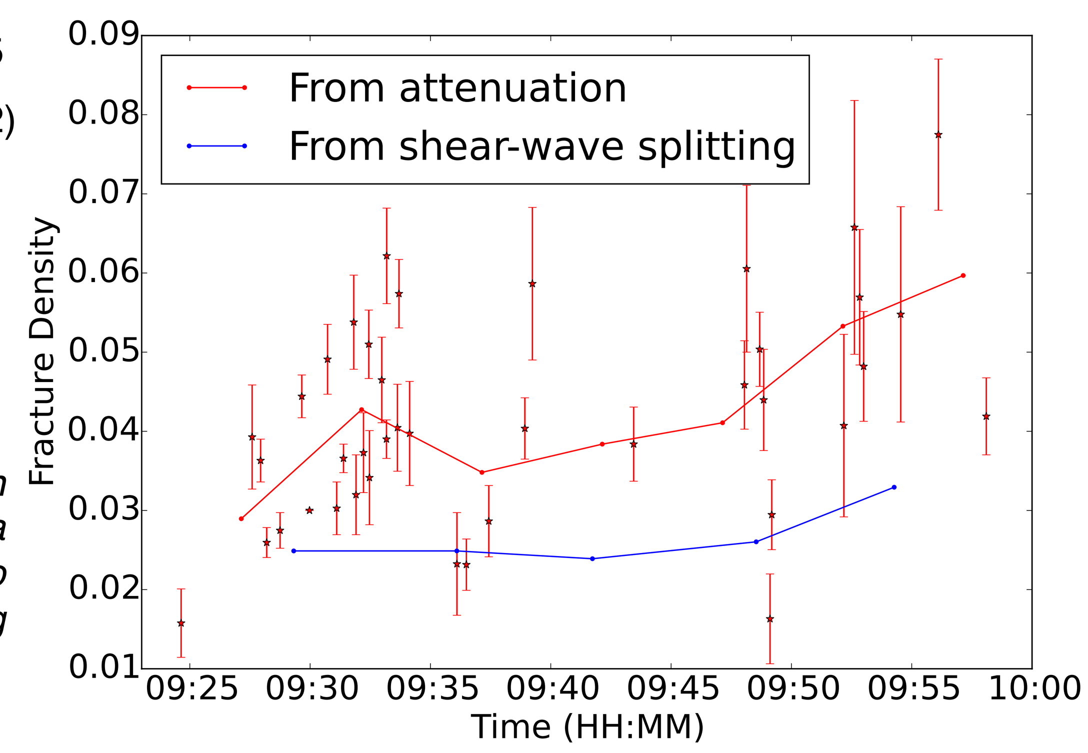

Fig 7. The predicted change in fracture density (red) given an initial model for the reference event. This shows a significant increase in fracture density from 0.015 up to 0.08. A similar trend is derived from shear-wave splitting measurements (blue), with a smaller gradient.

Conclusions

- Attenuation in S2 is sensitive to fracture density
- Increased attenuation has been measured, coinciding with injection and increased in shear-wave splitting delay time
- This can be interpreted as an increase in fracture density.

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