Grand Challenges in Earthquake Science

David D. Jackson

Department of Earth, Planetary, and Space Sciences, UCLA, Los Angeles, CA 90095

Abstract

After two decades of productive SCEC research, important basic questions remain. After another two decades, they may yet remain. Or, some outstanding earthquake research center might plan long-term experiments to address the questions head-on. Satisfactory answers would require specific formulation, a formal testing regime, a good null hypothesis, and coordinated teamwork. The list below may be too ambitious, but a few selected challenges might fall in a decade. Retrospective tests would be a good start.

1. Is California overdue for a magnitude 7 or larger earthquake? First define “due,” then “overdue,” and set a time window. “Due” involves seismic, geodetic, geologic, and historical data, as employed by UCERF. Test data: seismically observed earthquakes only. Null hypothesis: debts are current, or even overpaid.
2. Does static Coulomb stress from past earthquakes help forecast mainshocks better than statistical models can? Same for aftershocks, once a main shock has occurred?
3. Can “physics-based models” involving Coulomb stress and rate-state friction on prescribed faults forecast real earthquakes, or do statistical clustering models better capture basic earthquake physics?
4. What stops earthquake rupture? Ideas could be tested if resulting “conditional stopping probabilities” can be mapped. Rupture from moderate earthquakes may provide significant data.
5. Is the “b-value” a stress indicator? Are spatial variations indicative of future large earthquake probabilities?
6. Are there spatial and temporal behaviors of small to moderate earthquakes that signal the imminence of larger ones? Do small events gradually concentrate around future epicenters or faults on which big earthquakes will occur?
7. Are the spatial and temporal variations in forecast model parameters intrinsic or extrinsic? Have recent earthquakes modified the regional stress environment significantly or have geology and long past earthquakes set the stage?
8. Do proposed precursory anomalies in electromagnetic, ionospheric, geochemical or other variables signal the imminence of large earthquakes? What is the physical link between such proposed precursors and earthquake generation? Can identified precursors be used individually or collectively to improve earthquake forecasting systemactically?
9. Do small earthquakes trigger “sleeping giants?”

What makes a challenge “grand?” And why choose “earthquake rupture” to explore here?

- informs quake science broadly. segments? magnitudes? RSQSim? jumping? paleo-seis?
- improves forecasts. UCERFn; GEAR1.
- resolves alternate interpretations. residual stress? fault geometry? random?.
- testable within decades using available data. **All ruptures stop somewhere!**
- involves multiple specialties (e.g., seis, geol, geod, stats, engr.). seis, geol, stats.
- requires more thinking than new measurements. needs known faults, seismicity.

Possible Modeling Strategy, 1-D

- Divide source map into small sections (0.1 degree?).
- Use aftershocks to gauge rupture extent.
- Assign “conditional stopping probability” (**CSP**) for each section boundary.
- Use past seismicity, fault geometry, geology, imagination to estimate CSP
  1-D: Applicable only to prescribed faults.
- Already done for UCERF3, RSQSim, other recurrence models.

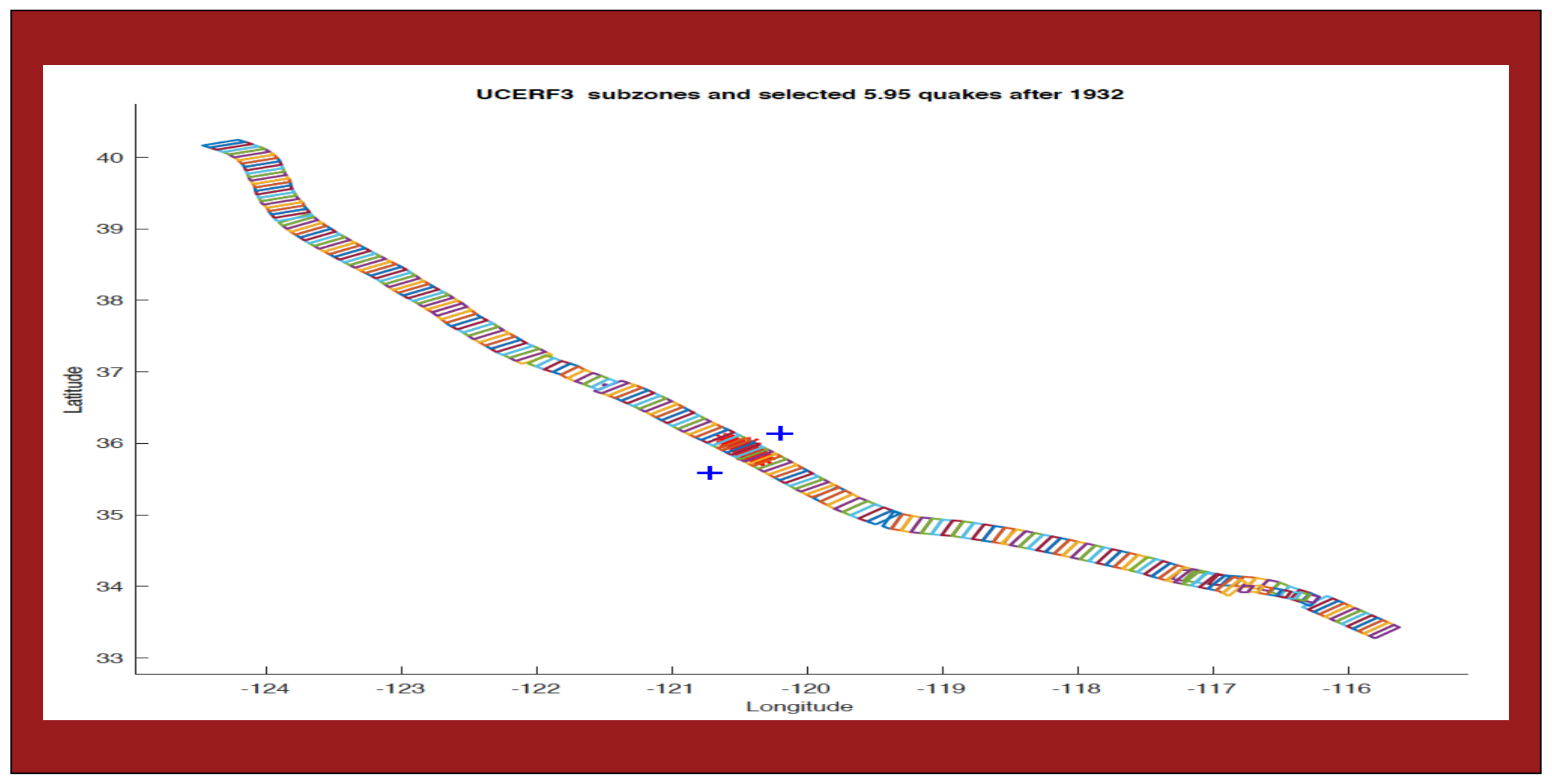

Figure 1: UCERF3 section representation for San Andreas fault; other main faults were represented similarly.

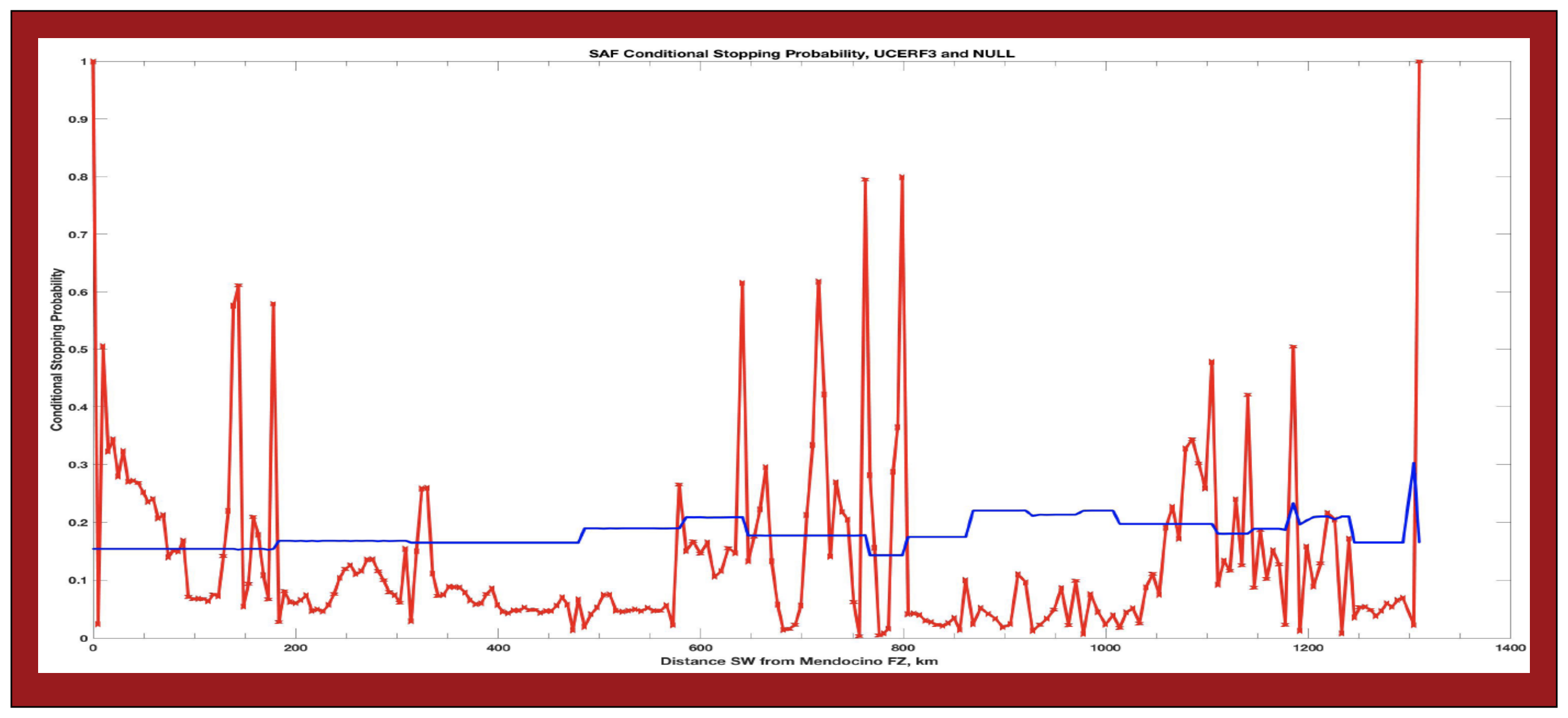

Figure 2: Conditional stopping probability (CSP) for each section boundary in Figure 1, from UCERF3 “Grand Inversion” simulation of thousands of ruptures. The tall spikes should stop most ruptures that reach them. The red curve represents just one hypothesis (UCERF3) for what stops earthquakes. The blue line is my “null hypothesis” with stopping probability dependent only on section length.

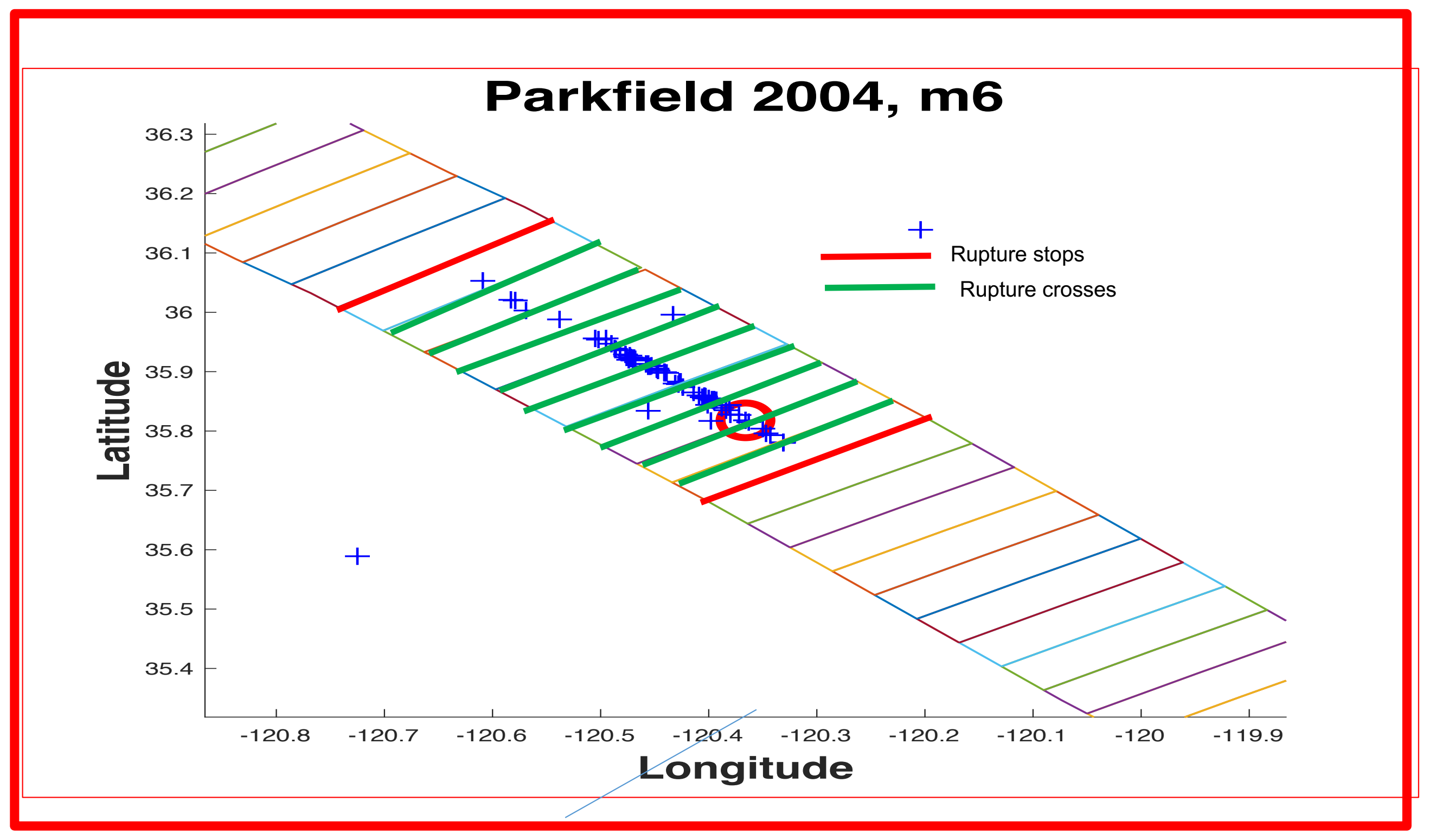

Figure 3: UCERF3 section representation for 2004 Parkfield (m=6) on San Andreas showing actual rupture defined by aftershock distribution. Red circle is mainshock epicenter; x’s are aftershock epicenters

Possible Modeling Strategy, 2-D

Some quakes rupture outside the prescribed section boundaries, and others (like Ridgecrest, 2019) rupture completely outside all boundaries. A comprehensive model could cover the entire state with 0.1 by 0.1 degree cells, with CSP specified on every cell edge. **The biggest job of the modeling project is to specify the CSP values on all cell edges for any reasonable hypothesis based on seismic history, paleo-seismic history, fault geometry, slip rate, geologic age, or any available data.** Figure 4 shows how the Parkfield 2004 rupture would be represented using 0.1 by 0.1 degree cells.

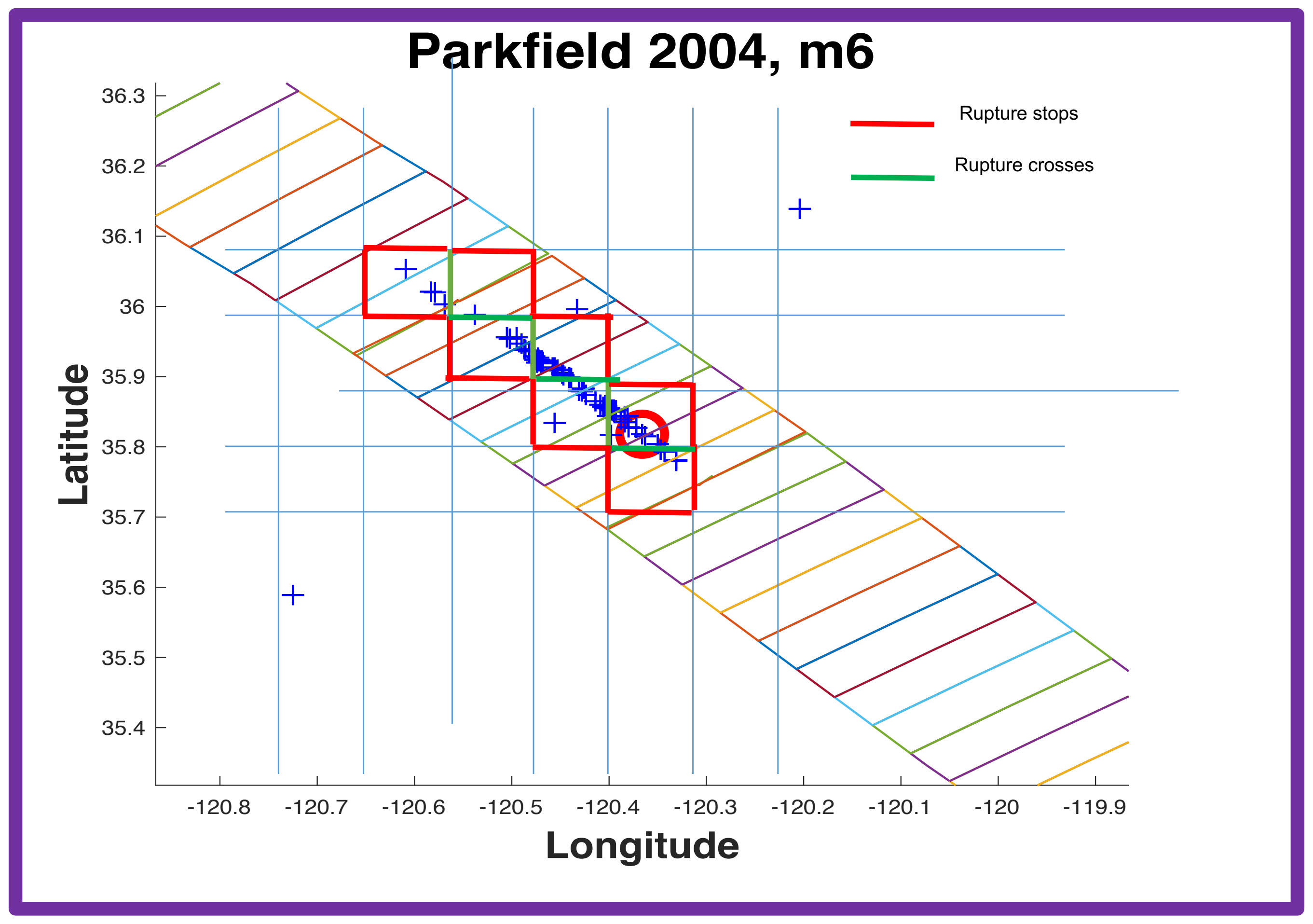

Figure 4: UCERF3 2-D section representation for 2004 Parkfield (m=6) on San Andreas showing actual rupture defined by aftershock distribution.

Possible Testing Strategy, 1-D or 2-D

Use aftershocks to gauge rupture extent

For any section edge,

P = CSP if only one adjacent cell contains aftershock (**Red in Fig 3 and 4**) or (1-CSP) if both adjacent cells have aftershocks (**Green in Fig 3 or 4**)

Log likelihood = sum(Log P) over all edges with one or two filled cells.

Summary

Earthquake interactions depend on geometry of buried faults, fractal behavior of faults, the rheology of crustal materials, and many other properties that cannot be determined from first principles or laboratory measurements. Yet earthquake safety requires forecast models that depend on those properties. So forecast models make reasonable but untested assumptions about them. The “Grand Challenges” listed above incorporate many such assumptions and solving them would help substantially test every assumption and improve the forecasts. I’ve outlined a possible approach to solving one: the process by which earthquake rupture stops. The others could be approached with similar efforts. By working focusing on big problems together, SCEC scientists could move the frontiers of earthquake science.

SCEC AN NSF+USGS CENTER

NSF

USGS science for a changing world

Acknowledgements

Thanks to Peter Bird, Yan Kagan, Leon Knopoff, Werner Marzocchi, Andrew Michael, David Rhoades, William Savran, Danijel Schorlemmer, Ross Stein, and Maximillian Werner for wonderfully stimulating discussions.