TWO PHYSICS-BASED MODELS FOR ESTIMATION OF MAGNITUDES OF FLUID-INJECTION-INDUCED EARTHQUAKES

Martin **GALIS**, Jean-Paul **AMPUERO**,
P. Martin **MAI** , Frédéric **CAPPA**

جامعة الملك عبدالله للعلوم والتقنية
King Abdullah University of Science and Technology

SEISMOLOGICAL LABORATORY
California Institute of Technology

GeoAZUR

aim

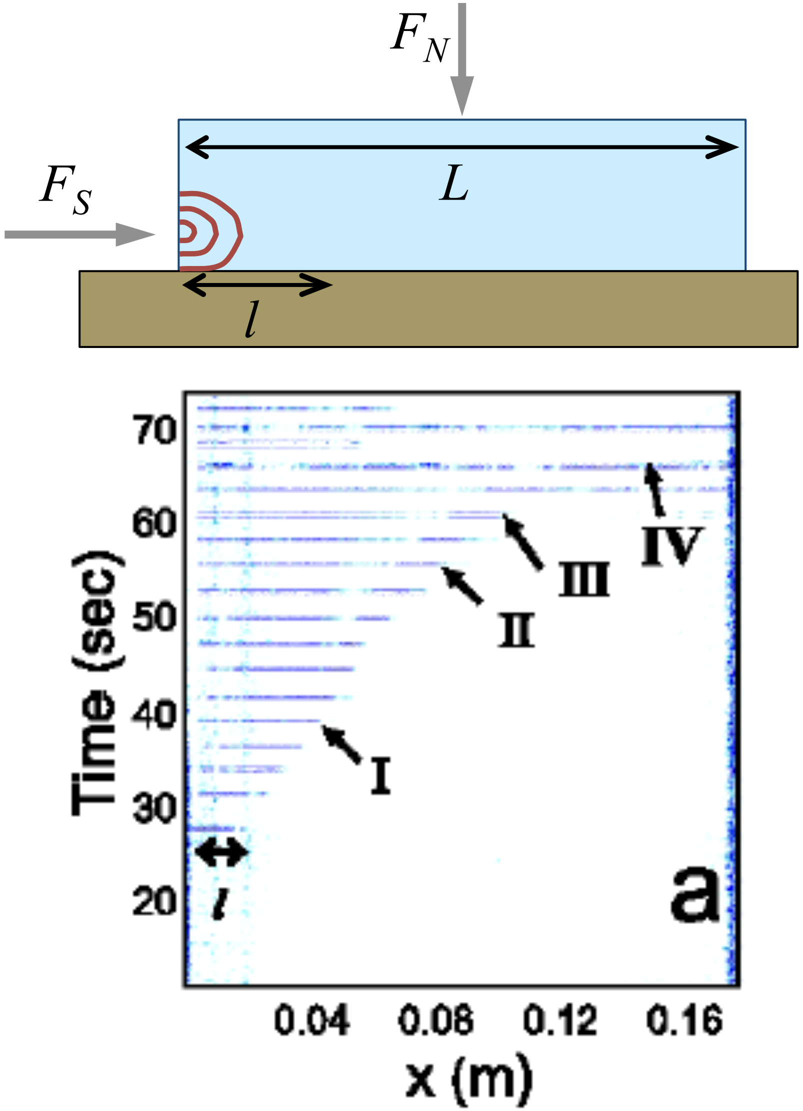
we focus on integrating fracture mechanics
into estimates of magnitudes of injection-induced earthquakes

our goal is to determine how large a rupture
can grow under different conditions

rather than modeling individual cases,
our aim is to understand general principles
driven by underlying physics

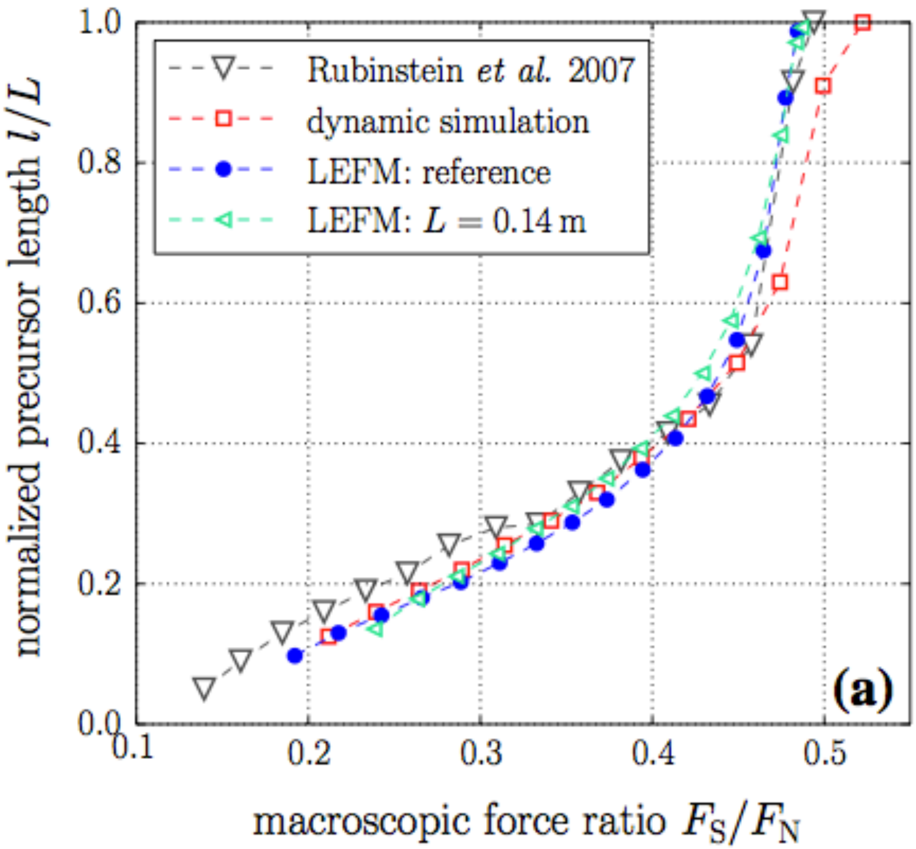
estimation of the precursor length

laboratory experiments
revealing arrested ruptures



Rubinstein, Cohen and Fineberg (2007)

LEFM estimates
of the laboratory results

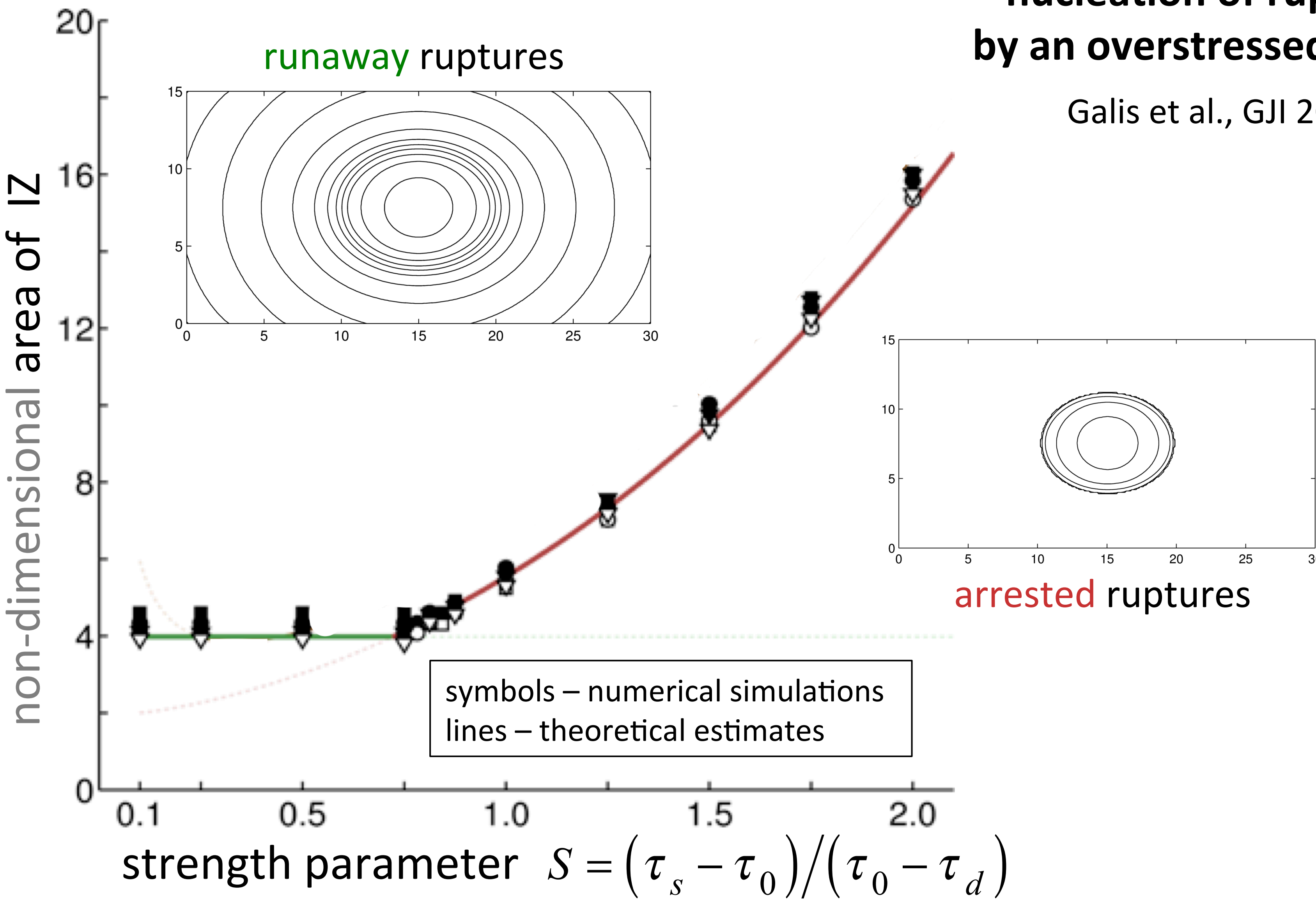


Kammer, Radiguet, Ampuero and Molinari
(Tribology Letters, 2015)

initiating ruptures in numerical simulations

nucleation of ruptures by an overstressed region

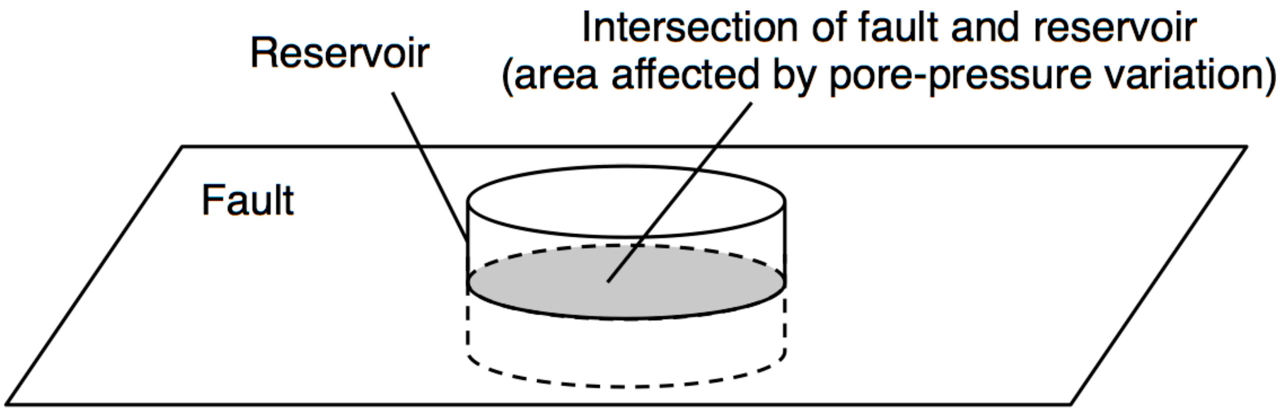
Galis et al., GJI 2015



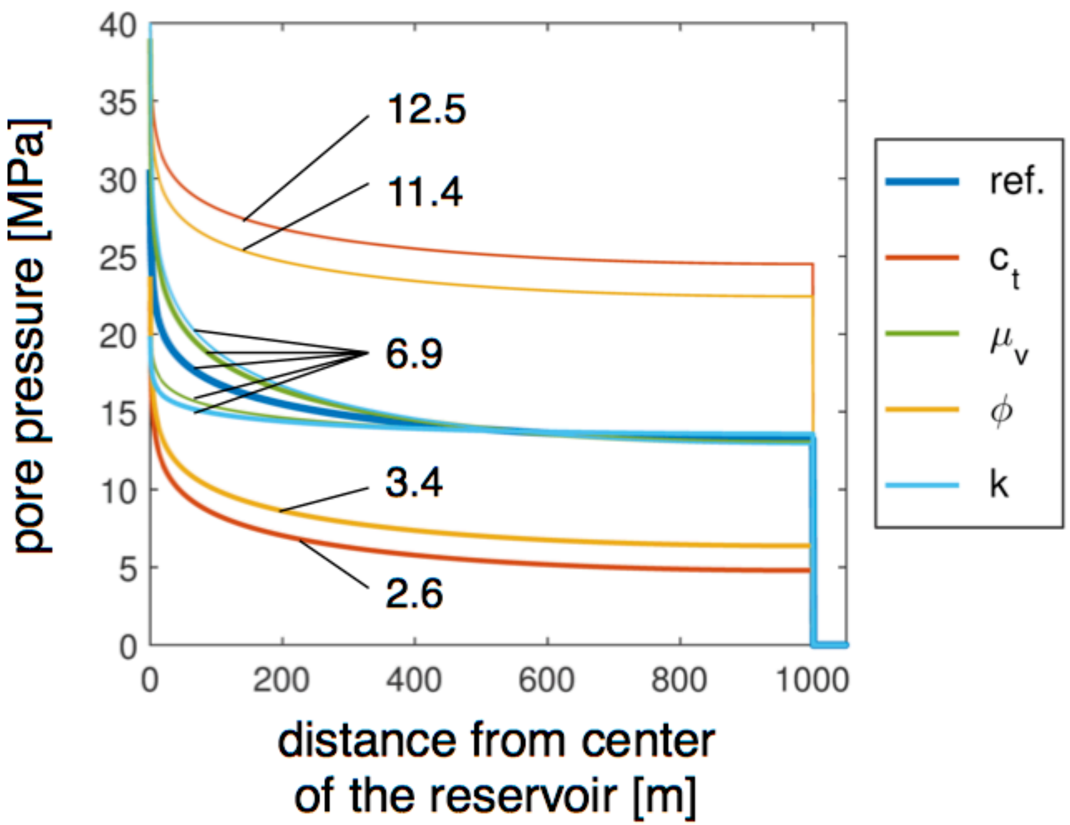
strength parameter $S = (\tau_s - \tau_0)/(\tau_0 - \tau_d)$

← Increasing background stress ←

assumptions and concept of our approach



pore-pressure distribution
inside a cylindrical reservoir
with no-flow boundaries
(Lee at al., 2003)



assumptions and concept of our approach

- circular crack
- axisymmetric stress drop
- static stress intensity factor averaged along crack rim is approximated by the expression for tensile cracks
- details of weakening inside the process zone are ignored – the rupture arrest criterion is based on fracture toughness K_c

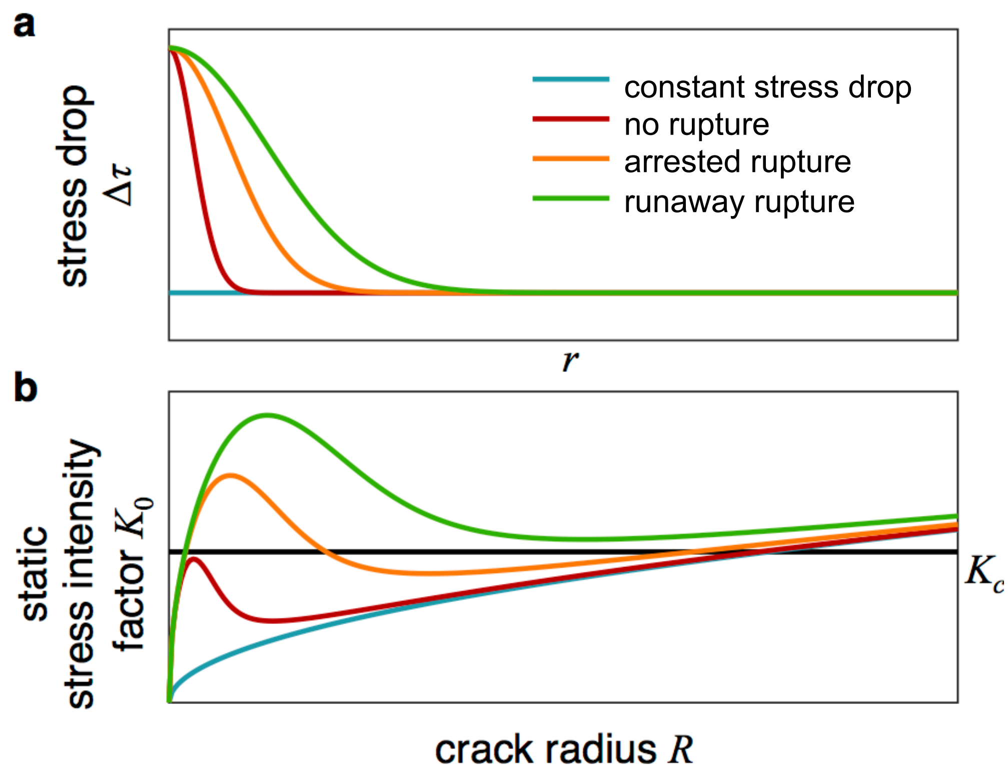
condition for rupture arrest

Griffith crack equilibrium criterion

$$K_0(R) = K_c(R)$$

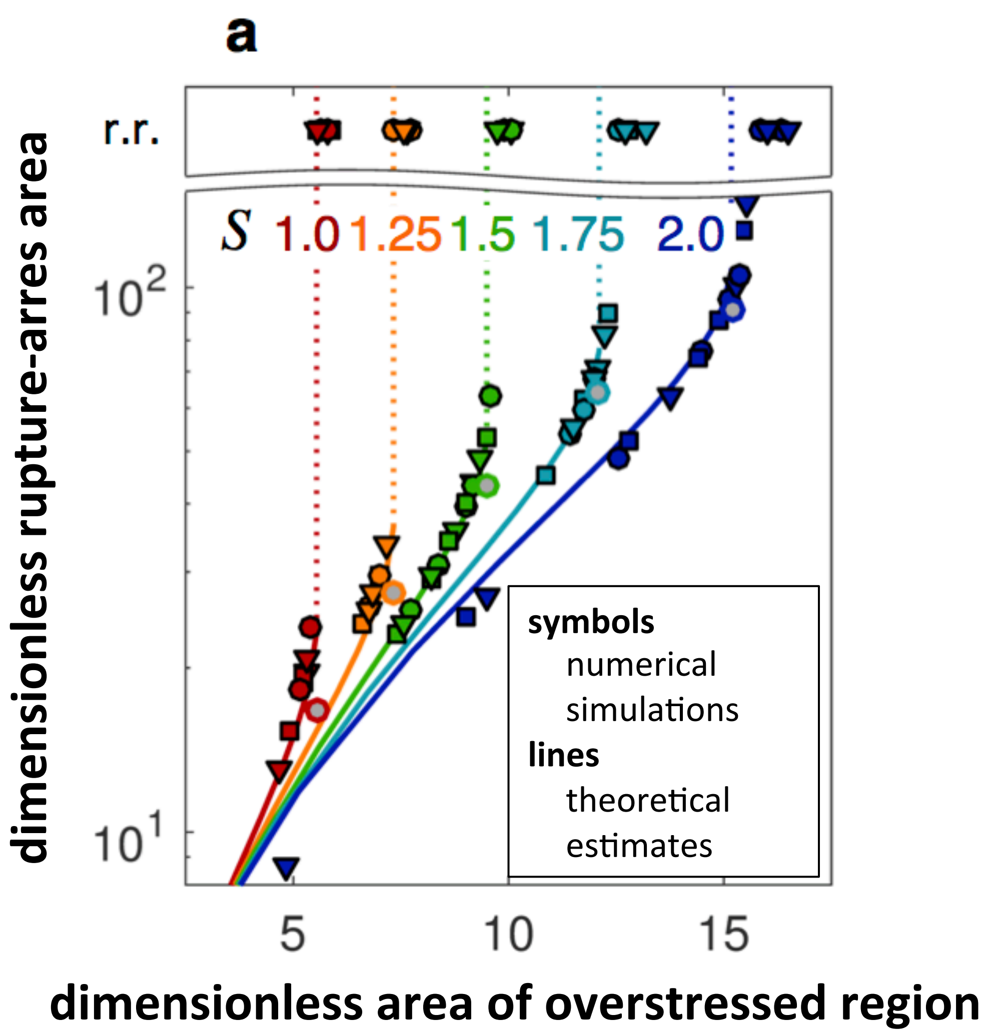
to discriminate
stable and unstable equilibrium

$$\frac{\partial(K_0 - K_c)}{\partial R} < 0$$

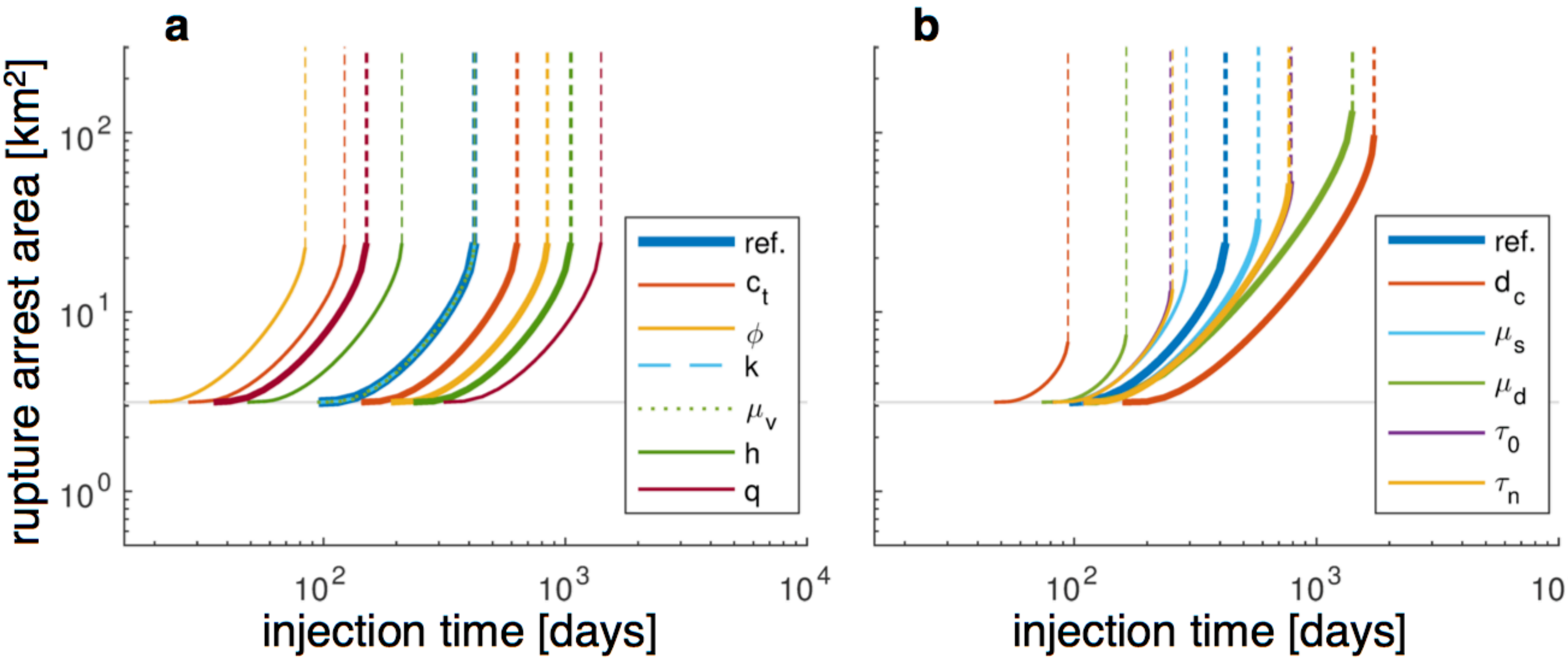


verification of our approach

ruptures initiated
by overstressed regions
with different shapes



conditions for rupture arrest are solved numerically



- pore-pressure related parameters only control shift in time
- shape of "rupture arrest area vs injection time" curves, including $A_{arr\text{-}max}$ at transition to runaway ruptures, depends only on fault-related parameters

II. analytical model

conditions for rupture arrest are solved analytically with additional assumptions

- pore-pressure perturbation inside the reservoir is approximated by a point load/force

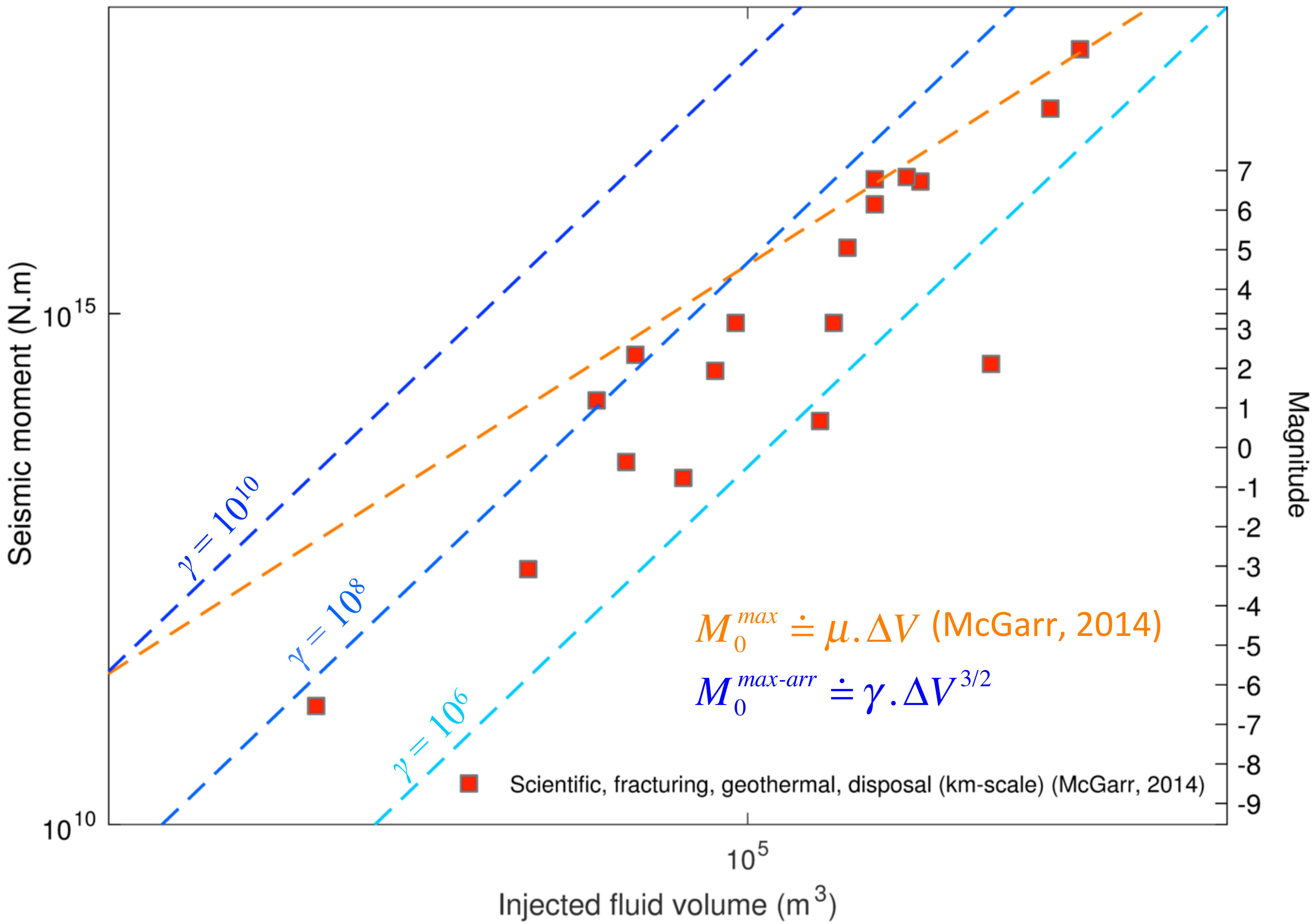
- average pore-pressure perturbation inside the reservoir is approximated as proposed by McGarr, 2014:

$$\Delta p = \kappa \frac{\Delta V}{V}$$

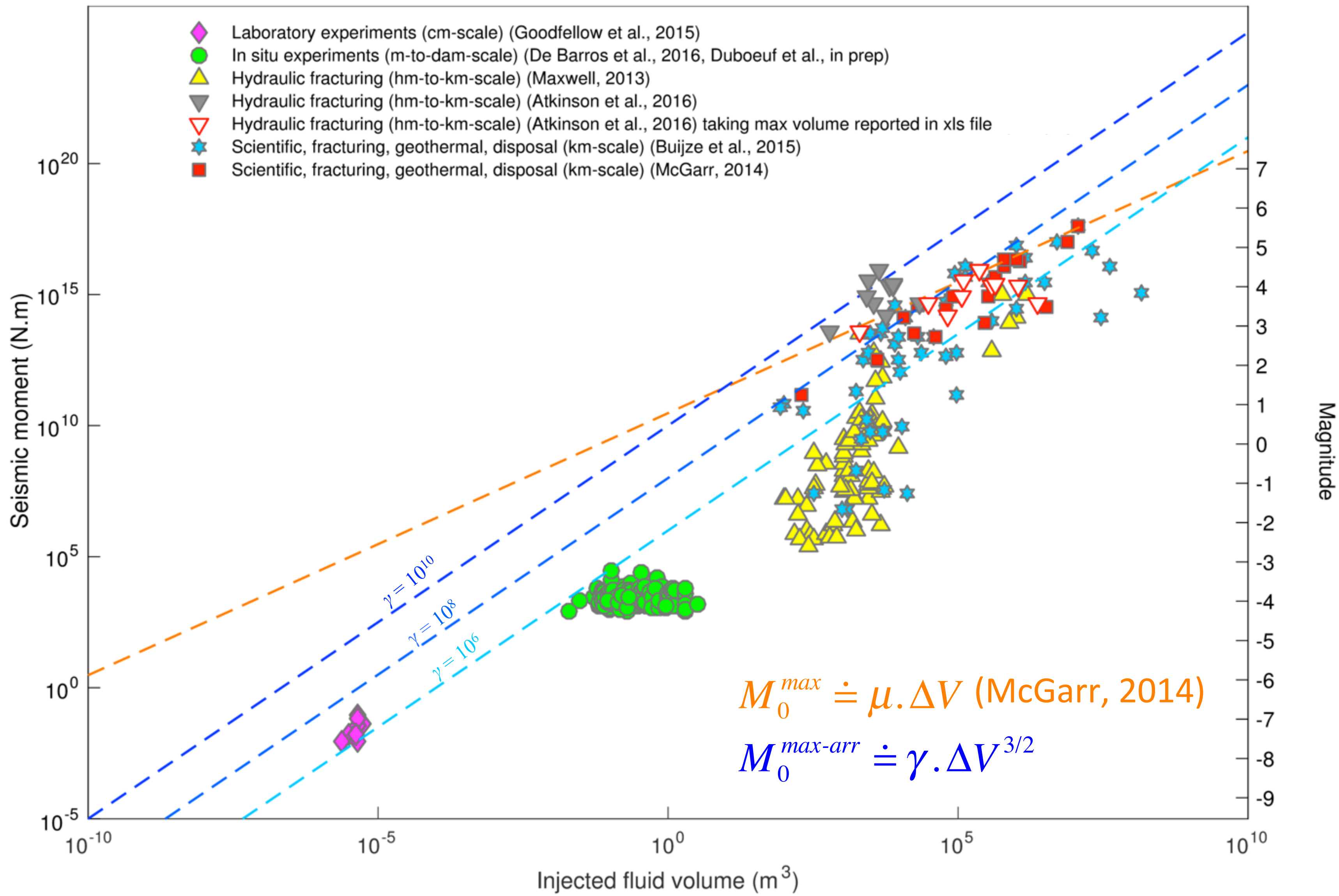
With these assumptions, we can estimate maximum seismic moment and magnitude before transition to runaway ruptures as a function of injected volume

$$M_0^{max\text{-}arr} \doteq \frac{0.4255}{\sqrt{\Delta\tau_0}} \left(\frac{\kappa \mu_d}{h} \right) \Delta V^{3/2} = \gamma . \Delta V^{3/2}$$

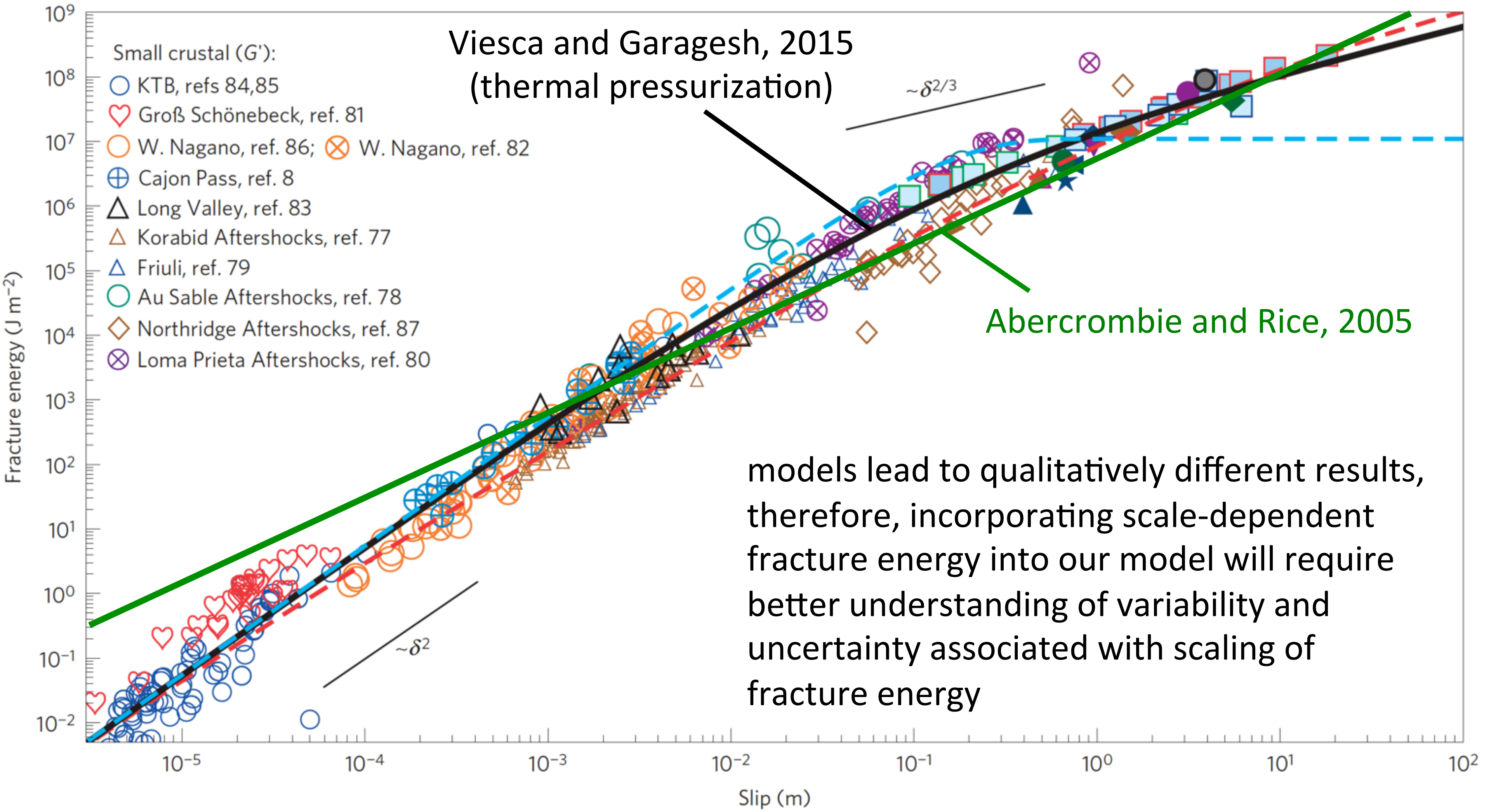
II. analytical model



II. analytical model



realistic scaling of fracture energy



models lead to qualitatively different results, therefore, incorporating scale-dependent fracture energy into our model will require better understanding of variability and uncertainty associated with scaling of fracture energy

background figure from Viesca and Garagesh, 2015

conclusions

- using fracture mechanics, we have derived a **physical model for estimating rupture arrest size**
- **numerical solution** of rupture-arrest condition provides **insight into roles of various parameters** of the reservoir-fault system
- **analytical solution** of further simplified problem **provides relation between $M_0^{max\text{-}arr}$ and injected volume**, similar to McGarr, 2014, however, **while McGarr's estimate predicts slope of 1, we find slope of 3/2, which seems to be consistent with observations** over a broad range of injected volumes and magnitudes

THANK YOU