南京大学
NANJING UNIVERSITY

Viscoelastic ruptures unbounded by classical speed limits

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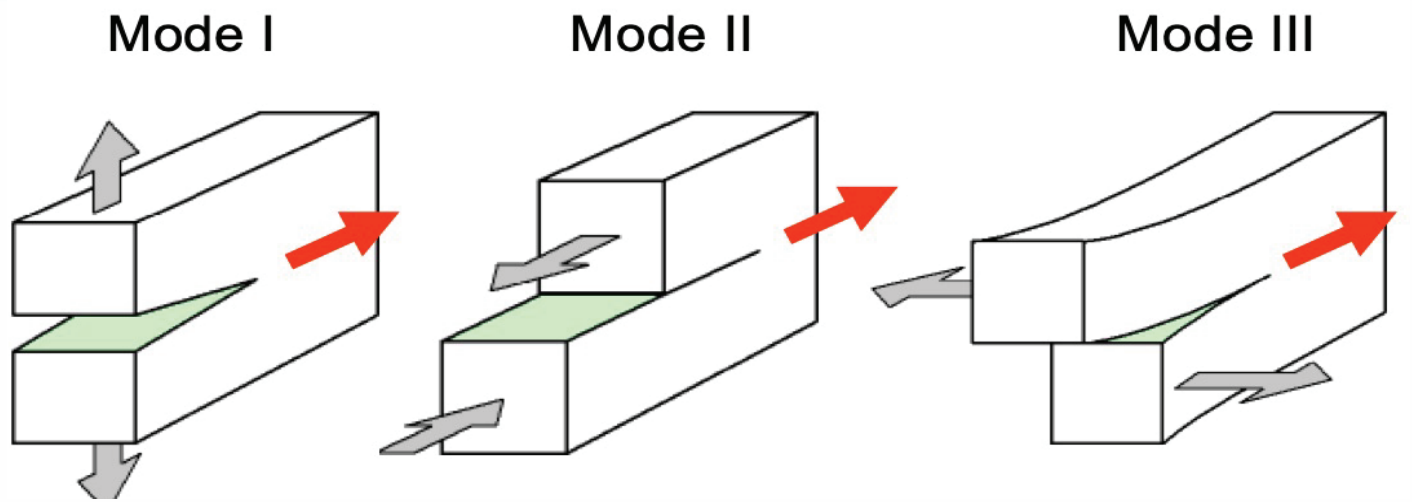
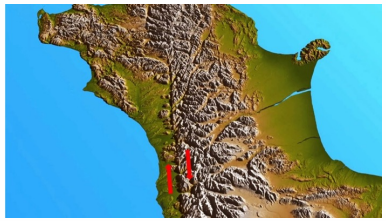
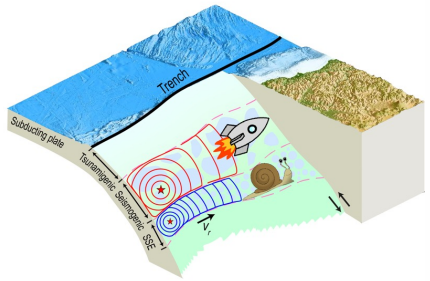
Monday, June 24, 2024
Smolenice Castle, Slovakia

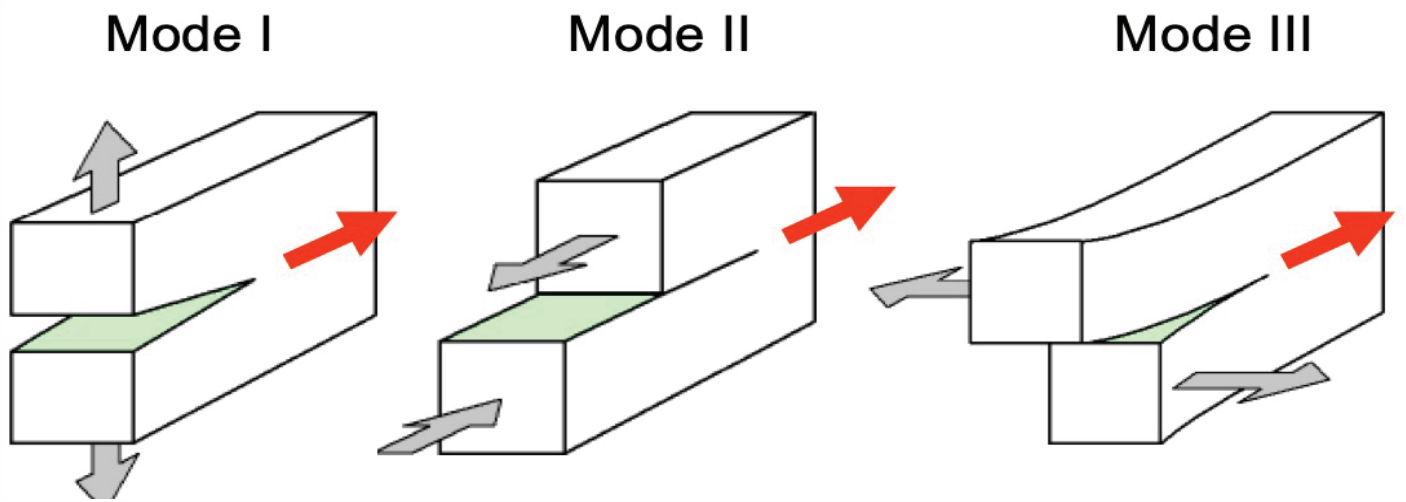
Rupture modes

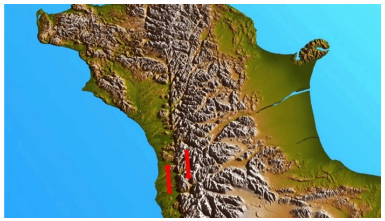


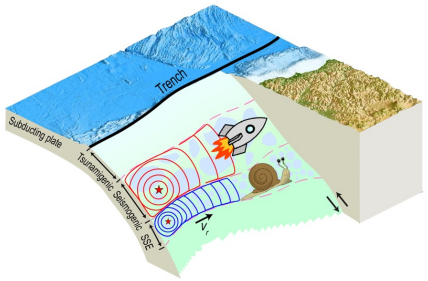


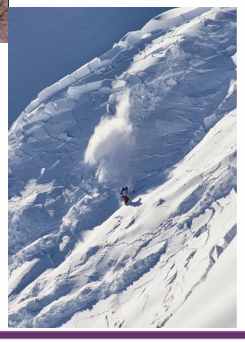


Rupture modes

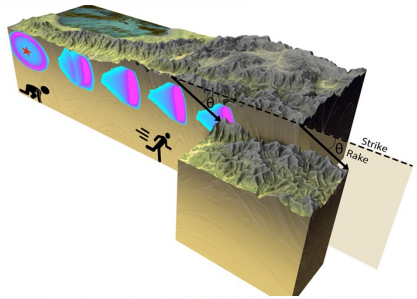






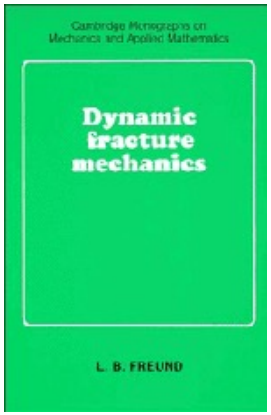


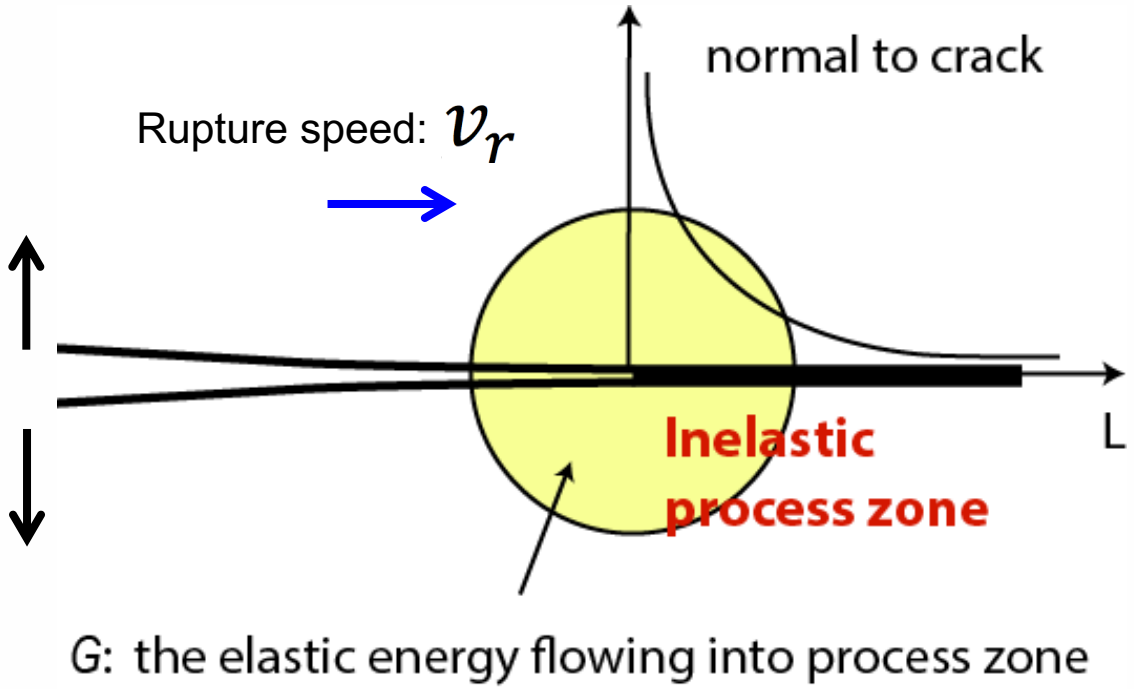
Mode -I + Mode II



Mode II + Mode III

2D Linear Elastic Fracture Mechanics



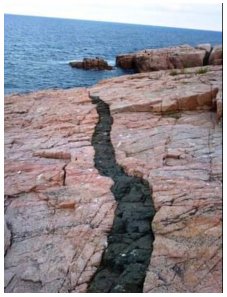


2D equation-of-motion: $G_c = G(v_r, L, \Delta\tau) \propto L$

Fracture energy Energy release rate

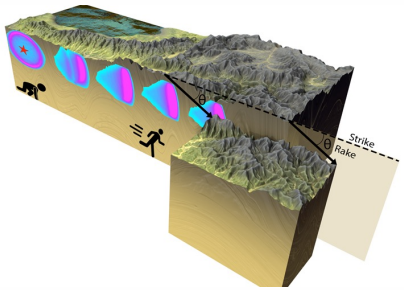
2-D theories, Kostrov, Freund, Andrews (60-70s)

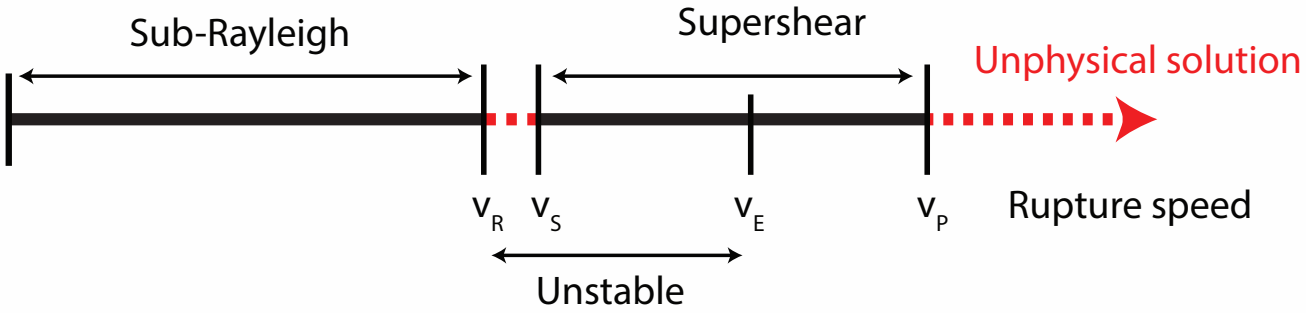
Classical speed limits



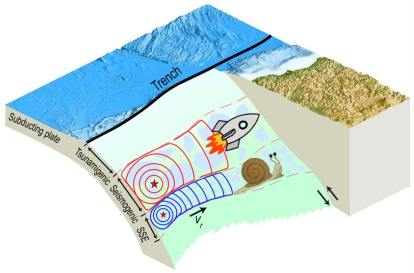
Modes I (dike)

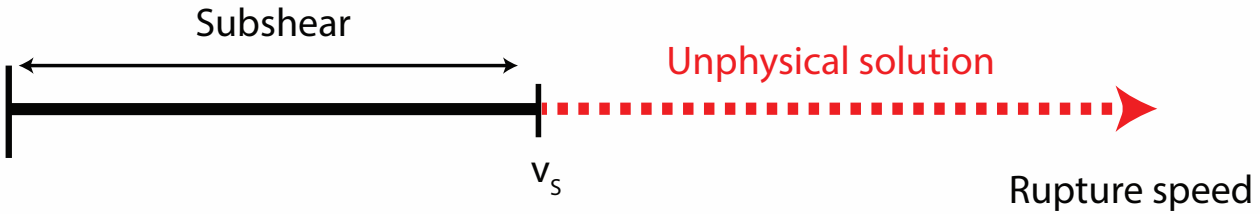
Modes II (strike slip)





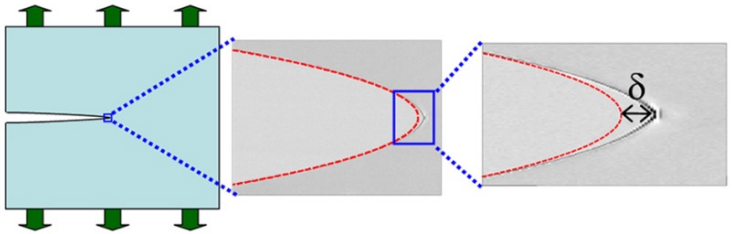
Modes III (dip slip)



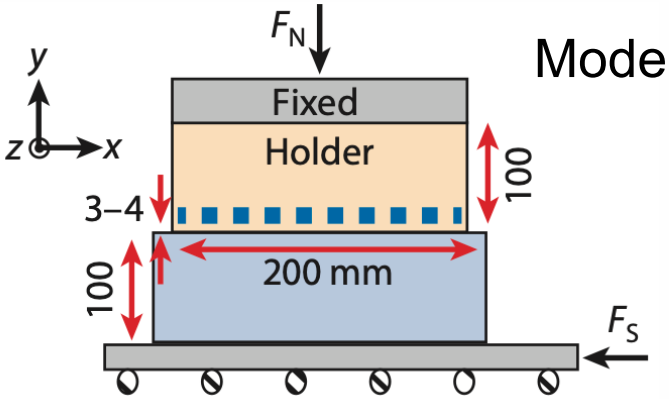


Validated speed limits in laboratory

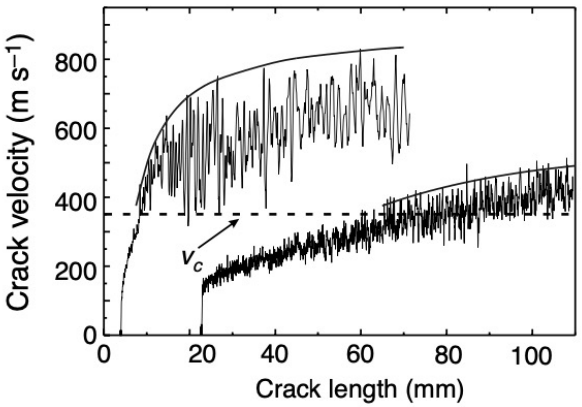
Mode I



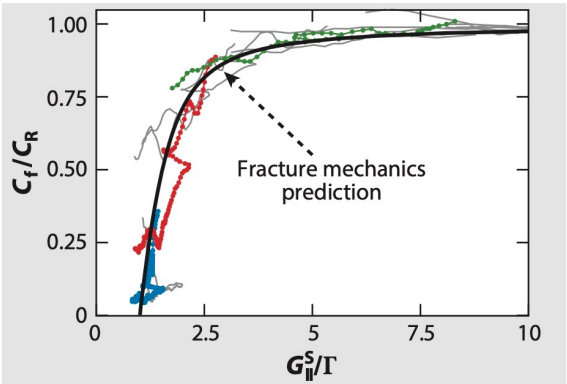
Mode II



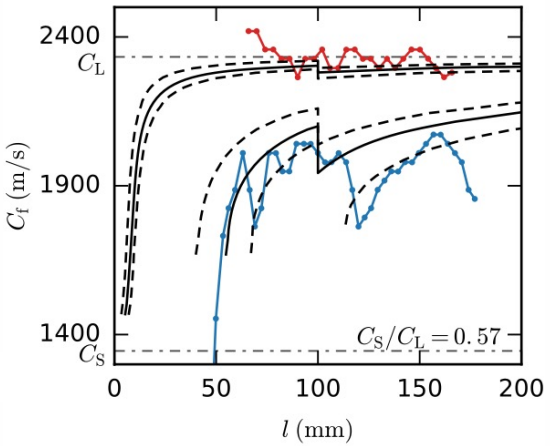
Subshear ($v < v_R$)



Subshear ($v < v_R$)



Supershear ($v < v_P$)

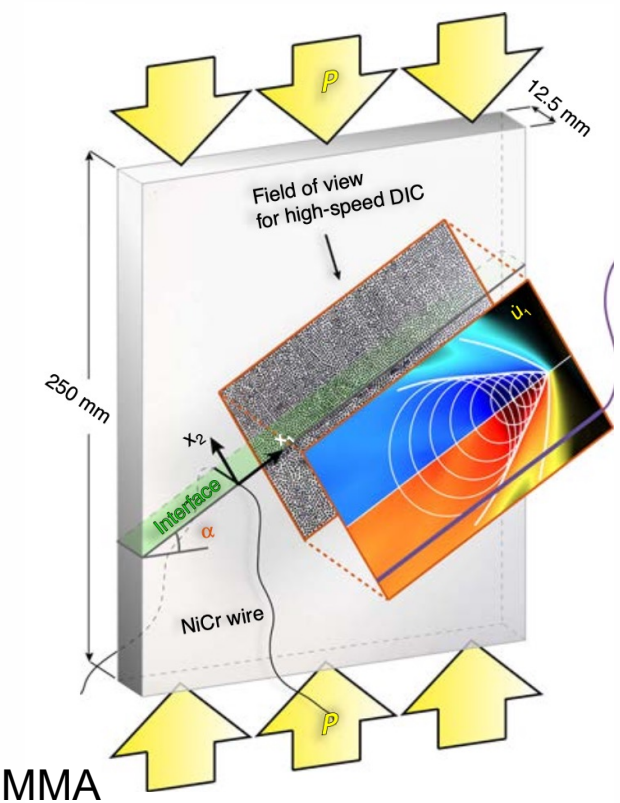


Sharon and Fineberg, 1999; Svetlizky et al., 2019; Kammer et al., 2018

Beyond classical speed limits in 2D

Mach cones

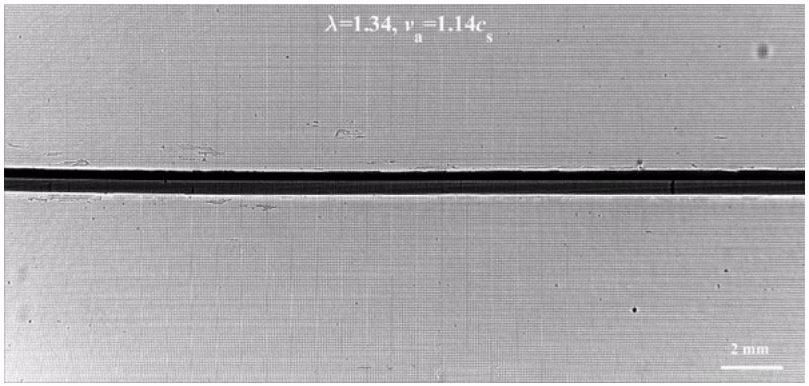
Supersonic crack in Mode II



PMMA

Viscoelastic behavior

Supershear crack in Mode I



Hydrogel

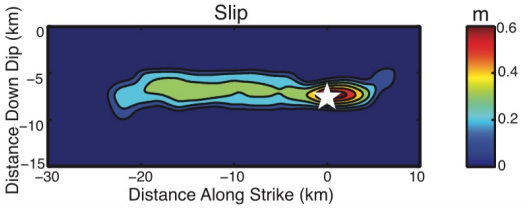
Hyperelastic behavior

Wang et al, 2023

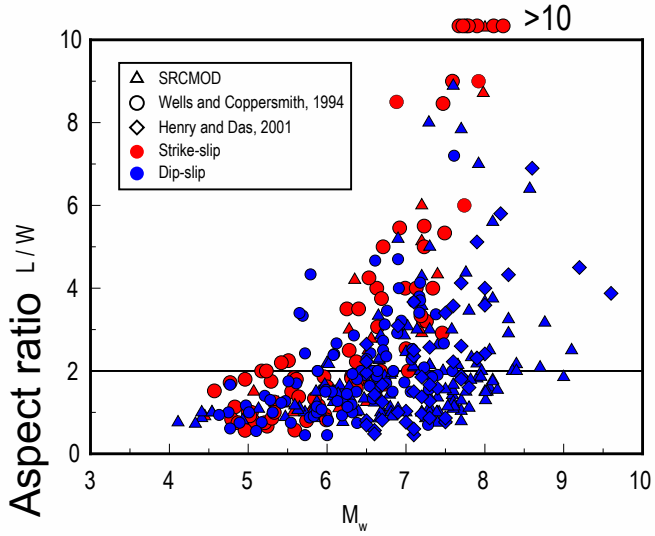
Gori et al, 2018

Finite rupture width in 3D

2004 Mw 6 Parkfield

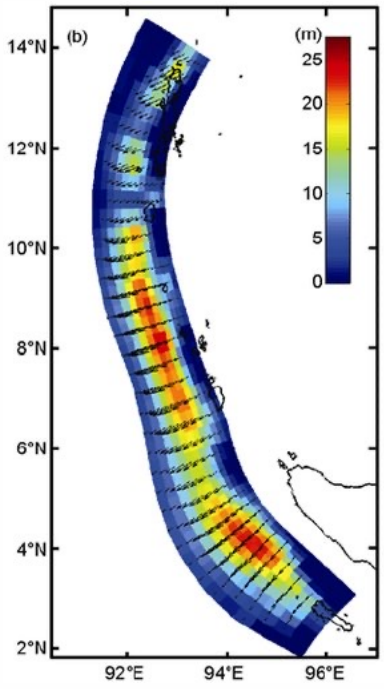


Ma et al 2008

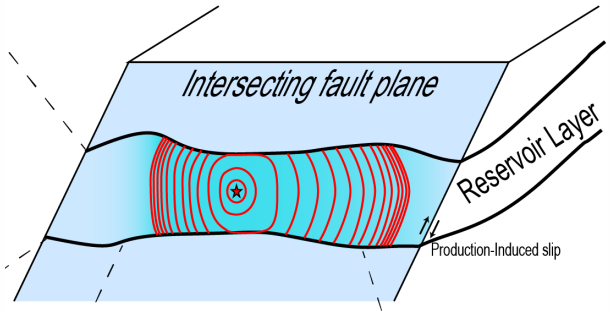


Weng and Yang, 2017

2004 Mw 9.3 Sumatra

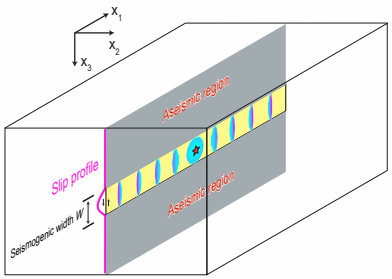


Wang et al 2011



Induced seismicity

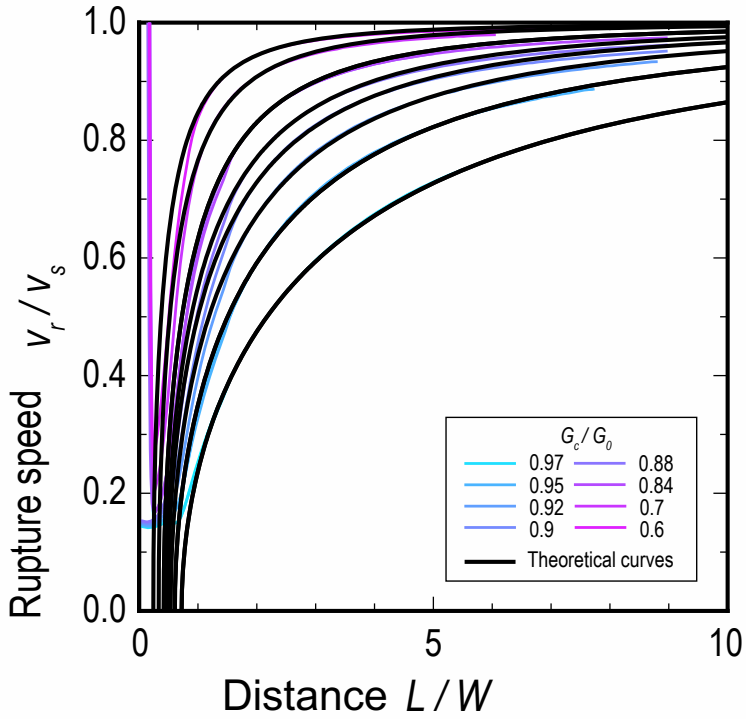
Extended 3D LEFM theory

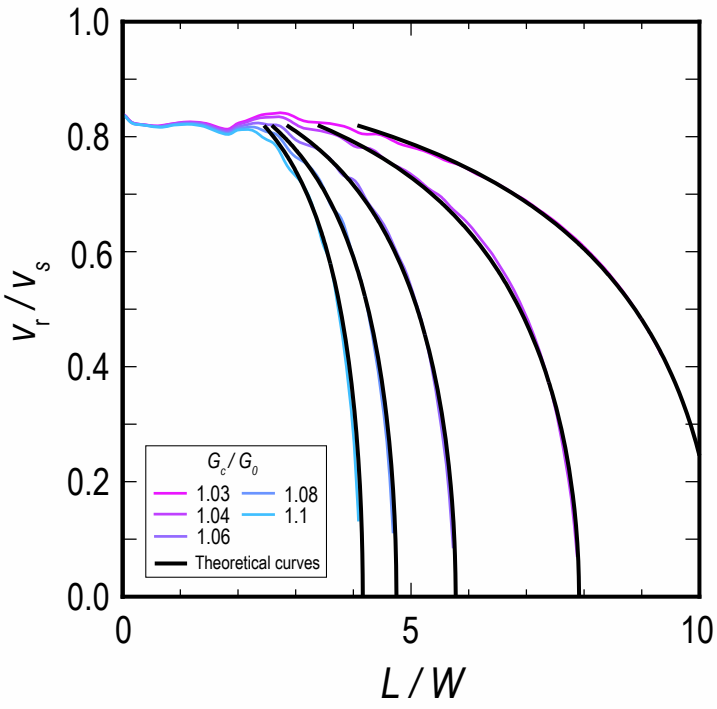


3D equation-of-motion:

$$F\left(G_c/G_0\right) = M\left(v_r\right) \cdot \dot{v}_r$$

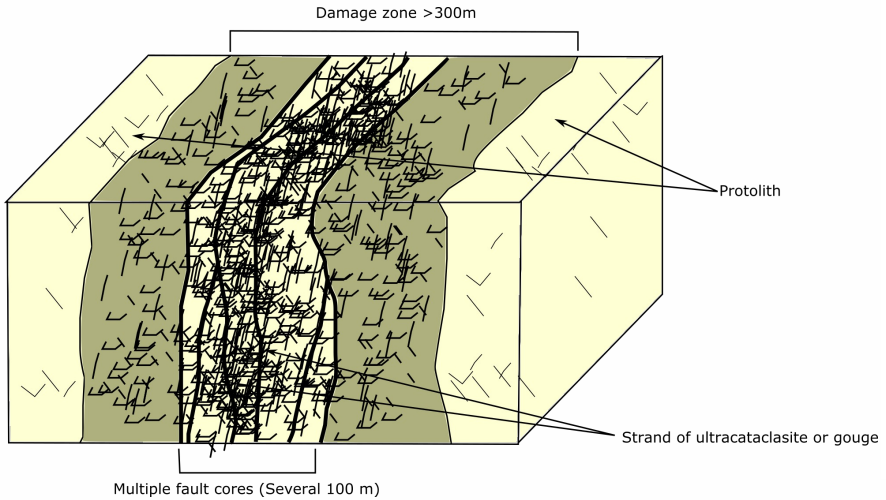
"Force" "Mass" Acceleration



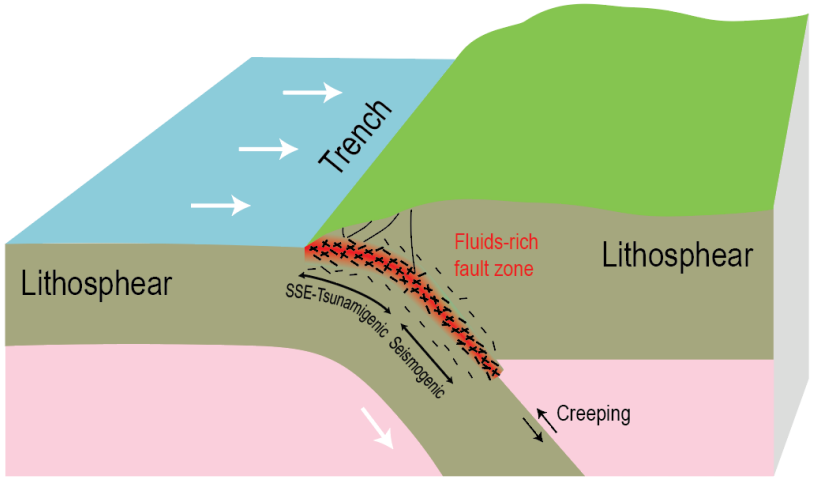


Weng and Ampuero, 2019

Highly damaged fault zone

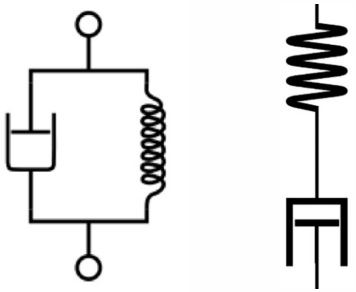


WordPress.com

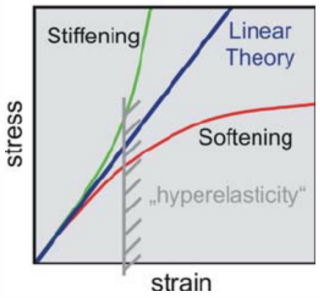


Elasticity?

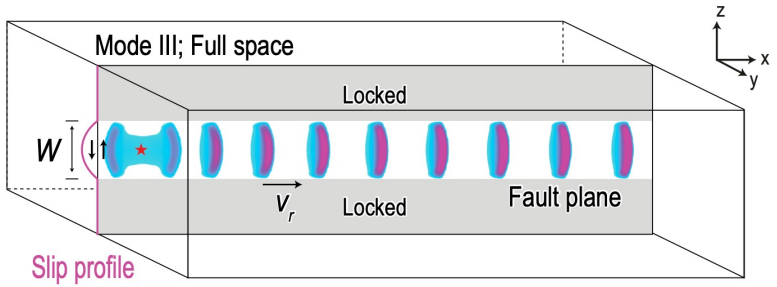
Viscoelasticity?

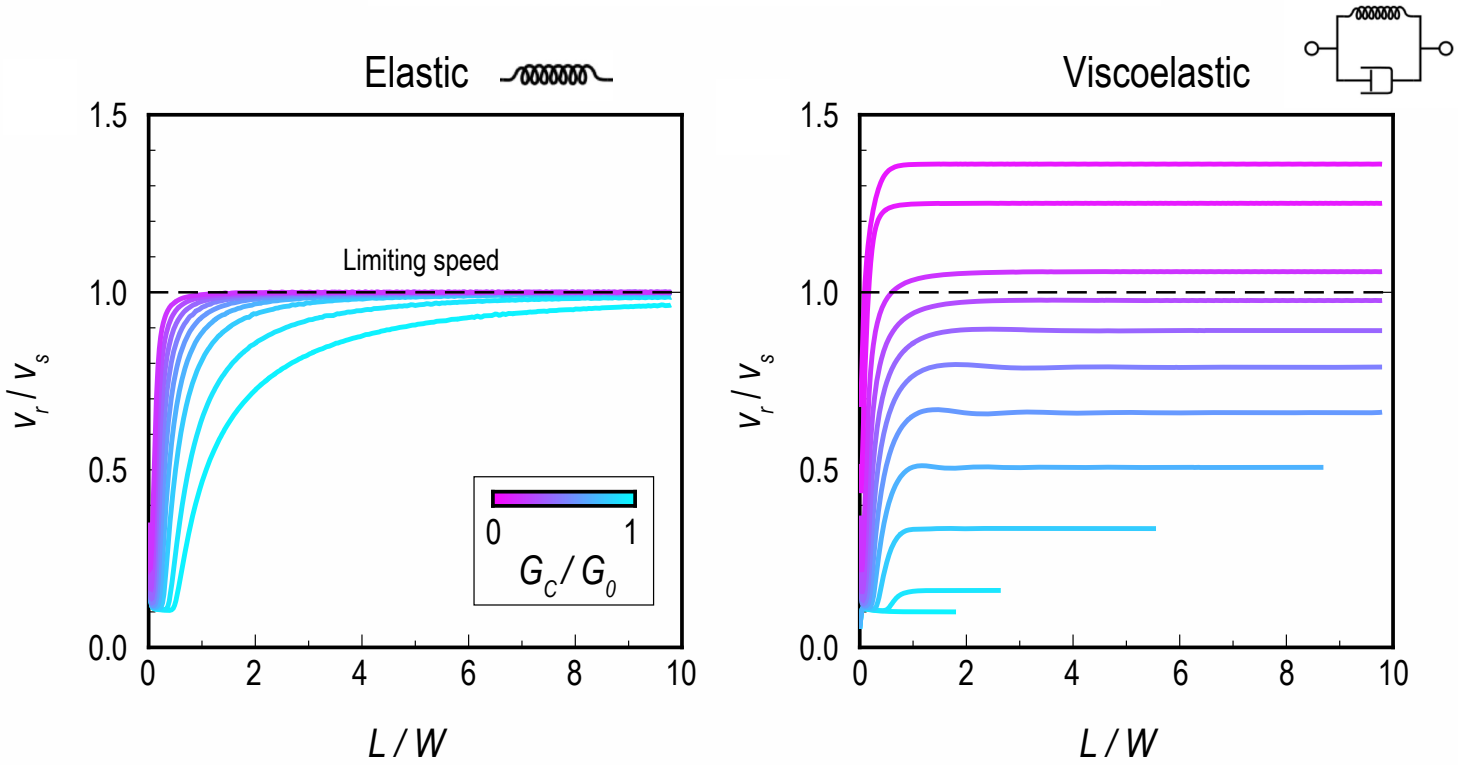


Hyperelasticity?



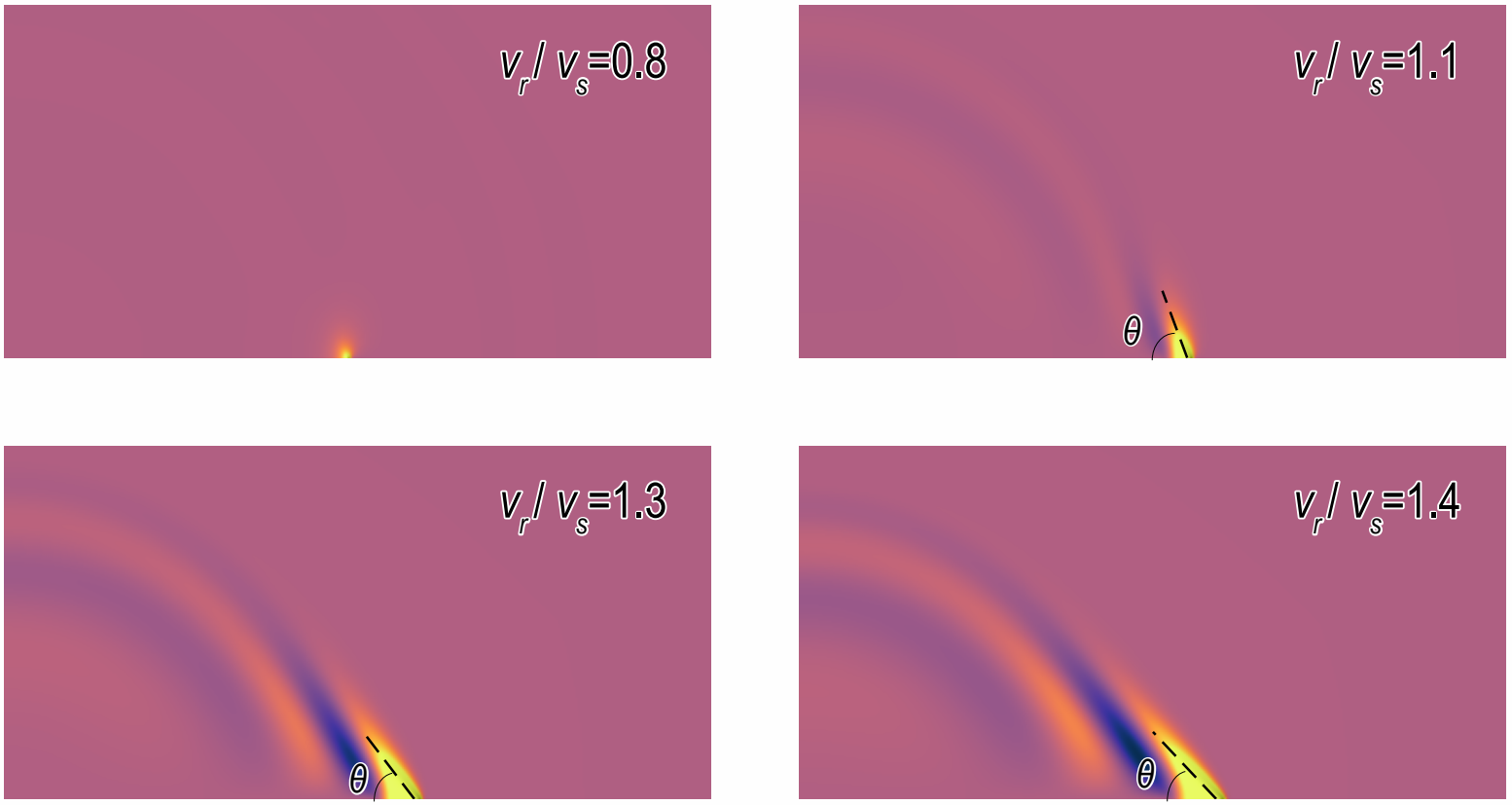
Unbounded ruptures in numerical simulations





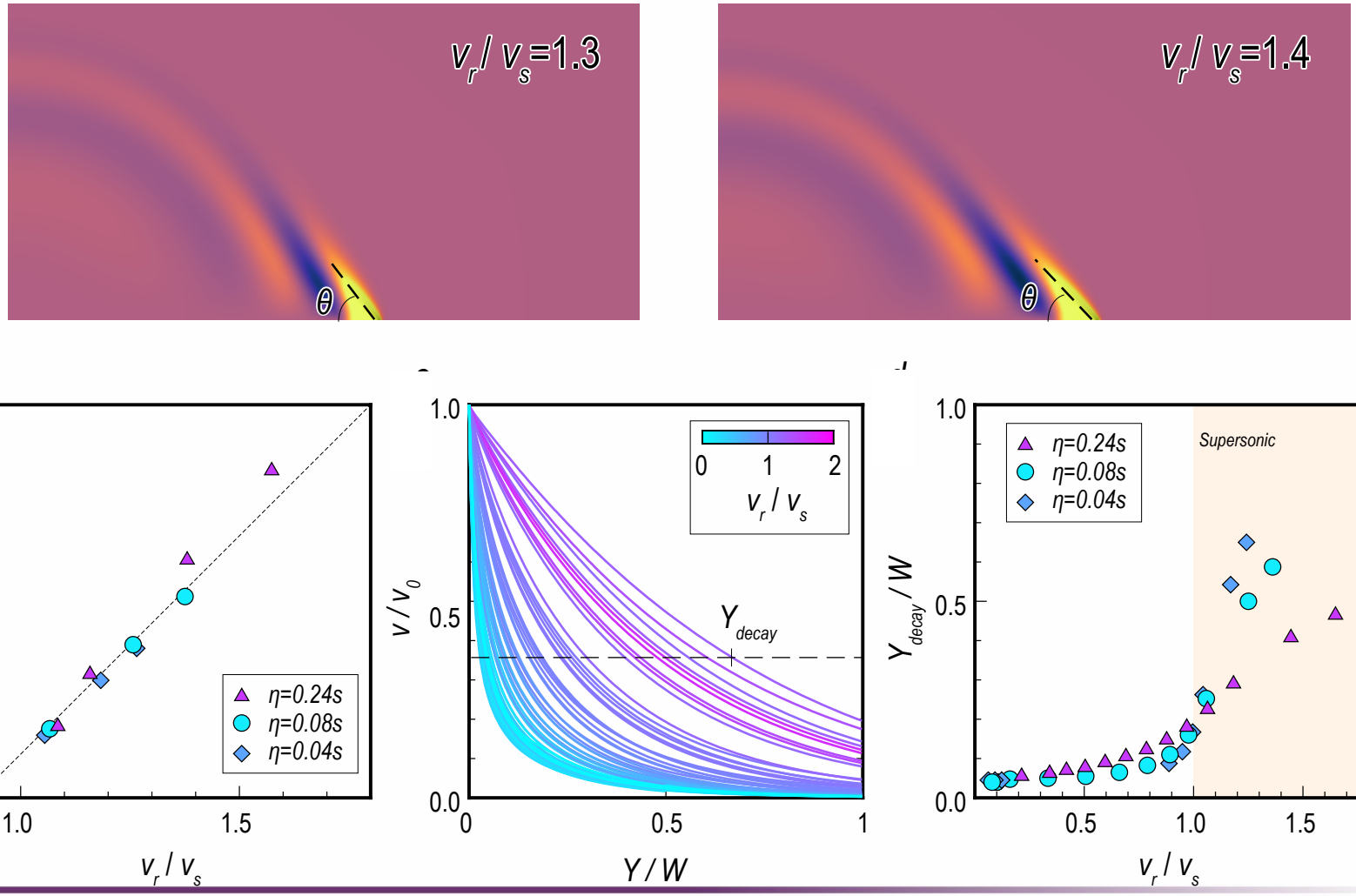
Weng, 2024, In review

Mach fronts in mode III



Weng, 2024, In review

Mach fronts in mode III



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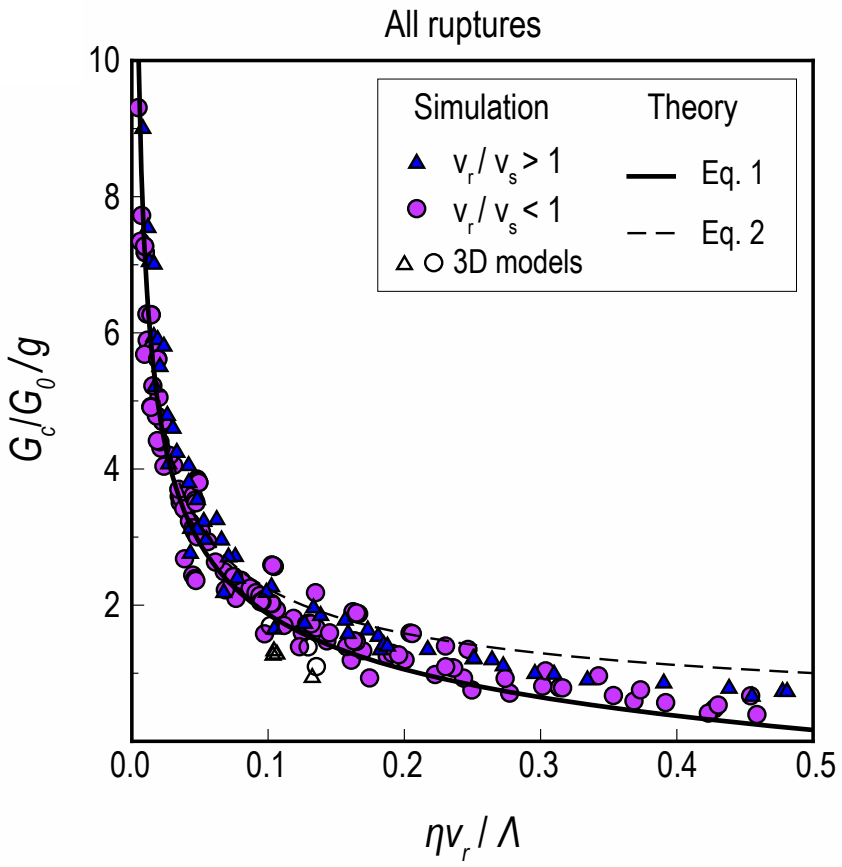
Theory for viscoelastic ruptures



Elastic model

$$F\left(G_c/G_0\right) = M\left(v_r\right) \cdot \dot{v}_r$$

Extended

Viscoelastic model

$$\frac{G_c}{G_0} = \Theta\left(\frac{\eta v_r}{\Lambda}\right) \cdot g\left(\frac{\eta v_r}{W}\right)$$

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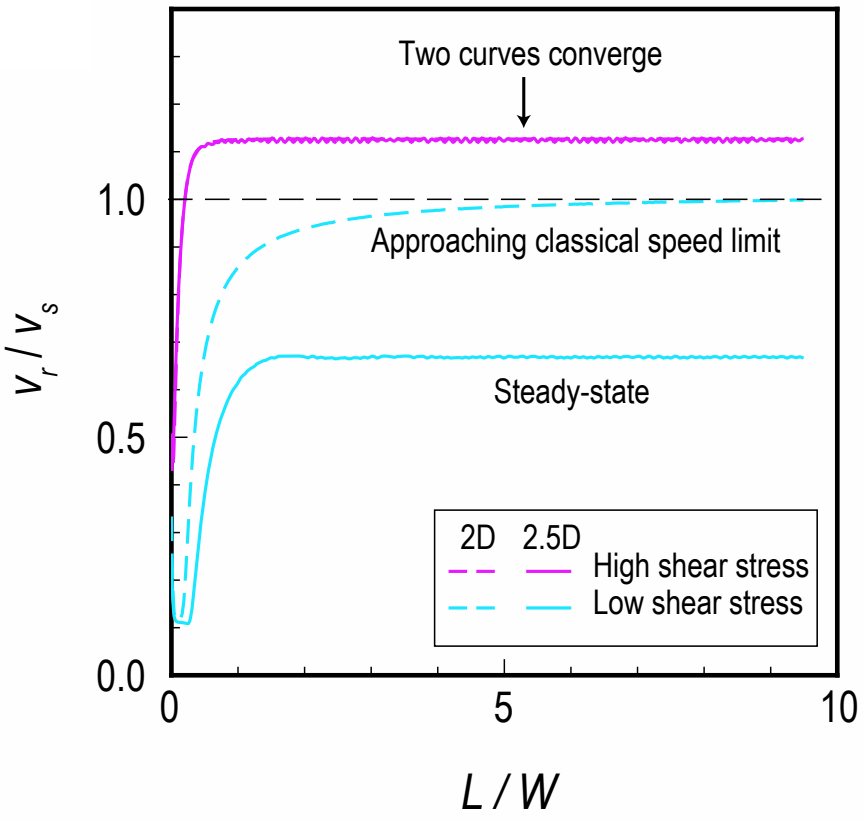
Theory for viscoelastic ruptures

Also valid in 2D



Asymptotically solution for supershear ruptures:

$$G_c \propto \frac{\Delta\tau^2\sqrt{\eta v_r \Lambda}}{\hat{\alpha}_s \mu}$$

$$\hat{\alpha}_s = \sqrt{(v_r/v_s)^2 - 1}$$

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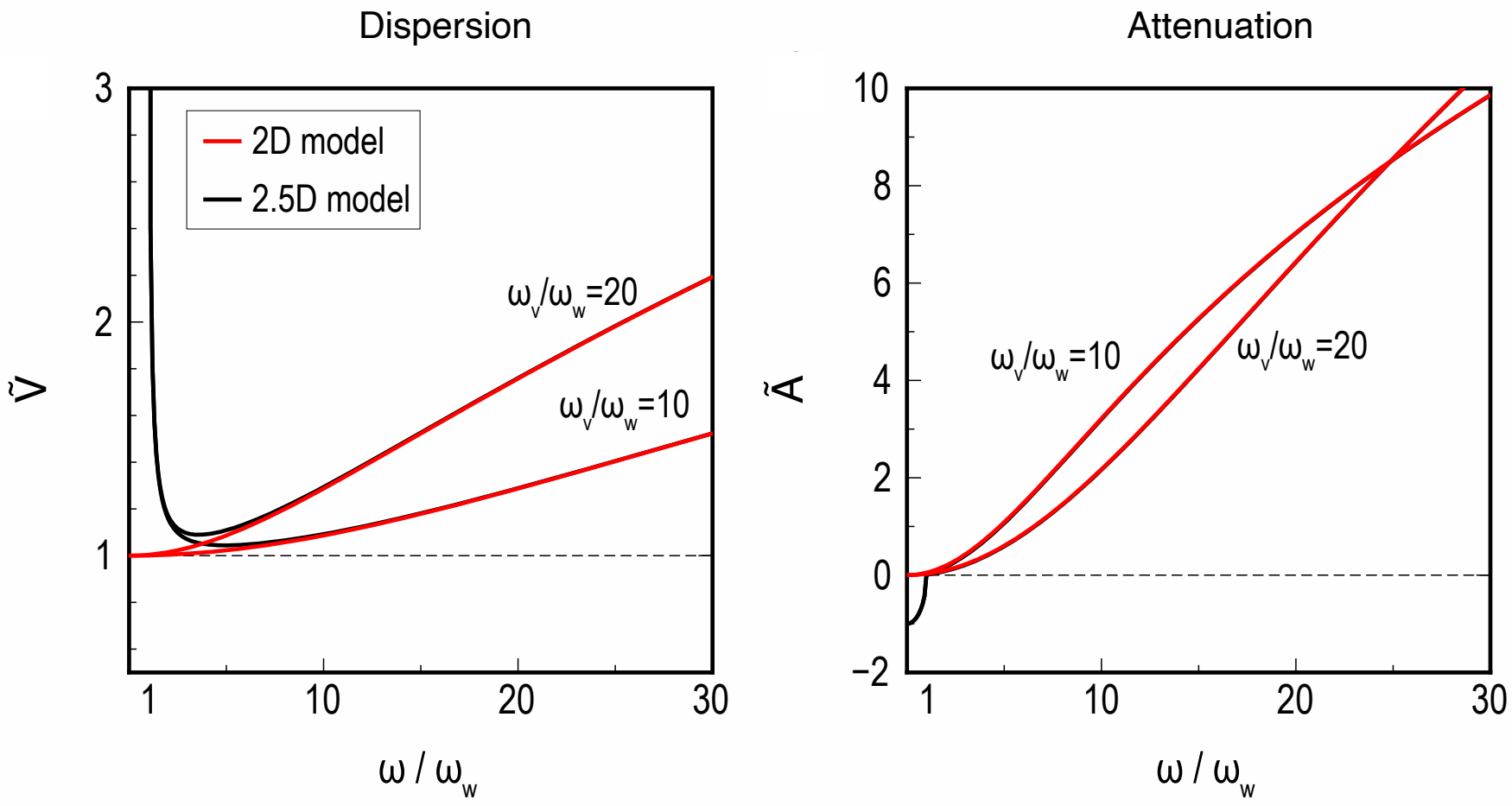
Velocity dispersion and attenuation



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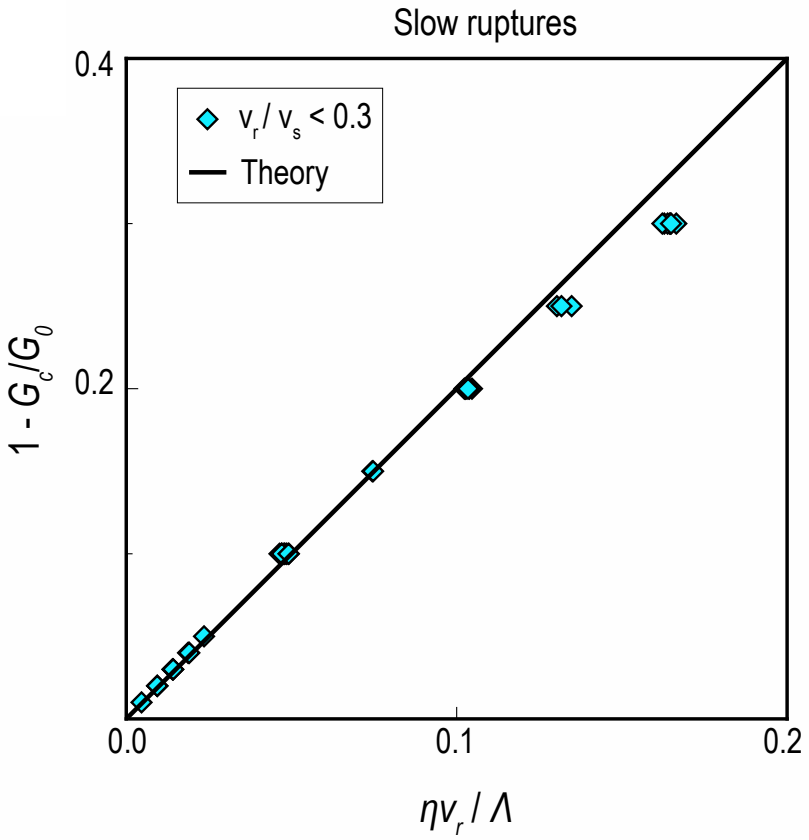
Theory for viscoelastic ruptures



Asymptotically solution for very slow ruptures:

$$G_0 = G_{equiv} \approx G_c(1 + 2\frac{\eta v_r}{\Lambda})$$

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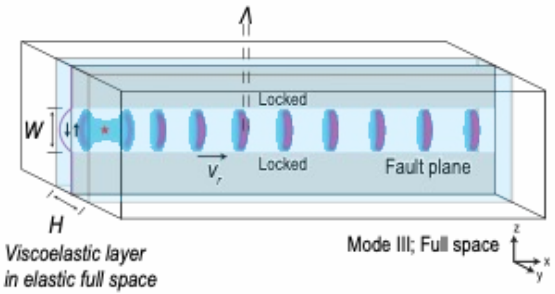
Finite thickness of viscoelastic layer



$H \to 0$ *Purely elastic model*

$H \to \infty$ *Purely viscoelastic model*

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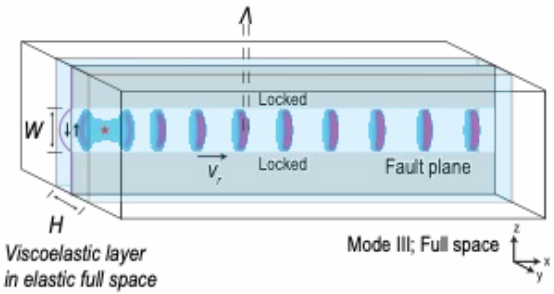
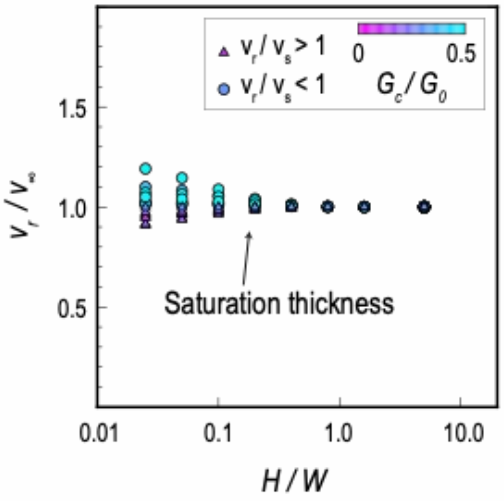
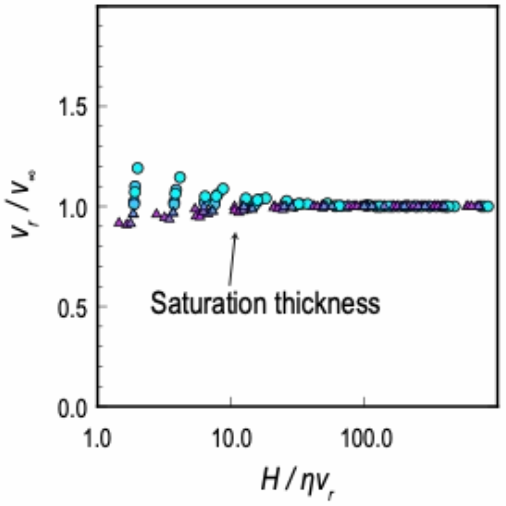
Finite thickness of viscoelastic layer

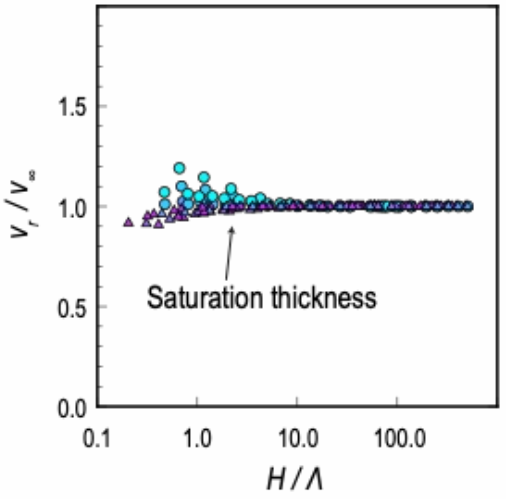


$H \to 0$ *Purely elastic model*

$H \to \infty$ *Purely viscoelastic model*







Weng, 2024, In review

Take-home messages

- Viscoelastic ruptures can propagate at a continuum of terminal speeds not bounded by classical speed limits.
- All simulated speeds are predicted by the new theory incorporating viscoelasticity.
- Beyond classical speed limits, rupture dynamics are independent of any macroscopic length and is controlled only by local properties around the rupture tip.