# Modeling earthquake ruptures with high-resolution fault-zone physics: An adaptive asynchronous space-time discontinuous Galerkin approach

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Earthquakes are among the most destructive natural hazards to mankind with losses exceeding thousands of lives and billions of US dollars annually. An outstanding challenge in computational seismology is to model accurately earthquake nucleation, propagation, and arrest and to predict the development of stress-accumulation patterns across regional fault networks and over the full seismic cycle. These capabilities would enable the development of physics-based seismic hazard models in support of informed risk analysis and policy making. The wide range of length and time scales involved in earthquake processes (from sub-millimeter scales to hundreds of kilometers and from milliseconds to centuries) poses a critical barrier to addressing these needs with conventional numerical schemes such as time-marching finite element and finite difference methods on non-adaptive meshes. The multi-scale character renders solutions by these methods computationally intractable, even on state-of-the-art supercomputing platforms. We propose an asynchronous space-time Discontinuous-Galerkin (aSDG) method with dynamic adaptive meshing to meet this challenge. The aSDG method easily accommodates variations of spatial and temporal resolution of several orders of magnitude across the solution domain.

We demonstrate the capabilities of the aSDG method for resolving rupture propagation across complex fault zones using a unique model with explicit representations of pre-existing small-scale secondary faults and branches. This model enables new insights into earthquake rupture dynamics that might not be realizable in homogenized isotropic plasticity or damage models that typically smear out the secondary cracks. Specifically, we show that in addition to acting as energy sinks, secondary faults can also be energy sources that promote transient accelerations of rupture-propagation speeds and slip rates on the main fault. We also show that these secondary features significantly affect the stress state on the main fault and contribute to the enhanced generation of high frequency radiation. The aSDG method accurately resolves the different phases of rupture growth and arrest as well as the radiation fields associated with the non-uniform propagation. The method's dynamic adaptive meshing provides unprecedented resolution of rupture process zones and global elastodynamic fields. We discuss the potential of the aSDG scheme to provide a unique computational pathway to efficient multiscale dynamic rupture simulations in seismology and a critical missing link for transitioning between physics-based simulation and societal risk management.