Kinetic-Global Coupling in Coronal Reconnection

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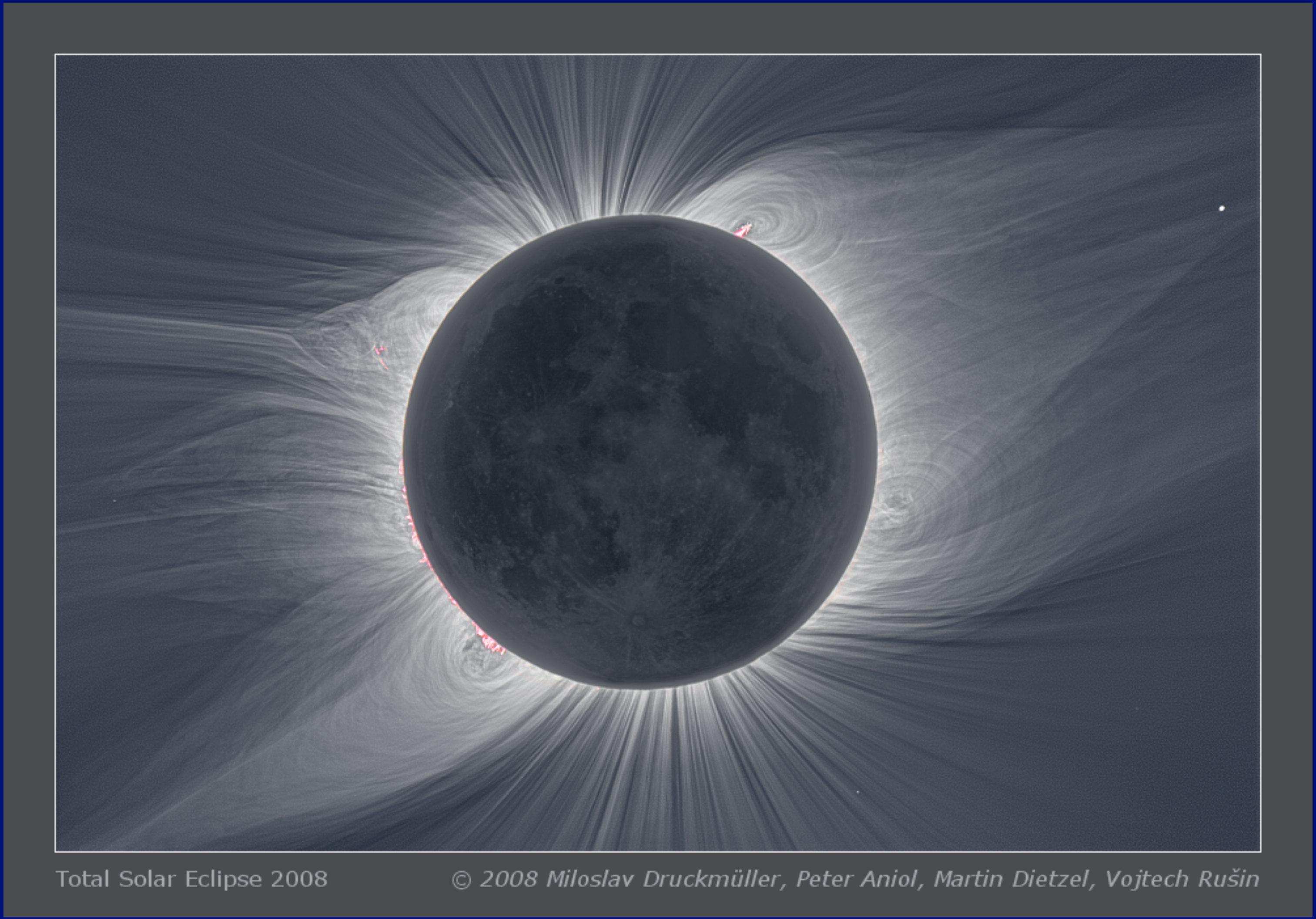
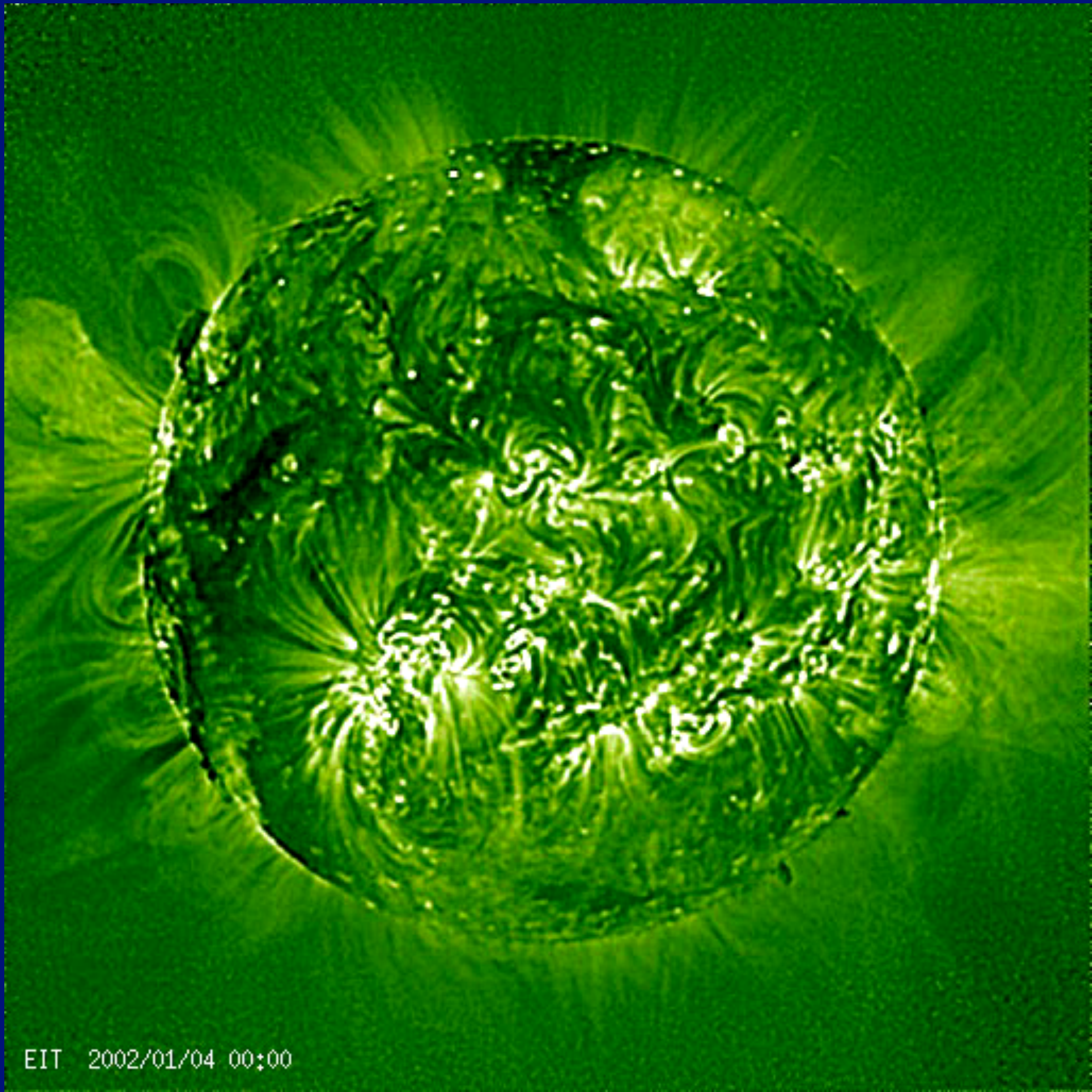


- B adds both structures and dynamics to corona and beyond
- Couples global and physical domains

Coronal Dynamics

Observations:

- Corona exhibits activity at all scales
- SOHO EIT Fe XII 195 A, T ~ 1.5MK
- Prominence ejection/ CME/flare: largest forms of explosive activity
  - Primary drivers of space weather
  - Flare heating/particles due to coronal reconnection
  - CME acceleration still debated



Coronal Activity

Physical properties of Sun's corona:

- $T \sim 10^6$ K, $n \sim 10^9$ cm^{-3}, $B \sim 10^2$ G,
- $V_A \sim 1{,}000$ km/s, $V_S \sim 100$ km/s, $V_{photo} \sim 1$ km/s
- $L \sim 10^9$ cm, $\lambda_{mfp} \sim 10^7$ cm, $\lambda_g \sim \lambda_i \sim 100$ cm
- $\tau_c \sim 1$ s, $f_p \sim 10^8$ /s, $f_{cp} \sim 10^4$ /s

- Low plasma $\beta \sim 10^{-2}$
- High Lundquist number $\sim 10^{10}$
  - Negligible diffusion, plasma frozen-in to B-field
  - B topology and reconnection all-important
- High-β, line-tied photosphere – E & K source
- But system open to heliosphere – E & K sink

Magnetically Driven Solar Activity

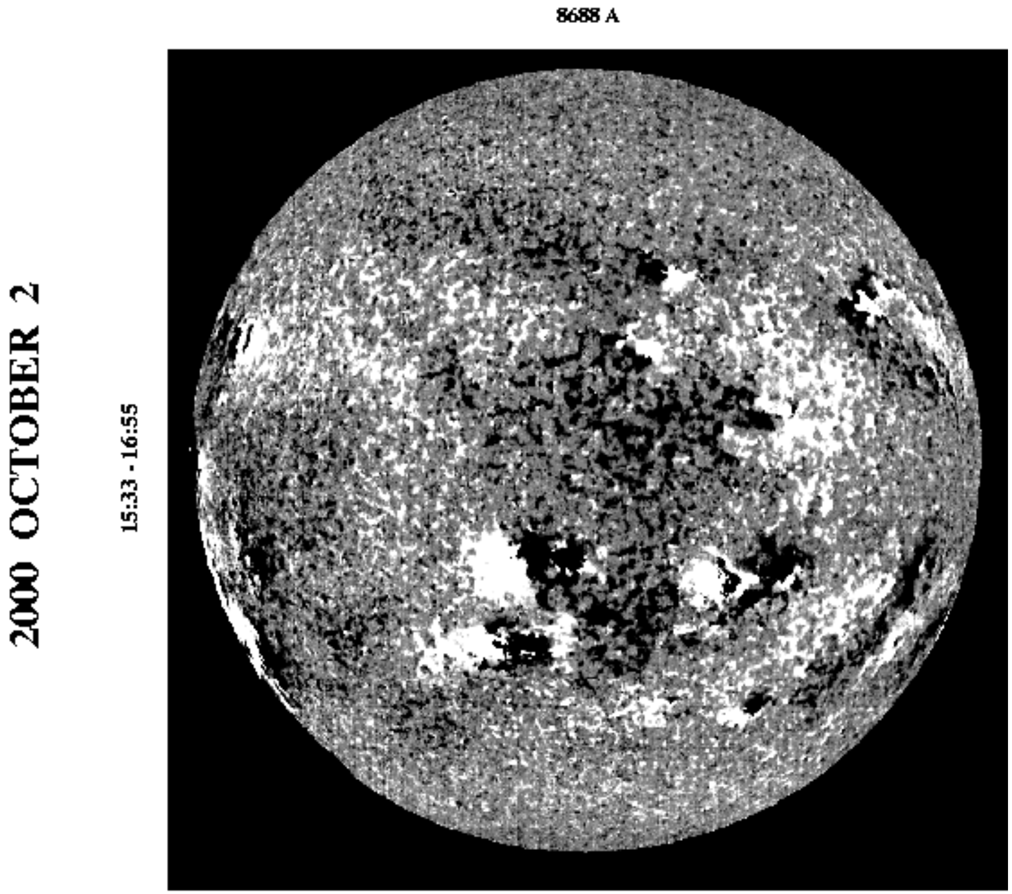
- Coronal energy injected quasi-statically ($\tau << t_A$) due to slow (V ~ 1 km/s) photospheric stressing
- Free energy builds up to critical levels, $E \sim 10^{32}$ ergs for CMEs/flares
  - Energy input & storage on global scales
- Energy lost either through ejection to heliosphere or heating/particles via reconnection
- But reconnection conserves helicity

$$K \equiv \int_V (\vec{A} + \vec{A}_p) \cdot (\vec{B} - \vec{B}_p)$$

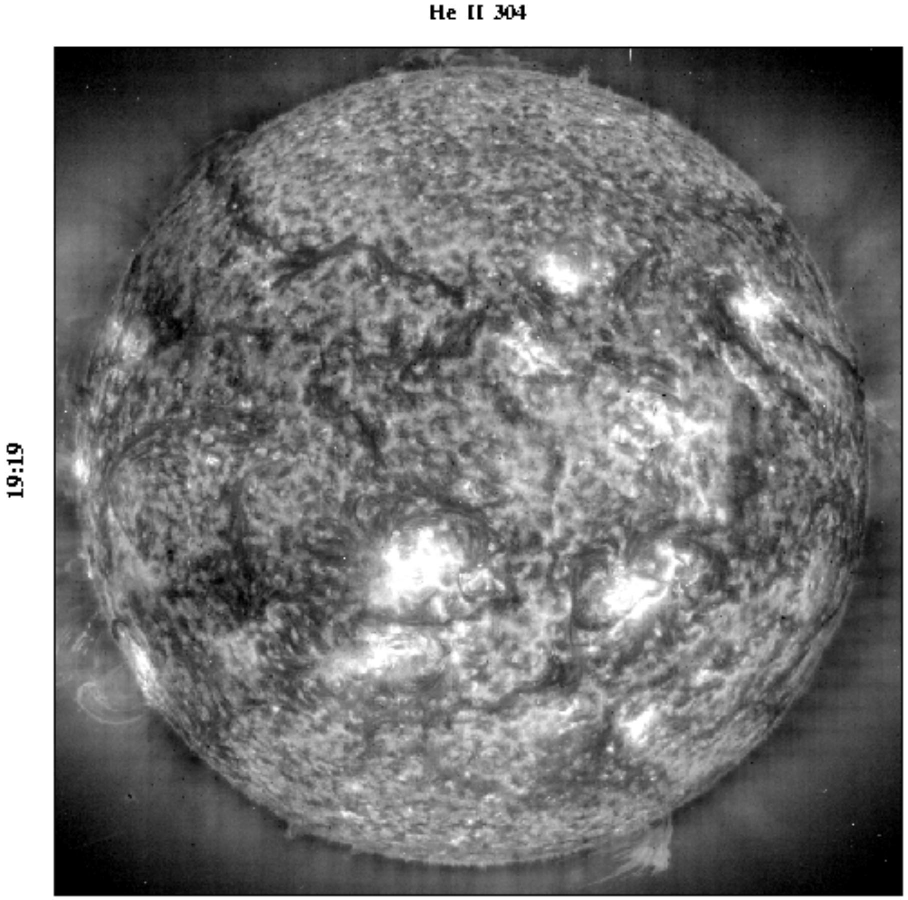
- Large-scale shear must be ejected

Coronal Free Energy and Helicity

- Strong shear in filament channels overlying polarity inversion lines
- Helicity concentration
- Fundamental origin of ejective activity



Kitt Peak magnetogram

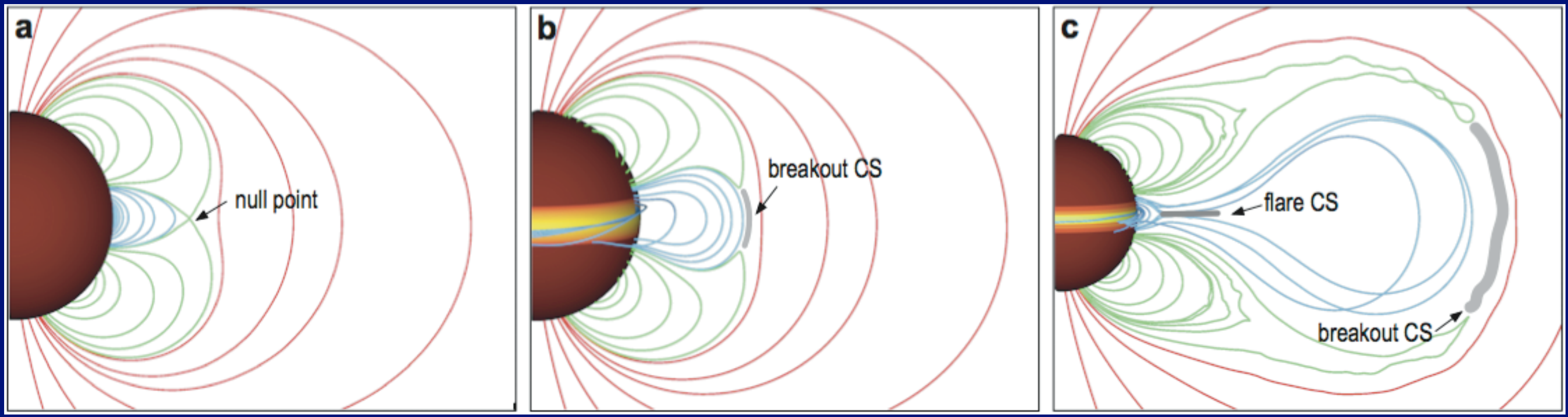


EIT/SOHO UV

Breakout Model for CME/eruptive flares

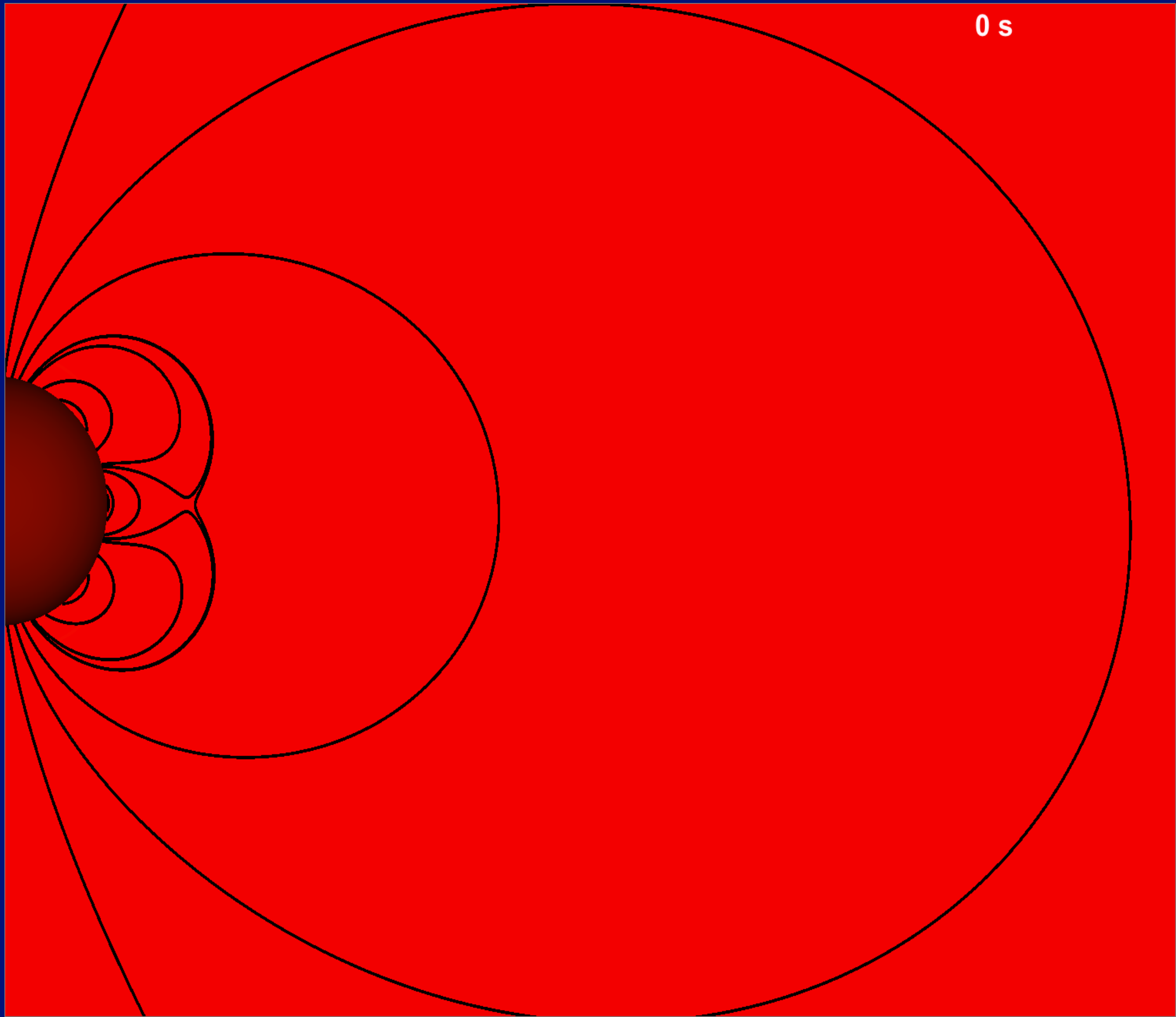
Striking example of local – global coupling:

1. Build up E & K with slow footpoint shear – ideal phase
2. Reconnection *(or ideal)* at null disrupts force balance
3. Stretching of field lines produces CS below rising flux
4. Flare reconnection produces explosive energy release and relaxes system back to ~ potential state,

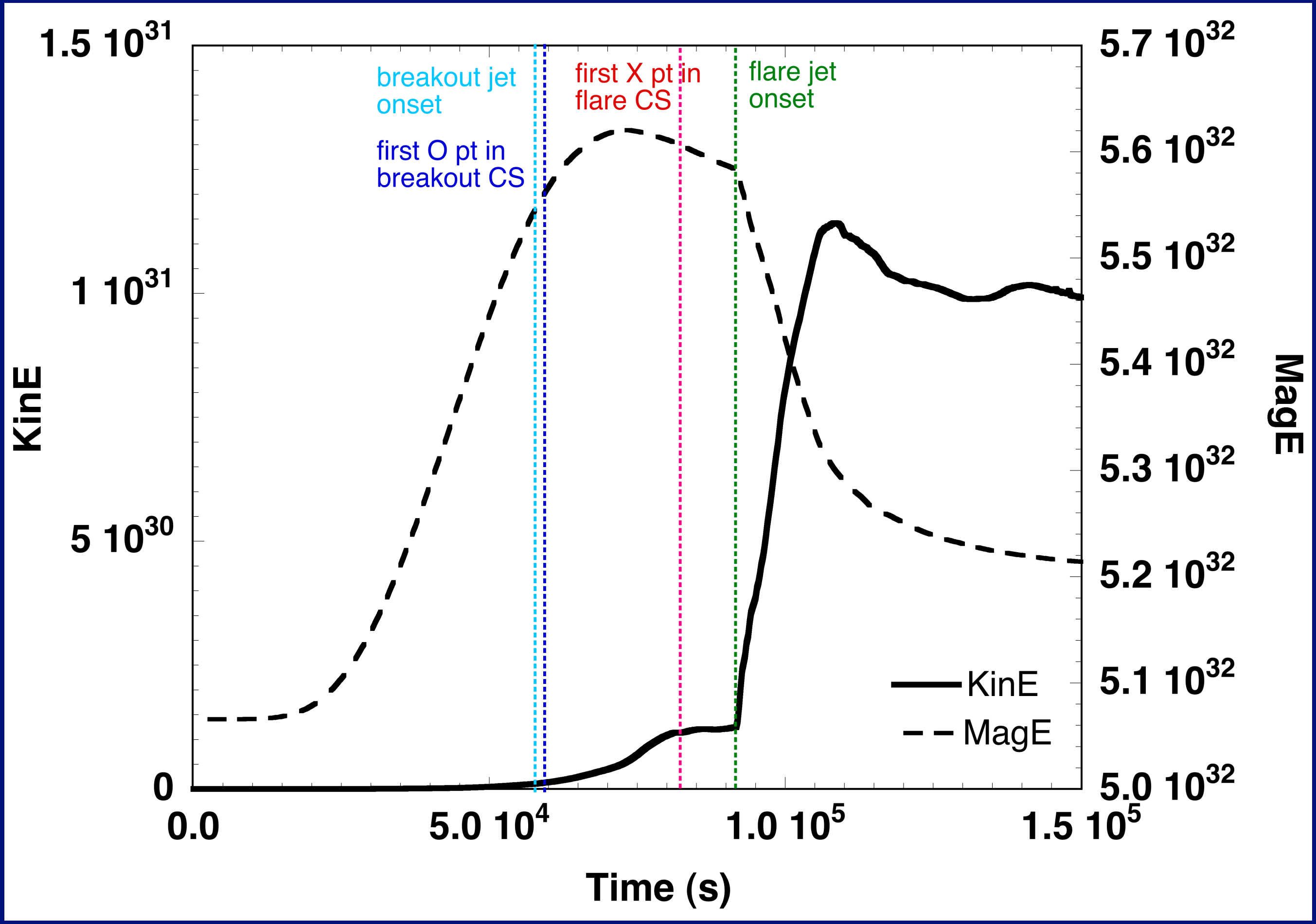


Coronal Mass Ejection

- Ultra-high resolution amr breakout simulations (Karpen et al 2012)
  - Clearly separates phases of event
- Null current sheet must extend to global scale in order to reach flux-breaking scale
- Reconnection dynamics dominated by magnetic islands (plasmoid or secondary tearing instability)
- Dependence on η?

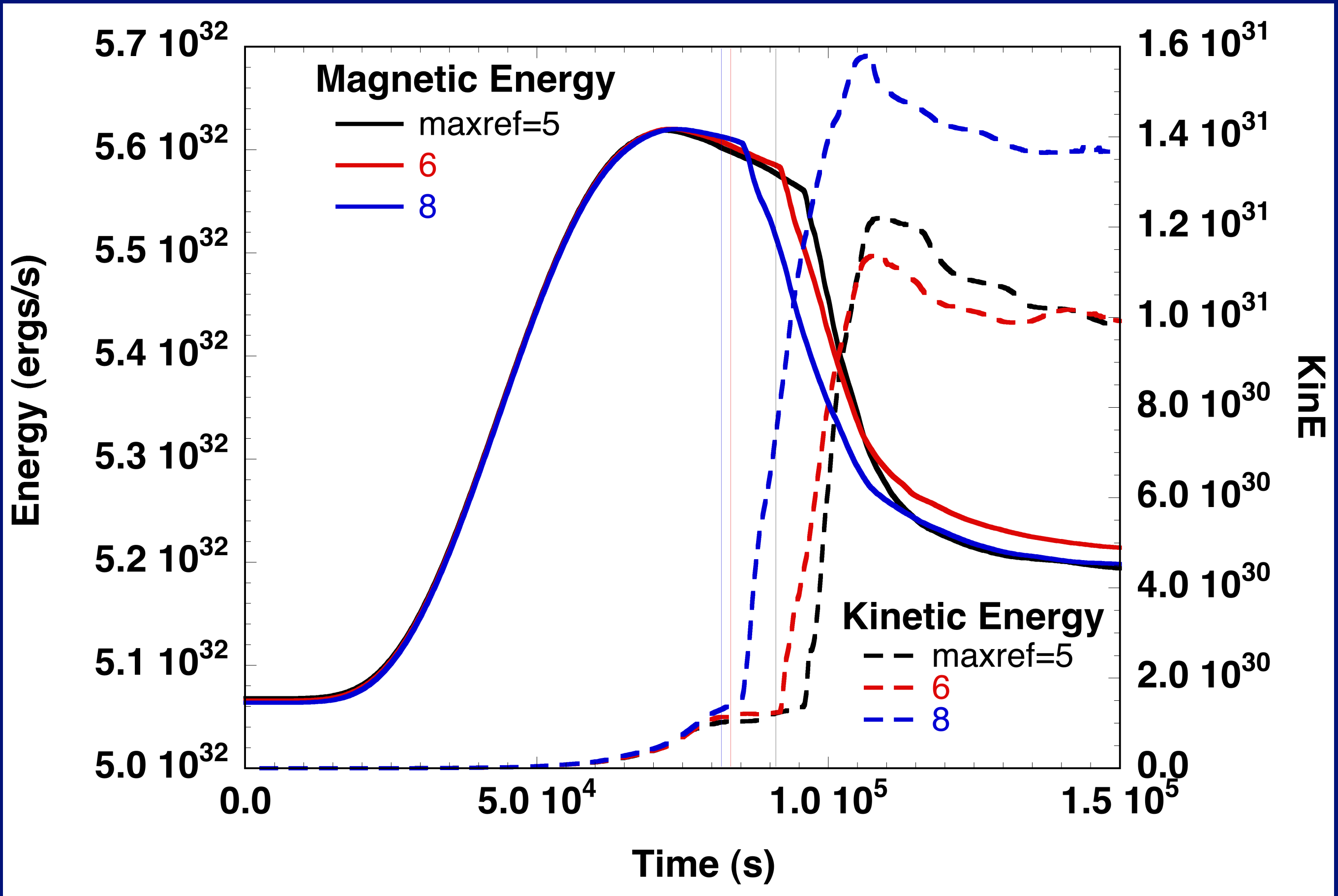


Energy Evolution



- CME onset corresponds to start of breakout reconnection
- Explosive acceleration corresponds to start of fast flare reconnection

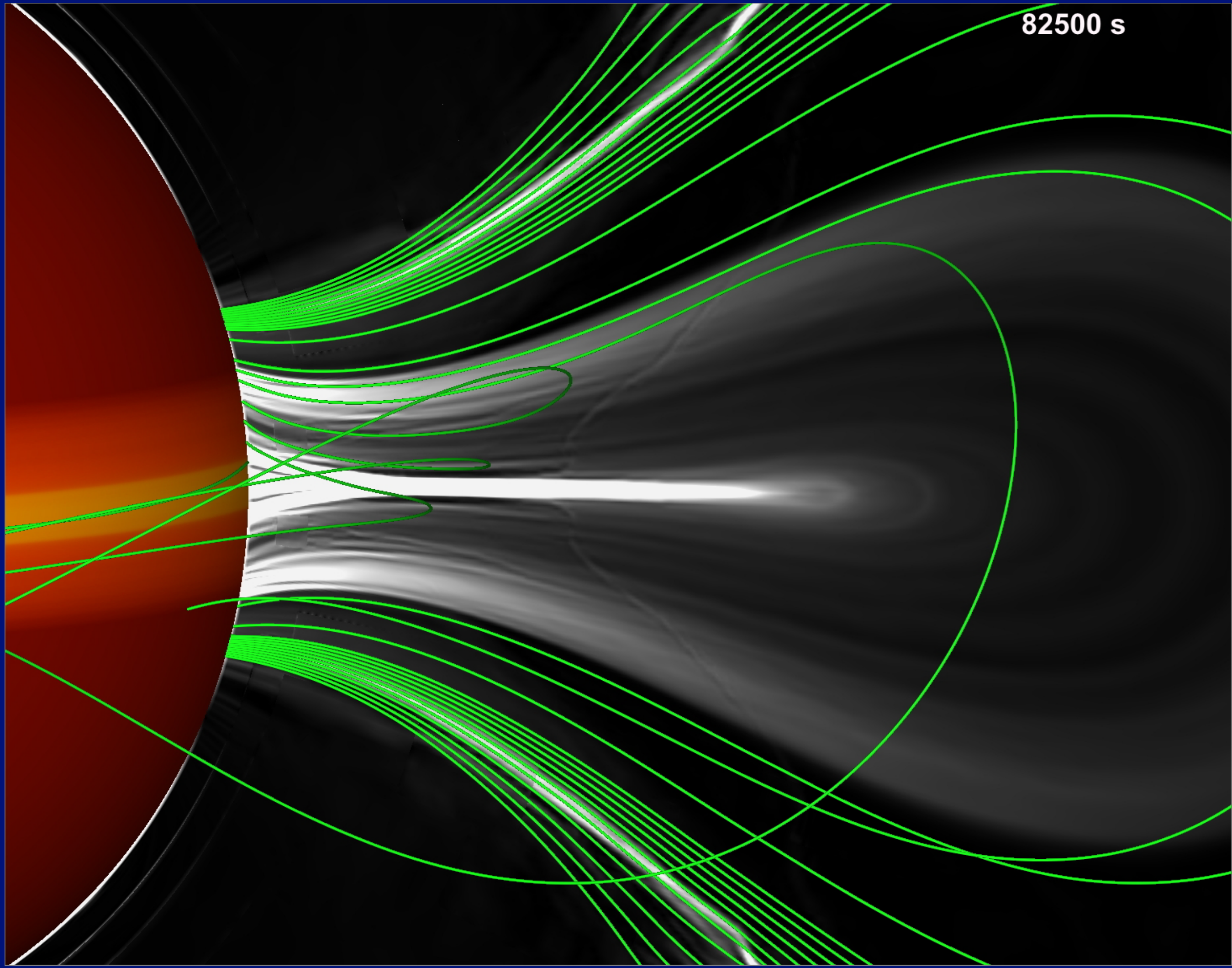
Energy Scaling with S



- Basic onset and take-off evolution unchanged
- Energetics essentially independent of S
- For numerical resistivity, reconnection keeps pace with erution

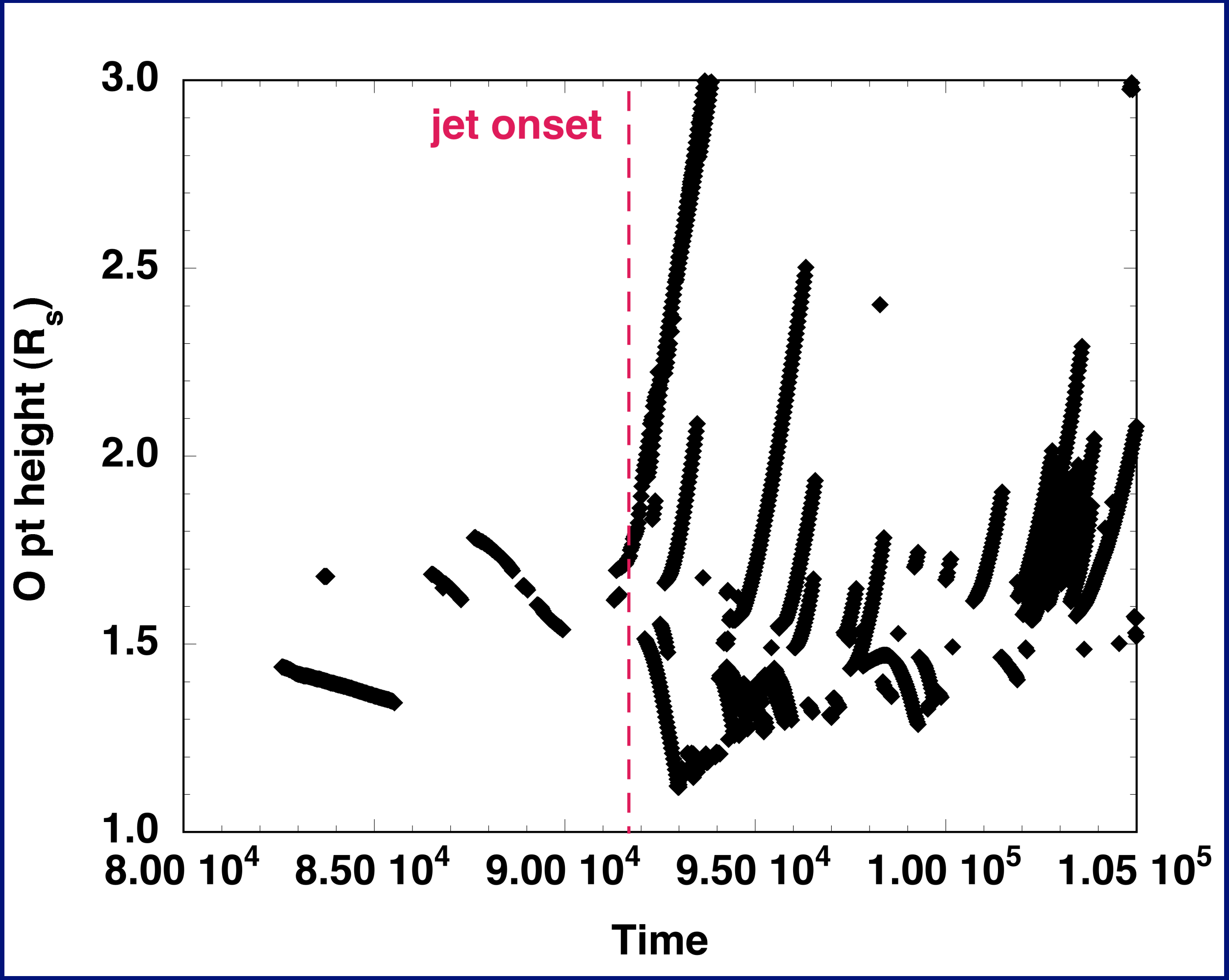
Solar Flare

- Dipolar stretching produces global-scale current sheet
- Extreme energy storage



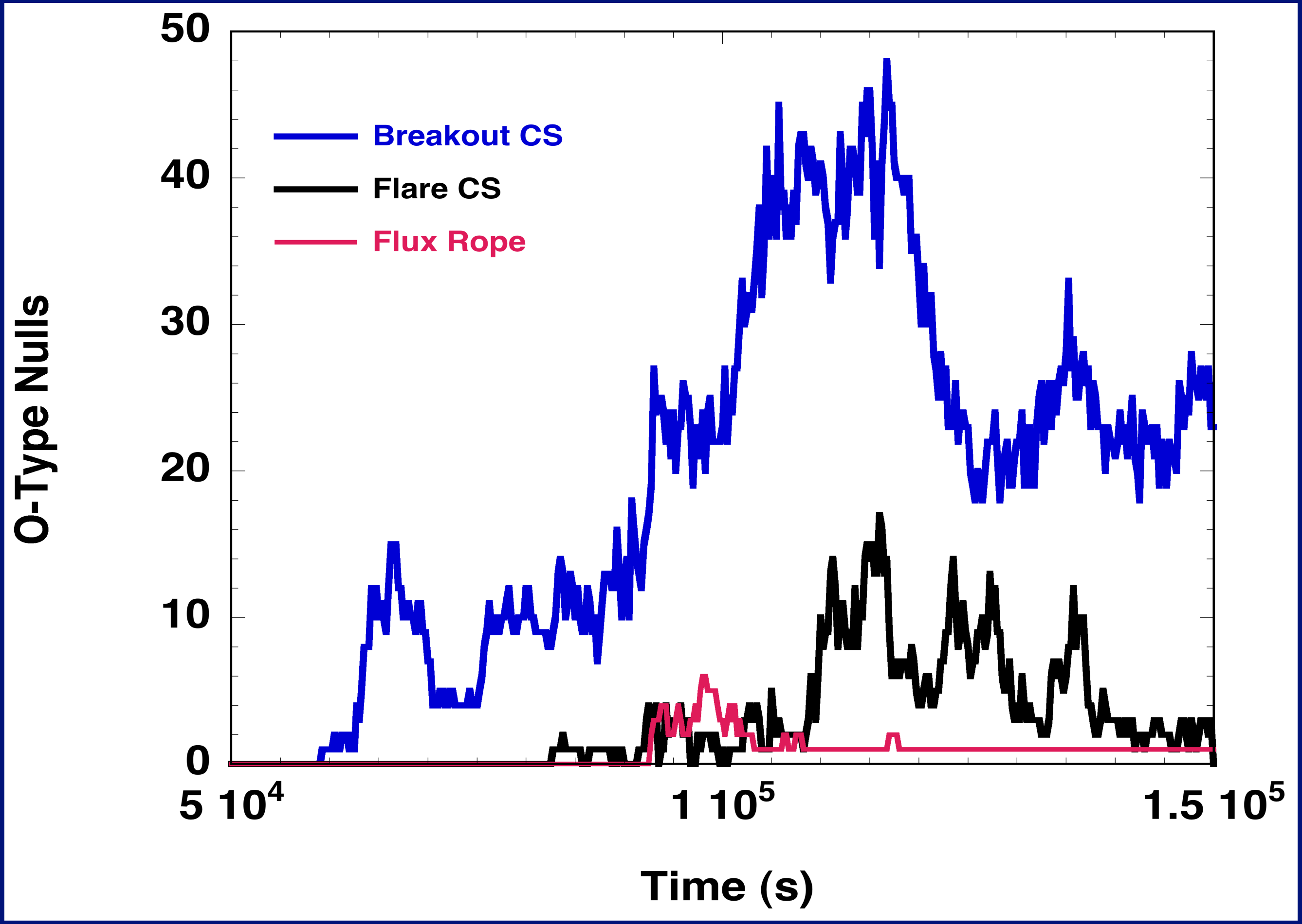
- Flare reconnection bulk of energy release for CME/ flares
- Two-phase reconnection, islands appear before Alfvenic motions
- Scaling with η?

Flare Reconnection



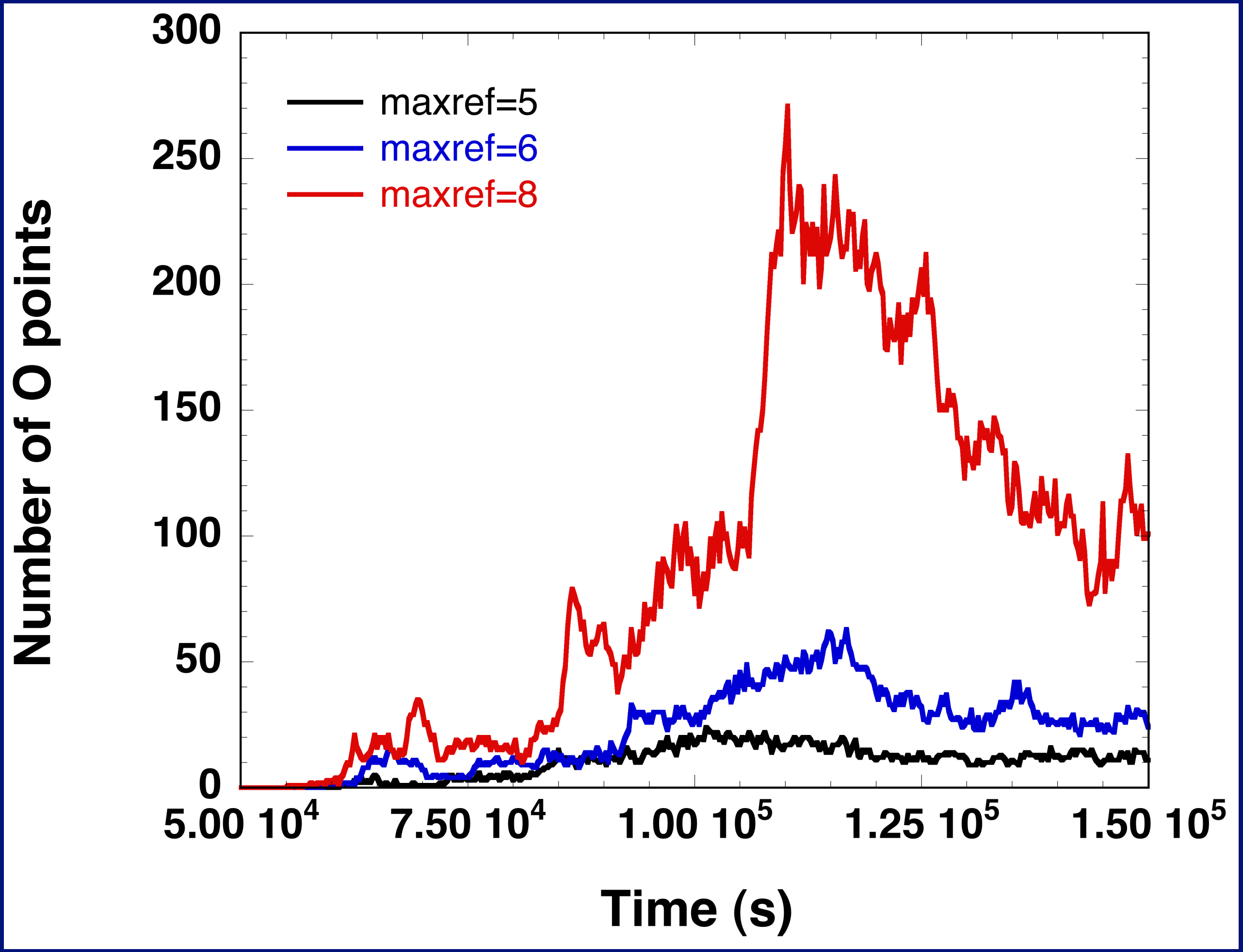
- Downward moving islands well before significant dynamics
- First upward moving O-point produces explosive feedback

Plasmoids



- Numbers of “O” nulls in breakout and flare current sheets
  - Clear increase during “take-off ” phase
- Reconnection “fast” ~ .09 V_A

Plasmoid Scaling with S



- Number of islands scales ~ S
- Required for fast reconnection

Conclusions and Challenges:

- Basic model works for numerical or uniform η
- Mechanism for shear buildup?
- Mechanism for force balance disruption: ideal or reconnection?
- Global and local dynamics for true kinetic flux breaking
- How can we capture the multiscale coupling in our models (space weather prediction)?
  - (e.g., work by Kuznetsova and Hesse)

Integrating Kinetic Effects into Global MHD

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Strategy:

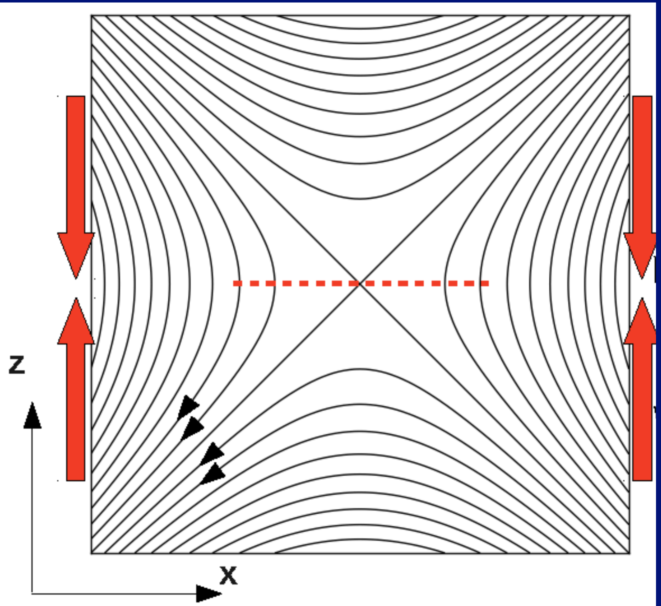
- Calculate complete energy input and release process with different physics models
  - MHD, Hall MHD, kinetic
- Assume kinetic gives ground truth and determine what needs to be added to MHD to match kinetic

Problems:

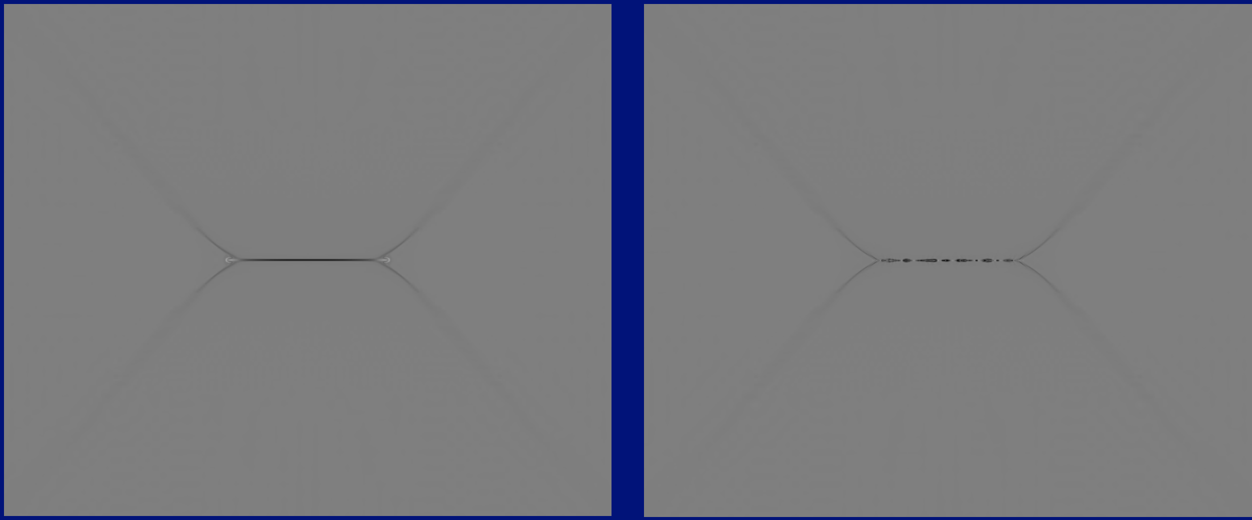
- Null-point current sheet formation and reconnection
- B-tail reconnection

Integrating Kinetic Effects into Global MHD

Null-point reconnection



Initial 2D equilibrium:



Uniform resistivity   numerical resistivity

J out of plane from MHD simulation: DeVore, Karpen, Black, & Antiochos (GSFC/NRL)

PIC results, L. Wang, N. Bessho, A. Bhattacharjee, K. Germaschewski (UNH)