

# Coronal Mass Ejection Plasma Heating by Alfvén Wave Dissipation

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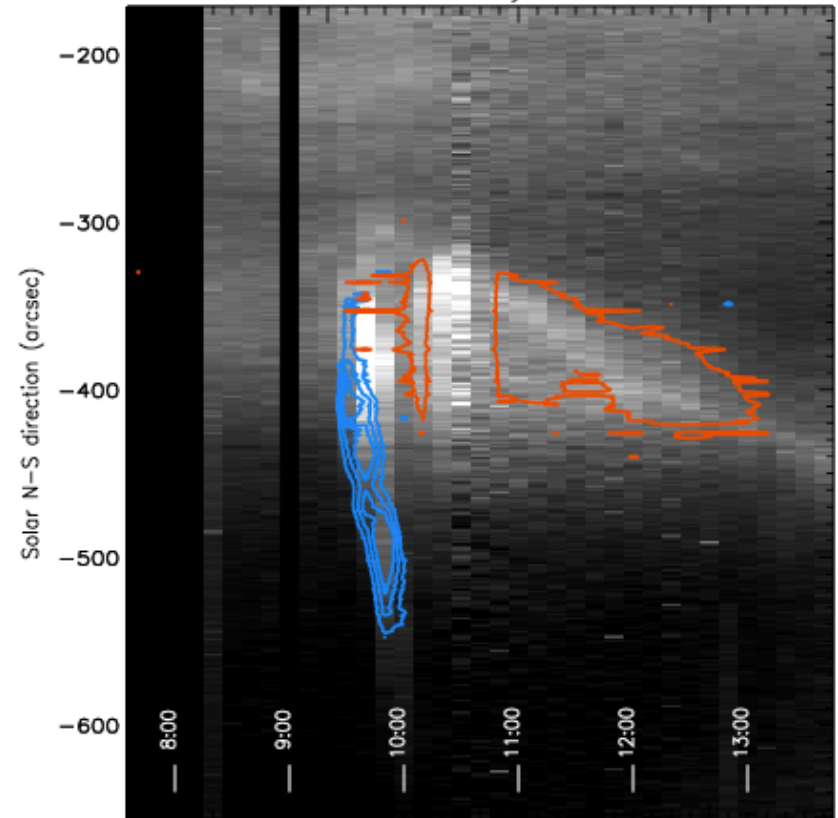


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# CME Plasma Properties Near the Sun

- Extensive data set
  - SDO/AIA; STEREO/EUVI, SECCHI; SOHO/ LASCO, EIT, UVCS; Yohkoh/SXT, Hinode/XRT, EIS; MLSO, and many more...
- Challenge to simultaneously determine speed, mass, and temperature
- Thermal energy can exceed kinetic energy (*Akmal et al. '01; Ciaravella et al. '01, Lee et al. '09; Landi et al. '10*)

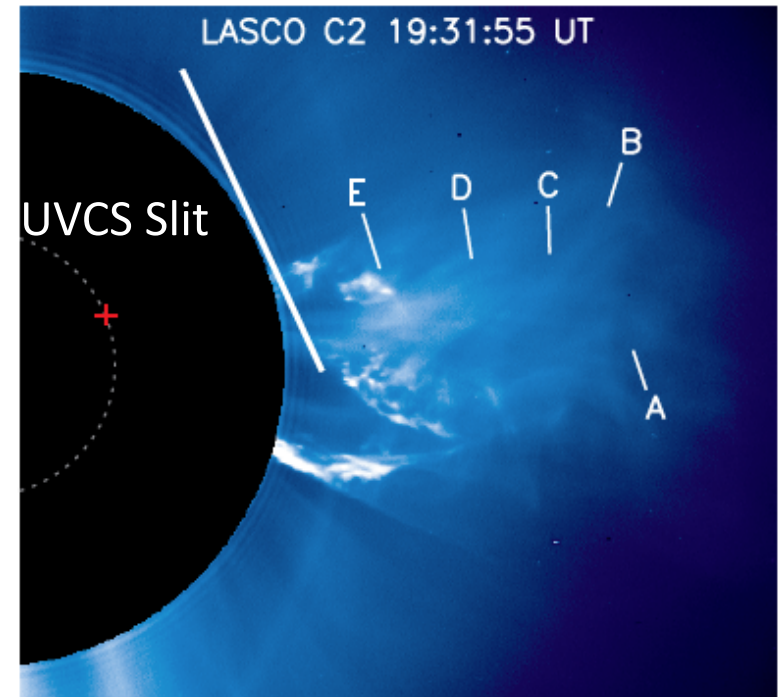
XRT images and EIS contours



*Landi et al. '12*

# Proposed Heating Sources

- Current sheets, slow shocks, kink instability, small-scale reconnection, wave heating, thermal conduction, energetic particles, counteracting flows, ohmic heating from net current in the flux rope...
- Case studies (*Landi et al. '10; Murphy, Raymond & Korreck '11*)
  - **Wave heating** based on models of fast solar wind
$$Q \sim \exp\left(-d/L\right)$$
  - **Conclusion: heating is orders of magnitude too weak**



*Murphy, Raymond & Korreck '11*

***What is the heating rate during transient events?***

# Numerical Experiment

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- **Space Weather Modeling Framework**

(*van der Holst et al. '10, Evans et al. '12, Toth et al. '12, Sokolov et al. '13*)

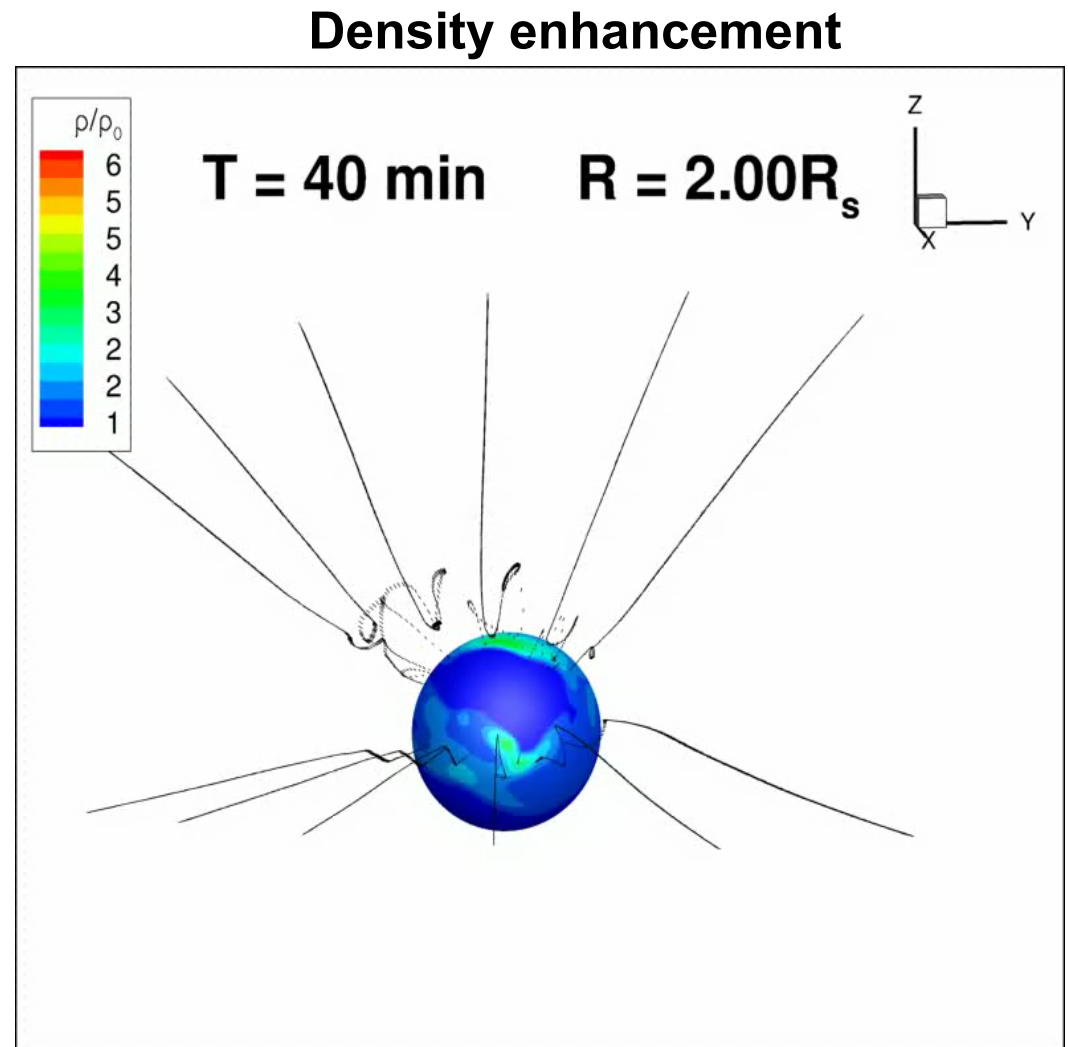
- Global, MHD, Alfven wave-driven solar wind model
- Wave energy transport eqn. coupled to MHD eqn.s
- **Self-consistent wave heating calculation**
  - Turbulent cascade ( $E_w, B, \rho$ )
  - Resonant absorption (*density gradient*)

- **Limitations/Simplifications:**

- Eruption is modeled as out-of-equilibrium flux rope
- Waves only along open field lines (lifted in *Sokolov et al. '13*)

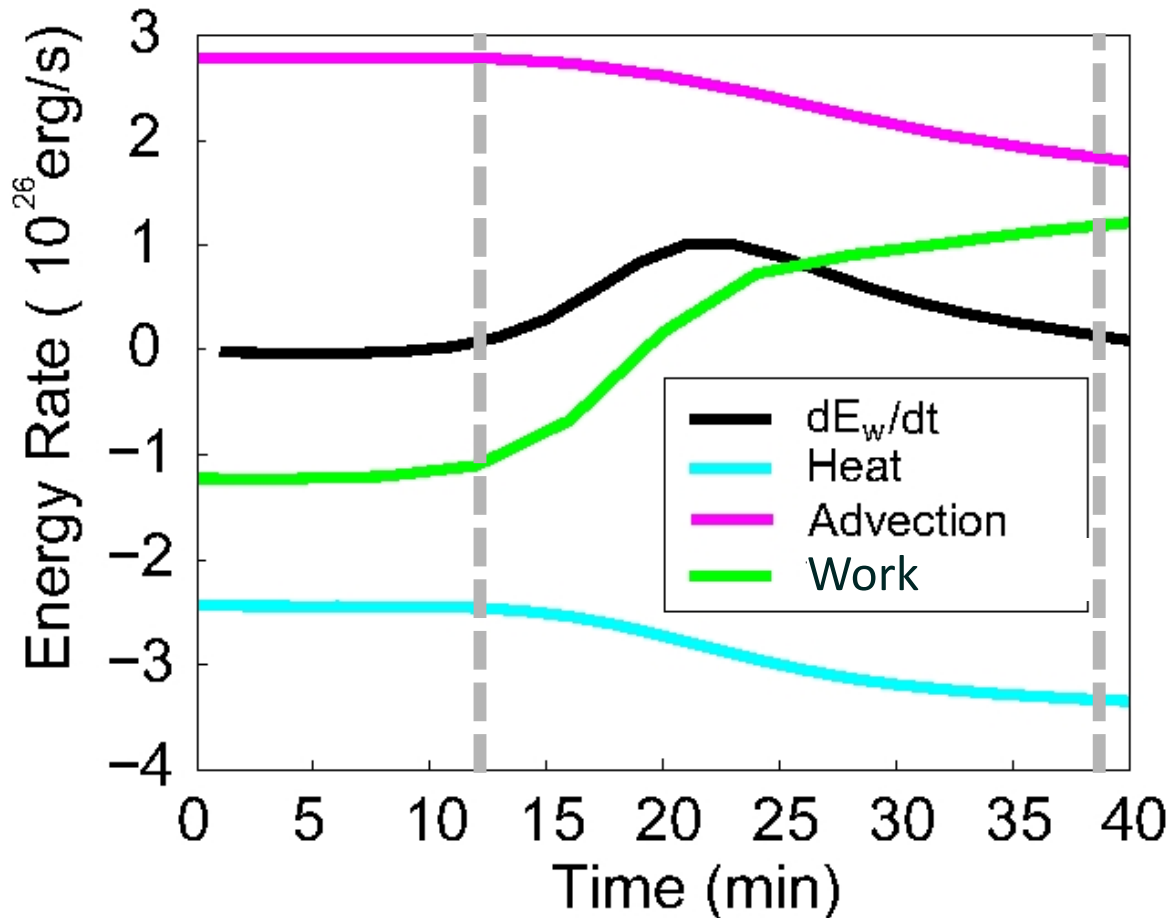
# CME Evolution

- Fast eruption, quickly drives a shock wave
  - $\sim 1,500$  km/s
- As ejecta expands, it piles up material in front of it, creating a *structured sheath region*  $\rightarrow$  wave damping



# Wave-Solar Wind Plasma Interaction

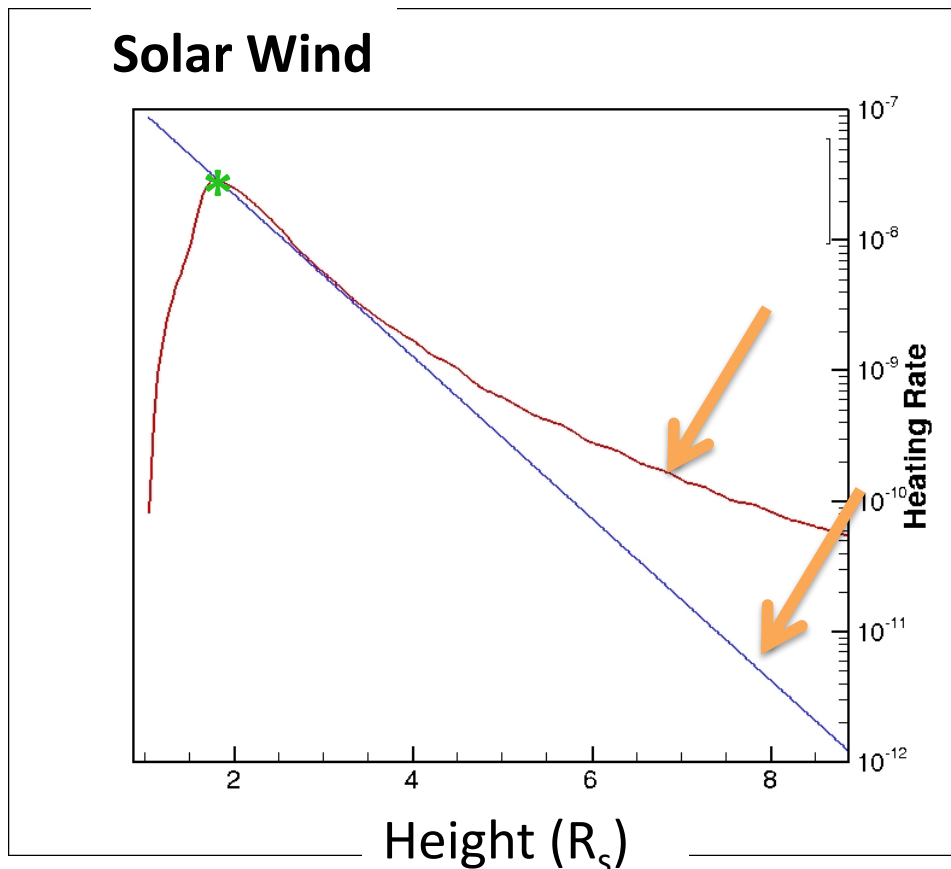
**Wave Energy Evolution:** 
$$\frac{dE_w}{dt} = -\nabla \cdot \left[ E_w \vec{V}_g + P_w \vec{U} \right] + \vec{U} \cdot \nabla P_w - \Gamma E_w$$



- Shock and piled-up compression regions lead to momentum exchange from plasma to waves
- More wave energy available to dissipate
- Also, damping rates are enhanced in structured sheath

# Evolution of the Wave Heating

- Heating rate along a radial line from 1-10  $R_s$ .
- Simulation (red line), Exponential form (blue line)  $Q \sim \exp(-d/L)$



$$Q = \Gamma_{SAW} E_w + \Gamma_{TURB} E_w$$

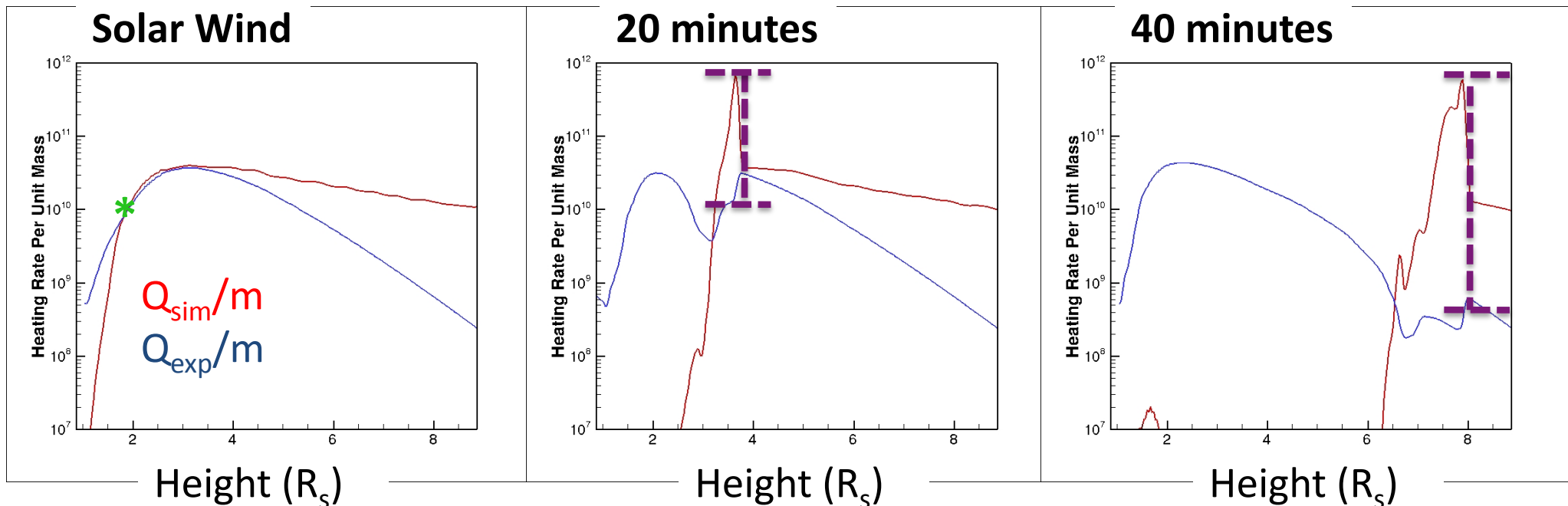
$$\Gamma_{SAW} = \frac{1}{C_{SAW}} \left( \frac{v_{sg}}{\rho / \nabla \rho} \right)_{\perp}$$

$$\Gamma_{TUR} = \frac{1}{C_{TUR}} \sqrt{\frac{E_w B}{\rho}}$$

# Evolution of the Wave Heating

- Heating rate per unit mass, along a radial line from 1-10  $R_s$ .
- Simulation (red line), Exponential form (blue line)  $Q \sim \exp(-d/L)$

*CME-sheath heating by waves may be orders of magnitude larger than in the solar wind*





# Next Steps

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- In this work, limited to CME-sheath because waves only in open field regions
- Wave energy is now present in entire simulation domain (*Sokolov et al. 2013*)
- Apply to CME 'blobs', connecting to observational studies
- Explore a range of coronal conditions and CME properties

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