

# Simulating Energy Emission Spectra in Solar Flares

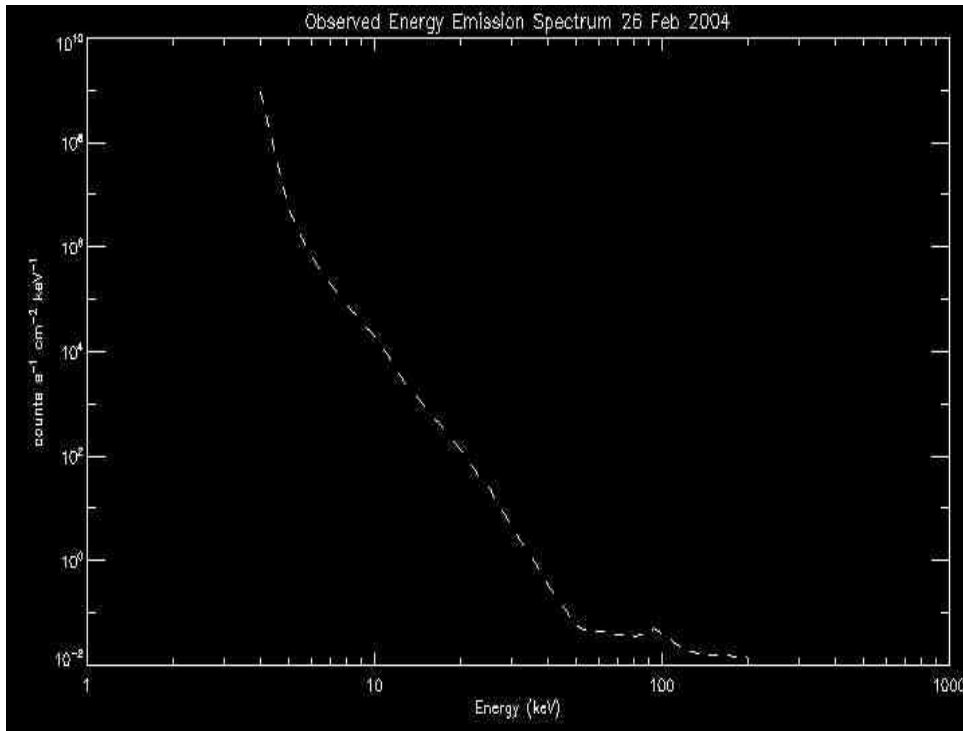
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# Sequence of Topics

- Observational Context
- Scientific Introduction
- The Model
  - Idea, governing equations, and parameters
- The Simulation
- Results
- Future Work
- References

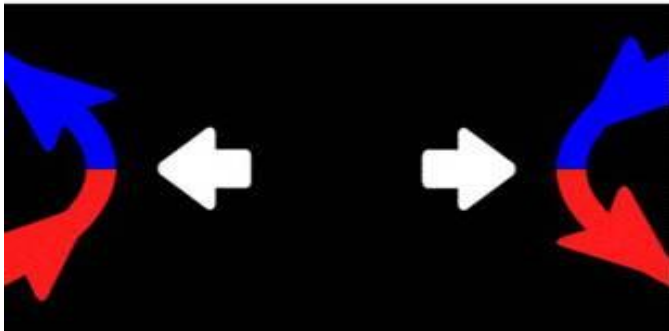
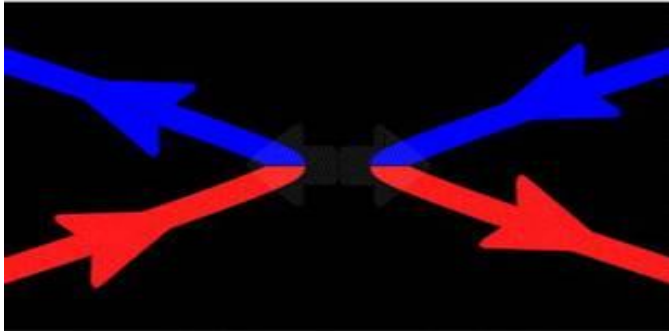
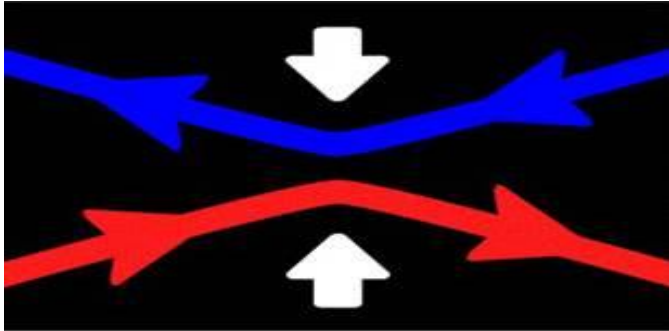
# Context : Observations



- X-class flare, 26 Feb 2004
- Unique traits:
  - Few non-thermal particles
  - Super-hot ( $T > 30\text{MK}$ )
  - Hard x-ray emission
- What mechanisms govern total energy release?

In the absence of non-thermal particles,  
**fluid-based magnetic reconnection**

# Magnetic Reconnection



- Change in magnetic topology to achieve lower-energy state
- Retraction of field lines due to tension converts stored magnetic energy into kinetic energy, heat

# The Model: Post Reconnection Evolution of a Flux Tube (PREFT)

- Initial conditions : bent flux tube in the post-reconnection state
- Energy is released as the flux tube retracts to equilibrium length
- Slow magneto-sonic shocks compress and heat the plasma to a loop-top source of hard x-ray emission

# Governing Equations (1D hydrodynamics)

- **Momentum Equation:**

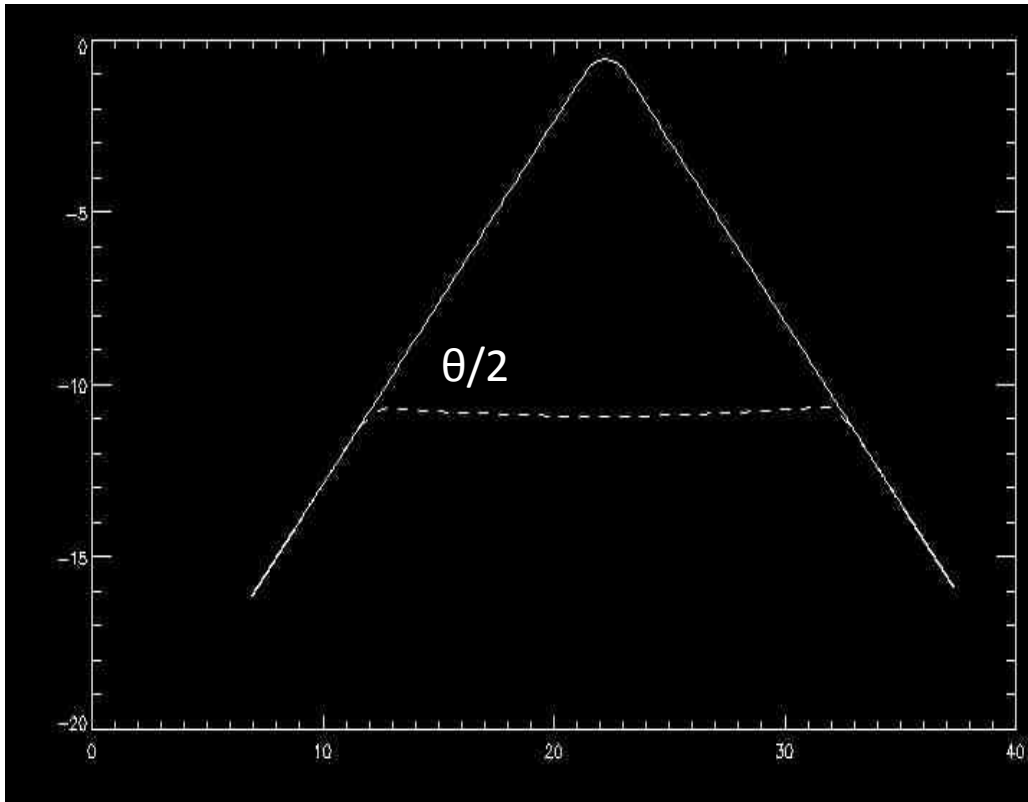
$$\rho \frac{dv}{dt} = \underbrace{\left( \frac{B^2}{4\pi} - p \right) \frac{\partial \hat{\mathbf{b}}}{\partial l}}_{\text{magnetic tension}} + \underbrace{\frac{\partial}{\partial l} \left( \frac{4}{3} \mu \hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial l} \hat{\mathbf{b}} \right)}_{\text{viscosity}} - \underbrace{\frac{\partial p}{\partial l} \hat{\mathbf{b}} + \rho \mathbf{g} \cdot \hat{\mathbf{b}}}_{\text{other forces}}$$

- **Energy Equation:**

$$c_V \rho \left( \frac{dT}{dt} \right) = \underbrace{-p \left( \hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial l} - \mathbf{v} \cdot \nabla \ln(B) \right)}_{\text{P dV work}} + \underbrace{\frac{4}{3} \mu \left( \hat{\mathbf{b}} \cdot \frac{\partial \mathbf{v}}{\partial l} \right)^2}_{\text{shock heating}} + \underbrace{\frac{\partial}{\partial l} \left( \frac{\partial T}{\partial l} \right) \kappa(T)}_{\text{thermal conduction}} - \underbrace{n_e^2 \Lambda(T)}_{\text{radiative losses}} + \underbrace{H_{eq}}_{\text{?}}$$

- (Assumptions:  $\beta \ll 1 \rightarrow$  Magnetic pressure dominates. Gravity, relativity negligible; magnetic field constant )

# Simulation Setup



- Measured parameters
  - Global magnetic field
  - Final tube length
- Free parameters
  - Reconnection angle ( $\theta$ )
  - Initial tube length
  - Initial loop-top temperature

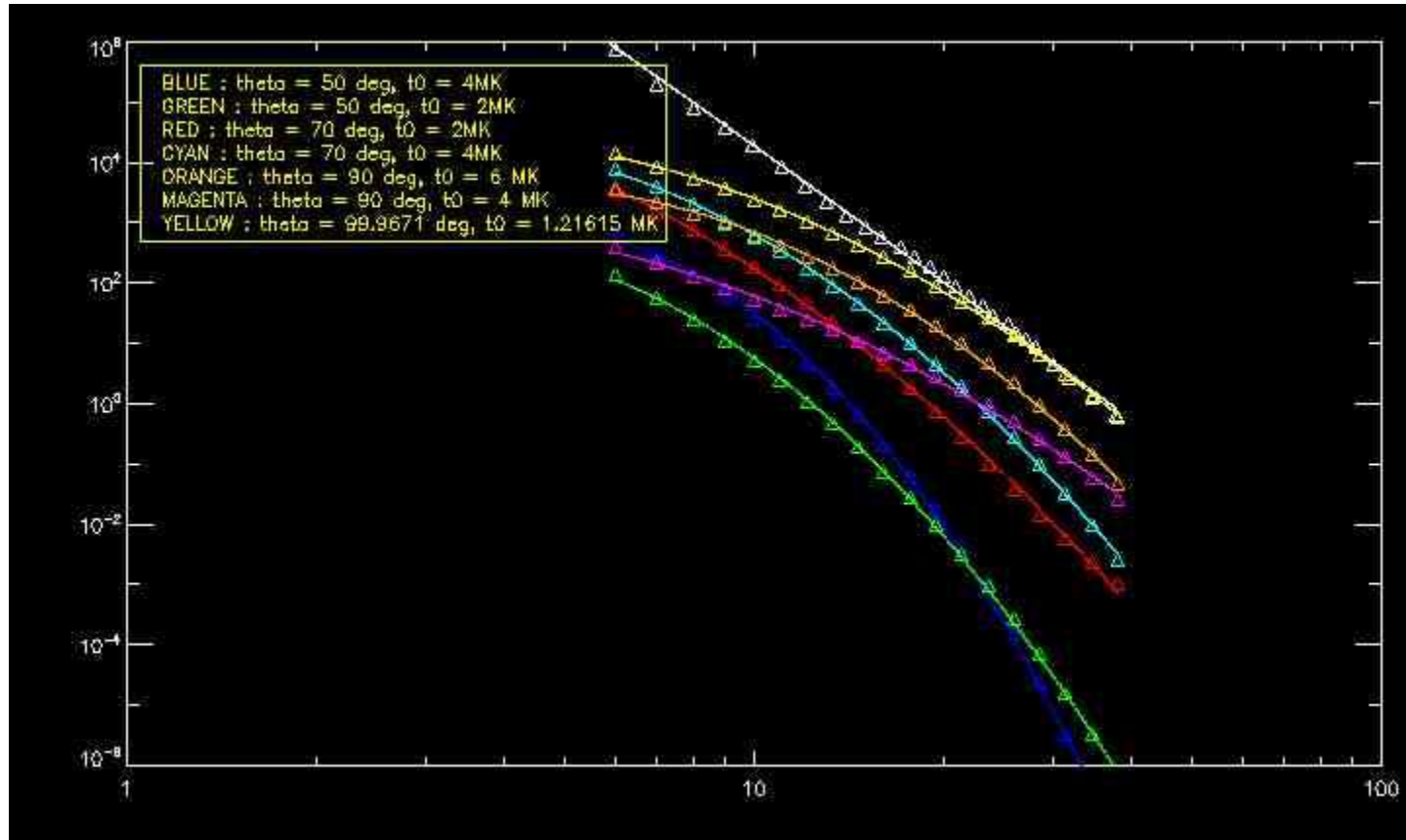
**Bonus:** 3-dimensional physics with 1-dimensional hydrodynamics (because of frozen-in theorem)!

# Simulation Specifics

- Dynamic length and time scales
  - Possible to recover small- and large-scale dynamics
  - Much easier in 1D!
- Progress of the Simulation
  - Retraction
  - “Straightening”
  - Cooling

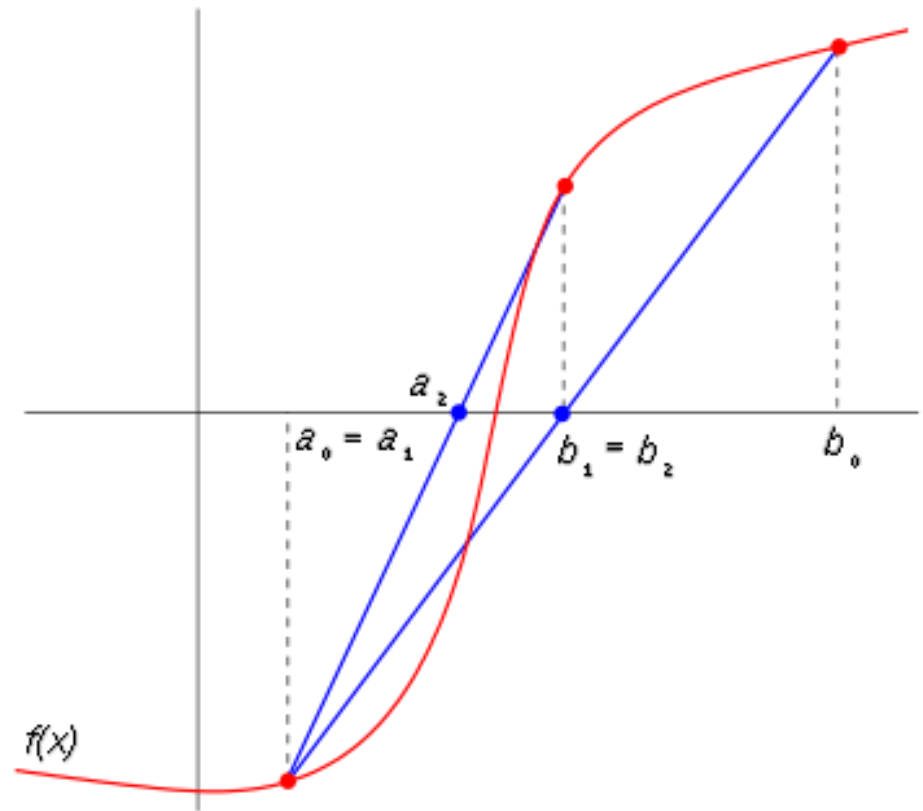


# Challenges of 3D parameter space



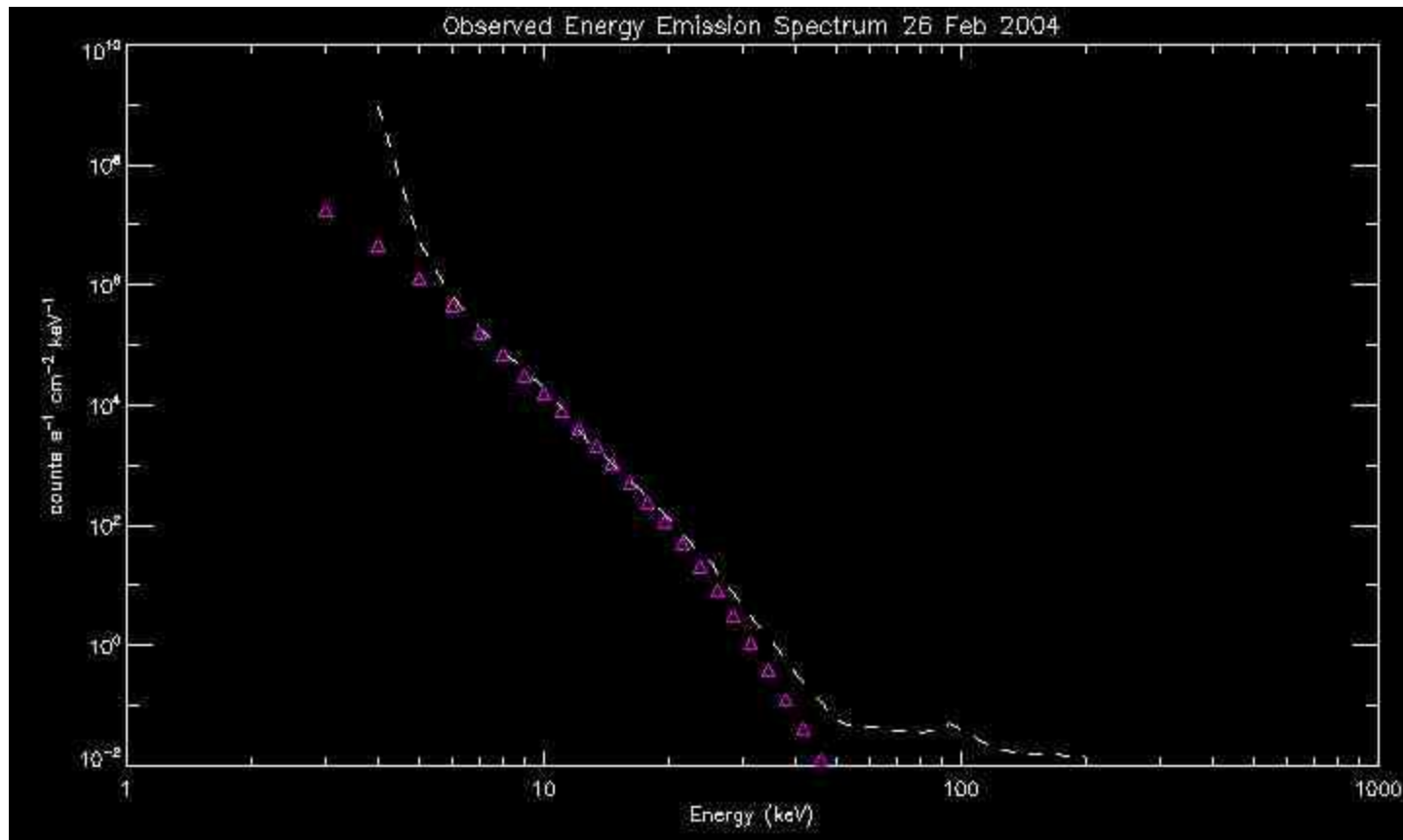
# Searching Parameter Space

- Root-finding in 3 (parameter) dimensions via generalization of the *regula falsi* (“false position”) method



# Preliminary Results

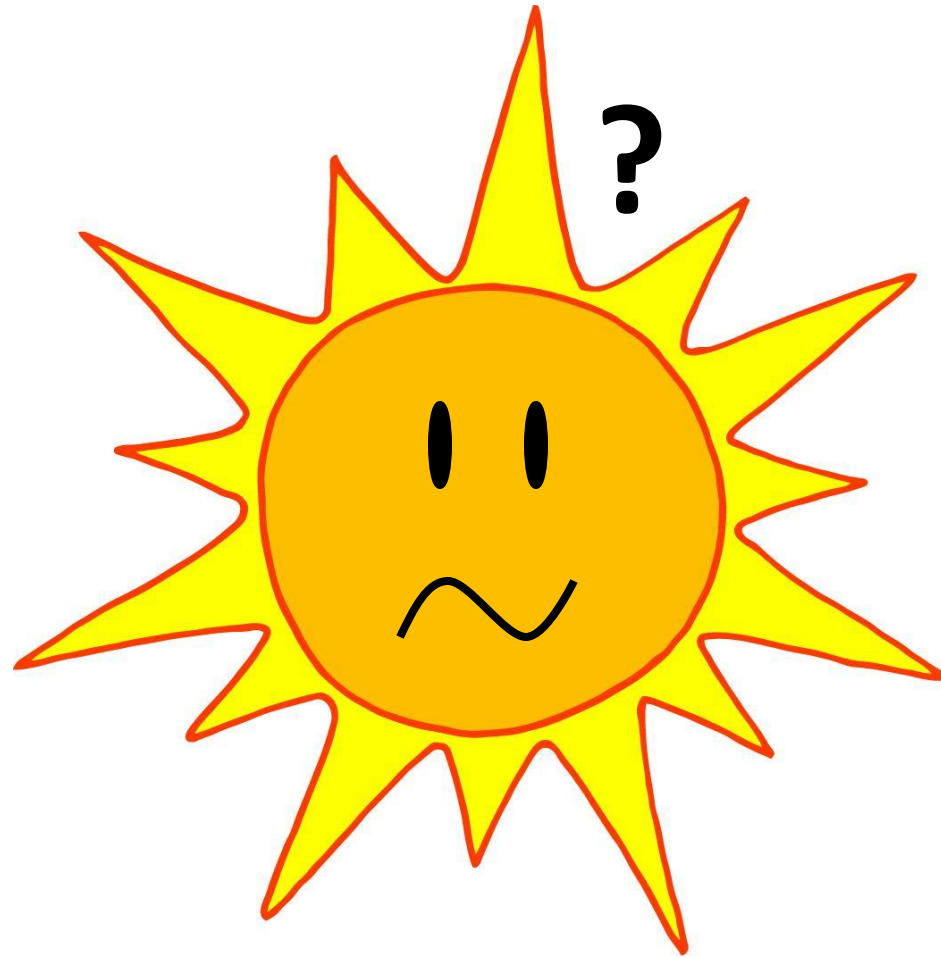
- Initial length = 43.5 Mm
- Initial loop-top temperature = 4.5 MK
- Reconnection Angle = 92 degrees
- Magnetic Field = 400 G
- Final Length = 35 Mm



# Future Work

- **STEP 1** : Are there parameters that will allow a better fit at high and low energies?
- **STEP 2** : Fitted to energy emission, how well does our simulation reproduce other observables from the flare?
- **STEP 0- $\infty$**  : What does this tell us about the physics of flares?

# Questions?



# References

- *“Modeling the Response of the Lower Atmosphere to Flare Reconnection”*.  
Presentation, Dana Longcope and Jiong Qiu
- *“A Quantitative Model of Energy Release and Heating by Time-Dependent, Localized Reconnection in a Flare with Thermal Loop-top X-ray Source”*. D.W. Longcope, A.C. Des Jardins, T. Carranza-Fulmer, J. Qiu