Heating of the Magnetically Closed Corona

James Klimchuk, PI
Therese Kucera, Deputy

Vladimir Airapetian
Jeffrey Brosius
Sherry Chhabra
Ineke De Moortel
Lars Daldorff
Craig Johnston
Judith Karpen
Kalman Knizhnik
Pankaj Kumar
James Leake
Marcelo Lopez Fuentes
Cecilia MacCormack
Samuel Schonfeld
Shanwlee Sow Mondal
Jenny Rodriguez Gomez
Vadim Uritsky
Peter Young
Nicholeen Viall
Yihua Zhang

Italic – joined after start

Problem:

Determine how the magnetically closed corona is heated and how the plasma responds to produce the spectrum of emitted radiation.

Long-term goal:

Develop a physics-based model of the solar spectral irradiance (SSI) with eventual operational capability.

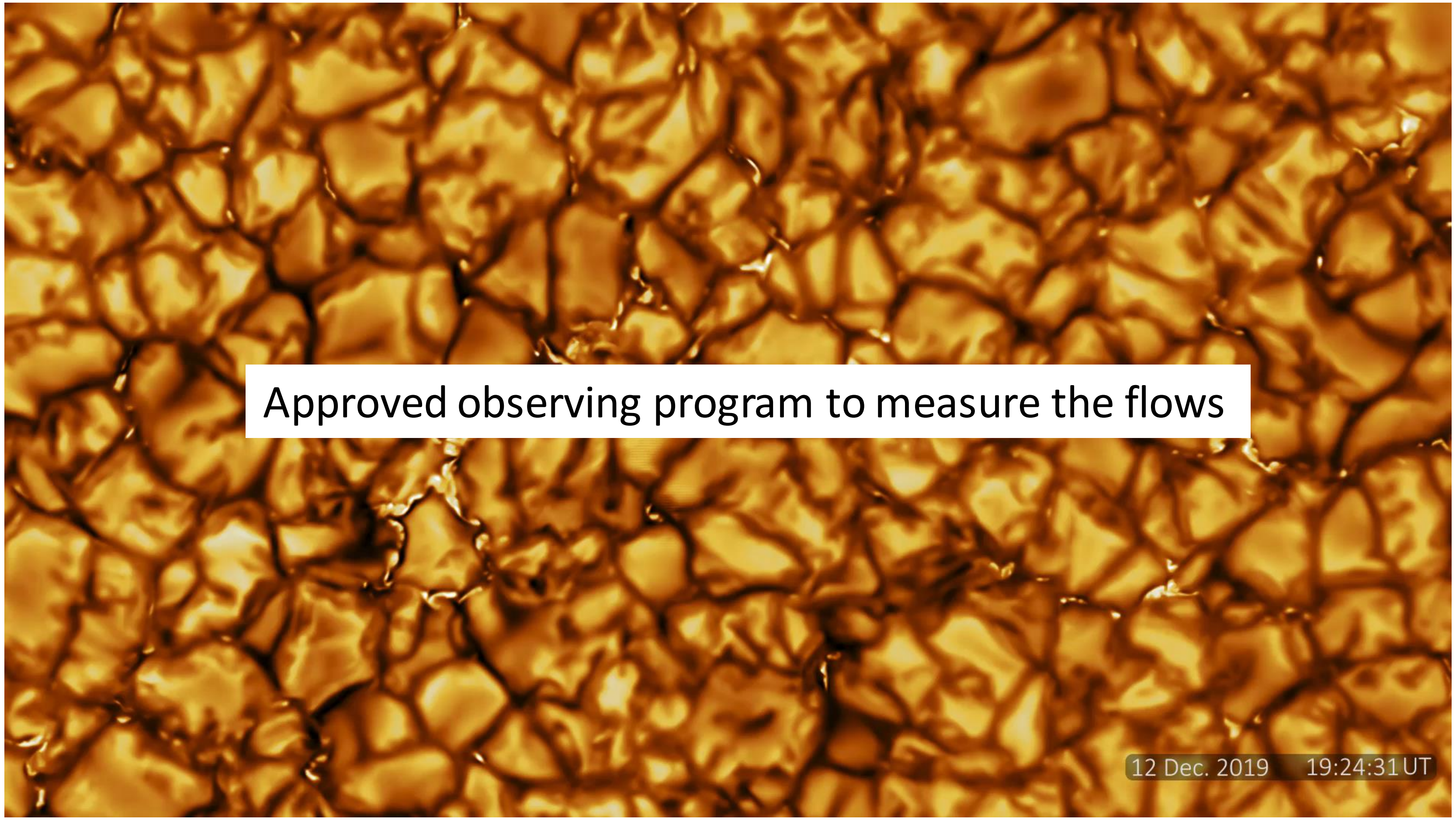
Challenges:

- Enormous range of spatial scales (> 6 orders magnitude)
- Physical couplings between scales and between different parts of the atmosphere
- Spatially unresolved features in observations (line-of-sight overlap)

Strategy:

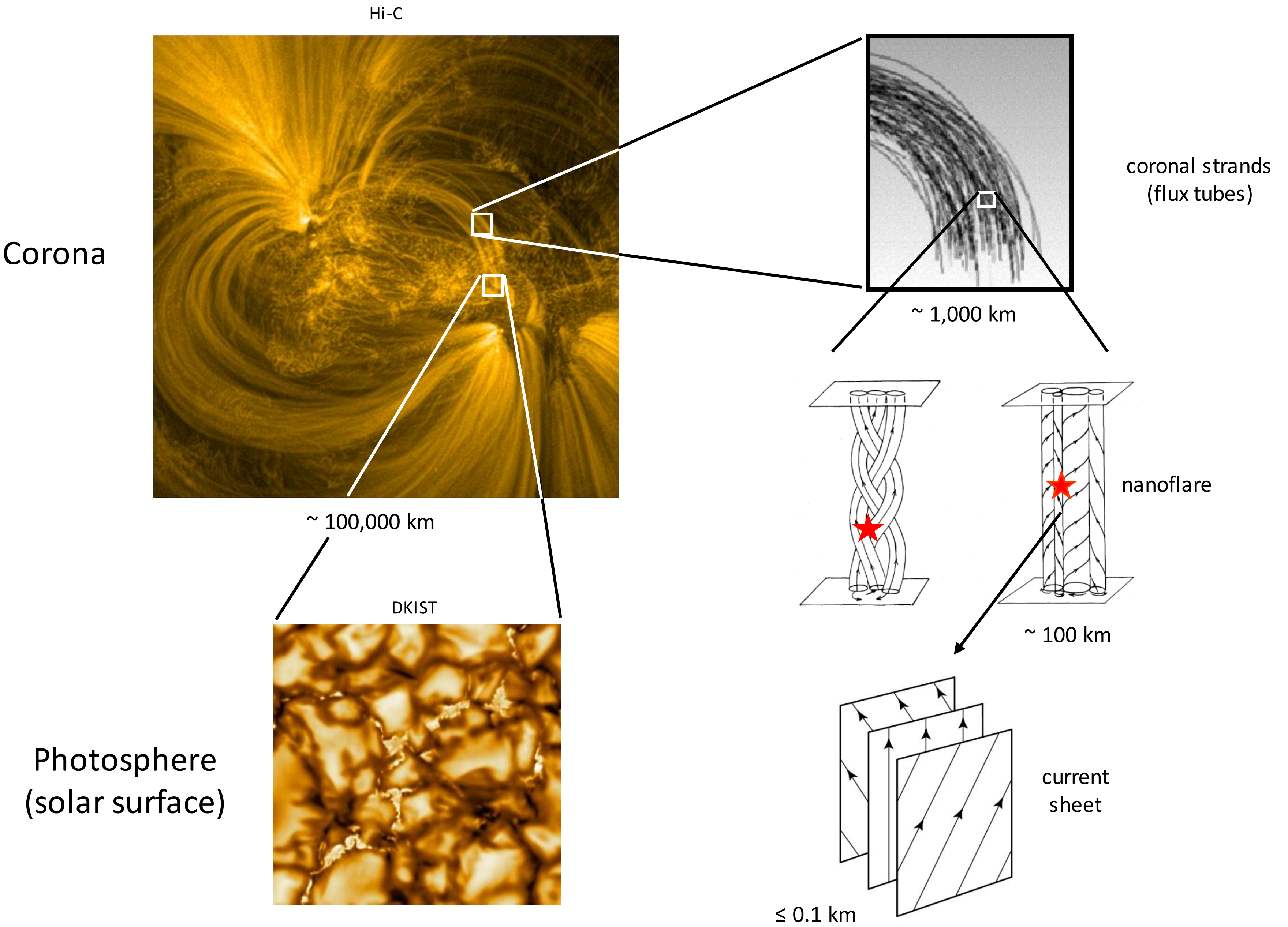
- Use a multi-faceted yet closely integrated (wholistic) approach
- Requires a wide range of numerical and observational skills and frequent interactions
- Ideally suited to a work package

Photospheric Convection: the Engine of Coronal Heating

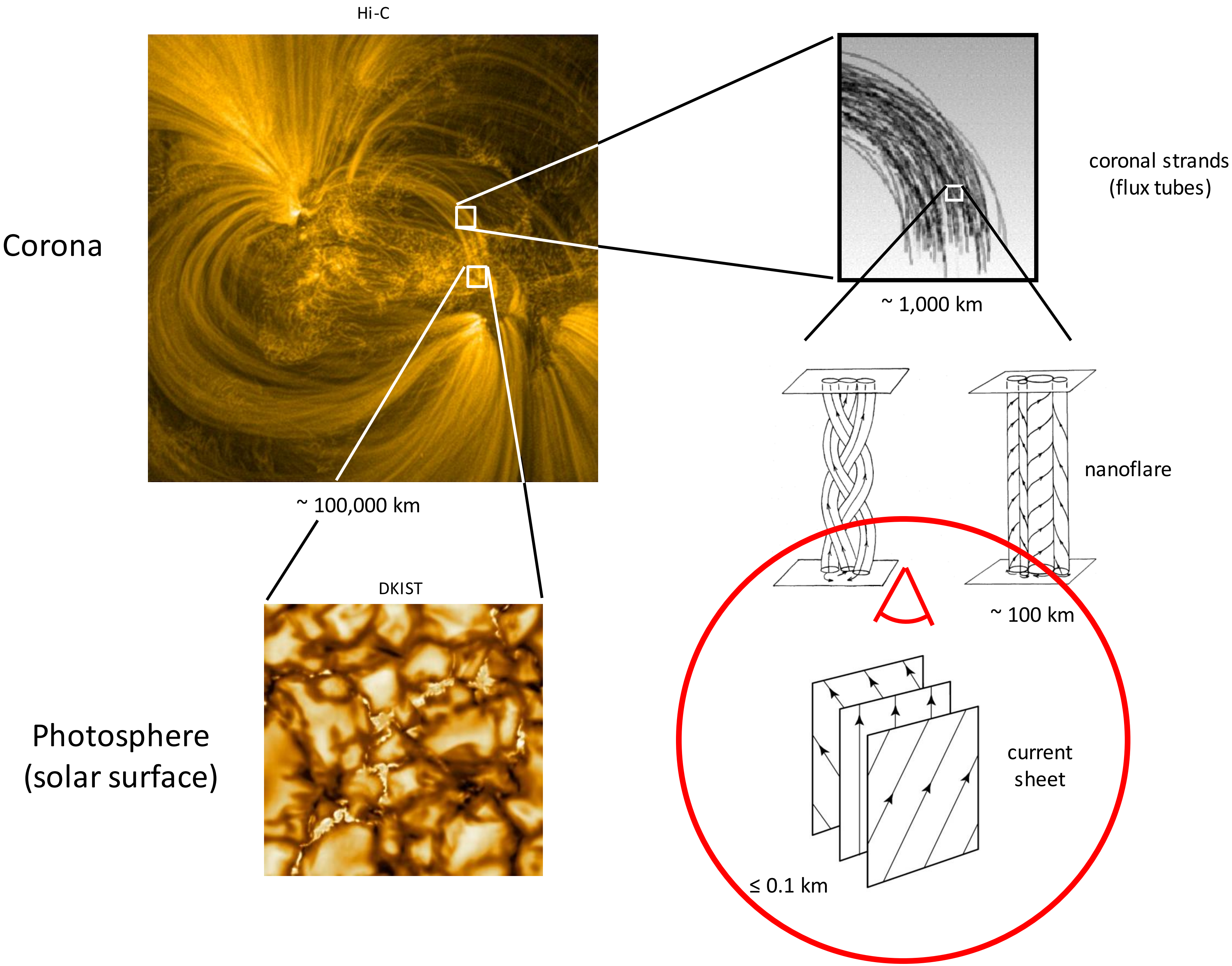


← 19,000 km (1% of solar diameter) →

Daniel K. Inouye Solar Telescope (DKIST)



Hi-C
Corona
~ 100,000 km
DKIST
Photosphere
(solar surface)
coronal strands
(flux tubes)
~ 1,000 km
nanoflare
~ 100 km
current
sheet
≤ 0.1 km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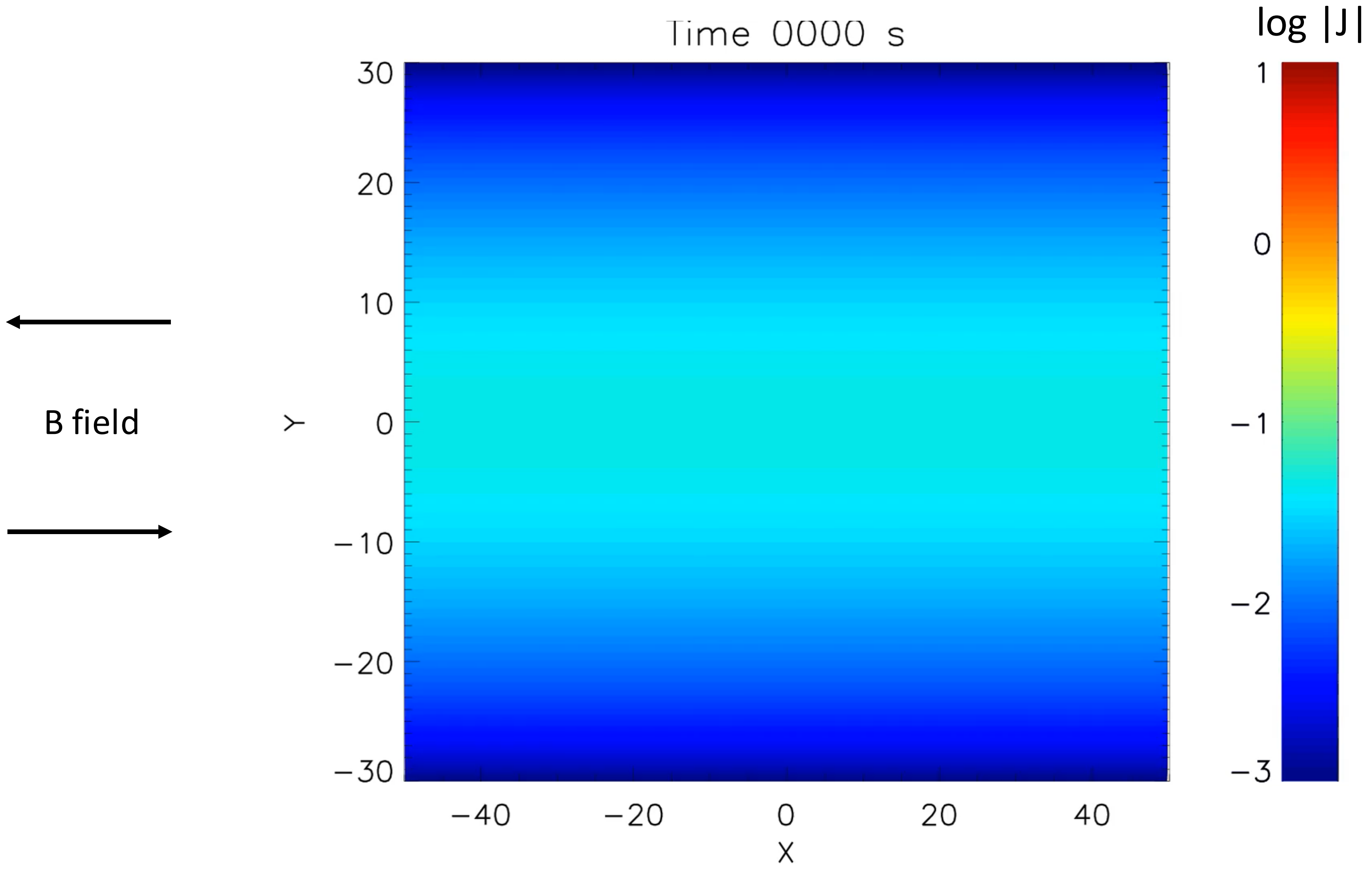
Thinning Current Sheet



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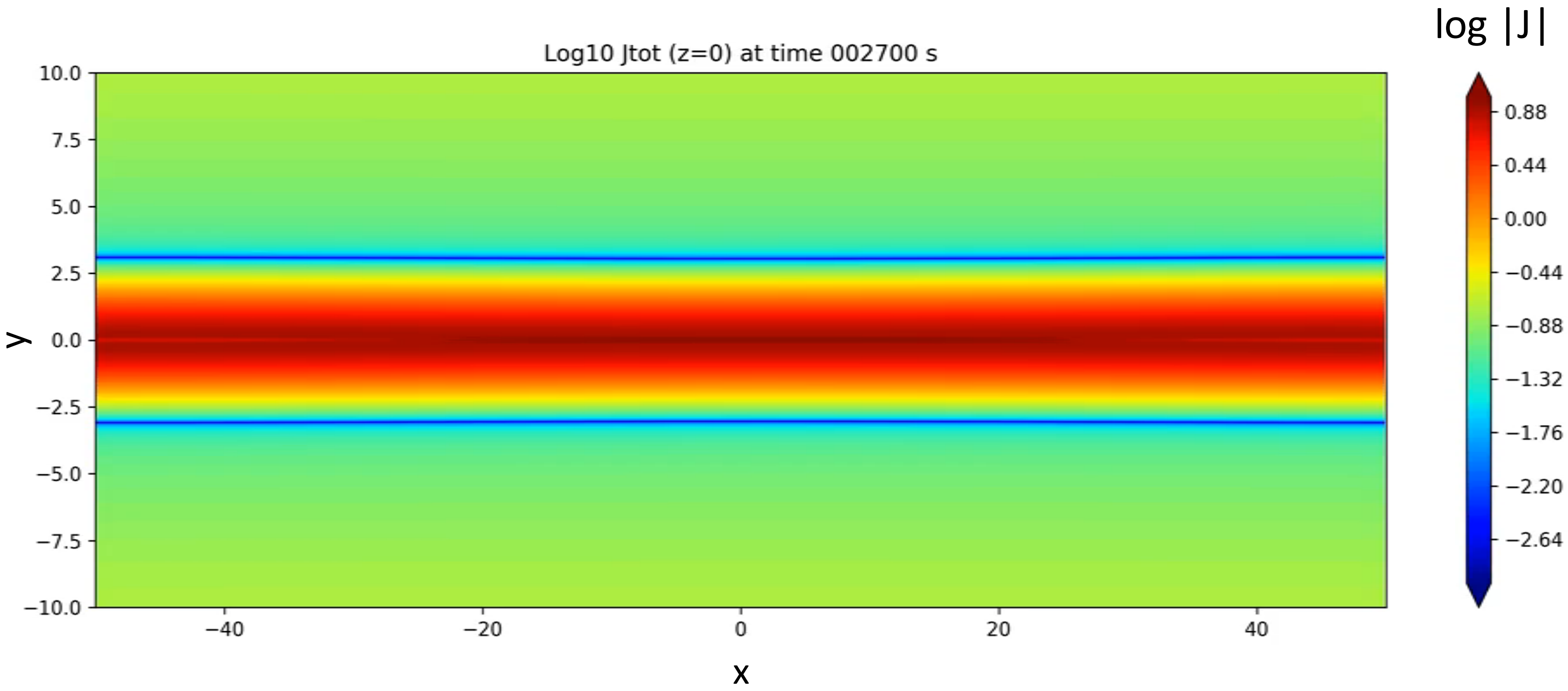
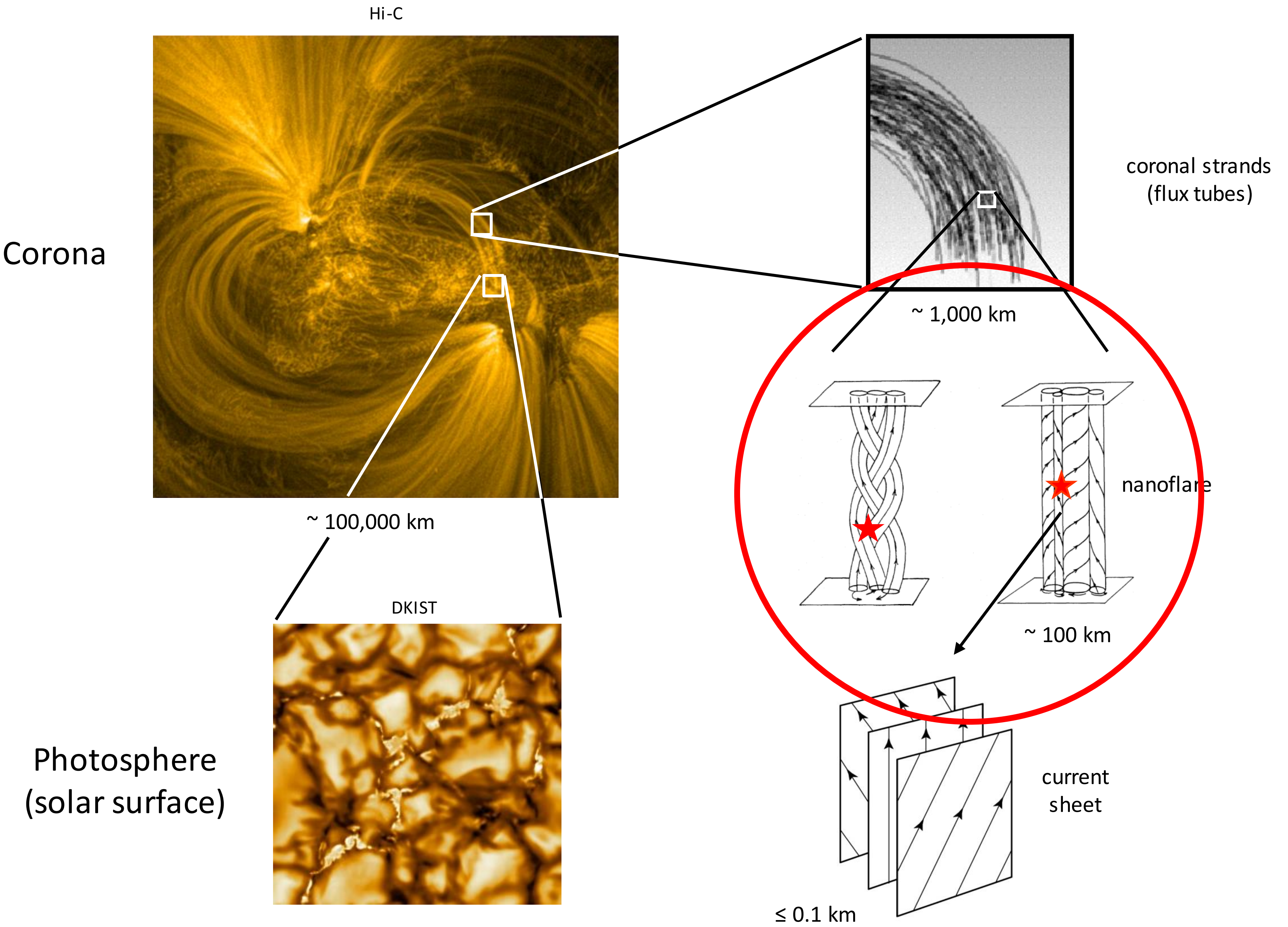


Reconnection occurs when tearing growth rate ≈ thinning rate.

Determines the level of magnetic energy build up and the magnitudes of nanoflares, CMEs, etc.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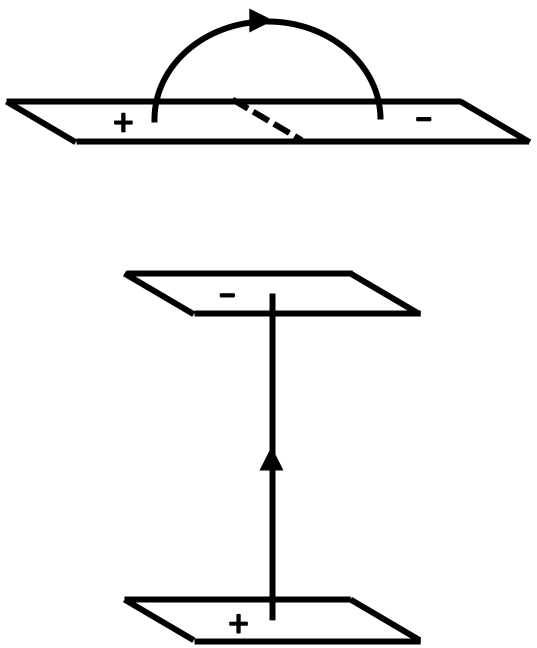
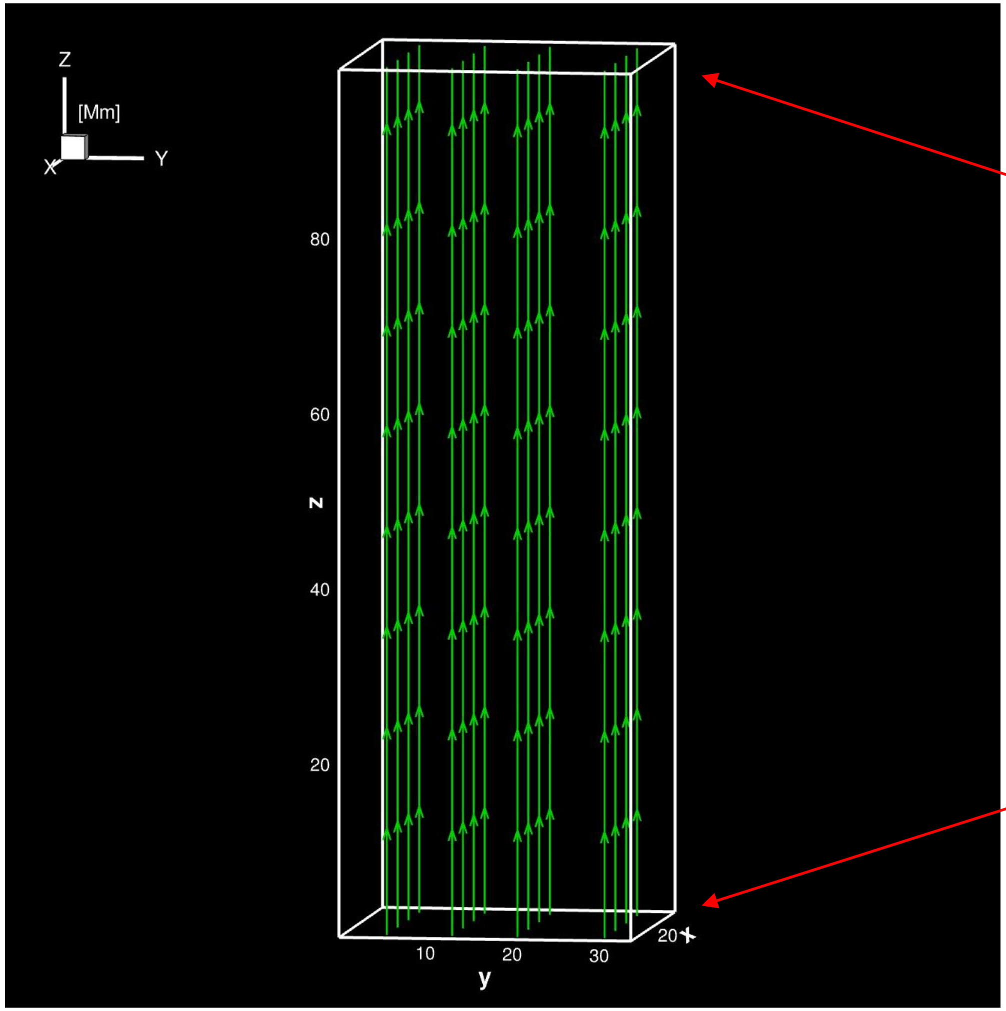
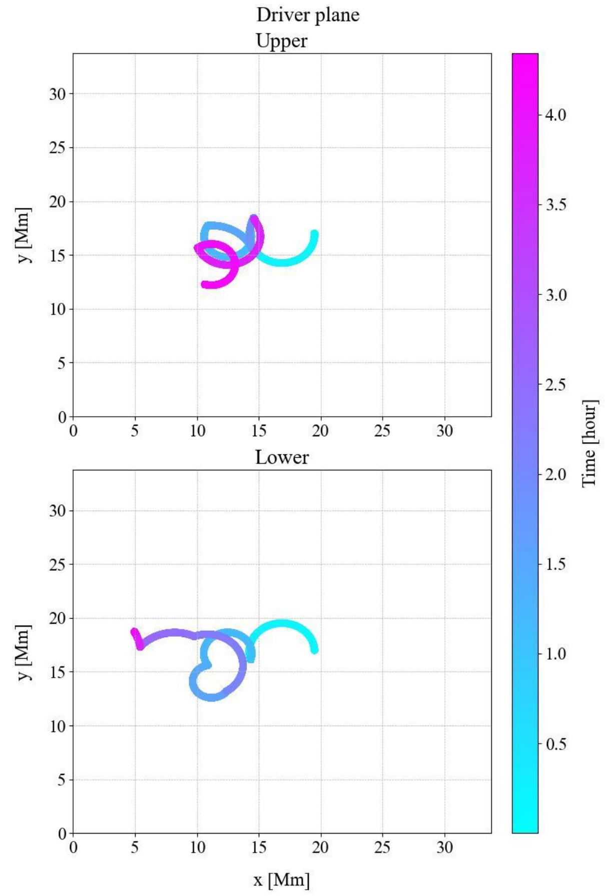


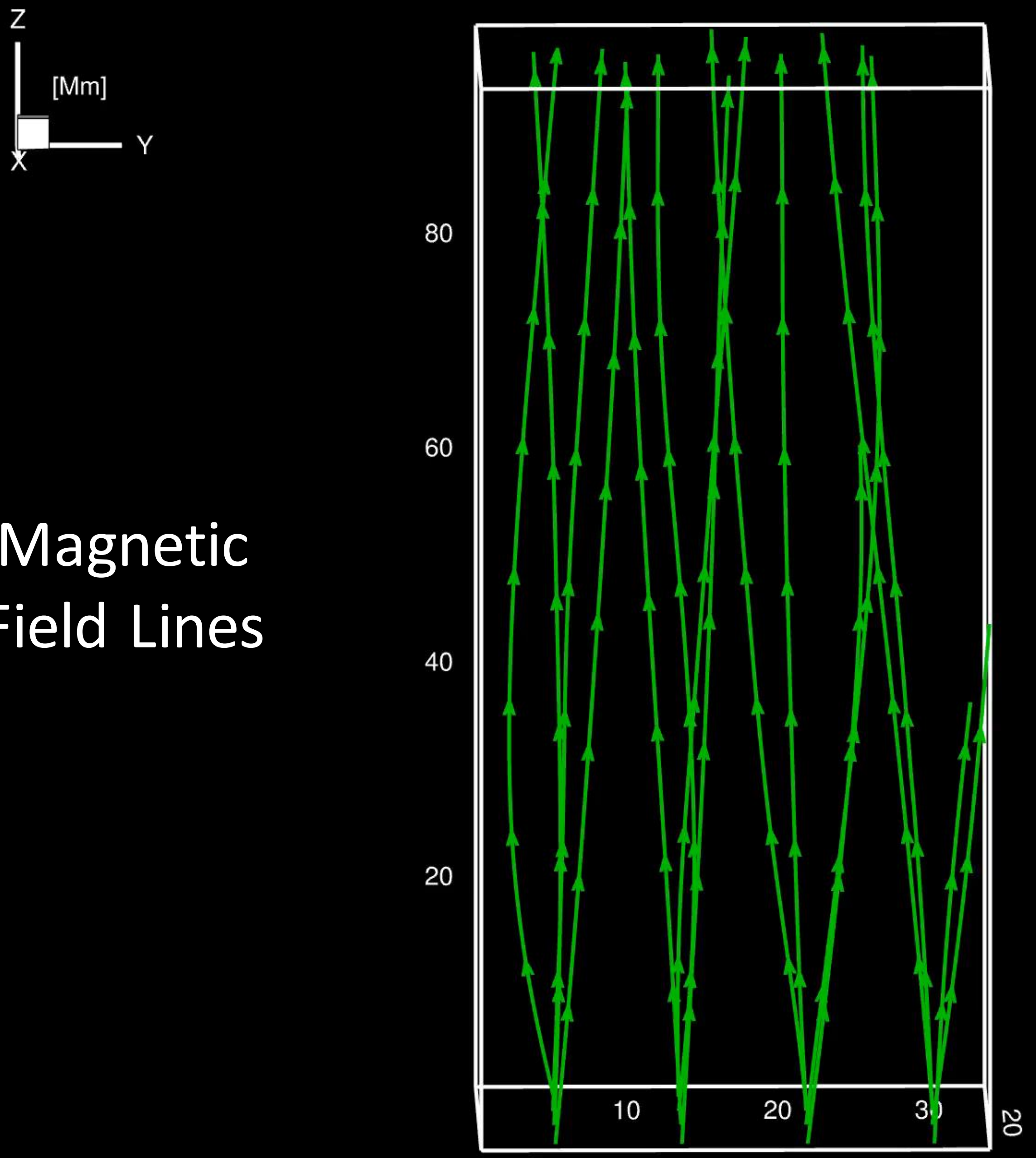
gravity of a curved loop

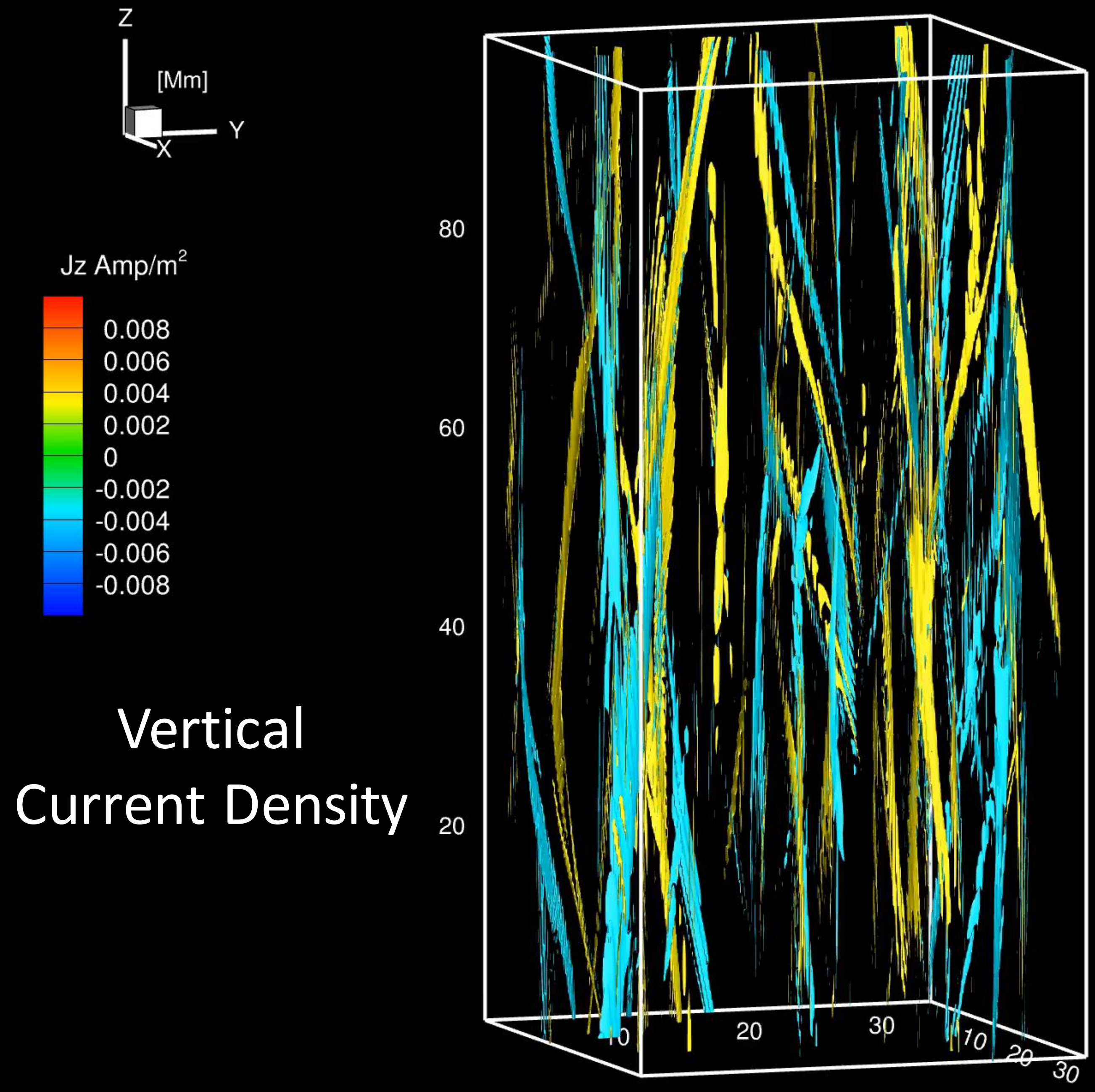


Boundary flow trajectory
(photosphere)



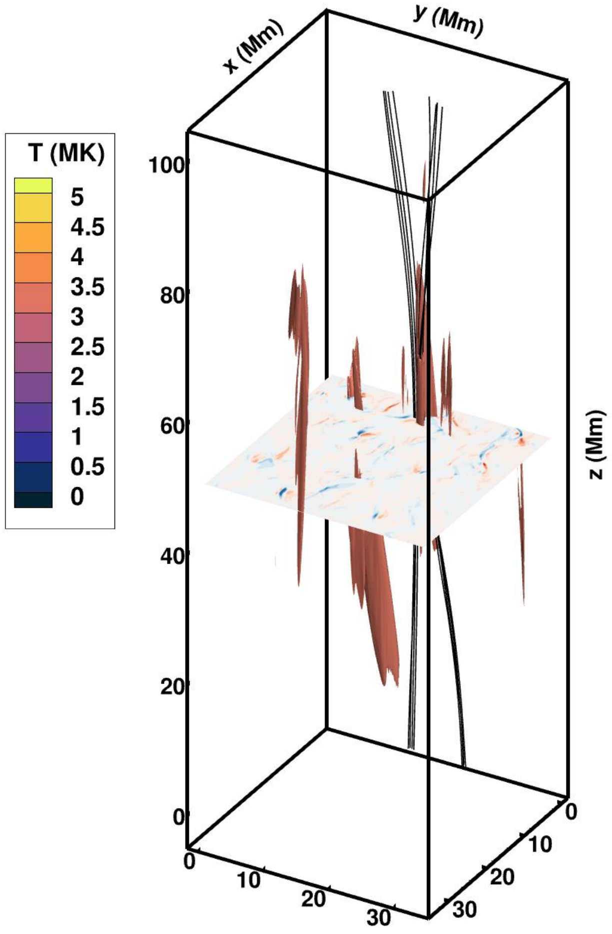
Magnetic Field Lines

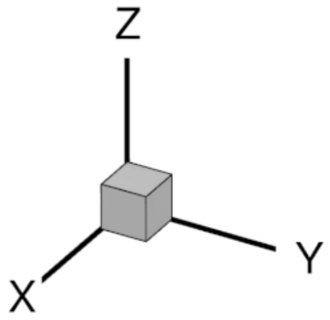




Vertical
Current Density

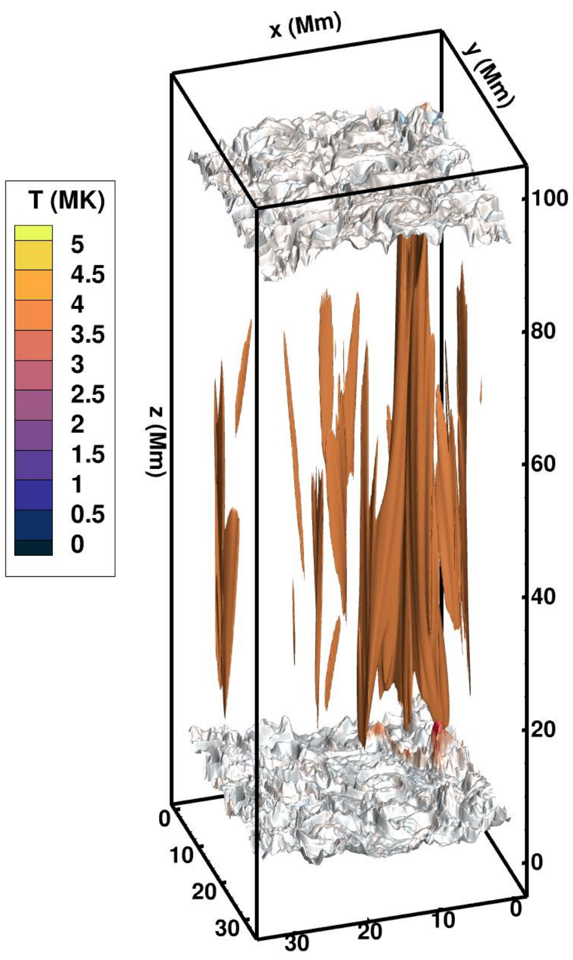
Reconnection Event – t = 68 mins

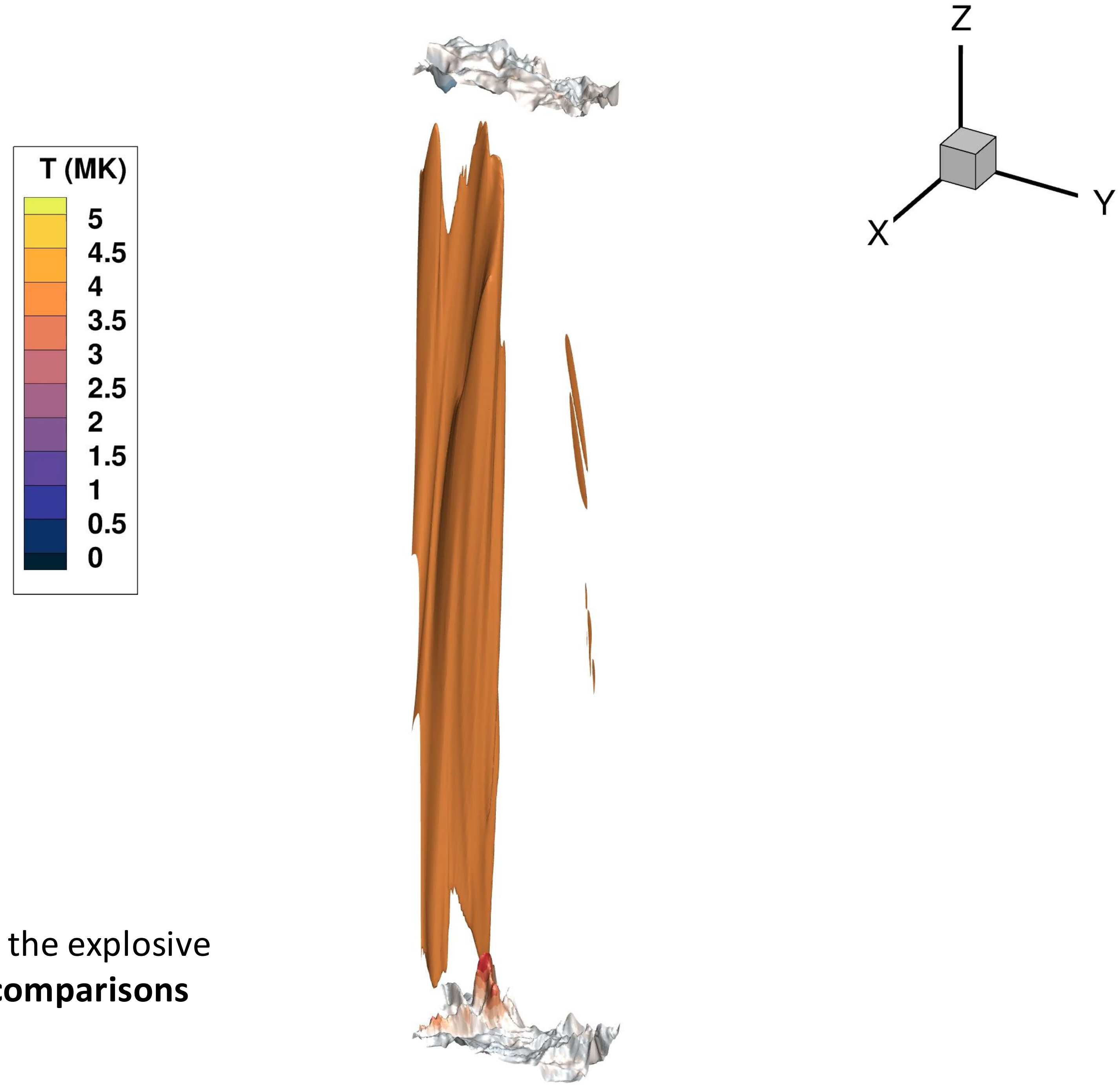




- Capturing **explosive energy release** from **narrow current sheets**: converting magnetic energy into kinetic and then thermal energy through viscous dissipation of the shocks.

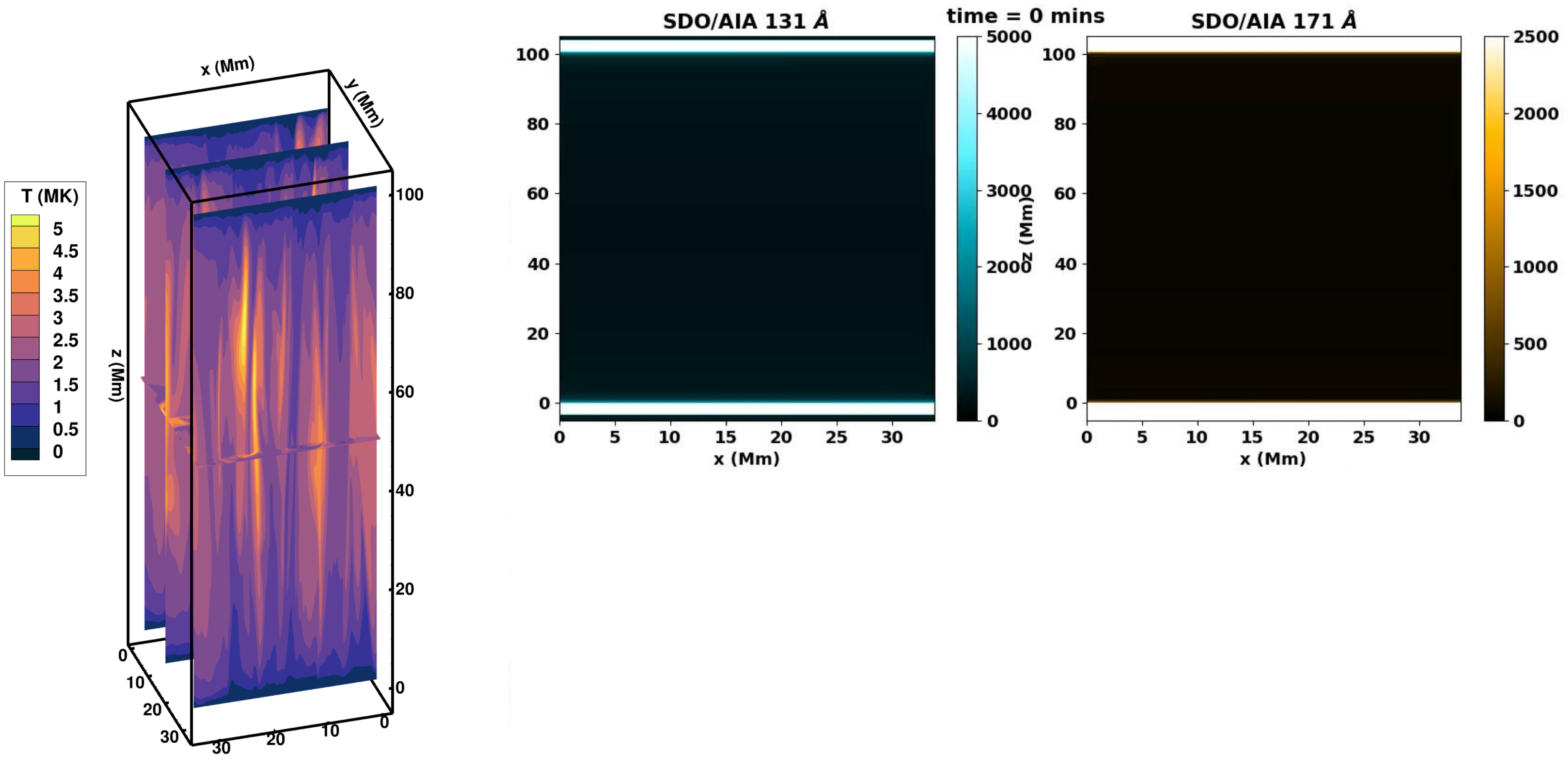
Evaporative Response – t = 71 mins



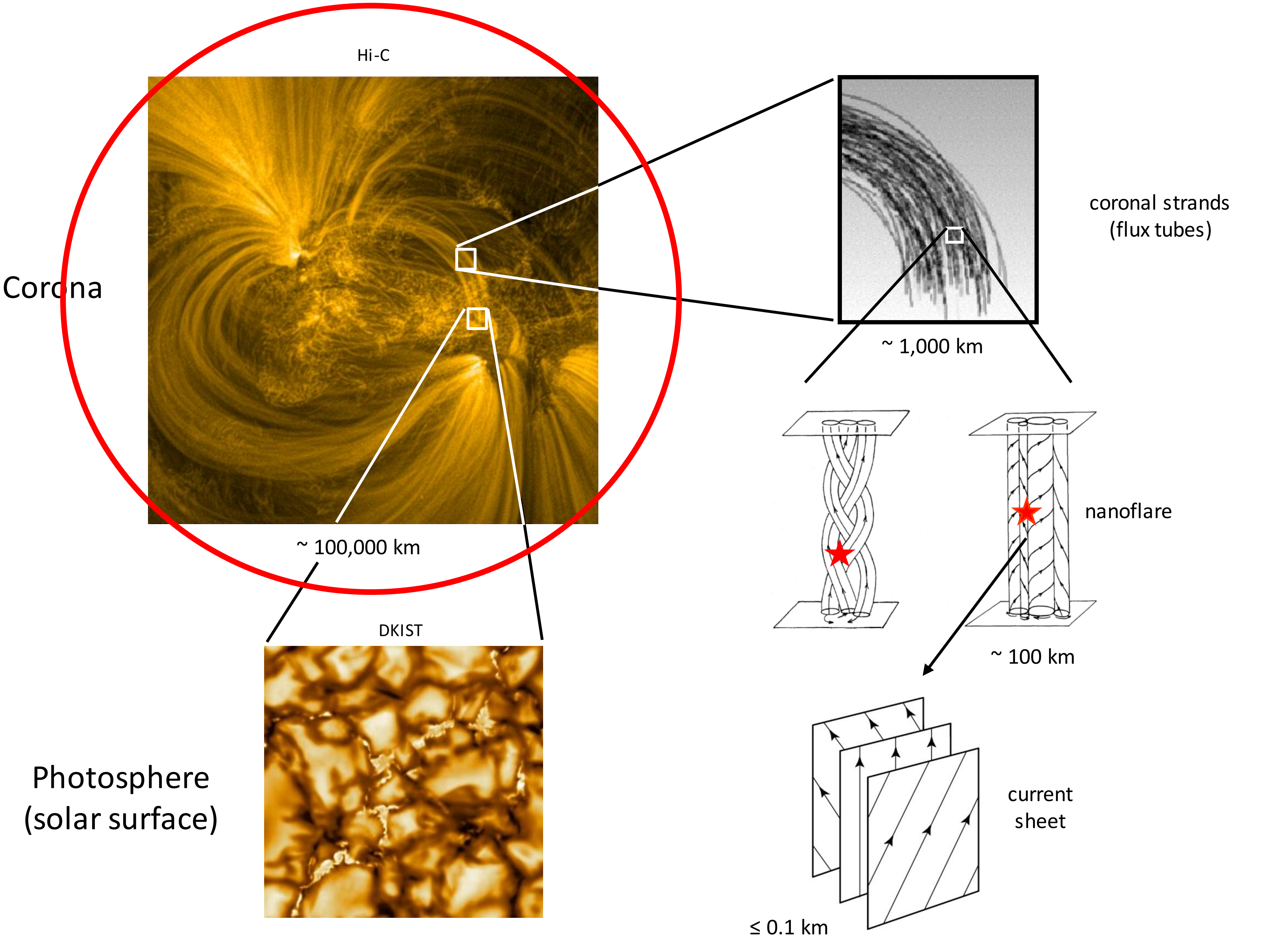


- Capturing **evaporative response** of the plasma to the explosive energy release, allowing us to make **meaningful comparisons** with **observations**.

Line-of-Sight Intensity



- Connecting simulations with observations.



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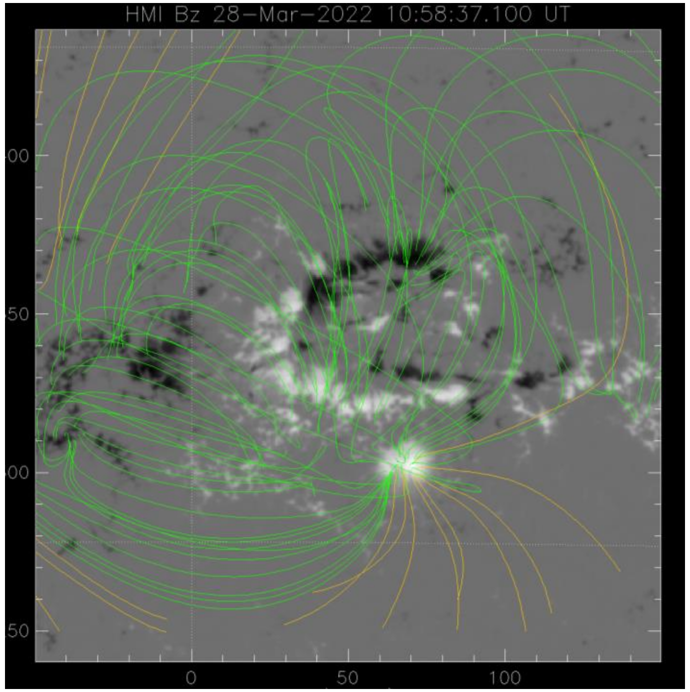
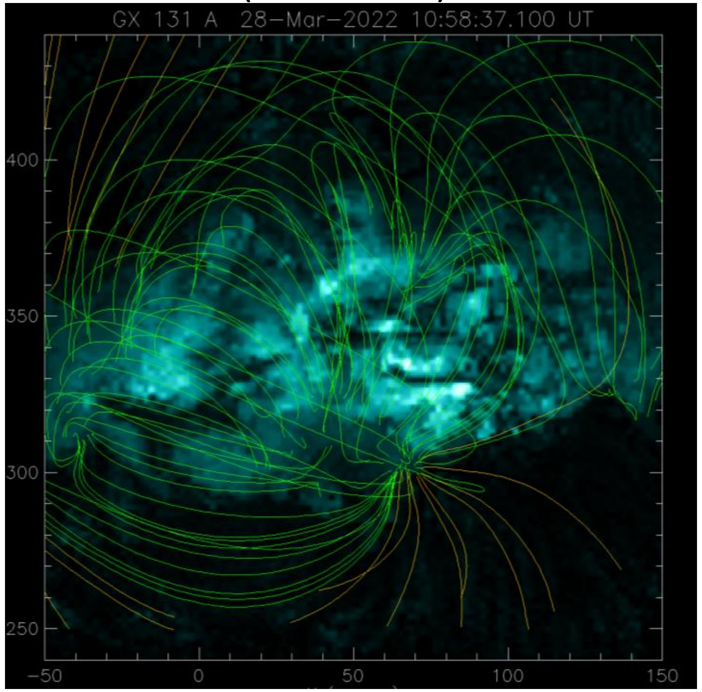
GX_Simulator Model Active Region

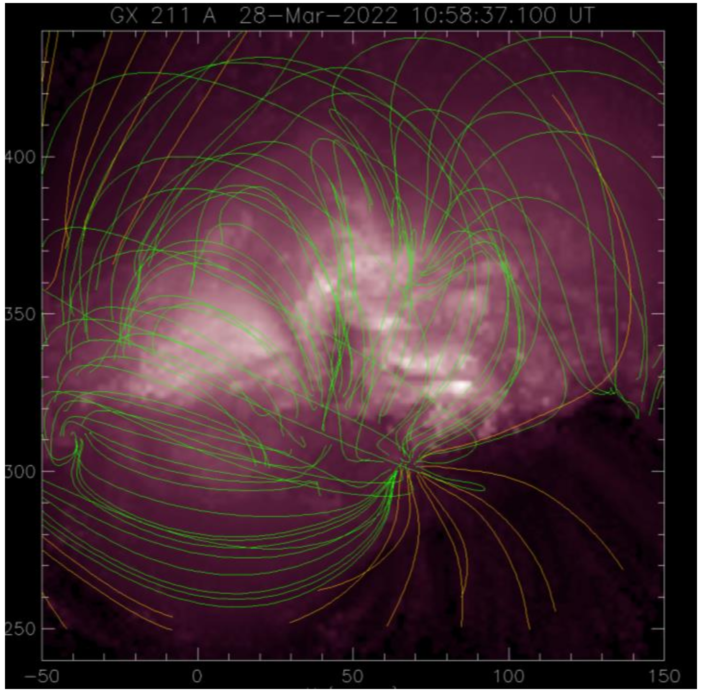
Observed
Photospheric Magnetogram



Simulated
SDO/AIA 131 A
(T ~ 0.5 MK)



Simulated
SDO/AIA 211 A
(T ~ 1.8 MK)



Flux tubes populated with plasma based on nanoflares with **assumed** properties.

Those properties must ultimately be **determined** from multi-strand MHD simulations.

Science Quality

- 28 peer-reviewed papers (13 first author) [1]
- 12 Decadal Survey white papers of relevance (2 first author)
- 61 presentations [1]
- Recognized world leaders in coronal heating science as evidenced by invited talks and awards (e.g., 2021 AGU Parker Lecture)

[1] since Oct. 1, 2021 (51 papers and 155 presentations since the start of the first work package)

Science Enabling (1 of 3)

- As leaders, we help guide the direction of international coronal heating research
- External collaborators (33 scientists from 21 institutions in 8 countries)
- Modeling tools for community use:
  - TRAC transition region module implemented in multiple MHD codes
  - EBTEL field-aligned hydro code improvements
  - Field-aligned thermal conduction improvements
  - MHD boundary driving improvements
  - GX_Simulator (active region model) improvements
  - CHIANTI spectroscopy package, new version
  - SunPy tool for generating synthetic images from simulations
- Student training (8 graduate students, 2 undergrads)
- Post-doc training (6 team members within 5 years of PhD at start)

Science Enabling (2 of 3)

- Meeting organization
  - Science Organizing Committee
    - Triennial Earth-Sun Summit (2022; Belleview, WA)
    - 10th Coronal Loops Workshop (2022; Paris, France)
    - Solar Physics Division (AAS) (2023; Minneapolis, MN)
    - IAU Symposium 371 (2022; Busan, Korea)
    - SunDC (2023; Washington, DC)
    - Goddard UV Symposium (2022; Greenbelt, MD)
  - Session Organizers
    - “Fast Magnetic Reconnection Onset” (AGU 2021)
    - “Coronal Heating” (TESS 2022)
    - “Solar Spectral Irradiance: Observation, Modeling, & Impacts” (TESS 2022)

- Broader National Capability
  - Lead International Space Weather Action Team (ISWAT) S2-06:
    Origins of the Spectral Irradiance and Its Intermediate Timescale Variability
  - Current capabilities and strategies for progress (Sp. Sci. Rev. paper, Decadal white paper)

Science Enabling (3 of 3)

- Mission Concept Development

  Coronal Microscale Observatory (CMO) (science motivation; synthetic observations)

- Support of current and upcoming missions

  Simulations have been and will be compared directly with observations from SDO, Hinode, IRIS, Hi-C, EUNIS, Chandrayaan-2, EUVST/Solar-C, MUSE

- Broader Impacts
  - Magnetic reconnection is a fundamental physical process (corona–magsphere differences)
  - Coronal heating on other stars impacts the origin and development of life throughout the universe

- Instrument Calibration (benefits all users of the data)

  EUNIS underflight of EIS/Hinode

- Synergies with other ISFM Work Packages
  - Viall WP (slow solar wind originates in magnetically closed structures; thermal nonequilibrium)
  - DeVore WP (boundary conditions for photosphere driving)

NASA Center Uniqueness

- Highly complex problem requiring a multi-faceted yet closely integrated (wholistic) approach
  - Results from one investigation motivate and inform other investigations
- Requires a wide variety of theoretical, numerical, and observational expertise
  - Our coronal heating team is **unique** in the world
- Requires regular face-to-face interactions (co-located team)
  - White boards are crucial!
- Requires stability (time frame for full success is not short)
- Eventual development of an operational model (long-term goal) will benefit from CCMC

Project Execution

Major progress on proposed milestones and deliverables, as indicated in the Year 1 Progress Report and our list of papers and presentations, available at our team website:

https://science.gsfc.nasa.gov/670/variability_workshop/heating.html

Highlights since the year 1 progress report:

- Multi-strand simulations with complex driving, thermal conduction, radiation, full coupling with the lower atmosphere
- 3D thinning current sheet simulations
- Spectral line profile diagnostics of nanoflare heating (observations and simulations)
- Equilibrium and nonequilibrium properties of finite length current sheets (theory)
- Heating of X-ray bright points (observations and simulations)
- Cross-sectional properties of overlapping coronal strands (observations, semi-analytical models, sims)