MHD Modeling of Magnetic Field Enhancement in the Solar Wind

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Background

- Interplanetary Field Enhancements (IFEs) are a unique type of solar wind structure characterized by a significant cusp-like enhancement in the magnetic field strength and a sharp rotation of magnetic field vector near the center of the field enhancement.
  - They are observed at a large range of heliocentric distances, and are relatively rare (few to tens of events per year), with similar structure regardless of duration or enhancement ratio.
  - While infrequent in the solar wind, IFEs possess sufficient field magnitude to impact the state of Earth's magnetosphere and other celestial bodies.
  - At STEREO-A, 96 IFE events were observed over 2008-2022 for statistical studies, and they are important for comparative studies with event lists by other missions, such as ACE at 1AU or Solar Obiter and Parker Solar Probe in the inner heliosphere.
- With multi-fluid MHD models (based on BATS-R-US), the two most probable generation mechanisms are examined.

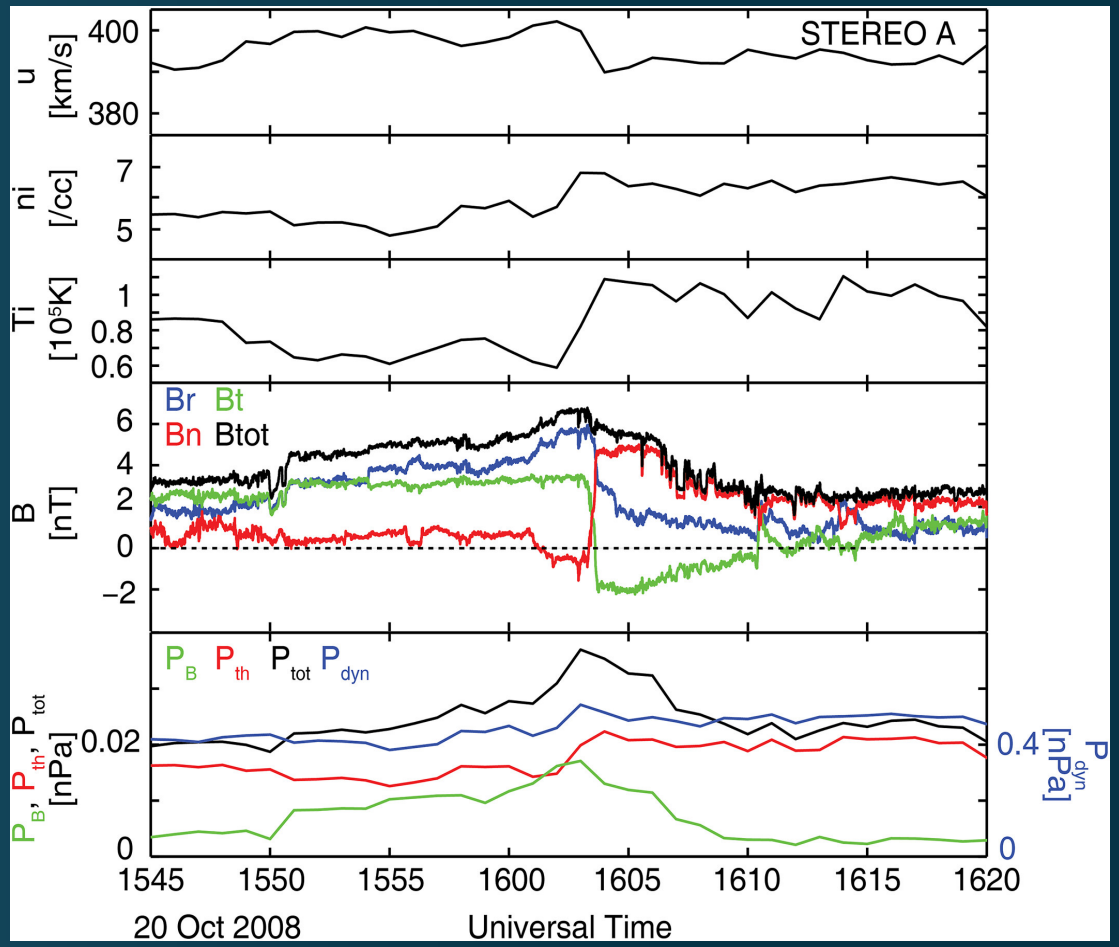
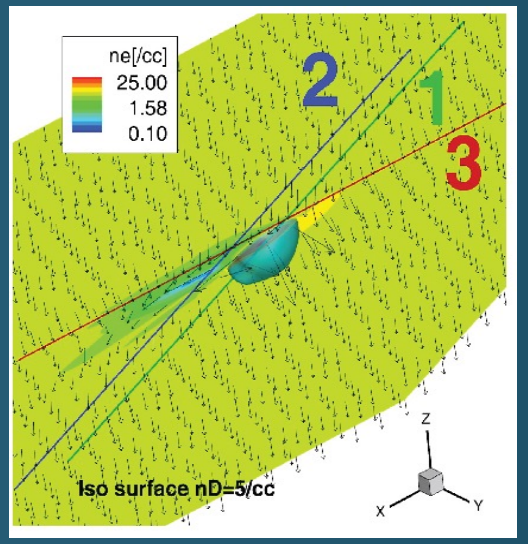


Figure above: An example of an IFE event observed by STEREO-A. *Credit: Jia et al. 2024*

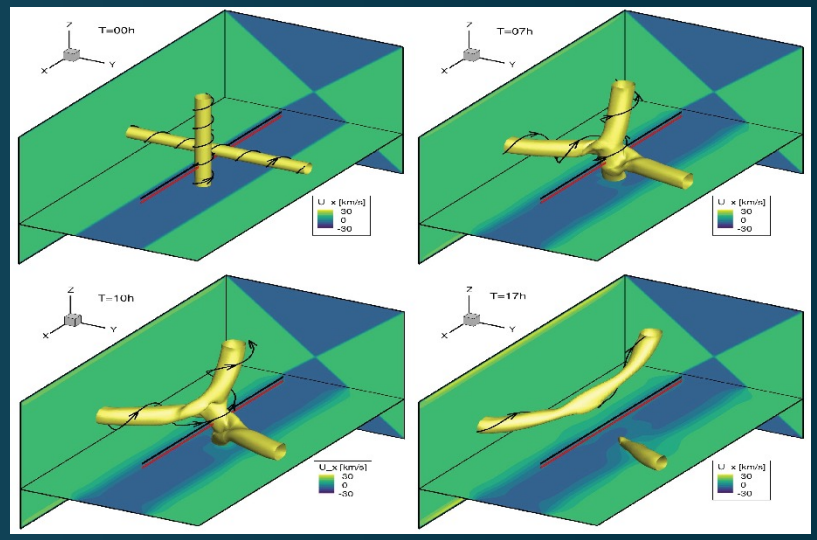
Analysis

Dust Pickup Model



Dust Model: Close up of modeled dust cloud interaction with solar wind.
Dust cloud is turquoise colored feature in the center. Black arrows show magnetic field direction and strength, and colors are electron density in the y=z plane. Lines show slices taken through the model data. The solar wind is flowing from the –X direction and the model shows disturbances associated with the dust cloud. *Credit: Jia et al. 2024*

Interlaced Flux-Rope Model



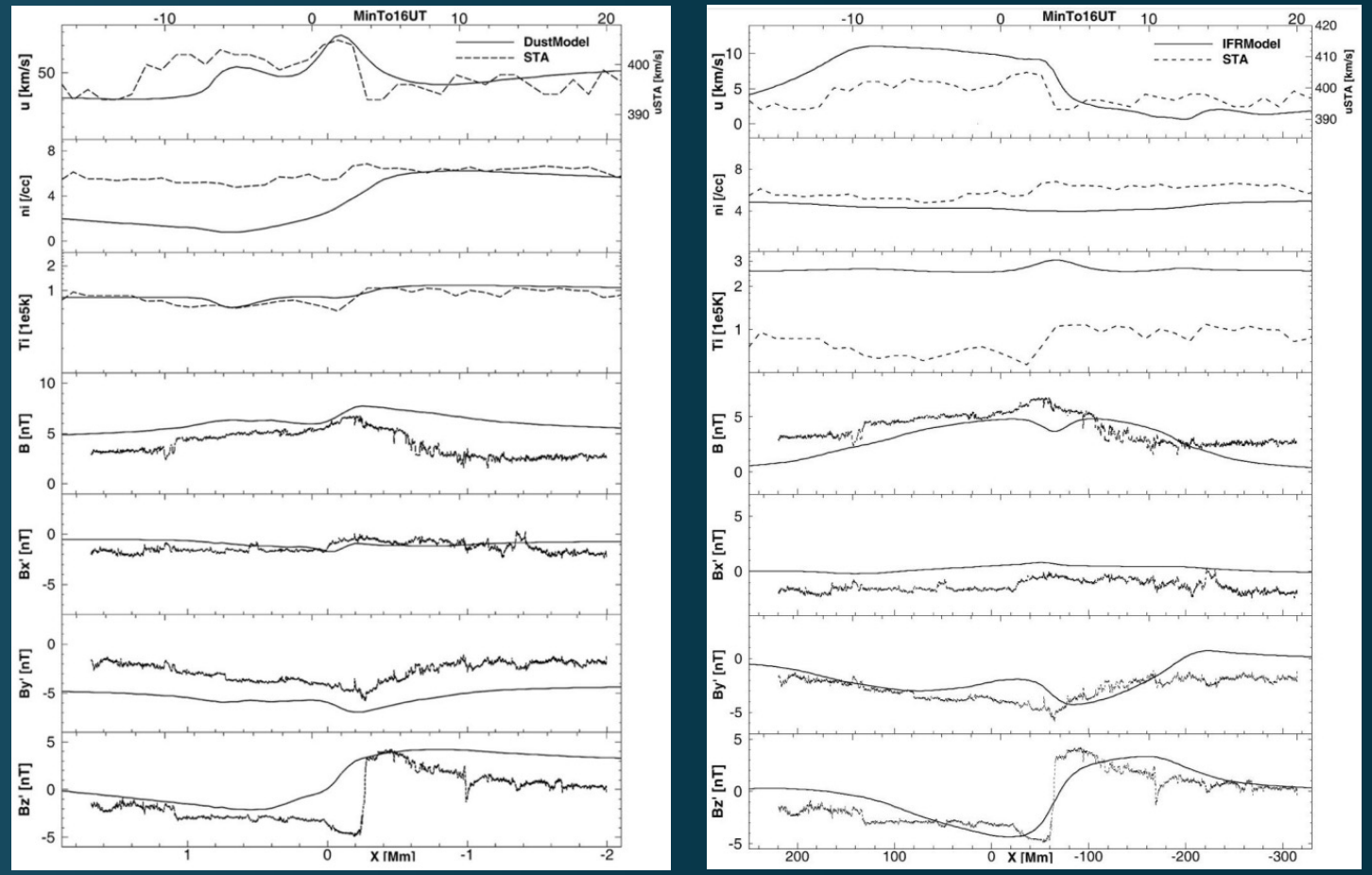
Magnetic Flux Rope Reconnection model: Model magnetic flux ropes (yellow), meeting, reconnecting and decoupling. *Credit: Jia et al. 2024*

- The two most probable IFE formation mechanisms are examined and compared with STEREO data.
  - A charged dust cloud, produced by catastrophic collisions of small meteors, are accelerated by the solar wind electromagnetic fields and lead to pileup and draping of the magnetic field.
  - Two magnetic flux ropes get interlaced/entangled when pushed towards each other, forming a sharp current sheet at their interface and reconnection eventually leading to de-tangling of the two flux ropes.
  - Both these possible mechanisms are important for understanding energy input into the solar wind.
- STEREO observations of IFE events are compared with the simulation results.

Impacts

- The simulations indicate that the two models may produce similar observations of enhancements when observed along particular trajectories at the right stage of the interaction.
- The models also provide guidance on how to differentiate the two types of interactions observationally with a combination of magnetic field and plasma data.
- Either of the two potential explanations, whether involving dust or flux ropes, contribute to understanding the conditions prevailing in interplanetary space, and thus would also contribute to space weather studies.
- This research enhances our knowledge of the inner heliosphere's dynamics and the influence of the solar wind on the Earth's magnetosphere, thereby shedding light on critical aspects of space weather and its potential impact on our planet.

STEREO data comparison with dust-pickup (left) and interlaced-flux-rope (right) models



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