ICME evolution from Mercury to 1 AU – possible early detection system for geomagnetic storms

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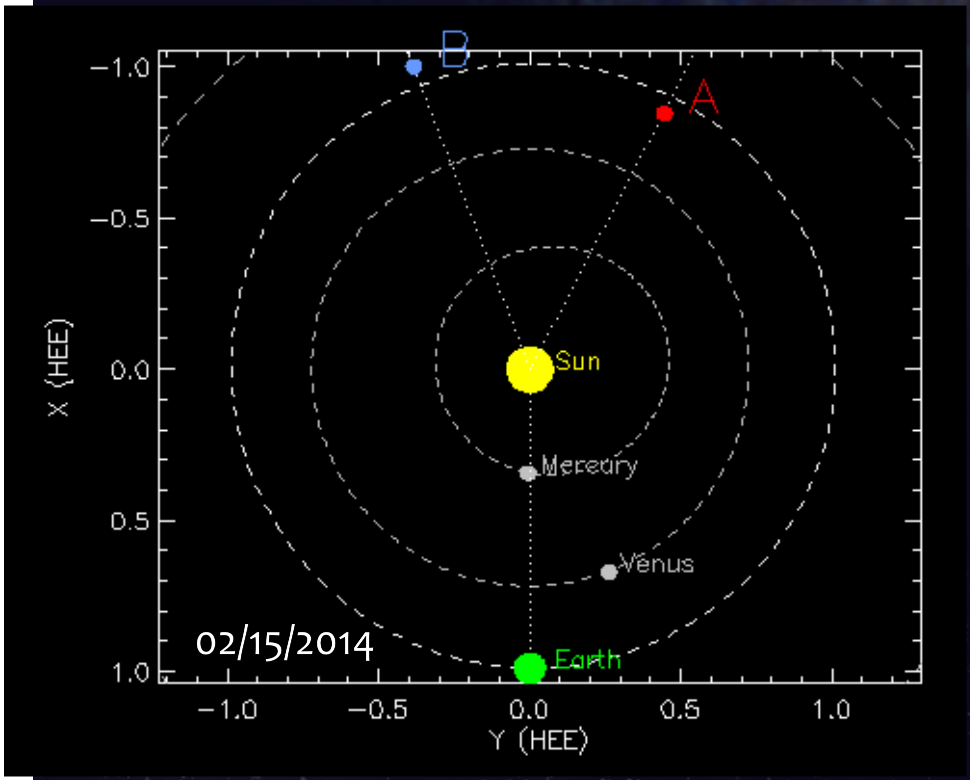
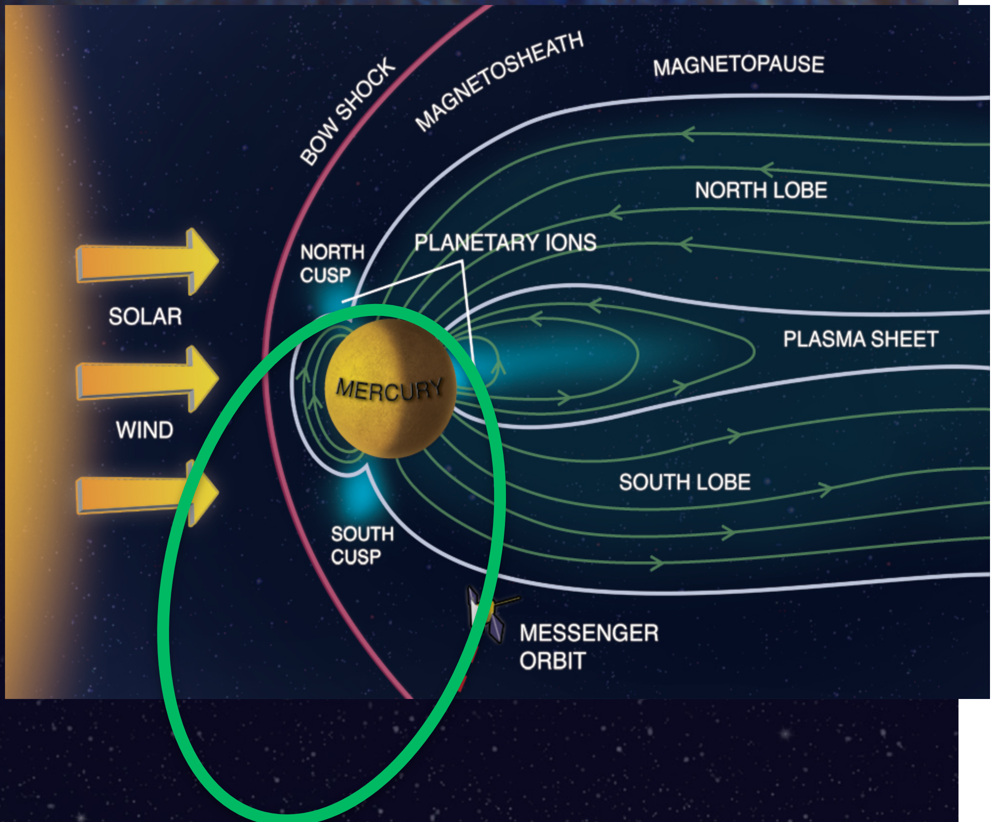
MESSENGER at Mercury:
Nominally positioned to observe ICMEs at < 0.5 AU





MESSENGER – First spacecraft since 1980's at < 0.5 AU.

- Allows observations of ICMEs in more 'pristine' conditions.
- At Mercury's orbital distances since 2008 (cruise + orbit data).

Background and Motivation

Background:

- *Möstl et al. (2012)* and *Nieves-Chinchilla et al. (2013)* highlight the need for multipoint in situ observations to resolve ICME evolution in the inner solar system.

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Main Goals:

- Trace ICME evolution from Mercury to 1 AU: effects of interaction with solar wind on CME speed and magnetic field.
- Determine if possible to predict ICME B_Z direction at 1 AU from observations with MESSENGER
    - If so, lay groundwork for improved geomagnetic storm prediction at Earth using in situ data from < 0.5 AU (prepare for Solar Orbiter).

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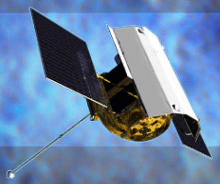

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Method:

- Use data from MESSENGER at Mercury + ACE, WIND, STEREO at 1 AU
- ICMEs not in conjunction: statistical study of ICME speed, ram pressure, magnetic field (sheath + cloud), shock normal direction.
- ICMEs in conjunction: in–depth study with MHD modeling of ICME propagation to yield 3-D picture of ICME expansion.

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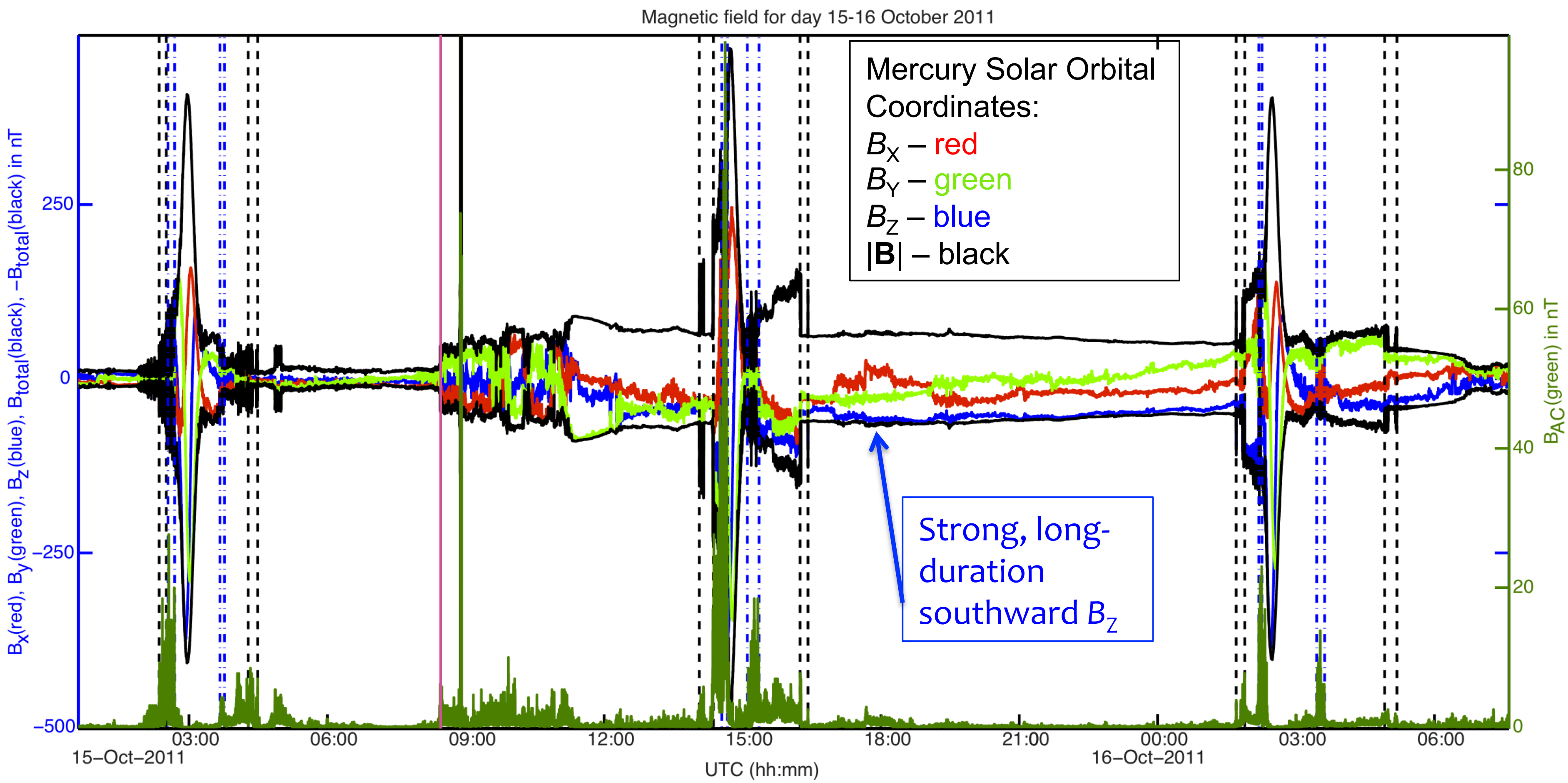
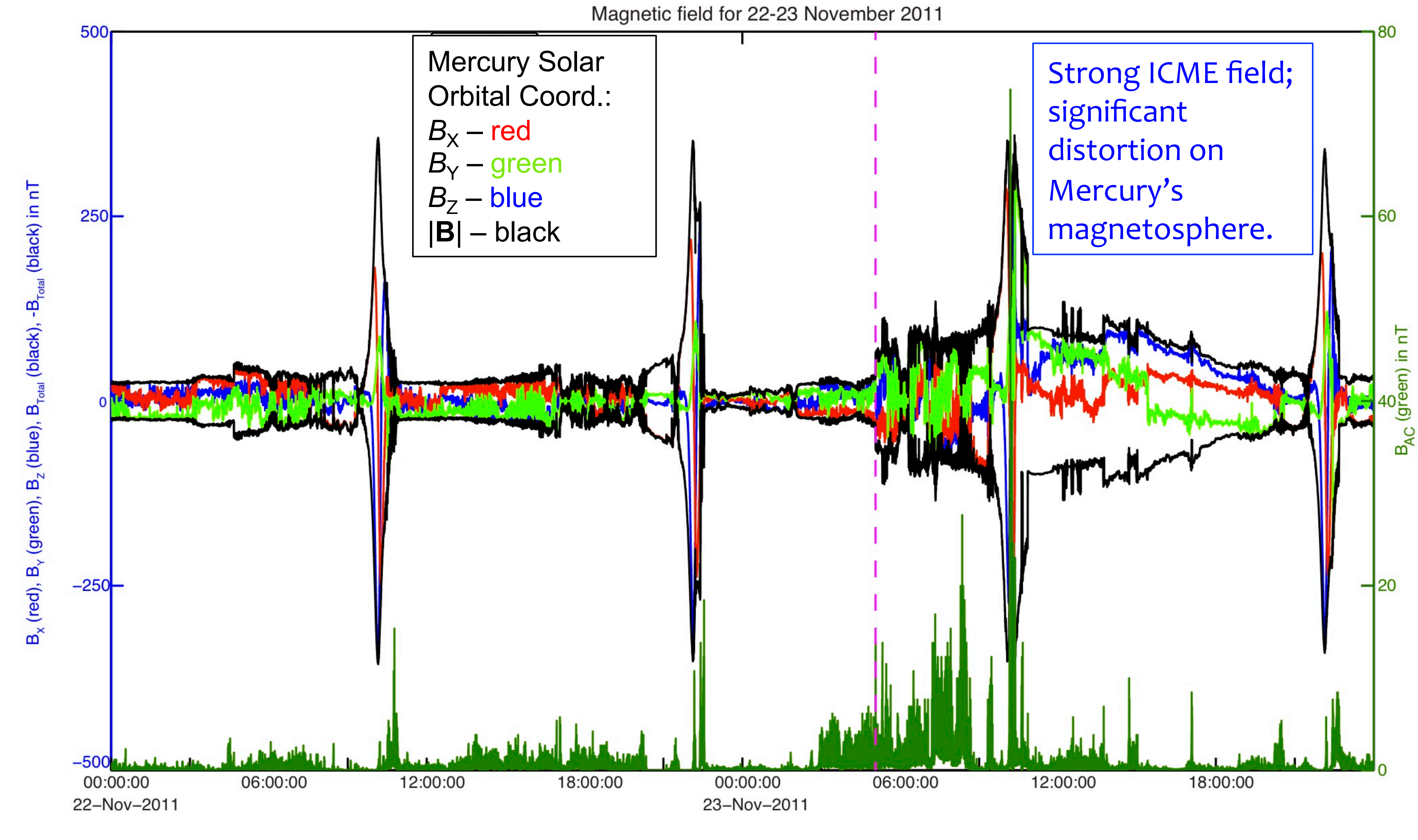
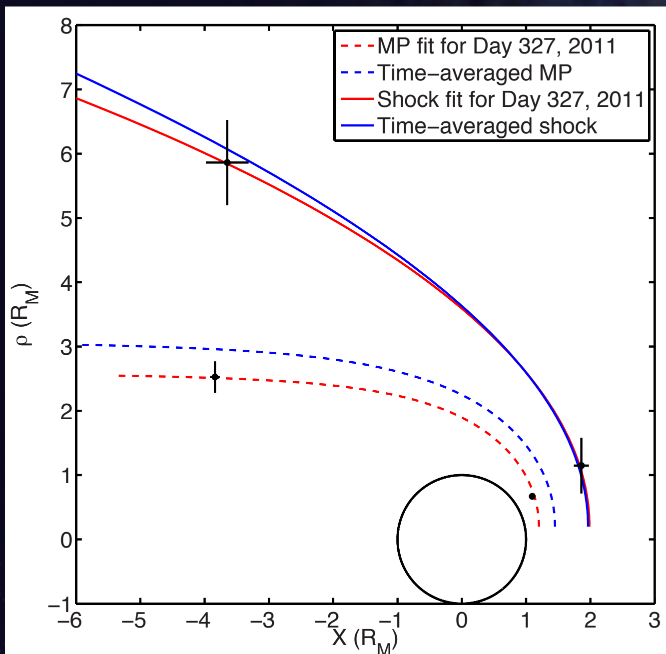
MESSENGER orbital observations of ICMEs: 10/15/2011 event

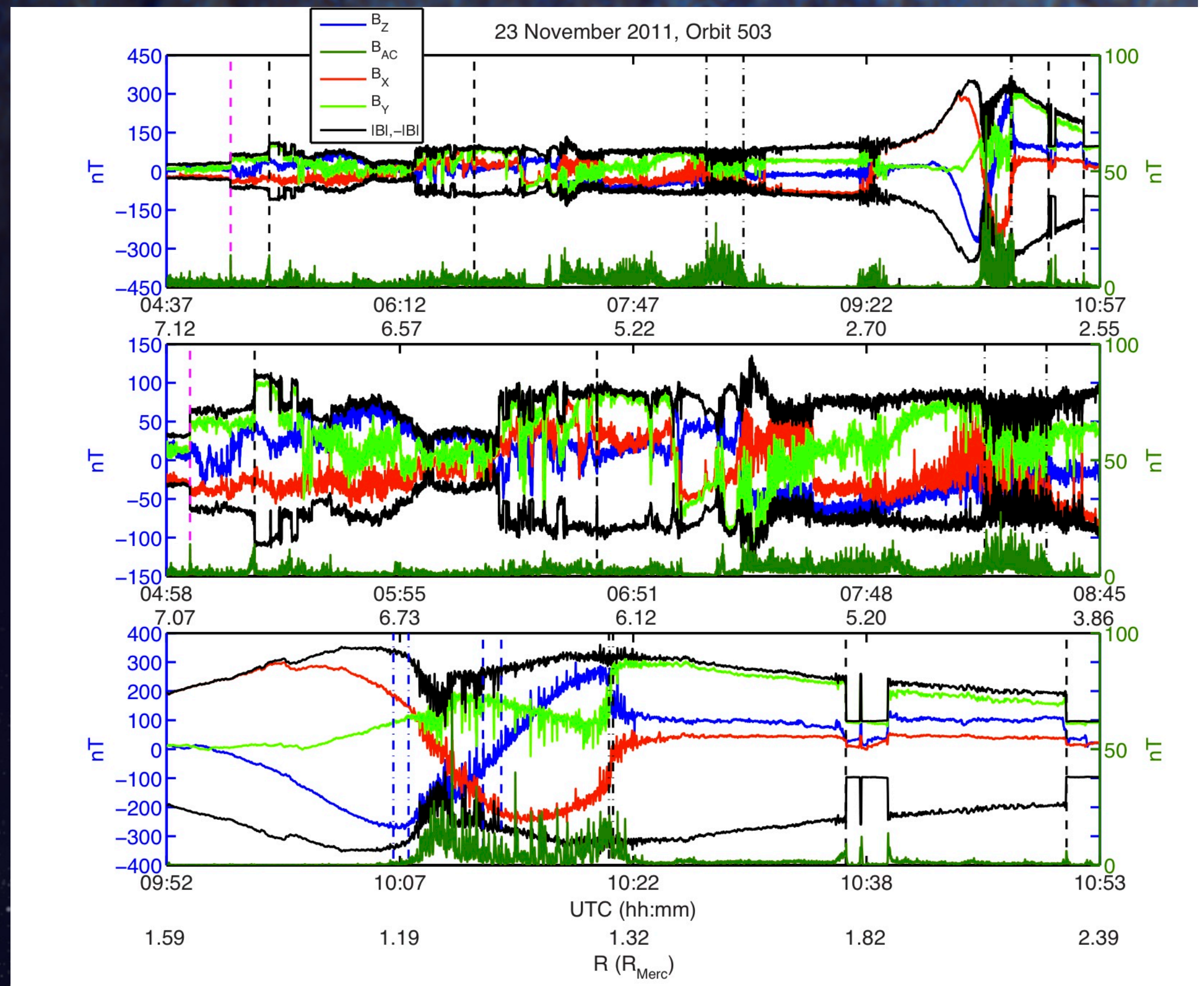


MESSENGER orbital observations of ICMEs: 11/23/2011 event



ICME influence on Mercury's magnetosphere: 11/23/2011 event





- Magnetopause much closer to planet (R_{SS} = 1.2 R_M) compared to average location (R_{SS} = 1.45 R_M) from *Winslow et al. (2013)*.
- Shock less flared than in *Winslow et al. (2013)*.

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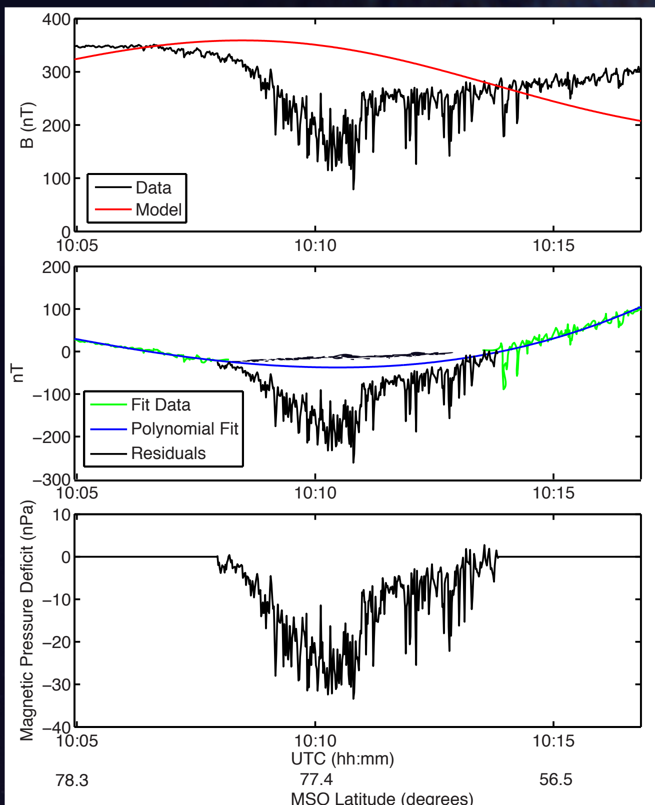

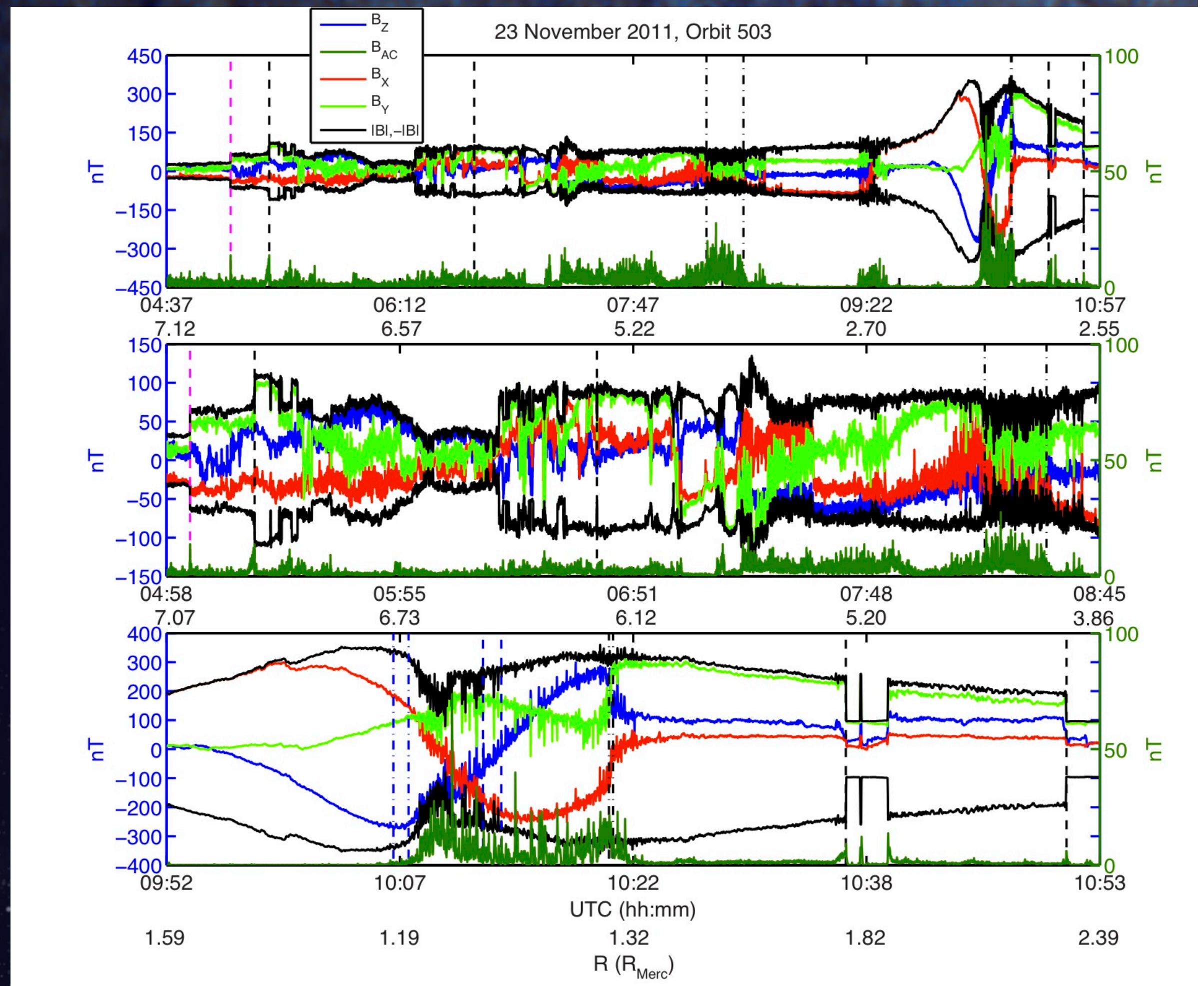

- Cusp latitudinal extent ~22° (twice the average extent found in *Winslow et al. (2012)*.
- Plasma pressure ~10x higher than average in *Winslow et al. (2012)*.

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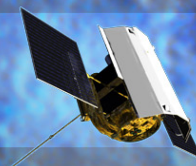

For large ICME events (such as ones shown) and ones that are observed in conjunction, conduct MHD modeling of ICME propagation.

Current model and simulation setup (open to suggestions and modeling collaborations):

- Space Weather Modeling Framework (SWMF) – developed at UMichigan by *Tóth et al. (2007)*
- Setup similar to *Lugaz et al. (2013)* and *Lugaz & Farrugia (2014)*
    - Simulation domain is a Cartesian box centered on Sun and extending +/- 220 R_{Sun}
    - Solar wind is driven by Alfvén waves (*van der Holst et al., 2010*)
    - CME initiation by Gibson-Low flux rope (*Gibson & Low, 1998*) inserted into steady-state solar corona.

Model runs:

- Obtain model outputs along MESSENGER trajectory through the ICME at Mercury and at all relevant spacecraft trajectories at 1 AU.

- **Model runs will be made available to the CCMC community.**

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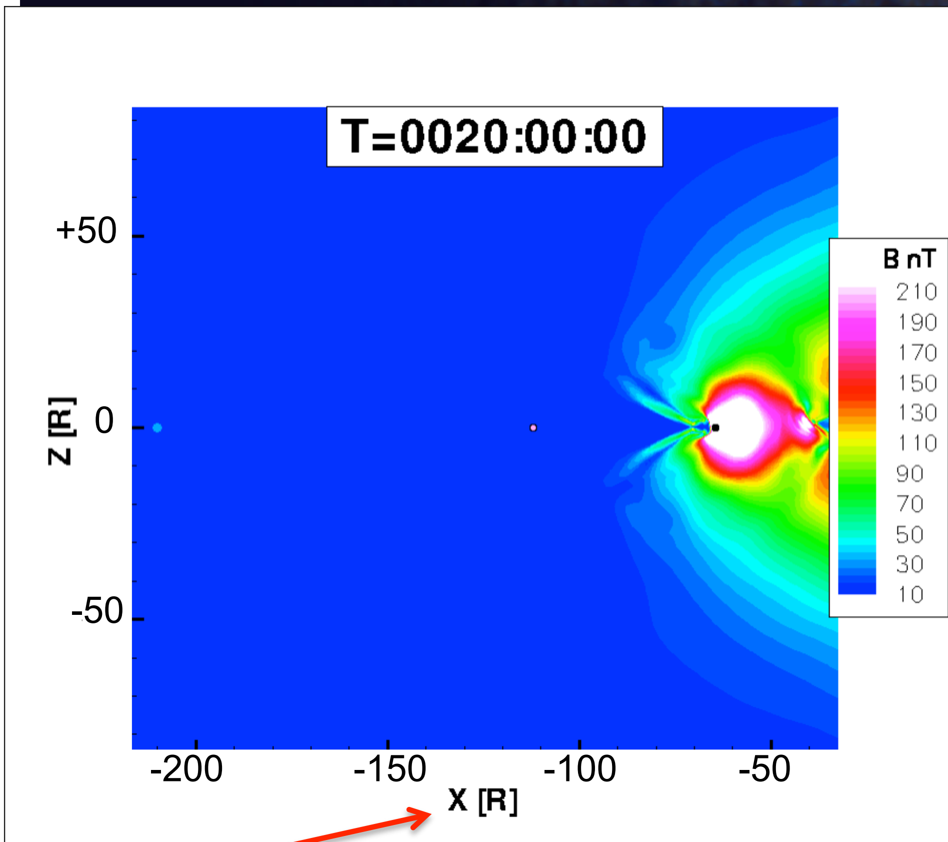
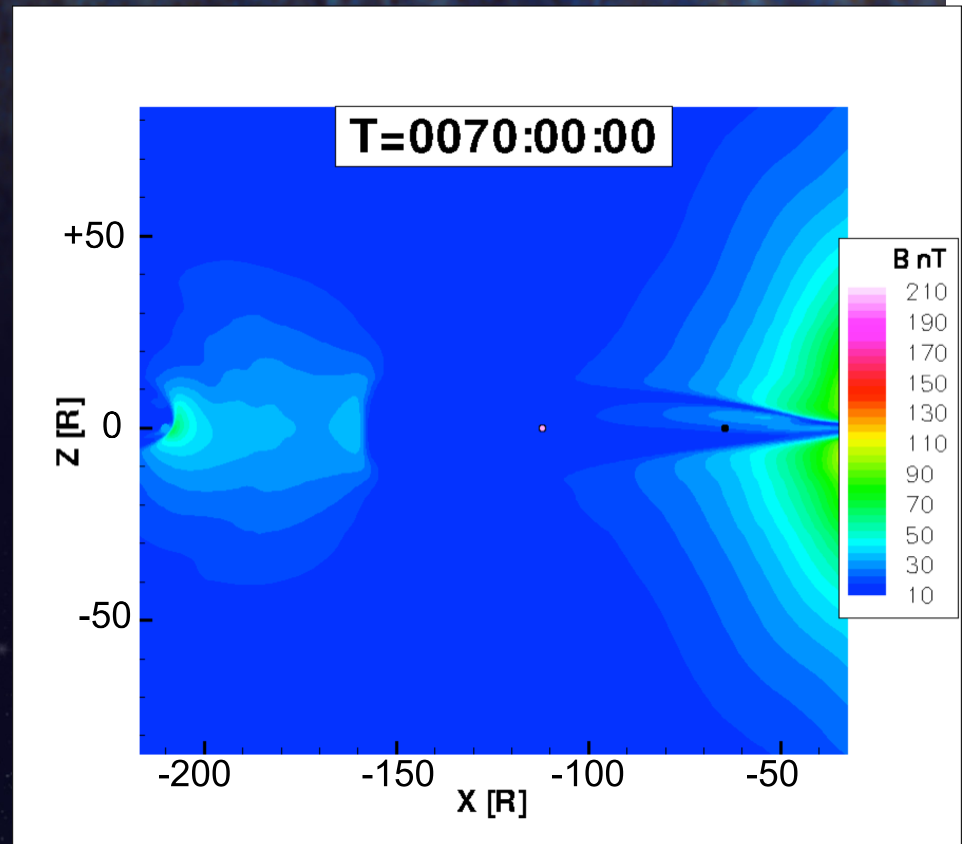
Initial simulation results:

Magnetic field strength (2-D cuts)

At 0.3 AU:



At 1 AU:



Solar Radii

Simulation outputs at 2 locations: 0.3 AU and 1 AU.

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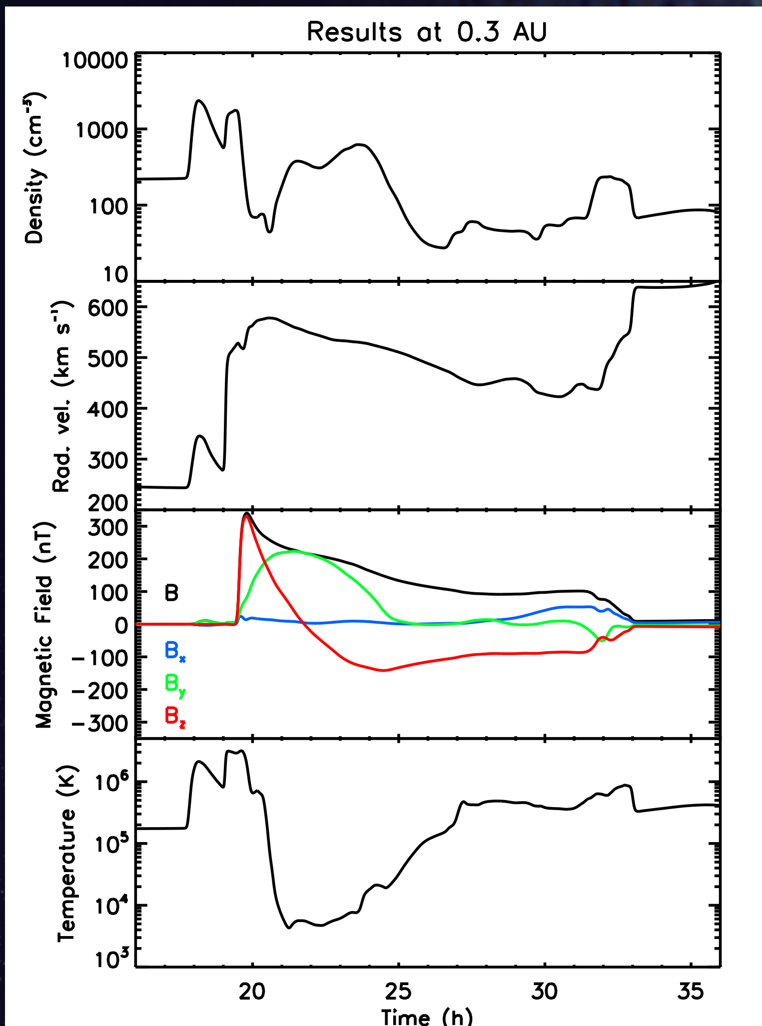
Initial simulation results:

1-D cuts in ecliptic plane

At 0.3 AU:



IMF:

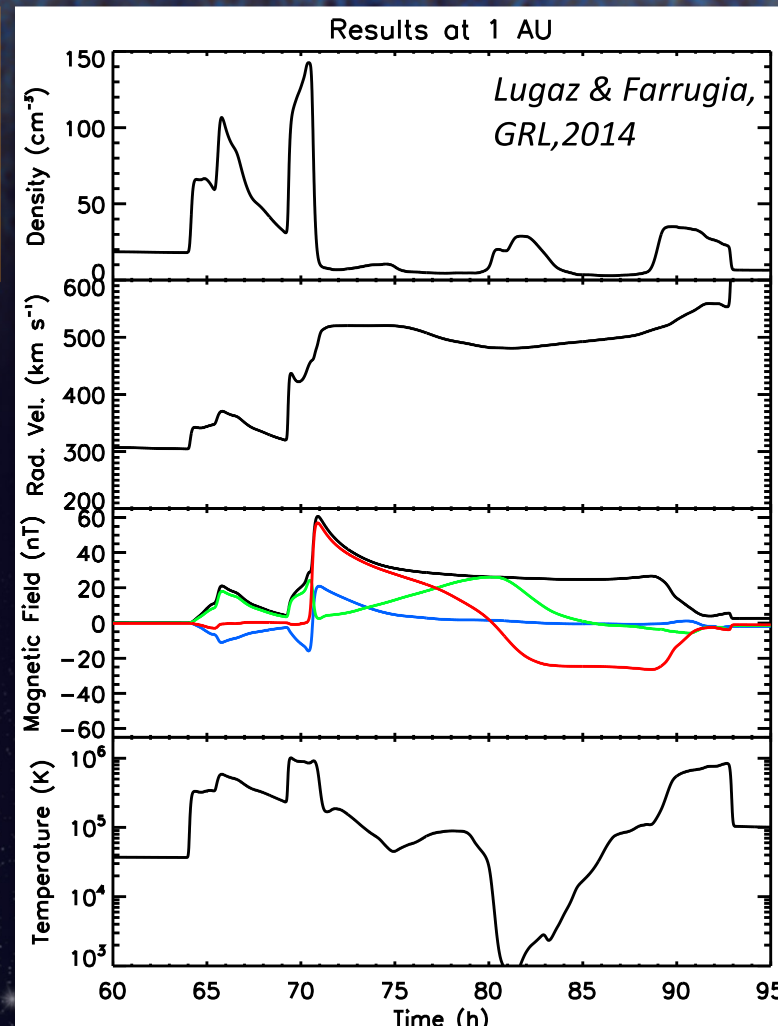
B_X – blue

B_Y – green

B_Z – red

|**B**| – black

At 1 AU:



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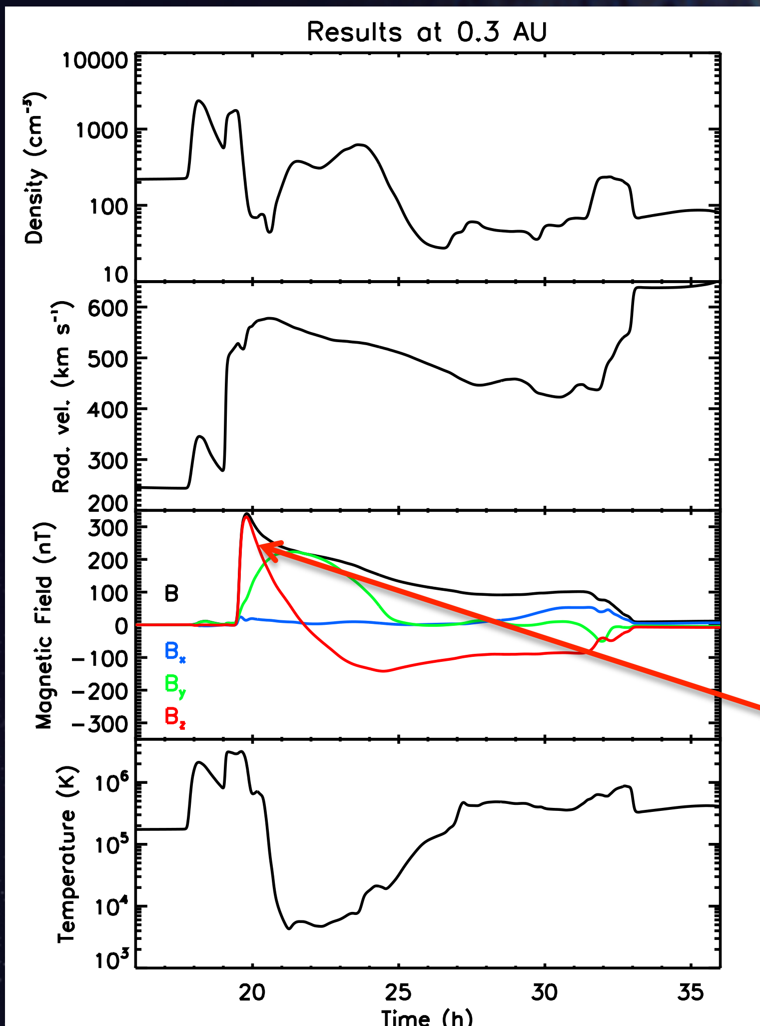

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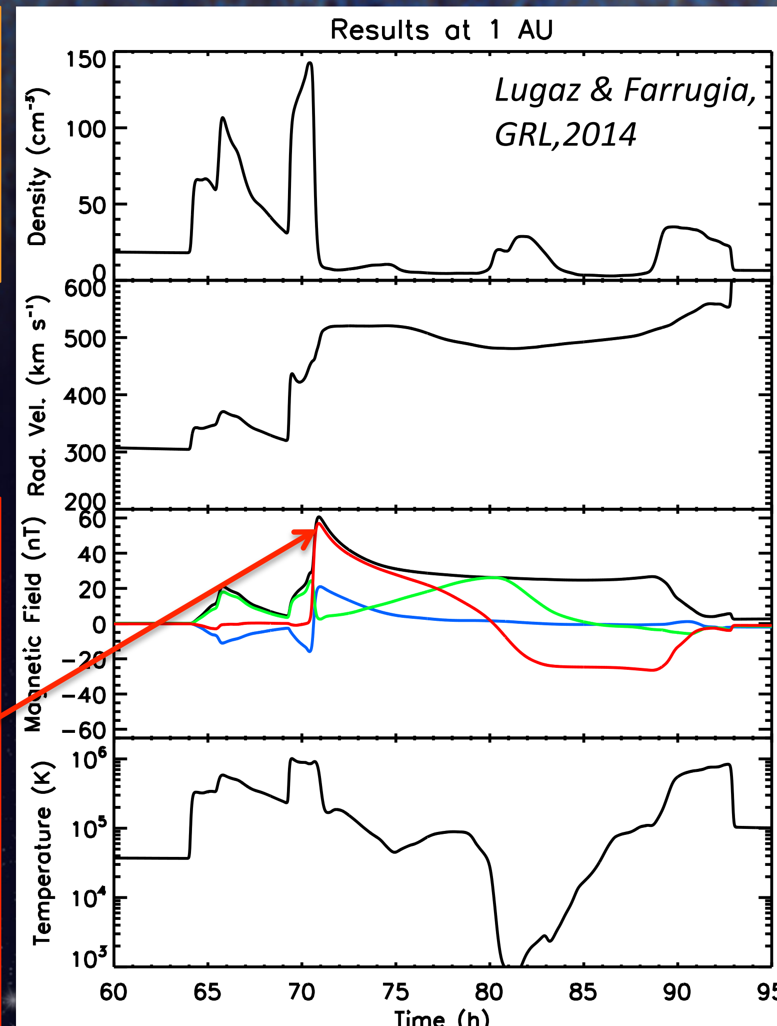
Note:

- Large drop in ICME |**B**| from 0.3 to 1 AU.
- B_Z - long southward pointing section still present.

At 1 AU:



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Work underway:

- For ICMEs not in conjunction, statistical study underway to determine average ICME characteristics at ~0.3 AU and 1 AU.

- ~5 ICME events in conjunction at Mercury and 1 AU in 2011 + 2012.
- In-depth study of these events, including:
  - **shock normal determination through minimum variance analysis**
  - **magnetic field direction in sheath and cloud**
  - **average ICME speed determination (limited solar wind measurements with MESSENGER)**
  - **ram pressure proxy determination at MESSENGER**

  +

  MHD modeling

→ Constrain evolution of ICME shock, magnetic field, speed, and ram pressure from 0.3 AU to 1 AU;

Potentially lay the groundwork for improved geomagnetic storm prediction for Solar Orbiter.

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