Effects of the solar cycle variations on the solar wind flows in the outer heliosphere and global dynamics

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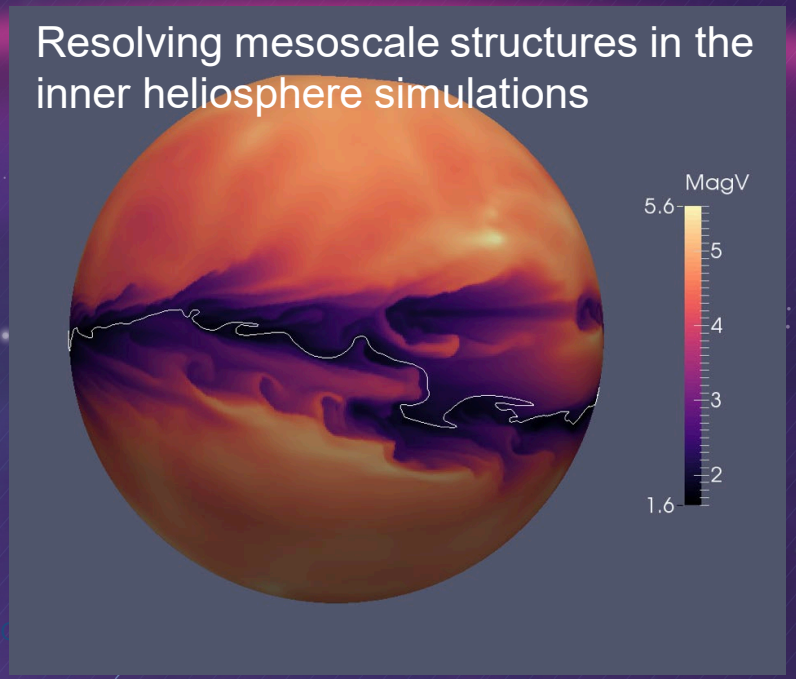
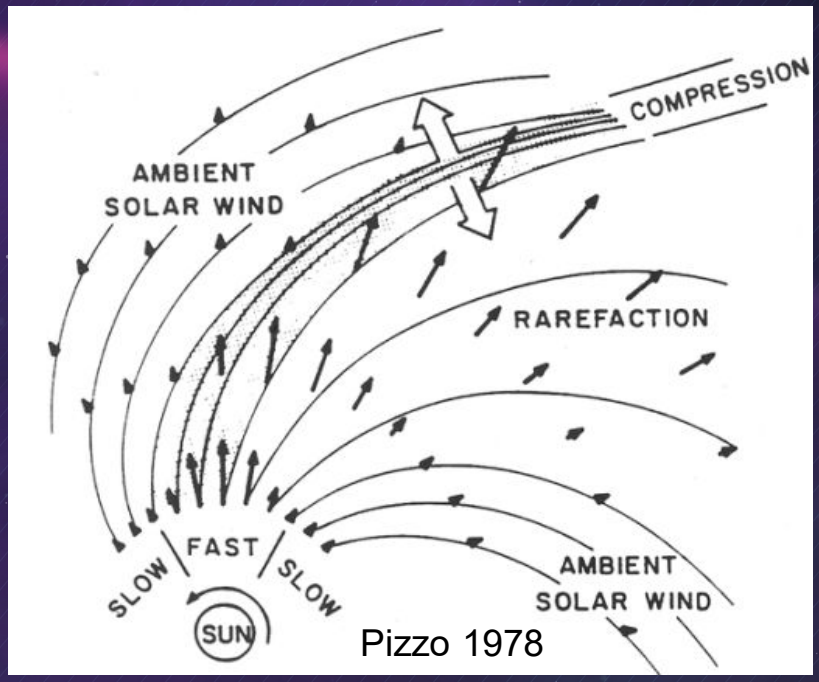
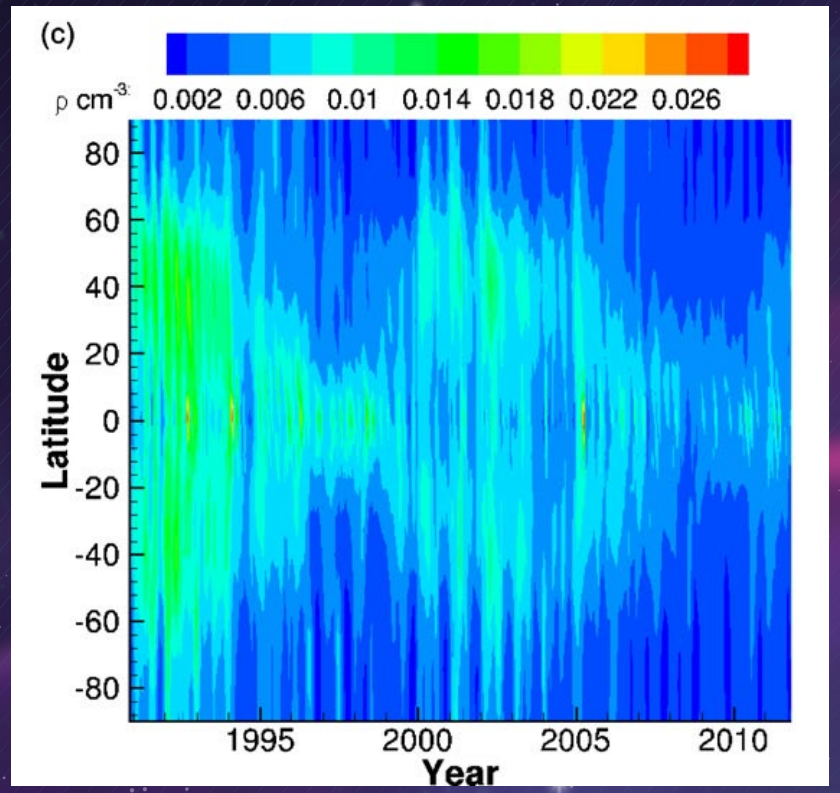
Sun launches disturbances of various scales to heliosphere

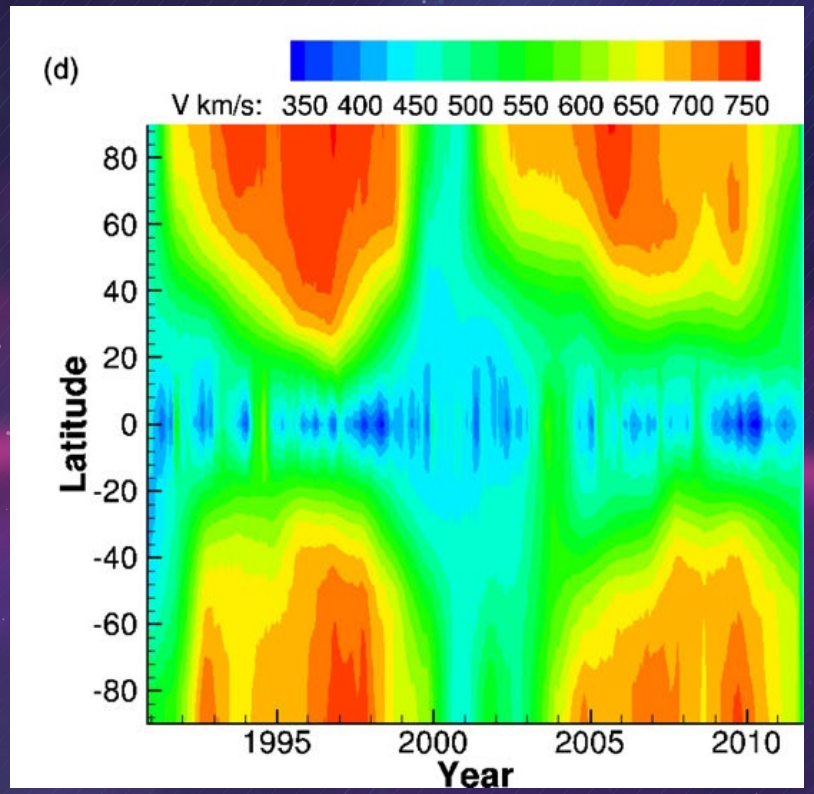
- Variations of the solar wind dynamic pressure over 11-year solar cycle
- Large-scale solar wind structures:
  - CMEs evolving into Merged Interaction Regions (MIRs) and Global MIRs (GMIRS) (Burlaga et al. 1993)
  - CIRs evolving into periodic structures observed in the solar wind and energetic particle enhancements (Lazarus et al. 1999, Hill et al. 2020)
- Mesoscale structures in the solar wind: flux ropes, density fluctuations (Kepko et al. 2019)
- Small scale: MHD and kinetic waves, turbulence (Usmanov et al. 2011)





11-year solar cycle effects: Global heliosphere simulations with the realistic boundary conditions at 1 AU

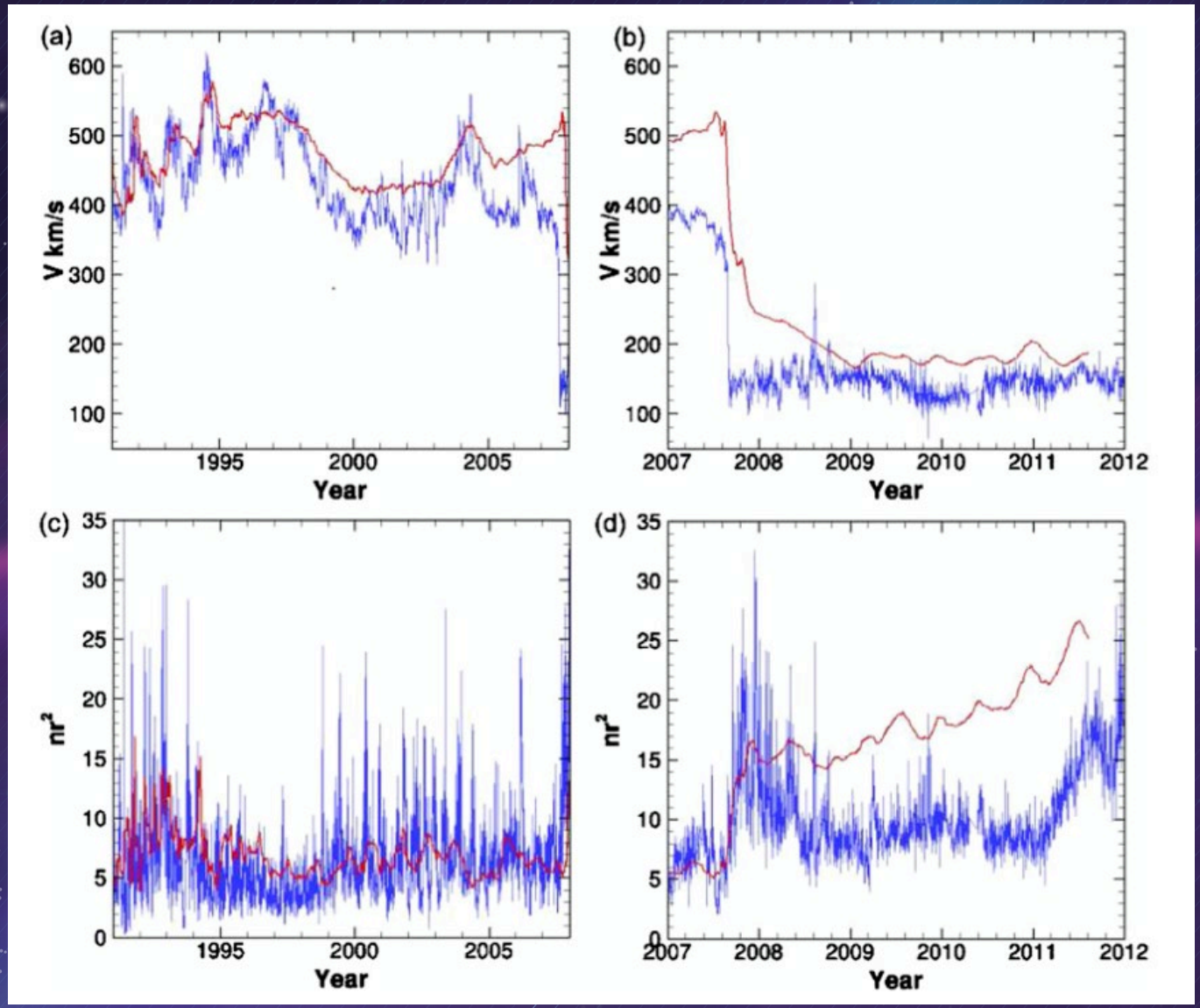




Provornikova et al. 2014

- 3D global multi-fluid model developed in Boston U group *(Opher et al. 2009, Provornikova et al. 2014)*
- Solar wind varies in time and latitude
- Boundary conditions inferred from Lyman-alpha data *(Quemerais et al. 2006; Lallement et al. 2010)* and IPS data

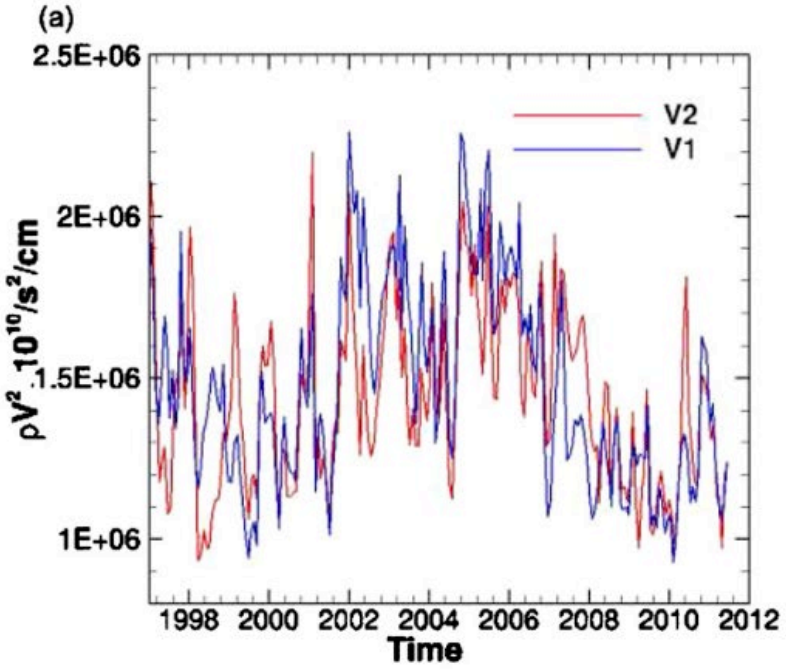
Comparison of global simulations with the Voyager 2 plasma data



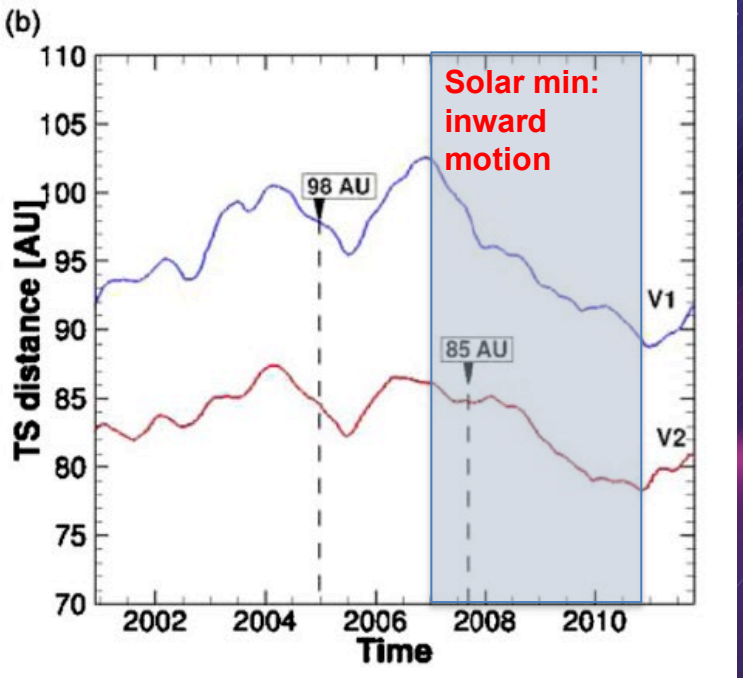
Provornikova et al. 2014

Motion of the heliosphere boundaries

Solar wind dynamic pressure at 1 AU

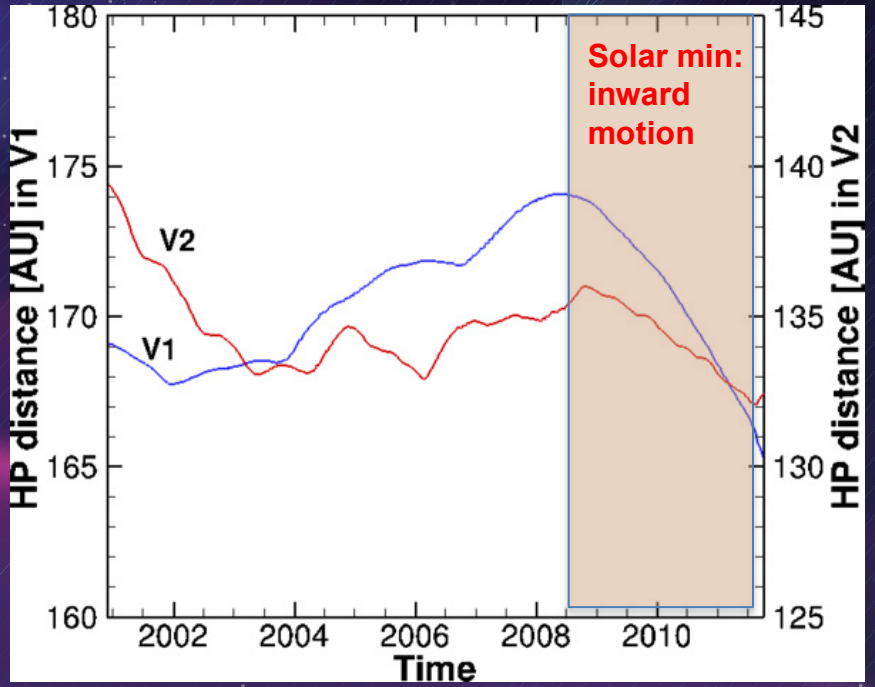


Termination Shock motion



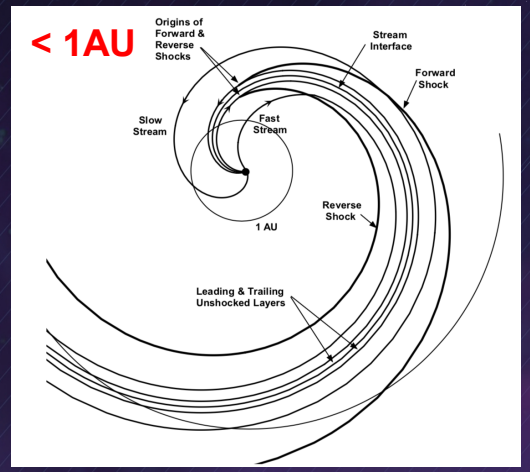
Termination shock distances agree with actual Voyager crossings

Heliopause motion



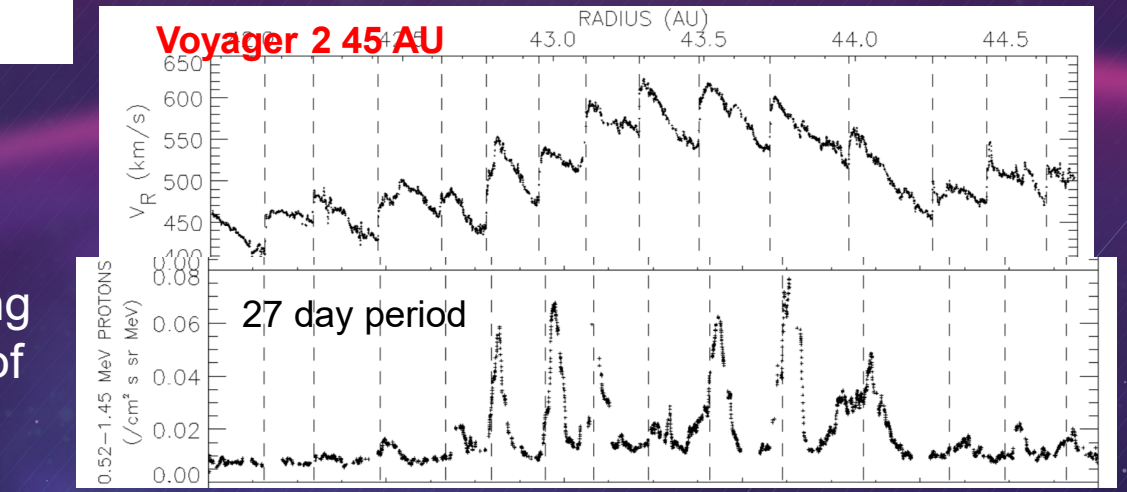
In simulations heliopause (140-170 AU) is too far from the Sun compared to Voyager crossings at ~120 AU

Corotating Interaction Regions in the outer heliosphere



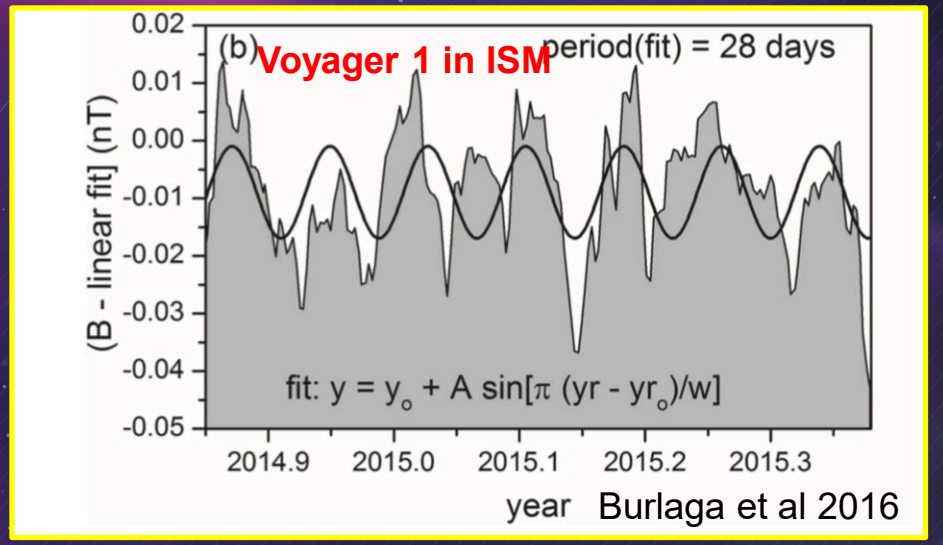
- CIRs are ***dominant*** structures in heliosphere during declining phase of the solar activity
- CIRs shocks form at >2 AU

- ***Long-lived*** structure (Ulysses: 30 solar rotations!)
- CIRs are efficient particle accelerators in the heliosphere (ions and electrons)



Lazarus et al 1999

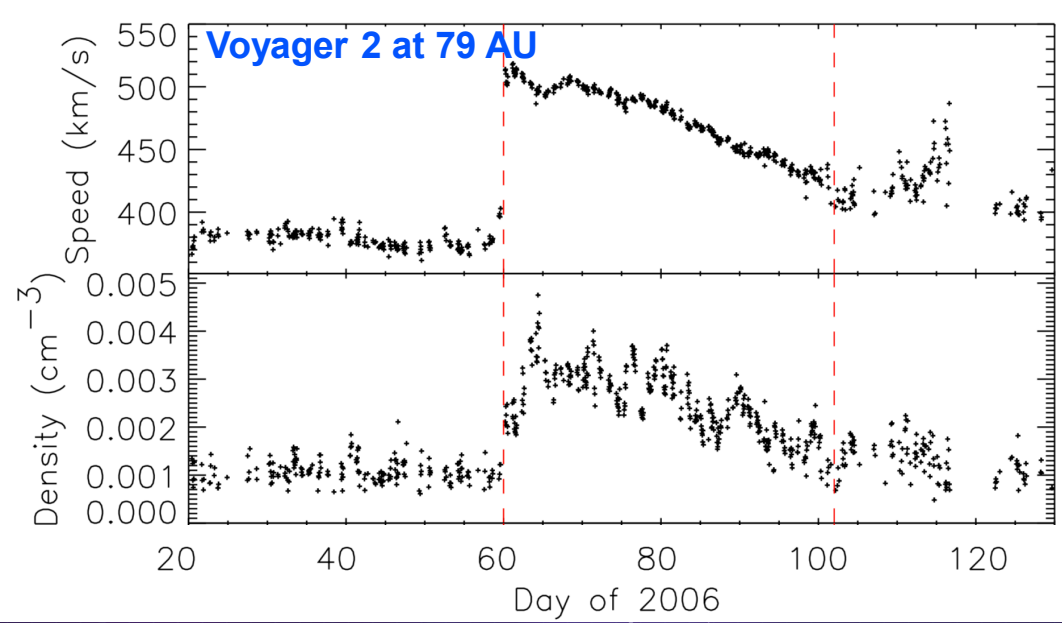
- In local ISM quasi-periodic B-fluctuations with period ~ **28 days** ≈ solar rotation
- Mechanism for fluctuations is unknown! CIRs?



Burlaga et al 2016

Solar Coronal Mass Ejections evolving into MIRs

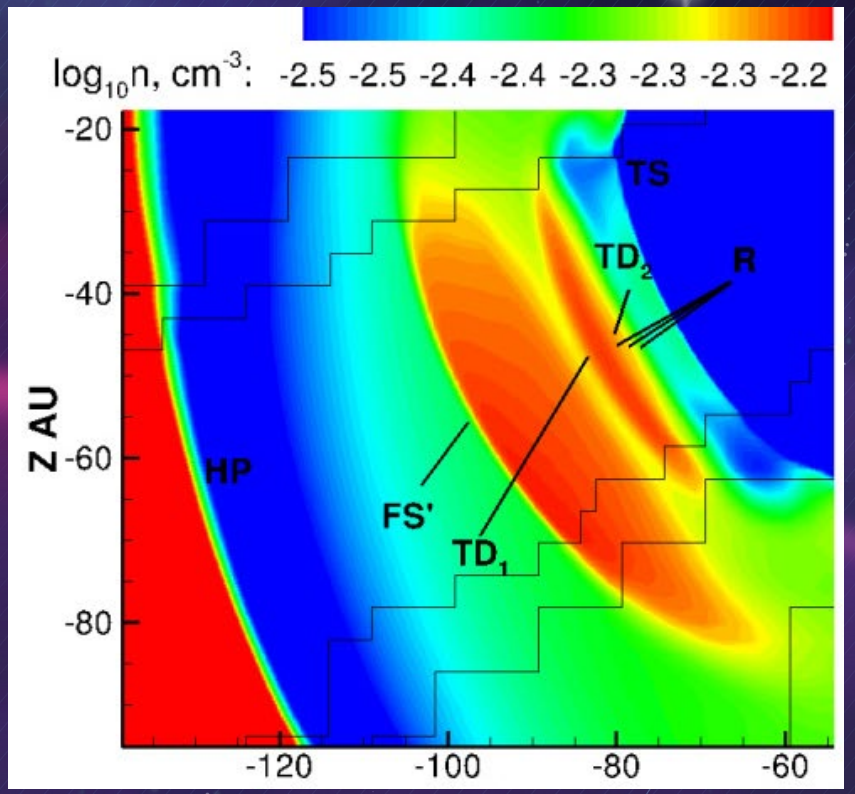
Merged Interaction Region in Outer Heliosphere



Richardson et al 2006

- CMEs expand, merge forming MIRs
- Drive shocks in outer heliosphere
- Significant change in solar wind parameters
- Modulate transport of cosmic rays

3D simulation of MIR-driven shock interaction with the Termination Shock



Provornikova et al. 2013

- Large fluctuations of solar wind due to shock-shock interaction
- Highly variable plasma in heliosheath

Summary and challenges

- Solar minimum conditions drive inward motions of the heliosphere boundary
- Heliopause is less sensitive to solar wind variations, displacements are smaller than of termination shock
- Signatures of CIRs are observed in the distant solar wind (40 AU) and beyond the heliosphere boundary in the ISM but evolution is not understood
- CMEs drive formation of shocks, rarefactions and tangential discontinuities in the heliosheath
- How disturbances evolve from the Sun throughout the heliosphere is an open question demanding new data and advances in simulations
- The major simulation challenge is to track evolution of CIRs and CMEs from the Sun to the heliosphere boundary with realistic boundary conditions in the model