West Virginia University

The Sun, Solar Wind, and Heliosphere

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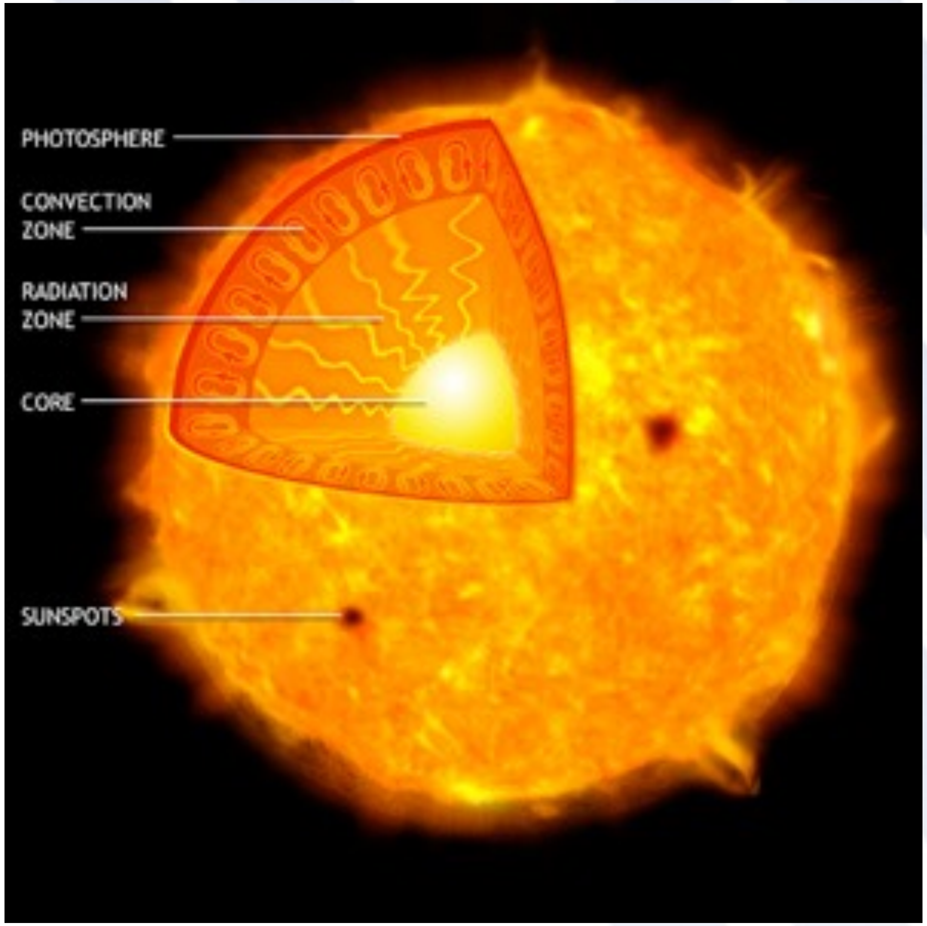
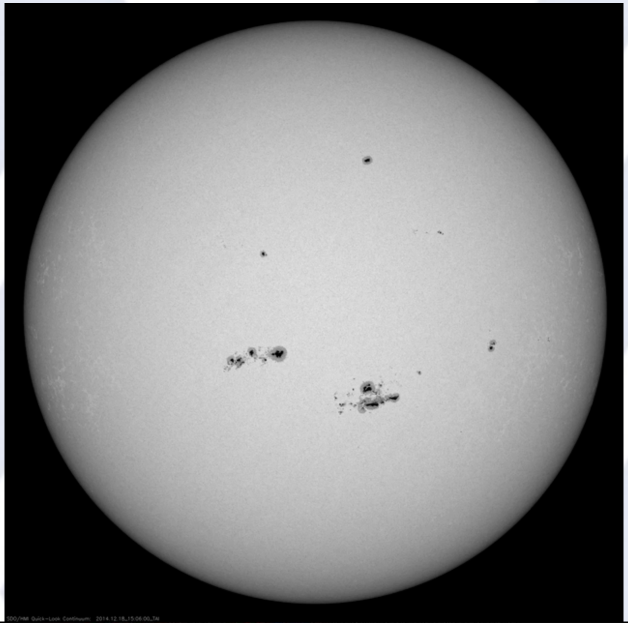
*Now at Catholic University of America/NASA Goddard Space Flight Center

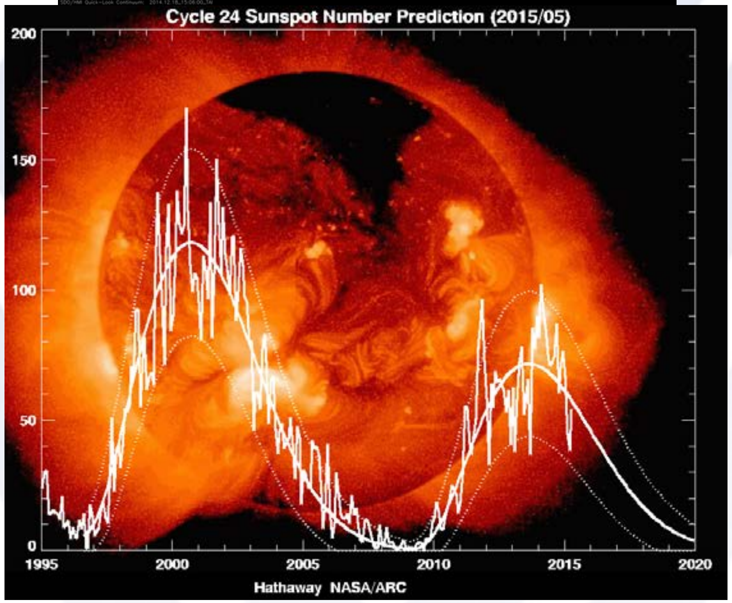


Meet our Sun and its interior.
Image courtesy of Harvard-Smithsonian.

Solar Overview

- Sunspots indicate regions of high magnetic activity
  - Likely locations of solar eruptions
- Sunspot number varies over 11 years





Solar Dynamics

(1) Prominences

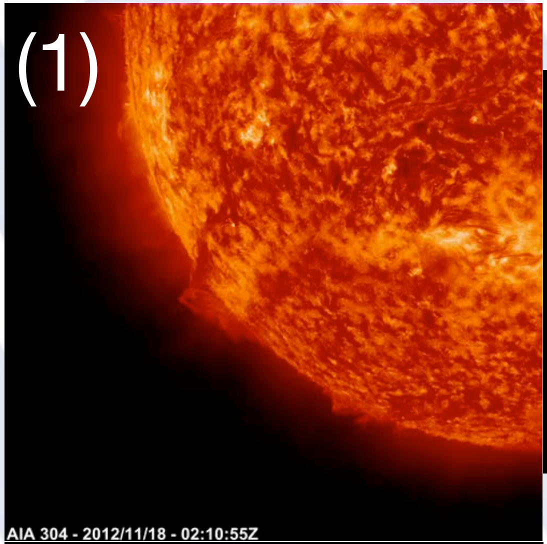
- Plasma circulation

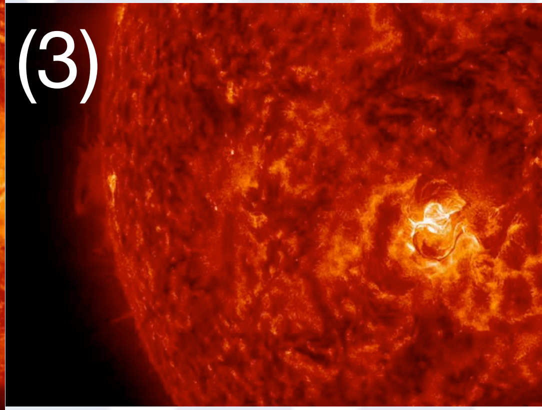
(2) Coronal Holes

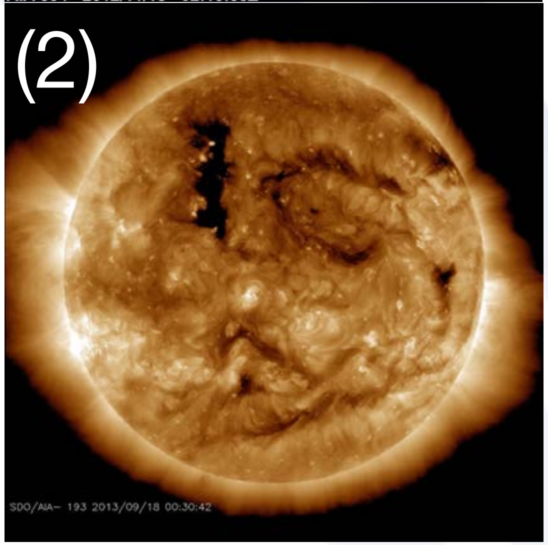
- Regions of weaker magnetic field
- Fast plasma escapes

(3) Solar Flares

- Energetic release of plasma to space







(1) Solar prominence on Nov. 18-19, 2012.

(2) Coronal hole on Sep. 18, 2013.

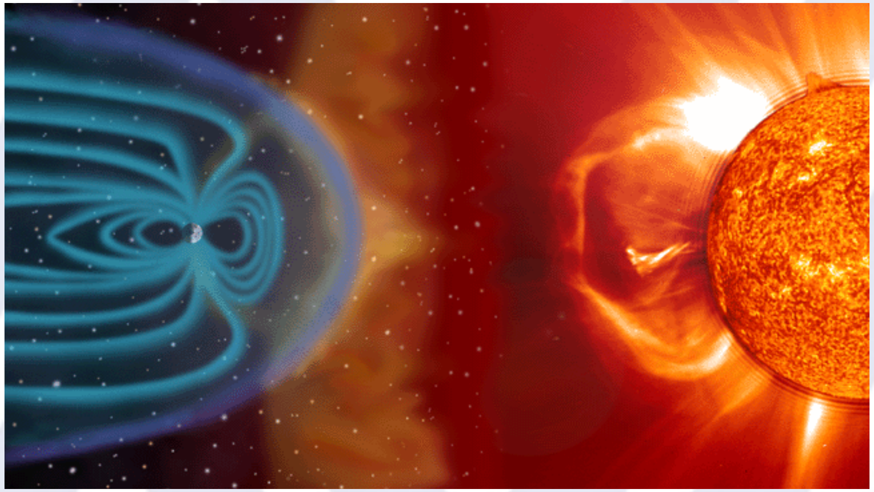
(3) X2 class flare on Mar. 11, 2015.

All images courtesy of (SDO-NASA)

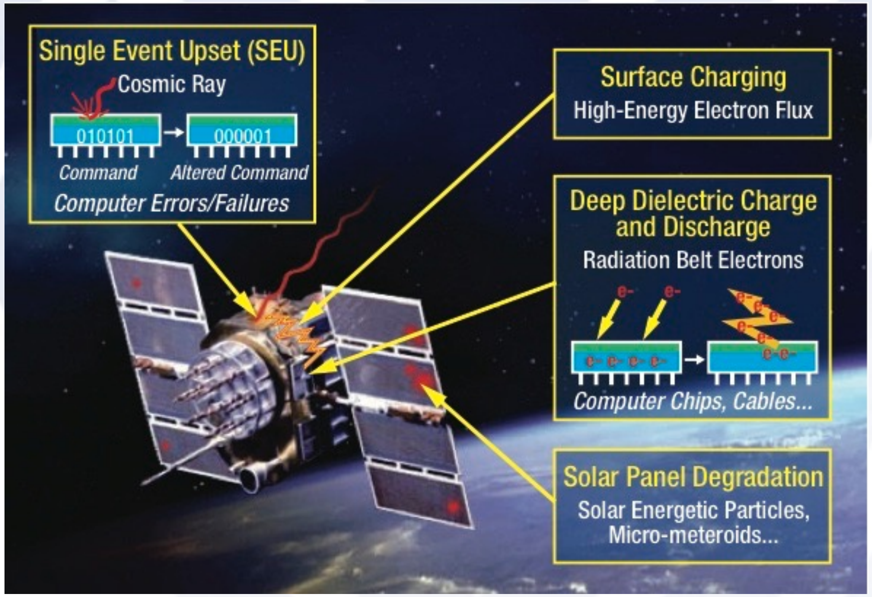
The Big Picture

- Solar storms release vast quantities of hot, ionized gas (plasma) into space
- "Solar wind" can interact with Earth's magnetic field
  - Damage electrical grid
  - Lethal radiation doses for astronauts
  - Damage satellites

Pressing need to understand "Space Weather"



Courtesy of SOHO/EIT/LASCO (NASA/ESA).

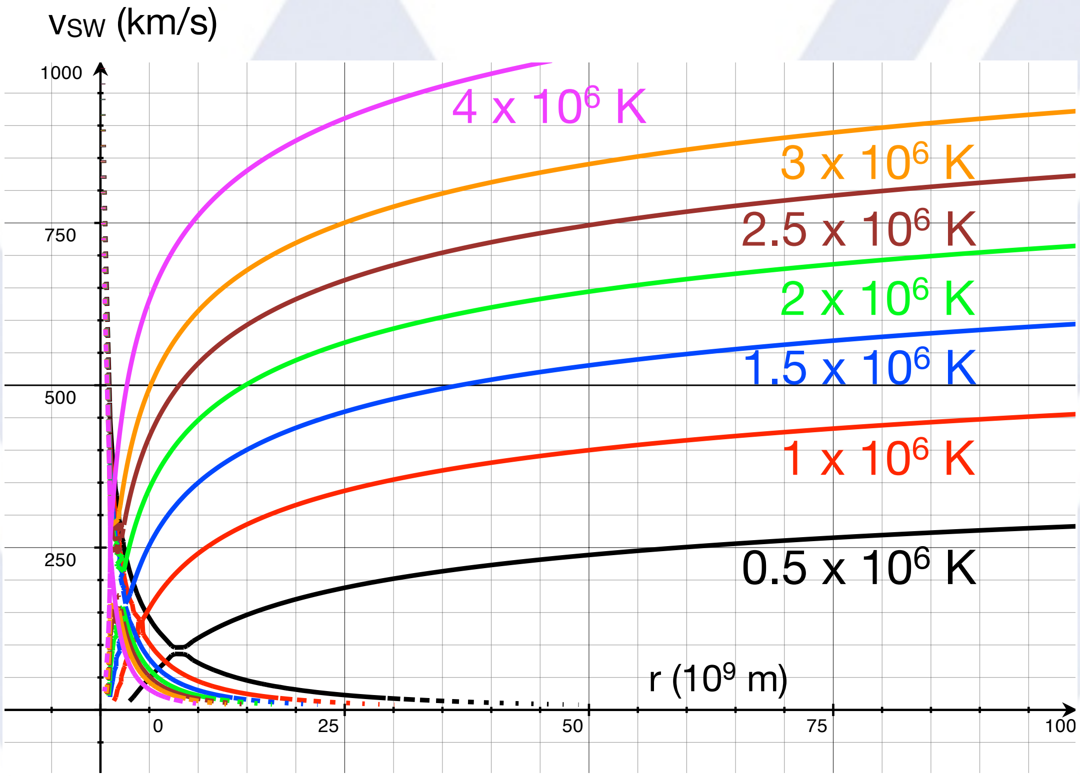


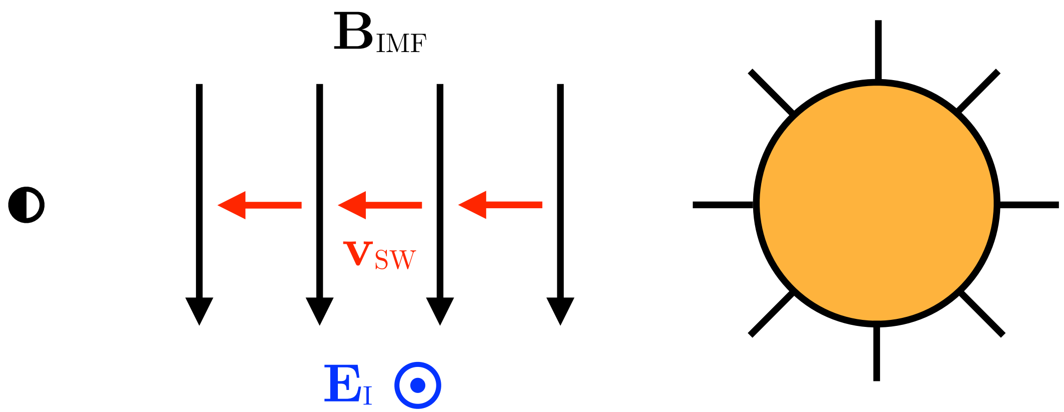
Courtesy of RBSP (NASA).

Solar Wind

- Solar plasma gains energy in solar corona
  - Escapes into interplanetary space
- Plasma carries magnetic field into interplanetary space
  - "Frozen-in" law

$$\mathbf{E}_\mathrm{I} + \mathbf{v}_\mathrm{SW} \times \mathbf{B}_\mathrm{IMF} = 0$$





Top: Solar wind solutions for various temperatures in the solar corona. (Adapted from Parker, 1958)
Bottom: Schematic diagram of frozen-in magnetic field.

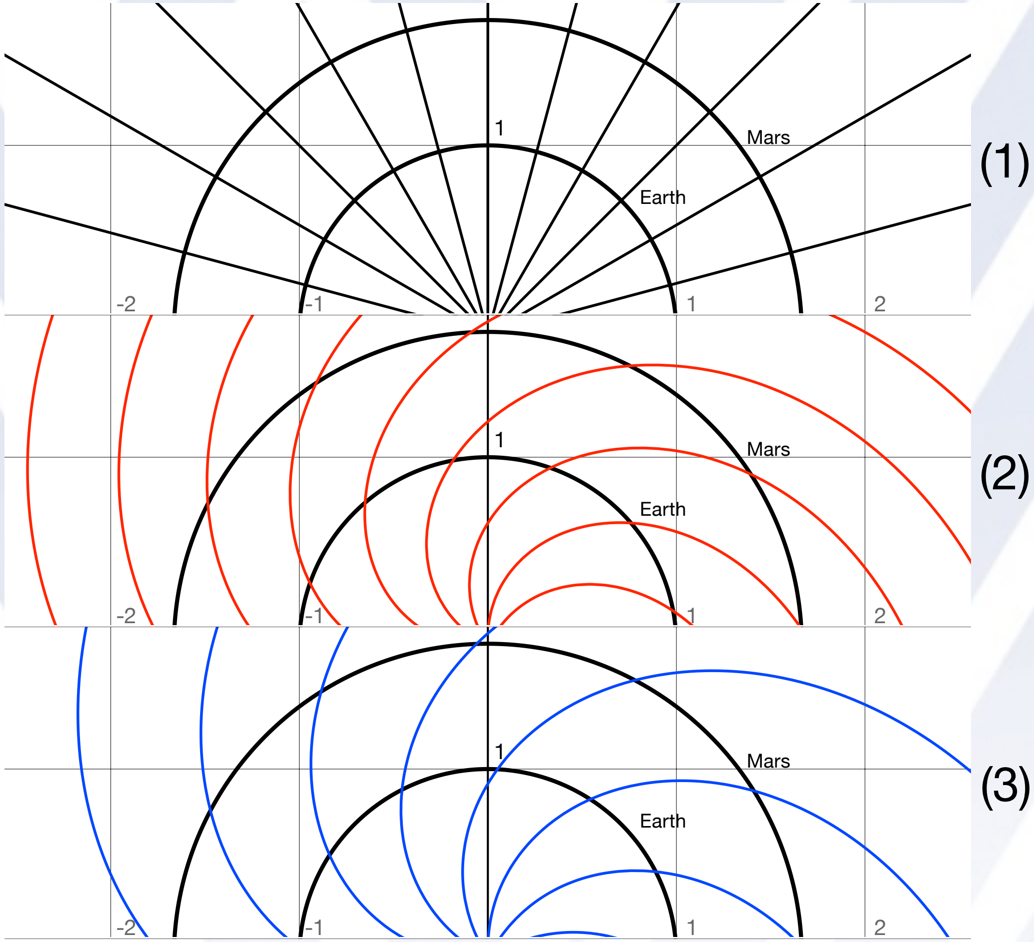
Parker Spiral

(1) At a sufficient distance, plasma travels radially outward in Sun's rotating reference frame (T ~ 27 days)

- In a stationary frame, solar wind travels along "Parker Spiral" arms

(2) v_{SW} = 400 km/s

(3) v_{SW} = 600 km/s (straighter arms)



Flow lines carry solar plasma into interplanetary space. Orbits of Earth (1 AU) and Mars (~1.65 AU) shown for reference. (Adapted from Parker, 1958)

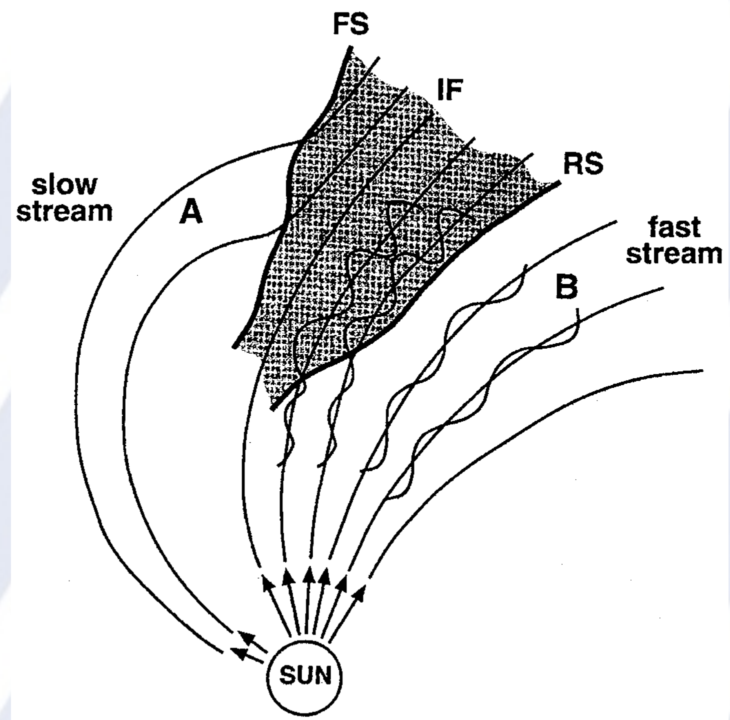
Interplanetary Plasma

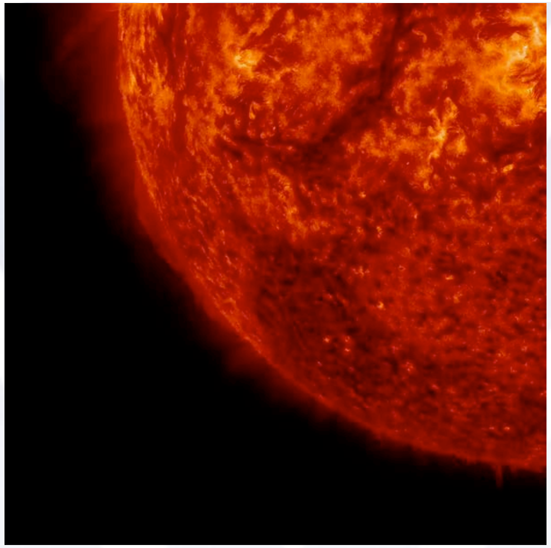
- Common solar wind
  $|v| \approx 400$ km/s, $|B| \sim 1$ nT,
  $n \sim 1\ cm^{-3}$, $T \sim 10^4$ K

- Co-rotating Interaction Region (CIR)
  $|v| \approx 600$ km/s, $|B| \sim 10$ nT,
  $n \sim 10\ cm^{-3}$, $T \sim 10^5$ K

- Coronal Mass Ejection (CME)
  $|v| > 10^3$ km/s, $|B| \sim 10$ nT,
  $n \sim 10\ cm^{-3}$, $T \sim 10^6$ K

(~ conveys order of mag.)

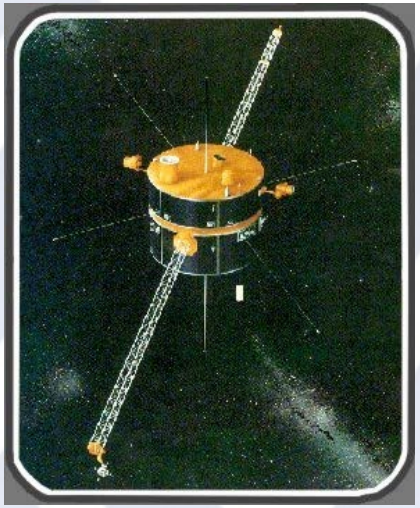




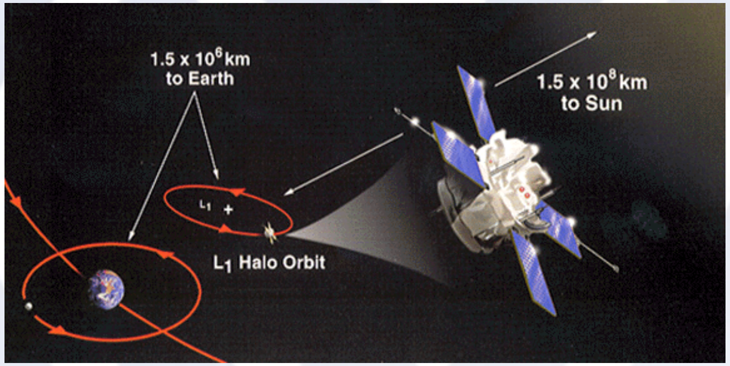
Top: Schematic of CIR formation. (Gonzalez et al., 1999)
Bottom: Filament releasing CME on Feb. 24, 2015. (SDO)

Solar Wind Monitors

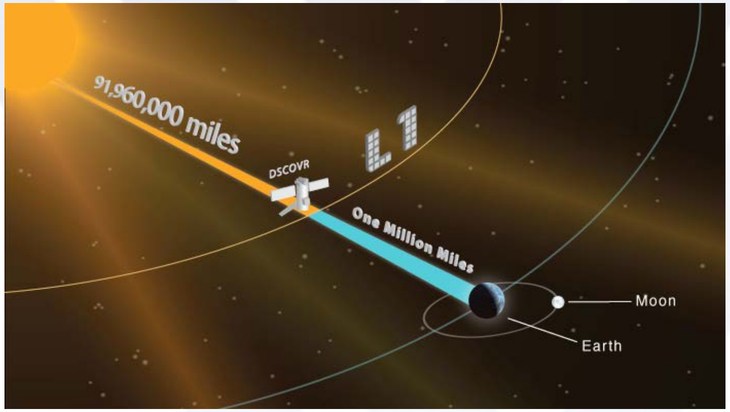
- WIND, ACE, DSCOVR
  - Orbiting L_1 (~230 R_E)
  - Launched: W - 1994; A - 1997; D - 2015
  - Measure **B**, T, n, **v**, energetic particles, cosmic rays (A only)
- All leading to predictive understanding



WIND



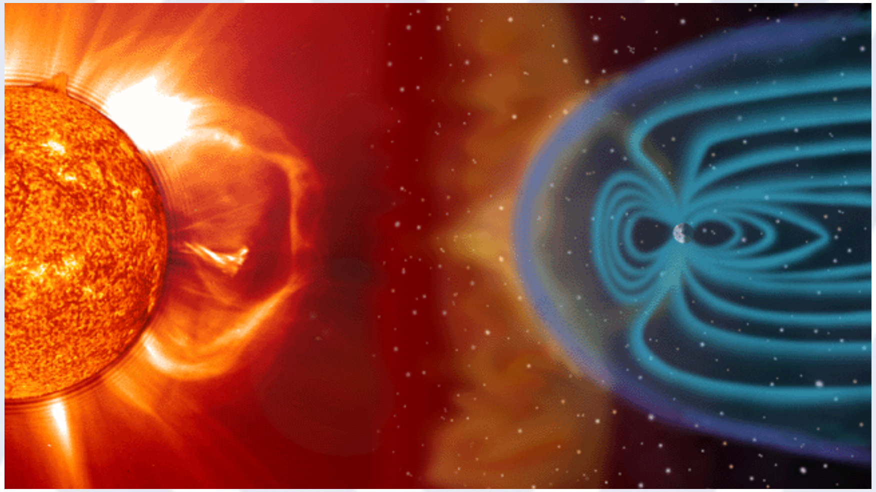
ACE

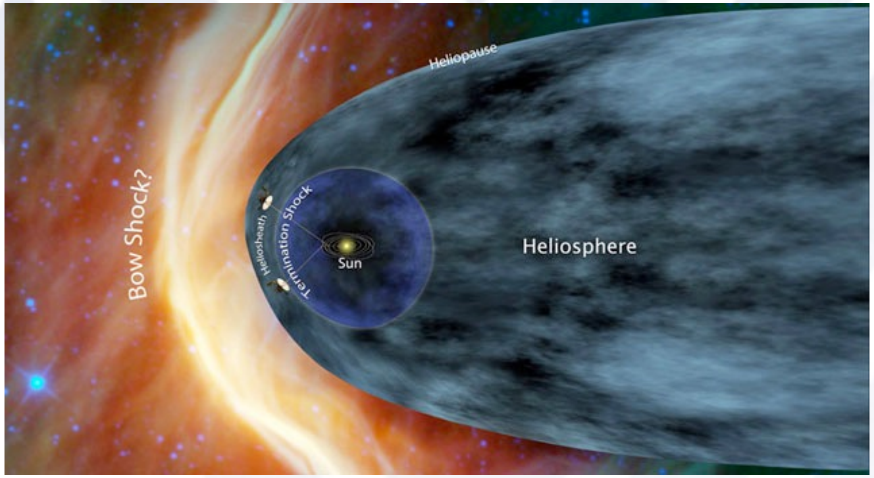


DSCOVR

Heliosphere

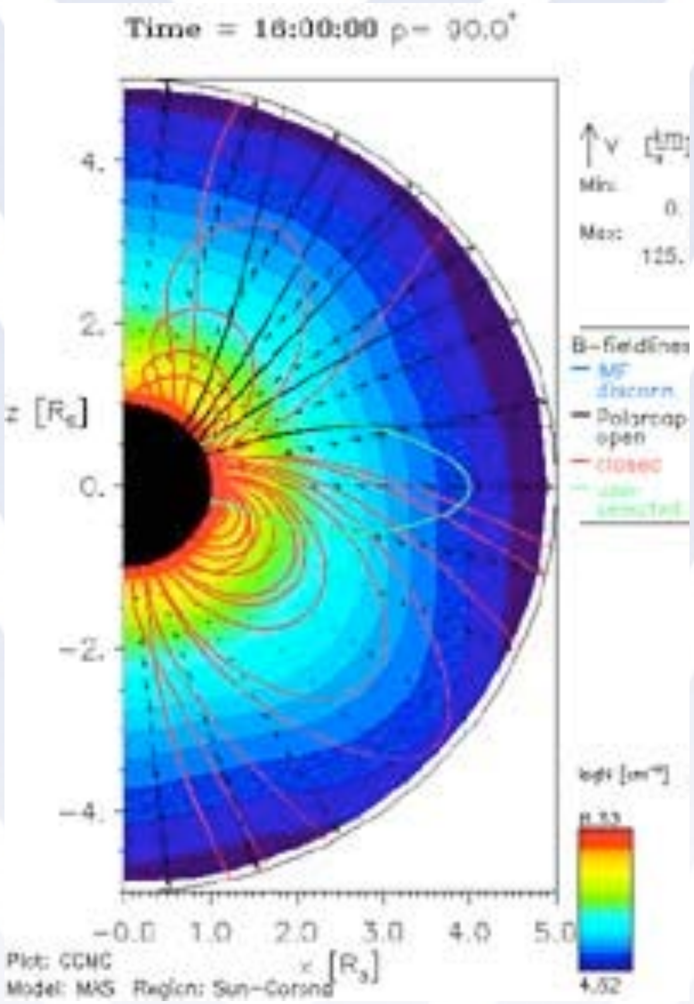
- Space dominated by solar magnetic field
  - Many features similar to magnetosphere! (IBEX: No bow shock…)
- Study familiar phenomena at heliopause
  - Voyager: fields, waves, cosmic radiation, ...
  - Simulations: Reconnection



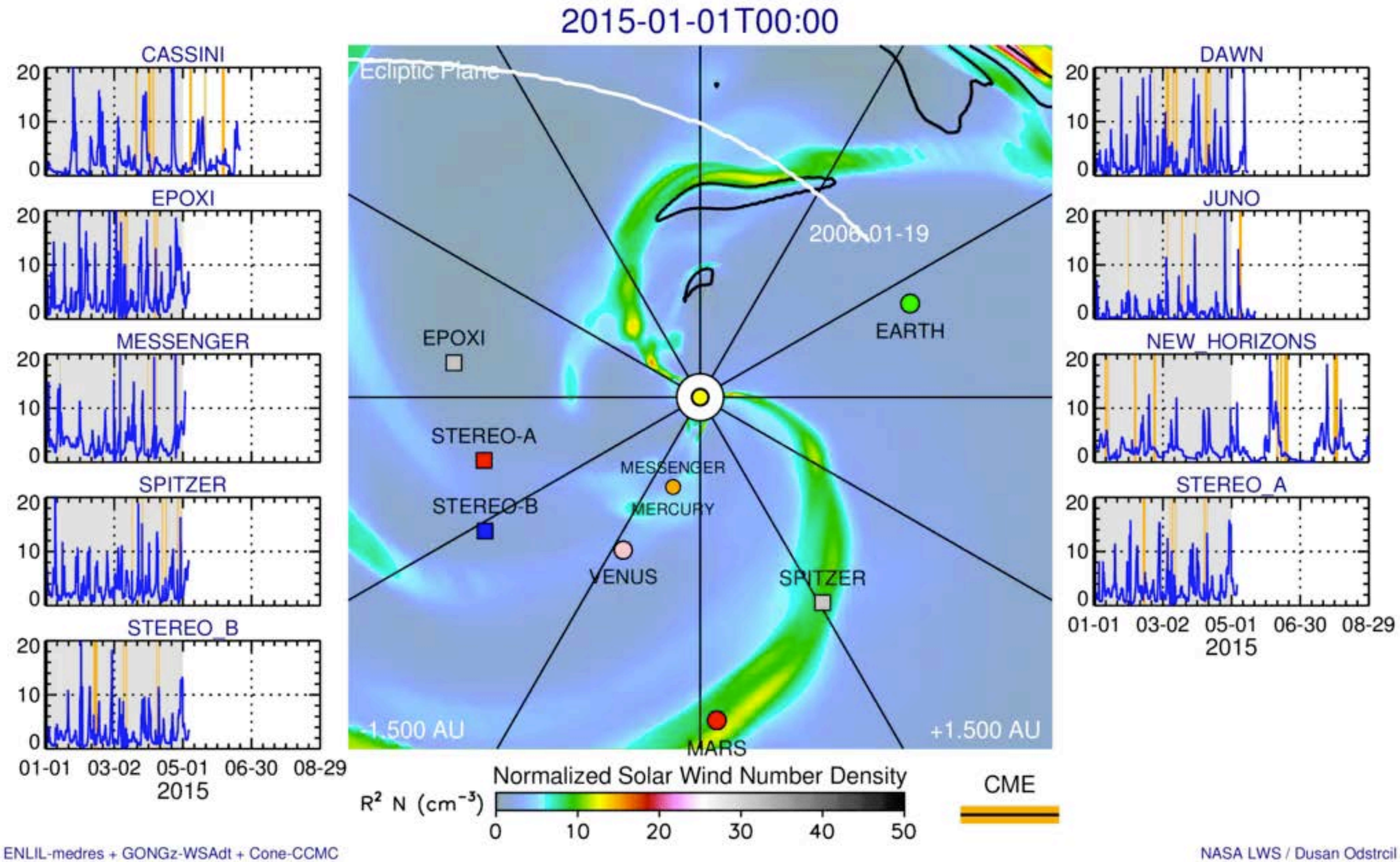


Computational Models

- CORHEL (MAS/WSA/ ENLIL) [PSI, AFRL, U. Colorado]
    - Input: Solar magnetogram
- SWMF [UMich]
    - Input: Carrington rotation
- Both models simulate corona and MHD heliosphere
- Output: n, T, P, **v**, **B**



Sample data output of CORHEL. Image courtesy of NASA CCMC.



The Complete Picture Courtesy of NASA's CCMC

Conclusions

- The sun is very complex and interesting (SHINE)
- Solar events source of magnetospheric phenomena
- Predictive capabilities under development

- Thanks to Ian and Robert for having me speak
- Support from NSF, GEM, and NASA WVSGC is gratefully acknowledged