Mission to the Sun-Earth L_5 Point

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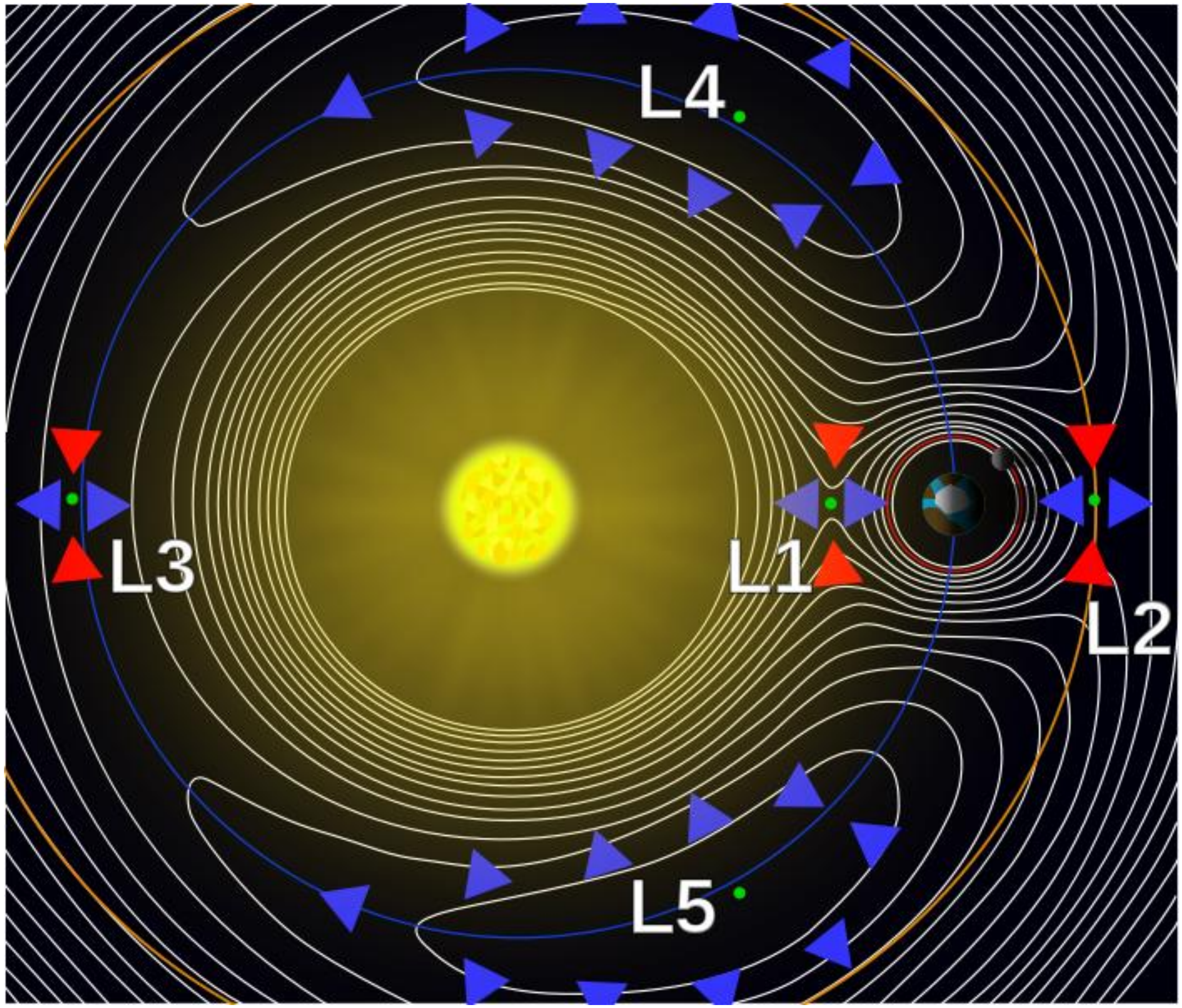


Motivation for an L5 Operational Science Mission

- **The STEREO mission, launched in 2006 and consisting of 2 identically instrumented spacecraft, has demonstrated the utility of observing the sun from vantage points off of the sun-earth line and the utility of the heliospheric imager concept from that vantage points.**
- **The coronagraph and the heliospheric imagers need large angular separations to observe the solar wind from sun to earth and CMEs with less projection effects than from the sun-earth line**
- **An L5 mission was considered by the Decadal Study by the US National Research Council and was published in 2012.**

Motivation for L5 (Continued)

- The payload requirements for an operational L5 mission must be defined.
  - The difference between the operational instrument requirements and those for scientifically innovative instruments would be relatively small.
  - Additional scientific instrumentation could also be accommodated as resources permit
- It is important to not only track the CMEs/CIR/etc. but also to refine the underpinning science
- This talk will detail the Decadal Study and to identify the costs associated with the candidate minimum mission

CORE ELEMENTS OF A ROBUST SPACE WEATHER PROGRAM

- The Decadal Survey proposed a new "Robust Space Weather Program"
- Continuous Measurements for Space Weather
  - Solar X-ray, extreme ultraviolet, and ultraviolet spectral irradiance and images, magnetograms
  - Solar coronal & heliospheric images
  - Solar wind (speed, density, temperature, ion composition)
  - Interplanetary magnetic fields
  - Energetic particles (solar and galactic)

Science Objectives

- Understand the physics of the propagation of CMEs from Sun to Earth
- Probe deeper into the solar interior to the bottom of the solar convective envelope (tachocline shear layer)
- Determine the origins and evolution of the earth-bound solar wind
- Determine the origins of SEPs
- Determine the structures involved in the CME process
- Monitor the solar wind 3-4 days ahead of Earth

Instrument Complement

- **Solar coronagraph**
- **Solar X-ray, EUV, and magnetic field imagers**
- **Off-limb Spectrograph**
- **Heliospheric imager**
- **Solar wind parameters (e.g., B, T, v, n, composition)**
- **SEP package**

- **Inst. Cost: ~$135M**

WHY L_5? -Unique Research Enabled by Viewpoint and Instrumentation

1. **Longitudinal evolution of the tachocline.**
   - Helioseismology from two (and varying) viewpoints (L5 & L1 or Earth).

2. **Origins and evolution of the Earth-bound solar wind.**
   - Off-limb spectroscopy of structures over western L_5 limb are measured in-situ at L_1 and Earth.

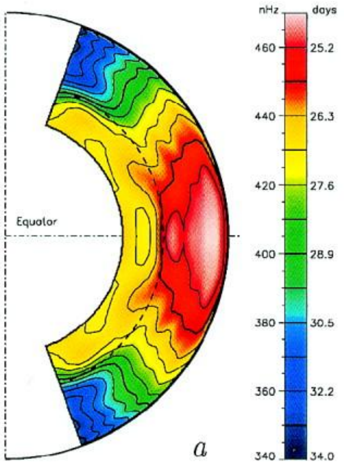
3. **Particle acceleration at the 'heart' of the coronal eruption.**
   - Hard X-ray imaging of faint loop-top sources and post-CME current sheets because their bright HXR emission is occulted from L_5.

4. **Long-term "stereo" studies of CME and CIR physics.**
   - EUV/Coronagraphic imaging of CME and CIR structures propagating towards Earth from an ideal angular separation.

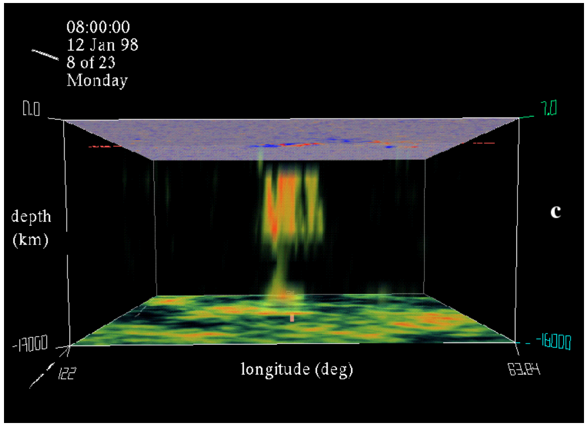
5. **The physical properties of the corona before and during eruption.**
   - HXR, Coronal Imaging + Earth-based assets. Ideal for Earth-bound CMEs.

Limitations of helioseismology from a single vantage point

- **Global helioseismology has been remarkably successful at revealing the Sun's internal radial structure and its internal rotation as a function of radius and latitude;**
  - **BUT global helioseismology can give no information about longitudinal variation of the solar interior.**



- **Local helioseismic techniques (e.g., time-distance helioseismology) give longitudinal information.**
  - **BUT they are restricted to probing the upper third of the convection zone (when the Sun is viewed from a single vantage point.)**



Importance of imaging the tachocline and its longitudinal variations

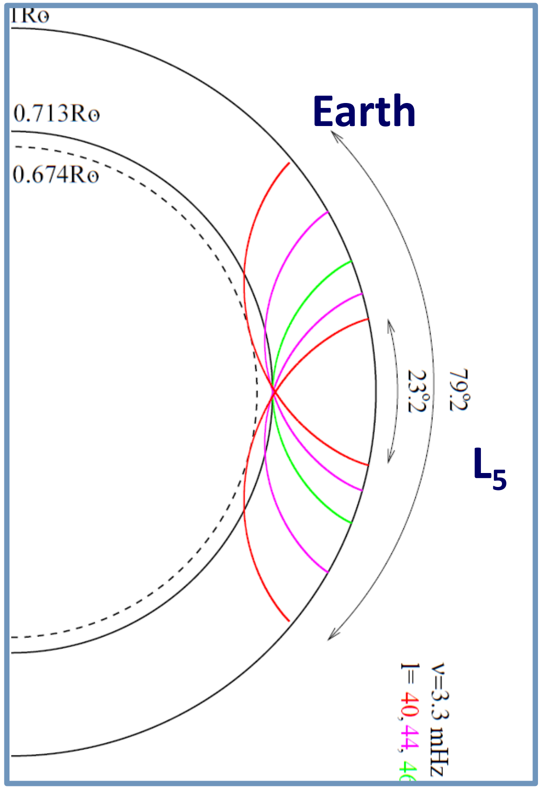
- ***The tachocline shear layer at the bottom of the Sun's convective envelope is believed to be the seat of the solar dynamo*.**
  - **Direct detection of the magnetic field in the tachocline is extremely challenging; but associated thermal anomalies and bulk flows are accessible to helioseismology, with the right observational datasets.**

- **Calculations of magnetoshear instabilities of the tachocline region, by Gilman, Cally, Dikpati and collaborators, predict *longitudinal variations* as signatures of the magnetic field present there.**

- **Active longitudes and hotspots of persistent surface magnetic activity of many rotations or even over more than one solar cycle are also likely associated with hotspots in the tachocline region which will only be revealed with longitudinal resolution of this region.**

Why include helioseismology on an L_5 mission?

- **Simultaneous helioseismic observations (Earth + L_5) detect both ends of long, deep wave raypaths. Such rays penetrate to the tachocline.**
- **By measuring travel times along such raypaths, the thermal anomalies and flows in the tachocline will be resolved in longitude for the first time.**
- **The resolution will be about 0.1 R_s, resolving azimuthal variations up to about wavenumber m=30.**



The processes and sources of the solar wind remain ambiguous

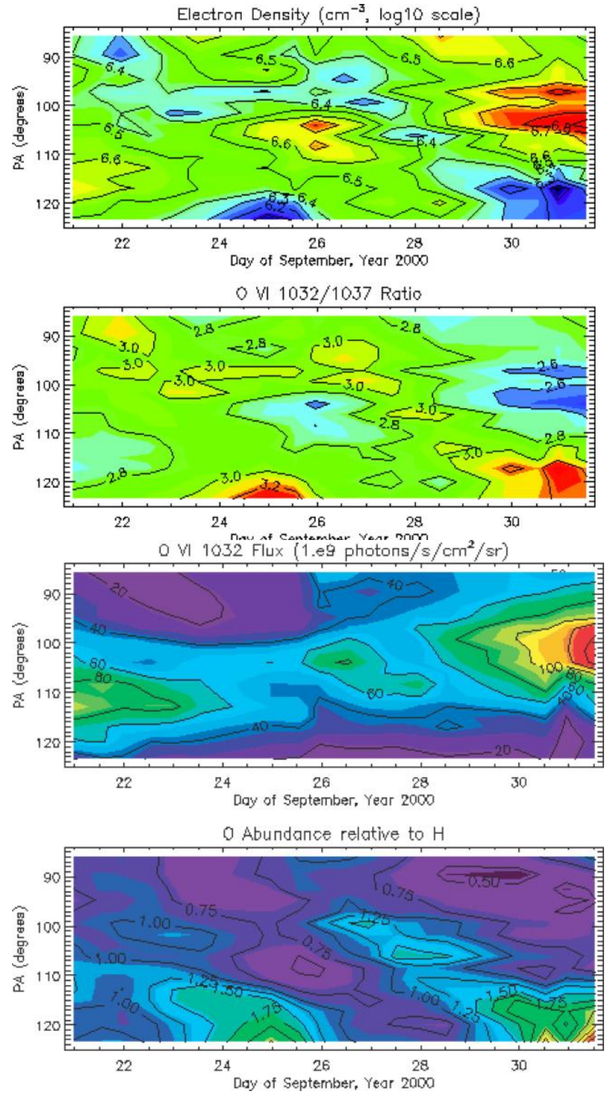
- Status:
  - To constrain solar wind theories and the initial conditions at the CME formation, we need spectroscopic observations in the low corona (>5R_s).
  - SOHO/UVCS observations provided our best observations and constraints for solar wind models.

- PROBLEMS:
  - Off-limb spectrographs NEVER observe the wind detected in-situ at L_1.
  - Off-limb spectrographs rarely capture the same CMEs or jets as coronagraphs or disk imagers due to small FOV (slit).
  - UVCS has low sensitivity, slow pointing.
  - Both Solar Probe+ or Solar Orbiter will provide important measurements of the wind, but not on a synoptic basis.

Limb spectroscopy from L_5 measures the properties of the Earth-bound solar wind

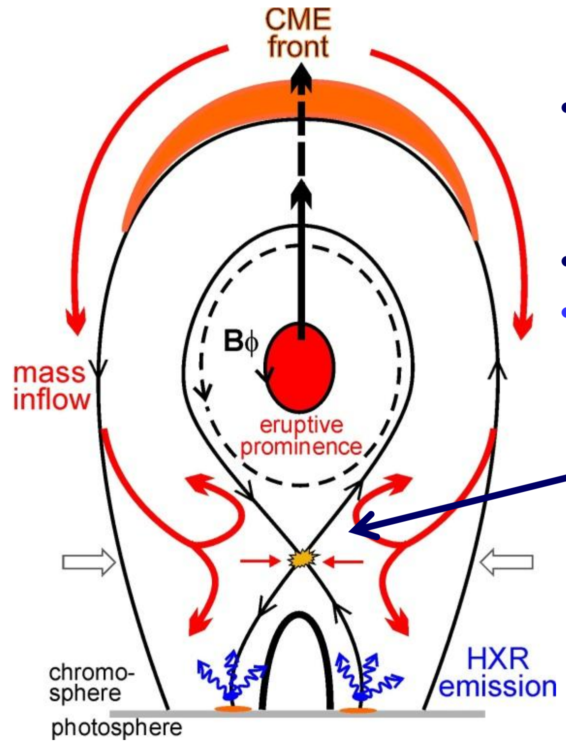
Sub-synoptic maps of the corona at 1.63 R_S built from 12 continuous days of UVCS observations (Ko et al. 2008).

- **An off-limb spectrometer from L_5 continuously monitors the coronal regions where the Earth-bound solar wind originates.**
- **The spectroscopic observations from L_5 provide coronal properties (density, temperature, outflow, abundance) of the same wind plasma observed at L_1.**
- **The results are stringent constraints for models of solar wind formation and robust inputs towards a self-consistent Sun-to-Earth solar wind model.**



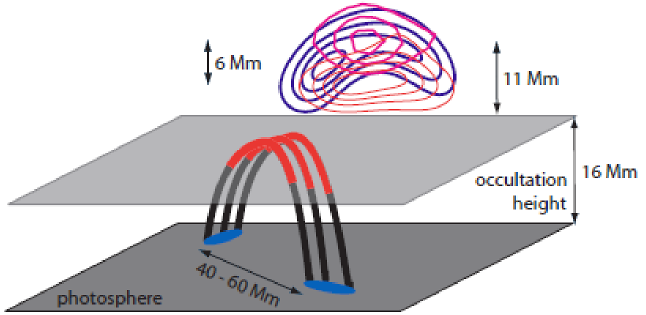
It is still unclear whether energetic particles are accelerated in Flares or CMEs

- **Electron beams heating the chromosphere and generating the SXR flare originate high in the corona (at the HXR looptop source) .**
- **HXR looptop sources seem to lie at the boundary of CME fluxrope and flaring loops.**
- **HXR looptop sources are much fainter that their footpoints. Observed only when footpoints are occulted.**



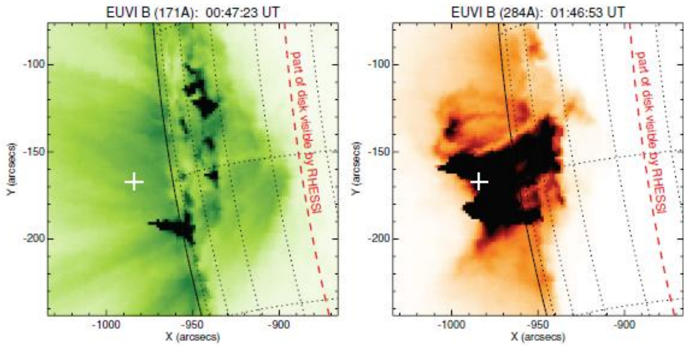
THE PROBLEM:

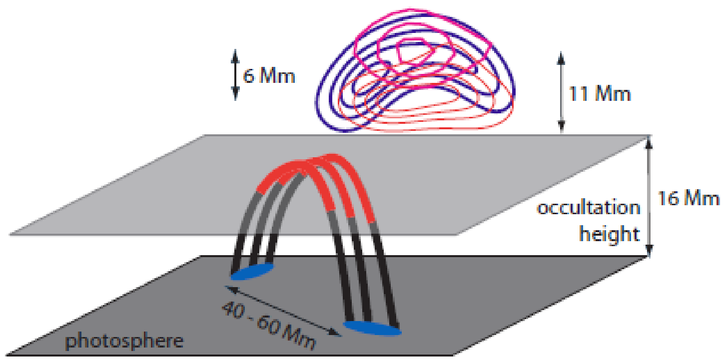
- **Observed HXR looptop emission requires huge amounts of accelerated electrons (10^{33} electrons; Krucker et al 2010).**
- **The corona is very tenuous.**
- **What is the acceleration mechanism?!**

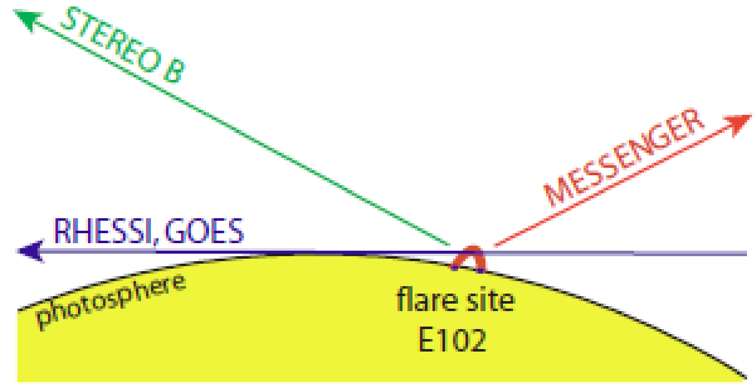


L_5 is unique for imaging the HXR sources of geo-effective SEP events

- Bright footpoint emission from L_1-connected flares is occulted from L_5.
- L_1 assets observe the source region of the flare.
- L_5 S/C observes both the HXR looptop sources and the SEPs.
- Especially powerful when combined with radio imaging from Earth (FASR).



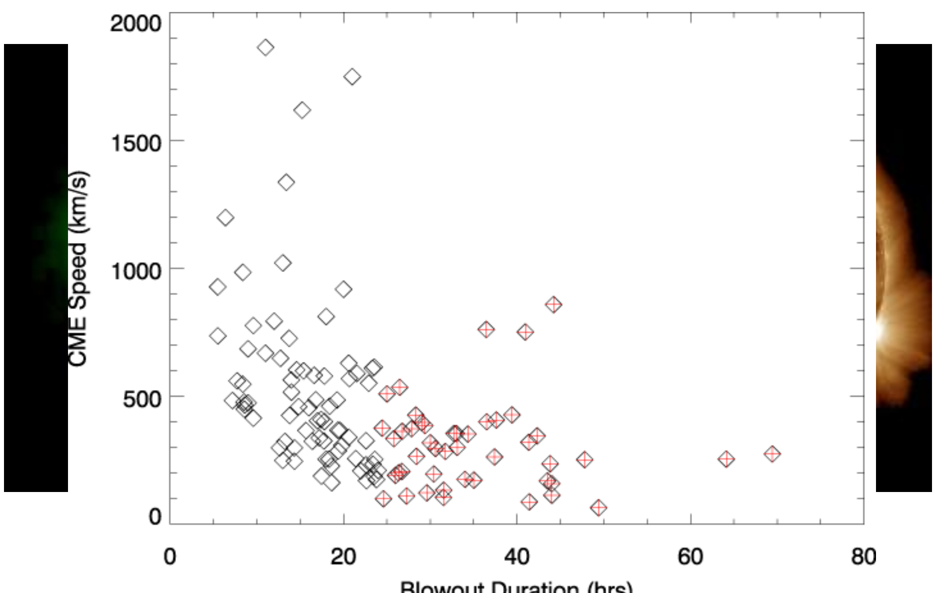


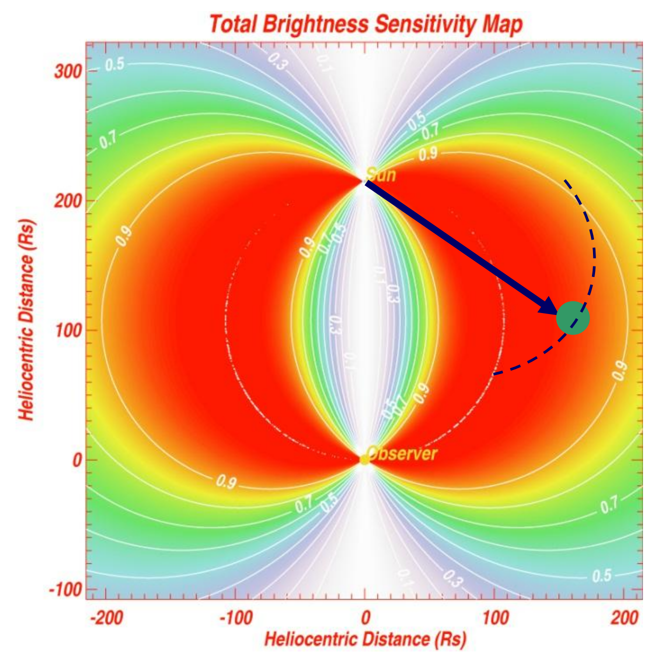


Example with STEREO-B & RHESSI observations of 12/31/2007 CME.

L_5 mission = *Nimbus* program for terrestrial weather

- **Ideal location for Space Weather studies**
  - > 4-day warning for recurrent disturbances (e.g., CIRs, Irradiance variations).
  - > 4-day warning of coronal activity (e.g., flux emergence, streamer inflation).
  - Earth-directed CMEs/solar wind lie on Thomson Surface
    → maximum sensitivity for white light obs.
  - 60% - 75% instantaneous photospheric field coverage (improved boundary conditions for Heliospheric models, e.g, ENLIL, SWMF, etc).
  - In-situ measurements of CIRs BEFORE they hit Earth.





Concluding Remarks

An L5 spacecraft is the optimum mission to solidify our understanding of solar wind evolution in the inner heliosphere and to develop a credible predictive capability for Space Weather.

- **Leverages the science returned from SOHO, STEREO, SDO and Hinode.**
- **Well-understood payload and science measurements.**
- **Does not require new technologies.**
- **Will result in new science and consistent inputs for operational models.**

- **This work was supported by the CNR (Chief of Naval Research).**