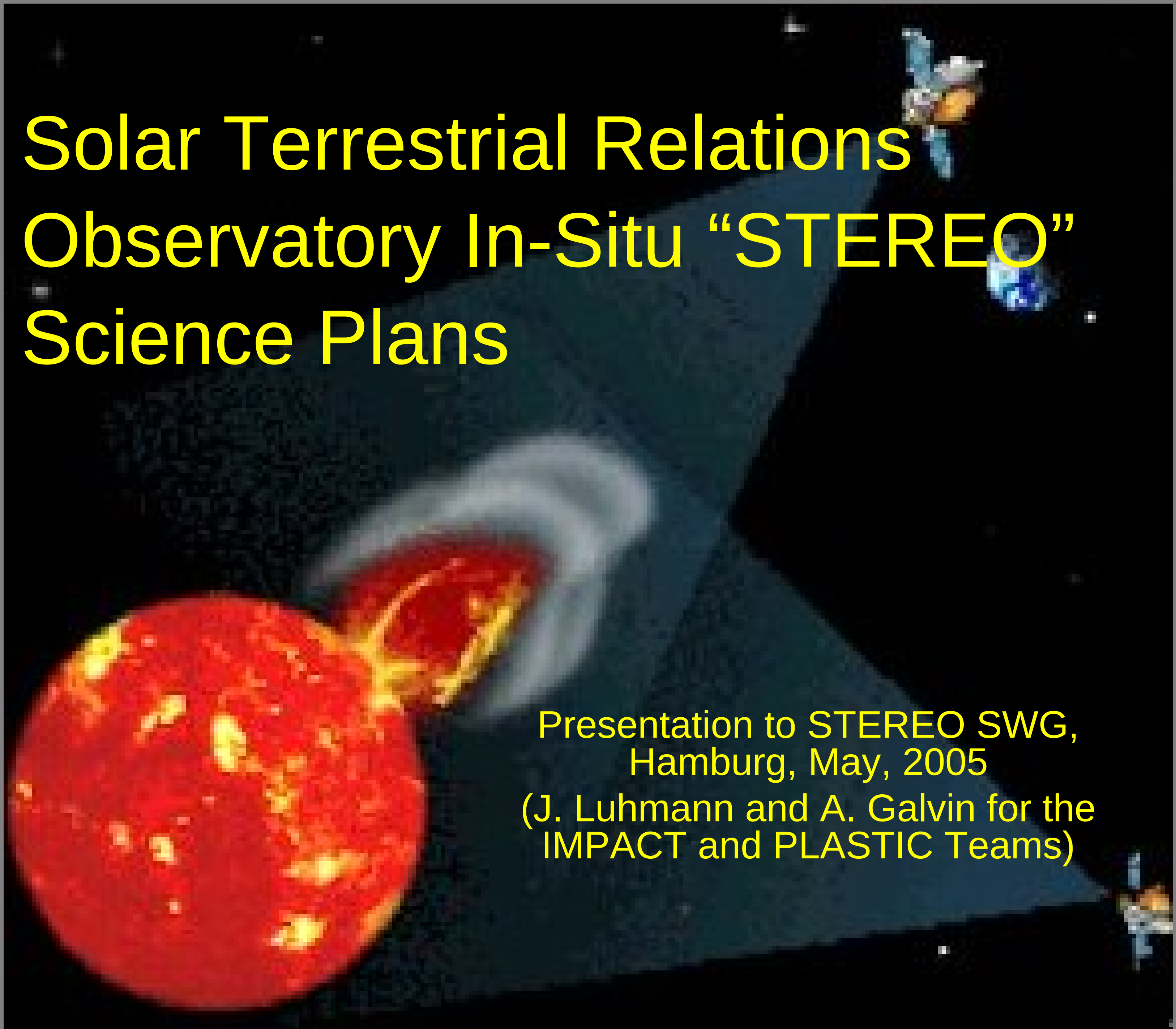
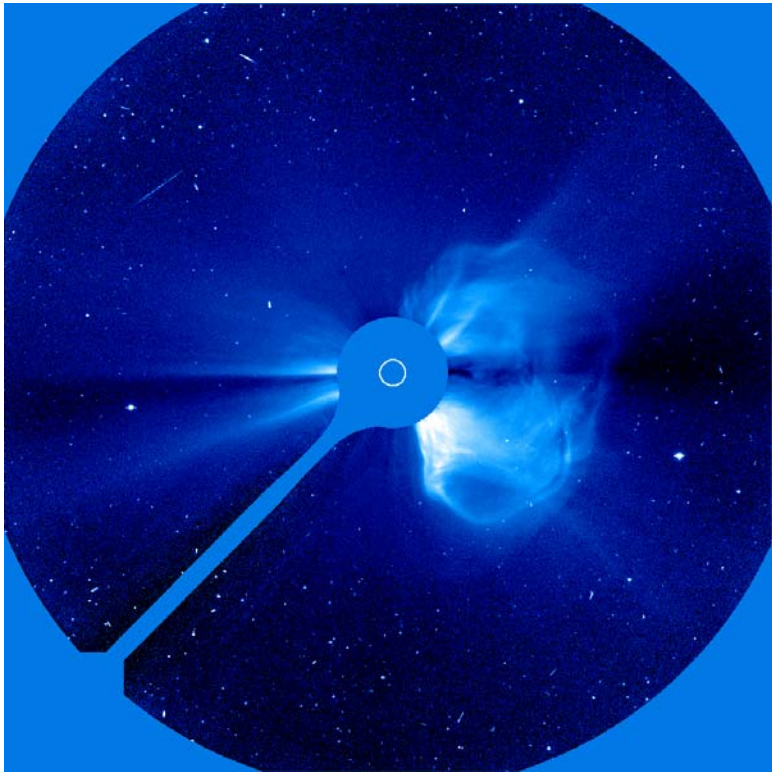
Solar Terrestrial Relations Observatory In-Situ "STEREO" Science Plans



Presentation to STEREO SWG,
Hamburg, May, 2005

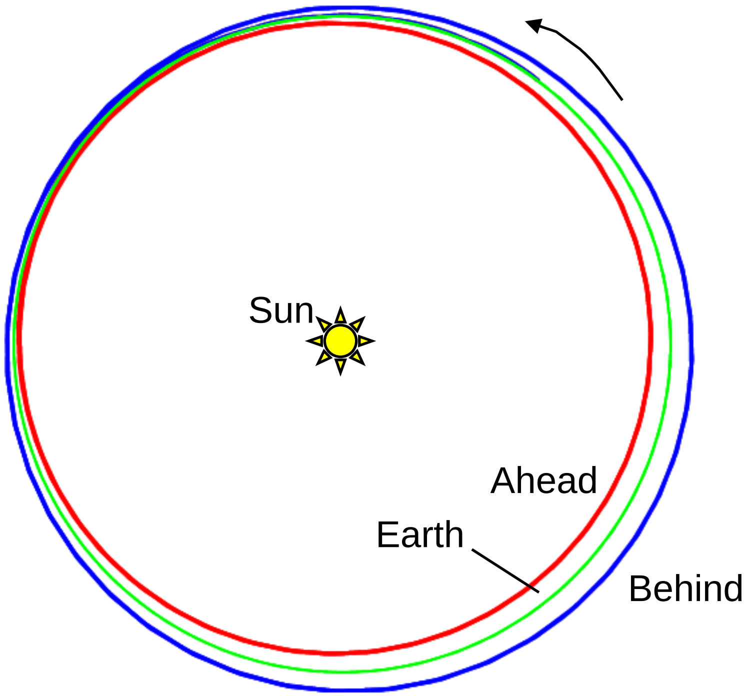
(J. Luhmann and A. Galvin for the
IMPACT and PLASTIC Teams)

STEREO Science Objectives

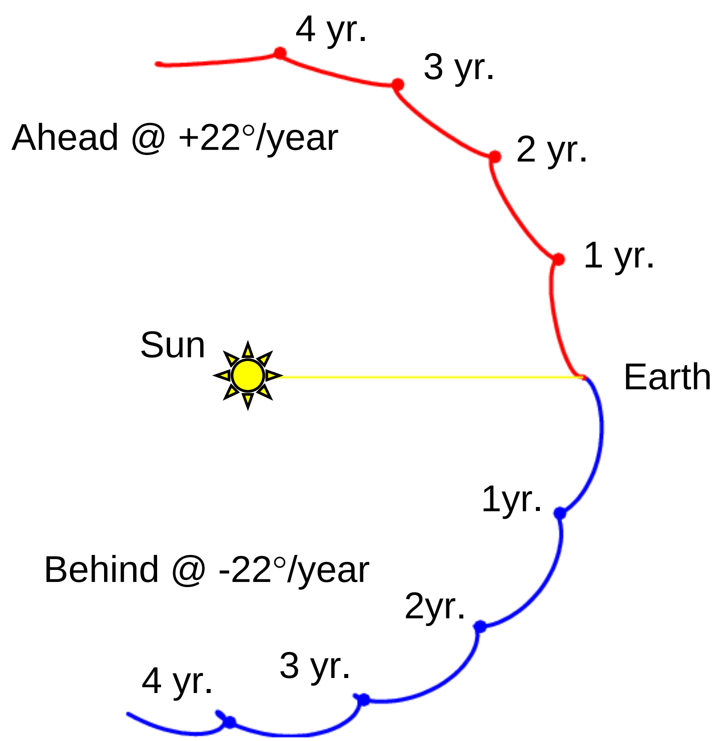


1. Understand the causes and mechanisms of CME initiation
2. Characterize the propagation of CMEs through the heliosphere
3. Discover the mechanisms and sites of energetic particle acceleration in the low corona and the interplanetary medium
4. Develop a 3D time-dependent model of the magnetic topology, temperature, density, and velocity structure of the ambient solar wind

Mission Orbit



Heliocentric Inertial Coordinates
(Ecliptic Plane Projection)



Geocentric Solar Ecliptic Coordinates
Fixed Earth-Sun Line
(Ecliptic Plane Projection)

STEREO IN-SITU INSTRUMENTS

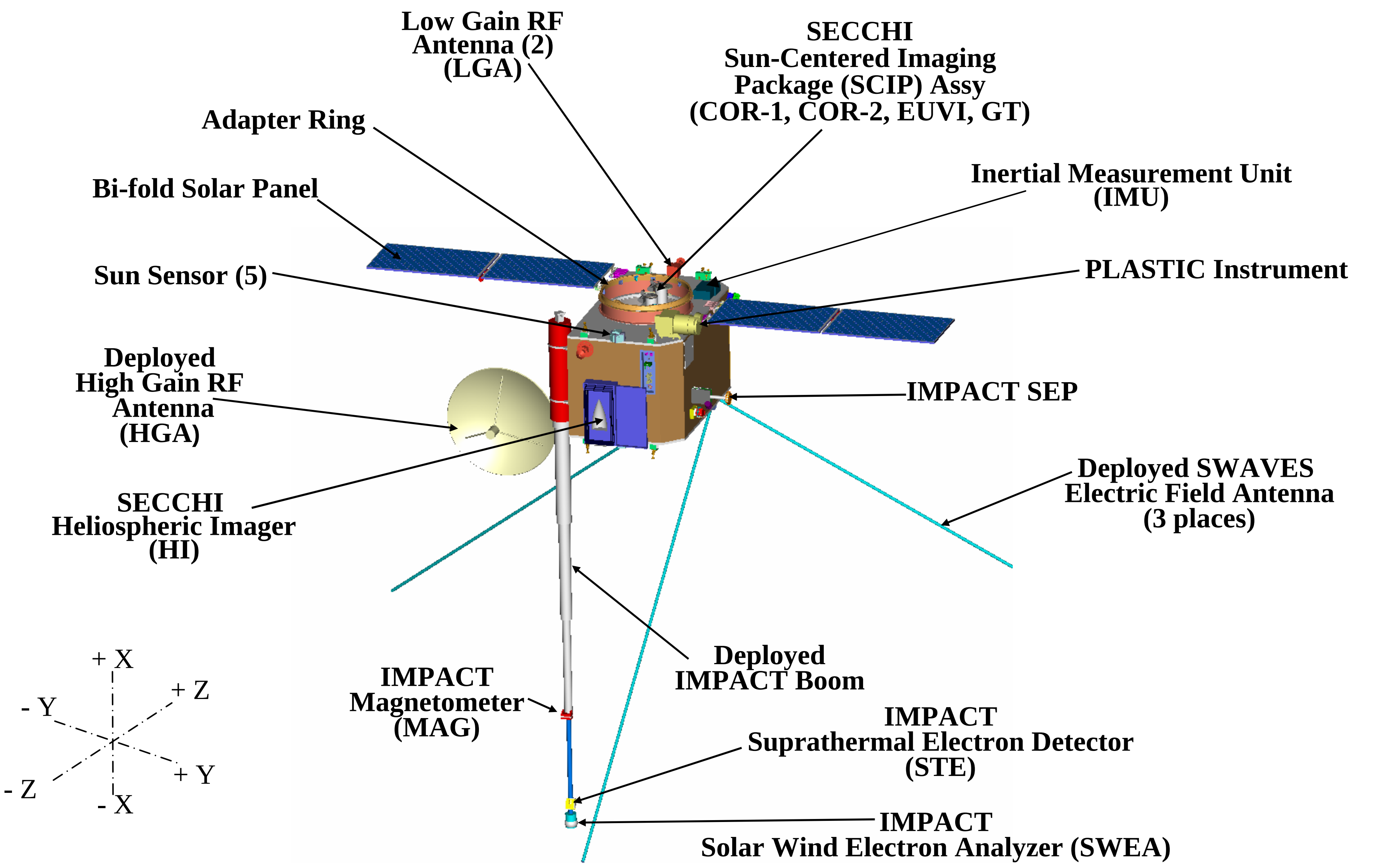
•**IMPACT**- will sample the 3-D distribution of solar wind plasma electrons, the characteristics of the energetic particle ions and electrons, and the local magnetic field.

- •Solar Wind Experiment (**SWEA**)-Measures ~0-3 keV electrons with wide angle coverage
- •Suprathermal Electron Telescope (**STE**)-Measures electrons from 2-100 keV with wide angle coverage
- •Magnetometer Experiment (**MAG**)-Measures the vector magnetic field at 65,536 nT and 500 nT ranges
- •Solar Energetic Particle Experiment (**SEP**) Suite
  - – Measures electrons from 0.02-6 MeV
  - – Measures protons from 0.02 – 100 MeV
  - – Measures helium ions from 0.03 – 100 MeV/nucleon
  - – Measures heavier ions form 0.03 – 40 MeV/nucleon

•**PLASTIC-** will provide the plasma characteristics of protons, alpha particles, and heavy ion. Provide composition measurements of heavy ions and characterizes the CME plasma

•**SWAVES-** in-situ as well as remote sensing instrument. Tracks CME Driven Shocks from the Corona to the Earth. (Covered in a separate presentation)

STEREO-B (BEHIND) OBSERVATORY



Unique In-Situ Science Opportunities from STEREO

- Stereo viewing by remote sensing suite to obtain 3D images of CMEs gives ideas of solar origins of in-situ (ICME) structures observed at each spacecraft
- Multipoint in-situ observations also
  - Reveal larger ICME structure as the spacecraft separate
  - Add to predictive capability at Earth (e.g. of corotating structures)
  - Combine with SWAVES to diagnose shock source of observed SEPs when it is located in the corona and inner heliosphere
  - Combine with SECCHI images of coronal holes to allow in-situ solar wind stream origins mapping


STEREO
IMPACT
UCB - NASA/GSFC- Caltech - U of MD - LANL - JPL - UCLA - SAIC - NOAA/SEC
U of MI - JHU/APL - MPAe - U of Kiel - CESR/CNRS - ESA/ESTEC -
DESPA/OBSPM - KFKI/RMKI

IMPACT (In-situ Measurements of Particles and CME Transients) Instrument Overview

Boom Suite:

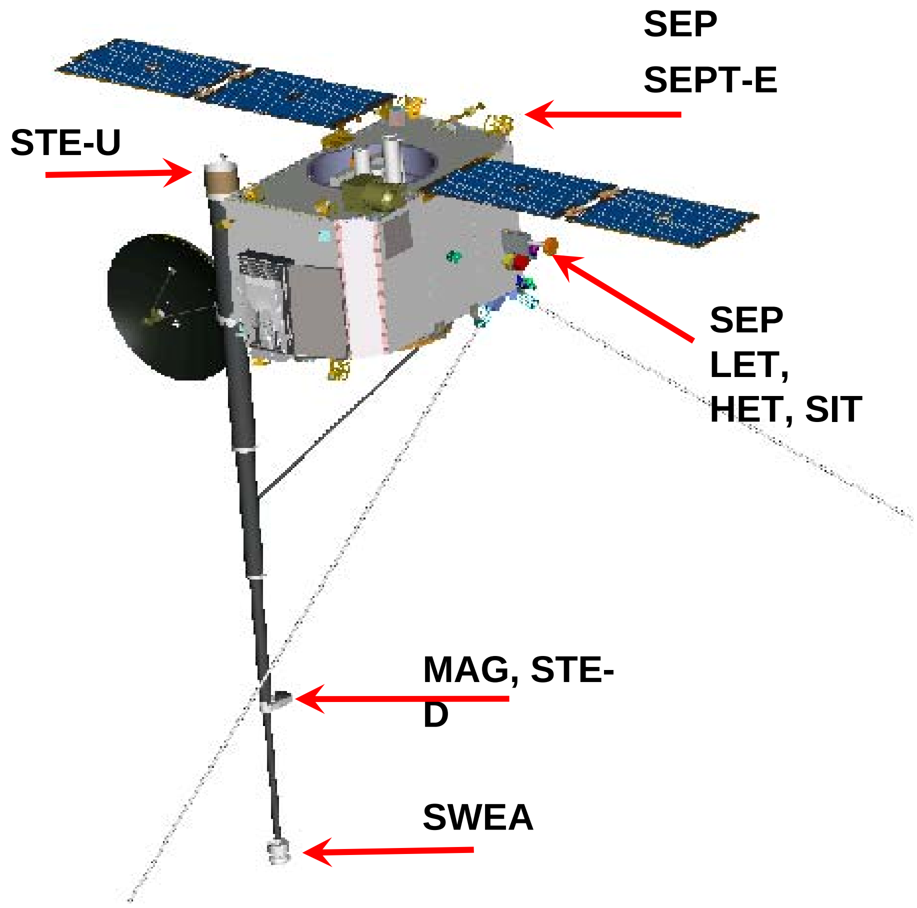
- •Solar Wind Electron Analyzer (SWEA)
- •Suprathermal Electron Telescope (STE)
- •Magnetometer (MAG)

Solar Energetic Particles Package (SEP):

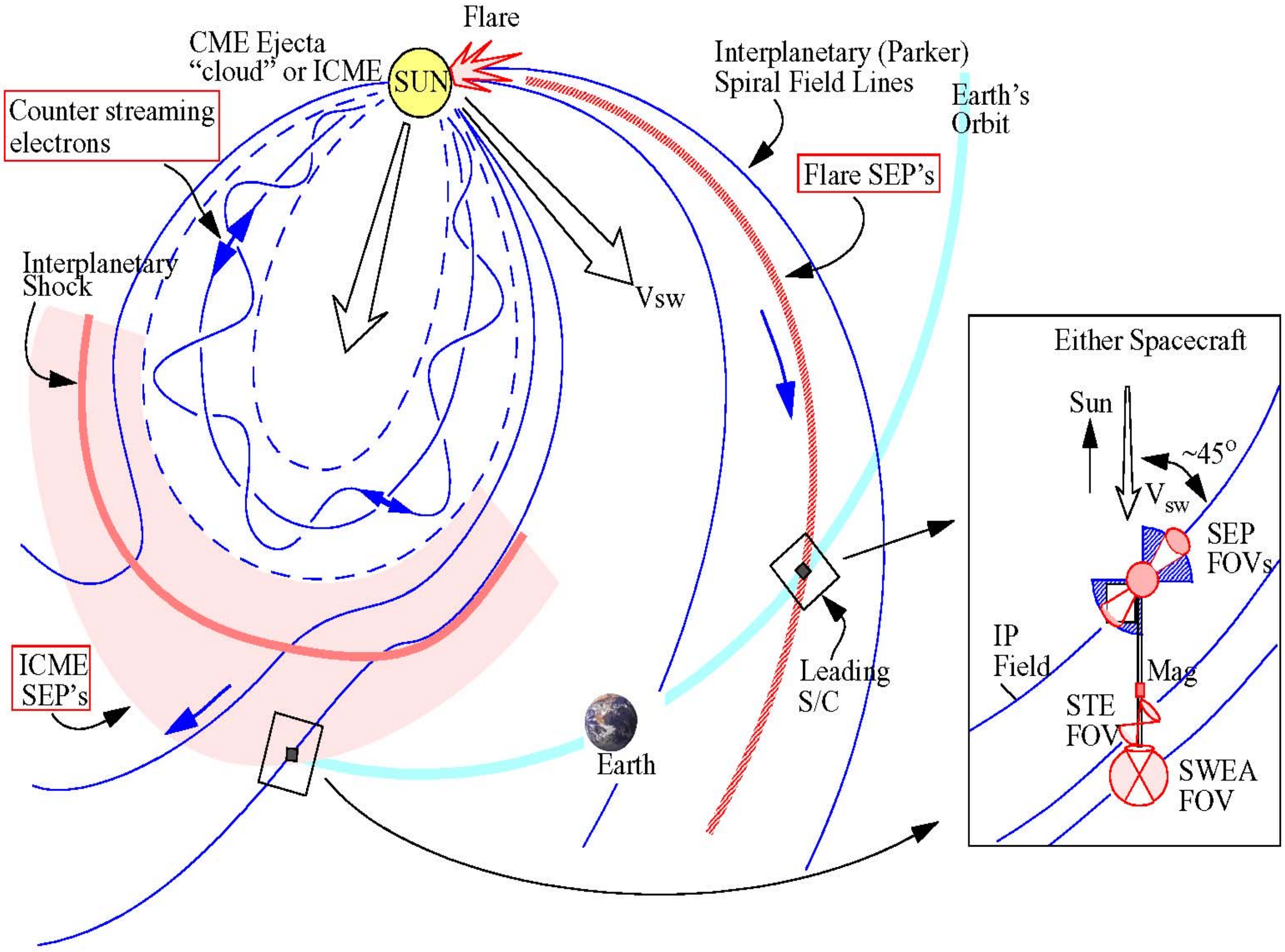
- •Suprathermal Ion Telescope (SIT)
- •Solar Electron and Proton Telescope (SEPT)
- •Low Energy Telescope (LET)
- •High Energy Telescope (HET)

Support:

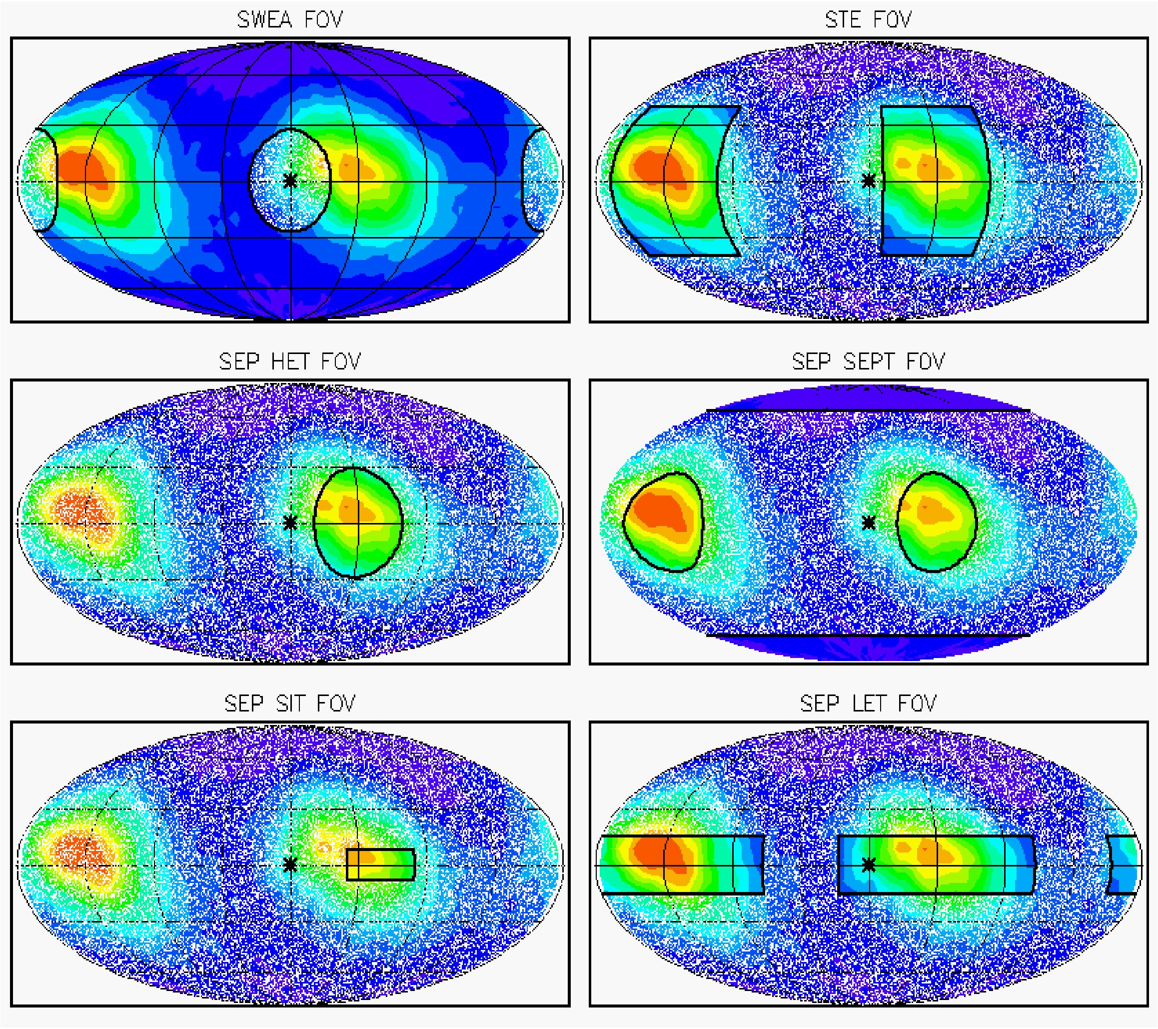
- •IMPACT Boom
- •SEP Central
- •Instrument Data Processing Unit (IDPU)



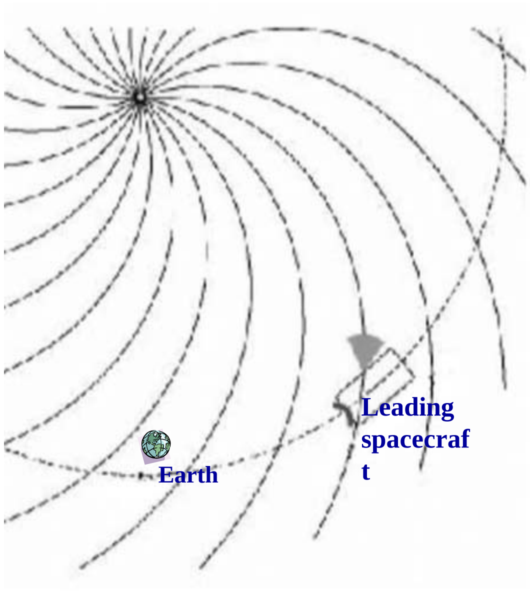
Overall IMPACT Investigation Rationale



IMPACT Directional Coverage

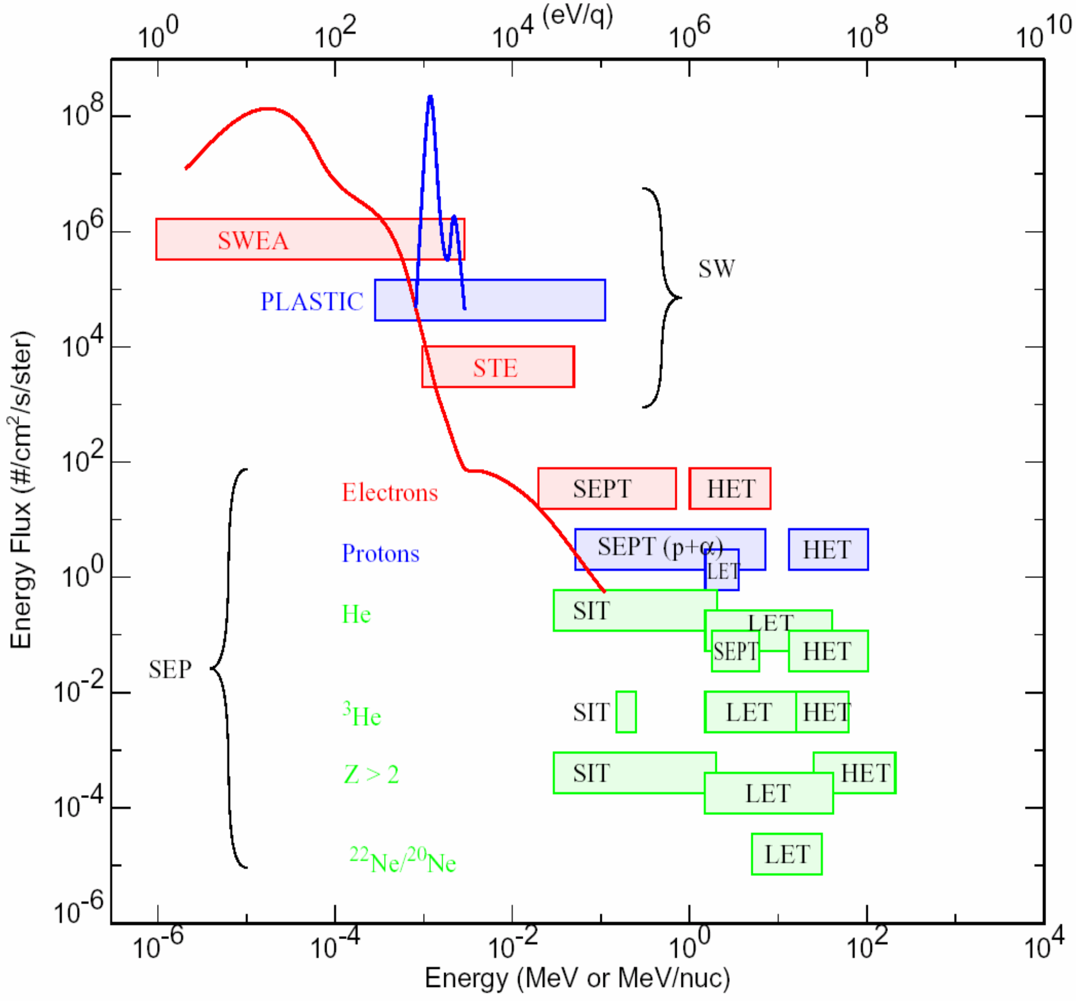


Parker Spiral

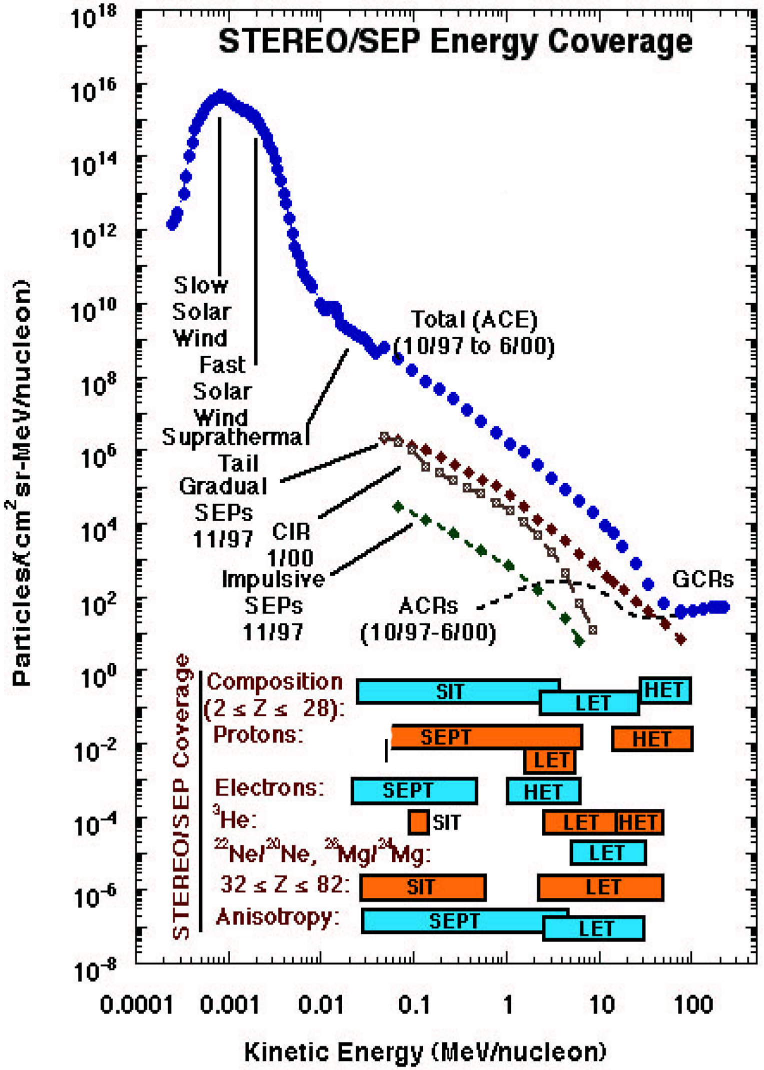


Mercator projection of 4 π angular coverage sphere. Sun in center. Contours show statistics of interplanetary field direction. Dark lines show IMPACT particle instrument fields of view.

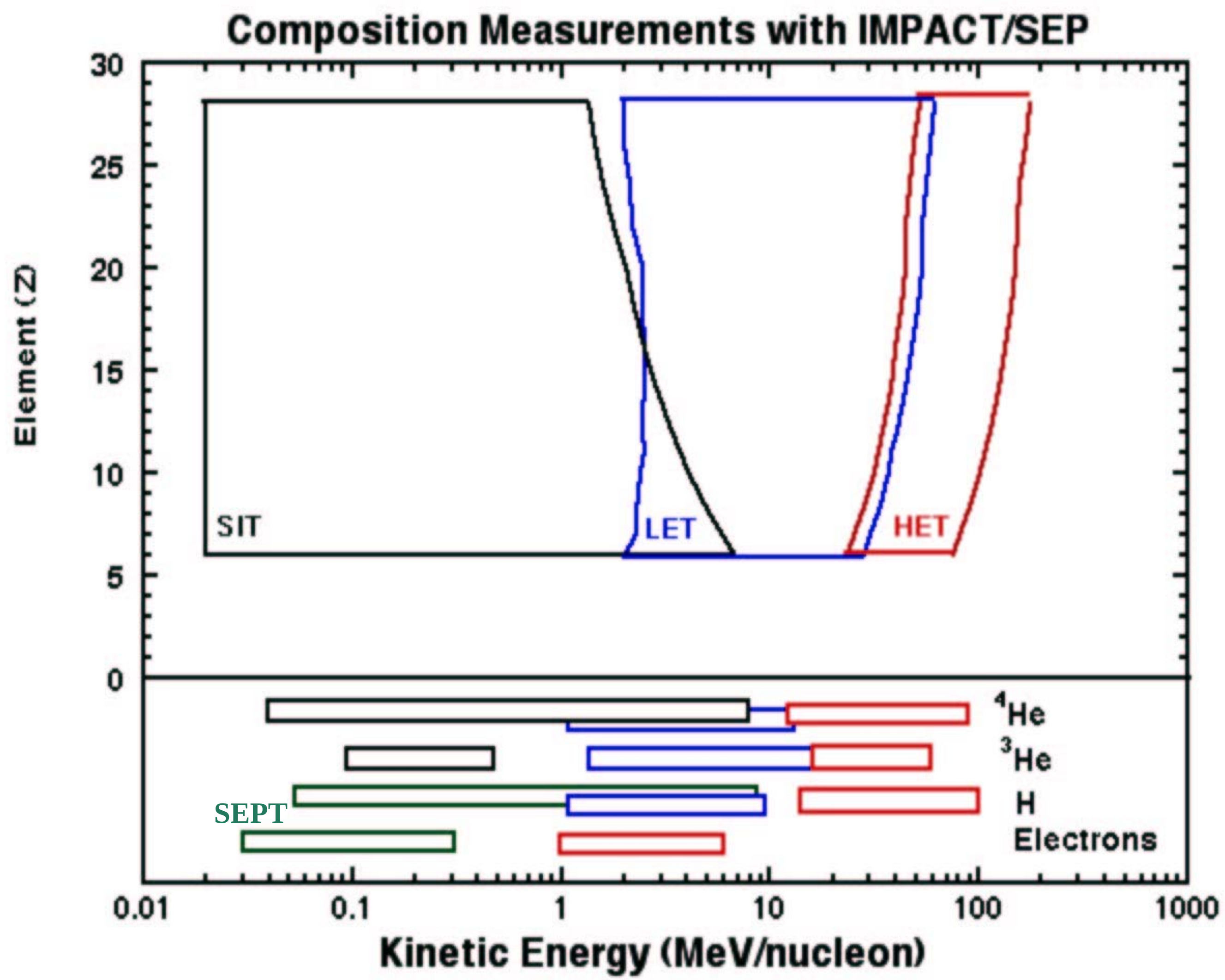
IMPACT Particles Domain: Solar Wind, Suprathermal and SEP electrons, SEP ions



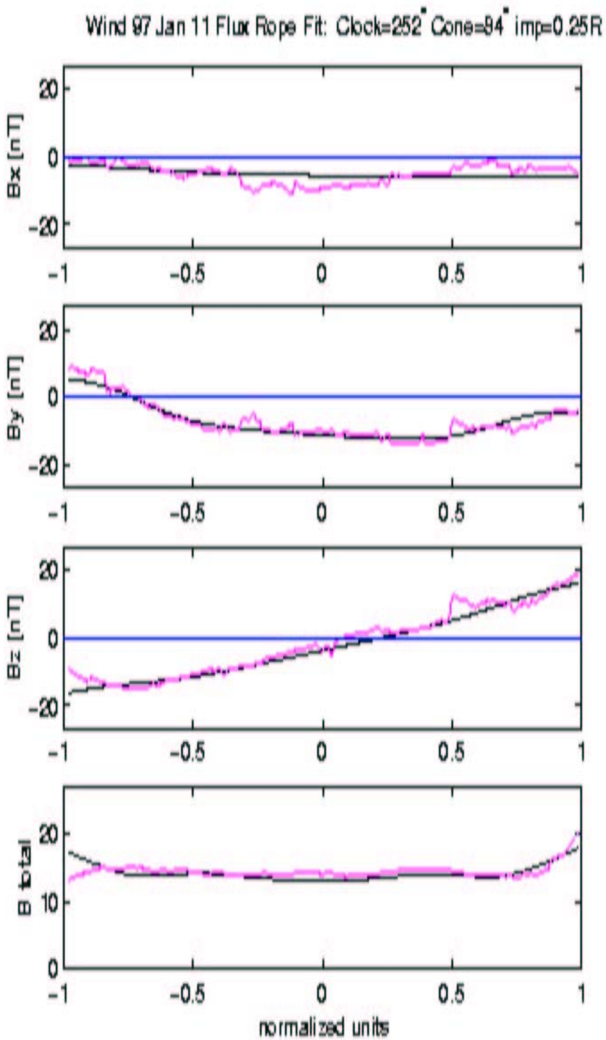
SEP Ions Spectral Coverage

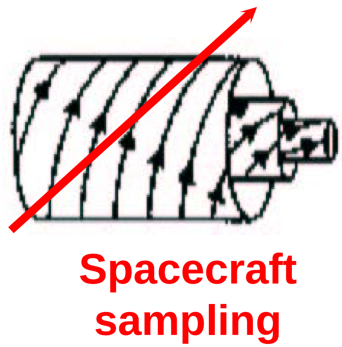


SEP Ions Composition Coverage

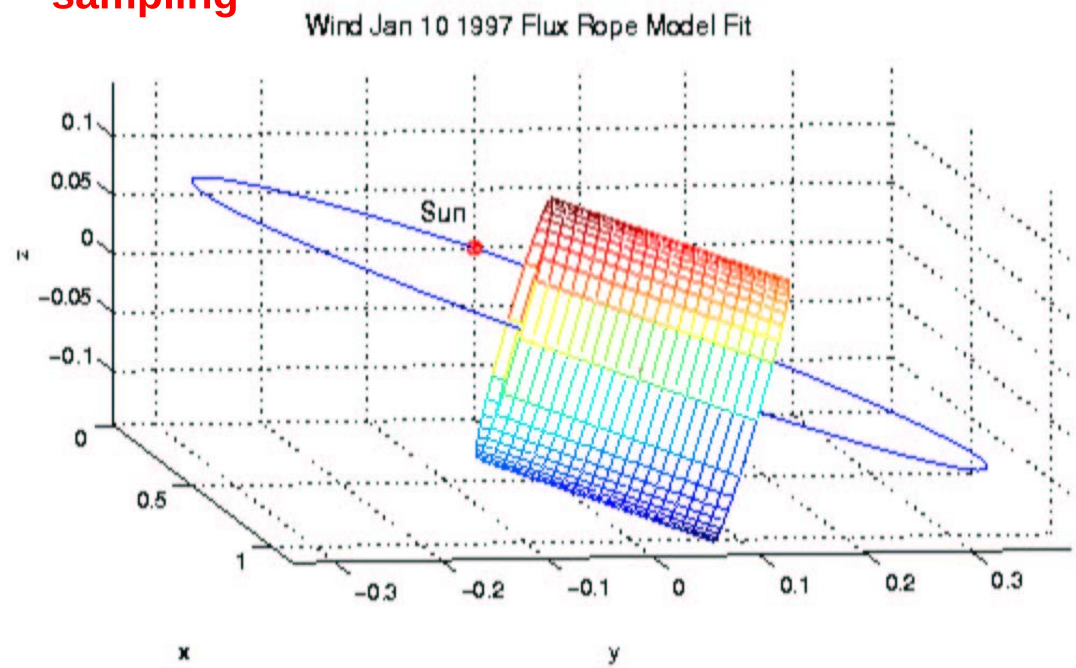


Magnetic Topology from Field Measurements





"Fly Through" Model ICME Flux Rope (or other models) to reproduce Vector Field observations.

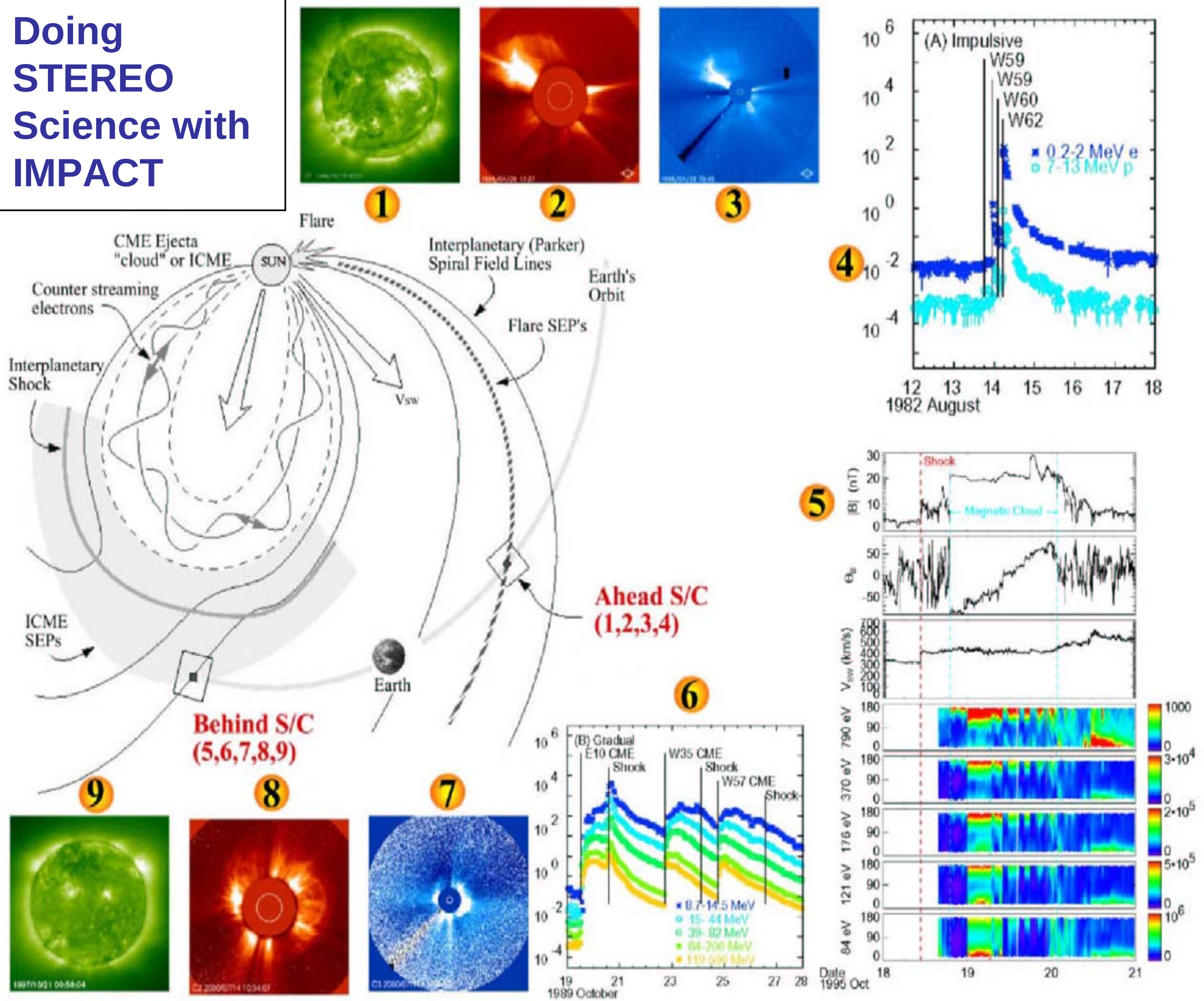


(flux rope fits by Tamitha Mulligan,UCLA, from the paper by Yan Li et al., JGR 2001)

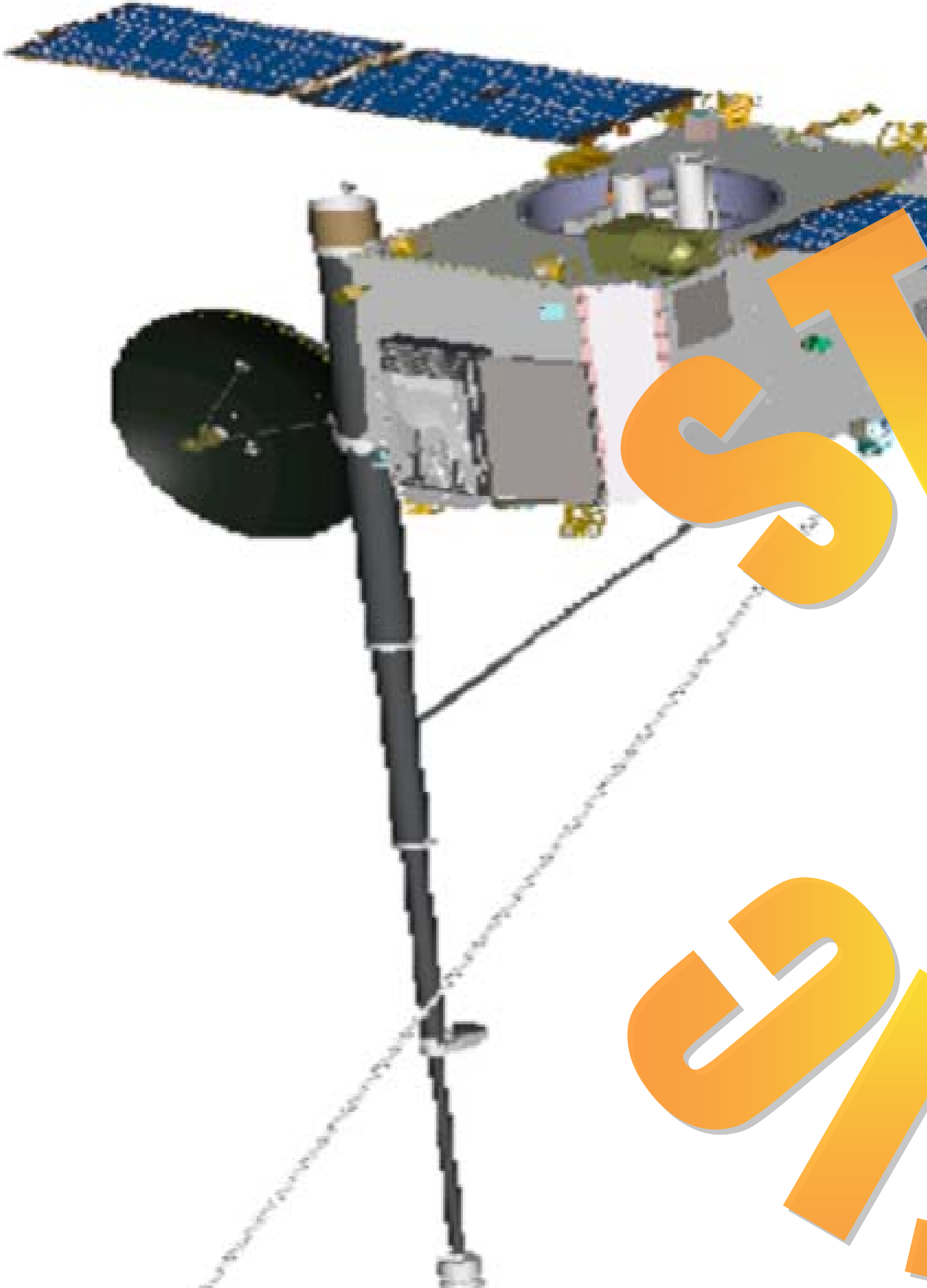
Basic IMPACT Measurements

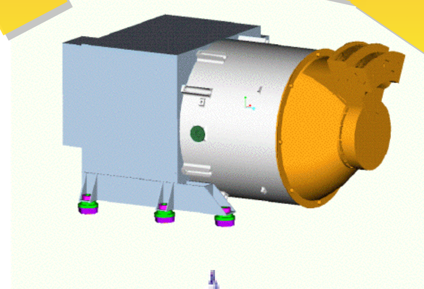
Experiment	Instrument	Measurement	Energy or Mag. field range	Time Res.	Beacon Time Res. (*)	Instrument provider
SW	STE	Electron flux and anistropy	2-100 keV	16 s	2D x 3E, 60s	UCB (Lin)
	SWEA	3D electron distrib., core & halo density, temp. & anisotropy	~0-3 keV	3D=1 min 2D=8s Mom.=2s	Moments, 60s	CESR (Sauvaud) + UCB (Lin)
MAG	MAG	Vector field	±500nT, ±65536 nT	1/4 s	60s	GSFC (Acuna)
SEP	SIT	He to Fe ions	0.03-2 MeV/nuc	1 min	3S x 2E, 60s	U. of Md. (Mason) + MPAE (Korth) + GSFC (von Rosenvinge)
		^{3}He	0.15-0.25 MeV/nuc	1 min	----	
	SEPT	Diff. electron flux	20-400 keV	1 min	3E, 60s	U. of Kiel (Mueller-Mellin) + ESTEC (Sanderson)
		Diff. proton flux	60-7000 keV	1 min	3E, 60s	
		Anistropies of e,p	As above	15 min	----	
	LET	Ion mass numbers 2-28 & anisotropy	3-30 MeV/nuc	1-15 min.	2S x 2E, 60s	Caltech (Mewaldt) + GSFC (von Rosenvinge) + JPL (Wiedenbeck)
		^{3}He ions flux & anistropy	2-15 MeV/nuc	15 min.	1E, 60s	
		H ions flux & anistropy	1.5-6 MeV	1-15 min.	1E, 60s	
	HET	Electrons flux	1-6 MeV	1-15 min.	1E, 60s	GSFC (von Rosenvinge) + Caltech (Mewaldt) + JPL (Wiedenbeck)
		H	13-100 MeV	1-15 min.	1E, 60s	
		He	13-100 MeV	1-15 min.	1E, 60s	
		^{3}He	15-60 MeV/nuc	15 min	----	
	SEP Common	----	----	----	----	Caltech (Mewaldt) + GSFC (von Rosenvinge)
IMPACT Common	IDPU (+Mag Analog)	----	----	----	----	UCB (Curtis)

Doing STEREO Science with IMPACT



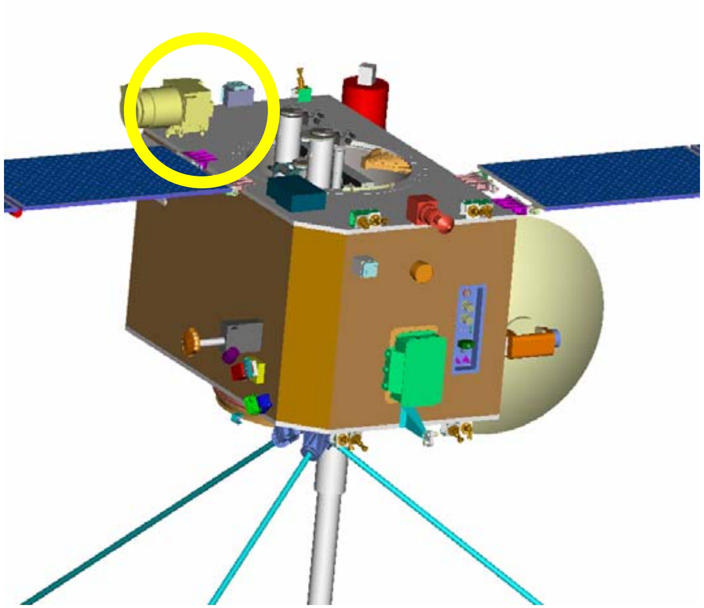
STEREO

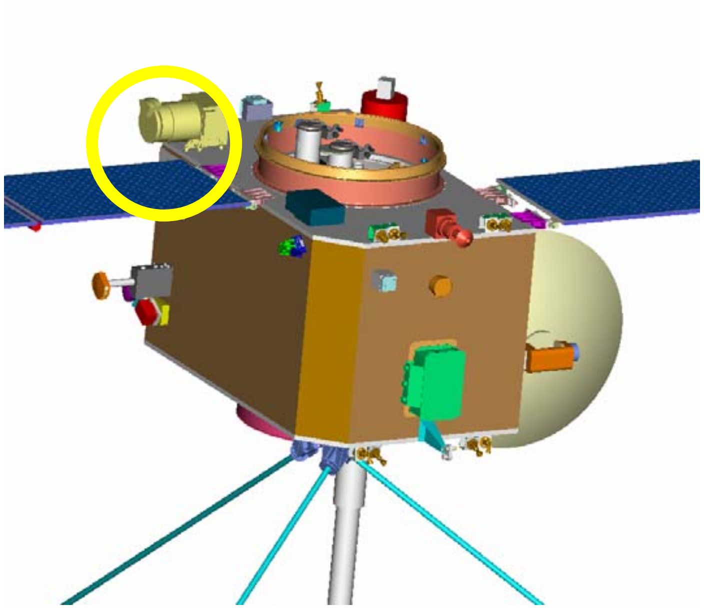




PLASTIC

PLASTIC Instrumentation on the Spacecraft





PLASTIC SCIENCE GOALS

CMEs: Solar Origins, Interplanetary Manifestation and Topology

- In-situ signatures of corresponding CME structures on the Sun, including...
- ICME identification and boundary determinations
- Global (3D) structure of CMEs at 1 AU, including ...
- Multipoint measurements of magnetic clouds and multiple ejecta

Gradual Solar Energetic Particles (SEP) and Heliospheric Studies

- Acceleration of ions at CME-driven shocks
- Global structure of stream interfaces and heliospheric current sheet dynamics
- Global structure of co-rotating interaction regions
- Pickup ions (longitudinal and solar wind parameter dependence)

Solar Processes and Solar Wind Studies

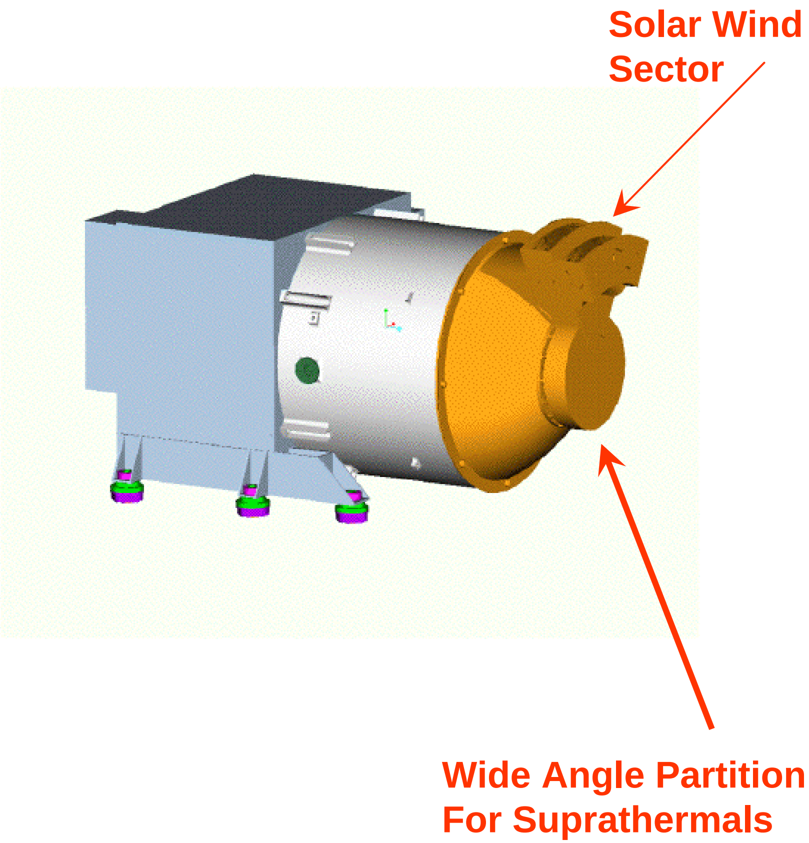
- Elemental composition: fractionation effects, including in ICMEs
- Charge states: coronal processes and solar wind (including ICME) formation
- Origins (slow solar wind, transition with fast solar wind)

PLASTIC incorporates three science sensor functions into one package:

⌦ The **PLASTIC *Solar Wind Sector* (SWS) Proton Channel** measures the distribution functions of **solar wind protons (H^+) and alphas (He^{+2})**, providing proton density (*n*), velocity (V_{sw}), kinetic temperature (T_k) and its anisotropy ($T_{\parallel}$, $T_{\perp}$), and alpha to proton (He^{+2} / H^+) ratios with a time resolution up to about one minute (60 seconds). (Time resolution may depend on instrument cycle mode).

⌦ The **PLASTIC *Solar Wind Sector* (SWS) Main (Composition) Channel** measures the elemental composition, charge state distribution, kinetic temperature, and speed of the more abundant **solar wind heavy ions** (e.g., C, O, Mg, Si, and Fe) by using Electrostatic Analyzer (E/Q), Time-of-Flight (TOF), and Energy (E) measurement to determine Mass and M/Q. Typical time resolution for selected ions will be ~ 5 x 60 = 300 seconds. (Time resolution depends on telemetry allocation).

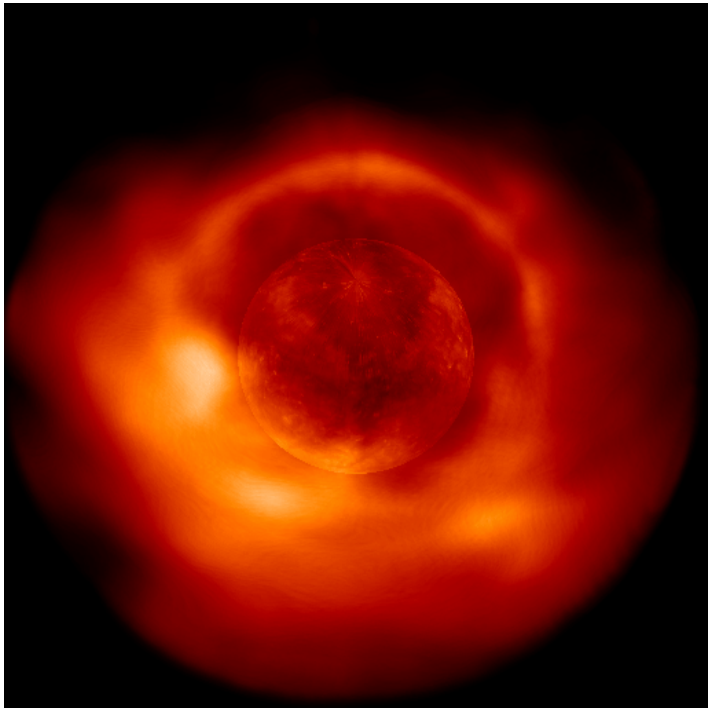
⌦ The **PLASTIC *Wide-Angle Partition* (WAP)** measures distribution functions of **suprathermal ions**, including interplanetary shock-accelerated (IPS) particles associated with CME-related SEP events, recurrent particle events associated with Co-rotating Interaction Regions (CIRs), and heliospheric pickup ions. Typical time resolution for selected ions will be several minutes to hours. (Time resolution depends on telemetry allocation and event statistics).



What is the Solar Wind?

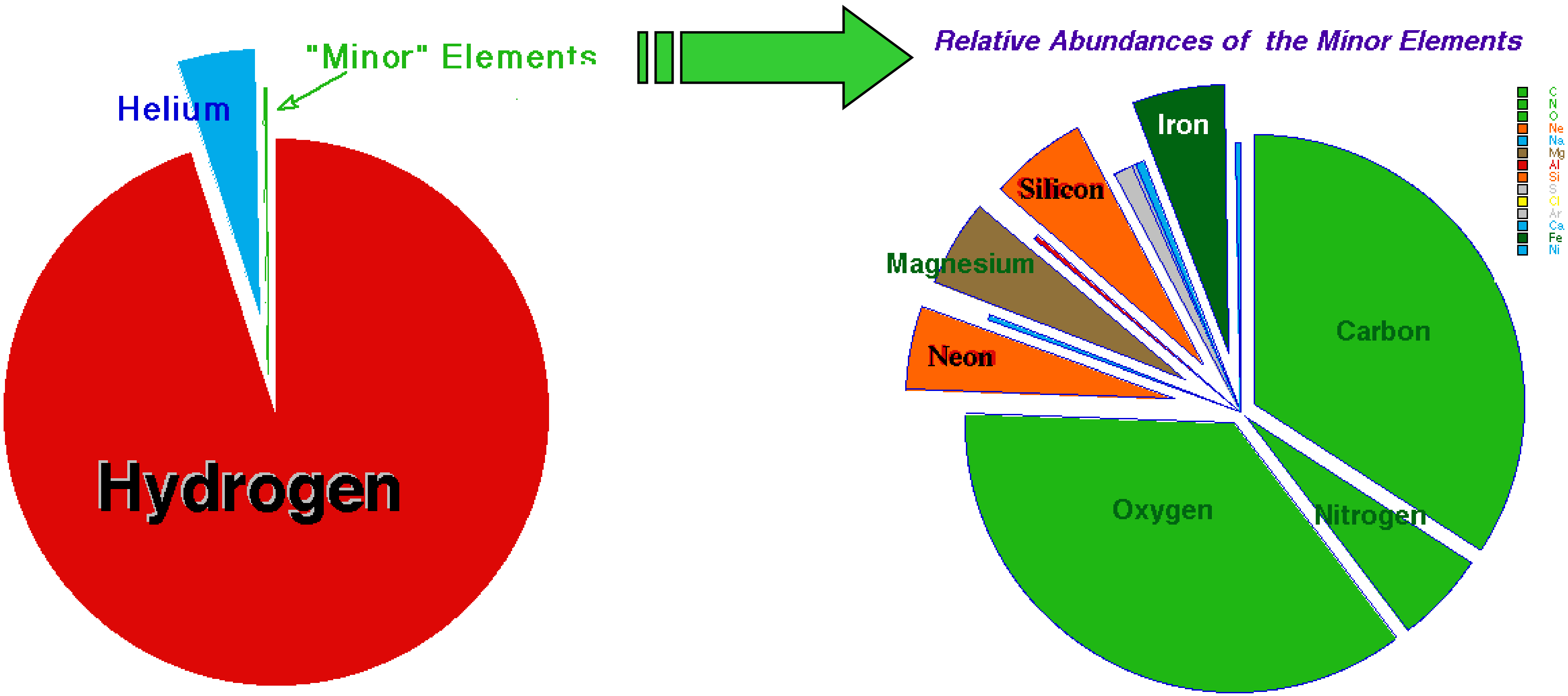
The solar wind is a plasma (electrons and ions) that continuously flows from the Sun's corona into interplanetary space. The solar wind is an extension of the corona into the interplanetary medium.

The solar wind ions are mostly H+ (95%), He+2 (5%), and the rest (C, N, O, Ne, Si, Mg, S, Ar, Fe….) (<1%).

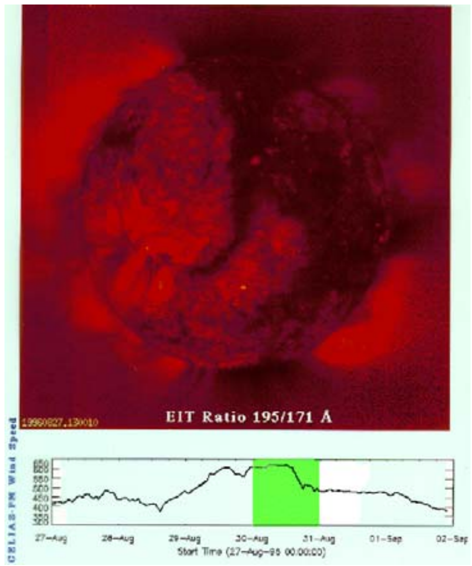


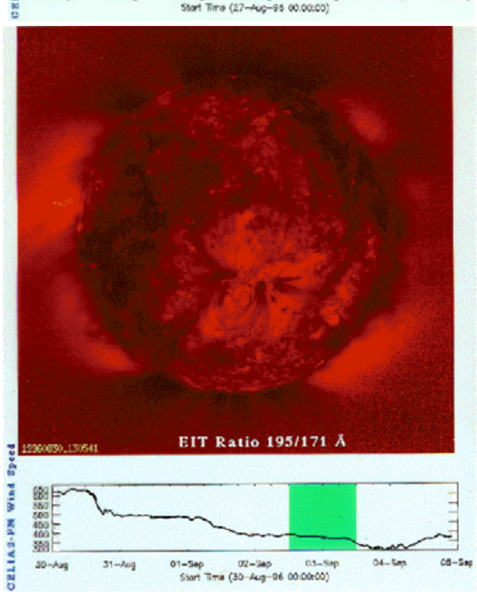
Ultraviolet and Extreme Ultraviolet view of the corona, taken by SOHO EIT + UVCS

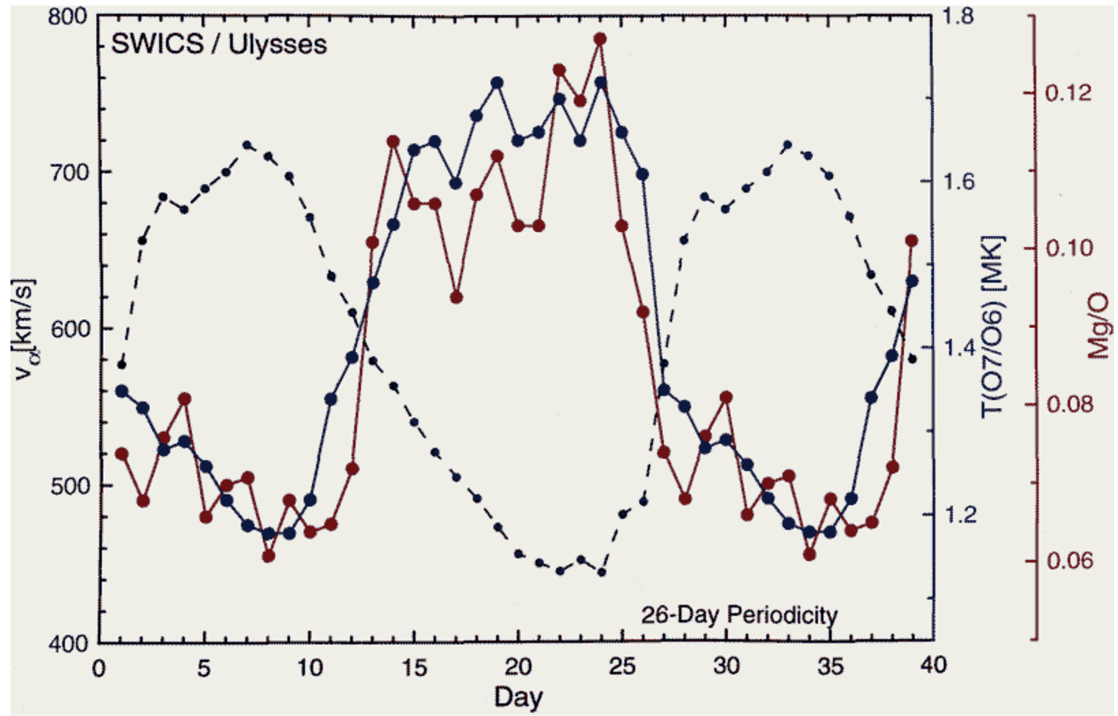
Solar Wind
Relative Elemental Abundances



Composition of Solar Wind Particles – key to coronal sources and conditions

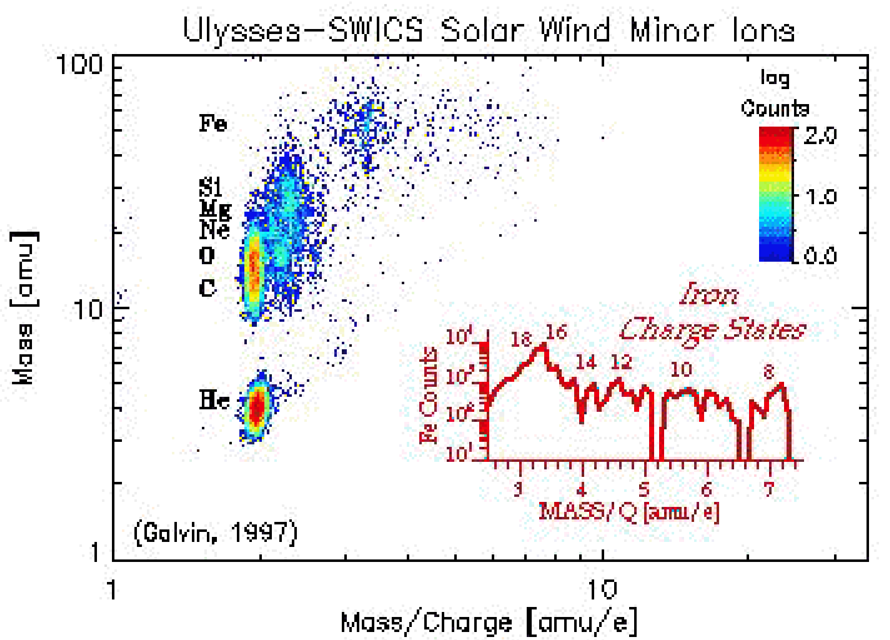


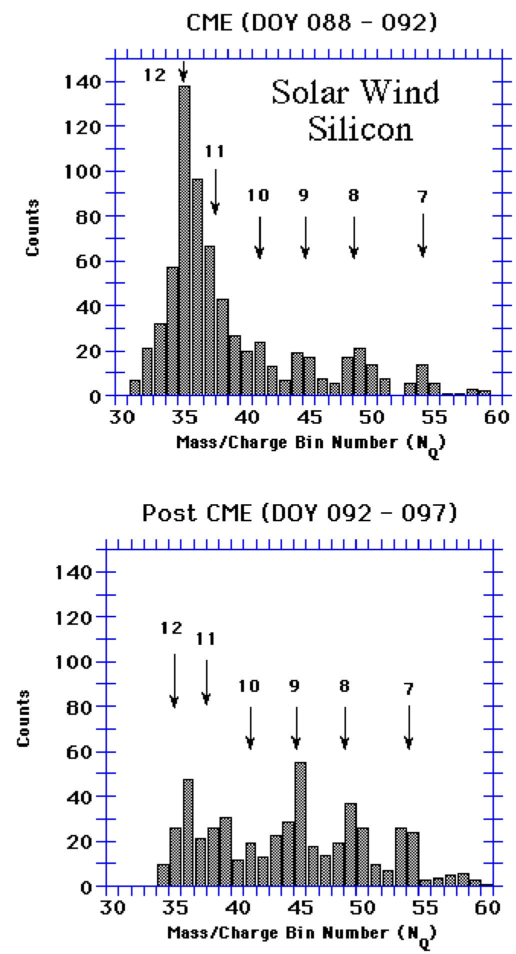




Different coronal structures emit solar wind with different speeds and different composition

Solar wind charge state composition is an indication of the coronal temperatures and conditions where the solar wind originated, including the initiation of CMEs.





(Galvin et al, 1993)

Solar wind in Interplanetary CMEs often exhibit higher ionization states than other solar wind flows

Composition of Energetic Particles – key to determination of source populations and acceleration mechanisms

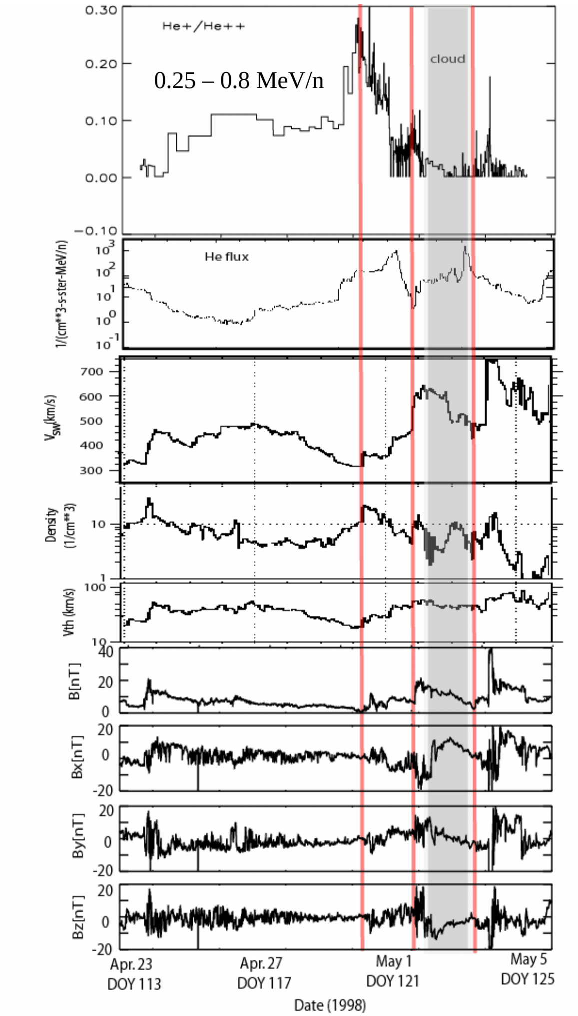
Gradual SEPs are likely coronal or solar wind particles accelerated by CME-driven shocks.

But the Sun is not the only ultimate source for particles that are accelerated by shocks in the heliosphere. Other sources include:

***Inside sources*, such as:**
leakage from planetary magnetospheres, stripping of planetary atmospheres (e.g., Venus tail rays), sputtering off the moon, outgassing from comets, solar wind – dust interactions.

***Outside sources*, such as:**
the interstellar medium, sputtering off of interstellar grains. At higher energies, galactic cosmic rays.

Different source populations are best distinguished by their composition (including charge states), spectra, and direction. For example, the source He+ accelerated at CME-shocks is typically more consistent with interstellar pickup ions instead of ICME He+.



Energetic He^{+} in a CME/Cloud Event …

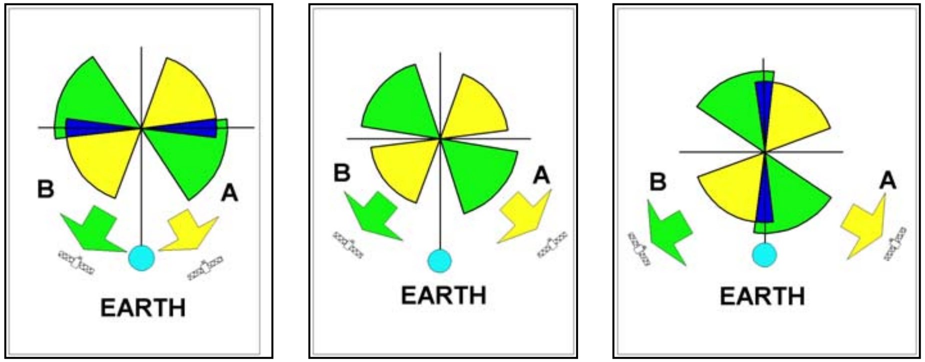
During this event a very high ratio of $He^{+}/He^{++} \approx 1$ at solar wind energies has been observed in the cloud. (Skoug et al., 1999).

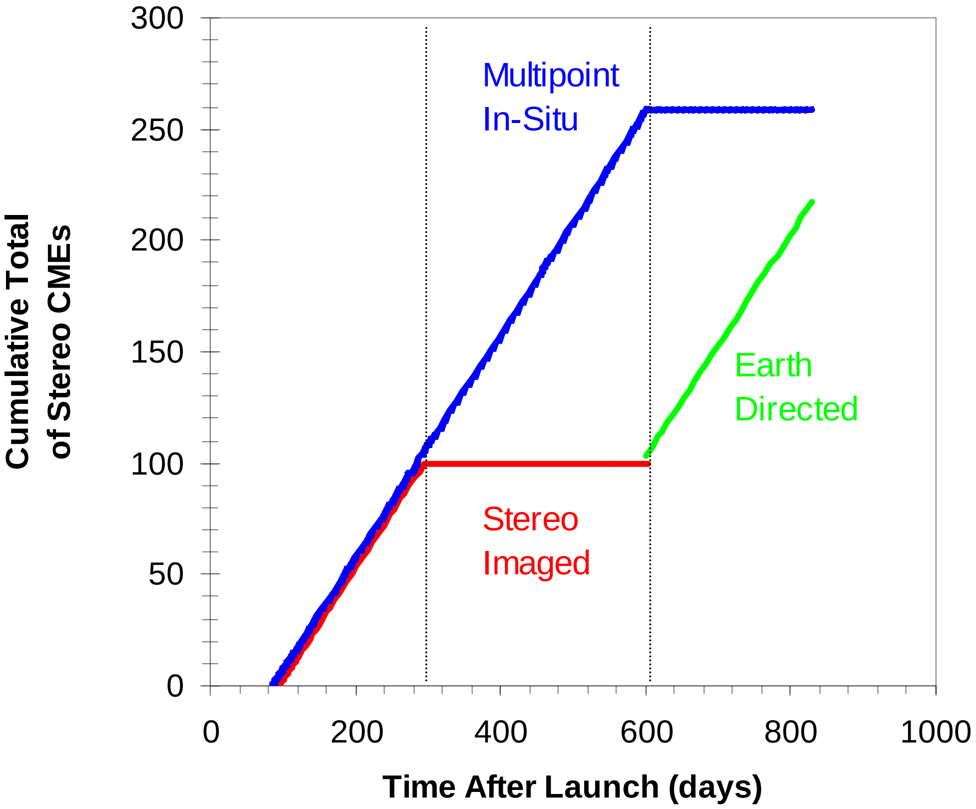
However, there is no significant enhancement of the energetic He^{+}/He^{++} ratio inside the cloud.

But, there is significant enhancement of the energetic He^{+}/He^{++} ratio at Shock 1.

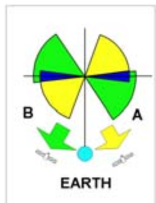
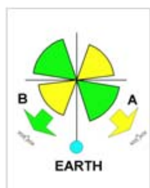
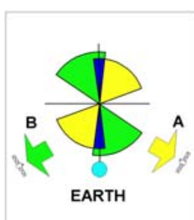
Shock 1: Significant enhancement of the energetic He^{+}/He^{++} ratio.
Shock 2: Driven by the CME; Some enhancement of the energetic He^{+}/He^{++} ratio.
Shock 3: Presumably overtaken the cloud.Very moderate enhancement He^{+}/He^{++} ratio.

Mission Phases



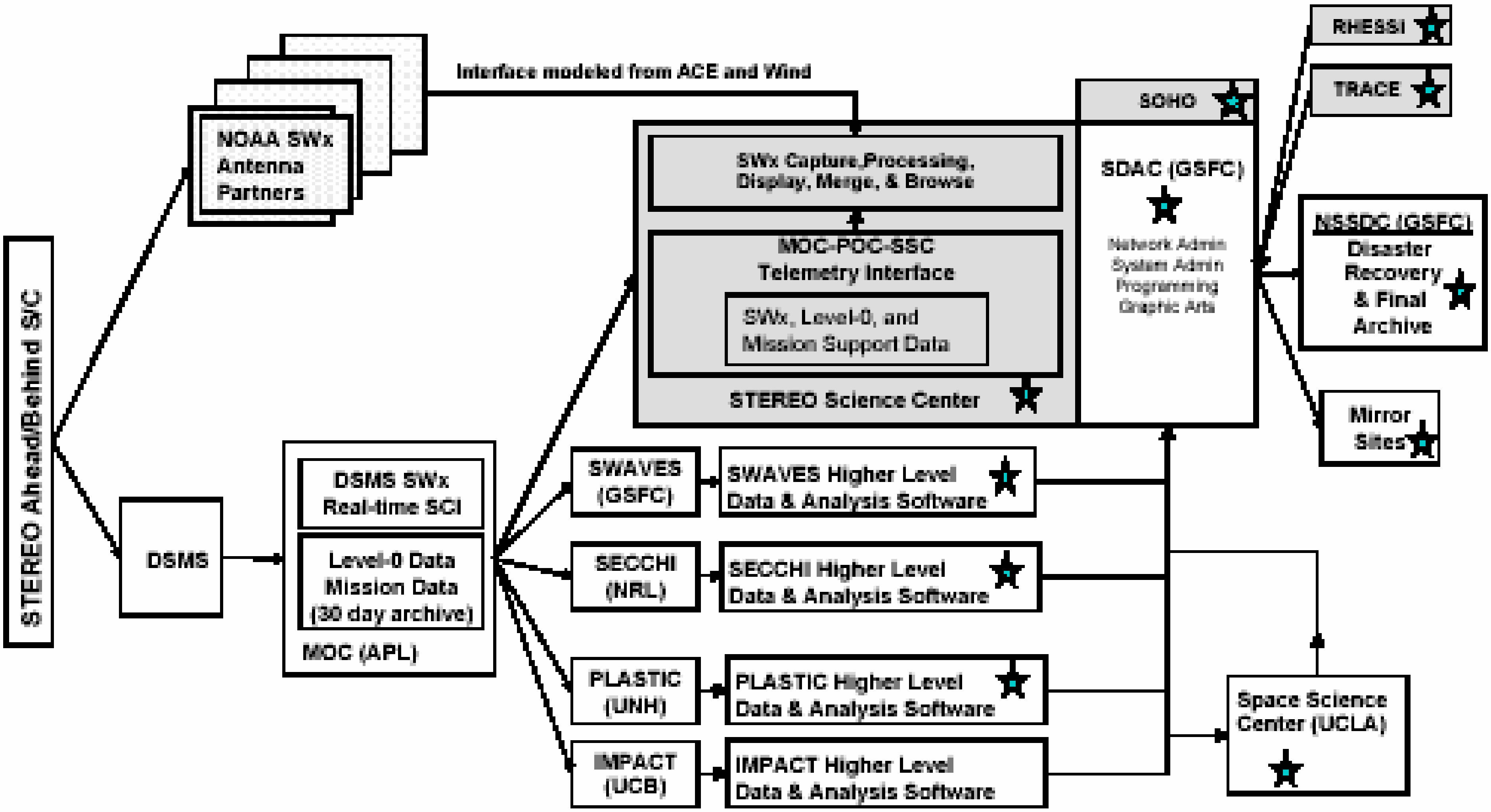


Mission Observational Capabilities

Mission Phase		Remote Sensing	In-Situ
Prime Stereo Science		•Stereo view of plane of sky CMEs and their propagation	•Multipoint observation of Earth directed CMEs
Multipoint Science		•Halo and limb CMEs and their propagation	•Multipoint observation of Earth directed CMEs
LWS Precursor Science		•Earth directed CMEs •STEREO-A at quadrature with STEREO-B	•STEREO-A at quadrature with STEREO-B

Data Flow/SSC Block Diagram

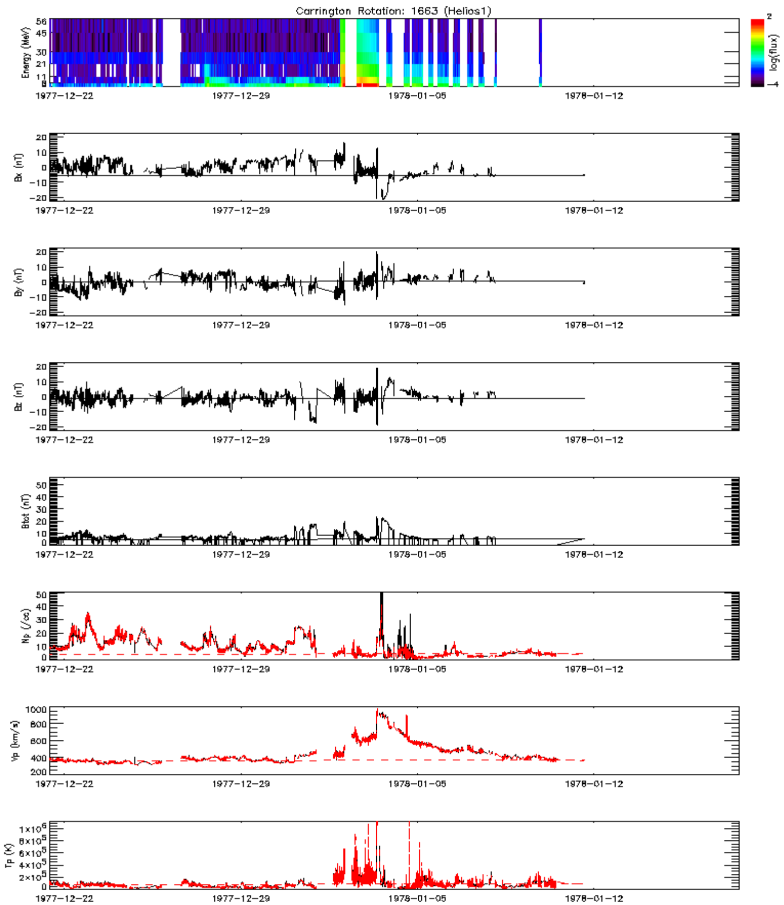
Public Internet Access ★

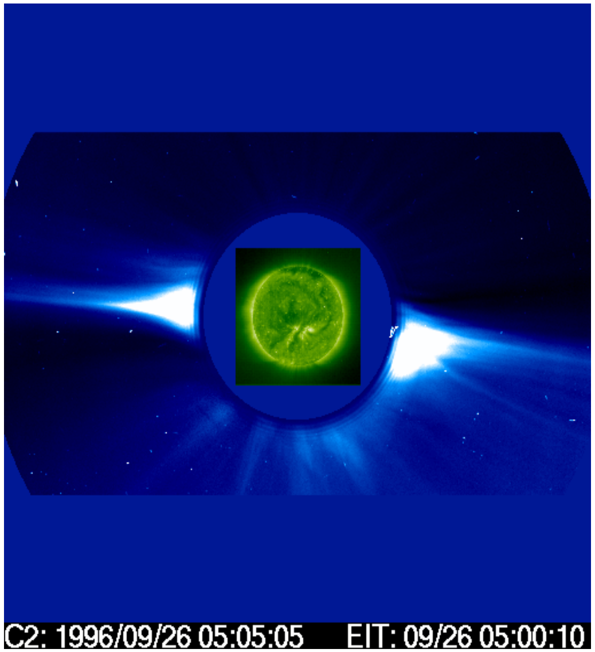


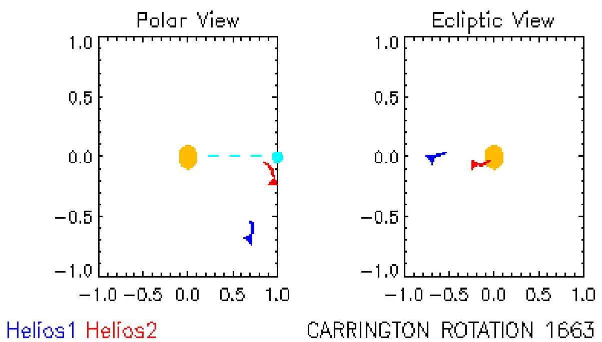
Working Archives

- Principal Investigators have committed to an open policy for data and software, including the in-situ measurements
  - **SECCHI**
    - .**Heritage: SOHO LASCO and EIT**
    - .**[lasco-www.nrl.navy.mil]**
  - **S/WAVES**
    - .**Heritage: WIND WAVES**
    - .**[www-lep.gsfc.nasa.gov/waves/waves.html]**
  - **IMPACT**
    - .**Heritage: WIND 3Dp, IMP-8, ISEE**
    - .**[www-ssc.igpp.ucla.edu/ssc]**
  - **PLASTIC**
    - .**Heritage: SOHO CELIAS**
    - .**[stereo.sr.unh.edu/data.html] and at UCLA with IMPACT**

A major challenge will be to Integrate the Multipoint Measurements of ICMEs and SEPs with the Images





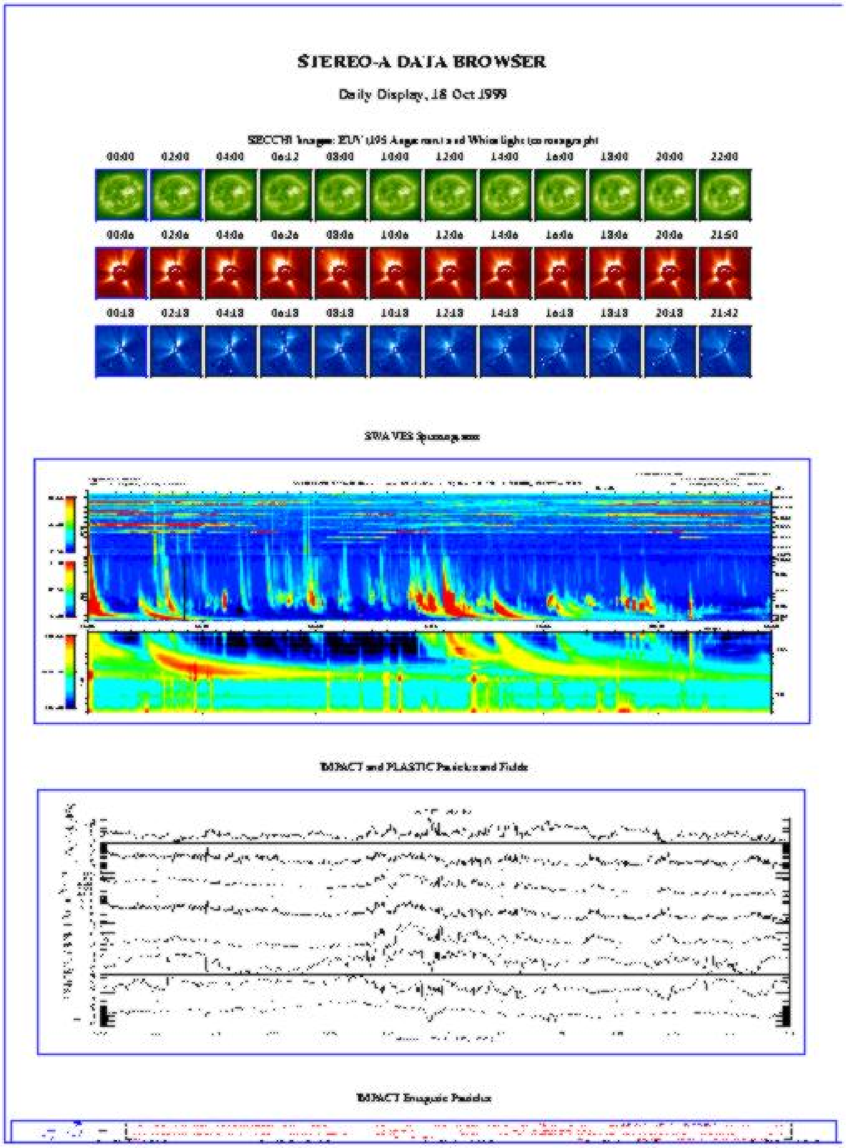


Example from Helios 1/2 data for Carrington Rotation 1663 (above), Spacecraft locations (bottom), and SECCHI image placeholder from SOHO (S. Yashiro CDAW website images)

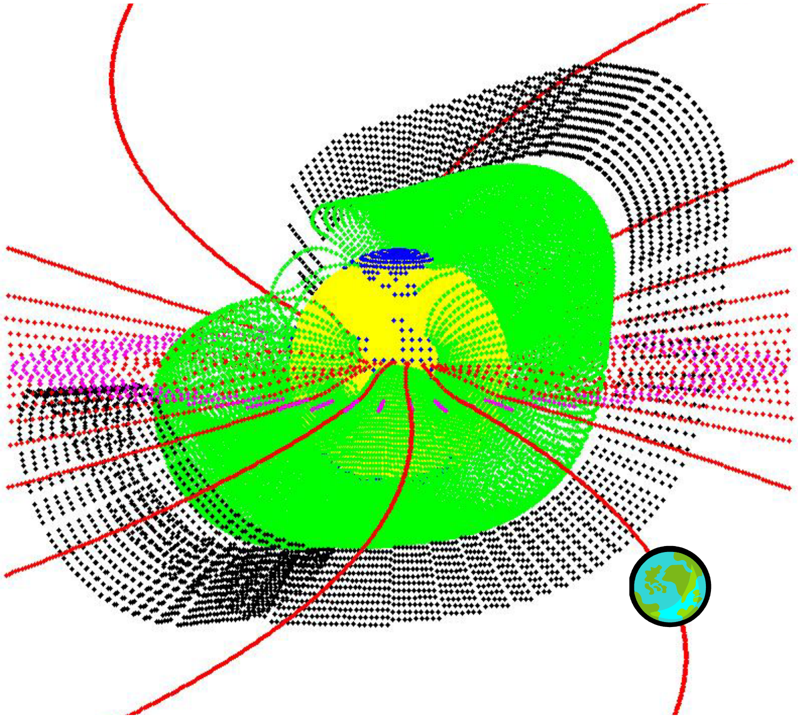
Special browsers need to be designed.

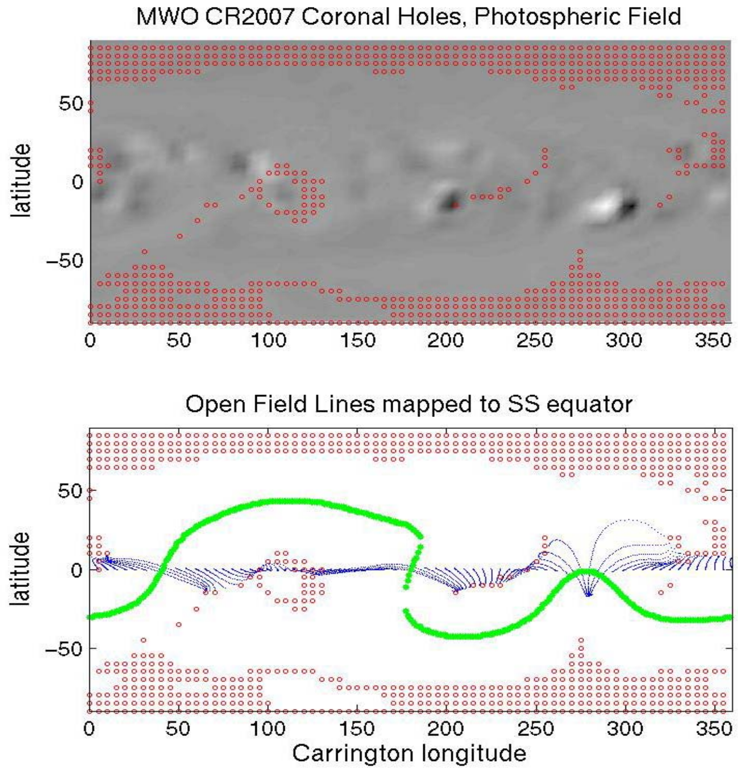
Combined Browser Ideas are Needed!

- Need to be able to see CMEs and prevailing coronal hole pattern fror images
- Need to be able to see SWAVES radio burst activity
- Need to include magnetograms and model reconstructions, predictions of measured parameters



Realistic coupled corona and solar wind models are now available that can be used to interpret STEREO In-Situ data



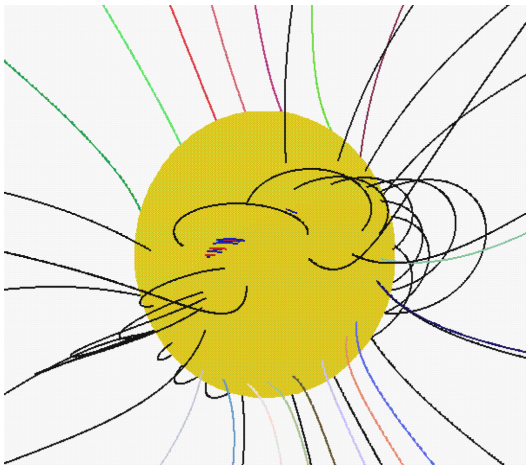


Solar Magnetograms from SOHO MDI, KPNO, MWO, WSO, GONG must be used to provide both model boundary conditions – and other supporting information for data interpretation. STEREO SWG needs to arrange these collaborations.

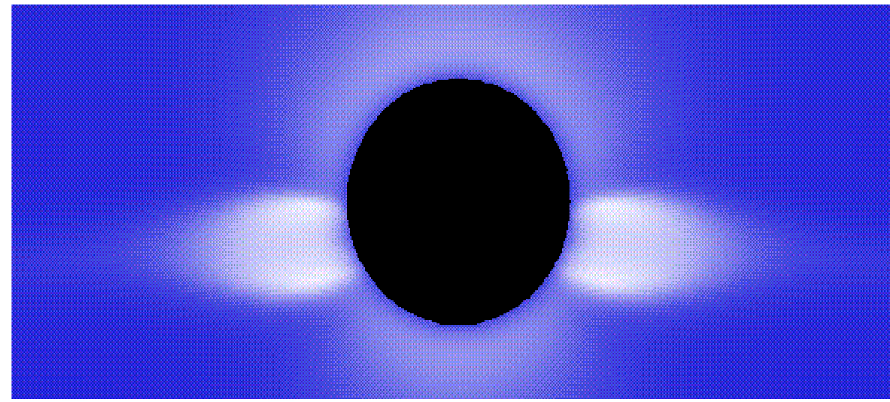
Also, models of CMEs will help physically connect IMPACT in situ observations of ICMEs to SECCHI images

(Shown: SAIC CME model, CISM merged CME/Solar Wind model)

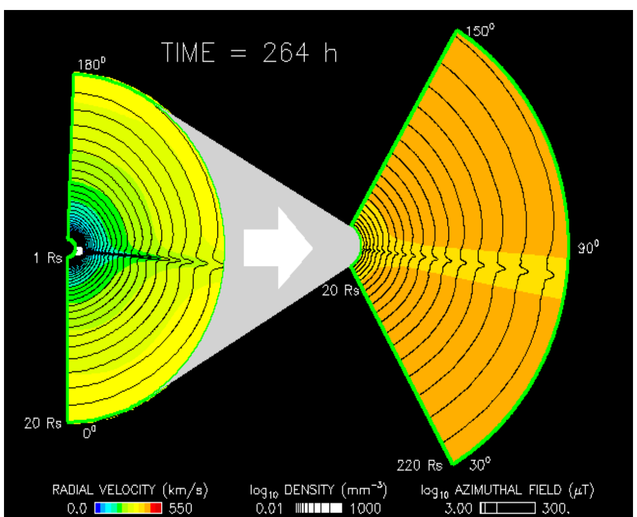
Simulate
d coronal
eruption
(CME)

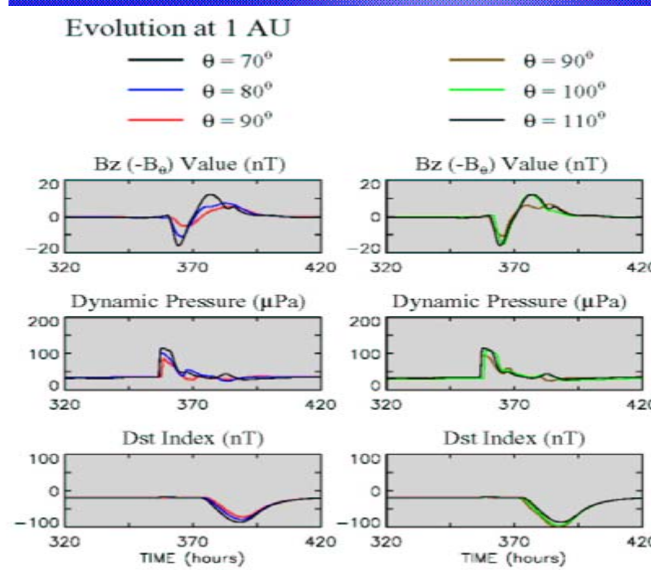


Simulate
d corona-
graph
image
(right)



Inter-
planetary
transport
(ICME)

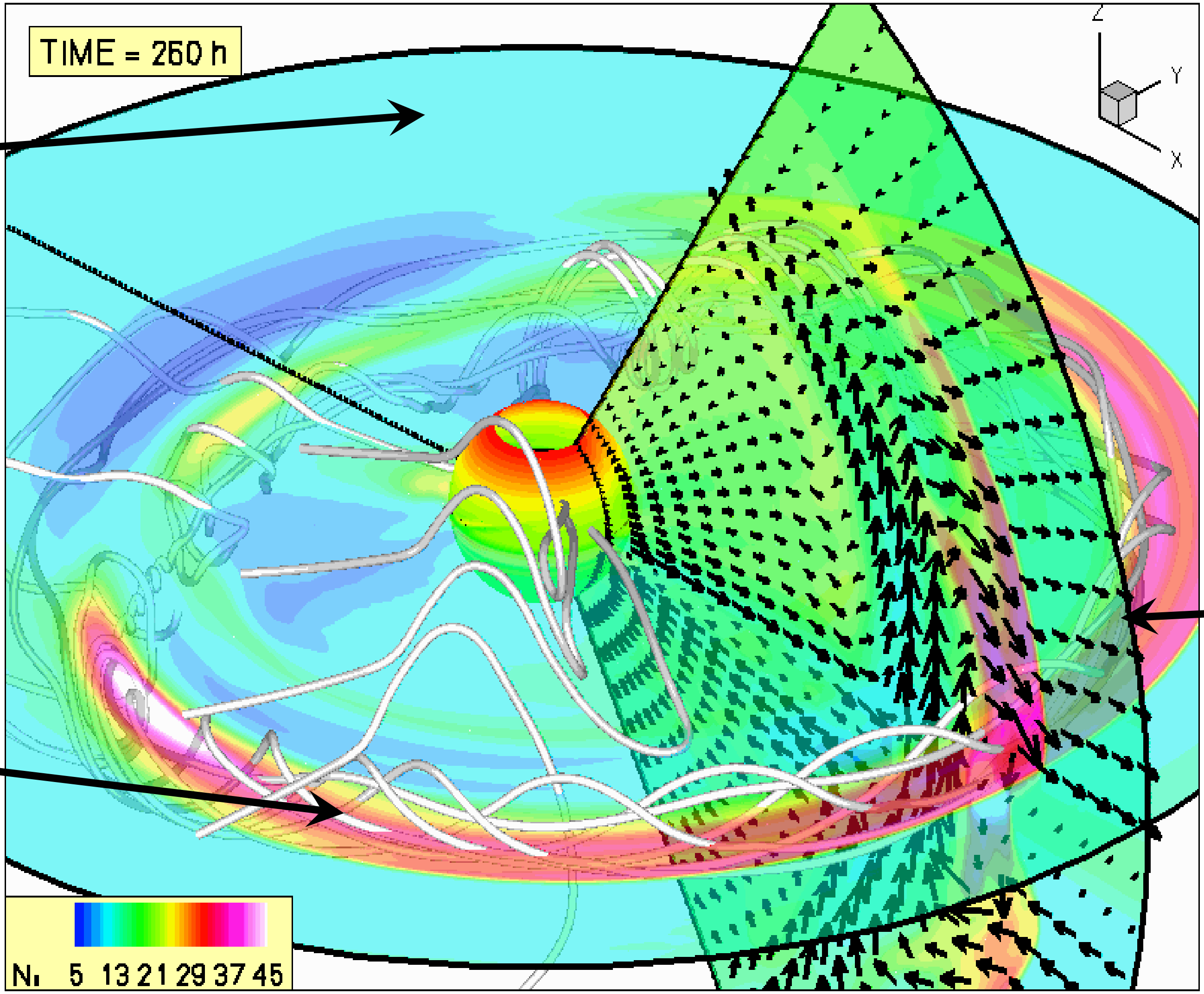




Simulated
time
series in
situ

Images courtesy of Jon Linker, SAIC, and Dusan Odstrcil, CIRES

Detail of an ad-hoc simulated CME in the model solar wind



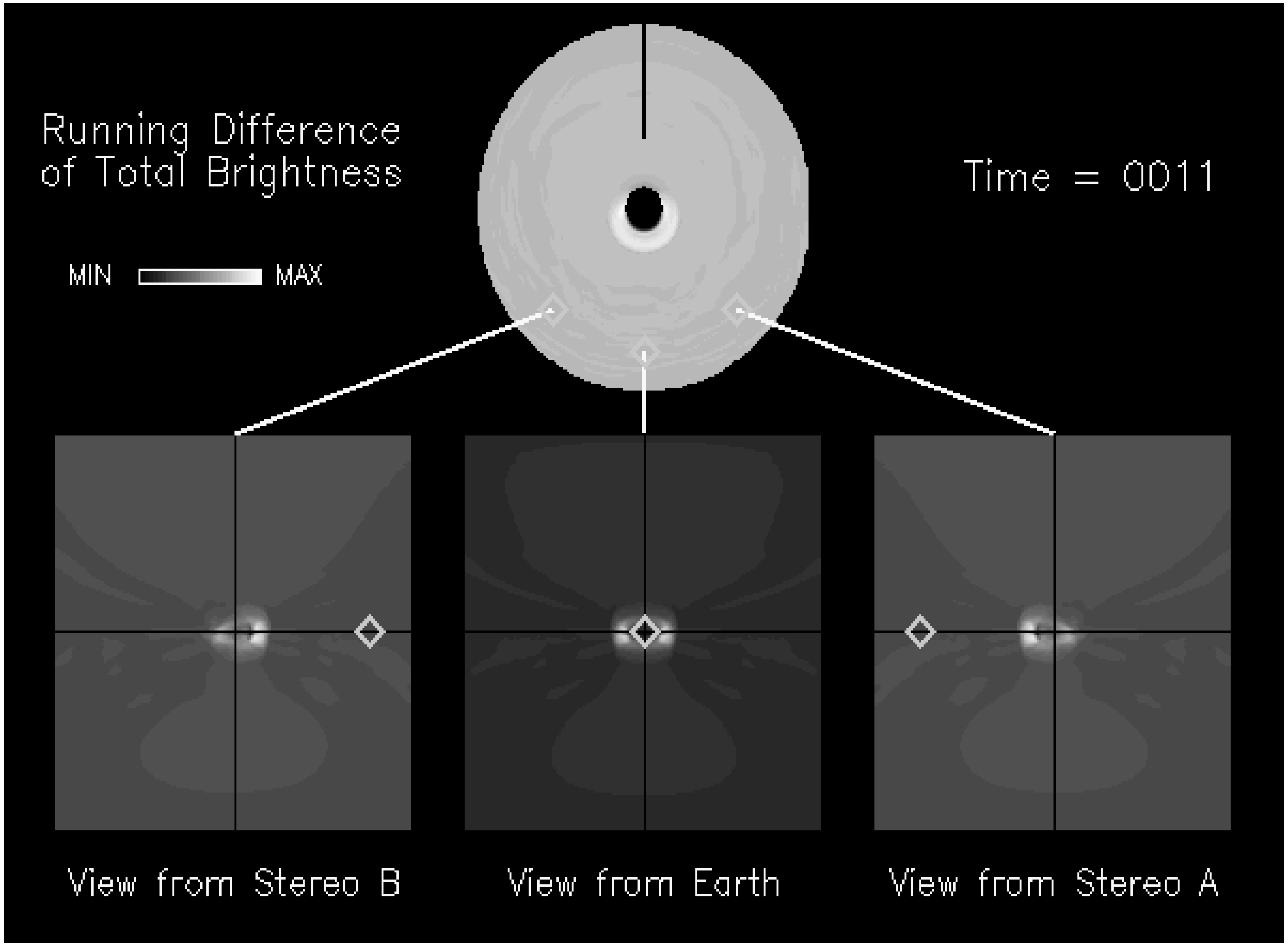
Ambient Solar Wind

ICME Shock and Sheath

ICME Flux Rope Field Lines

Image courtesy of Dusan Odstrcil, CIRES

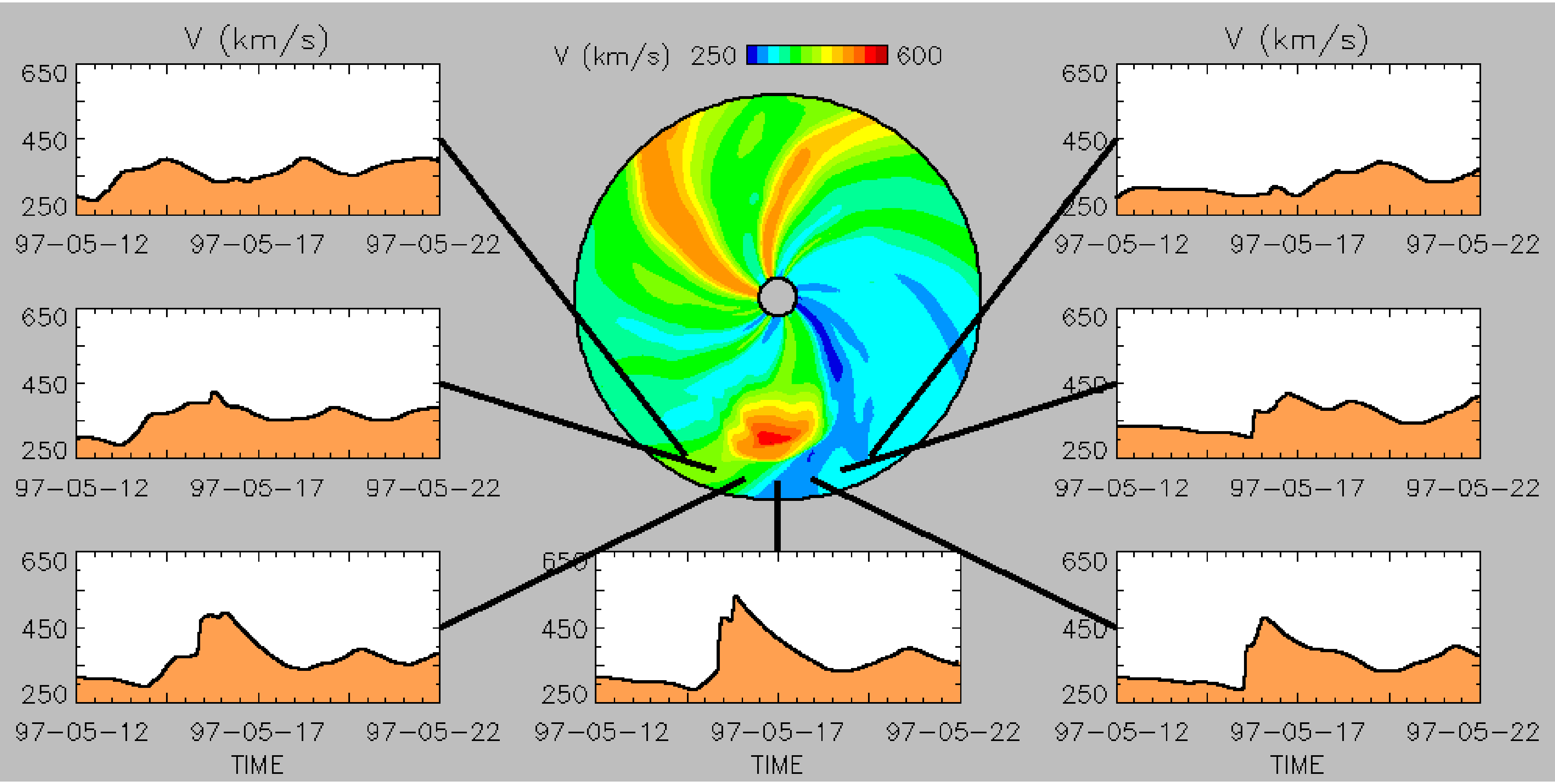
STEREO Multiperspective Images and Multi-Point In-situ measurements can be used to validate event simulations from Sun to 1AU



White light images of a simulated modeled CME event from 3 perspectives. In-situ data corresponding to the viewer location are readily obtainable.

Image courtesy of Dusan Odstrcil, CIRES

Models will be validated by STEREO In-Situ measurements and also help us to interpret them



(Figure from D. Odstrcil)