STEREO

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Presentation to the Senior Review of Heliophysics Missions
2013 April 23

Updates to the Proposal

- Addition/correction to proposal
- Prioritized science goals
- Science
  - GLEs / extreme event / SEP peak flux (Janet)
  - SECCHI science update (Angelos)
- Conclusion

Addition to Proposal

- Missing reference (validation of helioseismic tomography of the solar far side using SECCHI EUVI images):
  - *Liewer, P., González-Hernández, I., Hall, J.R., Thompson, W.T., and Misrak, A. 2012, Solar Phys., 281, 3, doi: 10.1007/s11207-012-9932-9*

Correction to Proposal

Calendar Year	Refereed Journals only
2006	1
2007	11
2008	63
2009	122
2010	125
2011	101
2012	163
2013 through April 15	15
Total	**601**

Prioritized Science Goals

STEREO Prioritized Science Goals

Goal set 1: Characterize space weather throughout the Inner Heliosphere

Goal Set 2: What can we learn from 360° coverage of the solar corona?

Goal Set 3: What can we learn from coverage of the full heliosphere?

Goal Set I

- *Characterize space weather throughout the Inner Heliosphere*
  - *Understand the large-scale structure of ICMEs*
  - *Understand the physics of ICME interactions*
  - *Understand how solar energetic particles are distributed so efficiently around the Sun*
  - *Radio and in situ, multispacecraft measurements of Type III bursts*
  - *Characterize space weather using multiple viewpoints throughout the inner heliosphere*

Goal Set 2

- *Goal Set 2: What can we learn from 360° coverage of the solar corona?*
    - *Uncover the large-scale couplings in solar eruptive events*
    - *Understand the lifetime of active regions, coronal holes, filaments, and filament channels*

Goal Set 3

- *What can we learn from coverage of the full heliosphere?*
    - *Provide longitudinal coverage of the solar wind and transients that can affect the outer heliosphere*
    - *Pickup ions*
    - *Improve our understanding of dust in the inner heliosphere*

Understanding the Causes of GLEs

An Extreme Interplanetary Event

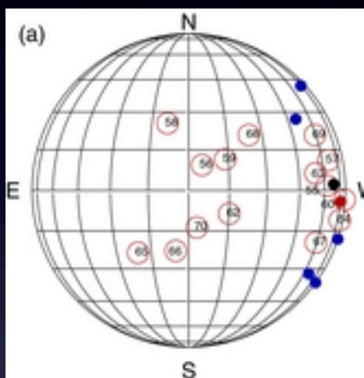
Longitudinal and Radial Dependence of SEP Peak Intensities

Janet Luhmann
IMPACT PI, Berkeley SSL

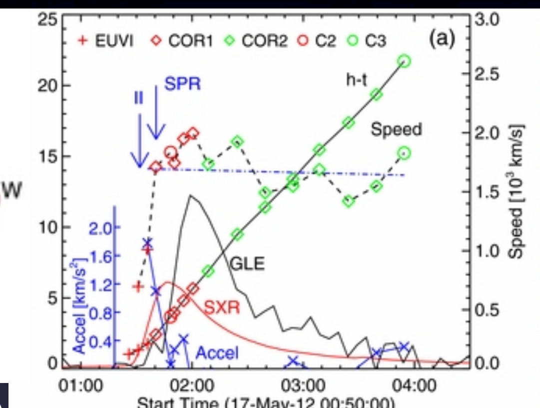
Toward Understanding the Causes of GLEs (Ground Level Events)

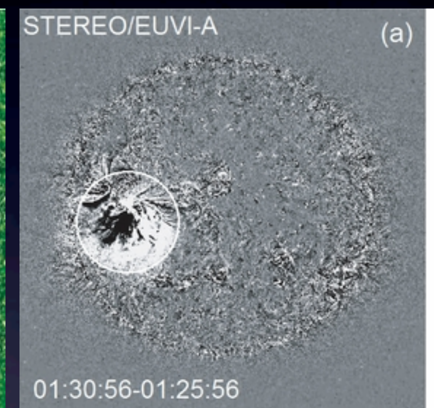
refs: Gopalswamy et al., ApJ Lett., March 2013; Shen et al., ApJ, February 2013

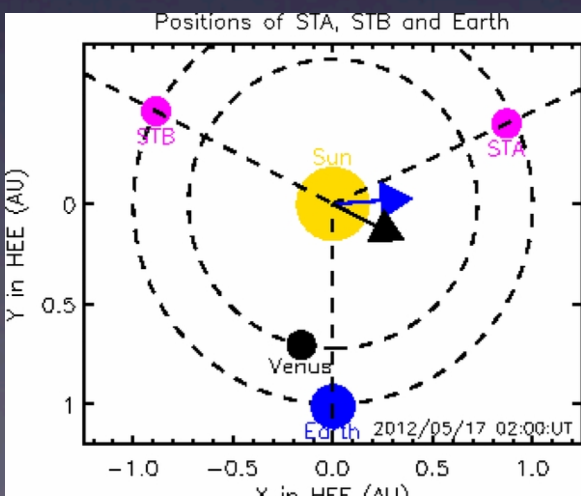
Ground Level Events are the most energetic SEP events affecting Earth, but their origins (flares vs. CME shocks) are still debated. Because they tend to connect to near the West limb of the Earth-facing disk, their sources are difficult to diagnose. Gopalswamy and coworkers use STEREO observations during a GLE in 2012 May to examine its source details.

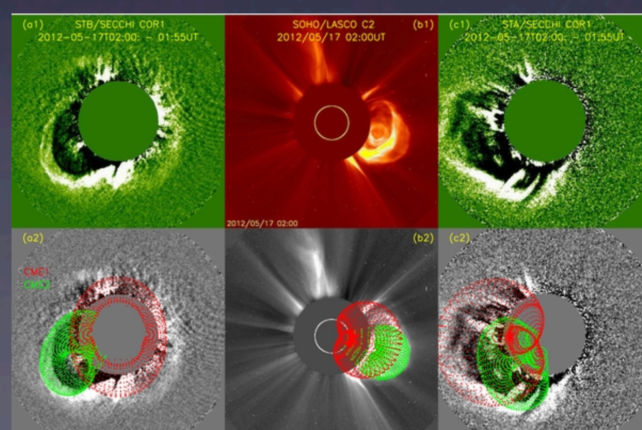


Selected Cycle 24 CMEs (dots) and Cycle 23 GLE-related CMEs







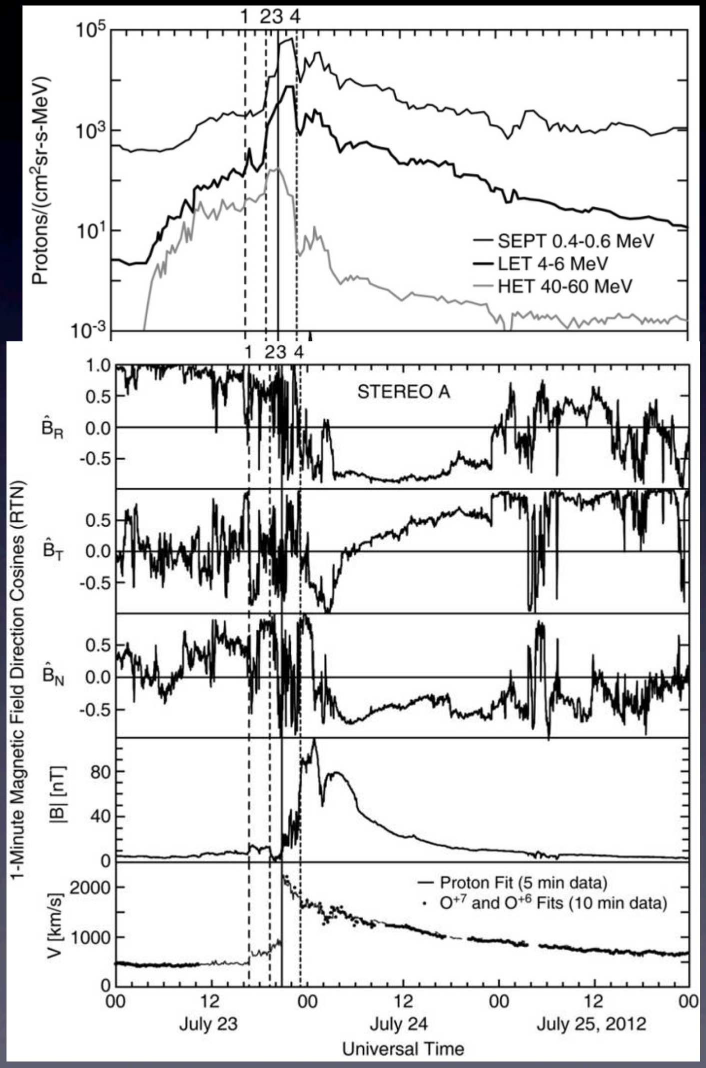


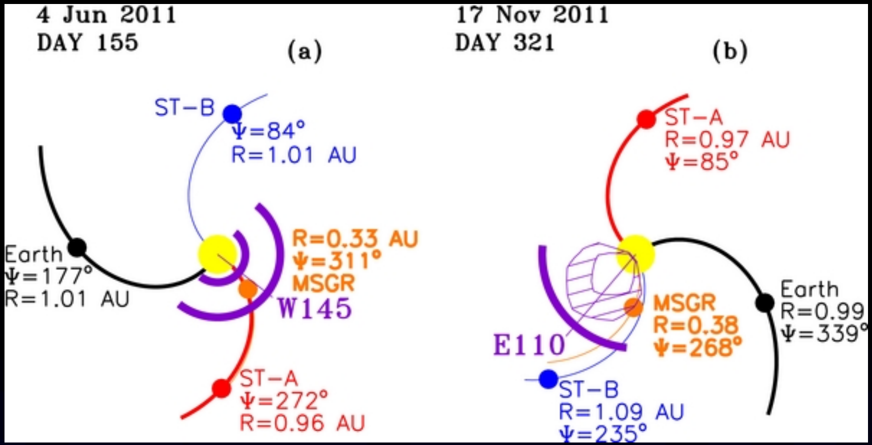
It has been suggested that GLEs are often associated with multiple CMEs from the same or proximate parts of the corona. Shen *et al.* use STEREO observations during the same event to further that argument.

Unusual properties of the extreme STEREO-A interplanetary event in July

ref: C.T. Russell et al., accepted for publication in ApJ Letters, 2013

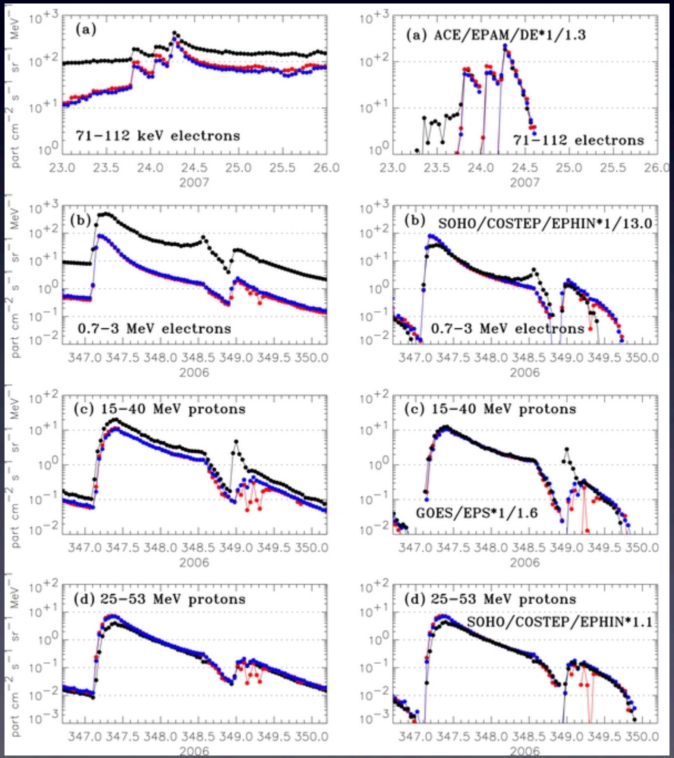
- On July 23, 2013, a strong burst of solar activity began on the farside shortly after 0200 UT and STEREO-A began to detect SEPs.
- The July 23, 2013 SEP event was unusually intense, about 1000x a normal event.
- The blast wave arrived swiftly, 17 hours from onset to compressional wave at 0.96 AU; 18 hours from onset to speed jump.
- The strong, superfast magnetic cloud with southward fields would probably have produced a superstorm had it hit the Earth, but the shock appears to have been weakened/modified by the many SEPs it accelerated.
- It is possible that the energetic protons raised the sound speed so much that the interaction became subsonic at the cloud interface and a thick slow wave formed by the time it reached STEREO-A at 1 AU.



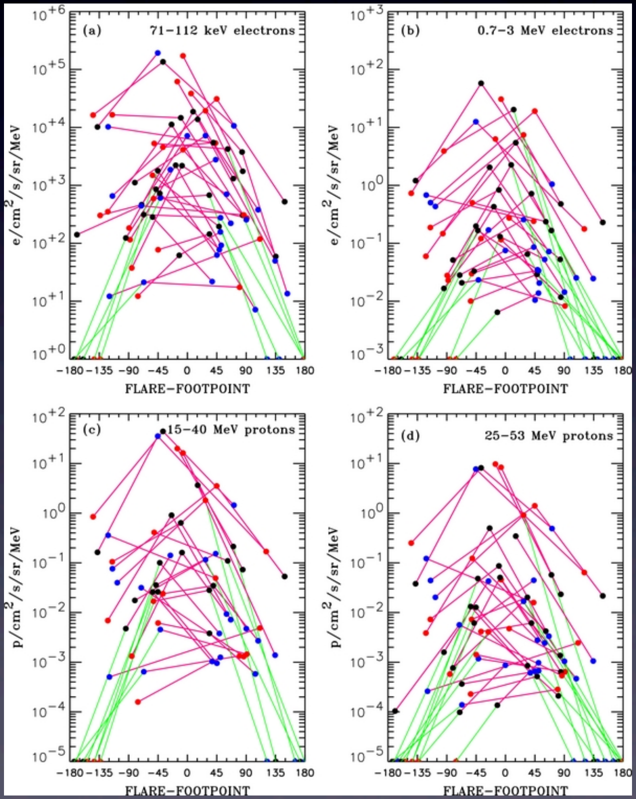


Longitudinal and Radial Dependence of Solar Energetic Particle Peak Intensities: STEREO, ACE, SOHO, GOES, and Messenger Observations

ref. Lario et al., ApJ, April, 2013



Example of a multipoint SEP event (STEREOs are red, blue in left panels)



35 SEP events with multipoint detections are used to further pin down SEP event strengths (prompt component) with respect to their solar sources (STEREO A, B provide red, blue points)

SECCHI Science Update

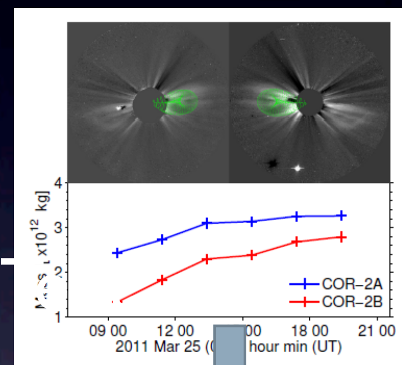
Angelos Vourlidas
SECCHI Project Scientist, NRL

Investigating the CME-Magnetosphere Coupling

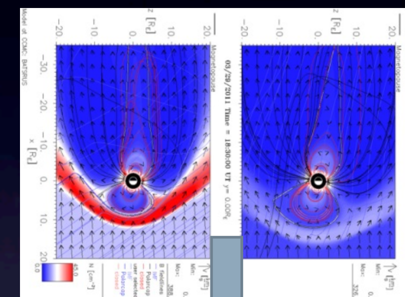
Using SECCHI observations in the corona to predict GICs (Ground Induced Currents).

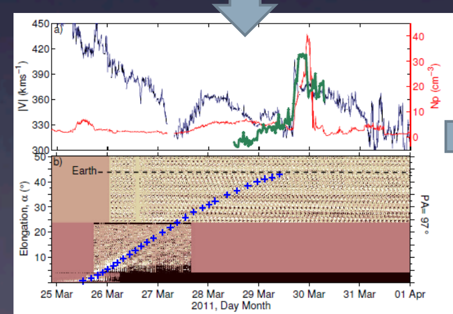
- A new research area for STEREO.
- Synergy with Van Allen Probes.
- Demonstrates the potential of L5/L4 observations for Space Weather.
- Based on coronagraph data. Not affected by large angles to Sun-Earth line.

Derive CME 3D properties. Extract density(t) along Earth direction.

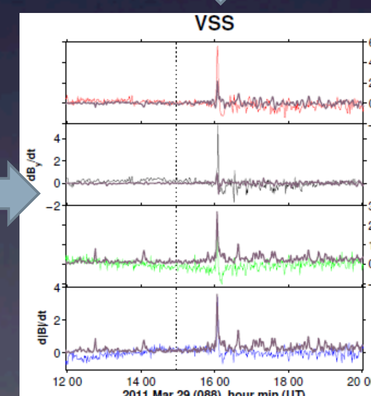


Run magnetospheric model





Extrapolate density time series to 1AU using velocity profile.
Obtain momentum flux prediction.



Obtain GIC predictions

How Strong Are Flares on the Far Side?

EUVI Becomes a GOES SXR Proxy: $F_{GOES} = 1.39 \times 10^{-11} F_{EUVI(195)}$

Why?

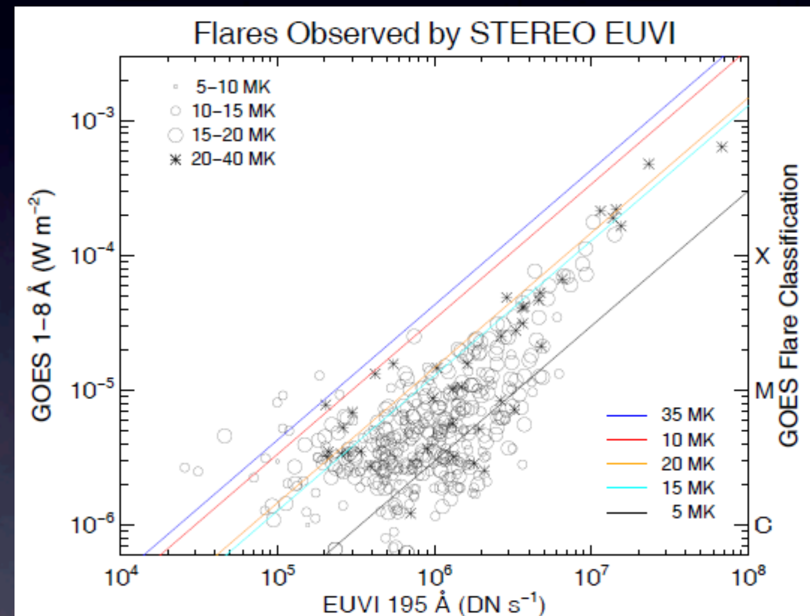
- Connect farside flare/SEP studies to past front-side work.
- Remove front-side bias in statistical studies.
  - Large flares don't always happen in the front side.
  - Largest flare of Cycle 24 on 2012 Sep. 20

Table 1. List of major events since 2010 that come from regions >30° behind the limb. These are either candidates of X-class flares or multi-spacecraft SEP events. The four events that are shown in Figure 9 are marked with asterisks.

Date	Time	A or B	Location	Est. F_{GOES}	Range	Refs
2010/01/17	03:55:40	B	S25 E128	$6.4 \cdot 10^{-5}$	M3.4 – M9.6	1, 2
2010/08/31	20:55:53	A	S22 W146	$1.7 \cdot 10^{-4}$	M8.4 – X2.5	
2010/09/01	21:50:53	A	S22 W162	$1.1 \cdot 10^{-4}$	M5.4 – X1.6	
2011/03/21	02:10:49	A	N20 W128	$3.1 \cdot 10^{-5}$	M1.3 – X1.3	3
2011/06/04	07:05:58	A	N15 W140	$1.0 \cdot 10^{-4}$	M5.2 – X1.6	
2011/06/04 *	21:50:58	A	N17 W148	$8.1 \cdot 10^{-4}$	X4.0 – X12	
2011/10/23	23:15:44	A	N19 W151	$1.1 \cdot 10^{-4}$	X5.3 – X1.6	
2011/11/03 *	22:40:44	B	N08 E156	$9.4 \cdot 10^{-5}$	M4.7 – X1.4	4
2012/03/26	22:16:02	B	N18 E123	$1.6 \cdot 10^{-4}$	M8.2 – X2.5	
2012/04/29	12:45:53	B, A	N12 E163	$1.7 \cdot 10^{-4}$	M8.3 – X2.5	
2012/07/23 *	02:30:56	A	S15 W133	$1.5 \cdot 10^{-4}$	M8.2 – X2.5	
2012/08/21	20:10:54	B, A	S22 E158	$1.4 \cdot 10^{-4}$	M6.8 – X2.0	
2012/09/11	07:55:50	B, A	S22 E178	$2.6 \cdot 10^{-4}$	X1.3 – X3.9	
2012/09/19	11:15:49	B, A	S15 E171	$1.8 \cdot 10^{-4}$	M9.1 – X2.7	
2012/09/20 *	15:00:48	B, A	S15 E153	$1.2 \cdot 10^{-3}$	X5.8 – X18	
2012/09/22	03:05:48	B	S15 E134	$1.7 \cdot 10^{-4}$	M8.4 – X2.5	

References: 1. Veronig *et al.* (2010), 2. Dresing *et al.* (2012), 3. Rouillard *et al.* (2012), 4. Mewaldt *et al.* (2012)

Nitta *et al.* 2013 (*Solar Phys.*, in press)
http://arxiv.org/abs/1304.4163



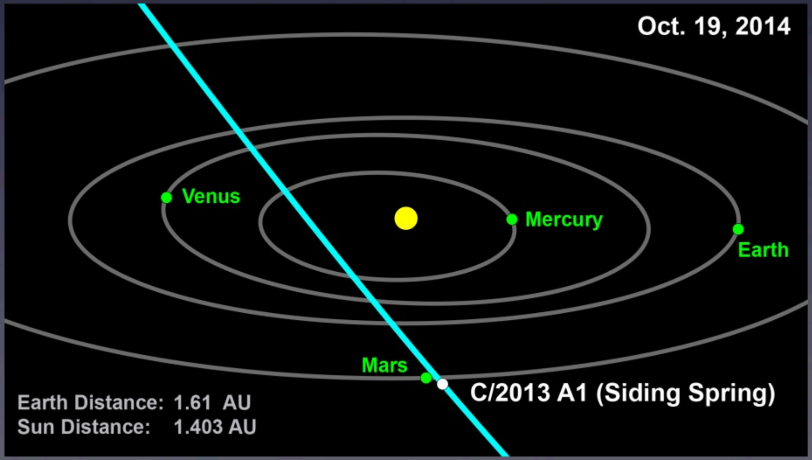
However…

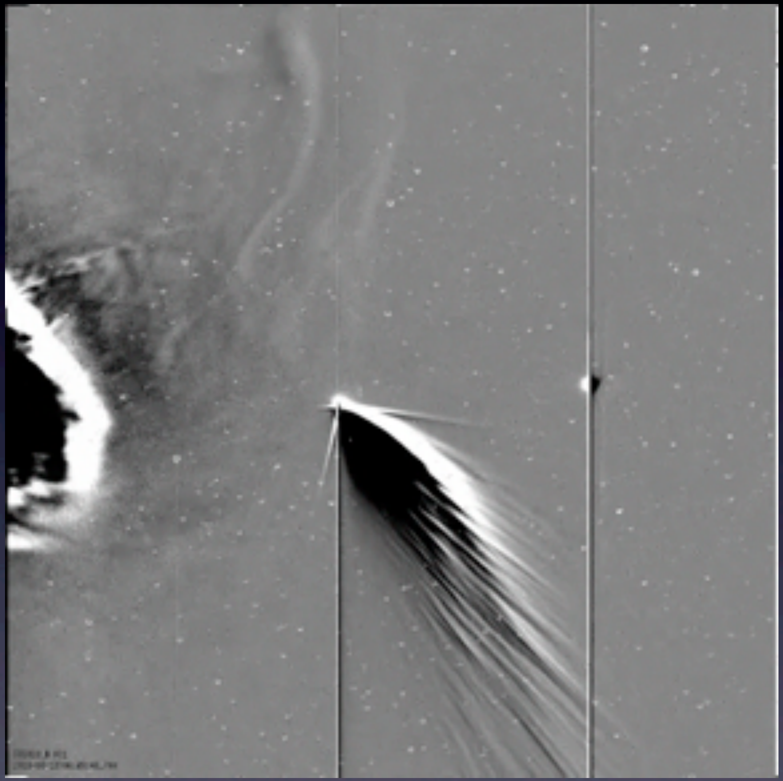
- Are SXR Classes still useful?
  - SXRs are a small part of the total E_{flare}.
  - SXRs do not indicate CME connection (no dimming).

STEREO Continues to be a Prolific Comet Observatory

- Comet ISON to attract large media and public attention. Preparations for special observing are under way (http://sungrazer.nrl.navy.mil/index.php?p=ison).

- Comet 2013-A1 Siding Spring on close approach to Mars (and MAVEN). SECCHI/HI2-B will provide imaging.





Comet PANSTARRS observed by STEREO Behind SECCHI HI-1 on 2013 March 9-15

In Conclusion

- *STEREO continues to make original and unique contributions to the Heliophysics system observatory*
  - *in both basic science and space weather forecasting*
  - *from original and unique viewpoints*

Supporting Material

- Relevance to Roadmap research focus areas
- Budget spreadsheet, FY10 - FY14
- Solar activity
- Telemetry rates

Scientific Insights, 2010 - 2012

- Science highlights include:
  - Improved understanding of CME/ICME structure
  - 360° SEP events
  - Langmuir wave eigenmodes in Type III bursts
  - Extreme event of 2012 July 23
  - CME arrival time (1 AU) prediction
  - Validation of farside helioseismic tomography
  - Nonlinear coupling of electron and ion dynamics
  - Pickup ions (Ne, O crescents)
  - Dust

Roadmap: "Frontier"

Research Focus Areas

- **F1** Magnetic reconnection
- **F2** Particle acceleration and transport
- **F3** Ion-neutral interactions
- **F4** Creation and variability of magnetic dynamos

Open the Frontier to Space Environmental Prediction

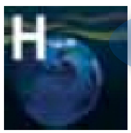
The Sun, our solar system, and the universe consist primarily of plasma. Plasmas are more complex than solids, liquids, and gases because the motions of electrons and ions produce both electric and magnetic fields. The electric fields accelerate particles, sometimes to very high energies, and the magnetic fields guide their motions. This results in a rich set of interacting physical processes, including intricate exchanges with the neutral gas in planetary atmospheres.

Although physicists know the laws governing the interaction of electrically charged particles, the collective behavior of the plasma state leads to complex and often surprising physical phenomena. As the foundation for our long-term research program, we will develop a comprehensive scientific understanding of the fundamental physical processes that control our space environment.

The processes of interest occur in many locations, though with vastly different magnitudes of energy, size, and time. By quantitatively examining similar phenomena occurring in different regimes with a variety of techniques, we can identify the important controlling mechanisms and rigorously test our developing knowledge. Both remote sensing and in situ observations will be utilized to provide the complementary three-dimensional, large-scale perspective and the detailed small-scale microphysics view necessary to see the complete picture.

Roadmap: “Home”

Research Focus Areas



- **H1** Causes and evolution of solar activity
- **H2** Earth’s magnetosphere, ionosphere, and upper atmosphere
- **H3** Role of the Sun in driving change in the Earth’s atmosphere
- **H4** Apply our knowledge to understand other regions

Understand the Nature of Our Home in Space

Humankind does not live in isolation; we are intimately coupled with the space environment through our technological needs, the solar system bodies we plan to explore, and ultimately the fate of our Earth itself. We regularly experience how variability in the near-Earth space environment affects the activities that underpin our society. We are living with a star.

We plan to better understand our place in the solar system by investigating the interaction of the space environment with the Earth and the effect of this interaction on humankind. We plan to characterize and develop a knowledge of the impact of the space environment on our planet, technology, and society. Our goal is to understand the web of linked physical processes connecting Earth with the space environment.

Even a casual scan of the solar system is sufficient to discover that habitability, particularly for humankind, requires a rare confluence of many factors. At least some of these factors, especially the role of magnetic fields in shielding planetary atmospheres, are subjects of immense interest to heliophysics. Lessons learned in the study of planetary environments can be applied to our home on Earth, and vise versa, the study of our own atmosphere supports the exploration of other planets.

Roadmap: "Journey"

Research Focus Areas

- **J1** Variability, extremes, and boundary conditions
- **J2** Capability to predict the origin, onset, and level of solar activity
- **J3** Capability to predict the propagation and evolution of solar disturbances
- **J4** Effects on and within planetary environments

Safeguard the Journey of Exploration

NASA's robotic spacecraft continue to explore the Earth's neighborhood and other targets in the heliosphere. Humans are expected once again to venture onto the surface of the Moon and one day onto the surface of Mars. This exploration brings challenges and hazards. We plan to help safeguard these space journeys by developing predictive and forecasting strategies for space environmental hazards.

This work will aid in the optimization of habitats, spacecraft, and instrumentation, and for planning mission operation scenarios, ultimately increasing mission productivity. We will analyze the complex influence of the Sun and the space environment, from origin to the destination, on critical conditions at and in the vicinity of human and robotic spacecraft. Collaborations between heliophysics scientists and those preparing for human and robotic exploration will be fostered through interdisciplinary research programs and the common use of NASA research assets in space.

Uptake of STEREO data

- > 27 Tbyte of STEREO data served by SSC in 2012 (up 17% compared with 2009, despite decrease in average data volume per day of 30% since then)
- SSC Website: > 19 Tbyte of downloads between 2012/05 and 2013/04 (up 50% from three years ago)
- Space weather beacon (near-realtime) mode data used for nowcasting by NOAA SWPC, CCMC, SIDC online services as well as SSC

Calendar Year	Refereed Journals only
2010	125
2011	101
2012	163
2013 (to 04/15)	15
Total	404

Includes one Solar Physics special issue (Sun 360)

Budget Detail

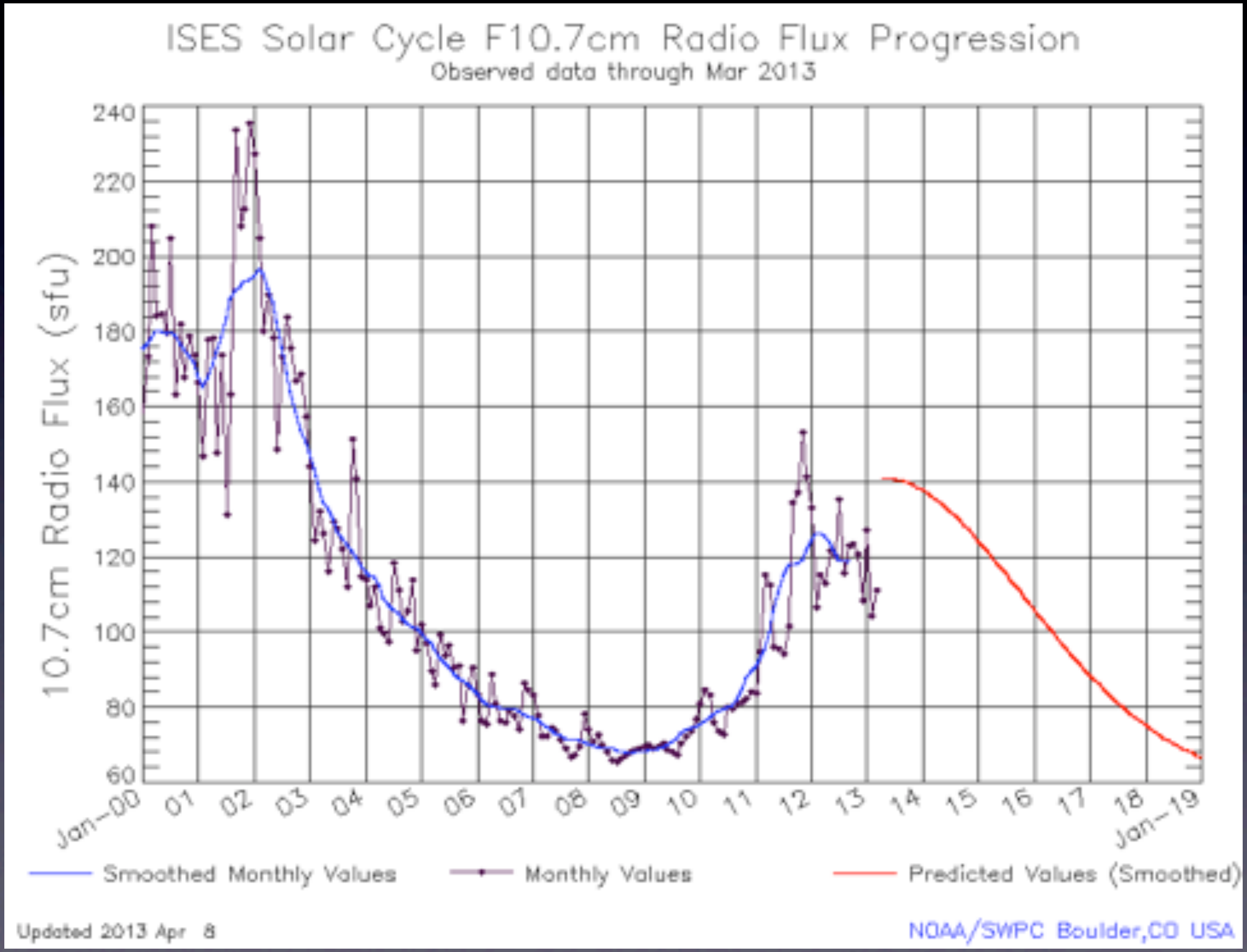
II. FY14 – FY18 '5-way' Functional Breakdown:	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
1. Development	260.0	148.0	35.0	0.0	0.0
2.a Space Communications Services	108.0	111.0	114.0	113.0	112.0
2.b Mission Services	3,611.4	3,749.4	3,673.0	3,468.8	3,570.8
2.c Other Mission Operations	60.7	62.2	67.6	77.3	66.5
3. Science Operations Functions	3,402.0	3,372.0	3,567.0	3,721.3	3,632.2
4.a Science Data Analysis	2,075.8	2,045.2	2,119.3	2,206.5	2,206.8
4.b Guest Observer Funding	0.0	0.0	0.0	0.0	0.0
5. E/PO	119.1	115.0	117.5	120.7	119.6
Total*	9,637	9,603	9,693	9,708	9,708

*Totals for Table II should be identical to totals in Table I.

IIa. FY14 – FY18 Labor breakdown:	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs	FTEs/WYEs
1. Mission Operations	8.9	8.9	8.9	8.9	8.9
1.a CS Labor	0.2	0.2	0.2	0.2	0.2
1.b WYE (Contractor) Labor	8.7	8.7	8.7	8.7	8.7
2. Science Operations and Data Analy	30.3	29.4	29.7	30.0	29.7
2.a CS Labor	1.7	1.7	1.7	1.7	1.7
2.b WYE (Contractor) Labor	28.6	27.7	28.0	28.3	28.0

III. FY14 – FY18 Instrument team breakdown	FY14 Budget ($k)	FY15 Budget ($k)	FY16 Budget ($k)	FY17 Budget ($k)	FY18 Budget ($k)
1. DA – PLASTIC	588.0	577.0	609.6	627.6	645.0
2. DA– IMPACT	1,392.3	1,370.8	1,440.1	1,461.7	1,462.0
3. DA – SWAVES	549.4	540.5	570.0	587.6	587.7
4. DA – SECCHI	2,526.9	2,492.7	2,619.9	2,685.9	2,675.6
DA – SSC and project scientist	606.9	621.9	676.5	773.4	665.0
Other mission expenses	3,973.4	4,000.4	3,777.0	3,571.8	3,672.8
Total**	9,637	9,603	9,693	9,708	9,708

Solar Activity, Cycle 24



Telemetry Rates

- Ahead is currently operating at 240 kbps, and Behind is operating at 120 kbps.
  - But can get higher rates (160 kbps or more) during high local altitude passes with 34 m antennas.
- Ahead will switch to 120 kbps on May 4.
- Occasionally passes are conducted using a 70 m DSN station. Behind is operated at 360 - 720 kbps for those contacts.
- Don’t expect to drop below 120 kbps for duration of far side operations
  - Enormous improvement over earlier expectations of as low as 30 kbps