Moon to Mars Space Weather Analysis

Heliophysics Investigations by Dr. Hilarie Davis & Dr. Sten Odenwald

6/3/25 HEAT Community Meeting

Predicting Space Weather

The **Integrated Solar Energetic Proton Alert/Warning System (ISEP)** project is a partnership between NASA Goddard's Community Coordinated Modeling Center (CCMC) and NASA JSC Space Radiation Analysis Group (SRAG) to transition research Solar Energetic Particle models to operations.

- The project aimed to identify, transition, and evaluate new models for Research to Operations (R2O), to develop software tailored for SRAG.
- CCMC has transitioned 6+ real-time models and built **the SEP Scoreboard application.**
- The tool was used in a real time setting by SRAG and M2M for the Artemis 1 mission.
- Currently working closely with missions like PSP, Solar Orbiter, and MAVEN who use M2M analyses and notifications to create a database specific for their missions.

Framework for Heliophysics Education (FHE)

Developed by NASA HEAT in 2022

https://science.nasa.gov/learn/heat/big-ideas/

Structured around NASA's **Big Heliophysics Questions**:

1. What are the impacts of the Sun on humanity?
2. How do the Earth, the solar system, and heliosphere respond to changes on the Sun?
3. What causes the Sun to vary?

FHE has Developed Big Ideas for the NASA Questions

1. What are the impacts of the Sun on humanity?

1.1 The Sun is really big and its gravity influences all objects in the solar system. (PS2, ESS1)

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

1.3 The Sun's energy drives Earth's climate, but the climate is in a delicate balance and is changing due to human activity. (PS1, PS2, PS3, LS4, ESS2, ESS3)

2. How do the Earth, the solar system, and heliosphere respond to changes on the Sun?

2.1 Life on Earth has evolved with complex diversity because of our location near the Sun. It is just right! (PS3, PS4, LS1, LS2, ESS2)

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

2.3 The Sun is the primary source of light in our solar system. (PS1, PS2, PS3,PS4, ESS1)

3. What causes the Sun to vary?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

3.2 Energy from the Sun is created in the core and travels outward through the Sun and into the heliosphere. (PS1, PS3, PS4, ESS1, ESS2, ESS3)

3.3 Our Sun, like all stars, has a life cycle. (PS1, LS1, ESS1)

Space Weather in the Framework with Standards

Question 1: What are the impacts of the Sun on humanity?

1.2 The Sun is active and can impact technology on Earth via space weather. (PS1, PS2, PS4, ESS2, ESS3)

Question 2: How do the Earth, the solar system, and heliosphere respond to changes on the Sun?

2.2 The Sun defines the space around it, which is different from interstellar space. (PS2, ESS1, ESS2)

Question 3: What causes the Sun to vary?

3.1 The Sun is made of churning plasma, causing the surface to be made of complex, tangled magnetic fields. (PS1, PS2, ESS1, ESS2)

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Modeling in the Next Generation Science Standards

"Developing and using models" is one of the eight core Science and Engineering Practices. It involves using models, like diagrams, simulations, or physical replicas to represent and understand phenomena, systems, or processes. Models help students make sense of complex ideas, communicate their understanding, and revise their explanations over time.

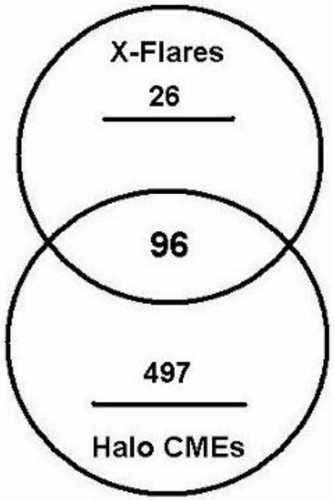
- **Dynamic Representation:** Models are not static representations but rather evolving tools that reflect a student's developing understanding of a concept.
- **Types of Models:** NGSS recognizes various forms of models, including diagrams, simulations, replicas, mathematical representations, and physical models.
- **Purpose of Modeling:** Modeling is used to: 1) Explain what is happening or predict what will happen, 2) Sift through and communicate prior knowledge, 3)Track the growth of conceptual understanding, 4)Demonstrate mastery of unit concepts.
- **Process of Modeling:** Modeling is a dynamic process that involves: 1) Recording initial thinking and understanding, 2) Returning to the model to revise and expand explanations.
- **Importance of Modeling:** Modeling is crucial for students to explore all fields of science and develop a deeper understanding of scientific concepts.

Introductory Level Investigation

When is it a high alert for space weather? Halo CMEs are potentially the most damaging. How do we predict them?

SpaceMath # 244 [Grade:4-7 | Topics: Percentages; Venn Diagramming]

Students create a Venn Diagram to summarize data on a series of solar storms and determine how often solar flares occur when a solar plasma eruption happens.



Between 1996 and 2006, SOHO detected 11,031 CMEs. Of these, 593 were Halo CMEs.

During these same years, there were 122 extremely intense X-flares. Of these 96 happened at the same time as the Halo CMEs.

Question: What percentage of Halo CMEs happened at the same time as an X-class flare?

The total number of Halo CMEs is 593. Of these only 96 occurred with an X-Flare, so the fraction of Halo CMEs is just 96/593 = 0.16 or 16%. (But if you see an X-class flare, about (96/122 =) 79% of the time you will see a Halo CME!) That's why space weather forecasters watch for X-class flares!

Intermediate Level Investigation

How do scientists calculate the speed of a Coronal Mass Ejection?

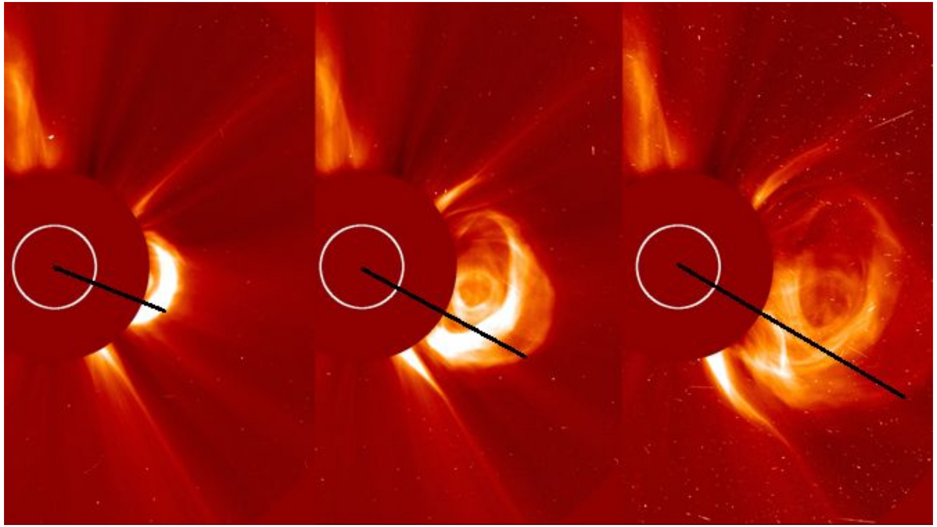
Scale; Proportions; Calculating speeds and times

$\Delta T = 0.5$ hours.

Lengths: D1= 2.1 Mkm at time=0 hours,
D2= 3.3 Mkm at time=0.5 hours,
D3= 4.6 Mkm at time=1.0 hours

Speeds: V1= (D2-D1) /0.5h = 2.4 Mkm/h
V2=(D3-D2)/0.5h = 2.6 Mkm/h

Arrival at Earth: T = 150 Mkm/(2.6 Mkm/h)
= **58 hours or 2.4 days**



CME September 6, 2017 (Credit:SOHO/LASCO)

See: Coronal Mass Ejections and Earth's Space Weather Environment, Sten Odenwald & Hilarie Davis, The Earth Scientist | Volume XLII, Issue 1 Page 13-20,.

Advanced Level Investigation

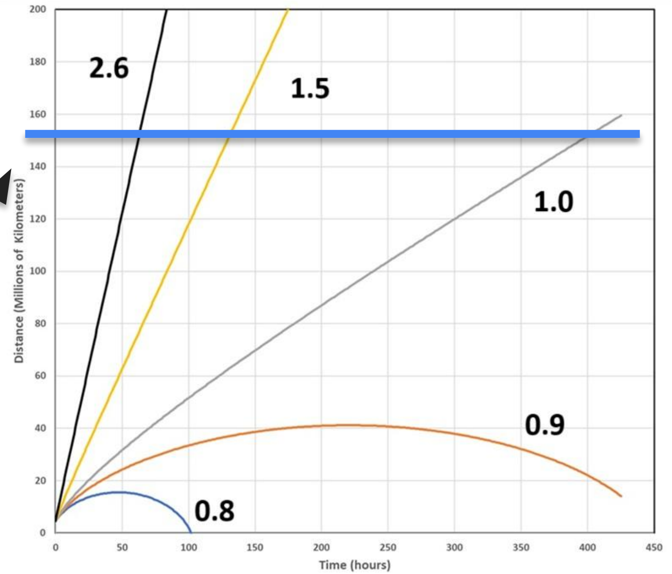
How do scientists know when a CME will arrive?

Algebra II: An application of the Ballistics Equation.

$$D = d_o + Vt + \frac{1}{2}at^2 \qquad a = -\frac{2.95}{d^2} \quad \text{Mkm/h}^2$$

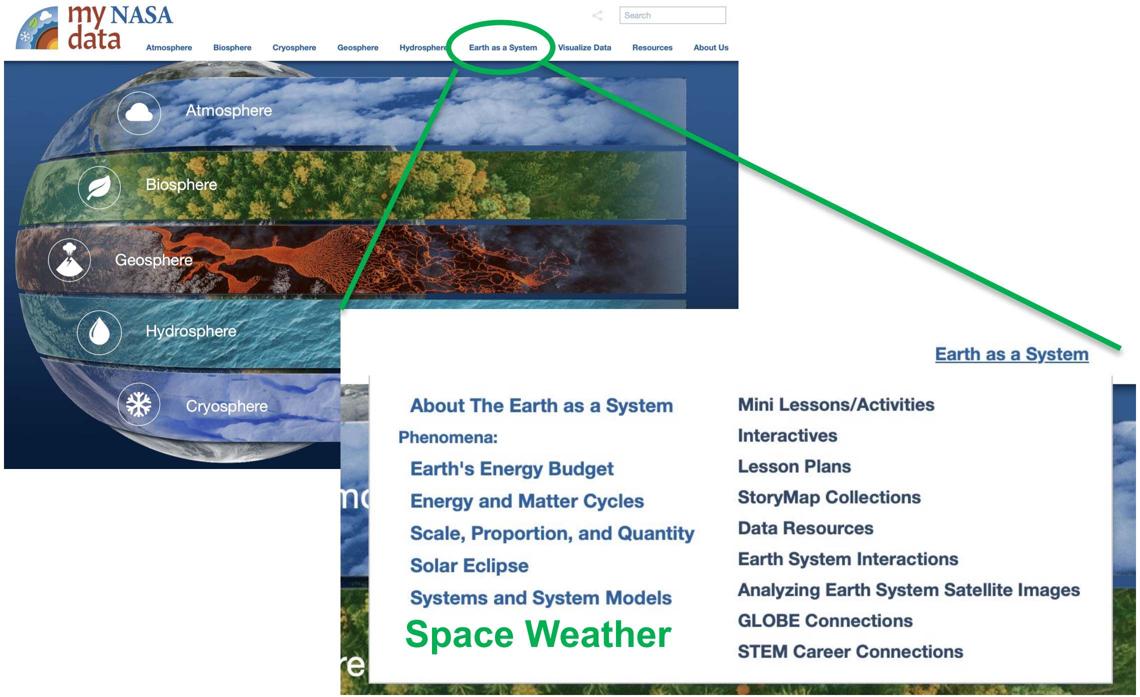
Because 'd' constantly changes, this has to be solved iteratively using a spreadsheet and taking time steps of 1 hour.

	A	B	C	D	E	F	G	H	I
1	Selections				Calculations				Answer
2	Variable	Value	Units		T (hrs)	d0	V	a	D
3	V=	2.6	Mkm/h		0	4.6	2.600	-0.080	4.6
4	d0=	4.6	Mkm		1	4.6	2.520	-0.080	7.2
5	a=	-0.08	Mkm/h^2		2	4.6	2.440	-0.033	9.6
6	Δt=	1	hours		3	4.6	2.407	-0.018	12.1
7					4	4.6	2.389	-0.012	14.5
8					5	4.6	2.377	-0.008	16.8
9					6	4.6	2.369	-0.006	19.2



For previous CME with V = 2.6 Mkm/hr, arrival at Earth in 62 hrs.

Coming Soon! My NASA Data Space Weather Phenomena



In Development:

- Mini-Lessons/Activities
- Interactives
- Lesson Plans
- StoryMap
  - **Engage:** What is space weather?
  - **Explore:** How do scientists predict space weather?
  - **Explain:** Space Weather Forecast
  - **Extend:** Aurora Viewing During Spolar Cycle 25
  - **Evaluate:** Why Space Weather Matters

Coming Soon My NASA Data Space Weather Phenomena

TOPICS

Space Weather
Solar Wind
Aurora
Magnetosphere
Magnetic Reconnection
Solar Cycle
Sunspots
CMEs
Solar Flares
Kp Index
Corona
Heliosphere
Coronagraphs
Ionosphere

MISSIONS

SOHO
Moon to Mars
IMAP
SDO
ICON
MMS
STEREO
IBEX
Voyager

Release of resources scheduled for August 2025 to coincide with the start of the school year and the IMAP launch in September 2025.

For more information on M2M Analyses

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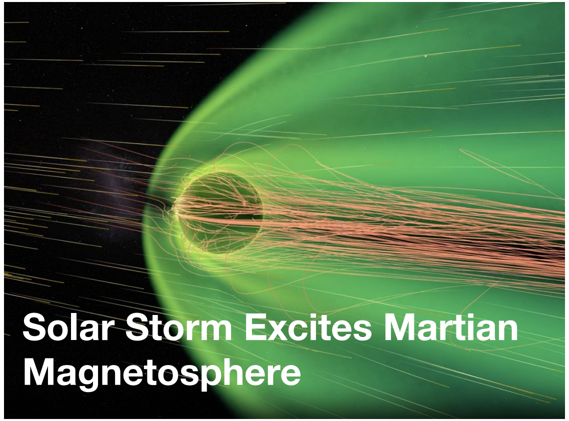
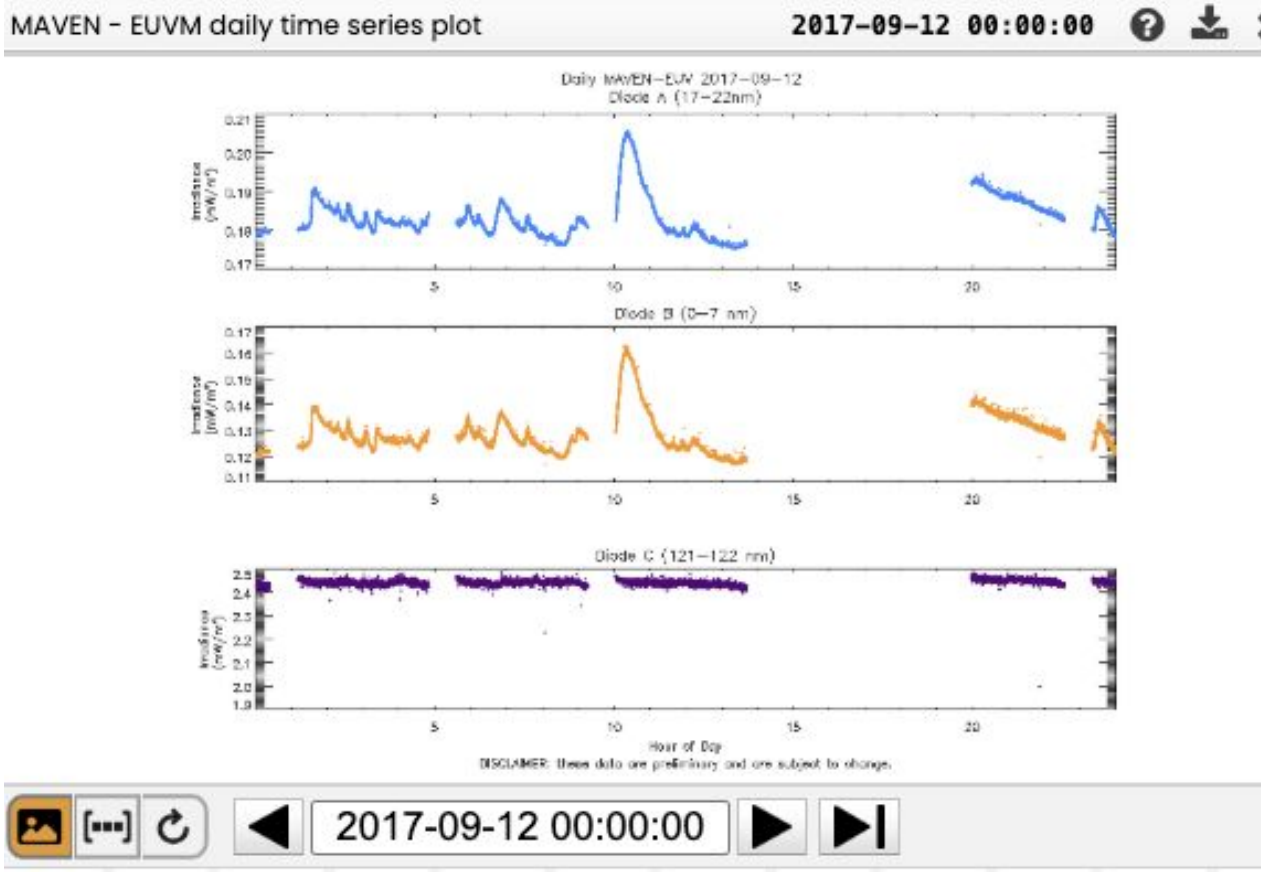
Framework for Heliophysics Education

https://science.nasa.gov/learn/heat/big-ideas/

Integrated Space Weather Analysis System (ISWA) Data



https://svs.gsfc.nasa.gov/5502



Using ISWA layouts for the storm on 2017-09-12 to generate a few plots of Mars SWx: https://iswa.ccmc.gsfc.nasa.gov/IswaSystemWebApp/?layout=marssw