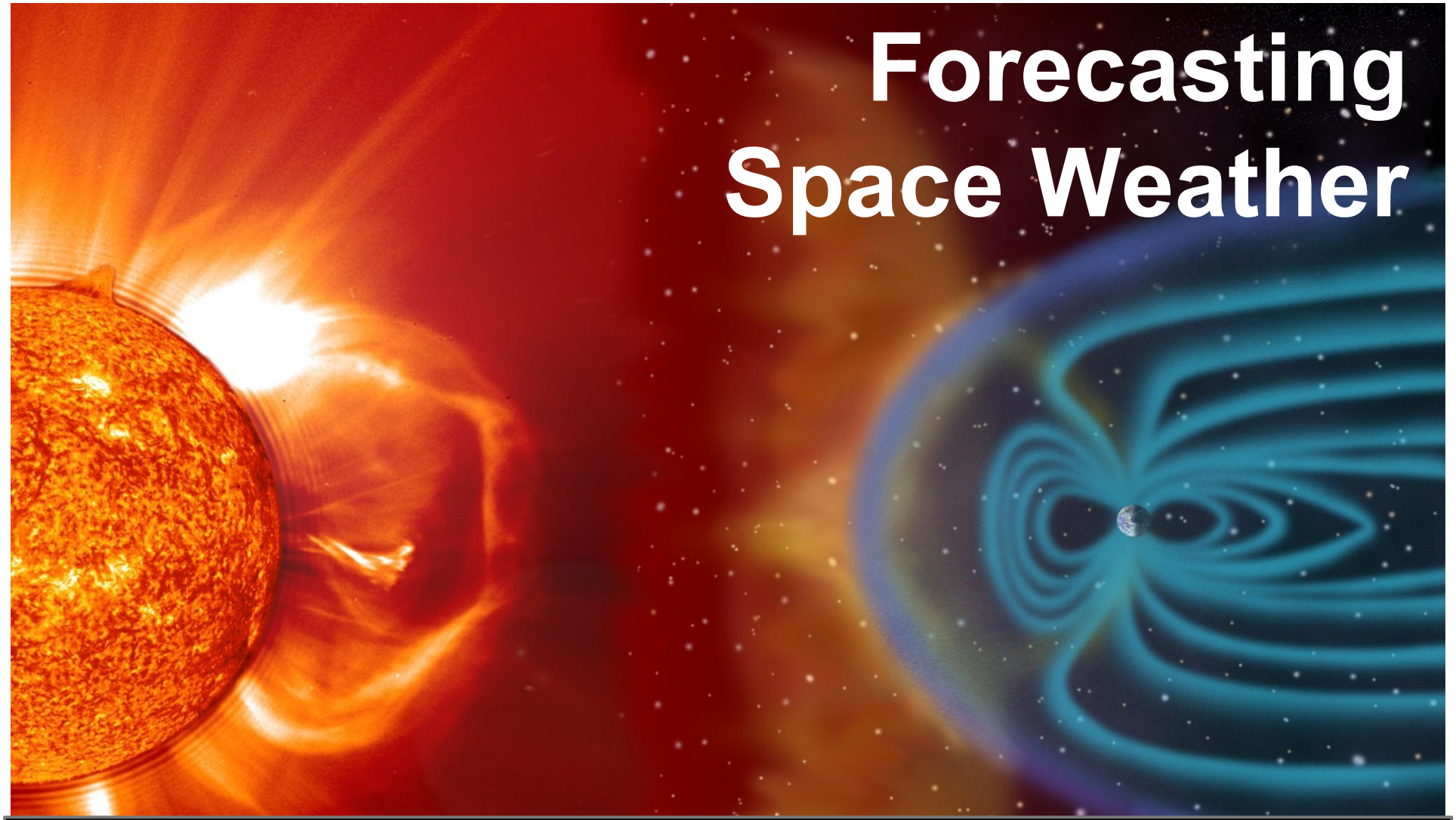
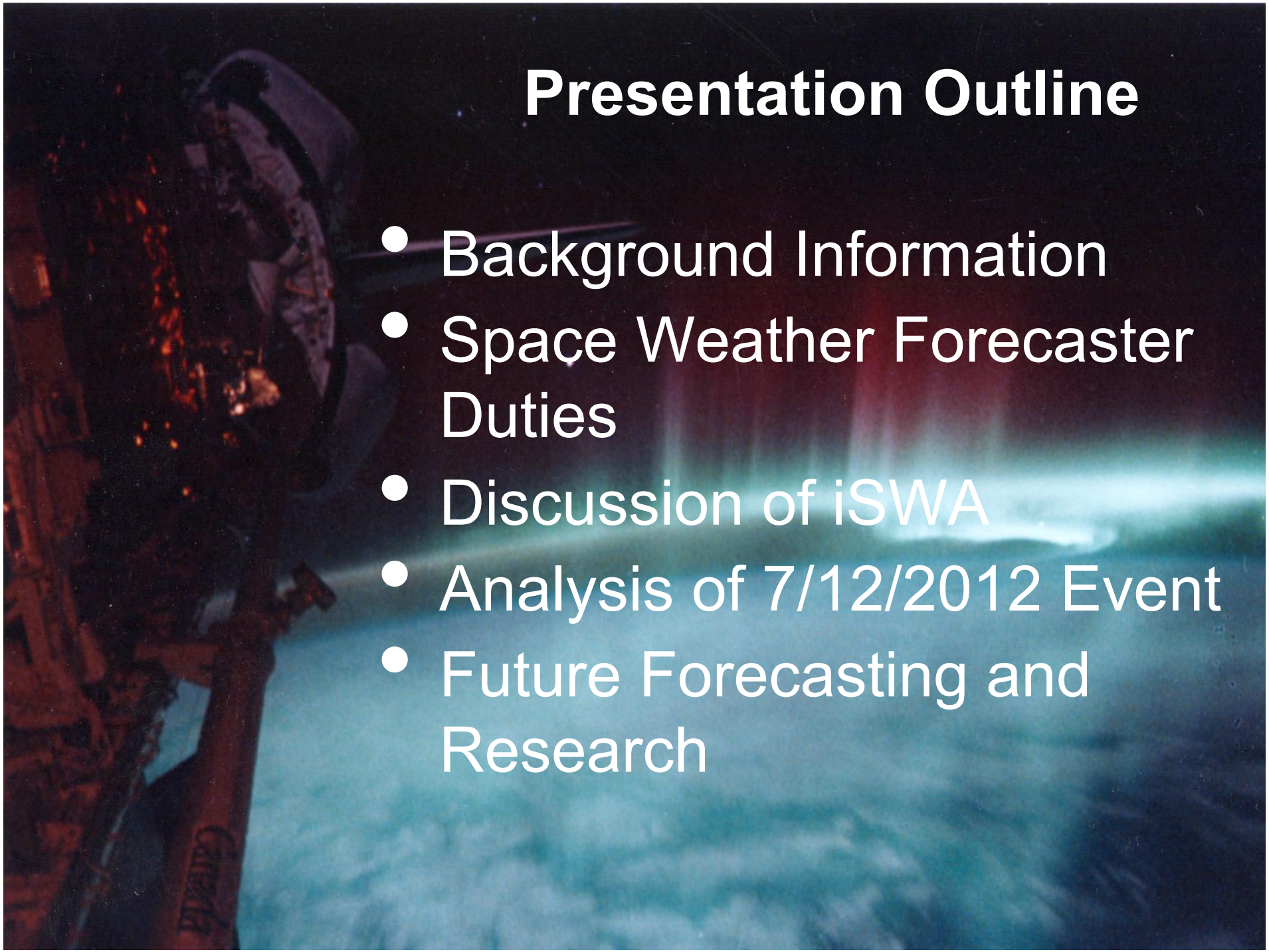
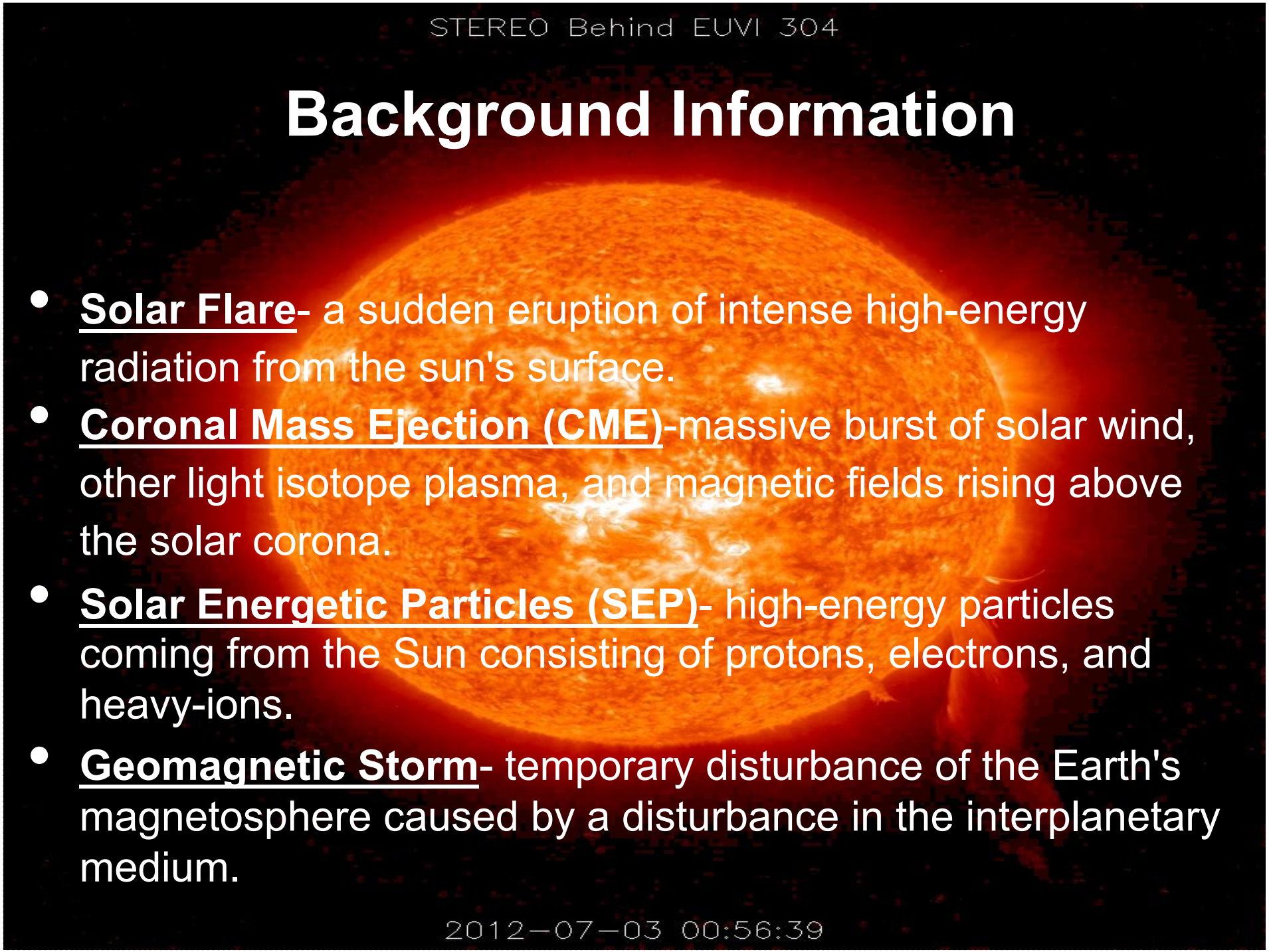
Forecasting Space Weather



Dhanesh Krishnarao
Michelangelo Romano

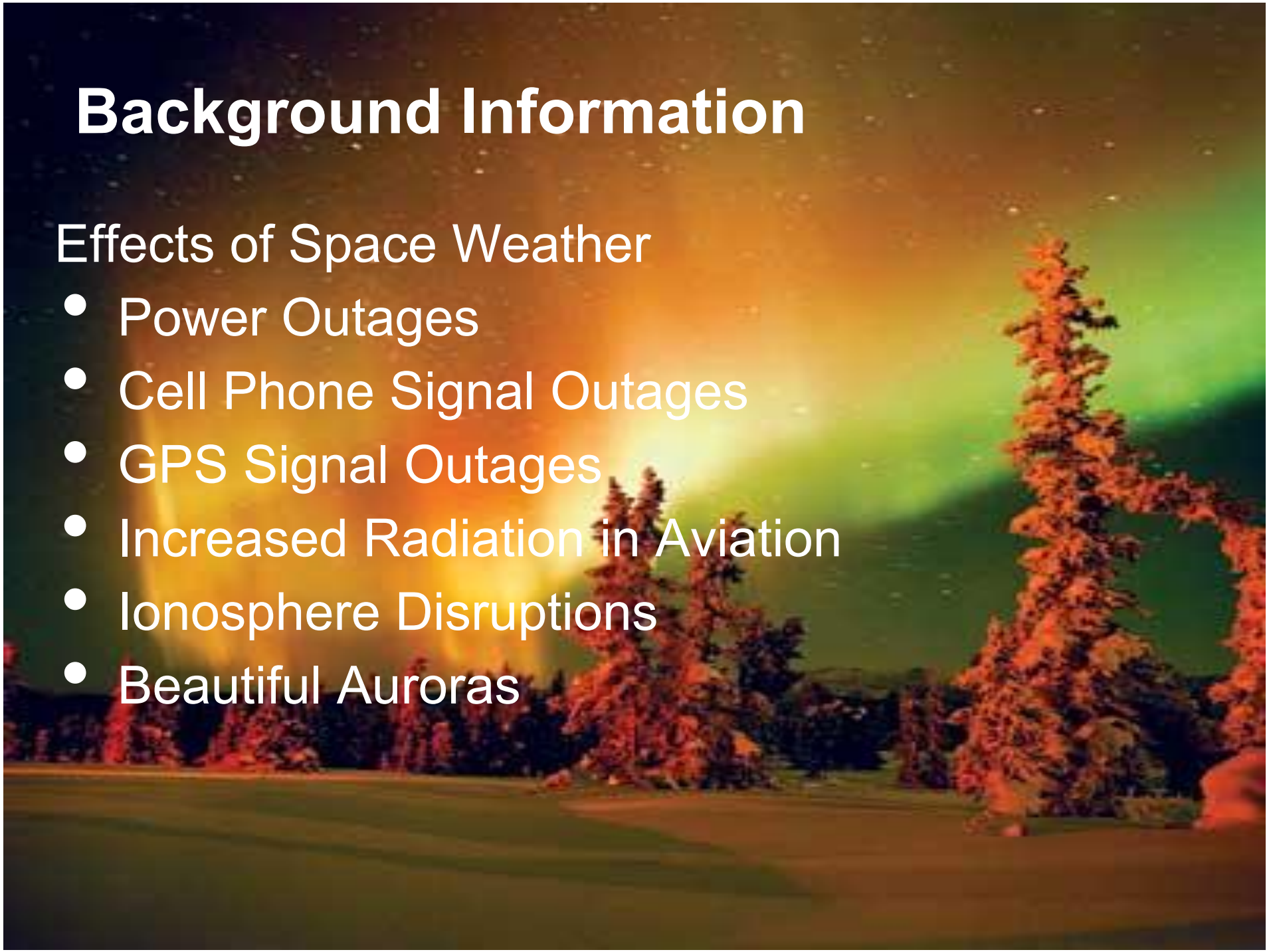
Steele Hill/NASA


Presentation Outline
Background Information
Space Weather Forecaster Duties
Discussion of iSWA
Analysis of 7/12/2012 Event
Future Forecasting and Research



Background Information

- **Solar Flare**- a sudden eruption of intense high-energy radiation from the sun's surface.
- **Coronal Mass Ejection (CME)**-massive burst of solar wind, other light isotope plasma, and magnetic fields rising above the solar corona.
- **Solar Energetic Particles (SEP)**- high-energy particles coming from the Sun consisting of protons, electrons, and heavy-ions.
- **Geomagnetic Storm**- temporary disturbance of the Earth's magnetosphere caused by a disturbance in the interplanetary medium.



Background Information

Effects of Space Weather

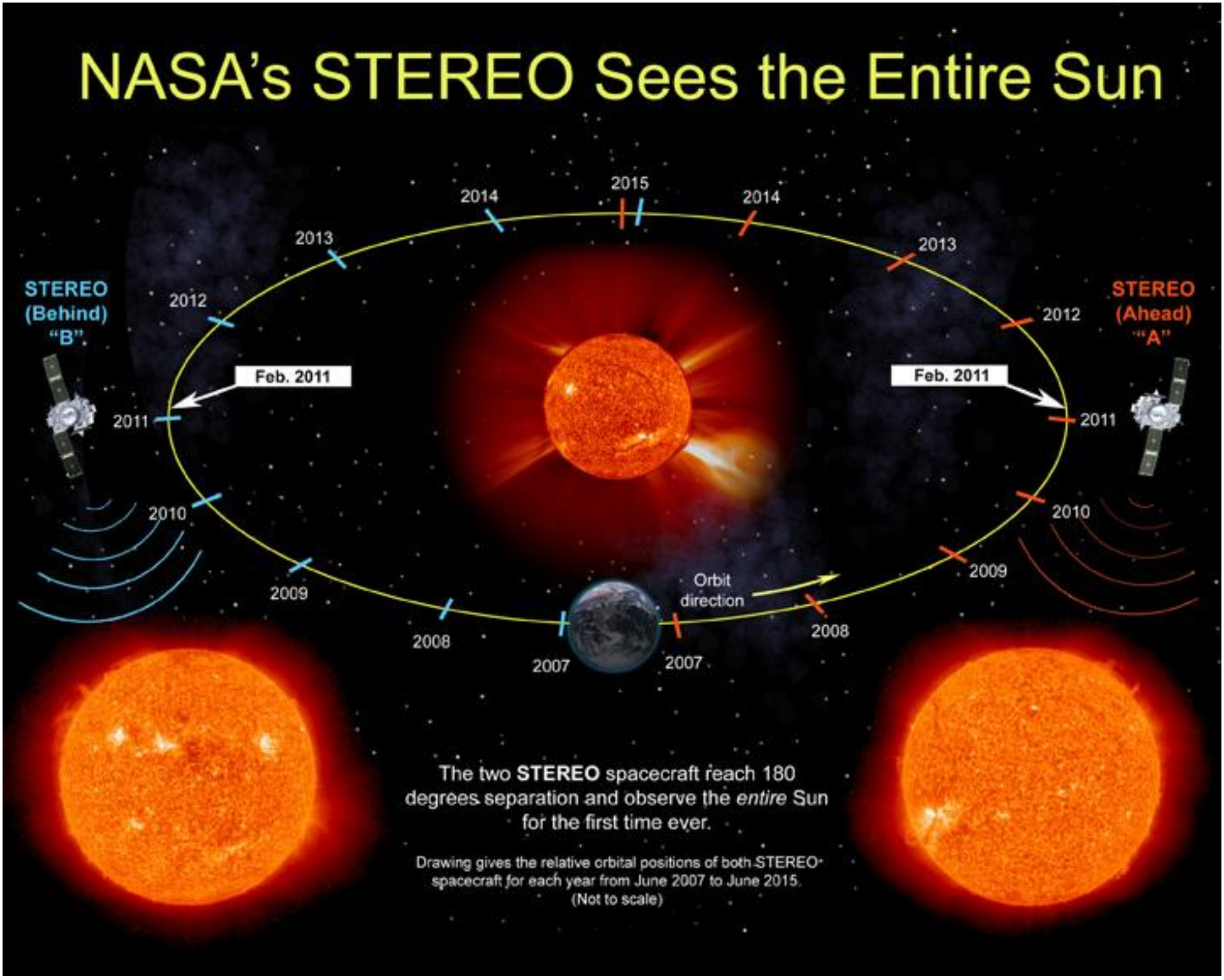
- Power Outages
- Cell Phone Signal Outages
- GPS Signal Outages
- Increased Radiation in Aviation
- Ionosphere Disruptions
- Beautiful Auroras

Background Information

Satellites

- Near the Earth
  - SOHO - Solar and Heliospheric Observatory
  - GOES - Geostationary Operational Environmental Satellites
  - ACE - Advanced Composition Explorer
  - SDO - Solar Dynamics Observaory
- Orbiting the Sun
  - STEREO A - Solar Terrestial Relations Observatory
  - STEREO B - Solar Terrestial Relations Observatory

NASA's STEREO Sees the Entire Sun

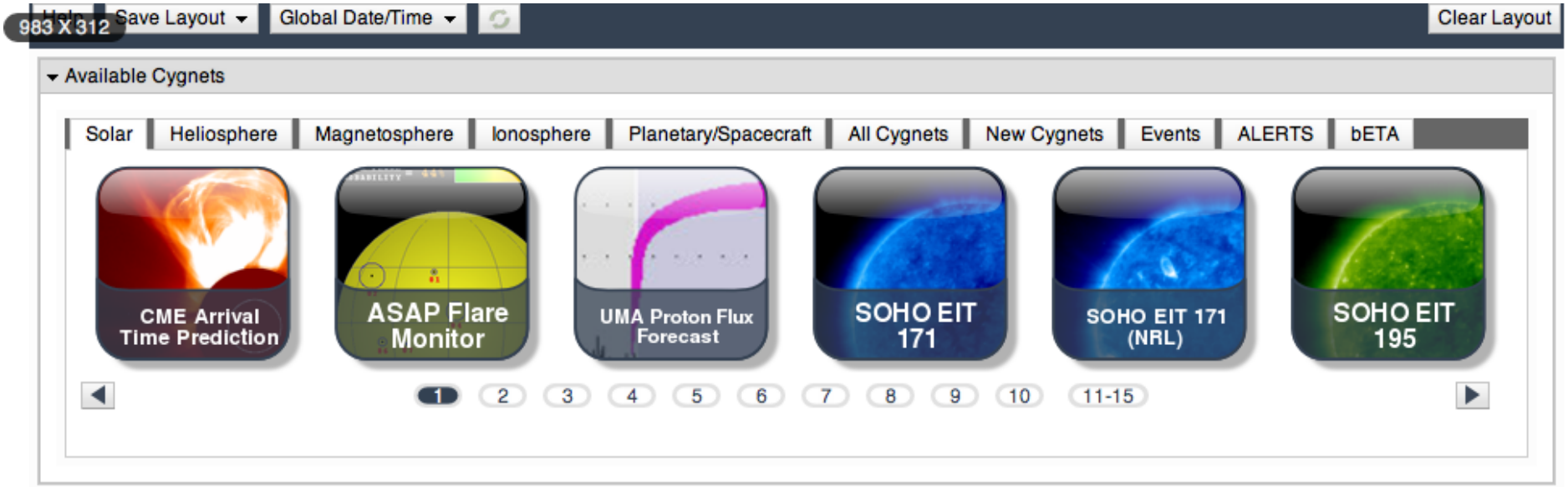


The two **STEREO** spacecraft reach 180 degrees separation and observe the *entire* Sun for the first time ever.

Drawing gives the relative orbital positions of both STEREO spacecraft for each year from June 2007 to June 2015.
(Not to scale)

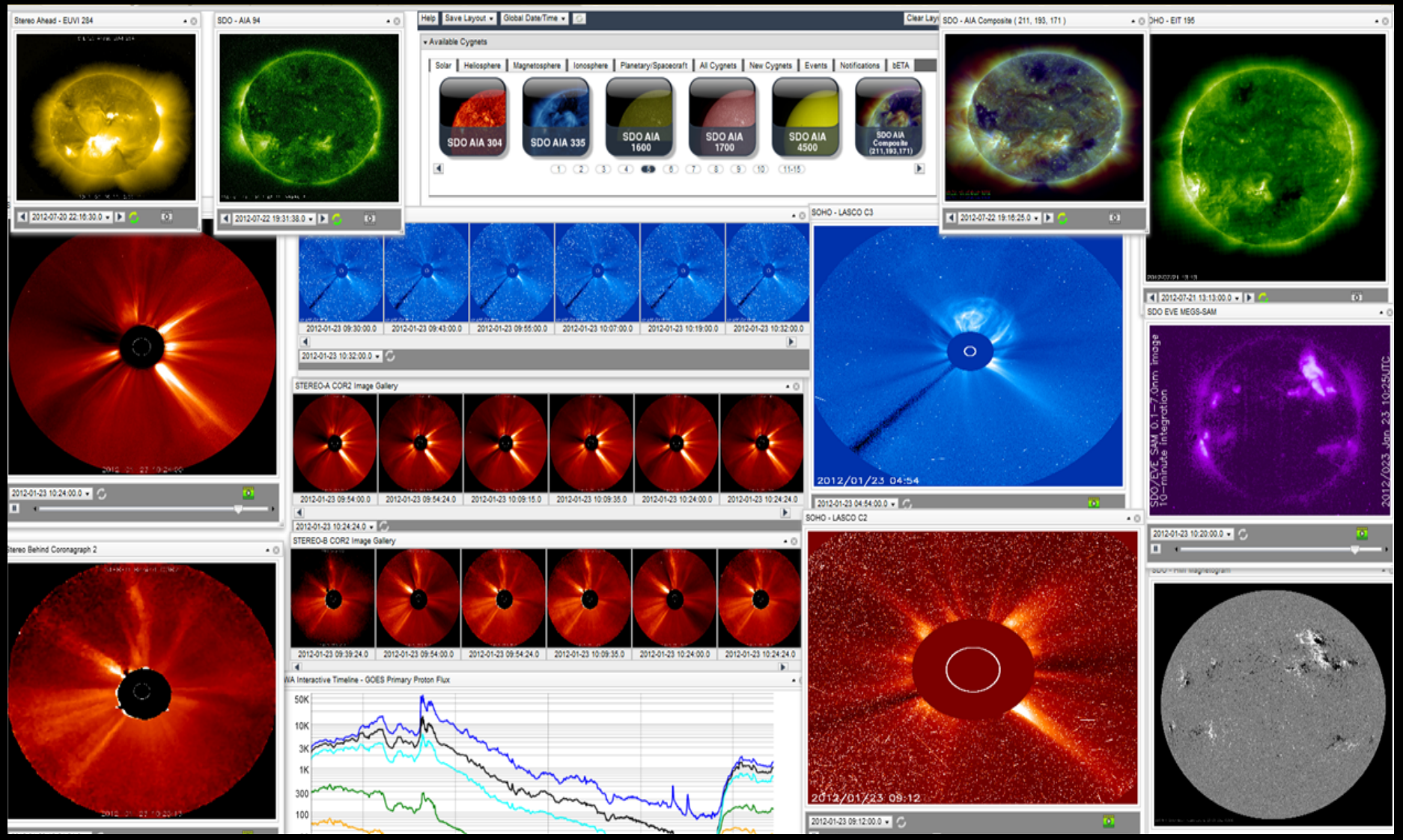
Space Weather Forecaster Duties

1. Monitor space weather and issue notifications.
2. Generate space weather summary reports.
3. Support NASA’s Robotic Missions.



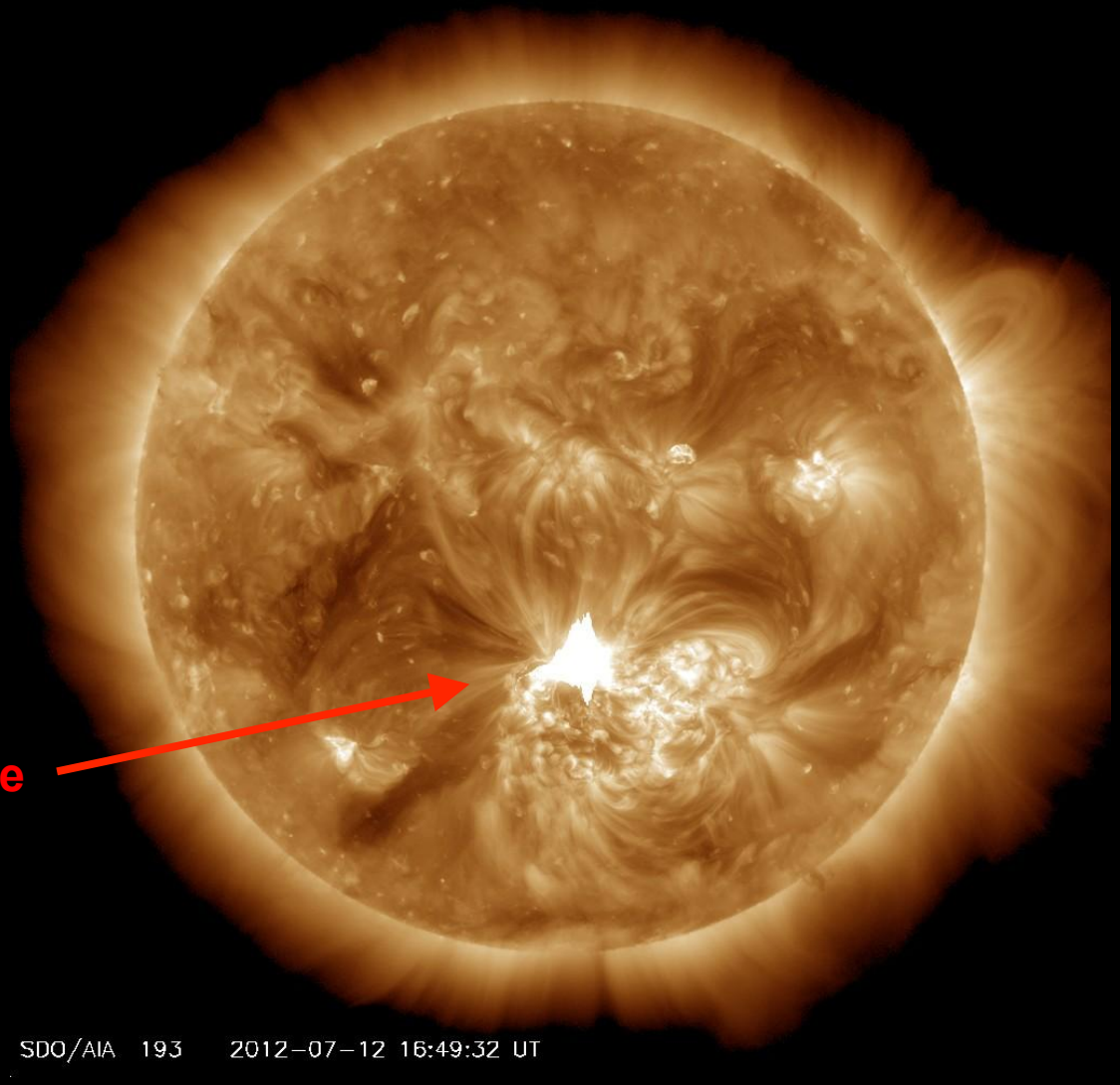
Discussion of iSWA

- Interface
- Data analysis
- Advantages

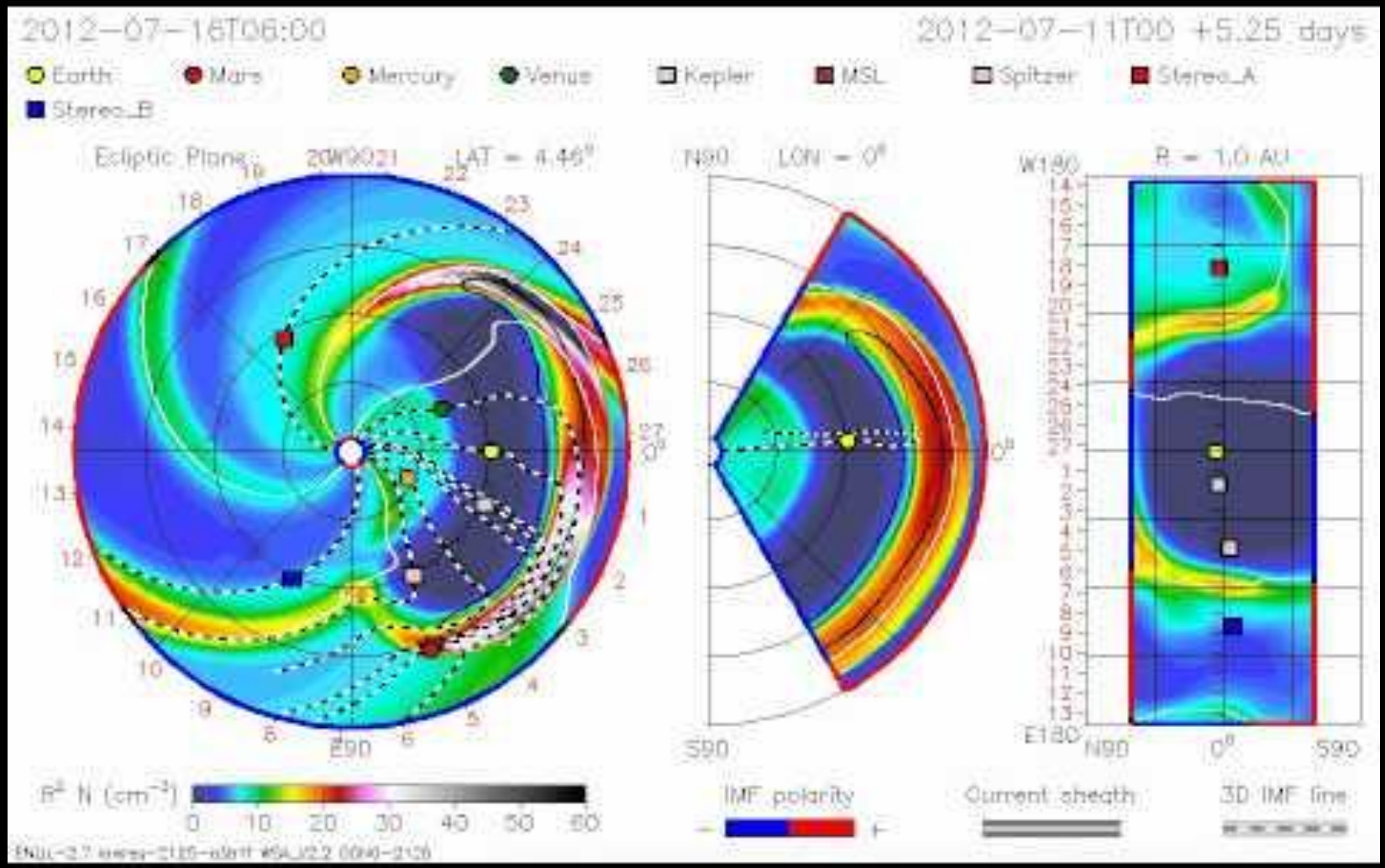


Sample iSWA Layout

Analysis of 7/12/2012 Solar Event



SDO AIA 193


2012-07-16T06:00
2012-07-11T00 +5.25 days
Earth
Mars
Mercury
Venus
Kepler
MSL
Spitzer
Stereo_A
Stereo_B
Ecliptic Plane
LAT = 4.46°
N90
LON = 0°
R = 1.0 AU
W180
E180
S90
IMF polarity
Current sheath
3D IMF line

ENLIL Model

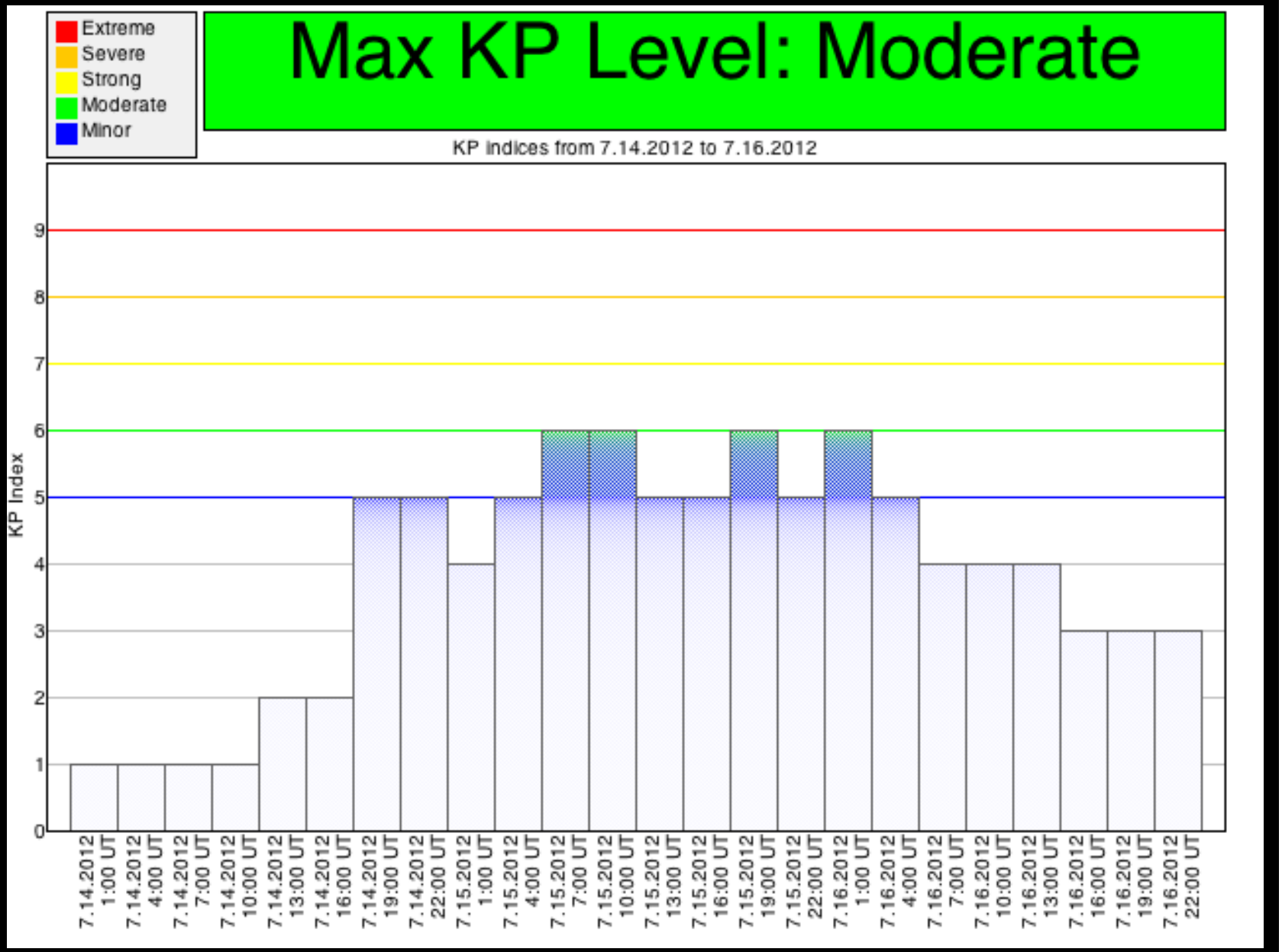
Extreme

Severe

Strong

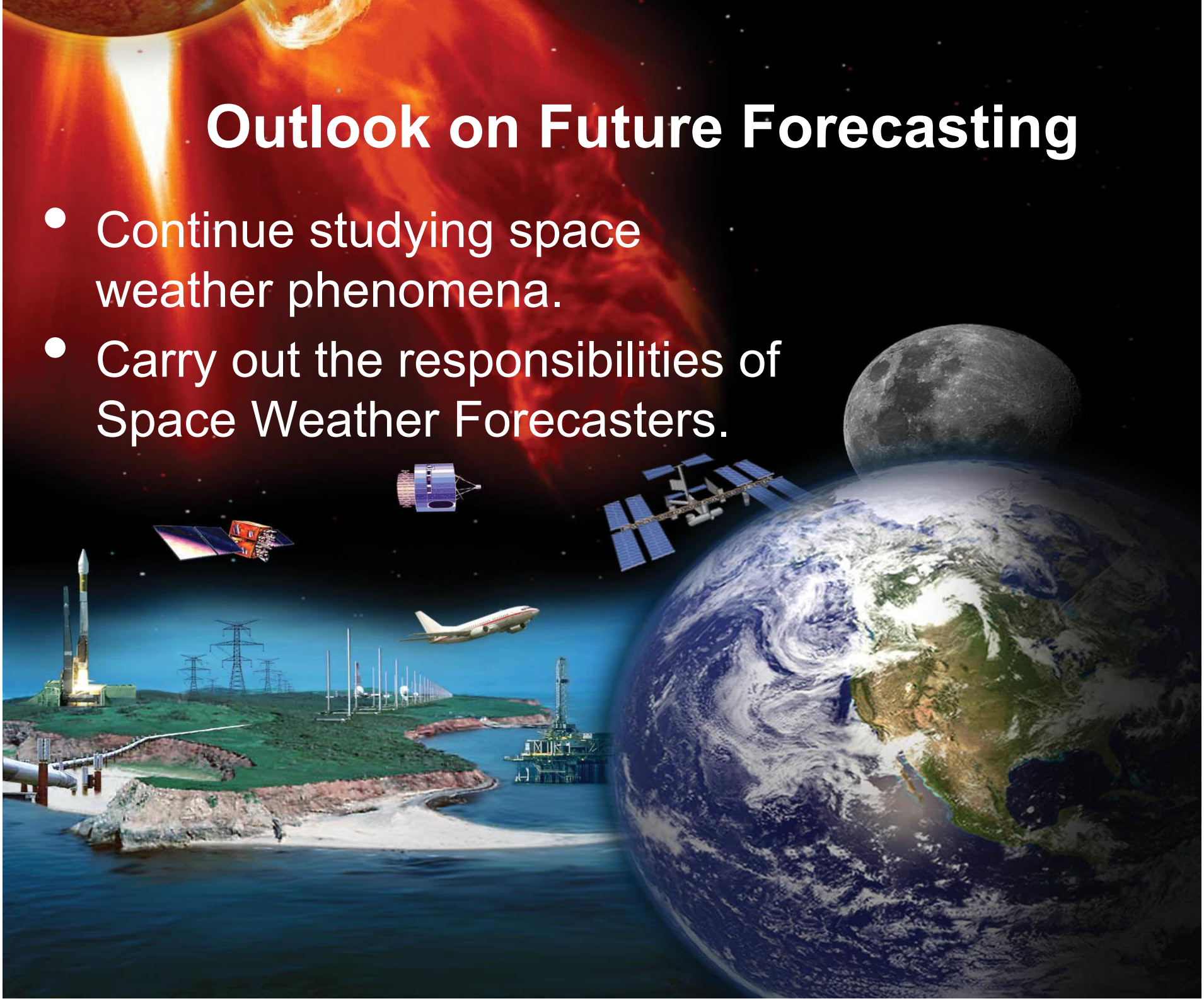
Moderate

Minor

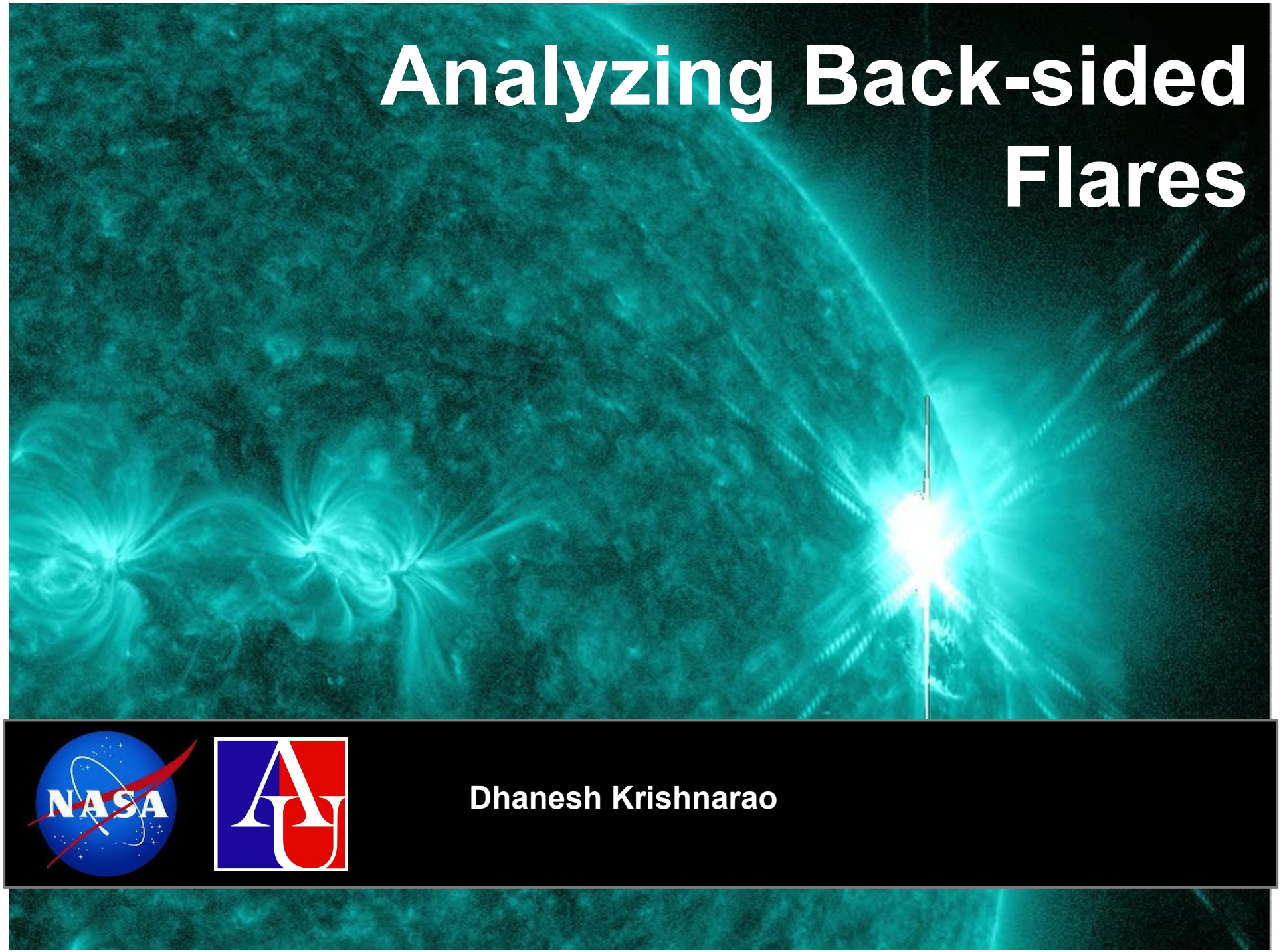


Outlook on Future Forecasting

- Continue studying space weather phenomena.
- Carry out the responsibilities of Space Weather Forecasters.

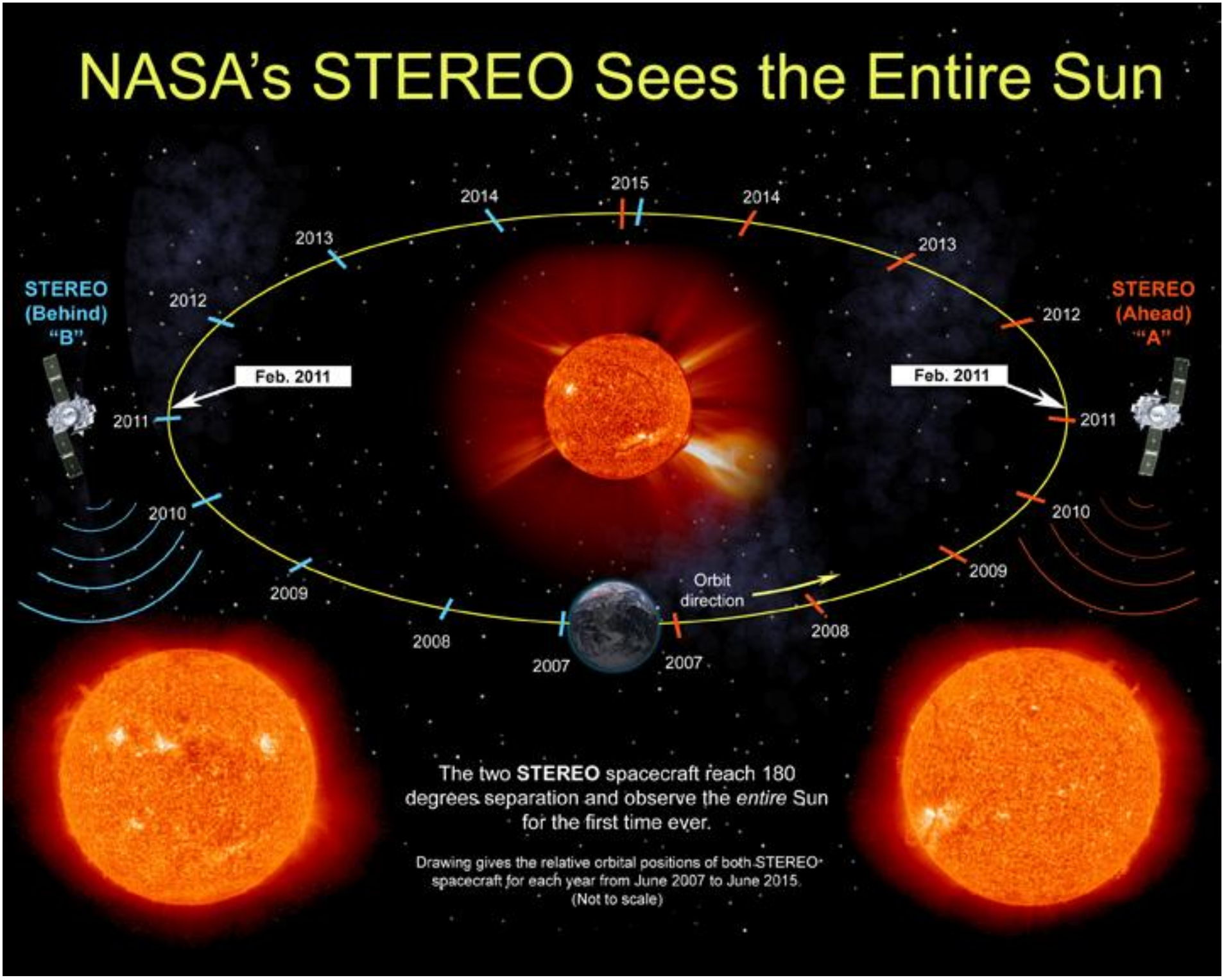


Analyzing Back-sided Flares



Dhanesh Krishnarao

NASA's STEREO Sees the Entire Sun

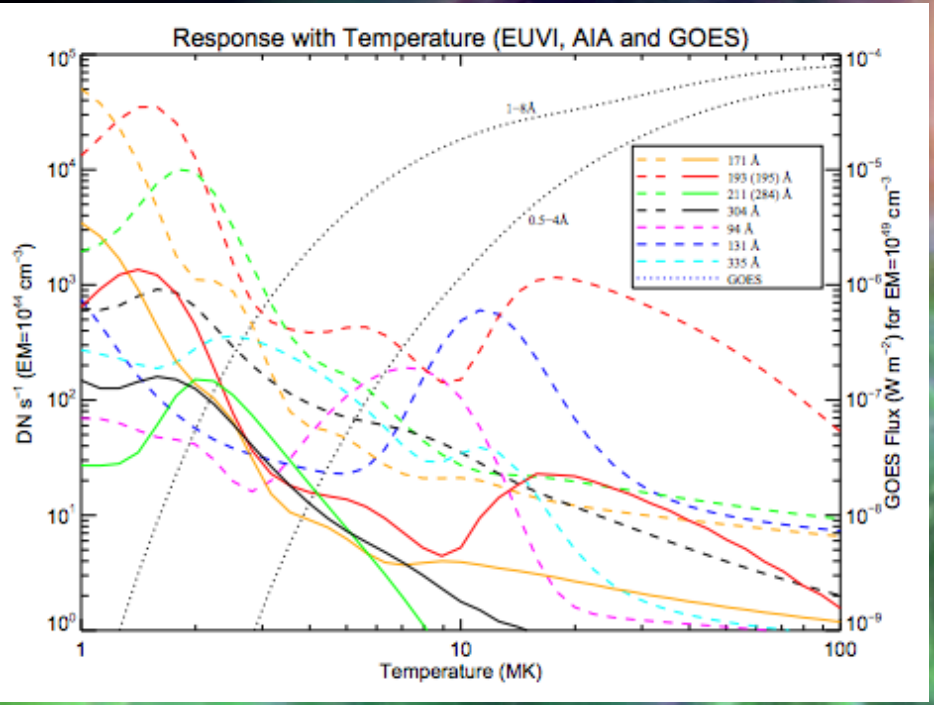


The two **STEREO** spacecraft reach 180 degrees separation and observe the *entire* Sun for the first time ever.

Drawing gives the relative orbital positions of both STEREO spacecraft for each year from June 2007 to June 2015.
(Not to scale)

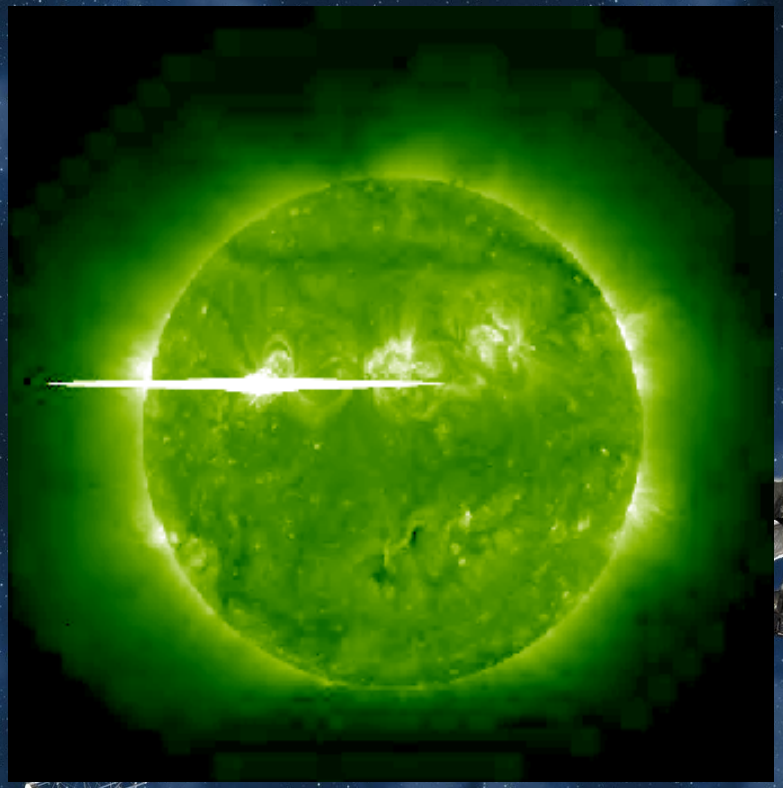
Background

- Use STEREO Beacon EUVI Data as a Proxy for GOES X-Ray Flux



- Four Channels:
  - 171 A
  - 195 A
  - 284 A
  - 304 A
- We use 195 A
  - distinct peak of response above 10 MK

Match with GOES X-Ray Data



- GOES 0.1-0.8 nm
- Using matching data from between 2007 - 2011
- Need to find a more effective way to match weaker flares

Additional Project for Summer 2014

- Spacecraft Environmental Anomalies Expert System (SEAES)
- Spacecraft anomaly resolutions for NASA mission operators
- Quantitative assessment space environment hazards on spacecraft.

Validating the WSA-ENLIL Model

Michelangelo Romano

The Catholic University of America
NASA Goddard Space Flight Center

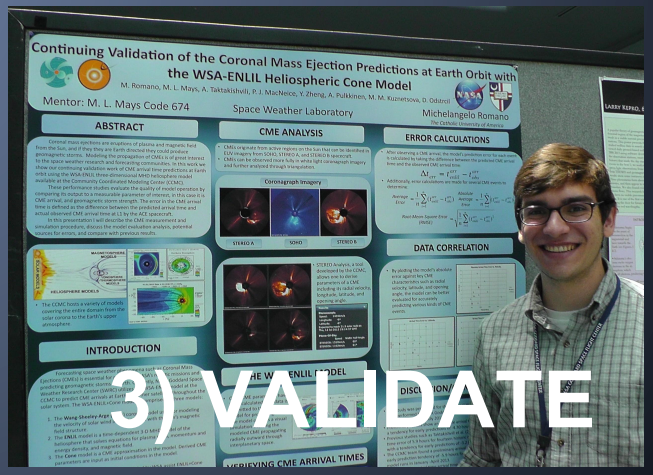
Outline

- Introduction
  - Tasks/Activities
- Background
- Motivation
- Analysis Process
- Results
- Conclusion
- Internship Experience

Tasks/Activities

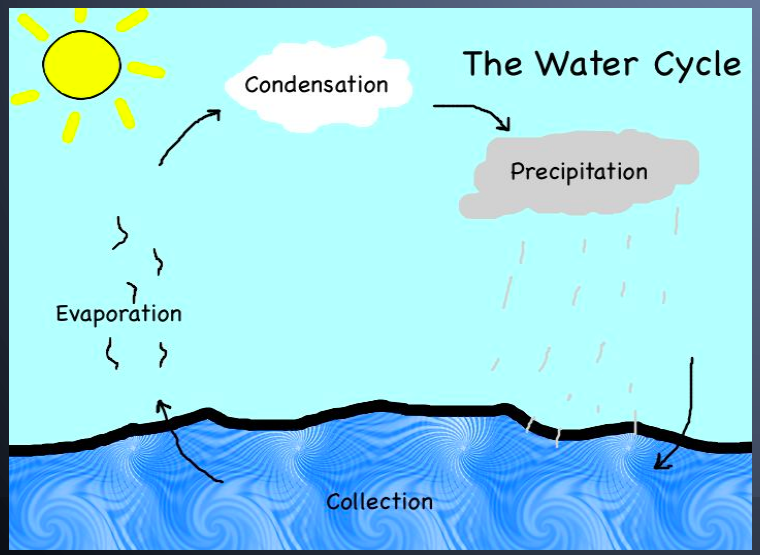
- Space Weather Forecaster (SWRC)
- Teaching Assistant for SW REDI Program
- Undergraduate Forecaster Mentor
- Model Validation
  - CME Analysis
  - Launching Simulations
  - Analyzing Data

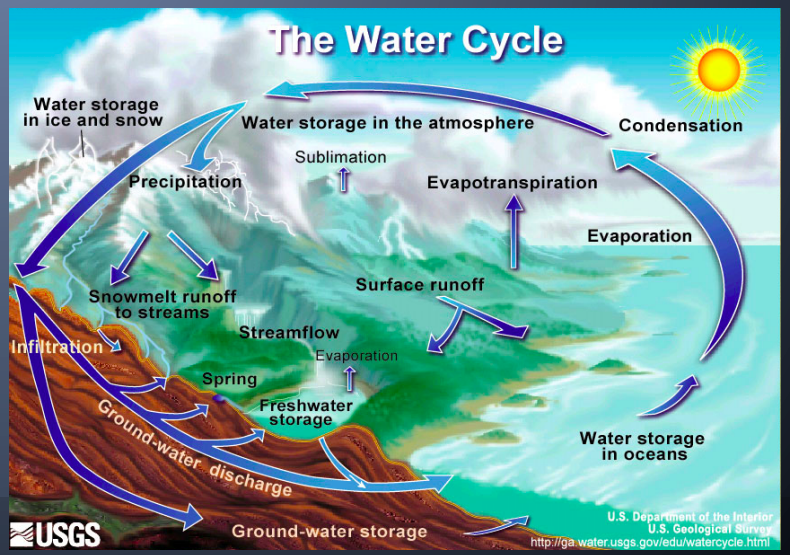
Introduction



Background

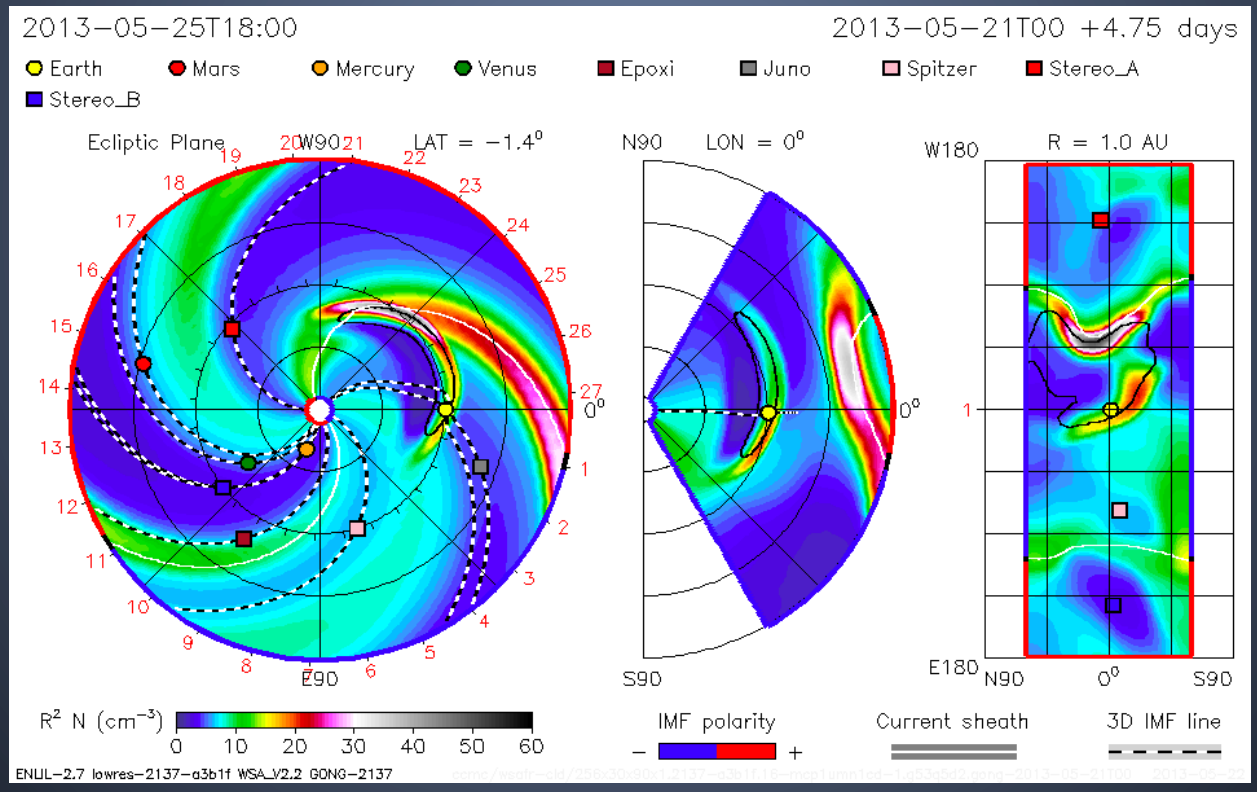
- What is a model?
  - “A schematic description of a system, theory, or phenomenon that accounts for its known or inferred properties and may be used for further study of its characteristics.” - www.thefreedictionary.com





Background

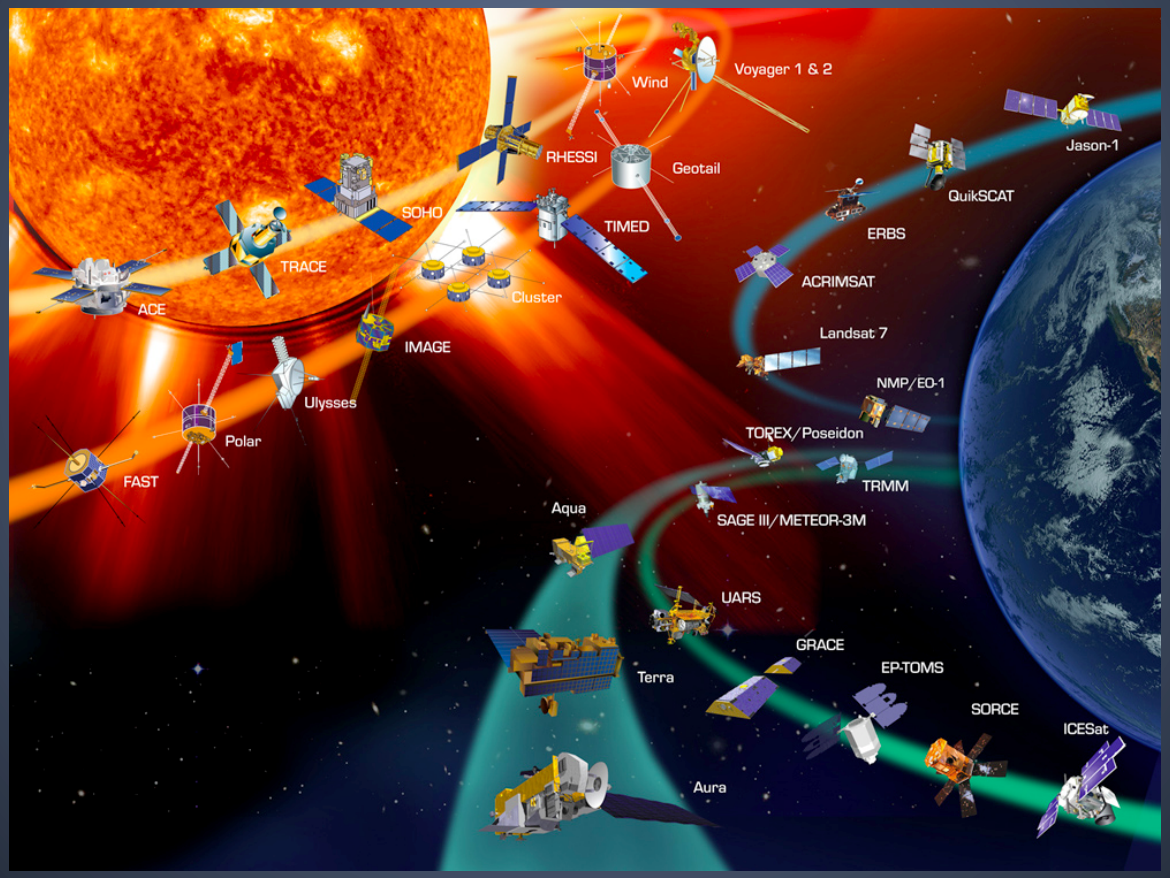
- What is the WSA-ENLIL+Cone Model?



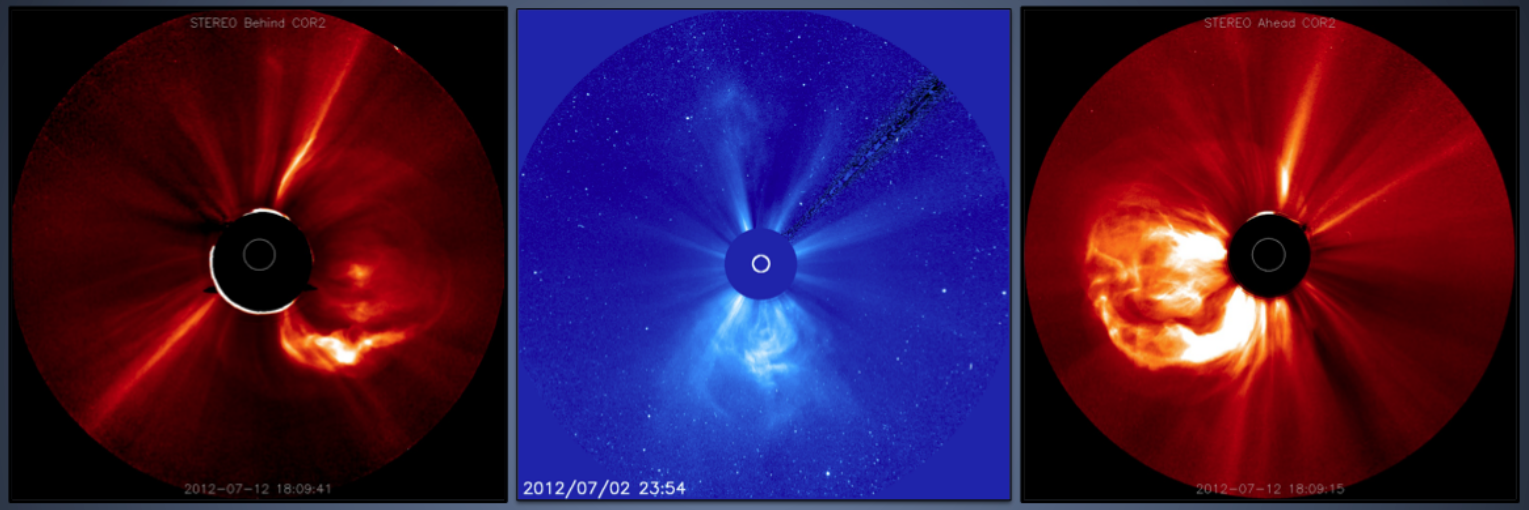
Background

- What is the Wang-Sheely-Arge (WSA) Model?
  - A model for solar wind velocity in combination with the Sun's magnetic field structure.
- What is the ENLIL Model?
  - A time-dependent 3-D MHD model of the heliosphere that solves equations for plasma mass, momentum, energy density, and magnetic field.
- What is the Cone Model?
  - A model for deriving and approximating CME parameters (i.e. radial velocity, latitude, etc.)

Motivation

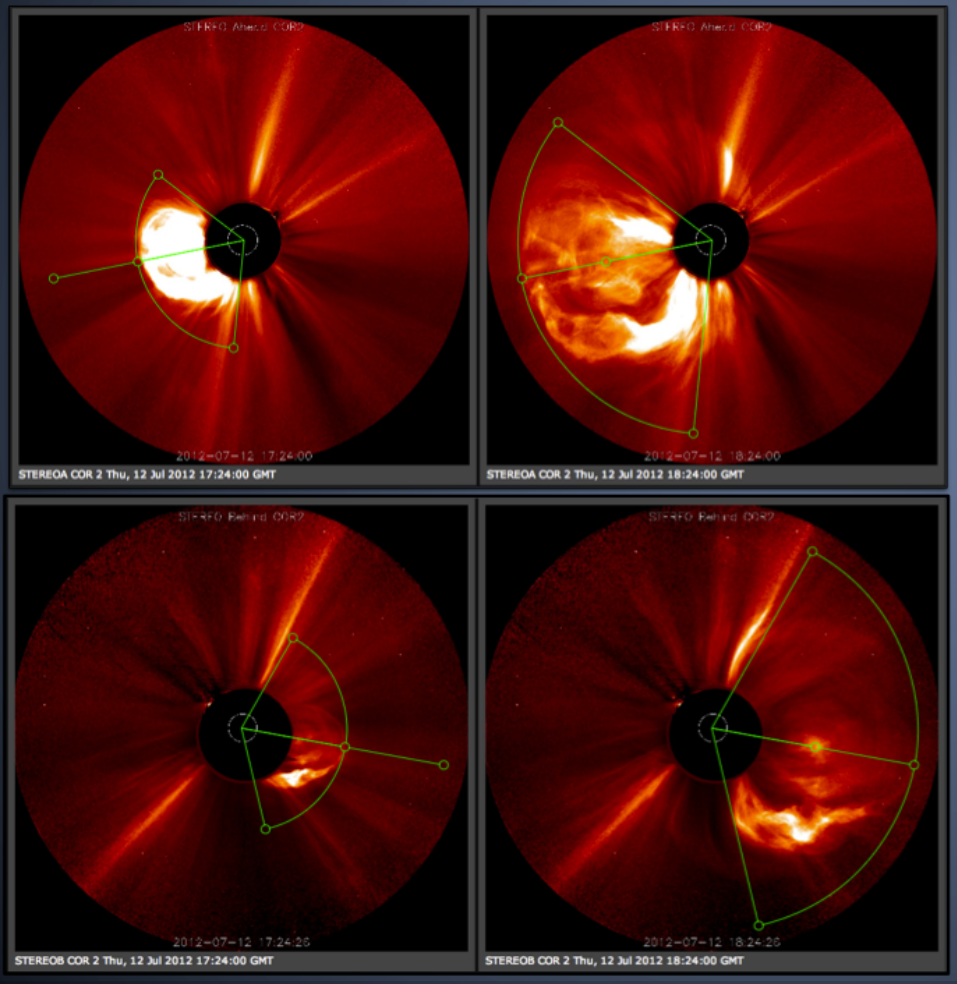

Wind
Voyager 1 & 2
RHESSI
Geotail
Jason-1
QuikSCAT
SOHO
TIMED
ERBS
TRACE
ACRIMSAT
Cluster
ACE
IMAGE
Landsat 7
NMP/EO-1
Ulysses
TOREX/Poseidon
Polar
TRMM
FAST
Aqua
SAGE III/METEOR-3M
UARS
GRACE
Terra
EP-TOMS
SORCE
ICESat
Aura

PROCESS
CME Analysis



- CMEs originate from active regions on the Sun that can be identified in EUV imagery from SOHO, STEREO A, and STEREO B spacecraft.
- CMEs can be observed more fully in white light coronagraph imagery and further analyzed through triangulation.

PROCESS
CME ANALYSIS



•StereoCat, a tool developed at the CCMC, allows one to derive parameters of a CME including its radial velocity, longitude, latitude, and opening angle.

Results

Stereoscopic

Speed: 1404km/s

Longitude: -9°

Latitude: -9°

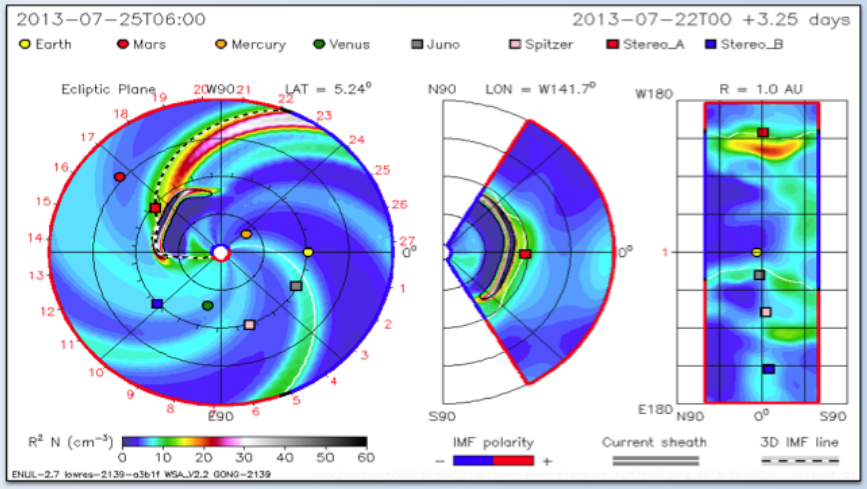
Expected to reach 21.5 solar radii at:
Thu, 12 Jul 2012 19:14:37 GMT

Plane-Of-Sky

	Speed	Width Half-Angle
STEREOB:	1350km/s	69°
STEREOA:	1102km/s	61°

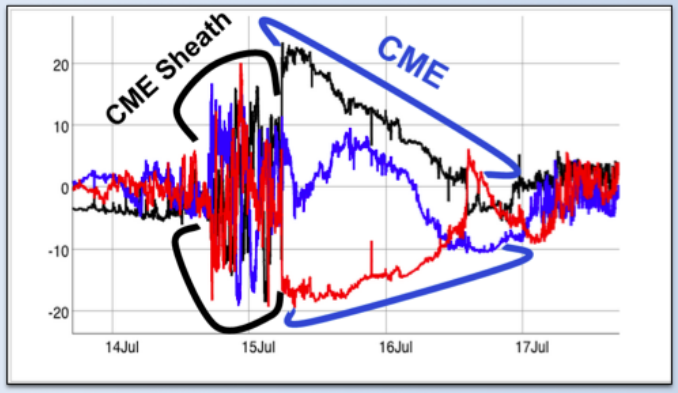
PROCESS
Launching the Model

- Once CME parameters have been calculated, this data is submitted to the WSA-ENLIL model for processing.
- The model outputs a visual simulation showing the modeled CME propagating radially outward through interplanetary space.



PROCESS
Verifying CME Arrival Times

- Irregular disturbances and fluctuations in the magnetic field and solar wind data from these satellites often indicate the arrival of a CME.



PROCESS
Error Calculations

- After observing a CME arrival, the model's prediction error for each event is calculated by taking the difference between the predicted CME arrival time and the observed CME arrival time:

$$\Delta t_{err} = t_{enlil}^{arr} - t_{obs}^{arr}$$

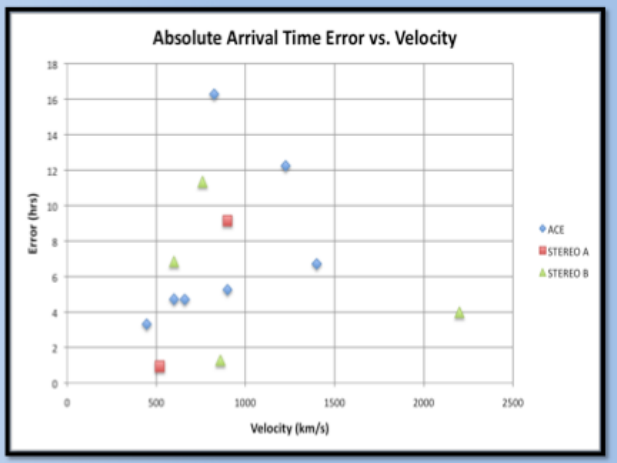
- Additionally, error calculations are made for several CME events to determine:

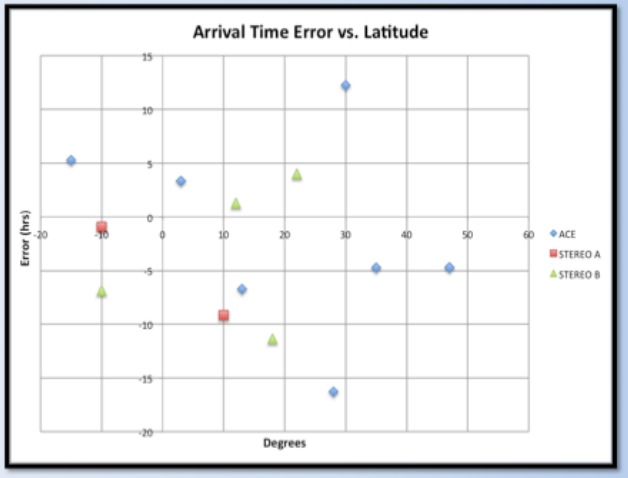
$$\textit{Average Error} = \frac{1}{n}\sum_{i=1}^{n}(t_{enlil}^{arr} - t_{obs}^{arr}) \qquad \textit{Absolute Average Error} = \frac{1}{n}\sum_{i=1}^{n}\left|(t_{enlil}^{arr} - t_{obs}^{arr})\right|$$

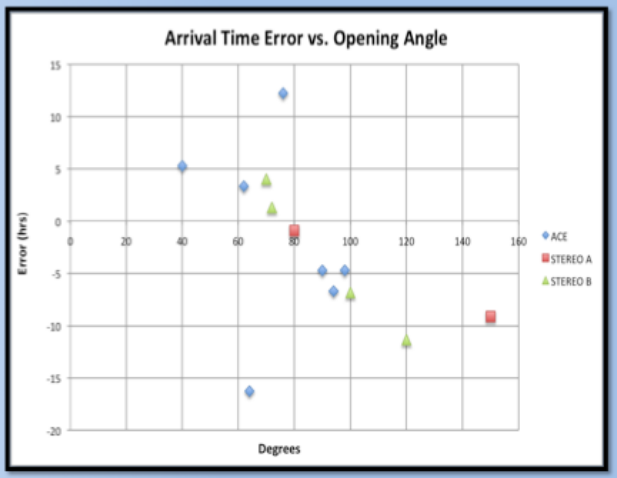
$$\textit{Root-Mean-Square Error (RMSE)} = \sqrt{\frac{1}{n}\sum_{i=1}^{n}(t_{enlil}^{arr} - t_{obs}^{arr})^2}$$

Results

- By plotting the model's absolute error against key CME characteristics such as radial velocity, latitude, and opening angle, the model can be better evaluated for accurately predicting various kinds of CME events.







Conclusion

- This study was performed for thirteen real-time WSA-ENLIL+Cone model runs performed by NASA Goddard Space Weather Research Center forecasters from Jan-July 2013.

- Research contributed directly to an ongoing larger model validation project which found an absolute prediction error of 7.52 hours for Earth.
  - (ENLIL version 2.7, 2011-2013)

Internship Experience

- Advanced my skills as a space weather forecaster.
- Explored an area of research with which I was unfamiliar.
- Learned to be more analytical and methodical with my research practices.
- Made great friends and found companions willing to explore the sciences with me!

Acknowledgments

- Fellow Interns
- CCMC Staff
- Dr. Leila Mays
- Dr. Sandro Taktakshivilli
- Dr. Antti Pulkkinen
- Dr. Yihua Zheng
- Dr. Masha Kuznetsova

Questions or Comments?