

# Space Weather Operations for Human Exploration



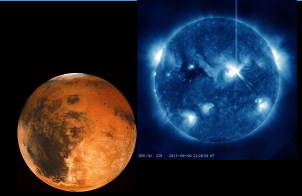
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*Johnson Space Center*



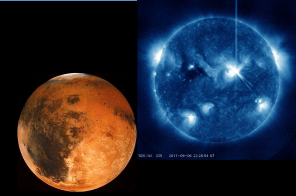
# Space Weather Impact



- Operational impact can be broken into three categories
  - Minimizing crew exposure
    - Dependent on crew activity (e.g. IVA versus EVA)
    - Ability to notify crew to seek ‘shelter’ without impact to critical activities on mission timeline
  - Maximizing mission activities (see where robotic fits for HEO)
    - Ability to ensure maximal return on mission activities
    - Ensuring safety of crew for critical activities
  - ‘Vehicle-as-a-System’ protection
    - Ability to ‘safe’ critical systems

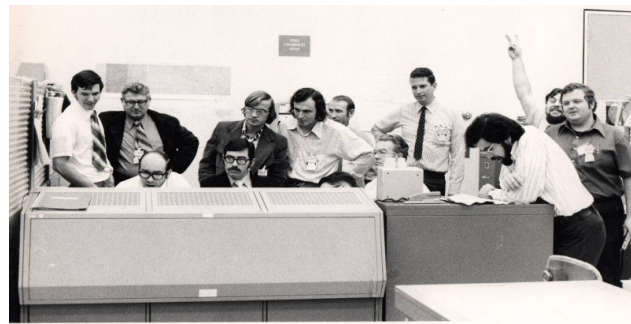


# What's a 'SRAG'?



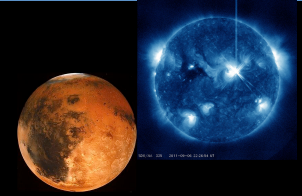
Approximately 20 members

- Physicists, Engineers, Health Physics, IT
- About half are certified for sitting console
- Provide real-time support to Flight Control Team 4-hours per day, 24/7 during contingency
- Fabricate, fly and post process all crew dosimeters and passive area monitors
- Operate one internal and one external real-time monitors (dose and spectral characteristics)
- Radiation shielding design
- Identification and transition of community forecasting models (collaborative effort)





# Protection Philosophy



## ALARA -As Low As Reasonably Achievable

Principle recognized throughout NASA's manned spaceflight requirements

A commitment to make all reasonable efforts to minimize exposure, therefore reducing risk

## Radiation protection philosophy

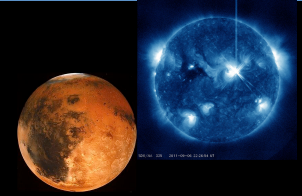
All radiation exposure, no matter how small, increases the health risk to that individual (No-Threshold Theory)

Astronaut exposures are much higher than terrestrial radiation worker

Space radiation more damaging than radiation encountered by ground-based workers, to the extent that the space field cannot be replicated on the ground.



# Sources of Concern



GCR – Galactic Cosmic Radiation (everywhere)  
High Energy – Very Penetrating – Hard to Shield  
Biologically Most Damaging  
Highest in open magnetic field areas (aka low cutoff zones)

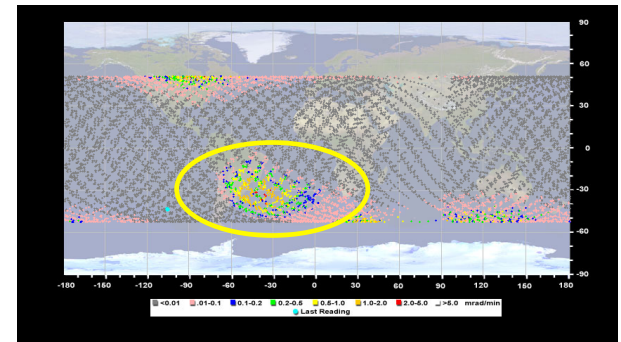
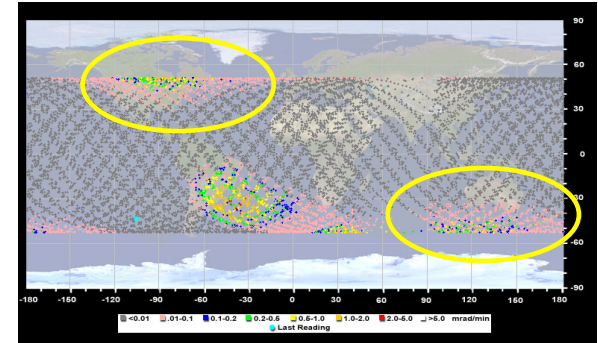
Trapped Radiation – South Atlantic Anomaly (LEO)  
Protons trapped by the magnetic field  
Specific location defined by Geomagnetic field offset and tilt  
Altitude dependent

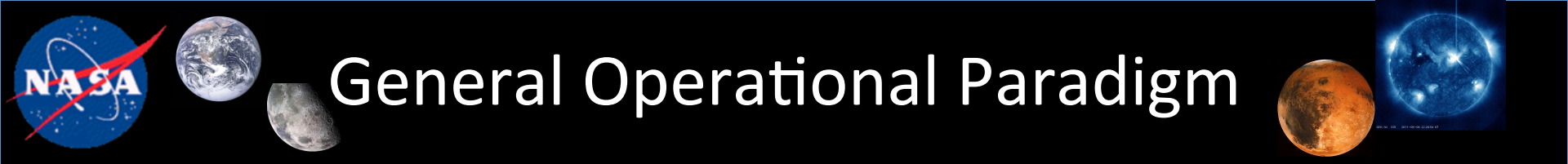
Trapped Electrons (LEO)  
EVA hazard  
Highest near low cutoff zones

Solar Energetic Protons (SEPs) (everywhere)  
Mostly protons from localized energy releases from the sun  
Exposure risk is from transits through low cutoff zones

Geomagnetic Storming (LEO)

CME/Shock (everywhere)



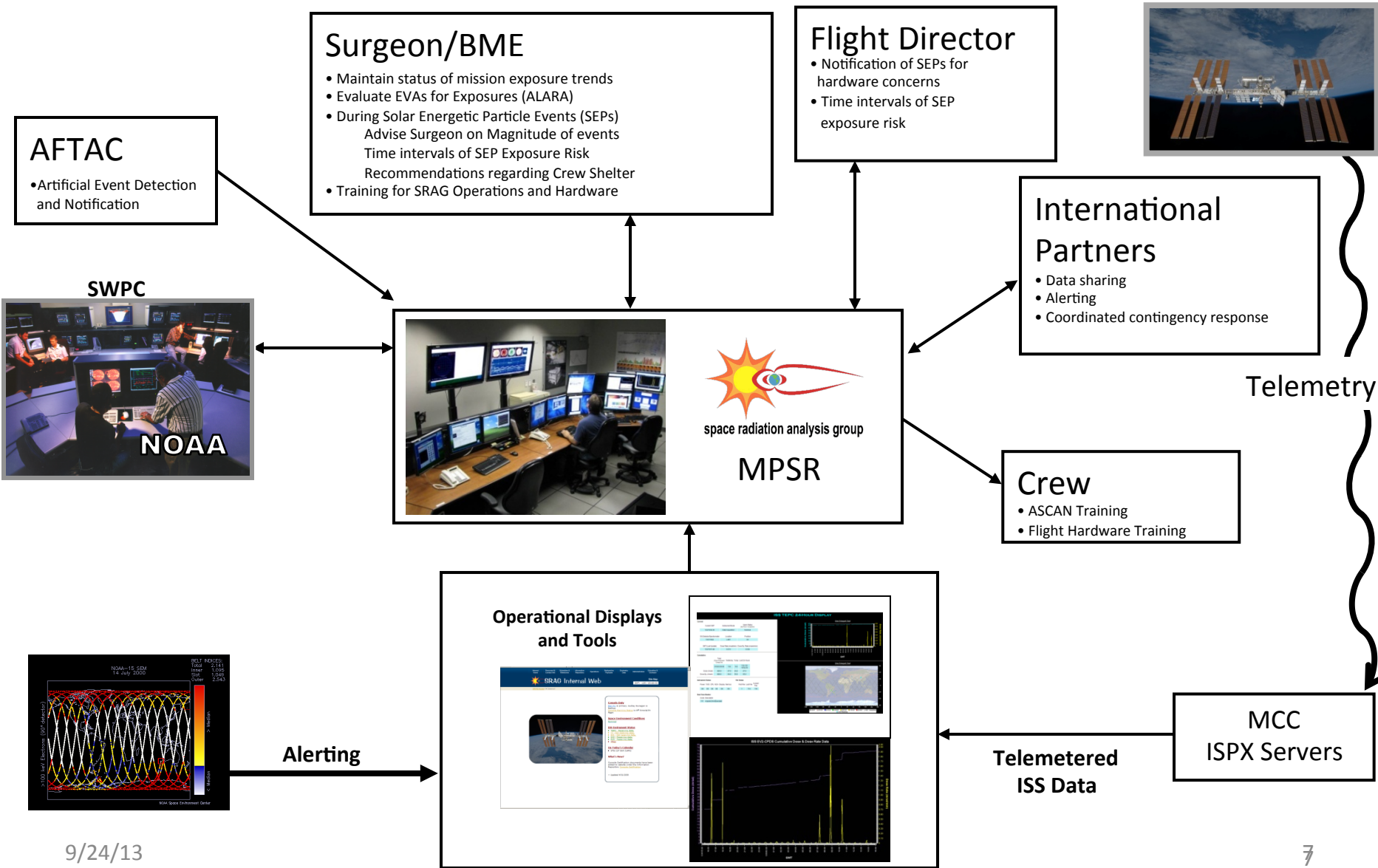
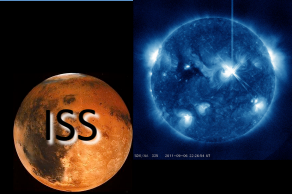


# General Operational Paradigm

- Monitor GOES data stream 24/7
- Alerts/Warnings sent from internal server to console operator
- 45-minute max recall time to console in contingency
- SRAG PAGER ALERTS
  - X-Ray Flare > M5
  - 10 MeV Protons > 10 pfu
  - 100 MeV Protons > 1 pfu (staff console)
  - RUN SPERT SPE analysis code autostart
  - Geomagnetic Storms >  $K_B = 6$  (staff console, under evaluation)
  - Datalink Outages Break in comm between Workstations, etc.
- NOAA E-MAIL/PAGER ALERTS
  - Proton Event Warning > 10 MeV Protons projected > 10 pfu
  - Radio Bursts Type II, Type III, Type IV and 10 cm bursts
  - Magnetic Storm Warning Expected  $K_B$  above 6
  - Sudden Impulse CME Shock arrival
- Lots of phone calls and a lot more pages

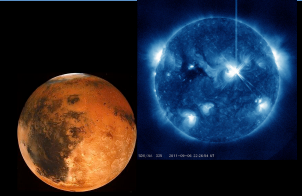


# Interfaces





# Ops in LEO (ISS)



## SEP Event

Characterized by short high-dose passes

Peaks will be 45 – 90 minutes apart

Passes correspond to trajectories in low cut-off areas

Usually bunched into 8-9 hour interval each day

South passes are larger than similar north passes (mag field tilt)

## Ground Support

Events of sufficient magnitude:

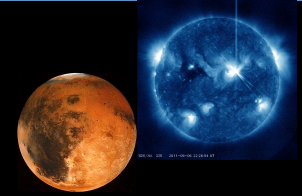
- characterize event progress, correlate with crew activities
- provide FCT (principally Surgeon, FD, MER) times of exposure  
“passes” with best estimate magnitudes
- recommendations for timeline manipulation to minimize exposure/impact

Outside of LEO will be an entirely different ballgame!





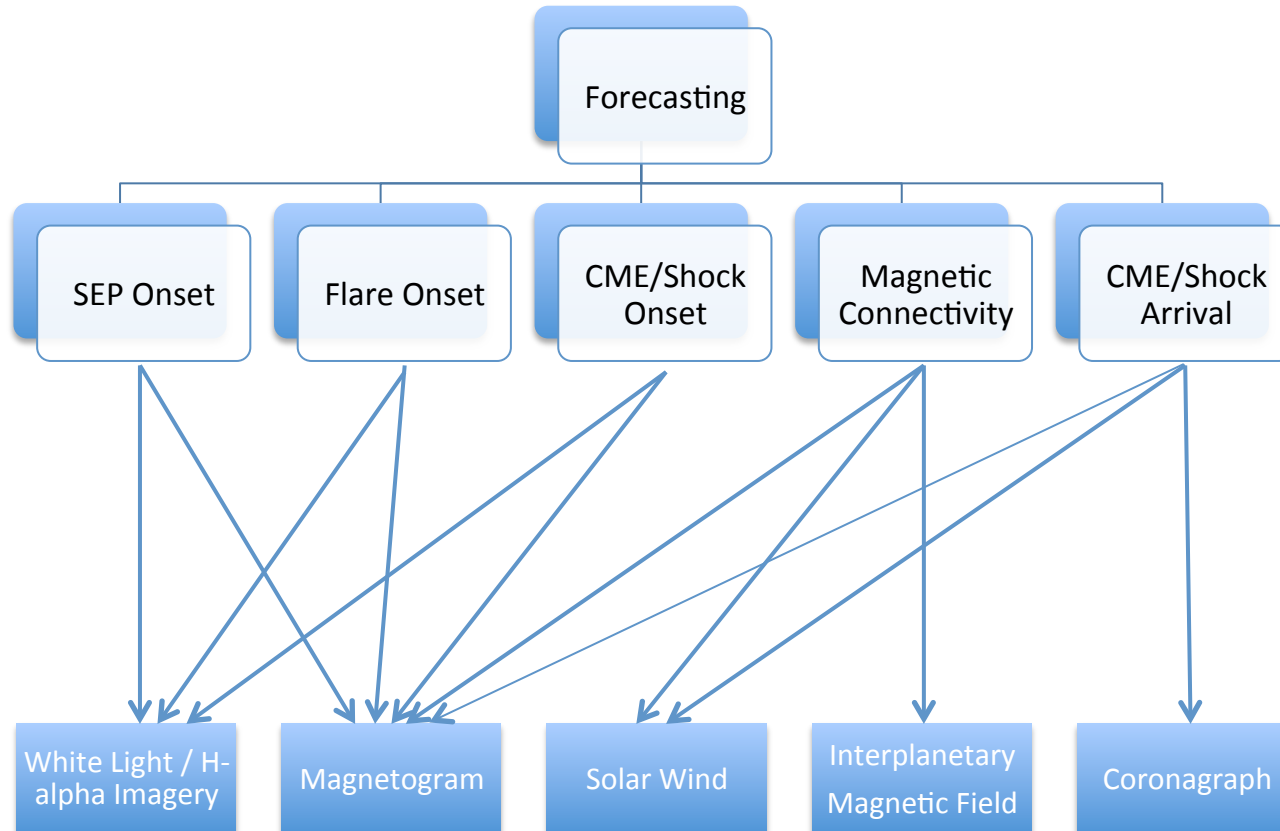
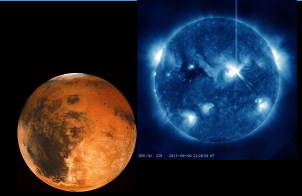
# The Future



- Overall, we ‘react’ to adverse conditions – nowcasting/situational awareness
- Not the right paradigm for long-duration missions outside of LEO
- Going forward beyond LEO, forecasting SEPs becomes increasingly important
  - Need ‘All-Clear’, duration and intensity forecasts
  - Working now through multi-center/University collaboration to develop demo forecasting suite
    - JSC/GSFC/LaRC/MSFC, Univ. of Alabama Huntsville, Univ. of Tenn.
    - ‘All-Clear’ forecasting, ensemble CME arrival forecasts, magnetic connectivity, probabilistic environment characterization (event spectra and dose, and event dose projection)
  - But....



# Forecasting Dependencies

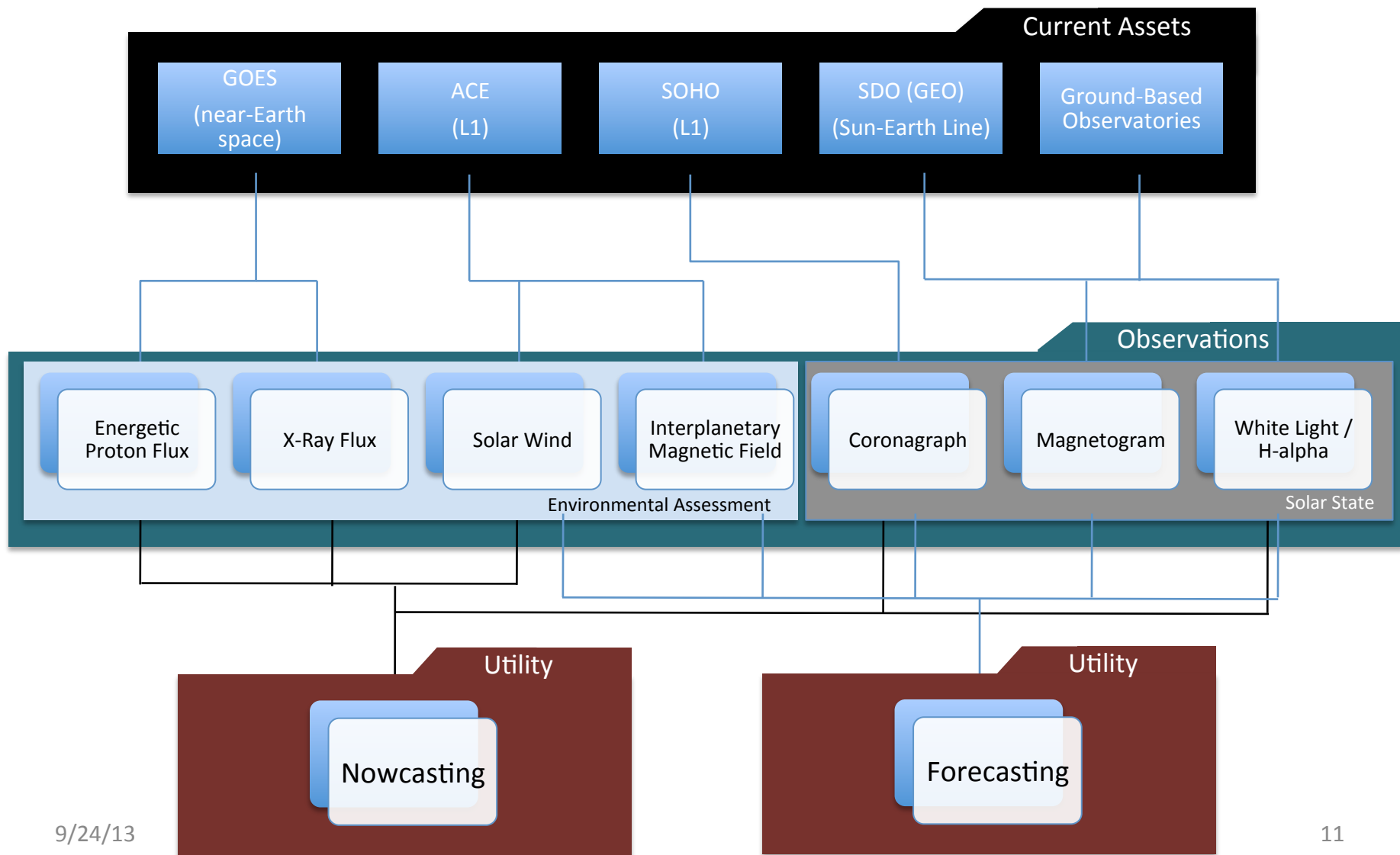
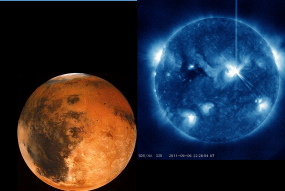


**\*\*If the data streams go away, developed capability will be unavailable, and prospects of new modeling techniques severely limited.\*\***

Without data, we cannot learn if forecasting capability can be developed by the time we need it.

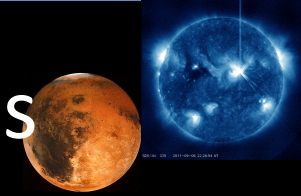


# Data Utility





# HEOMD Forecasting Needs



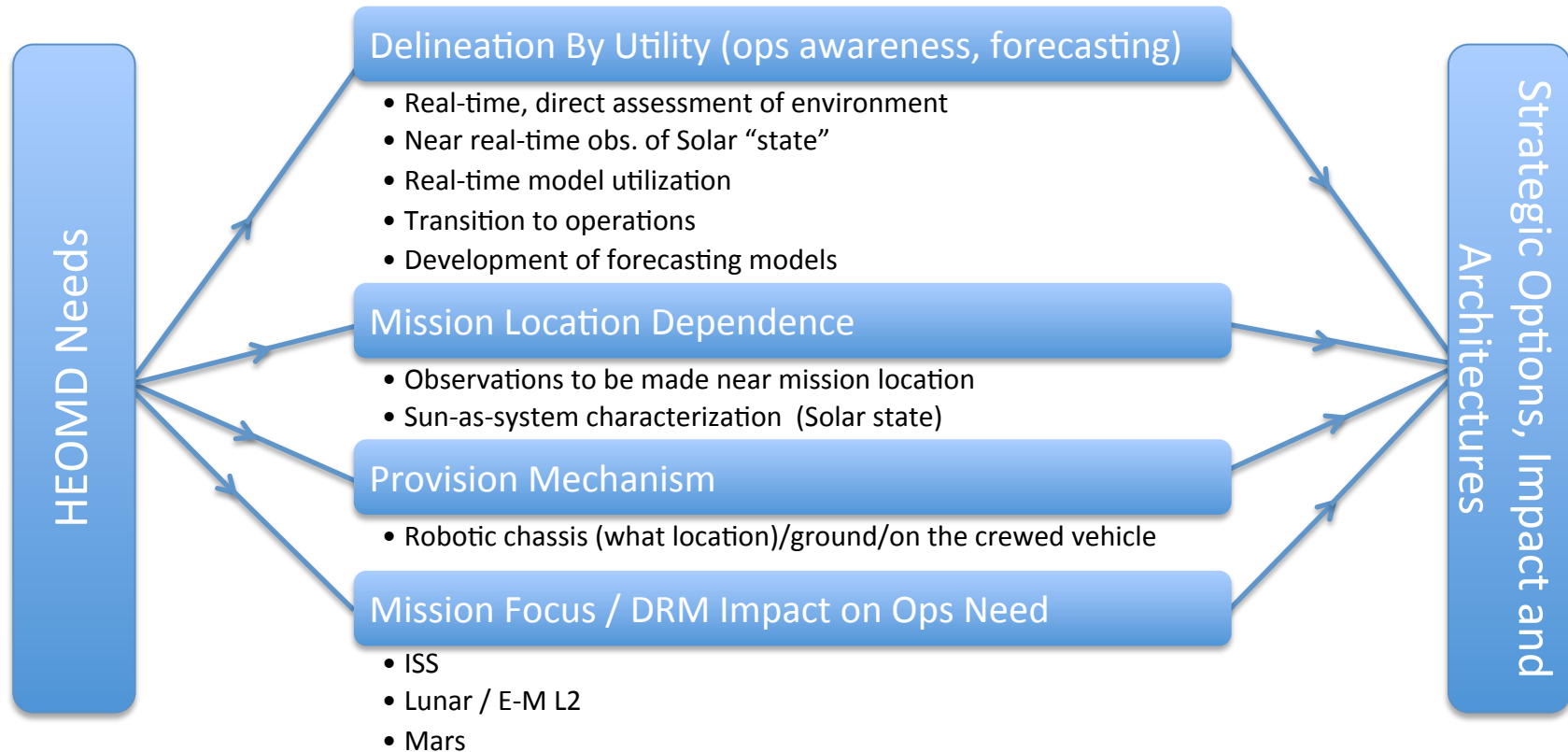
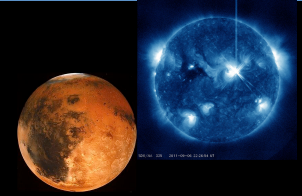
## Forecasting Data Streams\* (ordered in terms of decreasing priority)

Data Stream	Utility (What question will be answered?)	Current Asset
Magnetogram (Line-of-sight and vector)	Will SEP event occur in next 24 hours? Will x-ray flare occur in next 24 hours? Will CME occur in next 24 hours?	SDO
White Light / H-alpha Imagery	What region on solar disk is likely to produce a SEP / Flare / CME? What is the impact between a region on the solar disk and the current mission location?	Mt Wilson, GONG, other international observatories (all ground-based)
Interplanetary Magnetic Field	If SEP event occurs, will it have an impact at current mission location?	ACE
CME speed, direction and cone angle	When will CME / Shock arrive at current mission location?	SOHO, STEREO
Solar Wind (speed and density)	When will CME / Shock arrive at current mission location? If SEP event occurs, will it have an impact at current mission location?	ACE

\*The need is not mission specific. All assessment based upon the current state of knowledge of fundamental solar activity drivers, forecasting model maturity, and operational need.

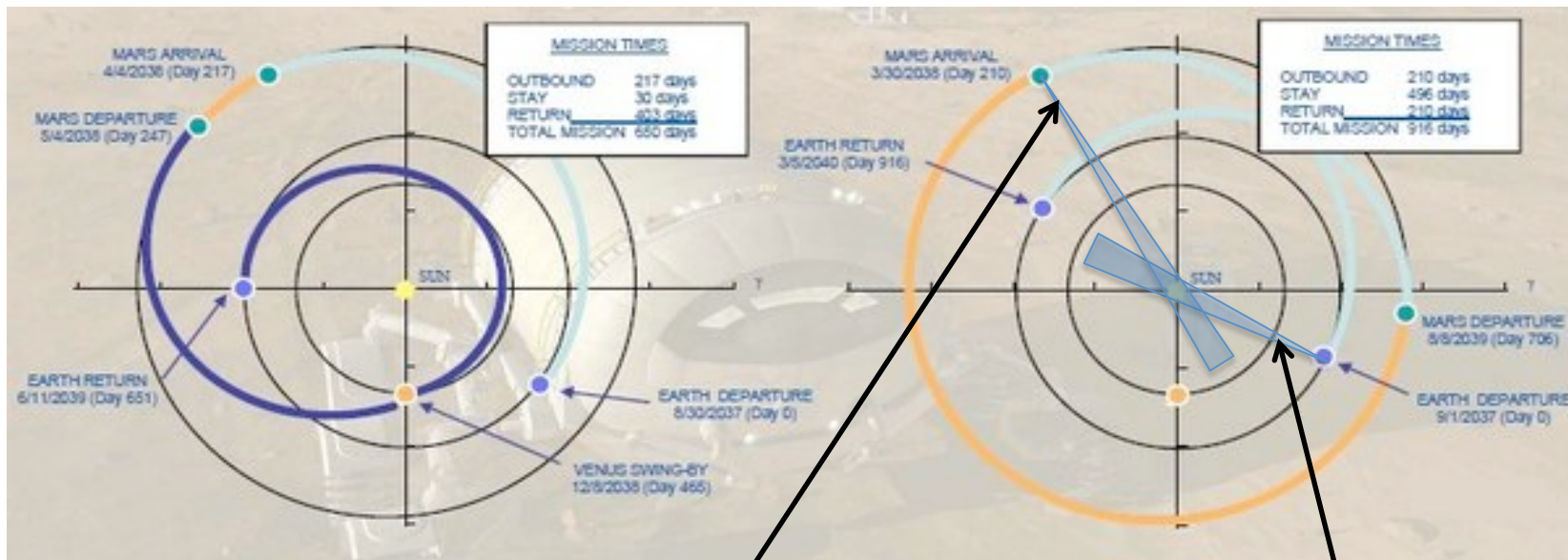
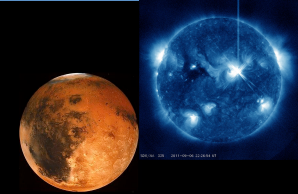


# From Needs to Options





# Delineation Parameters

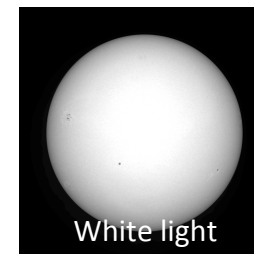
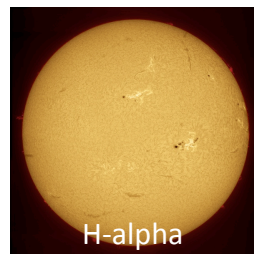
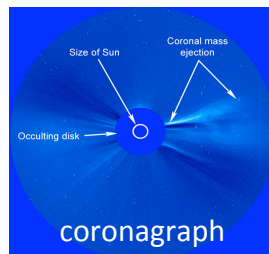
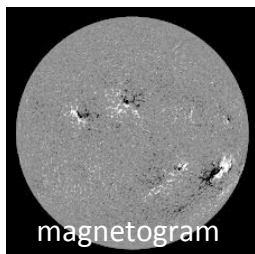


Off Sun-Earth Line (OSEL): e.g. Mars      Sun-Earth Line (SEL): e.g. ISS / Lunar / E-M L2

Nowcasting: real-time assessment of space weather environment and impact to crew.

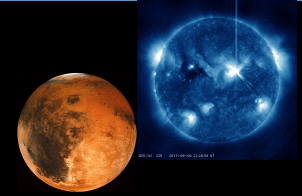
Forecasting: forward prediction of impending solar activity and impact to crew

Forecasting / Nowcasting location dependency: Imagery for identifying sunspot groups and characteristics (solar state) dependent on view of solar disk from crew perspective. Provision is not.





# Final Comments



- Path forward dependent on near-term V&V of identified forecasting models.
- Can't guarantee future forecasting capability
  - However, no data = no forecasting
- The more continuous observations are made the more we learn
  - 'Sun-as-a-System' knowledge gain
  - Future of forecasting dependent on reliable and continuous observations