SPACE WEATHER SUPPORT TO NASA OPERATIONS

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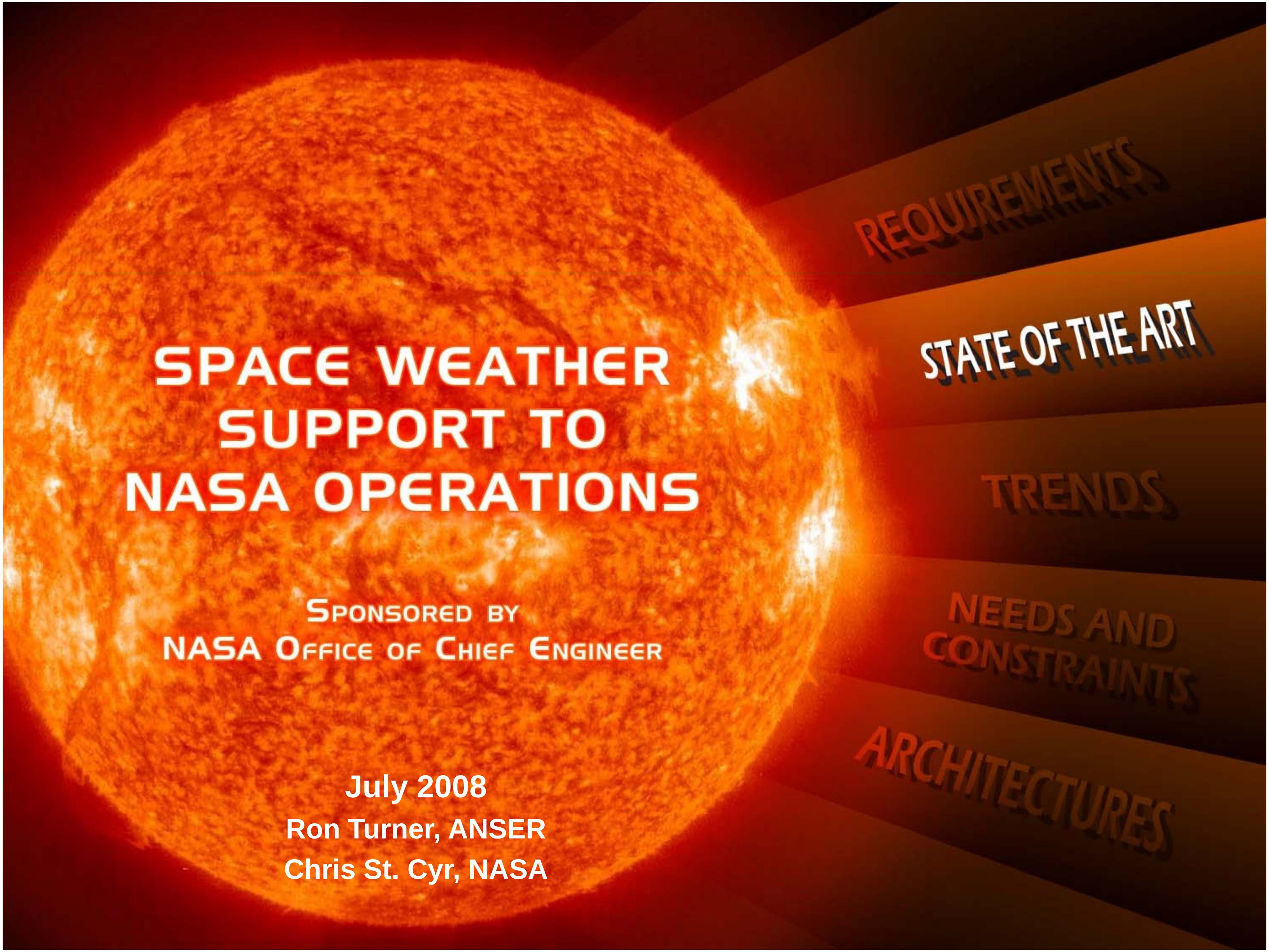

July 2008

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Chris St. Cyr, NASA

Overview

- This report is the second in a series designed to examine space weather support to NASA operations
- The focus of this increment is on how space weather support is provided to NASA today
  - A previous report looked at NASA's space weather requirements.
  - Subsequent reports will look at trends that may improve future space weather support and architectures that may be implemented to meet future NASA space weather operational support
- The following topics are covered:
  - NASA's human health radiation research program
  - Support to human space flight
  - Support to robotic missions
  - Space launch support

Key Points

- NASA's human health radiation research program is critical to reduce uncertainties in radiation effects to better define radiation limits on future space flight
- The NOAA Space Weather Prediction Center (SWPC) monitors and forecasts the space weather environment; SWPC works closely with the Space Radiation Analysis Group (SRAG) and with other operational NASA missions
- Operational support to human space flight is provided by a well-coordinated effort centered around the Space Radiation Analysis Group at NASA JSC
- Robotic mission support is focused on designing spacecraft to survive the space radiation environment; operational support varies widely from project to project

NASA's Human Health Radiation Research Program

Overview

- **The Office of the Chief Health and Medical Officer sets the radiation standards for human health**
- **The biological effects of ionizing space radiation is the largest source of uncertainty in establishing radiation risk management strategies for human space flight**
- **NASA has a program to improve understanding of space radiation effects that includes:**
  - **Internal and External Advisory Boards**
  - **Peer-reviewed research through Announcements of Opportunity**
  - **Active collaboration with other agencies**

Fundamental research on the biological effects of space radiation is a critical component of NASA's strategy for reducing space weather risk to astronauts

NASA Space Radiation Health Research

Advisory Organizations (examples)

National Council on Radiation Protection and Countermeasures (NCRP)

National Academies (NAS, IOM, NRC)

Internal and External NASA Advisory and Proposal Peer Review Groups

Funded Research

Human Research Program*

↓

Radiation Health Element

↓

Announcements of Opportunity

- NASA Specialized Centers of Research
- Independent Principal Investigators
- National Space Biomedical Research Institute

↓

NASA Space Radiation Laboratory
(High Energy Heavy Ions and Protons at Brookhaven National Lab)

Loma Linda (High Energy Protons)

↓

Validated research findings are incorporated into risk assessment models within the JSC Risk Assessment project and ultimately, through the OCHMO, into Permissible Exposure Limits

Interagency Collaboration

DOE Low Dose Radiation Research Program

National Institutes for Health (NCI, NIAID)

Armed Forces Radiobiology Institute

Brookhaven National Lab (NASA Space Radiation Laboratory)

*HRP is managed within ESMD and monitored by the Advanced Capabilities Division

Operational Support to Human Space Flight

→ Overview

→ NOAA Space Weather Prediction Center

→ NASA Space Radiation Analysis Group

→ Crew Surgeon and Radiation Health Officer

Overview

- Operational space weather support is provided through a close working relationship of:
  - The NOAA Space Weather Prediction Center
  - The Space Radiation Analysis Group
  - The Crew Surgeon and the Radiation Health Officer
- NOAA Space Weather Prediction Center, in Boulder, CO, monitors and forecasts space weather activity
- The Space Radiation Analysis Group (SRAG) at the Johnson Space Center is responsible for ensuring that the radiation exposure received by astronauts remains below established safety limits
- The Crew Surgeon provides the overall safety evaluation of crew radiation risks to the Flight Director
- The Radiation Health Officer (RHO) is an interface between the Crew Surgeon and SRAG

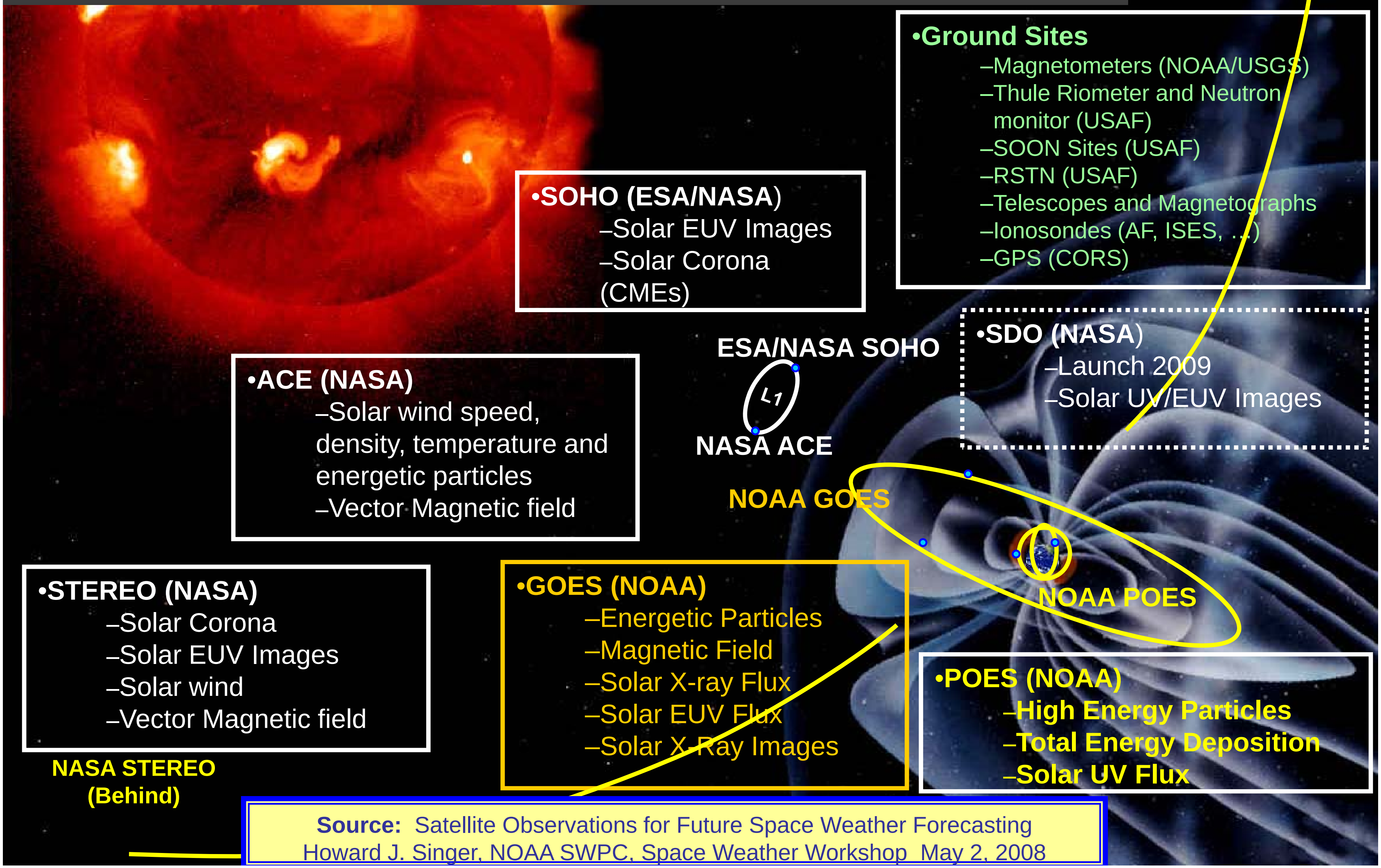
NOAA Space Weather Prediction Center

The Space Weather Prediction Center (SWPC) is one of nine National Centers for Environmental Prediction and provides real-time monitoring and forecasting of solar and geophysical events, conducts research in solar-terrestrial physics, and develops techniques for forecasting solar and geophysical disturbances.

SWPC Operations

- **SWPC monitors the space environment 24/7/365 from a facility in Boulder, CO**
- **Data sources include**
  - **NOAA-operated operational spacecraft (GOES and POES)**
  - **Ground-based solar optical and radio telescopes**
  - **Ground-based magnetometers**
  - **Ground-based neutron monitors**
  - **Data, as available, from instruments on NASA and ESA science missions**
    - ACE
    - SOHO
    - STEREO
- **Space environment data are posted in near-real-time on a website accessible to the public**
- **SWPC develops and maintains operational models to forecast the space environment**
- **SWPC produces a variety of products for the space weather community**
  - **Daily, weekly, and monthly routine reports**
  - **Alerts and warnings are sent to a broad distribution of recipients via email, phone, or pagers at the users' request**

Monitor, Measure and Specify: Data for Today's Space Weather



- **Ground Sites**
  - Magnetometers (NOAA/USGS)
  - Thule Riometer and Neutron monitor (USAF)
  - SOON Sites (USAF)
  - RSTN (USAF)
  - Telescopes and Magnetographs
  - Ionosondes (AF, ISES, …)
  - GPS (CORS)

- **SOHO (ESA/NASA)**
  - Solar EUV Images
  - Solar Corona (CMEs)

- **SDO (NASA)**
  - Launch 2009
  - Solar UV/EUV Images

- **ACE (NASA)**
  - Solar wind speed, density, temperature and energetic particles
  - Vector Magnetic field

- **STEREO (NASA)**
  - Solar Corona
  - Solar EUV Images
  - Solar wind
  - Vector Magnetic field

- **GOES (NOAA)**
  - Energetic Particles
  - Magnetic Field
  - Solar X-ray Flux
  - Solar EUV Flux
  - Solar X-Ray Images

- **POES (NOAA)**
  - **High Energy Particles**
  - **Total Energy Deposition**
  - **Solar UV Flux**

Source: Satellite Observations for Future Space Weather Forecasting
Howard J. Singer, NOAA SWPC, Space Weather Workshop May 2, 2008

GOES Space Environment Monitors

GOES 10, 11, 12

- X-Ray (10, 11, 12)
- Energetic Particles
  - Protons (10,11, 12)
  - Electrons (10, 11, 12)
  - High energy protons, alpha (10, 11, 12)
- Magnetometer (10, 11, 12)

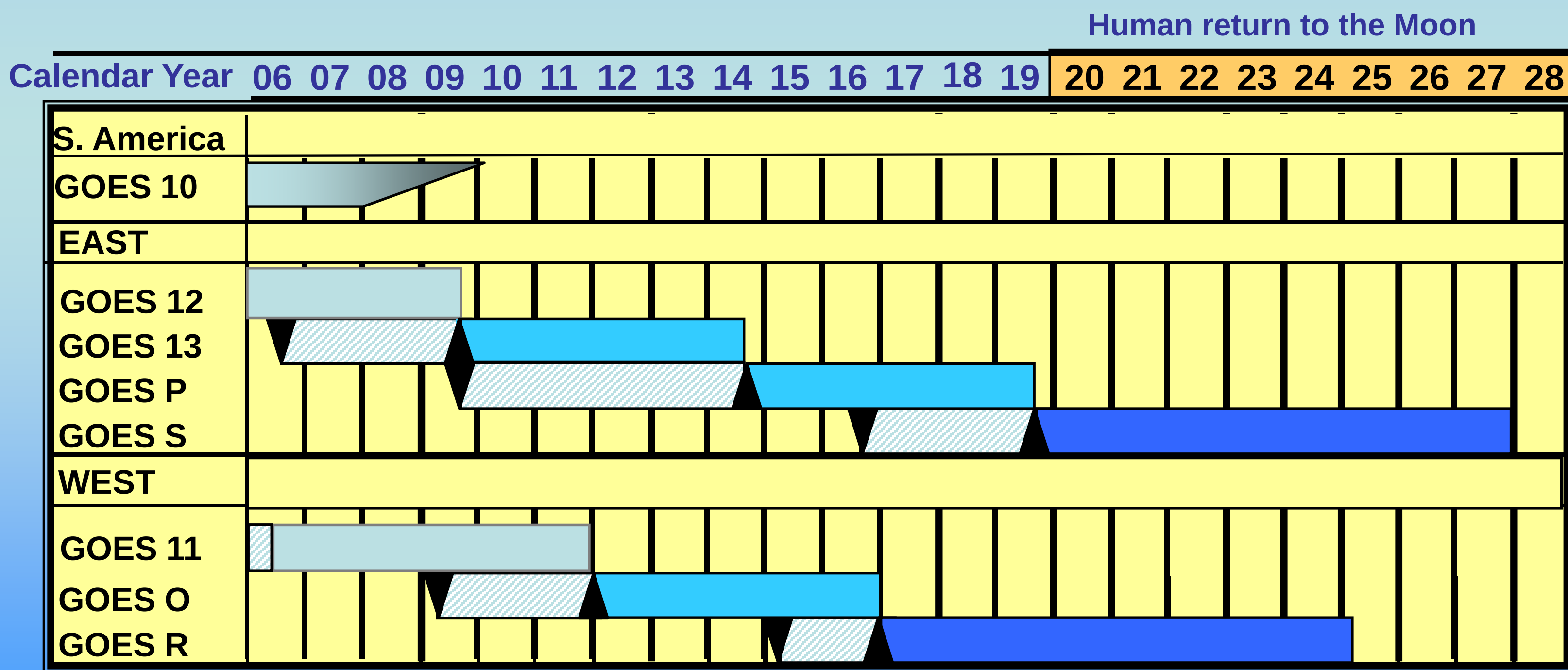
RED: Failed or not fully operational

GOES 13(N), O, P

- X-Ray (13, O, P)
- EUV (13, O, P)
- Energetic Particles (13, O, P)
  - Protons (adds medium energy)
  - Electrons (adds medium energy)
  - High energy protons, alpha
- Solar X-Ray Imager (13,O,P)
- Magnetometer (13, O, P)

GOES R, S

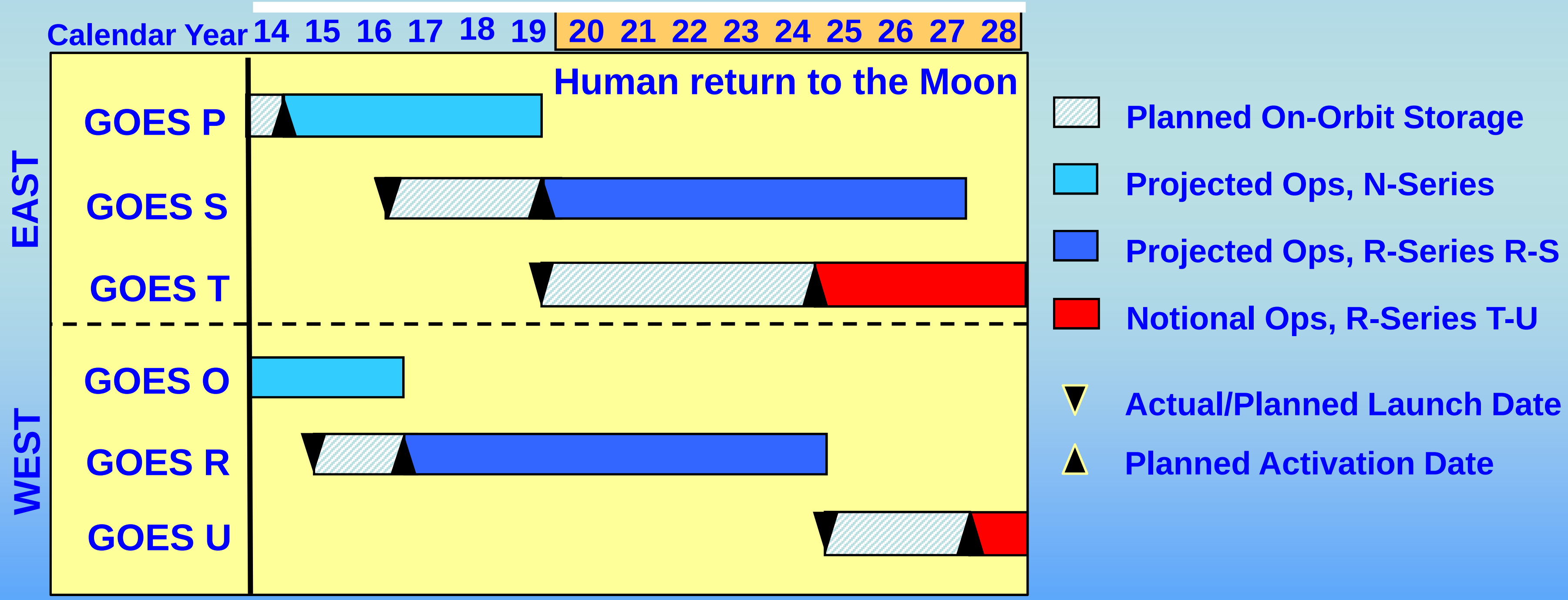
- X-Ray and EUV (EXIS)
- Energetic Particles (SEISS)
  - Adds heavy ions
  - Lower energy for protons
  - Lower energy electrons
- Solar Ultraviolet Imager (SUVI)
- Magnetometer



▼ Actual/Planned Launch Date
▲ Planned Activation Date
Operational
Planned On-Orbit Storage
Projected Ops, N-Series
Projected Ops, R-Series

GOES T/U

- GOES T and U are options to the GOES R series and do not show in the official manifest
- Space Environment Monitors are expected to be the same as R/S
- Changes to the GOES R space weather manifest would be costly
  - Spacecraft design assumes same space weather instruments for R through U
  - Space weather instruments for R/S are under contract
  - Spares for these instruments are purchased and are expected to be applied to T/U



NOTIONAL GOES T/U SCHEDULE
Based on keeping one spare on orbit
(Illustration only)

Science Mission Data for Operational Space Weather Support

- Some NASA Heliophysics missions transmits a subset of the science data in near real time ("Beacon Mode")
  - 1978-launched ISEE-3 spacecraft provided real-time L-1 solar wind data from ~1978-1983
  - First instance of planned operational use of science data was with the NASA WIND spacecraft
- Data is delivered through a network of ground sensors, some provided independently of NASA

NEAR REALTIME/BEACON MODE DATA

	PRODUCT	DATA DELIVERY
ACE	Solar wind speed, density Magnetic field, energetic particle flux	For about 21 of 24 hours per day, ACE sends data (~464 bps) to NOAA operated ground stations. During the other three hours when NASA is getting high rate data through the Deep Space Network, NOAA gets a copy of the real time data.
SOHO	X-ray, EUV images coronagraph images, energetic particle data	About ~16 hours/day of near real-time coverage (Will drop to 3 downloads of latest images per day after SDO launch)
STEREO	X-ray, EUV images, coronagraph images, energetic particle data	Five hours per day (per spacecraft) The beacon is gathered through DSN as part of the normal daily operations. The remainder of the day is from "partners" who volunteer their antennas. The coverage is good (50%-90% day-to-day).
SDO (Planned)	X-ray, EUV images, Helioseismic data	SDO will have continuous downlink (24x7)

Similar Beacon Mode support is under study for Geospace missions RBSP and MMS

NASA Facilities Supported by SWPC

NASA Facility	City	State
NASA Johnson Space Center	Houston	TX
NASA Jet Propulsion Laboratory	Pasadena	CA
NASA Goddard Space Flight Cent	Greenbelt	MD
NASA Glenn Research Center	Brook Park	OH
NASA/Launch Services Program	Kennedy Space Center	FL
NASA Marshall Space Flight Center	Huntsville	AL
NASA Langley Research Center	Hampton	VA
NASA Ames Research Center	Moffett Field	CA
NASA White Sands Complex	Las Cruces	NM
NASA Dryden	Edwards	CA

Source: Distribution of SWPC Data and Products to NASA,
William Murtagh, NOAA SWPC, June, 2008

SWPC Products to NASA

- Real time space weather data are available on the internet for anyone to access
- Users can subscribe to automated distribution of alerts and warnings
- SWPC's open architecture for distribution of alerts and warnings makes it difficult to quantify the extent of SWPC's support to NASA
- Primary recipients often package and redistribute alerts and warnings

Sample of NASA groups supported by SWPC

JSC	UTMB/NASA
Glenn	ZIN Technologies, Inc (supporting NASA GRC)
Kennedy	NASA/Launch Services Program
Marshall	NASA/MSFC/NSSTC/XD12
Marshall	NASA MSFC EV13
GSFC	NASA/EMOS
AMES	NASA Ames Computational Sciences Division
Langley	NASA/GATS
Langley	SSAI at NASA
Dryden	Tybrin, Inc/NASA Dryden
JPL	Flight Operations
GSFC	GSFC Flight Operations Teams
GSFC	GSFC, Space Physics Data Facility
Kennedy	Harris Government Communications Systems Division
JSC	Lockheed Martin
JSC	Canadian Space Agency
GSFC	HSTI
JSC	Space Radiation Analysis Group

Redistribution
Alerts, warnings, forecasts: forwarded to expanded list

- MCC-H BME
- MCC-M BME
- SRAG
- MCC-H SURG
- MCC-M SURG
- MCC-H FLTCTRL
- MCC-M FLTCTRL
- NASA MEDOPS
- NASA MGMT
- CSA MGMT
- ESA MGMT
- NASDA MGMT
- RSA MGMT
- LOCK MGMT
- NOAA SPPT
- CSA DSRHO
- CSA SRHO
- ESA DSRHO
- ESA SRHO
- IBMP DSRHO
- IBMP SRHO
- NASA DSRHO
- NASA SRHO
- NASDA DSRHO
- NASDA SRHO

Source: Distribution of SWPC Data and Products to NASA, William Murtagh, NOAA SWPC, June, 2008

NASA Space Radiation Analysis Group

Space Radiation Analysis Group

- The Space Radiation Analysis Group (SRAG) at the Johnson Space Center is responsible for ensuring that the radiation exposure received by astronauts remains below established safety limits
- To fulfill this responsibility, the group provides:
  - Radiological support during missions
  - Pre-flight and extra-vehicular activity (EVA) crew exposure projections
  - Evaluation of radiological safety with respect to exposure to isotopes and radiation producing equipment carried on the spacecraft
  - Comprehensive crew exposure modeling capability
  - Radiation instruments to characterize and quantify the radiation environment inside and outside the spacecraft

http://srag.jsc.nasa.gov/

SRAG Operations

SRAG's Multi-Purpose Support Room in the Mission Control Center at the Johnson Space Center

- **The radiation consoles in the Mission Control Center at Johnson Space Center are staffed**
  - **Four hours daily during nominal space weather conditions,**
  - **Continuously during extra-vehicular activities (EVA's)**
  - **Continuously during significant space weather activity**
- **SRAG staff have multiply-redundant communications**
  - **E-mail**
  - **Primary and Back-up Pagers**
  - **Phone numbers and processes to work through call lists**
- **SRAG works closely with the NOAA Space Weather Prediction Center (SWPC) in Boulder, Colorado.**
  - **Solar Forecasters at the SEC provide round-the-clock support, providing alerts and warnings about space weather conditions by telephone and pager and by displaying real time operational space weather data via the Internet**
  - **Even when there are no active solar storms, SWPC provides daily space weather briefs to SRAG**

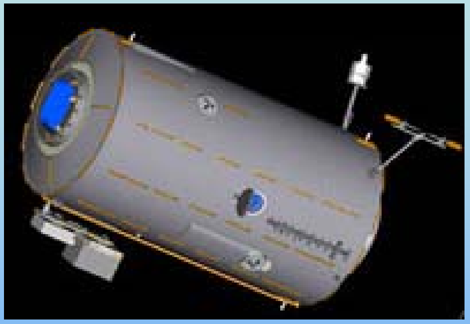
http://srag.jsc.nasa.gov/

Radiation Forecast Tools

- **Space environment conditions (interplanetary proton flux, status of the electron belts, geomagnetic field conditions) are integrated with mission parameters (altitude and inclination of the spacecraft, location and timing of EVAs) in order to project crew exposures**
- **SRAG maintains an extensive set of tools for estimating the exposure received by astronauts in Low Earth Orbit (LEO)**
  - **Time-resolved models of the Earth's magnetic field**
  - **Maps of the radiation fluxes trapped in the geomagnetosphere**
  - **Trajectory algorithms**
  - **State-of-the-art radiation transport codes**
  - **CAD-based geometry evaluation tools**

Examples of Space Weather Data Sources used by SRAG

GOES	**ACE**
SOHO	**STEREO**
TRACE	**WIND**
HINODE	



CAD Model of US Lab Module on ISS

http://srag.jsc.nasa.gov/

Shuttle Radiation Monitors

The SRAG provides an operational dosimetry system to monitor individual crewmember exposures in accordance with federal regulations, and to monitor the radiation environment to assist with operational decision-making

- **One Crew Passive Dosimeter (CPD) is assigned and provided to each crewmember who is required to wear the CPD through all phases of the mission, including EVAs**
- **Six Passive Radiation Dosimeters (PRDs) are provided for each flight and are deployed before launch at fixed locations inside the crew compartment**
- **The Area Passive Dosimeter (APD) and pocket ion chambers are supplied in a pouch and stored in a middeck locker with the Shuttle medical kits**
- **The Tissue Equivalent Proportional Counter (TEPC) is supplied for high-altitude (greater than or equal to 205 nautical miles) and/or high-inclination flights (greater than or equal to 50 degrees) and hard-mounted in the middeck**
  - The TEPC is nominally activated early on Flight Day 1, and is deactivated as close to, or during, deorbit prep, as possible. Daily status checks are performed

ISS Radiation Monitors

The Radiation Area Monitor (RAM) is a small set of thermoluminescent detectors (TLD) encased in a Lexan holder

- **Each crew member wears a Personal Radiation Dosimeter throughout the mission**
- **In addition, there are passive and active radiation monitors throughout the ISS**
- **The active monitors include:**
  - **Intra Vehicle Charged Particle Directional Spectrometer (IVCPDS)**
  - **Extra Vehicle Charged Particle Directional Spectrometer (EVCPDS)**
  - **Tissue Equivalent Proportional Counter (TEPC)**

The IV-CPDS displays the average dose rate and other parameters on a small LCD screen on the instrument for use by the astronauts, and sends similar information to Mission Control

The TEPC is designed to measure the dose that a small volume of tissue would receive from a wide variety of radiation sources.

http://srag.jsc.nasa.gov/

EV-CPDS: three CPDS instruments are mounted outside the ISS

Crew Surgeon and Radiation Health Officer

Each mission has a Crew Surgeon and Deputy Crew Surgeon. The CS and DCS provides all preflight, in-flight, and postflight medical care for each flight crewmember.

The Crew Surgeon

- **Before flight**
  - Assesses the status of the astronaut's career dose
  - Advises the crew of the risk of radiation
- **During flight**
  - If the radiation dose rate is high or projected to be high, with the SRAG, advises the Flight Director of impact and options
- **After flight**
  - Assesses the status of the astronaut's career dose

A Radiation Health Officer is the interface between SRAG and the Crew Surgeon, the "Physicist to Physician Dictionary*"

The RHO:

- **Before flight**
  - Supports the Crew Surgeon with briefings to the crew
- **During flight**
  - Reviews dose and dose rate data prepared by SRAG
  - Advises the Crew Surgeon
- **Post flight**
  - Compiles personal dosimetry and other recorded dose information to estimate update astronaut career dose

Quote attributed to Neal Zapp

Support to Robotic Missions

→ **Design/Development**

→ Operations

Support to Robotic Missions

Overview

- **Each robotic mission is unique**
  - **Location**
  - **Lifetime**
  - **Operations**
- **Focus of Space Weather support to robotic missions is on designing a survivable spacecraft**
  - **Ensure the system survives peak and total radiation exposure for the planned life of the mission through effective systems engineering**
  - **Requires good understanding of expected radiation environment**
  - **Requires component performance verification and validation through ground test**
- **Operational support implementation varies substantially from mission to mission**
  - **Mission operational support is managed individually by projects**

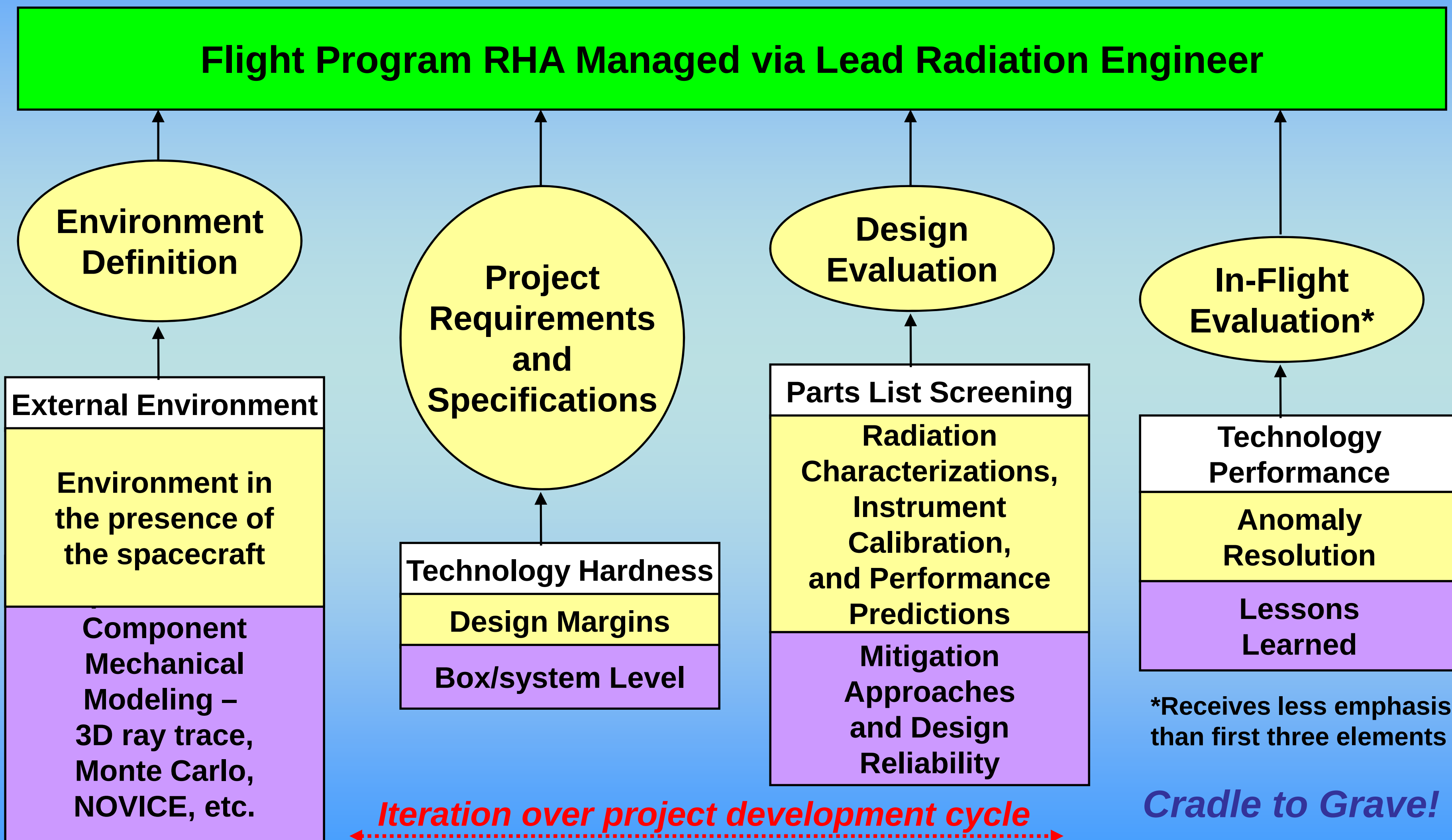
Radiation and Systems Engineering:
A Rational Approach for Space Systems

- **Design the spacecraft to survive the radiation environment**
- **Assign a lead radiation engineer to each spaceflight project**
  - **Treat radiation like other engineering disciplines**
  - **Provides a single point of contact for all radiation issues**
    - Environment, parts evaluation, testing,…
- **Each program follows a systematic approach to Radiation Hardness Assurance (RHA)**
  - **Develop a comprehensive RHA plan**
  - **RHA active early in program reduces cost in the long run**
    - Issues discovered late in programs can be expensive and stressful

Define the Environment
External to the spacecraft
Evaluate the Environment
Internal to the spacecraft
Define the Requirements
Define criticality factors
Evaluate Design/Components
Existing data/Testing/ Performance characteristics
"Engineer" with Designers
Parts replacement/Mitigation schemes
Iterate Process
Review parts list based on updated knowledge

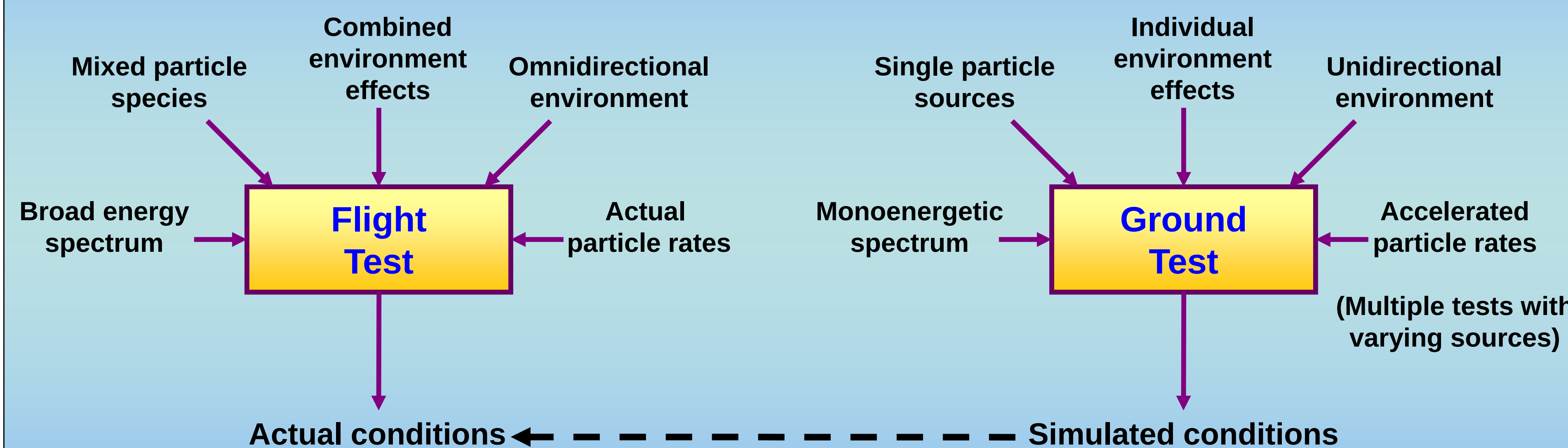
From: Space Radiation Effects on Electronics: ***A Primer for Designers and Managers, by Ken LaBel, NASA GSFC***

Flight Program Radiation Hardness Assurance (RHA) Flow



From: Space Radiation Effects on Electronics: *A Primer for Designers and Managers, by Ken LaBel, NASA GSFC*

Radiation Test Issue – Fidelity of a Ground Test



How accurate is the ground test in predicting Space Performance?

From: Space Radiation Effects on Electronics: *A Primer for Designers and Managers, by Ken LaBel, NASA GSFC*

Heavy Ion Facilities Supporting Radiation Effects on Electronics

- **Brookhaven National Lab (BNL) Single Event Upset Test Facility (SEUTF)**
- **Lawrence Berkeley National Lab**
- **Texas A&M University (TAMU) Cyclotron Facility**
- **National Superconducting Cyclotron Lab (NSCL) at Michigan State University (MSU)**
- **NASA Space Radiation Lab (NSRL) at BNL**

Multiple facilities are used by NASA to test the effects of ionizing radiation. These facilities provide a range of beam energy, intensity, and ion selection. They vary in availability and cost to NASA.

Support to Robotic Missions

→ Design/Development

→ Operations

Robotic Mission Operations

- **NASA has an extensive fleet of robotic explorers and infrastructure**
- **The NASA fleet extends throughout the solar system**
- **Mission Operation Control Centers are widely dispersed**

DIVISION	Number of Spacecraft Operating	Number of Spacecraft in Development
Astrophysics	11	6
Earth	18	6
Earth (GOES)	6	?
Heliophysics	27	4
Planetary	14	2
TDRSS	7	?
ISS	1	---
	84	**18**

SPACECRAFT LOCATION	
LEO equatorial	13
LEO polar or sun-synch	18
MEO	9
HEO	6
GEO	14
L1 or L2	4
Heliocentric ≤1 AU	3
Heliocentric >1 AU	10
Mars landers/orbiters	6
Saturn orbiter	1
	84

"In Development" includes missions that have been funded and are past the hurdle of Initial Confirmation Review by HQ

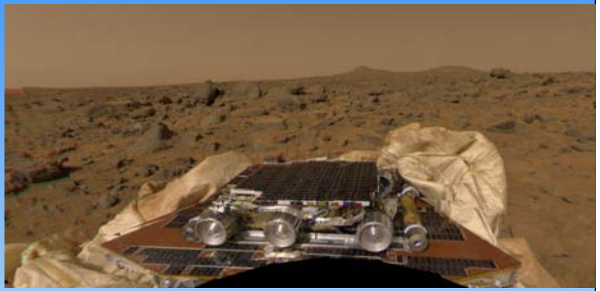
MOCC LOCATION	
APL	5
ESOC	9
GSFC	15
JAXA	4
JPL	15
JSC (ISS and STS)	1
LASP	3
NOAA (GOES)	7
UCB	7
USAF	2
WSC (TDRSS)	7
Other	9
	84

Mission Operations

- Mission operational space weather support is managed by individual projects and hence is extremely ad hoc
- Response to Space Weather fluctuations range from “ride it out” to “retreat to safe mode”
- Intermediate operational responses include:
  - Restrict mission operations
  - Shut down sensitive subsystems
  - Lower voltages on HV systems
  - Delay routine maintenance or complex procedures
- Space Weather situation awareness is also used to support anomaly resolution

At GSFC, at least 9 of the missions under a single operations contract (MOMS) have their own SWx alert system. This is because the Flight Ops Teams for two of those missions (SOHO and ACE) got educated via local scientists and SWPC. Those efforts continue and are now tied into the Community Coordinated Modeling Center interface to models.

Examples of Contacts Between Missions and NOAA SWPC



Pathfinder mission

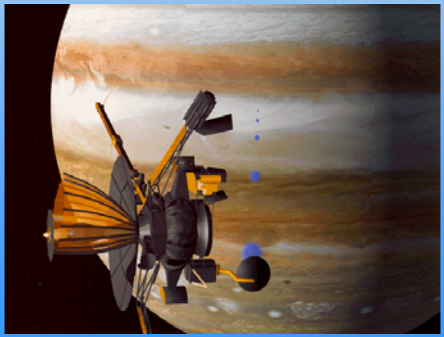
"During the Pathfinder mission to Mars in 1997, I used SWPC data to show that various minor operational anomalies with the Sojourner rover were well correlated with solar events. These…resulted in single-event effects within the commercial-grade (i.e. not radiation-hardened) microcircuits aboard Sojourner. With the benefit of this knowledge, we were able to complete our exceptionally successful Mars mission."

Jan A. Tarsala, Senior RF, Microwave, and Antenna Engineer,
Spacecraft Telecommunication Equipment Section,
NASA Jet Propulsion Laboratory

Galileo mission

"I have used products derived from the SWPC solar wind data in support of investigations of spacecraft anomalies, particularly on the Galileo mission to Jupiter. Not having the data easily accessible would have made the investigations more difficult or impossible."

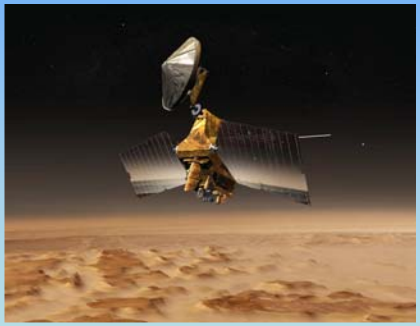
Lead Sequence Systems Engineer
Mars Odyssey, JPL, Pasadena, CA



Source: Distribution of SWPC Data and Products to NASA, William Murtagh, NOAA SWPC, June, 2008

Examples of Contacts Between Missions and NOAA SWPC

Mars Reconnaissance Orbiter



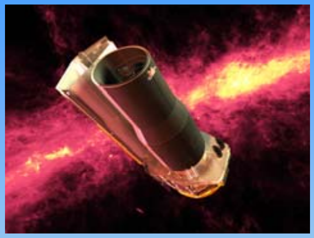
In March 2006, at the request of NASA's Mars Reconnaissance Orbiter (MRO) Mission, SWPC provided critical support to the MRO as the spacecraft neared its insertion phase into orbit around Mars. An unforeseen solar radiation storm between March 2 and March 10, could have potentially caused the loss of the spacecraft. SWPC Forecasters provided daily briefings to the MRO Mission Operations Assurance Group at the Jet Propulsion Lab.

Mars Exploration Rovers

During the Mars Exploration Rovers (MER) cruise period, a massive solar flare erupted which placed the twin rovers into an anomalous state. While not mission ending, the vehicles were not able to perform many in-flight operations. It was necessary to continuously monitor the space environment to ensure that no further flares were active when performing several critical operations, including a flight software load needed for the successful landing on Mars. The NOAA group provided additional support and alerts to ensure that the MER team was not caught unawares by major changes in space weather.

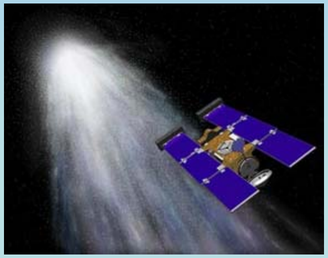
Source: Distribution of SWPC Data and Products to NASA, William Murtagh, NOAA SWPC, June, 2008

Examples of Contacts Between Missions and NOAA SWPC



Spitzer

During its in-orbit checkout period *Spitzer* encountered a very large solar proton storm beginning 2003 October 28. During the course of the storm the science instruments were powered off. Spitzer team members visited SWPC to discuss space weather support.



Stardust

"If we had not known about the flare we could have floundered for days and perhaps even sent commands that would have been detrimental. Once we knew we had had a flare, all of the efforts were based on the hypotheses that the failure to communicate was related to the flare and our efforts were focused to search for effects and remedies."

Don Brownlee, PI of NASA's Stardust

Chandra

There have been 49 events in which the Chandra science instruments were safed because of high solar activity. ACE data were used in every safing event to make this decision.

Chandra team, Cambridge, MA

Source: Distribution of SWPC Data and Products to NASA, William Murtagh, NOAA SWPC, June, 2008

Space Launch Support

Space Launch Support

- **Launch teams are concerned with the possibility of a proton event causing single-event upsets within the guidance computer**
- **Requirement and specific criteria are established by launch system provider, not NASA**
  - **It applies to west coast polar and high inclination launches**
  - **The launch contractor will monitor the proton flux on the NOAA/GOES website and will hold the launch if the protons flux exceeds threshold**
  - **NASA monitors for insight role**

Launch commit criteria for Atlas 5

Winds:

- **Maximum allowable launch wind is 30 knots**
- **If winds are from 060-110 degrees or 230 - 340 degrees, then the wind limit is 23 knots**

Temperature:

- **Ambient air temperature cannot be cooler than 40 degrees F**

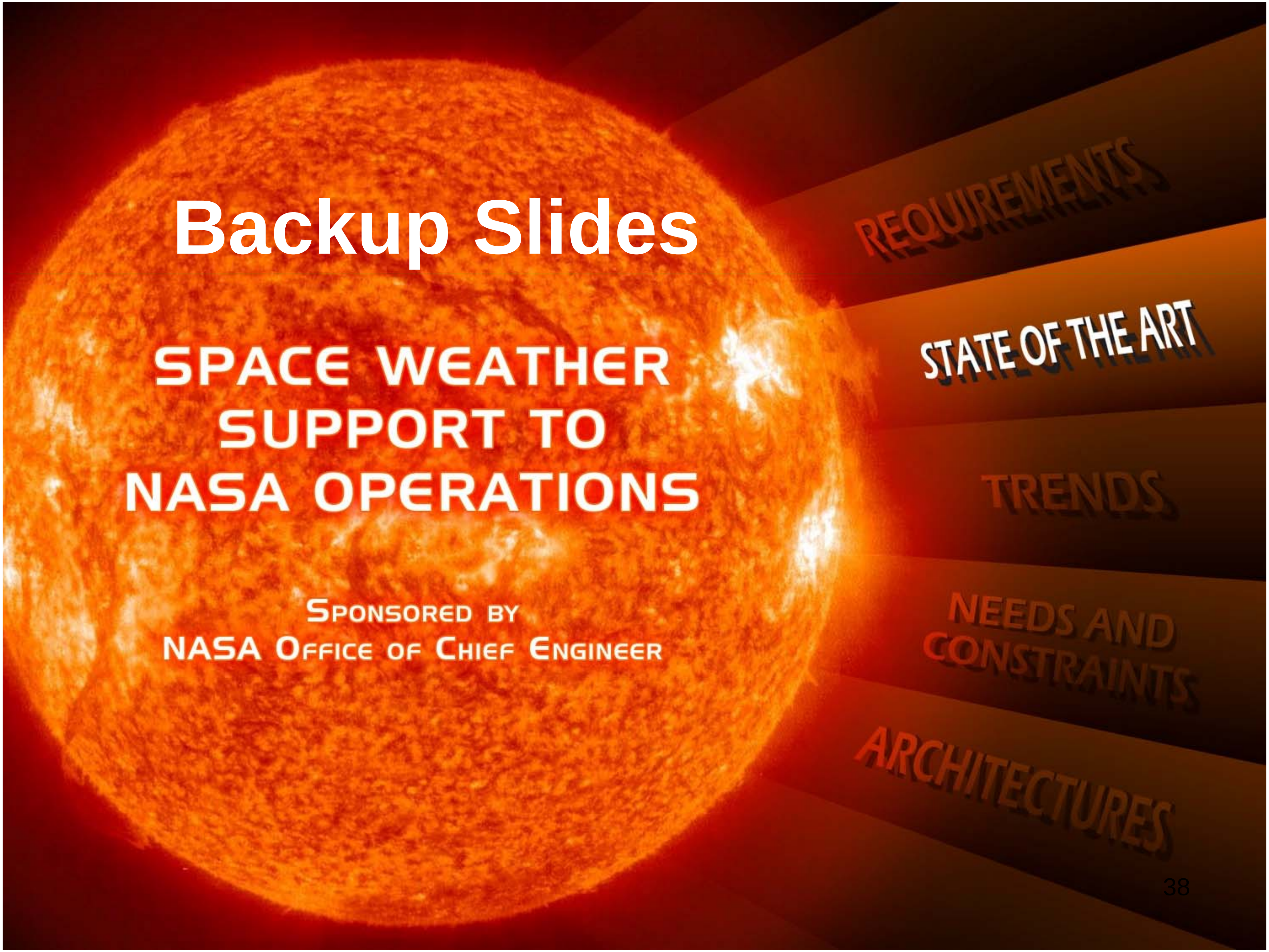
Solar Radiation:

- **50 MeV Proton Flux not greater than 100 pfu**

"*Distribution of SWPC data and products to NASA*" Briefing from NOAA SWPC to OCE, June 4, 2008

Kodiak Star launch was delayed a week due to solar event in Sept 2001

Backup Slides



Space Weather

For the purpose of this report, “space weather” refers to conditions of the space environment and includes short term fluctuations (meteorology) as well as long term averages and extremes (climatology)

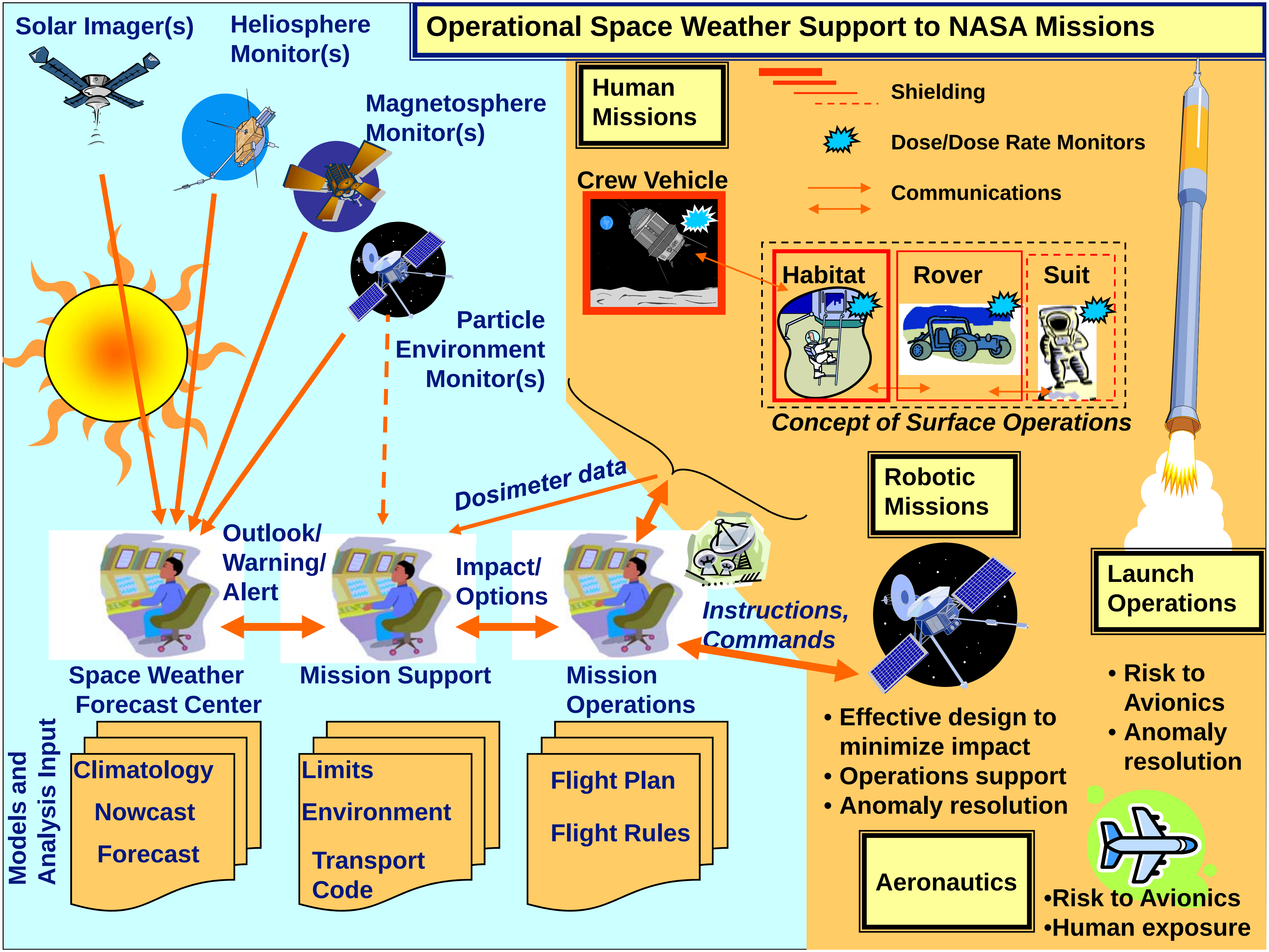
- The space environment extends from the Sun through the heliosphere and includes the magnetospheres and ionospheres of planets and moons of the solar system
- The space environment is characterized by the magnetic fields, charged and neutral components of the solar wind, and energetic particles superimposed on the solar wind from solar and galactic sources
- The space environment changes over time scales ranging from seconds to millennium, but the most common time scales of interest to operations range from minutes to hours or days; for mission planning and design the relevant time scales range from days to years or decades

“Space Weather” vs. “Radiation”

- There is a potential for confusion between the terms “space weather” and “radiation” in a study of operational requirements
- Space weather is the broader term and encompasses a wide range of phenomenology with operational impact
- The dominant subset of space weather impact is related to the radiation, or energetic particle, environment, including electrons, protons, neutrons, and charged ions with energies from KeV to GeV
- The radiation environment inside a spacecraft or habitat is modified by the surroundings (shielding, atmosphere, tissue, etc) and can be enhanced by human-induced radiation sources (power supplies, medical monitoring, invasive radioisotopic tracers)

Scope of Space Weather Impact

- **Human Space Flight**
  - **Radiation exposure increases risk to long term astronaut health, some risk of acute effects**
  - **Radiation event can damage/disrupt critical electronics or interfere with communications**
  - **Response to radiation event can temporarily suspend mission operations and/or be mission limiting**
- **Robotic Missions**
  - **Radiation exposure limits life of some electronics and components**
  - **Radiation event can damage/disrupt electronics or interfere with communications**
  - **Response to radiation event can temporarily suspend mission operations**
- **Launch Support**
  - **Single-event upset risk to avionics can lead to loss of vehicle**
  - **Response to radiation event can delay launch**
- **Aeronautics**
  - **Communications interference or loss**
  - **Risk to avionics**
  - **Enhanced radiation exposure to crew of high or frequent**



Operational Space Weather Support to NASA Missions
Solar Imager(s)
Heliosphere Monitor(s)
Magnetosphere Monitor(s)
Particle Environment Monitor(s)
Human Missions
Shielding
Dose/Dose Rate Monitors
Communications
Crew Vehicle
Habitat
Rover
Suit
Concept of Surface Operations
Robotic Missions
Launch Operations
Dosimeter data
Outlook/ Warning/ Alert
Impact/ Options
Instructions, Commands
Space Weather Forecast Center
Mission Support
Mission Operations
Models and Analysis Input
Climatology
Nowcast
Forecast
Limits
Environment
Transport Code
Flight Plan
Flight Rules
• Effective design to minimize impact
• Operations support
• Anomaly resolution
• Risk to Avionics
• Anomaly resolution
Aeronautics
•Risk to Avionics
•Human exposure