# CCMC Support to Robotic Mission Operations

Presentation to the CCMC Program Review

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# Overview

- A study for NASA's Office of the Chief Engineer identified a need for better coordination within NASA for space weather support to NASA's robotic missions
- A workshop, funded by NASA's Innovative Partnerships Program, examined the operational space weather needs of NASA robotic mission operations
- The iSWA tool developed under an OCE Technical Excellence Initiative provides one framework to help meet some of these needs
- There has not been a NASA-wide decision on how provide for NASA-unique operational space weather support to robotic missions

# NASA Robotic Mission Operations (1 of 2)

- **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 |

**Charts current as of June 2008**

Astrophysics
Earth Science
Heliophysics
Planetary Science

# Total Missions / Spacecraft 84 / 97

*9/16/09*

## Formulation 12 / 11

**JPL 2**
- NuSTAR
- SMAP

**GSFC 9/8**
- LDCM
- GPM
- GPM LIO
- BARREL (1/0)
- IRIS
- *Solar Orbiter*
- GEMS
- *Astro H (NEXT)*
- MAVEN

**MSFC 1**
- LADEE

## Implementation 15 / 18

**JPL 6**
- WISE
- ST-7
- *Aquarius*
- MSL
- JUNO
- GRAIL

**GSFC 8/12**
- JWST
- GOES-P
- Glory
- NPP
- SDO
- SET-1
- RBSP (2)
- MMS (4)

**DFRC 1/0**
- SOFIA(1/0)

## Primary Ops 18 / 18

**JPL 9**
- *Herschel*
- *Planck*
- Spitzer
- Kepler
- OSTM
- *Rosetta*
- DAWN
- EPOXI*
- NExT*

**GSFC 6**
- Fermi
- Aura
- TWINS-A
- CINDI
- TWINS-B
- IBEX

**MSFC 3**
- *Hinode*
- MESSENGER
- New Horizons

## Extended Ops 39 / 50

**LaRC 1**
- CALIPSO

**JPL 12/15**
- GALEX
- Cloudsat
- ACRIMsat
- GRACE (2)
- Jason-1
- QuikSCAT
- Voyager (2)
- *Mars Express*
- Mars Odyssey
- MER (2)
- Cassini
- MRO

**GSFC 25/33**
- HST
- *Suzaku*
- *Integral*
- RXTE
- WMAP
- XMM
- SWIFT
- Aqua
- SORCE
- EO-1
- ICEsat
- Terra
- TRMM
- Landsat 7~
- THEMIS (5)
- STEREO (2)
- AIM
- *Cluster-2 (4)*

RHESSI SOHO
TIMED TRACE
WIND ACE
GEOTAIL

**MSFC 1**
- Chandra

**Source:**

**Jeffry Hayes, NASA**

**Presentation to CCMC Review**

HST-SM4, SOFIA and BARREL are mission projects but do not add spacecraft

*Italics* = US instruments on foreign mission
X / Y = # of missions / # of spacecraft
* New missions for Deep Impact and Stardust, respectively
~ Operated by USGS

***In concept development*:**

JDEM, SIM-Lite, LISA, Con-X, *Mars 2016/ExoMars*, ILN, OPF, ICESat-II, Solar Probe +

# NASA Robotic Mission Operations (2 of 2)

- **Each NASA robotic mission is unique**
  - Location
  - Lifetime
  - Operations
- **Focus of NASA 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**

*OCE Study Finding:*

# Operational Space Weather Support

- Mission operational space weather support is managed by individual projects and hence is *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
  - Operational impact is not routinely fed back to mission designers and those who certify parts for space flight

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.

## *OCE Study Recommendation:*

# Provide efficient and effective space weather operational support to robotic missions

- **NASA robotic mission operations can benefit from better-coordinated space weather support**
- **NOAA SWPC will continue to be an important element of robotic mission support**
  - Alerts and warnings for near-Earth missions
  - State of the Near-side Sun for Planetary missions
- **The NASA SRAG-model may be a starting point for NASA-wide robotic support**
  - Diversity of robotic missions and operational environments may limit role to space environment situation awareness and interface to NOAA SWPC
- **The NASA Community Coordinated Modeling Center is developing a prototype system for compiling space weather models and data in a user-friendly format (OCE-sponsored Technical Excellence Initiative)**

# Robotic Support Workshop

**Funded by NASA's Innovative Partnerships Program**

- **A workshop at GSFC examined the operational space weather needs of NASA robotic mission operations**
  - Sep 16-17, 2009, NASA/GSFC, Building 21, Room 183
  - Dr. Antti Pulkkinen led workshop organization
- **The key objective of the project was to develop a document that will detail NASA's robotic mission operations needs from the space weather perspective**
- **The major elements of the workshop were**
  - Presenting current space weather situational awareness and forecasting capabilities to NASA robotic mission operators
  - Discussing/ presenting mission operator needs from the space weather perspective
  - Outlining a document that will describe a space weather system tailored to the needs of mission operators
- **A draft workshop report has been distributed**

# Attendees

- **The workshop had approximately 25 attendees including individuals who participated through an online option that provided both video and audio access to the workshop**
- **The workshop brought together space weather scientists and a wide representation of NASA mission operations**
  - Earth Science
  - Planetary and Lunar Science
  - Space Science
  - Astrophysics

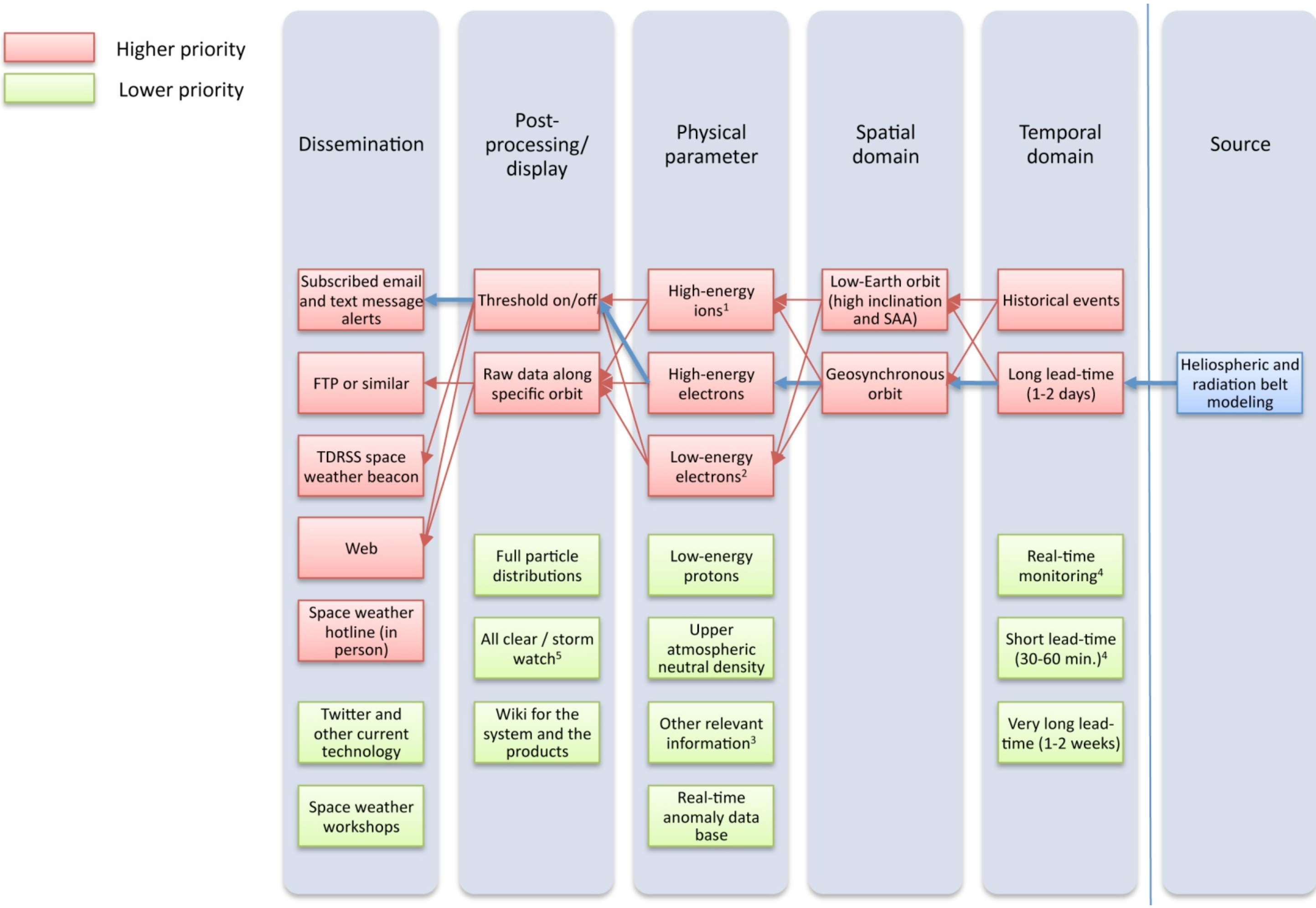
# Some Observations From the Draft Report (1 of 2)

- **The workshop identified several space weather-related system requirements common to all NASA robotic mission operations**
- **Detailed space weather impacts and system requirements depend heavily on the specifics of a particular mission, such as the phase of the mission, and on the design of the technology onboard each individual mission**
- **Flexibility and user-configurability of any space environment information system are universally accepted key requirements**
  - Robotic mission operators must be able to tailor the details of the system to fit their unique space weather information needs

# Some Observations From the Draft Report (2 of 2)

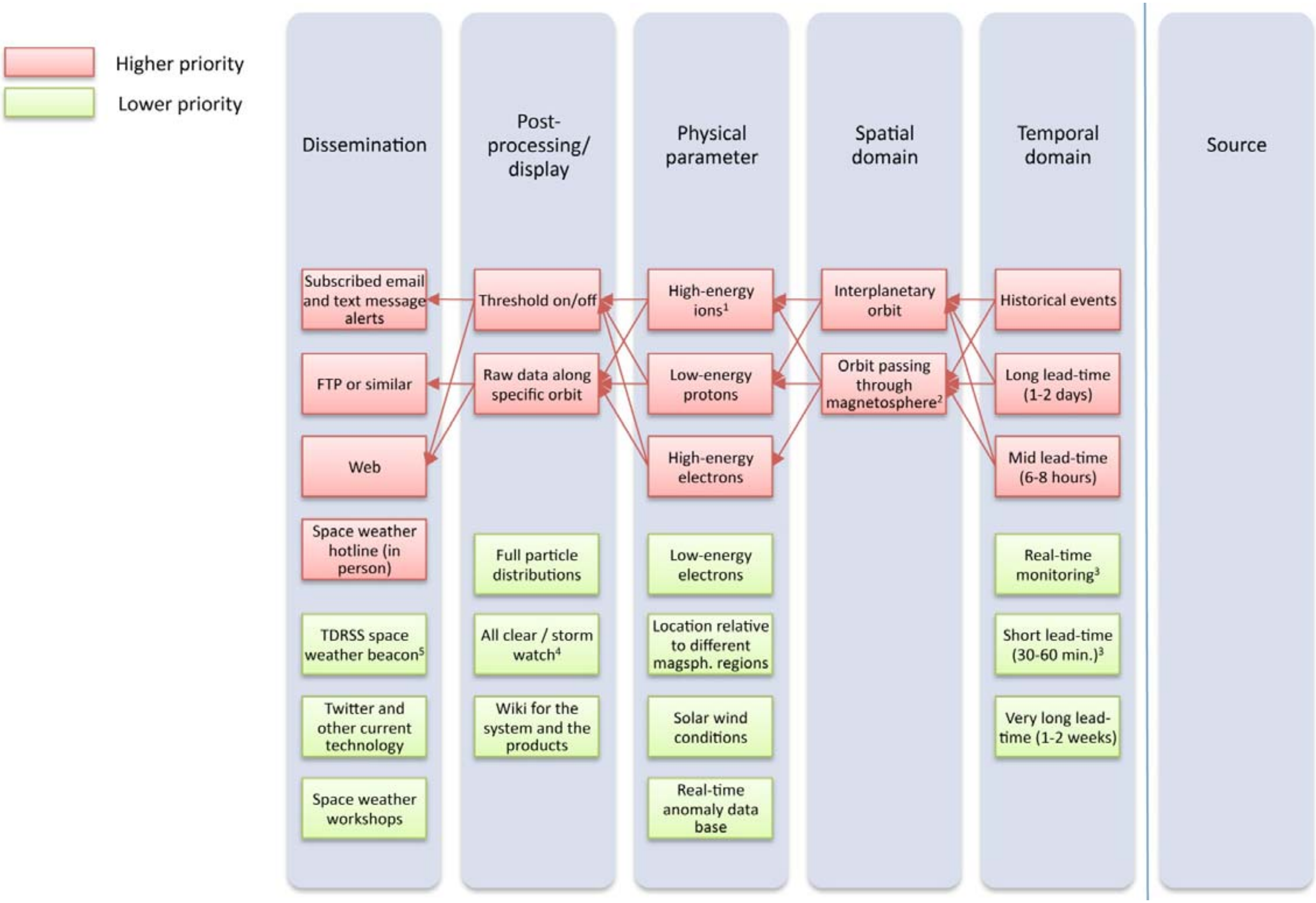
- **Onboard space environment monitoring and the sharing of the data between different robotic missions would be a highly desirable capability - assisting operators of the NASA spacecraft fleet in hazardous space weather conditions**
- **Operational decisions based solely on the information available via space environment information system can be costly**
  - For mission operators to benefit in their day-to-day operations, the information needs to be readily and reliably available
  - The requirement for redundancy is especially pressing for the capability to monitor upstream solar wind conditions

# Earth Science Mission and TDRSS Requirements



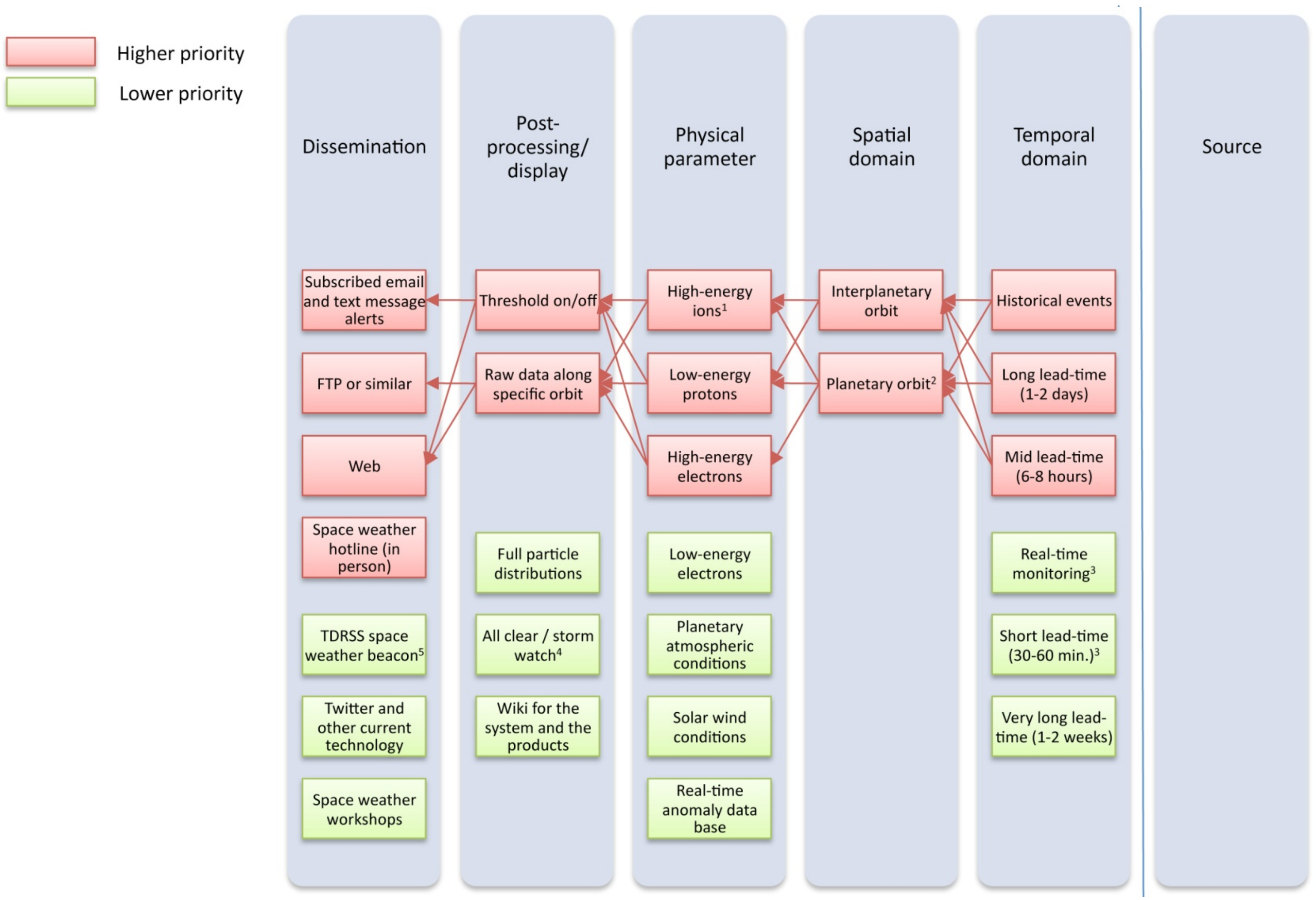

**[1]Including characterization of galactic cosmic rays and solar protons**
**[2]Including auroral electron fluxes**
**[3]Polar cap size, magnetic cutoff rigidity, Kp, Ap and Dst indices, f10.7 flux**
**[4]Provided that, for example, TDRSS space weather beacon can provide the information to spacecraft**
**[5]Including information about the start time, intensity and the end time of the event**

# Astrophysics Mission Requirements



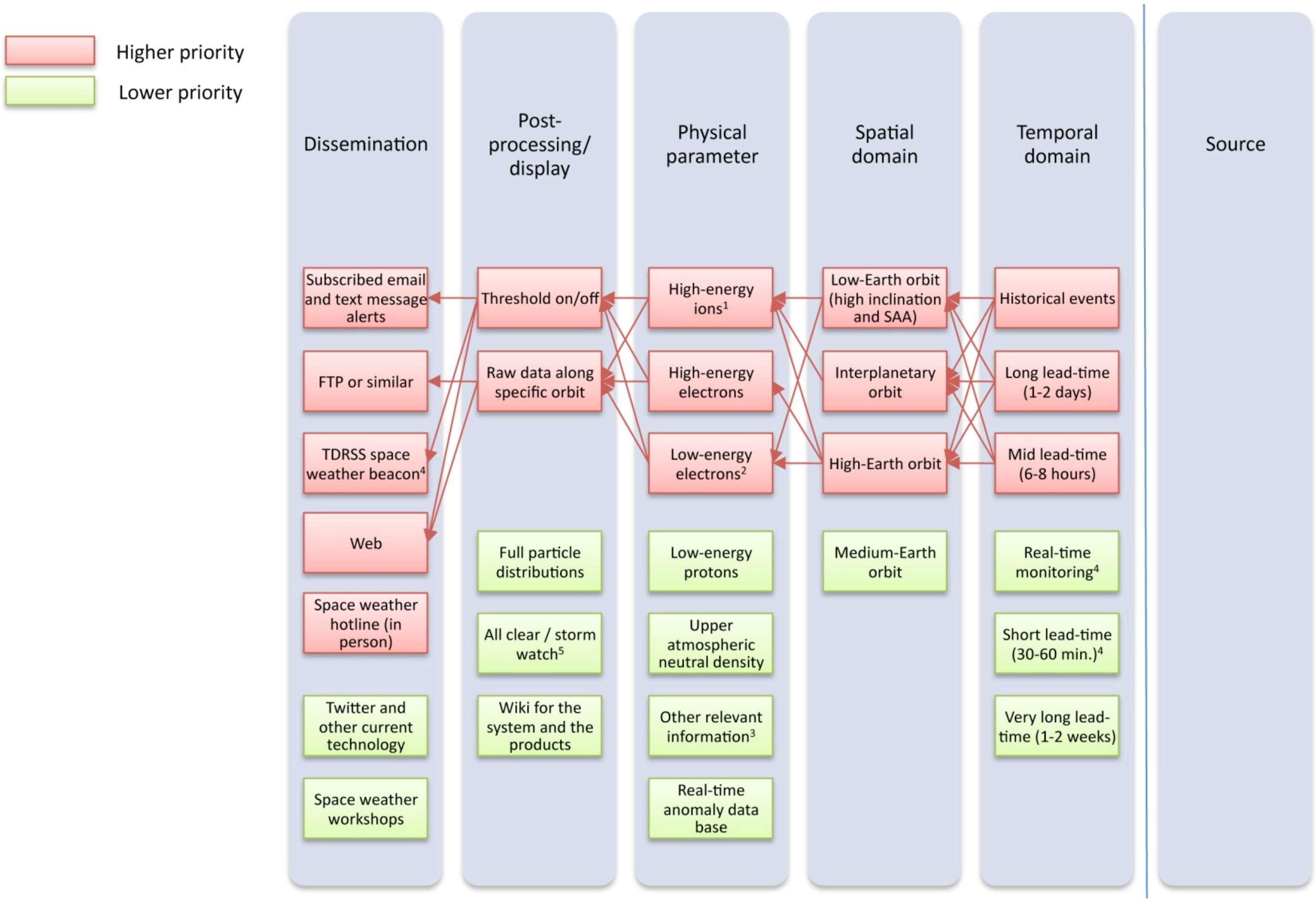

**[1]Including characterization of galactic cosmic rays and solar protons**
**[2]Including passes through radiation belts and high-inclination passes through auroral region**
**[3]Not necessarily usable due to low frequency of communications to spacecraft**
**[4]Including information about the start time, intensity and the end time of the event**
**[5]Only when close enough to the Earth**

# Planetary and Lunar Mission Requirements




[1]Including characterization of galactic cosmic rays and solar protons
[2]Including Jovian and Saturn radiation belts
[3]Not necessarily usable due to low frequency of communications to spacecraft
[4]Including information about the start time, intensity and the end time of the event
[5]Only when close enough to the Earth

# Space Science Mission Requirements




**[1]Including characterization of galactic cosmic rays and solar protons**
**[2]Including auroral electron fluxes**
**[3]Polar cap size, magnetic cutoff rigidity, Kp, Ap and Dst indices, f10.7 flux, location relative to magsph. regions**
**[4]Provided that, for example, TDRSS space weather beacon can provide the information to spacecraft**
**[5]Including information about the start time, intensity and the end time of the event**

# iSWA

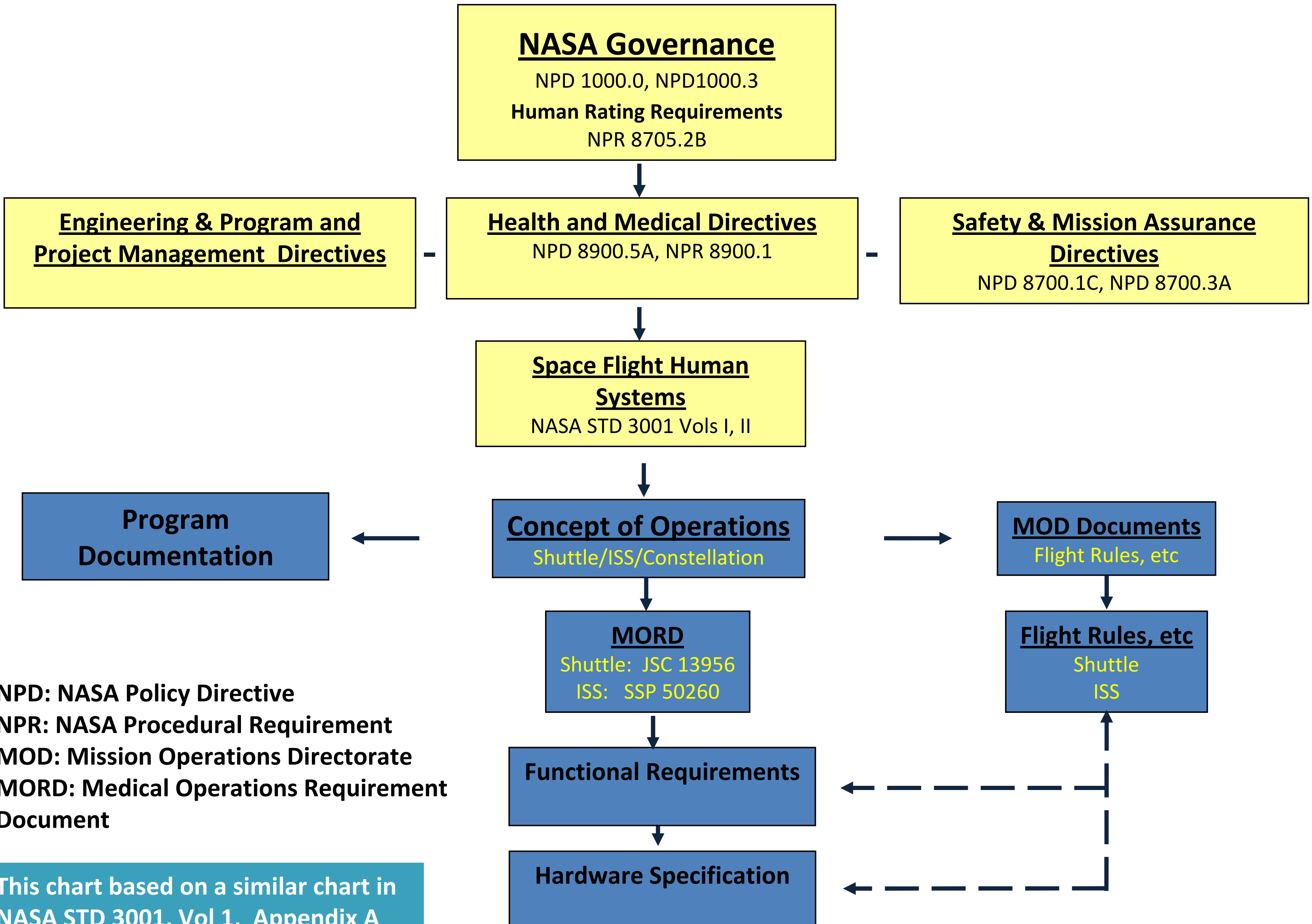
- **NASA's Office of the Chief Engineer funded the *integrated Space Weather Analysis* tool through a competitive Technical Excellence Initiative**
  - iSWA was funded prior to the OCE Space Weather Architecture study, along with several other TEIs, including one other Space Weather TEI
  - The product will be described by Marlo Maddox later in this session
- **The iSWA tool provides a means to meet a key component of an overall operational space weather support framework**

# What's Next?

- **NASA will continue to rely on NOAA for space weather forecasts, alerts, and warnings**
- **Formal documentation of requirements for robotic mission support is not as mature as it is for human mission support**
- **There has not been a NASA-wide decision on how to meet NASA-unique needs**
- **The Goddard Space Weather Laboratory is developing informal relationships with NASA operators to provide tailored, NASA-specific support**
  - SWL is providing information built around the iSWA interface
  - They will begin hosting a Space Weather Desk in mid-February

# Backup Slides

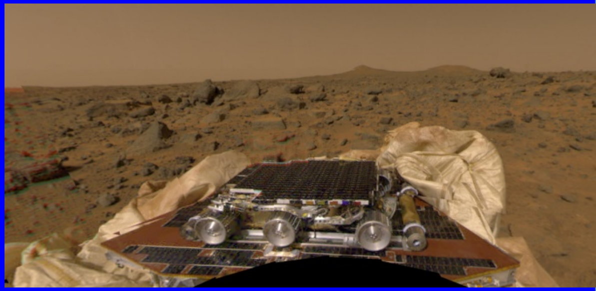
# Human Systems Radiation Requirements Document Map




**NPD: NASA Policy Directive**
**NPR: NASA Procedural Requirement**
**MOD: Mission Operations Directorate**
**MORD: Medical Operations Requirement Document**

**This chart based on a similar chart in NASA STD 3001, Vol 1, Appendix A**

# 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**

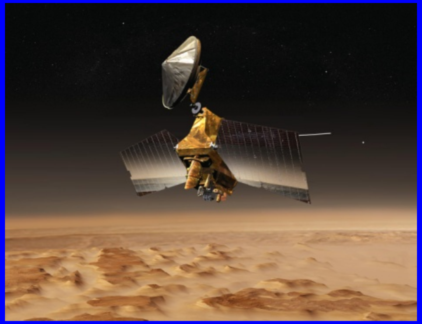
**"I have used products derived from the SWPC solar wind data in support of investigations of spacecraft anomalies, particularly on the Galileo mission to Jupiter. Not having the data easily accessible would have made the investigations more difficult or impossible."**

**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



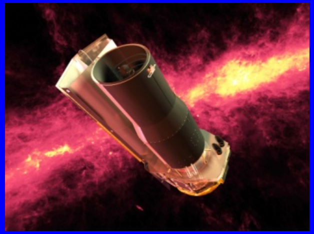
In March 2006, at the request of NASA's Mars Reconnaissance Orbiter (MRO) Mission, SWPC provided critical support to the MRO as the spacecraft neared its insertion phase into orbit around Mars. An unforeseen solar radiation storm between March 2 and March 10, could have potentially caused the loss of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

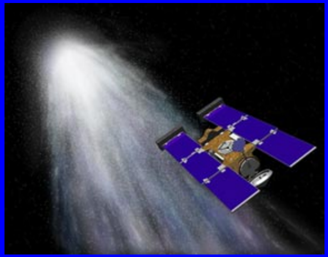
**Source: Distribution of SWPC Data and Products to NASA**, William Murtagh, NOAA SWPC, June, 2008

# 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