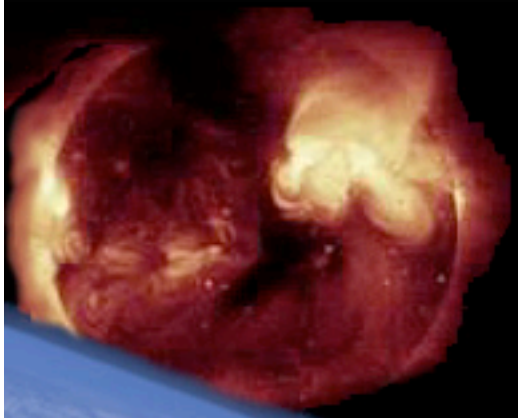
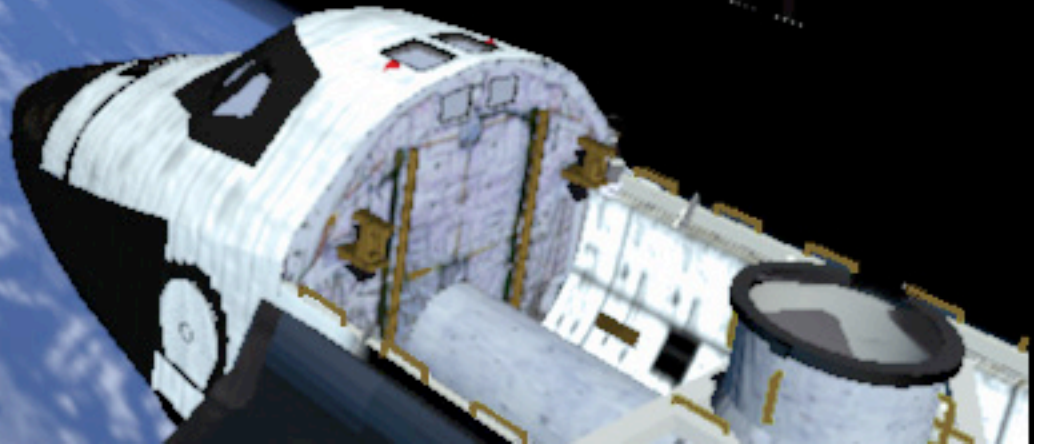
# Space Radiation Analysis Group's Top 10 List of Space Weather Needs





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# Disclaimer

The views expressed here are my own, and not necessarily those of NASA, although perhaps they should be.

(Robert L Park, APS, “What’s New” weekly email newsletter)

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# Presentation Objective

- Radiation exposure during space missions--*why do we care*?
- Okay, so radiation exposure is bad for astronauts' health--let's minimize their exposure (ALARA)
- How does space weather information help minimize astronaut radiation exposure?
- Space Radiation Analysis Group--*who are those guys and what are they concerned about*?
- Typical space weather-related questions from NASA flight management (questions from managers, hint, hint)
- What space weather providers are up against--*why won't they listen to us*?
- Space weather providers--what it takes to have an impact with NASA flight management

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# Presentation Objective (cont.)

- SRAG's "Top 10 List" of space weather needs
- A "faster, better, cheaper" bonus list!

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# Principal Health Risks from Radiation Exposure

- Acute affects
  - ✶ Extent and severity determined by type and amount of radiation exposure
  - ✶ Affects range from mild and recoverable to death
    - temporary to permanent male sterility
    - nausea and vomiting
    - bleeding and impairment of immune system
    - pneumonitis and gastrointestinal damage
    - central nervous system damage
  - ✶ Affects have an exposure threshold
  - ✶ Risk of acute affects during International Space Station missions is very small
- Long-term risks
  - ✶ Cancer risk increase
    - probability of resulting cancer related to the exposure and type of radiation—as the amount of exposure increases, the probability of cancer increases linearly
  - ✶ Cataracts
- Increase in cancer risk is principal concern for astronaut exposure to space radiation

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# Need for Maintaining Radiation Exposure As Low As Reasonably Achievable (ALARA)

- (Current) Radiation protection philosophy--any radiation exposure results in some risk
  - ✶ Any exposure, no matter how small, results in a finite (albeit small) increase in subsequent cancer risk (no threshold)
- ISS astronaut exposures will be much higher than typical ground-based radiation worker
- Space radiation more damaging than radiation typically encountered by ground-based workers
  - ✶ Experimental evidence that radiation encountered in space is more effective at causing the type of biological damage that ultimately leads to cancer than the gamma or x-rays commonly encountered on Earth
  - ✶ Animal experiment evidence of biological damage unique to high-energy heavy ions encountered in space--damage to the central nervous system similar to that associated with aging
  - ✶ Other unaccounted risks?

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# ALARA, NASA, and Space Weather

- Legal and moral reasons require NASA limit astronaut radiation exposures to minimize long-term health risks
- U.S. Occupational Safety and Health Administration officially classify astronauts as "radiation workers" and subject to the regulations that control occupational radiation exposure
  - ✶ An important component of these regulations is compliance with the ALARA concept
- Adherence to ALARA is recognized throughout NASA's manned spaceflight requirement documents
- Implementing ALARA primary basis of real-time radiological support
- Understanding and minimizing exposures from space weather events is an important implementation of ALARA for manned missions

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# Parameters Which Affect Astronaut Exposure

1. Spacecraft structure
2. Altitude
3. Inclination
4. ***EVA start time***
5. ***EVA duration***
6. ***Status of outer zone electron belts***
7. ***Status of interplanetary proton flux (SPE)***
8. Solar cycle position
9. ***Geomagnetic field conditions***

***Italics--Opportunity for ALARA***

**Red--Controlled by space weather activity**


# NASA Mission Support Team: Space Radiation Analysis Group (SRAG)

- Provide preflight crew exposure projections
- Provide real-time astronaut radiation protection support
- Provide radiation monitoring to meet medical and legal requirements
- Maintain comprehensive crew exposure modeling capability
- Small group of health physicists, physicists, and programmers
  - ✶ 0-1 civil servants
  - ✶ 4-5 contractors

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# SRAG Real-Time Flight Support

- Man console in Mission Control Center-Houston (MCC-H) 4 hr/day during nominal conditions
  - ✶ Examine available space weather data, reports, and forecasts for trends or conditions which may produce enhancements in near-Earth space radiation environment
  - ✶ Tag-up with NOAA SWO Solar Forecaster for “big picture” of space weather conditions
  - ✶ Check vehicle status and crew timeline for the potential for unscheduled EVAs
  - ✶ Report crew exposure status and space weather conditions to flight management
- Man console in MCC-H continuously during significant space weather activity

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# SRAG Real-Time Flight Support (cont)

- Provide periodic cumulative crew exposure updates to flight management
- Replanning/contingency EVA planning support
  - ✶ Tag-up day before to review EVA schedule and forecast space weather conditions
  - ✶ Provide EVA exposure analysis and start/stop time constraints to Flight Surgeon
- EVA egress-1 hour through ingress
  - ✶ EVA GO/NO GO recommendation
  - ✶ Real-time monitoring of space weather conditions
  - ✶ Immediate notification from NOAA SWO of evidence of solar particle event
  - ✶ Alert flight management of any changes to space weather conditions which may impact EVA crew exposure
  - ✶ Evaluate events and provide recommendations for continuing, delaying, or terminating EVA
  - ✶ Track exposure from nominal radiation environment
  - ✶ Monitor ISS radiation instrument data (when available)

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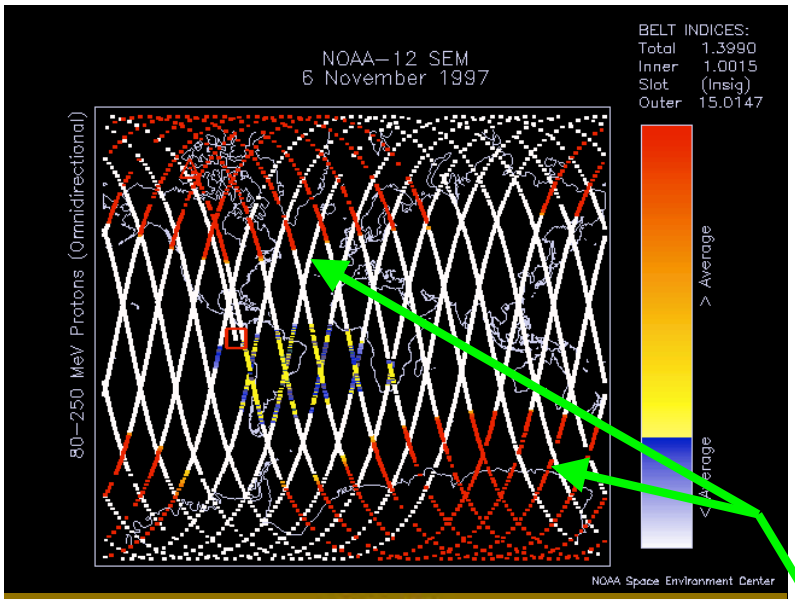
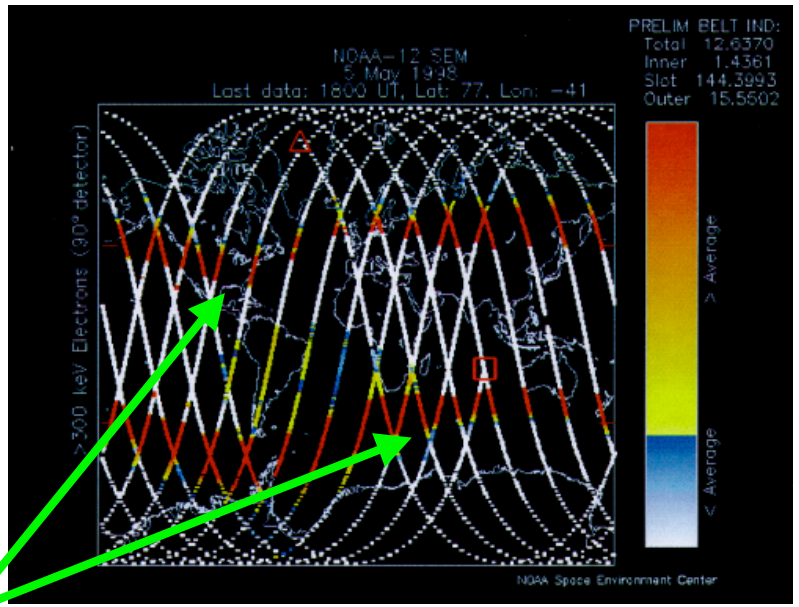
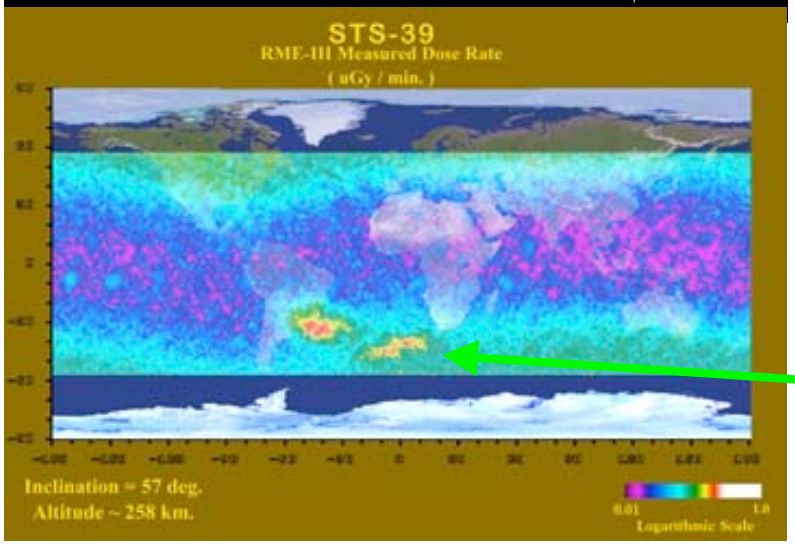
# Space Weather Induced Radiation Enhancements of Concern to ISS Operations




Outer Electron Belt Enhancement: electrons > 500 keV

SPE: protons > 10 MeV

Additional Radiation Belts: protons, high energy electrons?

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# Operational Space Weather Information Flow

**Mission Commander:**
*Responsible for safe execution of mission*

**IVA Astronaut:**
*Supports, monitors, and directs EVA crews*

**EVA Astronaut:**
*Performs task*

**CAPCOM:**
*Communicates with crew, represents crew requirements*

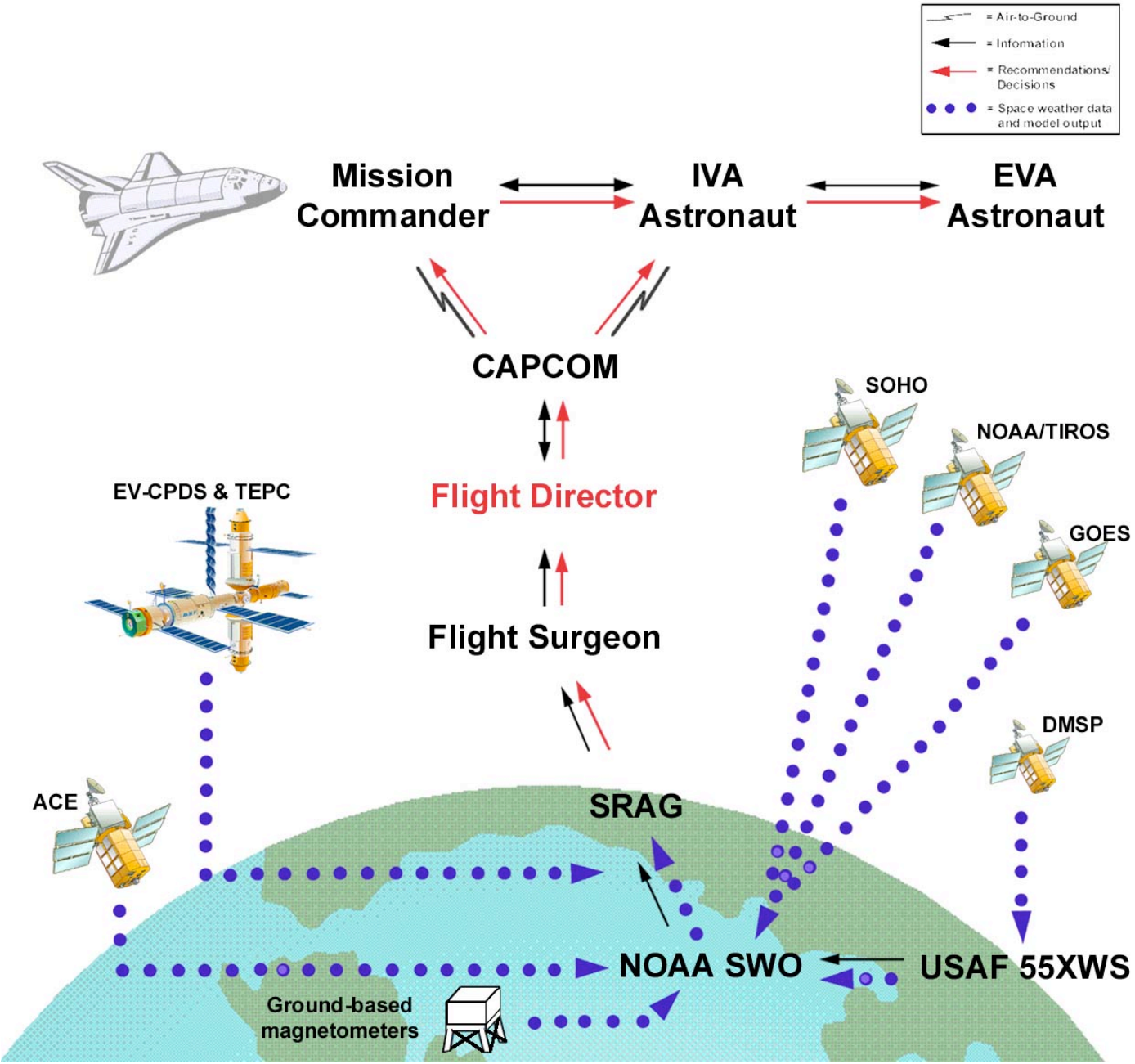
**Flight Director:**
*Overall responsibility for safe mission execution*

**Flight Surgeon:**
*Monitors crew health, emergency treatment*

**SRAG:**
*Monitors crew radiation exposure*

**NOAA SWO:**
*Monitors space environment conditions*

**USAF 55XWS:**
*Provides space environment support backup to NOAA SWO*



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# Typical Questions from Flight Management

- "We saw *fill in the anomaly* on the *fill in the hardware/system* at MET XXX:XX:XX. Was this caused by solar activity?"

OR

- "Is our bad downlink/bad comm today caused by solar activity?"
- "What's the solar forecast during tomorrow's EVA?"
- [as soon as a flare occurs] "Is there any impact to the crew/vehicle?"
- "Are you go for EVA?"
- "Can you make a picture of that for my post-shift briefing?"
- [as soon as SPE starts] "Are we going to exceed any crew exposure limits?"
- "How long is *fill in the event* going to last?"

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# Typical Questions . . . (cont.)

- "How reliable is that forecast/projection?"
- "Do I need to shutdown any systems?"
- "When do I need to shutdown systems?"
- "Are we going to exceed crew limits for this 90 day (90-360 day) mission?"
- "What is the probability a solar flare will occur during an EVA on *fill in the mission*?"

OR

- "What is the probability we'll have to postpone/cancel an EVA during *fill in the mission*?"
- "I just heard on CNN/read in *fill in the publication* about a big solar storm. How come you didn't warn me? What is the impact to crew safety?"

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# Typical Questions . . . (cont.)

- "Why is the F10.7 different from yesterday's forecast?"
- "Do the *fill in the International Partner* know about this?"

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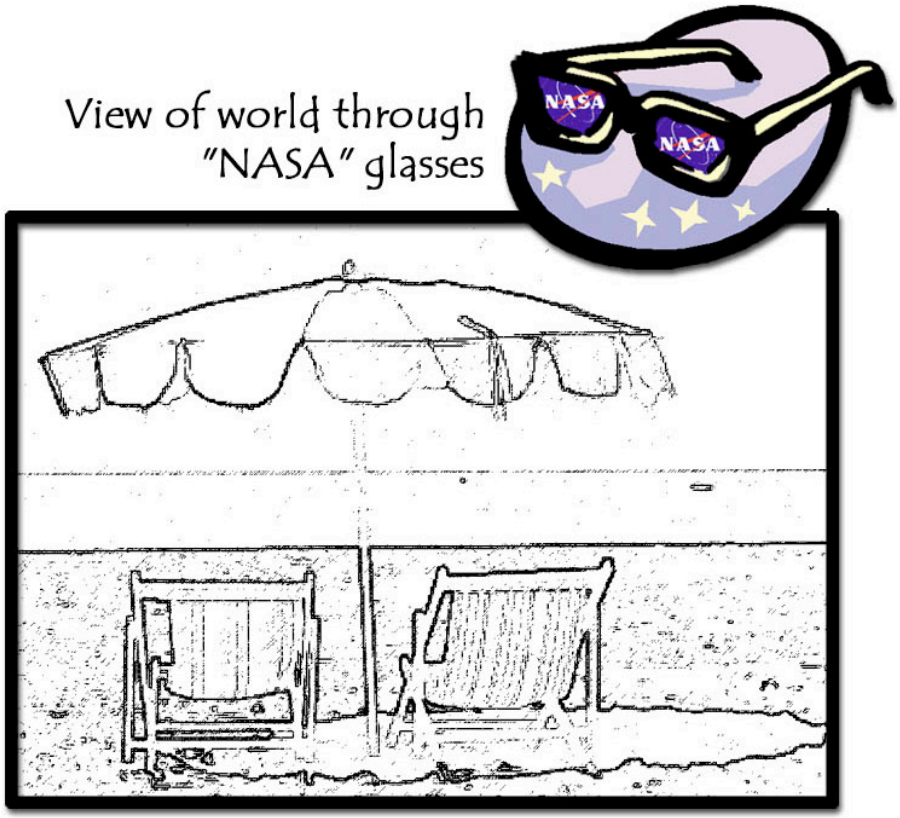
# What Space Weather Service Providers are Up Against--"Why Won't They Listen to Us?"

- Flight controllers/management are engineers, not scientists
  - ✶black and white world versus gray-scale world

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# . . . "Why Won't They Listen to Us?" (cont.)

- Unfamiliarity with space weather phenomenology
  - ✶ can't see it, hard to measure it, affects not readily apparent
- Probabilistic nature of phenomena and effects
  - ✶ not a 1-to-1 correlation between phenomena and effect
- No real history of any impact during U.S. or Russian manned space programs
  - ✶ a false impression of security
- The events which may impact a manned mission happen very infrequently
  - ✶ very large SPEs occur perhaps a few times per cycle
- Historically poor accuracy of forecasts for significant events

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# . . . "Why Won't They Listen to Us?" (cont.)

- Important human affects are not immediate, are probablistic in nature, and have large uncertainties
  - ✶ acute affects are virtually unlikely
  - ✶ cancer is the primary risk
  - ✶ large uncertainties in conversion of changes in space environment to a risk
- Cost of actions versus resulting risk
  - ✶ ~$500M per Shuttle mission
  - ✶ costs to program of not meeting mission objectives
    - – ISS assembly requires unbroken sequence of successful missions
- Extremely tight timelines, especially for EVAs
  - ✶ virtually every minute of missions are planned--delays or changes caused by space weather-related actions can have a tremendous "ripple" affect through remainder of mission
  - ✶ EVAs have ~1-2 orbits (90-180 minutes) of possible delay
  - ✶ emergency EVA termination carries risks to vehicle and crew

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# . . . "Why Won't They Listen to Us?" (cont.)

- Subjective balancing of risks
  - ✶ risks from taking actions to minimize space weather impact compared with catastrophic risks which have not been quantified
- Important hardware effects are probabilistic in nature
  - ✶ destructive latchups
  - ✶ SEUs
- Given all of the factors flight controllers must weigh in making operational decisions, space weather impacts which are not certain (or highly likely) lose out to the certainties of other spacecraft engineering problems.

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# Space Weather Data, Forecasts, and Models -- "What Does it Take to Have an Impact?"

## Requirements for Serious Use/Consideration by NASA Flight Management

- Very low false alarm rate
- Accurate results
- Quantification of probabilities
  - ✶ how likely?
- Quantification of uncertainties
  - ✶ how good are the predictions?
- Information/data can be easily obtained on Mission Control's computer systems
  - ✶ DEC Alpha workstations (now)
  - ✶ ? future platform

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# . . . "What Does it Take to Have an Impact?" (cont.)

- Data, forecasts, or model results must be produced within a relevant time frame
  - ✶ immediacy
- Data, forecasts, or model results must look far enough into the future
  - ✶ predictiveness
- Data, forecasts, or model results must directly apply to manned spacecraft effects
  - ✶ crew exposures
  - ✶ electronic upsets/failures
  - ✶ exterior surface/component degradation
  - ✶ spacecraft drag
  - ✶ communication disruption
  - ✶ apply to low-Earth orbits typically used by the Shuttle or ISS ( < 62° geographic latitude and <~500 km)

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# SRAG's Top 10 List of Space Weather Needs--"What Were They Thinking When They Made Their List?"

1. Maintain current space weather support capabilities into the future
2. Fix short comings in our current monitoring and crew exposure projection capabilities
3. Automate, automate, automate (make computers do the work for us)
4. Expand our crew exposure projection capabilities
5. Improvements to general operational radiological support

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# SRAG's Top 10 List of Space Weather Needs

10 Reconstruction of conditions for a given time/location of a spacecraft anomaly

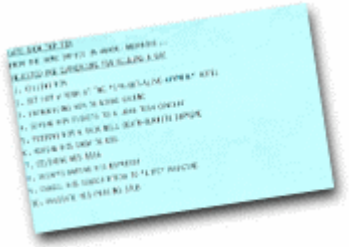
9 Maintain operations of most promising space weather sciences sensors/missions until operational versions are available (e.g., SOHO, ACE)

8 "All clear" forecast for next 24-72 hours

- ✶ used to optimize EVA planning
  - – ISS construction EVAs conducted from the Shuttle (majority of EVAs) have very limited schedule flexibility--need to plan to use planned contingency times carefully
  - – maintenance EVAs conducted from the ISS have more schedule flexibility and can benefit from forecasts of "all clear" periods

7 Geomagnetic storm forecasts

- ✶ important as in input to dynamic electron belt enhancement and geomagnetic cutoff models



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# SRAG's Top 10 List of Space Weather Needs

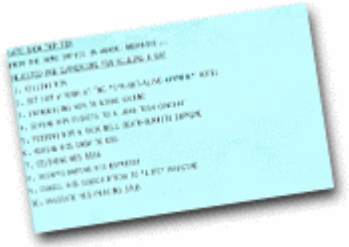
6 Dynamic geomagnetic cutoff model and/or real-time measurements of cutoff location

5 Improvements to solar particle event (SPE) phenomenology nowcasts and forecasts

- ✶ SPE flux profile projections
  - – periodically update profile projections using spacecraft measurements
- ✶ shockwave arrival timing
- ✶ heavy-ion flux information
  - – important hazard to critical ISS systems
- ✶ improved spectral fit of SPE integral proton flux beyond ~100 MeV

4 Realistic space weather simulation system

- ✶ required to test user real-time systems and train new flight controllers
- ✶ driven by historical data and/or model output
- ✶ data accessible by same mechanism as "real" data--same format and cadence



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# SRAG's Top 10 List of Space Weather Needs

3 API to allow direct output from data sources or models into user applications (via TCP/IP)

- ✶ e.g., Distributed Information Dissemination System

2 Quantitative dynamic model of electron belt flux (electron belt enhancements)

1 Healthy NOAA SEC, in particular Space Weather Operations

- ✶ robust national space weather service
- ✶ as goes the health of NOAA SWO, so goes the health of SRAG's support to spaceflight