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Presentation Objective

- Explain why radiation exposure is an important concern for manned spaceflight
- Discuss NASA’s emphasis on maintaining astronaut radiation exposures as low as reasonably achievable
- Show how space weather information is a fundamental tool for minimizing astronaut radiation exposure
- Outline NASA’s real-time radiological support for manned missions, including the role of space weather data and information
- Provide examples of recent improvements in NASA’s real-time use of space weather data

Space Radiation--A Fundamental Problem for NASA's Manned Spaceflight Objectives

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- Legal, moral and practical considerations require NASA limit postflight risks incurred by humans living and working in space to "acceptable" levels
- Radiation protection is essential to enable humans to live and work safely in space
- Astronaut radiation protection is addressed as part of the *NASA Strategic Plan*
  - ✶ "Understand the effects of space radiation on electronic, biological, chemical, and physical systems and processes." (strategy 1.1.3)
  - ✶ "Develop human support technologies and advanced systems to achieve exploration goals." (strategy 2.3.1)
  - ✶ Investigate human needs on future transportation systems, including protection from radiation environments (GCR to nuclear power sources)." (strategy 3.3.1)
- NASA Space Radiation Health Program to address radiation issue
  - ✶ Goal: Achieve human exploration and development of space without exceeding acceptable risk from exposure to ionizing radiation.

Principal Health Risks from Radiation Exposure

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- 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

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

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- (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?

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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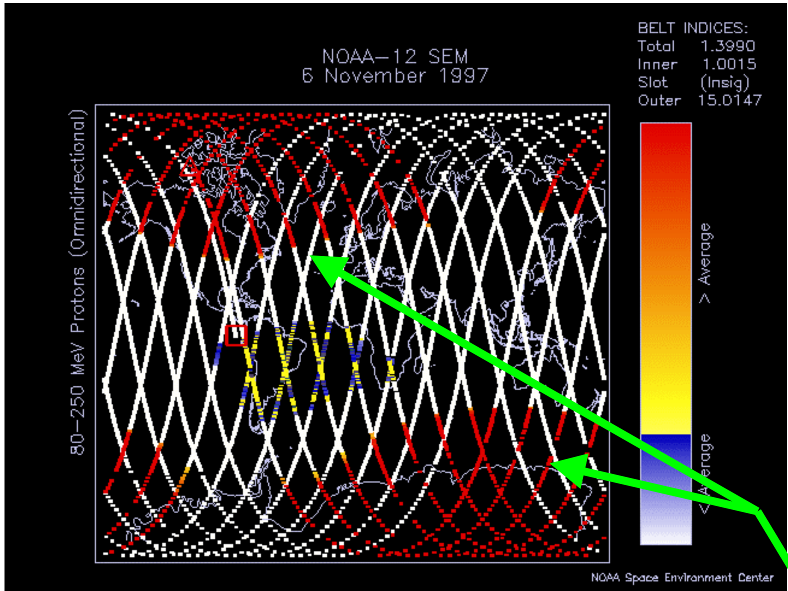
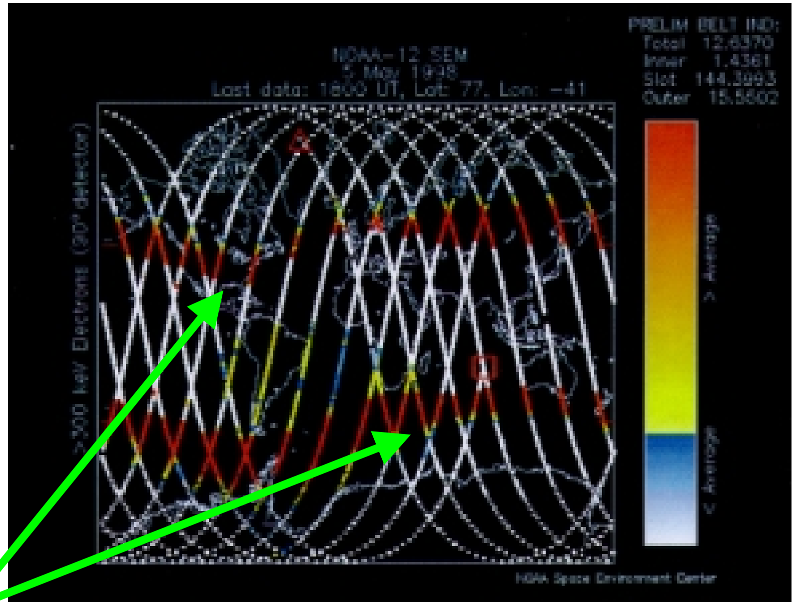
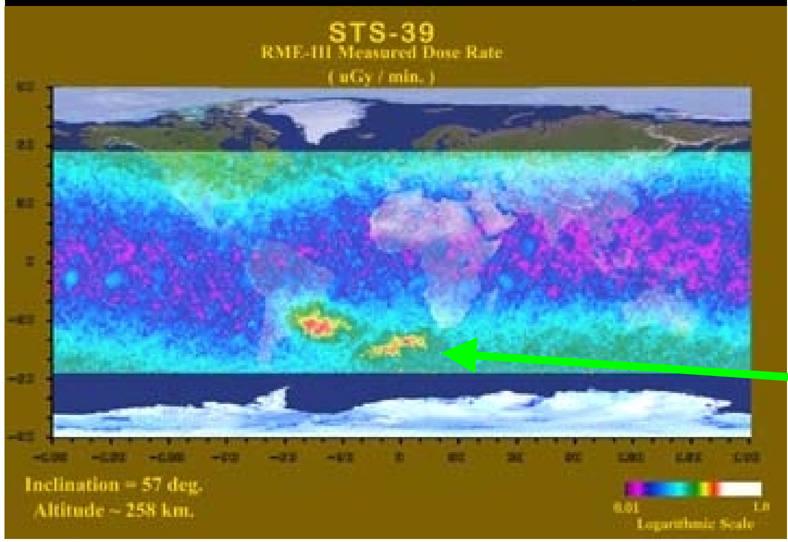
Space Weather Induced Radiation Enhancements of Concern to ISS Operations







Outer Electron Belt Enhancement: electrons > 500 keV

SPE: protons > 10 MeV

Additional Radiation Belts: protons, high energy electrons?

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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

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Example of ALARA and Space Weather-- Impact of Postponing an EVA During an SPE

		Shuttle				ISS			
		Nominal		Enhanced		Nominal		Enhanced	
		Dose (μGy)	Dose Eqv (μSv)	Dose (μGy)	Dose Eqv (μSv)	Dose (μGy)	Dose Eqv (μSv)	Dose (μGy)	Dose Eqv (μSv)
Inside Spacecraf	**BFO**	37.7 53.1	46.7 67.7	2120		18.9 23.2	23.0 28.8	621	
	Skin	59.2 105	74.3 140	5471		26.9 36.3	32.9 45.7	1296	
Inside EMU	**BFO**	74.0 120	92.5 156	6042		74.0 120	92.5 156	6042	
	Skin	1620 1580	2550 4270	9551		1620 1580	2550 4270	9551	
EVA Enhancement	**BFO**	36.4 66.4	45.8 88.4	3920		55.1 96.3	69.5 127	5420	
		96.4% 125%	97.9% 131%	185%		292% 415%	302% 442%	873%	
	Skin	1560 1470	2480 4130	4080		159 154	252 423	8260	
		2640% 1400%	3330% 2940%	74.6%		5930% 4240%	7650% 9250%	637%	

Notes: Nominal Environment—400 km, 51.6° inclination, AP8/AE8, solar max and solar min, worst case start time. Enhanced—19 Oct 1989 SPE, 6 hour flux beginning at 1350Z 20 Oct 1989 (just prior to shock arrival) with worst case trajectory. Shuttle location—heavily shielded location on middeck with airlock in payload bay. ISS location—middle of Hab module at assembly complete configuration. EMU—0.162 g/cm^2 Al equivalent shielding.

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
  - 2 civil servants
  - 4-5 contractors

SRAG Preflight Planning and Analysis Support

- L-4 months: complete preliminary EVA exposure analysis from nominal environment and forward to Flight Surgeon and Radiation Health Officer
- L-5 weeks: complete final analysis of EVA exposure from nominal environment
- L-4 weeks: report analysis of planned and contingency EVA exposures to EVA and Medical flight management at Flight Readiness Reviews

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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

SRAG Real-Time Flight Support (cont)

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- 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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SRAG Warning and Alert Criteria

- Watches/Warnings
  - ✶ X-Ray flare
  - ✶ SPE
    - ≥ 10 pfu @ ≥ 10 MeV
  - ✶ Energetic SPE
    - ≥ 1 pfu @ ≥ 100 MeV
  - ✶ Major Geomagnetic Storm
    - $A_B \geq 50$
    - $K_B = 6$

- Alerts
  - ✶ Major X-Ray Flare
    - ≥ M5
  - ✶ Major Integral X-Ray Event*
    - integral x-ray flux ≥ 0.3 $J\text{-}m^2$
  - ✶ SPE (yellow)
    - ≥ 10 pfu @ ≥ 10 MeV
  - ✶ Energetic SPE (red)
    - ≥ 1 pfu @ ≥ 100 MeV
  - ✶ SPE Onset*
    - ??? (15-44 MeV)
  - ✶ Major Geomagnetic Storm (yellow)
    - $A_B = 50\text{-}99$
    - $K_B = 6$
  - ✶ Severe Geomagnetic Storm (red)
    - $A_B \geq 100$
    - $K_B \geq 7$

[yellow] SRAG recall to Mission Control

[red] SRAG remain on console

* alert product still in development

Space Environment Support Teams

- NOAA Space Environment Center/Space Weather Operations (NOAA SWO)
  - ✶ Principle organization for providing space weather support to civilian customers
  - ✶ Boulder, CO
  - ✶ Space weather equivalent to National Weather Service
  - ✶ Receive real-time space environment data from variety of operational satellites, ground stations, ground-based solar observatories, NASA science spacecraft, and the USAF and make data and products available to customers
  - ✶ Solar Forecasters--24 hr/day support
  - ✶ SolTechs--24 hr/day support

NOAA Space Environment Center, Boulder, CO

Space Environment Support Teams (cont)

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- NOAA SWO (cont)
  - ✶ In-flight support
    - – provide appropriate alerts and warnings by phone and pager
    - – daily space weather reviews and forecasts via telecon
    - – weekly summaries and forecasts via email
    - – supplies real time/near real time operational space weather data via the World Wide Web, ftp, custom display software, and direct database access

NOAA Space Weather Operations Center

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Space Environment Support Teams (cont)

- USAF 55th Space Weather Squadron (55 XWS)
  - ✶ Principle organization for providing space weather support to military customers
  - ✶ Colorado Springs, CO
  - ✶ Receive space environment data from DoD operational satellites and NOAA SWO and produce various model outputs
  - ✶ Manned 24 hr/day by military staff
  - ✶ In-flight support
    - – provides space weather data and forecasts (auroral oval plots, real-time K_P, etc.) via NOAA SWO
    - – backup operational support

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

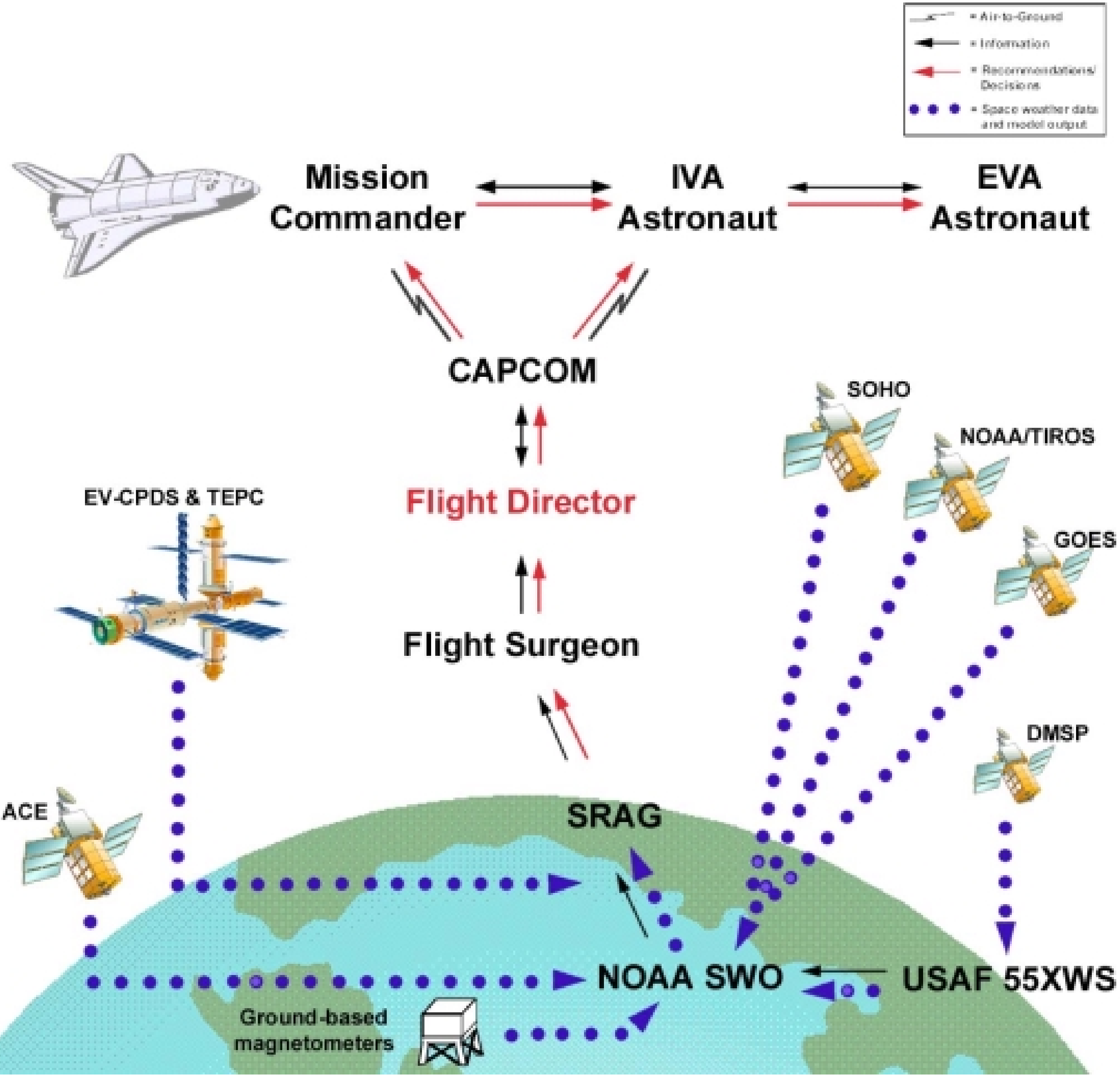
Flight Director:
Overall responsibility for safe mission execution

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



Radiation Monitoring System

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Key

EV-CPDS: ***Extra-Vehicular Charged Particle Spectrometer***

IV-CPDS: ***Intra-Vehicular Charged Particle Spectrometer***

TEPC: ***Tissue Equivalent Proportional Counter***

RAM: ***Radiation Area Monitors*** **(TLDs)**

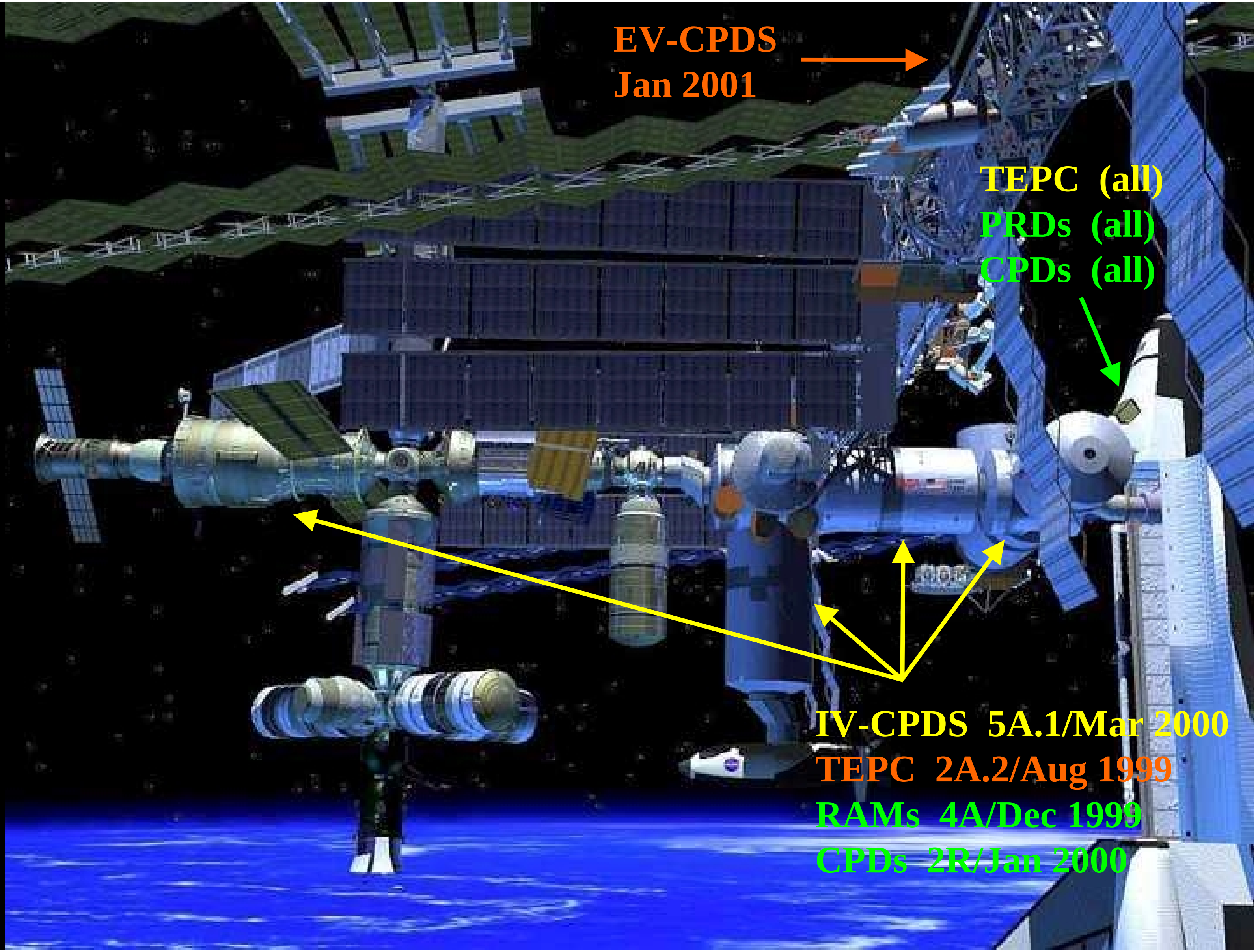
PRD: ***Passive Radiation Dosimeter*** **(TLDs)**

CPD: ***Crew Passive Dosimeter*** **(TLDs, PNTD)**

Active instrument real-time telemetry

Active instrument no real-time telemetry

Passive instrument



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SRAG Space Weather Support Improvements

- Trapped radiation belt index
- Direct access to real-time space weather data
- Space weather monitoring and alarm system
- Automatic alerting via alphanumeric pagers
- Real-time SPE analysis system (SPE-RT)
- Improved geomagnetic cutoff algorithms for SPE analyses
- Realistic space weather simulation system system

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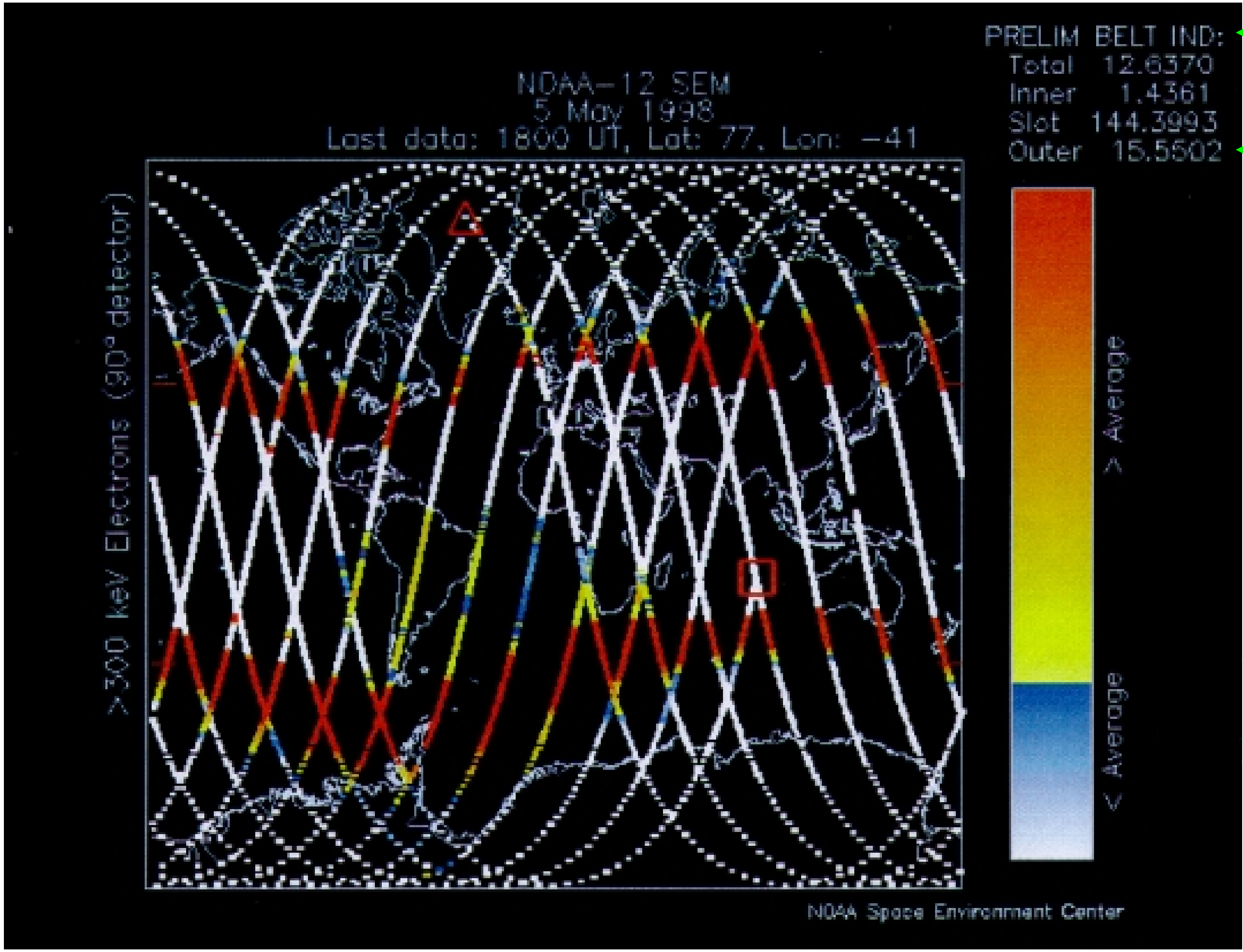
Trapped Radiation Belt Index

- Based on polar orbiting NOAA/TIROS satellite electron and proton detectors
- New index to quantify enhancements in trapped radiation belts relative to a 1-year average baseline
- Developed in conjunction with NOAA SEC
- Trapped belt index defined as

$$\int_{ephemeris} \phi_{i-actual}(>E) \; / \; \int_{ephemeris} \phi_{i-baseline}(>E)$$

- Excellent method to monitor outer trapped electron belts for enhancements following geomagnetic storms which may significantly increase the dose to EVA astronauts

Trapped Radiation Belt Index (cont)



Trapped Radiation Belt Indices

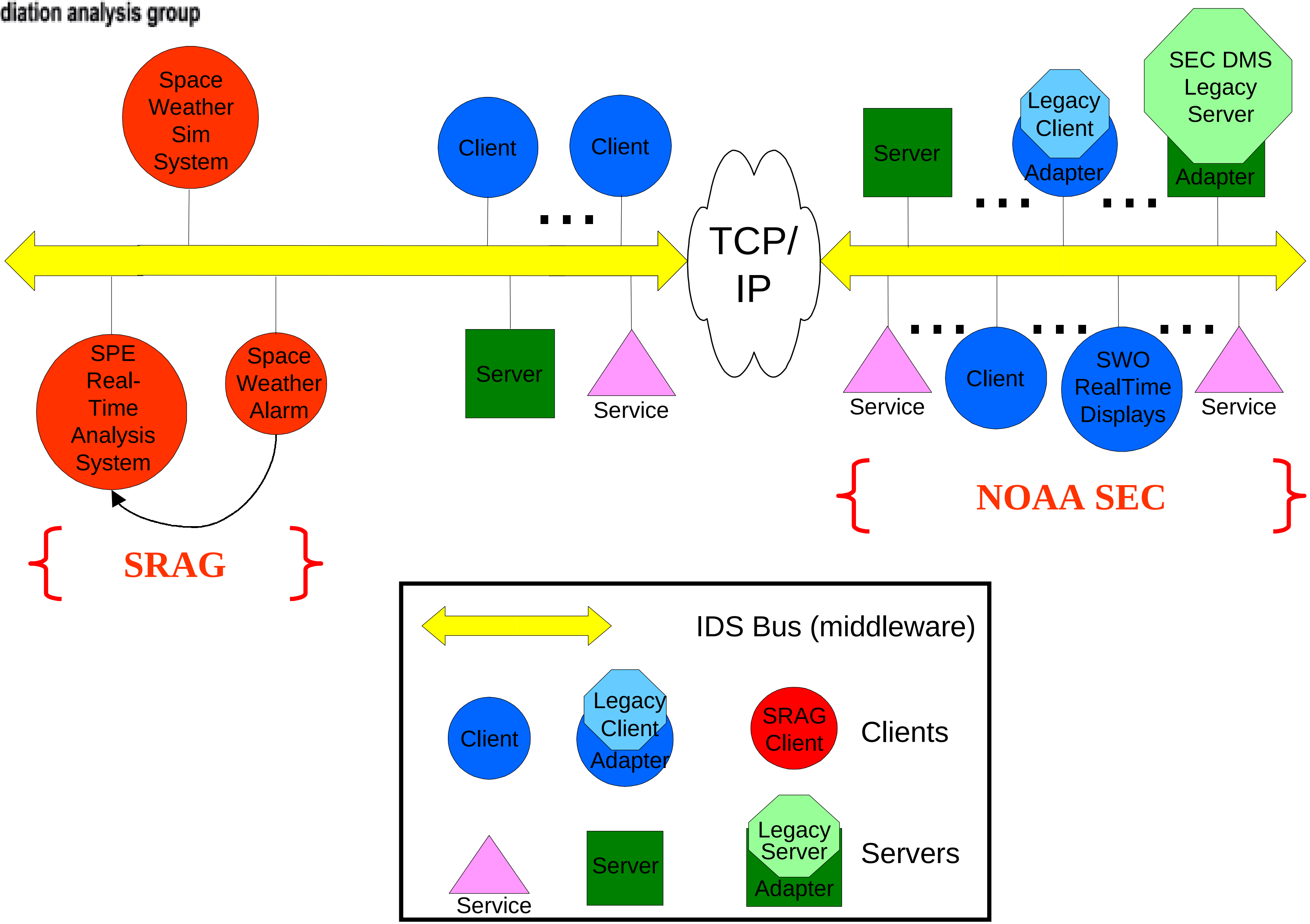
Outer zone electron flux is elevated a factor of 50 over background levels!

NOAA/TIROS energetic particle "tiger" plot with trapped belt indices (NOAA SEC web site)

Direct Access to Real-Time Space Weather Data

- NOAA SEC development of the Information Dissemination System (IDS)
  - ✶ Built around the Common Object Request Broker Architecture (CORBA)
  - ✶ Platform independent--can be used in heterogeneous computing environment
  - ✶ Applications and data stores are isolated from data bus by Interface Definition Language (IDL)
  - ✶ Very flexible and extensible architecture--easy to add new applications or data stores
  - ✶ Bi-directional data bus--easy to share SRAG data and model output with SEC
- SRAG applications directly accessing NOAA SWO space environment data stores via IDS Interface Definition Language (API)
  - ✶ Currently directly accessing serial data from SEC Data Management System (DMS) in SRAG Space Weather Monitoring and Alarm System and real-time SPE analysis system (FORTRAN- and C-based software)
  - ✶ Request data by keyword with optional date/time parameter
  - ✶ Data returned to "standard in"

Direct Access to Real-Time Space Weather Data (cont)



Space Weather Monitoring and Alarm System

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- SRAG Space Weather Monitoring and Alarm System
  - ✶ Running on DEC Alpha workstations
  - ✶ Two components
    - – data acquisition, monitoring, alarm, and logging system
      - ✓ runs continuously in background as a daemon
      - ✓ acquires data directly from SEC DMS
      - ✓ event alarm algorithms for x-ray flares, solar particle events, energetic solar particle events, and geomagnetic disturbances
      - ✓ tracks events' histories
      - ✓ monitors status of data acquisition for loss of connectivity
      - ✓ logs alarms and actions
      - ✓ issues alerts to alphanumeric pagers and email distribution list
      - ✓ automatically activate analyses programs (e.g., real-time SPE analysis)
    - – monitor and alarm status window
  - ✶ X-ray, SPE, energetic SPE, geomagnetic storm, and loss of network connectivity alarms running since Aug 98
    - – tuning event detection, event maximum, and event termination algorithms

Automatic Alerting via Alphanumeric Pagers

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- Due to funding constraints, SRAG cannot obtain sufficient staffing for 24 hour/day real-time flight support
- Automatic alerting of SRAG flight controllers via alphanumeric pagers allows rapid, on-call response
  - ✶ Automatically receive NOAA SWO alerts when events exceed SRAG criteria
  - ✶ Receive alert and status messages from SRAG Space Weather Monitoring and

NOAA SWO alert routed to pager

SRAG space weather alert

Real-Time SPE Analysis System (SPE-RT)

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- Improved SRAG SPE exposure analysis system
  - ✶ Couples temporal variations in SPE spectra with continuously varying geomagnetic cutoff at vehicle location
  - ✶ Improved geomagnetic cutoff calculation
  - ✶ Integrate exposure over proton spectrum from cutoff energy to 2.5 GeV
  - ✶ SPE dose calculation errors reduced from factors of 900-4300 to < factor of 2 (in comparison to dosimetry results from Shuttle and Mir)
  - ✶ Fast analysis system--can easily keep pace with real-time needs
  - ✶ Multiple options allow running software in “research” mode or “real-time” mode
    - – provide preexisting trajectory file or current spacecraft state vector
    - – provide preexisting GOES proton flux data file or retrieve real-time values from SEC DMS
    - – autonomous option automatically obtains spacecraft state vector from ISP servers and SPE data from SEC DMS
  - ✶ Exposure analysis system can be activated by SRAG Space Weather Monitoring and Alarm System

Real-Time SPE Analysis System (SPE-RT) (cont)

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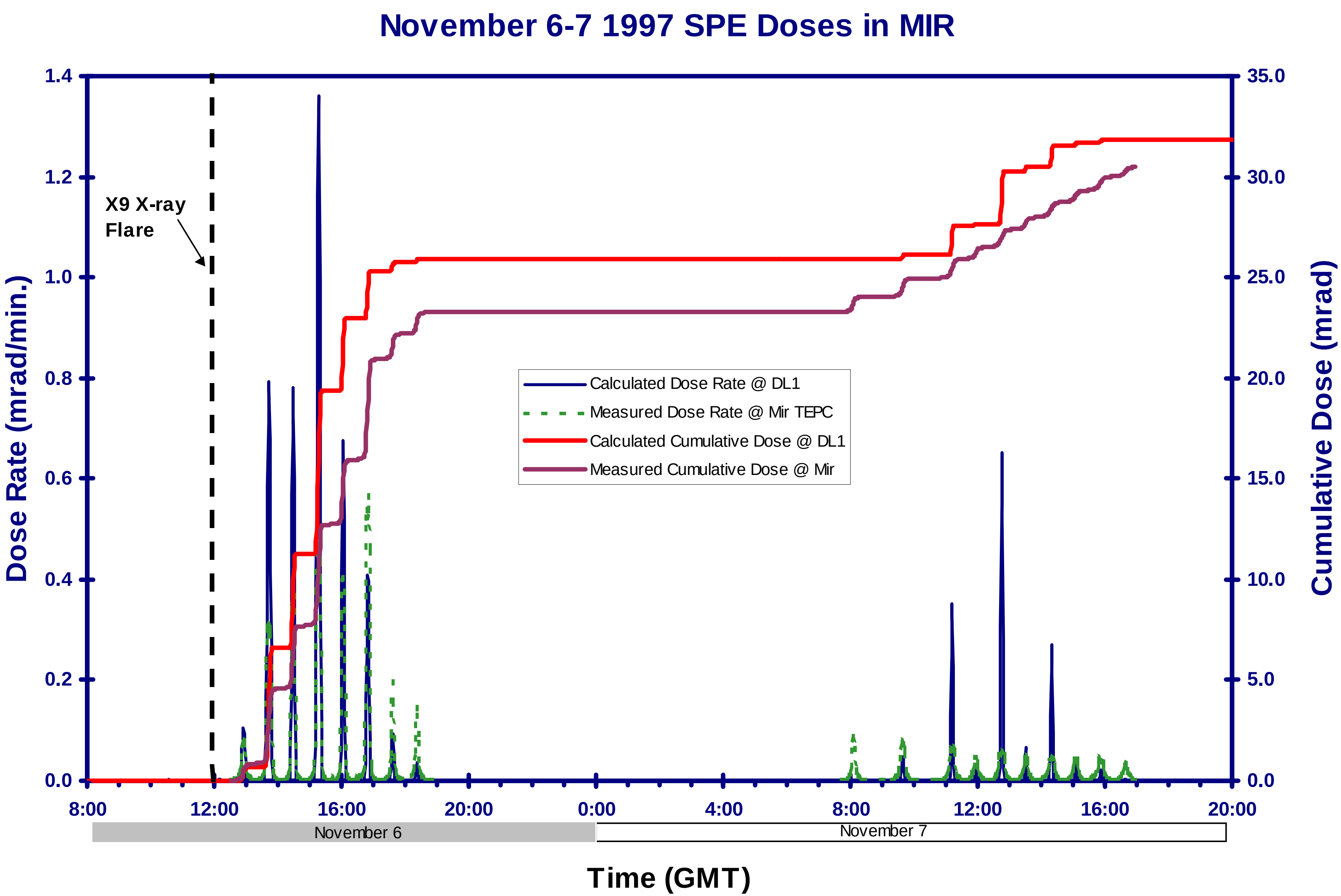

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Improved Geomagnetic Cutoff Algorithms for SPE Analyses

- Updated geomagnetic cutoff model
  - ✶ Smart and Shea vertical and westward cutoffs at 450 km
  - ✶ Discrete values over 5° latitude, 15° longitude grid for a 1990 epoch
  - ✶ Scale to different altitudes with McIlwain L-shell parameter
  - ✶ Valid only during quiescent periods
- Develop dynamic geomagnetic cutoff model
  - ✶ Contract with University of Alabama (Smart and Shea) to develop dynamic cutoff model
    - – equatorward movement of cutoff boundaries with increasing geomagnetic activity
  - ✶ Preliminary cutoffs for K_P = 0-5 delivered Sep 98 for evaluation

Improved Geomagnetic Cutoff Algorithms for SPE Analyses (cont)

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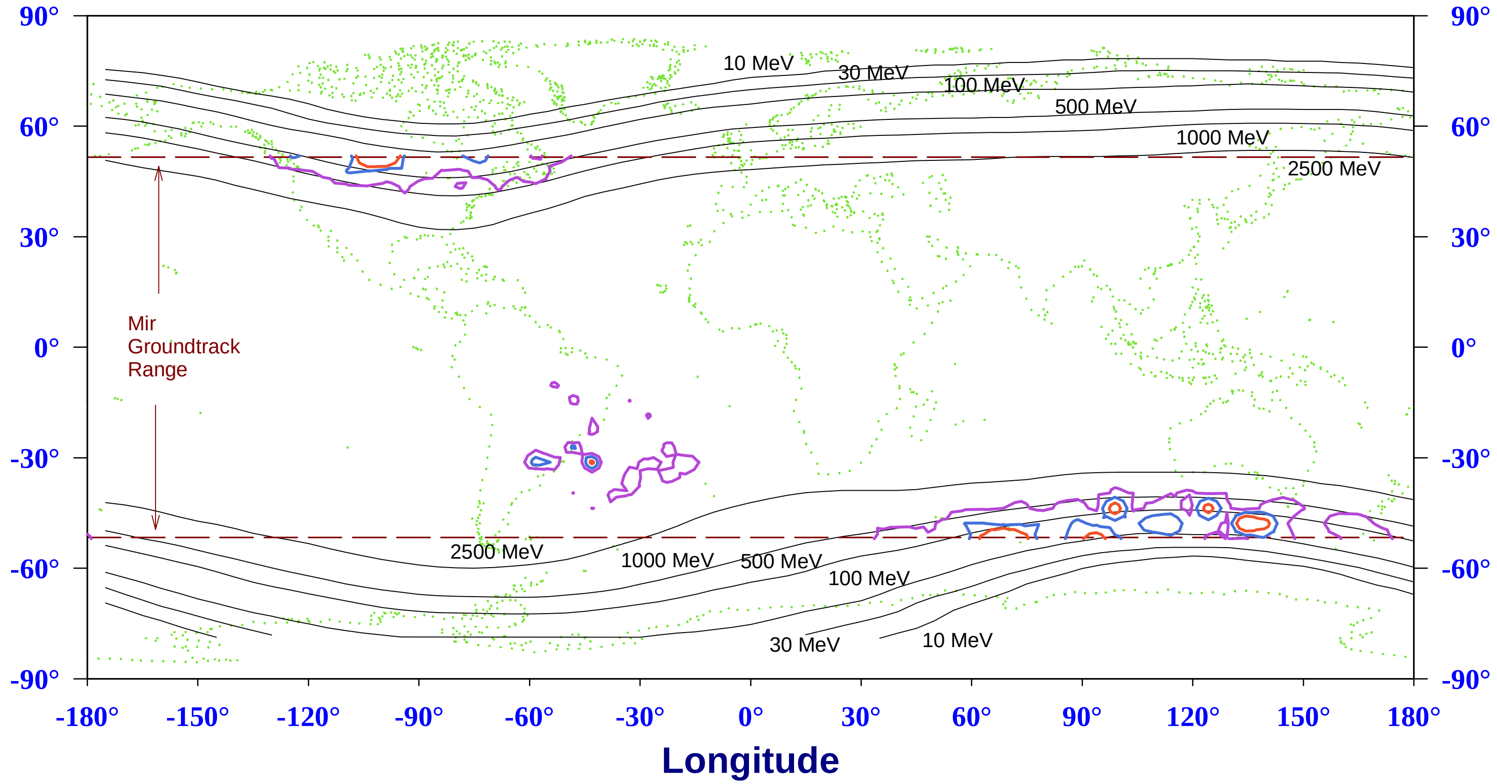
06-09 Nov 1997 SPE Radiation Environment Enhancement

Mir TEPC Data (Piroda Module) and Geomagnetic Cutoffs (p+)



M.J. Golightly / NASA JSC SN3 / (281) 483-6190

Realistic Space Weather Simulation System

- NOAA SEC development of the Data Simulation System (DSS)
  - ✶ "First-of-its-kind" high-fidelity space environment data simulation system
  - ✶ Simulation system initially be built around 10 "cases" based upon select historical events
  - ✶ Historical data "played back" through IDS as real-time data with current date/time
  - ✶ Simulation data will bear unique data ID and data flags to avoid inadvertent confusion with real-time data
  - ✶ Simulation starting point is user selectable
  - ✶ Simulation data will appear the same as real data to applications and data displays
  - ✶ Simulation system will allow end-to-end testing of SRAG applications (Space Weather Monitoring and Alarm System and SPE analysis system) prior to actual events
  - ✶ Permit joint, integrated simulations between SRAG and SEC to prepare for ISS support
  - ✶ *Development supported by SRAG*

Final Thoughts

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- Anonymous astronaut: “The radiation exposure scares me, because long after the mission is over I’m walking around with this potentially ticking time bomb inside me.”
- Of all the risks encountered by astronauts during space flight, the potential long-term health affects from radiation exposure are among the few which persist after successful landing
- It is not a matter of “if” radiation enhancements will occur while crews are aboard ISS, but “when” and “how serious”
- During construction of the ISS, there is a reasonably large probability that EVAs will coincide with a radiation enhancement The number of astronauts affected, the amount received, and the resulting risk to the astronaut cohort is unknown
- Space weather data and information is one of the key tools for minimizing ISS crew radiation exposures

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