Application of Space Environmental Observations to Spacecraft Pre-Launch Engineering and Spacecraft Operations

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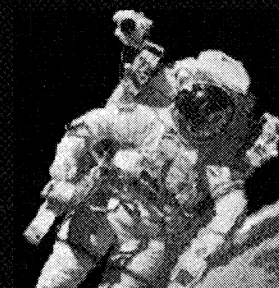
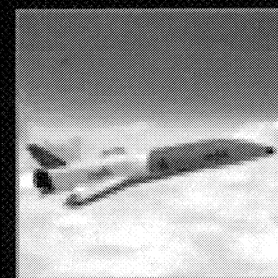
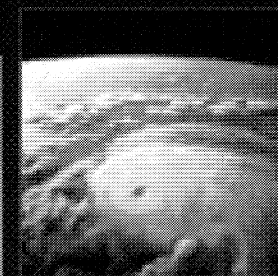
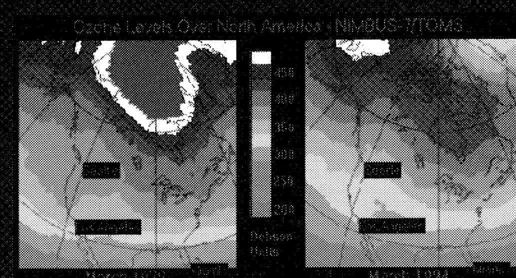
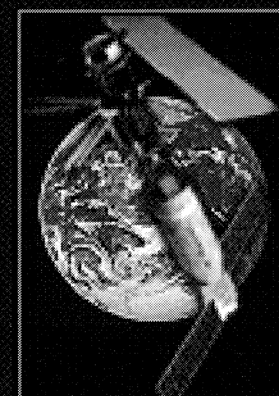
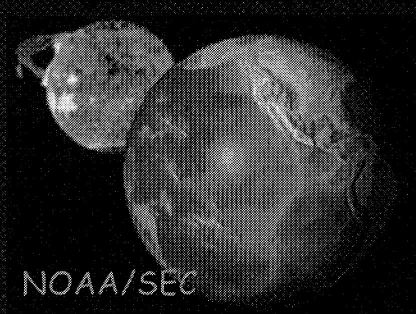
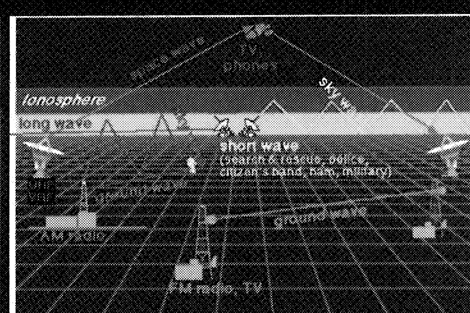
Outline

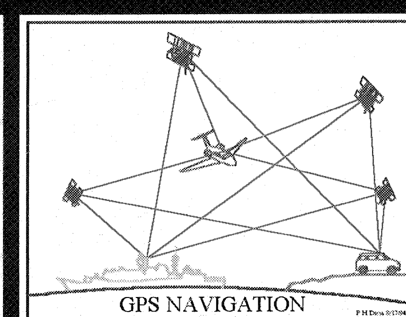
- Radiation environment hazards for space systems
- Space environment model use in mission life cycle
- Model requirements and data requirements
  - Mission concept & planning
  - Design
  - Launch & operations
- Examples of new models
- Example of anomaly resolution

Increasing Reliance on Support Functions Provided by Space Systems

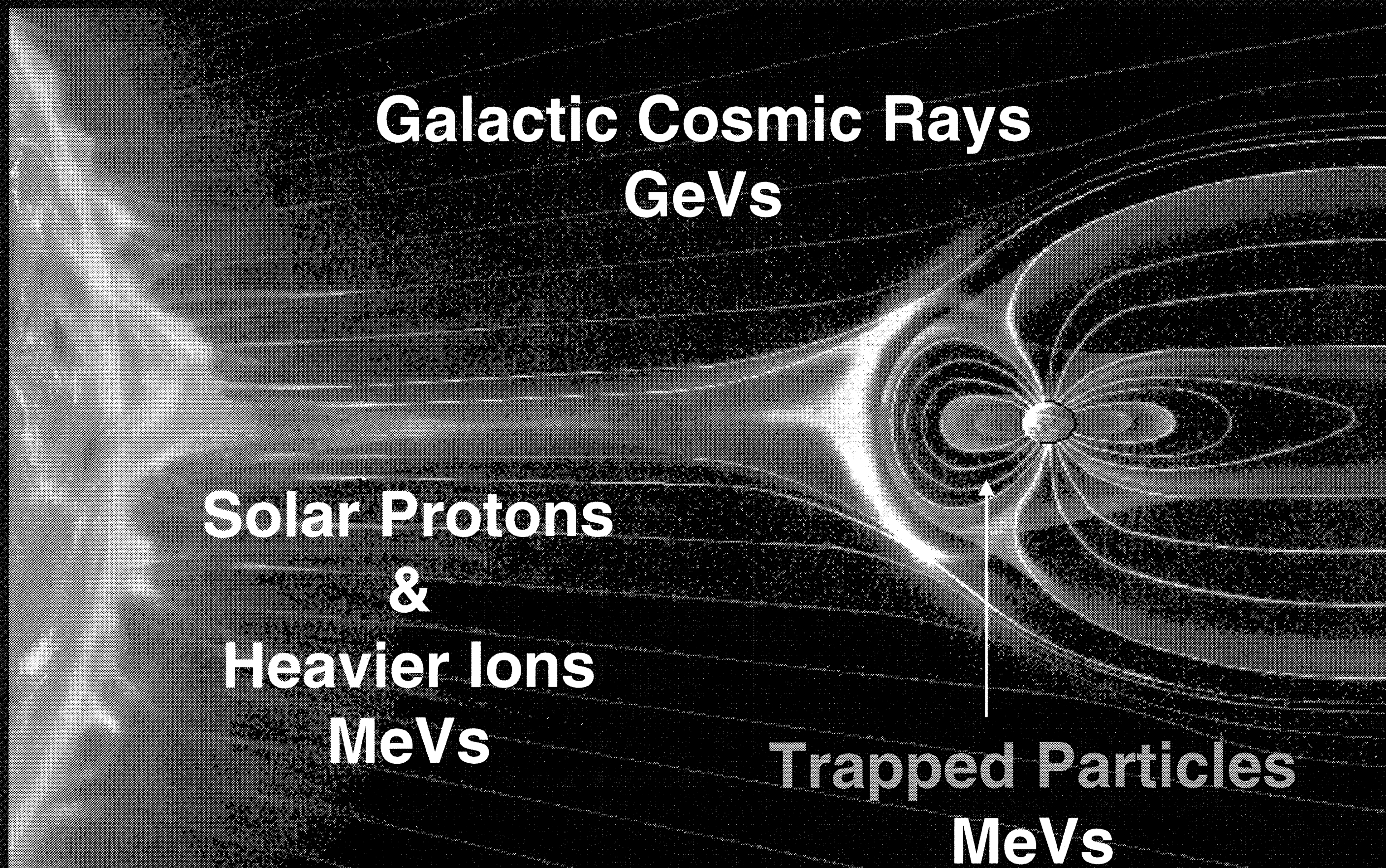
- Scientific Research
  - Science missions
  - Aeronautics and space transportation
  - Human exploration of space
- Navigation
- Telecommunications
- Defense
- Space Environment Monitoring
- Terrestrial Weather Monitoring

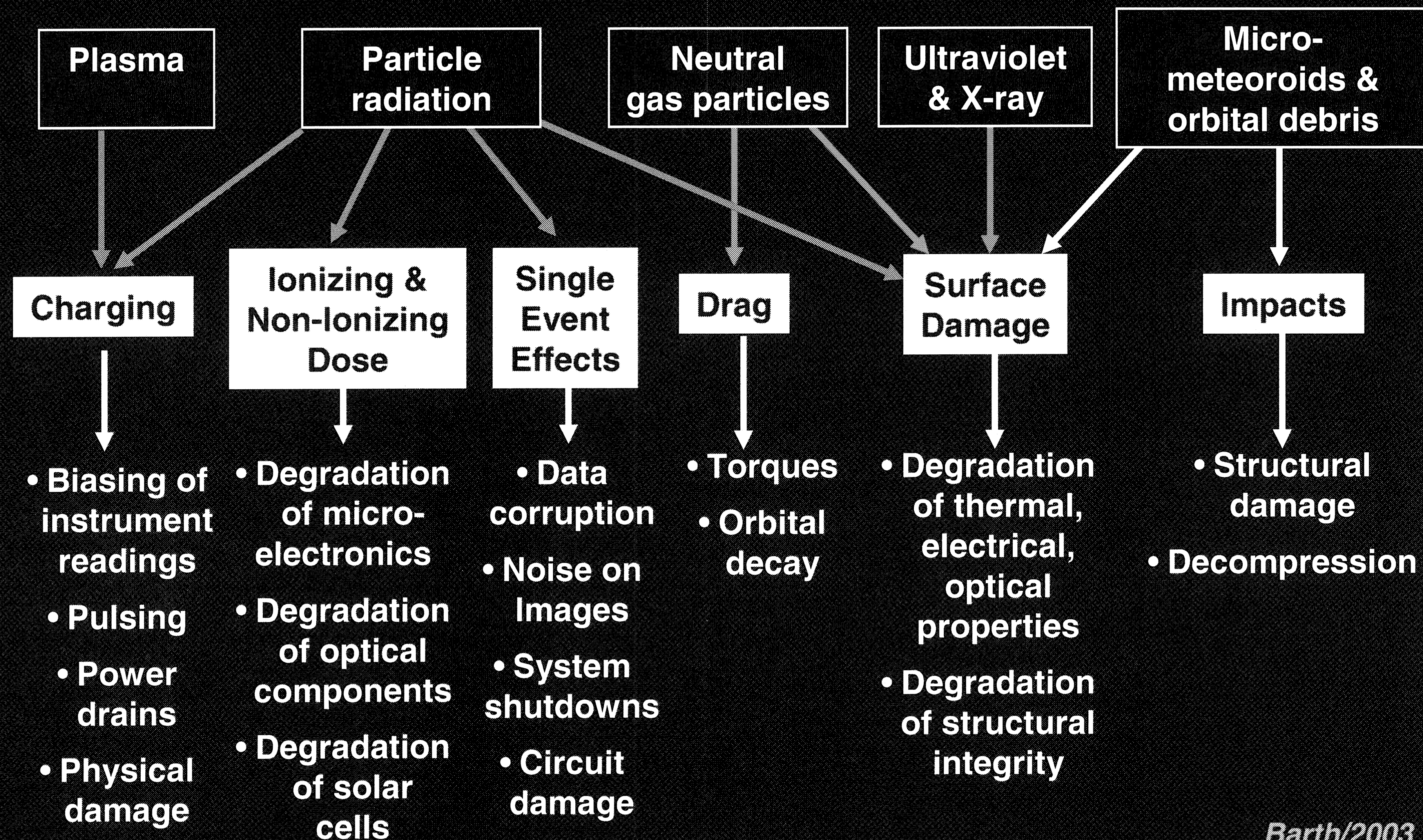


The Radiation Environment



Nikkei Science, Inc. of Japan, by K. Endo

Effects of Space Environments on Systems



Barth/2003

Space Environment Model Use in Mission Life Cycle

Mission Concept
Mission Planning
Design

→ **Space Climate**
Minimize Risk

Launch
Operations

→ **Space Weather**
Manage Residual Risk

Anomaly Resolution → **Both**

+
in situ
measurements

Model Use During Spacecraft Lifetime

- *Mission Concept*
  - Observation requirements and observation vantage points
  - Development and validation of primary technologies
- *Mission Planning*
  - Mission success criteria, e.g., data acquisition time line
  - Architecture trade studies, e.g., downlink budget, recorder size
  - Risk acceptance criteria – must include assessment of Space Weather forecasting capabilities
- *Design*
  - Component screening, redundancy, shielding requirements, grounding, error detection and correction methods
- *Launch & Operations*
  - Asset protection
    - Shut down systems
    - Avoid risky operations, such as, maneuvers, system reconfiguration, data download, or re-entry
  - Anomaly Resolution
    - Lessons learned need to be applied to <u>all</u> phases

Time-Scale Requirements

- Design Issue #1: Endurability/Wear-Out
  - Mission Total Dose
    - Long-term average
    - Long-term worst-case
    - Flux energy spectra
- Design Issue #2: Outages of rate-sensitive equipment
  - Example: processors, CCDs, etc.
  - Protons, electrons, heavy ions
  - Worst case 5 min, 1 hr, 1 day, 1 week
- Design Issue #3: Deep charging
  - Falls between rate-sensitive (flux) and long-duration (fluence)
  - Worst-case day, week, month, 3 months, 6 months electron flux spectra
  - Access to historical flux data for anomaly resolution

Particle Energy Range Requirements

- Energy bins in priority order:
  - All Orbits – high energies
    - High energy > 1 MeV electrons
    - > 50–60 MeV protons
  - Polar, MEO
    - > 50 keV electrons
    - > 5 MeV protons
  - GEO, Polar, MEO
    - > 500 keV electrons (near-term)
    - > 100 keV electrons (far-term)
  - Plasma (>1 keV now, > 30 eV later)

New Model Developments: Proton Belt Models

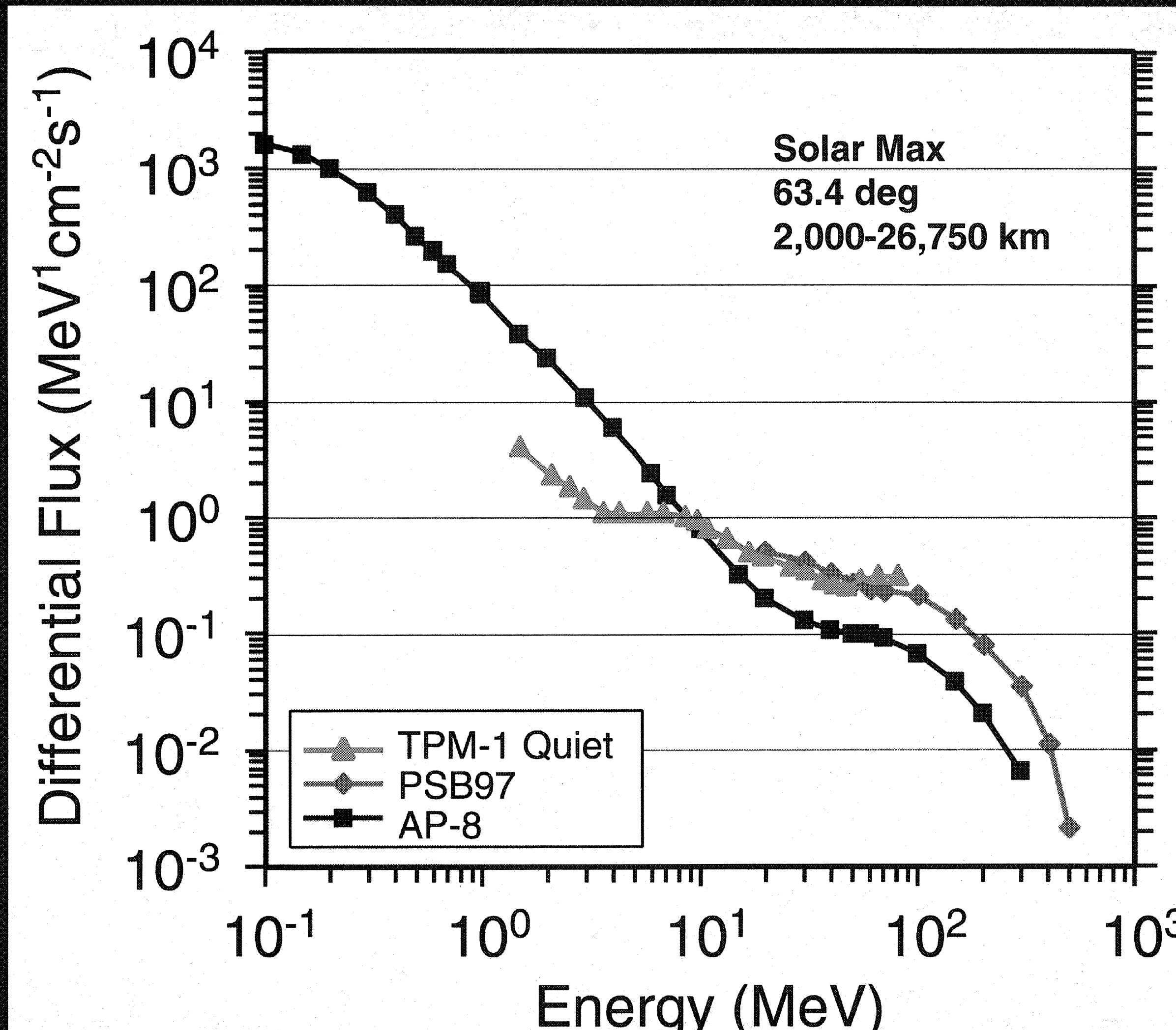
De facto standard is AP-8

- Combined Release and Radiation Effects Satellite PROton Model (CRRESPRO)
  - Brautigam et al. sponsored by US Air Force Research Laboratory (AFRL)
- Low Altitude Trapped Radiation Model (LATRM)
  - Huston et al. sponsored by NASA
- Trapped Proton Model-1 (TPM-1)
  - Huston et al. sponsored by NASA and AFRL
- SAMPEX/PET Model (PSB97)
  - Heynderickx et al. sponsored by ESA

Coverage of New Proton Models

Model Name	# of Years of Data	Spatial Coverage	Energy Range (MeV)	Data Source
CRRESPRO	1.2	1.15 < L < 5.5	1 < E < 100	CRRES
LATRM	17	< 1000 km	16 < E < 80	TIROS/NOAA
TPM-1	Depends on Region	1.15 < L < 5.5	1 < E < 100	CRRES, TIROS/NOAA
PSB97	4	1.1< L< 2.0	18.5 < E < 500	SAMPEX

Comparison of TPM-1, PSB97, AP-8



New Model Developments: Electron Belt Models

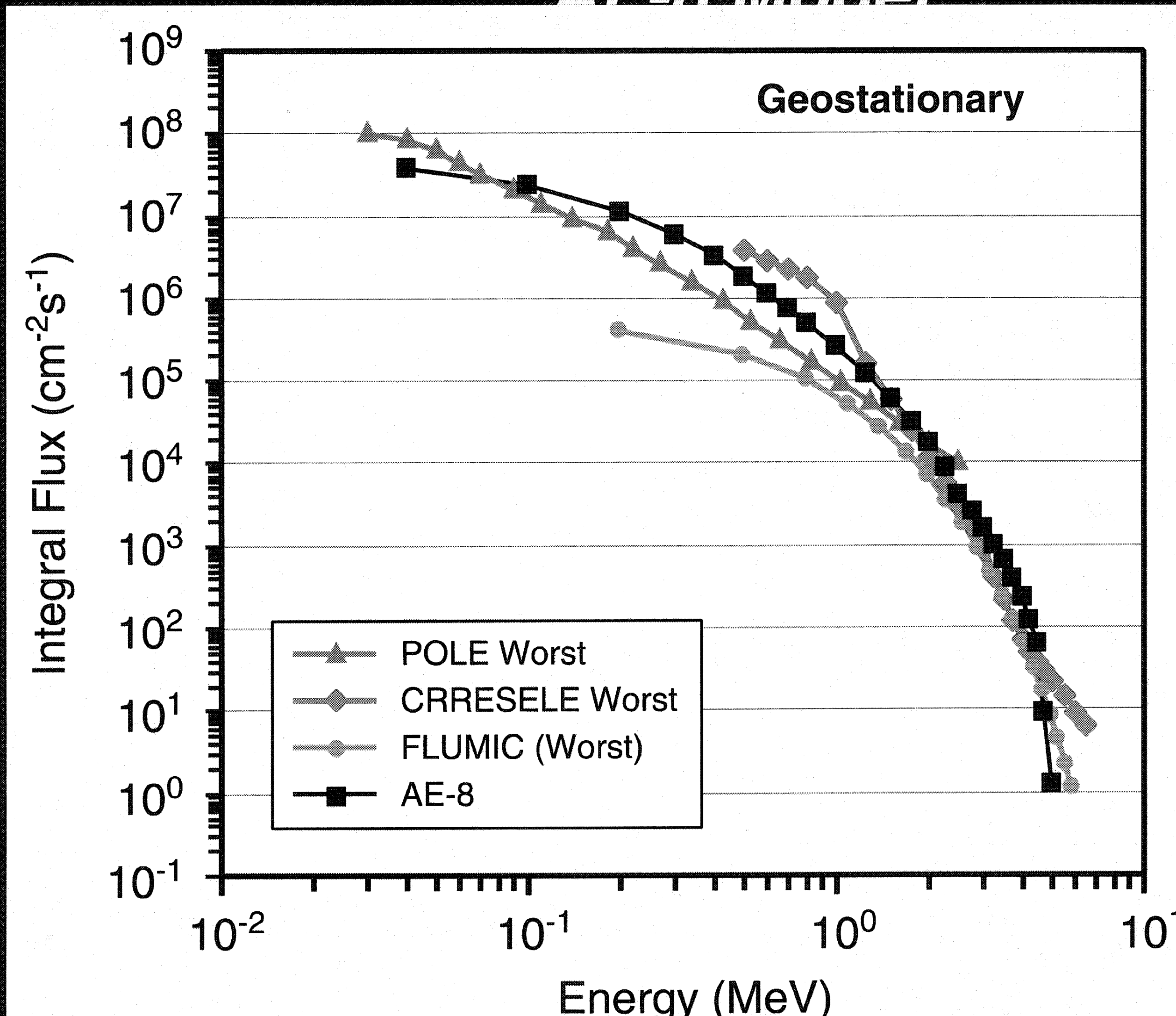
De facto standard is AE-8

- Combined Release and Radiation Effects Satellite ELEctron Model (CRRESELE)
  - Gussonhoven et al. sponsored by Air Force Research Laboratory (AFRL)
- FLUx Model for Internal Charging (FLUMIC)
  - Wrenn et al. sponsored by ESA
- Particle ONERA-LANL Environment Model (POLE)
  - Bourdarie et al. sponsored by ONERA, Los Alamos National Laboratory (LANL), and NASA

Coverage of New Electron Models

Model Name	# of Years of Data	Spatial Coverage	Energy Range (MeV)	Data Source
CRRESELE	1.2	2.5 < L < 6.8	0.5 < E < 6.6	CRRES
FLUMIC	11	Outer Zone	0.2 < E < 5.9	Various
POLE	25	Geostationary	0.03 < E < 6.0	LANL Instruments

Comparison of "Worst Case" POLE, CRRESELE, and FLUMIC Models with the AE-8 Model

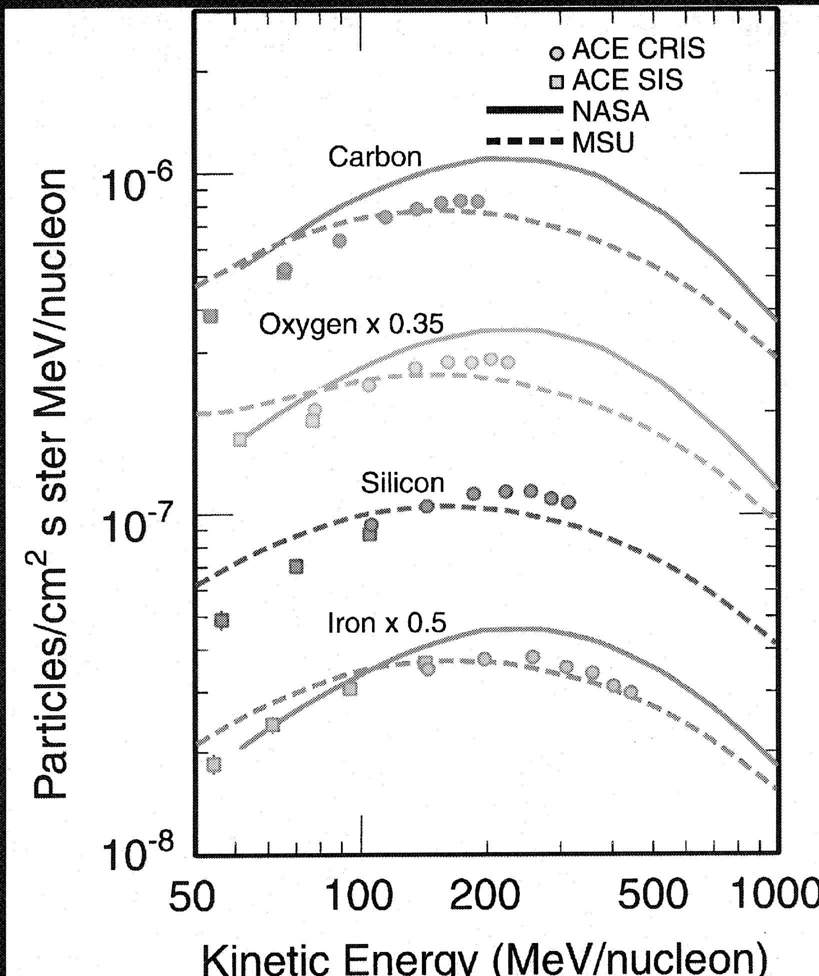


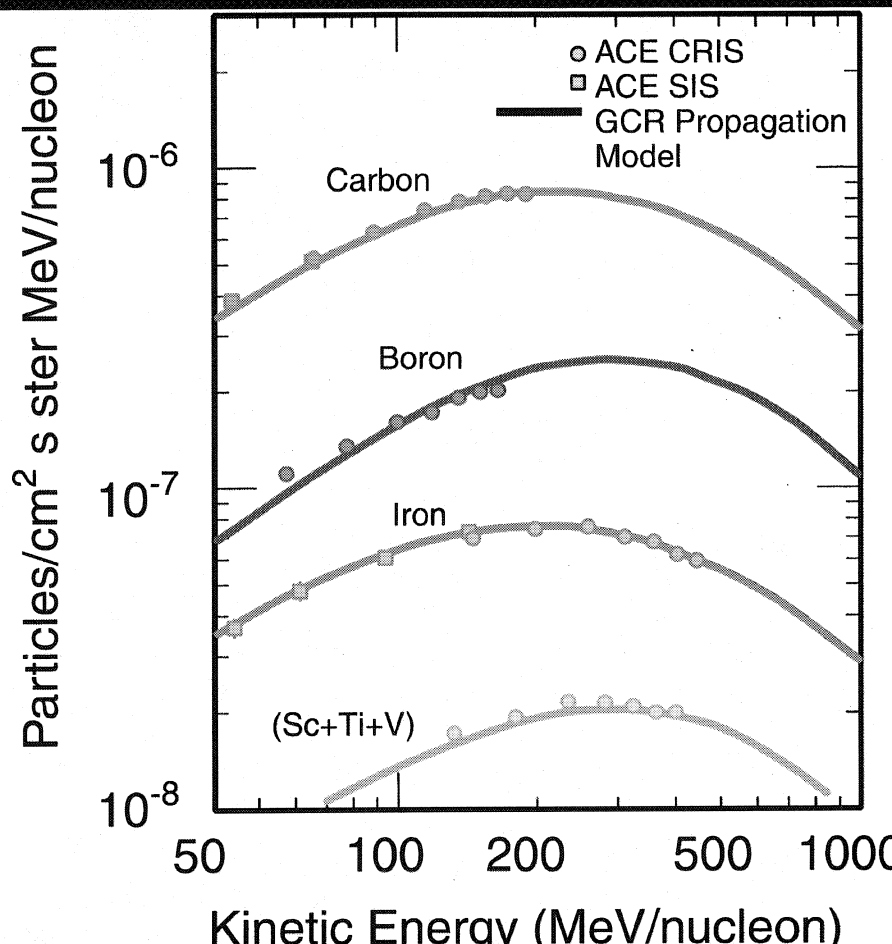
New Model Developments: Galactic Cosmic Ray Model

De facto standard is CREME86

- Galactic Cosmic Ray (GCR) Model from Moscow State University (MSU)
  - Solar variation is modeled with diffusion-convection theory of solar modulation
- Cosmic Ray Effects in MicroElectronics (CREME96)
  - CREME86 was updated with the GCR MSU Model
- NASA GCR Model from Badhwar and O'Neill
  - Similar approach to GCR MSU model with different implementation of the solar modulation theory
- New approach by Davis et al. at the California Institute of Technology (CIT)
  - Uses transport model for the GCRs through the galaxy preceding the penetration and subsequent transport in the heliosphere

Comparison of NASA, MSU, CIT Models with ACE Instrument Data



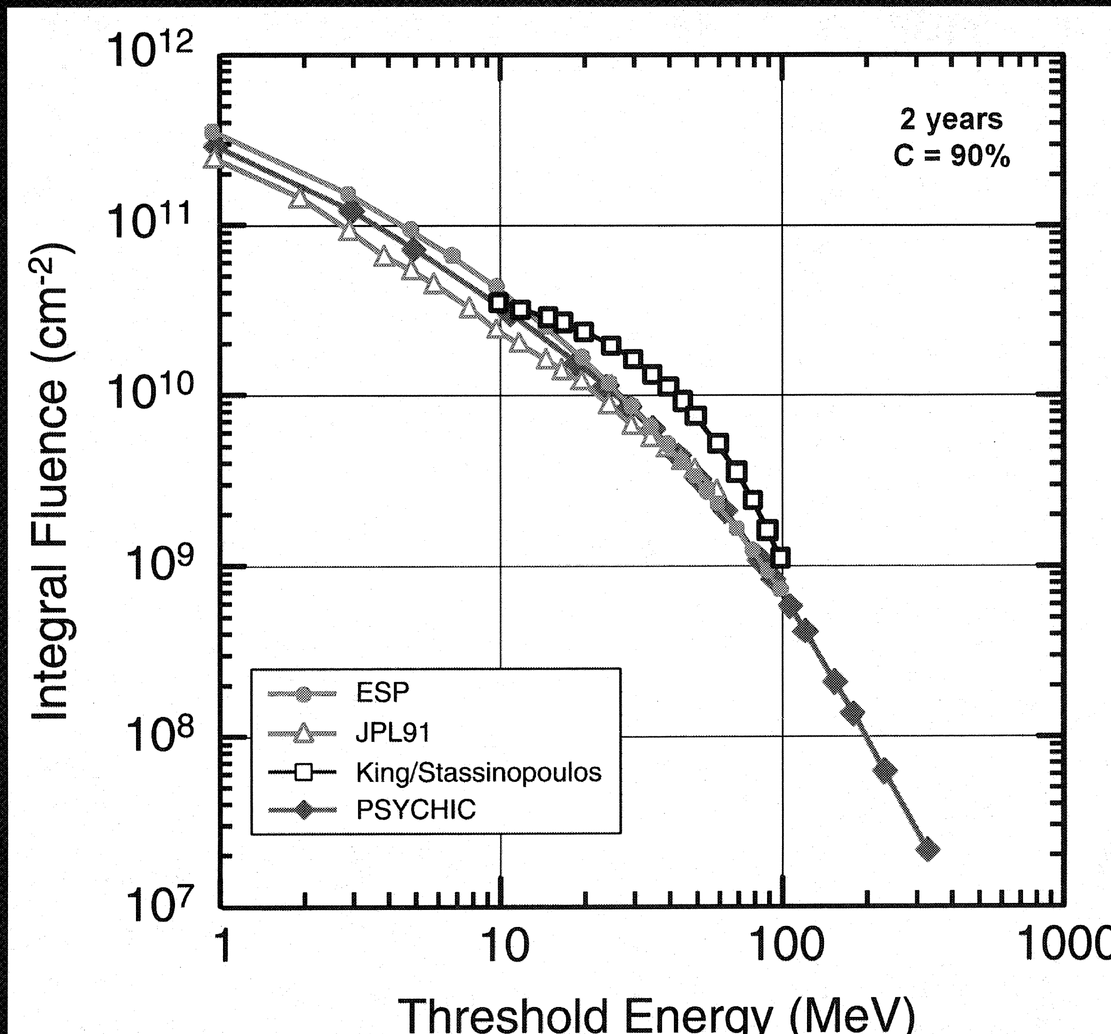


New Model Developments: Solar Proton Model

De facto standard is JP91 for cumulative fluence, CREME86/96 for worst case event fluence

- Solar Particle Event Fluence Model (SPE Fluence Model)
  - Nymmik et al. sponsored by Moscow State University
  - Based on power function distributions of event fluences
- Emission of Solar Proton Model (ESP)
  - Xapsos et al. sponsored by NASA
  - Based on satellite data from the 21 solar maximum years during solar cycles 20-22
  - Uses Maximum Entropy Principle to generate an optimal selection of a probability distribution, and Extreme Value theory to estimate worst case
  - Calculates cumulative and worst case solar proton fluences
- PSYCHIC
  - Xapsos et al. sponsored by NASA
  - ESP Model with satellite data set extended to cover the time period of 1966 – 2001
  - Energy range extended to over 300 MeV
  - Includes estimates for solar minimum spectra

Comparison of ESP, JPL91, King/Stassinopoulos, and PSYCHIC Models

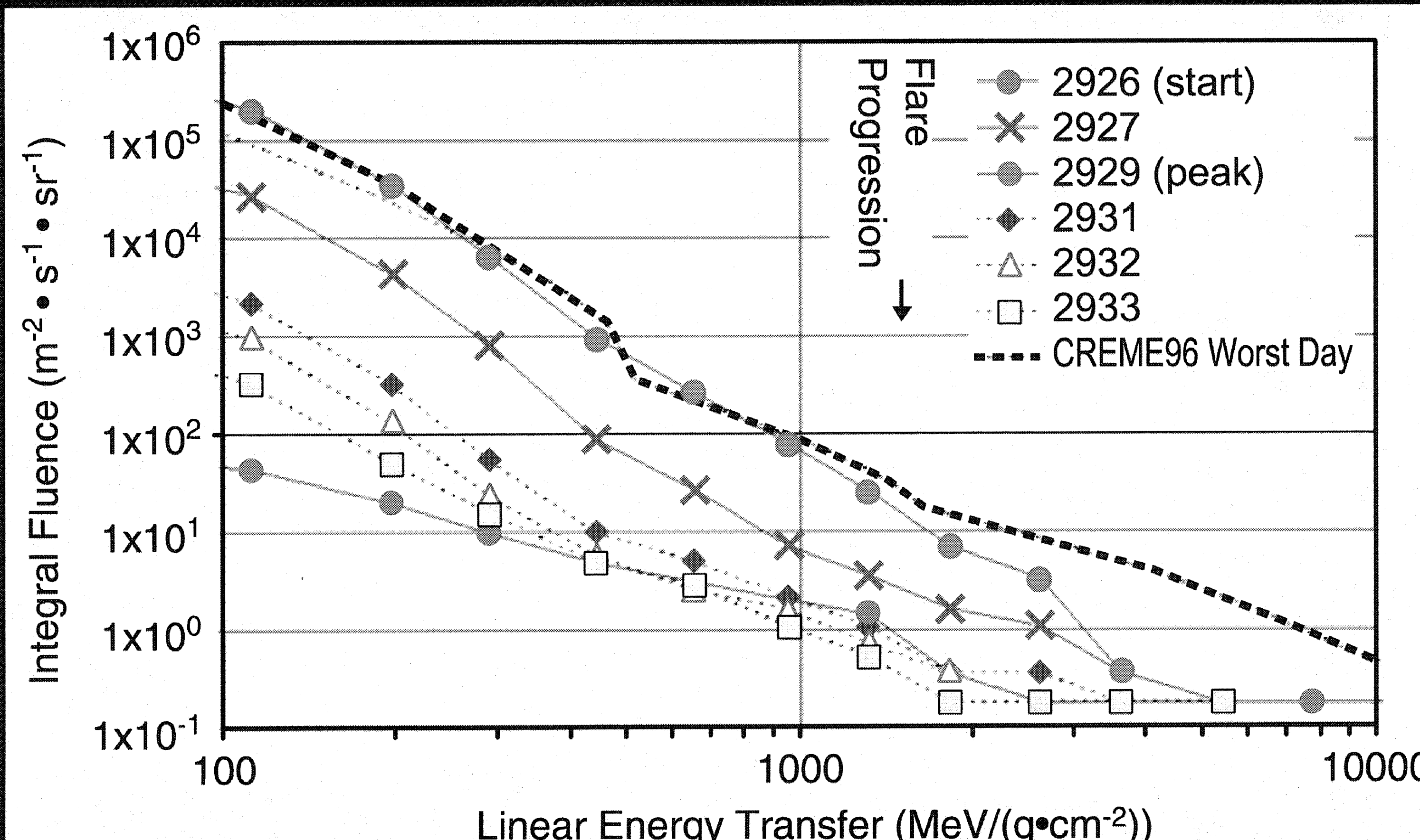


New Model Developments: Solar Heavy Ion Model

De facto standard is CREME86/96 for worst case event fluences

- CRRES/SPACERAD Heavy Ion Model of the Environment (CHIME) – Chenette et al. sponsored by US AFRL
  – Heavy ion abundances scaled to protons results in overestimates
- Modeling and Analysis of Cosmic Ray Effects in Electronics MACREE) – Majewski at al. sponsored by Boeing
  – Heavy ion abundances scaled to alphas results in less conservative estimates
- CREME96
  – Uses the October 1989 event as a worst case
  – Most extensive heavy ion measurements are for C, O, and Fe, and remaining elemental fluences are determined from a combination of measurements in 1 or 2 energy bins and abundance ratios

Comparison of CREME96 to CREDO Measurements During 2000 and 2002



PSYCHIC Heavy Ion Model

Xapsos et al.

Model Name	Measurement Period	Energy Range (MeV/n)	Data Source
Alpha Particles	1973-2001	1 < E < 200	IMP-8, GOES
C, N, O, Ne, Mg, Si, S, Fe	1997-2005	0.2 < E < 5.9	ACE/SIS
Less prevalent elements	-	-	Abundance model

Contact Information and WEB Sites

- Janet Barth
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- LWS Science WEB Site
  - http://lws-science/
- October Model Workshop
  - http://lws-science/RB_meeting1004.htm