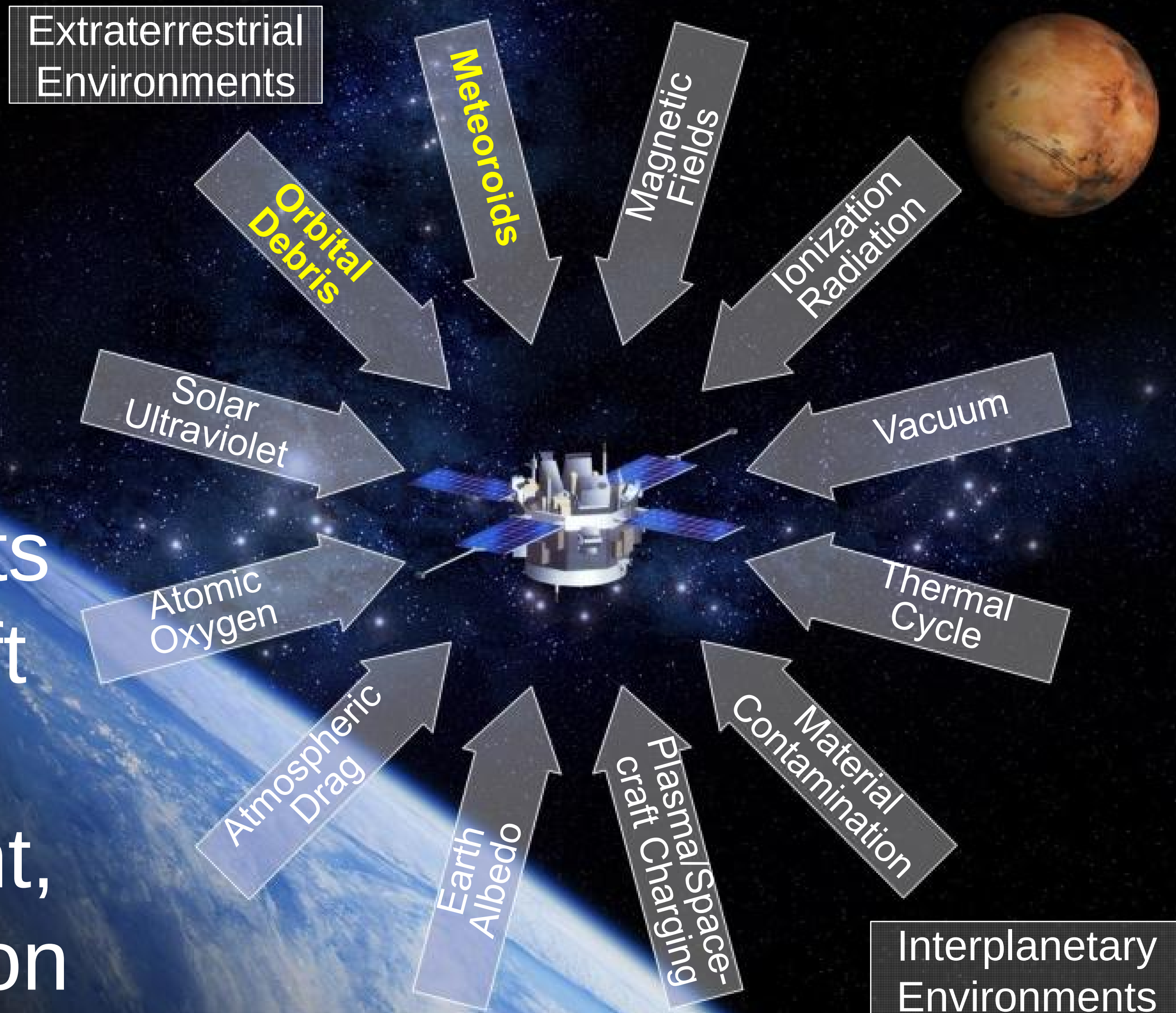

Influence of Natural Environments in Spacecraft Design, Development, and Operation

Dr. Dave Edwards
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Marshall Space Flight Center

July 18, 2012

Outline

- **Background**
- **Impact**
- **Guideline Process**
- **Environments**
- **Interactions**
  - **Contamination**
  - **Spacecraft Charging**
  - **Hypervelocity Impact**
  - **Radiation**
- **Summary (Putting it all Together)**

Background

Spacecraft are growing in complexity and sensitivity to environmental effects.

The spacecraft engineer must understand and take these effects into account in building reliable, survivable, and affordable spacecraft.

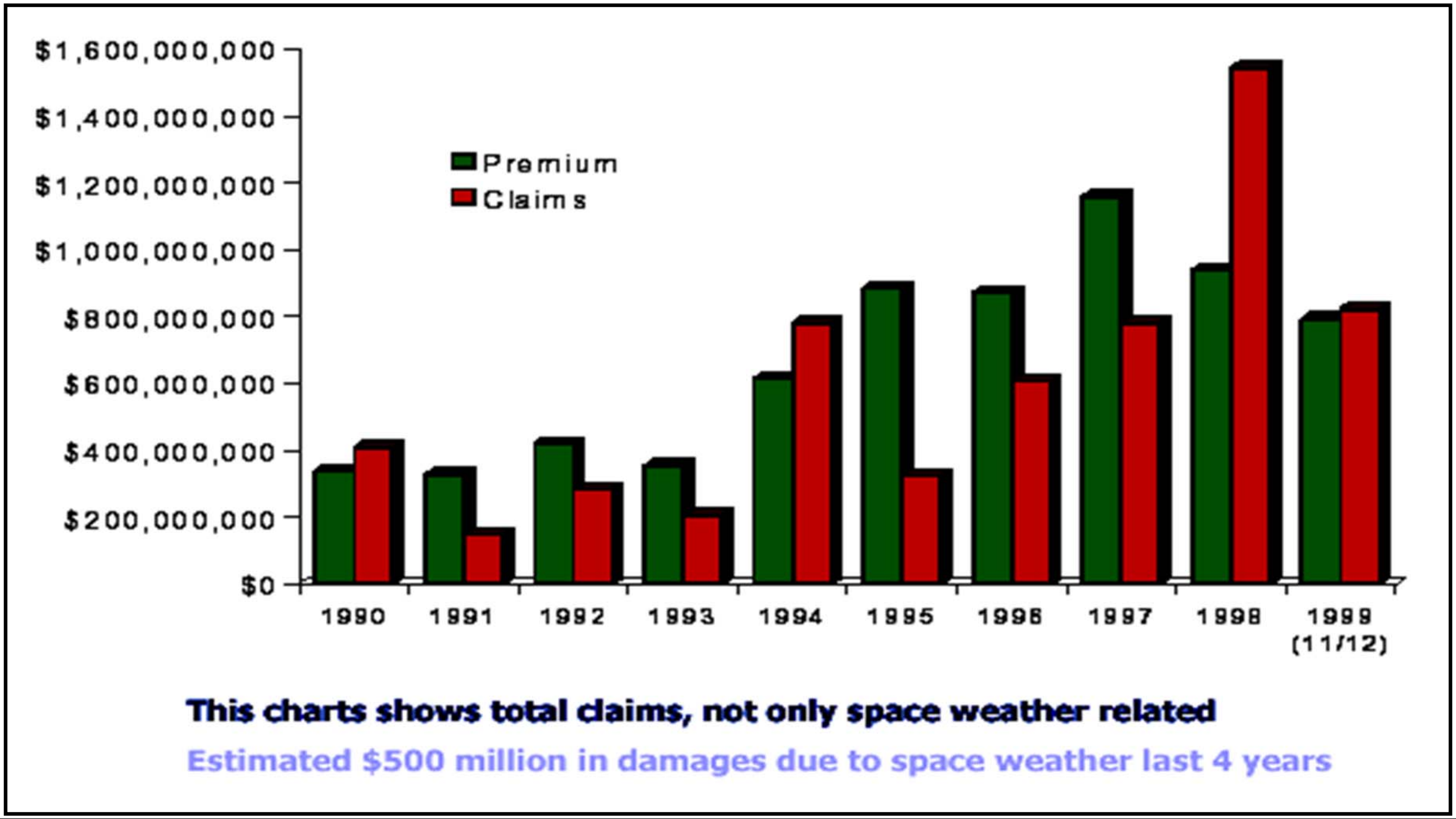
Too much protections, however, means unnecessary expense while too little will potentially lead to early mission loss.

The ability to balance cost and risk necessitates an understanding of how the environment impacts the spacecraft and is a critical factor in its design.

This presentation is intended to address both the space environment and its effects with the intent of introducing the influence of the environment on spacecraft performance.

Impact

- 600 satellites currently in orbit (1999) are worth \$50-\$100B with 235 insured for \$20B
- 1500 space payloads are expected to be launched 2000 – 2010 with a potential insured value of \$80 billion!
- 481 US satellites currently manifested from 2011 - 2020 at a total cost of \$150B



THE IMPACT OF THE SPACE ENVIRONMENT ON SPACE SYSTEMS†

Distribution by Anomaly Diagnosis

Diagnosis	Number of Forms
ESD - Internal Charging	74
ESD - Surface Charging	59
ESD - Uncategorized	28
Surface Charging	1
Total ESD & Charging	**162**
SEU - Cosmic Ray	15
SEU - Solar Particle Event	9
SEU - South Atlantic Anomaly	20
SEU - Uncategorized	41
Total SEU	**85**
Solar Array - Solar Proton Event	9
Total Radiation Dose	3
Materials Damage	3
South Atlantic Anomaly	1
Total Radiation Damage	**16**
Micrometeorid/Debris Impact	10
Solar Proton Event - Uncategorized	9
Magnetic Field Variability	5
Plasma Effects	4
Atomic Oxygen Erosion	1
Atmospheric Drag	1
Sunlight	1
IR background	1
Ionospheric Scintillation	1
Energetic Electrons	1
Other	2
Total Miscellaneous	**36**

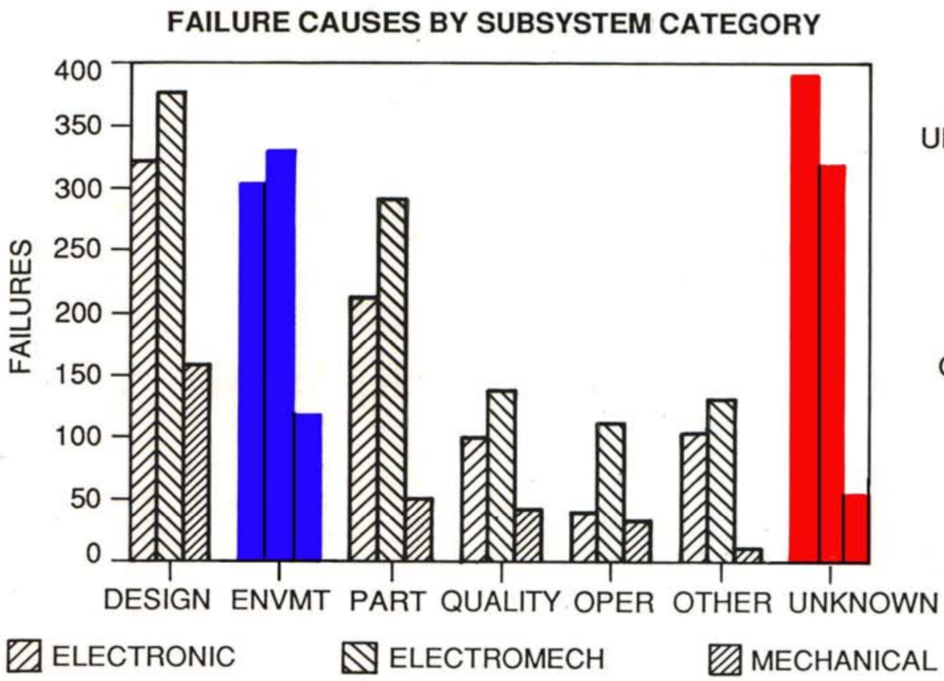
†Koons, H.C., J. E. Mazur, R. S. Selesnick, J. B. Blake, J. F. Fennell, J. L. Roeder, and P. C. Anderson, "The Impact of the Space Environment on Space Systems", presented at Charging Conference, Nov 1998.

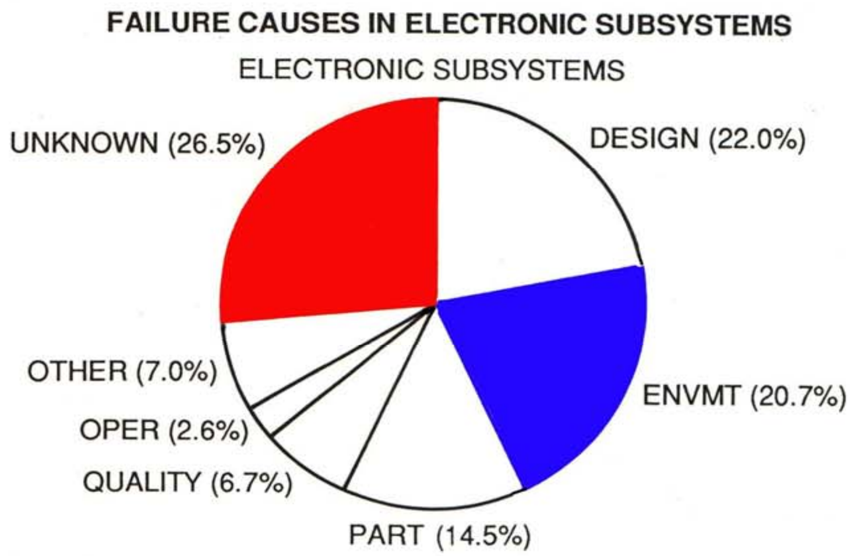
Missions Lost/Terminated Due to Space Environment

Vehicle	Date	Diagnosis
DSCS II (9431)	Feb 73	Surface ESD
GOES 4	Nov 82	Surface ESD
DSP Flight 7	Jan 85	Surface ESD
Feng Yun 1	Jun 88	ESD
MARECS A	Mar 91	Surface ESD
MSTI	Jan 93	Single Event Effect
Hipparcos*	Aug 93	Total Radiation Dose
Olympus	Aug 93	Micrometeoroid Impact
SEDS 2*	Mar 94	Micrometeoroid Impact
MSTI 2	Mar 94	Micrometeoroid Impact
IRON 9906	1997	Single Event Effect
INSAT 2D	Oct 97	Surface ESD

*Mission had been completed prior to termination

Subsystem In-flight Failure Causes (Hecht, 1985)





Mariner IV

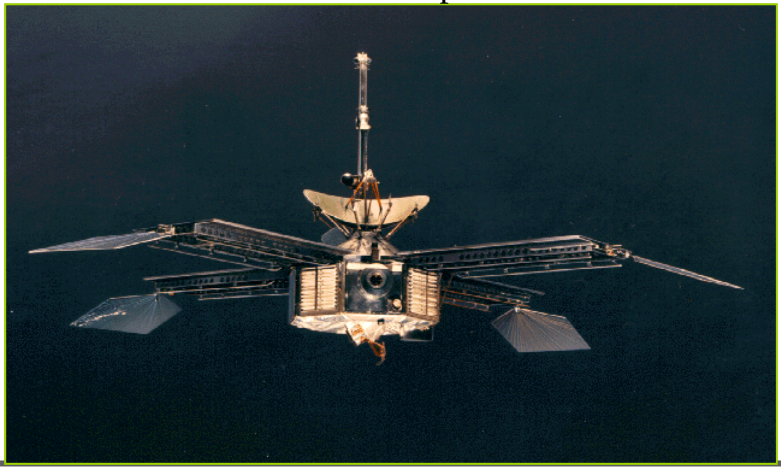
What: NASA planetary exploration spacecraft.

Event: Encountered meteoroid stream between the orbits of Earth and Mars in September 1967.

Consequences:

- Cosmic dust detector registered 17 hits within 15 minutes;
- 2-3 orders of magnitude more hits estimated over entire craft.
- Bombardment caused temporary change in attitude but no loss of power; torqued about the roll-axis.
- One-degree temperature drop indicative of thermal shield damage.

Outcome: Resumed normal operation within ~1 week.



Chandra X-Ray Observatory

What: NASA observatory.
Event: Struck by a Leonid or sporadic(?) near the time of Leonid shower peak in November 2003.

Consequences:

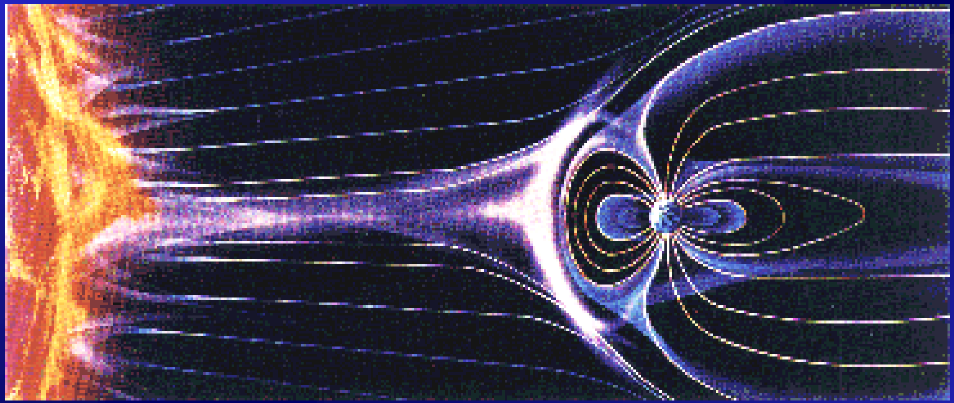
- Pointing stability discrepancy indicated strike, as no evidence of spurious thruster firings or an indication of an internal cause.
- Change in momentum – caused a "wobble".

Outcome: All systems continued to operate normally following the event.

Guideline Process

1. Define the environments
2. Analyze potential environmental interactions that could occur
3. Implement mitigation strategies to minimize/eliminate adverse interactions
4. Ground test to evaluate engineering performance in relevant environment
5. Analyze the data from the spacecraft to determine effectiveness of the process
6. Integrate information learned into process improvement

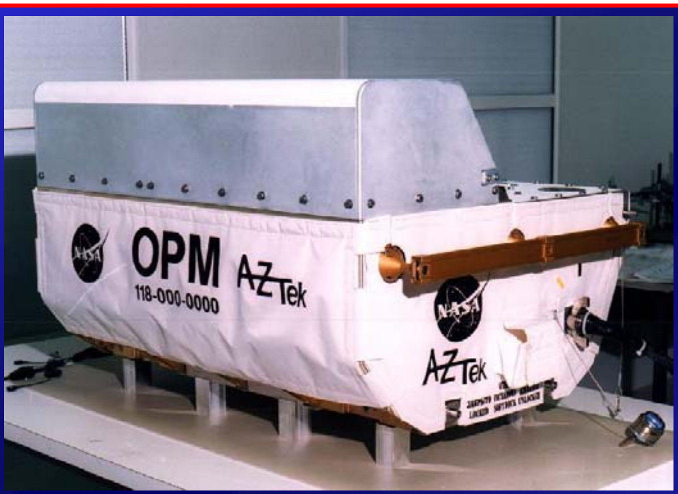
Environments

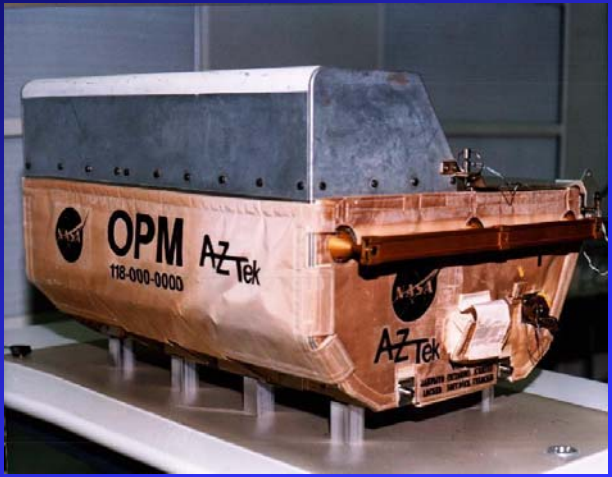


- – Atmospheres
- – Solar UV Flux
- – Atomic Oxygen
- – Space Vacuum
- – Thermal Cycling
- – Plasma / Charging Environments
- – Micro-Meteoroid/Space Debris
- – Spacecraft Induced Environment
- – Charged Particle Radiation
  - Radiation Belts
  - Auroral Region
  - Solar Wind
  - Interplanetary

Contamination

- **Particulate and Molecular**
  - **– Particulate Contamination Generated by Handling, Launch Vibration, AO, Moving Parts…**
  - **– Volatiles may Escape Materials due to Outgassing in Space, Venting, Engine Firing…**
    - **Outgassing Rate is Temperature Dependant**
    - **Deposition on other spacecraft surfaces**
    - **Deposition Rate Affected by Solar UV, AO, and Surface Temperature**



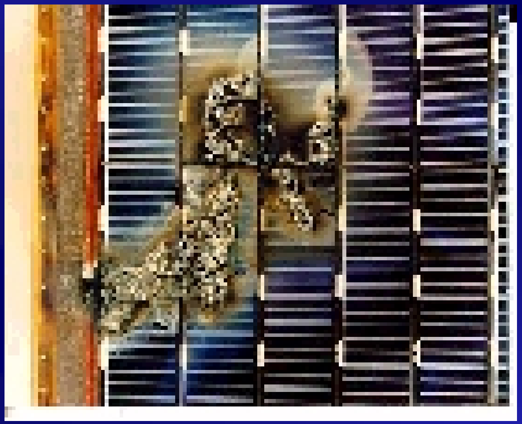


Contamination

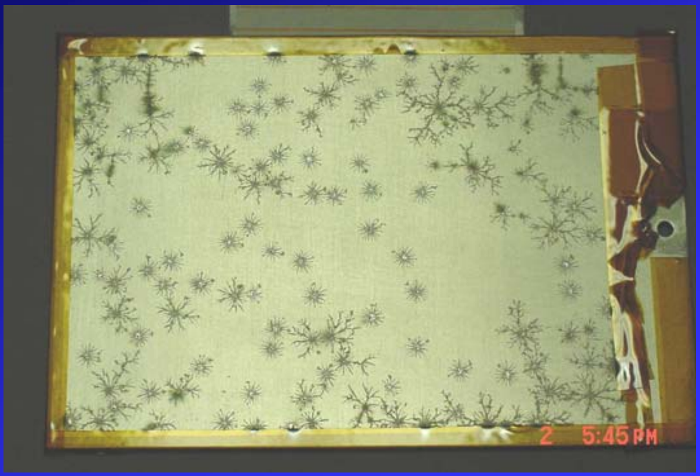
- Contamination Control
  - Contamination Control Imperative for Sensitive Optics and Thermal Control Surfaces
  - Ground Support Equipment is Considered a Potential Contamination Source
  - Standard Material Tests and Modeling for Contamination Exists
    - Databases of Materials are Maintained
  - Contamination Control can be Achieved
    - Material Selection, Thermal Vacuum Bake-out, Clean Room Control, Spacecraft Design

Plasma

- Spacecraft can Interact with Ambient and Induced Plasma Environments
  - High Voltage Solar Arrays can be Damaged by Arcing
  - Floating Potentials can Charge Spacecraft Leading to Damage on Surfaces
    - Dielectric Breakdown, Contamination from Ejecta, Sputtering due to Ion Impact
  - Currents Collected by Arrays Flow in Structure



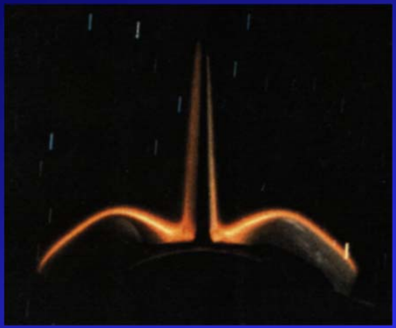
Solar Array Arc

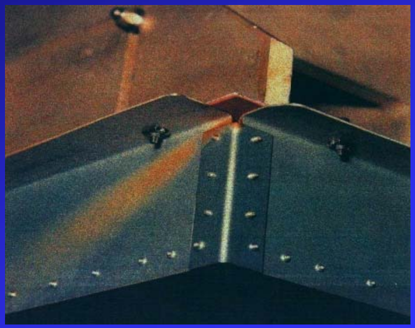


Dielectric Breakdown in Anodize Aluminum

Atomic Oxygen (AO)

- **The Main Constituent at 200-500 Km is AO**
  - The AO Density Decreases Exponentially with Altitude
  - Spacecraft Velocity > Thermal Velocity means that AO Impacts Ram Facing Surfaces with ~ 5eV
  - AO Erodes many Polymeric Materials
    - Mass Loss Affects Thermal, Optical and Mechanical Properties
    - AO Oxidizes Metallic Materials
  - AO Interaction with Exterior Materials can Produce Glow
  - AO Interaction can Enhance Contaminant Deposition





Thermal Vacuum

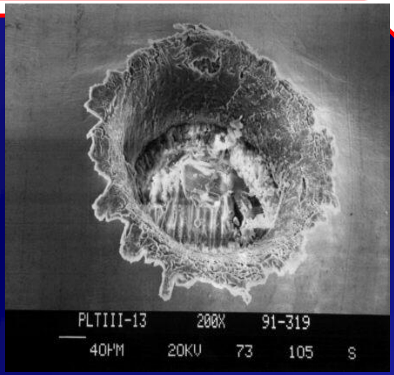
- Spacecraft Systems Affected by Vacuum Environment
  - Without Atmosphere, A Spacecraft Relies on Transferring Heat to its Surroundings by Radiating Infrared Energy.
    - Thermal Control Coatings Reflect Solar Energy Away and Radiate Thermal Energy
    - Degradation of these Materials may have Significant Affect on Spacecraft Thermal Control
  - Spacecraft Materials may Cycle Hundreds of Degrees C when going from Sunlight to Shadow.
  - High Thermal Environments enhance Diffusion processes

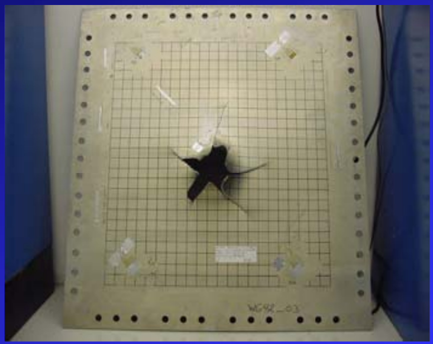
Electromagnetic Radiation (UV, Soft X-Rays)

- **Degradation of Material Properties**
  - Causes Darkening of Materials such as Silica Glass, Thermal Control Coatings, Polymer Films, Some Composites and Ceramics
  - Embrittlement of Polymer Films
  - Thermal Control Properties may be Seriously Degraded by UV Exposure of Contaminants Adsorbed onto Surfaces
    - Simultaneous UV and Contaminant Flux to a Surface can Significantly Enhance Permanent Contaminant Deposition

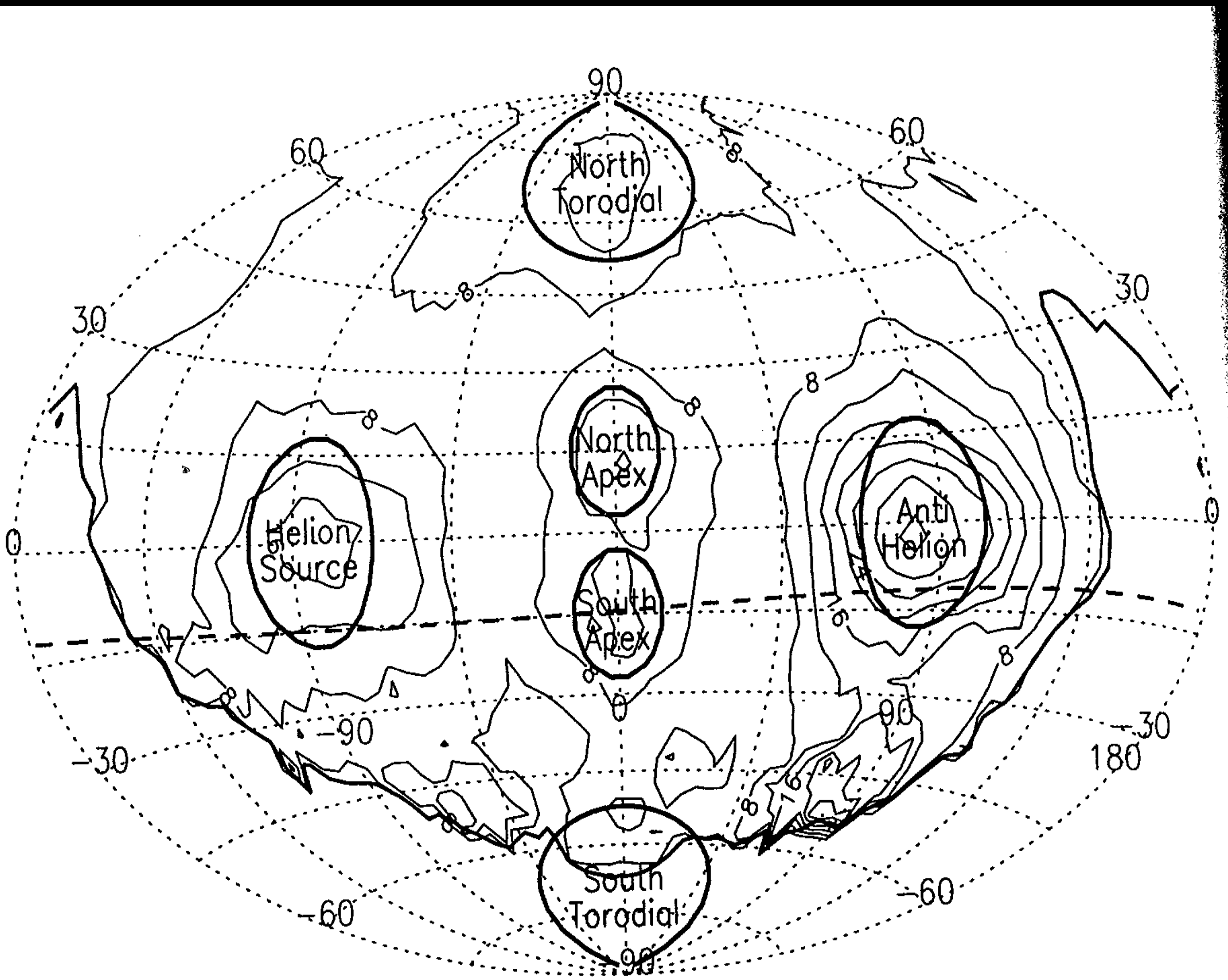
Micrometeoroid/Space Debris

- Naturally Occurring Particles are Meteoroids, Man-Made Particles are Orbital Debris
  - Average Velocity of 17 Km/s for Micrometeoroids and 8 Km/s for Orbital Debris
    - Models of Environment Exist and Probability of Impact can be Calculated
    - Impacts can Penetrate Walls, Cause Pitting of Optics, Degrade Solar Arrays, and Thermal Control Materials

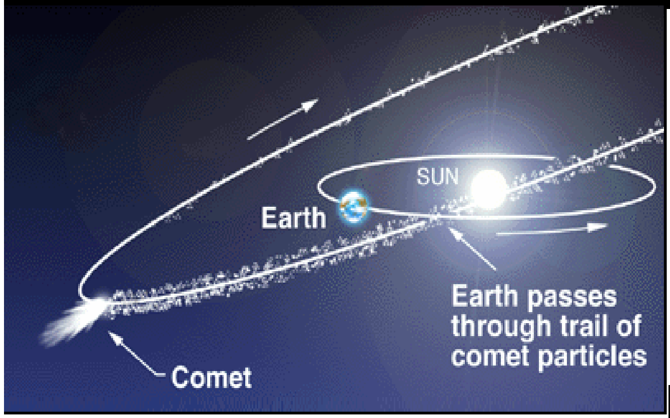




Environments - Sporadic Meteoroids



Environments - Meteoroid Streams



- Consist of particles ejected from the parent comet during a single passage around the Sun.
- Produce meteor showers and storms here on Earth.

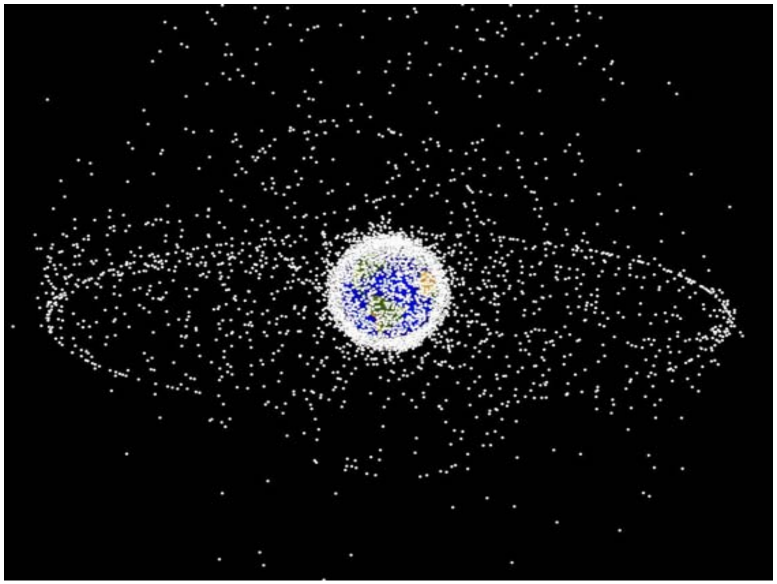
Over time

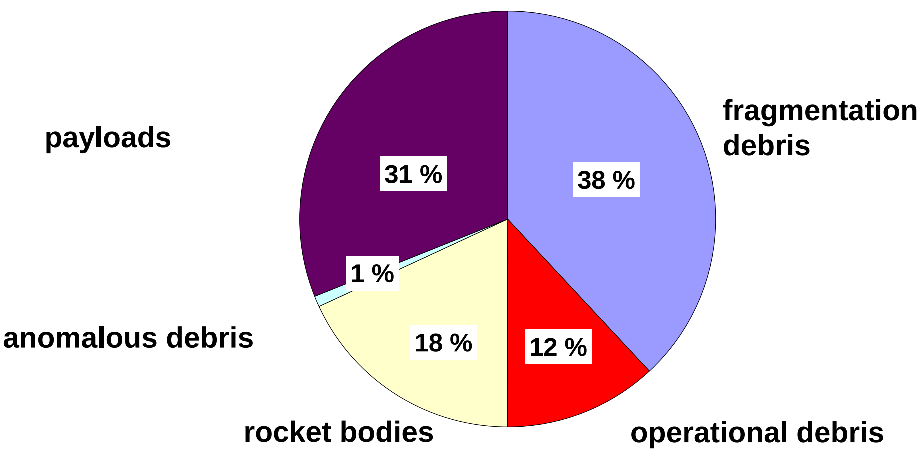
- slight differences between the comet's and particles' velocities
- perturbations caused by planetary gravity and solar radiation pressure

change the orbit of the stream so that it no longer follows the exact path of the comet.

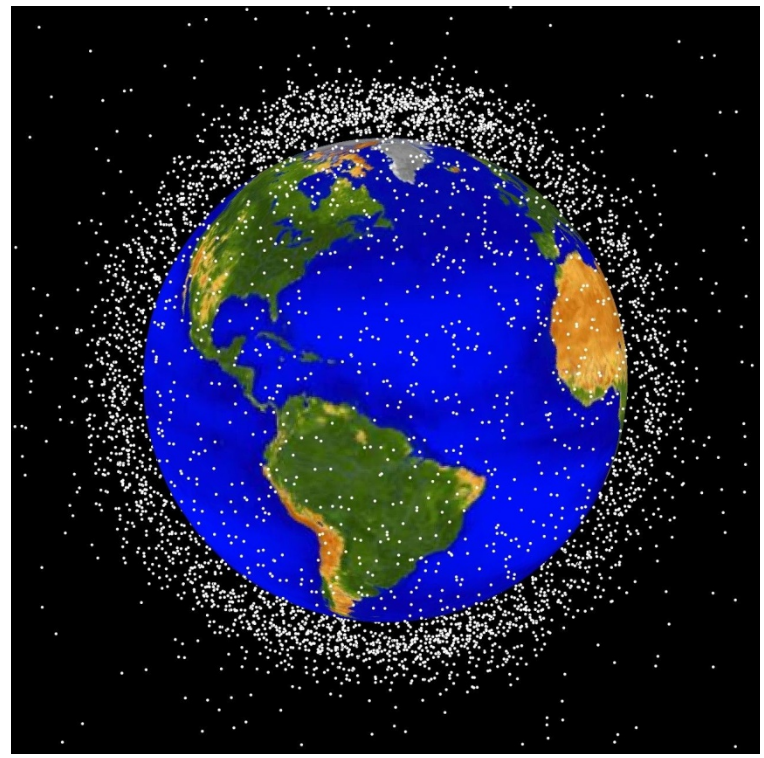
Shower	**Peak**	**RA**	**Dec.**	**Duration (days)**	**Rate (/hr)**
Quadrantids	Jan. 3	231	+50	0.5	90
Lyrids	Apr. 21	272	+32	2	5
Eta Aquarids	May 4	336	00	10	30
Northern Delta Aquarids	July 29	339	00	20	10
Perseids	Aug. 12	46	+58	5	70
Orionids	Oct. 21	95	+15	5	20
Taurids	Nov. 1	54	+21	30	5
Leonids	Nov. 16	152	+22	4	5
Geminids	Dec. 13	113	+32	6	100
Ursids	Dec. 22	217	+80	2	15

Environments – Orbital Debris



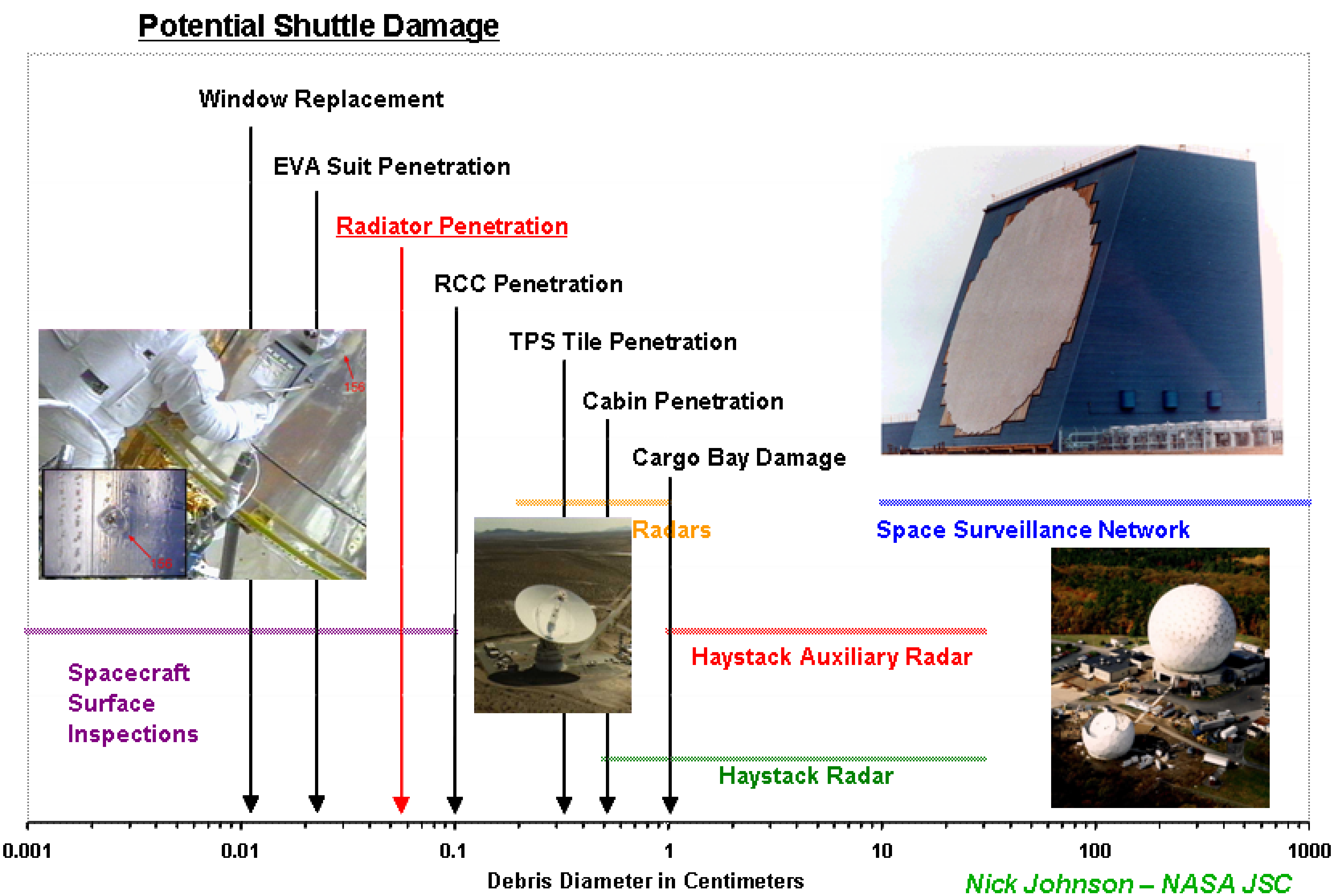


~12,000 tracked objects in 2003 (≥5 cm diameter)



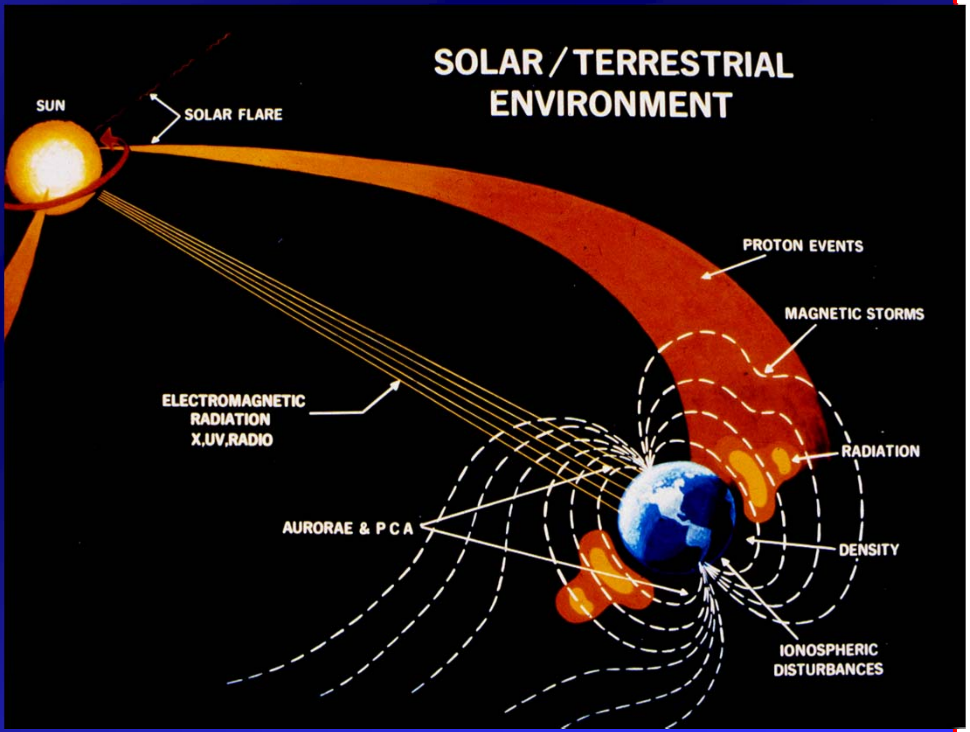
Courtesy NASA JSC, M. Matney, J.C. Liou

Environments

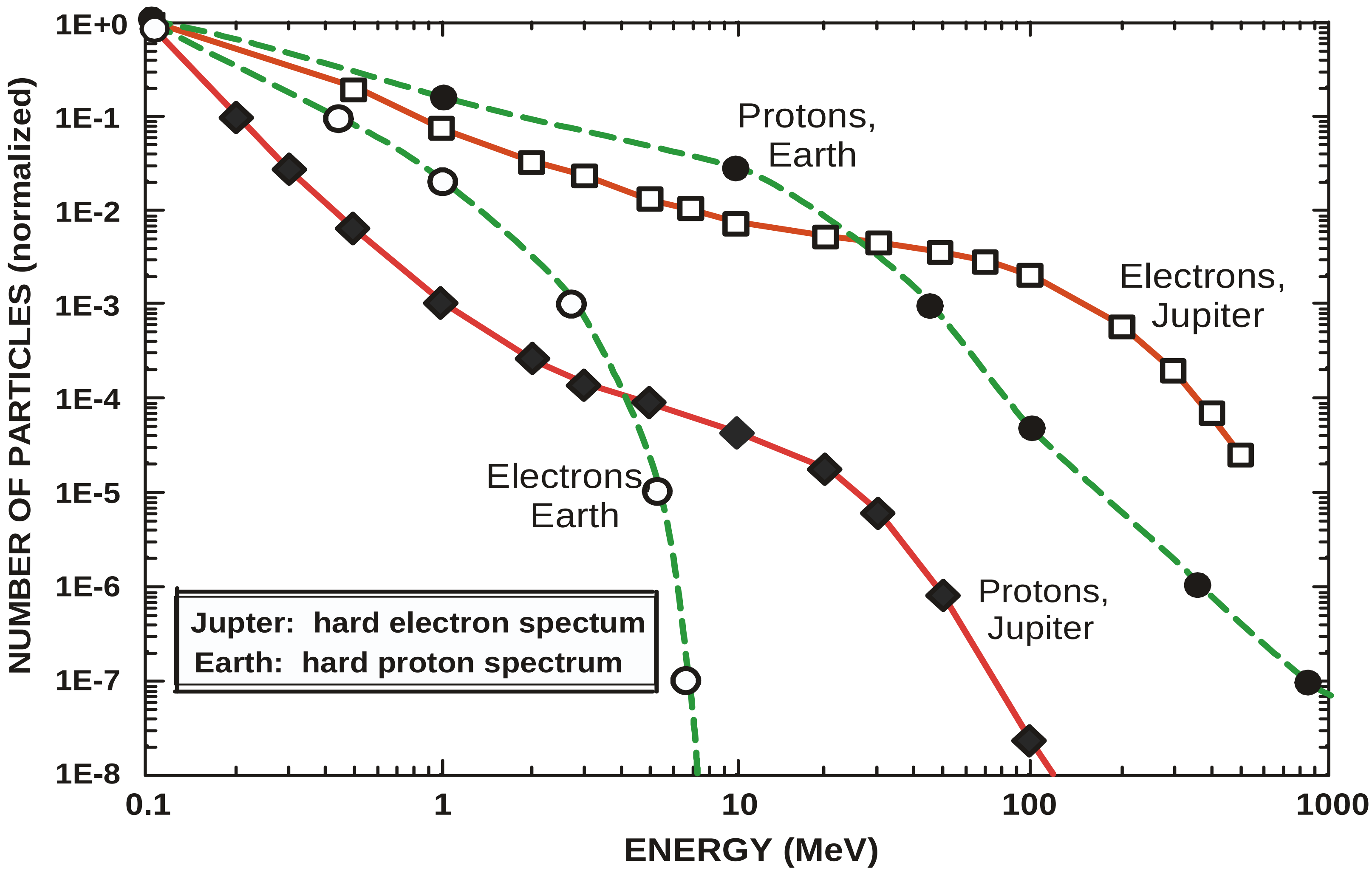


Radiation Environment

- Particle Radiation Displaces and Ionizes Material in its Path
  - Result is Degradation in Material Properties
  - Cross-Linking (Hardening) and Chain-Scission (Weakening) of Polymers
  - Degradation of Solar Cell performance
  - Single Event Upsets (SEU)
  - Darkening of material



Comparison of the Earth and Jovian Radiation Environments



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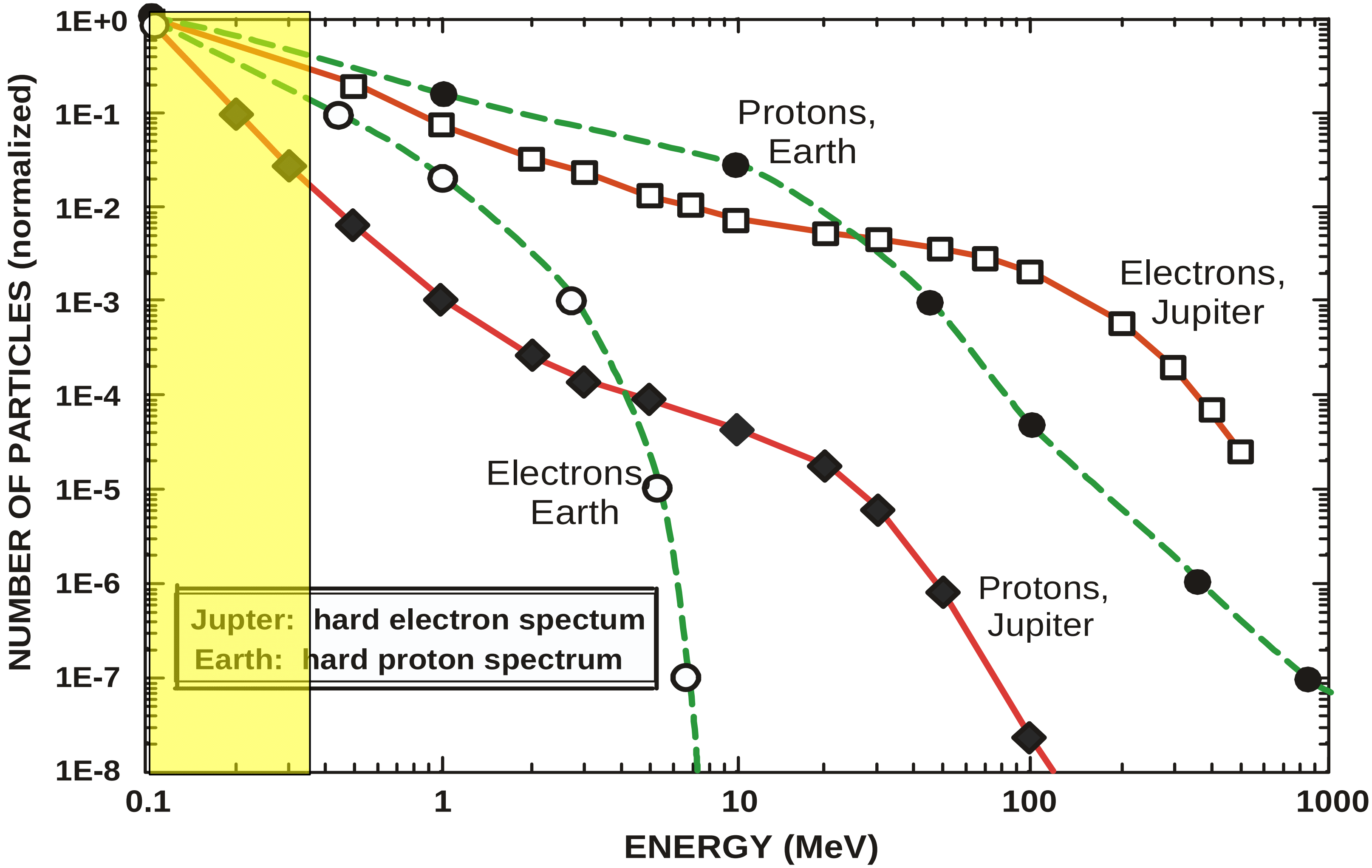

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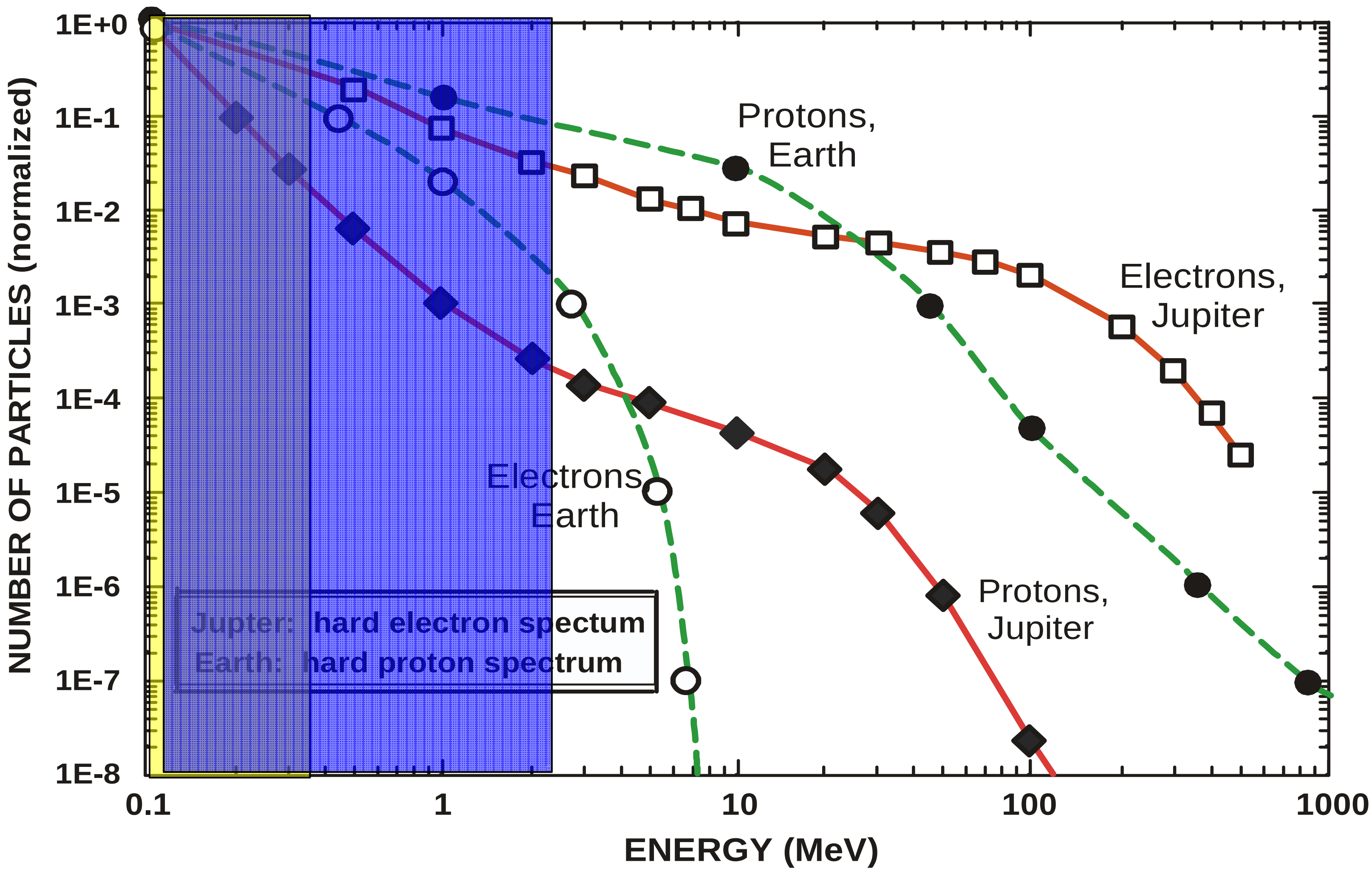

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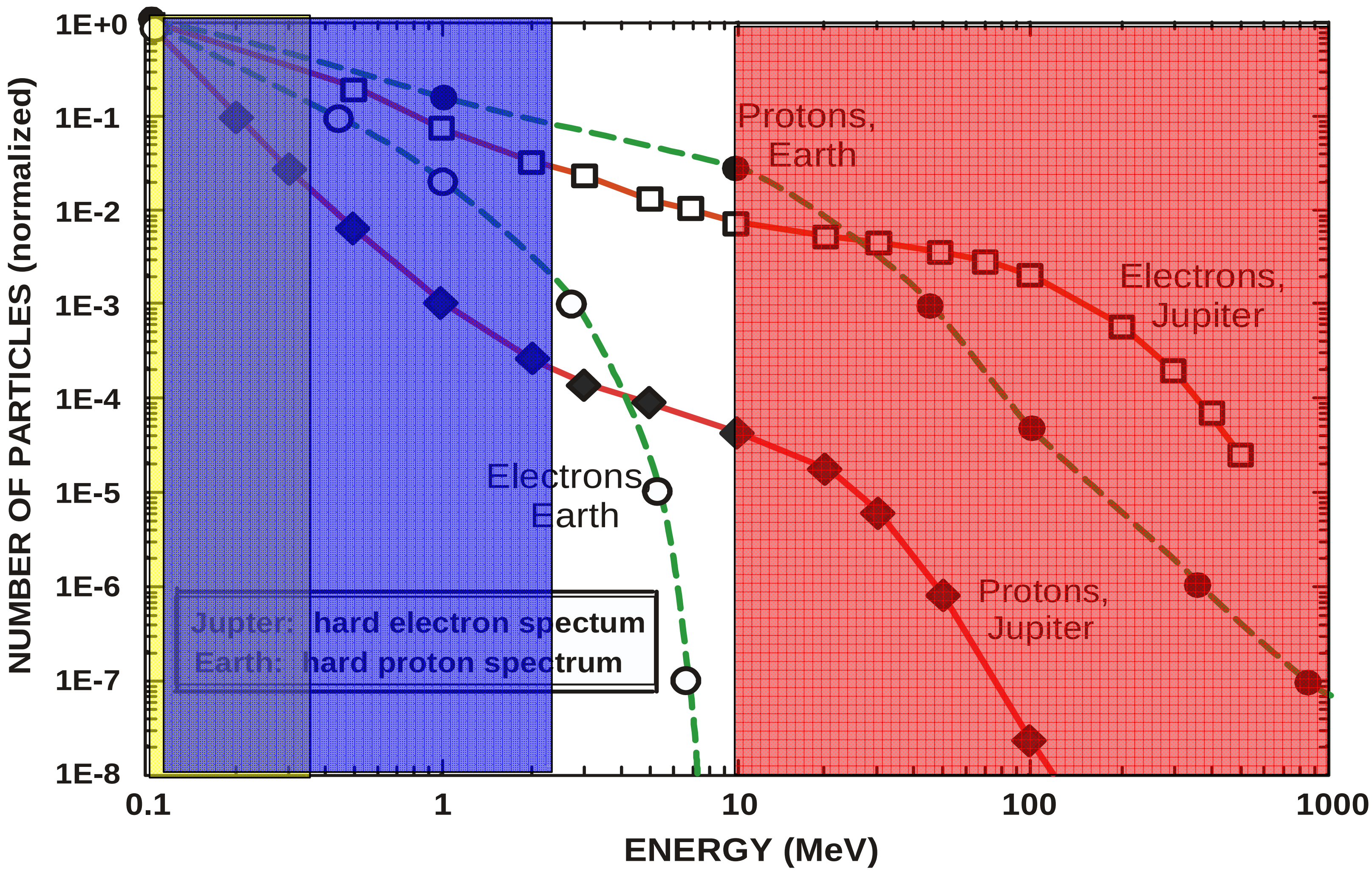

Summary

- Define the environment
- Be aware of the combined environmental effects: Synergisms
- Test materials and systems to ensure engineering performance is well above end of life at end of mission
- Literature search can save time and lower cost
- Flight heritage in one environment does not qualify for use in another environment
- How do I get help ?
  - Reference books
  - Web sites
  - Contacts

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USEFUL INTERNET SITES FOR SPACE ENVIRONMENT EFFECTS

http://envnet.gsfc.nasa.gov/	GSFC (EnviroNET) Homepage
http://see.msfc.nasa.gov/	MSFC SEE Homepage
http://akebono.tksc.nasda.go.jp/	Japanese SEE Homepage
http://crsp3.nrl.navy.mil/creme96/	CREME96 Homepage
http://sat-nd.com/special/index.html	Recent Satellite Outages and Failures
http://nppp.jpl.nasa.gov/	NASA EEE Space Parts Program
http://standards.nasa.gov/	NASA TECHNICAL STANDARDS PROGRAM
http://eis/engstnd/standard/engstnd.htm	Space Engineering Standards (JPL)
http://www.sel.noaa.gov/today.html	Today's Space Weather
http://spaceweather.com/	The NASA Space Weather Bureau
http://www.sec.noaa.gov/	NOAA Space Environment Center
http://www.ngdc.noaa.gov/	National Geophysical Data Center
http://geomag.usgs.gov/	USGS Geomagnetism Program
http://www.ngdc.noaa.gov/seg//potfld/tab1igrf.html#IGRF95	International Geomagnetic Reference Field
http://www.geolab.nrcan.gc.ca/geomag/e_digdat.html	Canadian Digital Magnetometer Data
http://medicine.wustl.edu/~kronkg/leonids.html	Leonid Meteor Shower
http://www.astro.ufl.edu/~oliver/xyz/	METEM Model FTP Site (Prof. John Oliver)
http://www.imo.net/index.html	International Meteor Organization Index
http://www.jpl.nasa.gov/releases/98/glrings.html	Jupiter's rings
http://sn-callisto.jsc.nasa.gov/model/modeling.html	Debris Models
http://www.geo.mtu.edu/weather/aurora/	The Aurora
http://www.pfrr.alaska.edu/~pfrr/AURORA/ACTV.HTM	Alaska Aurora Movies
http://www.ngdc.noaa.gov/dmsp/	DMSP Auroral Photos (Latest Aurora)
http://www.ngdc.noaa.gov/stp/GOES/goes.html	GOES Daily Satellite Data (Geosynchronous)
http://nssdc.gsfc.nasa.gov/cd-rom/cd-rom.html	NSSDC CD Catalog of Space Data
http://www.npi.msu.su/INP/SRD/lop.html	Russian Radiation Models
http://www.ipex.cz/klet/www.html	Astronomical Sites (Asteroid Orbits, etc.)
http://www.stsci.edu/pubinfo/Latest.html	HST Pictures
http://spacelink.msfc.nasa.gov/.index.html	Space Link Educational Data Base/PC Programs
http://www.jpl.nasa.gov/	JPL Homepage
http://www.sni.net/saa/digest.htm	Space Analytics Associates List of Useful URLs
http://www.spacecom.af.mil/usspace/links.htm#wx	US Space Command Space Weather Links
http://www.nrl.navy.mil/clementine/	NRL Clementine Site
http://www-vsbs.plh.af.mil/vsbs-projects.html	AFRL Space Hazards Branch Projects
http://umbra.nascom.nasa.gov/spd/	NASA Space Physics--Mission Descriptions
http://list.cup.cam.ac.uk	My Spacecraft-Environment Interactions Book