OVERVIEW OF ENVIRONMENTAL FACTORS*

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*Original figures not available at time of publication.

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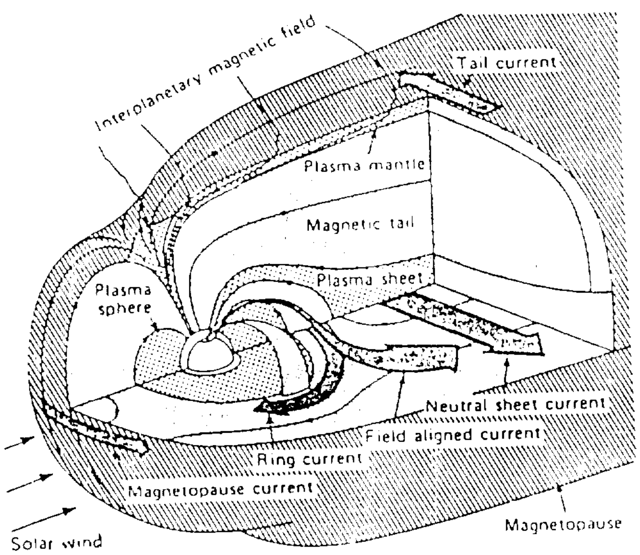
THE ENVIRONMENT

Near-Earth space is a complex, dynamic environment. The energies, densities, and constituents of the natural orbital environment vary with position (attitude, latitude, longitude), local time, season, and solar activity. The presence and activities of space systems modify many of the natural environment constituents (such as neutral particles and plasmas) so that the local environment may be quite different from the natural one. The local environment will interact with the system, its subsystems, surfaces, and structures. The impact of these interactions on the system must be assessed to ensure successful operation. Effects of the environment on the surface and structural materials play a crucial role in determining system function, reliability, and lifetime.

NEAR EARTH SPACE IS NOT EMPTY



THE EARTH'S MAGNETOSPHERE

IT CONTAINS
- O NEUTRAL ATOMS
- O PLASMAS
- O FIELDS
- O RADIATION
- O PARTICULATES

VARIES WITH
- O LOCAL TIME (DAY/NIGHT)
- O SOLAR CYCLE

SYSTEM PRESENCE AND OPERATIONS ALTER LOCAL ENVIRONMENT

SYSTEM-ENVIRONMENT INTERACTIONS
- O INCREASE WITH SYSTEM SIZE, POWER AND ACTIVITY
- O IMPACT SYSTEM/SUBSYSTEM
  - FUNCTIONAL
  - OPERATIONS
  - RELIABILITY
  - LIFETIME

THE TERRESTRIAL SPACE ENVIRONMENT

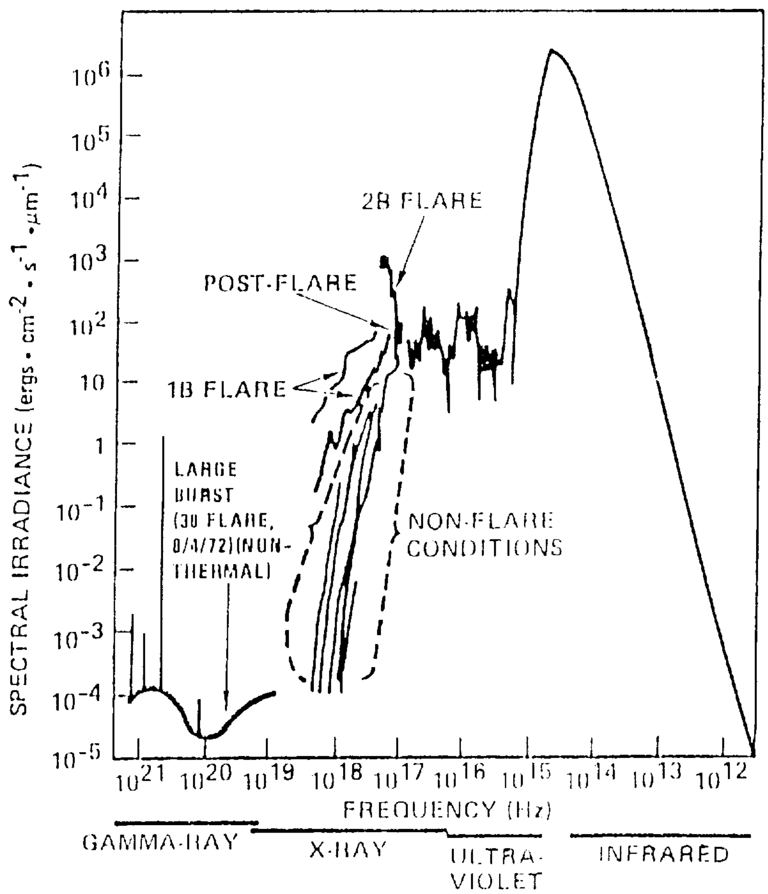
The terrestrial space environment comprises many factors, each of which can have important effects on space systems. These effects must be accounted for to ensure successful designs. This chart summarizes the natural environment factors (debris is included, though not truly a "natural" factor, because it is important and not generated by the system being considered) and their effects, and notes the importance of system-generated components. The "enhanced" or threat environment is noted for completeness, but it is not considered further here. Many of the effects listed are materials related. It is the environment factors associated with these effects on which we now focus. These are solar radiation, meteoroids and debris, neutral atmosphere, plasmas, trapped radiation, and system-generated contaminants. In what follows, each of these environments is overviewed briefly. More details will be found in the individual "environment" sections of the Workshop's focus sessions.

-EFFECTS ON SPACE SYSTEMS-

ENVIRONMENTAL FACTOR	EFFECTS
GRAVITY	ACCELERATION, TORQUES
SUNLIGHT & ALBEDO	HEATING, POWER, DRAG, TORQUES, PHOTOEMISSION, MATERIAL DAMAGE, SENSOR NOISE
METEOROIDS & DEBRIS	MECHANICAL DAMAGE, ENHANCED PLASMA INTERACTIONS
NEUTRAL ATMOSPHERE	DRAG, TORQUE, MATERIAL DEGRADATION, HEATING
FIELDS	TORQUES, DRAG, SURFACE CHARGES, POTENTIALS
PLASMAS	CHARGING, INDUCED ARCING, POWER LOSSES, POTENTIALS, ENHANCED CONTAMINATION, CHANGE OF E-M REFRACTIVE INDEX, PLASMA WAVES & TURBULENCE
FAST CHARGED PARTICLES	RADIATION DAMAGE, ARCING, SINGLE EVENT UPSETS, NOISE, HAZARD TO MAN
SYSTEM GENERATED	SYSTEM DEPENDENT: NEUTRALS, PLASMAS, FIELDS VIBRATION, TORQUES, RADIATION, PARTICULATES
ENHANCED	EMP & RELATED

THE SOLAR SPECTRUM

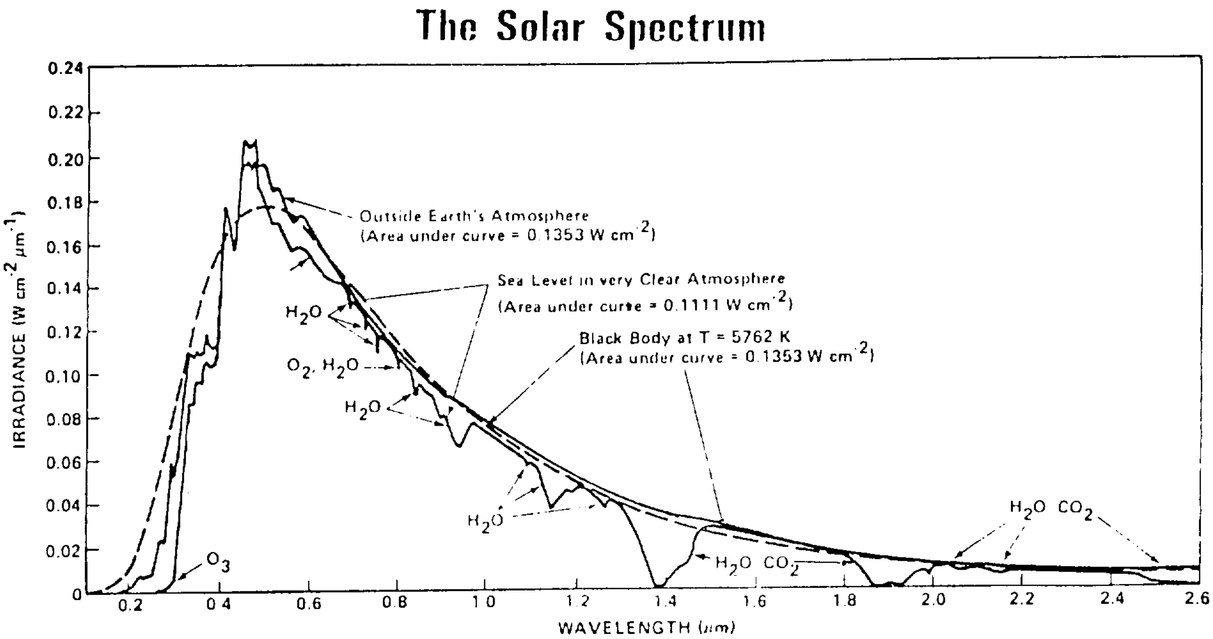
This chart gives an overview of the solar spectrum, from the gamma ray out to the far infrared. Some 99.5% of the Sun's radiant energy is in the 1200Å to 10 μm wavelength (2.5 × 10-^{15} - 3 × 10-^{13} Hz) range. The flux levels in the visible and near-ultraviolet (UV) are relatively stable, whereas those in the extreme ultraviolet (EUV), X, and gamma ray region are highly variable and depend on solar activity.



NASA-GODDARD SPACE FLIGHT CENTER
GREENBELT, MARYLAND
AUGUST, 1976

SOLAR IRRADIANCE

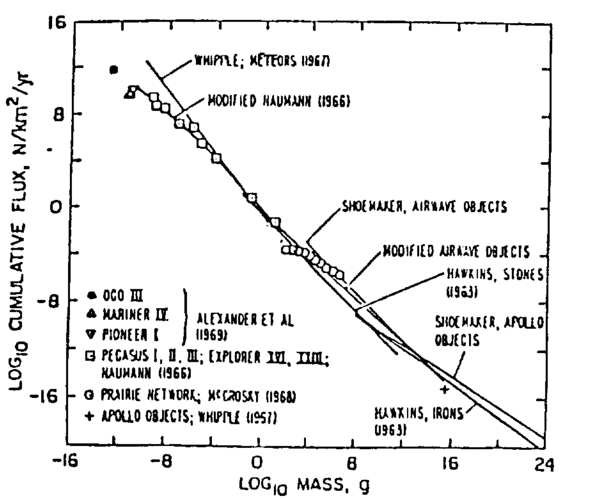
The solar irradiance spectrum in orbit in the UV through IR range is well approximated by black body radiation for a T = 5762°-K object.



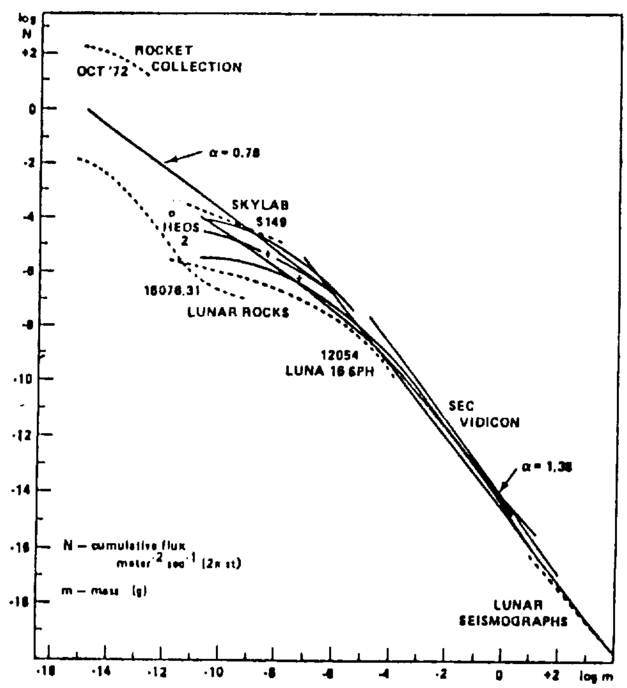
Normally incident solar radiation at sea level on very clear days, solar spectral irradiance outside the Earth's atmosphere at 1 AU, and blackbody spectral irradiance curve at T = 5762°K (normalized to 1 AU)

METEOROID ENVIRONMENT

Meteoroids are an obvious potential source of mechanical damage to spacecraft materials. Total mass influx of meteoroids is estimated as 10^{10} gm/year. Average velocity of meteoroids is considered in the models to be 20 km/second and density is considered to be approximately .5 gm/cm^3 for cometary meteoroids and approximately 2 gm/cm^3 for asteroidal ones. The figures show one-year average estimates of cumulative number fluxes from various sources. In modeling this environment, N is taken to be of the form $N = Const/m^{\alpha}$ where α is a slowly varying parameter of order unity (see right-hand figure).



Terrestrial mass-influx rates of meteoroids. N is the flux of particles with mass greater than m [2-29].



Cumulative particle fluxes from various data sources

METEOROID IMPACTS

Estimates of frequency of meteoroid impacts can be made using formulas given in NASA SP-8013 and SP-8042. These models are old but are still used for design.

NASA SP-8013 GIVES COMETARY METEOROID FLUX N AT 1AU AS:

$\mathrm{LOG}_{10}N = -14.37 - 1.213\ \mathrm{LOG}_{10}M \qquad 10^{-6} \leq M \leq 10^{0}$

$\mathrm{LOG}_{10}N = -14.34 - 1.584\ \mathrm{LOG}_{10}M - 0.063\ (\mathrm{LOG}_{10}M)^2 \qquad 10^{-12} \leq M \leq 10^{-6}$

N= # OF IMPACTS OF MASS M GRAMS AND LARGER PER SQUARE METER PER SEC.

MULTIPLY BY DEFOCUSING FACTOR G_e AND EARTH SHIELDING FACTOR $\mathcal{J}(R)$

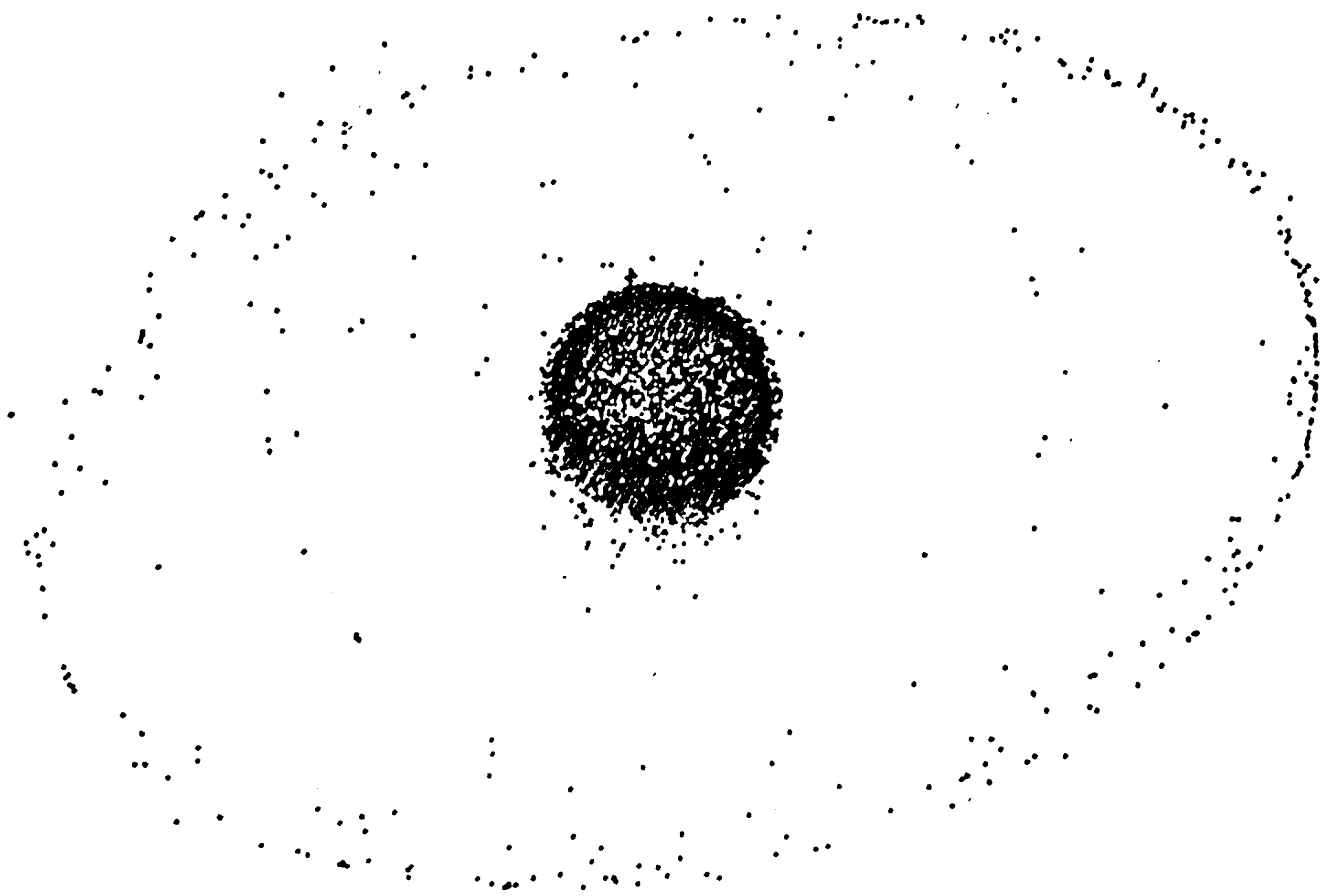
EXAMPLES:

M(GM)	$N_{1AU}(m^{-2}s^{-1})$	$R(R_e)$	$N_R(m^{-2}s^{-1})$	$N_R(m^{-2}yr^{-1})$
1	3.9×10^{-15}	1.05	2.1×10^{-15}	6.6×10^{-8}
		1.5	2.9×10^{-15}	9.1×10^{-8}
		6	2.5×10^{-15}	7.9×10^{-8}
10^{-6}	7.9×10^{-8}	1.05	4.3×10^{-8}	1.4
		1.5	5.8×10^{-8}	1.8
		6	5.1×10^{-8}	1.6
10^{-12}	4.0×10^{-5}	1.05	2.2×10^{-5}	6.9×10^{2}
		1.5	3.0×10^{-5}	9.4×10^{2}
		6	2.6×10^{-5}	8.2×10^{2}

[SEE ALSO NASA SP-8042 "METEOROID DAMAGE ASSESSMENT", 1970]

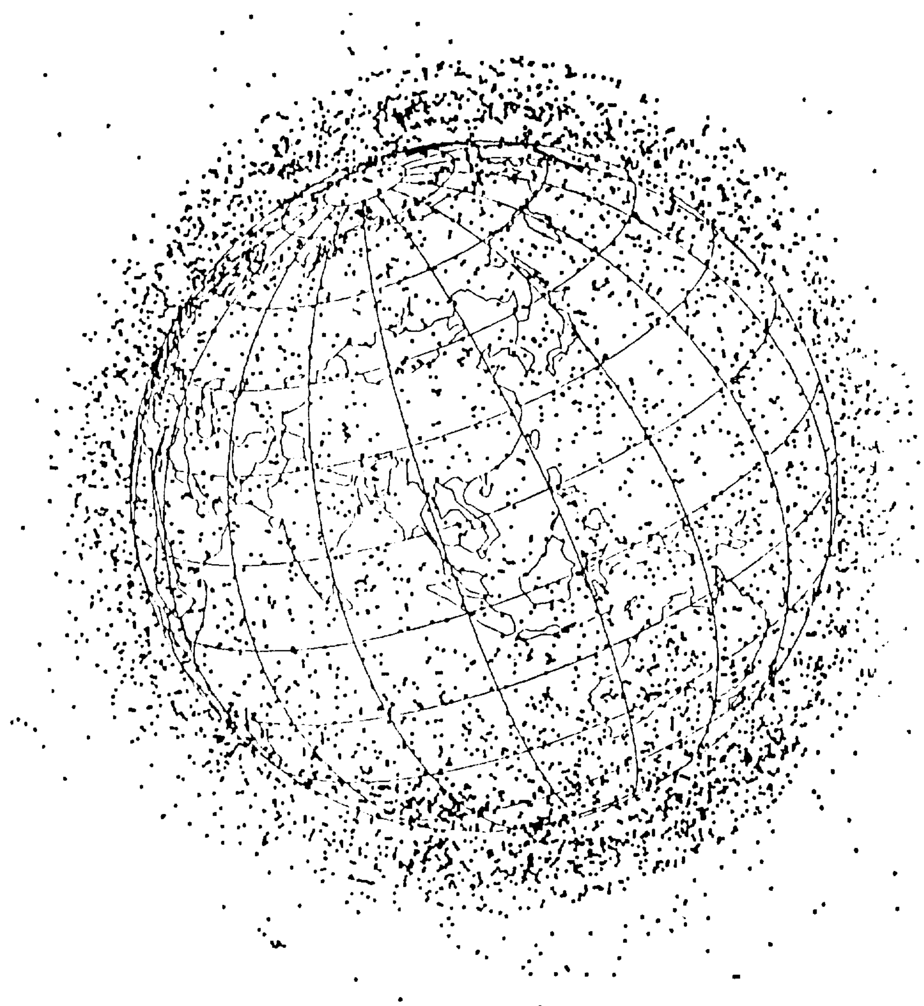
DISTRIBUTION OF DEBRIS IN EARTH ORBIT

This chart shows a representation of the distribution of debris in Earth orbit. The "ring" is at geosynchronous. Sources of debris include spent stages, nonfunctional spacecraft, fragments from staging operations, exploded stages, collision, disposed wastes, and residues from engine burns.



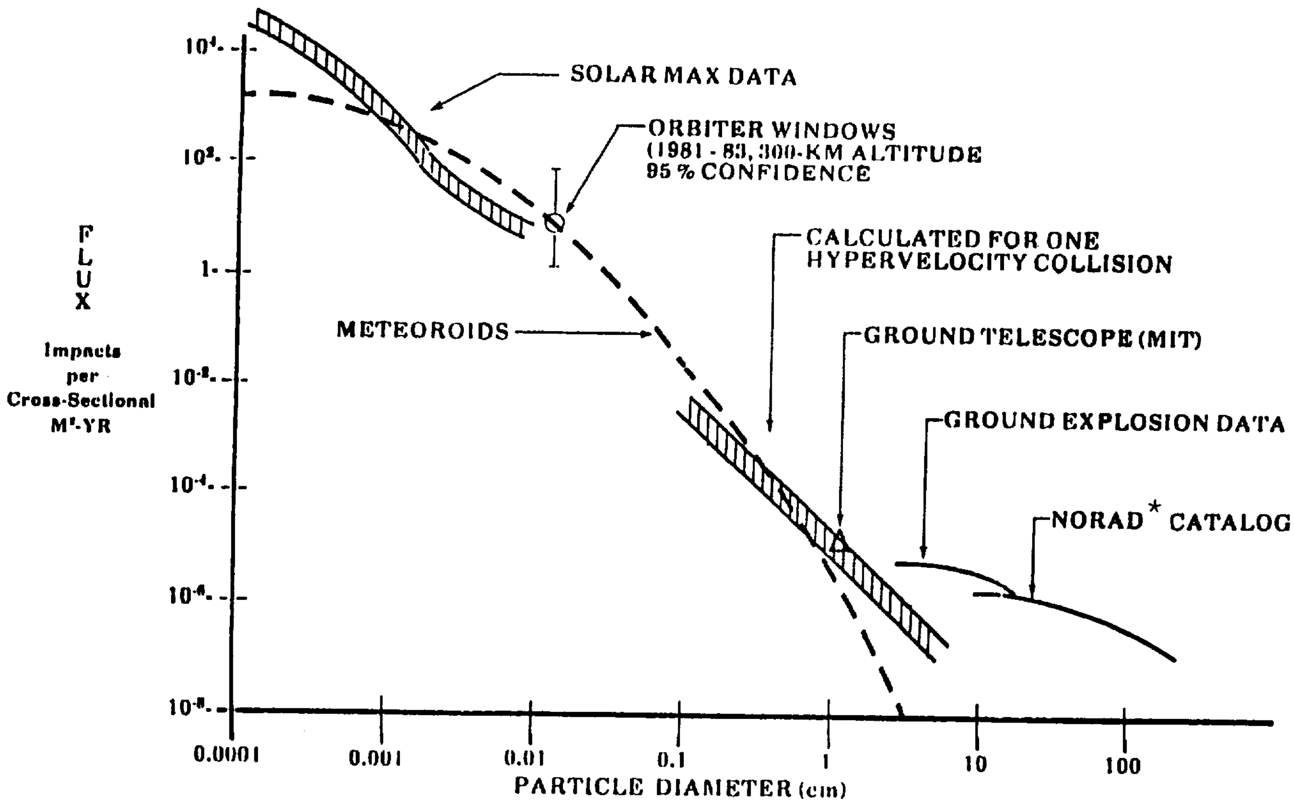
CLOSER VIEW OF DEBRIS DISTRIBUTION

A closer view illustrating the relative uniformity of debris distribution in low Earth orbit (LEO). Density of the debris falls off at altitudes $\gtrsim$1500 km.



ORBITAL DEBRIS MEASUREMENTS COMPARED TO METEOROID FLUX

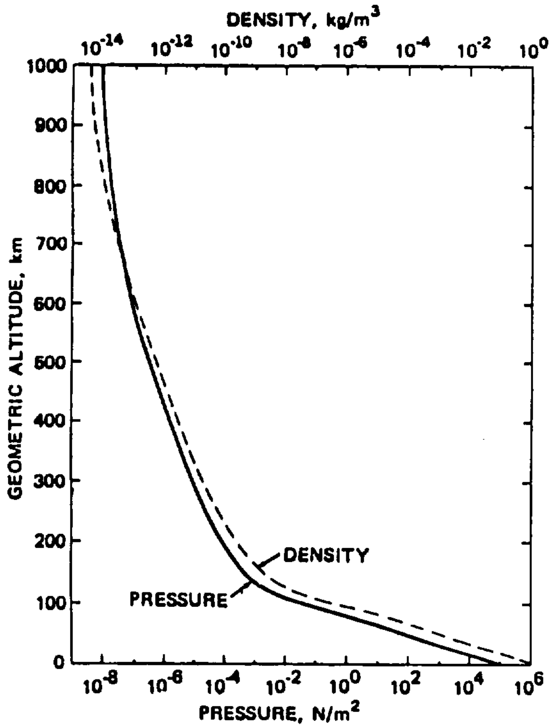
This shows a comparison of meteoroid and debris fluxes for various particle diameters. Debris is a more serious threat than meteoroids at the small and large extrema. Data on debris fluxes in the 1-mm to 1-cm diameter range is lacking.



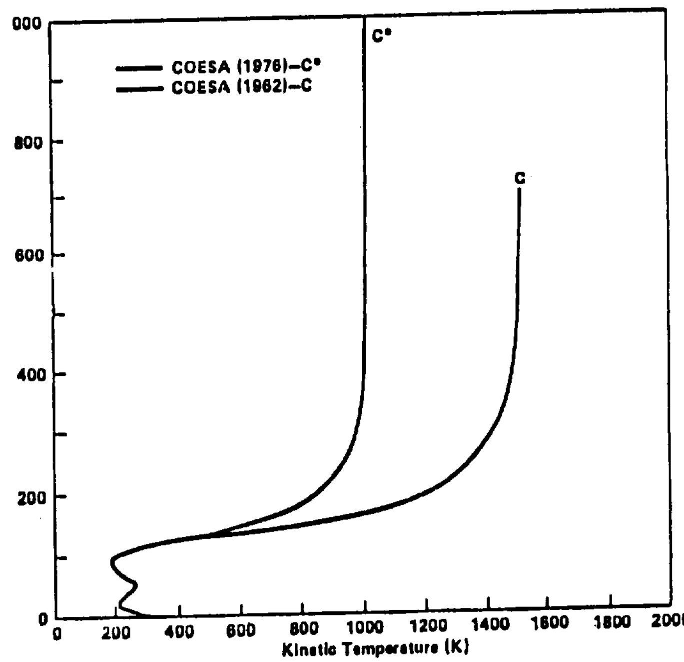
* North American Air Defense Command

NEUTRAL ATMOSPHERE

Atmospheric pressure and density decrease rapidly in suborbital regions ($\lesssim$200 km), while kinetic temperature increases. At orbital altitudes, the residual atmosphere is tenuous enough to be essentially collisionless.

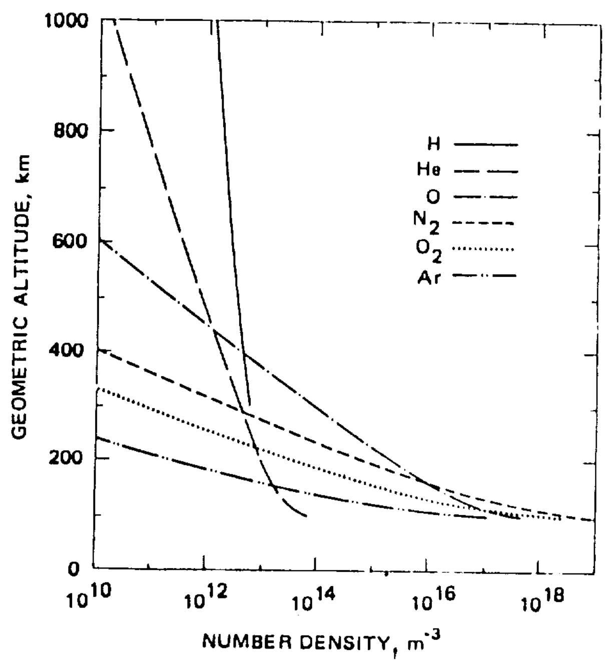


Total pressure and mass density as a function of geometric altitude

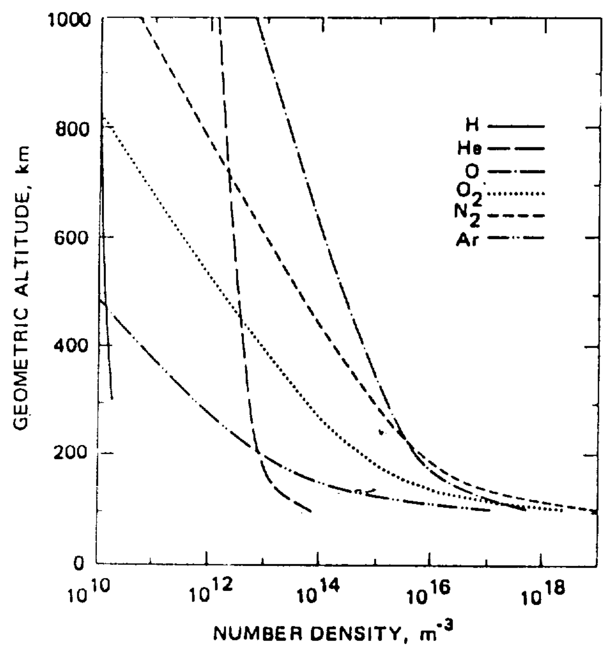


Kinetic temperature versus altitude

The density, composition, and temperature of the residual atmosphere vary with solar activity. In recent years the reactivity of atomic oxygen, which is the dominant constituent of the residual atmosphere at LEO, has been recognized as a serious threat to materials exposed to its ram flow. The motion of spacecraft through the residual atmosphere in LEO at velocities of the order 7.5 to 8 km/sec results in an equivalent impingement energy for O of 4.5 to 5 eV. Rapid degradation of some materials in this environment has been observed on STS.



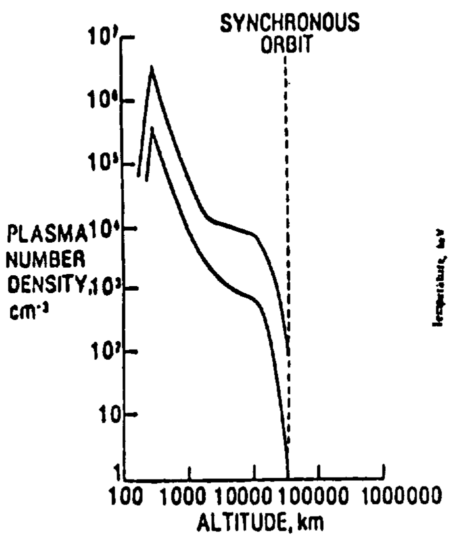
Relative concentrations of atmospheric constituents during periods of minimum solar activity



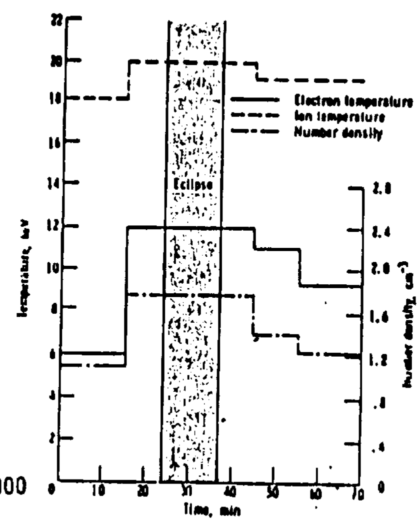
Relative concentrations of atmosphere constituents during periods of maximum solar activity

Near-Earth plasma regimes include the cold (~.1 eV) relatively dense (to ~$10^6/cm^3$) ionospheric plasmas whose densities gradually fall off with altitude; the hot (~KeV to ~10's of KeV), tenuous ($\leq 1/cm^3$) plasmas observed at geosynchronous and associated with geomagnetic substorm activity; and the fluxes of hot electrons due to these geosynchronous plasma injections which travel down magnetic field lines and precipitate in the auroral zones. The latter two plasma environments can charge spacecraft surfaces to kilovolt potentials; the cold ionospheric component interacts strongly with spacecraft power systems.

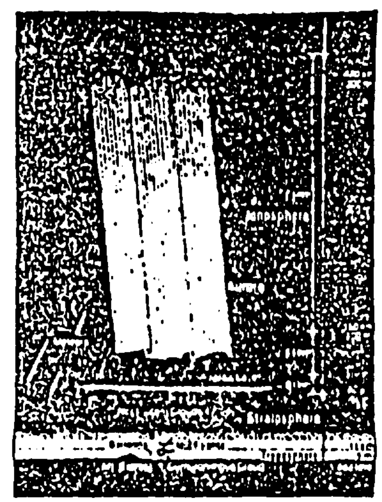
NEAR EARTH PLASMAS



IONOSPHERIC PLASMAS



GEOSYNCHRONOUS MODEL SUBSTORM



AURORAL PLASMAS HIGH LATITUDES

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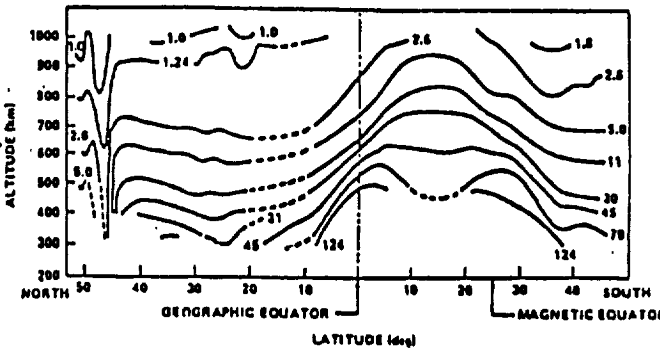
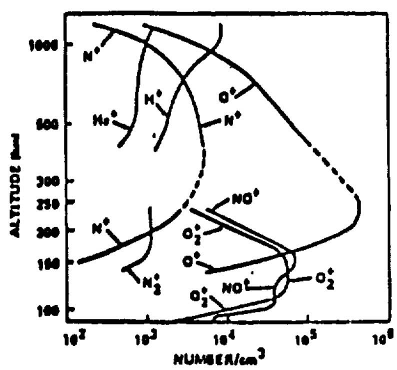
PLASMA DENSITY AND COMPOSITION IN THE IONOSPHERE

Plasma density and composition in the ionosphere vary daily, seasonally, latitudinally, and with solar activity, as is illustrated in these figures.

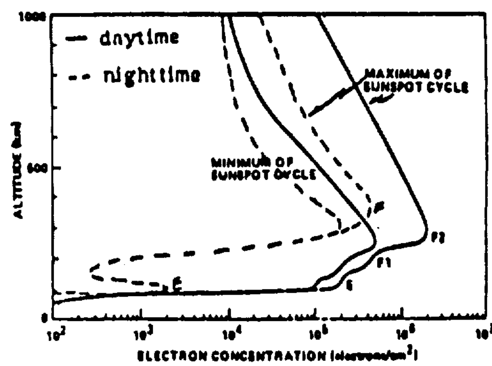


Daytime equal-electron-density contours (Units: 10^4/cm^3) (2-39).

IONOSPHERE



Ionic composition of the solar minimum daytime winter ionosphere (2-14).



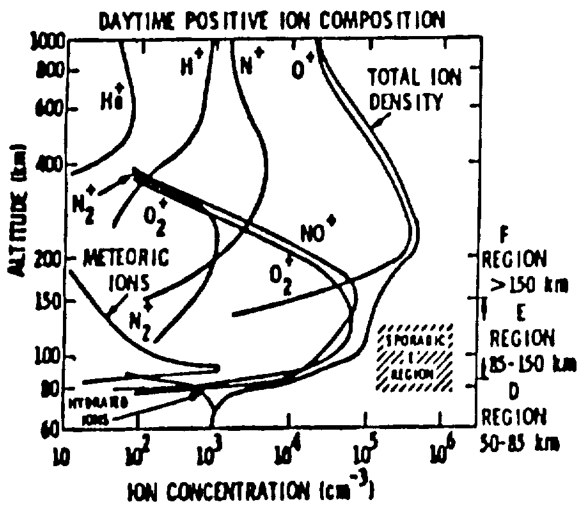
Normal electron distribution

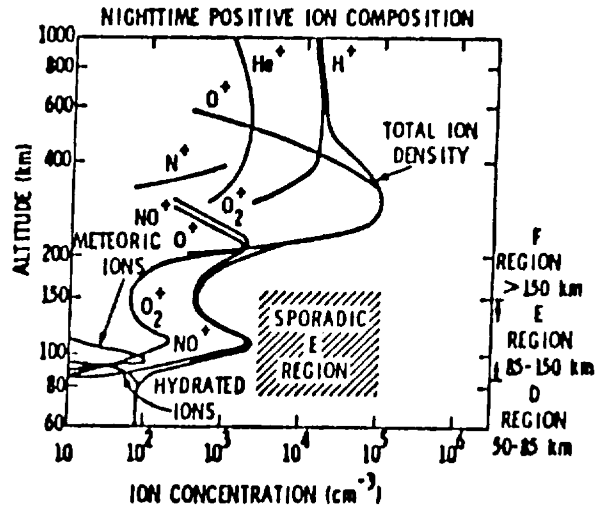
DIURNAL VARIATION IN ION DENSITY AND COMPOSITION

This figure illustrates the diurnal variation in ion density and composition for solar maximum at mid-latitude.

MID LATITUDE ION COMPOSITION

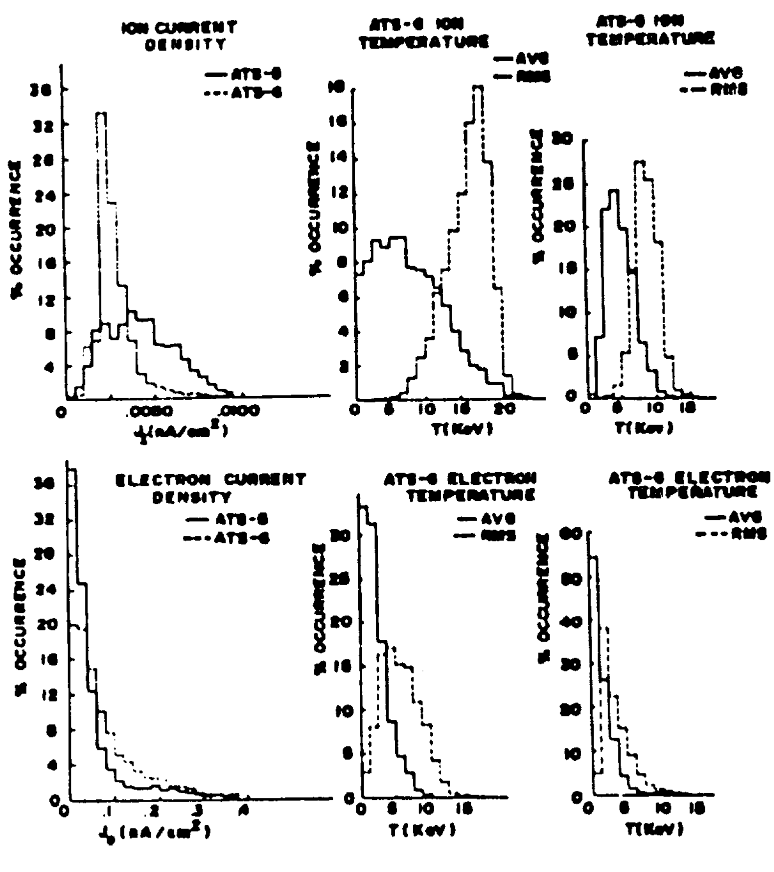
SOLAR MAXIMUM





This figure shows histograms of the occurrence frequencies of the electron and ion temperatures and current at geosynchronous orbit measured by Applications Technology Satellite (ATS)-5 and ATS-6. T(AVG) is two-third's the ratio of energy density to number density; T(RMS) is one-half the ratio of particle energy flux to number flux.

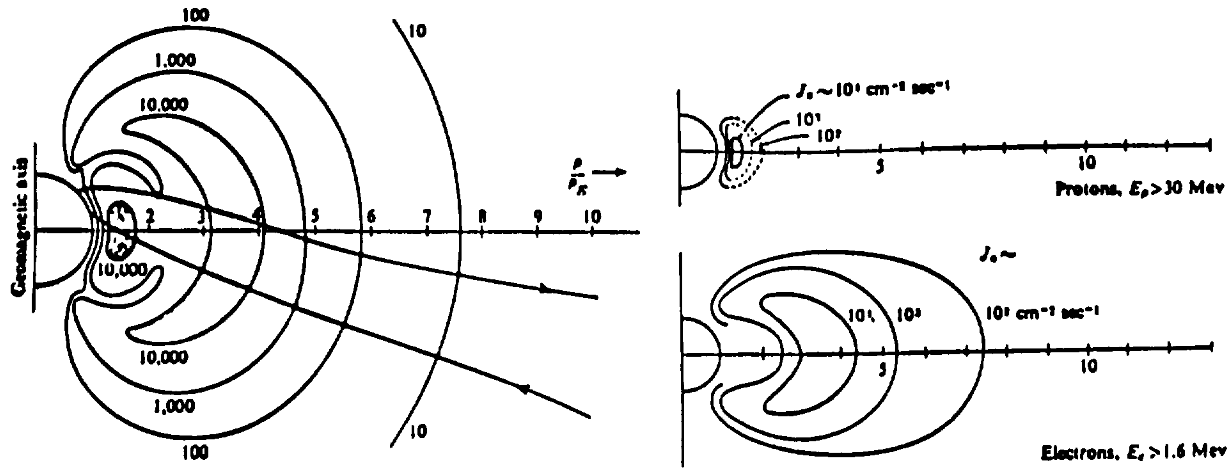
The hot plasmas were observed to charge the ATS-5 and ATS-6 spacecraft to kilovolt potentials in eclipse and to hundreds of volts in sunlight. Similar charging effects are anticipated for large spacecraft in auroral zones at LEO. The DMSP spacecraft (900 km) has been observed to charge to approximately 700 volts during auroral passage. Charging potentials are negative because electron fluxes dominate the process.



Histograms of the Occurrence Frequencies of the Electron and Ion Temperatures and Current at Geosynchronous Orbit as Measured by ATS-5 and ATS-6. T(AVG) is 2/3's the ratio of energy density to number density; T(RMS) is one-half the ratio of particle energy flux to number flux

TRAPPED RADIATION: THE VAN ALLEN BELTS

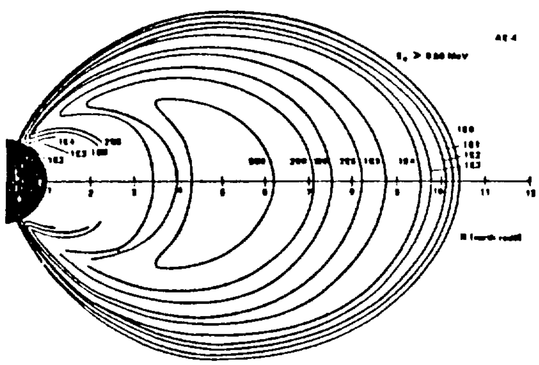
This figure shows Van Allen's first map of the radiation belt, showing the inner and outer zones of high count rate. The contours are labeled by the count rate of a Geiger counter of about 1 cm^2 area covered by 1 gm/cm^2 of lead.



Van Allen's first map of the radiation belt, showing the inner and outer zones of high count rate. The contours are labeled by the count rate of a Geiger counter of about 1 cm^2 area covered by 1 gm/cm^2 of lead [23].

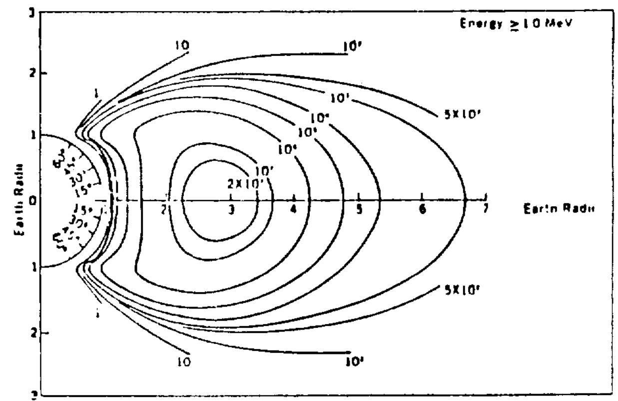
NSSDC TRAPPED RADIATION MODELS

Trapped radiation models are available from the National Space Sciences Data Center (NSSDC).



R-λ map of AE-4 electron fluxes for Epoch 1964, threshold energy 0.5 MeV. Solar minimum.

AP8MIN OMNIDIRECTIONAL FLUX (PROTONS/CM²-SEC)



AP8MIN R-λ plot of constant intensity flux contours with an energy of ≥ 1.0 MeV.

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SYSTEM GENERATED ENVIRONMENT

The system-generated environment is system-specific and may be quite complex. It is generally considered to be the main source of contaminants which can impact the system.

DEPENDS ON SYSTEM CHARACTERISTICS

- O NEUTRALS: OUTGASSING, THRUSTER EJECTA, DUMPS, RAM/WAKE
  - CHEMICAL REACTIONS: DEGRADATION, CONTAMINATION
  - LOCALLY ENHANCED PRESSURES

- O PLASMAS: PHOTOIONIZATION OR CHARGE EXCHANGE OF NEUTRALS, DIRECT, RAM/WAKE
  - ENHANCED PLASMA INTERACTIONS
  - COUPLING TO AMBIENT: POTENTIAL CHANGES

- O ENERGETIC CHARGED PARTICLES: ELECTRON OR ION BEAMS
  - BEAM-PLASMA INTERACTIONS: HEATING, WAVES, EMI*
  - INTERACTIONS WITH NEUTRALS: EXITATION, IONIZATION, BPD†
  - ENHANCED PLASMA INTERACTIONS
  - CURRENT BALANCE ALTERATIONS: POTENTIAL CHANGES

- O ELECTRIC AND MAGNETIC FIELDS: EXPOSED V's, CURRENTS, RESIDUALS, $\vec{V} \times \vec{B}$
  - TORQUES AND FORCES: ATTITUDE CONTROL
  - PLASMA SHEATH EFFECTS: PLASMA INTERACTIONS
  - STIMULATION OF WAVES, INSTABILITIES: EMI, PLASMA INTERACTIONS

*Electromagnetic interference
†Beam plasma discharge

SUMMARY

The orbital environment is complex, dynamic, and comprised of both natural and system-induced components. Several environment factors are important for materials. Materials selection/suitability determination requires consideration of each and all factors, including synergisms among them. Understanding and evaluating these effects will require ground testing, modeling, and focused flight experimentation.

ORBITAL ENVIRONMENT IS COMPLEX

- NATURAL
- SYSTEM-INDUCED

ENVIRONMENT FACTORS IMPORTANT FOR MATERIALS INCLUDE:

- SOLAR RADIATION
- METEOROIDS AND DEBRIS
- NEUTRAL ATMOSPHERE
- PLASMAS
- TRAPPED RADIATION
- SYSTEM-GENERATED CONTAMINANTS

MATERIALS SELECTION/SUITABILITY DETERMINATION REQUIRES CONSIDERATION OF ALL FACTORS