NATURE OF THE SPACE ENVIRONMENT

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In the broad sense, the word "space" is all inclusive. It includes the Sun, the Earth, and the other planets of the solar system. It includes the one hundred billion stars or more in our own galaxie, which we label the "Milky Way." It includes all the other galaxies of the universe which we see as nebulae. The great nebula in Andromeda is shown in the first slide. Certainly there are billions of stars in this disk-shaped conglomeration, some of which may have planets and living intelligent beings. If the environment near these billions of stars is right for living forms, then surely life will exist on some of them. This is a challenge for the future. Our solar system (Slide 2) is probably not unique even in our own galaxy, and we know that there are billions of galaxies in the universe.

The space environment includes all matter or the relative lack of matter in the high vacuum regions between the planetary and stellar mass concentrations. It likewise includes all transient excursions of matter through these regions, and the influence that these meteoroidal excursions might have on a space ship contained therein. It includes all radiation such as light, radiowaves, X-rays, and electromagnetic radiation. It includes all force fields such as gravity, electrostatic attractions, and magnetic fields. And the space environment must recognize the probabilities of cosmic rays, solar winds, and lethal radiations associated with solar flares.

I shall concentrate on solar space shown pictorially in Slide 3. Here you see what is to us the most important star of our universe in the lower right-hand corner. The Sun is, of course, the principal source of energy for the solar system. It has a diameter of some 860,000 miles. While the internal temperature of this gigantic thermonuclear reactor is about 40,000,000 degrees, the surface temperature is nowhere near this high. The effective temperature of the photosphere is about 6000°K.

The Sun (Slide 4), however, is far from being a quiet well-behaved source of heat and light. Intense storms project giant tongues of material into space at millions of degrees (coronosphere). There are magnetic storms in the form of sunspots that vary according to the sunspot cycles of about 11 years. In addition, the Sun rotates on its axis carrying these sunspots across its surface in a 27-day period. Each of these periods influence the environment, weather, and atmospheres of the planets. In addition, the solar prominences project streams of charged particles and magnetism outward to bathe the planets in a transiently varying solar atmosphere. Thus, each of the planets is bathed in the solar atmosphere, which would monotonically decrease in intensity as we proceed outward from the Sun's surface past the planets, Mercury, Venus, Earth, Mars, Jupiter, Saturn, Uranus, Neptune, and Pluto.

The intensity of radiation such as light and heat vary inversely as the square of the distance from the Sun. At the Earth's distance of 93,000,000 miles from the Sun (1 astronomical unit), the solar energy is 1.34 kilowatts per square meter. If this value were to change by only 10 percent, the Earth's weather would be drastically altered, with the possibilities of melting the polar ice caps, and so forth. A 5-percent change in the orbital diameter would do this.

The known planets in the solar system have distances from the Sun ranging from 0.387 for the planet Mercury to 39.52 A for the planet Pluto. The radiant energy intensity received by a spacecraft moving across the realms of solar space would therefore vary by a factor of 10,000 in making a trip from Mercury to Pluto. The planet Pluto is so far removed even from Earth (more than 300 light minutes) that the probability for manned flight beyond the solar system is questionable indeed. The nearest star is about 4.3 light years away.

I mentioned earlier that the space environment included all of the force fields contained therein. One of these force fields, the gravitational attraction, holds very special significance. The force of gravity between two masses varies as the inverse square of the distance between them:

$$F = \frac{k m m_1}{r^2} \tag{1}$$

Because of this force, the planets of the solar system are held in orbits about the Sun. It may easily be shown that these orbits can be elliptical, parabolic, or hyperbolic, depending on the relative velocities and the masses of the two bodies. We are most generally concerned with elliptical paths for the planets. Objects having parabolic or hyperbolic paths about the Sun, of course, leave the solar system after the first pass-by. The radius vector of a particular planet sweeps out equal areas in equal times. The square

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of the orbital period of the various planets is proportional to the cube of the distance of that planet from the Sun. Crudely speaking, the planets remain in orbit because the centrifugal force associated with the speed of the planet and the curvature of the path just balances the gravitational attraction. If the planet were not moving, it would quickly fall into the parent body to become part of it.

The gravitational attraction of the Sun and planets does something else for us. It serves as a gigantic pump to remove most of the non-orbiting material from space; thus, it builds up life-sustaining atmospheres on the planets and leaves very high vacuum conditions in the regions between the planets. We must recognize, however, that the gravitational pump is not perfect, so that even the high vacuum regions may be regarded as the outer fringes of the solar and planetary atmospheres.

At the surface of the Earth, our atmosphere sustains a pressure of 14.7 pounds per square inch, and the gas has an average molecular weight of about 29.4. We can estimate how the pressure varies with altitude if we assume that the force of gravity, the temperature, and the molecular weight remain constant. Take a small volume of gas with pressure differential from top to bottom equal to the weight
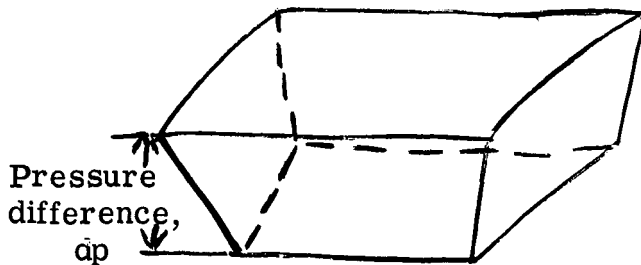
$$A\,dp = -\,\rho A\,dh \tag{2}$$

But from the gas law

$$pv = NRT$$

or

$$p = \rho \frac{R}{W}\,T \tag{3}$$

Hence, if T and W are constant (which they are not in the atmosphere),

$$\frac{dp}{p} = - \frac{W\,dh}{RT} \qquad (4)$$

or

$$p = p_0 e^{-\frac{W\,h}{RT}} \qquad (5)$$

In the atmosphere, experimentally, the pressure decreases approximately by a factor of 2 for each 16,000 feet. The uncertainty of this rule is indicated in the following table.

Pressure, atm.	Altitude ft
1/2	18,000
1/4	34,000
1/8	48,000
1/16	63,000

The pressure is roughly 0.01 atmosphere at 100,000 feet. It is about 10^{-8} millimeters of mercury at 300 miles.

Let us refine equations (2) through (5) somewhat. If we think of the individual constituents of the atmosphere, using partial pressures for the oxygen, nitrogen, carbon dioxide, water vapor, etc., and define a partial density as the mass of that constituent per unit volume, then without mixing, equation (5) would hold for the individual components such as oxygen, nitrogen, etc. The total pressure at any altitude would be the sum of the partial pressures of the individual components:

$$p = p_{01} e^{-\frac{W_1\,\Delta h}{RT}} + p_{02} e^{-\frac{W_2\,\Delta h}{RT}} + p_{03} e^{-\frac{W_3\,\Delta h}{RT}} \quad . \quad (6)$$

The volume percent of any particular gas j will be

$$\Delta_j = \frac{p_{0j} e^{\frac{W_j\,\Delta h}{RT}}}{p_{01} e^{-\frac{W_1\,\Delta h}{RT}} + p_{02} e^{-\frac{W_2\,\Delta h}{RT}} + p_{03} e^{-\frac{W_3\,\Delta h}{RT}}} \quad . \quad (7)$$

Note, however, that the exponentially decreasing partial pressures of the components decay at different rates due to the different molecular weights. The heavy gases decay faster than the light ones. Hence, the percentage of light gases at high altitude will increase. This, of course, is a complicated way of saying that the light gases of the atmosphere will float, and the heavy ones will sink.

You will recall that the equations were derived with the assumption of no mixing. Actually the turbulence of the weather band around the Earth produces so much mixing that the atmospheric composition does not change much up to an altitude of about 100 miles. There is, however, a band of helium at an altitude of perhaps 600 miles blending into a layer of hydrogen at a considerably higher altitude, (Slide 5) say about 1500 miles.

Other phenomena do occur, however, at the lower altitudes. Ozone may be formed. Atomic oxygen can occur below 600 miles; ionization is probable, etc. The variation in atmospheric composition with altitude including these latter effects implies that the absorption of the radiated energy in the solar spectrum will also vary with altitude. Likewise, when that energy is absorbed, chemical compounds are formed that intensify or modify the absorption characteristics.

You see, the Earth and its atmosphere along with the oceans, lakes, and rivers constitute a gigantic heat engine in a solar radiation environment. This heat engine has various forms of heat addition, heat transfer, mass transfer, and other complicating phenomena to yield the statistically fluctuating conditions leading to our weather, to our radio transmission, and to other phenomena such as northern lights, magnetic storms, etc.

Visible radiation and also radio waves penetrate the atmosphere to add heat to the Earth's surface. All others are generally absorbed before they reach the surface. The upper atmosphere can reach very high temperature levels, but, of course, the density is low.

Infrared radiation may be transmitted when the skies are clear but would be absorbed by cloud cover. Frost, for example, results when the infrared heat of the Earth's vegetation radiates enough heat to space on clear nights to lower the planet surface temperature below the freezing point, even though the air temperature is above freezing.

The atmosphere is opaque to ultraviolet rays below 2900 angstrom units. These rays cause the ionization in the ionosphere and generate the ozone layer at an altitude of about 15 miles. The ultraviolet rays do not penetrate the ozone layer. The absorption of the ultraviolet rays explains the rise in temperature of the chemosphere, the air layer just above the

stratosphere. At higher altitudes, ionization X-ray absorption, cosmic-ray absorption, and other complicated processes probably influence the heat and mass transfer and radio-wave reflection characteristics of our atmosphere.

What about radio reception? Radio transmission depends on several different kinds of waves (Figure 6). The ground wave is that part of the total radiation that is directly affected by the presence of the Earth and its surface features. The ground wave has two components, the Earth guided wave and the space wave. The tropospheric waves are those that are refracted and reflected by the troposphere. This refraction is due to changes in the index of refraction between the boundaries of air masses of differing temperature and moisture content. The ionospheric wave is that part of the total electromagnetic radiation that is directed through or reflected and refracted by the ionosphere. For nearby communication, the ground waves serve. For larger distances, refraction of the sky waves through the ionosphere is required. The amount of bending required is greater to receive the signal at R_1 than at R_2. A skip zone of no received signal occurs between the limit on the ground-wave propagation distance and the bending limit position of the sky-wave receiver.

The refractive index is close to unity in the troposphere so that refraction is generally slight. With an increase of altitude, layers of ionization are formed by the action of ultraviolet light on oxygen, nitrogen oxide, etc. Free electrons are therefore available to change the dielectric constant and the conductivity of the region for the relatively low frequencies of radio transmission. Much greater refraction of radio waves occurs in the ionosphere than in the troposphere.

Layers of ionization have been observed by reflection of radio waves. These are the D, E, F1, and F2 layers. The D ionization layers, altitudes of 40 to 50 miles, only persist in the daytime, and the intensity of ionization is proportional to the height of the Sun. The density of ions and electrons is so high that recombination quickly occurs in the absence of the Sun's radiation. The E layer is largely due to ionized oxygen atoms at altitudes of 60 to 80 miles. The intensity of ionization is greatest at local noon and is almost zero at night. The F layers have their maximum ionization at an altitude of about 175 miles. Here the density of ions is so low that recombination with electrons takes place only slowly. The minimum ionization intensity occurs just before sunrise. In the daytime, there are two F layers.

The degree of ionization depends on the intensity of the solar radiations. It varies from nighttime to daytime, from summer to winter, with the 28-day period of the Sun's rotation, and with the 11-year sunspot cycle. The ionization is greatest during a sunspot's maximum. The ionosphere is also strongly influenced by magnetic storms that may last several days. These so-called

storms include unusual disturbances in the Earth's magnetic field along with accompanying disturbances in the ionosphere.

For a given density of ionization, the degree of refraction becomes less as the wavelength becomes shorter. Bending is therefore less at high frequency than at low frequency. At the very high frequencies corresponding to TV channels, the bending is so slight that the wave does not return to Earth. This leads to the so-called "line of sight" limitation.

You will recognize that the conditions in the ionosphere are subject to the whims of the solar weather. By monitoring the conditions of the ionosphere with radio wave reflections, the long-distance communication networks can choose frequencies for best reception by use of extensive correlations. The Bureau of Standards also publishes prediction charts 3 months in advance on the usable frequencies above 3.5 megacycles for long-distance communications.

The use of satellites and high frequencies allows our long-distance radio communication systems to be free from the vagaries of the Sun. Because the wave would be transmitted through the atmosphere, the system would be dependable irrespective of solar disturbances, seasons, time of year, sunspot cycles, etc. Telstar and Relay are dramatic experiments demonstrating the feasibility of such communication systems.

There are numerous possibilities for satellites to serve as a link in a communication system. The first used is the message relay satellite as depicted on Slide 7. The satellite contains a tape recorder. Messages transmitted from A when the satellite is in view are relayed to the ground at point B. This system was used to deliver Eisenhower's Christmas greeting to the world from a Discoverer satellite. It has application for military dispatches and could feasibly also be a link to a rapid mail system. Using polar orbits, all parts of the globe would be covered about four times per day.

Passive satellites can serve in a communication network if there are enough of them. In this system, the signal transmitted from a ground station to a satellite is reflected down to other ground stations. Satellites of this type include the Echo balloon configurations, the wire dipoles of Project Westford, and contemplated shaped balloons to improve the signal reflection strength.

The passive satellites must generally be at fairly low altitudes in order to give sufficient signal strength at the receiver. This problem arises because the strength of the signal transmitted to the satellite, even with a very good antenna, essentially diminishes as the inverse square of the distance. Likewise, the strength of the reflected signal diminishes in a similar manner in returning to Earth. Thus, the signal strength at the receiving station is proportional to

the inverse fourth power of the altitude. Hence, altitudes of several thousand miles are about the upper limit. Individual satellites at these low altitudes do not remain in best signal reflecting position for very long, so many satellites would have to be employed to maintain continuous communication between any two stations.

Active satellites, such as Telstar and Relay, where the signal is received and amplified before being transmitted to the ground, can be used at much higher altitudes. At an altitude of 22,300 miles, the satellite would remain nearly stationary in the sky because its period would coincide with that of the Earth's rotation. Syncom (Slide 8) is the first satellite of this type. A single synchronous satellite can provide communication for nearly a hemisphere. Three such satellites could cover the entire Earth except for a small region around the poles, but I must continue with other subjects.

Have you ever noticed how much light there is in the sky on a clear, moonless night out in the country? Such light surely does not come from the stars and planets. Even the Milky Way is very specifically located. This "air glow" originates at an altitude of perhaps 90 to 100 kilometers. It is caused initially by a triple collision of three oxygen atoms. One of these at this altitude retains electrons in an elevated energy level. Some time later, this forbidden neutral oxygen atom releases its energy at a wavelength of 5577 angstrom units to give the "air glow." Carpenter carried along a special filter that would pass only light of 5577 + 10 angstroms. The air glow was still visible to Carpenter through this filter showing the cause conclusively.

This air glow is by far the best horizon for the astronauts. It, of course, lies above the Earth's horizon. Stars can be seen between the air glow and the Earth. Carpenter was able to determine the altitude of this air-glow horizon quite accurately. He did this by noting the exact time when individual known stars just entered and left the air-glow region. Since the altitude and position of the Mercury capsule were known, the rest of the computation follows in a straight-forward manner.

What else can the astronaut see from a satellite? He certainly can see the heavens unhampered by the turbulence of the atmosphere. Stars would therefore not twinkle.

He can get a marvelous view of the Earth's cloud cover and weather patterns; perhaps he can even detect hurricanes in their formation before ground-based stations can do so (Slide 9). This is far from the best cloud cover picture that has been obtained, but I like it because I believe that it represents the first photograph of a hurricane in the making taken from a rocket.

The Tiros satellites, with much more beautiful pictures, have demonstrated the ability to observe and improve the mapping of world-wide weather patterns. These satellites have been used to determine the center of a tropical storm that was in error by 500 kilometers by conventional methods; the break in an Australian heat wave was accurately predicted from Tiros II data; and Hurricane Esther was discovered by Tiros III, etc. These will be followed by contributions from more sophisticated satellites such as Nimbus and still later, Aeros.

These gross patterns will surely be visible to an astronaut. But how well can he detect details and Earth surface characteristics? The answer to this question comes from simple physics.

The quality of the image from an optical or radar viewing system is limited by the fact that electromagnetic radiations have wavelike character-istics. The circular aperture (or any other shaped opening) on such a viewing system will generate a diffraction pattern so that a point source will not give a point image on the viewing screen. The individual light intensities from the images of two point sources are plotted on Slide 10.

Clearly, if the two images are closely spaced, the light patterns will blend so that they cannot be distinguished as separate. Conventionally, this closest spacing for resolution occurs when the central maximum of one point source falls at the first minimum of the second point source. This gives a minimum angular resolution of

$$\varphi = 1.22 \frac{\lambda}{a} \tag{8}$$

where

λ is the wavelength of the radiation

a   is the aperture diameter

φ is the angular separation of the two point sources, radians

This angle (Slide 11) is also equal to the distance between the two point sources x divided by the distance d of the two sources from the observation station. Hence,

$$\varphi = \frac{1.22 \lambda}{a} = \frac{x}{d} \tag{9}$$

the quantity x approximates the uncertainty of position or definition of a viewed object.

Using equation (9), a 1-inch diameter optical telescope mounted on a
satellite 200 miles above the Earth can be used to resolve point light sources
if they are greater than 23 feet apart. With a 12-inch scope, the resolved
distance is 1.9 feet. This resolved distance approximately represents the
fuzziness of the boundaries of the object under observation. Thus with a
12-inch scope, ships, roads, buildings, trains, and general map character-
istics, including automobiles in parking lots, could be determined. A satellite
equipped with a reasonable telescope (12-in. objective) could probably detect,
classify, and establish the location of all our surface ships as well as mili-
tary installations and troop movements. We, in turn, could know the location
of all the Russian ships without the aid of espionage and code breaking. Such
a conclusion is certainly important to the Navy.

The question might be raised as to whether there is sufficient illumi-
nation for observation. During the daytime, there certainly is. The light
transmission coefficient through the entire atmosphere is about 85 percent
at the zenith so that the Earth would surely appear to be brighter than the
full Moon (actually by six or seven times). Viewing the zenith through the
entire atmosphere is about equivalent to looking at an object 5.3 miles away
on the surface. The visible light available to a satellite observer would be
much greater from the Earth than from the Moon because of relative sizes
and distances.

How small a light could one see on the ground? According to
H. N. Russell, Astrophy J. 45, 60 (1917), the unaided human eye requires
at least 2.5×10^{-9} ergs per second of energy to detect a point light source.
A 1-watt light bulb with a 1-percent efficiency should, therefore, be observable
from a satellite located at an altitude of 200 miles if a 12-inch telescope ob-
jective were used. A photographic plate might require a 60-watt light bulb
to be visible for a 1-minute exposure time. Thus, useful observations of
Earth could be made with a manned satellite even at night.

You all know, of course, that the stars appear to twinkle while the
planets do not. This twinkling effect is due to atmospheric turbulence and
temperature gradients. These disturbances modify the index of refraction
of the atmosphere and cause local bending of the light rays passing through it.
Thus, the position of a star appears to change transiently with time, which
leads to the twinkling sensation. The position of a star as seen through the
atmosphere is statistically uncertain by 1 to a few seconds of arc. Because
the angular size of the planets is larger, the twinkling is not apparent, even
though it is still there. (Mars, for example, subtends an angle from Earth
of about 17 sec at closest approach. A pinpointed object on the rim of the
Mars disc, or on the Moon for that matter, would have the same circle of
confusion due to turbulence as does a star).

The positional uncertainty of a satellite as viewed from the ground might be as much as 3 seconds of arc associated with atmospheric turbulence. The corresponding distance error for a satellite at 200 miles is about 15 feet. I told you earlier, however, that a satellite observer with a 12-inch lens could see the ground within an accuracy of 2 feet. You may ask, "How come?" Maybe I can clarify this difficulty with Slide 12.

You see, the index of refraction of a gas is related to its density. But the density of the atmosphere from equation (5) decreases exponentially with altitude. Hence, the air layers near the surface of the Earth (where the density of the air is high) produce the greatest bends on the light path. On Slide 12, the same light path is traveling between the ground observer and the satellite astronaut, but each appears to see his object along the projected tangent to the local light path. The bending is great near the ground observer while hardly any bending occurs near the satellite. Hence, you can see that the observational error of the astronaut in observing the ground is much less than that of the ground observer viewing the satellite. In fact, the ratio of the errors can be shown to be about 1 to 45. Thus, atmospheric shimmer causes an error of only a few inches in the astronaut's observation of the ground. An up to 6' diameter objective could be used on a satellite at 200 miles for viewing the ground before the inherent optical resolution was better than the resolution limit due to turbulence and atmospheric shimmer.

Having raised the question as to how well the astronaut can view the ground, it might be interesting to spend a few minutes discussing orbits (Slide 13). If the satellite is launched from either pole, only a polar orbit can be established. Of course, the entire Earth would come under surveillance as the Earth rotated under the satellite's orbit. Clearly, however, it is not possible to establish an equatorial orbit with a ballistic launch from the poles. In fact, the inclination of the orbital plane to the equator must be equal to or greater than the latitude of the launching site. Thus, only from the equator can all kinds of orbits, that is, equatorial, polar, etc. be established.

Now, the position of the orbital plane of the satellite depends on the inhomogeneities of the Earth's gravitational field. The Earth is not a perfect sphere, so that the idealized variation of the gravitational attraction with the inverse square law holds true only approximately (Slide 14).

The actual Earth bulges at the equator. The variation in gravity somewhat resembles that of a spherical Earth with a belt around the equator. The gravitational pull of this belt is stronger on a satellite at the equator than at the poles. The Earth's bulge thus influences the orbit of a satellite. The perturbations of this orbit may, in turn, be used to make geophysical measurements on the Earth's gravity. Such studies with Vanguard I lead to the discovery of the pear-shaped Earth.

There are two important ways in which the equatorial bulge influences the satellite's orbit. The first is to deflect the satellite toward the normal to the equator each time it crosses. Thus, the plane of an eastwardly launched satellite will rotate toward the west at a rate in degrees per day of about

$$R = 8 \cos \alpha \qquad (10)$$

where α is the inclination of the orbital plane to the equator. Also, the satellite speeds up in crossing the equator because of the bulge. This causes the major axis of the elliptical path to rotate in the plane of the orbit at a rate in degrees per day of about

$$S = 4 (5 \cos^2 \alpha - 1) \qquad (11)$$

The direction of this rotation reverses above latitudes of about 63°. This is about the plane angle of the early Russian satellites. Thus, they could keep the perigee over Russia, using this fact , which would enhance the data transmission to Russians. The numbers in equations (10) and (11) are for a 200-mile-altitude satellite.

You may note that the satellite is always falling in orbit toward the Earth. Because of the Earth's curvature, however, the astronaut's horizon keeps dropping in front of him so that he does not reach the surface but continues to go round and round. A body in free fall, such as the satellite, then experiences the phenomena associated with weightlessness.

The weightless environment is still of considerable worry to the space scientists. The influence of weightlessness on man for extended periods of time might lead to deteriorations of muscular and body functions through lack of stimulation. The fuel in a rocket tank may be undecided as to whether it should stay on the top, the bottom, or the sides of the tank. Hence, venting of the tank may be as much of a problem as locating the fuel at the tank discharge port.

Fortunately, forces normally neglected at 1 g can be utilized at zero g to help us. If the fluid wets the tank wall, the liquid will cling to the walls. Standpipes can also be installed to locate the liquid near discharge ports.

gravity   zero gravity
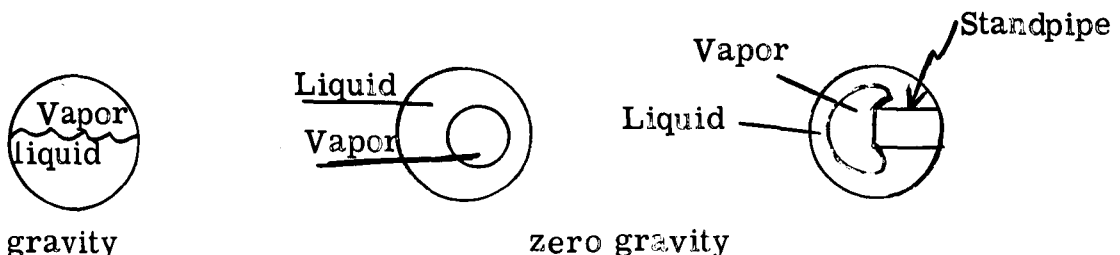
This is all I will say about zero "g" environment but it remains of continuing research interest and concern.

The thermal environment in space depends strongly on where one chooses to be in space. Space has such a high vacuum - of the order of 10^{-16} millimeters of mercury or better - that only a few molecules of hydrogen are present in each cubic centimeter. Hence, the normal definition of temperature that depends upon a statistical distribution of molecular or vibrational speeds probably has no meaning. Also, the heat transfer to or away from a spacecraft must be principally by radiation.

One might then define the temperature of space to be that equilibrium temperature that a body would assume in the absence of sunlight or planet light. This temperature for deep space is perhaps 3° to 4° K but may be as high as 20° K in portions of the Milky Way. The temperature of a body in solar space is then determined by equating the energy absorption by the body from the solar and planet radiations to the energy reradiated to deep space and to any nearby objects. The radiation from a black body is proportional to the fourth power of the absolute temperatures.

$$Q = k (T_1^4 - T_2^4) \tag{12}$$

Now, the energy received near the Earth from the Sun is 1.34 kilowatts per square meter. This energy is largely in the visible range. If it is absorbed by a spacecraft, the reradiation is largely in the infrared range, but materials have different absorption and emissivity coefficients according to the wavelength of the radiation. Hence, the temperature of spacecraft may be controlled by selection of appropriate surface coatings. A coating with high absorptivity in the visible region and low emissivity in the infrared region will have a higher equilibrium temperature than if the reverse is true. By combinations of stripes and selected coatings, spacecraft temperatures are usually adjusted to be near normal room temperatures. The coatings are pretty sophisticated, being adjusted for particular orbital paths or missions. Mariner, for example, would have a different coating than satellites near Earth. Even on near-Earth satellites, the coatings are altered if the orbital path is changed because of delays of a few days at launch.

A simple energy balance will indicate the variations of equilibrium temperature on a spacecraft in solar space. If we assume a sphere with sufficient conductivity to have uniform surface temperature, the black body solar energy absorbed will vary inversely as the square of the distance from the sun. The energy radiated will be proportional to the fourth power of the surface temperature. The equilibrium temperature obtained by equating the absorbed and radiated energy thus varies inversely as the square root of the radial distance from the Sun.

The Earth, as you all know, has a magnetic field. This field has an important influence on the near-Earth space environment. I would like now to show you briefly why this is the case. I hope you won't mind a very simplified discussion of magnetohydrodynamics.

A charged particle, such as an electron or a positive ion, feels a force if it is placed in an electric field. This force is proportional to the charge q and the field strength $\overline{E}$.

$$\overline{F} = q\overline{E} \tag{13}$$
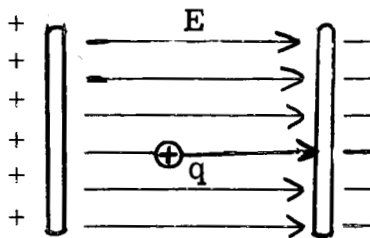
In the illustration, the field is established by the charges on the plates of a condenser. Clearly, a positive charge is forced in the direction of the field.

Also, when an electric current flows in a wire placed in a magnetic field, there is a force on that wire that is proportional to both the field strength and the current and is perpendicular to both. A magnetic field parallel to a current-carrying element produces no force.

current i

In vector notation   i   out of plane of
                                             paper
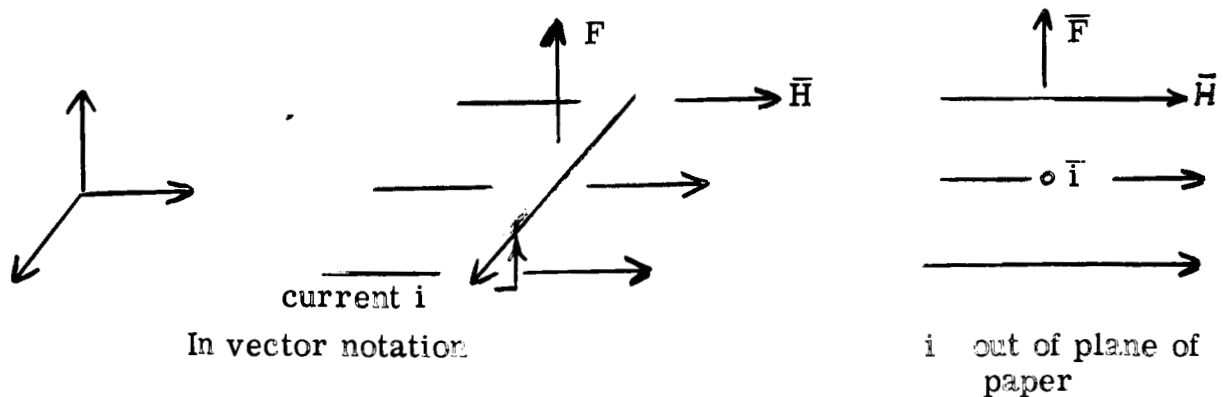
$$\overline{F} = \overline{i} \times \overline{H} \tag{14}$$

Now, the current $\overline{i}$ is the rate at which charge is passing a point. If we have a single charge q passing through our "conductor," the current is

$$\overline{i} = \frac{\overline{dq}}{dt} = q\overline{v} \tag{15}$$

Hence, the force on a moving charge due to the magnetic field is

$$\overline{F} = q\overline{v} \times \overline{H} \tag{16}$$

Thus, if we combine equations (16 and (13), the force on a charged particle moving in electric and magnetic fields is

$$F = q (\overline{E} + \overline{v} \times \overline{H}) \tag{17}$$

where consistent units must be used.

You will note in equation (16) that the force due to a magnetic field is always normal to the velocity. Hence, a steady magnetic field neither adds nor subtracts energy from the particle's motion. Thus, a moving charged particle in a constant magnetic field follows a circular path around the field line such that the magnetic force balances the centrifugal force:

$$F = \frac{mv^2}{r} = qvH$$

or the path radius is

$$r = \frac{m}{q} \frac{v}{H} \tag{18}$$

Thus, charged particles are trapped by a magnetic field.

If we now superimpose a force normal to the magnetic field lines, for example, by either an electric field or a gravitational field, the particles will be alternately accelerated and decelerated by this new force. Hence, the motion of the particle is that shown on Slide 15. This motion is the super-position of a constant drift velocity

$$\overline{W} = \frac{\overline{E} \times \overline{H}}{H^2} \tag{19}$$

and the circular orbital velocity without the electric field. You will note that the drift velocity is independent of the charge, so that both positive and negative charges migrate in the same direction even though their orbital velocities are opposite. The Earth's gravitational field produces a similar type motion in a direction normal to the magnetic and gravitational fields.

Now a velocity component parallel to the magnetic field produces no force; hence, charged particles can follow spiral paths along magnetic field lines, like this:

H
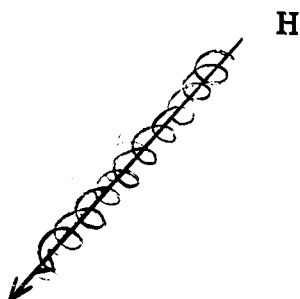
However, if the field is increasing in the direction of the spiral motion, then the radius of the path will decrease, and the converging field lines will produce a force to reflect the particle back in the direction whence it came. Thus, we could make magnetic mirrors to trap charged particles in the region between increasing magnetic fields:

Field lines

H

Distance
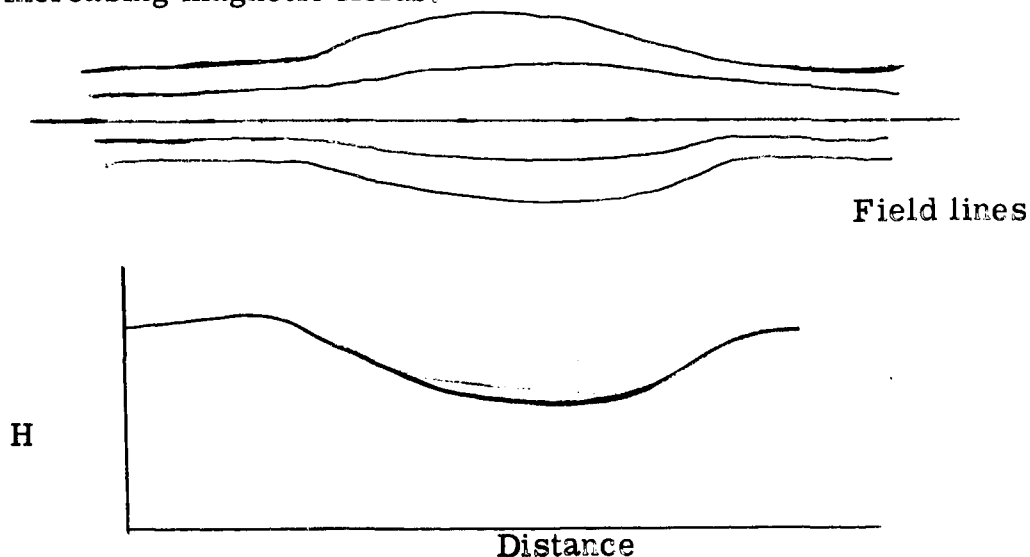
We can now talk about the Van Allen belts (Slide 16). You see, the Earth has a magnetic field surrounding it. This field increases toward the poles. Hence, the Earth's magnetism forms a magnetic bottle to trap charged particles. These particles are spiraling around the magnetic field lines, bouncing back and forth along spiral paths from pole to magnetic pole. Simultaneously, there is a very small drift velocity in the circumferential direction associated with the gravitational field. Thus, the charged particles diffuse around the Earth to form the Van Allen belts.

The Van Allen belts generally do not persist to the lower altitudes of Project Mercury space flights. If they did, the upper atmosphere would soon cause their decay. The belts are strongest in the regions between 1 and 10 Earth radii.

Data from Explorer XII (Slide 17) reversed previous conceptions of the belts. The entire region is actually a single system of charged particles instead of two distinct belts. These charged particles are trapped by the Earth's magnetic field.

The chief constituents of the Van Allen belts are electrons and slow moving protons. The number of each kind varies from altitude to altitude (Slide 18). At 2000 miles, the predominant particles were protons with energies of tens of millions of electron volts (10 Mev). This region has been modified by nuclear explosions. At 8000 miles, protons with only a fraction of an Mev predominate, and at 12,000 miles, protons with energies of 0.1 to 4 Mev and electrons with energies up to 2 Mev are blended. The exact source of the charged particles in these regions is still a matter of controversy.

The formation of one new artificial belt, however, is well understood. In this one, a high-altitude nuclear explosion filled the region with electrons. The surprise associated with this one is that the strength of the belt is persisting much longer than originally estimated. Current speculations suggest that the belt may be detectable for as long as a year. In the meantime, it has knocked out the power supplies of three satellites. This degradation is due to damage to the solar cells.

The outer regions of the Van Allen belts contain large numbers of low-energy protons. These protons pose less of a radiation hazard than high-energy electrons. Man, passing quickly through these regions on the way to the Moon or beyond, would be in little danger from the protons but would need to be protected from the X-rays generated by impingement of the electrons on the spacecraft components. On the other hand, the protons would pose a serious problem even for a heavily shielded vehicle to the occupants of an electric propulsion spacecraft or an orbiting laboratory if the residence time approached two weeks or longer.

Let me define some terms dealing with radiation exposure. The most common unit for a radiation dose is the rem or Roentgen equivalent man. The rem is that quantity of any type of ionizing radiation that, when absorbed in the human body, produces an effect equivalent to the absorption of 1 roentgen of X or gamma radiation at a given energy. The Roentgen is that quantity of X or gamma radiation required to produce in 1 cubic centimeter of dry air ions carrying 1 electrostatic unit of positive or negative charge. Now, for a

two-week exposure time in the inner Van Allen belt with a 25-rem exposure limit, the shield weight would have to be about 140 grams per square centimeter (55 in. of water thickness).

I don't want to leave you with the impression that the Van Allen belts are steady and unchanging. We have seen how they have been modified by nuclear explosions. They also are modified and distorted by the solar winds. During solar flares and intense sunspot activity, tongues of plasma (Slide 19) along w ith a trapped solar magnetic field are short out toward the Earth. The geomagnetic sphere of the Earth forms a shock wave in this plasma sheath; consequent distortions of the Van Allen belts occur as pictured in Slide 20. The edge of the geomagnetic sphere confined inside this shock wave and on the side of the Earth facing the Sun is at an altitude of some 30,000 to 40,000 miles.

We should now discuss briefly the space radiation hazard to man. The background normal cosmic ray intensity from all sources is about 0.65 rem per week. Thus, with a rather high 25-rem exposure limit, an unshielded space traveler would reach his limit on radiation exposure from this source alone in about 38 weeks. The composition of these cosmic rays is shown on Slide 21.

Much more serious are the cosmic ray bursts from the Sun. These particles are known to be mostly protons with energies ranging from less than 10 Mev to almost 50 Bev.

The classification of these solar flares is shown on Slide 22. The minor Class I and II flares are not particularly troublesome. The Class III and III+ flares are more serious, with 60 such events recorded between January 1956 and 1961. Hence, major flares might on the average occur monthly. Occasionally, giant solar flares larger than III+ have occurred. Seven have been observed in the past 18 years.

Weight limitations may restrict the Apollo shield to between 10 and 30 grams per square centimeter. This relatively thin shield will protect the man for the short times that he might spend in the Van Allen belts and against minor and major solar flares. His greatest danger could come from unpredicted giant solar flares.

Almost all protons of energies greater than 100 to 200 Mev will pass through a 10- to 30-gram-per-square-centimeter shield. These energies are prominent at flux levels as high as 10^4 protons per square centimeter per second for a Class III+ solar flare. The distribution of this flux is presented in Slide 23.

The energy loss mechanism (ionization and straggling) in thin shields is well behaved and understood. In thin shields, the protons will collide only occasionally with a shield nucleus, and hence secondary radiations are unimportant. The penetration of protons in carbon and aluminum is straightforward as is shown in Slide 24.

Future space flights of much longer duration, however, will require thick shields. Then the secondary radiations arising from nuclear reactions in the radiation shield and the spacecraft material become important. Some of these reactions are shown in the next slide (Slide 25). In the cascade reaction, a proton enters a heavy nucleus, which then disintegrates to a lighter nucleus with emission of protons and neutrons. These, in turn, cause other disintegrations. In the evaporation reaction, a proton enters a nucleus to form a radioactive atom. The latter might decay emitting a neutron to cause further reactions.

The effect of these secondary radiations is estimated in Slide 26 for the May 10, 1959 flare. I would like to caution you, however, that the many processes and radiation interactions needed for predicting the effectiveness of thick shields are understood only poorly. The "rad" shown is a measure of the energy imparted to matter by ionizing radiation and is equal to 100 ergs per gram of material. You can see that the secondary radiations become increasingly more important relative to the primary ones as the shield thickness increases.

The danger from giant solar flares results partly from the inability of Earth scientists to predict them. Some success has been obtained by first calculating the size of the dark-shaded area (penumbra) surrounding each sunspot group (Slide 4). Then the number of groups (flares) with penumbral area greater than 300 millionths of the solar surface, 500 millionths, 1000 millionths, etc. is calculated. These numbers are then used to predict whether one could expect a safe flight or not for a 4- or 7-day period corresponding to Apollo plans. Examination of the results by Harriet Malitson of the Goddard Space Flight Center showed the following:

(1) A criterion area of 1000 millionths of the solar surface reduces the usable flight time by 33 to 40 percent and still allows encounters about half the events. This is not good enough!

(2) Reduction of the area to 500 millionths of the solar surface takes care of all but one of the events for 1949 and 1950 but cuts down the "safe" time to 20 to 35 percent of the actual usable time. For the year 1951, even reduction of the exclusion area to 300 millionths of the solar surface leaves two encounters.

I wish to leave this subject with the thought that we do not have adequate methods for predicting the large solar flares. Hence, this radiation source would be dangerous to extended-time manned mission flights to Mars, etc.

The next environmental factor I would like to discuss is that of meteoroids. Let's start with some definitions. A meteoroid is any of the countless small bodies in the solar system. If the meteoroid passes with incandescence through the atmosphere, it is a meteor; and if it reaches the surface of the Earth, then it becomes a meteorite.

Now, the meteoroids vary in both size and density. Some of them may be as light as snow with a specific gravity of perhaps 0.15. The stony meteorites seen in museums have specific gravities of 2 to 3, while the specific gravities of the nickel-iron ones are more like 7 or 8. The sizes of the meteoroids range from infinitesimal up to perhaps a few pounds or heavier. You all have heard of the meteoroid crater in Arizona that is about a mile across. Meteors of sufficient size to produce such a change in the Earth's structure must be large indeed.

The meteoroid mass-frequency distribution estimated by several observers is shown in Slide 27. These curves are generally obtained by observers of meteor trails. By following the meteor and measuring its speed and deceleration in the atmosphere, the ratio $m/C_D A$ may be estimated. For example, the equation of motion for a verticle meteor is

$$m\left(\frac{d^2 y}{dt^2} - g\right) = -\frac{1}{2}\rho v^2 C_D A \qquad (20)$$
$$v = \frac{dy}{dt}$$

The acceleration $d^2 y/dt^2$ and the speed v are measured. The air density ρ is estimated from previous sonde data. Hence, an estimate of $m/C_D A$ is obtained. Now, reasonable guesses of the drag coefficients can be made.

We may also measure the brightness of the meteor, and brightness is related to temperature and rate of evaporation of material from the surface. Hence, an estimate of the mass of the meteoroid can be obtained. In this way, so crudely outlined, the curves shown are obtained (Slide 27). The possible errors due to the assumed efficiencies of the various processes can be large.

Recently, artificial meteors have been produced in Project Trailblazer. (Harvard). Here, the mass and the density of the artificial meteor were known prior to the launch of the rockets; hence, a calibration of the method results. This calibration suggests that some of the previous flux estimates were high by perhaps an order of magnitude, especially for the larger sized particles (Slide 27). The data on this curve also receive support from radar observations of the ionized meteor trails in the upper atmosphere. Likewise, as you can see on the slide, satellite data give some hazy confirmation. The earlier

satellite data shown here are generally obtained by recording impacts on a plate by means of a microphone. The flux in these experiments is fairly good, but there is considerable uncertainty of the mass. People are not sure whether the conversion of meteoroid speed to noise in the microphone is an energy- or a momentum-dependent process; and the question depends on the speed and direction relative to the impact plate.

The next natural question is "How are these particles distributed in space?" This is shown in Slide 28 in two ways. To an Earth observer, there are many more particles hitting the Earth on the leading hemisphere than on the trailing hemisphere as the Earth moves in orbit around the Sun. If these data are corrected for the speed of the Earth, then the opposite is true. That is, the majority of the particles are traveling in orbits, presumably around the Sun in the same general direction as the Earth.

The distribution of the particles relative to the plane of the ecliptic is shown in Slide 29. You can clearly see that most of the particles are within about 20° on each side of the orbital plane of the Earth about the Sun. Most of them are orbiting around the Sun, but some of them may also be trapped in orbits around our Earth-Moon system. Some of the particles make large angles to the plane of the ecliptic and are probably of cometary origin. We are guessing that these have very low densities - less than 0.5 gram per cubic centimeter.

Let us speculate as to the origin of this meteoritic material. It might come from outside the solar system. If so, one would expect it generally to pass on through and to leave the region again on hyperbolic-type orbits unless it suffered a gravity turn near one of the planets which would lead to trapping.

As an illustration of a gravity turn that may increase or decrease the energy of the particle, consider the path of a particle that makes a near approach to a planet. Relative to the planet, the path will be a hyperbola (sketches A_1 and B_1) with the same speed but a different direction after the near miss.

Sketch A_1
(Planet adds energy)

Sketch B_1
(Planet subtracts energy)
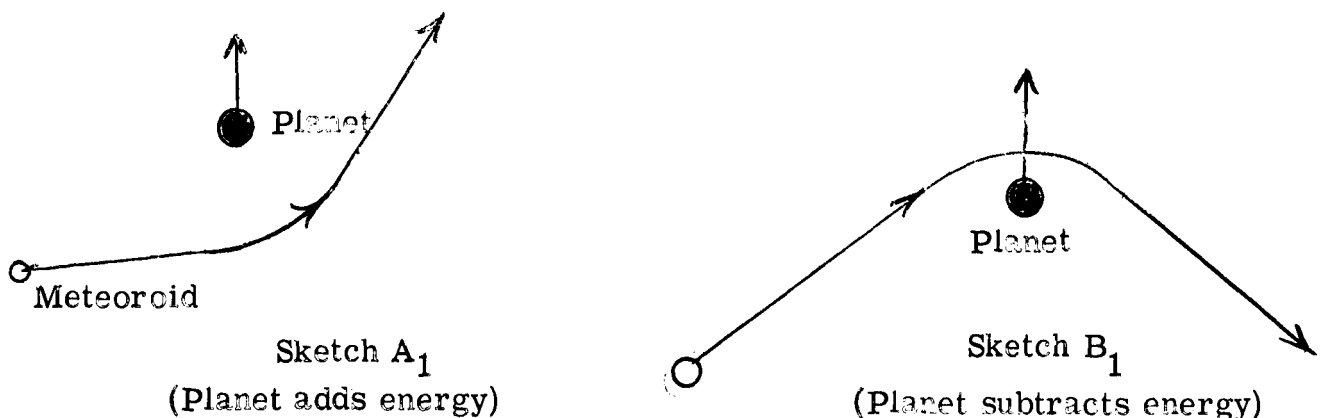
This means that, after the near encounter, the speed will be different relative to a fixed point in solar space. The vector diagrams A_2 and B_2 illustrate how the gravity turn adds or subtracts energy to the meteoroid at the expense of the planet.
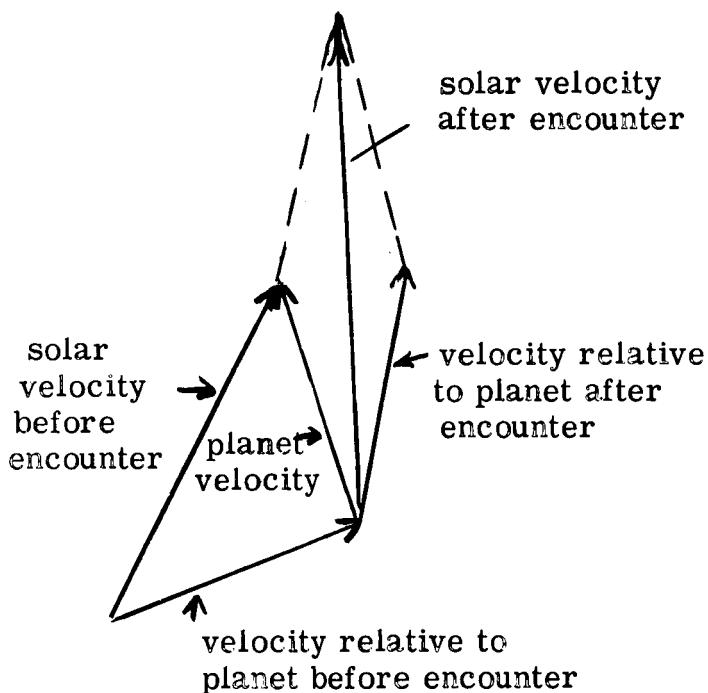
Sketch A_2

(Planet adds energy)
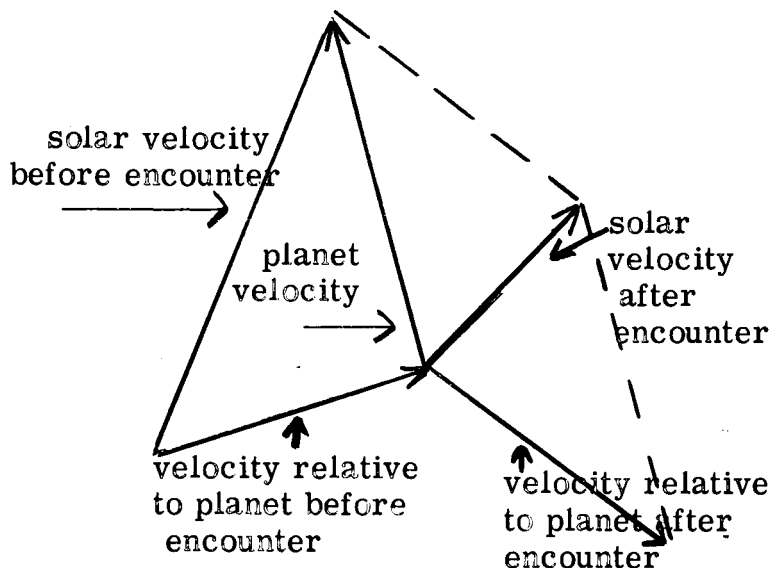
Sketch B_2

(Planet subtracts energy)

The meteoroids might come from the asteroid belt between Mars and Jupiter. You see, particles can diffuse out of this belt by a combination of gravity turns. The orbits of the individual particles can be altered upon close approach to another mass center. If this explains meteoroids, then surely the meteoroid population near Mars would be larger than near Earth.

The meteoroids near Earth might actually come from the Moon. You see, a meteoroid impact on the surface of the Moon may carry enough energy so that four or five times as much mass would be knocked off the Moon's surface to escape velocity as that of the impinging meteoroid. There are eminent scientists who believe that the tektites found on the Earth came from the Moon.

Then too, meteoroids may originate in the tails of comets. This theory is interesting but does not explain where the comet came from.

Why are we so interested in meteoroids? The principal reason is because there is a finite probability that the integrity of space vehicles might be destroyed by meteoroid puncture. We must make the various components sufficiently thick to prevent penetrations or destructive damage. Slide 30 gives some indication of the number of punctures to be expected in stainless steel. This chart is based upon Explorer XVI data obtained near Earth. Near Mars, the meteoroid population might be a factor of 2000 larger, but we don't know for sure.

The uncertainty of the information on both meteoroid flux and penetration criteria is great. You saw how one experiment, "the Trailblazer," changed the flux estimates. A corresponding uncertainty exists in the penetration criteria. The problems here are multiple. We do not have a very good feel for the density of the particles. And we don't have any ground-based data in the average speed range of the meteoroid particles. They range from 11 to 73 kilometers per second. The fastest gun barely approaches the lower figure. Hence, we urgently need to launch large-area meteoroid damage experiments in space to determine survival probabilities. Without this information, spacecraft will likely be either underdesigned leading to early loss of mission, or overdesigned, giving overweight or sluggish performance. Either situation is expensive. In fact, the whole future of electric propulsion may depend upon a clarification of the meteoroid survival probabilities for the radiator. Our present estimates of the weight of the system may be in error by as much as a factor of 3. This weight difference would make a tremendous difference in the performance of an electrically propelled spacecraft.

Before closing, I would like to discuss very briefly the planetary environments for manned exploration. The interest in manned flights to Venus cooled suddenly when Mariner II data suggested a surface temperature of 800°F. Since recent spectra showing the presence of water vapor have cast some question on this value, some interest is being revived. We need more instrumented probe data to decide whether manned landings on Venus would be feasible.

Mars has proverbially attracted the imagination as a planet for potential human development. However, on careful study, the environment on the Martian surface is anything but attractive. The surface pressure, for example, is about 25 millibars corresponding to about 85,000 feet altitude on Earth. The oxygen content is less than 1% corresponding to about 155,000 feet altitude on Earth. The water vapor content is perhaps only $\frac{1}{2000}$ th of the moisture on Earth so that rivers, lakes, and oceans would probably be non-existent.

What little water there is might be salty. Mars would also likely have its surface bombarded with asteroids and meteoroids from the asteroidal belt. This could be much more serious than on Earth because of the greater meteoroid population near Mars, and because of the thin atmosphere. On Earth, meteors penetrate to perhaps 50,000 feet altitude. A similar particle on Mars would strike the surface. Also, the theory of planet formation suggests that Mars would have a solid core and no mountains of the folded type. With a solid core, there probably is no appreciable magnetic field, and hence, no trapped radiation belts of the Van Allen type. Now in balloon flights over Minnesota radiation intensities of 1000 rem per hour were observed during a giant solar flare. These would be sufficient to fry a human being according to usual standards. On the surface of Mars, such radiation intensities would be expected because of both the rarefied atmosphere and the lack of magnetic field trapping of ionized particles. Thus, strong shielding would be required on the Martian surface during giant solar flares.

To survive, man would have to take his Earth environment with him. Conditions are so hostile that colonization is probably out of the question in our times. Nevertheless, manned exploration of Mars will take place and be justified solely on its scientific merits.

CS-17763

Figure 1

STARS AND GALAXIES

EXTERNAL
GALAXIES

STARS

INTERSTELLAR
GASES

SUN, EARTH AND
SOLAR SYSTEM

BLUE λ3100-λ5000   YELLOW λ5200-λ6600

RED λ6300-λ6750   INFRARED λ7200-λ8400
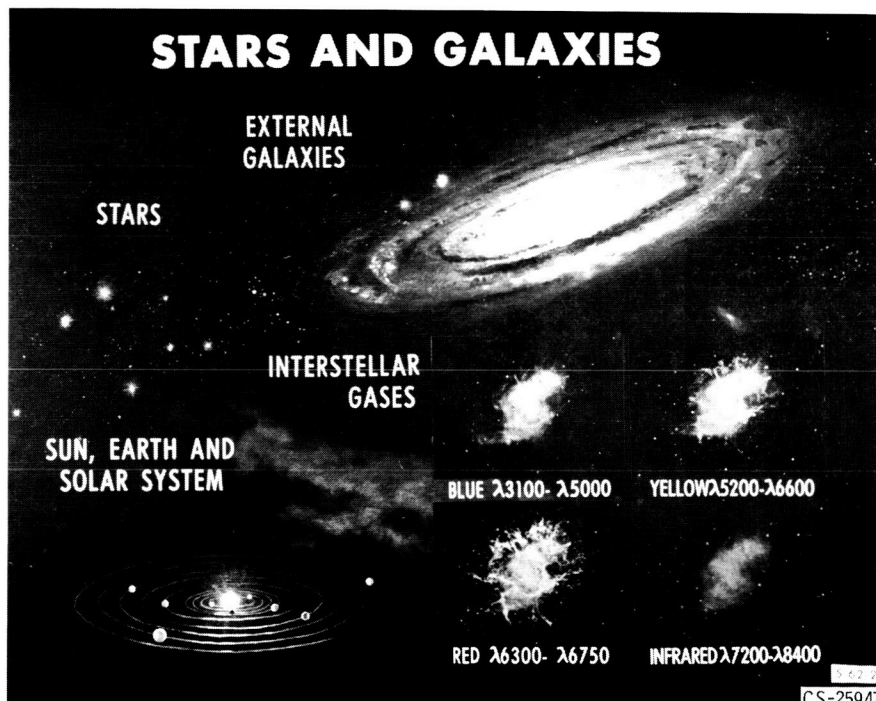
CS-25947
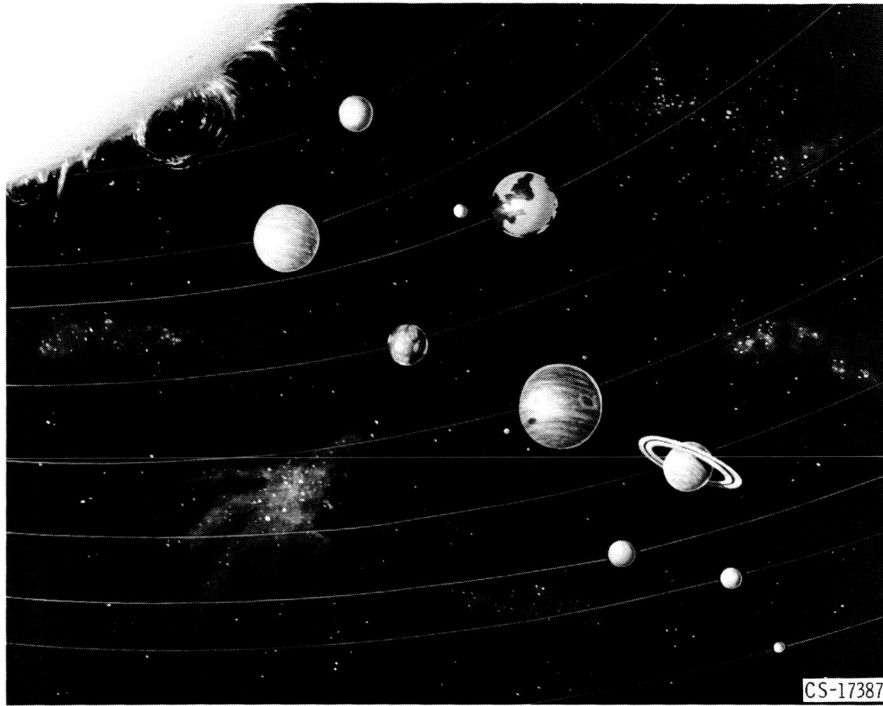
Figure 2

Figure 3
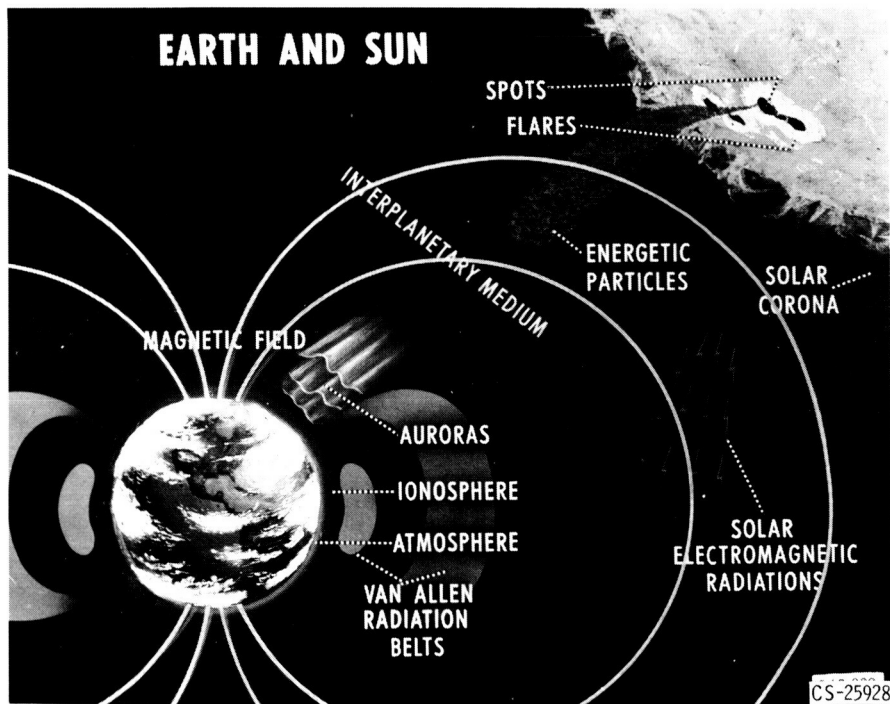
Figure 4

ATMOSPHERIC COMPOSITION

HYDROGEN

HELIUM

ATOMIC OXYGEN

OXYGEN-NITROGEN
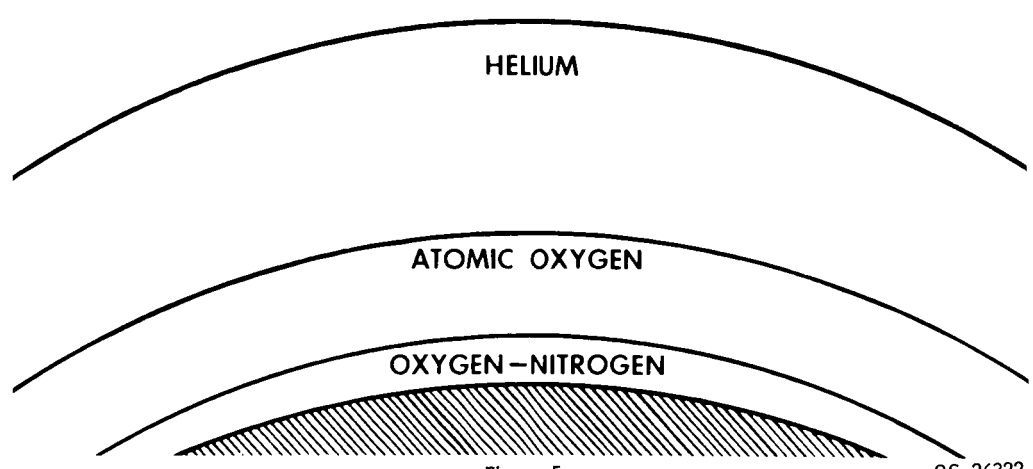
Figure 5   CS-26322

REFRACTION OF SKY WAVE

NOTE THE SKIP ZONE

IONIZED
LAYER

A

R₁

SKIP
ZONE

T

GROUND
WAVE

TANGENT

R₂

CS-16077

Figure 6

THE MESSAGE RELAY SATELLITE

POLAR
RELAY
STATION

N

A

B

SATELLITE

TRANSMITTING AND
RECEIVING STATION

S

LIFE OF MESSAGE
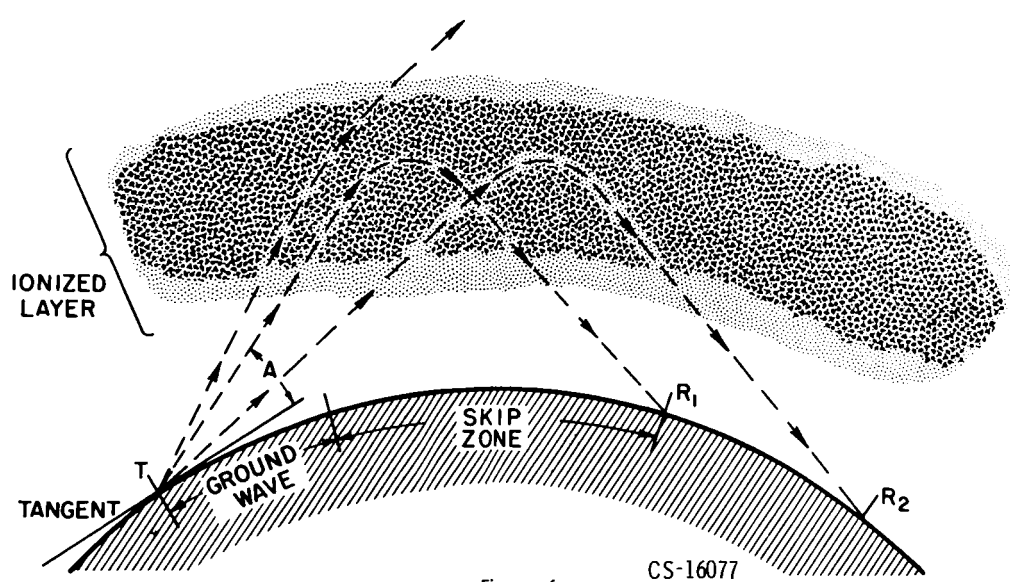
CS-16075
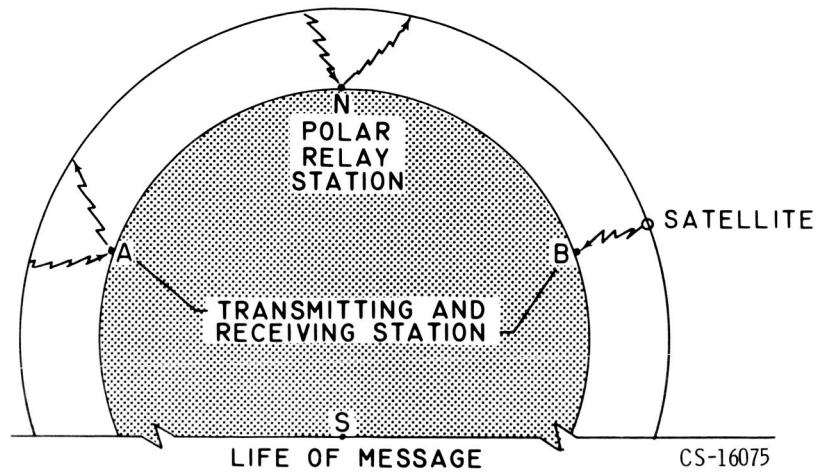
1. TRANSMITTED AT A, RECORDED
2. RETRANSMITTED, RECEIVED AT B
3. RELAYED AT POLE TO OTHER
   SATELLITES

Figure 7

SYNCOM

COMMUNICATIONS
ANTENNA

SOLAR
CELLS

VERNIER
ROCKETS

NITROGEN
GAS JETS

APOGEE
ROCKET MOTOR

TELEMETRY
ANTENNAS

SOLAR ANGLE
SENSORS

CS-24890

Figure 8

LENS,
DIAM a,
IN.

IMAGE

OBJECT

φ

x

d
(200 MI)
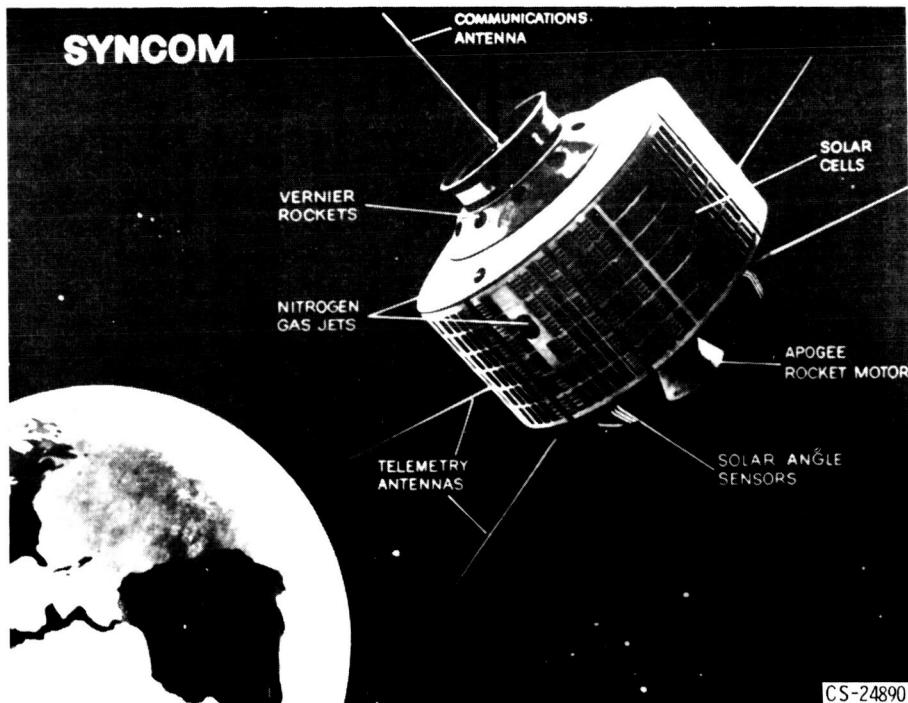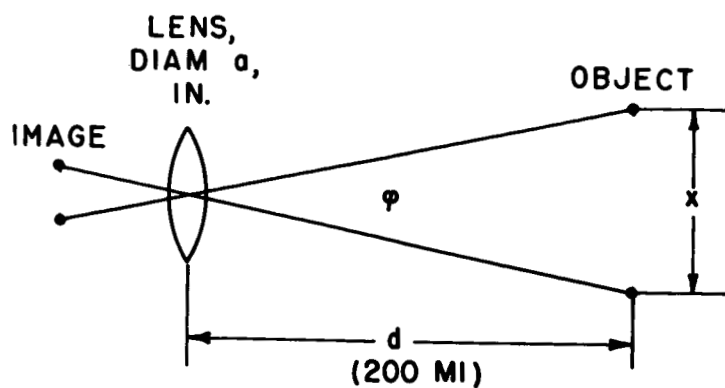
$$\varphi = 1.22 \frac{\lambda}{a} = \frac{x}{d}$$

FOR λ = 4500 A°
    xa = 23 FT

CS-16085

a = 1", x = 23 FT; a = 12", x = 1.9 FT

Figure 11

ATMOSPHERIC SHIMMER LESS SERIOUS
TO SATELLITE OBSERVER

APPARENT
POSITION

Δx_s

ACTUAL
POSITION

LIGHT
RAY

SATELLITE
ORBIT

APPARENT
POSITION

ACTUAL
POSITION

Δx_g

EARTH

$$\frac{\Delta x_s}{\Delta x_g} = 45$$

CS-16079
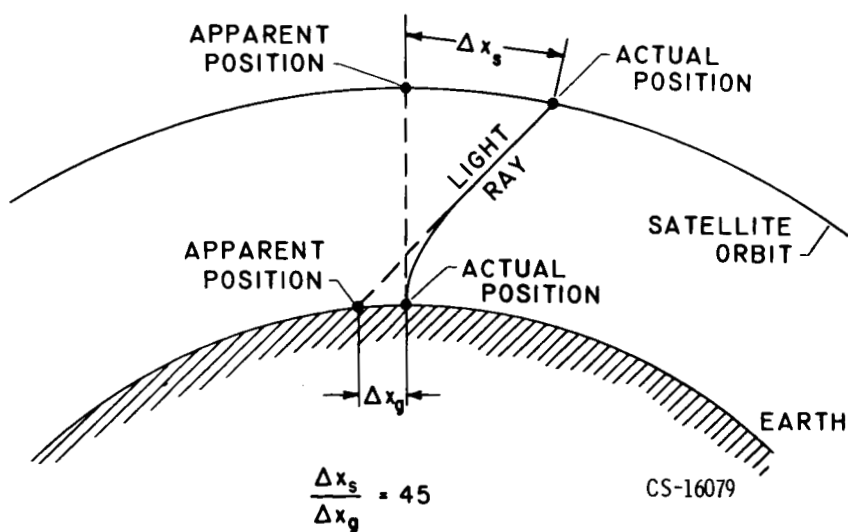
Figure 12

ROCKET VIEW FROM 100 MILES ALTITUDE
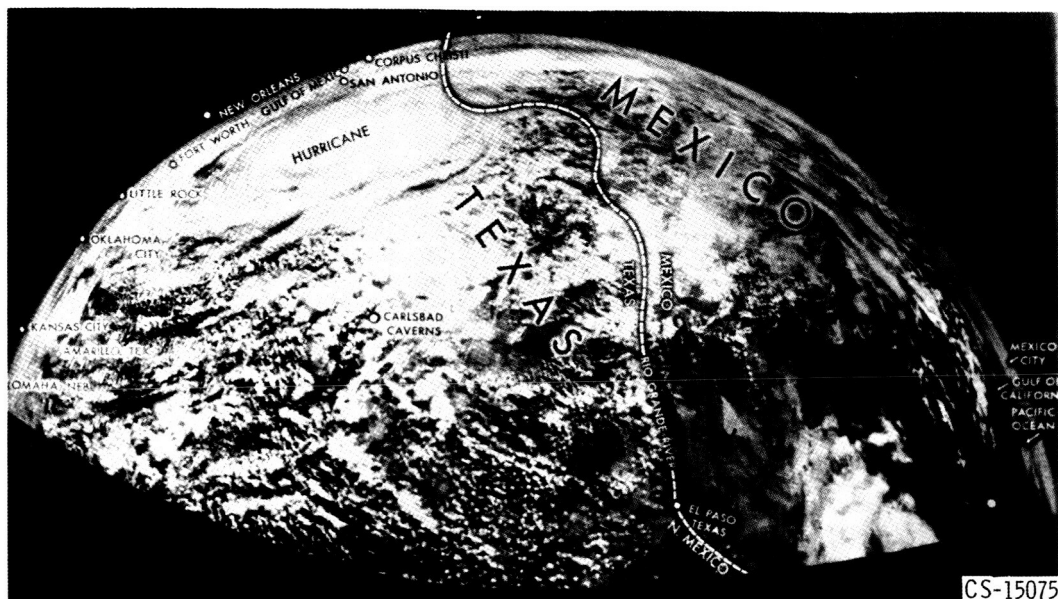
Figure 9

RESOLVING POWER FOR CIRCULAR APERTURE

$$\varphi = 1.22 \frac{\lambda}{a}$$
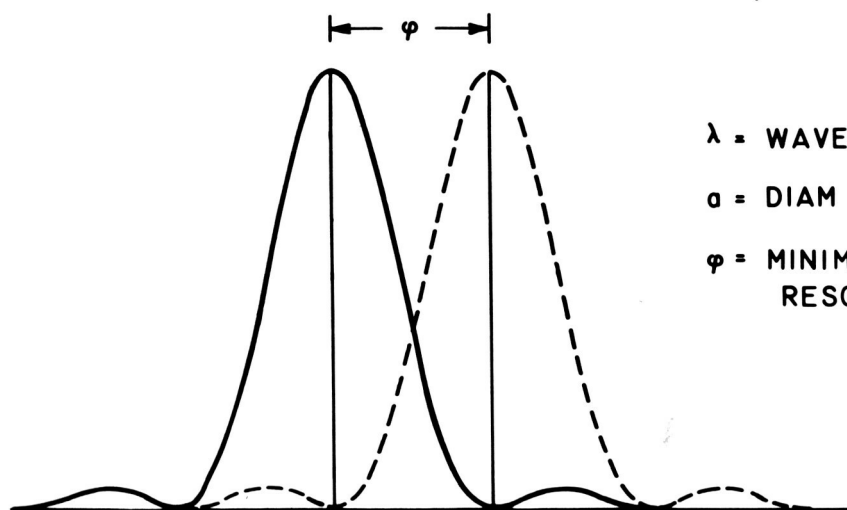
λ = WAVE LENGTH

a = DIAM OF APERTURE

φ = MINIMUM ANGULAR RESOLUTION

Figure 10

CS-16082

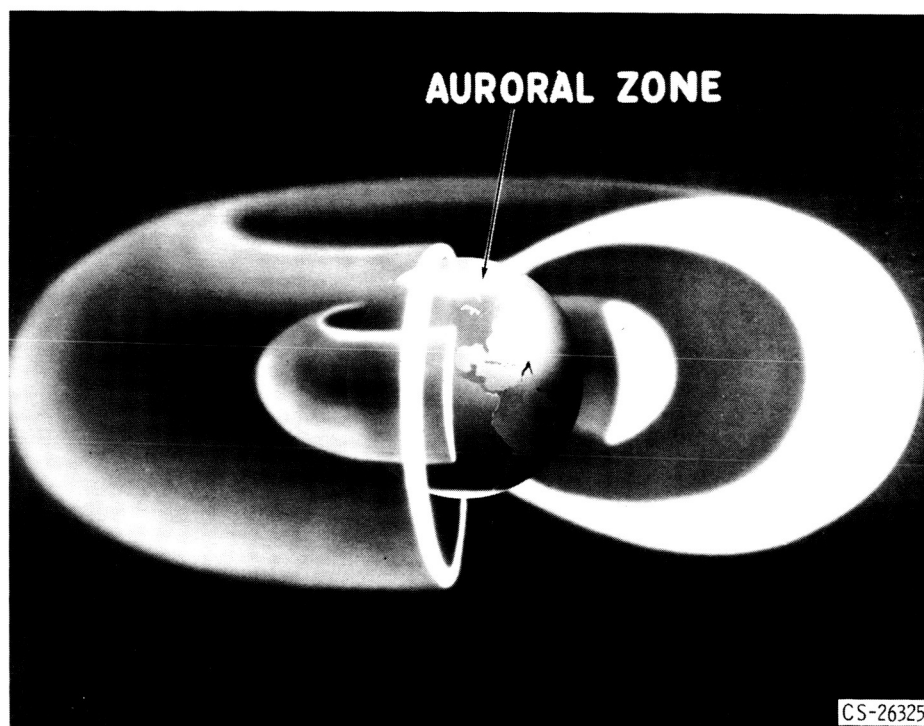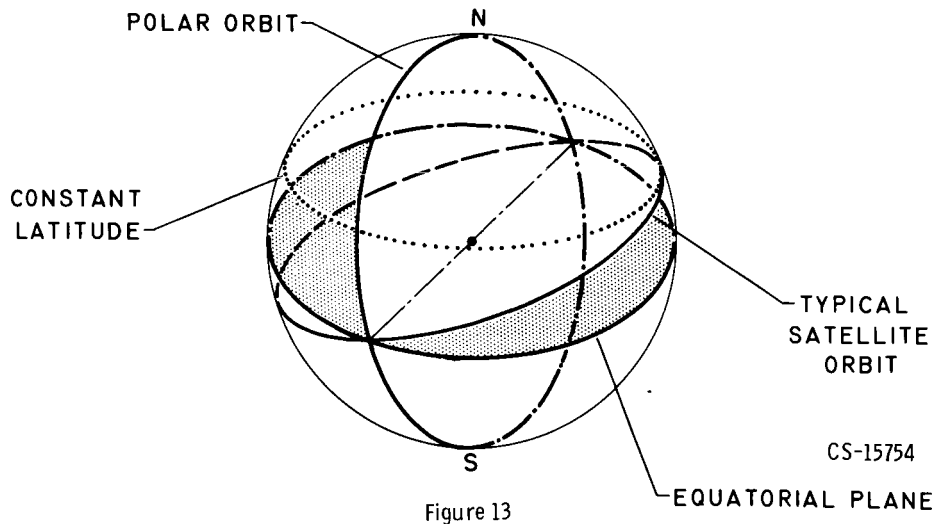# CHARGED PARTICLE MOTIONS IN MAGNETIC AND ELECTRIC FIELDS

ION

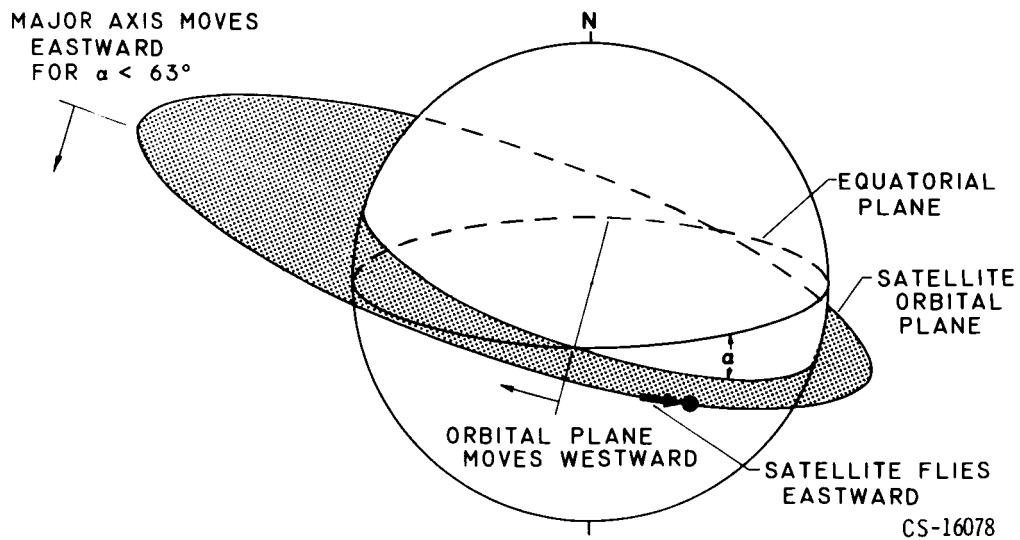DRIFT VELOCITY $\bar{E} \times \bar{B}/B^2$

ELECTRON

PERPENDICULAR
MAGNETIC FIELD

ELECTRIC FIELD

CS-18299

Figure 15

AURORAL ZONE

CS-26325

Figure 16

SATELLITE ORBITS

POLAR ORBIT

N

CONSTANT
LATITUDE

TYPICAL
SATELLITE
ORBIT

CS-15754

S

EQUATORIAL PLANE
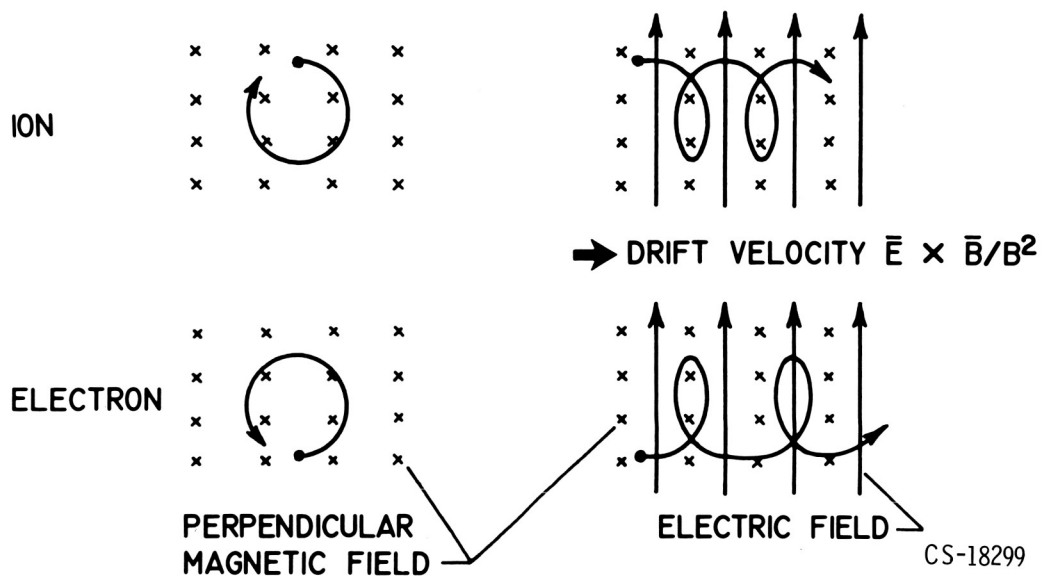
Figure 13

EFFECT OF EARTH ON SATELLITE MOTIONS

MAJOR AXIS MOVES
EASTWARD
FOR $\alpha < 63°$

N

EQUATORIAL
PLANE

SATELLITE
ORBITAL
PLANE

α

ORBITAL PLANE
MOVES WESTWARD

SATELLITE FLIES
EASTWARD

CS-16078

Figure 14

EXPLORER XII

BETTER DEFINITION OF
RADIATION BELTS

CS-25674
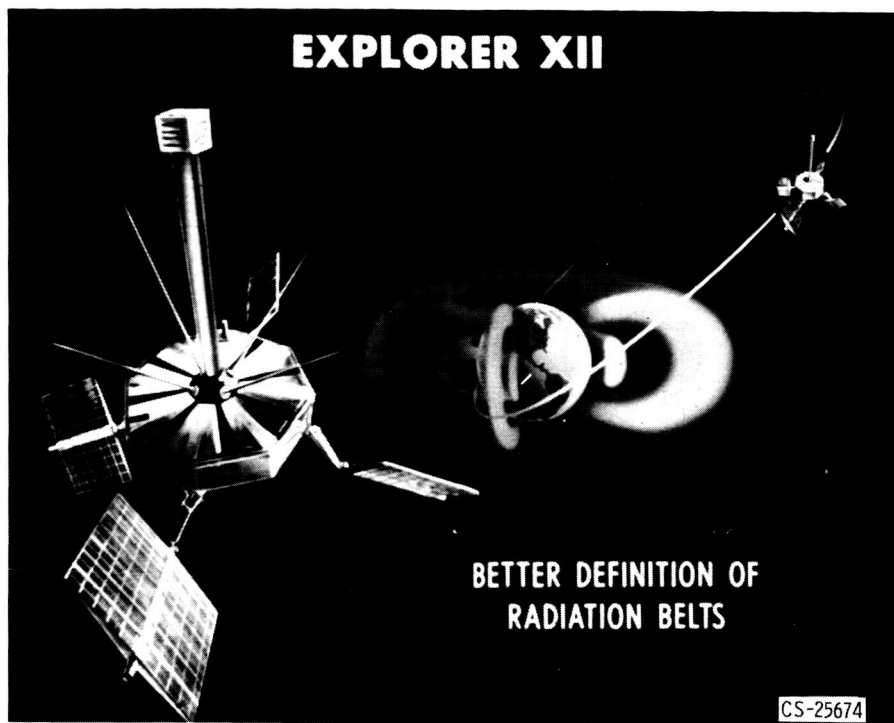
Figure 17

VAN ALLEN RADIATION

5,000 10,000 15,000

INNER BELT OUTER BELT km
(QUIET
PERIOD)

CS-25316

Figure 18

RADIATION BELT AND SOLAR DISTURBANCE

COSMIC RAY

COSMIC RAY

SOLAR PROTONS

CS-26323

Figure 19

NEUTRAL POINT

CAVITY BOUNDARY

8 6 4 2 2 4 6 8 10 12 14

EARTH RADII

SOLAR WIND

SOLAR FLUX = 10 PProtons per cm

VELOCITY = 500 Km/sec

NEUTRAL POINT

CS-26321
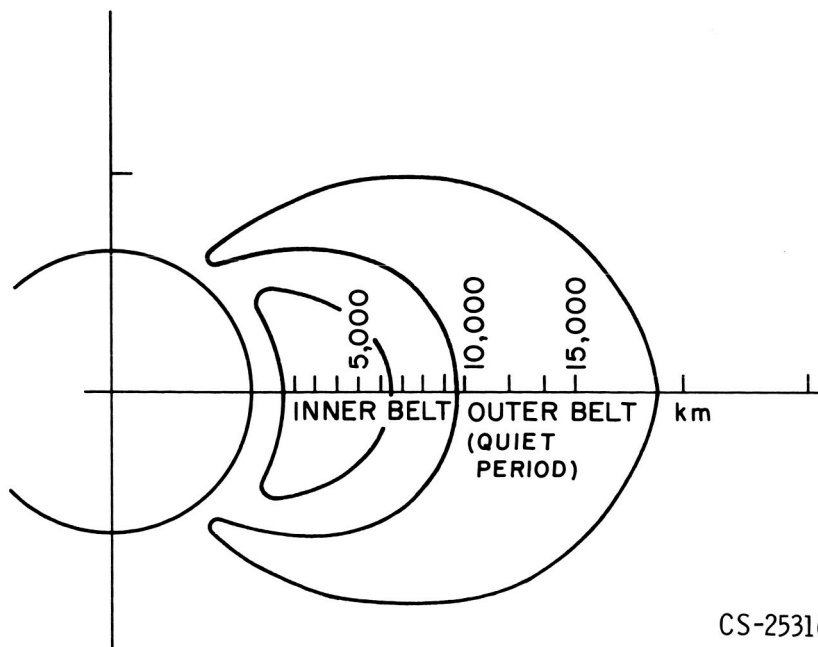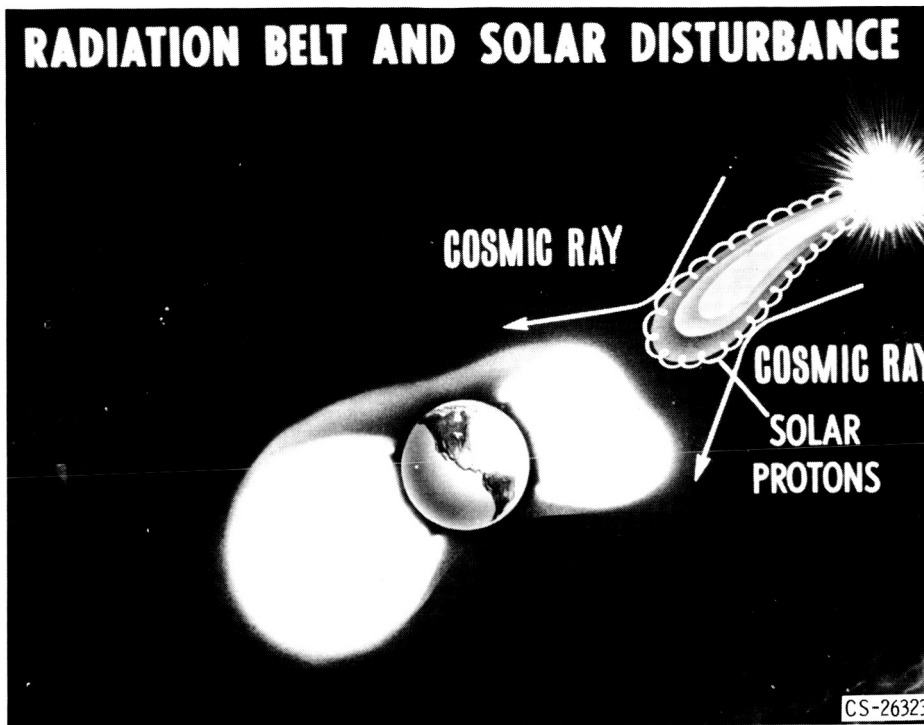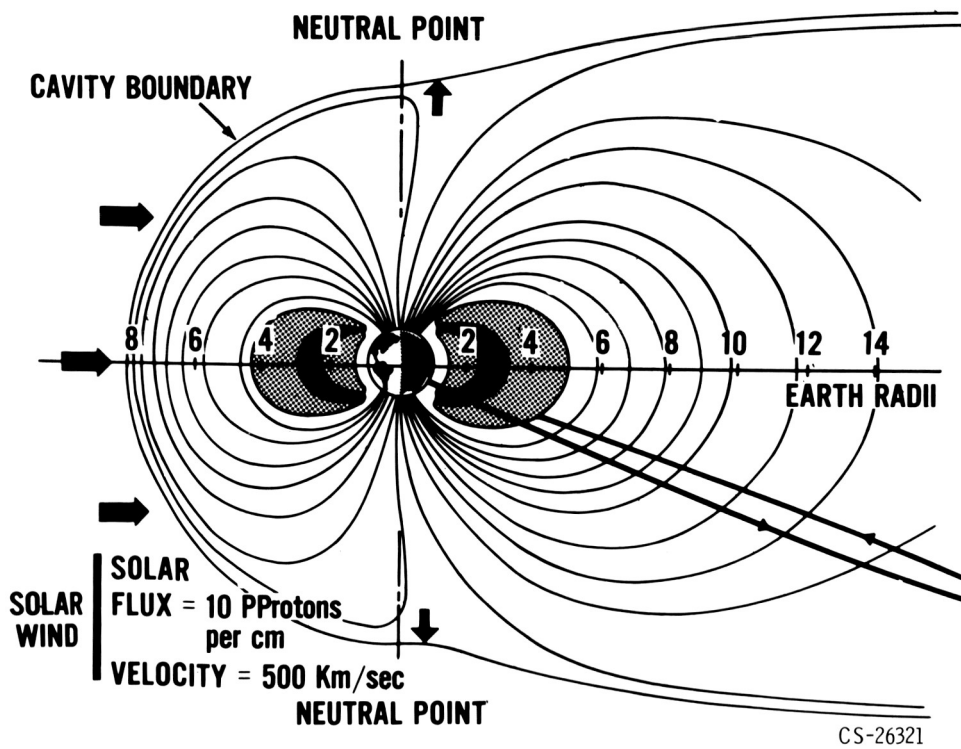
Figure 20

THE CHEMICAL COMPOSITION OF COSMIC RADIATION

Z	ELEMENT	RELATIVE ABUNDANCE IN COSMIC RADIATION	RELATIVE ABUNDANCE IN THE UNIVERSE
1	HYDROGEN	100,000	100,000
2	HELIUM	7,000	7,500
3, 4, 5	LITHIUM, BERYL- LIUM, AND BORON	35	3×10^{-3}
6	CARBON	190	10
7	NITROGEN	120	15
8	OXYGEN	190	50
$10 < Z < 30$		140	30
$Z > 30$		0.1	8×10^{-4}

Figure 21

CS-25314

SOLAR FLARE DATA

CLASS	DURATION, MIN	FREQUENCY	FRACTION OF VISIBLE HEMISPHERE $\times 10^{-6}$	ENERGY
1-	5 - 20		25	
1	4 - 43	2 PER HR	100 - 250	
2	10 - 90		250 - 600	
3	20 - 155	12 PER YEAR	600 - 1200	10^2 MEV
3+	50 - 430		> 1200	1 - 40 BEV

Figure 22

CS-25315

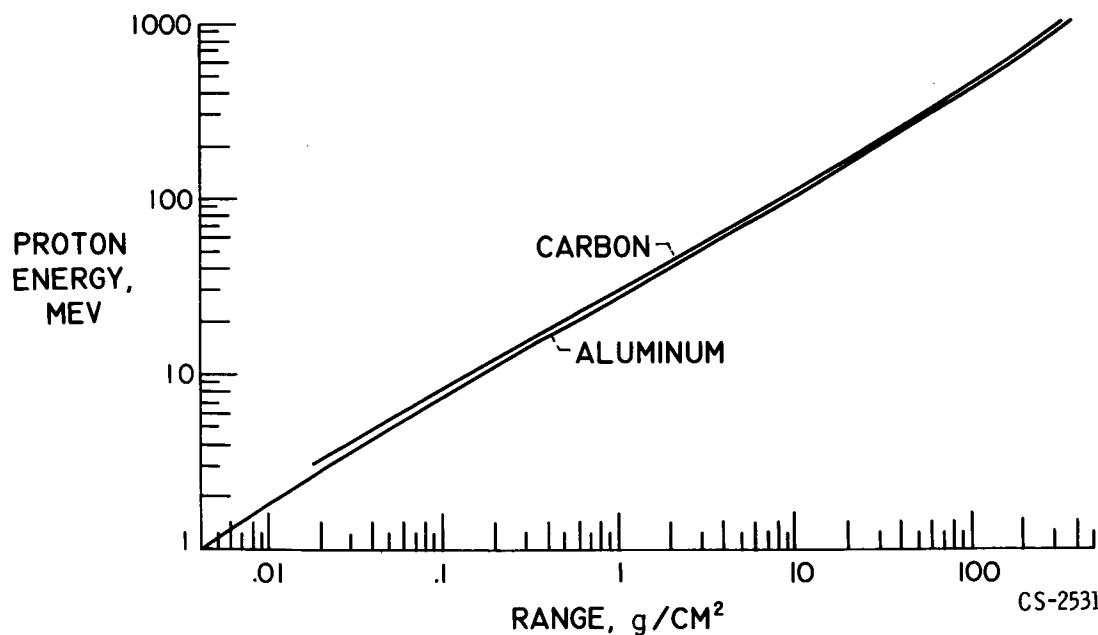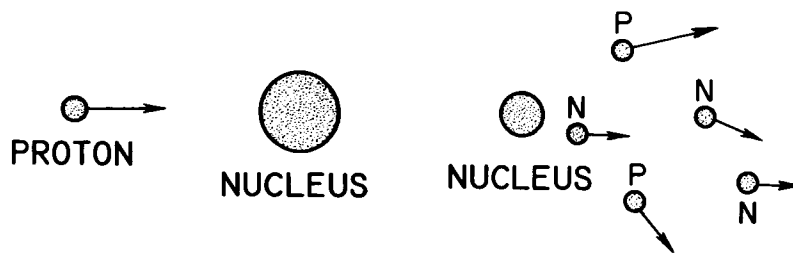# SOLAR FLARE INTENSITY
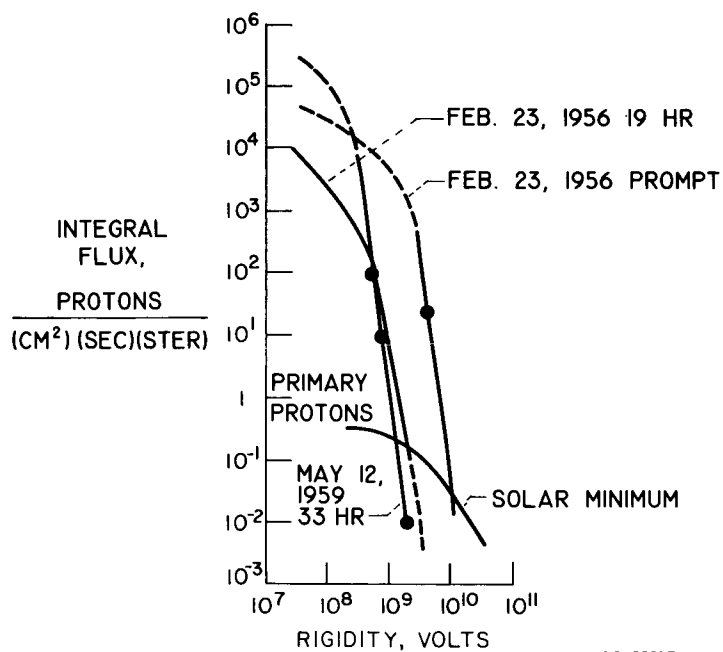
Figure 23

CS-25317

RANGE IN g/CM² VS ENERGY IN MEV FOR PROTONS

CS-25319

Figure 24

CASCADE REACTION

PROTON

NUCLEUS

NUCLEUS

P

N

P

N

N

N

EVAPORATION REACTION

PROTON

NUCLEUS

EXCITED
NUCLEUS

N
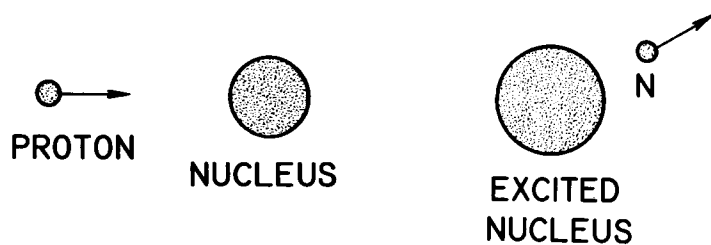
CS-25323

Figure 25

DOSE RATE VS SHIELD THICKNESS

MATERIAL: CARBON

SPECTRUM: MAY 10, 59
FLARE MEASURED 33
HRS AFTER ONSET

PRIMARY PROTONS

10^3

10^2

RAD/FLARE

CASCADE NEUTRONS

EVAPORATION NEUTRONS

10^1

SECONDARY PROTONS

10^0

0   20   40   60   80   100

GM/CM^2

CS-25318

Figure 26

METEOROID MASS—FREQUENCY DISTRIBUTION

Figure 27

Figure 28

NUMBER

ECLIPTIC

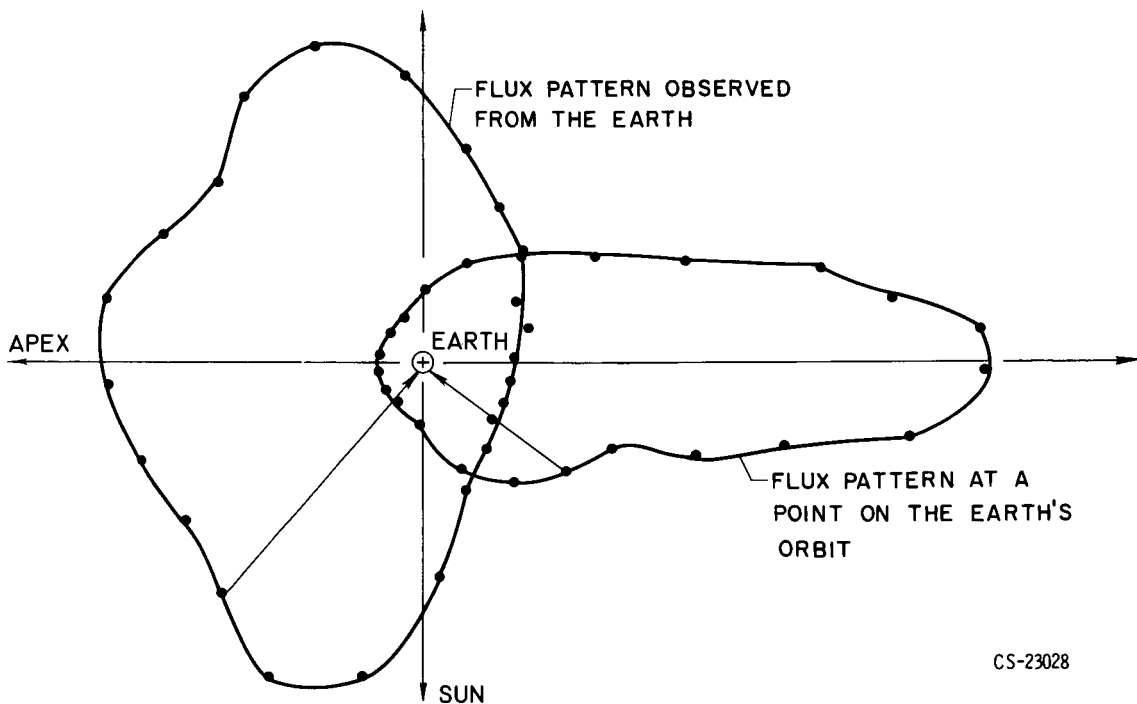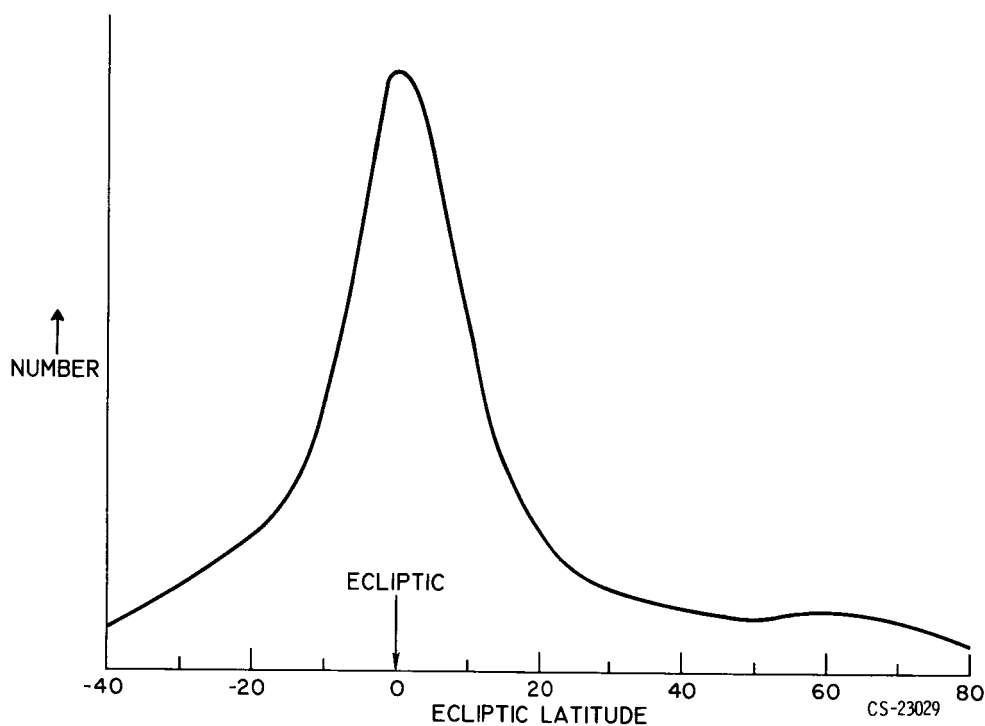-40   -20   0   20   40   60   80

ECLIPTIC LATITUDE

CS-23029
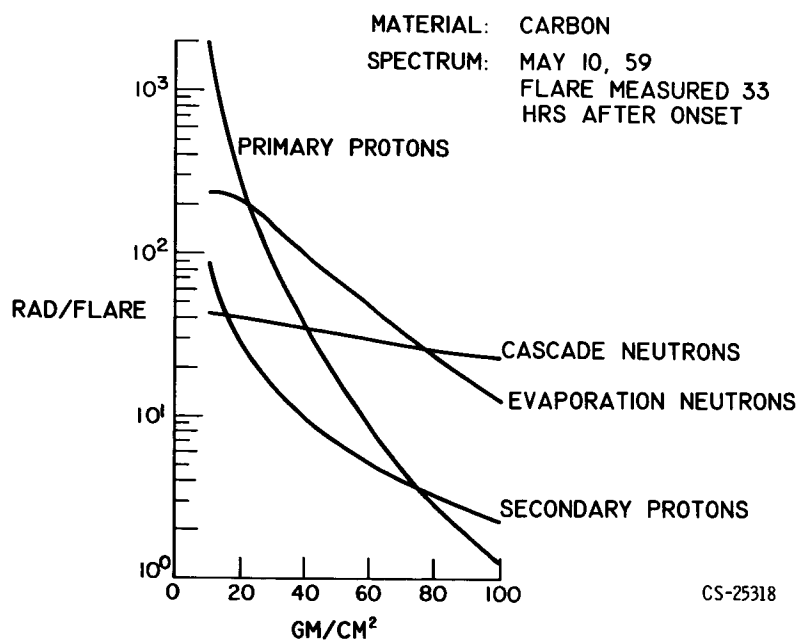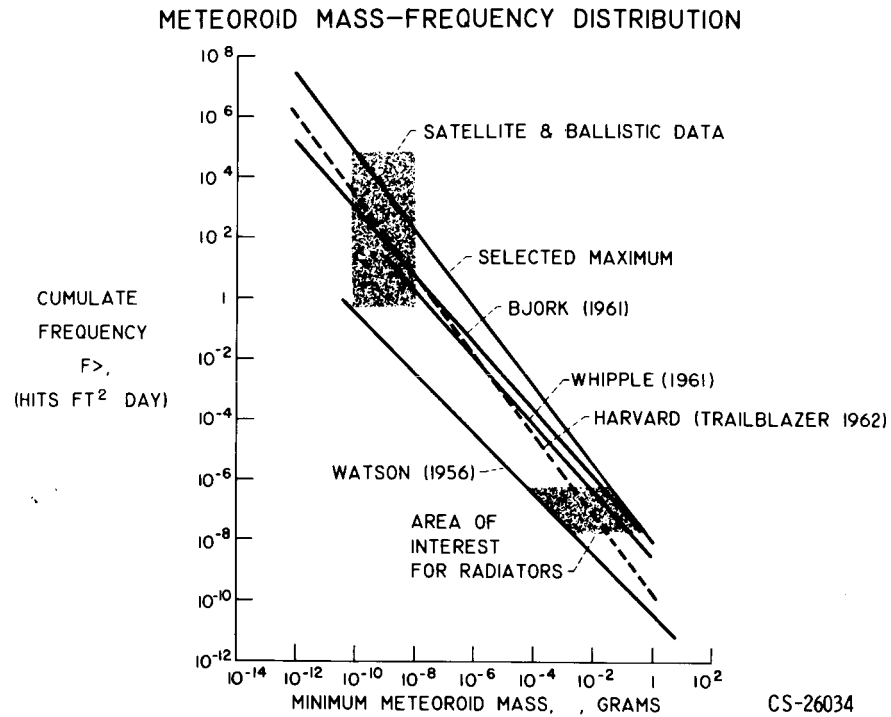
Figure 29

METEOROID PENETRATION RATE
EXPLORER XVI DATA — JAN 13, 1963

PUNCTURES/SQ FT/DAY

10^{-1}

10^{-2}

WHIPPLE (1961)
FLUX BJORK
PENETRATION

(2)
LEWIS

(10)
LANGLEY

( ) NUMBER
PENETRATIONS
RECORDED

WATSON (1956)
FLUX BJORK
PENETRATION

(1)
LANGLEY

.0001   .001   CS-27020   .010

SKIN THICKNESS, INCHES OF STAINLESS STEEL

Figure 30