THE HUMAN EYE IN SPACE*

(Physiologic Aspect)

By: Hubertus Strughold, M.D., Ph. D.**

The visual world encountered by the Astronaut in Space is to be exotic: different indeed in many respects from that he has seen from the Earth's surface. Under the stimulus of weightlessness, vision is the sensory means available to him for orientation in space. Except for periodic radio communication in the mysterious silence of space, vision offers the only other sensory contact with the outside world. What the human eye sees in space and how its function may be affected by the optical scenery is of tremendous importance to the astronaut; too, it is of scientific and general human interest.

A discussion will analyze the light conditions, i.e., the visible radiation spectrum which is considered essentially from a physiologic point of view (the standpoint of human physiology) as it relates to space.

In terms of physiologic optics we are dealing primarily with that area from about 3,800 to 7,800 A°ngstrom in the electromagnetic spectrum, to which the pigment of the human retina is specifically attuned.

First, we shall discuss this visible radiation as it is encountered in circumterrestrial or nearby space, with emphasis upon the brightness or luminance of the sky and the illuminance from the Sun. Secondly, we shall examine solar illuminance for the whole distance from Mercury to Pluto.

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**Professor of Space Medicine and Advisor for Research, School of Aviation Medicine, Brooks Air Force Base, San Antonio, Texas.

For a better understanding of light in space, it might be useful to contrast the conditions found there with those observed on the earth's surface and in the depths of the oceans.

Beginning with the latter, the deep regions of the oceans are permanently dark. It will be interesting to recall later in this discussion that in this lightless or aphotic abyss, numerous fish are found, some with light-producing (bioluminescent) organs as well as eyes, and others with vestigial non-functioning eyes. These blind deep sea fish sense their environment by means of mechano-receptors and chemoreceptors only.

When a person in a bathysphere ascends from these depths of the ocean, the first slight traces of light perceptible by the human eye, appear about 500 to 600 meters below sea level (W. Beebe, 3, Jacques Piccard, 20); they are of bluish color and shift with decreasing depth to green and greenish-yellow in the subsurface regions. One meter below the surface, illuminance from the sun is about [illegible]0,000 lumens per square meter or lux (lx)*. But even that close to the surface to a diver there appears to be no clear evidence of a sun.

Emerging from the hydrosphere to the bottom of the atmosphere, on a clear noon, we see the sun high in the sky with its rim blurred by an aureole which blends into a dome-shaped sky of bluish light. The aureole is caused by indirect sunlight, reflected by ice crystals in the higher atmosphere, and the blue sky is inderect sunlight, Scattered by the air molecules and fine dust. The photometric brightness, or luminance, of the blue sky, about 25° from zenith, as seen from sea level, is about [illegible],600 nit* (H. Haber, 11). Because of this veil of scattered light, the stars remain invisible, and the moon is scarcely discernible. The illuminance from the sun is, roughly, 108,000 lx (≈10,000 foot candles), representing the average value at noon during sunshine at sea level at middle latitudes in summer (H. Haber, 11; E. O. Hulburt, 13).

When man ascends in a rocket vehicle, he will find that the sky gradually becomes darker and the sun brighter because of the rarification of the air and the resulting disappearance of light-scattering. This has been observed in high altitude balloon flight by J. Piccard (19), A. W. Stevens and O. A. Anderson (1), D. G. Simons (23), and M. D. Ross and M. L. Lewis (22). At 30 km (18 mi) the luminance of the sky decreases to 30 nit, and at 160 km (100 mi) it is only about 3×100^{-5} nit (R. Tousey and E. O. Hulburt, 26; H. Haber, 11). Against this low field brightness the stars are visible all the time. Because of the absence of a reflecting and scattering medium the sun now shines without an aureole, as a luminous disk on the dark background. And, the color of the sun (and of the stars) should be more whitish, because no blue rays are scattered out by an atmospheric medium. Solar illuminance increases from its maximal sea level value of about 108,000 lx to about 140,000 lx at the top of the atmosphere (13,600 ft-c, according to H. Haber (11); 12,700 ft-c, according to F. S. Johnson (14); 14,000 ft-c at 30 km, according to R. B. Toolin and V. J. Stakutis (25). This extra-atmospheric value is called the solar illuminance constant, which of course is not a constant in the true sense of the word.

Such is the basic difference between the atmospheric and extra-atmospheric photic environment in nearby space during the day; a bright, blue sky with a bright sun, on the one hand, and a deep, dark sky with a still brighter sun on the other.

The darkness of space is not the same as that in a moonless, clear sky on earth at midnight. In this case the luminance of the dark sky between visible stars, or the background luminance, is greater. In the first place this is caused by night airglow in the upper atmosphere--a faint, diffuse light, emitted by atomic oxygen, nitrogen and sodium brought into excited states by solar ultra violet rays (D. Barbier, 2).

In the order of decreasing relative intensities the total night light of a terrestrial clear, moonless sky, comprises airglow, starlight, zodiacal light (sunlight reflected or scattered from micrometeorites and dust particles), (Van de Hulst, 29), and galactic light (Nebulae), all direct and scattered by the earth's atmosphere (K. S. Mitra, 18). The scattered component gives the background luminance a bluish shade. The total luminance is about 10^{-4} nit (11); the dominant light source is airglow, and in the sky in space this light source, of course, is absent.

The total light encountered in the dark sky of space includes therefore direct starlight, zodiacal light, and galactic light only. The dominant light source is the stars. The total luminance of the dark space sky is in the order of 10^{-5} nit, by a factor of ten lower than that of the terrestrial sky at night.

In the night sky, as seen from earth, the stars are embedded in the mild luminance of the airglow, which mollifies the contrast between them and the surrounding darkness. With airglow absent in space, zodiacal light remains the main background luminance, at least up to the distance of Jupiter (J. M. Levitt, 15). Against the darker background in space the stars should appear brighter by contrast, and actually they are brighter by about 30 percent; this is the attenuation of light when travelling vertically through the atmosphere (16). For the same reason more stars should be visible from above the atmosphere than from the earth's surface. And, of course, they would not twinkle because no atmospheric turbulence interferes. This has been observed by D. G. Simons during his balloon flight up to 30 km in 1957 (23).

From 200-800 km is the region to which manned satellite flight will be confined because of the Van Allen Radiation Belt, beginning at 800 km (28).

To the Astronaut, when the moon is in sight from an orbiting space vehicle, the sun-illuminated portion would be brighter by about 30 percent than seen from the earth, because the atmosphere no longer interferes. Brighter, also, should be the moon's portion not directly illuminated by the sun. This luminosity is "earthlight on the moon", which is actually indirect sunlight reflected from the earth.

Through this we recognize the earth itself as a source of light. Thirty-six percent of the solar light falling upon this planetary body <u>in toto</u> is reflected or scattered back into space. This causes the earth to be an illuminated celestial body with an albedo value about five times as high as that of the moon (0.07). Numerous photographs of the earth have already been made from rockets at considerable altitudes (C. T. Holliday, 12, J. G. Vaeth, 27). The color of the sunlight reflected or scattered back from the earth's atmosphere is bluish white, a conclusion made from spectrographic studies of the "earthlight" on the moon. A certain area of the earth would also portray to the orbiting astronaut the moonlight on the earth, just as we see from earth the earthlight on the moon's dark areas.

The physical optical conditions described for the upper atmosphere and nearby space are of greatest interest from the standpoint of Space Medicine, or bioastronautics. They pose psychologic, physiologic, and medical problems.

The appearance of the earth as a light source in the photic environment of nearby space is strange in that it is bright below and dark above, when seen from an orbiting space vehicle. This is reversed on the earth's surface, which appears generally--except in winter--in dark colors (green or brownish, with a bright dome of skylight above. As seen from space in the vicinity of the earth, the strange spatial distribution of light and darkness is of greatest interest from the standpoint of orientation in space, especially since the eye is the only sense organ on which this function depends in any space operation. This is so because the astronaut is weightless, and under this condition the mechanoreceptors--such as the otolith organ, the pressoreceptors of the skin, etc.--cannot provide any information concerning his position and movement in space; a like contrast to the life of deep-sea fish with non-functioning eyes which depend in this respect entirely on their mechanoreceptors, as already mentioned.

The low field brightness of the sky then, combined with an intensive illumination from the sun, represents to some degree a strange optical state found on earth only under artificial conditions like those employed for theatrical stage lighting. Everything that is exposed to sunlight--inside the cabin and outsid--appears extremely bright; everything in the shadow is dark. Light and shadow dominate the scenery. This photoscotic condition poses interesting problems in the field of contrast vision and retinal adaptation, and requires special attention in human engineering of the space cabin (P. Cibis, 7; H. Rose, 21).

The observation of the light sources, themselves, must be considered. Beginning with the weaker one, the sun-illuminated portion of the earth; which may produce at the plane of the eye an illuminance value of more than 20,000 lux at satellite distances below the Van Allen Radiation Belt (H. J. Merrill, 17), might easily cause a dazzling glare (as described by T. C. McDonald, 16, with regard to higher atmospheric altitudes), especially when the orbiting astronaut emerges out of the shadow of the earth. (The cone of the earth's shadow reaches about 1,385,000 km, or 859,000 miles into space). It should be added that for the first time a bird's-eye view of the Aurorae Polares will be possible from a polar satellite. And it might be interesting to learn whether or not astronauts will be able to perceive the so-called Gegenschein, or counterglow--a faint luminosity far above the earth's atmosphere opposite the sun, the cause of which is still a matter of dispute.

Special medical attention must be given to possible hazards to the eye from looking too long into the sun. In this respect retinal damages, with which we have to reckon, are actually heat effects caused by the visible and the near infrared rays focused by the lens upon a small area within the fovea retinae (A. Birth-Hirschfield, 4; F. H. Verhoeff et al, 30; H. G. Clamann, 8; and D. G. Cogan, 9). They occur frequently on earth when a solar eclipse is observed with an insufficiently smoked glass. The result may be a retinitis solaris and in severe cases a thermal coagulation necrosis of the retinal tissue or a retinal burn. Figure 1 shows a scar of such a retinal burn, which I acquired when I observed the total solar eclipse on the 17th of April 1912 in Europe with my right eye insufficiencly protected. This photograph, made more than 40 years later, shows that such retinal lesions can be irreversible. The subjective symptom is a small blind area or scotoma in the visual field, which is called eclipse blindness (scotoma helieclipticum).

The critical exposure time for the development of eclipse blindness is estimated to be one minute or less (F. C. Cordes, 10). Outside the atmosphere the danger of such retinal lesions associated with visual defects, which generally might be called helioscotoma, is of course greater because the intensity of solar radiation is about 30 percent higher (140,000 lx in space against maximally 108,000 lx on earth). Furthermore, because of the dark sky, the eye--when turned to the sun--is not adjusted by pupillary constriction to such an intensive illumination and is, therefore, so-to-speak, caught by a blitz-like surprise out of the darkness.

From data available in the literature about similar effects on rabbits produced by atomic flashes (V. A. Byrnes, D. V. L. Brown, H. W. Rose, and P. A. Cibis, 6), it can be estimated that an exposure time of about a quarter of a minute or less to the solar radiation in space at the earth's distance might be sufficient to cause retinal burn. On a flight in the direction to Venus, the critical time of exposure to this perpetual nuclear light source, of course, would be shorter. Caution in this respect, therefore, is indicated, and protection of the eye by means of strong absorbing glasses or electronic devices is necessary. Also, a retractable, light-scattering visor attached to the helmet, serving as a kind of blue sky simulator, would be useful to an astronaut on the moon. At what place in the remote regions of the solar system that the sun loses its retinal burning power is difficult to extrapolate, because we deal with living tissue which possesses reactive capabilities. It might be somewhere beyond Jupiter. Even beyond Saturn, according to H. Rose (21), solar illuminance is intense enough to cause a dazzling glare.

We have reached the point now to examine what the light conditions are in deep space, including the whole interplanetary range from Mercury to Pluto.

The illumination from the sun is the factor that interests us most because it is subjected to considerable variations with increasing planetary distances, in contrast to the brightness of the sky, which is dark everywhere, and may become a shade darker in the extrajovian space because of the disappearance of the zodiacal background light. As mentioned before, solar illuminance above the earth's atmosphere at the earth's mean solar distance amounts to about 140,000 lx (solar illuminance constant). According to the inverse square law, in the region of Venus this value increases to 268,000 lx, and at Mercury's distance to 938,000 lx; it decreases at Mars' distance to 60,000 lx, at Jupiter's distance to 5,200 lx, and at the mean orbital distance of Pluto to 90 lx. (Table I).

These tremendous variations in solar illuminance suggest a subdivision of the space of the solar system into photic zones. We might not go too far in speaking of a euphotic belt, which is the zone favorable to space operations and may include some 100 million km on both sides of the earth's orbital distance; this zone is surrounded by a hyperphotic and hypophotic zone.

The euphotic belt, or we might also call it biophotic belt, together with the euthermal belt, liquid water belt and oxygen belt, is an important component in the concept of a general life-favoring zone or ecosphere in the planetary system (H. Strughold, 24). The photic component in this relatively favorable ecologic belt is not only important from the standpoint of vision but also with regard to the utilization of light for photosynthesis in a space vehicle and with regard to the question of life on other celestial bodies, particularly on Mars which has a transparent atmosphere.

We get some idea about solar illumination within the planetary system by comparing the apparent size of the sun as seen at the distances of the various planets.

To an observer on Mercury the diameter of the solar disk would appear more than twice as large as when seen from the earth. As seen from Mars, the sun would have a considerably smaller apparent dimension than our Moon. At the distance of Jupiter, the sun's diameter is only one-fifth as large as seen from the earth; and at the distance of Pluto, the sun would not appear much larger than the evening star, Venus, appears to us on earth.

And, yet, the illuminance from the sun at the mean distance of Pluto is still 90 lx; this is considerably above the threshold for reading, which is about 20 lx, and also above the threshold for color vision. Below 10 lx, color discrimination becomes difficult. Solar illuminance decreases to this value in the region about three times the distance of Pluto, or about 18 billion km (or more than 10 billion miles) from the Sun. Here, then, insofar as it is related to the illuminating power of the sun, begins the colorless world of interstellar space. And the sun, itself, as seen with the eyes of a space traveller, joins the ranks of the multitude of the other stars of our galaxy.

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ANNEX

Photometric Terms and Units

Illuminance: Luminous flux incident on unit area.
Unit: Lux, foot candle.

Lux(lx), synonym metercandle:
An illuminance of one lumen per square meter.

Foot Candle (ft-c): Illuminance of one lumen per square foot.

Lumen(lm): The luminous flux emitted through a unit solid angle (one steradian) from a point source of one candela.

Luminance (photometric brightness): Luminous intensity of any surface in a given direction per unit projected area of the surface viewed from that direction.
Unit: nit.

Nit(nt): A luminance of one candela per square meter.

Candela(cd): Unit of luminous intensity. New defined and internationally accepted candle.