

# PHOTOGRAPHIC OBSERVATIONS OF NIGHTGLOW FROM ROCKETS

by

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## ABSTRACT

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Several very clear photographs of the earth's night airglow horizon over western Texas were obtained at altitudes up to 184 km from an Aerobee rocket launched at 0615 UT, 1 December 1964 from White Sands Missile Range, New Mexico. The vertical distribution of the airglow has been determined, showing the altitude of peak nightglow emission as  $95 \pm 4$  km with 90% of the emission between 80 and 116 km. The striking visual appearance of the airglow layer and surface lights and the altitude determination are compared with the observations reported by various astronauts and with other rocket measurements.

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Each of America's astronauts <sup>has</sup> have commented on the striking appearance of the earth's night airglow when viewed edge-on at the horizon from an orbiting spacecraft. Astronauts Glenn and Carpenter have reported their observations in the literature (1,2). Photographs of the nightglow were made by astronaut Cooper on the MA-9 flight and reported by Gillett, Huch, Ney, and Cooper (3). Relatively long exposures were made, however, during which time the spacecraft's attitude was not held fixed on the horizon with a resulting smear of the image. A review of the Mercury program's scientific results has been made by O'Keefe, et al. (4).

Long before the space age airglow observations were made with ground based visual and photoelectric photometers and by occasional photographs. An interesting set of photographs of the light of the night sky have been collected by Rudaux and De Vaucouleurs (5). These photographs were made with relatively fast cameras and exposures of an hour or more. The photographs include the contribution from zodiacal light and integrated starlight which contribute, according to Roach (6) and others, about 2/3 of the light of the night sky. In the early 1960's Ney and his colleagues at the University of Minnesota began to use unmanned balloons to photograph dim light phenomena in the night sky (7).

An interesting set of nightglow photographs were obtained from NASA Aerobee 4.83, launched last November to record ultraviolet nightglow spectra. In addition to the fast airglow spectrograph the rocket carried an electrically operated Nikon 35 mm camera with an f/1.4 50 mm lens using Tri-X pan film for recording aspect data. The film was developed in Kodak D-19 for 6 minutes. The rocket attitude was controlled to keep the airglow horizon centered in the spectrograph slit during the course of the flight. The launching took place some five hours

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before moon rise. Camera exposure times from 1/3 to 30 sec. were used, however, the 1/3 sec. exposures were too short to record more more than a faint trace of the airglow layer. The next longer exposure time of 3 sec. produced the best results, with longer exposure times showing excessive smearing caused by small rocket motions within the Attitude Control system error limits.

Fig. 1 is a 3 sec. exposure taken at apogee (184 km or 114 mi.) showing the thin airglow emission horizon well above the earth's physical horizon. The surface lights seen in the West Texas region stand out clearly. Figure 2 is a map of the same region identifying some of the brighter lights. Fig. 3 is a 10 sec. exposure taken at 183 km with considerably more rocket motion evident and with an extremely dense airglow band. The multitude of lights to be seen in even the sparsely populated West Texas region gives a hint of what a spectacular sight could be seen over more densely populated regions. The star trails reflect the rocket guidance maneuvers. Figure 4 is a 3 sec. exposure taken at 93 km as the rocket was on its way down. During this exposure the rocket attitude remained stationary with respect to the star background but the rocket moved a distance of 4 km vertically. The resulting smearing of the surface lights are in sharp contrast to the multitude of point star images. This altitude is right in the middle of the airglow layer.

It is of interest to compare Fig. 1 with the visual observations of the Mercury and Gemini astronauts. M. S. Carpenter in his three orbit Mercury flight (MA-7) of 24 May 1962 described the edge-on night glow and star field scene in a manner similar to that shown in the photograph (8). The star fields in the photograph are far richer than he or the other astronauts have indicated, however, even though the constellations Hydra and Sextans which make up the background of the photographs shown here are

not particularly rich regions of the sky. This difference is simply the result of a comparison between a camera with a 36 mm diameter lens and a 3 sec exposure and the dark adapted eye with approximately a 9 mm aperture and 0.2 sec. integration time. The photographs give the subjective impression that the nightglow layer and surface lights are relatively bright. From the remarks of the astronauts, however, we can infer that the visual brightness of the airglow is relatively low (1,2,8). The dark adapted eye is equivalent to about an  $f/2.5$  lens which is only about  $1/3$  the speed of the  $f/1.4$  camera lens. Furthermore, the astronauts, during most of their observations, were not in a completely dark adapted condition. In addition, the eye is responsive to an effective bandwidth which is only about 40% the bandwidth of the camera.

The excellent set of color photographs taken with an  $f/1$  camera by G. Cooper (3) on the MA-9 flight show a great deal less detail and much fainter images than does Fig. 1. Part of this can be attributed to the smearing caused by vehicle motion, part to the color film reciprocity losses during the 10, 30, and 120 sec exposures, part to the inherently lower sensitivity of color films, and part to the fact that the color pictures were taken through the thick, multi-layered spacecraft window which could contribute to a loss of contrast as well as give the possibility of absorption losses by deposits on the outer window.

Our results and those in (3) indicate that a considerable number of night sky phenomena could be photographed from a manned spacecraft with relatively short exposures. Table 1 lists some of these exposure times, based on a 2 sec. exposure being suitable for the horizon airglow.

In addition to its pictorial value Fig. 1. can yield some geophysical data. A densitometer trace of the airglow layer provides a relative intensity profile of the horizon as shown in Fig. 5. The zenith angle was determined quite accurately by finding the zenith distance of the star  $\lambda$  Hydra

TABLE 1

## Photographic Exposure Times for Dim Light Night Sky Phenomena

(f/1.4 lens, reciprocity effects neglected)

Phenomenon	Approximate Emission Rate (kilo-rayleighs)	Approximate Exposure Times (seconds)
Milkway (average)	0.7	100
Gegenschein	0.8	90
Aurora IBC-I	1	70
Nightglow (zenith)	1	70
Zodiacal Light (30° elongation)	6	10
Nightglow (edge-on)	35	2
Great Orion Nebula M42	300	1/4 sec.
Aurora IBC - IV	1000	1/15 sec.

which lies in approximately the center of the luminous band in Fig. 1. The earth's limb is at a zenith angle of  $103.6^\circ$ . Also shown on the figure are the altitudes at which a line of sight from the rocket, at the respective zenith angle, is tangent to a surface concentric to the earth (i.e. the closest point of approach).

The vertical distribution of the nightglow emission has been determined from the information in Fig. 5 by assuming that the airglow arises from a region between 70 and 122 km and that none of it is absorbed. If this altitude region is then divided into 26 layers of 2 km each there is a unique set of relative emission intensities per km which can be assigned to the 26 layers to produce the profile in Fig. 5. The result of this calculation (9) is shown in Fig. 6.

The vertical distribution of the nightglow given in Fig 6 is, of course, smeared by the amount of rocket motion seen in Fig. 1. This smearing amounts to  $0.22$  degrees in the direction normal to the airglow horizon, and corresponds to an uncertainty of 4 km in the altitude of peak emission intensity. The brightest section of the horizon profile, at a zenith angle of 100 degrees in Fig. 5, corresponds to a tangent altitude of 85 km, whereas the deduced peak is at 95 km in Fig. 6. From the vertical distribution it can be seen that the layer thickness between points of half intensity was  $26 \pm 4$  km. The ratio of the horizon intensity to the intensity observed looking straight down can be determined from the data used to make up Figs. 5 and 6. This ratio of edge-on/zenith intensity is 36, which agrees with the value of 35 used in (3) but is less than that used by Stecher (10) for the ultraviolet region. The continuum recorded here is apparently more spread out with altitude than the line emissions, and the photographic smearing tends further to

reduce the apparent edge-on brightness.

The altitude of peak emission in Fig. 6 is in good agreement with the values determined from rocket measurements (10, 11, 12) and the results derived from Carpenter's visual observations (2). Gillett, Huch, Ney, and Cooper (3) found a large variation in airglow altitude with latitude in their photographic observations from the Mercury MA-9 flight, and our own observations suggest that photographic determination of airglow emission altitudes should be a relatively simple technique for finding altitude variations across the surface of the earth.

The 5577A green line intensity was about 145 R at the zenith during the flight (13) which was about average for the time of year and phase of the solar cycle. Because of the broad spectral sensitivity of the film and lens combination which defined the sensitive region between 3700 and 6500A, the blue and green continuum can be assumed to make up 85% of the total emission (14). No attempt has been made to measure absolute emission rates.

Towards the left and right edges of Fig. 1 can be seen a faint dark band separating the airglow into an upper and lower strip approximately 17 minutes apart. This faint band shows up as the dimpled peak in Fig. 4 and the slight double peak in Fig. 5. Although it might appear to be a photographic effect caused by rocket motion or film behavior, the fact that it appears in several of the 3 sec exposures, each with different smearing patterns, indicates that it is probably real. Perhaps this banding is caused by a double layered continuum emission region as suggested by Packer (11), or more likely it is the effect of adding a small (10%) Na 5893A peak at 85 km onto a broader, more intense, continuum peak (11). Carpenter, in his flight (2), observed no structure during the time he looked at the nightglow.

Link (15) has suggested the existence of a tenuous dust layer in the region 81-119 km coinciding with the airglow emission region. This dust layer would produce extinction of transmitted light and, on nights when the moon was up, an enhanced apparent continuum emission rate from scattered moonlight. Figs. 1, 3, and 4 were taken with no moon present so that any scattered component would be absent. Although the photographs taken during this flight are not suitable for precision photometry, an examination of the 20 useable negatives show no obvious extinction of stars passing behind the nightglow layer. This result is in support of the same observations in (3).

These photographs, and the results in (3), show that there is a great deal of geophysical data which can now be gathered by photographs from either recoverable unmanned satellites or manned space platforms. Image intensifiers or image convertors with gains of  $10^3 - 10^4$  are available and can be used effectively both to extend the spectral sensitivity of the eye and film and to reduce exposure times drastically thereby permitting significant increases in both spatial and spectral resolution. The observation of daytime, twilight, and night sky phenomena by high altitude imaging devices will produce a wealth of information about our atmosphere which has thus far been gathered only in a painstaking manner from the ground.



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9. By calculating the slant path lengths through each of the layers for various zenith angles a set of equations is developed, the solution of which is the vertical distribution of airglow intensity.

$$B_z = \sum_n L_{nz} I_n$$

where  $B_z$  is the measured, integrated relative intensity along a slant path through the airglow, tangent at some altitude  $Z$ ;  $L_{nz}$  is the set of calculated path lengths through each layer  $n$  for each slant path; and  $I_n$  is the relative emission intensity per km for each 2 km thick layer  $n$ . The method for calculating path lengths  $L_{nz}$  and solving this equation were developed and carried out by the NASA Project for Space Sciences Data Processing and Analysis in the school of Engineering and Applied Science of the George Washington University, Wash., D. C.

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13. These values of the nightglow intensity were kindly  
furnished by Dr. June Jones of Geo-Science, Inc.,  
Alamogordo, New Mexico from the set of continuous  
measurements made at the airglow observatory site at  
Sacramento Peak, New Mexico.
14. If we use a value for the continuum emission rate in the  
zenith of  $0.5R/A$  (3) then there are about 1400 R of  
continuum and about 150R of OI 5577A and 100R of Na 5893A  
(13).
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(North-Holland Publ. Co., Amsterdam, 1964).

## CAPTIONS

- Fig. 1 The night airglow above western Texas photographed from 184 km in a 3 sec exposure with an f/1.4 camera using Tri-X film. The earth's horizon is 1500 km away. The exposure was made at 2319 MST, 30 Nov. 1964, at Lat.  $32.7^{\circ}\text{N}$ , Long.  $106.5^{\circ}\text{W}$ .
- Fig. 2 A map of the region pictured in Fig. 1 identifying the brighter stars and cities.
- Fig. 3 A 10 sec exposure taken at 183 km. The Gulf of Mexico occupies the dark region at the upper right horizon.
- Fig. 4 A 3 sec exposure taken at 93 km. The rocket is moving down at 1.3 km/sec but its attitude remained stationary with respect to the star background.
- Fig. 5 The airglow horizon relative intensity profile taken from a densitometer trace of Fig. 1. The zenith angle is determined from the zenith distance of the star  $\lambda$  Hydra. At the right is the tangent altitude (closest approach) of a line of sight for several zenith angles.
- Fig. 6 The airglow vertical distribution of relative emission rate per km derived from the data in Fig. 5.