Reports

Gemini V Experiments on Zodiacal Light and Gegenschein

The light of the moonless night sky as viewed from the ground consists principally of contributions from scattered light from cities, from twilight and starlight, zodiacal light, airglow, and aurora (*1*). All of these contributing sources of light vary either with time or position in the sky, or both. The quantitative observation of any of these from the ground is further complicated by the effects of the scattering and absorbing atmosphere between the observer and the source of light. For several years, a program has been carried out at the University of Minnesota aimed at separating and understanding the individual contributions to the night sky brightness. In this study, we have used balloon-borne photometers, polarimeters, and special camera techniques. More recently, we have had the assistance of the manned space program in obtaining special photographs in earth-orbiting missions (MA9 and Gemini V).

The principal purpose of this report is to describe the Gemini V observations in the context of their relation to ground-based and balloon experiments on dim light phenomena.

The zodiacal light is the visible manifestation of dust grains in orbit about the sun. The brightness of the light at 20° elongation from the sun and on the ecliptic is about 2×10^{-12} of the sun's surface brightness or about the same as the zenith sky observed from the ground at time of full moon. At 60° elongation, the brightness is about 2×10^{-13} of the sun's surface brightness or about one-half the brightness of the brightest milky way. At larger elongation angles, the zodiacal light becomes obscured by the terrestrial continuum airglow which has an average surface brightness of about 2×10^{-14} of the sun's surface brightness. In the direction approximately opposite to the sun is the phenomena of the gegenschein which is believed to be about 2×10^{-14} of the sun's surface brightness. No previous attempts to photograph the gegenschein have been successful.

As observed from the ground, the zodiacal light is grossly distorted by the effects of atmospheric extinction. From balloons at 100,000 feet, the effects of atmospheric extinction may be essentially eliminated even in the horizontal direction, and Fig. 1 shows a balloon photograph of the zodiacal light made with Ansco film 529, an $f/0.8$ lens and a 1-minute exposure. The solar elongation at the horizontal direction is 21°. Figure 2 shows the star field, horizontal, and ecliptic appropriate for Fig. 1. The balloon photograph was taken over Texas to eliminate aurora. The airglow shows in the photograph as a diffuse light increasing toward the horizontal according to the Van Rijn variation of brightness with zenith angle. There is no twilight evident in Fig. 1, but twilight makes measurements of the zodiacal light from balloons impossible at elongation angles of less than 19°. One of the objectives of the Gemini V experiment was to determine the minimum angle from the sun at which the zodiacal light could be studied without twilight contamination.

In order to estimate the airglow contamination of zodiacal light measurements in the visible region of the spectrum, an experiment was performed in the MA9 flight (*2*). Cooper carried a camera with an $f/1$ lens and photographed the airglow in profile from above with exposures of 10 seconds, 30 seconds, and 120 seconds on Ansco film 529. Figure 3 shows one of these photographs. The moon had not risen so the earth is dark, the horizon is delineated by very distant lightning strokes, and the airglow layer shows with a sharp line on top and a rather diffuse illumination below. The importance of the photographs was that they showed that at least the greatest majority of the light in the visible region of the spectrum arises in a layer 20 km thick and at an altitude of about 95 km. Although this result was not unexpected, it had not previously been demonstrated because the height measurements of the airglow have been made for selected lines and small regions of the continuum. The principal brightness, however, is throughout the continuum, and broad-band spectral observations with the MA9 photographs show that all the important illumination within the film bandwidth arises in a thin layer. This statement cannot of course be taken to include the 6300 line of oxygen or the infrared to which the film is not sensitive. Sensitometry of the MA9 negatives showed that only 10 percent of the light was reaching the film and only third-magnitude stars could be identified because of the low transmission of the Mercury spacecraft window.

The MA9 experiment, however, had conclusively shown that experiments on extraterrestrial light could be performed without airglow contamination at altitudes above 90 km. The Gemini V experiments were addressed to the following questions: (i) What is the smallest elongation at which zodiacal light measurements can be made from an earth-orbiting spacecraft above the airglow layer? (ii) Can the gegenschein be detected and measured from above the airglow layer?

The camera designed for the experiments was $f/1$, used Eastman Kodak Tri X film, and was programmed with transistor circuits to take doubling exposures in sequence starting at ½ second and finally reaching 3 minutes. Between successive exposures, 20 seconds of shutter-closed time was allowed for spacecraft maneuvering. The field of view of the camera was 50° by 130°, and this was obtained by rotating the optical system during the exposure. With the camera mounted in the pilot's window, a photosensitive eye was arranged to start the programmed sequence at sunset. In the actual experiment, the photo eye was not called upon because the camera was turned on by Conrad precisely at sunset.

The experiment was performed on orbit 46, 24 August 1965, and was composed of two parts. Before sunset, the command pilot (Cooper) acquired a definite spacecraft orientation previously agreed upon in which he used his reticle and the Southern Cross as a reference. This placed the other window and the camera in the correct position to photograph the twilight and the zodiacal light. After 5 minutes of stepped exposures, the spacecraft was

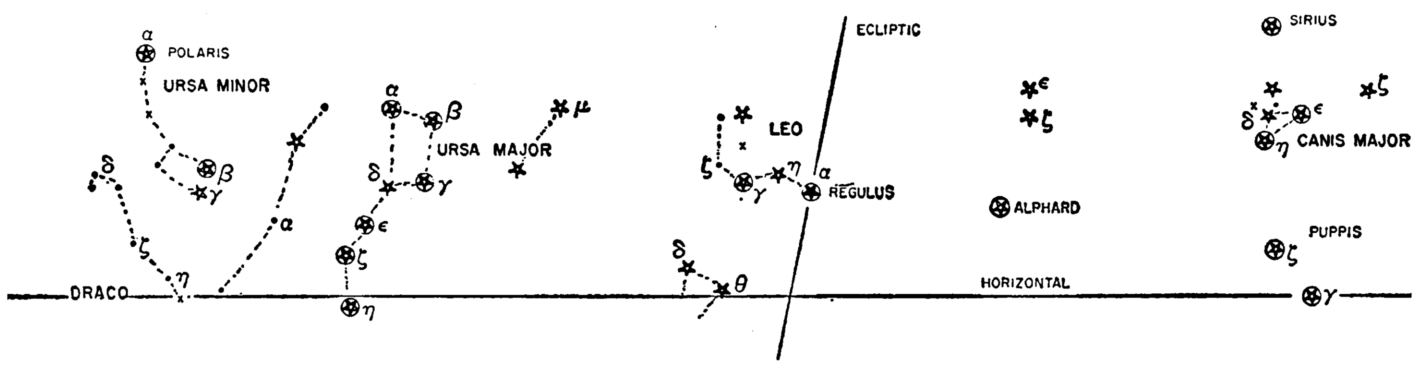


Fig. 1 (top). Balloon-borne camera photograph of the sky taken 30 September 1962. The zodiacal light is rising in the east. Also clearly evident are the Milky Way on the right and the airglow becoming brighter near the horizon. Fig. 2 (bottom). Drawing of the star field for the photograph of Fig. 1.

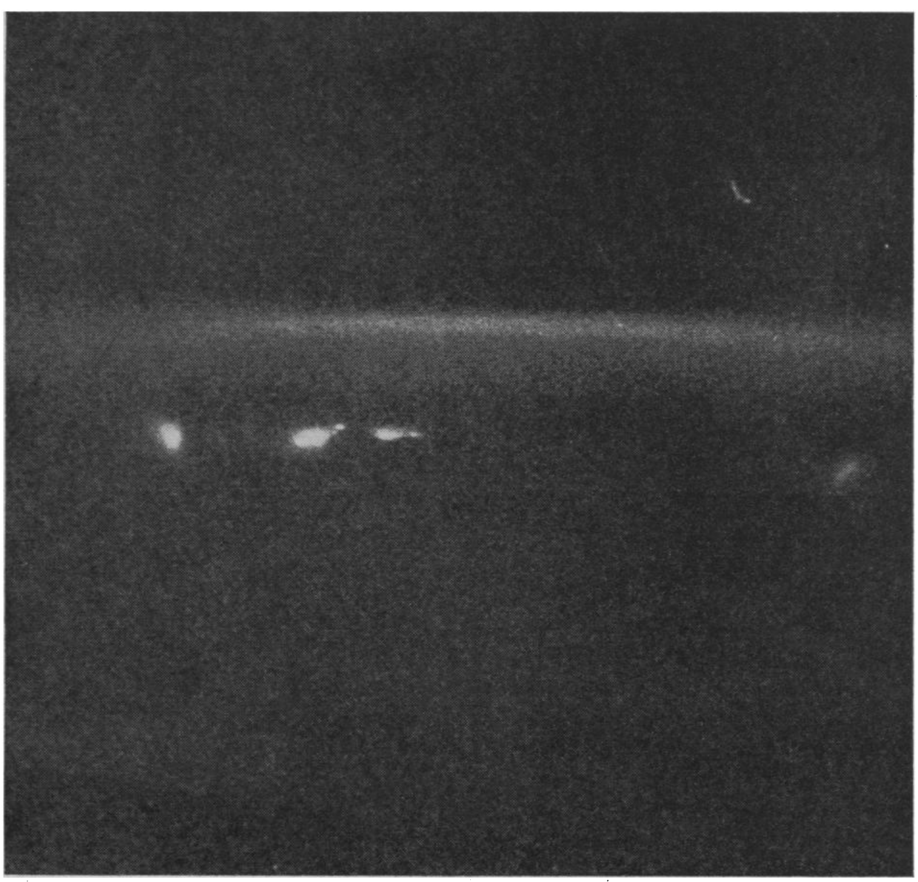
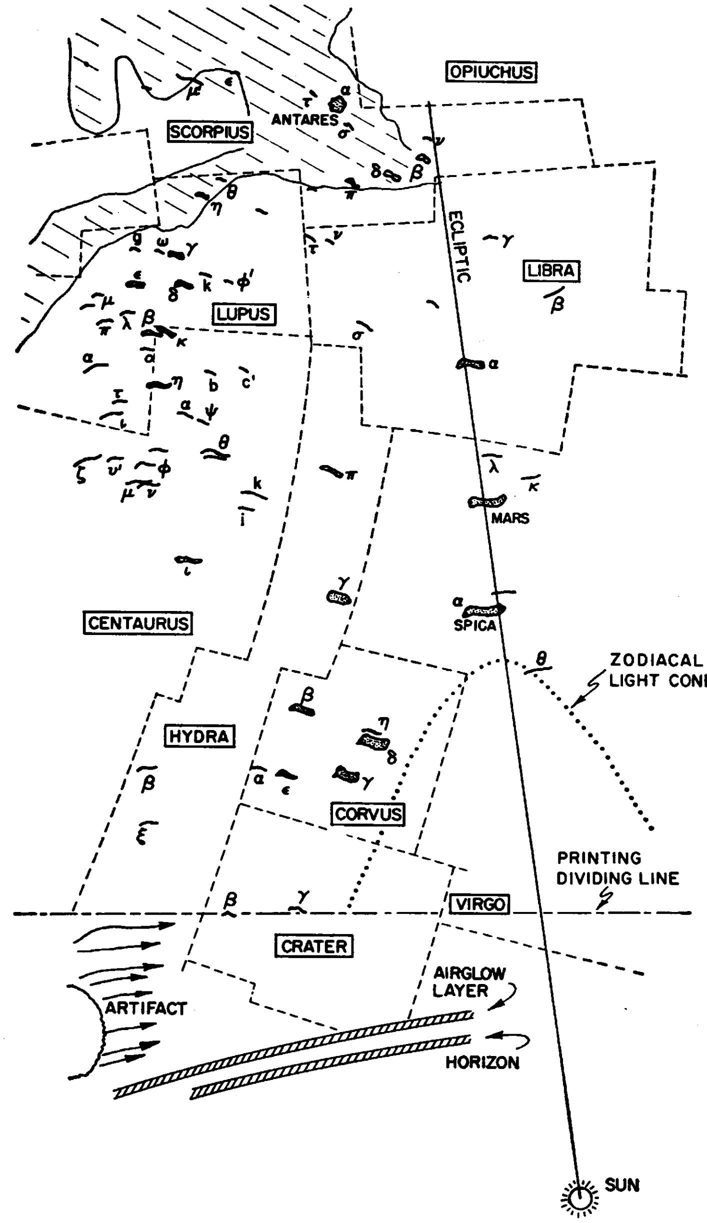


Fig. 3. Photograph of the airglow viewed in profile from above. This was one of the exposures taken in MA9. The 30-second $f/1$ exposure shows the airglow in spite of a factor of about 10 in attenuation through the Mercury window. The lightning flashes in this picture are on the distant horizon and the sky is moonless.

Fig. 4 (opposite page, top left). Print of frame 7, from Gemini V experiment. The upper portion of the print has been given 40 times the exposure of the bottom. The quality of the bottom portion is degraded by a developing artifact, but the airglow layer and the horizon lit by twilight can be clearly seen. The zodiacal light is centered on the ecliptic. In the original negative, the zodiacal light can be seen as far as the star α Libra. Because of the manner in which the field is exposed, the top and bottom of the frame have less exposure than the center.

Fig. 5 (opposite page, top right). Sketch of the pertinent features of the photograph of Fig. 4.

Fig. 6 (opposite page, bottom). Print of frame 15, from Gemini V experiment. The contrast in this picture is enhanced by photographic reproduction but the exposure in the gegenschein area is quite evident on the original negative. Two photographs were obtained of this area and both show the enhanced exposure in the gegenschein direction.



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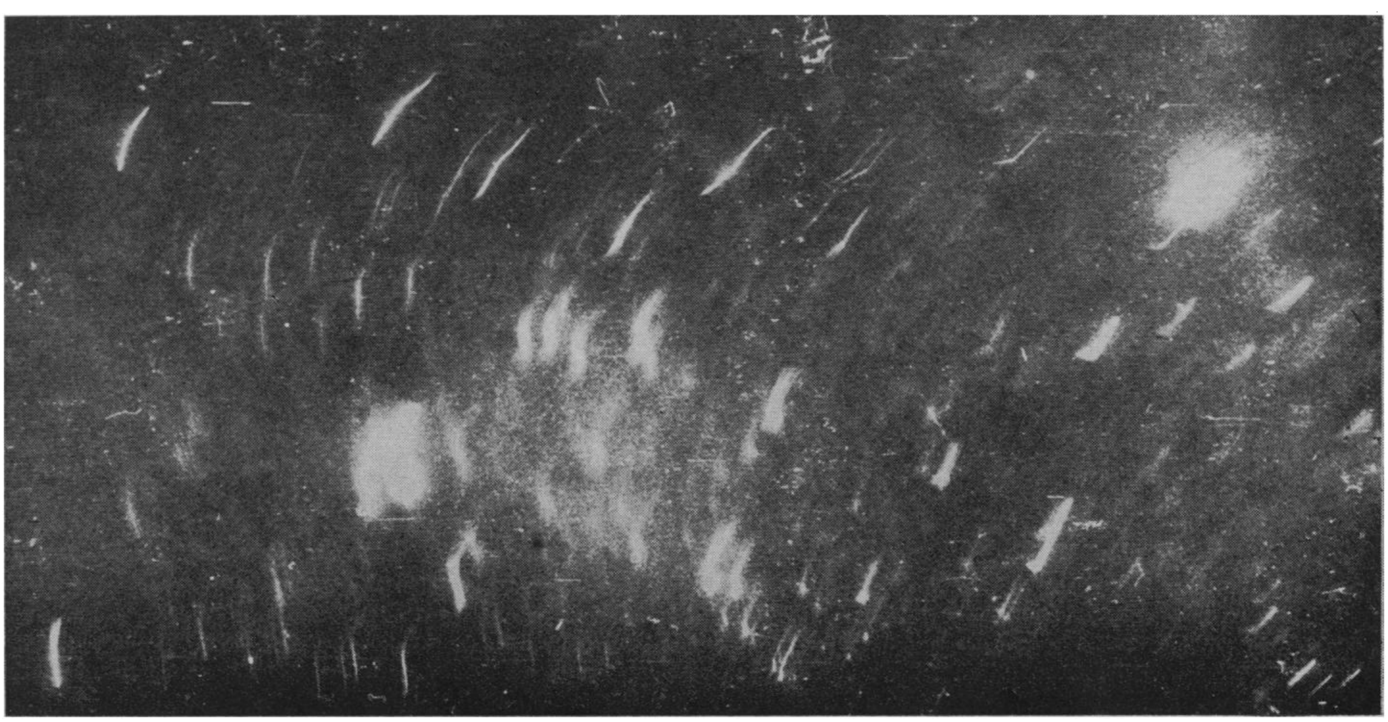

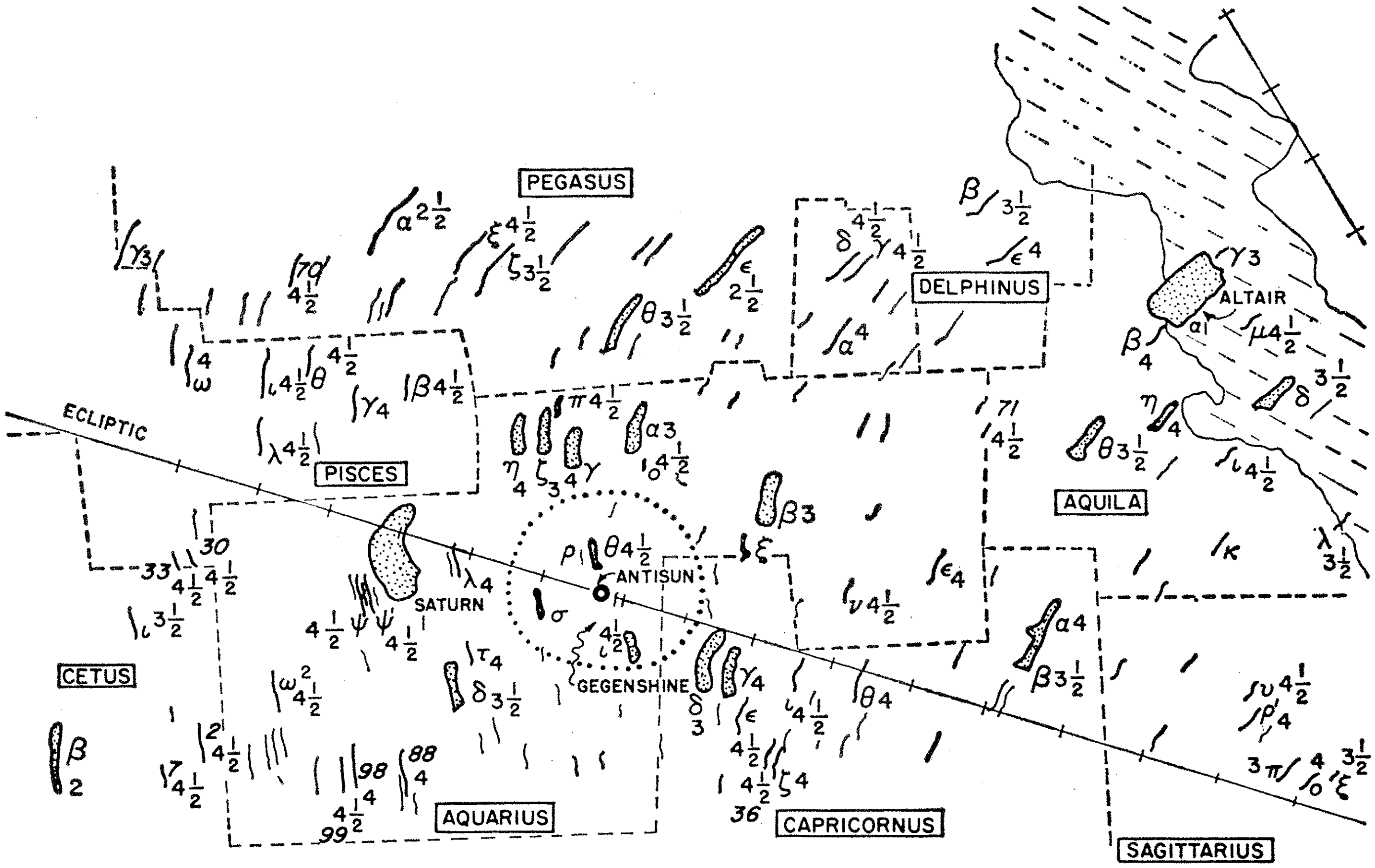

Fig. 7. Drawing of the star field for Fig. 6. The bright stars are identified and their visual magnitudes are written next to the Greek letters. For example, θ Aquarius is fourth magnitude. Saturn and Altair are first magnitude. Sixth magnitude stars are identified in spite of the motion during this 160-second exposure.

maneuvered to the Constellation Grus, where α and β Grus and Fomalhaut supplied the reference field for the reticle, and the camera was pointed in the correct direction to center the position opposite the sun in the field. In this position, the spacecraft motions were stopped as far as possible (using the reference stars) to attempt an inertial fix. In all, 17 exposures were taken and, of these, three are of special interest. Frames 1 through 5 are properly exposed but show that the twilight was so bright it obscured the zodiacal light. Frame 7 shows the zodiacal light with an 81-second exposure. Also visible in this negative is the illuminated horizon, with the airglow layer showing in profile above it. It represents approximately the smallest elongation at which zodiacal light may be studied without external occulting, and this elongation is 16°.

There is a possibility of studying this photograph quantitatively for airglow brightness and zodiacal light but this appears very difficult because of an artifact introduced during development at the Manned Spacecraft Center. Figure 4 is a print of the zodiacal light, frame 7. The bottom portion of the negative was printed with a ratio of 1/40 the exposure of the top part. This brings out the earth limb and airglow layer which show in spite of the artifact. The airglow layer viewed in profile has about the same surface brightness as the zodiacal light at 16° elongation. The zodiacal light at this elongation (*3*) is 4×10^{-12} of the sun's surface brightness. The ratio of the profile to zenith brightness of the airglow is about 40, so the inferred zenith airglow brightness is 10^{-13} of the sun's surface brightness. This is about three times brighter than the average nighttime airglow but within the range of variation commonly observed. Figure 5 is a drawing identifying the features of the photographs of Fig. 4.

Frames 8 and 9 show exposure of the film by thruster light, and frames 10 through 14 show excessive motion of the star field. However, frames 15 and 16 represent good celestial holds and both of these negatives appear to show the gegenschein. Its center is about halfway between θ and ι Aquarius and it appears to have an angular size of about 10°. It is within a few degrees of being in the direction opposite to the sun. Its brightness is estimated as $5 \pm 4 \times 10^{-14}$ of the sun's surface brightness. Figure 6 shows the star field photographed in the gegenschein experiment. Stars to sixth magnitude may be identified. This is a print of frame 15. Figure 7 is a drawing representing the star field shown in Fig. 6. The direction opposite to the sun should be the direction of the gegenschein if it is produced by back scattering of sunlight by dust. There is no evidence of a westerly displacement which might be expected if the gegenschein resulted from a cometary-like dust tail of the earth.

E. P. Ney
W. F. Huch
School of Physics and Astronomy, University of Minnesota, Minneapolis

References and Notes

1. Although lightning is an important contributor and cerenkov light from cosmic ray air showers is a detectable source, we confine ourselves here to slowly varying sources of light.
2. F. C. Gillett, W. F. Huch, E. P. Ney, G. Cooper, *J. Geophys. Res.* **69**, No. 13, 2827 (1964).
3. F. C. Gillett, W. A. Stein, E. P. Ney, *Astrophys. J.* **140**, No. 1, 292 (1964).
4. We would like to express our congratulations and appreciation to Astronauts Cooper and Conrad for their excellent performance of this experiment in spite of the great odds imposed by the many problems of their flight. We thank the alternate flight crew, Neil Armstrong and Elliot See, and R. Mercer for their help in planning the spacecraft maneuvers. The care and attention of J. Stoddart for the construction and testing of the flight camera was essential to the success of the experiment.

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