Reports

Far-Ultraviolet Photography of Orion: Interstellar Dust

Abstract. *Wide-angle photography of Barnard's Loop Nebula suggests that the nebular emission is much less intense in the 1230- to 2100-angstrom spectral region than in the 2200- to 3200-angstrom near-ultraviolet region. This contrast may be due to differences in the absorption or scattering properties of the interstellar grains in these two wavelength regions.*

Matter distributed between the stars consists of extremely dilute gas (largely hydrogen) plus "dust" of uncertain composition. This dust reveals itself by reddening the light of distant stars, absorbing (or scattering) blue radiation most strongly. Study of the effects of the dust on ultraviolet stellar radiation has led to the discovery (*1*) of a second component of the interstellar dust; we now report an experiment that provides new information on the properties of this component.

At 0205 (M.S.T.), on 21 September 1969, an Aerobee rocket carried an electronographic camera developed at the Naval Research Laboratory (NRL) (*2*) to an altitude of 161 km. During the 3.5-minute operation of the payload, 30 7-second exposures of five regions in the constellations Orion and Monoceros were obtained. Photographs of the three regions that include portions of Barnard's Loop (a huge nebular shell around the central portion of Orion) are discussed here. Photographs of the two other regions and the results of densitometry of all the star images are in preparation.

The importance of Barnard's Loop Nebula in the study of interstellar dust has resulted from the work of Henize and his collaborators (*3*). Visible light emitted by the Loop is predominantly thermal reradiation of energy whose ultimate source is hot stars, but the nebula's strong near-ultraviolet radiation and the differences between its visible and ultraviolet morphologies require another explanation. Henize believes that the nebula contains quantities of dust, in addition to the hot gas, and that this dust scattered the ultraviolet radiation of the hot Orion stars nearly 90° into his camera (which was operated by Gemini astronauts Conrad and Gordon). We wished to see if this property of strong scattering persisted into the far ultraviolet, where the nature of the particles causing the scattering is different (*1*). We find that the property does not persist. This may permit conclusions regarding the nature of the new component of the interstellar dust.

We used a rather conventional Schmidt camera (Fig. 1, the corrector plate is not shown) of focal ratio 1, entrance aperture 5.1 cm, with a field of view 25° in diameter, and a mirror coated with aluminum plus magnesium

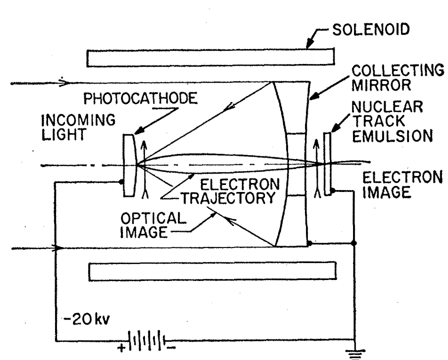


Fig. 1. An electronographic camera similar to the one flown. The latter had a Schmidt optical system with a calcium fluoride corrector plate placed in the incoming beam behind the photocathode. Ultraviolet light of shorter wavelength than 1230 Å passes through this corrector plate and is focused at the cesium iodide photocathode, where those photons of shorter wavelength than about 2100 Å are able to efficiently release electrons. The 20,000-volt potential difference between the photocathode and the film accelerates the electrons into the film; they are focused by the magnetic field of the solenoid.

fluoride. For efficient use of the limited time available on a sounding-rocket flight, electronographic, rather than photographic, recording is employed. The ultraviolet image is formed on a cesium iodide photocathode that is maintained at 2×10^4 volts negative potential with respect to the film. The released photoelectrons are focused onto nuclear-track film by a magnetic field produced by the surrounding solenoid, and each electron has sufficient energy to cause blackening of an emulsion grain. The wavelength sensitivity of the system is set on the long wavelength end by the decline in sensitivity of the cesium iodide photocathode toward 2100 Å. At the short wavelength end, the calcium fluoride corrector plate provides a sharp cutoff near 1230 Å; this is vital in excluding the strong geocoronal Lyman-α (1216 Å) nightglow, which might otherwise fog the photographs. The section of the rocket housing the instrument is vacuum-sealed and is evacuated on the launch pad. Pumping out the camera for several hours prior to flight ensures that the instrument will reach a high vacuum within moments after the door opening at altitude. Otherwise, outgassing of the film and camera could cause breakdown of the high voltage and fog the film.

Figure 2 (*4*) sketches the constellation Orion; the sizes of the images indicate the visible-light brightness of the stars for comparison with the far-ultraviolet images seen in our photographs. The optical position of Barnard's Loop is also shown, and the positions of the three regions photographed are indicated.

Figure 3 is a photograph of the northern part of Orion, obtained in the present experiment (target 1, frame 28). The most striking indication that this is indeed a far-ultraviolet photograph is the complete absence of the star α Orionis (Betelgeuse), which, to the eye, is the brightest star in the entire constellation. Betelgeuse is a cool supergiant star, red in appearance, and not expected to emit much ultraviolet light. A number of the stars in the photograph may be identified through reference to Fig. 2. All of the images in all of the photographs occur at the positions of known O, B, and early A type (hot) stars. No unusual image occurs near the Orion belt, where one group (*5*) reported a broad intense source in 1958. Heath (*6*) has revived the idea that such sources may be real, and it is therefore unfortunate that our photographs do not cover any region where he has reported strong ultraviolet signals.

It is clear by comparing Fig. 2 with Fig. 3 that we detect no sign whatsoever of Barnard's Loop. Traces of some diffuse (rather than point) images do appear in other locations, but these are all entirely spurious. The streak in the northeast, the small smear northwest of the belt, and the visibility of the western edge of the field of view are all produced by very weak residual high-voltage discharge. This is proved by the fact that, when other star fields are photographed (see Figs. 4 and 5), the "nebulae" appear in the same location relative to the edge of the field. In none of the photographs obtained is there any evidence for the presence of true nebulosity. Tests for this included the examination of prints from superpositions of several separate frames of the same star field.

Figure 4 is a photograph (target 4, frame 7) of the central and southern portion of Orion. A discharge streak makes the search for Barnard's Loop difficult, but the result is still negative. Most of the star images fall on another part of the photocathode than in Fig. 3, and image quality is not as high. Some of the images (42 and υ Orionis) are of the right density to reveal residual chromatic aberration in the optics.

Figure 5 (target 5, frame 4) was obtained near the end of the flight; so the stars are slightly dimmed owing to Schumann-Runge (molecular oxygen) absorption caused by Earth's atmosphere. In fact the image of β Canis Majoris (east of Orion in Fig. 5) was obtained with that star actually below the horizon as viewed from the ground, but despite the slight loss of sensitivity caused by this absorption a clear view of the Loop region was obtained, and again no trace of the nebula was seen.

In each photograph, the region of the Orion Nebula is seen. The position is entirely dominated by the Trapezium stars (θ Orionis); and the image (especially as seen in Fig. 3) is essentially, if not entirely, starlike. That the hot Trapezium stars dominate the cooler nebula is unsurprising. The limited angular resolution of our camera (about 2 minutes of arc), prevented detection of possible nebular emission from regions very close to the exciting stars, or of the nebulosity around 42 Orionis and HR 1923 that was reported by Stuart (*7*).

In order to draw any conclusions concerning the properties of the dust particles, we must compare the relative brightness of the Loop as observed in the near ultraviolet by Henize and in the far ultraviolet by us. We need information on the relative sensitivities of the two systems, and also the background (noise) levels encountered. Complete data on this have not been published by Henize, and in our own case only a rather crude guess at the sensitivity is possible. Nevertheless, we hope to show that the difference in brightness of the Loop between the two spectral regions is so gross that little doubt will exist regarding its reality.

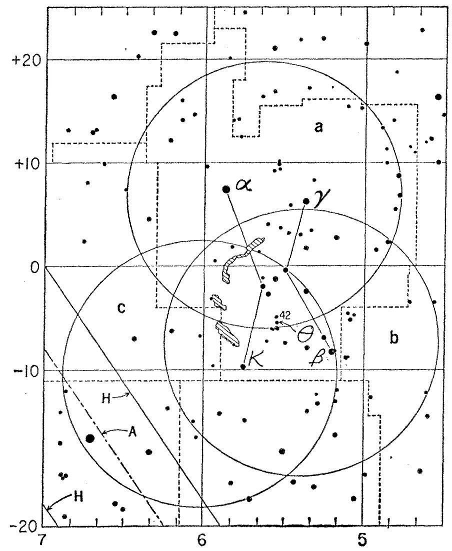


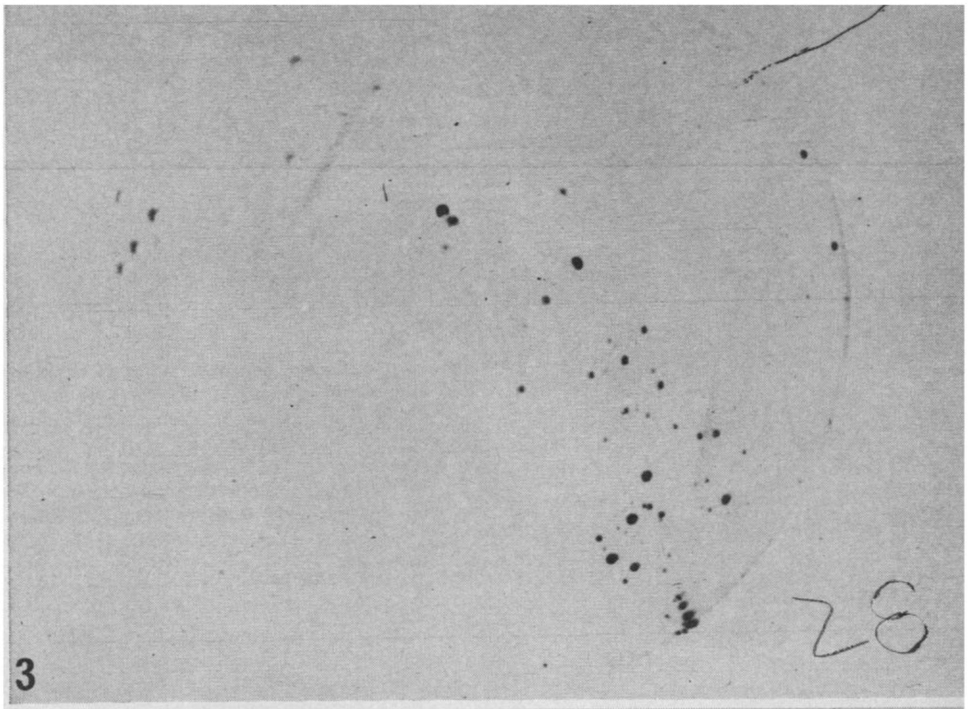
Fig. 2. The constellation Orion, adapted from the *Atlas Coeli*, showing (large circles) the regions *a*, *b*, and *c* that were photographed and that are shown in Figs. 3, 4, and 5, respectively. The position, in visible light, of Barnard's Loop Nebula is indicated by the shading. The straight lines (*H*) are the positions (at midflight) of the horizon, as viewed from the ground and from the rocket. The dashed straight line (*A*) is the position of the 97-km altitude airglow layer (*19*) as viewed from the rocket.

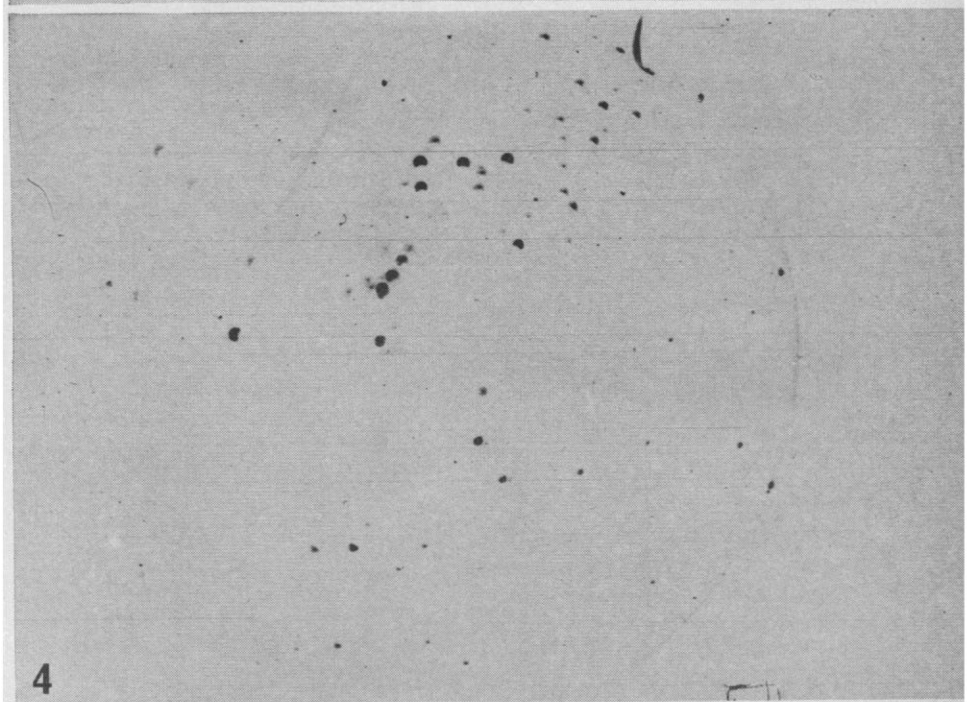
If we err in our discussion, we wish to err in attributing too great a sensitivity to the system of Henize and too low a sensitivity to our own system. If despite such conservative assumptions a difference is found to exist, we may be confident that it is real. The sensitivities that we adopt are shown in Fig. 6, together with theoretical spectra of hot stars (*8*). In our own case (NRL), the efficiency is the product of a typical mirror reflectance, corrector plate transmission, and photocathode sensitivity. A test plate of the actual mirror coating was measured over the wavelength range of 1200 to 1650 Å, to show that it was at least as reflective as the typical value used. The corrector plate transmission was measured over the wavelength range of 1230 to 1650 Å. The absolute quantum yield of a test plate of the photocathode coating was measured over the wavelength range of 1000 to 2200 Å. Cesium iodide photocathodes are hygroscopic and they decrease in sensitivity if exposed to humid air. However, the photocathode we used was kept in vacuum, nitrogen atmosphere, or a desiccated air atmosphere, from manufacture until flight, except for at most 20 minutes during payload preparation. We have found that cesium iodide photocathodes kept in a desiccator deteriorate negligibly over a period of several months. The limiting magnitude recorded by our system (about eighth magnitude B stars) also indicates that our system reached the expected sensitivity since it is somewhat fainter than the anticipated limiting magnitude. Eventually, of course, densitometry of star images of known ultraviolet brightness (and of HD 34989 and HD 35166, used as comparison standards by Henize) will provide an independent calibration of the two systems.

Henize's exposure times were 2 minutes, 17 times longer than ours, but his camera had a focal ratio of 3.3 which cost him a factor of 11 in extended-image sensitivity relative to us. The net time and camera speed factor is, therefore, 1.6 in favor of Henize. He indicates (*3*) that his system's sensitivity is flat for constant incident intensity in units of ergs per angstrom; this means that his quantum efficiency varies approximately as the reciprocal of the wavelength ($1/\lambda$). He uses a fast photographic film in conjunction with a lens system, and we guess the quantum efficiency of this combination to be 0.33 percent at 4900 Å. To be unquestionably conservative, however, we arbitrarily multiply this quantum efficiency by a factor of 10. The final result, plotted in Fig. 6, is our very conservative guess at the efficiency of Henize's system relative to our own.

We must now discuss the question of background, for it could be contended that however high our sensitivity we did not see the Loop simply because we had a noisy system. Henize required a film fast in the ultraviolet; such film is generally noisy just because of its relatively high sensitivity. Also, and more importantly, Henize (because the sensitivity of his system extended into the visible) encountered a rather strong background caused by starlight. This can be proved from his figure 1 (*3*) by comparing the general background near the Loop with the darkness present out of the frame, or on the Gemini space capsule. In contrast, our system employed a slow, fine-grain film having a very low inherent noise level. The noisiest item in our system is the photocathode as discussed above. Inspection of Figs. 3, 4, and 5 shows that in a 7-second exposure the eastern edge of the field of view cannot be detected. In a superposition of eight frames of another star field (not illustrated), this edge can be distinguished faintly, but with certainty. We conclude that for purposes of finding Barnard's Loop, our noise level is probably no worse than that of Henize.

We accept the contention of O'Dell, York, and Henize (*3*) that scattered ultraviolet radiation from hot stars is responsible for the signal they detected from Barnard's Loop. Models of the wavelength dependence of the emergent photon intensity of typical hot stars, developed by Mihalas, Morton, Adams, and Hickok (*8*), are given in Fig. 6. Some evidence exists (*9*) that stars may not actually be as bright in the far ultraviolet as this theory suggests, but this is not certain. We have multiplied the photon intensities given by the hot star models by the relative sensitivities of the two systems shown. We have dropped Henize's sensitivity to zero at 3600 Å in accord with his view that his Loop image is largely formed by near-ultraviolet rather than by optical radiation. The result (which is not strongly affected by this last adjustment) is that, integrated over wavelengths, the





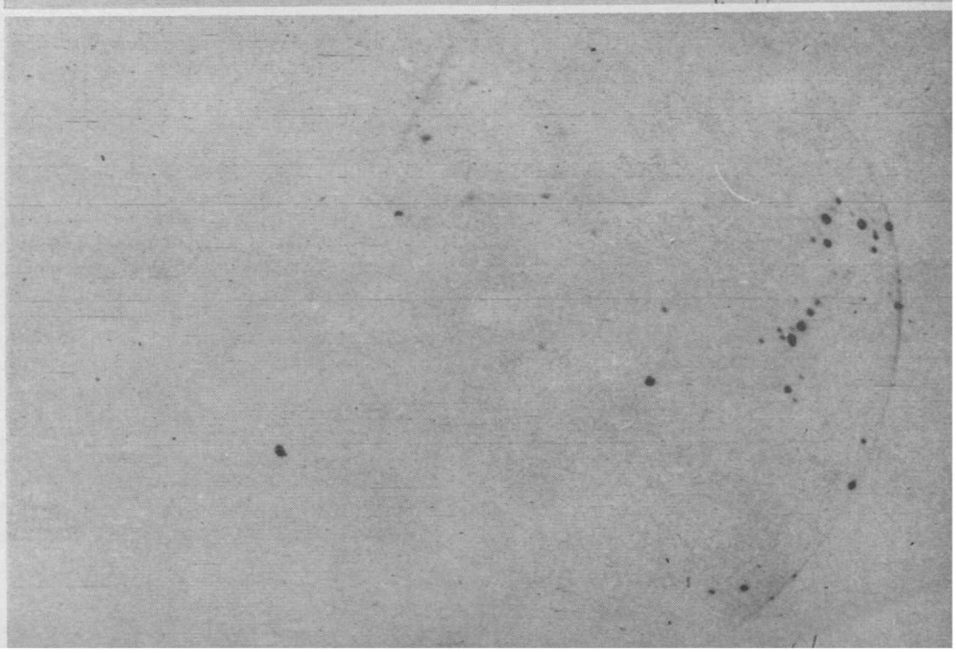


Fig. 3. Far-ultraviolet (1230 to 2000 Å) photograph of the northern portion of Orion. The western edge of the 25° field of view is distinguishable. The Belt of Orion is prominent, and the Sword is clearly seen at the bottom of the picture. Betelgeuse and Barnard's Loop Nebula are absent. The streak above the center of the field is an instrumental effect.

Fig. 4. The central and southern portion of Orion. The instrumental streak (see Fig. 3) falls near the expected position of Barnard's Loop. Chromatic aberration is present in some star images, and particularly in that of θ Orionis, the cluster of hot stars which excites the Orion Nebula. The far-ultraviolet radiation of θ Orionis dominates that of the nebula, which was not detected.

Fig. 5. This photograph of the southeast part of Orion was made late in the flight and therefore from a lower altitude; atmospheric absorption dims the star images slightly. The Barnard's Loop region is again devoid of nebular images.

two systems should obtain roughly equal signals from grayly scattered (wavelength independent) "hot" starlight. In view of the clearly stronger Loop image obtained by Henize, and our very conservative assumption concerning his sensitivity, we conclude that the intensity of Barnard's Loop Nebula in Orion is substantially lower in the 1230- to 2100-Å far-ultraviolet region than in the 2200- to 3600-Å near-ultraviolet region, and hence conclusions regarding the character of the scattering particles should follow.

A simple and valuable check uses the star images to verify our conclusions about the actual relative sensitivities of the two systems. A camera will obtain images of density L for stars according to the expression

$$L \sim \frac{A}{a} qkTe$$

where A is the clear aperture, a is the size of the star image, q is the quantum efficiency, k is the system transmission, T is the duration of observation, and e is a factor proportional to the brightness of the stars at the wavelength observed. For nebular images, however, the density l is given by

$$l \sim Tqke/f^2$$

where f is the focal ratio of the camera, and the nebula is assumed to have a starlike spectrum. Then in comparing the Henize (H) and present (P) systems, we have

$$\frac{(l/L)_P}{(l/L)_H} = \left(\frac{a_P}{a_H}\right)\left(\frac{A_H}{A_P}\right)\left(\frac{f_H}{f_P}\right)^2 = 2.4$$

Inspection of stars in the photographs shows that both systems reached about the same limiting magnitude; so we can conclude that the ability of the present system to detect a reflection nebula is about twice that of the Henize system. This is not quite as strong a conclusion as we arrived at above and suggests that Henize's system is actually rather more efficient than we suggested, or our own system is less efficient—perhaps both. Nevertheless, it is clear that we should have seen the nebula, and we did not. We suggest that the nebular intensity in the far ultraviolet is less than one-third of that reported by Henize at longer wavelengths.

The interpretation of our result in the context of the extinction (by which we mean scattering plus absorption) properties of the interstellar dust is aided by Fig. 7, where the system sensitivities from Fig. 6 are placed in a diagram of the interstellar extinction ("reddening") law. The extinction (in stellar magnitudes) between each wavelength λ and the (nominal effective) wavelength of the V (visual) magnitude [of the familiar Ultraviolet-Blue-Visual (UBV) photometric system], relative to the extinction that occurs between the B (blue) and V wavelengths, is plotted against inverse wavelength. The ordinate, to clarify, is logarithmic, with large values indicating high extinction. Reddening curves such as those illustrated are obtained by comparing the intensity distribution in the spectra of reddened and unreddened stars. The plot against inverse wavelength is conventional because a nearly straight line results in the visible portion of the spectrum, as may be seen in Fig. 7. In the far ultraviolet, Boggess and Borgman (*1*) showed that the extinction continues to rise instead of falling off as Mie theory (*10*) and simple models predict. Stecher (*1*), with much better wavelength resolution, detected the bump at 2200 Å (4.5 μ^{-1}) and suggested that it was due to transfer of π electrons from the valence to the conduction band in graphite. The more conventional view that the interstellar grains are ices, including H_2O ice, has been further undermined by the work of Danielson, Woolf, and Gaustad (*11*) and of Knacke, Cudaback, and Gaustad (*12*), who searched for and did not find the 3.07-μ infrared resonance of H_2O ice.

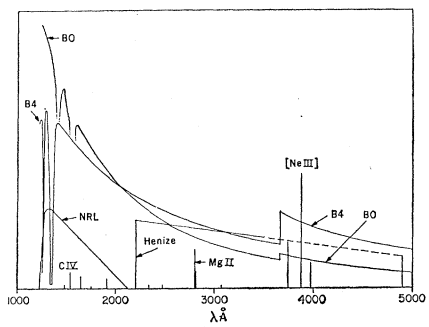


Fig. 6. The adopted relative quantum efficiencies (linear scale) of our system (*NRL*) and that of *Henize* are platted against wavelength. In order to be conservative, we have adopted an efficiency for Henize's system that we believe to be ten times higher than its actual efficiency. Theoretical spectra (*8*) of the type of hot stars *B4, B0*) believed to be the ultimate source of the ultraviolet signal from Barnard's Loop Nebula are also shown (with a linear intensity scale), and a few nebular lines (*C IV, Mg II, Ne III*) are also indicated for reference. Efficiency times the photon flux is seen to give roughly equal image intensity expected for us and for Henize, contrary to observation.

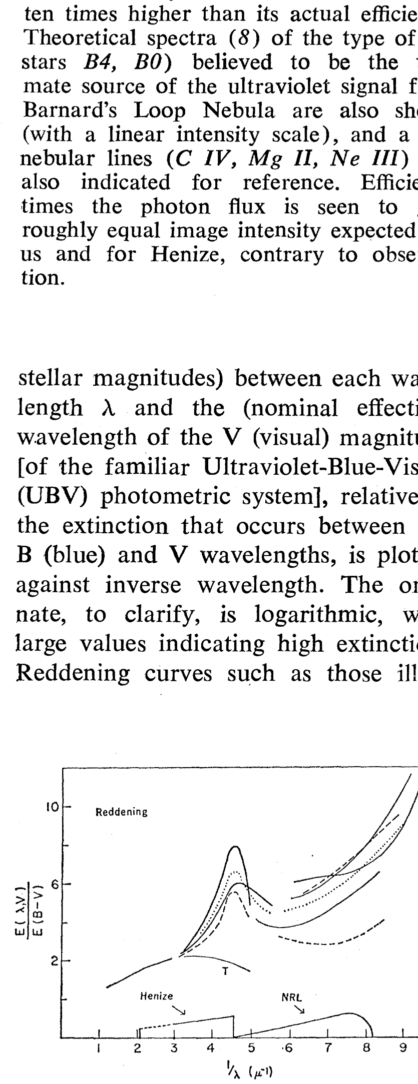


Fig. 7. Experimental interstellar reddening curves (*1*) demonstrate the relative ability (on a magnitude scale) of interstellar "dust" particles to remove light from a directed beam of white radiation. One theoretical Mie-type curve (*T*) is also shown. Henize believes that this dust scattered near-ultraviolet stellar radiation to his detector (sensitivity curve shown); we show that comparable far-ultraviolet scattering to our detector (*NRL*) does not occur. The high far-ultraviolet reddening thus must be caused by absorption or small-angle scattering rather than by large-angle scattering.

The ultraviolet extinction curves are a number of preliminary measures for different star pairs obtained by Bless and Savage (*1*) using the University of Wisconsin and National Aeronautics and Space Administration's Orbiting Astronomical Observatory. The rise in extinction at shorter wavelengths beyond the 2200-Å bump is apparently due to a previously unknown component of the interstellar dust. It is clear from Fig. 7 that our experiment is sensitive to light scattered by this new component, while that of Henize responds to light scattered by the "graphite." The radiation observed by Henize cannot be due to the "bump" extinction, for this is presumed to be caused by absorption rather than by scattering. For each ultraviolet star pair, the far-ultraviolet extinction is at least as great as the near-ultraviolet extinction away from the "bump," and for most it is as great as the linear extrapolation of the near-ultraviolet extinction into the "bump" wavelength region. Then, because we have concluded above that the intensity of the Loop is substantially less in the far ultraviolet than in the near ultraviolet, we now may conclude that a substantially smaller portion of the far-ultraviolet extinction is made up of large-angle scattering than is the case in the near ultraviolet. This is our fundamental conclusion from our data. We finish by discussing briefly the possible implications that this conclusion has regarding the nature of the "far-ultraviolet" grains.

Because these grains have their effect on the shorter-wavelength photons, it is slightly tempting to refer to them as "small" grains. The major contribution of the work of Bless and Savage (*1*) is that it shows (Fig. 7) that the amount of the far-ultraviolet extinction is variable from star to star. Looking at the figure, we can easily imagine that greater or lesser amounts of a second wavelength-dependent extinction component are combined with a Mie-type falloff in extinction (marked T in the figure) of the larger dust grains. The conclusion that the particles are small is not necessary, however, as a larger size and a lower index of refraction will produce an identical result (*10*). Without meaning to be comprehensive, we shall mention several possibilities. Small iron particles can reproduce most of the observed reddening curve (*13*) and are efficient absorbers rather than scatterers, although it is not immediately clear that they would scatter relatively less at 1500 Å than they (or graphite) would at 2000 Å. The usual objection to iron is that more of it would be required than we expect to exist in any form in interstellar space, if the interstellar material originates in stars. Differential light pressure between large and small dust particles could conceivably produce the separation needed to explain the variability in extinction from star to star, and observations of θ Orionis in the far ultraviolet support this hypothesis (*1*). These measurements show much less than the expected extinction and indicate a large deficiency in the "second component" in this region of high radiation pressure.

Stecher and Donn (*14*) have suggested that the "small particle" extinction might be caused by the dielectric mode of graphite, but this seems difficult to reconcile with the observed variability from star to star. Hydrogen mantles on graphite particles were very tentatively suggested by Bless and Savage (*1*), following the presentation of the idea by Hoyle, Wickramasinghe, and Reddish (*15*). The (presumed) low index of refraction of solid hydrogen accounts for the appearance of the added extinction in the far ultraviolet, and the result of our experiment is easily explained in terms of the strong forward-scattering phase function that would be expected because the photons would go off into Monoceros instead of being scattered at right angles toward the earth. Finally, perhaps the ease of evaporation of a hydrogen mantle could explain the variation of the far-ultraviolet extinction from star to star and its deficiency in such high-flux regions as θ Orionis. Greenberg and others (*16*) have emphasized the great difficulty of cooling grains to the point where a hydrogen mantle can form. A recent discussion of the problem (*17*) suggests that perhaps mantles on SiO_2 are a better possibility; we have not investigated the consistency of this suggestion with our experimental result. Also, Solomon and Wickramasinghe (*18*) have studied the formation of solid H_2 coatings on grains in dense interstellar clouds, and have shown that the process is quite feasible at densities of the order of 10^4 molecules per cubic centimeter. Hence, prior to the formation of the early-type stars, the grains in the Orion dust clouds could easily have acquired H_2 coatings.

Finally, we must consider the possibility (suggested by the variability shown in Fig. 7) that the dust in Barnard's Loop simply does not contain any of the "small grain" (or "H_2 coating") component. One possibility exists for partially testing this. The hot star HD 113167 falls in the same general direction as part of the Loop, and is visible (very faintly) in our photographs (Fig. 3). Because this star probably lies beyond the Loop, its far-ultraviolet intensity should indicate to what extent "small grain" extinction is taking place in this direction in the sky. Although the stars HR 2031 and 2058 are also in the right direction, and were clearly detected, they cannot with certainty be said to lie beyond the Loop dust.

To summarize, we have shown that the far-ultraviolet spectral intensity of the Loop is much less than its near-ultraviolet intensity. If the near-ultraviolet radiation is starlight scattered by dust, the newly discovered dust component that extinguishes far-ultraviolet radiation is either more strongly absorbing or has a much more strongly forward-directed scattering function than the dust component that scatters the near-ultraviolet radiation. These conclusions provide a new constraint on the nature of the newly discovered dust component.

RICHARD C. HENRY

E. O. Hulburt Center for Space Research, Naval Research Laboratory, Washington, D.C. 20390, and *Johns Hopkins University, Baltimore, Maryland 21218*

GEORGE R. CARRUTHERS

E. O. Hulburt Center for Space Research

References and Notes

1. A. Boggess and J. Borgman, *Astrophys. J.* **153**, 566 (1968); T. P. Stecher, *ibid.* **142**, 1683 (1965); G. R. Carruthers, *ibid.* **157**, L113 (1969); T. P. Stecher, *ibid.*, p. L125; R. C. Bless and B. D. Savage, *International Astronomical Union Symposium 36th*, Lunteren (1969).
2. G. R. Carruthers, *Appl. Opt.* **8**, 633 (1969).
3. K. G. Henize, L. R. Wackerling, F. G. O'Callaghan, *Science* **155**, 1407 (1967); C. R. O'Dell, D. G. York, K. G. Henize, *Astrophys. J.* **150**, 835 (1967).
4. A. Becvar, *Atlas Coeli* (Sky, Cambridge, Mass., 1962).
5. J. E. Kupperian, Jr., A. Boggess III, J. E. Milligan, *Astrophys. J.* **128**, 453 (1958); E. T. Byram, T. A. Chubb, H. Friedman, *ibid.* **139**, 1135 (1964).
6. D. F. Heath, in *Significant Accomplishments in Science* (NASA SP-195, Washington, D.C., 1969).
7. F. E. Stuart, *Astrophys. J.* **157**, 1255 (1969).
8. D. Mihalas and D. C. Morton, *ibid.* **142**, 253 (1965); F. R. Hickok and D. C. Morton, *ibid.* **152**, 203 (1968); T. F. Adams and D. C. Morton, *ibid.*, p. 195.
9. C. B. Opal, H. W. Moos, W. G. Fastie, M. Bottema, R. C. Henry, *ibid.* **153**, L179 (1968).
10. N. C. Wickramasinghe, *Interstellar Grains* (Chapman & Hall, London, 1967).
11. R. E. Danielson, N. J. Woolf, J. E. Gaustad, *Astrophys. J.* **141**, 116 (1965).
12. R. F. Knacke, D. D. Cudaback, J. E. Gaustad, *ibid.* **158**, 151 (1969).
13. C. Schalen, *Ark. Astron.* **4**, No. 1 (1965).
14. T. P. Stecher and B. Donn, *Astrophys. J.* **142**, 1881 (1965).
15. N. C. Wickramasinghe and V. C. Reddish, *Nature* **218**, 661 (1968); F. Hoyle and N. C. Wickramasinghe, *ibid.* **214**, 969 (1967).
16. J. M. Greenberg and T. de Jong, *ibid.* **223**, 251 (1969).
17. P. A. Feldman, M. J. Rees, M. W. Werner, *ibid.* **224**, 752 (1969).
18. P. M. Solomon and N. C. Wickramasinghe, *Astrophys. J.* **158**, 449 (1969).
19. T. P. Stecher, *Geophys. Res.* **70**, 2209 (1965).
20. We thank Aerojet-General Corporation for pointing the rocket precisely; H. W. Merchant for technical support; and Drs. T. A. Chubb and H. Friedman for suggestions and criticism. Dr. N. Paul Patterson supervised the rocket. One of us (R.C.H.) was partly supported by NSF grants GP-7086, 8313, and 11855. The E. O. Hulburt Center for Space Research is partially supported by NASA.

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Carbon Dioxide Clathrate in the Martian Ice Cap

Abstract. *Measurements of the dissociation pressure of carbon dioxide hydrate show that this hydrate ($CO_2 \cdot 6H_2O$) is stable relative to solid CO_2 and water ice at temperatures above about 121°K. Since this hydrate forms from finely divided ice and gaseous CO_2 in several hours at 150°K, it is likely to be present in the martian ice cap. The ice cap can consist of water ice, water ice + CO_2 hydrate, or CO_2 hydrate + solid CO_2, but not water ice + solid CO_2.*

On the basis of the infrared radiometer experiment of Mariner 7, Neugebauer *et al.* (*1*) have reported that the temperature of the ice cap of Mars is 153°K. On the basis of the radio occultation measurements from Mariner