THE ASTROPHYSICAL JOURNAL, 204:L25–L28, 1976 February 15

THE POLARIZATION OF THE INFRARED SOURCE CRL 2688 (THE EGG NEBULA)

STEPHEN J. SHAWL
University of Kansas
AND
MASSIMO TARENGHI*
Steward Observatory
Received 1975 October 1; revised 1975 November 20

ABSTRACT

Polarization observations of CRL 2688 (the Egg Nebula) show the polarization to vary from 40 percent at 3800 Å to 52 percent near 9400 Å. Observations of both components are also given. Polarization and reddening models seem to indicate graphite rather than silicate particles, with a column density of $\sim 10^9$ cm^{-2}.

Subject headings: infrared: sources — nebulae: general — polarization — stars: individual

I. INTRODUCTION

The properties of the infrared source CRL 2688, also called the Egg Nebula, have recently been discussed by Ney (1975) and Ney *et al.* (1975), and by Crampton, Cowley, and Humphreys (1975). It is an object consisting of two components of visual magnitude 13.5 and 15 separated by $\sim 8''$. Found in the course of the Air Force Cambridge Research Laboratory infrared rocket survey, the infrared source, which is prominent at 10 and 20 μ, is about 2″ across, and is situated between the components of the visual double object (Ney *et al.* 1975). Each component has the spectrum of a F5 Ia star (Crampton, Cowley, and Humphreys 1975), with some peculiarities such as C_3 in absorption and [S II] and C_2 in emission. The object was found to be highly polarized by Cooke, Warner, and Ney with a simple apparatus. Impressive photographs in two orthogonal polarimetric planes were obtained at Steward Observatory by Cromwell and Strittmatter (Ney 1975). Ney (1975) and Ney *et al.* (1975) point out that observations by Hudson and Stein with an "improvised" photopolarimeter gave a polarization of 43 percent at visual wavelengths with an approximately constant value from 4000 to 9000 Å. The purpose of this *Letter* is to present new observations of polarization from 3700 to 9400 Å; observations of each component are also presented. The observations are interpreted in terms of scattering from dust grains.

II. OBSERVATIONS

The observations were made with a dual-channel half-wave plate polarimeter coupled to a NOVA computer (Gehrels and Teska 1960; Serkowski 1974). The 1.5 m telescope at the Catalina Station of the Lunar and Planetary Laboratory at the University of Arizona has been used during the different moonless nights of 1975 January 13, 14, and 15, May 6, and June 5 and 6, with seeing reaching 1″. The inverse effective wavelengths of the filters are U (2.71), B (2.25), G (1.90), R (1.14), and I (1.05) (Coyne, Gehrels, and Serkowski 1974), if colors $(U - B) = 1.15$ and $(B - V) = 1.10$ (Ney *et al.* 1975) are assumed. The results of the observations are given in Table 1, which gives the percentage polarization and position angle in each filter for the entire object, using a diaphragm of 15″ centered between the two components, and for the individual components with a diaphragm of 10″ (faint component) and 5″ (bright component) centered on the two positions of highest brightness.

The wavelength dependence of the polarization for the data listed in Table 1 and plotted in Figures 1 and 2 is similar to that found in reflection nebulae (see, for example, Zellner 1973). Within the errors of measurement no substantial variation of polarization has been noted in the 5-month time interval or when using different apertures. There is some evidence of differences in the polarization between the north and the south components, as shown in Figure 2. A detailed study of the fine polarization structure requires more observations with high spatial resolution. In the following dis-

TABLE 1

POLARIZATION RESULTS

Parameter	Total Nebula	North Component	South Component
A* (arcsec)	15	5	10
P_U	37.3±3.1	40.6±3.6	50.8±15.2
P_B	42.7±0.2	43.8±0.5	48.0±0.5
P_G	44.9±0.3	46.2±0.3	49.0± 0.6
P_R	49.9±0.4	51.1±0.7	54.5±0.9
P_I	49.0±0.5	50.9±1.7	53.1± 1.8
θ_U	108	110	120
θ_B	108	107	110
θ_G	108	106	111
θ_R	110	108	112
θ_I	111	109	111

* Diaphragm size.

* On leave from Laboratorio Fisica Cosmica e Tecnologie Rel., Milano, Italy.

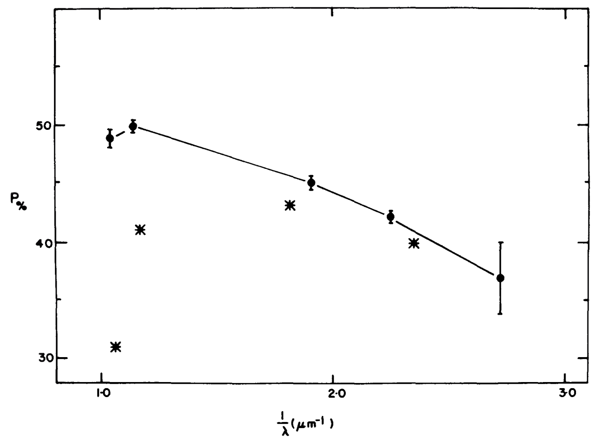

FIG. 1.—Wavelength dependence of polarization for the total nebula. The aperture was 15″. Dots are the present data, while stars represent the data of Hudson and Stein (Ney *et al.* 1975).

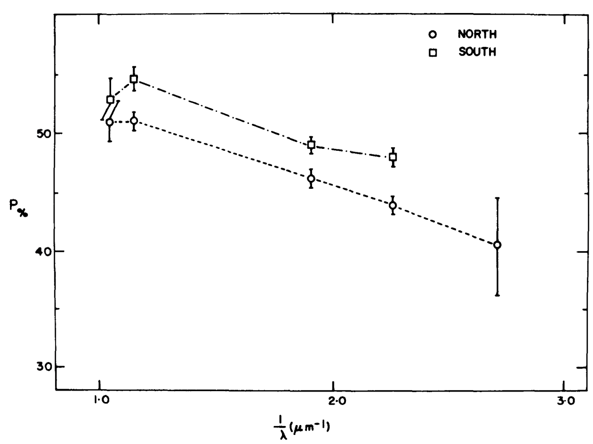

FIG. 2.—Wavelength dependence of polarization for the two components of the nebula.

cussion only the measurements for the total nebula will be taken into consideration.

III. DISCUSSION

Ney *et al.* (1975) suggest a model consisting of a star surrounded by a toroidal disk such that the direct radiation from the star is obscured but allowing illumination of two optically thin clouds on either side of the disk. This model is assumed for the present discussion. The model is closely approximated by the double sector used by Kruszewski, Gehrels, and Serkowski (1968) and by Shawl (1975) in calculating the polarization and reddening from asymmetric circumstellar clouds. The geometry is similar to a figure eight of revolution about the long axis such that the axis of revolution is in the plane of the sky. The details of the model calculation are given by Shawl (1975). The polarization of *scattered* light from such a model (i.e., the direct light from the star is blocked) is about 20 percent for small silicate and graphite particles. The degree of polarization can be increased to the observed value of about 50 percent by confining the scattering to angles near 90°; the effect on the geometry is a decrease in the geometric depth of the cloud. Figure 3 shows the resulting polarization for various cloud depths (depth along the line of sight). From Figure 3 we conclude that the ratio of cloud length (the cloud size in the plane of the sky) to cloud depth is greater than 10.

The wavelength dependence of polarization for clouds composed of silicate and graphite particles with a single particle size is shown in Figures 4 and 5. No silicate

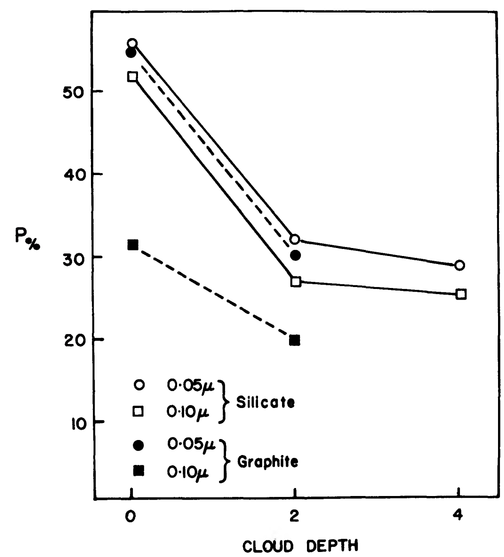

FIG. 3.—Polarization at 5000 Å as a function of cloud depth. Cloud depth of 0 corresponds to an infinitely thin distribution of particles (that is, the particles are confined to a plane that contains the star and is normal to the line of sight); cloud depth of 2 corresponds to a cloud depth to length ratio of approximately 1/10 while a depth of 4 has a ratio of approximately 1/5.

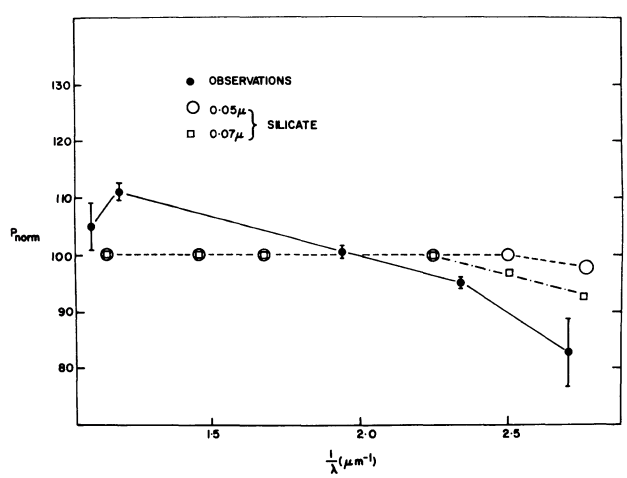

FIG. 4.—Wavelength dependence of normalized polarization for silicate particles. Polarization has been normalized to a value of 100 at $\lambda^{-2} = 2\ \mu$.

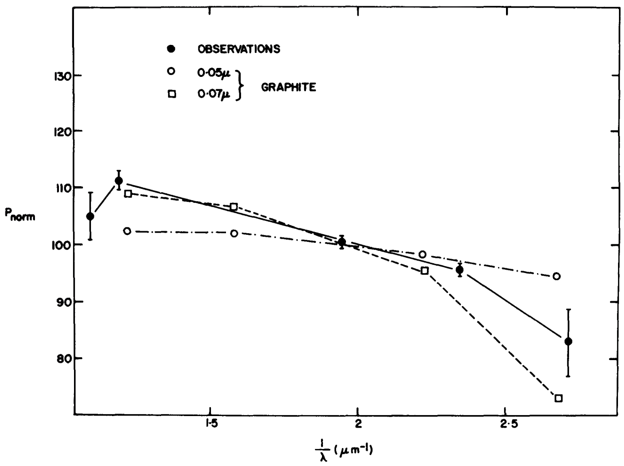

FIG. 5.—Wavelength dependence of normalized polarization for graphite particles.

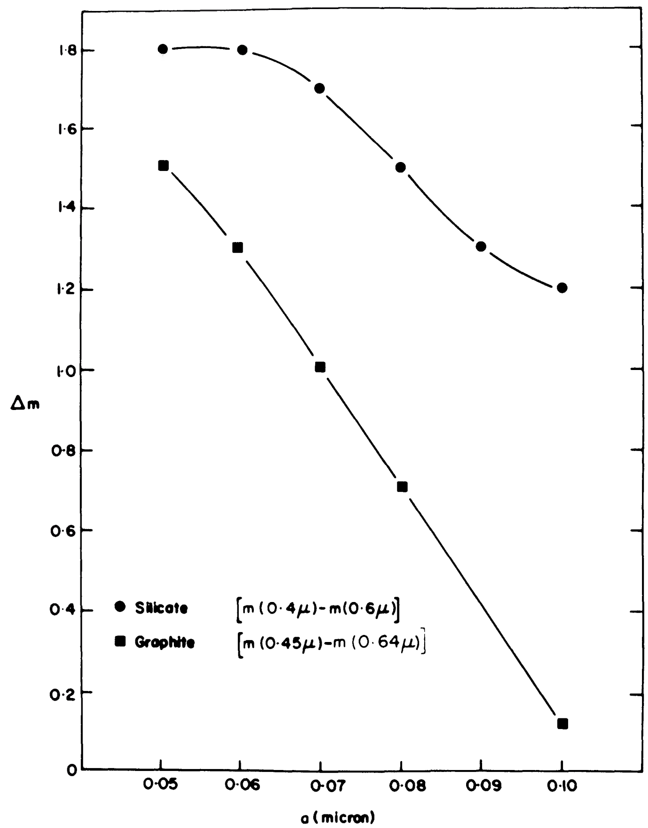

FIG. 6.—Reddening of scattered light as a function of particle size for silicate and graphite particles. Note that the wavelengths are not the same for both particles.

models will fit the observations in the red ($\lambda^{-1} < 2$), although they will in the blue ($\lambda^{-1} > 2$). Graphite models with particle radii of 0.07 μ will fit well in the red but deviate from the observations in the blue. (On the basis of the calculations presented by Shawl 1975, iron particles, which have polarizing properties similar to graphite, would also fit although such models were not calculated for the present work.) If there is indeed significant radiation from the infrared source in the Johnson *R* and *I* filters (Ney *et al.* 1975) the observed polarization will be below the polarization produced by the scattering process in the cloud. Thus, the true deviation in the red between the observed polarization and that calculated for the silicate models will be greater than or equal to that shown in Figure 4. Because of the large deviation of the silicate models in the red, graphite models are preferred. In addition, a distribution of particle size will probably produce a better fit to the data for graphite but not for silicates.

The results of calculations of the reddening produced by silicates and by graphite are shown in Figure 6. Because of the similar, neutral colors of the two components, silicate particles tend to be ruled out. Using the intrinsic colors for a F5 Ia star given by Johnson (1966), we find a color excess $E_{B-V} = 0.73$; this is the amount by which the cloud reddens the F5 Ia star. This low value of color excess is further evidence for graphite particles instead of silicate particles.[1]

Since $\tau_s = \pi a^2 Q_s NL$ where τ_s is the scattering optical depth, a is the particle radius, Q_s is the scattering efficiency, and NL is the column density of scattering particles, we find (assuming graphite particles of 0.09 μ in radius) $NL \approx 10^9 \text{cm}^{-2}$ *for the scattering clouds.*

Ney *et al.* (1975) and Crampton *et al.* (1975) point to various types of similarities between CRL 2688 and VY CMa, IRC +10216, η Car, and Herbig-Haro objects. All these latter objects are known to have high polarizations of 5–25 percent [VY CMa (Serkowski 1969*a*, *b;* Shawl 1969; Dyck, Forbes, and Shawl 1970; Herbig 1971), IRC +10216 (Shawl and Zellner 1970; Dyck *et al.* 1971), η Car (Visvanathan 1967; Schmidt 1971), Herbig-Haro objects (Strom, Grasdalen, and Strom 1974)]. In the light of the entire object, CRL 2688 has the largest polarization of all of these objects. This is probably due simply to the obscuring cloud directly in front of the illuminating star. At least in the case of VY CMa, the observations can only be explained by silicates and not by graphite (Dyck, Forbes, and Shawl 1971), while for CRL 2688 the observations are best explained by graphite. The observations of η Car are explained by Visvanathan (1967) as due to electron scattering because of the flat wavelength dependence, while Schmidt (1971) argues that a dust hypothesis is not ruled out. The cometary nebula R Mon has a large, variable polarization whose wavelength dependence is also flat (Zellner 1970). Thus polarization similarities and differences show these various objects to be far from identical.

We gratefully acknowledge the Lunar and Planetary Laboratory for observing time, and Dr. K. Serkowski

[1] The preference of graphite over silicates, first made on the basis of the fitting of the polarization models to the data, was made prior to our knowing of the existence of carbon lines in the spectrum (Crampton *et al.* 1975) or of the lack of a 10 μ feature (Forrest *et al.* 1975). See Shawl and Tarenghi (1975).

for useful discussions. An anonymous referee is thanked for his pertinent comments.

One of us (M. T.) would like to acknowledge ESRO for fellowship support, while S. J. S. wishes to acknowledge the University of Kansas for a General Research Fund grant in support of this work.

REFERENCES

Coyne, G. V., Gehrels, T., and Serkowski, K. 1974, *A.J.*, **70**, 581.
Crampton, D., Cowley, A. P., and Humphreys, R. M. 1975, *Ap. J. (Letters)*, **198**, L135.
Dyck, H. M., Forbes, F. F., and Shawl, S. J. 1970, *A.J.*, **76**, 901.
Forrest, W. J., Merrill, K. M., Russell, R. W., and Soifer, B. T. 1975, *Ap. J. (Letters)*, **199**, L181.
Gehrels, T., and Teska, T. M. 1960, *Pub. A.S.P.*, **72**, 115.
Herbig, G. H. 1971, *Ap. J.*, **172**, 375.
Johnson, H. L. 1966, *Ann. Rev. Astr. and Ap.*, **4**, 193.
Kruszewski, A., Gehrels, T., and Serkowski, K. 1968, *A.J.*, **73**, 677.
Ney, E. P. 1975, *Sky and Tel.*, **49**, 21.
Ney, E. P., Merrill, K. M., Becklin, E. E., Neugebauer, G., and Wynn-Williams, C. G. 1975, *Ap. J. (Letters)*, **198**, L129.
Schmidt, T. 1971, *Astr. and Ap.*, **12**, 456.
Serkowski, K. 1969*a*, *Ap. J. (Letters)*, **156**, L139.
———. 1969*b*, *ibid.*, **158**, L107.
———. 1974, In *Methods of Experimental Physics: Astrophysics*, ed. N. Carleton (New York: Academic Press), p. 361.
Shawl, S. J. 1969, *Ap. J. (Letters)*, **157**, L57.
———. 1975, *A.J.*, **80**, 595.
Shawl, S. J., and Tarenghi, M., 1975, *Bull. AAS*, **7**, 498.
Shawl, S. J., and Zellner, B. H. 1970, *Ap. J. (Letters)*, **162**, L19.
Strom, S. E., Grasdalen, G. L., and Strom, K. M. 1974, *Ap. J.*, **191**, 111.
Visvanathan, M. 1967, *M.N.R.A.S.*, **135**, 275.
Zellner, B. H. 1970, *A.J.*, **75**, 182.
———. 1973, *In Proc. IAU Symposium No. 52: Interstellar Dust and Related Topics*, ed. J. W. Greenberg, and H. C. van de Hulst (Dordrecht: Reidel), p. 109.

STEPHEN J. SHAWL: Department of Physics and Astronomy, University of Kansas, Lawrence, KA 66045

MASSIMO TARENGHI: Laboratorio Fisica Cosmica e Tecnologie Rel., Via Celoria 16, 20133 Milano, Italy