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DUST CLOUDS WITHIN GLOBULAR CLUSTERS: POLARIZATION

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ABSTRACT

Multicolor polarization and CCD photometry are presented for four dust cloud candidates in the globular clusters NCG 362, 6266, 7078, and 7099. The results are in agreement with previous arguments (Forte and Méndez), suggesting the physical membership of the clouds in the clusters. Tangential polarization is present in the last three objects. The observed polarization, after correction for dilution effects, is consistent with a "gray" behavior and $P \sim 2\%–3\%$. Alternatively, the dark patch in NGC 362 shows a polarization similar to that of the cluster nucleus, probably with an interstellar origin. The detection of scattered polarized light at angular distances close to 4 core radii shows that the dust complexes may be considerably extended.

Subject headings: clusters: globular — interstellar: grains — polarization

I. INTRODUCTION

For many years, globular clusters have been assumed to be free of nebular matter. This has been a consequence of the negative results coming from gas searches (both in the optical and radio domains), despite frequent reports about "dark patches" detected visually and on photographic plates (see Roberts 1988, for a thorough review of the historical situation). However, a recent paper (Forte and Méndez 1988, hereafter FM) based on multicolor CCD observations and image analysis has shown that (*a*) the existence of dark patches is a relatively frequent phenomenon in globular clusters, and (*b*) the behavior of the apparent extinction with wavelength, in these patches, is consistent with the presence of dust clouds within the clusters. These clouds are hidden by geometric (position) and scattering effects. In a simple approach that behavior can be matched with a three-parameter model: (1) the intrinsic visual extinction, A_v; (2) the position within the cluster, l (measured in terms of the fractional contribution to the surface brightness arising in stars between the cloud and the observer); (3) a parametric description of the behavior of the scattered light with wavelength S_λ.

The cloud modeling in FM suggested that the scattering effects should be more easily detectable toward shorter wavelengths. The extension of the cloud photometry to the near-ultraviolet (Johnson's U), confirmed this effect even in those cases where the wavelength dependence of the apparent extinction was mild (Méndez, Forte, and Orsatti 1989). The errors associated with the ultraviolet photometry (e.g., from lower signal-to-noise ratios, uncertainties in the transformations to the standard system, etc.) are usually larger than in the other bands. However, a systematic behavior can be detected in the study of a large number of cloud candidates (Méndez and Forte, in preparation).

The paper by Méndez, Forte, and Orsatti (1989) also presented arguments for the existence of the clouds based on image processing techniques that revealed an apparent asymmetry in the stellar distribution in the nuclear region of NGC 362.

Another argument for the existence of intracluster dust in globulars comes from the *IRAS* observations discussed by Gillett *et al.* (1988). The presence of an extended 100 μm source in 47 Tuc is attributed to optically thin dust heated by the integrated starlight. However, as pointed out by those authors, substantial amounts of cold dust could be present without introducing significant emission in the *IRAS* bands.

This work presents further and independent arguments based on multicolor polarimetry, following the lines given in Martin and Shawl (1981; hereafter MS). As in reflection nebulae, the scattered light will be polarized, and, in the case of small particles, the polarization vector will be perpendicular to the radius joining the cloud and the cluster center ("tangential" polarization). The main problem for the detection of this effect is the presence of nonpolarized stellar light that dilutes the intrinsic polarization and, in the case of very dark clouds, the existence of depolarization arising in multiple scattering.

The clusters discussed in this paper, NGC 362, NGC 6266 (M62), and NGC 7099 (M30), were all found by FM to contain dust cloud candidates. In the case of NGC 6266 there is a strong deviation from circularity of its isophotal contour, detectable at a few r_c from the cluster center. This deviation gradually disappears at larger angular distances where the apparent flattening becomes practically null (White and Shawl 1987).

NGC 7078 (M15) was observed because it contains one of the "historically suspected" clouds and was reported by MS as a tentative detection of tangential polarization. This cloud also appeared as a suitable candidate for testing the technique for the determination of the apparent extinction on an obvious dark patch.

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As explained in FM, the detection of dust clouds based on model subtraction will generally fail in the innermost regions of the clusters where the overlapping of the instrumental and seeing profiles of the brightest giant stars will preclude the sampling of the faint stellar population. The method will be also constrained at large angular distances from the cluster nuclei, where the stellar background becomes increasingly "noisy." However, large distances from the centers will increase the asymmetry of the illuminating field and, hence, the amplitude of the polarization vector (see Jura 1978; MS, for a discussion of the optically thin case) making the dust more easily detectable. In this frame, and as a compromise between the described criteria (i.e., background bright enough for the estimate of the apparent extinctions and large apparent angular distances from the cluster centers), we selected two suitable spots in NGC 6266 and NGC 7099 which appear at angular radii comparable to that of the suspected cloud in NGC 7078.

II. OBSERVATIONS AND DATA HANDLING

Previous CCD observations ($BV-RI_{KC}$) have been described in FM. These frames were supplemented with near-ultraviolet (Johnson system) frames taken during 1987 September with the 0.9 m telescope at CTIO in combination with a 800 × 800 pixel (binned by two) TI chip. The observing logbook is given in Table 1.

On the other side, polarimetric observations, in moon-less nights, were carried out with the 2.15 m telescope at CASLEO (San Juan, Argentina) and the VATPOL polarimeter (see Magalhaes, Benedetti, and Roland 1984, for references) in 1988 July. The observations, described in Table 2, were made with a 15″ circular diaphragm and included series of cloud (avoiding obvious stars) and sky measures. Standard stars for polarization were observed periodically along the run.

TABLE 1

CCD Observations Logbook

Object	Filter	Exposure (s)	Date (1987)
NGC 6266.....	*U*	300	Sep 13
	U	300	Sep 13
	U	300	Sep 13
	U	300	Sep 13
	U	300	Sep 14
	U	450	Sep 14
	U	450	Sep 14
NGC 7078.....	*U*	300	Sep 13
	U	300	Sep 13
	B	60	Sep 13
	B	60	Sep 13
	B	30	Sep 13
	V	30	Sep 13
	V	20	Sep 13
	V	20	Sep 13
	R	30	Sep 13
	R	30	Sep 13
	I	20	Sep 13
	I	20	Sep 13
NGC 7099.....	*U*	300	Sep 13
	U	300	Sep 13
	U	300	Sep 13

Image processing and analysis was performed with the "quasi-interactive" image processing system developed for an HP-1000 computer at La Plata Observatory.

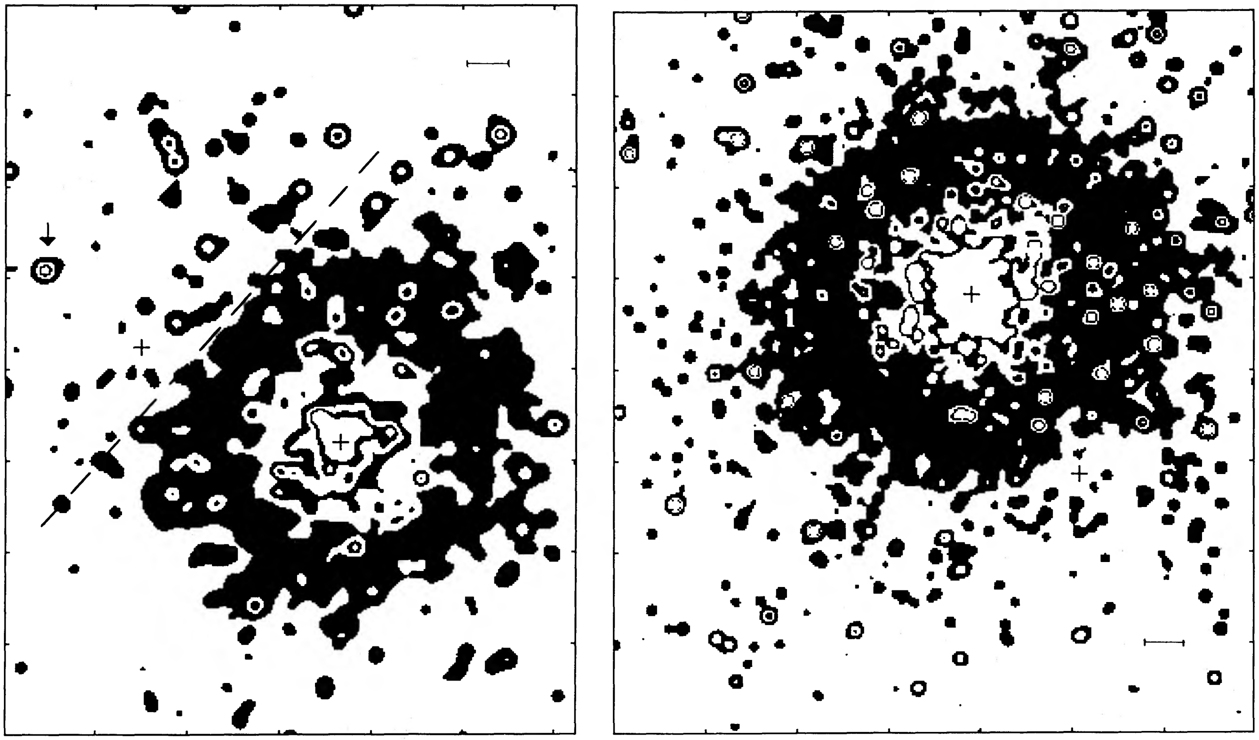
III. BEHAVIOR OF THE APPARENT EXTINCTION WITH WAVELENGTH

Figure 1 shows isophotal contours for three of the globulars and the position of the observed dark patches (identified in Table 2 according to their *x*-*y* coordinates, following FM,

TABLE 2

Multicolor Polarimetric Observations

Object	$X-Y$	r	P.A.	Filter	P (%)	ϵ_p	θ	Integration Time (minutes)
NGC 362 nuc	...	0	...	*B*	0.24	0.02	97°8	10
NGC 362 .... (cloud)	227 − 221	38″	215°	*B*	0.23	0.08	91.1	32
NGC 6266 nuc	...	0	...	*U*	1.29	0.07	58.4	30
				B	1.61	0.02	54.8	40
				V	1.74	0.02	55.3	5
				R	1.73	0.02	51.9	4
				I	1.61	0.02	55.0	5
NGC 6266 .... (cloud)	75 − 238	62″	330°	*U*	1.58	0.15	66.5	45
				B	1.98	0.13	64.0	106
				V	2.15	0.05	61.6	45
				R	1.82	0.10	60.1	15
				I	1.80	0.06	59.4	20
NGC 6266-1 .... (reference star)	...	90″	330°	*B*	1.39	0.05	47.0	40
				V	1.64	0.05	54.0	10
				R	1.60	0.10	50.0	20
				I	1.60	0.07	56.0	10
NGC 7078 nuc	...	0	...	*B*	0.05	0.01	37.0	45
				V	0.07	0.02	15.0	5
				R	0.03	0.01	21.0	5
NGC 7078 .... (cloud)	...	59″	125°	*B*	0.35	0.02	12.6	140
				V	0.15	0.06	...	15
				R	0.21	0.04	2.0	25
NGC 7099 nuc	...	...	...	*B*	0.11	0.03	96.2	15
NGC 7099 .... (cloud)	...	50″	77°	*B*	0.58	0.20	1.0	40



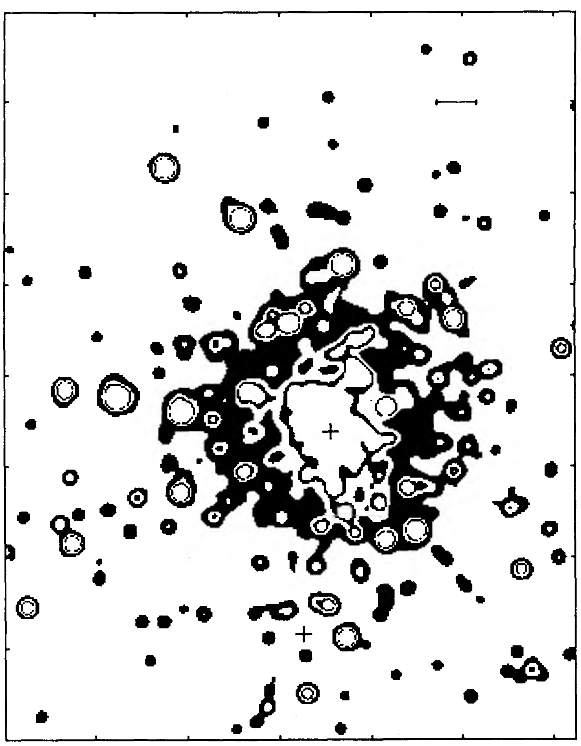


FIG. 1.—Isophotal contours for NGC 6266, NGC 7078, and NGC 7099. The cluster centers and observed spots are indicated by crosses. The reference star in the NGC 6266 field is identified with an arrow. The isophotal deformation in this cluster is indicated with a dashed line. The horizontal line is 10″ long. North is left, east is down.

angular distance from the cluster center, and position angle). The remaining cloud candidate in NGC 362 is depicted in FM (Fig. 3). The apparent extinctions A_λ versus inverse wavelength are shown in Figure 2, except for the last cluster, discussed in Méndez, Forte, and Orsatti (1989). Two sets of apparent extinctions are shown for the clouds in NGC 6266 and NGC 7078. The first was obtained with a sampling window 1″.5 on a side (i.e., similar to that employed in FM), while the second corresponds to a larger window, 5″.5 on a side, comparable to the size of the polarimeter aperture. We only show a tentative estimate of the apparent extinctions in the core of the NGC 7099 cloud where the errors, due to the faint stellar back-

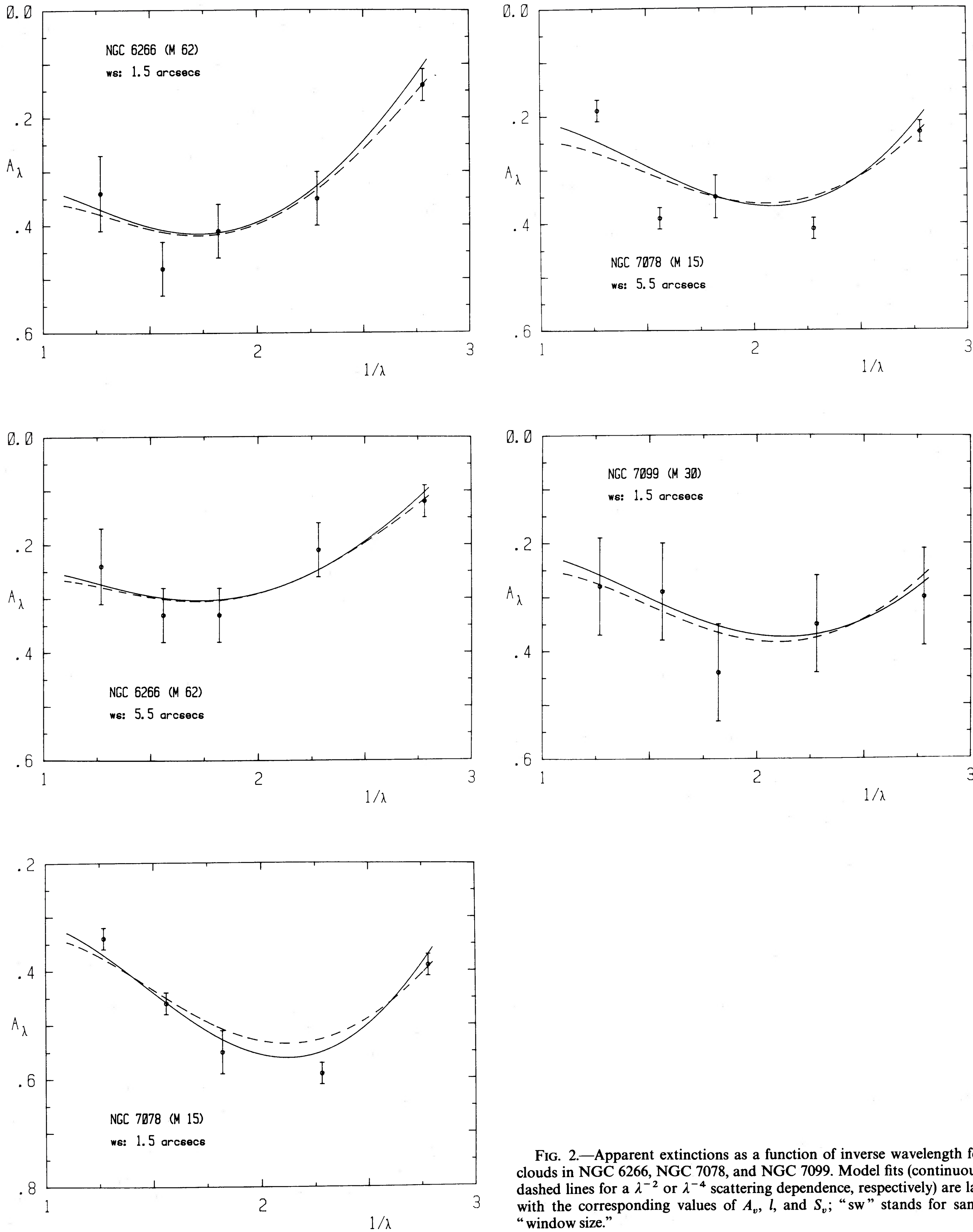


FIG. 2.—Apparent extinctions as a function of inverse wavelength for the clouds in NGC 6266, NGC 7078, and NGC 7099. Model fits (continuous and dashed lines for a λ^{-2} or λ^{-4} scattering dependence, respectively) are labeled with the corresponding values of A_v, l, and S_v; "sw" stands for sampling "window size."

ground, become very large when the sampling window size is increased.

The apparent extinctions were obtained, as in previous papers, by subtracting the smooth background derived from the modal analysis of the pixel brightness distribution and were fitted with

$$A_{\lambda\,\mathrm{app}} = -2.5 \log [l + (1 - l) \exp(-\tau_\lambda) + S_\lambda] ,$$

where τ_λ is the optical depth ($A_\lambda = 1.086\tau_\lambda$, with $A_U = 1.54A_V$, $A_B = 1.29A_V$, $A_R = 0.77A_V$, and $A_I = 0.61A_V$, which are appropriate values for the interstellar extinction against a light background with integrated spectral type F–G and assuming "normal" dust grains) and S_λ is the contribution from scattered light.

We note that, in general, the associated error bars do not allow the simultaneous and unambiguous estimate of the complete set of parameters defining a given cloud model, the main uncertainty arising in the shape of the S_λ function. However, the analysis of several apparent extinction curves in different clusters shows that the wavelength dependence of the scattered light can be matched only with coefficients $\Delta C(B, V)$, $\Delta C(V, I)$ (in the Witt and Schild 1986 nomenclature) ranging from 0.24, 0.30 to 0.30, 0.70. The first set of values belong to a λ^{-2} dependence, while the second one is a λ^{-4} law.

Some galactic reflection nebulae (e.g., NGC 2068 in Fig. 5 of Witt and Schild 1986) show a differential "blueing" compatible with these power-law dependences. However, this is attributable to the high optical depth of the illuminating star and not necessarily to abnormal properties of the dust grain population. The situation seems different in the case of the globular cluster cloud candidates where an important fraction (dominant at large distances from the center) of the scattered light is provided by the overall unreddened radiation field.

The adoption of a steeper dependence for S_λ will yield, in general, larger values of A_v and l and smaller values of S_v, when compared with fits of equal quality but adopting a smaller exponent.

Figure 2 also shows the fits, listed in Table 3, obtained for both dependences using a linearization method that minimizes the square of the residuals. However, as discussed later, the analysis of the multicolor polarimetry might help in discriminating the most adequate wavelength dependence for the scattered light.

We point out that the extinction curves show the same trend as in NGC 362 (Méndez, Forte, and Orsatti 1989), that is, a clear decrease of the apparent extinction toward the ultraviolet. The effect is also evident in the NGC 7078 cloud. This last object can be detected without any processing and has been the target of previous works (Kanagy and Wyatt 1978; MS). The model fitting suggests a very low value of l (0.0–0.20) and indicates that the cloud is practically in front of the cluster, then favoring its immediate detection. The presence of scattering effects in the blue-ultraviolet colors can also be seen in the Kanagy and Wyatt (1978) diagrams (but went unnoticed). The differences in the values derived by those authors and our values can be found in the different sizes of the sampling windows.

TABLE 3

Dark Cloud Model Parameters

Object	Window Size	A_V(mag)	l	S_V
Scattering Dependence: λ^{-2}				
NGC 6266 75 − 238	1.5	2.0	0.4	0.18
	5.5	1.7	0.5	0.15
NGC 7078 96 − 143	1.5	0.9	0.0	0.17
	5.5	0.7	0.0	0.18
NGC 7099 163 − 392	1.5	0.7	0.0	0.17
Scattering Dependence: λ^{-4}				
NGC 6266 75 − 238	1.5	2.9	0.6	0.05
	5.5	2.9	0.7	0.04
NGC 7078 96 − 143	1.5	0.9	0.2	0.05
	5.5	0.6	0.2	0.05
NGC 7099 163 − 392	1.5	1.1	0.5	0.03

IV. POLARIZATION

As a consequence of the presence of interstellar matter along the line of sight between the observer and the cluster, the observed polarizations will include foreground components which, presumably, will behave according to Serkowski's law (Serkowski, Mathewson, and Ford 1975). These components must be removed from the observed values. The problem is not serious in the cases of NGC 362, 7078, and 7099 (with color excesses $E_{B-V} = 0.05$, 0.08, and 0.04, respectively, according with Reed, Hesser, and Shawl 1988), but deserves a careful analysis for NGC 6266, located at low galactic latitude ($b = 7°$) and exhibiting a reddening $E_{B-V} = 0.44$. In order to estimate the value of the foreground polarization, we observed the cluster nuclei and, in the case of the last cluster, also a field star whose position is radially aligned with the cloud and the cluster nucleus. This particular arrangement allows the detection of eventual changes of the foreground polarization on an angular scale of some 1′.5 on the sky.

Among the observed dark patches, the one in NGC 362 shows a polarization vector which is, to within the error bars, equal to that measured for the cluster nucleus, suggesting that both arise in the interstellar medium along the line of sight to the cluster. This result could be explained either if the dark patch is not a cloud or, as discussed later, if some effect destroys the polarization pattern.

For the other cloud candidates, the results can be summarized as follows.

a) *Geometry*

Since the existence of polarized scattered light was expected and since shorter wavelengths are scattered more strongly, we adopted the blue filter as the most suitable one for long integrations and the estimate of the position angles. We assumed that the polarization vectors observed at the cluster nuclei are representative of the foreground interstellar components, and these values were subtracted from the observed polarizations in the dark patches (in the Stokes plane).

The corrected polarization vectors for the three dark patches are depicted in Figure 3. The geometry of this diagram has been normalized using the core radius of each cluster (14″.5, 13″.7, and 13″.7 for NGC 6266, 7078, and 7099, respectively). This figure also includes the ideal tangential direction (*dashed lines*) at the position of each cloud. The largest discrepancy amounts to some 22° in the case of NGC 7078. The probability of this arrangement of the polarization vectors just as a chance situation is only 1.5%, and we conclude that the existence of tangential polarization has been detected in NGC 6266 and NGC 7099 and confirmed for NGC 7078 (MS). We note that a perfect tangential alignment is an ideal situation since the resultant polarization will be a composition of the contribution

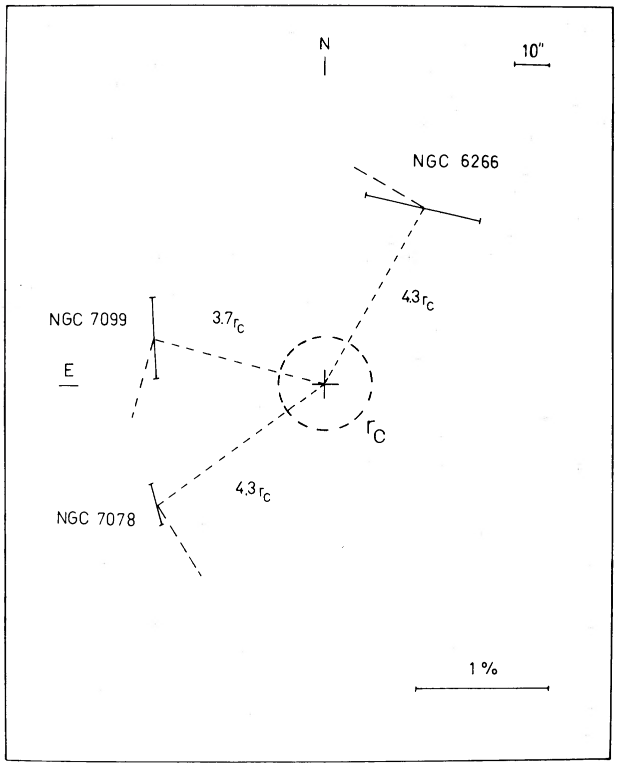


FIG. 3.—Corrected polarization vectors in the blue filter for the dust clouds observed in NGC 6266, NGC 7078, and NGC 7099. The radial and tangential directions are shown as a dashed line for each cloud. The central circle has a radius r_c (core radius).

arising in the whole illuminating field and the local conditions (i.e., the light coming from inside or the immediate neighborhood of the cloud).

b) *Wavelength Dependence*

The largest amplitude of the blue polarization vector was found in NGC 6266, and we selected this object in order to determine the wavelength dependence of the polarization.

Figure 4 shows P_λ versus wavelength for the cluster center and for the dust cloud. The cluster nucleus follows, very closely, a Serkowski law, i.e., $P_\lambda/P_{\lambda\,\mathrm{max}} = \exp\,[-1.15\,\ln^2(\lambda_{\mathrm{max}}/\lambda)]$, with $P_{\mathrm{max}} = 1.74\%$ and $\lambda_{\mathrm{max}} = 0.6$ μm, which belongs to a ratio of total to selective absorption $R = 3.3$. The reference star also shows this behavior, with a slightly different value of the maximum polarization ($\sim 1.65\%$), suggesting that the variation of the foreground polarization on the angular scale defined by the nucleus and the cloud is negligible. Alternatively, the dust cloud shows a distinct behavior, well beyond the error bars.

In order to determine the foreground polarization for this cluster, we obtained an error-weighted average of the polarizations observed at the cluster nucleus (P.A. $55° \pm 2°$) and for the reference star (P.A. $53° \pm 4°$). The corrected polarizations at each wavelength ($P_{\mathrm{obs}\,\lambda}$ in what follows) for the dark patch resulted in $P_U = 0.60$, $P_B = 0.70$, $P_V = 0.60$, $P_R = 0.33$ and $P_I = 0.27$ (%). These values show that the foreground-corrected polarization in the *UBV* range is nearly as twice that observed in the *RI* bands, a behavior consistent with that expected for scattered light.

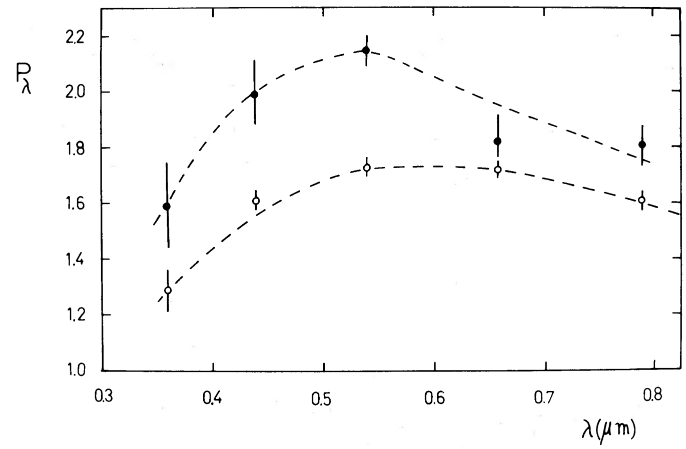


FIG. 4.—Dependence of the observed polarization with wavelength for the nucleus (*open circles*) and dark cloud in NGC 6266. The dashed line fitted to the nucleus observations is a Serkowski law with $\lambda_{\mathrm{max}} = 0.6$ μm and $P_{\mathrm{max}} = 1.75\%$.

c) *A Tentative Model for the Cloud 75 – 238 in NGC 6266*

An estimate of the properties of the intrinsic polarization in this cloud can be derived by combining the observed apparent extinctions ($A_{\lambda\,\mathrm{app}}$) and polarizations. The observed polarization $P_{\mathrm{obs}\,\lambda}$ can be written in terms of the position of the cloud within the cluster, l, the scattered light S_λ, and intrinsic extinction A_λ as:

$$P_{\mathrm{obs}\,\lambda} = S_\lambda P_{\mathrm{int}}/[l + (1 - l)\exp(-\tau_\lambda) + S_\lambda]$$
$$= P_{\mathrm{int}}/10^{-0.4A_{\lambda\,\mathrm{app}}}\,,$$

where P_{int} is the "intrinsic polarization" (i.e., corrected for dilution effects arising in foreground or background cluster stars) at λ. Then if the intrinsic polarization is assumed to be "gray" (i.e., P_{int} is wavelength-independent):

$$S_\lambda/S_v = (P_{\lambda\,\mathrm{obs}}/P_{v\,\mathrm{obs}})10^{-0.4(A_\lambda - A_v)_{\mathrm{app}}}\,.$$

Figure 5 shows this last ratio as a function of wavelength for the cloud in NGC 6266. This ratio can be fitted with $S_\lambda/S_V = 0.31\lambda^{-1.83}$ (derived with the *VRI*, measures where we expect

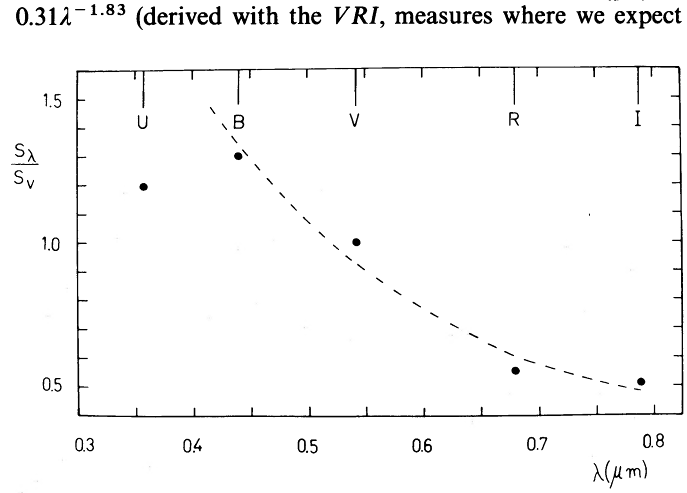


FIG. 5.—The ratio of scattered light at wavelength λ to S_v, derived fro the NGC 6266 cloud, assuming gray polarization. Note that the U value falls at about half of the expected value. This may be a consequence of depolarization in the near-ultraviolet band, perhaps as a result of multiple scattering. The dashed line is a $\lambda^{-1.8}$ law.

the minimum effects of depolarization). The inclusion of the blue value in this fit leads to a slightly smaller exponent (-1.74). However, the observed value in the U filter falls to about one-half of the expected one. This fact can be attributed to the fast increase of the optical depth in the ultraviolet, producing depolarization, and is a known effect in dense galactic reflection nebulae (see, e.g., Martin 1978). The wavelength dependence of the scattered light, derived with the assumption of gray polarization, gives an approximate description (to within $\pm 20\%$) of the run of the product $a_\lambda \tau_\lambda$, where a_λ is the dust albedo and τ_λ is the total optical depth, for grains with $a_\lambda =$ from 0.40 to 0.70 (for the near-infrared and blue bands, respectively), similar to those adopted by Witt (1985) in the modeling of reflection nebulae. That product is proportional to the amount of scattered light in the optically thin case, the situation that presumably holds in the outer regions of the dust clouds. The unconstrained solution for the $15'' \times 15''$ window observations of the cloud in NGC 6266, adopting $S_\lambda \sim \lambda^{-1.8}$ ($A_v = 1.7$ mag, $S_v = 0.15$, and $l = 0.5$) leads to $P_{\rm int} = 3\%$.

The derived intrinsic polarization can be compared with the results from numerical models (or see the analytical approach in MS for a particular case). An upper estimate of the expected polarization can be obtained with a model where the illuminating field of a cluster (per unit volume and solid angle) with core radius r_c is represented with

$$\epsilon(r) = \epsilon_0/[1 + (r/r_c)^2]^{3/2} .$$

If the impact parameter of a visual line through the cluster (at the position of the cloud) is $z = hr_c$, the surface brightness at z will be given by

$$I_0 = 2\epsilon_0 r_c/(1 + h^2) .$$

With these approximations (that assume infinite tidal radius) an elementary volume dV at a distance d from a cloud with effective area σ will contribute with a scattered flux toward the observer:

$$dF = \epsilon(r)\sigma\phi(g)/d^2 ,$$

where $\phi(g)$ is the phase function of the dust grains. The amplitude of the polarized contribution will be given, in the small particle approximation, by

$$Q = (\cos^2 \theta - 1)/(\cos^2 \theta + 1) ,$$

θ being the scattering angle in the case of spheres, measured at the cloud position. A negative value of Q means a polarization vector perpendicular to the plane defined by the line of sight and the line joining the illuminating volume dV and the cloud. The total polarization is then obtained by integrating the contribution from the whole cluster in the Stokes plane. As a consequence of the geometry of the illuminating field, the integrated polarization vector shows a "tangential" alignment. This estimate of "intrinsic" polarization assumes single scattering and is independent of the dust albedo or cloud size. However, these parameters play a role on the observable polarization through their incidence on the S_λ coefficient.

The resulting value of the maximum polarization for the NGC 6266 cloud ($l = 0.5$) is, in the case of isotropic scattering, $P_{\rm max} = 39\%$. This polarization is one order of magnitude larger than the derived $P_{\rm int}$, a result similar to that obtained by MS in the NGC 7078 cloud. The discrepancy may arise in the following factors:

a) Depolarization effects originated by multiple scattering which may amount to some 0.5 for $\tau_\lambda = 1.5$ (see Martin 1978).

b) A nonisotropic phase function. For example, the adoption of $g = 0.65$ decreases $P_{\rm max}$ to 24%.

c) Diaphragm aperture versus cloud size effects. A small diaphragm leaves out most of the external regions of the cloud, where single scattering would be dominant.

d) The small particle approximation may not be adequate, suggesting that the size of the grains that dominate the polarization in the VRI bands is larger than 350 Å. The adoption of grains with 0.15 μm in diameter and the polarization efficiency given by Blumer (1925) for silicates decreases $P_{\rm max}$ from 39% to 20% in the isotropic case.

e) Light scattered from stars inside the cloud (with almost null integrated polarization). This effect will not be important, on average, for clouds far from the cluster center where the main contribution to the radiation field is provided by the whole cluster, but must be considered in the case of clouds in the inner regions. We note that the negative results obtained for cloud candidates in M3 and M13 (MS) belong to dark patches located at angular distances ranging from 1 to $2r_c$.

f) Lower albedos. Low albedos mean smaller S_λ and may increase the $P_{\rm int}$ value. For example, the adoption of $S_v = 0.04$, which mean a factor 3–4 times smaller than the albedos implied by the A_λ versus $1/\lambda$ fit and the $S_\lambda = \lambda^{-1.8}$ dependence, yields $A_v = 1.1$ mag, $l = 0.53$ and leads to $P_{\rm int} = 12\%$. This value would be in good agreement with the expected $P_{\rm max}$, after correction by the effect described in *a*. However, even though these parameters give good agreement between the observed and computed polarizations and satisfy the A_λ versus $1/\lambda$ curve in the *VRI* bands, they fail to reproduce the apparent extinctions in the blue and ultraviolet. Both behaviors might be reconciled by postulating the coexistence of particles with very small sizes which contribute little to the polarization in the *VRI* bands but dominate the scattering in the shorter wavelengths. This fact should increase the optical depth in the B and U filters, leading to depolarization effects (as suggested by Fig. 5) due to multiple scattering.

A statistical study of several cloud candidates may help in discriminating about the relative importance of these factors. In the case of the NGC 7078 cloud the mild wavelength dependence of the observed polarization suggests a slowly varying value of S_λ in the *VRI* range. The average of our B, V values is $P_{BV} = 0.25\% \pm 0.05\%$, in very good agreement with the observations by MS (0.28 ± 0.06), who employed a broader passband. The difference between their position angle and ours in the blue filter (36° and 12°6, respectively) in part, probably arises in slightly different positionings of the apertures of the polarimeters.

The adoption of an average value for the observed polarization in the *VRI* filters ($P \sim 0.20\%$) yields $P_{\rm int} = 2.3\%$. We note that this object shows almost null polarization in the nuclear regions, which, in combination with the low E_{B-V} color excess, denotes that the foreground material will have little effect on the polarization of the scattered light.

Finally, the error bars associated with the A_λ values of the NGC 7099 cloud make the model parameters more uncertain. In this cloud the intrinsic polarization would be close to $P_{\rm int} = 1.8\%$.

Remarkably, the three clouds (seen at the same projected angular distances of the cluster centers, $\sim 4r_c$) show comparable values of the intrinsic polarizations, suggesting a similitude of the dust grain properties.

V. CONCLUSIONS

The photometric arguments presented in FM supporting the physical existence of dark clouds within globular clusters have been strengthened by (*a*) the results from the ultraviolet photometry which show that scattering effects become more evident toward short wavelengths. The observations suggest a steep wavelength dependence for the scattered light in the blue-near ultraviolet region. *b*) The geometry of the polarization vectors in three different clusters which denote that, at large angular distances from the cluster centers, the orientation of these vectors is dominated by the overall radiation field. (*c*) The analysis of the observed polarization which, after correction for dilution effects, seem consistent with a "gray" behavior (in the range from 0.44 to 0.79 μm) and P from 1.8% to 3.0%. As a reference, it can be mentioned that this kind of behavior is seen in reflection nebulae as CRL 2688 (the "egg" nebula), as reported by Cohen and Kuhi (1977). In the case of NGC 6266 (the only cluster measured in all filters), the observed polarizations, combined with the observed dependence of the apparent extinctions, suggest the possible existence of an "excess" of small particles.

The detection and careful mapping of tangential polarization at large distances from the cluster centers, although it requires a large investment of telescope time, may provide a clearer picture regarding the extent of the dust complexes and eventually their total masses. Previous estimates (as in Kanagy and Wyatt 1978 or FM) might be considerably increased. *IRAS* observations of 47 Tuc (Gillett *et al.* 1988) show, after the subtraction of a model background, the existence of an extended 100 μm source attributed to an optically thin mass of $4 \times 10^{-4} M_\odot$ of heated dust. These observations, though, are not sensitive to the possible presence of dust in the outer region of the clusters where the dilution of the radiation field sets a very low equilibrium temperature. The same situation holds in the interior of dark (optically thick) dust clumps whose main contribution to the infrared emission would be beyond the *IRAS* bands.

The origin of the dust clouds is probably related with the process of mass ejection during the red giant phase. Frogel and Elias (1988) have presented arguments that support the existence of cool dusty envelopes around red variables in globular clusters. These envelopes may also be detected through polarization measures of individual giant stars (White, Shawl, and Coyne 1984). The problem of the apparent lack of gas (detectable in the radio domain) remains as an open question. Several mechanisms have been proposed in the literature that would lead to the depletion of the nebular material (like nova-driven shocks or stellar winds; Scott and Durisen 1978). However, these mechanisms must be somewhat selective and able to leave dust behind probably as a consequence of radiation pressure effects.

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