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IDENTIFICATION OF A NEBULOUS BLUE OBJECT NEAR MAFFEI 1

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Photometric and spectroscopic data have been acquired for a small nebulous blue object near the heavily obscured galaxy Maffei 1. The observations show that the object is a galactic reflection nebula illuminated by an early, main-sequence B star at a distance of about 3 kpc. Application of the Q-method to the photometry of the star indicates that Maffei 1 suffers at least 3.3 magnitudes of visual extinction.

Key words: galaxies—interstellar reddening—reflection nebulae

I. Introduction

Maffei 1 is a galaxy at low galactic latitude which appears heavily obscured by dust in the galactic plane. Upon making a finding chart, one of us (R.J.B.) noticed a striking nebulous blue object only 5.6 arc min to the northeast of the galaxy's center (see Fig. 1). On the E (red) print of the Palomar Sky Survey, the object presents a slightly fuzzy image resembling that of a small, high surface brightness galaxy. On the corresponding O (blue) print, a bright stellar center is surrounded by a faint, nebulous, elliptical halo. This halo has dimensions of 0.84 by 0.62 arc min and is more clearly visible on the glass copy of the Palomar Sky Survey. Van den Bergh (1971) also noticed the object, and suspected it to be a galactic reflection nebula. Another possibility, although perhaps more remote, is that it is a blue emission-line galaxy seen through a clear hole in the dust distribution of the galactic plane.[1] If the latter were true, there would be important implications for the study of galactic extinction. We have made photometric and spectroscopic observations of the object to obtain an unambiguous identification.

II. Observations and Reductions

A. *Photometry*

Photometric observations of the nebulous blue object were made on five nights in 1978 and 1979 with the 0.76-m and 0.91-m telescopes of McDonald Observatory. The observations, summarized in Table I, were made in the Johnson *UBV* system using an Amperex 56 DVP photomultiplier on 1979 January 5, an RCA 8850 on 1979 August 26, and a Hamamatsu 1P21 (dry-ice cooled to $-78°$ Celsius) on the remaining nights. Transformations to the standard system were made from observations of 5 to 19 Landolt standards (Landolt 1973), including several pairs of red and blue extinction stars. The standard deviation of the residuals from the standards for these nights was typically $\pm\ 0^{m}.02$, $\pm\ 0^{m}.01$, and $\pm\ 0^{m}.03$ for the V, $(B-V)$, and $(U-B)$ measurements, respectively. Reductions were performed with a standard *UBVRI* computer program written by F. J. Lopez-Lopez which is described by de Vaucouleurs and de Vaucouleurs (1972). The two-step procedure described in that paper has also been applied to the data presented here.

In order to minimize possible contamination of the stellar component by light from the nebula, all the measurements were made with small diaphragms, ranging from 8.2 to 16.0 arc sec on the 0.91-m telescope and in a 19.2 arc sec diaphragm on the 0.76-m telescope. The mean of the three V magnitude measurements made through the 16.0 arc sec aperture on the 0.91-m telescope is somewhat brighter than that of the single measurement made through the 8.2 arc sec aperture on the same telescope, which could indicate that some contamination is present in the larger aperture, but the scatter of the measurements suggests that the contamination is small. The adopted mean magnitude and color indices of the nebulous blue object are listed in Table I; the errors given are mean external errors based on the five measurements.

B. *Spectroscopy*

Spectroscopic observations were made with the Cassegrain Digicon Spectrograph on the 2.1-m Struve reflector at McDonald Observatory. This instrument is a dual-aperture sky-subtracting spectrograph with a Digicon detector (Tull, Vogt, and Kelton 1979). A digicon is a self-scanned photodiode array (Reticon) mounted inside an image tube. Reticon photodiode arrays have been shown to be linear over four orders of magnitude (Vogt, Tull, and Kelton 1978).

The spectrum of the nebulous blue object was observed on 1978 July 19 with entrance apertures of 4.0 by 7.4 arc sec (the long dimension being east-west and perpendicular to the dispersion) and a 600-groove-per-millimeter grating giving a two-diode resolution of 7.5

[1]In some respects the object morphologically resembles the peculiar elliptical galaxy NGC 1510 as seen on the Whiteoak prints of the Palomar Sky Survey. Although this object is of early morphological type, it has very blue colors due to the presence of strong emission lines (Disney and Pottasch 1977).

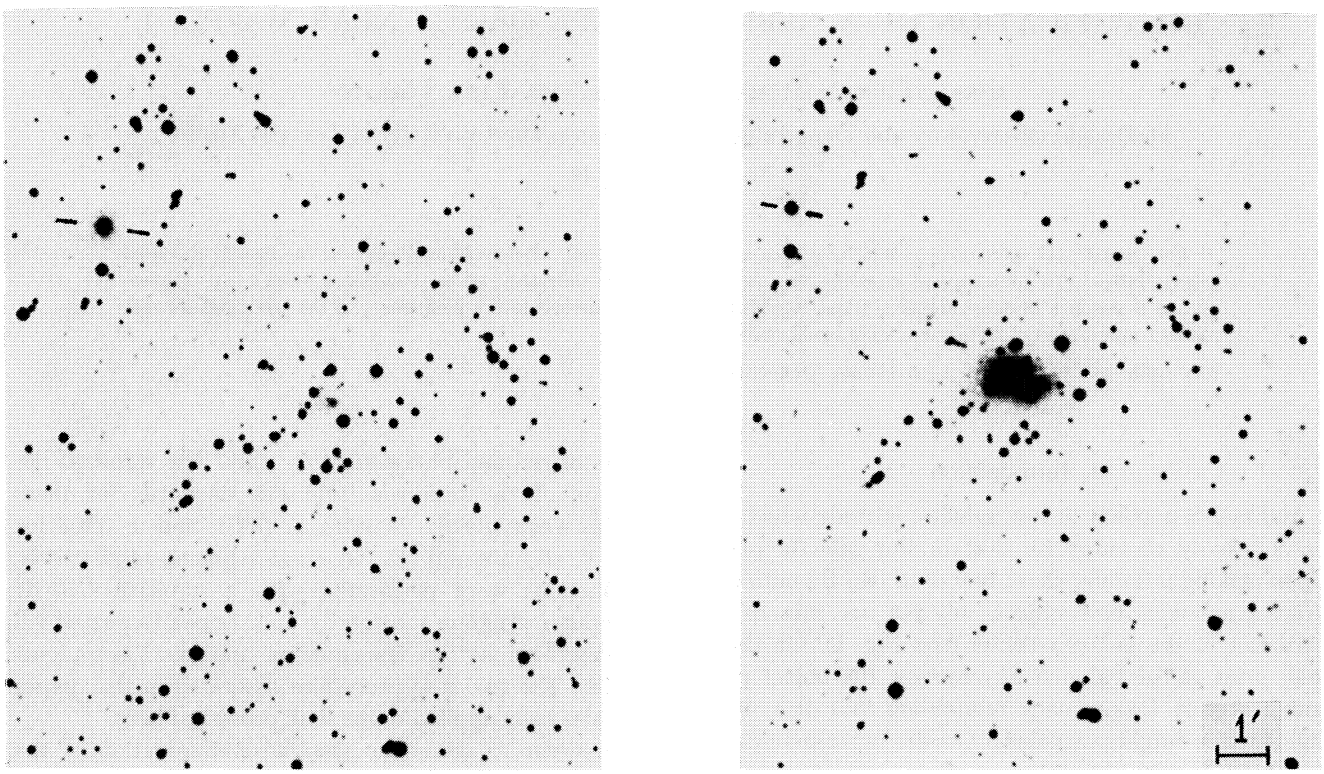

FIG. 1—Photographs of the field of Maffei 1 from the Palomar Sky Survey O print (left) and E print (right). The nebulous blue object (1950 coordinates $\alpha = 02^h33^m.2$, $\delta = +59°29'$) is indicated by the bars. North is at the top and east is at the left. Copyright by the National Geographic Society—Palomar Observatory Sky Survey. Reproduced by permission from the Hale Observatories.

TABLE I

PHOTOMETRIC OBSERVATIONS

Date	Ap (arcsec)	V	B-V	U-B	Tel
781029	8.2	13.96	+0.86	-0.02	0.91m
790105	19.2	13.86	+0.80	+0.02	0.76m
790826	16.0	13.85	+0.81	+0.03	0.91m
791021	16.0	13.92	+0.87	+0.02	0.91m
791025	16.0	13.96	+0.79	-0.04	0.91m
Mean		13.91	+0.83	0.00	
Mean error		0.024	0.016	0.014	

Angstroms. Wavelength calibration was done using observations of neon and argon lamps and flat-field variations were removed using observations of an incandescent lamp. Instrumental response was removed using observations of the spectrophotometric standards BD +40°4032 and Feige 15 calibrated by Stone (1977). Corrections for atmospheric extinction were derived from the mean values for McDonald Observatory. The fully calibrated spectrum is shown in Figure 2. We estimate the relative calibration of the observation to be accurate to about 5%. Due to thin clouds, the absolute flux scale may be in error by as much as 25%.

Observations of the spectrophotometric standards BD +25°3941 and Feige 25 were obtained on 1978 July 15 and 1979 January 30, respectively, with the same instrument in the same configuration. These spectra, along with the observation of BD +40°4032, were used to determine the spectral type of the nebulous blue object. Basic data for BD +25°3941, BD +40°4032, and Feige 25 are given in Table II. The data for the BD stars are from Hiltner (1956) and the parameters for Feige 25 are taken from Sargent and Searle (1968). The intrinsic color indices of the stars have been derived from the spectral types using the tabulations of Johnson (1963), and the color excesses for each have been computed. Values of A_V were computed using $R = A_V/E_{B-V} = 3.2$ (Olson 1975) and the observations were corrected for galactic extinction using the normal reddening law of Schild (1977). The resulting calibrated and dereddened spectra are displayed in Figure 3 along with the dereddened spectrum of the nebulous blue object (derived below).

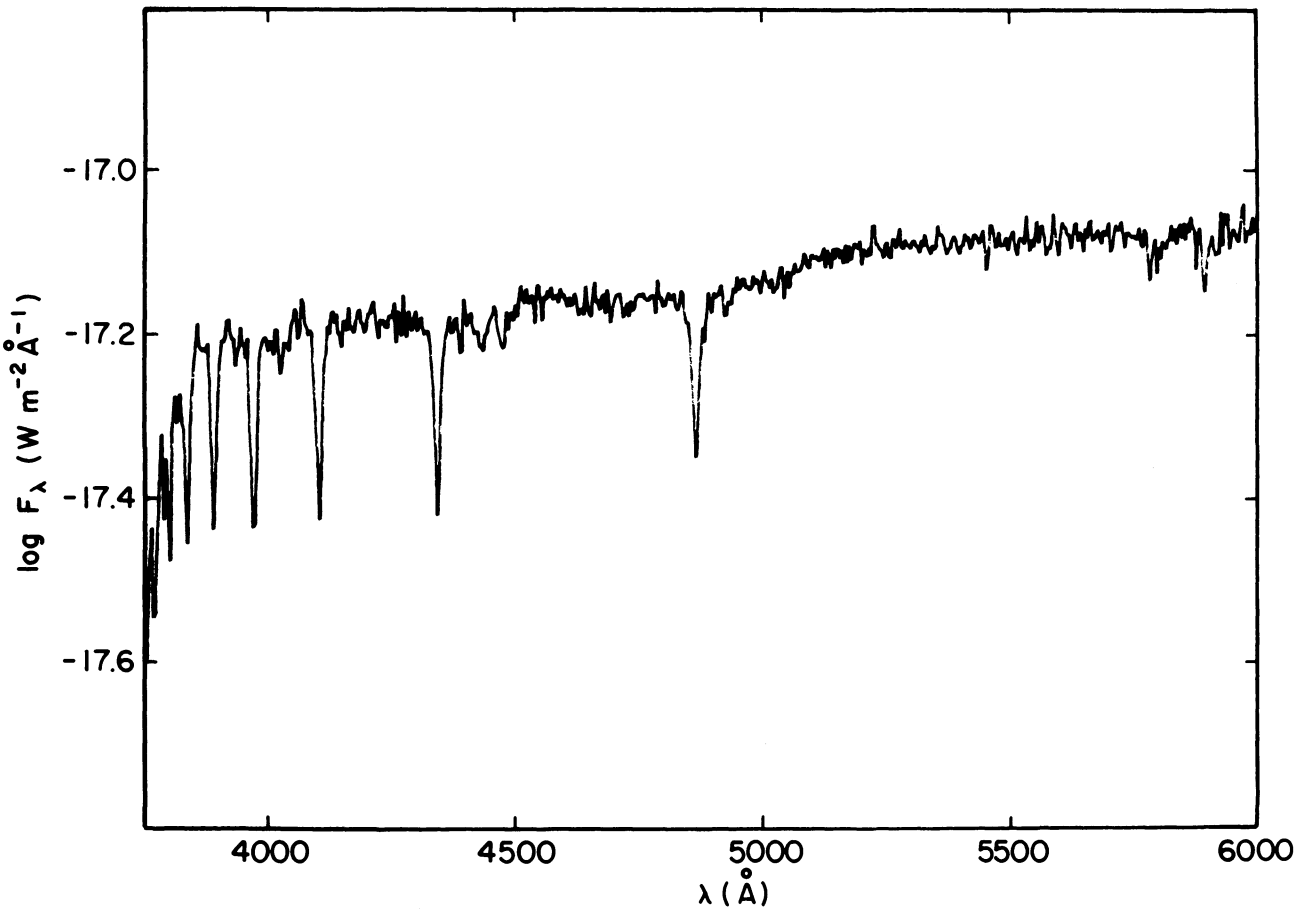

FIG. 2—The observed spectrum of the nucleus of the nebulous blue object, uncorrected for reddening.

TABLE II

SUMMARY OF BASIC DATA AND DERIVED PARAMETERS

Object	Sp	V	B-V	U-B	E_{B-V}	A_V	V_o	$(B-V)_o$	$(U-B)_o$
BD+25°3941	B1.5V	10.41	+0.70	-0.19	0.95	3.04	7.37	-0.25	-0.90
BD+40°4032	B2III	10.44	+0.25	-0.55	0.49	1.57	8.87	-0.24	-0.89
Feige 25	B6V	12.1	-0.04	-0.39	0.10	0.32	11.8	-0.14	-0.49
Blue Object	B3V	13.91	+0.83	0.00	1.04	3.33	10.58	-0.21	-0.77

III. Discussion

It can be seen in Figure 3 that the spectrum of the nebulous blue object contains strong hydrogen absorption lines as well as the helium absorption lines at λλ4026, 4144, 4388, 4471, and 4922 Angstroms which are characteristic of early to mid-B-type stars. No emission lines are present. In fact, the spectrum is very similar to those of the three standards. Since the spectrum shows no significant redshift and does not exhibit the composite spectral characteristics of a normal galaxy, we conclude that the nucleus of the nebulous blue object is a star. A comparison with the spectra of the three spectrophotometric standards shows that the spectral type is probably not later than B4. From the helium lines, we estimate the spectral type to be B3. A star with a spectral type this late will not excite an H II region, which explains the absence of emission lines (Kaplan and Pikelner 1970). It is, however, early enough to produce a blue reflection neb-

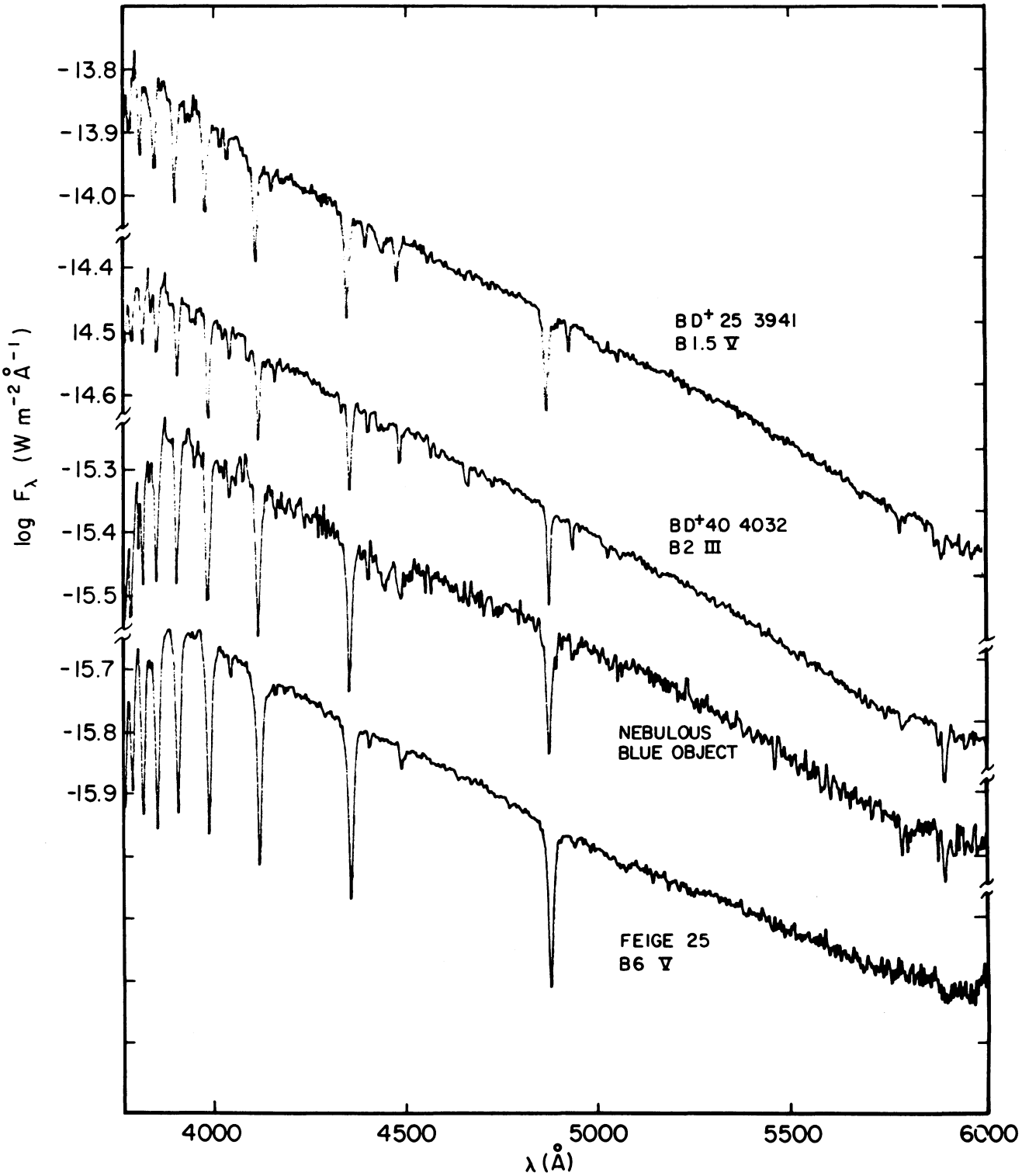

FIG. 3—The spectrum of the nucleus of the nebulous blue object, corrected for a visual extinction of $A_V = 3.33$ magnitudes. Also shown are the spectrophotometric standards BD +25°3941, BD +40°4032, and Feige 25, corrected for visual extinctions of 3.04, 1.57, and 0.32 magnitudes, respectively.

ula from surrounding dust (Hubble 1922*a*,*b*; van den Bergh 1966). We conclude that the nebulosity surrounding the star is a reflection nebula. The hydrogen lines are considerably broader than in the giant BD +40°4032 (B2 III) which suggests that the object is a main-sequence star (the instrumental profile is considerably nar-

rower than the width of the Balmer lines). This is confirmed by a measurement of the equivalent width of Hγ (W = 6.6 Angstroms). For a spectral type of B3, this equivalent width corresponds to luminosity class V (Balona and Crampton 1974).

The intrinsic color index of a B3 V star is $(B-V)_0 = -0.20$ (Johnson 1963) which is very different from the observed $(B-V) = +0.83$, indicating that the star is significantly reddened. An estimate of the amount of reddening can be obtained by application of the Q-method to the UBV photometry (Johnson and Morgan 1953). Because we are uncertain of the exact spectral class of the star, and because the color excess is large, we use the nomogram version of the Q-method given in Johnson (1958) to estimate the intrinsic color index of the star:

$$(B-V)_0 = -0.21 \pm 0.01$$

(the estimated uncertainty is based on the mean errors in the color indices). The resulting $(B-V)$ color excess, $E_{B-V} = 1.04 \pm 0.02$, allows us to determine a reddening-corrected value for the $(U-B)$ color excess using equation (3) of Johnson (1958):

$$E_{U-B}/E_{B-V} = (0.72 - \Delta X) + (0.05 + 0.5\,\Delta X)\,E_{B-V} \quad .$$

According to Johnson's Table I, $\Delta X = 0.07$ for a spectral type of B3 V. We get

$$(U-B)_0 = -0.77 \pm 0.02 \quad .$$

The values of $(B-V)_0$ and $(U-B)_0$ are consistent with those for a B3 star (Johnson 1963).

Taking the ratio of total-to-selective extinction to be $A_V/E_{B-V} = 3.2$ we derive the following for the visual absorption:

$$A_V = 3^{\mathrm{m}}.33 \pm 0^{\mathrm{m}}.06 \quad .$$

This leads to $V_0 = 10.58 \pm 0.07$ for the corrected visual magnitude. The spectrum of the nebulous star in Figure 3 has been corrected for this amount of extinction using the reddening law of Schild (1977).

Finally, we use the absolute magnitude calibration of a B3 V star to estimate the distance to the nebulous blue object. Adopting $M_V = -1.7$ (Blaauw 1963; Walborn 1972; Balona and Crampton 1974), we obtain a distance modulus of $V_0 - M_V = 12.3$, or $D = 2.9$ kpc. The galactic coordinates of this object, $\ell = 136°$, $b = -0°.6$, and the derived distance are consistent with it being in the Perseus arm of the Galaxy. This arm extends from $\ell = 95°$ to $145°$ at a distance of 2.5 to 5 kpc (Georgelin and Georgelin 1976).

The value of the derived extinction, $A_V = 3.33$ magnitudes, is also consistent with a previous determination of the galactic extinction in the region. Kohoutek and Haug (1972) applied the Q-method to 111 B stars within one degree of the center of Maffei 1 and derived $A_v = 3^{\mathrm{m}}.1 \pm 0^{\mathrm{m}}.4$. Because the nebulous star is very close to Maffei 1, our results indicate that Maffei 1 itself must suffer an extinction of at least 3.3 magnitudes provided the dust density is not significantly enhanced around the star. Note, however, that previous spectroscopic work on Maffei 1 has indicated that the total visual extinction toward the galaxy could be as great as 5 magnitudes if the contribution due to internal absorption is small (Spinrad et al. 1971). A detailed study of the galactic extinction toward Maffei 1 by a variety of methods is currently in progress and will be reported in a future paper.

IV. Conclusions

We conclude that a bright nebulous blue object near Maffei 1 is a galactic reflection nebula. The derived reddening of the associated star indicates that Maffei 1 suffers a visual extinction of at least 3.3 magnitudes.

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