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# THE HD 200775/NGC 7023 COMPLEX: A QUESTION OF REDDENING

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## ABSTRACT

The separation of the observed reddening of HD 200775 into intrinsic and interstellar components is rediscussed in the light of new surface-brightness data for NGC 7023, the reflection nebula surrounding HD 200775. Appropriate correction for the nebular contribution to reported ultraviolet flux measurements of HD 200775 leads to new values due to dust reddening: $E(B-V)_D = 0.44$, and due to intrinsic reddening: $E(B-V)_I = 0.13$–$0.26$. The newly derived extinction curve for HD 200775 is characterized by an abnormally weak interstellar 2200 Å absorption feature, and the deduced nebular brightness in the far-ultraviolet is consistent either with dust in NGC 7023 having a relatively high albedo ($a \approx 0.6$) and a nearly isotropic phase function ($g \approx 0.2$), or with low albedo dust ($a \approx 0.3$) with a forward-throwing phase function ($g \approx 0.6$).

*Subject headings:* nebulae: individual — nebulae: reflection — stars: individual

## I. INTRODUCTION

The Be star HD 200775 is the source of illumination for the reflection nebula NGC 7023. Viotti (1976) reported observations of the ultraviolet flux distribution of HD 200775 as obtained with the S2/68 experiment of the *TD 1* satellite (Boksenberg *et al.* 1973). From his analysis Viotti concluded that HD 200775 displays reddening due to dust measured by $E(B-V)_D = 0.29 \pm 0.04$, while its intrinsic reddening amounts to $E(B-V)_I = 0.28$ to $0.41$, depending on the method of determination of the color excess.

If true, this large amount of intrinsic reddening would place HD 200775 into a very exceptional role among Be stars. Recent studies by Briot (1978) and Schild (1978) indicate that intrinsic reddening in Be stars is generally less than $E(B-V)_I = 0.20$, with typical values closer to $E(B-V)_I = 0.10$. Garrison (1978) has studied HD 200775 spectrophotometrically as one of a group of 18 Herbig Ae/Be stars. He finds HD 200775 to be a typical member of this class. With regard to their circumstellar shell emission, giving rise to a smaller than normal Balmer discontinuity and the appearance of intrinsic reddening, these stars are indistinguishable from the classical Be stars studied by Schild and Briot (Garrison, private communication). In addition, there are independent reasons which suggest to us that Viotti's (1976) conclusions concerning HD 200775 could be in error. Viotti based his analysis on two important assumptions. First, the nebular contribution to the observed ultraviolet flux was assumed to be negligible; and second, the strength of the 2200 Å absorption feature was considered to be the true indicator for the amount of dust extinction occurring in the flux from HD 200775. We are presenting an alternative analysis of the *TD 1* observations of HD 200775, which will examine the validity of these assumptions in the light of new data on the surface brightness of NGC 7023.

## II. THE NEBULAR CONTRIBUTION

The ultraviolet spectrophotometer S2/68 had an entrance aperture of $12' \times 17'$[1] (Boksenberg *et al.* 1973). The average radius of NGC 7023, the reflection nebula surrounding HD 200775, is between 6′ and 10′ in the visible (Dorschner and Gürtler 1966), and thus the nebula essentially fills the spectrometer aperture. The photometer channel at 2740 Å had an aperture of $17' \times 2'$, so that only a part of NGC 7023, including the brightest nebulosity surrounding HD 20775, filled the field of view of the photometer channel. Viotti (1976) assumed that the nebular contribution to the measured ultraviolet flux attributed to HD 200775 was negligible, based on published measurements of the nebular surface brightness in the visible (Johnson 1968) and based on the fact that the photometric response at 2740 Å did not exhibit the anomalous broadening expected from scanning over an extended source.

Two circumstances cast doubt on this assumption. New photoelectric measurements of the surface brightness of NGC 7023 in four radial directions (Witt and Cottrell 1980) covering the wavelength range 3500–5500 Å indicate that the nebular intensity is increasing slowly with decreasing wavelength when compared with the stellar flux and is significantly higher than reported by Johnson (1968). The level of intensity near the star, combined with a relatively small surface-brightness gradient, results in a significant nebular flux when the integration is carried

[1] The entrance slot size of $12' \times 1'$ quoted by Viotti (1976) was incorrect, the error having occurred during typesetting (Viotti, private communication).

out over a 12′ × 17′ aperture, and a still nonnegligible flux for the 17′ × 2′ aperture of the photometer channel.

The second fact already quoted by Viotti (1976) is the flux measurements of HD 200775/NGC 7023 by the *Astronomical Netherlands Satellite* (*ANS*) using a 2.′5 × 2.′5 aperture.

Through the kind cooperation of Drs. C. C. Wu and J. Koornneef we have obtained these *ANS* measurements of HD 200775, and they are plotted for comparison in Figure 1 together with the fluxes reported by Viotti based on the S2/68 data. In addition, we have included in Figure 1 the HD 200775 fluxes measured with *TD 1* and published by Thompson *et al.* (1978) for the wavelengths 2740, 2365, 1965, and 1565 Å. It appears that the *ANS* fluxes are systematically smaller than those found by the S2/68 spectrometer of *TD 1*. We interpret this difference as being due to the smaller nebular contribution entering the *ANS* aperture, since a comparison of the absolute calibration of the two experiments (Strongylis and Bohlin 1979) indicates much smaller differences. In fact, in the far-ultraviolet, S2/68 fluxes tend to be lower by a few percent than corresponding *ANS* fluxes for identical sources (Wu, private communication).

An alternate explanation would be a real change in the ultraviolet flux distribution between the two observing epochs. HD 200775 is known to vary its optical shell spectrum on relatively short time scales of days or weeks, but there is no report on measurable photometric variations in the visible continuum. If variable line blocking by low-excitation lines in the UV were responsible for the measured difference in flux between the *ANS* and *TD 1* observations, correspondingly opposite flux variations should be observable in the visible in analogy to the Ap phenomenon (see, e.g., Molnar and Wu 1978). In the absence of such observations and in light of the

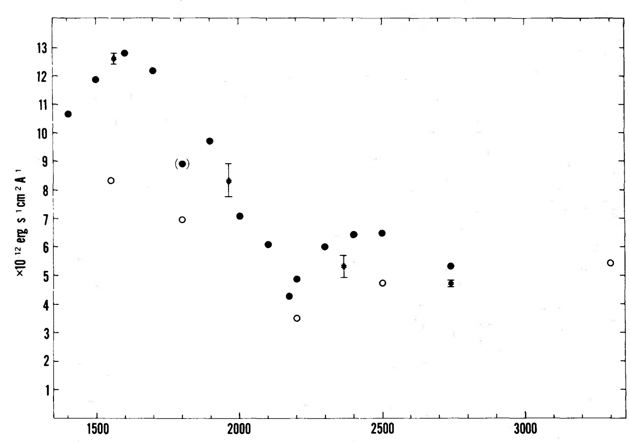


FIG. 1.—The reported flux measurements for HD 200775 by *TD 1* due to Viotti (1976) (*filled circles*) and to Thompson *et al.* (1978) (*stars with error bars*), as well as those by *ANS* provided by Wu and Koornneef (private communications) (*open circles*). The errors of the *ANS* observations lie within the size of the symbols.

demonstrated existence of the nebula NGC 7023 we prefer the hypothesis of a different nebular contribution in the two series of measurements, unless this approach leads to inconsistent or unreasonable results.

Experience has shown that the surface-brightness distribution in reflection nebulae can be represented by a power law to a good approximation (Andriesse, Piersma, and Witt 1977; Witt and Cottrell 1980). Let

$$\log (S/F^*) = p \times \log r + \text{const} \qquad (1)$$

represent this distribution, where $S$ is the nebular surface brightness in units of ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$ sr$^{-1}$, $F^*$ is the flux from the star received at the Earth in units of ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$, and $r$ is the angular distance from the illuminating star in arcseconds. In Figure 2, we have calculated the ratio of nebular flux to stellar flux, $F^N/F^*$, integrated over the apertures of the *TD 1* and *ANS* instruments, respectively, for a range of brightness distributions determined by the value of $\log (S/F^*)$ at $r = 100''$ distance and values of the power $p = -1.0$, $-1.5$, and $-2.0$. Extrapolation of the ground-based observations of NGC 7023 by Witt and Cottrell (1979) leads to an estimate of $\log (S/F^*)_{100''} = 5.1 \pm 0.15$ and $p = -1.40 \pm 0.15$ for the far-ultraviolet, indicating that in the *TD 1* observations the nebular contribution could be in excess of 40% of the total flux measured, based on Figure 2.

A similar calculation for the 17′ × 2′ aperture of the 2740 Å photometer of *TD 1* shows for the same conditions that approximately 20% of the total flux measured could be due to nebular contribution.

Independently, we have calculated the ratio of the flux—stellar plus nebular—seen by *TD 1* (except for 2740 Å) and by *ANS* as a function of $\log (S/F^*)_{100''}$ and $p$. These results are shown in Figure 3.

We then used the data shown in Figure 1 to derive observed ratios $F_{\text{tot}}(TD\ 1)/F_{\text{tot}}(ANS)$, entered with these into the graph of Figure 3 for $p = -1.4$ to derive values of $\log (S/F)_{100''}$, which in turn, when used in Figure 2, yielded our determinations of $F^N/F^*$ as a function of wavelength. The resulting values of this ratio are listed in column (3) of Table 1, while the values of $\log (S/F)_{100''}$ determined in the course of this process are shown as solid squares in Figure 4. It is important to note that the nebular surface brightness required to explain the observed difference between the *ANS* and the *TD 1* observations of HD 200775 is actually *less* than what might have been expected on the basis of an extrapolation of the ground-based observations of NGC 7023 by Witt and Cottrell (1980).

Actual observation of NGC 7023 in the ultraviolet can still reveal slightly different values of $\log (S/F)_{100''}$ if it is found that $p$ differs from the assumed value of $-1.40$ and if the nebula does not fill the entire large *TD 1* aperture. In § IV we shall demonstrate that the level of nebular contribution found is indeed consistent with expectations based on multiple scattering calculations, assuming reasonable parameters for nebular and dust-related parameters.

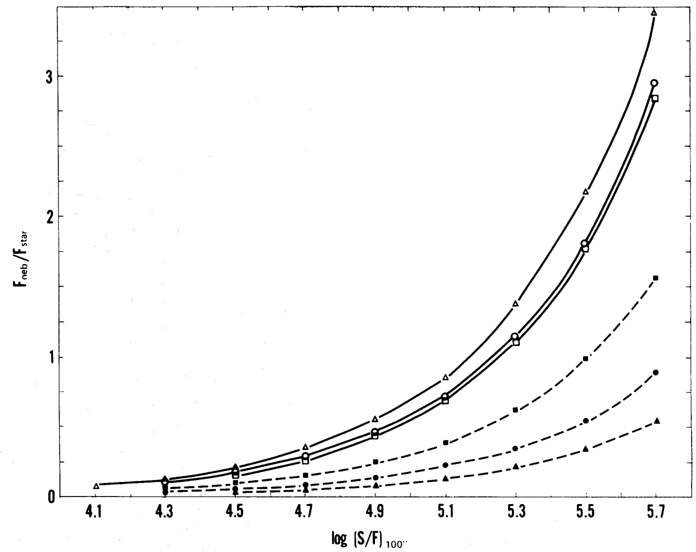


FIG. 2.—The ratio of nebular flux to stellar flux from the HD 200775/NGC 7023 complex as seen by the *ANS* (*dashed lines*) and the *TD 1* (*solid lines*) spectrophotometers, respectively. The nebular surface-brightness distributions are described by the relative surface brightness at 100″ from the star, log $(S/F^*)_{100''}$ and by the power $p$ of the power law brightness distribution: *triangles*: $p = -1.0$; *circles*: $p = -1.5$; *squares*: $p = -2.0$.

### III. THE ULTRAVIOLET EXTINCTION OF HD 200775

The principal effect of allowing for the nebular contribution in the measured *TD 1* flux of HD 200775 is a reduction of the ultraviolet stellar flux relative to the known stellar flux in the visual spectral region. As a consequence we predict larger values for the ultraviolet extinction, and by inference, for the visual extinction as well.

We base our discussion on Viotti's (1976) data as listed in his Table 2. His extinction curve for HD 200775, normalized to $\Delta(m_\lambda - m_{2740}) = 0.00$, was derived through comparison with the B3 IV, V stars $\nu$ Ori, $\xi$ Ori, and $\eta$ UMa, and was fitted to the mean extinction curve of Nandy *et al.* (1975) with the assumption that the 2200 Å absorption feature in HD 200775 is normal and, indeed, the best indicator for the total extinction for this star at all wavelengths. It should be noted, however, that HD 200775 has also been classified as late as B5 (Strom *et al.* 1972),

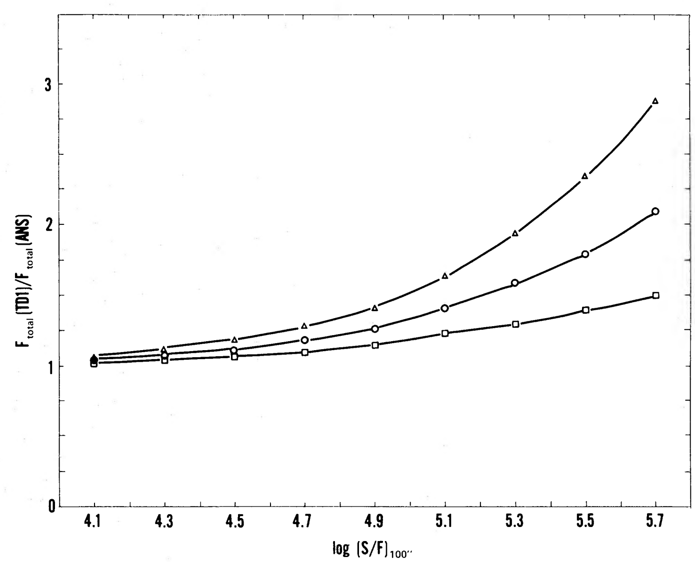


FIG. 3.—The ratio of the total *TD 1* flux and the total *ANS* flux, including HD 200775 and the respective parts of NGC 7023 seen by the two instruments. The nebular surface-brightness distributions are described by log $(S/F^*)_{100''}$ and the values of $p$: *triangles*: $p = -1.0$; *circles*: $p = -1.5$; *squares*: $p = -2.0$.

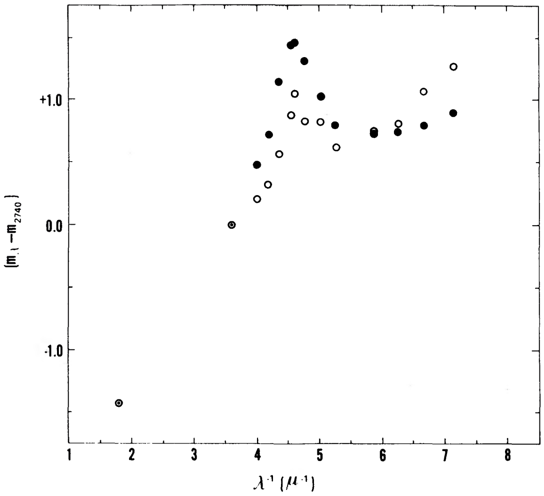


FIG. 4.—Mean magnitude difference HD 200775 minus three unreddened B3 IV, V stars ($\nu$ Ori, $\xi$ Ori, $\eta$ UMa), normalized to $(m_\lambda - m_{2740}) = 0.0$. Symbols: *open circles*: solution with variable nebular contribution of Table 1; *filled circles*: standard extinction curve normalized to $(m_v - m_{2740}) = -1.42$ (Nandy *et al.* 1975).

which would make a corresponding difference in its intrinsic energy distribution and a reduction in the derived reddenings.

If $F_\lambda$ is Viotti's (1976) total flux, and if $F^*(\lambda)$ and $F^c(\lambda)$ are the flux of HD 200775 and the relative fluxes of the three comparison stars, respectively, so that $F^c(2740)/F^*(2740) = 1$, then

$$\frac{F^c(\lambda)}{F^*(\lambda)} = \frac{F_\lambda}{F^*(\lambda)} \frac{F^*(2740)}{F_\lambda(2740)} \times 10^{0.4\Delta}\,, \qquad (2)$$

where the quantity $\Delta$ is taken from Table 2 of Viotti. From the ratio (2) new values for the mean magnitude difference between HD 200775 and the three B3 comparison stars $(m_\lambda - m_{2740})$ can be calculated.

TABLE 1

HD 200775/NGC 7023 FLUX AND REDDENING DATA

| λ (Å) (1) | $F_\lambda$[a] (2) | $(F^N/F^*)_\lambda$ (3) | $F_\lambda^*$[a] (4) | $(m_\lambda - m_{2740})$[b] (5) |
|---|---|---|---|---|
| 1400.... | 1.07 | 0.71 | 0.63 | 1.27 |
| 1500.... | 1.19 | 0.70 | 0.70 | 1.07 |
| 1600.... | 1.28 | 0.68 | 0.76 | 0.82 |
| 1700.... | 1.22 | 0.65 | 0.74 | 0.75 |
| 1800.... | (0.89) | 0.63 | (0.55) | ... |
| 1900.... | 0.97 | 0.59 | 0.61 | 0.61 |
| 2000.... | 0.71 | 0.53 | 0.46 | 0.82 |
| 2100.... | 0.61 | 0.48 | 0.41 | 0.82 |
| 2175.... | 0.43 | 0.41 | 0.30 | 1.05 |
| 2200.... | 0.49 | 0.41 | 0.35 | 0.87 |
| 2300.... | 0.60 | 0.42 | 0.42 | 0.57 |
| 2400.... | 0.64 | 0.42 | 0.45 | 0.33 |
| 2500.... | 0.65 | 0.42 | 0.46 | 0.21 |
| 2740.... | 0.53 | 0.22 | 0.43 | 0.00 |
| 5556.... | 0.41 | 0.00 | 0.41 | −1.42 |

[a] In units of $10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$.

[b] Normalized to 0.0 at 2740 Å.

In Table 1 we summarize the relevant data. We assume that $(F^N/F^*)_\lambda$ is variable with wavelength, declining from 0.71 at 1400 Å to 0.22 at 2740 Å, in accordance with the difference between the *ANS* and the *TD 1* fluxes as shown in Figure 1. The most significant differences between our solution and that of Viotti lie in the value of $m_{5556} - m_{2740}$. We find $-1.42$ in our case, to be compared with $-1.18$ in his case. The structure of the ultraviolet portion of the extinction curve when compared with Viotti's result is changed only slightly in the direction of a somewhat steeper rise at wavelengths shortward of 1900 Å in our case.

We see no particular reason to assume that the strength of the 2200 Å absorption feature in HD 200775 is normal. Savage (1975) shows that stars such as $\theta$ Ori, $\sigma$ Sco, $\rho$ Oph, and NU Ori, where the extinction most likely arises in a dense cloud intimately associated with the star in question, generally exhibit a weaker 2200 Å feature than expected on the basis of their visual extinction. Since the extinction of HD 200775 is produced primarily in the surrounding nebulosity NGC 7023, a similar result may be expected here. A further suggestion of abnormal extinction conditions for HD 200775 comes from the work of Snow (1973) and Snow, York, and Welty (1977), which recognizes the extreme weakness or absence of diffuse interstellar features in this star, typical for stars with mainly circumstellar extinction (Snow and Wallerstein 1972); but it must also be recognized that the correlation between the strength of the 2200 Å feature and other diffuse interstellar features is not particularly strong (Dorschner, Friedemann, and Gürtler 1977). We also note that by requiring a normal 2200 Å dust extinction, Viotti had to accept an exceptionally large intrinsic reddening in $B - V$ and a very significant deviation of the derived extinction curve for HD 200775 from the adopted curve at wavelengths shortward of 1600 Å. The intrinsic reddening, of course, is characterized by a total absence of the 2200 Å feature, since presumably it is not caused by dust at all (Schild 1977).

To illustrate the effect of the adoption of an alternative assumption, we shall take $(m_{5556} - m_{2740}) = -1.42$ of Table 1 as a measure of the true extinction in HD 200775. By scaling the extinction values relative to 2740 Å in Table 1, column (5), according to the extinction law of Nandy *et al.* (1975) with a ratio $A_v/E(2740 - V) = 0.95$ we arrive at the extinction curve for HD 200775. A listing of the adopted extinction curve and unreddened flux distribution for HD 200775 is contained in Table 2. A comparison with Viotti's values for the unreddened flux shows our fluxes to be approximately twice as large at most wavelengths.

A comparison of our adopted extinction curve with the mean wavelength dependence of interstellar extinction of Nandy *et al.* (1975) possessing the same value of $(m_{5556} - m_{2740})$ is shown in Figure 4. A reddening value of $E(B - V) = 0.44$ is found, leaving for the intrinsic reddening an amount $0.13 \le E(B - V)_I \le 0.26$, reflecting the uncertainty in the

TABLE 2

ADOPTED EXTINCTION AND FLUX DISTRIBUTION FOR HD 200775

| $\lambda$ (Å) (1) | $A_\lambda^{\text{adopt}}$ (mag) (2) | $F_\lambda{}^0$ ($10^{-11}$ ergs cm$^{-2}$ s$^{-1}$ Å$^{-1}$) (3) |
|---|---|---|
| 1400........ | 4.05 | 26.3 |
| 1500........ | 3.85 | 24.3 |
| 1600........ | 3.60 | 20.9 |
| 1700........ | 3.53 | 19.1 |
| 1800........ | ... | ... |
| 1900........ | 3.39 | 13.8 |
| 2000........ | 3.60 | 12.7 |
| 2100........ | 3.60 | 11.3 |
| 2175........ | 3.83 | 10.2 |
| 2200........ | 3.65 | 10.1 |
| 2300........ | 3.35 | 9.2 |
| 2400........ | 3.11 | 7.9 |
| 2500........ | 2.99 | 7.2 |
| 2740........ | 2.78 | 5.6 |
| 5556........ | 1.36 | 1.43 |

derived color excess of HD 200775 (Viotti 1976). This level of intrinsic reddening is entirely consistent with the findings of Briot (1978) and Schild (1978) for a collection of Be stars.

We find that our adopted extinction curve is steeper than the standard curve in the far-ultraviolet. While such a difference has been found elsewhere, and could be due to different dust properties, e.g., in $\zeta$ Oph (Bless and Savage 1972), the effect could be caused by a spectral mismatch between HD 200775 and the B3 comparison stars or an intrinsic ultraviolet flux deficiency in HD 200775 as discussed by Viotti (1976). The outstanding difference, however, lies in the relative weakness of the 2200 Å feature. The equivalent width of the 2200 Å feature is estimated to be about 50% of the standard value.

## IV. SCATTERING PROPERTIES OF THE NEBULAR DUST

NGC 7023 is only a small illuminated portion of an extended molecular cloud in which HD 200775 is embedded (Elmegreen and Elmegreen 1978; Haslam *et al.* 1978). The expected surface brightness of this reflection nebula, including the contribution due to multiple scattering, can be calculated by the methods described by Witt (1977*a*, *b*). The detailed geometry of the HD 200775/NGC 7023 system is not known; however, it can be taken to be independent of wavelength. We, therefore, have attempted to model the surface brightness near the star, $\log (S/F^*)_{100''}$ assuming that the star is embedded in the nebula by a wavelength-dependent optical depth given by the derived extinction of Table 2, column (2). For simplicity we have assumed that the star is centrally located in a uniform spherical dust cloud of radius $r$ at distance $d$ from the observer. This simplified model is fully adequate as long as our aim is only to calculate the nebular intensity *near* the star and to subsequently find the required scattering properties of the dust at different wavelengths, given the values of the albedo and the phase function asymmetry at 5500 Å. These values were assumed to be $a(5500) = 0.7$, and $g(5500) = 0.7$, in accordance with FitzGerald, Stephens, and Witt (1976) and in good agreement with other determinations of the visual scattering properties (Mattila 1970; Lillie and Witt 1976). The radius of the entire cloud was assumed to be $r = 5$ pc, and the distance $d$ was taken to be 350 pc, well within the uncertain distance range determined by Viotti (1969).

Results of the calculations are shown in Figure 5 in comparison with the values of $\log (S/F^*)_{100''}$ derived from the observations of Witt and Cottrell (1980) at 5550, 4700, 4100, and 3500 Å. The values of $\log (S/F^*)_{100''}$ in the ultraviolet derived from the difference in the *ANS* and *TD 1* fluxes at 1550, 1800, 2200, 2500, and 2740 Å are also shown. We note that these values, in relationship to the ground-based data at longer wavelength, appear very conservative and could likely be higher by 0.1 in $\log (S/F^*)_{100''}$. The indicated error bars are standard errors of the mean.

We conclude that within these errors the model matches the observations quite well, if one assumes a constant phase function with $g = 0.7$ at wavelengths $\lambda > 4000$ Å. At 3500 Å there is an indication of a reduction in either the value of the albedo, the phase function asymmetry, or both. If the albedo were held constant at $a = 0.7$, a value of $g \approx 0.6$ would be appropriate at this wavelength. Alternatively, a reduction in the albedo by an amount of 0.1 would be required. We slightly favor the former explanation, however, because the analysis of the surface-brightness distribution of the Merope nebula (Witt 1977*c*) indicated a first significant change in the phase function also at 3500 Å, and in that case the cause could be determined more definitely.

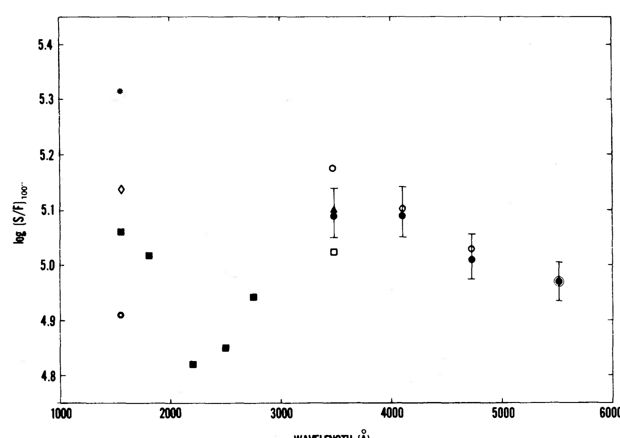


FIG. 5.—Comparison of observed values of $\log (S/F^*)_{100''}$ with predictions from multiple-scattering radiative transfer models. *Filled circles*: ground-based observations of Witt and Cottrell (1979); *filled squares*: results in the ultraviolet, this paper. Models: *open circles*: $a = 0.7$, $g = 0.7$; *open triangle*: $a = 0.7$, $g = 0.6$; *open square*: $a = 0.7$, $g = 0.5$; *star*: $a = 0.6$, $g = 0.6$; *open diamond*: $a = 0.6$, $g = 0.25$; *double circle*: $a = 0.6$, $g = 0$.

TABLE 3

IMPLIED SCATTERING PROPERTIES OF NGC 7023 DUST AT 1550 Å

| Albedo | Phase Function Asymmetry |
|---|---|
| 0.60................ | 0.20 |
| 0.50................ | 0.25 |
| 0.33................ | 0.60 |

The situation at 1550 Å is particularly interesting. If $\log (S/F^*)_{100''} = 5.06$ is indeed the correct value for the nebular surface brightness at 1550 Å, some possible combinations of $a$ and $g$ are listed in Table 3. The case for a high ultraviolet albedo can only be made if, at the same time, a nearly isotropic phase function is assumed. Alternatively, a forward-throwing phase function with $g = 0.6$ to 0.7 would require a low albedo $a \approx 0.3$. While the study of other reflection nebulosities over a wide range of wavelengths (Andriesse, Piersma, and Witt 1977; Witt 1977*c*; Witt and Lillie 1978) has rather strongly supported the case of a nearly isotropic phase function with high albedo in the far-ultraviolet, observations of the detailed surface-brightness distribution of NGC 7023 at $\lambda < 2000$ Å would be required to resolve this question in this instance.

The variation of $\log (S/F)_{100''}$ with wavelength at 1800, 2200, 2500, and 2740 Å is suggestive of an albedo variation similar to that found by Lillie and Witt (1976) with an albedo minimum at 2200 Å.

## V. CONCLUSIONS

1. We find convincing reasons to assume that the *TD 1*–S2/68 flux measurement of the B3e star HD 200775 was severely contaminated by a nebular contribution from the surrounding reflection nebula NGC 7023. In the far-ultraviolet, only approximately 60% of the total measured flux is attributed to HD 200775.

2. This result forces the derivation of a new extinction curve for HD 200775. In contrast to Viotti (1976), we suggest that the 2200 Å interstellar absorption feature in this star is not normal but rather abnormally weak, while the far-ultraviolet extinction as well as the extinction in the visual range appears more normal.

3. A new value for the intrinsic reddening of $0.13 \leq E(B-V)_I \leq 0.26$ has been derived for HD 200775. This value is significantly smaller than the value proposed by Viotti, and it is now consistent with typical values found for intrinsic reddening in Be stars by Briot (1978) and Schild (1978). We find no evidence that HD 200775 differs from normal Ae/Be stars of its type.

4. The dust scattering properties at 1550 Å, derived from the inferred nebular surface brightness in the far-ultraviolet, permit a high albedo of $a = 0.6$ only if the phase function is nearly isotropic.

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## REFERENCES

Andriesse, C. D., Piersma, Th. R., and Witt, A. N. 1977, *Astr. Ap.*, **54**, 841.
Bless, R. C., and Savage, B. D. 1972, *Ap. J.*, **171**, 293.
Boksenberg, A., *et al.* 1973, *M.N.R.A.S.*, **163**, 291.
Briot, D. 1978, *Astr. Ap.*, **66**, 197.
Dorschner, J., Friedemann, C., and Gürtler, J. 1977, *Astr. Ap.*, **58**, 201.
Dorschner, J., and Gürtler, J. 1966, *Astr. Nach.*, **289**, 57.
Elmegreen, D. M., and Elmegreen, B. G. 1978, *Ap. J.*, **220**, 510.
FitzGerald, M. P., Stephens, T. C., and Witt, A. N. 1976, *Ap. J.*, **208**, 709.
Garrison, L. M., Jr. 1978, *Ap. J.*, **224**, 535.
Haslam, C. G. T., Hills, D. L., Matthews, H. E., and Salter, C. J. 1978, *Astr. Ap.*, **70**, 575.
Johnson, H. M. 1968, in *Nebulae and Interstellar Matter*, ed. B. M. Middlehurst and L. H. Aller (Chicago: University of Chicago Press), p. 65.
Kurucz, R. L., Peytremann, E., and Avrett, E. H. 1974, *Blanketed Model Atmospheres for Early-Type Stars* (Washington, D.C.: Smithsonian Institution).
Lillie, C. F., and Witt, A. N. 1976, *Ap. J.*, **208**, 64.
Mattila, K. 1970, *Astr. Ap.*, **9**, 53.
Molnar, M. R., and Wu, C.-C. 1978, *Astr. Ap.*, **63**, 335.
Nandy, K., Thompson, G. I., Jamar, C., Monfils, A., and Wilson, R. 1975, *Astr. Ap.*, **44**, 195.
Savage, B. D. 1975, *Ap. J.*, **199**, 92.
Schild, R. E. 1977, *Bull. AAS*, **9**, 373.
———. 1978, *Ap. J. Suppl.*, **37**, 77.
Snow, T. P. 1973, *Pub. A.S.P.*, **85**, 590.
Snow, T. P., and Wallerstein, G. 1972, *Pub. A.S.P.*, **84**, 492.
Snow, T. P., York, D. G., and Welty, D. E. 1977, *A.J.*, **82**, 113.
Strom, S. E., Strom, K. M., Yost, J., Carrasco, L., and Grasdalen, G. 1972, *Ap. J.*, **173**, 353.
Strongylis, G. J., and Bohlin, R. C. 1979, *Pub. A.S.P.*, **91**, 205.
Thompson, G. I., Nandy, K., Jamar, C., Monfils, A., Houziaux, L., Carnochan, D. J., and Wilson, R. 1978, *Catalogue of Stellar Ultraviolet Fluxes* (London: Science Research Council).
Viotti, R., 1969, *Mem. Soc. Astr. Italiana*, **40**, 75.
———. 1976, *Astr. Ap.*, **51**, 375.
Witt, A. N. 1977*a*, *Ap. J. Suppl.*, **35**, 1.
———. 1977*b*, *Ap. J. Suppl.*, **35**, 21.
———. 1977*c*, *Pub. A.S.P.*, **89**, 750.
Witt, A. N., and Cottrell, M. J. 1980, *A.J.*, in press.
Witt, A. N., and Lillie, C. F. 1978, *Ap. J.*, **222**, 909.

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