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INFRARED SOURCES IN SHARPLESS 228

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ABSTRACT

Infrared photometry from 1.65 to 20 μ of the optical nebula Sharpless 228 indicates the pressure of a compact (< 5″) emission region within an extended region of low but uniform surface infrared brightness. The flux density of the compact source rises steeply from 1.65 to 3.5 μ and somewhat less so from 3.5 to 20 μ. The compact source is associated with a stellar-like optical object having emission lines of Hα and [N II] and suffering from considerable extinction. It appears to be a compact H II region.

Subject headings: infrared sources — nebulae, individual — spectrophotometry

I. INTRODUCTION

Sharpless 228 (Sharpless 1959) is a small, approximately circular (diameter 2′) H II region located in a more extended region of diffuse emission. Radio-continuum measurements have been reported by Terzian (1970), Terzian and Pankonin (1972), Felli and Churchwell (1972), and Churchwell and Walmsley (1973). These data indicate that Sh 228 is probably a thermal source and may be optically thick at 1400 MHz. The nebula was included in a study of the infrared properties of small H II regions and has been singled out here because of its unique and interesting characteristics.

II. INFRARED OBSERVATIONS

The infrared observations were made on the 60-inch (152-cm) Tillinghast reflector at Mount Hopkins Observatory. A PbS photoconductor was used from 1.65 to 3.5 μ, and a Ge:Ga bolometer was used at 10 and 20 μ. Both systems have cooled filters and apertures. A region 5′ square around Sh 228 was scanned at 2.2 μ, and one extended source of emission was found corresponding in position to the optical nebula.

Very close to the center of this source an unresolved (diameter < 5″) source of 3.5 μ emission was also found. Subsequently, observations of the extended source were made at 1.65, 2.2, and 3.5 μ with apertures of diameter 15″ to 55″ centered on the unresolved source./Since emission at these wavelengths comes from a region larger than the largest aperture used, it was necessary to correct the measurements for flux entering the reference beam of the photometer. The technique is the same as that discussed by Frogel and Persson (1972). In order to examine the spatial distribution of the flux, the measurements made through the 15″ aperture (where the flux is due primarily to the unresolved source) were subtracted from the larger apertures. To compensate for this subtraction, the actual aperture diameter was reduced so that $\pi \times$ (new aperture radius)^2 would give the area of the resulting annulus. The results are shown in figure 1. The errors at 2.2 and 3.5 μ are especially large because the flux from the unresolved source dominates the emission at these wavelengths. The energy distribution of the extended source as measured with an equivalent aperture diameter of 54″ is shown in figure 2.

The unresolved source was measured at 10 and 20 μ with a 13″.5 diameter aperture. These results were combined with the measurements made with the 15″ aperture at 1.65–3.5 μ to produce the energy distribution shown in figure 2.

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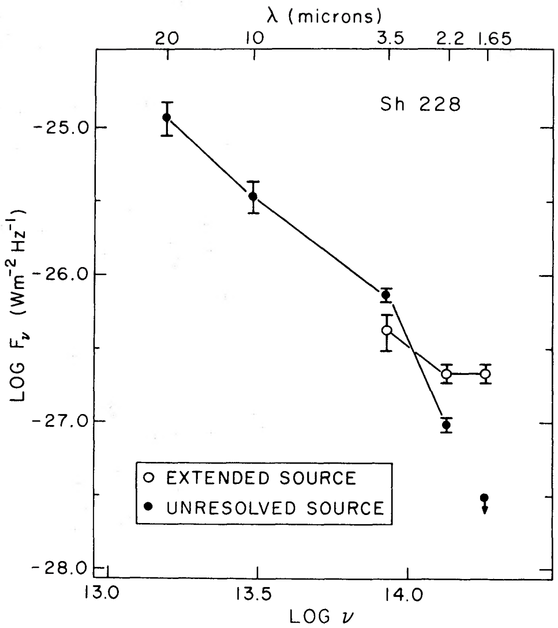

FIG. 1.—The observed log F_ν (W m^{-2} Hz^{-1}) (with the measurements through the 15″ aperture subtracted), versus equivalent aperture diameter (arc sec) plotted logarithmically for the extended source Sh 228. The dashed line shows the distribution of a source of constant surface brightness.

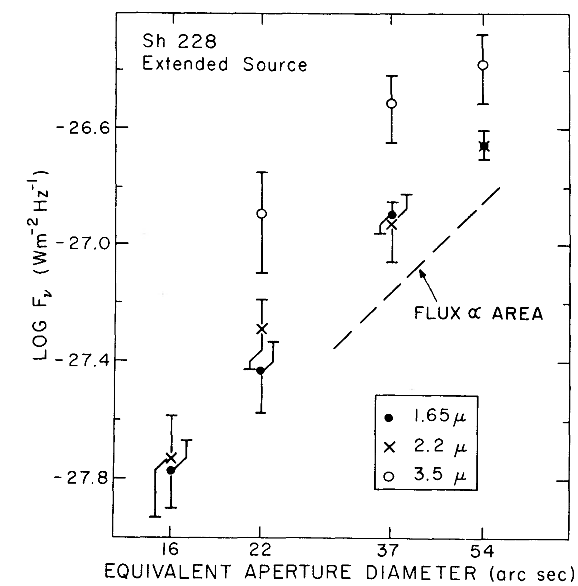

FIG. 2.—The spectral energy distribution log F_ν (W m^{-2} Hz^{-2}) versus log ν (Hz) for the two sources in Sh 228.

The absolute position of the unresolved source was determined by offsetting from field stars whose positions were subsequently measured with respect to a Smithsonian Catalog star. The (1950.0) position is

$$\alpha = 5^{\mathrm{h}}10^{\mathrm{m}}0^{\mathrm{s}}.4 \pm 0^{\mathrm{s}}.3\,; \qquad \delta = +37^\circ 23' 41'' \pm 3''\,.$$

III. OPTICAL OBSERVATIONS

Sharpless 228 was observed with the 200-inch (508-cm) Hale reflector as part of a large program of spectrophotometric observations of H II regions and planetary nebulae. Photographs obtained with the television guiding system showed a faint starlike object at the position ($\pm 2''$) of the unresolved infrared source. Optical observations made with the multichannel spectrophotometer clearly indicate Hα, [N II] λ6584, and continuum emission from the starlike object. Owing to time limitations and the faintness of the source, the measurements of Sh 228 are not complete. With a $3''.5$ diameter aperture we find $I(\mathrm{H}\alpha) = 1.3 \pm 0.2 \times 10^{-13}$ ergs cm^{-2} s^{-1}, $I(\lambda 6584)/I(\mathrm{H}\alpha) \simeq 0.3$, $F_\nu(\lambda 10{,}500) = 2.8 \pm 0.4 \times 10^{-26}$ ergs cm^{-2} s^{-1} Hz^{-1}, and $F_\nu(\lambda 5000) < 2 \times 10^{-27}$ ergs cm^{-2} s^{-1} Hz^{-1}.

The details of the observing procedure will be published separately. The data were corrected for seeing losses by observing standard stars with two apertures, but the observed fluxes may be underestimated if the entire object is not included in an $3''.5$ aperture. Nevertheless, the presence of hydrogen recombination- and forbidden-line emission implies that the starlike object is an H II region. In fact, the ratio of the intensity of [N II] λ6584 to Hα is the same as that found for the optical component of the compact H II region K3-50 (Persson and Frogel 1973).

IV. DISCUSSION

The infrared spectral energy distribution of the compact source in Sh 228 (fig. 1) is similar to but bluer than that of K3-50, a compact H II region with small or unresolved radio, infrared, and optical components (Neugebauer and Garmire 1970; Rubin and Turner 1971; Persson and Frogel 1973). The luminosity of the Sh 228 compact infrared source in the 3.5 to 20 μ region is $10^3(D/4\ \mathrm{kpc})^2\, L_\odot$ (a distance D of 4 kpc places Sh 228 in the Perseus arm), a value considerably lower than that of other compact H II regions. In terms of color and luminosity, this source bears a closer resemblance to W3/IRS 5 (Wynn-Williams, Becklin, and Neugebauer 1972), an unresolved infrared source with no associated radio emission, than to those that are associated with radio emission.

The $[1.65\ \mu] - [2.2\ \mu]$ color of the extended source (fig. 1) is consistent with hydrogenic recombination emission insignificantly affected by reddening. The 2.2-μ total flux is $\geqslant 0.3$ f.u., consistent with 0.5 f.u. predicted from the 2.7-GHz flux. There is an excess of emission at 3.5 μ, however, compared with the 2.2-μ emission. This is taken as due to thermal emission by heated dust grains in the optical nebula Sh 228. The manner in which the fluxes increase with increasing aperture size (fig. 2) indicates that (*a*) the surface brightness of the ionized hydrogen emission within the central arc minute of Sh 228 is constant; (*b*) there are no strong differential reddening effects at 1.65 and 2.2 μ; and (*c*) the ratio of dust to gas emission, as given qualitatively by the $[3.5\ \mu] - [2.2\ \mu]$ color, does not show any large variation over the face of the nebula.

From the optical data, the upper limit on $F_\nu(\lambda 5000)$ can be used to show that $C[\equiv \Delta \log(\mathrm{H}\beta)] > 3$. This assumes that the Hα flux gives the contribution from the hydrogen (recombination plus two-photon) continuum to the flux at 10,500 Å. The excess flux at this wavelength is attributed to light from the star, which is in the compact optical nebula and presumably is responsible for its excitation. This excess is used to predict the reddened flux at λ5000 Å, if $F_\nu \propto \nu^2$ for the starlight. Similarly, if it is assumed that all of the flux at 10,500 Å is due to reddened recombination emission, then a conservative upper limit of $C < 6$ is established.

The absence of measurable reddening for the $[1.65\ \mu] - [2.2\ \mu]$ colors of the extended infrared component, together with the lower limit for C, show that the large amount of extinction found for the small optical source must be caused by dust in its immediate vicinity. If the flux at 1.65 μ and 2.2 μ of the compact infrared source is due primarily to recombination emission, its $[1.65\ \mu] - [2.2\ \mu]$ color provides additional evidence for localized extinction. The *Palomar Sky Survey* prints suggest that a narrow dust lane runs through Sh 228, close to the position of the compact infrared and optical sources. This dust lane could be responsible for the large amount of extinction.

Finally, we point out that although the compact optical and infrared sources are closely associated, the data presented here do not allow us to say that they are spatially coincident. Observations at high resolution are required to resolve this question.

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REFERENCES

Churchwell, E., and Walmsley, C. M. 1973, *Astr. and Ap.*, **23**, 117.
Felli, M., and Churchwell, E. 1972, *Astr. and Ap. Suppl.*, **5**, 369.
Frogel, J. A., and Persson, S. E. 1972, *Ap. J.*, **178**, 667.
Neugebauer, G., and Garmire, G. 1970, *Ap. J.* (*Letters*), **161**, L91.
Persson, S. E., and Frogel, J. A. 1973, *Ap. J.*, to be submitted.
Rubin, R. H., and Turner, B. E. 1971, *Ap. J.*, **165**, 471.
Sharpless, S. 1959, *Ap. J. Suppl.*, **4**, 257.
Terzian, Y. 1970, *A.J.*, **75**, 1160.
Terzian, Y., and Pankonin, V. 1972, *A.J.*, **77**, 115.
Wynn-Williams, C. G., Becklin, E. E., and Neugebauer, G. 1972, *M.N.R.A.S.*, **160**, 1.