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OBSERVATIONS OF NGC 6302 FROM 0.35 TO 20 MICRONS

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ABSTRACT

Observations of NGC 6302 from 0.35 to 20 μ have been made. From 3.5 to 20 μ there is a large excess of emission that can be attributed to dust particles heated by resonantly trapped Lα photons. The continuous emission from 0.35 to 2.2 μ can be accounted for by hydrogen and helium recombination emission at an electron temperature of 17,400° K. The value of the interstellar reddening constant C has been determined to be 1.0 ± 0.1. When combined with previous results, this work shows that NGC 6302 is similar to the nebula NGC 7027 in several respects.

Subject headings: infrared sources — nebulae, individual — planetary nebulae — spectrophotometry

I. INTRODUCTION

The peculiar southern nebula NGC 6302 has been studied at optical wavelengths by Evans (1959), Minkowski and Johnson (1967), and Oliver and Aller (1969). These observations show that NGC 6302 is a very irregular and filamentary nebula that exhibits a wide range of excitation and ionization conditions, and is expanding in a manner suggesting an explosive origin. Large errors in the radio continuum measurements, summarized by Higgs (1971), prevent a straightforward interpretation of the radio spectrum of NGC 6302, but the data do point to an electron density $>10^4$ cm^{-3}. In this *Letter* we present optical spectrophotometric and infrared photometric data for NGC 6302 that allow a comparison to be drawn between it and the planetary nebula NGC 7027.

II. OPTICAL OBSERVATIONS AND RESULTS

Photoelectric observations of NGC 6302 were made on four nights in April 1973 with a two-channel scanner on the 36-inch (92-cm) telescope at Cerro Tololo Inter-American Observatory, Chile. A rectangular entrance aperture ($17'' \times 34''$, aligned east-west) was centered on the brightest knot in the nebula but did not include the entire object. An exit slit of 20Å in the second order was used to measure strong emission lines and 10 line-free continuum points in the wavelength range 3500–8100 Å. Standard stars listed by Oke (1964), and a mean of the Hayes (1970) and Oke and Schild (1970) calibrations of Vega, were used to obtain absolute fluxes. The line strengths used in this paper have been corrected for the contamination by the underlying continuum, and are given in table 1. Further observational results will be given in a subsequent paper.

The interstellar extinction of NGC 6302 has been derived from a comparison of the observed Balmer decrement for Hβ, Hγ, and Hδ, with the theoretical value expected under case B conditions (Brocklehurst 1971). The Hα flux was not used because it is several times weaker than the neighboring [N II] lines with which it is blended. The observed Hδ flux was corrected for the presence of the N III line at 4097.31 Å by using the data of Oliver and Aller (1969). A value of the interstellar absorption

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TABLE 1

EMISSION-LINE FLUXES FROM NGC 6302

λ	ION	LOG FLUX (ergs cm^{-2} s^{-1})* Observed	Corrected for Extinction	σ_m
4101	H I	−11.50	−10.29	±0.03
4340	H I	−11.23	−10.09	0.02
4363	[O III]	−11.32	−10.18	0.02
4471	He I	−12.08	−10.98	0.04
4686	He II	−11.00	−9.96	0.02
4861	H I	−10.77	−9.77	0.02
5007	[O III]	−9.60	−8.64	0.02

* Flux entering an aperture $17'' \times 34''$.

parameter $C(\equiv\Delta\log \mathrm{H}\beta) = 1.00 \pm 0.10$ was obtained from both Balmer line ratios for the Whitford reddening law. This value was used to obtain the corrected line fluxes given in table 1. The radio flux is consistent with our measured value of the Hβ flux and this value of C when account is taken of the limited size of the measuring aperture. The [O III] ratio λ5007/λ4363 was used with the formula of Aller and Czyzak (1968) to deduce an electron temperature $T_e = 17{,}400°$ K. The agreement of this result with that of Oliver and Aller (1969) must be regarded as fortuitous in view of the differences in the observed fluxes and the derived values of the reddening parameter.

The observed line-free continuum fluxes corrected for reddening and normalized by the observed Hβ flux are presented in figure 1. Also shown in figure 1 is the theoretical continuous spectrum of H and He (Brown and Mathews 1970) for $T_e = 17{,}400°$ K, a two-photon efficiency corresponding to $N_e = 10^4$ cm^{-3}, and no conversion of Lα to the two-photon continuum. The He abundances used in this computation were $N(\mathrm{He}^+) = 0.13N(\mathrm{H}^+)$, and $N(\mathrm{He}^{++}) = 0.06N(\mathrm{H}^+)$, which were obtained from our values for the fluxes in the λ4471 line of He I and the λ4686 line of He II. A discussion of this apparently high He abundance is deferred to a later paper. It is clear that the shape, level, and Balmer jump of the observed continuum are in good agreement with those expected from recombination processes at a temperature near that indicated by the forbidden lines.

III. INFRARED OBSERVATIONS AND RESULTS

The infrared observations reported here were made on the 40-inch (1-meter) telescope of the Las Campanas Observatory in Chile. A PbS photoconductor was used from 1.65 to 3.5 μ in 1972 April, and a Ge:Ga bolometer at 10 and 20μ in 1973 March. Both systems use cooled filters and concentric circular focal-plane apertures.

The telescope was centered on the optically brightest part of the nebula, which is 2″–3″ west of the dark lane that runs approximately NS through the bright central condensation. A right ascension scan at 10 μ through the nebula showed that the optical and infrared centers coincide.

Figure 2*a* shows that the energy distribution F_ν varies as ν^{-3} between 3.5 and 20 μ, and at 20 μ is 100 times greater than expected from the 10-GHz flux (assumed to arise from optically thin thermal bremsstrahlung) of 2.4×10^{-26} W m^{-2} (Higgs 1973). This excess is similar to those observed in some H II regions (e.g., Becklin *et al.* 1973; Kleinmann 1973) and in the planetary nebula NGC 7027 (Gillett, Low, and Stein 1967; Willner, Becklin, and Visvanathan 1972). The dependence of flux on aperture is given in figure 2*b*. It is evident that NGC 6302 is an extended infrared

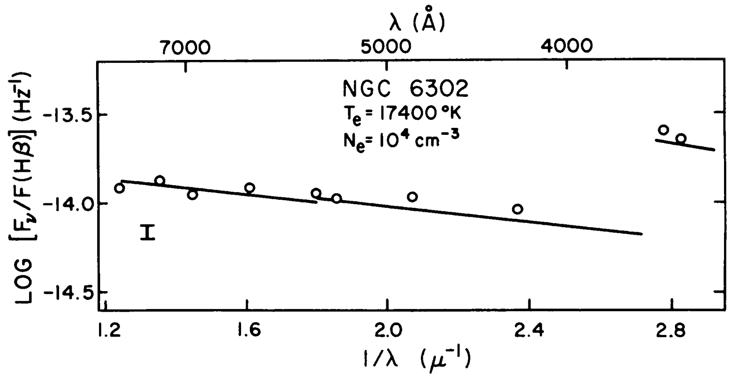

FIG. 1.—The continuous spectrum of NGC 6302. *Circles,* the observational data corrected for reddening. The single bar represents an estimate of the maximum probable error for the faintest points. *Solid line,* the theoretical continuum for $T_e = 17{,}400°$ K, $N(\mathrm{He}+) = 0.13\ N(\mathrm{H}+)$, and $N(\mathrm{He}++) = 0.06\ N(\mathrm{H}+)$. An electron density of 10^4 cm^{-3} was assumed in order to estimate the two-photon efficiency.

source, since the flux increases with increasing aperture size at all wavelengths. The 2.2-μ flux measured with an aperture of 59″ agrees with that expected from ionized hydrogen emission alone if allowance is made for extinction at 2.2 μ [$\Delta\log F_\nu$ (2.2 μ) = 0.08], and for the fact that even an aperture of 59″ diameter does not encompass the outlying wisps of nebulosity. The [1.65 μ] — [2.2 μ] color corrected for reddening ($C = 1.0$) is that expected for ionized hydrogen.

It was not possible to measure the total 10- and 20-μ fluxes from NGC 6302. Figure

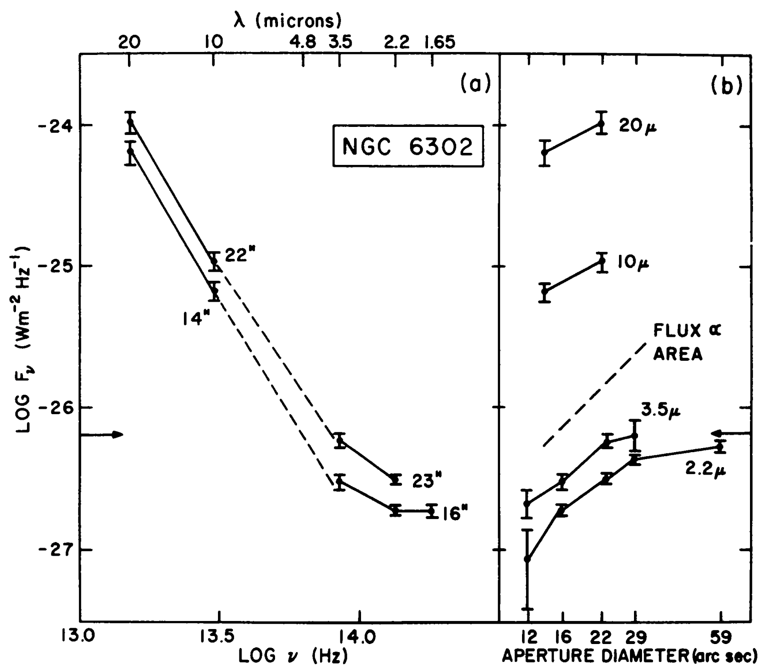

FIG. 2.—(*a*) The infrared energy distribution of NGC 6302. The aperture diameters (in arc seconds) are labeled. (*b*) The distribution of infrared flux with aperture diameter (plotted logarithmically). In each figure the arrow indicates the 2.2-μ flux predicted from the radio flux with the formula of Willner *et al.* (1972). Error bars are 1 standard deviation of the mean.

2*b* shows, however, that the dependences of flux on aperture are not very different at 2.2, 10, or 20 μ. Scaling up the long-wavelength fluxes to an aperture of 59″ arc sec then gives for the total fluxes, $2.0 \pm 0.5 \times 10^{-25}$ and $2.0 \pm 0.5 \times 10^{-24}$ W m^{-2} Hz^{-1} at 10 and 20 μ, respectively. The flux integrated over frequency from 3.5 to 25 μ is then $2.4 \pm 0.6 \times 10^{-11}$ W m^{-2}. This apparent luminosity may be compared with the predicted Lα luminosity of $2.7 \pm 0.3 \times 10^{-11}$ W m^{-2}, which is obtained from the radio data and the formula of Rubin (1968). That these luminosities are comparable indicates that the 3.5- to 25- μ excess flux is probably due to dust particles heated by Lα photons resonantly trapped within the nebula.

IV. CONCLUSIONS

From 0.35 to 25 μ the continuous spectrum of NGC 6302 can be explained by thermal processes alone. In the optical and near-infrared region this spectrum arises from hydrogen and helium recombination emission at an electron temperature near 17,400° K. From 3.5 to 25 μ the emission may be plausibly ascribed to radiation from dust particles mixed with the ionized gas and heated by the ambient Lα radiation field. In these respects, NGC 6302 is quite similar to NGC 7027, a filamentary object having $T_e = 18{,}000°$ K (Danziger and Goad 1972; Miller and Mathews 1972). Several other properties are also common to both objects. The central stars, which must be of very high temperature to give the high ionization and excitation observed in both nebulae, are not visible. Additionally, in both there is a wide range in the ionization conditions of various elements. For example, they radiate strong lines of [O I] at λλ6300, 6363, as well as the recombination line of He II at λ4686, and lines of [Ne V]. Minkowski and Johnson (1967) point out that there is patchy obscuration in the vicinity of NGC 6302. The recent high-resolution radio map of NGC 7027 (Scott 1973) shows by comparison with an Hα photograph that there is obscuration associated with this object too. We conclude, therefore, that NGC 6302 is a nebula not unlike NGC 7027, with mass motions that must yet be explained.

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