THE SPECTRAL ENERGY DISTRIBUTION OF NGC 1275

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ABSTRACT

An analysis of absolute spectral energy distributions for NGC 1275 (Per A) covering the wavelength interval λλ3300-10800 is presented. The data are consistent with the heavy reddening discovered by Wampler. The Hα intensity varied by less than 10 percent between the times of Wampler's earlier measurements and the two occasions of our observations. The line emitting region has a characteristic density $\sim 10^{4.5}$ cm^{-3}, a mass $\sim 10^{5.5} M_{\odot}$, and a volume filling factor $\sim 10^{-6}$. The gas may be ionized by shock waves or by nonthermal or stellar radiation.

It is again suggested, in the vein of Minkowski's original proposal, that the high velocity, emission-line knots described by Minkowski are H II regions in a Perseus cluster galaxy or intergalactic gas cloud seen in projection against NGC 1275.

I OBSERVATIONS

The nuclear region of NGC 1275 was observed with the 200-inch (5-meter) multichannel spectrometer on the nights of 1970 November 19-20 and 1974 October 9-10. The observations gave complete wavelength coverage in the interval $\lambda\lambda$3300-10800 with bandpasses of 40 Å for $\lambda < 5900$ Å and 80 Å for $\lambda > 5900$ Å. An aperture diameter of 7" was used for both observations. The overall energy distributions are similar on the two dates but the continuum is 0.28 mag brighter in 1974. The difference is almost certainly real. Figure 1 shows the absolute spectral energy distribution for the 1974 observation. The fluxes are based on the absolute calibration of α Lyrae given by Oke and Schild (1970). A comparison of the absolute intensities of the stronger emission lines on the two nights shows no evidence that they have changed in the interval. A comparison with Wampler's (1971) data also shows no evidence for changes in the emission-line strengths. Differences in weaker line intensities can be attributed to low resolution and uncertainty in the continuum level. The average of our emission-line intensities, and those measured by Wampler (1971) are listed in table 1.

II REMARKS

a) Reddening

Wampler (1971) determined the reddening in NGC 1275 by comparing the [S II] λ10320 and λ4072 line intensities. Since our data in the infrared are not of high quality we cannot verify the measurements. We have adopted $E_{B-V} = 0.63$, which is very close to Wampler's result. In table 1 reddening corrected line intensities relative to Hβ, are listed; they are based on Whitford's (1958) reddening law. The adopted reddening yields a ratio for Hα/Hβ of 4.6, if we adopt the N II/Hα ratio found by Anderson (1970) and Wampler (1971). This Hα/Hβ ratio is somewhat larger than the radiative recombination value of 2.9.

Further hints about the reddening can be obtained by looking at the infrared measurements. In figure 2 absolute fluxes (log f_ν ergs s^{-1} cm^{-2} Hz^{-1}) are plotted both without reddening corrections and then with the adopted (Wampler) reddening. The infrared measurements are taken from Rieke and Low (1972) and Penston et al. (1974). In the unreddened case the overall energy distribution is relatively smooth and steep although there is a possible suggestion of an irregularity near log ν = 14.0. When reddening is allowed for this irregularity becomes the approximate point where the continuum slope shows a marked change. The adopted reddening appears reasonable although by no means proved by this argument.

There appears to be a break in the continuum slope near $\log \nu = 14.9$. If the continuum is not reddened (lower curve) this break would correspond to that seen in normal elliptical galaxies; it is produced by the H and K lines and other strong absorption features farther in the violet. If the reddening found for the emission lines applies (upper curve) the break is much more likely to be the Balmer jump produced by hot stars in the field of view.

b) The Helium Abundance

Osterbrock (1971) has suggested a low helium abundance, N(He)/N(H) = 0.03, for NGC 1275. The absence of [NeV] emission indicates that the weakness of λ4686 may be an ionization effect, and therefore He I lines such as λ5876 are the main helium abundance indicators. Our data indicate I(λ5876)/I(Hβ) < 0.2. The strength of [O I] λ6300 betokens a large region of partial ionization where helium may be neutral. A hypothetical O^0, H^+, He^0 region at 6500° K could contribute the observed [O I] emission and two-thirds of the Hβ but no He I; in this case the observed upper limit on λ5876 would be consistent with a normal helium abundance. If the line is weaker than the upper limit quoted, then the helium abundance may indeed be low.

c) Physical Conditions

NGC 1275 has I(λ7325)/I(λ3727) = 0.12 and I(λ4072)/I(λ6720) ≈ 0.8. Each of these ratios is an order of magnitude larger than expected in the low density limit at $\sim 10^{4\circ}$ K, and this indicates a characteristic electron density $N_e \simeq 10^{4.5}$ cm^{-3}.

For this density, the extinction corrected Hβ luminosity, $L(H\beta) = 10^{42.5}$ ergs s^{-1}, implies a mass of $10^{5.5}$ $M_{\odot}$. If the emission-line region has a typical radius of ∿100 pc, the emitting filaments have a filling factor $\sim 10^{-6}$. A larger mass of lower density gas may exist between the filaments.

d) Ionization

NGC 1275 has, among Seyfert galaxies, a spectrum of unusually low excitation; He II and [Ne V] are weak, whereas [OI] is strong. For $I(\lambda 4686)/I(H\beta) < 0.3$, as observed, a power-law ionizing continuum must have $\alpha \lesssim -1.5$ (Williams 1972). This is steeper than usually observed in QSO spectra (Oke et al., 1970) or inferred from the stronger He II emission of other Seyfert galaxies (Shields 1974; Shields and Oke 1975), but it is consistent with the observed ν^{-2} continuum uncorrected for reddening. However, the UV extrapolation of this observed continuum gives less than the minimum ionizing photon luminosity, $Q(H^0) = 6 \times 10^{54}$ s^{-1}, implied by the extinction-corrected Hβ luminosity ($V_r = 5300$ km s^{-1}, $H = 50$ km s^{-1} Mpc^{-1}; cf. § III). On the other hand, a continuum $L_{\nu} = 5 \times 10^{27} (\nu/1\ Ry)^{-1.5}$ erg s^{-1} Hz^{-1} gives the required $Q(H^0)$; and if it undergoes the same extinction as the emission lines, this continuum would contribute roughly half the observed continuum, the rest presumably being starlight. This is consistent with Walker's (1968) detection of optical polarization in NGC 1275. Alternatively, an exponential continuum, $L_\nu \propto e^{-\nu/\nu_c}$, with $\nu_c \lesssim 4$ Ry, or radiation from hot stars with $T \lesssim 1.1 \times 10^5$ K (Hummer and Mihalas 1970) also would be consistent with our upper limit for I(λ4686).

Another possibility is ionization by shock waves with $v \sim 150$ km s^{-1} (Cox 1972) which produce little He^{+2}, relative to H^+. Shock models agree with the comparatively weak λ5007 and strong λ6300 emission from NGC 1275 (Osterbrock 1971). Although shock models give I(λ3727)/I(Hβ) $\sim$ 10, it can be argued that λ3727 is collisionally suppressed by about the right factor to reduce the shock prediction to the observed value.

Shields and Oke (1975) have argued that time-dependence in photoionized nebulae can lead to spectra resembling those of shocks, and this may be relevant to NGC 1275. In particular, Jura (1973) suggested that the weakness of λ4686 in 3C273 can be understood if He^{+2} has already recombined since the latest hypothetical flash of ionizing radiation. This may be an explanation of the weakness of the He II and [Ne V] lines of NGC 1275.

Although the low excitation of the emission-line spectrum is consistent with ionization by stars, the presence of a nonthermal radio source in the nucleus supports the idea of a nonthermal ionization mechanism. NGC 1275 coincides with the radio source 3C 84, which has a variable nuclear component with complex structure at VLB resolution (Shaffer and Schilizzi 1975), a larger component ~5' in diameter, and a halo ~26' in diameter (Ryle and Windram 1968). Especially interesting is the apparent interaction between NGC 1275 and the neighboring galaxies NGC 1265 and IC 310, which Ryle and Windram have interpreted in terms of particles ejected from NGC 1275 radiating in the magnetic fields of the other galaxies. This brings to mind the possibility that the emission-line region of NGC 1275 is ionized by fast particles. Souffrin (1969) showed that for the high ionization stages observed in typical Seyferts, the required particle flux would cause excessive Coulomb heating; but for the lower degree of ionization in NGC 1275, a consistent model using fast particles may be possible.

III A SECOND GALAXY

The emission-line spectrum of NGC 1275 shows two distinct velocities. The broad emission lines of the nucleus have a redshift of 5300 km s^{-1} (Burbidge and Burbidge 1965); and presumably this is the measured velocity of the galaxy, since it equals the mean velocity of the Perseus cluster, in which NGC 1275 is centrally located (Humason, Mayall, and Sandage 1962). Interference-filter photographs in Hα at this velocity show a web of luminous filaments around the nucleus, resembling the Crab nebula (Lynds 1970). Minkowski (1957) discovered Hα emission knots NW of the nucleus with a velocity of 8200 km s^{-1}, and he proposed that the system consists of two galaxies in collision. However, Burbidge and Burbidge (1965) argued for explosive ejection of the filaments from the nucleus.

Recent radio observations of Per A by De Young, Roberts, and Saslaw (1973) revealed a 21-cm absorption line at 8100 km s^{-1}, with a half-width of only ∿6 km s^{-1}. De Young et al. suggested two models to explain the coincidence in velocity between the radio feature and the high-velocity Minkowski knots: (1) Gas has been ejected from the nucleus and closely regulated to a relative velocity of ∿2900 km s^{-1} by radiation-pressure line-locking or by a "nozzle" effect. This material is behind the optical continuum source but still inside the nuclear radio source. (2) There is a second galaxy on the line of sight to NGC 1275. (A relative velocity of 2900 km s^{-1} is consistent with the extremes of the velocity distribution of the Perseus cluster.)

We note two arguments against the first hypothesis. (1) If gas were ejected at a single magic velocity of

$\sim$2900 km s^{-1}, the velocity component projected on the line of sight to the earth would depend on a factor cos θ leading to different radial velocities for the radio feature and the various high velocity knots. (These knots occupy a range of position angles relative to the nucleus.) (2) If the high velocity material were ejected from the nucleus, it should now lie on the far side of NGC 1275. On the contrary, photographs by Minkowski (1957) and Burbidge and Burbidge (1965) show absorption lanes in (and only in) the sector containing the high velocity knots. This implies that the high velocity material is in front of NGC 1275, as does the straightforward interpretation of the 21-cm absorption.

We therefore propose the following picture for NGC 1275. The Crab-nebula-like system of filaments with a redshift of 5300 km s^{-1} (Lynds 1970) has been ejected from the nucleus, as argued by Burbidge and Burbidge from their study of the velocity field. The radio absorption feature, the 8200 km s^{-1} emission knots, and the dust lanes in the NW sector, occur in a second, intervening galaxy. If these emission knots have a density of $\sim$100 cm^{-3}, then they can be photoionized by the Seyfert nucleus [$Q(H^0) \simeq 10^{54}$ s^{-1}] if they are within 10^5 pc. Alternatively, the knots may be H II regions ionized by hot stars in the second galaxy, in which case the two galaxies may be far apart. Burbidge and Burbidge (1965) have noted that the high velocity knots have a low value of

I([NII])/I(Hα). The same holds for the giant HII regions in the outermost spiral arms of M33 and M101 (Searle 1971), and for the "isolated extragalactic H II regions" observed by Searle and Sargent (1972). If the high velocity knots are metal-poor H II regions in a superimposed galaxy, their spectra should show narrow lines, strong [OIII] emission, and a flat stellar continuum leading to an Hβ equivalent width of ∿50 to 200 Å. The reddening corrected continuum (see above) does suggest the presence of hot stars.

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TABLE 1

NGC 1275 Emission-Line Fluxes

Ion	λ	Emission line flux I(λ) (10^{-13} ergs s^{-1} cm^{-2}) Wampler (1971)	This paper	I(λ) (corrected for reddening; Hβ = 1
[SIII]	9532,9069	3.3*	1.4	0.30
[OII]	7325	1.5	1.1	0.35
[SII]	6720	4.7	3.5	1.33
Hα	6563	14.3	13.9 (Hα + [NII])	5.44 (Hα + [NII])
[NII]	6584,6548	2.7		
[OI]	6363,6300	2.3	3.4	1.48
HeI	5876	≤0.3:	<0.3	<0.2
[OIII]	5007,4959	6.8	5.6	4.33
Hβ	4861	1.3	1.2	1.00
HeII	4686	-	<0.3	<0.3
[OIII]	4363	-	0.3 ([OIII] + Hγ)	0.33 ([OIII] + Hγ)
Hγ	4340	0.24:		
Hδ	4101	0.2	0.9 (Hδ + [SII])	1.11 (Hδ + [SII])
[SII]	4072	0.6		
[NeIII]	3869	-	1.0	1.43
[OII]	3727,3729	2.7	1.8	2.90
[NeV]	3426	-	<0.3	<0.5

*Wampler corrected this to 8×10^{-13} to allow for telluric H_2O absorption; presumably, a similar correction factor should be applied to our measurements.

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Figure Captions

Fig. 1.- Absolute spectral energy distribution for NGC 1275 on 9-10 October 1974 using an aperture of 7" diameter. The flux f_ν is in units of ergs sec^{-1} cm^{-2} Hz^{-1}. Emission lines of interest are marked even if not present. The statistical errors of the points are no larger than the dots except for those at the extreme ends of the plot.

Fig. 2.- Infrared and visual fluxes for NGC 1275. The lower solid curve is the continuum from fig. 1 while the upper curve is the continuum corrected for reddening $E_{B-V} = 0.63$. Solid dots are observations of Rieke and Low (1972) probably using a 6" diameter aperture. The open circles are measures by Penston et al. (1974) using a 10" aperture made on 21 September 1971 and 27 September 1971. Points marked X indicate reddening corrected fluxes.

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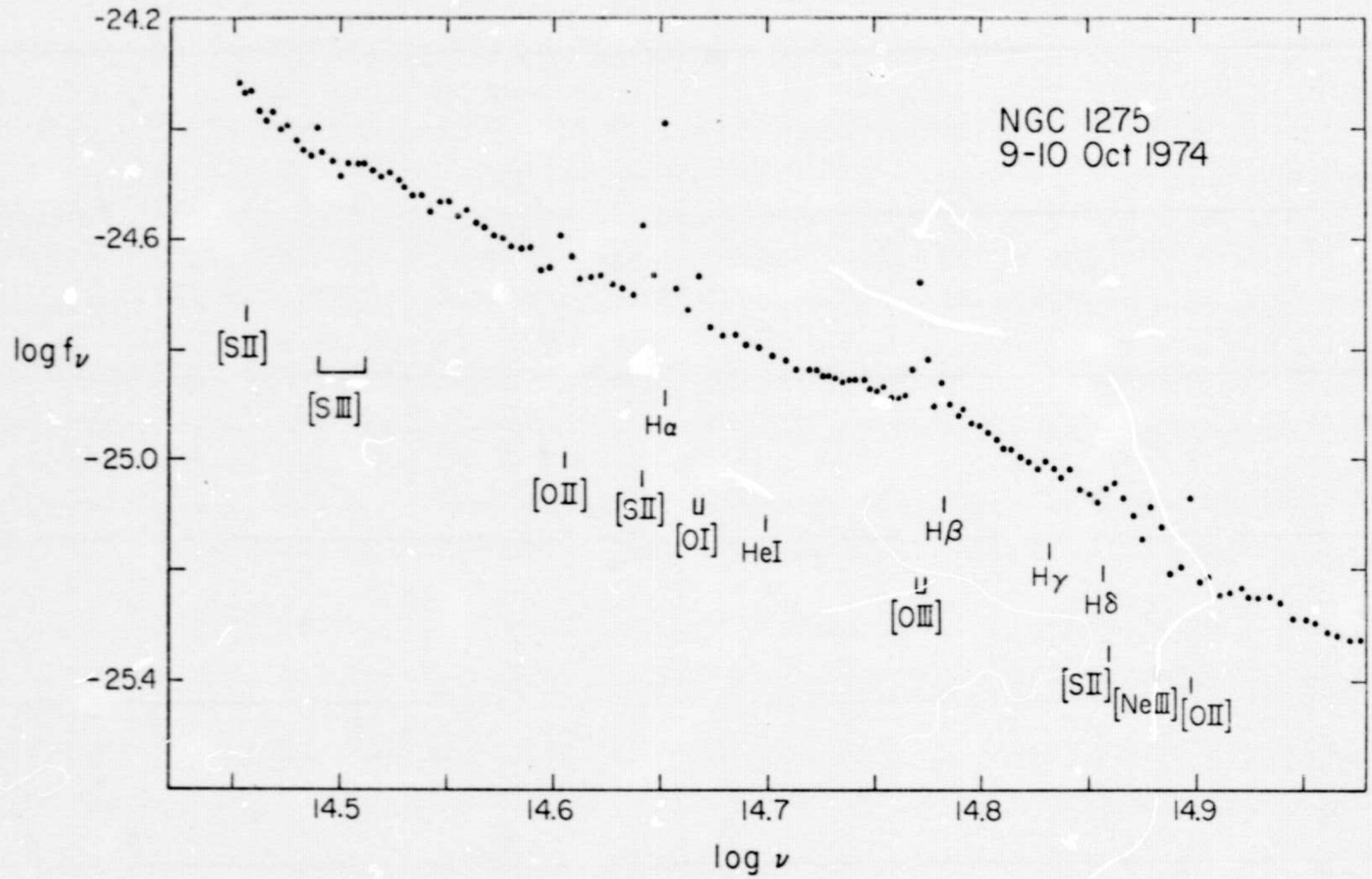
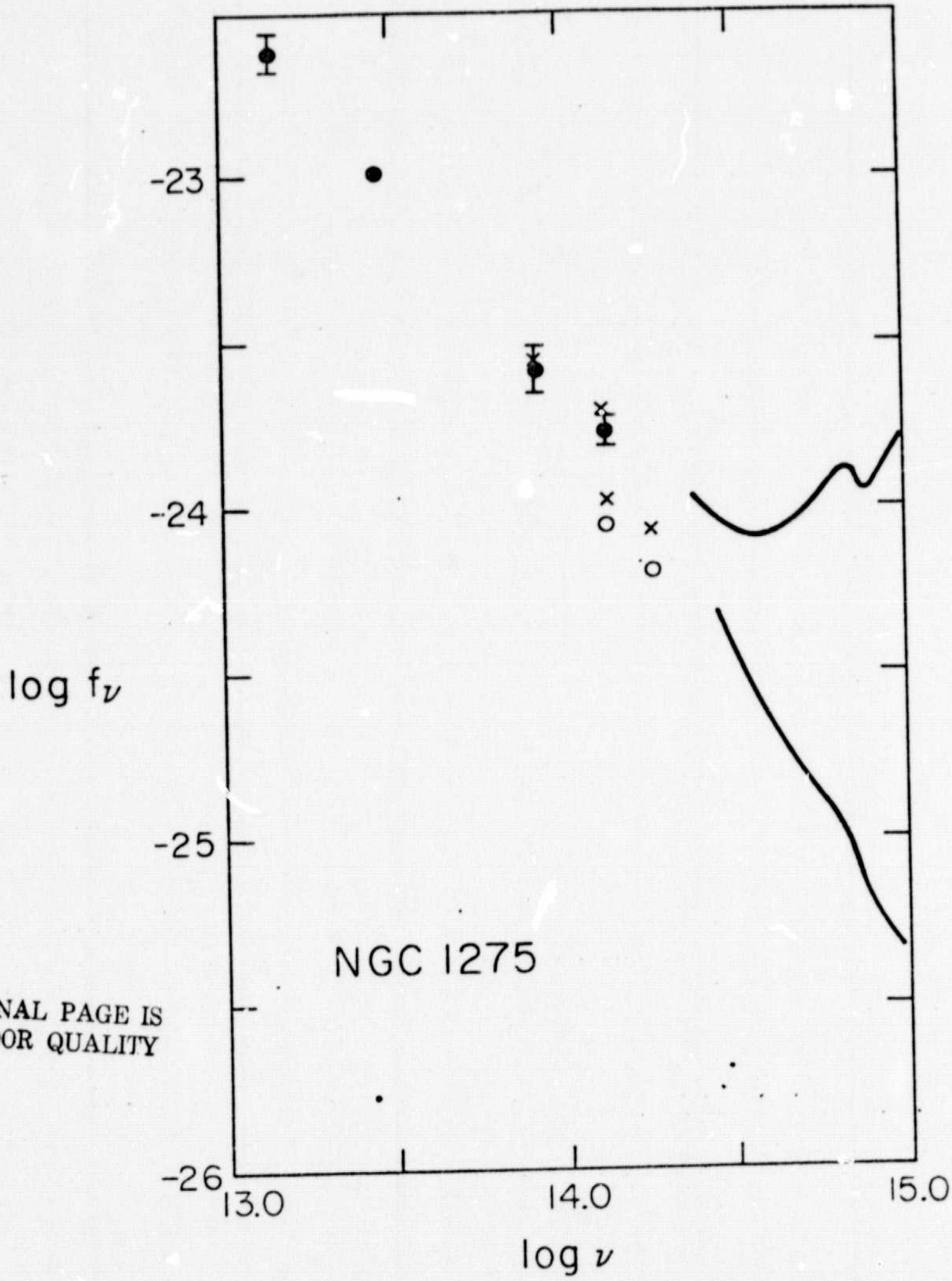


Shields & Oke Fig. 1.



Shields & Oke Fig. 2.