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NGC 1275: A BURGEONING ELLIPTICAL GALAXY[1]

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ABSTRACT

We present large-aperture spectrophotometry of the peculiar galaxy NGC 1275. Emission lines from Hβ, [O II], [O III], and [Ne III] dominate this spectrum, while Hδ, Hε and Na D appear in absorption. A population synthesis model for the absorption-line spectrum suggests that ~20% of the optical luminosity is produced by B stars. On the basis of this and the calculated Hβ emission line flux, we estimate that the current star formation rate in NGC 1275 is ~30 $M_\odot$ yr^{-1}. This leads to a predicted supernova rate of 1 yr^{-1}. The resulting supernova heating rate is ~one-half the cooling rate predicted by current accretion models and may thus significantly alter the accretion flow. We propose that in NGC 1275 we may be witnessing the formation of an elliptical galaxy in the cluster potential.

Subject headings: galaxies: individual — galaxies: photometry — galaxies: stellar content — stars: formation

I. INTRODUCTION

The enigmatic galaxy NGC 1275 (=Per A = 3C 84) is the dominant member ($M_v = -24.3$) of the Perseus cluster of galaxies (A426). While appearing as a normal elliptical on photographs, early spectra of the nucleus revealed strong line emission (Humason 1932). Seyfert (1943) later investigated the nuclear emission lines and included it in his original list of galaxies which now are known as Seyferts. Subsequent spectroscopic studies (Minkowski 1957; Burbidge and Burbidge 1965) showed this emitting gas was composed of two components centered at velocities of +5200 km s^{-1} (the absorption-line redshift of NGC 1275) and +8200 km s^{-1}. Although various interpretations for the latter component have been discussed in the literature (Baade and Minkowski 1954; Burbidge and Burbidge 1965), it may be that this gas is merely an edge-on Sc galaxy superposed on NGC 1275 (Adams 1977; Rubin *et al.* 1977; although van den Bergh 1977 argues that no interpretation agrees with all the data).

Modern spectra of NGC 1275 show an A type stellar absorption spectrum with moderately broad emission lines of H I, [S II], [O II], [O III], and [Ne III] (Pronik 1975; Shields and Oke 1975; Oort 1976; Doroshenko, Terebizh, and Chuvaev 1976; Rubin *et al.* 1977; Kingham and O'Connell 1979; Geller, Turner, and Bruno 1979). The size of the H II emitting region can be clearly seen on Lynds' (1970) Hα photograph. The long, filamentary strands of Hα emission extend ≈100″ (≈50 kpc) from the center of the galaxy and resemble the filamentary structure seen in the Crab Nebula. Oort (1976) suggested these filaments were ejected during a burst of star formation that created the present A type population.

Intense X-ray emission from the Perseus Cluster was first observed by Fritz *et al.* (1971). Wolff *et al.* (1974) and Wolff, Helava, and Weisskopf (1975) showed this emission extends throughout the cluster and is centered on NGC 1275. More sensitive X-ray observations by Gorenstein *et al.* (1978) and by Helmken *et al.* (1978) showed the compact X-ray emission centered on NGC 1275 could not be fitted by an isothermal-hydrostatic model. These authors suggested the distribution of X-ray emission could be understood if NGC 1275 were accreting hot intracluster gas as proposed by Cowie and Binney (1977) and by Fabian and Nulsen (1977). Cowie, Fabian, and Nulsen (1980) combined these results with a more detailed discussion of the accretion flow from intracluster gas onto a central galaxy. They concluded the X-ray contours and the structure of the optical filaments in NGC 1275 were consistent with an accretion flow of 200 $M_\odot$ yr^{-1}. The increased resolution of *Einstein* allowed Grindlay, Branduardi, and Fabian (1979; cf. Fabian, Nulsen, and Canizares 1982) to probe the X-ray structure of NGC 1275 more deeply. Their X-ray contours generally follow the optical filaments and the diffuse emission outside the nuclear region.

In this article, we present new spectrophotometric data on the central 13 kpc of NGC 1275. We find this galaxy is actively forming stars at a somewhat lower rate than that of the accretion flow modeled by Cowie, Fabian, and Nulsen (1980). The implied astration rate in NGC 1275 (≈30 $M_\odot$ yr^{-1}) will add a significant amount of mass to this galaxy over its lifetime, and we speculate that we may be presently observing the extended birth of an elliptical galaxy.

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II. OBSERVATIONAL DATA

The spectrophotometric observations presented here were obtained in 1981 October with the cooled dual-beam Intensified Reticon Scanner (IRS) mounted on the No. 1 91 cm telescope at Kitt Peak National Observatory. A 600 line mm^{-1} grating on this instrument gives a resolution of 15 Å over ≈3400–5800. The object and sky positions were defined by two apertures, each 25″ in diameter, separated by 1′. Observations of a quartz lamp, wavelength calibration source, bias or dark, and four standard stars were made during the night to place the data on an absolute flux scale. Complete details of the data reduction may be found in Hunter (1982).

The resulting spectrum of the central 25″ of NGC 1275, not corrected for galactic extinction, is shown in Figure 1. One may clearly see the intense emission lines that led to its original classification as a Seyfert galaxy as well as a strong underlying continuum. The widths of all of these lines are comparable to the instrumental profile implying that their FWHM $\lesssim 400$ km s^{-1}. This spectrum differs from earlier observations (e.g., Rubin *et al.* 1977) chiefly because the large aperture used covers 13 kpc of NGC 1275 at our adopted distance of 110 Mpc (for $H_0 = 50$ km s^{-1} Mpc^{-1}).

The emission-line fluxes have been determined using a Gaussian fitting package available at the Illinois Image Processing Center. These fluxes are listed in Table 1. The Hβ flux has been corrected for galactic extinction and underlying absorption using the population synthesis results. Based on an analysis of a large sample of galaxian spectra obtained and reduced in the same manner, we estimate the standard deviations in these fluxes to be ≈15%. The line identified in Table 1 as high redshifted [O III] λ5007 emission is probably due to the anomalous high velocity gas. Since the redshift difference between the two components is 3000 km s^{-1}, the Hβ flux in Table 1 is not contaminated by high-velocity gas. The weakness of the high velocity [O III] line indicates contamination of the continuum is also small. In the following discussion, only the low-redshift gas is considered.

TABLE 1

EMISSION-LINE FLUXES

Line	Flux (ergs cm^{-2} s^{-1})
[O II] λ3727	4.6×10^{-13}
[Ne III] λ3869	1.7×10^{-13}
$H\beta_{corr}$	3.5×10^{-13}
[O III] λ4959	1.8×10^{-13}
[O III] λ5007	4.8×10^{-13}
[O III] λ5007 (high redshift)	4.2: $\times 10^{-14}$

III. THE NUCLEAR CONTRIBUTION

The nucleus of NGC 1275 is a source of nonstellar radiation (cf. Geller, Turner, and Bruno 1979; Matveenko *et al.* 1980), so it is important to measure the nuclear contribution to the IRS spectrum. The irregular variability of the galaxy makes comparison of this spectrum with previously published data rather difficult. Broad-band photometry was obtained by one of us (A. W.) at Wyoming Infrared Observatory (WIRO) nearly simultaneously with the IRS spectrum. A multi-aperture comparison can thus be made without the problem of the large light variations characteristics of

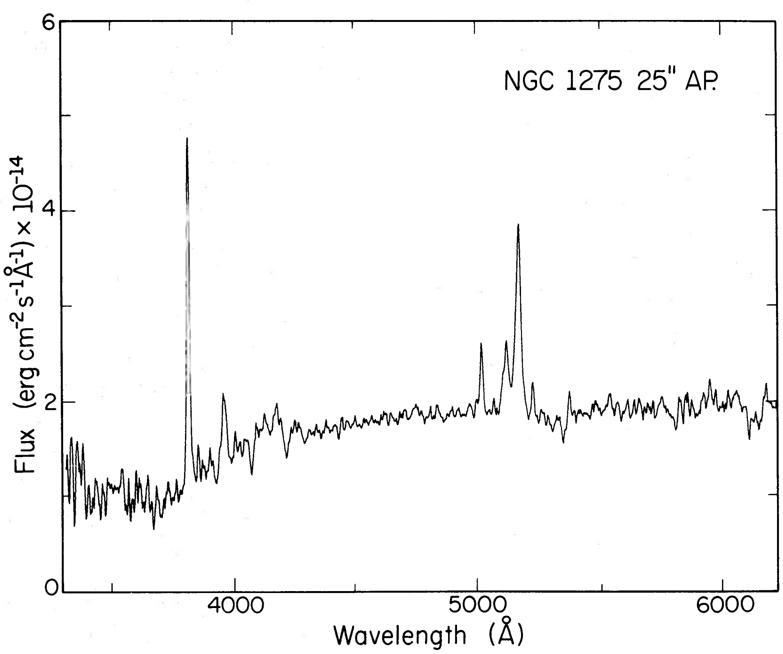

FIG. 1.—Spectrum of NGC 1275 obtained with the KPNO 91 cm telescope and IRS, uncorrected for galactic extinction

long time scales (Geller, Turner, and Bruno 1979; Kingham and O'Connell 1979).

The WIRO data consist of *UBV* photometry through an 11″ aperture (taken a few hours before the IRS scan) and *UBR* "images" (taken a few hours after the IRS scan). The images were constructed by stepping a 2″ aperture back and forth along the galaxy to describe a rectangular raster (see Wirth 1982 for details on data acquisition and reduction). In Table 2 we summarize the observed *UBV* photometry obtained with the 11″ aperture and the innermost 2″ of the "image" and colors synthesized from the IRS spectrum. The *V* magnitude for the 25″ aperture presented here agrees with that measured by Sandage (1972) and is consistent with other observations presented in the literature (i.e., Kingham and O'Connell 1979; Penston *et al.* 1974; Lyutyj 1977).

From the data in Table 2 we conclude that the nuclear contribution to the light in the 25″ aperture is about 6% at *B* and 9% at *U*. Further evidence comes from photographic photometry obtained by Rubin *et al.* (1977). We have used their plot of the luminosity profile of NGC 1275 to compare the light within 5″ [the radius (r) at which a plot of $2\pi r f_v(r)$ declines steeply] to that within 12″.5. The nuclear component found from these data contributes at most 20% of the total light. Penston *et al.* (1974) also estimated that the nucleus provides only 28% of the light in a 10″ aperture, which results in 6% for a 25″ aperture. We also note that the WIRO and Rubin *et al.* data fit an $r^{1/4}$ law out to large radii. Furthermore, in Figure 1 the continuum break around 4000 Å and the absorption features indicate that stars *are* important contributors to the spectrum. Therefore, the contribution to the continuum by the nuclear nonthermal source is expected to be ~10%–20%, and our data are more representative of the extranuclear region of the galaxy than those published previously.

The source of the emission lines deserves further consideration. The extended emission seen in Hα images (e.g., Lynds 1970) makes photoionization due to the nuclear activity alone seem unlikely (Shields and Oke 1975). However, shock ionization is a possibility, and variations in emission-line strengths found by Kingham and O'Connell (1979) might lend support to this. A comparison of the observed line ratios to those calculated from shock models (Raymond 1979) for metal-poor cases shows that the observed [O III]/Hβ ratio is at least 20%–30% too low. In view of the unusual activity taking place in this galaxy (i.e., the high rate of gas infall, etc.), it seems likely that some material *is* shocked. In fact, this could be important in the star formation process. We cannot, however, determine the degree to which the emission lines in Figure 1 are contaminated by shocked material, and so the star formation rate (SFR) derived below from the Hβ flux must be considered an upper limit until further data are available. However, the stellar continuum will remain unaffected and, thus, the results of population synthesis presented in the next section will not suffer from this ambiguity.

TABLE 2
UBV OBSERVATIONS

Aperture	*V*	*B*	*B−V*	*U−B*
2″	...	16.7	...	−0.4
11″	13.28	13.89	0.61	−0.14
25″	13.08	13.74	0.66	−0.05

IV. INTERPRETATION

a) *Population Synthesis*

A knowledge of the stellar populations present in the main body of NGC 1275 is necessary to correct the Hβ emission flux for effects of stellar absorption and to examine the history of star formation in the galaxy. The unconstrained linear programming population synthesis code developed by Peck (1980) has been used to produce a model of the composite stellar population in NGC 1275. O'Connell (1973) colors synthesized from the spectrophotometry serve as input for the population synthesis code. Passbands contaminated by emission features were not used. During the synthesis procedure, hydrogen emission flux is iteratively corrected for underlying stellar absorption (cf. Gallagher and Hunter 1983). A brief summary of the resulting population model is given in Table 3, where we have listed the relative contributions of the main constituents of the model to the total light of the system at three wavelengths. As a check on these results, colors predicted from the synthesis were compared to observed colors over the range λλ3400–34,000 (Penston *et al.* 1974). In all cases, the agreement between these colors was better than 0.2 mag, which is well within the expected errors. The largest errors occur near the Balmer jump, suggesting that contamination from the nonthermal source may slightly influence the synthesis model.

Taking the synthesis model at face value, it is possible to estimate the star formation rate based on the number of young stars present. The *V* magnitude of NGC 1275 inside a 25″ aperture is 13 (Sandage 1972), which leads to a *V* luminosity of 10^{11} $L_\odot$ ($H_0 = 50$ km s^{-1} Mpc^{-1}), after correction for 0.6 mag of absorption (Weedman 1975). In our model, ~10^8 B5 stars are needed to produce ~20% of the light at

TABLE 3
RESULTS OF POPULATION SYNTHESIS

Spectral Group	Percentage Contribution λ3570	λ4400	λ5050
B5	52.0	29.6	19.5
F1	38.7	45.3	39.3
G6	5.3	9.2	12.0
K3	3.0	12.7	23.0
M5	1.0	3.2	6.2

5050 Å. Given a mass and main-sequence lifetime for these stars (5 $M_{\odot}$ and 7×10^7 yr, respectively), this requires $\approx 7\ M_{\odot}$ to be converted into B stars each year. The standard Miller-Scalo IMF then requires a total SFR of 50 $M_{\odot}$ yr^{-1}. There are reasons to believe the IMF is unusual in NGC 1275 (Fabian, Nulsen, and Canizares 1982), but the synthesis model yields no information on the total number of very low-mass stars.

b) Hβ *Flux*

The Hβ flux from a star forming region is related to the SFR via a technique outlined by Hunter, Gallagher, and Rautenkranz (1982, hereafter HGR). This method assumes all ionizing photons are absorbed by the emitting gas, and a normal IMF. Applying the technique, an observed Hβ flux of 3.5×10^{-13} ergs cm^{-2} s^{-1} implies a SFR of 7 $M_{\odot}$ yr^{-1} for NGC 1275. Infrared observations by D. A. Harper (private communication) indicate that dust absorption in the emitting gas may be very important (see below). Substantial dust absorption would require a higher SFR for a given Hβ flux, although emission from shocked gas may also be important as discussed earlier.

c) *Best Estimate for the Star Formation Rate*

In NGC 1275, D. A. Harper (private communication) finds $\approx 5 \times 10^{10}\ L_{\odot}$ is emitted by dust grains at 100 K. Presumably, some fraction of this emission is due to heating by young stars in the star forming region (cf. Telesco and Harper 1980). If a few $\times 10^4\ L_{\odot}$ is the typical luminosity of an OB star, the observed far-IR flux implies as much as a few $\times 10^6$ OB stars are not accounted for in the Hβ method. The estimated upper limit to the star formation rate becomes $\approx 30\ M_{\odot}$ yr^{-1} if these stars are included. The fair agreement of this rate with the synthesis model prediction lends support to the idea that contamination of the Hβ emission from shocked gas is small. Furthermore, we can consider the consequences of such a large SFR. If all stars with $M > 6\ M_{\odot}$ become supernovae, the predicted supernova rate is 1 yr^{-1}. Lyutyj (1977) has monitored the *UBV* magnitudes of NGC 1275 over a period of several years and reports finding flarelike events with amplitudes of 0.2 mag and 10–20 day duration. This is precisely the behavior expected if Type II supernovae with L_{max} = few $\times 10^{10}\ L_{\odot}$ occur in the star forming regions of this galaxy. Over a period of 7 years, nine of these flarelike events were observed, consistent with a supernova rate of 1 yr^{-1}. We emphasize that this variability is not necessarily confined to the nuclear region of the galaxy, where it could be due to nonstellar processes. Multi-aperture photometry obtained on different nights (Penston *et al.* 1974) suggest variations of ~0.1–0.2 mag may occur *outside* the nucleus. This is consistent with our picture of supernova events randomly distributed through the nonnuclear star forming regions, although more data are needed to confirm this. We also note that there is marginal evidence for a detection of [N I] λ5200 emission in Figure 1. This line is seen in supernova remnants.

One further piece of information is available from the synthesis model. The dominant contributors to the optical light in the model are A–F stars with typical lifetimes of 10^9 years. This suggests star formation has been occurring in NGC 1275 for at least the last few $\times 10^9$ years. In the same way that the recent SFR may be derived from the OB star population, an estimate of the mean SFR over the lifetime of an A–F star may be obtained. For NGC 1275, the mean rate is $\approx 25\ M_{\odot}$ yr^{-1} for a Miller-Scalo IMF. While this should be treated as a very rough approximation, it is probably good evidence that the star formation process currently ongoing in NGC 1275 is not a short-lived phenomenon.

V. DISCUSSION

When combined with the X-ray observations, the results presented above allow us to construct a self-consistent picture for the behavior of NGC 1275. The reader should note that each of the methods used here to estimate the SFR suffers from major uncertainties, as noted above. The results from these methods lend weight to the concept that star formation provides the necessary sink for the accreted gas. As noted by Cowie and Binney (1977) and by Fabian and Nulsen (1977), intracluster material in the Perseus Cluster is accreted by NGC 1275. As this matter flows to the central regions of the galaxy, it cools and eventually forms stars. This produces a population of B stars which ionizes the surrounding gas to form H II regions near the center of NGC 1275. Some of this ionizing radiation luminosity leaves the central parts of the galaxy as optical emission lines (e.g., Hβ), while the rest is converted into infrared radiation by dust grains. The OB stars also produce the supernovae possibly observed by Lyutyj (1977). The supernova rate estimated from the observed star formation rate (which has been determined from population synthesis and the Hβ flux) is consistent with the observed frequency of flares. However, the observed star formation rate (30 $M_{\odot}$ yr^{-1}) is a factor of 5 lower than the accretion rate estimated from the X-ray emission and the appearance of the optical filaments.

Several ways exist to bring these two rates into accord. For example, if the IMF is in fact much steeper than Miller-Scalo (Fabian *et al.* 1981), significantly more mass will be converted into stars for a given mass of upper main-sequence objects. Another possibility is that the heat input from star formation modifies the accretion flow. The models developed for accretion flows require a cooling mechanism for the gas as it falls into the galaxy. For a gas temperature $> 2 \times 10^7$ K, this mechanism is bremsstrahlung cooling, while for lower gas temperatures optical emission lines dominate the cooling (Cowie and Binney 1977). In our picture, supernovae introduce a heat source which could, in principle, slow down the cooling of the infalling material. Taking 1 $M_{\odot}$ and 10^4 km s^{-1} as the typical mass and velocity of supernovae ejecta, the rate of kinetic energy input into the surrounding medium for 1 SN yr^{-1} is $\sim 10^{10}$ $L_\odot$. This is a substantial fraction of the thermal and gravitational energy of the accreting gas (~ 2–3×10^{10} $L_\odot$ for $T \approx 10^8$ K and $\dot{M} \approx 200$ $M_\odot$ yr^{-1}). Thus supernovae may be an important energy source in the accretion flow (thermal conduction may also be important; cf. Tucker and Rosner 1983), especially near the central regions of NGC 1275. More detailed modeling of accretion flows in galaxies is needed.

Finally, we would like to suggest the phenomenon observed in NGC 1275 may not be exceptional except, perhaps, in magnitude. Cooling accretion flows have been observed in other galaxies (cf. Ford and Burcher 1979), and Heckman (1981) has shown that extended optical emission is not uncommon in dominant cluster galaxies, although the strong Balmer absorption lines seen here are. Silk (1976) has proposed the concept of galaxies condensing from the intracluster gas within a pre-existing potential well. This is precisely the process we propose to explain the peculiarities of NGC 1275. Thus, we may be witnessing the formation of a giant elliptical galaxy at close range. Clearly, NGC 1275 is deserving of much more extensive and detailed observational study than it has heretofore been accorded. Such investigations may shed light upon some of the perplexing questions we have about galaxy formation and the nature of dominant cluster galaxies.

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