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THE NATURE OF THE IONIZING SOURCE OF THE NUCLEAR GAS IN NGC 1052[1]

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ABSTRACT

We examine the ionization and physical state of the emission-line region in the nucleus of the elliptical galaxy NGC 1052. The [O III] λ4363/λ5007 ratio, frequently used as a diagnostic for ionization mechanisms, is very poorly determined because of difficulties in matching the underlying stellar continuum spectrum, which is unusual in having very strong lines for the galaxy luminosity. Within these limitations, we find the [O III] temperature to be only marginally compatible with shock models, and the overall emission spectrum to be better fitted by photoionization models with a very dilute flat-spectrum central source. In any event, the case for NGC 1052 as a shock-heated nucleus is not strong.

Subject headings: galaxies: nuclei — shock waves

I. INTRODUCTION

There has been considerable interest in the nature of the process which ionizes the emitting gas in the nuclear region of the giant elliptical galaxy NGC 1052. An early study by Minkowski and Osterbrock (1959) showed that the emission was strongly concentrated to the center and that the gas was of low density, but they were not able to determine the ionizing mechanism. Later studies attempted to do this by measuring the temperature of O^{++} since, in general, ionization by shocks would be expected to produce much higher temperatures as measured from the [O III] lines than if photoionization were taking place. Temperature measurements based on lines of O^+ and S^+ are of no value for distinguishing between these two types of ionization since, in the shock case, these ions are formed in relatively cool regions well behind the front and the temperatures expected for them are indistinguishable from those expected in photoionized gases. Thus O^{++} is of crucial importance for optical studies.

In their study of the electron temperature of the gas in NGC 1052, Koski and Osterbrock (1976) derived a temperature of 33,000 K from [O III] and concluded that the gas is shock ionized. Similar results were obtained by Fosbury *et al.* (1978). These results are of considerable importance since NGC 1052 is at present the most convincing case in the literature for shock ionization in the nucleus of an active galaxy. It plays a crucial role in the Baldwin, Phillips, and Terlevich (1981) scheme for using emission-line ratios to determine the nature of the ionization mechanism in emission-line nuclei. This *Letter* presents new observations of NGC 1052 and a study of the absorption-line spectrum of the galaxy with the aim of improving our knowledge of the temperature (and its uncertainties) in the nuclear gas.

II. MEASUREMENT OF THE [O III] TEMPERATURE

The primary evidence in favor of shock heating as the exciting source for the emission-line gas in NGC 1052 (and by analogy other low-ionization nuclei) has been the temperature-sensitive [O III] λ4363/(λ4959 + λ5007) line ratio. Koski and Osterbrock (1976) and Fosbury *et al.* (1978) reported electron temperatures in the [O III] zone of 25,000–30,000 K, considerably higher than those expected in simple photoionization models.

There are several factors that weaken this conclusion. Neither of the results above is very secure, largely because of problems in subtracting the spectrum of the stellar population in NGC 1052 from the observed spectrum. Koski and Osterbrock (1976) used the similar (but emission-free) galaxy NGC 584 as a "template" to be subtracted from NGC 1052. Fosbury *et al.* (1978), in contrast, subtracted scaled versions of spectra of NGC 1052 itself, taken away from the nucleus and beyond the area of strong emission. This approach is complicated by the fact that elliptical galaxies are known to have significant gradients in absorption-line strength with distance from the nucleus. Since the λ4363 line is in a spectral region heavily affected by a number of absorption features, a very accurate continuum subtraction must be done if it is to be measured accurately. Stellar absorption features still appear in the subtracted spectrum of Koski and Osterbrock (1976), notably the Mg *b* band.

Furthermore, the [O III] temperatures reported are not as high as expected for shocks giving the level of

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ionization seen in NGC 1052. The [O III] zone behind a shock in which [O III] λ5007 exceeds [O I] λ6300 in strength has a temperature range of about 3.0–20 × 10^4 K (Shull and McKee 1979, especially their Fig. 3). Because of the strong increase in [O III] emissivity with temperature, the [O III] temperature will reflect the higher end of that in the zone in which it radiates, so that temperatures of the order of 5 × 10^4 K are expected for [O III] in shocked gas under conditions appropriate to match the spectrum of NGC 1052. The measured temperature falls in an intermediate range not simply accounted for by shocks or simple photoionization models. However, Dalgarno and Sternberg (1982) have studied the importance of charge-transfer effects in the reaction

$$O^{+3} + H^0 \rightarrow O^{+2} + H^+,$$

which will always result in a stronger λ4363 line than expected otherwise. They find that this enhancement will be greatest in plasmas photoionized by power-law (or similar) radiation fields of such intensity that large amounts of neutral gas are present. This is just the situation in those photoionization models which most closely match the spectra of low-ionization nuclei (Ferland and Netzer 1982).

To explore the effects of various assumptions about the stellar content of NGC 1052 on the [O III] measurement, we have compared blue region spectra of NGC 1052 and three gas-free ellipticals. These spectra were obtained with the image dissector scanner (IDS) spectrograph at the Shane 3 m telescope of Lick Observatory. The properties of the galaxies are summarized in Table 1, with catalog quantities from Sandage and Tammann (1981). NGC 3379 and NGC 4472 were observed in the same way as NGC 1052, with flux calibration performed through observations of standard stars. The strong-line galaxy NGC 4564 was observed by Faber, who kindly made her spectrum of it available. This was taken for a different purpose and was not flux-calibrated; an approximate calibration was performed by matching its broad-band energy distribution to that of NGC 1052, interpolating smoothly across the Hβ-[O III]-Mg *b* region to avoid loss of information on the depth of the *b* band. The spectra were shifted to the emitted wavelength frame and manipulated as described below to attempt to find a close match to the absorption spectrum of NGC 1052. The three "template" galaxies were chosen to cover a wide range in luminosity and line strength (NGC 4564, though of relatively low luminosity, has very strong lines—Faber and Morea 1983).

Matching the spectrum of NGC 1052 proved difficult. Its absorption-line strengths are at the high end of the range covered by elliptical galaxies. Two assumptions about the reddening toward the nucleus were tested by trials with $E_{B-V} = 0$ and 0.09. The assumption of nonzero reddening was motivated by the visibility of an absorption patch near the nucleus on images obtained by one of us (W. C. K.) with the videocamera at the Kitt Peak 2.1 m telescope and confirmed by Lick CCD images obtained by Lauer (1982). For low values of the reddening, the strength of λ4363 as measured is, as expected, not strongly dependent on the reddening correction if the subtraction is normalized at a wavelength near 4363 Å. However, the nature of the galaxy subtracted makes a great difference in both λ4363 and Hγ. Subtraction of NGC 3379, a slightly less luminous elliptical, gives Hγ/Hβ = 0.39. This is close to the case B recombination value of 0.46, but the residuals in this spectrum are rather poor; the MgH band at 5000–5200 Å is still in absorption, and several discrete features do not cancel. Use of NGC 4472 as a standard gives much weaker Hγ, with Hγ/Hβ = 0.11. The spectra are otherwise a closer match. The overall best spectrum match found was with NGC 4564, but neither Hγ nor λ4363 is detected with certainty in the subtraction. The

TABLE 1

GALAXY PROPERTIES

Name	v_0	Type	M_B (H_0 = 50)
NGC 1052 ...	1539	E3	−20.91
NGC 3379 ...	759	E0	−20.58
NGC 4472 ...	822	E1	−22.38
NGC 4564 ...	894	E6	−19.83

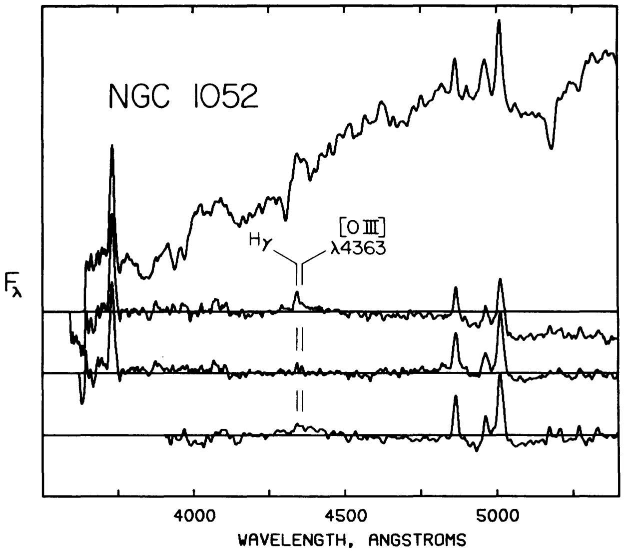

FIG. 1.—Spectra of NGC 1052 as observed and with three emission-free elliptical galaxy spectra subtracted. Galaxies used for the galaxy-subtracted spectra were (*top to bottom*) NGC 3379, NGC 4472, and NGC 4564. The positions of Hγ and [O III] λ4363 are marked. The observed spectrum of NGC 3379 is shown at top for comparison.

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TABLE 2

NGC 1052 [O III] AND Hγ/Hβ LINE RATIOS

Galaxy Subtracted	[O III] λ4363/ (4959 + 5007)	Hγ/Hβ	T_e (K)
NGC 3379	0.032	0.39	25,000
NGC 4472	0.037	0.11	27,500
NGC 4564	< 0.030	< 0.10	< 23,500

spectrum subtractions are shown in Figure 1, and the measurements of Hγ and λ4363 are listed in Table 2. In each case, the subtraction was also tried with a smaller galaxy contribution to see whether nonthermal diluting radiation is important; none was found at a level above about 10% at 4000 Å. The major difficulty in measuring weak emission lines in NGC 1052 is thus matching the stellar component of the spectrum to the required precision. The absorption spectrum of NGC 1052 is not very well matched by that of any of the other galaxies considered here and may well be anomalous in ways other than having systematically strong lines. Whether this is related in any way to the properties of the nucleus remains pure speculation. In any case, NGC 1052 does not obey the usual line-strength versus luminosity relation for elliptical galaxies (e.g., Faber 1977).

The strongest conclusion from this effort is that measurements of λ4363 are difficult to make and may be very unreliable. We estimate that λ4363/($\lambda\lambda$4959 + 5007) is certainly no greater than 0.038 and may be considerably smaller. Using the line ratio–temperature relation from Osterbrock (1974) transforms this to a temperature upper limit of 27,000 K and possibly (using the limit based on subtracting NGC 4564) less than 22,000 K. These values are somewhat, though not greatly, lower than those found by previous workers. They do not give strong support to shock heating as the principal energy source for the line emission in NGC 1052.

III. NGC 1052 AS A POWER-LAW PHOTOIONIZED NUCLEUS

The presence of a nonthermal continuum in the nucleus of NGC 1052 has been found in the infrared (Rieke, Lebofsky, and Kemp 1982) and radio (Heeschen 1970; Cohen *et al.* 1971). It is possible that the nuclear gas is in fact photoionized by the ultraviolet end of the central source's spectrum. Extrapolation of the infrared continuum is broadly consistent with this picture, if a value of U (= ionizing photons/particle) of 10^{-3} is appropriate, as implied by the models of Ferland and Netzer (1982). The extrapolated observed infrared continuum fails by about an order of magnitude to provide enough ionizing photons, based on the Ferland and Netzer models, given the approximate nature of the assumptions in the models, and the possibility of variability of the ionizing source (the radio source is in fact variable), this may not be a serious problem. As noted by Rieke, Lebofsky, and Kemp (1982), the extrapolated continuum is well below the galaxy contribution in the optical, so failure to find a large nonthermal contribution to the spectrum is not inconsistent with its presence at important levels. Note that the relevant continuum level is an average over several centuries because of the large spatial extent of the emitting region. Searches for an optical continuum at various times will be important in this regard. It may be that the polarization measurement by Heeschen (1973) referred to a high state of the ionizing source.

In light of several recently published models, a discussion of the entire optical emission spectrum of NGC 1052 is of interest. The line intensities measured on several 3 m telescope scans, after subtracting the spectra of other elliptical galaxies, are compared in Table 3 with several models; note that these lines are strong enough that difficulties in matching the galaxy spectrum will not introduce large uncertainties. The models are the two Shull and McKee (1979) shock models with the

TABLE 3

THE EMISSION SPECTRUM OF NGC 1052 AND RELEVANT MODELS[a]

LINE	NGC 1052	POWER-LAW PHOTOIONIZATION		SHOCKS[d]	
		$\alpha = -1$[b]	$\alpha = -1.5$[c]	90 km s^{-1}	100 km s^{-1}
[O II] λ3727...........	4.0	4.59	6.40	9.15	7.00
[O III] λ5007	1.65	1.22	2.18	1.49	3.71
[O I] λ6300............	1.88	2.23	0.96	0.33	0.82
[S II] $\lambda\lambda$6717, 6731 ...	5.31	6.06	2.5	2.57	4.09
[N I] λ5199	0.25	...	0.26	...	...
[S II] λ4072	0.35	...	...	...	...
[N II] λ6584...........	4.00	2.55	1.56	1.83	2.19

[a] All line intensities are relative to Hβ.
[b] Kent and Sargent 1979.
[c] Ferland and Netzer 1982.
[d] Shull and McKee 1979.

most similar properties: those with velocities of 90 and 100 km s^{-1} and solar abundances, the low-ionization power-law model by Kent and Sargent (1979), with an index $\alpha = -1$ and solar abundances, and the most detailed Ferland and Netzer (1982) low-ionization parameter model, with $\alpha = -1.5$, 0.3 times solar abundances, and ionization parameter $U = 10^{-3.5}$. NGC 1052 falls between the two photoionization models in all quantities except [N II] strength; this is strongly dependent on abundance and could be roughly matched by scaling the Ferland and Netzer model to solar abundances or slightly higher. The shock models predict too little [O I] and [S II] if [O III] is matched. The closer agreement of power-law photoionization calculations with the observed spectrum provides some support for an interpretation based on such models and should encourage calculations intended specifically to match such individual cases as NGC 1052. The two models quoted here are in agreement as regards the dilute nature of the radiation field and its flat spectrum, but new calculations will be needed to see how consistent in detail such a model can be made.

IV. CONCLUSIONS

For the present, we conclude that there is considerable uncertainty in the [O III] temperature of the gas in the nucleus of NGC 1052, and that it cannot be considered as established that shocks are responsible for the ionization. Photoionization models appear to be more satisfactory in matching the observed line spectrum. High signal-to-noise ratio data and a better match to the absorption spectrum of the galaxy are needed if further observational progress is to be made.

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