THE ASTROPHYSICAL JOURNAL, 304:L37–L40, 1986 May 15

THE HIGHLY OBSCURED NUCLEUS OF 3C 219[1]

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Received 1985 December 20; accepted 1986 February 21

ABSTRACT

We report the detection of a strong, and possibly broad, Paschen-α line from the narrow-line radio galaxy 3C 219. The detected flux is larger than predicted from the Hα line and the case B recombination. This implies the presence of a highly reddened line-emitting region in the nucleus.

Subject headings: galaxies: nuclei — galaxies: Seyfert

I. INTRODUCTION

Optical searches for active nuclei are biased against the discovery of heavily obscured, reddened objects. Searches in the mid- to far-infrared, on the other hand, are biased toward objects showing strong dust emission. There are, however, two wavelength bands that allow searches that are unbiased with respect to the presence or absence of obscuring dust and gas: hard X-rays (Lawrence and Elvis 1982) and radio (Rudy 1984).

Based on a hard X-ray selected sample of active nuclei, Lawrence and Elvis (1982) proposed that narrow-line Seyfert 2 galaxies are simply broad-line Seyfert 1 galaxies in which the compact broad-line region is heavily obscured but the larger narrow-line region is only slightly reddened and remains visible. This proposal was extended to radio galaxies by Fabbiano *et al.* (1984), who suggested that narrow-line radio galaxies were heavily reddened broad-line radio galaxies. Direct evidence for an obscured broad-line nucleus in a Seyfert 2 galaxy has now been found in the detection of a broad Hβ line in the polarized spectrum of the prototype object of this class NGC 1068 (Antonucci and Miller 1985). Direct evidence for broad-line nuclei in narrow-line radio galaxies has not yet been found.

One technique that can be used to search for dust-obscured broad-line regions is to measure the permitted hydrogen transitions in the near-infrared where the effects of reddening are much reduced ($A_K = 0.09\ A_V$). Paschen-α (1.875 μm) is the strongest of these lines, and for redshifts betwen 0.11 and 0.27 it lies in a region of good atmospheric transmission. The ratio of Paα to Hα is a good, and generally the only available, indicator of reddening. Hα/Hβ can be strongly affected by radiative transfer effects (e.g., Canfield and Puetter 1980; Kwan and Krolik 1981), but the intrinsic Paα/Hα is near 0.1 (the case B value) in all reasonable models. Observed Paα fluxes confirm this result even in objects where radiative transfer has greatly changed the Balmer decrement (Puetter *et al.* 1981; Lacy *et al.* 1982).

Radio galaxies may be more reddened than their Seyfert counterparts. Two broad-line radio galaxies have been shown to be reddened using the Paα/Hα ratio (3C 445 by Rudy and Tokunaga 1982; 3C 109 by Kollatschny and Fricke 1981 and Rudy *et al.* 1984). Even larger reddening is required in a type "1.9" radio galaxy (3C 234; Carleton *et al.* 1984) in which the broad component of Hα is very weak (Grandi and Osterbrock 1978). A reddening of $A_V \approx 2.6$ is needed to account for the strong, broad Paα line. In all these objects the optical continuum is steepened and the absorbed energy is reemitted in the near- to mid-infrared (Elvis *et al.* 1984; Carleton *et al.* 1984).

The accumulation of evidence for highly obscured nuclei encouraged us to search for Paα in a purely narrow-line radio galaxy. We selected 3C 219 based on its redshift (0.1744) and on the presence of an L band excess (Lily, Longair, and Miller 1985; our unpublished data). Here we report the detection of an anomalously bright Paα emission line in 3C 219.

II. OBSERVATIONS

All of the observations were made with the facility infrared photometer at the Multiple Mirror Telescope. Table 1 gives the observing log with broad-band photometric observations reported on the CIT system (Elias *et al.* 1982). The J, H, and K filters are close to the standard ones (Willner *et al.* 1985), while the 3.4 μm filter has an effective wavelength similar to the L band but is only 0.2 μm wide. The $K - [3.4\ \mu\text{m}]$ color of 3C 219 is similar to that reported by Lilly, Longair, and Miller (1985) and implies that about 60% of the 3.4 μm emission is from sources other than stellar photospheres.

Spectrophotometric wavelengths were defined by a circular variable filter having resolution of 1%. Each observing session included approximately equal observing time at the line and supposed "continuum" wavelengths. The order of observing on-line and continuum points was alternated to avoid systematic biases. In 1984 April the "continuum" wavelengths chosen were only 2/3 of a resolution element on each side of the line and probably contain considerable line flux, especially if the line is broad (see below). On all other occasions, the continuum points were well separated from the line. The results of the spectrophotometric observations are shown in

[1]Observations reported here were obtained at the Multiple Mirror Telescope Observatory, a joint facility of the Smithsonian Astrophysical Observatory and the University of Arizona.

TABLE 1

BROAD-BAND OBSERVATIONS OF 3C 219

Date (UT)	J	H	K	[3.4 μm]	Beam
1983 Dec 20[a]......	15.11	14.50	13.78	12.56 ± 0.24	5″
1984 Apr 14.......	15.21	14.57	13.84	12.69 ± 0.21	5
1984 Apr 15.......	...	14.61	13.88	...	5
1984 Apr 16.......	...	14.48	13.78	...	5
1984 Jun 13.......	...	14.57	13.73	...	5
1984 Jun 14.......	...	14.49	13.84	...	5
1985 May 5.......	...	...	13.89	...	5
1985 Jun 1........	...	...	13.65	...	9
Averages[b]	15.16	14.54	13.81	12.64 ± 0.16	...

[a] No spectroscopic measurement.
[b] Of measurements in 5″ beam.

TABLE 2

SPECTROPHOTOMETRY OF 3C 219

WAVELENGTH[a] (μm)	FLUX DENSITY (10^{-19} W cm^{-2} μm^{-1}) 1984 Apr[b]	1984 Jun[b]	1985 May[c]	1985 Jun[c]
2.114...........	...	1.12 ± 0.10	1.49 ± 0.14	1.41 ± 0.20
2.162...........	...	...	1.28 ± 0.14	1.27 ± 0.23
2.193...........	1.67 ± 0.16	...	...	...
2.208...........	1.64 ± 0.11	1.30 ± 0.12	1.49 ± 0.09	1.54 ± 0.10
2.223...........	1.69 ± 0.15	...	...	...
2.253...........	...	...	1.04 ± 0.16	1.32 ± 0.15
2.297[d]...........	...	...	1.28 ± 0.34	...

[a] Line center is at 2.202 μm.
[b] 5″ beam.
[c] 9″ beam.
[d] This point is of low statistical significance and is not plotted in Fig. 1.

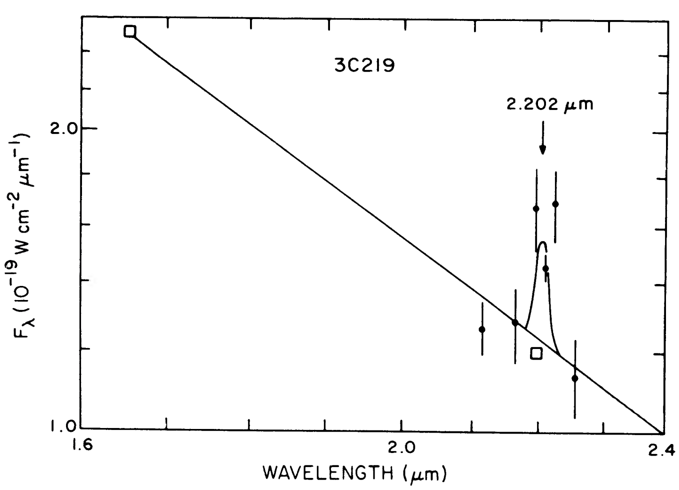

FIG. 1.—Infrared data on 3C 219 plotted logarithmically. Observations at the same wavelengths have been averaged. The large squares denote broad-band observations with widths of 0.4 μm (K) and 0.3 μm (H), while the points denote spectrophotometry with 1% resolution. The solid line denotes the power-law continuum fit to the data plus a Gaussian having the instrumental resolution; the best-fit Gaussian is twice as broad and about equally high.

Table 2 and Figure 1, where all observations at a given wavelength have been averaged. The observations represent about 9.5 hr of telescope time.

The beam size for photometry was nearly always 5″, while the spectrophotometry used 5″ and 9″ for roughly equal times. The chopper spacings ranged from 12″ to 30″ with no detectable difference in signal. The single photometric measurement with a 9″ beam (at K) indicates a 15% increase in signal in the larger beam. This was not confirmed by the spectrophotometric observations, which indicate only about a 5% signal increase. The smaller increase is more consistent with the appearance of the object on the Palomar Sky Survey. We have therefore combined all the data without normalization for beam size. Normalizing the 9″ data to the 5″ beam would give no change in the line flux or the significance of the detection, though Figure 1 would appear slightly different.

The flux of the Paα line was determined by fitting the data with models consisting of a power-law continuum and a Gaussian line profile of various widths. Line detection was confirmed by dividing the data into four parts, each based on a single telescope run. Fitting any two parts gives about a 4 σ detection of a line with consistent fluxes, and the continuum derived is consistent with the 2.2 μm broad-band observations. The line width is poorly determined and could range from the instrumental resolution of 1% up to about 3%. If the intrinsic line width is much smaller than the instrumental resolution, the line flux is $0.73 \pm 0.13 \times 10^{-14}$ ergs cm^{-2} s^{-1}. The best fit is a line about 2% wide (including the instrumental broadening), which would have a flux of $1.54 \pm 0.22 \times 10^{-14}$ ergs cm^{-2} s^{-1}. In each case, the uncertainties quoted are statistical and indicate the likelihood of having detected a line, while the unknown line width dominates the total uncertainty.

III. DISCUSSION

As shown in the previous section we have found evidence of strong Paα emission in the narrow-line radio galaxy 3C 219. In the line flux consistent with the observed optical line spectrum of this galaxy, or does it imply the presence of internal reddening?

In order to determine the reddening, our Paα flux must be compared to the Hα flux. Two published values exist but appear to disagree. Yee and Oke (1978) observed 3C 219 with 160 Å resolution in a 7″ aperture. They detected a blend of Hα, [N II], [S II], and [O I] having a flux of 3.7×10^{-14} ergs cm^{-2} s^{-1} with an uncertainty between 25% and 60%. Cohen and Osterbrock (1981) observed 3C 219 through a smaller aperture (2″.7 × 4″) but with better spectral resolution (10 Å). Their observed flux for the blend is 2.7 times smaller than the value reported by Yee and Oke. However, the small aperture does not permit high photometric accuracy, and the continuum is poorly determined because their spectrum cuts off just longward of the lines (R. Cohen, private communication). In particular, it would be difficult to discern under these conditions a weak broad component to Hα.

In order to estimate the Hα flux, we have applied the line ratios determined by Cohen and Osterbrock to the total flux given by Yee and Oke. The resulting "most likely" Hα flux is 1.2×10^{-14} ergs cm^{-2} s^{-1}. This estimate may still be too large as Yee and Oke determined their total flux by subtracting an elliptical galaxy model from the observations. If, instead, a local fit to the continuum were used, a smaller value for Hα would be derived. For comparison, Cohen and Osterbrock measured 0.5×10^{-14} ergs cm^{-2} s^{-1} in Hα alone, a value we regard as a lower limit.

We can also find the most conservative upper limit consistent with the uncertainties in the determination of the Hα emission. We assume that the discrepancy between the Yee and Oke and the Cohen and Osterbrock values is due entirely to an extended (spatially or spectrally) Hα or to variability and that Cohen and Osterbrock detected all of the flux in the other emission lines. (These lines presumably come from an extended region and are unlikely to vary.) Under these assumptions, an upper limit to the observed Hα flux is 2.9×10^{-14} ergs cm^{-2} s^{-1}.

Cohen and Osterbrock found that the narrow Balmer lines Hα, Hβ, and Hγ had ratios consistent with case B (Osterbrock 1974) emission in the presence of an interstellar reddening of $E(B-V) = 0.24$ ($A_V = 0.74$). This value of $E(B-V)$ together with the "most likely" Hα flux implies a dereddened Hα flux of 2.3×10^{-14} ergs cm^{-2} s^{-1} and a corresponding value of Paschen-α, assuming Paα/Hα = 0.117 for case B, of $f(\mathrm{Pa}\alpha) = 2.5 \times 10^{-15}$ ergs cm^{-2} s^{-1}. This predicted Paα flux is a factor of 3–6 times smaller than the detected value. If we use the maximum Hα in the same calculation, we obtain a predicted Paα flux of 5.4×10^{-15} ergs cm^{-2} s^{-1}. This is still below our minimum detected Paα flux of 7.3×10^{-15} ergs cm^{-2} s^{-1}. Therefore, the detected Paα line cannot simply be due to an extrapolation of the Balmer line component seen in the optical, unless the actual reddening is larger than $E(B-V) = 0.4$.

If we are thus unable to account for the strength of our observed Paα line by extrapolation of the narrow Balmer lines, it must follow that most of our Pα comes from another source. An obvious candidate is a broad-line region that is more strongly reddened than the narrow-line region. Our data do not allow us to state positively that the Paα is broad, but we do nominally obtain a better fit for a line whose breadth exceeds the instrumental width of 3000 km s^{-1}, as stated above.

The Paα measurement implies a lower limit on the amount of reddening to the nucleus of 3C 219. We can derive this limit as follows: We assume that all of the flux detected by Yee and Oke (1978) and not otherwise accounted for is due to Hα from the reddened component. We choose the lowest allowed Paα flux and subtract the flux attributable to the component measured by Cohen and Osterbrock (1981), leaving 6.4×10^{-15} ergs cm^{-2} s^{-1} in Paα which must come from the reddened component. Comparing these values implies (Paα/Hα) > 0.3 and $A_V > 1.6$ mag if the intrinsic ratio is 0.117 (case B). If the intrinsic ratio is 0.095 (as estimated by Carleton *et al.* 1984 for typical broad-line regions) $A_V > 1.8$ mag. We emphasize that this estimate is rather conservative because any large flux in Hα is likely to come from a broad line, but a broad line would have greater Paα flux (see § II). Using the best-fit Paα rather than the minimum value, for example, would increase the derived A_V by 1.3 mag. We conclude that 3C 219 contains a highly reddened line emitting region.

A reddening of $A_V \approx 1$–2 is consistent with the nonstellar continuum found by Yee and Oke in the optical. They infer that ~ 30% of the flux in the U band is nonstellar, decreasing to 5%–10% in the V band. A power law in the range $\nu^{-0.5}$ to $\nu^{-1.5}$ could represent this component. In those type 1 Seyferts with little reddening Ward *et al.* (1986) find, however, that $f(\nu)$ is actually increasing in this region about as $\nu^{+0.25}$. This rise is due to the presence of the optical-UV "big bump" which has been modeled by Malkan and Sargent (1982) and others as thermal radiation from an accretion disk. To redden this typical slope from +0.25 to −0.5 or −1.5 requires an A_V in the range 0.6–1.4.

Since the optical continuum and the Paα line emitting region are both more heavily reddened than the narrow Balmer lines (see above the Cohen and Osterbrock 1981), the obscuring material has to lie well within the narrow-line emitting region. If there is dust at typical broad-line region radii it will be relatively hot (~ 1000 K; Rees *et al.* 1969). The observed L band excess could be consistently explained as thermal emission from this warm dust. However, one data point is insufficient to determine the temperature or mass of the dust, or even to be sure that the infrared excess is indeed dust emission.

IV. CONCLUSIONS

We have detected Paα emission in the narrow-line radio galaxy 3C 219 in excess of the prediction of case B recombination. The emission implies a line-emitting region that is not seen in the optical lines due to the presence of strong internal reddening. Most likely this region is a broad-line nucleus. We can set a firm lower limit of $A_V > 1.6$ mag. Good optical spectrophotometry of 3C 219 through an aperture consistent with the infrared beam (~ 6″) is needed to obtain more precise limits to the Paα/Hα ratio for the broad components of the lines. Nevertheless, it seems clear that at least some narrow-line radio galaxies contain highly reddened broad-line regions in their nuclei.

We thank MMTO staff members K. Gilmore and W. Kindred for their help in setting up the infrared photometer and the three telescope operators, C. Heller, J. McAfee, and J. Robertson, for their help in obtaining the observations. This work was supported in part by NASA contract NAS8-30751.

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