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A Hidden Broad-Line Region in the Weak Seyfert 2 Galaxy NGC 788

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ABSTRACT

We have detected a broad Hα emission line in the polarized flux spectrum of the Seyfert 2 galaxy NGC 788, indicating that it contains an obscured Seyfert 1 nucleus. While such features have been observed in $\sim$ 15 other Seyfert 2s, this example is unusual because it has a higher fraction of galaxy starlight in its spectrum, a lower average measured polarization, and a significantly lower radio luminosity than other hidden Seyfert 1s discovered to date. This demonstrates that polarized broad-line regions can be detected in relatively weak classical Seyfert 2s, and illustrates why well-defined, reasonably complete spectropolarimetric surveys at Hα are necessary in order to assess whether or not *all* Seyfert 2s are obscured Seyfert 1s.

Subject headings: galaxies: individual (NGC 788) — galaxies: Seyfert — polarization

1. INTRODUCTION

One of the most pressing issues in the study of active galactic nuclei (AGNs) is the nature of the nuclear activity in Seyfert 2 galaxies, which are defined by the absence of the broad permitted optical emission lines that characterize Seyfert 1 galaxies and quasars. Initially, the spectroscopic differences between type 1 and type 2 Seyferts were thought to arise simply from differences in the location of the permitted line-emitting gas in their nuclei (Weedman 1977). However, the obscuring torus model of Antonucci & Miller (1985), which is based primarily on observations of the prototype Seyfert 2 galaxy NGC 1068, has provided a more sophisticated physical picture of Seyfert galaxies. To account for their spectropolarimetry data, which revealed a broad-line component in the polarized flux, Antonucci & Miller suggested that NGC 1068 contains a hidden Seyfert 1 nucleus whose continuum source and broad-line clouds are completely blocked from view by a thick molecular torus. Only a fraction of the radiation leaving the central source is Thomson-scattered into our line of sight by a gas of warm electrons above the torus. By now, about 15 Seyfert 2 galaxies have had their hidden broad-line regions (BLRs) revealed in polarized light (Miller & Goodrich 1990; Tran, Miller, & Kay 1992; Kay et al. 1992; Tran 1995a,b; Young et al. 1996; Heisler, Lumsden, & Bailey 1997), indicating that they are really Seyfert 1 galaxies for which we are located in an unfavorable viewing direction. For these objects, the orientation of the nucleus to our line of sight is principally responsible for their spectroscopic properties. The unification of the two types of Seyfert galaxies in these cases is straightforward and elegant; for this reason, it is frequently assumed to apply to *all* Seyferts.

The extrapolation of the obscuring torus model to all Seyferts has been challenged on a number of occasions. For example, recent studies have indicated that the galaxian environments (De Robertis, Yee, & Hayhoe 1998) and dust properties (Malkan, Gorjian, & Tam 1998) of Seyfert 1 and Seyfert 2 galaxies may differ; if so, these are circumstances which cannot be explained in terms of geometrical effects on parsec scales. Similarly, Moran et al. (1992) reported that all known hidden Seyfert 1s have nuclear radio powers at the high end of the Seyfert 20 cm radio luminosity function. Evidence for a hidden BLR should not correlate with radio power if the orientation of the nucleus to our line of sight is the only parameter responsible for the spectroscopic classification of Seyfert galaxies. Using this reasoning, Moran et al. suggested that there may be two types of Seyfert 2 galaxies, hidden type 1 objects and "true" Seyfert 2s, which do not emit broad emission lines. But since the known hidden Seyfert 1s were not drawn from the sample of Seyfert galaxies used to construct the radio luminosity function, the connection between radio luminosity and the presence of polarized broad emission lines needs to be re-investigated.

Even if the correlation between radio power and evidence for a hidden BLR is verified, it may not provide a definitive test of the universality of the unified Seyfert model. Compared to the general population of Seyfert 2s, hidden Seyfert 1s discovered by spectropolarimetry tend to have a lower fraction of unpolarized host galaxy starlight in their optical spectra (Kay 1994a), suggesting that they are more luminous objects relative to their host galaxies. If they are also more luminous Seyfert nuclei in absolute terms, an apparent correlation between radio power and the existence of a hidden BLR could arise from the fact that (1) the more luminous Seyferts at optical wavelengths are also the brighter objects in the radio (e.g., Edelson 1987; Whittle 1992) and (2) spectropolarimetry is more effective at uncovering polarized broad emission lines in objects with lower galaxy-light fractions (Kay 1994a,b).

In order to address these issues in an objective manner, we have initiated a spectropolarimetric survey of a large distance-limited sample of Seyfert 2 galaxies for which complete radio information is available. Observations of about half of the sample have been carried out to date. In this *Research Note* we report the discovery of a hidden broad-line region in the Seyfert 2 galaxy NGC 788, which is noteworthy because of the low radio power and the starlight-dominated optical continuum this object possesses.

2. OBSERVATIONS

Observations of NGC 788 ($z = 0.0136$) were obtained under clear skies on 1997 September 29–30 using the 3m Shane reflector at Lick Observatory with the Lick spectropolarimeter and the red beam of the KAST Spectrograph. The 600 l mm^{-1} grating and 1200 × 400 Reticon CCD provided a dispersion of 2.35 Å/pixel and a resolution of 6–7 Å (FWHM) over the 4600–7400 Å range. NGC 788 was observed for a total of two hours. Each one-hour set consisted of four exposures with the halfwaveplate rotated to 0°, 22.°5, 45°, and 67.°5. Data reduction and analysis were performed using the *VISTA* software package, and additional routines (Miller, Robinson, & Goodrich 1988). All data were summed in the Stokes parameters Q and U, from which average values for polarization P, postion angle θ, and polarized flux $P \times F$ were computed.

3. RESULTS

The total flux, polarization, polarization position angle, and the corresponding polarized flux of NGC 788 are displayed as a function of wavelength in Figure 1. The measured polarization has not been corrected for interstellar polarization or dilution by galaxy starlight. Even though the average measured polarization P is low—0.6% at position angle 124°—it clearly increases across the Hα line to a value of 1.2% while displaying little change in position angle. Most interesting, though, is the presence of a broad Hα component in the *polarized* flux spectrum. The broad Hα line peaks at the same wavelength as the narrow component of Hα in the direct-light spectrum and has an estimated velocity width of 4800 km s^{-1} (FWHM). Broad Hβ is probably present as well, but it is difficult to see in the low S/N ratio polarized flux spectrum. The narrow lines of [O III], [N II], and [S II] are also visible in polarized flux, suggesting that some of the measured polarization results from transmission through a dust screen in either the Milky Way or the host galaxy. The nuclear radio source in NGC 788 is unresolved at $\sim 1''$ resolution (Ulvestad & Wilson 1989), so we cannot compare the polarization and radio source position angles.

It is instructive to compare the radio and optical continuum properties of NGC 788 to those of the other hidden Seyfert 1s discovered to date. To do so, we draw upon the survey of Kay (1994a), which contains a magnitude-limited sample of 50 Seyfert 2s, including NGC 788 and the ten hidden Seyfert 1s studied by Tran (1995a). For most of the galaxies, Kay (1994a) estimated the contribution of starlight to the optical spectrum. Meaurements of their core (arcsecond scale) nuclear radio luminosities have been culled from the literature by Kay et al. (1998).

The blue spectrum of NGC 788 (Kay 1990) and that of the dwarf elliptical galaxy M32 are displayed in Figure 2. As evidenced by the strength of various stellar absorption features, such as Ca II λ3968, the G band (λ4302), Mg I b λ5176, and the Na I D lines ($\lambda\lambda$5890,5896), it is clear that the Seyfert spectrum contains a great deal of starlight and just a small amount of featureless continuum. Near a wavelength of 4400 Å, the fraction of the continuum arising from galaxy starlight $F_{\rm g}$ is $\sim$ 80% (Kay 1994a). This fraction is rather typical for type 2 Seyferts in general ($\bar{F}_{\rm g} = 0.70$), but is much higher than the average value of 0.30 found for objects known to have polarized broad emission lines (Kay 1994a).[1] In Figure 3 we have plotted the distribution of $F_{\rm g}$ for 47 Seyfert 2s in the Kay (1994a) sample; the ten Seyfert 2s with hidden BLRs studied by Kay (1994a) and Tran (1995a) (i.e., Mrk 3, Mrk 348, Mrk 463E, Mrk 477, Mrk 1210, NGC 513, NGC 1068, NGC 7212, NGC 7674, and Was 49) are shaded. With the exception of NGC 513, NGC 788 has a higher starlight fraction than the other hidden Seyfert 1s on the plot. NGC 513 actually has a prominent broad Hα component in its total-flux spectrum (Tran 1995b), and is not, strictly speaking, a type 2 Seyfert.

The radio luminosity of NGC 788 would appear to distinguish it from other hidden Seyfert 1 nuclei as well. With a core 20 cm radio power of 1.6×10^{21} W Hz^{-1}, NGC 788 falls

[1] Estimates of $F_{\rm g}$ reported for a given galaxy in different studies vary because of a number of factors, such as the amount of galaxy light falling on the spectrograph slit, the wavelength range considered in the analysis, and how closely the type and reddening of the template galaxy match those of the program object (Kay 1994a). Although recent authors report finding higher values of $F_{\rm g}$ for their small samples of Seyfert 2s, (e.g., Tran 1995a; Cid Fernandes et al. 1998), we use measurements reported by Kay (1994a) since they were determined for a large number of objects (both BLR and non-BLR Seyfert 2s) using a *consistent* procedure.

at the faint end of the radio luminosity function for nearby Seyferts (Ulvestad & Wilson 1989). As illustrated in Figure 4 (taken from Kay et al. 1998), the other Seyfert 2s known to have polarized broad emission lines are at least 30 times more luminous than NGC 788.

Several authors have suggested that the infrared colors of Seyfert 2s may be related to the presence of a polarized hidden BLR in their nuclei (Hutchings & Neff 1991; Heisler et al. 1997). For example, Heisler et al. (1997) have claimed that Seyfert 2s with polarization evidence for a hidden BLR are more likely to have "warm" infrared colors (i.e., low $f_{60\mu\mathrm{m}}/f_{25\mu\mathrm{m}}$ ratios). Unfortunately, the *IRAS* satellite obtained only an upper limit for the 25 μm flux density of NGC 788, which does not provide a useful constraint on its infrared color. Thus, we are unable to compare the infrared properties of NGC 788 to those of other Seyfert 2s.

4. CONCLUSIONS

NGC 788 is a weak Seyfert 2 galaxy: its radio power is below average compared to other classical Seyfert galaxies, and the amount of starlight in its optical continuum is above average. The detection of a polarized broad Hα emission line in this galaxy demonstrates that hidden Seyfert 1 nuclei can be uncovered in such unremarkable objects, which provides some interesting perspective on the debate about the connection between core radio power and the presence of of a hidden BLR. Clearly, polarized broad emission lines are not exclusive to the most powerful Seyfert 2s, contrary to the suggestion by Moran et al. (1992). On the other hand, it appears that spectropolarimetry does not necessarily bias against the detection of hidden BLRs in objects with starlight-dominated continua. We cannot draw more specific conclusions from just a single example; however, we are confident that the results of our full survey, which will examine the degree to which evidence for a hidden BLR correlates with isotropic properties of Seyfert 2 galaxies, will provide important new insight into issue of Seyfert unification.

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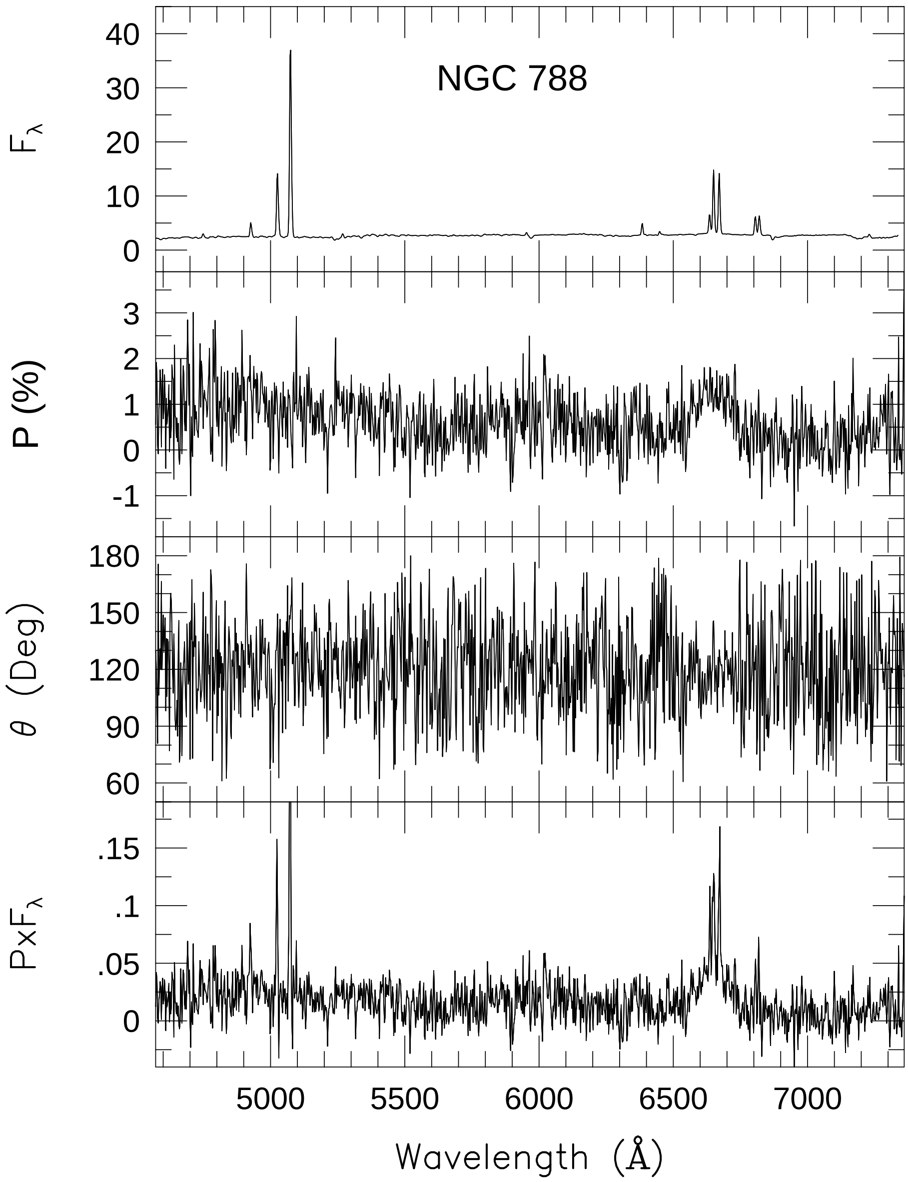

Fig. 1.— Spectropolarimetry of NGC 788, uncorrected for reddening, redshift, or galaxy starlight. The flux (top panel) is in units of 10^{-15} ergs s^{-1} cm^{-2} Å^{-1}. The second panel shows the percent polarization (actually, the rotated Stokes parameter, which is Stokes Q rotated through the average polarization position angle). The polarization position angle is displayed in the third panel, and the bottom panel shows the corresponding polarized flux (the Stokes flux, which is the product of the flux and the rotated Stokes parameter).

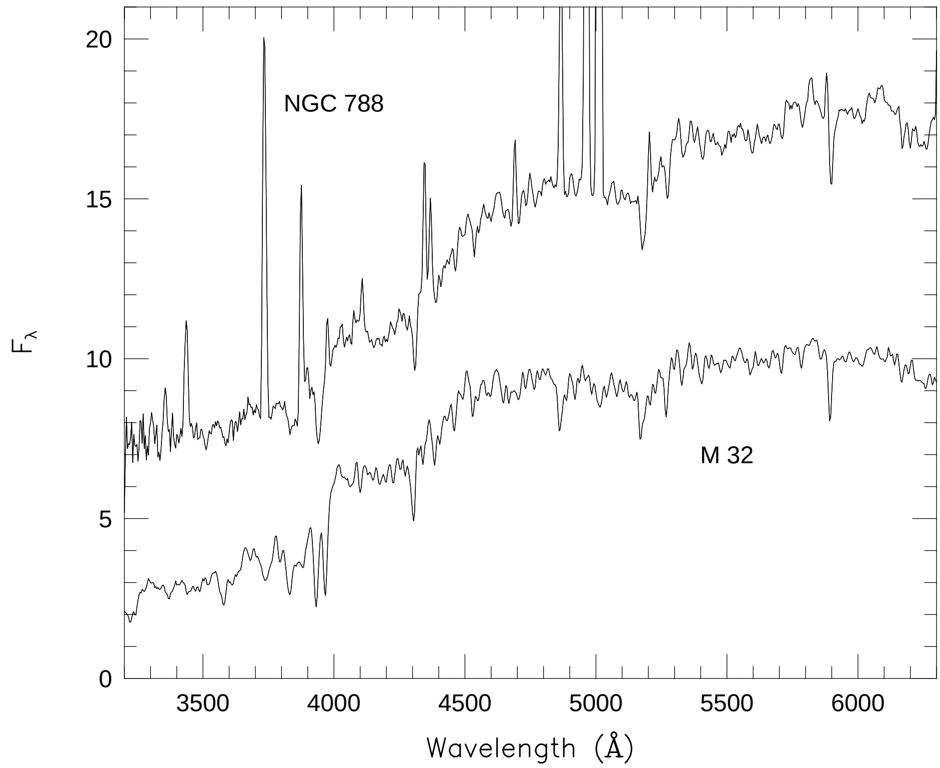

Fig. 2.— Blue spectra of NGC 788 and M 32, showing the high starlight content in the NGC 788 spectrum. The data were obtained using the Lick 3m with the UV Schmidt camera in 1988 and 1989 (Kay 1990).

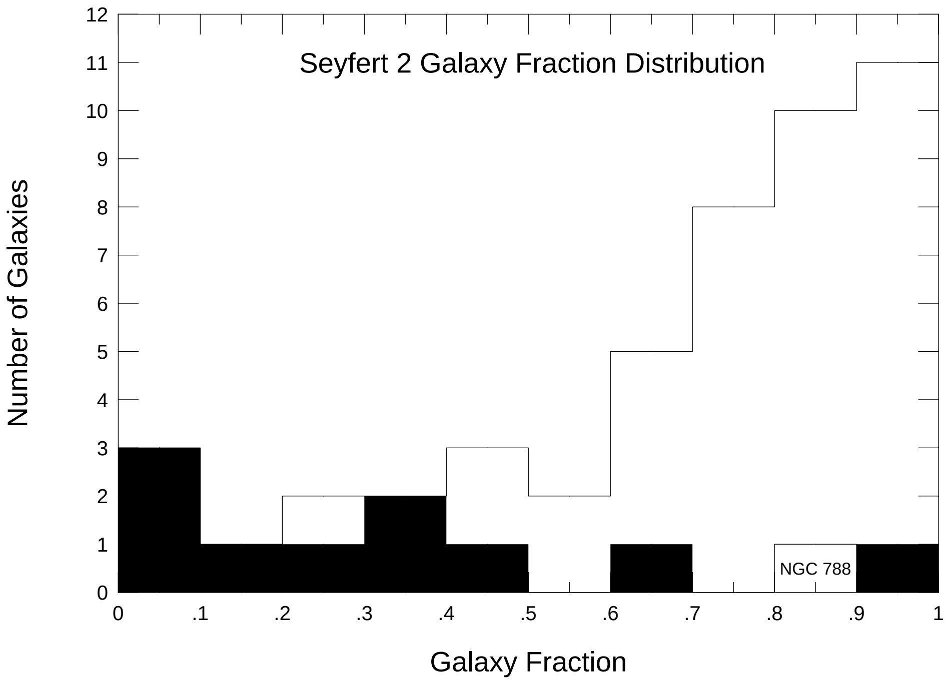

Fig. 3.— Distribution of F_g for the Seyfert 2s in Kay (1994a); shaded boxes represent the ten hidden BLR Seyfert 2s discussed in Tran (1995b).

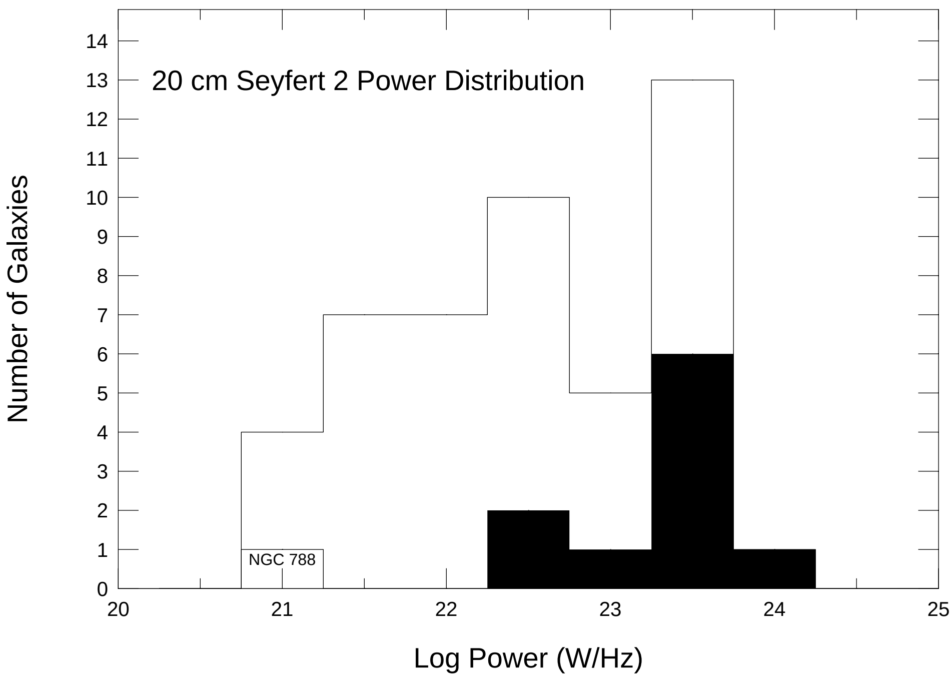

Fig. 4.— Distribution of 20 cm radio power (in W Hz^{-1}) for the Seyfert 2s in Kay (1994a), as compiled by Kay et al. (1998). Shaded boxes are as in Fig. 3. The luminosities were calculated assuming $H_0 = 50$ km s^{-1} Mpc^{-1} and $q_0 = 0$.