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NGC 5506 unmasked as a Narrow Line Seyfert 1:

A direct view of the broad line region using near-IR spectroscopy*

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Abstract. This letter presents incontrovertible evidence that NGC 5506 is a Narrow Line Seyfert 1 (NLSy1). Our new 0.9–1.4 μm spectrum of its nucleus clearly shows the permitted O I λ1.1287 μm line (with full width at half maximum <2000 km s^{-1}) and the "1 micron Fe II lines". These lines can only originate in the optically-thick broad line region (BLR) and, among Seyfert nuclei the latter series of lines are seen only in NLSy1s. The obscuration to the BLR, derived from a rough estimate of the O I λ1.1287 μm/O I λ8446 ratio and from the reddening of the near-IR Paschen lines, is $A_V > 5$. Together, these results make NGC 5506 the first identified case of an optically-obscured NLSy1. This new classification helps explain its radio to X-ray properties, which until now were considered highly anomalous. However, interesting new concerns are raised: e.g., NGC 5506 is unusual in hosting both a "type 1" AGN and a nuclear water vapor megamaser. As the brightest known NLSy1, NGC 5506 is highly suitable for study at wavebands less affected by obscuration.

Key words. line: formation – line: identification – galaxies: active – galaxies: individual: NGC 5506 – galaxies: Seyfert – galaxies: infrared

1. Introduction

The Seyfert nucleus of NGC 5506 has resisted a clear type classification within Seyfert galaxies, and there is a long standing debate on whether it is an intermediate type 1 (broad Hα directly visible) or type 2 (broad Hα not directly visible) Seyfert. The presence of "broad" Paβ has been reported by Blanco et al. (1990), Rix et al. (1990), and Ruiz et al. (1994), but Goodrich et al. (1994) found that the "narrow" line emission profiles become broader at longer wavelengths and suggested that the "broad" Paβ was the strong, highly reddened wings of this profile. Based on data available at that time Goodrich et al. (1994) interpreted the broadening of emission lines with wavelength as due to obscuration of the inner parts of the narrow line region. Morris & Ward (1985) reported a marginal detection of O I λ8446, characteristic of Seyfert 1s, and suggested the presence of high-density optically thick gas. At odds with other type 2 objects, the nucleus of NGC 5506 is dominated by a bright compact core at all near-IR wavelengths and 60% of the J-band (1.25 μm) flux in its central few arcsec is non-stellar in origin (Oliva et al. 1999; Alonso-Herrero et al. 2001). In the hard X-ray it is one of the most luminous and brightest Seyferts in the local universe ($L_{2-10\ \mathrm{keV}} \sim 10^{43}$; Mushotzky 1982) and its obscuring column ($N_H = 3.4 \times 10^{22}$ cm^{-2}; Bassani et al. 1999) is intermediate between typical values for Seyfert 1s and 2s. Nuclear water vapor masers, a property highly correlated with a type 2 spectral classification (Braatz et al. 1996), have been detected towards its nucleus (Braatz et al. 1994).

The host galaxy causes additional complications. The galaxy disk is close to edge on ($i = 70°$), and dust in the galaxy disk is responsible for some or all of the nuclear reddening (Veilleux et al. 1997; Imanishi 2000). NGC 5506 is therefore variously treated as a type 1.9 or type 2 Seyfert in the literature and in either case is usually an outlier among the members of its class.

In this letter we report on near-IR spectroscopy of NGC 5506, which unequivocally identifies it as a Narrow Line Seyfert 1 (NLSy1). In a NLSy1 the broad line region (BLR) is directly visible with the BLR emission lines having widths typically ≤2000 km s^{-1}, significantly narrower than those in classical Seyfert 1s. NLSy1s show several anomalous properties, most notably in the X-ray (for a nice overview of these see Véron-Cetty et al. 2001) and explanations for these include accretion rates close to the Eddington rate (implying lower black hole masses than other Seyferts) or a view to the AGN along its axis.

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* Based on observations made with the Italian Telescopio Nazionale Galileo (TNG) operated on the island of La Palma by the Centro Galileo Galilei of the INAF (Istituto Nazionale di Astrofisica) at the Spanish Observatorio del Roque de los Muchachos of the Instituto de Astrofisica de Canarias.

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2. Observations and data reduction

Data were obtained on 17 January 2001 using NICS, the near-IR imager and spectrograph on the 3.5 meter Telescopio Nazionale Galileo (TNG). We used the low-resolution IJ grism and a slit width of 0.″75, yielding a dispersion of 5.7 Å/pix (resolution 16 Å) over the wavelength range 0.89–1.46 μm, and a scale of 0.25″/pixel along the slit. The slit was centered on the near-IR peak and rotated to position angle 140° North of East. Total integration time on source was 20 min, consisting of four 5 min exposures in the standard "ABBA" position raster. The observations were immediately followed by observations of the star HIP 69160 using the same instrument setup. The sky was not photometric and the seeing about 1″.

Data were reduced using standard tasks within IRAF. The spectrum of HIP 69160 (stellar type G5V) was corrected for its intrinsic spectral shape and then used to correct the atmospheric absorption lines in the spectrum of NGC 5506. Absolute flux calibration was derived by previous observations of photometric standard stars and should be accurate to about 30%. Finally, the spectrum was Doppler corrected using a recessional velocity of 1815 km s^{-1} as derived from H I observations (de Vaucouleurs et al. 1991). The final resolution was ~16 Å over the full wavelength range.

3. Results

The final nuclear spectrum of NGC 5506 is shown in Fig. 1 with emission-line fluxes listed in Table 1. The main result of this paper is based on our clear detection of the *permitted* O I λ1.1287 μm line and the detection of the "1 micron Fe II lines". The O I λ1.1287 μm line, along with O I λ8446, is produced by Lyβ pumping in a Bowen fluorescence mechanism (Grandi 1980). The latter line was tentatively detected by Morris & Ward (1985). Both the above O I lines are produced only by high density optically-thick gas and are usually seen in Seyfert 1s but never in Seyfert 2s (e.g. Morris & Ward 1985).

The "1 micron Fe II lines" at λ0.9997 μm, λ1.0501 μm, λ1.0863 μm, and λ1.1126 μm are posited to originate in BLR clouds. Theoretically, such Fe II lines and their related optical and UV counterparts are expected in only type 1 objects and to be strongest in NLSy1s (e.g. Collin & Joly 2000). Observationally, these lines have been previously detected in only six extragalactic objects, all NLSy1s: I Zwicky 1 (Rudy et al. 2000), Mrk 478 (Rudy et al. 2001), 1H 1934, Ark 564, Mrk 335, and Mrk 1044 (Rodríguez-Ardila et al. 2002). Detailed discussions on the origin of the lines can be found in these papers. Two of the four lines are clearly detected in our spectrum (Fig. 1). The third, Fe II λ1.0863 μm, is blended with the very strong He I λ1.083 μm line and the fourth, Fe II λ1.1126 μm, is only marginally detected as it is in a region of atmospheric absorption. A broad emission feature at 1.07 μm, just blue-ward of He I λ1.0630 μm, is also present. This feature is also seen in all six NLSy1s listed above but has not been identified.

The Paβ line has a broad pedestal (Fig. 2) and is best fit (after deconvolving the instrumental resolution) by two Gaussians with full width half maximum ($FWHM$) 500 km s^{-1} and 1800 km s^{-1}; the broader line contains ~53% of the flux. The similarity between the O I (BLR only) and Paβ (BLR+NLR) line profiles (Fig. 2) suggests that this double Gaussian fit does not perfectly separate emission from the NLR and BLR, respectively. The [Fe II] line profile is only slightly resolved at our instrument resolution, but nevertheless appears different from that of Paβ (Fig. 2). These results are different from those of Veilleux et al. (1997) who found that both Paβ and [Fe II] have similar profiles, with their wings well fitted with a Lorenzian rather than a broad Gaussian component. We were unable to satisfactorily fit our line profiles following the functional form of their fit. It is likely that the line profiles are affected by significant variability. Given the $FWHM$ of the broad components of Brγ (1550 ± 100 km s^{-1} from data taken by R. Maiolino in 1995) and Brα (1200 ± 100 km s^{-1}; Lutz et al. 2002), it appears that the width of the broad component of the near-IR permitted lines does not increase with wavelength, suggesting that the O I λ1.1287 μm and Paβ profiles trace the bulk of the BLR rather than only the outer less obscured part. If this is true, the profile of the Hα emission from the BLR should be

Table 1. Line fluxes in NGC 5506.

Line (1)	Obs. flux (2)	Eg. Dered. (3)	A_λ/ A_V (4)	Comments (5)
O I 0.8447	<6:	<27:	0.55	Morris & Ward
[S III] 0.9069	39	105	0.48	
Pa9+Fe II 0.923	9	23	0.47	blend
[S III] 0.9531	125	280	0.44	includes Pa8
[C I] 0.9850	3	6	0.42	
[S VIII] 0.9913	1?	2?	0.41	marginal det.
Fe II 0.9997	6	12	0.41	
Paδ 1.0049	18	34	0.40	case-B = 34
He II 1.0123	8	15	0.40	
[S II] 1.033	12	21	0.38	
Fe II 1.0501	6	10	0.37	
?? 1.070	5	8	0.36	seen in NLSy1s
He I 1.083	74	110	0.35	
Fe II 1.0863	8?	12	0.35	blend with He I
Paγ 1.0938	36	54	0.35	case-B = 55
Fe II 1.1126	1:	1:	0.35	marginal det.
O I 1.1287	14	19	0.33	
[P II] 1.1882	4	5	0.30	
[Fe II] 1.2567	20	21	0.27	
Paβ 1.2818	100	100	0.26	case-B = 100
[Fe II] 1.3206	6	...	0.25	
Paβ flux	84	280		10^{-15} erg/cm^2/s

Column (2) lists the flux measured in our 0.″75 × 1.″25 nuclear aperture, relative to a Paβ flux of 100, except for the O I 0.8446 line which was measured in a 1.″5 × 10″ nuclear aperture (Morris & Ward 1985). Entries marked with a "?" or ":" are uncertain. The absolute flux of the Paβ line (accurate to ±30%) in units of 10^{-15} erg cm^{-2} s^{-1} is listed in the last line of the table. Column (3) lists the measured flux after dereddening by an illustrative extinction of $A_V = 5$ (see text), relative to a (dereddened) Paβ flux of 100. Column (4) lists the A_λ/A_V values, derived from the standard extinction curve, used to calculate Col. (3). The expected relative fluxes for the first three lines in the Paschen series, assuming Case B recombination, are listed in Col. (5).

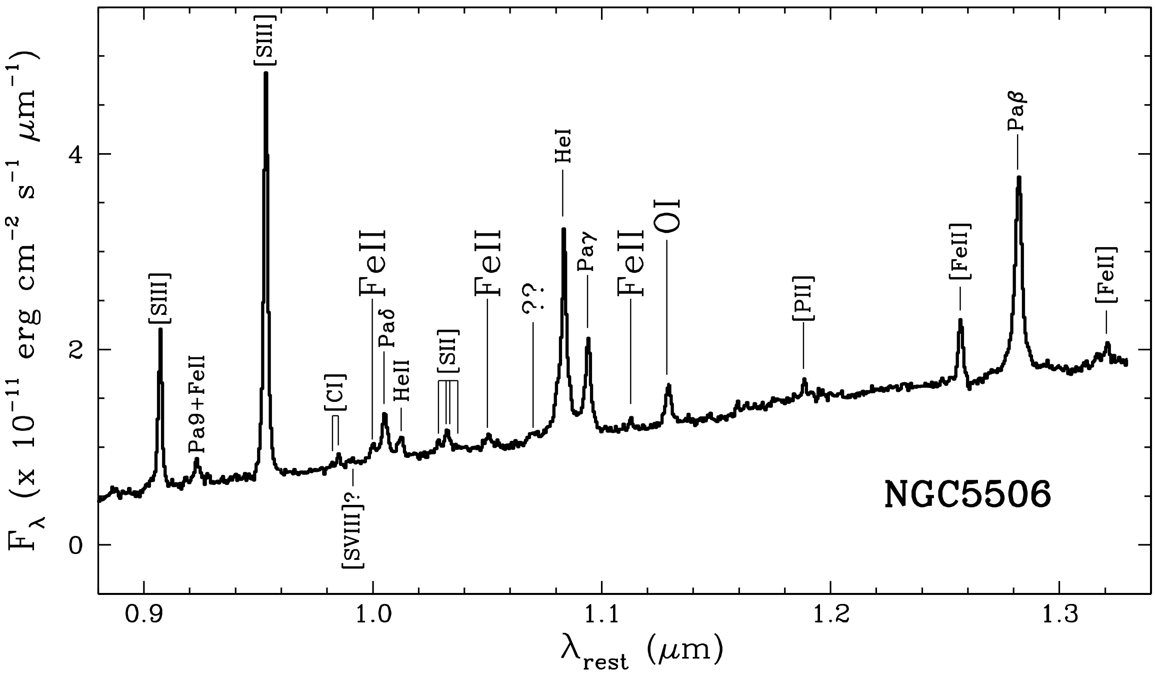

Fig. 1. NICS/TNG spectrum of NGC 5506 in an 0.″75 × 1.″25 nuclear aperture. Most detected lines are labelled.

similar to that of O I (Grandi 1980), though the latter line may be narrower in NLSy1s (Rodríguez-Ardila et al. 2002).

The observed Paβ, Paγ, and Paδ fluxes are consistent with those expected when viewing case-B recombination through an extinction of $A_V = 5$ (Cols. 3 to 5 of Table 1). That is, for the case-B assumption and an error of ~13% in the Paβ/Paδ ratio, our data are consistent with extinction $A_V = 5 \pm 1$ mag towards the Paschen lines. The true extinction to the broad line region is expected to be higher than this illustrative value as our aperture (~100 pc at the distance of NGC 5506) includes emission from the presumably less-extincted narrow line region.

A more direct measure of the extinction to the BLR comes from the O I λ1.1287 μm/O I λ8446 ratio, which is reddening sensitive (intrinsic value = 1.34). In all the published spectra of NLSy1 the observations are compatible with zero relative extinction between the two lines (Rudy et al. 2000, 2001; Rodríguez-Ardila et al. 2002). The only available data on O I λ8446 in NGC 5506 is the spectrum of Morris & Ward (1985, 1988) where this line is only marginally detected. Their spectrum is flux calibrated and partially overlaps with ours. From a comparison between both absolute O I fluxes and O I fluxes scaled to the [S III] lines[1] we find a lower limit of 2 for the O I λ1.1287 μm/O I λ8446 flux ratio, which translates into a relative reddening $A_{0.8446} - A_{1.1287} > 1$. Adopting a standard reddening curve, this gives $A_V > 5$. This result is uncertain due to potential variability, different aperture sizes, and non-photometric conditions. Simultaneous observations of both O I lines are therefore highly desirable.

[1] A direct comparison of absolute fluxes gives O I λ1.1287 μm/O I λ8446 ≥ 2 (higher if we consider that our narrower slit captured less light from the seeing-limited BLR). A comparison of O I fluxes scaled to the [S III] lines (after correcting for differences in the apertures) gives O I λ1.1287 μm/O I λ8446 ~4 (higher if the aperture corrections are not used).

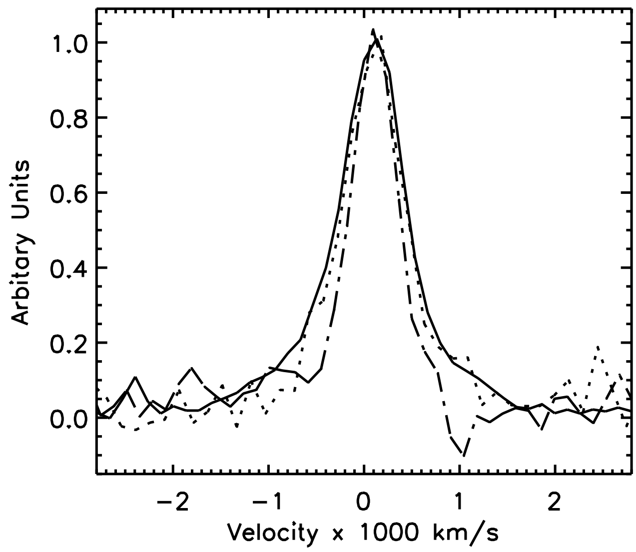

Fig. 2. Comparison of the velocity profiles of Paβ (solid line), O I λ1.1287 μm (dotted line), and [Fe II] λ1.2567 μm (dash-dot line). The instrumental resolution (16 Å at all three lines) has not been subtracted out.

4. Discussion

The currently used classification for NLSy1s (from Pogge 2000) is: 1. narrow permitted lines only slightly broader than forbidden lines; 2. $FWHM$(Hβ) < 2000 km s^{-1}; 3. [O III]/Hβ < 3, but exceptions allowed if there is also strong [Fe VII] and [Fe X] present, unlike what is seen in Seyfert 2s.

We have shown that the BLR emission is detected in the near-IR and that the O I and Paβ line profiles likely sample the bulk of the BLR. Thus, with O I (from the BLR only) and Paβ (from BLR and NLR) line widths <2000 km s^{-1}, NGC 5506 directly satisfies the first two conditions. The observed [O III]/Hβ ratio is 7.5 at the nucleus and this ratio remains high over most of the extended emission-line region (Wilson et al. 1985). If the BLR is highly extincted as our results suggest then the BLR contribution to the Hβ flux would likely change the unextincted nuclear [O III]/Hβ ratio to <3, bringing NGC 5506 into agreement with the third condition for classification as a NLSy1. A high extinction to the BLR would also explain the lack of strong optical Fe II lines as usually seen in NLSy1s. NGC 5506 shares other properties unique to NLSy1s including the presence of the "1 micron Fe II lines" as shown here, a high X-ray luminosity, steep X-ray slope, and fast X-ray variability (Lamer et al. 2000). NGC 5506 is now the brightest known NLSy1 and therefore most suited for studies in wavebands not affected by obscuration. An important issue raised is whether several other X-ray bright and highly variable "type 2" Seyferts are, like NGC 5506, partially obscured NLSy1s.

Several properties of NGC 5506 still remain, or now become, anomalous. Mathur et al. (2001) find evidence that NLSy1s have preferentially lower black hole masses and are accreting at high values of $L/L_{\rm Eddington}$. However, the high central velocity dispersion in NGC 5506 (180 km s^{-1}; Oliva et al. 1999) though somewhat uncertain, implies a relatively high black hole mass among Seyferts, if the scaling between velocity dispersion and black hole mass is valid among Seyferts (Wandel 2002). NGC 5506 is also unusual in being a type 1 AGN with a nuclear megamaser. Both the X-ray column (Risaliti et al. 2002) and narrow maser lines (Braatz et al. 1996) are variable, and it may be that the latter are produced during periods when the column to nucleus is temporarily higher.

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