Optical emission line properties of some little-known Narrow Line Seyfert 1 galaxies

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Abstract. We analyse medium resolution optical spectra of six Active Galactic Nuclei (AGN) with iron emission spectra and characteristics associated with the class referred to as Narrow-Line Seyfert 1 galaxies (NLS1). These were observed using the 1.9 m telescope at the South African Astronomical Observatory (SAAO) in Sutherland. The objects are among the brighter sources of that description accessible from the southern hemisphere: Fairall 265, NPM1G −15.0297, CTS J03.19, EUVE J0414−59.6, A0644–1, and HE 2116−3609. For each target we performed multiple integrations totalling between 1 and 2.5 hours, yielding spectra in the range $\sim$3700–6000 Å with relatively high signal-to-noise ratios. This enabled us to locate multiple spectral emission features, including the strong Fe II bands in the range 4000–5400 Å as well as other prominent emission lines associated with the Balmer series, helium and the [O III] nebular doublet. Our measurements include the flux, width and peak wavelength shifts of the lines, which sometimes displayed multiple components. We summarize some of the properties found for our sample, compare these to other representatives of the NLS1 class and interpret the results in the context of AGN theory.

1. Introduction

Narrow Line Seyfert 1 (NLS1) galaxies are a type of active galactic nuclei (AGN) that form a subclass of Seyfert 1 galaxies in which they exhibit unusually narrow broad emission lines compared to their broad-line counterparts and many of them also display strong optical Fe II lines in their spectra. The defining features of this subclass include that the Hβ full width at half maximum (FWHM) must be less than 2000 km s^{-1}, and the flux ratio [O III]/Hβ must be smaller than 3 [1]. Though NLS1s were initially also required to have strong optical Fe II emission [2], there are quite a few AGN referred to as NLS1 that only have weak or moderate strength Fe II lines.

Emission line properties such as the width, strength and profile are affected by the system dynamics, geometry, central gravitational field, temperature of emitting clouds, excitation mechanisms, etc. The random motion and possible inflow, outflow and orbital trajectories of the gas clouds leads to line broadening due to the Doppler effect [3]. Emission line variability is a common feature in AGN, but there are suggestions that these variations are much less significant in NLS1, see for example Hu et al. [4].

In this paper, we present a preliminary analysis of the optical spectra of six little known AGN for which previous spectra suggested they might be NLS1. These sources were amongst the brighter known or suspected NLS1 that were initially considered (but ultimately not chosen) for regular monitoring. Our measurements include emission line ratios and widths of Fe II lines and other major emission lines. We also compare the spectra with previously published ones to establish the extent of line variations and explore the significance of our findings.

2. Observation, data reduction and emission line fits

Table 1: The sample of AGN observed. Column 4 shows the angular diameter of the source taken from the NED. Column 5 shows the V magnitude of the AGN from the SIMBAD database (https://simbad.u-strasbg.fr). Column 7 lists the date of observation and the number of 20 minute exposures (in brackets) taken on that night.

AGN Name	RA J(2000.0)	Dec J(2000.0)	Diameter (arcsec)	V (mag)	Redshift z	Date (exposures)
EUVE J0414−59.6	04 14 19	−59 41 31	21	16.50	0.071	19 Jan 2016 (3)
Fairall 265	06 56 29	−65 33 37	45	14.55	0.030	14 Dec 2016 (7)
A0644–1	08 17 39	−07 33 09	17	16.69	0.073	19 Jan 2016 (5)
NPM1G−15.0297	09 06 48	−15 17 44	33	16.58	0.054	13 Jan 2016 (3)
CTS J03.19	10 15 56	−20 02 27	38		0.054	13 Jan 2016 (3)
HE 2116−3609	21 19 20	−35 56 25		16.64	0.092	08 Jul 2018 (5)

The AGN in this study were observed with the 1.9 m telescope at the SAAO's Sutherland Observatory using the SpUpNIC optical spectrograph [5]. We performed between three and seven integrations of 20 minutes for each object, which were then averaged to secure better signal-to-noise ratios. The details of the targets and observations are given in Table 1.

We used grating 6 set at an angle of 12.5° to obtain a medium resolution of ≈ 1.4 Å per pixel and the spectra covering the wavelength range ∼ 3700–6000 Å. Each target was placed at the centre of the slit, set to a width of 0.9 arcsec, smaller than the typical seeing, which allowed the light to be recorded from the nucleus, while minimising photons originating from the surrounding host galaxy. For wavelength calibration, we took an emission spectrum using a Cu-Ar lamp before and after each AGN spectrum. Well-known spectrophotometric standard stars were also observed for flux calibration purpose [6].

All observed data were processed and calibrated for wavelength and flux using standard packages in IRAF. This included applying Doppler corrections to shift the spectra of the redshifted AGN to the rest frame. We used the task `onedspec.continuum` in IRAF to remove the continuum flux contribution in the spectra. An Fe II template [3] was used to model the strong Fe II lines in the range 4000–5400 Å (see Figure 1). The template fits a single Gaussian function to each Fe II line and hence determines the strengths and widths of each set of Fe II lines. Other emission lines in the spectra were investigated after subtracting the fitted Fe II lines from the original spectra. Emission line profiles are the result of multiple components originating from different emission regions in AGN. The line profiles in NLS1 galaxies may be represented as a combination of Gaussian functions [3, 7, 8]. Multiple Gaussian functions were used for fitting other major emission lines in the spectra (see Figure 2, and Figure 3 and also Table 2). The area under the overall line fit was taken to be the total flux for each emission line.

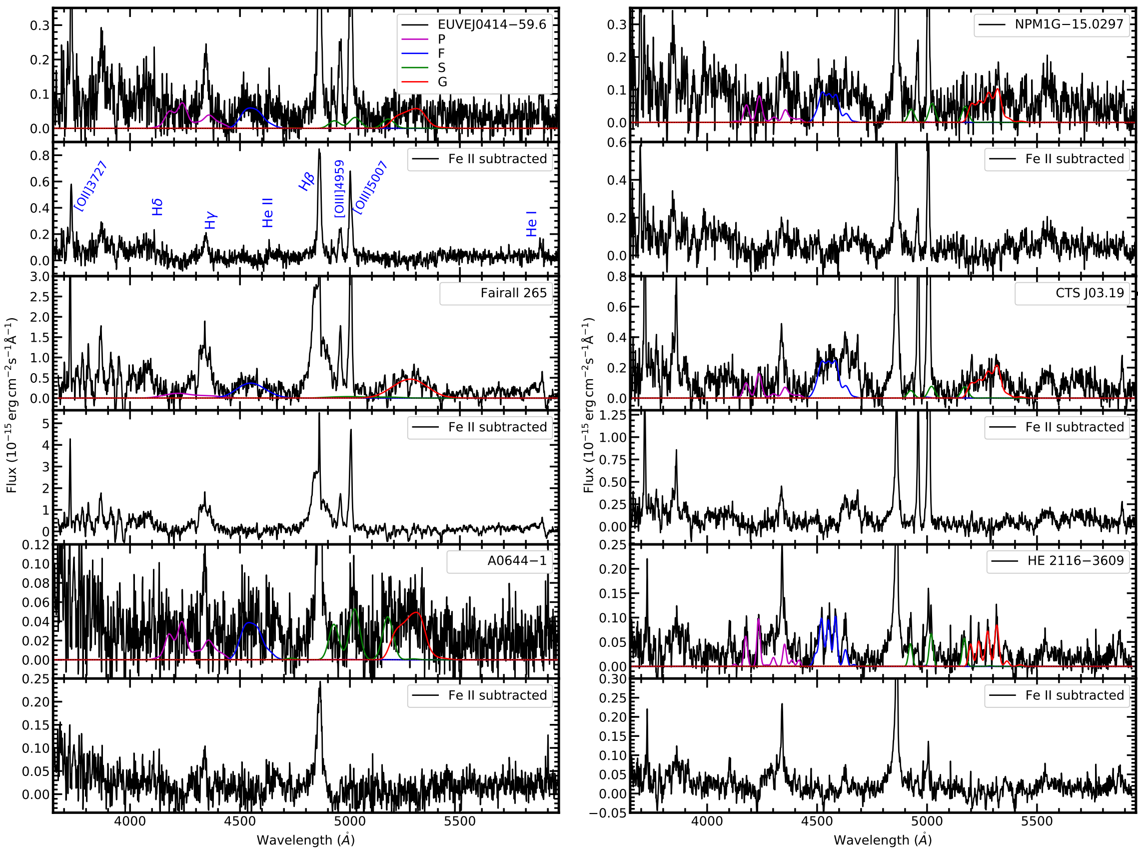


Figure 1: The Fe II fitted spectra followed by the Fe II subtracted spectra of the six AGN analysed in this study. The fit for different Fe II bands (P, F, S and G) are highlighted in colours. The lines of interest in the spectra other than the Fe II lines are marked in the second spectrum of the left plot.

3. Analysis and Discussion

Few studies have been undertaken for the objects investigated in this paper. Not all turned out to be NLS1 as expected. Fairall 265, originally discovered with the same telescope [9], is a Seyfert 1 galaxy at $z = 0.0295$ with broad Balmer lines and a [O II]/[O III] 5007 Å ratio of 0.76 [10], while this ratio measured for the spectrum in this sample is 0.40. The broad Balmer lines measured for Hβ for the spectrum in this study is 2912 km s^{-1} and this was measured to have a width of 2800 km s^{-1} [11]. This corresponds to a black hole mass of $10^{7.33} M_\odot$ [12]. This AGN is not considered as an NLS1 galaxy as the width of its broad Balmer line is greater than the upper limit by which the NLS1 subclass is defined, which confirms in this study as well. The line ratios relative to [O III] 5007 Å of different emission lines in the spectra are given in Table 2. Fairall 265 has a relatively strong [O III] 5007 Å line, but helium is almost absent. Its Balmer lines have an asymmetric profile with thin emission line peaks, which may be a sign of a superimposed H II region near the AGN.

EUVE J0414−59.6 was identified as an X-ray emitter, and its optical spectral observation yielded a redshift of $z = 0.071$ [13]. It was incorrectly classified as a Seyfert 2 galaxy in its discovery paper, whereas its spectrum is characteristic of NLS1. Its Hβ profile is asymmetric, its helium lines are weak and it displays an abnormally strong [O II] 3727 Å line.

HE 2116−3609 has the comparatively strongest Fe II lines in the sample, while its Hβ line is also much stronger than [O III]. Its helium lines are weak and the Hβ shows hints of a broad component at its base. The [O II] 3727 Å line is the strongest in this sample relative to [O III] 5007 Å with a ratio of [O II] 3727 Å/[O III] 5007 Å = 0.97.

NPM1G−15.0297 is an NLS1 with weak Fe II lines. The FWHM was measured as 390 km s^{-1} for [O III] and 1181 km s^{-1} for the Hβ broad component of this object [14], while these values measured in this sample are 558 km s^{-1} and 1308 km s^{-1} respectively, consistent with the FWHM criteria defined for NLS1 galaxies. The Hβ line is mostly symmetric in shape, while, unlike other AGNs in this sample, its [O III] 5007 Å also has more of a symmetric shape.

CTS J03.19 is an NLS1 galaxy with Hβ FWHM of 560 km s^{-1} and 1932 km s^{-1} for the narrow and broad components respectively, a [O III] 5007 Å FWHM of 570 km s^{-1} [15] and a [O II]/[O III] 5007 Å ratio of 0.163 [10]. In this sample those values for the Hβ components turned out to be 538 km s^{-1} and 1890 km s^{-1} respectively, while a [O III] 5007 Å FWHM of 520 km s^{-1} and [O II]/[O III] 5007 Å ratio of 0.28. Its He II 4686 Å is the strongest in the sample, and is also much broader than the Hβ line. The total [O III] 5007 Å strength is much greater than that for total Hβ.

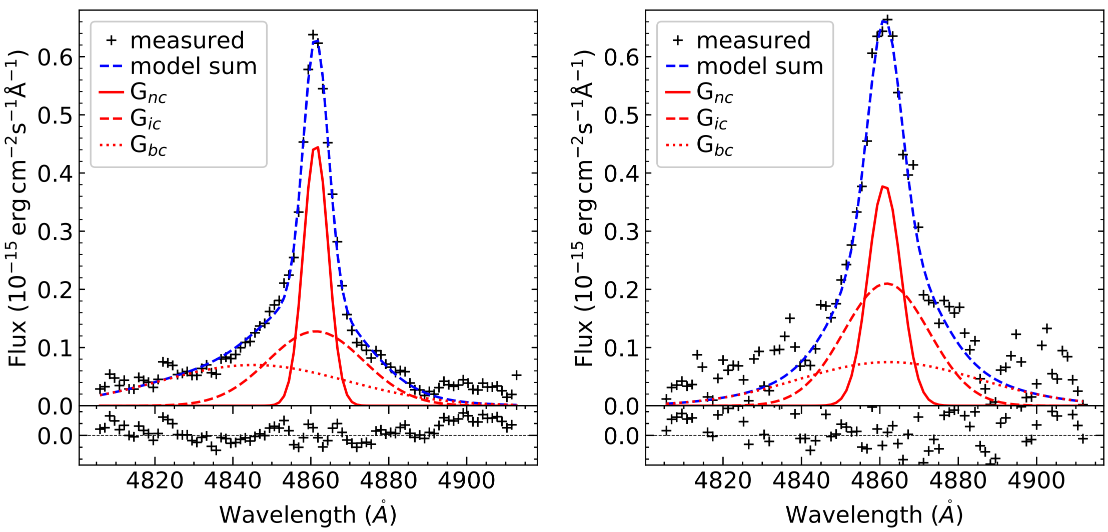
A0644–1 was identified as a NLS1 by Martini et al. [16] and their spectrum displayed rich Fe II emission. In the observation reported here, the Hβ profile is visible and this is the only AGN in the sample with no clear sign of [O III] or other forbidden lines in the spectra, while a He II 4686 Å line is visible. Compared to Hβ, almost all other emission lines in its spectra are very weak or not visible. If the apparent weakness of Fe II is not due to high noise levels in our spectrum then this would be a rare instance of a NLS1 that has experienced long term major changes in its iron line spectrum. This warrants further investigation requiring higher quality data.

It has previously been noted that NLS1 show an anti-correlation between [O III] and Fe II strengths [17]. We can also confirm this from the AGN examined by us. Among the sources in the sample, HE 2116−3609 has strong Fe II lines, while [O III] lines are less prominent. On the other hand, CTS J03.19 has the strongest [O III] lines in the sample, but Fe II emission is relatively weak. Asymmetric profiles associated with [O III] emission lines in AGN have been identified in many studies [3, 8, 18, 19]. NPM1G−15.0297 has an almost symmetric [O III] shape, while for A0644–1 [O III] is too weak to establish the existence and nature of any asymmetry. The [O III] profiles of Fairall 265, CTS J03.19 and HE 2116−3609 have clear asymmetric blue wings. In contrast, there is asymmetry in the form of a red [O III] wing in EUVE J0414−59.6. The two-component modelling of the [O III] profile gives the indication of two distinct locations in the Narrow Line Region (NLR) in these AGN in which the broader asymmetric component of the [O III] line could be a sign of the presence of emitting gas clouds turbulent in nature due to its location in the NLR closer to the accretion disc, and the asymmetry is caused as a result of strong wind and outflows from the accretion disc [7, 8, 19, 20, 21, 22].

NLS1 galaxies usually do not show large variations in the optical compared to many other classes of AGN, and their variability is often considered lower than that of other Seyfert 1 galaxies. To understand the scale of variability, two spectra found in the literature were compared with our spectra for NPM1G−15.0297 and CTS J03.19 (see Figure 4). We detect no significant differences in the emission lines.

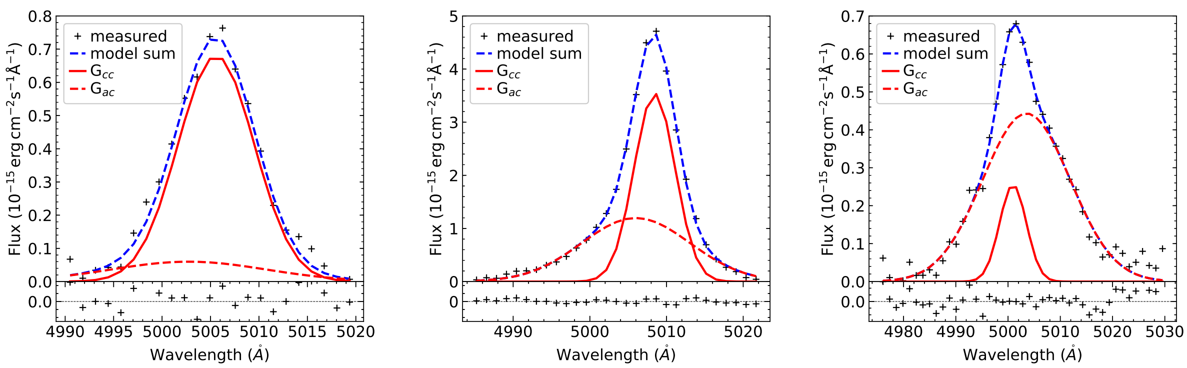
4. Summary

- We confirm that five of the six AGN investigated here are indeed NLS1. This includes EUVE J0414−59.6, which had previously been misclassified as a Seyfert 2. Fairall 265 has Balmer lines that are broader than 2000 km s^{-1} and that are furthermore currently displaying asymmetric profiles. It is hence a normal Seyfert 1 rather than a NLS1.
- The asymmetric blue wing is evident in three AGN in the sample (Fairall 265, HE 2116−3609 and CTS J03.19) and is presumably a result of outflowing gas from the central nucleus. EUVE J0414−59.6 exhibits a clear red wing [O III] profile, while NPM1G−15.0297 mostly



(a) (b)

Figure 2: Examples of the Hβ profile fitted as the sum of three Gaussian functions for HE 2116−3609 (a) and NPM1G−15.0297 (b) respectively. The observed data is represented using crosses. The Gaussian components, *narrow, intermediate and broad*, are shown in *solid, dashed and dotted red lines* respectively and the fitted sum is shown as *dashed blue line*. The residual of the fitted sum is shown at the bottom.



(a) (b) (c)

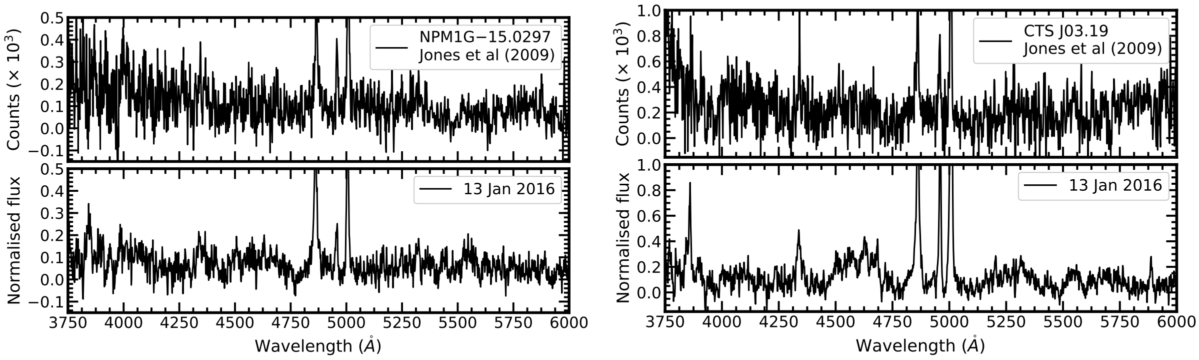
Figure 3: Different [O III] 5007 Å profiles: A symmetric shape for NPM1G−15.0297 (a) and asymmetric blue and red wings for CTS J03.19 (b) and EUVE J0414−59.6 (c) respectively. The spectral line is fitted as a combination of two Gaussians.

shows a symmetric shape. The [O III] 5007 Å is not evident for A0644–1.

- When comparing with older spectra from the literature, the spectra collected in this study (i.e. for NPM1G15.0297 and CTS J03.19) usually do not show much change in emission line strength or shape, in line with previous findings.

Table 2: Flux ratios relative to total [O III] 5007 Å: Columns 2 to 8: ratios of total strength for the line relative to [O III]. Column 9 is the ratio of total Fe II strength relative to [O III] in the range 4000–5400 Å. The table excludes A0644–1 and some ratios in other targets, as the lines there are either too weak to measure reliably or seem to be absent in the spectra.

AGN Name	Hβ	Hγ	Hδ	He II 4686 Å	He I 5876 Å	[O III] 4959 Å	[O II] 3727 Å	Fe II
EUVE J0414−59.6	1.73	0.34				0.32	0.53	3.69
Fairall 265	1.56	0.27			0.10	0.38	0.40	3.64
NPM1G−15.0297	1.76	0.36				0.30		5.72
CTS J03.19	0.68	0.14		0.13	0.06	0.34	0.28	2.18
HE 2116−3609	8.12	2.38	0.83				0.97	20.29



(a) (b)

Figure 4: Comparison of continuum subtracted spectra for NPM1G−15.0297 (a) and CTS J03.19 (b) respectively with earlier spectra from the literature [23].

Acknowledgments

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