LETTER TO THE EDITOR

The Close AGN Reference Survey

Mrk 1018's return to the shadows after 30 years as a Seyfert 1

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Draft as of June 30, 2016

ABSTRACT

We report the discovery that the known 'changing look' AGN Mrk 1018 has changed spectral type for a second time. New VLT-MUSE data taken in 2015 as part of the Close AGN Reference Survey (CARS) shows that the AGN returned to its original Seyfert 1.9 classification. The CARS sample is selected to contain only bright type 1 AGN, but Mrk 1018's broad emission lines and continuum, typical of type 1 AGN, have almost entirely disappeared. We use spectral fitting of the MUSE spectrum and previously available spectra to determine the drop in broad line flux and the Balmer decrement. We find that the broad line flux has decreased by a factor of 4.75 ± 0.5 in Hα since an SDSS spectrum was taken in 2000. The Balmer decrement has not changed significantly implying no enhanced reddening over this period, but the remaining broad lines are more asymmetric than those present in the type 1 phase. We posit that the change is due to an intrinsic drop in flux from the accretion disk rather than variable extinction or a tidal disruption event.

Key words. Galaxies: individual, Seyfert

1. Introduction

The various spectral classes of active galactic nuclei (AGN) have been unified based on the inclination of the accreting black hole (BH) to the line of sight (see Antonucci 1993). Under this scheme type 1 AGN, distinguished by their extremely broad permitted optical emission lines, are inclined to the observer such that we have a direct view onto the accretion disk. Type 2 AGN, devoid of these broad emission lines, possess only narrow lines suggesting that radiation from their accretion disks is blocked by what is commonly assumed to be a dusty torus. Intermediate objects complicate this simple dichotomy and are labelled as type 1.2, 1.5, 1.8, or 1.9 depending on the breadth and relative flux of narrow and broad emission lines (Osterbrock & Koski 1976).

Mrk 1018, a late-stage merger at $z = 0.043$ (see Figure 1), was one of the earliest examples of a 'changing look' AGN, changing from a type 1.9 to 1 over the course of < 5 years (Cohen et al. 1986). Since then a number of galaxies have been found to change type optically (e.g. Aretxaga et al. 1999; Denney et al. 2014) or in the X-ray domain (e.g. LaMassa et al. 2015; Ricci et al. 2016). A much smaller sample of AGN have changed spectral type not once, but twice. Only a few galaxies have been

observed to undergo this full cycle. Mrk 590 was observed to change from a type 1.5 to 1.0 from 1973 to 1989, then to gradually lose all evidence of broad lines until 2014 when it appeared as a type 2 AGN (Osterbrock 1977; Denney et al. 2014). Similarly NGC 4151, originally classified as a Seyfert 1.5, lost then regained its broad emission lines (Osterbrock 1977; Antonucci & Cohen 1983; Shapovalova et al. 2010).

Recent work on accretion timescales suggests that AGN flicker on short timescales, $\sim 10^5$ years, rather than remaining at a constant luminosity (Schawinski et al. 2015). Elitzur et al. (2014) posit that AGN may not be statically type 1 or type 2 throughout their lifetimes, and can change type as they increase or decrease in luminosity. AGN that have changed type can help us to understand the accretion physics and associated timescales.

There are a few main hypotheses used to explain why AGN may change spectral type. Variable obscuration of the nuclear region or a patchy torus would allow for the same object to be viewed as a type 1 or type 2 AGN over time (Elitzur 2012). In this scenario, the intervening absorption along our line of sight is changing and not the intrinsic luminosity. An alternative option, is that a drop (or increase) in the accretion rate onto the BH leads
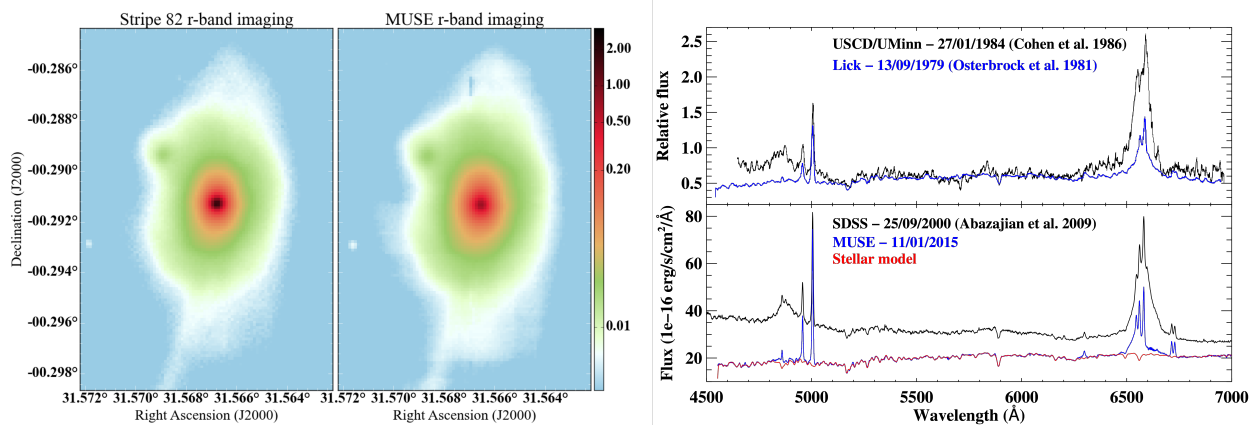
Fig. 1. *Left:* A comparison of the stacked Stripe 82 and re-constructed MUSE *r* band image. The images are scaled logarithmically in units of 10^{-16} erg/s/cm^2/Å. *Right:* The top panel shows the original type 1.9 spectrum from 1979 (Osterbrock 1981) and the follow up type 1 spectrum from 1984 (Cohen et al. 1986) in units of relative flux. These spectra were extracted from the PDFs of the aforementioned papers, and scaled such that their continuum level and narrow emission lines matched. The bottom panel shows the SDSS spectrum (2000) and a 3" aperture spectrum from the MUSE data cube (2015), with the fit to the stellar component of the galaxy over-plotted in red.

to a different AGN classification. Merloni et al. (2015) discuss how tidal disruption events (TDE) of stars close the central BH cause AGN to flare and dramatically increase their luminosity leading to their classification as 'changing look' AGN.

In this paper, we present the serendipitous discovery that Mrk 1018 has changed type again. New data show that Mrk 1018 presents spectral signatures typical of a type 1.9 AGN once more, with drastically dimmed broad lines and continuum.

2. Observations and data analysis

2.1. MUSE 3D spectroscopy

We observed Mrk 1018 with the Multi-Unit Spectroscopic Explorer (MUSE, Bacon et al. 2010) at the Very Large Telescope on 2015-01-11 as part of the Close AGN Reference Survey (CARS, `cars-survey.org`). CARS aims to provide a detailed multi-wavelength view of 40 nearby ($0.01 < z < 0.06$) type 1 AGN.

Mrk 1018 was observed under clear sky conditions at an average seeing of 1″2 and split into two 400 s exposure with a rotation of the FoV by 90°. We reduced the data with the ESO-MUSE pipeline v1.2.1 (Weilbacher et al. 2012) using the standard calibrations. The sky background was estimated and subtracted from the object free signal in the large $1' \times 1'$ Field-of-View (FoV) of MUSE using the pipeline. The final cubes are sampled at 0″2 per spaxel and cover a wavelength range of 4750–9300Å with a spectral resolution of 2.4Å (FWHM).

Mrk 1018 shows spectral features of a type 1.9 AGN (see Fig. 1) with a nearly undetectable broad Hβ line. However, several previous spectroscopic observations (listed in Table 1) are consistent with a type 1 AGN. Thus, our new MUSE observations show that Mrk 1018 has changed optical spectral type again after ~30 years of being a luminous unobscured AGN.

2.2. Continuum and emission line analysis

We take the SDSS spectrum to be representative of Mrk 1018's high luminosity state. We extract an equivalent MUSE spectrum using a 3" diameter aperture centred on the AGN position and correct for absolute flux calibration offsets by matching the strength of stellar absorption lines. The MUSE spectrum has weaker AGN continuum and broad emission lines allowing us to

Table 1. Available spectra for Mrk 1018.

Source	Date	Rest λ-range (Å)	Ref.
Lick	13/09/1979	4500 - 8800	(1)
USCD/UMinn	27/01/1984	4500 - 6900	(2)
HST	08/10/1996	6200 - 9200	
SDSS	25/09/2000	3600 - 8800	(3)
HES	01/12/2000	3400 - 8700	(4)
6df	15/08/2004	3700 - 7200	(5)
Keck	22/01/2009	3400 - 5300	(6)
MUSE	11/01/2015	4500 - 9000	This work

References. (1) Osterbrock (1981); (2) Cohen et al. (1986); (3) Abazajian et al. (2009); (4) Wisotzki et al. (2000); (5) Jones et al. (2009); (6) Bennert et al. (2011)

model the stellar continuum by fitting a super-position of Indo-U.S. Library of Coudé Feed Stellar Spectra (Valdes et al. 2004) with PPXF (Cappellari & Emsellem 2004) excluding regions with emission lines. The MUSE spectrum and the best-fit continuum model are shown on the bottom right of Fig. 1. We then subtract this stellar light contribution from the MUSE *and* SDSS spectra.

A faint broad Hβ emission line is clearly recovered in the MUSE data after continuum subtraction. We fit both the narrow and broad emission lines as a super-position of Gaussians and an additional local power-law continuum for the SDSS spectrum. The light travel time to the narrow line region (NLR) is likely hundreds of years. As such, no significant change in flux is expected within ten years, which is consistent with the data. For accurate Hα and Hβ emission line fluxes we must rely on the extrapolated stellar continuum model, which is made up of a subset of the stellar templates. Uncertainty due to template mismatch is simulated by selecting a random subset of 16 templates from the 504 in the full Indo-U.S. library and repeating the fitting 100 times. We then measure the variance of the output fluxes.

From the emission-line modelling we obtain a broad Hα line fluxes of $(3.3 \pm 0.1) \times 10^{-13}$ erg s^{-1} cm^{-2} for the SDSS spectrum and $(7.0 \pm 0.2) \times 10^{-14}$ erg s^{-1} cm^{-2} for the MUSE spectrum, corresponding to a flux decrease by a factor of 4.79 ± 0.3. Similarly, we obtain broad Hβ line fluxes of $(8.0 \pm 0.1) \times 10^{-14}$ erg s^{-1} cm^{-2} and $(2.2 \pm 0.2) \times 10^{-14}$ erg s^{-1} cm^{-2} corresponding to Hβ dimming by a factor of 3.57 ± 0.5. The Balmer decrement of Hα to Hβ is

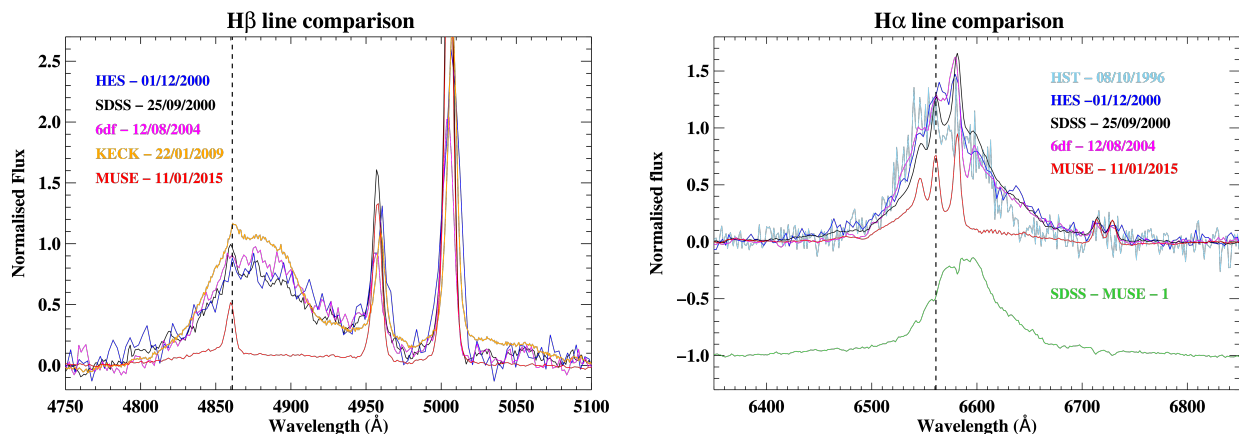**Fig. 2.** Archival spectra focussed on the Hβ (left panel) and Hα (right panel) emission lines. The spectra are plotted in continuum subtracted normalised flux to account for any discrepancies in flux calibration, units, or aperture size. Coloured annotations indicate the date and source of each spectrum. The systemic redshift of Hα and Hβ based on the narrow emission lines is indicated by the dashed black line in both cases. The Keck spectrum from 2009 is plotted in orange and covers only the Hβ line. The Hα residual of the SDSS spectrum (2000) minus our MUSE spectrum (2014) is plotted in green (left panel) to emphasise the change in flux and line shape.

3.3 ± 0.8 for the MUSE and 4.2 ± 0.4 for SDSS spectrum. This tells us that the extinction has not increased, as new obscuration along the line of sight to the BLR would lead to an increased Balmer decrement, but a decrease in the AGN luminosity would not.

The evolution of the Hβ and Hα emission line profile is shown in Fig. 2 over the period 1996-2014. While the broad-line shape remains almost unchanged during the bright state, our most recent MUSE shows a drastically different profile. More flux is lost on the red wing, as shown by the difference of the SDSS and MUSE spectrum (the green line) in Fig. 2 (right panel). The residual is redshifted with respect to the systemic redshift from the narrow Hα line. A similar difference is observed in the Hβ emission line. The Keck spectrum was the last one obtained during the bright state and the Hβ line shows a decrease on the red side. We find broad Hα line width (FWHM) of $4000 \pm 100\,\mathrm{km\,s^{-1}}$ (SDSS) and $3300 \pm 200\,\mathrm{km\,s^{-1}}$ (MUSE). We expect the broad line flux to increase as the AGN luminosity falls to preserve derived M_{BH} estimates (**?**). The observed decrease in emission line width may suggest that the BLR is not in an equilibrium state or the virial factor has changed.

2.3. Photometry

We study the long-term variability of Mrk 1018 with archival observations in MIR and optical (u and r) bands. These include SDSS Stripe 82 (Abazajian et al. 2009), Palomar transient factory (PTF, Law et al. 2009), *SWIFT* UV-optical telescope (Roming et al. 2005), Liverpool telescope imaging (Feb. 2016) at optical bands, and WISE in the MIR (Wright et al. 2010).

It is crucial to decompose the AGN and host galaxy light to infer the intrinsic variability of the nucleus. We estimate the 2D surface brightness distribution of the host galaxy by fitting a simple two component, PSF plus Sersić, to the deep u and r band co-added Stripe 82 images with GALFIT (Peng et al. 2002). The best-fit parameters for Sersić model are slightly different with $r_e = 14\farcs6$, $n = 2.23$ and $b/a = 0.56$ for the u band and $r_e = 9\farcs9$, $n = 2.77$ and $b/a = 0.62$ for the r band. We then fit each individual image keeping those parameters fixed for the u and r band, respectively, and use an empirically constrained PSF from a bright unsaturated star close to Mrk 1018. Only integrated magnitudes can be reported for the *WISE* images.
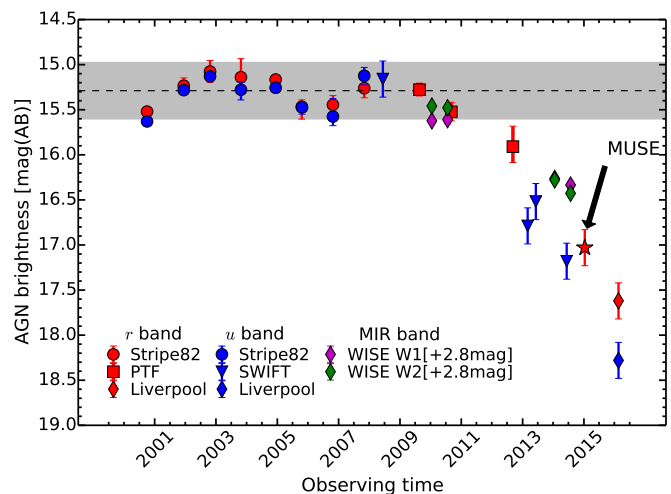

Fig. 3. Time series of archival photometric data for Mrk 1018. Optical r band data is shown in red, u band in blue, and MIR in purple and green. The dashed line shows the mean magnitude of the core (15.28 mag) in the r band and the grey band is the ±2-sigma scatter. The photometry indicates a rapid decline in AGN flux beginning around 2011. The MUSE data point is marked with a star.

The late evolution in the AGN light curve is shown in Fig. 3. The mean magnitude of the core was 15.28 mag (AB) in the r band with a 1-sigma scatter of 0.15 dex prior to the rapid decline in all bands which started in 2011. This corresponds to the change in optical AGN classification at the time of the MUSE observations. The latest data point from Liverpool telescope indicates that the AGN brightness is still declining.

3. Discussion

Our spectroscopic analysis shows that the Hα broad emission line flux in the MUSE spectrum (2015) is a factor of ~4.75 lower compared to the SDSS spectrum (2000) and has changed shape markedly. The multi-epoch photometry shown in Fig. 3 indicates that rather than peaking in luminosity before dimming down to its current state, Mrk 1018 had a relatively constant luminosity

before dropping. Below we discuss the possible scenarios that could have led to apparent dimming of the nucleus.

The tidal disruption of a massive star by the central BH can cause AGN to change spectral type due to a flare in accretion. A tidally disrupted star temporally provides fuel for the nucleus until it is destroyed or too far away (Merloni et al. 2015). We calculate the mass accreted over the bright phase assuming that the luminosity remained constant. Our measurements of $L_{H\alpha}$ and M_{BH} from the SDSS spectrum lead to a bolometric luminosity of $L_{bol} = 3.1 \times 10^{44}$erg s^{-1} and Eddington ratio of $L_{bol}/L_{Edd} = 0.03$. Taking the efficiency of an accretion disk to be 0.1 this gives a mass accretion rate of 0.055 M$_\odot$ yr^{-1} or a total mass accreted over the bright phase (≈ 30 years) of 1.65 M$_\odot$. Typically $\sim 50\%$ of the disrupted stars mass is accreted, requiring a 3.2 M$_\odot$ star. While this could feasibly come from a single star a TDE is characterised by a rapid increase in AGN luminosity, which then peaks before decreasing again over a maximum of several years (Guillochon & Ramirez-Ruiz 2013). We see a 30 year plateau in Mrk 1018's luminosity and no defined peak (only the last 10 years are shown in Fig. 3). To our knowledge, no TDE model predicts a bright phase this prolonged which leads us to conclude that it is unlikely a TDE caused Mrk 1018's recent change.

Could the Mrk 1018's change be the result of a declining accretion rate? As the ionising radiation from an AGN falls the broad line emission comes from faster moving BLR gas closer to the BH. Observationally, the BLR luminosity drops, velocity dispersion increases, and the shape of the lines may change. Therefore, if the altered broad line shape is due to decreased AGN luminosity the velocity dispersion of the emission lines should increase. We observe the opposite. The BLR represents a potential reservoir of fuel for the accretion disk approximately 24 light days away (following Bentz et al. (2013) using $L_{H\alpha}$ converted to L_{5100} (Woo et al. 2015)). This is equivalent to a radial inflow time of ~ 5 years based on the measured velocity dispersion. If the declining accretion rate were due to gradual depletion of fuel we would not expect continuing BLR emission. A disruption of the accretion flow could cause the disc to be temporarily starved, while leaving the BLR unconsumed. The observed decrease, rather than increase, in velocity dispersion as the nuclear luminosity fell may be due to a change in the virial factor. This would imply that the BLR structure and kinematics have been altered. Since Mrk 1018 is a late stage major merger, two SMBHs may orbit one another at the centre of the galaxy. Such a nearby massive object may cause instabilities in the accretion disk and BLR, leading to a rapid drop in accretion rate and changed emission line shape. We lack the spatial resolution to resolve a hypothetical dual SMBH system, which can only be done with long baseline radio interferometry.

We see no evidence for increased extinction, but it is possible that there is new gas or dust along our line of sight blocking our view to the AGN. To explain the lack of reddening this obstacle would have to be extremely opaque with a very high A_V. Additionally, the obscuring material would have to be placed such that select parts of the BLR are still visible. This could explain the new line shape as the redshifted wing of the broad line may be in the region that is blocked from view. However, this argument requires a complex and convoluted geometry in order to explain our observations.

4. Conclusions

In this letter we presented evidence for the AGN Mrk 1018 returning to its Seyfert 1.9 state after ~30 years as a Seyfert 1. Using MUSE data from the Close AGN Reference Survey along-

side archival spectroscopic and photometric observations we explored the possible causes of this change; a decline in accretion rate or lack of fuel, a TDE, obscuration, and disruption of the accretion disk. We reason that the length and consistency of Mrk 1018's bright phase makes a TDE an unlikely explanation, but we cannot rule out a simple decline in accretion rate. The Balmer decrement between the Seyfert 1 and 1.9 phases implies that the obscuration along our line of sight has not increased, but a highly opaque column of gas selectively obscuring our view is still a possibility.

In light of this exciting discovery we were awarded Chandra, HST, and VLA directors discretionary time to investigate how Mrk 1018 has changed since our MUSE observations. While the data presented in this paper cannot definitively tell us the nature of the change in Mrk 1018's nucleus these newer observations in the UV, X-ray, and radio bands will provide further constraints.

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