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Gas flows in a changing-look AGN

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Abstract. The galaxy Mrk 590 is one of the few known 'changing-look' Active Galactic Nuclei (AGN) to have transitioned between states twice, having just increased its flux after a period of ∼10 years of low activity. In addition to the increase in flux, the optical broad emission lines have reappeared but show a different profile than what was observed before they disappeared. The gas motions in the host galaxy of this changing-look AGN show outflows and dynamical structures able to drive gas to the nucleus, suggesting an interplay between inflow and outflow in the centre of the galaxy.

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1. Introduction

Optical changing-look Active Galactic Nuclei (AGN) transition between types (type 1 to type 2 or vice versa) in a matter of years or decades. This fast transition is characterised by a dramatic change in flux and by the appearance or disappearance of broad emission lines. While the first changing-look AGN were discovered serendipitously, more recent studies have employed systematic searches to find more examples of this class of objects (e.g. Runco *et al.* 2016; Ruan *et al.* 2016). AGN that show extreme levels of variability (>1 mag in a timescale of years or decades) seem to have lower Eddington ratios than their less variable counterparts (Rumbaugh *et al.* 2018). Out of these highly variable AGN, 30% of them are expected to show changing-look characteristics (MacLeod *et al.* 2018), suggesting that there are still a significant number of changing-look AGN that we have not discovered yet. Most of the changing-look AGN found are not caused by obscuration but by a change in the black hole mass accretion rate, possibly driven by a rapid change in the accretion physics. Strong evidence of this comes from observations in the mid-infrared and radio (e.g. Stern *et al.* 2018; Koay *et al.* 2016b), which are wavebands less affected by obscuration but that also show changing-look transitions. Understanding dramatic mass accretion rate changes occurring in a matter of years or decades is a challenge for this field. Several options to modify our accretion disc paradigm have been put forward (e.g. Ross *et al.* 2018; Noda & Done 2018), but there is still some difficulty in matching the short timescales observed. The appearance and disappearance of the broad emission lines is likely associated with the change in mass accretion rate, suggesting the existence of a threshold value in luminosity or a combination of luminosity and black hole mass (e.g. Elitzur *et al.* 2014), for the formation of broad emission lines.

2. Mrk 590

Mrk 590 is one of the few changing-look AGN that has gone through a type transition (at least) twice (Raimundo *et al.* 2019a). In the 1970's and 1980's spectra of Mrk 590 showed a broad Hα line and weak Hβ broad component. In the following decade the

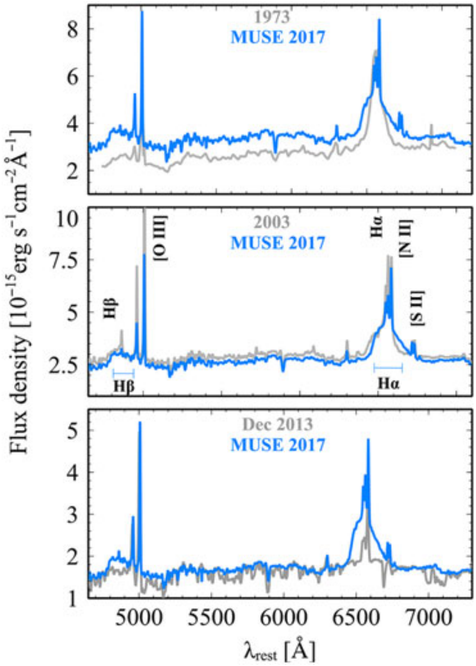

Figure 1. Comparison between spectral features observed in Mrk 590. The grey solid lines show spectra measured at different dates, from top to bottom: 1973, 2003 and 2013 (Denney *et al.* 2014). The blue solid lines are spectra from 2017, obtained with the Multi Unit Spectroscopic Explorer (MUSE) in the Very Large Telescope (Raimundo *et al.* 2019a), and extracted using artificial apertures to match each of the grey spectra. To note the asymmetric shape of the broad Hα line observed in 2017, significantly different from the shape observed in 2003 and 1973.

AGN flux increased until Mrk 590 became a typical Seyfert type 1 galaxy in the 1990's, accreting with an Eddington ratio of $\sim$0.1 (e.g. Peterson*et al.* 2004; Koay *et al.* 2016a), and showing a strong AGN continuum and broad Balmer emission lines in the optical (Peterson *et al.* 1998). Since then, the AGN continuum flux has decreased by a factor of more than 100 across all wavebands and sometime between 2006 and 2012 the broad Hβ emission line disappeared (Denney *et al.* 2014). Raimundo *et al.* (2019a) found that in 2017 the optical broad lines (Hβ and Hα) had reappeared after a period of absence of $\sim$10 years. The AGN optical continuum flux has not increased to the highest levels observed and it is still $\sim$10 times lower than that in the 1990s. According to the model of Elitzur *et al.* (2014), the small increase in continuum luminosity in Mrk 590 would have been enough to cross the luminosity/black hole mass ratio threshold for broad line production. Since UV photons are known to be present (Mathur *et al.* 2018) to produce the broad emission lines, a lack of optical photons suggests that despite producing broad emission lines, Mrk 590 has not fully built its accretion disc yet (Raimundo *et al.* 2019a).

2.1. *Evolution of the spectral shape*

Fig. 1 compares the spectral shape of Mrk 590 at different epochs. The 2017 spectrum in each panel was extracted from the MUSE/VLT datacube shown in Raimundo *et al.* (2019a) using an artificial aperture to match the slits used in the archival spectra. A compilation of archival spectra for Mrk 590 can be found in Denney *et al.* (2014). Here we only show the epochs from 1973, 2003 and 2013 to compare the shape of the Hα broad emission line. The flux calibration is uncertain for some epochs so we focus our discussion

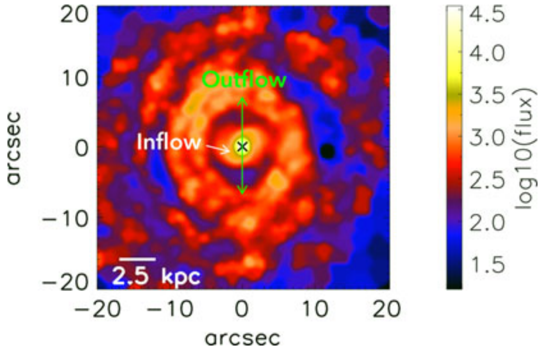

Figure 2. Ionised gas flux map adapted from Raimundo *et al.* (2019a). The arrows illustrate the dynamical properties of the gas in the nucleus and the black cross indicates the position of the AGN. Nuclear spirals, as the one shown for Mrk 590, are candidate mechanisms to drive gas inflows (e.g. Maciejewski 2004; Fathi *et al.* 2006). A gas outflow in the north-south projected direction and extending out to r ∼ 1.5 kpc is detected from the [O III] emission - see Raimundo *et al.* (2019a).

on the spectral shape. As can be seen from Fig. 1, the shape of the Hα broad emission line has changed significantly between epochs. During 2013, the AGN was in a low state and no broad Hα emission was observed. In 1973, an epoch where the AGN was increasing its luminosity (as in 2017) the broad line was narrower than that observed in 2017 and with a 'red shoulder'. The most striking difference is between the 2003 and 2017 line shapes. The broad Hα line from 2003 is stronger in the blue side of the peak while in 2017 the opposite happens, with a strong red tail appearing in the line. The gas producing this line originates from within light-days distance from the black hole, with gas motions away from, or towards the observer contributing to the redshifted or blueshifted components of the broad line (e.g. Raimundo *et al.* 2019b). Such a strong difference in the line shapes may be associated with changes occurring within the dynamical timescale of the broad line region or associated with the process of starting the production of broad emission lines after a quiescent period. Since broad line shapes contain information on the gas geometry and dynamics in the broad line region (e.g. Raimundo *et al.* 2020), more observations of AGN going through this transition may shed light on the physics behind the production of broad emission lines.

2.2. *Host galaxy properties*

The host galaxy shows the presence of ionised and molecular gas in the nucleus, surrounded by a nuclear spiral (clearly observed between r ∼ 0.5−2 kpc) and a star-forming ring (r ∼ 4.5 kpc) (Raimundo *et al.* 2019a). The gas observed indicates that the AGN in Mrk 590 will not run out of gas to fuel its activity but that there may be a cyclical mechanism (likely at the accretion disc scales) responsible for the change in black hole accretion rate. At the hundreds of parsecs scales the gas dynamics in Mrk 590 suggest a balance between gas inflow and outflow (Fig. 2), that can replenish or remove gas from the nucleus, modulating the gas available to the black hole.

3. Conclusions and Outlook

The fast transitions observed in changing-look AGN allow us to probe changes in supermassive black hole accretion physics within a human lifetime. While explaining such transitions is currently challenging, understanding why black holes transition between states can shed light on how and why black holes become active or quiescent. To make

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progress in this field we need to study both the spectral changes and host galaxy properties (as in Mrk 590) but with a high cadence monitoring to observe changes as they happen. We also need to expand the sample of known changing-look AGN for population studies. Current and new time domain surveys will play a major role in this, as hundreds of new changing-look AGN are expected to be found each year in surveys such as e.g. Zwicky Transient Facility (Graham *et al.* 2019), the Young Supernova Experiment (Jones *et al.* 2019, Jones *et al.* in prep.) and the upcoming Vera C. Rubin Observatory Legacy Survey of Space and Time (LSST).

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