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CHANGING-LOOK SEYFERT GALAXIES WITH OPTICAL LINEAR POLARIZATION MEASUREMENTS

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Abstract. In this lecture note, we make the case for new (spectro)polarimetric measurements of "changing-look" AGNs (CLAGNs), a subclass of the AGN family tree that shows long-term (months to years) large flux variability associated with the appearance or disappearance of optical broad emission lines. We discuss how polarization measurements could help to distinguish which of the several scenarios proposed to explain such variations is/are the most likely. We collected all the past polarization measurements of nearby, Seyfert-like CLAGNs and take stock that almost all polarimetric information we have on those fascinating objects dates from the 80's and 90's. We thus explain how polarization could help us understanding the physical processes happening in the first parsecs of CLAGNs and why new polarization monitoring campaigns are strongly needed.

Keywords: Galaxies: active, galaxies: quasars, galaxies: Seyfert, polarization

1 Introduction

Among active galactic nuclei (AGNs), a new class of object is nowadays recognized. Those specific AGNs have time-dependent spectroscopic signatures that makes them appear as type-1 AGNs for a certain period and then as type-2 AGNs after a while(see, e.g., Khachikian & Weedman 1971; Cohen et al. 1986; Goodrich 1989). Type-1 AGN are characterized by large optical fluxes associated with broad (> 1000 km.s^{-1}) and narrow (≤ 1000 km.s^{-1}) emission lines, while type-2s only shownarrow emission lines and lower optical fluxes. The large Doppler widths result from photo-ionization of an equatorial reservoir of gas composed of many cloudlets that have large Keplerian velocities and densities (Gaskell 2009). Depending on the inclination of the system with respect to the observer, this broad emission line region (BELR) may be hidden by an optically thick, equatorial, circumnuclear layer of dust. This orientation dependence has been used to explain the observational differences between the two AGN types for decades now and is still a very robust interpretation (Antonucci 1993). However, there are rogue AGNs that have shown type transitions on timescales of months to years. Examples of such objects are Mrk 1018, which varied between type-2 and type-1 between 1979 and 1984 (Cohen et al. 1986), NGC 4151 that changed from type-1 to type-2 between 1974 and 1984 (Penston & Perez 1984), or 3C 390.3 that followed the same type transition between 1975 and 1984 (Penston & Perez 1984). From dynamical timescale arguments, it is physically impossible that a parsec-sized object has changed its whole inclination in a human time frame. Then, how can we explain those "rapid" changes of type ? There are several theories involving the appearance or disappearance of optically thick material in front of the observer's line-of-sight (Goodrich 1989; Elitzur 2012), tidal disruptions events (TDEs, Rees 1988; Lawrence et al. 2016) or rapid mass accretion rate drop resulting in the disappearance of the BELR (Noda & Done 2018). In this lecture note, we will expound how (spectro)polarimetric measurements of those "changing-look AGN" (CLAGNs) could help understand the physical processes happening around active supermassive black holes. Here, we will focus on nearby, low-luminosity CLAGNs, and refer to Hutsemékers et al. (2019) for high luminosity objects (quasars).

2 Optical polarization of Seyfert-like CLAGNs

There are at least three scenarios* to explain the dramatic flux variation and spectral change of Seyfert-like CLAGNs. The first one invokes the appearance or disappearance of obscuring material in front of the observer's line of sight. In this case,

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*We also take note of the controversial explanation of large amplitude microlensing by stars in foreground galaxies to explain CLAGNs (Lawrence et al. 2016) a cloud from either the outer BELR or the circumnuclear torus passes in front of the line-of-sight and (partially) obscures the central source, resulting in an opacity-dependent dimming and the apparent disappearance of the broad emission line signatures (Goodrich 1989; Tran et al. 1992). The second scenario explains CLAGNs using unusually luminous TDEs (Lawrence et al. 2016). When a star orbits close enough to the central supermassive black hole of AGNs, it is torn apart by tidal forces and a fraction of the mass is accreted, resulting in a sudden brightening of the black hole. The change in luminosity can easily last for several hundreds of days (Rees 1988). Finally, a third scenario postulates that the CLAGN phenomenon is due to modifications in the source of ionizing radiation, likely a variation in the rate of accretion onto the central supermassive black hole (Penston & Perez 1984; Elitzur et al. 2014; Noda & Done 2018).

Spectroscopic and photometric observations can be explained by one or several of those scenarios, depending on the target. However, their polarization signatures are unique (Marin et al. 2016; Hutsemékers et al. 2017; Marin 2017; Hutsemékers et al. 2019).

- If the central source is intrinsically dimming, at the onset of the flux variation the polarization degree experiences sharp decreases and increases associated with rotations of the polarization angle. Those time-dependent variations are due to lower amounts of direct, unpolarized flux from the central engine and constant amounts of reprocessed (delayed) radiation from the equatorial region. The duration of the high polarization degree peak depends on the distance of the scatterer from the source and can be used to achieve polarized reverberation mapping of the inner CLAGN regions. The polarization degree and polarization position angle then return to a stability period after several years/decades (see Marin & Hutsemékers, A&A, submitted). On the other hand, if the BELR disappears, electron scattering inside the BELR becomes inefficient, the polarization degree decreases and the polarization position angle rotates by 90°. Polarized light echoes are much less bright due to the absence of an electron-filled, nearby scattering target. The duration of the echo is also extended due to the fact that radiation has to scatteronto the parsec-scale torus/winds rather than onto the sub-parsec scale BELR. At the end of the echo, the polarization position angle rotates again by 90°, returning to the initial value at the same time than the polarization degree returns to a stability period. This could, in turn, provide us with an estimation of the inner radius of the torus if the polarized light echo is detectable.

- In the case of cloud obscuration, radiation mainly escapes the central (obscured) region by scattering inside the polar outflows, similarly to what has been postulated for the Unified Scheme of AGNs (Antonucci 1993). This results in much higher polarization degrees (10 – 20%, see e.g., NGC 1068 Antonucci & Miller 1985) and a rotation of the polarization position angle due to the fact that equatorial scattering is no longer visible. The flux and polarization variations are also time-dependent but are likely to be shorter depending on the size and radial distance of the cloud to the central engine (Gaskell & Harrington 2018).

All differences are detailed in Marin (2017) for further details. In any case, it is vital to obtain polarization measurements of CLAGNs, before and after the change of look. We thus compiled the historical spectral type changes and polarization measurements of known changing-look Seyferts (at our best knowledge) in Tab. 1. The spectral types of changing-look Seyferts and the epoch at which they were measured are given in Col. 2. A range of dates indicates that the spectral types measured at these two dates are identical, with no change recorded in between. We emphasize that this does not imply absence of spectral type variations during this period. For some objects, exhaustive monitorings were carried out. In such cases, only some representative types/epochs are reported in Tab. 1. The polarization degrees given in Col. 4 refer to the optical continuum polarization measured in various broad-band filters. For a few objects the polarization was monitored during several years. In such cases, we give three representative values at most in Tab. 1. In total, there are only 23 polarization measurements of Seyfert-like CLAGNs. Among the 23, only 3 observations have been carried out after 2000, which means that our knowledge of the polarization of CLAGNs is based on data that are at least 20 years old. There are only 6 objects (Mrk 6, NGC 1566, NGC 4151, NGC 7603, Fairall 9 and 3C 390.3) that have repeated polarimetric measurements but none of them happened coincidentally with the change of look. At best, we can estimate the past polarization level of CLAGNs before their transition but there is very little we can do about determining the correct physical explanation of the spectral/flux change without new and periodic polarization measurements of those objects.

3 Discussion and conclusions

We have seen that the pool of archival polarimetric measurements of state transitions in CLAGNs is very limited, almost non-existent. This is rather detrimental since polarimetric observational data along with numerical models are a unique tool to determine what are the physical causes of the changes of look, unveiling new frontiers in the AGN physics. New and repeated polarimetric measurements are thus needed as part of a monitoring campaign. There are at least 23 candidates for

Table 1. Changing-look Seyferts with optical linear polarization measurements

Object	Spectral type (year)	References	Polarization degree (year) (%)	References
Mrk 6	2 (1968) → 1.5 (1969-2013)	1,2,3	0.54±0.15 (1976) → 0.90±0.03 (1997) → 0.74±0.17 (2013)	4,5,3
Mrk 372	1.5 (1986) → 1.9 (1990)	6	1.49±0.46 (1976)	4
Mrk 590	1.5 (1973) → 1 (1989-1996) → 1.9 (2006-2014) → 1 (2017)	7,8	0.32±0.30 (1976)	4
Mrk 1018	1.9 (1979) → 1 (1984-2009) → 1.9 (2015)	9,10	0.28±0.05 (1986)	11
NGC 1566	1 (1962) → 1.9 (1969) → 1 (1980) → 1.9 (1985) → 1 (2018)	12,13,14	0.60±0.24 (1980) → 1.33±0.18 (1997)	4,15
NGC 2617	1.8 (1994-2003) → 1 (2013-2016)	16,17,18	0.43±0.15 (1998)	19
NGC 2622	1.8 (1981) → 1 (1985-1987)	11	2.35±0.03 (1986)	11
NGC 3516	1 (1996-1998) → 1 (2007) → 2 (2014-2017)	20	0.15±0.04 (1997)	5
NGC 4151	1 (1974) → 1.9 (1984-1989) → 1.5 (1990-1998) → 1.8 (2001)	21,22,23	0.26±0.08 (1976) → 1.18±0.05 (1992) → 0.32±0.30 (2014)	4,24,25
NGC 7582	2 (1980-1998) → 1 (1998)	26,27	1.03±0.12 (1981)	4
NGC 7603	1 (1974) → 1.8 (1975) → 1 (1976-1998)	28,29	0.32±0.29 (1976) → 0.42±0.03 (1987) → 0.25±0.04 (1997)	4,11,5
Fairall 9	1 (1977-1981) → 1.8 (1984) → 1 (1987)	30,31	0.40±0.11 (1981) → 0.37±0.13 (1997)	4,5
3C 390.3	1 (1975) → 1.9 (1980-1984) → 1 (1985-1988) → 1 (2005-2014)	21,32,33	0.84±0.30 (1976) → 1.30±0.10 (1986) → 1.13±0.18 (2014)	4,34,35

(1) Khachikian & Weedman (1971); (2) Khachikian et al. (2011); (3) Afanasiev et al. (2014); (4) Martin et al. (1983); (5) Smith et al. (2002); (6) Gregory et al. (1991); (7) Denney et al. (2014); (8) Raimundo et al. (2019); (9) Cohen et al. (1986); (10) McElroy et al. (2016); (11) Goodrich (1989); (12) Pastoriza & Gerola (1970); (13) Alloin et al. (1986); (14) Oknyansky et al. (2019); (15) Felton (1999); (16) Moran et al. (1996); (17) Shappee et al. (2014); (18) Oknyansky et al. (2017); (19) Wills et al. (2011); (20) Shapovalova et al. (2019); (21) Penston & Perez (1984); (22) Malkov et al. (1997); (23) Shapovalova et al. (2008); (24) Martel (1998); (25) Afanasiev et al. (2019); (26) Ward et al. (1980); (27) Aretxaga et al. (1999); (28) Tohline & Osterbrock (1976); (29) Kollatschny et al. (2000); (30) Kollatschny & Fricke (1985); (31) Lub & de Ruiter (1992); (32) Veilleux & Zheng (1991); (33) Sergeev et al. (2017); (34) Impey et al. (1991); (35) Afanasiev et al. (2015)

Mrk 6 : Variations in type 1.5 state on short timescales. Equatorial scattering dominated (Smith et al. 2004). Polarization reverberation (Afanasiev et al. 2014). No strong variation of PPA.
Mrk 590 : Variations are likely intrinsic. Candidate for polarization echoes.
Mrk 1018 : Variations are likely intrinsic. Candidate for polarization echoes.
NGC 1566 : Recurrent variations with outbursts from type 1.9/1.8 to type 1.5/1.2 during decades. No strong variation of PPA.
NGC 2617 : Variations are likely intrinsic. Candidate for polarization echoes.
NGC 2622 : Variations are likely due to obscuration. Polar scattering dominated (Smith et al. 2004).
NGC 3516 : Complex variability from 1999 to 2008. Variations are likely due to obscuration.
NGC 4151 : Complex variability on multiple timescales. Equatorial scattering dominated (Smith et al. 2004). Polarization reverberation (Gaskell et al. 2012). No strong variation of PPA.
NGC 7582 : The transition to type 1 was fast, and short.
NGC 7603 : Variations are likely due to obscuration.
3C 390.3 : Complex variability. Radio galaxy. Polarization reverberation (Afanasiev et al. 2015).

a follow up program and a handful more of radio-loud AGNs (Hutsemékers et al. 2019). Ideally, broad-band polarization measurements should be obtained twice a year during typically one or two decades. For the brightest objects (Seyferts) this could be achieved with robotic 1m class telescopes. On the other hand, a follow-up of the polarization of CL quasars as those studied in Hutsemékers et al. (2019) would require 2-4m class telescopes, in particular when the objects are in their faint type-2 phase.

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