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Persistence of the blazar state in flat-spectrum radio quasars

Krishan Chand [1,2]★ and Gopal-Krishna[3]★

[1]*Aryabhatta Research Institute of Observational Sciences (ARIES), Manora Peak, Nainital 263002, India*
[2]*Department of Physics, Kumaun University, Nainital 263002, India*
[3]*UM-DAE Centre for Excellence in Basic Sciences, Vidyanagari, Mumbai 400098, India*

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ABSTRACT

Flat-spectrum radio quasars (FSRQs), whose brightness is dominated by a relativistically beamed core, are frequently found in the 'blazar state' commonly inferred from a high optical polarization (> 3 per cent) and/or a large continuum variability. Here we use these two prime optical markers to investigate continuance of an FSRQ in the blazar (or non-blazar) state over an exceptionally long time baseline spanning four decades. Our basic sample is a well-defined, unbiased set of 80 FSRQs whose blazar state stood confirmed during the 1980s from optical polarimetry. Four decades later, the blazar state of each FSRQ is ascertained here from variability of their optical light curves with a typical duration of ∼3.5 yr, a low noise (rms ∼2 per cent) and good cadence (∼3 d), obtained under the Zwicky Transient Facility project, which has been ongoing since 2018. For about 40 per cent of these FSRQs, the blazar state could be ascertained additionally from the opto-polarimetric survey RoboPol (2013–2017). From both these data bases, it is found that only ∼10 per cent of the FSRQs have undergone a blazar ↔ non-blazar state transition over the past three to four decades. This reinforces the case for the long-term stability of the blazar state in individual FSRQs, despite their state fluctuating more commonly on year-like time-scales.

Key words: galaxies: active – BL Lacertae objects: general – galaxies: jets – galaxies: nuclei – galaxies: photometry – quasars: general.

1 INTRODUCTION

Early studies of quasi-stellar objects (QSOs) unveiled a polarimetric distinction between the overwhelming majority (∼99 per cent) of optically selected QSOs and the remaining ∼1 per cent of them that showed a high fractional optical polarization ($p_{\rm opt} > 3$ per cent; Stockman, Moore & Angel 1984). This tiny radio-loud minority also resembled BL Lacertae objects in their optical and radio continua (Stein, O'Dell & Strittmatter 1976). Although apparently arbitrary, this polarization threshold has since become the established method for separating high-polarization quasars (HPQs; which are nearly always radio-loud) from low-polarization radio quasars (LPRQs). It was also found that a compact (parsec-scale) radio core exhibiting a flat/inverted radio spectrum, as a result of synchrotron self-absorption, is a distinctive feature of HPQs. The term 'blazar' was adopted (Angel & Stockman 1980; Moore & Stockman 1981) for HPQs, jointly with BL Lacs, which also exhibit a strong and variable polarization, but differ from HPQs in having very weak optical/ultraviolet emission lines. In both, the dominant contribution to the observed highly variable emission (continuum and polarized) at centimetre and shorter wavelengths comes from a jet of non-thermal emission relativistically beamed towards us (Blandford & Rees 1978).

From the radio perspective, a flat/inverted radio spectrum of a quasar, which marks the dominance of its radio core, has often been deemed adequate for assigning a blazar designation. For instance, it was asserted in Impey & Tapia (1990, hereafter IT90), that essentially every quasar whose radio emission is dominated by its core exhibits a prominent blazar component at optical wavelengths (see also Wills et al. 1992; Maraschi & Tavecchio 2003; Meyer et al. 2011). The criterion of strong linear polarization ($p_{\rm opt} > 3$ per cent) as the marker of the prominent optical synchrotron component has been employed to identify blazars among flat-spectrum radio quasars (FSRQs), with a success rate of 40–50 per cent (Fugmann & Meisenheimer 1988; Wills 1989; IT90). Actually, this is an underestimate as the variability of polarization is a key attribute of blazars, so the polarization of some genuine blazars may sometimes dip below the 3 per cent threshold, resulting in their mis-classification as an LPRQ.

The issue of the duty cycle of the high optical polarization state (i.e. blazar state) among FSRQs was examined, for example, by Fugmann (1988) and IT90, and it was estimated that about two-thirds of FSRQs have $p_{\rm opt} > 3$ per cent some of the time. In fact, it has been suggested that all quasars with a dominant compact radio core have $p_{\rm opt} >$ 3 per cent at least some of the time, and the duty cycle in this HPQ (i.e. blazar) state increases with radio compactness (Fugmann 1988; Impey, Lawrence & Tapia 1991, hereafter ILT91; see also Lister & Smith 2000). While bearing in mind the possibility that a blazar's polarization might occasionally dip below $p_{\rm opt} = 3$ per cent (e.g. Moore & Stockman 1984; Lister & Smith 2000), the division at $p_{\rm opt} = 3$ per cent (see above) to discriminate between LPRQs and HPQs, as also adopted here, remains largely valid (see, e.g. Algaba, Gabuzda & Smith 2011, and references therein). Exceedingly rare cases of QSOs, such as PHL 5200, are known, which have $p_{\rm opt}$

★ E-mail: krishanchand007.kc@gmail.com (KC); gopaltani@gmail.com (GK)

> 3 per cent (as a result of scattering; see Stockman, Angel & Hier 1981), but lack radio detection (e.g. Gopal-Krishna & Sramek 1980). Note also that some blazars may never appear as HPQs; for example, the nucleus of the intensively monitored quasar 3C 273 is found to harbour a mini-blazar, but its expected variable contribution is almost never able to push $p_{\rm opt}$ beyond the 3 per cent threshold (Courvoisier et al. 1988; Impey, Malkan & Tapia 1989; Wills 1989).

Variable flux density is another fundamental characteristic of blazars and their polarized and continuum optical emissions are known to vary on time-scales that can be as short as minutes (see, e.g. reviews by Wagner & Witzel 1995; Ulrich, Maraschi & Urry 1997; Marscher 2016; Gopal-Krishna & Wiita 2018). A variable optical continuum, like fractional polarization, has a strong statistical link to blazar activity, emphasizing that high polarization is associated with the variable component (Moore & Stockman 1984). ILT91 have highlighted the near-identical dependence of polarization and optical continuum variability on radio compactness – on the very large baseline interferometry (VLBI) scale – which is a proxy for the relativistically beamed synchrotron component. Their inference was partly based on the nearly two decades long monitoring campaigns to measure optical variability of over 100 active galactic nuclei (AGNs) on year-like time-scales (Pica et al. 1988; Webb et al. 1988). However, as noted by ILT91, this time scale is suboptimal because optical polarization had been observed to vary on much shorter (week-like) time-scales. This limitation of sensitivity and cadence of optical light curves (LCs) has been largely overcome in the present study.

Intra-night optical variability (INOV) is yet another, key attribute of blazars, with variability amplitudes (ψ) above 3–4 per cent occurring with a duty cycle of around 40–50 per cent (Gopal-Krishna & Wiita 2018, and references therein). The dependence of INOV on $p_{\rm opt}$ was investigated by Goyal et al. (2012) in an extensive campaign of intra-night optical monitoring of nine HPQs and 12 flat-spectrum LPRQs. Whereas strong INOV (ψ > 4 per cent) was detected for the HPQs on 11 out of 29 nights, it was seen for the LPRQs on just one out of 44 nights. This striking contrast demonstrated that INOV is more fundamentally linked to optical polarization than it is to relativistic beaming of the nuclear radio jet. Rather unexpectedly, the tight correlation of INOV with $p_{\rm opt}$ was observed even though the polarimetric classification of the FSRQs subpopulations monitored by Goyal et al. (2012) had been done more than two decades prior to their INOV campaign. Although this strong correlation only reflects long-term ensemble behaviour of the two FSRQ subpopulations monitored by them, it does not seem to tie up with the findings of IT90, based on optical polarimetric measurements of 41 quasars at two epochs with a median separation of ∼1 yr, in which almost a quarter of the quasars were found to switch their polarization state (LPRQ to HPQ, or vice versa). Here we endeavour to probe the issue of the persistence of the polarization state of individual FSRQs, employing a larger quasar sample, together with optical continuum variability (on week- to year-like time-scales) as an alternative, well-established tracer of the blazar state (e.g. Bauer et al. 2009). For this, we make use of the optical LCs of high sensitivity and cadence, obtained for a large number of quasars, under the ongoing Zwicky Transient Facility (ZTF) project launched in 2018 (Bellm et al. 2019).

2 THE QUASAR SAMPLES AND OPTICAL VARIABILITY

The two samples of radio-loud quasars studied here are derived from the opto-polarimetric study of IT90, which is primarily based on two statistically complete sets of quasars drawn from the 1-Jy catalogue of 518 sources, defined at 5 GHz by Kühr et al. (1981). Their first set consists of 90 quasars stronger than 2 Jy at 5 GHz and the second set contains 50 FSRQs (α (2.7–5 GHz) > −0.5) having flux densities between 1.5 and 2 Jy at 5 GHz. For both sets, we downloaded on 2022 March 24 the LCs of the ZTF survey,[1] in the more sensitive r and g bands, after excluding the two quasars for which $p_{\rm opt}$ was not given in IT90, as well as quasars for which (i) a ZTF LC was not available in at least one of the two bands, (ii) the available LC in neither band has at least 25 measurements ($N < 25$), or (iii) the LCs are very noisy (i.e. median σ for the data points is > 0.15 mag). These exclusions from the first set of IT90 led to our sample 1 (60 quasars, including 48 FSRQs) and those from their second set led to our sample 2 (30 quasars, all FSRQs). Basic optical/radio data for each quasar in these two samples are provided in Tables S1(a) and S1(b) in the online supporting information, together with relevant information on their ZTF LCs and the optical variability parameters derived from them, as well as the published optical polarimetric data taken from IT90 and the recent opto-polarimetric survey RoboPol (Blinov et al. 2021). For the LCs in both our samples, Fig. S1 in the online supporting information displays the histograms of time duration (observed and rest-frame) and σ (median) (typically, ∼0.02 mag and ∼0.03 mag for the LCs in the r and g bands, respectively). The rest-frame (i.e. intrinsic) time duration, $T_{\rm int}$ is > 1 yr for 90–95 per cent of the LCs. Excellent consistency is found between the LCs in the r and g bands, but because the two often do not fully overlap in time, the temporal coverage for many quasars has been augmented by considering the two LCs jointly. For deriving the peak-to-peak variability amplitude (Δm) of a quasar, we have used the LC of the band that shows a higher variability amplitude (Δm), where Δm is given by (Heidt & Wagner 1996; Romero, Cellone & Combi 1999)

$$\Delta m = \sqrt{(A_{\rm max} - A_{\rm min})^2 - 2\sigma^2}. \quad (1)$$

Here, $A_{\rm max}$ and $A_{\rm min}$ are the maximum and minimum values in the LC and σ^2 is the mean square rms error for the data points.

For each quasar in samples 1 and 2, we have assigned a variability type, based on our visual inspection of its LCs (column 14 in Table 1). Although we do not use this (subjective) classification for statistical purpose, it is retained here as a useful global descriptor of continuum variability, both its amplitude and time-scale (Figs S1a–S60a and S1b–S30b in the online supporting information). The adopted classifications for variability time-scale are: medium-term (Mt) for week-/month-like and long-term (Lt) for year-like. The five variability types assigned to the LCs are: (i) 'steady' or 'very mildly variable' (S/VMV); (ii) 'mildly Variable' (MV); (iii) 'variable' (V); (iv) 'violently variable' (VV); (v) aperiodic 'CONfined FLARE(s)' (CONFLARE), superposed on a relatively quiescent LC of S/VMV, or MV type. In these LCs, the S/VMV type variability is always found to be long-term (Lt) only, while the V and VV type LCs always exhibit medium-term (Mt) variability. Nearly always, these variability types are found to have: Δm < 0.5 mag (S/VMV), 0.5–1.0 mag (MV), 1.0–3.0 mag (V) and >3 mag (VV). Representative LCs for each variability type in our samples are shown in Fig. 1.

3 RESULTS

In column 8 of Tables S1(a) and S1(b) in the online supporting information, we reproduce from IT90 the 'first pass' value and the maximum known value of $p_{\rm opt}$ for each quasar, out of the available measurements (at most a few, for most of the quasars).

[1]The database of the ongoing ZTF project, https://www.ztf.caltech.edu

Table 1. The basic radio/optical data for sample 1, together with information derived from the ZTF optical LCs (Bellm et al. 2019) and the opto-polarimetric survey RoboPol (Blinov et al. 2021). The full Table S1(a) (sample 1) and Table S1(b) (sample 2) are available in the online supporting information. Column 3 gives the redshift, where the upper value is from Impey & Tapia (1990) and the lower value is from the NED. Column 4 gives the flux density at 5 GHz, taken from Impey & Tapia (1990). Column 5 gives the radio spectral index, taken from Kühr et al. (1981). Column 8 is the 'first pass' measured value of optical polarization given by (a) Impey & Tapia (1990) and (b) Impey et al. (1991); their maximum measured value, p_{opt}(max), is given in parentheses. Column 9 is the polarization class of the source: p_{opt}(max) < 3 per cent for LPRQs and > 3 per cent for HPQs. The polarization class in parentheses is for those three sources for which the quoted 1σ error on p_{opt}(max) would push the source to the other polarization class. Column 10 is the number of points in the ZTF LC. In column 11, the value in parentheses is the intrinsic duration (in d) of the ZTF LC, i.e. total duration $[T/(1+z_{NED}]$. Column 12 gives the median value of the rms errors of the N points in the ZTF LC. Column 13 is the total (peak-to-peak) variation of apparent magnitude in the ZTF LC (equation 1). Column 14 is the assigned variability type (see Section 2). Column 15 gives the RoboPol measured p_{opt}, taken from Blinov et al. (2021) (see Section 4). The JD in parentheses marked with '∗' corresponds to the Julian date minus 245 0000 and the parameter N in parentheses corresponds to the number of polarization measurements. The terms $p1$, $p2$ and $p3$ are explained in Section 4.

Source SDSS name (1)	Other name (2)	z (3)	Flux at 5 GHz (Jy) (4)	Radio sp. index α ($f_\nu \propto \nu^\alpha$) (5)	App. mag. (SIMBAD) B V R (6)	App. mag. (SDSS) g r (7)	p_{opt} (%) (8)	Pol. class (9)	N (LC) g r (10)	Total duration (T) of the LC T_{obs}, (T_{int}) (d) (11)	σ_{med} (12)	Δm_g Δm_r (13)	Variability type (14)	p_{opt} (%) RoboPol $p1$ (JD∗) $p2$ (JD∗) $p3$ (JD∗) mean p, (N) (15)
0106+013	4C 01.02	2.107	2.41	0.12	18.54		2.2 ± 1.1 (7.1)[a]	HPQ					V (Mt)	
J010838.77+013500.32		2.099			18.39	18.29			235	1251.76 (403.92)	0.036	1.88		
					19.05	18.10			238	1261.68 (407.12)	0.034	2.35		
0133+476	OC 457	0.860	2.92	0.57	–		20.8 ± 0.7 (20.8)[a]	HPQ					V (Mt)	14.6 ± 0.8 (6591)
J013658.59+475129.10		0.859			18.00	18.70	20.8 ± 0.7 (20.8)[b]		271	1257.77 (676.58)	0.100	2.46		6.4 ± 1.5 (7617)
					19.25	18.13			423	1260.88 (678.26)	0.067	2.79		4.1 ± 1.5 (7607)
														⟨8.75⟩, (N = 64)
⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮	⋮

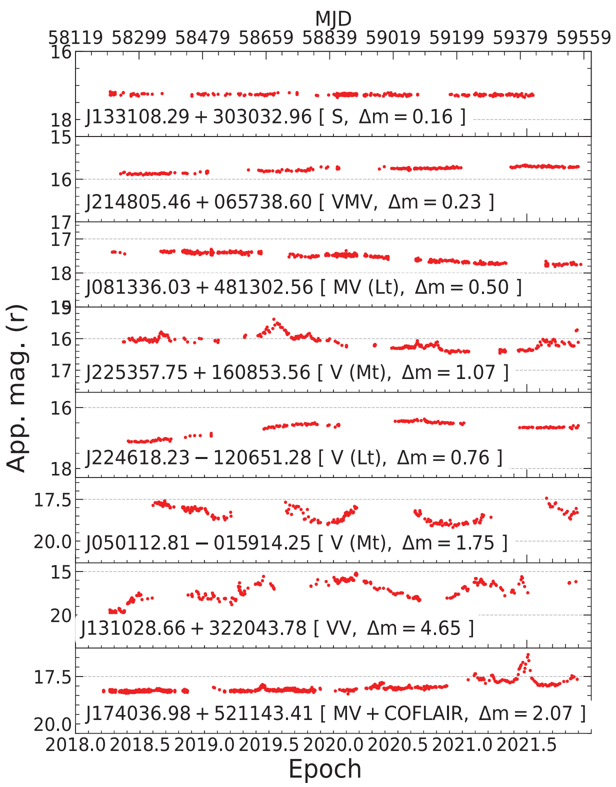

Figure 1. Representative LCs (r band) for the different variability types (Section 2).

Often, the two values listed for a quasar in IT90 are identical, as just one polarimetric measurement was available then. In view of the small number of measurements available for individual quasars, we prefer to use p_{opt}(max) for polarimetric classification, instead of mean polarization, in order to reduce the possibility of mis-identifying genuine HPQs as LPRQs, as a result of the polarization variability of HPQs. Thus, for the quasars in our two samples, with HPQ designation, a blazar state had been identified in the 1980s, based on optical polarimetry (Tables S1a and S1b, column 8). Now, after an interval of four decades, we can check for each of the quasars individually, the status of its blazar activity, on the basis of the amplitude of optical continuum variability in its ZTF LCs (Figs S1a–S60a and S1b–S30b in the online supporting information). Conversely, we can also look for the quasars whose low polarization, p_{opt}(max) < 3 per cent, during the 1980s indicated a non-blazar state then, but which have now entered a blazar state, as signified again by a strong variability in their ZTF LCs. For this check, we extracted from Tables S1(a) and S1(b), two categories of quasars that are candidates for transition to the opposite state, i.e. either from a confirmed blazar state in the 1970–1980s to a clearly quiescent (i.e. non-blazar) state now, or vice versa, during the intervening four decades. To facilitate a quantitative estimation, we adopt the following reasonably robust criteria to define these two types of transitions as: (i) blazar to non-blazar state, p_{opt}(max) > 3 per cent to $\Delta m < \sim 0.5$ mag; (ii) non-blazar to blazar state, p_{opt}(max) < 3 per cent to $\Delta m > \sim 1.0$ mag. Comments on the quasars short-listed under these two categories of state transition are given in the following (see also Tables S1a and S1b).

3.1 *Category I: blazar to non-blazar state*

J0405−1308. The two available measurements prior to 1990 gave $p_{opt} = 20.2$ per cent and 3.8 ± 0.5 per cent, demonstrating its blazar state. The observed mild optical variability ($\Delta m = 0.45 \pm 0.02$) confirms this FSRQ as a strong case of state transition.

J0823+2223. With $p_{opt} = 5.2 \pm 1.2$ per cent (IT90), the source was a known HPQ in the 1980s. However, its ZTF LCs are short ($T_{int} \sim$ five months) and poorly sampled, with a large gap. The possibility that its observed Δm of 0.37 ± 0.02 may be seriously underestimated, rendering this blazar a weak candidate for state transition.

J0957+5522. With $p_{\rm opt} = 9.6 \pm 1.8$ per cent (IT90) and 6.4 ± 0.5 per cent (ILT91), this FSRQ was a bona fide blazar in the 1980s. Its well-sampled ZTF LCs give a low $\Delta m = 0.53 \pm 0.03$ (g band) and 0.45 ± 0.02 (r band), making it a strong case of state transition.

3.2 *Category II: non-blazar to blazar state*

J0530+1331. Its designation as LPRQ (i.e. non-blazar) in the 1980s is based on a single available measurement ($p_{\rm opt} = 0.3 \pm 1.0$ per cent; Fugmann & Meisenheimer 1988). So, this could even be a case of an HPQ masquerading as an LPRQ. Secondly, although its Δm of 1.43 mag seems large, its LCs in both r and g bands are noisy and also poorly sampled (see Table S1a and Fig. S13a), rendering it a weak case for state transition.

J0750+1231. It was a bona fide non-blazar (LRPQ) based on the two measurements available in the 1980s, giving $p_{\rm opt} = 1.0 \pm 1.0$ per cent (IT90) and 2.1 ± 1.1 per cent (Wills et al. 1992). The observed Δm of 1.43 mag is based on a good-quality ZTF LC (Fig. S18a), making it a robust case of transition to the blazar state, which is further reinforced by the relatively recent RoboPol measurements yielding $p_{\rm max} = 12.3 \pm 1.5$ per cent (Table S1a).

J0956+2515. The available two early measurements, giving $p_{\rm opt} = 0.7 \pm 0.4$ per cent (IT90) and 2.2 ± 0.8 per cent (Moore & Stockman 1984), confirmed its non-blazar state in the 1980s. The high Δm of 1.60 mag, based on good-quality ZTF LCs (see Fig. S19b and Table S1b), makes it a strong case of blazar state transition.

J1357−1527. Its identification in the 1980s as a non-blazar (LPRQ) rests on a single measurement ($p_{\rm opt} = 1.4 \pm 0.5$ per cent; IT90), which therefore does not rule out that it was an HPQ in the 1980s. Thus, in spite of a strong variability ($\Delta m = 1.14$ mag; see Table S1b), based on good-quality ZTF LCs (see Fig. S22b), this FSRQ remains an uncertain case of state transition.

J1557−0001. Given that its LPRQ (non-blazar) classification in the 1980s rests on a single measurement ($p_{\rm opt} = 1.2 \pm 1.3$ per cent; IT90), there is a non-negligible chance that it was an HPQ then. Thus, despite a strong variability ($\Delta m = 1.66$ mag; see Table S1a) seen in its high-quality ZTF LC (Fig. S41a), this FSRQ remains a weak case of state transition.

J1635+3808. The old designation of this FSRQ as a non-blazar (LPRQ) is secure, based on three available measurements during the 1980s: $p_{\rm opt} = 2.6 \pm 1.0$ per cent (Moore & Stockman 1984), 1.1 ± 0.2 per cent (ILT91) and 0.8 ± 0.9 per cent (Wills et al. 1992). Thus, the high variability ($\Delta m = 2.67$ mag) seen in its good-quality ZTF LCs establishes it as a strong case of state transition. This transition was already highlighted in Lister & Smith (2000) and confirmed in its RoboPol polarimetry, giving $p_{\rm opt}$ (median) $= 9.9 \pm 0.1$ per cent (Angelakis et al. 2016).

4 DISCUSSION

From the above analysis, it is seen that out of the 49 quasars in Tables S1(a) and S1(b), which had been established (through optical polarimetry) as HPQs during the mid-1970 to mid-1980s, only two (i.e. 4 per cent) show robust signs of transition to the non-blazar state in their ZTF LCs obtained around 2020. The corresponding numbers for the reverse transition, from LPRQ (i.e. non-blazar) to the blazar state, are three quasars out of 41 (7.3 per cent). Even if the 10 steep-spectrum ($\alpha < -0.5$) LPRQs are excluded, the transition fraction for the remaining 31 LPRQs would still be only 9.7 per cent. Thus, from this analysis of sources, it is evident that despite the elapsing of close to four decades, $< \sim 10$ per cent of the FSRQs show clear signs of change in their blazar state in either direction. A broadly similar inference, albeit on the basis of ensemble behaviour, was reached by Goyal et al. (2012), in their INOV campaign around 2006 (Section 1), which showed that the memory of polarization state identified in the 1980s had endured and had been strongly reflected in the INOV behaviour about two decades later. Here we find a similarly high level of persistence of the blazar (or non-blazar) state over a two times longer time baseline (i.e. four decades), by checking the blazar state of each FSRQ individually. How then to reconcile these results with the finding of IT90 that a significant fraction of FSRQs change polarization state on year-like time-scales (Section 1)?

To further scrutinize this point, we now subject our quasar sample (Tables S1a and S1b) to an additional check in which the blazar status of a quasar at both ends of the time baseline is determined using optical polarimetric data alone (this option entails a substantial reduction in the sample size, however). For this, we focus attention on those FSRQs in our samples 1 and 2 extracted from the polarimetric survey of IT90, which are also covered in the RoboPol survey conducted during 2013–2017, which is after an interval of nearly three to four decades (Blinov et al. 2021). Out of the 90 quasars in our two samples, 10 are LPRQs of steep radio spectrum (the two HPQs, although having moderately steep radio spectra, will be deemed as FSRQs and put together with these). The remaining 80 quasars (FSRQs) include 49 HPQs and 31 LPRQs, and 32 of these FSRQs have been observed in the RoboPol survey, mostly multiple times (median $N = 21$). A proper comparison of these measurements, using the sources, with the old polarimetric data provided in IT90, should be based on a similar number of measurements in the two data sets. Because IT90 report no more than a few polarimetric measurements for the vast majority of their sources, the comparison sample has been derived here from the RoboPol data base by limiting to three measurements per source ($N = 3$). For sources with more than three RoboPol measurements, we selected three values using a random number generator. The values based on this unbiased selection process are listed in column 15 of Table 1, together with the total number of available measurements (N) and their average value of p as published in the RoboPol catalogue. Comparison of these opto-polarimetric measurements with the old opto-polarimetric measurements (columns 8 and 9) reveals the following strong cases of polarization state transition: (i) J0405−1308, HPQ to LPRQ transition (consistent with the 'mildly variable' classification of its ZTF LC); (ii) J1635+3808, LPRQ to HPQ transition (also mentioned in Section 3, and again consistent with the 'variable' classification of its ZTF LC). Besides these two confirmed cases, J0750+1231 may have also undergone transition (from the LPRQ to HPQ state), but its LPRQ classification in IT90 is based on just one measurement, which leaves a significant chance that it was a case of HPQ masquerading as LPRQ. Thus, in summary, a comparison of the IT90 and RoboPol opto-polarimetric surveys independently confirms that at most two to three (i.e. <10 per cent) out of the 32 FSRQs common to both surveys have undergone a change of polarimetric state during the intervening three to four decades. This independent estimate of state change, based purely on polarimetric data, is fully in accord with our above estimate using a 2.5 times larger sample of FSRQs and comparing their blazar/non-blazar states as inferred from the polarimetric (IT90) and photometric (ZTF) surveys separated by four decades. It is thus remarkable that $> \sim 90$ per cent of the FSRQs that had been identified as HPQs in the 1970–1980s (IT90) have retained their blazar mode for nearly four decades, as inferred using the ZTF LCs (2018 onwards) and corroborated using the polarimetric survey RoboPol during 2013–2017. The fluctuating polarization state of around a quarter of FSRQs on year-like time-scales, as reported in

IT90 and also seen using our above-mentioned 32 FSRQs covered in the RoboPol survey (see below), does not seem to swamp the long-term stability of the opto-polarimetric state, which is found to persist for at least a few decades. Conceivably, the observed short-term polarization fluctuations may be related to transient events, such as the formation/ejection of radio knots mapped on VLBI scales and probably manifested by γ-ray flares (e.g. Marscher et al. 2008; Gupta et al. 2017), which also seem to have a year-like occurrence rate, on average (Savolainen et al. 2002; Lister et al. 2009; Liodakis et al. 2018).

Finally, in order to quantify the occurrence of the polarization state transition on year-like time-scales, we have selected out of the present sample of 32 RoboPol FSRQs all 27 FSRQs for which $N > 1$. Fig. S2 in the online supporting information shows for these 27 FSRQs a plot of p_{max} against p_{min}, for which the time interval is found to have a median value of 1.1 yr (see column 15 of Table 1). It is evident that seven of the 27 FSRQs ($\sim$ 26 per cent) crossed the $p_{opt} = 3$ per cent threshold on year-like time-scales, confirming an early independent estimate by IT90. Note, however, that the actual fraction may be higher because another seven FSRQs are border-line cases (i.e. within 1σ error of $p_{opt} = 3$ per cent), some of which could be genuine transitions.

5 CONCLUSIONS

Since the 1980s, it has been argued that, at a given time, about two-thirds of a sample of FSRQs are in a blazar state, which is marked by a high level of optical polarization (>3 per cent) and flux variability. Here we have endeavoured to estimate for how long an individual FSRQ, upon entering the blazar state, remains in that state. Although optical polarimetry had hinted that nearly a quarter of FSRQs undergo a change of state on year-like time-scales, INOV observations indicated that memory of the blazar state persists for at least an order-of-magnitude longer time-span (Section 1). We have examined this apparent dissonance by studying a well-defined sample of 80 FSRQs whose blazar states were determined during the 1980s through optical polarimetry (and confirmed for 49 of them). We have now checked these same FSRQs by measuring their optical continuum variability in the high-quality LCs obtained in the ongoing ZTF project launched in 2018. We find that only $< \sim 10$ per cent of the FSRQs have changed their blazar state over the four decades. Furthermore, this estimate is found to be reinforced by the opto-polarimetric survey RoboPol (2013–2017), which covers $\sim$40 per cent of our FSRQ sample. This leads us to conclude that, typically, the blazar state of an FSRQ is likely to persist for at least a few decades, although state transitions on year-like time-scales may also occur in some cases, probably associated with short-term processes, such as the formation and ejection of relativistic plasma blobs (VLBI knots) from the active nucleus.

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DATA AVAILABILITY

The data used in this study are publicly available in ZTF Data Release 8 and the RoboPol database.

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SUPPORTING INFORMATION

Supplementary data are available at *MNRAS* online.

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