Prospers for Detecting X-Ray Polarization in Blazar Jets

Ioannis Liodakis®, Abel L. Peirson, and Roger W. Romani®
KIPAC, Stanford University, 452 Lomita Mall, Stanford, CA 94305, USA; ilioda@stanford.edu

Abstract

X-ray polarization should provide new probes of magnetic field geometry and acceleration physics near the base of blazar jets, but near-future missions will have limited sensitivity. We thus use existing lower energy data and X-ray variability measurements in the context of a basic synchro-Compton model to predict the X-ray polarization level and the probability of detection success for individual sources, listing the most attractive candidates for an Imaging X-ray Polarimetry Explorer campaign. We find that, as expected, several high-peak blazars such as Mrk 421 can be easily measured in 100 ks exposures. Most low-peak sources should only be accessible to triggered campaigns during bright flares. Surprisingly, a few intermediate peak sources can have anomalously high X-ray polarization and thus are attractive targets.

Key words: galaxies: active – galaxies: jets – relativistic processes

Supporting material: machine-readable table

1. Introduction

The characteristic two peaked spectral energy distribution (SED) of blazar jet emission is understood to consist of a low energy synchrotron peak and a high energy maximum generally attributed to Compton emission, although in some models hadronic processes may also contribute to the high energy flux (Boettcher 2012). Blazars are often classified by the synchrotron peak frequency νS, with low-peak LSP reaching νF maxima in the millimeter-IR bands, intermediate ISP sources peaking in the optical/UV, and HSPs peaking in the X-rays. Dramatic variability, on timescales down to minutes in a few cases (Ackermann et al. 2016), is another hallmark of blazar emission. While radiation-zone models can reproduce this general emission pattern, many details remain to be explained and the underlying mechanisms of jet energization and collimation are still a subject of debate (Blandford et al. 2018).

Polarization can be an important tool for probing the physics of the acceleration zone, especially in characterizing the magnetic field structures that control the expected shocks and induce synchrotron radiation. Very long baseline interferometry polarization maps have long been effective at measuring jet fields at parsec scales (e.g., Hovatta et al. 2012), while more recent optical polarization has provided new information on the field orientation and variability in the unresolved core (Blinov et al. 2018). X-ray polarization, to be measured by the approved Imaging X-ray Polarimetry Explorer (IXPE; Weiskopf 2018, launch 2021) and Enhanced X-ray Timing and Polarization mission (eXTP; Zhang et al. 2016, launch ~2025), offers new opportunities to probe the jet fields and radiation physics even closer to the acceleration site. In particular, polarization can help answer whether the leptonic or the hadronic process dominate in a given band (e.g., Zhang 2017).

However, the sensitivities of the near-future missions are modest and long exposures will be required, so in light of the variability and limited low energy polarization information one must choose the expected targets with care. We explore such a choice here based on a simple synchro-Compton model. In Section 2, we characterize the X-ray variability of sources observed in optical polarization monitoring programs. In Section 3, we use our model to predict X-ray polarization levels (I_X). In Section 4, we combine these factors to quantify the success probability of an IXPE measurement for reasonable exposure in an untriggered observation, identifying a list of prime targets, and suggesting other X-ray bright sources that can also be of interest if they exhibit strong optical polarization. We conclude by discussing new measurements that could improve these predictions and monitoring campaigns that could make additional sources, as well as additional classes of polarization behavior, accessible in the X-ray band.

2. X-Ray Variability

Since X-ray polarization measurements are generally sensitivity limited, source flux variability plays a key role in the prospects for a secure, 99% confidence, measurement of a given expected polarization level. We must therefore characterize the variability of likely targets, the great majority of which turn out to be sources detected by the Fermi-LAT (Acero et al. 2015). We use 2–10 keV flux measurements from 2005 to 2017 measured by the Neil Gehrels Swift Observatory’s (hereafter Swift) LAT source monitoring program (Stroh & Falcone 2013) supplemented by 2–10 keV fluxes (from 1995 to 2012) from the RXTE AGN timing and spectral database (Rivers et al. 2013). Stroh & Falcone (2013) analyze the individual Swift observations; we employ their mean spectral parameters tabulated for each source to convert epoch count rates to erg cm⁻² s⁻¹ (2–10 keV) using WebPIMMS. Thirty-five sources (19 LSPs, 2 ISPs, 13 HSPs, and 1 unclassified source) have at least 20 observations; thus, we can attempt a detailed variability analysis. Hereafter, we characterize their flux variability with a simple mean and standard variation.

Blazar high energy variability has been modeled as a lognormal distribution (e.g., Romoli et al. 2018; Shah et al. 2018), which may reflect disk-driven fluctuations (Lyubarskii 1997) or

1 https://www.swift.stsci.edu/monitoring/
2 We have included all sources in the RXTE database classified as either BL Lac object or flat spectrum radio quasar (FSRQ) with at least 20 observations: https://cassin.ucsd.edu/~rxteagp/.
3 SED classification from the 3rd Fermi AGN catalog (Acero et al. 2015): https://www.soderberggroup.com/fermi3lac/.
variations in the jet particle acceleration (Sinha et al. 2018). This suffices for some of our sources, but others show wider variability. This may indicate multiple jet states (e.g., quiescent and active flaring episodes), which can be represented by a double normal (Gaussian mixture) model (in log-space; Liodakis et al. 2017). Of course if we have not sampled the full range of a source’s variability the two log-normals might be subsets of a broader single log-normal. Here, using the historical fluxes, we represent our flux distribution functions as either single or double log-normal models without attaching physical significance to the single- or double-mode behavior. The likelihood function for the single Gaussian model is defined as

\[ l_{\text{obs}} = \frac{1}{\sqrt{2\pi(\sigma_q^2 + \sigma_{\text{obs}}^2)}} \exp\left(-\frac{(S_q - S_{\text{obs}})^2}{2(\sigma_q^2 + \sigma_{\text{obs}}^2)}\right), \]  

where \( S_q \) and \( \sigma_q \) are the mean and standard deviation of the underlying distribution and \( S_{\text{obs}} \) and \( \sigma_{\text{obs}} \) are the observed fluxes and their uncertainties (in log-space). For the Gaussian mixture the likelihood is defined as

\[ l_{\text{obs}} = \frac{1 - f}{\sqrt{2\pi(\sigma_q^2 + \sigma_{\text{obs}}^2)}} \exp\left(-\frac{(S_q - S_{\text{obs}})^2}{2(\sigma_q^2 + \sigma_{\text{obs}}^2)}\right) + \frac{f}{\sqrt{2\pi(\sigma_a^2 + \sigma_{\text{obs}}^2)}} \exp\left(-\frac{(S_a - S_{\text{obs}})^2}{2(\sigma_a^2 + \sigma_{\text{obs}}^2)}\right), \]  

where we add mean and standard deviation \( S_a \) and \( \sigma_a \) for a brighter “active” state, which is realized a fraction \( f \) of the observed samples. With such a model, we can draw an arbitrary number of samples from the modeled distribution. To choose between models for a given source we use the Bayesian information criterion. Figure 1 shows examples of best-fit

models for PKS 0558-504 (top panel) and BL Lacertae (bottom panel). There are 15 sources best described as unimodal, and 20 sources prefer a bimodal distribution. LSPs show no preference, while HSPs slightly more commonly match a bimodal distribution (eight versus five). The parameters of the best-fit distributions for all the sources are given in Table 1. For sources with <20 observations, we simply record the mean and variance of the log of the flux, which can be used to form a log-normal distribution.

Measurements are easiest for high polarization \( \Pi_X \) sources in bright large \( S_{\text{obs}} \) states. Since both quantities are highly variable, we should test if they correlate, as might be expected from e.g., shock-driven flares (e.g., Marscher et al. 2008). Of course we lack \( \Pi_X \), so we use the optical polarization (\( \Pi_O \)) from the Robopol and Steward observatory monitoring programs, which have significant temporal overlap with the Swift data for 17 sources. We use optical polarization as a tracer of the energetic electrons at the jet base that may also contribute X-ray synchrotron; radio polarization can be dominated by downstream emission. While we cannot make meaningful statements about individual sources, we can check the major source classes by stacking all contemporaneous observations from, say, the HSP. We find that both the LSP and HSP have a mild positive correlation (Spearman’s \( \rho \approx 0.12 \), significance \( p \)-value < 0.05). The two ISPs showed no correlation. Thus for LSPs and HSPs we draw a flux at a given level in their cumulative distribution function (CDF; e.g., a flux in the top \( X\% \)) and then draw from that source’s polarization CDF at the same top \( X\% \) level. For the ISP, we will assume random uncorrelated draws (see Section 4.1). In practice, we find that this makes a small <20% difference to the source detectability, so this assumption is not critical. However, it should be tested with future monitoring campaigns.

3. Expected \( \Pi_X \)

We must use the lower energy (optical) polarization degree \( \Pi_O \) to predict the polarization in the X-ray band. For the HSPs and some ISPs, the X-rays come from the same (synchrotron) component, while for the LSPs and many ISPs, they come from the low energy end of the high energy (here assumed to be Compton) peak. Particularly interesting are the ISPs for which the synchro-Compton transition occurs within the IXPE band. To quantify this connection, we adopt a multizone jet picture (Peirson & Romani 2018), where the observed modest \( \Pi_O \) are the result of incoherent averaging of \( N_{\text{eff}} \) effective emission zones, each of which radiates with the \( \Pi_{\text{max}} \approx 70\% \) expected for a uniform field, for a power-law population of electrons with index \( \approx 2 \), producing the observed synchrotron spectrum. From observed polarization levels we typically infer \( N_{\text{eff}} \approx 30–100 \) for the emission cone contributing to the Earth’s line of sight. In practice, the zones have different angles to the line of sight and different characteristic particle energies \( \gamma_{\text{max}} \), so the number of zones, and thus \( \Pi \), becomes a function of the observation frequency (e.g., Marscher & Jorstad 2010; Marscher 2014, L. Peirson & R. W. Romani 2019, in preparation, hereafter PR2019).

This multizone picture, with distributions in \( \gamma_{\text{max}} \) and \( B \) field orientations, generally improves the match to observed blazar SEDs over that of a single-zone model. It also means that the \( \nu_{\text{Se}} \) for the individual zones varies and so the number of zones \( N_{\text{eff}} \) contributing half of the integrated flux is a function of
frequency. A computation with $N_{\text{eff}}$ related to the peak of the integrated spectrum, assuming typical jet beaming parameters, $B = 0.1$ G and a uniform squared distribution of $\gamma_{\text{max}}$ randomly distributed among the zones is shown in the inset of Figure 2. The consequence is $\Pi \propto \Pi_{\text{peak}} / \sqrt{N_{\text{eff}}}$, with a small increase from the incoherently averaged half of the flux from the remaining zones (see PR2019 for details). Thus $N_{\text{eff}}(\nu/\nu_{\text{peak}})$ allows us to relate the polarization at different frequencies across the synchrotron component. Note that the $N_{\text{eff}}$ decrease and $\Pi$ increase can be dramatic for $\nu \sim 10^3 \nu_{\text{peak}}$; some ISPs can be in this regime.

The behavior in Figure 2, where the $\gamma_{\text{max}}$ range is more important than the effective Doppler factor variation, is slightly conservative. In some models, such as the shock model of Marscher (2014), $\gamma_{\text{max}}$ may depend on the angle of $B$ to a shock front and hence to the jet axis; this organized variation further decreases $N_{\text{eff}}$ when one is well above the synchrotron peak. We find that this effect is only important for $3 < \log(\nu/\nu_{\text{peak}}) < 4$, but there the polarization increase can be as much as an additional $\sim 2 \times$; a few ISPs may have synchrotron X-rays from this extreme regime.

For HSPs, we can directly convert the optical band polarization level to the X-ray band using the square root of the ratios of the $N_{\text{eff}}(\nu)$. We truncate at $N_{\text{eff}} = 1$ since our statistical estimate breaks down anyway. For some ISPs, the $\Pi$ increase can be substantial as long as the Compton component contributes weakly at $1-10$ keV. For ISPs, we used the Space Science Data Center tools\(^4\) to construct the SED of each source and to determine whether the X-ray emission is synchrotron dominated. If so, we expect a substantial $\Pi$ increase compared to the optical.

For LSPs (and ISPs with hard X-ray spectra), our model assumes that we observe Compton X-ray flux. This will only show polarization if the seed photon population is highly polarized (e.g., synchrotron emission). PR2019 find that for isotropic, many-zone scattering in typical jet geometries the resulting Compton polarization is $0.2-0.36 \times$ that of the seed photons. This does depend on the viewing angle, opening angle, and Lorentz factor of the jet (see PR2019 for details). However, for the typical jet parameters assumed in the present work (Liodakis et al. 2018) the retained polarization is near maximal, so we will assume $\Pi_{\text{Comp}} = 0.36 \times \Pi_{\text{seed}}$. To get the latter, we scale from $\Pi_0$ using Figure 2. For X-ray Compton emission typical seed photons are in the millimeter-band, we will assume here $\sim 100$ GHz, but the dependence on the weighted effective seed photon frequency is weak. Note that

\(^4\) https://tools.ssdc.asi.it/SED/
we are assuming that all seed photons are synchrotron. If external photons contribute to the seed photon population \( \Pi_{\text{Comp}} \) will be lower. This means that our estimates of the LSP polarization may be optimistic. This is useful because any observed LSP polarization higher than our estimate indicates that the emission should be non-Compton in nature (e.g., proton synchrotron).

With these two effects we predict a \( \Pi_{\text{X}} \) for each source (Table 2). Figure 2 shows the shift from \( \Pi_{\text{O}} \) to \( \Pi_{\text{X}} \) for a few sources in each class, with an inset showing the \( N_{\text{eff}} \) dependence on frequency.

### 4. Blazar Detectability

Our prime target candidates are the sources measured with the RoboPol program\(^5\) (Pavlidou et al. 2014; Blinov et al. 2018) and the Steward observatory\(^6\) (Smith et al. 2009). For some of these we have Swift and/or RXTE monitoring, and so we can construct a detailed variability model (Section 2). For the remainder we collect typical fluxes from the HEARSAC\(^7\) database. There are 103 sources with known SED class and at least one measurement in optical polarization and X-ray flux.

Armed with estimates of the X-ray flux and polarization \( \Pi_{\text{X}} \) and their variability we can make predictions for detectability. We focus on IXPE as the most imminent facility, whose sensitivity is estimated using the dedicated online tools.\(^8\) (Soffitta 2017; O’Dell et al., 2018). Typical exposures will be \( \sim 100 \) ks, although the longest may approach a megasecond. Figure 3 shows the X-ray flux and predicted X-ray polarization degree using the median and 1\( \sigma \) confidence intervals from the PDFs for each source. These PDFs are estimated following Section 3. Note that with our assumed correlated fluctuations, HSPs and LSPs will vary diagonally (UR to LL) within these error bands. As expected, several HSPs are detectable at 100 ks, while a few (e.g., Mrk 421) might give significant measurements in 10 ks, allowing a detailed variability study. Only a few LSP sources are detectable, even with megasecond exposures, under typical conditions. A few sources (e.g., 3C 454.3) are occasionally accessible in shorter time when they are bright and highly polarized.

Note. The X-ray fluxes are all in erg cm\(^{-2}\) s\(^{-1}\) (log). Polarization degree is in %. The table lists sources with \( >0.5\% \) X-ray polarization and X-ray flux \( \times 10^{-13} \) erg cm\(^{-2}\) s\(^{-1}\).

This table is available in its entirety in machine-readable form.

---

**Table 2 X-Ray Flux and Polarization**

| Name          | Alt. Name  | Redshift | SED   | \( \nu_{\text{peak}} \) | \( S \) | \( \sigma_{S} \) | \( \Pi_{\text{O}} \) | \( \Pi_{\text{X}} \) |
|---------------|------------|----------|-------|----------------|-------|-------------|----------------|----------------|
| J0017−0512    | CGRaBS J0017−0512 | 0.227 | LSP | 13.69 | −11.66 | 0.01 | 7.99 | 3.66 | 2.68 |
| J0035+5950    | 1ES 0033+595 | 0.086 | HSP | 17.12 | −10.5 | 0.26 | 3.1 | 0.01 | 3.3 |
| J0045+2127    | RX J00453+2127 | ... | HSP | 16.0 | −10.52 | 0.0 | 7.4 | 2.13 | 8.43 |
| J0102+5824    | PLCKERC217G124.4 | 0.664 | LSP | 12.94 | −11.52 | 0.06 | 15.9 | 8.27 | 5.14 |
| J0108+0135    | PKS 0106+01 | 2.099 | LSP | 13.18 | −11.81 | 0.25 | 12.47 | 4.6 | 4.09 |
| J0136+4751    | S4 0133+47 | 0.859 | LSP | 13.08 | −11.59 | 0.02 | 11.5 | 5.76 | 3.75 |
| J0152+0146    | 1RXS J015240.2+01 | 0.080 | HSP | 15.46 | −11.21 | 0.29 | 6.2 | 6.49 | 7.87 |
| J0211+1051    | CGRaBS J0211+1051 | 0.200 | ISL | 14.21 | −11.33 | 0.41 | 23.1 | 6.93 | 35.0 |
| J0217+0837    | PLCKERC217G156.1 | 0.085 | LSP | 13.79 | −11.44 | 0.19 | 5.8 | 3.09 | 1.96 |
| J0222+4302    | 3C 66A | 0.340 | HSP | 15.09 | −11.16 | 0.36 | 7.8 | 2.94 | 11.1 |

---

**Figure 2.** Dashed lines show the shift from observed (optical, “+”) to predicted (X-ray, “•”) \( \Pi_{\text{X}} \) for a few objects in each source class: LSP (black), ISL (red), and HSP (green). The diagonal lines show the IXPE sensitivity for a source with photon index \( \approx 2 \) in a given exposure time. The inset shows the frequency dependence of the effective zone number using the median Lorentz factor and viewing angle from Liodakis et al. (2018).

4.1 Detectability Duty Cycle

We must consider the substantial flux (Section 2) and polarization variability (e.g., Angelakis et al. 2016; Kiehlmann et al. 2017) when predicting the success of an X-ray polarization search. The uncertainty ranges in Figure 3 already give some idea of these effects. But some sources vary well outside these ranges, especially in occasional large \( S_{\text{X}} \) flares and less often in polarization increases. Thus we use distribution function models to characterize the full variability range. For the X-ray variability we either use the parameters in Table 1 to construct a flux distribution function or use the mean and standard deviation to define a single log-normal model (see Section 2). For the optical polarization, we use distribution functions from the maximum likelihood modeling results of Angelakis et al. (2016) for RoboPol sources; for Steward Observatory-monitored sources we use their empirical CDF.

---

\(^{5}\) http://robopol.org/

\(^{6}\) http://james.as.arizona.edu/~psmith/Fermi/

\(^{7}\) https://heasarc.gsfc.nasa.gov/

\(^{8}\) https://ixpe.msfc.nasa.gov/cgi-aft/w3pimms/w3pimms.pl
(Smith et al. 2009). As noted above for the ISPs we draw randomly for the CDFs, while for LSPs and HSPs we draw an $S_X$ and then adopt $P_X$ from the same probability level. We consider only sources with at least three observations in both optical polarization and X-ray flux and estimate the joint detection probability ($DP$) by computing the MDP$_{99}$ in a given exposure time and comparing with the predicted $P_X$. We consider a simulated observation as a detection if $P_X > MDP_X_{99}$. By repeating this calculation $10^4$ times we estimate the fraction of trials in which a source was detected. Dropping the flux-II correlations results in a <20% decrease in the LSP, HSP detectability estimates. For the RXTE and Swift monitored sources we use the average spectral parameters and WebPIMMS to estimate the MDP$_{99}$ from the drawn flux value. For the remaining sources we use a photon index of 1.5 for inverse Compton and 2.5 for synchrotron emitting sources. In any case, assuming different spectral parameters results in only ~5% change in DP. Table 3 gives these detection probability values for an assumed 100 ks IXPE exposure. They can be interpreted as the chance of success for a random observation at this exposure, or as the duty cycle for a triggered (by, e.g., flux and/or $P_O$ monitoring) campaign. Of course, if one wants to measure a particular source, one can obtain more acceptable

![Figure 3](image)

**Figure 3.** Predicted X-ray polarization degree vs. the X-ray flux: LSP (black), ISP (red), and HSP (green). Lines show the 1σ variability range in each quantity. Sources lacking at least three observations each in $S_X$ and $P_O$ are shown by open squares. Stars have >3 measurements in one quantity, solid squares have >3 in both. Red dashed lines show simple estimates for IXPE sensitivity for a source with photon index $\gtrsim 2$ in a given exposure time.

### Table 3

| Name        | Alt. Name          | SED  | $P_X$ peak | Det. Prob. (%) |
|-------------|--------------------|------|------------|----------------|
| J1959+6508  | IES 1959+650       | HSP  | 16.86      | 72.9           |
| J1725+1152  | 1H 1720+117        | HSP  | 16.01      | 60.6           |
| J2001+4352  | 1FGL J2001.1+435   | HSP  | 15.21      | 60.3           |
| J1104+3812  | Mrk 421            | HSP  | 17.07      | 58.5           |
| J0211+1051  | CGRAs J0211-1051   | ISP  | 14.12      | 49.2           |
| J2158+3013  | PKS 2155-304       | HSP  | 15.97      | 42.1           |
| J1653+3945  | Mrk 501            | HSP  | 16.12      | 30.7           |
| J0222+4302  | 3C 66A             | HSP  | 15.09      | 17.0           |
| J1555+1111  | PG 1553+113        | HSP  | 15.47      | 14.4           |
| J2253+1608  | 3C 454.3           | LSP  | 13.34      | 10.2           |
| J0721+7120  | 0S 0716+714        | LSP  | 14.6       | 5.6            |
| J1838+4802  | GB01838+4802       | HSP  | 15.8       | 4.5            |
| J2347+5142  | 1ES 2344+514       | LSP  | 15.87      | 3.4            |
| J0958+6533  | S4 0954+658        | LSP  | 13.49      | 3.4            |
| J2202+4216  | BL Lacertae        | LSP  | 13.61      | 2.5            |
| J1642+3948  | 3C 345             | LSP  | 13.23      | 1.8            |
| J1256−0547  | 3C 279             | LSP  | 13.11      | 1.8            |
| J0957+5522  | 4C 55.17           | ISP  | 14.23      | 1.5            |

**Note.** The table is sorted according to detection probability and lists only sources with DP >1%. 

---

\[\text{Table 3 Detectability Duty Cycle}\]

| Name | Alt. Name | SED | $P_X$ peak | Det. Prob. (%) |
|------|-----------|-----|------------|----------------|
| J1959+6508 | IES 1959+650 | HSP | 16.86 | 72.9 |
| J1725+1152 | 1H 1720+117 | HSP | 16.01 | 60.6 |
| J2001+4352 | 1FGL J2001.1+435 | HSP | 15.21 | 60.3 |
| J1104+3812 | Mrk 421 | HSP | 17.07 | 58.5 |
| J0211+1051 | CGRAs J0211-1051 | ISP | 14.12 | 49.2 |
| J2158+3013 | PKS 2155-304 | HSP | 15.97 | 42.1 |
| J1653+3945 | Mrk 501 | HSP | 16.12 | 30.7 |
| J0222+4302 | 3C 66A | HSP | 15.09 | 17.0 |
| J1555+1111 | PG 1553+113 | HSP | 15.47 | 14.4 |
| J2253+1608 | 3C 454.3 | LSP | 13.34 | 10.2 |
| J0721+7120 | 0S 0716+714 | LSP | 14.6 | 5.6 |
| J1838+4802 | GB01838+4802 | HSP | 15.8 | 4.5 |
| J2347+5142 | 1ES 2344+514 | LSP | 15.87 | 3.4 |
| J0958+6533 | S4 0954+658 | LSP | 13.49 | 3.4 |
| J2202+4216 | BL Lacertae | LSP | 13.61 | 2.5 |
| J1642+3948 | 3C 345 | LSP | 13.23 | 1.8 |
| J1256−0547 | 3C 279 | LSP | 13.11 | 1.8 |
| J0957+5522 | 4C 55.17 | ISP | 14.23 | 1.5 |
Sources without Optical Polarization

| Name          | Alt. Name | Redshift | SED  | $\nu_{\text{peak}}$ | $S$     | $\sigma_S$ | $\Pi_{\text{O,min}}$ |
|---------------|-----------|----------|------|---------------------|---------|------------|---------------------|
| J0030−0929    | PKS J0030−0929 | 0.635    | ISP  | 14.61               | −11.09  | 0.01       | 9.76                |
| J0112+2243    | 3C 0108+22  | 0.265    | ISP  | 14.32               | −11.62  | 0.01       | 13.76               |
| J0416+0105    | QSO B0416+009 | 0.287    | HSP  | 16.64               | −10.7   | 0.02       | 10.79               |
| J0650+2502    | 1ES 0657+250 | 0.203    | HSP  | 16.42               | −10.51  | 0.01       | 8.57                |
| J1103−2329    | 1ES 1101−23.2 | 0.186    | HSP  | 17.19               | −10.07  | 0.01       | 5.66                |
| J1243+3627    | Ton 116    | 1.066    | HSP  | 16.15               | −10.67  | 0.02       | 10.12               |
| J1417+2543    | QSO B1415+259 | 0.236    | HSP  | 15.45               | −10.6   | 0.01       | 8.22                |
| J1422+5801    | QSO B1422+580 | 0.635    | HSP  | 17.72               | −10.73  | 0.03       | 11.65               |
| J1442+1200    | QSO B1440+122 | 0.163    | HSP  | 16.35               | −10.68  | 0.02       | 10.38               |
| J1443−3908    | PKS 1440−389 | 0.065    | HSP  | 15.68               | −10.93  | 0.01       | 12.63               |
| J1936−4719    | PMN J1936−4719 | 0.265    | HSP  | 16.52               | −10.94  | 0.03       | 14.14               |

Note. The X-ray fluxes are all in erg cm$^{-2}$ s$^{-1}$ (log). Column $\Pi_{\text{O,min}}$ lists the minimum optical polarization degree (%) required for an *IXPE* detection at 100 ks.

detection odds by increasing the exposure duration. While several HSPs have reasonable detection probabilities, only one ISP (CGRaBs J0211+1051) and one LSP (3C 454.3) are detected at $>10\%$ duty cycle. Thus long monitoring campaigns to allow bright trigger thresholds and/or longer *IXPE* exposures will be needed to reliably detect these source classes. It should be noted that source $\Pi_0$ can vary by $\times 2$ over a few days so longer exposures are not strictly “snapshots” as computed here. Intraday variability is seen, but is uncommon enough to leave our $\sim 1$ day detectability estimates unaffected.

4.2. Sources without Measured Optical Polarization

While many of the best and brightest candidates have been observed in existing optical polarization campaigns, there are other blazars that might be of interest. For example, we find 208 blazars from the BZ catalog (Massaro et al. 2015) present in the *Swift* master catalog, 97 of which have $S_X > 5 \times 10^{-13}$ and a known spectral $\nu_S$ class, so that we can evaluate their observability as a function of the unknown optical polarization level. With the observed X-ray flux we estimate the MDP$_{99}$ (accounting for the different source spectra as in Section 4.1) as a function of exposure time. We convert this to expected optical polarization using the relation in Figure 2. Figure 4 and Table 4 show the best prospects from this exercise. Table 4 also lists the minimum optical polarization that we would require for $\sim 100$ ks *IXPE* detections. This suggests that several more HSPs and a few ISPs are accessible in reasonable exposures, although one should obtain reconnaissance $\Pi_0$ measurements first.

5. Summary

We have used the archival SEDs of bright blazars along with observed optical polarization levels, to predict the expected 1–10 keV X-ray polarization in a basic synchro-self-Compton model. This estimate, together with the historical X-ray flux level allows us to evaluate the detectability of X-ray polarization for a given mission sensitivity. Including the flux and polarization variability as estimated by CDFs modeled from historical data allows us to assess the probability that an exposure of given duration will achieve success. Equivalently, this gives the duty cycle for observations triggered by a monitoring campaign to be successful at a given exposure level. We compute these values for the characteristic *IXPE* mission sensitivity, giving a list of top candidate sources, useful for planning an observing campaign.

Unsurprisingly, HSPs dominate the easily detectable sources, but a few ISPs with X-ray emission well above the synchrotron peak are surprisingly observable. In contrast, few LSPs can be accessed, and only with long exposures. Recalling that our LSP estimate assumes correlated $S_X/\Pi_0$ variability, and that no external seed photon flux dominates the up-scatter to the X-ray band, these LSP predictions should be considered optimistic for a Synchro-Compton model. However, other emission scenarios (e.g., proton synchrotron) for the high energy component can produce large $\Pi_X$, so a few LSP observations, especially when hadronic emission is indicated, would be desirable.

While our evaluation includes many of the brightest blazars, we have also identified a set that may be interesting targets, if the typical polarization level is sufficiently large. Optical reconnaissance to measure these $\Pi_0$ and evaluate as possible targets for *IXPE* and/or *eXTP* are strongly encouraged.

This work has made use of light curves provided by the University of California, San Diego, Center for Astrophysics and Space Sciences, X-ray Group (R.E. Rothschild, A.G.
Markowitz, E.S. Rivers, and B.A. McKim), obtained at https://cass.ucsd.edu/~rxteagn/. Skinakas:1.3m is a collaboration involving the University of Crete, the Foundation for Research and Technology—Hellas, the California Institute of Technology, the Max-Planck Institute for Radioastronomy, the Nicolaus Copernicus University, and the Inter-University Centre for Astronomy and Astrophysics. Data from the Steward Observatory spectropolarimetric monitoring project were used. This program is supported by Fermi Guest Investigator grants NNX08AW56G, NNX09AU10G, NNX12AO93G, and NNX15AU81G and NASA grant NNM17AA26C. This research has made use of data and/or software provided by the High Energy Astrophysics Science Archive Research Center (HEASARC), which is a service of the Astrophysics Science Division at NASA/GSFC and the High Energy Astrophysics Division of the Smithsonian Astrophysical Observatory.

Facilities: Swift, RXTE, RoboPol, Steward Observatory.

ORCID iDs
Ioannis Liodakis https://orcid.org/0000-0001-9200-4006
Roger W. Romani https://orcid.org/0000-0001-6711-3286

References
Acero, F., Ackermann, M., Ajello, M., et al. 2015, ApJS, 218, 23
Ackermann, M., Anantua, R., Asano, K., et al. 2016, ApJL, 824, L20
Angelakis, E., Hovatta, T., Blinov, D., et al. 2016, MNRAS, 463, 3365
Blandford, R., Meier, D., & Readhead, A. 2018, arXiv:1812.06025
Blinov, D., Pavlidou, V., Papadakis, I., et al. 2018, MNRAS, 474, 1296
Boettcher, M. 2012, arXiv:1205.0539
Hovatta, T., Lister, M. L., Aller, M. F., et al. 2012, AJ, 144, 105
Kiehlmann, S., Blinov, D., Pearson, T. J., & Liodakis, I. 2017, MNRAS, 472, 3589
Liodakis, I., Hovatta, T., Huppenkothen, D., et al. 2018, ApJ, 866, 137
Liodakis, I., Pavlidou, V., Hovatta, T., et al. 2017, MNRAS, 467, 4565
Lyubarskii, Y. E. 1997, MNRAS, 292, 679
Marscher, A. P. 2014, ApJ, 780, 87
Marscher, A. P., & Jorstad, S. G. 2010, arXiv:1005.5551
Marscher, A. P., Jorstad, S. G., D’Arcangelo, F. D., et al. 2008, Natur, 452, 366
Massaro, E., Maselli, A., Leto, C., et al. 2015, Ap&SS, 357, 75
O’Dell, S. L., Baldini, L., Bellazzini, R., et al. 2018, Proc. SPIE, 10699, 106991X
Pavlidou, V., Angelakis, E., Myserlis, I., et al. 2014, MNRAS, 442, 1693
Peirson, A. L., & Romani, R. W. 2018, ApJ, 864, 140
Rivers, E., Markowitz, A., & Rothschild, R. 2013, ApJ, 772, 114
Romoli, C., Chakraborty, N., Dorner, D., Taylor, A., & Blank, M. 2018, Galax, 6, 135
Shah, Z., Mankuzhiyil, N., Sinha, A., et al. 2018, RAA, 18, 141
Sinha, A., Khatoon, R., Misra, R., et al. 2018, MNRAS, 480, L116
Smith, P. S., Montiel, E., Rightley, S., et al. 2009, arXiv:0912.3621
Soffitta, P. 2017, Proc. SPIE, 10397, 103970L
Stroh, M. C., & Falcone, A. D. 2013, ApJS, 207, 28
Weisskopf, M. 2018, Galax, 6, 33
Zhang, H. 2017, Galax, 5, 32
Zhang, S. N., Feroci, M., Santangelo, A., et al. 2016, Proc. SPIE, 9905, 99051Q