The Multimessenger Chakra of Blazar Jets
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Identifying γ-ray emitting blazars in the PASIPHAE era: polarimetry as a unique probe

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Abstract. The Fermi γ-ray telescope has detected 6658 sources, with 1845 of them remaining unidentified. We show that polarimetry of γ-ray fields is a powerful asset in the hunt of active galactic nuclei (AGN) as potential optical counterparts for γ-ray sources. We have studied an unidentified *Fermi* field (3FGL J0221.2+2518) and found a previously-unknown highly-polarized extragalactic object as a potential optical counterpart within the 1-sigma error ellipse of the corresponding γ-ray source. Based on a collection of data, we find that it most probably is a composite object: a star-forming galaxy accompanied by AGN. PASIPHAE is a large polarimetric experiment which will measure the polarisation of sources away from the galactic plane. This will provide an excellent opportunity to study hundreds of unidentified γ-ray sources and unveil potential optical counterparts, using polarimetry.

Keywords. techniques: polarimetric; galaxies: active; gamma rays: galaxies; Astrophysics - High Energy Astrophysical Phenomena

1. Introduction

The *Fermi* spacecraft was launched in 2008 and has been scanning the sky to collect data on γ-ray sources. The latest data release (4FGL-DR3, Abdollahi et al. 2022) contains 6658 sources from the first 12 years of operation. While 1845 sources still remain unidentified, $\sim 86\%$ of identifications and associations consist of different types of active galactic nuclei (AGN).

Efforts for classifying γ-ray sources have been carried out using a variety of techniques, such as machine learning (Doert and Errando 2014; Chiaro et al. 2016; Salvetti et al. 2017), very long baseline interferometry (VLBI, Kovalev 2009), and multi-wavelength observations (Acero et al. 2013).

For the first time, we introduced optical polarimetry as a promising method to indentify AGN as potential optical counterparts for unidentified gamma-ray sources (UGSs), and proposed a new candidate for one of the *Fermi* fields (Mandarakas et al. 2019). Liodakis and Blinov (2019) utilised optical polarisation data together with machine learning techniques and identified the same source as a potential optical counterpart for the same *Fermi* field.

AGN constitute the vast majority ($\sim 86\%$) of the already indentified γ-ray sources in the *Fermi* catalogue, and are known to be highly polarized due to the synchrotron nature of their optical emission (Angel and Stockman 1980; Angelakis et al. 2016). However, not only AGN can appear polarized in the sky. In any given line of sight, the light passes through the interstellar medium (ISM) of our galaxy and becomes linearly polarized due

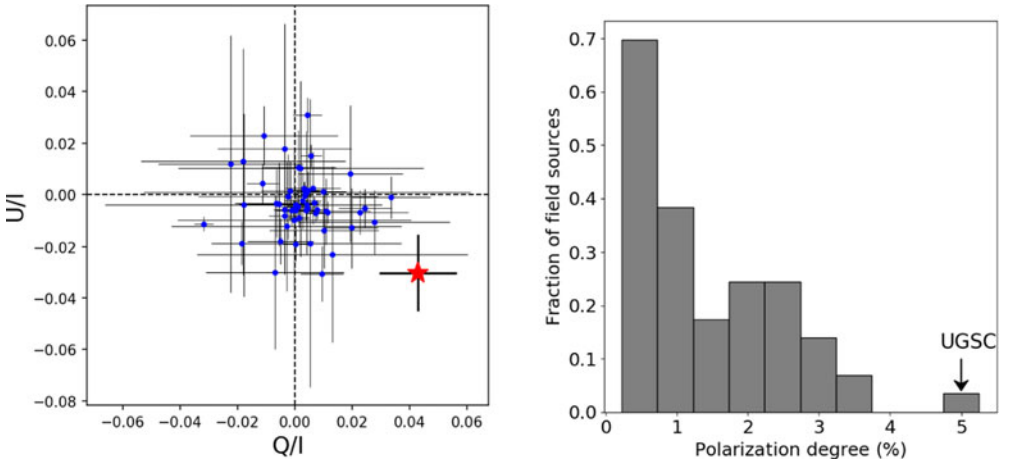

Figure 1. Left: Distribution of q and u Stokes parameters of the 3FGL J0221.2+2518 field sources. UGSC is shown by the red star. Right: Distribution of the polarisation values for the observed sources in the field.

to dichroic extinction from dust grains that are aligned with the interstellar magnetic field (Andersson et al. 2015). The ISM-induced polarisation is typically in the levels of a few percent, which can be significant enough to be compared to the intrinsic polarisation of AGN. In addition, AGN can be variable in polarisation, which can make their polarisation drop down to the ISM-induced polarisation, thus making them indistinguishable. We used data from the RoboPol survey (Blinov et al. 2021) to simulate AGN in the UGSs. We demonstrated that in high galactic latitudes, where the interstelllar polarisation is expected to be at the $\sim$ 1% level, an AGN in the field will significantly stand out in polarisation $\sim 80\%$ of the times (for the details refer to Mandarakas et al. 2019).

2. Demonstration of the technique

In order to demonstrate our method, we used the RoboPol instrument mounted on Skinakas 1.3 m telescope†. RoboPol is a novel polarimeter with no rotating parts that can measure the linear q and u Stokes parameters with a single exposure (Ramaprakash et al. 2019). We note that at the time of this work, the latest available *Fermi* data release was the 3FGL catalogue (Acero et al. 2015). We measured the polarisation of optical sources within the 3 σ position ellipse of the 3FGL J0221.2+2518 γ-ray field. The results are demonstrated in Fig. 1, where it is evident that there is a source that significantly stands out in polarisation from the average of the field. This is our proposed Unidentified Gamma-ray Source Candidate (UGSC). The polarisation of UGSC is $5.2 \pm 1.3\%$ while the field average is $p_{av} = 0.91\%$. We obtained the spectrum of the source, using the Skinakas 1.3 m telescope and we verified that our candidate is an extragalactic source, and most probably a composite object: a starburst galaxy accompanied by an AGN (for the details refer to Mandarakas et al. 2019).

2.1. *The predictive power of polarimetry*

The UGSC is located at RA=02 21 33.3s, DEC=+25 12 47.2 (J2000), and is listed in SDSS as J022133.31+251247.3. Based on the position of the γ-ray source reported in the third data release of *Fermi* (which was the newest version available at the time of the study), UGSC lies between the 2 and 3 σ error ellipses of the γ-ray source location (left

† https://skinakas.physics.uoc.gr/en/

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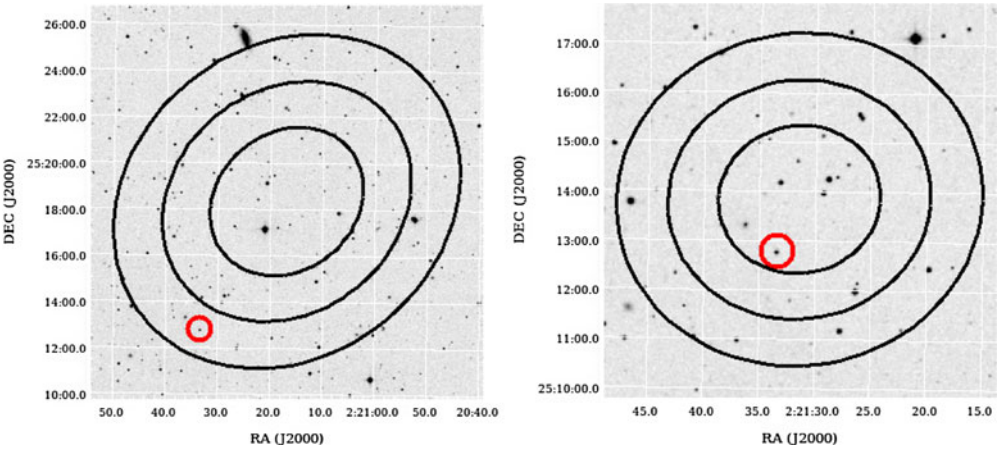

Figure 2. Left: DSS image of 3FGL J0221.2+2518 field and the position of UGSC (red circle). Right: DSS image of 4FGL J0221.5+2513 and the position of UGSC (red circle). The ellipses represent $1\,\sigma$, $2\,\sigma$, and $3\,\sigma$ uncertainties of the γ-ray source positions. The position of the γ-ray source has shifted between the two versions of the *Fermi* catalogue and has come to agree better with the polarimetric candidate. Note the scale difference. Localisation is improved in the latest version of the catalogue.

of Fig. 2). However, in the latest *Fermi* data release, where the localisation and overall analysis has been improved, our candidate lies within the $1\,\sigma$ error ellipse of the γ-ray source location (right of Fig. 2). This is indicative of the potential of polarimetry in the identification of optical counterparts of yet-unidentified *Fermi* sources: the refinement of γ-ray data led to a shift of the γ-ray source to coincide with the candidate proposed by this polarimetric study.

3. Future prospect

PASIPHAE is a groundbreaking survey that aims to scan the sky away from the galactic plane in both hemispheres and measure the polarisation of millions of objects within its range (Tassis et al. 2018). PASIPHAE will make use of two state-of-the-art wide-field polarimeters, which will split the light in four orthogonal polarisation states and project each one in a different CCD camera, leading to high-quality observations (Maharana et al. 2021, 2022). The diversity of the mapped sources will be rich, including stars, galaxies, AGN and hundreds of unidentified *Fermi* γ-ray sources. By mining the PASIPHAE data, and making use of the excellent prospect of optical polarimetry, discoveries of AGN as potential optical counterparts for γ-ray sources will come for free, and could yield hundreds of new identifications.

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