Unidentified Active Galactic Nuclei in the Fermi era

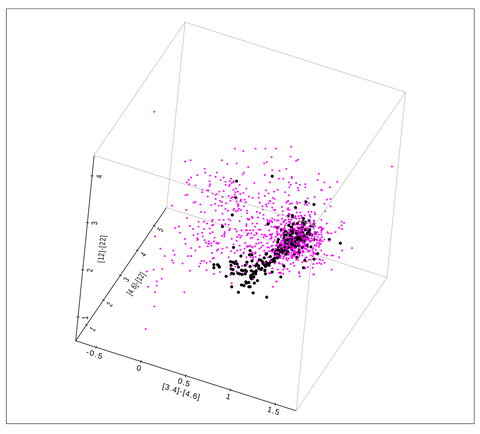
F. Massaro[1,2], R. D'Abrusco[1], G. Tosti[2,3,4], M. Ajello[2], D. Gasparrini[5], J. E. Grindlay[1], H. A. Smith[1],
[1] Harvard - Smithsonian Astrophysical Observatory, USA. [2] SLAC National Laboratory and Kavli Institute for Particle Astrophysics and Cosmology, USA. [3] Dipartimento di Fisica, Universita' degli Studi di Perugia, Italy. [4] Istituto Nazionale di Fisica Nucleare, Sezione di Perugia, Italy. [5] ASI Science Data Center, ESRIN, Frascati, Italy.
email: fmassaro@stanford.edu

1 Introduction

Despite the large number of new discoveries recently occurred in γ-ray astronomy with the advent of *Fermi* mission, the origin of the unidentified γ-ray sources (UGSs) is still a mystery. The first step toward a complete understand of the nature of the UGSs is to identify those that could be associated with blazars, i.e., the most detected extragalactic sources in the γ-ray sky. **Here, we illustrate a parametric method to test if a generic γ-ray source have a blazar counterpart associated within its γ-ray positional error region.**
We apply this method to the Active Galactic Nuclei of uncertain type (AGUs) as they have been listed in the second γ-ray Fermi catalog (2FGL) to estimate the fraction of γ-ray sources with a candidate blazar counterpart.

2 The *WISE* Blazar Strip

When the *WISE blazar Strip* has been discovered and introduced for the first time (Massaro et al. 2011), it has been identified as a region in the [3.4]-[4.6]-[12] μm color-color diagram built using the *WISE* infrared survey data, of the blazar counterparts of the ROMA-BZCAT (Massaro et al. 2009). However, it is a volumetric region in the 3D color diagram delineated by the infrared colors of blazars. We also distinguish between that identified by the entire blazar population (*WISE blazar Strip*), and the subregion occupied only by those blazar that are emitting at γ-ray frequencies, indicating the latter as the *WISE* gamma-ray blazar strip (i.e., γ *strip*, D'Abrusco et al. 2011).



A 3D representation of the *WISE blazar Strip* and the subregion of the γ *strip* are shown in Fig. 1.

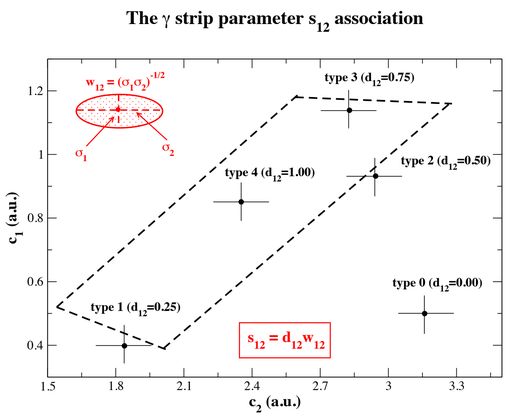
3 The sample selections

• The first sample is constituted by all the blazars, present in the ROMA-BZCAT, associated with a *Fermi* source, as reported in the 2FGL and having a counterpart in the *WISE* archive within 2.4″ (Massaro et al. 2011). In the 2FGL there are only 659 (347 BZBs and 312 BZQs) of the entire 2FGL blazar population (i.e., 805) classified accordingly to the ROMA-BZCAT, but, only 296 (143 BZBs and 153 BZQs) having a *WISE* counterpart within 2.4″ and constituting the 2FB sample (i.e., 2FGL Blazars on the γ *strip*).

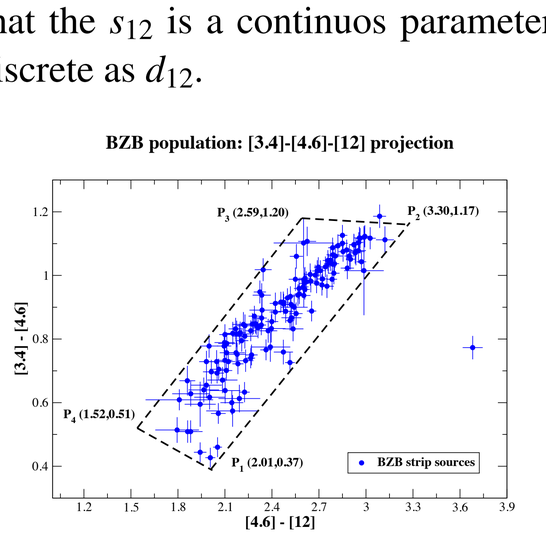
• The second sample adopted in our analysis is constituted by all the AGUs already classified in the analysis of the 2FGL sample (Abdo et al. 2011), but having a *WISE* counterpart corresponding to 123 *Fermi* sources (hereinafter 2FAU sample). The association between each AGU and the *WISE* sources have been evaluated on the basis of the same criterion chosen for the blazars on the *WISE blazar Strip*, considering the position of the radio counterpart for each AGU as reported in the 2FGL.

4 The γ *strip* parametrization procedure

We ranked the different types of sources using a *discrete strip parameter d* ranging between 0 and 1, accordingly to the schematic view reported in Figure 2. Then, for example, in the case of the c_1-c_2 2D projection of the γ *strip*, we assign to sources of type 4 a value of d_{12} =1 while source of type 0 corresponds to d_{12} =0.



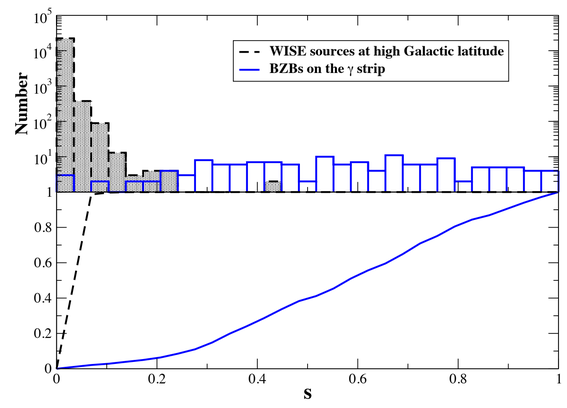
On the same c_1-c_2 2D projection, we also assign a *weight strip parameter* w_{12} to each value of the d_{12} parameter equal to the geometric mean of the errors on both axes: w_{12}= $(\sigma_1\,\sigma_2)^{-1/2}$, that is proportional to the ellipse described by the error bars of each point (see inset of Figure 2). Then, we calculate the *continuos strip parameter* s_{12} simply as $s_{12} = d_{12}\,w_{12}$. The parameter w_{12} has been chosen to take into account of the different error on both axes when comparing two sources. We note that the s_{12} is a continuos parameter rather than discrete as d_{12}.



The [3.4]-[4.6]-[12] μm 2D projection of the γ *strip* for the BZB population is shown. **Finally, we define the *strip parameter*, *s*, calculating it by the geometric average of the *s* values of each 2D projection: $s = (s_{12}\,s_{23}\,s_{13})^{1/3}$. and it has been re-normalized in the range 0 and 1, taking into account of the *s* values of the BZB and BZQ that lie on the γ *strip*.**

5 The *s* values parametrization procedure

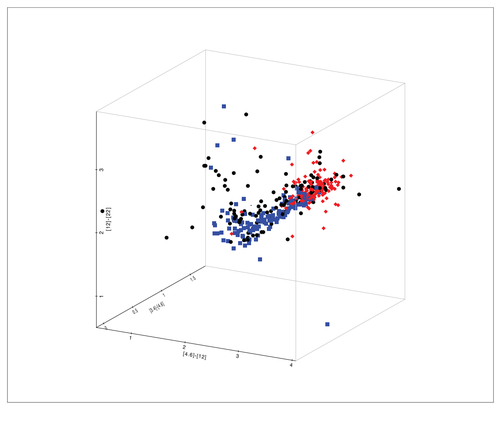
We calculated the *s* parameters for all the *WISE* sources in a region of radius 1 deg at high Galactic latitude for ∼29000 *WISE* sources. This analysis provides an estimate of the probability to find a generic *WISE* source in the sky with a particular value of *s*.



The distribution of the strip parameter *s* for the BZBs that lie on the γ *strip* in comparison with the generic *WISE* sources at high (upper panel) and low (lower panel) Galactic latitude. The normalized cumulative distributions are shown in the bottom panels.

6 *WISE* counterparts of the AGUs

We estimated the infrared colors of the AGU counterpart as they have been associated in the 2FGL to verify if the *WISE* counterparts of the γ-ray sources in the 2FAU sample lie on the γ *strip*. To perform this test we searched for the *WISE* counterpart of the AGUs in the 2FAU sample and we found that only 123 of them are uniquely associated with a *WISE* source with a chance probability of 0.008. Then, we evaluated their *s* values and we considered source with s <0.14 outliers of the γ *strip* because, accordingly with the previous analysis, only there are less than 3% of blazars that lie on the γ *strip* with this value of *s*. **Following our procedure we found that there are 23 outliers of the γ *strip* out of 123 AGUs in the 2FAU sample.** In Figure 5 we show the comparison between the 123 AGUs with a *WISE* counterpart, constituting the 2FAU sample and the γ *strip*, where it is possible to see the outliers found from our analysis.



Acknowledgments
R. D. gratefully acknowledges the financial support of the US Virtual Astronomical Observatory, The work is partially supported by the NASA grants NNX10AD50G, NNH09ZDA001N and NNX10AD68G. F. M. also acknowledges the Fondazione Angelo Della Riccia for supporting his research at SAO and the Foundation BLANCEFLOR Boncompagni-Ludovisi, née Bildt.