Classification of unassociated fermi-LAT sources

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Abstract. The Large Area Telescope (LAT) on board NASA's Fermi Gamma-ray Space telescope has detected 5788 sources in the 4FGL catalogue. Among them, 271 have been associated to pulsars, 3436 to blazars, and 1782 remain unassociated sources. Unassociated sources are object for which there is not a clear counterpart in other wavelengths. In this paper I investigated which are the parameters that can distinguish efficiently between pulsars and blazars among unassociated sources. I found that the most powerful parameters are the flux variability, power law index and latitude. Starting from these parameters, I have determined good cuts that disentangle pulsars from blazars. I have applied the cuts for the above cited parameters to the unassociated sources and determined that 142 of them are pulsars. The selection used in this paper can be applied to other sources to examine whether they are pulsars or blazars, which will contribute to the determination of the type of the newly detected sources

Keywords: Astrophysics, Data analysis, Pulsars.

1 Introduction

Pulsars and blazars are two source populations present in the Universe and that are the most numerous in Fermi-LAT catalogues. They have different characteristics in the spectrum of gamma rays, which can help people to distinguish between them. The Fermi-LAT catalogue of 8 years, named as 4FGL, suggests that the number of balzars (3436) is far greater than the number of pulsars (271). [1] In the Fermi-LAT catalogue there are also sources, which are named 'unassociated'. These are sources detected in gamma rays and without a clear counterpart in other wavelengths. The goal of my research is to categorize them as blazars or pulsars.

1.1 Pulsars and blazars

Blazars are highly variable extragalactic sources powered by an active supermassive black hole in the centre of the host galaxy. Blazars are one of the most violent celestial activity phenomena in the Universe, and have become an important topic in astronomy. Blazars have relativistic jets pointing towards the earth's. These jets of protons or electrons produce radiation in the entire electromagnetic spectrum for Synchrotron radiation, Bremsstrahlung and Inverse Compton scattering. The fact that one of the two jets is aligned with respect to

the line of sight make the luminosity of these sources very high. As a consequence, blazars have high variability in their fluxes. Many blazars even exhibit superluminal motion within a few seconds of the jet, which may be caused by relativistic shock waves. [2]

Pulsars are a rapidly spinning neutron stars. Most of them are about 10km in diameter and rotate at a very fast speed. Pulsars can periodically emit pulse signals. This electromagnetic wave is intermittent and has a strong regularity. Because of its strong regularity, pulsars are considered to be the most accurate clock in the universe. Generally, pulsars deserve more scientific attention. [3] [4]

The study presented in this paper aim at determining the region of parameters that separate pulsars from blazars and other kind of stars or quasars.

1.2 Variability flux (Var)

The variability of the gamma-ray flux is a significant characteristic of blazars and it depends on the energy band considered. Blazars have higher variability since blazars are constantly emitting electrons of different energies and different acceleration and cooling times contribute preferentially to the distinct bands. On the other hand, pulsars are less variable compared to blazars. In particular, we are considering the variability observed in gamma rays that is calculated with the Var parameters through monthly measurements of the flux.

1.3 Galactic Latitude (GLAT)

The latitude in the galactic coordinate system is called the Galactic latitude, which is expressed by an angle. Starting from the galactic plane, it is measured north or south on the Galactic meridian where the celestial body is located, from 0 ° to ± 90 °, the north of the Galactic is positive and the south is negative. The galactic latitude of the North Galactic pole (NGP) is + 90 ° and that of the South Galactic pole (SGP) is - 90 °.

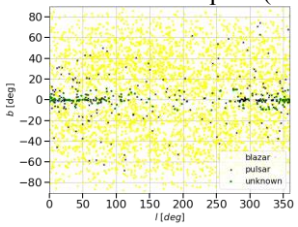

Fig.1. Galactic latitude of the sources.

Fig. 1. This is the map of the pulsars, blazars and the unassociated sources. The x-axis is longitude and y-axis is latitude. The data is from 4FGL catalog.

Although the longitude of pulsars and blazars is in a great variety, the latitude is a powerful parameter to separate them. The main reason for this is that pulsars are Galactic sources so they mostly populate the Galactic plane. Instead, blazars are extragalactic and thus they have an isotropic distribution.

2 Curvature significance of log parabola (LPsign)

2.1 Flux and Spectral Model

The Energy flux is the rate of photons received by the Large Area Telescope (LAT) from sources. The 4FGL catalogue adopted multiple spectral shapes, depending on the observed

source properties. Pulsars are modelled by an exponentially cut-off Power Law. Blazars are modelled as a Log Parabola if statistically significant curvature (according to Signif_Curve) is detected, or as a simple Power Law otherwise. Most of blazers do not exhibit a curvature in their SEDs. [5]

2.2 Significance of curvature

The curvature significance is the probability that the spectrum energy distribution (SED) is curved. In particular it is measured the significance in sigma. Generally, we will consider the curvature present if the significance is greater than 5sigma. Pulsars spectra are typically curved while blazars are not.

3 Methods and materials

3.1 Research Object and the source of the data

All the data used in this study is from the fourth catalog of gamma-ray sources detected by the Fermi Large Area Telescope (4FGL). The 4FGL is based on the first eight years of mission from the Fermi Gamma-ray Space Telescope mission in the energy range from 50 MeV to 1 TeV and it is the deepest yet in this energy range. Relative to the 3FGL catalog, the 4FGL catalog has twice as much exposure as well as a number of analysis improvements, including an updated model for the Galactic diffuse gamma-ray emission, and two sets of light curves (1-year and 2-month intervals). [1]

3.2 The Determination of the Powerful Parameters

In order to investigate which are the parameters that are the most promising to disentangle between blazars and pulsars in the 4FGL, I have made the histograms of the parameters of pulsars and blazars. [6]If pulsars and blazars are present in different range of a parameter, then this parameter can successfully be a candidate. On the other hand, if pulsars and blazars show the same characteristic for a parameter, then this is not useful for the research. The plots suggest that among all of the parameters, variability, curvature significance of Log Parabola and Latitude are the most powerful parameters that can be used to distinguish between pulsars and blazars. [7]

4 Results

4.1 The Region of the parameters

4.1.1 Variability

Blazars are highly variable, and some of them have very high variability from 20 to 100. On the other hand, pulsars are less variable with on average variability below 20. The plot above shows the histogram of the variability for pulsars, blazars and unassociated sources. This suggests that the sources of which variability is smaller than 20 are pulsars.

In the graph, we can see clearly that the variability of the unassociated sources is from 0 to 20, which suggests that most of them could be pulsars.

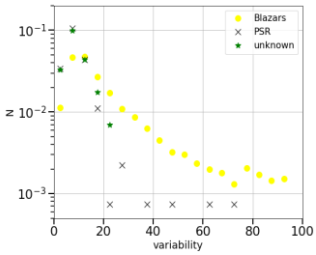

Fig. 2. Variability of the sources.

4.1.2 Galactic Latitude (GLAT)

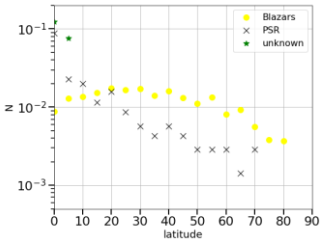

Fig. 3. Galactic latitude of the sources.

According to the graph, the latitude of pulsars is close to zero, but the Blazars are more spread out in the galaxy. The reason for this result is that blazers are extragalactic sources and thus are isotropically distributed in the galaxy and in latitude. Instead, pulsars are of galactic origin and thus are more concentrated at low latitudes. In the graph, clearly, the proportion of pulsars is obviously greater than the proportion of blazars in the region of GLAT<20, so we are able to conclude that the sources that GLAT<20 are probably pulsars. For the unassociated sources, the latitude of most of them is close to zero, which means that they are probably pulsars.

4.2. Curvature Significance of Log Parabola (LPsign)

According to the plot on the left, the curvature significance for the Log Parabola spectrum of Blazars is generally less than 5sigma. On the contrary, the significance of most pulsars is from 0 to 80sigma since their spectra are more curved. According to the plot on the right, we can see that the proportion of pulsars is significantly greater than the proportion of blazars in the region of LPsign>5. We can conclude that the sources that LPsign>5 are probably pulsars, and the sources that LPsign<5 are probably blazars. For the unassociated sources, their significance lies between 0 and 12.5 and is larger than the significance of blazars.

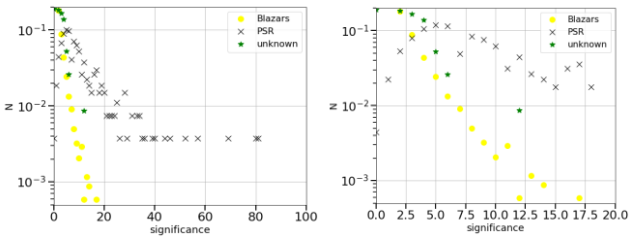

Fig. 4. Significance of the sources.

4.3 Pulsar candidates in the unassociated sources

According to the conclusions presented in 3.1.1, 3.1.2 and 3.1.3, we consider sources of which variability<20, absolute value of the galactic latitude<20 and LPsign>5 are pulsar candidates. After applying these conditions to the unassociated sources in Python, we have determined the following 142 candidates that may be pulsar:

Name GLAT **4FGL J0906.8-2122 17.182617**	**Name GLAT** **4FGL J0906.8-2122 17.182617**
4FGL J0933.8-6232 -7.9074183	4FGL J1738.1-2453 3.5415926
4FGL J0940.3-7610 -17.449461	4FGL J1740.7-2640 2.104205
4FGL J0947.0-3548 13.512758	4FGL J1743.7-4321 -7.1661515
4FGL J1005.5-5708c -1.2154778	4FGL J1747.0-3505 -3.462644
4FGL J1026.2-5731 0.022287028	4FGL J1748.3-2906 -0.6043984
4FGL J1046.7-6010 -0.9672107	4FGL J1750.0-3849 -5.8692975
4FGL J1048.5-5923 -0.1666718	4FGL J1753.8-2538 0.12693389
4FGL J1127.9-6158 -0.6798978	4FGL J1754.6-2933 -2.0071337
4FGL J1139.2-6247 -1.0660292	4FGL J1757.7-6032 -17.186884
4FGL J1203.9-6242 -0.33813143	4FGL J1801.6-2326 -0.31522205
4FGL J1204.5-5032 11.636577	4FGL J1802.4-3041 -4.0421247
4FGL J1207.4-4536 16.575975	4FGL J1803.8-2908 -3.54446
4FGL J1208.0-6900 -6.4596033	4FGL J1805.1-3618 -7.2373652
4FGL J1210.4-6250 -0.33482808	4FGL J1806.2-2126 -0.25252265
4FGL J1231.6-5116 11.483131	4FGL J1808.2-2028e -0.1820724
4FGL J1231.6-6511 -2.4016714	4FGL J1808.4-3358 -6.725435
4FGL J1306.3-6043 2.0990448	4FGL J1812.2-0856 4.502029
4FGL J1309.1-6223 0.40559182	4FGL J1814.7-3420 -8.055587
4FGL J1317.5-6316 -0.55519617	4FGL J1817.9-3334 -8.28481
4FGL J1329.9-6108 1.3843493	4FGL J1818.6+1316 13.199313
4FGL J1351.6-6142 0.34008345	4FGL J1819.9-1530 -0.2553561
4FGL J1358.3-6026 1.3609829	4FGL J1823.2+1209 11.699215
4FGL J1403.5-6236 -0.88337934	4FGL J1823.3-1340 -0.1149143
4FGL J1405.1-6119 0.2836073	4FGL J1824.2-0621 3.1016934
4FGL J1409.1-6121e 0.12567082	4FGL J1824.2-5427 -18.049017
4FGL J1412.1-6631 -4.899744	4FGL J1827.5+1141 10.5546

4FGL J1444.9-5939 0.11439446	4FGL J1830.8-3132 -9.806819
4FGL J1447.4-5757 1.5231397	4FGL J1834.2-0827c -0.07172557
4FGL J1449.8-5923c 0.091335036	4FGL J1834.7-0724c 0.3115942
4FGL J1501.0-6310e -3.8907757	4FGL J1834.9-0800 -0.013645585
4FGL J1517.9-5233 4.1421294	4FGL J1840.4-1139 -2.8786254
4FGL J1526.6-3810 15.278664	4FGL J1842.1+2737 14.085746
4FGL J1539.4-3323 17.532059	4FGL J1847.2-0141 0.16072634
4FGL J1553.8-5325e 0.27877477	4FGL J1854.7+0153 0.11998991
4FGL J1603.3-6010 -5.699764	4FGL J1855.3-0740 -4.3513784
4FGL J1610.3-5154c -0.22677961	4FGL J1856.7+0125c -0.52188915
4FGL J1611.9-5125c -0.03662832	4FGL J1857.1+0056 -0.8492683
4FGL J1613.0-5102 0.11350931	4FGL J1858.0+0354 0.3096627
4FGL J1616.6-5341 -2.1694973	4FGL J1900.4+0339 -0.34116748
4FGL J1616.6-5009 0.3726569	4FGL J1900.7+0426 -0.046061184
4FGL J1619.3-5047 -0.38626578	4FGL J1900.9+0538 0.47065985
4FGL J1622.7-4934c 0.09190126	4FGL J1902.2+0448 -0.2154043
4FGL J1629.3-4822c 0.15445924	4FGL J1904.7-0708 -6.200763
4FGL J1634.0-4742c 0.031737383	4FGL J1906.1+1651 4.4507213
4FGL J1636.9-4710c 0.03242511	4FGL J1906.9+0712 -0.1481562
4FGL J1639.3-5146 -3.3325295	4FGL J1908.7+0812 -0.077988505
4FGL J1649.3-4441 0.03385913	4FGL J1908.8-0131 -4.571059
4FGL J1651.7-4359 0.15195034	4FGL J1912.7+0957 -0.14555876
4FGL J1653.2-4349 0.057707638	4FGL J1913.4-1526 -11.745806
4FGL J1656.5-2733 9.677605	4FGL J1916.8-3025 -18.42003
4FGL J1700.2-4237c -0.1971766	4FGL J1919.4+1313 -0.08241083
4FGL J1702.7-5655 -9.229002	4FGL J1922.7+1428c -0.20529965
4FGL J1704.8-4030 0.42582232	4FGL J1924.8-1035 -12.168449
4FGL J1709.9-0900 17.773561	4FGL J1929.0+1729 -0.088364385
4FGL J1711.0-3002 5.6433907	4FGL J1931.1+1656 -0.79363585
4FGL J1711.9-1922 11.6571	4FGL J2038.4+4212 0.5427818
4FGL J1714.9-3324 3.0092595	4FGL J2041.1+4736 3.4537694

4FGL J1717.5-5804 -11.504704	4FGL J2056.4+3142 -8.818813
4FGL J1721.3-5257 -9.12776	4FGL J2116.2+3701 -8.34101
4FGL J1730.4-0359 15.995311	4FGL J2208.4+6443e 7.148063
4FGL J1736.1-3422 -1.1655407	4FGL J2220.8+6319 5.2186275

5 Discussion

In this research I have investigated the region of the parameters for the gamma-ray flux to separate unassociated Fermi-LAT sources of the 4FGL among pulsars and blazars. We found that the variability, latitude, significance of curvature are the most promising and used them to determine the pulsar candidates in the unassociated sources from the 4FGL catalog. The result found is shown before and report that 142 of the unassociated sources are probably pulsars.

All of the data analysis is done by Python in Jupyter Notebook. It is a powerful tool that helped to make histograms and select the pulsar candidates. With Python, we can easily deal with the huge amount of data and make precise prediction to the pulsar candidates. Those conclusions for the region of parameters can also be applied to any newly detected unassociated sources in the future programs. [8]In other words, the result in this research can be used to find out pulsars for other catalogs.

However, there might be other parameters that weren't detected by Fermi Large Area Telescope also helpful to distinguish between pulsars and blazars. In the future, if there are some new parameters detected in another catalog, other researchers can analyze the new data and determine whether they are helpful to distinguish between pulsars and blazars or not. I believe that the result can be more accurate if more parameters are found and more conditions are added to search for the pulsar candidates.

Also, we can see that there are pulsars which don't follow the conclusion presented in 3.2, which means that if we apply the conclusion to a unassociated source, it could be a pulsar even if its variability>20, galactic latitude>20 or LPsign<5. As a result, the addition of other powerful parameters to help distinguish pulsars is necessary for the accuracy of the determination of the pulsar candidates.

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