PWNCAT2

*Todo list

1. Unpulsed magnetospheric emission, and PWN searches

In this section, we will search for emission in the phase range between the peaks of the pulsar's light curve. This potential DC emission could originate in the pulsar's winds, from inside the pulsar's magnetosphere, or the emission could be spatially coincidental but physically unrealted to the pulsar.

The GeV emission in the off-peak from LAT-detected pulsars has been studied in several previous publications. In particular, the spatially-extended Vela X pulsar wind nebula has been detected by the LAT in the off-peak phase region of the Vela pulsar (Ackermann et al. 2011) and the Crab nebula has been detected by the LAT (Abdo et al. 2010b). Surprisingly, this GeV emission from the Crab nebula was found to be variable in time (Abdo et al. 2011).

Most prominently, a dedicated analysis was performed using LAT data of the off-peak emission of 54 LAT-detected pulsars using 16 months of survey observations (Ackermann et al. 2011). The search discovered ten pulsars wich significant off-peak emission. Along with Vela X and the Crab nebula, the search discovered a source coincident with the TeV source HESS J1023-575 in the off-peak window of PSR J1023-5746. In addtion, four of hte other regions showed a significantly cutoff pulsar-like spectrum and are suspected to be be of magnetospheric origin.

We expand upon this previous work by searching in the off-peak region of all 107 pulsars presented in this catalog. In addition to the larger list of pulsars, in this earch we use an expanded data set, a larger energy range, and an improved analysis method.

1.1. Off-peak Phase Selection

To study the off-peak emission of LAT-detected pulsars, we first developed a new method for defining the off-peak emission. The primary constraint for this method was that it was systematic, computationally efficient, and model independent.

The method we developed procedes by deconstructing a pulsar phaseogram into a Baysian blocks using the implementation described in Jackson et al. (2003).

Set the ncpPrior parameter to 5?

Figure 1 shows the off peak selection for some pulsars...

How to implement Baysian blocks on periodic data.

1.2. Analysis of the *Fermi*-LAT data

We develope a procedure for characterizing any emission found in off-peak phase internals for the pulsars in this catalog. This proceure used both the spectral and spatial characteristics of any observed emission to determine the physical origin of the emission.

Pulsar wind nebula are expected in many cases to be spatially extended. For example, Vela X and HESS J1825-137 are PWN that have been observed by the LAT to be spatially extended (Ackermann et al. 2011; Grondin et al. 2011). On the other hand, not all pulsar wind nebula are expected to be significantly spatially resolved at GeV energies due to the finite instrument resolution of the LAT. For example, the Crab nebula appears as a point-like source in the LAT but is distinuished in the off-peak from the Crab pulsar by its hard spectrum for E$\gtrsim$1 GeV. (Abdo et al. 2010b).

On the other hand, a previous analysis by the Fermi LAT collaboration found seven off-peak regions to have significant emission which is point-like in nature that is characterized by a pulsar-like cutoff spectrum (Ackermann et al. 2011). We can thefore use either spatial extension or significant emission at high energy to distinguish the PWN scenario and point-like emission with a cutoff spectrum to distingiugh the pulsar scenario.

To perform this test, we used the likelihood fitting pacakge `pointlike` to study the spatial character of emission in the off-peak regions and `gtlike` to study the spectral character of the emission. These tools provide complementary features and this method is very similar to the approach used in the second LAT catalog (Nolan et al. 2012) and a followup search for spatially extended sources (Lande et al. 2012).

First, we assumed the potential emission to have a point-like spatial model and we used `pointlike` to fit the position of the off-peak region. The localization procedure is described in Nolan et al. (2012). Following the position fit, we used the best fit positions obtained through `pointlike` and performed a spectral analysis using `gtlike`.

Describe assumed spectral model

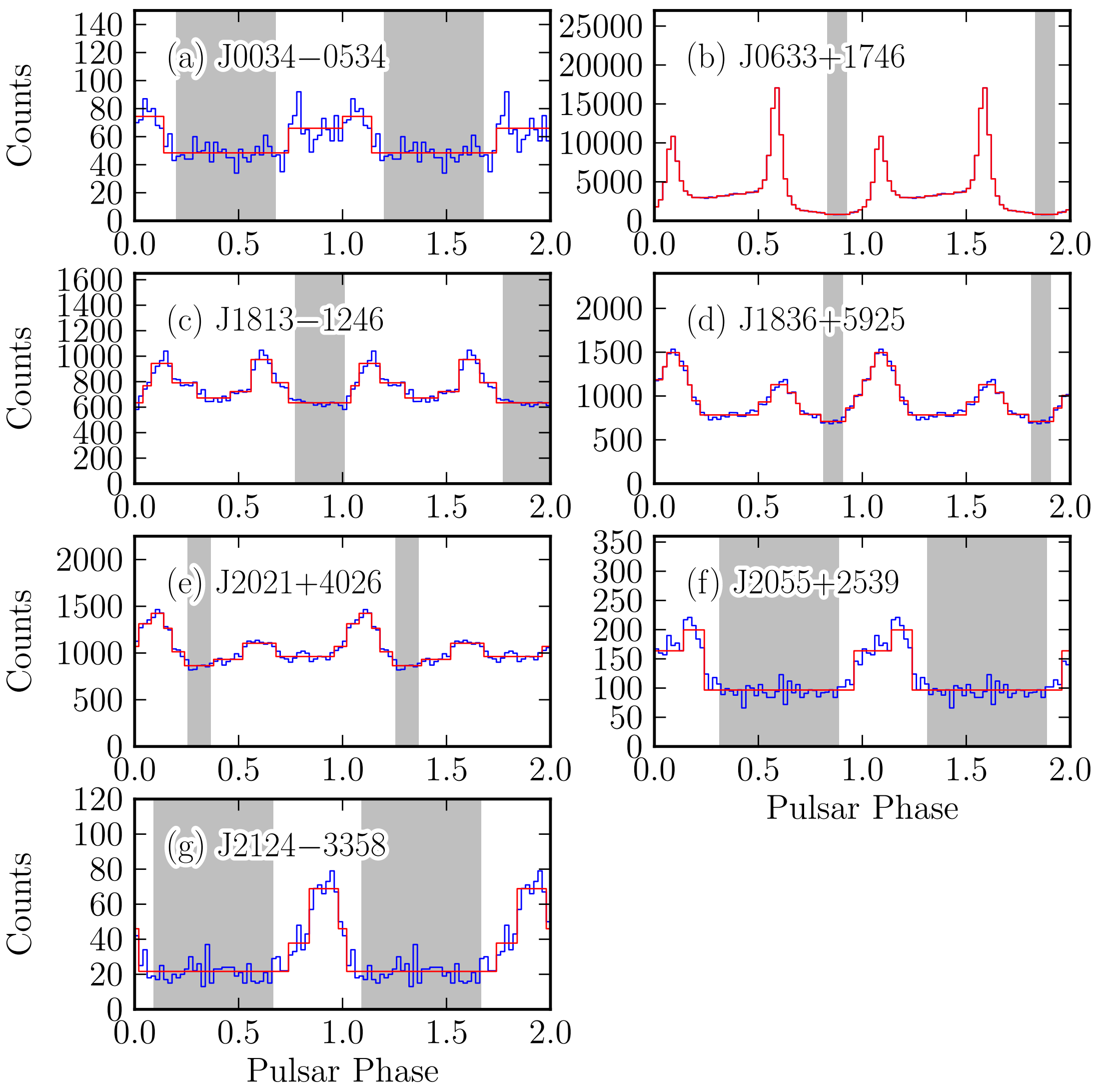

Fig. 1.— Off peak selection for some pulsars. . .

After fitting the position of a source, we use `gtlike` to perform a likelihood ratio test for the detection of the source. Here, TS is defiend as

$$\mathrm{TS} = 2\log(\mathcal{L}_{\mathrm{pt}}/\mathcal{L}_{\mathrm{bg}}) \tag{1}$$

where $\mathcal{L}_{\mathrm{pt}}$ is the poission likelihood for a model including the source and $\mathcal{L}_{\mathrm{bg}}$ the likliehood for a model not including the source. We set the threshold for detection of signfiicant emission at $\mathrm{TS} > 25$, corresponding to a significance just over 4σ (Abdo et al. 2010a).

We then used `pointlike` to test wheter the observed emisssion was spatially extended, assuming a radially-symmetric Gaussian spatial model. `pointlike` canb e used simulatenously fits the position and the extension of the assumed Gaussian source, following the description in (Lande et al. 2012). After the extension fit, we refit the spectrum of the spatially extended source using `gtlike` and performed a likelihood ratio for the significance of the extenstion of a source.

$$\mathrm{TS}_{\mathrm{ext}} = 2\log(\mathcal{L}_{\mathrm{ext}}/\mathcal{L}_{\mathrm{pt}}) \tag{2}$$

We set the thresholt for detecting the significance of a spatially extended soruce at $\mathrm{TS}_{\mathrm{ext}} > 16$, corresponding to a 4σ detection (Lande et al. 2012).

(Lande et al. 2012).

From `gtlike`, we obtained

$$\mathrm{TS}_{\mathrm{cutoff}} = 2\log(\mathcal{L}_{\mathrm{expcut}}/\mathcal{L}_{\mathrm{pt}}) \tag{3}$$

1.3. Results

First, we tested the sources to see if they were spatially extended. The localization results are in Table 1.

Next, we performed a spectral analysis over all energy using the best fit morphology. XXX shows the results of the all energy analysis of the off-peak emission for each pulsar.

Next, we fit a powerlaw independently in each energy bin. XXX shows the results of the analysis in separate energy bins of each pulsar.

Finally, we tested sources to see which were variable. XXX shows the results of the cutoff test for pulsars with significant low-energy emission.

Figure 2 shows the cutoff test…

We tested all sources for variability.

Table 1. Off-Peak Spatial and Spectral Results

PSR	Phase	TS_{point}	TS_{ext}	TS_{cutoff}	$F_{0.1-316}$ (10^{-9} erg cm^{-2} s^{-1})	Γ	E_{cutoff} (GeV)
J0007+7303	0.53 - 0.89	71.6	7.4	0.0	47.21 ± 8.49	2.62 ± 0.14	⋯
J0034−0534	0.21 - 0.68	43.6	0.0	5.9	16.16 ± 4.53	2.42 ± 0.17	⋯
J0102+4839	0.81 - 0.57	66.0	0.0	9.0	25.05 ± 4.94	2.39 ± 0.11	⋯
J0218+4232	0.82 - 0.21	39.5	0.0	4.5	53.76 ± 13.40	2.76 ± 0.23	⋯
J0340+4130	0.13 - 0.64	27.0	0.0	18.3	2.25 ± 1.68	1.55 ± 5.25	544.00 ± 876.90
J0534+2200	0.59 - 0.87	4862.3	0.0	0.0	519.09 ± 20.53	2.22 ± 0.02	⋯
J0631+1036	0.62 - 0.16	25.8	65.1	2.8	302.72 ± 32.23	2.37 ± 0.09	⋯
J0633+1746	0.83 - 0.93	3677.0	2.5	237.1	718.70 ± 27.60	-1.38 ± 0.09	945.80 ± 105.06
J0734−1559	0.28 - 0.84	33.0	24.8	28.0	88.57 ± 13.00	2.28 ± 0.09	⋯
J0835−4510	0.81 - 0.03	388.5	235.3	0.0	443.84 ± 24.09	2.13 ± 0.03	⋯
J0908−4913	0.66 - 0.04, 0.17 - 0.54	25.5	35.9	18.2	135.03 ± 8.13	2.04 ± 0.03	⋯
J1023−5746	0.67 - 0.02	89.3	83.3	5.4	298.89 ± 39.35	2.08 ± 0.04	⋯
J1044−5737	0.57 - 0.97	33.1	187.8	6.8	376.32 ± 860.20	2.04 ± 0.73	⋯
J1112−6103	0.31 - 0.04	124.3	63.2	1.7	192.26 ± 19.97	2.11 ± 0.04	⋯
J1119−6127	0.59 - 0.18	111.2	40.3	9.7	173.17 ± 20.77	2.13 ± 0.05	⋯
J1410−6132	0.55 - 0.24	51.0	108.9	0.7	78.28 ± 13.61	1.72 ± 0.05	⋯
J1420−6048	0.57 - 0.06	None	None	None	None	None	None
J1513−5908	0.53 - 0.15	96.8	1.4	0.0	21.04 ± 9.34	1.82 ± 0.14	⋯
J1658−5324	0.65 - 0.27	44.7	0.0	0.0	38.26 ± 6.94	2.54 ± 0.07	⋯
J1744−1134	0.14 - 0.74	62.7	0.0	13.0	38.59 ± 8.06	2.31 ± 0.10	⋯
J1746−3239	0.41 - 0.97	54.1	53.0	24.9	283.83 ± 84.37	2.05 ± 0.05	⋯
J1747−2958	0.65 - 0.08	47.0	5.6	61.6	142.09 ± 23.97	0.15 ± 0.32	295.46 ± 46.65
J1809−2332	0.53 - 0.91	30.2	13.4	16.9	72.74 ± 24.64	-0.30 ± 1.23	313.61 ± 226.55
J1813−1246	0.77 - 0.01	58.8	0.0	8.3	159.81 ± 33.18	2.50 ± 0.12	⋯
J1836+5925	0.77 - 0.9	6171.1	0.0	233.1	474.22 ± 16.75	-1.44 ± 0.06	1785.54 ± 191.02
J2021+4026	0.27 - 0.36	4235.6	21.4	250.1	1321.58 ± 33.52	2.23 ± 0.02	⋯
J2032+4127	0.27 - 0.55, 0.67 - 0.99	36.5	23.3	0.0	51.69 ± 19.27	1.62 ± 0.11	⋯
J2055+2539	0.37 - 0.87	117.0	0.0	29.9	25.16 ± 7.71	-0.78 ± 0.83	527.74 ± 295.01
J2124−3358	0.09 - 0.69	102.5	0.0	26.9	6.67 ± 2.88	-0.07 ± 1.11	852.20 ± 521.28
J2229+6114	0.68 - 0.1	68.7	41.1	6.9	179.61 ± 20.58	2.15 ± 0.06	⋯
J2241−5236	0.6 - 0.67	103.4	2.1	3.1	21.86 ± 5.31	1.98 ± 0.12	⋯
J2302+4442	0.75 - 0.23	115.8	0.9	11.0	31.84 ± 5.11	2.32 ± 0.09	⋯

Note. —

Put table comments

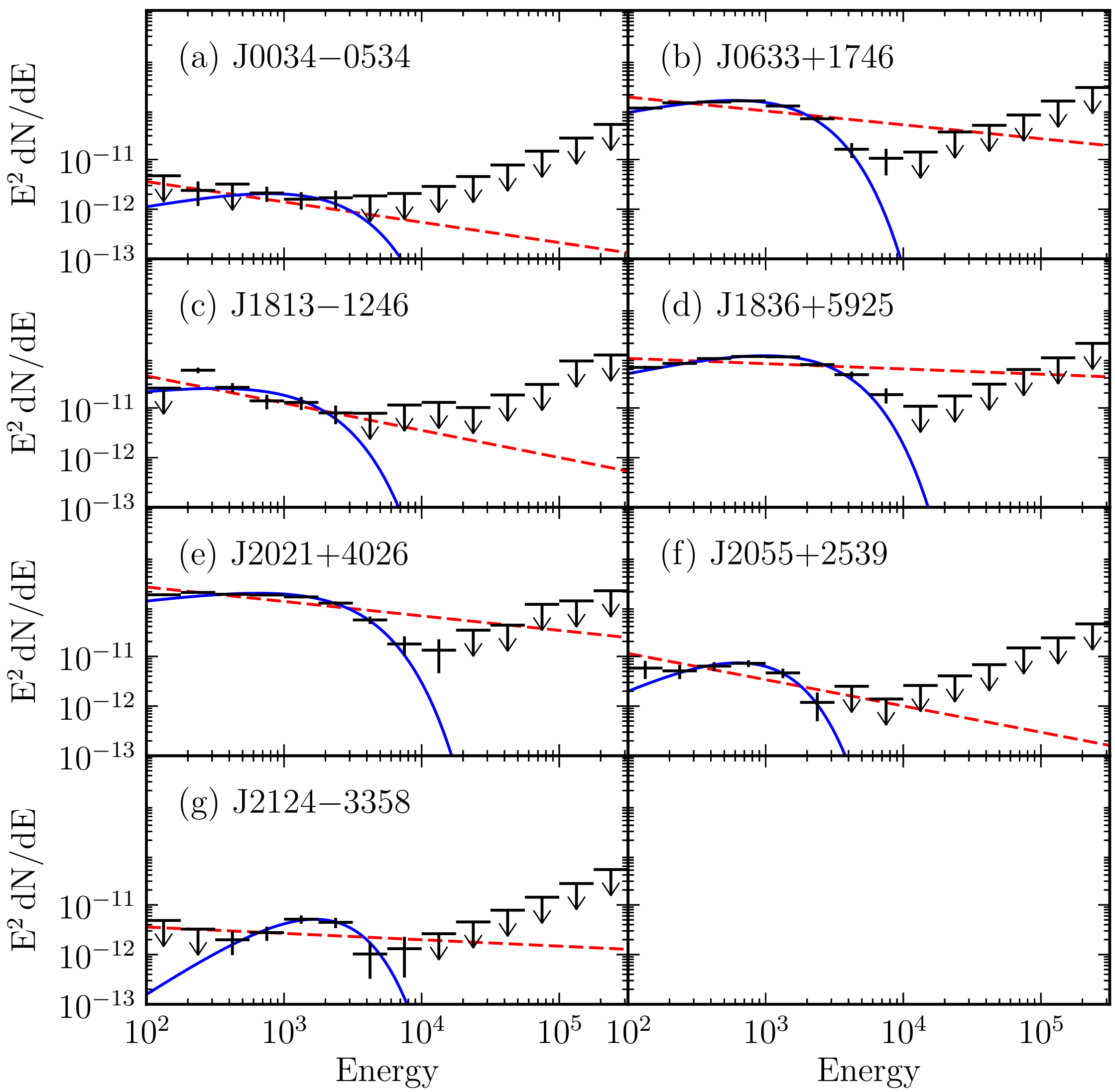

Fig. 2.— Cutoff test for some pulsars…

Special cases:

- Crab has a funny spectrum, we have (so far) fixed it to
- Vela X

1.4. Discussion

Maybe a pulsar physics person can fill in this discussion.

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