An observability study for the tentatively identified 3EG sources likely to be detected by the next-generation Cherenkov telescopes

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Abstract

We study 22 tentatively identified gamma-ray sources from the Third EGRET Catalog in terms of their observability with the next-generation imaging atmospheric Cherenkov telescopes (CTs). In a previous publication, these objects were determined to be among those unidentified EGRET objects which could possibly be detected by CTs given the predicted sensitivities. Taking into account the source models from the tentative identifications (where available), we study the observability in more detail and suggest observing strategies.

Introduction

The Third EGRET Catalog (3EG, Hartman et al. 1999), comprises 271 objects. Among these, 197 are not identified with a counterpart at lower wavelengths (radio, optical or X-rays) with certainty. These are the unidentified EGRET objects (UNIDs). A sizable number of researchers is working on identifying the UNIDs and so far more than 38 have a published tentative ID which still needs to be confirmed by either more observations or improved analysis of archival data. We call these sources the tentatively identified EGRET objects (TIDs).

New contributors to the field will be the next-generation Cherenkov telescope (CT) observatories which are under construction in Australia (CANGAROO III, e.g. Mori et al. 1999), Namibia (HESS I, e.g. Hofmann et al. 1999), La Palma (MAGIC I, e.g. Lorenz et al. 1999) and Arizona (VERITAS, e.g. Krennrich et al. 1999).

These new instruments will reach thresholds below 100 GeV and source location accuracies of about 1'. All UNIDs are unidentified because their position is only known with insufficient accuracy, some of the position probability maps having 95% confidence level contour radii of more than 1°. With an order of magnitude increase in location accuracy, deep well-targeted observations in the radio, optical and X-ray range become possible and make an identification almost certain. In addition, the much improved photon statistics of CTs (collection areas $> 10^4$ m^2) result in a higher sensitivity for pulsed components and thus Pulsar identifications. However, CTs can only contribute for those sources which show emission above several 10 GeV.

In Petry (2000), a catalog was compiled which contains all UNIDs which may possibly be detectable by the next-generation Cherenkov telescopes under moderate assumptions about spectral steepening and taking into account the elevation-dependent sensitivity of the instruments. This catalog contains 78 objects. Among them are 22 TIDs. These objects justify a closer examination since for their tentative counterparts various pieces of information exist which are not available for the other UNIDs:

- We have an exact source position which can be targeted.
- We know the source type and have therefore at least vague model predictions for the spectrum beyond the EGRET energy range.
- We have also model predictions for the variability characteristics of the source.

In this poster we present first results of our data compilation and studies concerning the 22 TIDs which may exhibit significant emission beyond 10 GeV and for which the next-generation Cherenkov telescopes may provide the clue to their final identification.

The data presented here

Table 1 gives a summary of the data presented here. For each object we examine:

- What is the predicted emission of the TID in the energy regime near the threshold of the next-generation Cherenkov telescopes (CTs)?
- Which of the four observatories can observe the object?
- Is the emission variable?
- What is the angular size of the tentative counterpart?
- Are bright stars nearby which may influence the sensitivity of the CTs?
- Are there neighbouring EGRET objects which may lead to source confusion?
- What chances are there for a detection if the tentative identification turns out to be wrong?

Simulated Camera Responses

We show the predicted response of the VERITAS photomultiplier camera to the starfield at each of the 22 source positions. The images were obtained from a simulation of the VERITAS optics and wavelength-dependent photomultiplier response and are shown here for the first time. The starfield information was extracted from the SKY2000 master star catalog (Sande et al. 1998). Shown is the size of the Poisson signal fluctuations in units of photoelectrons caused by the starlight and diffuse NSB for an integration time of 20 ns.

Acknowledgements

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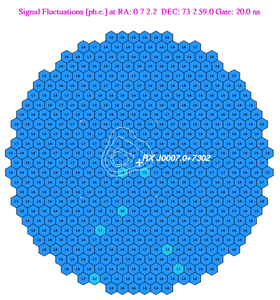
This research has made use of the SIMBAD database, operated at CDS, Strasbourg, France.

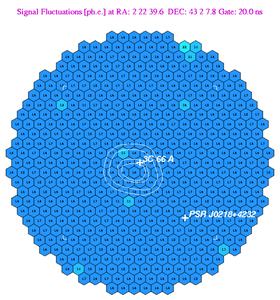
3EG name	tent. ID[1]	RA/DEC (FK5 2000)[2]	l/b[3]	z[4]	spect.[5]	dF/dE(60 GeV)[6]	observ.[7]	var.[8]	size[9]	stars[10]	neighb.[11]	scan[12]
0010+7309	RX J0007.0+7302 in SNR CTA1	00 07 02.2 +73 02 59	119.66 +10.46	-	-1.6[a]	8.3E-16	M, V	0.31	*p*	no	none	no
0222+4253*	3C 66A	02 22 39.6 +43 02 07.8	140.14 -16.77	0.444	-2.0	3.1E-10[f]	M, V	[e]	*p*	no	none	no
0241+6103	LSI+61°303	02 40 31.67 +61 13 45.6	135.68 +1.09	-	-2.2	1.3E-10[f]	M, V	0.49	*p*	no	none	no
0617+2238	1WGA J0617.1+2221 in SNR IC443	06 17 06.1 +22 21 30	189.23 +2.90	-	-1.8[b]	2.2E-10[f]	H, M, V	0.26	*p*	yes	none	no
0808+4844*	QSO B0809+483	08 13 36.09 +48 13 02.5	171.17 +33.24	0.87	-2.3	2.9E-11[f]	M, V	n/a	*p*	no	none	yes
0812-0646*	PKS 0805-077	08 08 15.54 -07 51 09.9	229.04 +13.16	1.84	-2.4	2.0E-11[f]	C, H, M, V	n/a	*p*	no	none	yes
0917+4427	QSO B0917+449	09 20 58.46 +44 41 54.0	175.70 +44.82	2.18	-2.1	2.8E-11[f]	M, V	n/a	*p*	no	none	yes
1009+4855*	QSO B1011+496	10 15 04.23 +49 26 00.7	165.53 +52.71	0.20	-2.0[d]	7.5E-11[f]	M, V	n/a	*p*	no	none	yes
1323+2200	QSO B1324+224	13 27 00.86 +22 10 50.2	3.38 +80.53	1.40	-1.9	3.0E-10[f]	M, V	2.69	*p*	no	none	no
1410-6147	RX J1420.1-6049 in SNR 312.4-00.4	14 20 07.8 -60 48 56	314.45 +1.38	-	-2.0[b]	1.8E-10[f]	C, H	0.33	?	yes	none	no
1800-2338	SNR W28	18 01.0 -23 11	6.71 -0.05	-	-2.0[c]	2.2E-10[f]	C, H, M, V	0.03	0.7[n]	yes	none	no
1824-1514	LS5039	18 26 14.9 -14 50 51	16.88 -1.29	-	-2.4	7.5E-11[f]	C, H, M, V	n/a	*p*	yes	none	yes
1835+5918	RX J1836.2+5925	18 36 13.82 +59 25 28.9	88.88 +25.00	-	-1.7[b]	≈1.4E-15	M, V	0.24	*p*	yes	none	no
1856+0114	PSR 1853+01 in SNR W44	18 56 10.89 +01 13 20.6	34.56 -0.50	-	-1.8	8.3E-15	C, H, M, V	0.80	*p*	yes	none	no
1903+0550	SNR 040.5-00.5	19 06.9 +06 33	40.52 -0.44	-	-2.5	3.7E-11[f]	C, H, M, V	0.35	?	yes	none	yes
2016+3657	TXS 2013+370	20 15 28.89 37 10 58.7	74.87 +1.22	?	-2.0[c]	1.3E-10[f]	M, V	0.37	*p*	yes!	none	no
2020+4017	RX J2020.2+4026 in SNR G78.2	20 20 17.1 +40 26 09	78.09 +2.27	-	-2.0[b]	1E-17	M, V	0.07	*p*	yes!	none	no
2100+6012*	B2101+6003	21 02 40.31 +60 15 09.8	97.96 +9.01	?	-2.1[d]	3.5E-11[f]	M, V	0.15	*p*	yes	none	no
2206+6602*	TXS 2206+650	22 08 03.20 +65 19 38.8	106.94 +7.66	?	-2.3	2.6E-11[f]	M, V	0.27	*p*	yes	none	yes
2227+6122	RX J2229.0+6114	22 29 04.97 +61 14 12.9	106.65 +2.95	-	-2.2	6.1E-11[f]	M, V	0.10	*p*	no	none	no
2255+1943*	QSO B2246+2051	22 53 07.36 +19 42 34.8	88.33 -35.09	0.284	-2.3[d]	4.3E-11[f]	C, H, M, V	0.41	*p*	no	none	yes
2352+3752*	QSO 2346+385	23 49 20.91 +38 49 17.6	109.89 -22.47	1.03	-2.6[d]	1.3E-11[f]	M, V	24.92	*p*	no	none	yes

Table 1. The tentatively identified EGRET sources likely to be detected by the next-generation Cherenkov telescopes (Column titles: (1) name of the tentative counterpart (we partially use the nomenclature of the SIMBAD database), (2) equatorial coordinates of the counterpart, (3) galactic coordinates of the counterpart, (4) redshift for the extragalactic counterparts if known, (5) spectral index at 100 MeV from 3EG, (6) predicted differential flux at 60 GeV (cm^{-2}s^{-1}MeV^{-1}), for comparison: predicted Crab Nebula flux at 60 GeV is 1.28×10^{-11}cm^{-2}s^{-1}MeV^{-1}, (7) source observability (C = CANGAROO, H = HESS, M = MAGIC, V = VERITAS), (8) variability index of the 3EG source as defined in Thompkins (1999), (9) angular extension of the counterpart, (10) problematic starfield?, (11) other 3EG sources within 1.5° radius?, (12) will new pointings be necessary if the tentative identification turns out to be wrong?) (Abbreviations: [a] Source does not belong to the prime candidates in Petry (2000), [b] high energy cutoff visible in EGRET data, [c] soft low energy tail in EGRET data, [d] low statistics in EGRET data, [e] short-time variability observed, [f] integral flux above 60 GeV (cm^{-2}s^{-1}), *p* the counterpart angular size is point-like.)



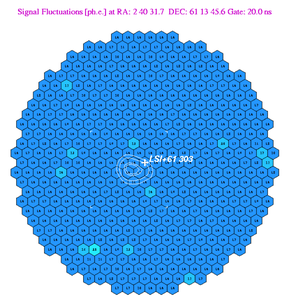
3EG J0010+7309

This source has a steady flux and a hard spectrum, softening above 2 GeV. Brazier et al. (1998) find the source suggestive of emission from a radio-quiet neutron star well within the SNR CTA 1, a non-thermal X-ray plerion. The suggested X-ray counterpart is RX J0007.0+7302. Zhang & Cheng (1998) calculate a thin outer gap model for the possible pulsar. An extrapolation of their model to 60 GeV results in a differential flux of 7 % the Crab Nebula. A pulsed component may well be detectable. The observing conditions are good.



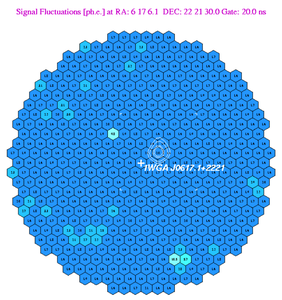
3EG J0222+4253

For this object two different counterparts have to be considered: The well-known blazar 3C 66A (Mattox et al. 1997) and the millisecond-pulsar PSR J0218+4232 (Kuiper et al. 2000). Although PSR J0218+4232 is spatially consistent with 3EG J0222+4253 for the energy range 100-300 MeV, above 1 GeV the BL Lac 3C 66A is the only evident counterpart. For CT observations, this TID therefore has to be treated like a blazar, i.e. a point-like source with no pulsed component. At a redshift of 0.44, absorption in the intergalactic IR background may set in beyond 100 GeV. A simple extrapolation of the EGRET spectrum to 60 GeV gives an integral flux of 30 % of the Crab Nebula. The source should therefore be well detectable. Neshpor et al. (2000) report a detection at TeV energies.



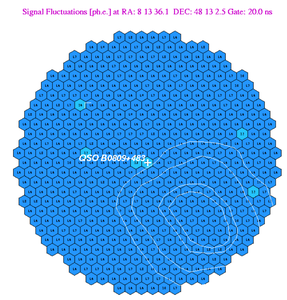
3EG J0241+6103

Kniffen et al. (1997) find that this object, which is clearly identical with the COS B source 2CG 135+0126, has as its only probable counterpart the radio source LSI+61°303. Tavani et al. (1997) show that the flux from 2CG 135+01 as measured by EGRET is time variable but not modulated. The object is therefore not a pulsar, but also no blazar-like counterparts exist and LSI+61°303, an X-ray binary, remains a valid option. Low-energy γ-ray data remain inconclusive (Strickman et al. 1998). More recent X-ray and radio data revealed many interesting features but cannot be described here in detail. An extrapolation of the EGRET flux to 60 GeV assuming modest steepening gives 13 % of the Crab Nebula. CT observations are well justified and the conditions are good.



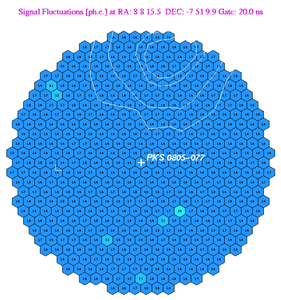
3EG J0617+2238

Keohane et al. (1997) and Bocchino & Bykov (2000) find a hard X-ray source near the SNR IC443 which they interpret as synchrotron emission from TeV electrons produced in a region of enhanced particle acceleration where the SNR interacts most strongly with a molecular cloud. Very recently, Olbert et al. (2001) have presented evidence that the X-ray feature near IC 443 is more probably synchrotron emission powered by an energetic neutron star, i.e. the source is a synchrotron nebula with an embedded pulsar. Observations around 60 GeV should help to further distinguish these scenarios. The EGRET data indicate a high-energy cut-off. A mildly pessimistic extrapolation to 60 GeV gives still a flux of 20% of the Crab Nebula. Two bright stars may slightly decrease the sensitivity of CT observations.



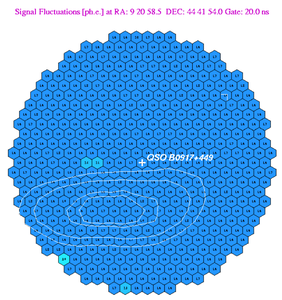
3EG J0808+4844

This object is a weak source well outside the galactic plane tentatively identified as the QSO B0809+483 from purely spatial coincidence. Mattox et al. 2001 confirm this tentative identifications as plausible under statistical aspects. A precise source location, i.e. a high-energy detection will settle the question. At a redshift of 0.87, the absorption in the intergalactic IR background may still be weak below 100 GeV. A mildly pessimistic extrapolation to 60 GeV results in a flux estimation of 3 % of the Crab Nebula flux. If the TID should prove wrong, CT observations would probably have to target the 3EG position in order to get the large 95% c.l. contour fully into the field of view.



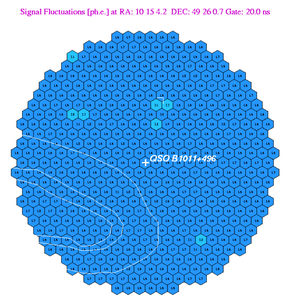
3EG J0812-0646

The suggested identification with PKS 0805-077 dates back to the spatial coincidence with a 1EG source (Fichtel et al. 1994). After the publication of the following EGRET source catalogs and the application of statistical methods to spatial coincidences, Mattox et al. (1997, 2001) do not consider this tentative identification likely. While the object can be observed by all four CT observatories, its weak flux and relatively steep spectrum at EGRET energies together with the high redshift (1.8) of the counterpart make it likely that observing times of more than 50 hours have to be invested to detect this object. Under these conditions and because of the large distance to the extended 3EG contour, CT observers should consider targeting the 3EG position instead of PKS 0805-077 itself.



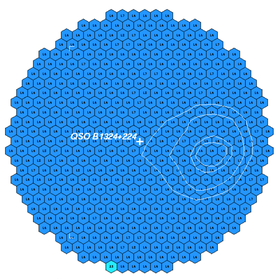
3EG J0917+4427

The suggested identification with QSO B0917+449 dates back to the spatial coincidence with a 1EG source (Fichtel et al. 1994) and has been considered by Mukherjee et al. (1997) in an AGN-object study. Mattox et al. (1997, 2001) do not consider this tentative identification likely for statistical reasons. Assuming modest steepening, the extrapolated flux at 60 GeV is 3 % of the Crab Nebula. The high redshift (2.2) of the counterpart would make a detection especially interesting for examinations of the intergalactic IR background.



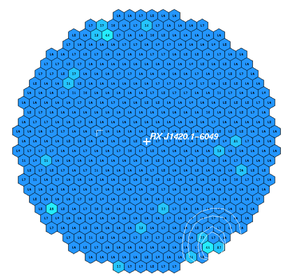
3EG J1009+4855

The identification with the QSO B1011+496 has been suggested in the 3EG catalog. Mattox et al. (2001) do not consider this a likely identification for statistical reasons. As already remarked in the 3EG, source confusion and the hint for extended emission due to multiple source contamination put this source among the rather problematic identifications. Its flat spectrum at EGRET energies and hence its reasonably large extrapolated flux at 60 GeV (8 % of the Crab Nebula assuming modest steepening) together with the low redshift of the possible counterpart justify CT observations. If QSO B1011+496 should prove the wrong candidate, CT observations will have to re-target to the actual 3EG position in order to move the whole 3EG position contour into the FOV.



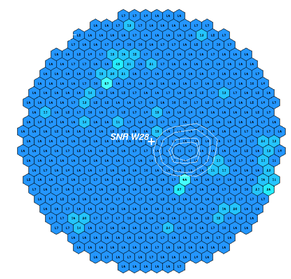
3EG J1323+2200

The identification with QSO B1324+224 has been suggested in the 2EGS catalog and by Mattox et al. (1997) as a potential identification. However, in the context of the expanded database of the 3EG catalog this earlier suggestion has been revised by Mattox et al. (2001). The flat EGRET spectrum and large extrapolated flux at 60 GeV (30 % of the Crab Nebula assuming modest steepening) make CT observations very promising. If QSO B1324+224 is the counterpart, its large redshift of 1.4 makes a detection especially interesting for measuring the intergalactic IR background.



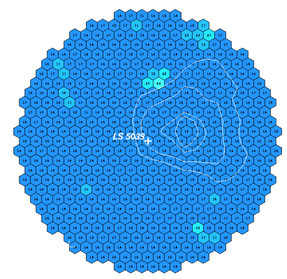
3EG J1410-6147

This object in the complex region near the SNR 312.4-00.4 has been studied in detail (Roberts et al. 2000 and references therein). Roberts et al. analyse X-ray data around the position of the emission above 1 GeV, i.e. the source GeV J1417-6100 which is shifted w.r.t. 3EG J1410-6147. Taking into account radio and infrared data, they conclude that the GeV source may either be a pulsar wind nebula around the recently discovered PSR J1420-6049 (coincident with RX J1420.1-6049) or a new SNR. CT observations will help distinguishing these scenarios. Assuming modest steepening the extrapolated flux at 60 GeV is 18 % of the Crab Nebula, i.e. well detectable. In the case of a pulsar counterpart, the emission should be much weaker. Some bright stars may slightly reduce the CTs' sensitivity.



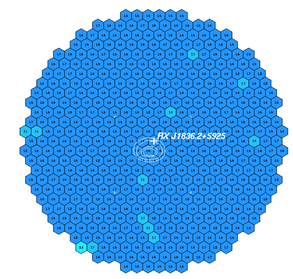
3EG J1800-2338

This object was studied by many authors and is generally associated with W28, a mixed-type SNR consisting of a centrally filled X-ray and shell-like radio component. A radio point-source and a pulsar (PSR J1801-23) consistent with the 3EG position are also present. Rowell et al. (2000) give a useful overview. Zhang & Cheng (1998) conclude that the high-energy emission seen by EGRET from the complex region near SNR W28 is probably a superposition of γ-ray pulsars, interactions from density enhancements of ISM gas and/or local acceleration of cosmic rays in SNRs. Extrapolating their thin outer gap model for PSR J1801-23 to 60 GeV results in a flux of 30 % of the Crab Nebula. While several bright stars may decrease the CT sensitivity slightly, the object is a promising target.



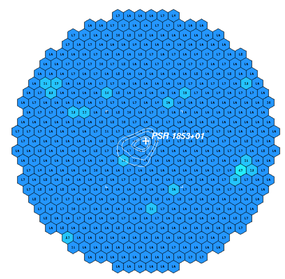
3EG J1824-1514

Very recently, Paredes et al. (2000) suggested an identification of this EGRET source with the newly discovered microquasar LS 5039. An earlier attempt at an identification suggested PSR B1823-13 (Merck et al. 1996). Zhang & Cheng (1998) find that the pulsar could be a valid identification on the basis of a reasonable model fit using a consistent parameter set from the radio source. An extrapolation of their thin outer gap model results in a flux of 21 % of the Crab Nebula at 60 GeV which is well detectable by CTs. However, the positional coincidence with LS 5039 is better. The expected emission of LS 5039 at several 10 GeV still has to be modeled. An extrapolation of the EGRET spectrum assuming modest steepening gives a flux of 8 % of the Crab Nebula at 60 GeV.



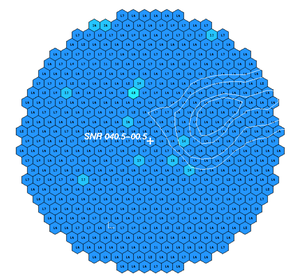
3EG J1835+5918

Long without any counterpart, this object was suggested to be a radio-quiet neutron star (Reimer et al. 2000). Two independent multi-frequency identification campaigns yielded an X-ray counterpart (Mirabal et al. 2000, Reimer et al. 2001), which is now agreed to be a radio-quiet isolated neutron star candidate at the position of RX J1836.2+5925 (Mirabal et al. 2001). The extremely flat EGRET spectrum shows a cutoff above 4 GeV. Extrapolating this to 60 GeV results in a differential flux of about 10 % of the Crab Nebula. The object may be well detectable by CTs.



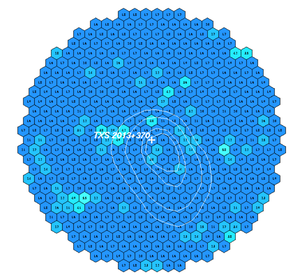
3EG J1856+0114

This object has a flat spectrum with no obvious cut-off below 10 GeV. Due to its proximity to the SNR W44, it has been studied extensively (see e.g. the overview in Buckley et al. 1998). W44 is a radio shell-type SNR with an angular diameter of about 0.5° associated with PSR 1853+01. There is both evidence for a synchrotron nebula and interactions with molecular clouds. Extrapolating the thin outer gap model of Zhang & Cheng (1998) to 60 GeV yields a differential flux of 65 % of the Crab Nebula. The object is an ideal candidate for CT observations and is accidentally the only UNID which can be equally well observed both from the southern and the northern hemisphere. It can therefore be used to cross-calibrate the four CT observatories (Petry 2000).



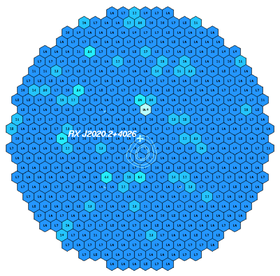
3EG J1903+0550

Zhang & Cheng (1998) conclude that this source could not be fitted with a consistent parameter set in an outer gap model. Therefore the association with PSR B1900+05 as suggested by Yadigaroglu & Romani (1997) seems unlikely. However, an association with SNR 039.2-0.3 has been noticed by Romero et al. (1999). CT observations below 100 GeV - also if only an upper limit on the emission can be given - would add valuable clues. A mildly pessimistic extrapolation of the EGRET spectrum to 60 GeV gives a flux of 4 % of the Crab Nebula. A bright star in the FOV may slightly decrease the CT sensitivity.



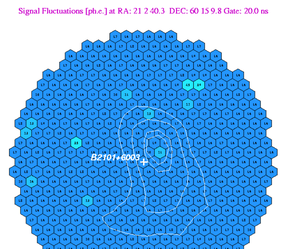
3EG J2016+3657

This source has very recently been identified with the blazar-like radio source TXS 2013+370 shining through the galactic plane (Mukherjee et al. 2000, Halpern et al. 2001b) and is therefore not strictly to be regarded as an UNID or TID anymore. Still, a follow-up by CT observatories could further harden the evidence. The redshift of the counterpart is not yet available and predictions for the flux around 60 GeV are therefore problematic. Assuming a modest steepening, the extrapolated flux at 60 GeV is 10 % of the Crab Nebula. CT observations will have to cope with several bright stars in the FOV.



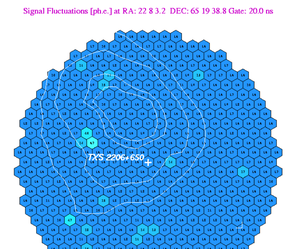
3EG J2020+4017

This object has been studied extensively due to its proximity to the SNR γCyg (G78.2+2.1, see e.g. Buckley et al. 1998 for an overview). While it has been suggested that the shell-type remnant (diameter $\approx$ 1°) has a shock front colliding with a dense molecular cloud and producing high-energy γ-rays in hadronic interactions, it was pointed out by Brazier et al. (1996) that the size and location of the 3EG source is inconsistent with this and that RX J2020.2+4026, an X-ray point source with a Geminga-like F_x/F_γ, is a more probable counterpart. Cheng & Zhang (1998) apply their outer gap model to the spectrum (which shows a cutoff at high energies) of 3EG J2020+4017 and find a good fit. Extrapolated to 60 GeV this gives a differential flux of only 1 % of the Crab Nebula. SNR emission, however, would be expected to be much stronger. Several bright stars in the FOV will hamper CT observations.



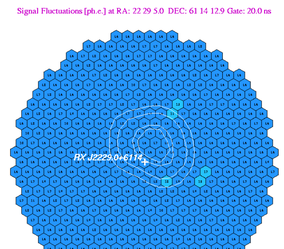
3EG J2100+6012

A tentative identification with QSO B 2105+598 is listed in the 3EG catalog. However, Mattox et al. (2001) find that this is unlikely to be correct. If any FSRQ can account for the observed emission, it is rather B2101+6003 although this is also below the threshold of being considered a potential identification. No redshift measurement for B2101+6003 is available, hence a flux prediction is problematic. Assuming modest steepening, the extrapolation of the EGRET spectrum to 60 GeV yields a flux of 4 % of the Crab Nebula.



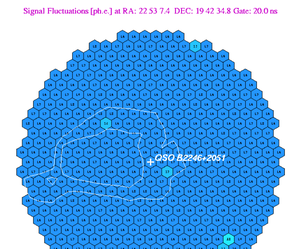
3EG J2206+6602

The identification with TXS 2206+650 has been suggested in the 3EG catalog. Mattox et al. (2001) do not consider this a likely identification for statistical reasons. As already remarked in the 3EG, source confusion and the hint of extended emission due to multiple source contamination put this source among the problematic identifications. The redshift of the potential counterpart is unknown, so also flux extrapolations are difficult. The extrapolation assuming modest steepening gives 3 % of the Crab Nebula at 60 GeV. A few bright stars may slightly decrease the CT sensitivity. If TXS 2206+650 is not the counterpart, new pointings will be necessary to fully cover the large EGRET position contour.



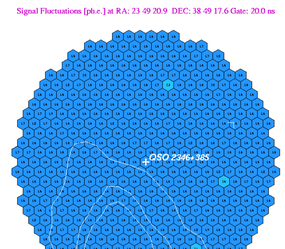
3EG J2227+6122

Halpern et al. (2001) suggested the X-ray source RX J2229.0+6114 as the counterpart of this 3EG object. The X-ray source may be a young neutron star with an associated wind-blown bubble or bow-shock nebula and an example of the class of radio-quiet pulsars which are expected to be behind many of the UNIDs. A similarity to the Crab Pulsar is noted. However, RX J2229.0+6114 is more distant. If this identification is correct, the expected flux at several 10 GeV should roughly scale with the EGRET flux as the Crab spectrum (the modest steepening assumption used in Petry (2000)). This would result in a flux of 6 % of the Crab Nebula at 60 GeV. Observing conditions for CTs are good.



3EG J2255+1943

QSO B2250+1926 is the ID tentatively suggested in 3EG. Mattox et al. (2001) find this very unlikely. A better candidate, although still not considered a likely identification, is QSO B2246+2051. As already noted in 3EG, source confusion and the hint for extended emission due to multiple source contamination put this source among the problematic identifications with 3C 454.3 (3EG J2253+1615/GEV J2253+1622) rather closeby. The redshift of QSO B2246+2051 is 0.28. Absorption in the intergalactic IR background should therefore not be expected below about 150 GeV and the object, if detected by CTs, would be a valuable stepstone on the way to higher redshifts. Assuming modest steepening, the flux at 60 GeV would be expected to be 4 % of the Crab Nebula. The observing conditions are good.



3EG J2352+3752

First suggested in the 2EGS catalog to be associated with QSO 2346+385, Bloom et al. (1997) studied this source at radio wavelengths but did not draw any definite conclusion. Mattox et al. (2001) do not consider this identification likely on statistical grounds. In absence of other suggestions, CTs can first test QSO 2346+385 and then scan the remaining part of the large EGRET position contour if no emission can be detected. With a redshift of 1.0, the counterpart would be expected to show cutoff features and even if only a very gradual steepening is assumed, the source should not be expected to have a flux more than 1 % of the Crab Nebula at 60 GeV.

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