Source Identification with GLAST

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Abstract: With more than 50% of unidentified sources, the third EGRET catalogue reflects the complexity of source identification in the GeV domain. The main hurdle for identification of GeV sources is the limited angular resolution of past (EGRET) and even future telescopes (e.g. AGILE and GLAST), leading in general to ambiguities in the assignment of the correct gamma-ray counterpart. For this reason, additional signatures, such as spectral or timing informations, are crucial in disentangling the various plausible counterparts. We present here our approach of finding plausible counterparts for sources detected by the LAT telescope aboard GLAST. We developed a dedicated ScienceTool dubbed ***gtsrcid*** for the general purpose of source identification. Since source identification is a complex process, highly dependent on the source class, gtscrid has been designed in a very flexible way. gtsrcid performs cross-correlation of the LAT catalogue with catalogues of plausible candidate sources, computing a user-definable figure-of-merit for each possible association. The figure-of-merit is naturally based on spatial coincidence, and can include any additional information available in the catalogues, such as fluxes, spectral indices, source luminosity or distance, or variability. We demonstrate that gtsrcid can be used to reproduce results that have been formerly obtained for the identification of EGRET sources. We further employed gtsrcid to identify sources simulated during the second Data Challenge (DC2). Our source identification strategy and the results for DC2 are presented. Thanks to the lessons learned during this period, we propose some updates in the identification procedures that could be used when GLAST will operate.

Source identification in the GeV domain

The GeV sky has been esthablished by EGRET, that operated during the nineties onboard CGRO. The third - and so far the latest - EGRET catalog (3EG, *Hartman et al. 1999*) contains 271 sources of which 63 % are unidentified. Despite following efforts with regards to Blazars identification (*Mattox et al. 2001*, *Sowards-Emmerd et al. 2005*), the actual fraction of unidentified sources is still about 50%; thus, reflecting the complexity of source identification in this energy range. Only two classes of GeV sources have been firmly established during the EGRET era : Blazars and Pulsars. The main hurdle for identification of GeV sources is the limited angular resolution of the telescopes, leading in general to ambiguities in the assignment of the correct gamma-ray counterpart. For this reason, additional signatures, such as spectral or timing informations, are crucial in disentangling the various plausible counterparts.

Combining a better angular resolution and a larger effective area than EGRET, GLAST has a sensitivity 25 times better. Therefore, extrapolating the EGRET log(N)-log(S) down to the LAT sensitivity, we expect to discover several thousands of new sources. In this context, GLAST source identification is very challenging. First, we have to adapt identification procedures of established source to the GLAST case. On the other hand, the emergence of new GeV source classes has to be anticipated. In this regards, emergent TeV source classes revealed by Tcherenkov telescopes, like supernova remnants (SNR) or pulsar wind nebulae (PWN), will be of prime interest.

We developed a software, dubbed *gtsrcid*, to help us accomplish this task in an automatic way. The tool itself is presented below. Then, its use in the context of the Data Challenge II (DC2) is described. Finally, the global results, lessons learned, and perspectives are given in the last panel.

gtsrcid : a tool for GLAST source identification

We developed a dedicated ScienceTool dubbed *gtsrcid* for the general purpose of source identification. Since source identification is a complex process, highly dependent on the source class, *gtsrcid* has been designed in a very flexible and modular way. *gtsrcid* performs cross-correlation of the LAT catalogue with catalogues of plausible counterpart sources.

The standard figure-of-merit, naturally based on spatial coincidence, is defined as :

$$P_{pos} = \exp\left(\frac{-\varphi}{\sqrt{\theta_{src}^2 + \theta_{cpt}^2}}\right)$$

φ : angular distance between source and counterpart
θ_{cpt} : error on the counterpart position
θ_{src} : error on the source position

However, *gtsrcid* offers the possibility to define a user-defined figure-of-merit that can include any additional information available in the catalogues, such as fluxes, spectral indices, source luminosity or distance, or variability. In case supplementary information is needed, even external data can be injected thanks to a text file. We demonstrated that *gtsrcid* can be used to reproduce results that have been formerly obtained for the identification of EGRET sources. Working examples for source identification are available in the *gtsrcid tutorial* on the SAS Workbook pages (http://glast-ground.slac.stanford.edu/workbook/). In particular, the analysis scheme proposed by *Mattox et al. (2001)* for the identification of Blazars by considering the flatness of counterpart candidate radio spectra has been adapted to the GLAST case.

Finally, a catalogue data base has been developed (http://www.cesr.fr/~lonjou/cat_db/catalog_db.html). Its main goal is to provide an easy access to relevant catalogues for the purpose of source identification. All catalogues have been tested, and if necessary modified, to insure compatibility with *gtsrcid*. As a further matter, we compiled catalogues specific to the GLAST source identification issue like the HESS point source catalogue (*HESScat*) or a Microquasar catalogue (*Paredes et al. 2004*).

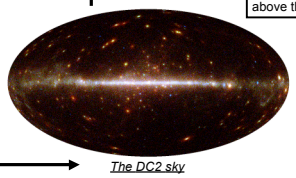
The Data Challenge II sky

The DC2 was an exercise consisting in the creation and processing of a data set equivalent to 55 days of GLAST operation (*McEnery et al. 2007*). The *DC2 sky model* consists in 1719 discrete sources on top of the extragalactic and galactic diffuse emission. Orbit, spacecraft attitude, time lost in the SAA passage as well as instrumental dead time are include in the simulation; leading to a very realistic data set. DC2 was also a unique opportunity to test and improve our source identification techniques. Further, we employed *gtsrcid* in this context. This is described in more detail to the right.

Data simulation :
- 1109 Blazars
- 413 Pulsars
- 7 Plerions
- 11 SNRs
- 5 X-ray Binaries
- 4 OB associations
- 40 High Latitude Molecular Clouds
- 5 Galaxies
- 120 3EG sources not already accounted for above

Data processing :

DC2 LAT catalogue : 380 point sources detected over a total of about 700 simulated sources that are above the limit sensitivity.



The DC2 sky

DC2 source identification

The first step of our method is to identify potential counterparts for each source class separately. The table below summarizes the different catalogues, and the associated FoM, that have been used in this regards. For DC2, only simple FoM have been used; mainly based on spatial correlation. As a priority, more sophisticated FoMs will be developed in the future.
Then, as multiple association are probable, and comparison of FoM originating from different source classes is difficult, we adopt a priority scheme to select a unique counterpart for each LAT source. In case several counterparts are attributed to a unique LAT source, the one that is best ranked in our scheme is selected to be the unique one. In this regards, galactic and extragalactic sources are very rarely in competition since these two categories of sources exhibits very different spatial distributions. However, as a choice needs to be done, we preferred galactic sources since they potentially include new GeV classes. Then, generally speaking, we placed first source classes that are already established; Pulsar concerning galactic sources and Blazars in the extragalactic case. Microquasars are ranked second since they have a common property - the presence of a jet - with Blazars, and because that jet seems to be one of the main ingredient leading to a high energy emission. LMXB, HMXB and SNR complete the galactic sub-group. In the extragalactic case, all sources are AGN. We ranked first the Blazars as determined by *Mattox et al. 2001* since the method they employed has demonstrated his efficiency on EGRET data.

Catalogues

Source Class	Reference	Method, comments	
Pulsars	*Manchester et al., 2006*	Spatial correlation + threshold on [dE/dt] / d^2: ATNF Pulsar catalogue	galactic
Microquasars	*Paredes, 2004*	Spatial correlation	galactic
LMXB & HMXB	*Liu et al.,2000 & 2001*	Spatial correlation	galactic
SNR	*Green., 2004*	Spatial correlation taking the spatial extension into account	galactic
Blazars	*Mattox et al., 2001*	Specific figure-of-merit based on 3 radio catalogues + spectral index in the radio domain	extragalactic
BL Lac	*Veron-Cetty et al., 2003*	Spatial correlation	extragalactic
Blazars	*Sowards-Emmerd et al., 2003*	Spatial correlation	extragalactic
Seyfert	*Lipovetsky V.A. et al.1988*	Spatial correlation	extragalactic
AGN	*Veron-Cetty et al., 2003*	Spatial correlation	extragalactic
QSO	*Veron-Cetty et al., 2003*	Spatial correlation	extragalactic

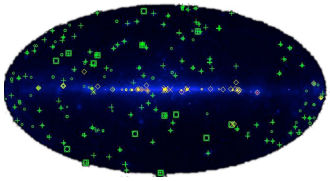
Decreasing priority in case of multiple association

Results

- 200 of 380 sources where identified leading to a fraction of unidentified sources of 47%. If we suppress the EGRET unidentified sources from the DC2 catalogue, the fraction of DC2 unidentified sources drops to 32 %.
- 77% of the identification are correct with better success for extragalactic sources (85%) with respect to galactic ones (44%).
- 54% of the sources have more than one counterpart. This justifies the adoption and the importance of a priority scheme.

Extragalactic sources
- Blazars : 136
- Seyfert : 8
- AGN & QSO : 15

•TOTAL = 159



Galactic sources
- Pulsars : 22
- Micorquasars : 1
- LMXB/HMXB : 12
- SNR : 6

•TOTAL = 41

The DC2 sky as identified with gtsrcid

Conclusion and Perspectives

- Among all sources classes, our blazars identifications are the most reliable ones: out of 136 DC2 LAT sources that we identified as blazars, 85% have been correct. This success is mainly due to the past efforts that have been undertaken to identify EGRET blazars (*Hartman et al. 1999, Mattox et al. 2001, Sowards-Emmerds et al. 2003*) and that we have adapted for the case of GLAST. Improvements of the actual scheme are currently seeked by several groups (*Giommi et al. 2005, Massaro et al. 2005, Sowards-Emmerd et al. 2005*) and we project to also implement these schemes for the identification of sources in the LAT catalogue.
- Pulsar identification using the ANTF pulsar catalogue seems promising, yet we still had 36% of false identification in DC2. In order to reduce this number, we actually investigate FoM that make use of various physical quantities such as the *open field line voltage* or *magnetic field at the light cylinder*. Moreover, a survey of the best GeV pulsars candidates will be performed when GLAST will operate (*Romani et al. 2007*). In case one of the candidate exhibits a pulsation the GeV range, we would unambiguously associate the right pulsar counterpart to the GLAST source using its unique timing signature.
- Except for Pulsars, galactic source identification procedures are at an early stage. We will investigate each class with particular regards to promising ones like :
  - SNR : it's now an established TeV class that is also very promising for GLAST (Funk 2007). We didn't succeed in their identification in the frame of DC2. An obvious reason is the difficulty to properly take into account their spatial extension in the identification process. Furthermore, the age of the SNR and its possible interaction with ambient interstellar clouds may impact critically the likelihood for the object of being a GeV emitter. To take such criteria into account, we actually plan to compile a new SNR catalogue that integrates the relevant information.
  - PWN are another likely source of GeV emission, that has now been clearly established as high-energy emitter in the TeV range. The compilation of a PWN catalogue, which gathers all information that may be relevant for the probability of a source being also a GeV emitter, is currently ongoing.
  - Microquasars : we will develop a specific FoM based on physical criteria (flux at others wavelengths and geometry for example).
- Since chance coïncidence is a recurrent problem because of the combination of the poor angular resolution and the good effective area of the LAT, we are carrying out a way to determine reliably the local counterpart density. Therefore, we will be able to properly take into account the chance coïncidence probability in any figure-of-merit.
- Compilation / update of new catalogues is on going : TeV sources, PWM, SNR, Microquasars. They will be distributed online thanks to the *gtsrcid catalog data base*.

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