Exploring the association of Fermi sources with Young Stellar Objects

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Abstract

Massive protostars have associated bipolar outflows which can produce strong shocks when interact with the surrounding medium. In these conditions particle acceleration at relativistic velocities can occur leading to gamma-ray emission, as some theoretical models predict. To identify young stellar objects (YSOs) that may emit gamma rays we have crossed the Fermi First Year Catalog with some catalogs of known YSOs, and we have conducted Monte Carlo simulations to find the probability of chance coincidence. With this crossing we obtained a list of YSOs spatially coincident with Fermi sources that may show gamma-ray emission. Our results indicate that ~70% of the candidates could be YSOs with a confidence of ~5 σ. We have studied the coincidences one by one to check the viability of these YSOs as potential counterparts of Fermi sources and plan further detailed observations of low of them.

y-ray production scenario

Massive YSOs show collimated outflows and thermal radiation has been detected up to distances of 10–100 pc from the central star. These are strongly supermassive jets and in some cases, non-thermal radio lobes have been detected at distances of 2–10 pc (Garay et al. 2003). These radio lobes are probably generated by strong terminal shocks of the jets, which also shock the material. The possibility of YSOs to be γ-ray emitters has already been discussed in Aradillo et al. 2007 and Bosch-Ramon et al. 2010. Magnetic fields should also be present, since they play an important role in supporting the cloud before the gravitational collapse. Under these conditions, particles can be accelerated up to relativistic energies via diffusive shocks (Fermi I) acceleration (e.g. Bell 1978). These particles would produce the non-thermal radiation found in the radio lobes and could generate significant emission in a broad spectral range, from radio- to γ-rays (Bosch-Ramon et al. 2007). The non-thermal radio lobes are the regions in which protostellar jets terminate.

The action of the jet head on the external medium leads to two shocks (Fig. 1), one moving in the cold material and one more rapidly moving into the dense circumstellar dust envelope. This is therefore the most logical and unbiased way of searching for γ-ray emitters. The case R=1 means that the RMS source is just on the border of the 95% confidence regions, power-law spectral fits and flux measurements in 5 energy bands for each source.

The First Fermi-LAT Catalog (1FGL)

The 1FGL contains 1451 high-energy sources detected in the 100 MeV to 100 GeV range by the Large Area Telescope, the primary science instrument on the Fermi Gamma-ray Space Telescope during the 11 months of the mission, which started on 2008 August 4 (Abdo et al. 2010). The 1FGL includes source location regions, defined as the 95% confidence regions, power-law spectral fits and flux measurements in 5 energy bands for each source.

Method

- We have used a computer code that determines the angular distance between two points in the sky, taking into account the positional uncertainties in each of them.
- We ran the data with the 1392 sources of Table 2 associated with YSOs from Table 1 with the Fermi source positional uncertainties.
- We have used the 1392 sources of Table 1 and 1392 Fermi sources to perform a random binned distribution in galactic latitude (left) and longitude (right) of the 1392 Fermi sources used in the simulations.
- The separation between the Fermi source and the YSO is calculated in each case using the statistical parameter R (Aradillo et al. 2007)

\[
R = \frac{\sqrt{\sigma_x^2 + \sigma_y^2}}{\sigma_r}
\]

where \(\sigma_x\), \(\sigma_y\) is the uncertainty in the position of the source, and \(\sigma_r\) are Fermi and RMS sources, respectively. The case R=1 means that the RMS source is just on the border of the error ellipse of the Fermi source.

Results

- We find 13 Fermi sources being positionally coincident with 24 YSOs (see Table 1).
- Of these Fermi sources have not any cataloged possible counterpart (like SNR, PWN, pulsar, etc.) in the gamma emission within the error ellipse.
- From Table 2 we can see that there is a correlation at 5 σ level.
- The probability of a pure chance association is as low as 2.0 x 10^-3 for the 2''-binning simulations (2.2 x 10^-3 for the 3''-binning).

When we considered the restrictions in both (1) and (3) Table 1, the chance probability raised, but still shows a quite negligible values (=10^-5).

One of the most interesting coincidences is the one of the Fermi source 1FGL J1934.3+2340 (see Fig. 3). We can see in the radio-map from the NVSS survey (Condon et al. 1998) there is a region of massive star formation with many X-ray sources, where the YSO from the RMS survey is located.

Another interesting case is the one of the Fermi source 1FGL J1932.1+2052 (see Fig. 4). This source has an error circle of more than 50 pc, which, even when the source has no proposed counterpart, is probably candidates to be the responsible of the γ-ray emission.

Finally, we can comment the case of the Fermi source 1FGL J1952.0+0141 in which we have studied the coincidences one by one to check the viability of these YSOs as potential counterparts of Fermi sources and plan further detailed observations of low of them.

References


The RMS Survey

MYSOs are luminous (L > 10^4 L☉), embedded infrared sources that still have to begin their circumstellar disks to form an ultra-compact SO region. They are likely to be already burning hydrogen in their cores, whilst still accreting at the surface. They drive bipolar molecular outflows and often have a compact ionized stellar wind and associated bipolar radio lobes which also ionize the shocked material. The possibility of YSOs to be γ-ray emitters has already been discussed in Abadillo et al. 2007 and Bosch-Ramon et al. 2010. The non-thermal radio lobes are the regions in which protostellar jets terminate.

The Red MSX Source (RMS) survey is an ongoing multi-wavelengt observational program with the objectives of providing a well-selected sample of MYSOs in the entire Galaxy, and searching for such objects.

The survey also uses high resolution radio continuum observations at 8cm obtained with the VLA in the northern hemispheres, and at 3.6 cm and 6 cm with ATCA in the southern hemispheres. The RMS survey has targeted MYSO candidates such as Ultra Compact HII regions, evolved stars or Planetary Nebulae, that contaminate the sample. In addition to these targeted observations, archival data of previous VLA survey of the inner Galaxy has been used.

The ongoing program has provided a sample of 556 well identified MYSOs up to day, which have been used in our work.

Table 1: Positional coincidence of Fermi sources with MYSOs. The c in the Fermi source name indicates that based on the region of the sky the source is considered to be potentially coevalized with Galactic diffuse emission.

Table 2: Statistical results obtained from simulations with a random distribution in galactic longitude.

Table 3: Statistical results obtained from simulations constrained both in galactic latitude and galactic longitude.

Diagram of the termination region of the jet of a massive YSO. The two shocks are represented.

Radio image of the region of the source 1FGL J1943.4+2340 from the NVSS. The black ellipse is the error ellipse of the Fermi source. The black cross is a YSO from the RMS survey and the red circle is the position where the jet head would be.