# Discovery of GeV emission from the direction of the luminous infrared galaxy NGC 2146

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## Motivation

Ackermann et al.(2012) examined a sample of 64 dwarf, spiral and luminous and untra-luminous infrared galaxies using three years of data collected by the Large Area Telescope(LAT) on the *Fermi Gamma-Ray Space Telescope*(*Fermi*). Four of them are detected at GeV Band with TS value larger than 25. The promising 7 star-forming galaxies beyond Local group are expected to be detected over a 10 year *Fermi* mission). We search for GeV emission from these candidate galaxies.

## Interaction Process

Galactic cosmic rays (CR) are accelerated by supernova remnant (SNRs) shocks. CR protons interact with the interstellar gas and produce neutral pions (schematically written as $p + p \rightarrow \pi^0 + \text{other products}$), which in turn decay into gamma-rays ($\pi^0 \rightarrow \gamma + \gamma$). The high SN rate in starburst galaxies implies high CR emissivities, so they are predicted to be bright gamma-ray sources. The gamma-ray luminosity of starbursts depends not only on the CR intensity, but also on the conversion efficiency of CR proton energy into pionic gamma-rays. This efficiency in turn depends on the ratio of the timescale of pion production to the escape time of protons. Protons escape by advection in galactic winds or by diffusion. A galaxy becomes a "proton calorimeter" when the pion production time is shorter than the escape time.

## Method and Procedure

**Software** The *Fermi Science Tools package, version v9r32p5*.
**Data selection** Observations from 2008 August 4(MJD 54, 682) to 2014 April 4(MJD 56,752). Photons with energy between 100MeV and 100 GeV, 10 degrees around optical position of galaxy, with *P7REP_SOURCE_V15*.
**GeV Detection** Performing the unbinned likelihood for each source. If TS of candidated galaxy is above 25, then claim its detection.

## References

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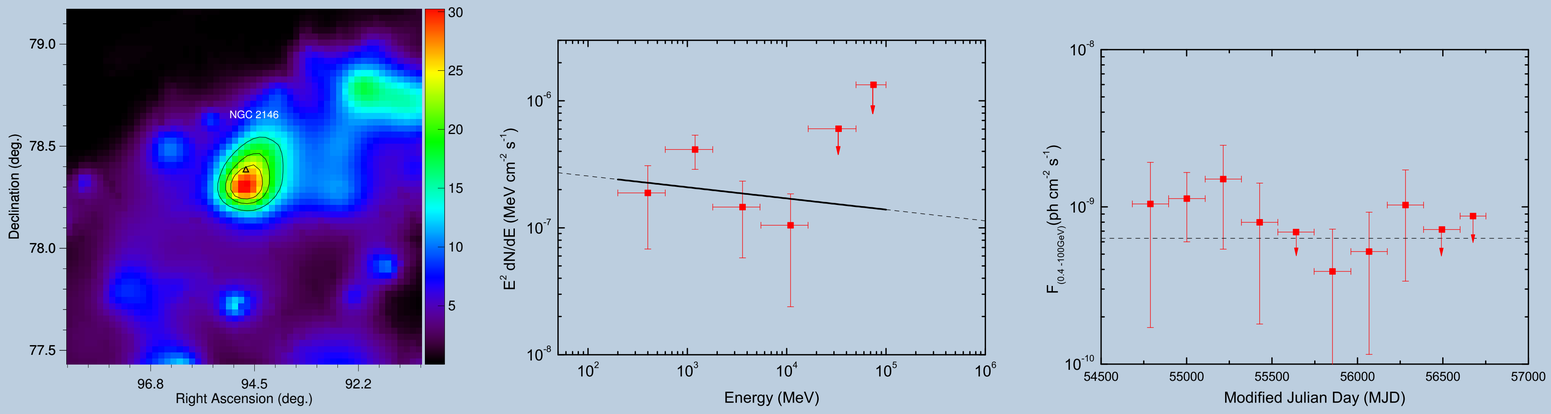
## Results and discussion

**Results:** By searching for high-energy gamma-ray emission from the 7 best candidate galaxies for LAT detection beyond the Local group (ACK12), we found significant high-energy gamma-ray emission above 100 MeV from a source spatially coincident with NGC 2146, the nearest LIRG galaxy. The significance of the detection is about 5.5 $\sigma$. This is the first time that a LIRG galaxy has been detected by Fermi/LAT.

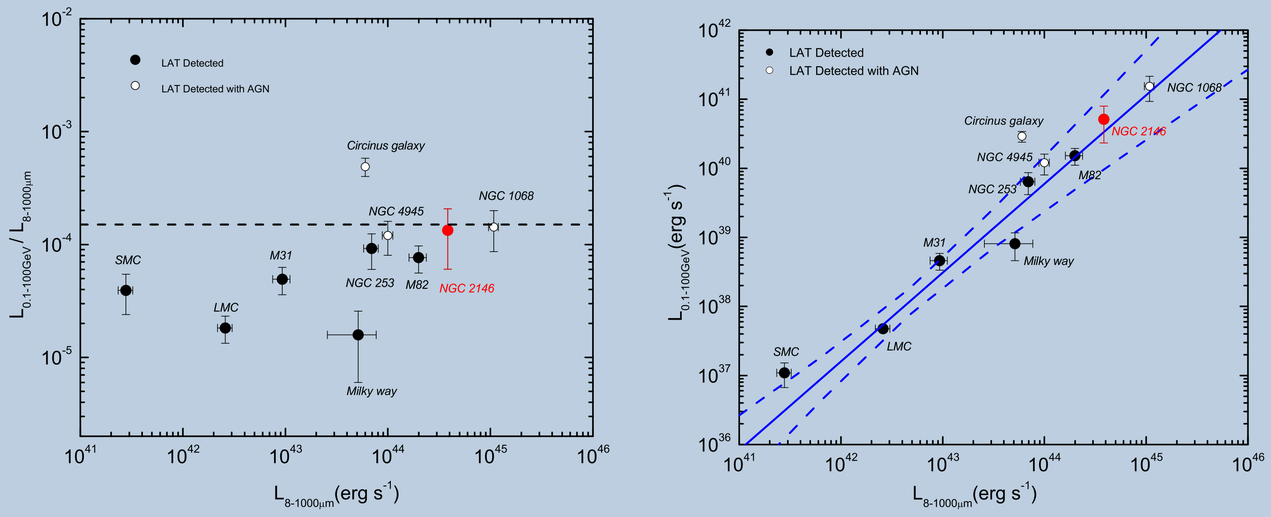



**Discussion A:** The ratio between the total gamma-ray luminosity and the total infrared luminosity in the calorimeter limit is

$$\xi \equiv \frac{L_\gamma(>0.1\text{GeV})}{L_{8-1000\mu\text{m}}} = 1.5 \times 10^{-4} E_{51} \eta_{0.05} \beta_{17}, \quad (1)$$

as has been predicted in Thompson et al.(2007). We compare the ratio between the observed gamma-ray luminosity and total infrared luminosity of NGC 2146 with this limit ratio in lower left Figure (together with other LAT detected galaxies) and find that NGC 2146 lies close to this calorimeter limit. Thus, we suggest that NGC 2146 is probably a "proton calorimeter".
**Discussion B:** Correlation between the $\gamma$-ray luminosity and total IR luminosity. As Figure lower right, We fit the data with a simple power-law and find the relation

$$\frac{L_{0.1-100\text{GeV}}}{\text{erg s}^{-1}} = 10^{39.772\pm0.085} \left(\frac{L_{8-1000\mu m}}{10^{44}\text{erg s}^{-1}}\right)^{1.285\pm0.058}, \quad (2)$$




It is found that NGC 2146 extends the quasi-linear scaling relation between the gamma-ray luminosities and total IR luminosities of star-forming galaxies to a higher luminosity, thus strengthening the connection between massive star formation and gamma-ray emission of star-forming galaxies.

## Other GeV detection in the vicinity of galaxies

Four more sources with significant gamma-ray excesses were found in the vicinity of M51(TS=29.9), NGC 1365(TS=44.4), Arp 220(TS=52.2) and M83(59.1); however, the best-fit positions are all far from the core of the corresponding galaxies, i.e, the angular separation is larger than $r_{95}$, c.f., Table 1. We therefore explored possible candidate sources for those gamma-ray excess within $r_{95}$. We also report all our searching results as below. These galaxies should still have large probablity of GeV detection in recent year. It is for those detection by releasing Pass 8 data and new point source catalog.

**Table 1**
Best-fit Position and Analysis Results of the Five New Significantly Detected gamma-ray Sources in the Vicinity of the Galaxies

| Galaxy | R.A. and Decl.[a] (deg) | $r_{95}$[b] (deg) | $\delta$Angle[c] (deg) | $F$(0.2–100 GeV) ($10^{-9}$ ph cm$^{-2}$ s$^{-1}$) | $\Gamma$ | TS | Association[d] |
|---|---|---|---|---|---|---|---|
| NGC 2146 | (94.55, 78.30) | 0.11 | 0.06 | $1.1 \pm 0.5$ | $2.1 \pm 0.2$ | 30.8 | (1) |
| M51 | (201.66, 47.81) | 0.21 | 0.80 | $2.8 \pm 0.8$ | $2.8 \pm 0.2$ | 29.9 | (2) |
| NGC 1365 | (54.17, −36.33) | 0.30 | 0.65 | $3.2 \pm 0.7$ | $2.6 \pm 0.2$ | 44.4 | (3) |
| Arp 220 | (233.24, 23.58) | 0.20 | 0.46 | $3.2 \pm 0.7$ | $2.3 \pm 0.1$ | 52.2 | (4) |
| M83 | (203.84, −29.82) | 0.07 | 0.36 | $1.2 \pm 0.5$ | $1.8 \pm 0.2$ | 58.1 | (5) |

**Notes.**
[a] Best-fit position of gamma-ray excess.
[b] The 95% containment error circle radius around the best-fit position.
[c] The angular separation between the best-fit position and the position of the core of the galaxy.
[d] The most likely associated source, as shown in Sections 2.2 and 2.3: (1) NGC 2146; (2) SDSS J13261+4754; (3) PKS 0335−364; (4) CRATES J153246+234400; (5) MS 13326-2935(2E 3100).