Fermi Gamma-ray Space Telescope

Detection of GeV Emission from Starburst Galaxies with the Fermi LAT

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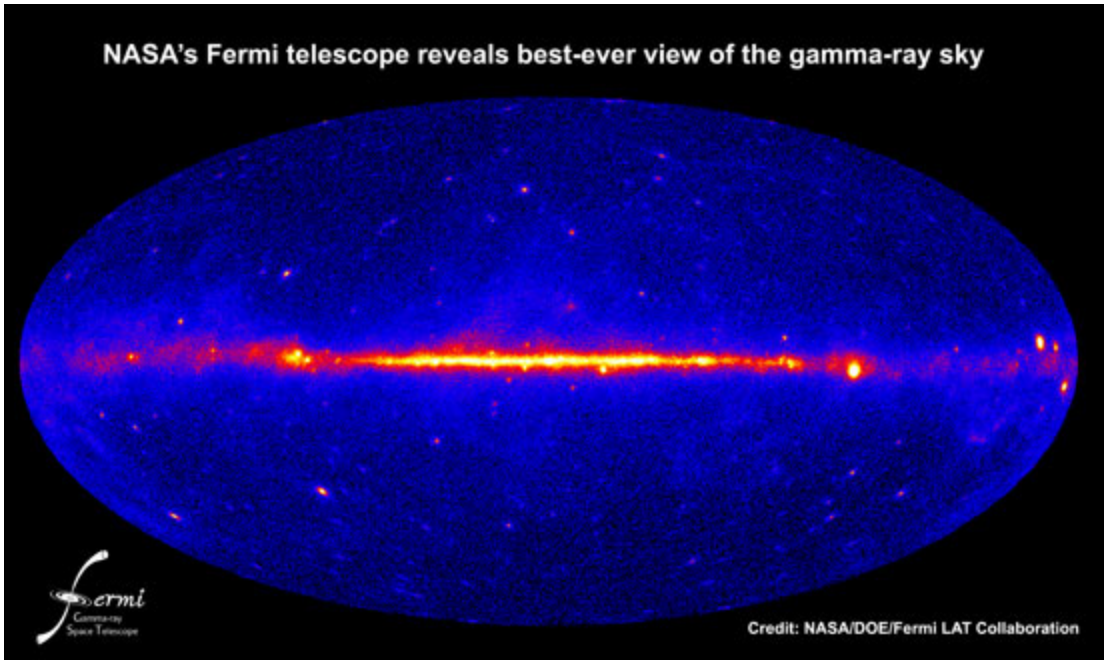
Outline

- **Fermi LAT has detected steady, point-like, emission above 200 MeV from two starburst galaxies**
  - **M82 (6.8σ)**
  - **NGC 253 (4.8σ)**
- **Diffuse gamma-ray emission from star-forming galaxies**
  - **Starburst galaxies M82 and NGC 253**
- **Observations and results**
  - **Detection significance maps**
  - **Point-like and steady**
  - **Integral fluxes consistent with galactic diffuse emission**
- **Interpretation**
  - **Correlate star-formation with enhanced cosmic-ray intensity**

Diffuse Galactic Gamma-ray Emission

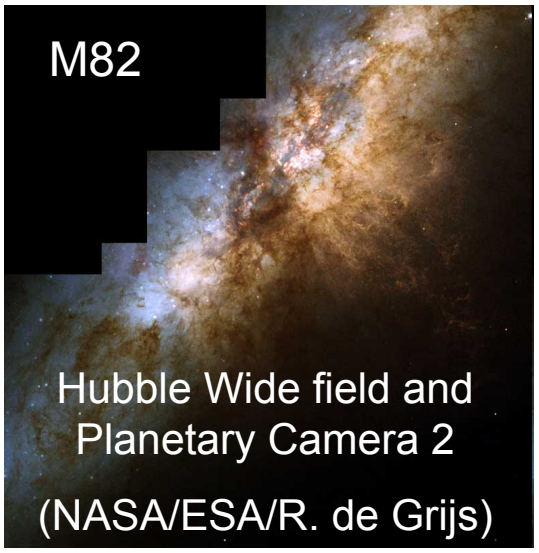


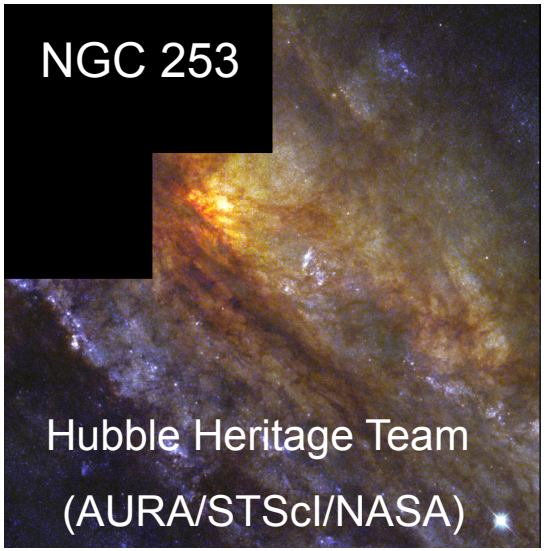
The most striking feature of the GeV gamma-ray sky is the diffuse emission from our own galaxy

Cosmic rays interacting with interstellar medium

- **$CR_{protons}$ + gas → neutral pion-decay**
- **$CR_{electrons}$ + radiation fields → inverse Compton**
- **$CR_{electrons}$ + ambient protons → bremsstrahlung**

Starburst Galaxies





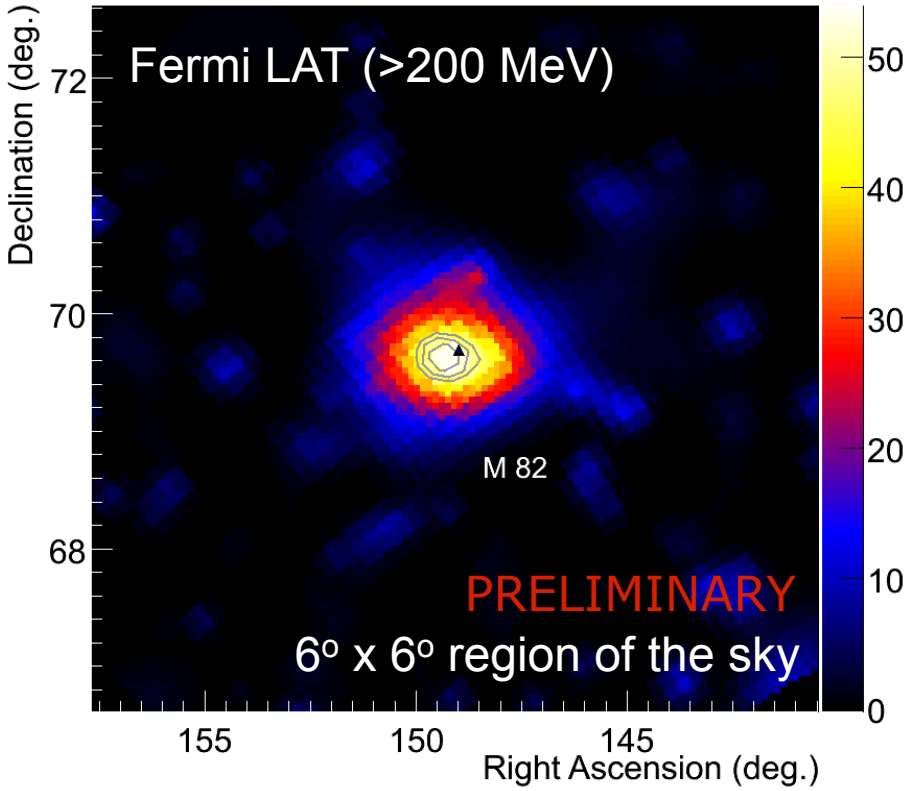
- **Starburst galaxies distinguished by regions of rapid star formation, 10-1000 × Milky Way rate**
  - **Correspondingly high supernovae rates**
  - **Dense clumps of molecular gas**
  - **Highly luminous at infrared wavelengths, radio correlation**
- **M82 and NGC 253**
  - **Two closest starburst galaxies (~3 Mpc)**
  - **Edge-on viewing angles**
  - **Small (~100 pc scale) starburst regions**
  - **Star formation rate ~10 × Milky Way rate**
  - **Lack active nuclei**
  - **Extensively studied in multiple wavebands, detailed modeling/predictions**

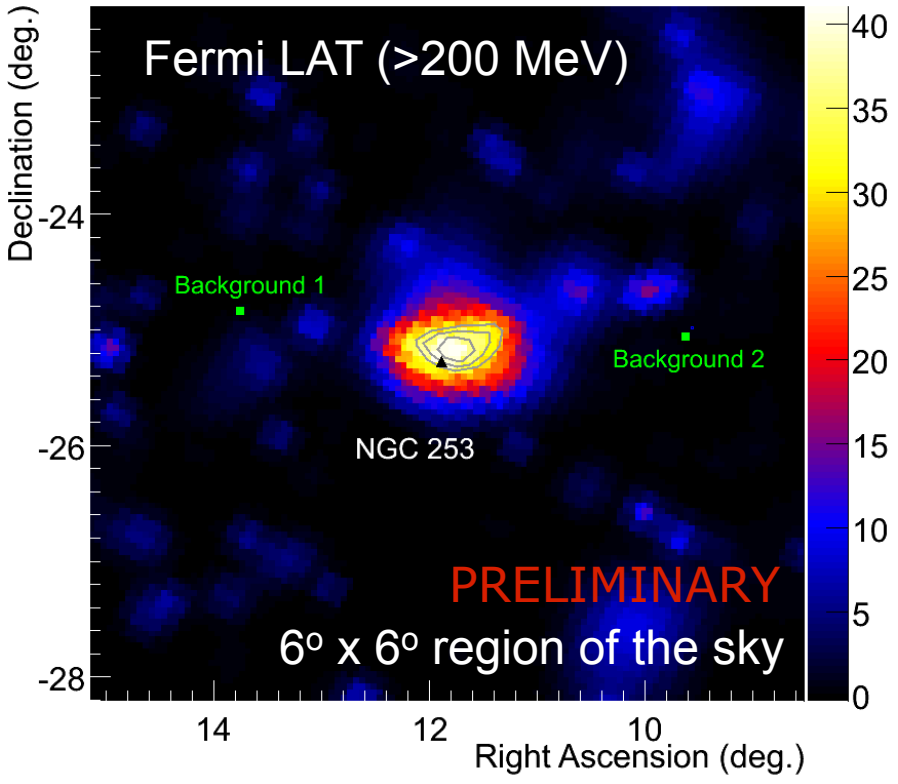
LAT Observations

- **Observation periods**
  - **11 months (August 2008 to July 2009)**
  - **Exclude time periods when Earth limb enters field of view (rocking angle cut at 43°)**
- **Event selection**
  - **Energy > 200 MeV**
  - **Diffuse class (cosmic-ray background contamination < 10 %)**
  - **Zenith angle < 105°**
  - **Post launch instrument response functions (P6_V3)**
- **Model the region**
  - **10° radius region of interest**
  - **Galactic diffuse (template / hybrid / ring) + isotropic component**
  - **Include all significantly detected LAT sources within region of interest (1st year Catalog)**

Detection Significance Maps

Galactic diffuse, isotropic diffuse, and point sources subtracted





Test Statistic (TS) = -2 log(L_{source} - $L_{no\ source}$)

0.68, 0.95, 0.99 confidence level localization contours

Appear as LAT point sources, starburst regions unresolved

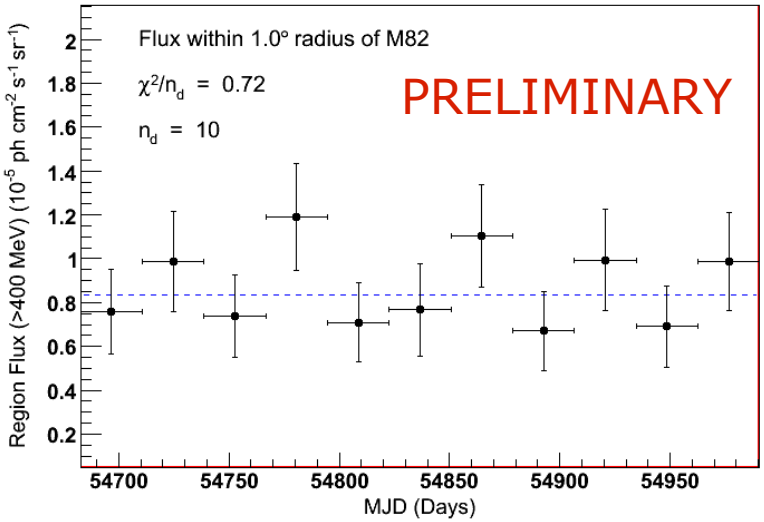
Point-like and steady emission

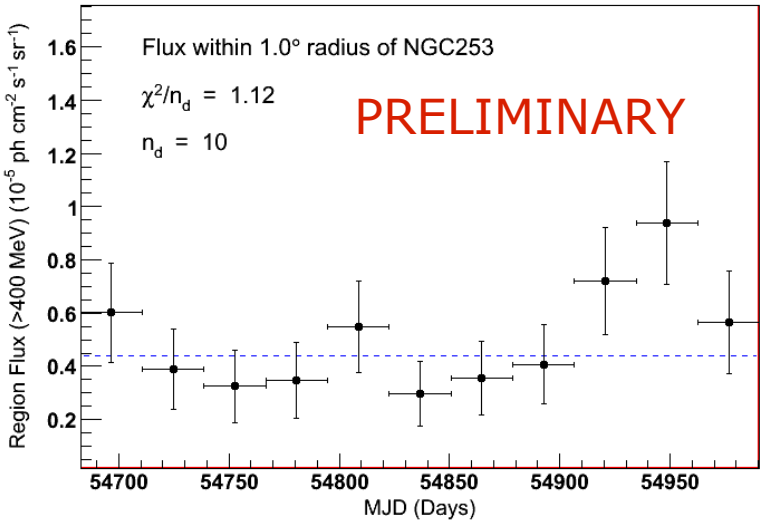
- **Spatial extension upper limits**
  - **Gaussian model, radius which contains 68 percent of flux (R_{68})**

	R_{68} 95% confidence upper limit	Disk extent (optical)
M82	**0.18°**	**0.19°**
NGC 253	**0.30°**	**0.45°**

- **Both sources consistent with constant flux level**

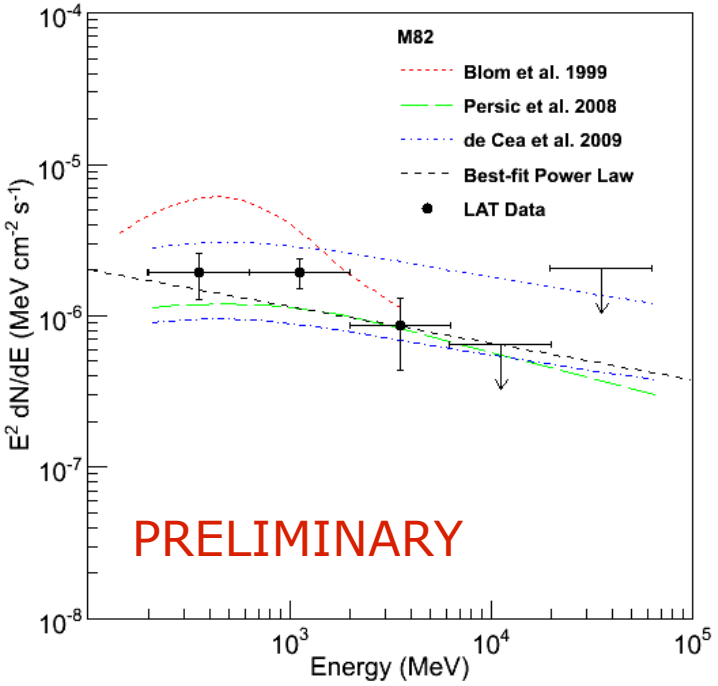
Monthly count of the photons in the direction of each source (Aug 08 - Jul 09)

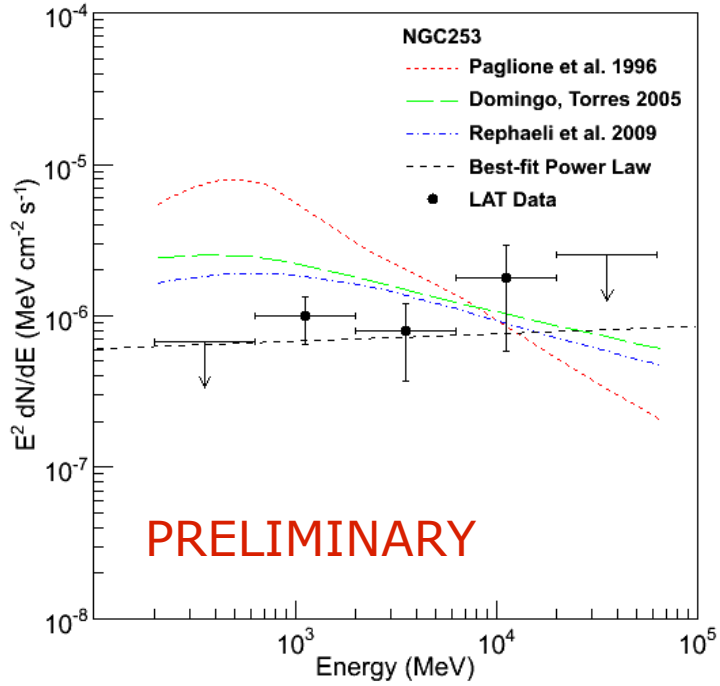




Spectra

Observed integral fluxes consistent with models of diffuse galactic gamma-ray emission, but data do not yet tightly constrain spectral shapes

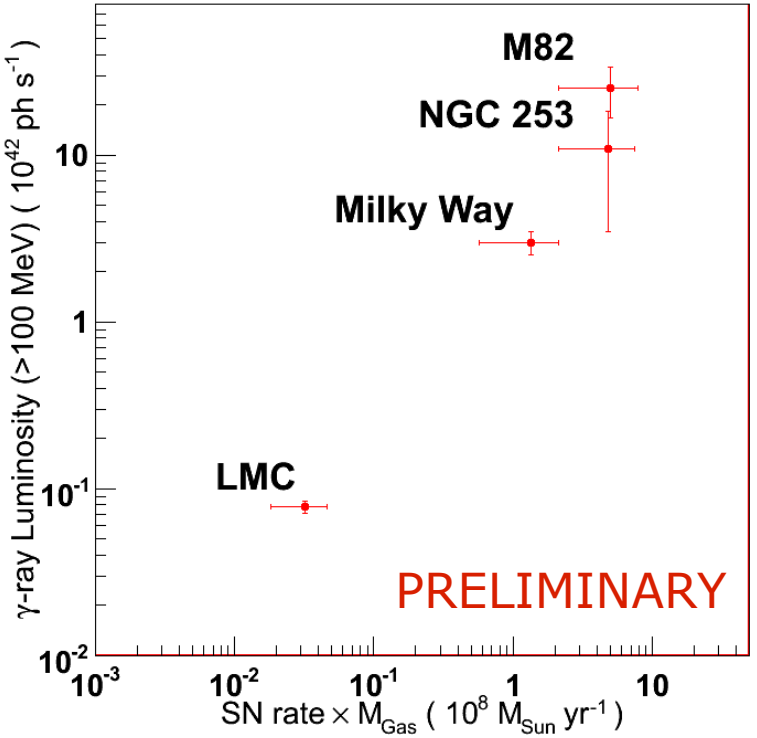




	Flux (>100 MeV) (10^{-8} ph cm^{-2} s^{-1})	Photon Index
M82	$1.6 \pm 0.5_{stat} \pm 0.3_{sys}$	$2.2 \pm 0.2_{stat} \pm 0.05_{sys}$
NGC 253	$0.6 \pm 0.4_{stat} \pm 0.4_{sys}$	$1.95 \pm 0.4stat \pm 0.05_{sys}$

Diffuse Gamma-ray Emission from Galaxies

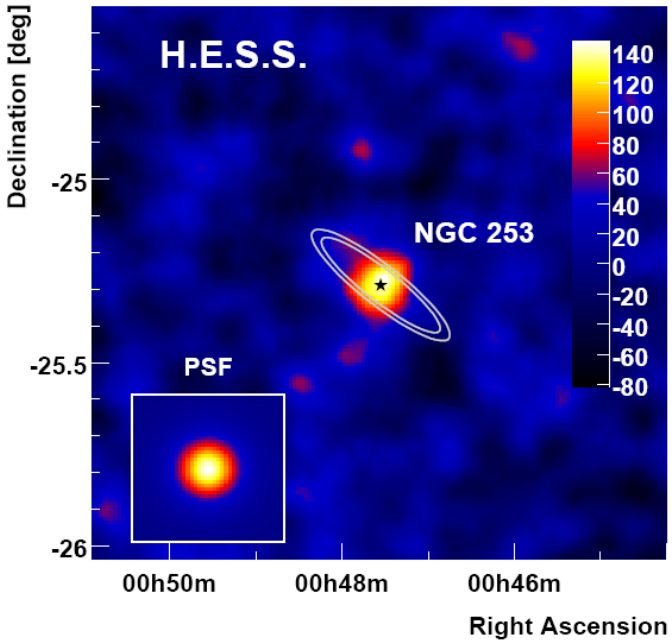
- **Enhanced cosmic-ray intensity required to explain the observed starburst gamma-ray fluxes**
- **Supernovae trace massive star formation**
  - **Supernovae remnants are probable source of galactic cosmic rays, although data not yet conclusive**
- **Beware!**
  - **Star-formation rate and gas density *non-uniform* throughout galaxies (Resolved LMC gamma-ray image)**
  - **Large uncertainty in distance measurements**



Compare gamma-ray luminosity and product of supernovae rate and gas mass in each galaxy

GeV to TeV Gamma-ray Connection

- TeV detections summer 2009
  - NGC 253 (H.E.S.S.)
  - M82 (VERITAS)
- Fermi LAT results combined with the TeV data will fill in spectral energy distributions
  - Discern spectral shapes with greater certainty, constrain emission mechanisms
- TeV observations confirm steady sources
- Starbursts unresolved, TeV emission predominantly in central region
- LAT all-sky survey can point out additional candidates for TeV observatories



Summary and Outlook

- **Two starburst galaxies, M82 and NGC 253, detected in 1st year of the Fermi mission**
  - **New class of gamma-ray sources**
  - **Diffuse emission arising from cosmic-ray interactions**
- **Searching for the source of galactic cosmic rays**
  - **Cosmic-ray intensity linked to massive star formation**
- **Ongoing Fermi LAT all-sky survey will look for additional starbursts and other star-forming galaxies**
  - **Normal star-forming galaxies are much more common than active galaxies but most often are fainter and unresolved**