Fermi Gamma-ray Space Telescope

Gamma-ray emission from CR-ISM interactions in star-forming galaxies

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Introduction

Outline of the talk

- Population study of star-forming galaxies in the GeV-TeV
- What has been achieved so far ?
- What will come out soon ?
- Perspectives for that research area

A new dimension in CR studies

Previously, in CR experimental physics (< PeV)

- Local particle measurements (p,$e^{\pm}$,B/C,^{10}Be/^{9}Be,…)
- Milky Way diffuse emission (MHz → TeV)
- Accelerator studies (SNRs, PWNe,..)
- Radio synchrotron from CRe in external systems

CRe: CR leptons
CRp: CR hadrons

Up to Fermi, little evidence on galactic CRp outside the MW

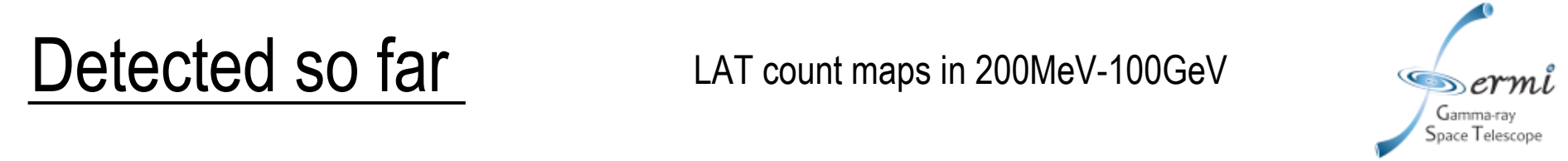
- Only LMC detected by CGRO/EGRET but hardly resolved
- Importance of SMC non-detection: CRs are not metagalactic !

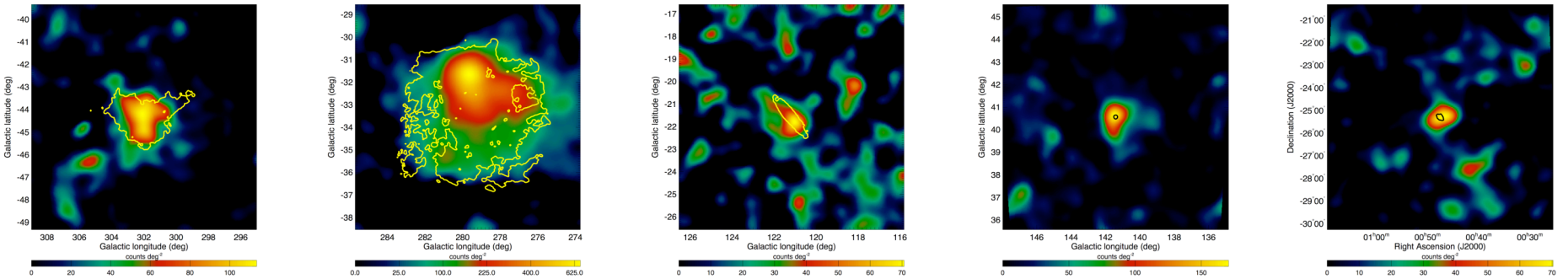
With Fermi, now possible to study CRp/CRe in other galactic systems

- Morphology: CR distribution (source, propagation)
- Photometry: CR density (injection rate, confinement)
- Spectrometry: CR spectrum (transport processes)
- Population study: Effect of global properties
- Source and transport aspects closely connected

Detected so far

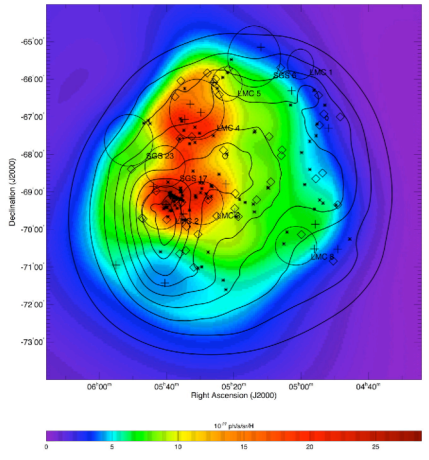
LAT count maps in 200MeV-100GeV





Lessons learned

- Strong correlation of γ-rays with massive stars in LMC
- Suggested short diffusion/penetration length from LMC
- Underdensity of CRs in SMC/LMC/M31 (wrt local)
- Overdensity of CRs in M82/NGC253 (wrt local)



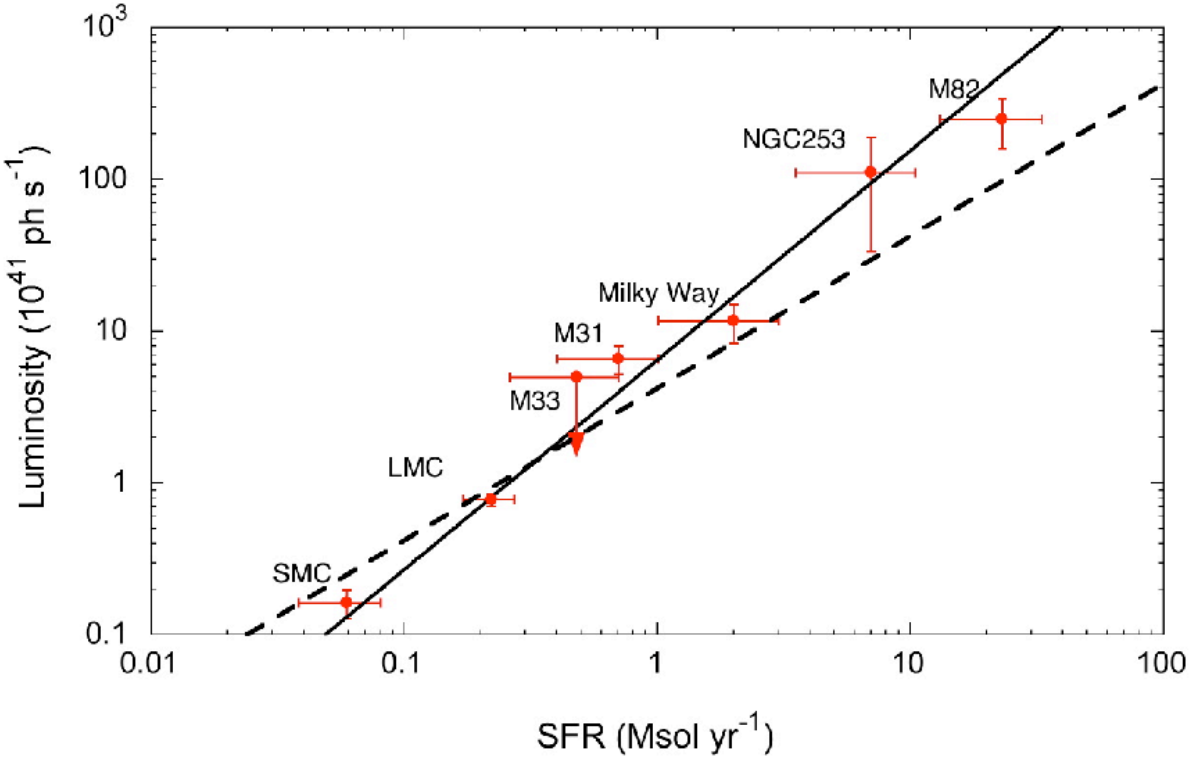
LMC emissivity map

Detected so far

Correlation L_γ-SFR

- Power-law relation to Local Group objects also holds for starbursts (slope 1.4 ±0.3)
- Surprisingly close to linear for widely-differing galaxies
- If robust, M33 to be detected within ~2 yrs

Notes:
MW point from GALPROP runs
SFRs from literature screening
Luminosity >100MeV



Investigate a larger sample to confirm this !

Extended sample

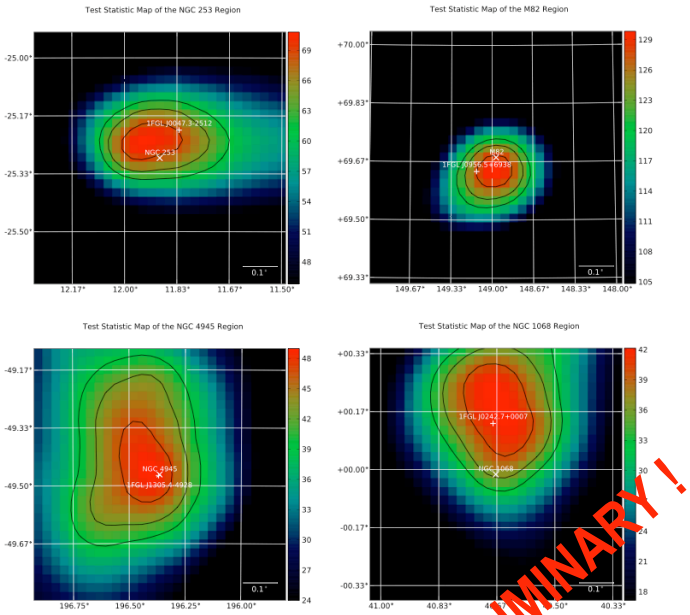
Sample selection

- From HCN line survey (tracer of dense H_2 hence SFR hence CR injection)
- 64 star-forming galaxies beyond Local Group
- 22 LIRGS $L_{8\text{-}1000\mu m}>10^{11}\ L_{\odot}$, 9 ULIRGS $L_{8\text{-}1000\mu m}>10^{12}\ L_{\odot}$ (MW has ~$10^{10}\ L_{\odot}$)
- 9 galaxies have AGN activity (from Swift/BAT 58-month catalog)
- Largest redshift is z~0.06

Extended sample

Analysis setup

- 24 months of low-background ‘diffuse’ class data
- 200MeV-100GeV in 27 logarithmic bins
- P6V11 IRFs, Science Tools 09-21-00
- 15°×15° regions of interest
- Binned maximum likelihood analyses
- Public isotropic and galactic diffuse models
- Preliminary 2FGL source list



Results

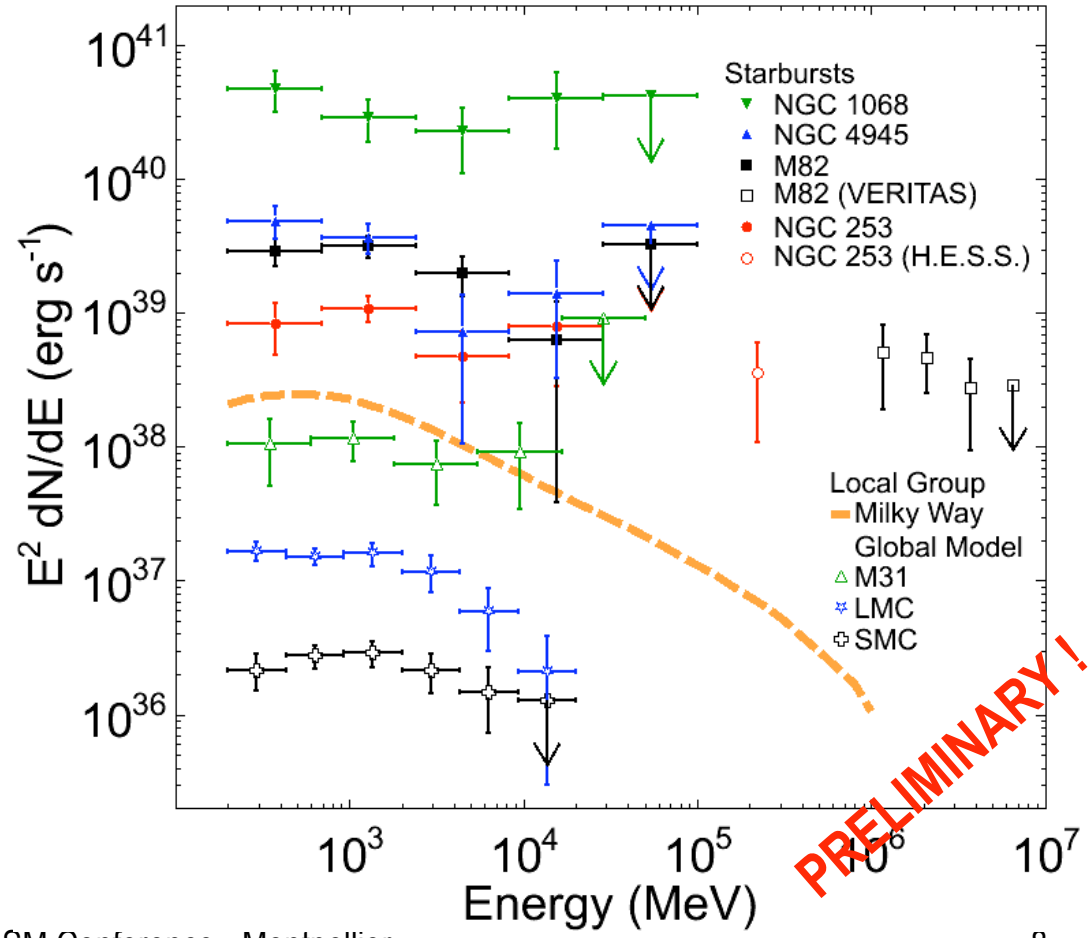
- 4 galaxies with TS>25: M82, NGC253, NGC1068, NGC4945
- All in 1FGL and addressed in 2 previous publications (Abdo-2010, Lenain-2010)
- No coincident blazar or radio sources
- No time variability over 29 months for 80-day bins
- NGC1068 and NGC4945 may include some degree of AGN contribution

Comparison of all spectra

Main points

- All quite flat in GeV range (indices 2.1-2.4)
- LAT data cannot distinguish between power-law and renormalised MW spectrum.
- Usefulness of TeV lever arm.
- GeV-TeV spectra of starbursts significantly harder than MW. Suggests different transport scenario (energy-independent process like calorimetry or advection that preserves CR injection spectrum).

Note: MW spectrum from typical GALPROP run

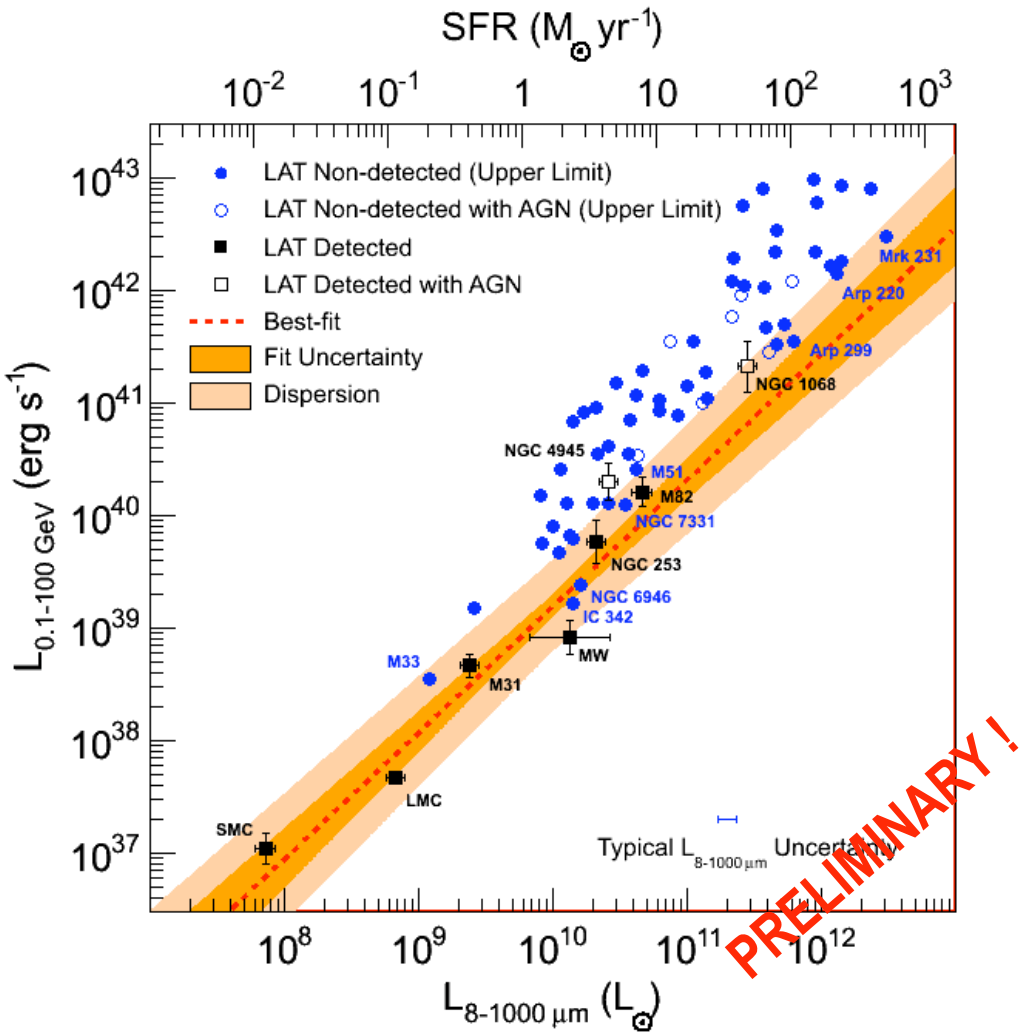


Multiwavelength luminosity comparison

Correlation L_{IR}-L_{γ} (also L_{RC}-L_{γ})

- Full sample: P-value of ~2.10^{-4}
- Excluding AGNs: P-value of ~2.10^{-3}
- Power-law index 1.0-1.2
- ULIRGS/LIRGS upper limits disfavor stronger non-linearity

Notes: Significance of correlation based on Kendall-tau rank correlation test and simulated uncorrelated data sets, taking into account errors on distance measurements of up to 20%.



Multiwavelength luminosity comparison

Towards an understanding: hadronic aspects

- Some correlation with SFR expected (traces CR injection rate)
- Linear dependence expected for CRp calorimeter
- but MW-like galaxies are not, and starbursts neither apparently
- Slight increase of calorimetric efficiency across the galaxy range ?
- Transition from diffusion-dominated to convection-dominated ?

Towards an understanding: leptonic aspects

- CRe can account for up to 50% of the MW luminosity >100MeV
- … and CRe calorimetry is thought to be achieved for most galaxies
- In starbursts, secondaries may dominate over primaries
- … but in pp interactions, more energy goes to γ-rays than to leptons
- Relative contributions of synchrotron/IC across galaxy range ?

Other considerations

- Contribution of discrete sources
- Dark matter contribution

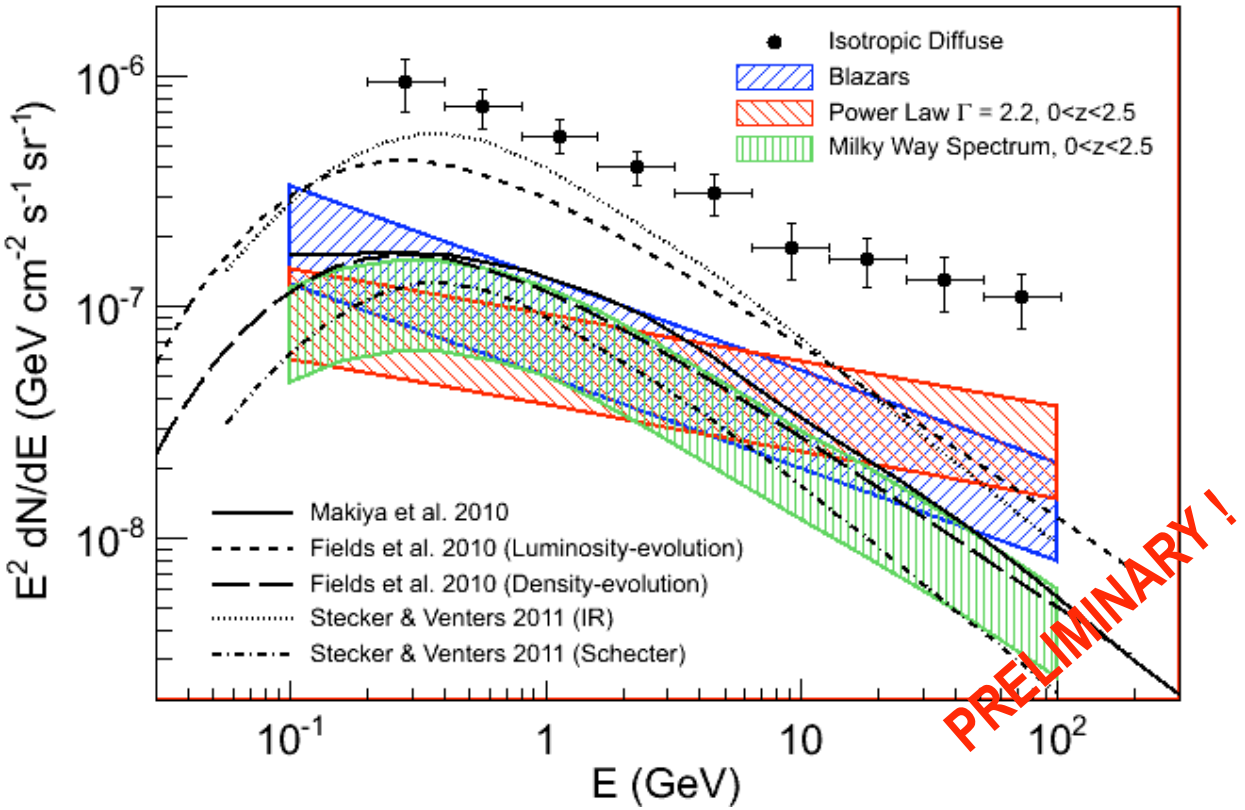
Contribution to extragalactic background

Approach

- Relationship L_γ-L_{IR} identified in this work
- IR luminosity function from *Spitzer* up to z~2.5(Rodighiero-2010)
- Integration over luminosities and redshifts (for 2 bracketing spectral shapes in γ-rays)

Star-forming galaxies can contribute up to 25% of EGB in 0.1-100GeV (in photon intensity)

Room for other contributions than unresolved blazars and star-forming galaxies



Summary / Perspectives

Up to now…

- Fermi and modern ACTs have created a new research area in CR astrophysics
- Star-forming galaxies are a new class of GeV-TeV objects with 6-7 detections
- Interesting correlation L_γ-L_{IR} (or SFR)
- Possible substantial contribution to EGB

And beyond…

- TeV observations for better spectral characterisation (CTA)
- Modelling works to explore the L_γ-L_{IR} correlation (ex: Lacki et al.)
- Radio observations will help (halos, magnetic fields)
- Connection with the well-studied FIR-RC correlation