Review of Diffuse Gamma-Ray Emission from Normal Galaxies

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Working Group 1 – LAT Collaboration Meeting

October 23-25, 2002, NASA/GSFC

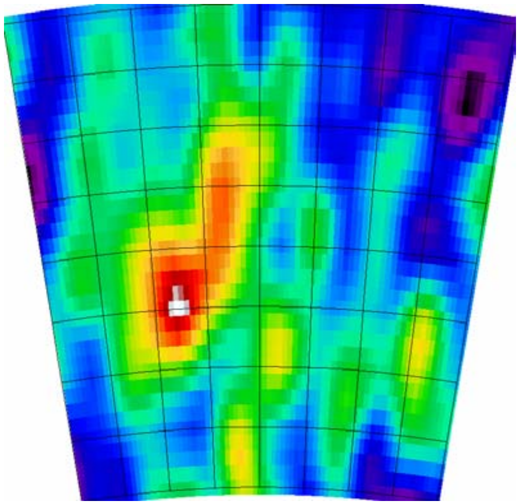
Outline

- Observational status (EGRET results)
- Predictions of fluxes (including for starburst galaxies)
  - Milky Way as a reference
  - Approaches that have been applied for estimating gamma-ray fluxes
    - Cosmic rays, gas content, and interstellar radiation field content
- Expectations for the LAT
  - Resolved emission from LMC & M31
  - Including estimated contribution to the isotropic extragalactic emission
- Bibliography

Observational Status

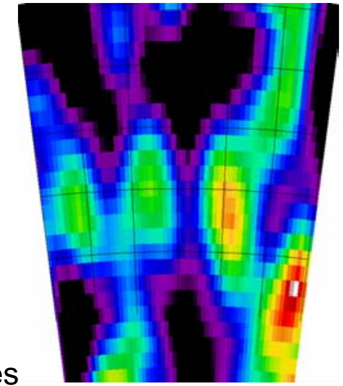
- Plausible candidates were Local Group galaxies + nearest starburst galaxies
- Large Magellanic Cloud (55 kpc distant) was the only external galaxy detected by EGRET in the light of its diffuse gamma-ray emission (Sreekumar et al. 1992)
- Upper limit for the Small Magellanic Cloud (64 kpc; Sreekumar et al. 1993), with flux several times less than would have if cosmic-ray density were the same as in the MW or LMC (see later) allowed conclusion that cosmic rays are not universal
- Andromeda (M31; 690 kpc) upper limit
- Starburst galaxies (few Mpc) also yielded upper limits

LMC



$(1.9 \pm 0.4) \times 10^{-7}$ cm^{-2} s^{-1}

SMC



>100 MeV EGRET
Intensity scaling is the same in the two images

$<0.5 \times 10^{-7}$ cm^{-2} s^{-1}

Predictions of Gamma-Ray Fluxes

- Milky Way for perspective
  - Diffuse flux >100 MeV is 2.3×10^{42} γ s^{-1} (Hunter, priv. comm., evaluated from the gas, interstellar radiation field, & cosmic-ray model used to calculate the EGRET diffuse emission model)
  - Not all that significant relative to the rest of the EM spectrum

Band	Luminosity (erg s^{-1})
>100 MeV	4×10^{39} (1×10^{6} $L_{☼}$)
Radio	3×10^{38}
IR	3×10^{41}
Optical	3×10^{43}
X-ray	10^{39-40}

Zombeck, M. V. 1990, Handbook of Astronomy and Astrophysics, Second Edition (Cambridge, UK: Cambridge University Press).

  - Note that diffuse gamma-ray emission from the Milky Way >> the luminosity of its point sources
    - Typical luminosity ~ (1–15) × 10^{35} erg s^{-1} (isotropic) for a Galactic point source (characteristic distance 1–6 kpc), Mukherjee et al. (1995)
    - Blom et al. (1999) find similar result, ~2% contribution, based on radio pulsar population and typical gamma-ray emission characteristics

Predictions of Fluxes (2)

- Modelling gamma-ray production (eqn. after Akyuz et al. 1991)

$$F(>100\mathrm{MeV}) = q_\gamma^{MW}(>100\mathrm{MeV}) \frac{M}{m_H} \frac{\rho_{cr}}{\rho_{cr}^{MW}} \frac{1}{4\pi d^2}$$

  – Not profound, but reflection that have too many degrees of freedom
- Cosmic-ray densities
  – Ozel & Fichtel (1988) – cosmic-ray density varies on large scales (scales of arms), cosmic-ray density scale factors estimated on a galaxy-by-galaxy basis (for LMC, SMC, M31)
  – Pohl (1994) – prediction of cosmic-ray densities by ‘fractional calorimeter’ effect; in steady state the losses in the various gamma-ray production channels can be related to the CR densities; detailed modeling for spiral galaxies
  – Blom et al. (1999) – CR modelling normalized to radio continuum spectra
  – Pavlidou & Fields (2001) – assume cosmic-ray density is that of the Milky Way scaled by relative SNR rates

Predictions of Fluxes (3)

- **Gas contents**
  - Standard 21-cm line of H I and 115 GHz line of CO
  - Intensity of CO line is assumed to be proportional to column density of H_2
  - The proportionality is not known well in external galaxies.
  - Uncertainty introduced in overall mass estimate is probably small, owing to dominance of atomic hydrogen, except for starburst galaxies
- **Interstellar radiation field**
  - Cosmic microwave background
  - Infrared and optical-UV densities considered in varying level of detail

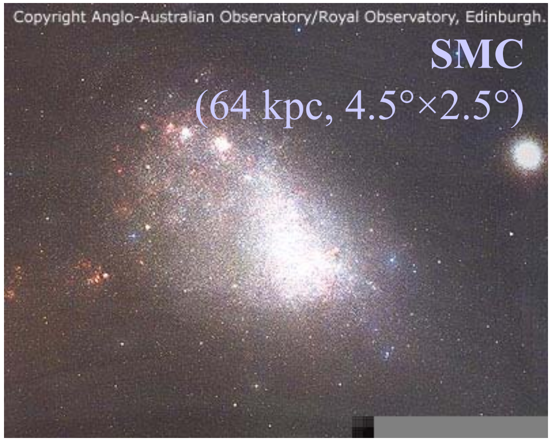
Predictions of Fluxes (4)

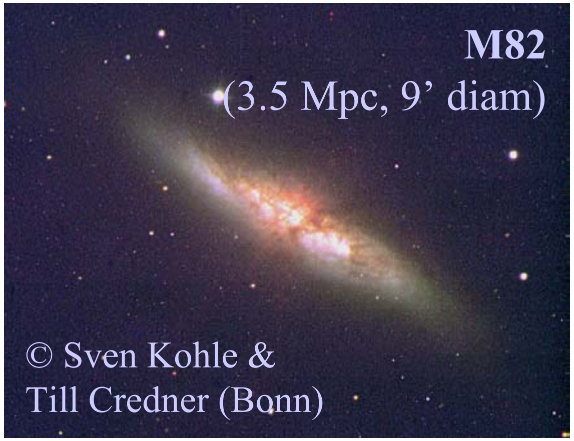
- **The short list of local group and starburst galaxies that the LAT may be expected to detect**

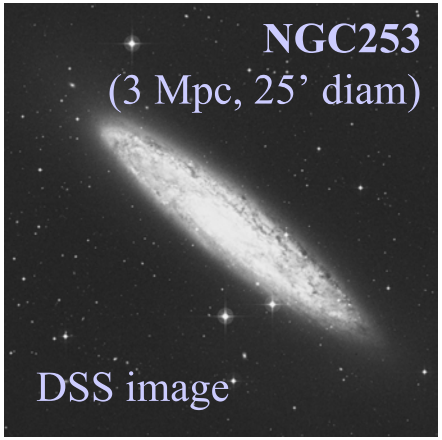
Galaxy	Ref.	EGRET flux (10^{-8} cm^{-2} s^{-1}, >100 MeV)*	Pred. fluxes (10^{-8} cm^{-2} s^{-1}, >100 MeV)	Will LAT Measure Spectrum?	Will LAT Spatially Resolve?
LMC	6	19 + 4		y	y
SMC	3,4,6	<5	25, 1.7	y	n?
M31	2,3,4,5	<1.6	2, 0.9, 1.0	y	~y
M82	1	<4.4	1.4, 2, 1.7	n	n
NGC253	2	<3.4	1.6	n	n

*Upper limits are 2σ

1. Akyuz et al. (1991); 2. Blom et al. (1999); 3. Ozel & Fichtel (1988); 4. Pavlidou & Fields (2000); 5. Pohl (1994); 6. Sreekumar et al. (1992); 7. Sreekumar et al. (1993)

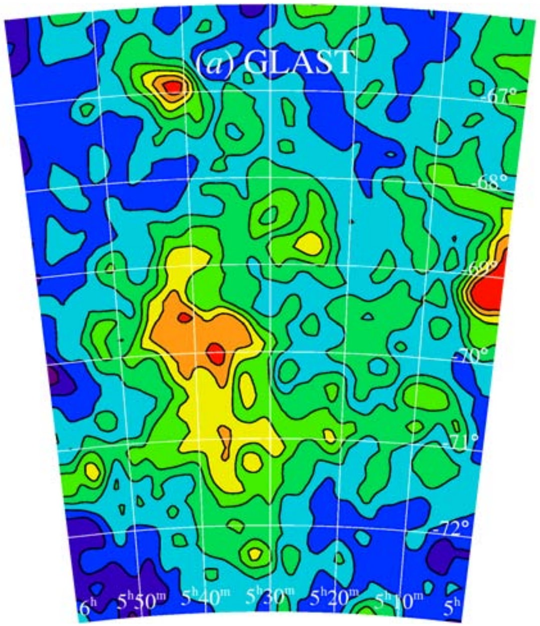




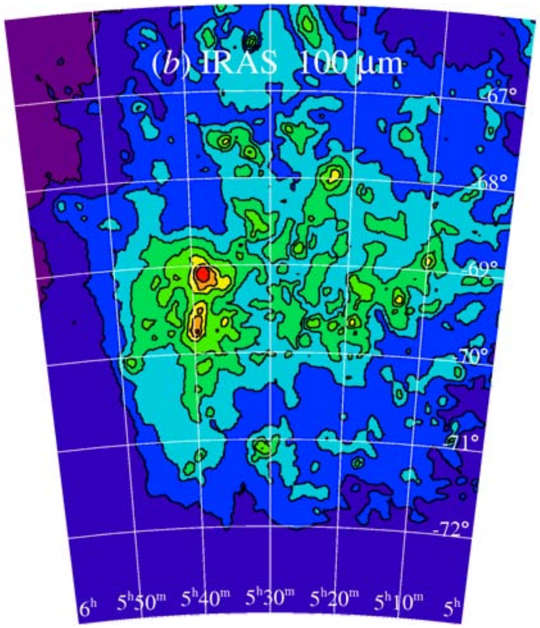


Expectations for LAT

- **LMC – Should be well resolved, suitable for (relatively) detailed modeling of cosmic rays**



Simulated >100 MeV map from LAT sky survey, based on LMC model by Sreekumar (priv. comm.) & including Galactic foreground and blazar background

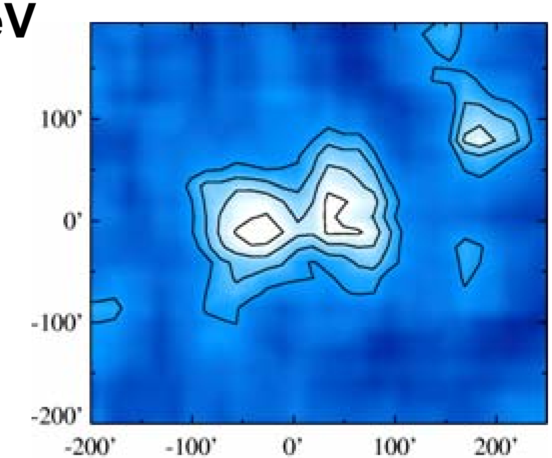


IRAS 100 μm intensity, largely re-radiated starlight from recently-formed massive stars embedded in dust clouds

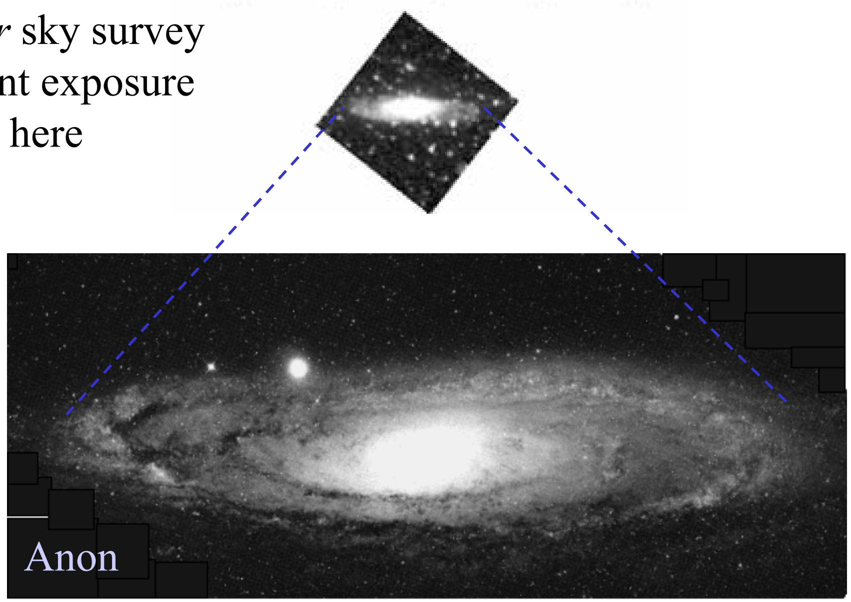
Expectations for LAT (2)

- **M31 – Strongly detected, but marginally resolved and then only at ~> 1 GeV**

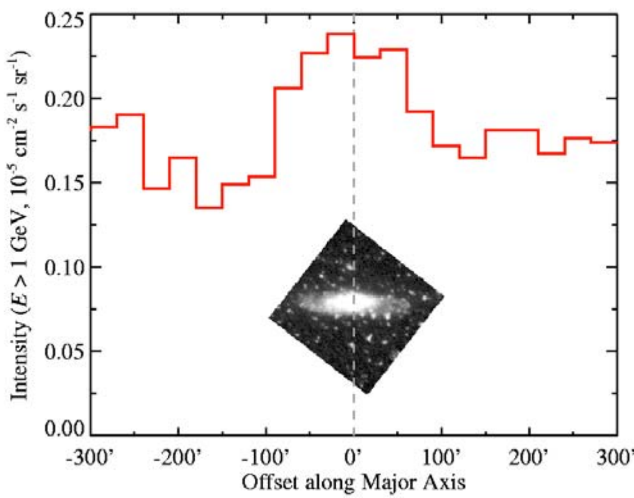
Simulated LAT intensity map (>1 GeV)



N.B. *5 yr* sky survey equivalent exposure assumed here



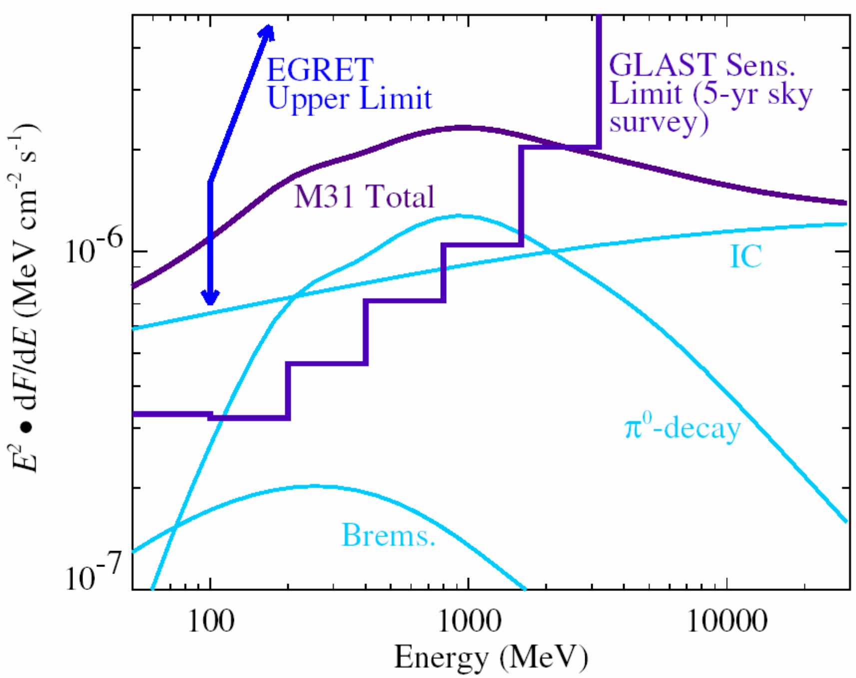
Profile along major axis (>1 GeV)



Expectations for LAT (3)

- **For M31, spectroscopy should at least better constrain models**

DON'T TAKE LITERALLY



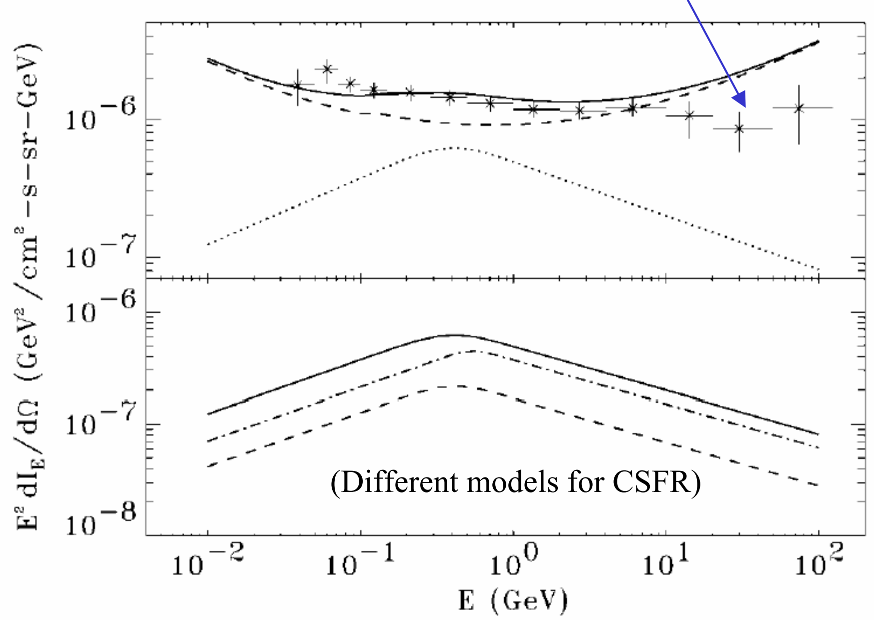
Strong et al. spectral components of Milky Way, *scaled* to predicted flux of M31

DON'T TAKE LITERALLY

Gamma-ray Background from Normal Galaxies

- **Concept: Their flux is not great, but there are a lot of them**
- **Pavlidou & Fields (2002) estimate the contribution to the isotropic spectrum by scaling the spectrum of the Milky Way by 'cosmic star formation rate' and evolving gas mass fraction with *z*, and taking care of the cosmology**
  - **The result depends too directly on their spectrum for the Milky Way, which itself looks a little suspicious.**
  - **The conclusion, however, is probably plausible: the contribution to the EGRB from normal galaxies is much less than for blazars, but at some energies (~850 MeV), the normal galaxy component might be ~1/3rd of the total isotropic intensity.**

Absorption against EBL?



Points: Sreekumar et al. (1998)
Dashed: Stecker & Salamon (1996) blazar contribution
Dotted: Pavlidou & Fields (2002) normal galaxies

Bibliography

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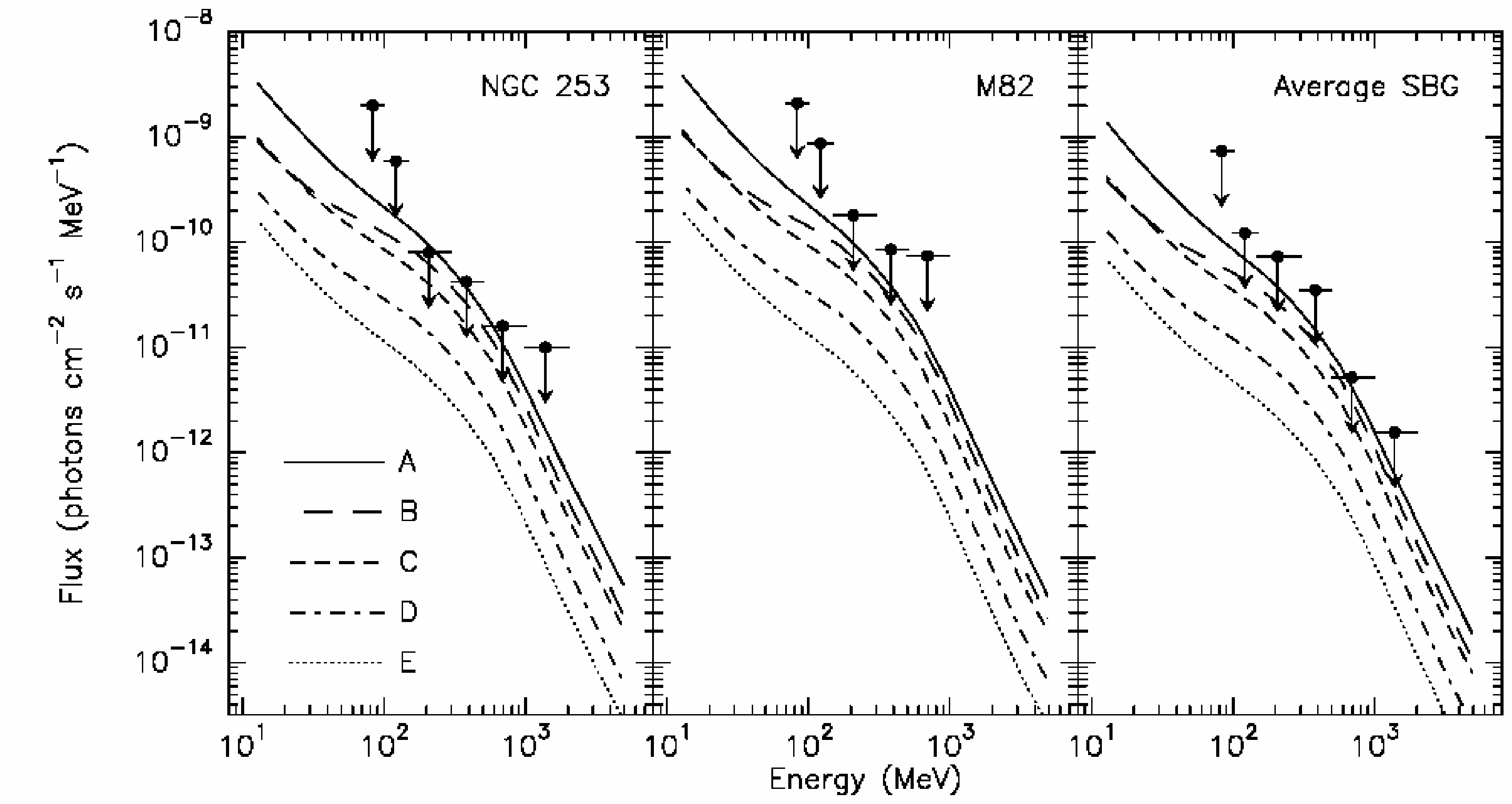
Backup slides follow

Starburst Galaxies



Blom et al. (1999)