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The *Fermi* gamma-ray sky: implications for cosmic-ray acceleration and propagation

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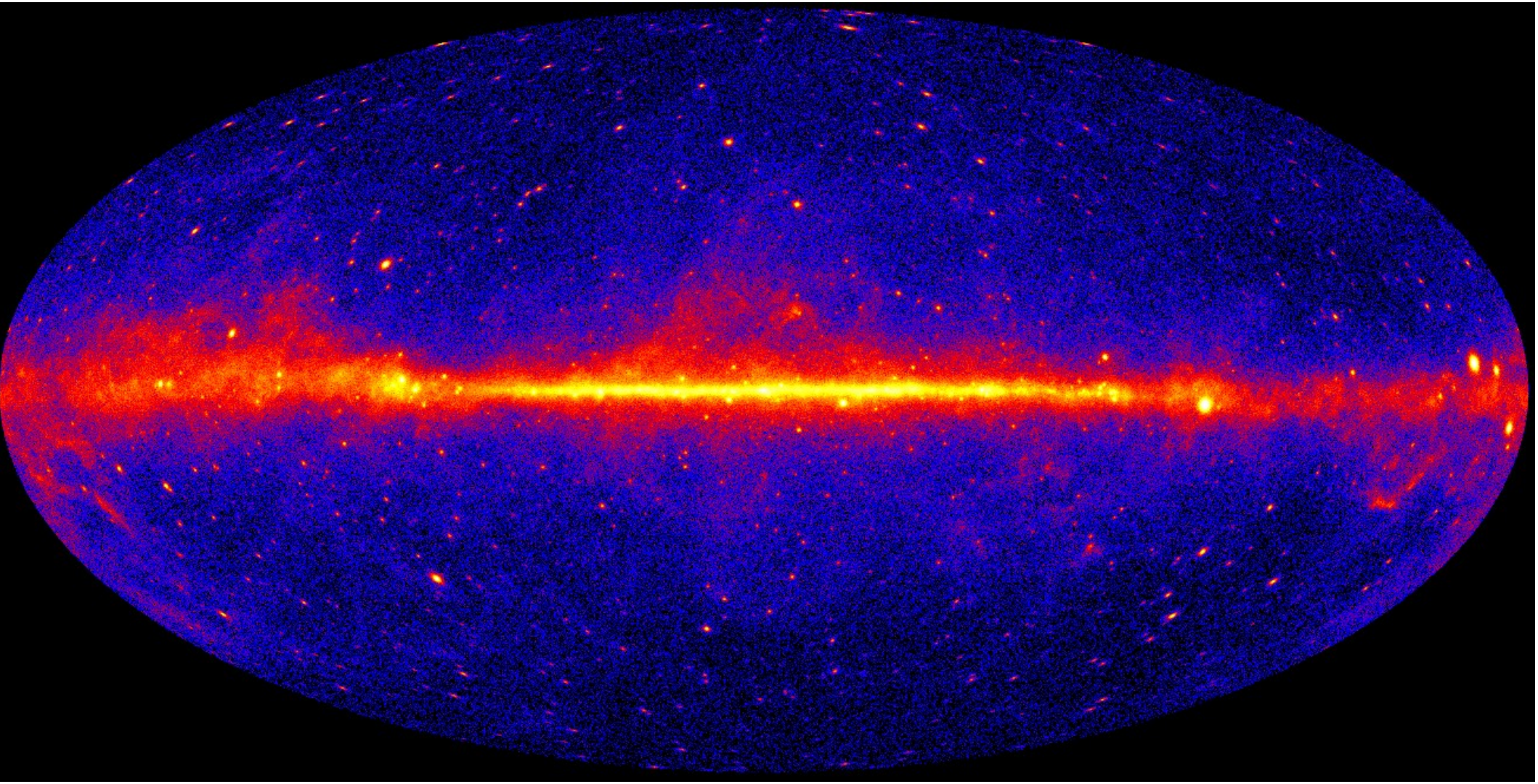
on behalf of the *Fermi* LAT Collaboration

1. The gamma-ray sky seen by the *Fermi* Large Area Telescope

The *Fermi* gamma-ray sky

Two years of LAT data, photons with energies > 1 GeV



nonthermal → high-energy particles

Diffuse emission

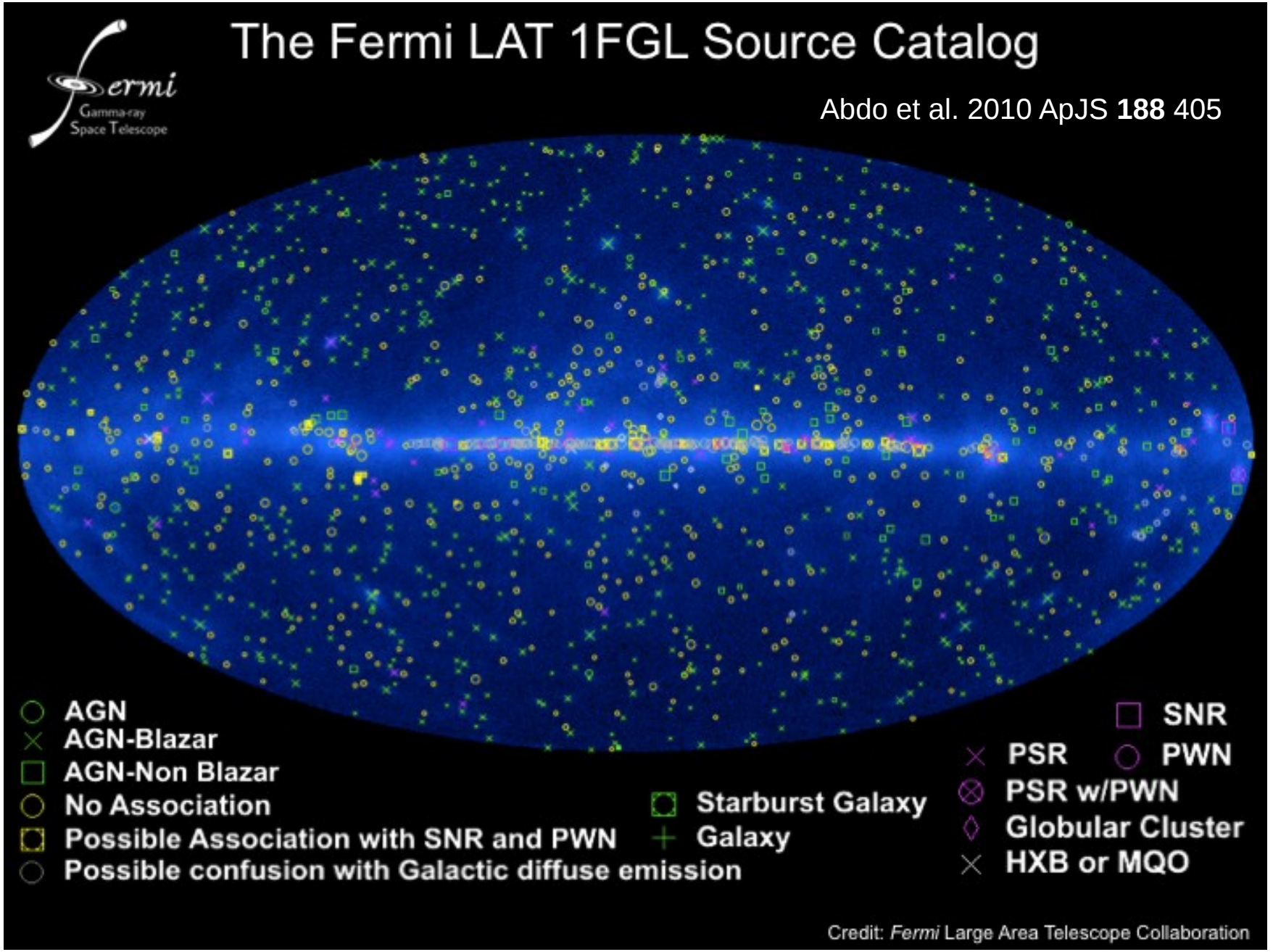
unresolved sources

exotic processes???

Galactic interstellar emission: interactions of cosmic rays (CRs) with interstellar gas/radiation fields

isotropic (extragalactic?) gamma-ray emission + residual background from misclassified cosmic rays

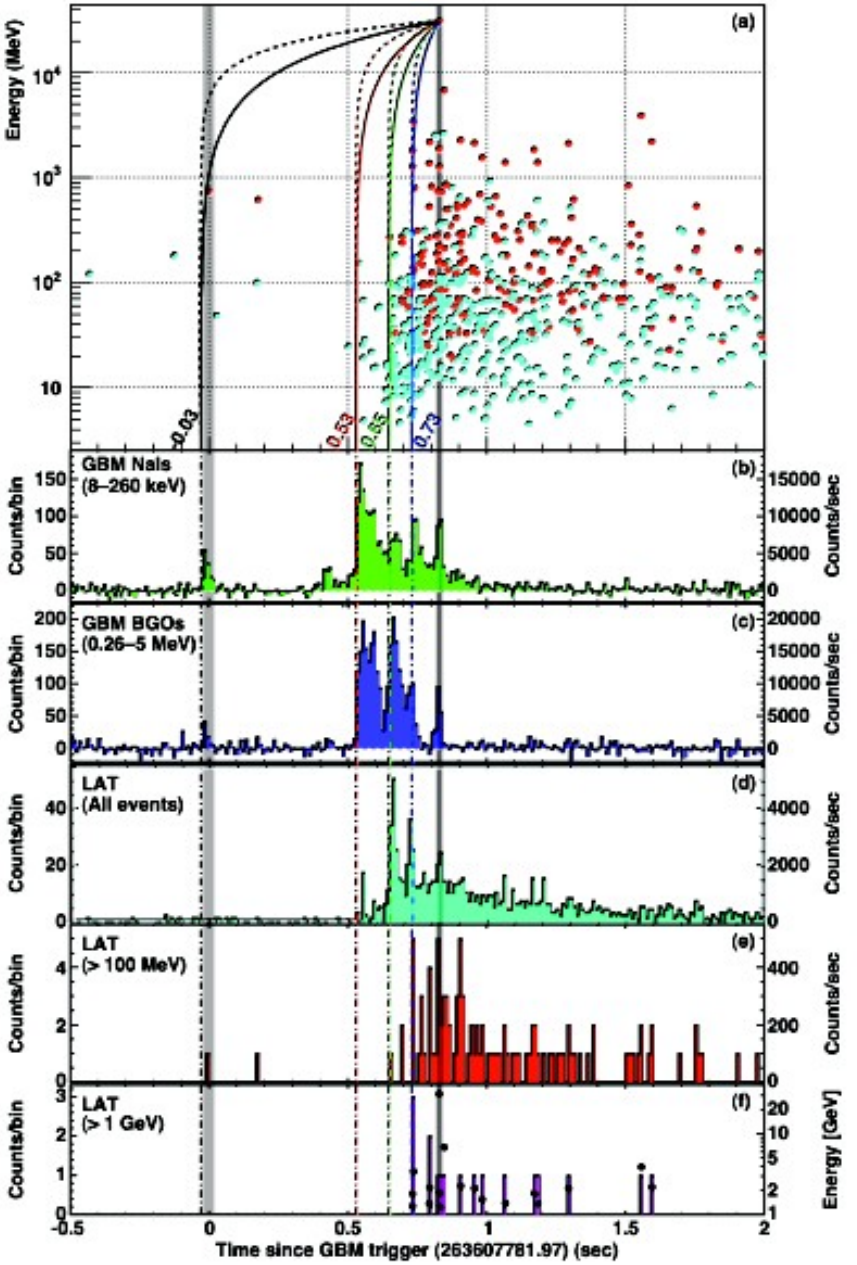
Gamma-ray sources



2. Overview of high-energy gamma-ray sources

Gamma-ray bursts

- both long (> 2 s, core-collapse supernovae) and short (< 2 s, compact object merging)
- emission mechanism: leptonic or hadronic?
- 31 GeV photon from GRB 090510 (z=0.903)
  - bulk Lorentz factor > 1000
  - limit on breaking of Lorentz invariance: $M > 1.19\ M_{Planck}$



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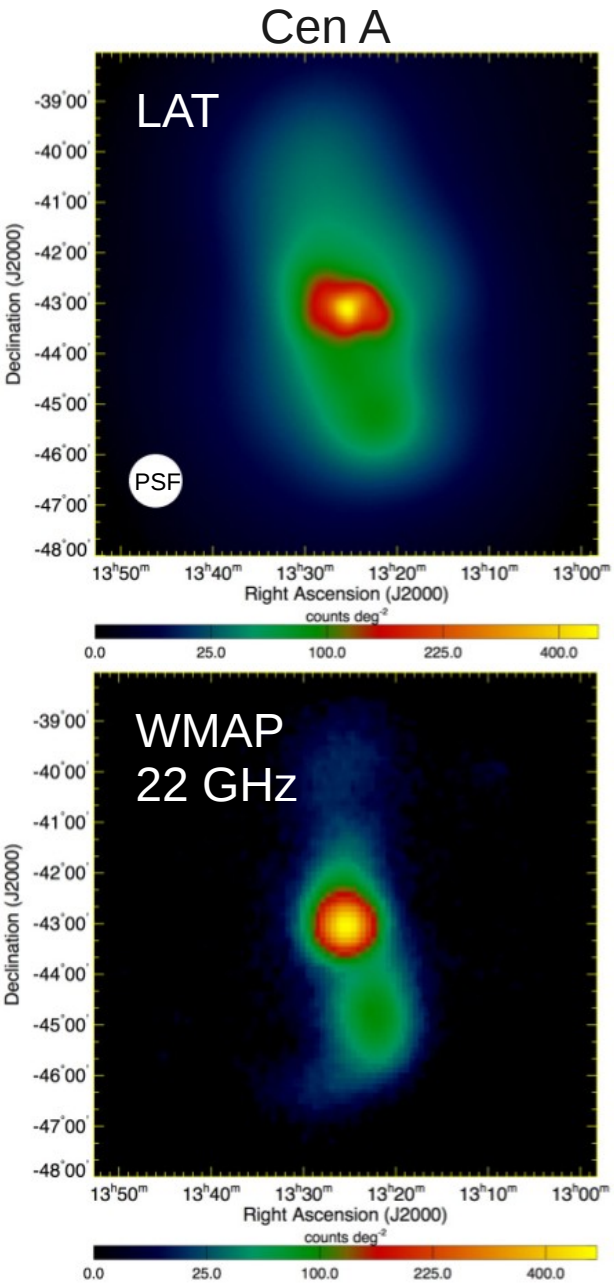
Active Galactic Nuclei

- accretion on super-massive black hole
- first non power-law spectra: internal opacity or cutoff of accelerated particles?
- Centaurus A: first AGN resolved in gammas
- 3C 279: correlated gamma-ray flare and change in optical polarization → emission at > 10^5 gravitational radii from BH
- luminosity function → < 30% of extragalactic background made by unresolved AGNs
- open questions:
  - radiation mechanism: hadronic vs leptonic?
  - emission region and beam formation



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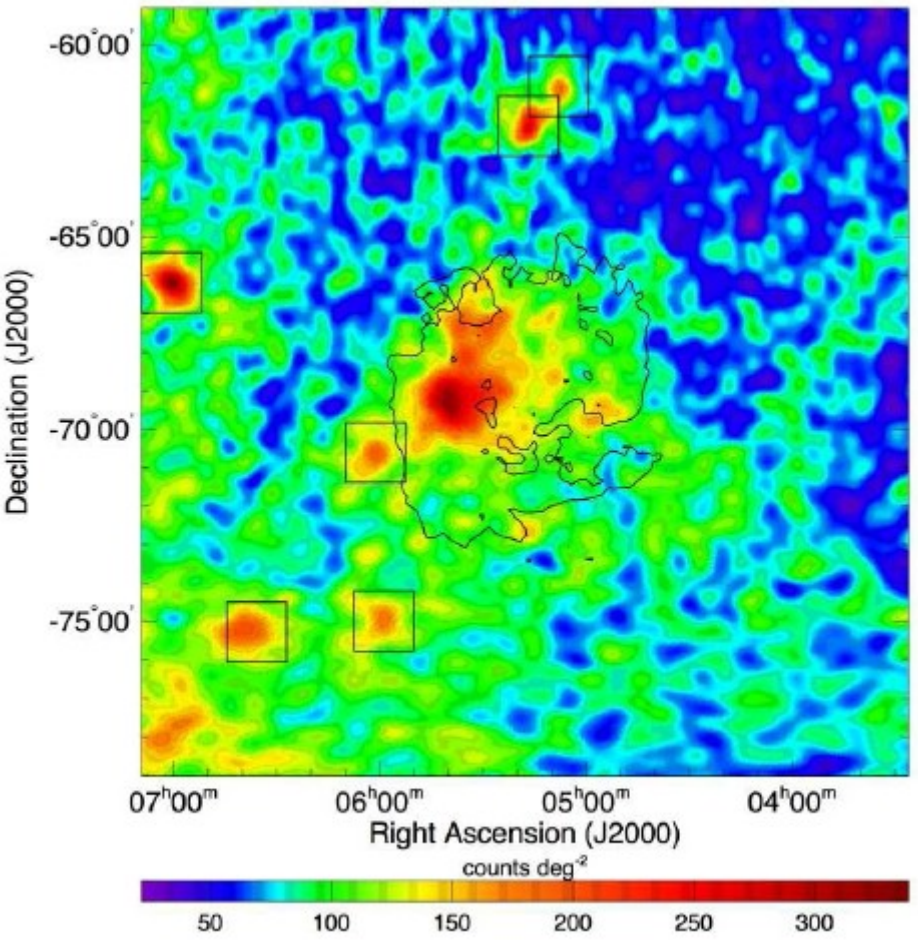
External galaxies (non AGN)

- CR interactions in interstellar space, both nuclei and electrons
- from 1 to 5 detected so far
- local group (LMC,SMC,M31) or nearby starbusts (M82,NGC 253)
- the closest (LMC,SMC) are resolved
  → CR acceleration/propagation



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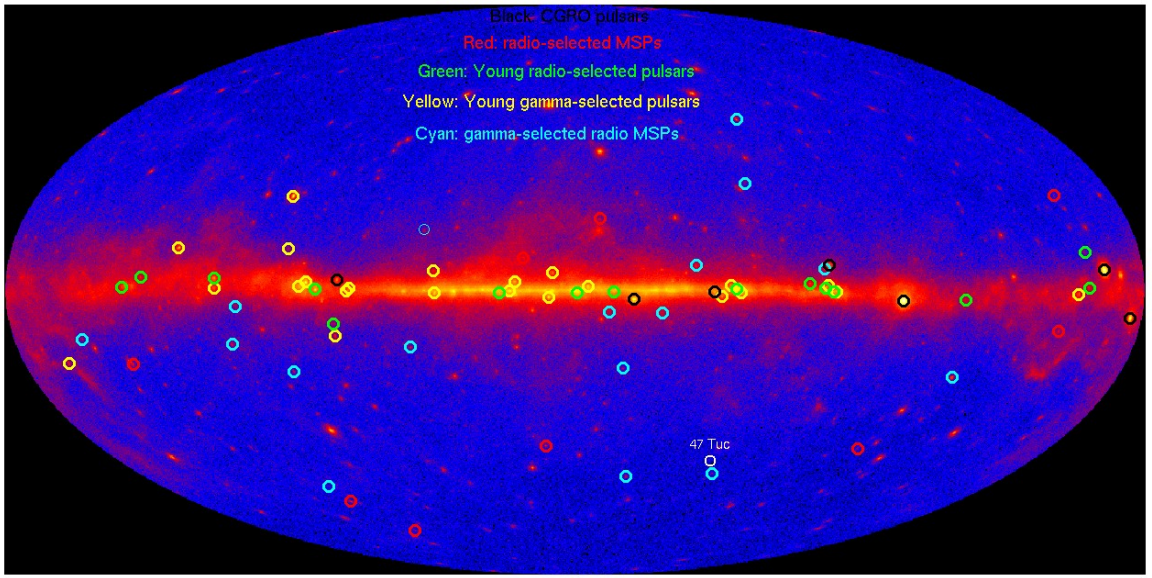
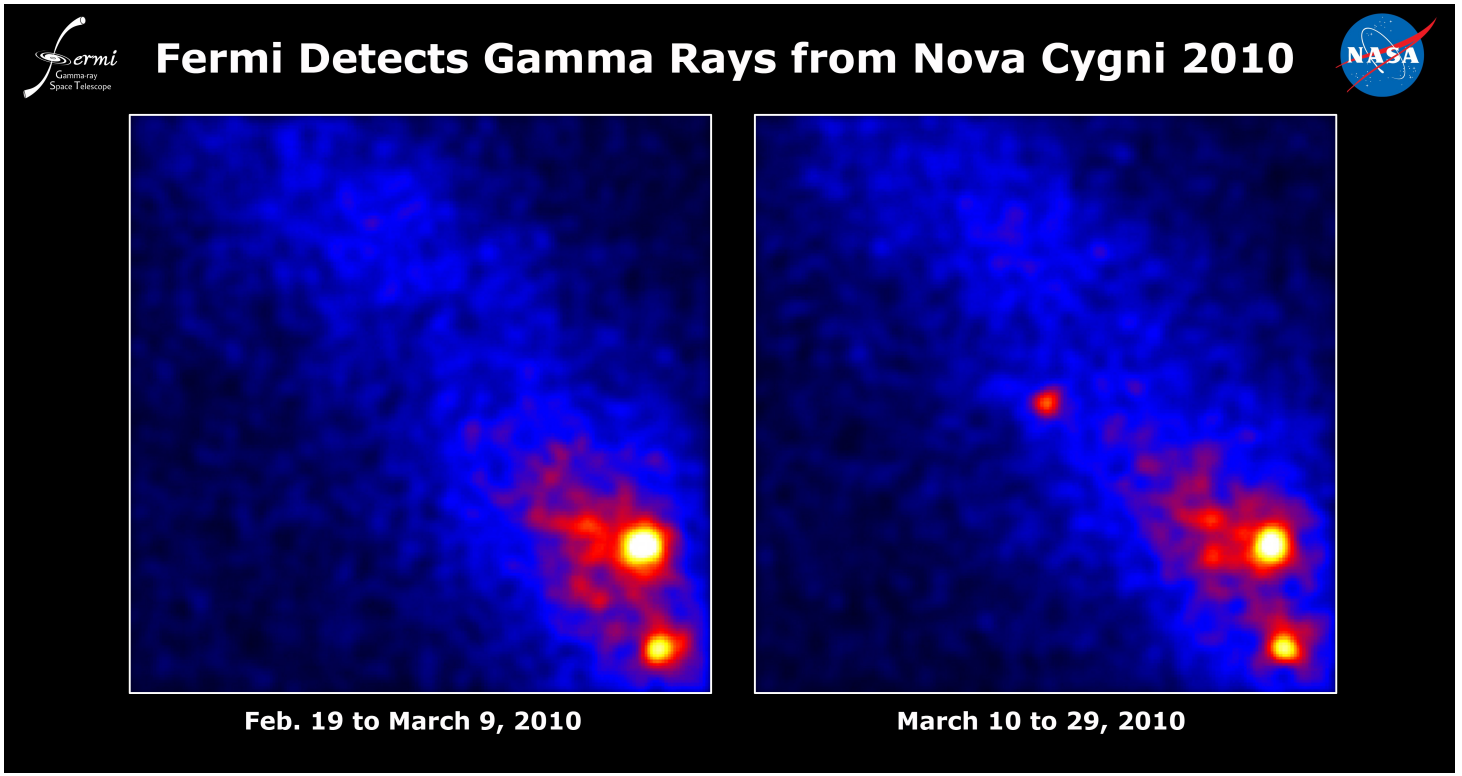
Pulsars and pulsar winds

- PSR: rotating neutron stars with high magnetic fields
  - from 6 to > 70, including several gamma selected and ms
  - particle acceleration at high B
  - contribution to cosmic rays?
  - pulsar timing arrays → gravitational waves
- mechanical energy into PSR wind: particle acceleration at terminal shock
  - a few detected
- gamma-ray production mechanism is **leptonic**
- first variability detection from Crab Nebula:
  - synchrotron from PeV electrons within 17 light days → terminal shock



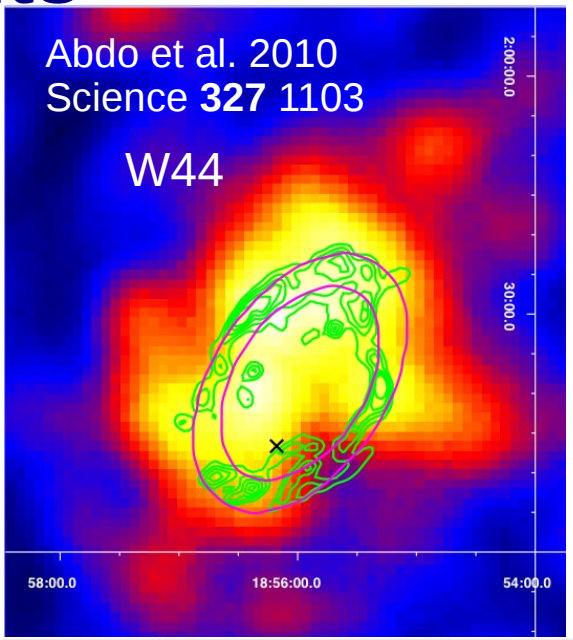
Binaries and Nova(e)

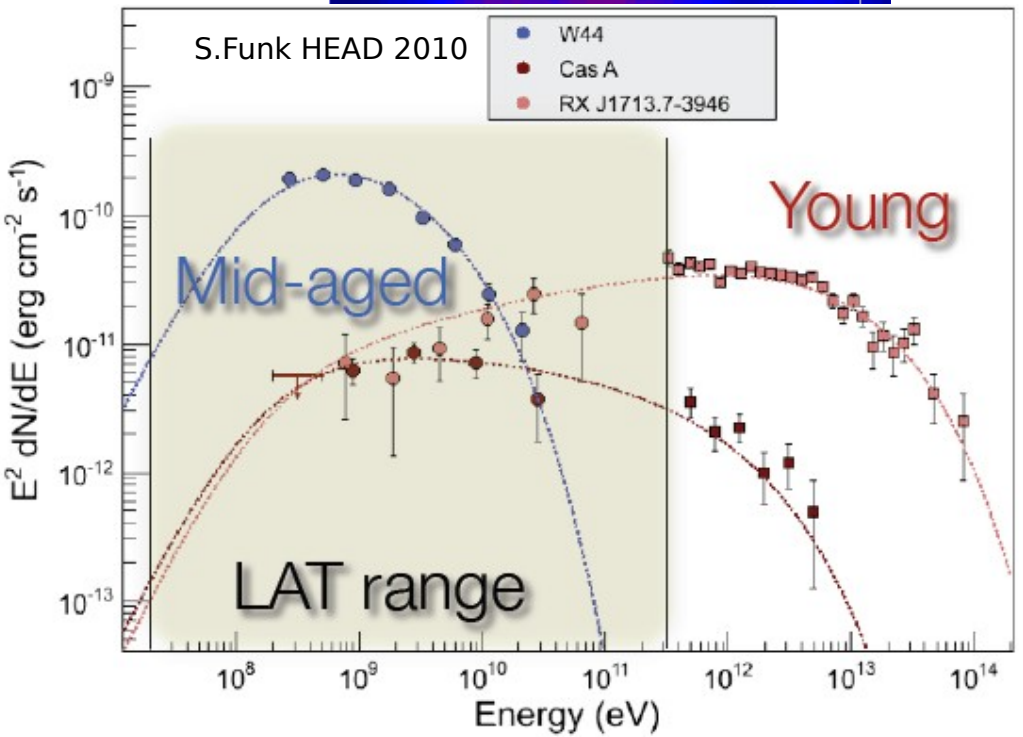
- high-mass binaries (n star or black hole+star) identified as Gev-TeV sources through orbital modulation
  - emission mechanism unclear, most GeV spectra similar to PSR
- unexpected discovery of gamma-rays from a nova (white dwarf+red giant) → supernova little cousin
  - hadronic interactions of shock-accelerated ions?



Supernova remnants

- high-energy particles accelerated by collisionless shock acceleration
  - they do for electrons
  - not so obvious (yet) for ions
- SNRs resolved → association between gamma rays and shock region
- most associated with molecular clouds
- middle-aged SNRs (> 10^4 years):
  - show spectral break at few GeV
  - many favor hadronic scenario

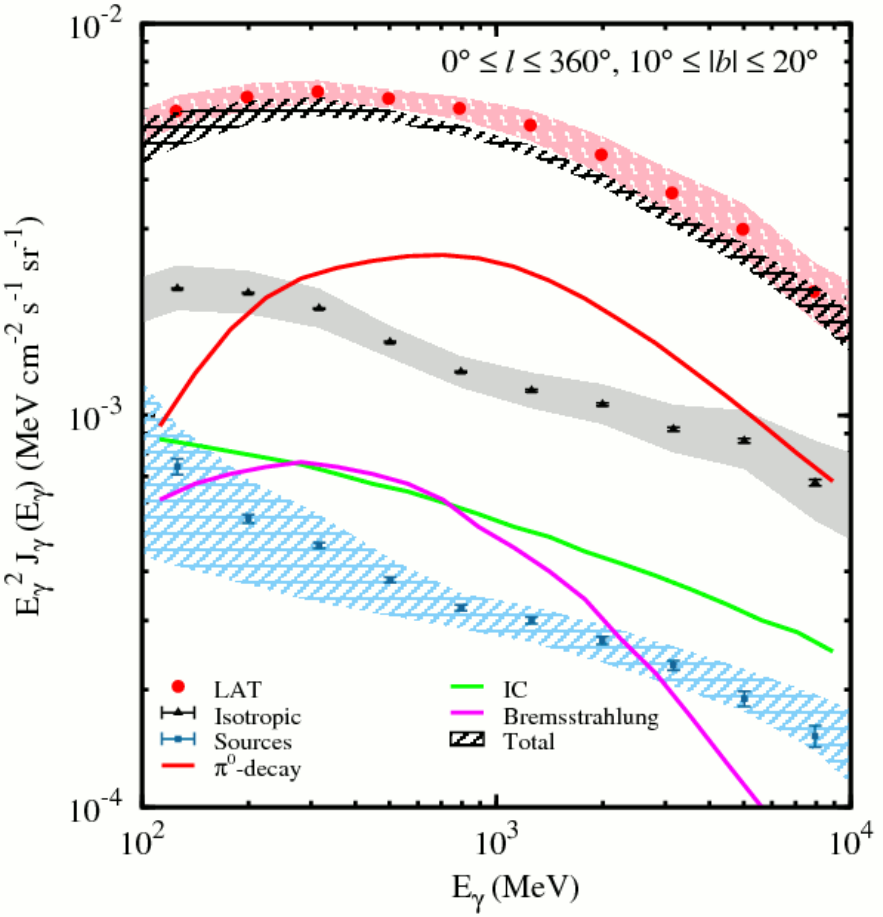




3. Interstellar emission and the gamma/cosmic-ray connection

Local interstellar emission

- basic emission mechanisms understood
- no confirmation of GeV excess (related DM scenarios)



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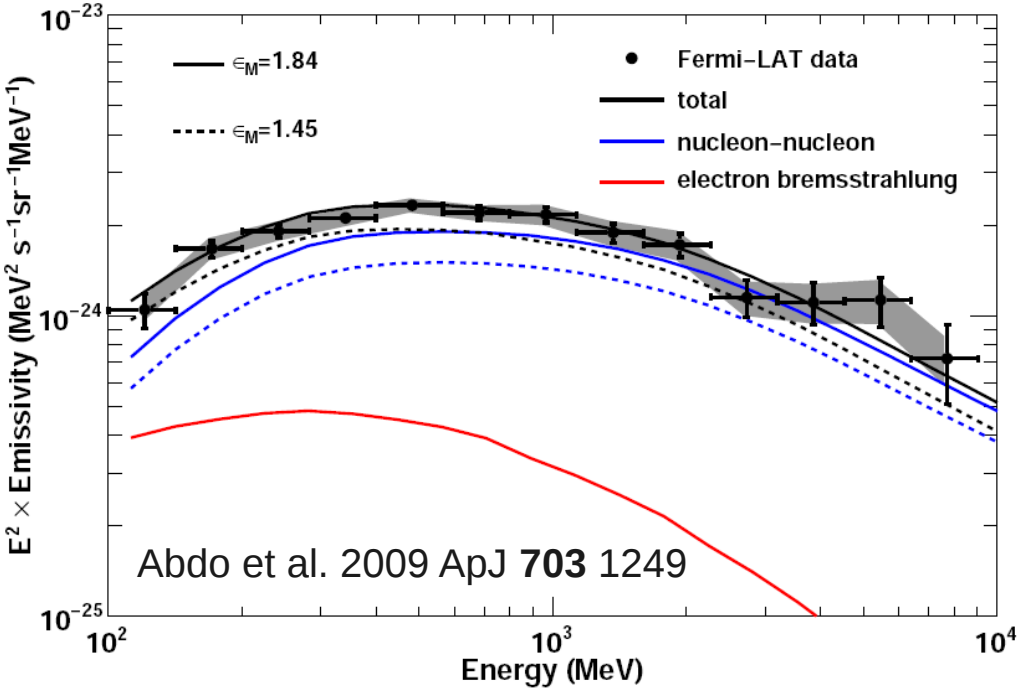
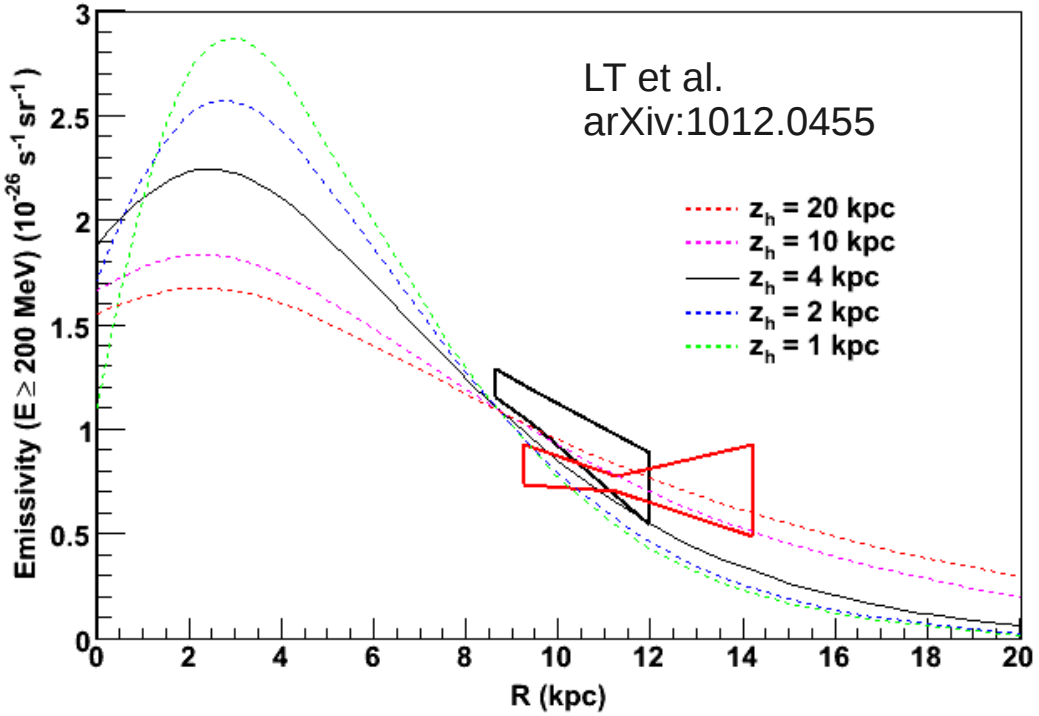
- gamma-ray emission from local interstellar matter → within 1 kpc CR spectra similar to what we measure at the Earth



emissivity = gamma-ray emission rate per H atom

Large-scale emission from the Milky Way

- interstellar emission traces CRs throughout the Galaxy
- first surprise: large CR densities in outer Galaxy
  - large propagation halo (or more complex propagation scenarios)
  - dark accelerators or dark gas
- more to come from comparison with propagation models over the whole Galaxy

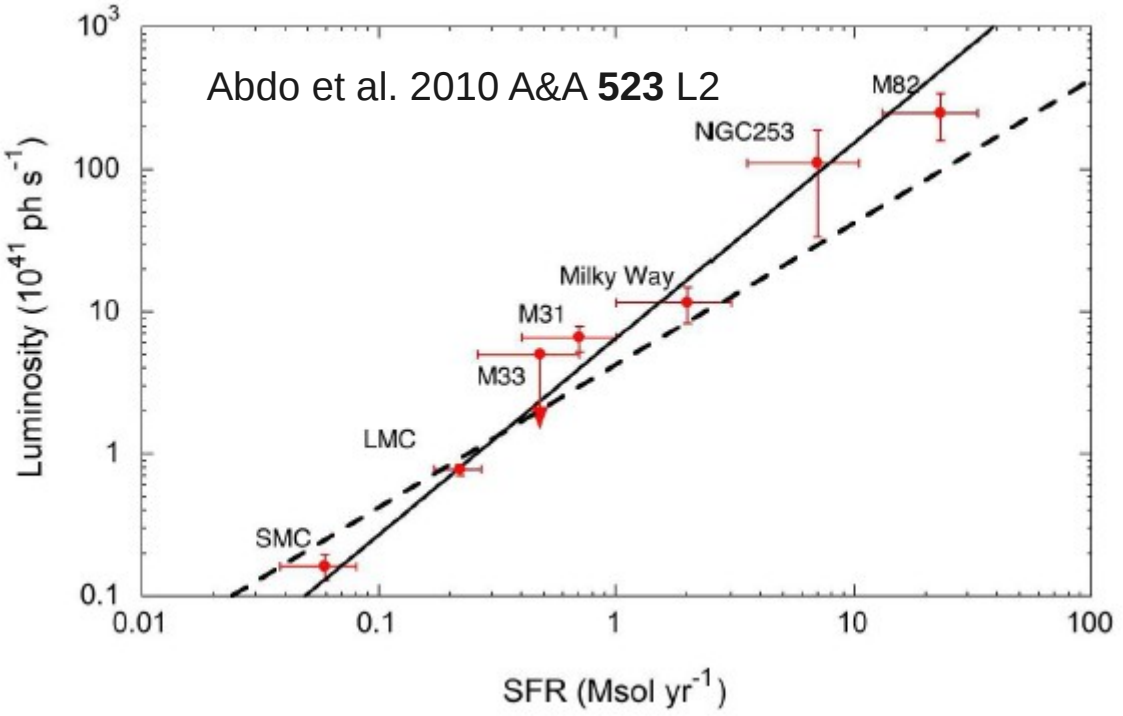


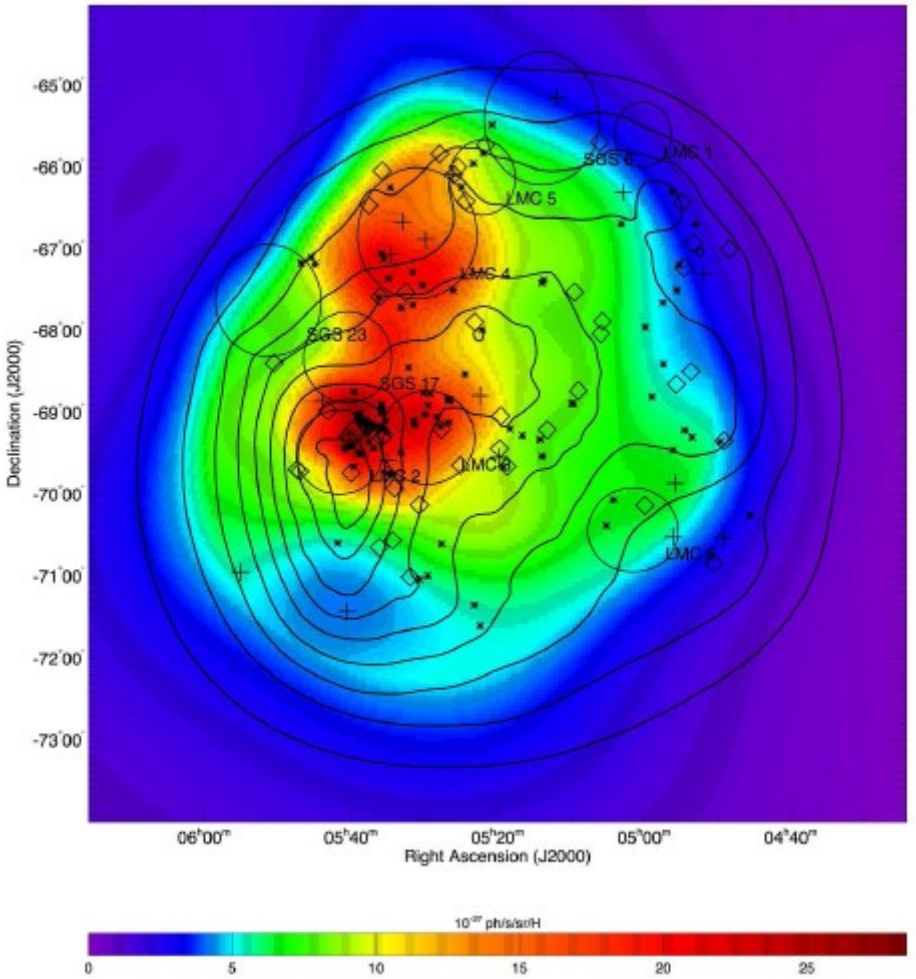
External galaxies: the role of massive stars

Emissivity maps of LMC shows correlation with:

- Hα line
- Wolf-Rayet stars and super shells

→ massive star formation





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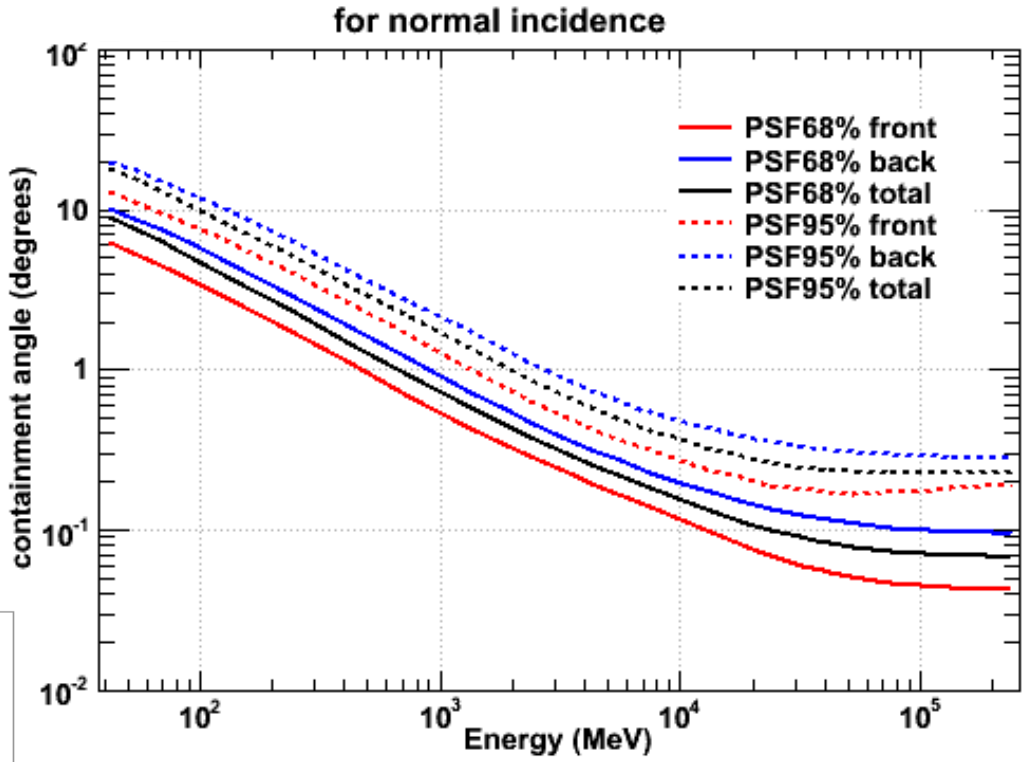
Gamma luminosity-star formation rate correlation.

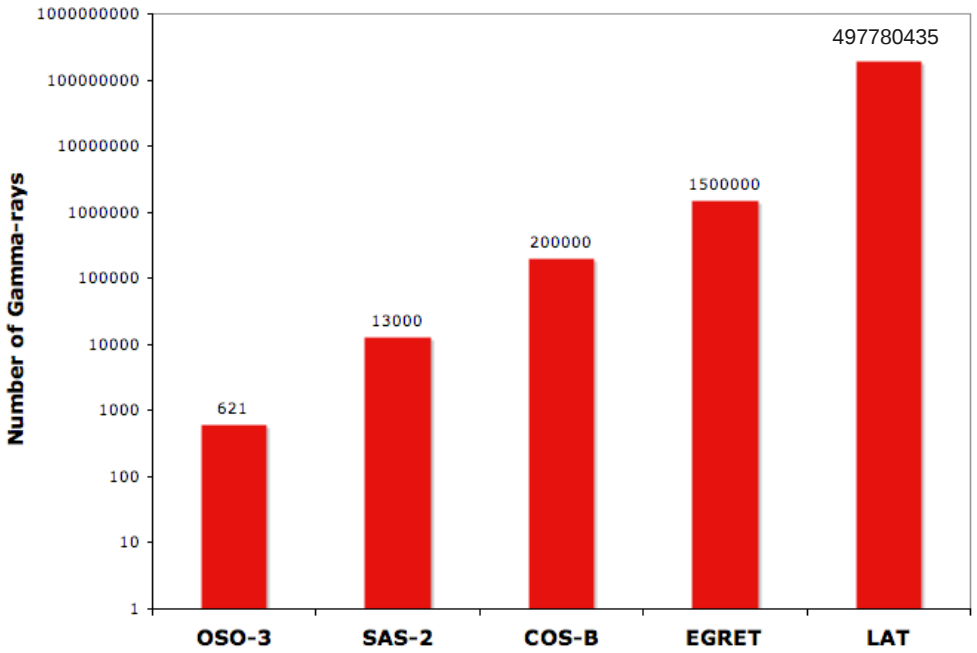
4. Final remarks: Particle Physics and Astrophysics

The technological link

E.g.: LAT advances due to Si tracking devices

- Improved angular resolution
- Improved detection efficiency (together with geometry ...)





Primarily developed in Particle Phys. experiments

→ large impact on HE Astrophys.

Cosmic-ray Physics

- Interfacing two infinities:
  - birth of subnuclear Physics
  - fundamental component of galaxies
  - signatures of Physics beyond the Standard Model?
- The LAT is contributing to the understanding of HE particles in the Universe
  - studying possible acceleration sites
  - tracing their spreading all around
- Interconnection with:
  - accelerator experiments
  - charged CR detectors
  - neutrino experiments
  - gravitational waves searches