THE COSMOLOGICAL PHYSICS OF
STAR-FORMING GALAXIES
AND THE GAMMA-RAY BACKGROUND

Brian Fields
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-Conclusions-

★ star formation guaranteed gamma rays
★ Fermi/GLAST “near field”:
   Milky Way spectrum: **feature**! calibrates extragalactic signal
   will detect Local Group galaxies: tests calibration (cosmic rays)
★ star-forming galaxies imprint **feature** in diffuse gamma sky
★ impact on cosmological physics
★ star-formation gamma rays & the primordial Li problem
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Guaranteed Gamma-Rays from Star-Forming Galaxies

- star formation $\rightarrow$ supernova explosions
- supernova shocks accelerate cosmic rays
- cosmic-ray propagation in ISM $\rightarrow$ gamma-rays

$$pp \rightarrow \pi^0 \rightarrow \gamma \gamma$$

ergo...

- star formation $\rightarrow$ (hadronic=pionic) gamma rays
- gamma-rays probe
  - star formation
  - cosmic-ray acceleration

Fermi/GLAST First Light Image
Excessive? Hadronic Cosmic Rays: EGRET & Milagro

Prodanovic, BDF, Beacom 2006


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Unresolved point sources?
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* Puzzles cry out for Fermi/ACTs!

---

**GeV excess?** Galactic Plane, \( 40^\circ < l < 100^\circ, |b| < 5^\circ \)

**TeV excess?**

\[
pp \rightarrow \pi^0 \rightarrow \gamma\gamma
\]

\[
\frac{m(\pi^0)}{2}
\]
**Observable**: gamma-ray flux

**Laboratory**: the Local Group

\[
F_\gamma = \frac{\dot{N}_\gamma}{4\pi r^2} \quad \dot{N}_\gamma = \Phi_p \sigma \frac{M_{\text{gas}}}{m_p}
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**EGRET**

- only LMC detected (marginally)
- gamma flux consistent with \( \Phi_p \propto R_{\text{SN}} \)
**Gamma-Ray Tests & Calibration of Star-Formation/Supernova Cosmic Rays**

*Pavlidou & BDF 2001*

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- tests star-formation/gamma-ray link: supernova acceleration, confinement in spirals, dwarfs
Cosmic-Ray Sources
Across the Star-Forming Universe
Lichti, Bignami, & Paul 1978; Pavlidou & BDF 2002

Modeling the cosmic history of cosmic-ray interactions
★ supernovae as cosmic-ray sources
★ interstellar medium as targets
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Pavlidou & BDF

- star-forming galaxies: a feature!
  peak ~0.5 GeV
  offset from MW peak: distinguishable
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Gamma Signal from Starbursts

Individual starbursts: Torres, Reimer, Domingo-Santamaria, & Diegel 2004
- farther than Local Group but very high star-formation rates
- 13 sources likely observable by GLAST

Cosmic starbursts: Thomson, Quataert, & Waxman 2007
- dominate star formation at z>1
- Contribute ~50% of star-forming EGRB
- key assumption: starbursts gammas are cosmic-ray “calorimeters”: collisional pion production dominates energy losses
The Payoff:
Impact on Cosmological Physics

With observed signal from star-forming, cosmic-ray accelerating galaxies:
The Payoff: Impact on Cosmological Physics

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★ measure of *cosmic star-formation rate*

but other direct probes available  Lien talk
which allows gamma-rays to...

Prodanovic, Pavlidou, & BDF
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★ Star-forming galaxy signals are *foreground to exotica*
  
  cosmological cosmic rays  Keshet talk
  dark matter annihilation
Fermi/GLAST Impact

★ Extragalactic diffuse background
  sensitivity, angular resolution: better foreground separation
  intensity, spectrum probes normal galaxies

★ AGN
  resolved foreground lowers AGB background contribution, galaxies stand out

★ Local Galaxies
  Multiple Local Group galaxy detections
  tests cosmic-ray dependence on local environment (star formation) and
  universality of cosmic-ray confinement

★ Milky Way
  better diffuse/point source separation
  identification of pion bump?
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Hadronic gamma production inevitably means *lithium synthesis*

**Observables**

- **gammas**: measure mean CR fluence across universe
- **lithium abundance**: measures local CR fluence

\[
\frac{\text{Li}}{\gamma} \sim \frac{\int \Phi_{\text{CR}}(\text{local}) \, dt}{\int \Phi_{\text{CR}}(\gamma\text{path}) \, dt}
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Complementary:

use one to probe the other
Paleolithography: Lithium Probes of Cosmic-Ray History
Prodanovic & BDF

Hadronic gamma production \( pp \rightarrow \pi^0 \rightarrow \gamma\gamma \)
inevitably means \textit{lithium synthesis} \( \alpha\alpha \rightarrow ^{6}\text{Li} + \cdots \)

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Primordial Nucleosynthesis: The Lithium Problem

Cyburt, BDF, Olive 2003, 2008
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Predict:

BBN theory: abundances vs baryon density

WMAP baryons → BBN+CMB abundances (blue)

Compare with Observations (yellow)
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Results:
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- $^7$Li discordant: factor 4-5, 5sigma
  systematic errors in obs? theory? new physics?
Cosmic rays pollute primordial Li

\[ 7\text{Li}_{\text{observed}} = 7\text{Li}_{\text{CR}} + 7\text{Li}_{\text{BBN}} \]

But \( 6\text{LiBeB}_{\text{GCR}} \rightarrow 6,7\text{Li}_{\text{GCR}} \)

Infer true \( 7\text{Li}_{\text{BBN}} ! \)

How to calibrate for galactic, pre-Galactic Lithium?

use gamma/Li dosimetry!

diffuse pionic background

galactic, pre-galactic(?) Li production

Sharpens Li observations! But…
- makes WMAP Li problem worse!