



What Can Gamma-Rays Tell Us About Lithium Production



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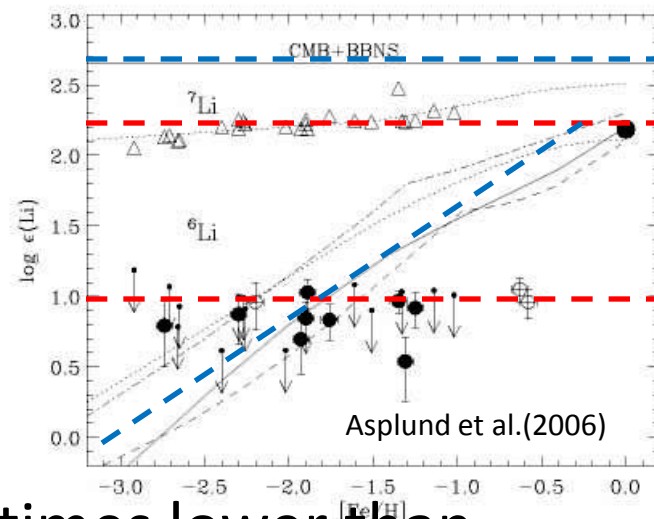
Caltech





How Well Do We Understand Li?

- ${}^7\text{Li}$ origin: cosmic rays + BBN
- ${}^6\text{Li}$ *only* made by cosmic rays via fusion $\alpha + \alpha \rightarrow {}^6\text{Li}$ and spallation $p, \alpha + \text{CNO} \rightarrow {}^6\text{Li}$
- But problems!
 - Pregalactic Li (Spite) “plateau” ~ 3 times lower than primordial WMAP predicted Li (eg. Cyburt et al. 2008)!
Li depleted in stars?
 - Unexpected pregalactic ${}^6\text{Li}$ plateau (Asplund et al. 2006, but see Steffen et al. 2010)? New source or stellar modeling?
 - ANY new source: a solution and oil to the fire!
- **Must find independent way to probe!**

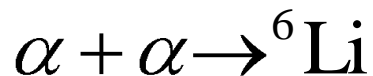




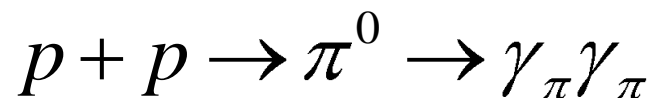
Cosmic-Rays: A Common Denominator

- Hadronic cosmic-ray interaction production of

Lithium



Gamma rays



**Li & pionic gamma-rays
connected!**

Li- γ -ray Connection

- Any cosmic-ray source produces both gamma-rays and lithium
- Connected essentially with ratio of reaction rates
(Fields & Prodanović 2005)

$$\frac{\gamma_{\pi}}{\text{Li}} \propto \frac{1}{y_{\alpha,ism} y_{\alpha,cr}} \frac{\langle \sigma_{\gamma} \rangle}{\langle \sigma_{\alpha\alpha} \rangle}$$

- Li abundance: local CR fluence
- Diffuse *extragalactic* γ_{π} : CR fluence across Universe (cosmic mean)
- **Use extragalactic gamma-ray background (EGRB) to constrain Li!**

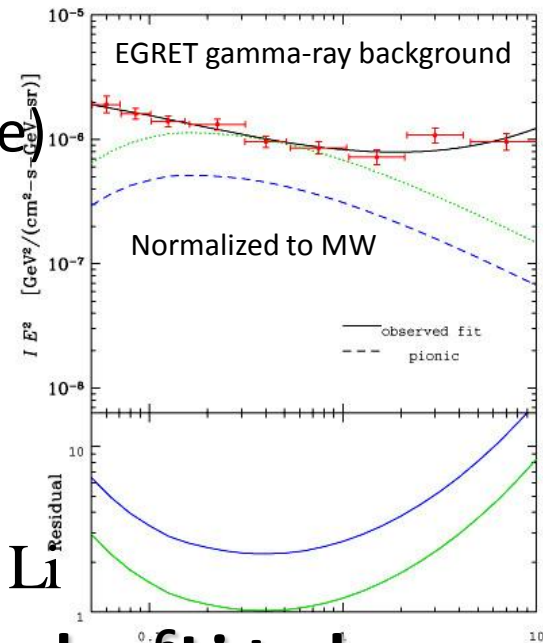


Galactic CRs and ${}^6\text{Li}$

- ${}^6\text{Li}$ made by galactic cosmic rays – test!
- Pionic gamma-ray fraction of EGRB
 - Normalized to the Milky Way at $z=0$ (blue)
 - $\sim 40\%$ of the total EGRB (normal gal.)
- ${}^6\text{Li}$ production channels included
 - fusion $\alpha + \alpha \rightarrow {}^6\text{Li}$
 - spallation $p, \alpha + \text{CNO} \rightarrow {}^6\text{Li}$
 - 2-step reactions, eg. $\text{O} + \text{H} \rightarrow {}^{11}\text{B} + \text{H} \rightarrow {}^6\text{Li}$
- **Gamma rays allow for only $\sim 50\%$ of solar ${}^6\text{Li}$ to be produced by GCRs!** (Prodanović & Fields 2006)
- Need new source? Result of model/obs?

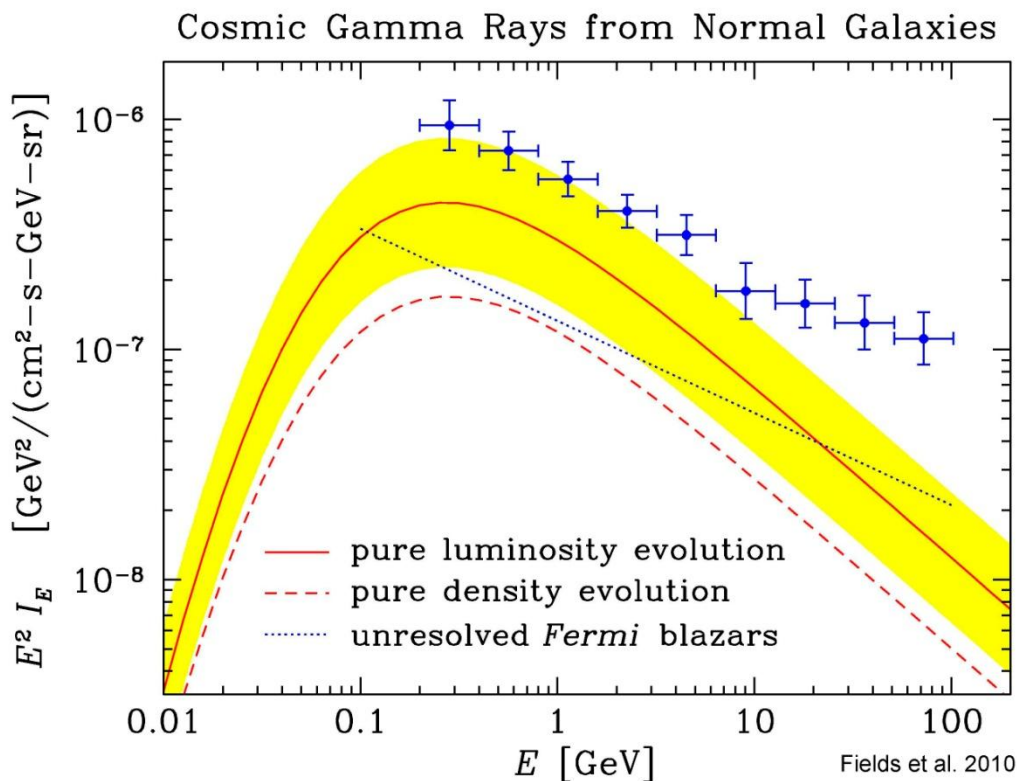
Prodanović & Fields (2006)

Strong et al. data



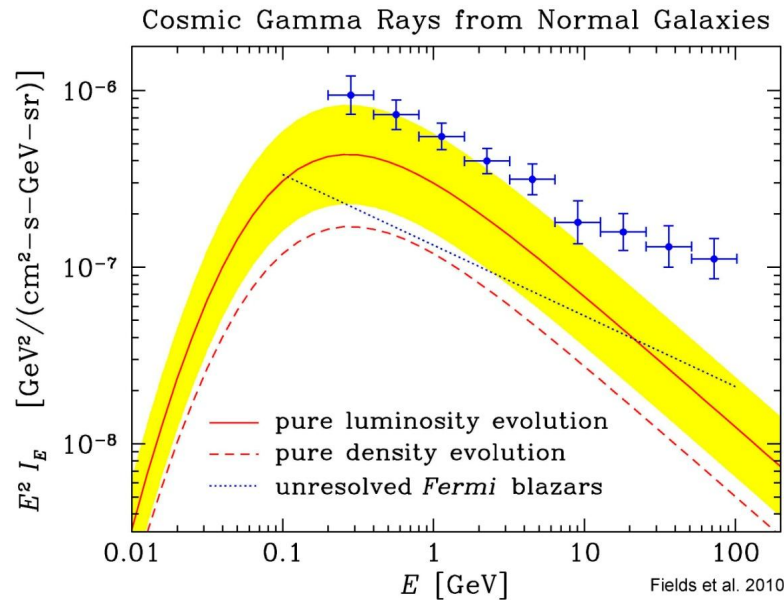


New EGRB with Fermi



- Substantial change in the EGRB from *EGRET* (Strong et al. 2000) to *Fermi* (Abdo et al. 2010a)
- New prediction of the normal, star-forming galaxy contribution to the EGRB (Fields et al. 2010) $\sim 35\%$

Galactic CRs and ${}^6\text{Li}$: Problem?



Fields et al. 2010

Preliminary!

- New *EGRB Fermi* data make things worse!
- New estimate of GCR-made ${}^6\text{Li} \sim 20\%$ of solar abundance!
- New source? Low-energy CRs (don't affect gammas)?
Cosmological cosmic rays (different gamma spectrum)?

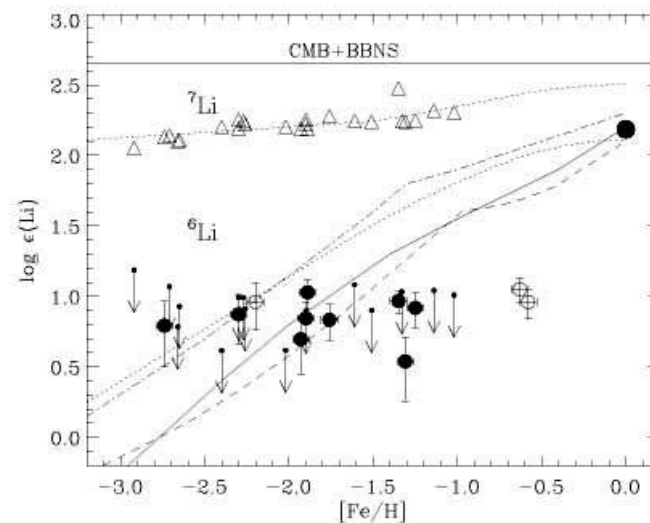
Cosmological CRs and Li

- Shocks from baryonic infall and mergers during growth of large-scale structures (Miniati 2000; Pavlidou & Fields 2006)
- Structure formation/cosmological cosmic rays (SFCRs)
- Primordial composition
- Pre-galactic Li production (Li without BeB)
- Can add to the Spite plateau – contaminant!
- ${}^6\text{Li}$ in halo stars can constrain hypothetical SFCRs! (Suzuki & Inoue 2002)
- Also pionic gamma-ray signatures!



Cosmological CRs and Li

- Utilize gamma-Li connection both ways
- Use Asplund et al. 2006 ${}^6\text{Li}$ “plateau” – SFCRs can contribute at least 5% of the *EGRET* EGRB (Prodanovic & Fields 2007) and $\sim 10\%$ of the *Fermi* EGRB (**preliminary**)

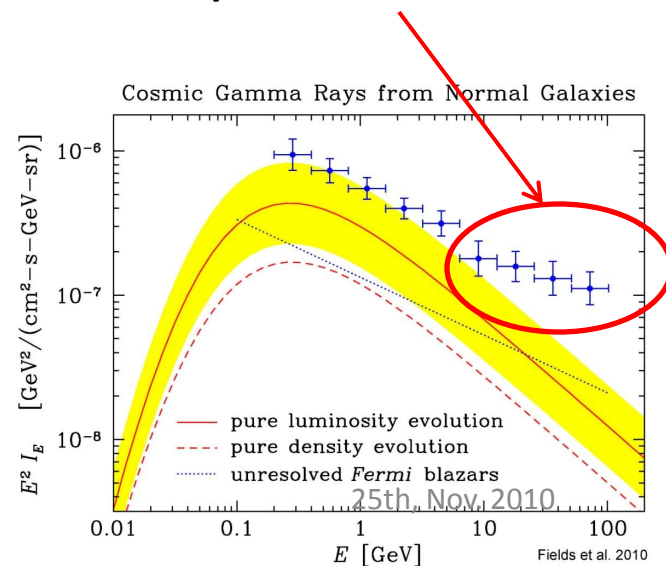




Cosmological CRs and Li

Preliminary!

- Use EGRB shape to constrain SFCRs
 - “Flattening” @ 10 GeV? Slope consistent with SFCRs
 - Assume “flattening” due to SFCRs resurfacing (but see Fields et al. 2010: due to distribution of CR spectral indices in star-forming galaxies)
 - SFCRs make ~ 20-45% of EGRB?
 - Make at least 10% of solar ${}^6\text{Li}$
 - Consistent with low-metallicity halo stars ${}^6\text{Li}$ measurements



SMC: A New Test

- Small Magellanic Cloud – low metallicity environment $\sim \frac{1}{4}$ solar
- Li recently measured in SMC ISM (Howk et al. 2010) – first detection outside the MW
 - ${}^7\text{Li}$ - 3 times higher than in MW stars at such metallicity, but consistent with WMAP
 - ${}^6\text{Li}/{}^7\text{Li}$ lower than expected from MW
 - **Implies higher CR exposure in SMC and/or pre-galactic ${}^6\text{Li}$ production!**
- SMC also observed in gamma-rays by *Fermi* (Abdo et al. 2010b)
- **Use gamma-Li connection to test!**

Conclusion

- Pressing Li problem(s)
- Difficult measurements with stellar modeling
- Another approach: Li-gamma rays connection!
- New *Fermi* gamma-ray data available and upcoming
- Exploit the connection to
 - Test ${}^6\text{Li}$ origin
 - Constrain cosmological cosmic rays
 - Learn about the SMC cosmic-ray history
 - Check the severity of Li problem
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Thank You!

