Lithium-6 and Gamma-Rays: Constraints on Primordial Lithium, Cosmic Rays and Cosmic Star Formation

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Abstract

Cosmic-ray (CR) reactions with the interstellar gas produce both Li (predominantly via $\alpha + \alpha \rightarrow^{6,7}\mathrm{Li}$) and γ-rays (via $\mathrm{p}+\mathrm{p} \rightarrow \pi^0 \rightarrow \gamma\gamma$). We establish the link between them analytically, then apply it to constrain both galactic CR nucleosynthesis as well as extragalactic γ-ray production. We exploit the extragalactic γ-ray spectrum to place constraints on the hadronic production by cosmic rays, and then use the $\gamma - \pi^0 - \mathrm{Li}$ connection to place upper limits on the production of non-primordial Li via cosmic rays accelerated in the shocks arising from cosmological structure formation. Turning the problem around, we use observations of the Galactic Li both in the Solar System and in the ancient halo stars, to constraint the contribution of the galactic cosmic rays to the diffuse extragalactic γ-ray background.

T. Prodanović, & B.D. Fields, 2004,[astro-ph/0403300], Astroparticle Physics , *in press*
B.D. Fields, & T. Prodanović, 2004, [astro-ph/0407314]

1 Cosmic-Ray Populations

We consider two cosmic-ray populations:

- Galactic Cosmic Rays (GCR)-originate in the supernovae remnants
- Structure Formation Cosmic Rays (SFCR)-originate in shocks associated with baryonic infall and merger events during the growth of large-scale cosmic structures [3]

2 Cosmic Rays and ^{6}Li

- Light elements Li, Be, and B (LiBeB) produced as CR fragment heavy nuclei in interstellar gas (e.g. $\mathrm{p}+\mathrm{O} \rightarrow {}^9$Be) thus LiBeB evolution depends on metallicity of CR and ISM $\Rightarrow$ different CR origin $\longrightarrow$ different LiBeB trends
- $\alpha_{\mathrm{cr}} + \alpha_{\mathrm{ism}} \rightarrow^{6,7}\mathrm{Li}$ (yield *lithium* isotopes *exclusively*!) is the dominant source of ^{6}Li while ^{7}Li also has a large primordial component

  $\Rightarrow$ ^{6}Li is a unique CR diagnostic tool!

3 Cosmic Rays and Gamma-rays

- Higher energy ($>$280 MeV/nucleon) cosmic-rays produce γ-rays via

$$\mathrm{p}_{\mathrm{cr}} + \mathrm{p}_{\mathrm{ism}} \rightarrow \pi^0 \rightarrow \gamma\gamma$$

$\Rightarrow$ CR populations also contribute to a diffuse extragalactic γ-ray background (EGRB)

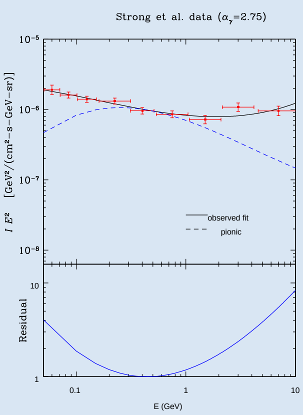
4.1 Li-γ-ray Connection: Formalism

Hadronic γ-rays and Li intimately linked (same CR origin) $\Rightarrow$ direct connection between CR Li production and "pionic" γ-rays

$$\frac{I_{\gamma_\pi}(t)}{Y_{i_{\mathrm{Li}}}(\vec{x},t)} = \frac{n_{\mathrm{b}}c}{4\pi y_\alpha^{\mathrm{cr}} y_\alpha^{\mathrm{ism}}} \frac{\sigma_\gamma}{\sigma_{\alpha\alpha}^i} \frac{F_p(t)}{F_p(\vec{x},t)}$$

where $\frac{F_p(t)}{F_p(\vec{x},t)}$ is the ratio of the line-of-sight baryon-averaged to the local fluence.

6 GCR and ^{6}Li



Plotted above is maximized "pionic" (γs from decay of pions produced via GCR) flux propagated over the redshift history of sources [5] (EGRB data [4]).
From the Li-γ connection we find that this maximized "pionic" γ-ray flux is accompanied by ^{6}Li abundance that is *only* 25% of the Solar value.

$$\frac{F_p(t)}{F_p(\vec{x},t)} \frac{{}^6\mathrm{Li}_{\mathrm{gcr}}}{{}^6\mathrm{Li}_{\odot}} = 0.25$$

That is, we find that the Solar ^{6}Li abundance *requires* **2-6 times larger EGRB** than the observed one if our local fluence is assumed to be equal to the line-of-sight average.
The other interpretation would be that $F_p(\vec{x},t) > F_p(t)$ i.e., Milky Way cosmic-ray fluence has to be greater than the average if we want GCRs to make Solar lithium.

4.2 Li-γ-ray Connection: Astrophysics

- GCRs- believed to be the source of ^{6}Li

  $\Rightarrow$ ^{6}Li $-\ \gamma$ connection can test this
- SFCRs- produce pre-Galactic Li which "contaminates" the primordial ^{7}Li content of metal-poor halo stars

  $\Rightarrow$ use ^{6}Li $-\ \gamma$ connection to place upper limits on the possible level of contamination

5 " Pionic" γ-rays

- Distinct spectrum, peaks at $m_{\pi^0}/2$ (in pion rest frame)$\equiv$ "pion bump"
- No "pion bump" observed

  $\Rightarrow$ constrain maximized "pionic" γ-ray flux so that the "pion bump" stays below the observed EGRB

References

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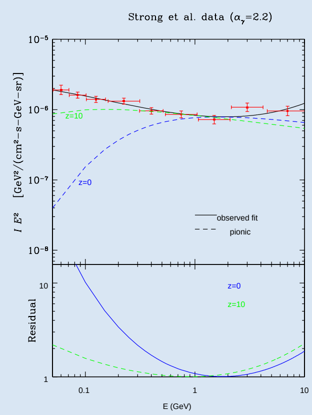
7 SFCR and Li



Plotted above is maximized "pionic" (pions produced via SFCR) flux for two extreme redshifts of origin (assume all "pionic" γ-rays originate at the single redshift). EGRB data from [4]. We find that this flux is accompanied with total lithium abundance in the range (compared to the "CMB-based" primordial lithium abundance [6])

$$0.30 \leq \frac{\mathrm{Li}_{\mathrm{sfcr}}}{\mathrm{Li}_{\mathrm{p}}} \leq 4.09$$

Thus, we see that our constraint, although model-independent, is not strong enough to rule out pre-galactic Li production via SFCR as an minor contaminant to the observed primordial Li.

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