Cosmic-Ray Lithium Production at a Type Ia Supernova Following a Nova Eruption

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Norita Kawanaka (Kyoto University)
Shohei Yanagita (Ibaraki University)

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Galactic Cosmic-rays (p, He, Li-Be-B, C,...)

(probably) produced via shock acceleration at SNRs

proton, He, C, etc. : primarily produced at SNRs, power-law spectrum

Li-Be-B : secondarily produced via spallation of heavier elements, steeper spectrum than primary CRs

However …
Direct measurements of CRs by PAMELA / CREAM / ATIC / AMS-02 etc.

(1) The spectra of $p$ and He are hardened above $\sim 300$ GeV

(2) The spectrum of Li (considered as secondary particles) is also hardened above $\sim 300$ GeV

(3) The hard components have similar indices

Is it implying the existence of primary sources that accelerate $p$, He and Li?
Galactic Lithium sources: novae

$^7\text{Be}$ absorption lines in the early phase spectra of Classical nova V339 Del, $X(^7\text{Be}) \sim 10^{-4}$ (Tajitsu et al. 2015) ... synthesized via $^3\text{He} (\alpha,\gamma)^7\text{Be}$ → decay into $^7\text{Li}$ by $\text{e}^-$ capture ($\tau_{1/2} \sim 53.22$ days)

Other observations:
$^7\text{Be}$ absorption lines (V5668 Sgr, V2944 Oph; Tajitsu+ 2016)
$^7\text{Li}$ absorption lines (V1369; Izzo+ 2015)
Type Ia supernova after a nova eruption?

**Classical nova:** gas accretion onto a white dwarf from its companion star → thermonuclear runaway

**Type Ia SN:** gas accretion onto a white dwarf from its companion star at higher rate → thermonuclear disruption (single degenerate scenario)

Nova eruptions may be followed by a Type Ia supernova (e.g.: PTF 11kx; Dilday+ 2012)

**Hypothesis:** CR Li nuclei are accelerated when a nova ejecta is swept up by a blast wave of a subsequent Type Ia SN.
Model

Distribution function of CRs emitted at the distance $r$ and time $t$

$$f_i(r, R, t) = \frac{Q_{i,0}(R)}{(4\pi Dt)^{3/2}} \exp \left(-\frac{r^2}{4Dt}\right) \quad R: \text{rigidity}$$
$$D: \text{diffusion coefficient}$$
$$Q_{i,0}: \text{source spectrum}$$

Assuming $Q_i \propto \varepsilon^{2.2}$, $D = D_0 (R / 1 \text{ GV})^\delta$, the peak rigidity is

$$R_p = \left[ \frac{\delta}{\alpha + \frac{3}{2} \delta} \frac{r^2}{r_0^2} \right]^{1/\delta} \quad r_0 = (4D_0 t)^{1/2}: \text{diffusion length for 1GV particles}$$

**Necessary conditions:**

1. $R_p \lesssim 300$ GeV: the hard component does not have a break
2. $E_{\text{CR, tot}} \lesssim 10^{50}$ erg: typical CR energy injected into CRs per SN

Fitting with the AMS-02 results (p, He, and Li)
Results

\[ r = 150 \text{ pc}, \quad t = 6 \times 10^3 \text{ yr}, \]
\[ D = 1 \times 10^{28} \left( \frac{\epsilon}{1 \text{ GeV}} \right)^{1/3} \text{ cm}^2 \text{ s}^{-1} \]

total amount of CRs

\[ M_{\text{CR},p} \sim 2 \times 10^{-6} M_{\text{sun}} \]
\[ M_{\text{CR},\text{Li}} \sim 1 \times 10^{-8} M_{\text{sun}} \]

Note: From the conditions (1) and (2), the source should be located within \(<~ 350 \text{ pc}, \) being independent of \( D \)
Is it natural?

(1) total amount of accelerated particles

typical nova ejecta \( \sim 10^{-4} M_{\text{sun}} \)

\( \Rightarrow \) implying the efficiency \( \sim 10^{-2} \)

typical temperature of nova ejecta \( \gtrsim 10^4 \text{ K} \) \( \Rightarrow \) O.K.

(2) composition

\([\text{CR Li}] / [\text{CR } p] \sim 3 \times 10^{-3}\)
in a nova ejecta \( \text{Li} / p \sim 10^{-4}\)

However, the first ionization potential of \( \text{Li} (\sim 5 \text{ eV}) \) is much lower than that of \( p (\sim 13 \text{ eV}) \) \( \Rightarrow \) more efficiently accelerated by a factor of \( \sim 30\)

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**Dogiel et al. arXiv:1701.0548**
Predictions from our model

• No hard component in Beryllium or Boron spectra (they are not synthesized in novae)
• Steepening in the B/C ratio (Carbon is efficiently synthesized in novae)
• Anisotropy (existence of a nearby source)
• The isotopic ratio $^7\text{Li}/^6\text{Li}$ increases with energy above ~300 GeV ($^6\text{Li}$ is not produced in novae)
• candidate SNR?
  ... Cygnus loop (~ 500 pc, $\sim10^4$ yr, but generally regarded as a core-collapse SN)
  ... SN Ia might have occurred in the low-density, high-latitude region, they are not always so bright in radio or X-ray.
We propose the nearby Type Ia supernova occurring after a nova eruption, where a large amount of Li is synthesized, as the birth place of the hard CR Li component appearing $>\sim 300$ GV.

The energy spectra of p/He/Li, total mass, abundance ratios, and efficiencies implied from observations are consistent with our scenario.

Our scenario can be tested in various ways (Be and B spectrum, B/C, anisotropy, Li isotopic ratio) → AMS-02, CALET, DAMPE, ISS-CREAM, etc.