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

(arXiv:1707.00212)

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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 …

supernova remnant

primary (p, He, C,…)

Secondary (Li-Be-B)

$dN/d\varepsilon$

ε
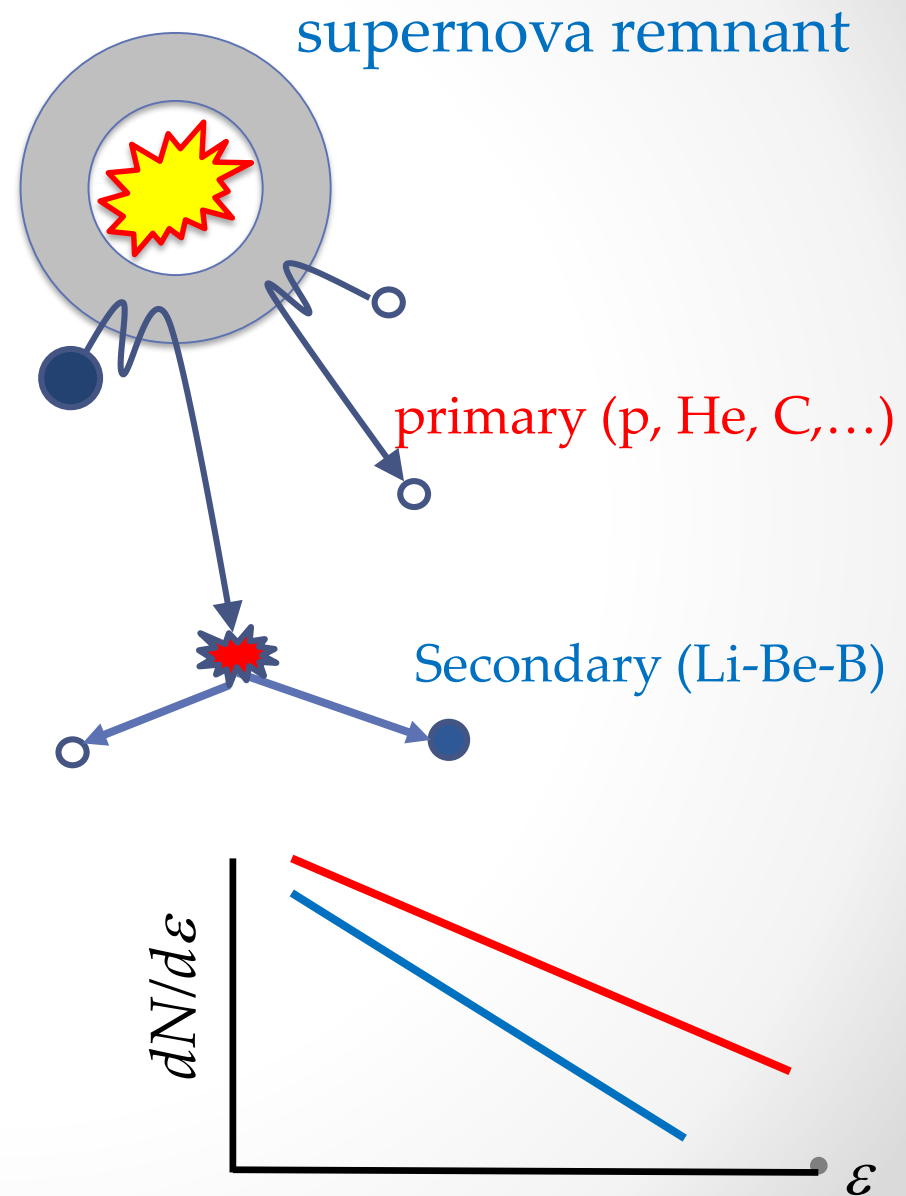
Spectral hardening of p, He, Li (and heavier nuclei)

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

(1) The spectra of p and He are hardened above ~300 GeV

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

(3) The hard components have similar indices

AMS-02 collaboration, 2016
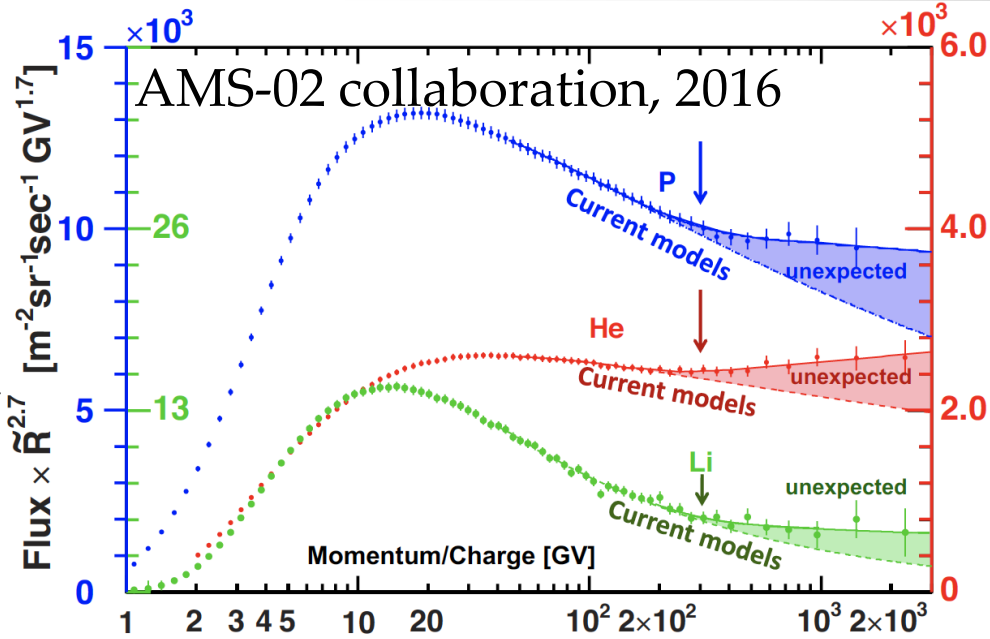
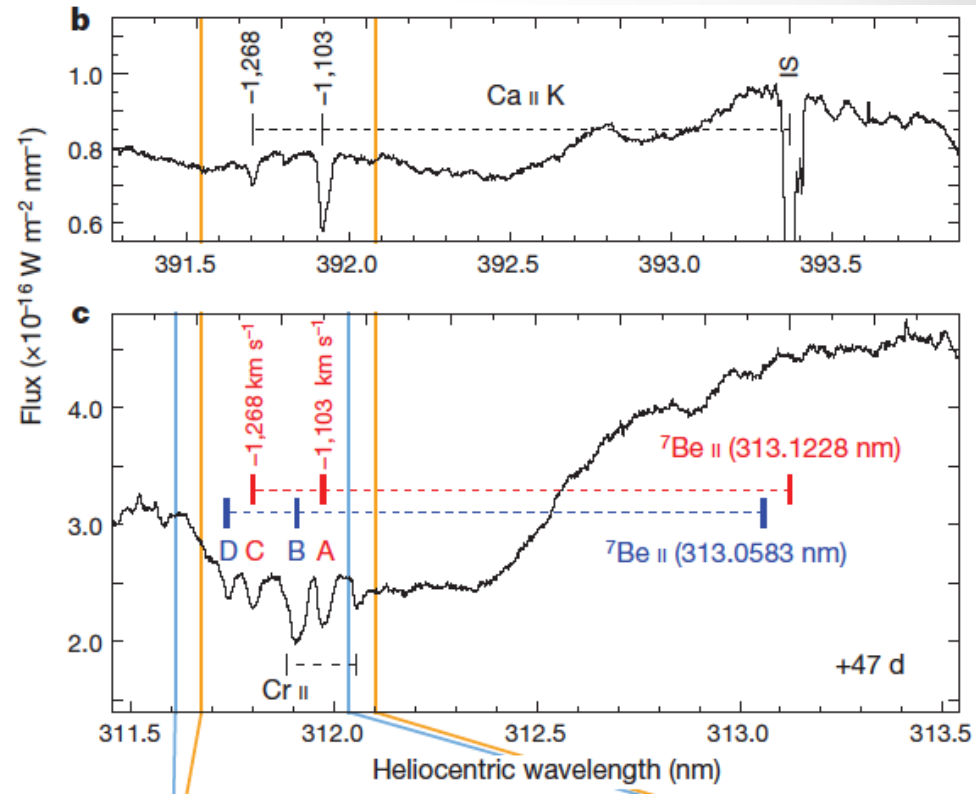Is it implying the existence of primary sources that accelerate p, He and Li?

Galactic Lithium sources: novae

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

Tajitsu+ 2015

Other observations:
^{7}Be absorption lines (V5668 Sgr, V2944 Oph; Tajitsu+ 2016)
^{7}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)

nova ejecta (Li-rich)

SN ejecta

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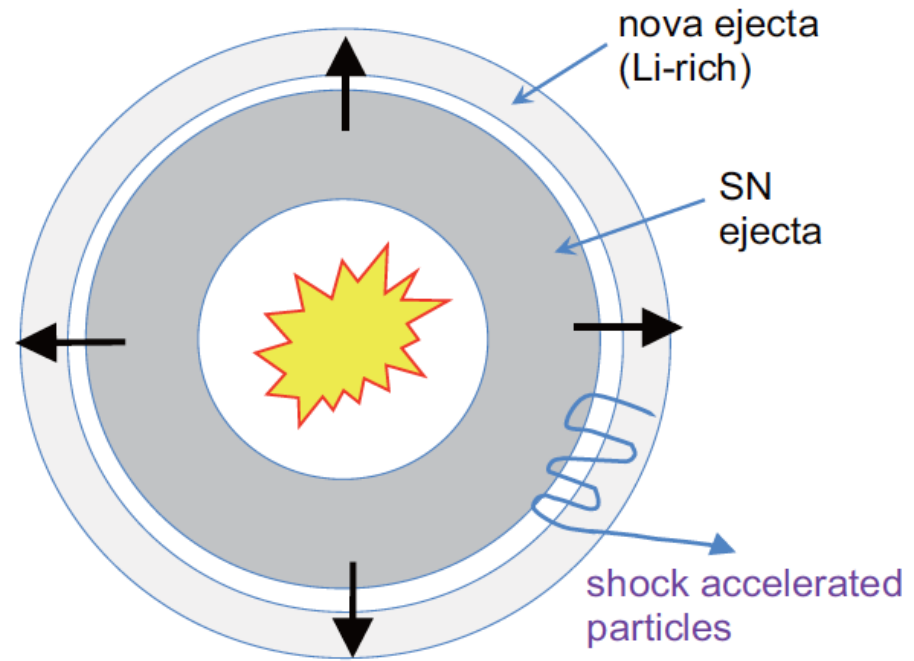
Hypothesis： CR Li nuclei are accelerated when a nova ejecta is swept up by a blast wave of a subsequent Type Ia SN.

Model

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

$$f_i(r, R, t) = \frac{Q_{i,0}(R)}{(4\pi D t)^{3/2}} \exp\left(-\frac{r^2}{4Dt}\right)$$

R : rigidity
D : diffusion coefficient
$Q_{i,0}$: source spectrum

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

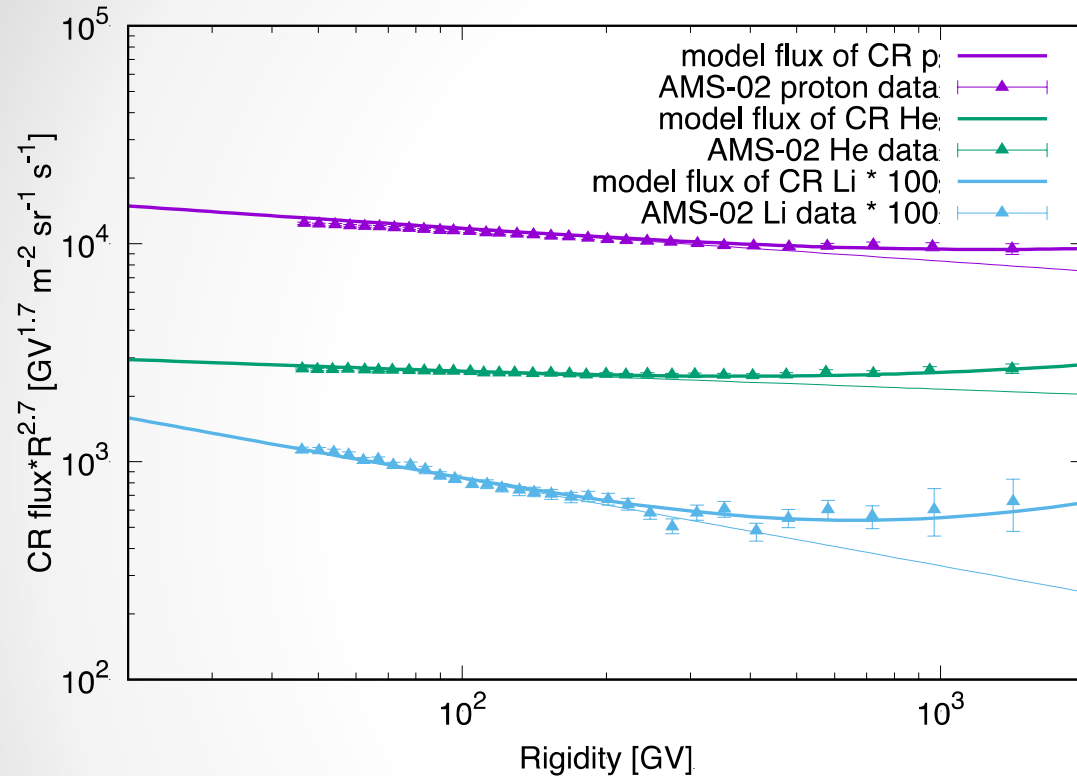$$R_\text{p} = \left[\frac{\delta}{\alpha + \frac{3}{2}\delta} \frac{r^2}{r_0^2}\right]^{1/\delta}$$

$r_0 = (4D_0 t)^{1/2}$: diffusion length for 1GV particles

Necessary conditions:
(1) $R_\text{p} <\sim 300$ GeV : the hard component does not have a break
(2) $E_\text{CR,tot} <\sim 10^{50}$ erg: typical CR energy injected into CRs per SN

➡ **fitting with the AMS-02 results (p, He, and Li)**

Results

$\underline{r = 150 \text{ pc}, t = 6 \times 10^3 \text{ yr},}$
$\underline{D = 1 \times 10^{28} (\varepsilon/1 \text{ GeV})^{1/3} \text{ cm}^2 \text{ s}^{-1}}$

total amount of CRs

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

Note : From the conditions (1) and (2), the source should be located within <~ 350 pc, being independent of D

Is it natural?

(1) total amount of accelerated particles

typical nova ejecta ~ 10^{-4} M_{sun}
→ implying the efficiency ~10^{-2}
  typical temperature of nova
ejecta >~ 10^4 K → O.K.

dotted：shock acc.
solid：stochastic acc.

Dogiel et al. arXiv:1701.0548

(2) composition

[CR Li] / [CR p] ~ 3 × 10^{-3}
in a nova ejecta Li / p ~ 10^{-4}
However, the first ionization
potential of Li (~5 eV) is
much lower than that of p
(~13 eV) → more efficiently
accelerated by a factor of ~ 30

Meyer 1985
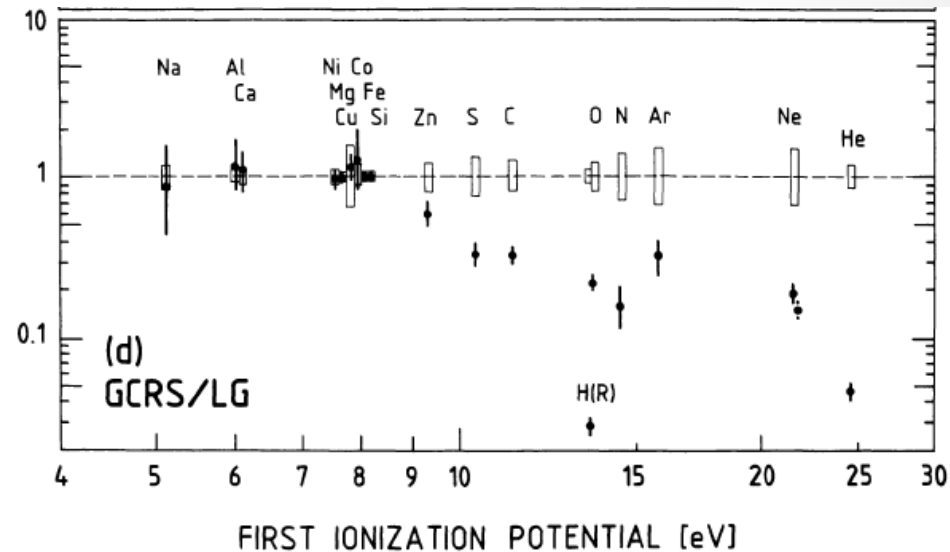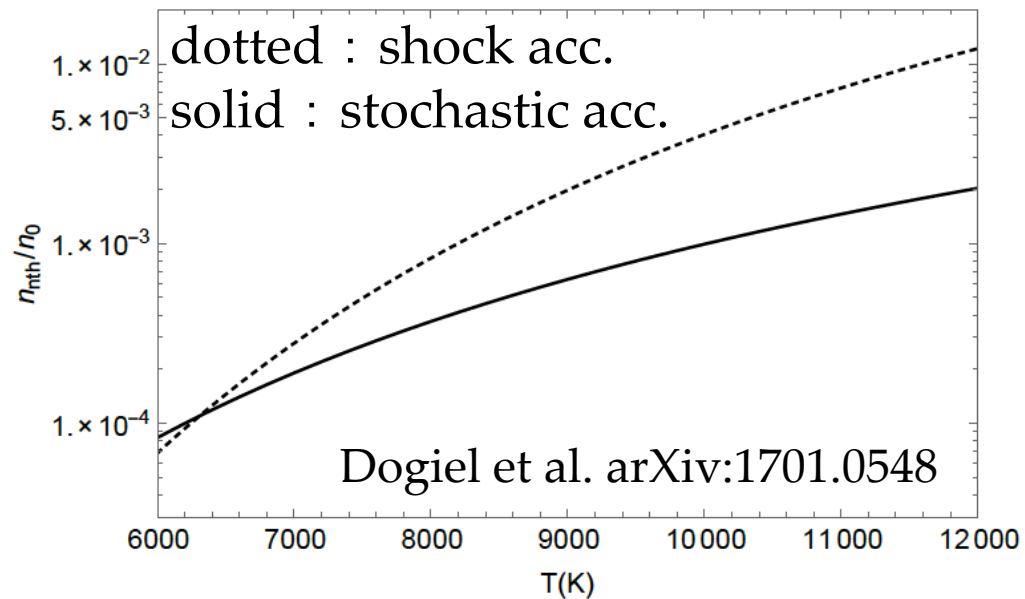
Predictions from our model

- 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 $^7Li/^6Li$ increases with energy above ~300 GeV (^6Li is not produced in novae)
- candidate SNR?

… Cygnus loop (~ 500 pc, ~10^4 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.

Summary (see arXiv:1707.00212 for the detail)

- 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 >~ 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.

nova ejecta (Li-rich)

SN ejecta

shock accelerated particles