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

(arXiv:1707.00212)

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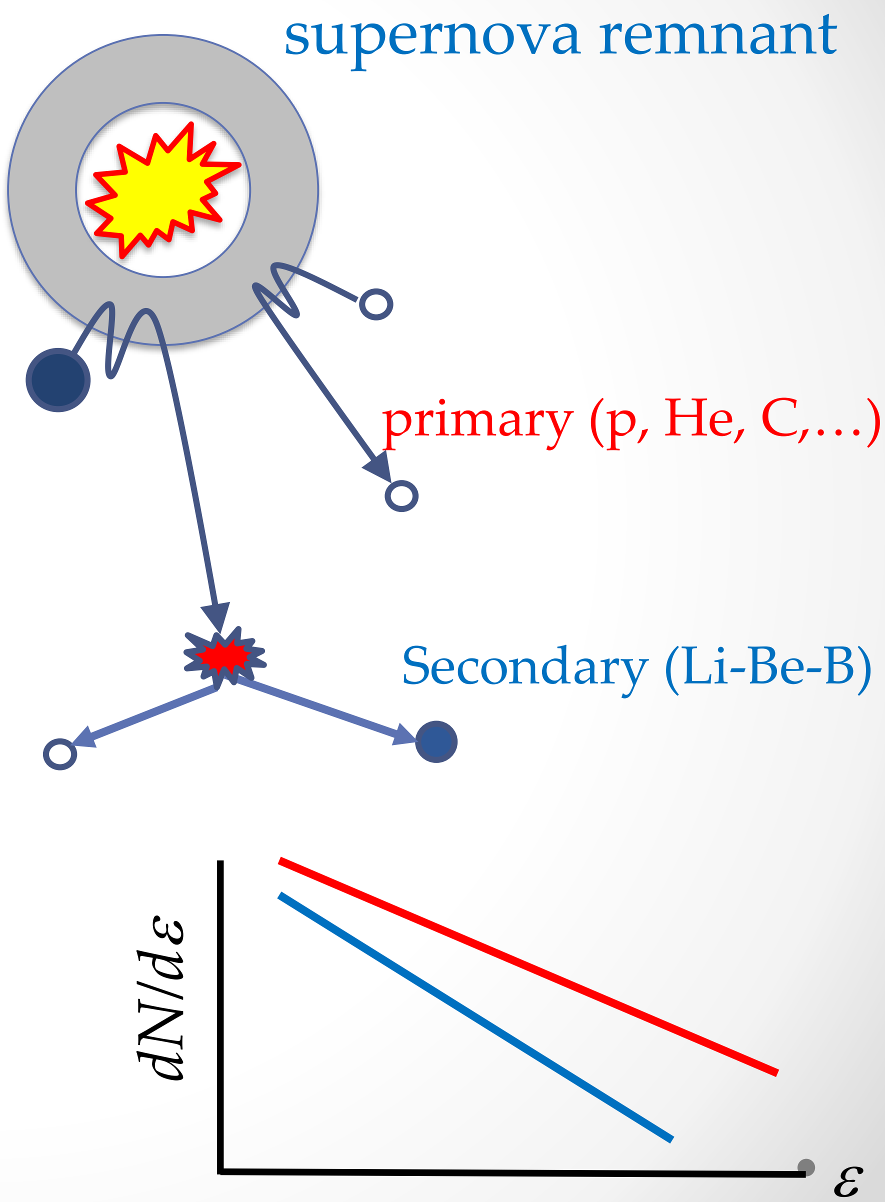
Galactic Cosmic-rays (p, He, Li-Be-B, C,…)

(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 …



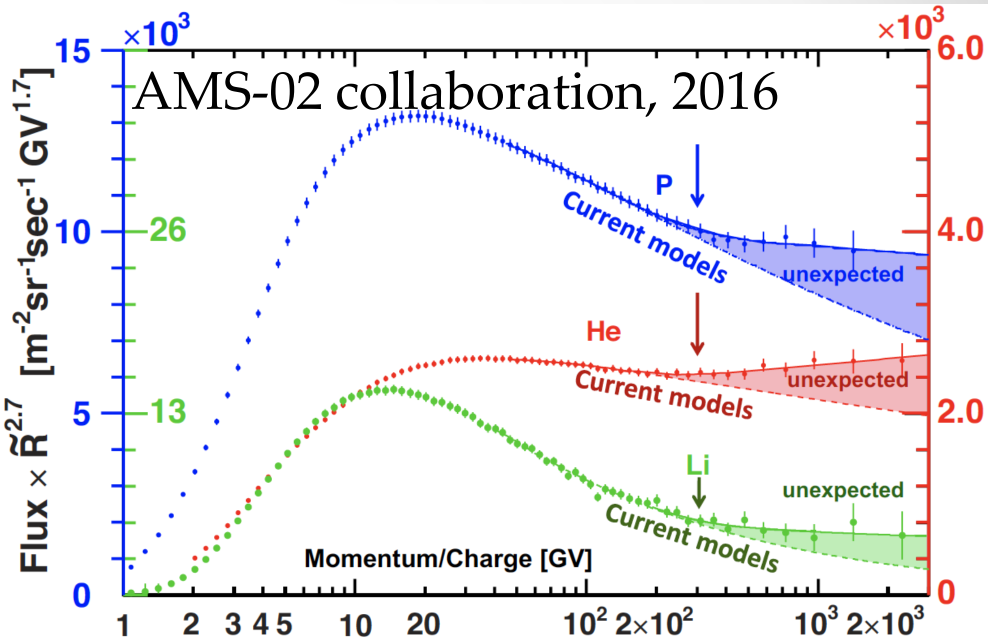
Spectral hardening of p, He, and Li

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

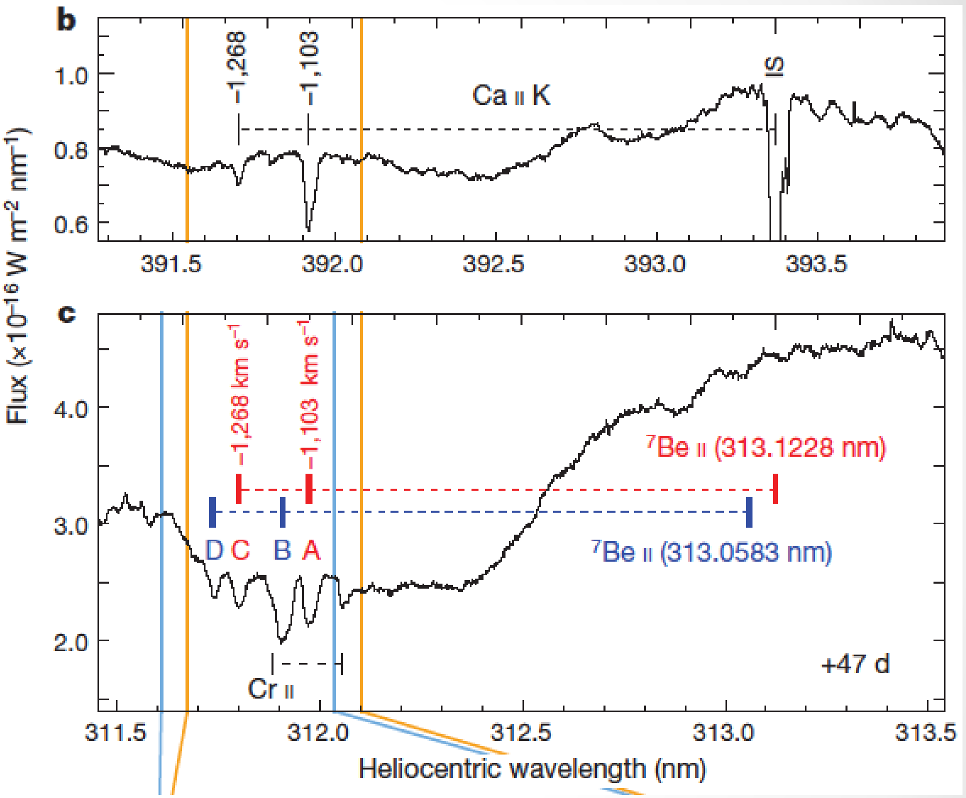
(3) The hard components have similar indices



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)



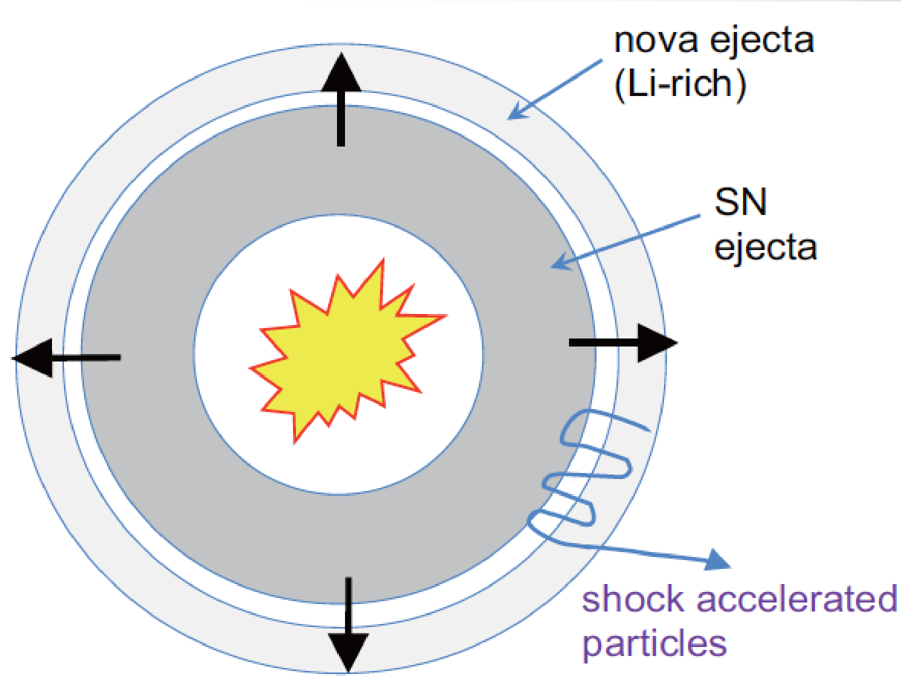
Tajitsu+ 2015

Other examples:
^{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)

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

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

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

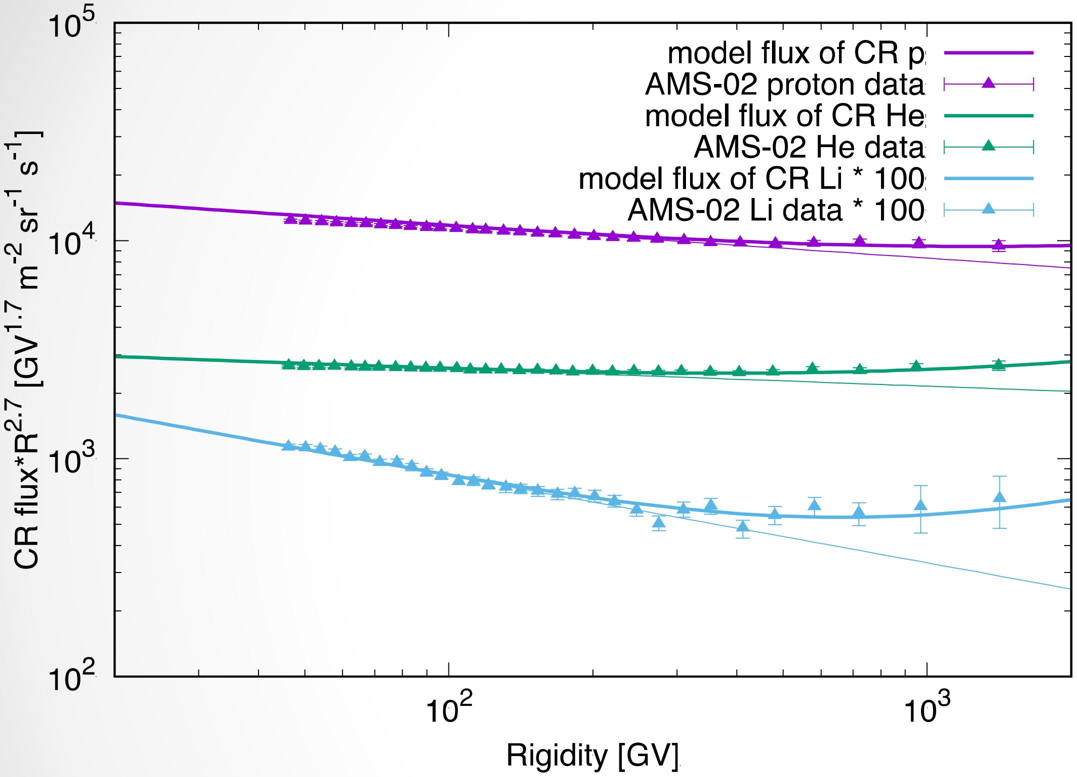
<u>Necessary conditions:</u>

(1) R_{p} <~ 300 GeV : the hard component does not have a break

(2) $E_{\mathrm{CR,tot}}$ <~ 10^{50} erg: typical CR energy injected into CRs per SN

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

Results



<u>r = 150 pc, t = 6×10^3 yr,</u>
D = 1×10^{28} (ε/1 GeV)$^{1/3}$ cm^2 s^{-1}

total amount of CRs

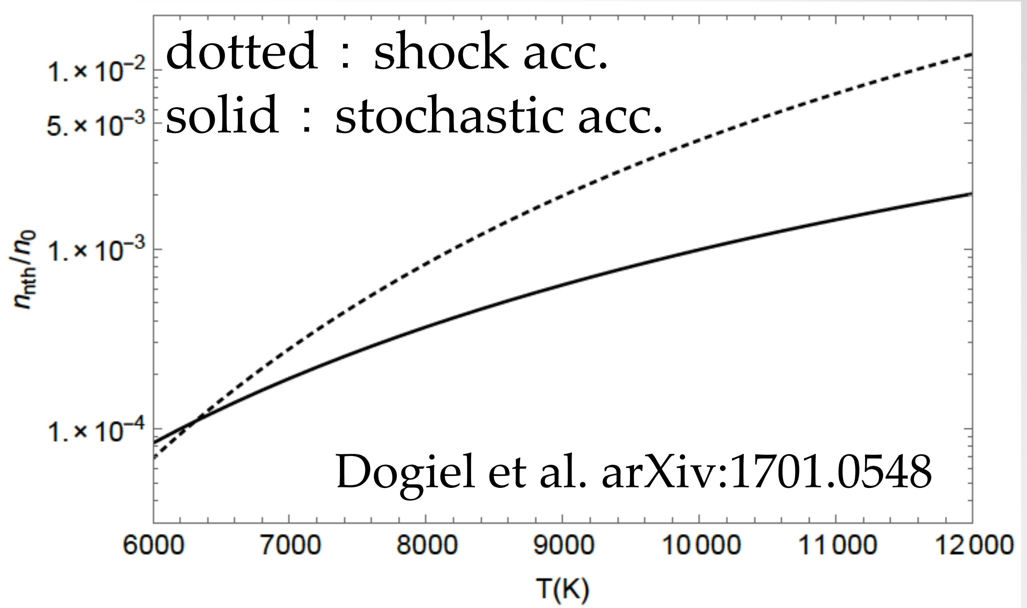
$M_{CR,p}$ ~ 2×10^{-6} M_{sun}
$M_{CR,Li}$ ~ 1 ×10^{-8} M_{sun}

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

Is it natural?

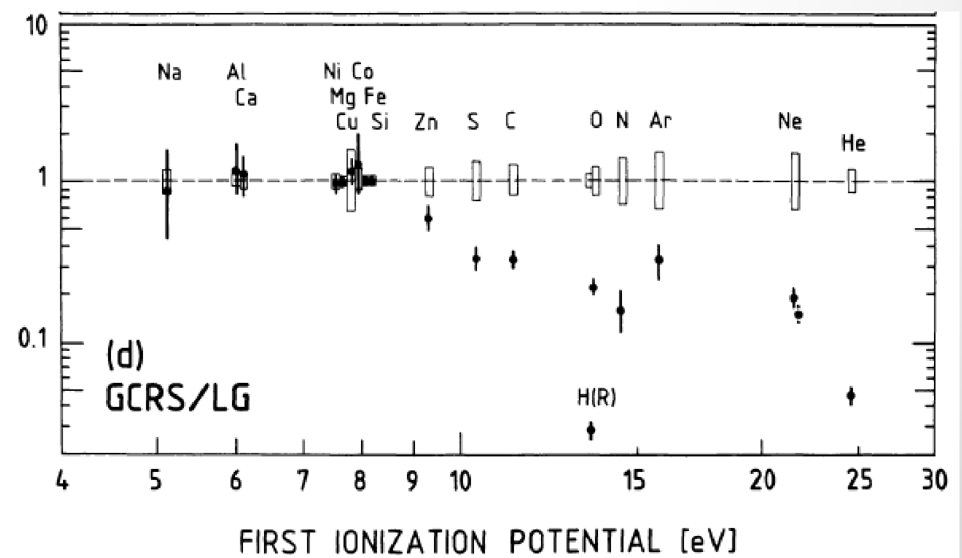
(1) total amount of accelerated particles

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



(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)
- Hard component in Carbon spectrum and steepening in B/C (Carbon is efficiently synthesized in novae)
- Anisotropy (existence of a nearby source)
- The isotopic ratio $^{7}Li/^{6}Li$ increases with energy above ~300 GeV (^{6}Li 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.