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

(arXiv:1707.00212)

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

TeVPA 2017 @ Columbus, OH, USA 7/8/2017

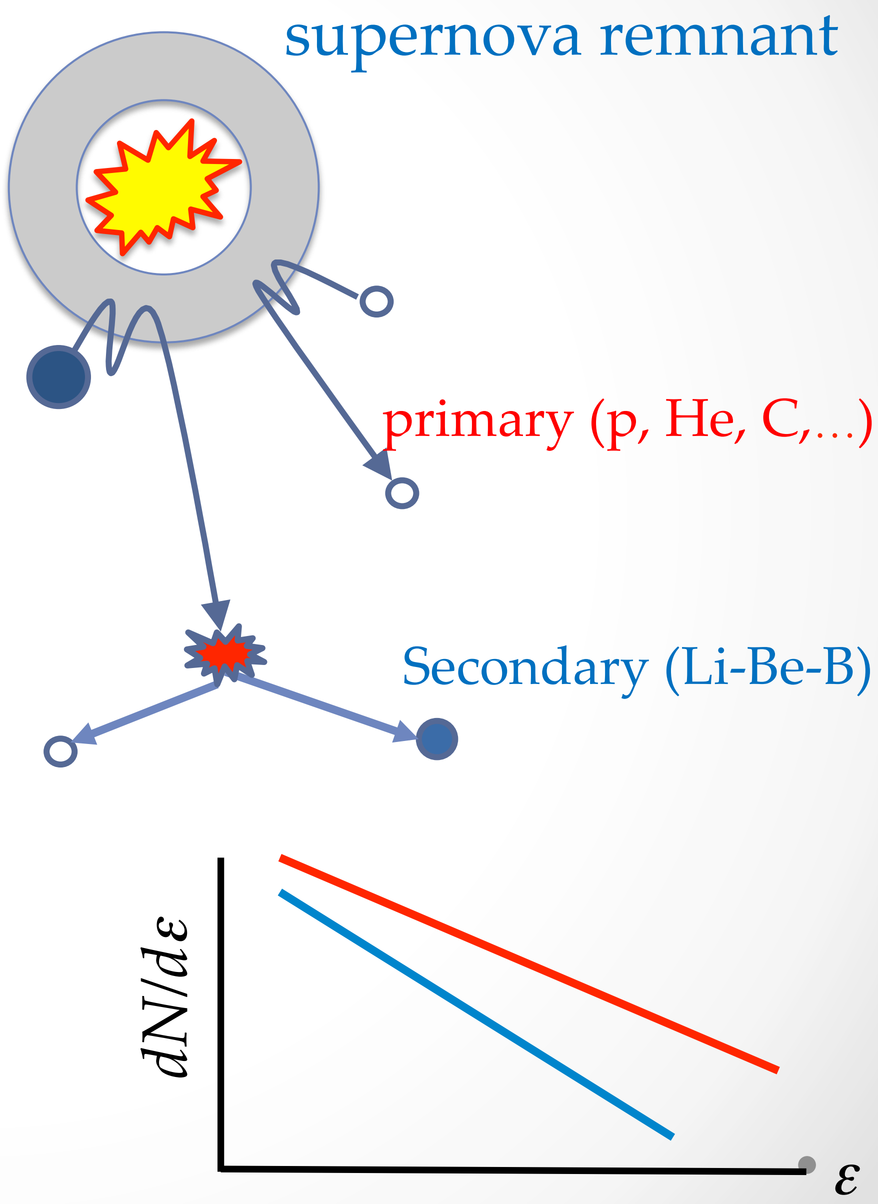
Galactic Cosmic-rays (p, He, Li-Be-B, C,...)

(probably) produced via shock acceleration at SNRs

<u>proton, He, C, etc.</u> : primarily produced at SNRs, power-law spectrum

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

However …



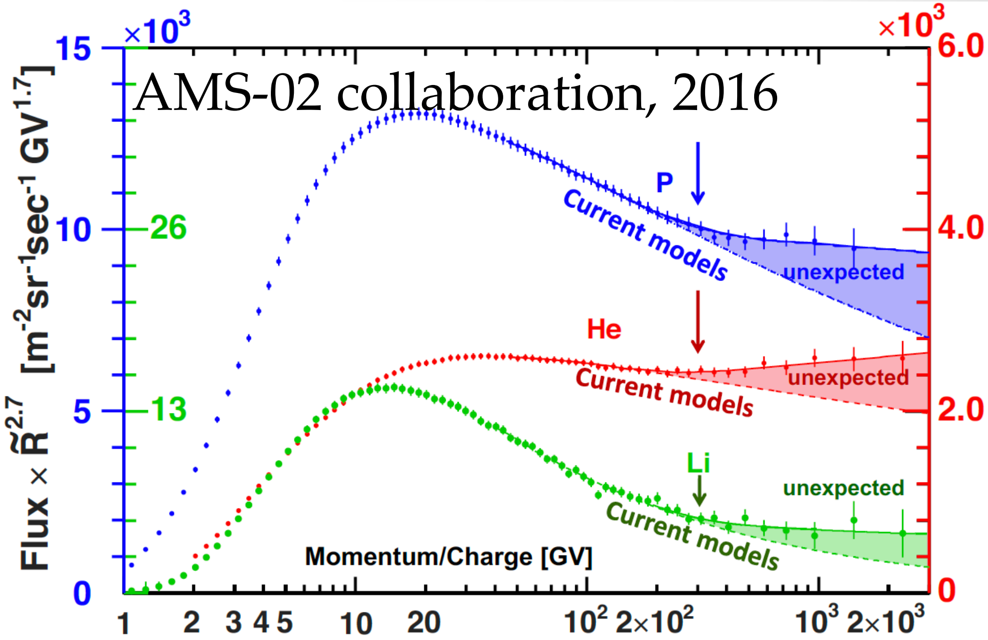
Spectral hardening of p, He, and Li

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

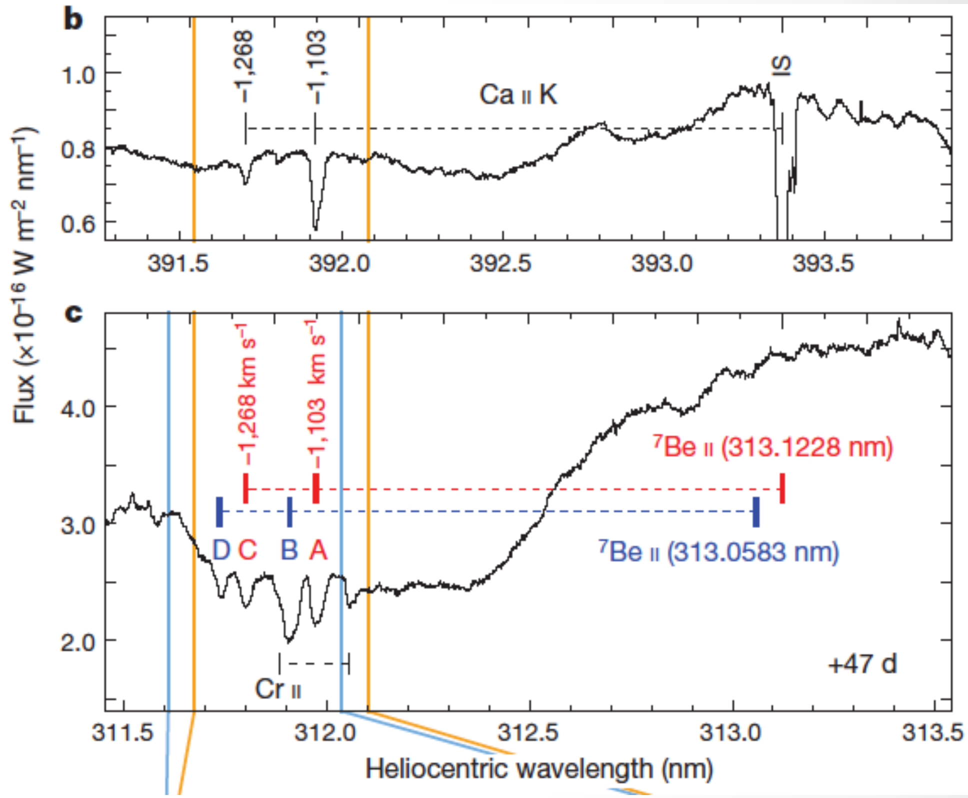
(3) The hard components have similar indices



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, $X(^{7}\mathrm{Be}) \sim 10^{-4}$
(Tajitsu et al. 2015)
… synthesized via
$^{3}\mathrm{He}(\alpha,\gamma)^{7}\mathrm{Be}$
→ decay into ^{7}Li by e^{-} capture ($\tau_{1/2} \sim 53.22$ days)



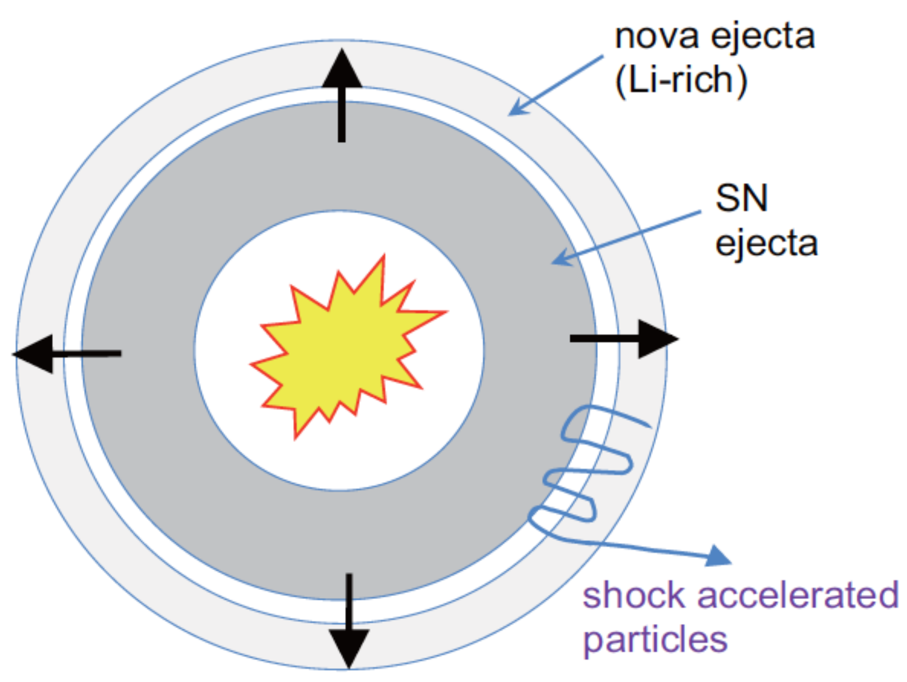
Tajitsu+ 2015

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)

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*

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

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

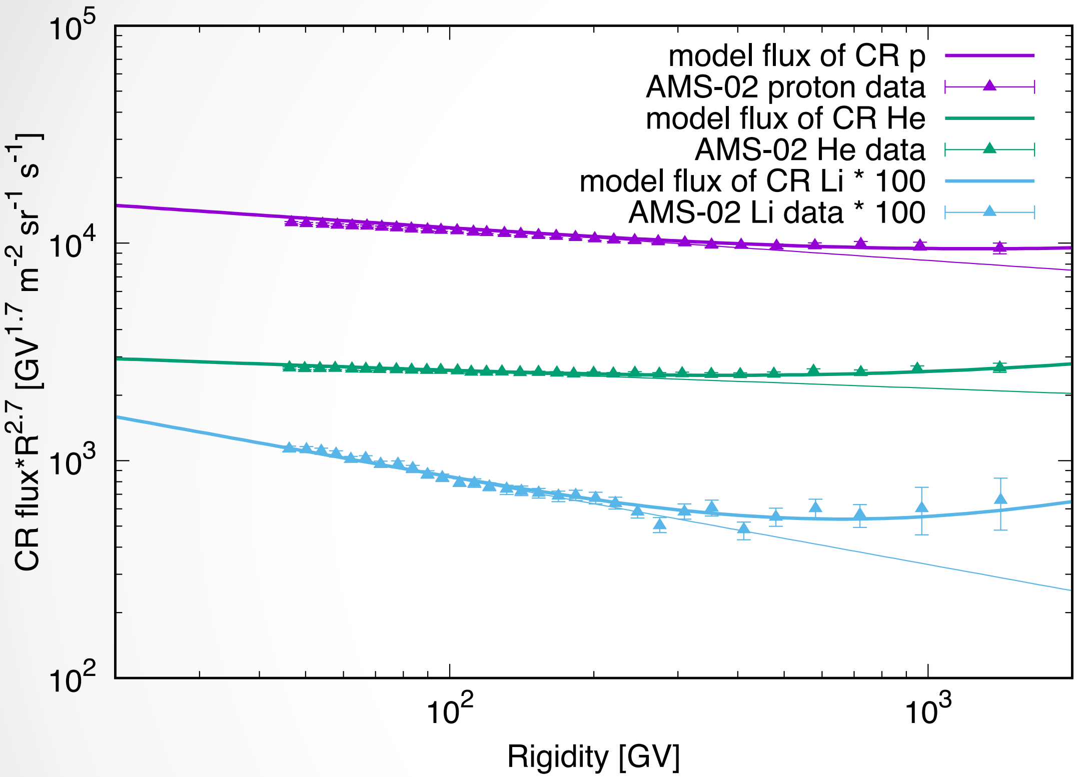
$$R_\mathrm{p} = \left[\frac{\delta}{\alpha + \frac{3}{2}\delta}\ \frac{r^2}{r_0^2}\right]^{1/\delta}$$

$r_0 = (4D_0 t)^{1/2}$: 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



$\underline{r = 150 \text{ pc}, t = 6\times10^3 \text{ yr},}$
$D = 1\times10^{28}\ (\varepsilon/1\ \text{GeV})^{1/3}\ \text{cm}^2\ \text{s}^{-1}$

total amount of CRs

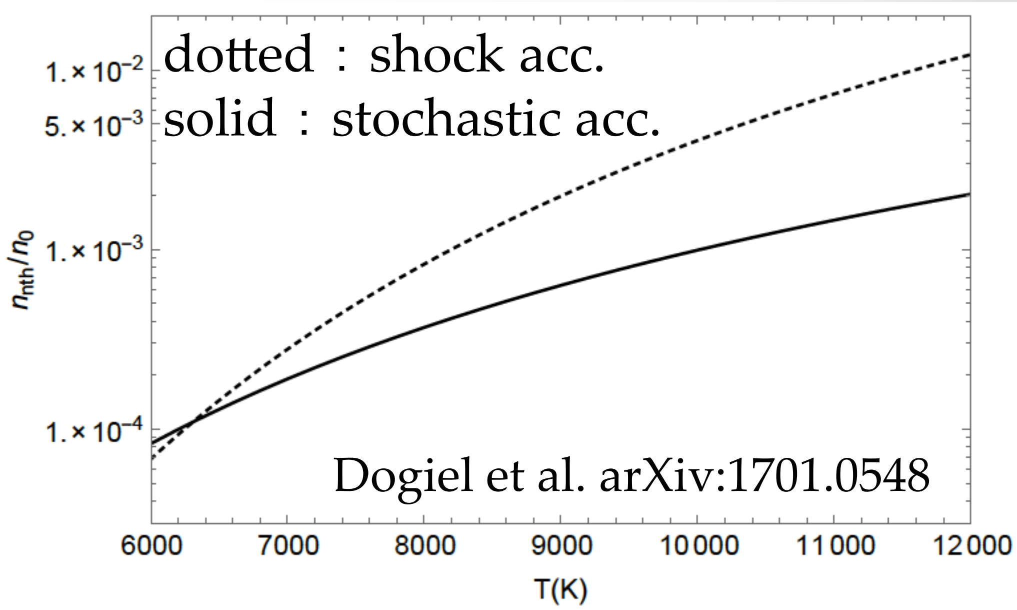
$\boldsymbol{M_{CR,p} \sim 2\times10^{-6}\ M_{sun}}$
$\boldsymbol{M_{CR,Li} \sim 1\times10^{-8}\ M_{sun}}$

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

Is it natural?

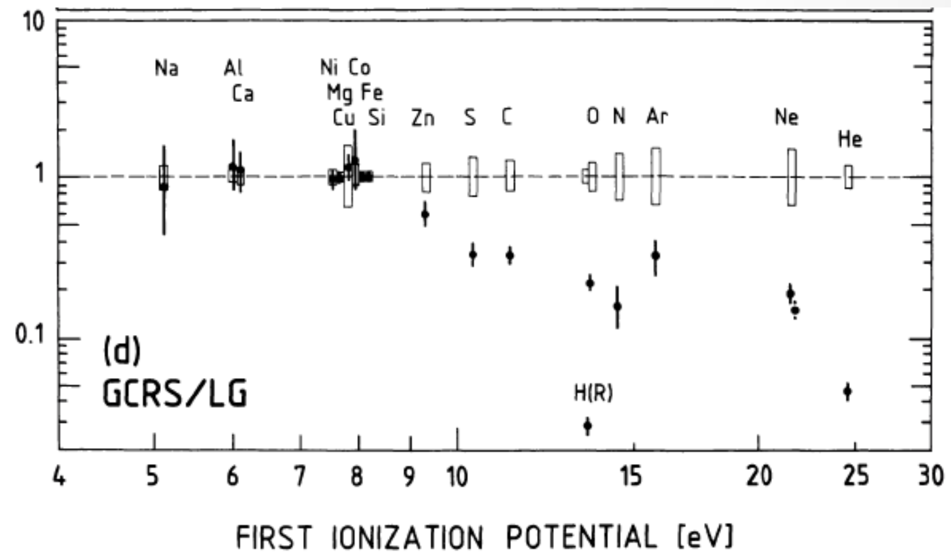
(1) total amount of accelerated particles

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)
- steepening in the B/C ratio (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.