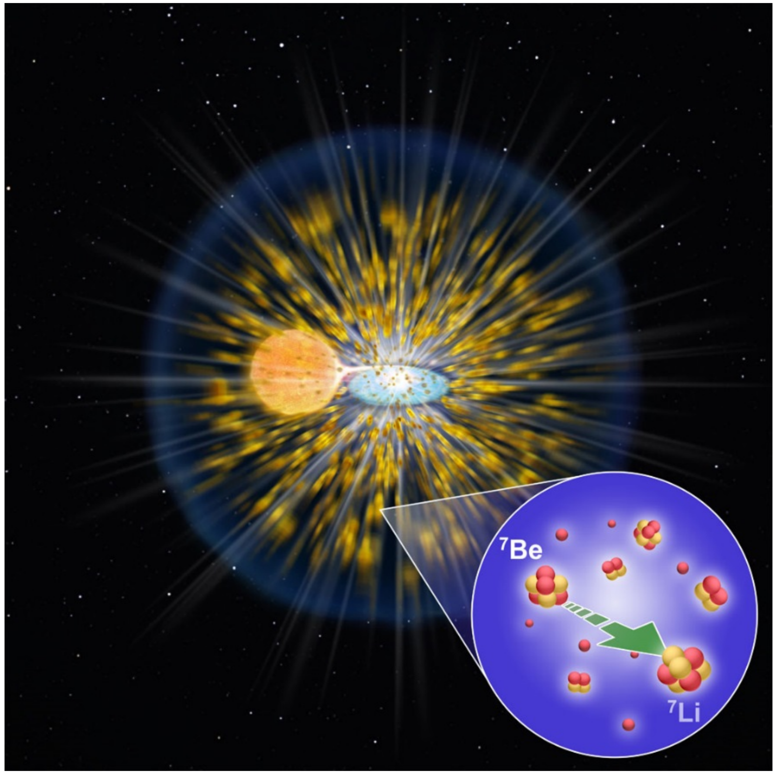
Discovery of Explosive Li Production in Classical Novae



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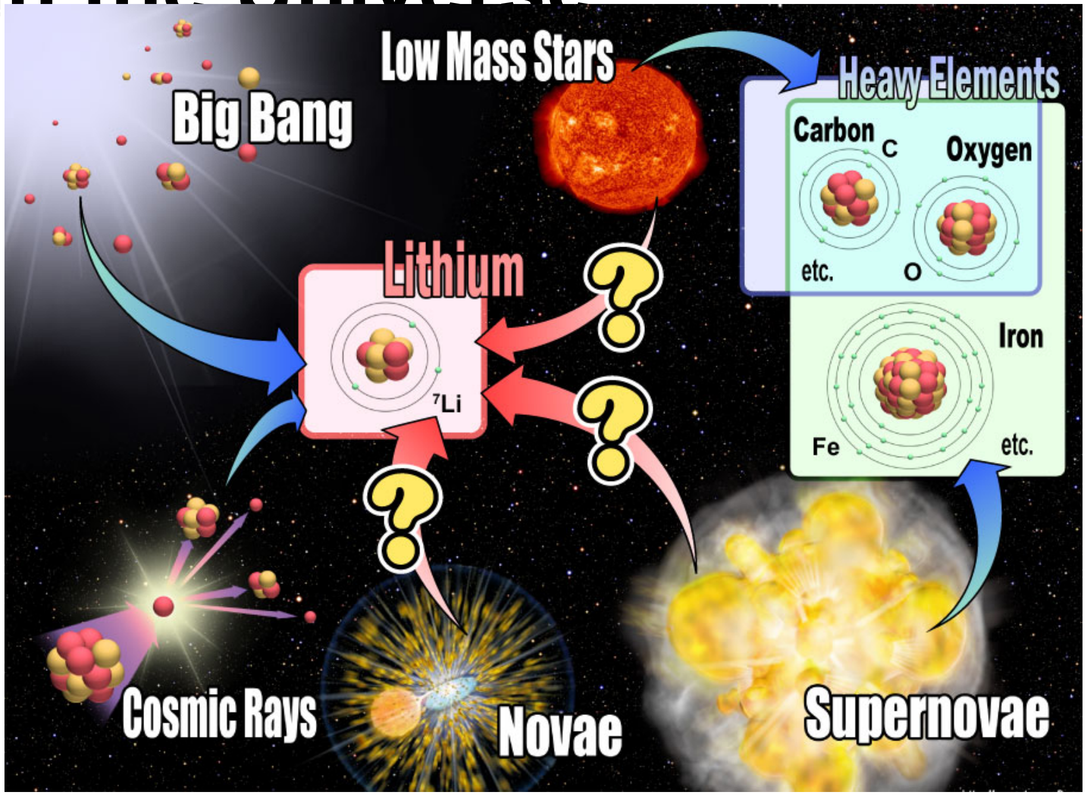
- Tajitsu et al. (2015) ① **Nova Del 2013**
  "Explosive lithium production in the classical nova V339 Del (Nova Delphini 2013)", **Nature 518, 381** (published in 2015.2.19)
- + Tajitsu et al. (2016) ApJ *in press* ② **Nova Sgr 2015 No.2 & ③ Nova Oph 2015**

<u>Lithium</u> — Key to Understanding the Nucleosynthesis in the Universe

- Big Bang nucleosynthesis
  H, He, and *(small amount of)* <u>Li</u>
- Heavy elements
  C, N, O, …., Fe, ….
  produced in ***stars and/or SNe***
- **Lithium** *(above +)*
  - Galactic **Cosmic Rays** (GCR)
    Interaction w/ISM
  - <u>Novae</u>



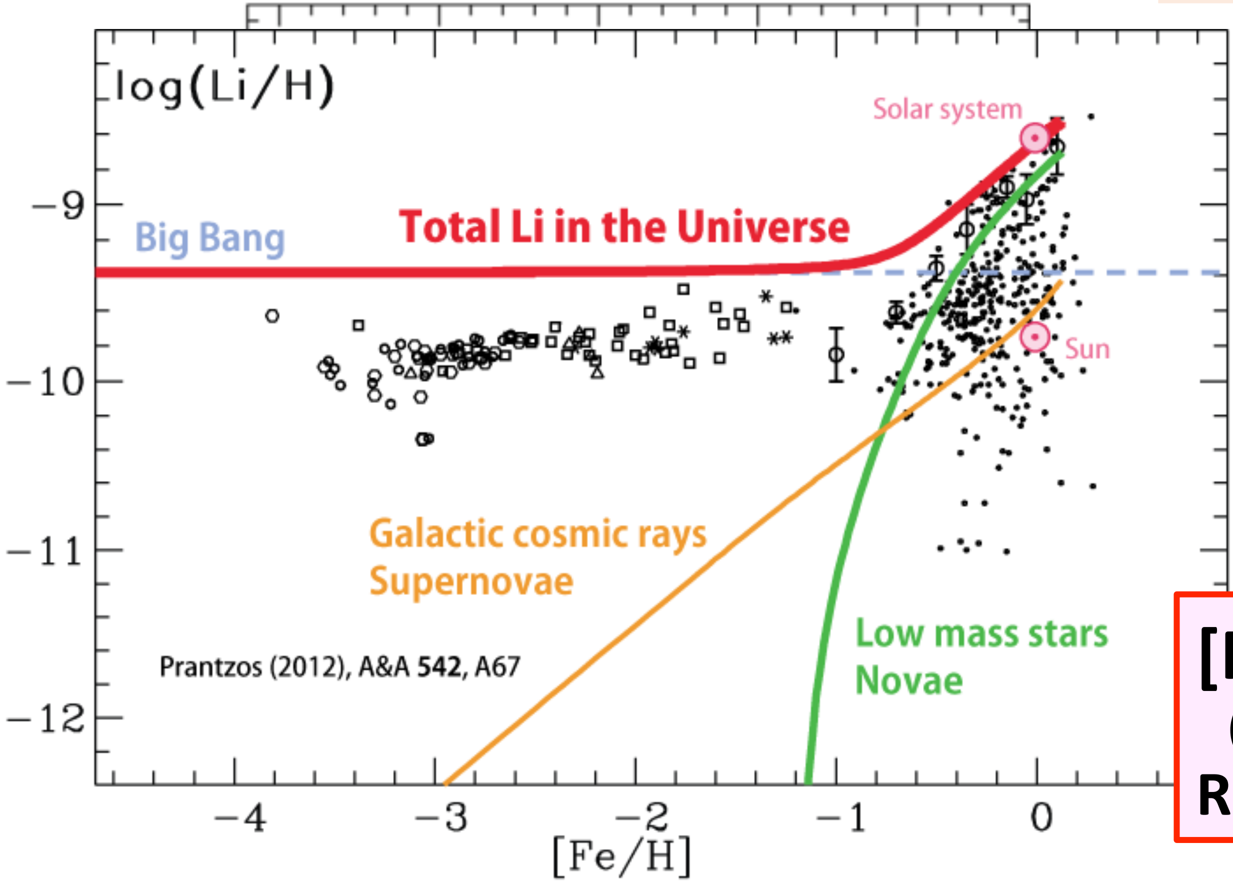
Li is the best indicator to probe the complete chemical evolution of the universe !

But, stellar origin Li suppliers (>60%) have never been confirmed…

Galactic Li evolution

[Li/H] is not proportional to [Fe/H].

Prantzos (2012), A&A **542**, A67



Lithium Evolution Curve
＝① + ② + ③

① Big Bang nucleosynthesis
SBBN + WMAP ～ 12%

② CCSN + GCR（massive star）
GCR ～20%, CCSN < 20%

③ RG, AGB, nova（low mass）
> 50% in solar system

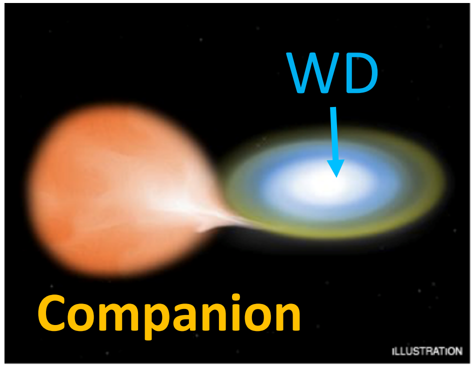
[Fe/H] > -1
(2.5 Gyr from Big Bang)
Rapid increase of Li

③（from low mass stars）is most dominant in current universe（>50%）

But, NO observational evidence!!

Li is destroyed at low T（～2.5MK）➡ hard to be produced in stellar interiors.
broken by convection etc.

^{7}Li production in classical novae



Cameron & Fowler (1971), ApJ **164**, 111

Boffin et al. (1993), A&A **279**, 173. Henanz et al. (1996) ApJ **465**, L27.

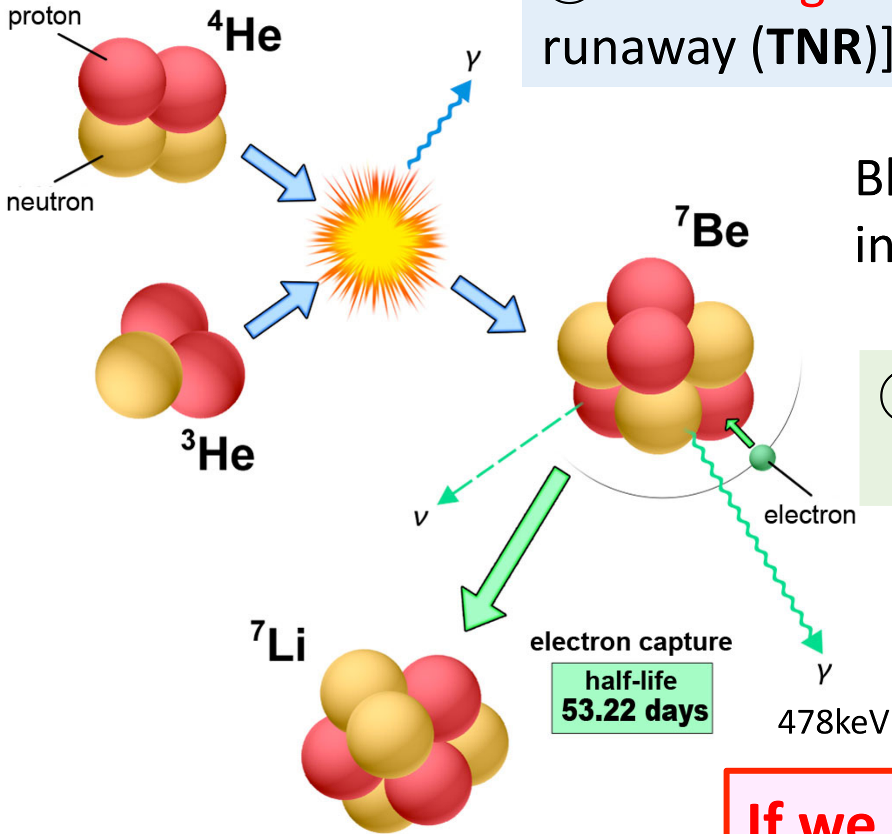
①H-burning on the surface of a WD [Thermonuclear runaway (**TNR**)] ⇒ **^{3}He(α,γ)^{7}Be** , simultaneously

⬇

Blow away the accumulated gas envelope involving **^{7}Be**

⬇

②**^{7}Be** decays into **^{7}Li** by electron capture in circumstellar gas clumps



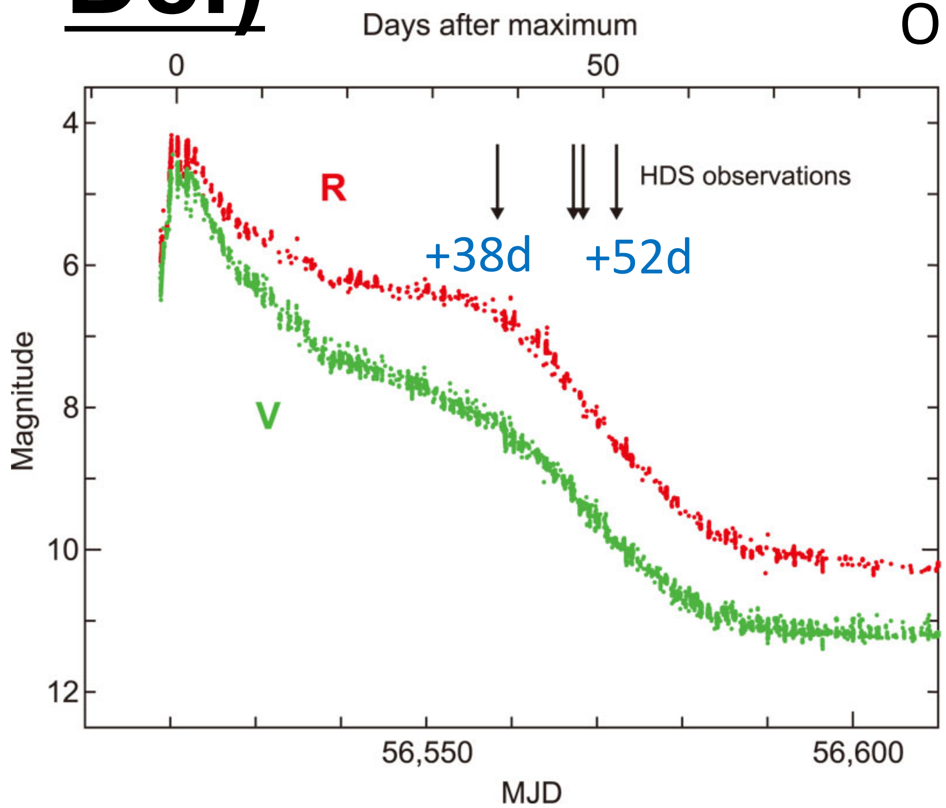
- ^{7}Li is not destroyed in hot environment
  ^{7}Li(p,α)^{4}He (T > 2.5 MK)
- ^{7}Be has a short lifetime (**$\tau_{1/2}$〜53d**)

If we found ^{7}Be ⇨ Production of ^{7}Li

But, NO observational confirmation!!

No detection of γ-ray (478keV) etc.

Nova Delphini 2013 (=V339 Del)



Optical max. 2d after its discovery

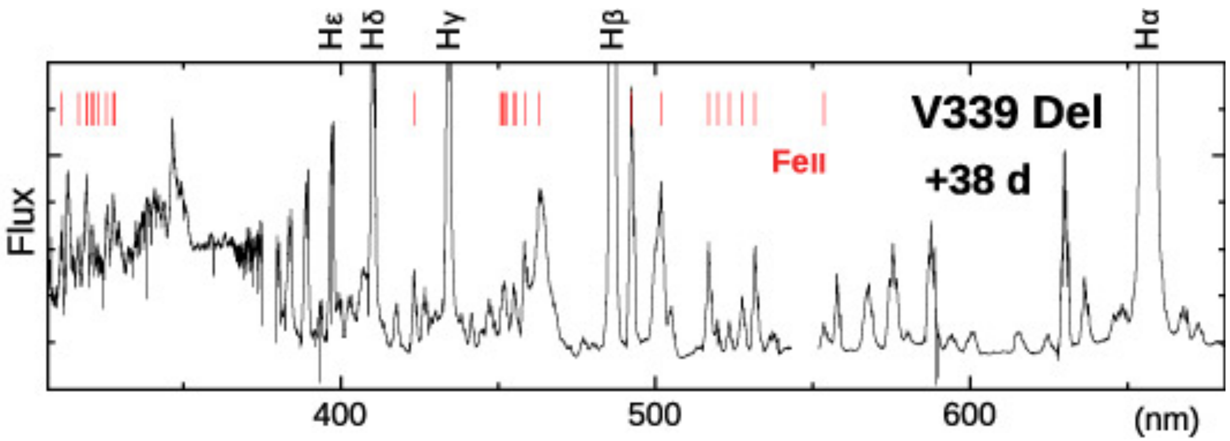
HDS observations

+38, +47, +48, +52d

（before & during rapid decline by dust formation）

- **λ～ 303-936 nm** (StdUb, Yb, NIRb)
- R～60,000-90,000

typical light curve style



- H I, He I, Fe II emission lines
  Fe II type nova
  ➡ ～60% of all novae
- **C-O WD** (No Ne lines)

One of the ordinary, well-known CO novae

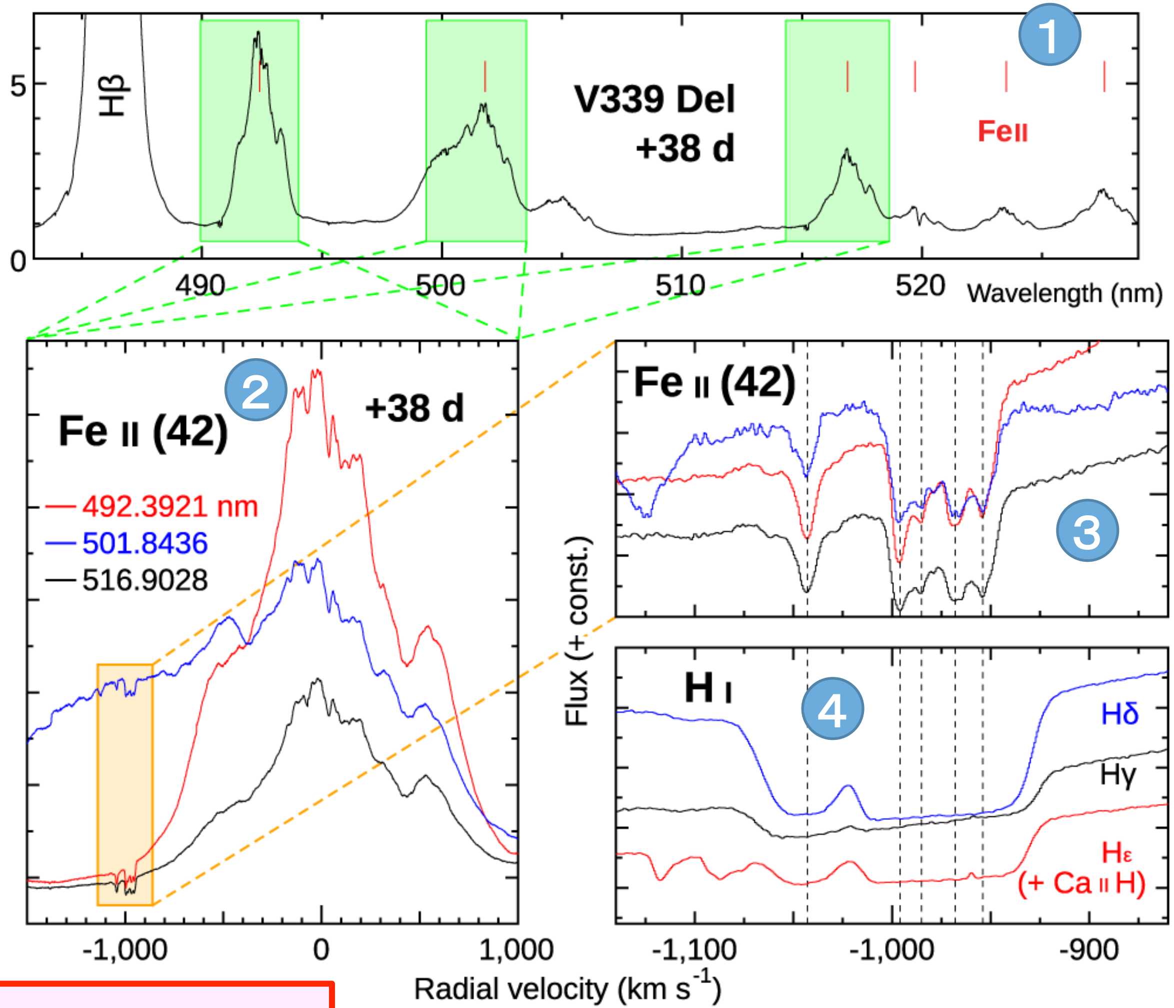
Spectrum of V339 Del (enlarged view)

1. Fe II emission (green)
   Multiplet (42)

2. Sharp, blue-shifted multiple absorption lines at blue edges

3. **Same shape, dips!!**
   - V_{rad} ~ -1000 km/s
   - Multiple components

4. Same components in H I Balmer and other lines



Many absorption lines in UV

Ti, Cr, Fe … permitted lines originating from

singly ionized Fe-peak elements

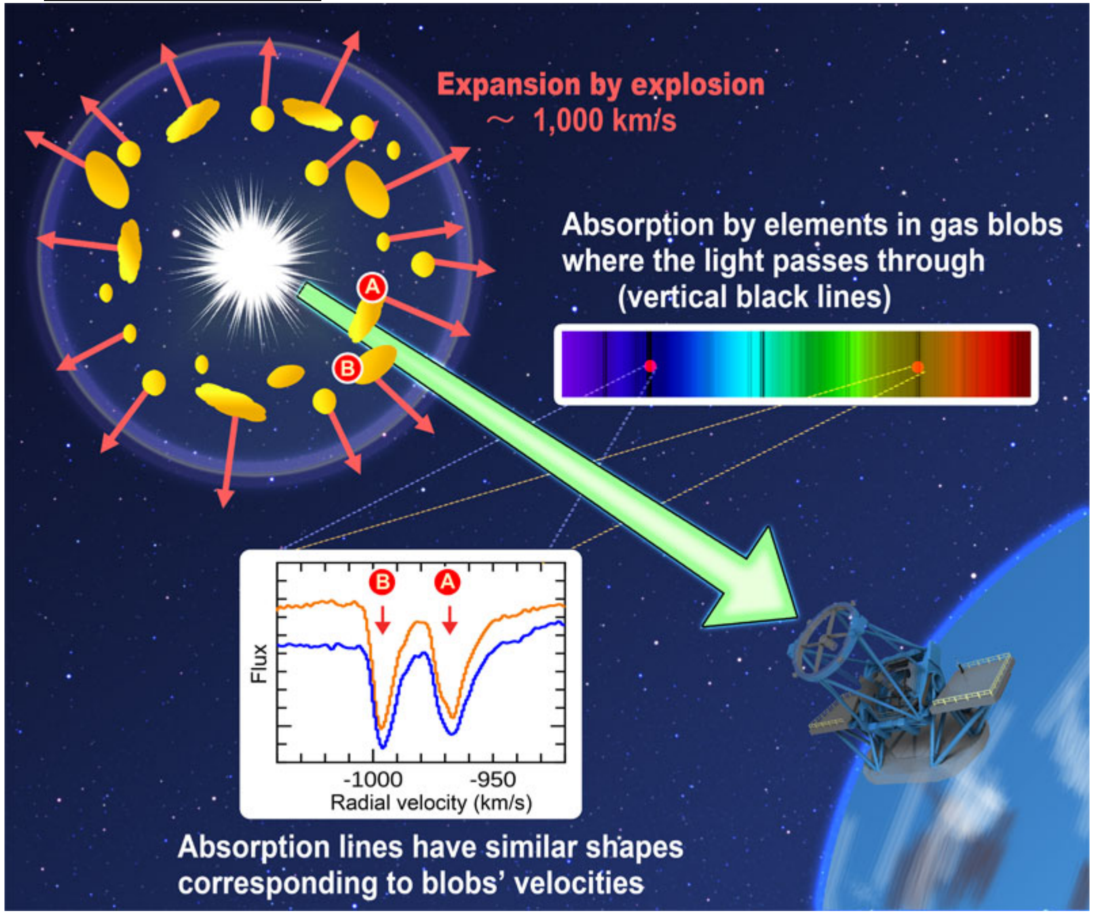
Low excitation potential (E_{low}< 4 eV)

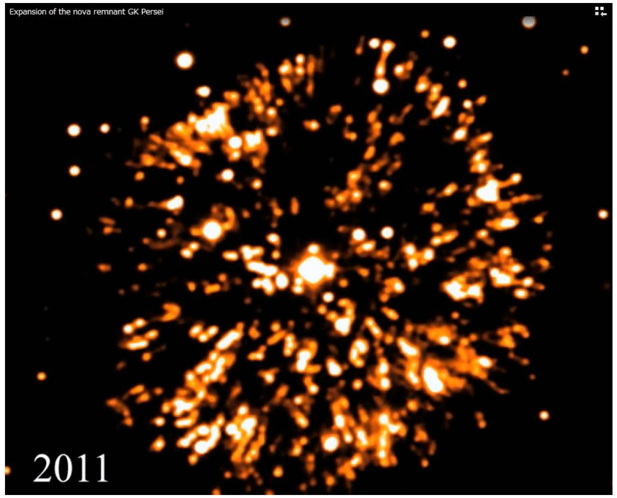
Transient **H**eavy **E**lement **A**bsorption

Williams+ (2008), ApJ **685**, 451

heavy element lines found only in 2-8 weeks after outbursts

What are the blue-shifted absorption lines?





Credit: Liimets et al., 2012, ApJ, **761**, 34 and AAS.

Nova Persei 1901 (GK Per)

110 years after its explosion

resolved due to its small distance (~460 pc) and long time duration after the explosion

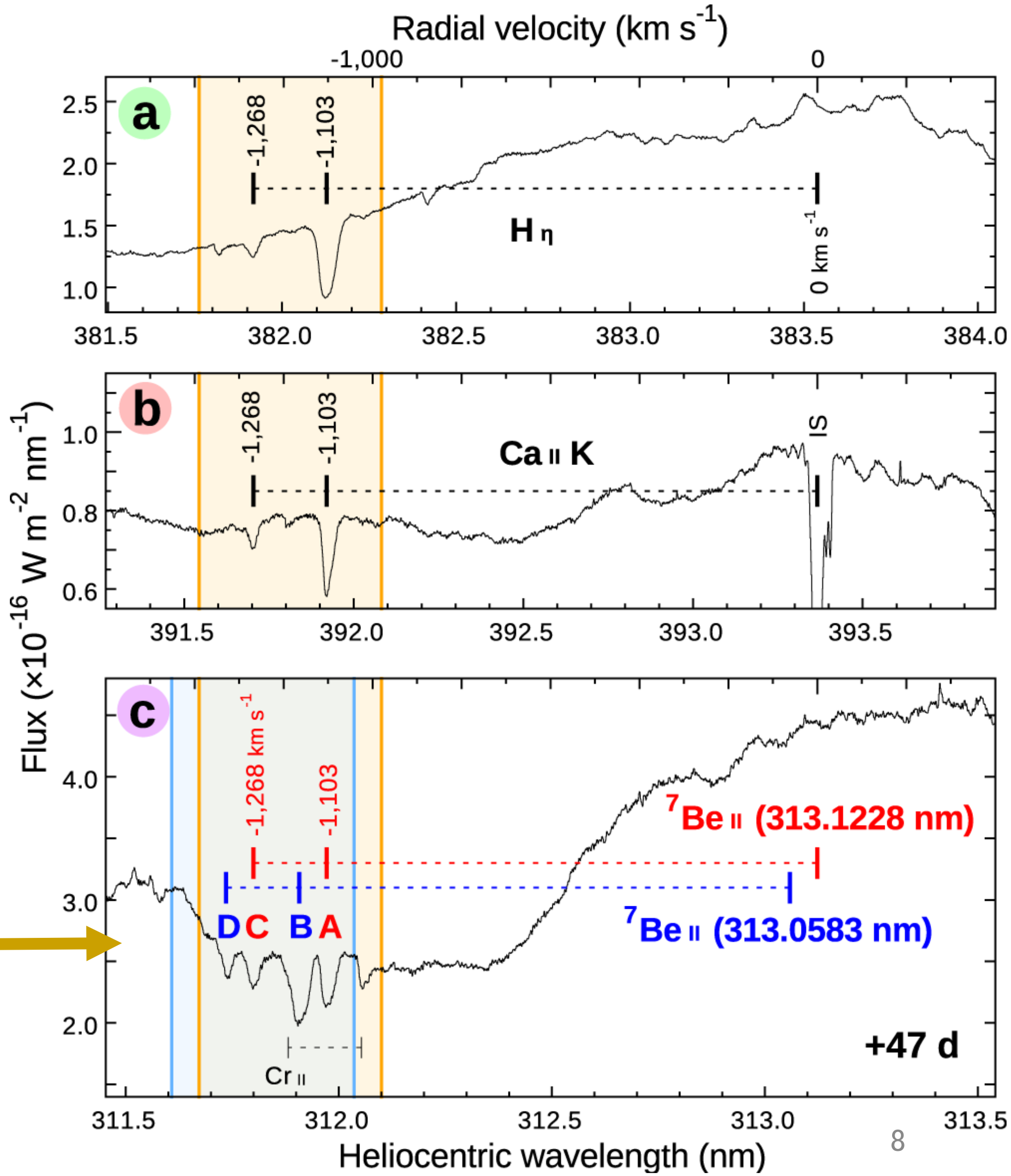
Elements in gas blobs blown away from the surface of a WD

Among these blue-shifted lines, we found absorption lines originating from **an isotope of beryllium（^{7}Be）!** ⇐ **should be produced during TNR**.

Detection / Identification of ^{7}Be ①

- +47d (2nd HDS Obs.)
- Two components in the blue-shifted absorption line system
  -1,103 km/s
  -1,268 km/s

At λ=312 nm in UV range
Resonance doublet
—— Singly ionized radioactive isotope of Be（^{7}Be II）



The velocity scale in the panel of ^{7}Be II is adjusted to one of the doublet（red）.
A & C coincide with two blue-shifted absorption components in H I & Ca II.

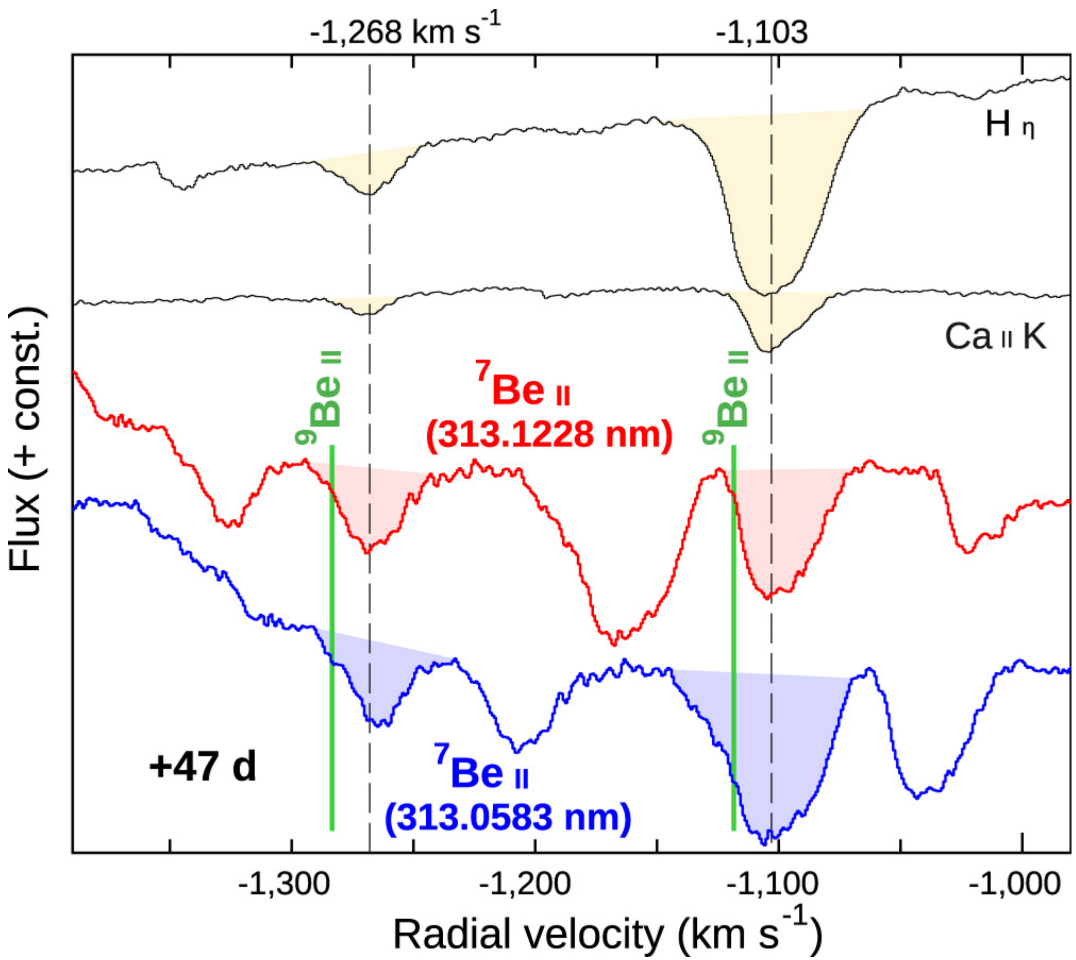
Detection / Identification of ^{7}Be ②

^{9}**Be** —— only the stable isotope of Be

only ^{7}Be is detected in the spectrum

^{7}Be is *unstable radioactive* isotope with $\tau_{1/2}$ = 53d

Detected ^{7}Be must be produced in *this* nova explosion !!



We detected neither **Li I λ670.8 nm** nor Na I D.

Both Li and Na are **ionized** ?

Isotopic shift : Δλ = 0.0161 nm (15.4 km/s)

Yan et al. (2008), Phys. Rev. Lett. **100**, 243002

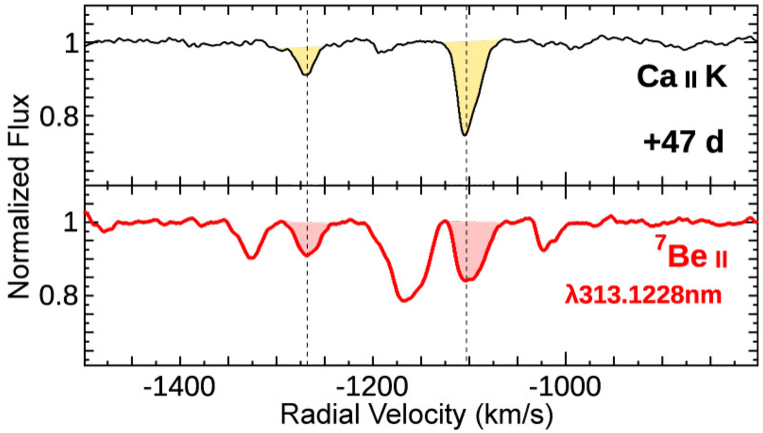
^{7}Be (= ^{7}Li) abundance in nova ejecta

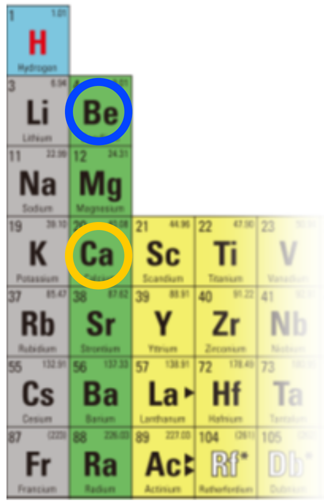
- Ca and Be —— **Group 2** elements

  Ca II HK lines & Be II λ313nm (**resonance doublet**)

  Similar transition in Term diagram

Direct comparison of absorption strengths → **^{7}Be/Ca ratio**

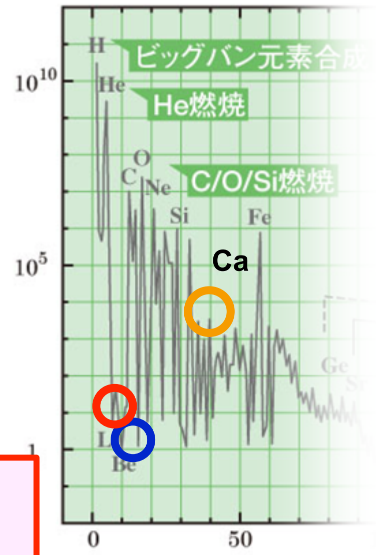




- **Similar strengths** between Ca and ^{7}Be

  → **The amount of produced ^{7}Li is comparable to that of Ca!!**

  Li ~ 0.1% of Ca in solar system



We confirmed the theoretical prediction that classical novae produce significant amount of Li !!

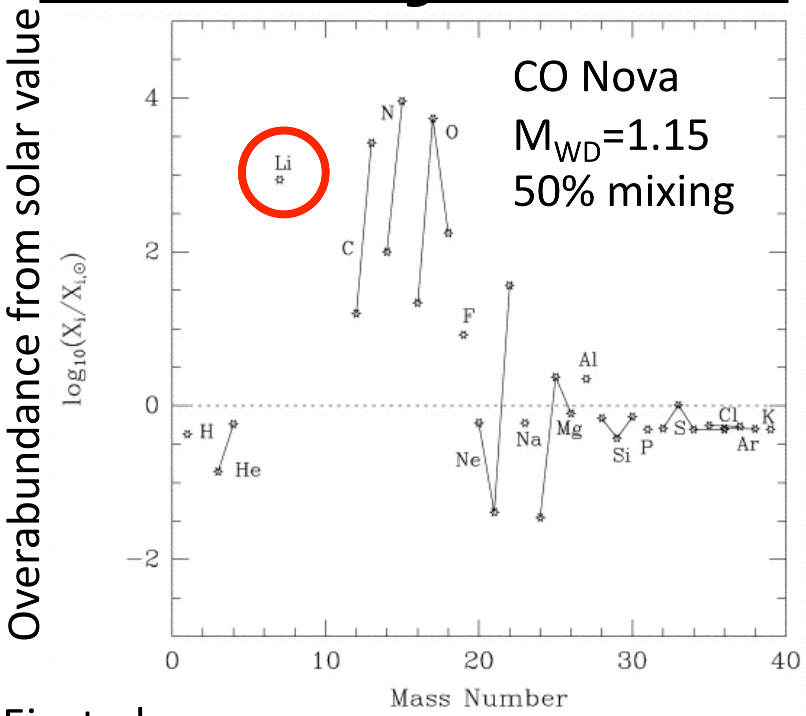
Theoretical prediction of nucleosynthesis

José & Hernanz (1998), ApJ **494**, 680

- yields from C-O/O-Ne Nova
- Most optimistic Li yields

Boffin et al. (1993), A&A **279**, 173

mass fraction: **$X(^7Be) < 10^{-5.1}$**



Ejected mass Yields from CO Nova Models (Mass Fractions)

Nucleus	CO1	CO2	CO3	CO4	CO5	CO6	CO7[a]
	Model						
^{1}H	5.1E – 1	3.3E – 1	3.2E – 1	4.7E – 1	3.0E – 1	1.2E – 1	3.0E – 1
^{3}He	7.0E – 6	9.2E – 6	6.1E – 6	1.5E – 6	4.1E – 6	2.8E – 6	3.7E – 6
^{4}He	2.1E – 1	1.4E – 1	1.5E – 1	2.5E – 1	1.6E – 1	9.0E – 2	1.6E – 1
^{7}Be	4.4E – 7	9.6E – 7	3.1E – 6	6.0E – 6	8.1E – 6	4.0E – 6	3.1E – 6
^{11}B	1.1E – 13	2.2E – 14	1.7E – 12	2.6E – 11	2.2E – 11	7.4E – 12	1.9E – 12
^{12}C	1.4E – 2	5.3E – 2	3.6E – 2	2.9E – 2	4.8E – 2	6.8E – 2	3.2E – 2
^{13}C	3.4E – 2	1.1E – 1	1.3E – 1	4.4E – 2	9.6E – 2	1.9E – 1	1.0E – 1
^{14}N	9.5E – 2	1.1E – 1	1.1E – 1	7.1E – 2	1.1E – 1	1.4E – 1	1.4E – 1
^{15}N	9.9E – 4	9.3E – 4	6.2E – 3	2.3E – 2	4.0E – 2	2.9E – 2	5.5E – 3
^{16}O	1.3E – 1	2.5E – 1	2.4E – 1	8.6E – 2	2.1E – 1	3.4E – 1	2.3E – 1
^{17}O	3.3E – 3	4.4E – 3	8.0E – 3	1.2E – 2	2.1E – 2	1.9E – 2	8.6E – 3
^{18}O	8.4E – 4	5.6E – 4	2.2E – 3	4.4E – 3	3.8E – 3	3.7E – 3	3.9E – 3
^{19}F	8.5E – 7	4.4E – 7	9.9E – 7	5.0E – 6	3.4E – 6	1.8E – 6	1.7E – 6
^{20}Ne	1.2E – 3	8.2E – 4	8.5E – 4	1.4E – 3	9.7E – 4	5.2E – 4	8.7E – 4
^{21}Ne	2.9E – 8	4.0E – 8	5.6E – 8	1.9E – 7	1.7E – 7	7.2E – 8	3.4E – 8
^{22}Ne	2.6E – 3	5.0E – 3	5.0E – 3	2.2E – 3	4.8E – 3	7.3E – 3	5.0E – 3
^{22}Na	3.4E – 7	3.0E – 7	1.6E – 7	3.8E – 7	2.9E – 7	1.1E – 7	8.5E – 8
^{23}Na	3.6E – 5	3.6E – 5	3.4E – 5	1.6E – 5	2.0E – 5	2.4E – 5	3.4E – 5

Observed ^{7}Be in V339 Del

- Ca = solar abundance $X(Ca) \sim 10^{-4.2}$
- All Ca and ^{7}Be are **singly ionized**
- **Color of BG** light is ignored
- Log(gf) Ca II K = +0.135
  Be II λ3131 = -0.479

$X(^7Be) \sim 10^{-4.3 \pm 0.3}$

Impact of this Research

Direct Confirmation of Li Production in Classical Novae

➡ First observational evidence of **Li supply from stellar origin objects to ISM**

➡ This discovery **confirms the theoretically predicted chemical evolution model** from the Big Bang to the current universe.

Future Perspectives

How much contribution of novae in Galactic Li evolution?

- Significant amount of Li is actually produced in V339 Del.
- V339 Del —— one of the **very ordinary type novae**（C-O WD, Fe II type）
- The **observed amount of Li** produced in this nova is **higher than predicted by theoretical estimates**. (x 6-10 in ^{7}Be abundance ratio)

Nova explosions may be very major Li suppliers in the universe?

More obs. of various types of classical novae will answer the question.

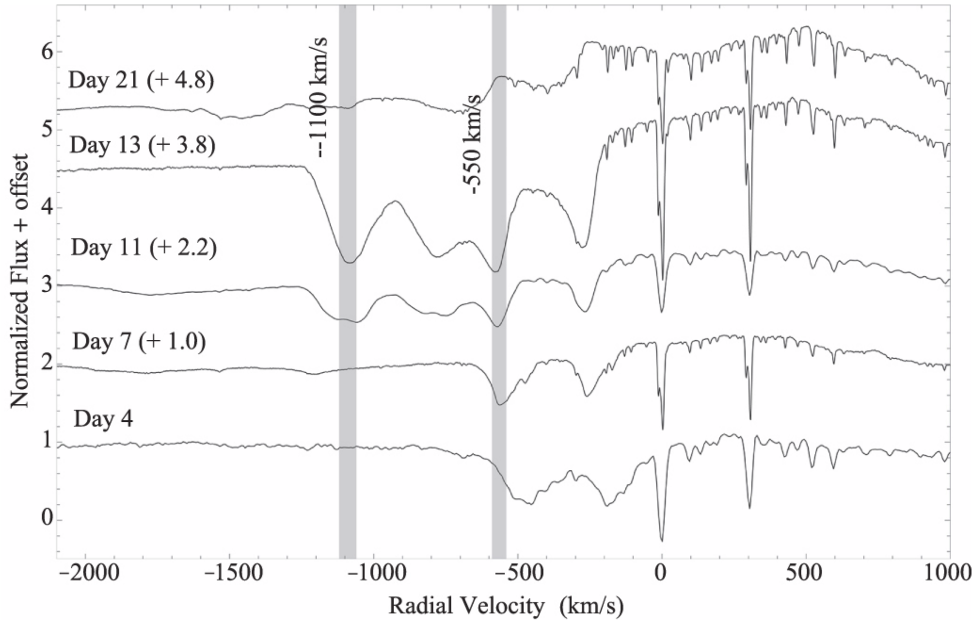
20-40 novae/yr in Galaxy (~**10 novae/yr discovered**)

1st detection of Li I λ6708 in classical nova

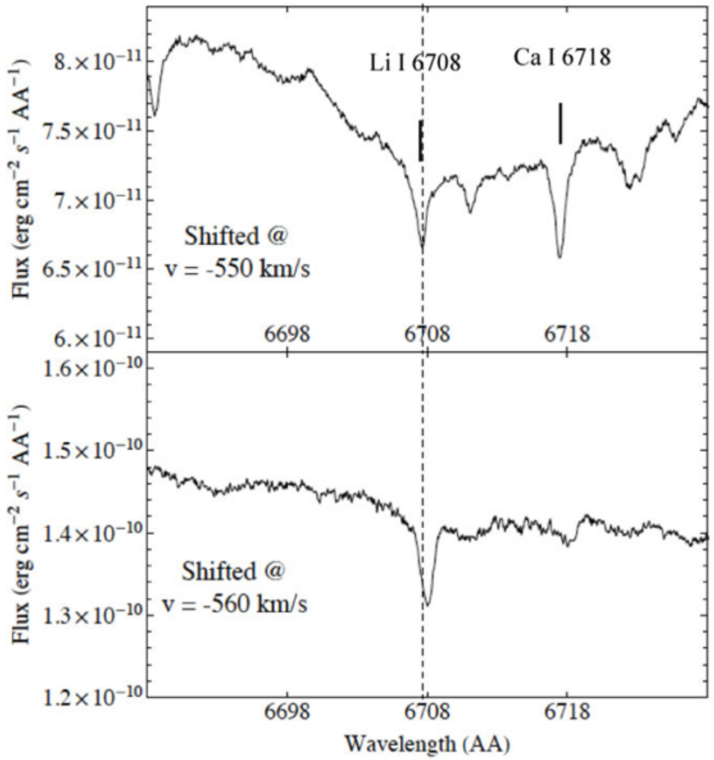
Nova Cen 2013 (+7d, +13d)

Izzo et al. 2015, ApJ **808**, L14

Na I D



Li I



X(Li) ∼ $10^{-4.3 - -6.5}$

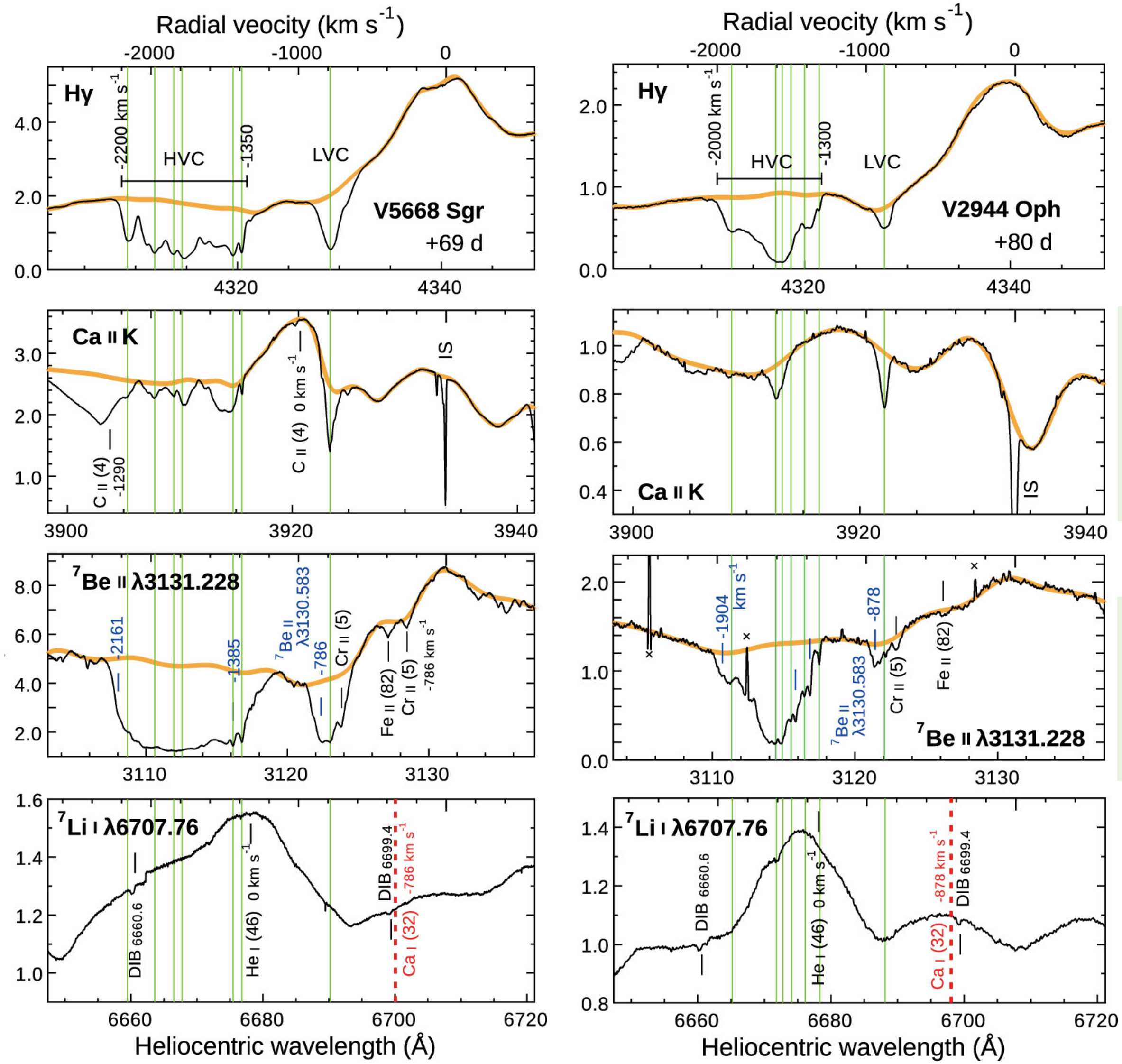
We **never detected Li I** in V339 Del.

^{7}Be detection in novae : 2nd & 3rd sample

Tajitsu+ (2016), ApJ *in press*

^{7}Be ② Nova Sgr 2015 No.2 | **^{7}Be ③** Nova Oph 2015

X(^{7}Be) ～ $10^{-4.0}$ | **X(^{7}Be) ～ $10^{-4.5}$**



～ 12 – 4 times higher than simulation by José & Hernanz (1998)

LVC ～ -800 km/s

HVC ～ 2000 – 1300 km/s

Li I λ6708 might be **rarely detected** in blue-shifted absorption line systems of post-outburst novae.

On the other hand, the detection of **^{7}Be II λ3131** might be **rather common**.

Ionization state?

Li I λ6708
No detection

There is no doubt that explosive Li production is popular phenomenon among classical novae !!

- We **never detected Li I** in observed 3 novae in which the ^{7}Be II doublet is detected.

  Ionization state in absorbing gas?

- Model of the **blue-shifted absorption** line system?

  The system (including H I, Fe II, Ca II, … and ^{7}Be II) is ***disappeared*** *in +52 d (V339 Del).*

  Covering factor? Background light source?

- How about in **ONe** novae?

  Our observed 3 novae seem to have CO WD.

⇨ More samples + "Time-monitoring spectroscopy" of Li and ^{7}Be

ToO w/Subaru-HDS (Arai et al.) S15B 0.5x6 nights, ~~S16A~~ ×

Li production in O-Ne vs. C-O novae?

Modeling of absorbing ejecta etc.

End of presentation