

# The lithium riddles

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20 ref papers in common (45 nr)



*In collaboration with*

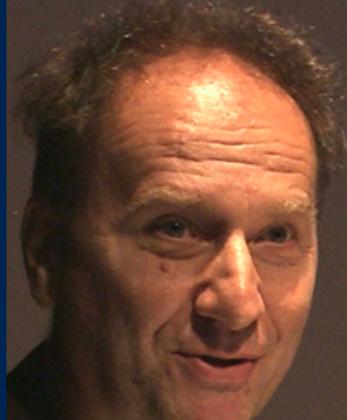
**Luca Izzo**



**Piercarlo  
Bonifacio**



**Gabriele  
Cescutti**



**Pierluigi  
Selvelli**

**Massimo  
della Valle**

**Guido Cupani**

**et al. ....**

# The “major” Lithium riddles:

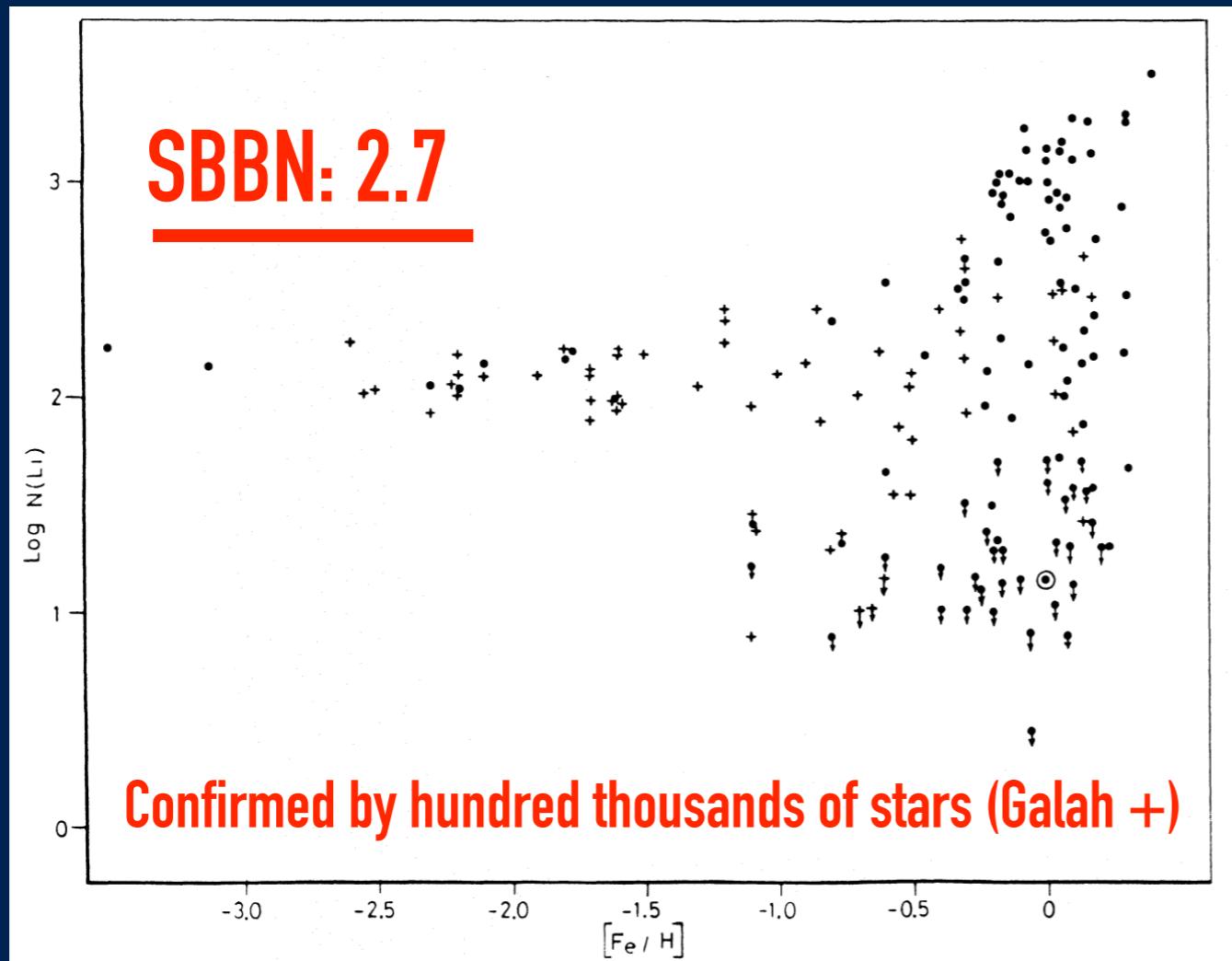
1. What is the primordial value of Li?
2. What is the astronomical origin of the rest?

SBBN

Rebolo PM Beckman 1988; PM phd 1987

-1.1

GALAH  
1 million stars



Meteorites:  $A(Li)=3.3$

From 2.7 (or 2.2) to 3.3  
what are the sources?

$$A(Li) = \text{Log}(Li/H) + 12$$

# Li sinks:

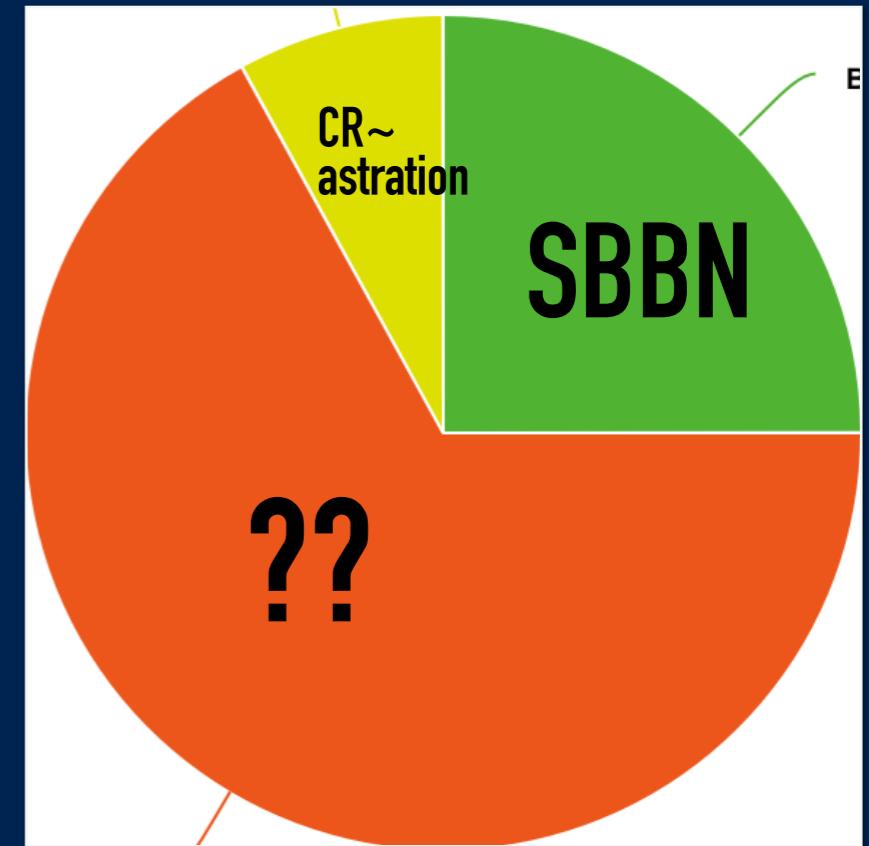
- Li destroyed inside stars

$$^7\text{Li}(\text{p},\text{a})^4\text{He} \sim 2 \times 10^6 \text{ K}$$

- astration: -10%

# Li sources

- Primordial 10-20%
- CNO Spallation ~10% (from  $^9\text{Be}$ )
- AGB <2%
- Red Giants ? (Li-rich RG <1-2%)
- Novae? ~10% theoretical yields, Li searched unsuccessfully for years



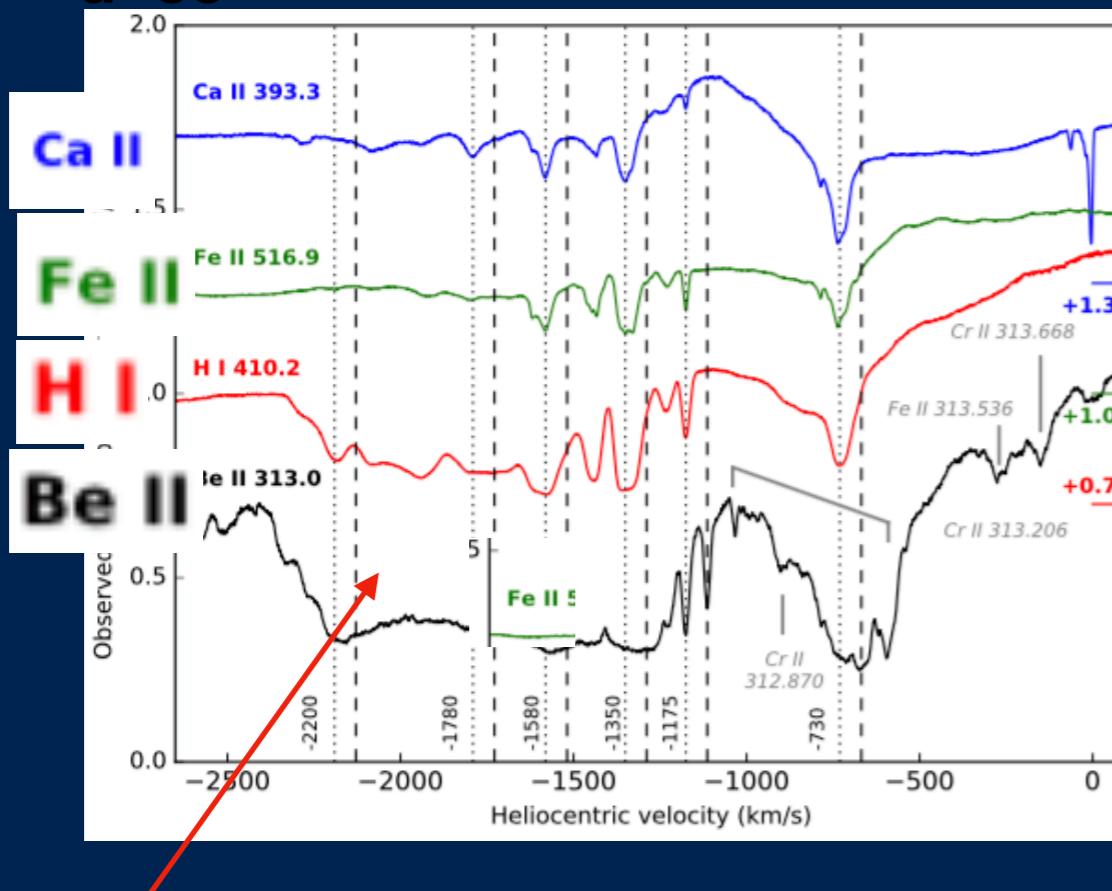
In the more optimistic way > 50% not accounted

# $^{7}\text{Be}$ in novae

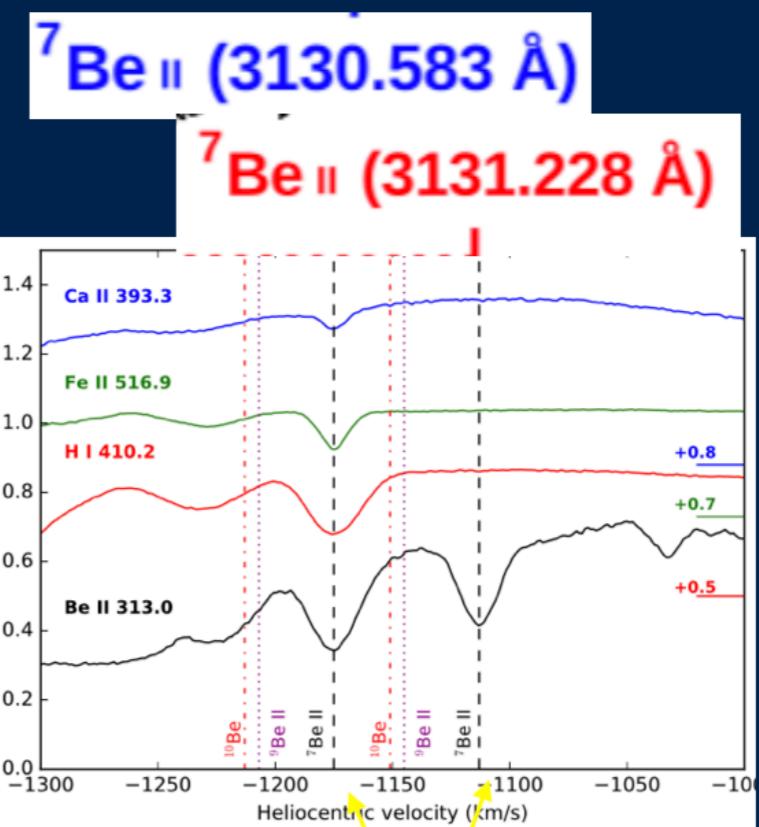
- Nova Del 2013

Tajitsu, Sadakane, Naito, Arai & Aoki 2015

d=PM+2016



$^{7}\text{Be}!$



$^{7}\text{Be}$  not  $^{9}\text{Be}!$

Perfect separation 61.8 km/s

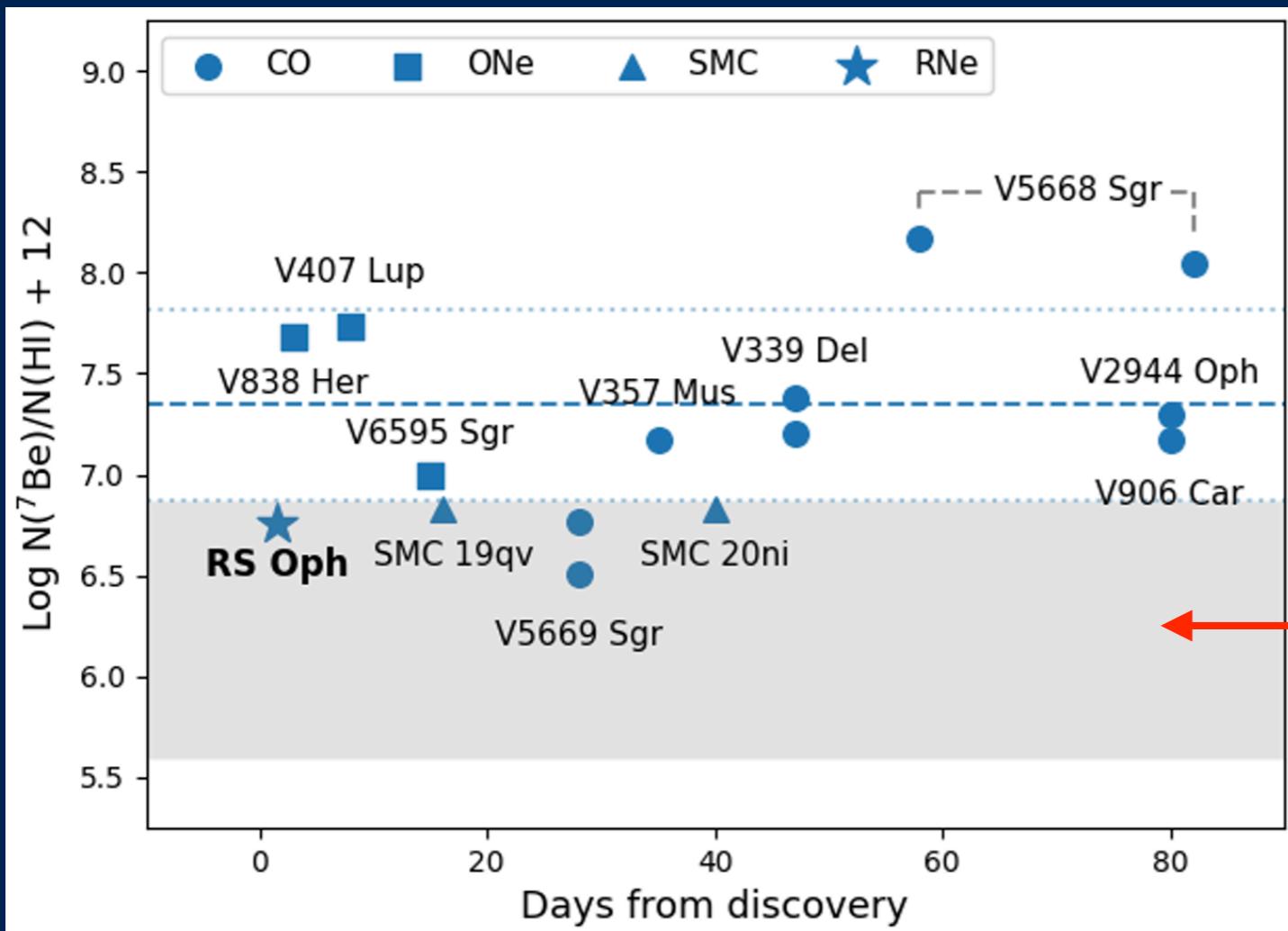
→ TNR shows reactions make  $^{7}\text{Be}!$   
(the only place where you can see  $^{7}\text{Be}!$  !)

# $^{7}\text{Be}$ (= $^{7}\text{Li}$ ) yields

- Unsaturated and resolved components
- Relative to CaII, or MgII (assumed solar)
- CaII and BeII dominant ionisation stage

- 8 CO, 3 ONe , 2 SMC 1 RN

PM+ 2023 and references there in



Nova Models  
Starrfield+20,23

Tension with theory!

$\langle \text{A(Li)} \rangle \sim 7.4 !!$

4 dex > meteoritic

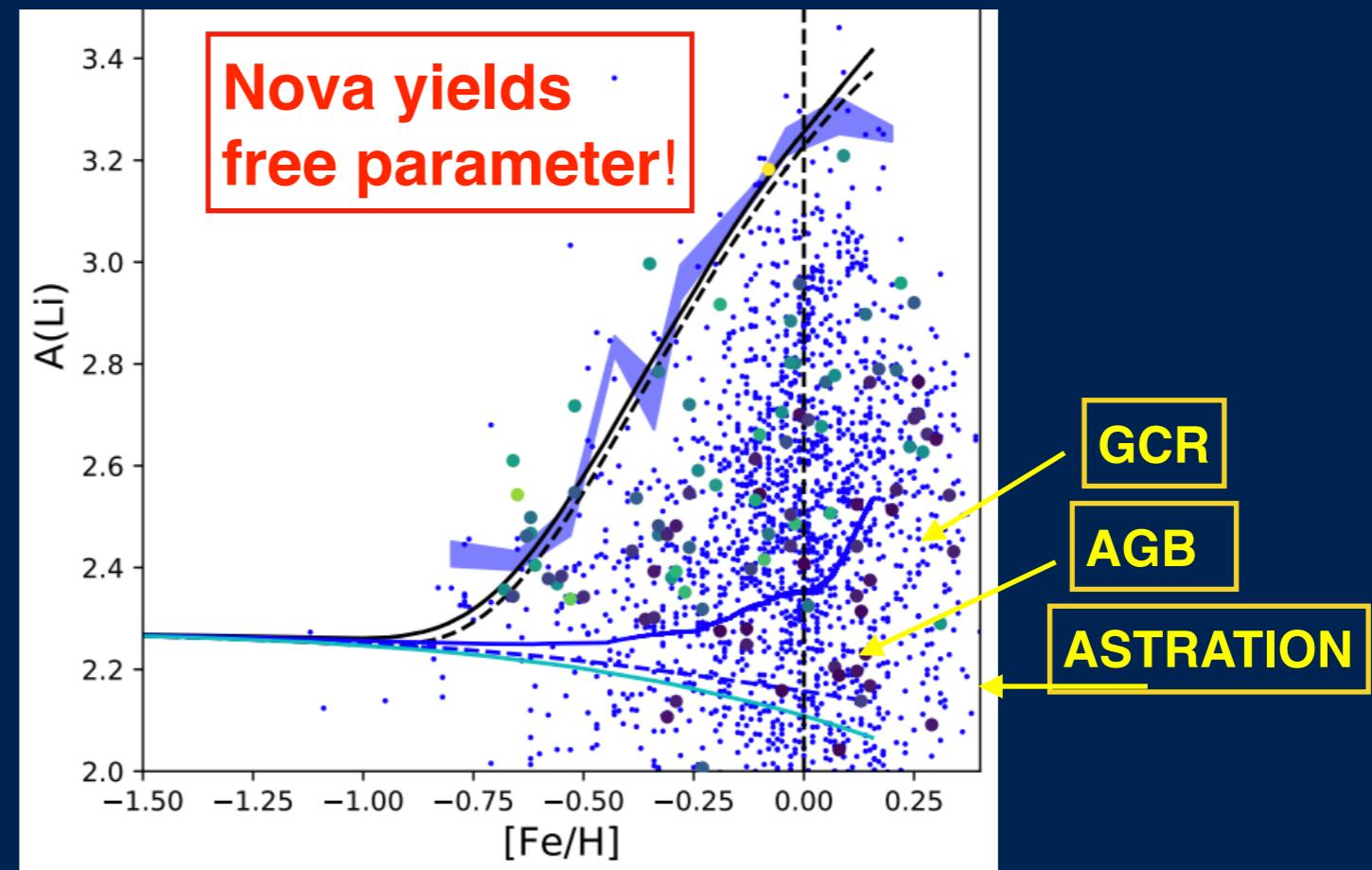
# Nova contribution to the Galactic Li?

$^7\text{Li}$  nova event for ejecta =  $10^{-5} M_\odot$  (could be  $10^{-4} M_\odot$ )

$$^7\text{Li} \sim 1.4 \times 10^{-9} M_\odot$$

Cescutti & PM, 2019

- State of the art CE model(Romano+01)
- Li Sources:
  - AGB+GCR+BBN
  - CN to match the observed rate



$$\text{Required: } 1.8 \times 10^{-9} M_\odot$$

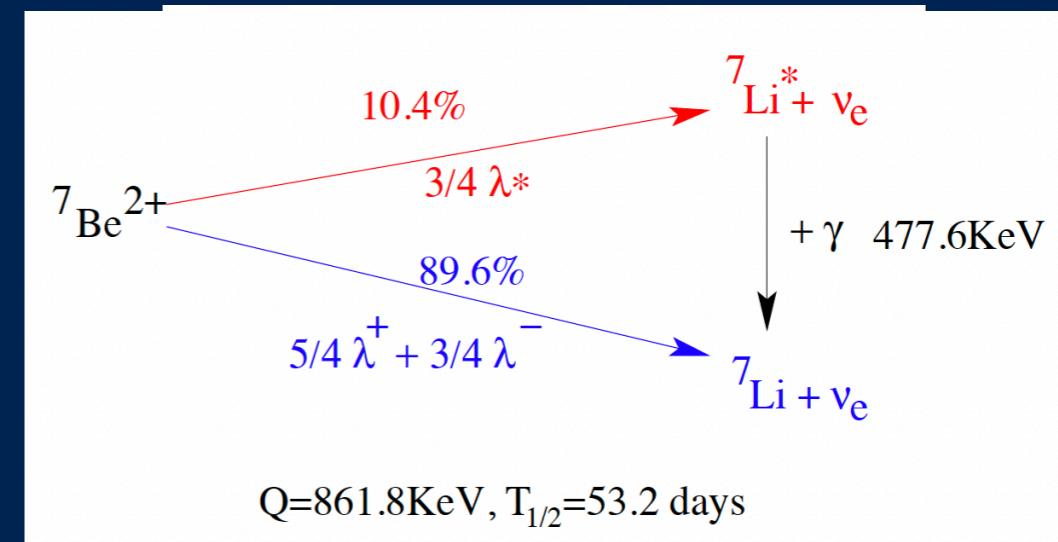
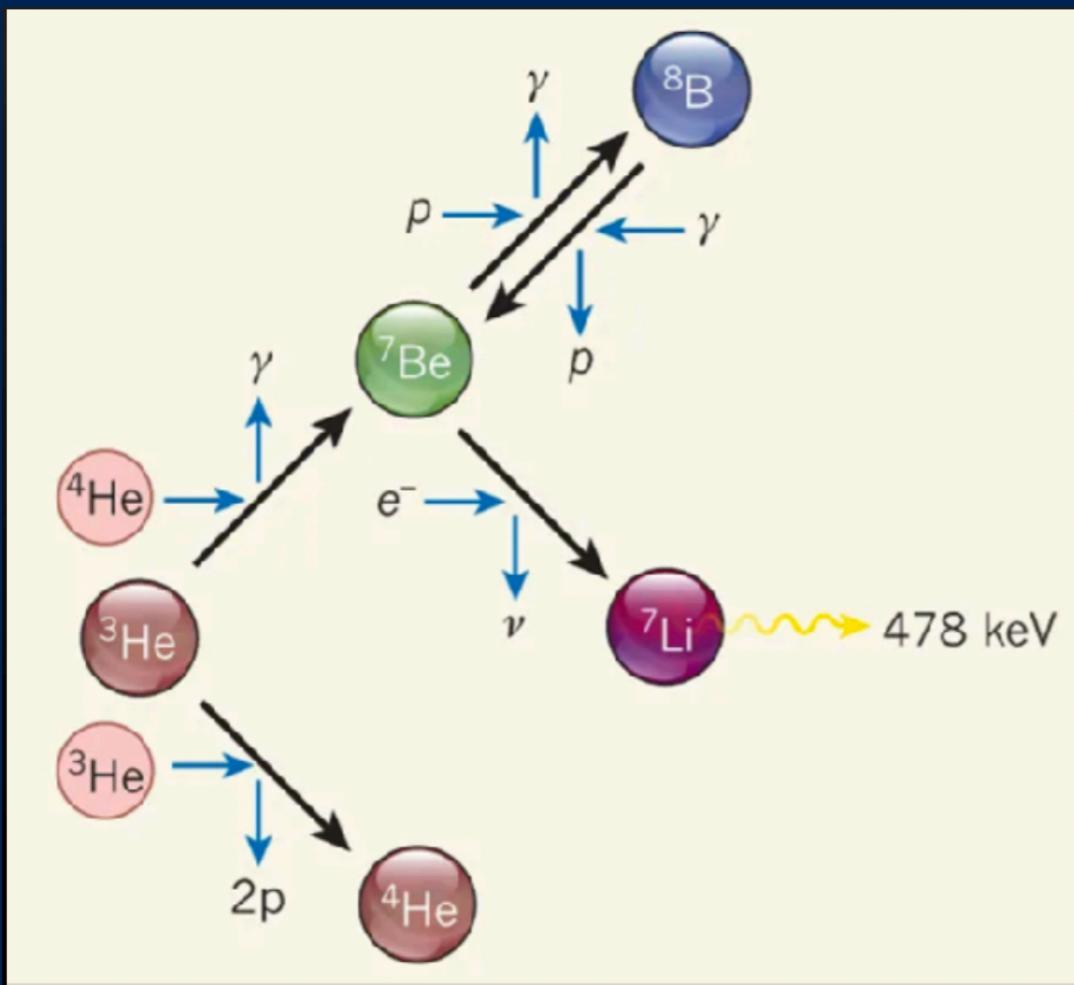
CN are the potential source!

But only if “observational” yields are the right ones !

# Observations versus theory

Who is right?

- $^{7}\text{Be}$  decays into  $^{7}\text{Li}$  with an emission at 478 KeV (Clayton 1981)



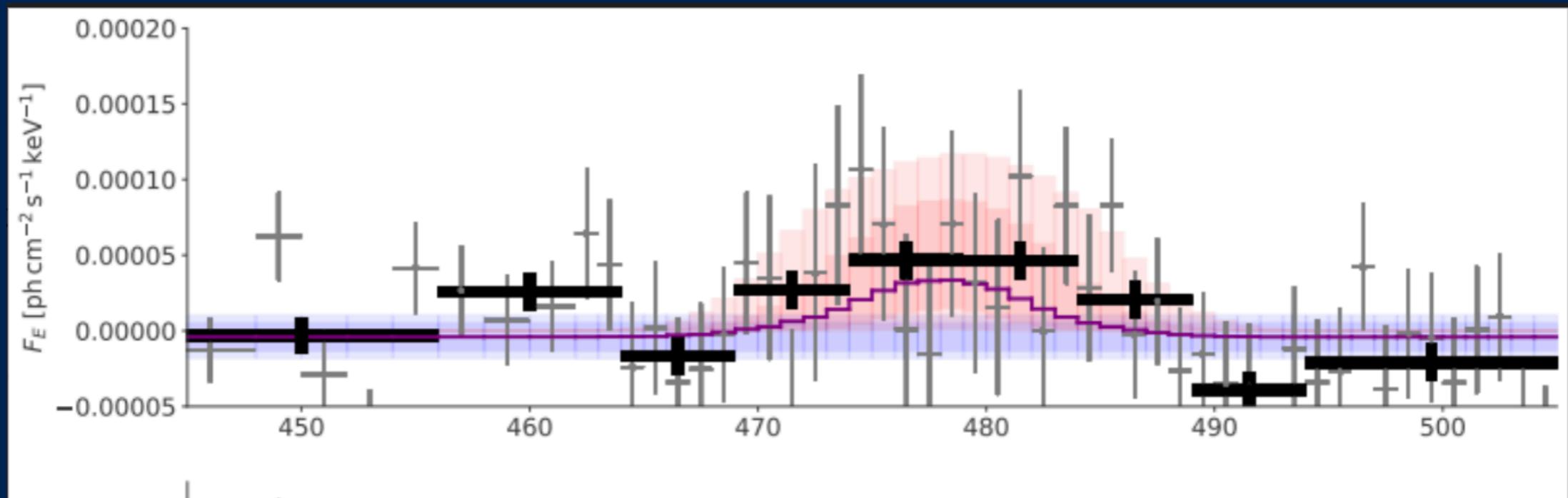
$$M_{^{7}\text{Be}}(t) = F_{^{7}\text{Be}} \frac{\pi d^2 m_{^{7}\text{Be}} \tau_{^{7}\text{Be}}}{\rho_{^{7}\text{Be}}} \exp \frac{t + \Delta t}{\tau_{^{7}\text{Be}}}$$

- Long-sought of the 478 keV emission (Siegert, PM+ 2018)

# 478 keV detection in Nova V1369 Cen A

Luca Izzo, Thomas Siegert, Pierre Jean,  
Margarita Hernanz, della Valle, Bonifacio PM,  
2024 submitted

- Bright nova: V=2.5 dereddened)
- Li detected (Izzo+2015)
- INTEGRAL: SPI Texp ~ 90 Ks, distance <2.7°



Gaussian 8 KeV FWHM

→ 479 ( $\pm$ ) 2 KeV

→ Flux:  $4.9 (\pm 2) \times 10^{-4}$  ph/cm $^2$ /s; 2.5 sigma

## $^{7}\text{Be}$ Mass

$$M_{^{7}Be}(t) = F_{^{7}Be} \frac{4\pi d^2 m_{^{7}Be} \tau_{^{7}Be}}{p_{^{7}Be}} \exp \frac{t + \Delta t}{\tau_{^{7}Be}}$$

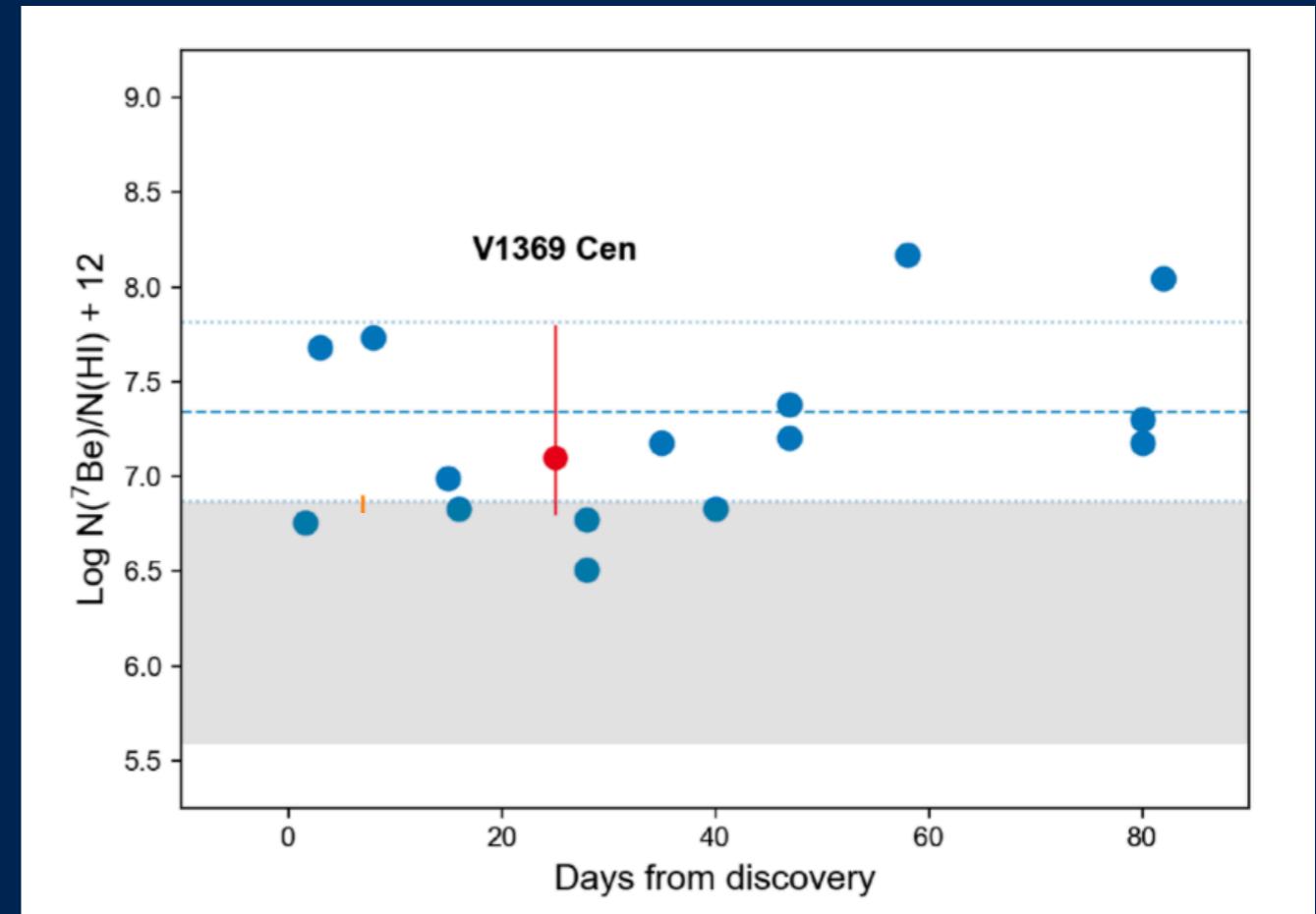
Distance:  $d = 634 (+^{405}_{-112})$  pc (GAIA-DR3 Schaefer 2022)

$M(^{7}\text{Be}) = 1.2(+^2_{-0.6}) \times 10^{-8} M_{\odot}$

## Mass of Ejecta

From ASKAP:  $1.4(\pm 0.17) \times 10^{-4} M_{\odot}$   
(Gulati + 2023)

→  $A(\text{Li}) = 7.1 (+0.7-0.3)$

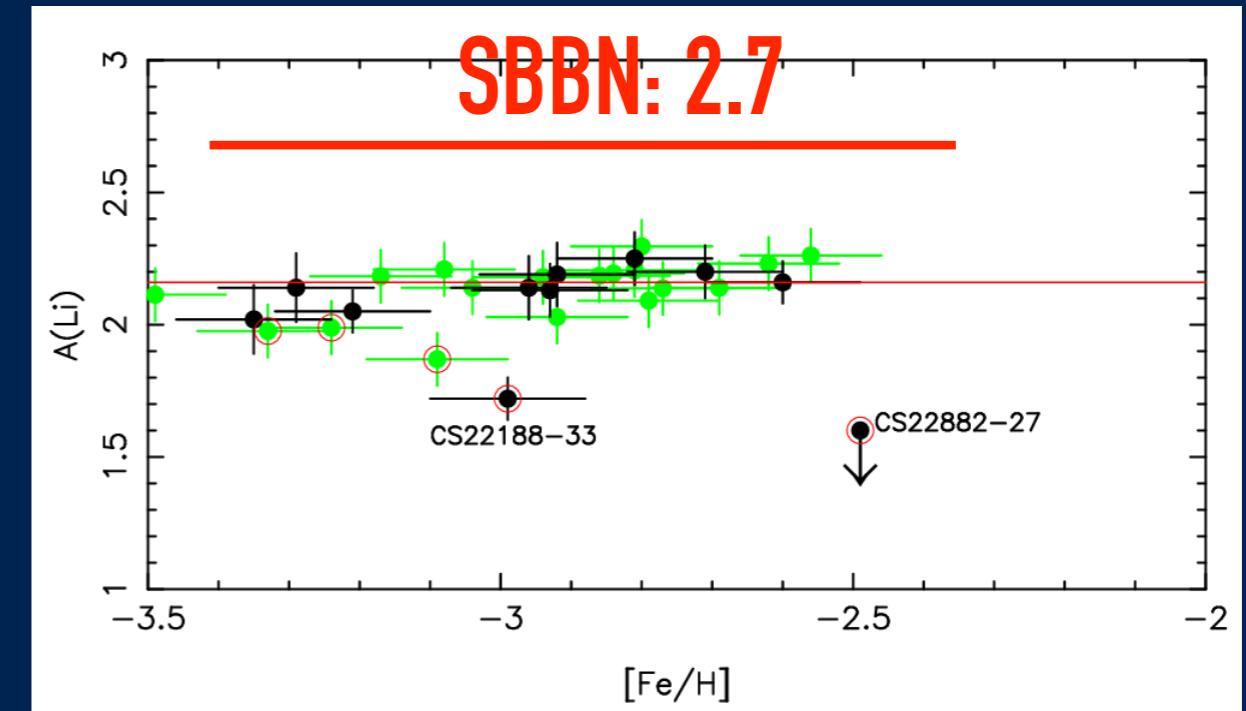
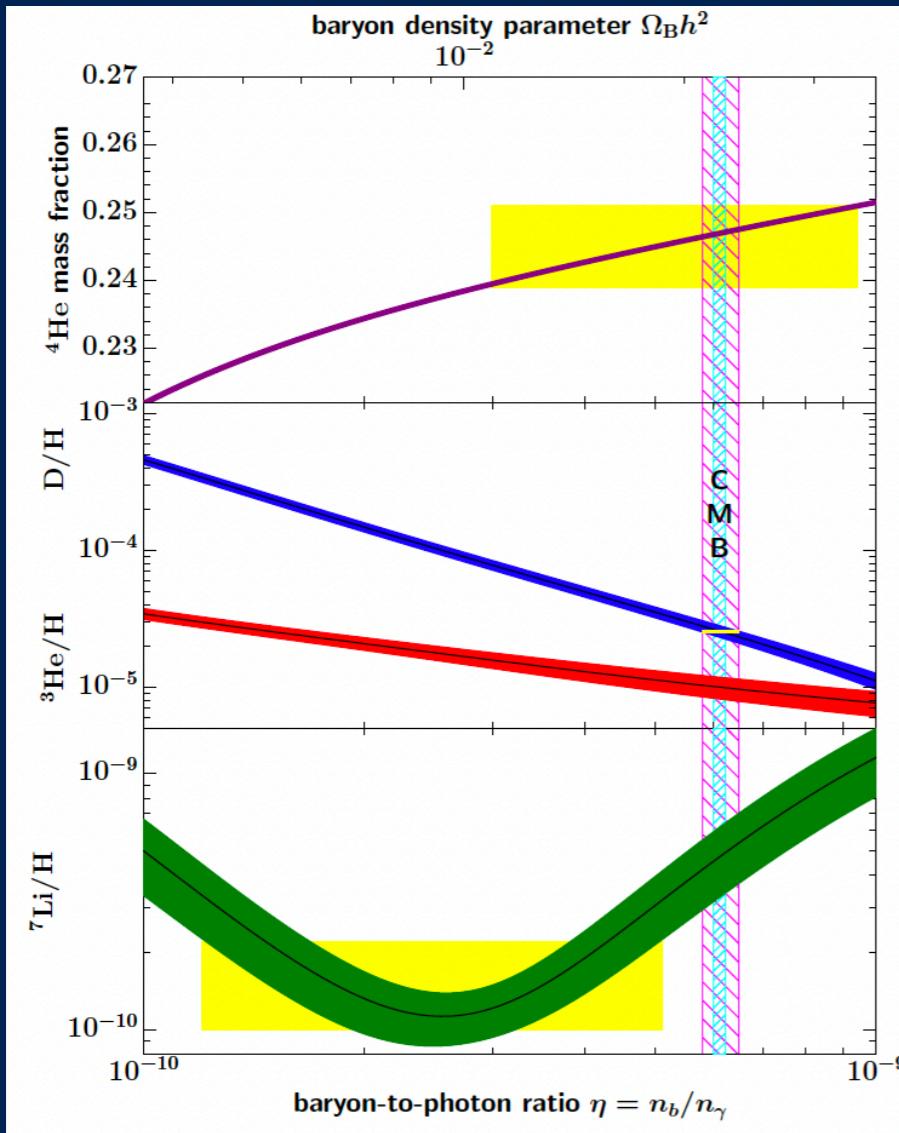


478 k detection suggests observational yields are ok, and novae could be the source

# Riddle 2: The cosmological Li problem

Fields, PM Sarkar PDG review 2024

Matas Pinto + 2021



- $A(\text{Li})_{\text{BBN}} = 2.69 (\pm 0.02)$  from D/H and CMB (Yeh+21)
- no CEMP
- $A(\text{Li}) \sim 2.16 (\pm 0.07); -3.5 < [\text{Fe}/\text{H}] < -1.5$
- J0023-0307 @ $[\text{Fe}/\text{H}] -5.5$   $A(\text{Li}) \sim 2.02 (\pm 0.08)$
- Spite plateau resists at the lowest metallicities

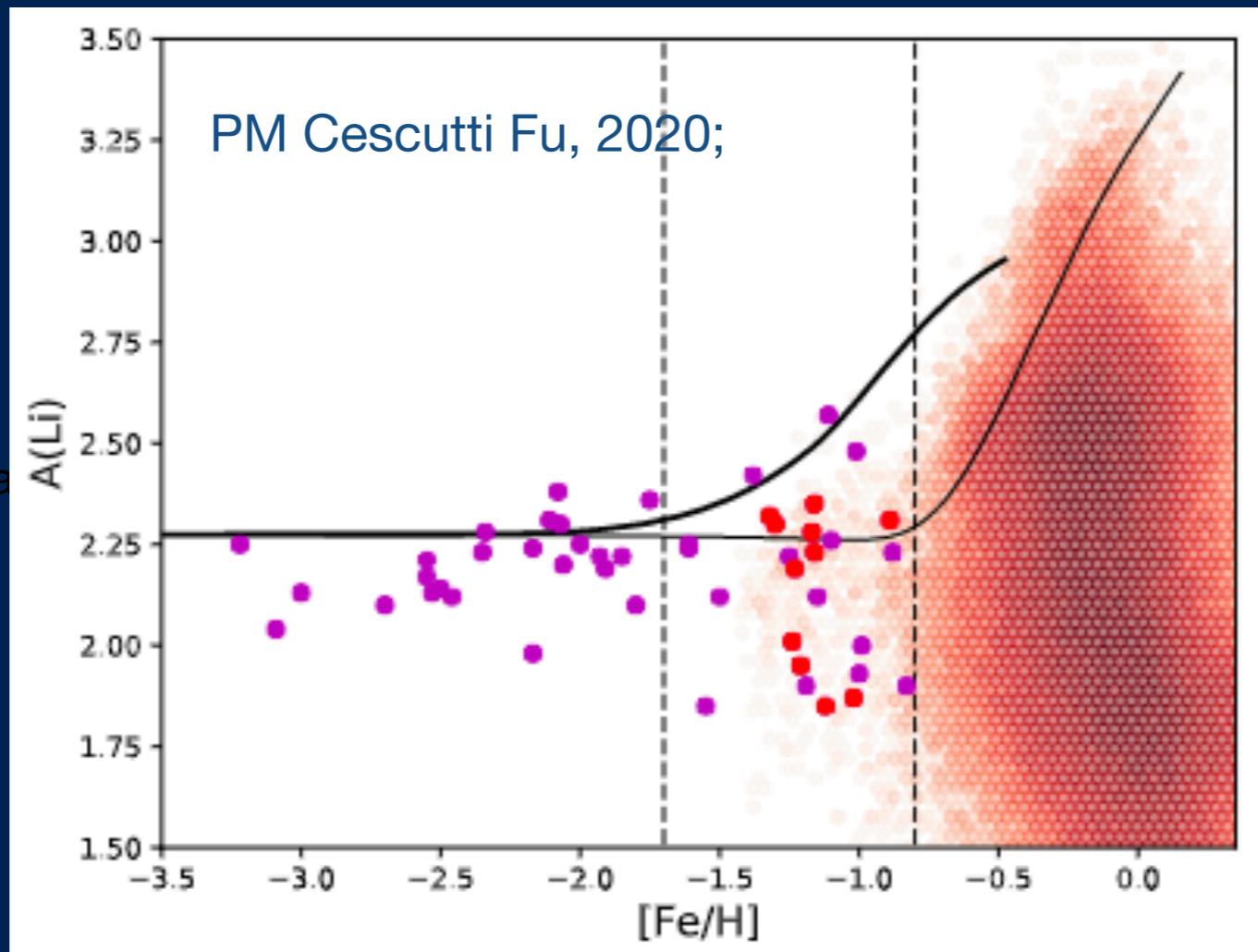
## A stellar problem?

- diffusion+turbulence (Borisov+24)
- PMS depletion (Fu+15)

# Li in GSE

- MS stars out of reach the best proxy: GAIA-Sousage-Enceladus(Belokurov+18, Helmi+18,Haywood+18)

36 GSE star

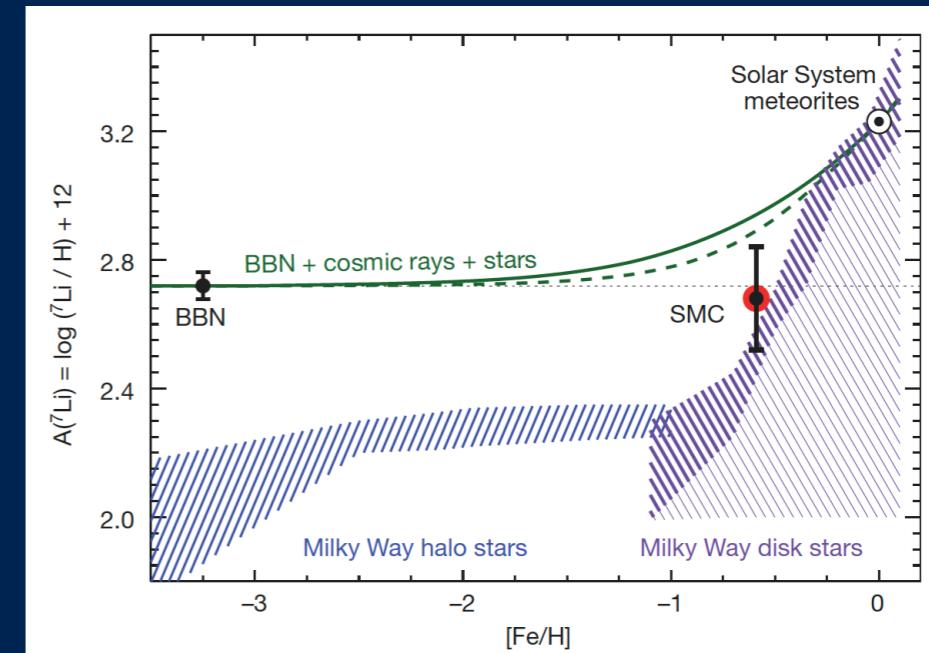
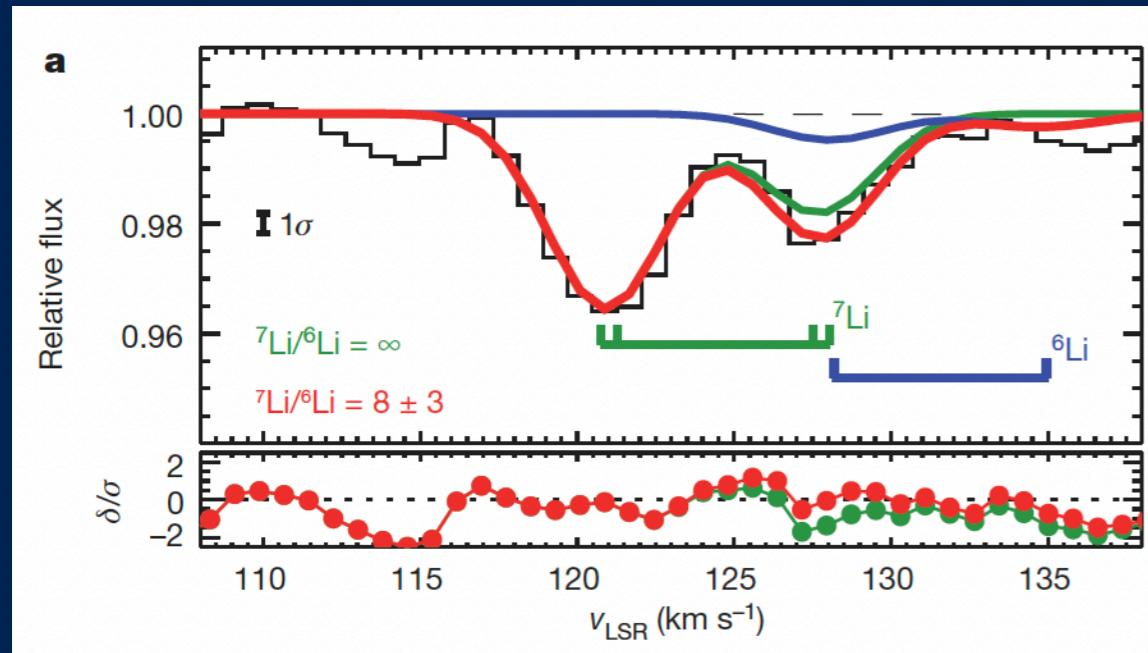


- Enceladus stars  $[\text{Fe}/\text{H}] < -2$ :  $A(\text{Li}) = 2.18 \pm 0.10$
- Confirmed by Simpson+ 2021, with GALAH  $A(\text{Li}) = 2.3$ 
  - ➡ Sequoia under study (Monaco + 2024)
  - ➡ The Li “problem” is not a Galactic feature

# IS Li towards Sk 143

- Unique measure in low metallicity gas
- Interstellar Li is free from stellar “complications”

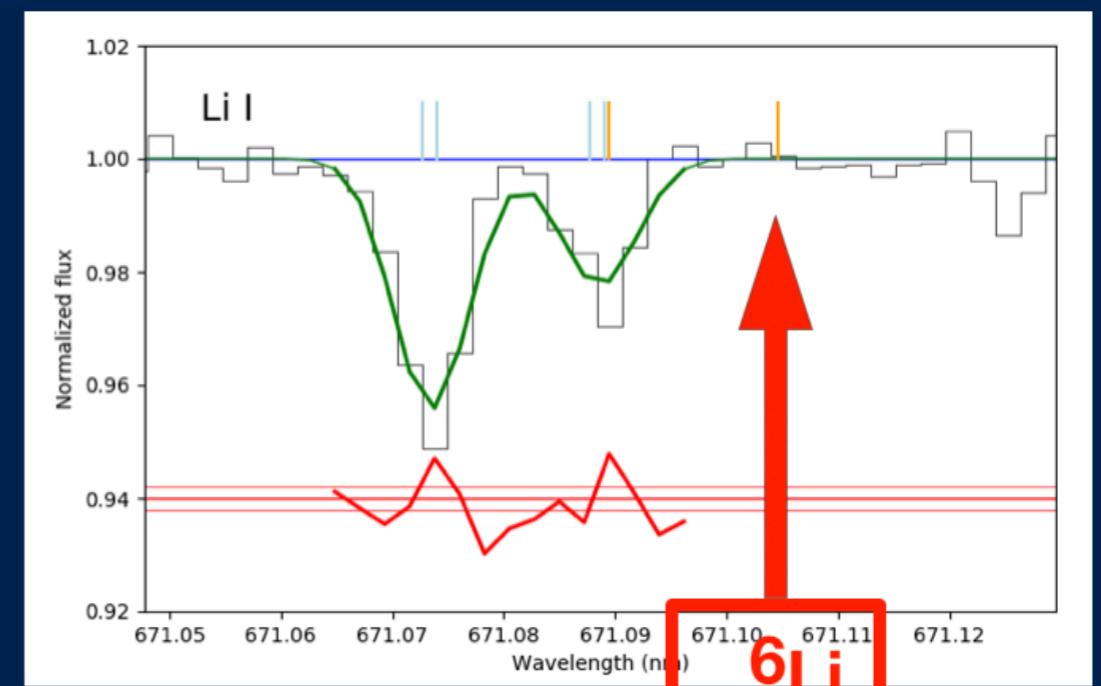
Howk+2012



## New analysis: ESPRESSO

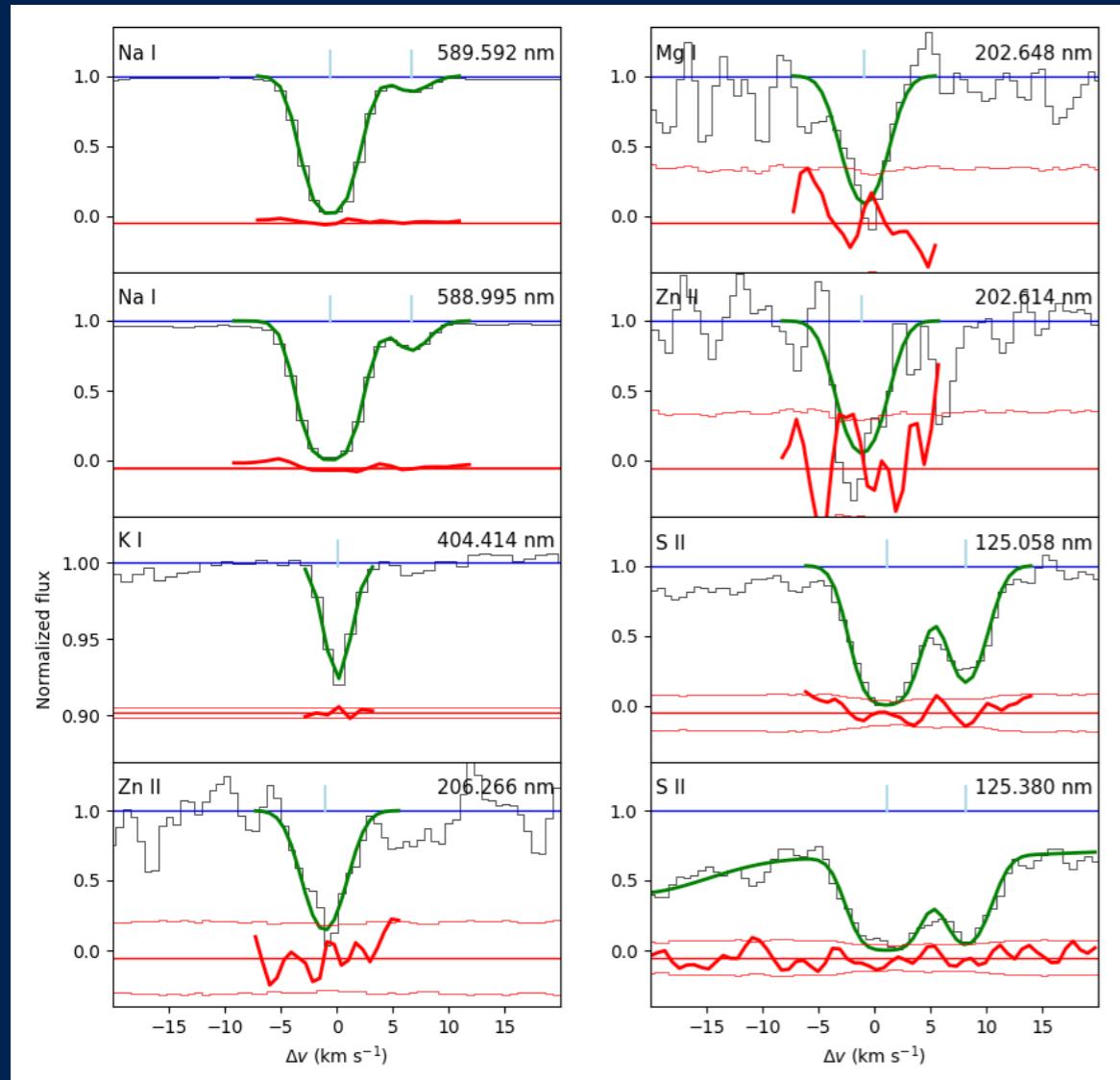
- exp: 20x1h,  $R \sim 145\,000$
- PM, Bonifacio, Cupani Howk+24

→ No evidence of  ${}^6\text{Li}$  :  ${}^6\text{Li}/{}^7\text{Li} < 0.1$



# New metallicity for the intervening cloud

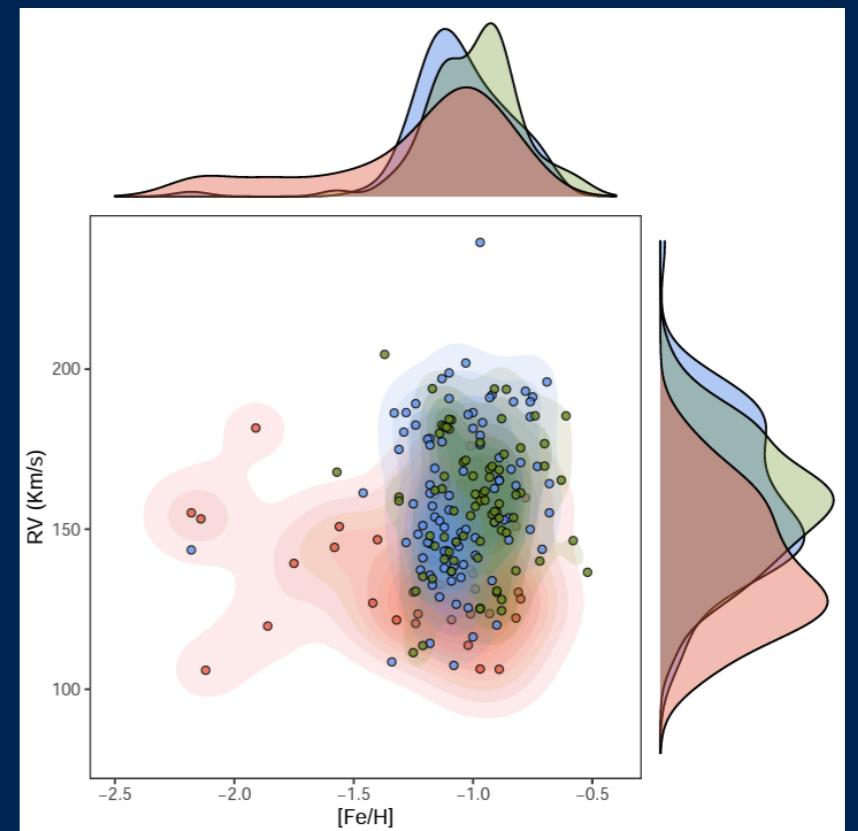
- STIS HST data of SK143



$$[\text{S}/\text{H}] = -0.6 (\pm 0.11)$$

$$[\text{Zn}/\text{H}] = -1.18 (\pm 0.09)$$

- Mucciarelli+23 stellar component with  $\text{RV} \sim -132 \text{ km/s}$  shows  $[\text{Fe}/\text{H}] < -1$



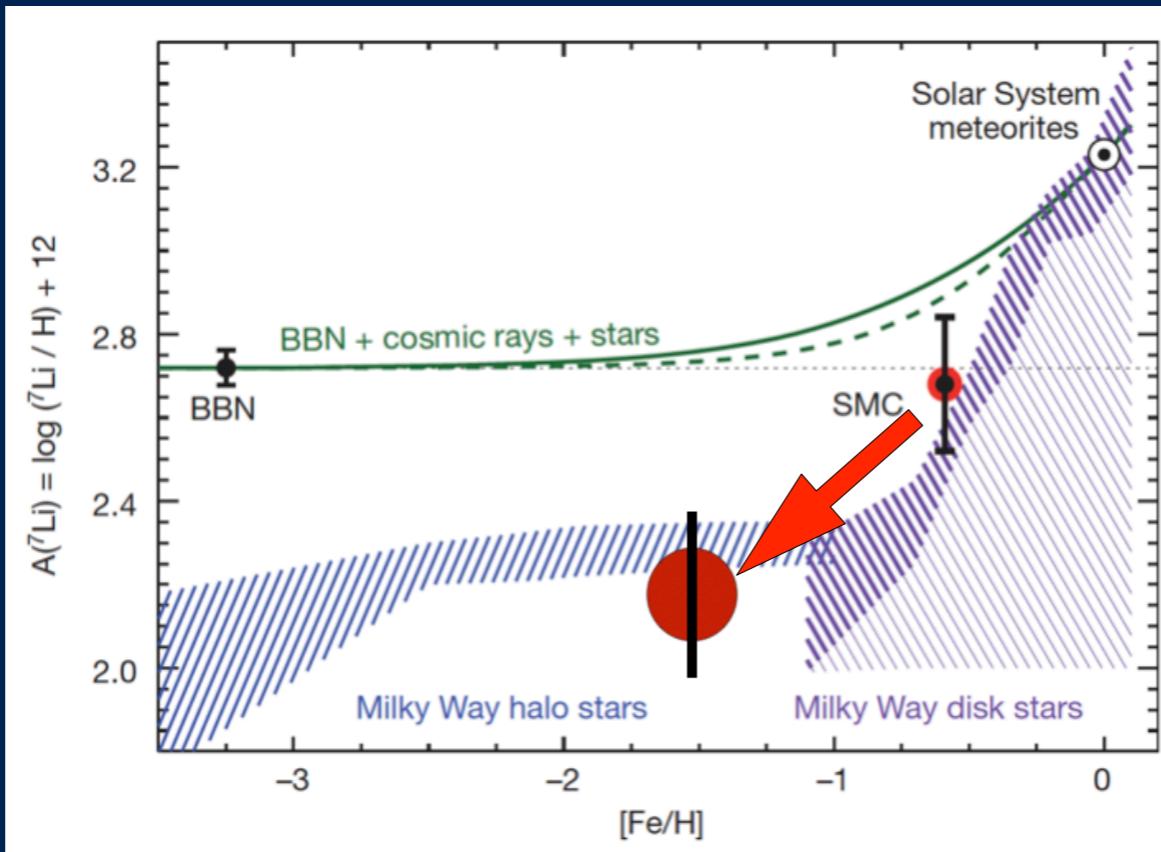
De Cia+24 from several elements considering differential dust  
 $[\text{M}/\text{H}] = -1.09 (\pm 0.24)$

- Li dust & ionisation corrections with KI (as in Howk+12)

$$A({}^7\text{Li})_{\text{SK143}} = A({}^7\text{Li})_{\odot} + [K/H]_{\text{SK143}} + [{}^7\text{Li}/K]_{\text{SK143}},$$

$$A({}^7\text{Li})_{\text{SK143}} = 3.27 (\pm 0.03) - 1.18 (\pm 0.09) + 0.07 (\pm 0.08)$$

**A(Li)~2.16 ( $\pm 0.12$ )**



Lower metallicity of the cloud is the only difference

The only IS measurement at low metallicity agrees with halo stars.

# Summary

- Riddle of Galactic Li main source
  - Novae are the ONLY potential source..
  - but observational yields “need” to be right ones..
  - Detection of the 478 keV in Nova Del 2013 suggest this
- Riddle of primordial Li
  - Li shows tension in the SBBN
  - Stellar fix possible, but fine tuning required
  - Interstellar Li towards SK143 exacerbates the tension



Thank you!

2009 Ilha Grande, pic by Ramiro de la Reza