Gas-phase abundances in the universe: lithium to lead

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Outline

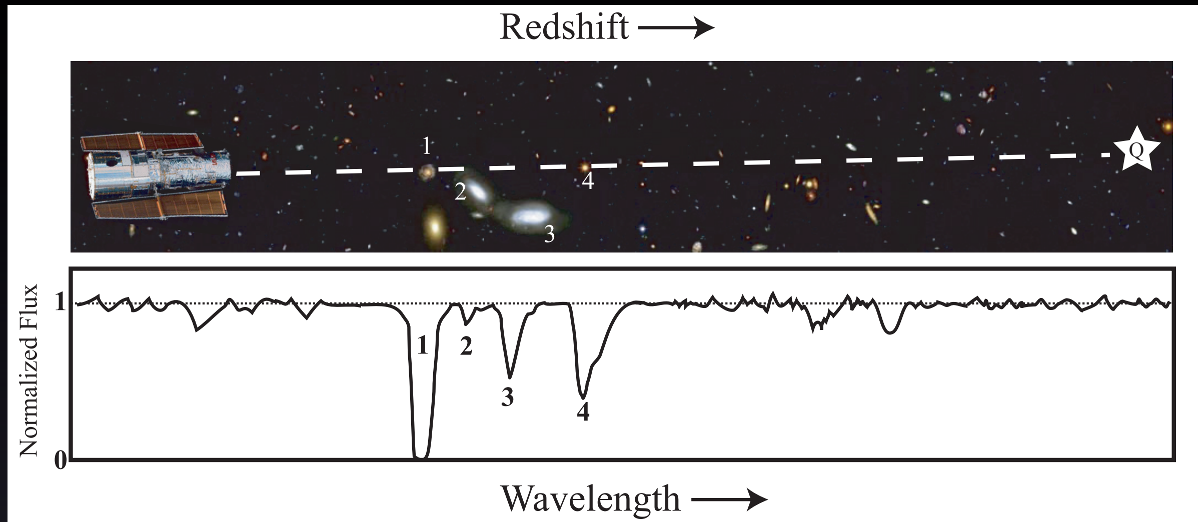
- Gas-phase abundances: techniques & nucleosynthesis impact
- Interstellar lithium as a probe of the pre-galactic abundance

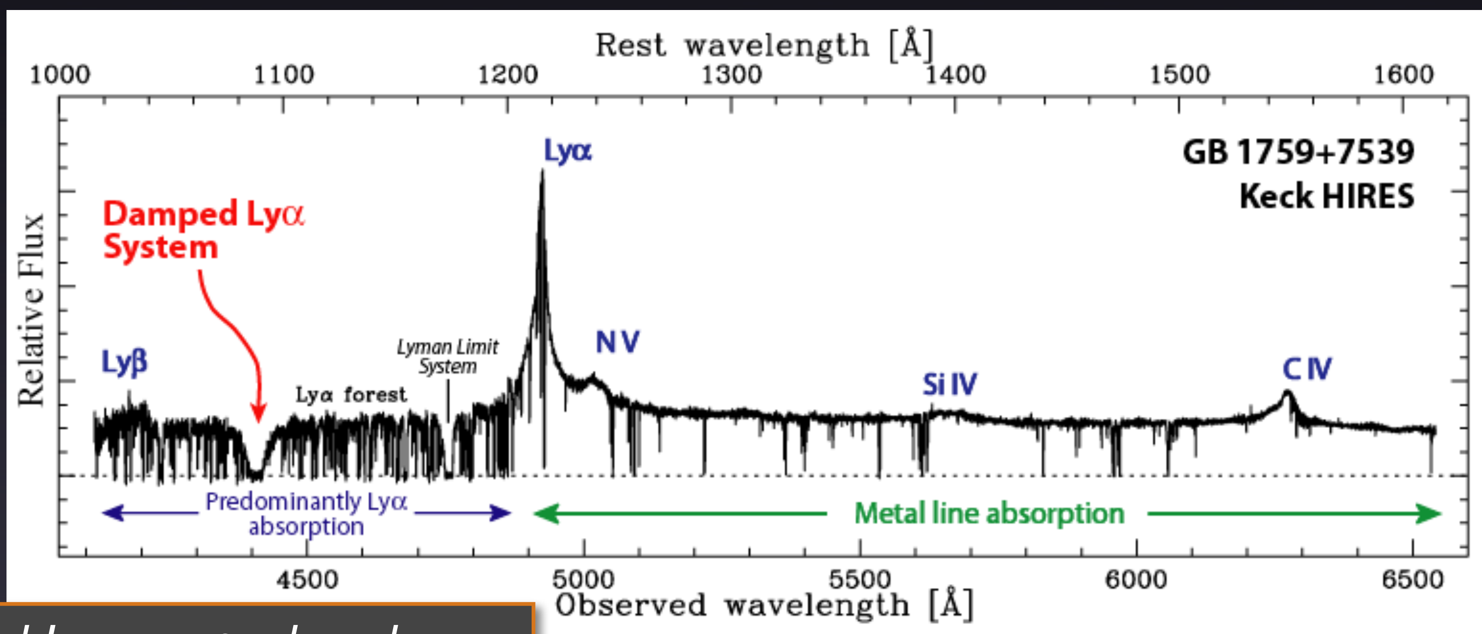
Gas-phase abundances in the universe

Techniques

Damped Lyman-α Systems as a Probe of Nucleosynthesis

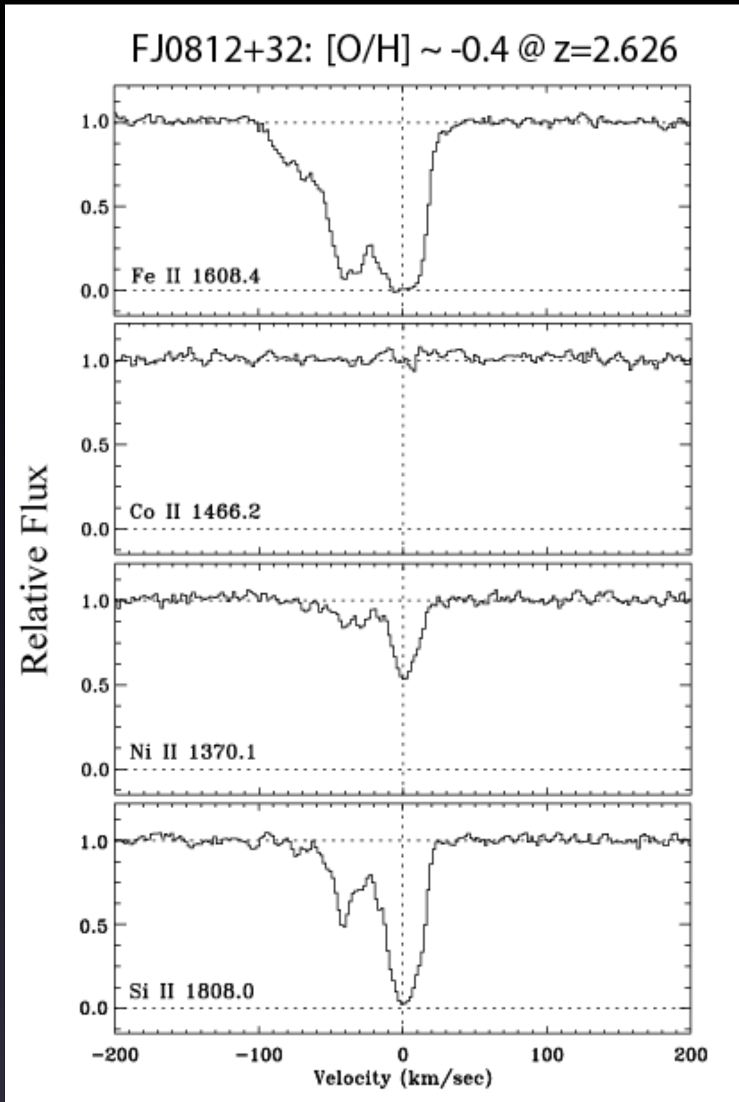
Probing nucleosynthesis in damped Lyα systems





Damped Lyman-α absorbers:
N(H I) > 2×10^{20} cm^{-2}

Probing nucleosynthesis in damped Lyα systems

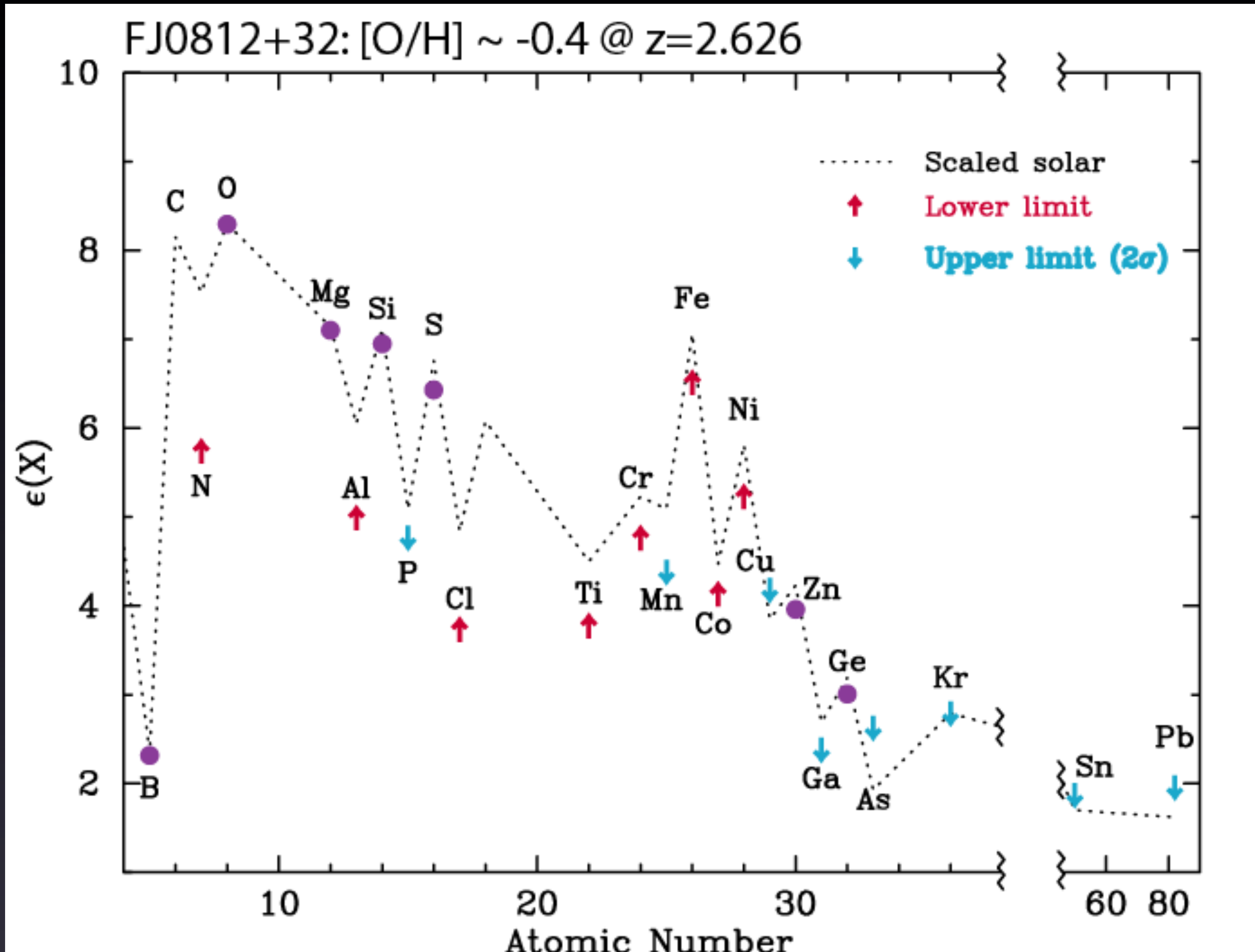


*[X/Y] ≡ log (X/Y) – log (X/Y)$_\odot$

- High-resolution spectroscopy gives gas-phase abundances with typical uncertainties:
  - σ([X/H]) ~ 0.05 to 0.10 dex (10-25%)
  - σ([X/Y]) ~ 0.02 to 0.05 dex (5-10%)
- Ionization corrections are typically minimal (Vladilo et al. 2001). *Dust* corrections often not minimal (Jenkins 2009).
- A wide range of elements can be accessed:
  - Commonly measured: Fe, Si, Ni, Zn, Cr
  - Occasionally measured: N, S, P, Ti, Ar, Mn
  - Rarely available: C, O, Al, Mg, Co, Kr, Ge, Cl, B, Cu, Ga, Sn, Pb, As
- Detecting the rarest species requires high metal column density absorbers.

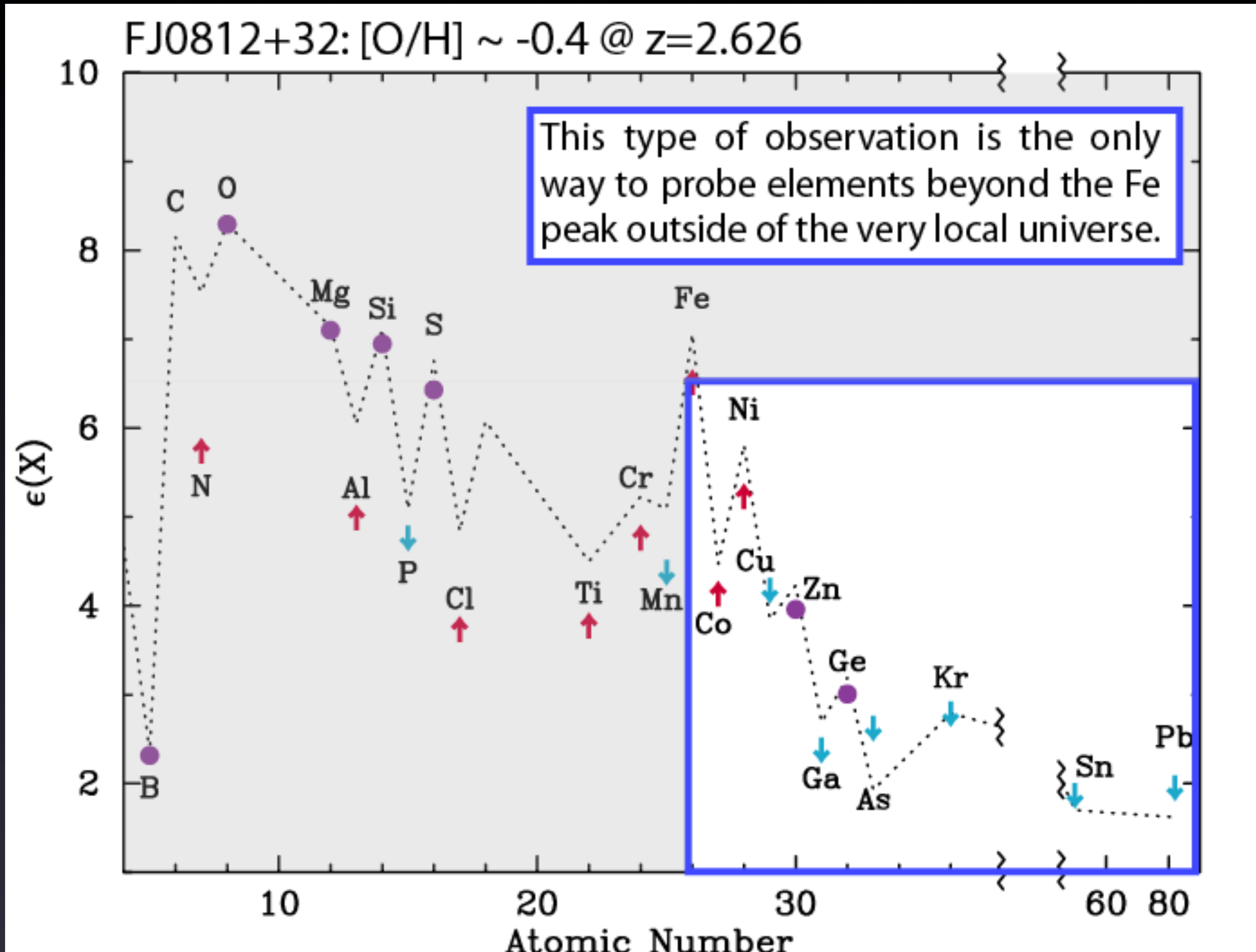
$$N(X) = 10^{[X/H]}\, N(\mathrm{H\ I})$$

Probing nucleosynthesis in damped Lyα systems



Prochaska, Howk, & Wolfe (2003)

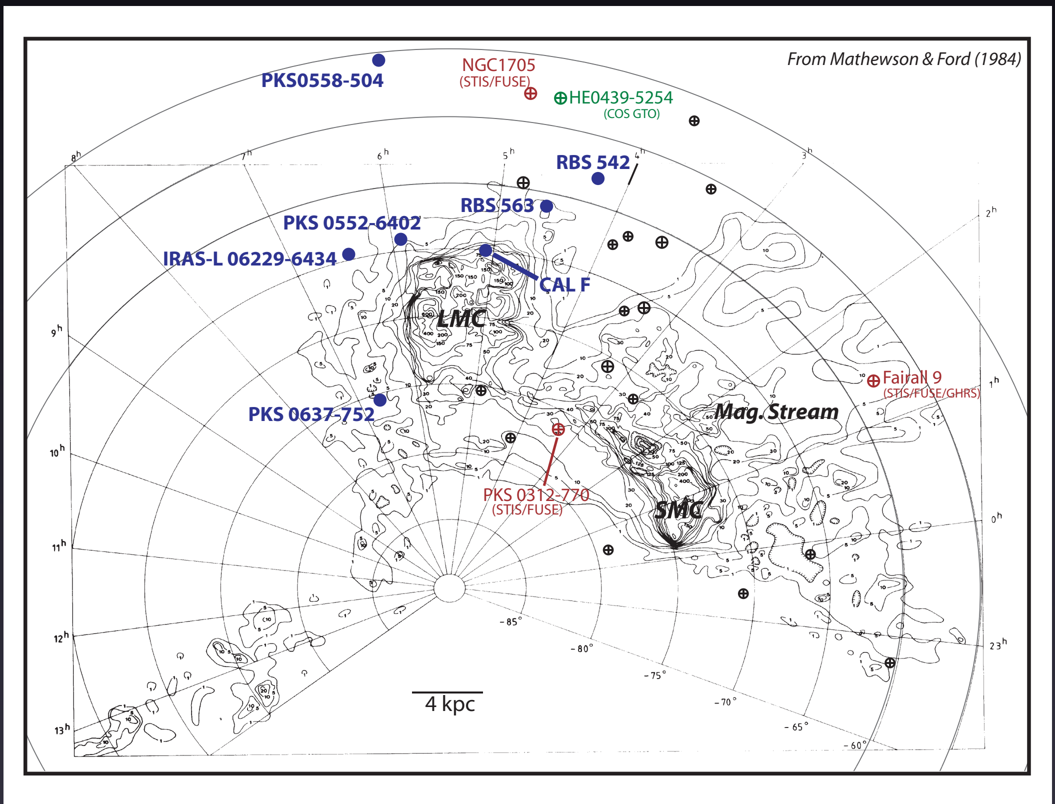
Probing nucleosynthesis in damped Lyα systems

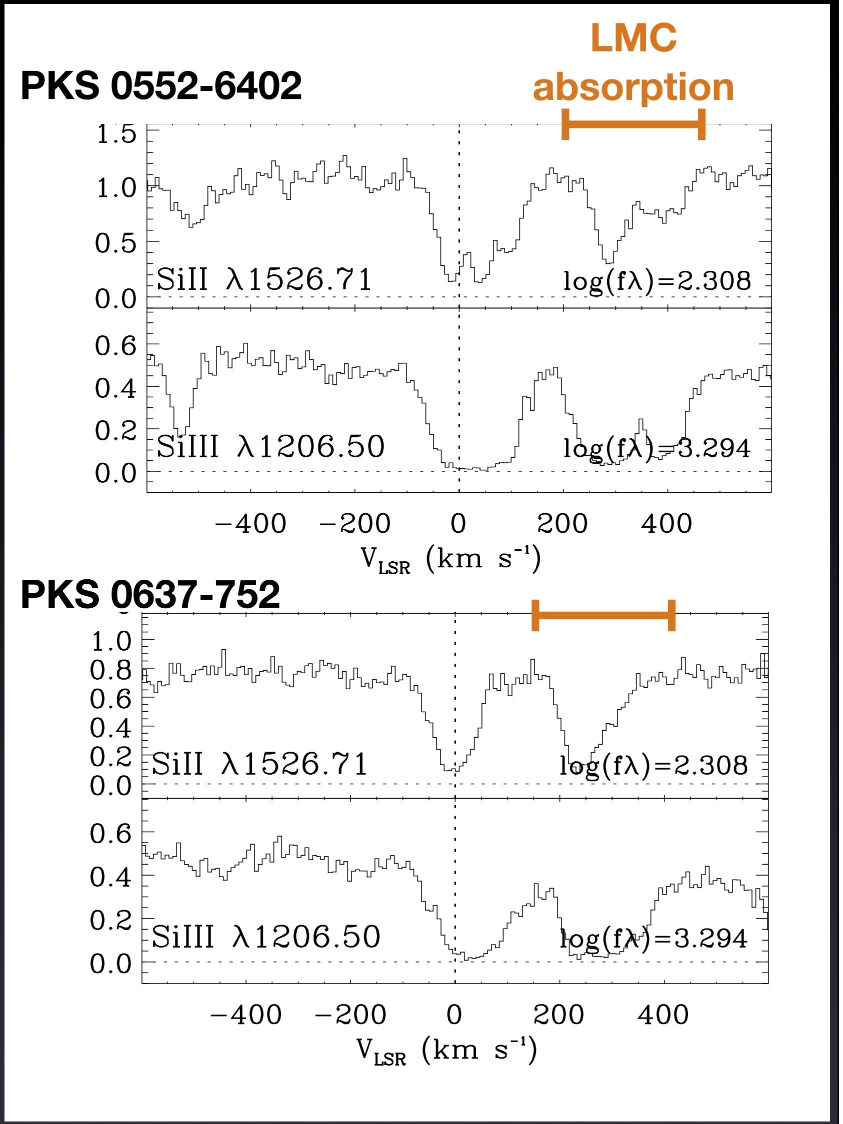


Prochaska, Howk, & Wolfe (2003)

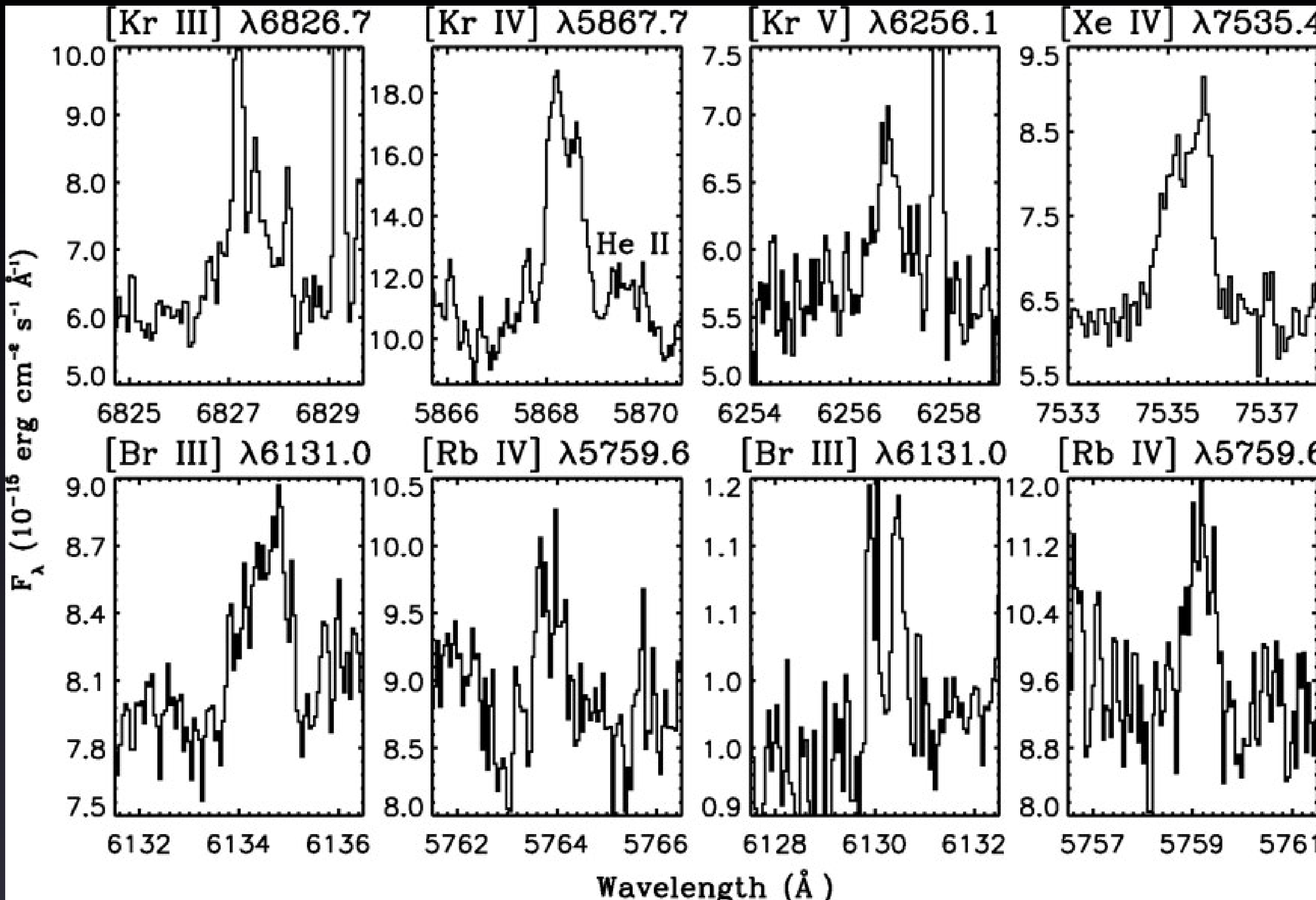
Identifying low-redshift galaxies in absorption

Gas measurements allow us to probe the distribution of metals in the universe.





Probing nucleosynthesis in nebulae



Sterling et al. (2009)

Interstellar constraints on the cosmic evolution of lithium

The Lithium Problem

A New Approach to Cosmic Lithium

Lithium in Population II stars

The Spite "Plateau"

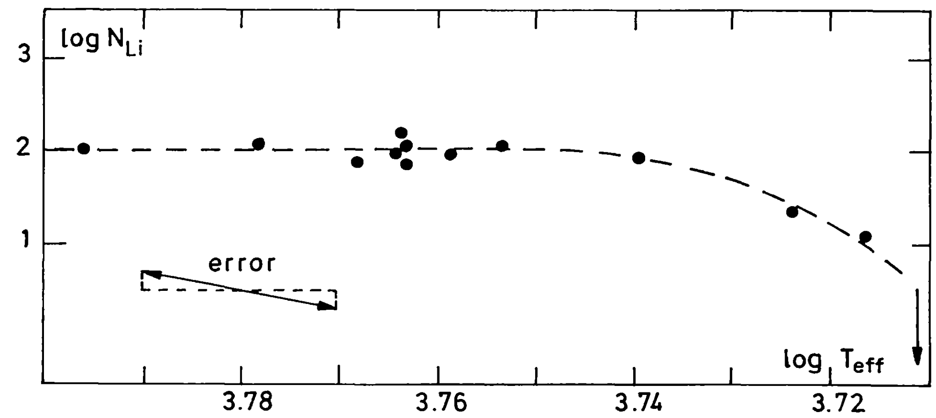


Fig. 5. N_{Li} versus log T_{eff} for old halo stars

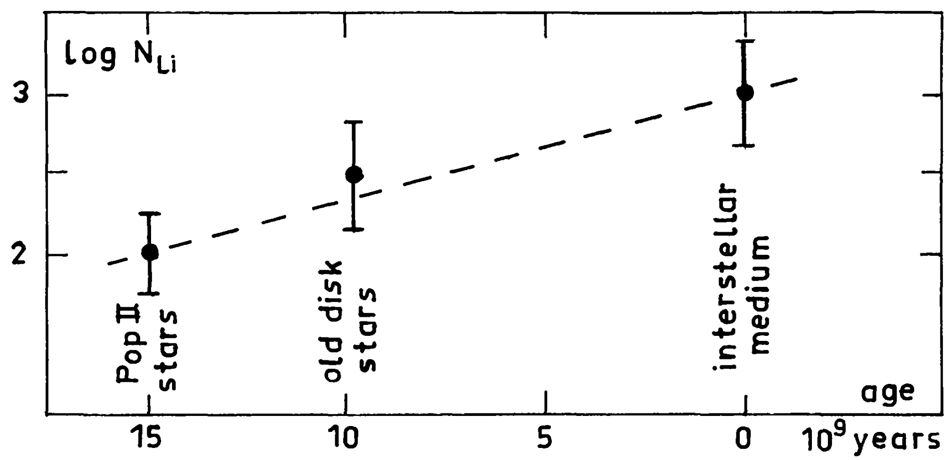
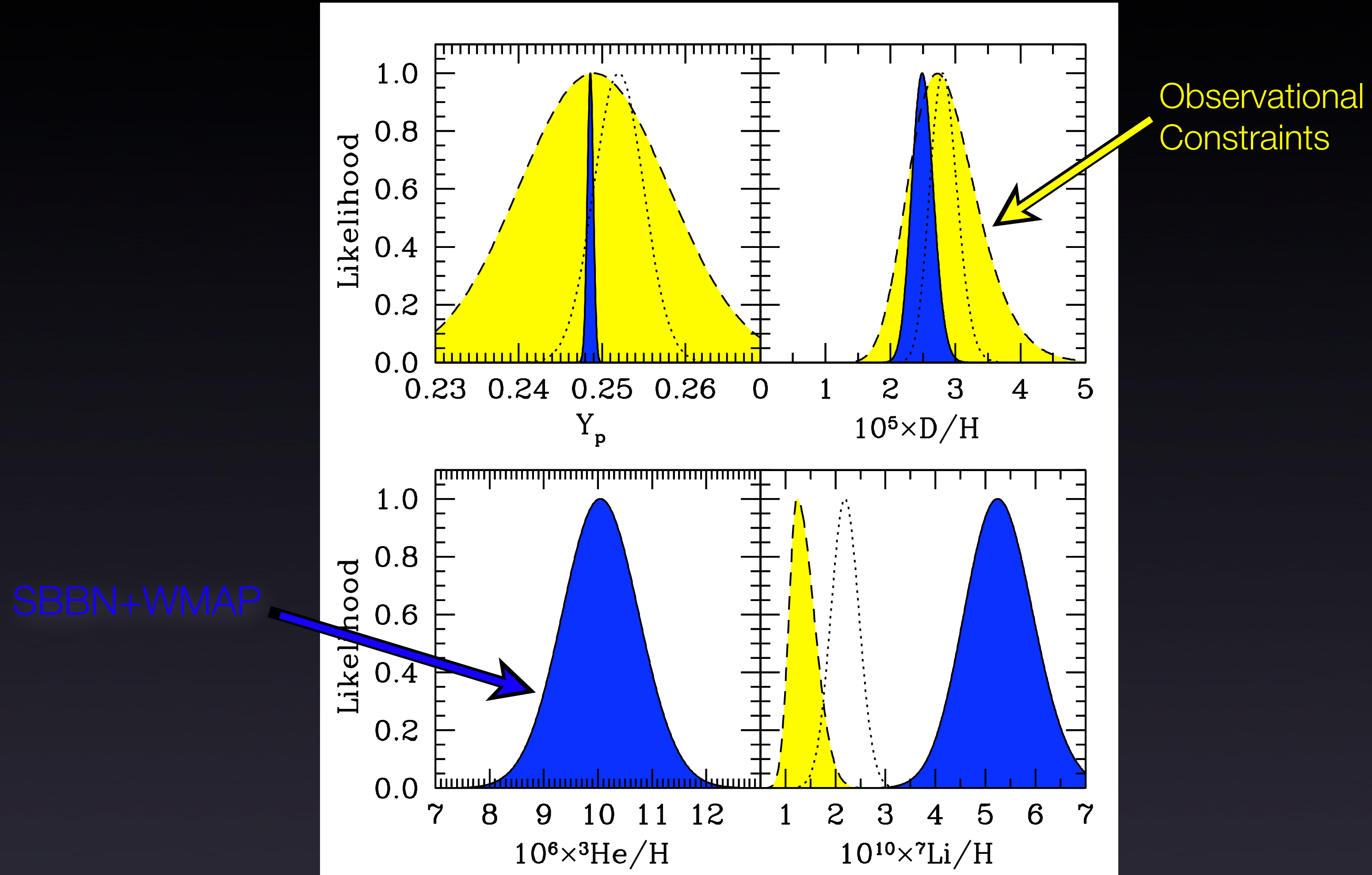


Fig. 6. Evolution of the Li abundance during the life of the Galaxy

Spite & Spite (1982)

The lithium problem

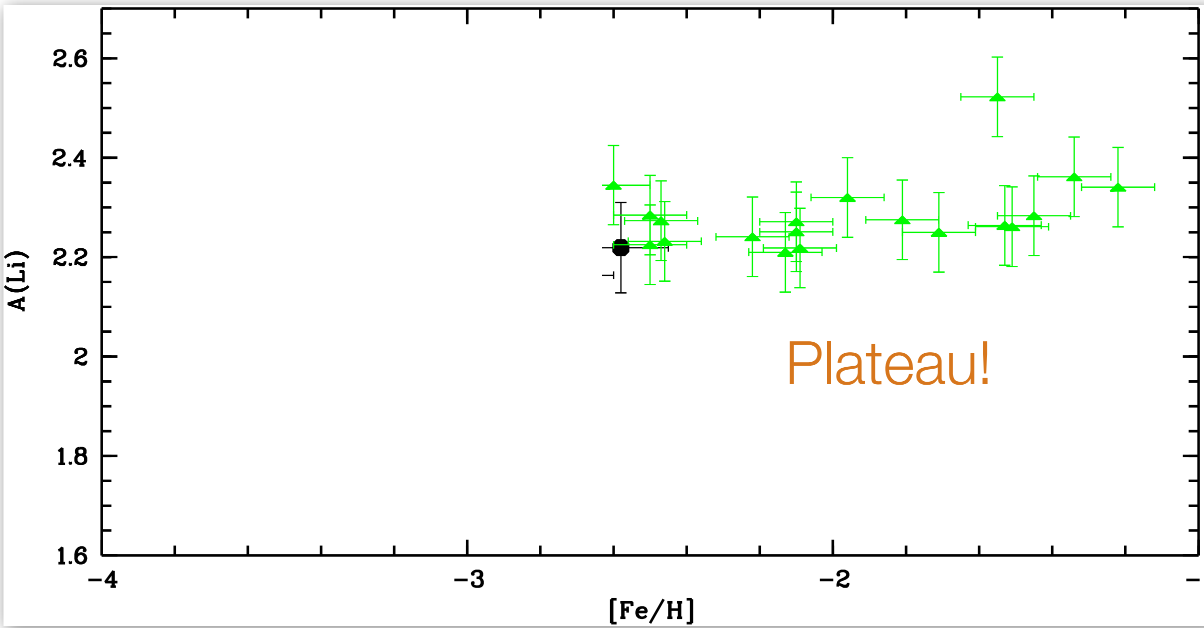


Cyburt et al. (2008)

$$({}^7\mathrm{Li/H})_{\mathrm{WMAP}} = (5.24^{+0.36}_{-0.33}) \times 10^{-10}$$

$$({}^7\mathrm{Li/H})_{halo\ stars} \simeq (1.25 \pm 0.30) \times 10^{-10}$$

Lithium in Population II stars



Cayrel et al. (2009)

Lithium in Population II stars

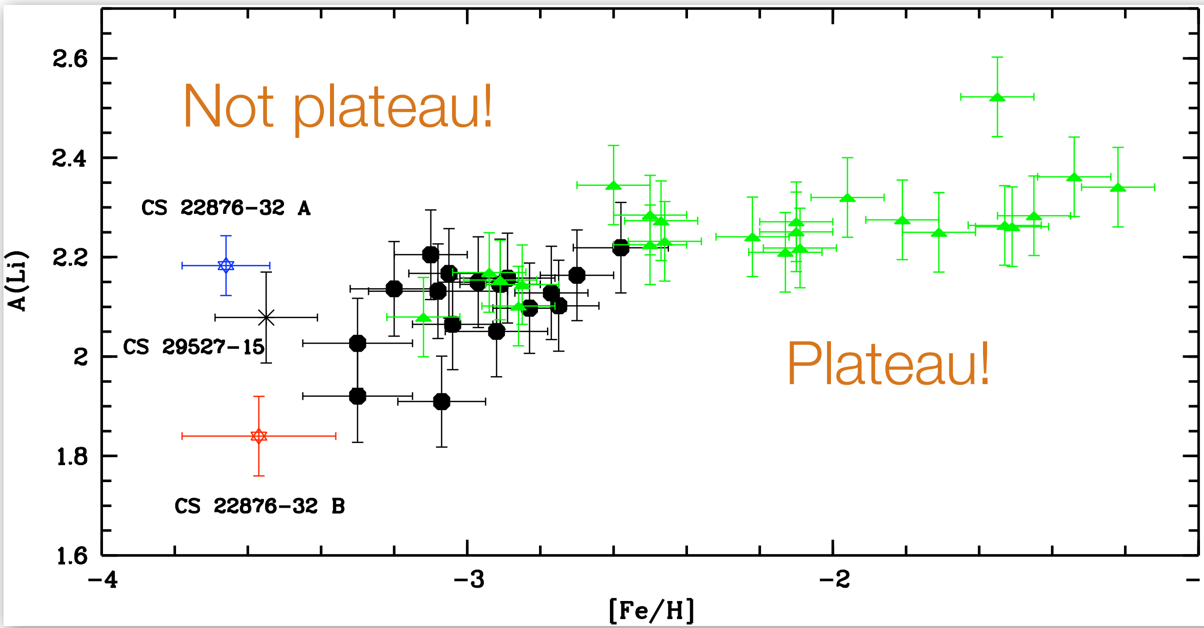
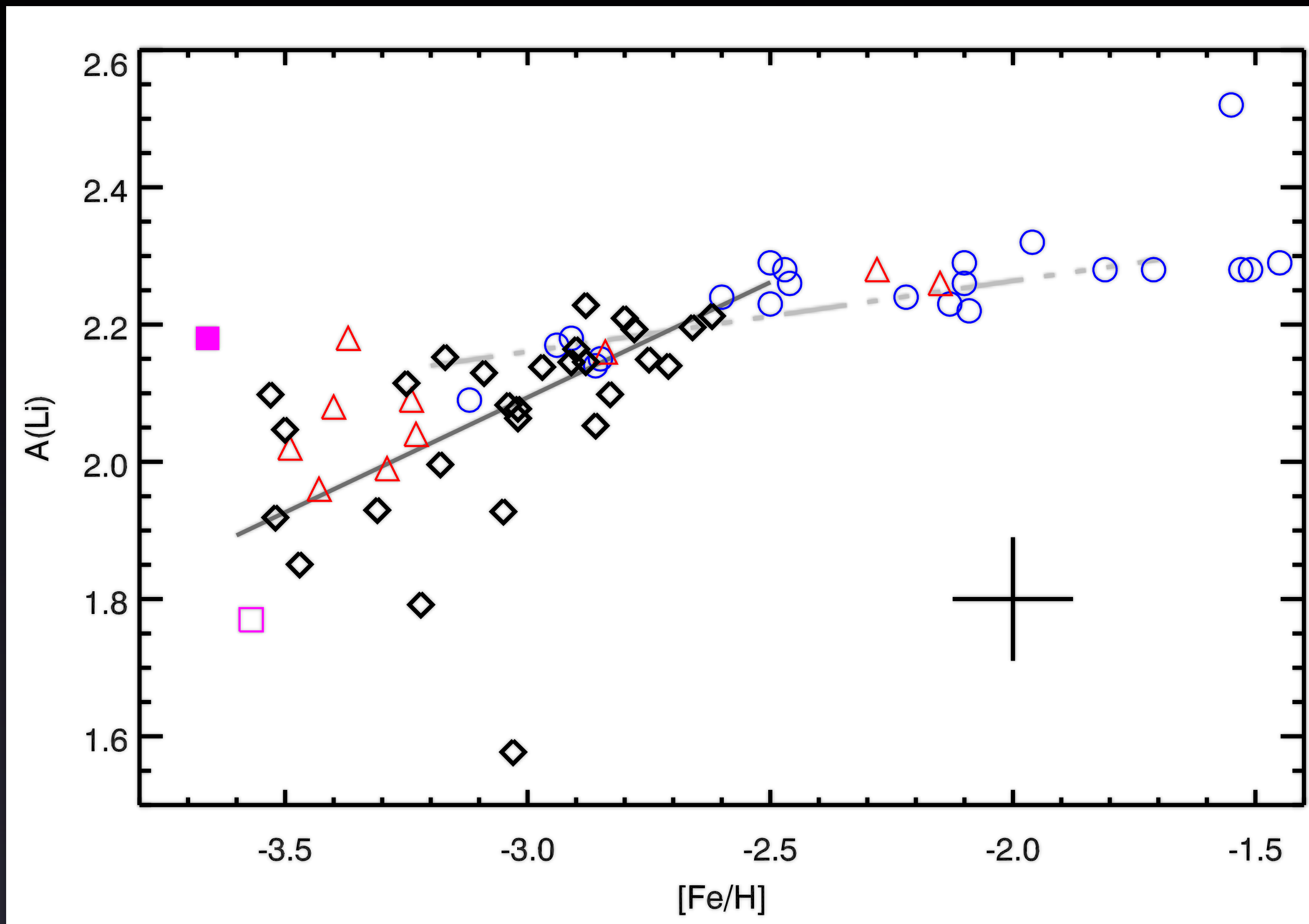


Figure 1: The metal-poor end of the Spite plateau. Note the increased scatter, and the trend towards a drop of the Li abundance at the lowest mean metallicities. Adapted from Bonifacio et al. 2007 [16] and González Hernández et al. 2008 [17].

Cayrel et al. (2009)

Lithium in Population II stars



Sbordone et al. (2010)

Interstellar Li as a probe of pre-galactic production

The idea:

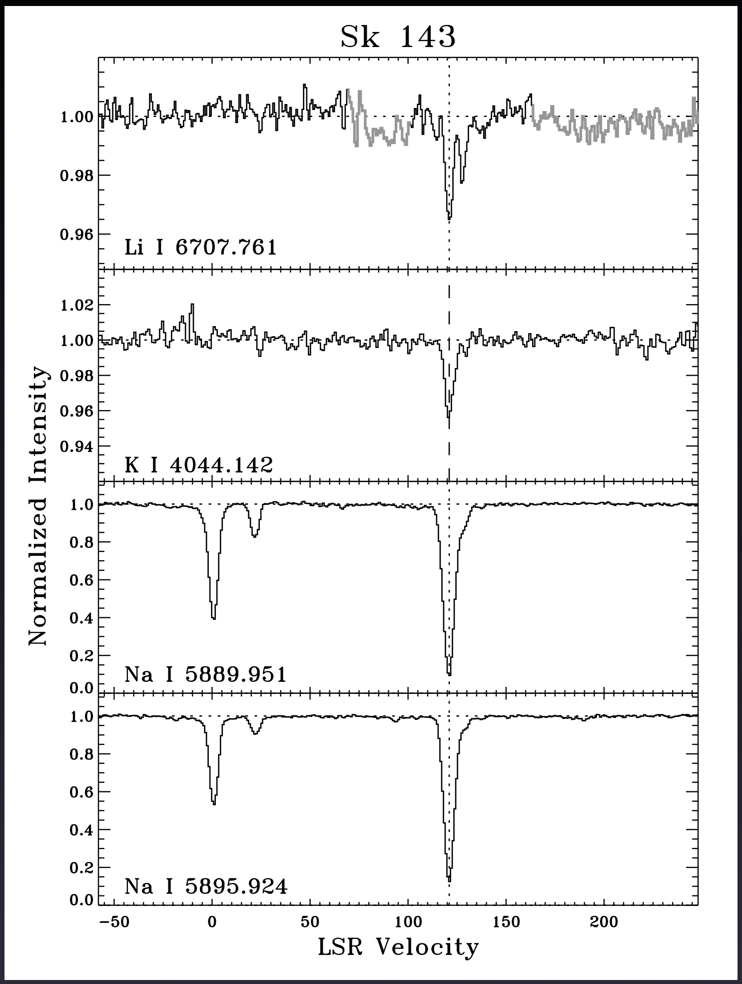
Use measurements of interstellar Li in low metallicity environments as a probe of the contemporary Li abundance.

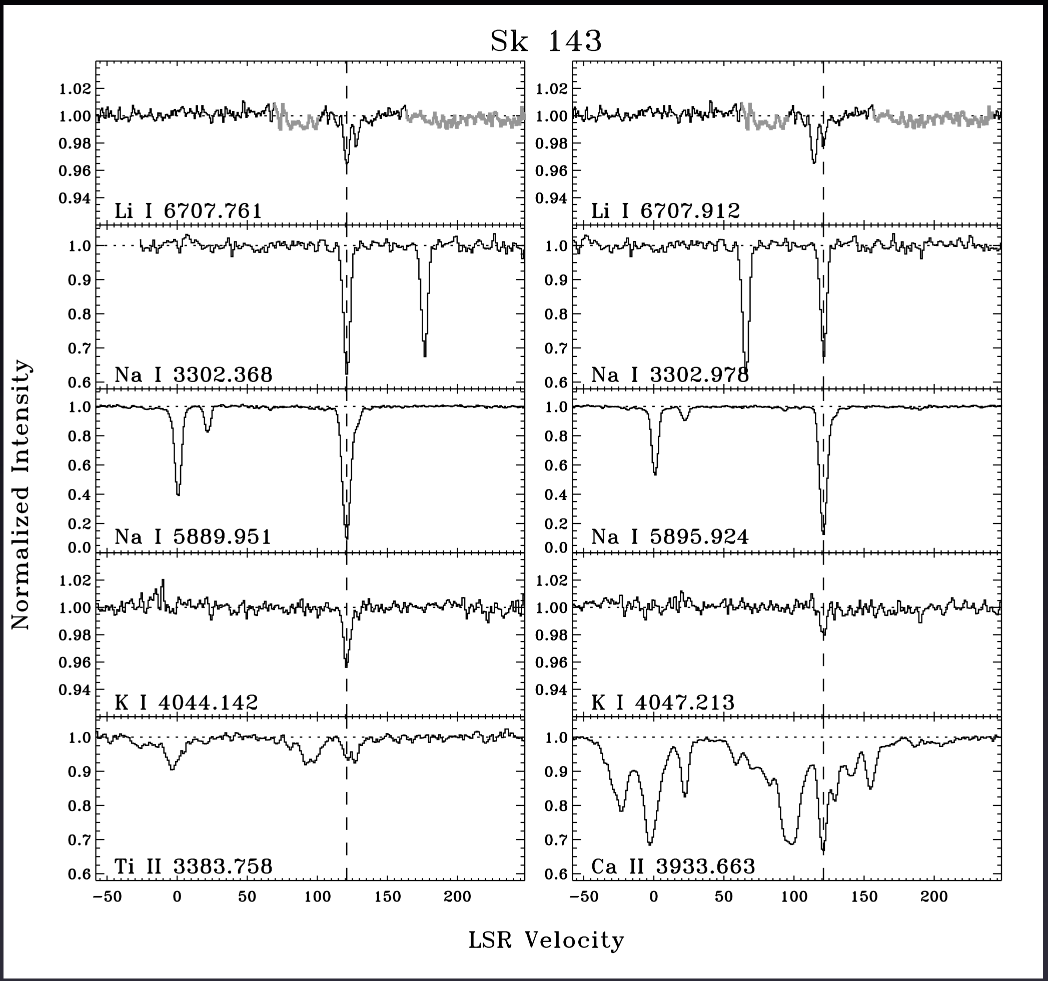
The chemical evolution of Li will still be complex, one does not worry about stellar destruction modifying the abundance of Li relative to other elements.

There will be significant systematics associated with (photo)ionization and incorporation of Li into dust grains, *but these are completely independent of those affecting stellar measurements.*

Interstellar Li as a probe of pre-galactic production

The Small Magellanic Cloud as probe of pre-galactic Li





Also detected: Ca I, Fe I, Rb I
CH, C_2, C_3, CN
H I, H_2

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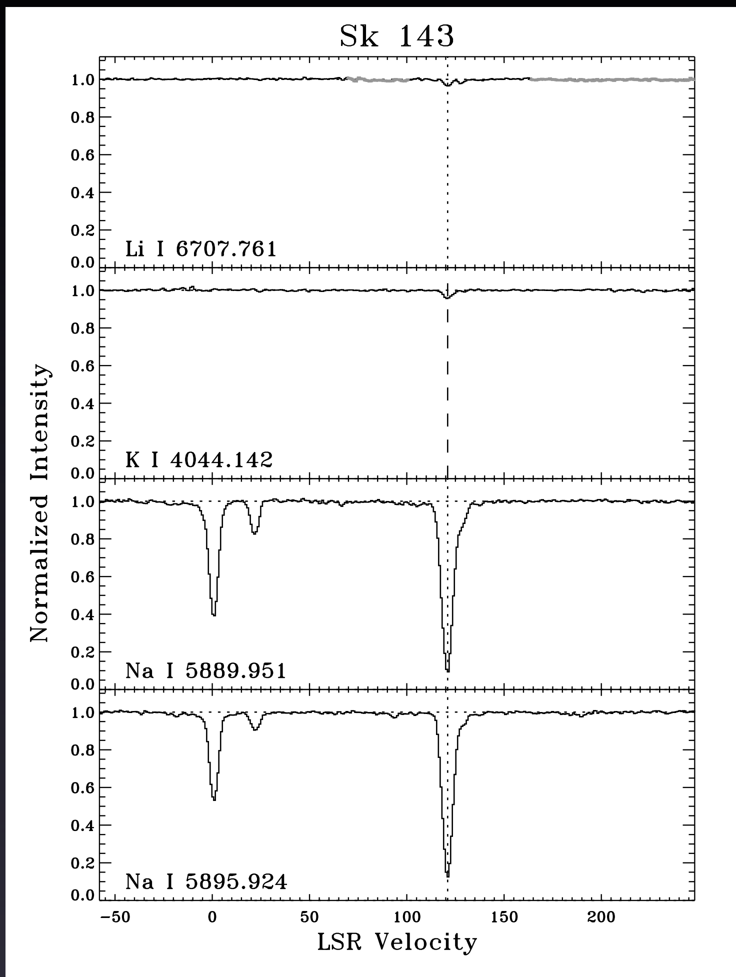

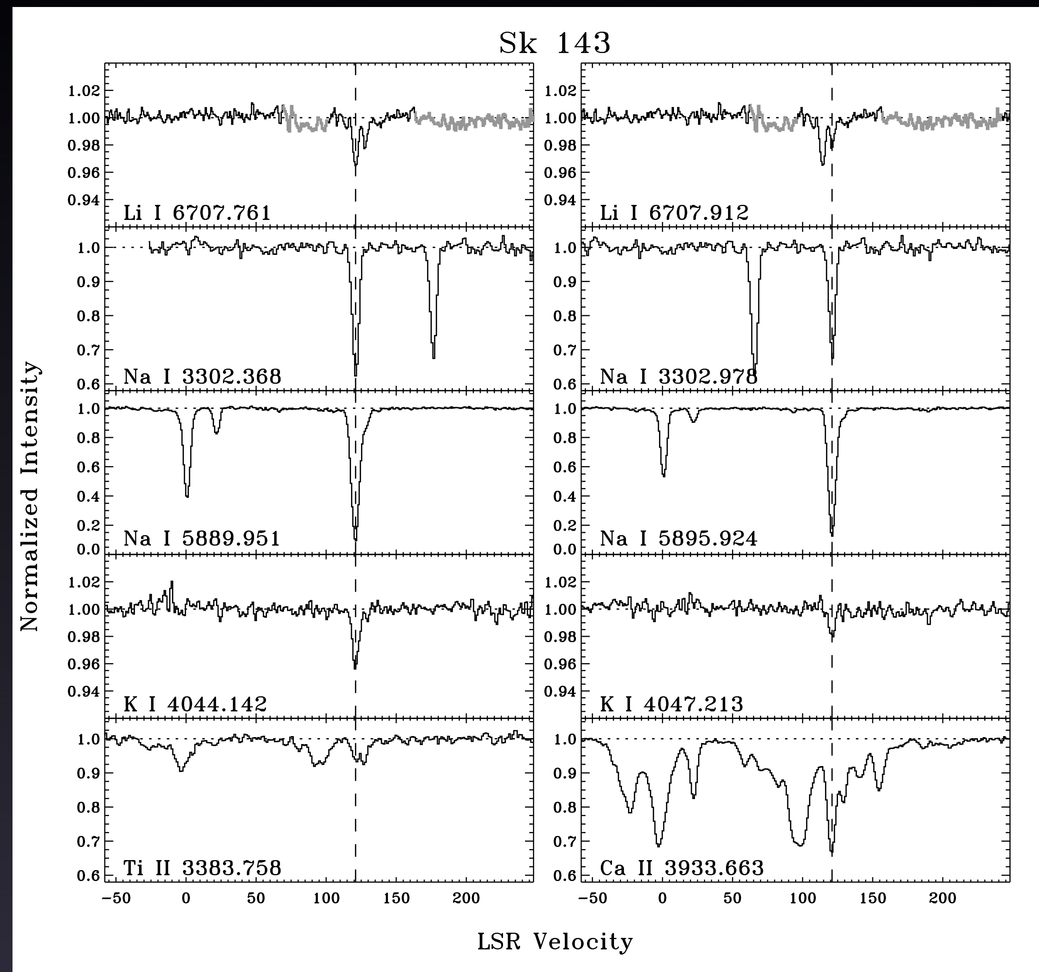

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Interstellar Li as a probe of pre-galactic production

Interstellar Systematics

$$(\mathrm{Li/H}) = N(\mathrm{Li\ I})\ N(\mathrm{H\ I})^{-1}\ x(\mathrm{Li}^0)^{-1}\ \delta_{\mathrm{Li}}^{-1}$$

- $x(\mathrm{Li}^0)$ -- Ionization fraction of Li^0.
  Use HST/STIS + UVES observations of other singly ionized species to constrain this.

- δ_{Li} -- Depletion factor for Li.
  Use new Jenkins (2008) *F** parameterization of dust depletion effects to estimate this.

- N(H I) -- H I column in the SMC.
  Use a combination of HST/STIS Lyman-α observations and ATCA H I 21-cm observations to estimate H I.

Interstellar Li as a probe of pre-galactic production

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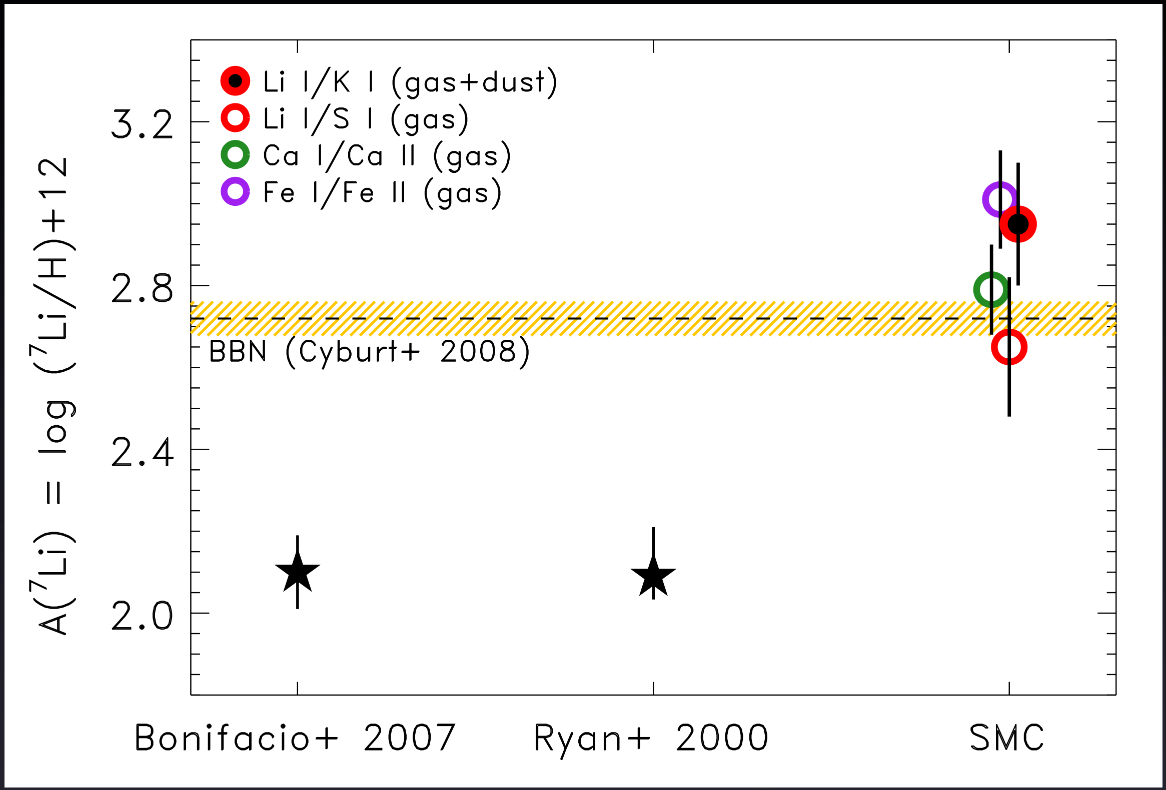

- $[Li/K]_{SMC} = +0.04 \pm 0.10$
- $A(Li)_{SMC} = 2.95 \pm 0.16$
- $(^6Li\ /\ ^7Li)_{SMC} = 0.13 \pm 0.05$

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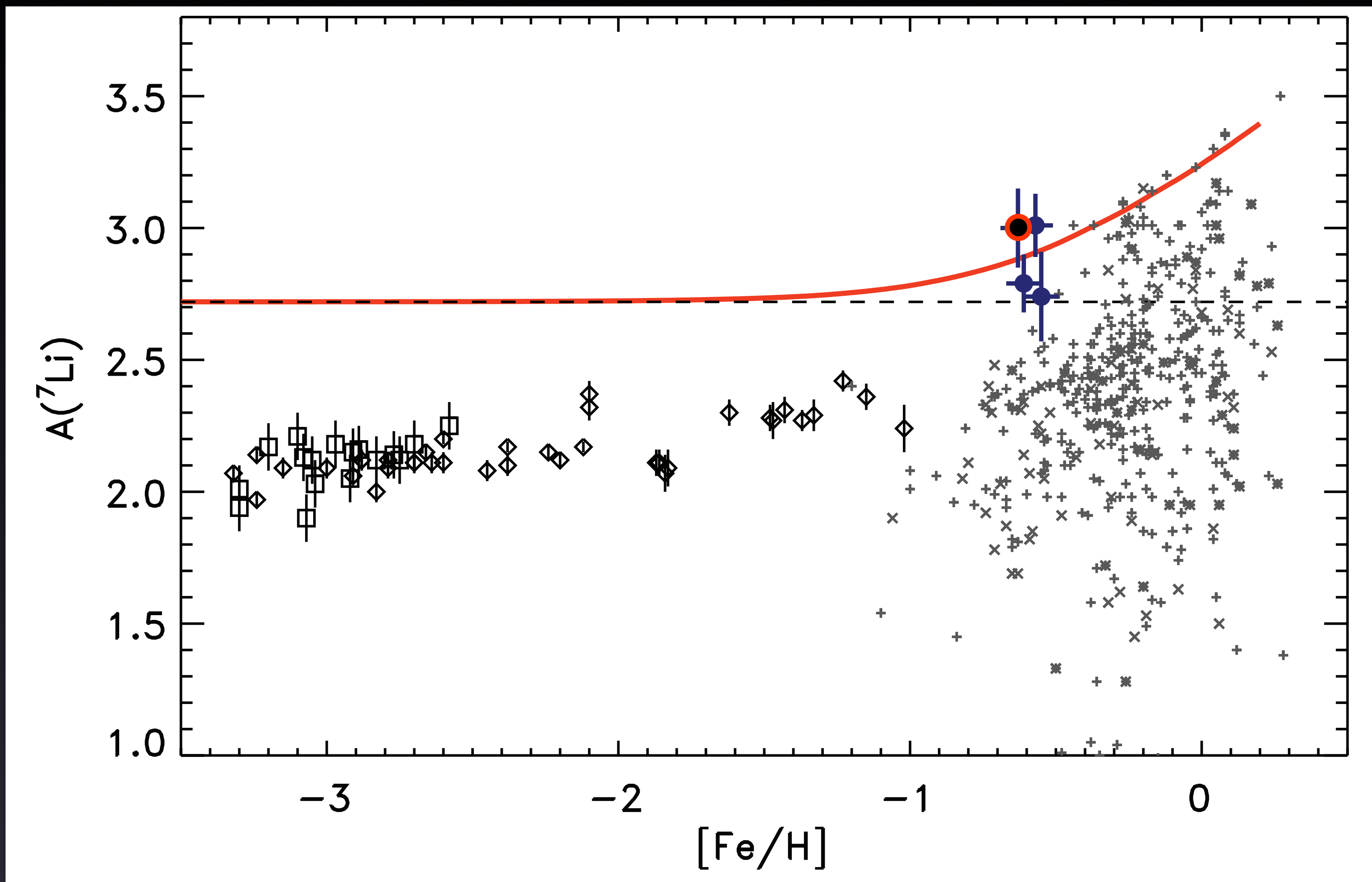

Prantzos (2010)

Interstellar Li as a probe of pre-galactic production

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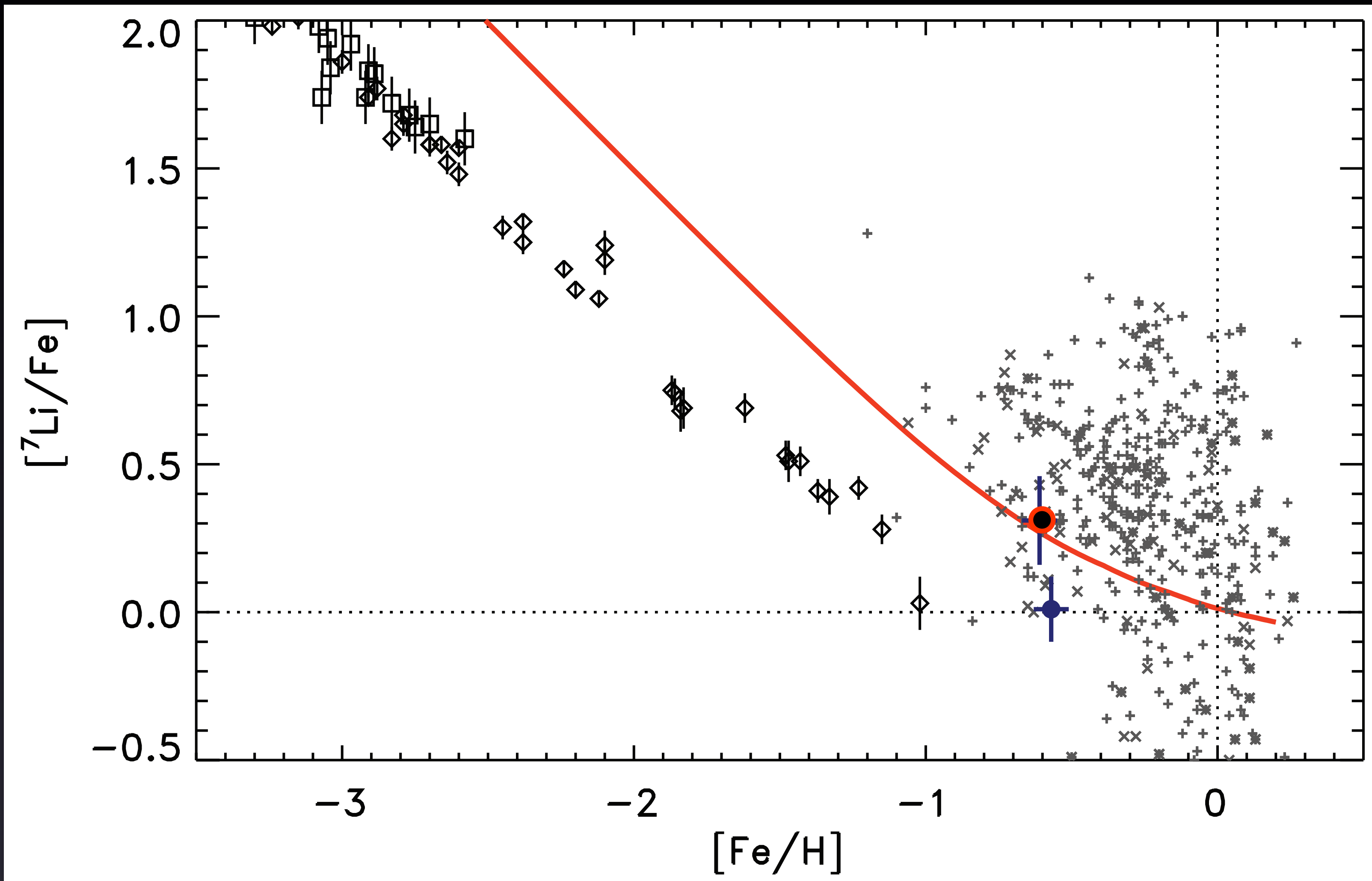


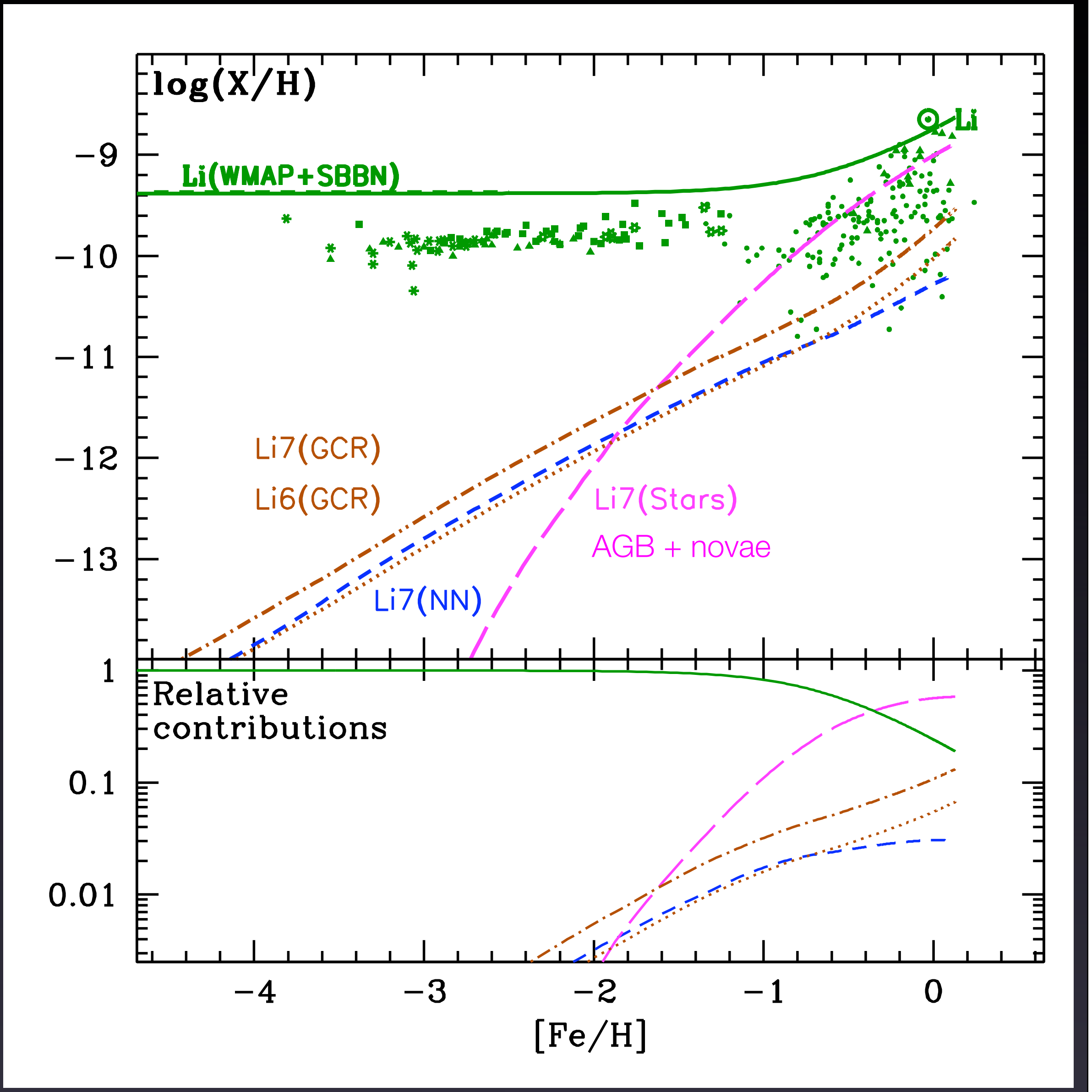
Prantzos (2010)

Stellar Li production

- *SNe II:* ν-process of Woosley et al. (1990)
- *AGB stars:* Hot bottom burning – Cameron-Fowler (1971) mechanism

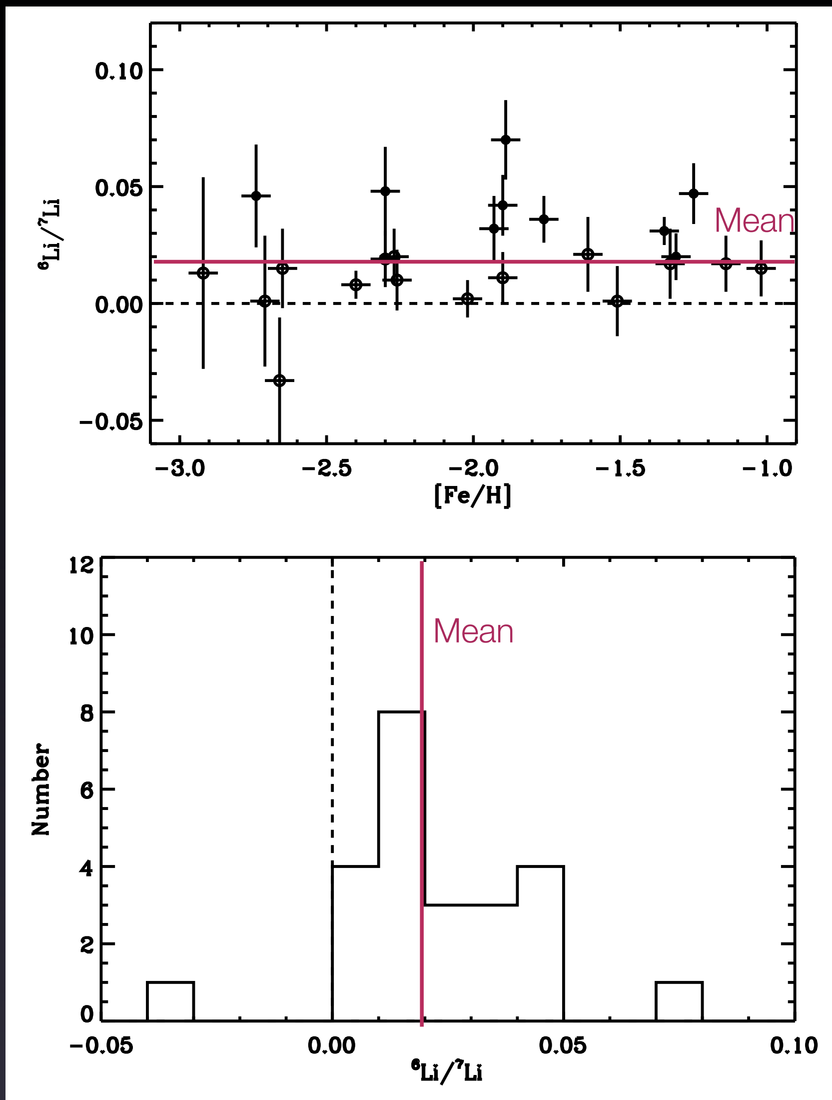
  $^{3}He(\alpha,\gamma)^{7}Be(\beta^{-},\nu)^{7}Li$

- *Novae*



Prantzos (2010)

Lithium in Population II stars

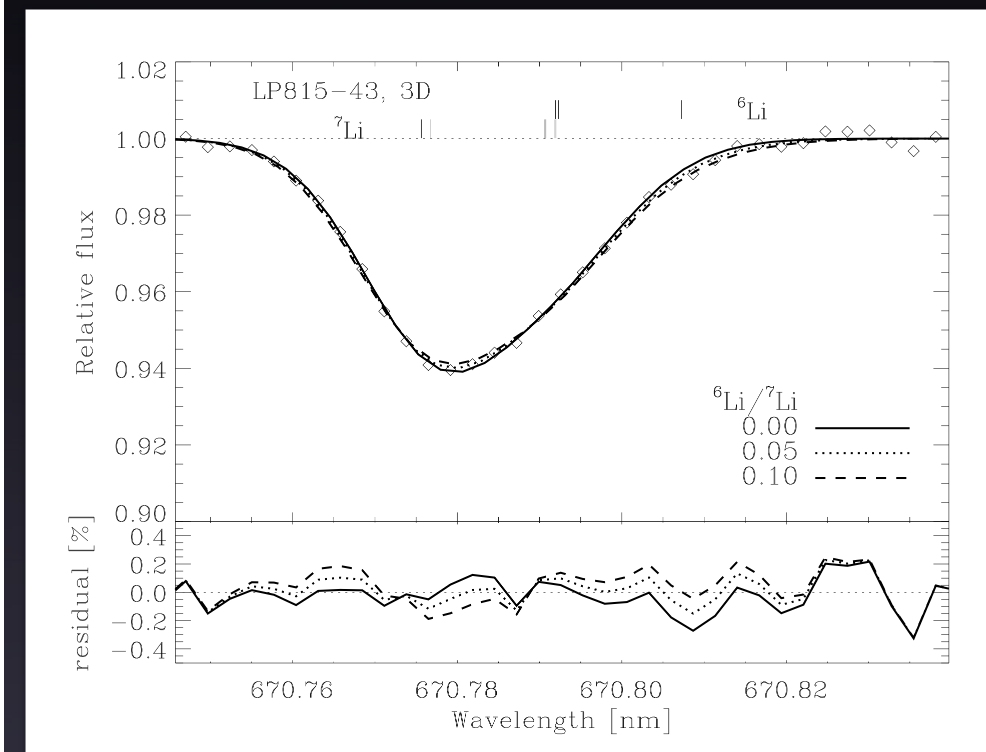


Asplund et al. (2006)

A ^{6}Li Plateau?

- SBBN predicts ^{6}Li/H ~ 10^{-14}.

- Stellar measurements at very low metallicity suggest 〈^{6}Li/H〉 ~ 2×10^{-12}.



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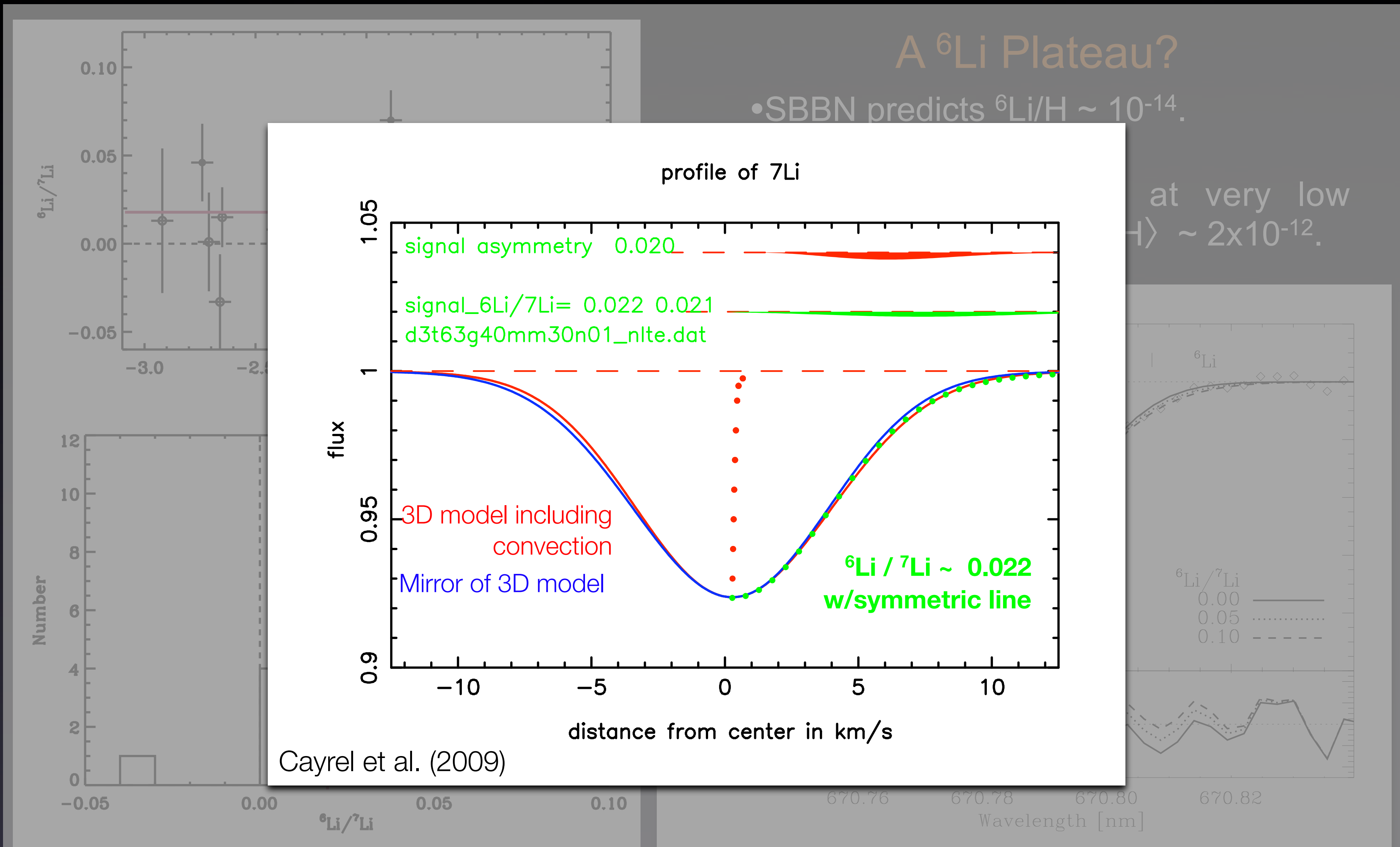

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Interstellar Li as a probe of pre-galactic production

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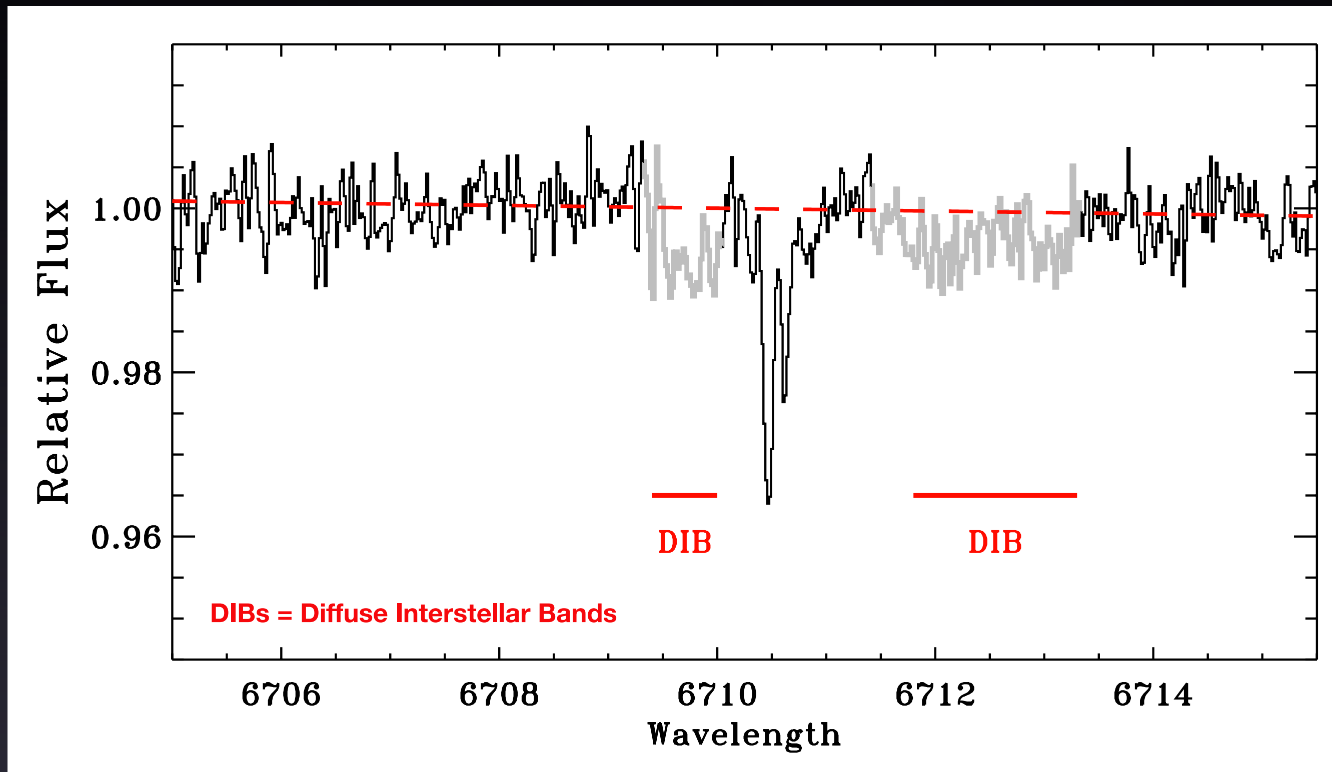

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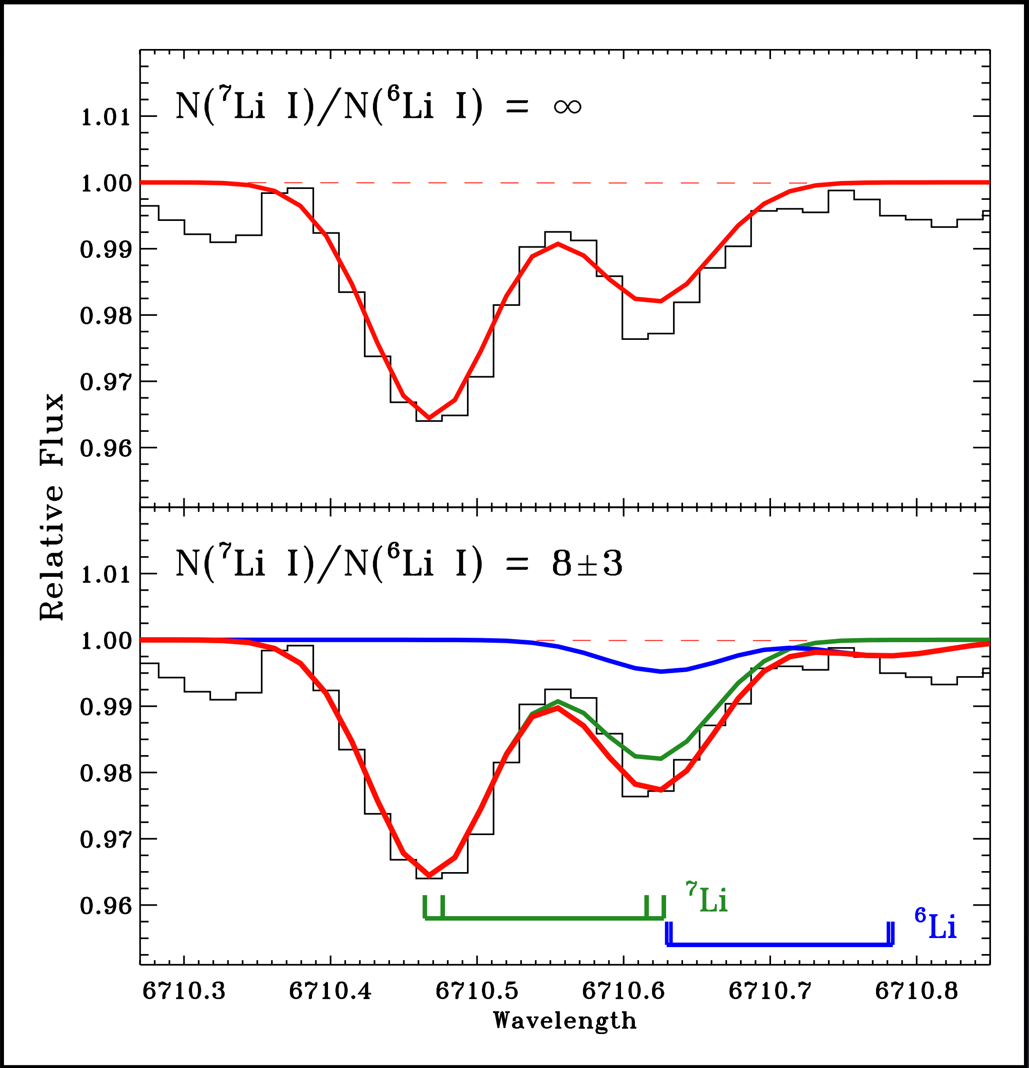

$({}^7\mathrm{Li}/{}^6\mathrm{Li})_\odot \sim 12$

$\langle {}^7\mathrm{Li}/{}^6\mathrm{Li} \rangle_{MW} \sim 7.6$

$({}^7\mathrm{Li}/{}^6\mathrm{Li})_{CR} \sim 1.6$

The measured isotopic ratio is consistent with the solar ratio and the isotopic ratio measured in the ISM of the Milky Way.

Assuming the ^{6}Li is produced via cosmic ray spallation, our measurement implies ~(20±7)% of the ^{7}Li has been produced by cosmic rays.

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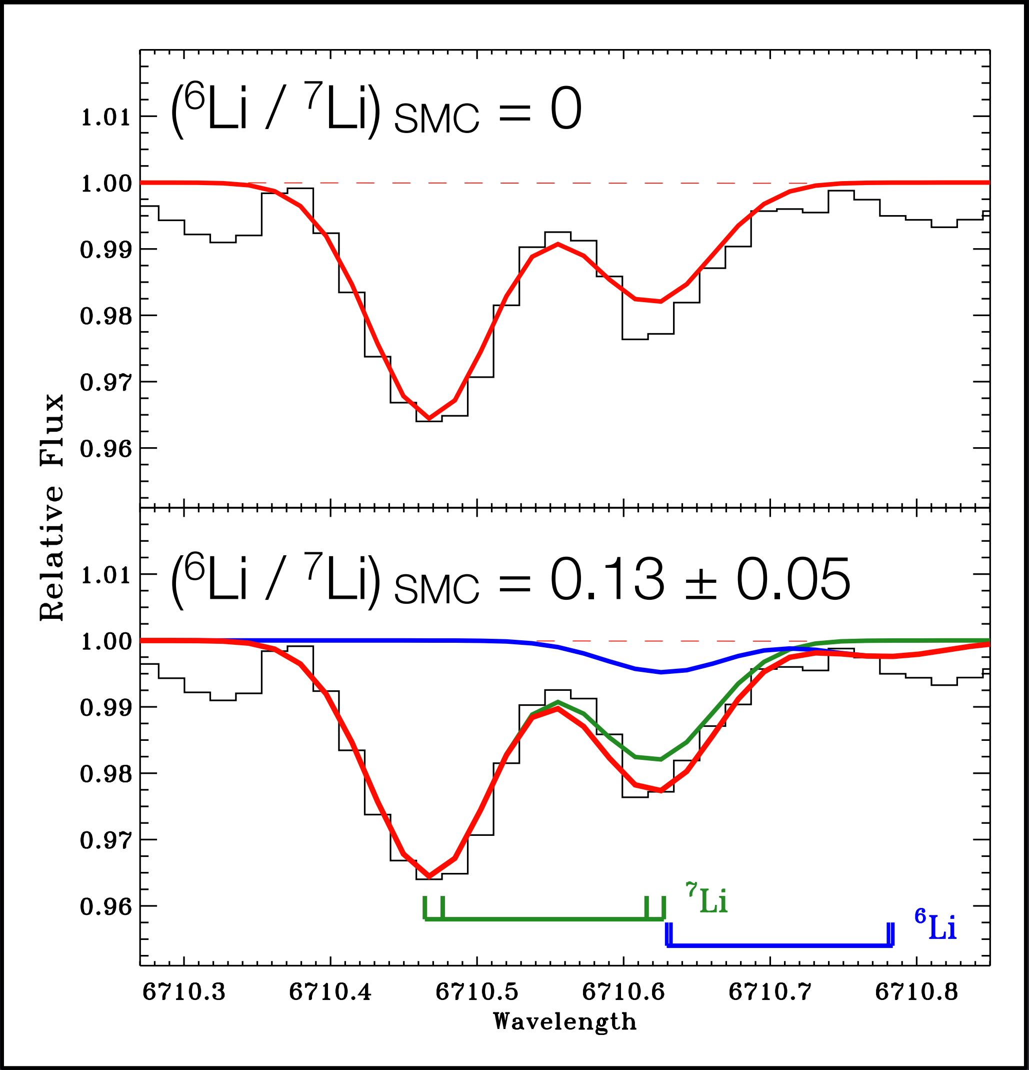

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Summary

- Gas phase abundance measurements provide an alternate approach to probing galactic chemical evolution (although perhaps not Galactic chemical evolution).

- Measurements of interstellar lithium in low metallicity galaxies will allow us to probe primordial and pre-galactic production of Li (including the ^{7}Li/^{6}Li ratio) in a way that is independent of the systematics associated with stellar determinations.

- The first measurement of gas-phase Li in the SMC suggests an absolute abundance of Li that is larger than those seen in Milky Way stars of similar metallicity. It is consistent with the BBN-predicted primordial abundance, but may not rule out the lower stellar abundance.