Stellar abundances: Probes of stellar process, Galaxy formation & cosmology

T. Sivarani
Indian Institute of Astrophysics
Bangalore

Outline

- Lithium problem - An introduction

- Towards solving Li-problem with TMT-HROS
  Probing the pre-galactic Li abundances with new sites

- Lithium and Beryllium to trace the Cosmic ray nucleosynthesis
  Blue sensitivity at 313nm BeII doublet line (TMT-HROS)

- Early CNO evolution(TMT-WFOS and HROS)

- r-process-origin ==> using r-process abundances outside Milkyway (TMT-HROS) with **blue sensitivity**

Possible sources of Lithium

- Big bang Nucleosynthesis A(^{7}Li) = 2.72, A(^{6}Li) = -2.00, ^{6}Li/^{7}Li ~2 10^{-5}

Observed ==> Lithium Plateau A(Li) = 2.1, A(6Li) = 1.0, 6Li/7Li ~ 0.1 in metal poor stars, ISM value = 0.09-0.2 at solar metallicity.

- RGB, AGB stars - Cameron-Fowler Mechanism
- SN and Novae
- Cosmic ray spallation of CNO nuclei
- **Depletion of Lithium in stars, $2.5x10^{6}$, $2.0x10^{6}$**

Lithium problem-1,2,3…?

1. Discrepancy between Lithium plateau (Spite & Spite) and the CMB prediction a factor of 2-3 (Aoki-san)

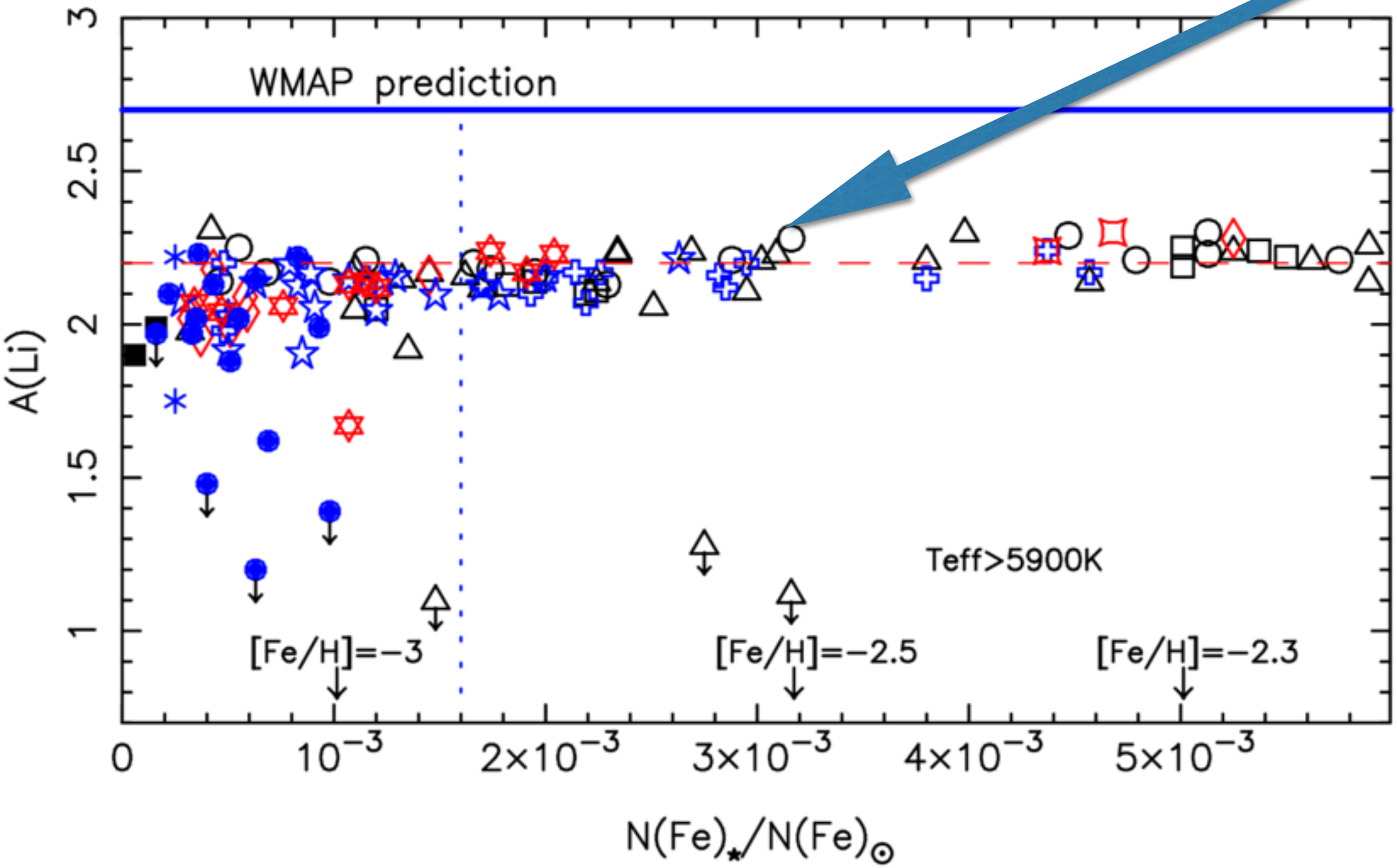
2. Decreasing Lithium abundances below [Fe/H] < -2.5

3. Isotopic lithium abundances, 6Li - plateau (Aoki-san)

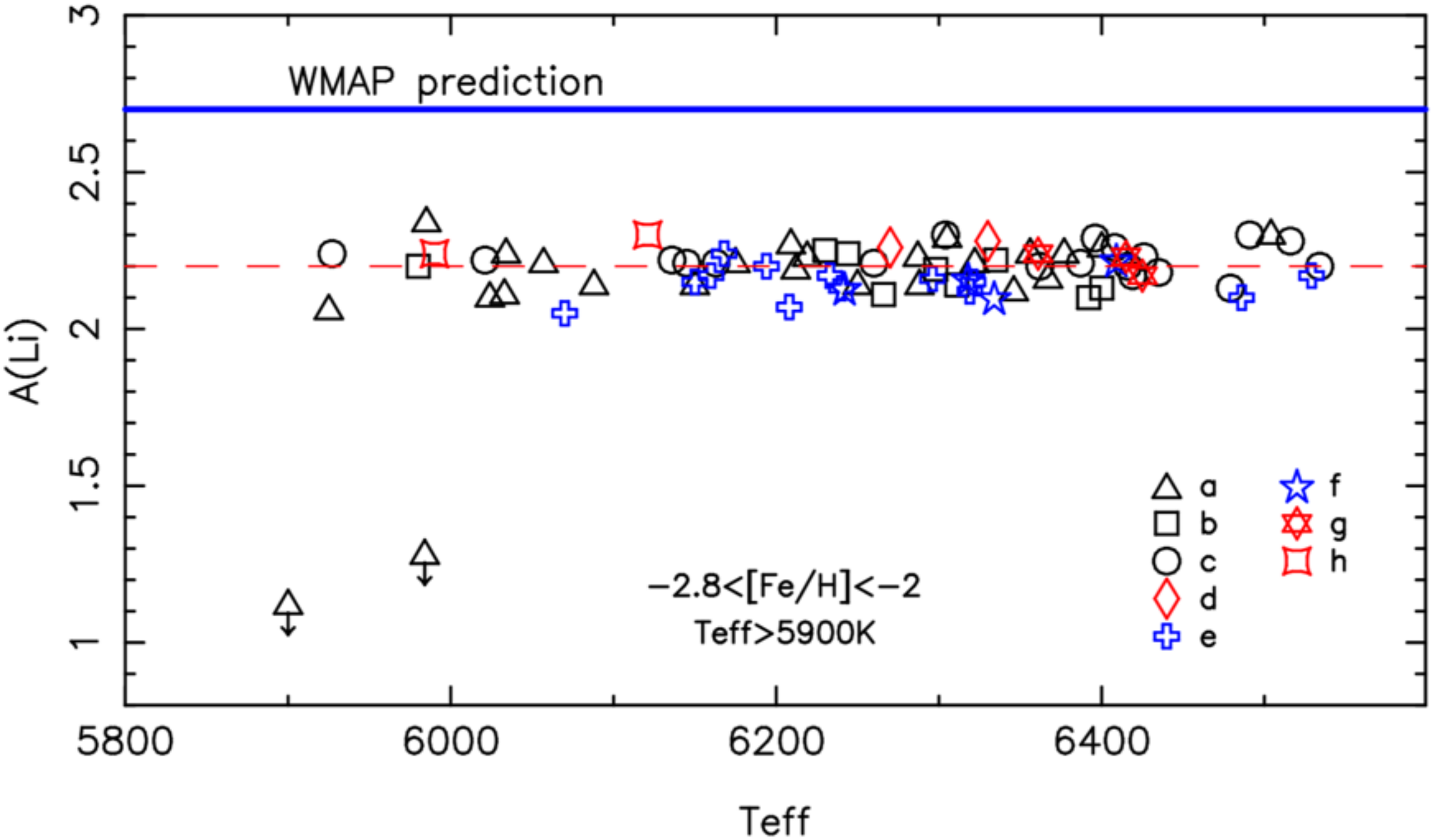
4. Sources of Lithium at solar metallicities (Caty Pilachowski)

Li-problem-1

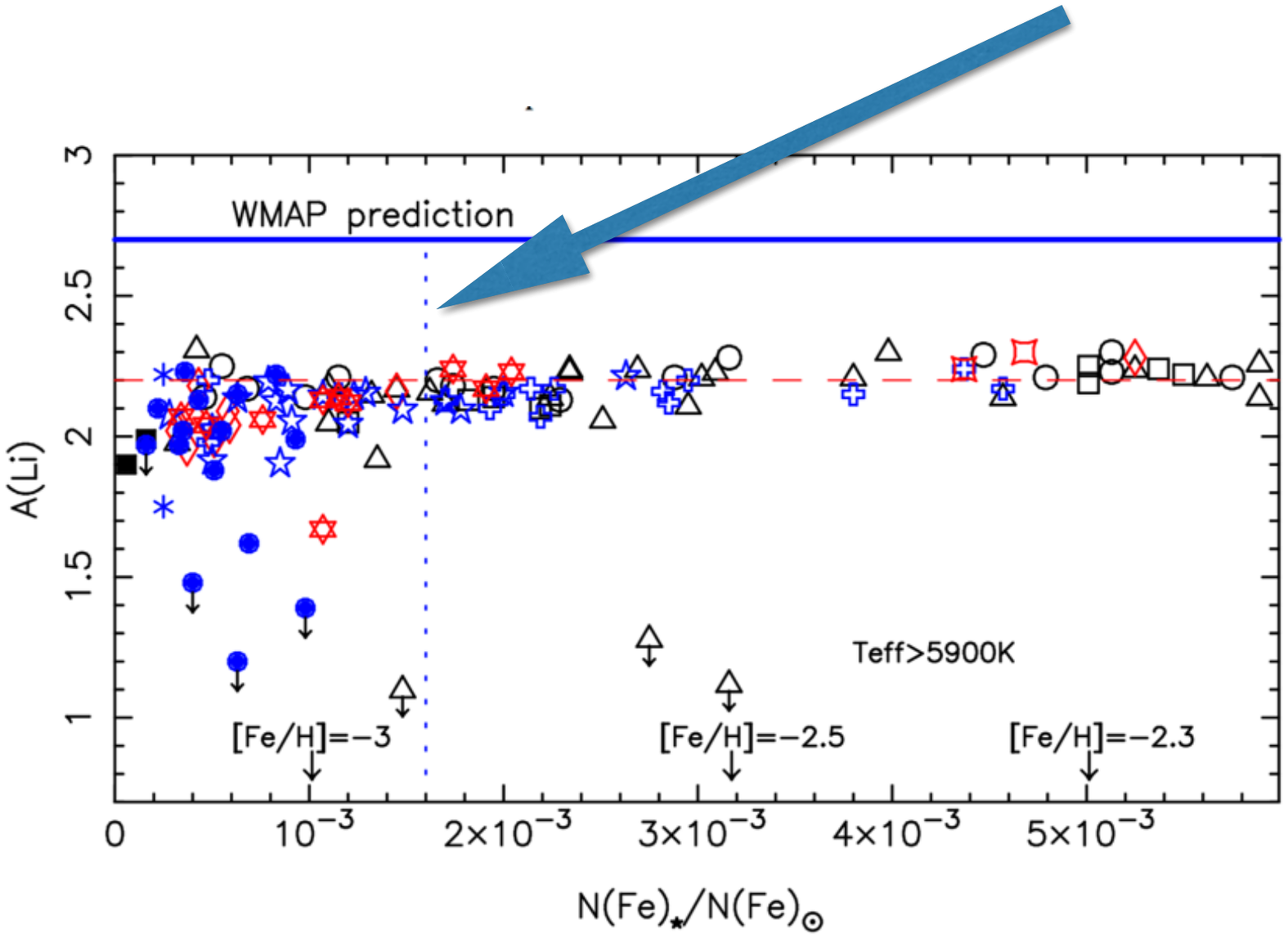
Observed Lithium plateau
2-4 times lower than CMB prediction



Spite et al. 2012, Sbordone et al 2009, Bonifacio et al., Aoki et al. 2009 Asplund et al
Garcia-perez et al. Melendez et al. Charbonnel & Primas


WMAP prediction
A(Li)
Teff
−2.8<[Fe/H]<−2
Teff>5900K
a
b
c
d
e
f
g
h
3
2.5
2
1.5
1
5800
6000
6200
6400

Lithium problem-2 at [Fe/H] < -2.5

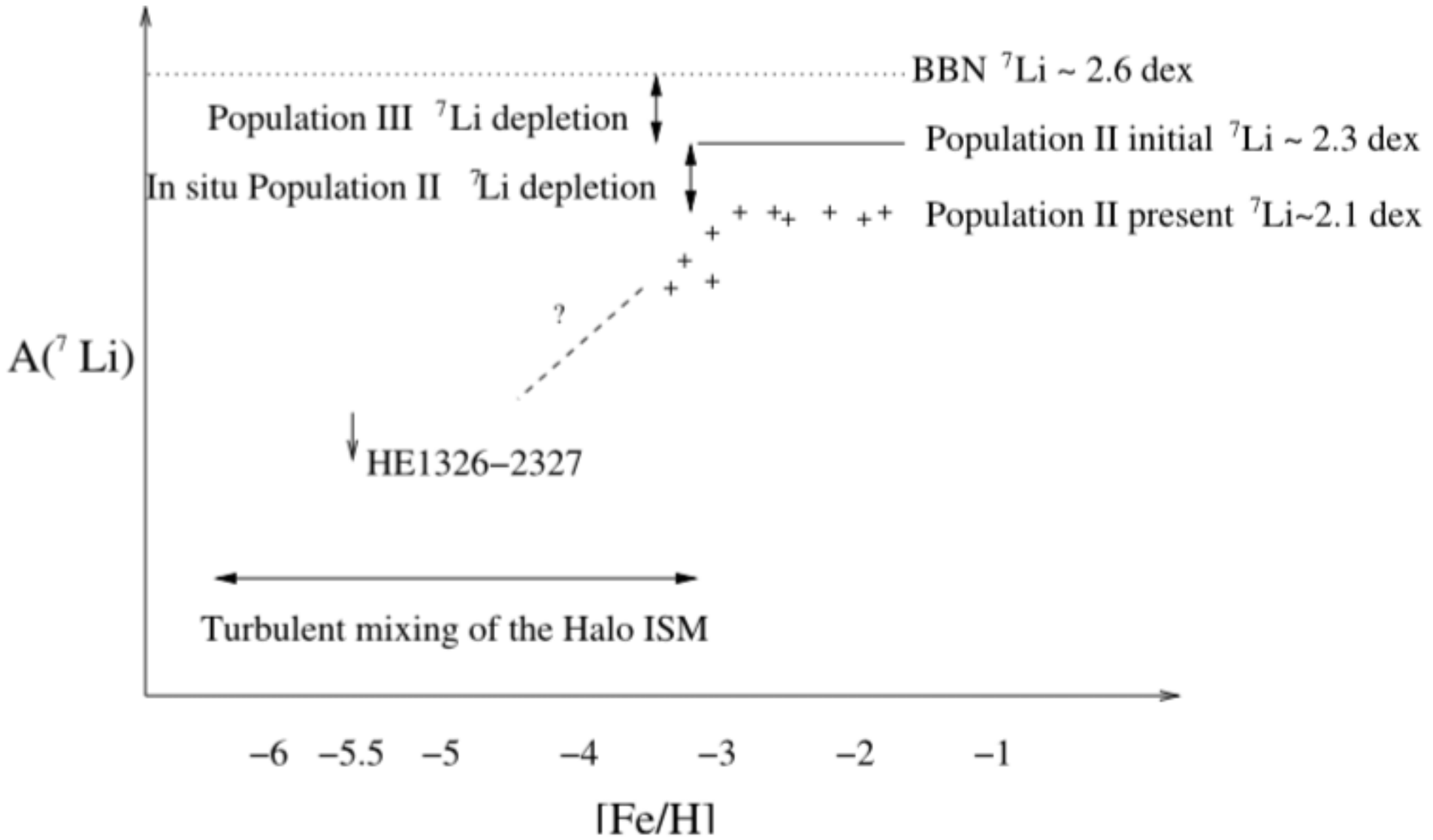


[Fe/H] < -2.5

- No MW GCs at these metallicities
- Tail of the metallicity distribution
- Further depletion of Li
- r-process rich stars [r/Fe] > 1.5
- Scatter in abundances and trends in low/high n-capture elements
- CEMP-no stars start to dominate

==> Pop-III astration

Lithium destruction by Pop-III stars

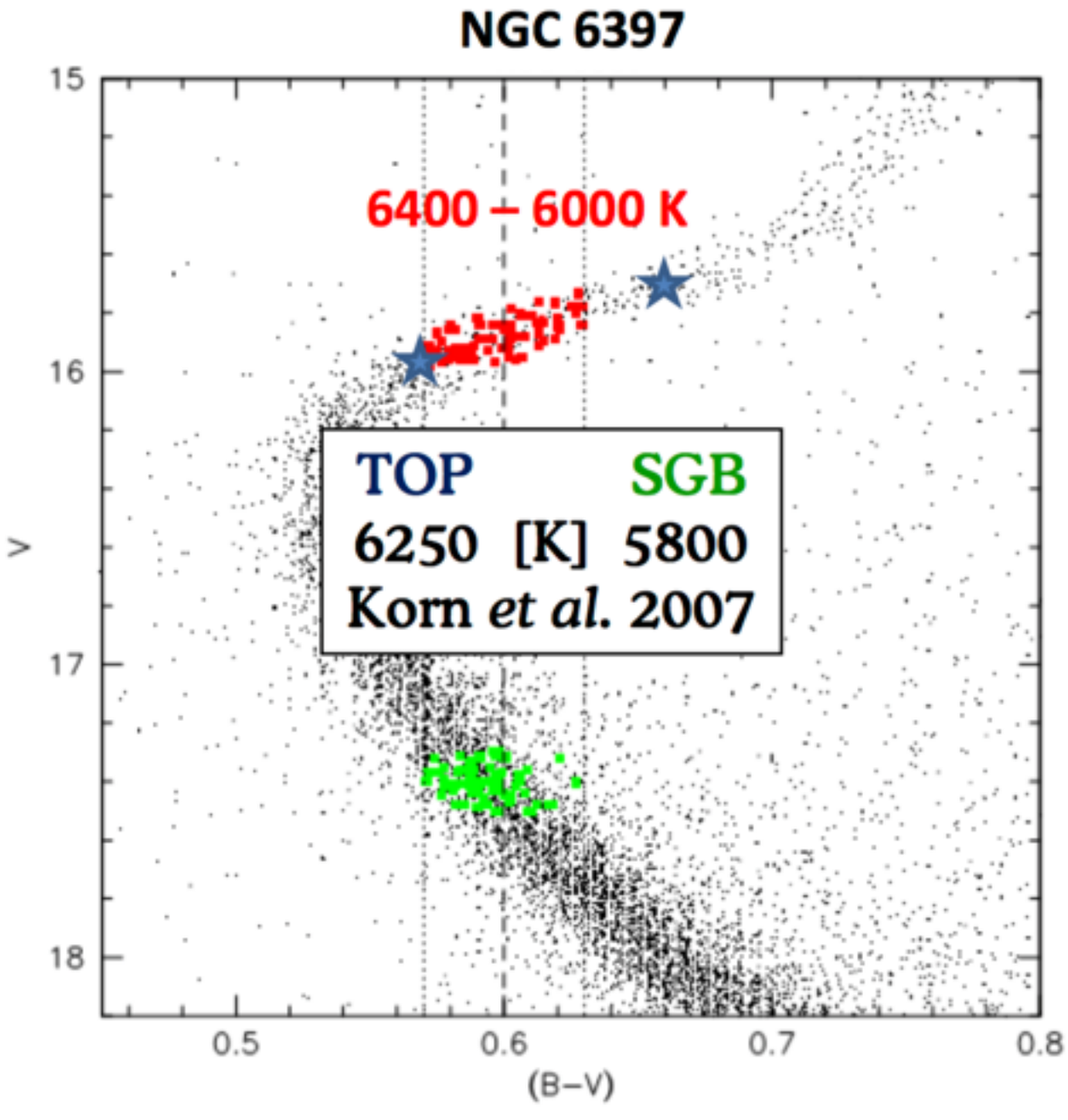


Piau et al. 2006

Metallicity increases too quickly! -Prantzos (2013)

Stellar diffusion? - Globular clusters as a testbeds

Richard (2005), Korn et al. (2007), Lind et al. (2009)



- Uniform of depletion
- no Temperature dependance
- **Multiple population in Globular clusters :(**

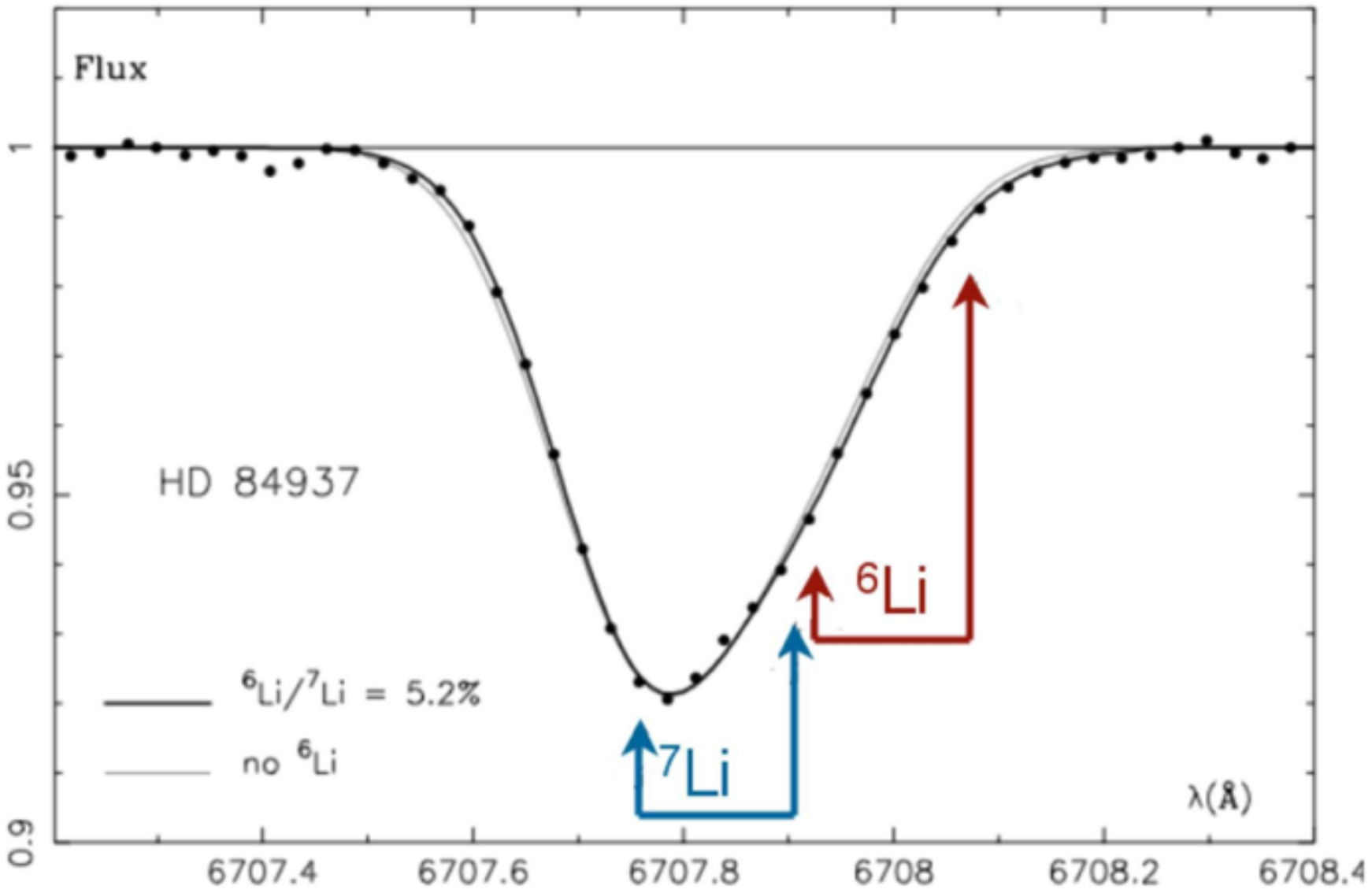
TMT- HROS with some multiplexing will be ideal to test this R> 20000-30000

Alternate sites to probe the Pre Galactic Lithium using TMT

- Lithium in the metal poor, main sequence stars of Milkyway satellites
- Lithium Metal poor gas - High velocity clouds
- Lithium in inner and outer halo stars

R > 20000-30000 and multiplexing

Lithium problem-3
Lithium isotopic ratio



Asymmetry due to convective up flows

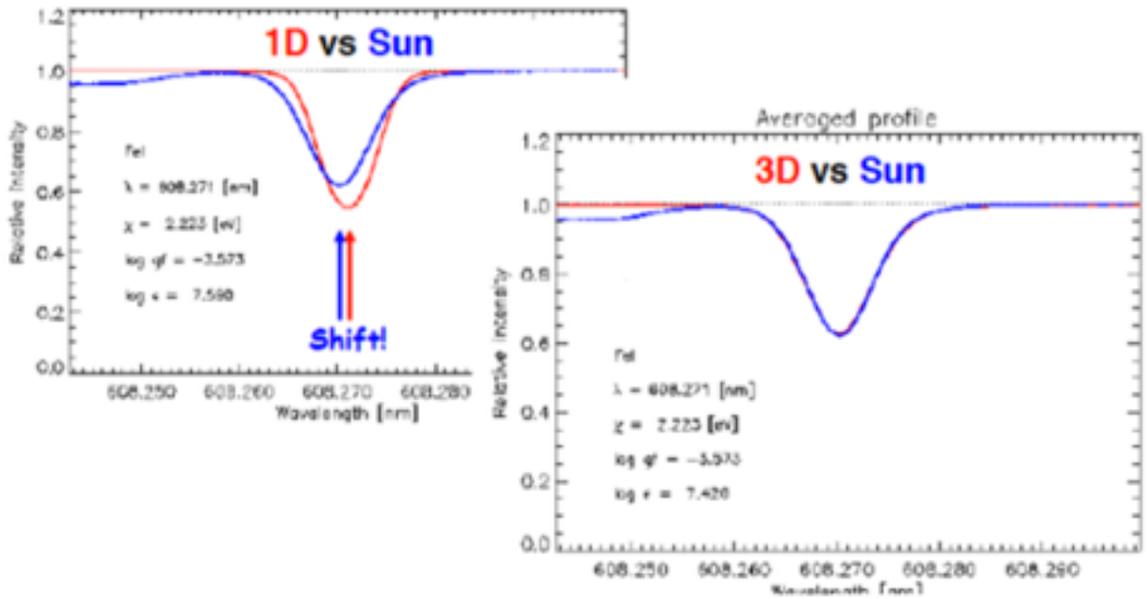
Successes of 3D models

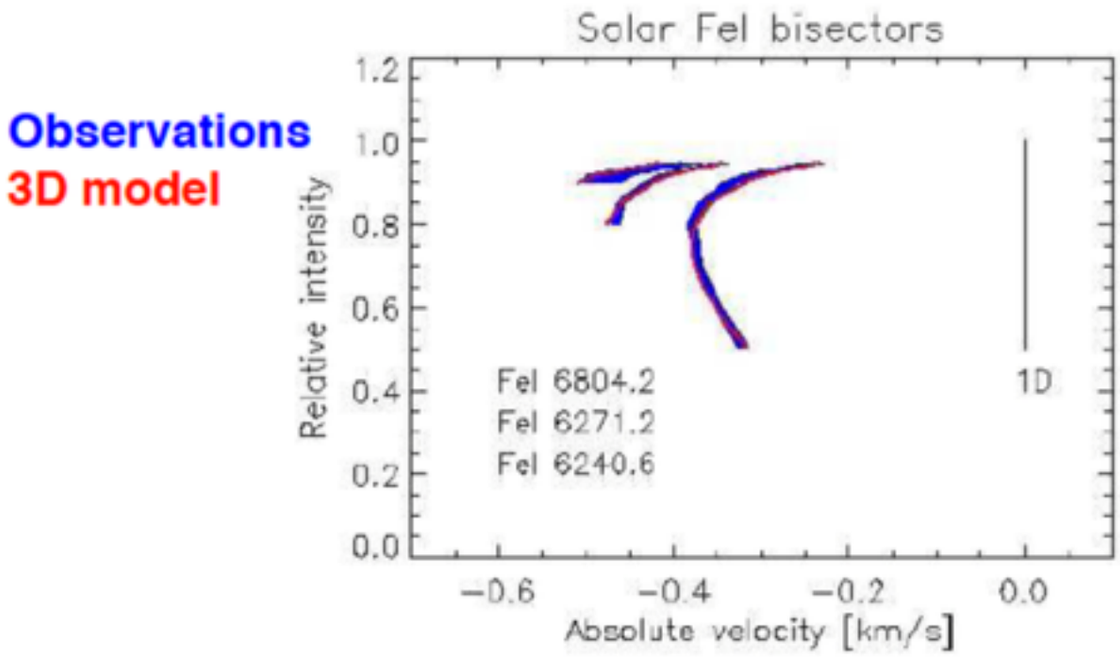
1. line profiles reproduced well -- convective motions and their structure are realistic

2. No micro- or macro-turbulence needed in 3D

3. Line asymmetries and shifts match better

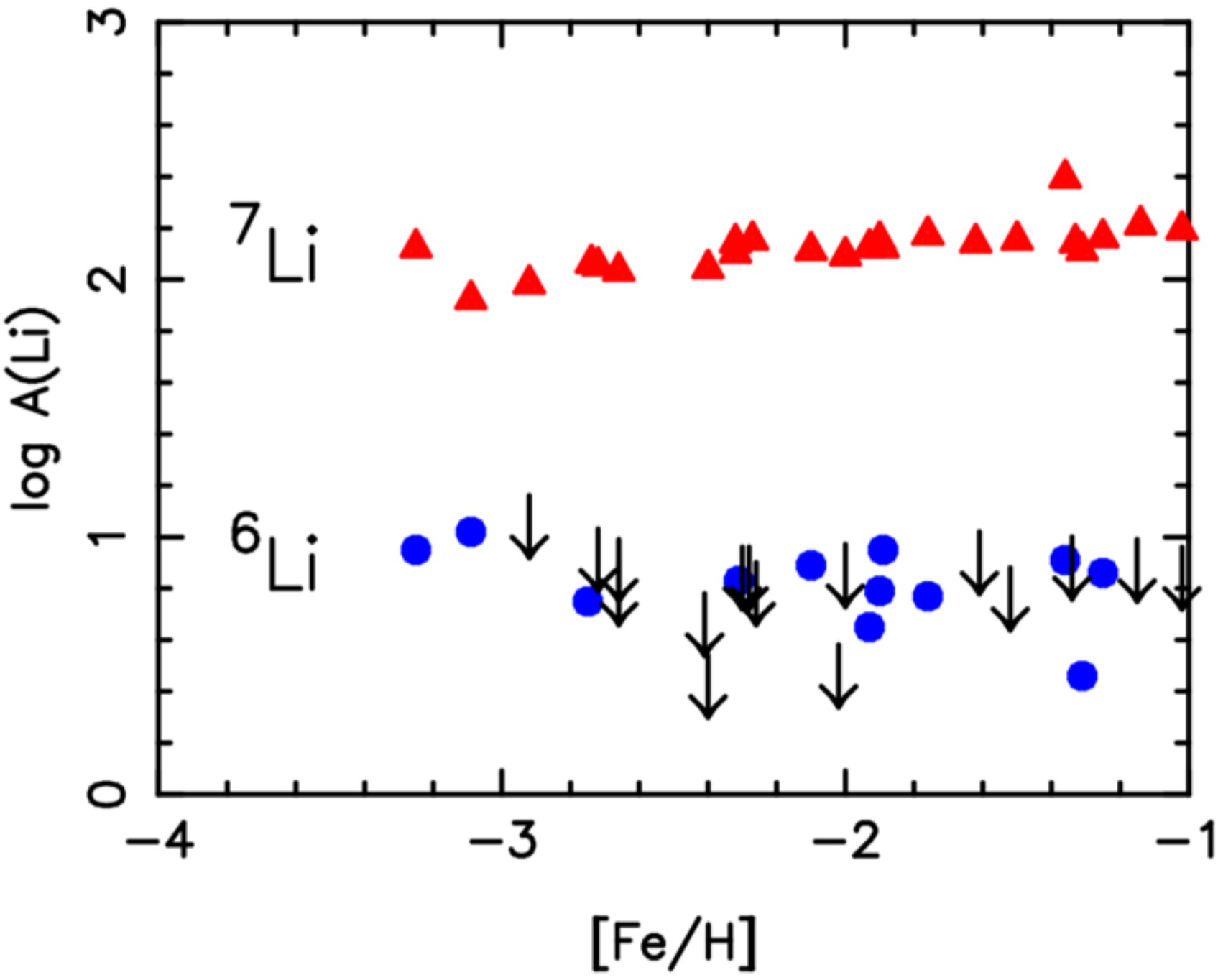
Credit: Grevesse (2014)





$^{6}Li/^{7}Li$ Isotope ratio using 3D stagger code

Lind et al. 2012



6Li/7Li - discrepancy

- Alternate Cosmic ray or stellar production mechanism ==> Elevates the 7Li -BBN problem

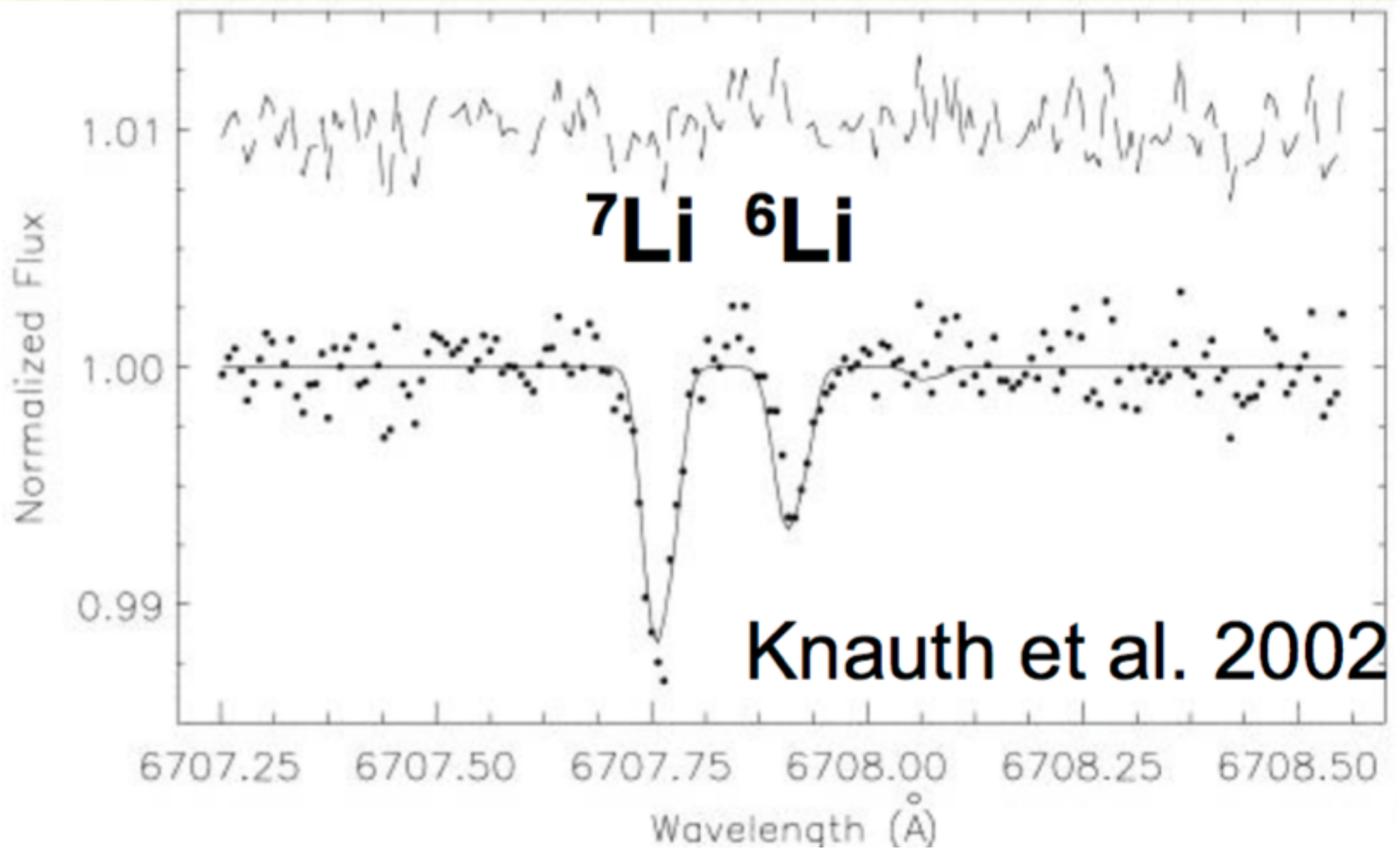
- Accurate Stellar parameters & models - GAIA would help

- Simplistic data reduction

  Slit tilt due to quasi littrow angle

  Accurate slit profile - complicated due to Image slicers

Lithium isotopes in ISM - simpler solution



Lithium isotopic ratios in high velocity clouds

nearby metal poor gas-rich galaxies? - ALF-ALFA survey metal poor systems with TMT

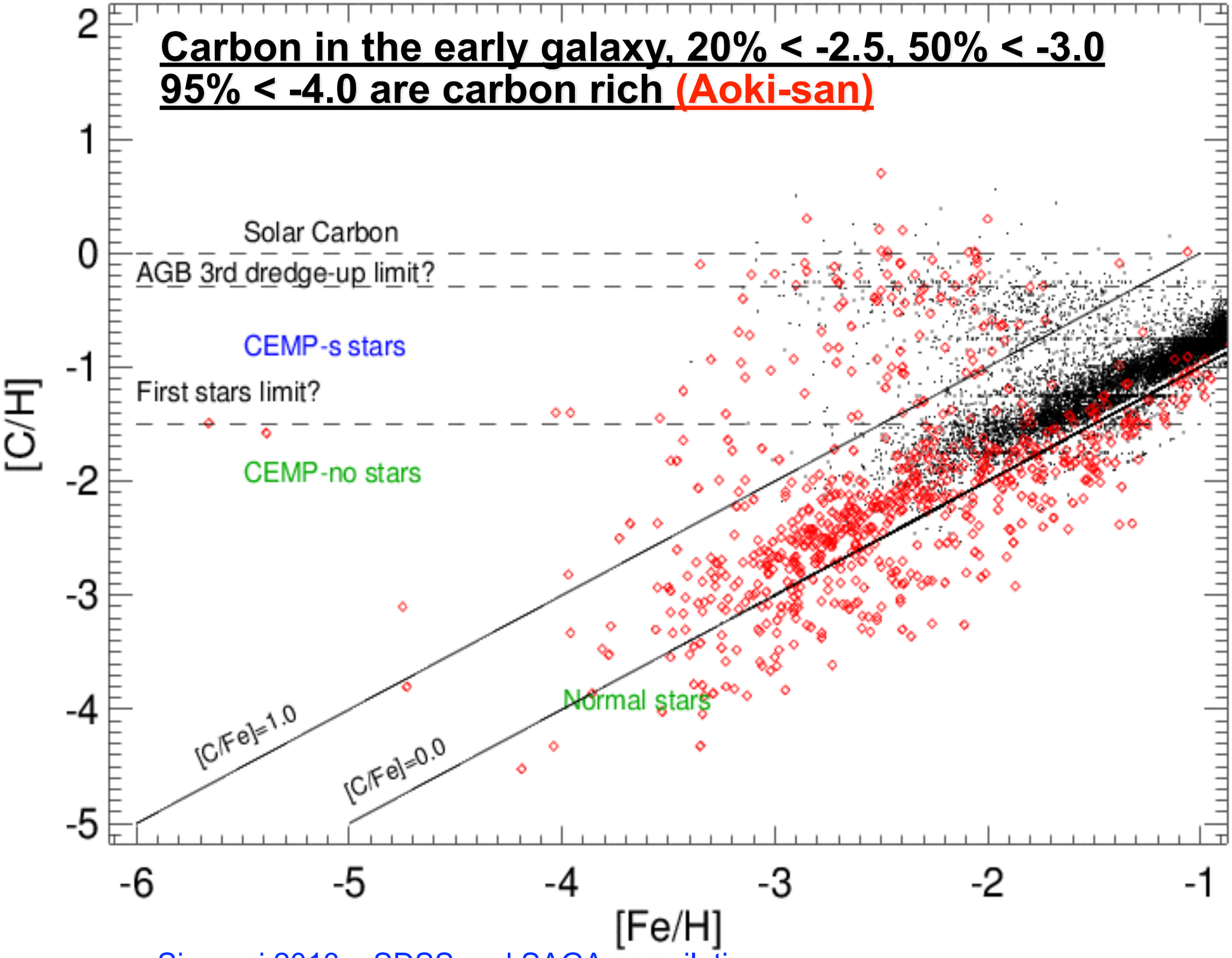
Cosmic ray Spallation contribution to 6Li production

- Beryllium and Boron abundances

Beryllium

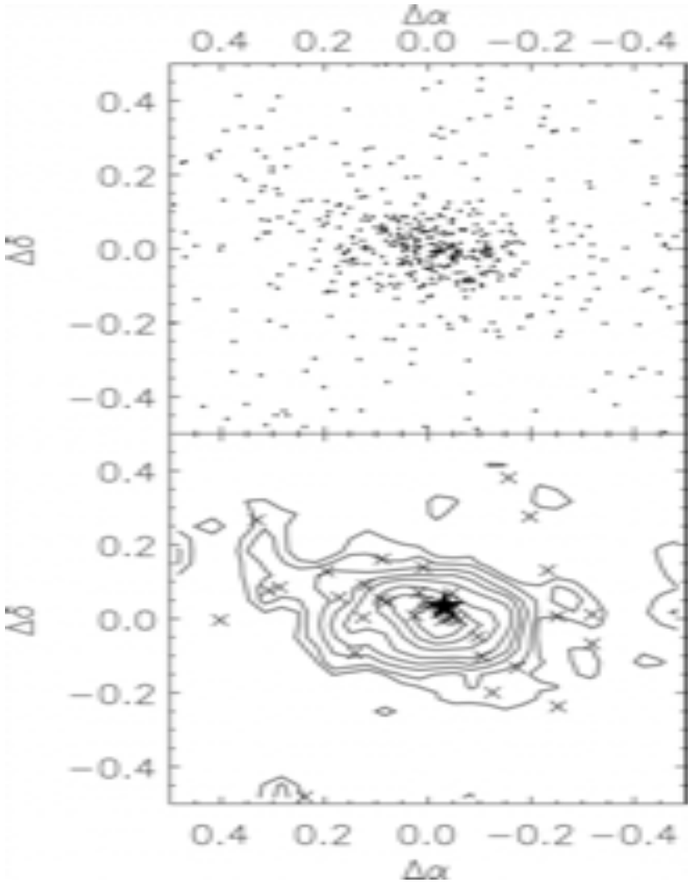
- Very minor contribution from BBN N(Be/H) 10^{-17}
- Spallation reaction between Galactic Cosmic rays and CNO nuclei
- Beryllium to probe cosmic magnetic fields, coherence length? (Zwiebel)
- TMT blue sensitivity 313nm is important
- VLT-CUBES - brazillian collaboration

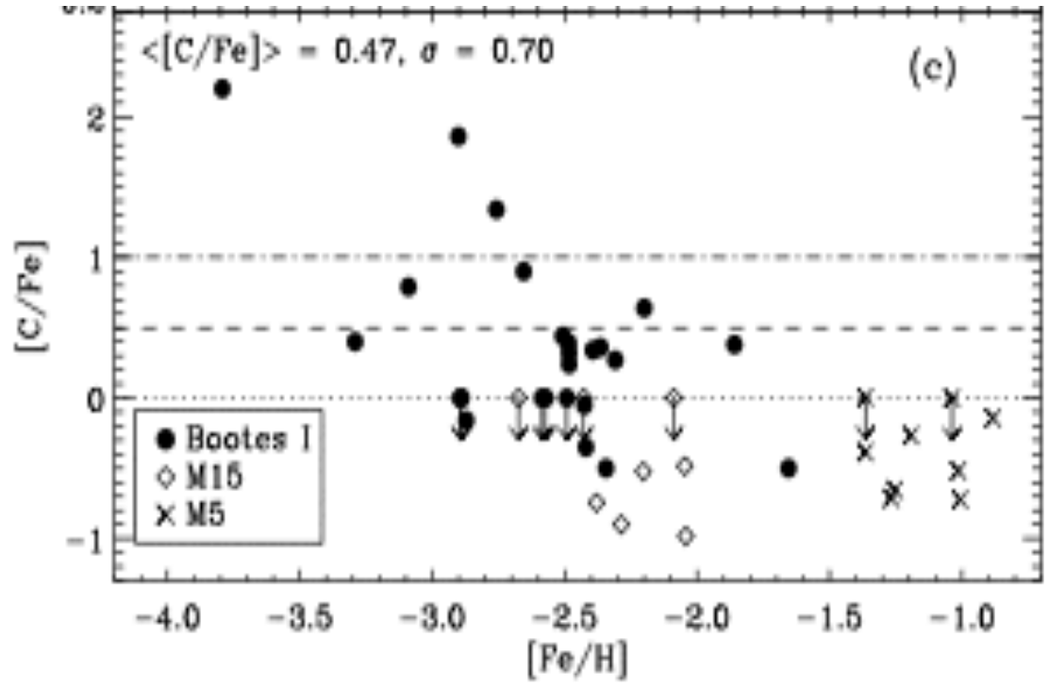
Carbon in the early galaxy, 20% < -2.5, 50% < -3.0
95% < -4.0 are carbon rich (Aoki-san)



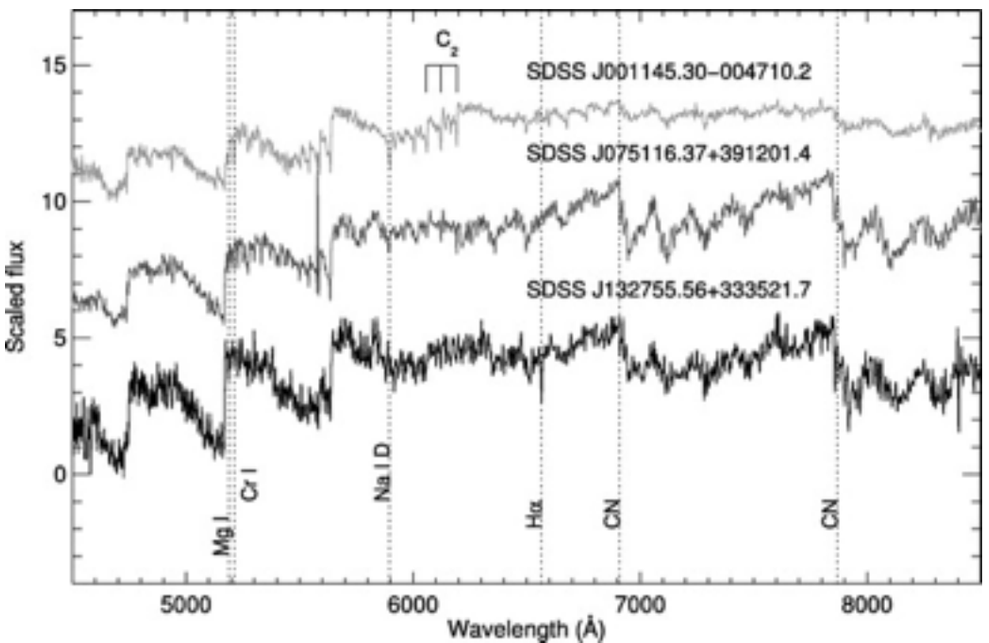
Sivarani 2013, SDSS and SAGA compilation

Carbon enhancement Galactic or pre-galactic Ultra faint dwarf satellite galaxies





Lai et al. 2011



Zucker et al. 2006

C,N,O in the early Galaxy

- Frequency of carbon rich stars increase at low metallicities 15% @ -2.5, 30%@ -4.0, 95% < -4.0
- Contribution from Pop-III stars? ==> metal poor stars in MW satellite galaxies should show this?
- CH 435nm, CN 388nm, NH 338nm using WFOS
- OI 630nm TMT-HROS

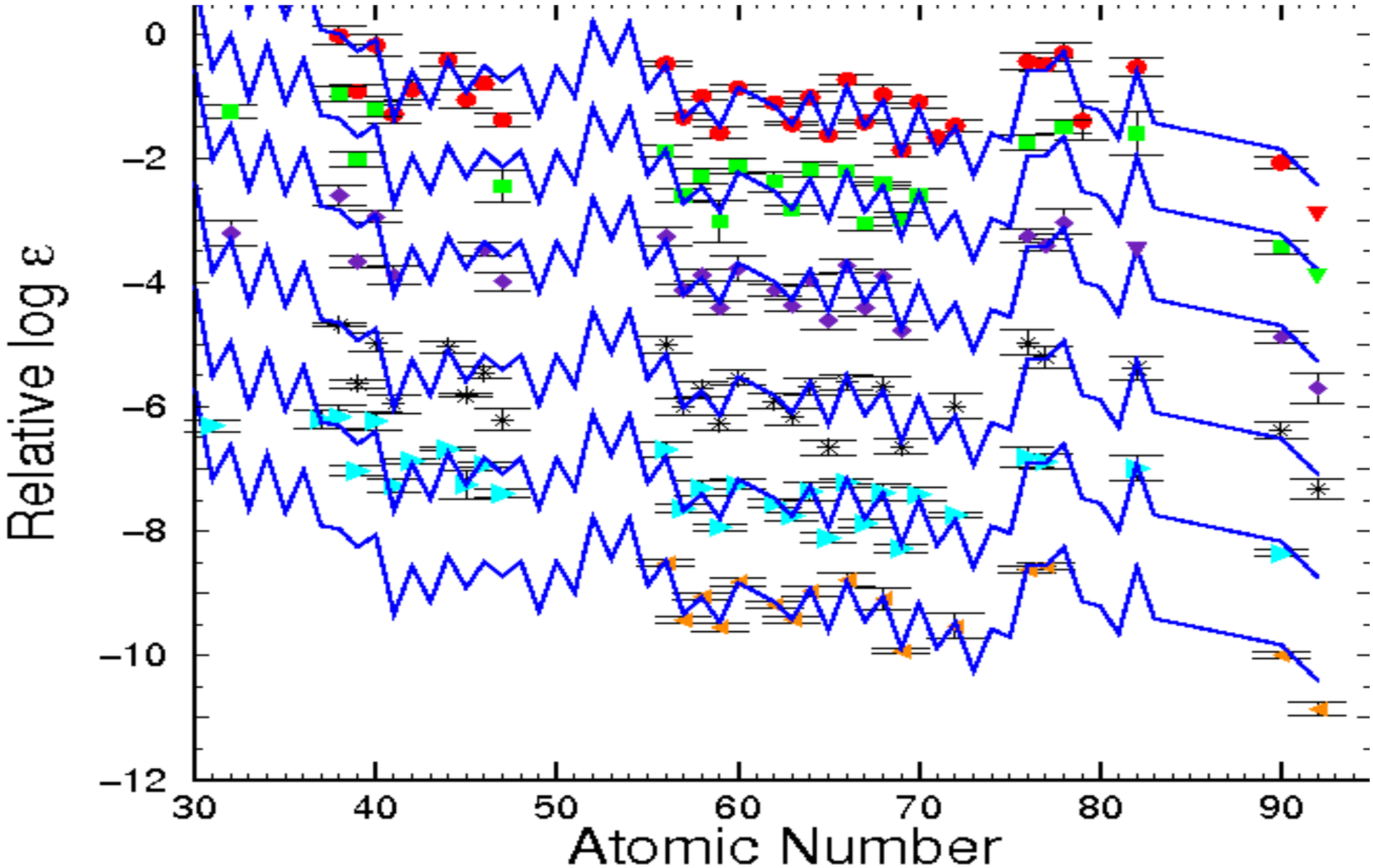
r-process sites

- Core collapse SN & NS-NS mergers

==> Universality of main r-process

==> Evolution of r-process at different metallicities

Universality of r-process

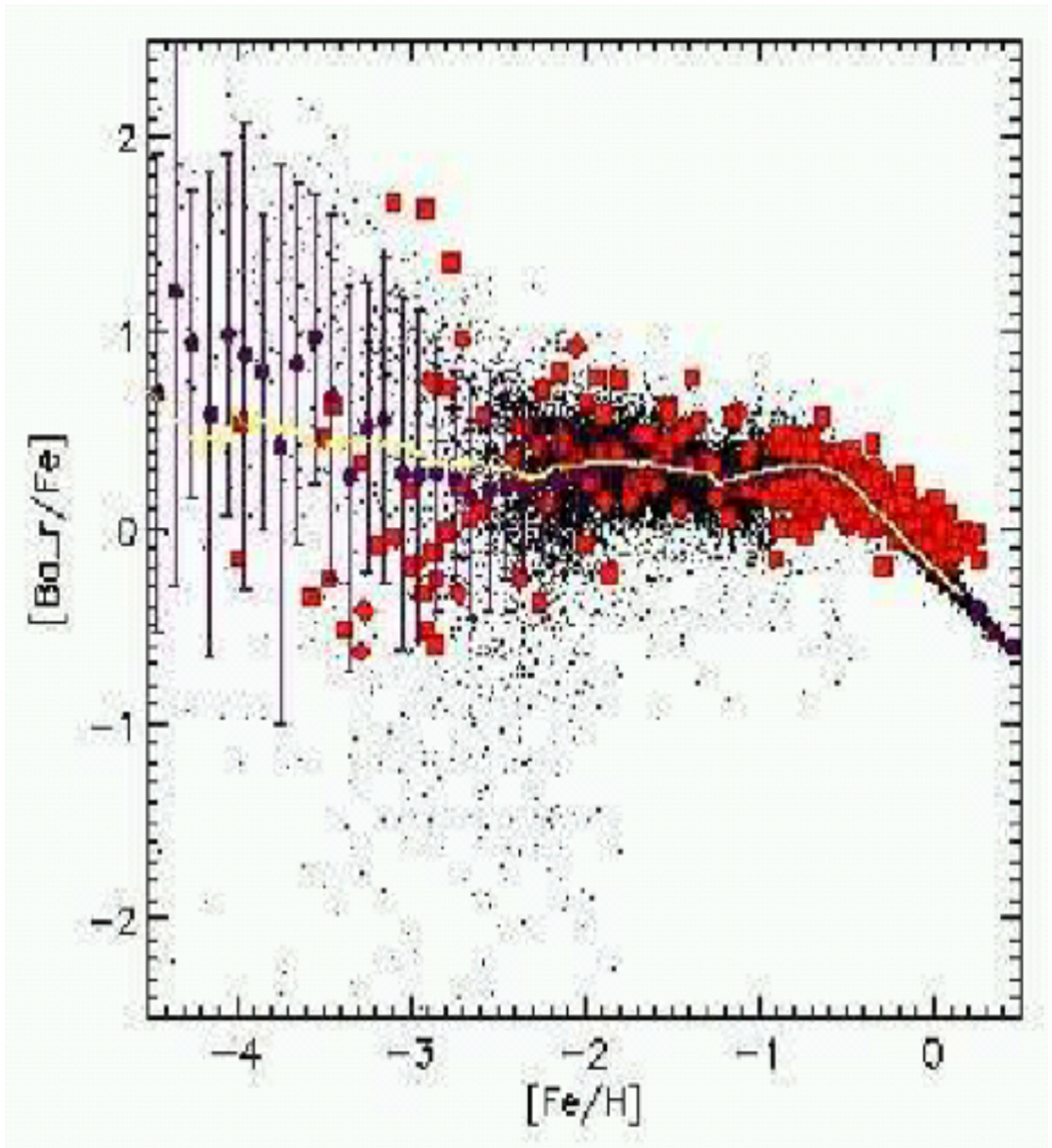


- **Solar r-process contribution**
- **from many events**

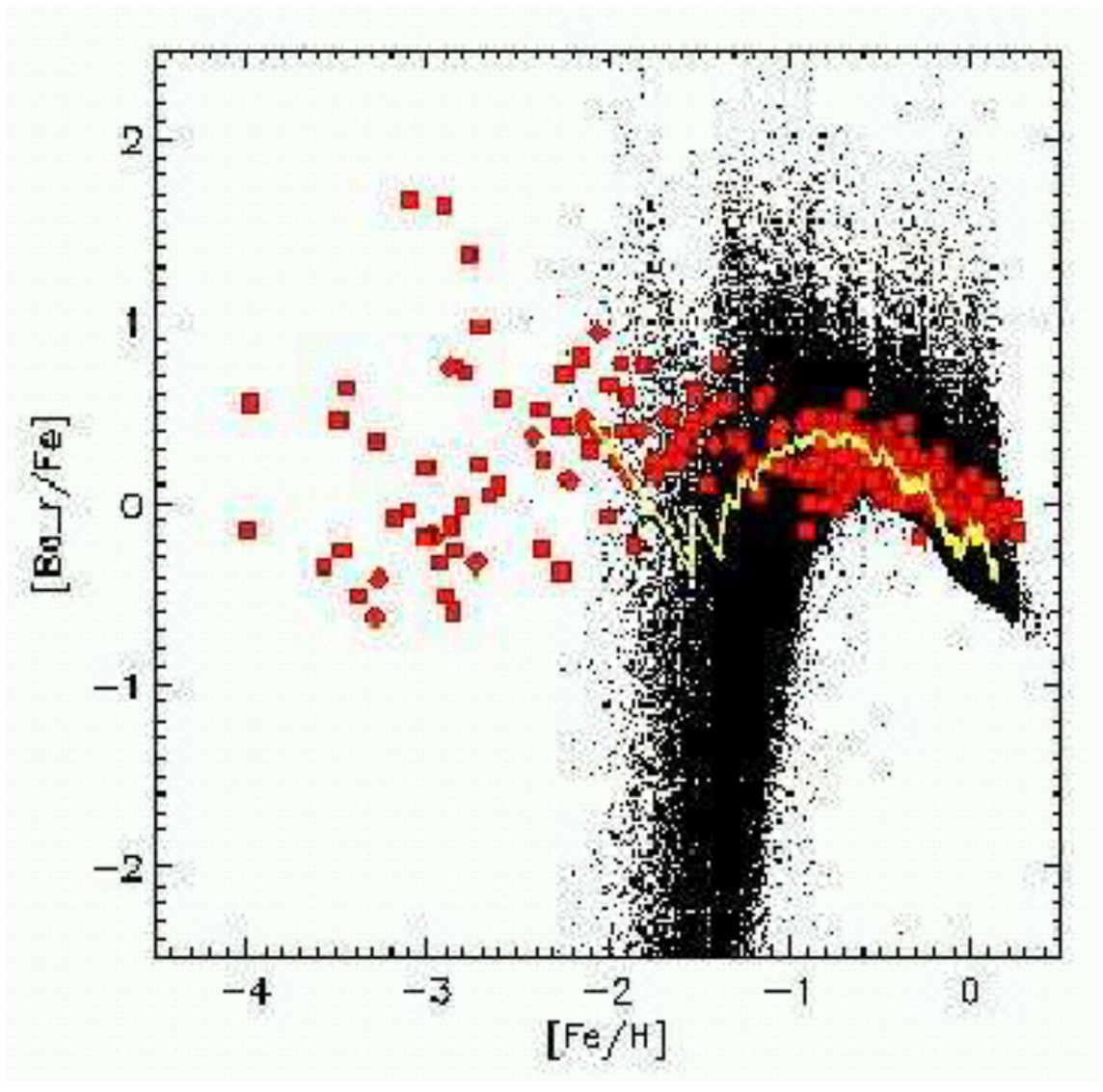
- **J. Cowan**

r-process sites

SN-II

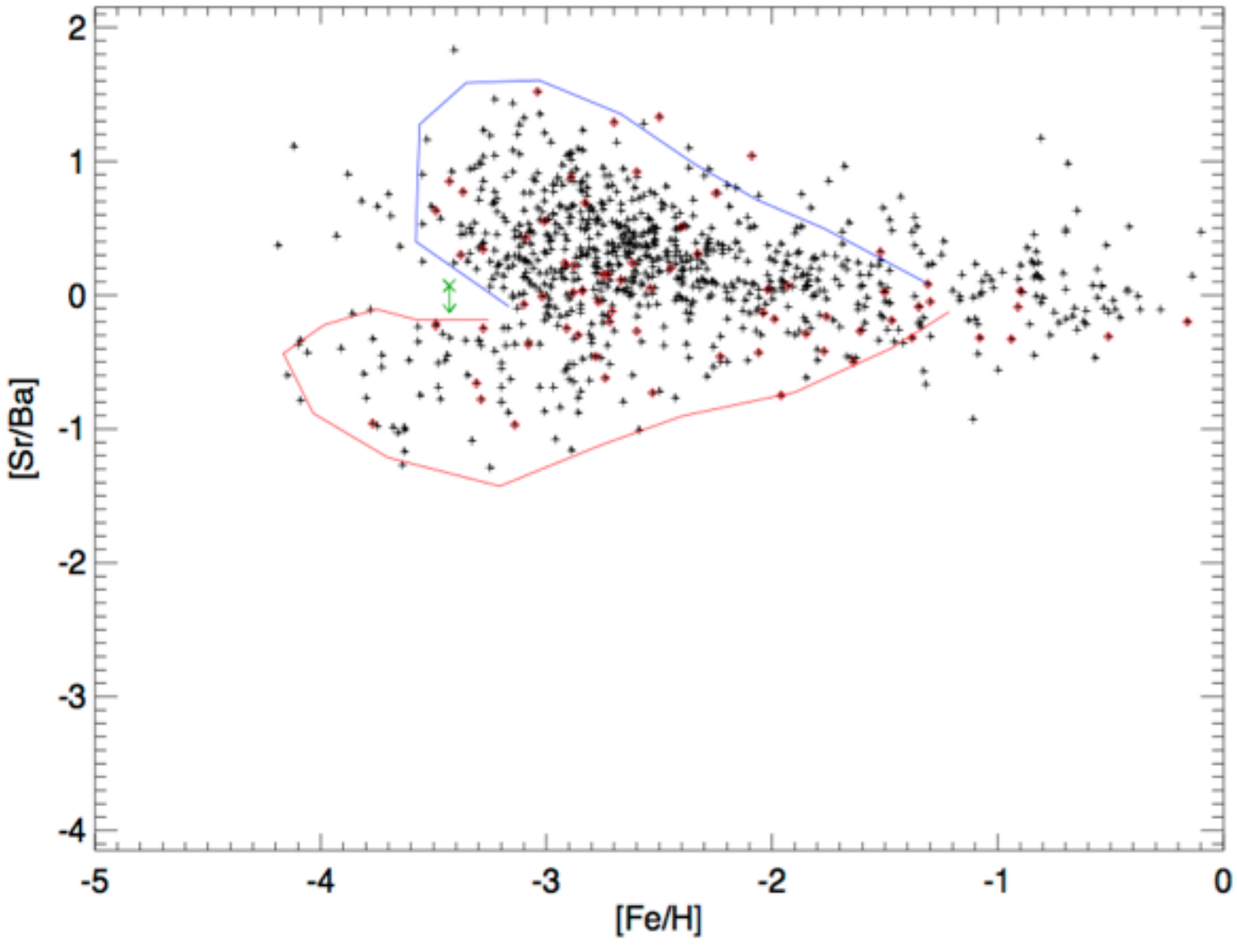


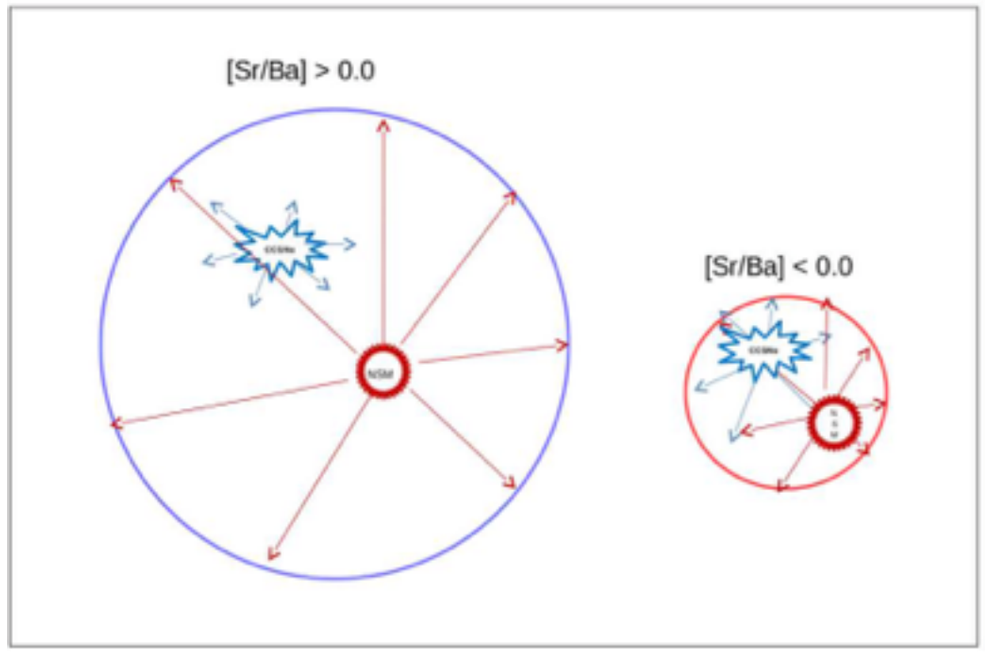
NS Mergers – the Kilo Nova?



- **Argast et al. (2004) , Wanajo**

Probing the r-process origin in MW within hierarchical Galaxy formation





Susmitha Rani, Sivarani et al. 2016, Tsujimoto 2015

TMT - C-HROS

Resolution	Seeing (90% encircled)	S/N	Limiting mAB in 6 hrs
100,000	1.0	100	17.5
100,000	0.5	100	18.9
100,000	0.2	100	20.4
100,000	0.5	50	19.4
50,000	0.5	100	19.7
50,000	0.5	50	20.5
20,000	0.5	50	21.2
20,000	0.5	20	22.3

Courtesy Cynthia Froning

Summary

- Stellar and ISM abundances of Milkyway and its neighbourhood using TMT will helps to understand

- Lithium problem, light element production in GCR

- Origin of CNO in the early Galaxy - complementary to high-z IGM, high-z SN, GRBs

- Origin of r-process evolution - complementary to high-z studies

- GAIA Synergy in accurate stellar parameters/kinematics

Globular cluster and Halo connection

Globular clusters

- Lowest metallicity ~ -2.5

- C-poor N-rich
- r-process similar to halo
- Na-O anticorrelation

➔ pollution of hydrogen burning products

Halo

- Extended tail ~ -5.0
  many stars < -2.5

- C-normal/C-rich

$$[Fe/H] = \log(N(Fe)/N(H)) - \log(N(Fe)/N(H))\odot$$

[Fe/H] = 0.0 - Solar metallicity

[Fe/H] = -1.5 - Halo or (PopII)

[Fe/H] ~ -2.5 - Metal poor Globular clusters

[Fe/H] < -2.5 - Extreme metal poor (EMP) stars

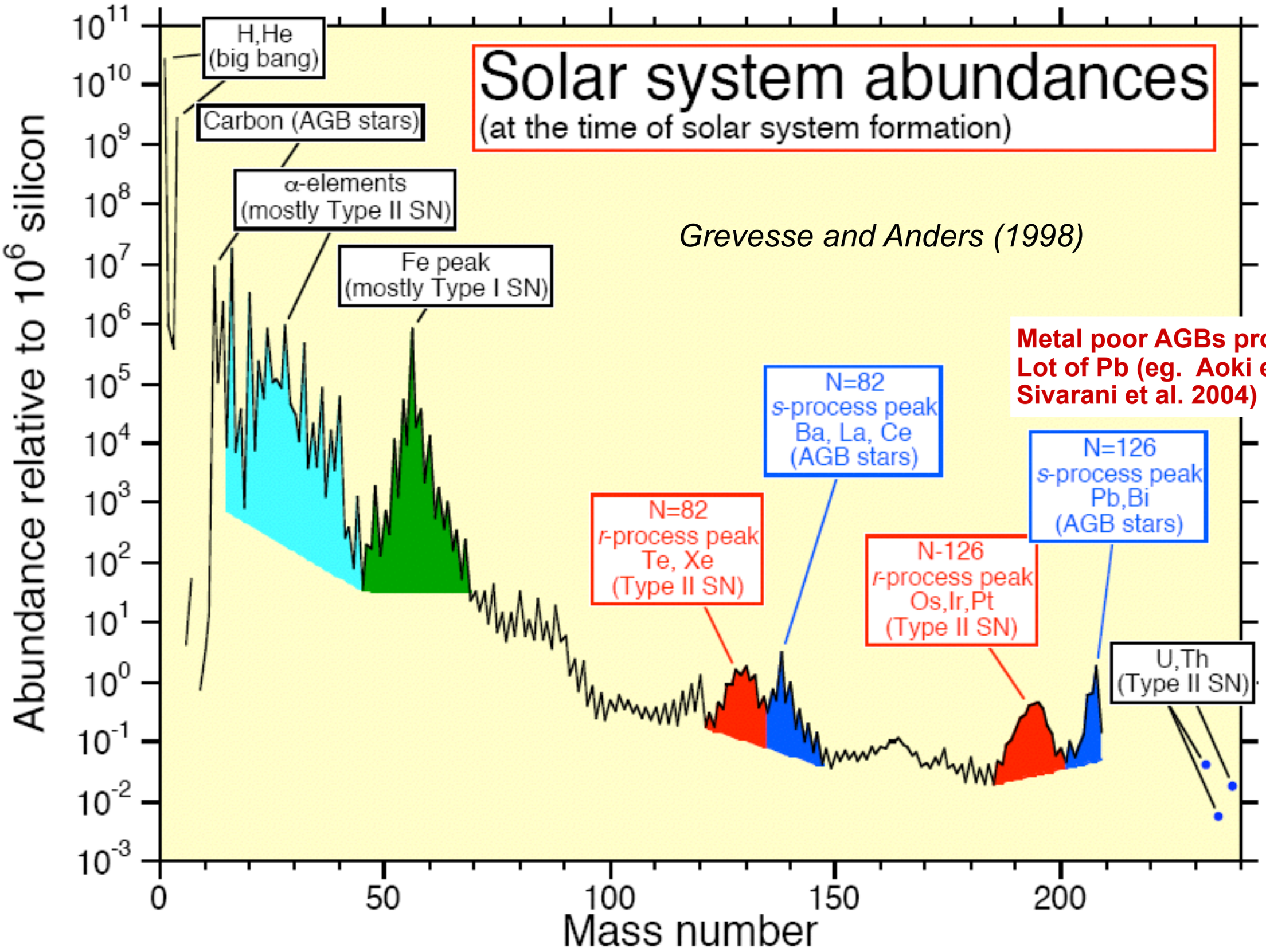
[Fe/H] < -5.0 - Hyper metal poor (HMP) stars

[C/Fe] > 0.7-1.0 - Carbon enhance metal poor (CEMP) stars

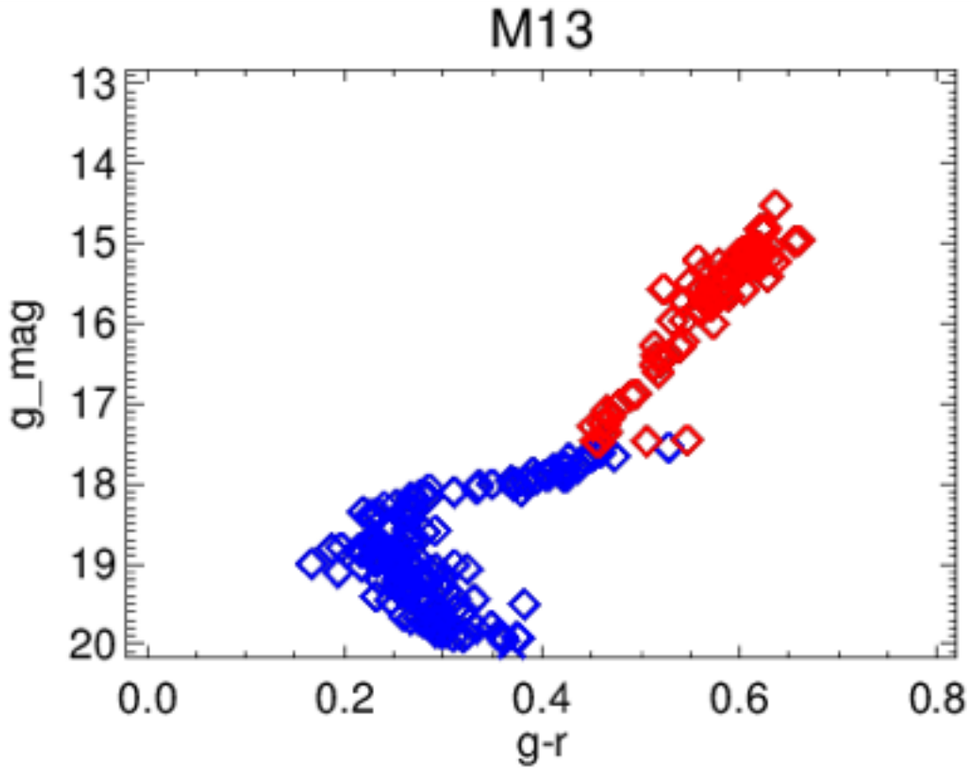
Metal poor DLA ~ -3.0 (Kobayashi et al. 2011)

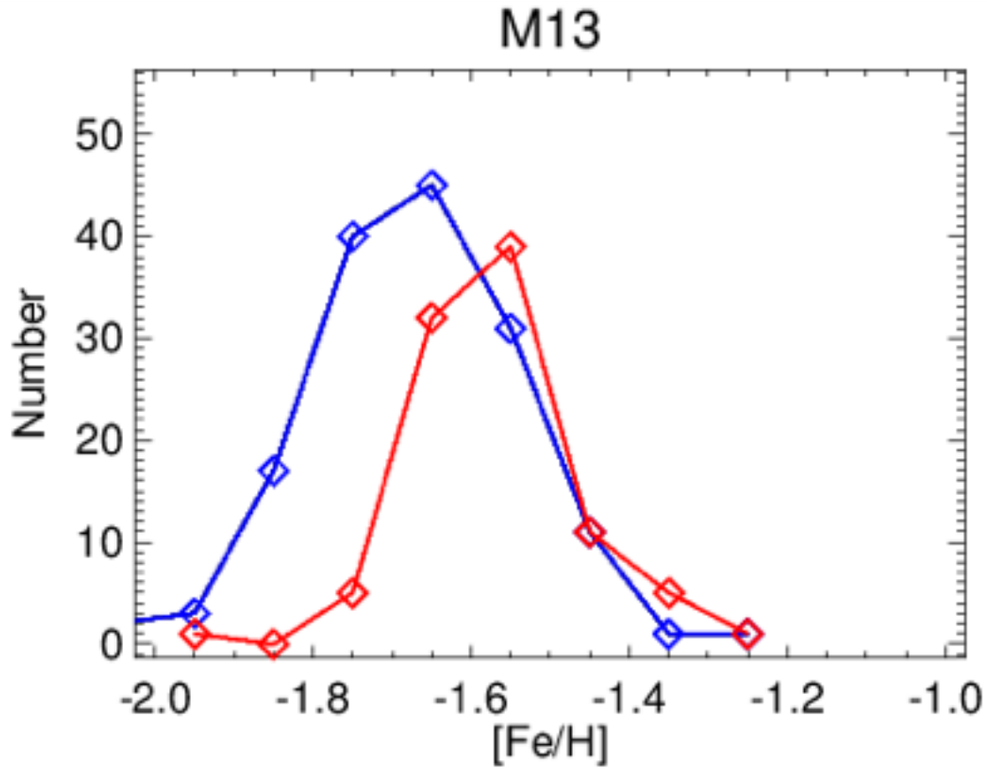
Metal poor LLS < -4.0 (Fumagali et al. 2011)

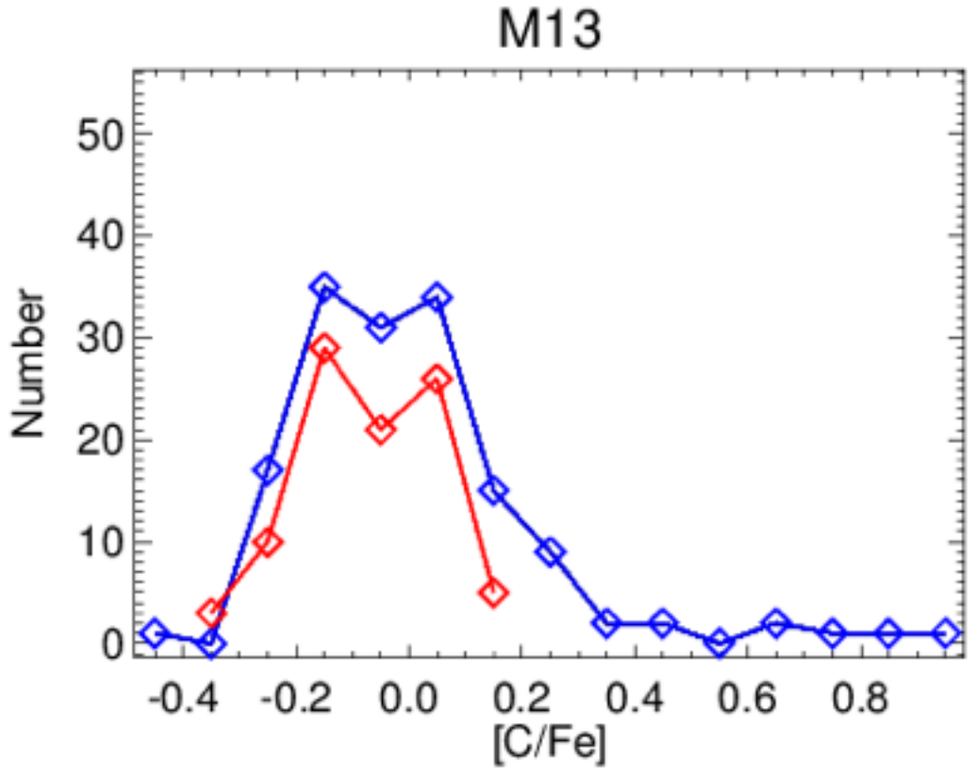
Cosmic Abundances

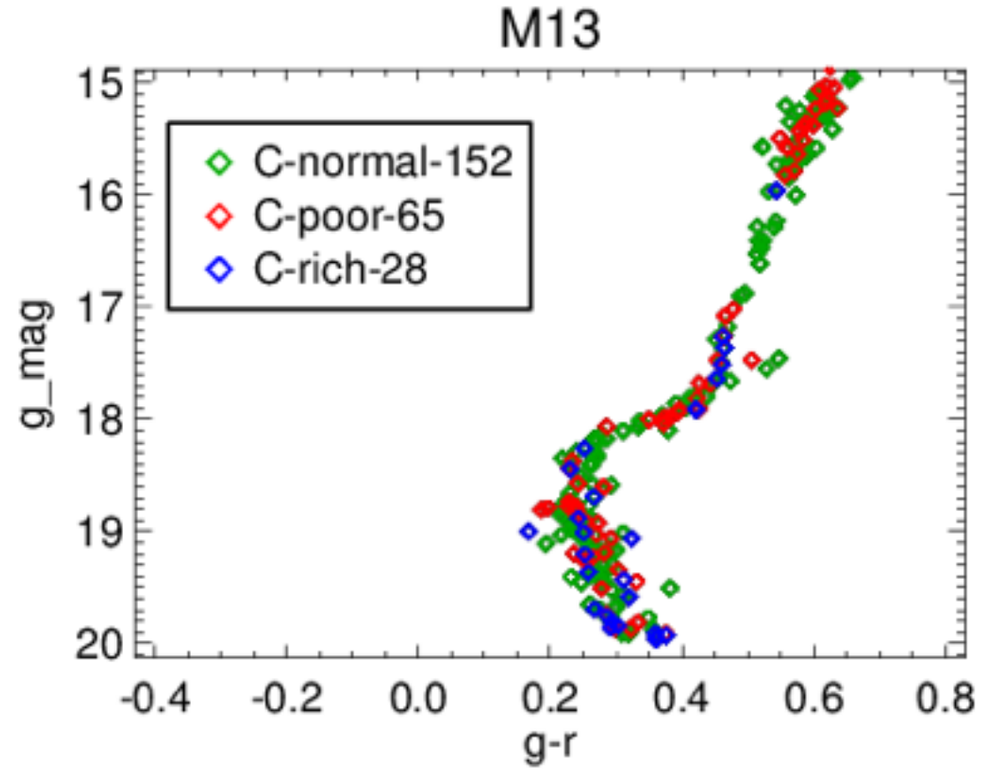


Metal poor AGBs produce
Lot of Pb (eg. Aoki et al.
Sivarani et al. 2004)

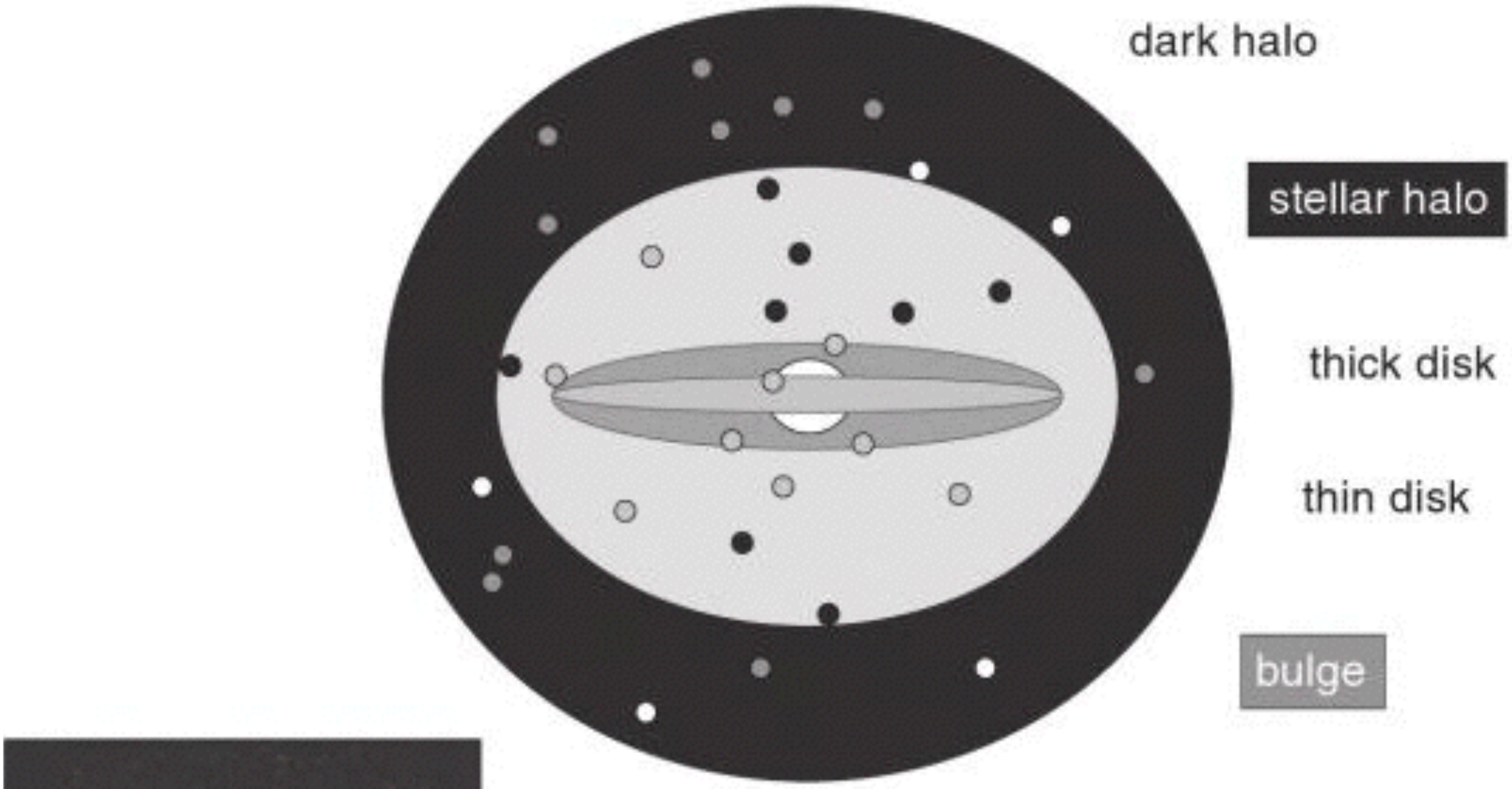

M13
g_mag
g-r
13
14
15
16
17
18
19
20
0.0
0.2
0.4
0.6
0.8

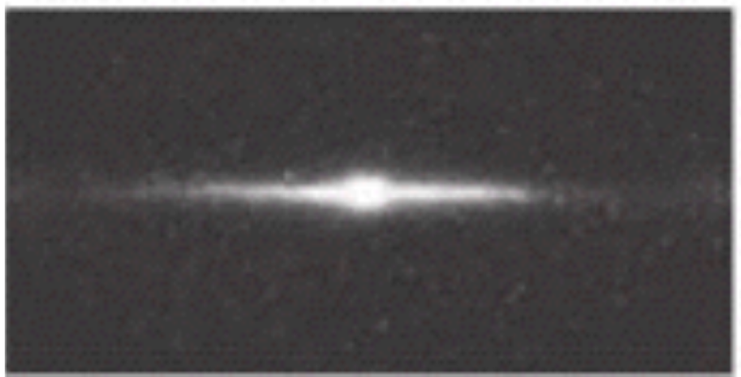

M13
Number
[Fe/H]
0
10
20
30
40
50
-2.0
-1.8
-1.6
-1.4
-1.2
-1.0


M13
Number
[C/Fe]
0
10
20
30
40
50
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8


M13
C-normal-152
C-poor-65
C-rich-28
g_mag
g-r
15
16
17
18
19
20
-0.4
-0.2
0.0
0.2
0.4
0.6
0.8

Components of Milky way

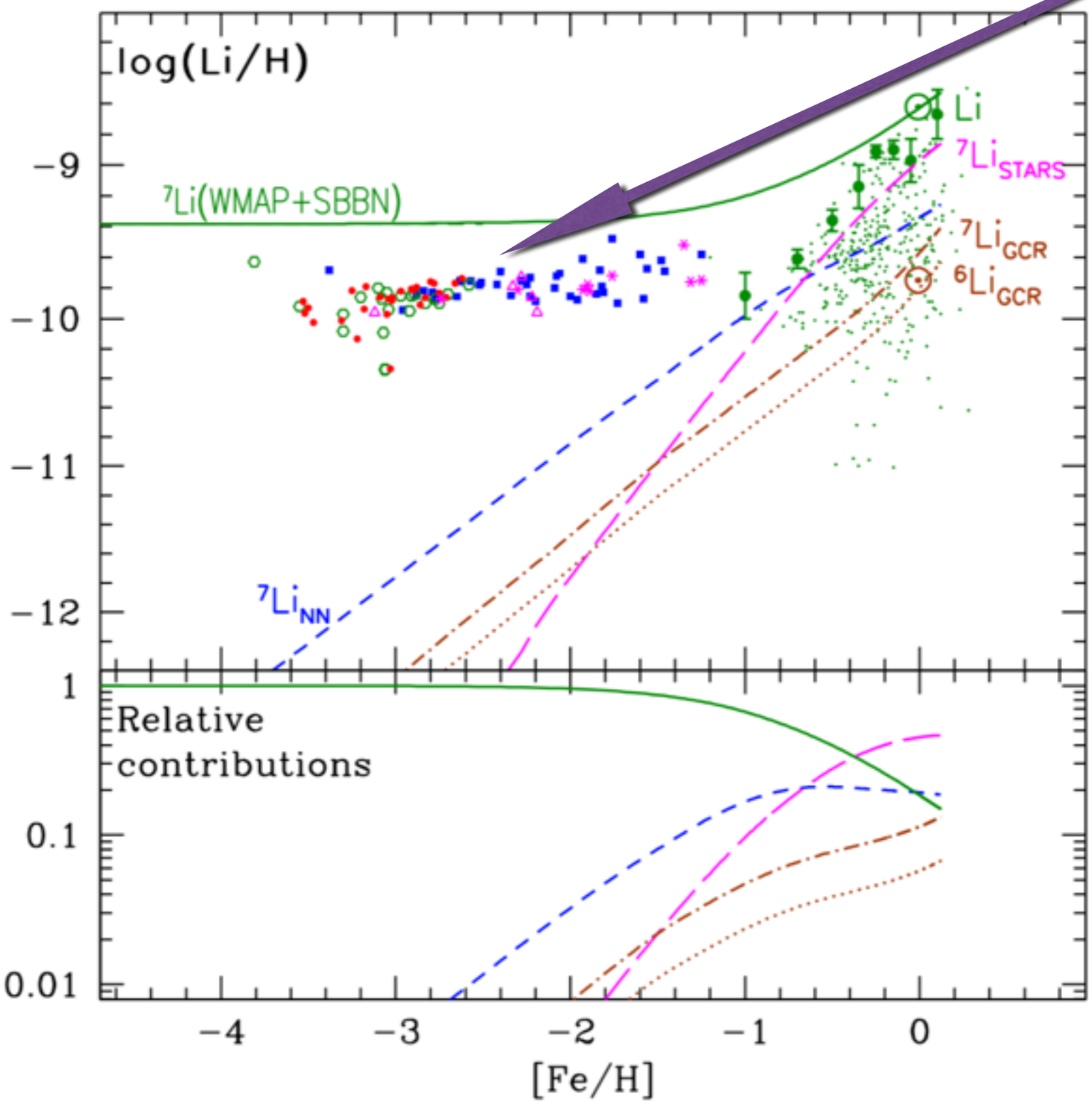




Freeman 2008

Lithium evolution

Lithium Plateau



Prantzos (2012)