BBN in a bigger picture

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Points to Discuss

1. BBN, from a far-fetched concept to precision probe of the early Universe. Synergy of the BBN and precision CMB
2. Current success: D, He, possibly Li.
   Current problems: Li, possibly D, He
3. Is BBN done to the very end, or would future hold anything new?
4. How to improve things

The birth of BBN – not exactly a new subject

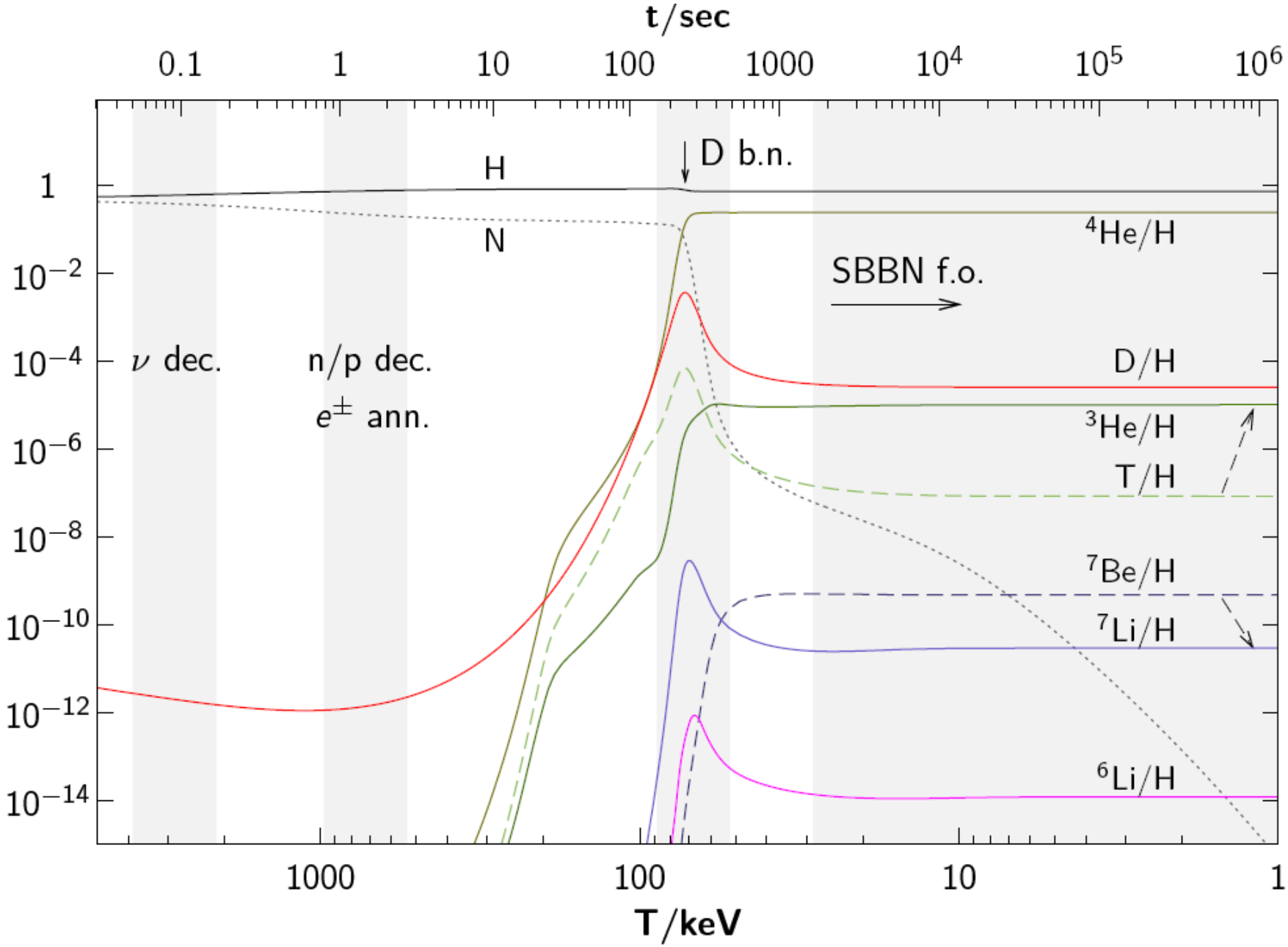
Early works: Gamow, Alpher, Herman, Hayashi.

Lots of good ideas (and a lot of mistakes)

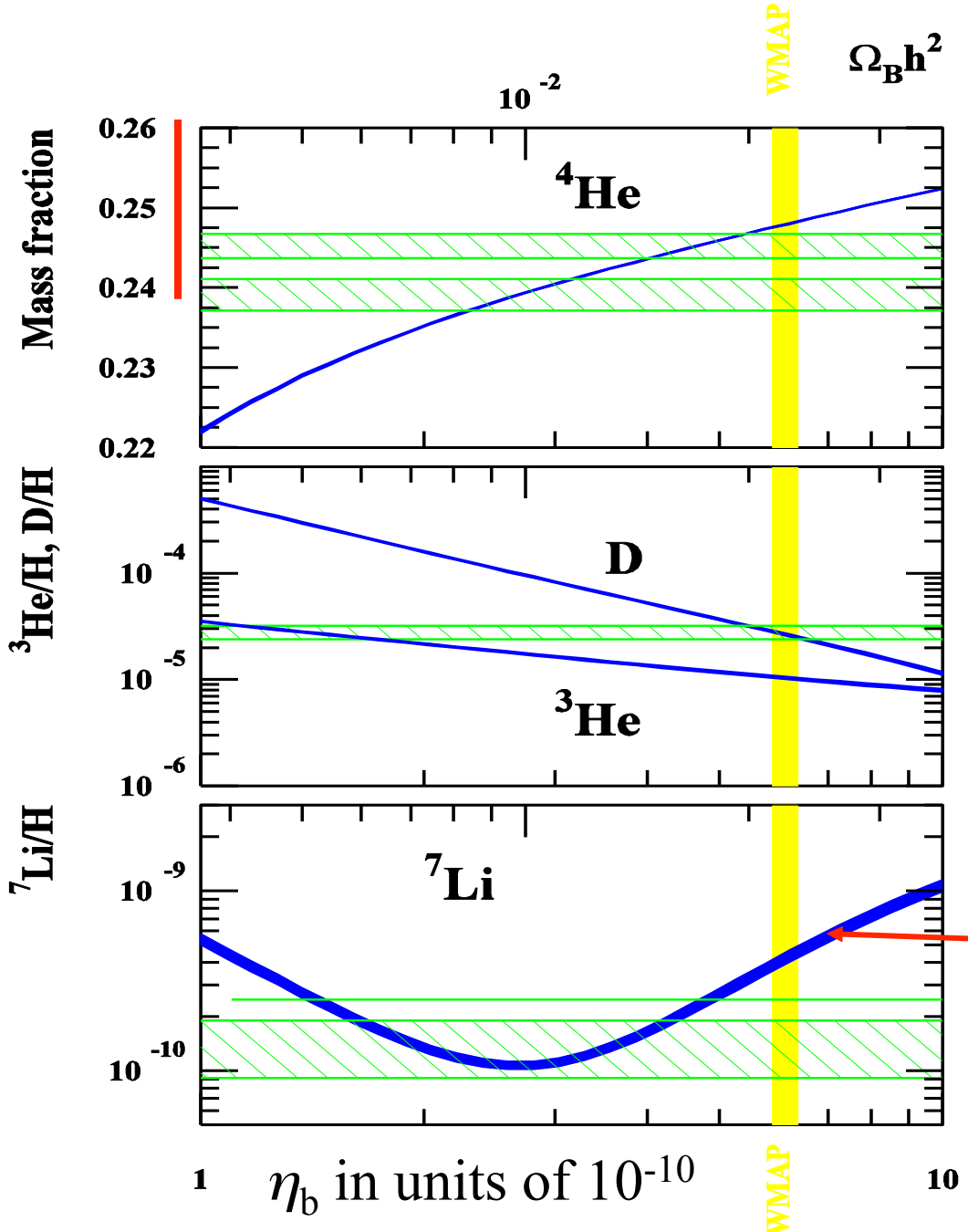
Wagoner, Fowler, Hoyle – the modern foundation of BBN.
Prediction of primordial Li.

(Photo from D. Clayton webpage, w/o permission, sorry)

Synergy of BBN and CMB: $\eta=\eta_{WMAP}$



- *BBN success:*
- With no free parameters, and simplest possible cosmology, we predict He that agrees with observations at sub-4% level, Deuterium at ~ 25%; and Li within a factor of a few (but at 10^{-10} level!)
- *BBN problems:*
- We do not have that many observables, and Li is now discrepant by 3-5 – it sounds like a tragic waste to give up on it.
- Deuterium observations show significant scatter. Is it just because the measurements have additional systematic issues or this scatter is physical?
- Huge statistics in He measurements may not be sufficient in making meaningful progress in accuracy for Y_p



2003 Status

Blue lines: theoretical predictions of abundances as functions of η_b

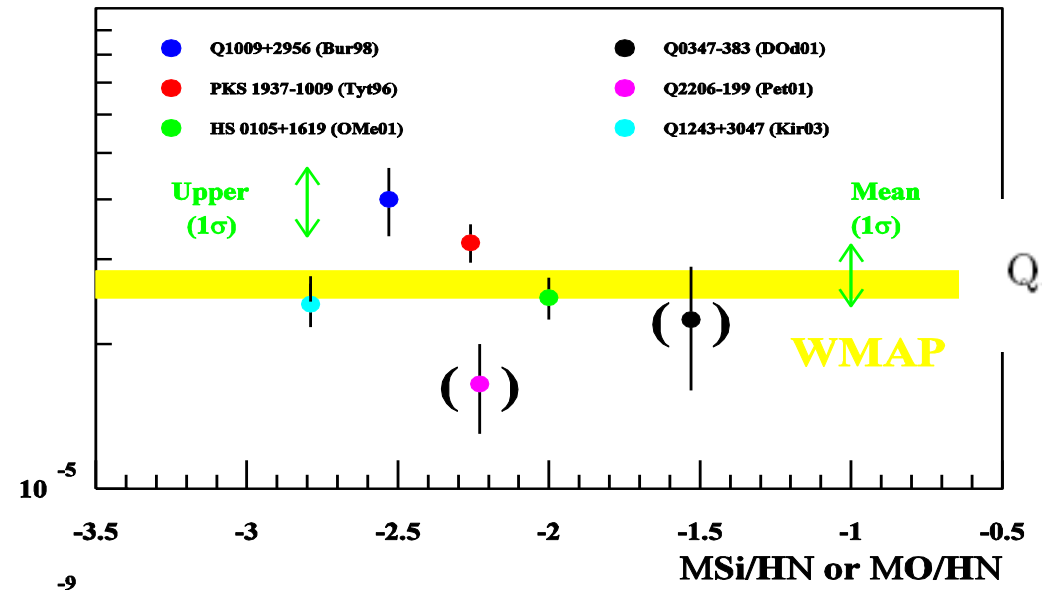
Green bands: observational values for primordial abundances of ^{4}He, D, and ^{7}Li

Yellow band: WMAP-suggested input for baryon to photon ratio $\eta_b = 6\ 10^{-10}$

^{7}Be branch

Coc et al, ApJ 2004

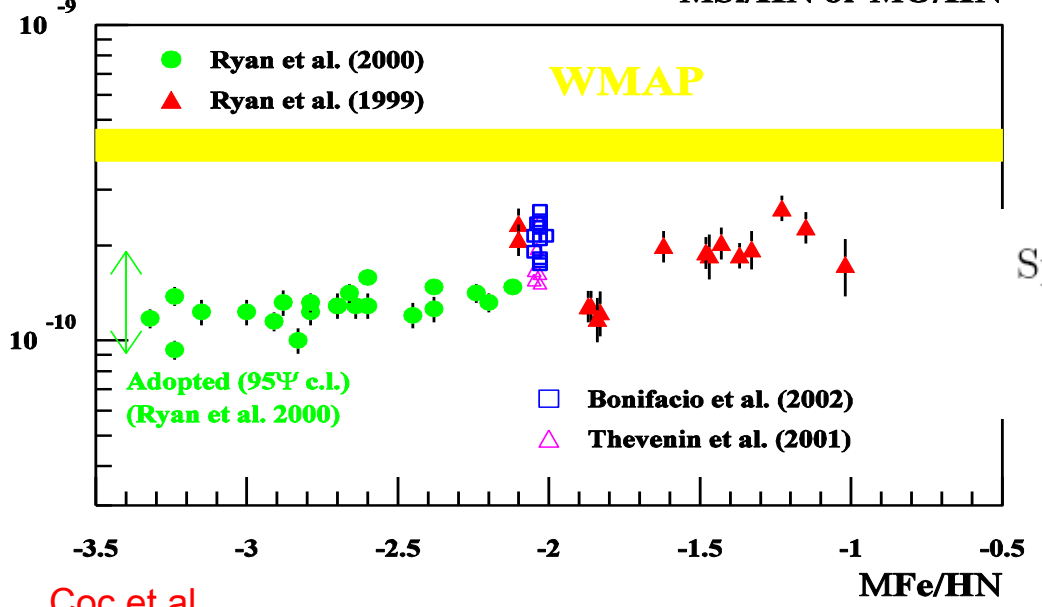
Status of standard BBN with CMB input (η=6.2 10^{-10})



$$\text{SBBN}: \quad D/H = 2.49 \pm 0.17 \times 10^{-5}$$

$$\text{QALS observations}: \quad \frac{D}{H} = (2.82 \pm 0.21) \times 10^{-5}$$

Deuterium seems OK, (but large scatter)



Coc et al, ApJ 2005

$$\text{Spite plateau value}: \quad \frac{^7\text{Li}}{H} = 1.23^{+0.34}_{-0.16} \times 10^{-10}$$

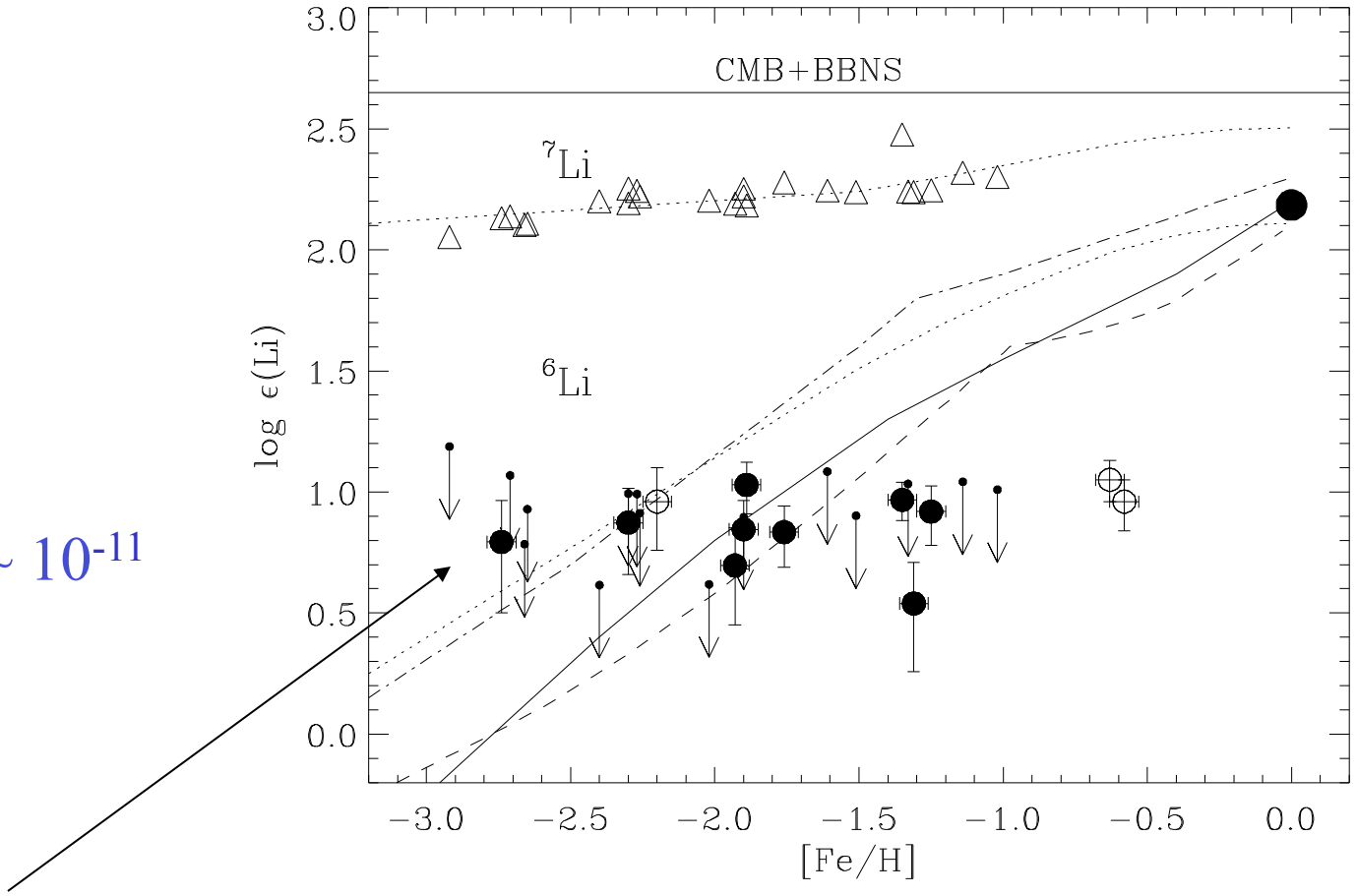
$$\text{BBN theory}: \quad \frac{^7\text{Li}}{H} = 5.24^{+0.71}_{-0.67} \times 10^{-10}$$

Serious "lithium deficiency"

Lithium problem !!

^{6}Li is detected in a handful of stars
A lot of speculations about primordial ^{6}Li!

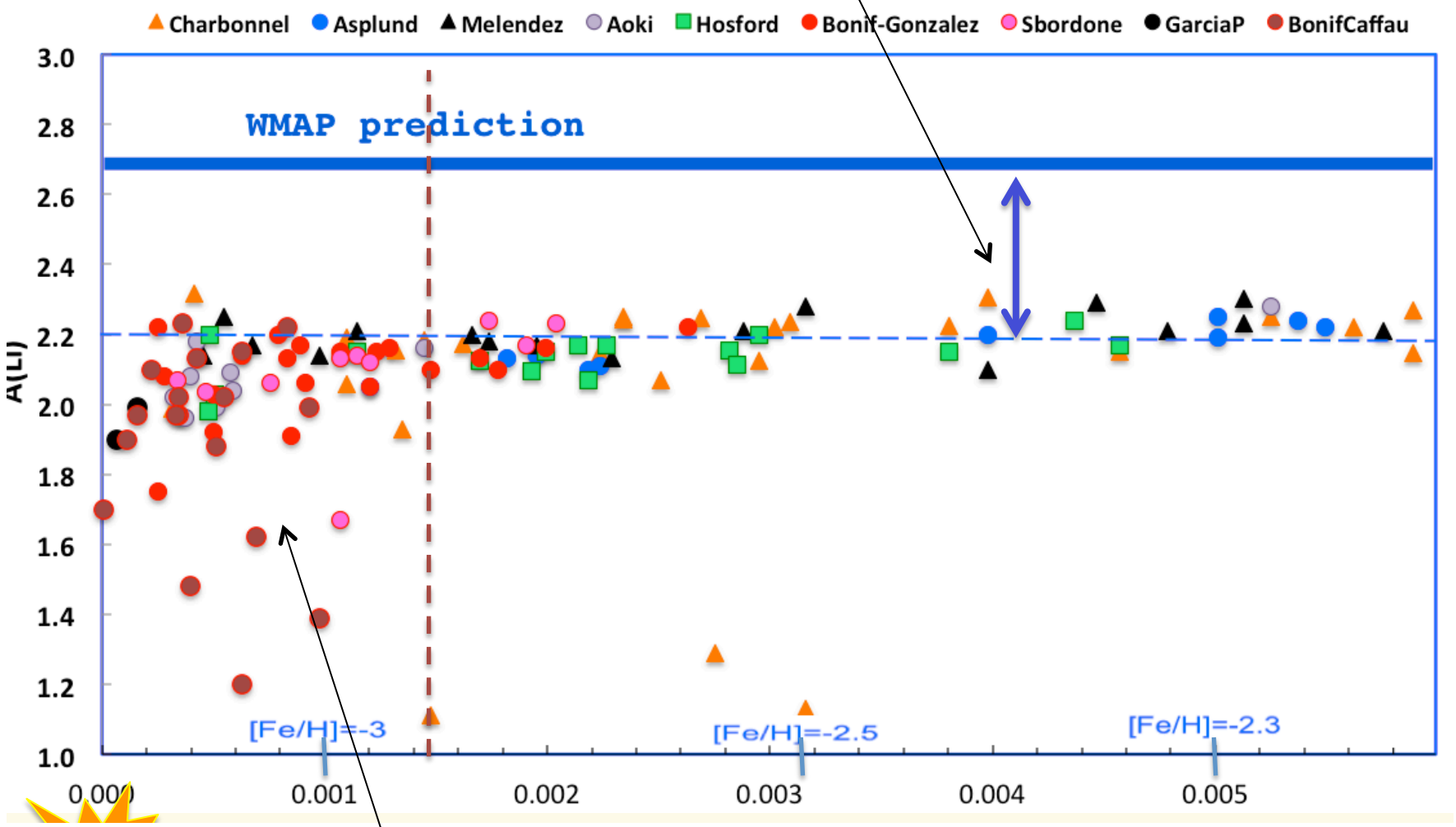
^{6}Li/H ~ 10^{-11}



Unexpected plateau (?) of ^{6}Li with metallicity (Asplund et al., 2005);

Claim is challenged in Cayrel et al, 2007. *Unlikely a problem at this point*

More than one problem with ^{7}Li?



M. Spite talk IAP 2012

Ways the ^{7}Li problem can be resolved

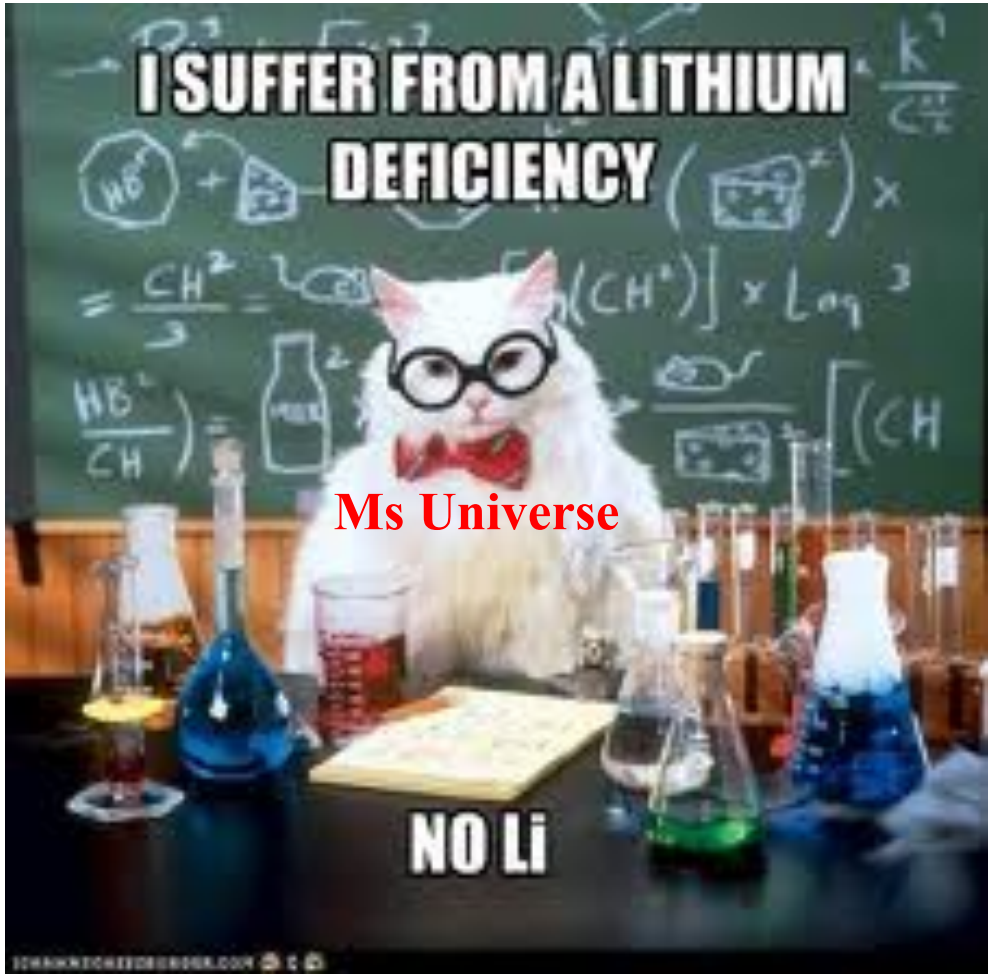
- *Astrophysical:* Depletion of lithium along Spite plateau is ~ 3 – 5 due to diffusional settling.
- *Nuclear:* SBBN prediction is somehow not correct. Some subdominant but poorly known reactions play a role?
- *Particle physics:*

  Decays of heavy relics can reduce ^{7}Li.

  ^{7}Li can also be destroyed in catalyzed reactions.
- *Cosmological:*

  ^{7}Li is measured *locally*, while D and especially baryon-to-photon ratio *globally*. If there is a downward fluctuation of baryon density in proto-Milky Way region, local ^{7}Li/H can be smaller. There can be also physical mechanisms

Lithium deficiency is a serious condition that needs treatment



Is BBN basically a done story?

(We did what we could and now we are at impasse for future improvements limited by systematic errors or astrophysics modeling)

or

Will it rock again?

(Future can lead to more precise comparisons of theory and observations, resulting in new information/constraints on primordial Universe)

Possible experimental/developments

1. **Any chance for increasing the sample of high-quality D/H measurements (Cooke and Pettini, 2012)?**

2. **More of non-stellar observations of Li 7 and 6, similar to Howk et al, and at lower metallicities?**

3. **Is indeed ^{6}Li present in a number of metal poor stars?**

4. **More observations of extremely metal poor stars to see "what happens" to Spite plateau.**

5. **Any chance to improve measurements of all BBN reactions beyond few %? Sort out controversy τ_n already!**

6. **CMB determinations of many additional parameters if Planck is successful: Y_p and N_{eff}**

Theoretical directions

1. **Do we need an ultimate BBN code with all additional corrections that come at sub-% level?**
2. **For Li 7 and 6, it would be great if other than astro people check the whole diffusion story from start (given its importance)**
3. **Ab-initio calculations of several key reaction rates?**
4. **Physical diffusion of elements after H recombination to PopIII stars and beyond needs to be reconsidered. So far done in the linear regime ($\delta \rho/\rho << 1$). We may encounter huge surprises there. What is the natural variation in abundances as a function of space and time?**
5. **Think of new ways of sorting out hints on sterile ν – implications for BBN.**
6. **In the most *liberal* assumptions about what stars and post-BBN evolution can do to elements, can we derive constraints on primordial ranges for all light elements up to and including C?**

Culture issues

1. **Nurture cross-disciplinary experts. The ones that understand well nuclear physics, cosmology and stellar evolution.**

2. **Inject more scientific approach in places where we can. Error bars in astro literature. Blind analysis in the measurements of D/H where the "BBN prior" is known.**

3. **Be open to a possibility of "unknown unknowns". Do not try to "adjust" your stellar models to "fit WMAP/BBN", because it creates bias, and may not be complete theory. Also, new rad degrees of freedom may well turn out to be a reality.**