

Non-LTE* abundance patterns in M67

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*: non-LTE (Local Thermodynamic Equilibrium)

Open clusters

- **Properties:**

1. Formed by the same molecular cloud
2. Similar age
3. Chemical homogeneous
4. Loosely bound by mutual gravitational attraction

- **Scientific Motivation :**

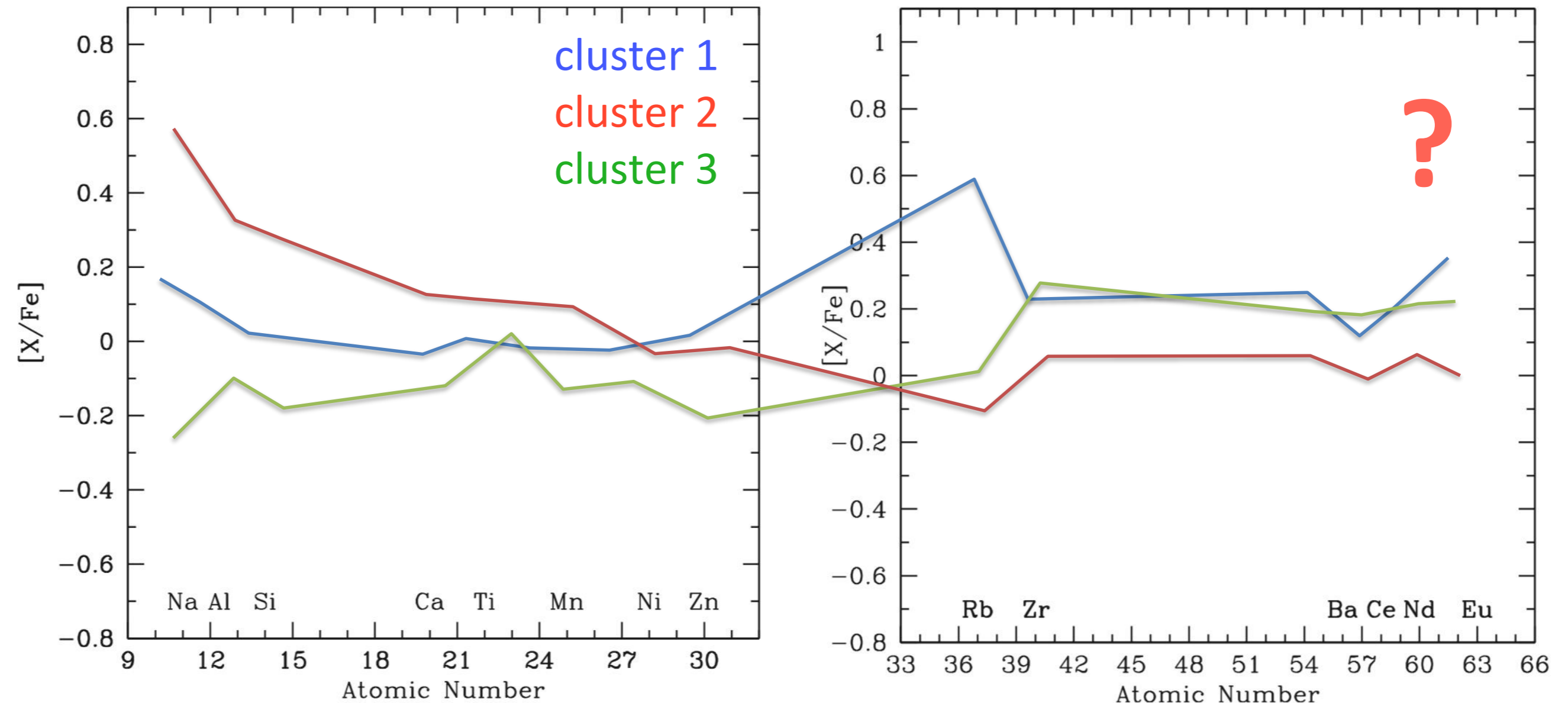
- Galactic Archeology :

reveal the formation history of galaxies



Chemical Tagging

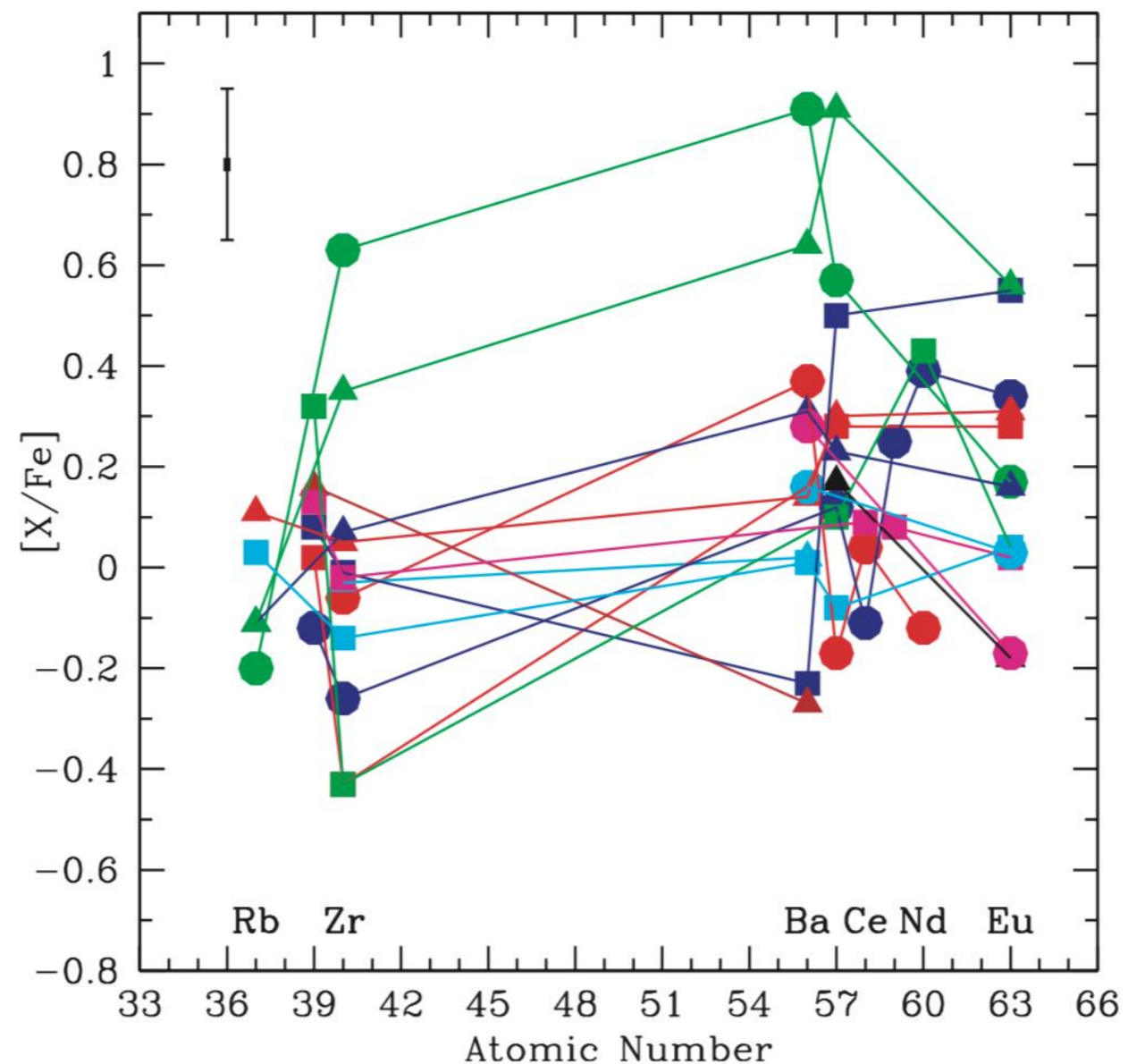
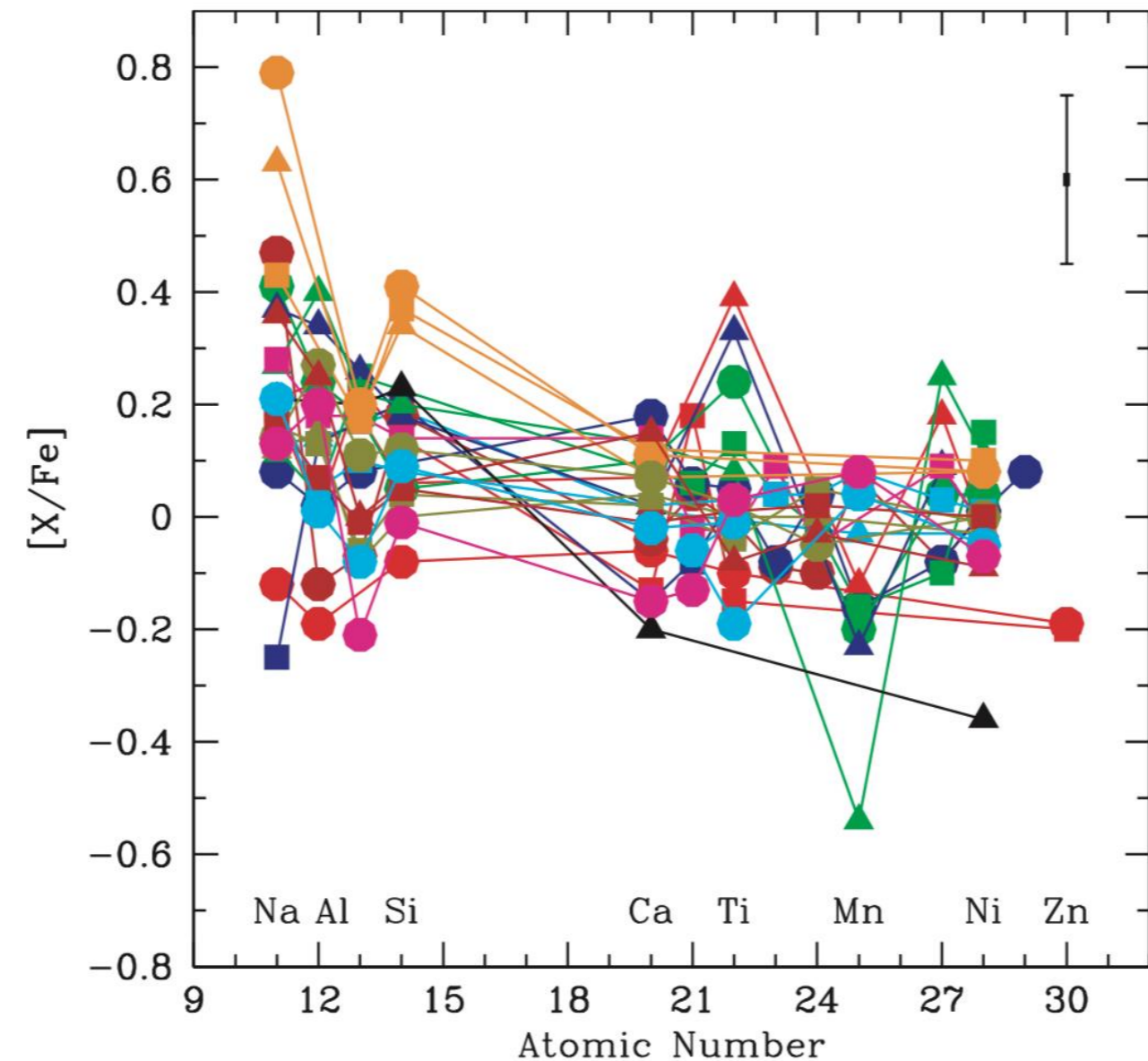
- Different clusters should have different abundance patterns



| | | | | | |
|-----------|----------|-----------|-----------|-----------|-----------|
| ● NGC7142 | ● Hyades | ● NGC2243 | ● NGC2141 | ● Be 32 | ● NGC6819 |
| ● NGC6939 | ● Mel 71 | ● Tom 2 | ● Mel 66 | ● NGC3960 | ● NGC2477 |
| ● IC4756 | ● Be 20 | ● Be 29 | ● Be 31 | ● NGC2660 | ● NGC2324 |
| ● Cr 261 | ● M 67 | ● NGC6253 | ● NGC7789 | ● NGC6791 | ● M 11 |

Chemical Tagging

- Different clusters should have different abundance patterns
- Like a stellar DNA profile



De Silva et al. 2009

Requirements for chemical tagging



- The clusters should be chemically homogeneous

M67 is chemically inhomogeneous for solar twins at the 0.05 dex

Liu et al. 2016

- High accurate abundances

Non-LTE is necessary

- Abundances patterns should truly reflect their original composition

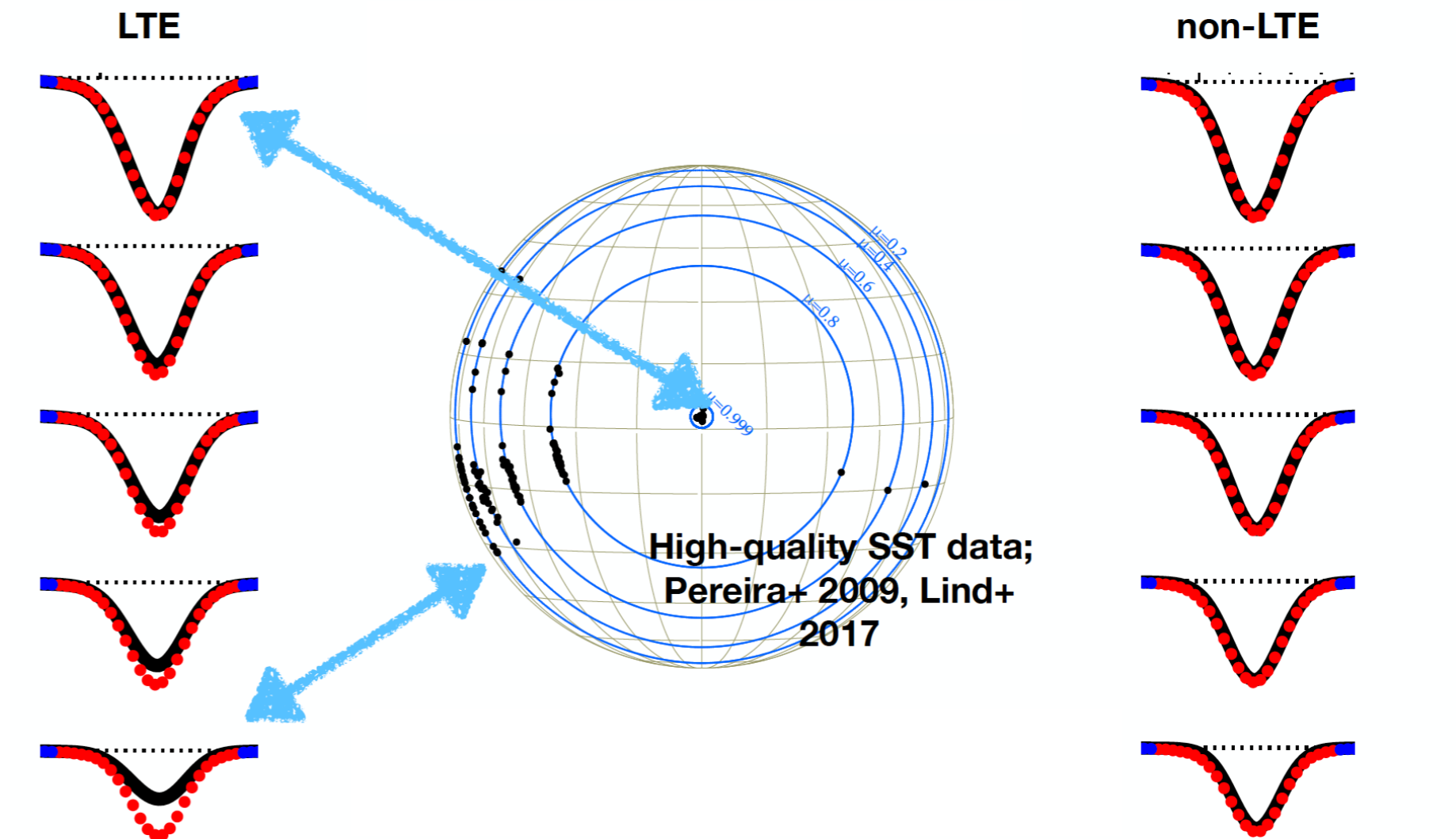


Atomic diffusion effect for M67 can reach at most 0.1 dex Michaud et al. 2009

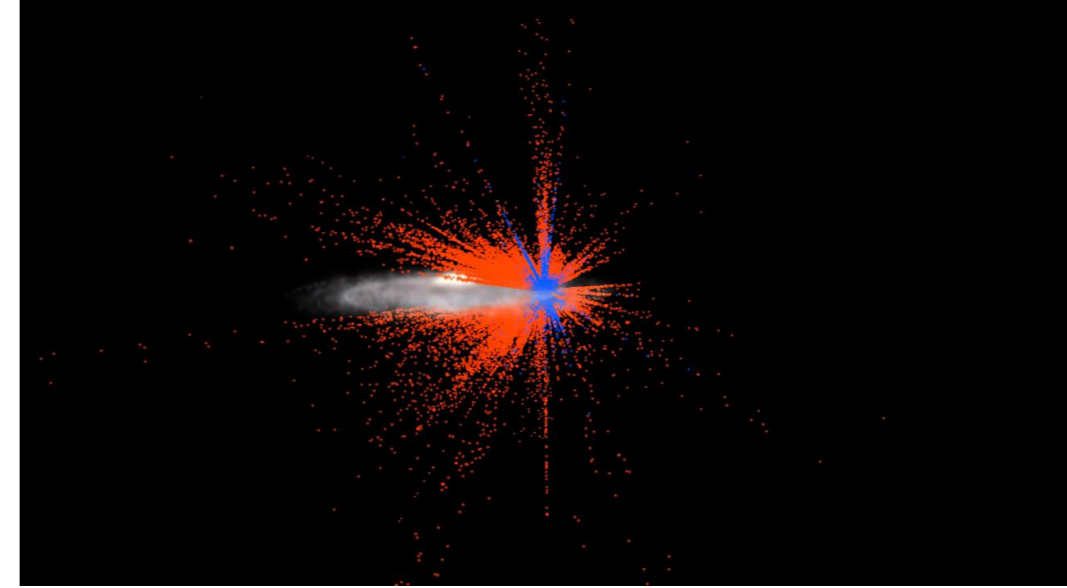
How much does non-LTE matter?

- Is LTE an acceptable assumption?
 - Collisional rates must exceed radiative rates

- **Non-LTE is needed** **OI 777nm CLV**



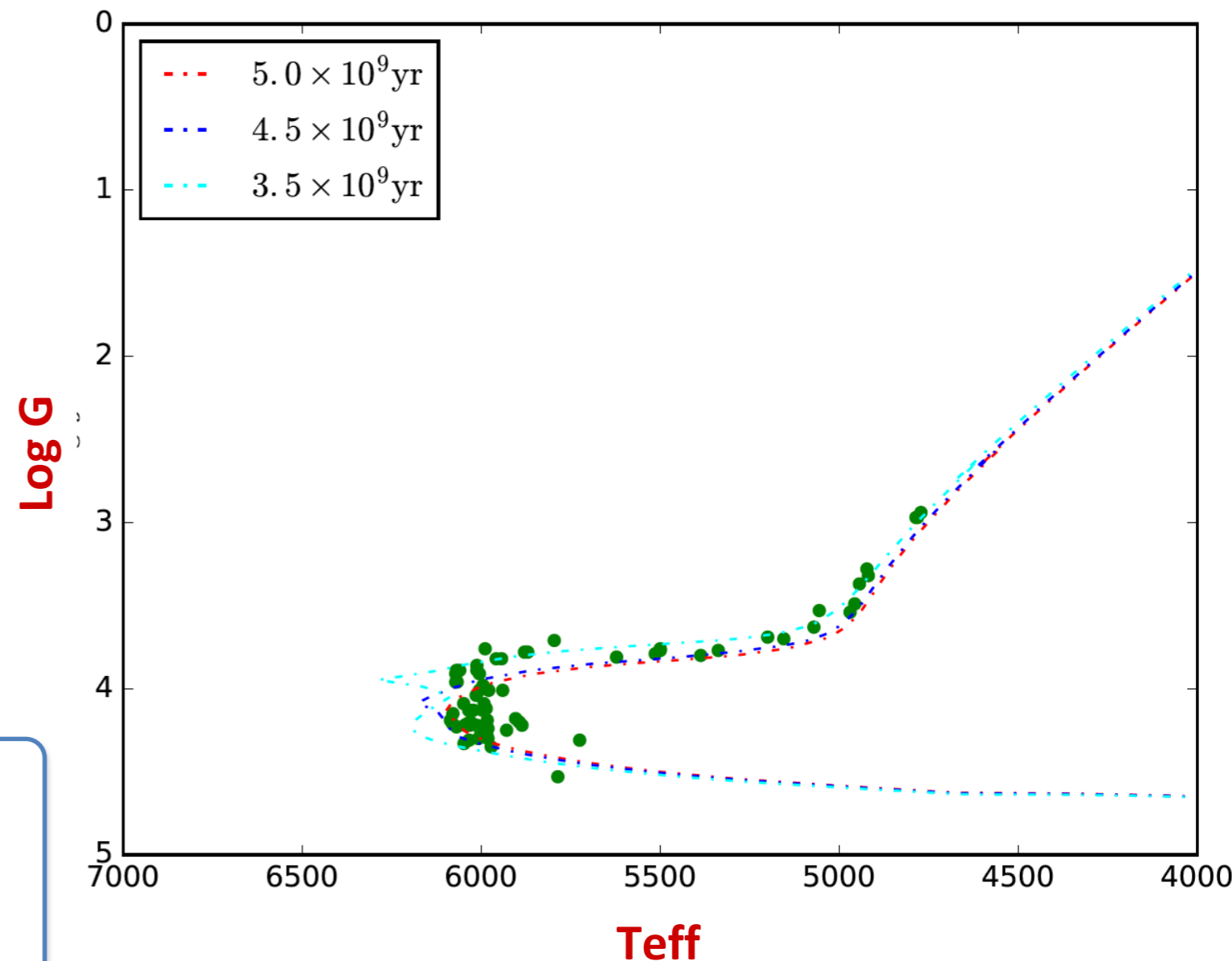
Dataset



- GALAH survey
- High resolution spectra $R \sim 42,000$ from pilot project Feb. 2014
- Stacked the spectra of same object ($\text{SNR} > 50$)

- M67
- Age ranging from 3.5 to 4.8 Gyr
- $[\text{Fe}/\text{H}]$ ranging from -0.04 to +0.05
- Selected by RV measurements
- Fe, Li, O, Na, Mg, Al, Si

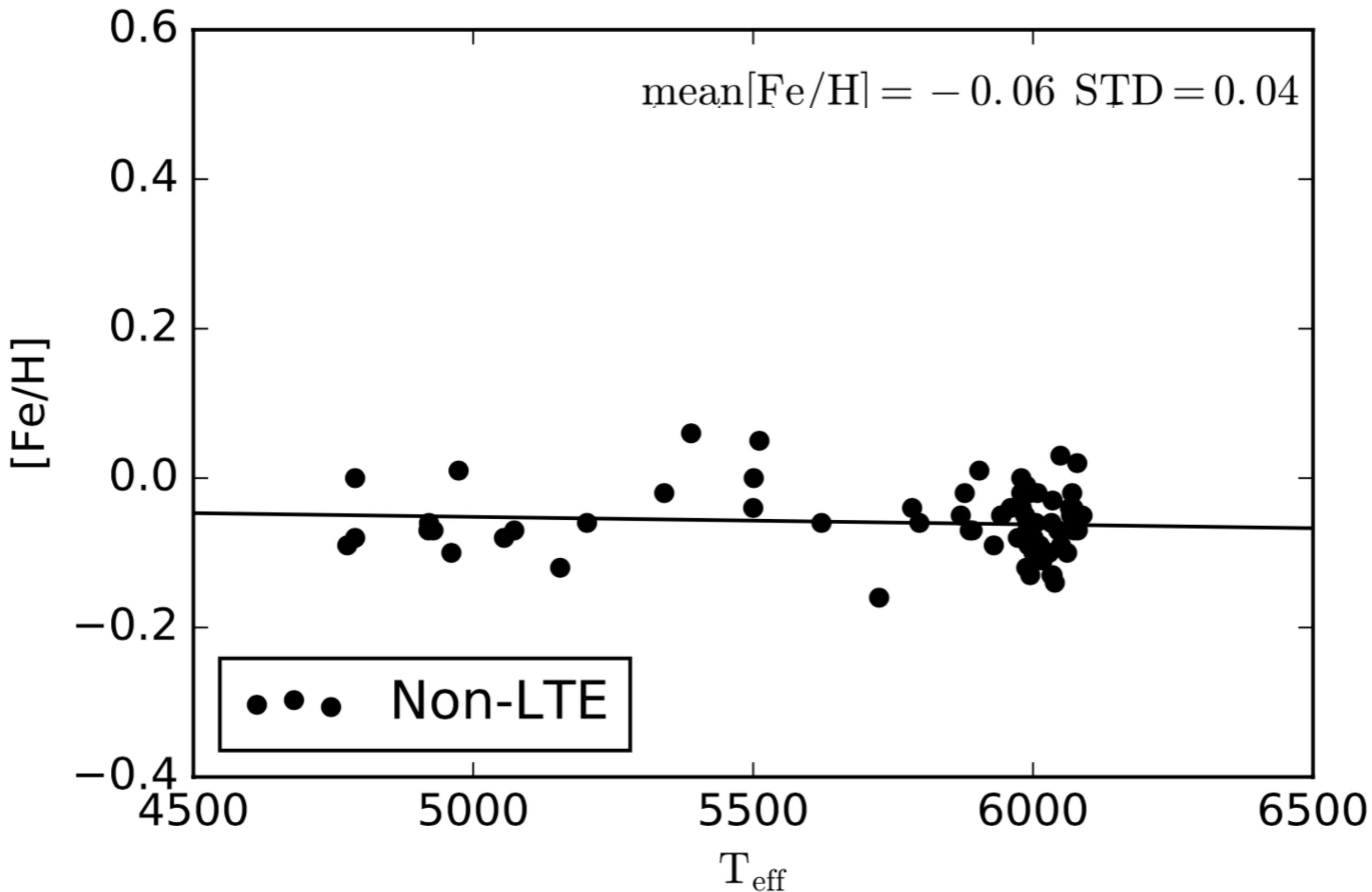
Isochrone



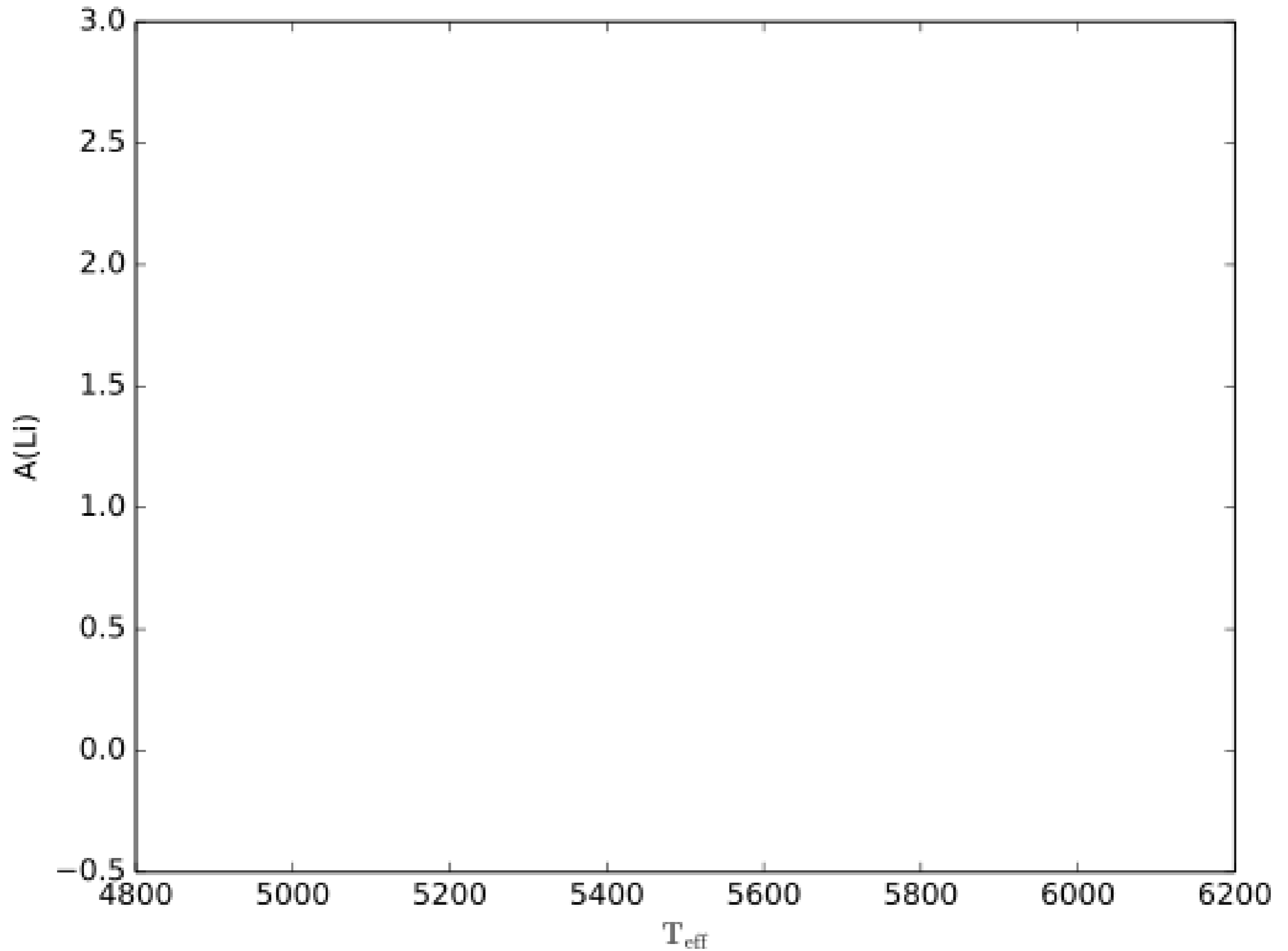
new non-LTE grids

1D MARCS
new atomic data
Multi 2.3

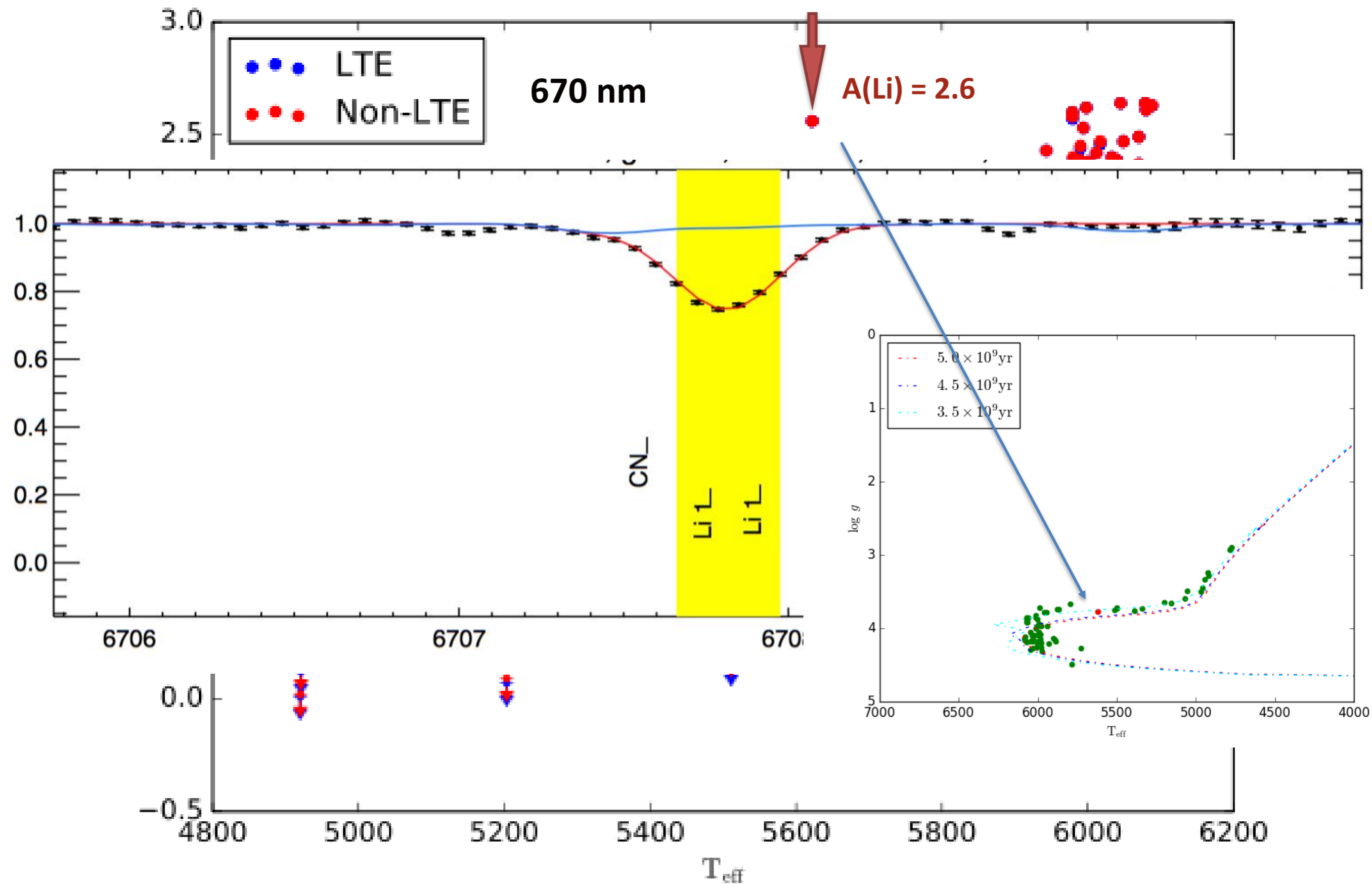
Abundances of M67



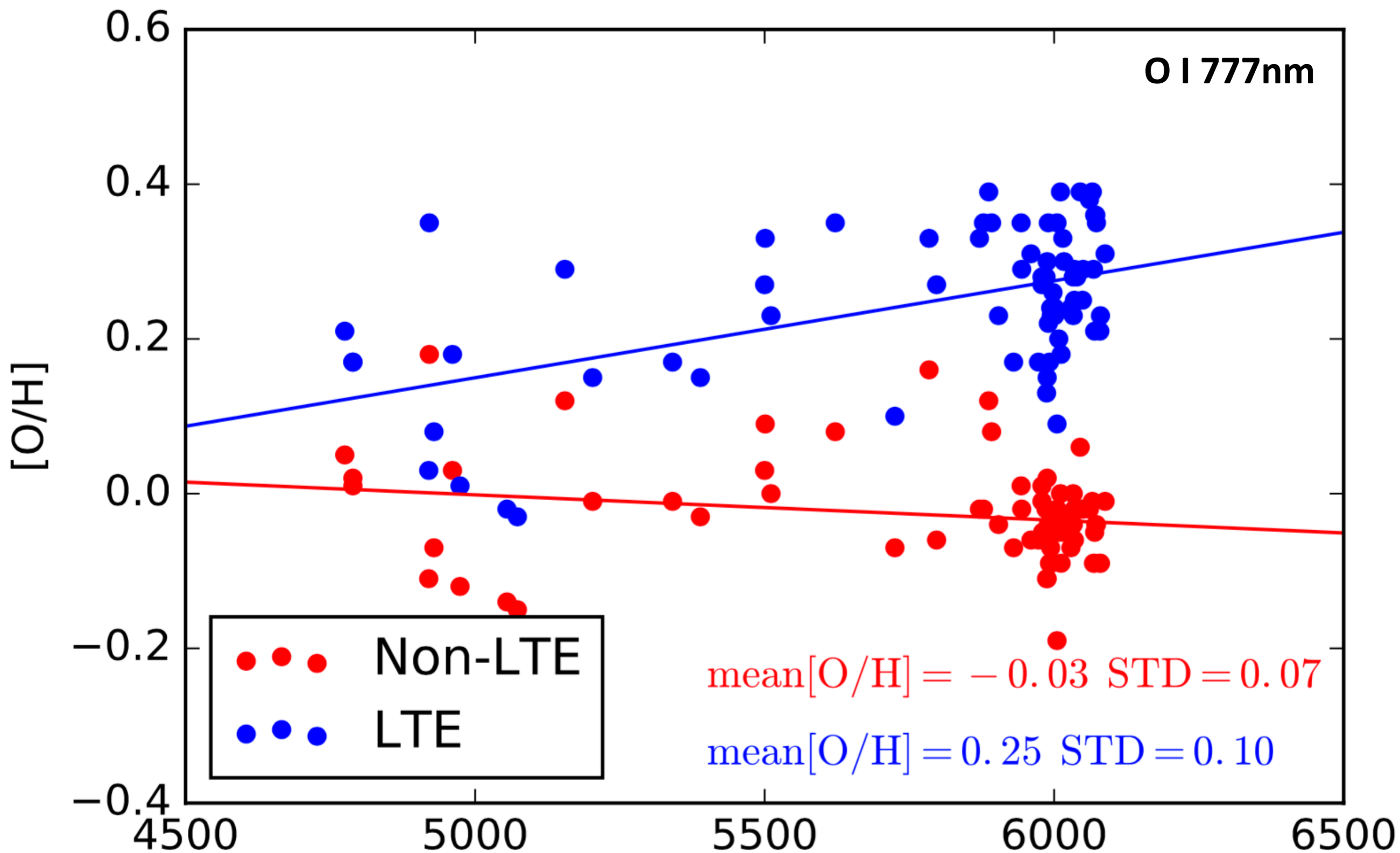
Abundances of M67



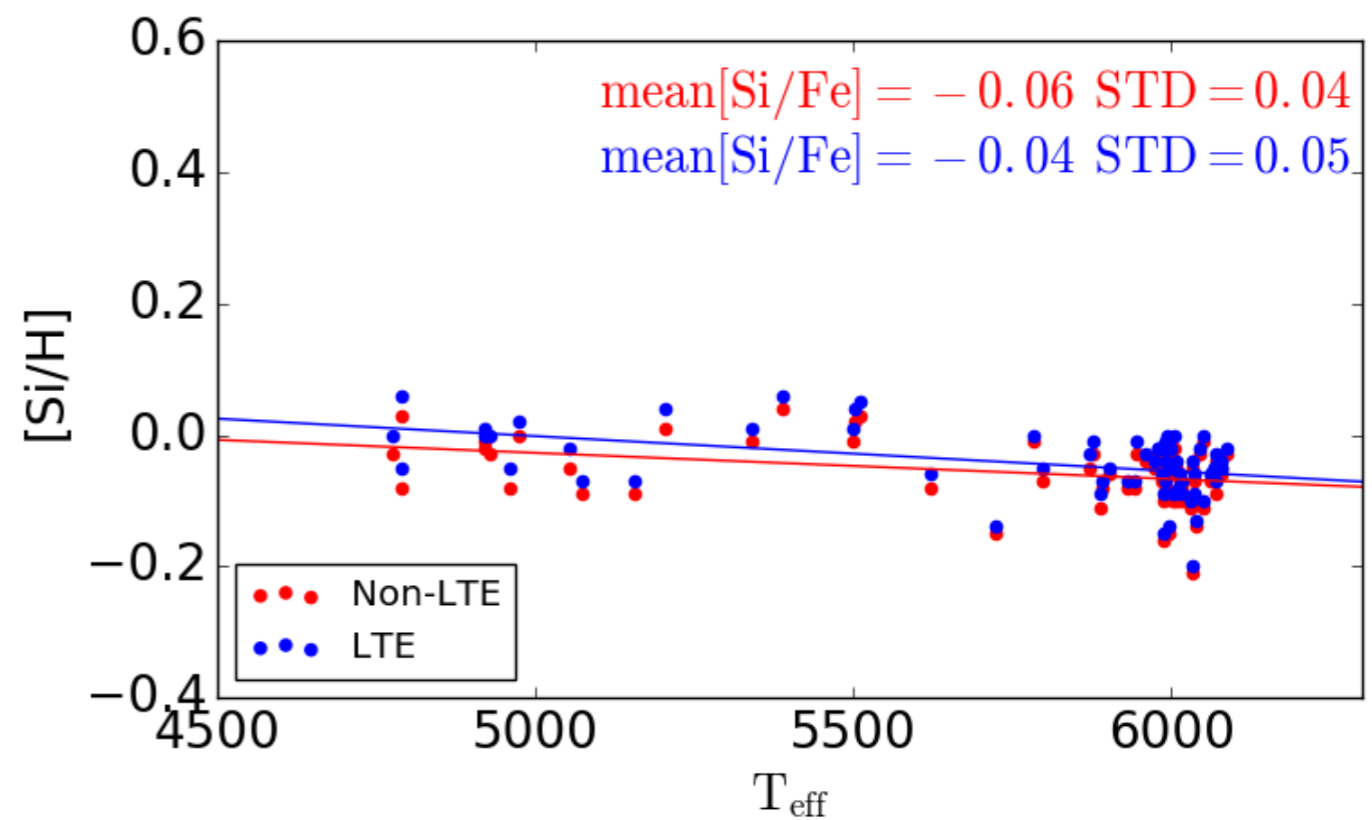
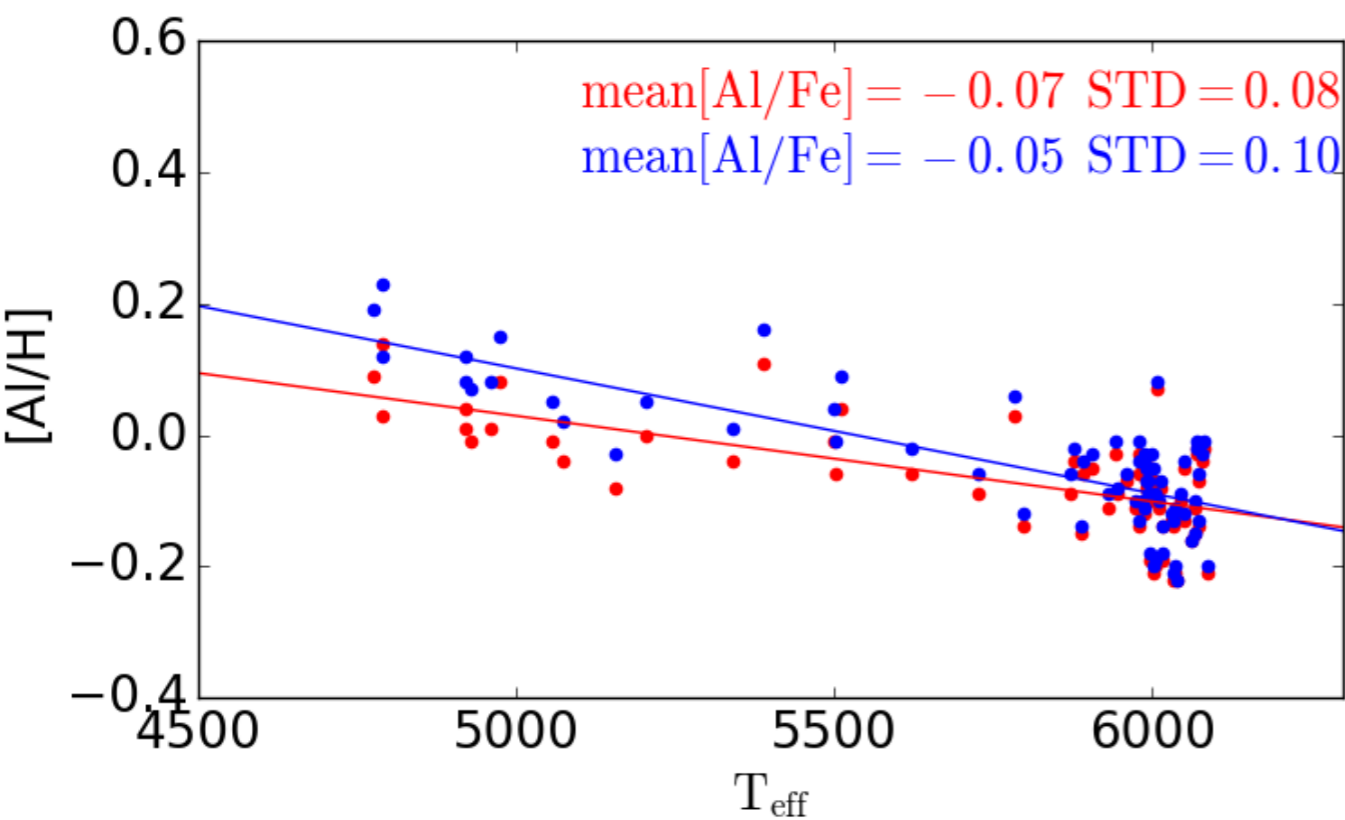
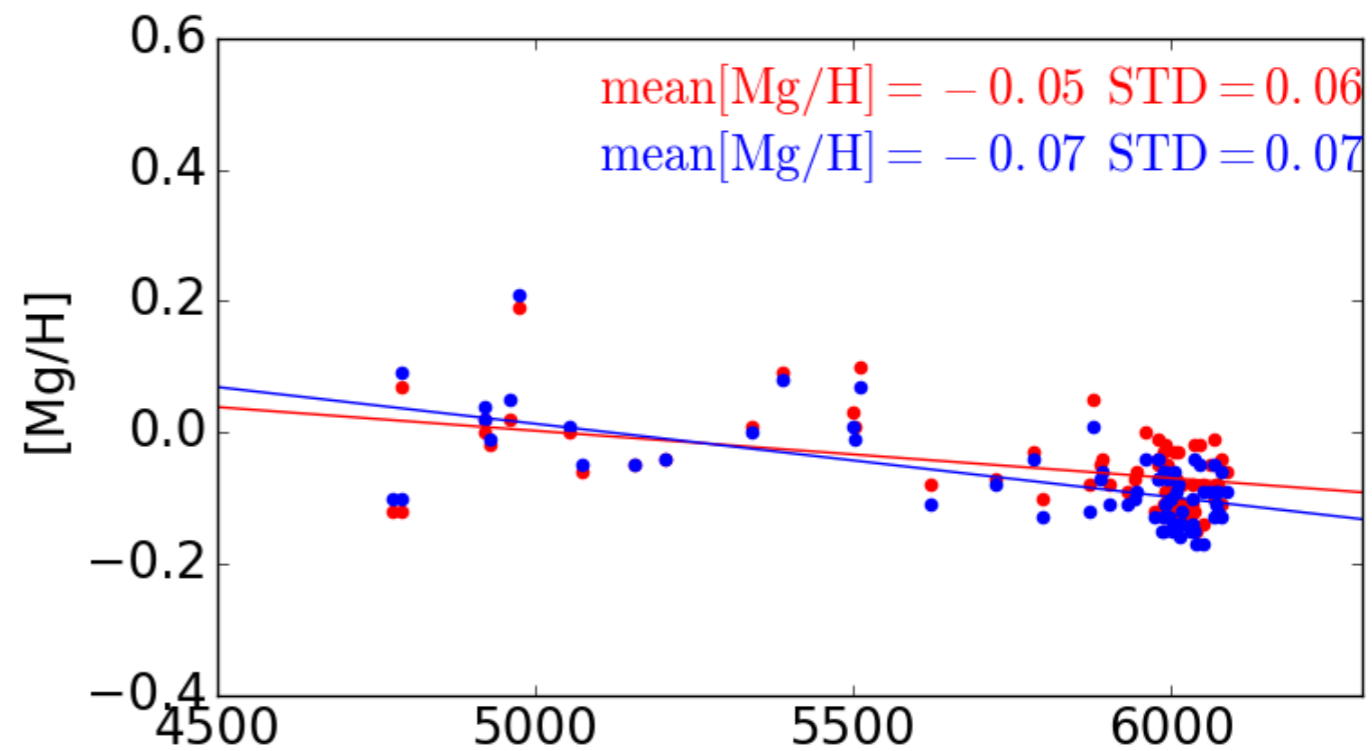
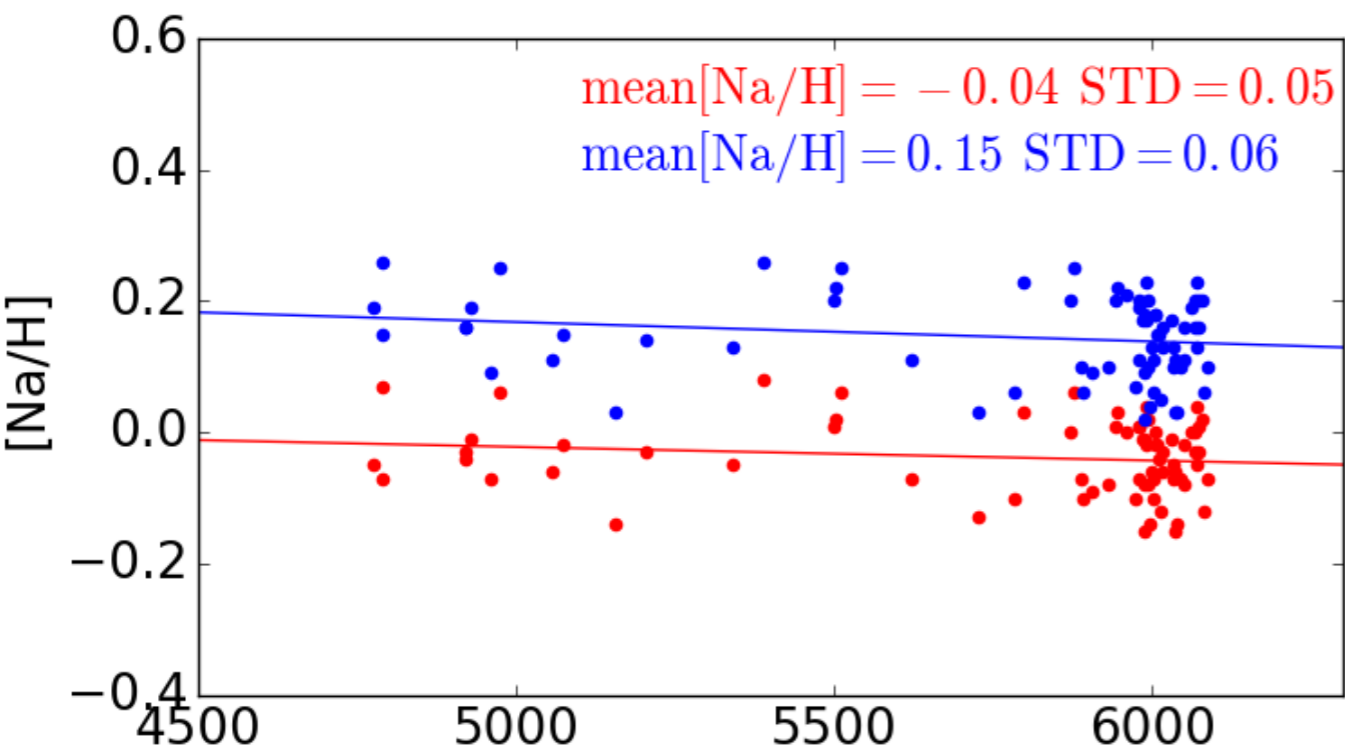
Abundances of M67



Abundances of M67



Abundances of M67

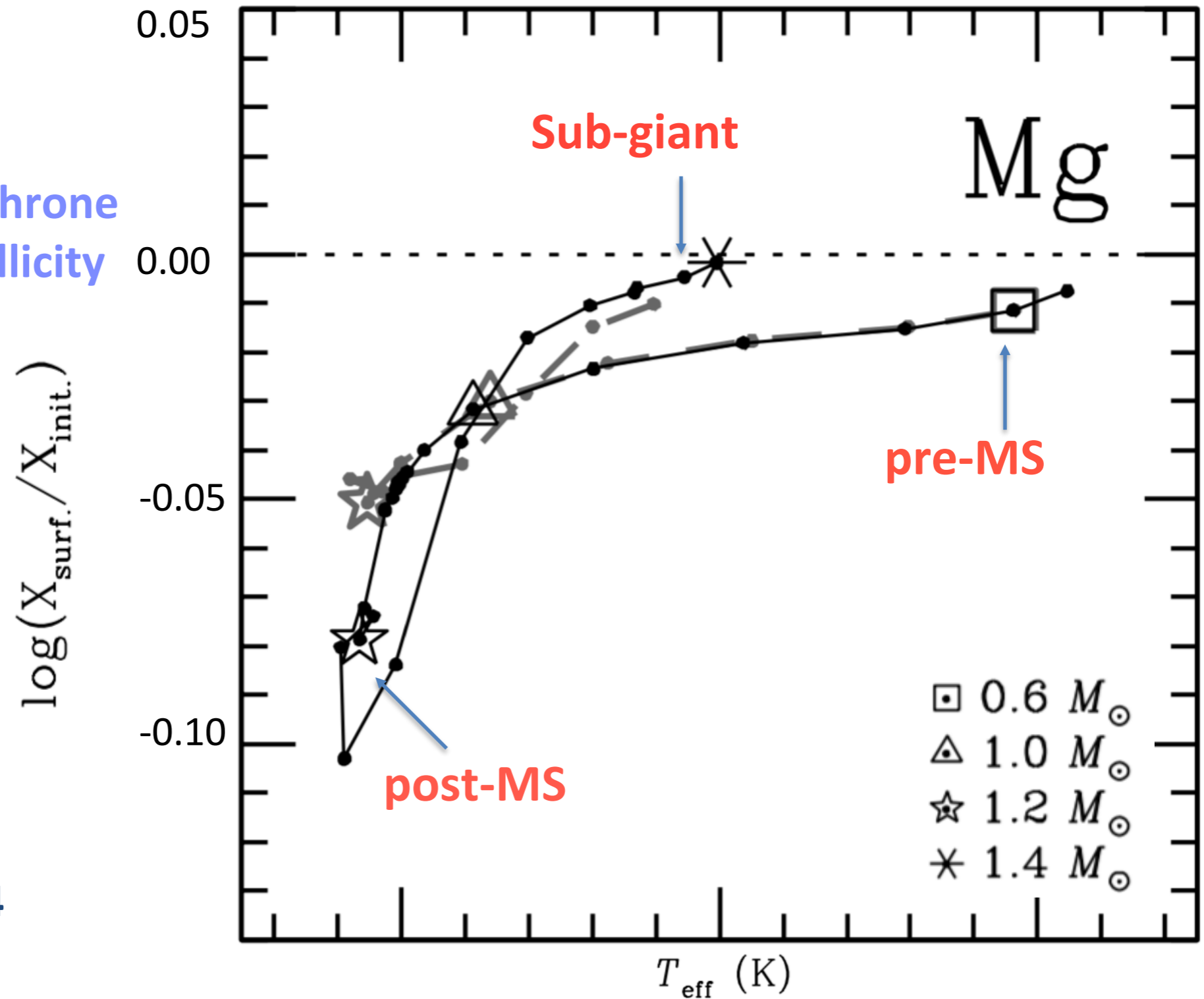


Abundance ratios are all in same scale

Possible explanation for the remaining trends

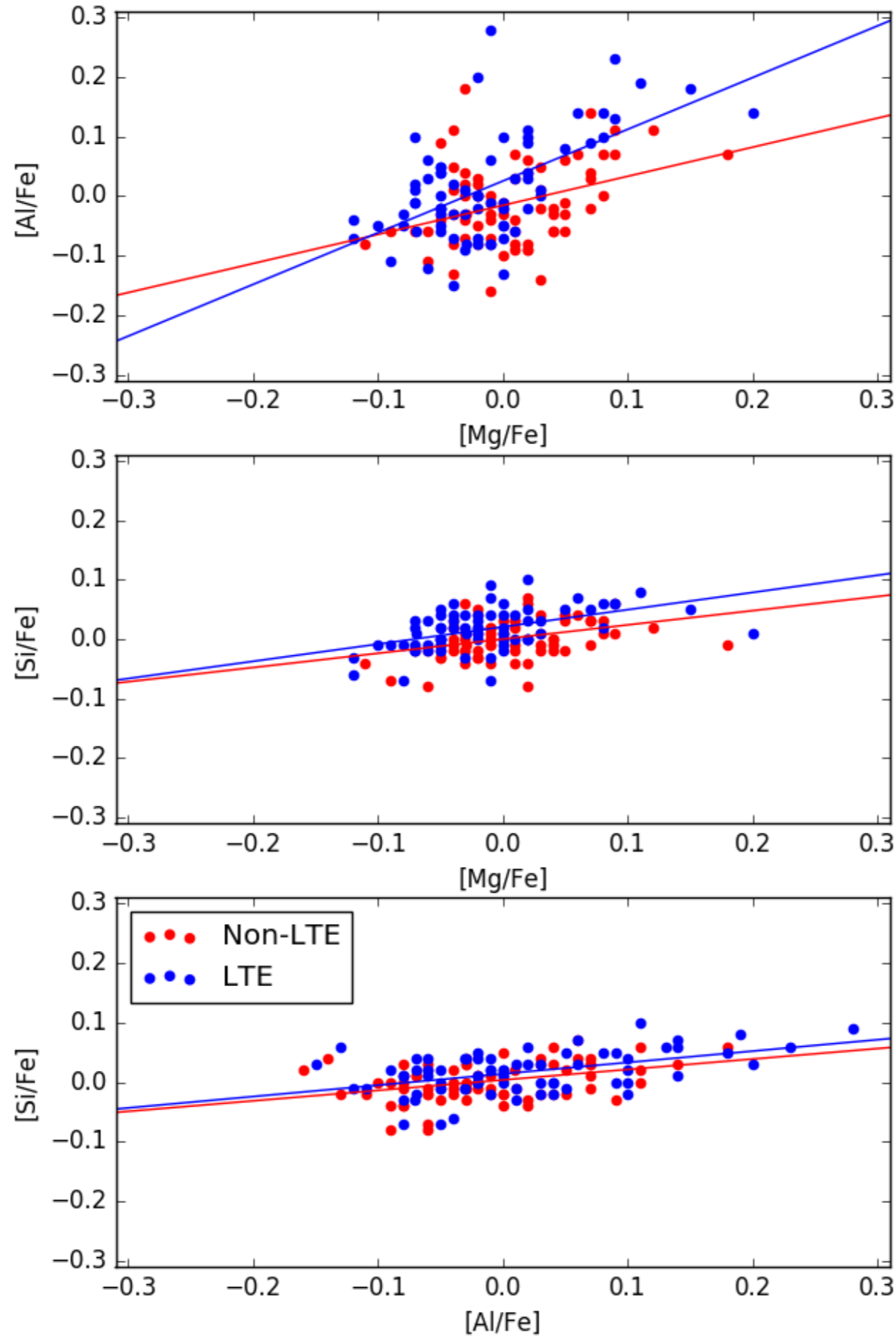
- Atomic diffusion

Surface abundance isochrone
of M67 with solar metallicity
at 3.7 Gyr



Michaud et al. 2004

Abundance correlations



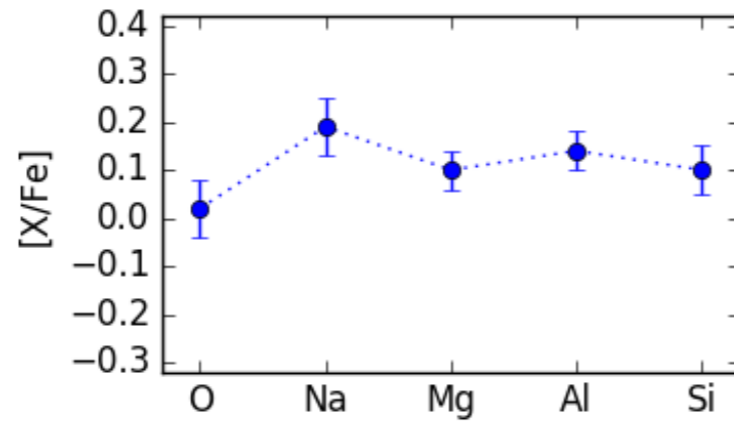
same abundance scale

Comparison with other studies

Tautvaisiene et al. 2000

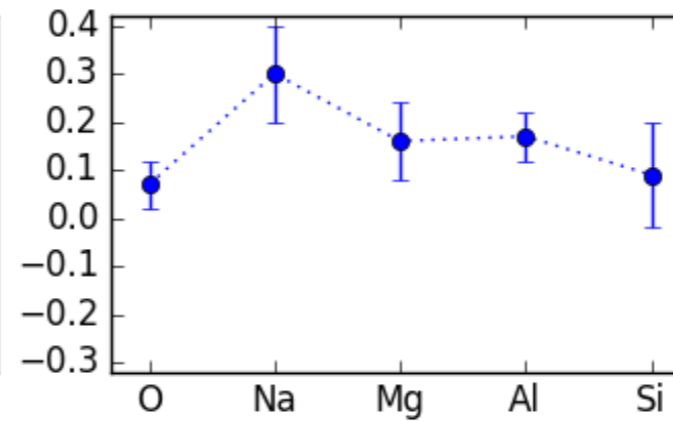
6 red clump stars

3 giant stars



Young et al. 2005

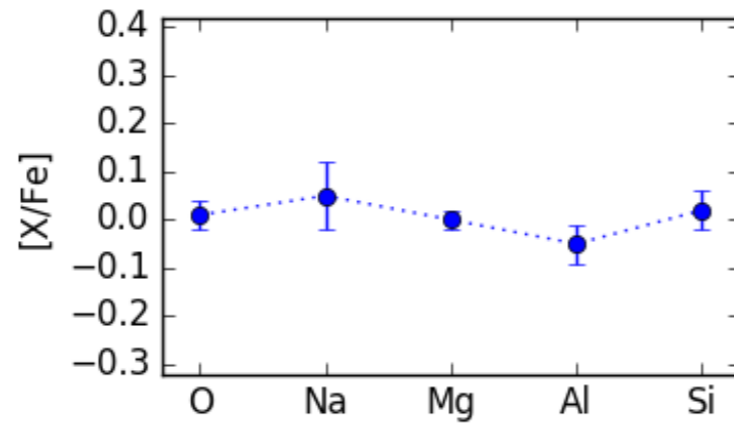
3 red clump stars



Randich et al. 2006

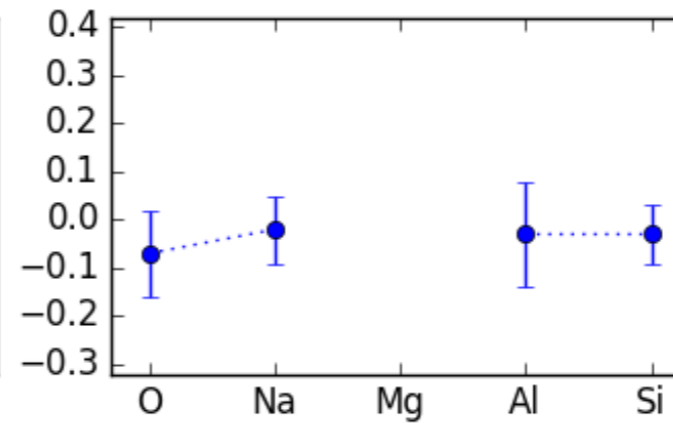
8 dwarf stars

2 slightly evolved stars



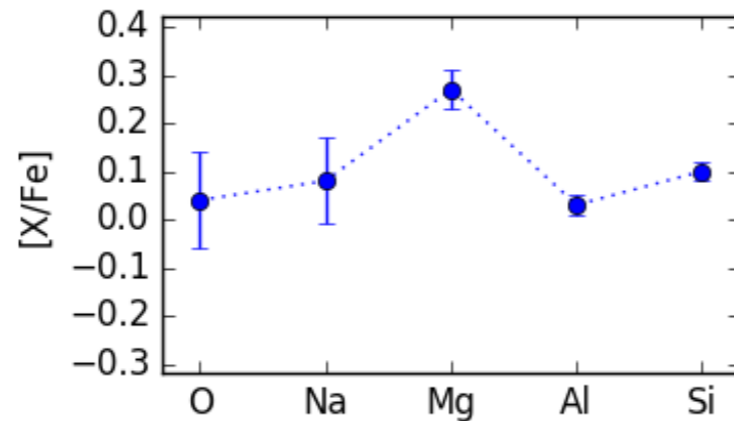
Pace et al. 2008

6 main-sequence stars



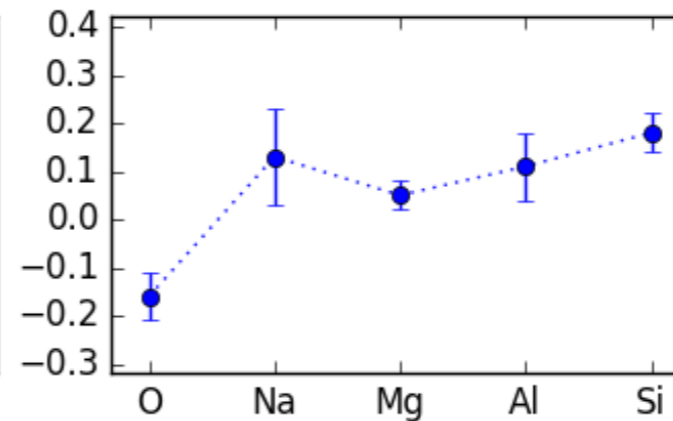
Pancino et al. 2010

3 red clump stars



Friel et al. 2010

3 red clump stars



Abundance ratios are all in the same scale

Conclusion

- Non-LTE is crucial for chemical abundances determination
- A Li-rich sub-giant star has been found
- Chemical inhomogeneities in open clusters complicate chemical tagging
- Non-LTE results have a significant improvement over pure LTE results