Probing stellar evolution with abundance patterns in globular clusters

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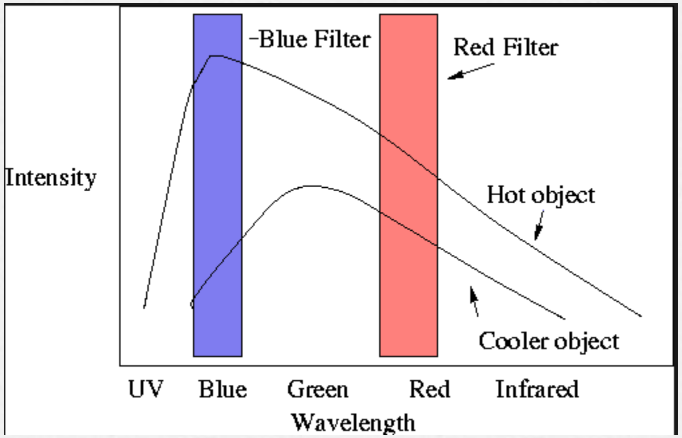
Garching

Outline

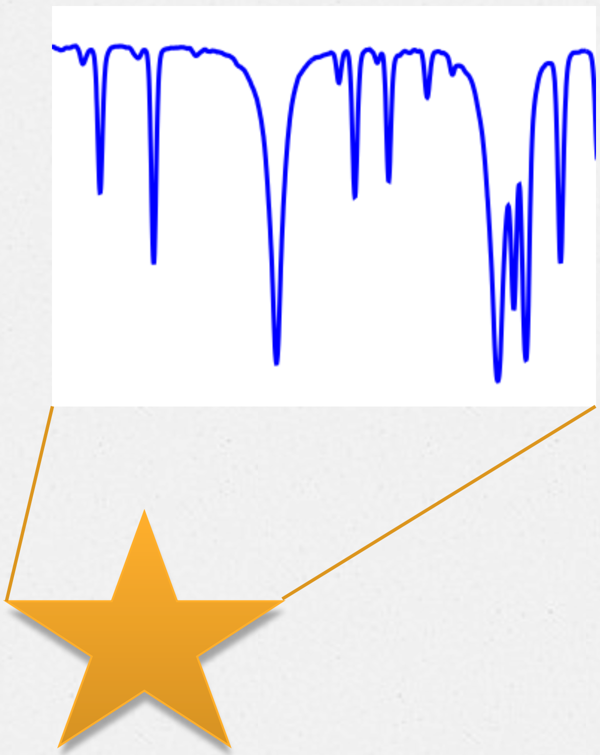
- How we collect information about single stars
- Challenging canonical stellar models using globular clusters

Photometry –
many millions of individual stars

- Colours of single stars indicate their surface temperatures
- Clever filter combinations can add constraints on surface gravity and metal content

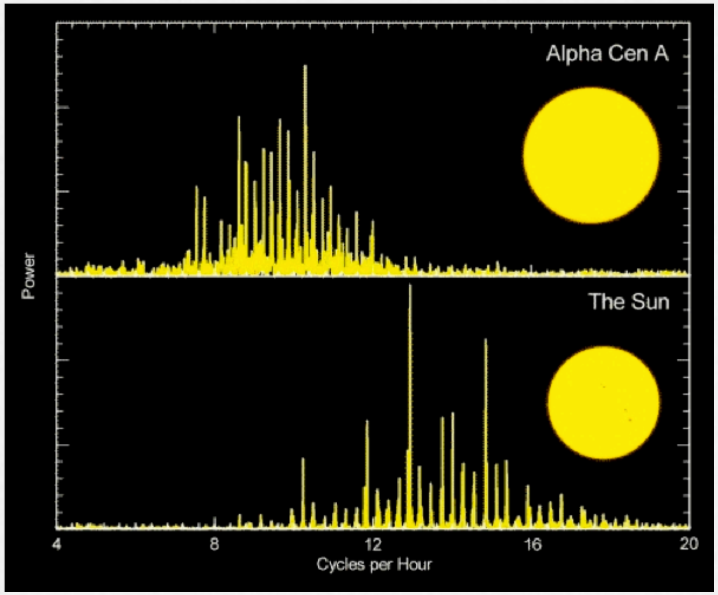


Spectroscopy –
hundreds of thousands of individual stars



- Precise constraints on surface conditions:
  Teff, log(g), [X/H]
  ($v_{rot}\sin i$, activity)
- Requires a model of the atmosphere
- Systematic uncertainties: 1D, LTE

Astroseismology –
thousands of individual stars



- The power spectrum of magnitude oscillations can constrain:

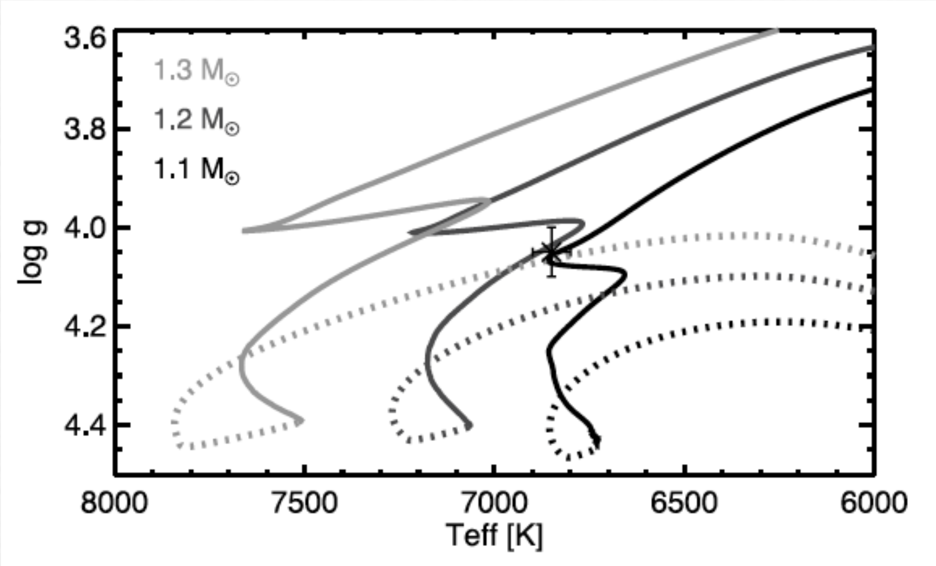
  M, R, L, distance

- Need prior information on T_{eff} and [Fe/H]

Image: www.hao.ucar.edu

Stellar structure models

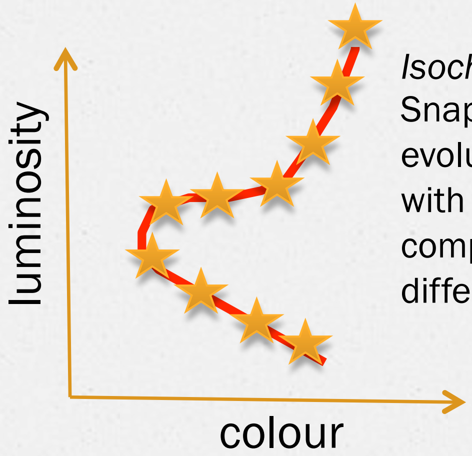
- Needed to put the observables into context and derive stellar ages
  - Given [X/H] and M, age is well-constrained post-MS
  - Without M, parameter degeneracy is high



Serenelli et al. 2013

Challenging the models

- Globular clusters are stellar laboratories. To 1st approximation all stars:
  - .. are coeval
  - .. share same *initial* chemical composition
  - .. are located at the same distance

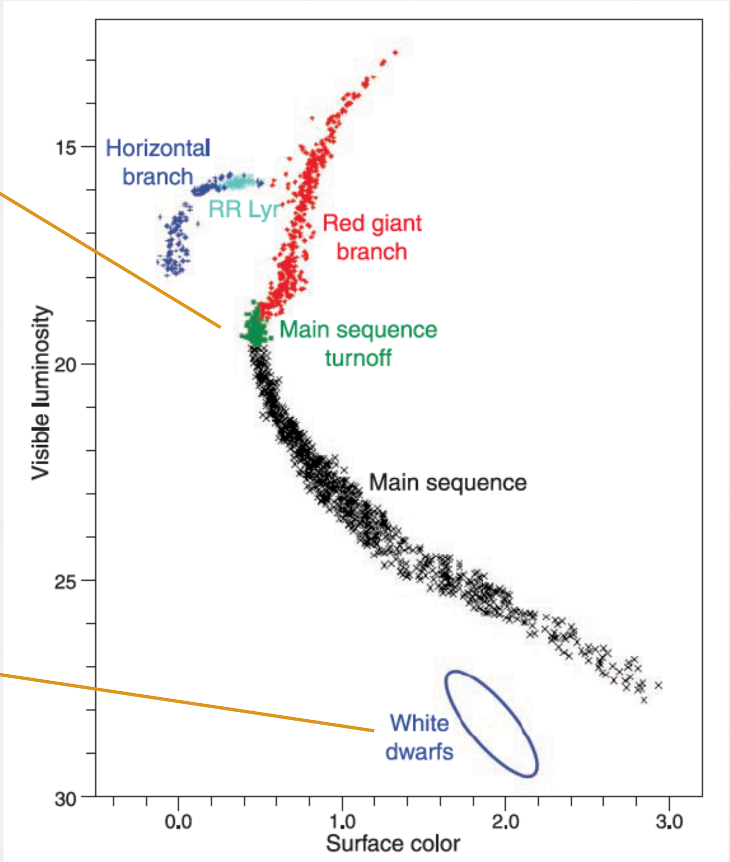


Isochrone: Snapshot in time of evolutionary tracks with same chemical composition but different mass

Ages of GCs

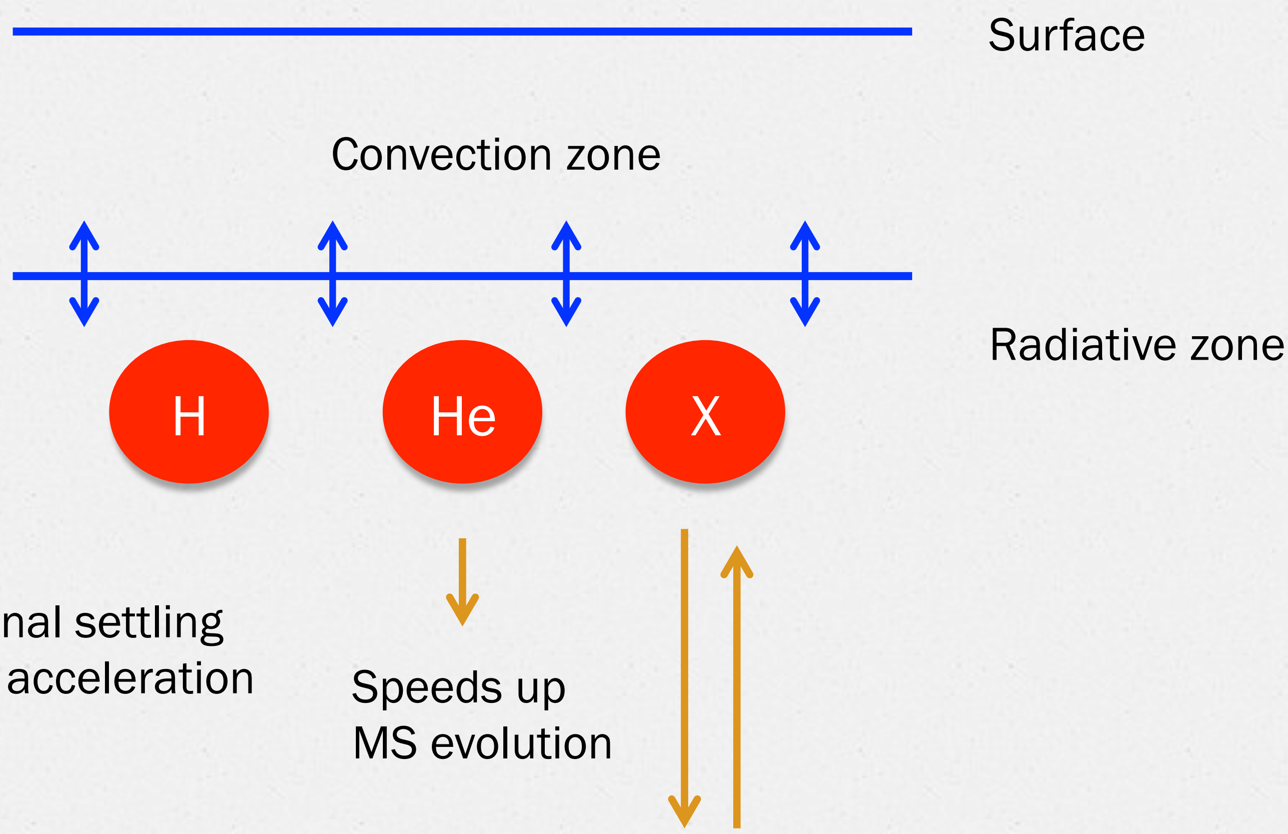
Luminosity of MSTO:
Age
Distance
[X/H]
Stellar models
He diffusion
Convection

Alternative method:
WD cooling sequence



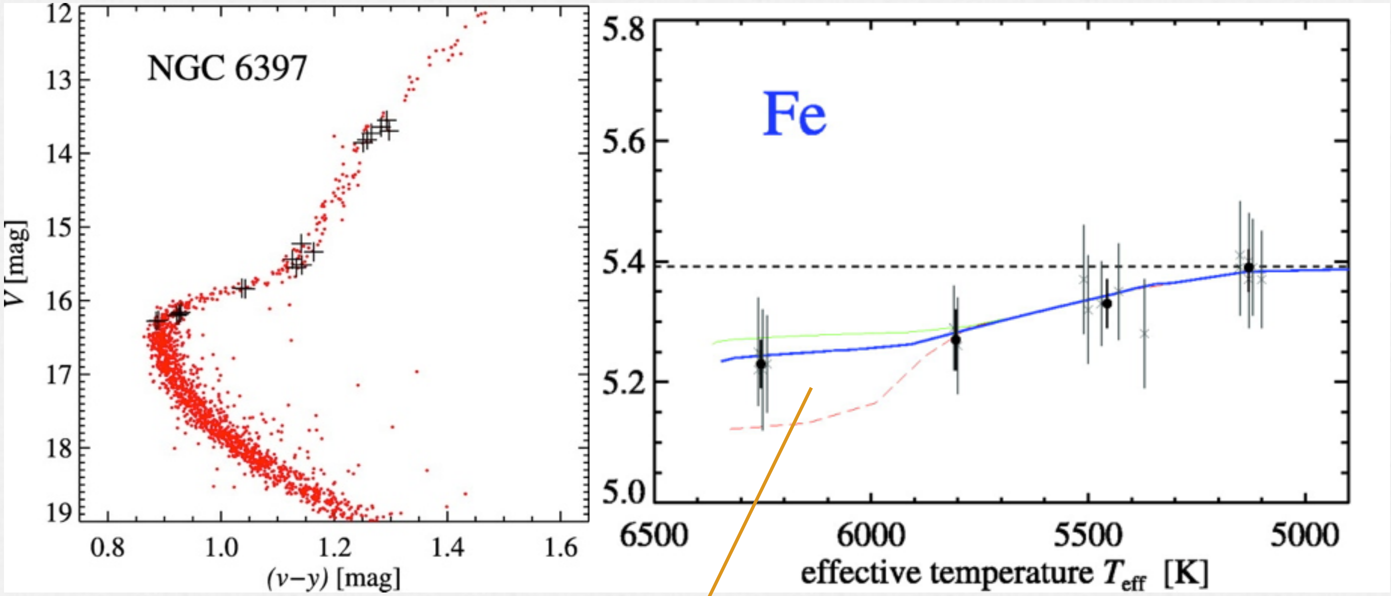
Krauss & Chaoboyer 1996

Atomic diffusion



Gravitational settling
Radiative acceleration
Mixing

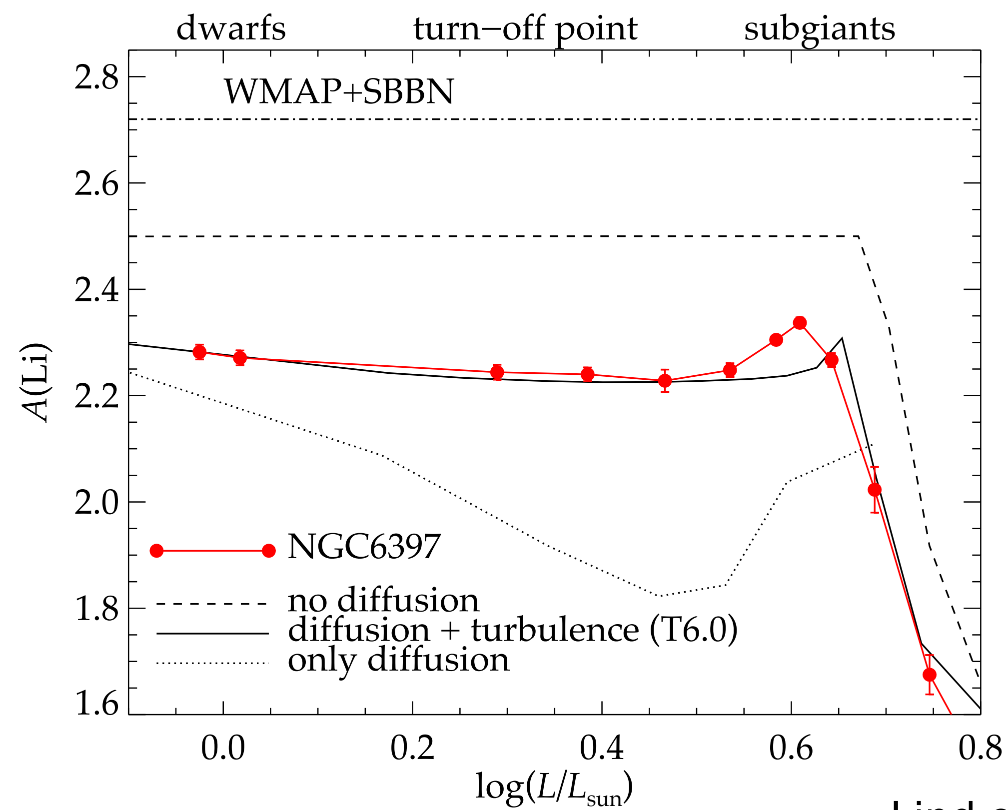
Observational signatures I



Constrains mixing efficiency

Korn et al. 2007

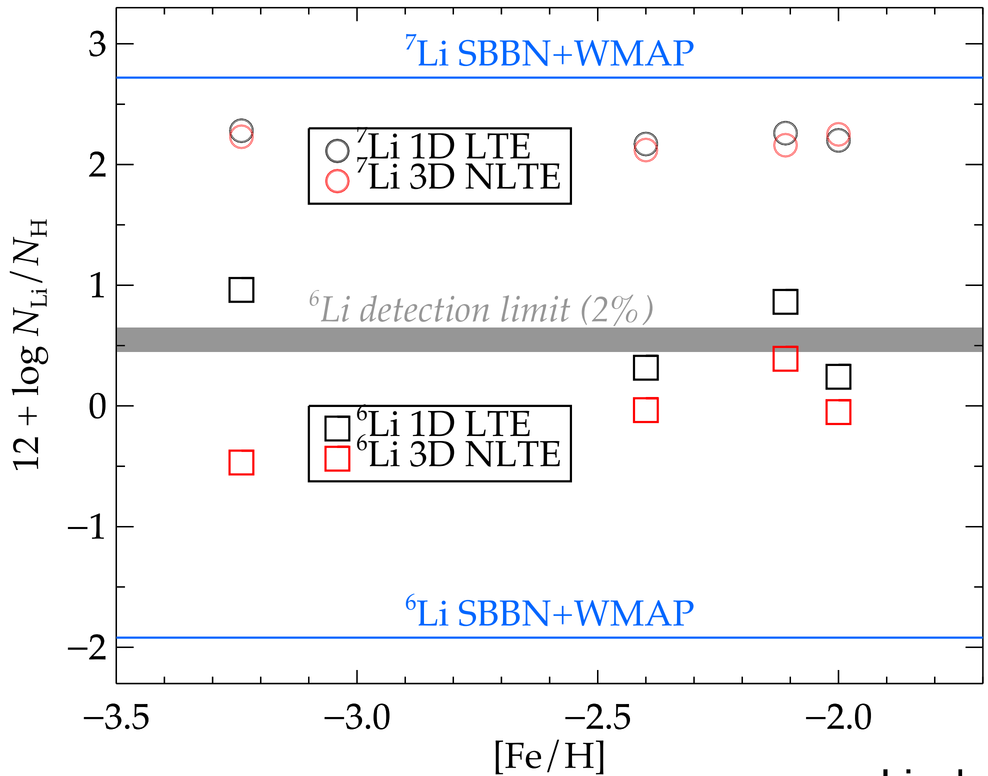
Observational signatures II



$^7Li(p,\alpha)^4He$

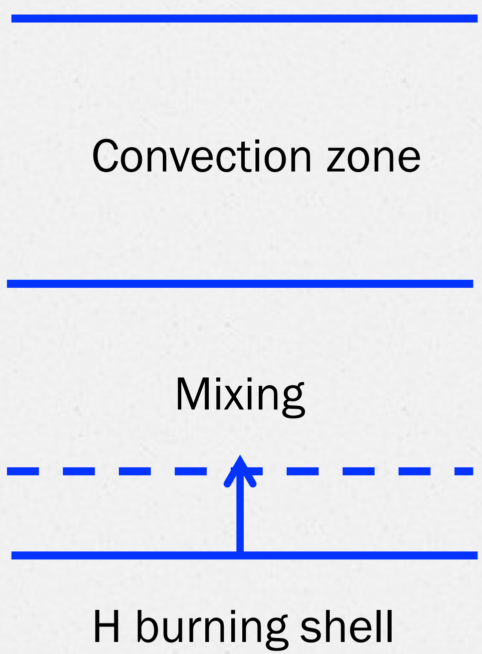
Lind et al. (2009)

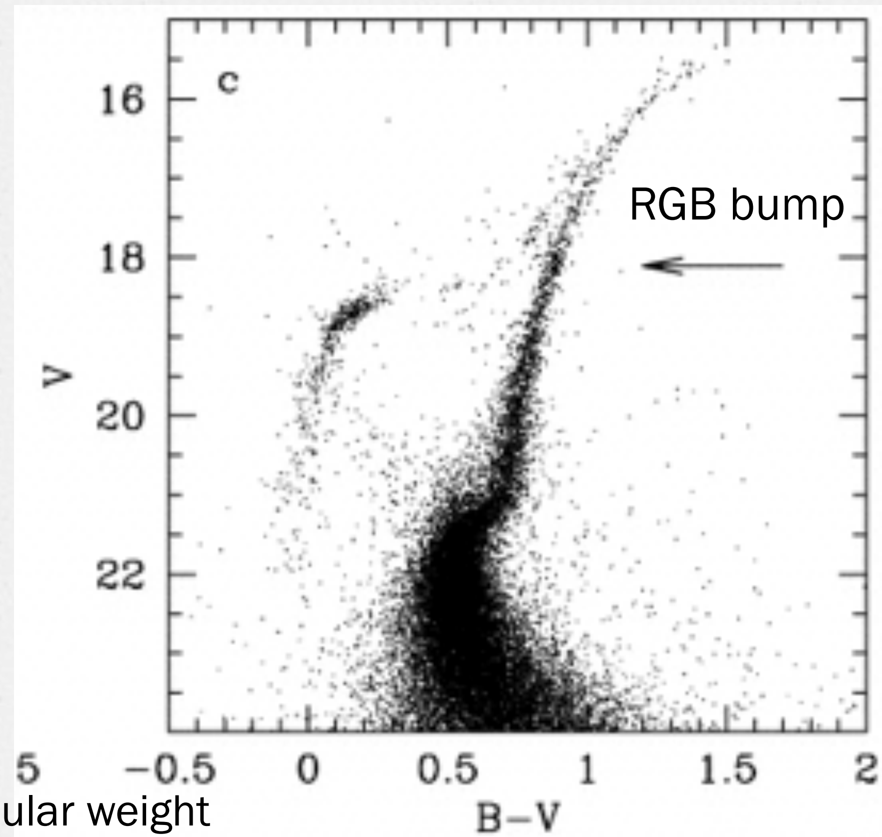
The 2nd Li problem



Lind et al. 2013

RGB evolution

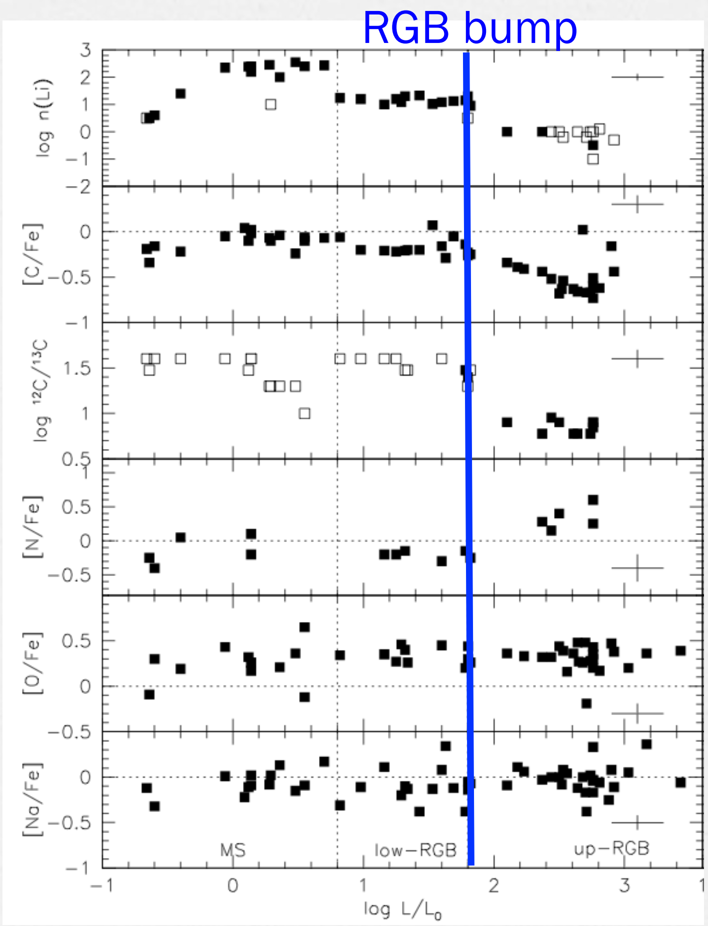




$^{3}He(^{3}He,2p)^{4}He$ lowers molecular weight
→ Thermohaline mixing → Stars do not produce ^{3}He

Charbonnel & Zahn 2007

Observational signatures III



Li decreases

C decreases

$^{12}C/^{13}C$ decreases

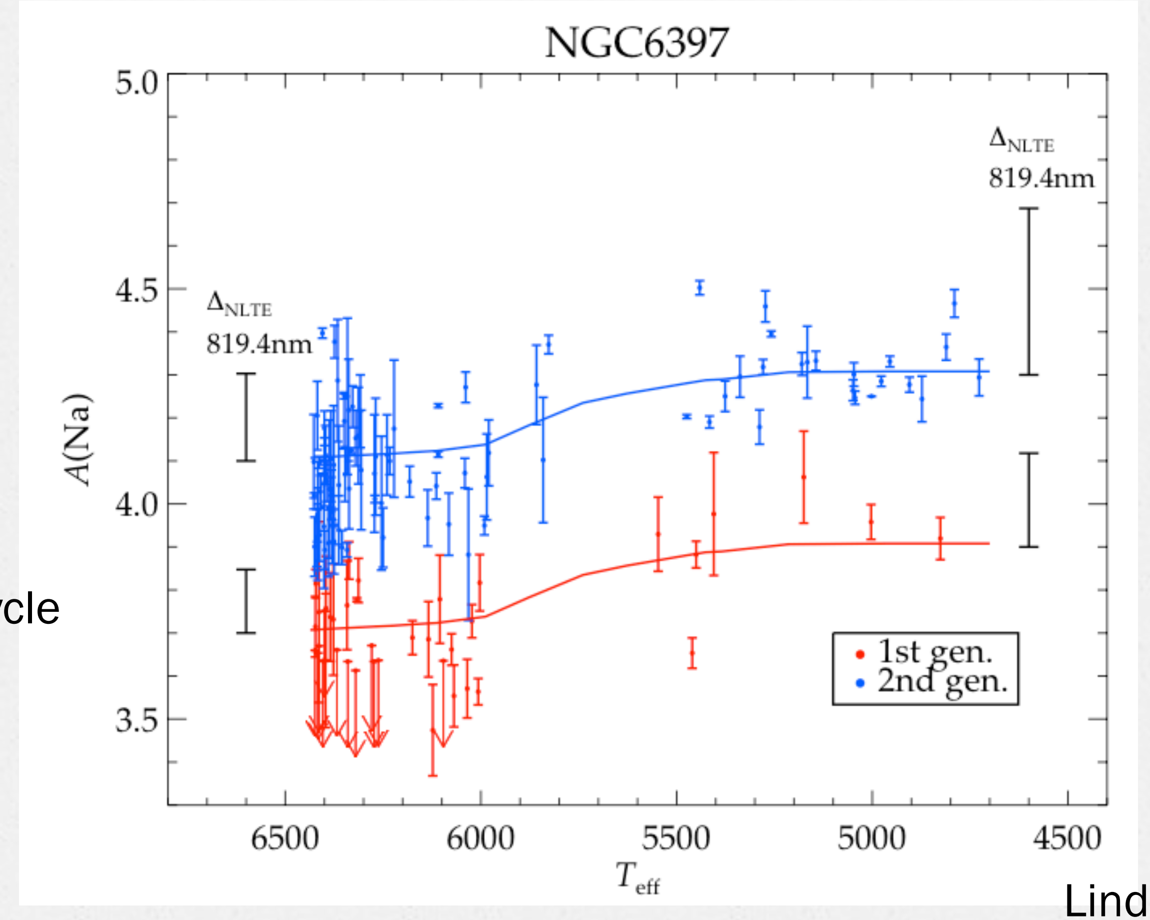
N increases

O unaffected

Na unaffected

Gratton et al. 2000

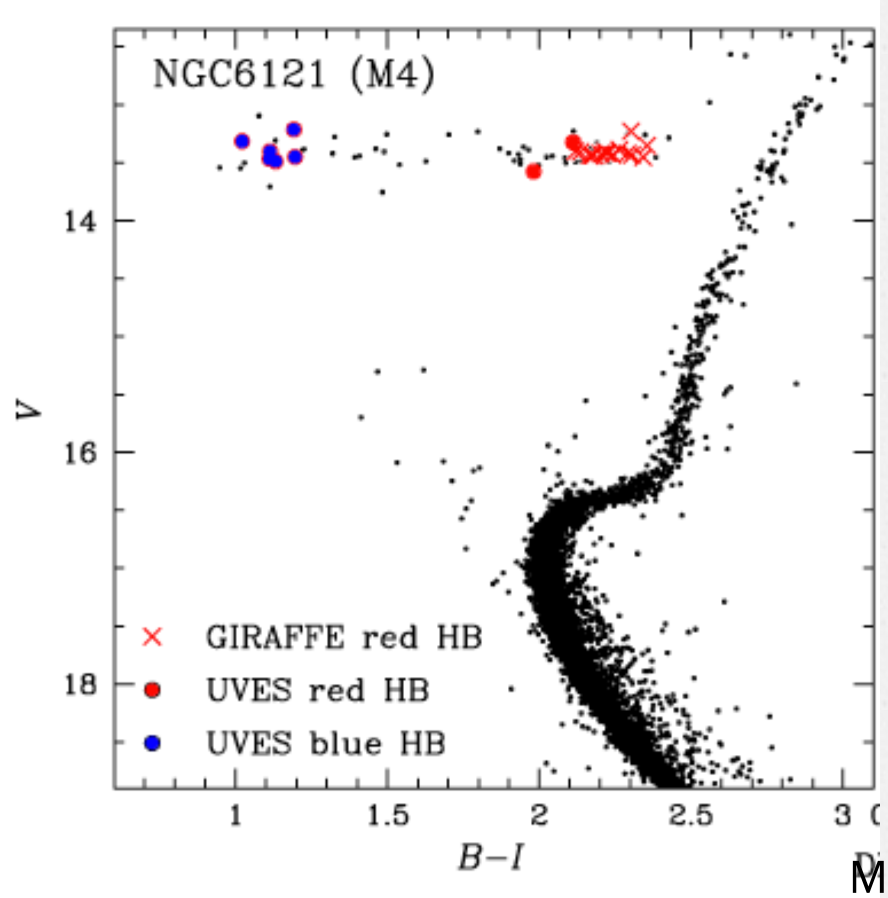
GC complication



Ne-Na cycle

Lind et al. 2011

The horisontal branch



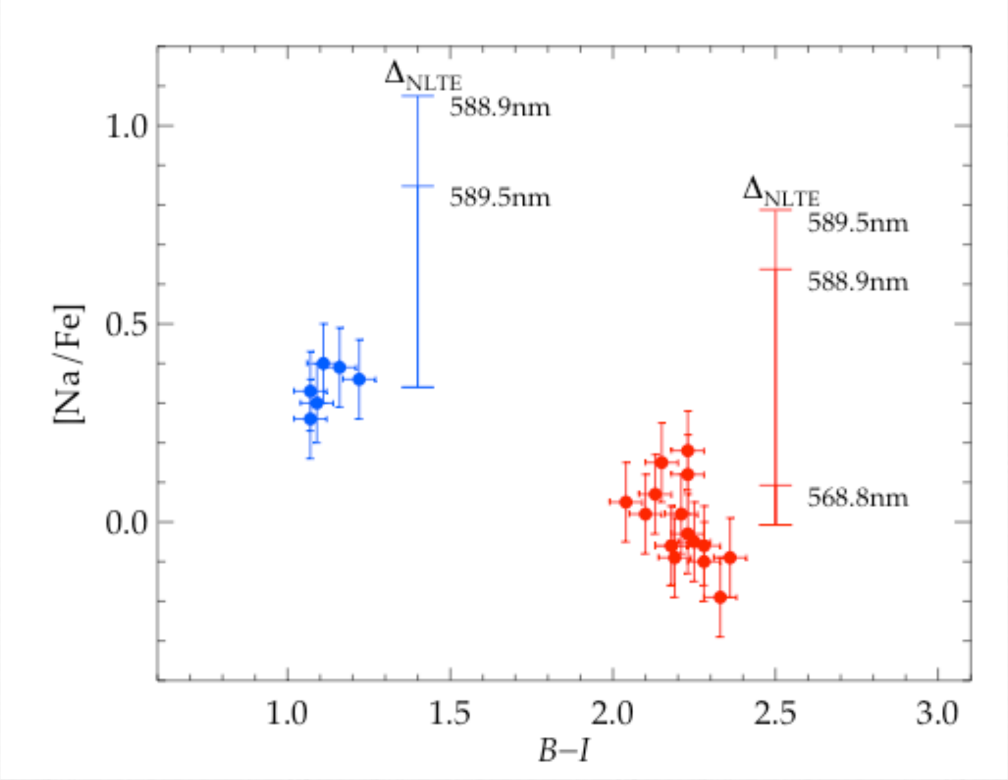
Marino et al. 2011

He enhancement

Blue HB:
Elevated Na →
Elevated He

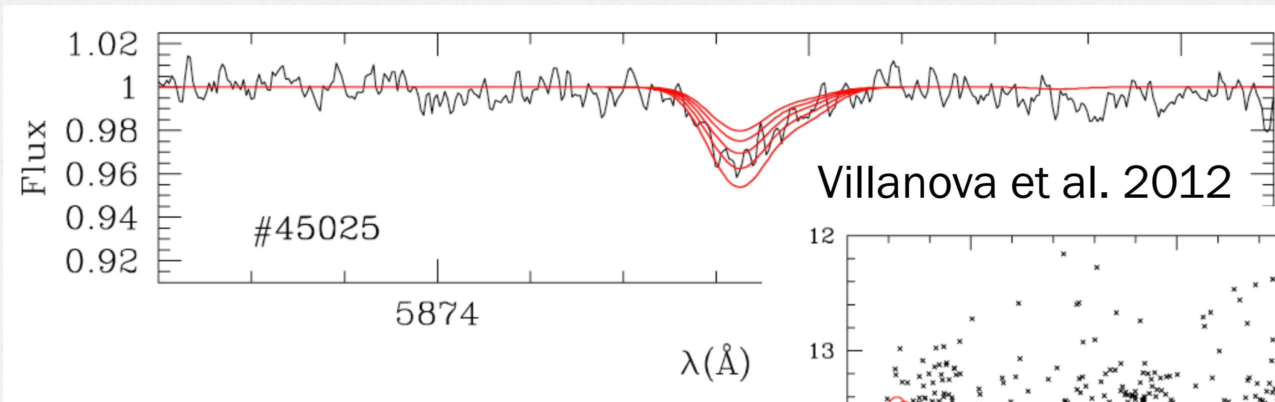
Many uncertainties
in HB modelling:

He abundance
Mass loss on RGB

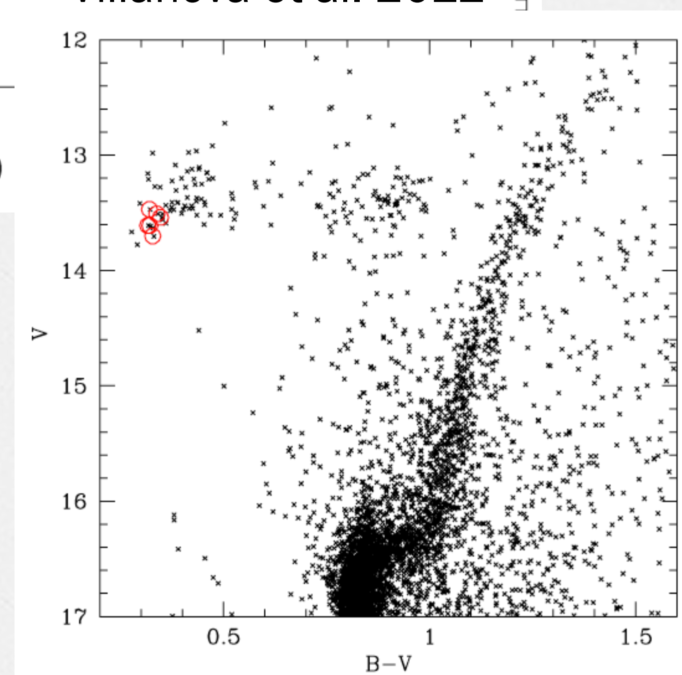


Marino et al. 2011

Direct He measurements



Villanova et al. 2012



Possible for very hot stars

Departures from LTE unknown

Summary

- Through spectroscopic studies of globular clusters, canonical stellar models are challenged and new discoveries made
- 1D, LTE abundances are prone to systematic uncertainties of various sizes
- We need to understand **atomic diffusion and mixing** in radiative zones:
  - to age-date clusters
  - disentangle intrinsic and evolutionary effects
  - shed light on the cosmological Li problem
- **Helium** is a key to explaining the HB morphology