Milky Way helium enrichment constrained by red clump stars

Emma Willett

Andrea Miglio, Marco Tailo

European Research Council
Established by the European Commission

ASTERO CHRONOMETRY

UNIVERSITY OF BIRMINGHAM

Stellar ages are important

Stellar physics

Galactic Archaeology

Exoplanet systems

… but challenging

Fundamental

Only possible for the Sun

Semi-fundamental

Nucleocosmochronometry, Kinematic or Expansion Ages

Limited scope and rely on challenging measurements

Model dependent

Physics challenges

convection, mixing, rotation…

Model input and databases

atmospheres, opacities, ***abundances****…*

Numerical challenges

Observational tests and constraints

Soderblom 2010
Guzik 2014

Helium in low mass stars

- Helium spectral lines are difficult to measure

- Usually, we assume a helium-to-metal enrichment ratio

$$Y = Y_P + \frac{\Delta Y}{\Delta Z} Z$$

But there are many open questions…

Helium in low mass stars

- Helium spectral lines are difficult to measure

- Usually, we assume a helium-to-metal enrichment ratio

$$Y = Y_P + \frac{\Delta Y}{\Delta Z} Z$$

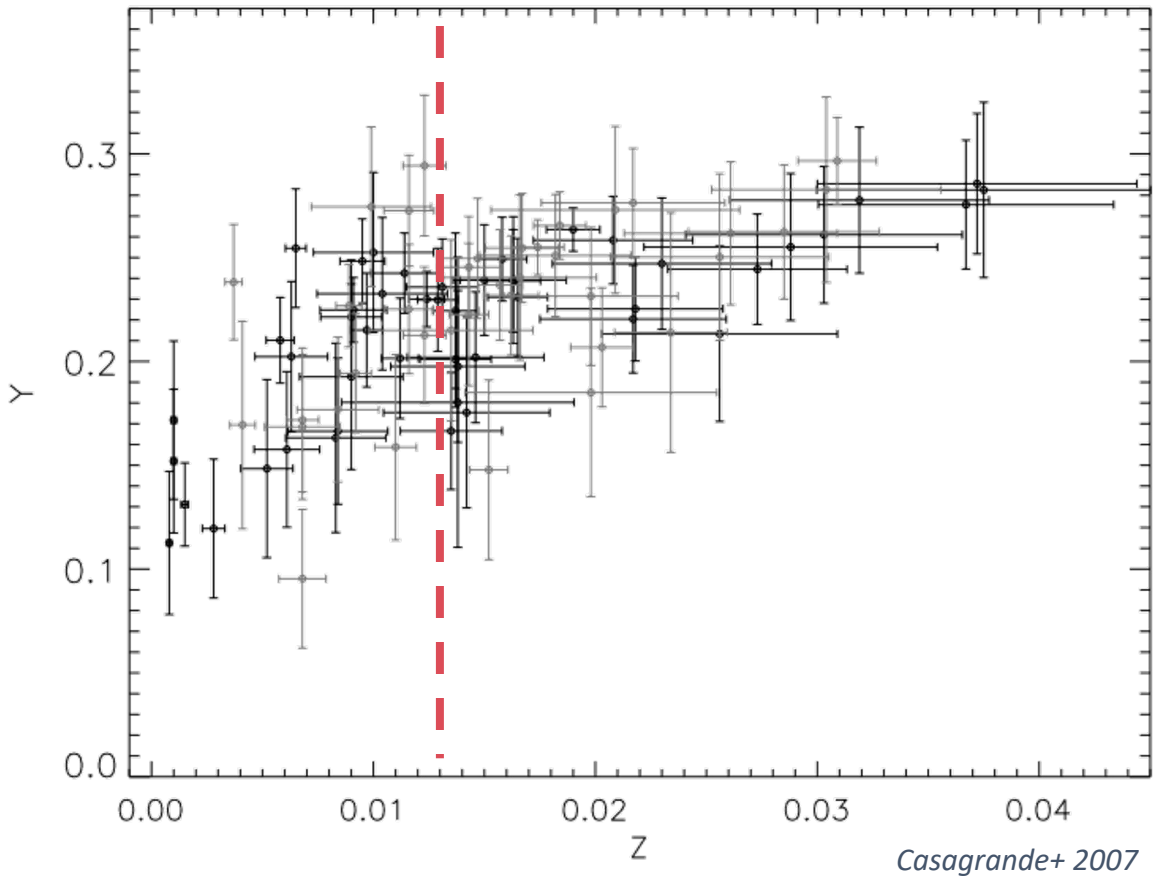
But there are many open questions…

- Range of methods…
  - *Clusters, K-dwarf main sequence, extragalactic HII, asteroseismic glitches*

- …Give many answers
  - Usually $\Delta Y / \Delta Z \approx 2 \pm 1$
  - But you can find $0.5 \rightarrow 5$

  - http://www.pas.rochester.edu/~emamajek/memo_dydz.html

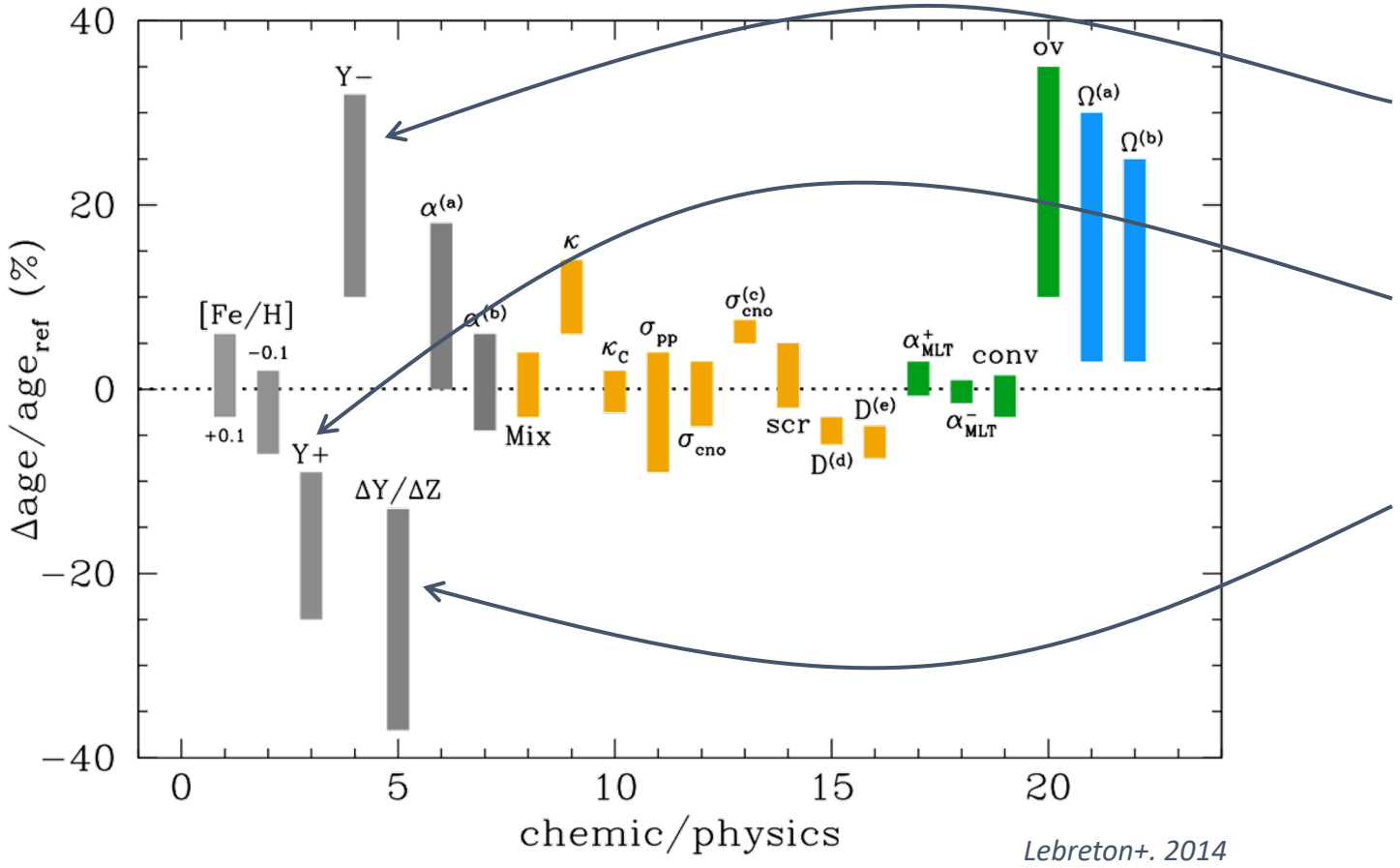
Helium in low mass stars



Casagrande+ 2007

- Is a single enrichment ratio valid?
  - *Spread at low-Z*
  - *Very low Y_P*

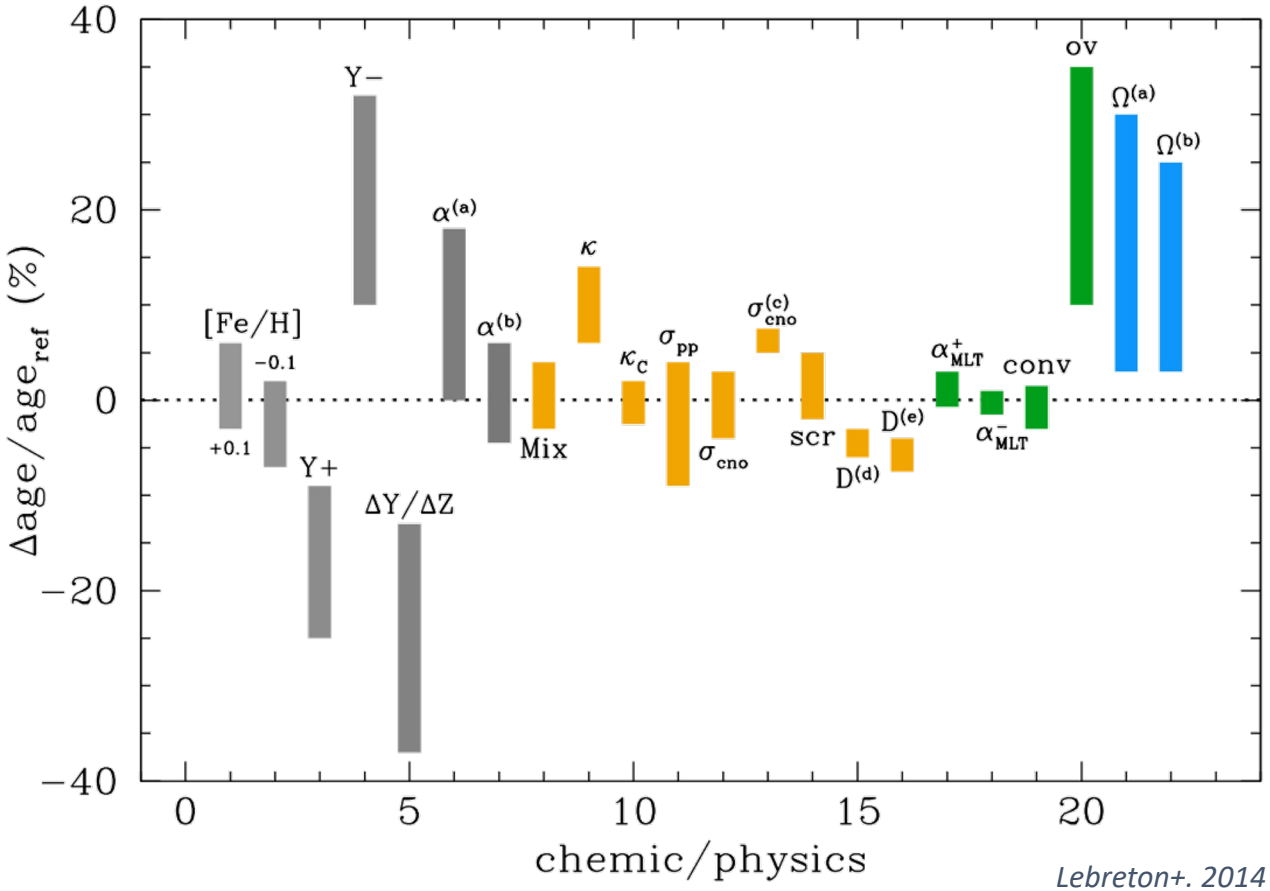
Helium in low mass stars



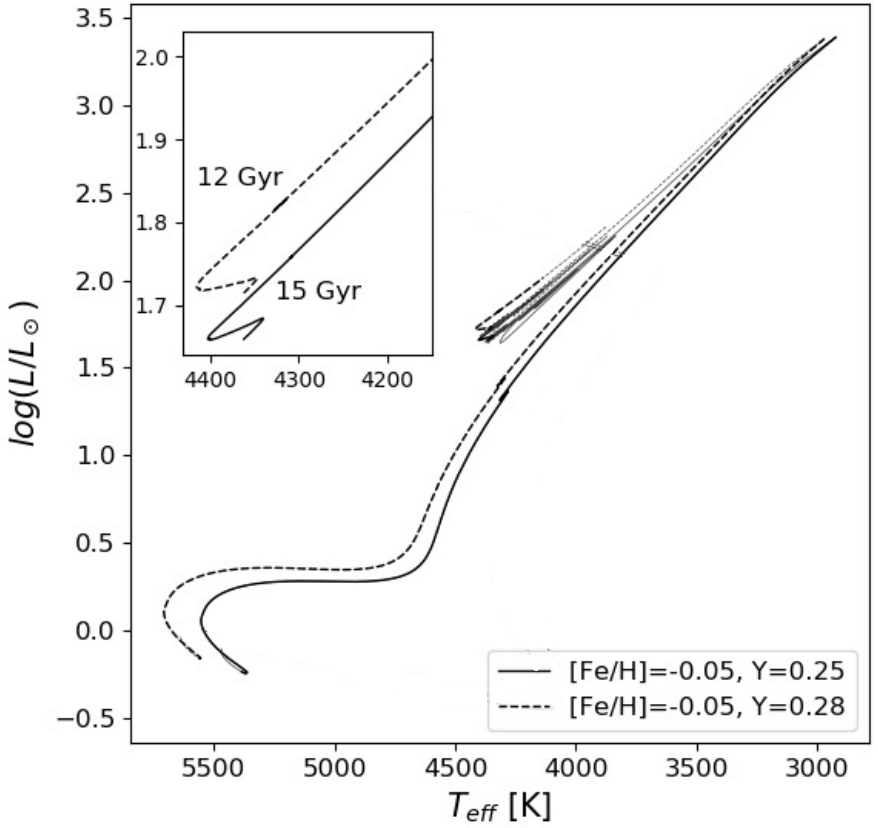
Lebreton+. 2014

- Decrease from $Y = 0.28$ to $Y = 0.25$
- Increase from $Y = 0.28$ to $Y = 0.31$
- Increase from $\frac{\Delta Y}{\Delta Z} = 2$ to $\frac{\Delta Y}{\Delta Z} = 5$

Helium in low mass stars



Lebreton+. 2014

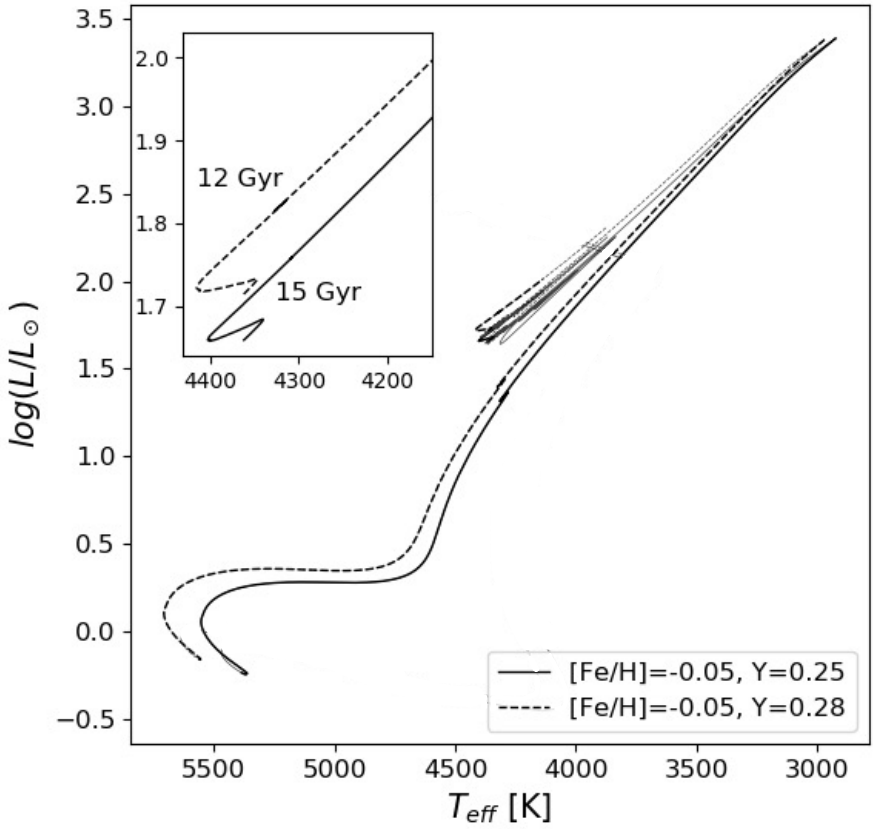


RC luminosity and Y

- Low mass: degenerate core on the RGB

- He-ignition delayed until critical core mass
  ~ *independent of total mass, [Fe/H]*

Very similar core mass
→ Very similar central conditions
→ very similar luminosity



$\upsilon_{max}, \Delta\upsilon$
Yu+ 2018

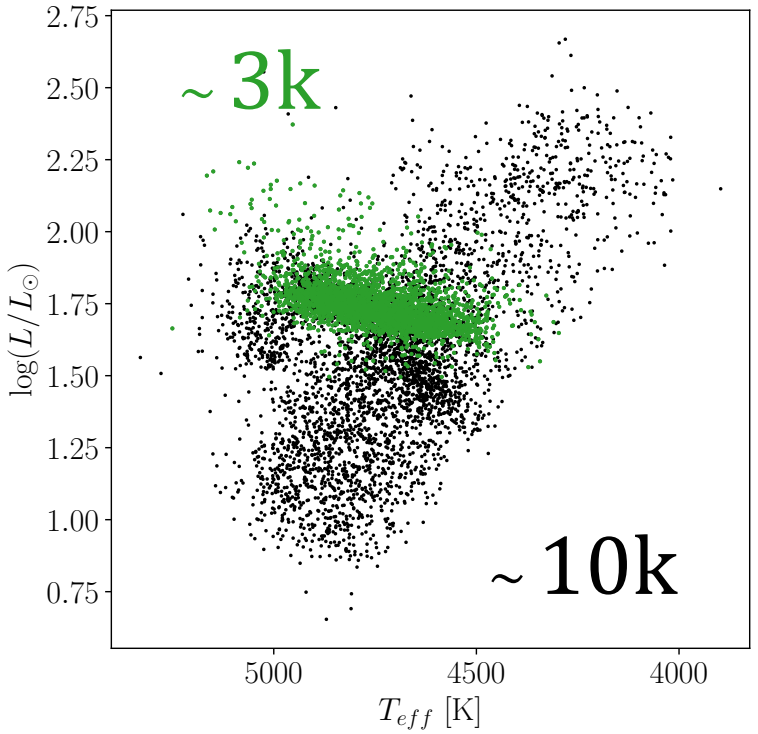
×

[Fe/H], [Mg/Fe]
APOGEE DR17

×

ra, dec, ϖ
Gaia DR3

→



+ PARAM
Rodrigues+ 2017

→ *Stellar parameters*
$M, R_*, \tau \ldots$

+ BCs
Casagrande & VandenBerg 2014
E(B-V)
Green+ 2019

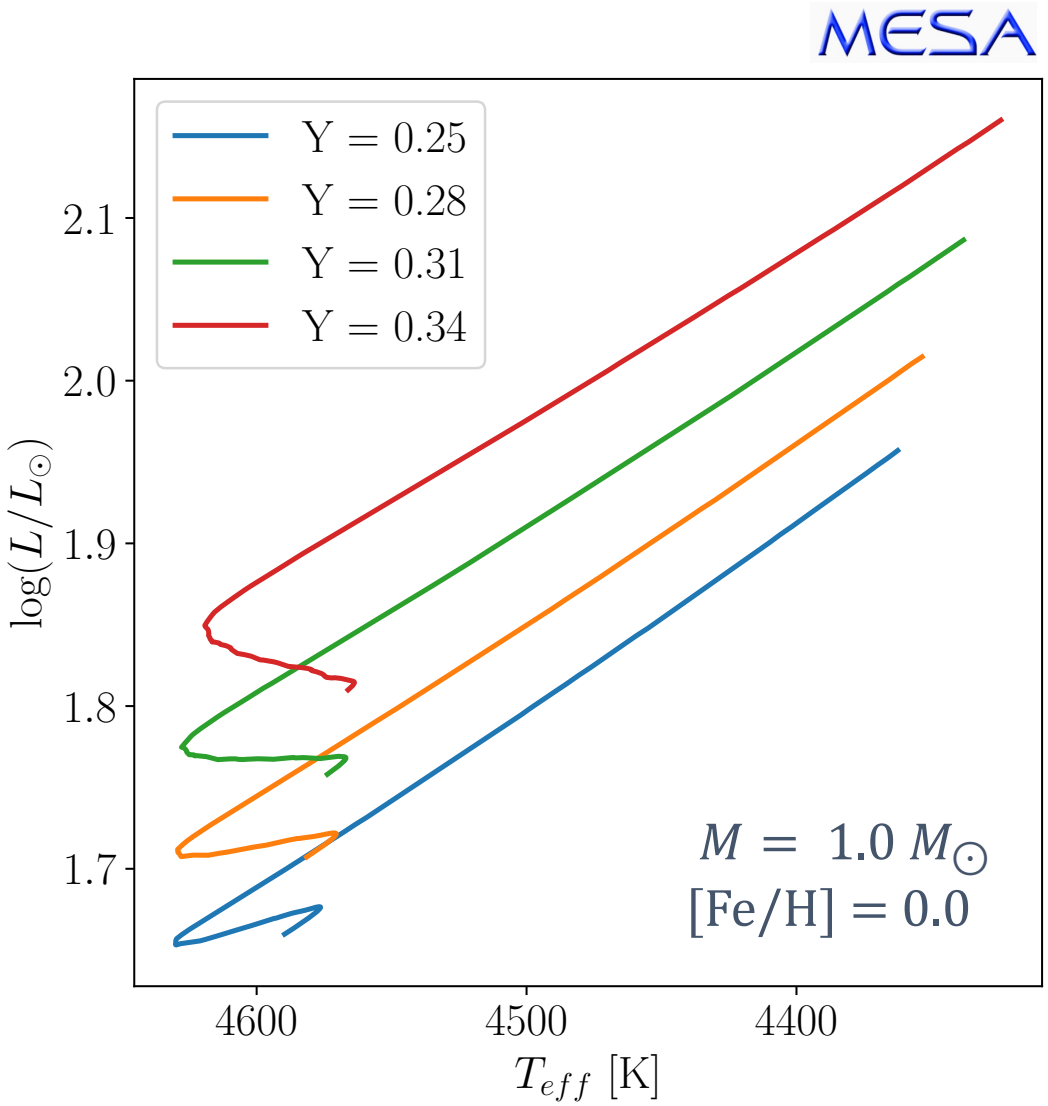
→ *Luminosities*

Models

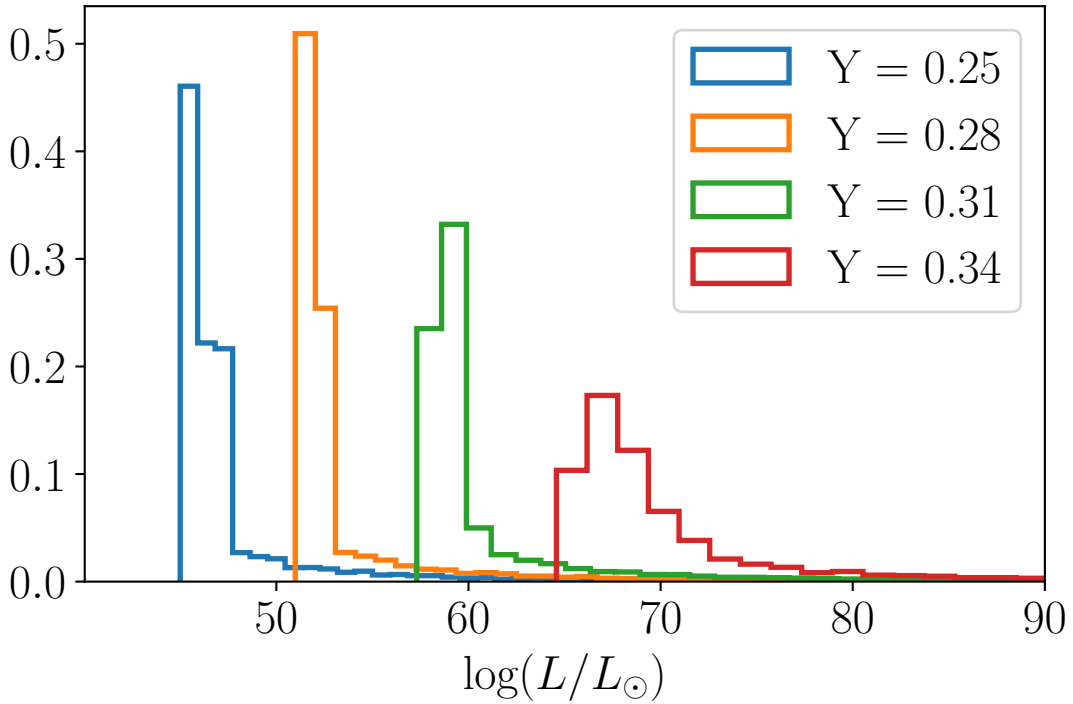
- Grid with no assumed $\Delta Y/\Delta Z$

- M spacing = $0.1 M_{\odot}$
- [Fe/H] spacing = 0.1 dex

- Independent Y at each grid point

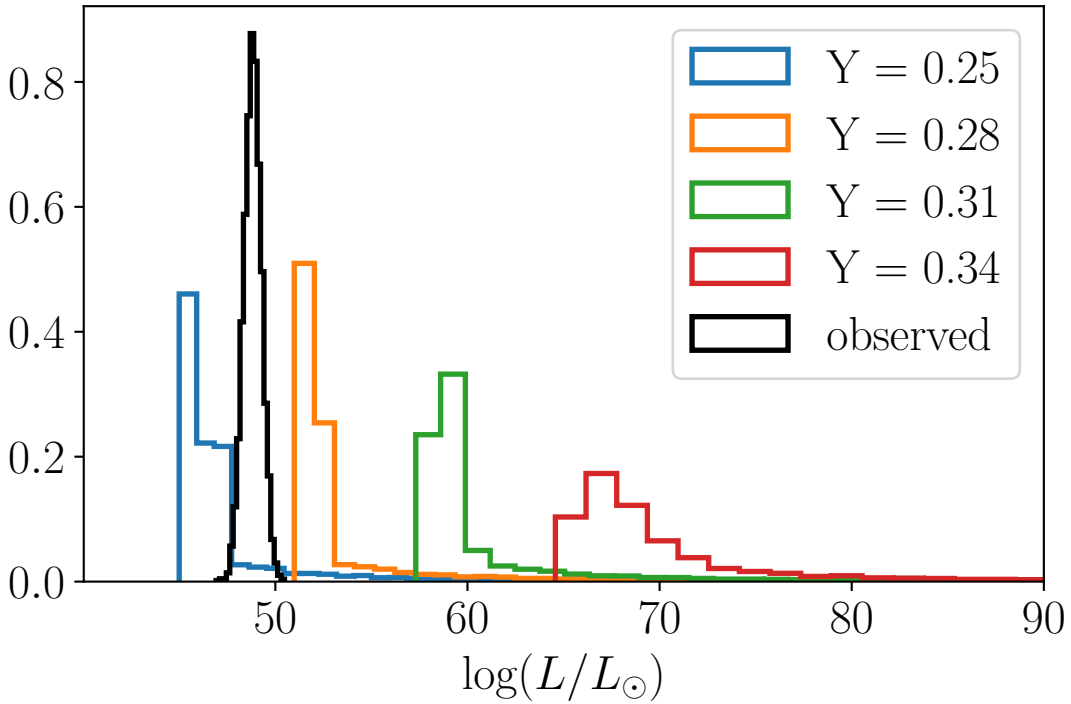


Helium – luminosity relationship



$M = 1.0\ M_\odot$
$[\mathrm{Fe/H}] = 0.0$

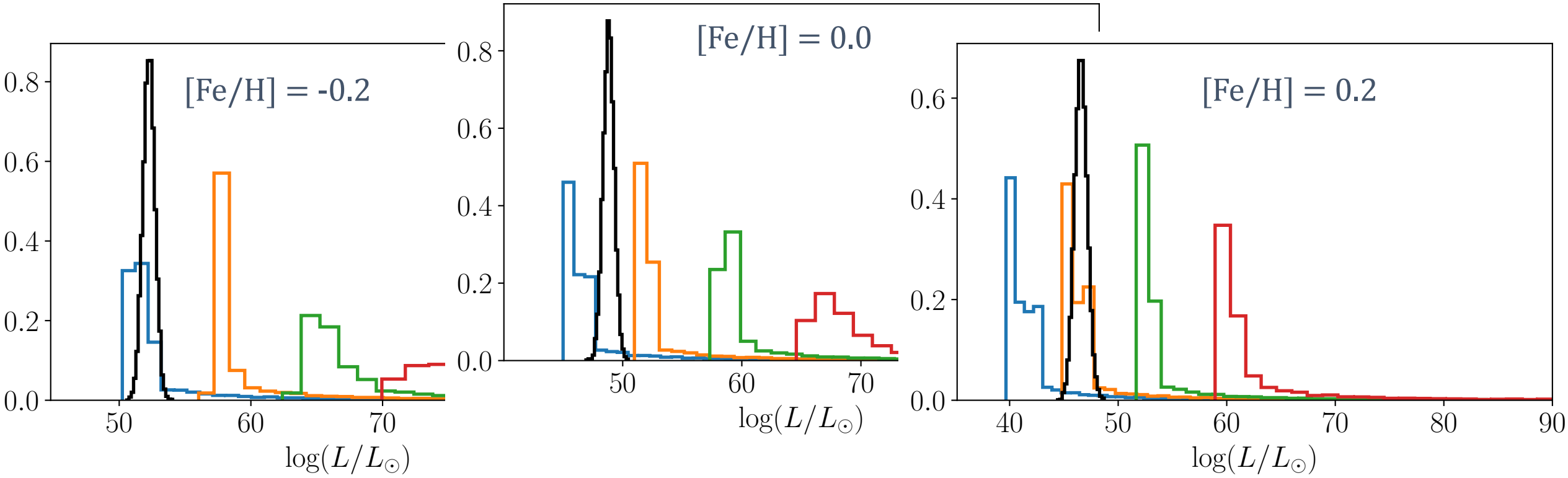
Comparing models and observations



$M = 1.0\ M_\odot$
$[\mathrm{Fe/H}] = 0.0$

* Distribution of median luminosities of the population over MC

Comparing models and observations

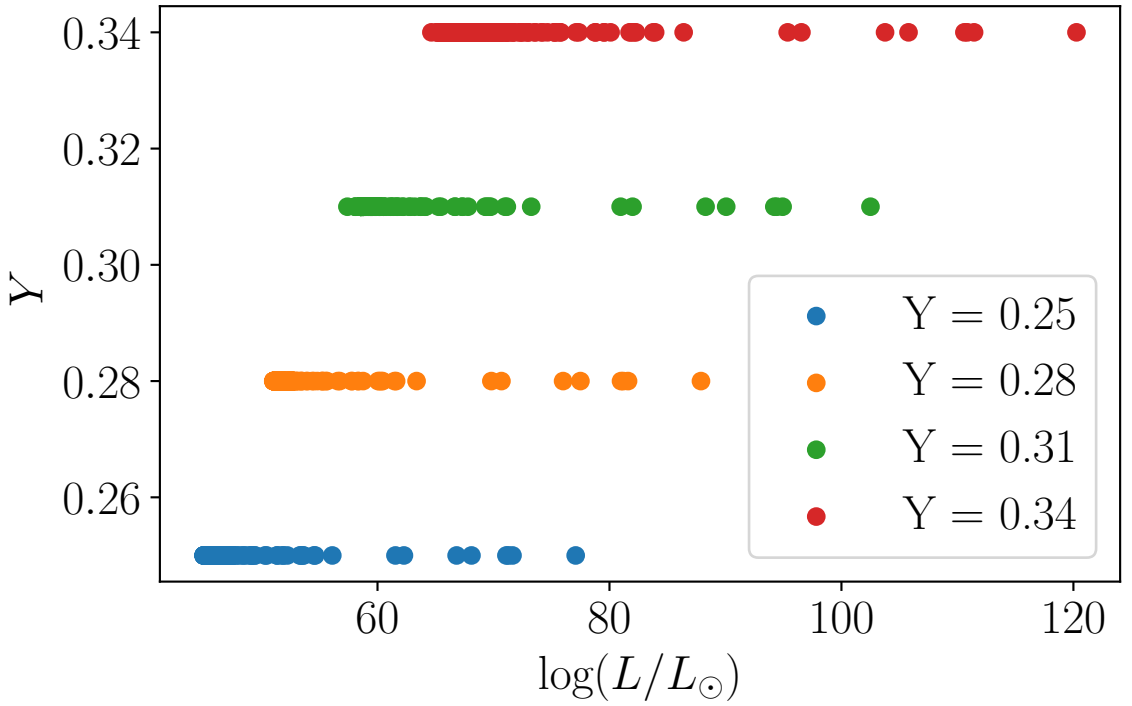


Inferring Y and Z

- Evolution to high luminosities is important, but not easy to model

- Use MC for a non-parametric approach

1. Make samples in fractional age

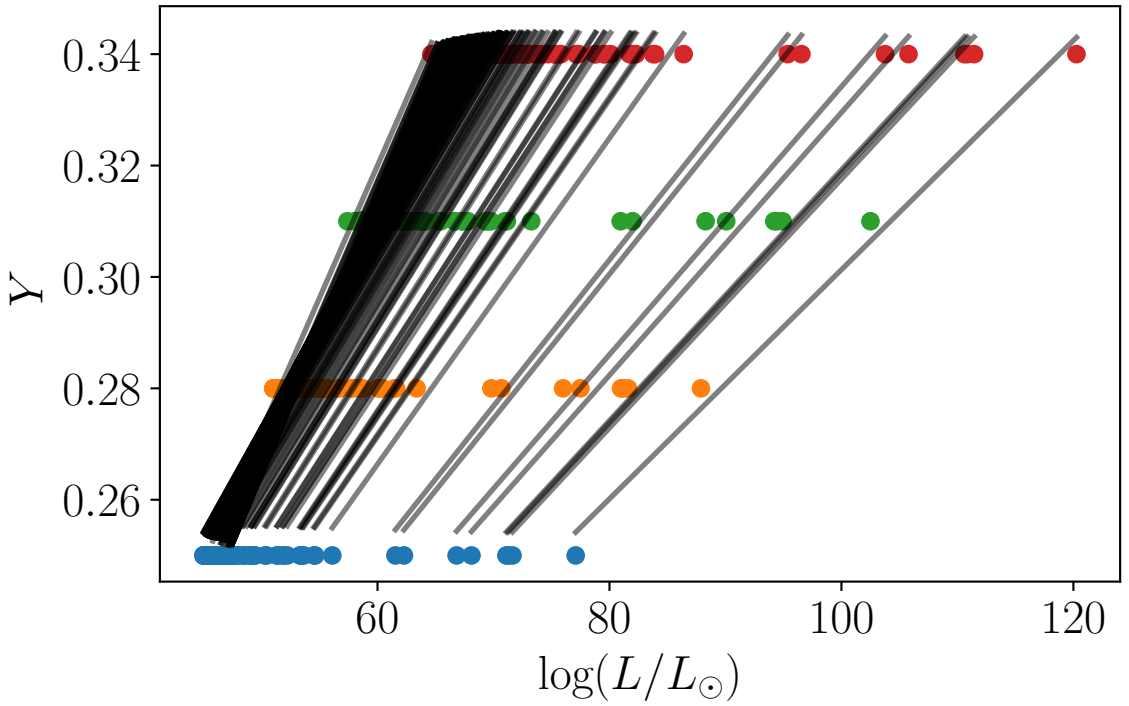


Inferring Y and Z

- Evolution to high luminosities is important, but not easy to model

- Use MC for a non-parametric approach

1. Make samples in fractional age
2. Constrain Y(L)

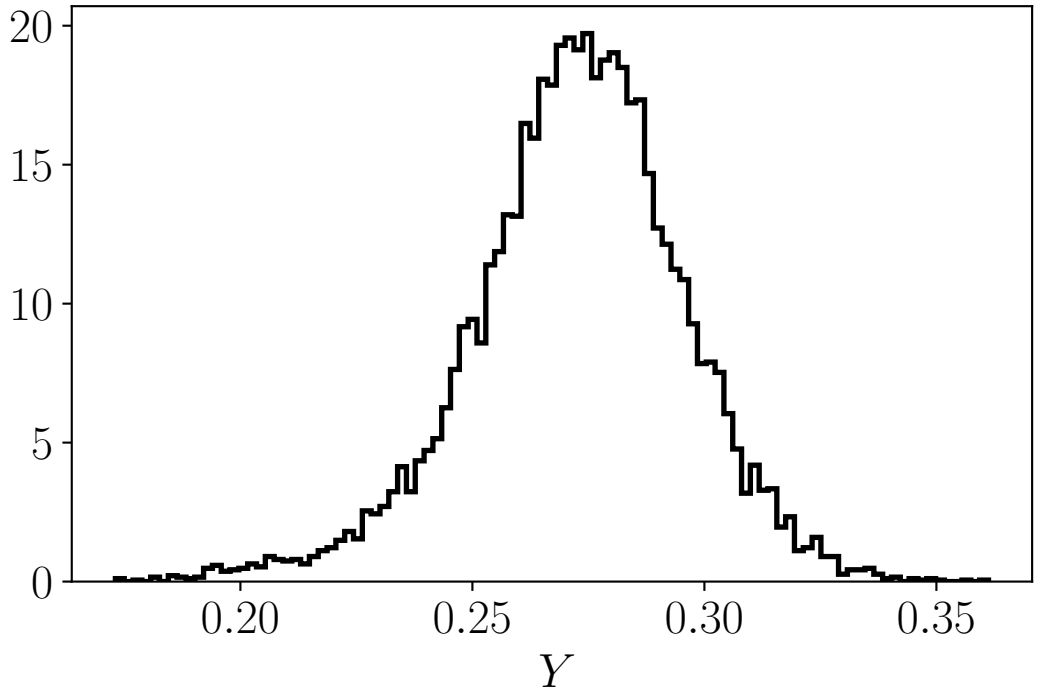


Inferring Y and Z

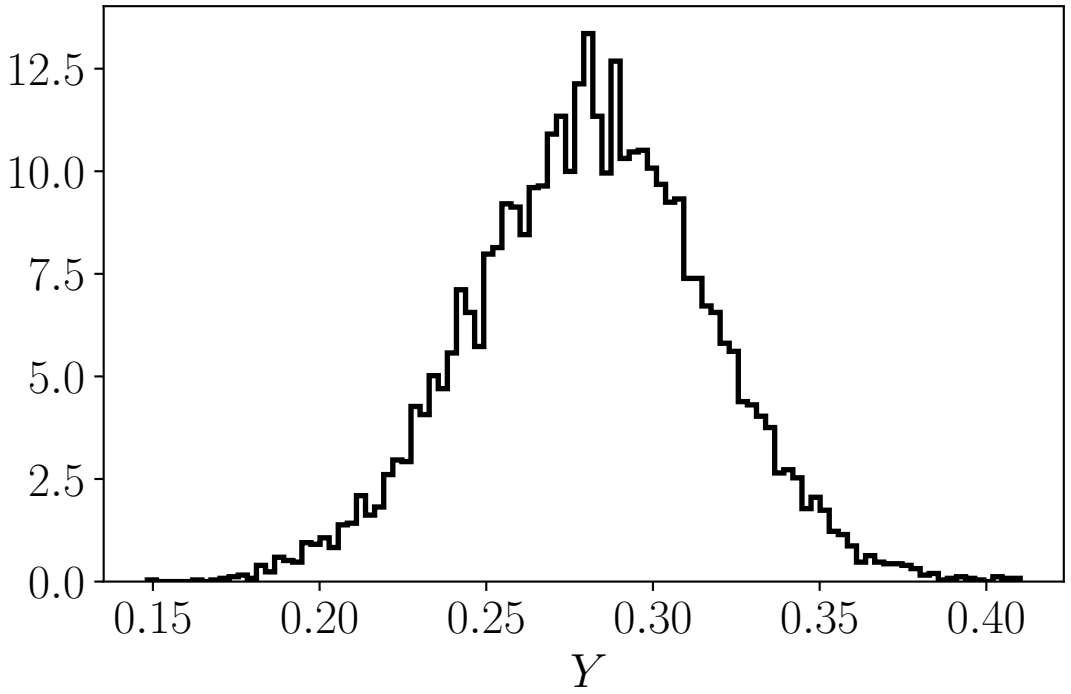
- Evolution to high luminosities is important, but not easy to model

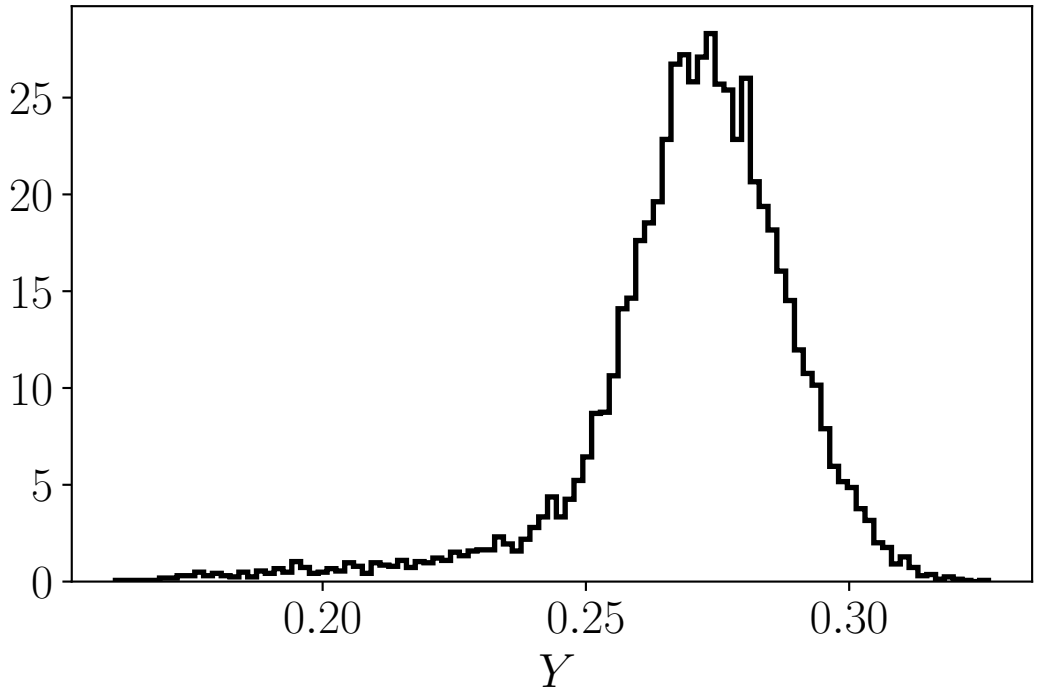
- Use MC for a non-parametric approach

1. Make samples in fractional age
2. Constrain Y(L)
3. Compare realisations of observed L

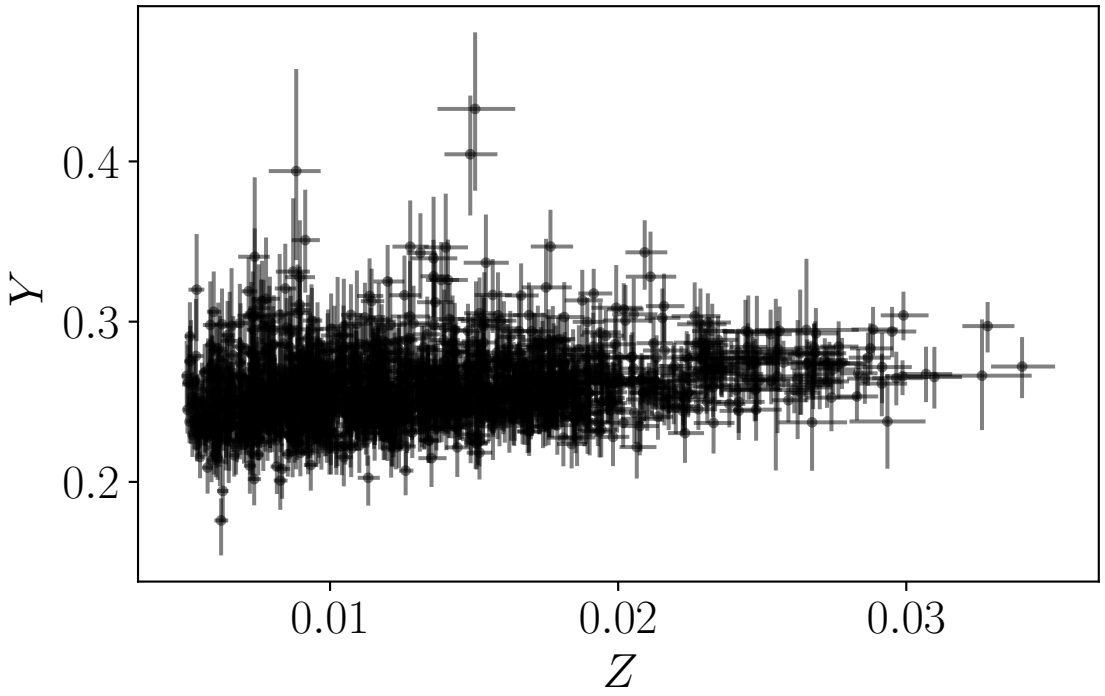


Inferring Y and Z





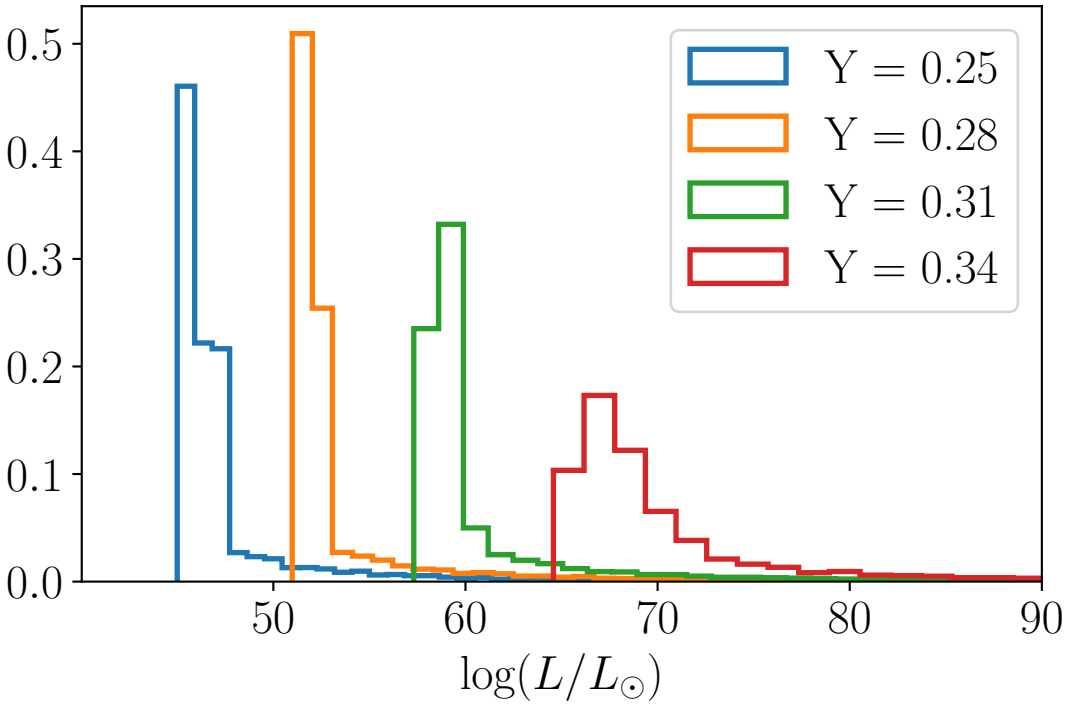
Constraining $\Delta Y / \Delta Z$

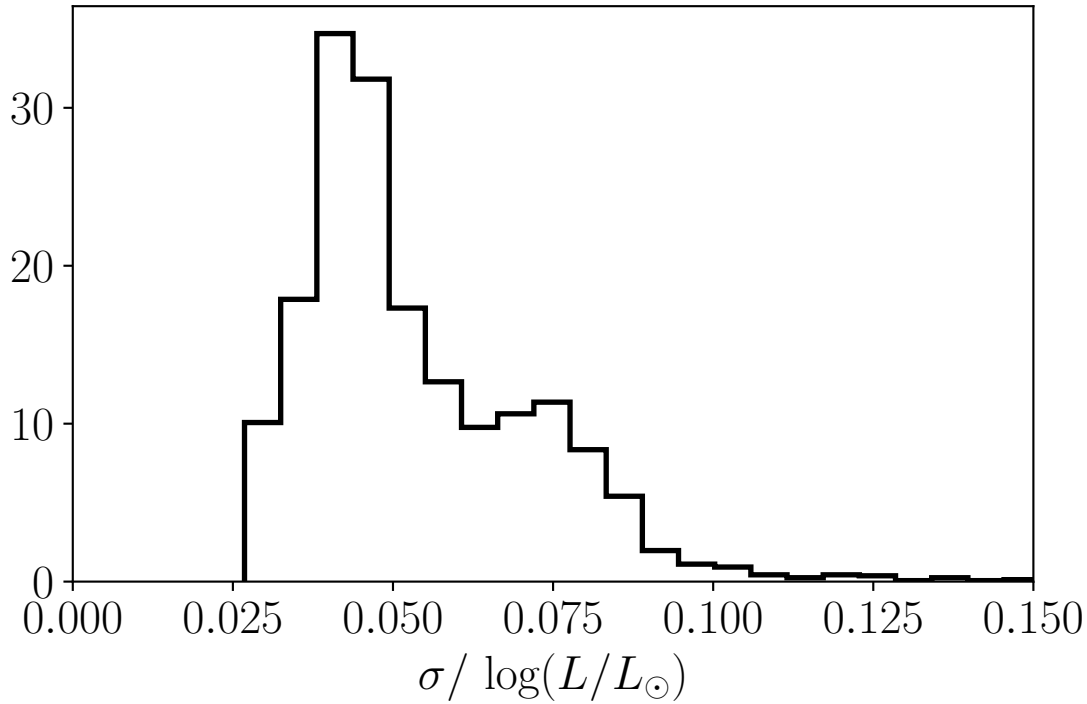


Very naïve look suggests $\Delta Y / \Delta Z \approx 1.5$

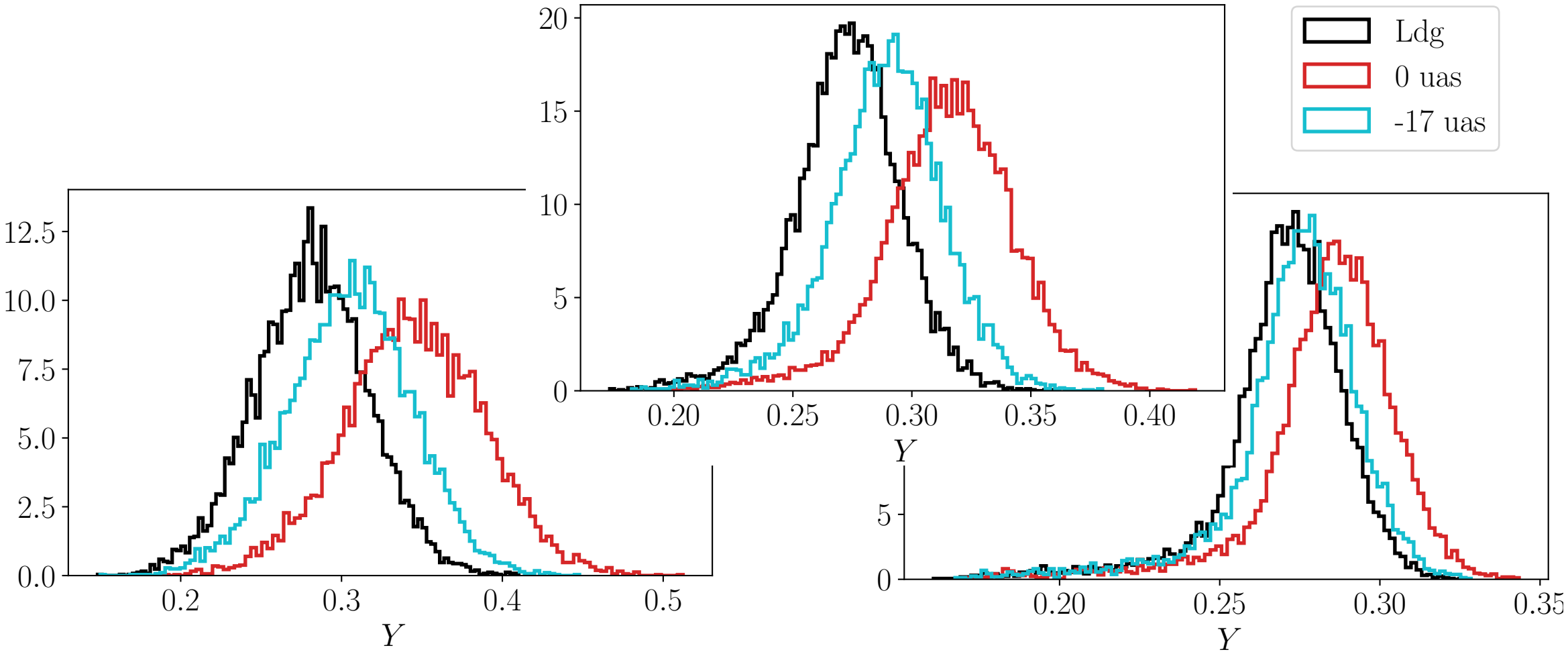
→ how to make best use of the Y distribution

More on Gaia luminosities

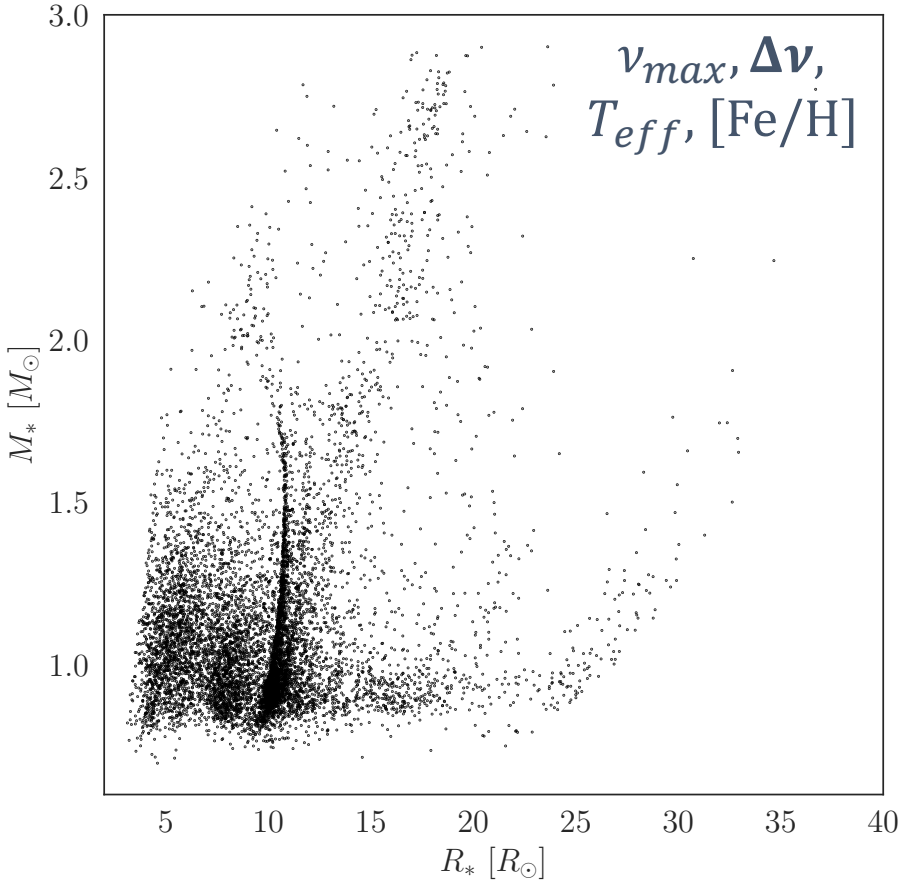




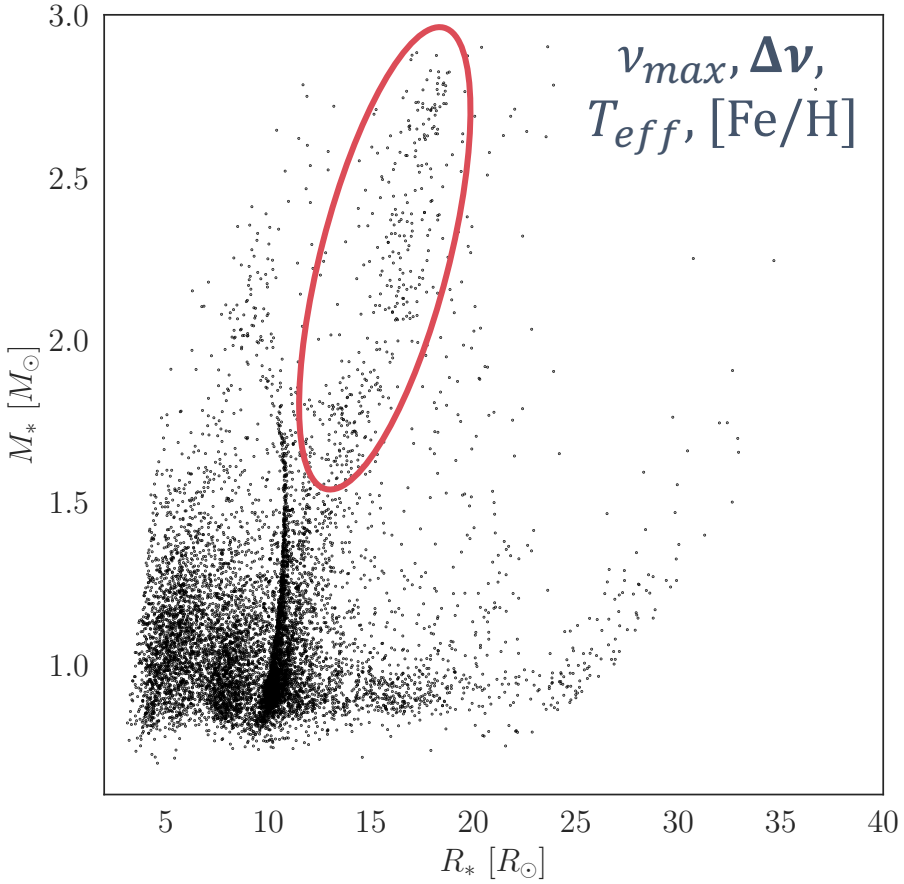
More on Gaia luminosities



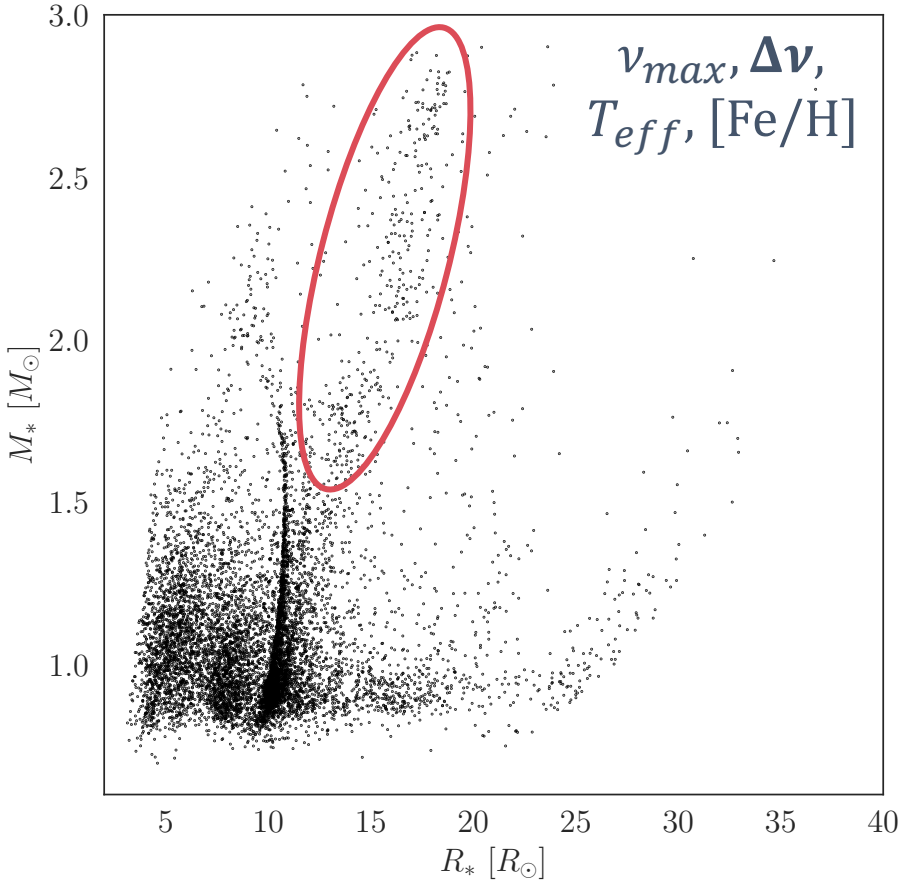
Gaia luminosity and asteroseismology

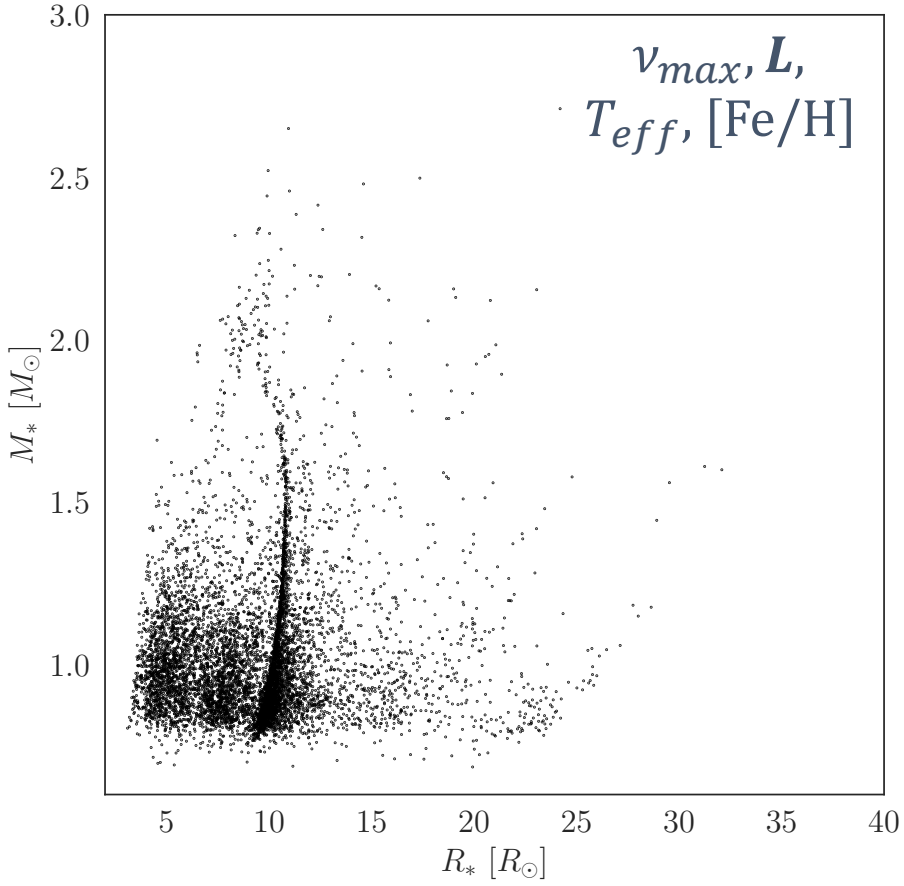


Gaia luminosity and asteroseismology

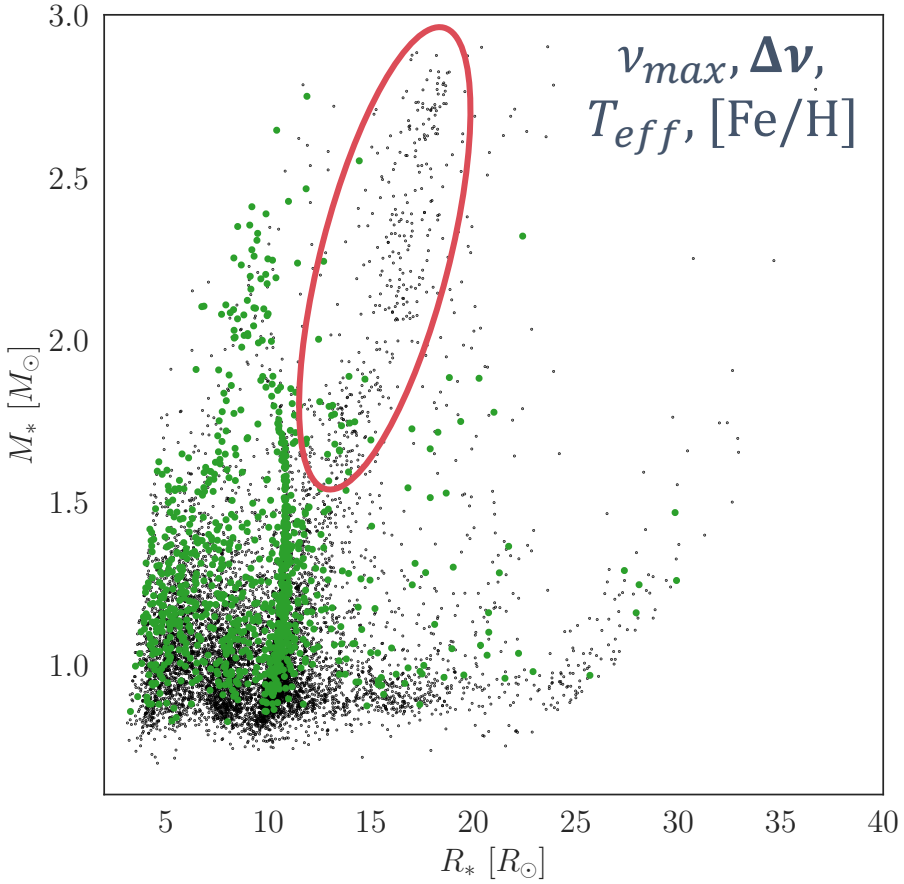


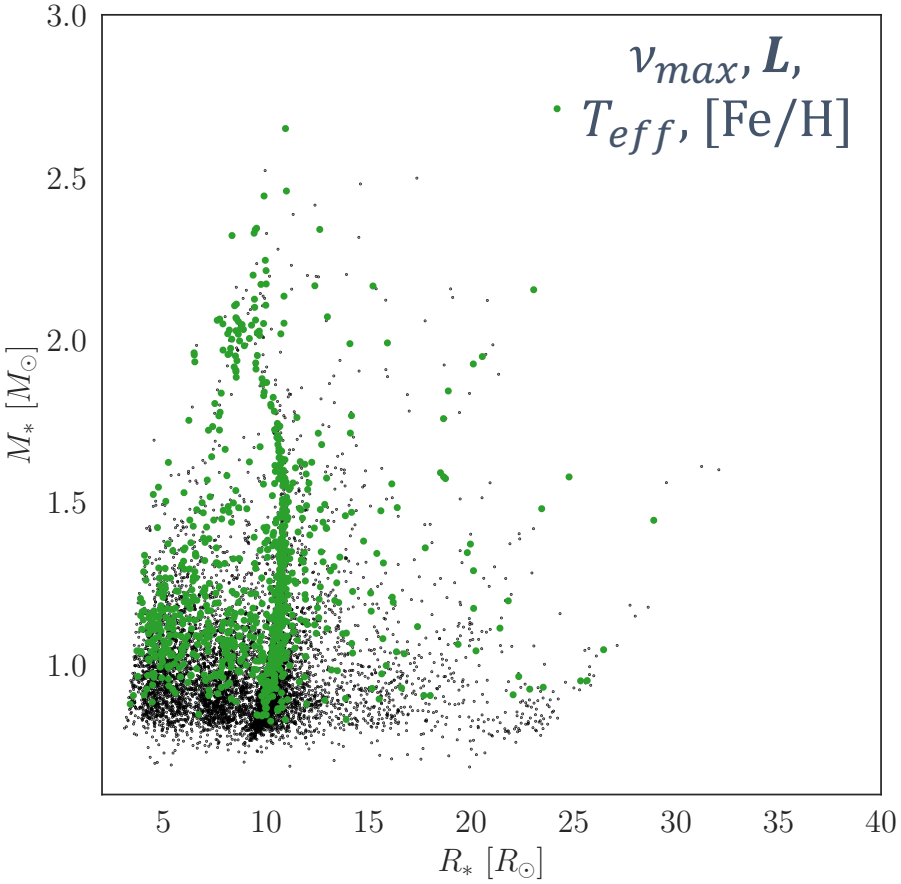
Gaia luminosity and asteroseismology



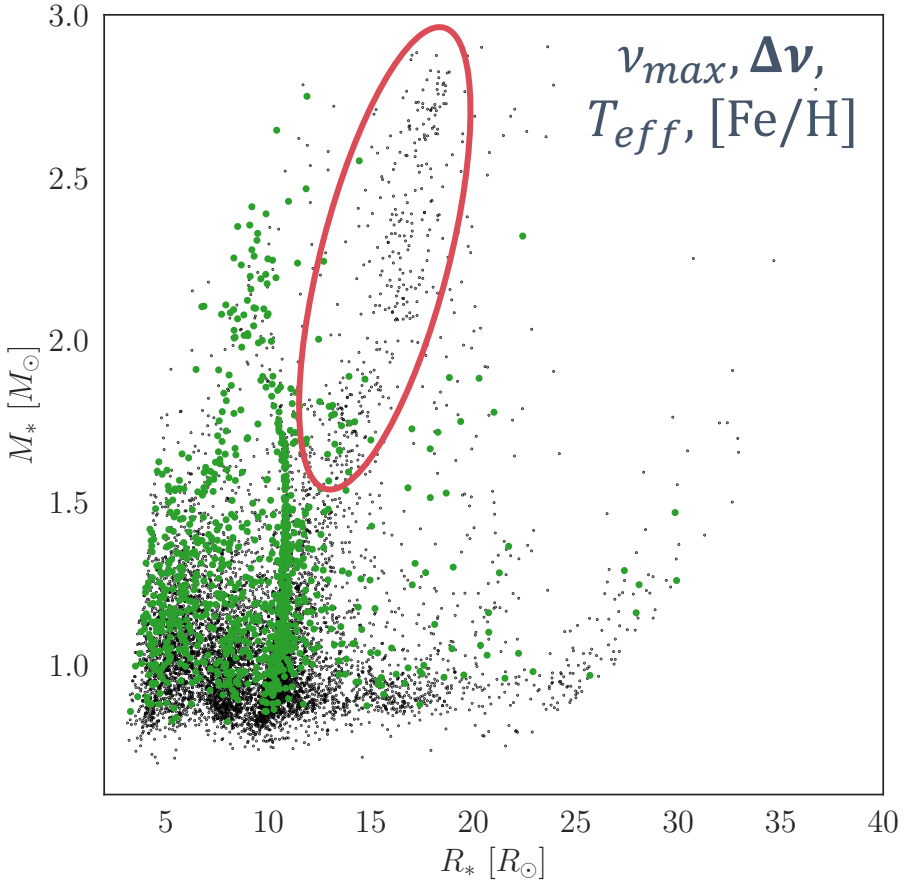


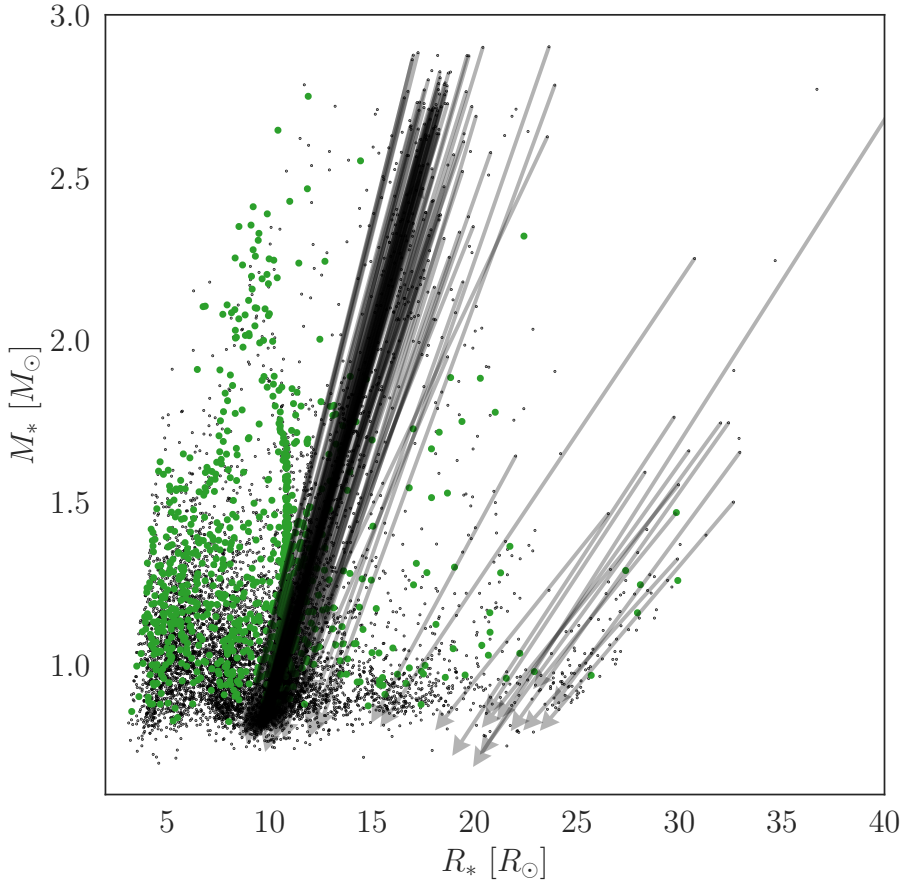
Gaia luminosity and asteroseismology





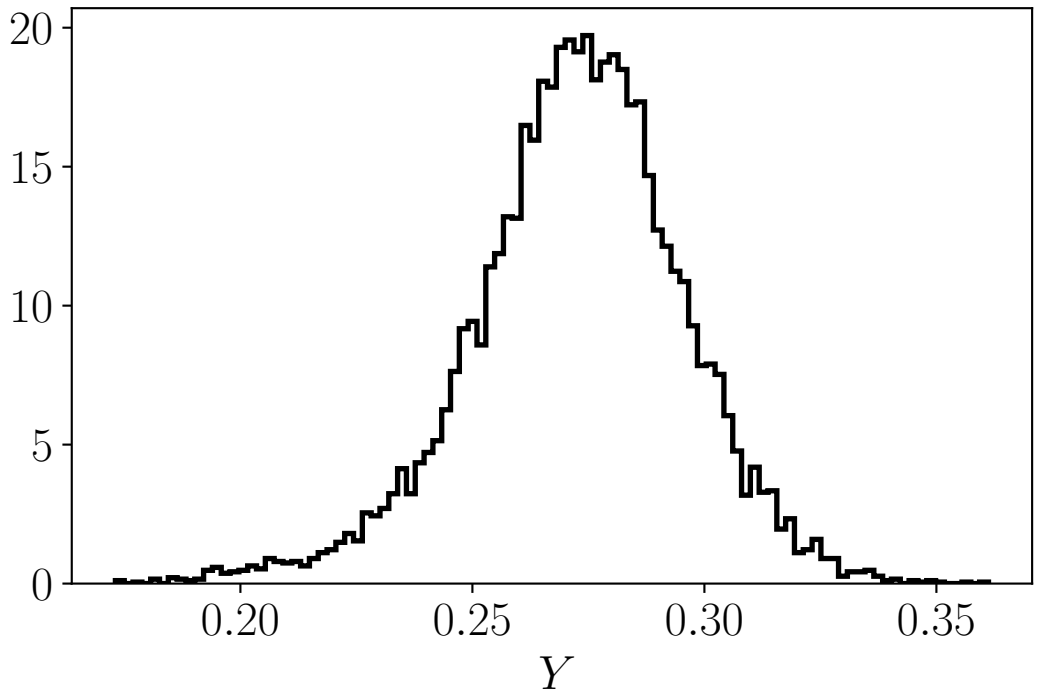
Gaia luminosity and asteroseismology





Outlook

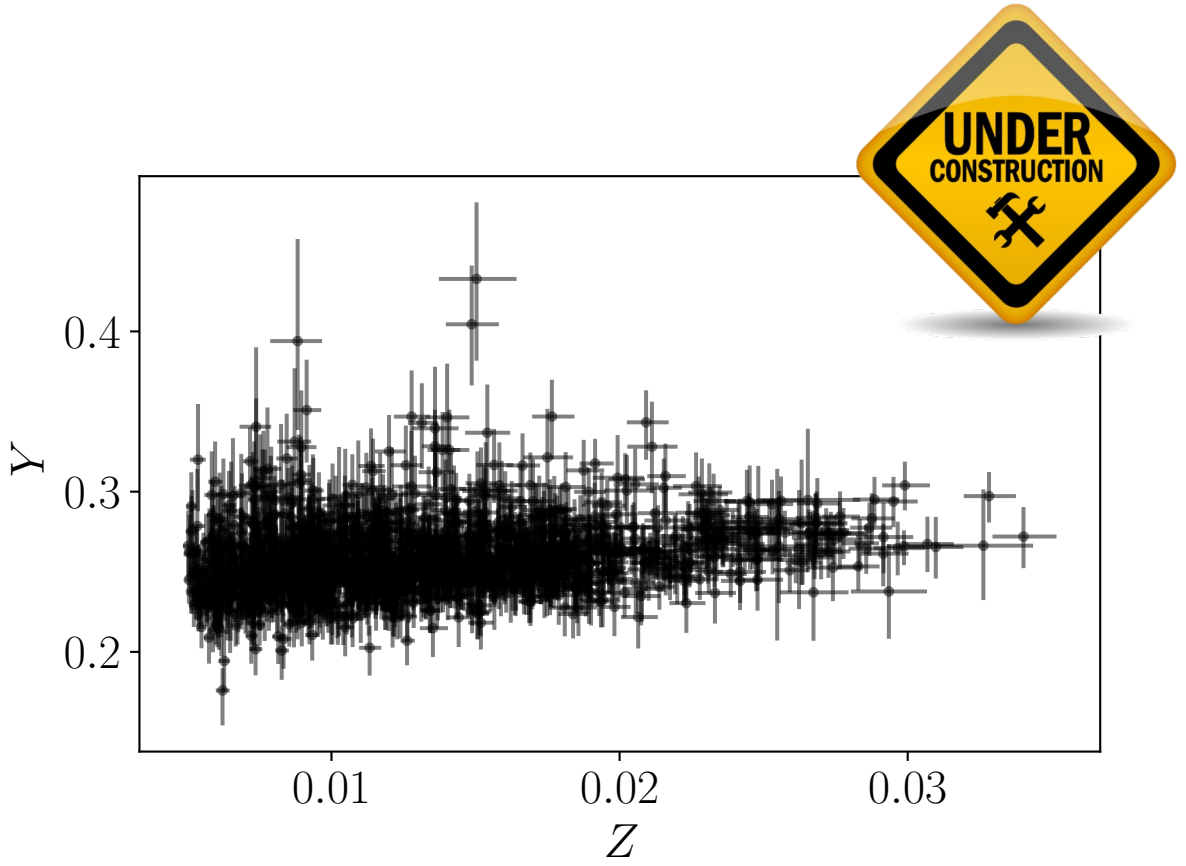
- Gaia luminosities make helium inference possible



Outlook

- Gaia luminosities make helium inference possible

- To do: validate a statistical technique to constrain $\Delta Y / \Delta Z$

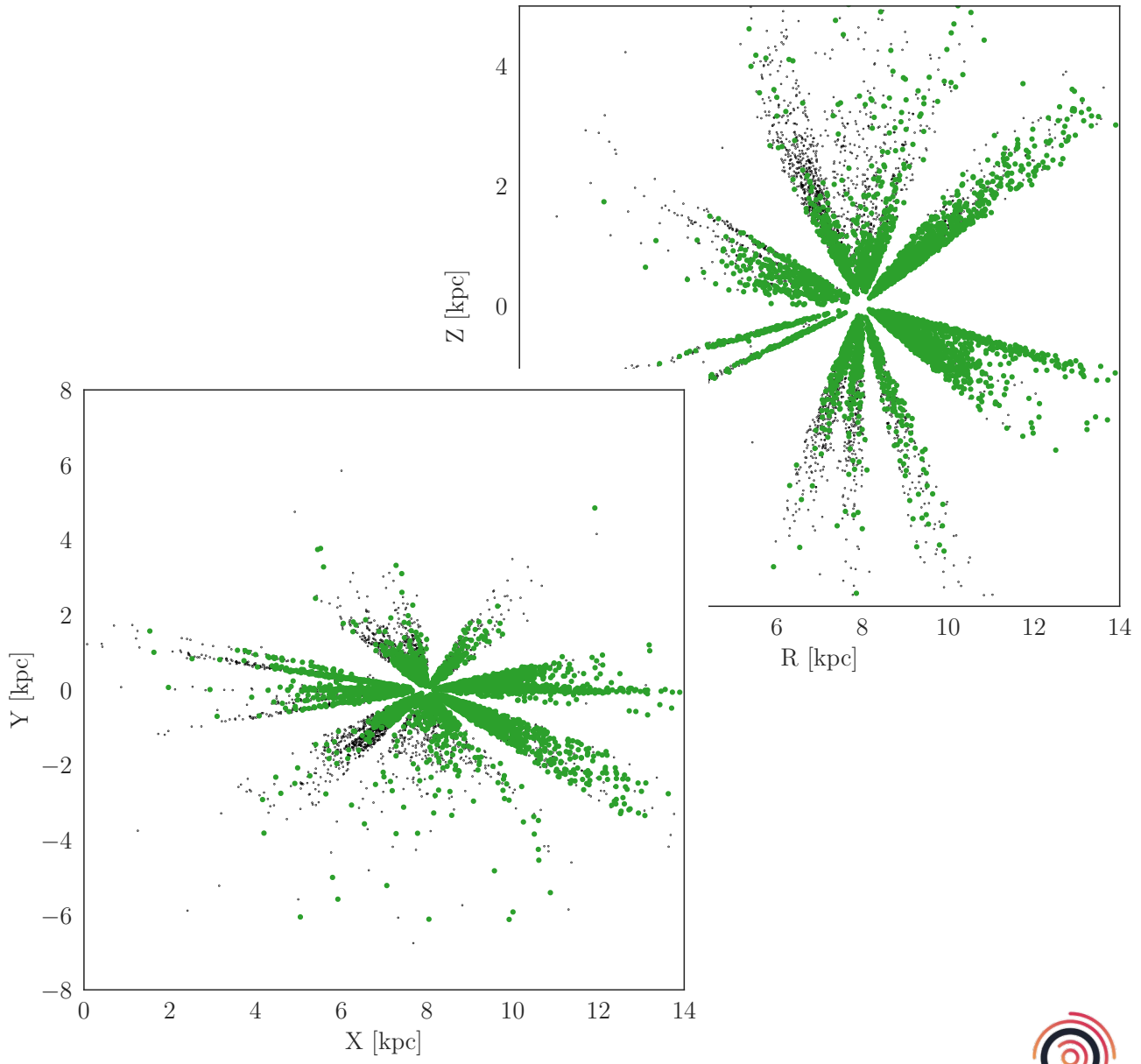


Outlook

- Gaia luminosities make helium inference possible

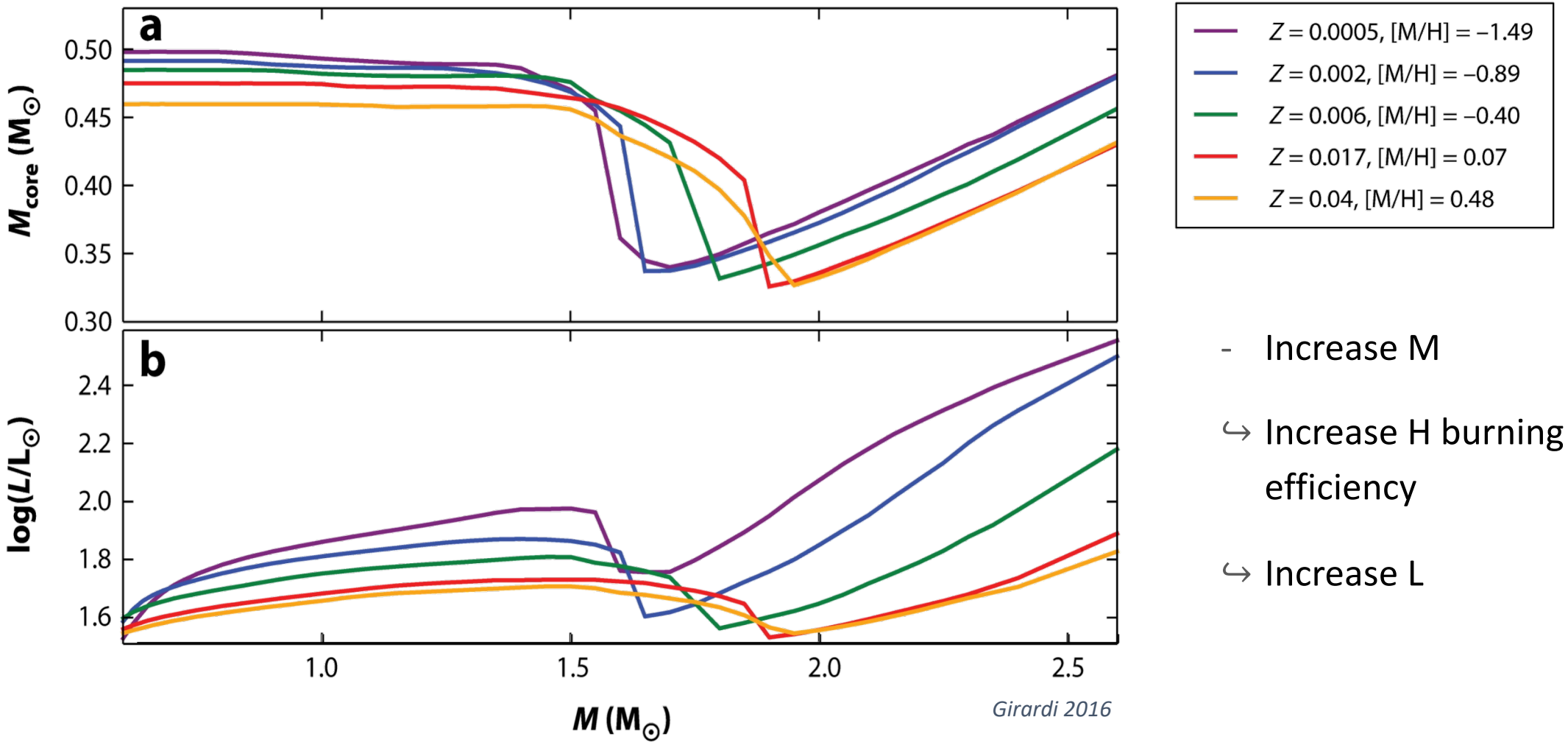
- To do: validate a statistical technique to constrain $\Delta Y / \Delta Z$

- And then… Extend to K2 to map helium around the galaxy



Extras

Effect of mass



Girardi 2016

- Increase M

↪ Increase H burning efficiency

↪ Increase L

Effect of Composition

- Increase Y

↪ Increase internal temperature

↪ Decrease M_{core} → Decrease L

↪ ***Also:*** increase H burning efficiency

↪ **Increase L**

- Increase Z

↪ Heat core more quickly

↪ Decrease M_{core} → Decrease L

↪ ***Also:*** increase envelope opacity

↪ Decrease L