The vertical age structure of the Milky Way disc

Luca Casagrande

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Photometric parameters for stellar and Galactic studies

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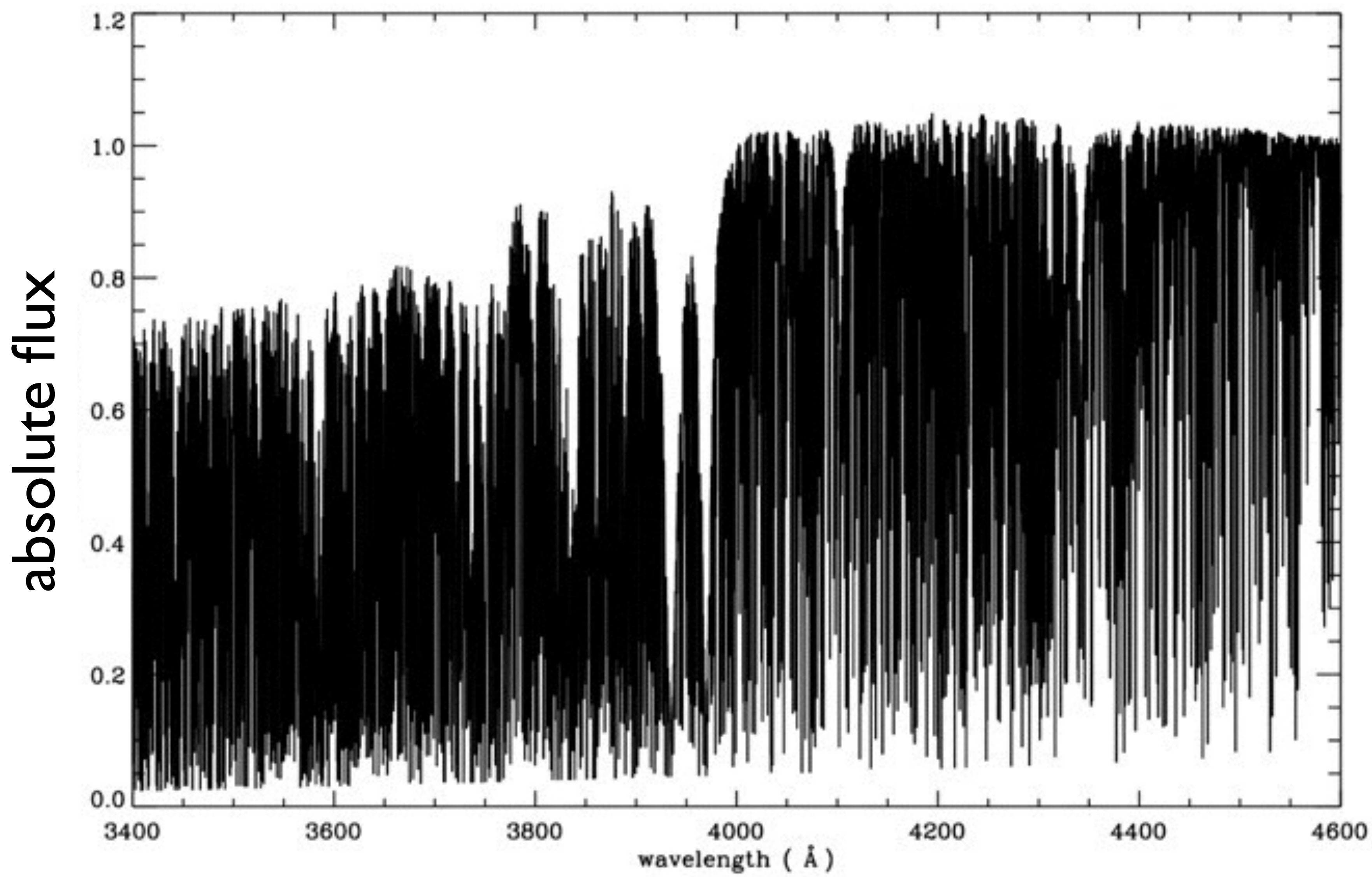
Fossils

chemical composition: ISM at the time and place of their formation
orbits: encode residual information on dynamical history

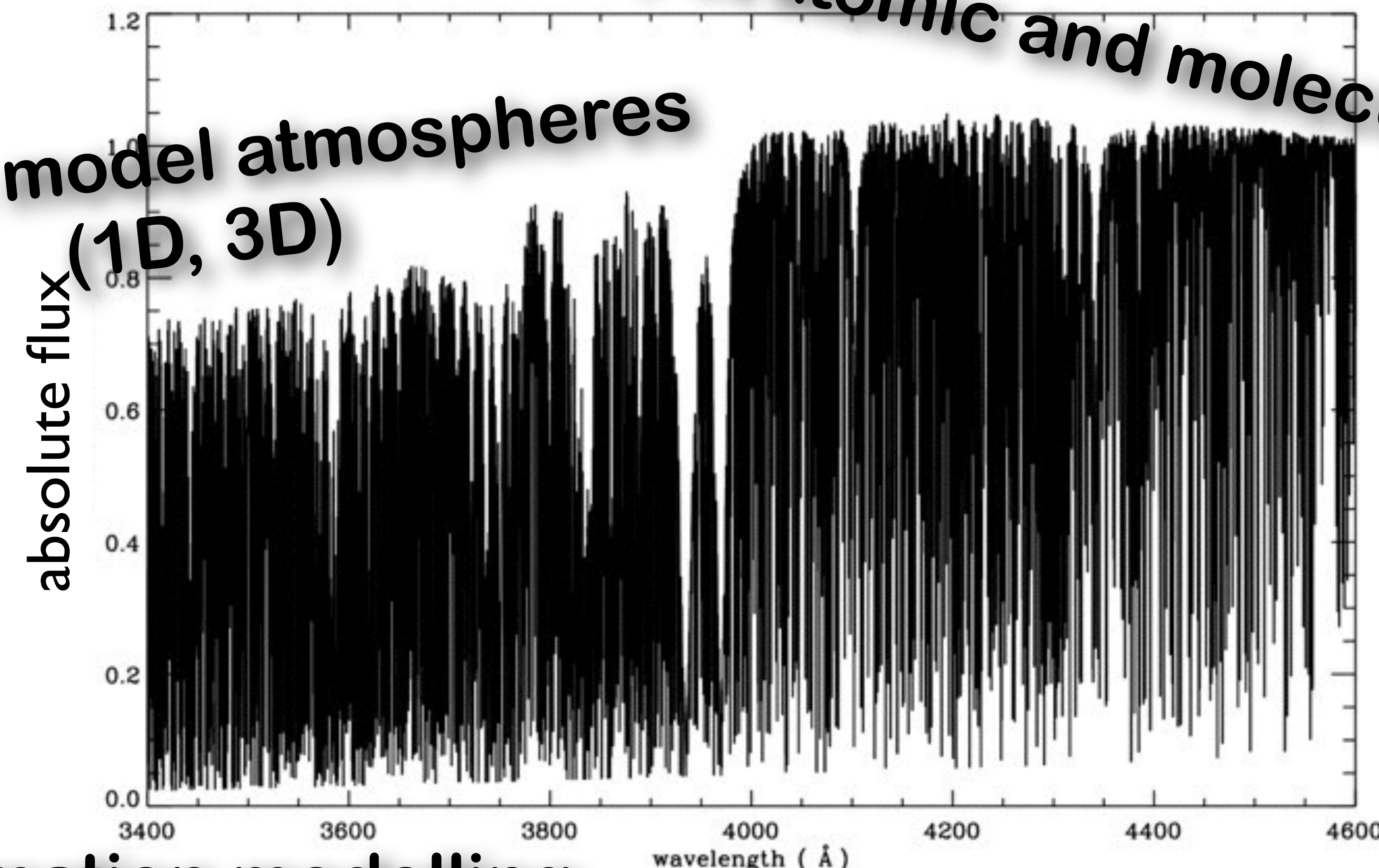
Ways to classical stellar parameters



Ways to classical stellar parameters

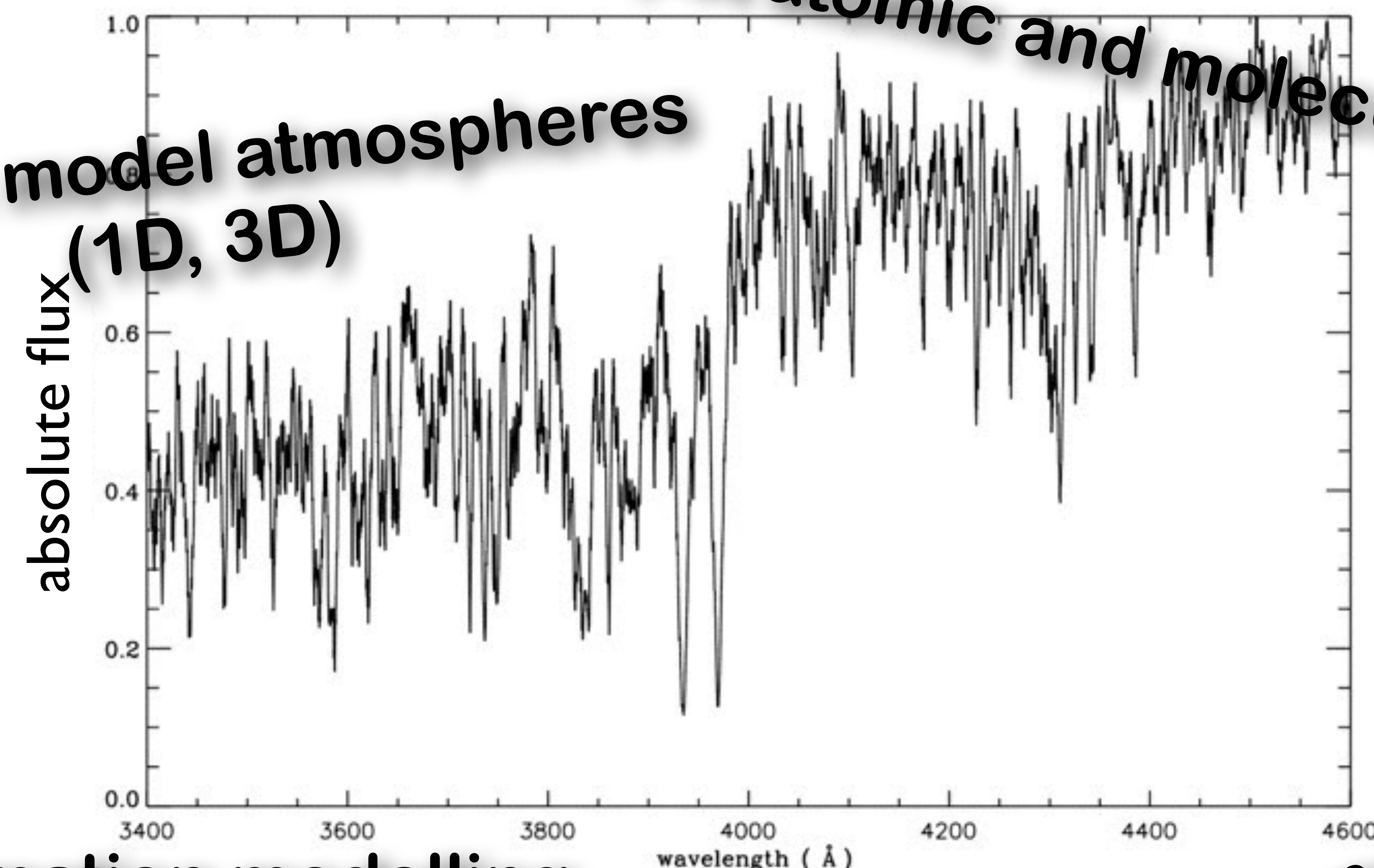
input atomic and molecular physics

realistic model atmospheres (1D, 3D)



line formation modelling (LTE, NLTE)

Ways to classical stellar parameters



input atomic and molecular physics

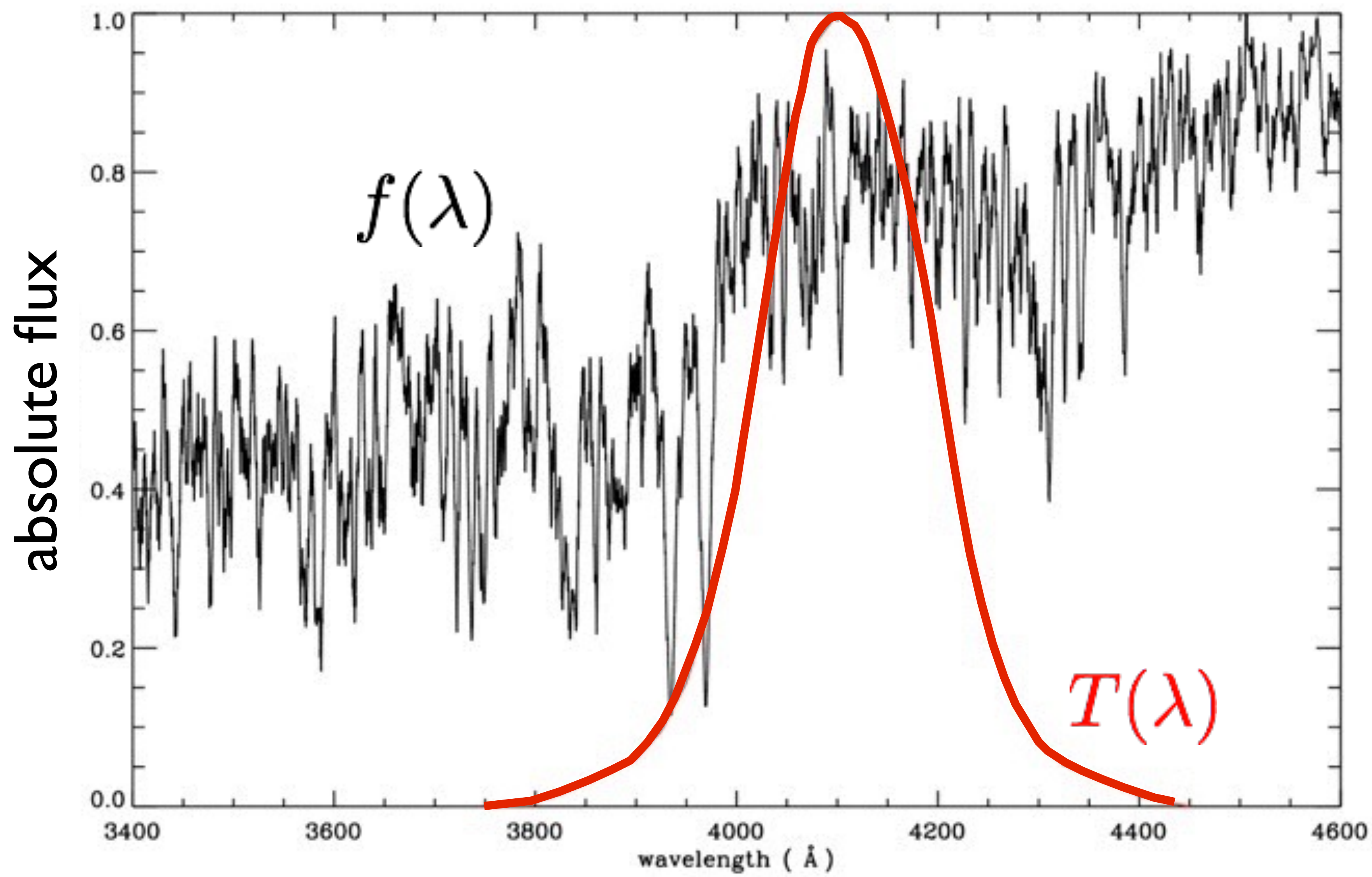
realistic model atmospheres (1D, 3D)

line formation modelling (LTE, NLTE)

resolution and signal-to-noise

e.g., **Asplund (2005, ARAA), Bergemann (2014)**

Ways to classical stellar parameters

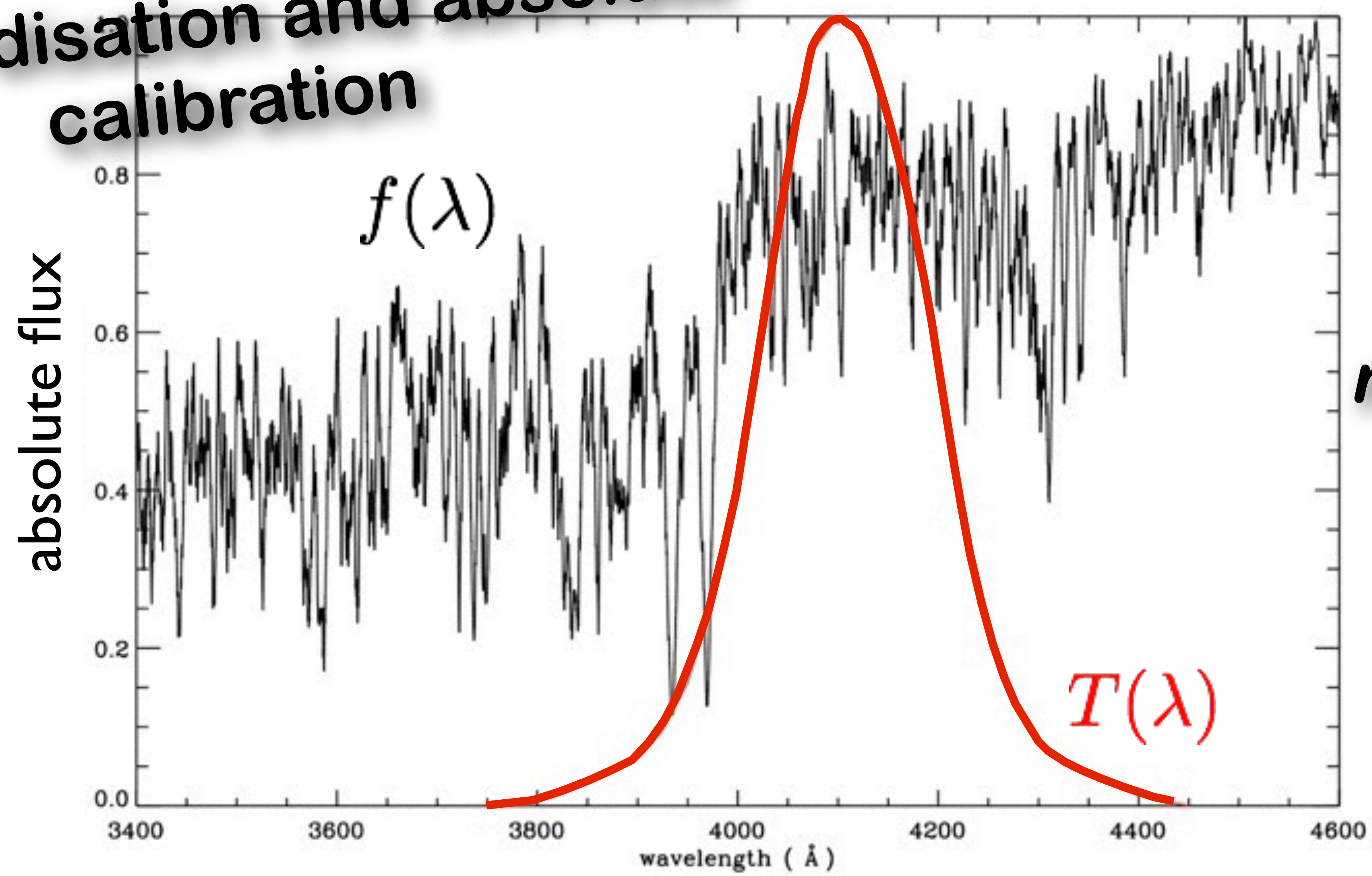


$$\int f(\lambda)T(\lambda)\mathrm{d}\lambda$$

e.g., **Bessell (2005, ARAA),**
Giradi et al. (2002),
Casagrande & VandenBerg (2014)

Ways to classical stellar parameters

standardisation and absolute calibration



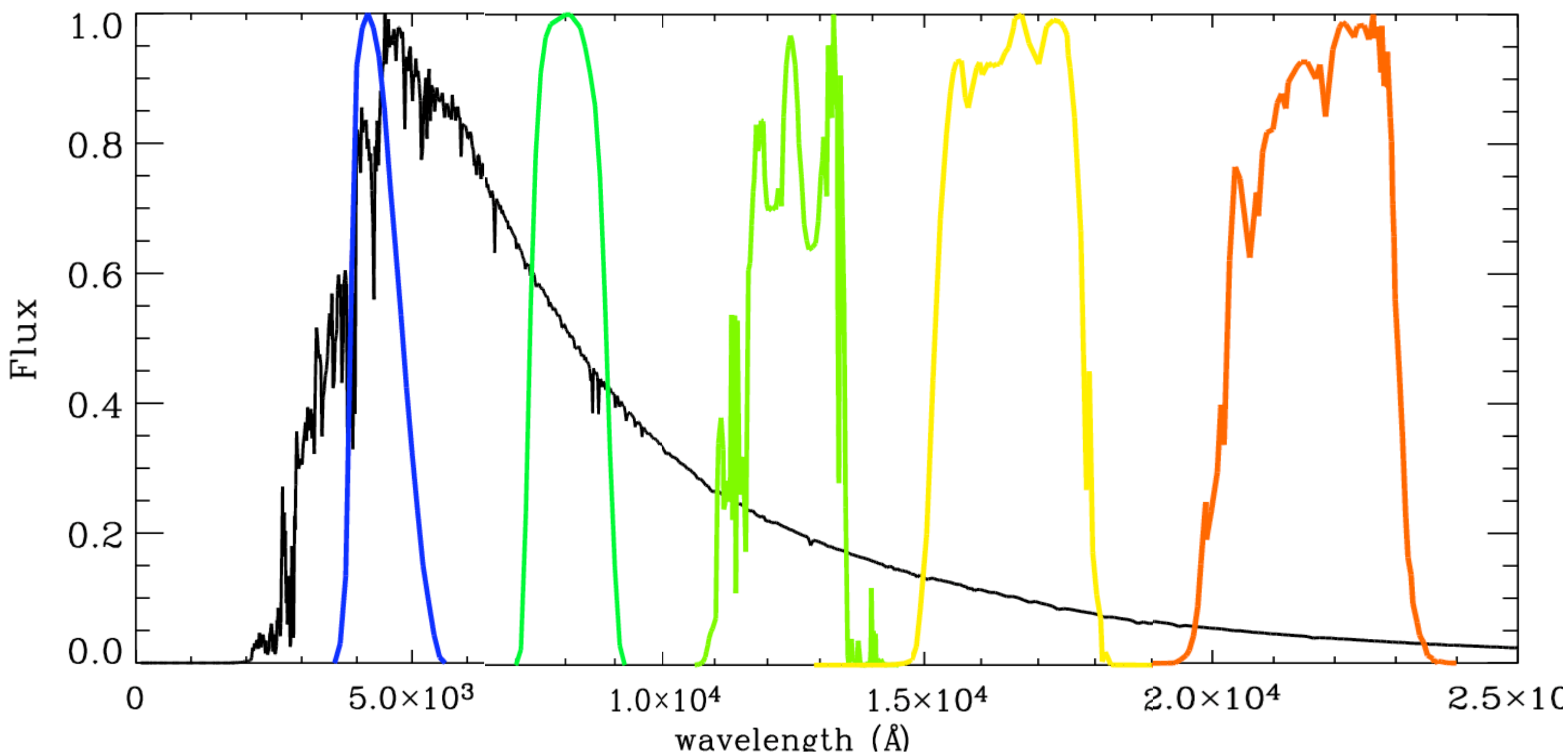
reddening

$$\int f(\lambda)T(\lambda)\mathrm{d}\lambda$$

e.g., **Bessell (2005, ARAA), Giradi et al. (2002), Casagrande & VandenBerg (2014)**

Standardisation and absolute calibration

$$\mathcal{F}_\lambda(\mathrm{Earth}) = \mathcal{F}_\lambda^{\mathrm{std}}(\mathrm{Earth})10^{-0.4(m_\lambda - m_\lambda^{\mathrm{std}})}$$



Even if the definition of a photometric system is sound:

- its actual realisation at the telescope is non-trivial (surprise, surprise!)
- converting magnitudes back into fluxes is non-trivial.

As a matter of fact, we always introduce some zero-point correction(s) trying to satisfy the original definition.

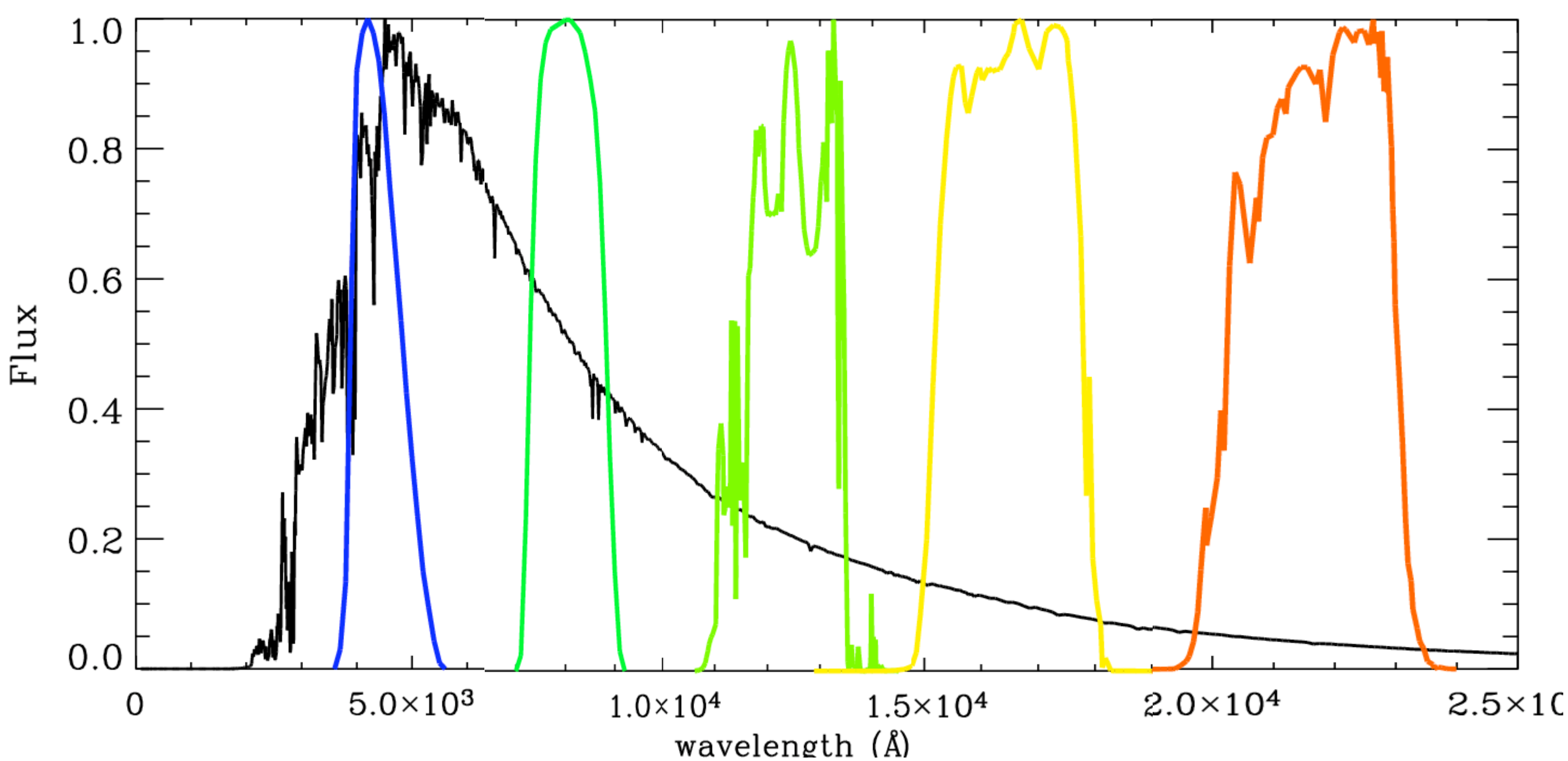
Standardisation and absolute calibration

$$\mathcal{F}_\lambda(\text{Earth}) = \mathcal{F}_\lambda^{\text{std}}(\text{Earth})\, 10^{-0.4(m_\lambda - m_\lambda^{\text{std}})}$$

≃2 or 3%

≃ 0.01 mag

≃ 4% ≃ 80K



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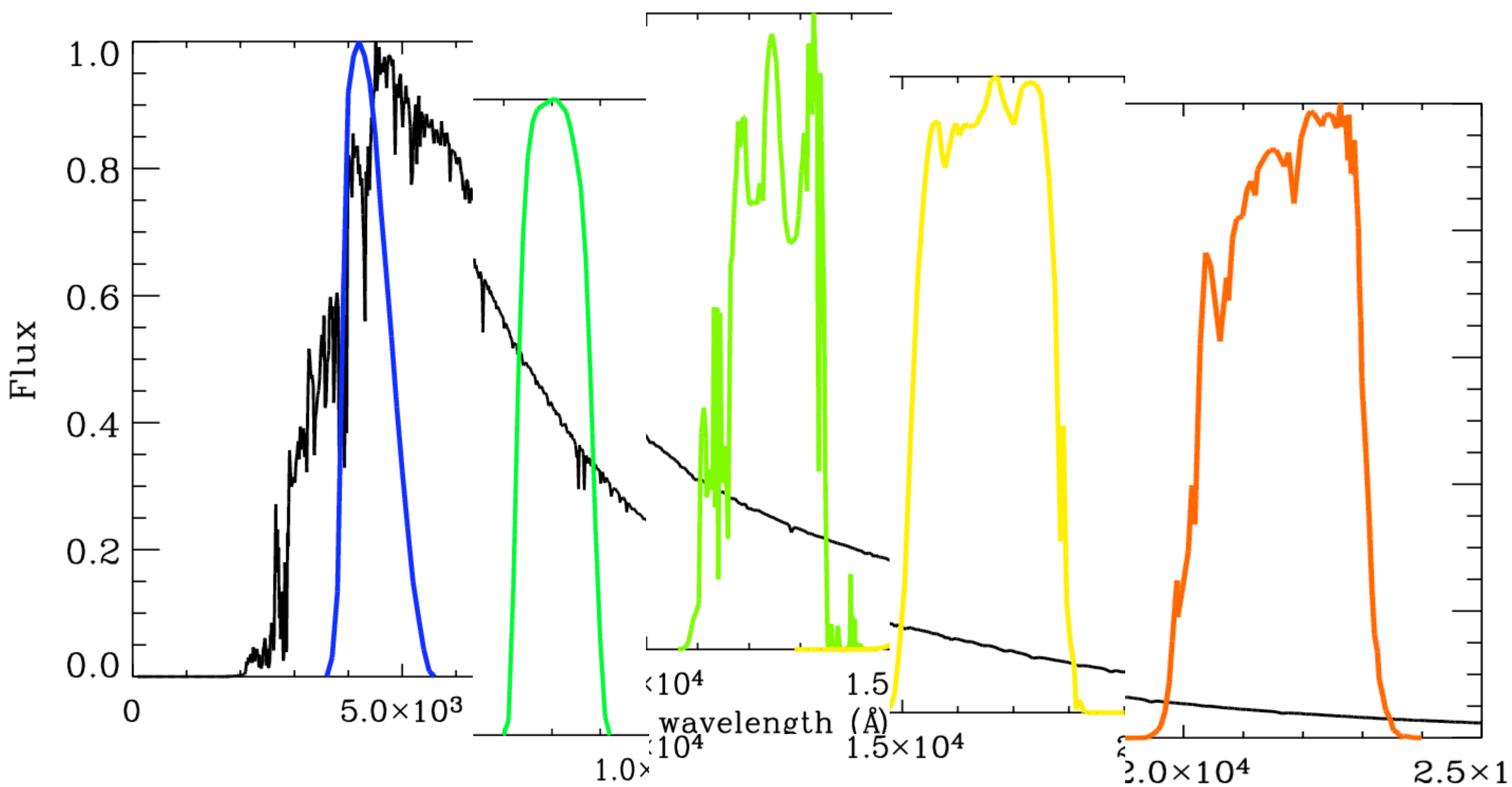

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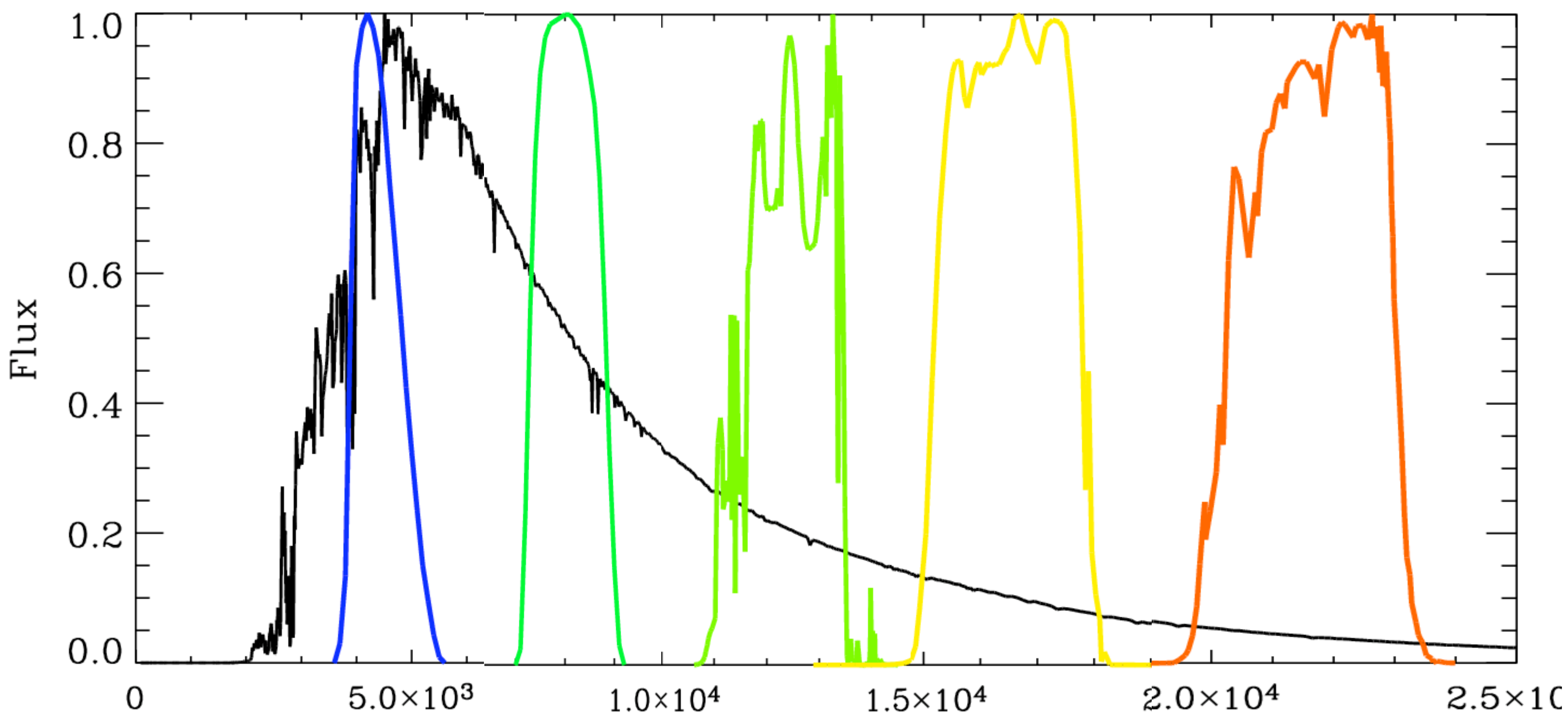
Standardisation and absolute calibration

$$\mathcal{F}_\lambda(\mathrm{Earth}) = \mathcal{F}_\lambda^{\mathrm{std}}(\mathrm{Earth})10^{-0.4(m_\lambda - m_\lambda^{\mathrm{std}})}$$

≃ 1% ≃ 20K



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Reddening

Heterochromatic measurement

$$\frac{\int f_\lambda T_\zeta \,\mathrm{d}\lambda}{\int T_\zeta \,\mathrm{d}\lambda}$$

$\longrightarrow$

Effective wavelength

$$\frac{\int \lambda f_\lambda T_\zeta \,\mathrm{d}\lambda}{\int f_\lambda T_\zeta \,\mathrm{d}\lambda}$$

Reddening

Heterochromatic measurement

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In presence of reddening

$$A_\lambda = R_V E(B-V)[\ldots\lambda\ldots]$$

(this is the extinction, or attenuation)

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Heterochromatic measurement

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$\longrightarrow$

Effective wavelength

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In presence of reddening

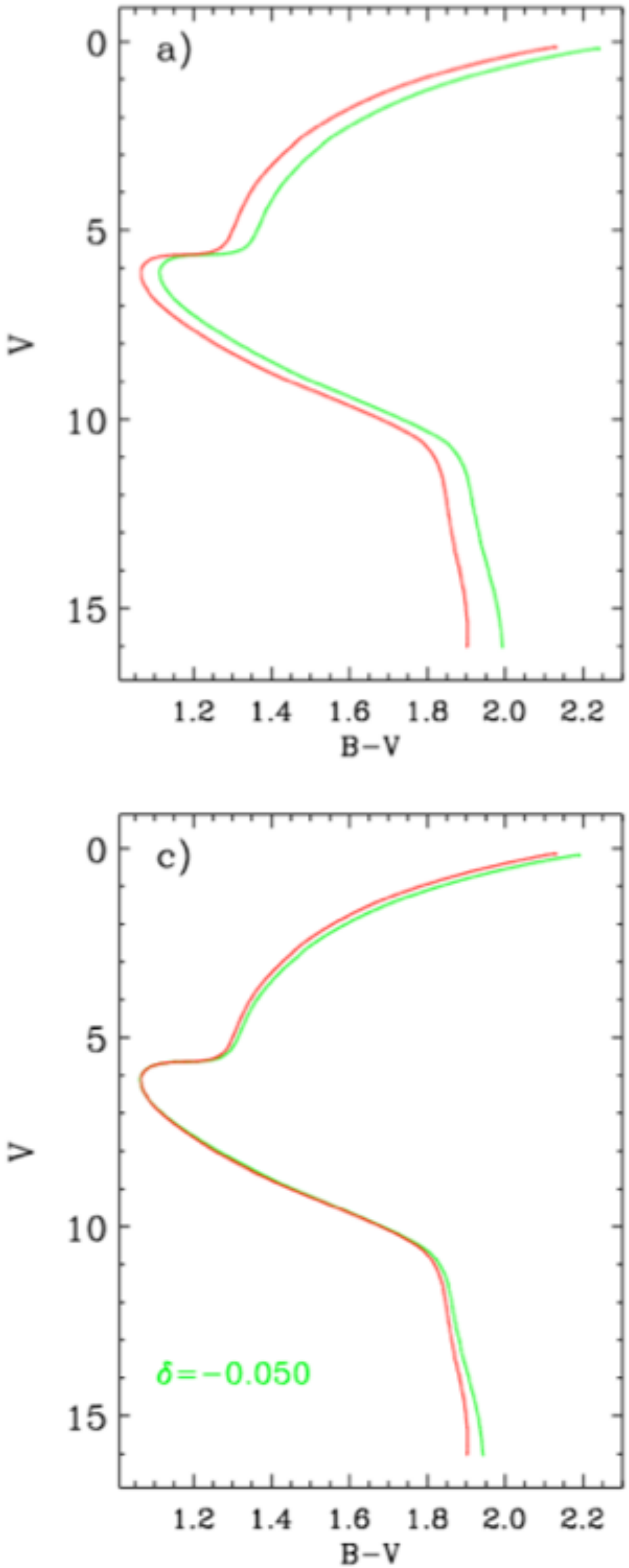
$$A_\lambda = R_V E(B-V)[\ldots\lambda\ldots]$$

(this is the extinction, or attenuation)

$\downarrow$

$$f_\lambda \longrightarrow f_\lambda 10^{-0.4 A_\lambda}$$

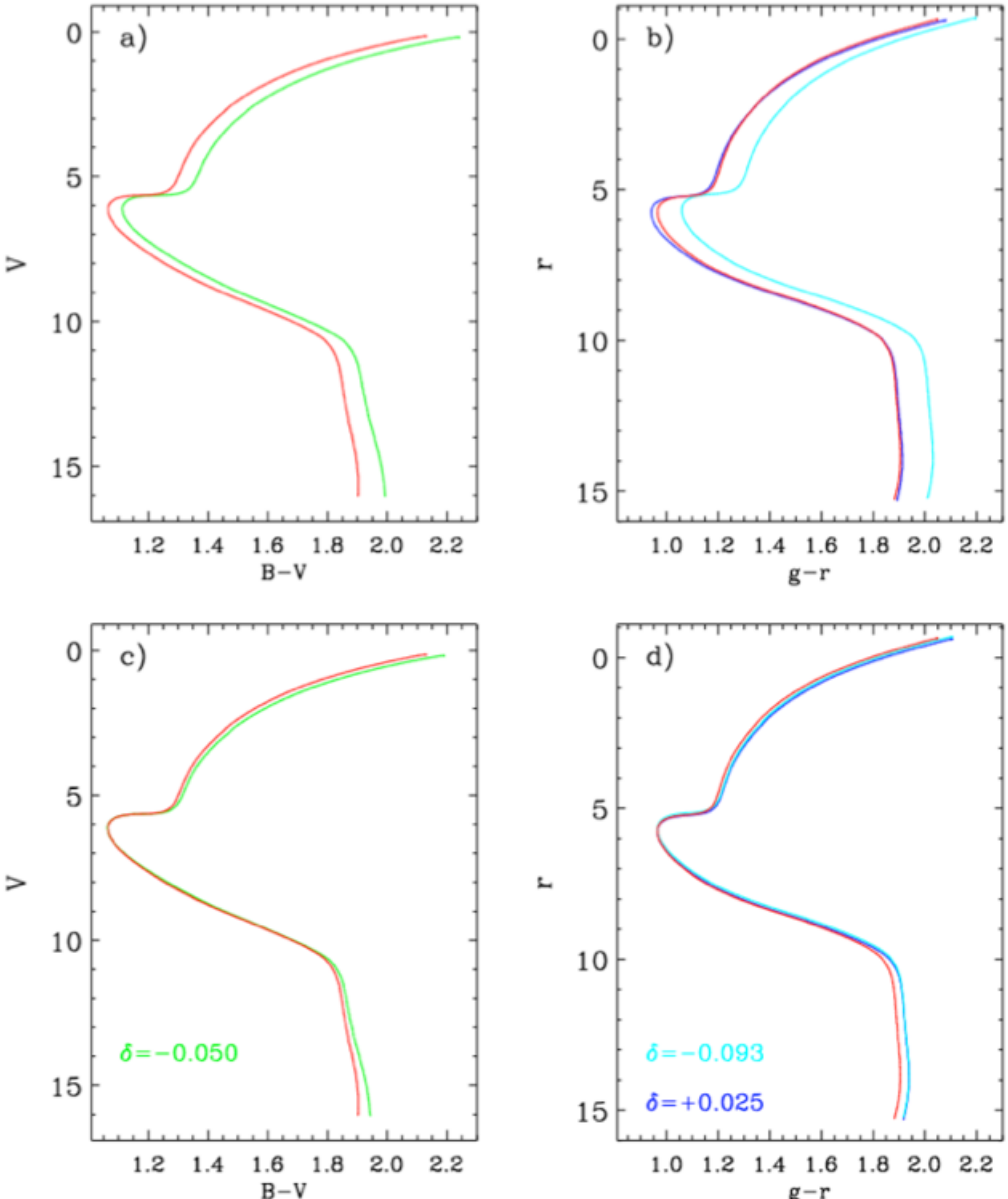
In presence of extinction, the flux changes, and so does the effective wavelength of a filter



Self-consistent E(B-V)=0.6, R_V=3.1

Using E(B-V)=0.6 and R_V=3.1

Casagrande & VandenBerg (2014)



Self-consistent E(B-V)=0.6, Rv=3.1

Using E(B-V)=0.6 and Rv=3.1

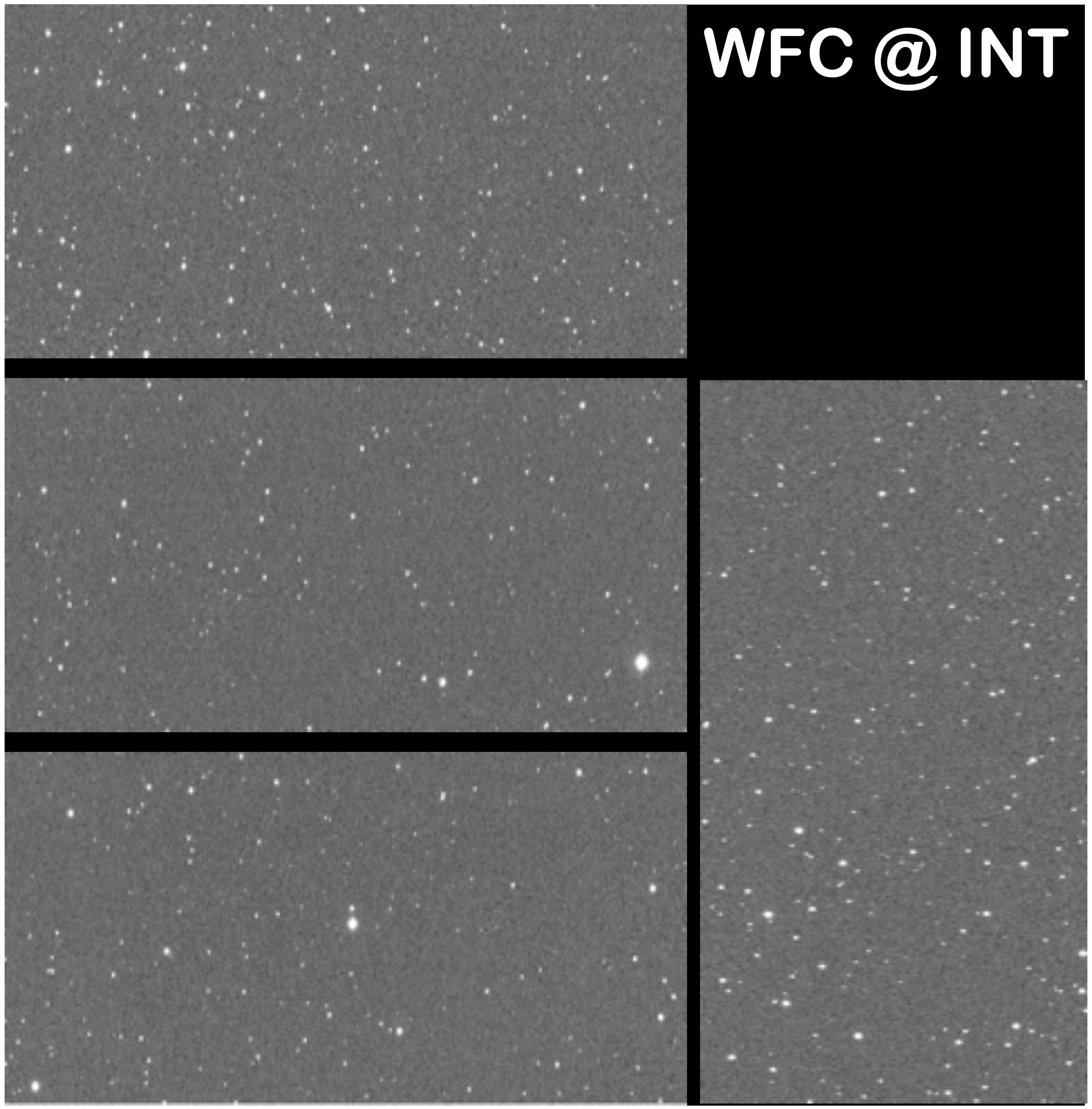
Using E(B-V)=0.6 with An et al (2009) coefficients

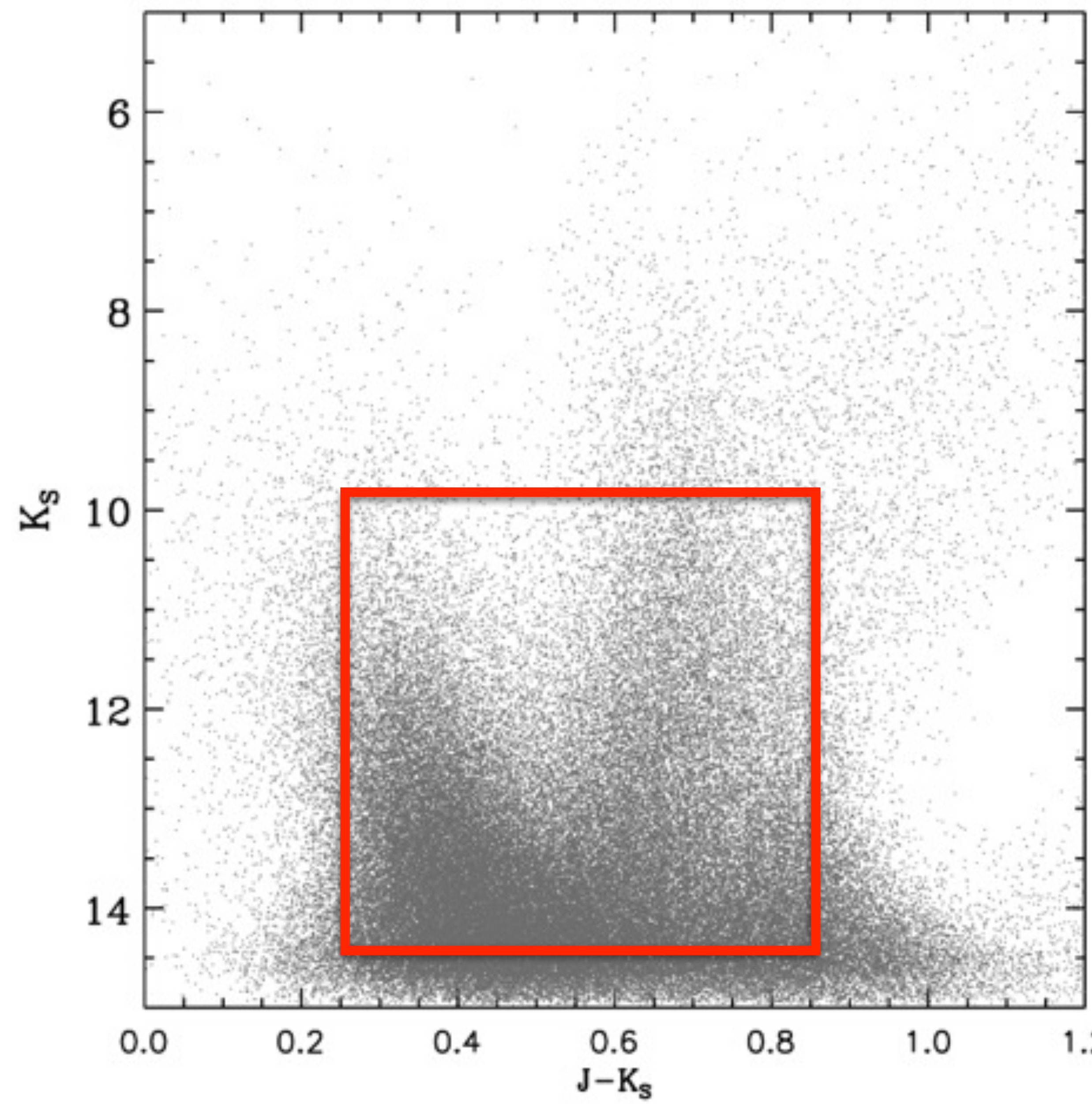
Using E(B-V)=0.6 with McCall (2004) coefficients

all these coefficients are correct for the spectral types they have been derived for! They cannot be applied at their face value to every stars (unfortunately this is often done)

Casagrande & VandenBerg (2014)

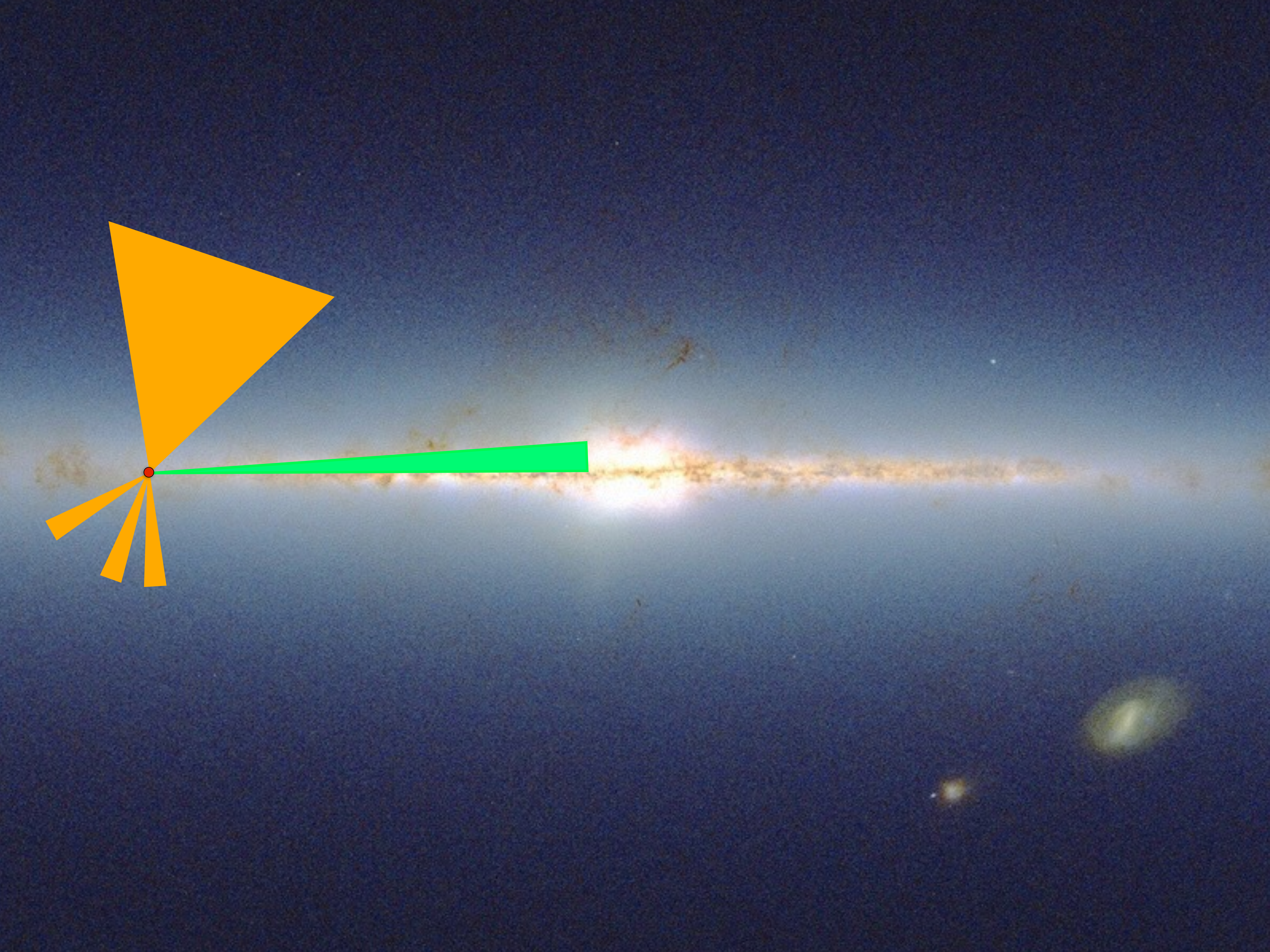
Unbiased



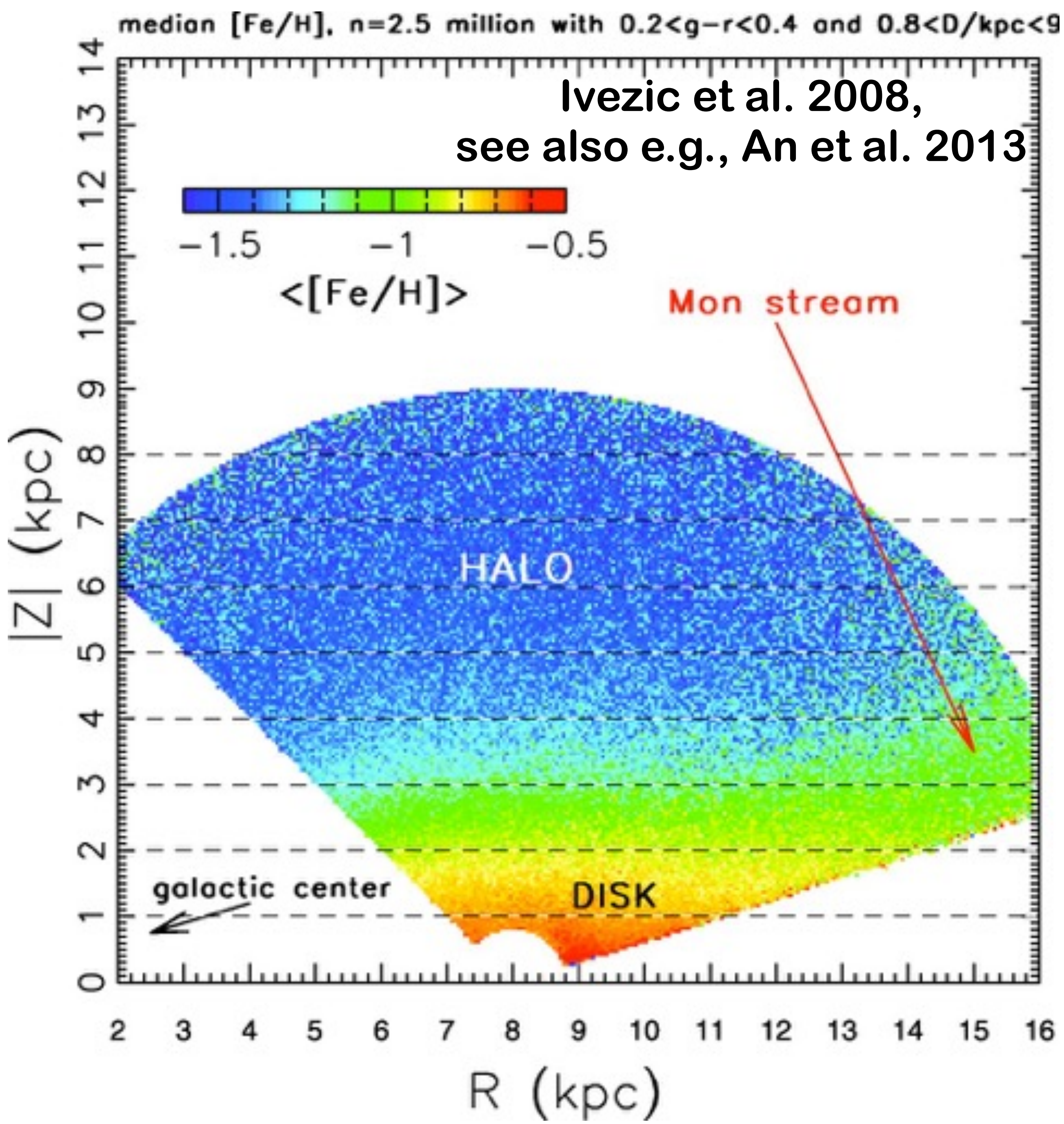


- target selection based on observables (colour and mag)
- luxury of throwing away a few % of your stars
- large colour interval

Read the **fine print**: forward modelling and/or minor bias corrections might still be needed.

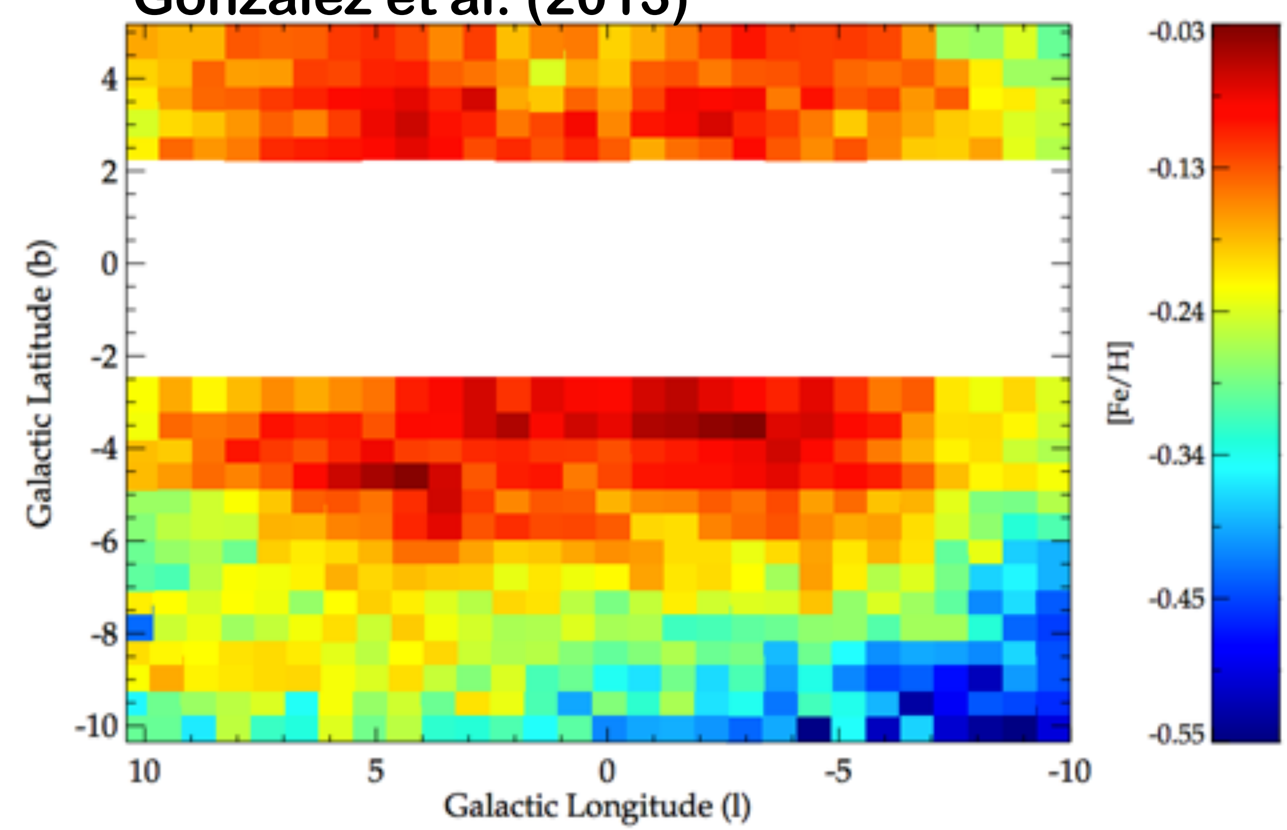


Disc/halo tomography



Bulge: metallicity / reddening / structure

Gonzalez et al. (2013)



see also e.g., Wegg & Gerhard (2013)
Nataf et al. (2015)

Solar Neighbourhood

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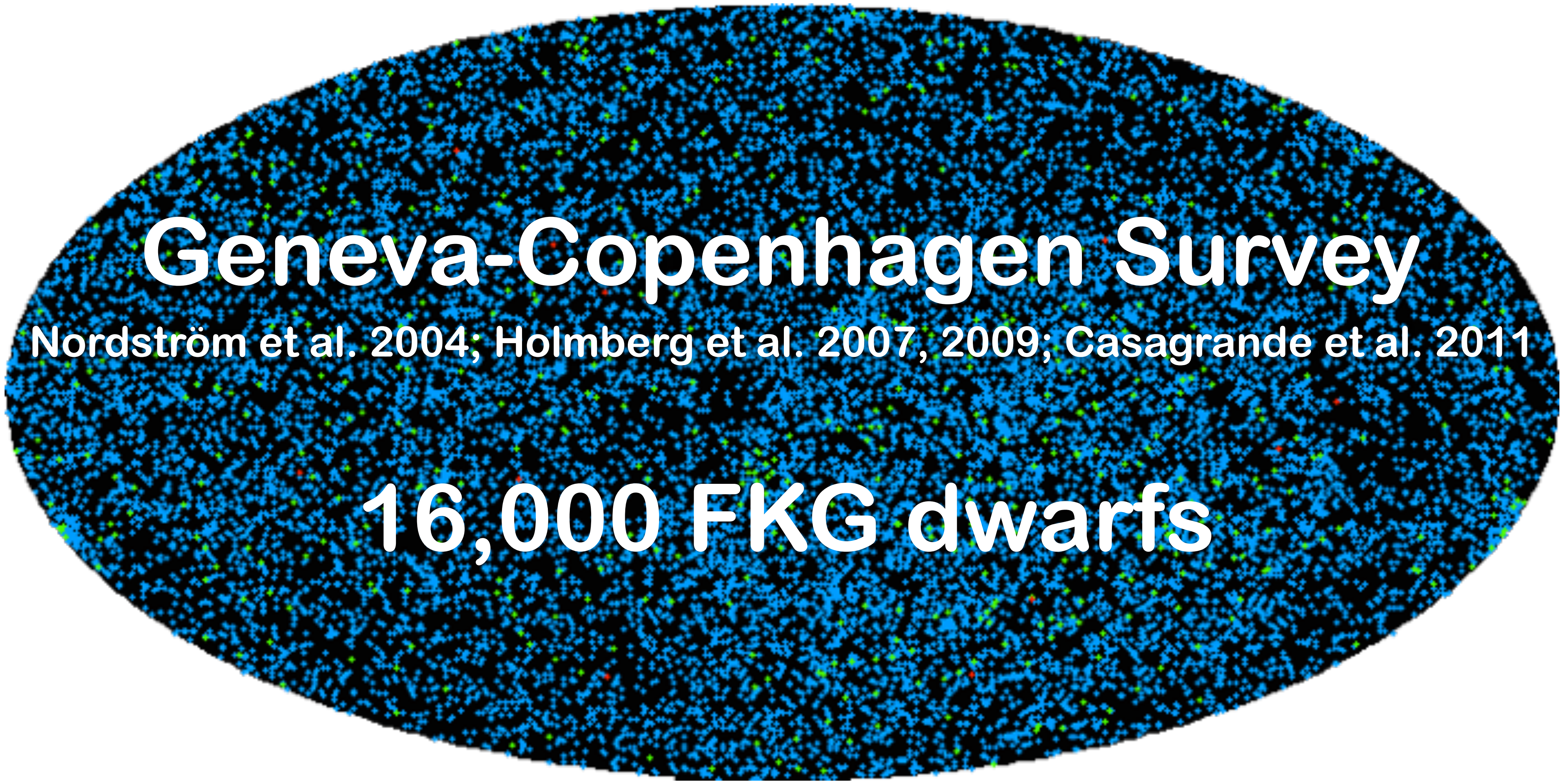
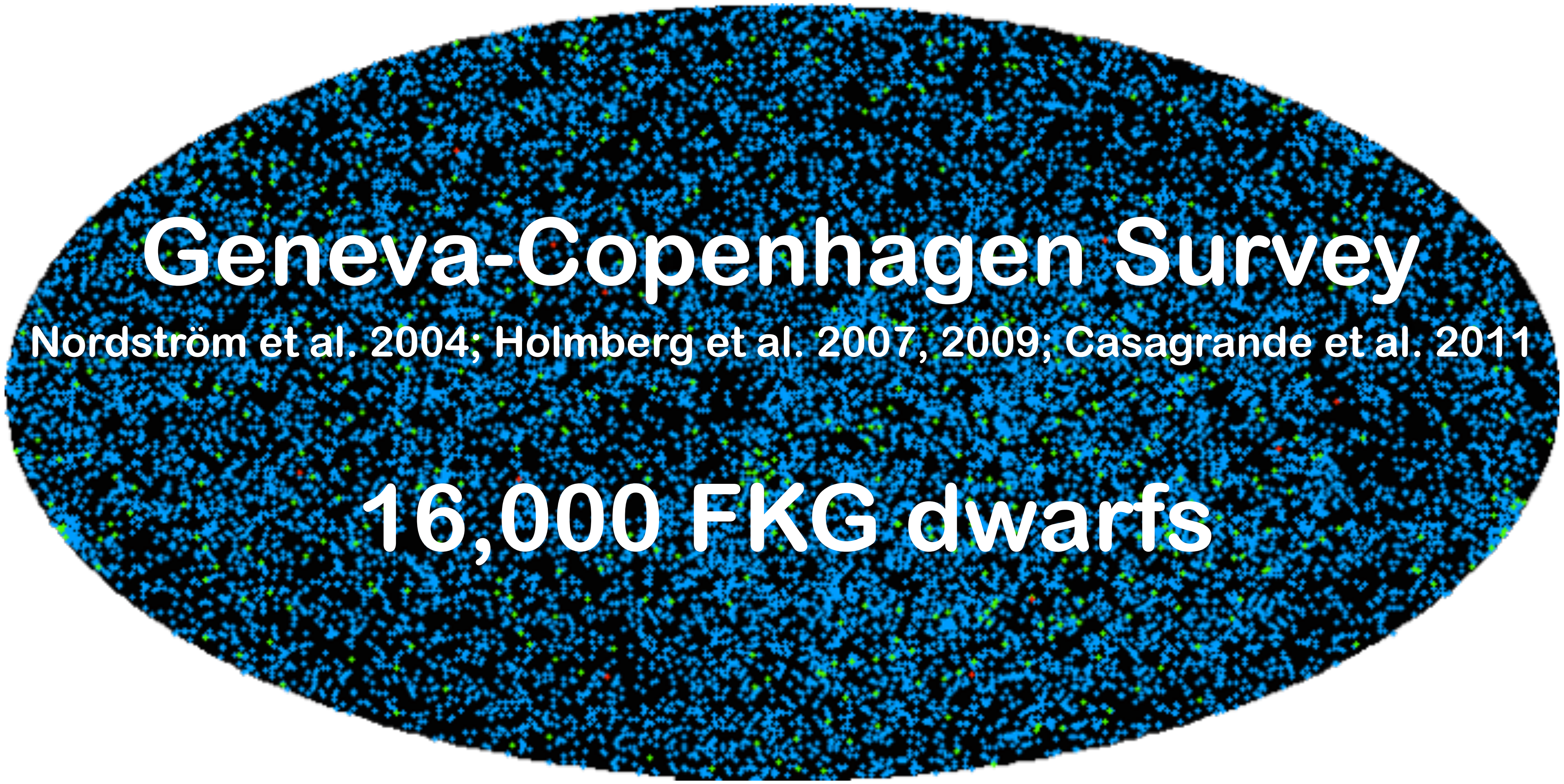


- ✓Kinematic (U,V,W)
- ✓Hipparcos (i.e. π, Tycho2 photometry)
- ✓2MASS photometry
- ✓Strömgren colours

Solar Neighbourhood



✓Kinematic (U,V,W)
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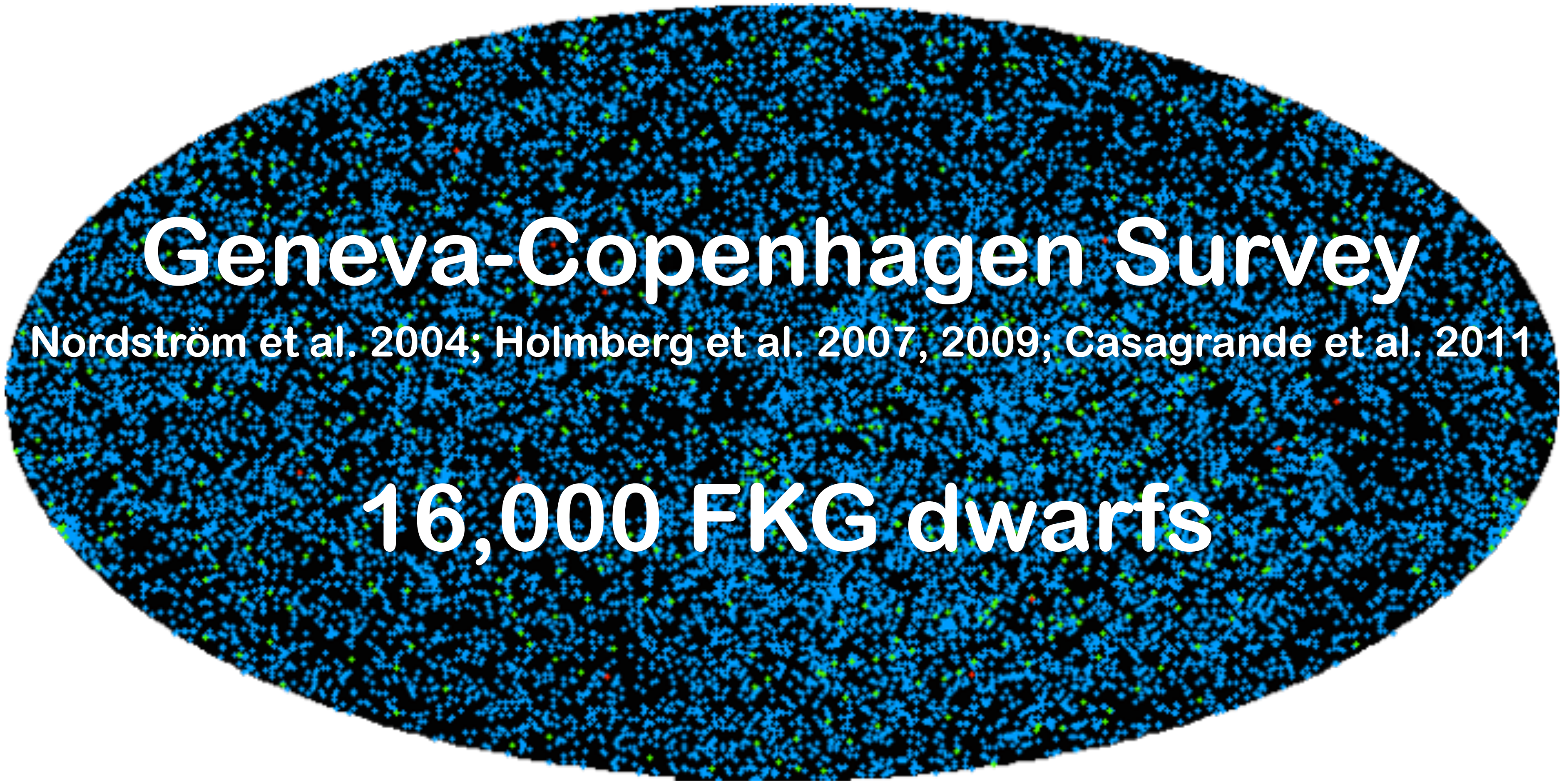
✓Strömgren colours

⟶

✓Metallicities

Solar Neighbourhood



✓Kinematic (U,V,W)
✓Hipparcos (i.e. π, Tycho2 photometry)
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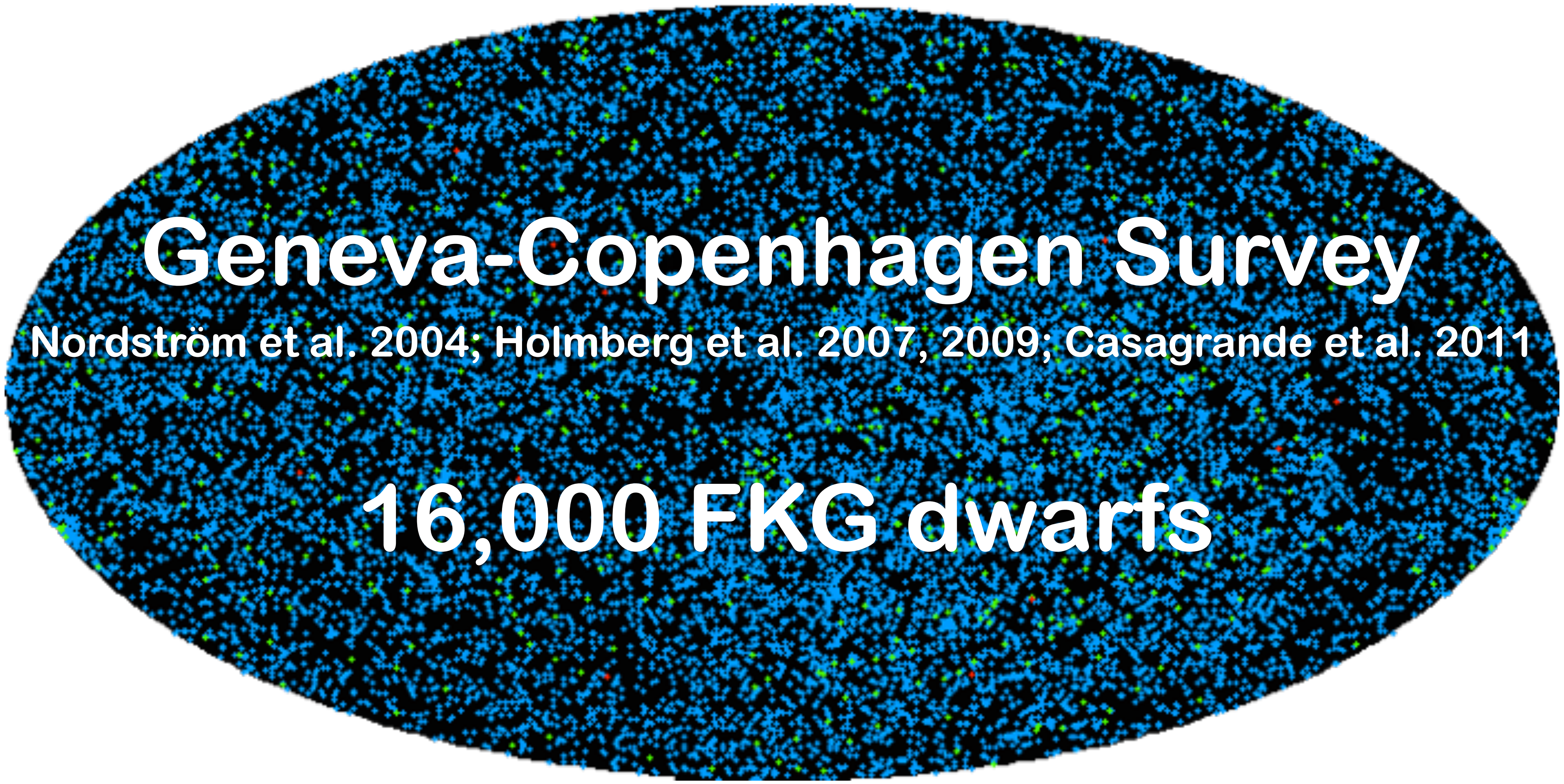
→

✓Stellar Parameters (T_{eff})
✓Metallicities

Solar Neighbourhood



✓Kinematic (U,V,W)
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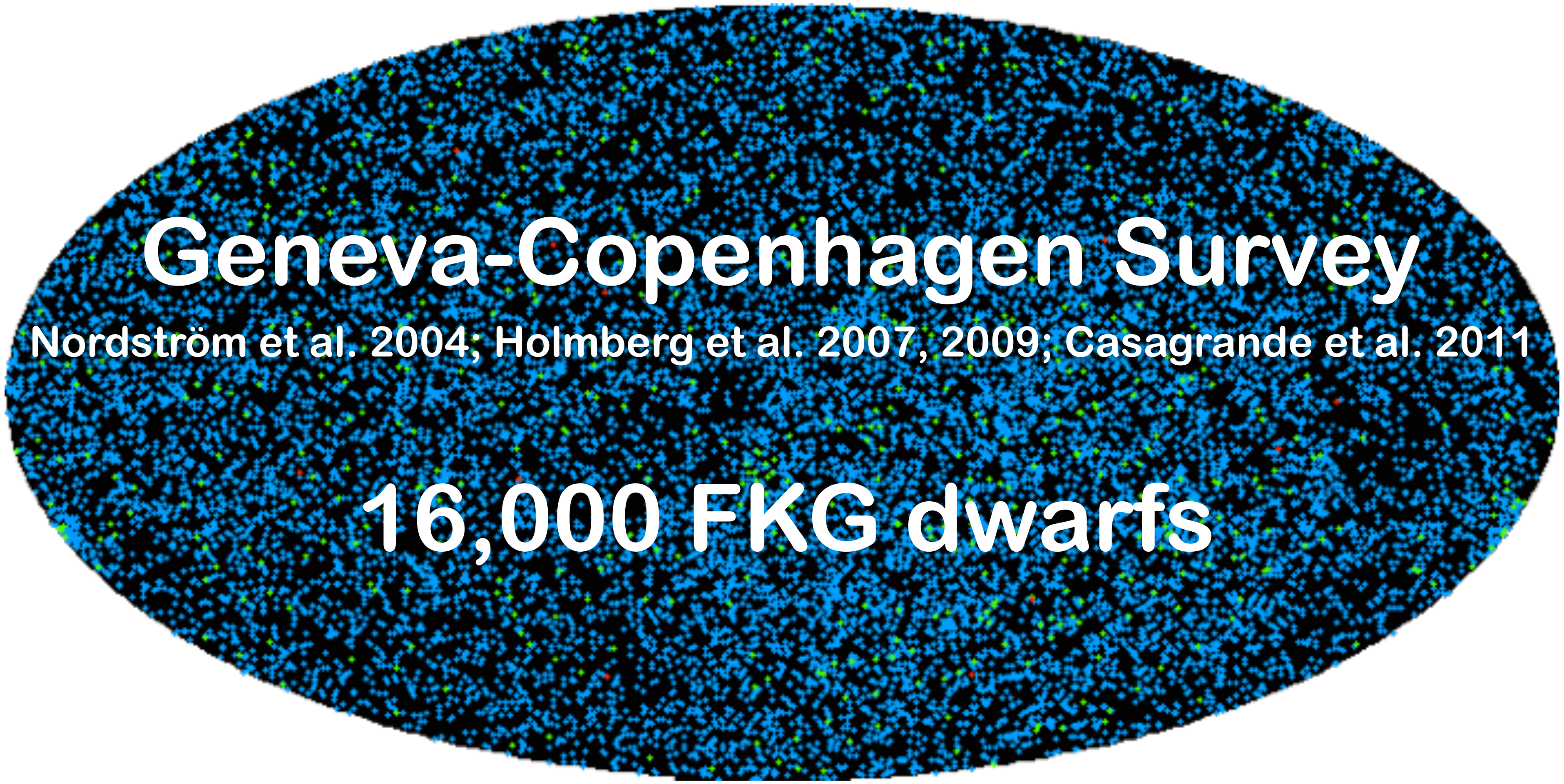
✓Stellar models: ages
✓Stellar Parameters (T_{eff})
✓Metallicities

Solar Neighbourhood



- ✓Kinematic (U,V,W)
- ✓Hipparcos (i.e. π, Tycho2 photometry)
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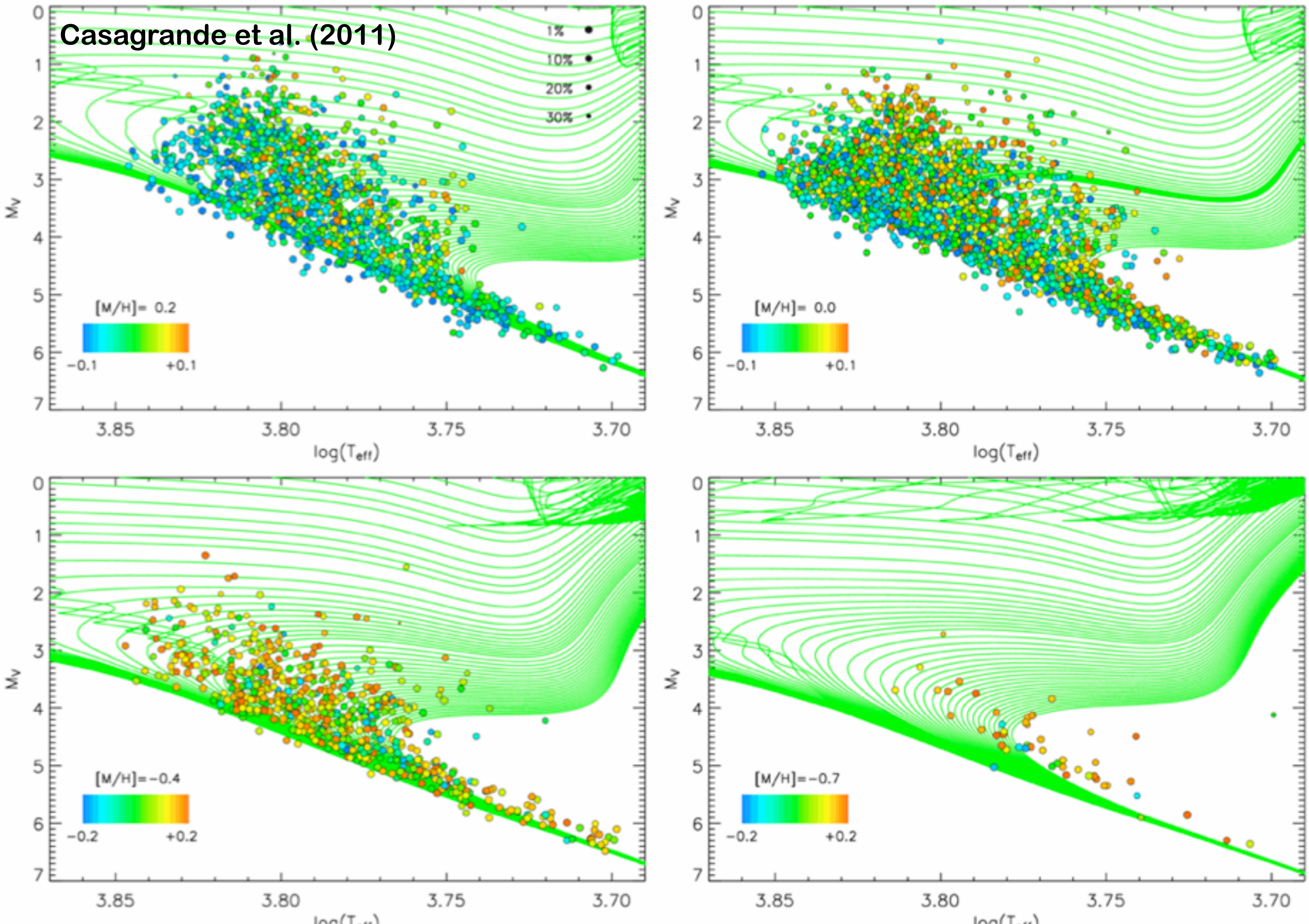
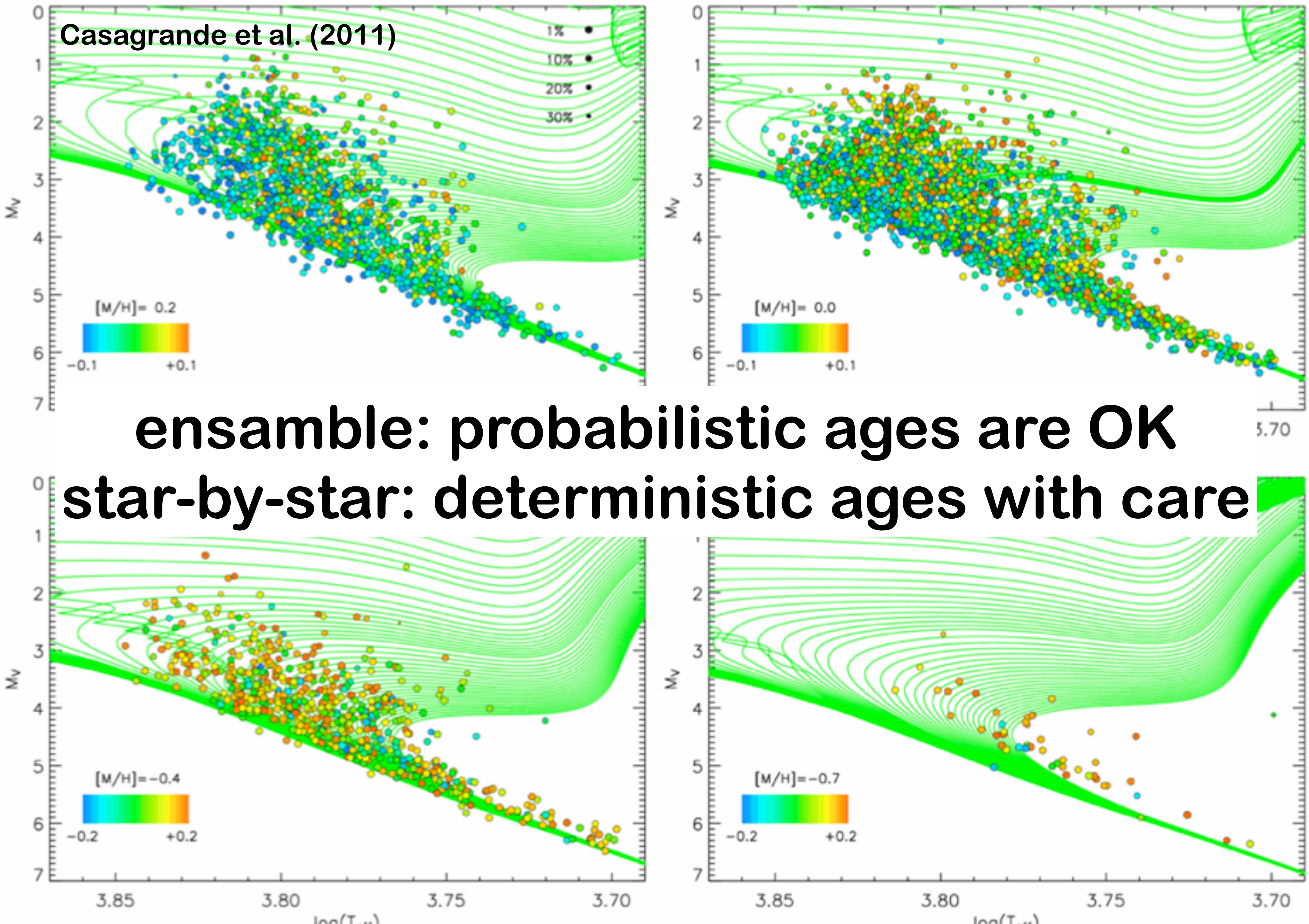
→

- ✓chemical & dynamical evol.
- ✓Stellar models: ages
- ✓Stellar Parameters (T_{eff})
- ✓Metallicities



cf. e.g. Pont & Eyer (2004), Jørgensen & Lindegren (2005), Burnett & Binney (2010), Serenelli et al. (2013)

Sweeping (many things) under the rug



ensamble: probabilistic ages are OK

star-by-star: deterministic ages with care

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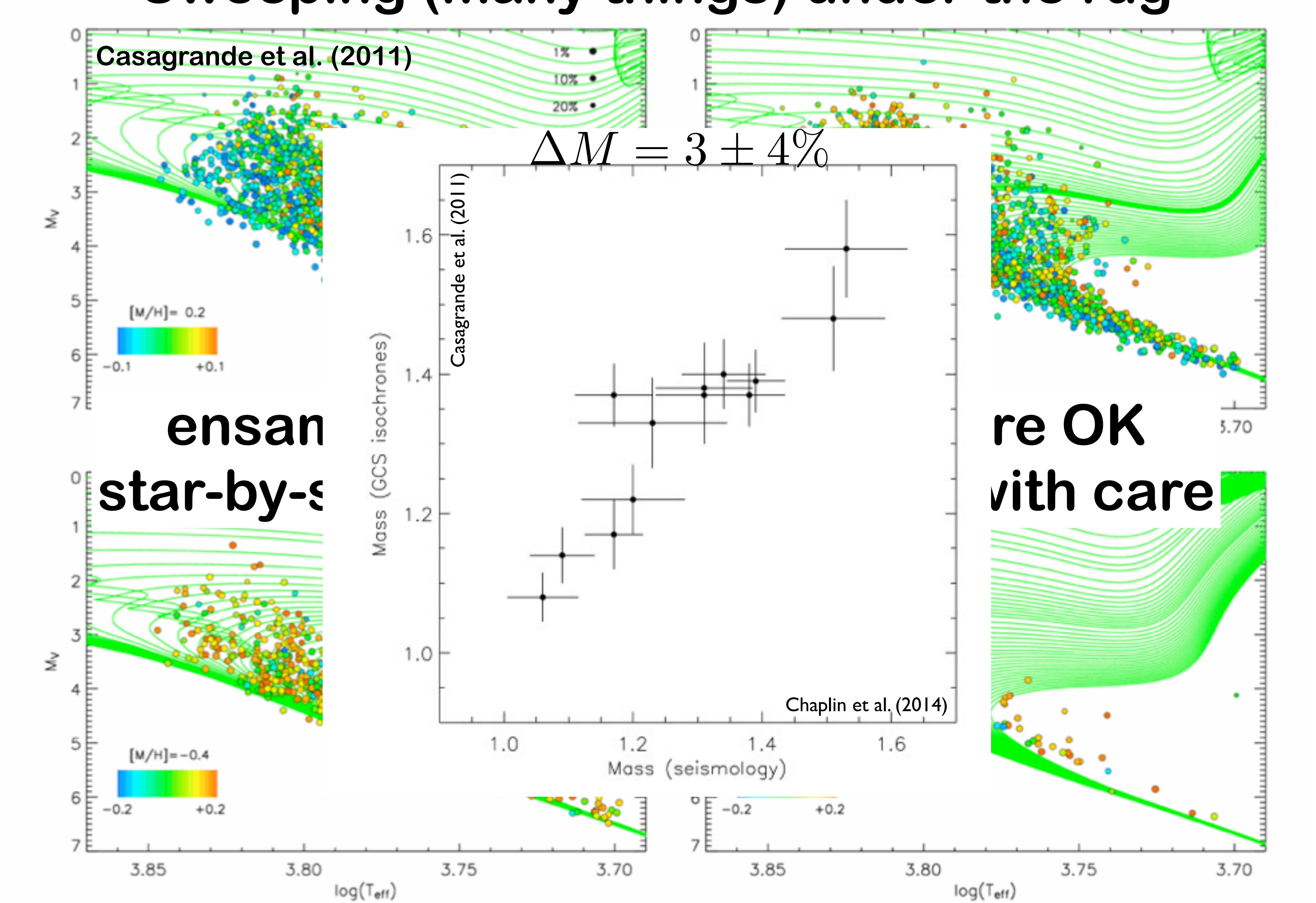

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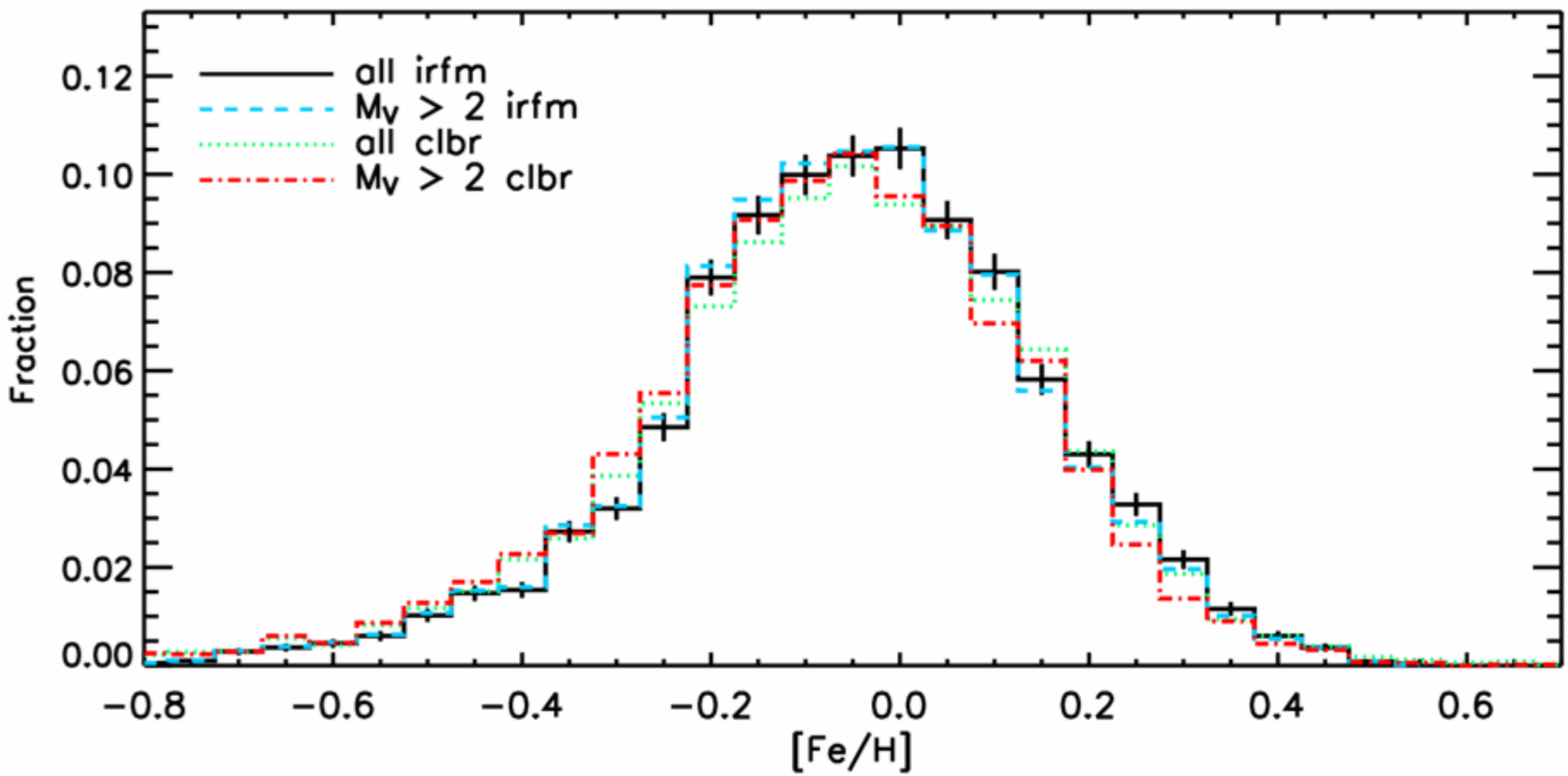
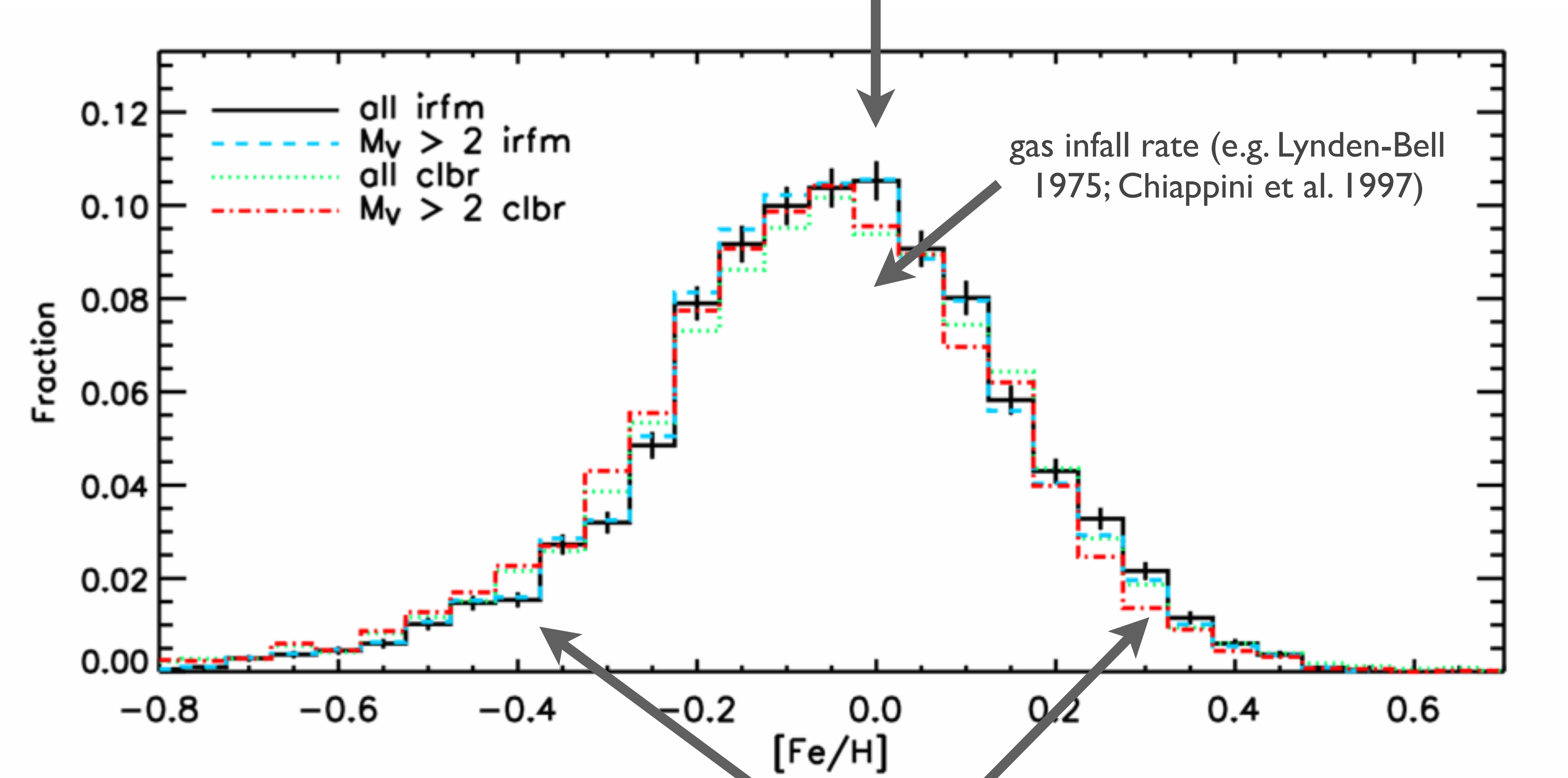
Metallicity Distribution Function



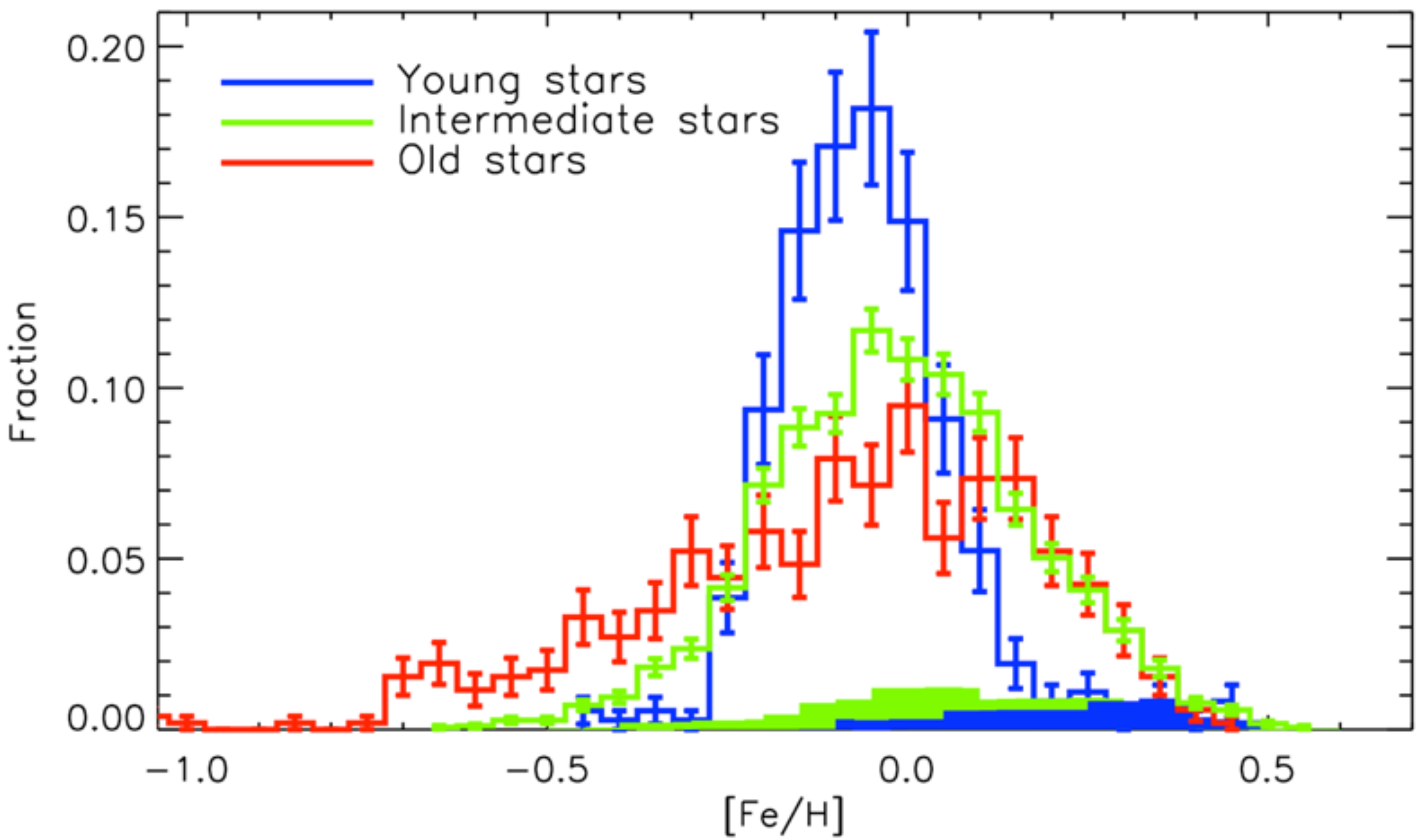
Metallicity Distribution Function

Sun: whiter/whence?



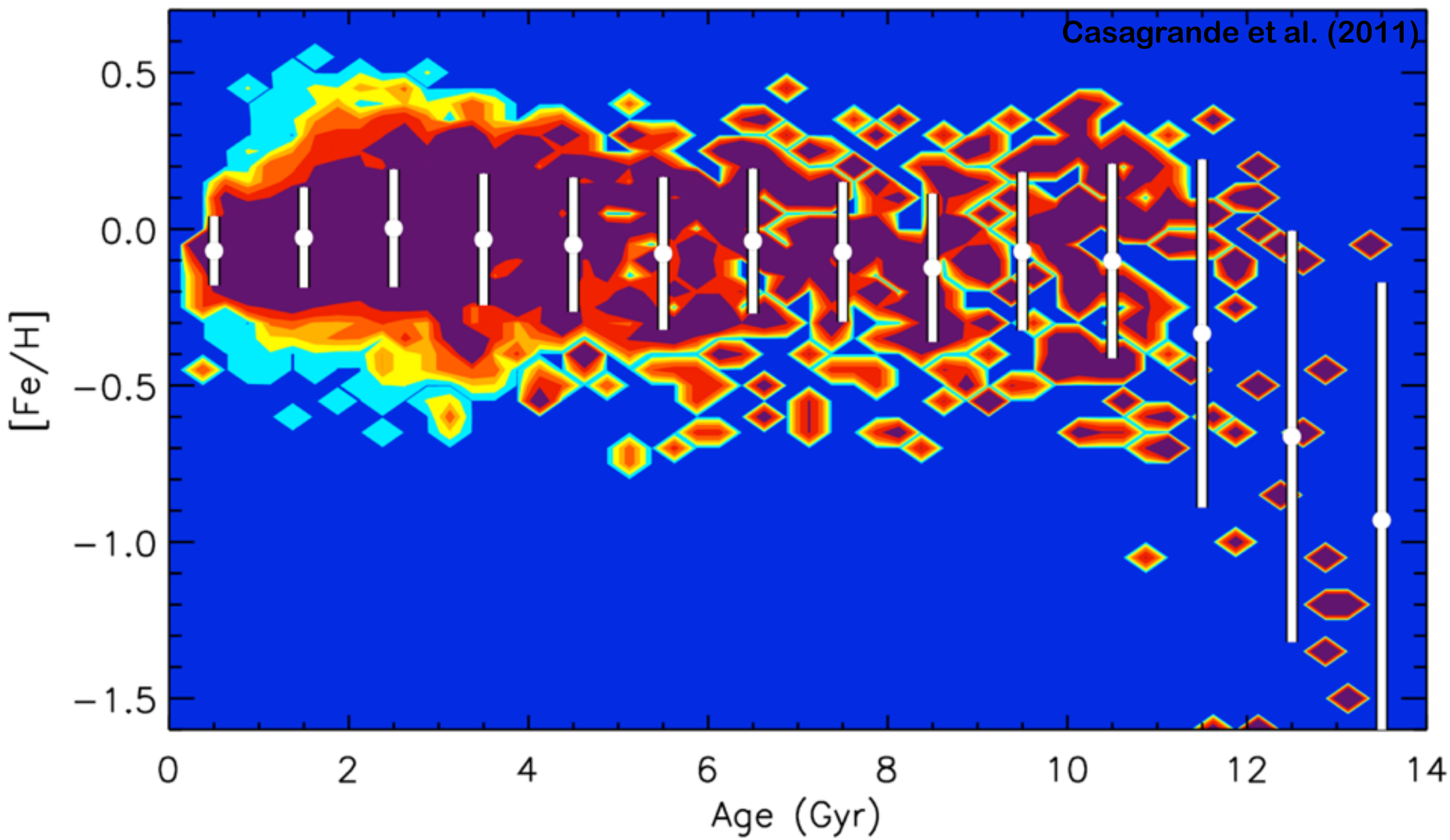
more??

Age-Metallicity Distribution Function



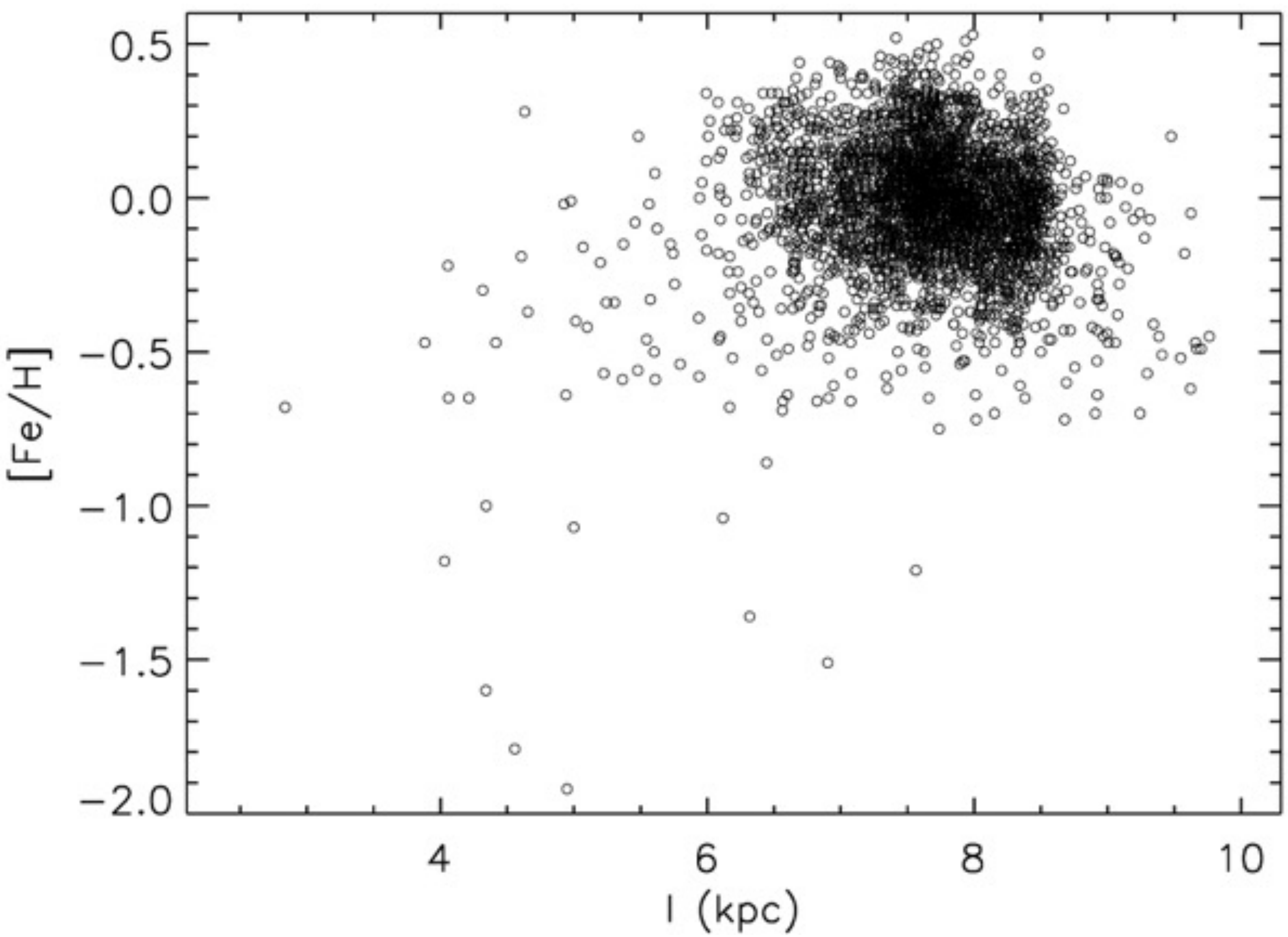
only good ages are used: σ < 1Gyr or relative uncertainty < 25%

Age-Metallicity Relation



YES/Maybe/NO: e.g, Twarog+ 1980, Edvardsson+ 1993, Rocha-Pinto+2000, Feltzing & Holmberg 2001, Nordstrom+ 2004, Haywood+ 2008, Bergemann+ 2014

Ages and Gradients



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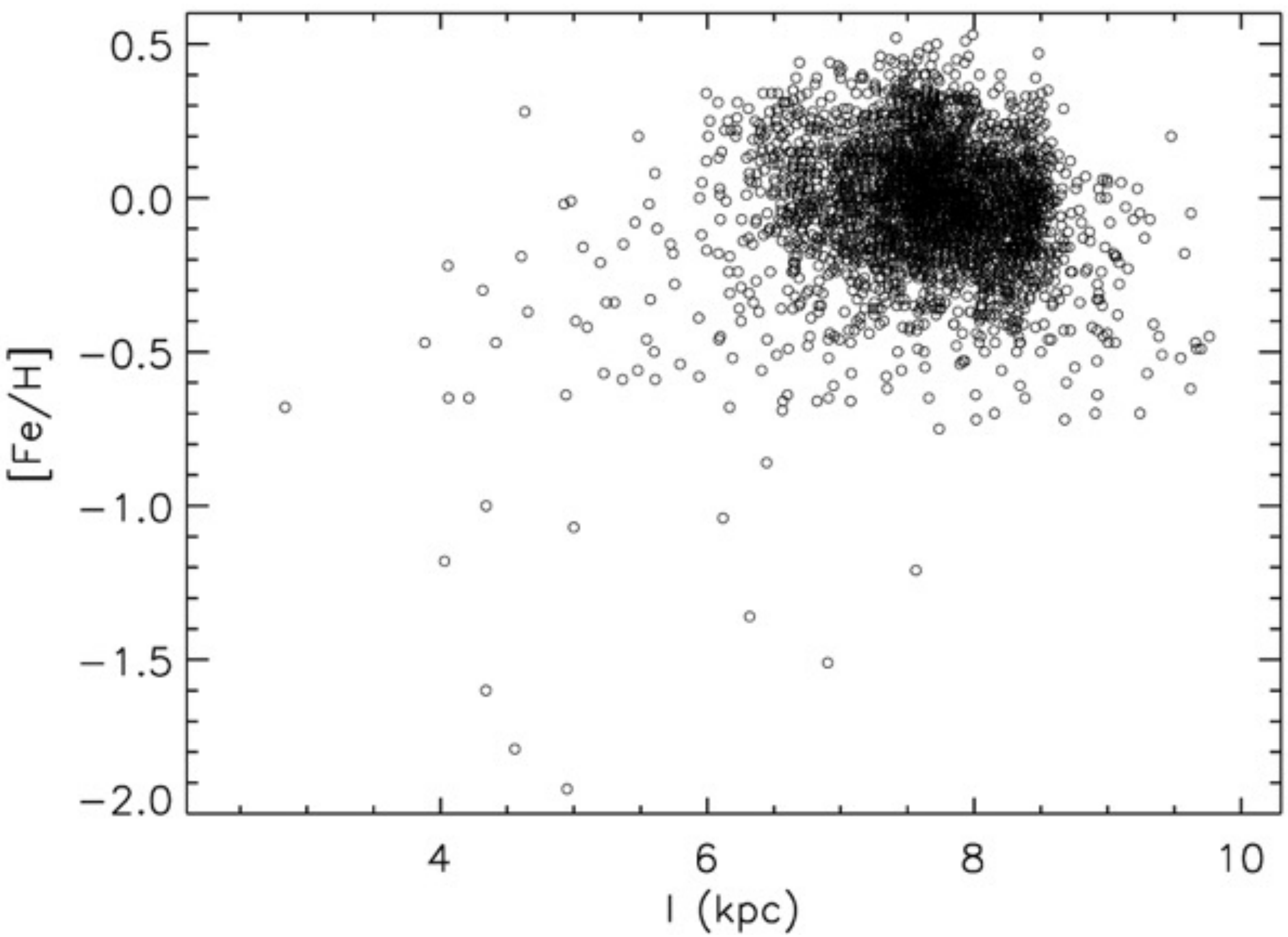

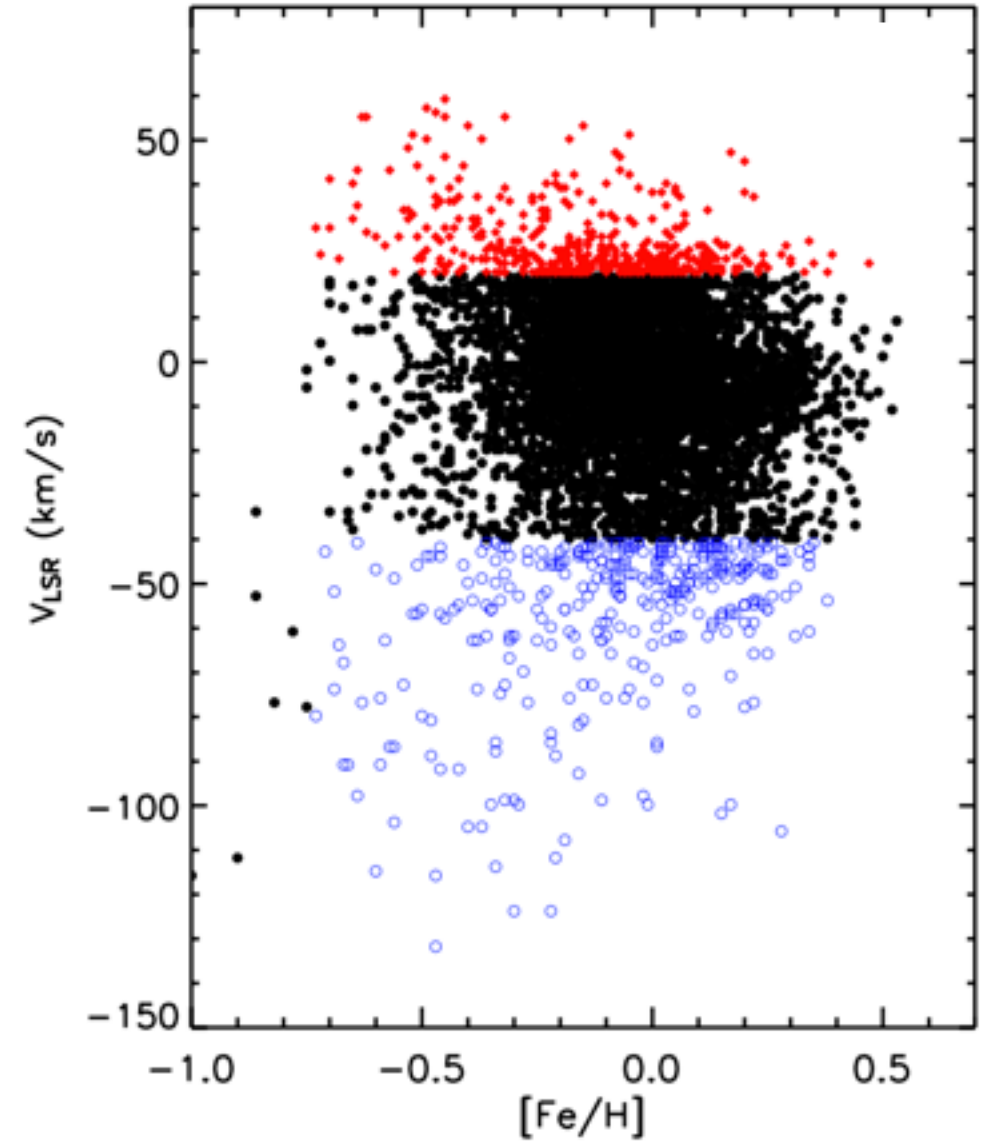

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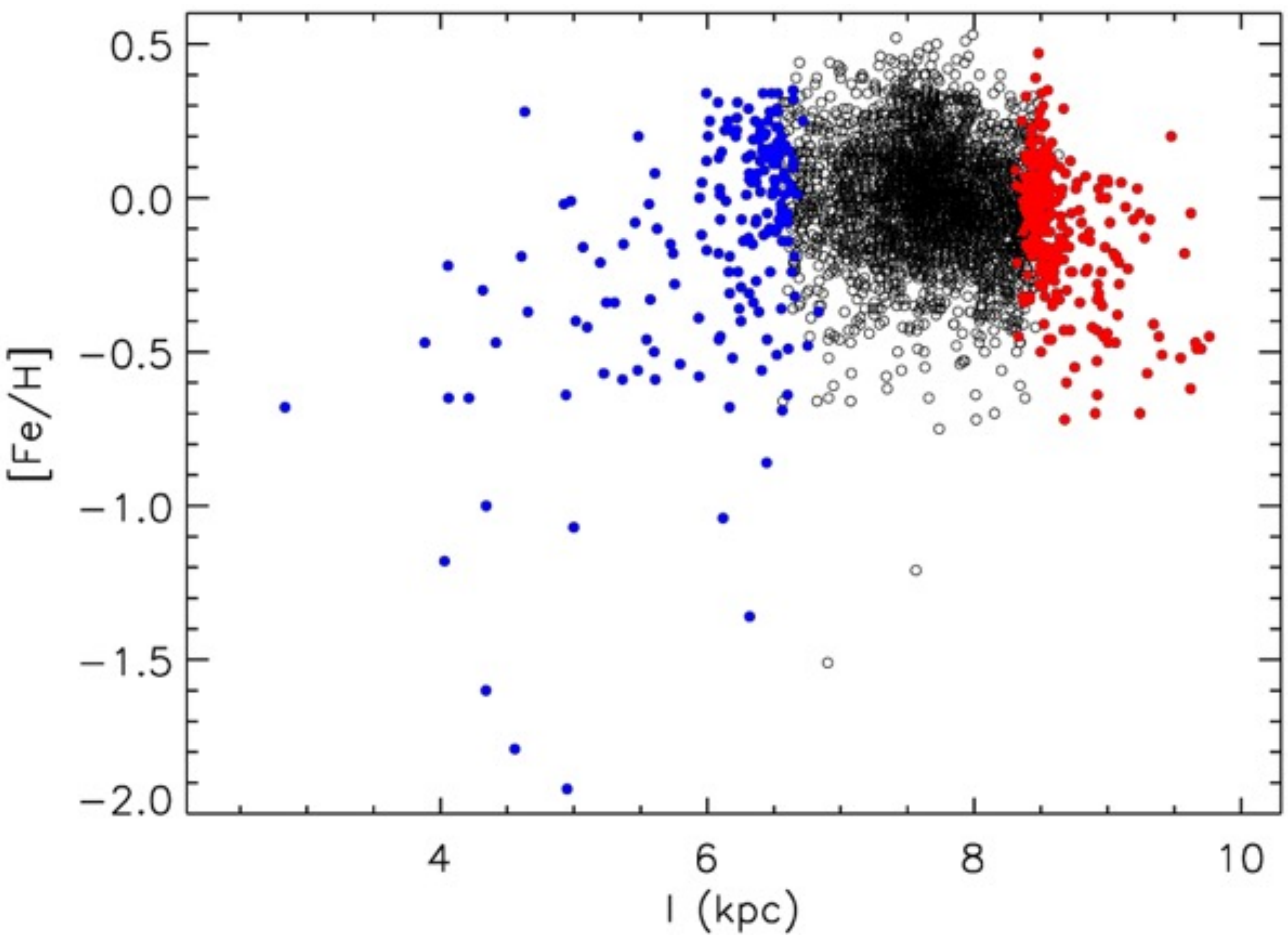

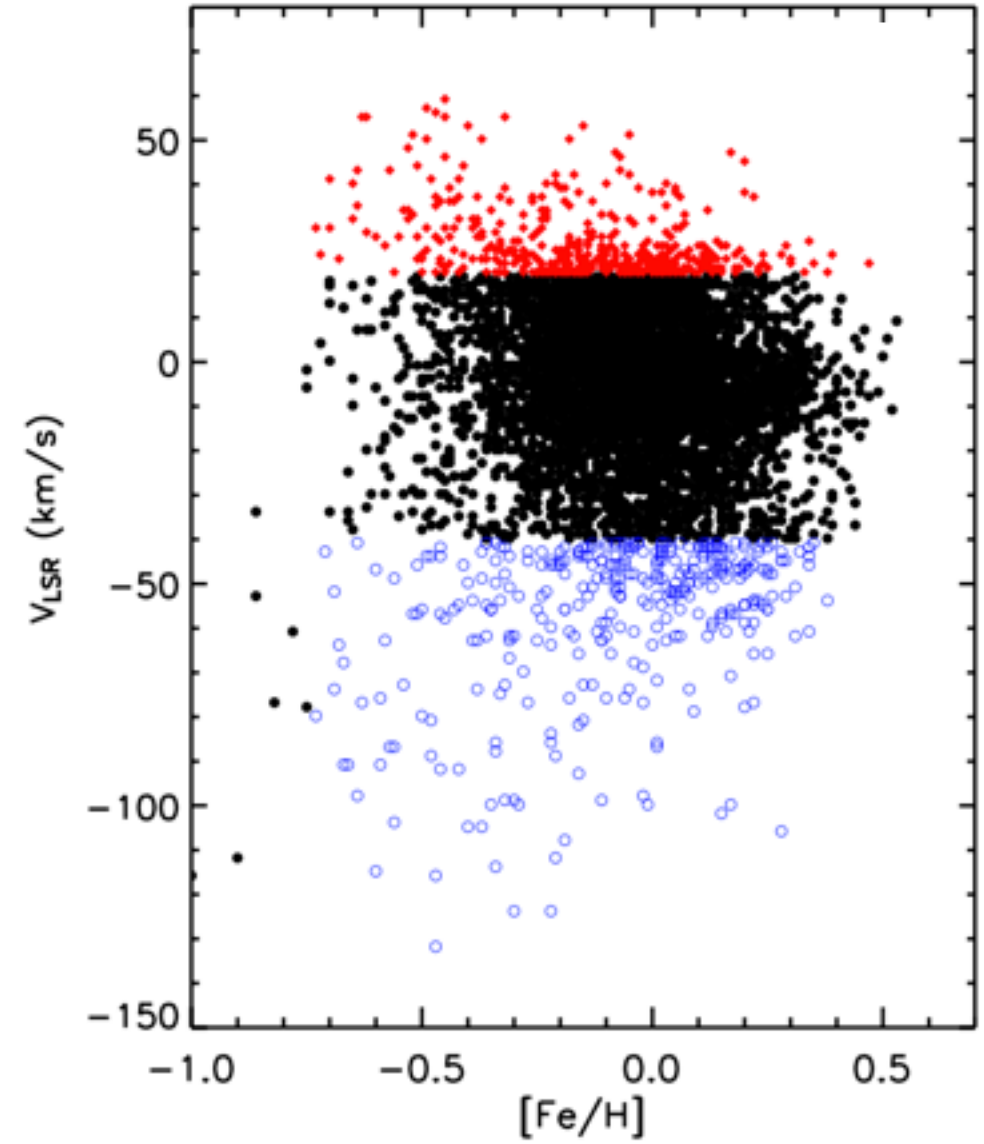

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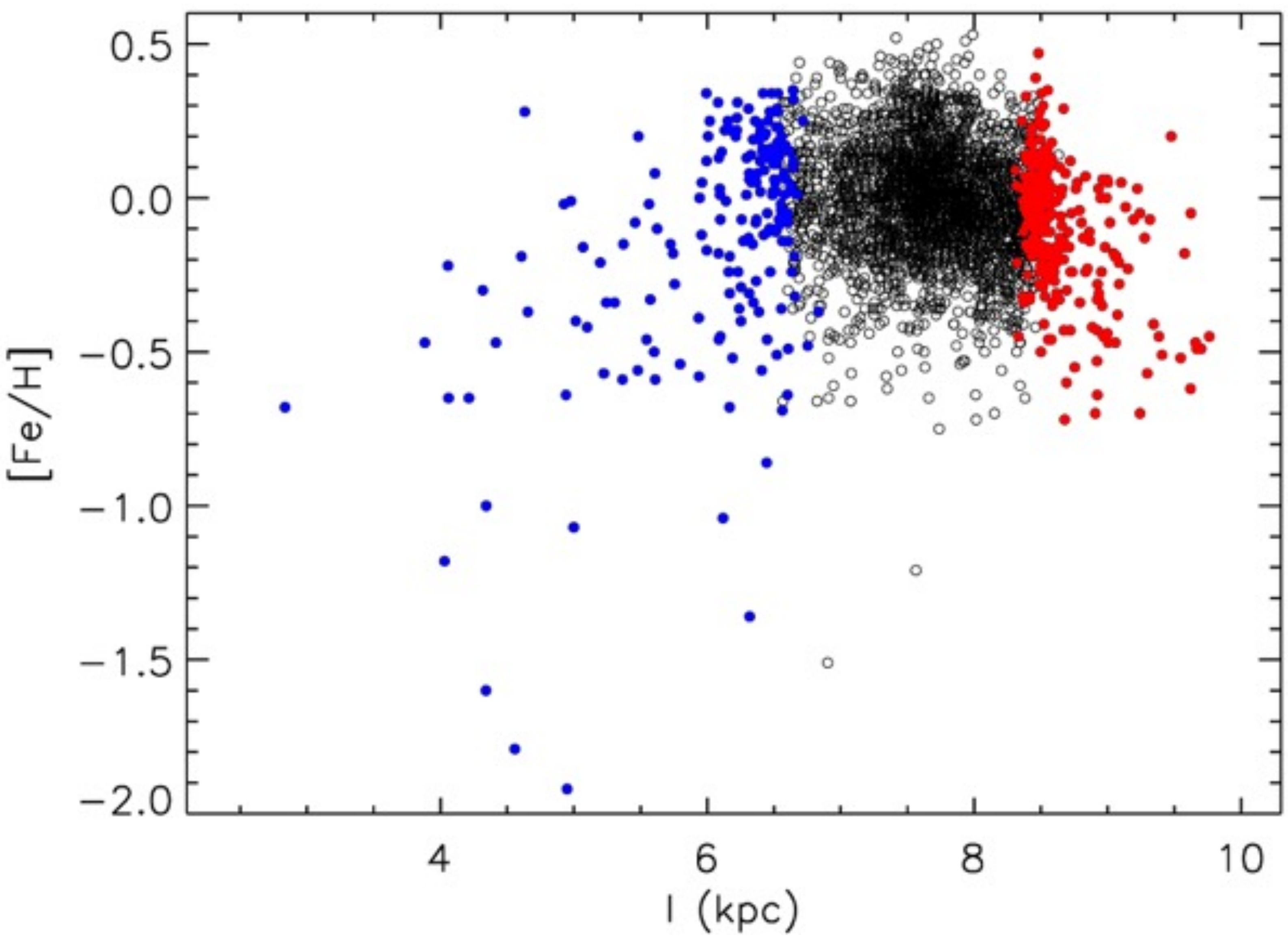
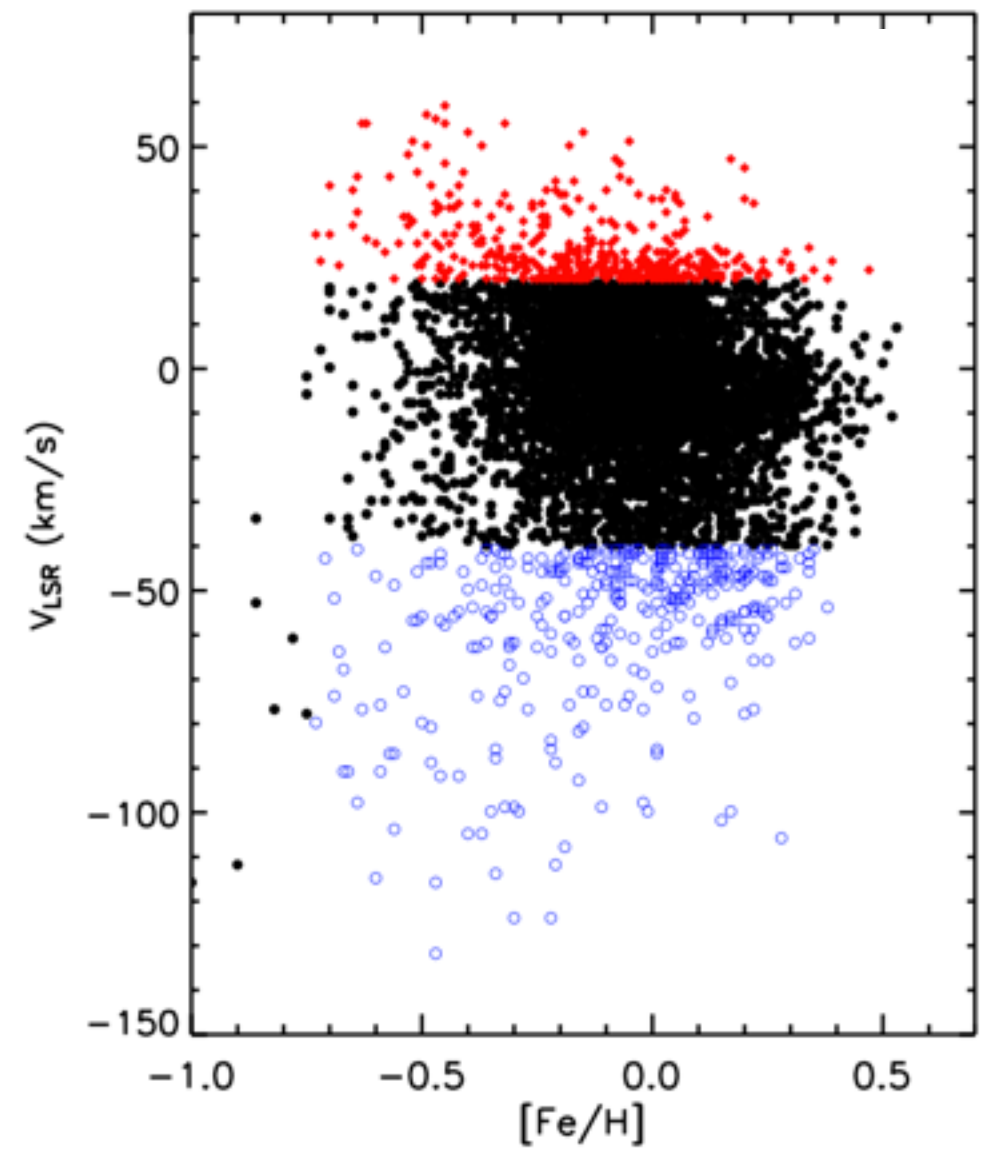
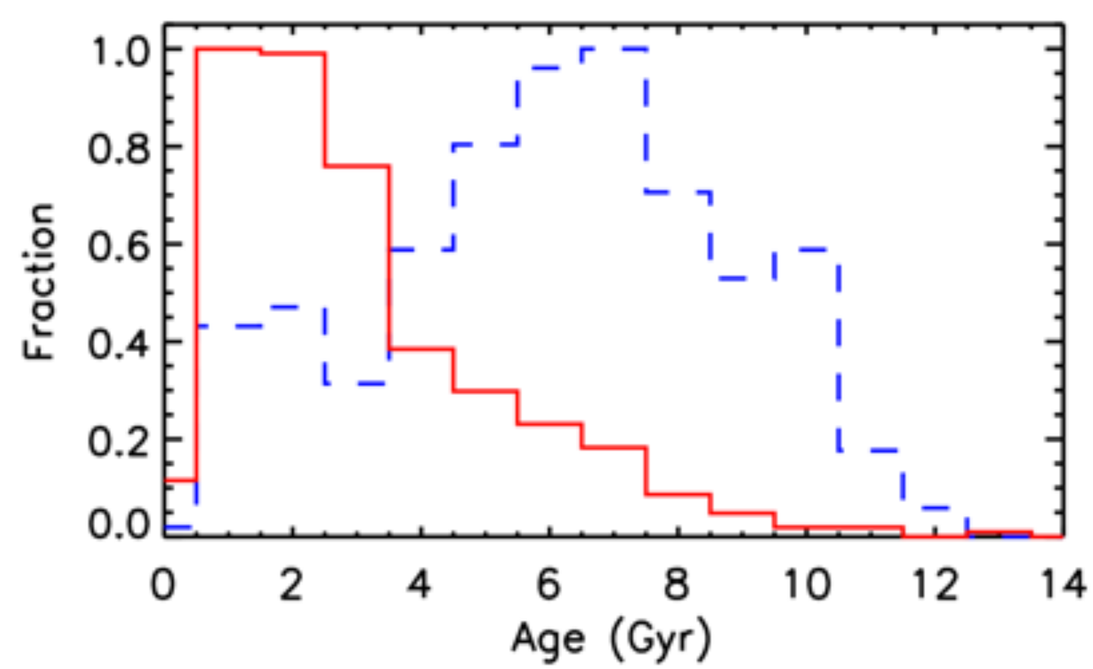
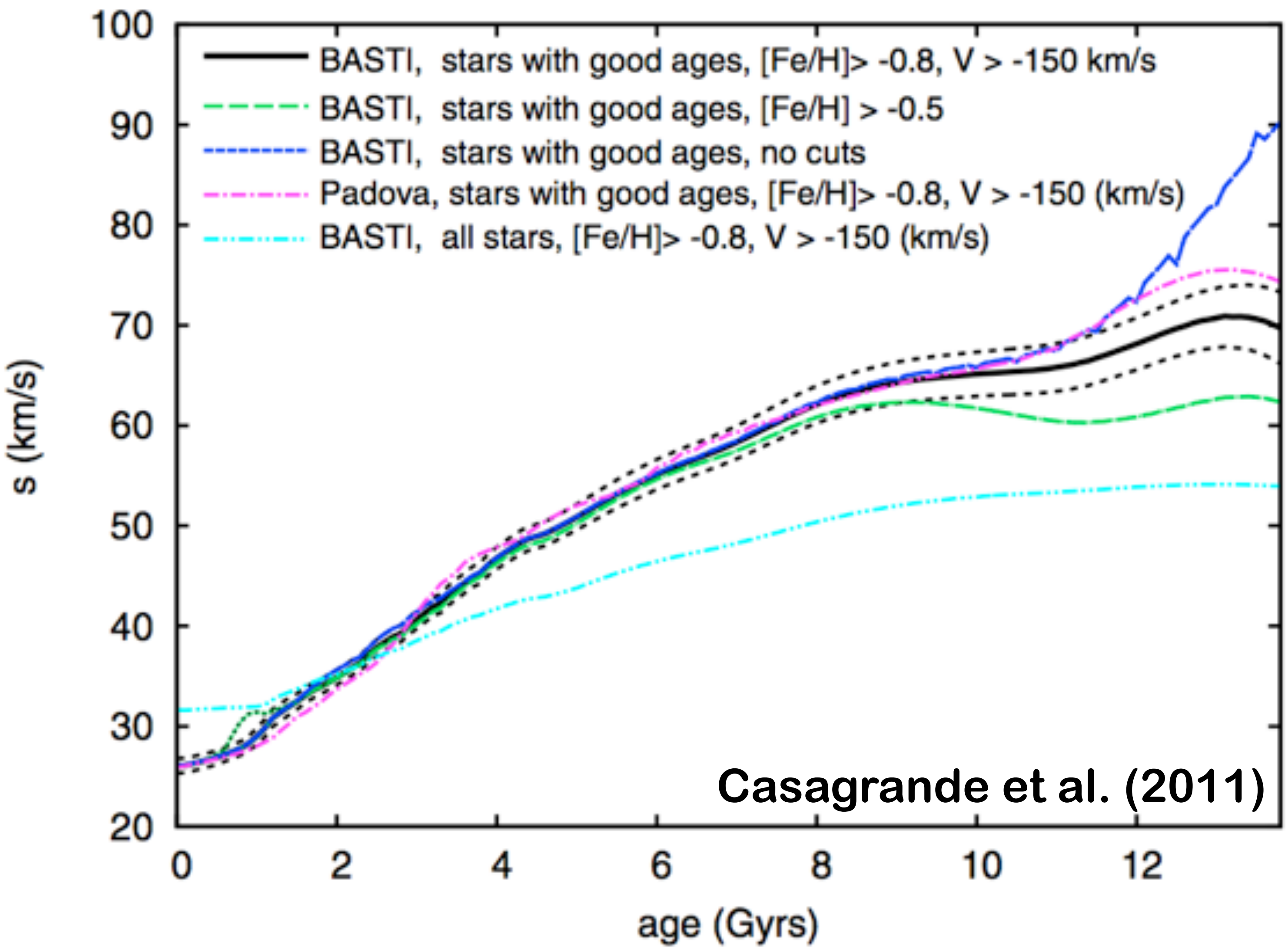


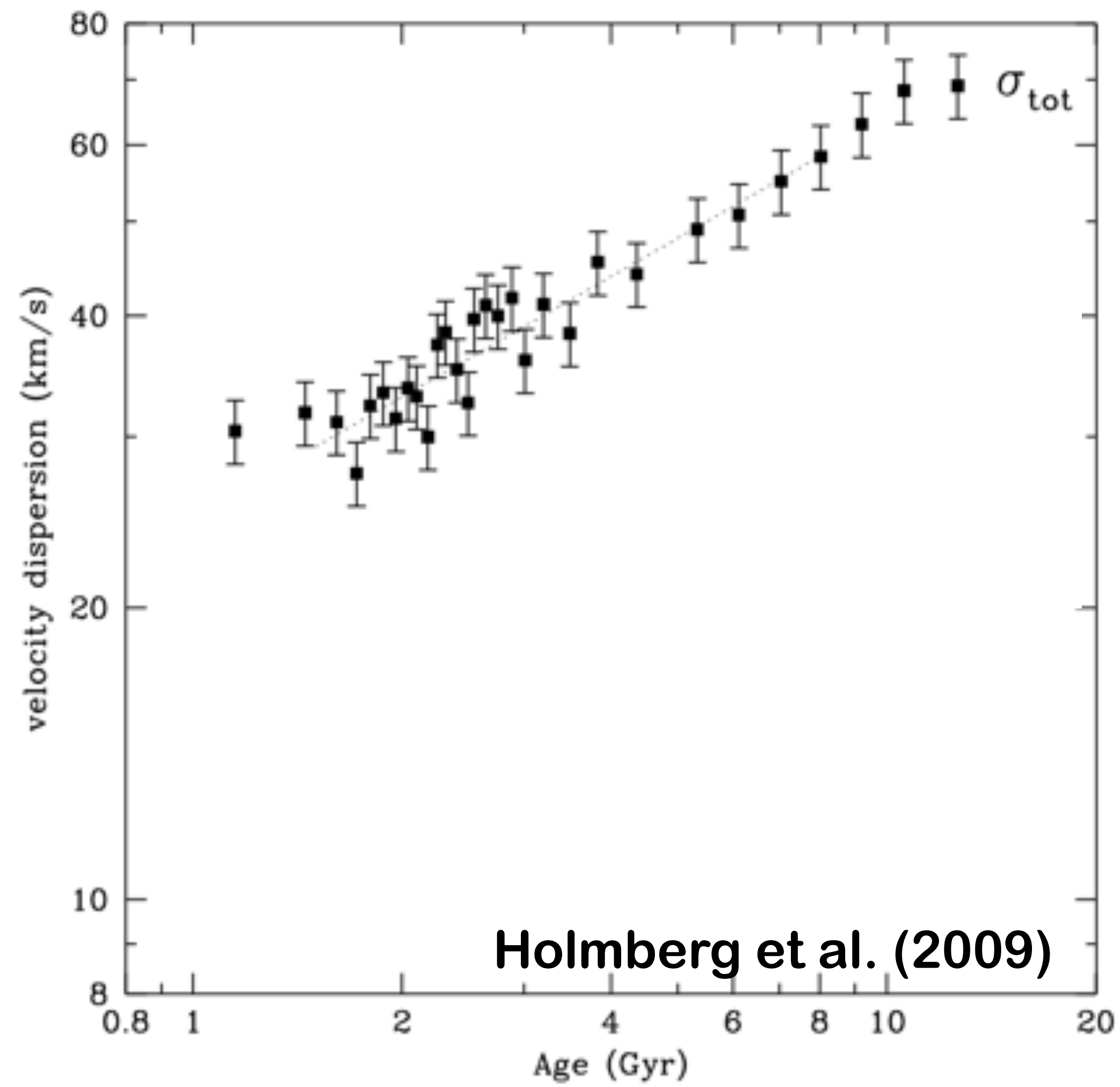


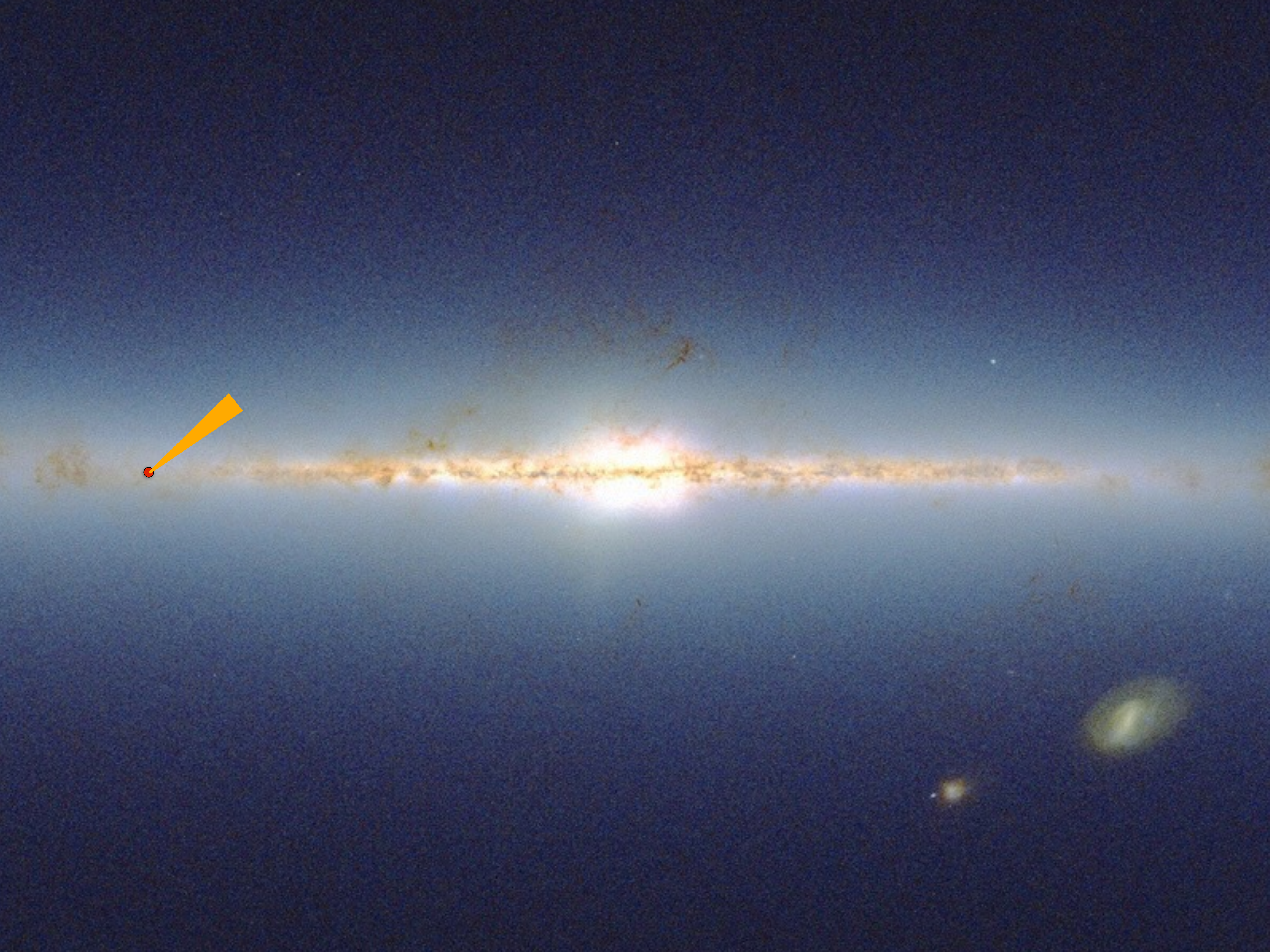


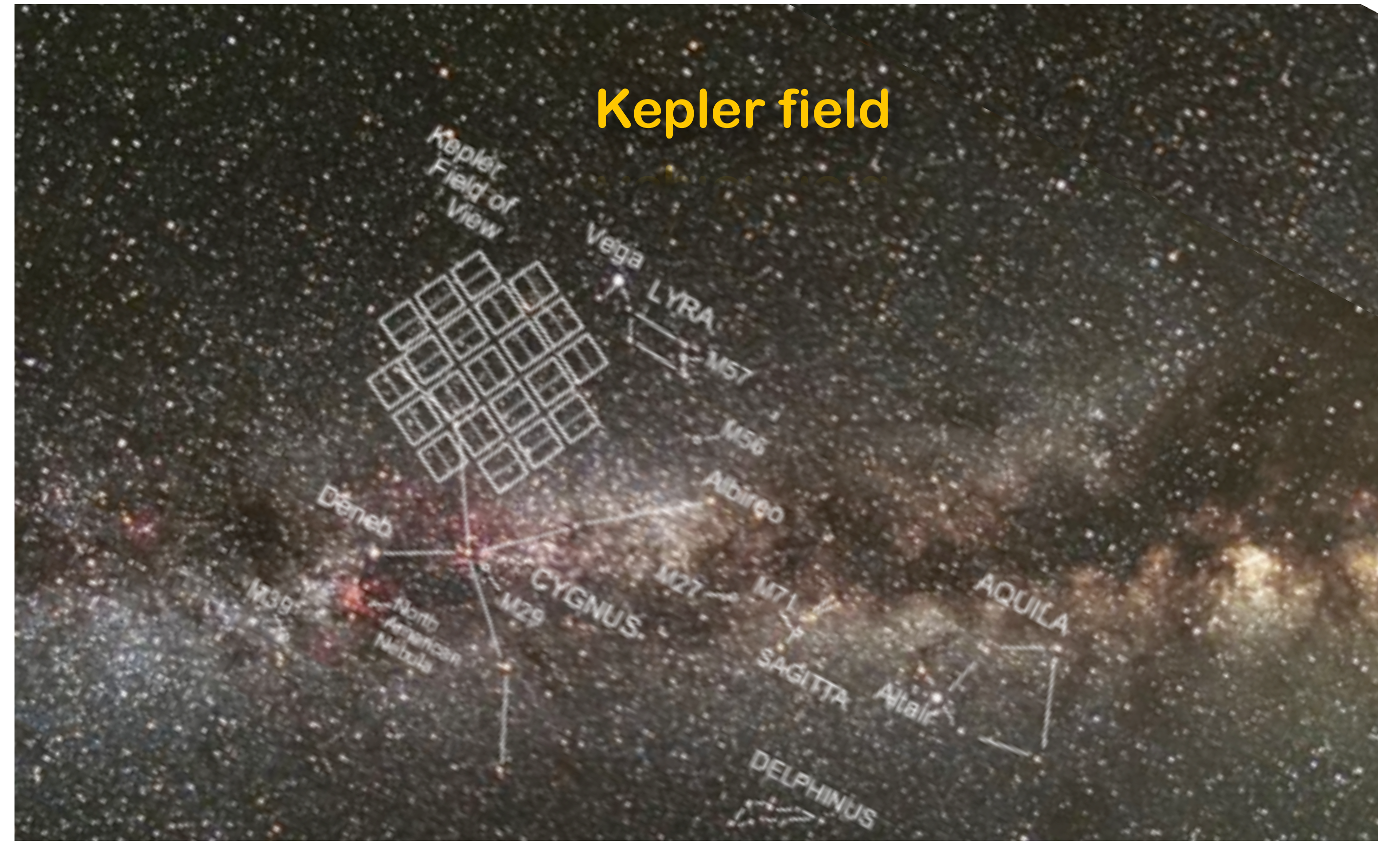
Age Dispersion relation

e.g. von Hoerner 1960, Mayor 1974

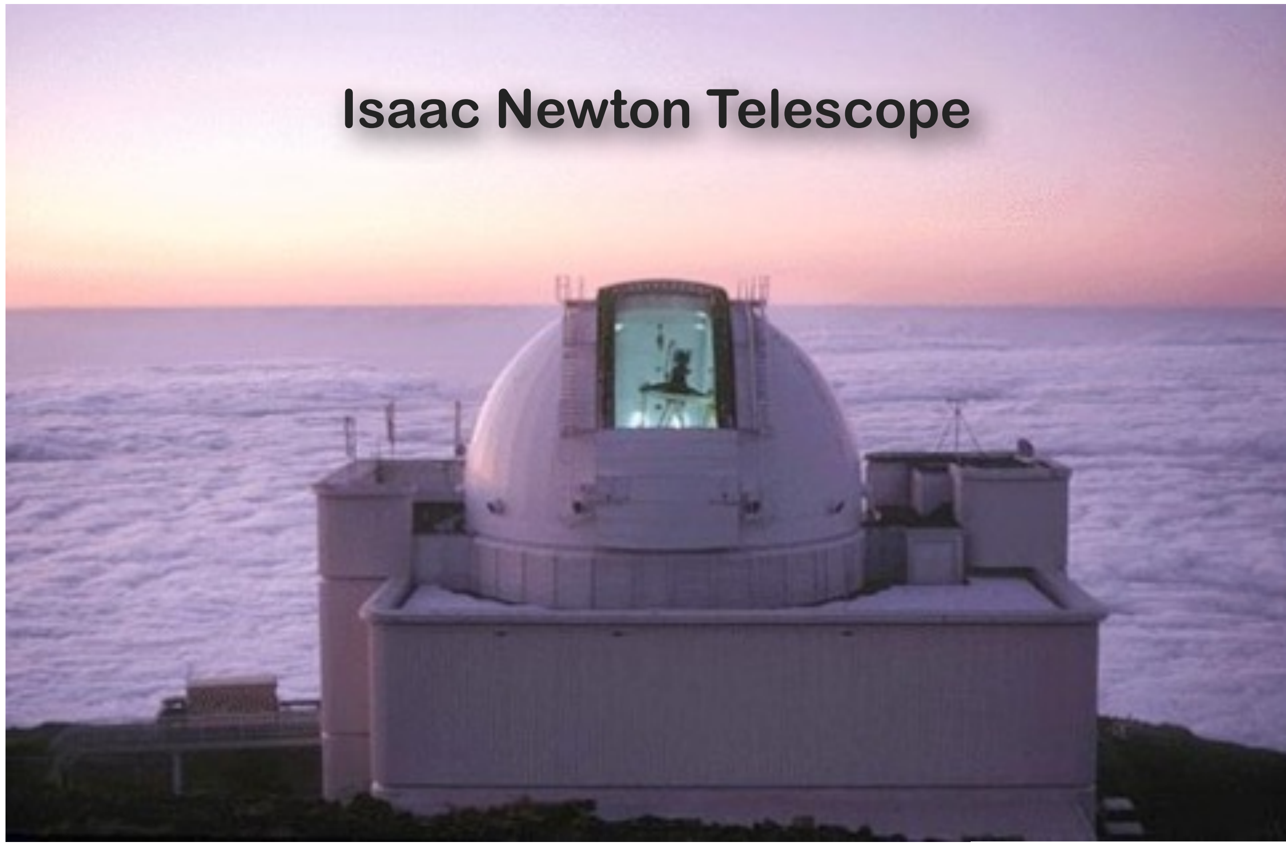


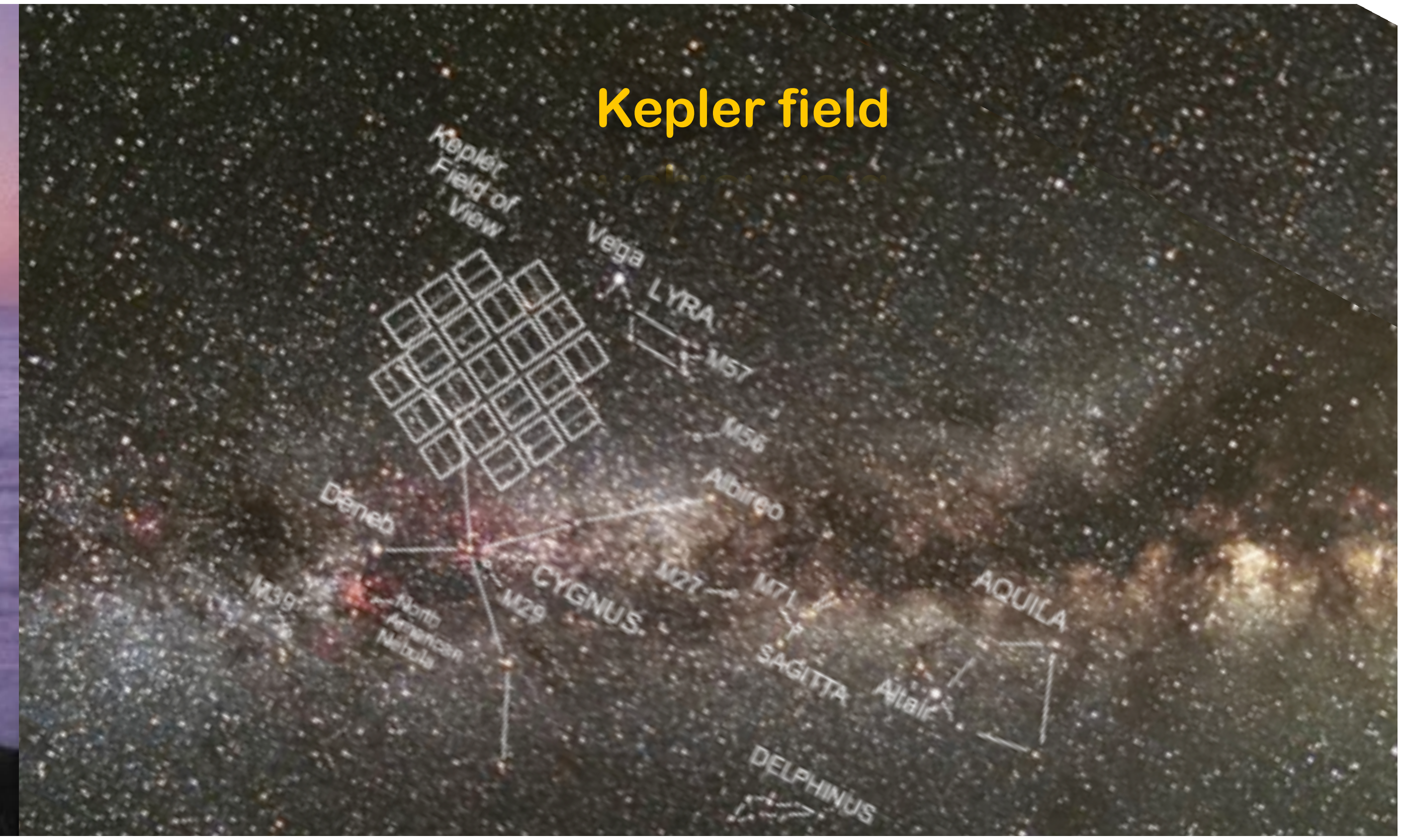





Kepler field
Kepler Field of View
Vega
LYRA
M57
M56
Albireo
Deneb
CYGNUS
M29
M39
North American Nebula
M27
M71
SAGITTA
Altair
AQUILA
DELPHINUS

Strömgren survey for Asteroseismology and Galactic Archaeology

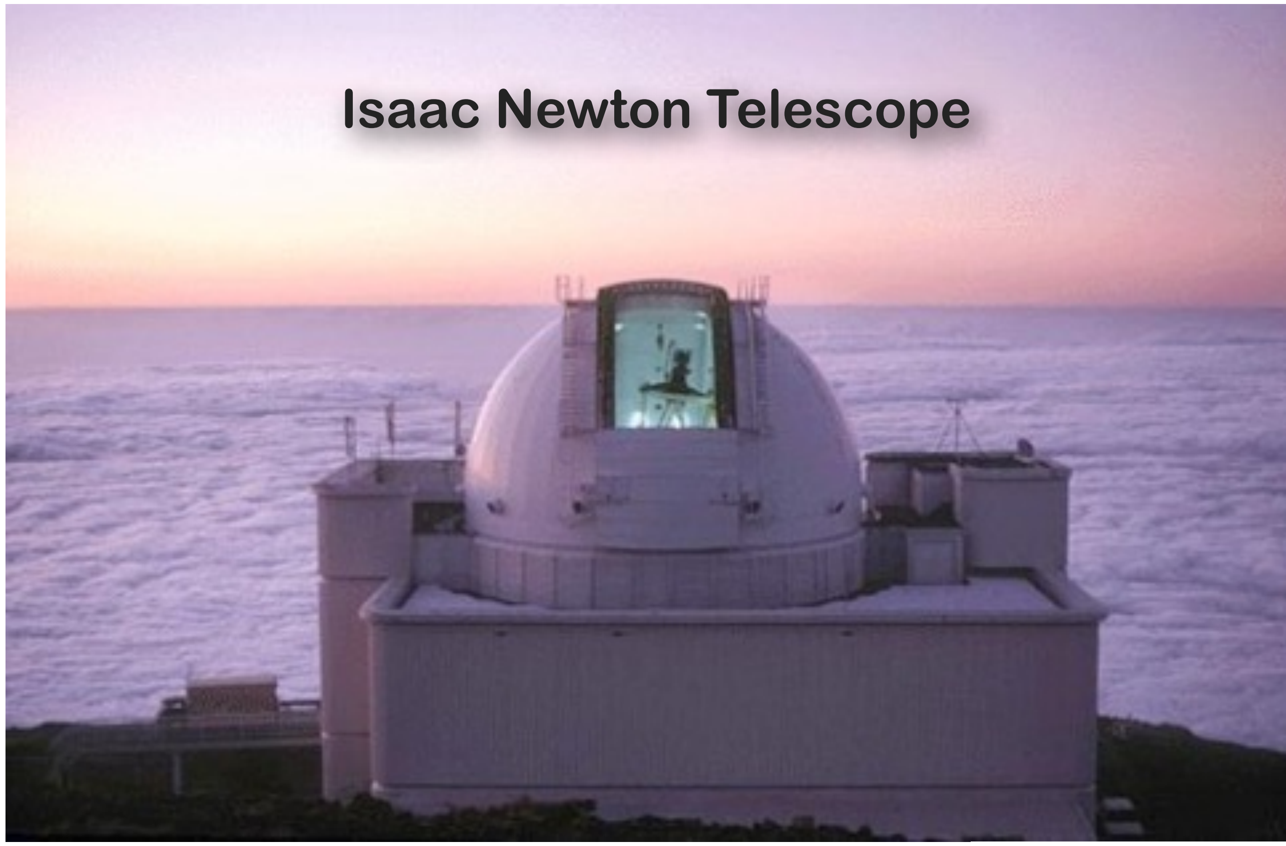


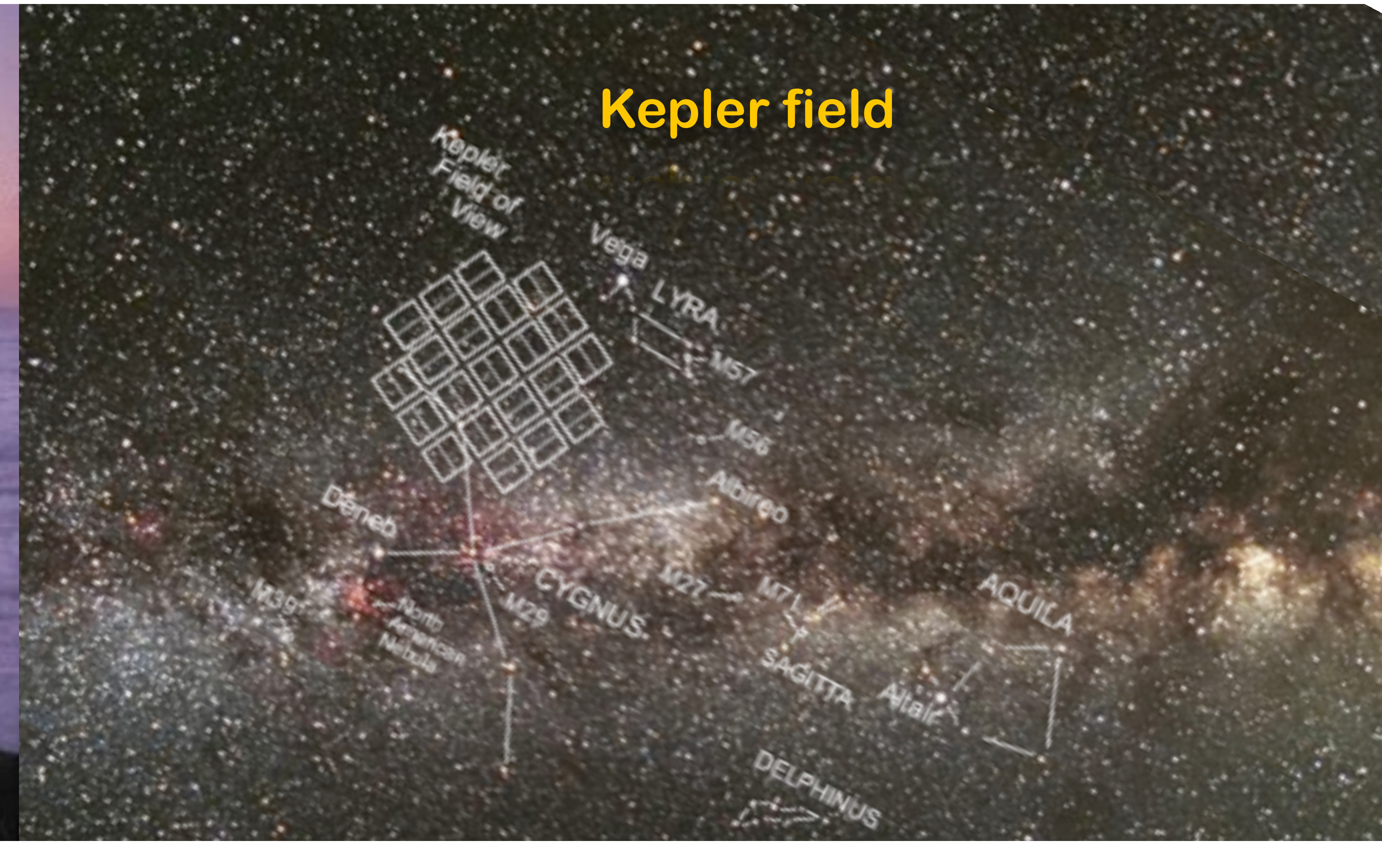


WFC @ INT:
- 2.5 m
- 34' x 34' FOV
- Strömgren uvby
- 28 nights (2012-2014)
- 37 nights (2015)

Casagrande, Silva Aguirre, Serenelli, Stello, Huber, Feltzing, Schlesinger

Strömgren survey for Asteroseismology and Galactic Archaeology





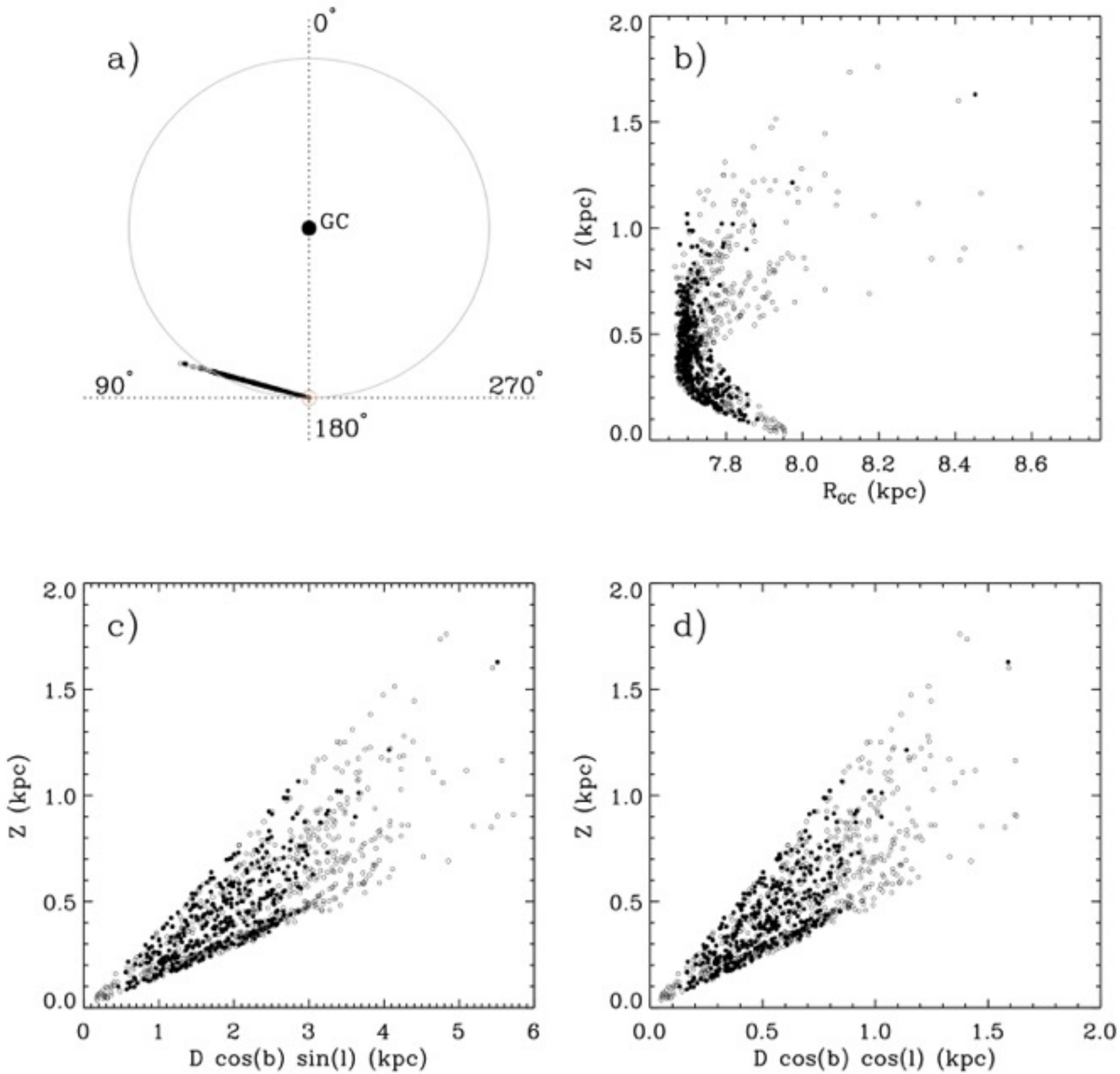
WFC @ INT:

- 2.5 m
- 34’ x 34’ FOV
- Strömgren uvby
- 28 nights (2012-2014)
- 37 nights (2015)

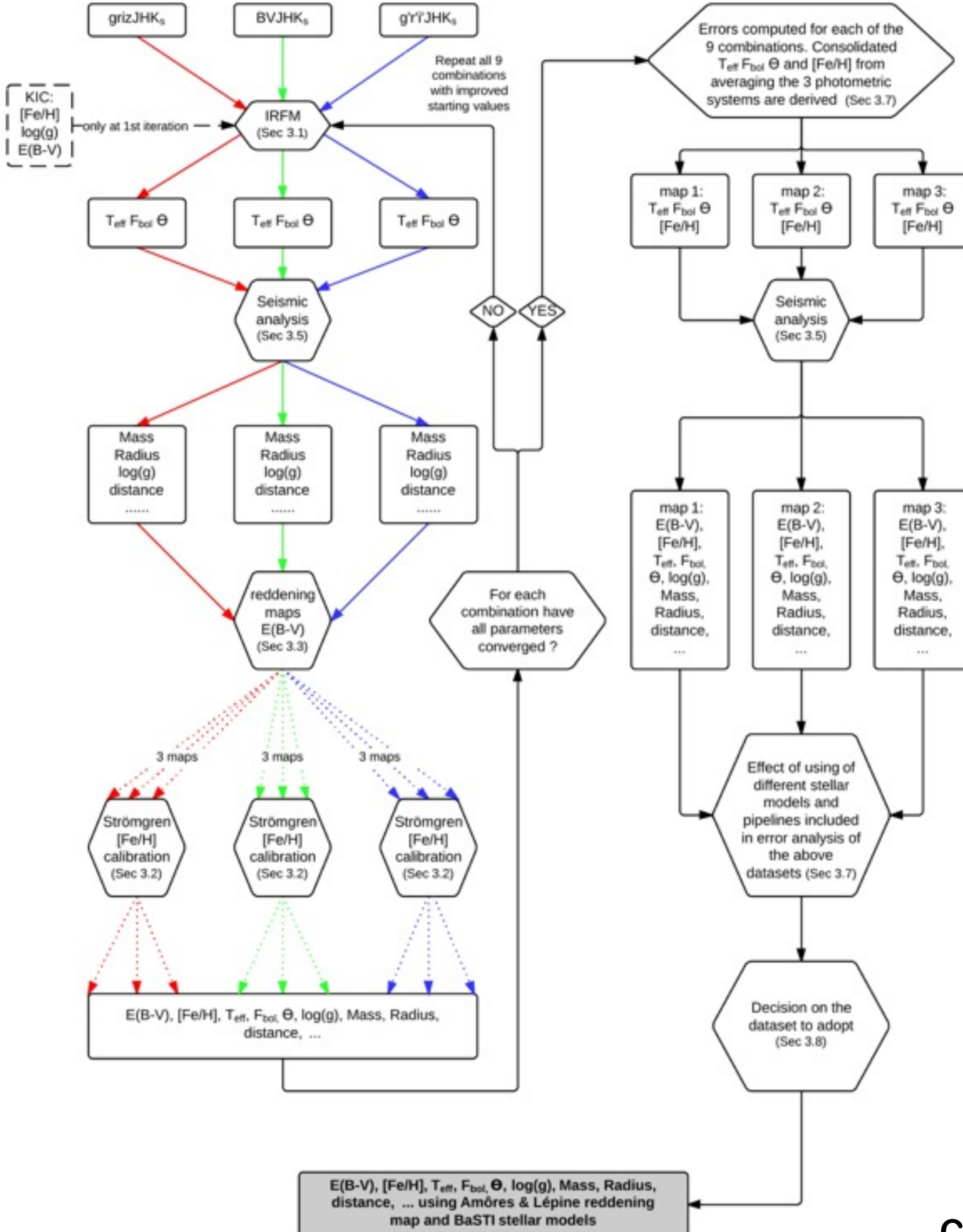
989 seismic stars
29000 stars

Casagrande, Silva Aguirre, Serenelli, Stello, Huber, Feltzing, Schlesinger

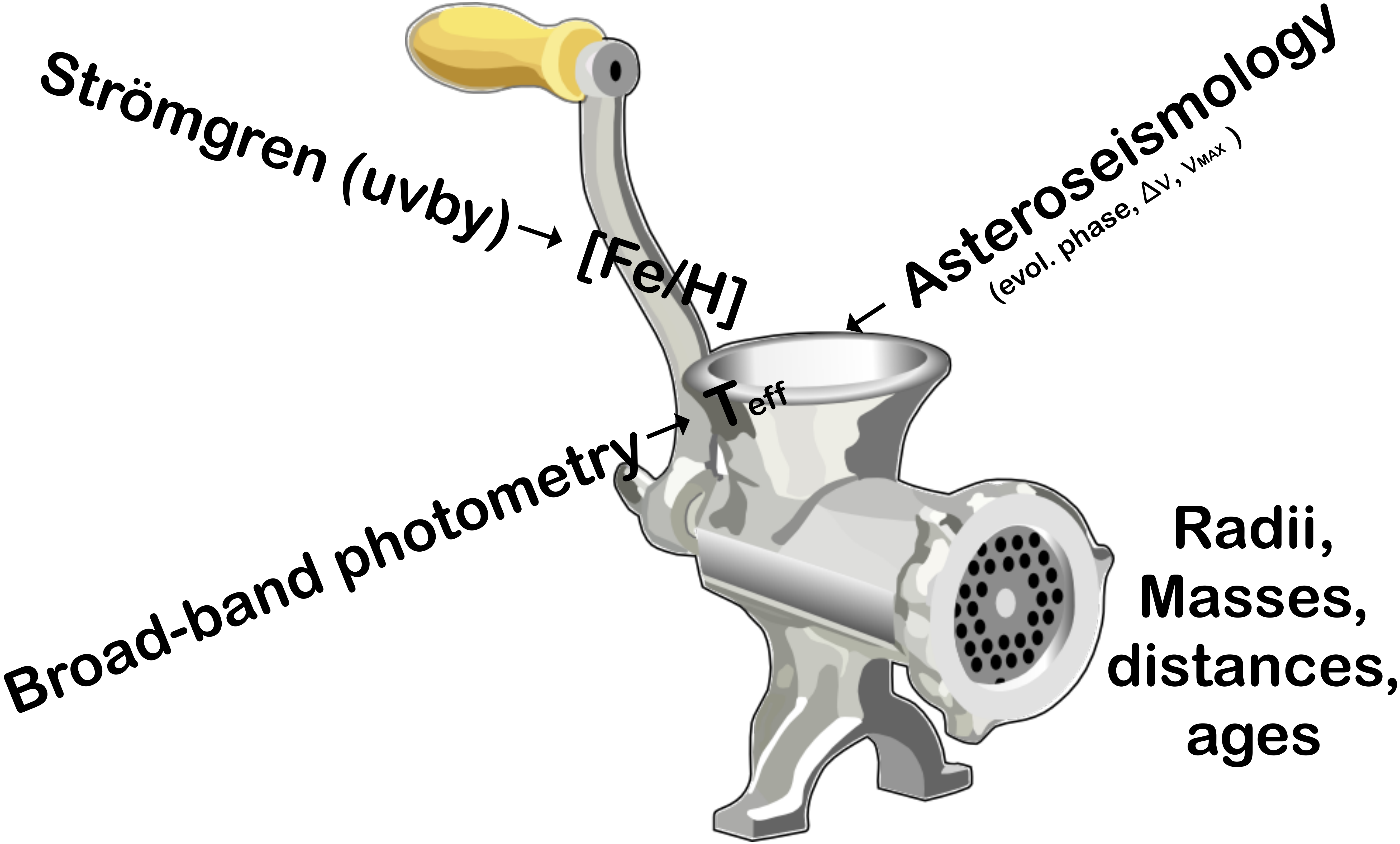
In situ

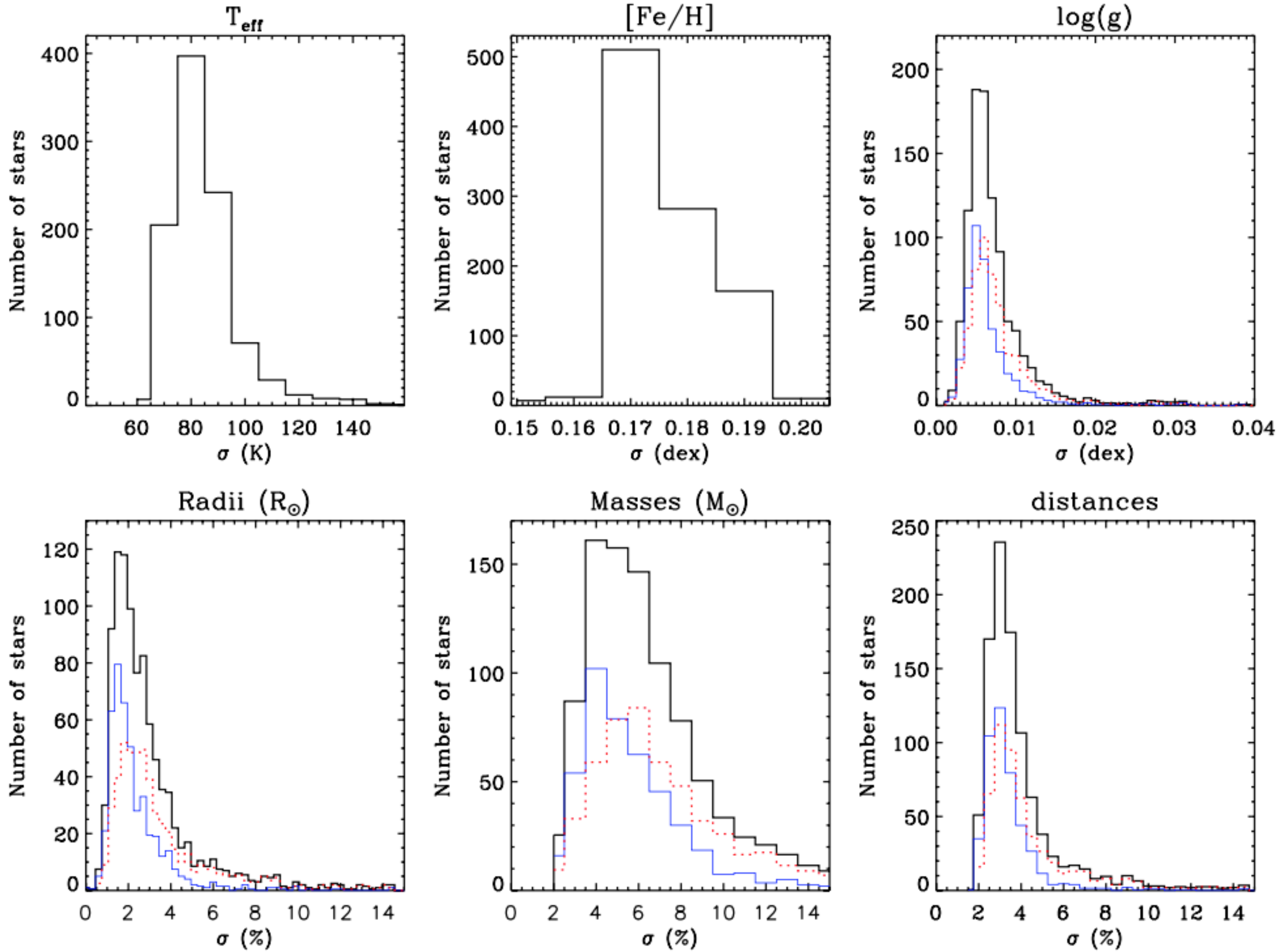


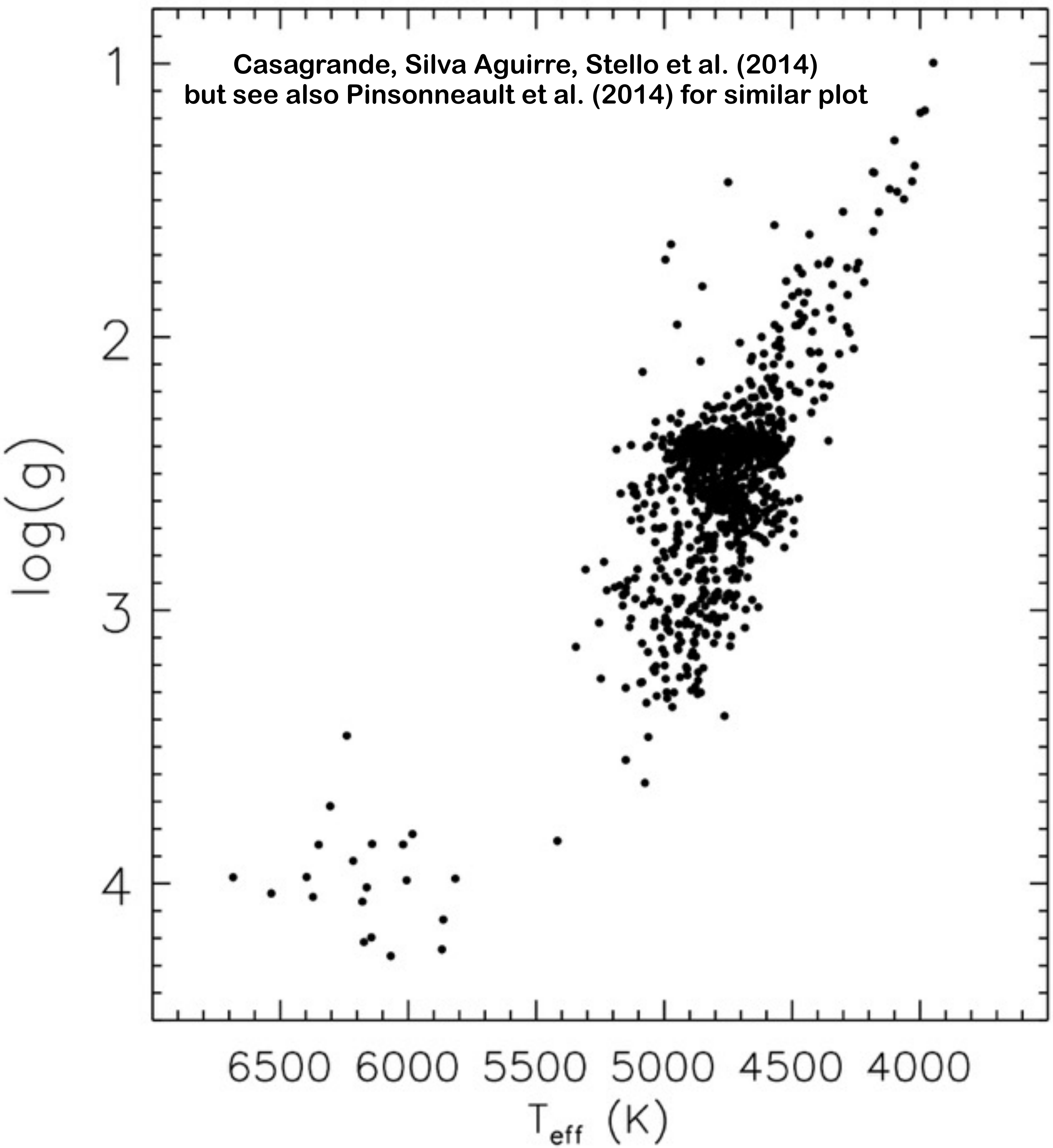
a)
0°
90°
270°
180°
GC
b)
Z (kpc)
R_{GC} (kpc)
c)
Z (kpc)
D cos(b) sin(l) (kpc)
d)
Z (kpc)
D cos(b) cos(l) (kpc)



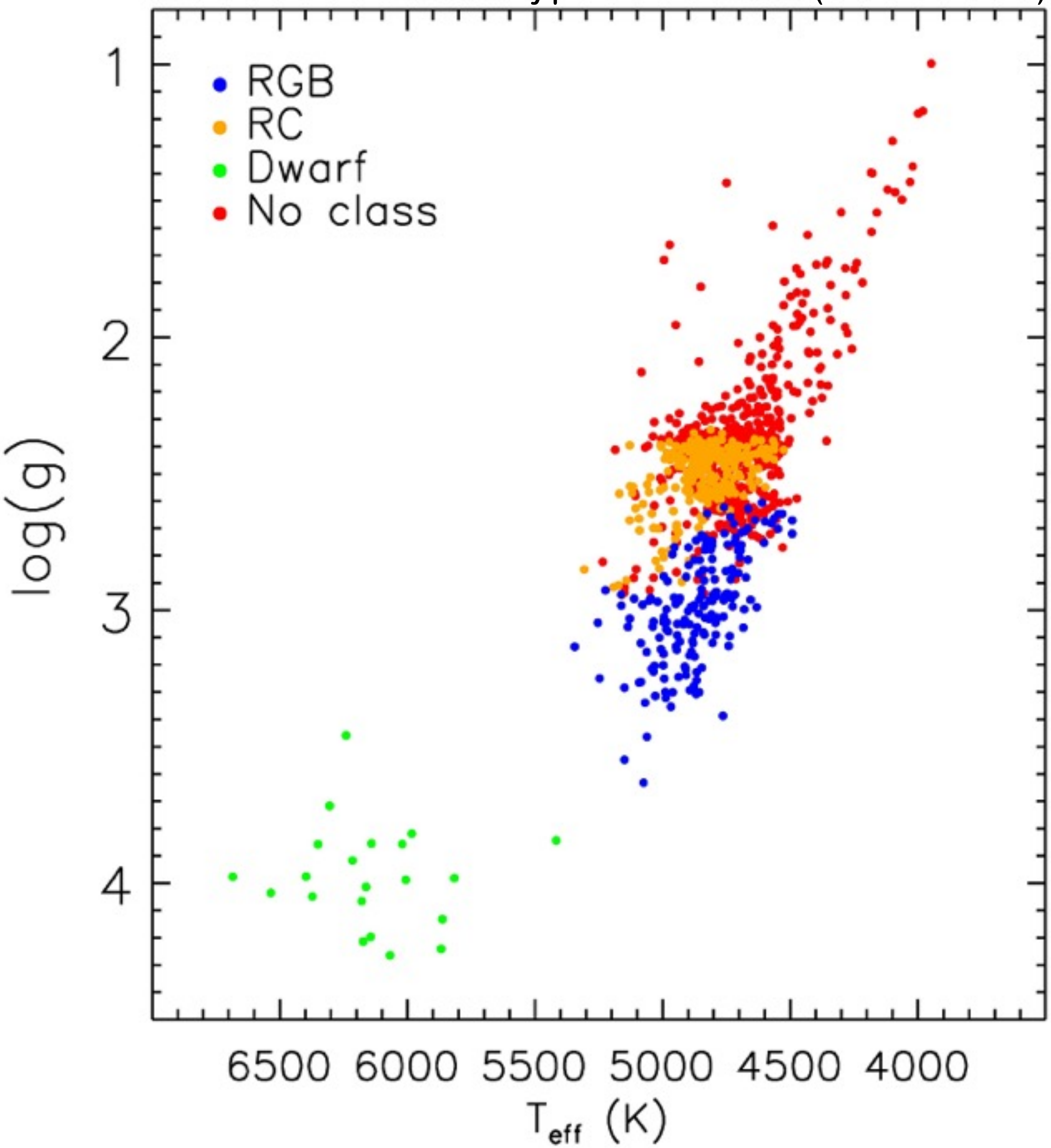
Casagrande et al. (2014)

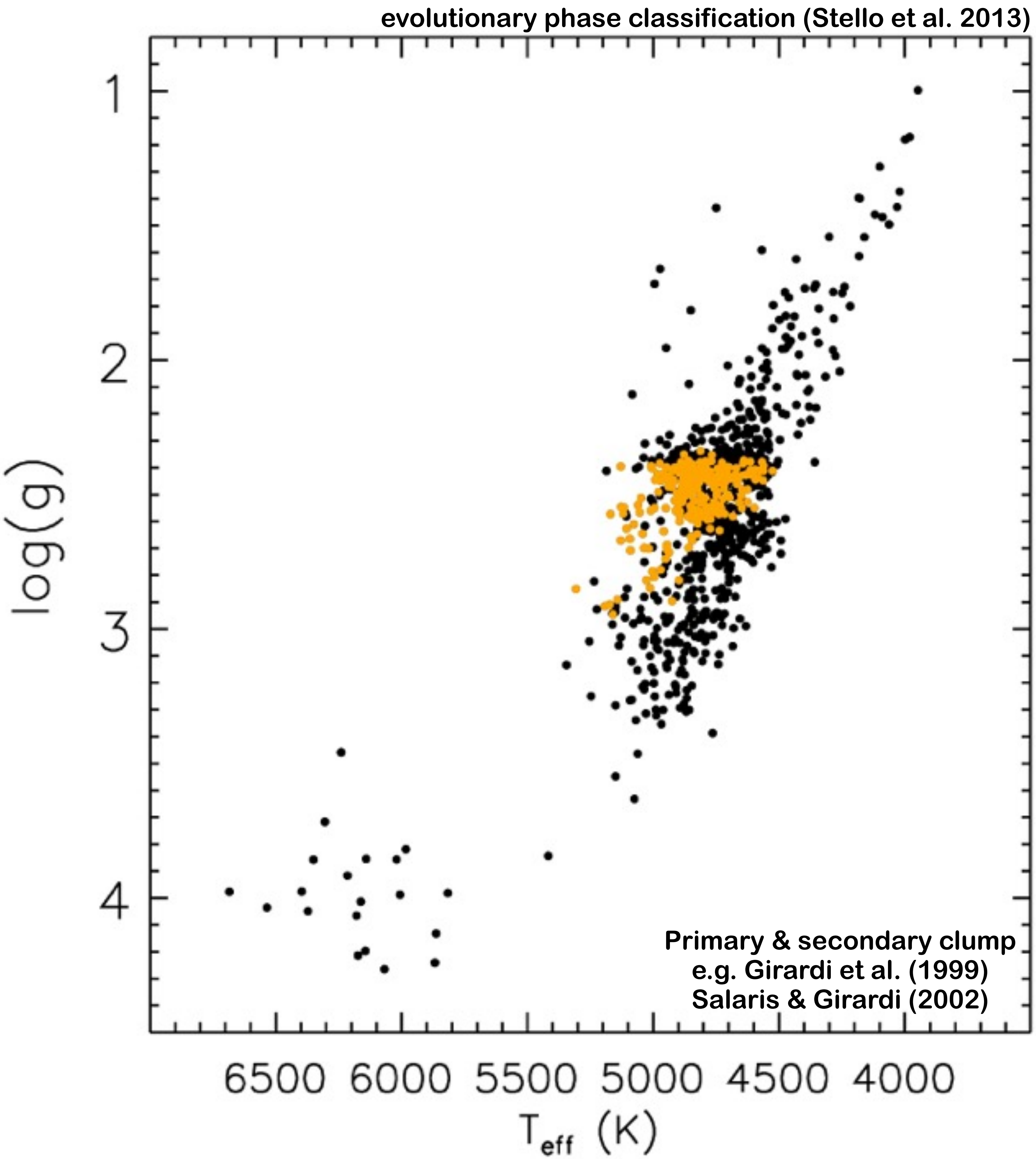

Strömgren (uvby)→ [Fe/H]
← Asteroseismology
(evol. phase, $\Delta\nu$, ν_{MAX})
Broad-band photometry→ T_{eff}
Radii,
Masses,
distances,
ages


T_eff
[Fe/H]
log(g)
Radii (R_⊙)
Masses (M_⊙)
distances
Number of stars
σ (K)
σ (dex)
σ (%)


Casagrande, Silva Aguirre, Stello et al. (2014)
but see also Pinsonneault et al. (2014) for similar plot
log(g)
1
2
3
4
6500
6000
5500
5000
4500
4000
T_{eff} (K)

evolutionary phase classification (Stello et al. 2013)

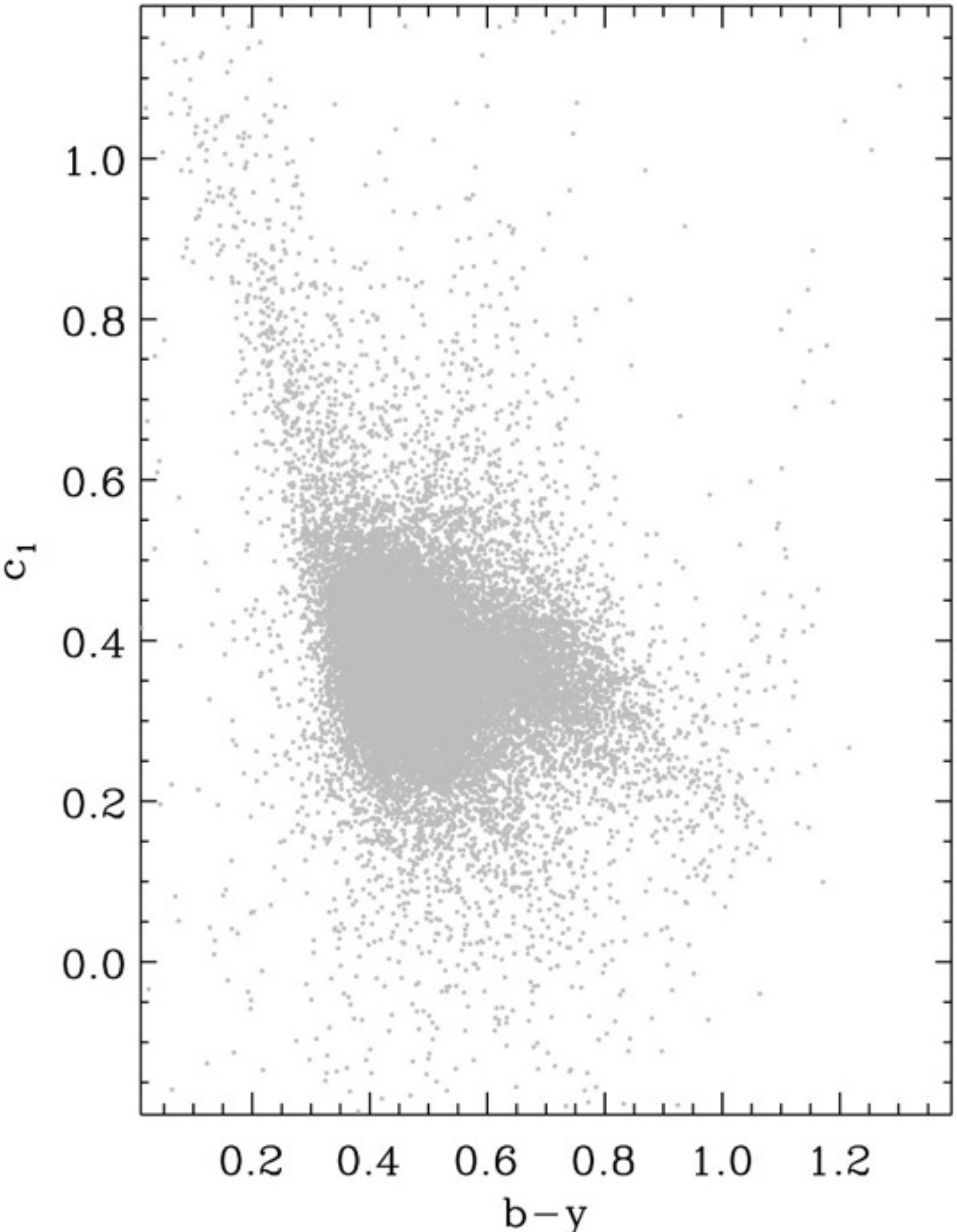



evolutionary phase classification (Stello et al. 2013)
log(g)
1
2
3
4
6500
6000
5500
5000
4500
4000
T_eff (K)
Primary & secondary clump
e.g. Girardi et al. (1999)
Salaris & Girardi (2002)

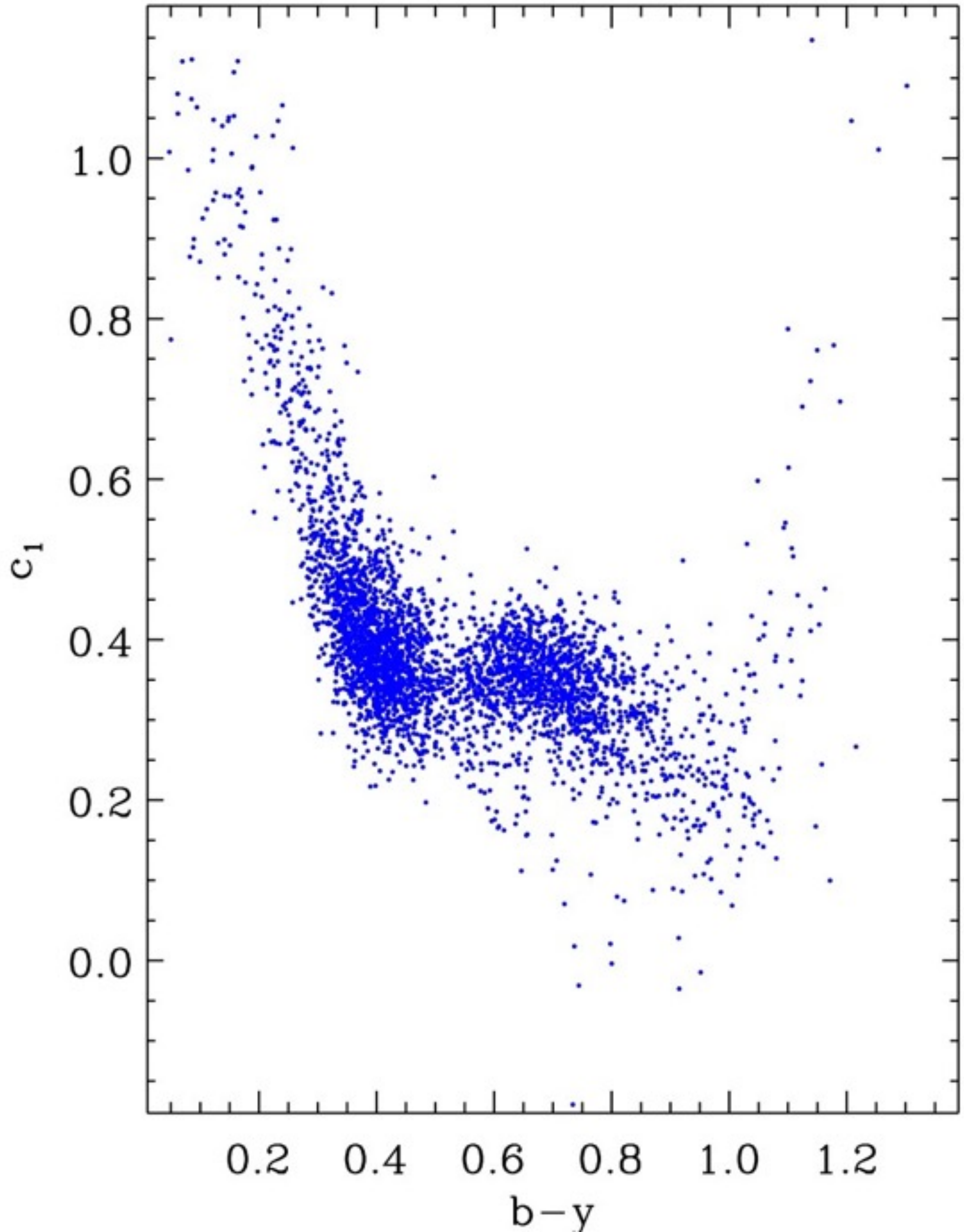
WYSIWYG?

(the magic of asteroseismology?)

Benchmarking

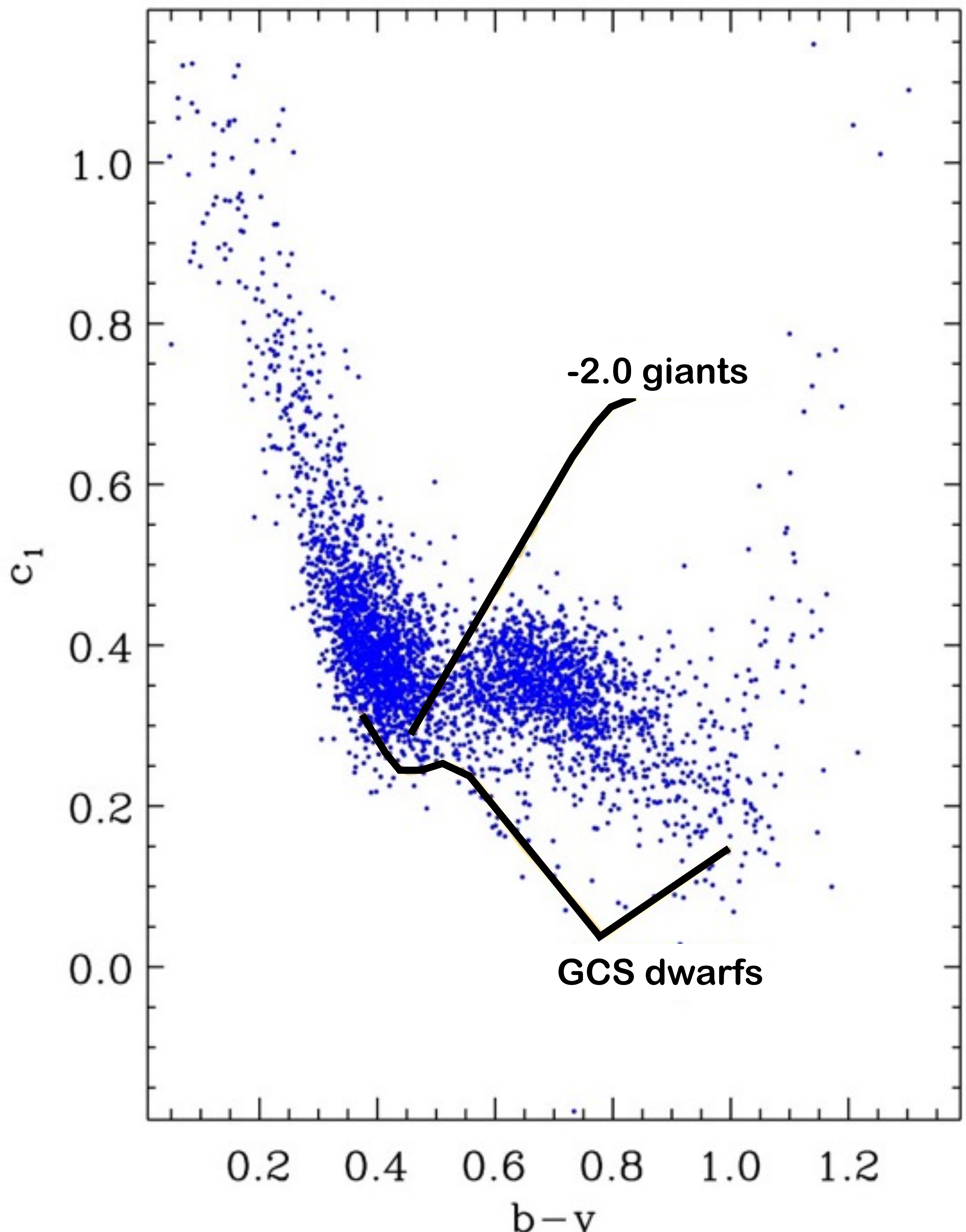


Benchmarking



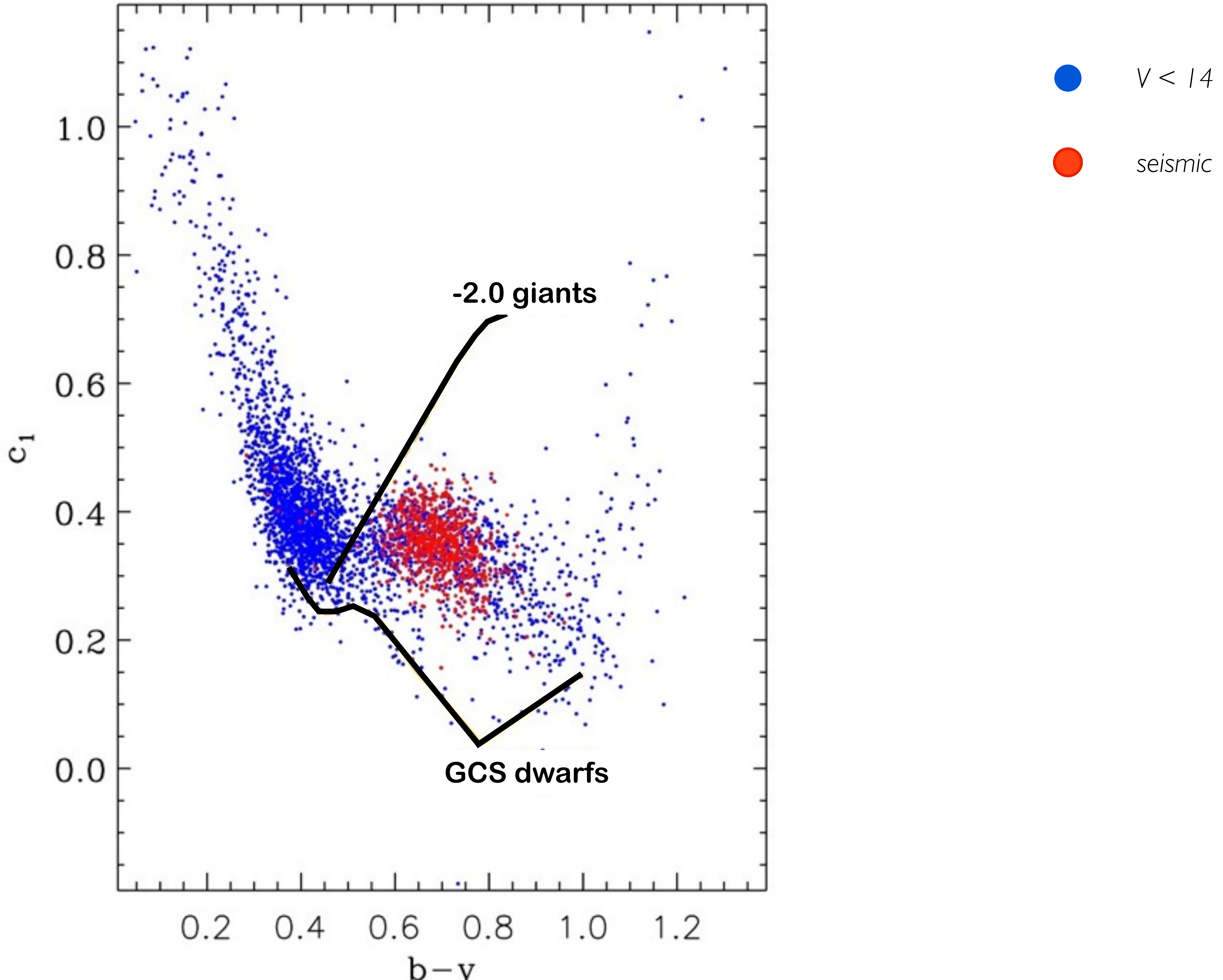
$V < 14$

Benchmarking

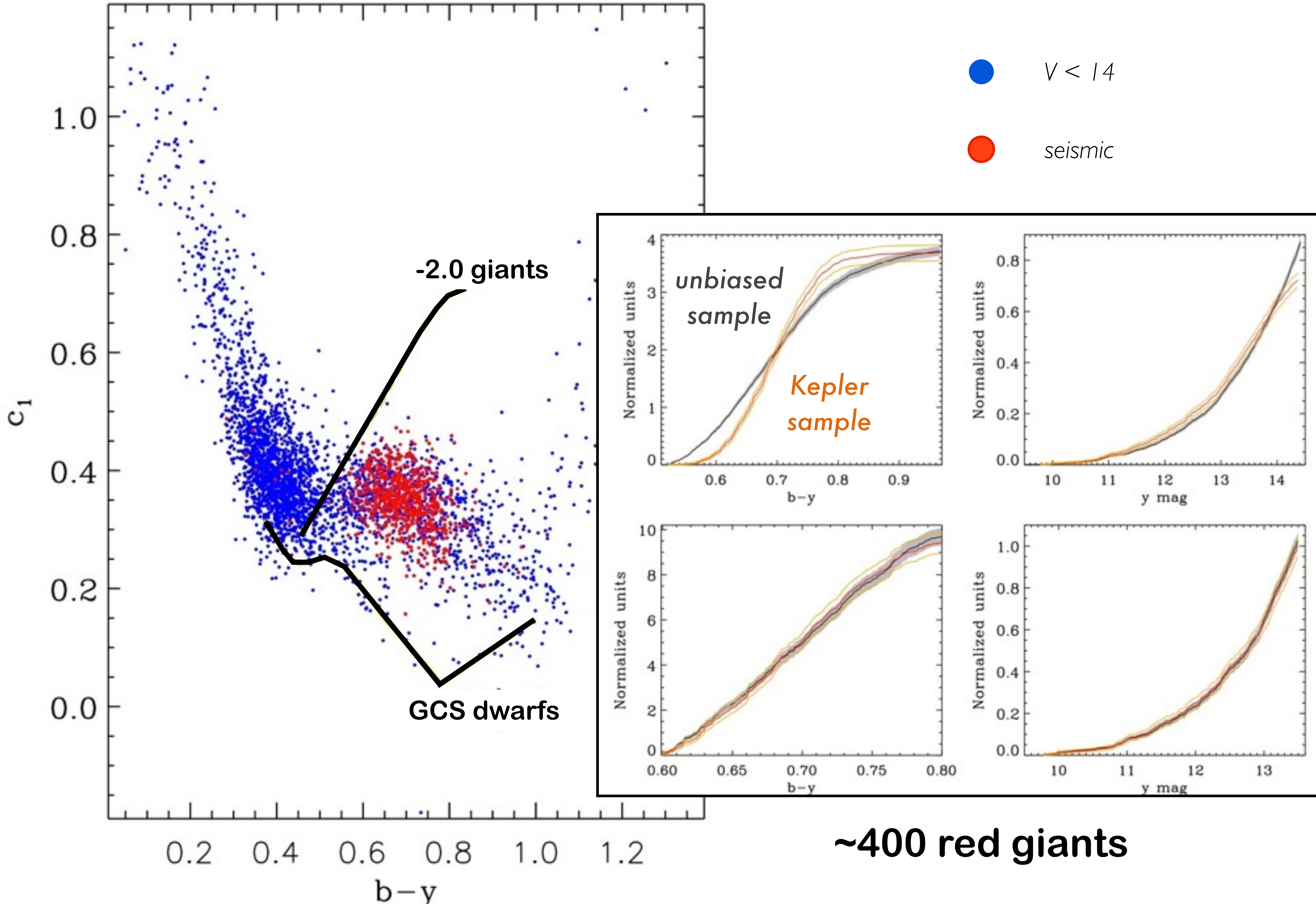


V < 14

Benchmarking



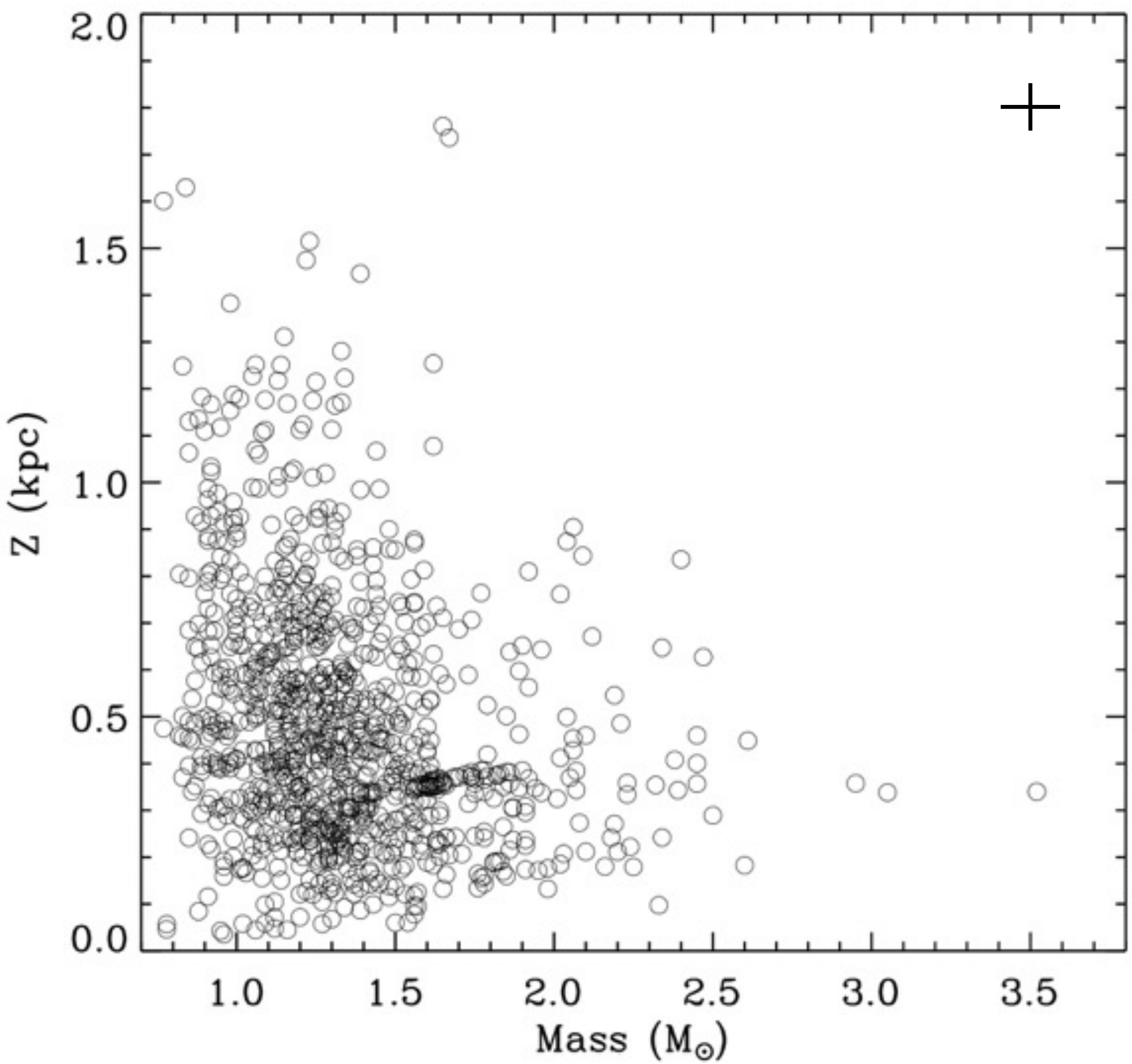
Benchmarking



~400 red giants

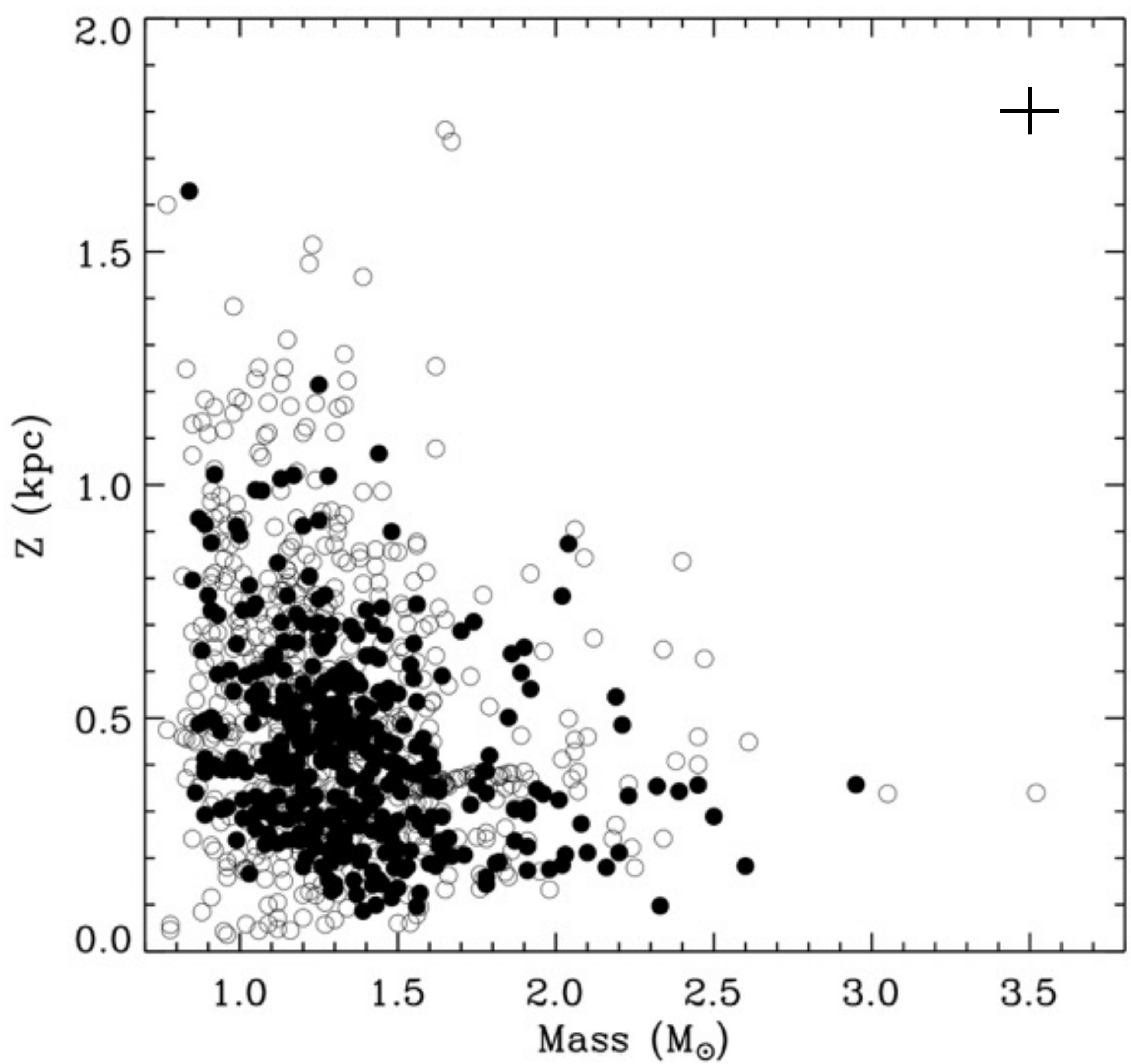
Stellar mass gradient

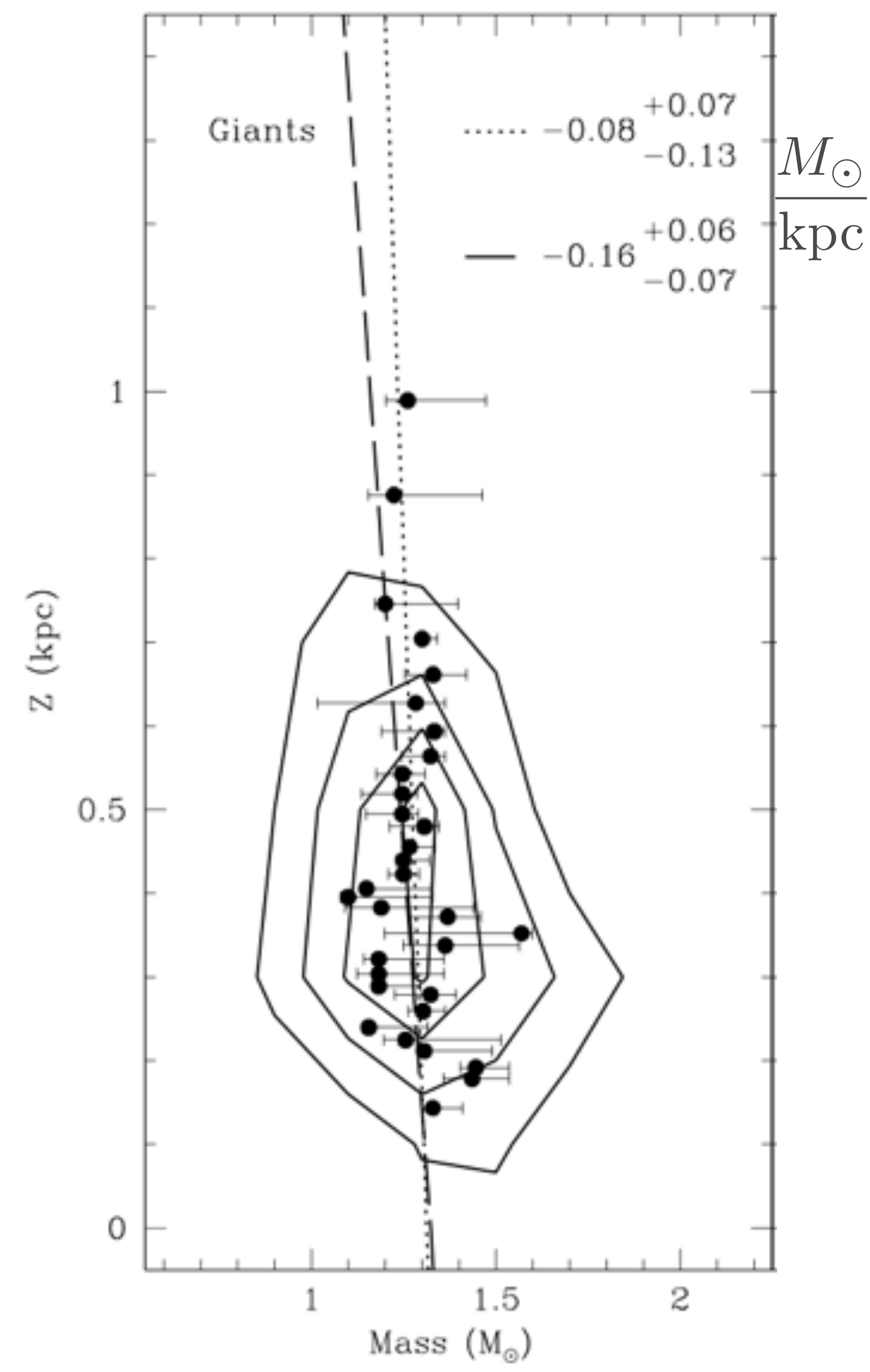
Casagrande, Silva Aguirre, Schlesinger et al. (submitted)



Stellar mass gradient

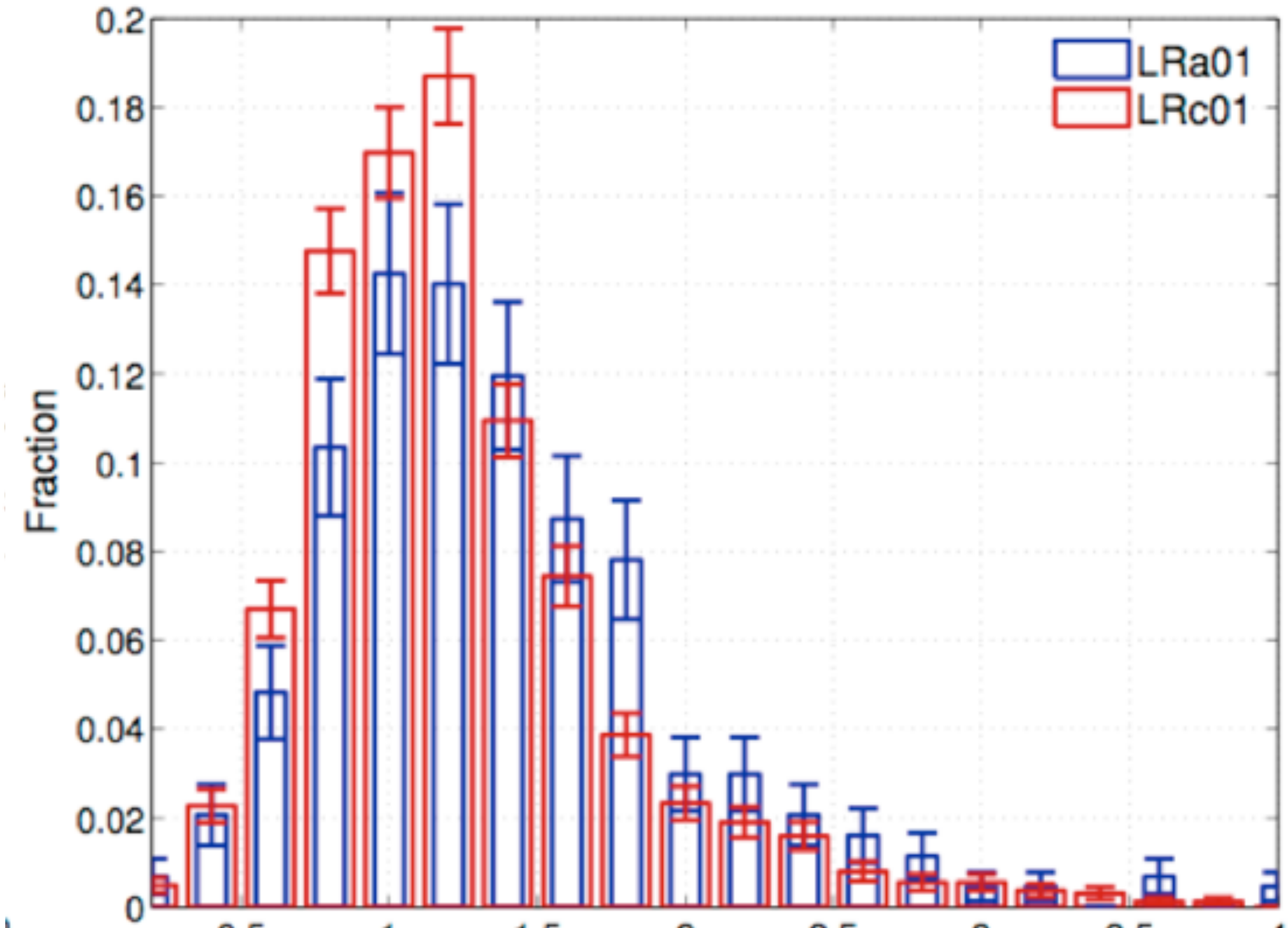
Casagrande, Silva Aguirre, Schlesinger et al. (submitted)



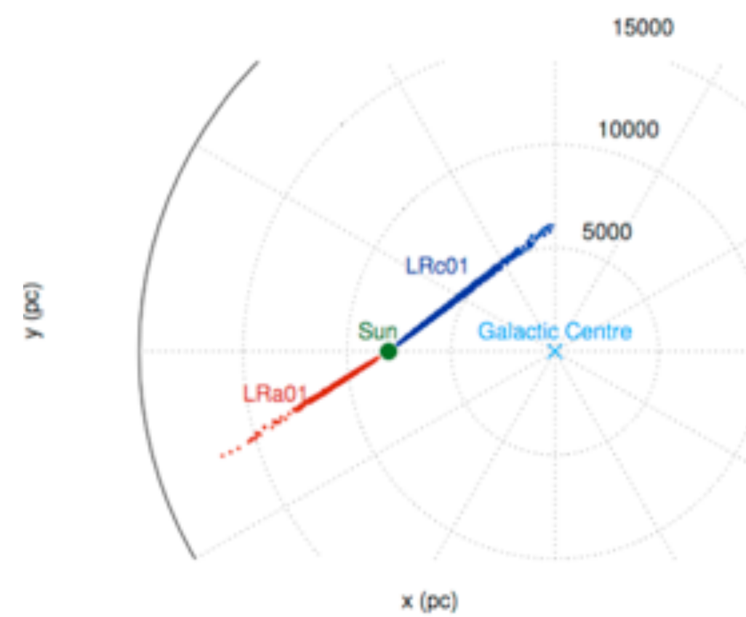


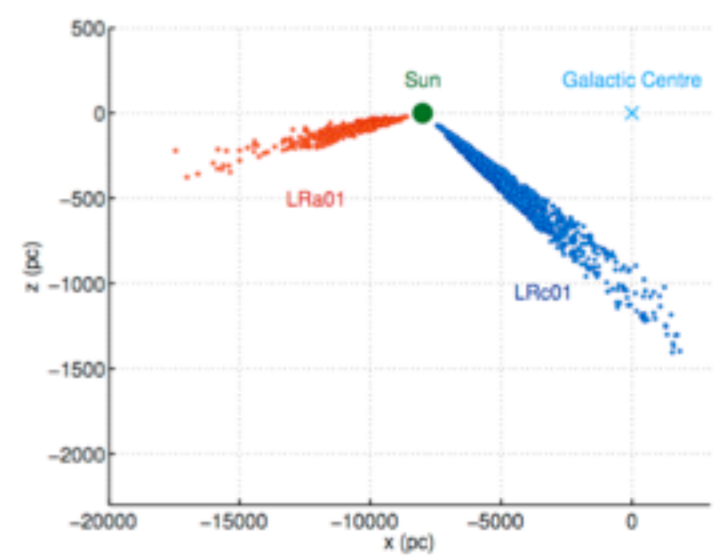
Ages: Giants

RGB : Once a star has evolved to the red-giant phase, its age is determined to good approximation by the time spent in the core-hydrogen burning phase, and this is predominantly a function of mass.



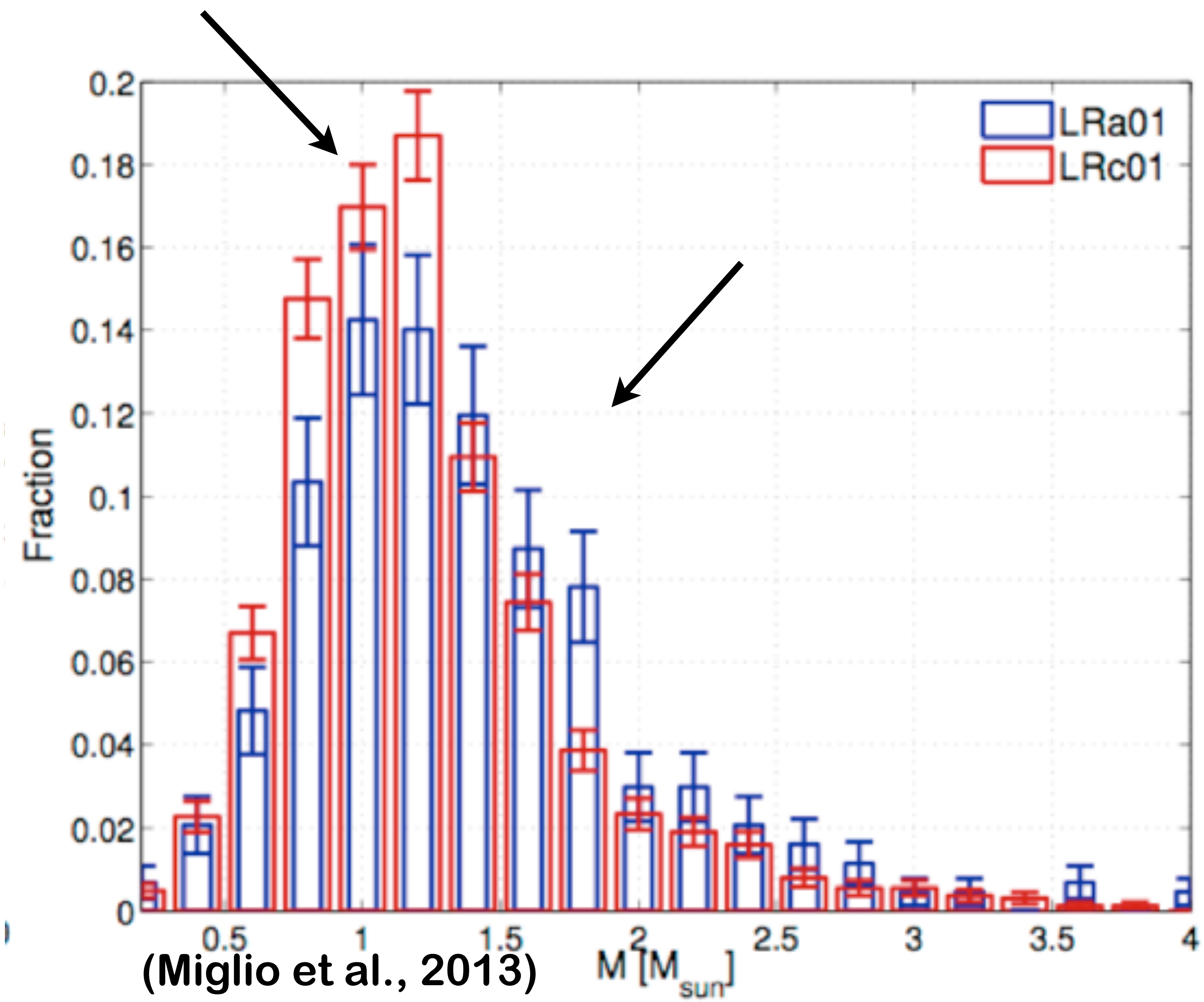
(Miglio et al., 2013)



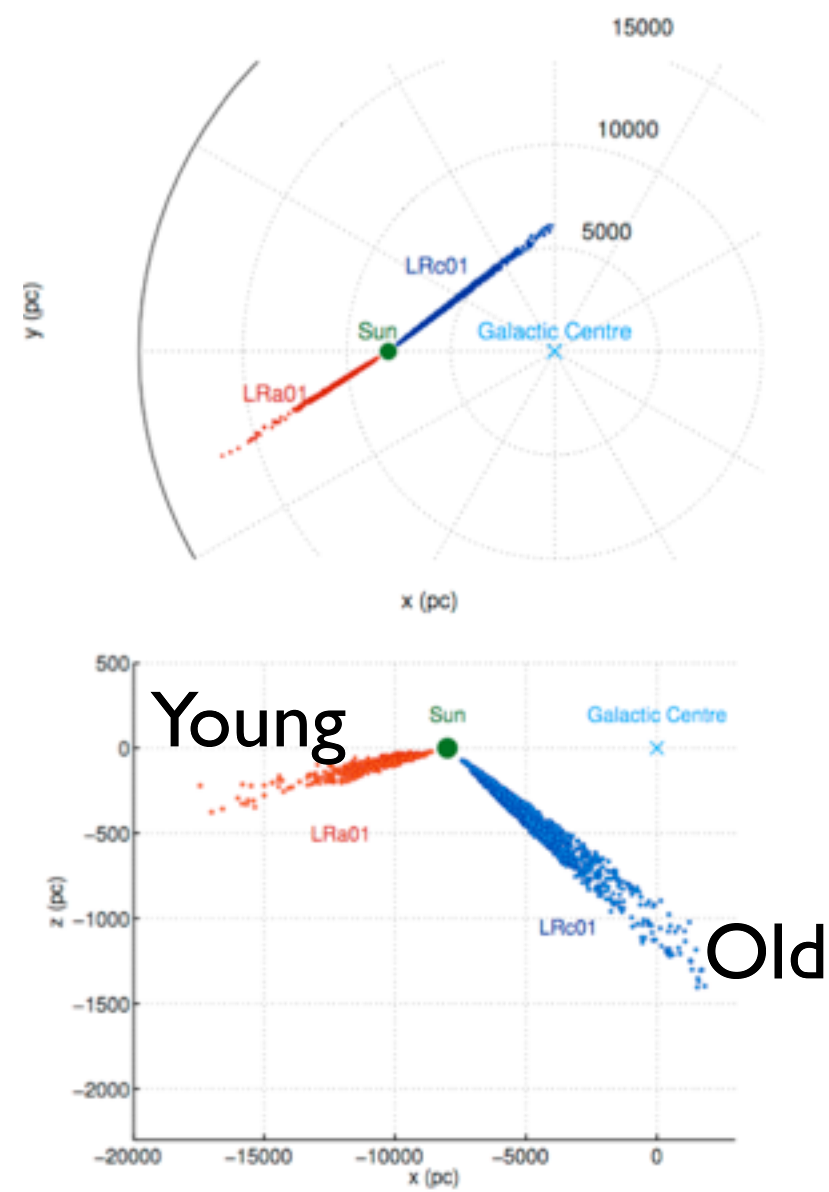


Ages: Giants

RGB : Once a star has evolved to the red-giant phase, its age is determined to good approximation by the time spent in the core-hydrogen burning phase, and this is predominantly a function of mass.

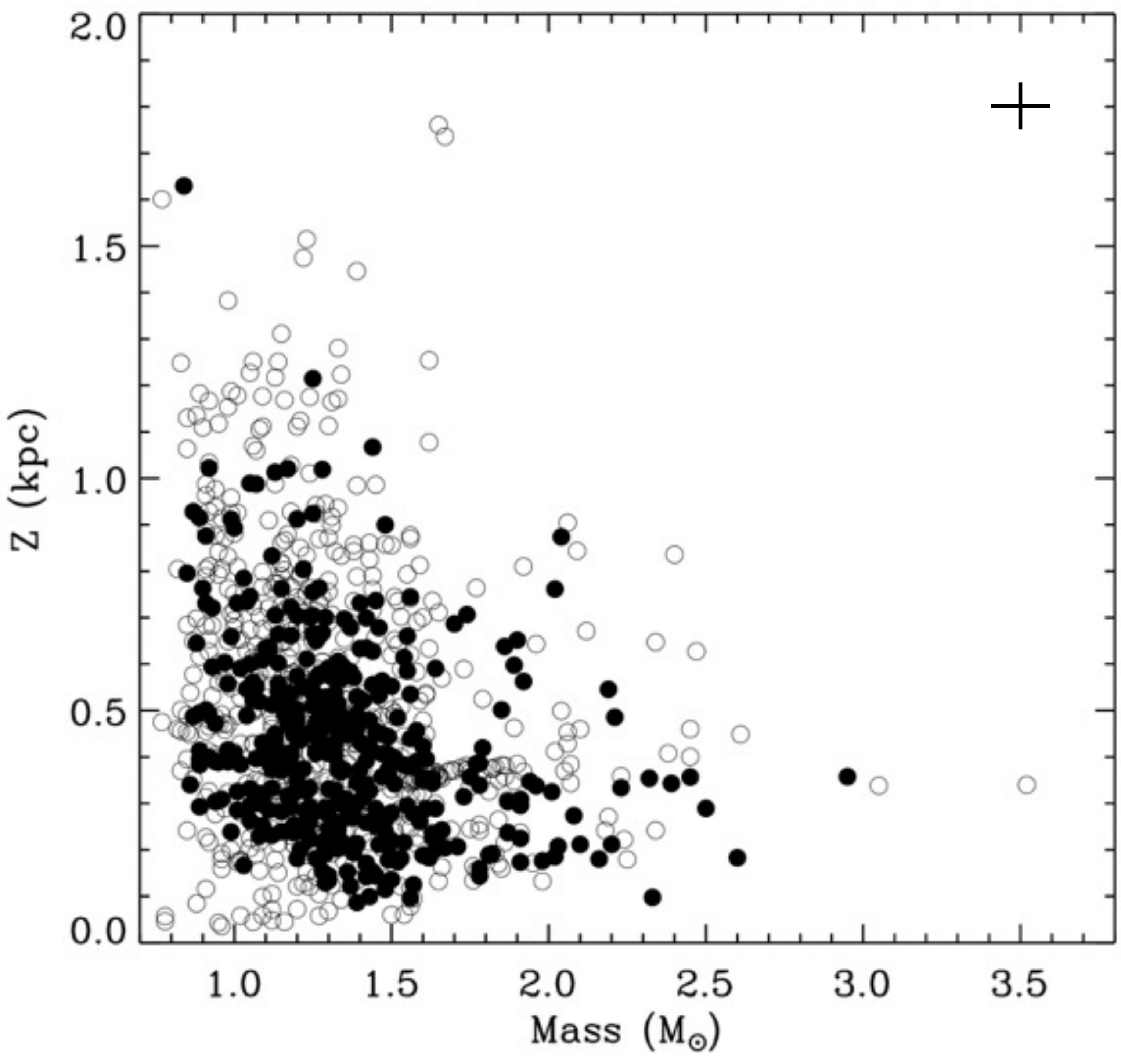


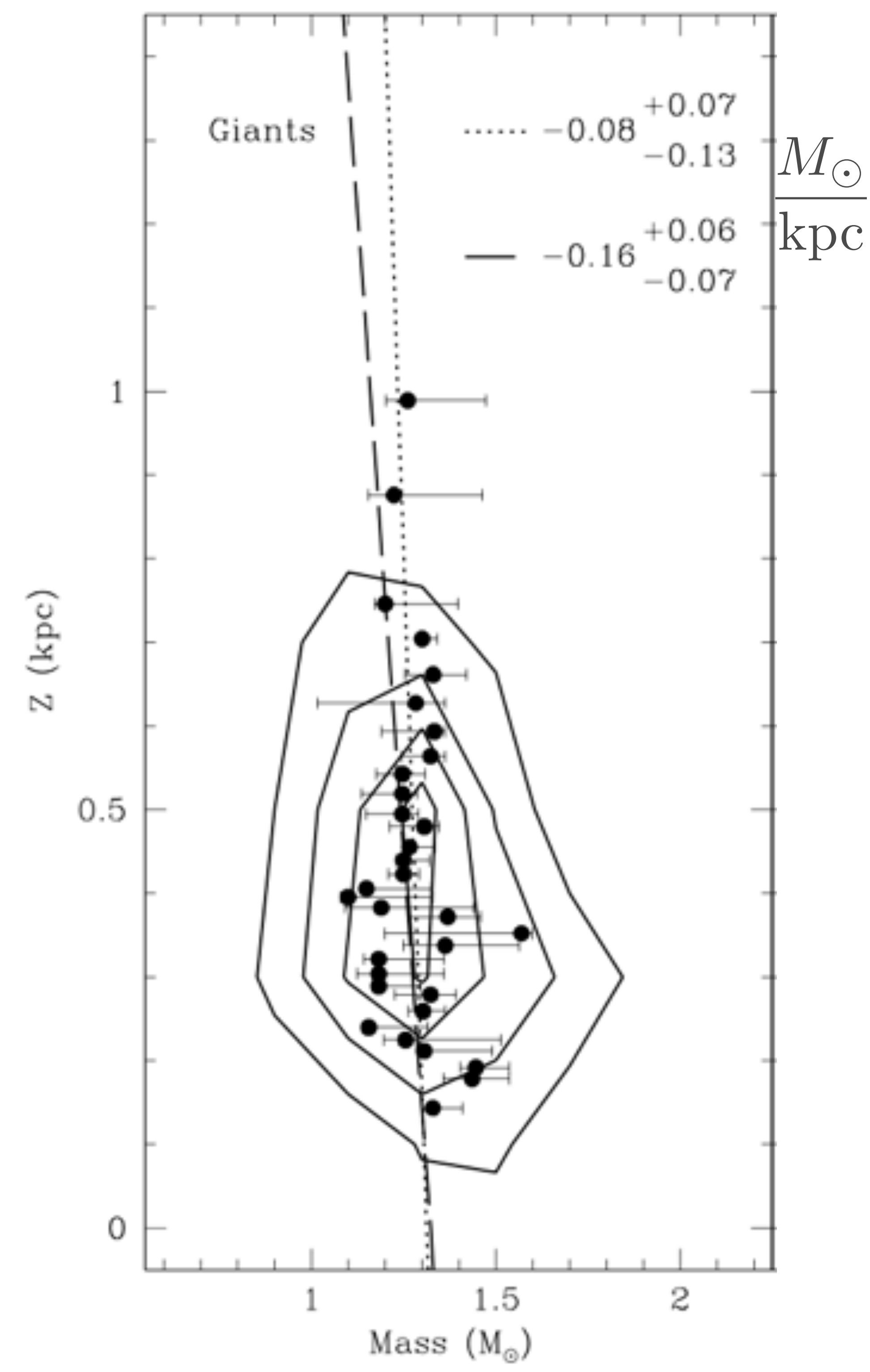
(Miglio et al., 2013)



Stellar mass gradient

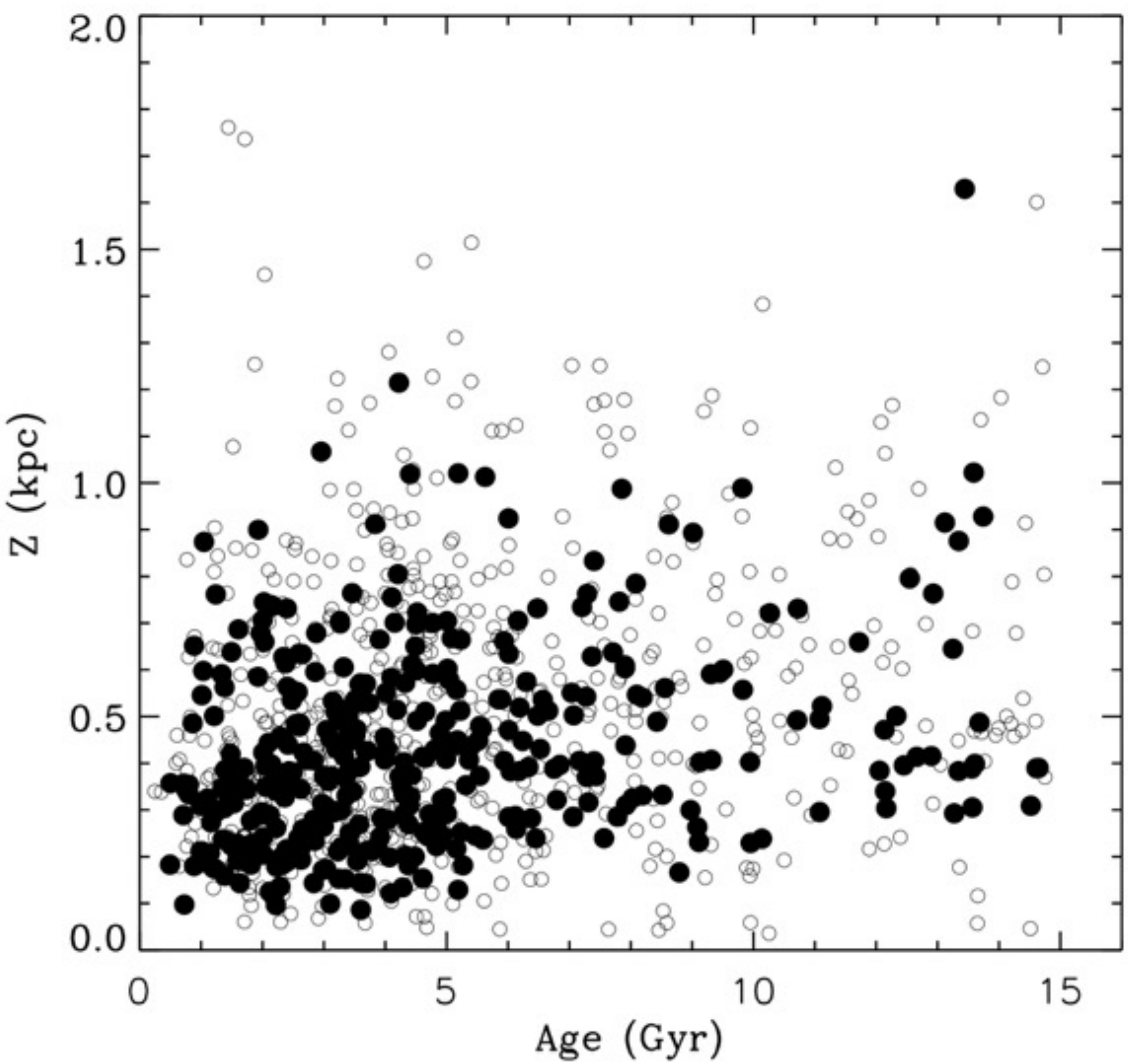
Casagrande, Silva Aguirre, Schlesinger et al. (submitted)





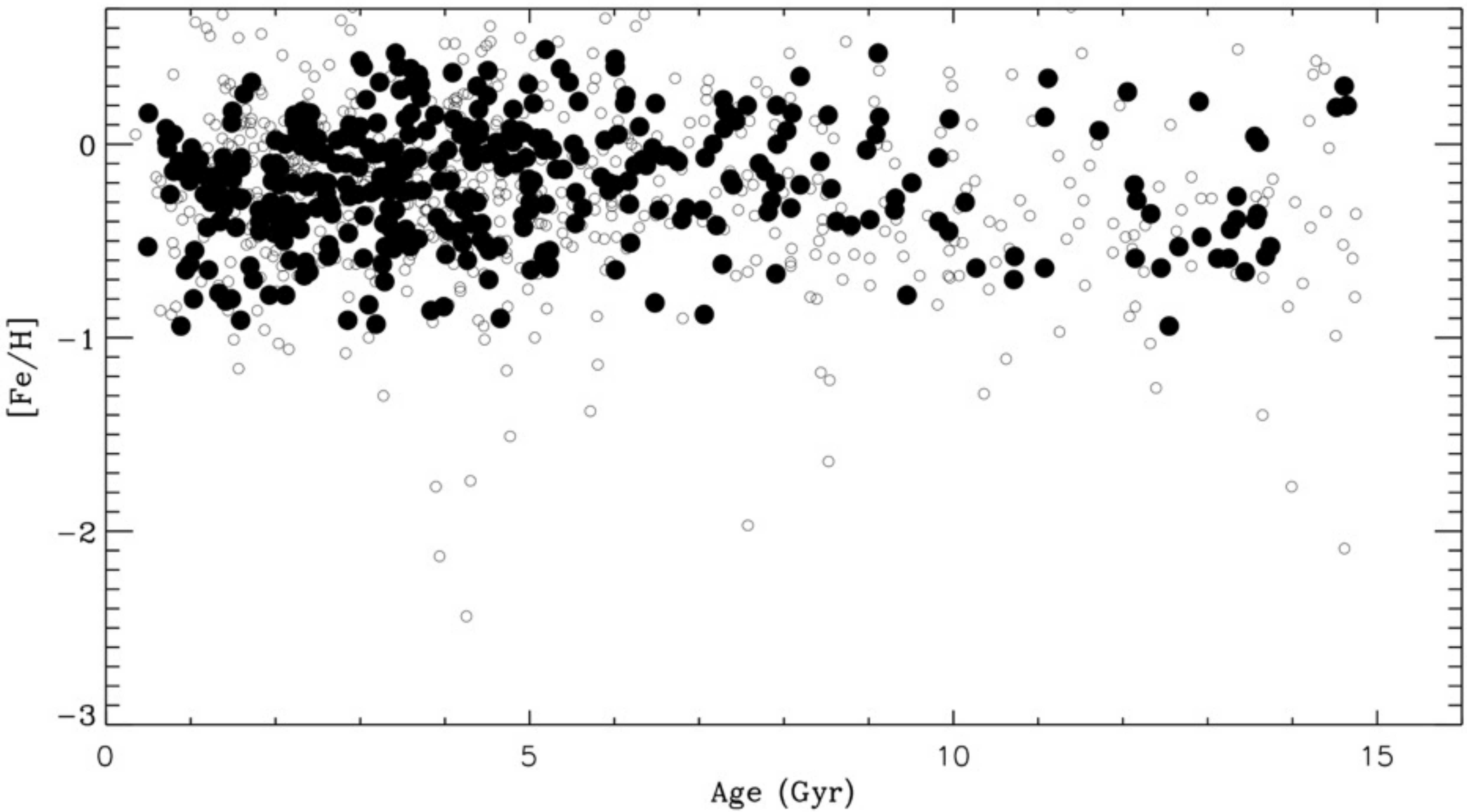
Vertical age gradient

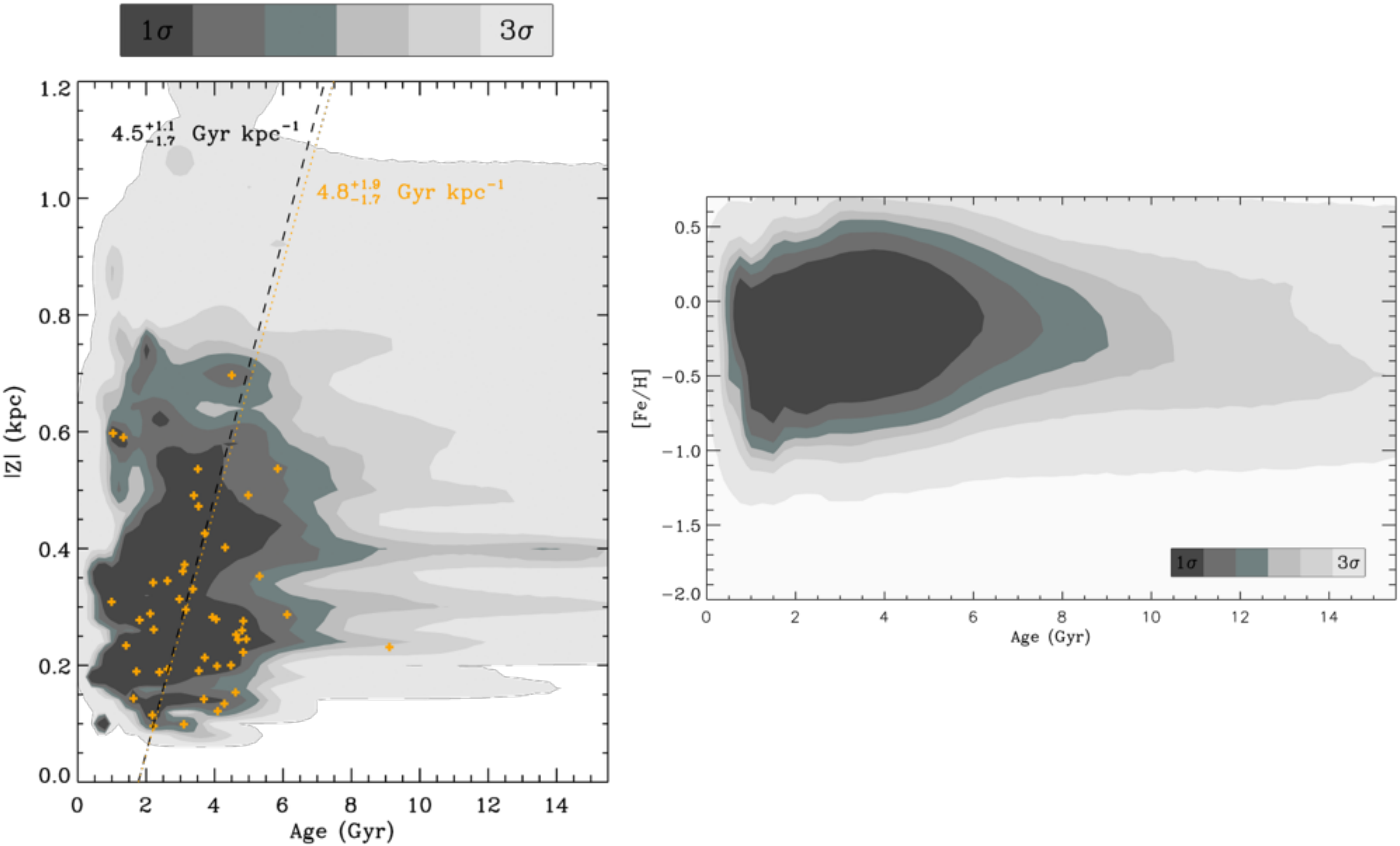
(MNRAS, submitted)



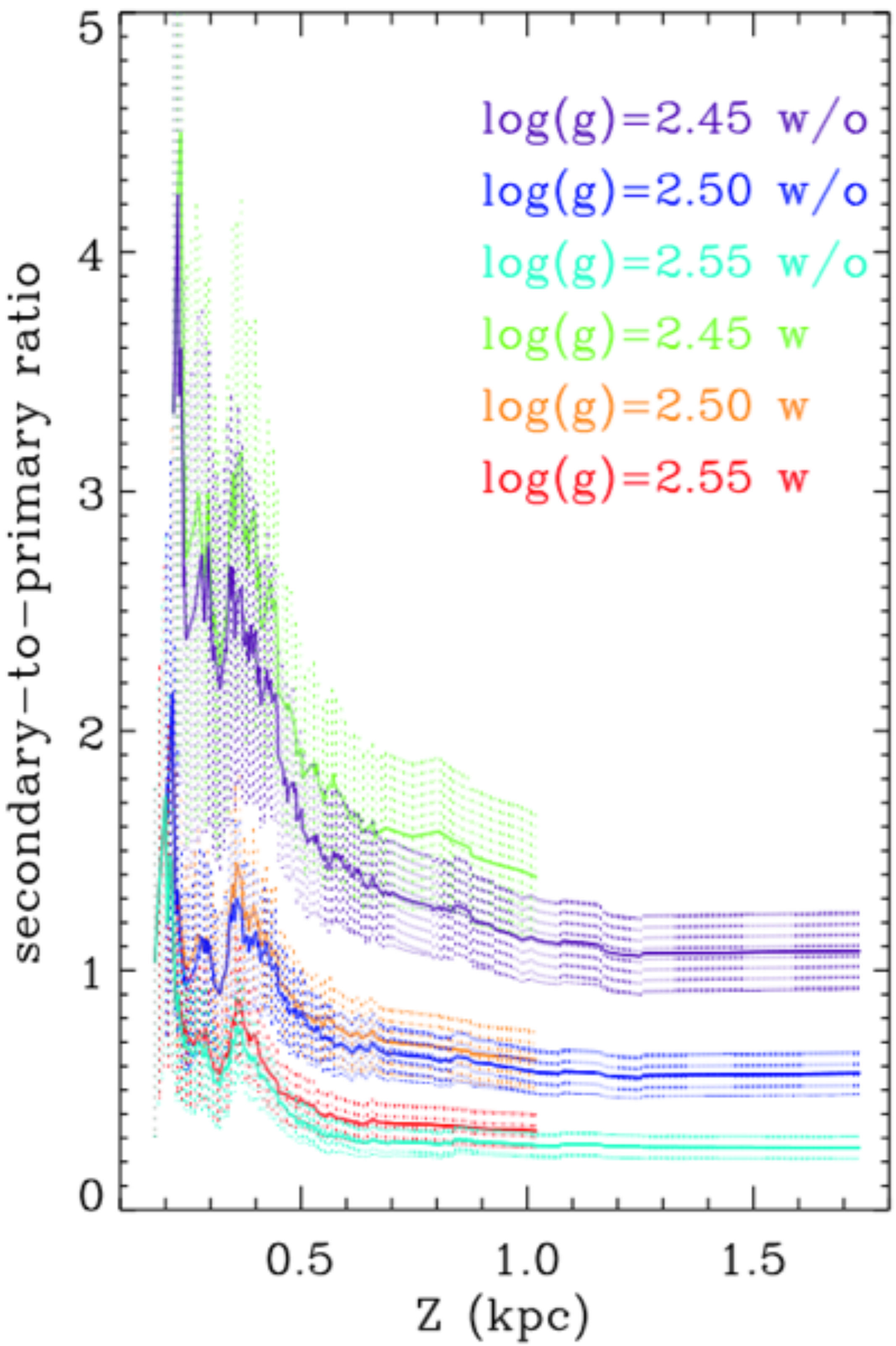
Age Metallicity Relation

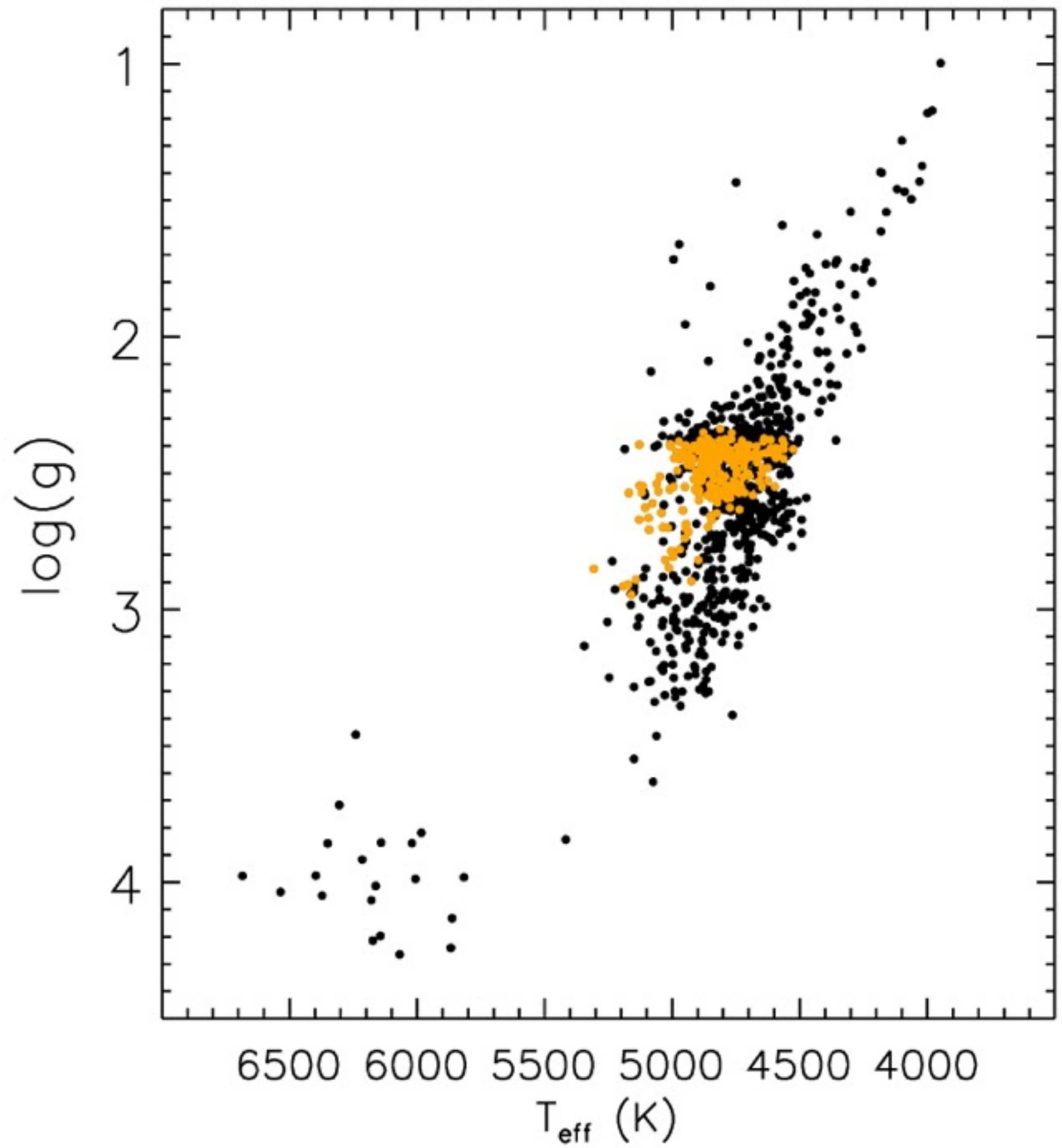
(MNRAS, submitted)



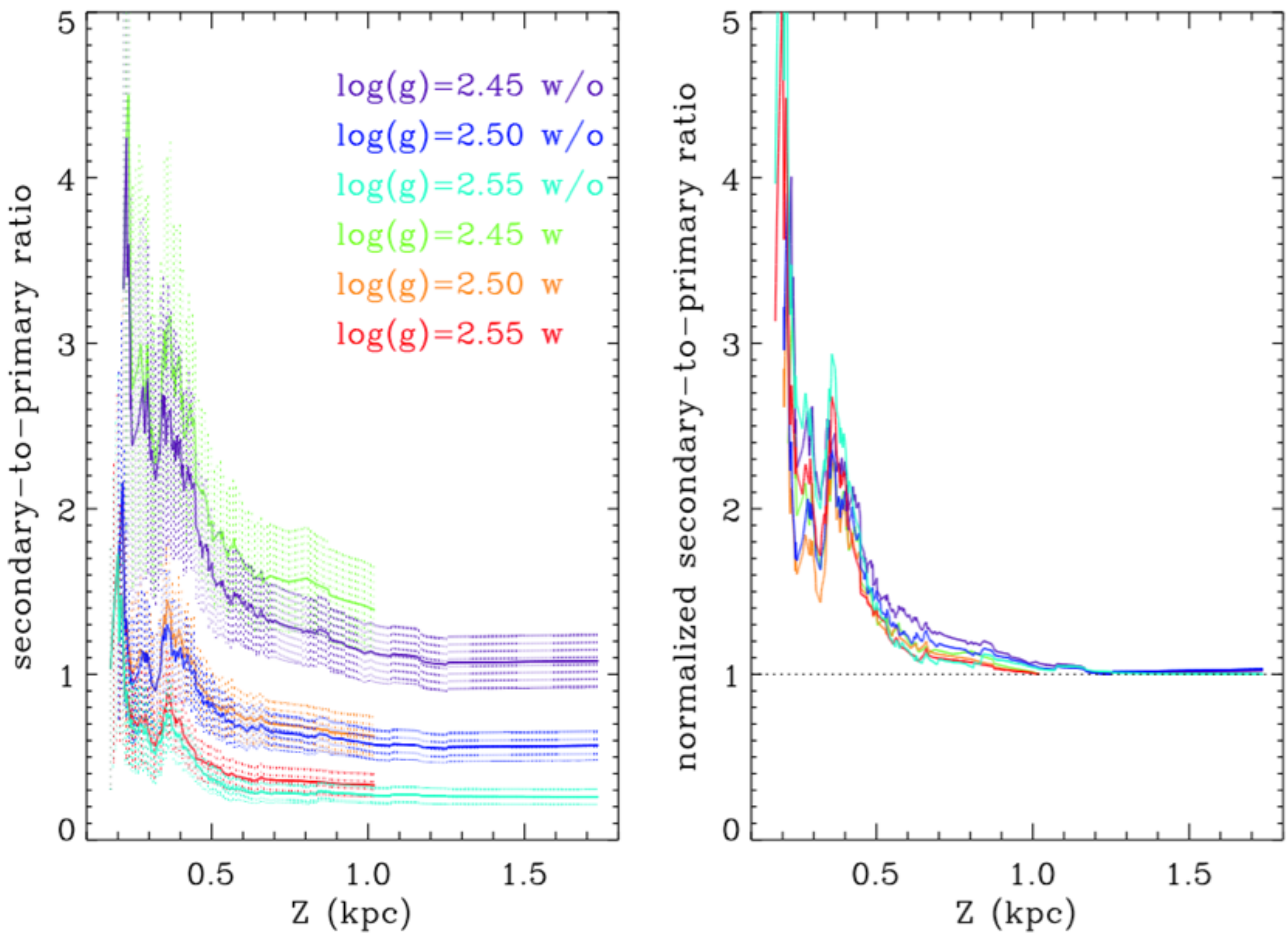

1σ
3σ
4.5 +1.1 −1.7 Gyr kpc⁻¹
4.8 +1.9 −1.7 Gyr kpc⁻¹
|Z| (kpc)
Age (Gyr)
[Fe/H]
Age (Gyr)
1σ
3σ

Secondary to primary # ratio





Secondary to primary # ratio



Conclusions

Photometry: powerful tool gauge into selection function(s)

Asteroseismic R,M,t: "if it is not true, it is well conceived!"

Galactic studies: we can now obtain constraints similar to those available for the solar neighbourhood