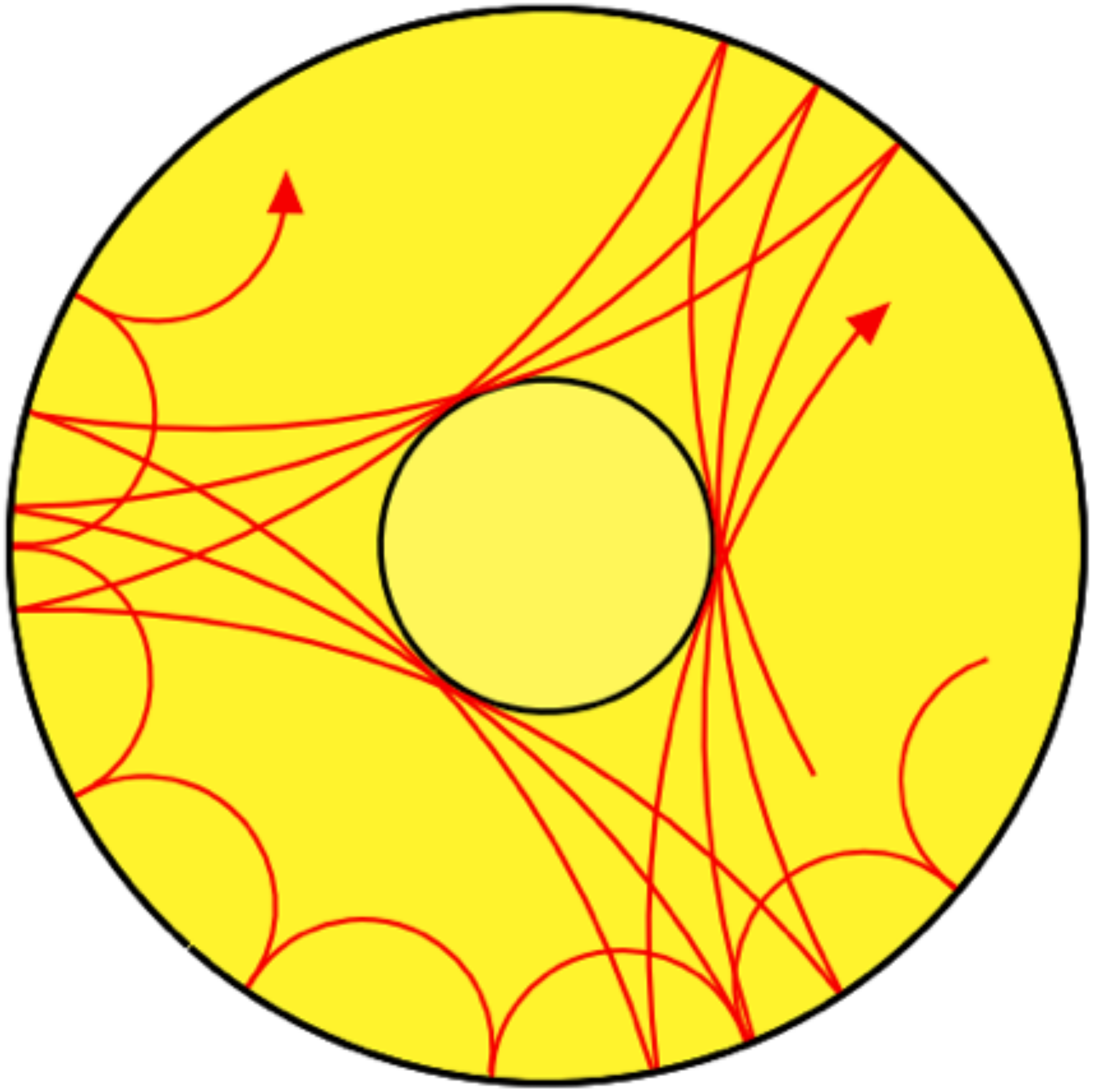
Measuring the vertical age structure of the Galactic disc using asteroseismology

Luca Casagrande

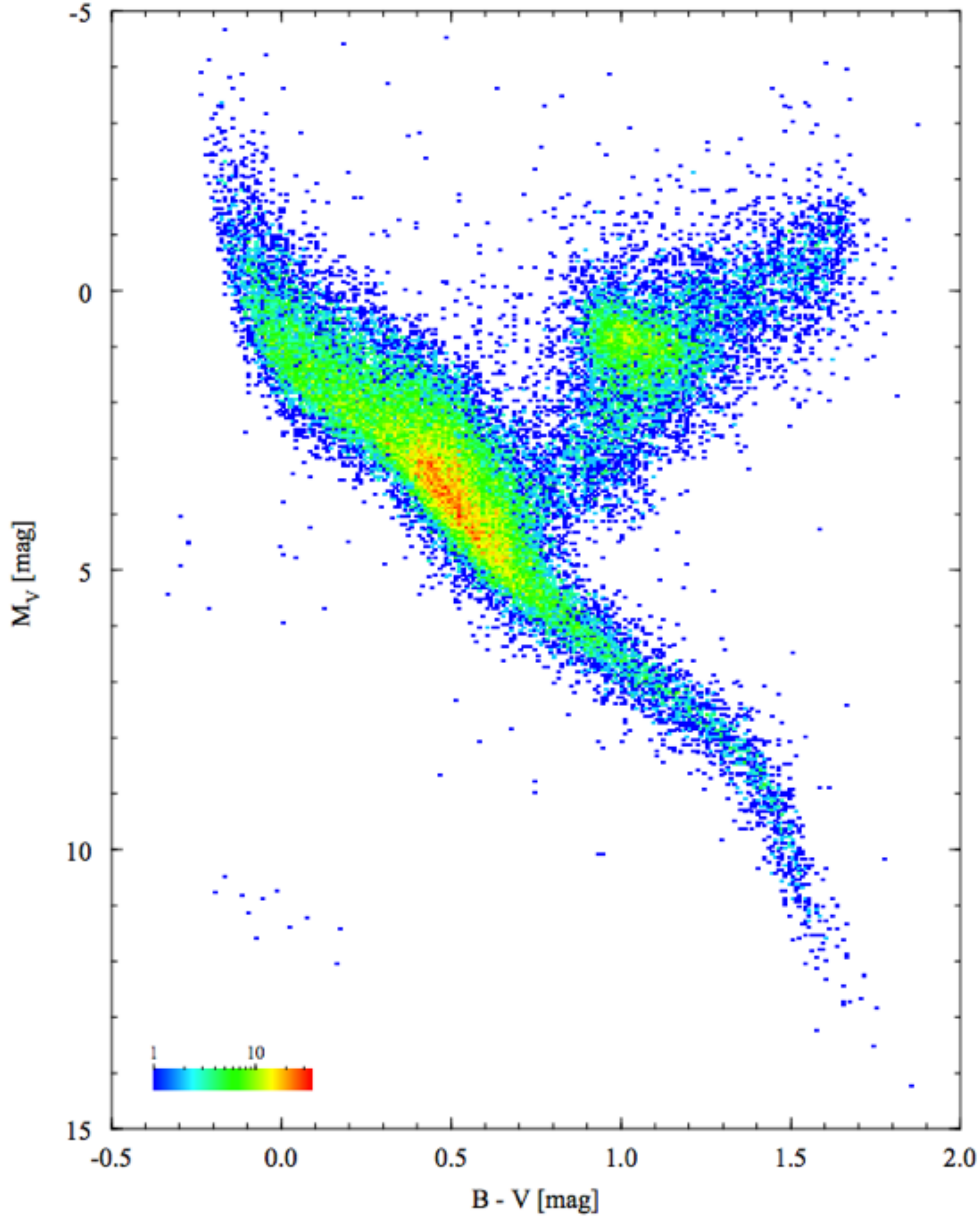
Australian National University

Victor Silva Aguirre, Aldo Serenelli, Dennis Stello, Ralph Schönrich, Sofia Feltzing, Antonino Milone, Simon Hodgkin

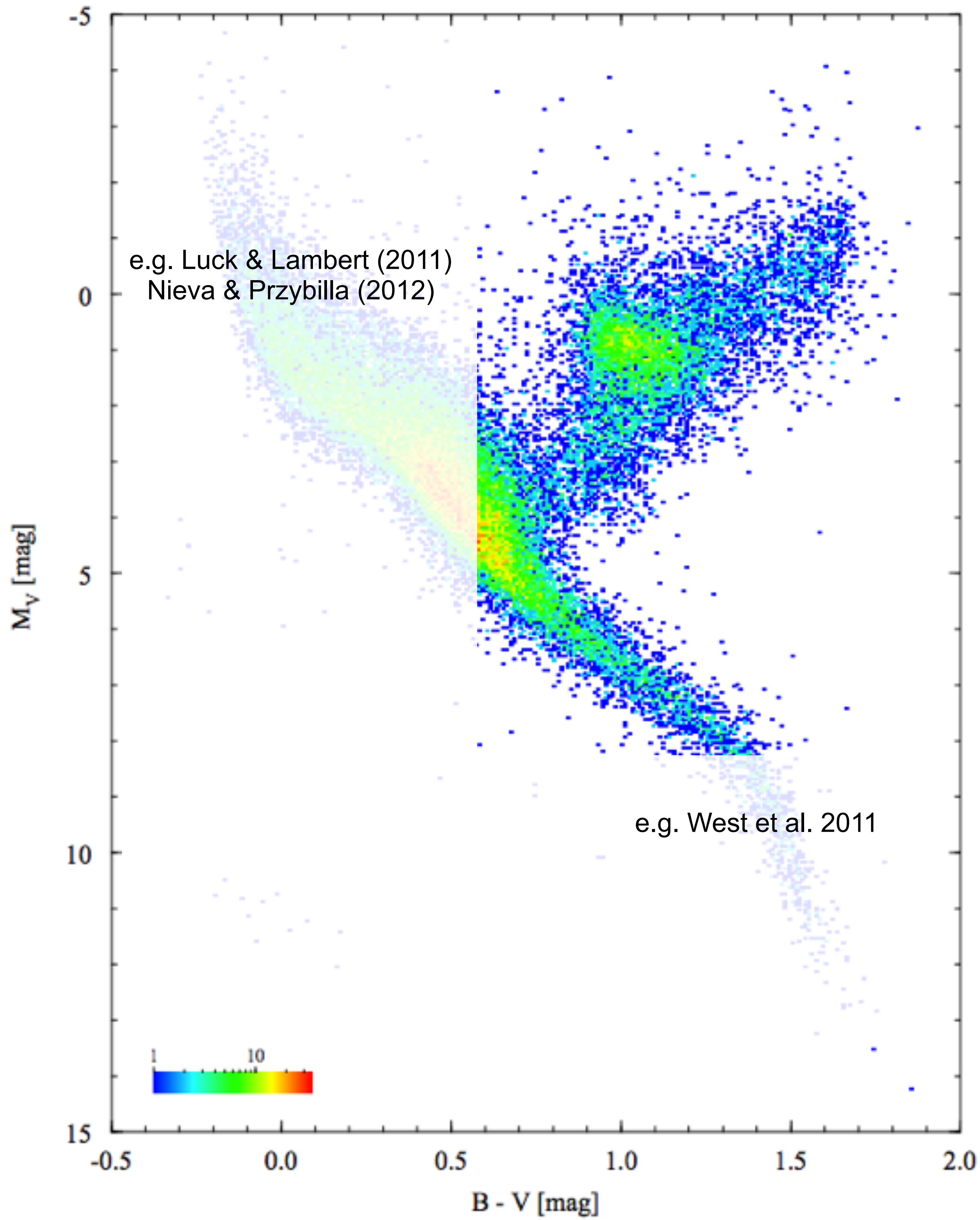


Fossils

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



http://www.rssd.esa.int/SA-general/Projects/Hipparcos/images/f3_5_005.pdf



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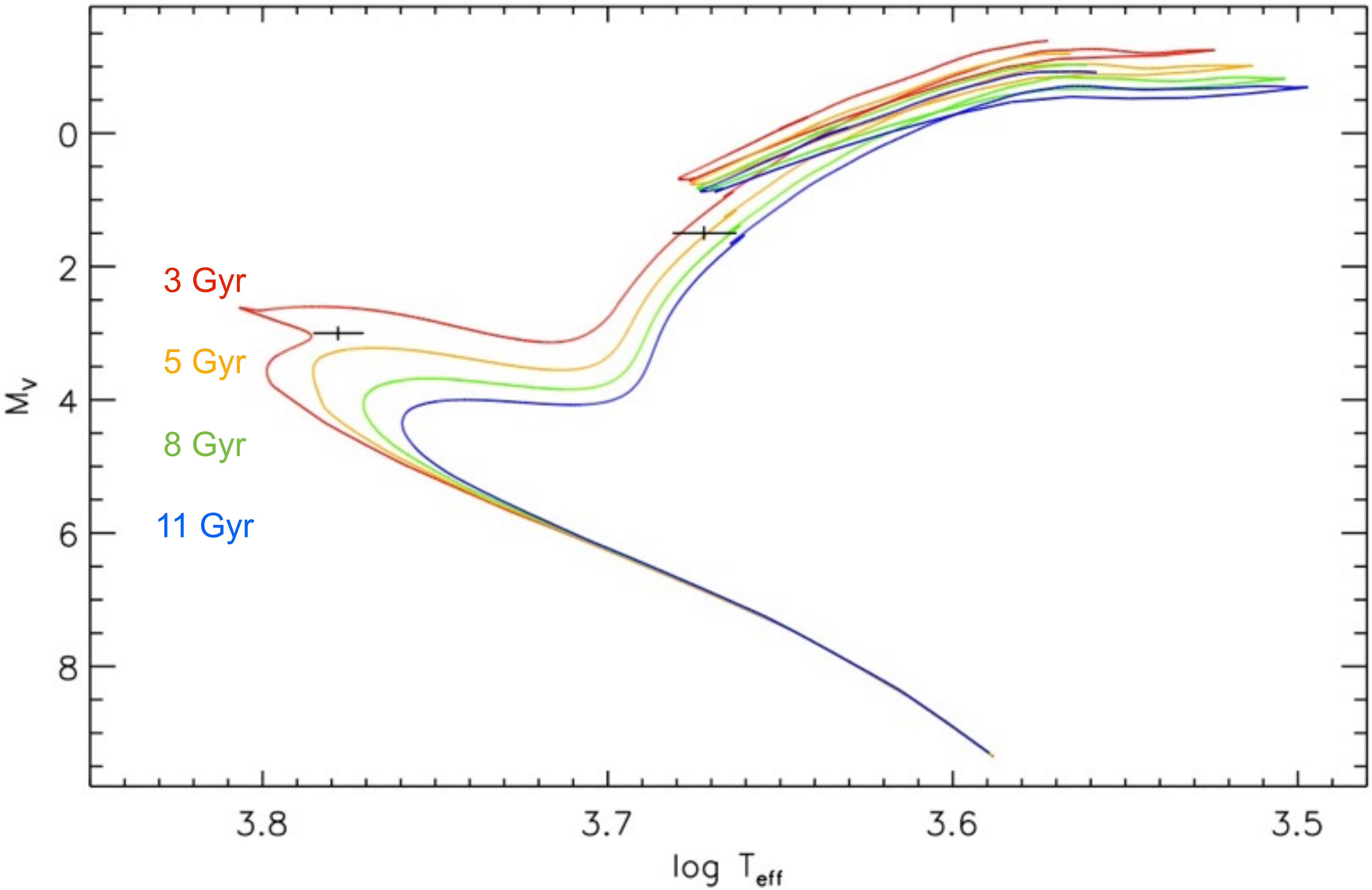
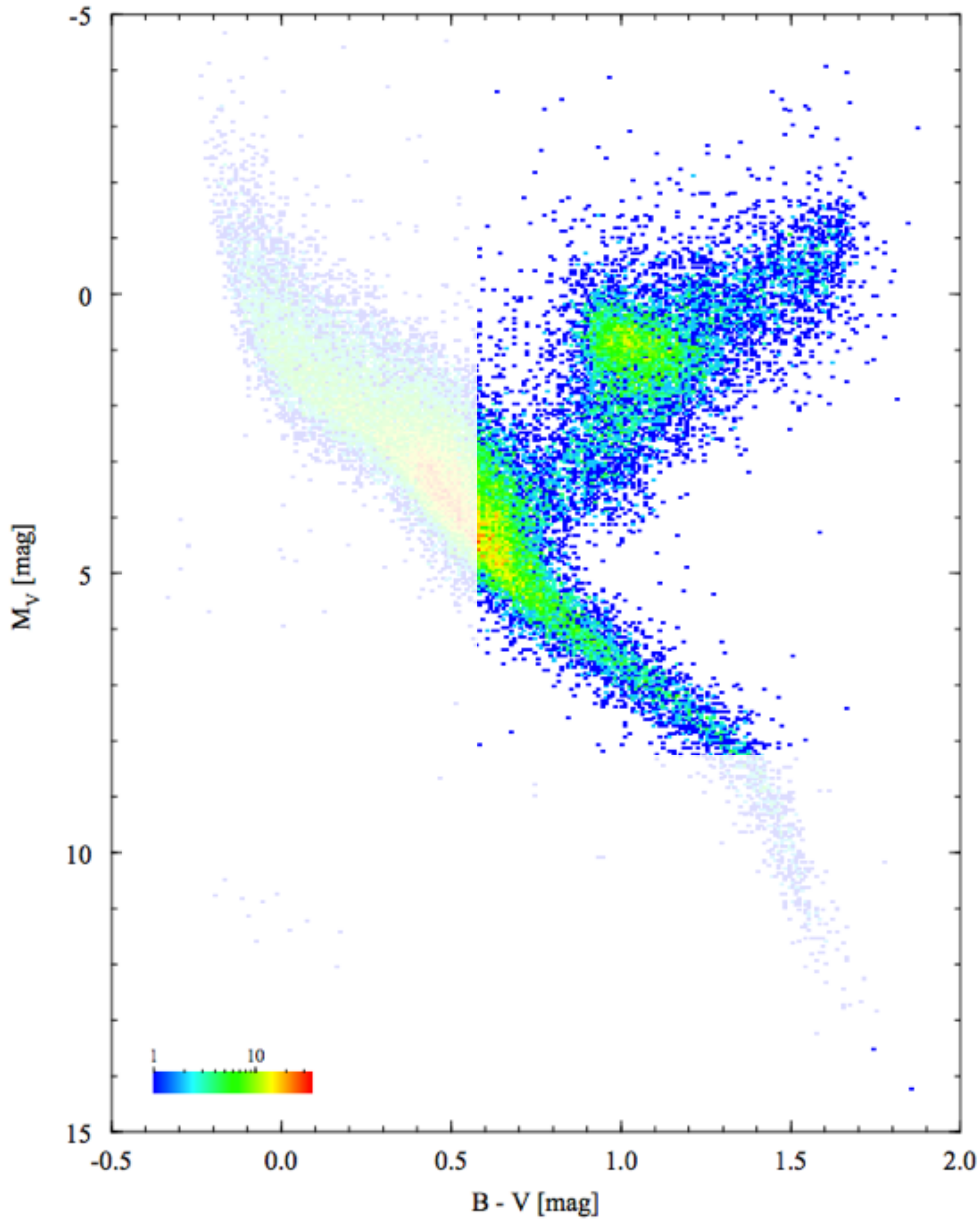
Astrometry



e.g. Soderblom (2010, ARAA)



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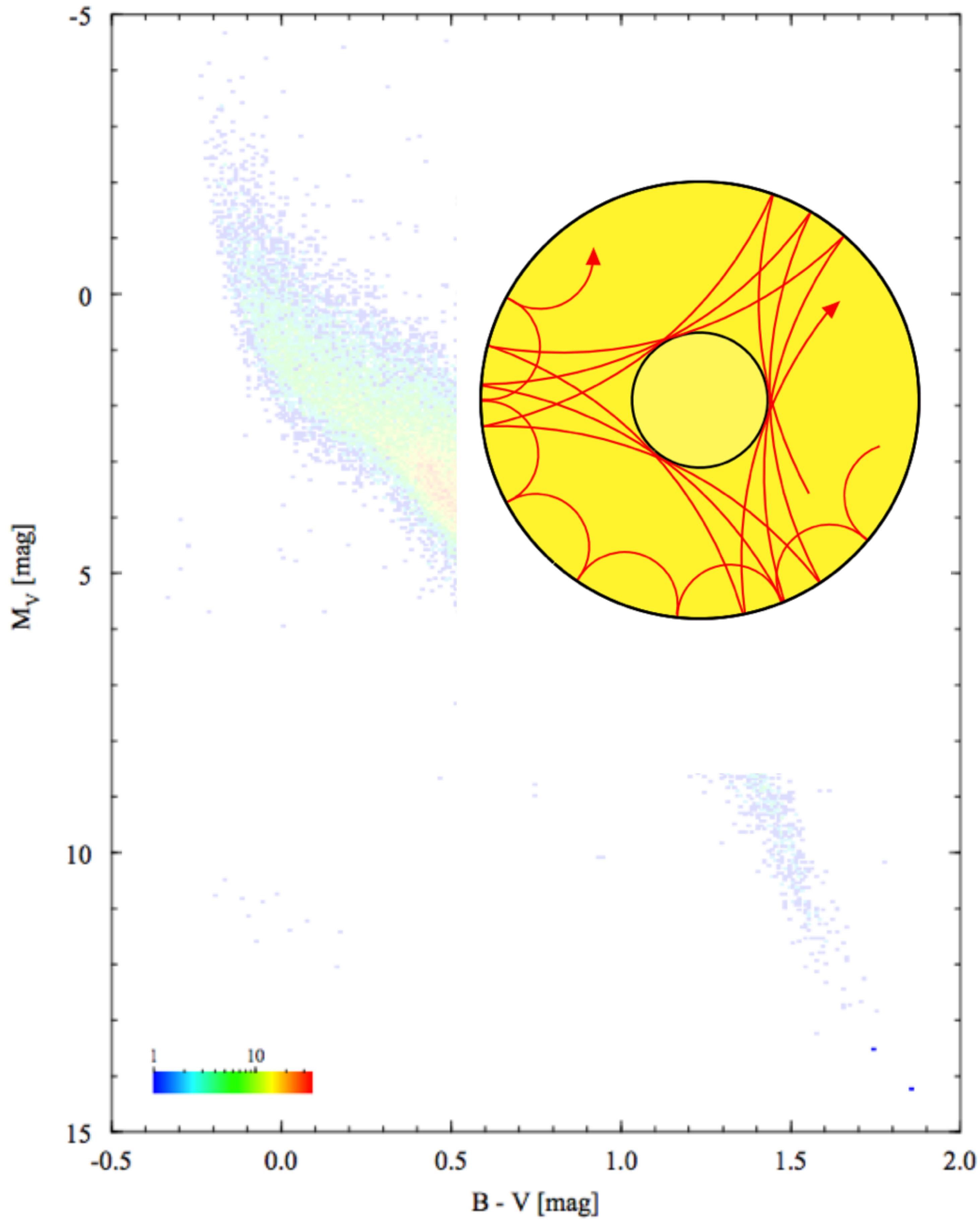

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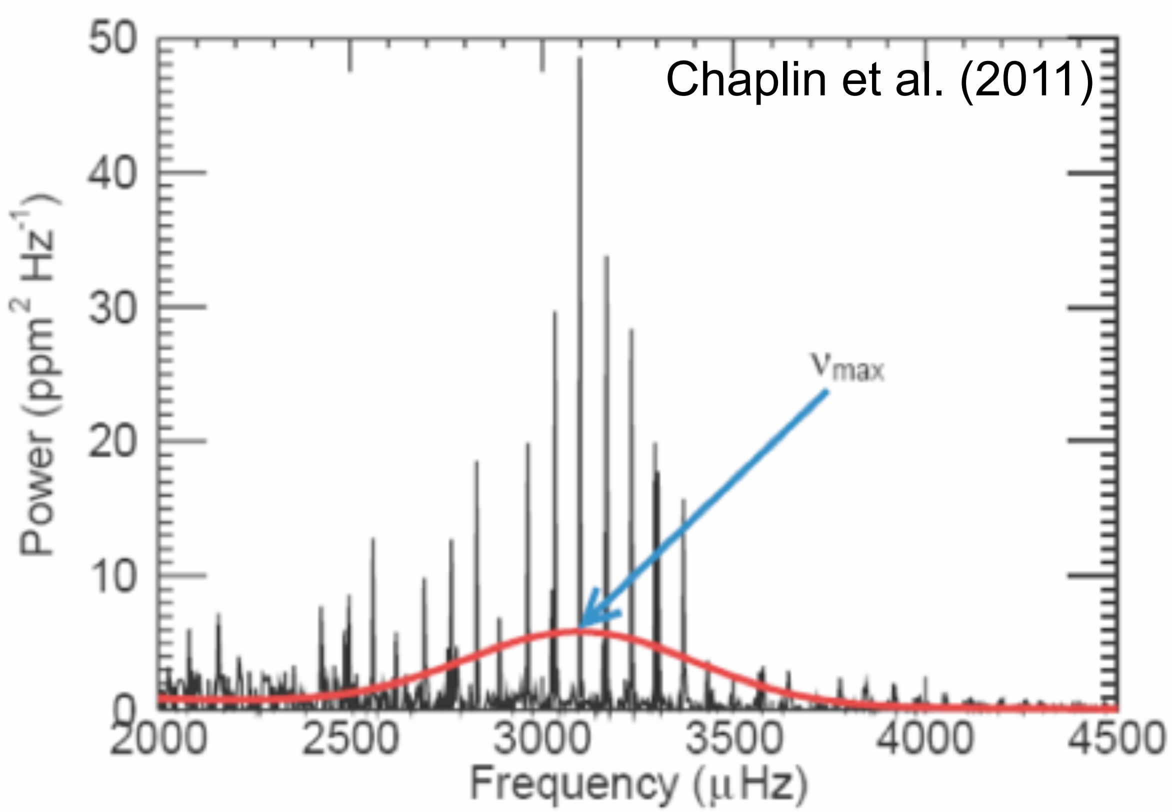
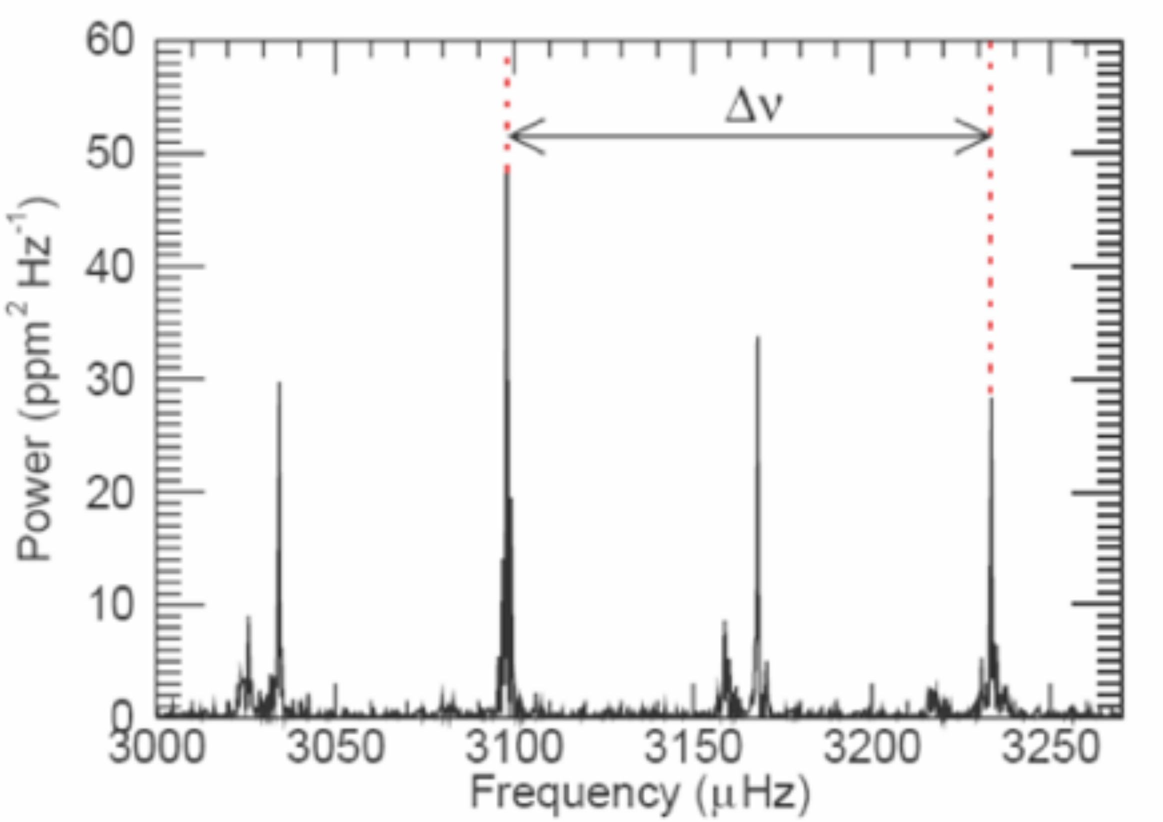
Asteroseismology (solar-like oscillations)

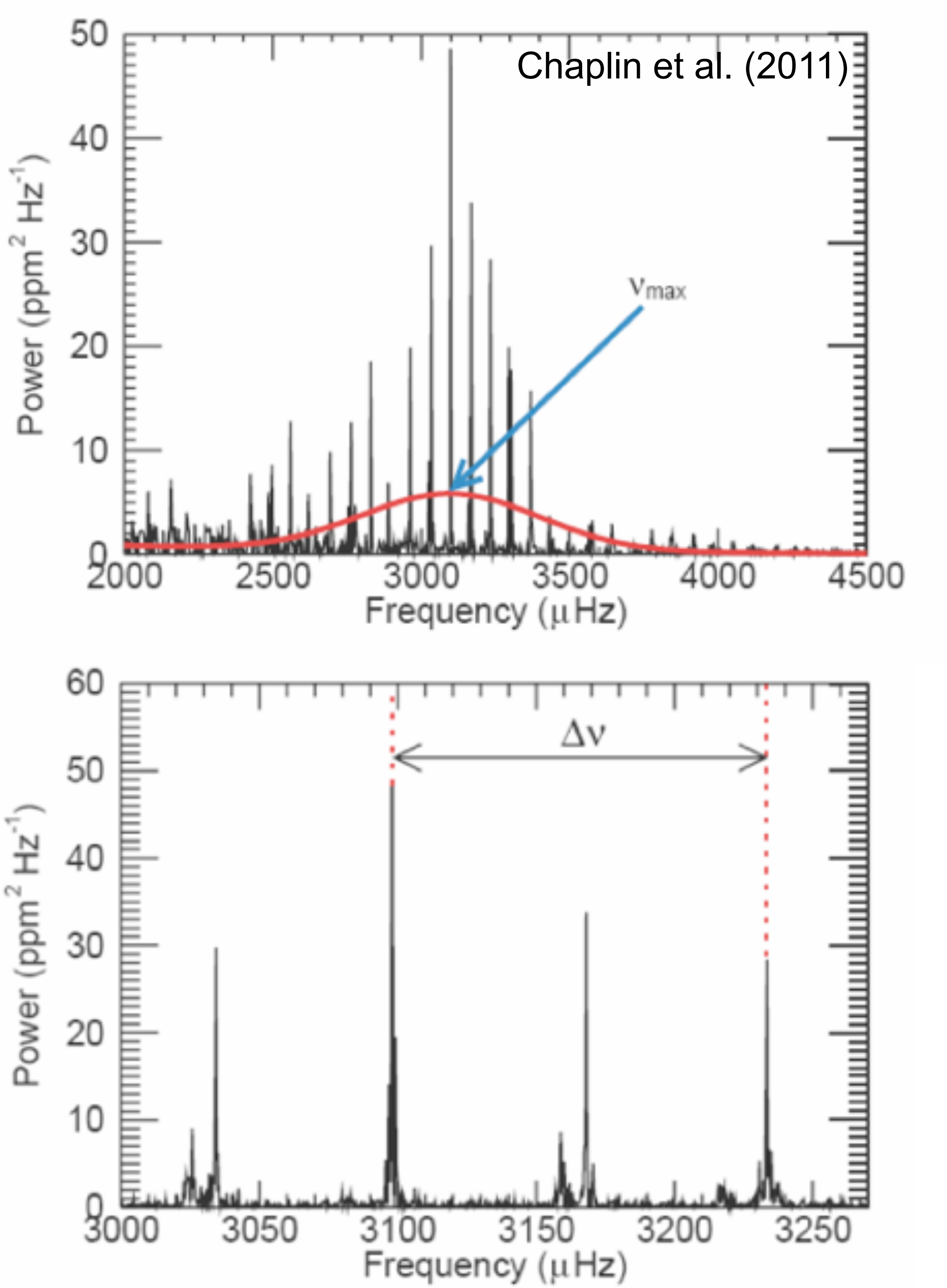




$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2}$$

Asteroseismology (solar-like oscillations)



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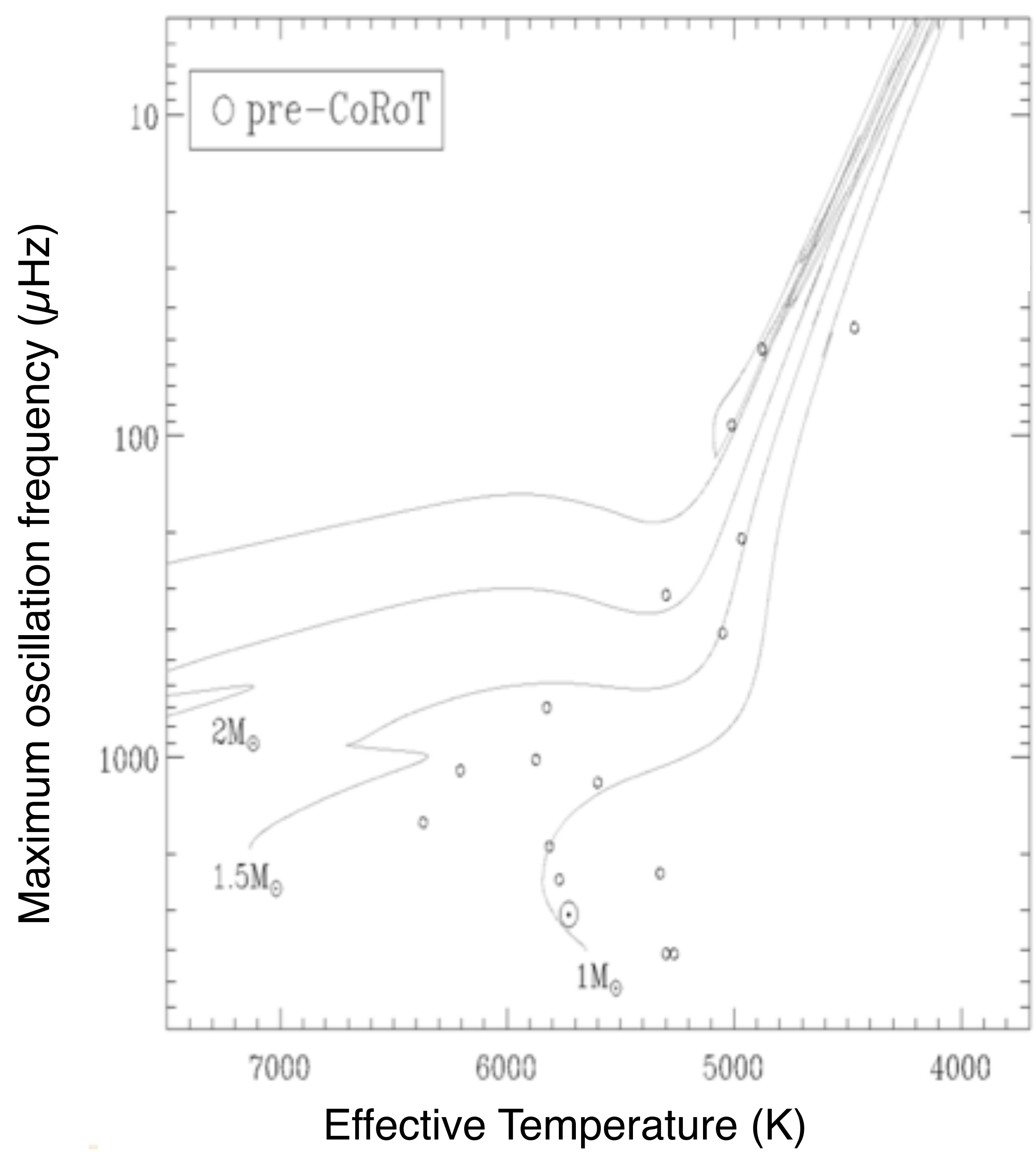
(e.g. Hekker et al. 2009, Stello et al. 2009)

Asteroseismology (solar-like oscillations)



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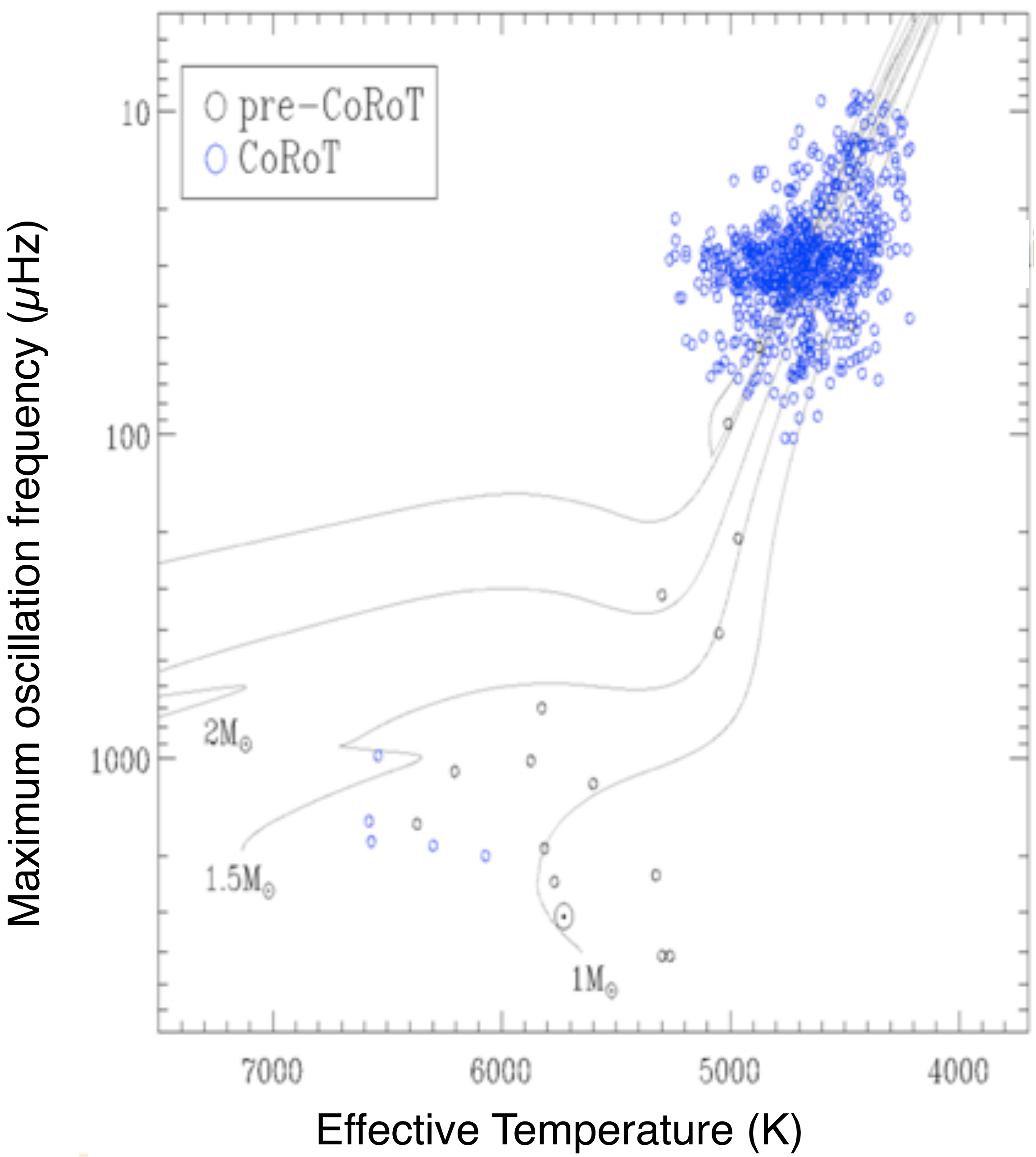

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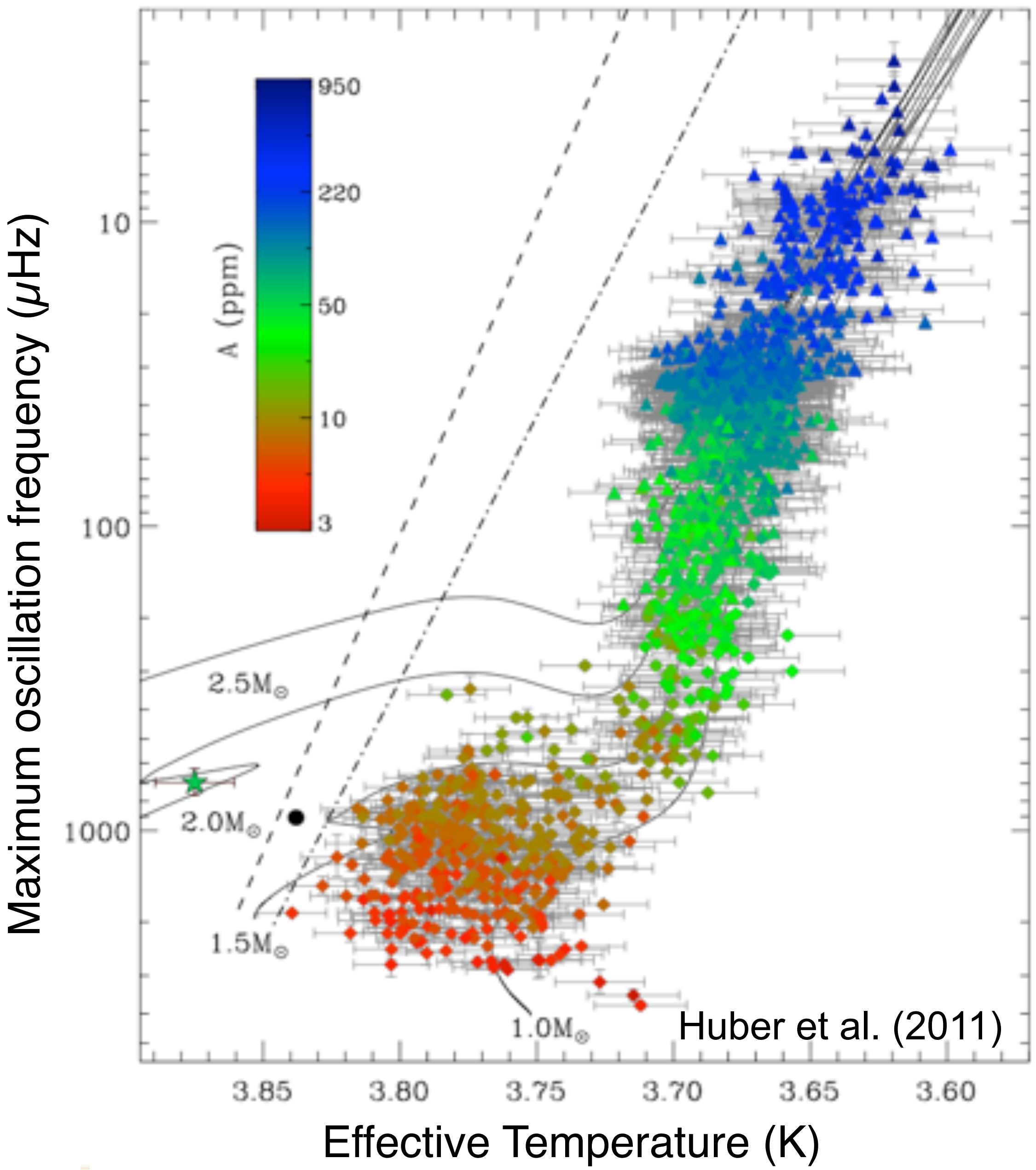

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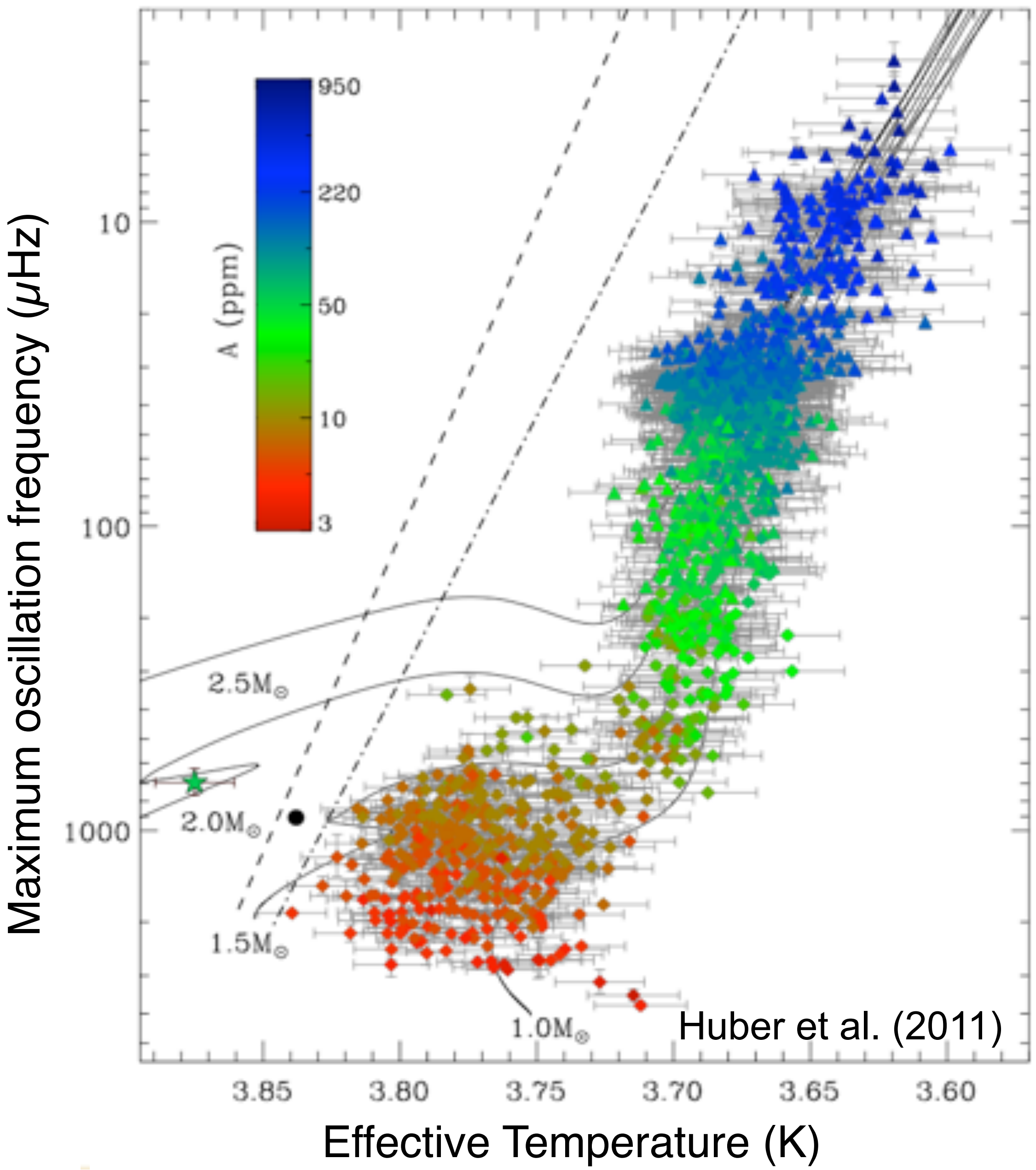

ages

$$\frac{M}{M_\odot} \simeq \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right)^3 \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-4} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{3/2}$$

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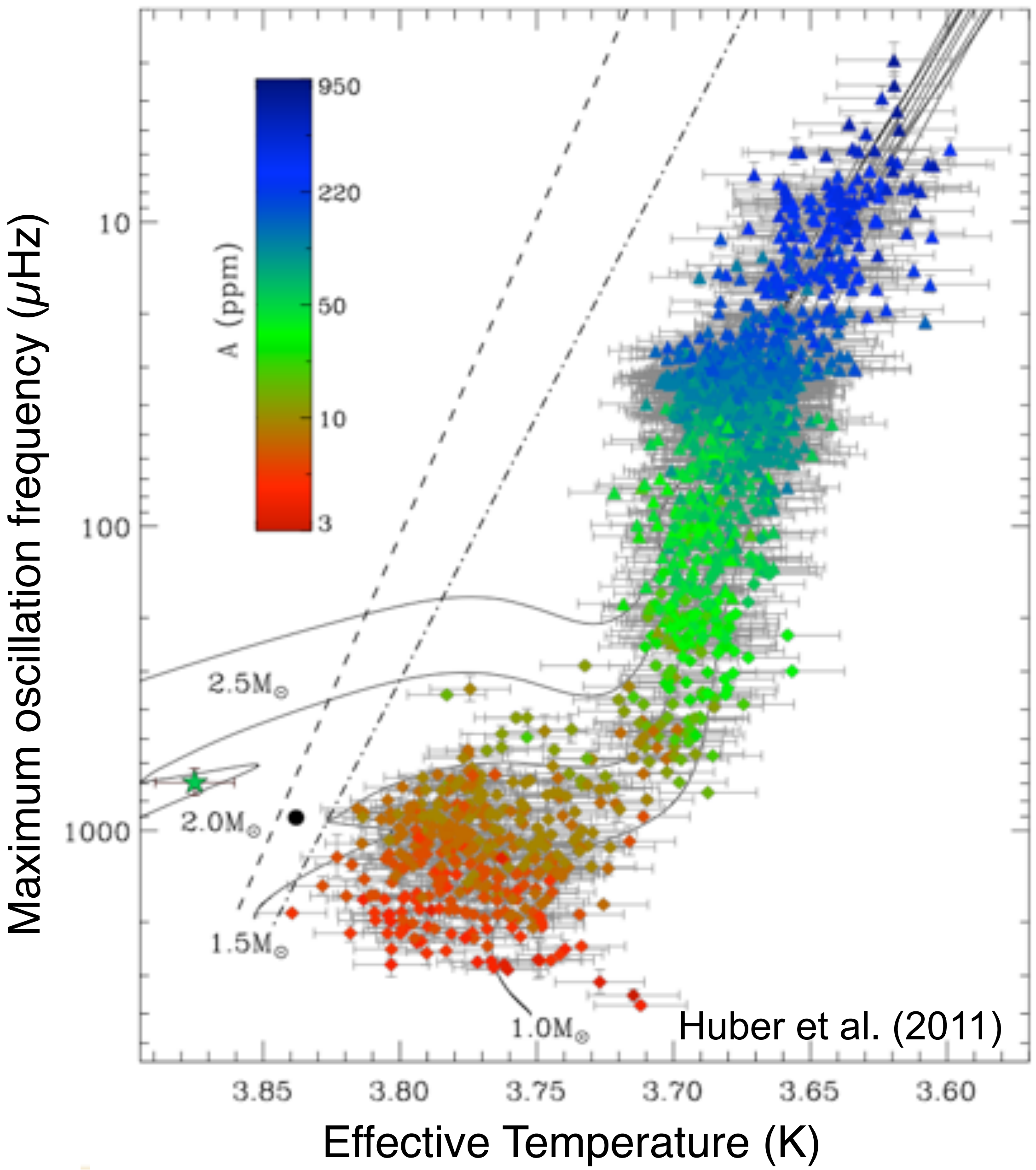
Asteroseismology
(solar-like oscillations)



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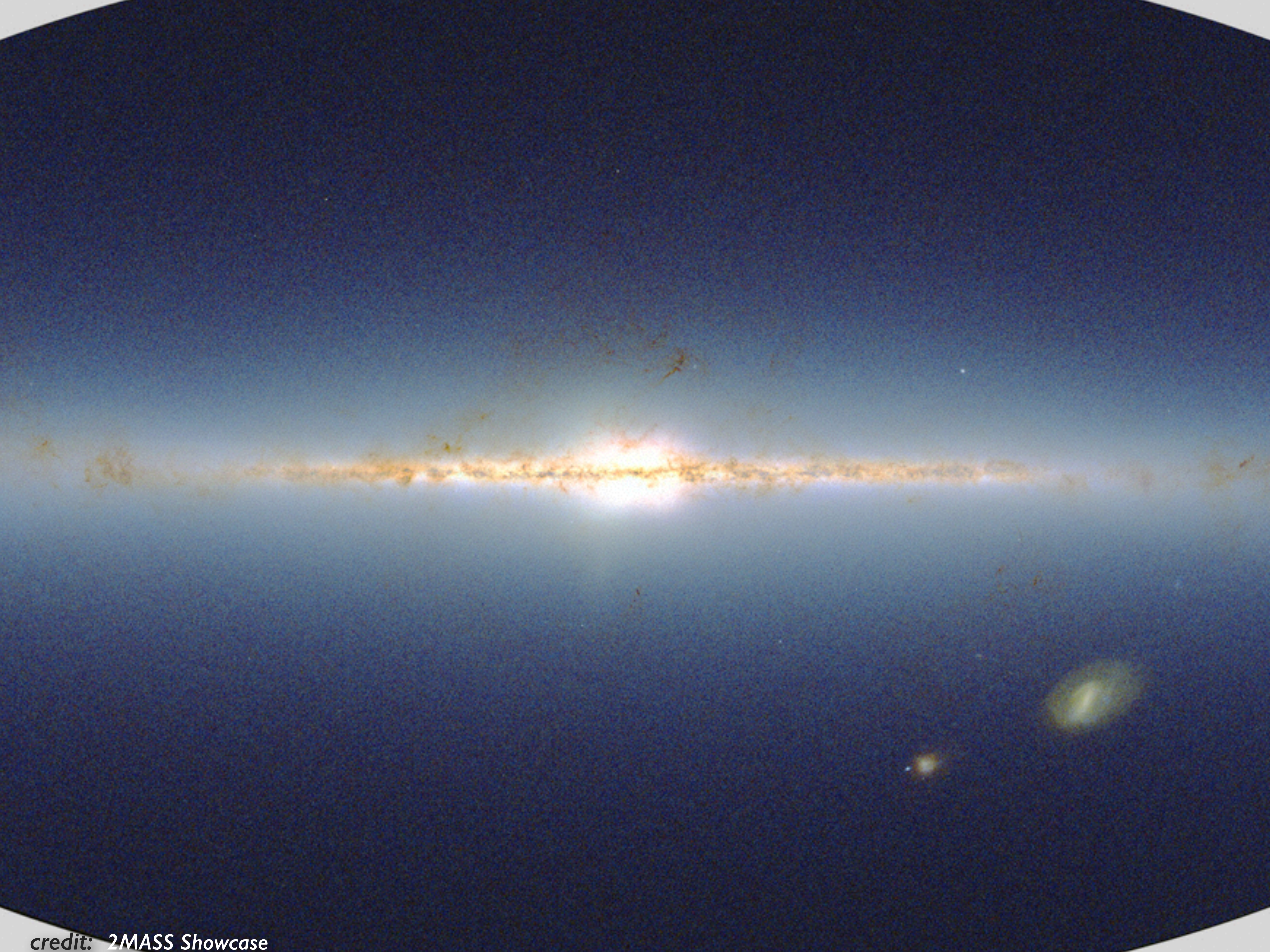
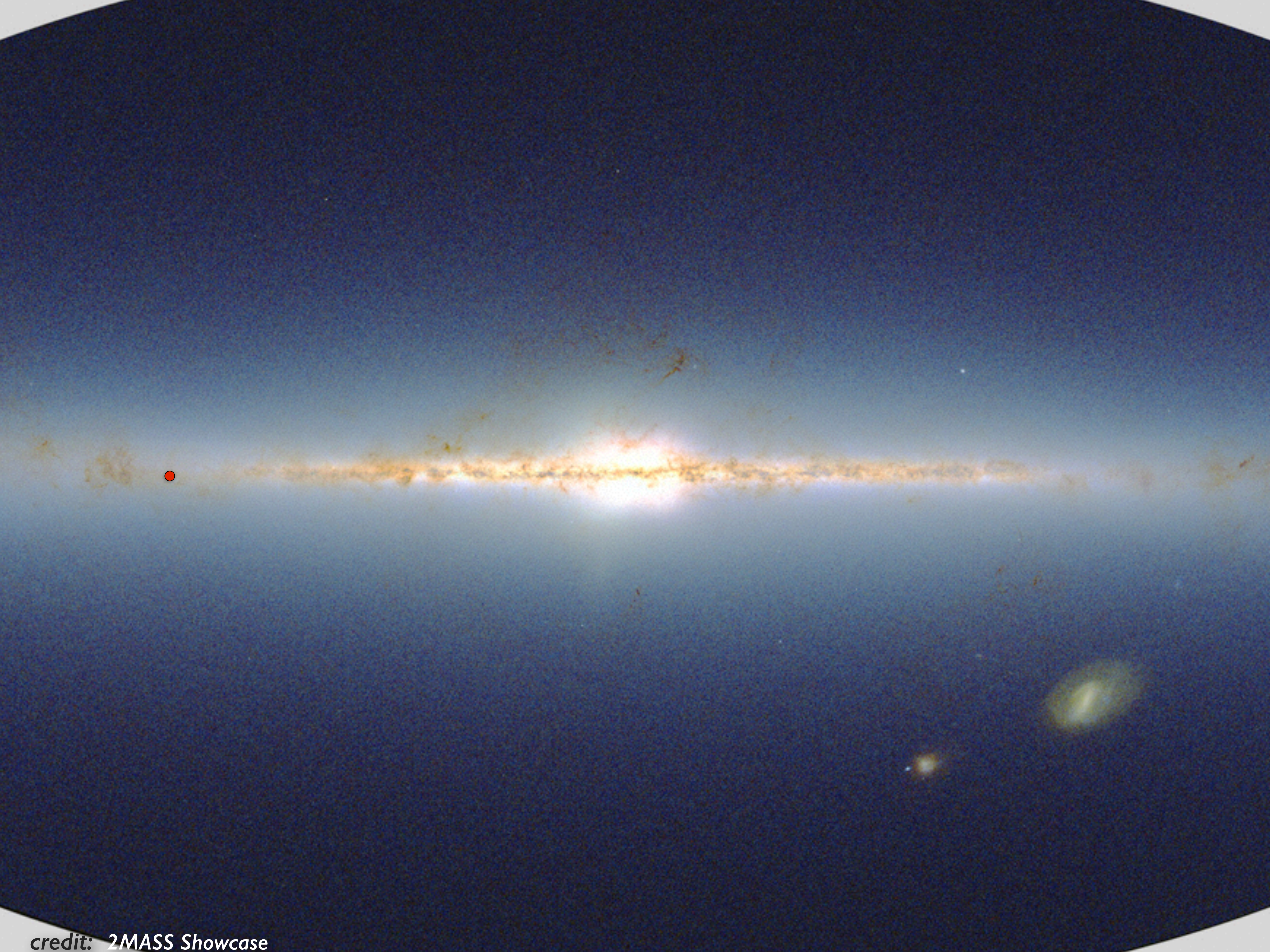
distances



credit: 2MASS Showcase



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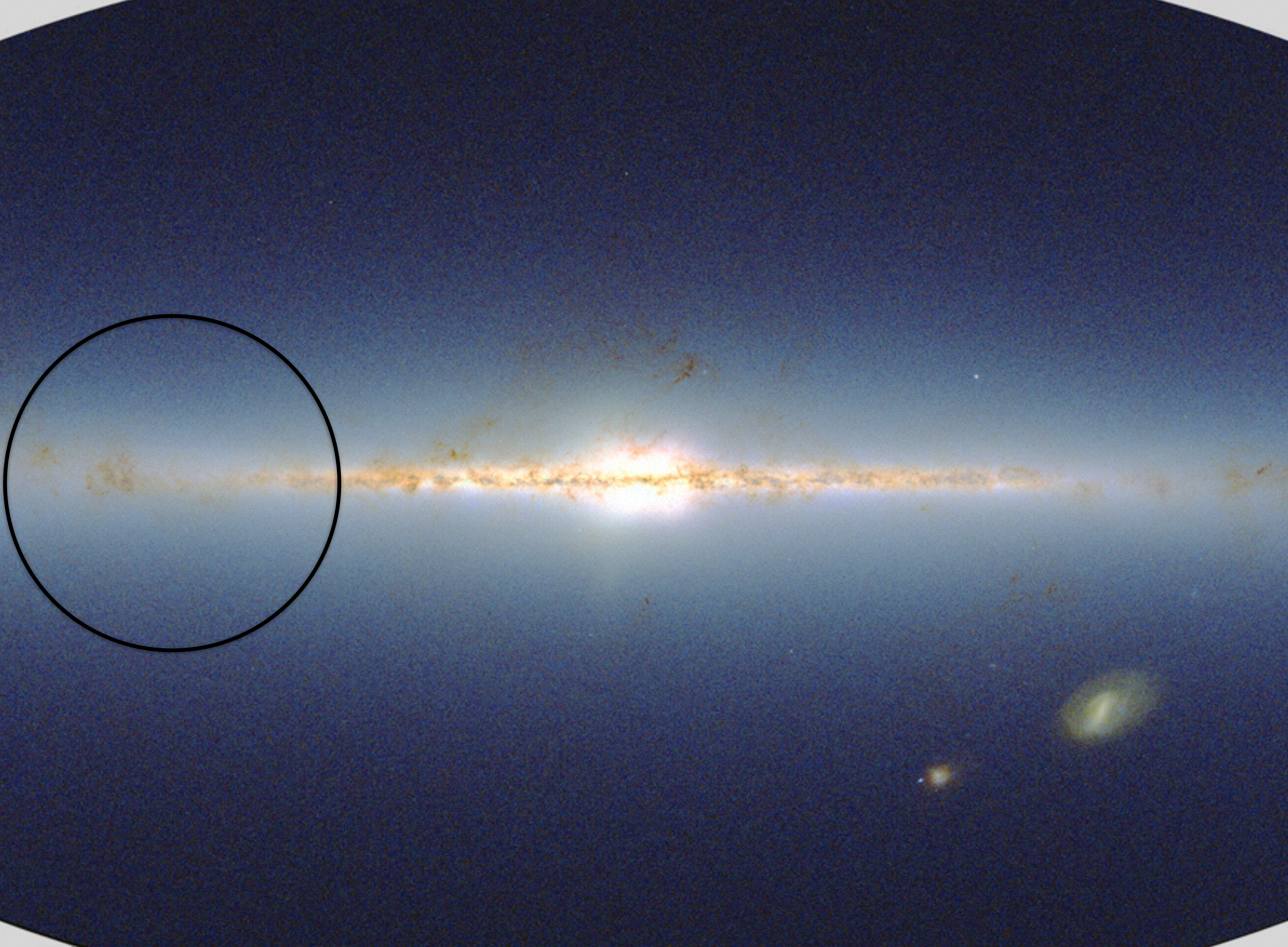

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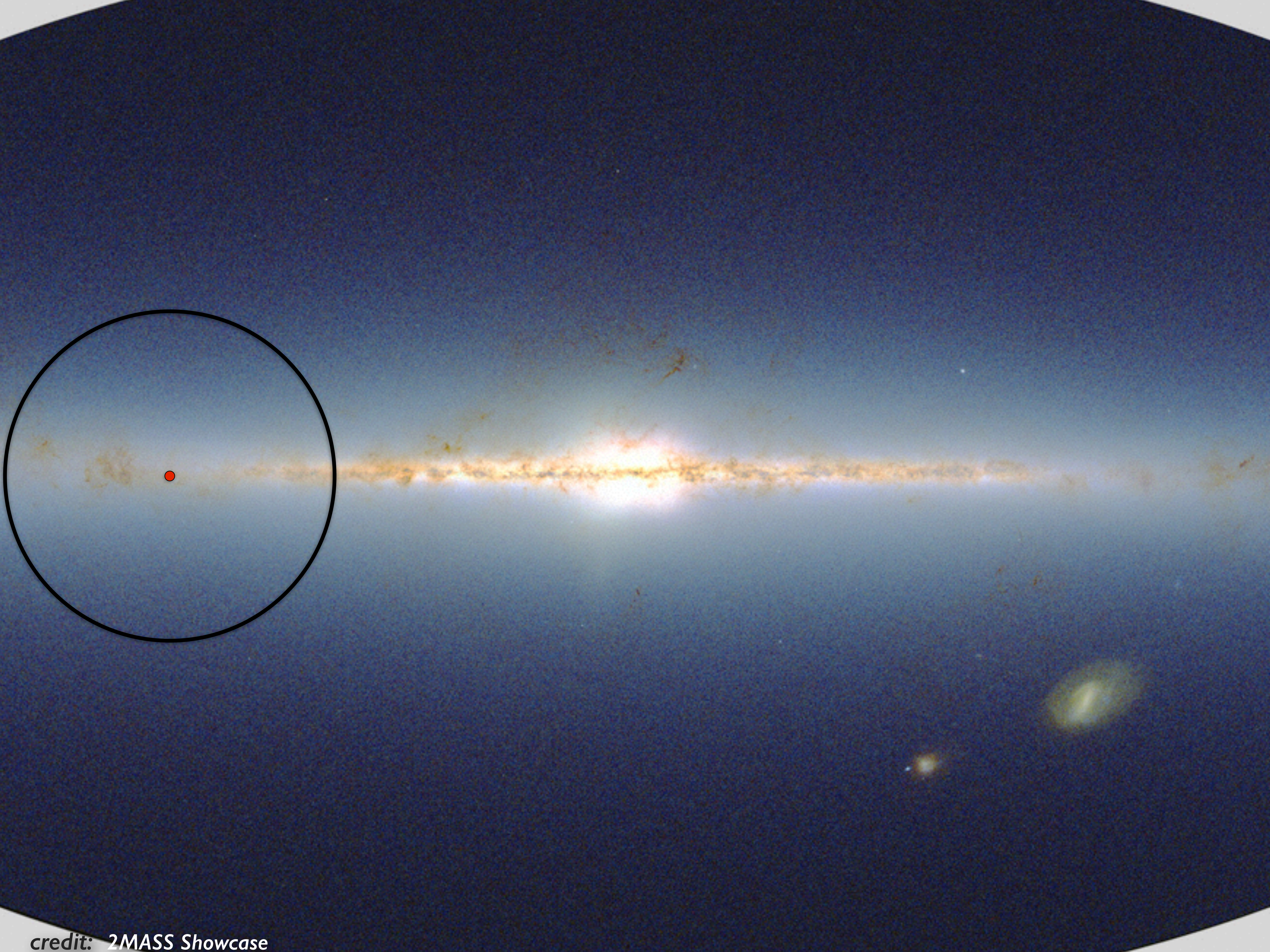
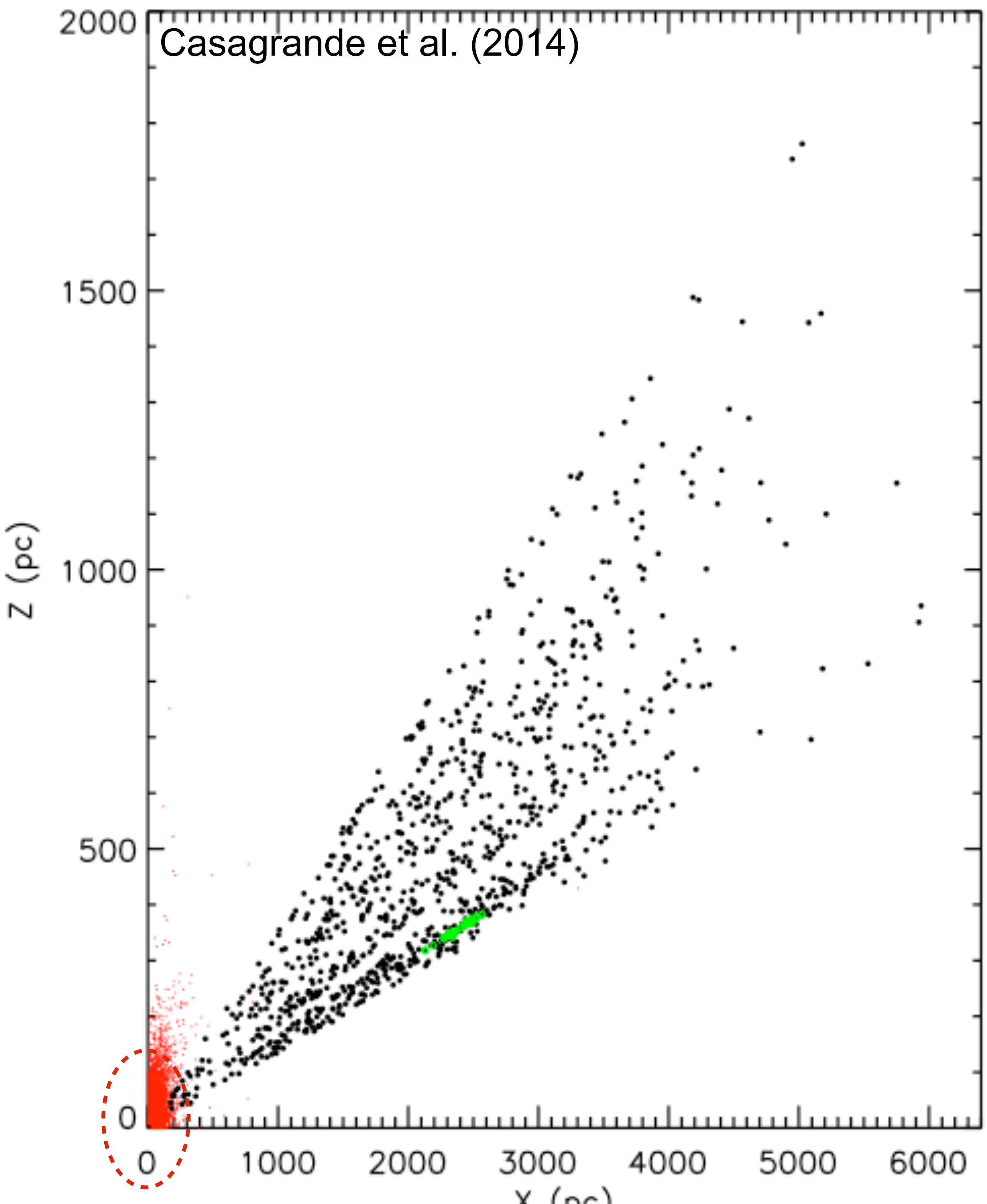
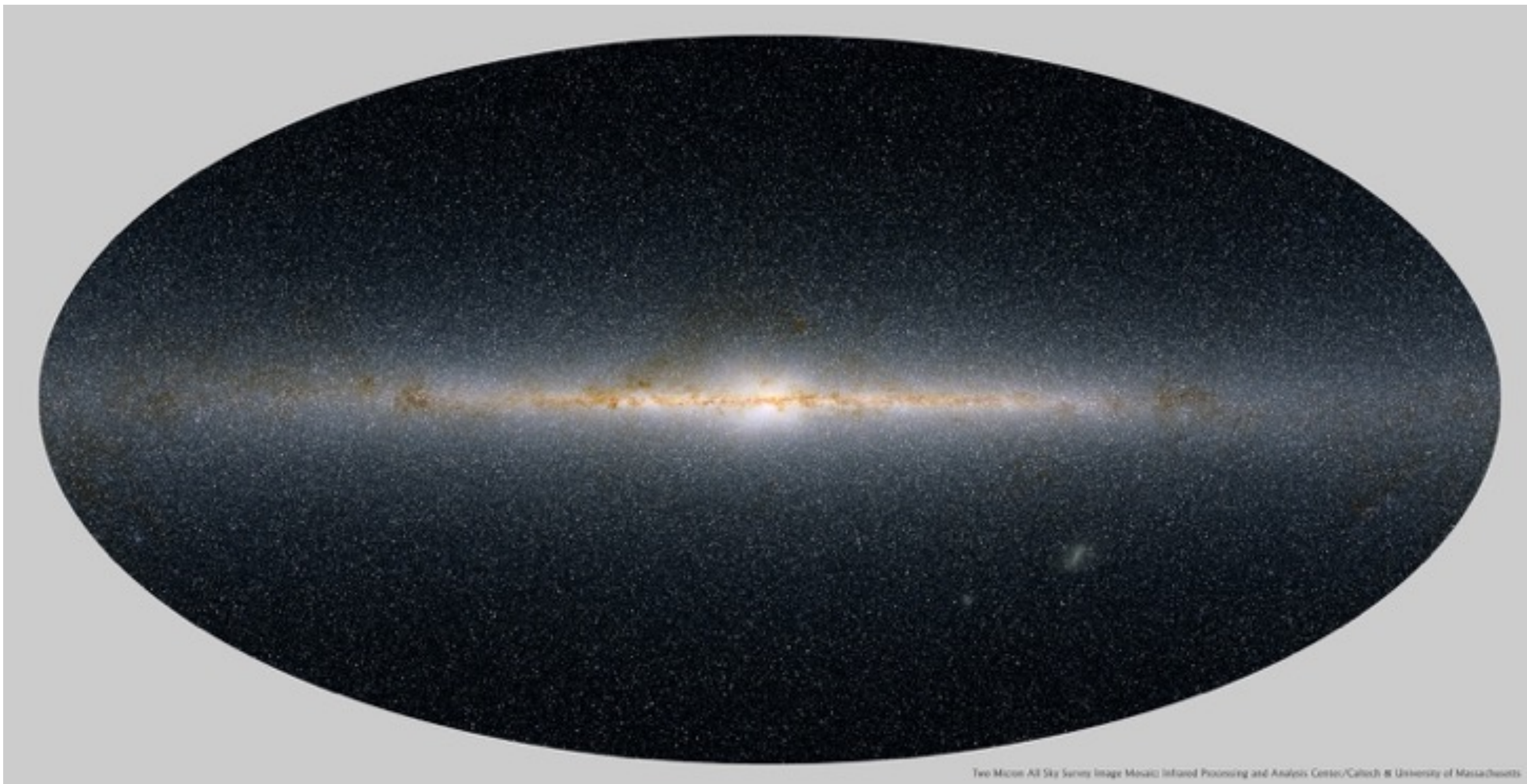

credit: 2MASS Showcase

Leaving the Neighbourhood



Geneva-Copenhagen Survey

(GCS, Nordström et al. 2004, Holmberg et al. 2009, Casagrande et al. 2011)



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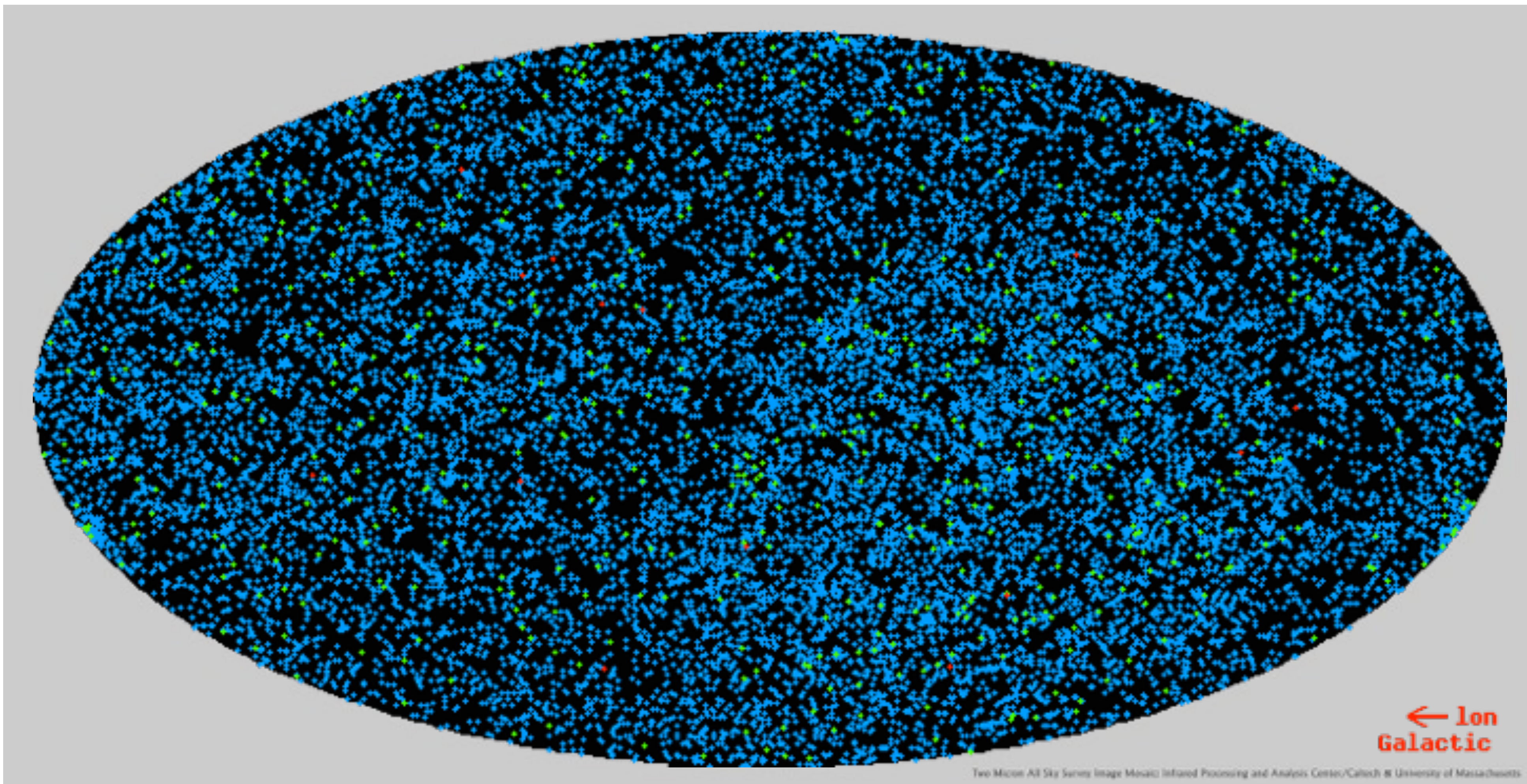

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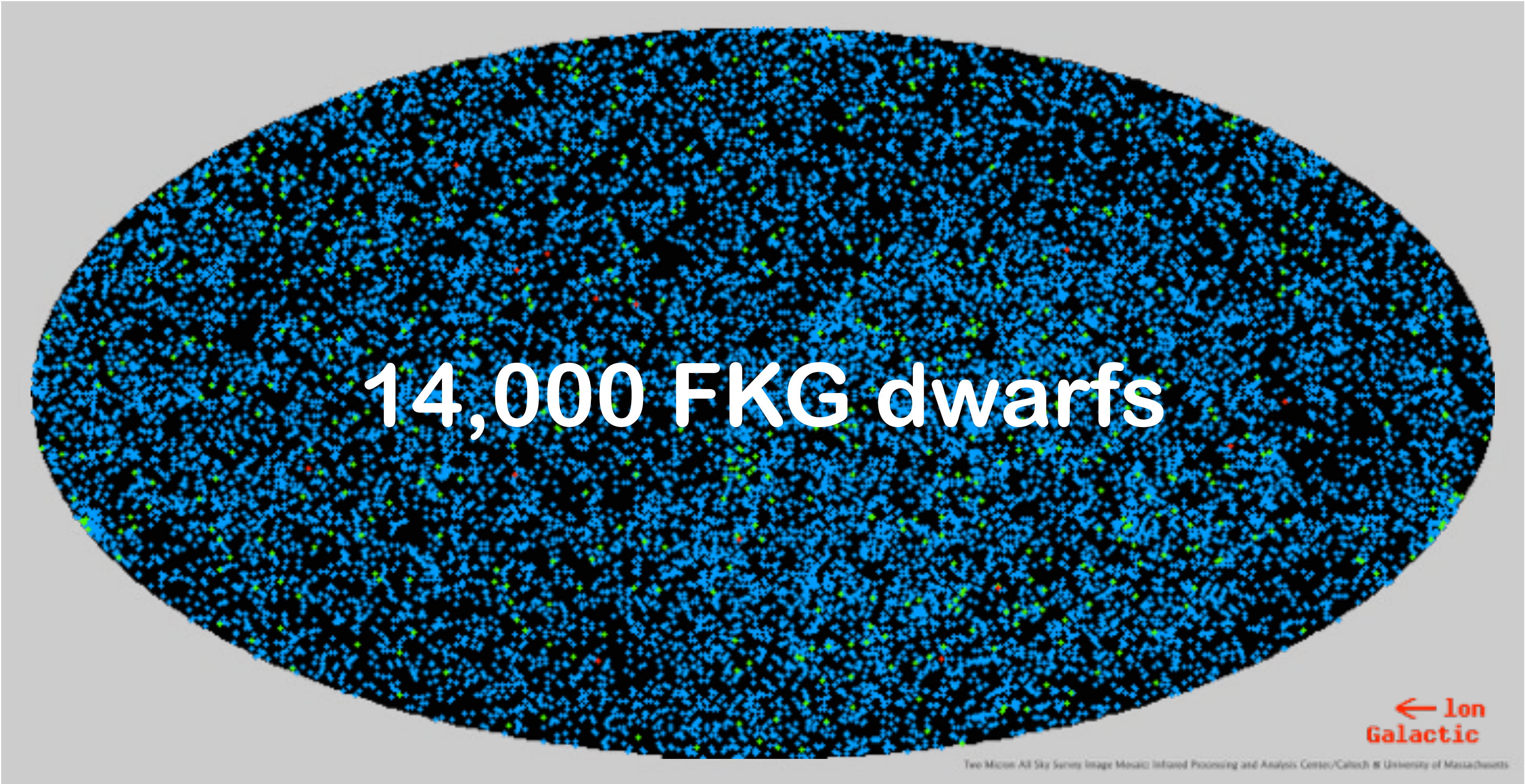
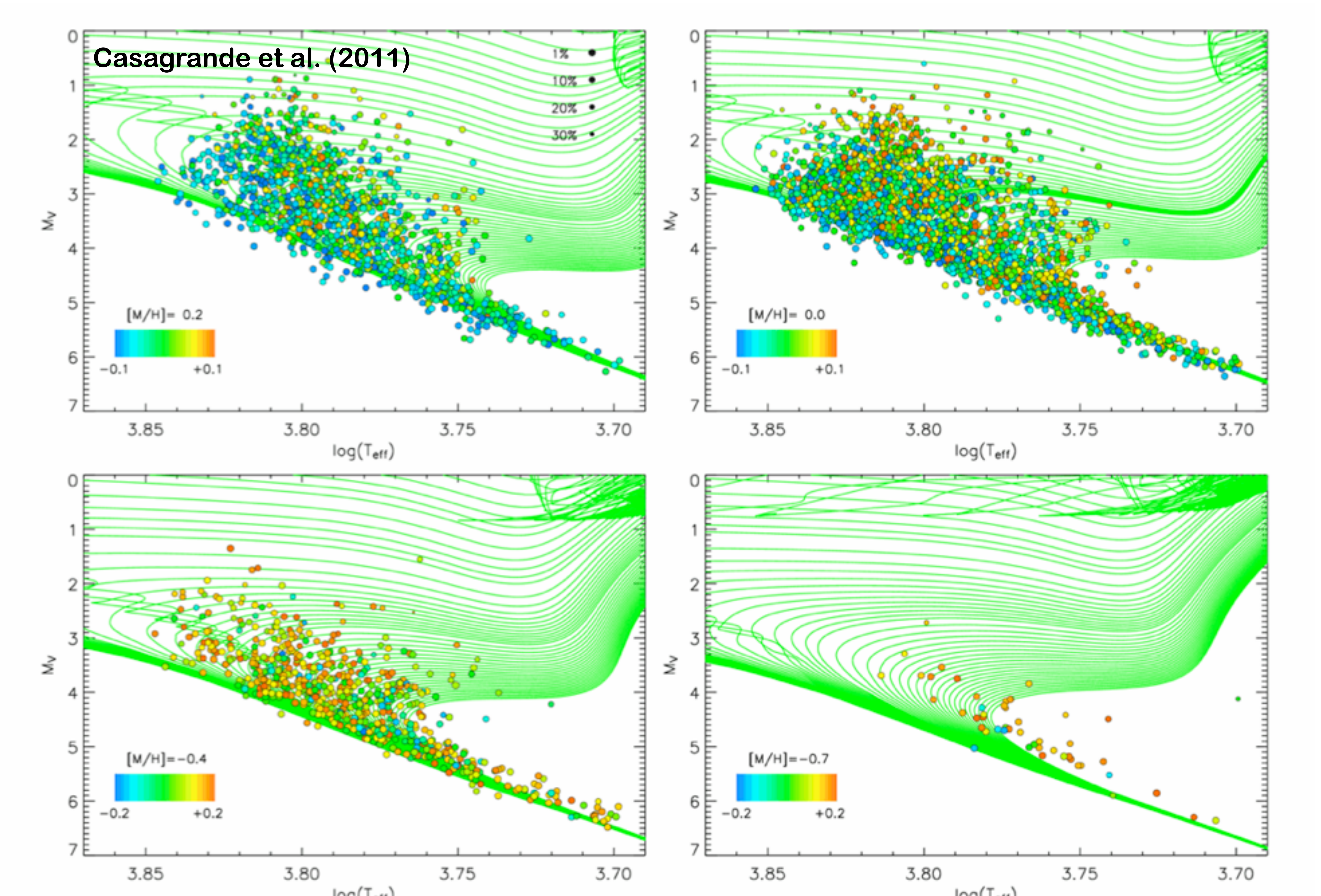
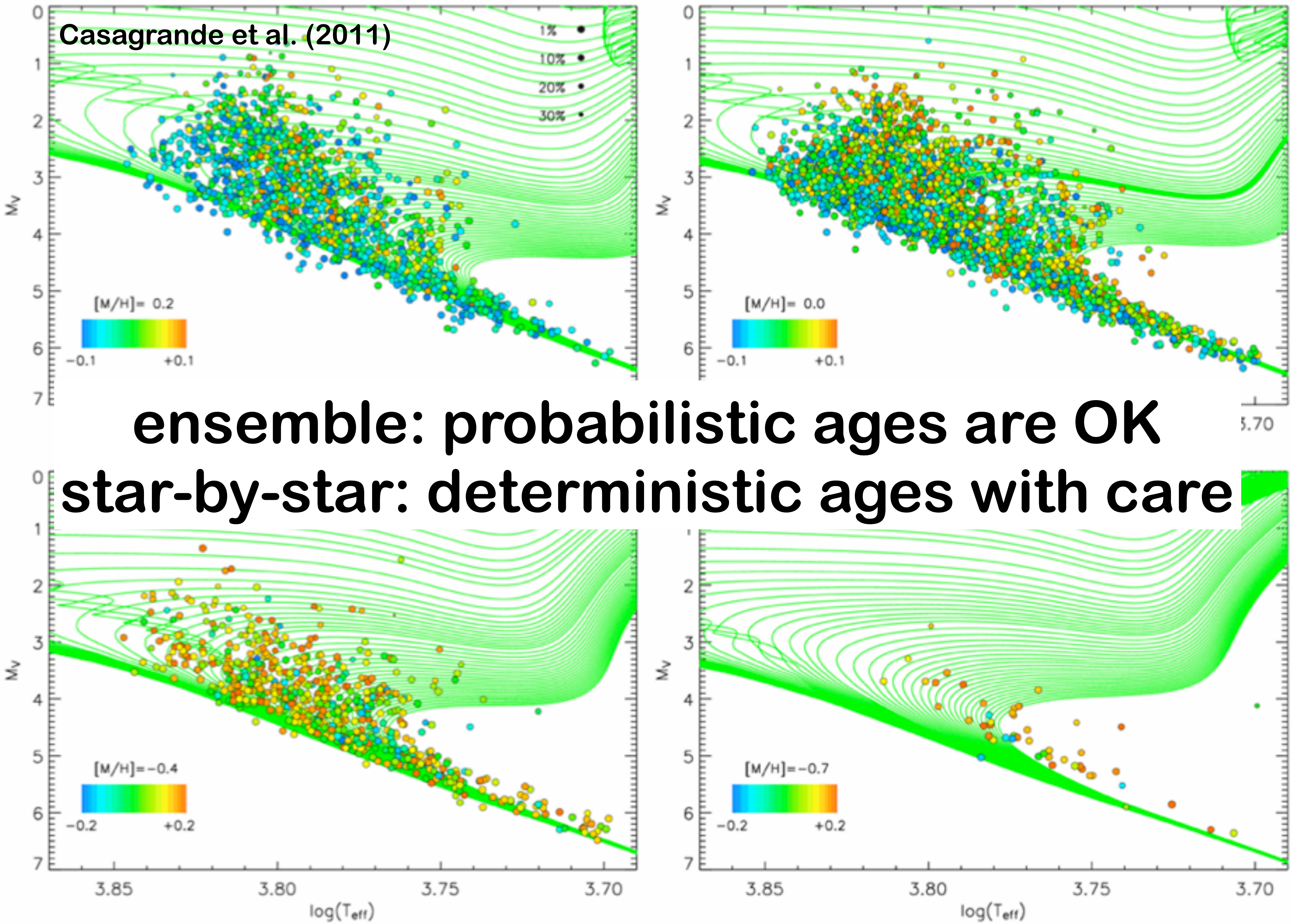




cf. e.g. Pont & Eyer (2004), Jørgensen & Lindegren (2005), Burnett & Binney (2010), Serenelli et al. (2013)

Sweeping (many things) under the rug



ensemble: probabilistic ages are OK

star-by-star: deterministic ages with care

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

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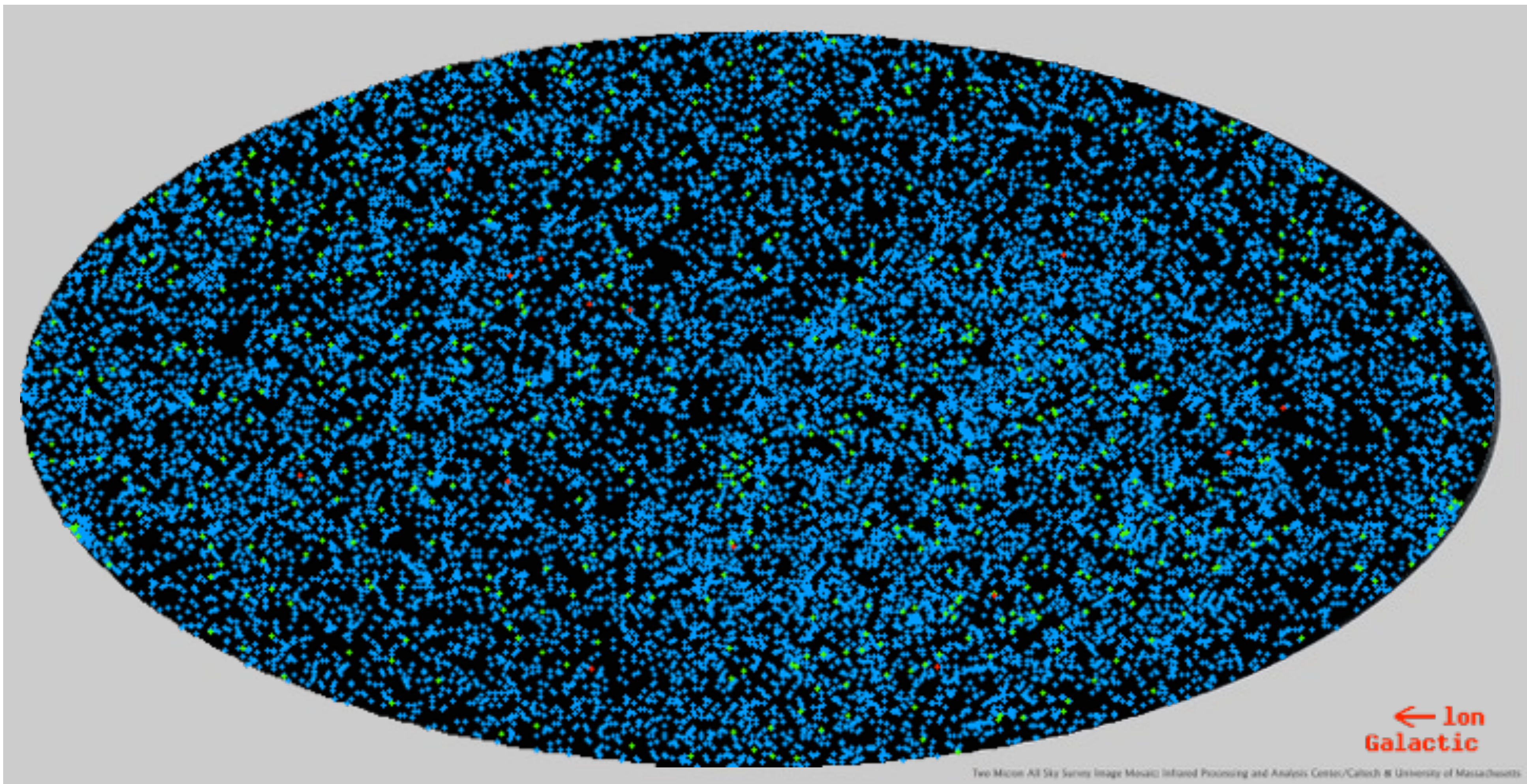

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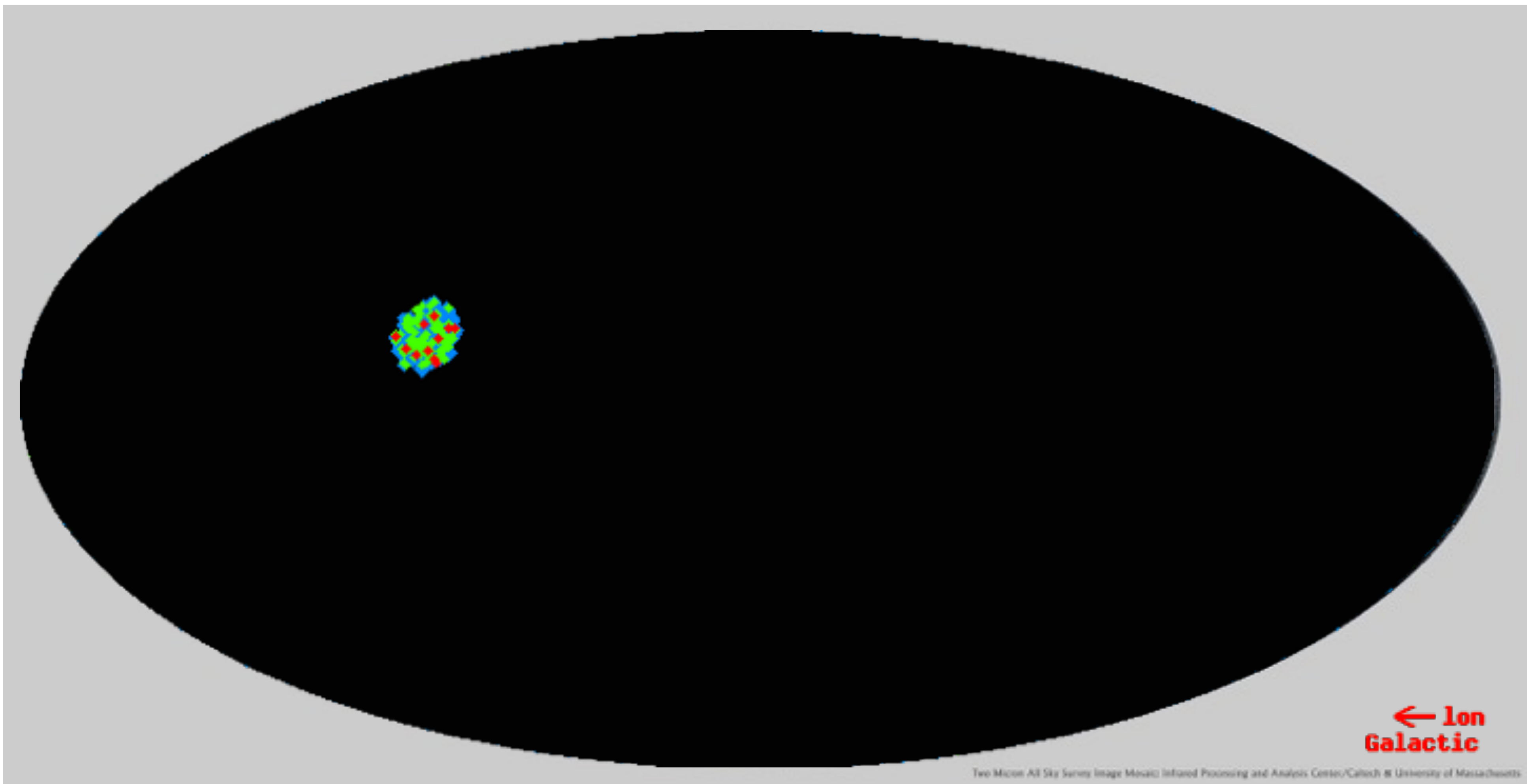
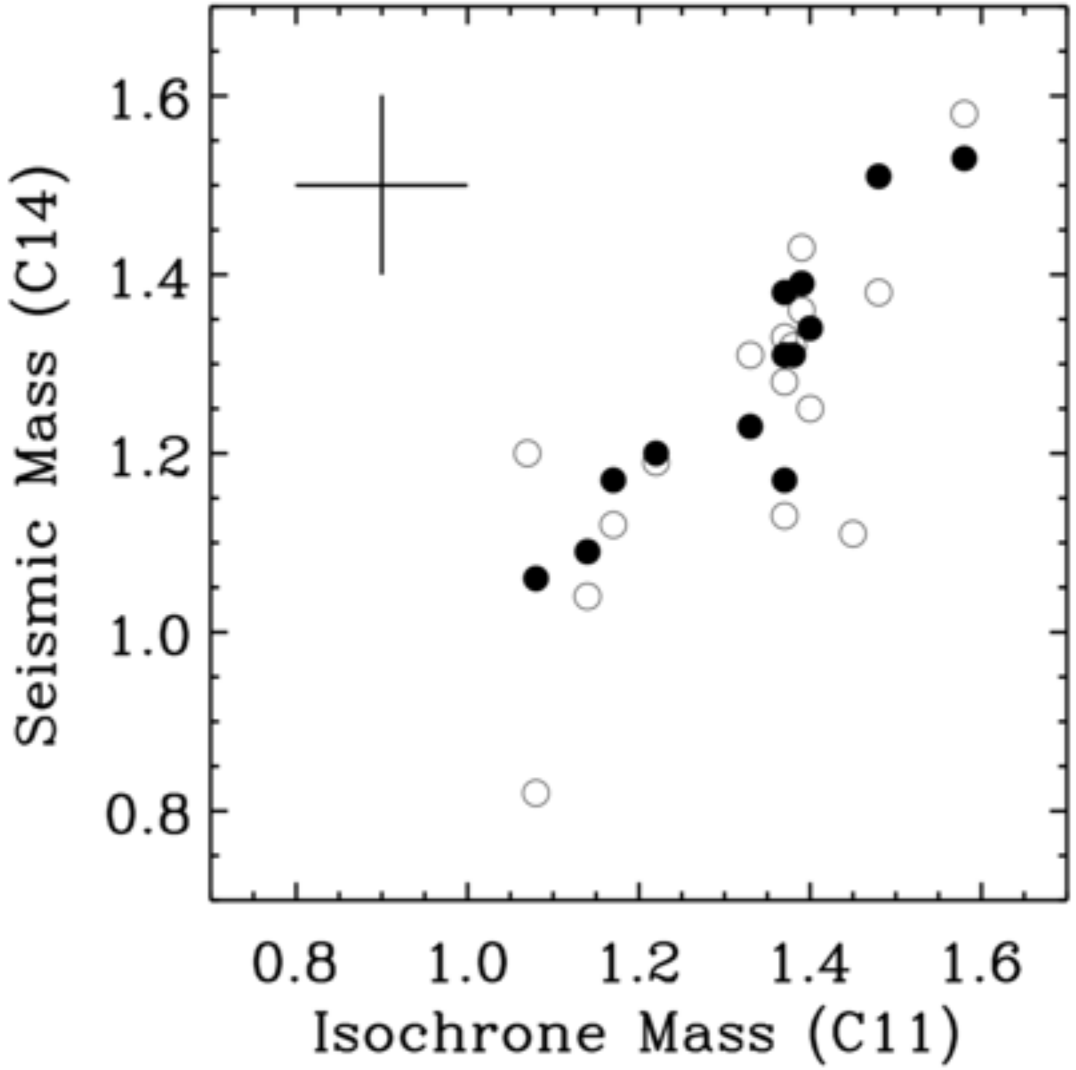
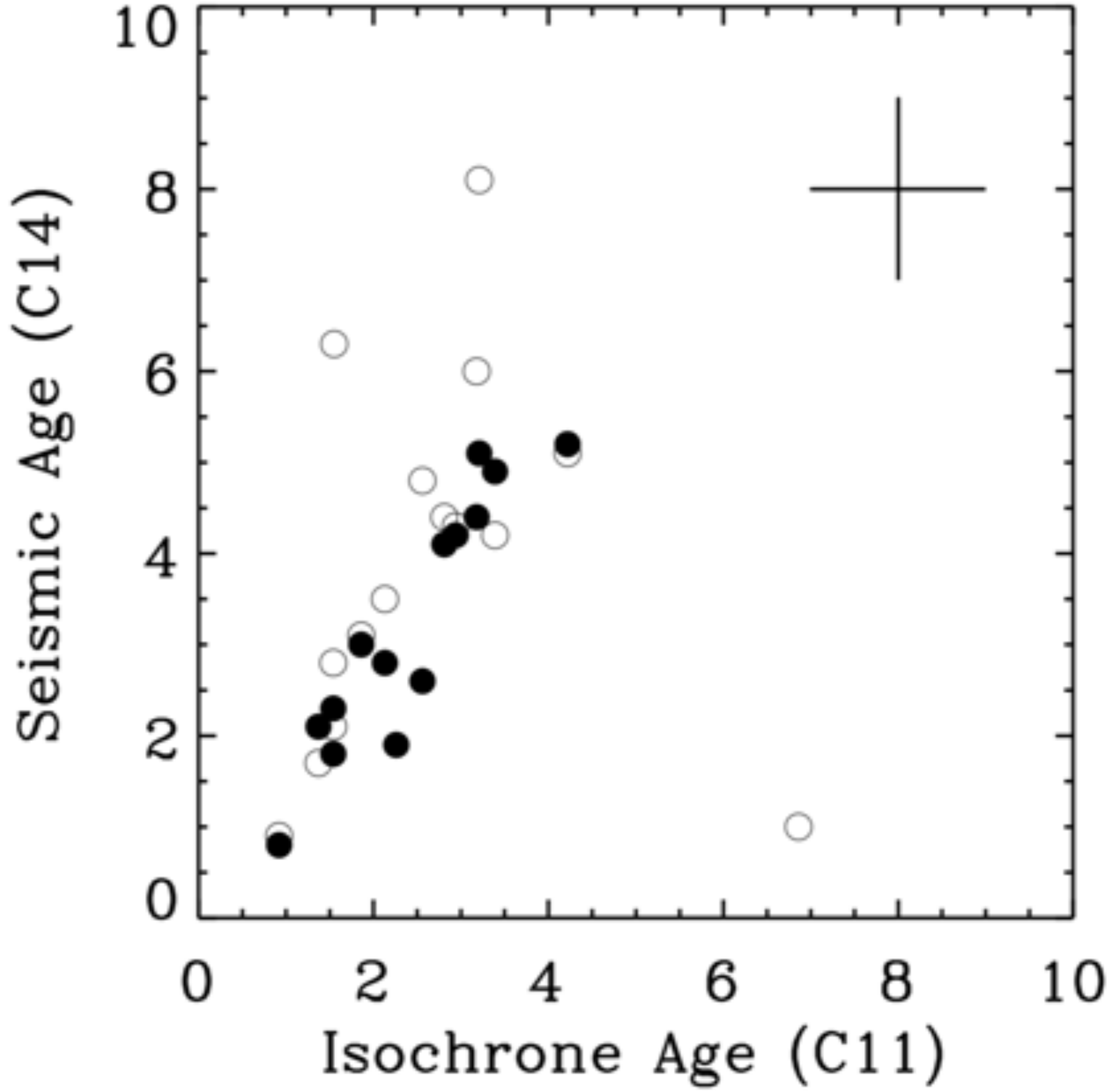


Hipparcos vs Kepler

Casagrande (arXiv: 1512.02283)



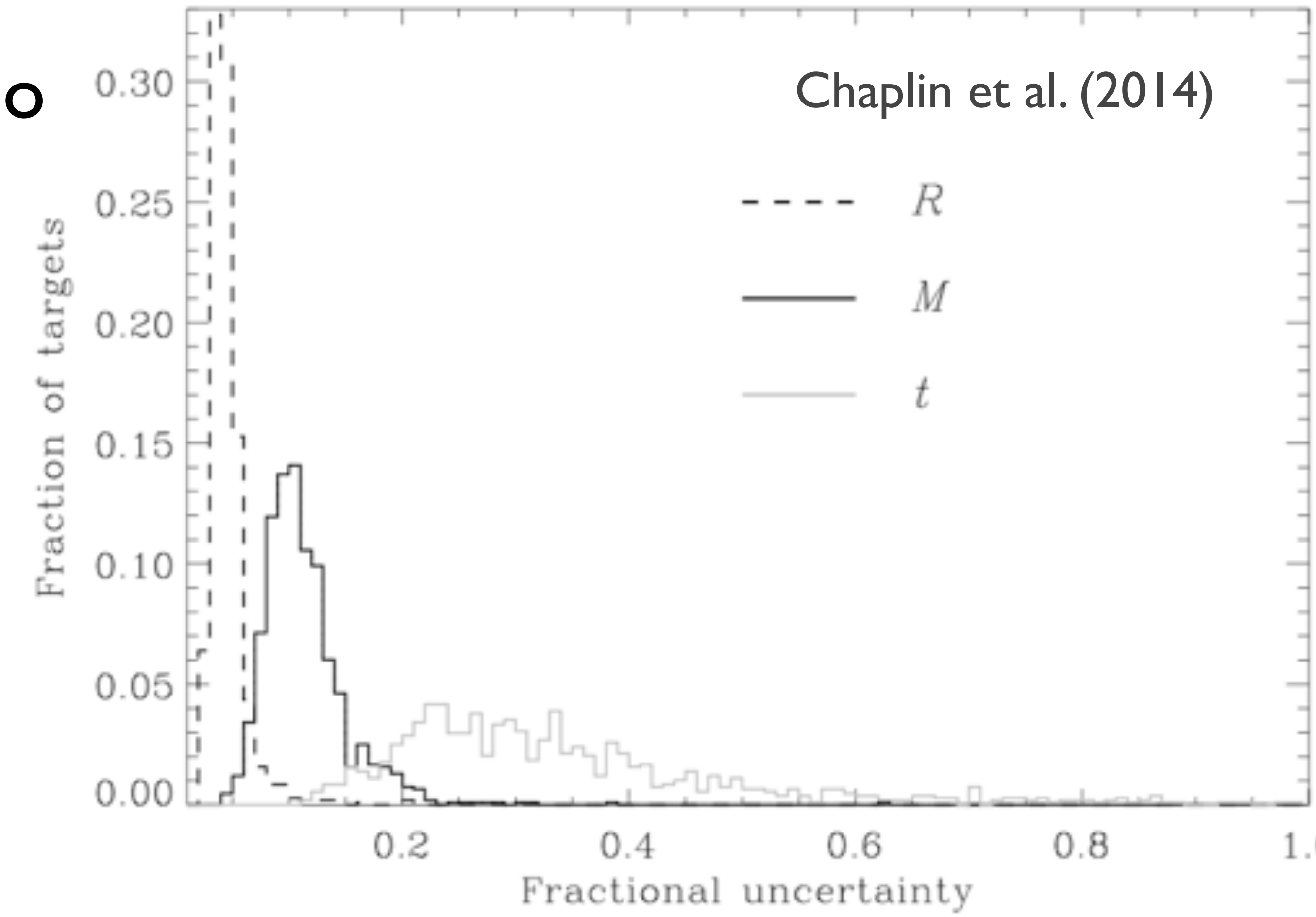


asteroseismology: the least we can do

$$\nu_{\max}$$

$$\Delta\nu$$

$$T_{\rm eff}$$



asteroseismology: the least we can do

$$\nu_{\rm max}$$
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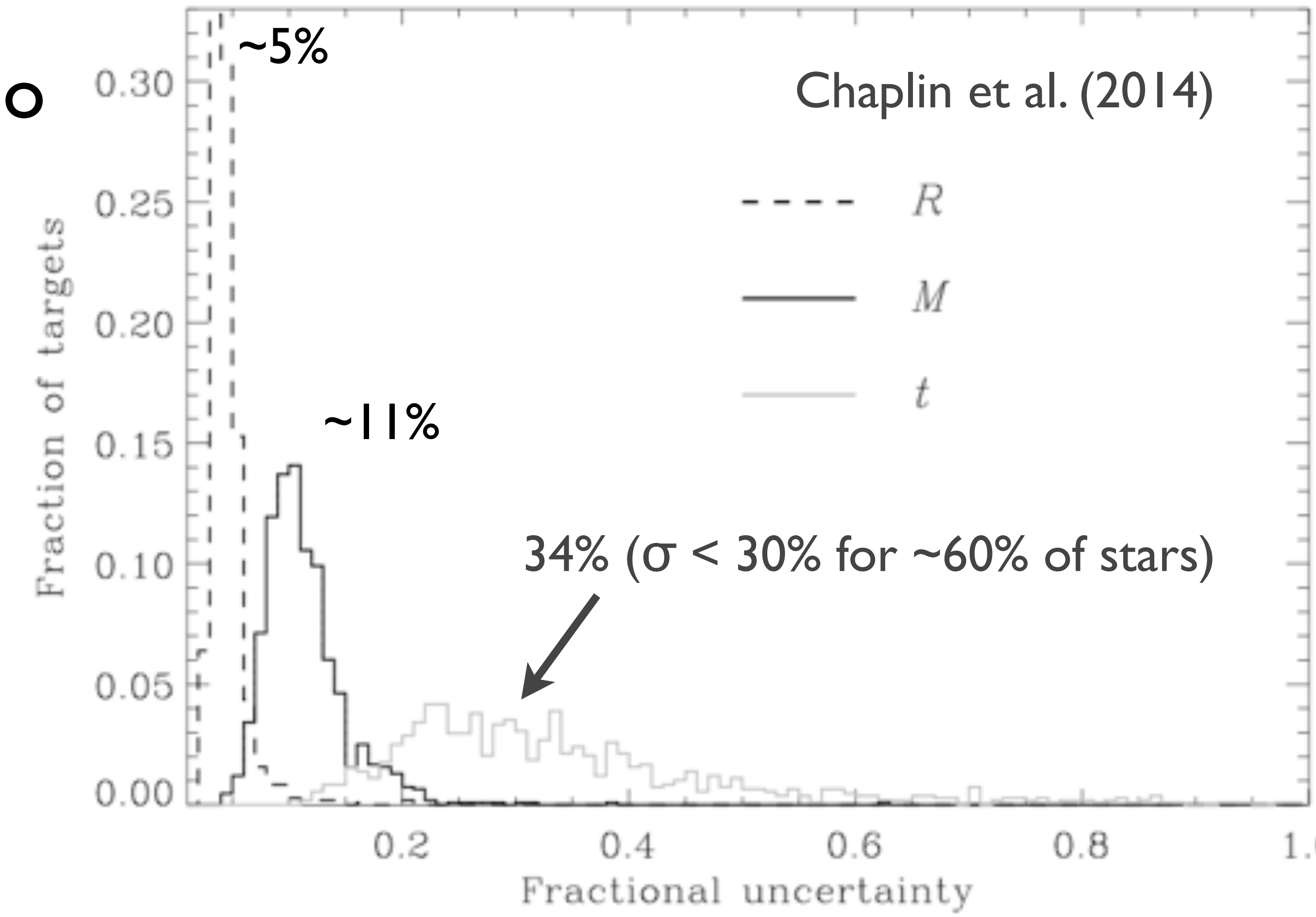

asteroseismology: the least we can do

$\nu_{\max}$

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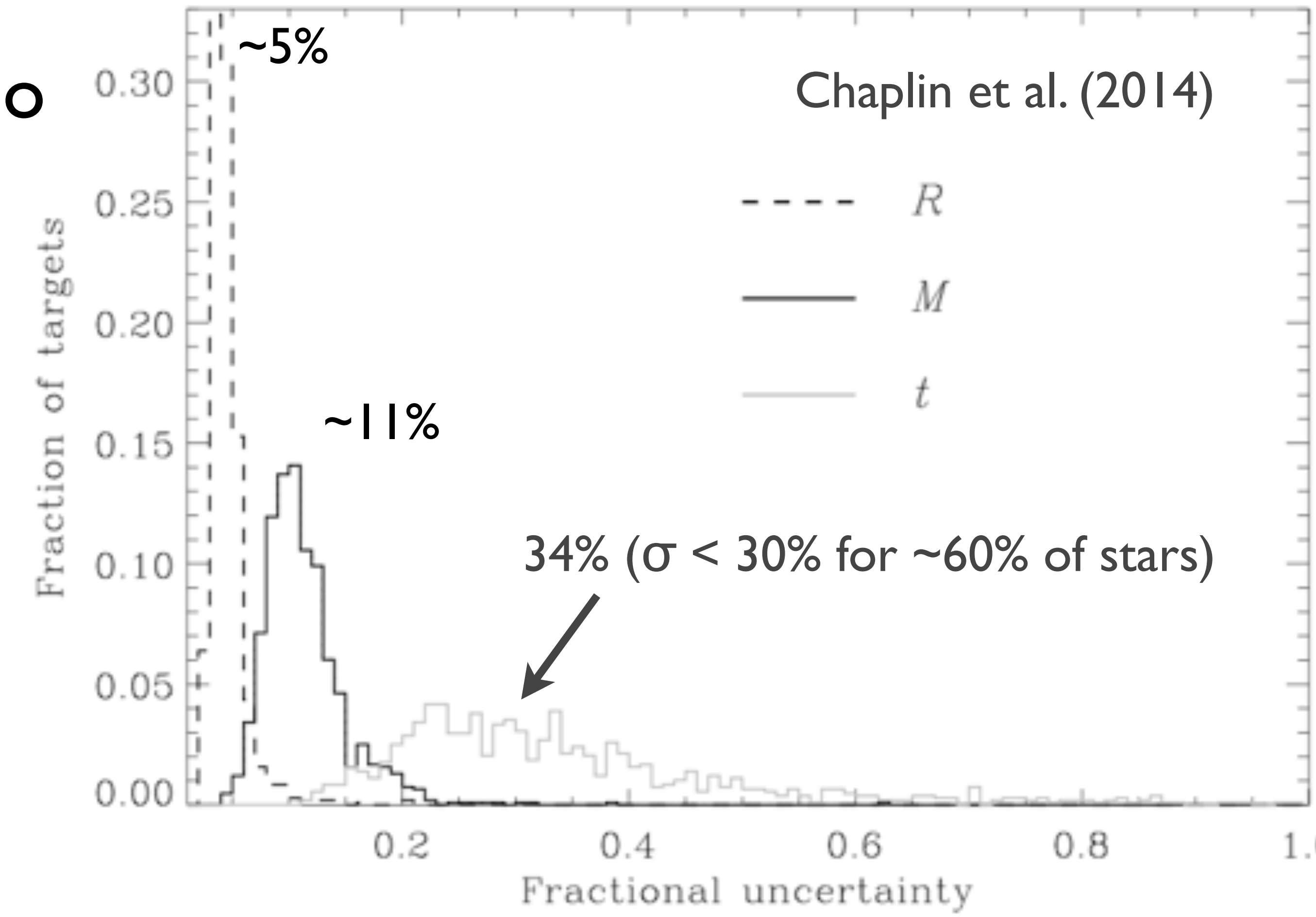
T_{eff}

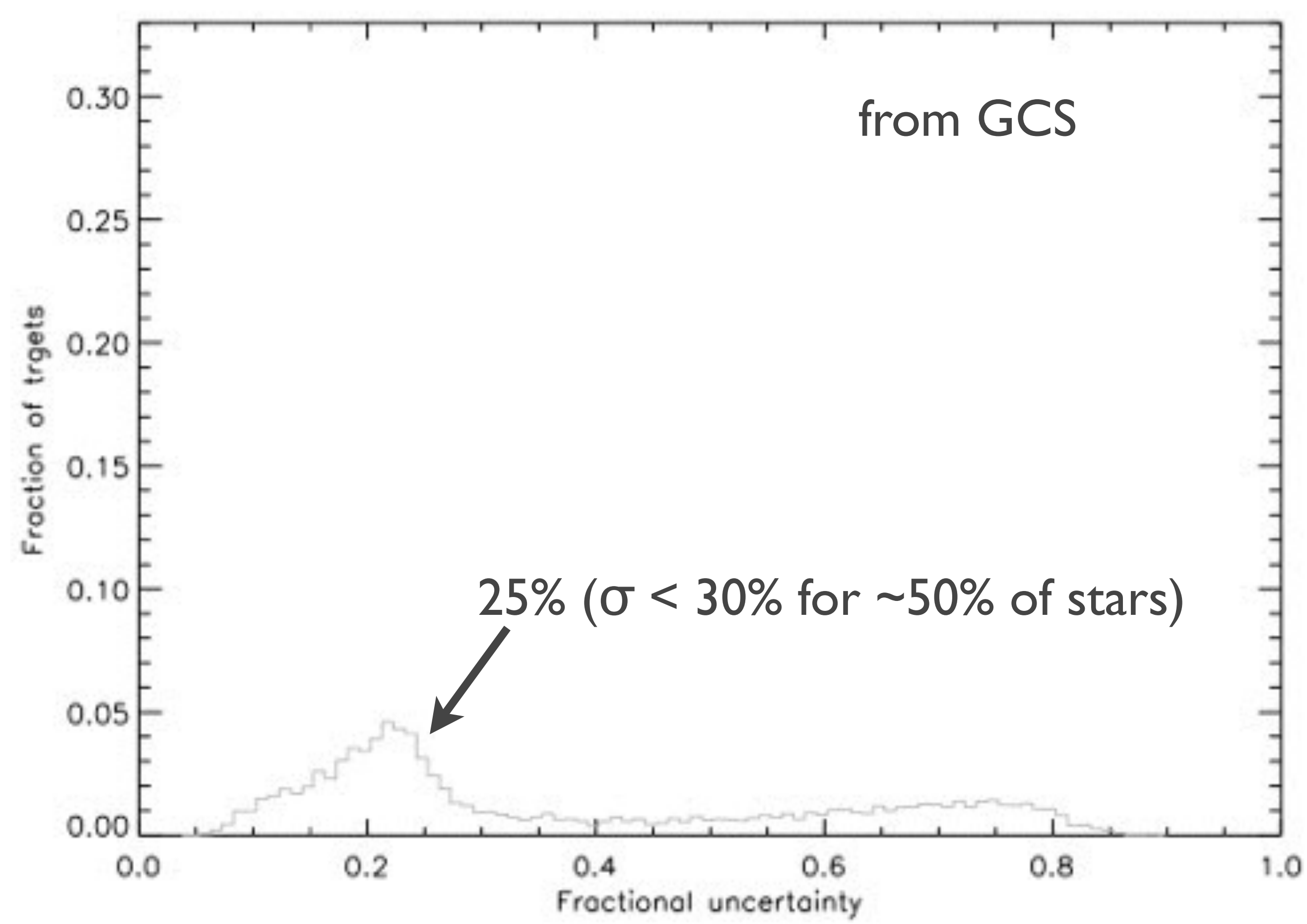


isochrone fitting: the best we can do

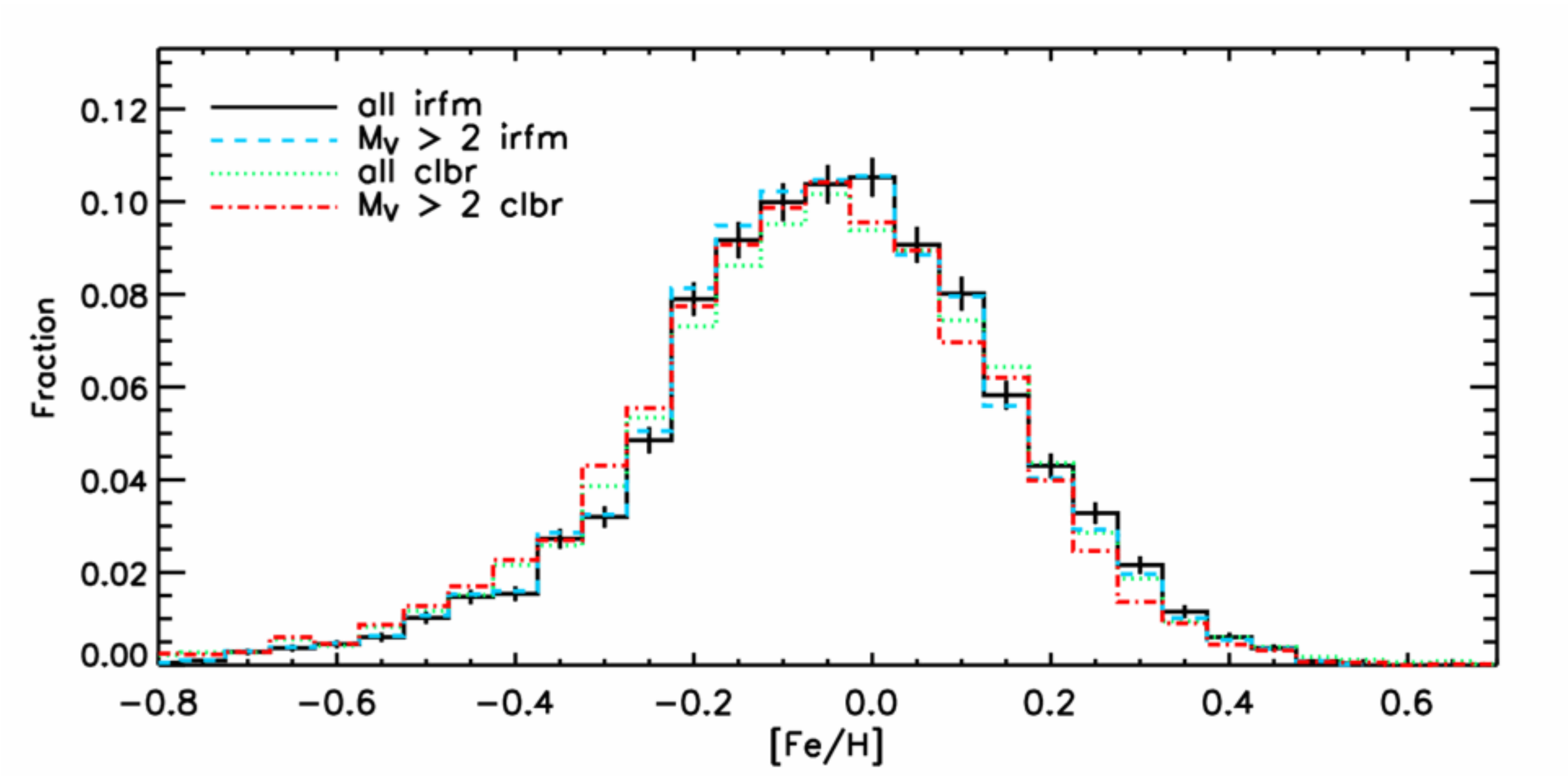
$[Fe/H]$

π

T_{eff}



Metallicity Distribution Function



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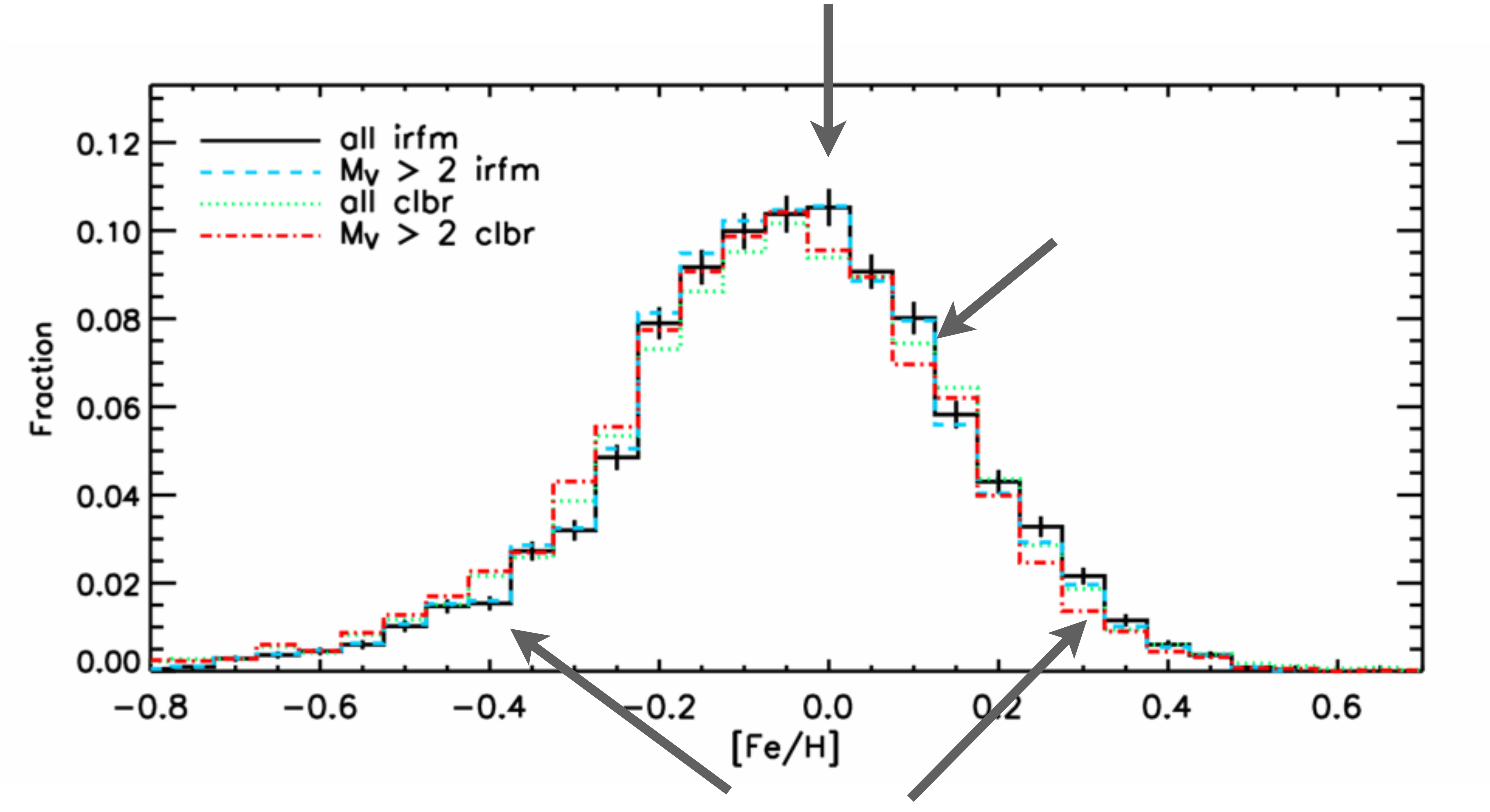
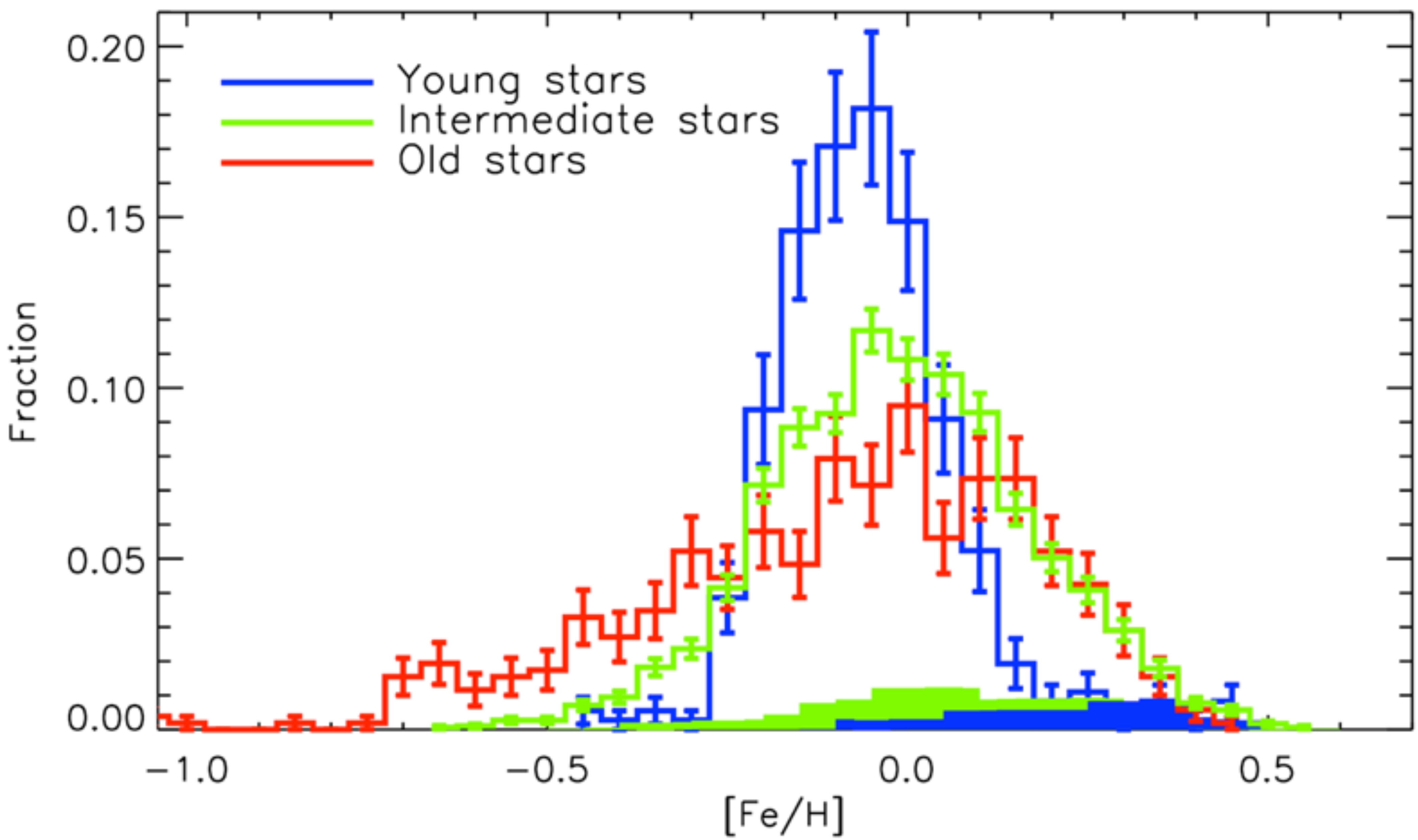
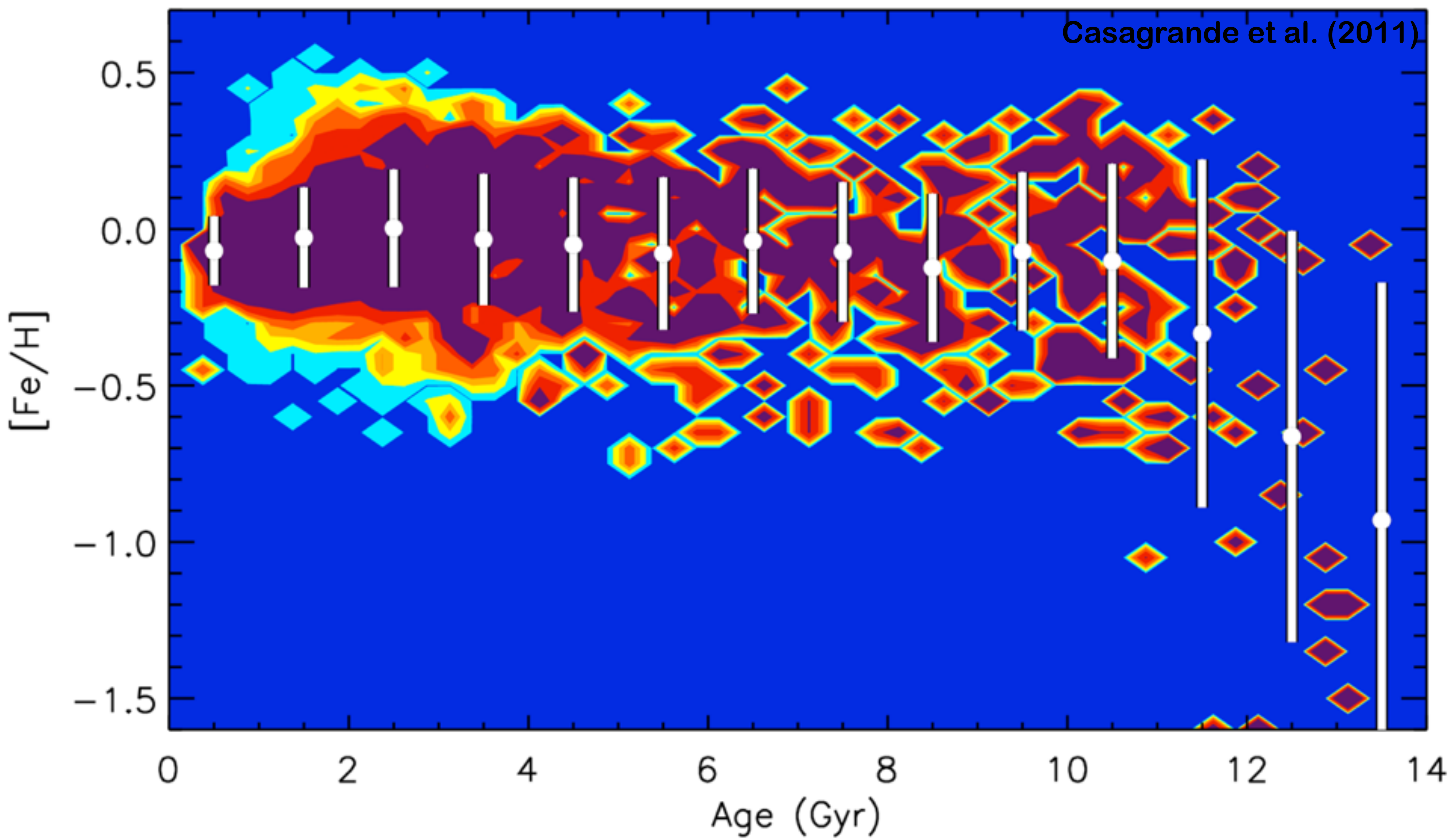


Age-Metallicity Distribution Function

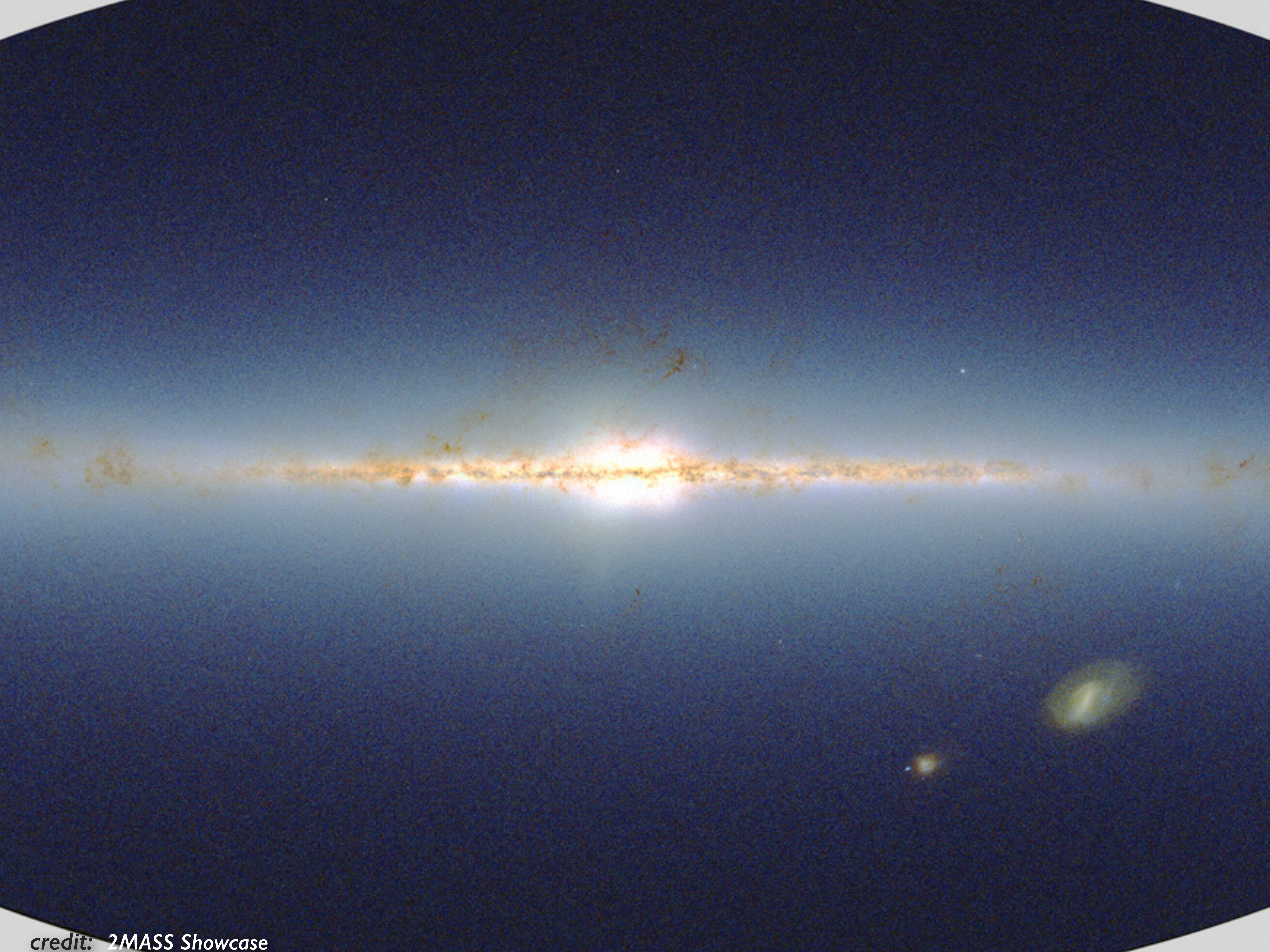


only good ages are used: σ < 1Gyr or relative uncertainty < 25%

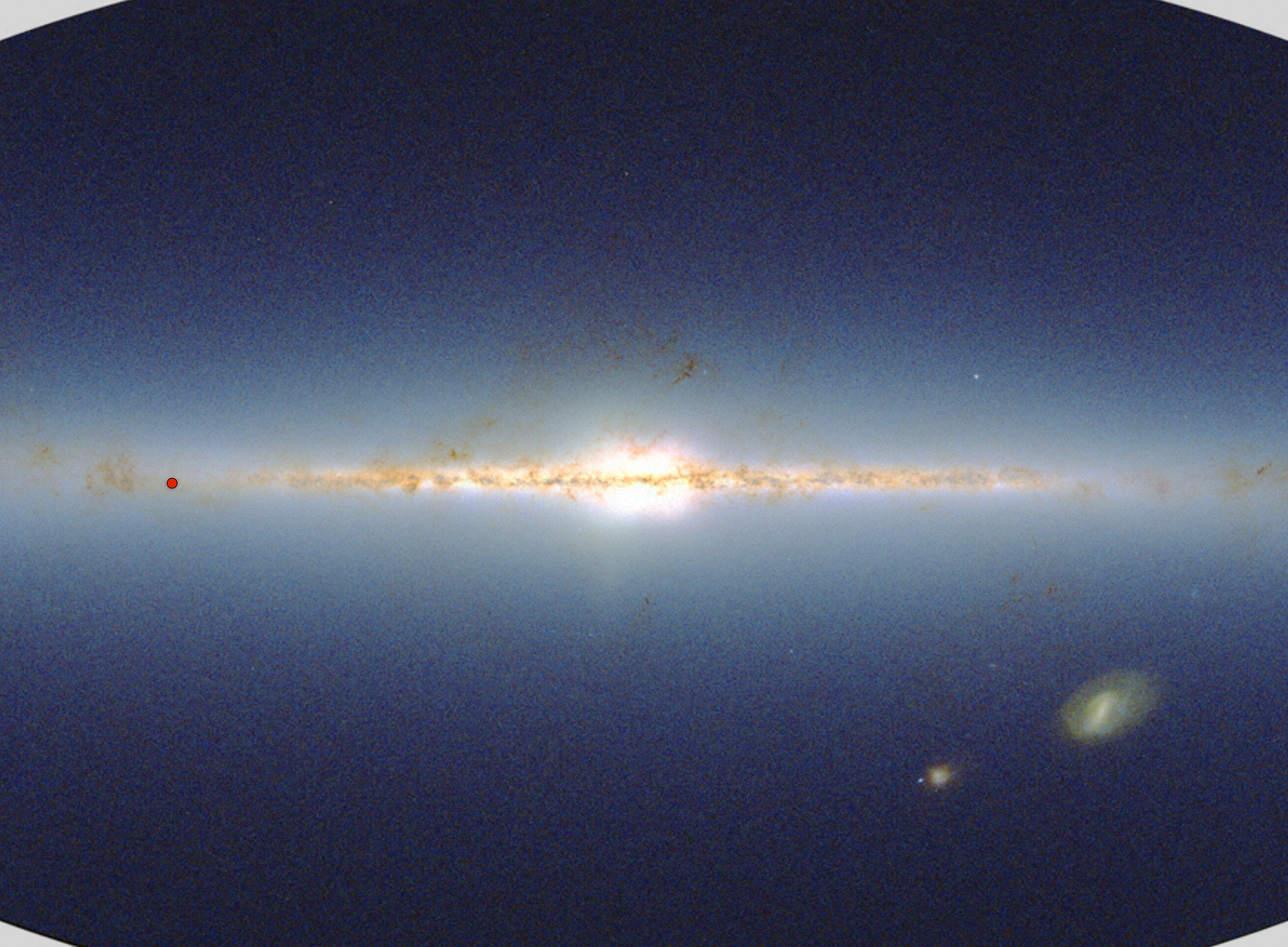
Age-Metallicity Relation



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



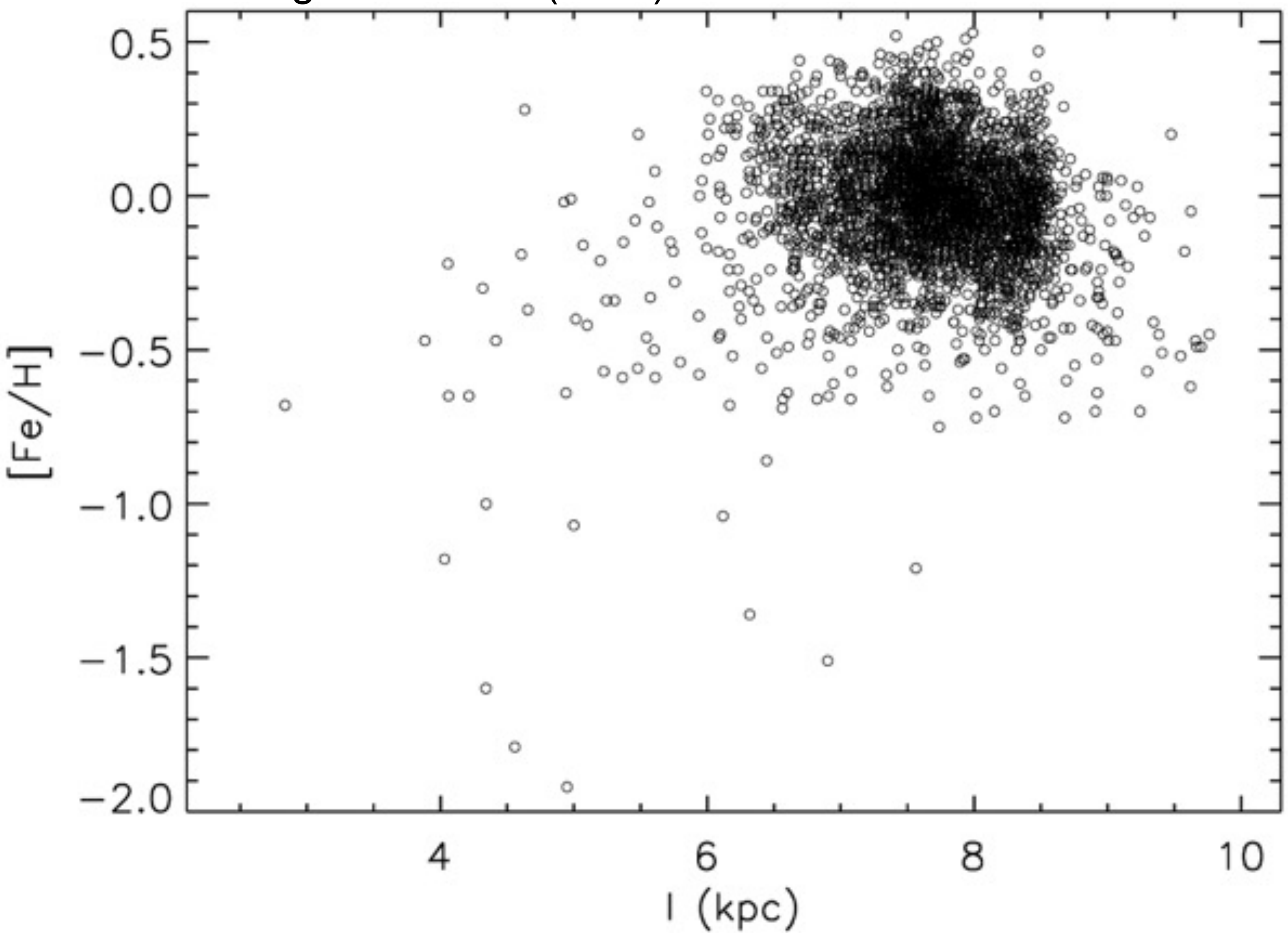
credit: 2MASS Showcase



credit: 2MASS Showcase

Ages and Gradients in the GCS

Casagrande et al. (2011)



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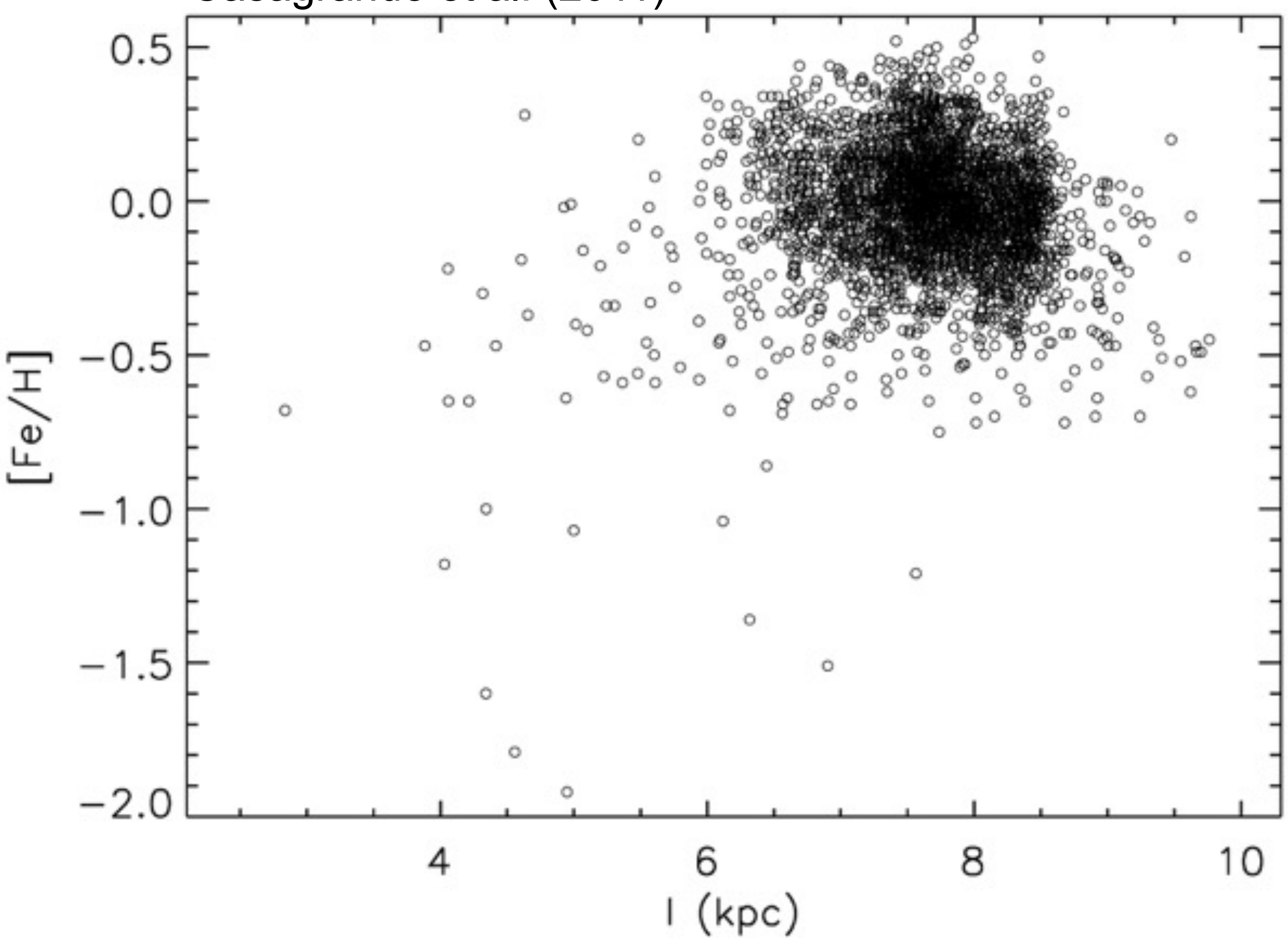

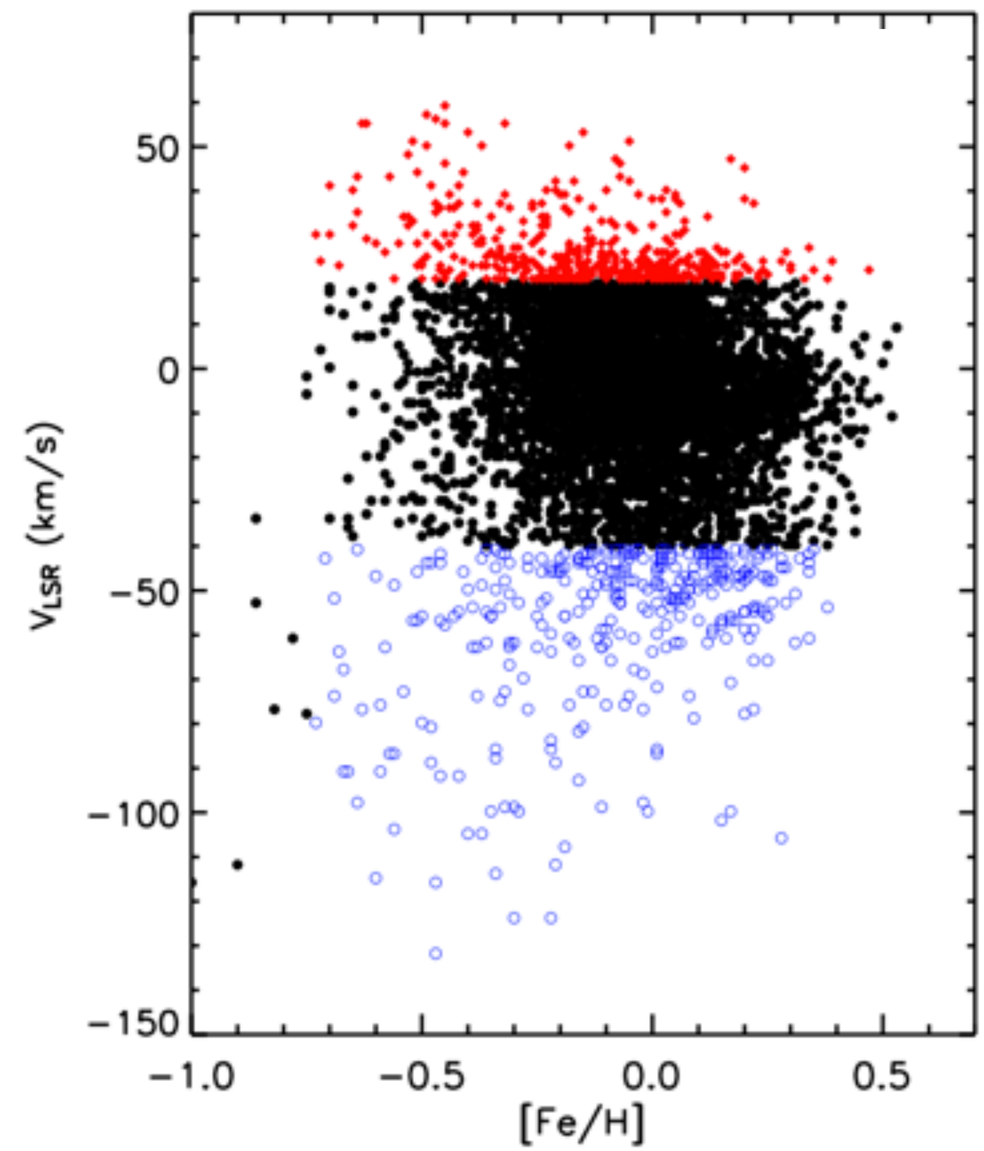

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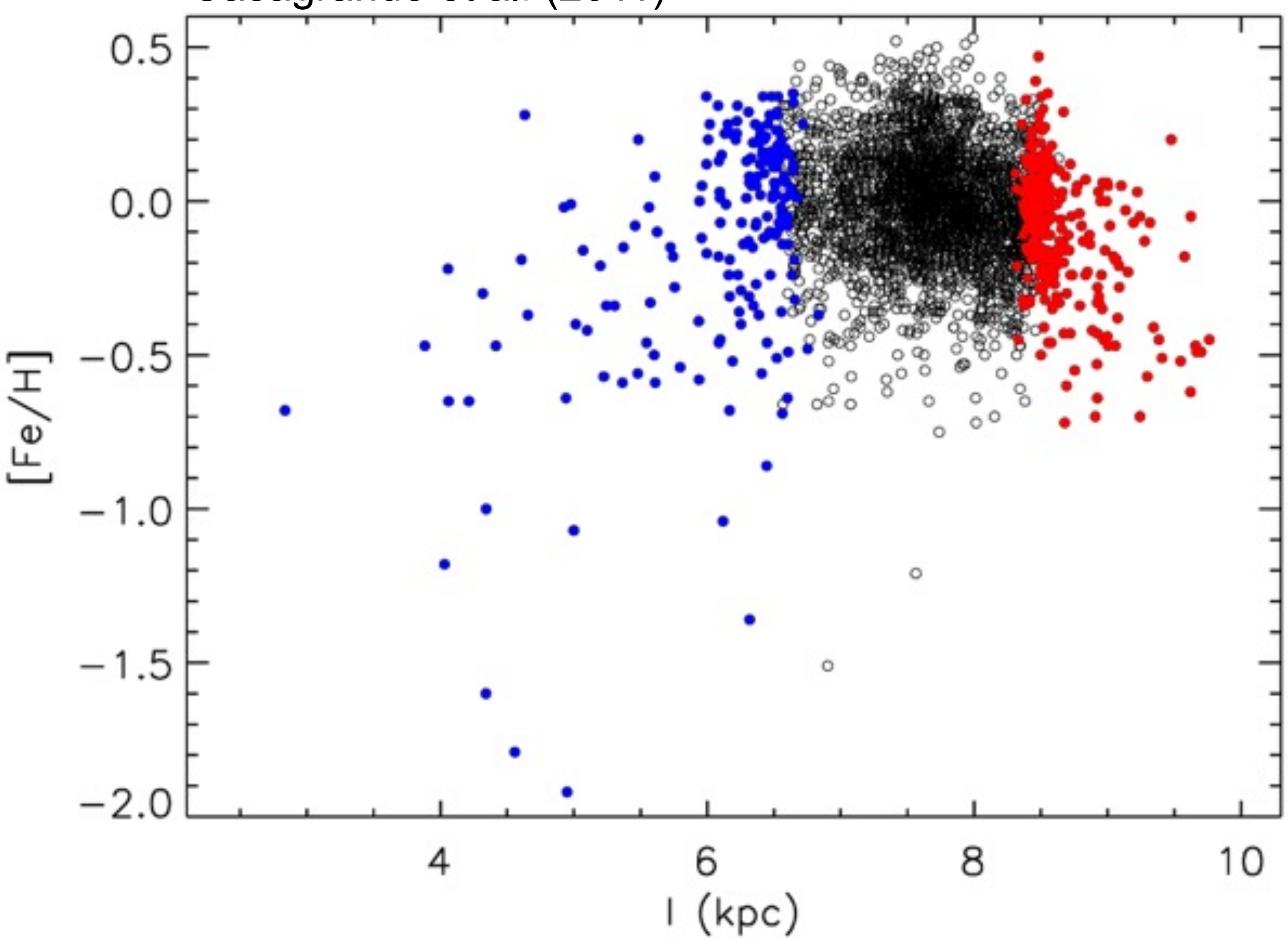

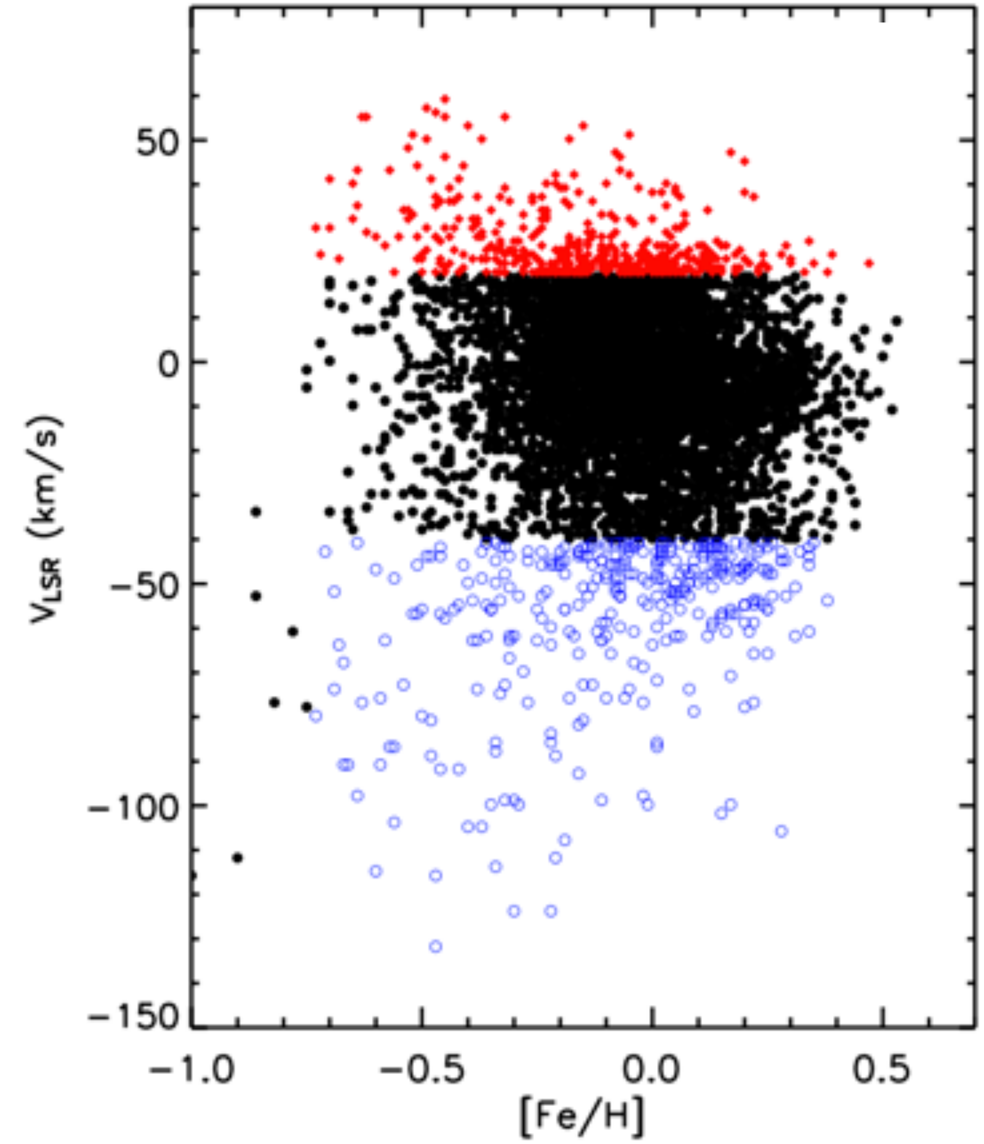

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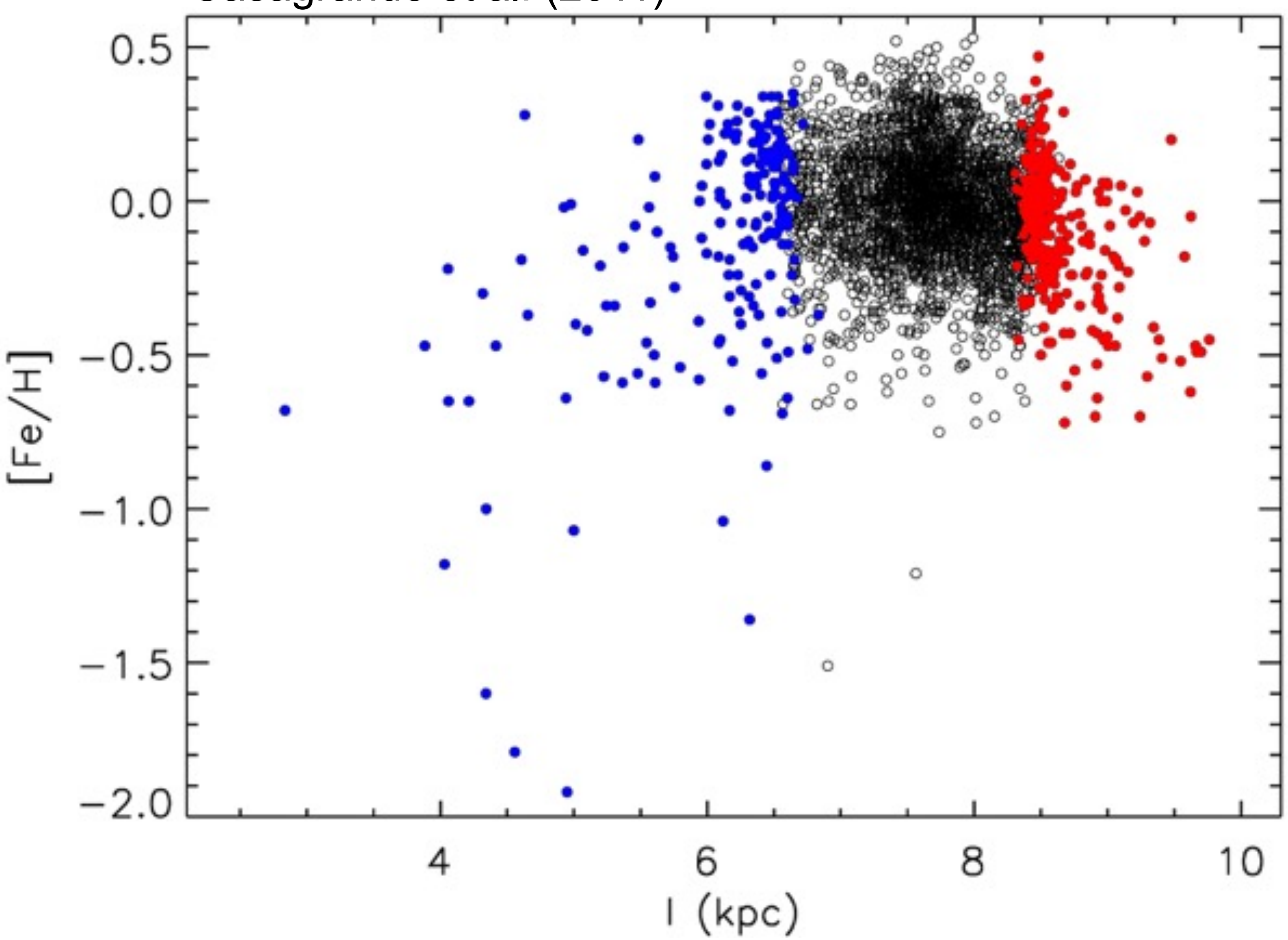
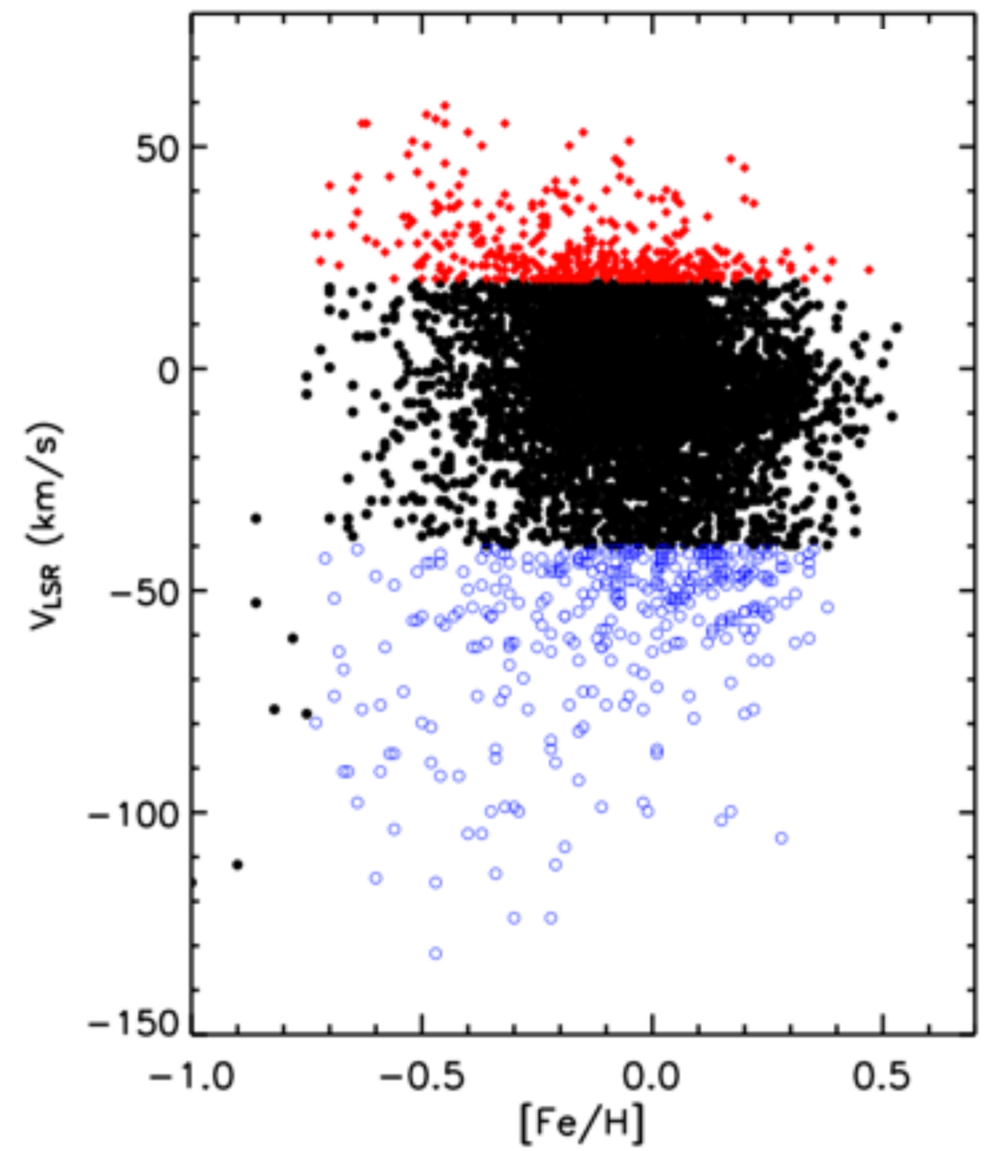
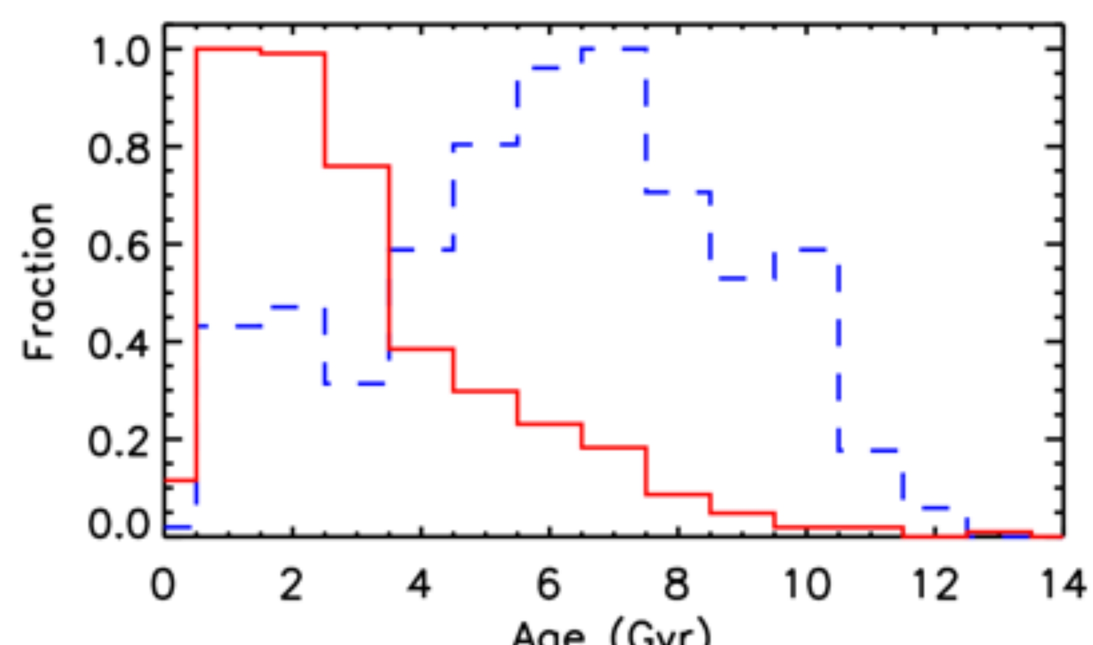
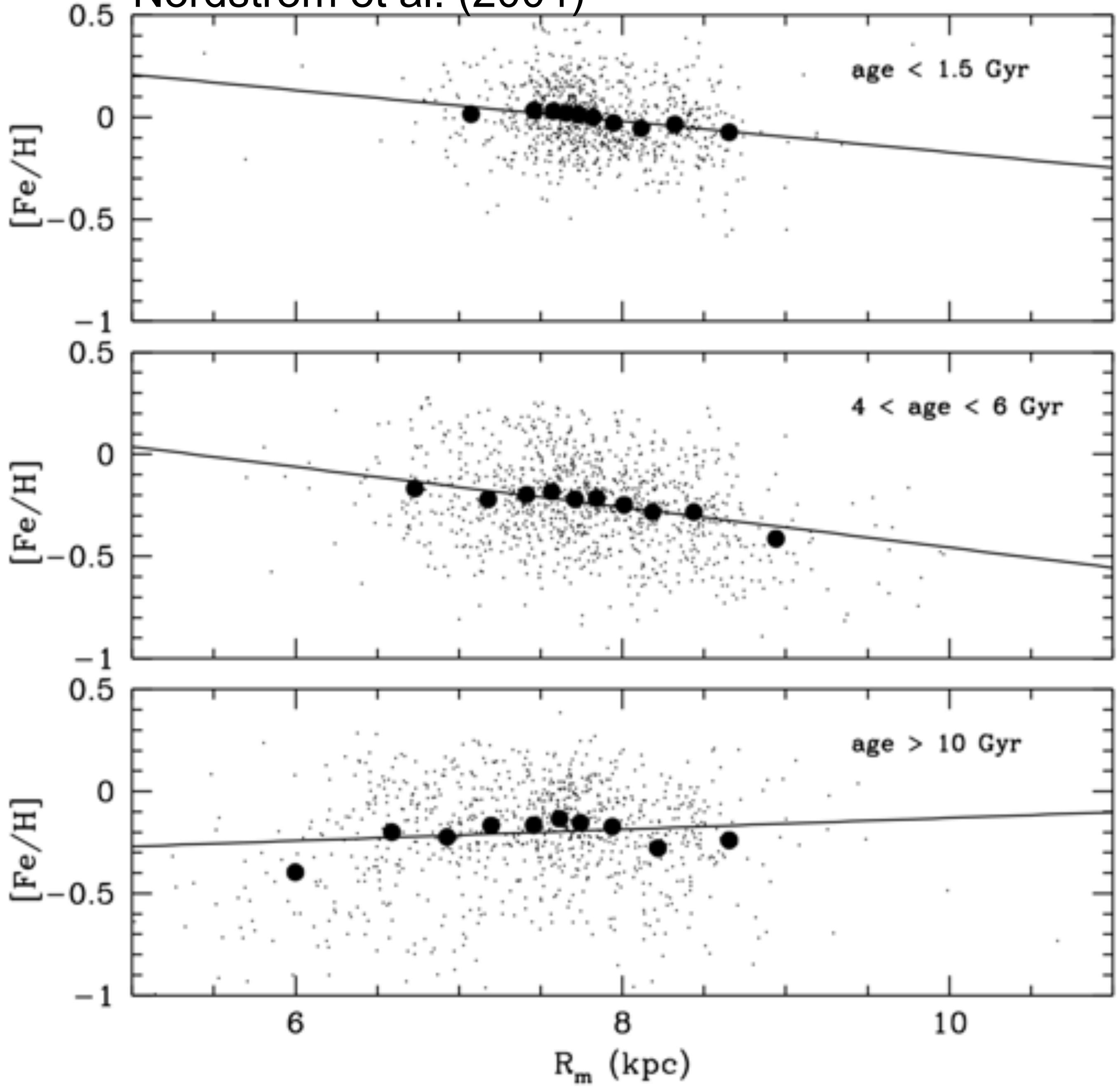




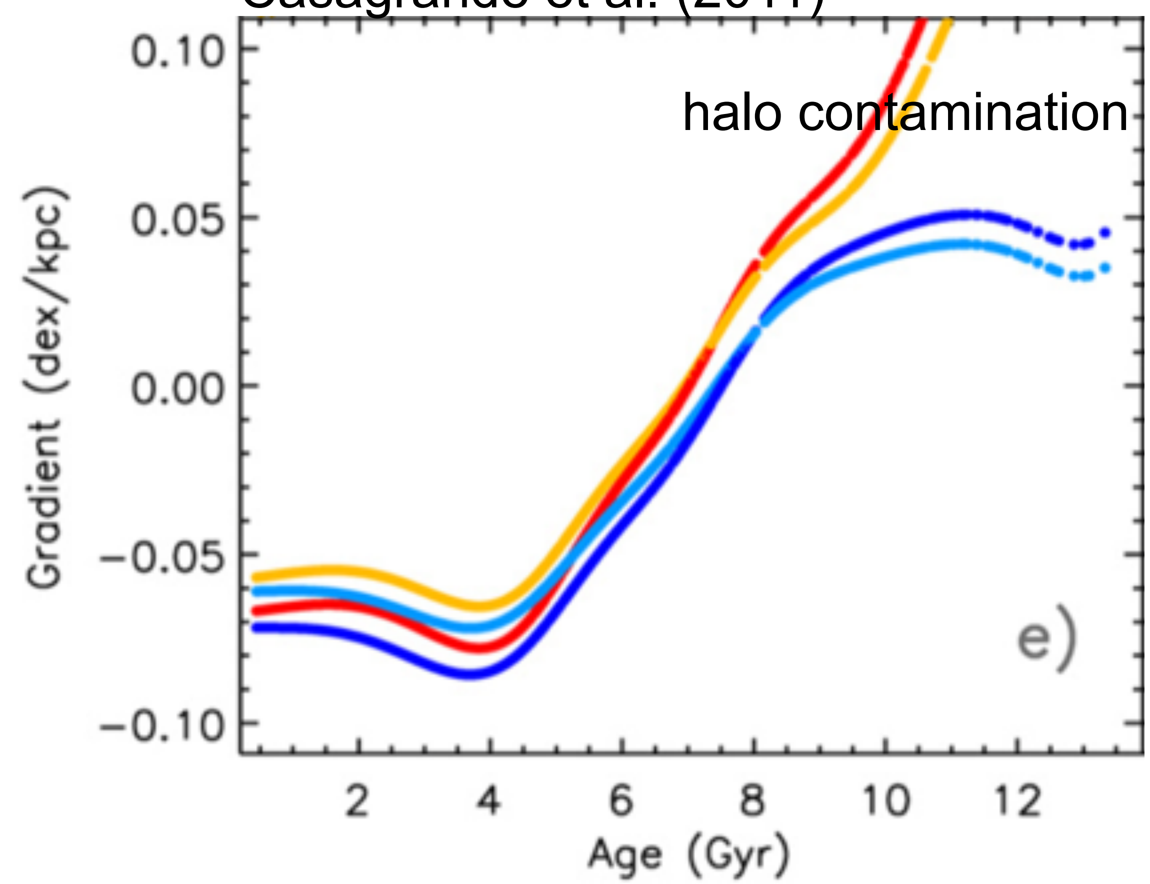


Ages and Gradients in the GCS

Nordström et al. (2004)

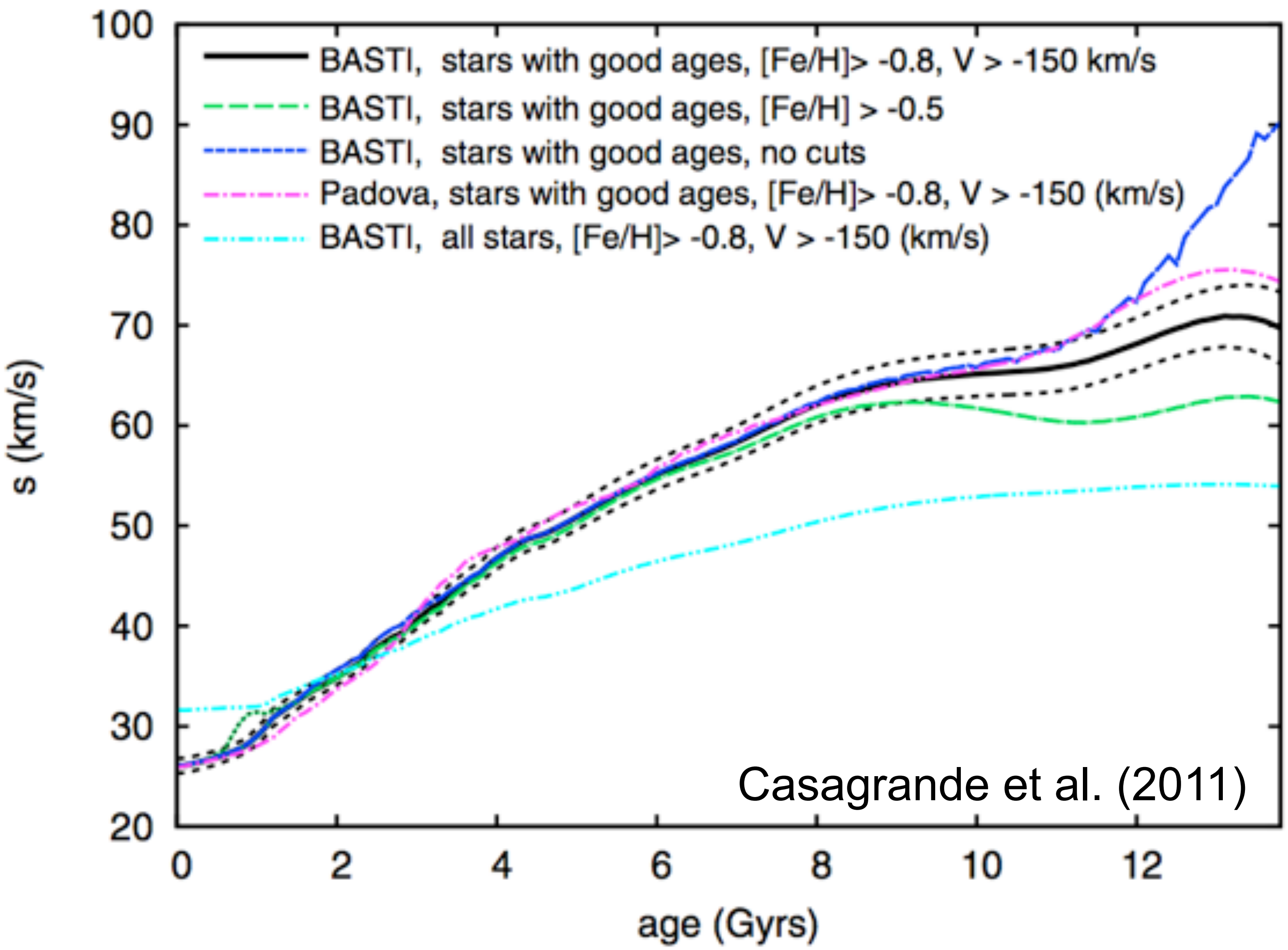


Casagrande et al. (2011)



Age Dispersion relation

e.g. von Hoerner 1960, Mayor 1974



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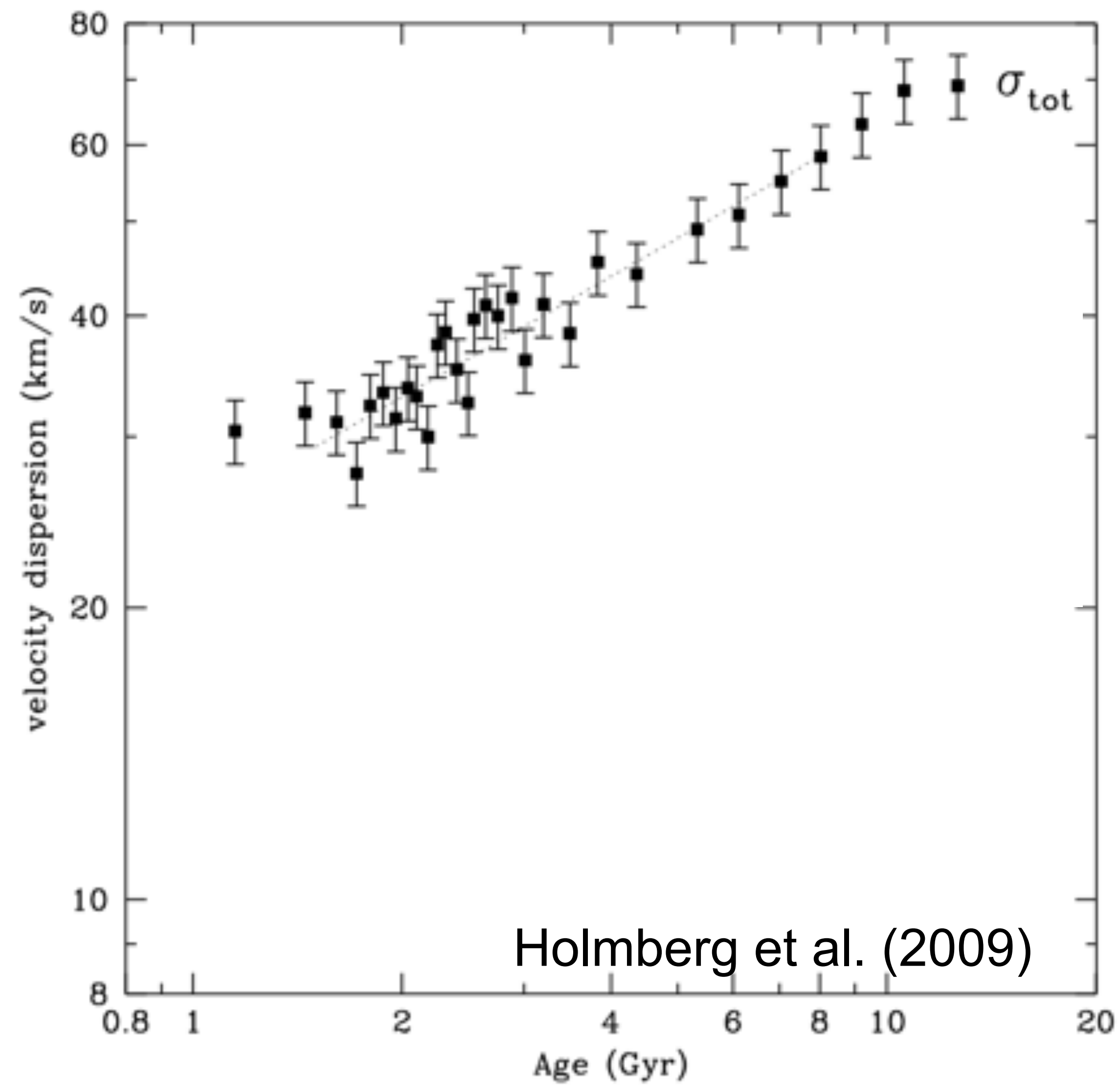
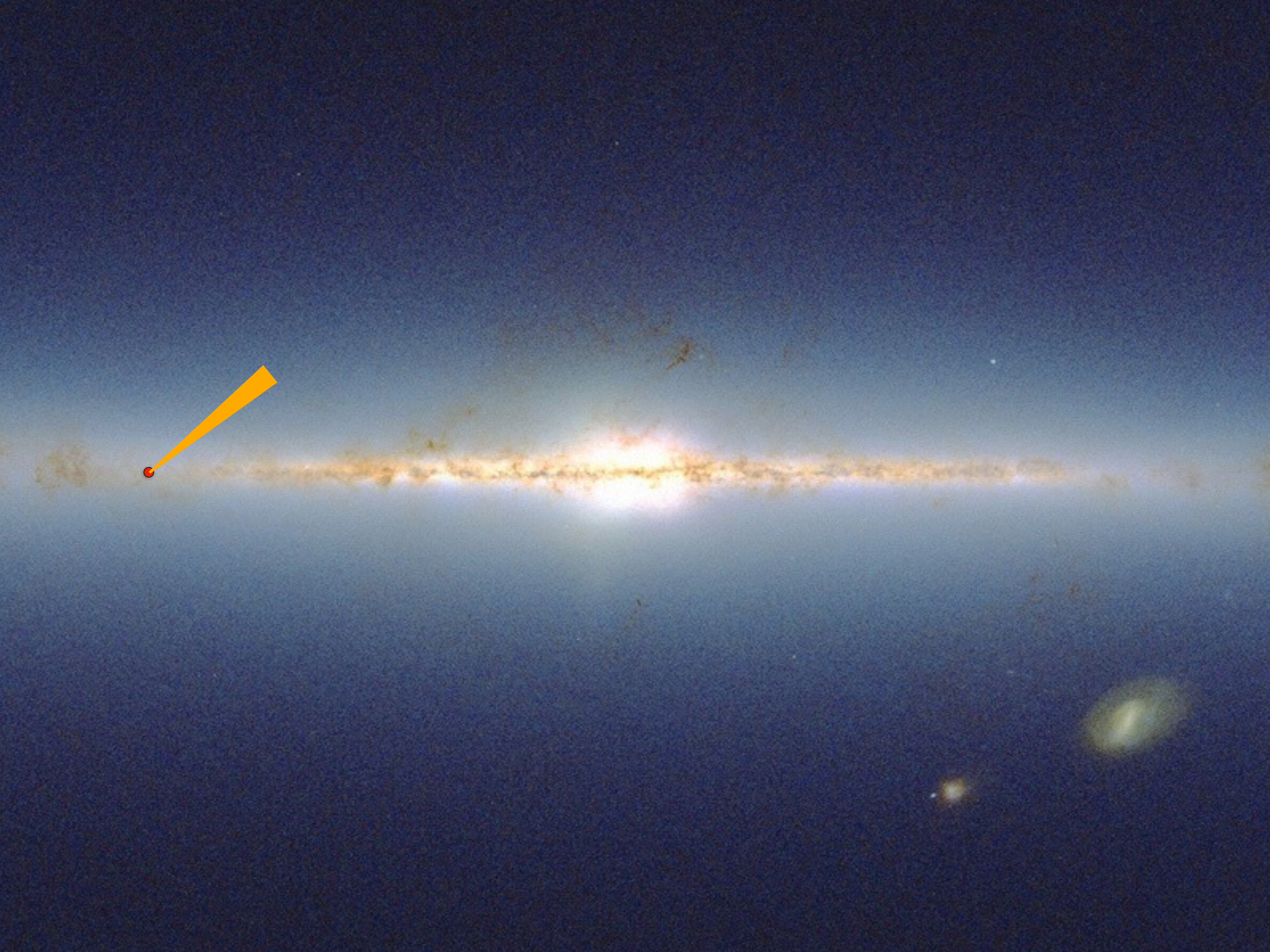
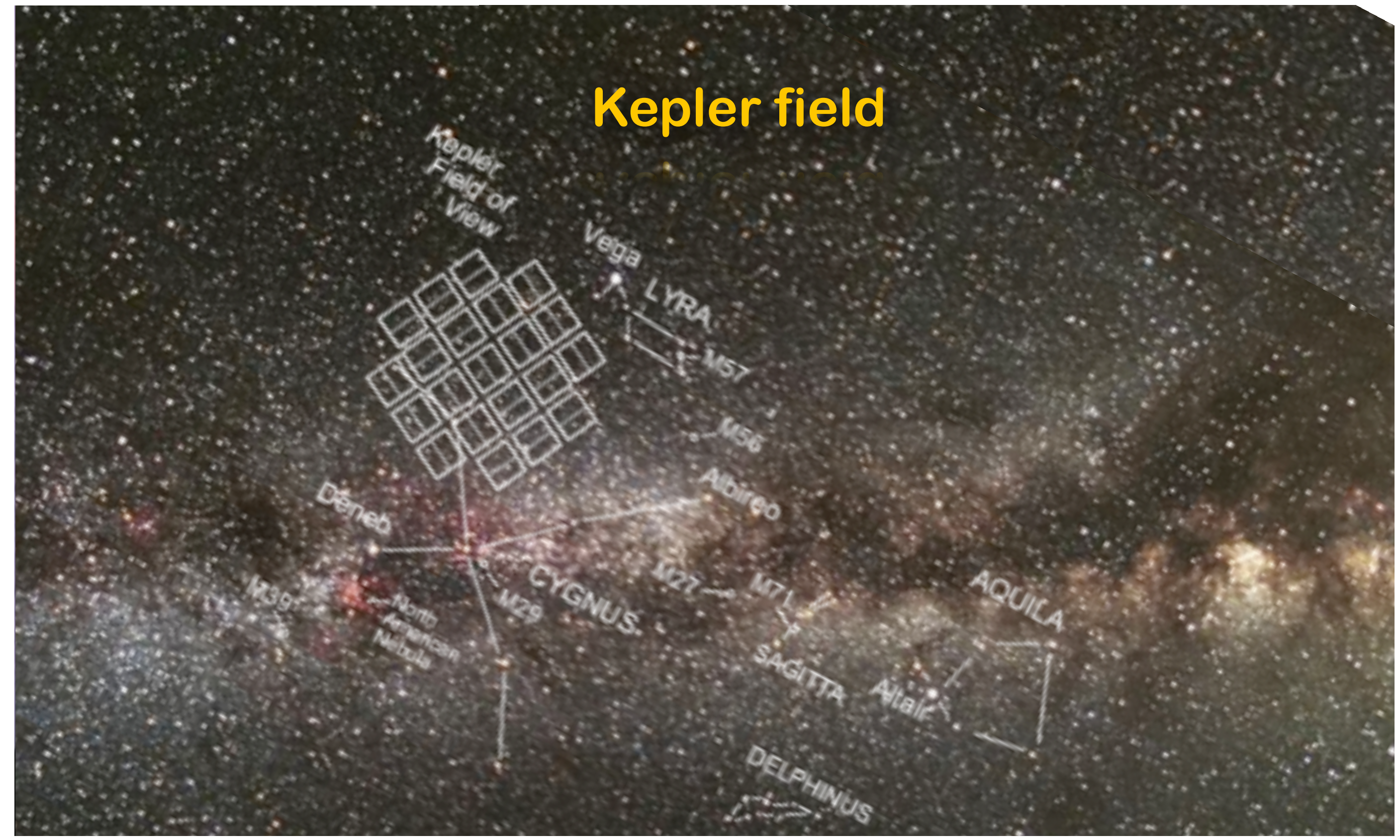
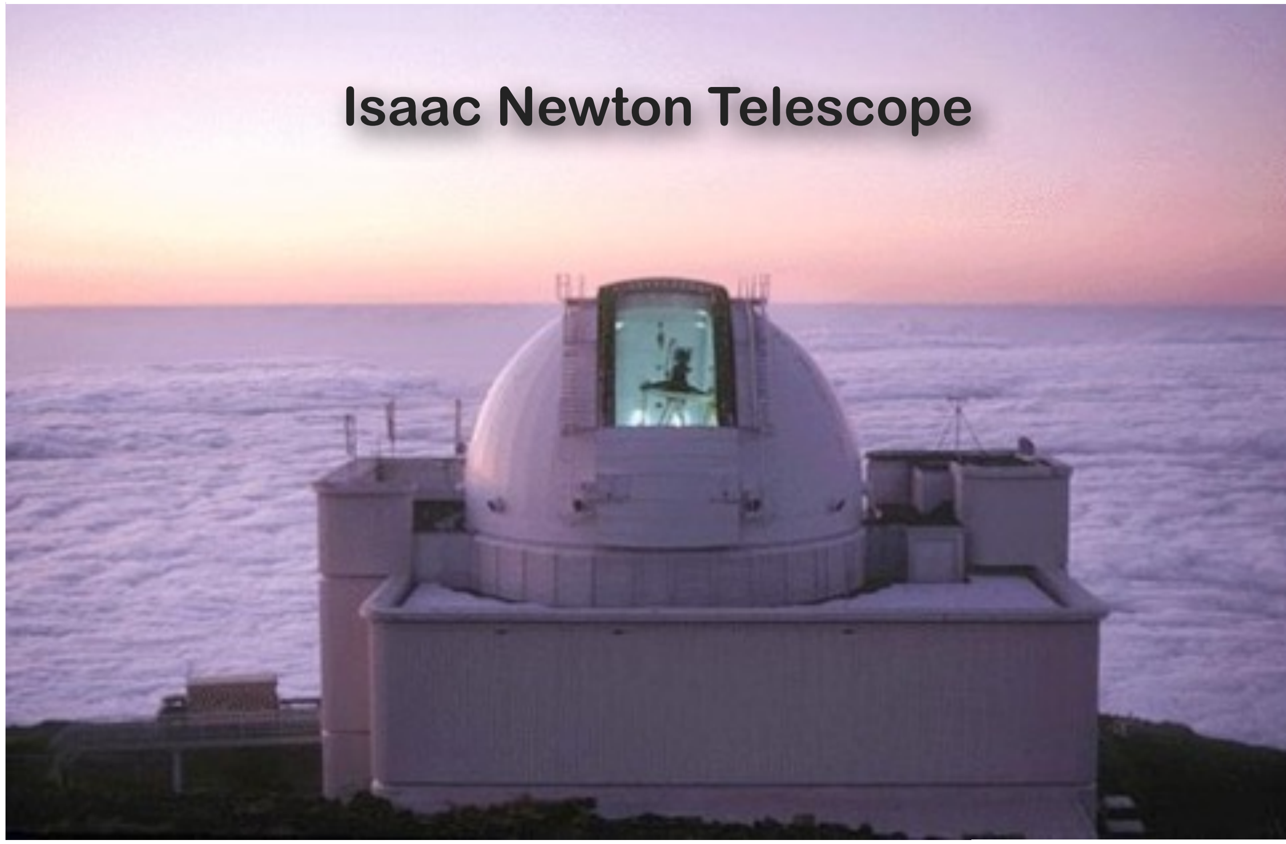


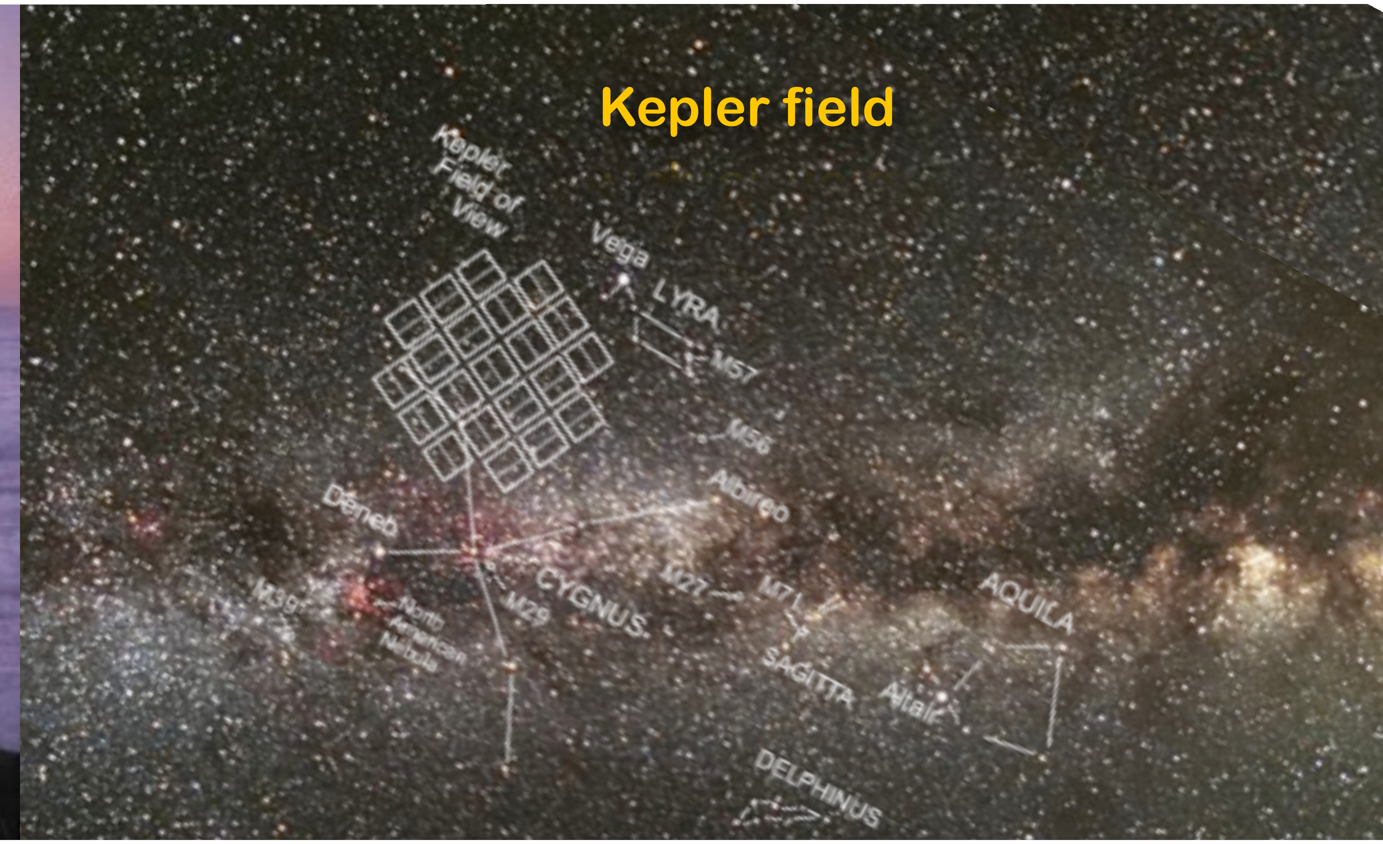
Holmberg et al. (2009)




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

Strömgren survey for Asteroseismology and Galactic Archaeology





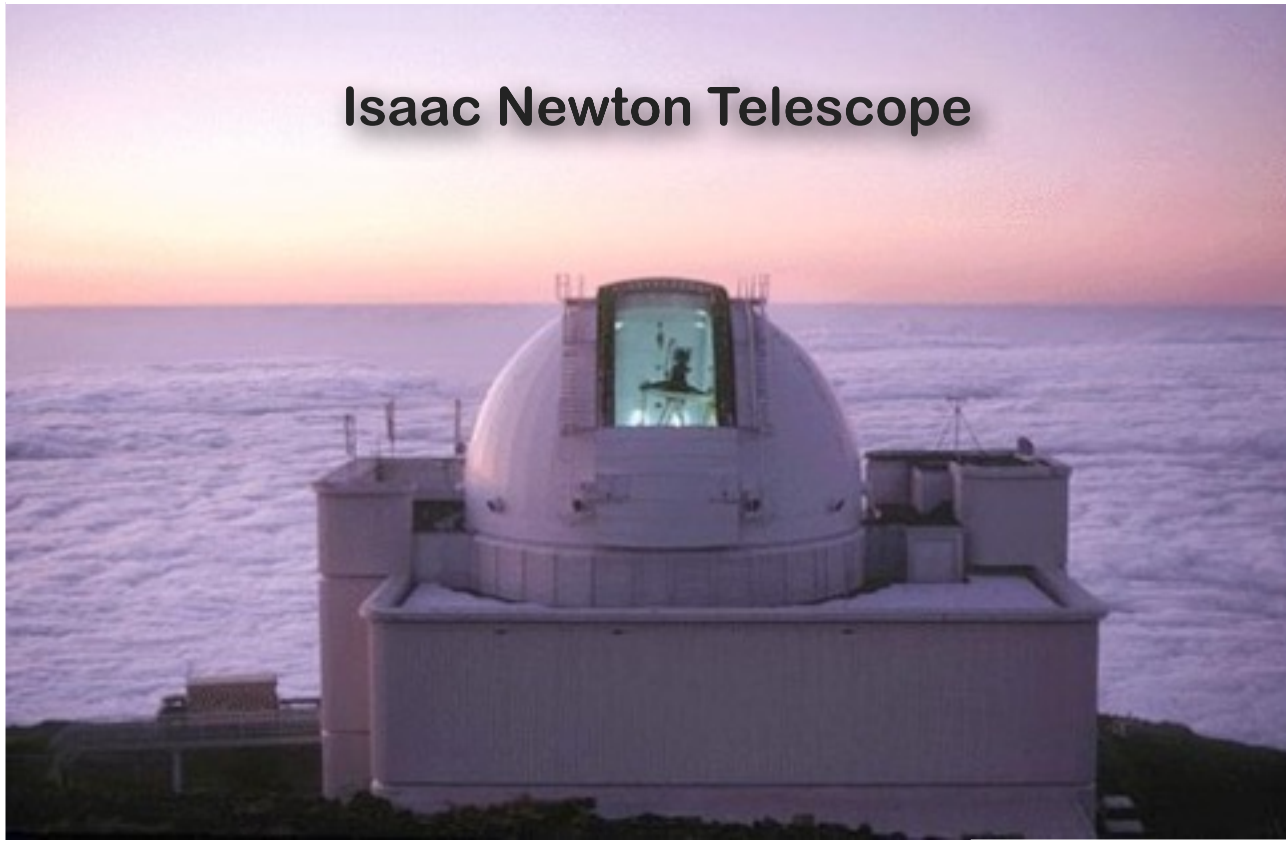
www.mso.anu.edu.au/saga

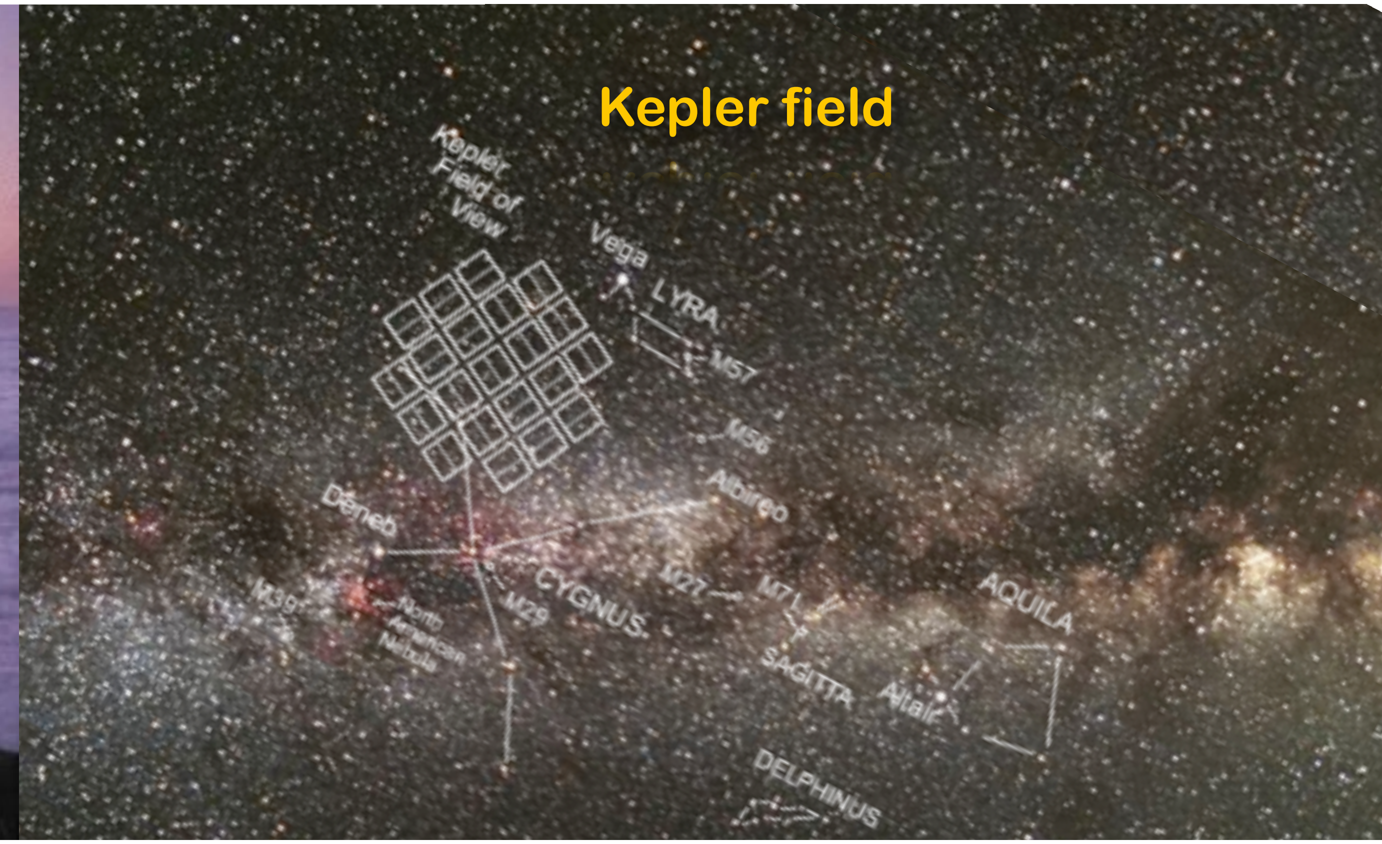
WFC @ INT:

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

Casagrande, Silva Aguirre, Stello, Huber et al. (2014)

Strömgren survey for Asteroseismology and Galactic Archaeology





www.mso.anu.edu.au/saga

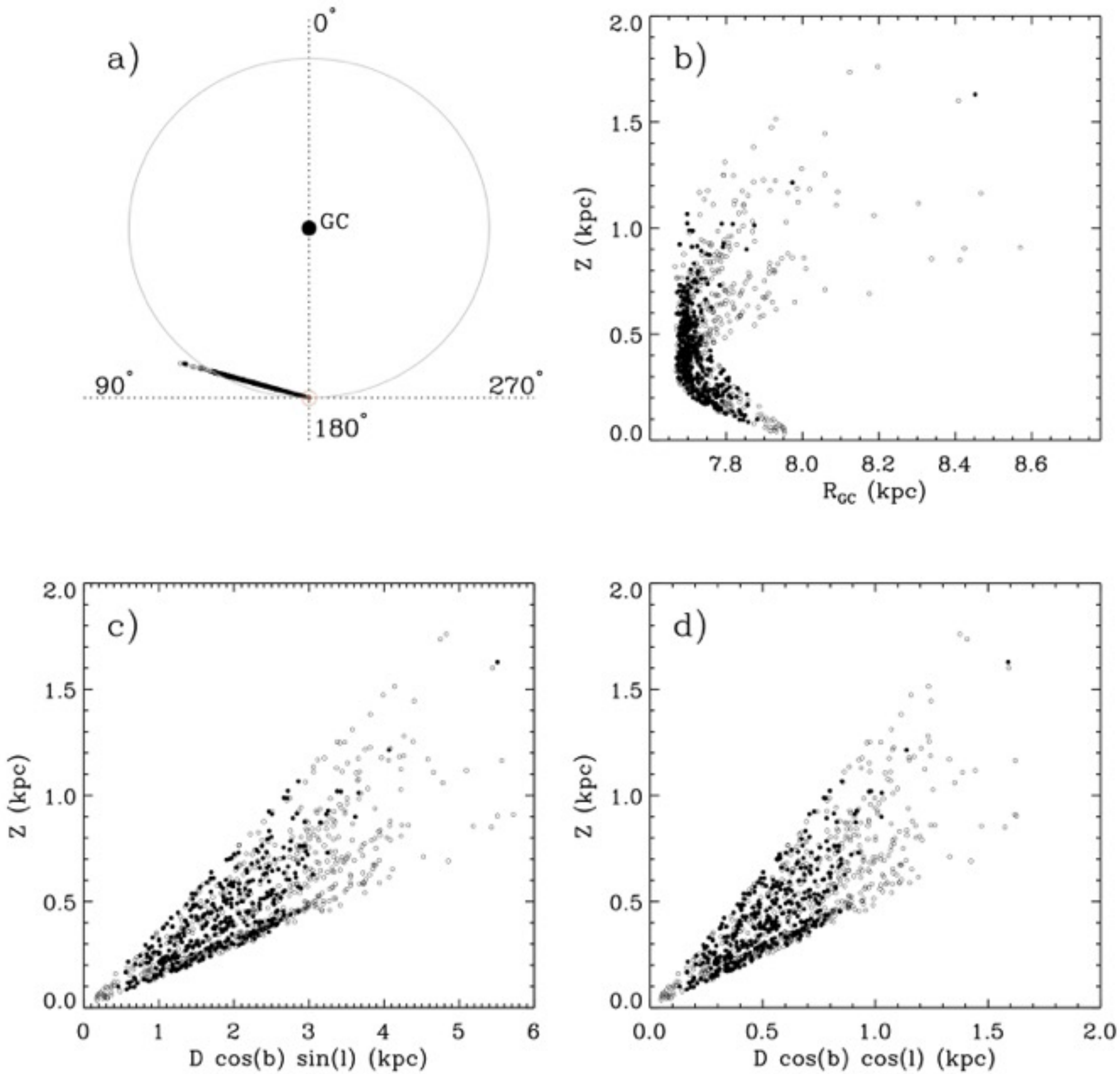
WFC @ INT:

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

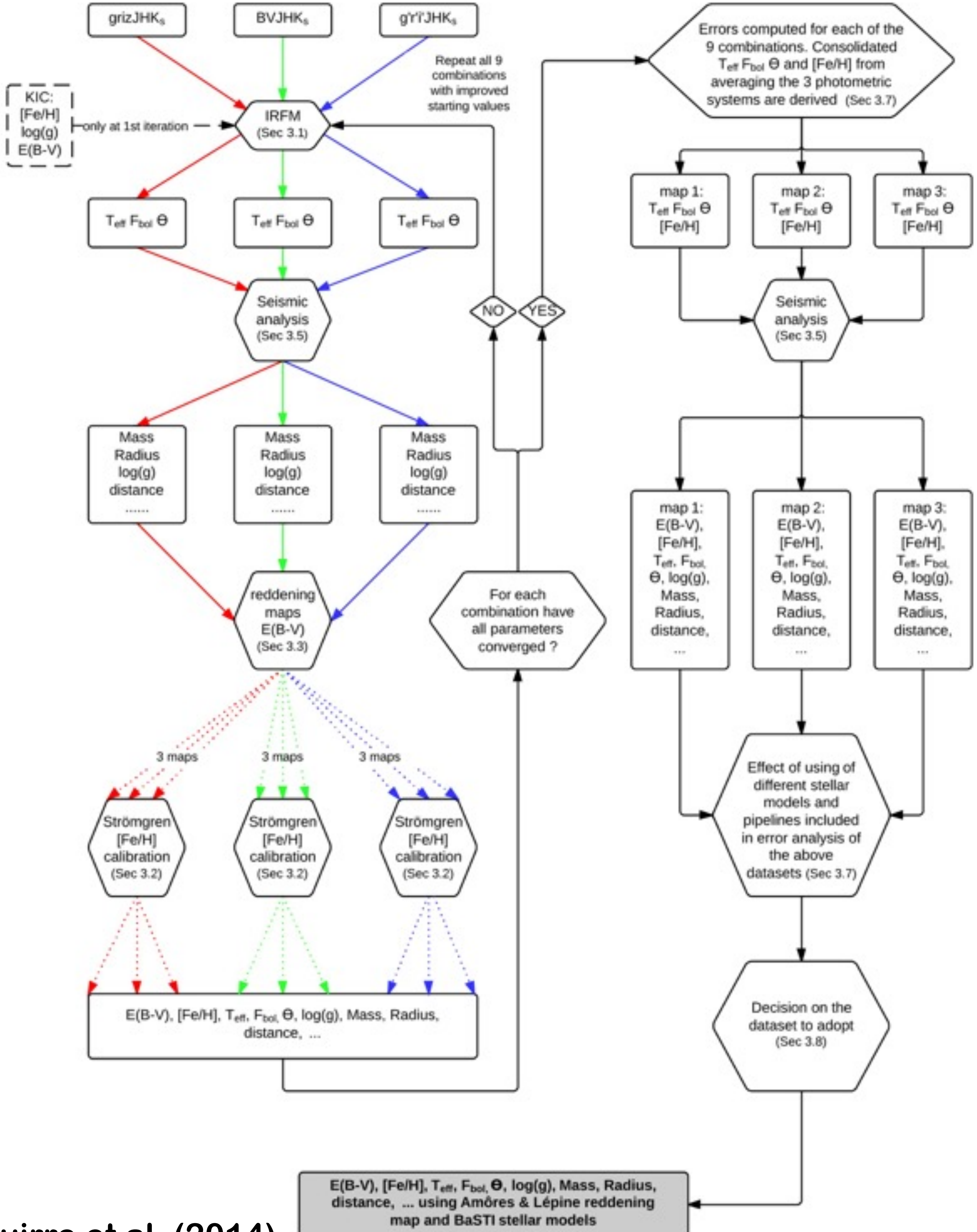
989 seismic stars
29000 stars

Casagrande, Silva Aguirre, Stello, Huber et al. (2014)

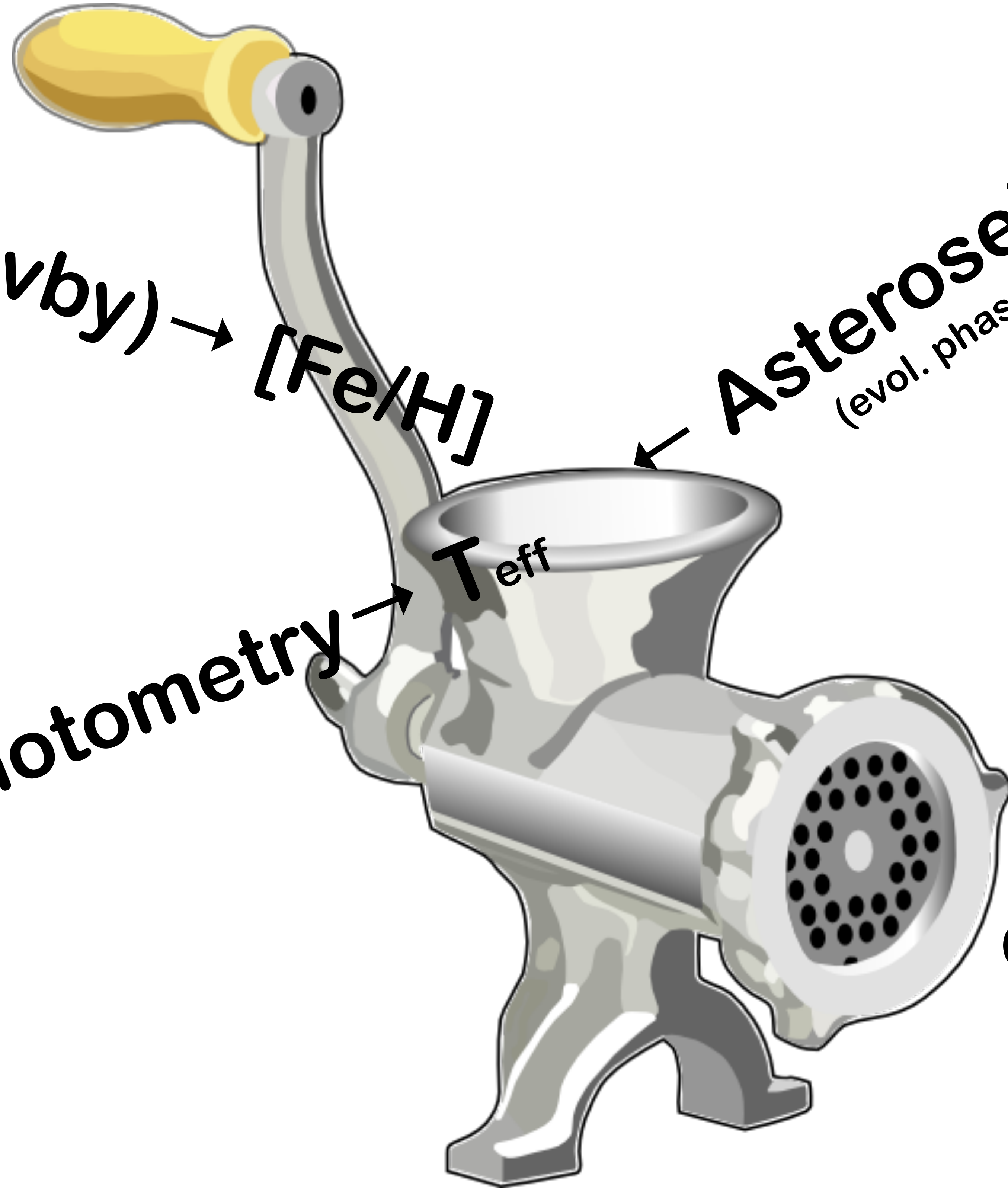
In situ

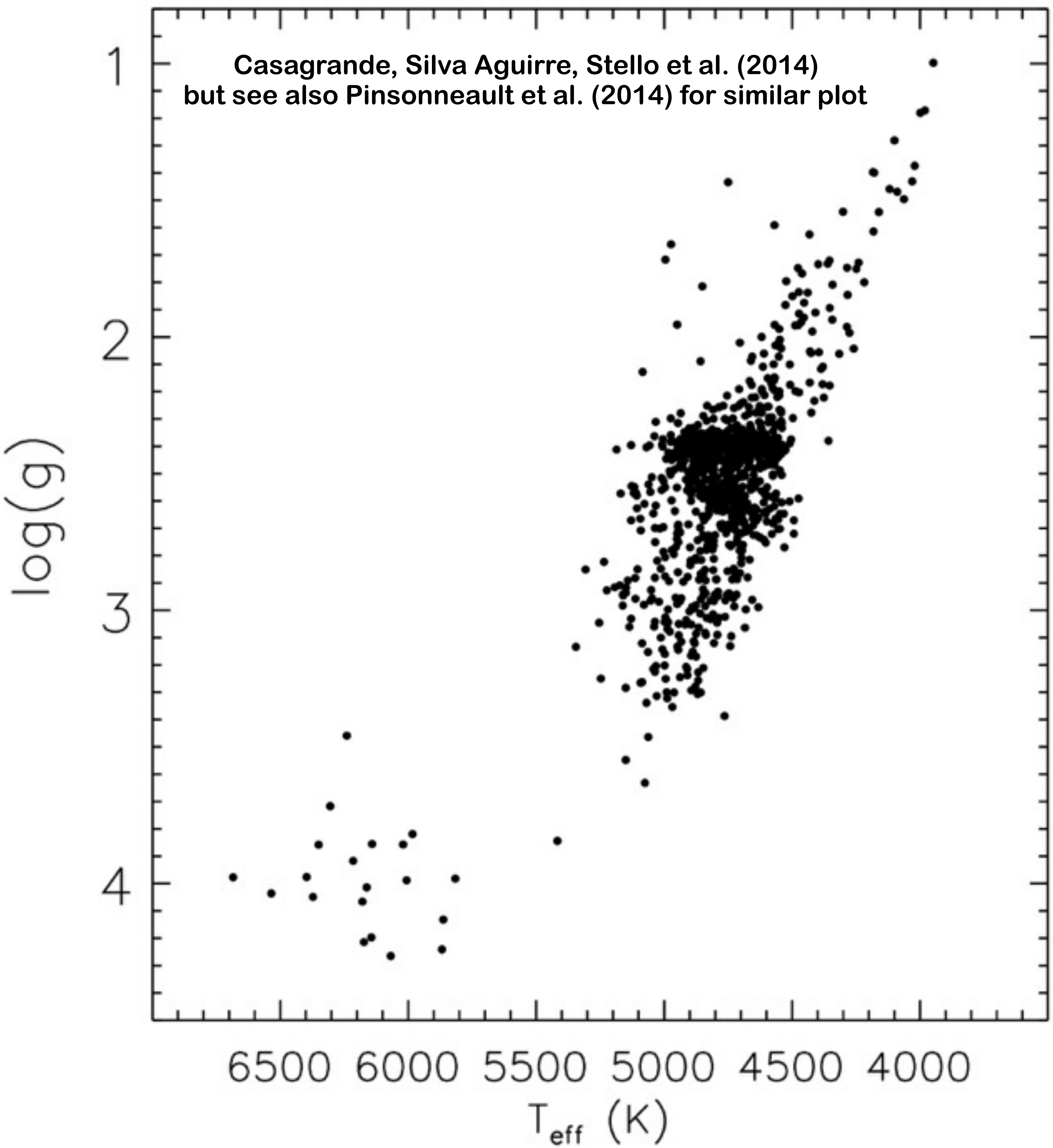


a)
0°
GC
90°
270°
180°
b)
Z (kpc)
R$_{GC}$ (kpc)
c)
Z (kpc)
D cos(b) sin(l) (kpc)
d)
Z (kpc)
D cos(b) cos(l) (kpc)

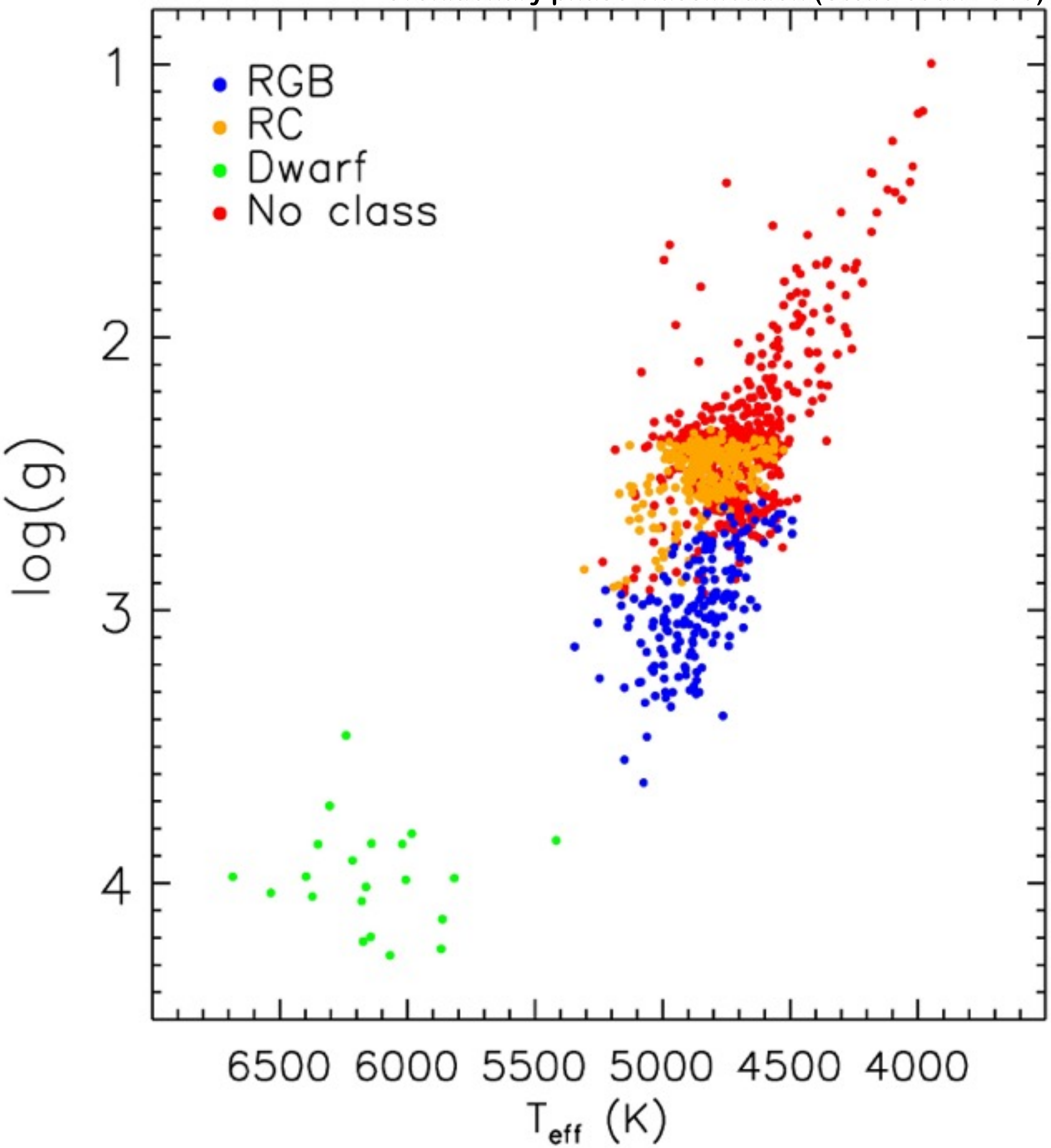


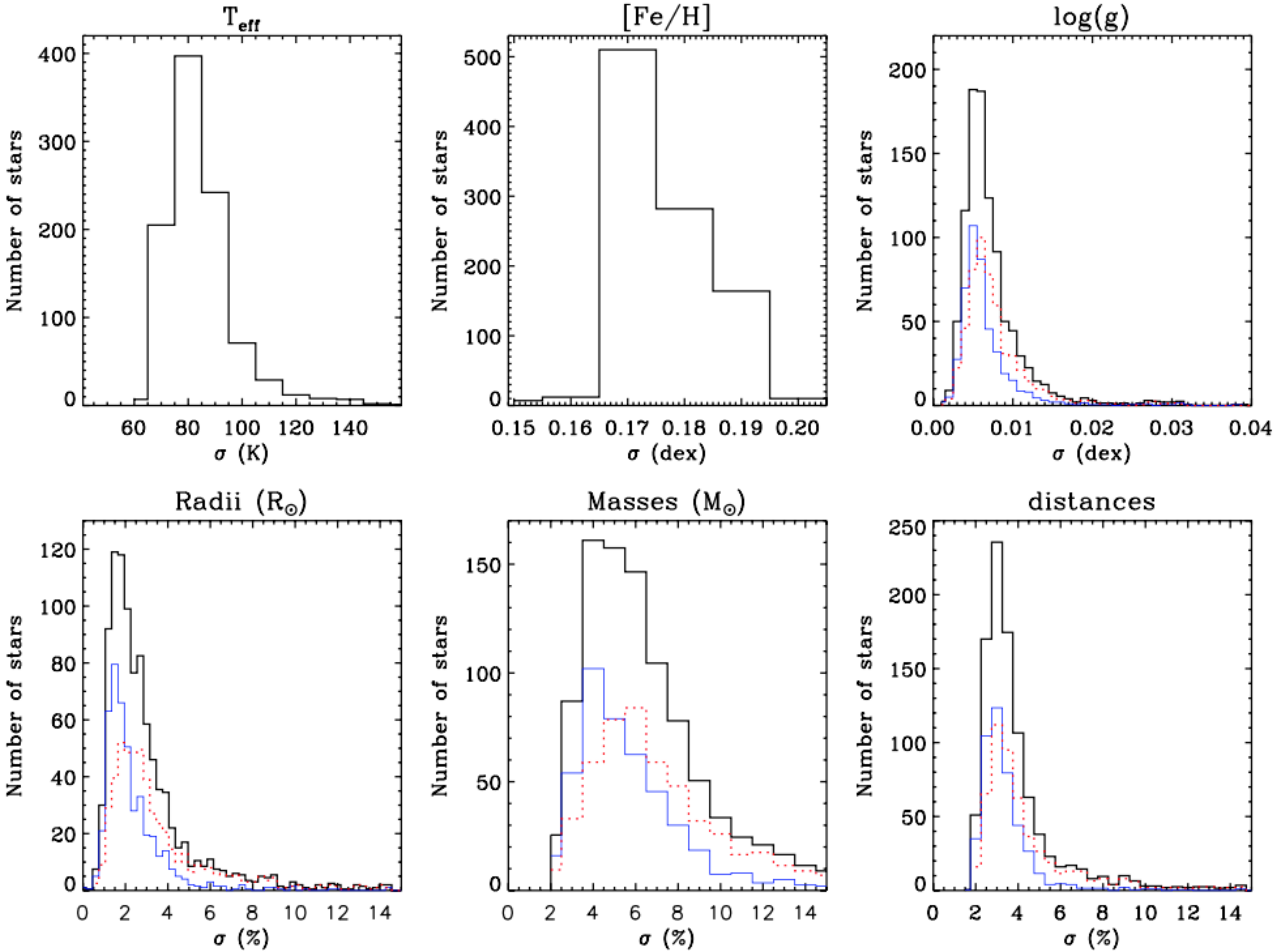
Casagrande, Silva Aguirre et al. (2014)


Strömgren (uvby) → [Fe/H]
← Asteroseismology
(evol. phase, Δν, νMAX)
Broad-band photometry → Teff
Radii,
Masses,
distances,
ages

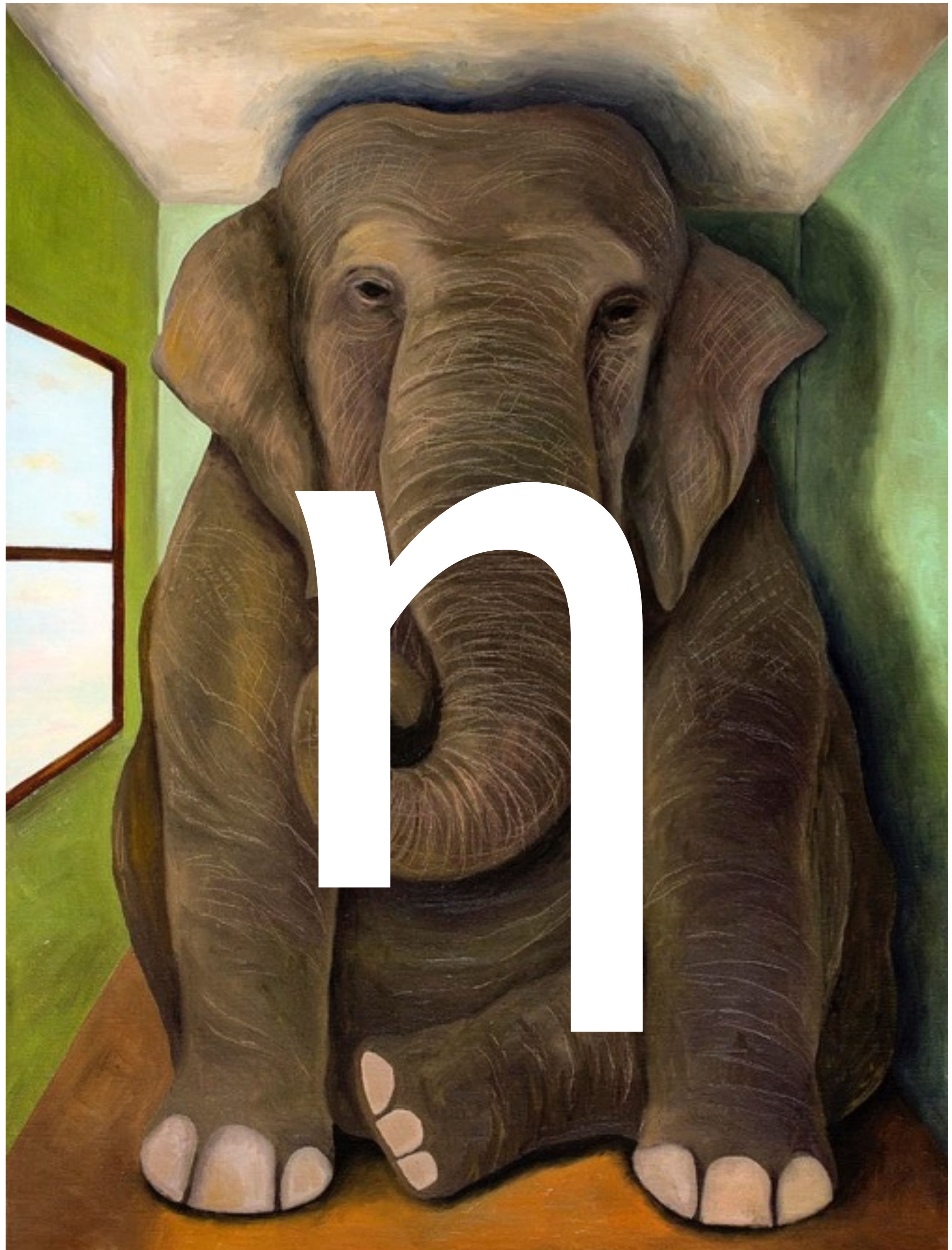

Casagrande, Silva Aguirre, Stello et al. (2014)
but see also Pinsonneault et al. (2014) for similar plot
log(g)
1
2
3
4
6500
6000
5500
5000
4500
4000
T_{eff} (K)

evolutionary phase classification (Stello et al. 2013)

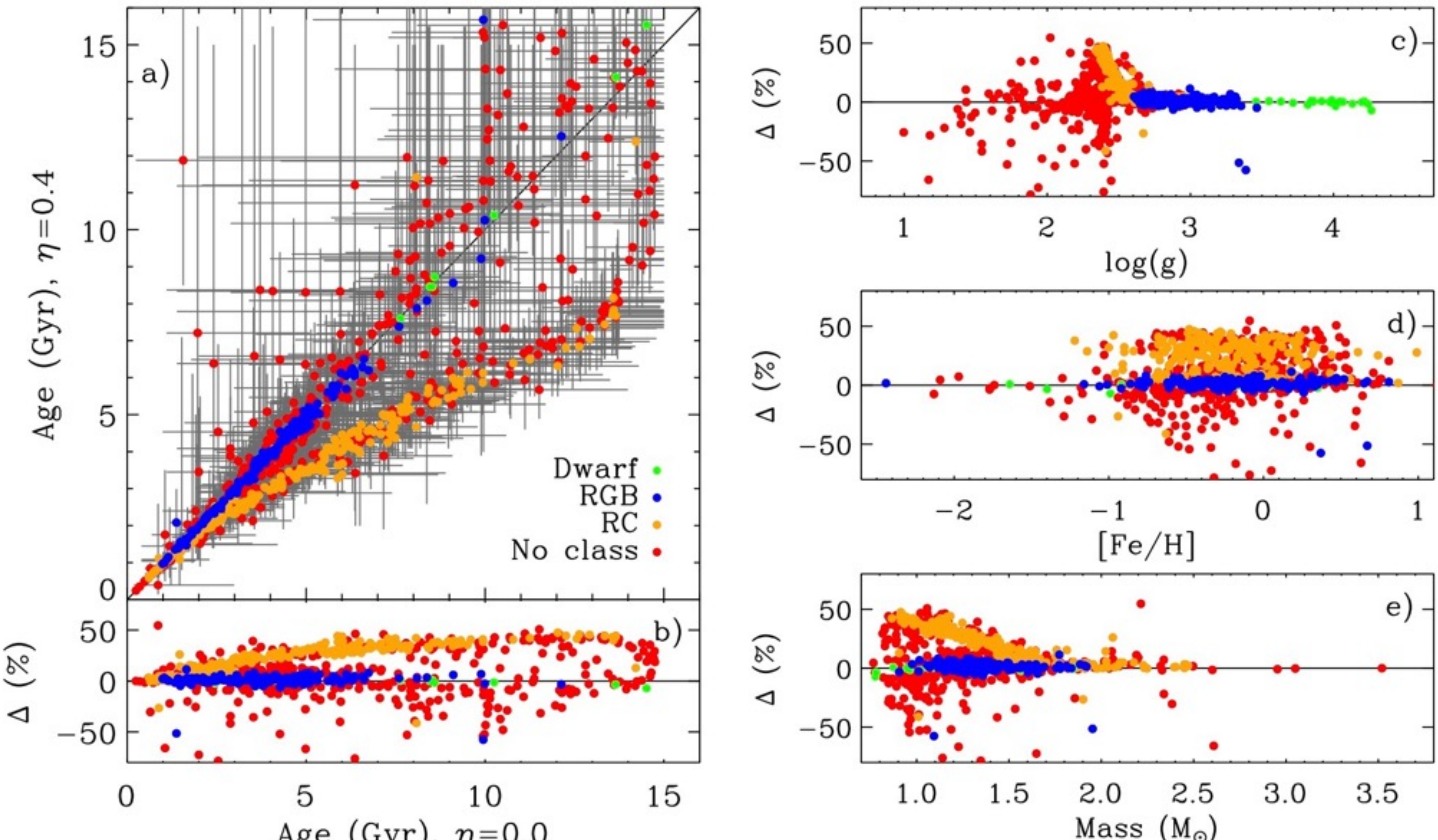




T_eff
Number of stars
σ (K)
[Fe/H]
Number of stars
σ (dex)
log(g)
Number of stars
σ (dex)
Radii (R☉)
Number of stars
σ (%)
Masses (M☉)
Number of stars
σ (%)
distances
Number of stars
σ (%)

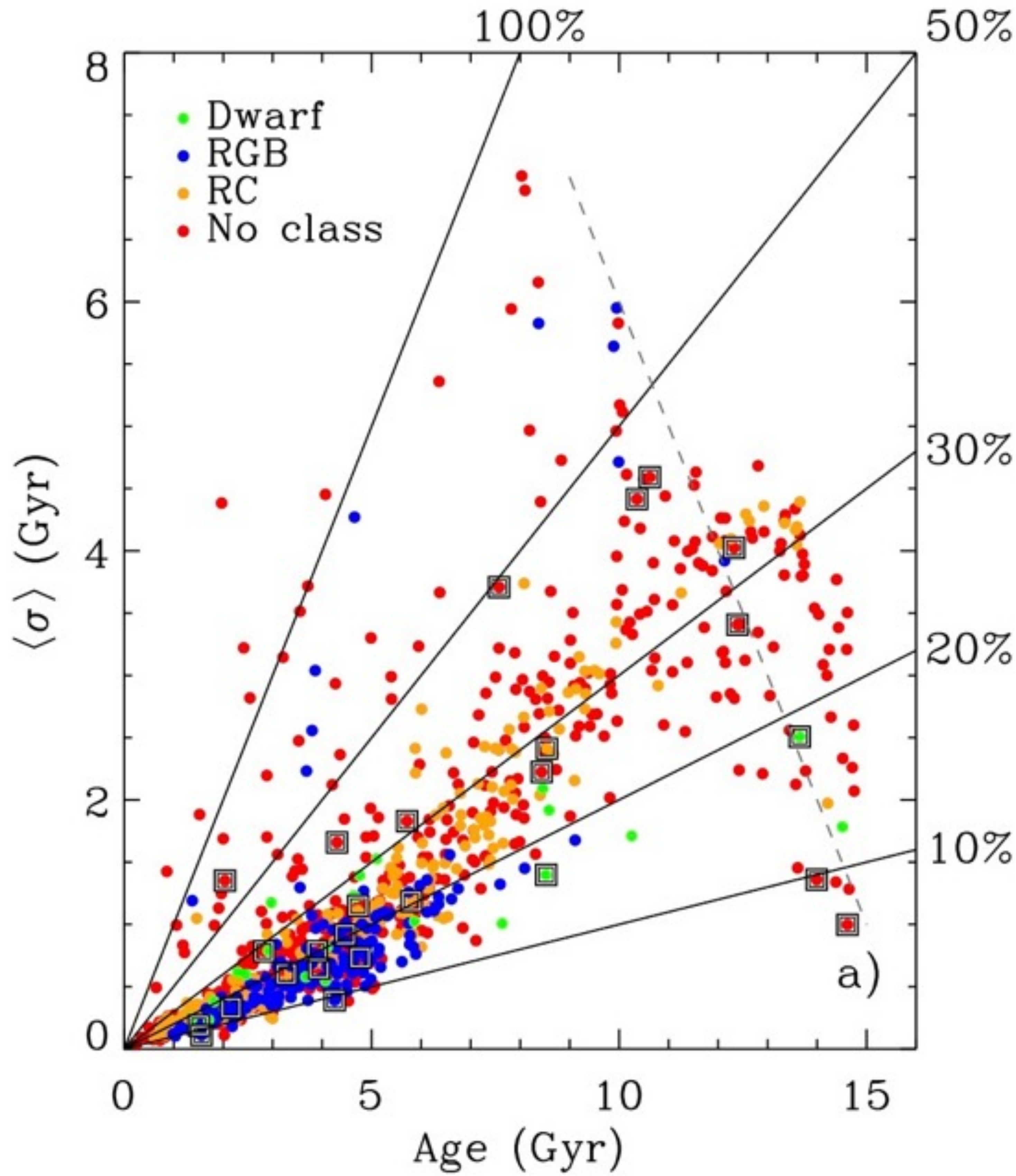

η

mass-loss



e.g. Miglio et al. 2012; Origlia et al. 2007, 2014; Heyl et al. 2015

total error budget



WYSIWYG?

(the magic of asteroseismology?)

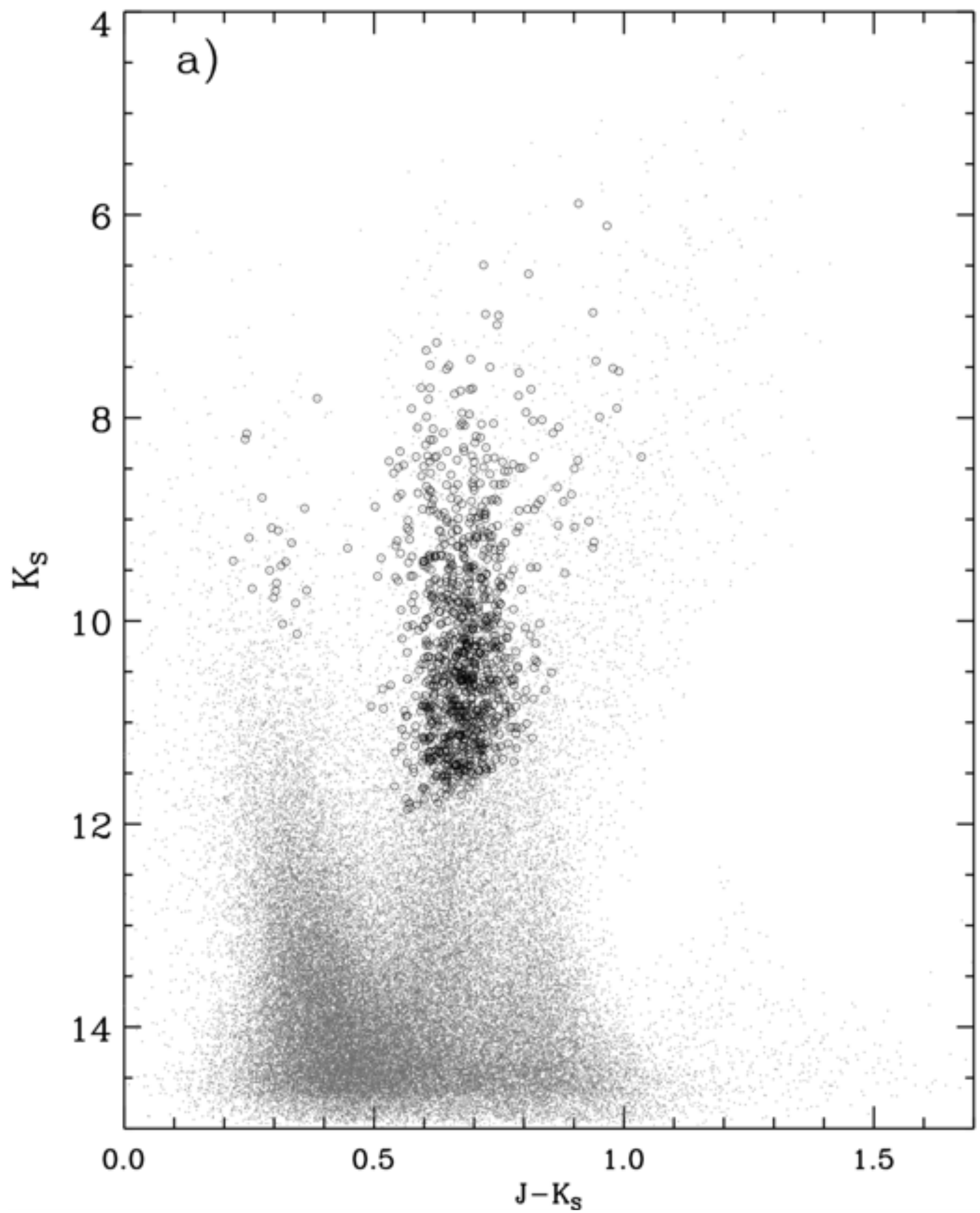
✓ Kepler selection function:

how well the red giants observed by Kepler are representative of the underlying population of giants in the field (benchmarking against an unbiased sample).

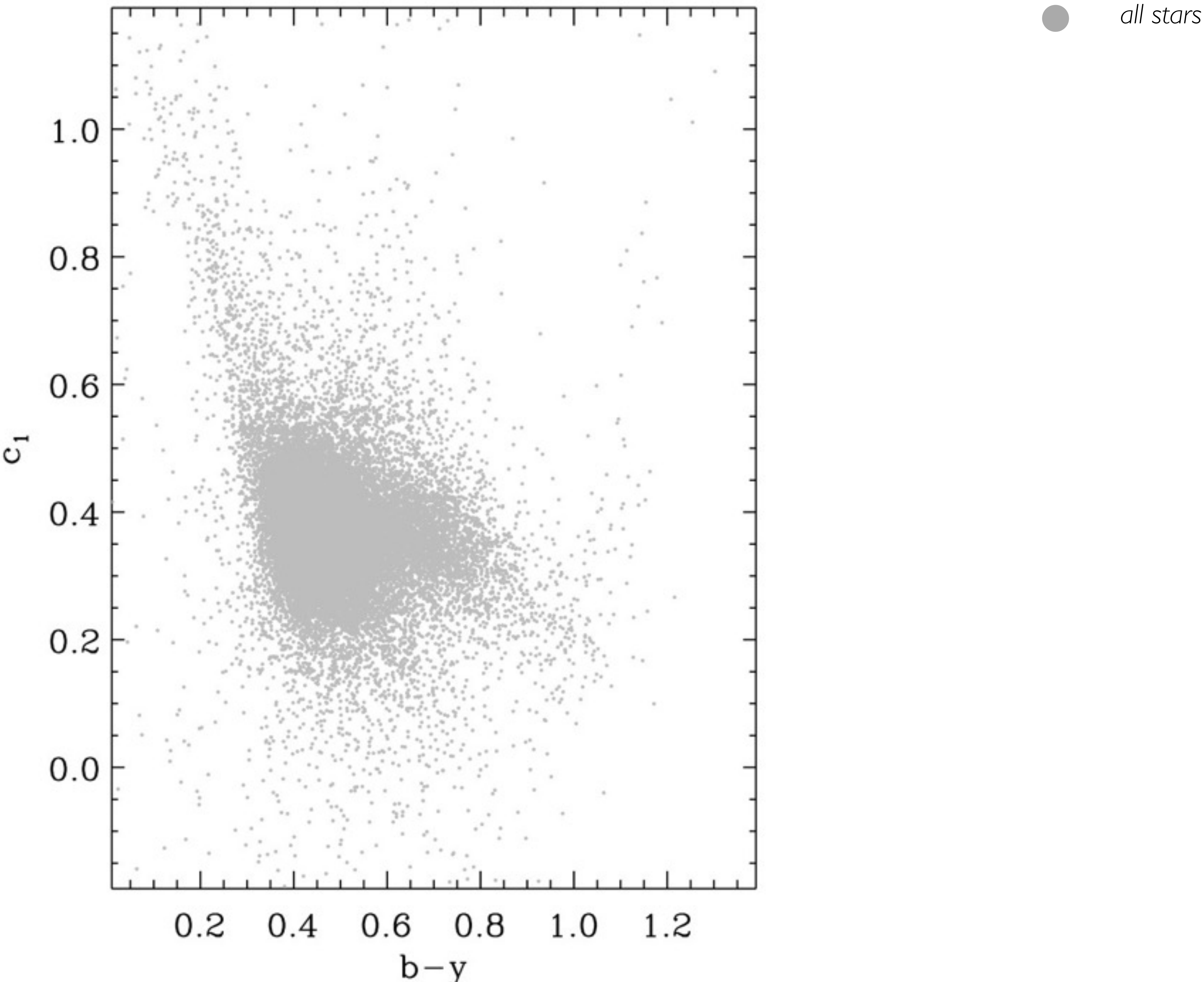
✓ Target selection effects:

once the selection function is known, how this bias the observations (population synthesis).

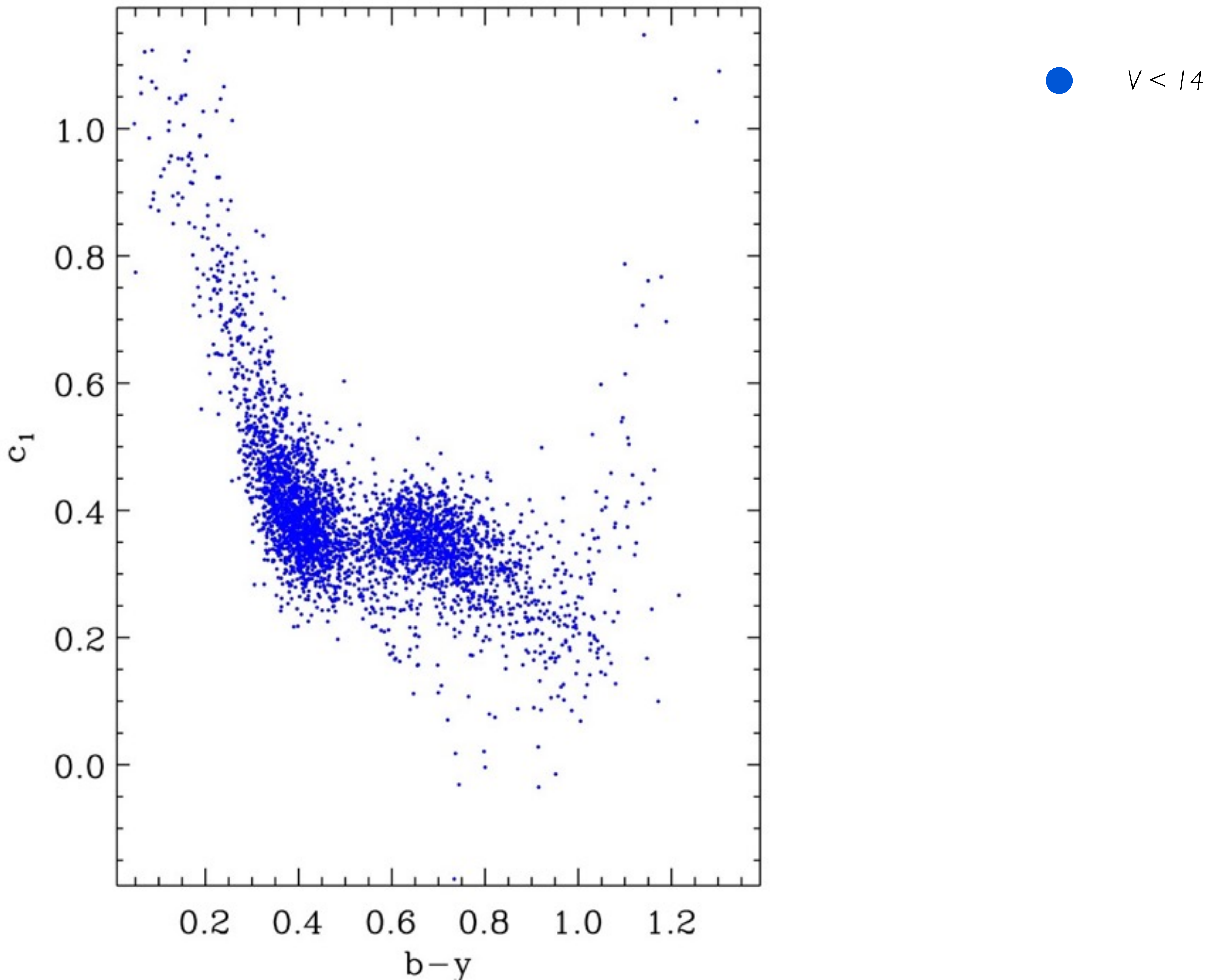
Kepler selection function



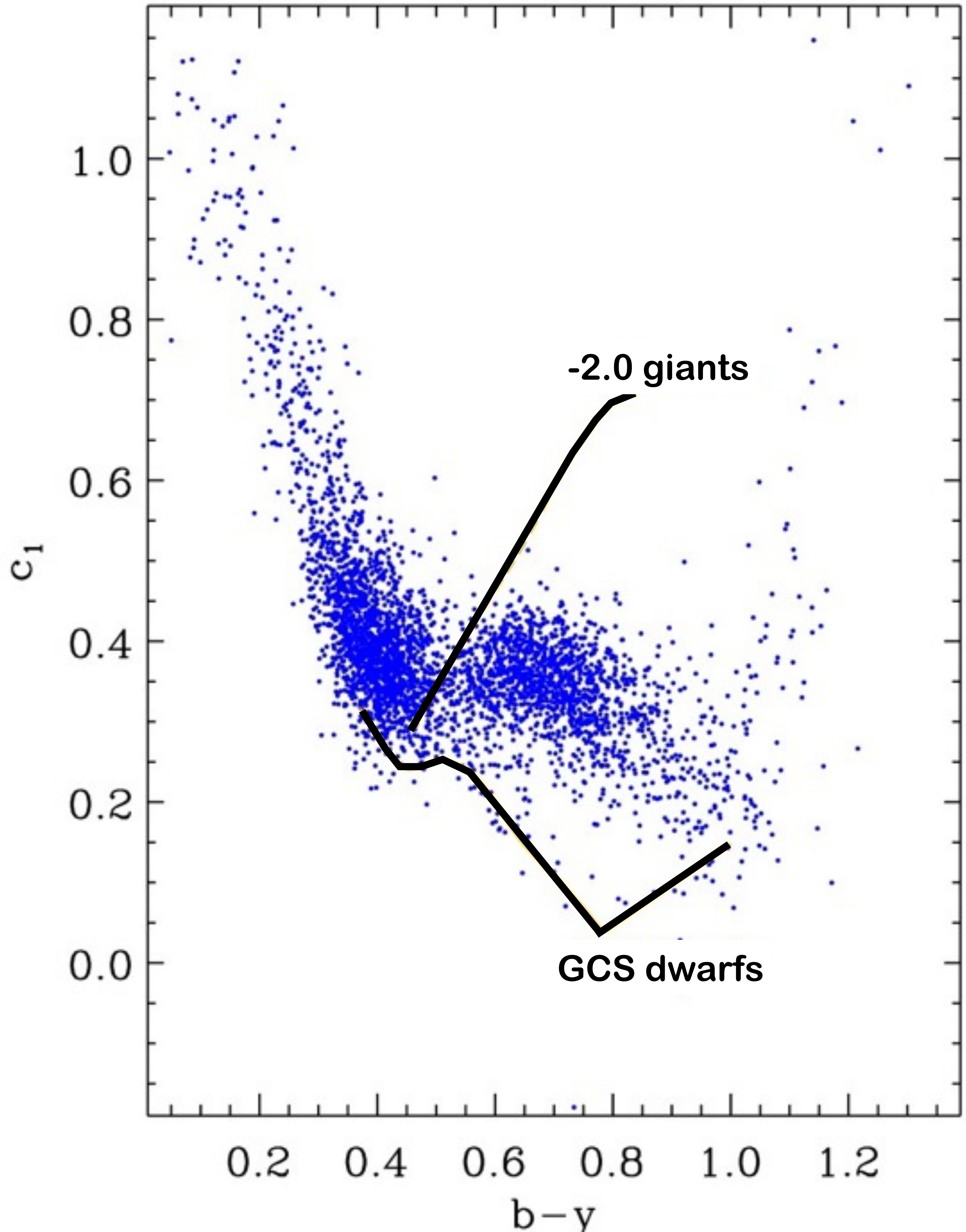
Kepler selection function



Kepler selection function

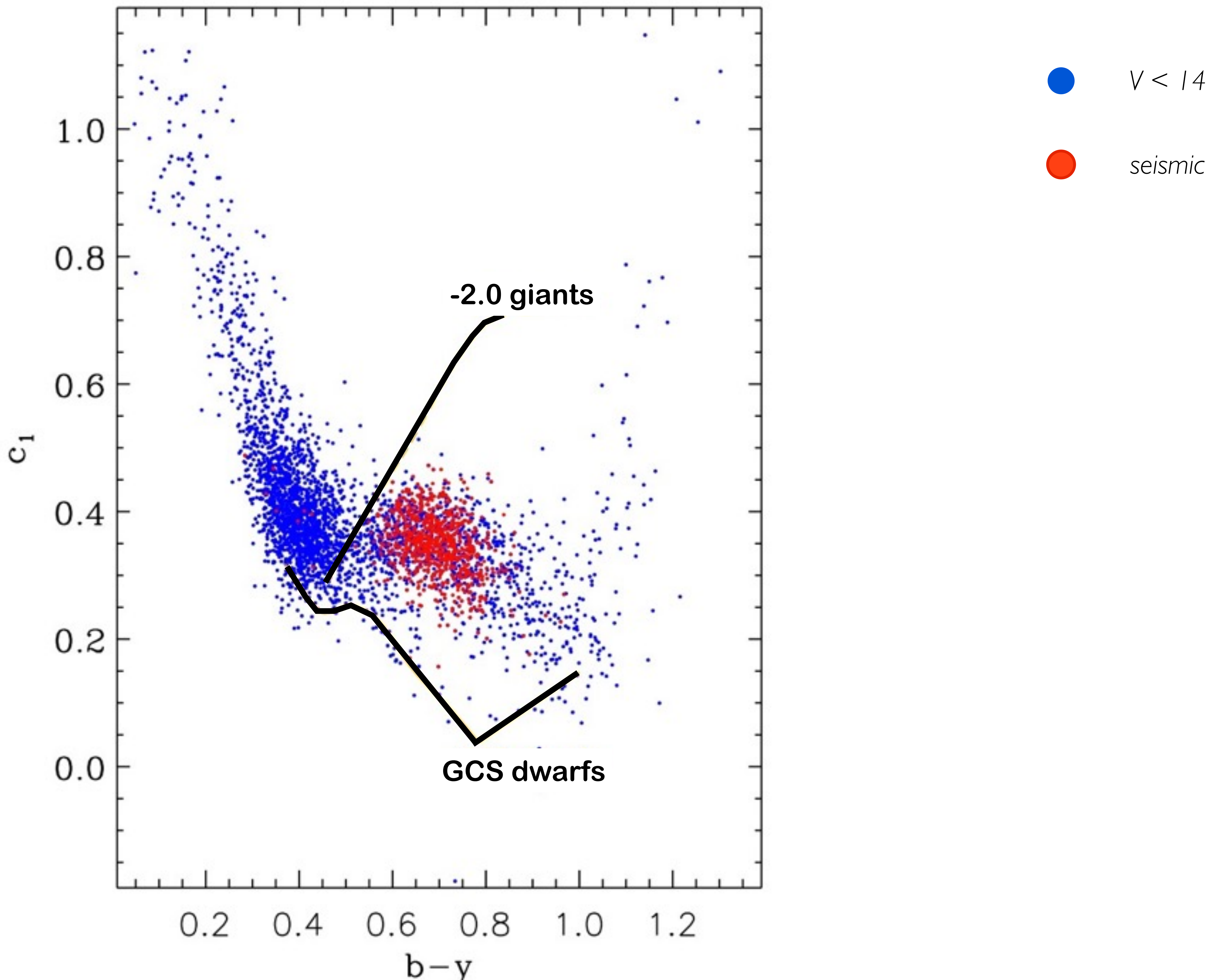


Kepler selection function

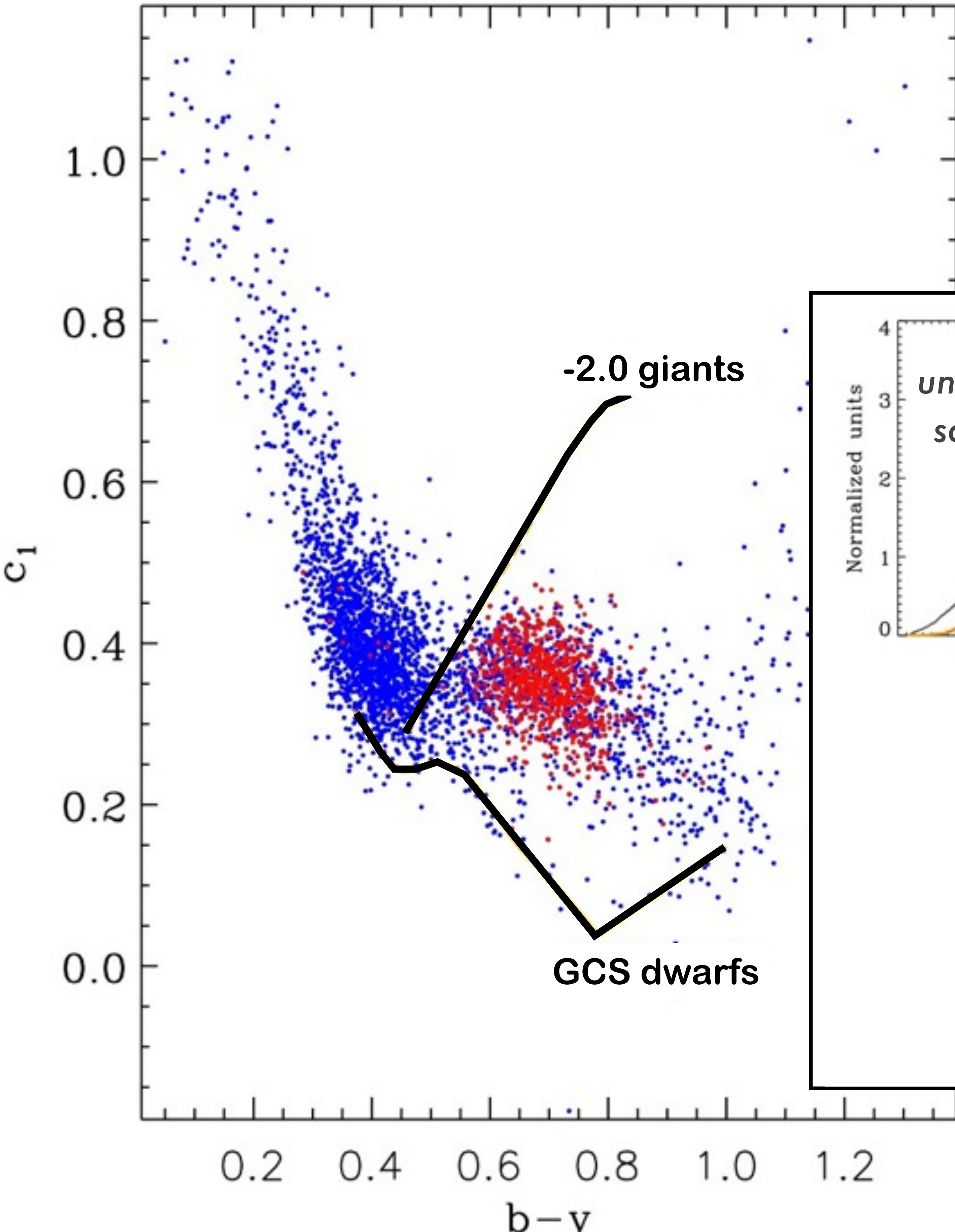


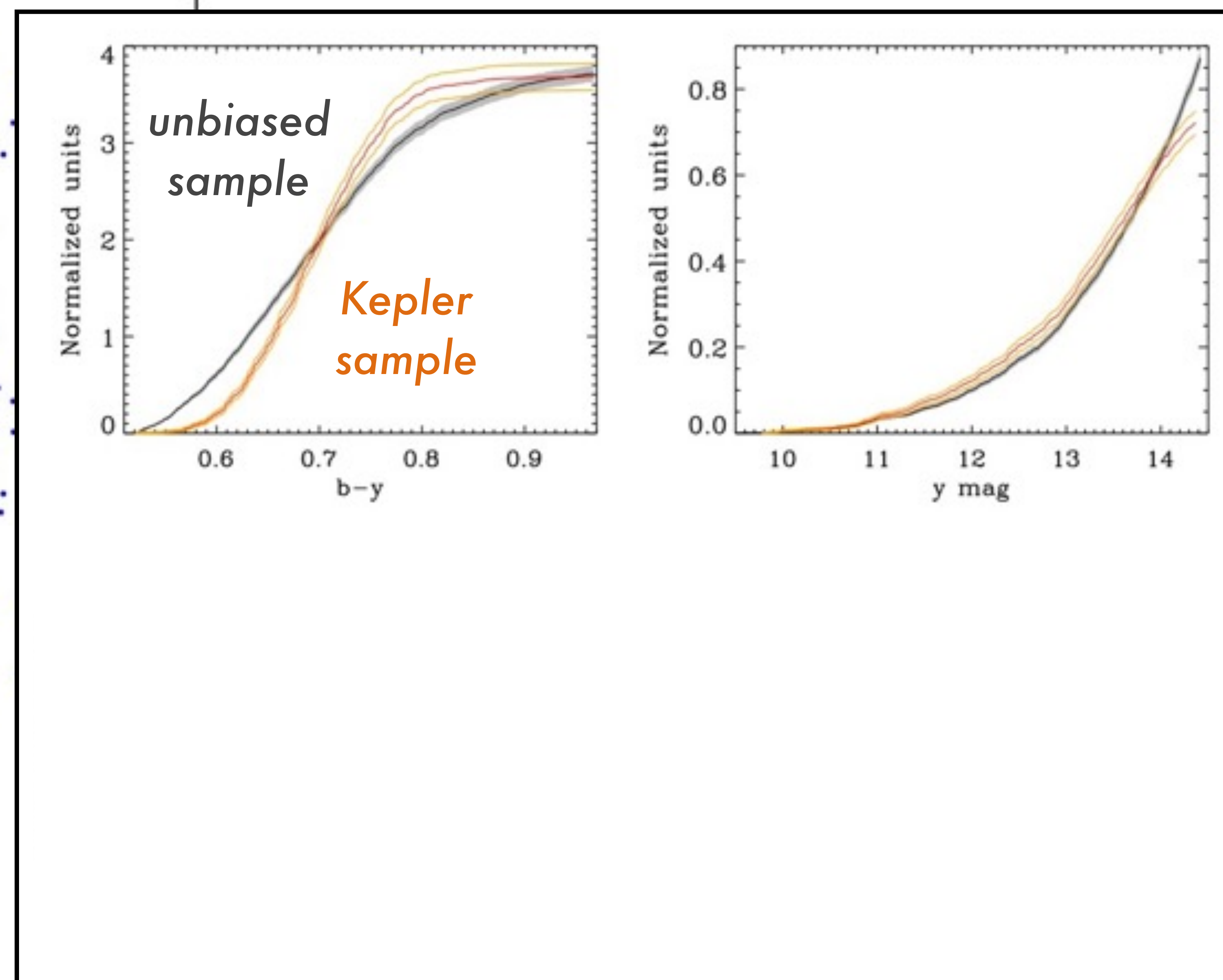
V < 14

Kepler selection function



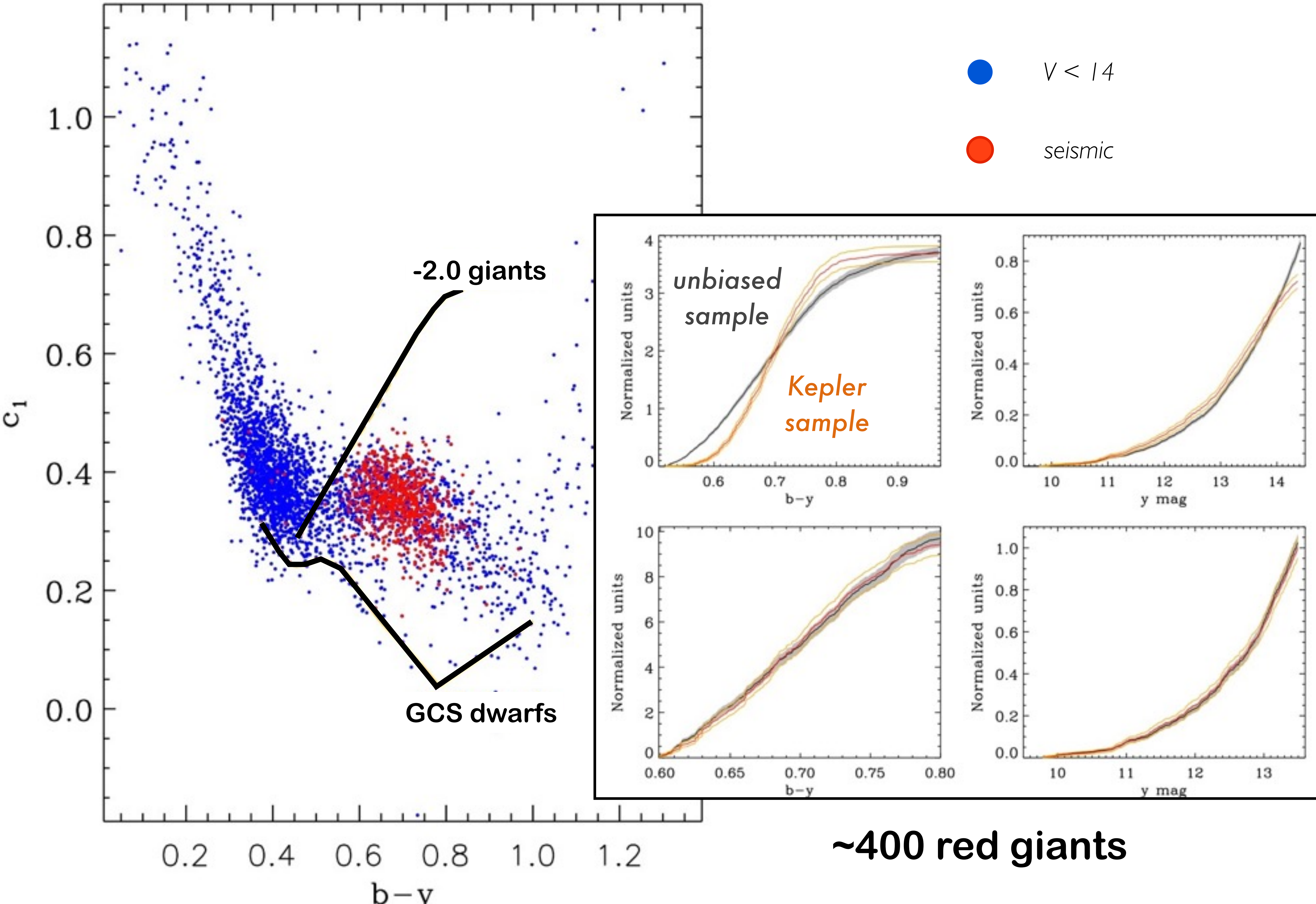
Kepler selection function





~400 red giants

Kepler selection function



~400 red giants

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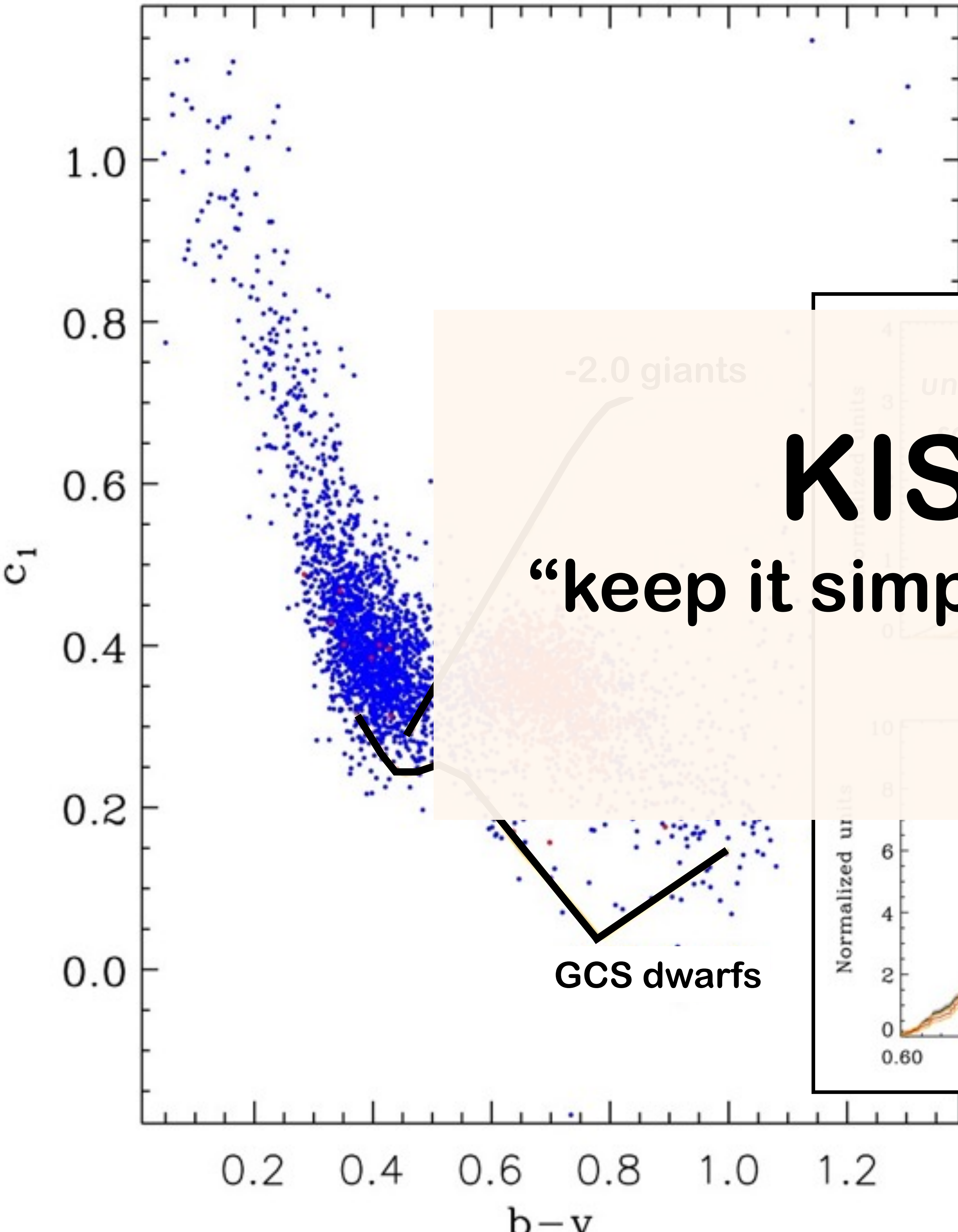
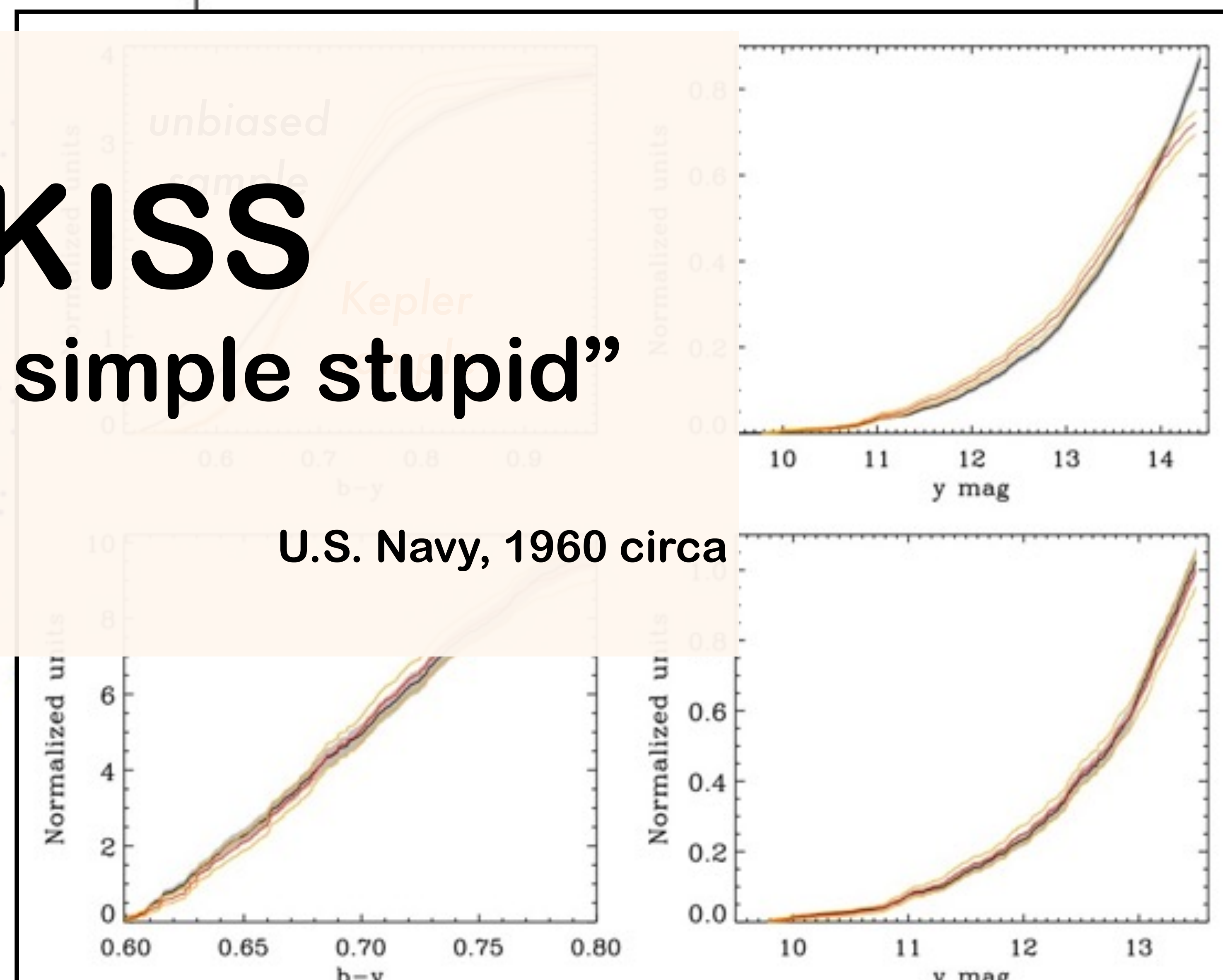




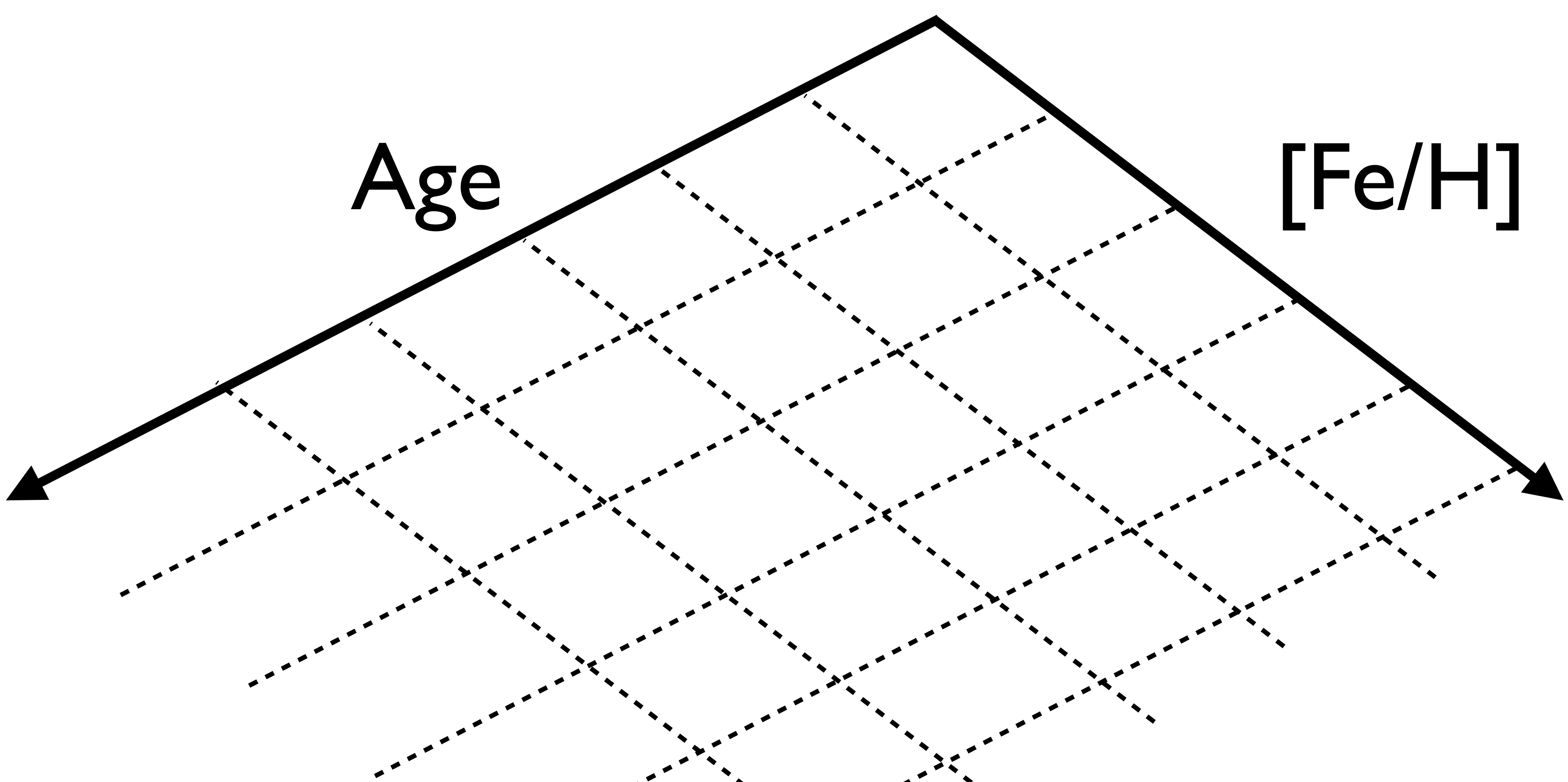
KISS

“keep it simple stupid”

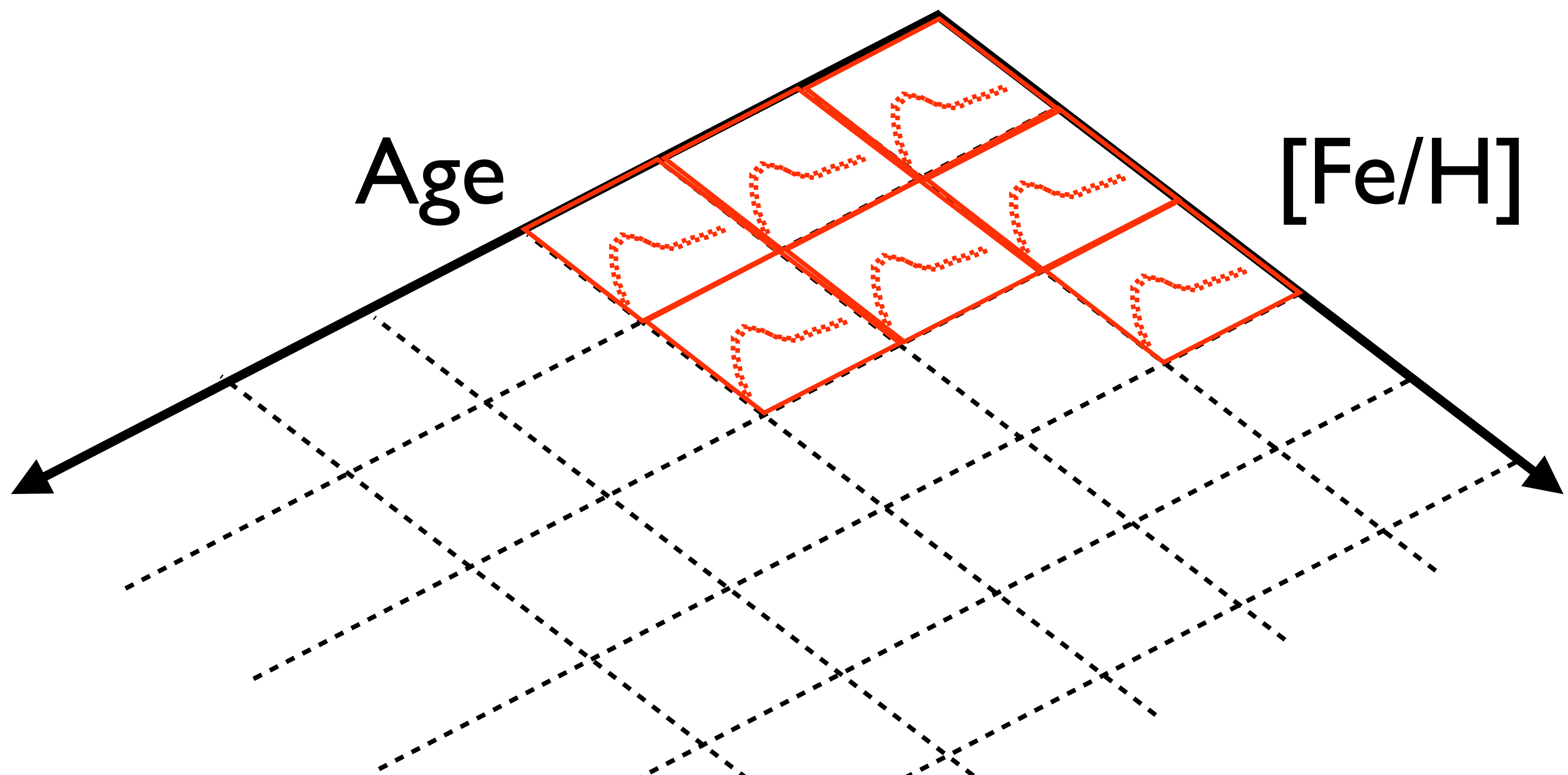
U.S. Navy, 1960 circa

~400 red giants

Target selection effects



Target selection effects



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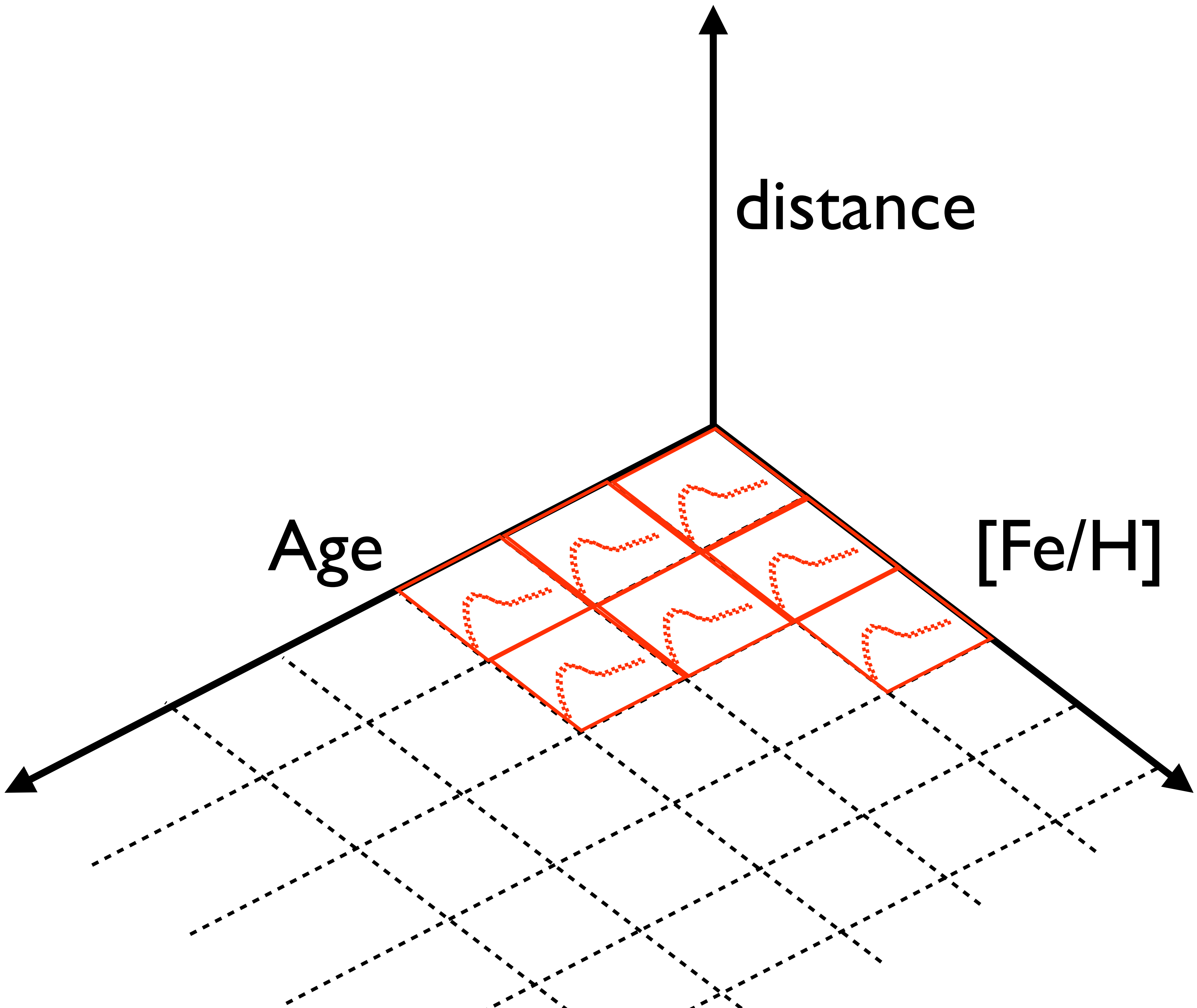
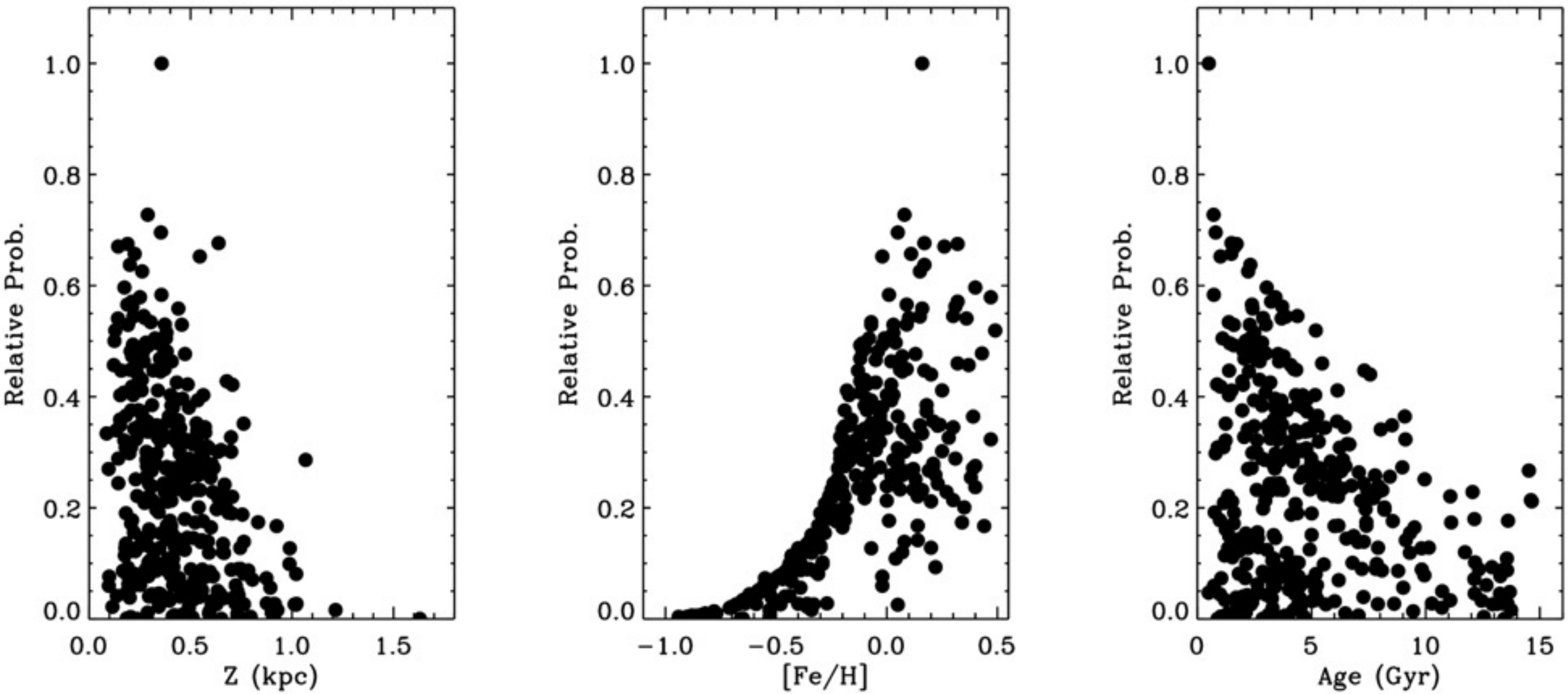
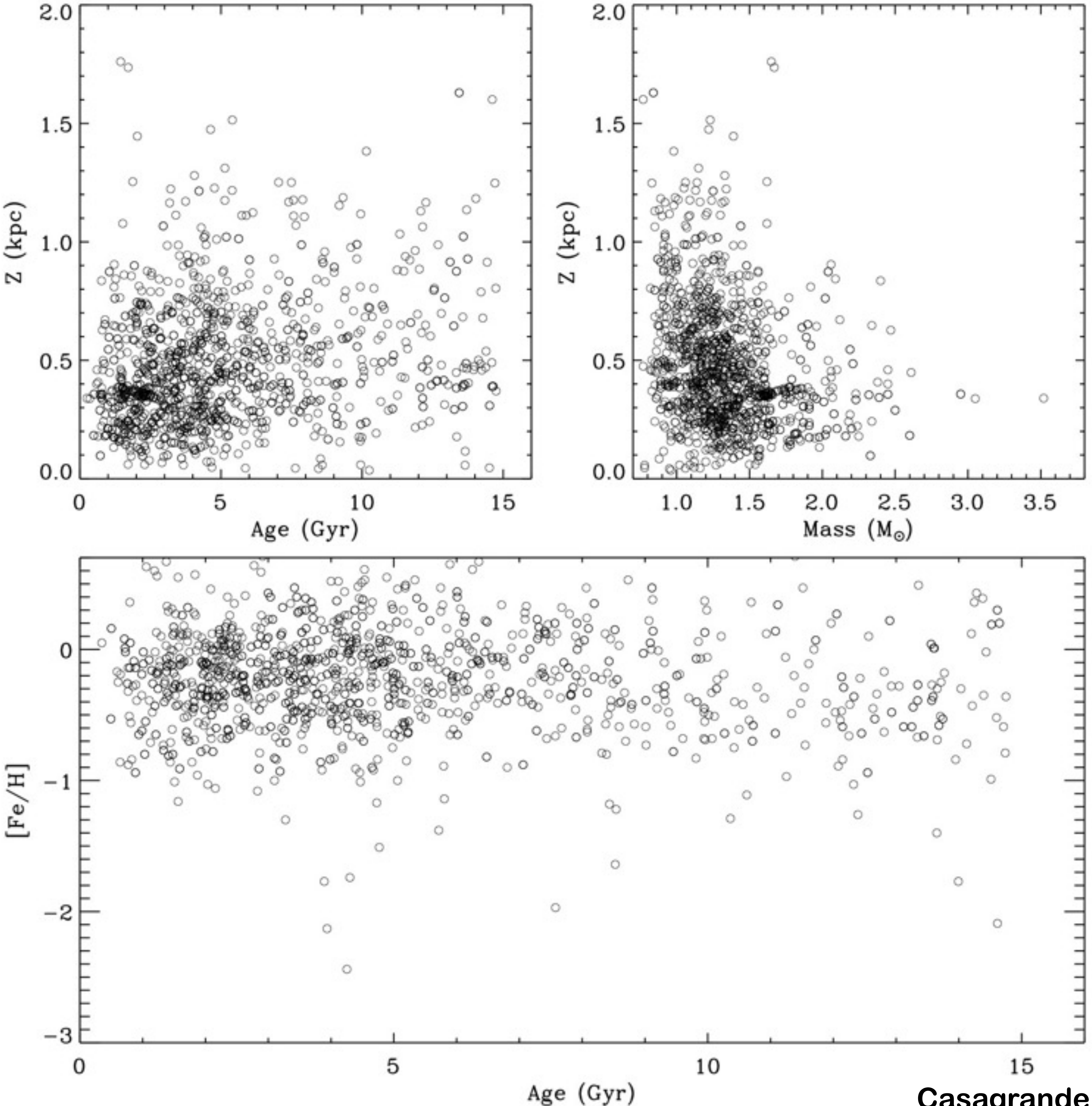


Target selection effects



Casagrande et al. (2016)



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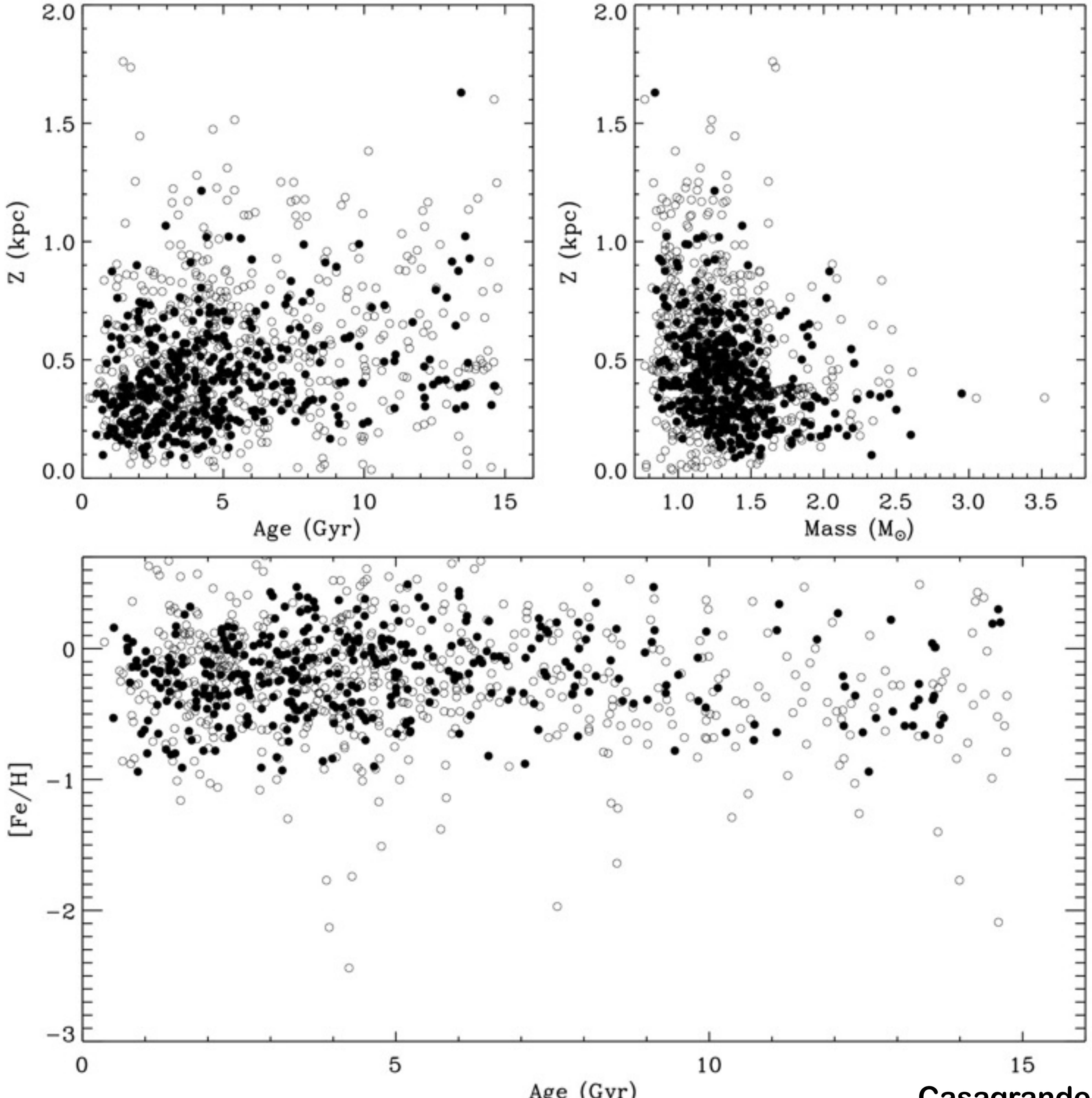

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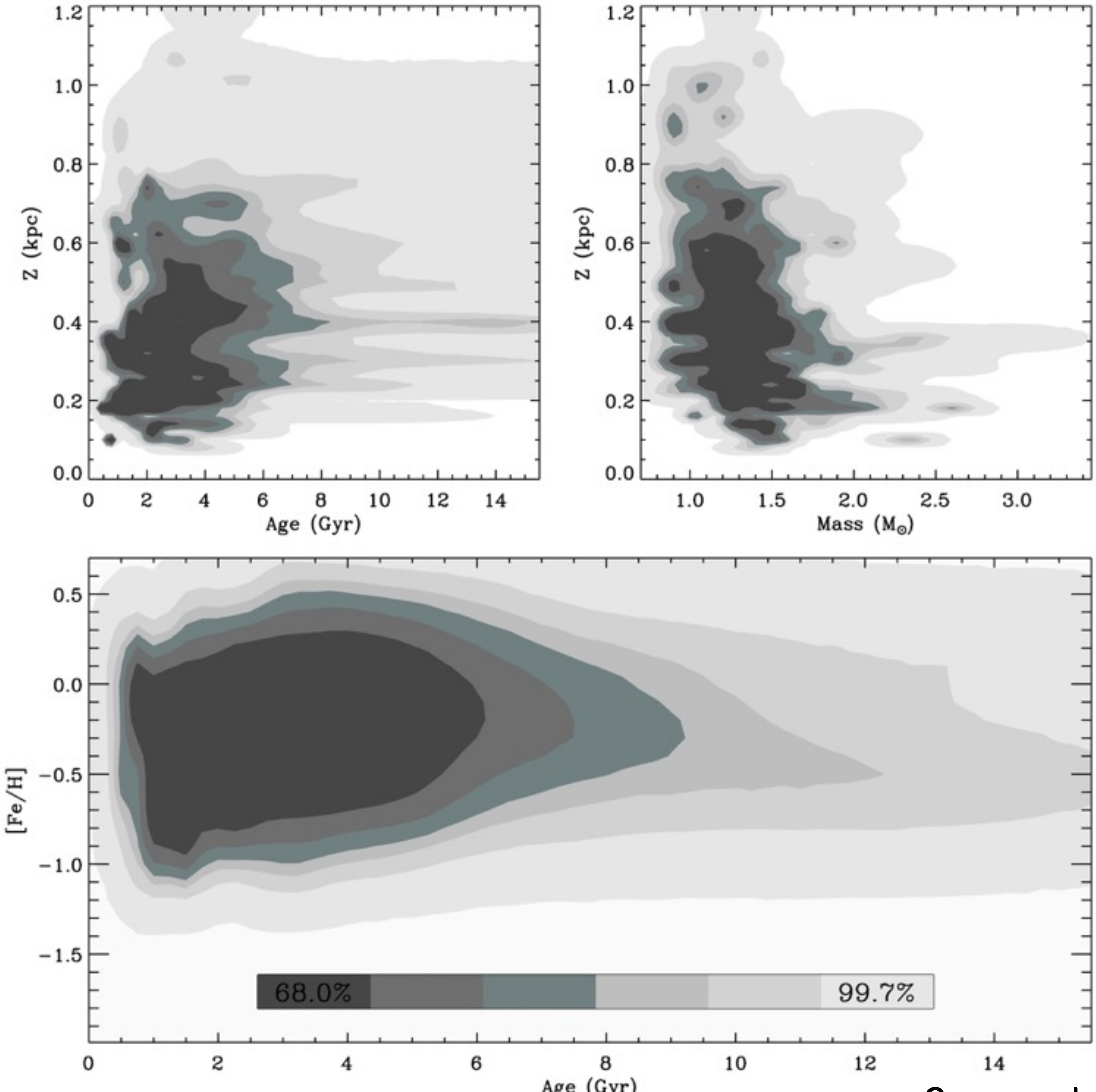
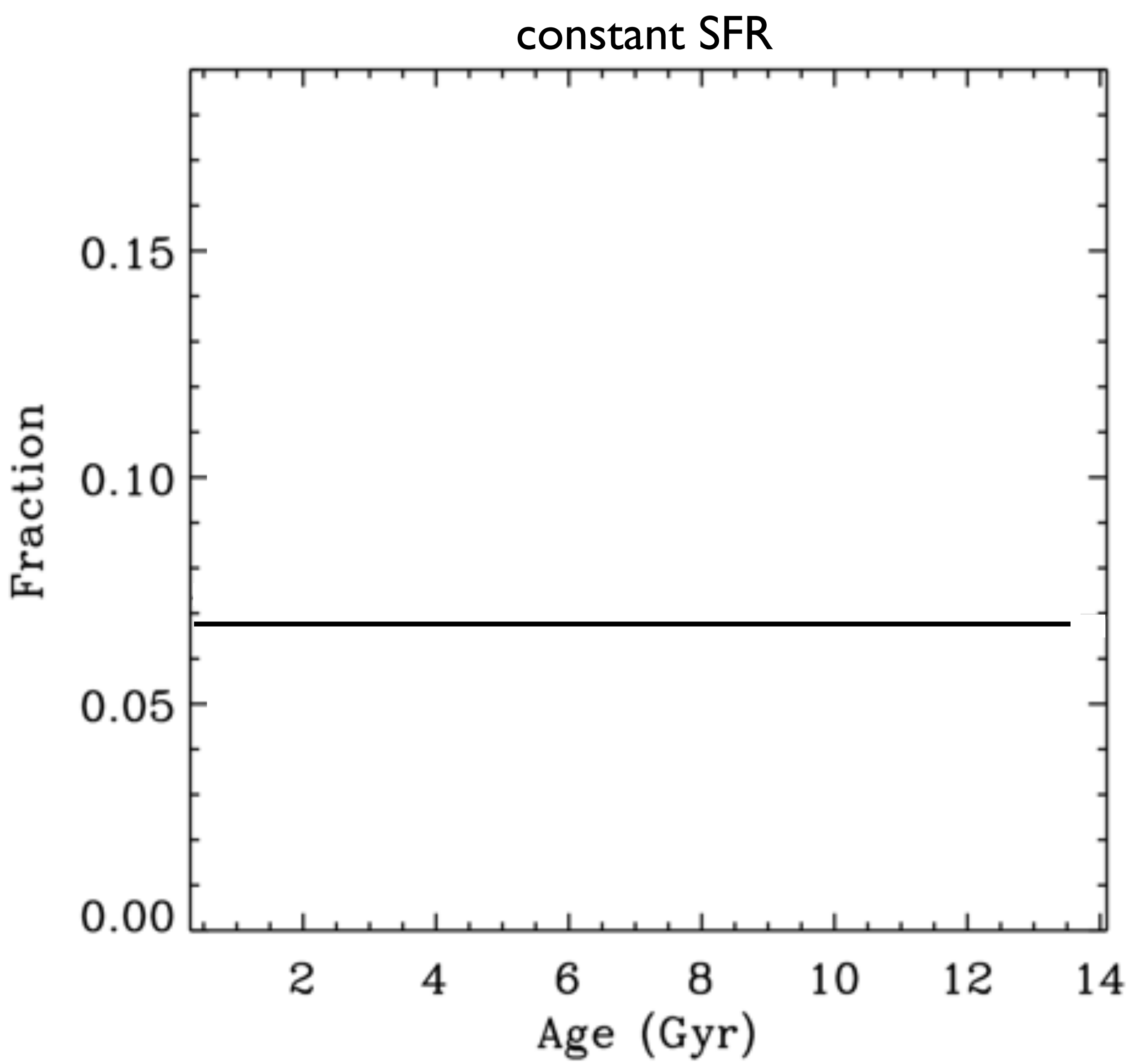
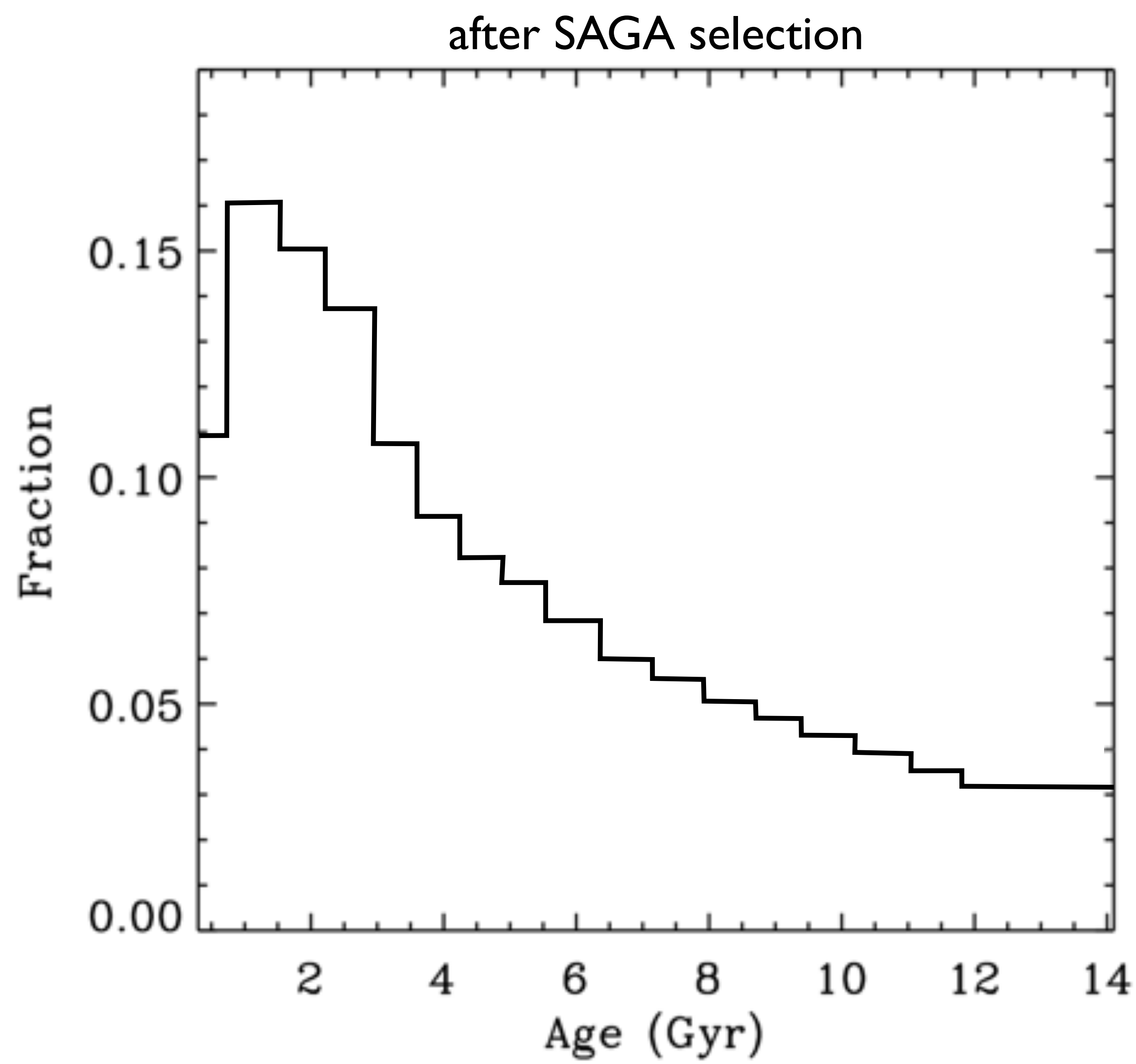


Casagrande et al. (2016)

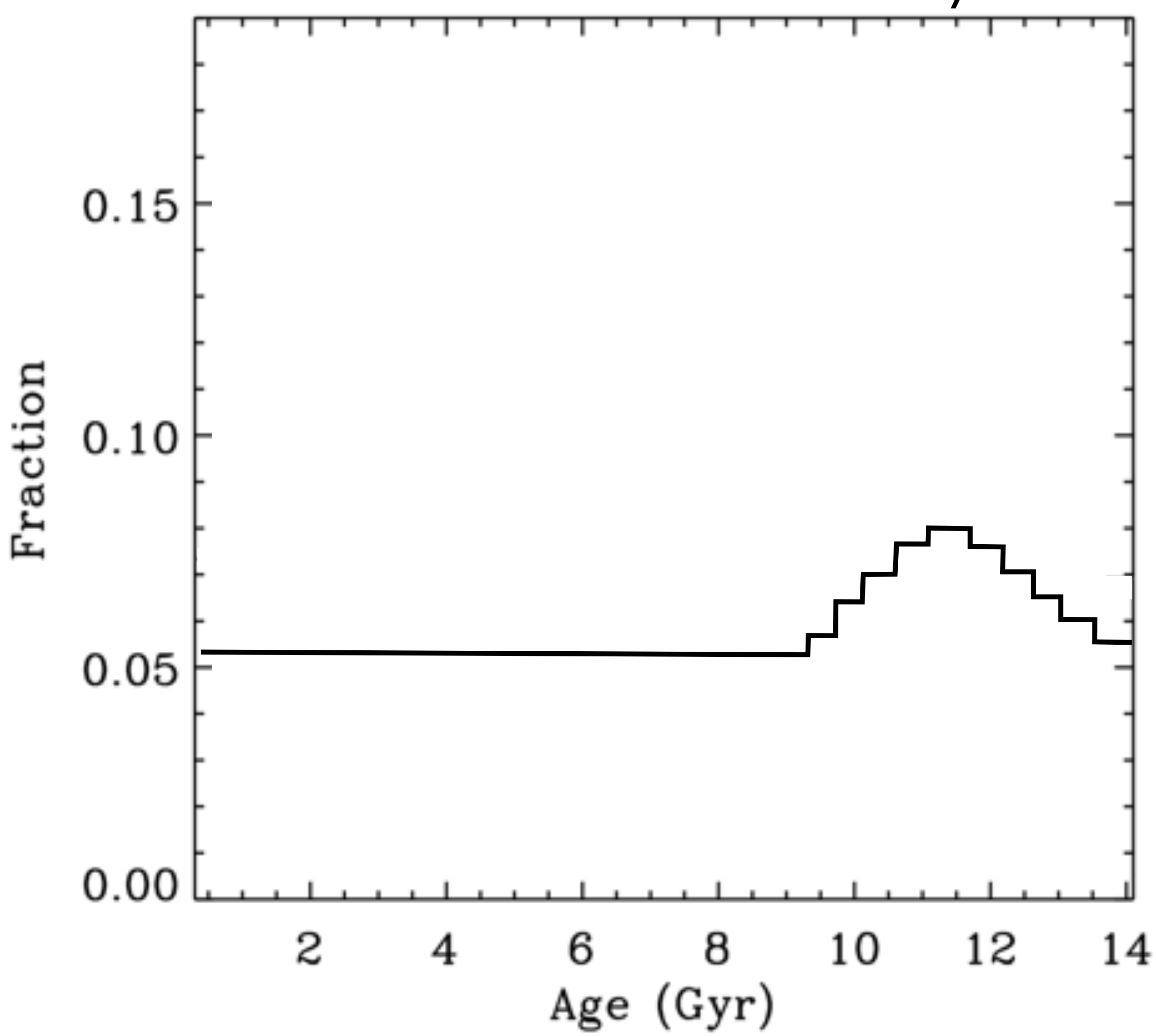
Age distribution



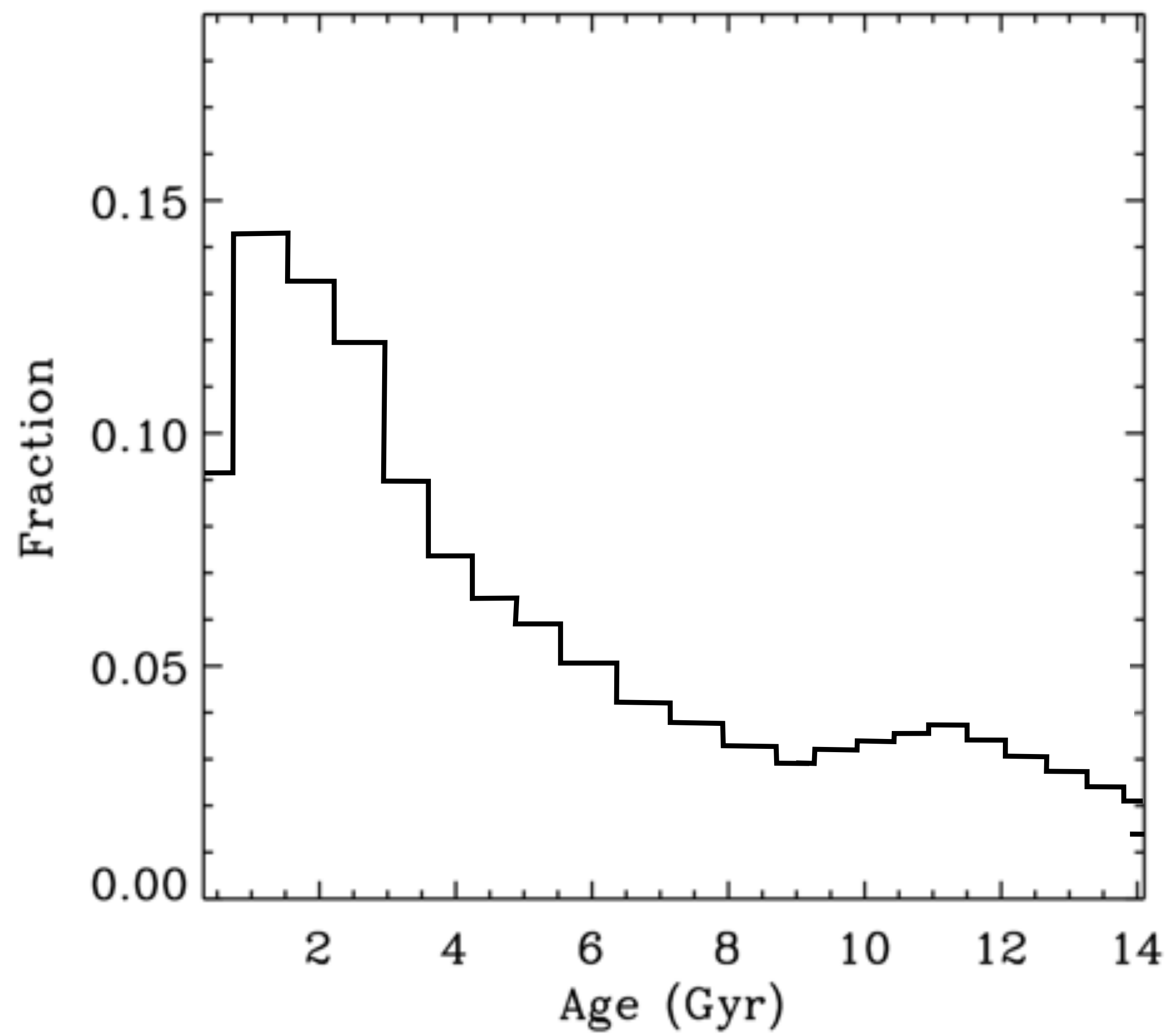


Age distribution

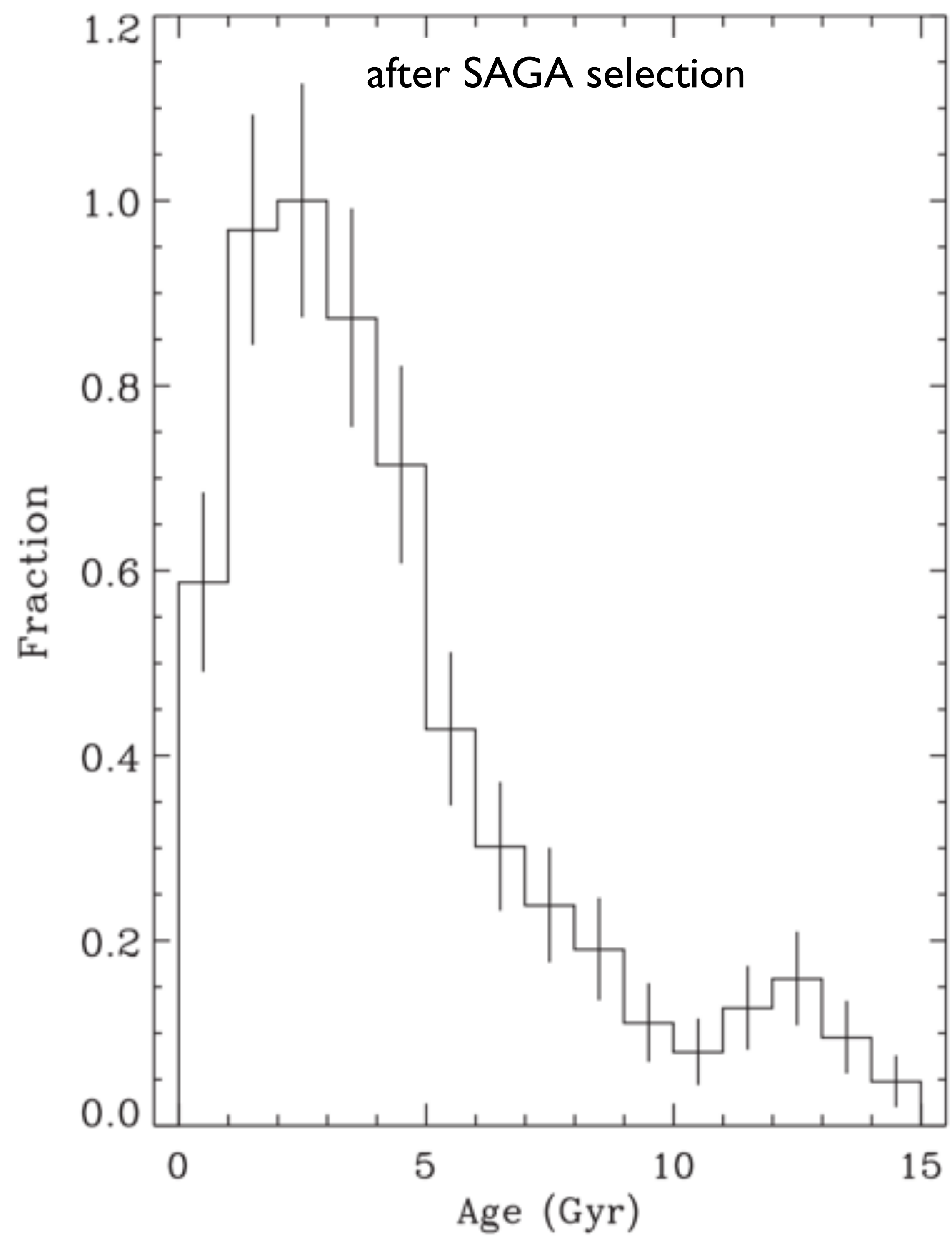
constant SFR + burst at ~11 Gyr



after SAGA selection



Age distribution



Conclusions

Photometry: powerful tool
gauge into selection function(s)

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

- ➡ age-metallicity
- ➡ vertical age gradient
- ➡ age distribution

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Mass loss: crucial to derive better ages for red giants

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