Classical observations of stellar properties

Luca Casagrande

Max Planck Institute
for Astrophysics

M. Bessell - J. Meléndez - I. Ramírez / M. Asplund R. Schönrich /
V. Silva Aguirre

Spectroscopy $F(l)$: lots of info, but also model dependent

Photometry $\int F(l)T(l)dl$: info is more degenerate, 'less' model dependent

→

- Stellar population studies / Stellar modeling
- Galactic Chemical Evolution
- Ensemble asteroseismology

Classical observations of stellar properties

$T_{\rm eff}$ → L, R

$[Fe/H]$ → X, Y, Z

$\log(g)$ → M, R

+ ages

MEASVRE,

For Meaſure.

Actus primus, Scena prima.

Enter Duke, Eſcalus, Lords.

Duke.

EScalus.

Eſc. My Lord. (fold,

Duk. Of Gouernment, the properties to vn-
Would ſeeme in me t'affect ſpeech & diſcourſe,
Since I am put to know, that your owne Science
Exceedes (in that) the liſts of all aduice
My ſtrength can giue you: Then no more remaines
But that, to your ſufficiency, as your worth is able,
And let them worke: The nature of our People,
Our *Cities Inſtitutions*, and the Termes
For Common Iuſtice, y'are as pregnant in
As Art, and practiſe, hath inriched any
That we remember: There is our Commiſſion,
From which, we would not haue you warpe; call hither,
I ſay, bid come before vs *Angelo*:
What figure of vs thinke you, he will beare.
For you muſt know, we haue with ſpeciall ſoule
Elected him our abſence to ſupply;
Lent him our terror, dreſt him with our loue,

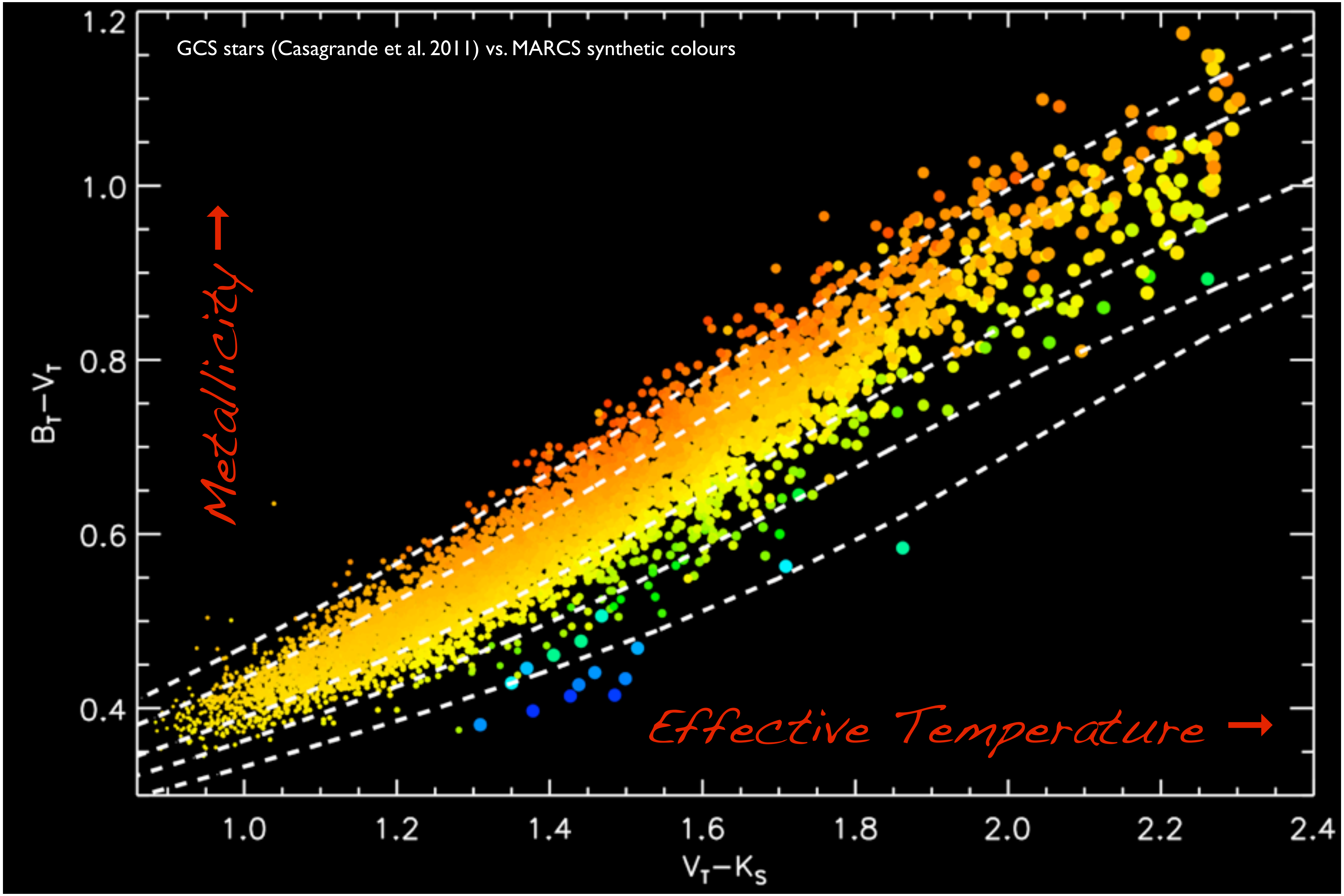
To one that can my part in him aduertiſe;
Hold therefore *Angelo*:
In our remoue, be thou at full, our ſelfe:
Mortallitie and Mercie in *Vienna*
Liue in thy tongue, and heart: Old *Eſcalus*
Though firſt in queſtion, is thy ſecondary.
Take thy Commiſſion.

Ang. Now good my Lord
Let there be ſome more teſt, made of my mettle,
Before ſo noble, and ſo great a figure
Be ſtamp't vpon it.

Duk. No more euaſion:
We haue with a leauen'd, and prepared choice
Proceeded to you; therefore take your honors:
Our haſte from hence is of ſo quicke condition,
That it prefers it ſelfe, and leaues vnqueſtion'd
Matters of needfull value: We ſhall write to you
As time, and our concernings ſhall importune,
How it goes with vs, and doe looke to know
What doth befall you here. So fare you well:
To th' hopefull execution doe I leaue you,
Of your Commiſſions.

Ang. Yet giue leaue (my Lord,)

Photometry



GCS stars (Casagrande et al. 2011) vs. MARCS synthetic colours
Metallicity
Effective Temperature
$B_T - V_T$
$V_T - K_S$
1.2
1.0
0.8
0.6
0.4
1.0
1.2
1.4
1.6
1.8
2.0
2.2
2.4

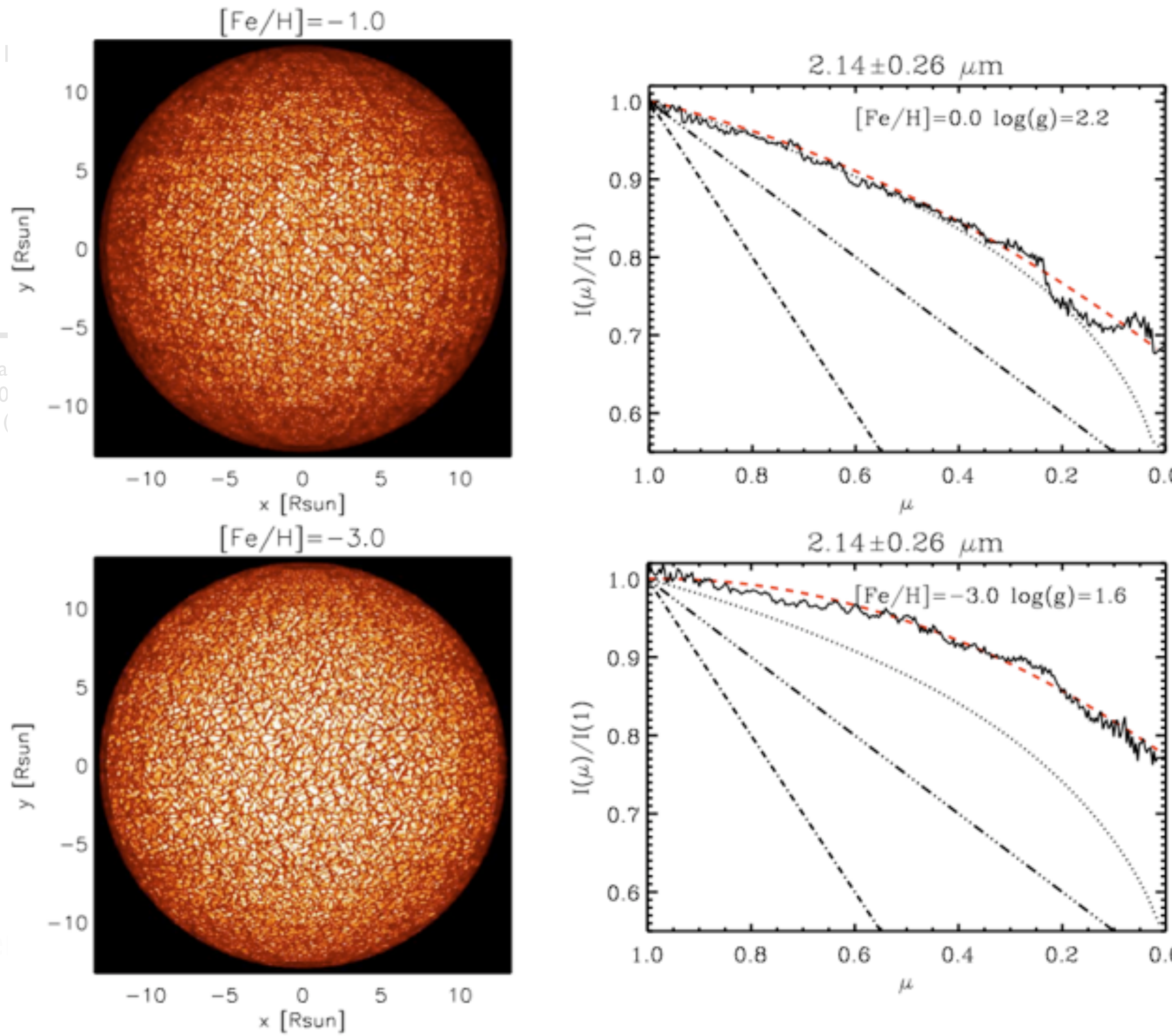
Effective Temperature

Direct: interferometry (Hanbury Brown et al. I

- ✓ precise & accurate
- \- nearby stars (limited range)
- \- uniform disk

UD

Allende Prieto et a
Bigot et al. (20
Koesterke et al. (



Chiavassa, Collet, Casagrande & Asplund (2010)

Semi-Direct: InfraRed Flux Method

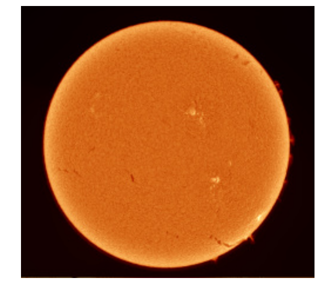
- ✓ precise
- ✓ ~ model-independent
- ✓ any star (photometry)
- \- reddening
- \- accuracy: absolute calibration

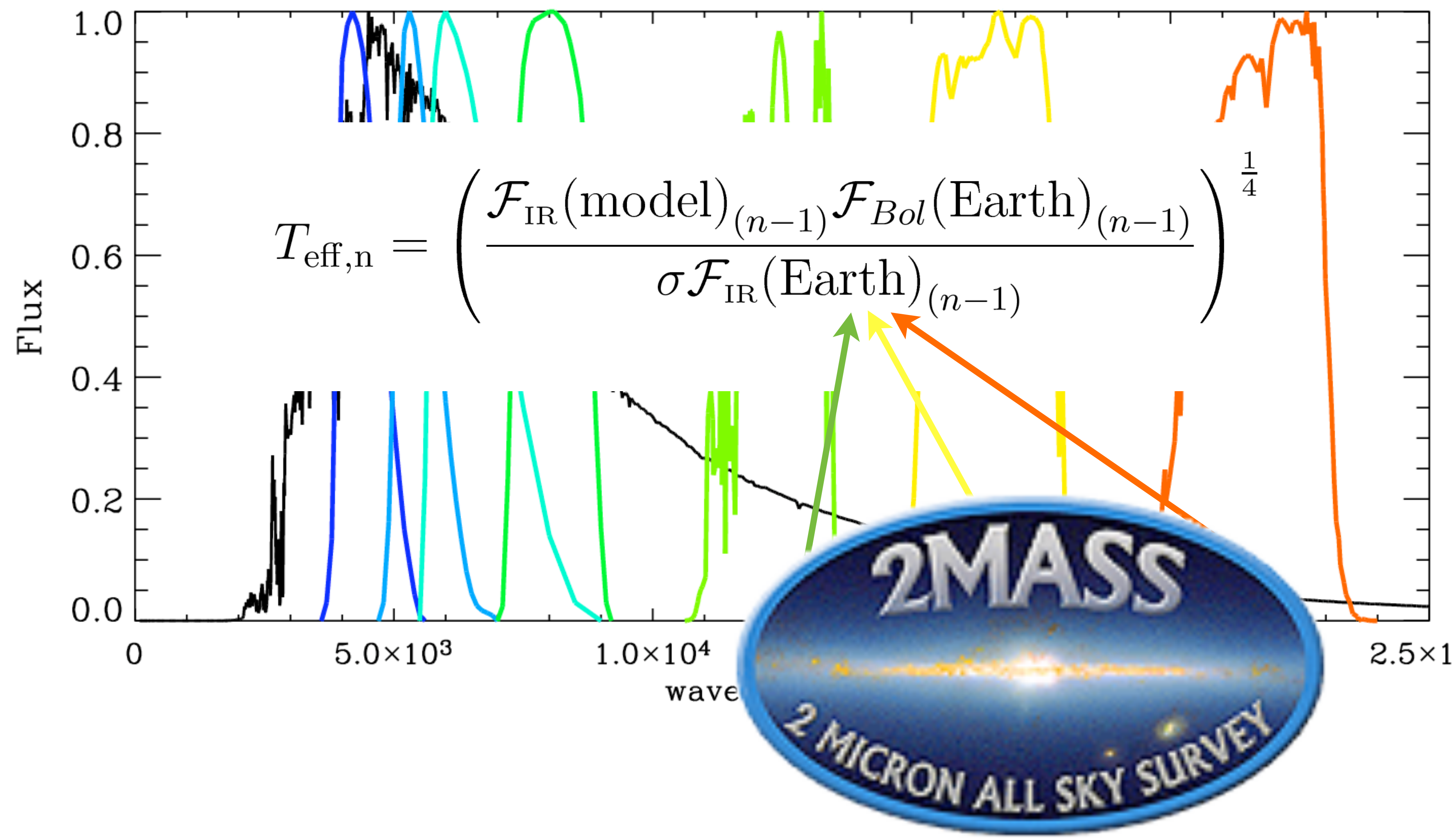
Indirect: ionization/excitation, Balme

InfraRed Flux Method

Blackwell et al. (1977,1978,1979), Alonso et al. (1996, 1999), Ramirez & Melendez (2005), Casagrande et al . (2006, 2010)

$$\frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})}$$



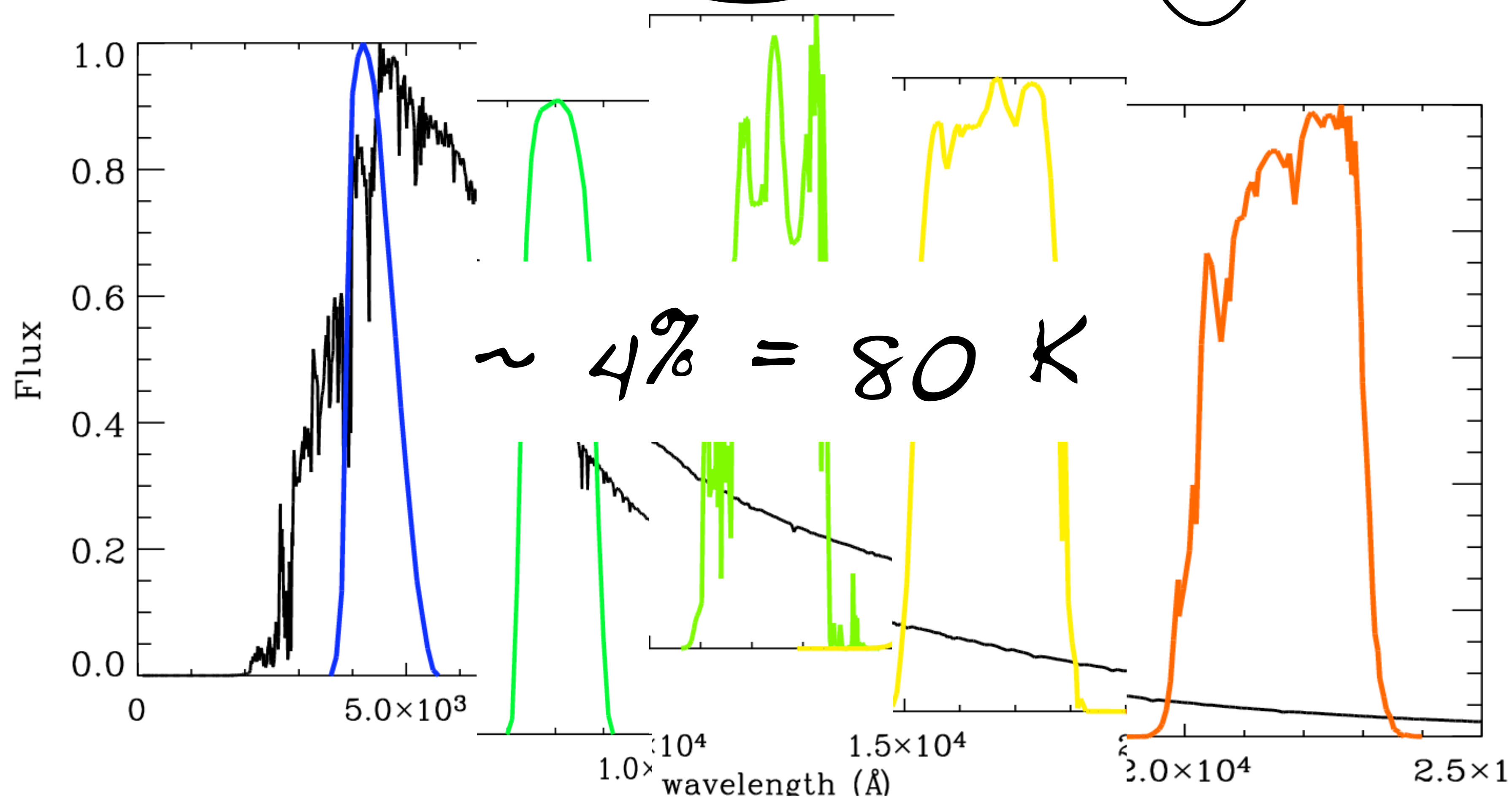


$$T_{\mathrm{eff,n}} = \left(\frac{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})_{(n-1)} \mathcal{F}_{Bol}(\mathrm{Earth})_{(n-1)}}{\sigma \mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})_{(n-1)}} \right)^{\frac{1}{4}}$$

IRFM: Pros & Cons

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

~2/3% ~0.01 mag



But recently, towards 1% accuracy :

HST absolute fluxes (Bohlin, 2007)

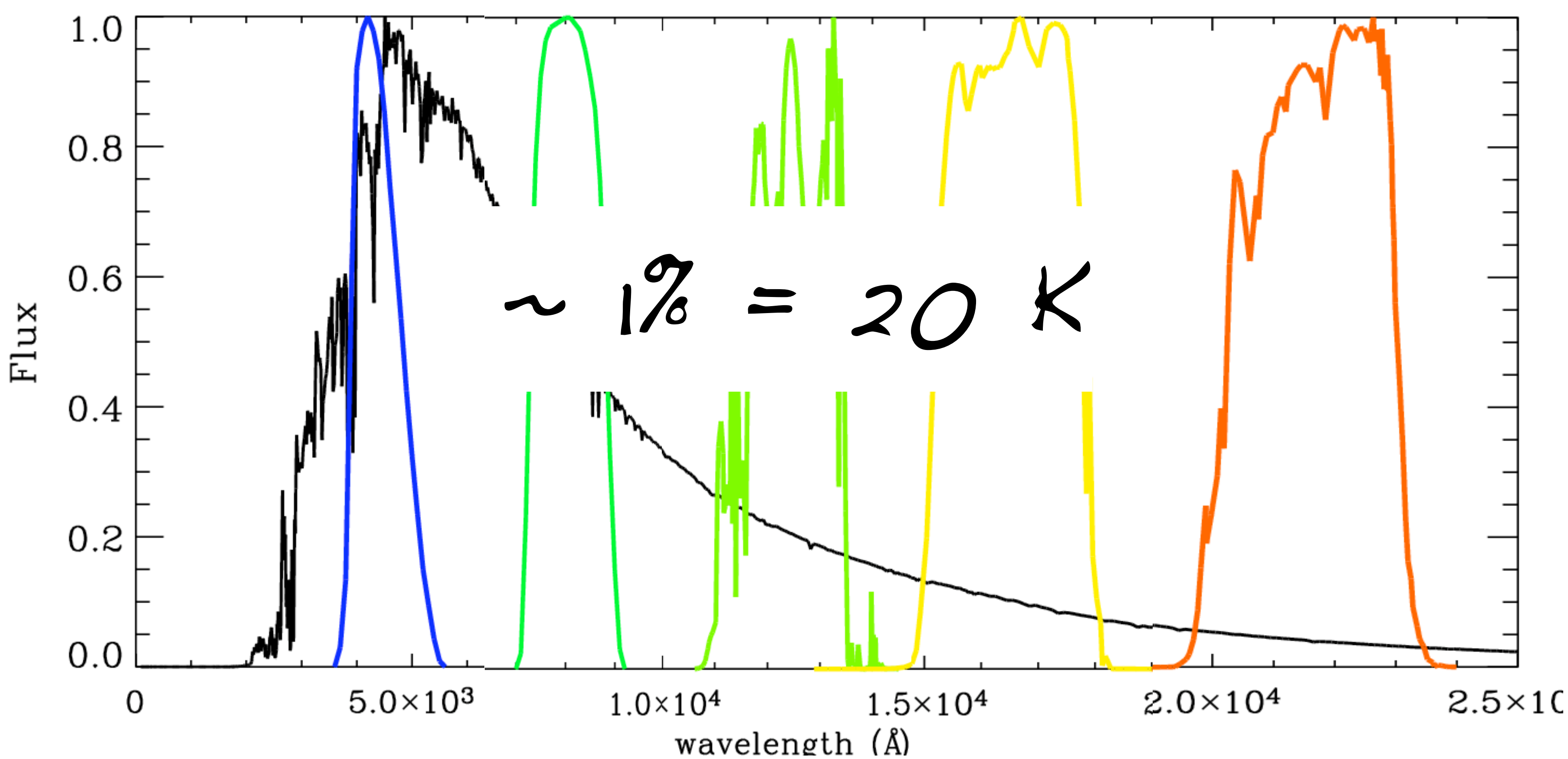
Solar twins (Meléndez et al. 2009)

IRFM: Pros & Cons

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

~2/3%

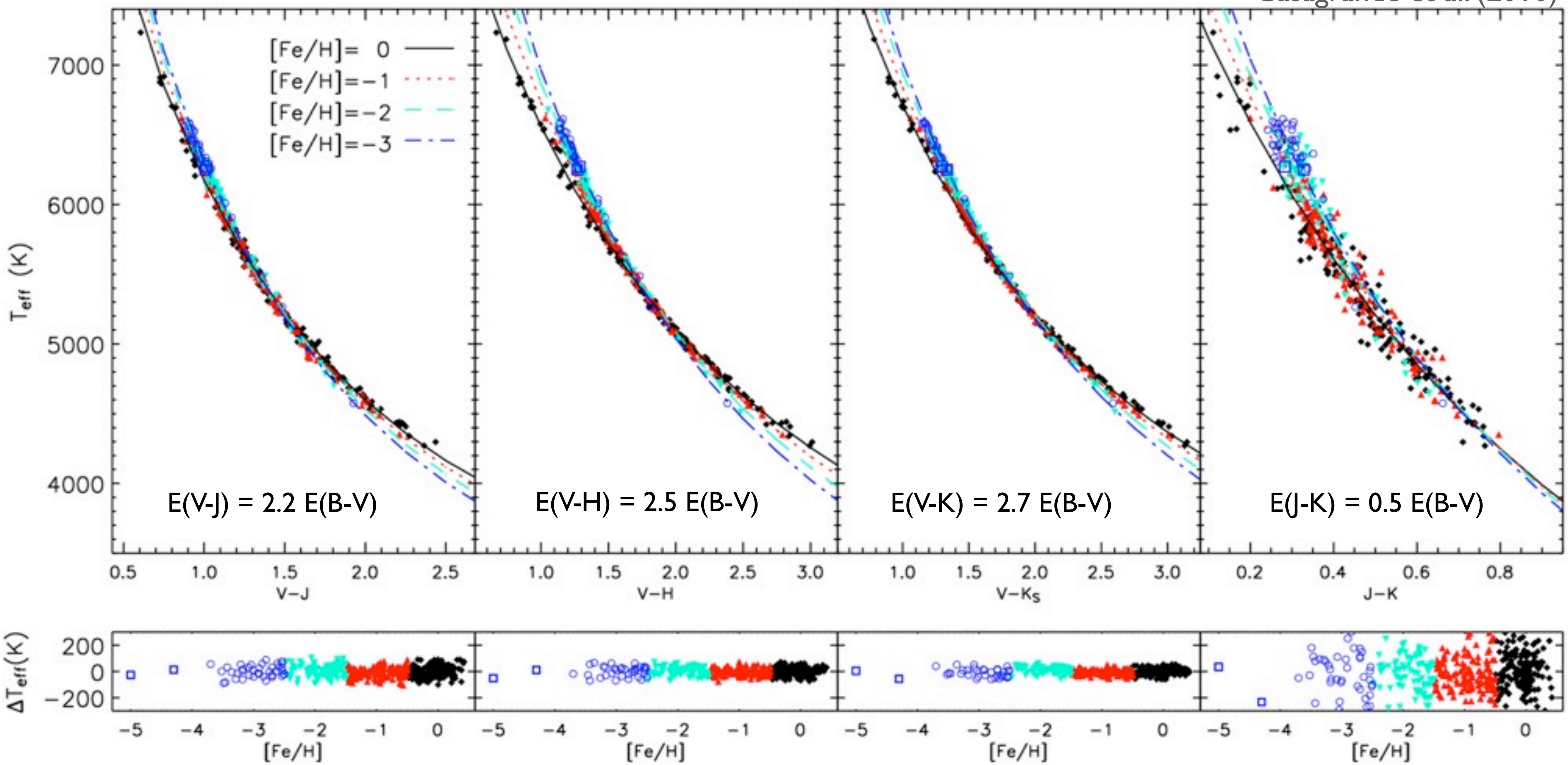
~0.01 mag



Reliable absolute calibration → absolute zero-point T_{eff} scale

Color information

Casagrande et al. (2010)



see also VandenBerg, Casagrande & Stetson (2010), extensive testing of T_{eff} scale and zero-points vs. cluster photometry; similarly An et al. (2009), Pinsonneault et al. (2011). Agreement within few tens K for most band, but shorter baselines (J-K) more uncertain at the hot end

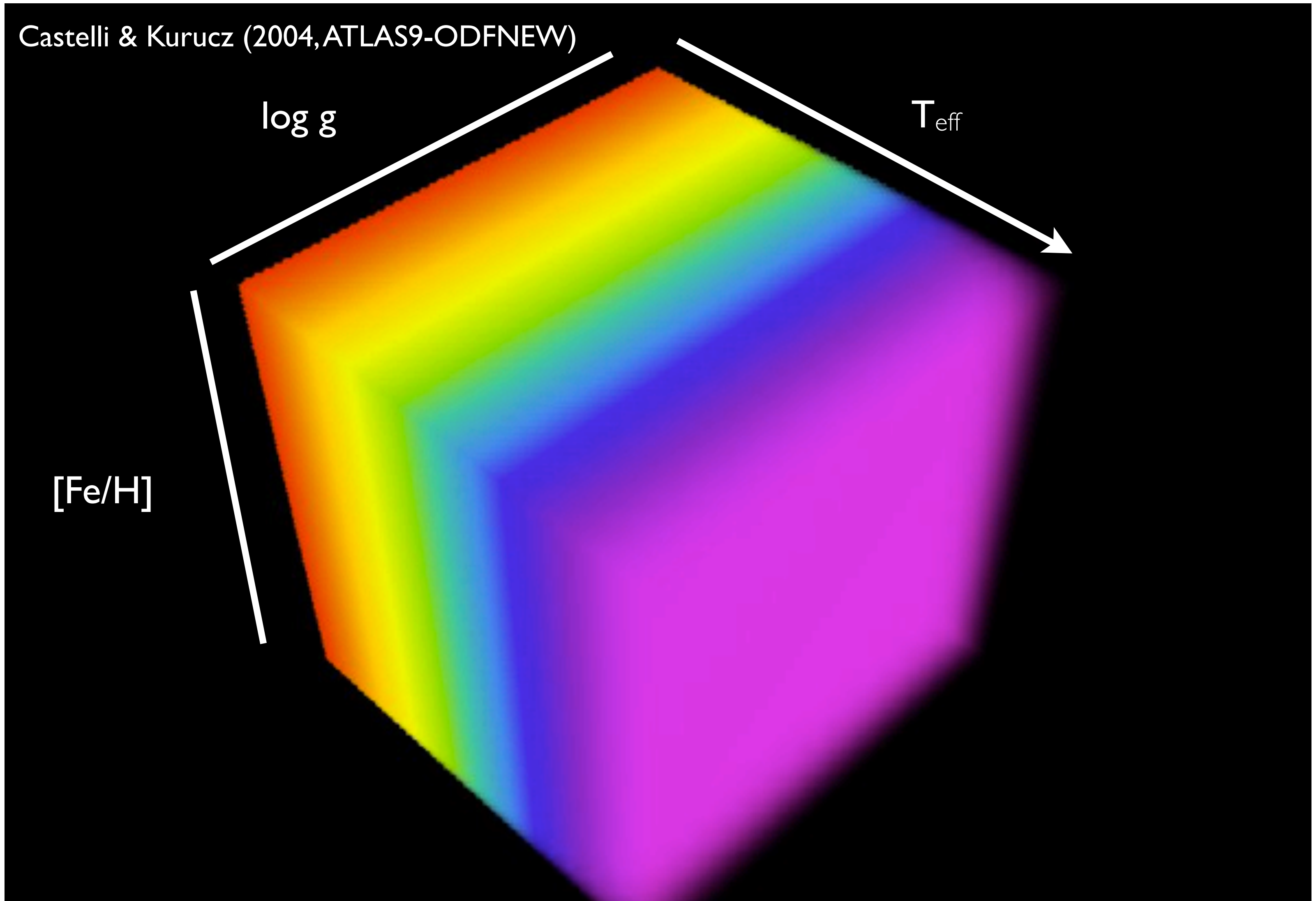
InfraRed Flux Method

- Mostly empirical (80%)
- weak sensitivity of broad-band to logg and [Fe/H] (e.g. Bessell 2007)

$$\frac{\mathcal{F}_{Bol}(\mathrm{Earth})}{\mathcal{F}_{\mathrm{IR}}(\mathrm{Earth})} = \frac{\sigma T_{\mathrm{eff}}^4}{\mathcal{F}_{\mathrm{IR}}(\mathrm{model})}$$

20K →

Rayleigh-Jeans tail



Error budget (e.g. Alonso et al. 1996; Casagrande et al. 2006)

- zero-point: 20 K
- photometry (Montecarlo): 30-50 K
- log(g): ± 0.5 dex → ~30 K
- [Fe/H]: ± 0.1dex → 20/30 K
- reddening systematics

IRFM for some 700 Kepler stars at www.mpa-garching.mpg.de/~luca

InfraRed Flux Method

BV(RI)$_C$ JHK$_S$

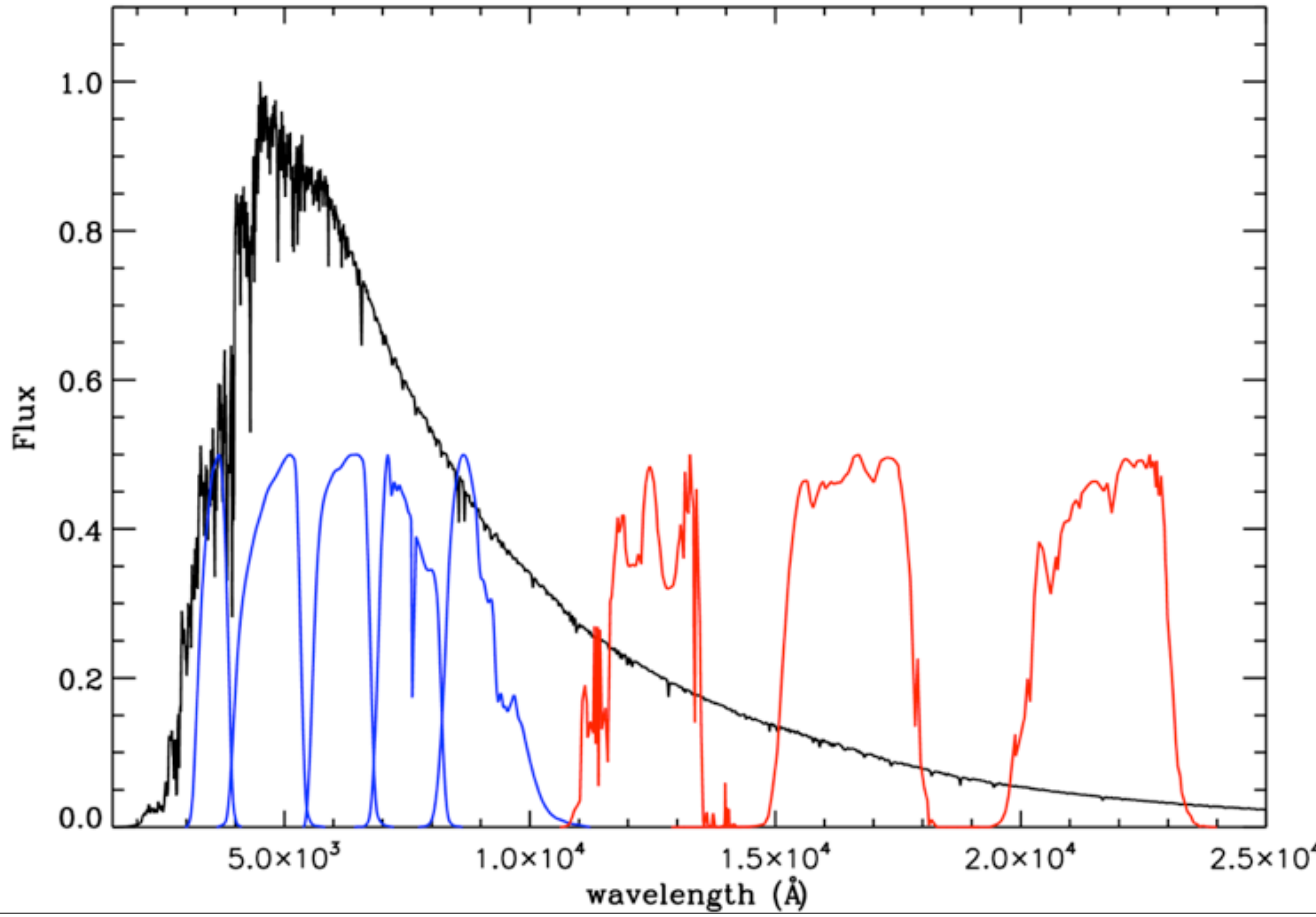
Casagrande et al. (2010)

ugriz JHK$_S$

in prep.

SDSS ugriz

KIC ugriz



Tying SDSS *ugriz* to *BV(RI)*$_C$

Stripe 82

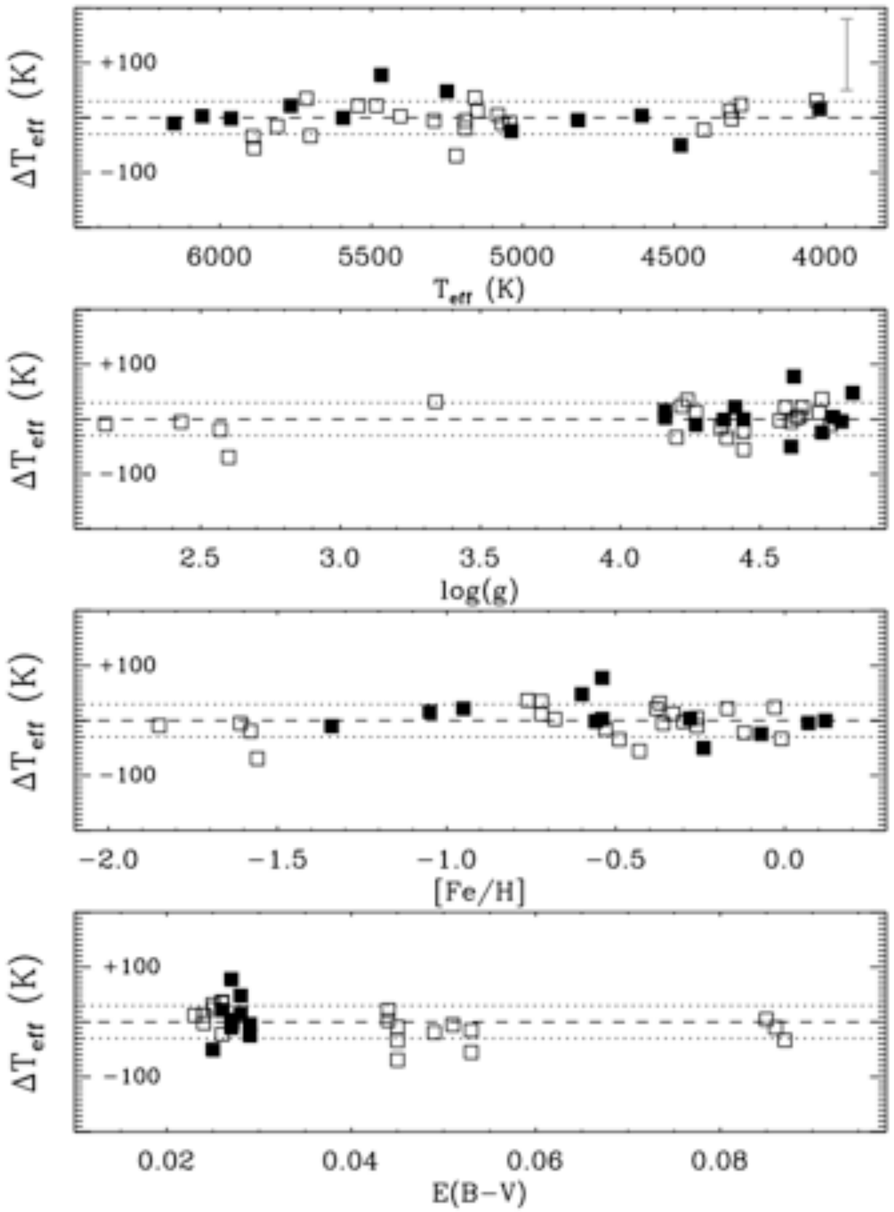


Fig. 3. $\Delta T_{\rm eff}$: $ugrizJHK_S - BV(RI)_CJHK_S$ for the IRFM as function of different quantities (log *g* and [Fe/H] from SSPP). Dotted lines are

Star clusters

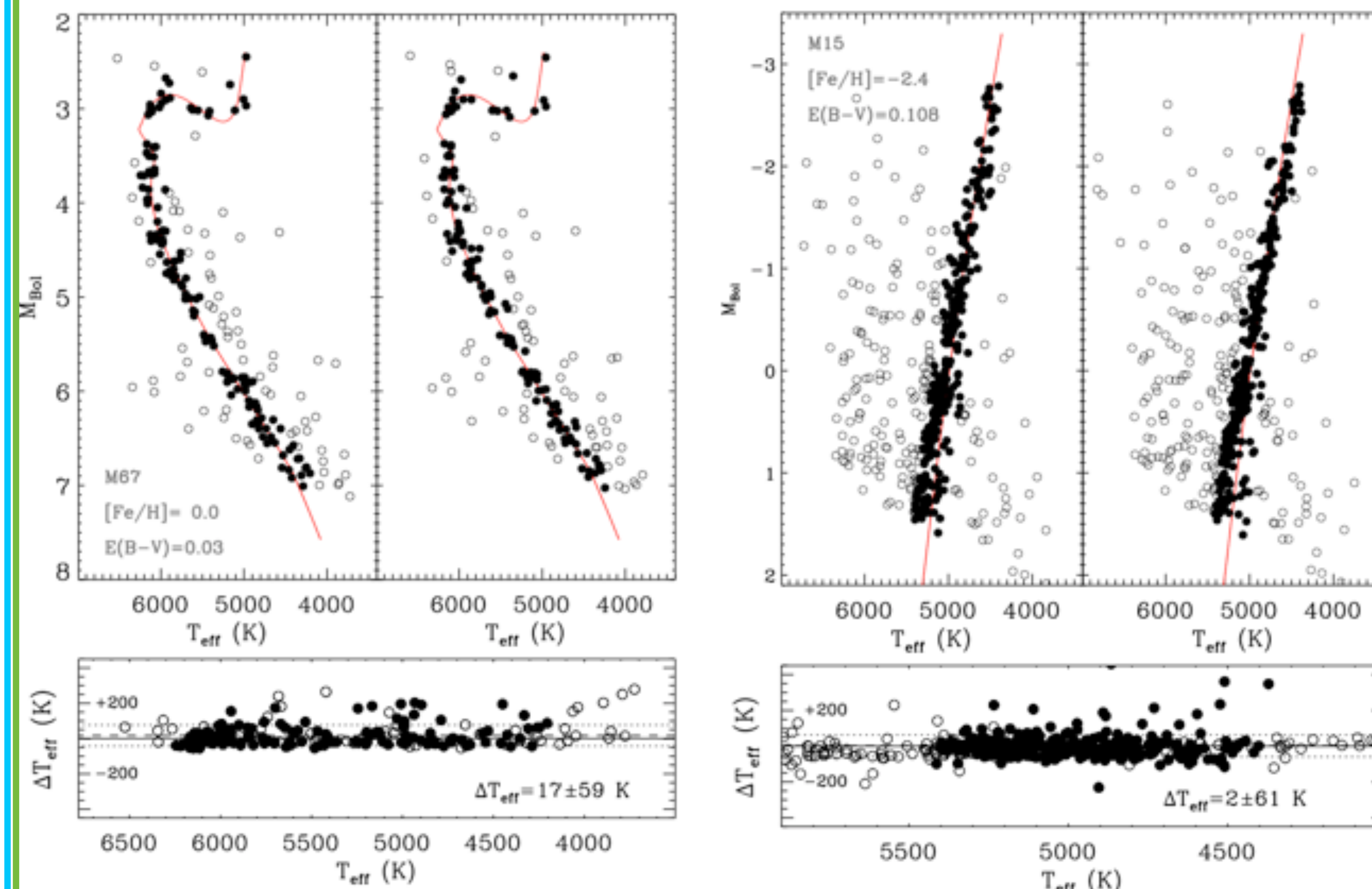
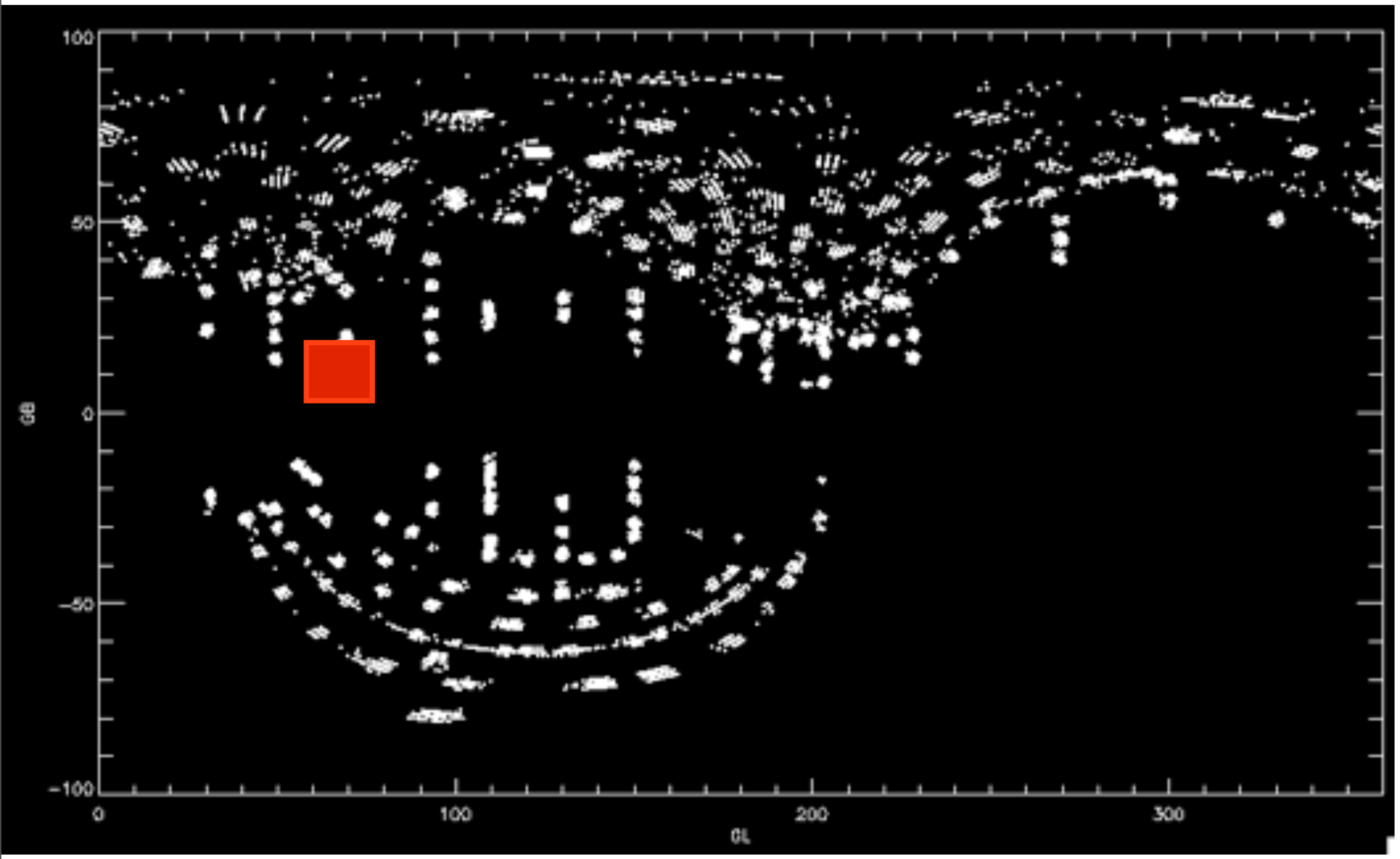


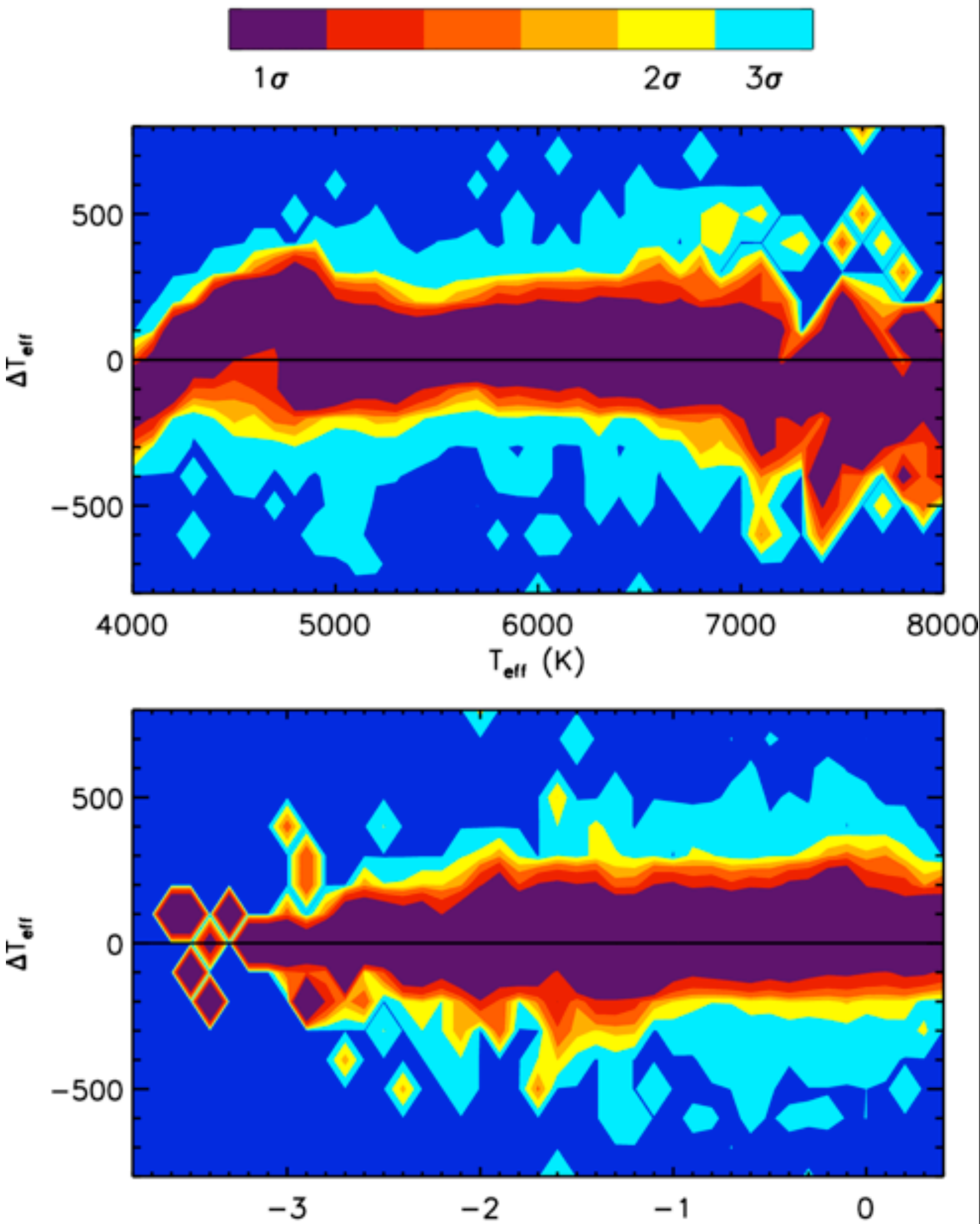
Fig. 6. *Top left panel*: $T_{\rm eff}$ and $M_{\rm Bol}$ determined in $BV(RI)_CJHK_S$ for stars in M67. Filled circles are stars within ±200 K of the reference isochrone. *Top rigt panel*: same as left panel, but for the $ugrizJHK_S$ system. *Lower panel*: $\Delta T_{\rm eff}$: $ugrizJHK_S - BV(RI)_CJHK_S$ for the same stars. Now, filled circles are stars marked as such in at least one of the

Casagrande et al. (in prep.)

IRFM on SDSS-SEGUE

SEGUE *(Sloan Extension for Galactic Understanding and Exploration)*: low resolution (R~2000) spectra for several 10^5 stars. Stellar parameters derived via SSPP pipeline (Lee et al. 2008a,b; Allende Prieto et al. 2008).

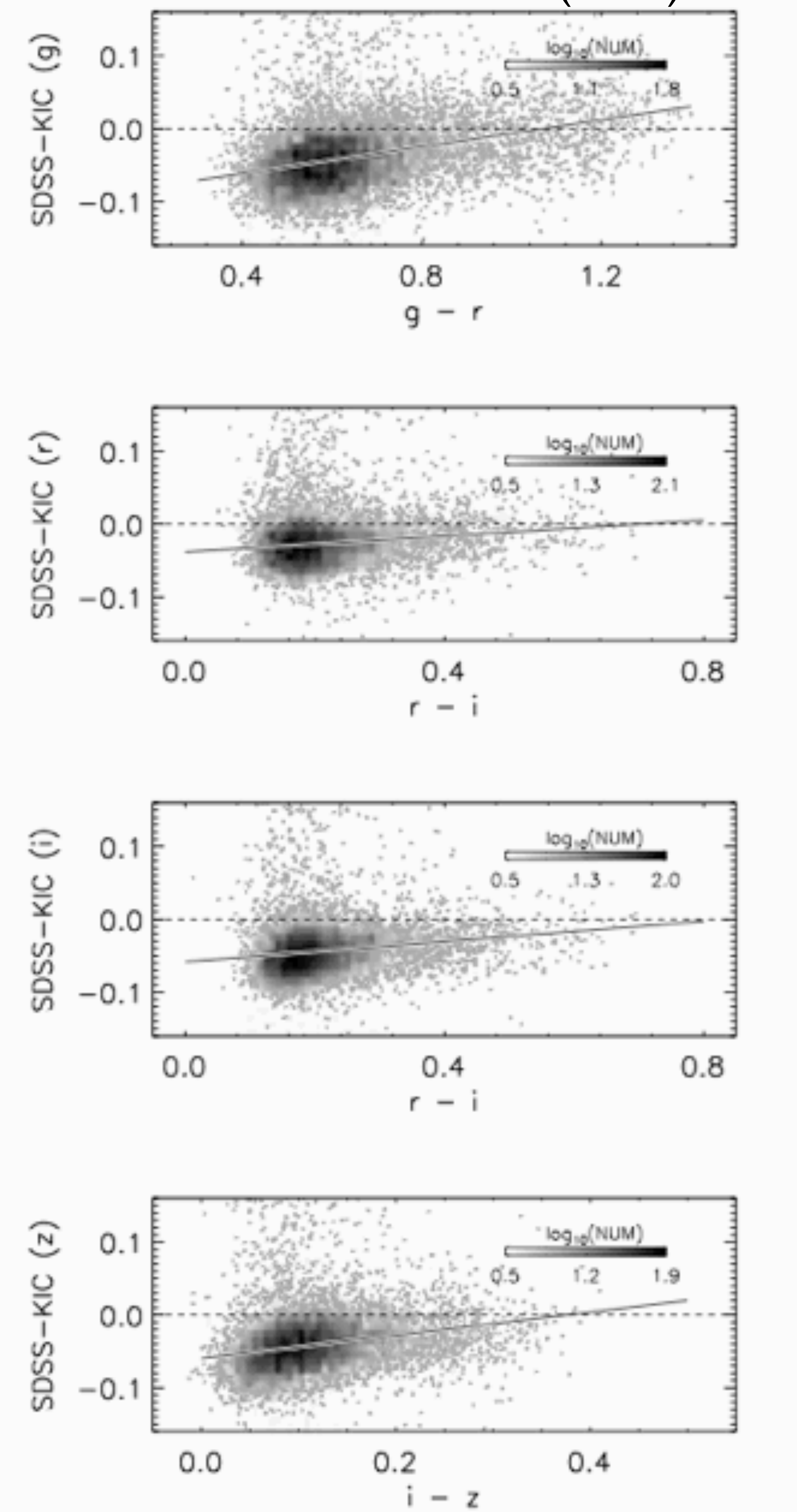


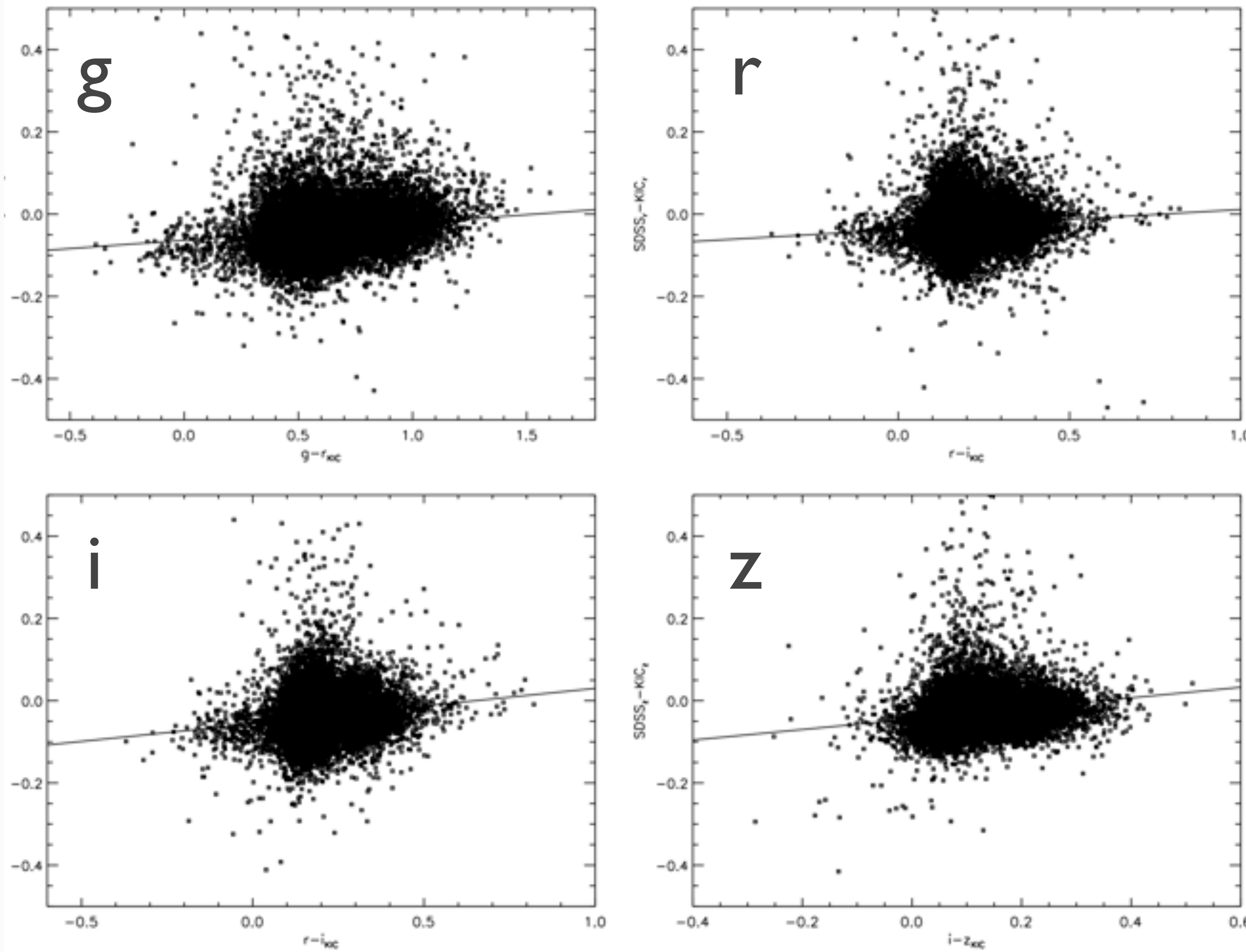


Casagrande et al. (in prep.)

IRFM on KIC (u)griz

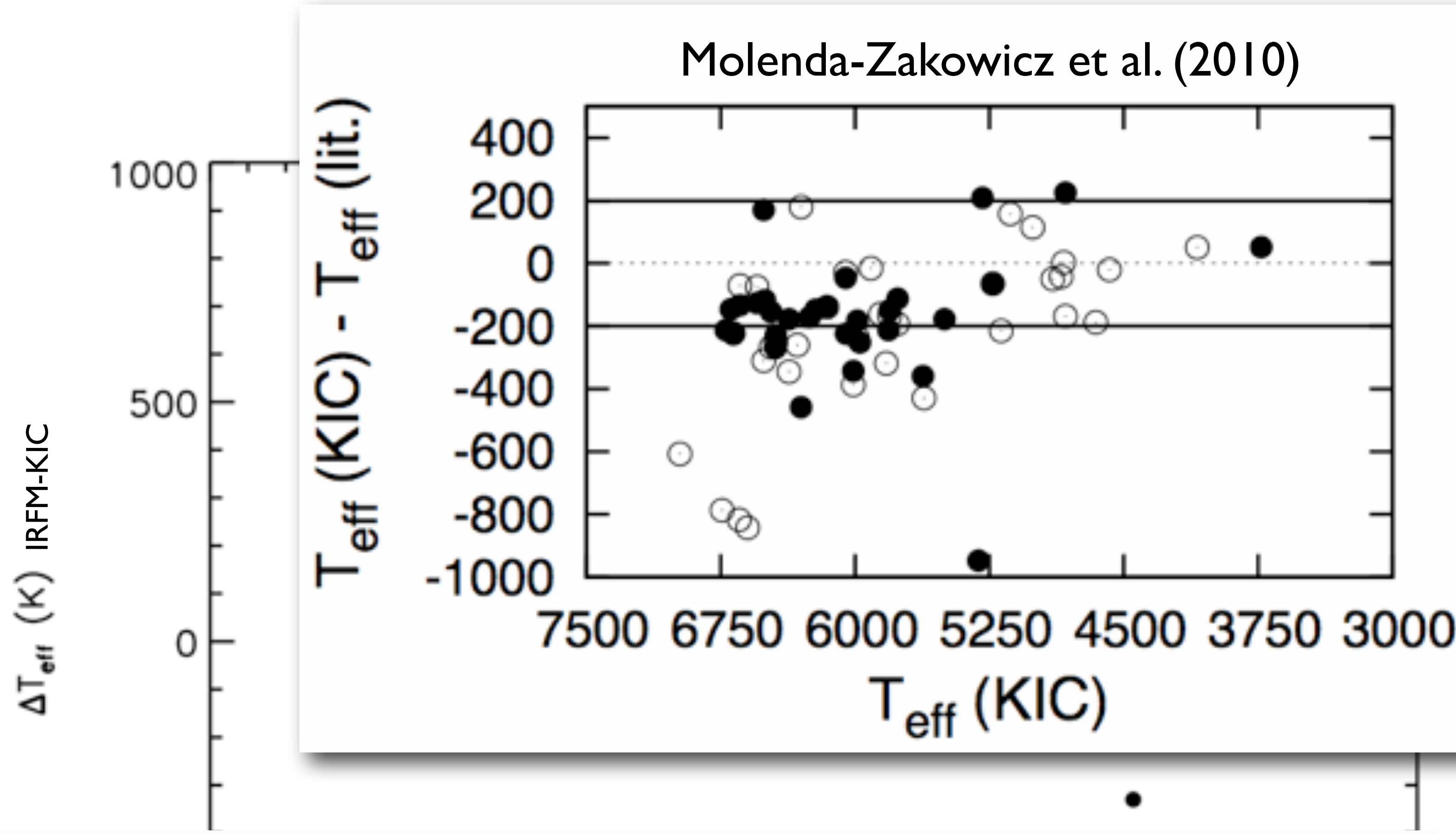
Pinsonneault et al. (2011)





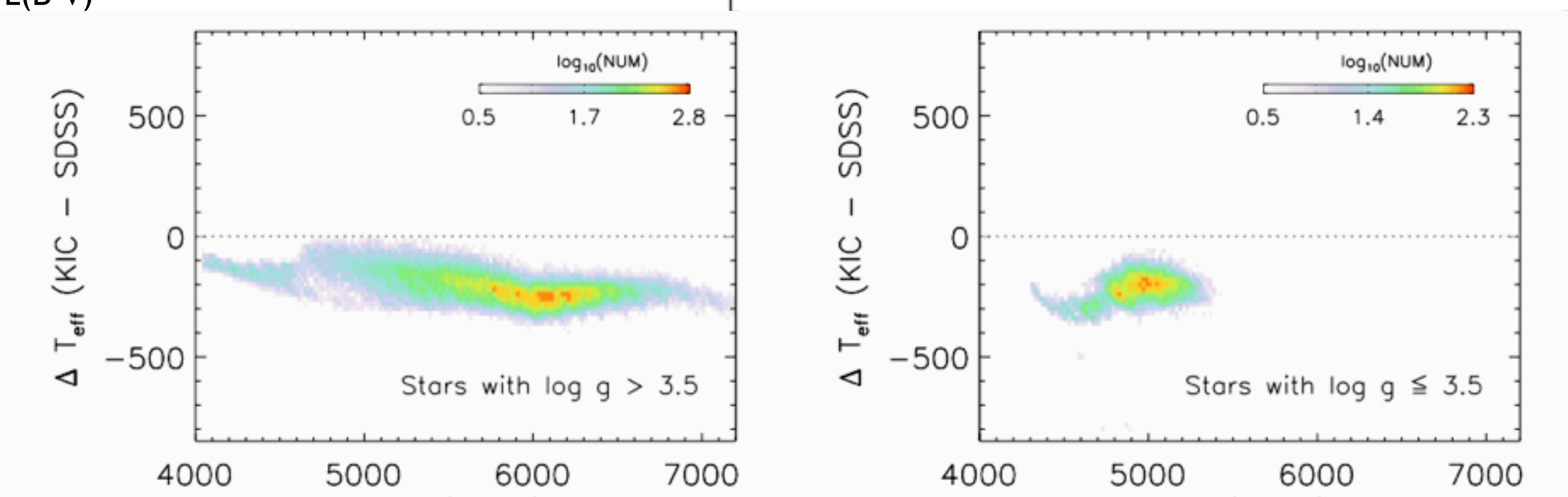
based on stars in common between Sloan and KIC

IRFM on KIC



KIC *(Kepler Input Catalogue)*:

- (u)griz
- T_{eff}
- [Fe/H]
- logg
- E(B-V)
-



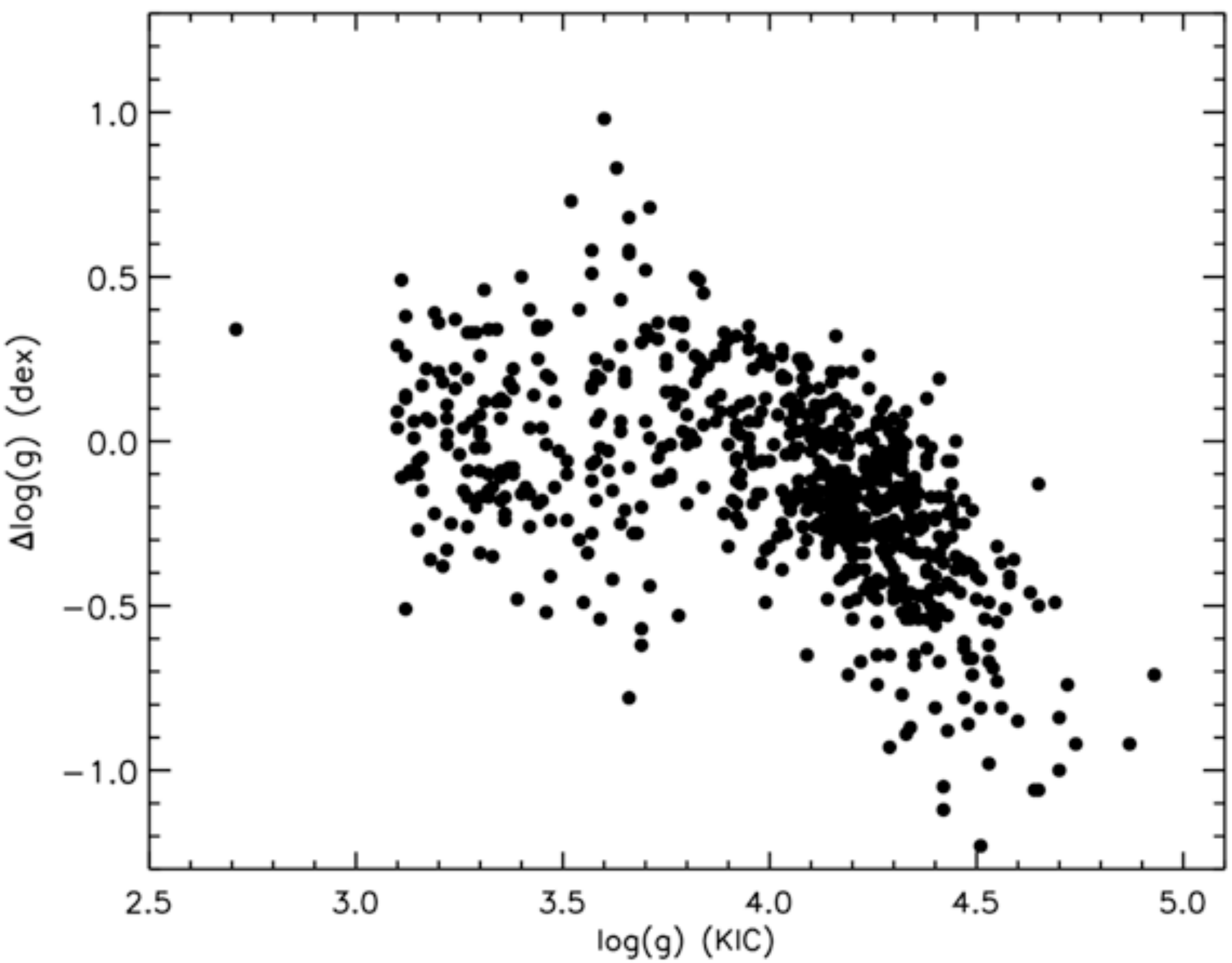
Pinsonneault et al. (2011)

IRFM on KIC

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

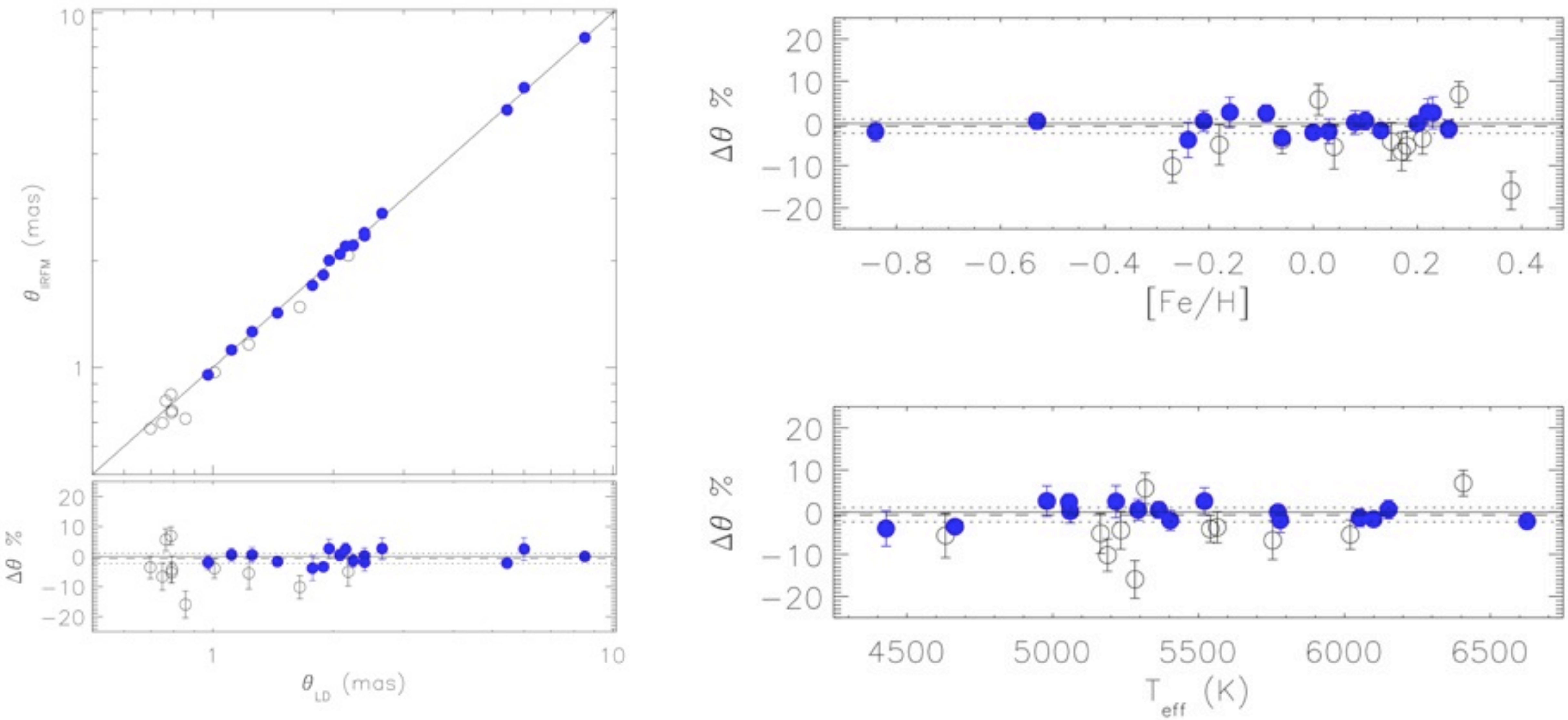
$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\max}}{\nu_{\max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2},$$

(e.g. Hekker et al. 2009, 2011, Stello et al. 2009)



from Silva Aguirre et al. (2011)

$\mathcal{F}_{Bol} = \left(\frac{\theta}{2}\right)^2 \sigma T_{\rm eff}^4$: a useful by-product!



$$\Delta\theta = -0.6 \pm 1.7\% \longrightarrow \Delta T_{\rm eff} = 18 \pm 50{\rm K}$$

DISTANCES!

work in progress, with V. Silva-Aguirre, W.J. Chaplin, A. Miglio

SCALING RELATIONS

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

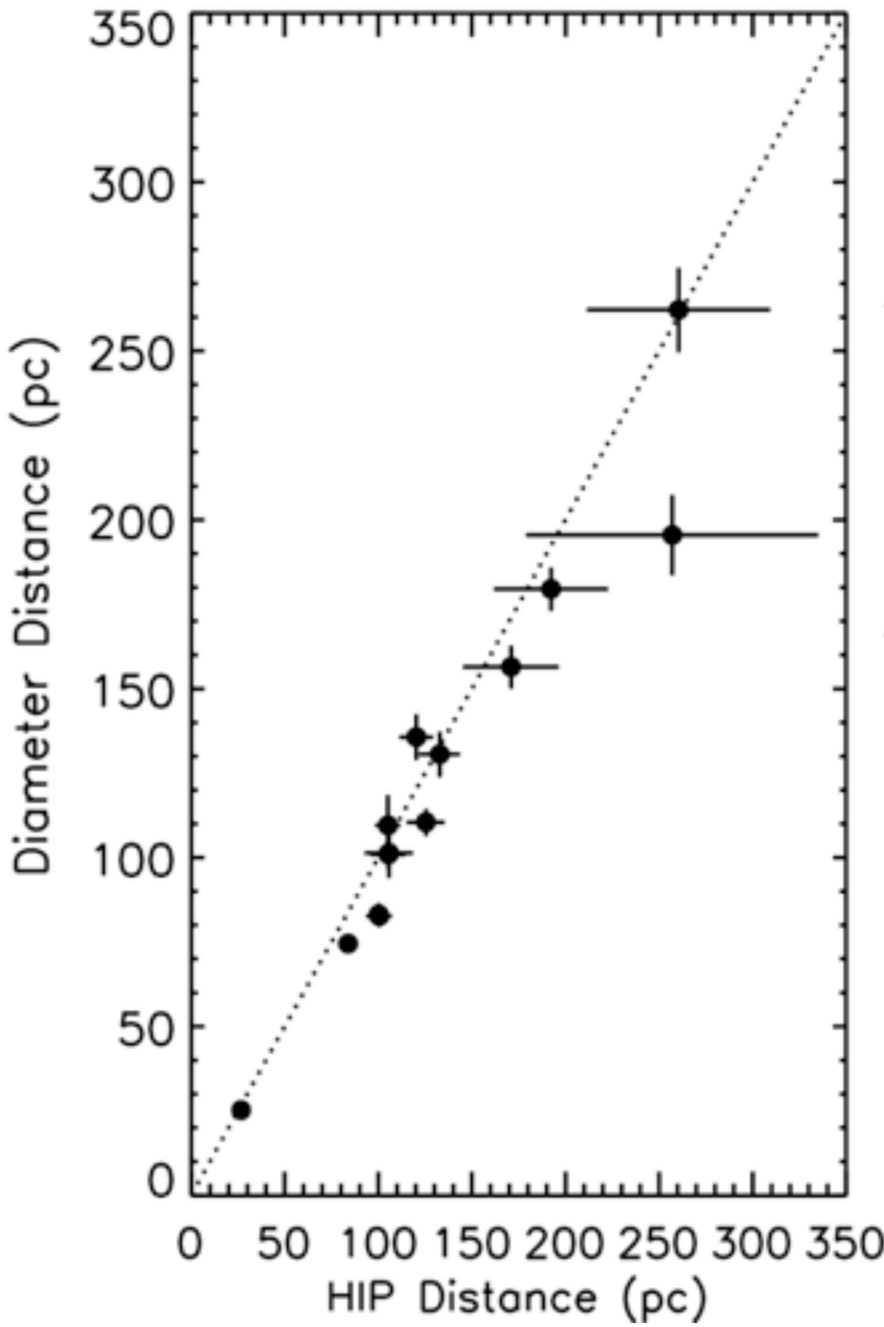
$$\frac{R}{R_\odot} \simeq \left(\frac{\nu_{\rm max}}{\nu_{\rm max,\odot}}\right) \left(\frac{\Delta\nu}{\Delta\nu_\odot}\right)^{-2} \left(\frac{T_{\rm eff}}{T_{\rm eff,\odot}}\right)^{1/2},$$

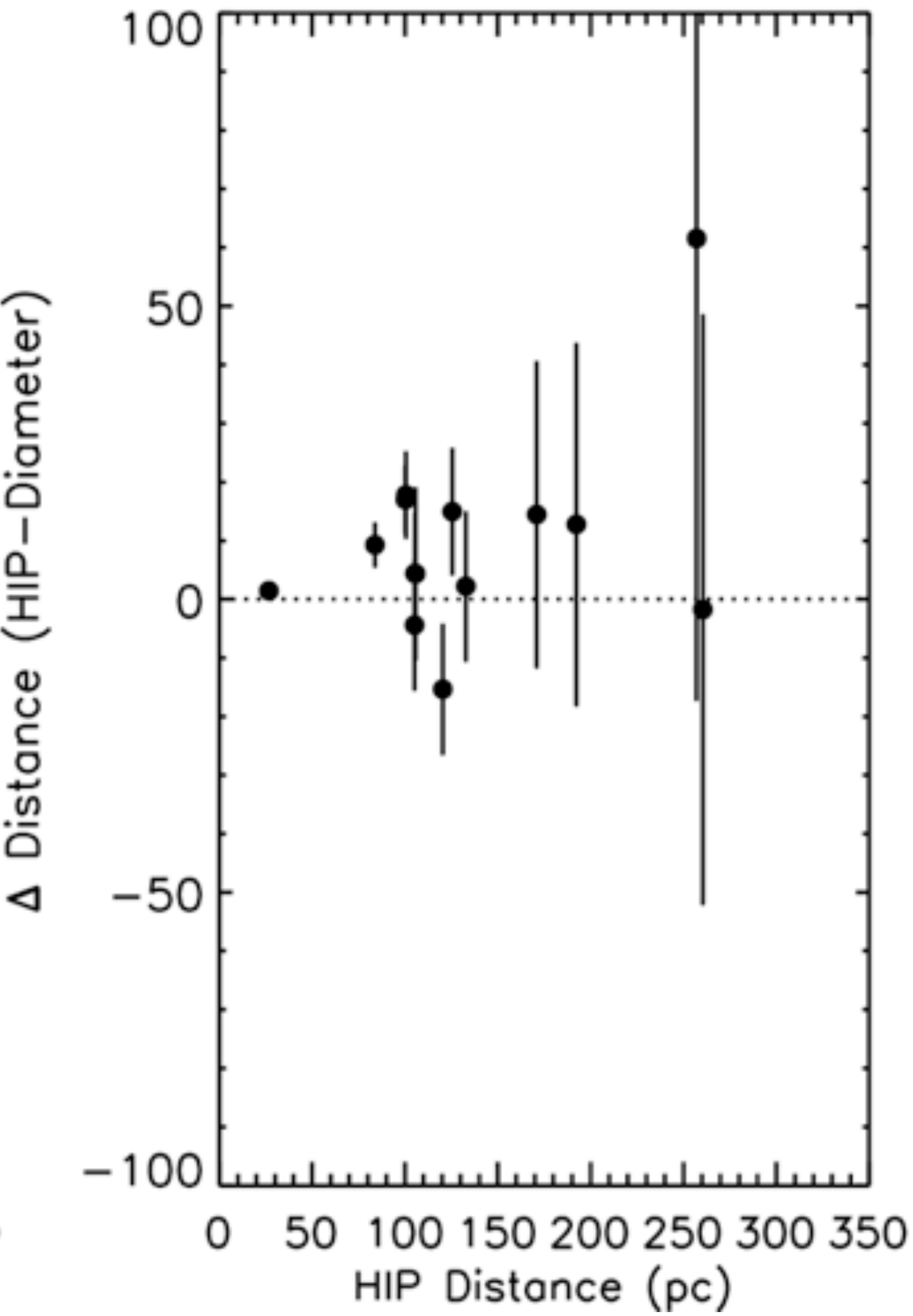
Photometry (IRFM)

$T_{\rm eff}$

$\mathcal{F}_{Bol}$

θ





ALL'S Well, that Ends Well?

Actus primus. Scœna Prima.

Enter yong Bertram Count of Roſſillion, his Mother, and Helena, Lord Lafew, all in blacke.

Mother.

IN deliuering my ſonne from me, I burie a ſecond husband.

Roſ. And I in going Madam, weep ore my fathers death anew; but I muſt attend his maieſties command, to whom I am now in Ward, euermore in ſubiection.

Laf. You ſhall find of the King a husband Madame, you ſir a father. He that ſo generally is at all times good, muſt of neceſſitie hold his vertue to you, whoſe worthineſſe would ſtirre it vp where it wanted rather then lack it where there is ſuch abundance.

Mo. What hope is there of his Maieſties amendment?

Laf. He hath abandon'd his Phiſitions Madam, vnder whoſe practiſes he hath perſecuted time with hope, and finds no other aduantage in the proceſſe, but onely the looſing of hope by time.

and atcheeues her goodneſſe.

Lafew. Your commendations Madam get from her teares.

Mo. 'Tis the beſt brine a Maiden can ſeaſon her praiſe in. The remembrance of her father neuer approches her heart, but the tirrany of her ſorrowes takes all liuelihood from her cheeke. No more of this *Helena*, go too, no more leaſt it be rather thought you affect a ſorrow, then to haue——

Hell. I doe affect a ſorrow indeed, but I haue it too.

Laf. Moderate lamentation is the right of the dead, exceſſiue greefe the enemie to the liuing.

Mo. If the liuing be enemie to the greefe, the exceſſe makes it ſoone mortall.

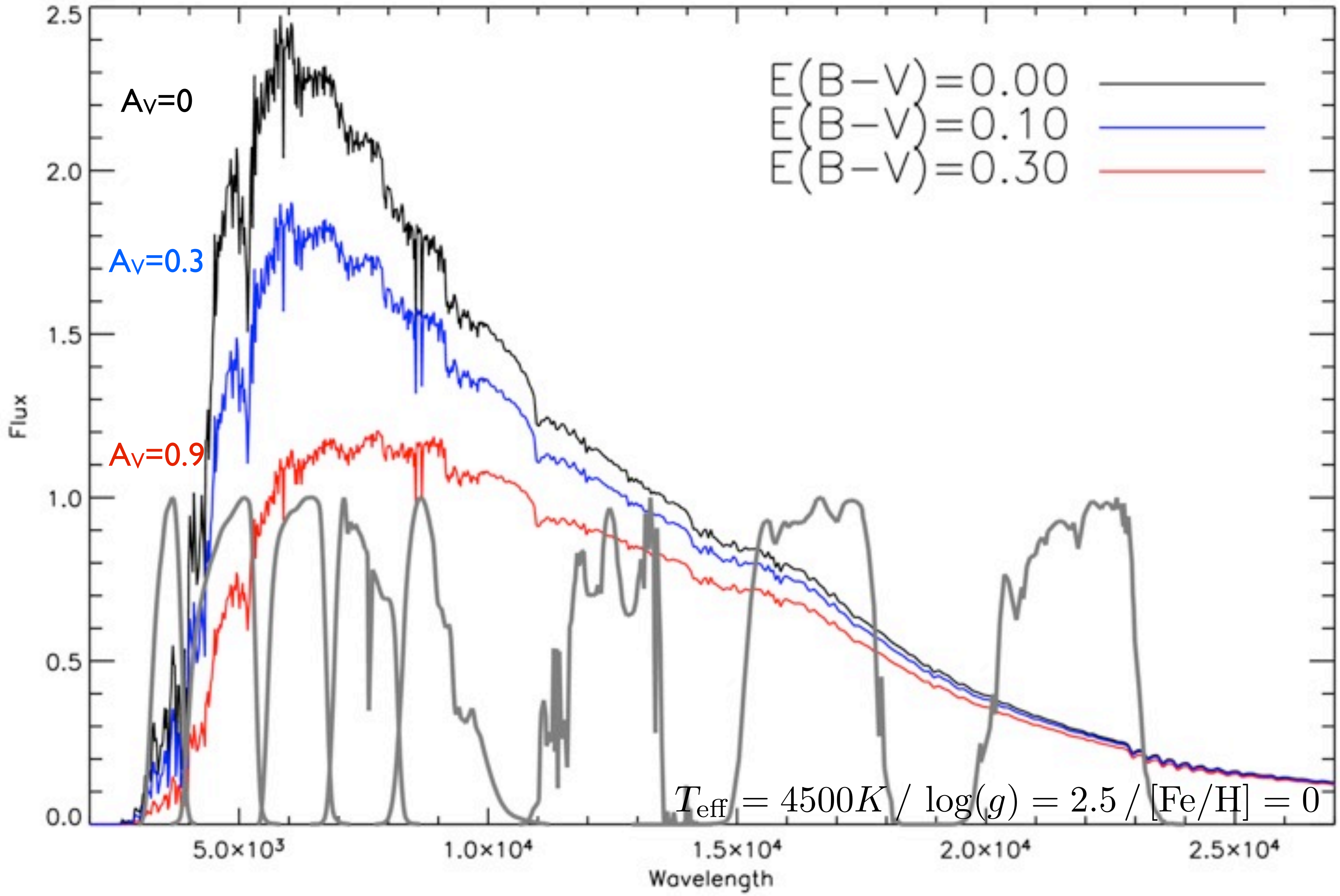
Roſ. Maddam I deſire your holie wiſhes.

Laf. How vnderſtand we that?

Mo. Be thou bleſt *Bertrame*, and ſucceed thy father
In manners as in ſhape: thy blood and vertue
Contend for Empire in thee, and thy goodneſſe
Share with thy birth-right. Loue all, truſt a few,
Doe wrong to none: be able for thine enemie

Extinction

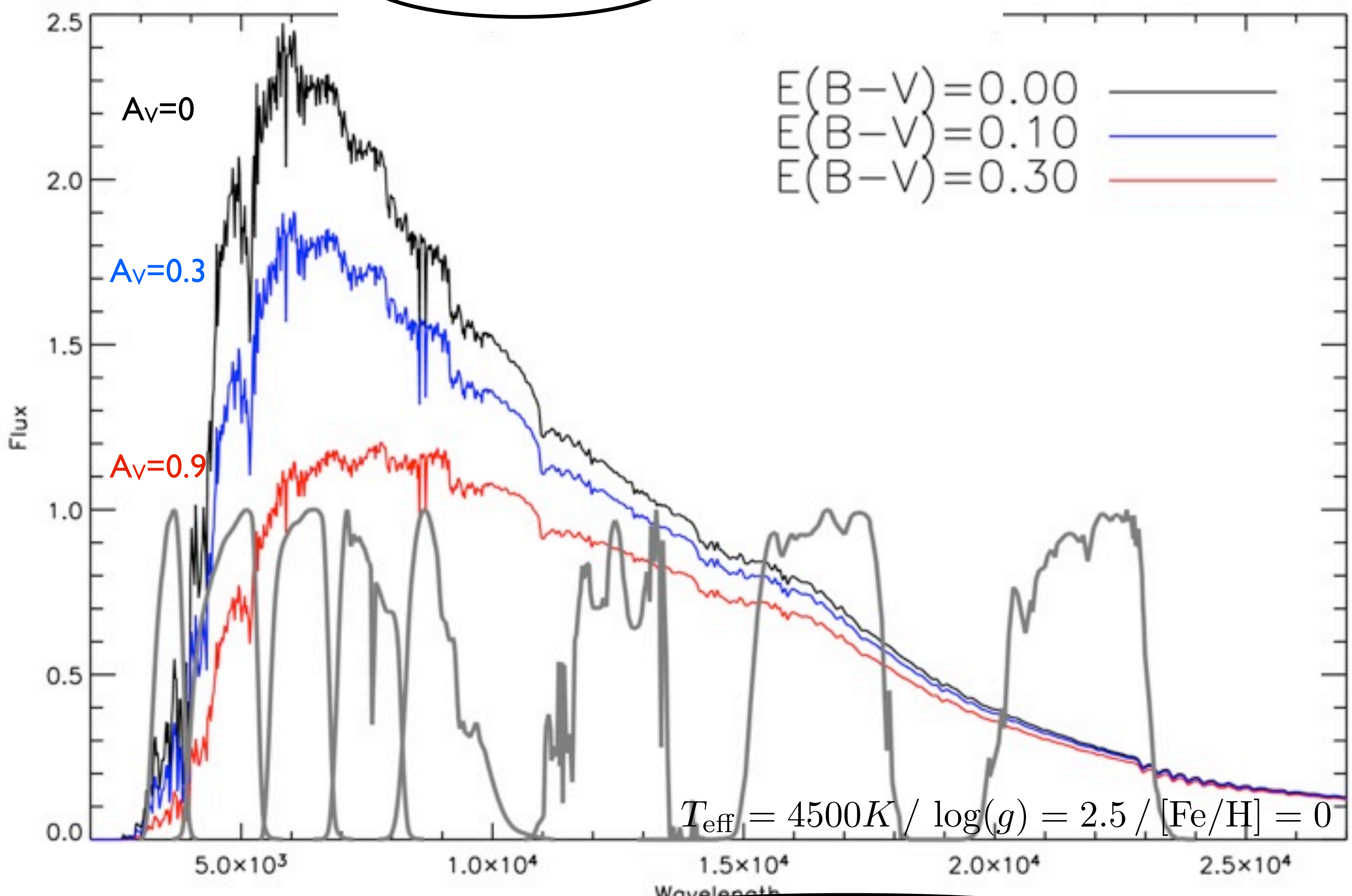
$$\mathcal{F}(\lambda) \rightarrow \mathcal{F}(\lambda)10^{-0.4A_\lambda}$$



	u	g	r	i	z	J	H	K
Δm=	0.48	0.37	0.27	0.21	0.15	0.09	0.05	0.03
Δm=	1.45	1.10	0.81	0.63	0.46	0.26	0.15	0.09

Extinction

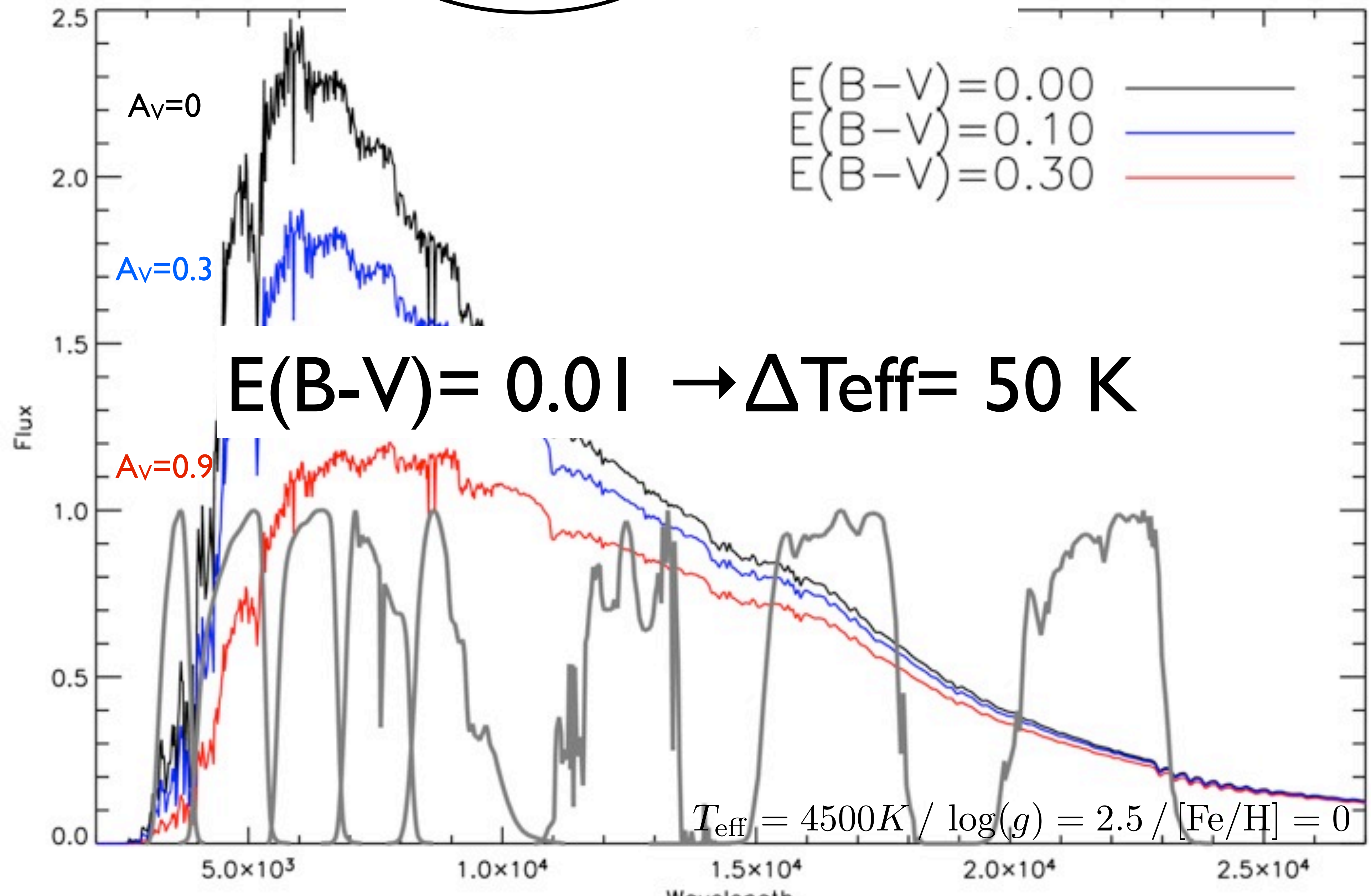
$$\frac{\mathcal{F}_{Bol}(\text{Earth})}{\mathcal{F}_{\text{IR}}(\text{Earth})} = \frac{\sigma T_{\text{eff}}^4}{\mathcal{F}_{\text{IR}}(\text{model})}$$



	u	g	r	i	z	J	H	K	
Δm=	0.48	0.37	0.27	0.21	0.15	0.09	0.05	0.03	→ +100K systematic
Δm=	1.45	1.10	0.81	0.63	0.46	0.26	0.15	0.09	→ +300K systematic

Extinction

$$\frac{\mathcal{F}_{Bol}(\text{Earth})}{\mathcal{F}_{\text{IR}}(\text{Earth})} = \frac{\sigma T_{\text{eff}}^4}{\mathcal{F}_{\text{IR}}(\text{model})}$$



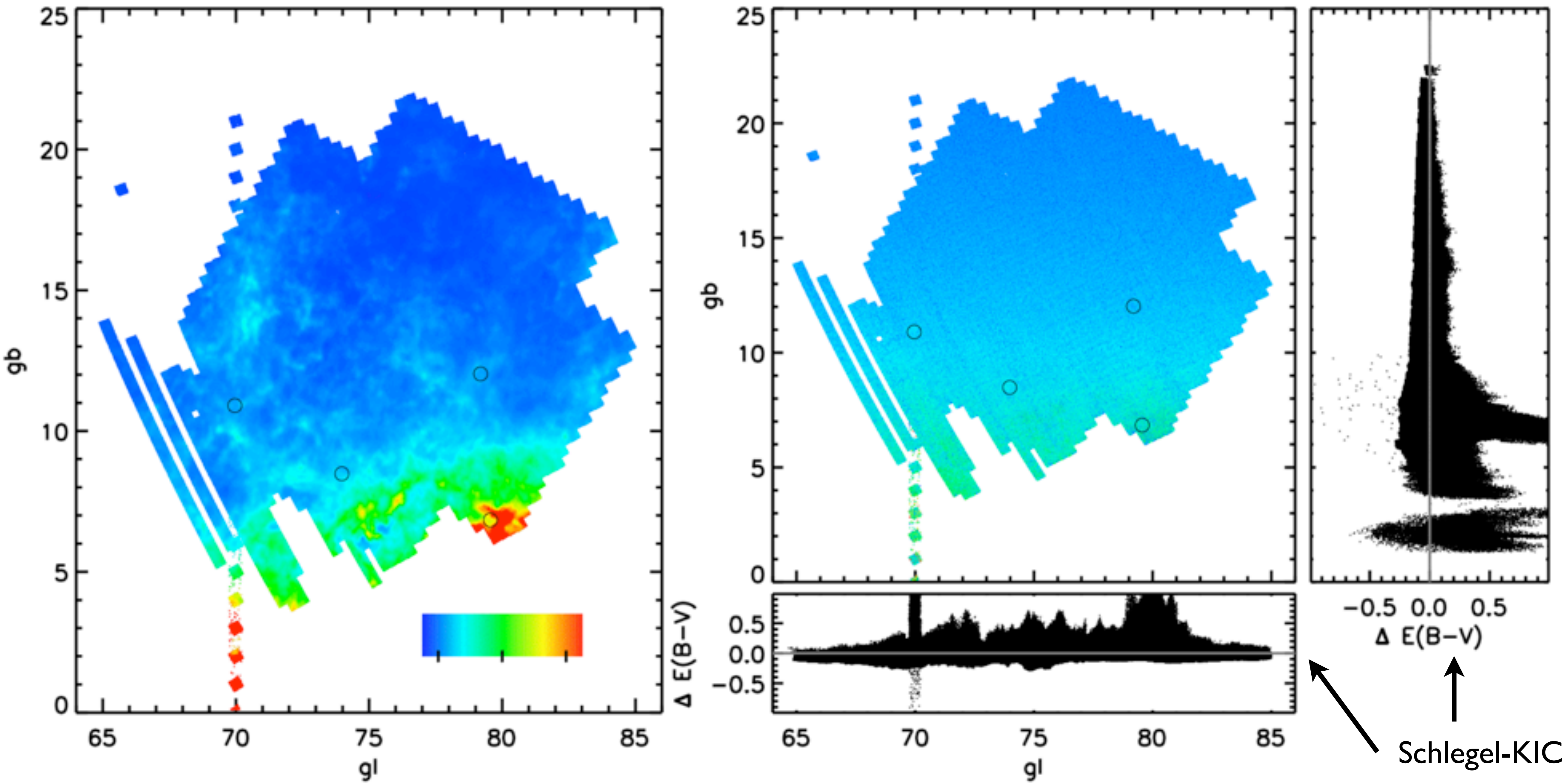
E(B-V)= 0.01 →ΔTeff= 50 K

	u	g	r	i	z	J	H	K	
Δm=	0.48	0.37	0.27	0.21	0.15	0.09	0.05	0.03	→ -500K systematic!
Δm=	1.45	1.10	0.81	0.63	0.46	0.26	0.15	0.09	→ -1500K systematic!

E(B-V)

Schlegel map

KIC

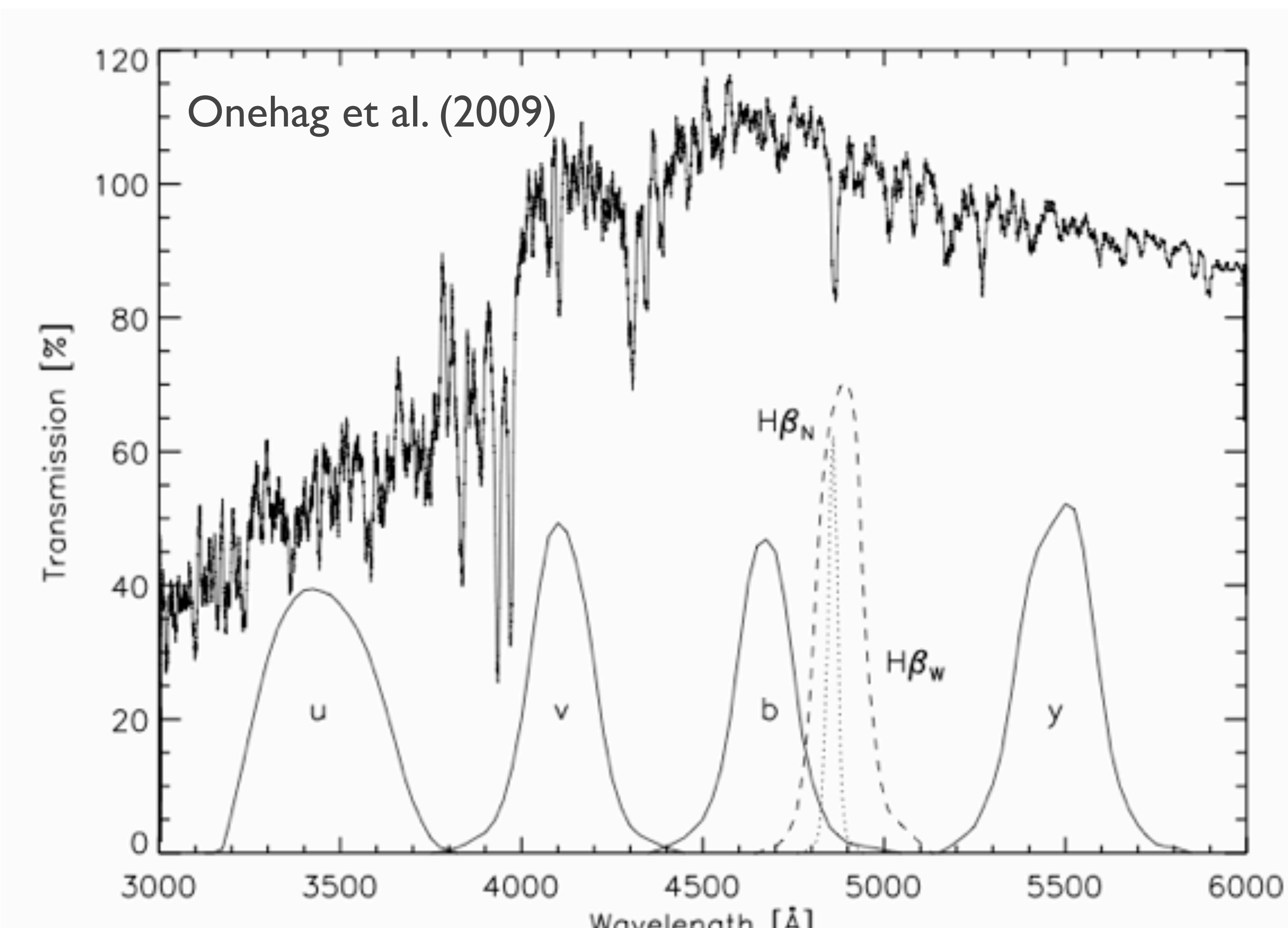


$$1 - e^{-\frac{|D \sin b|}{h}}$$

Intermediate band photometry: Strömgren system

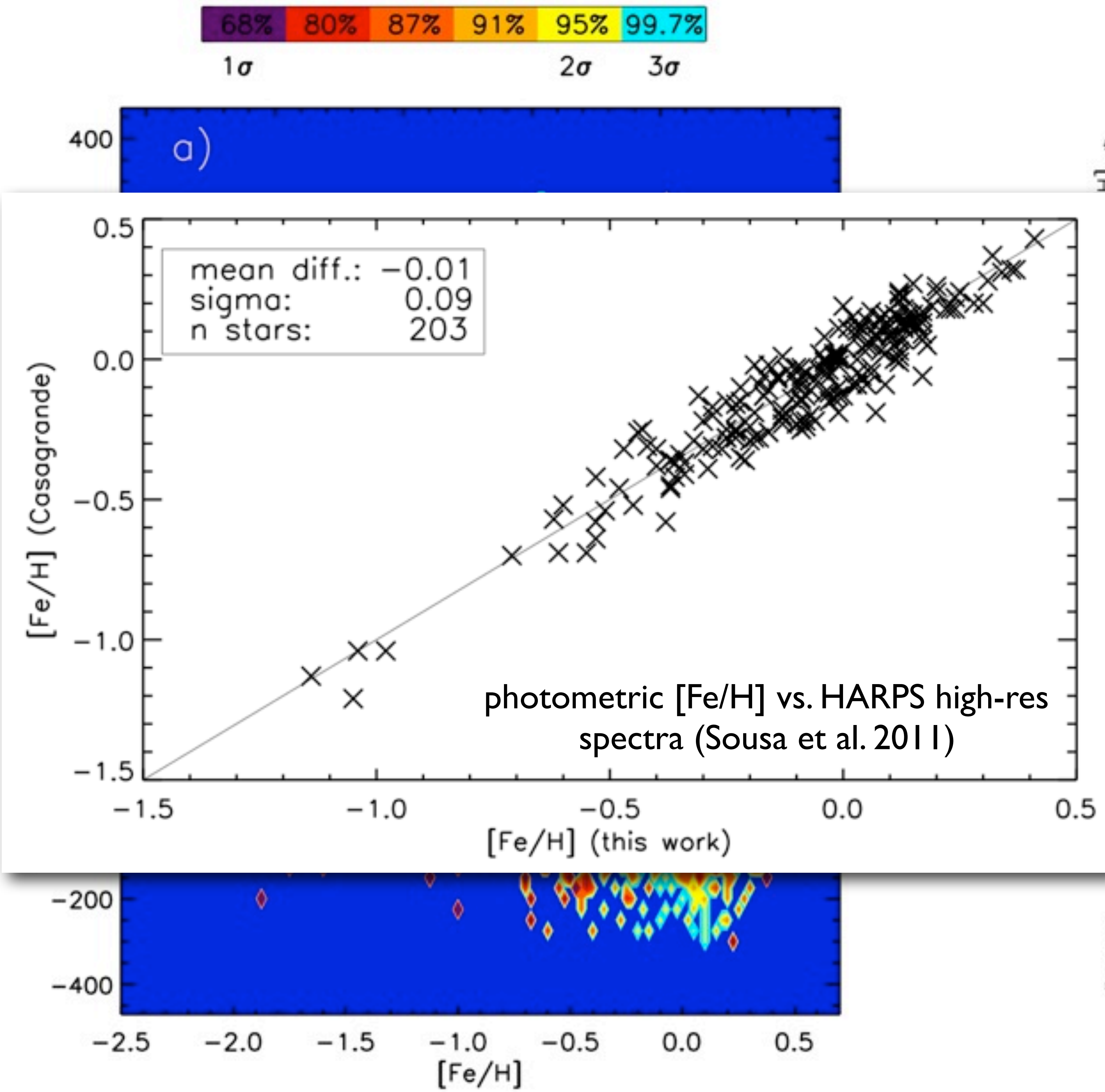
$(b-y)$	continuum slope	⟶	T_{eff}
$m_1 = (v-b)-(b-y)$	blanketing at 4100 Å	⟶	[Fe/H]
$c_1 = (u-v)-(v-b)$	Balmer discontinuity	⟶	log(g)
$\beta = \beta_w - \beta_n$	H β line	⟶	E(B-V)

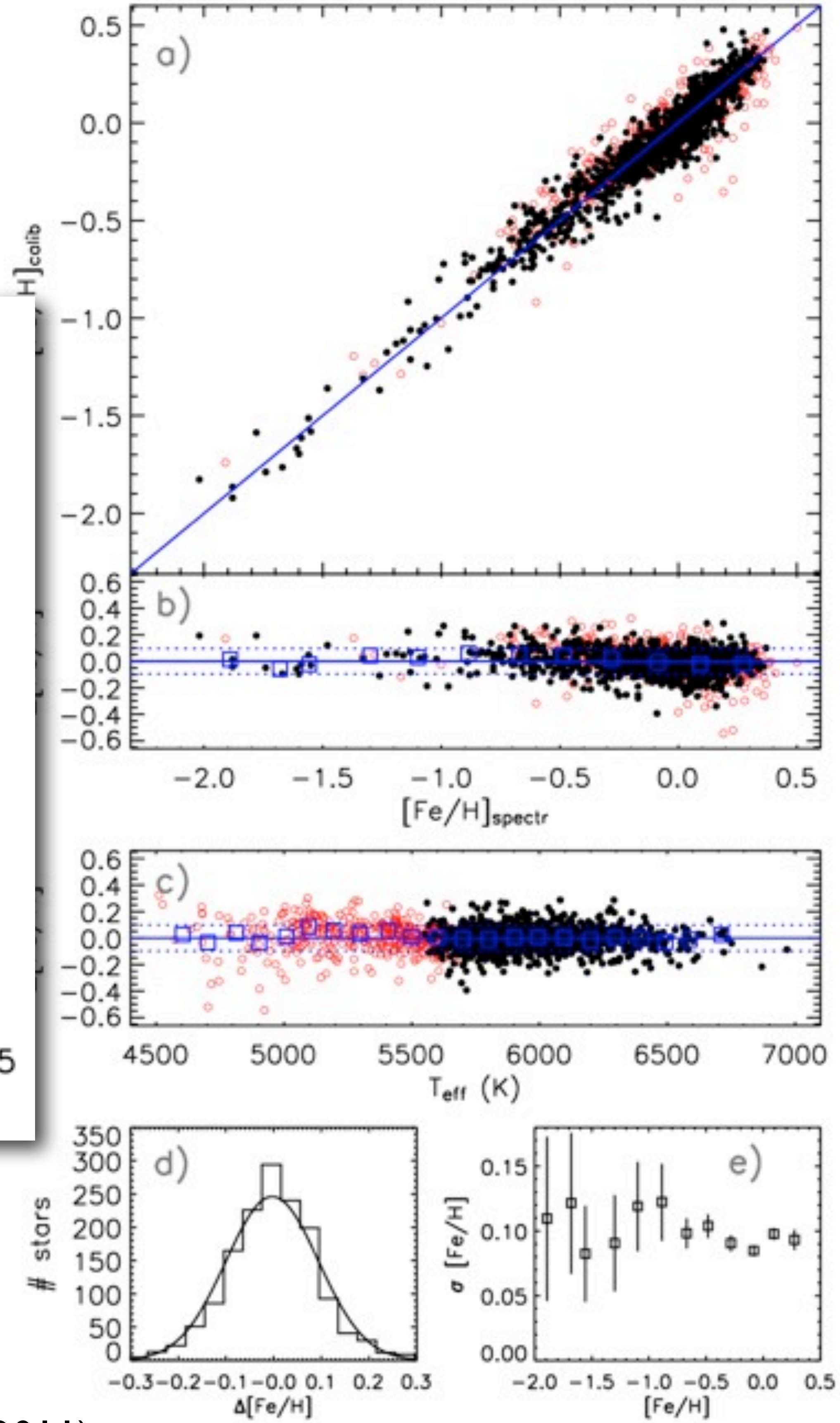
e.g. Bessell (2005)



Intrinsic colour-calibration to cope with reddening (e.g. Olsen 1984; Schuster & Nissen 1989; Karatas & Schuster 2010)

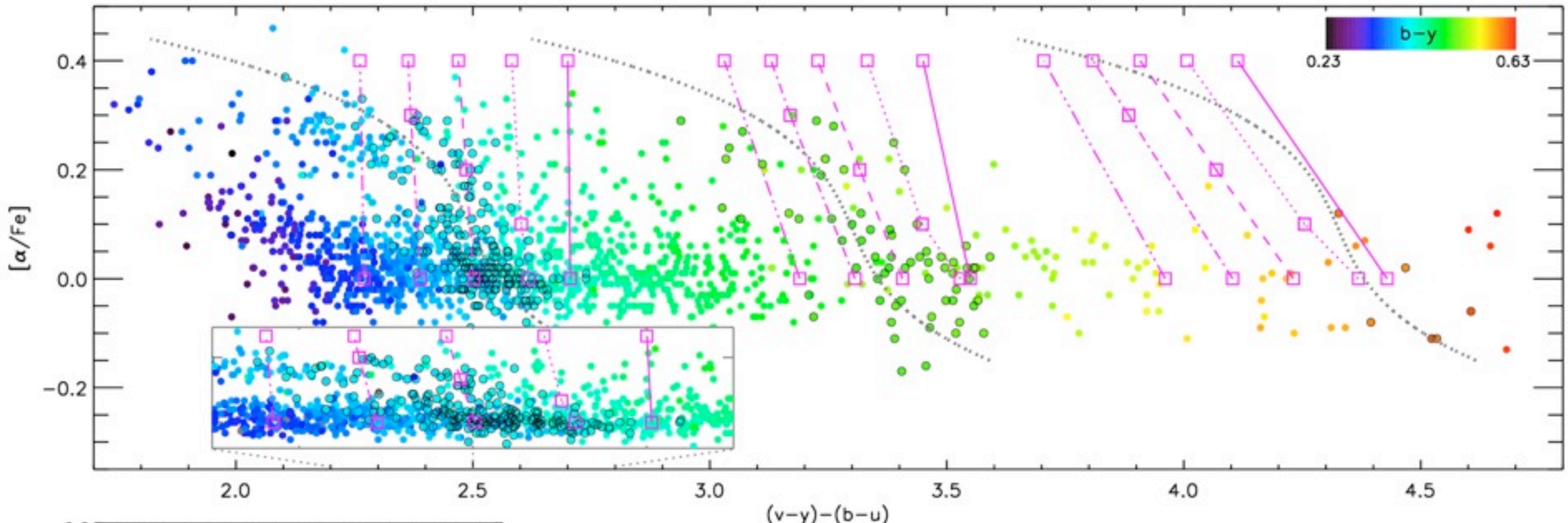
Strömgren [Fe/H]

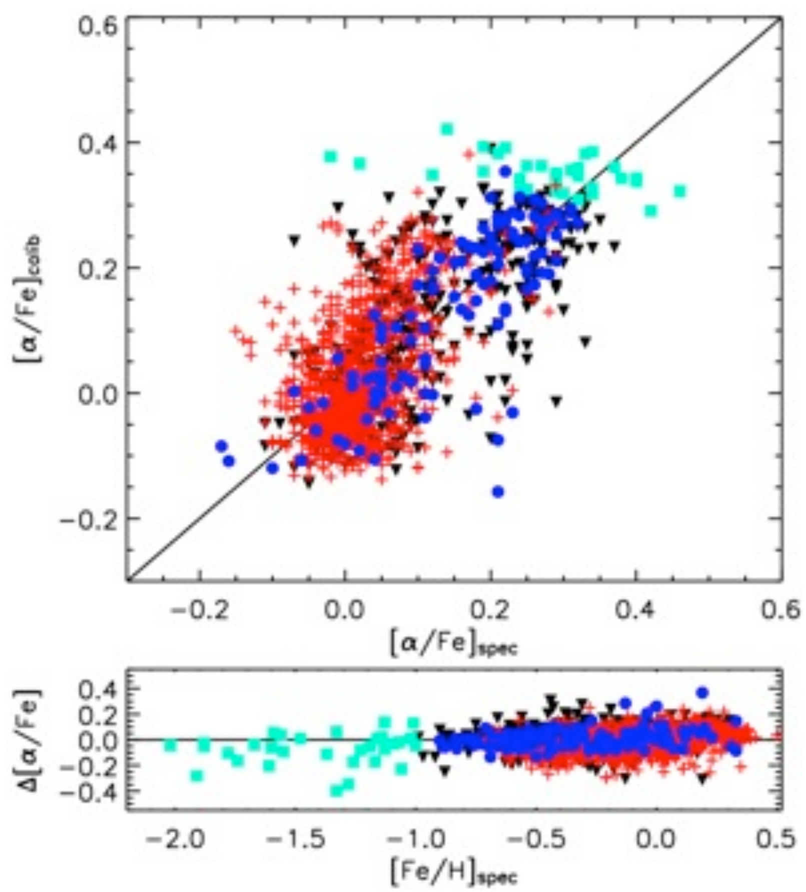


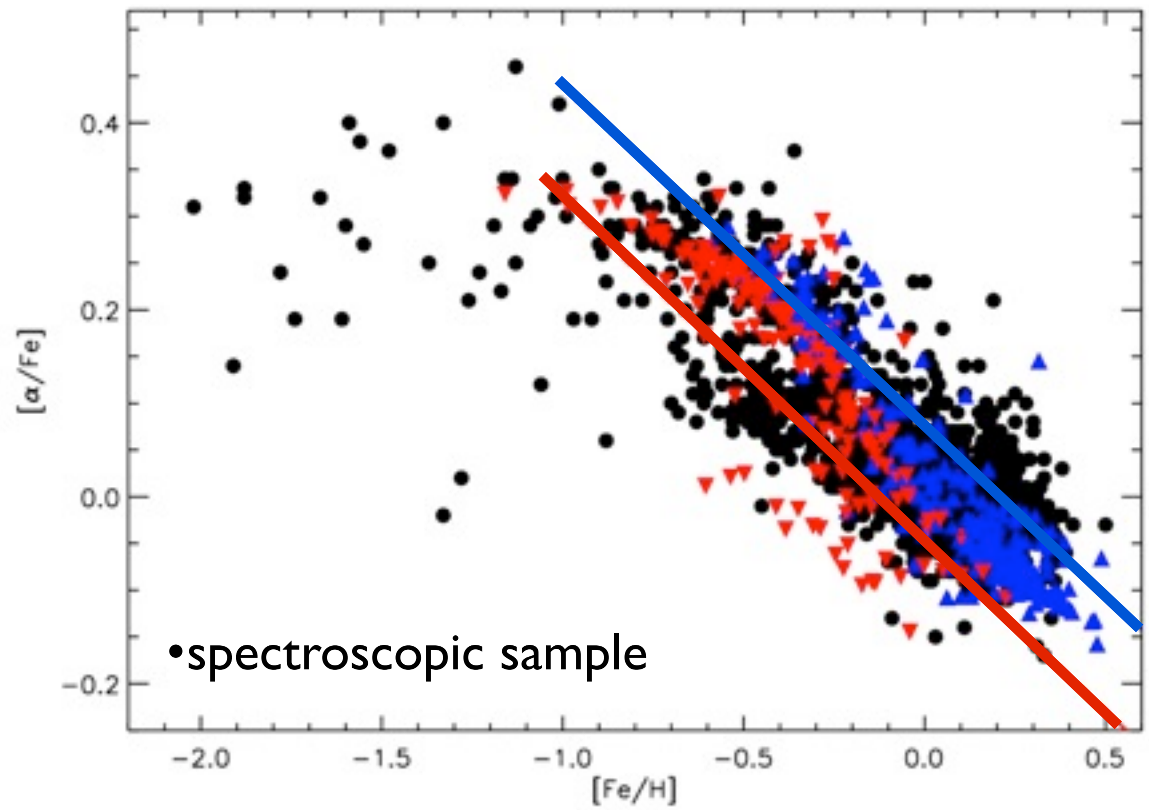


Casagrande et al. (2011)

[α/Fe] ?

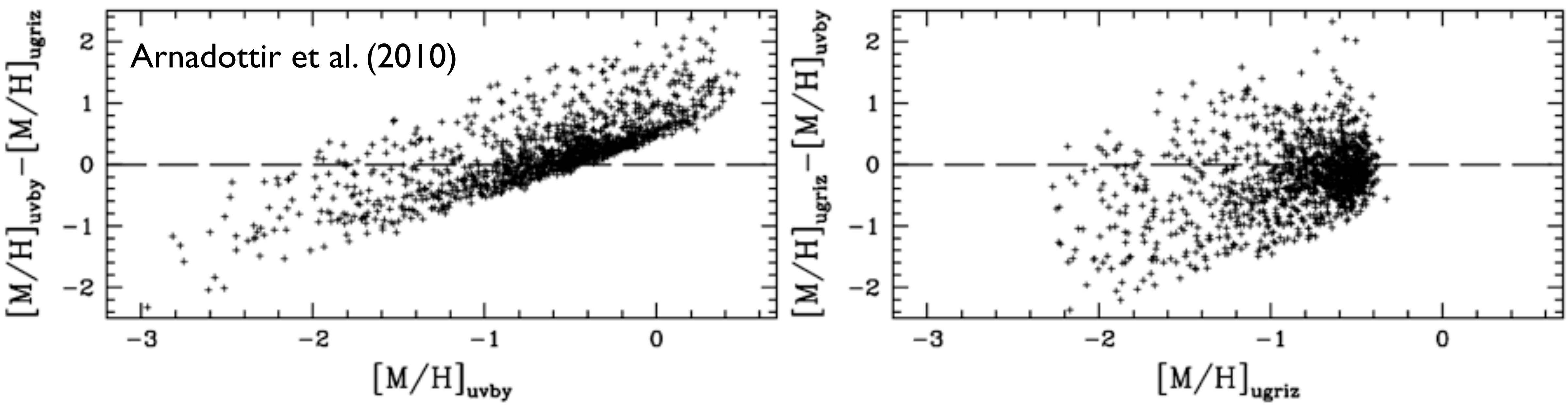

b−y
0.23
0.63
[α/Fe]
(v−y)−(b−u)


[α/Fe]calib
[α/Fe]spec
Δ[α/Fe]
[Fe/H]spec


•spectroscopic sample
[α/Fe]
[Fe/H]

Broad-band [Fe/H] ?

Historically, yes (UV excess δ(U-B), e.g. Sandage & Ellen 1959, Wallerstein 1962; Eggen et al. 1962)



- ugriz system originally devised for extragalactic purposes (i.e. as much flux as you can) → not optimal for metallicities
- good u band data are needed

See also Arnadottir et al. (2010) for a discussion of logg (g) sensitivity. Bottom line: rough log(g) estimates are possible

GREAT EXPECTATIONS

BY

CHARLES DICKENS.

Wednesday, November 9, 2011

Bridging Stellar and Galactic astronomy

Broad-band photometry:

✓T_{eff}

✓F_{Bol}

✓θ

Metallicity distribution function

Intermediate-band photometry

✓[Fe/H]

✓E(B-V)

✓~log(g)

Age-metallicity relation

Asteroseismology

✓M

✓R

✓L

✓ages (differential)

✓distances

Metallicity gradients

Metallicity gradient(time)

Radial velocities from APOGEE

ORBITS

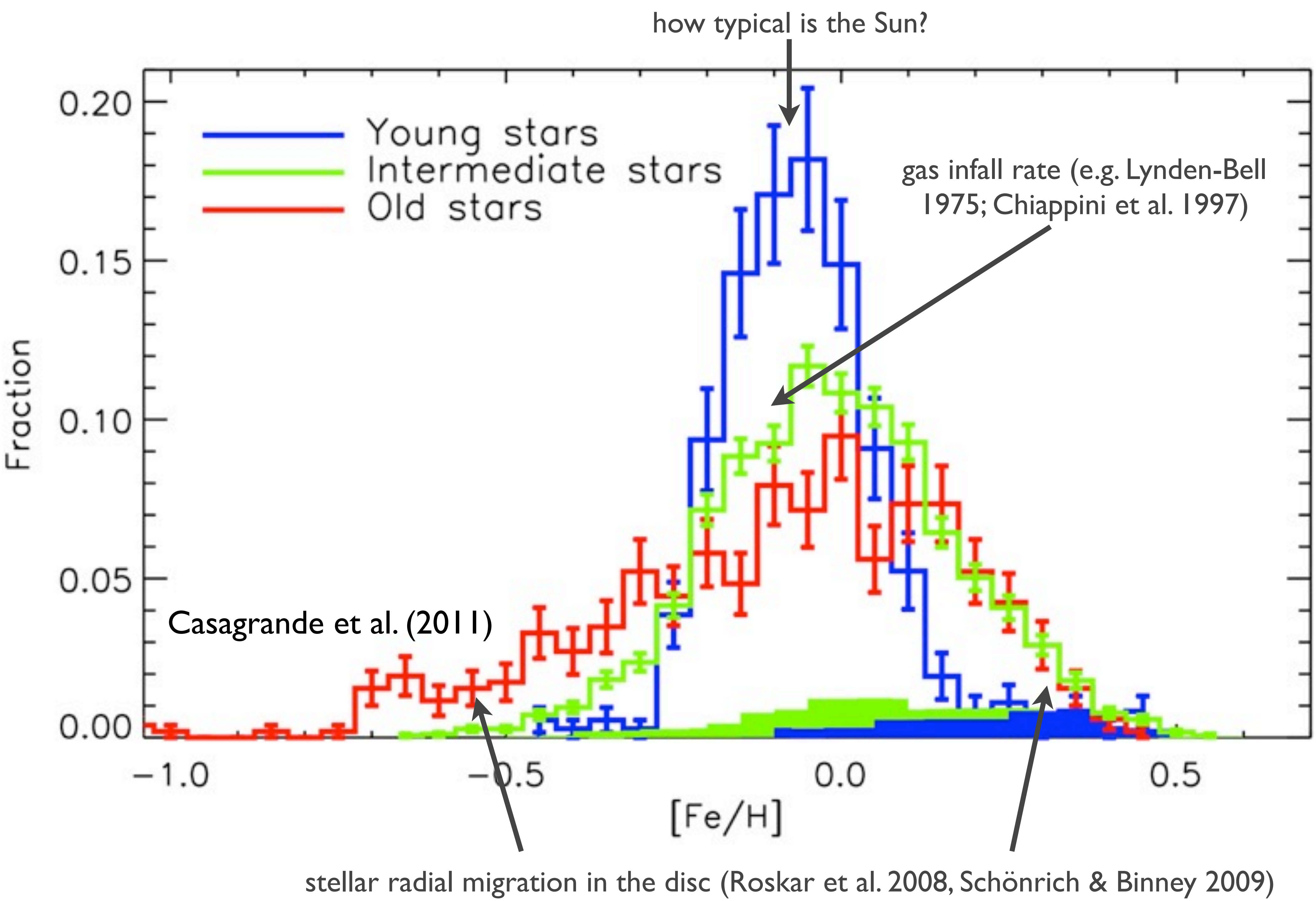
Bridging Stellar and Galactic astronomy

Nördstrom et al. (2004), Holmberg et al. (2007,2009), Casagrande et al. (2011)

- √ Kinematic (U,V,W)
- √ Hipparcos (distances)
- √ Broad-band photometry: T_{eff}, F_{Bol}
- √ Strömgren colours: [Fe/H], E(B-V)

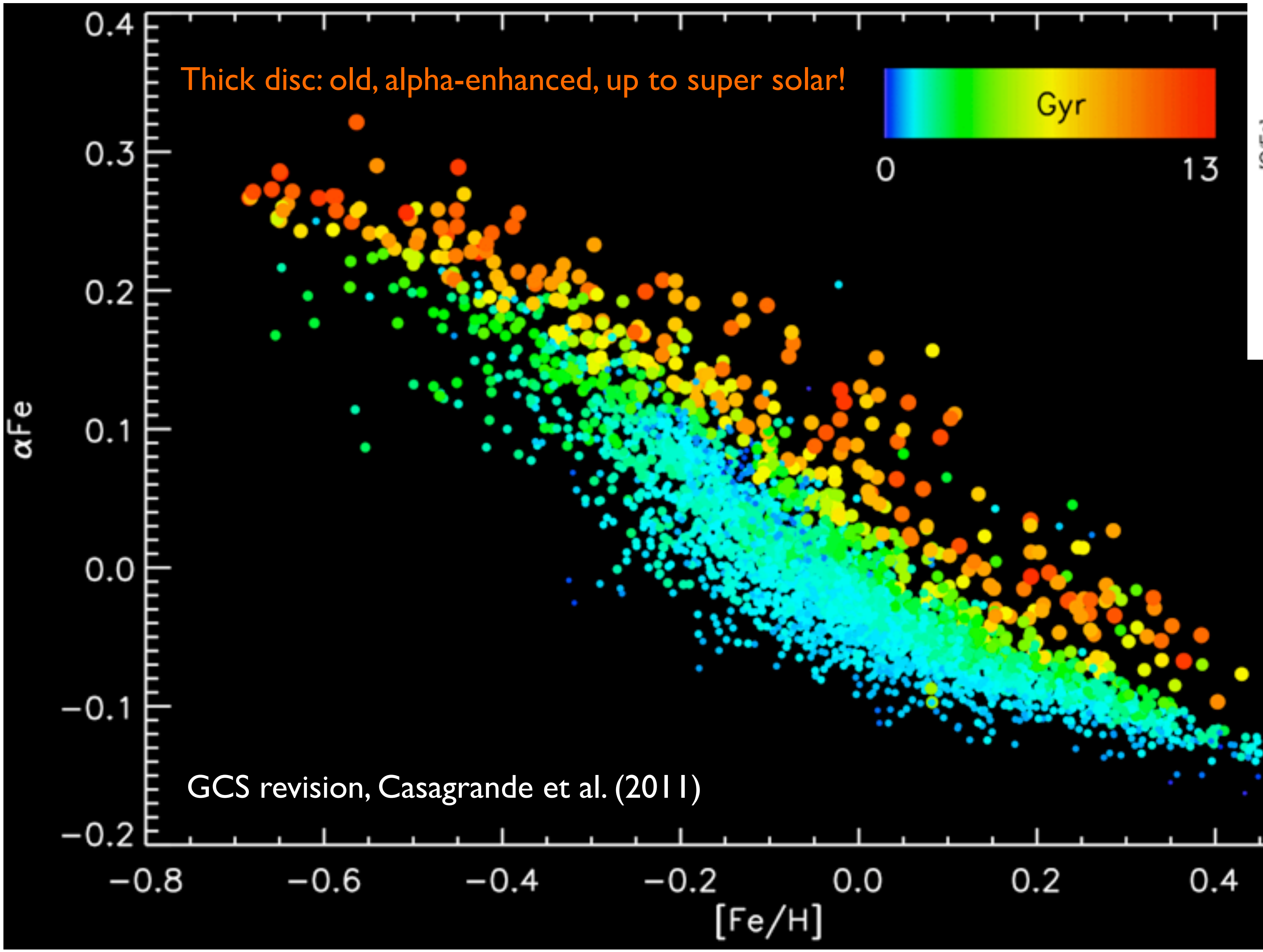
Age-Metallicity Distribution Function (Solar Neighbourhood)

from isochrones

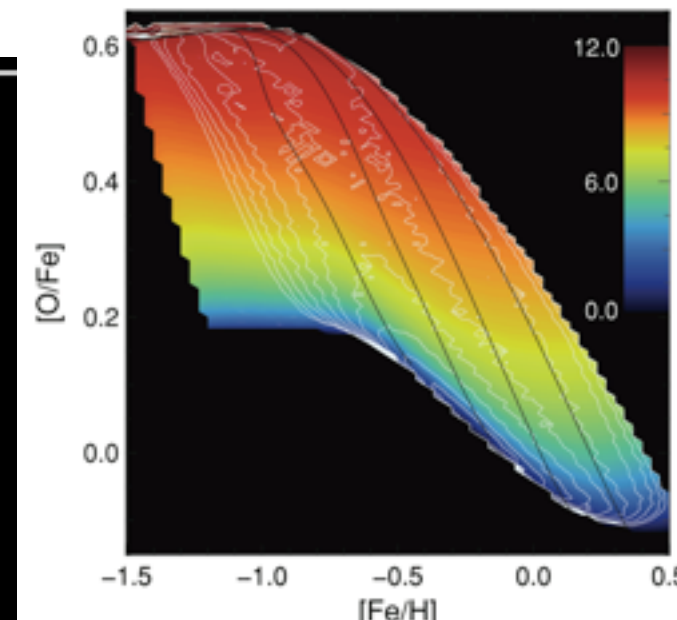


age-[Fe/H]-αFe

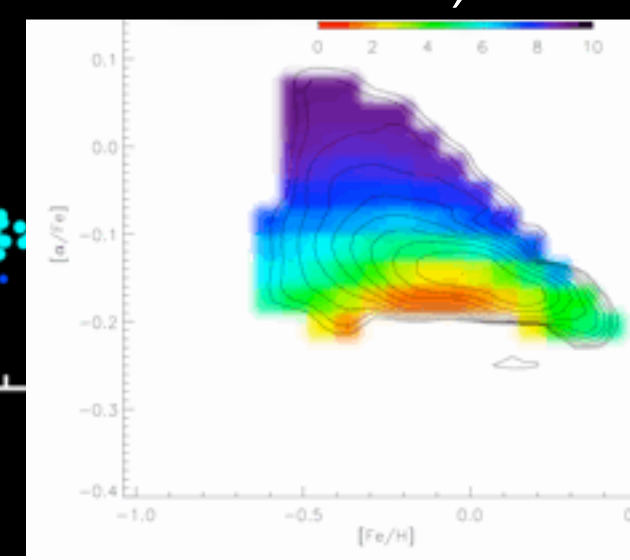
from isochrones



Schönrich & Binney (2009)

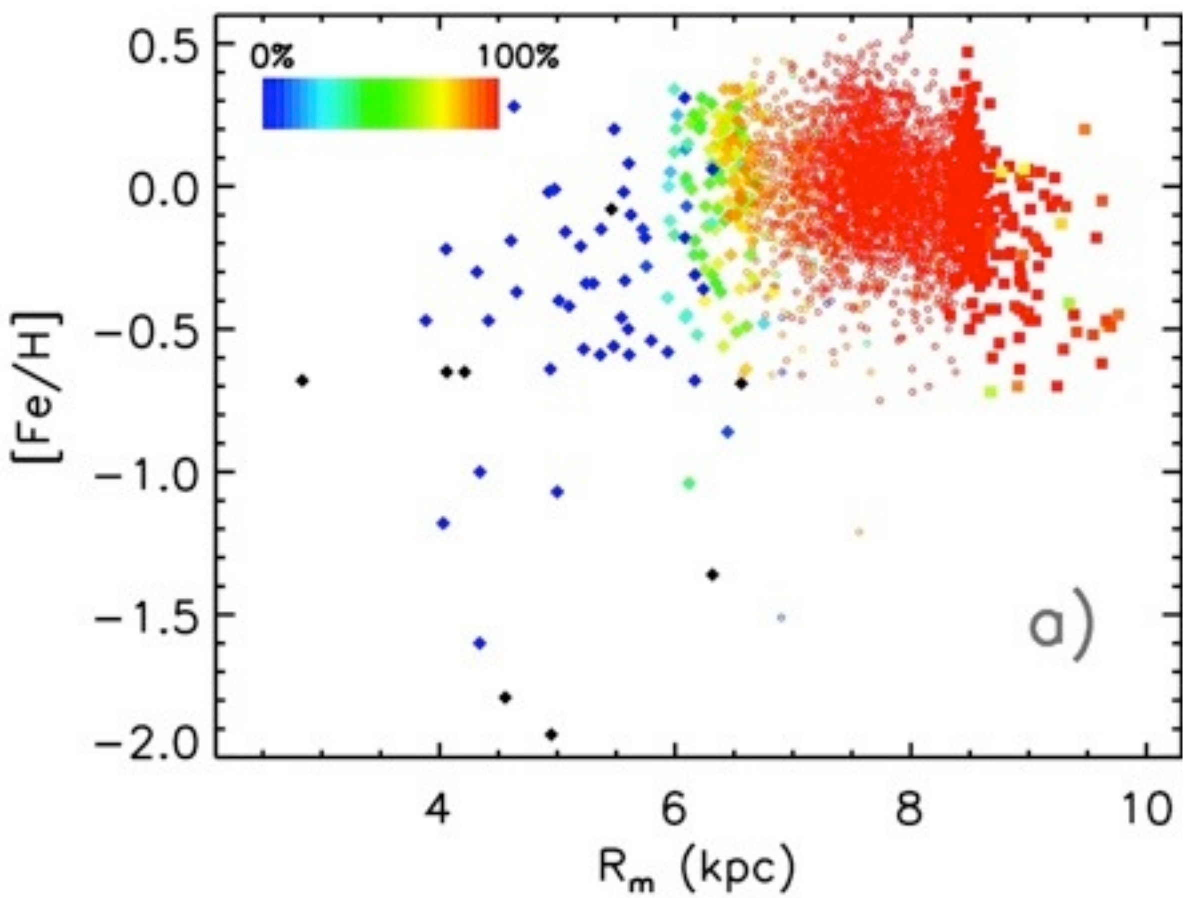


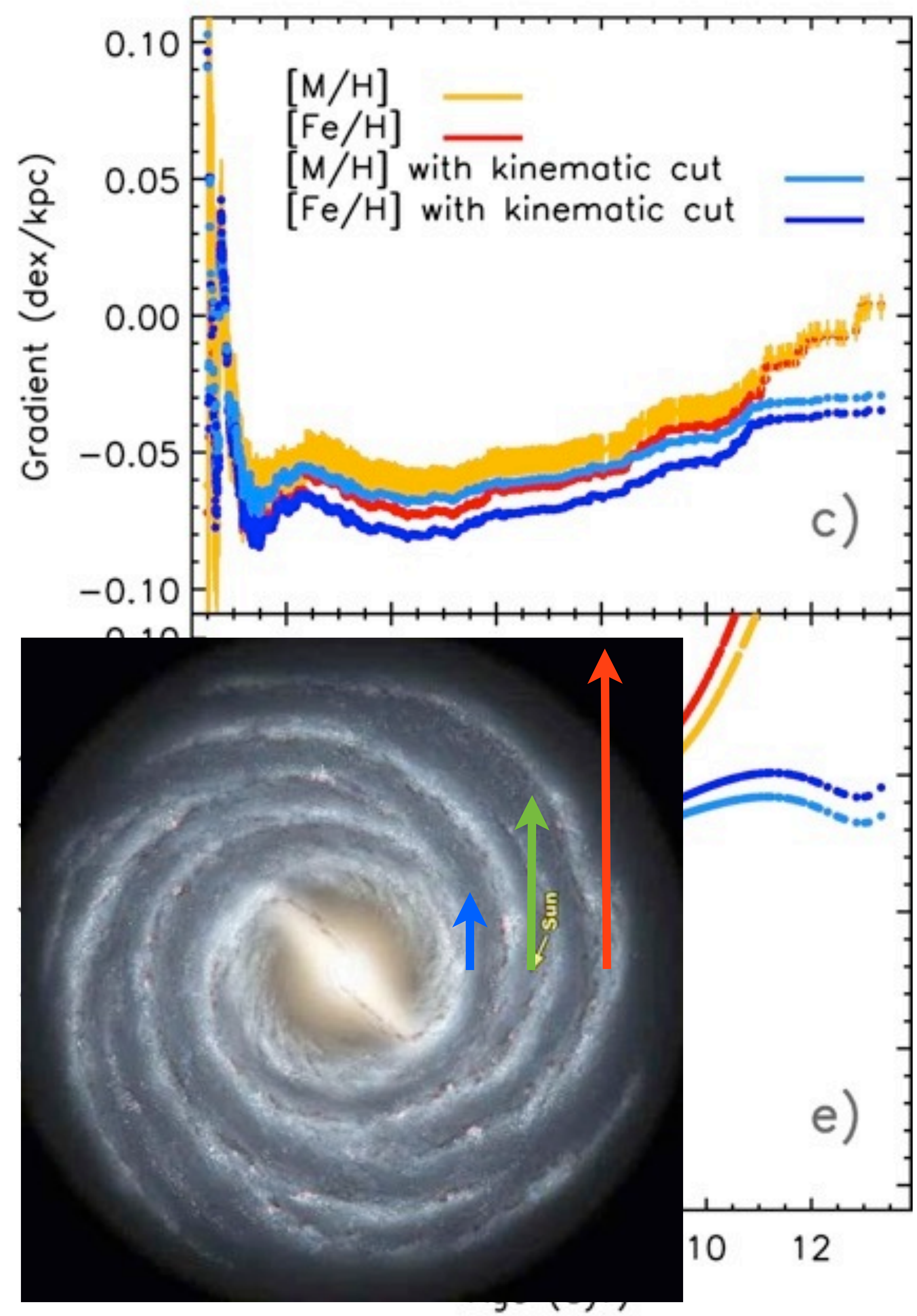
Constraining thin/thick disc formation mechanism (e.g. migration, merging, accretion ?)

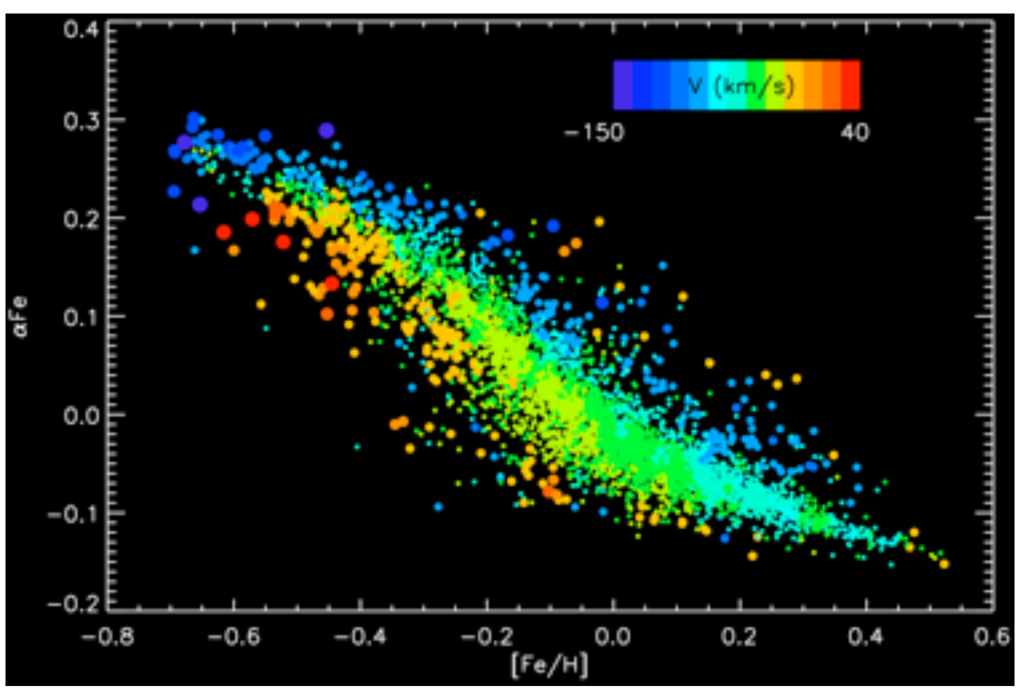


Loebman et al. (2010)

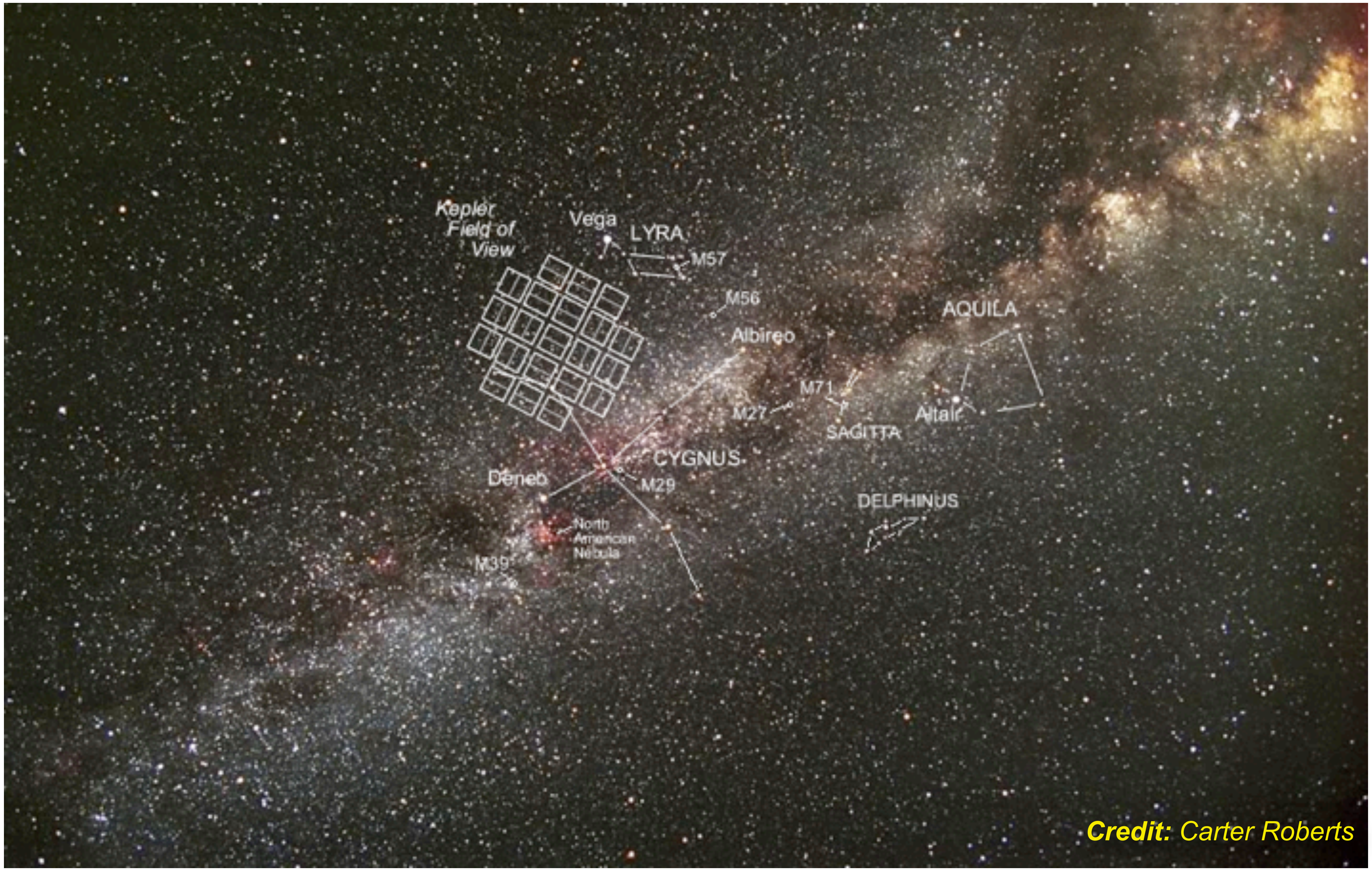
Gradient(s)


0%
100%
a)
[Fe/H]
R_m (kpc)
0.5
0.0
−0.5
−1.0
−1.5
−2.0
4
6
8
10


[M/H]
[Fe/H]
[M/H] with kinematic cut
[Fe/H] with kinematic cut
Gradient (dex/kpc)
c)
e)
0.10
0.05
0.00
−0.05
−0.10
10
12
Sun

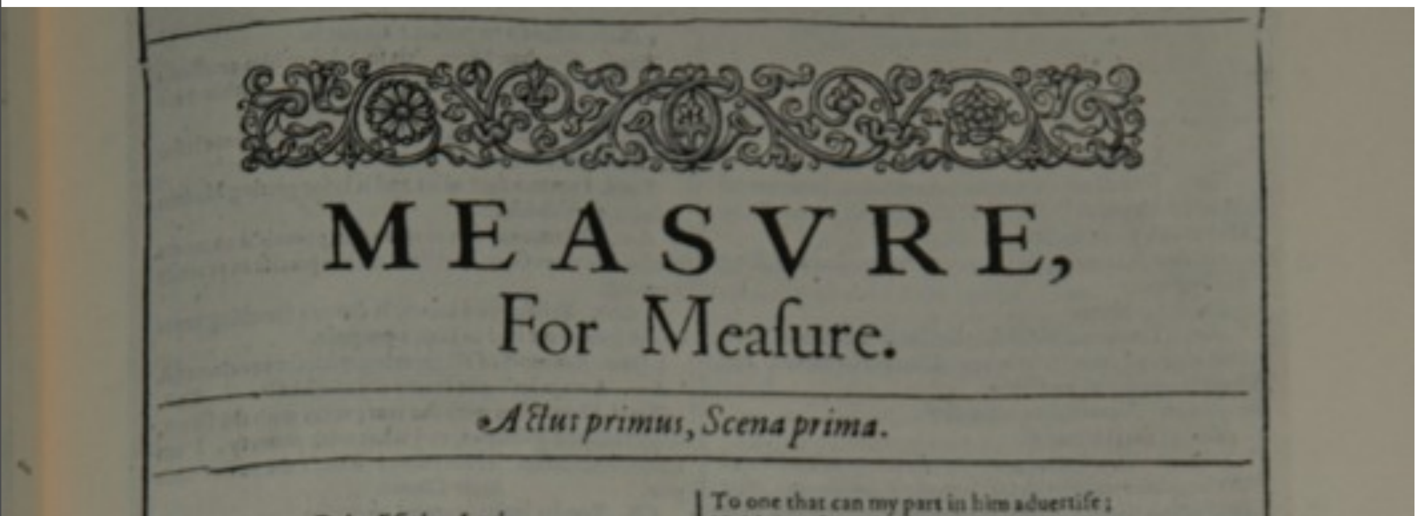

V (km/s)
−150
40
αFe
[Fe/H]

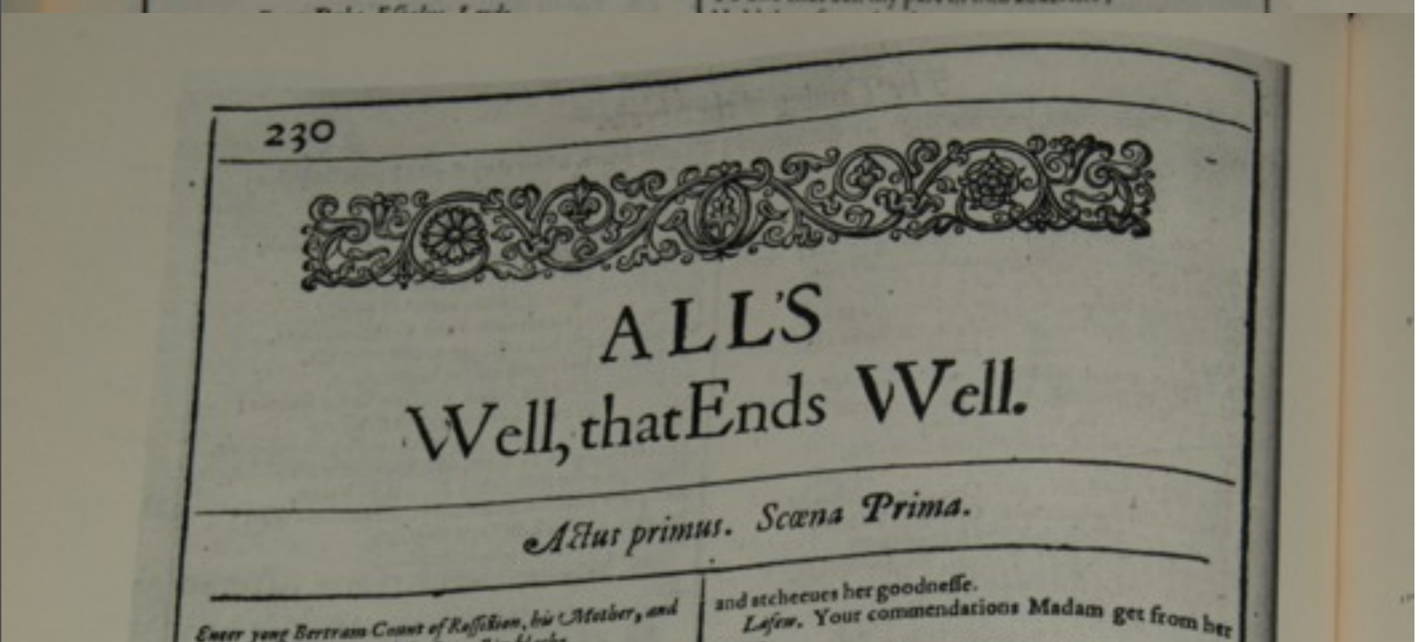
Bridging Stellar and Galactic astronomy

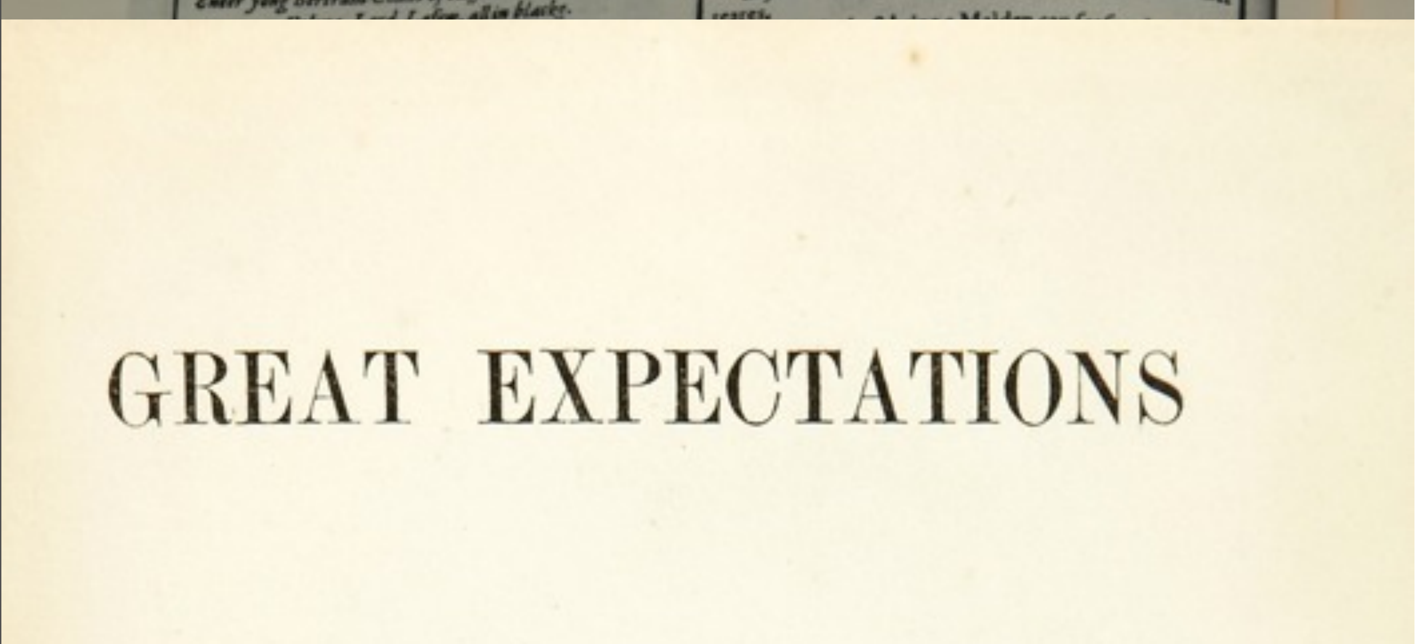


Same (or better!) constraints from fields in the Galaxy other than the Solar Neighbourhood!

Epilogue







Photometry

- a wealth of information
- reliable stellar parameters (IRFM: T_{eff}, F_{Bol}, θ)
- T_{eff} in KIC are too cool
- complementary to asteroseismic parameters (distances)

(www.mpa-garching.mpg.de/~luca)

Reddening and other stories

- intermediate band photometry: reddening, metallicity (surface gravities)

From stars to the Galaxy

- from fundamental properties of stars to fundamental properties of the Galaxy (gradients, age-metallicity, age-chemistry-kinematic interplay, etc ..)