Spectroscopy of Blue Supergiants in the Disks of Spiral Galaxies: Metallicities and Distances

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ΛCDM-universe → metallicity of galaxies depends on their mass

metal-rich

M81

metal-medium

NGC 300

metal-poor

WLM

Lequeux et al., 1979, A&A 80, 155

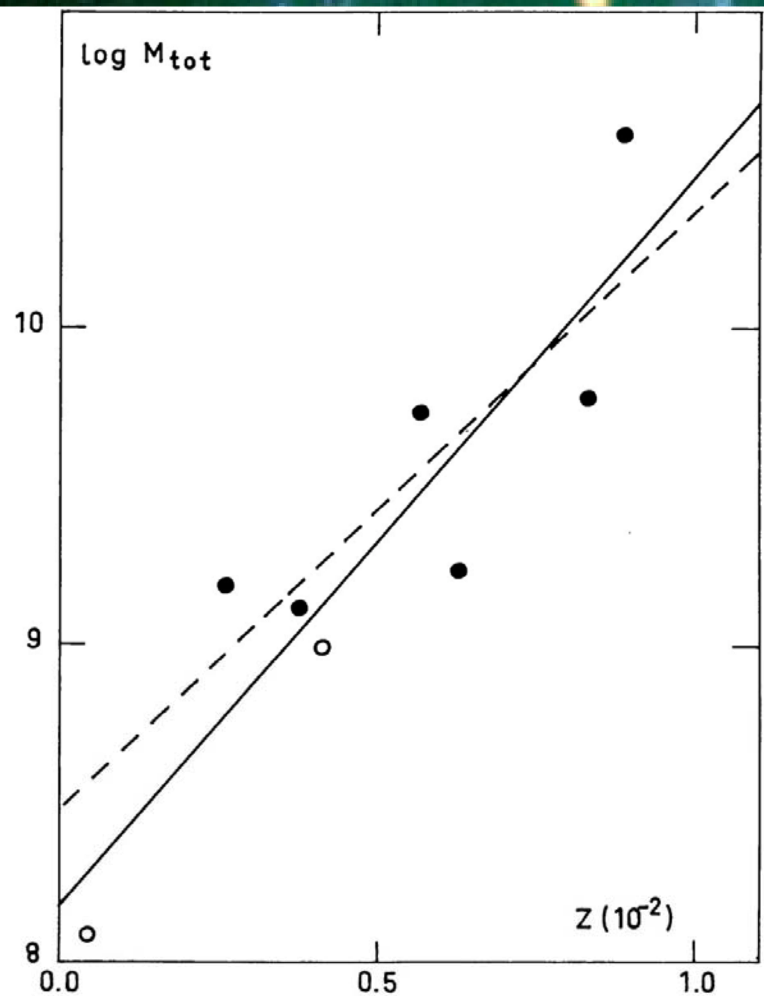
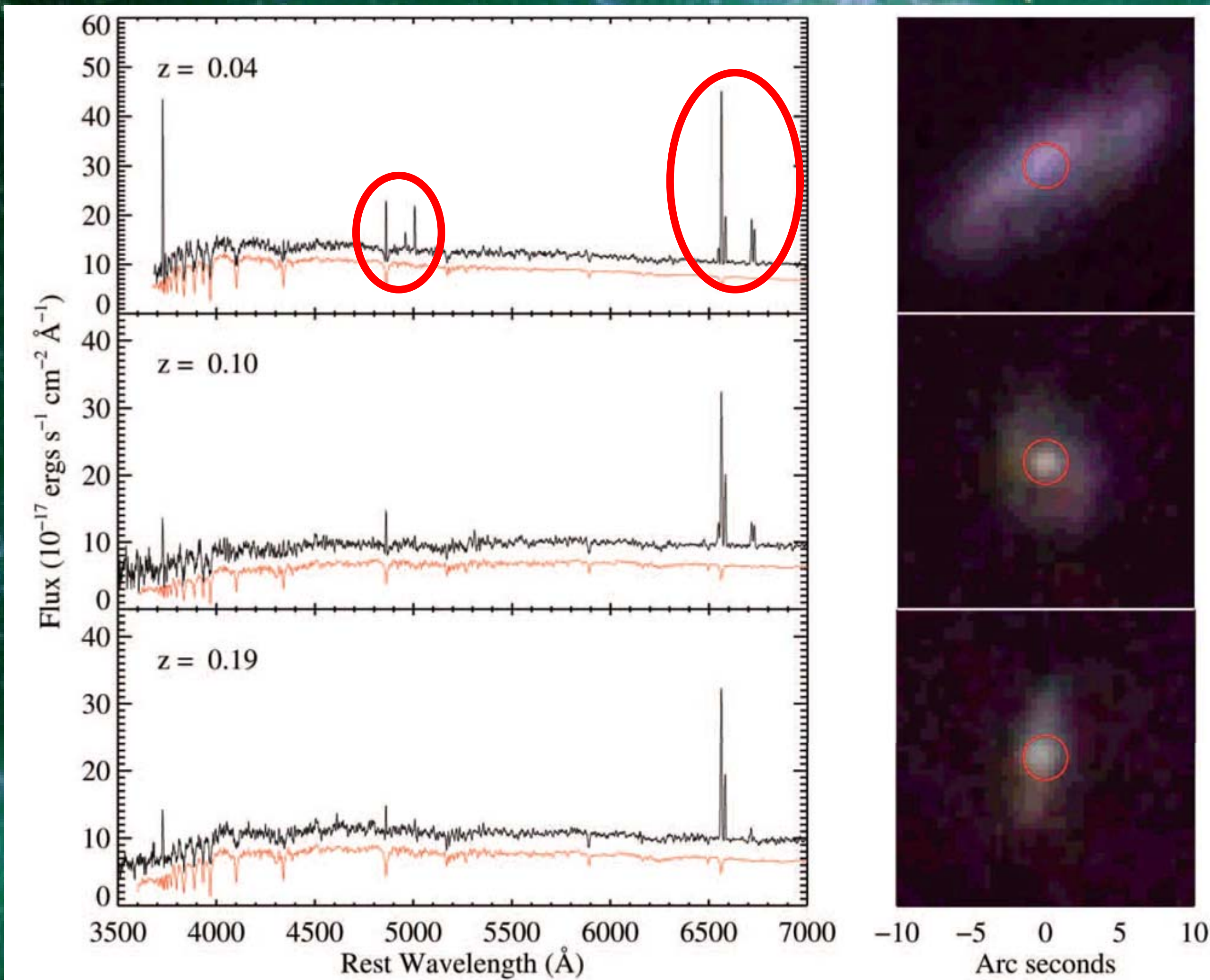


Fig. 4. Observed heavy element abundance, Z, versus total mass for the compact and irregular galaxies under consideration. Filled circles are objects with known mass; open circles are lower limits to the total mass for I Zw 18 and II Zw 40 (for which we adopted 9.9 10^8 $M_\odot$). *Solid line*, least-squares fit for all galaxies ($\log M_{tot} = 8.18 + 229\,Z$). *Dashed line*, least-squares fit for galaxies of known mass ($\log M_{tot} = 8.48 + 187\,Z$)

the pioneering paper

data from HII regions using strong line methods

Tremonti et al., 2004, ApJ 613, 898

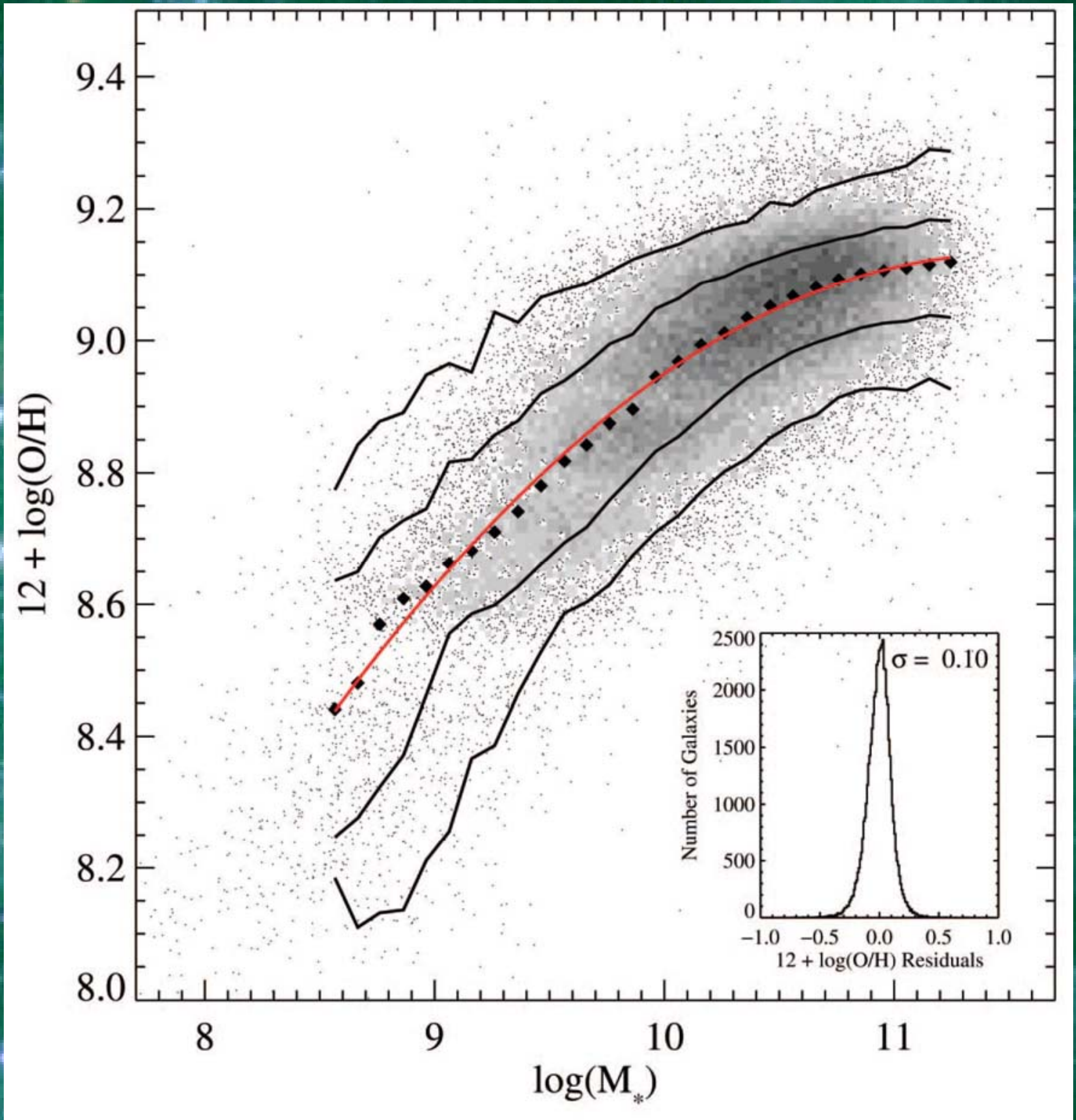


strong nebular emission lines: hydrogen, oxygen, nitrogen

50,000 starforming galaxies with Sloan spectra

mass-metallicity relationship

Rosetta stone
to understand
galaxy formation
and
chemical evolution!



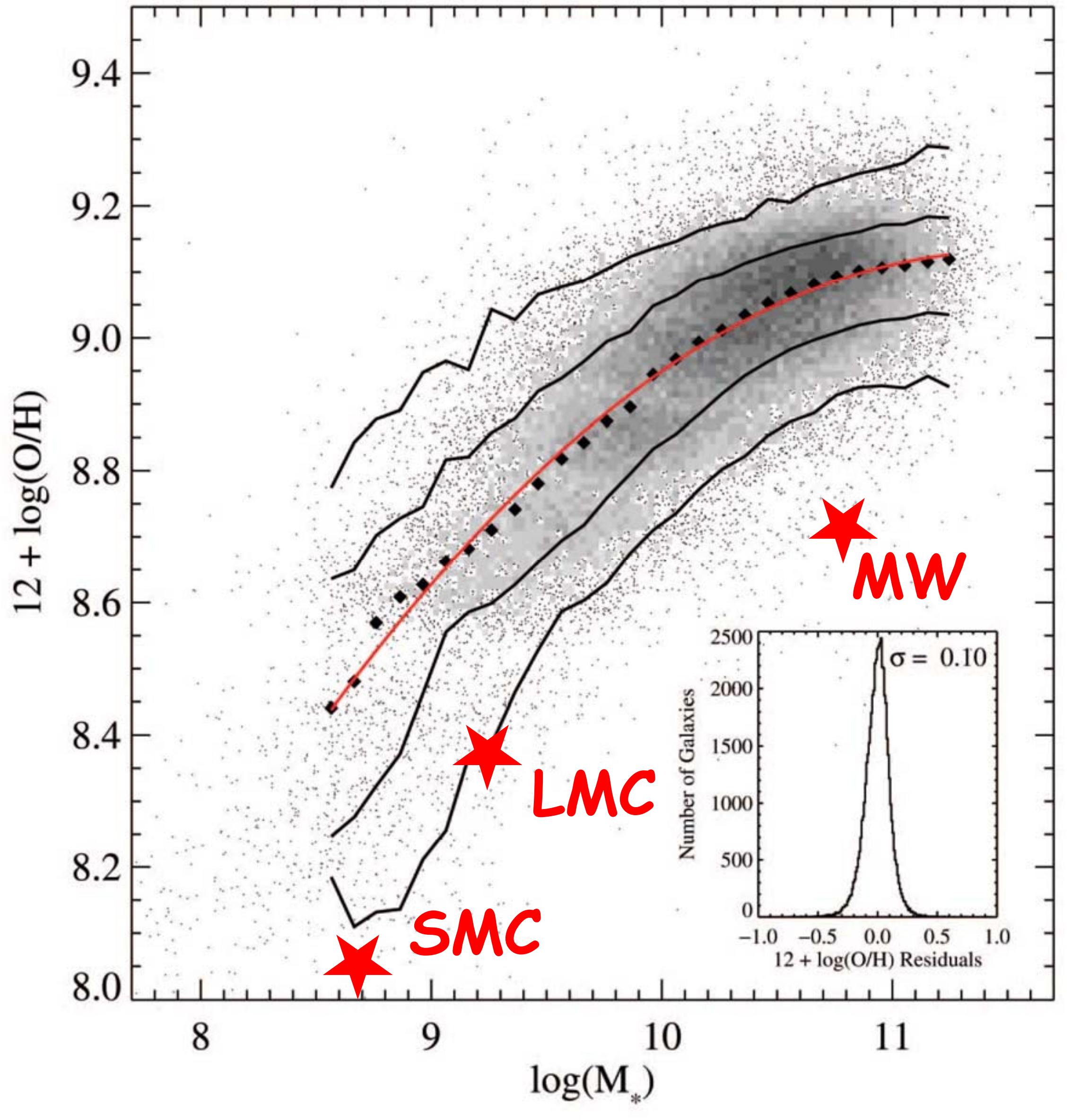
Tremonti et al., 2004, ApJ 613, 898

mass-metallicity relationship

However…

Something must be wrong….

It's based on very simplified emission line analysis….



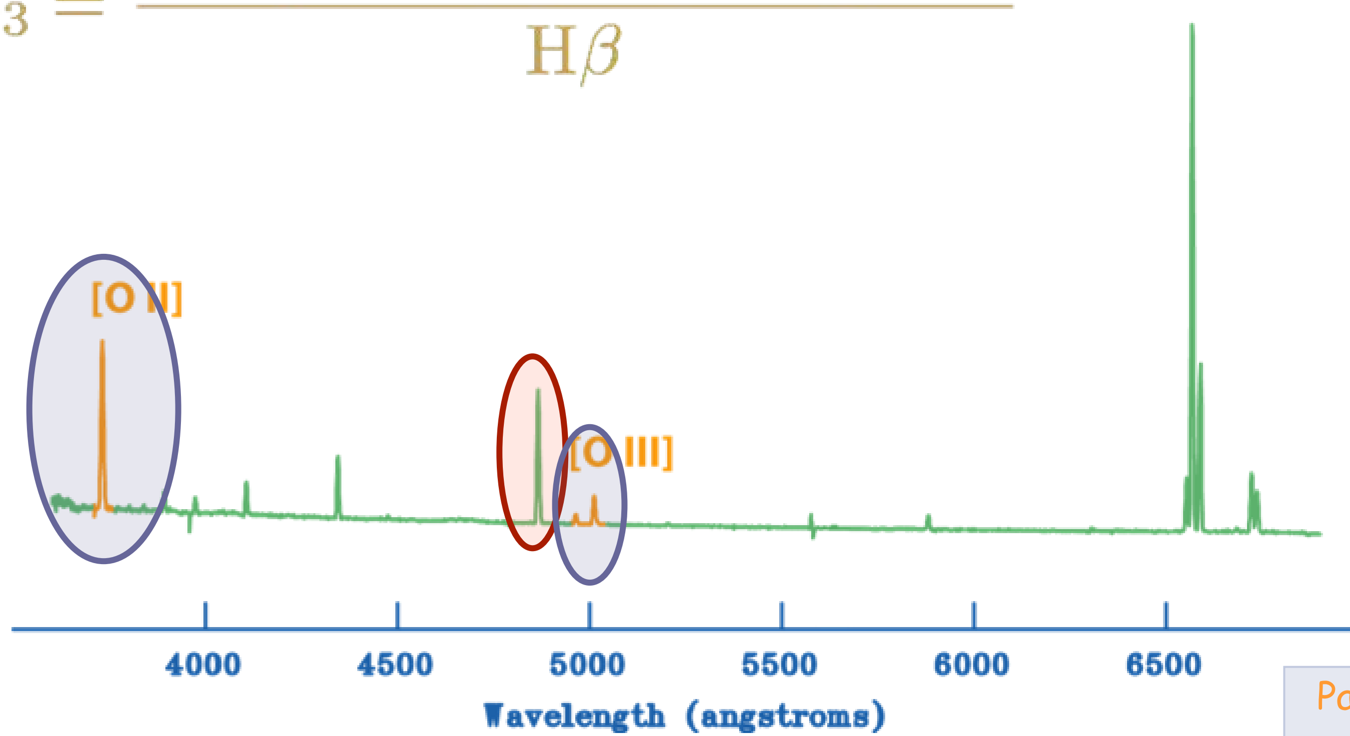
Tremonti et al., 2004, ApJ 613, 898

strong line method: R_{23} = f[N(O)/N(H)]

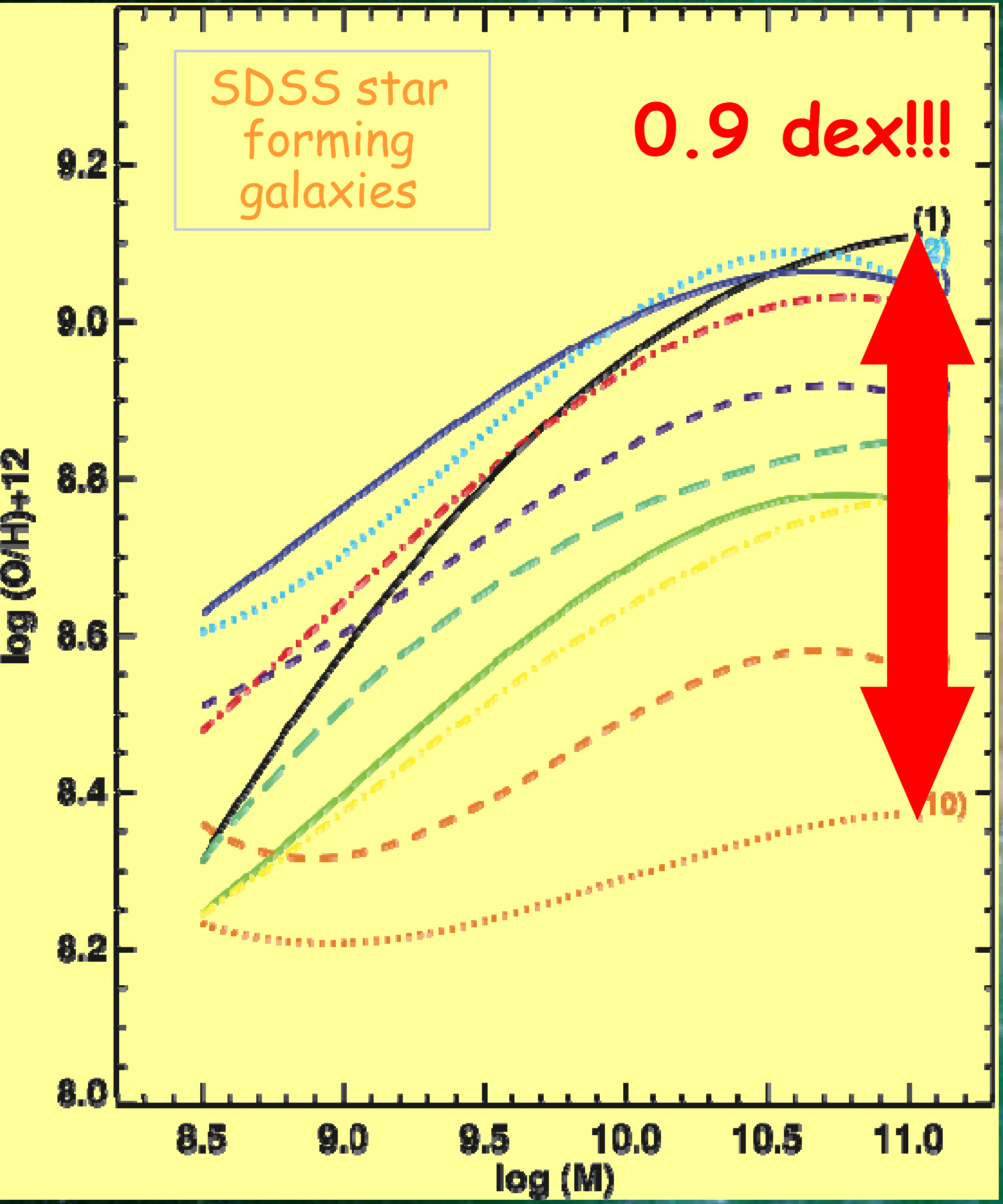
simple empirical calibration
but...

R_{23} depends on
- $T_{electron}$
- $n_{electron}$
- nature of ionizing stars
- gas imhomog.
- filling factors
- depletion into dust.....

$$R_{23} = \frac{[\mathrm{O\,II}]3727 + [\mathrm{OIII}]4959, 5007}{\mathrm{H}\beta}$$



Pagel, Edmunds, Blackwell et al. 1979



Kewley & Ellison 2008

mass – metallicity relationship

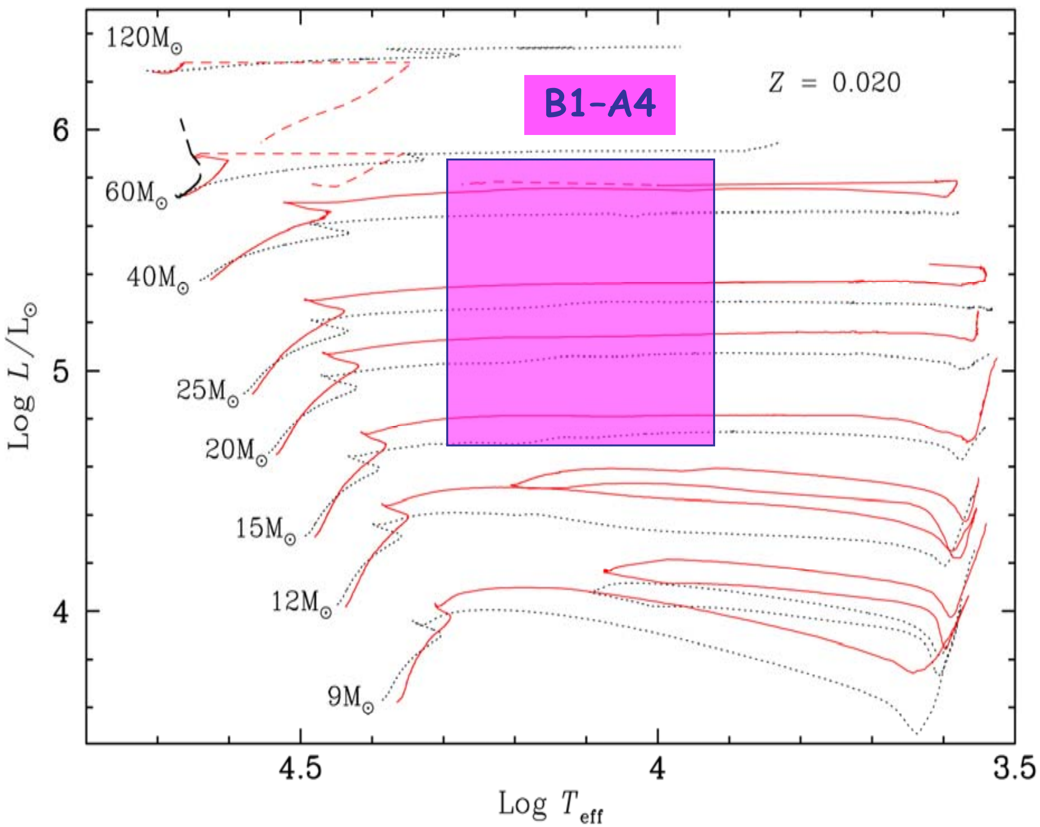
depends crucially on strong line method calibration

supergiant stars will come to rescue !!!!

supergiants - objects in transition

Brightest normal stars at visual light: $10^5..10^6\ L_{sun}$

$-7 \geq M_V \geq -10$ mag

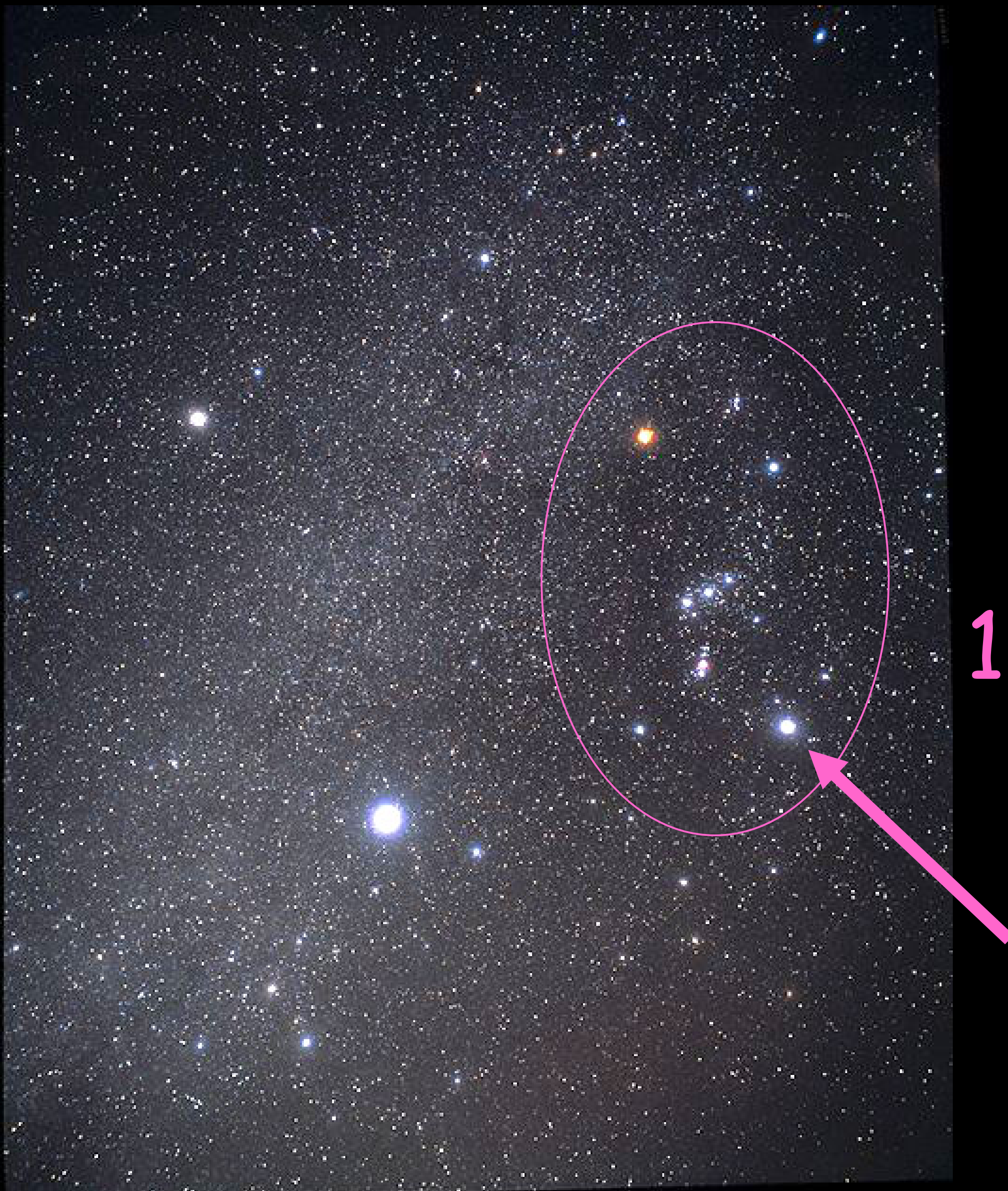


$t_{ev} \sim 10^3$ yrs

L, M ~ const.

ideal to determine

- chemical compos.
- abundance grad.
- SF history
- extinction
- extinction laws
- distances of galaxies



nearby supergiants

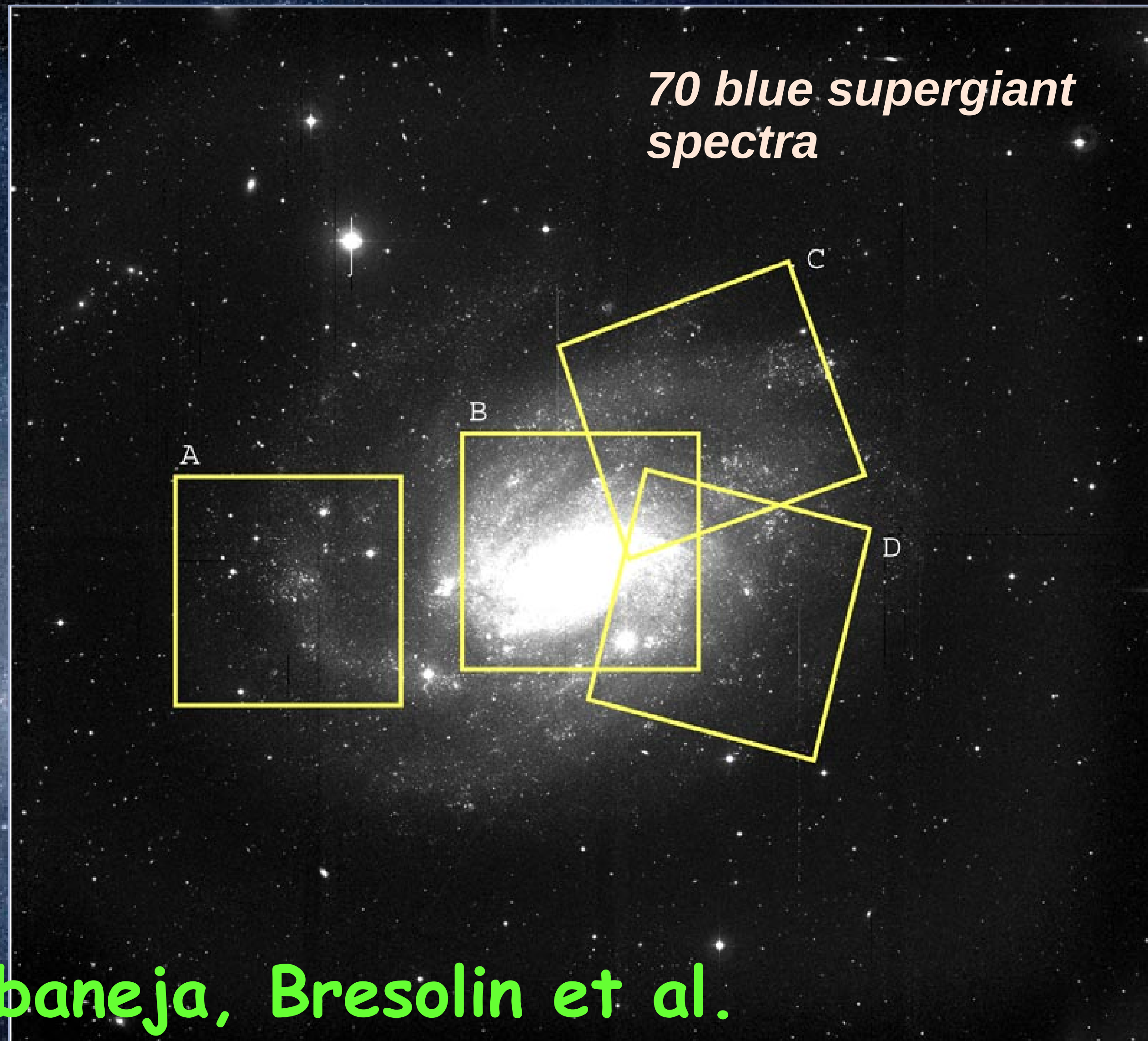
in Orion

1000 Lyrs away

Rigel

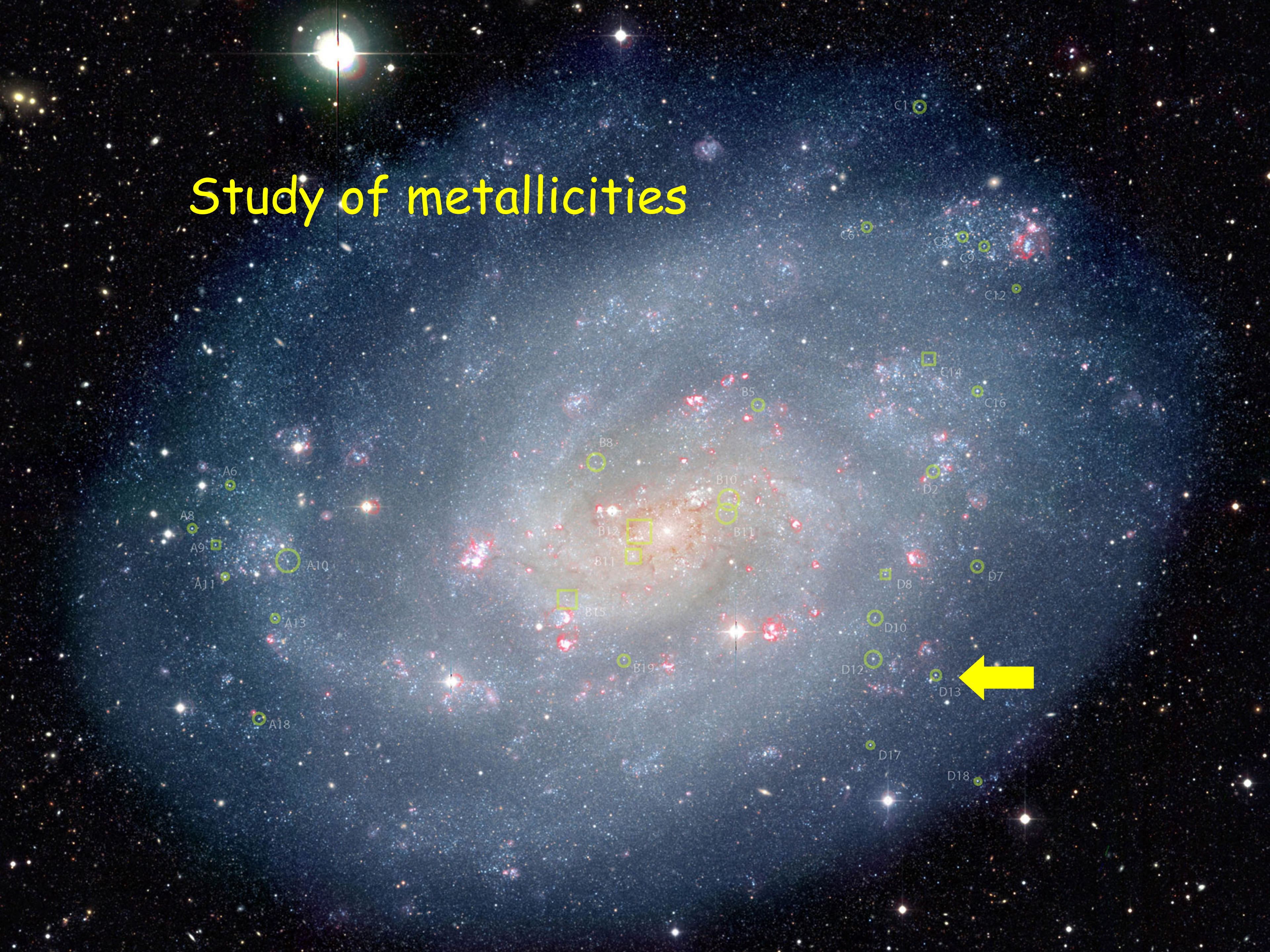

Heidelberg, Goettingen & Munich
astronomers on the way to Paranal
FORS 1

pilot study

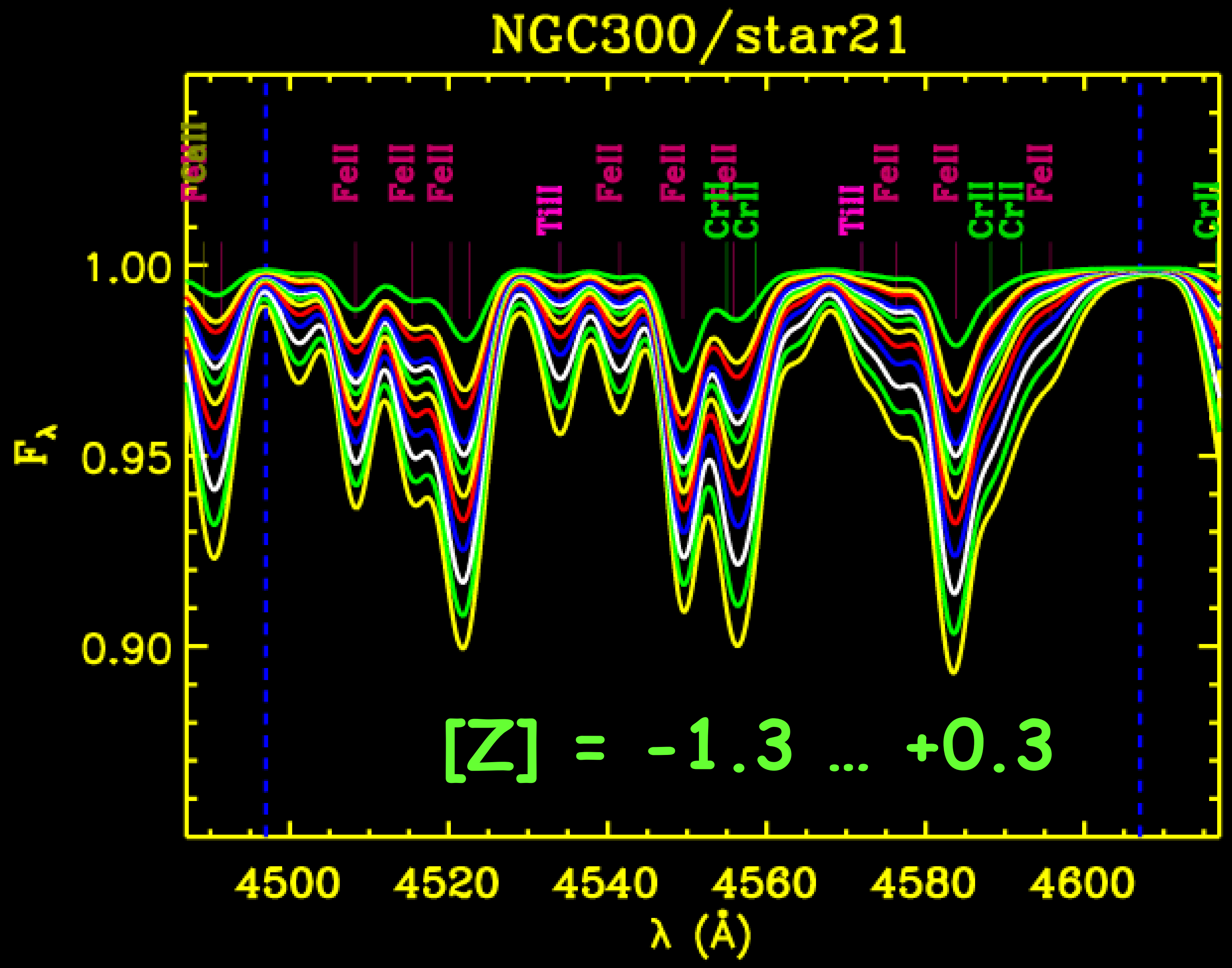


Kudritzki, Urbaneja, Bresolin et al. 2008, ApJ 681, 269

Study of metallicities



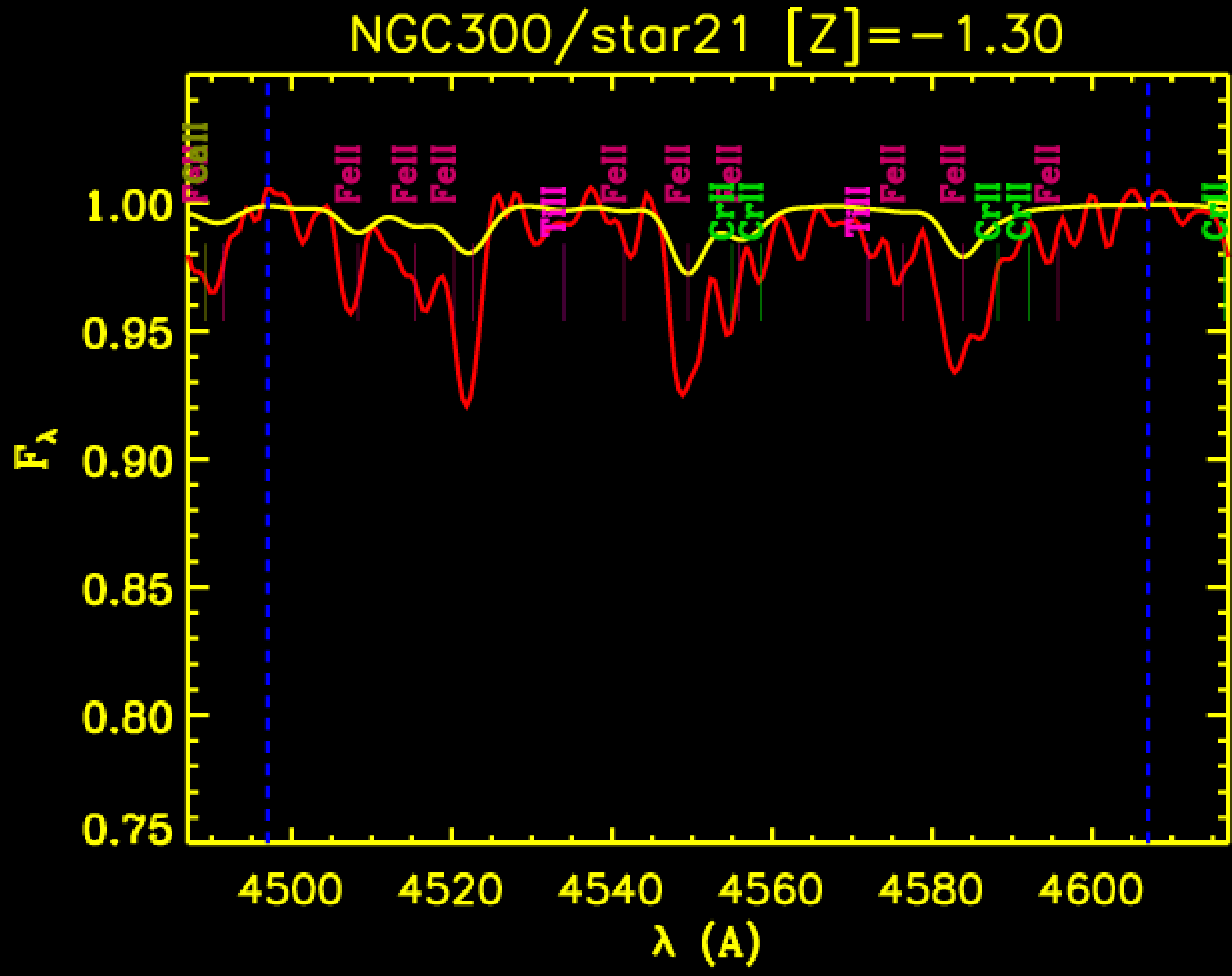
ESO50



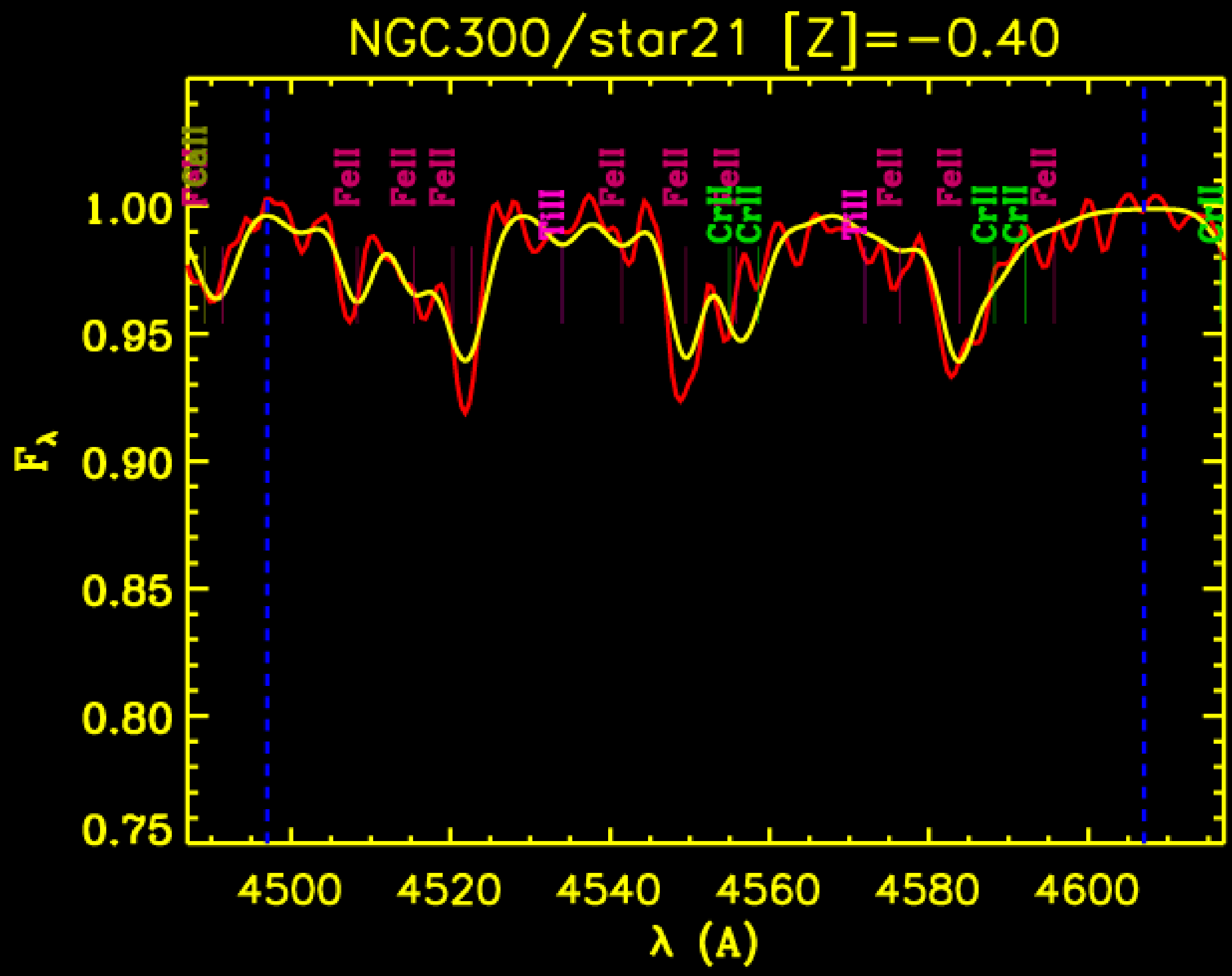
NGC300/star21
FeII
TiII
CrII
1.00
0.95
0.90
F_λ
4500
4520
4540
4560
4580
4600
λ (Å)
[Z] = -1.3 ... +0.3

ESO50

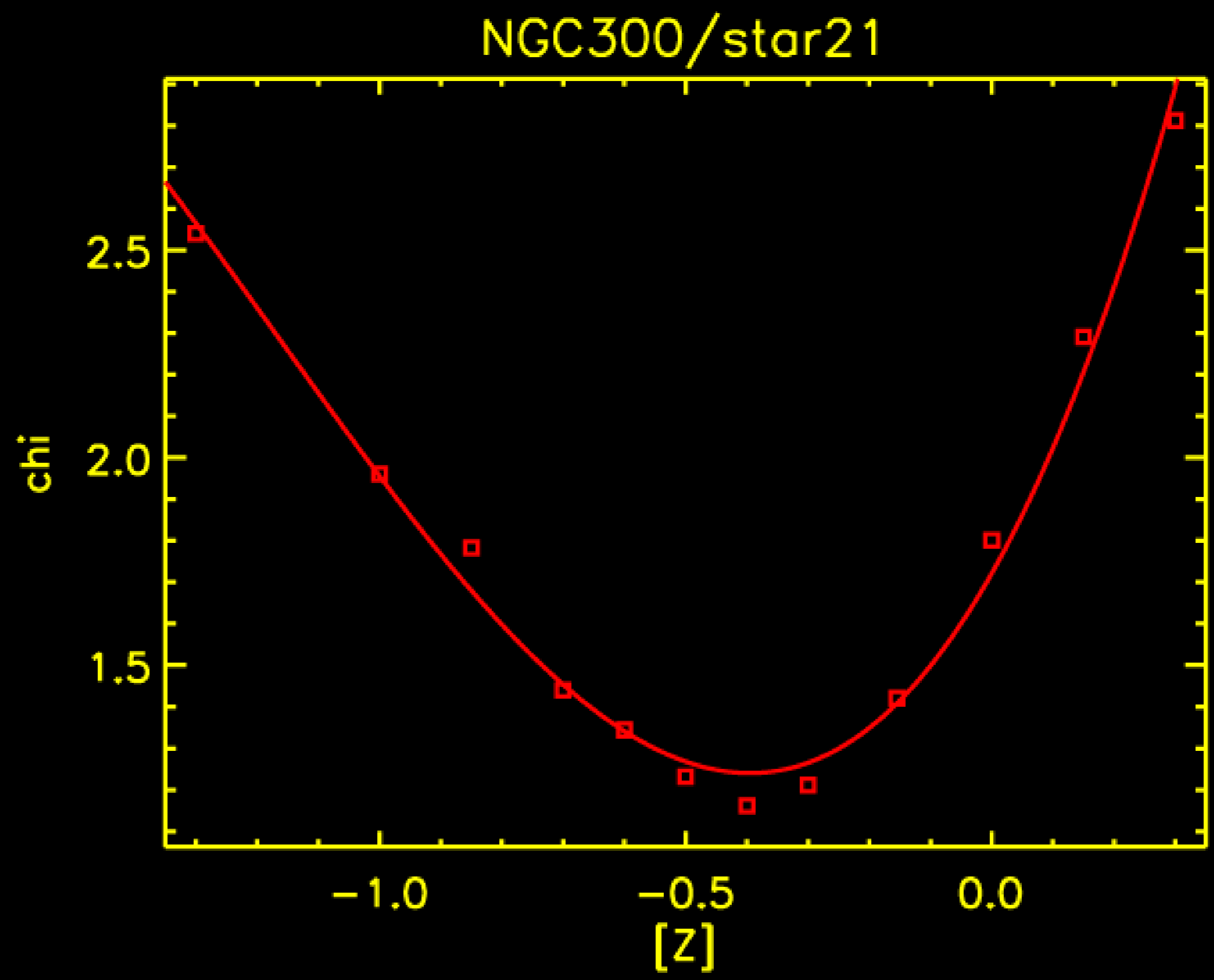
Spectral window 4497-4607Å



Spectral window 4497-4607Å

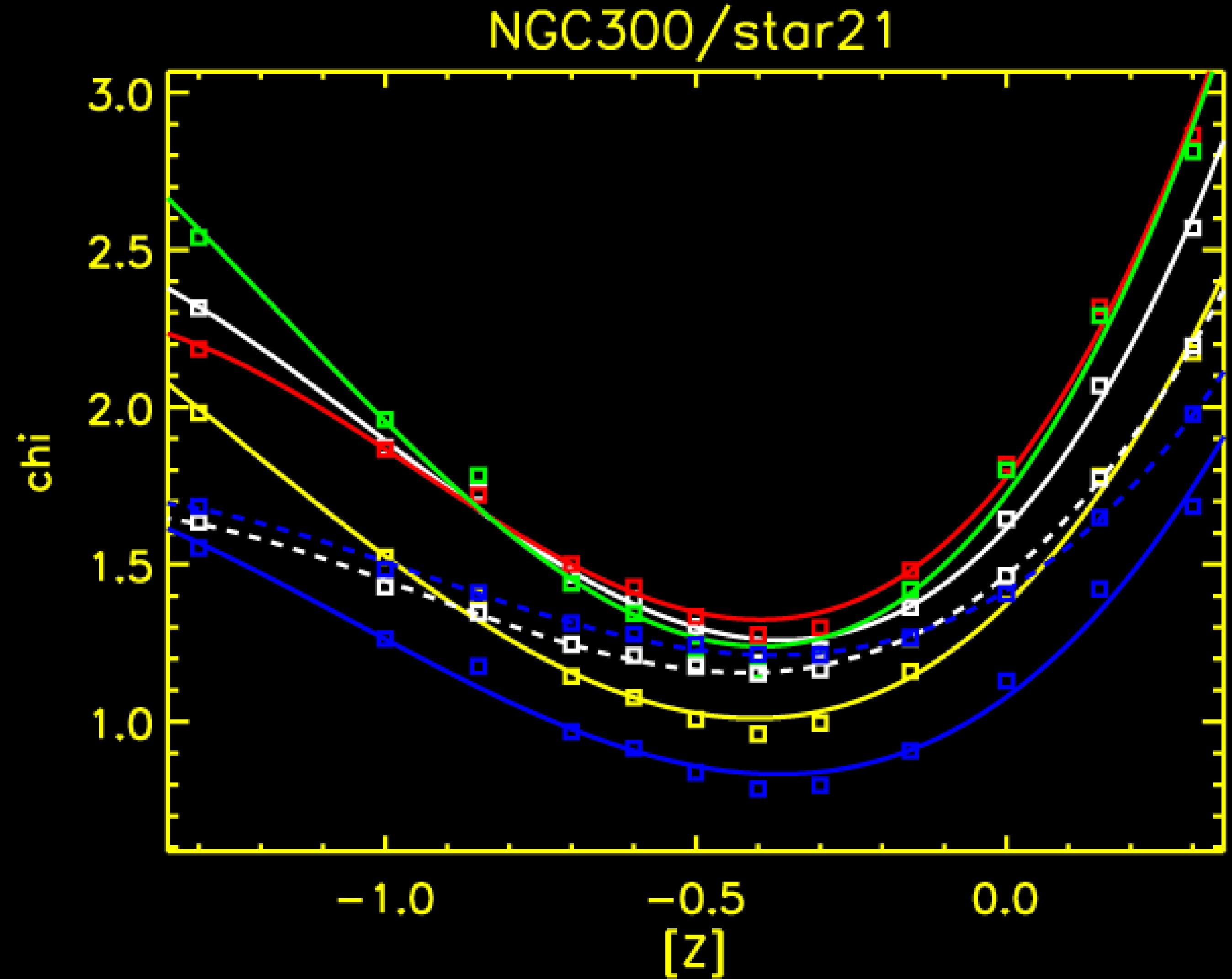


χ_i spectral window 4497-4607Å

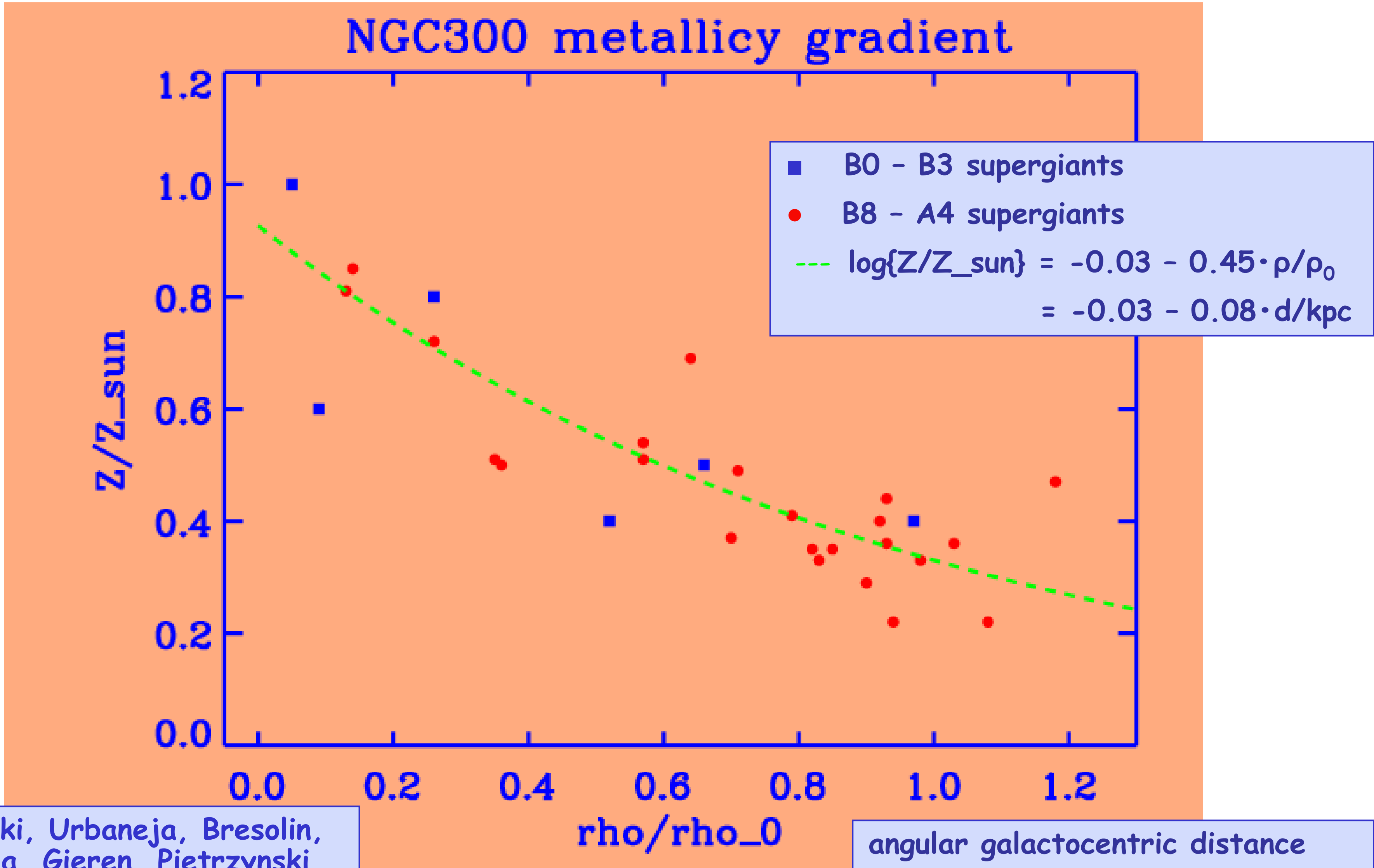


ESO50

X_i all windows → [Z] = -0.4±0.1



Stellar metallicity gradient in NGC300

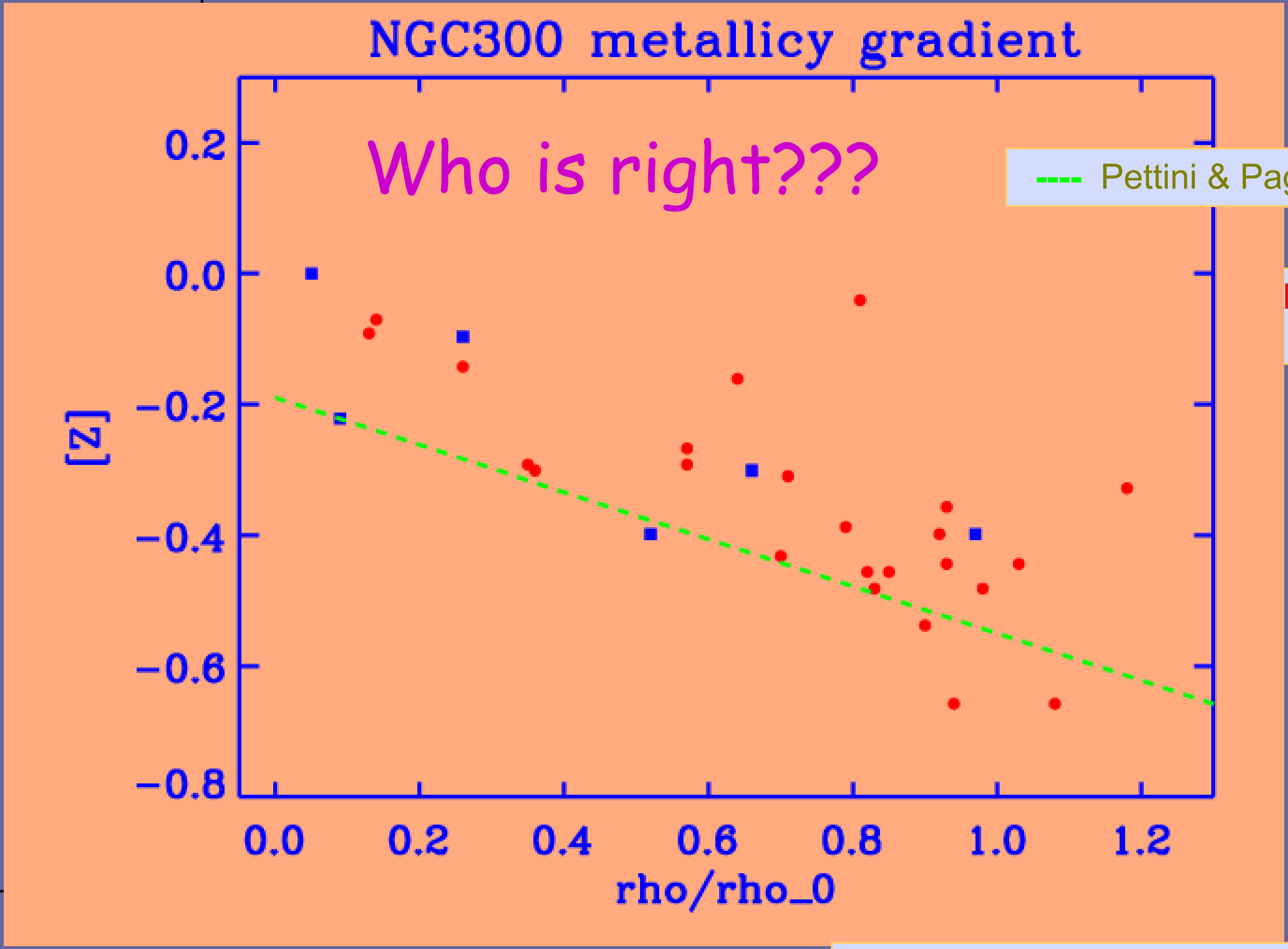


Kudritzki, Urbaneja, Bresolin, Przybilla, Gieren, Pietrzynski, 2008, ApJ 681, 269

angular galactocentric distance

ρ_0 = 9.75 arcmin ≈ 5.7kpc

Stellar vs. HII metallicity gradient

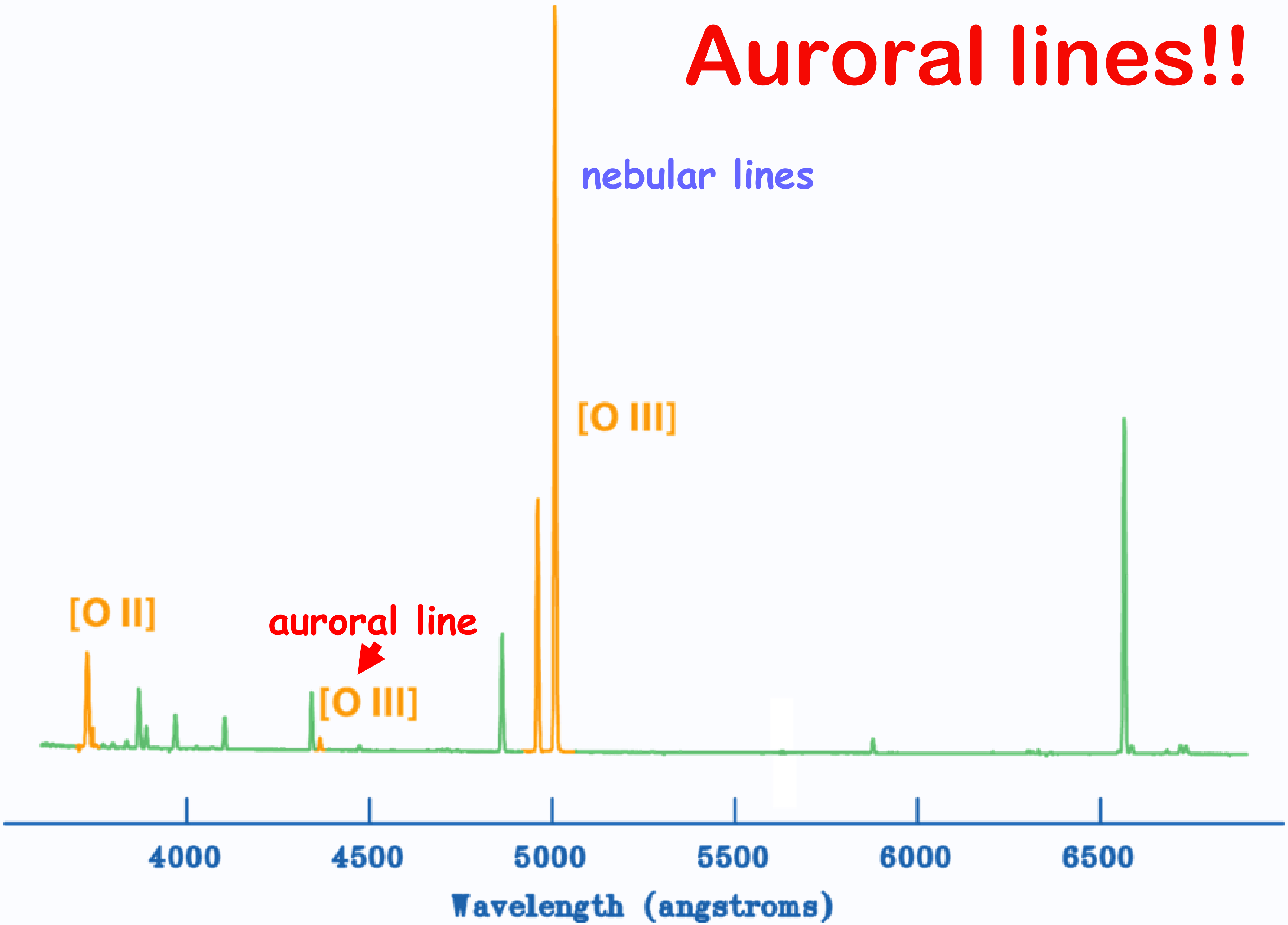


---- Pettini & Pagel (2004)

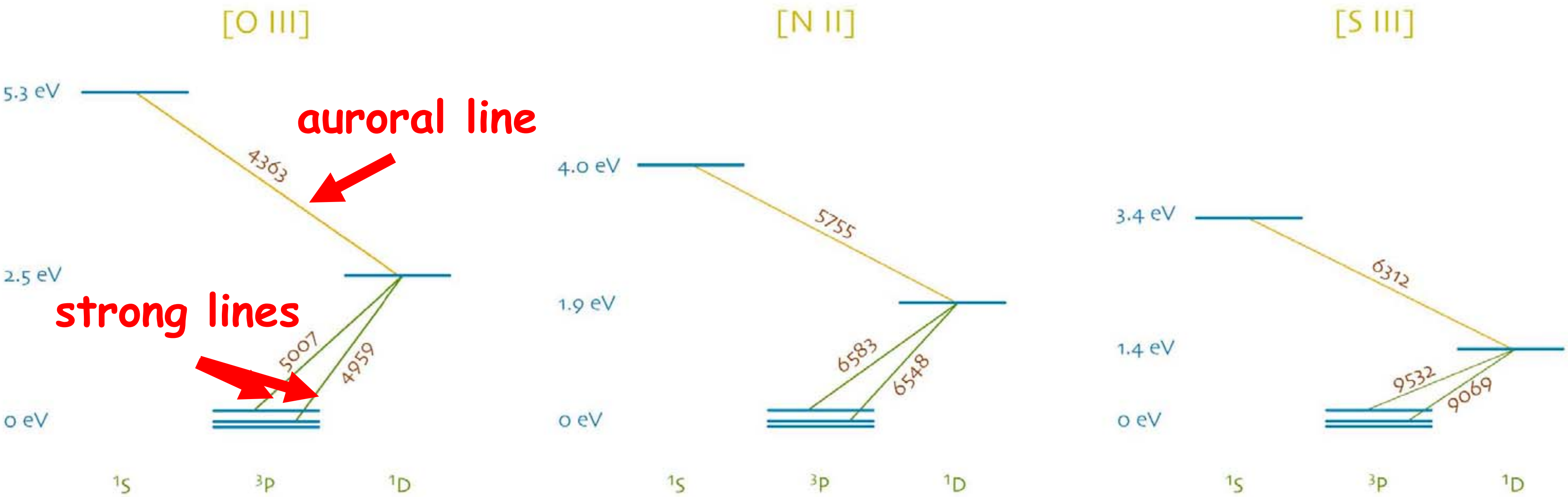
l with stellar

Kudritzki et al., 2008, ApJ 681, 265

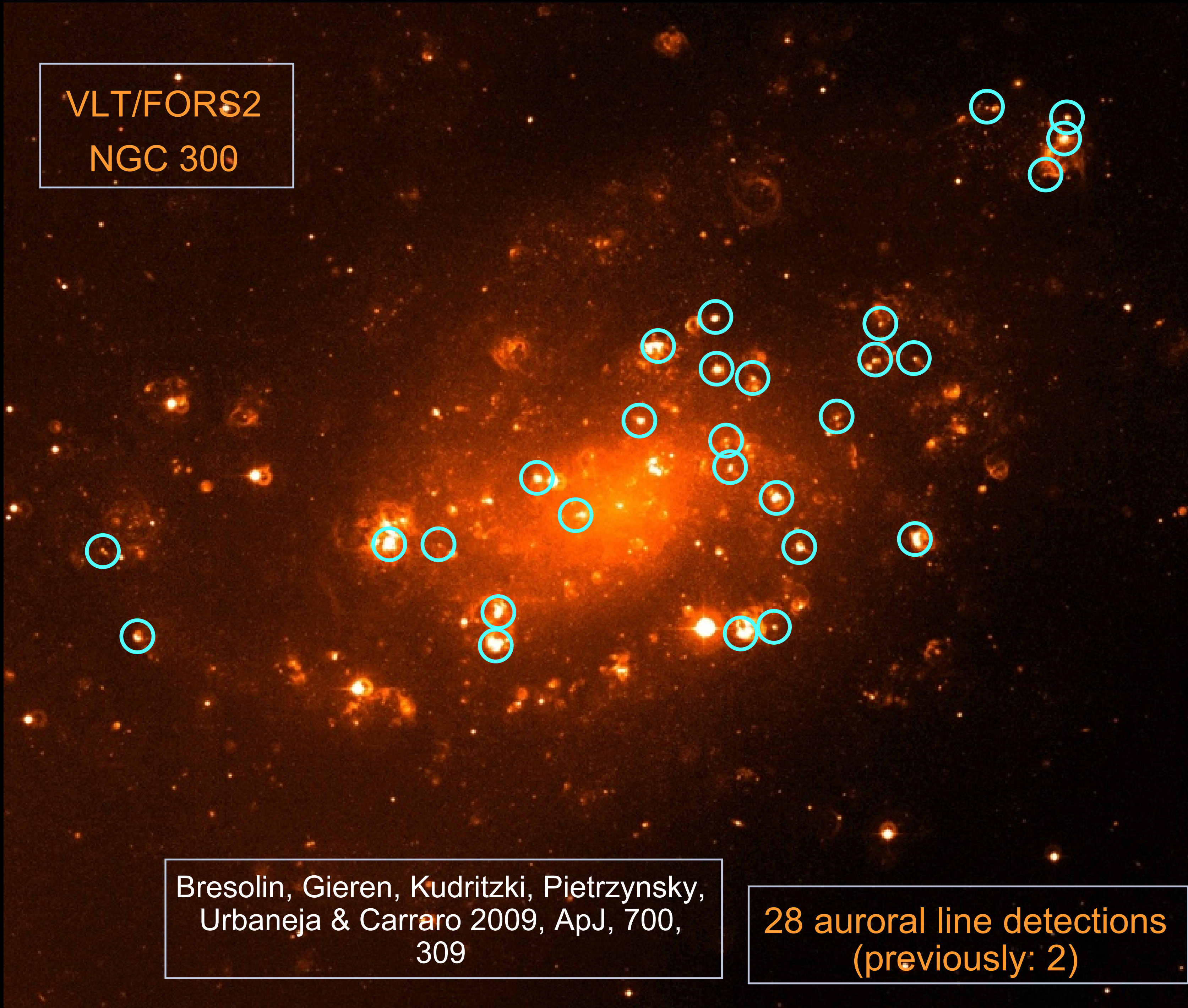
The solution? Auroral lines!!



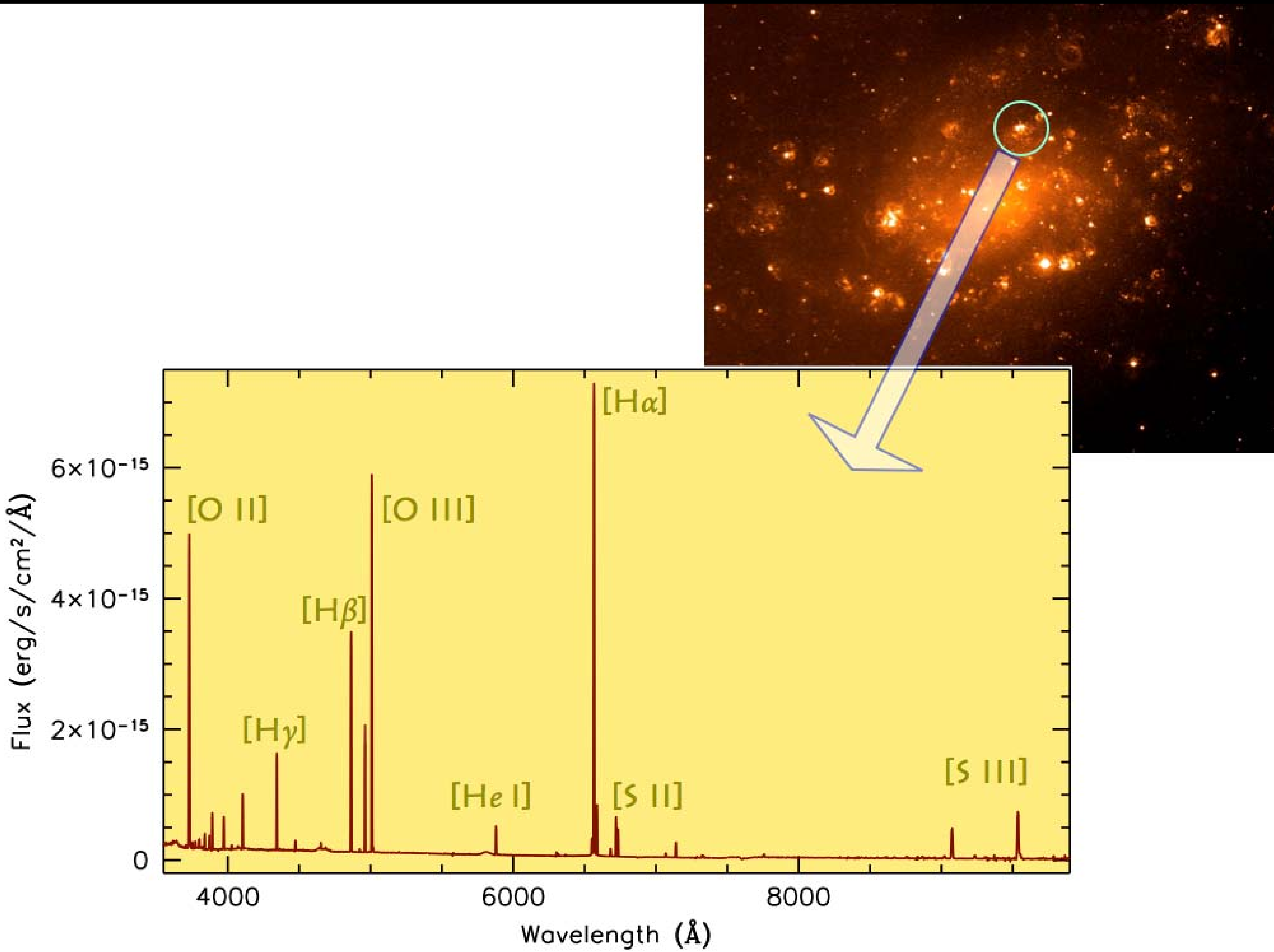
strong lines and auroral lines



Bresolin, 2009

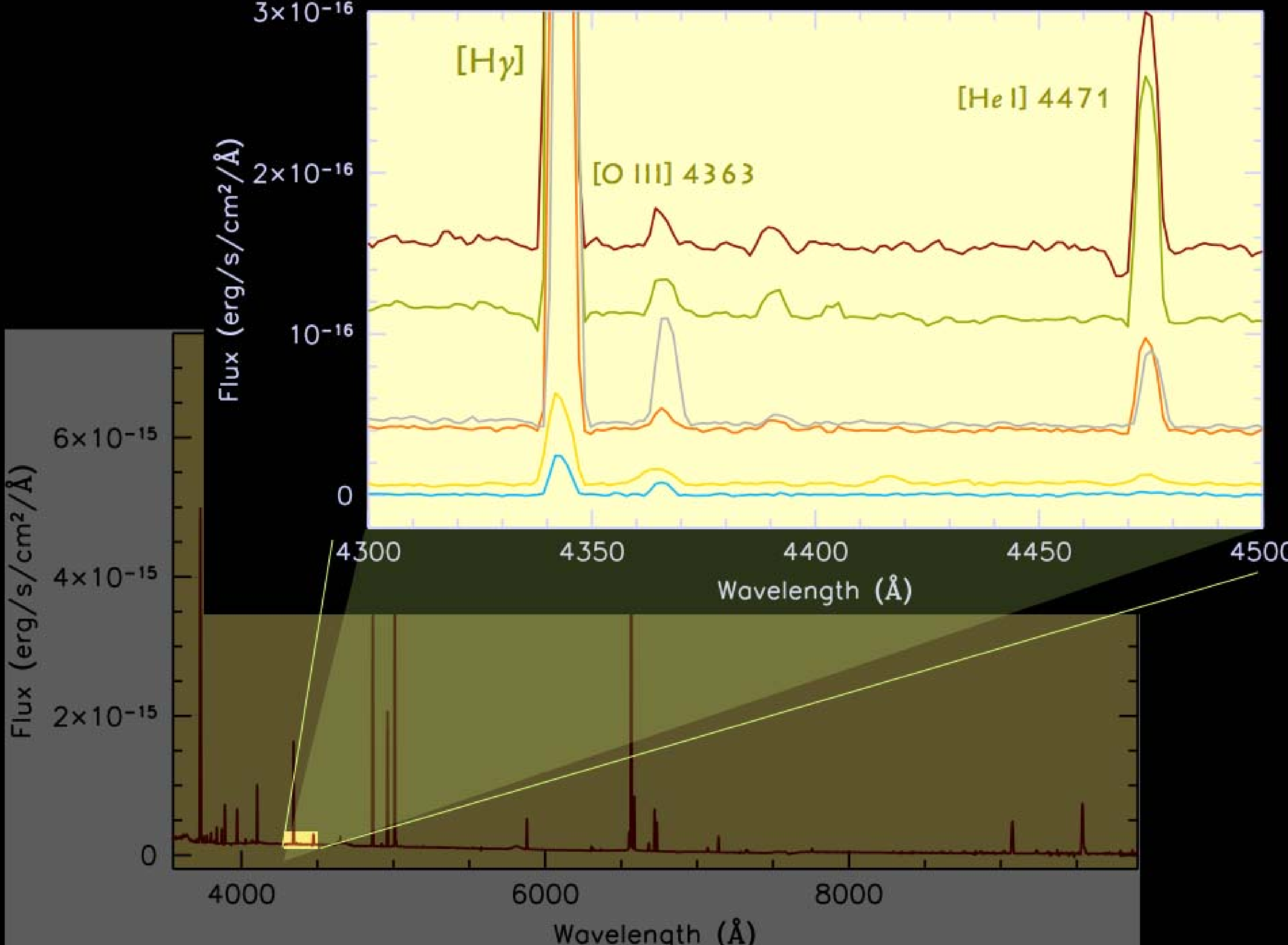

VLT/FORS2
NGC 300
Bresolin, Gieren, Kudritzki, Pietrzynsky, Urbaneja & Carraro 2009, ApJ, 700, 309
28 auroral line detections (previously: 2)

ESO50

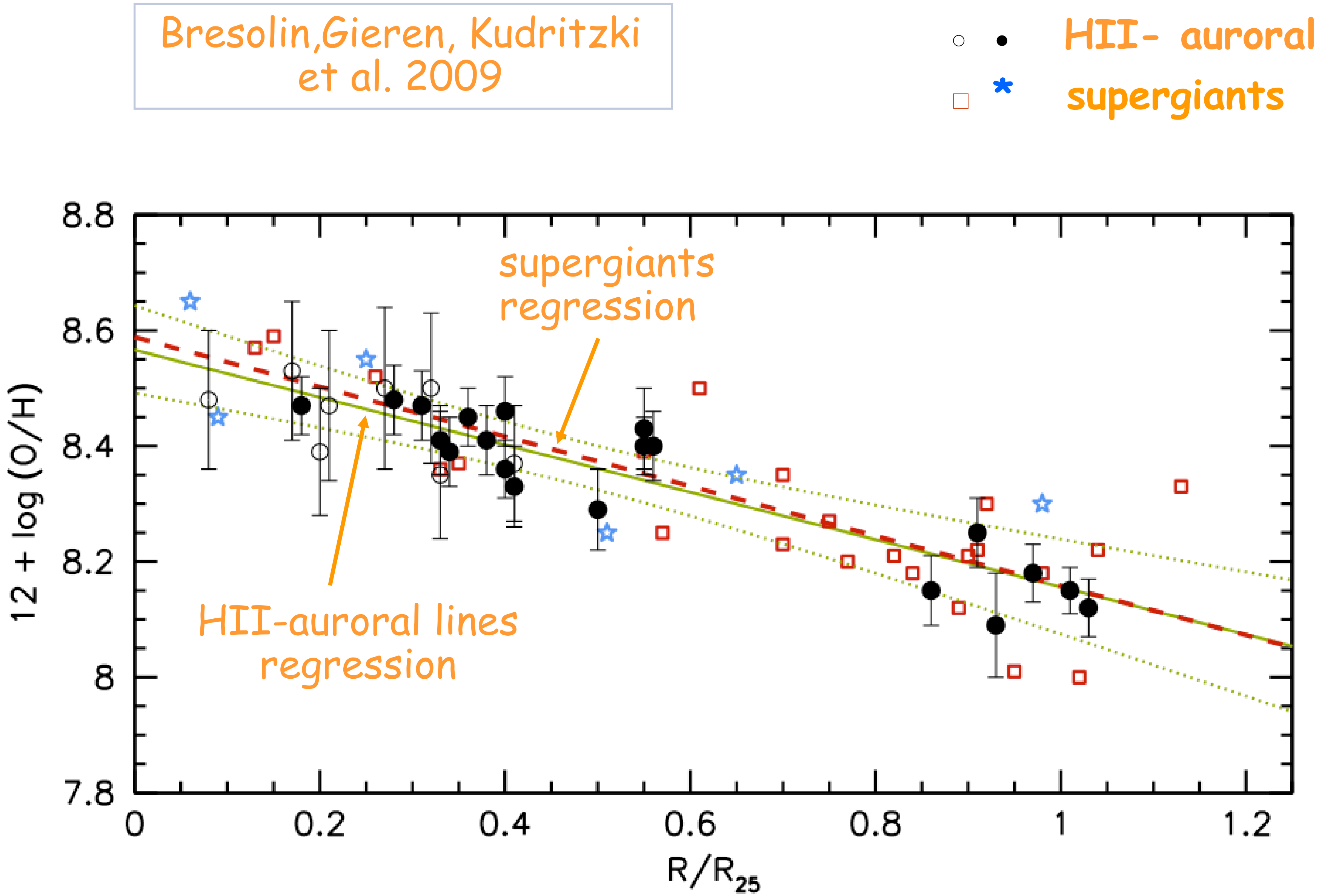


[O II]
[Hγ]
[Hβ]
[O III]
[He I]
[Hα]
[S II]
[S III]
6×10⁻¹⁵
4×10⁻¹⁵
2×10⁻¹⁵
0
Flux (erg/s/cm²/Å)
4000
6000
8000
Wavelength (Å)

ESO50

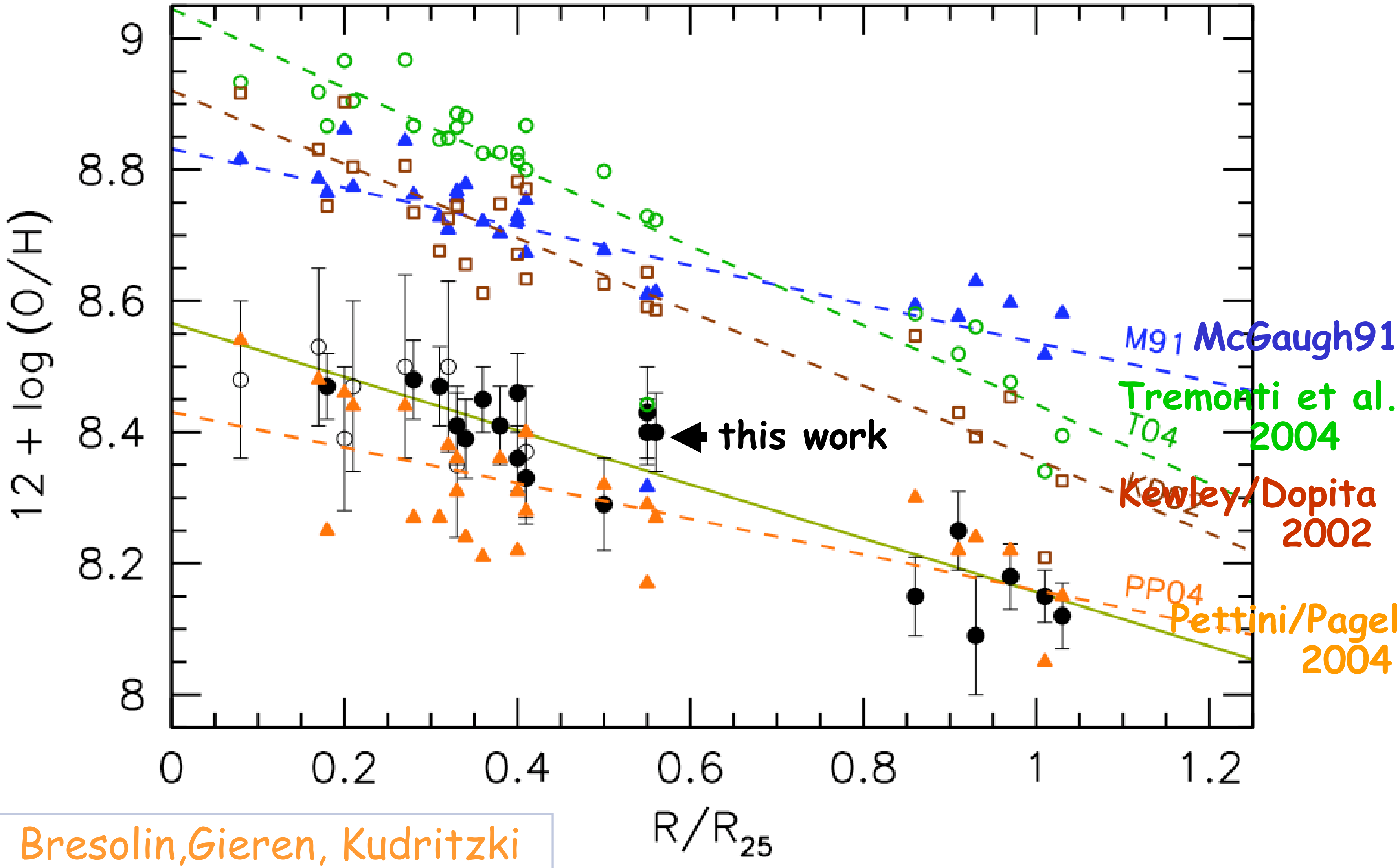


3×10⁻¹⁶
2×10⁻¹⁶
10⁻¹⁶
0
Flux (erg/s/cm²/Å)
[Hγ]
[O III] 4363
[He I] 4471
4300
4350
4400
4450
4500
Wavelength (Å)
6×10⁻¹⁵
4×10⁻¹⁵
2×10⁻¹⁵
0
Flux (erg/s/cm²/Å)
4000
6000
8000
Wavelength (Å)



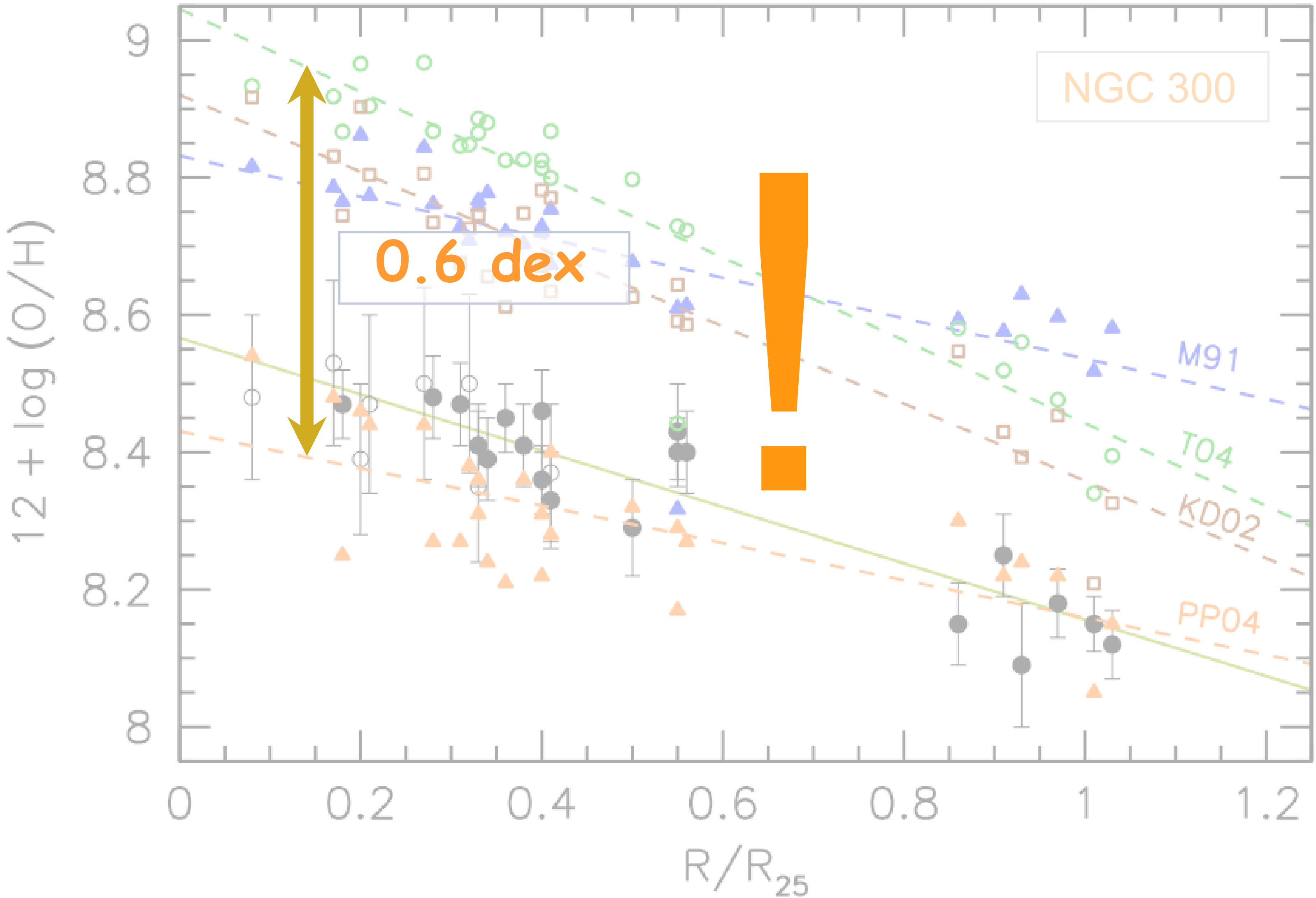
Excellent agreement between auroral lines and supergiants !!

Auroral lines vs. strong lines calibrations – a horror story !!



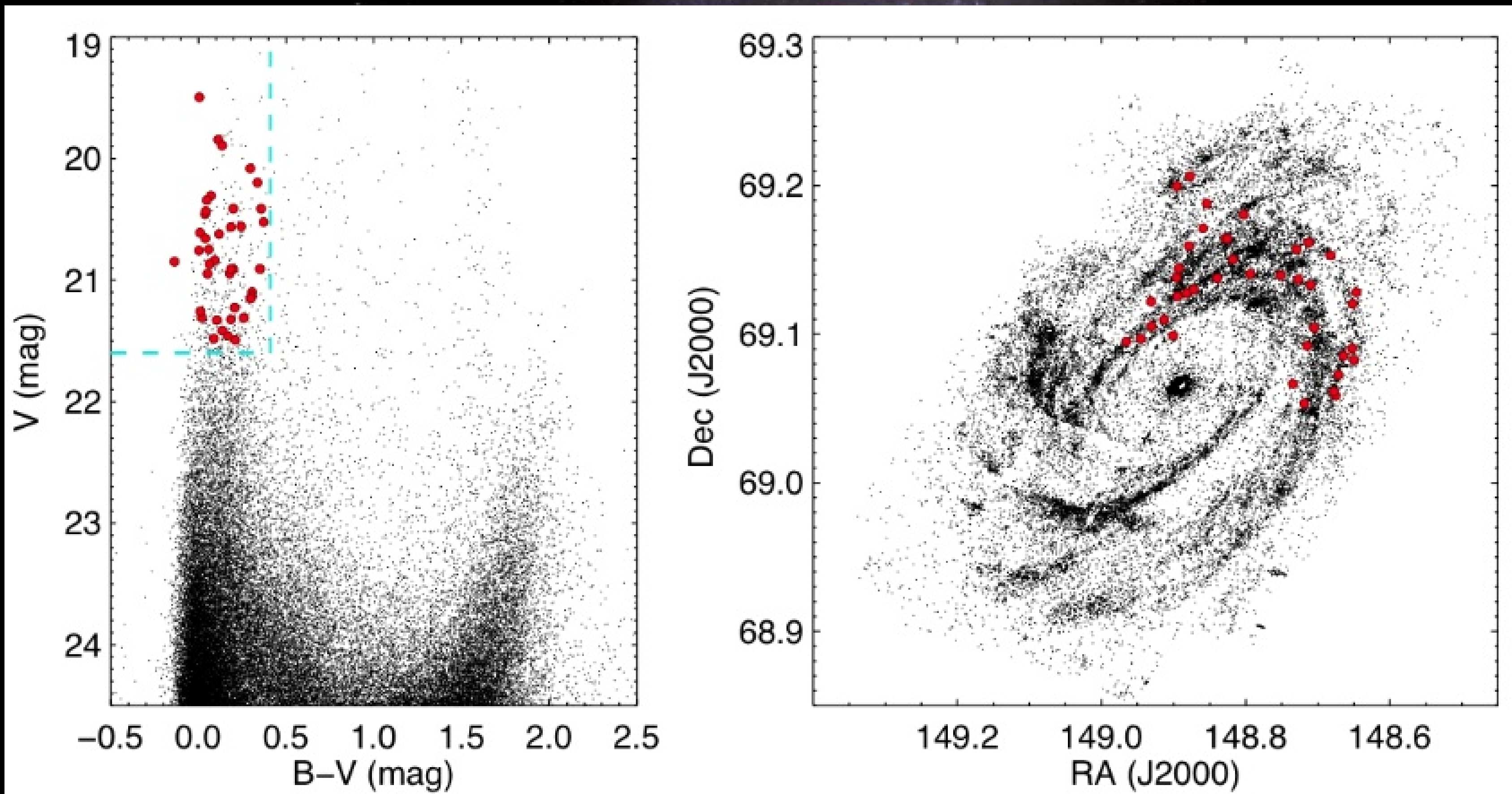
Bresolin,Gieren, Kudritzki et al. 2009

Bresolin, Gieren, Kudritzki,
Pietrzynsky, Urbaneja & Carraro
2009, ApJ, 700, 309



M81

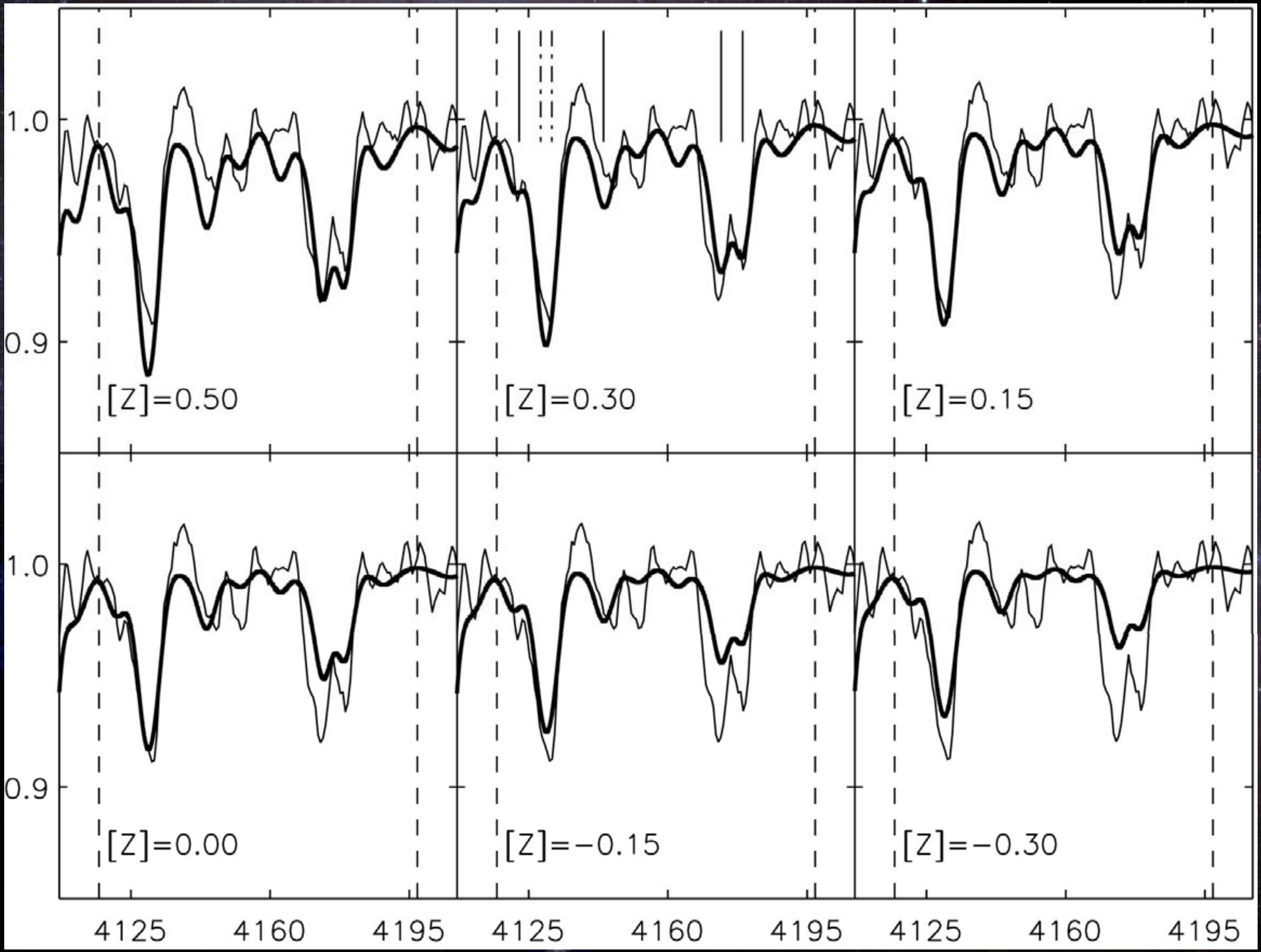
Keck LRIS



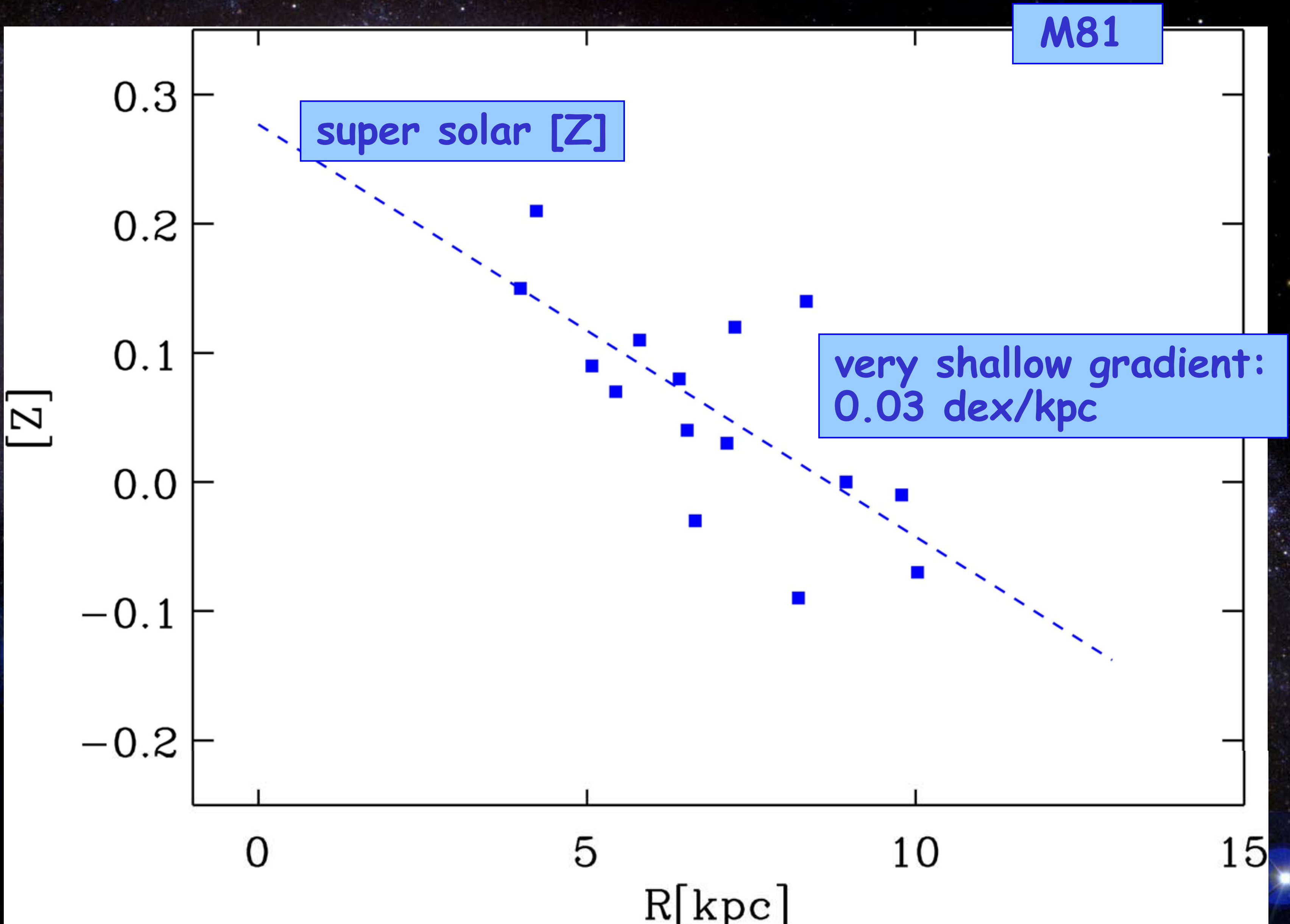
Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

M81

object C20

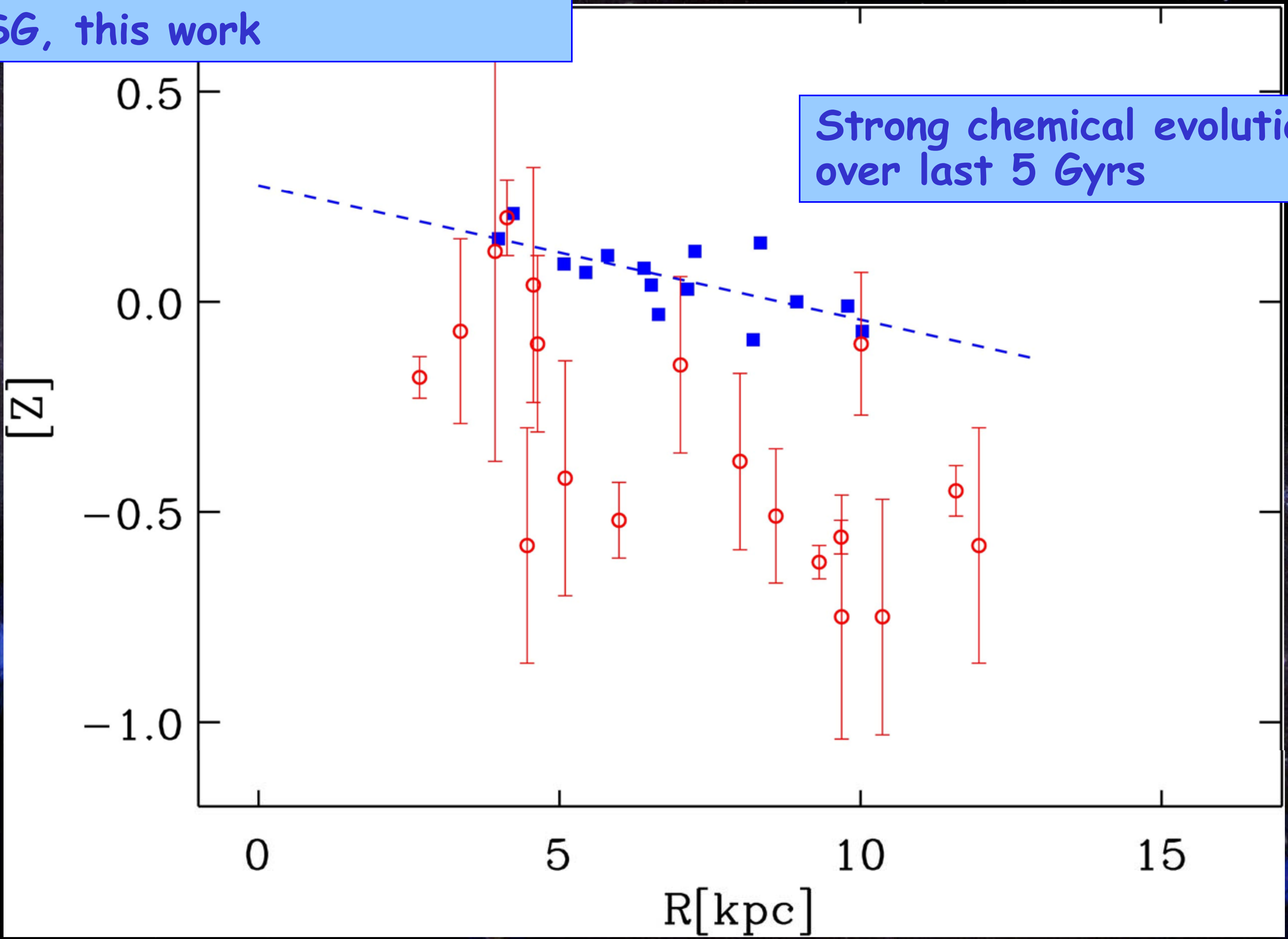


Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15



Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

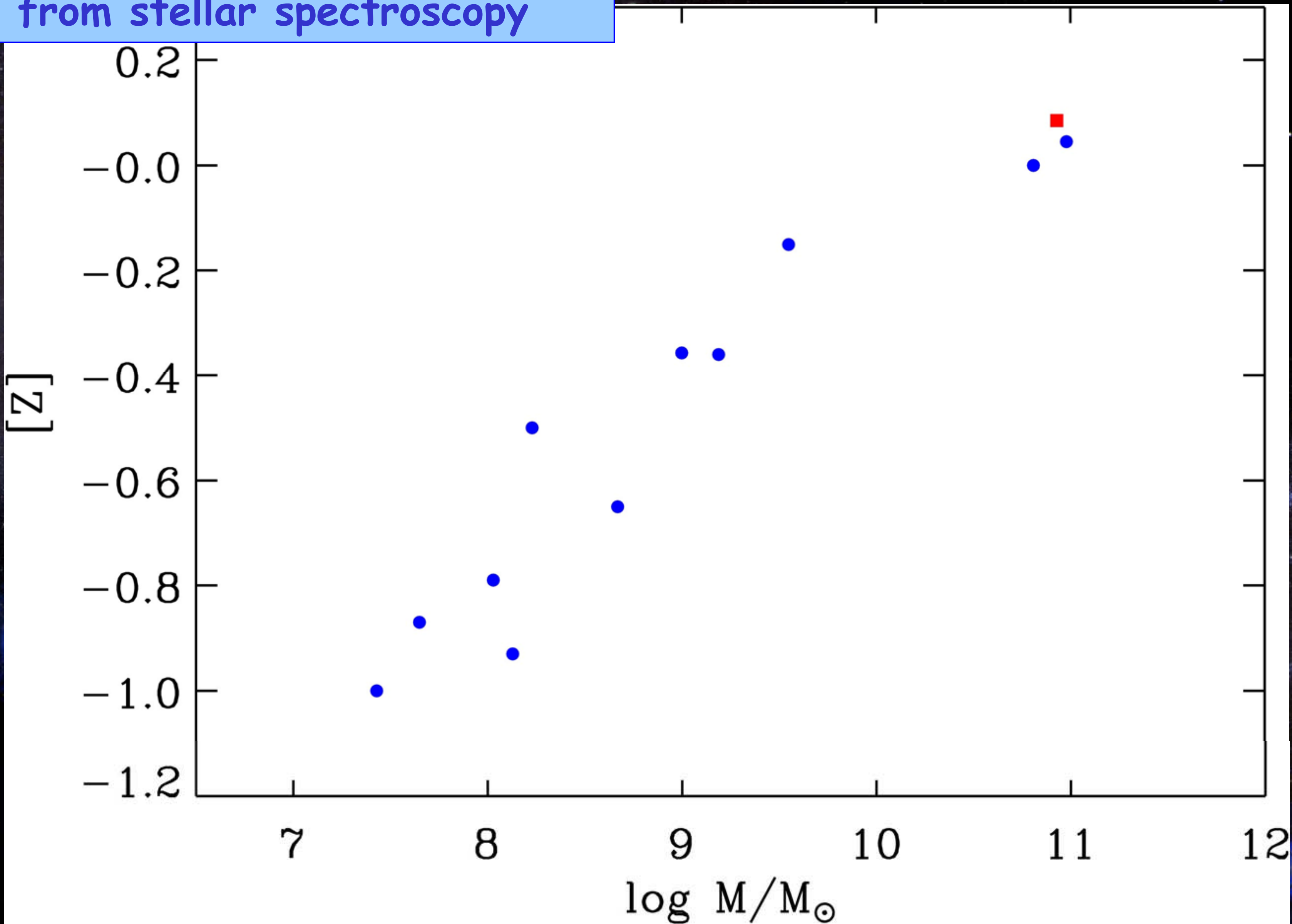
• PNe, Stanghellini et al. 2010
▪ BSG, this work



Strong chemical evolution over last 5 Gyrs

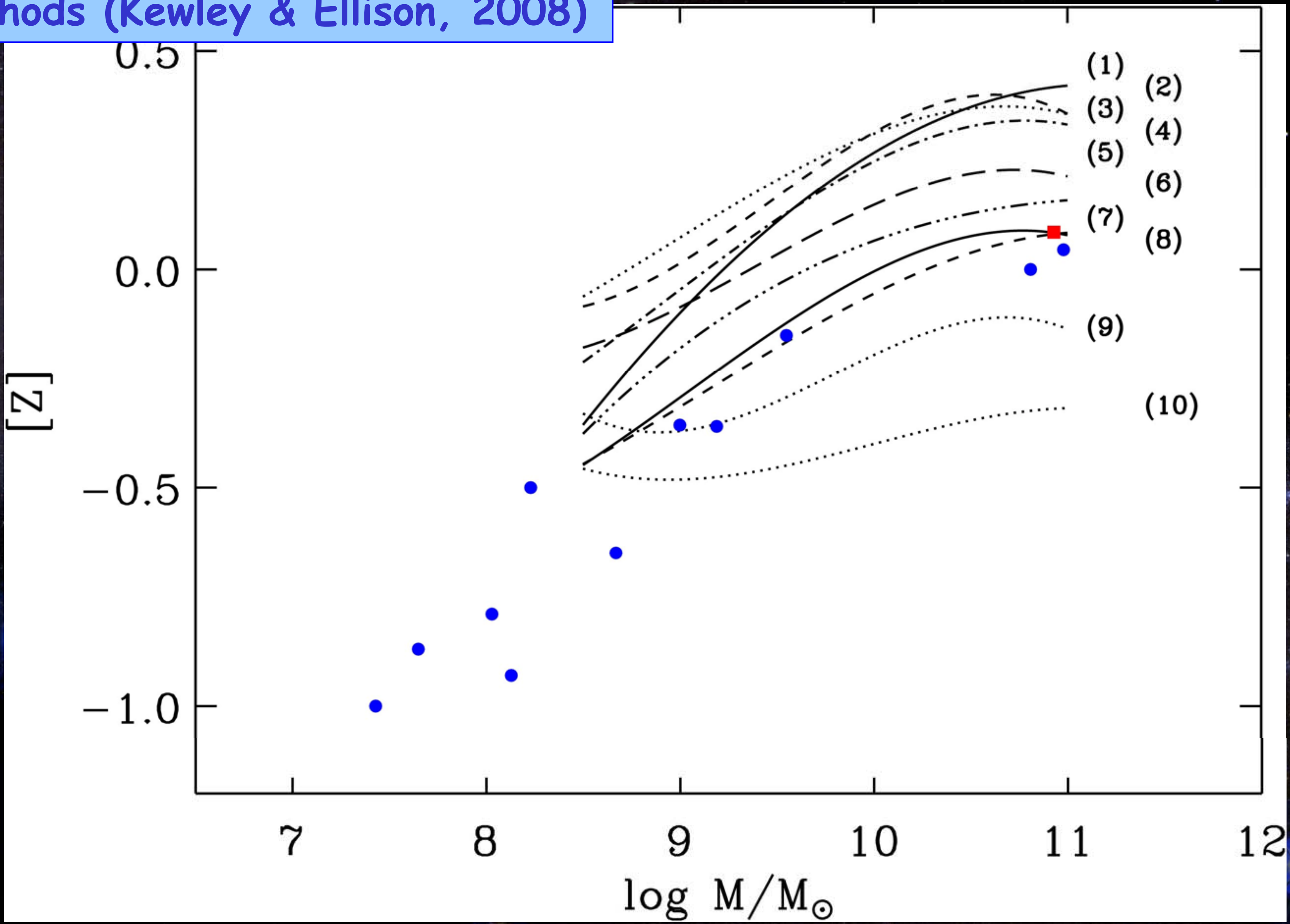
Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

A mass-metallicity relationship only from stellar spectroscopy



Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

Comparison with HII strong line methods (Kewley & Ellison, 2008)



Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15


trust the stars….

H_0 uncertainty and universe equation of state

Hubble constant uncertainty → EoS parameter w

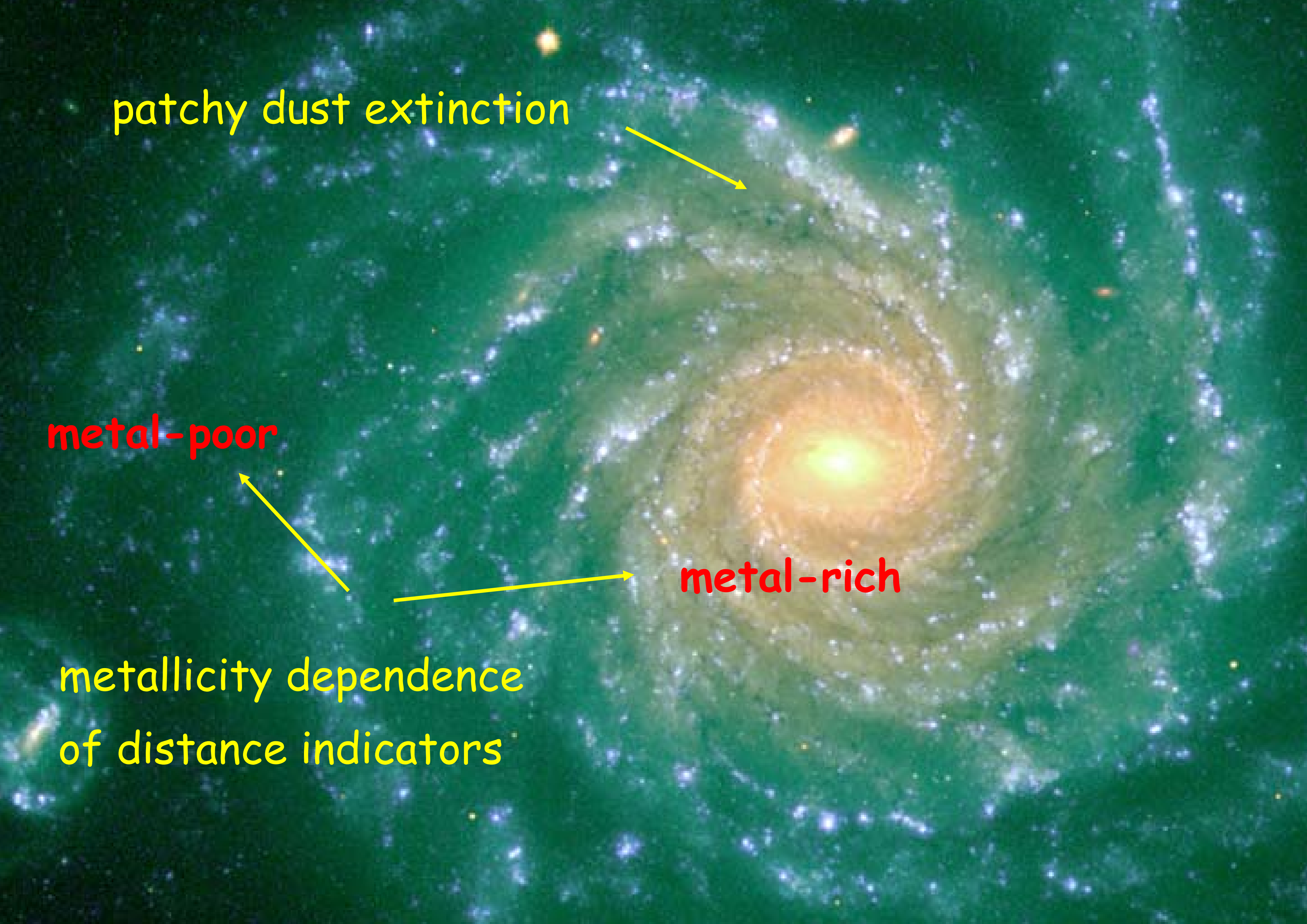
$$\frac{\delta w}{w} \approx 2\frac{\delta H_0}{H_0}$$

$$w = \frac{p}{c^2 \rho}$$

despite enormous effort still: δH_0 ~ 10% → δw ~ 0.2

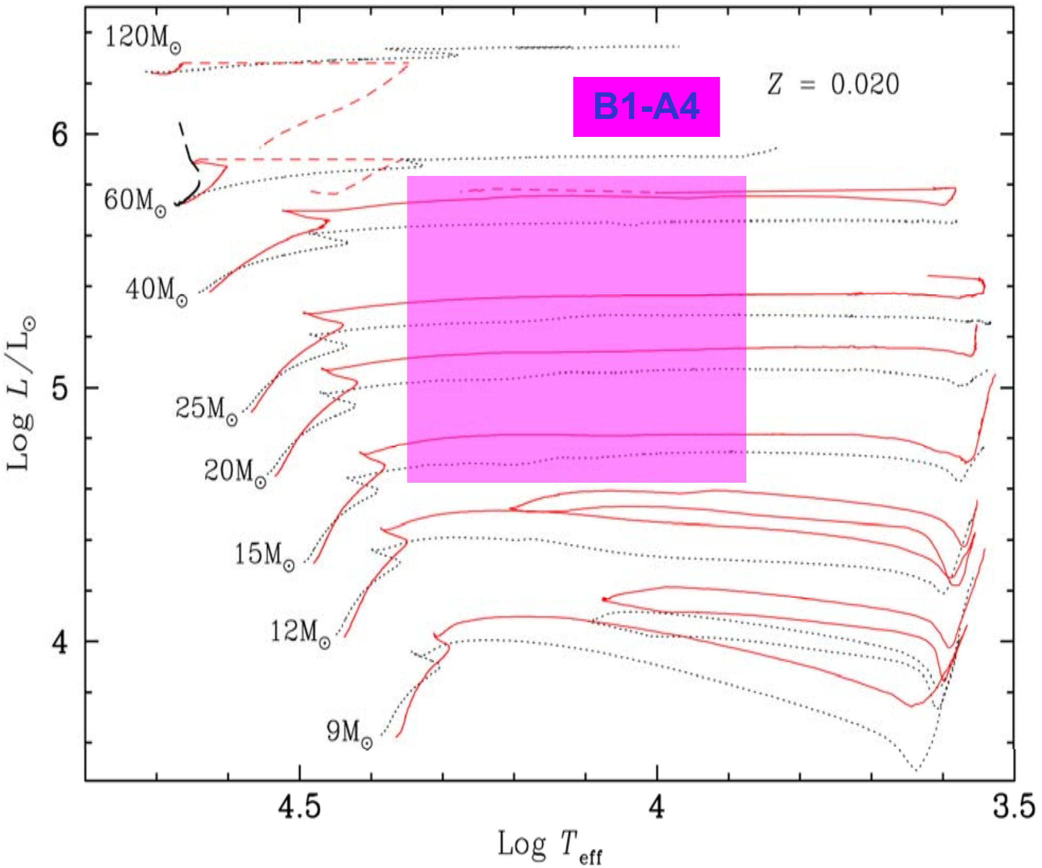
compare
Freedman et al., 2001
Saha et al., 2001, Sandage et al., 2006
Mould & Sakai, 2008, 2009ab
Riess et al., 2009, 2011, 2012 → δH_0 ~ 3%

The perennial problem of extragalactic distances



Flux weighted Gravity - Luminosity Relationship (FGLR)

Kudritzki, Bresolin, Przybilla, ApJ Letters, 582, L83 (2003)



L,M ~ const.

$M \sim g \times R^2 \sim L \times (g/T^4) = const.$

↑ const.

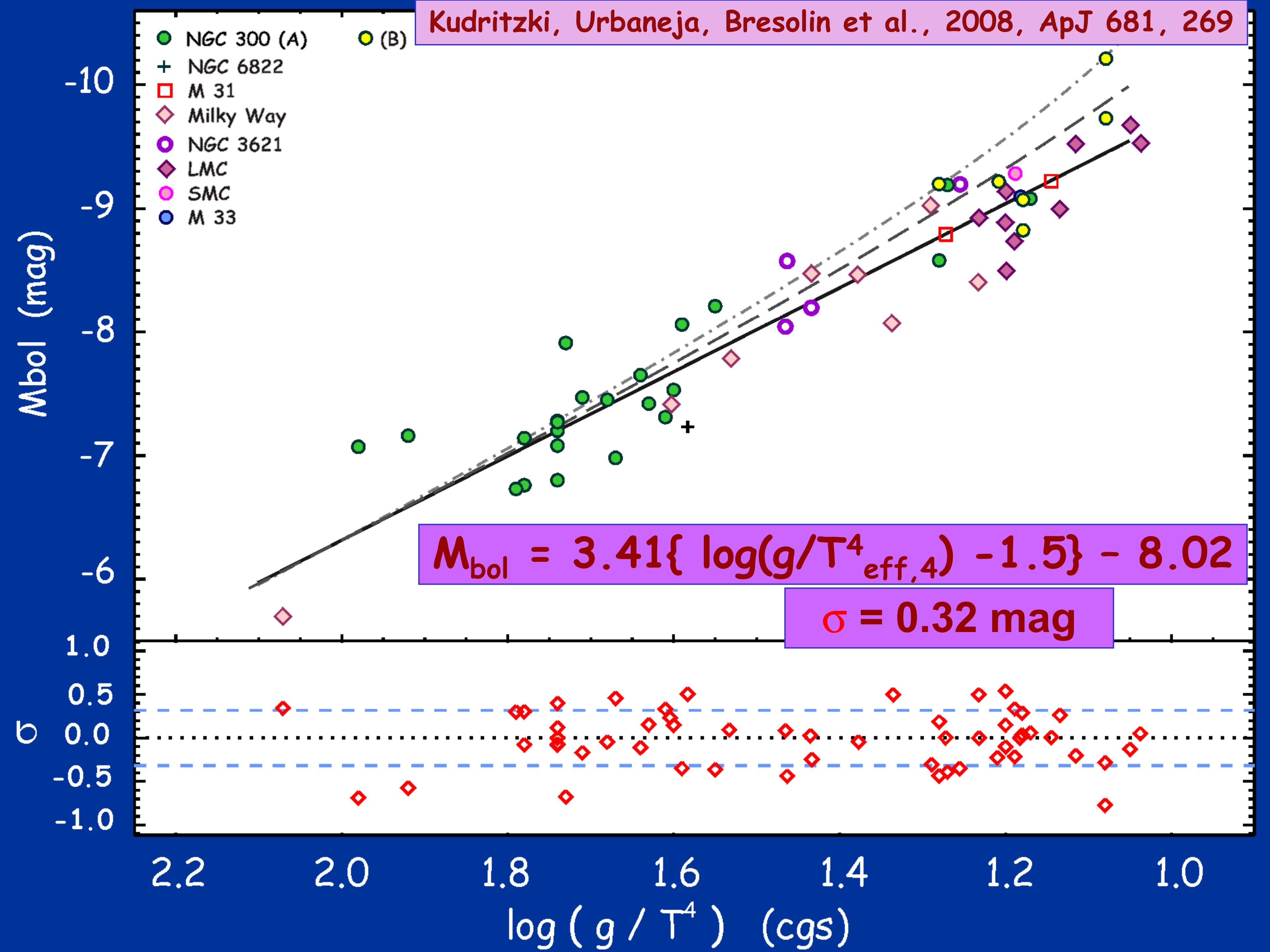
with $L \sim M^x \sim L^x (g/T^4)^x$, $x \sim 3$

→ $L^{1-x} \sim (g/T^4)^x$

or with $M_{bol} \sim -2.5 \log L$

$M_{bol} = a \log(g/T^4) + b$ FGLR

$a = 2.5\, x/(1-x) \sim 3.75$

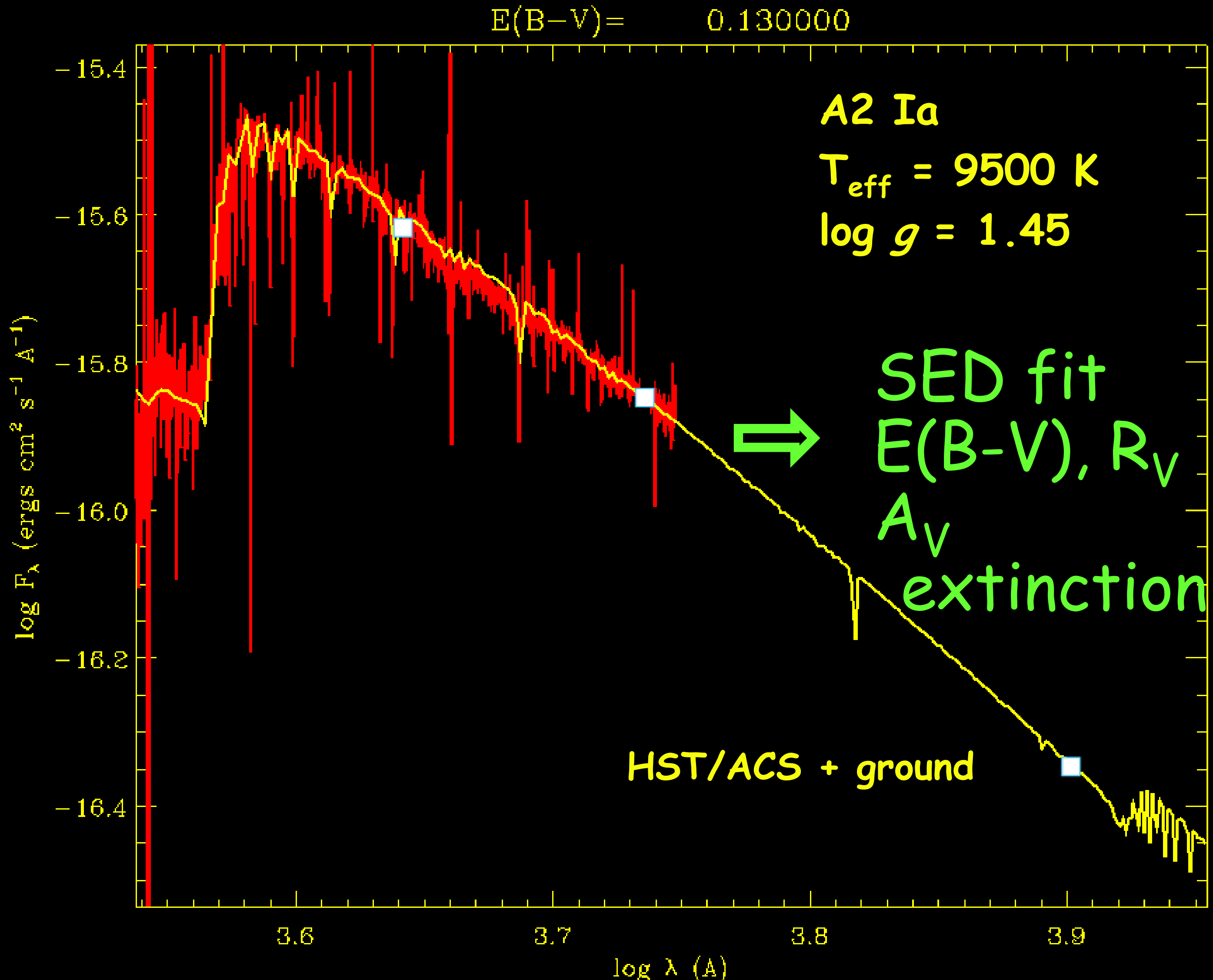


Kudritzki, Urbaneja, Bresolin et al., 2008, ApJ 681, 269
NGC 300 (A)
(B)
NGC 6822
M 31
Milky Way
NGC 3621
LMC
SMC
M 33
Mbol (mag)
-10
-9
-8
-7
-6
M_{bol} = 3.41{ log(g/$T^4_{eff,4}$) -1.5} - 8.02
σ = 0.32 mag
σ
1.0
0.5
0.0
-0.5
-1.0
2.2
2.0
1.8
1.6
1.4
1.2
1.0
log (g / T^4) (cgs)

ESO50

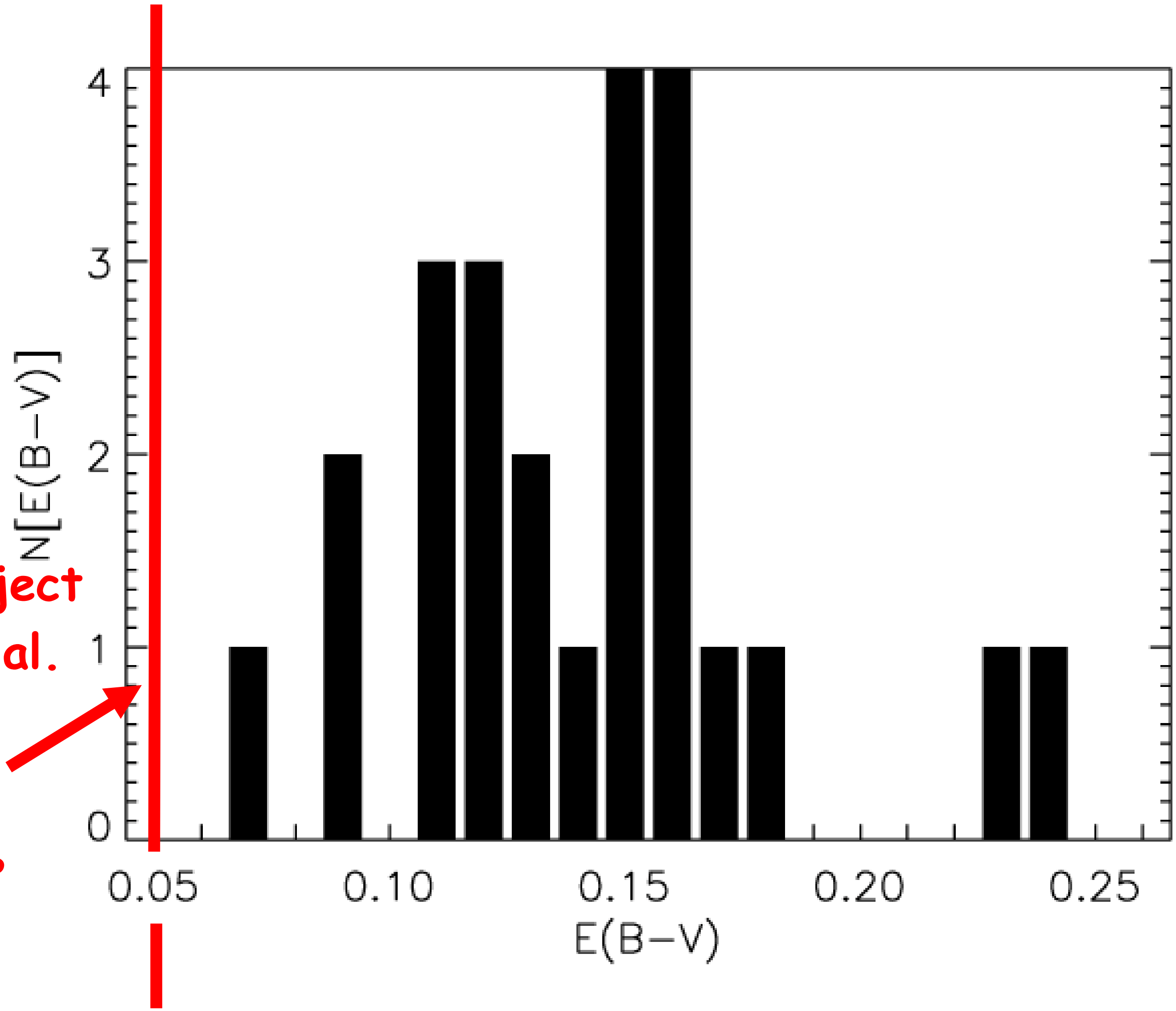
A supergiant SED

Kudritzki, Urbaneja & Bresolin et al. 2008



⇨ SED fit
E(B-V), R_V
A_V
extinction law

E(B-V) distribution in NGC 300

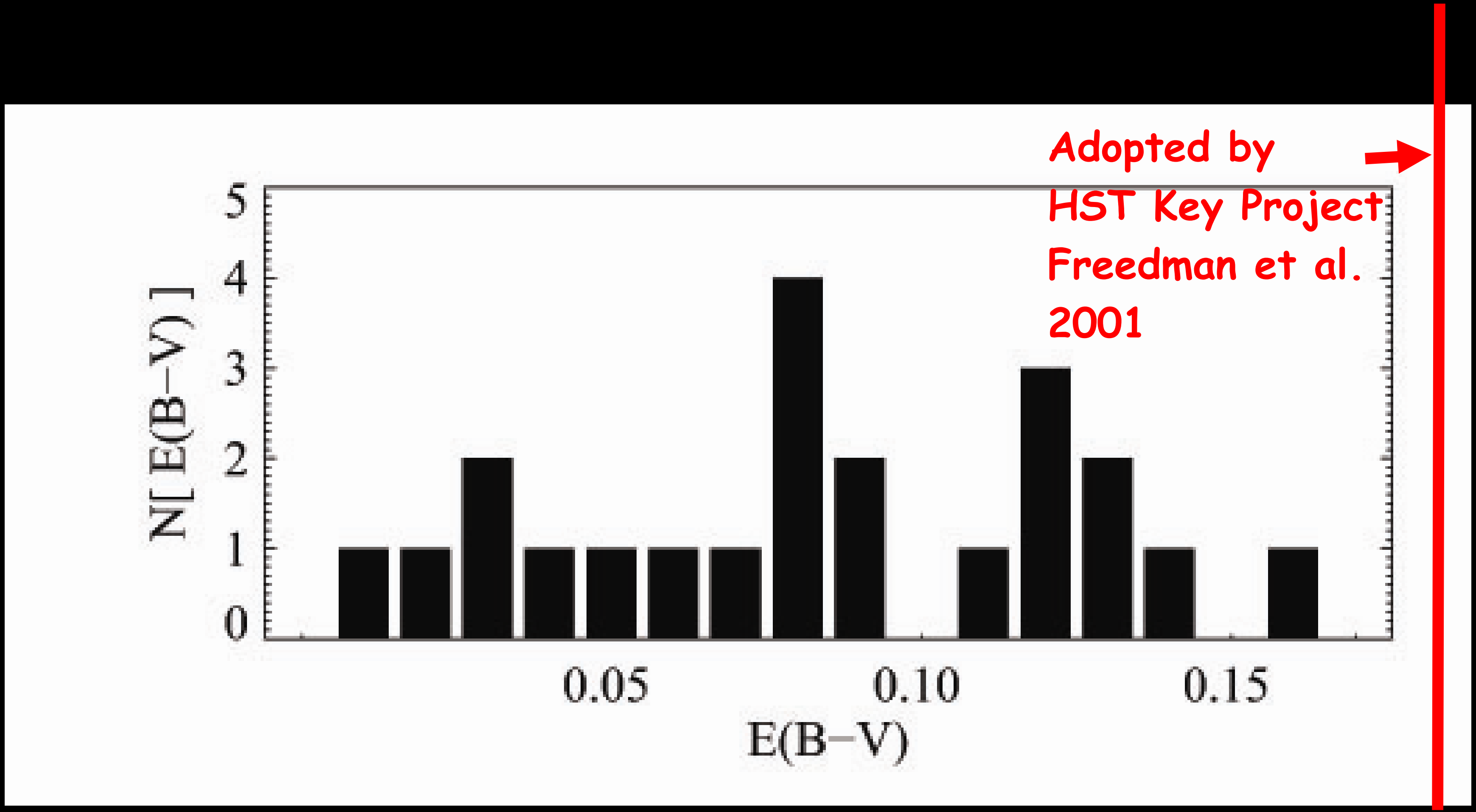


Adopted by HST Key Project Freedman et al. 2001

→

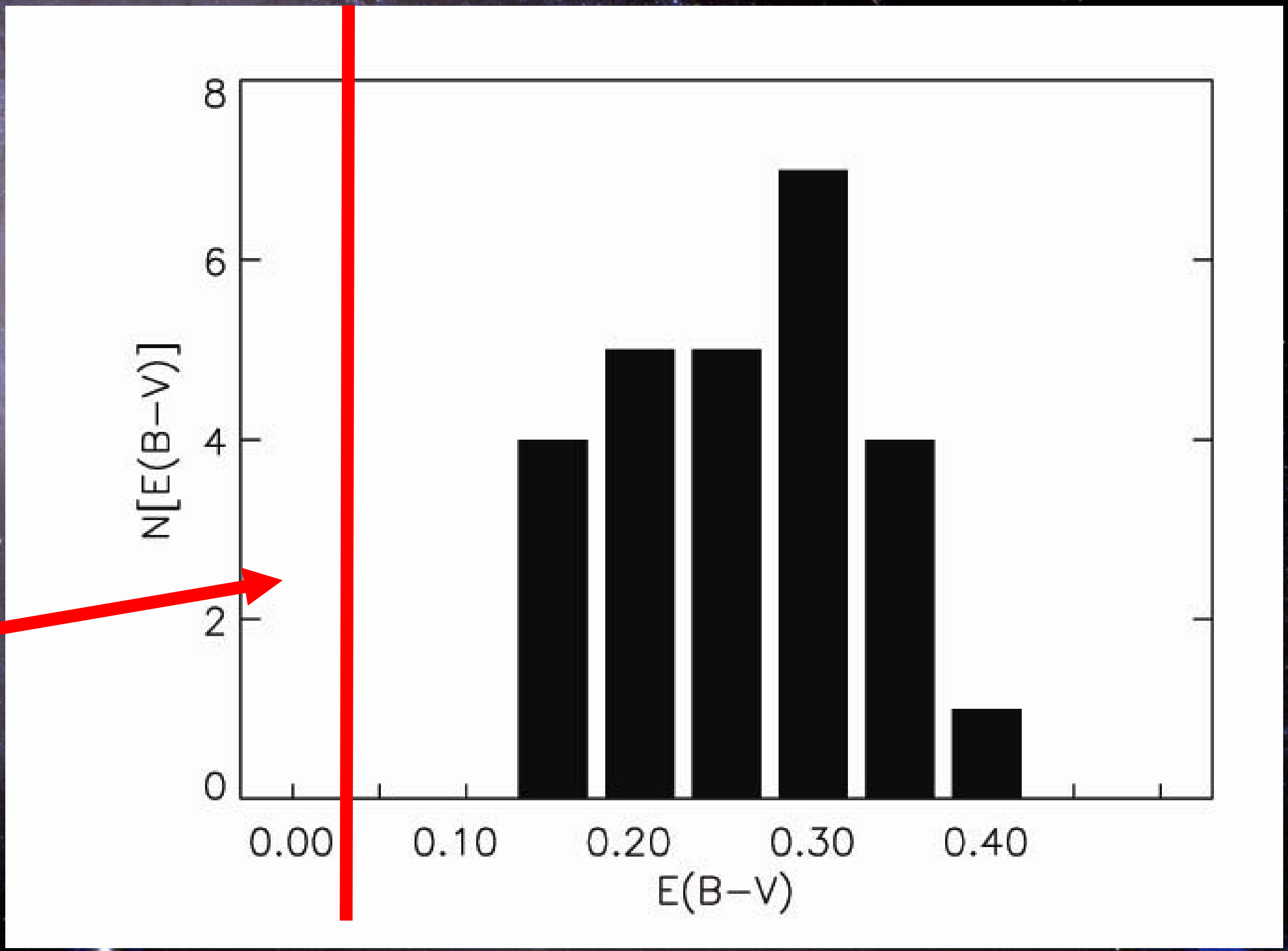
Distance 15% too large

B&A supergiants in M33 - reddening



Vivian U, Urbaneja, Kudritzki, Jacobs, Bresolin, 2009, ApJ 740, 1120

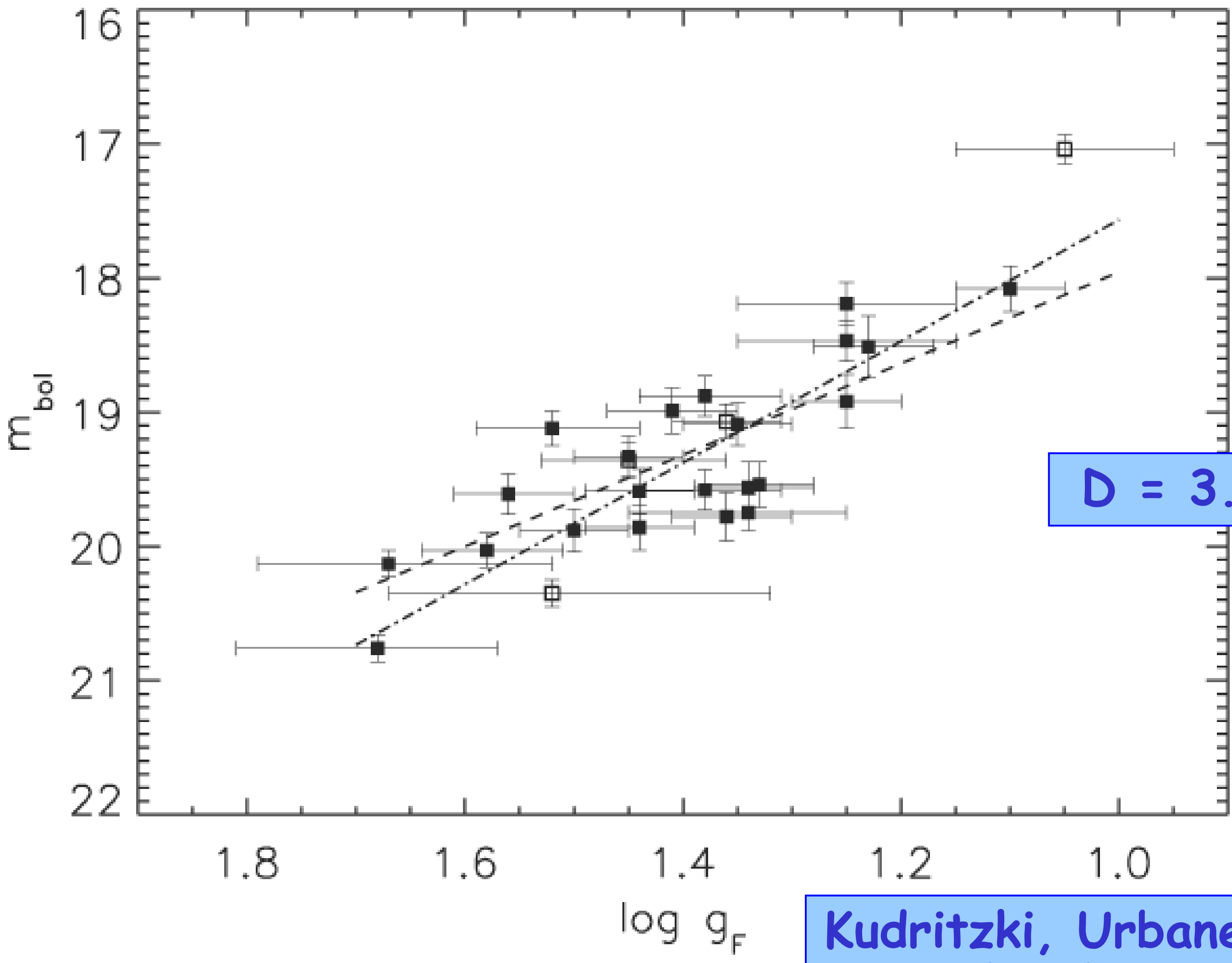
M81 extinction



Adopted by
HST Key Project
Freedman et al.
1994
→
Distance too large

Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

M81 FGLR



D = 3.47 ± 0.16 Mpc

Kudritzki, Urbaneja, Gazak et al.
ApJ 747, 15

Conclusions and TMT/ELT perspectives

WFOS → quantitative spectroscopy
possible down to m_V ~ 24.5 mag

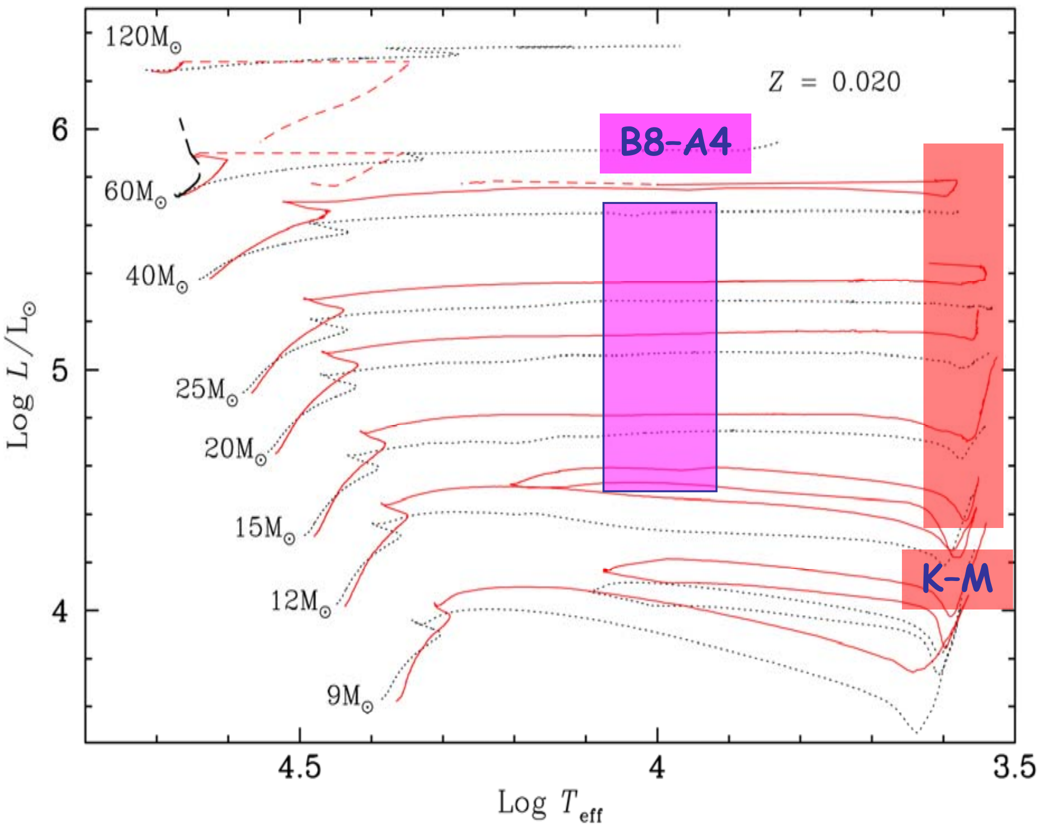
→ with objects $M_V \leq$ - 8 mag

m – M ~ 32.5 mag ~ 30 Mpc possible

chemical evolution studies
SF
ISM, extinction, extinction laws
distances
10 objects per galaxy
→ $\Delta(m-M)$ ~ 0.1 mag

red supergiants J-band spectroscopy

Brightest stars at infrared light: $-8 \geq M_J \geq -11$ mag



Davies, Kudritzki, Figer, 2010 MNRAS, 407,1203

Evans, Davies, Kudritzki et al. 2011 A&A, 527, 50

Keck/MOSFIRE, VLT/KMOS:
15 Mpc

TMT/IRMS, E-ELT/EAGLE:
70 Mpc

Star Super Clusters:
~10 times further out