Blue Supergiant Stars – Distances and Metallicities in Galaxies beyond the Local Group

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in collaboration with

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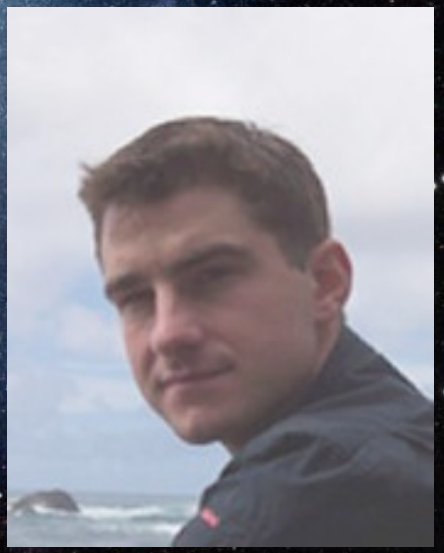
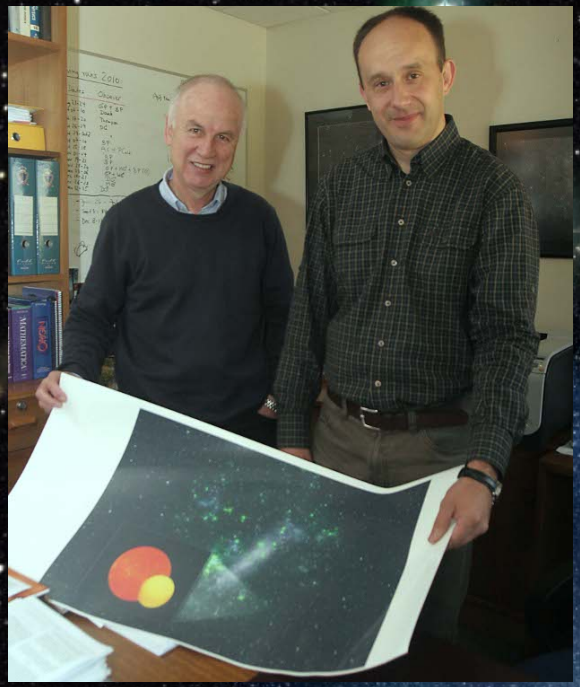


Chris Evans

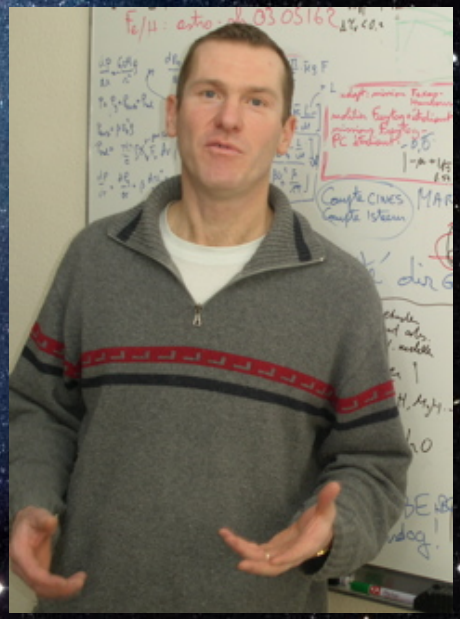


Wolfgang Gieren
Grzegorz Pietrzynski

Maria Bergemann

Norbert Przybilla

Matt Hosek

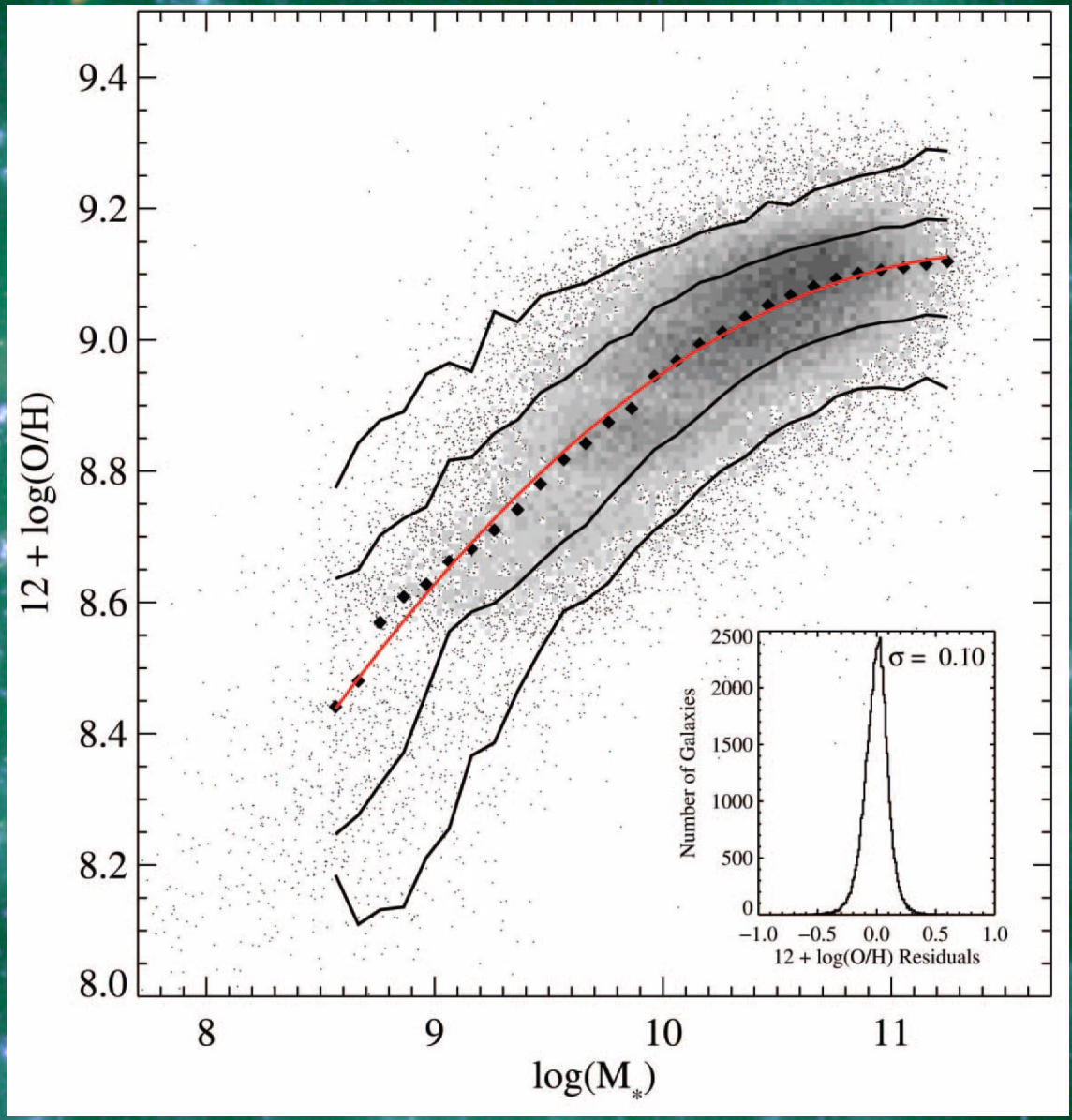


Bertrand Plez

mass-metallicity relationship

Rosetta stone
to understand
galaxy formation
and
chemical evolution!

50,000 star forming
galaxies with
SDSS spectra



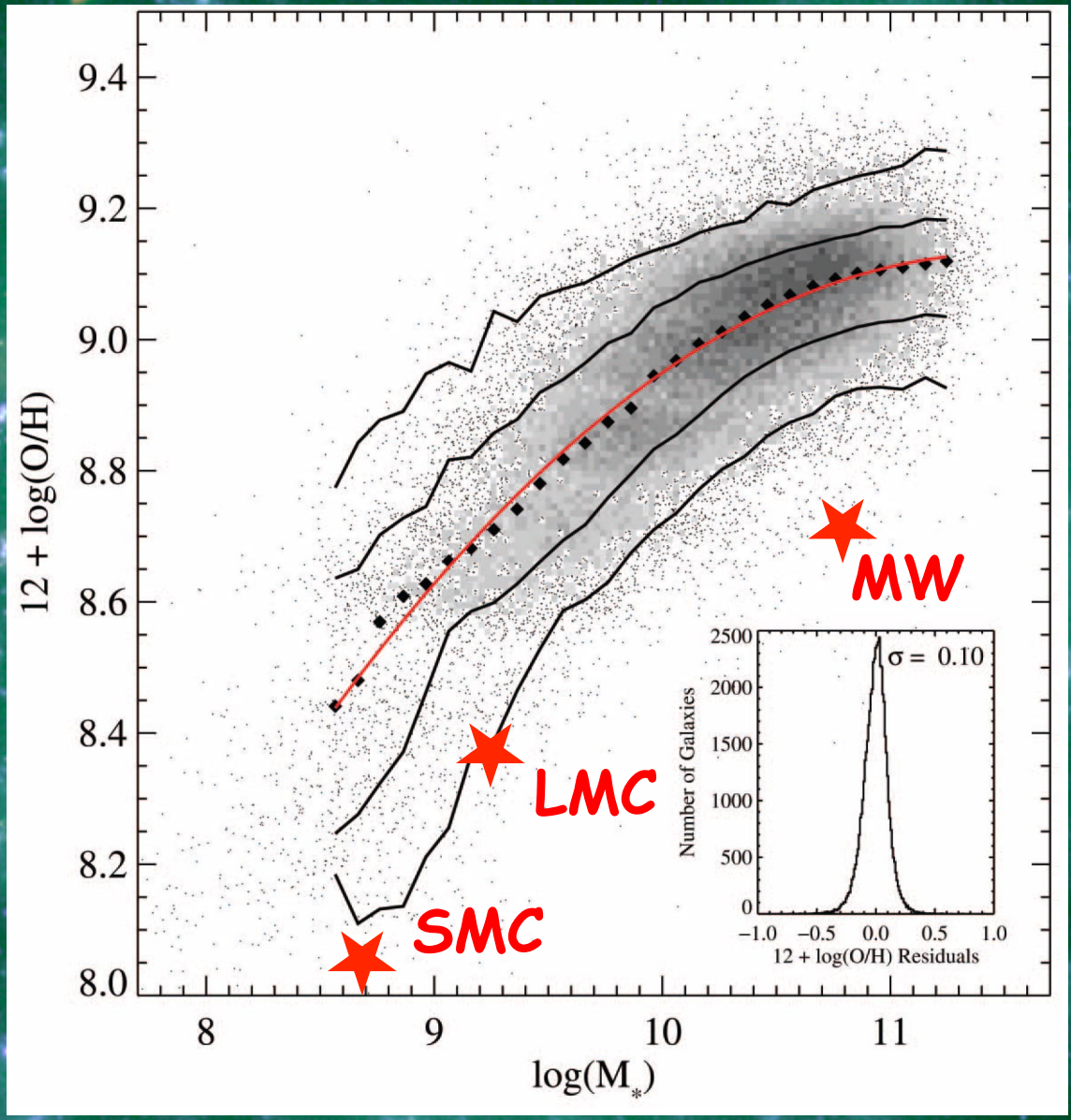
Tremonti et al., 2004, ApJ 613, 898

mass-metallicity relationship

However…

Something must be wrong….

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



Tremonti et al., 2004, ApJ 613, 898

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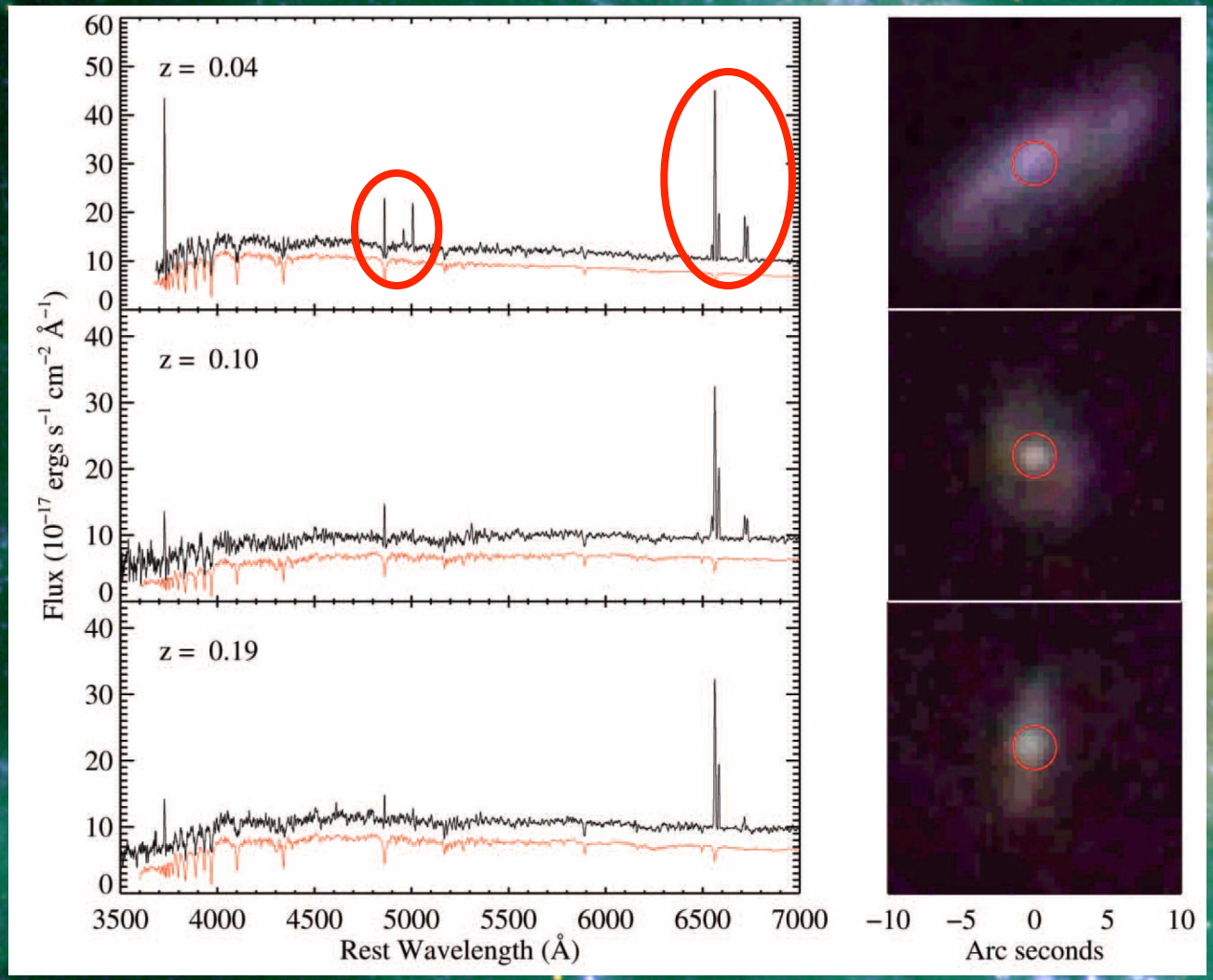


strong nebular emission lines: hydrogen, oxygen, nitrogen

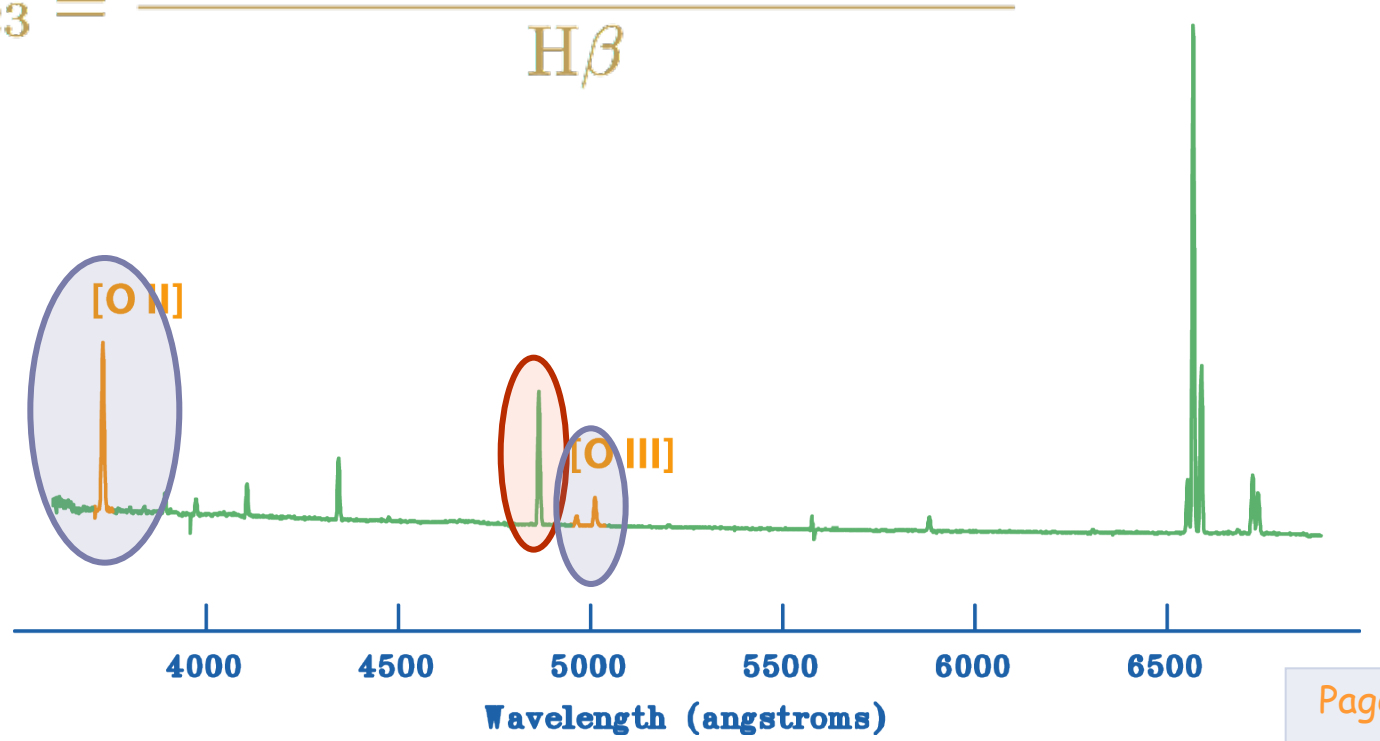
50,000 star forming galaxies with SDSS spectra

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

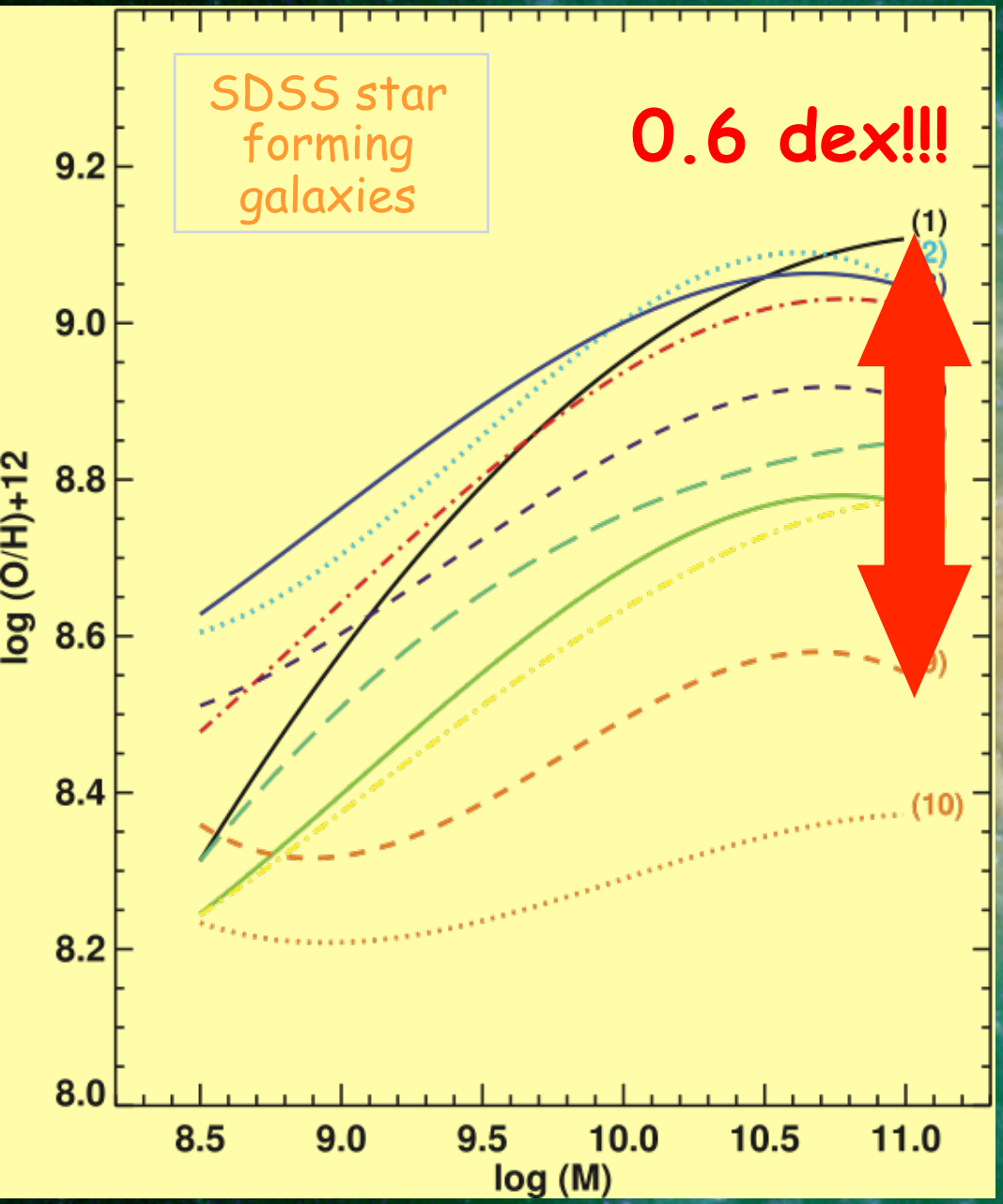
simple empirical calibration but…

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

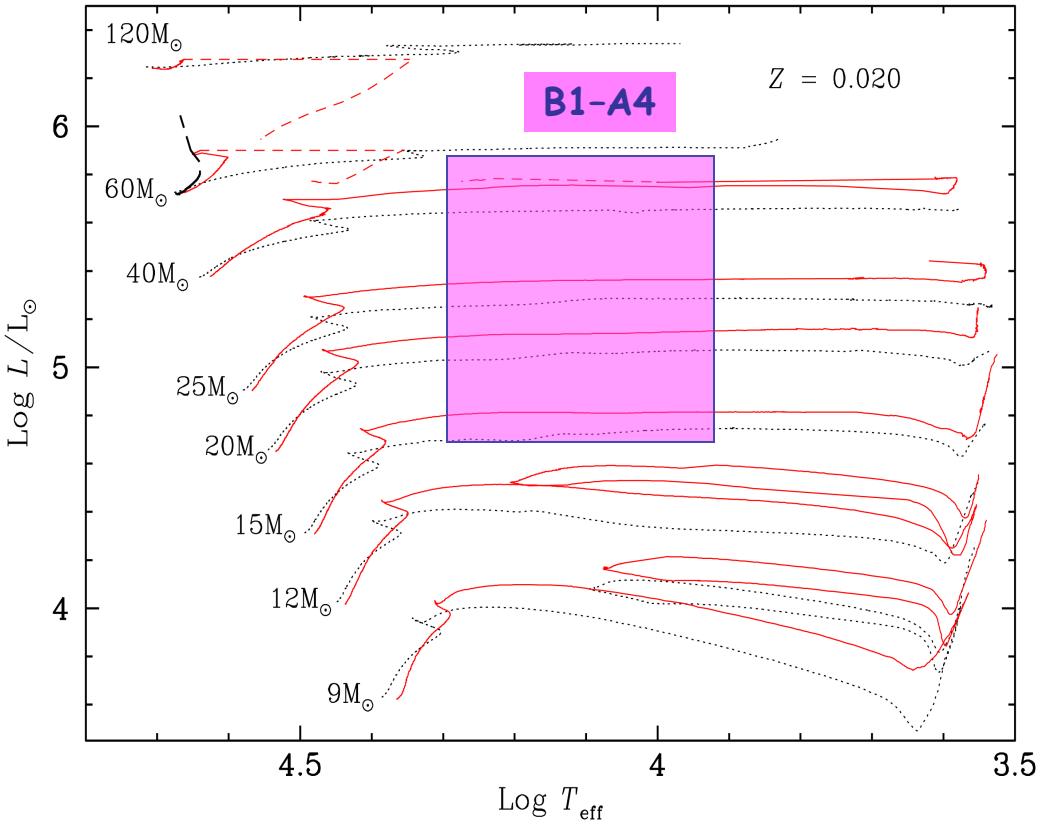
mass – metallicity relationship

depends crucially on strong line method calibration

supergiant stars will come to rescue !!!!

Blue 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

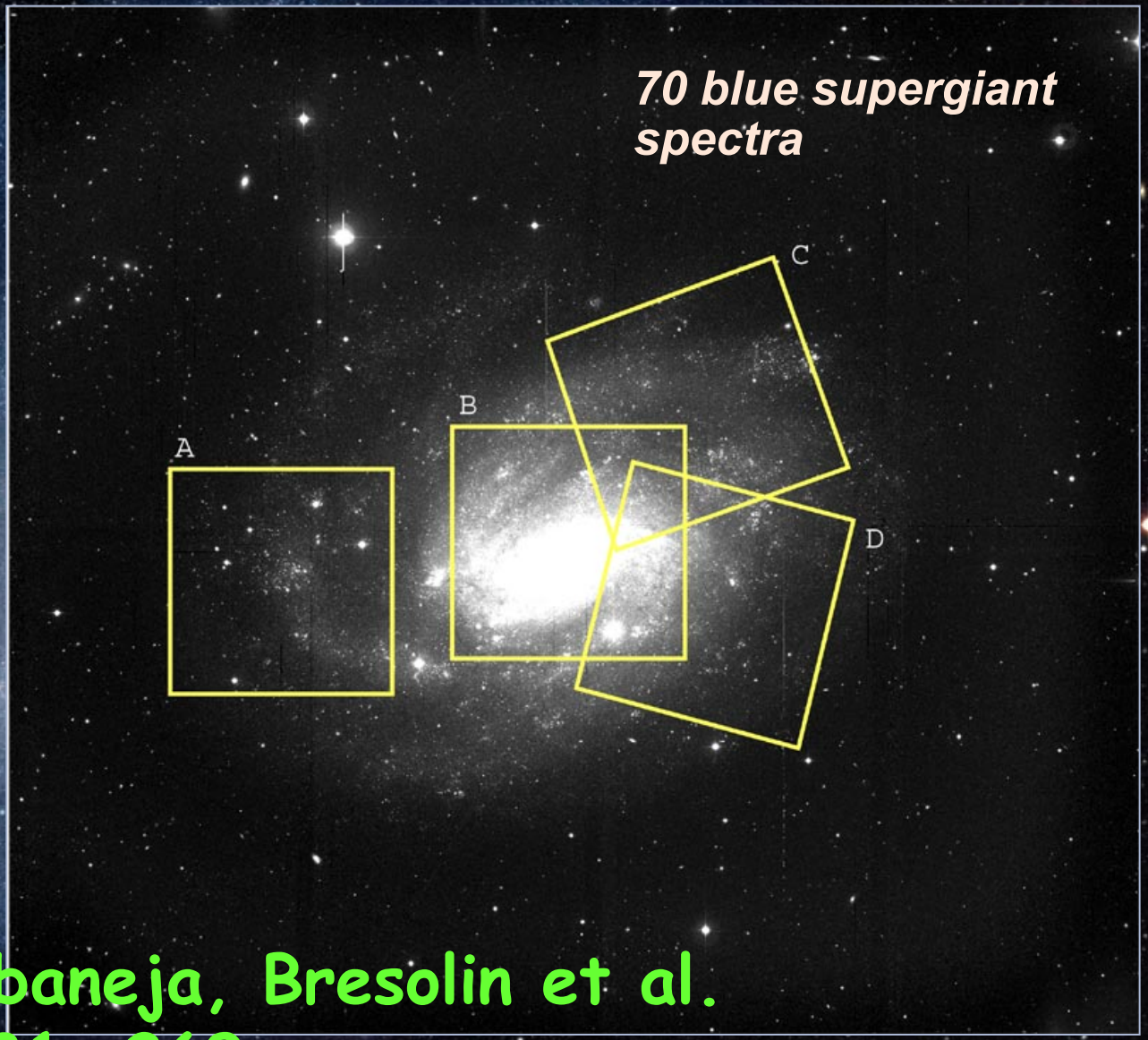
- chemical compos.
- abundance grad.
- SF history
- extinction
- extinction laws
- distances of galaxies

Spectroscopy of individual BSGs beyond the Local Group

- selection of targets from wide field CMDs
- HST ACS imaging
- multi-object spectroscopy
  $\Delta\lambda$ ~ 4-5 A with FORS @ VLT
  LRIS @ Keck

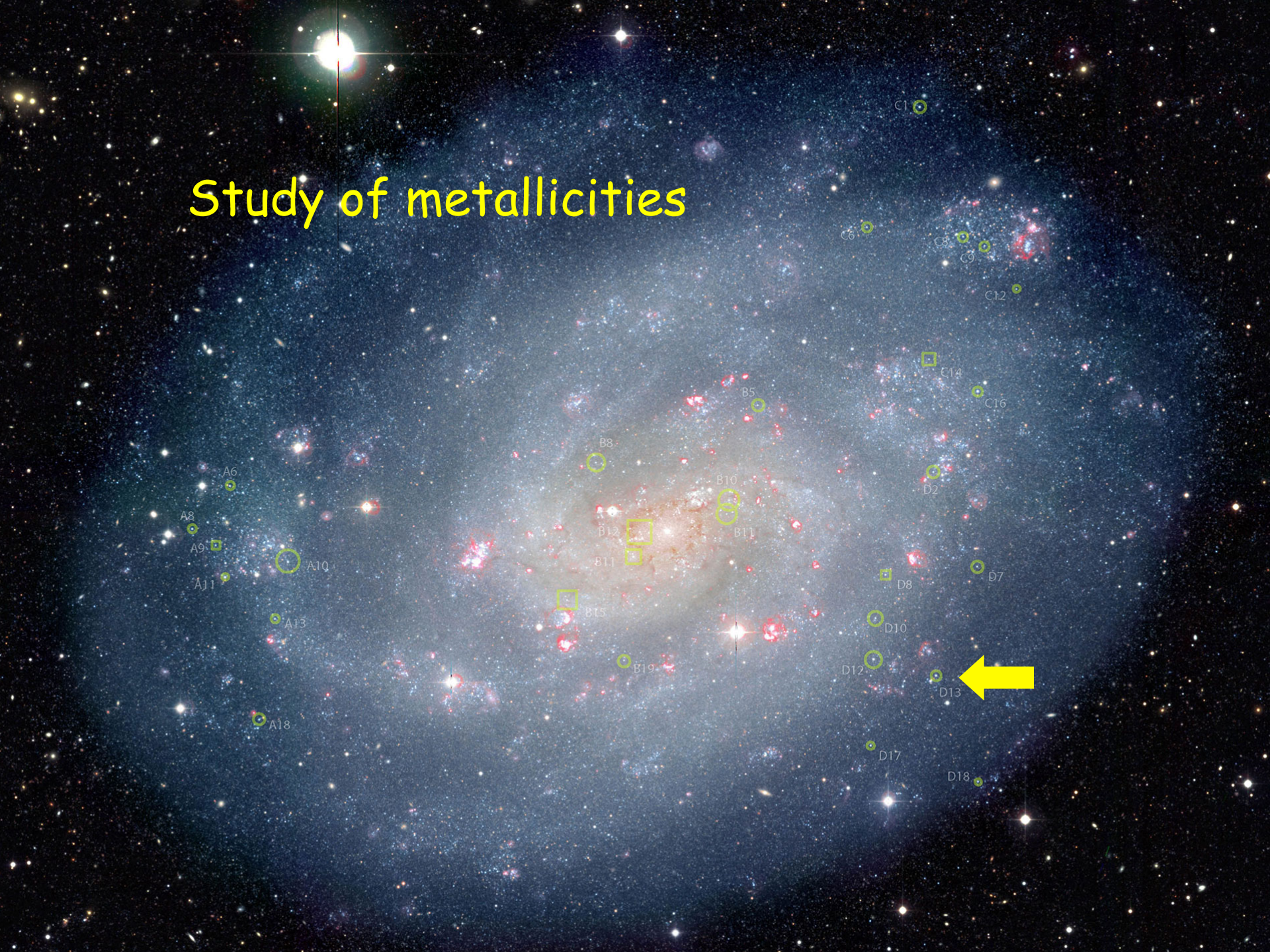
  → detailed NLTE model atmospheres
  T_{eff} ~ 4%, Δ log g ~ 0.05,
  metallicity ~ 0.1 dex
- galaxies out to 10 Mpc
  with TMT/E-ELT 30 Mpc

pilot study



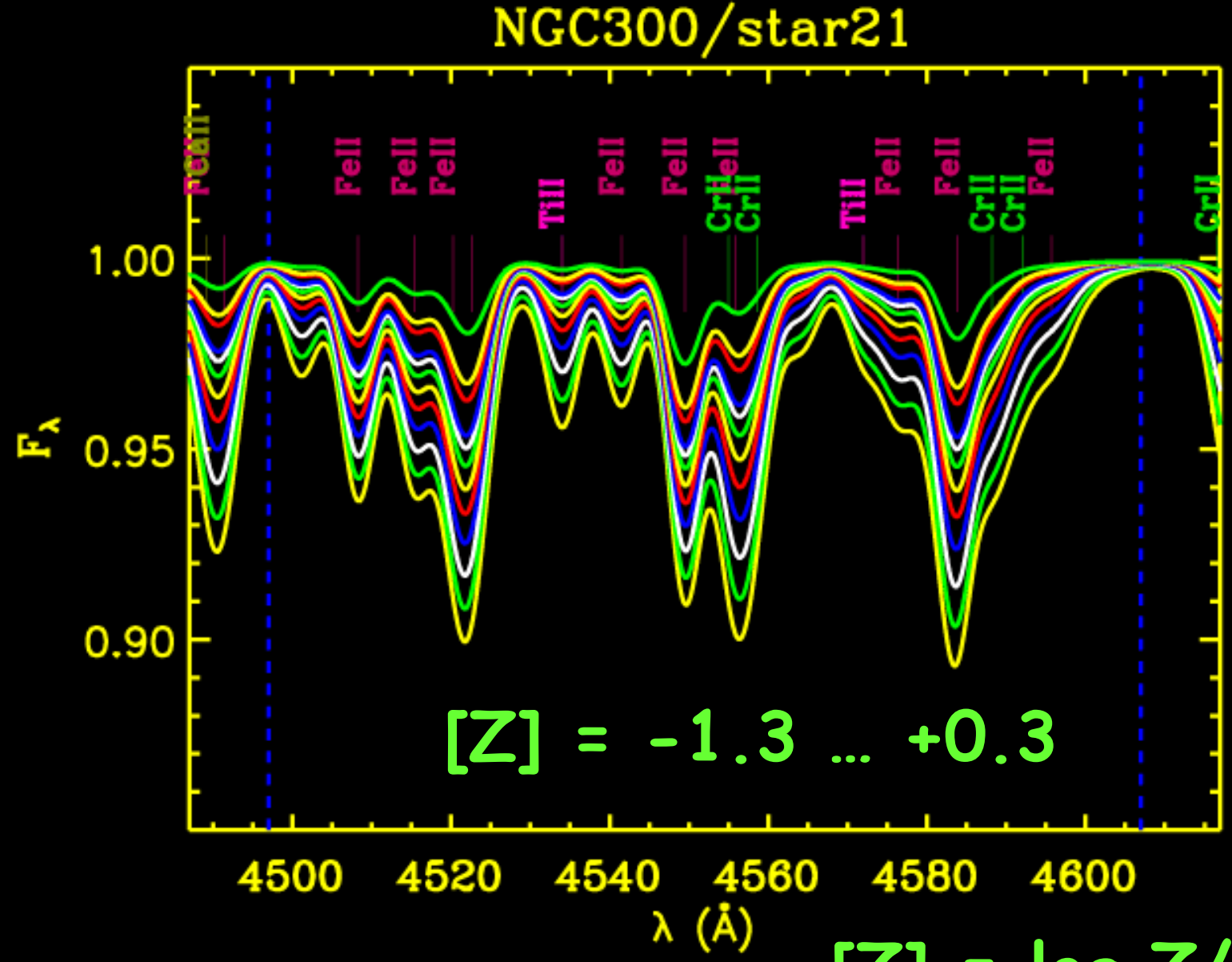
Kudritzki, Urbaneja, Bresolin et al.
2008, ApJ 681, 269

Study of metallicities



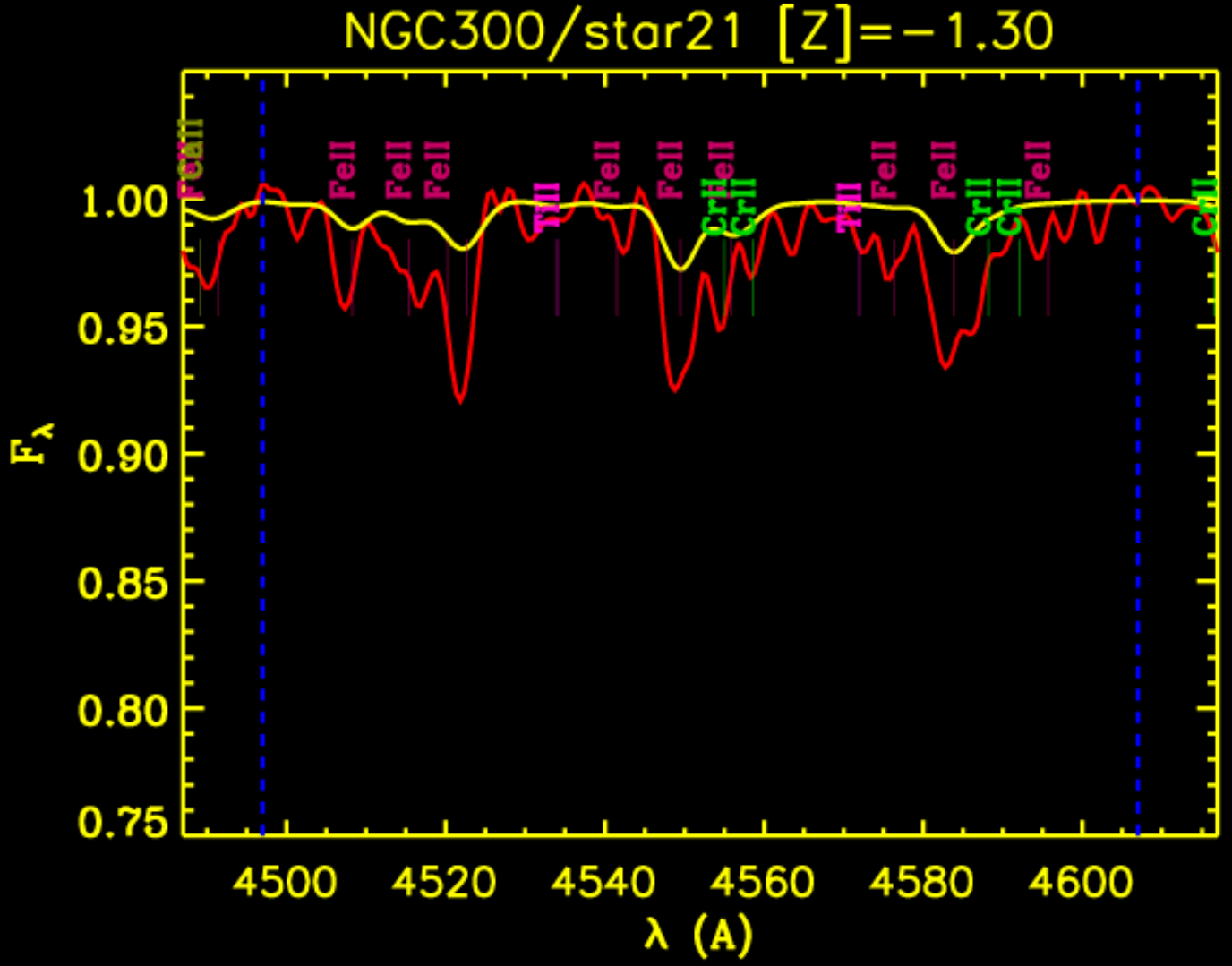
Athens 2013

Advanced atmosphere models: ~ 10^6 lines in NLTE



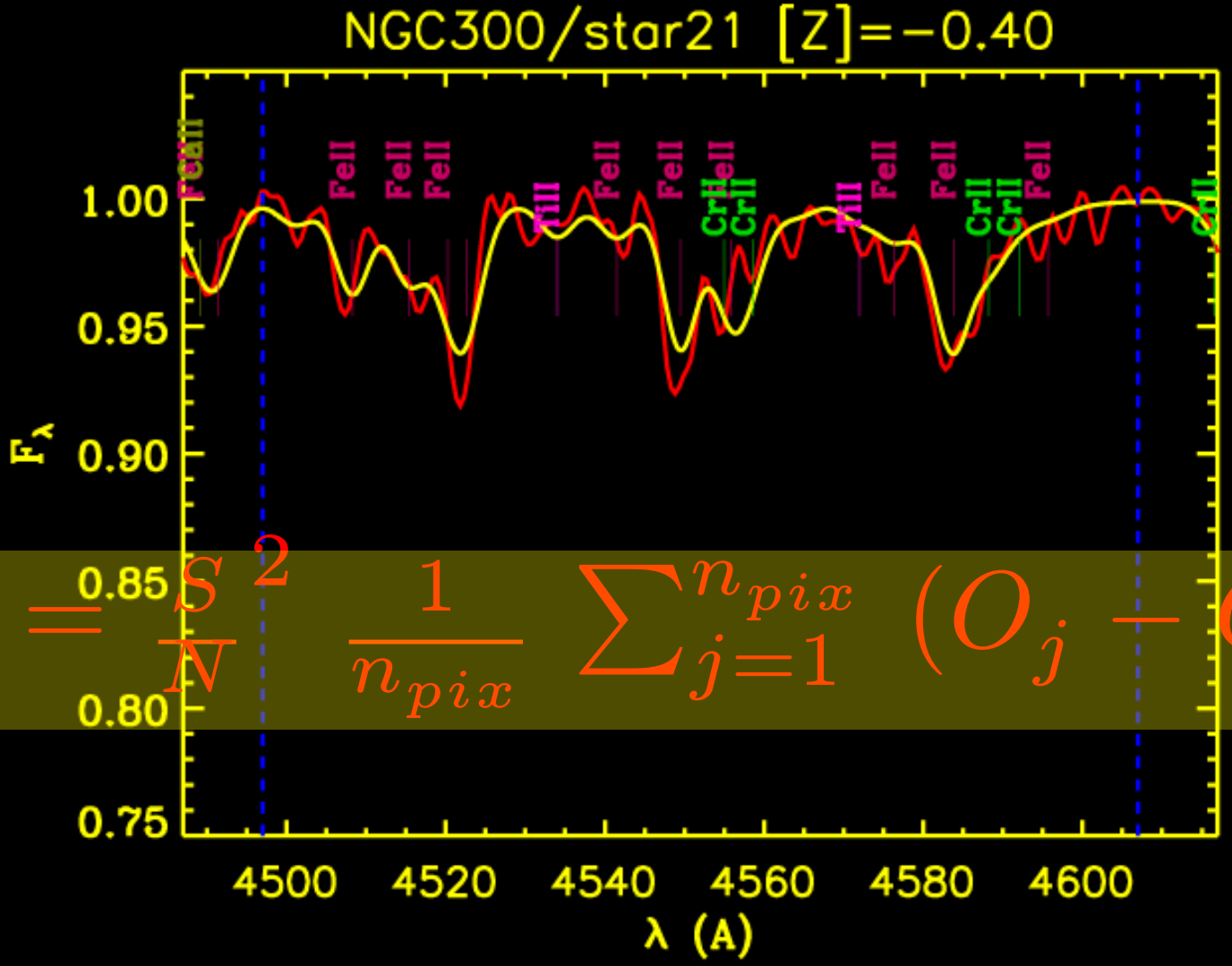
$[Z] = \log Z/Z_{sun}$

Spectral window 4497-4607Å



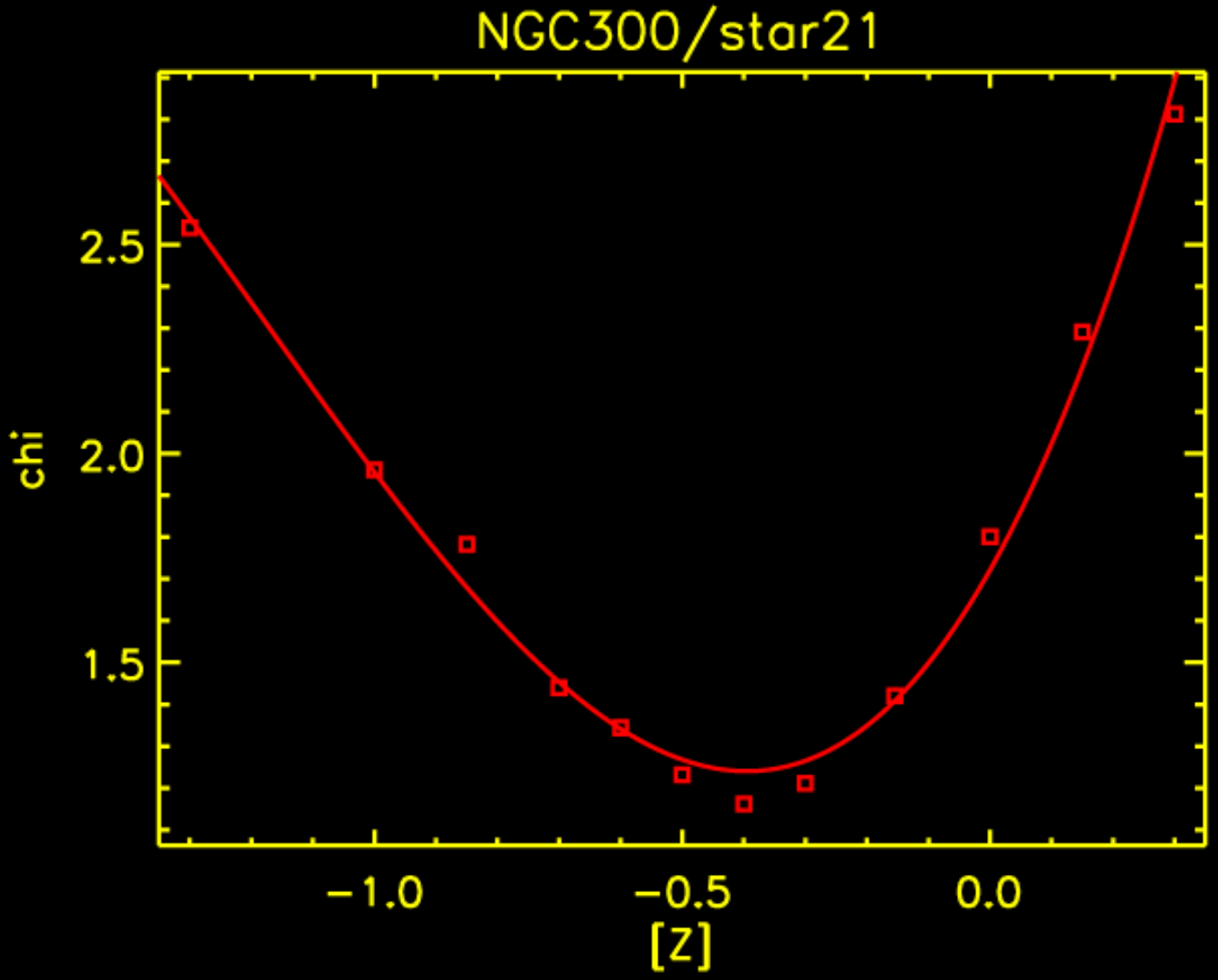
Spectral window 4497-4607Å

IfA 2012

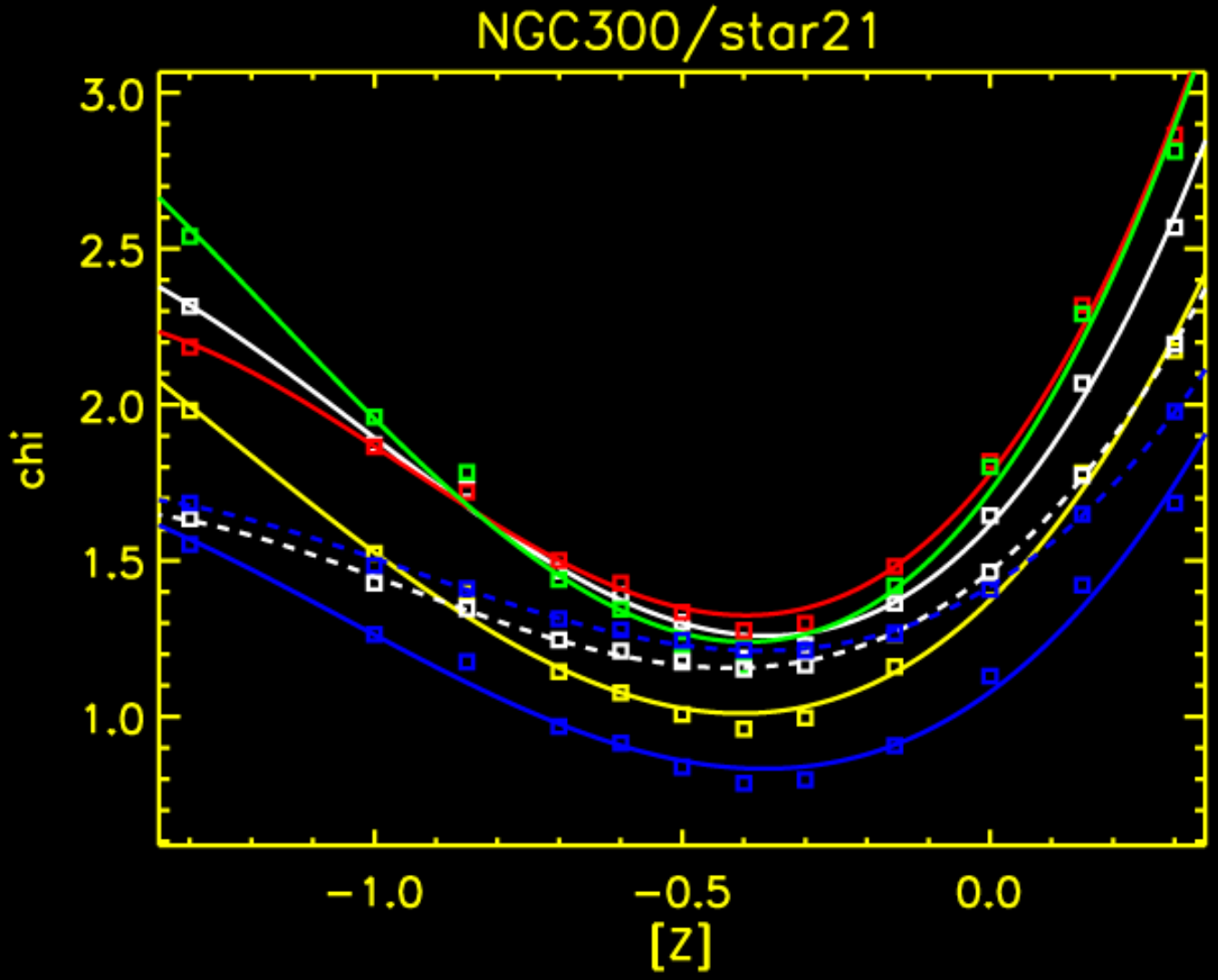


$$\chi_i^2 = \frac{S}{N}^2 \frac{1}{n_{pix}} \sum_{j=1}^{n_{pix}} (O_j - C_j)^2$$

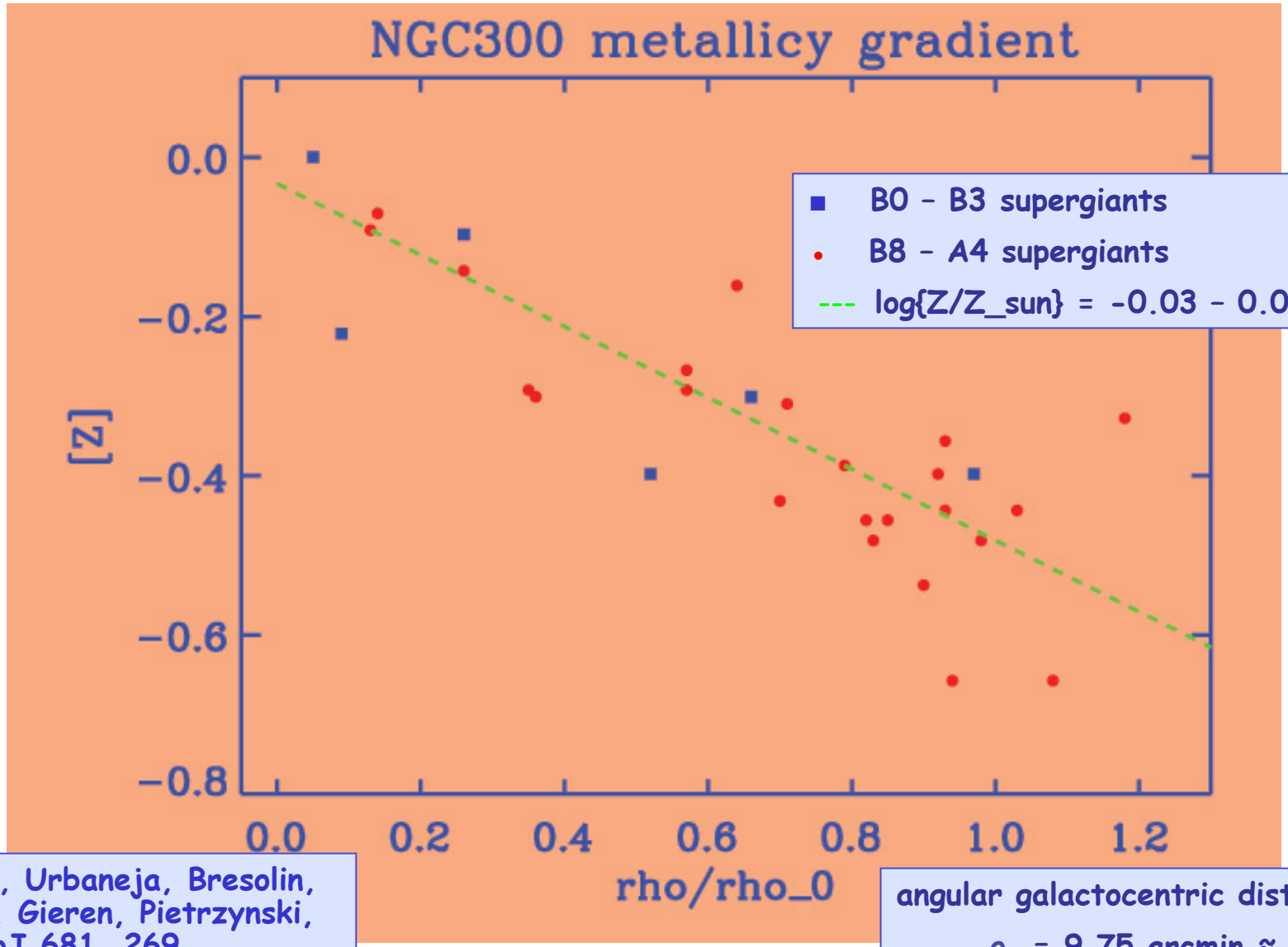
χ_i spectral window 4497-4607Å



X_i all windows → [Z] = -0.4±0.1



Stellar metallicity gradient in NGC300



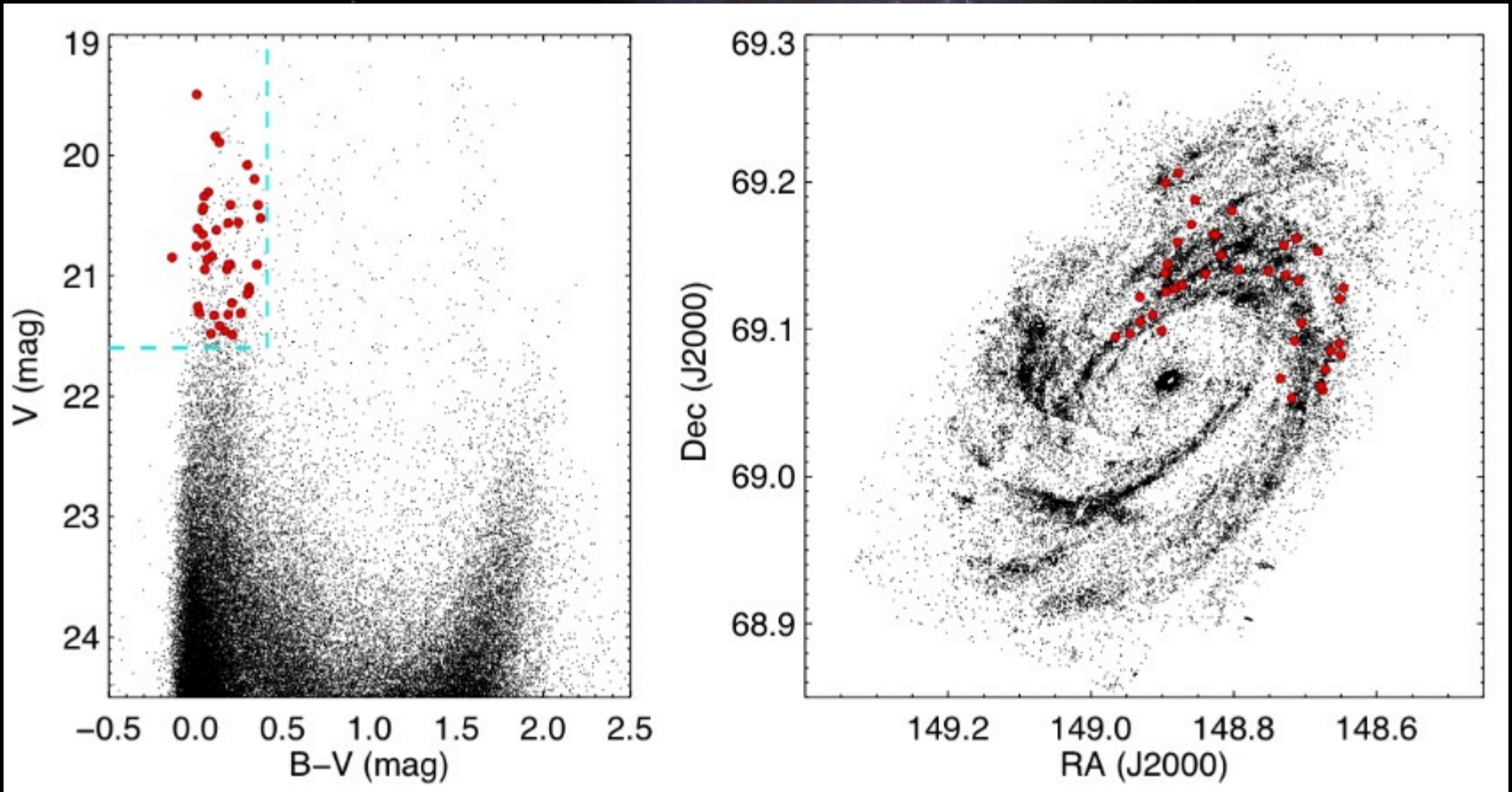
Kudritzki, Urbaneja, Bresolin, Przybilla, Gieren, Pietrzynski, 2008, ApJ 681, 269

angular galactocentric distance

ρ_0 = 9.75 arcmin ≈ 5.7kpc

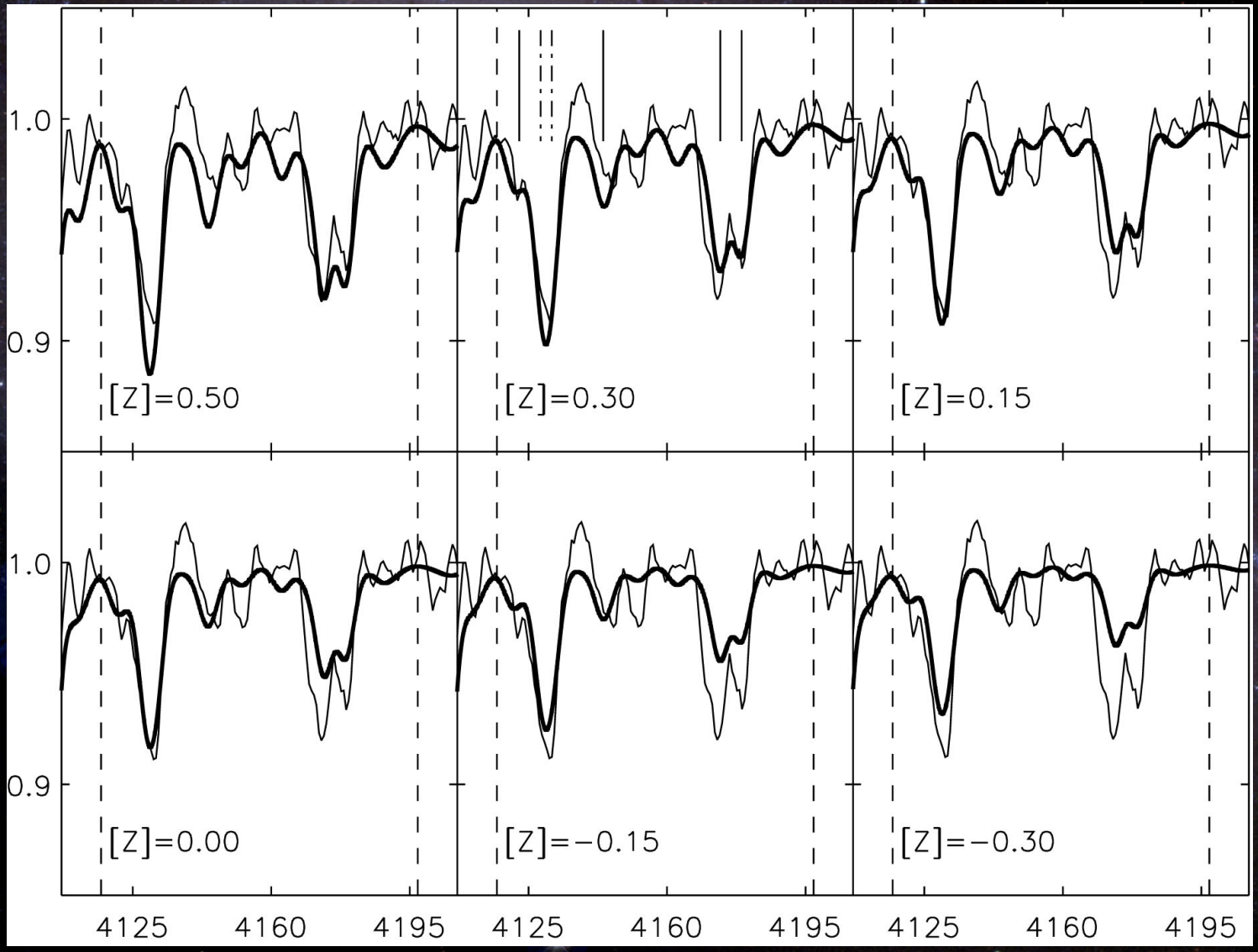
M81

Keck LRIS

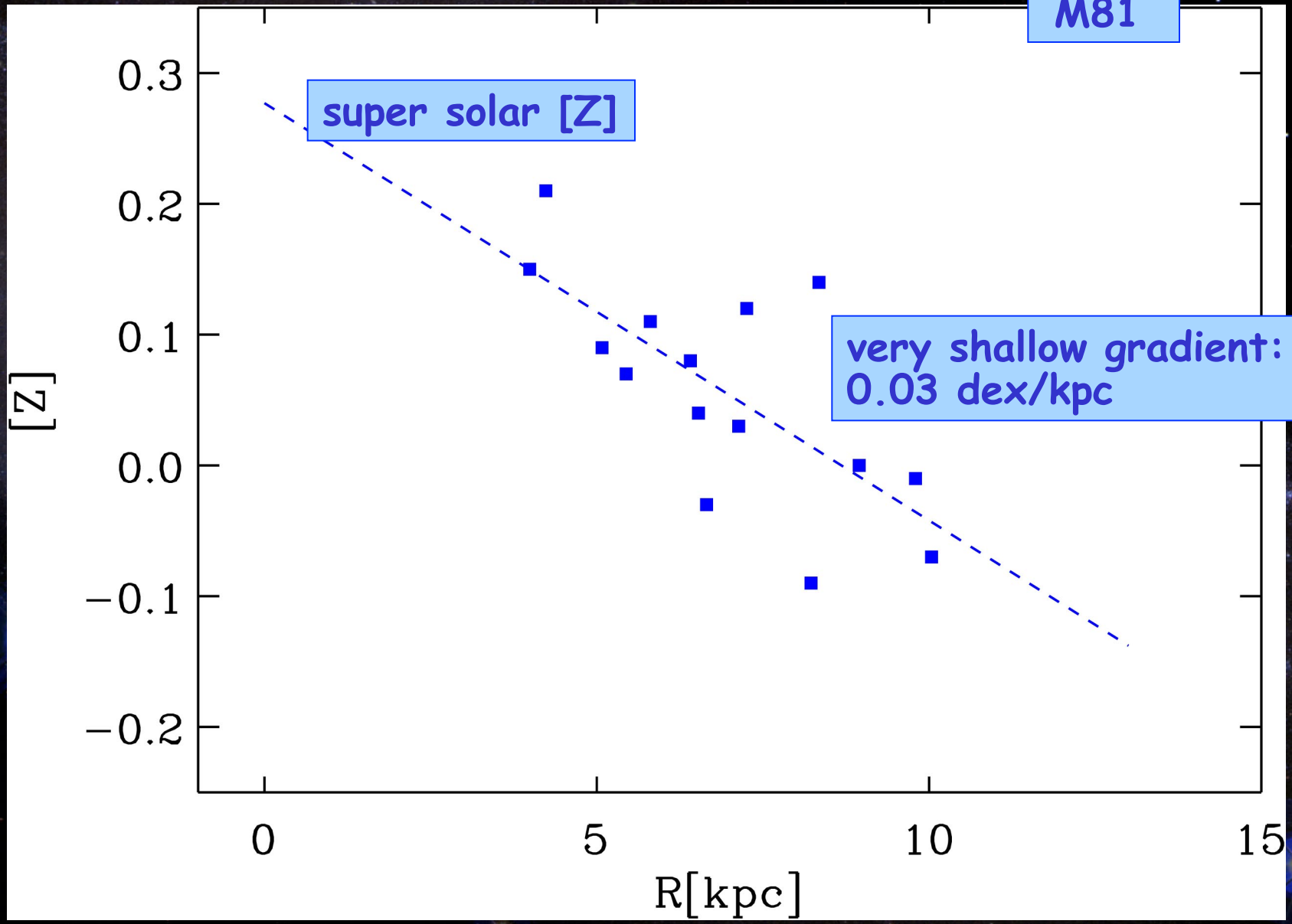


Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

M81
object C20

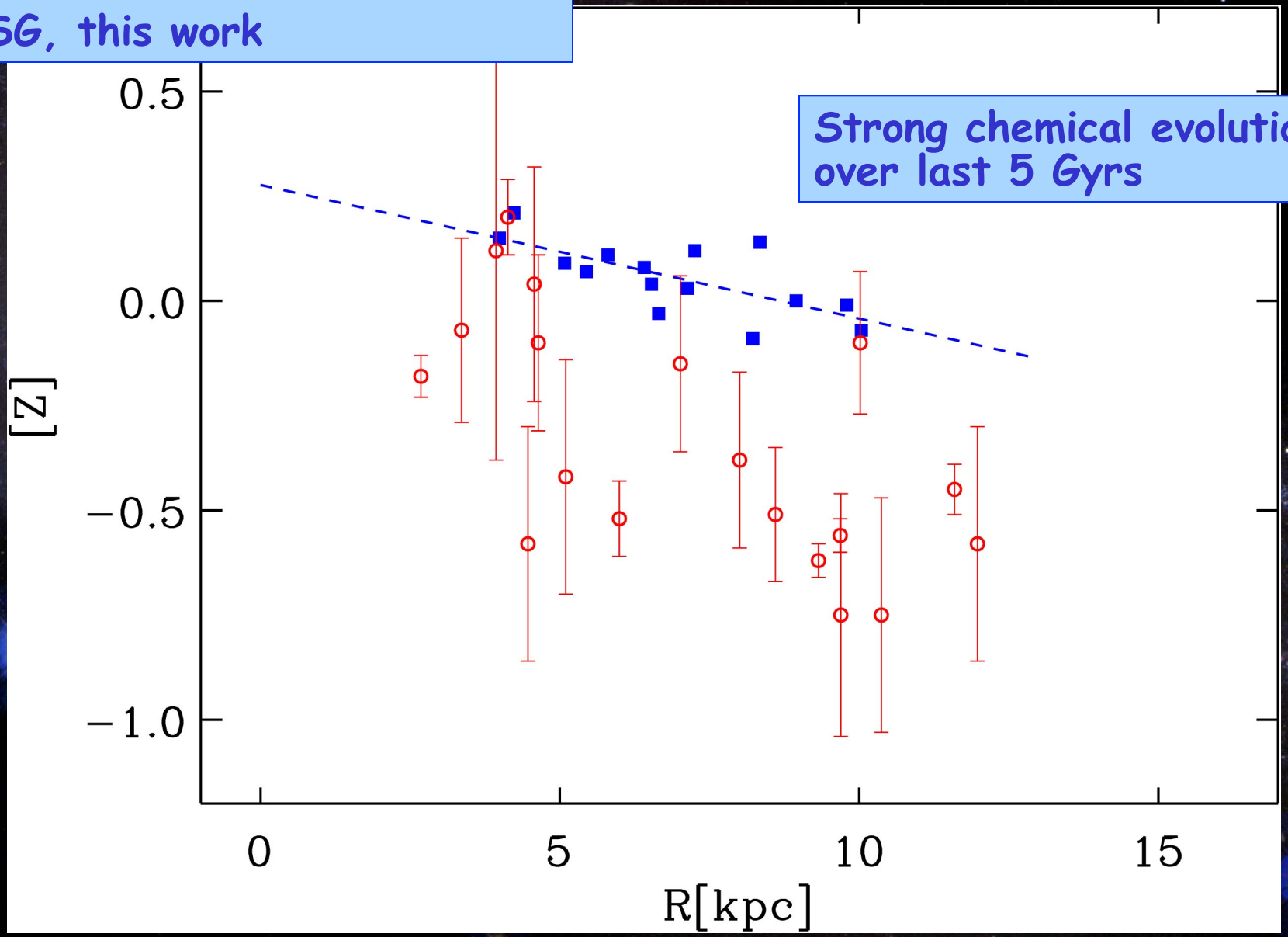


Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15



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

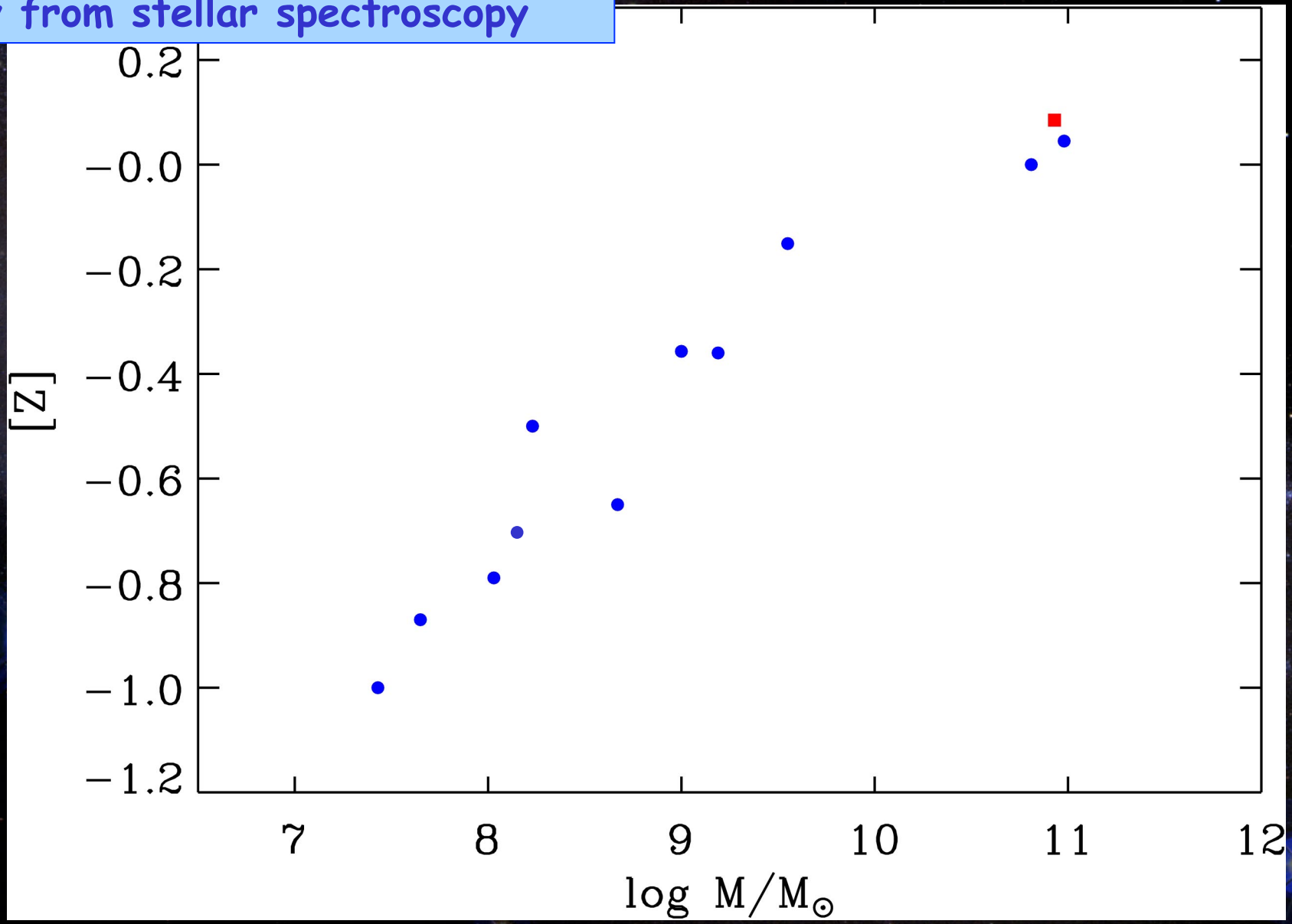
- PNe, Stanghellini et al. 2010
- BSG, this work



Strong chemical evolution over last 5 Gyrs

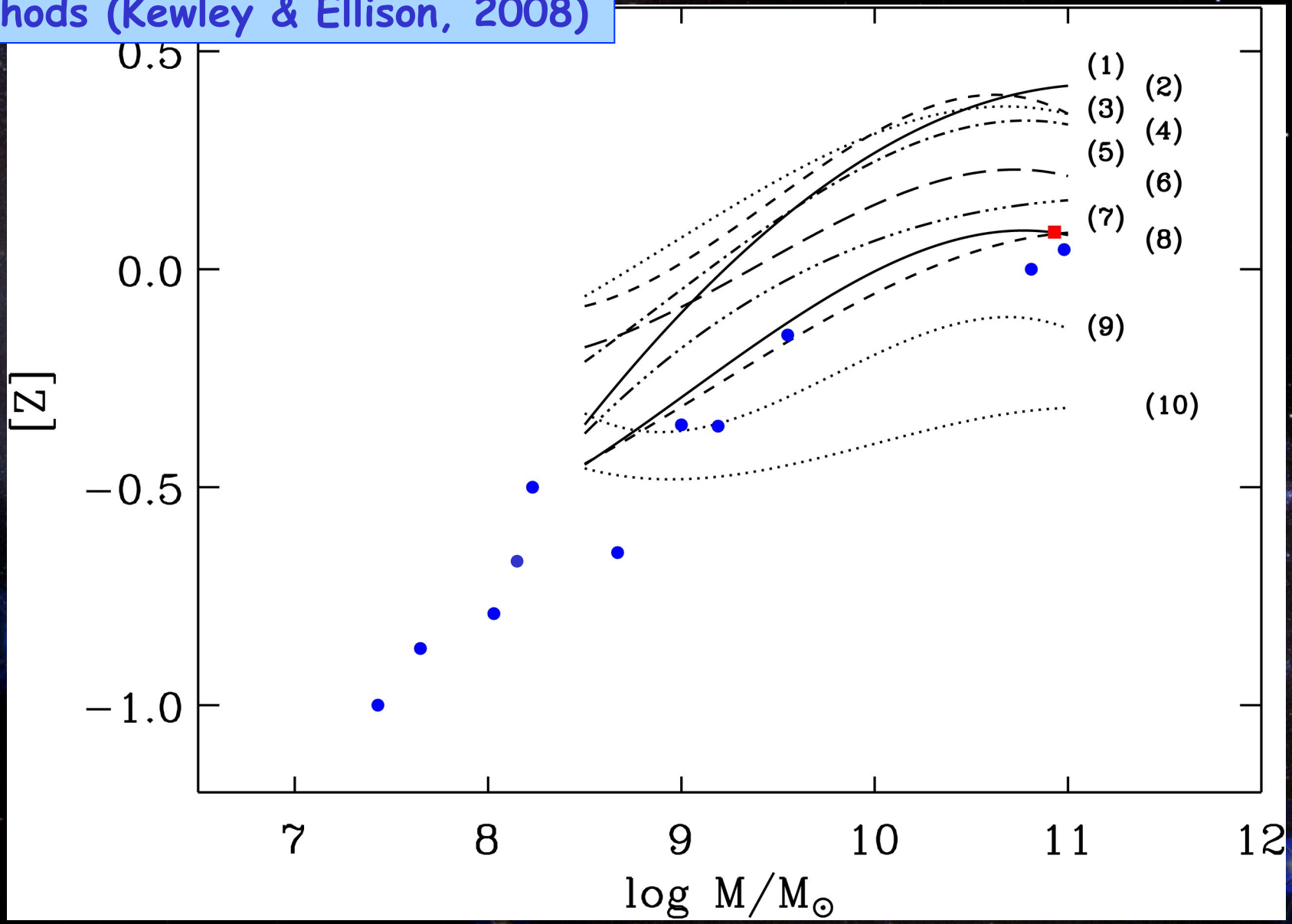
Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

A mass-metallicity relationship only from stellar spectroscopy



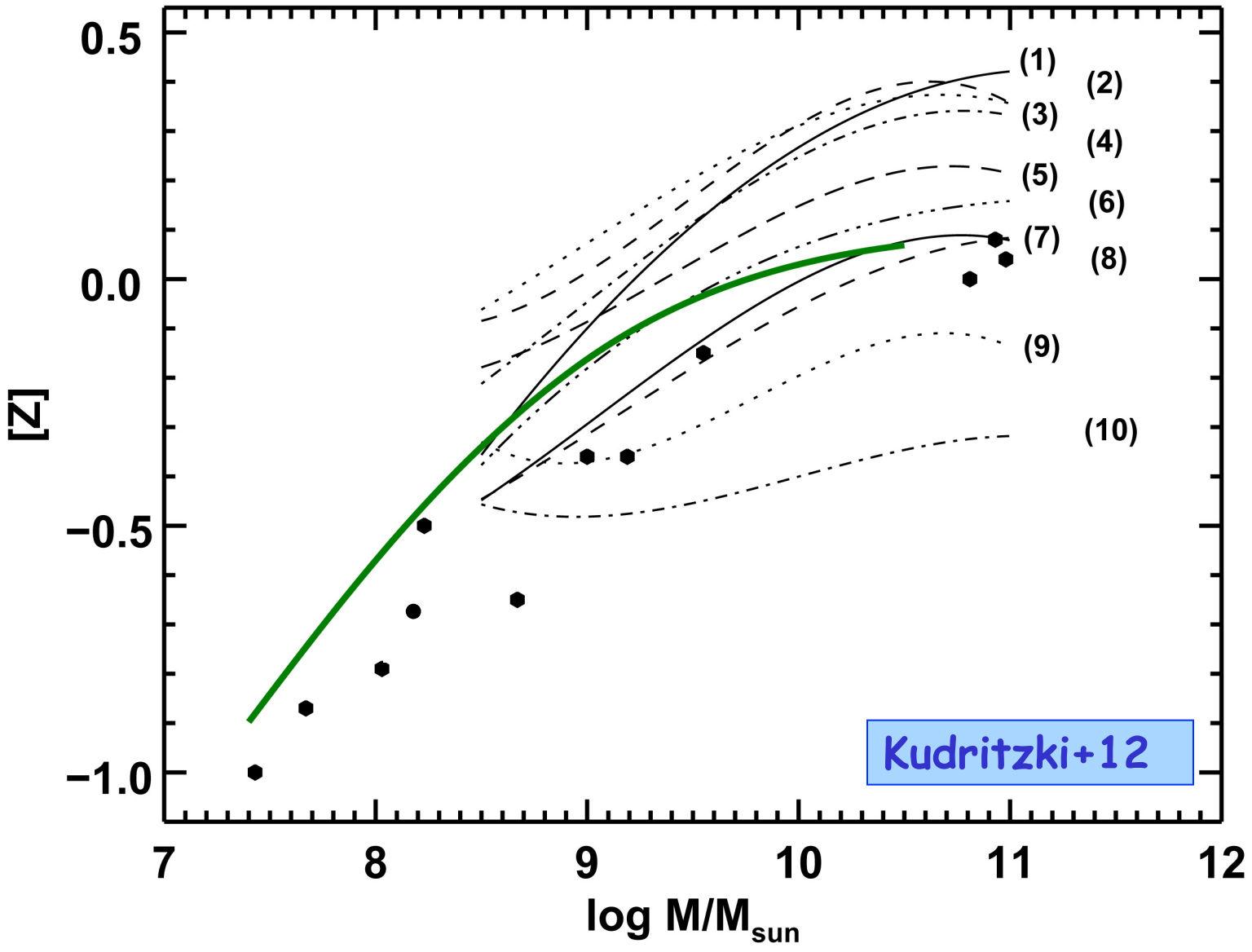
Kudritzki, Urbaneja, Gazak et al., 2012, ApJ 747, 15

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



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

HII auroral line method –staggered SDSS spectra
Andrew & Martini, 2013



H_0 uncertainty and universe equation of state

Hubble constant uncertainty → EoS parameter w

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

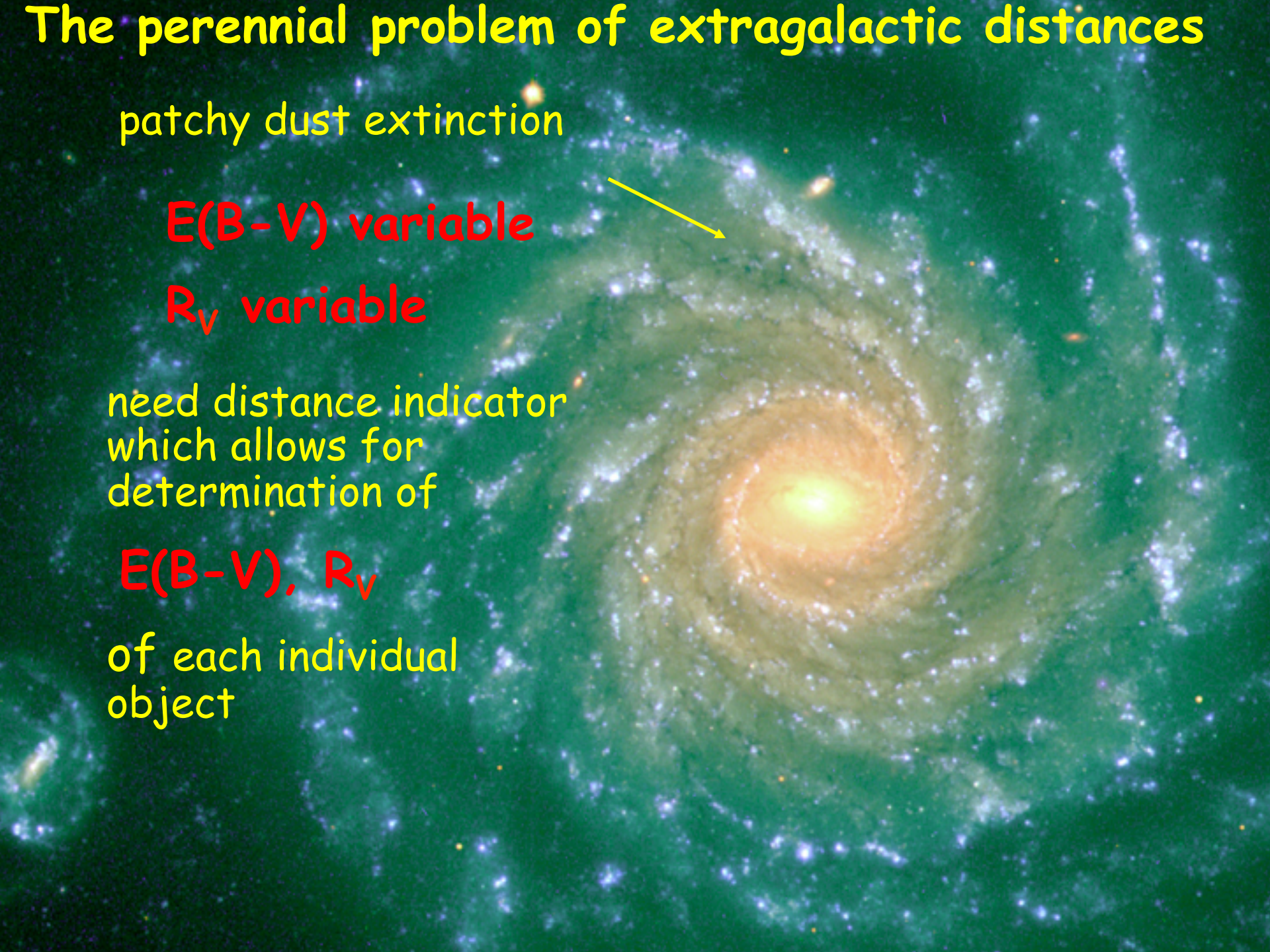
$$w = \frac{p}{c^2 \rho}$$

δH_0 ~ 10% → δw ~ 0.2

1% → δw ~ 0.02 goal for next decade !!

Riess et al., 2009, 2011 → δH_0 ~ 3%

The perennial problem of extragalactic distances



patchy dust extinction

E(B-V) variable

R_V variable

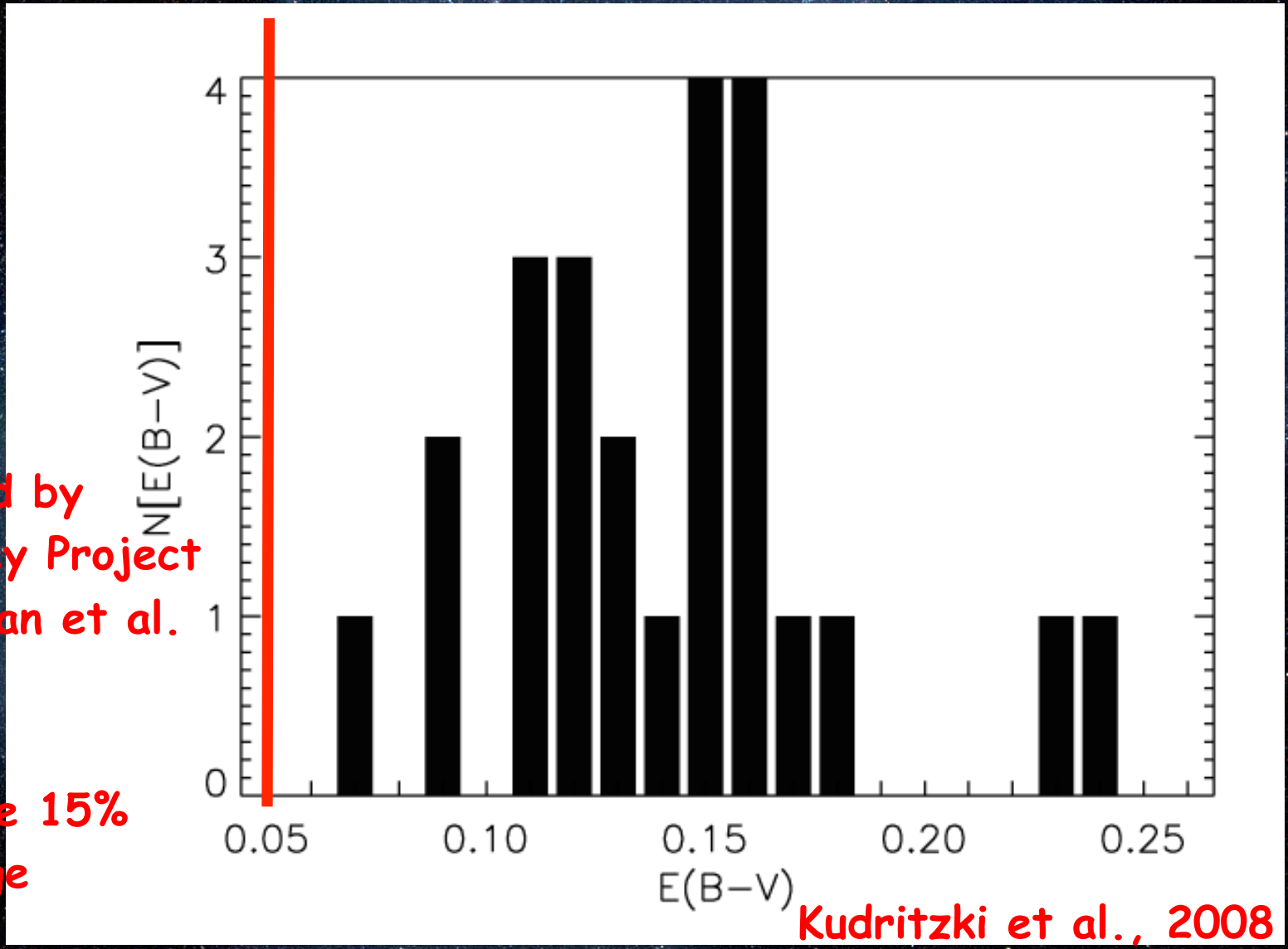
need distance indicator which allows for determination of

E(B-V), R_V

of each individual object

NGC 300 at 1.9 Mpc

E(B-V) from BSG spectroscopy



Kudritzki et al., 2008

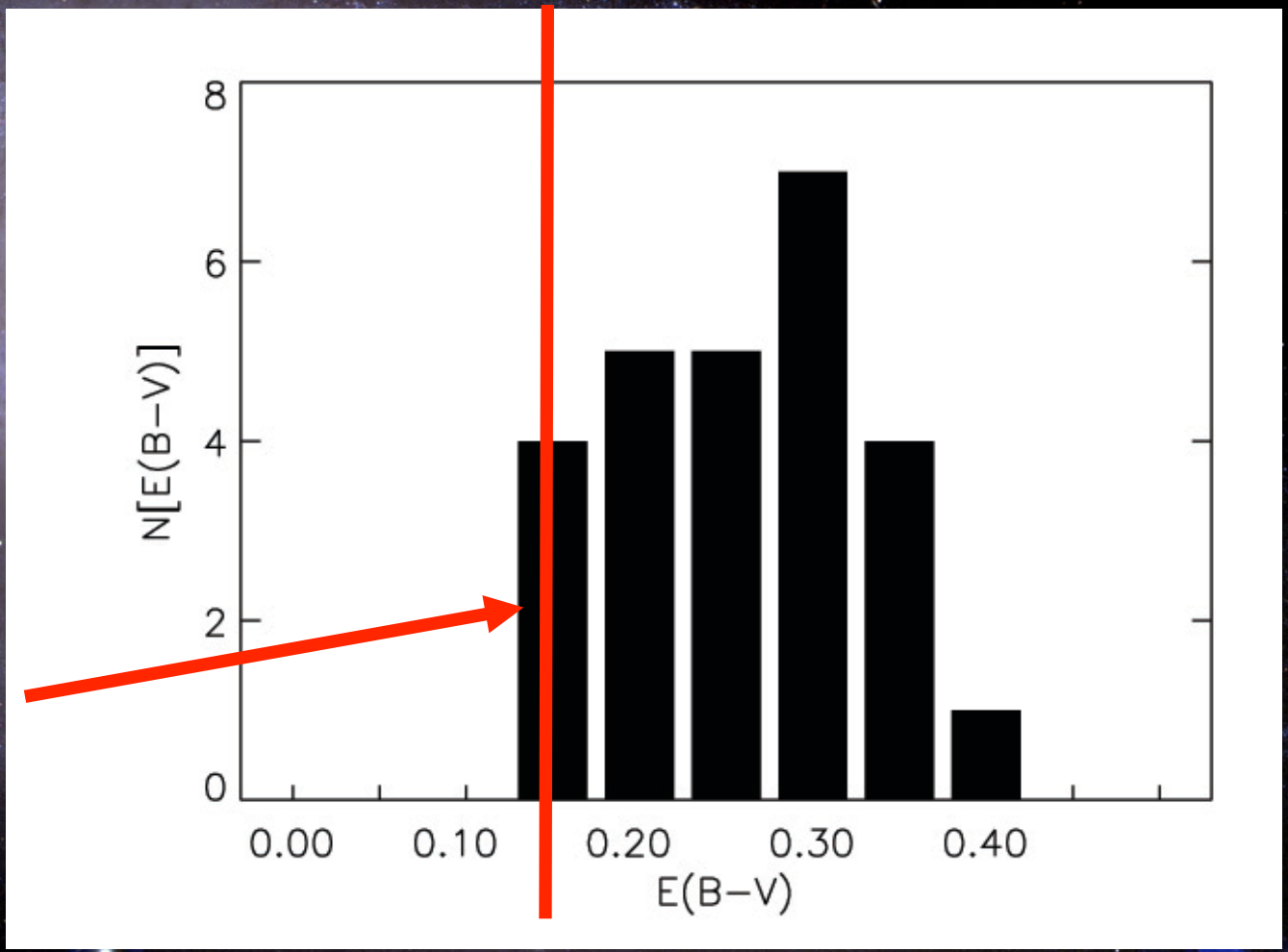
Adopted by HST Key Project Freedman et al. 2001

→

Distance 15% too large

M81 at 3.5 Mpc

E(B-V) from BSG spectroscopy



Adopted by HST Key Project Freedman et al. 2001

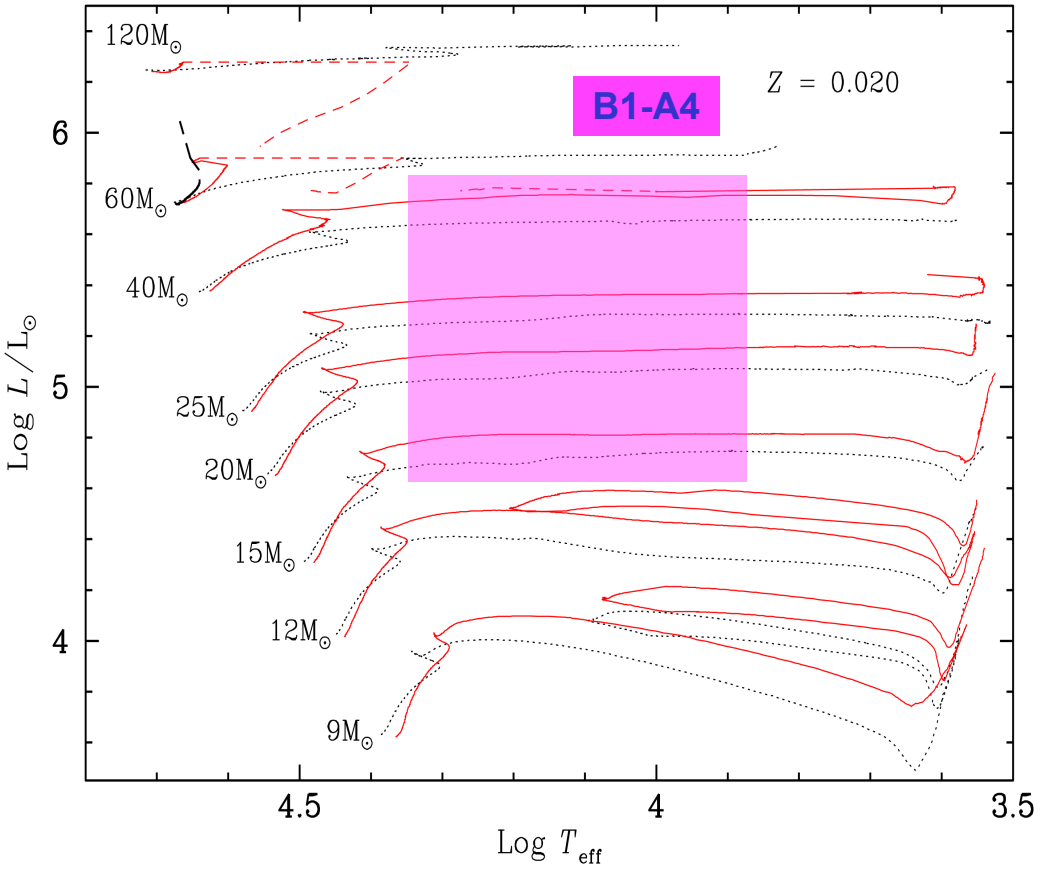
→

Distance too large

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

Flux weighted Gravity – Luminosity Relationship (FGLR)

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



L,M ~ const.

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

const.

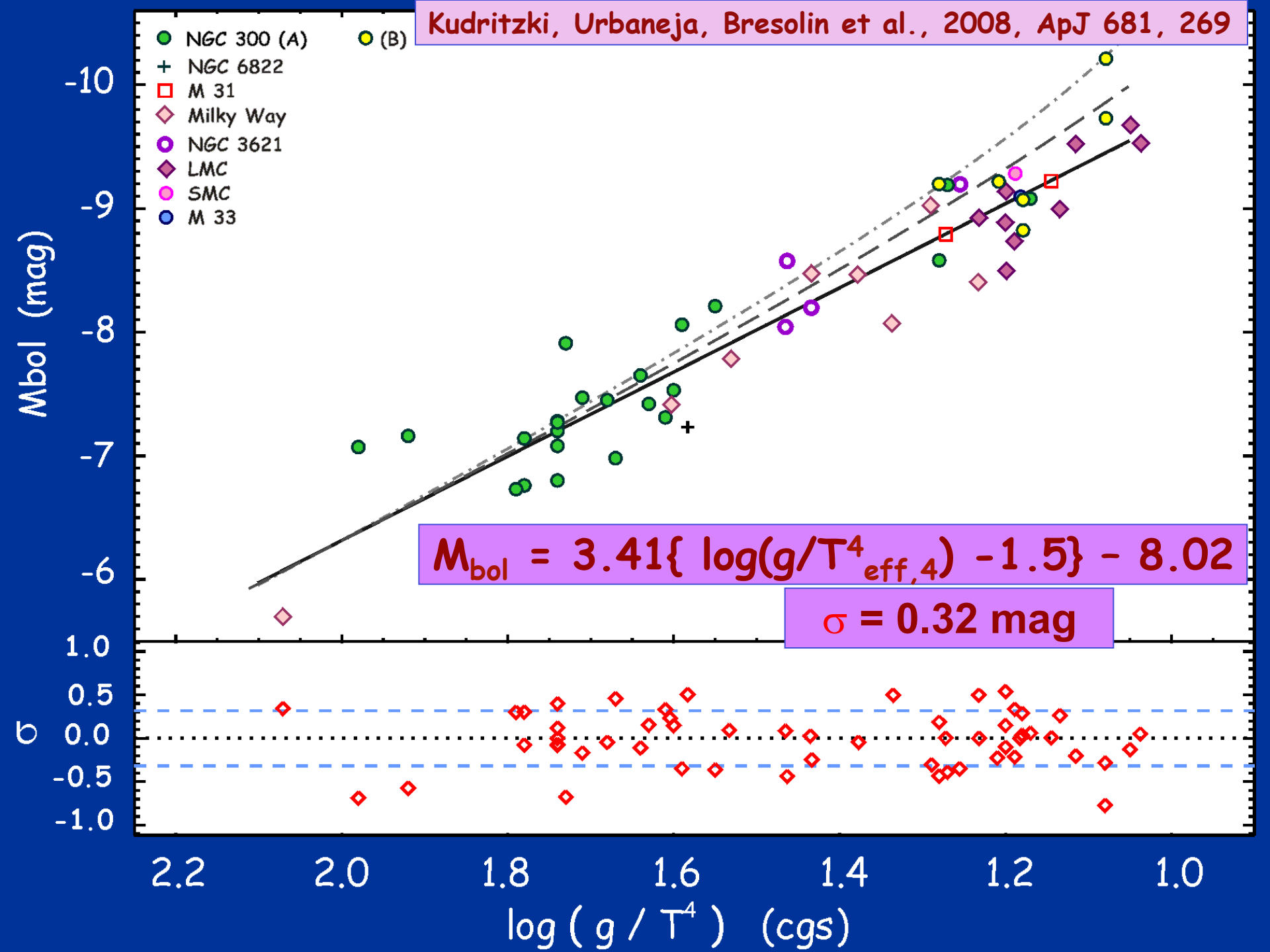
with $L \sim M^x \sim L^x (g/T^4)^x$, $x \sim 3$

$\rightarrow L^{1-x} \sim (g/T^4)^x$

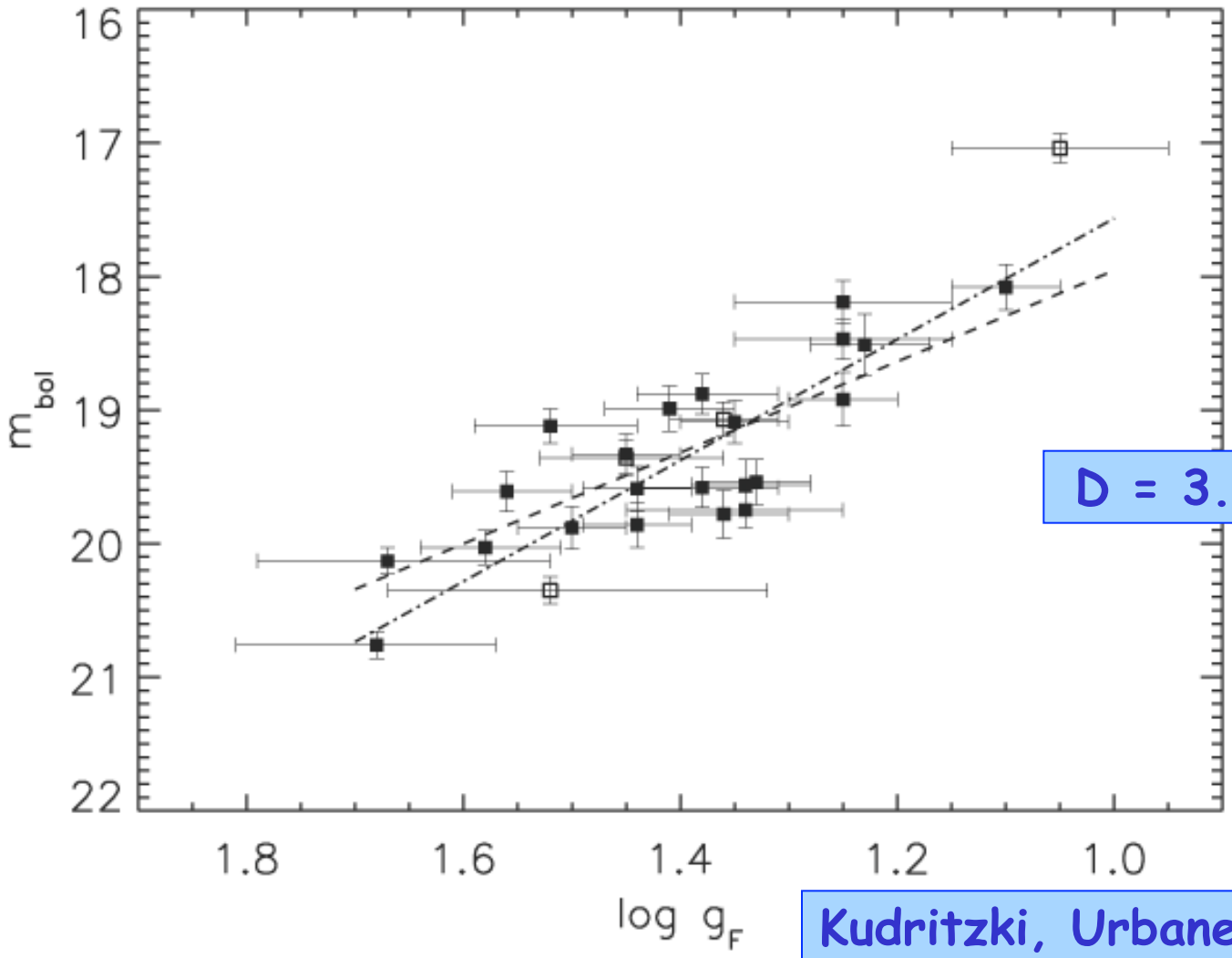
or with $M_{bol} \sim -2.5 \log L$

$M_{bol} = a \log(g/T^4) + b$ 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
$M_{bol} = 3.41\{ \log(g/T^4_{eff,4}) - 1.5\} - 8.02$
$\sigma = 0.32$ mag
Mbol (mag)
-10
-9
-8
-7
-6
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)

M81 FGLR



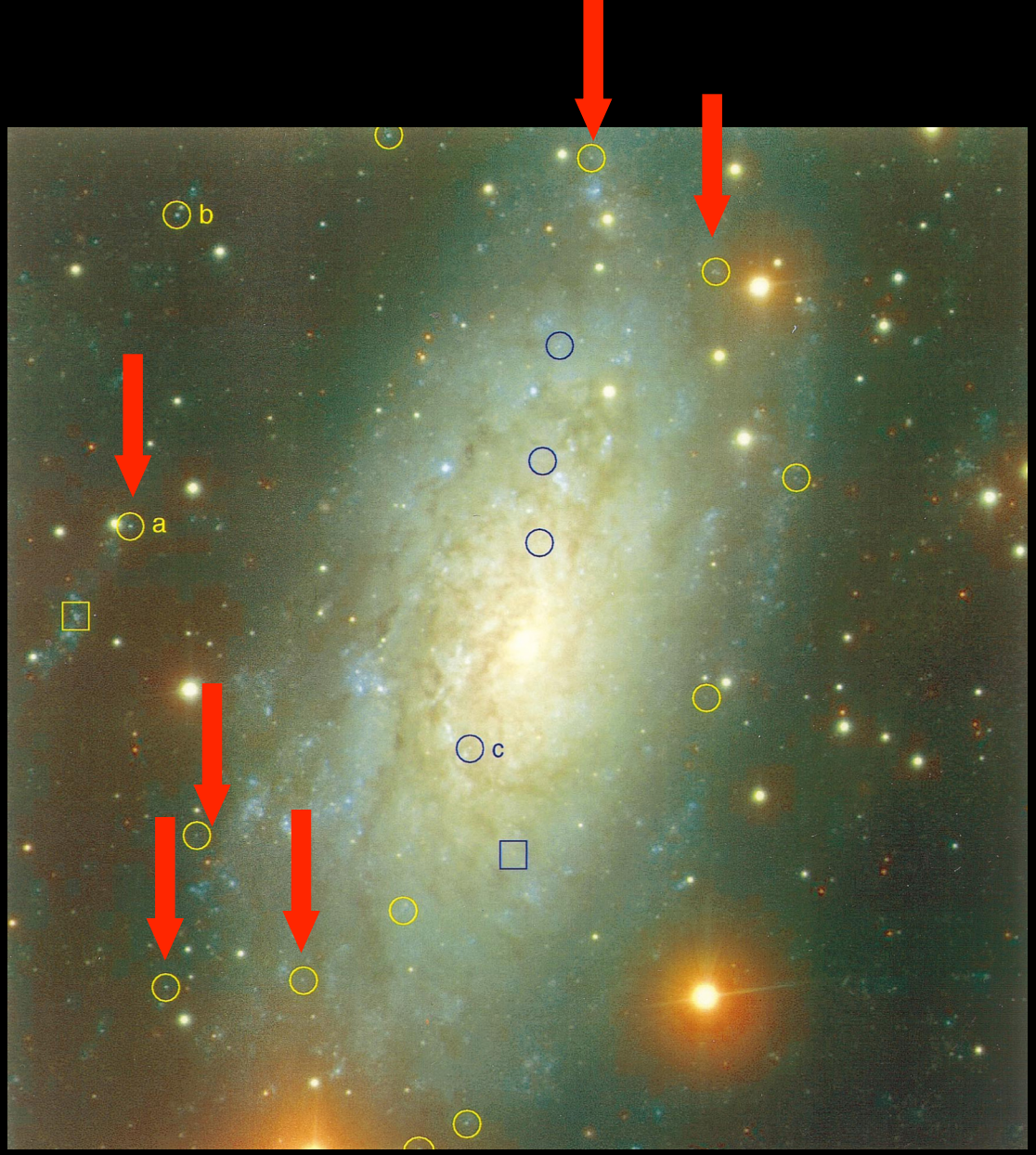
D = 3.47 ± 0.16 Mpc

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

NGC 3621

Key Project galaxy at 6.5 Mpc

Tully-Fisher calibrator

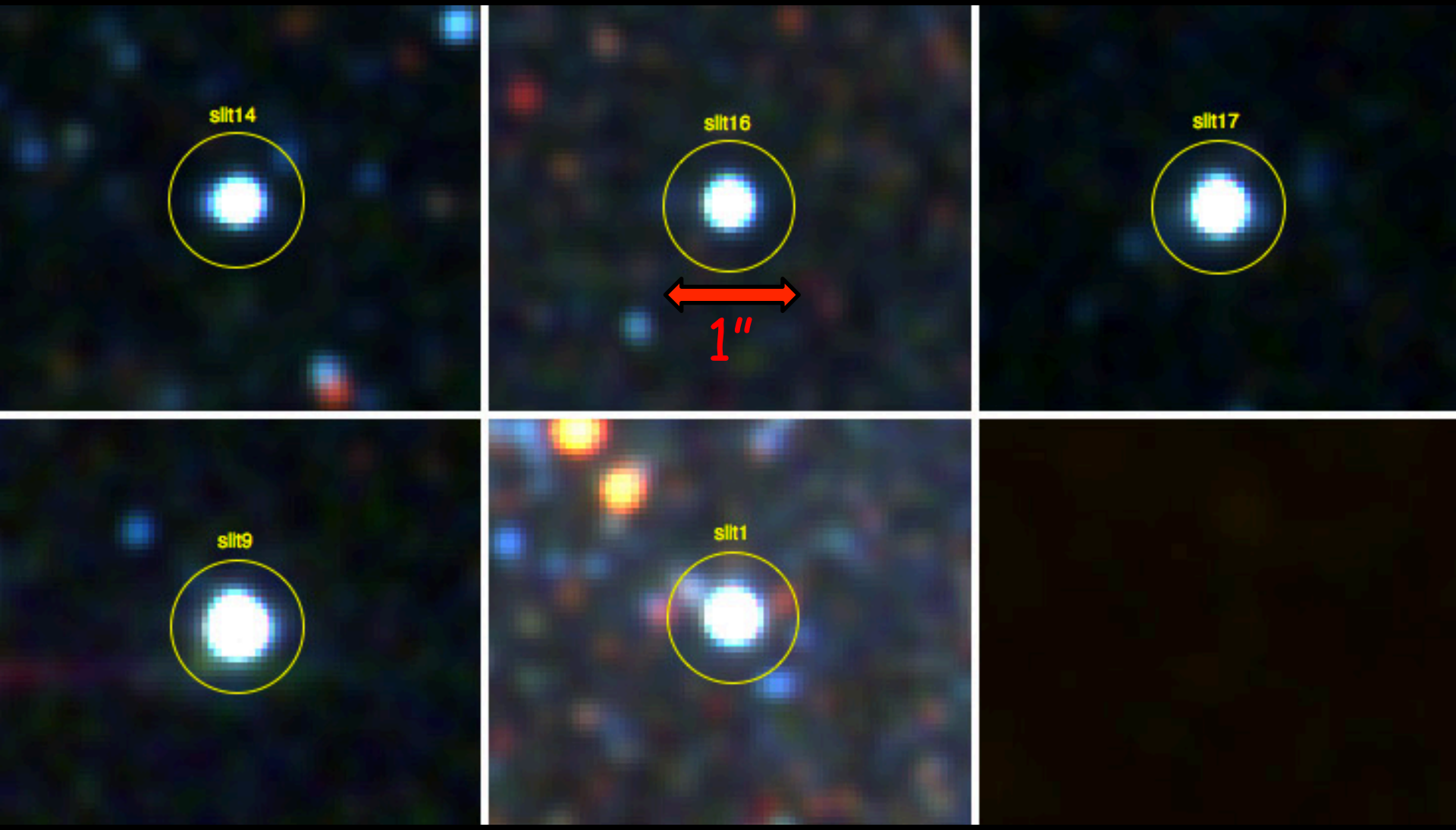


BSGs in NGC 3621

VLT/FORS spectra

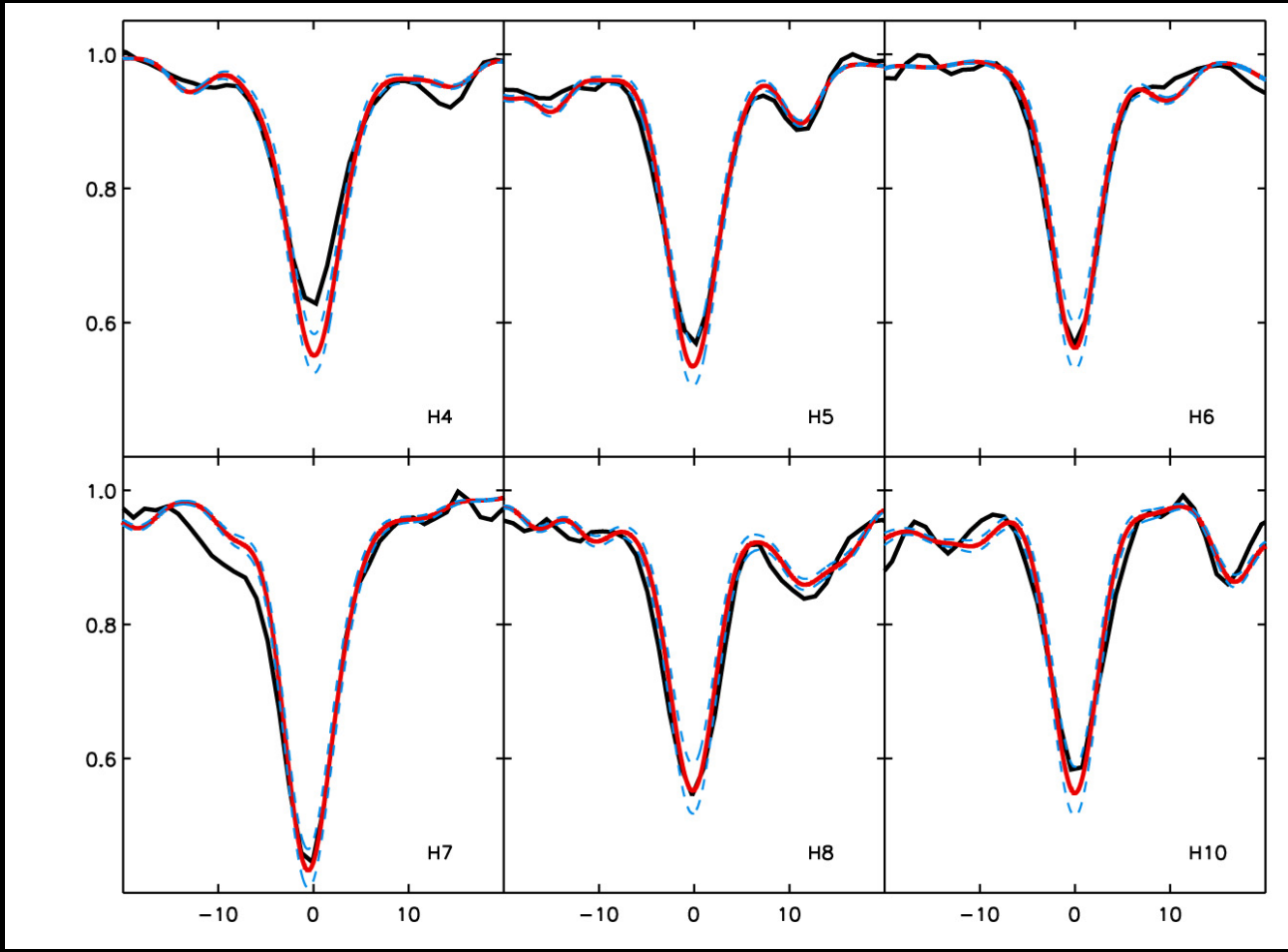
Kudritzki, Urbaneja, Bresolin, Hosek, Przybilla, 2014, ApJ, 788, 56

BSGs in NGC 3621: HST ACS



Fit of Balmer lines → log g

NGC 3621 slit 17



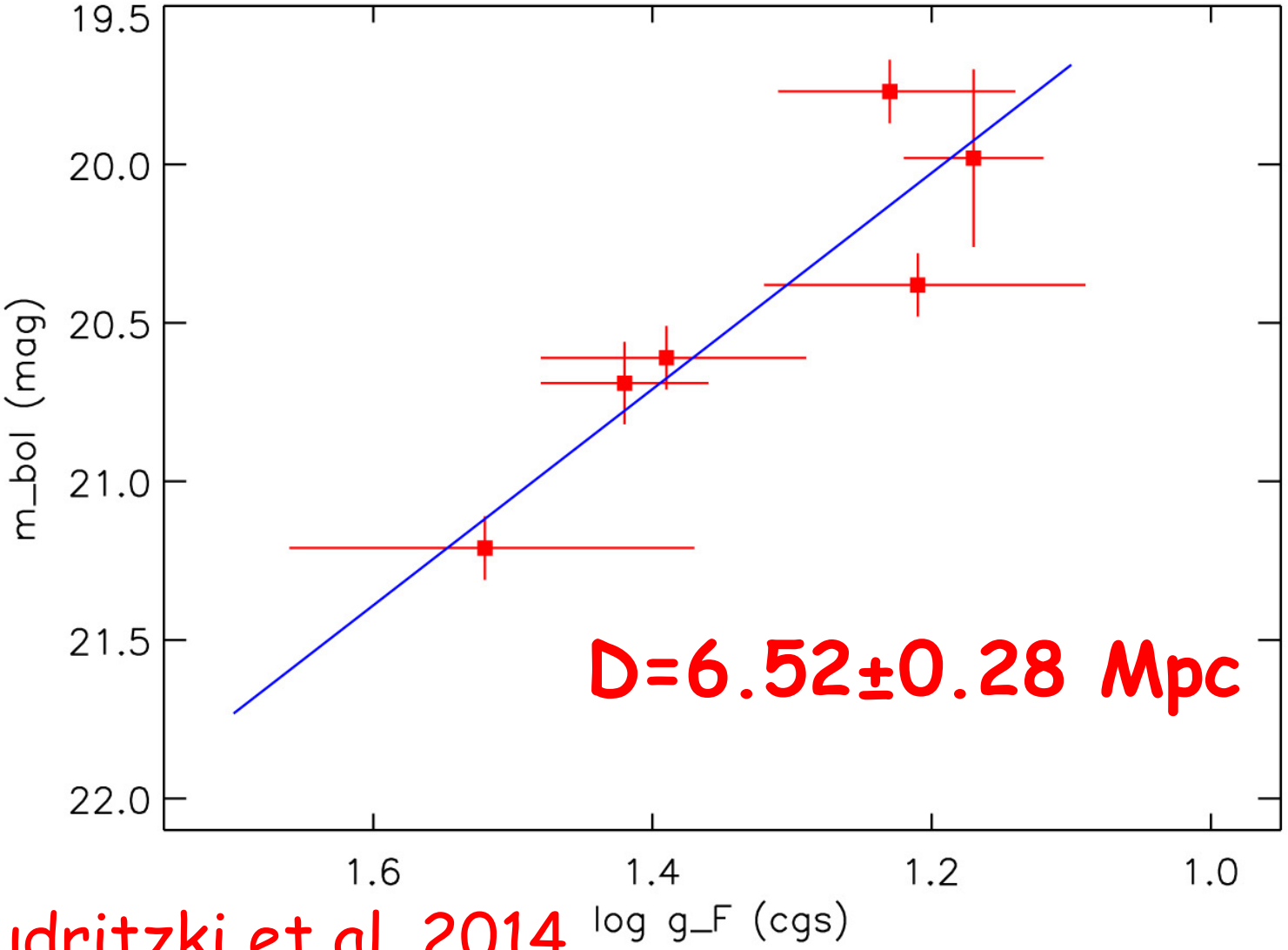
best log g fit

--- Δlog g = ±0.05

At fixed T_{eff}

Δ log g ≤ ± 0.05

NGC 3621 FGLR and distance

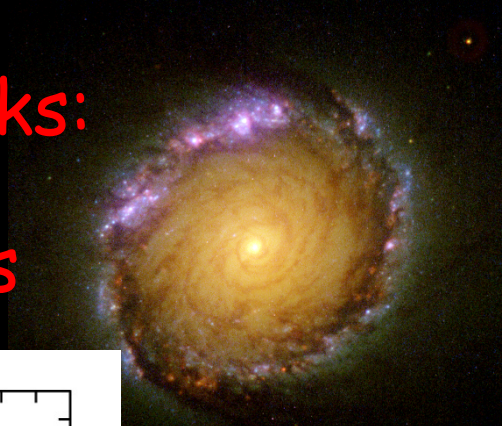


Kudritzki et al. 2014

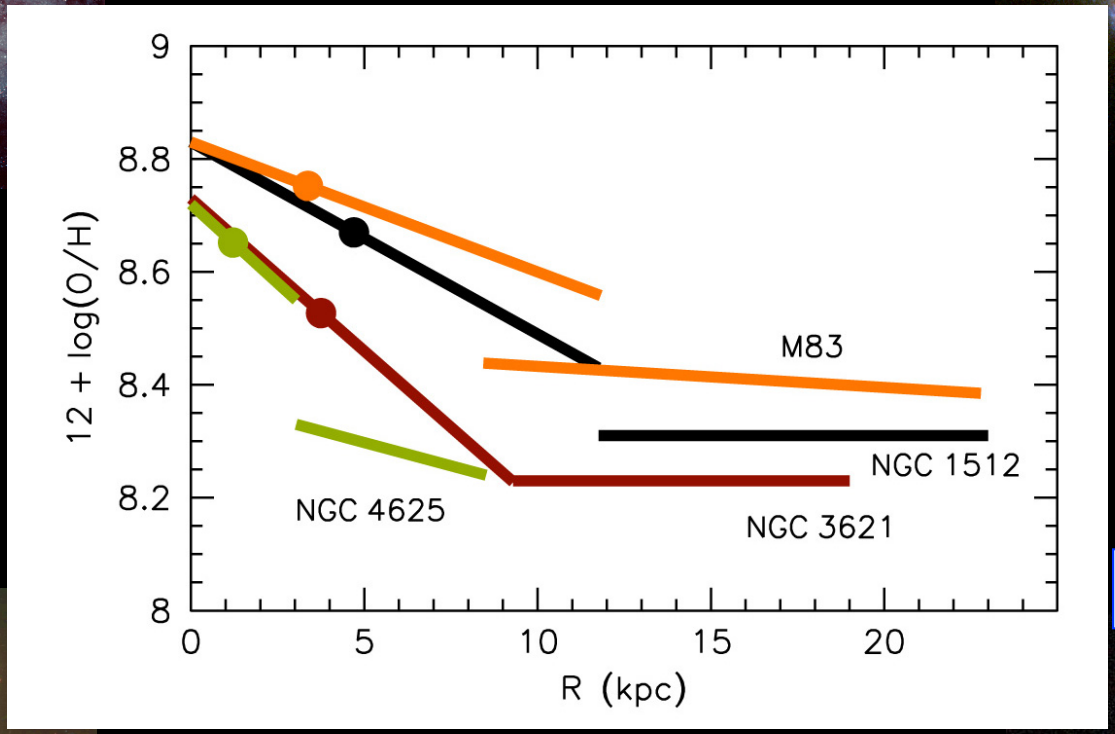
spirals with extended disks:

flat metallicity profiles

M83

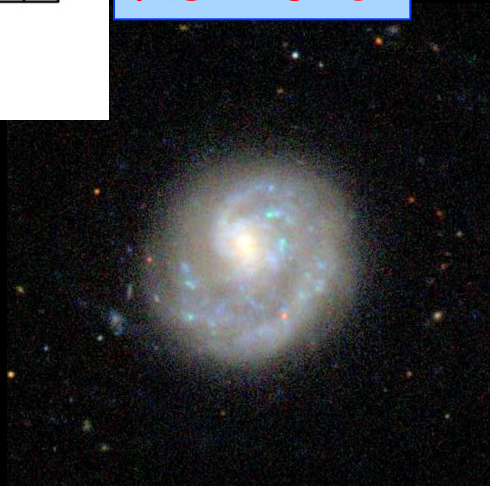


NGC1512

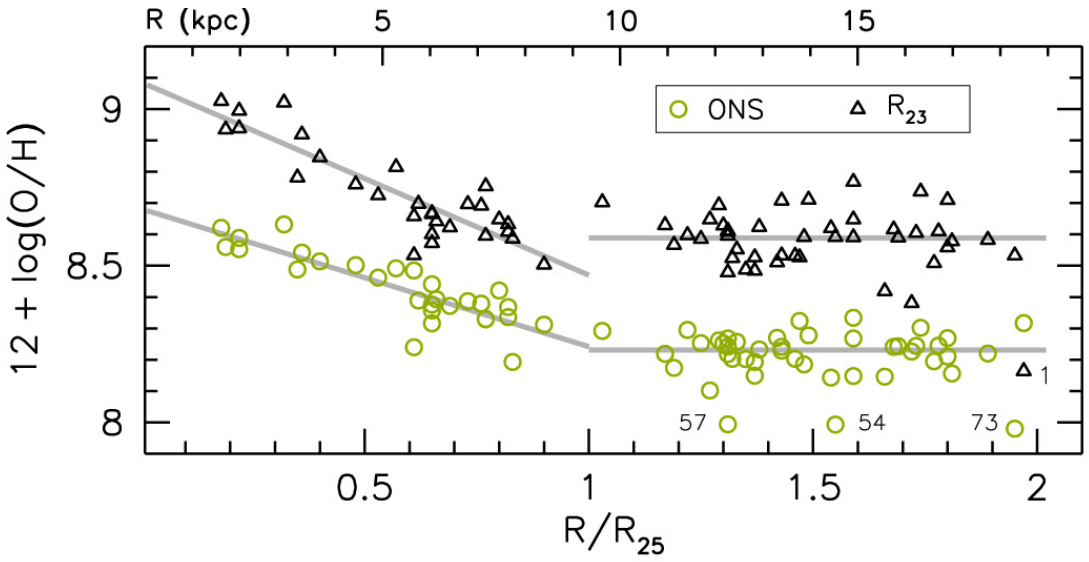


NGC3621

NGC4625



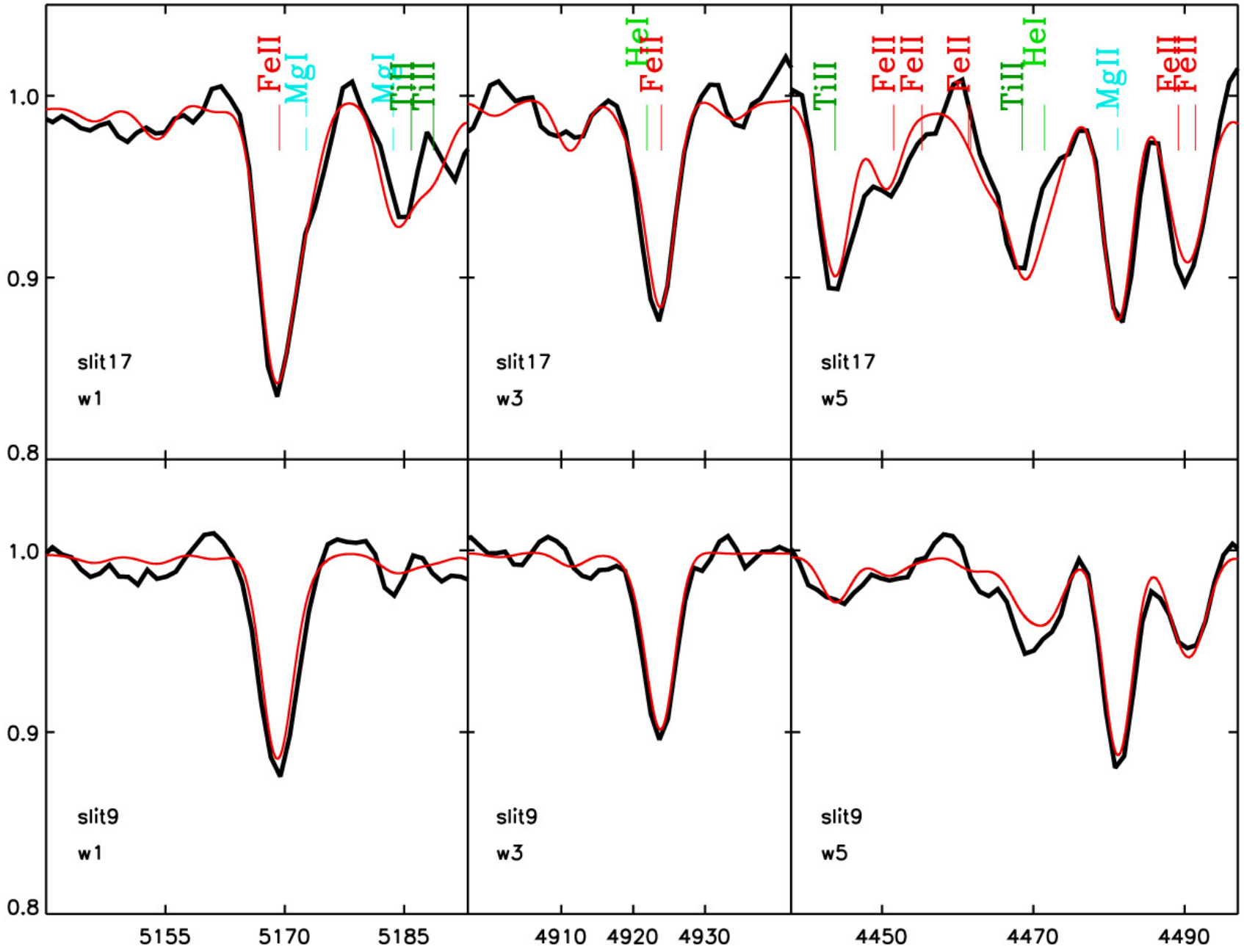
Bresolin et al. 2012, ApJ 750, 122



NGC 3621
different HII strong line methods

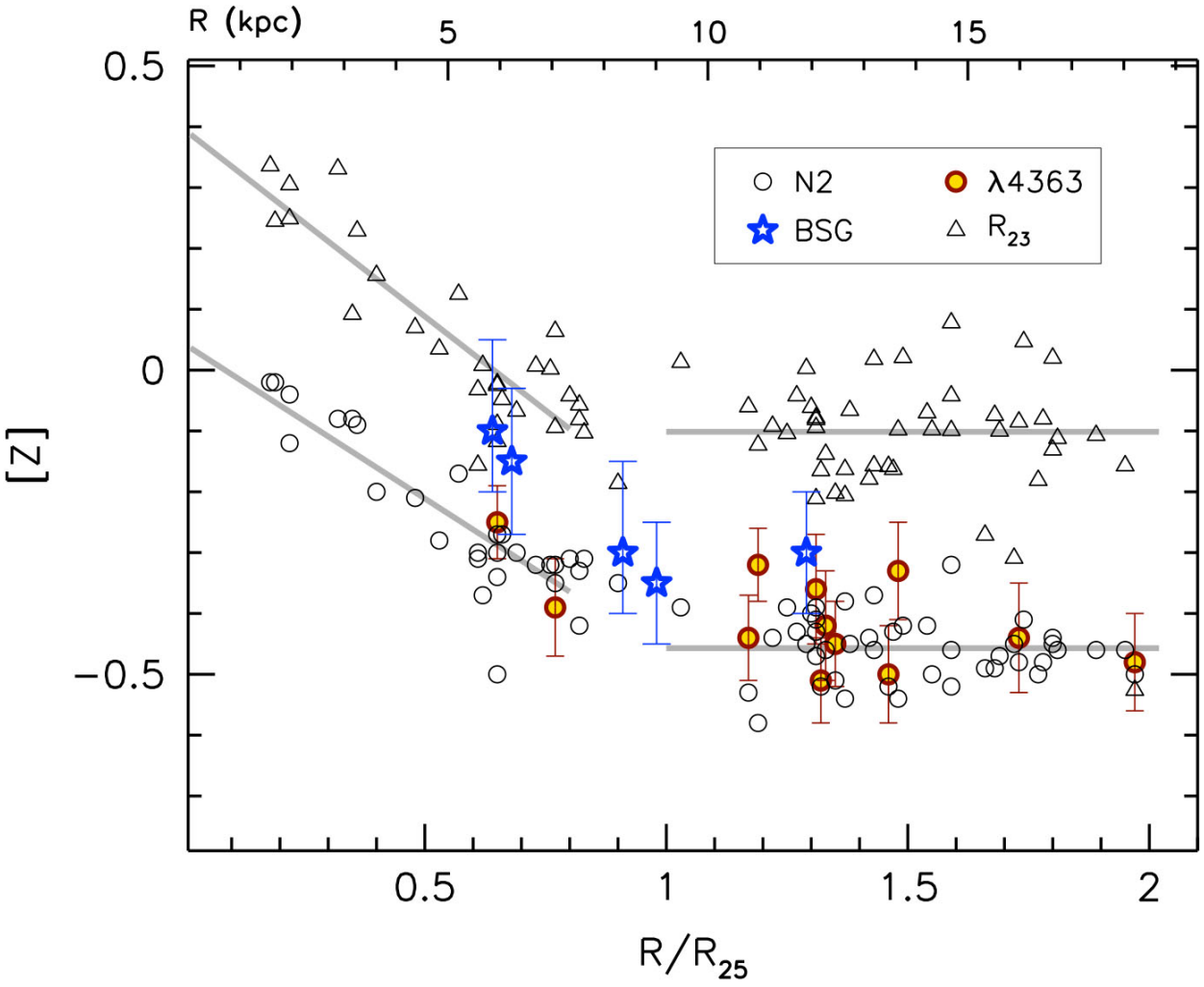
Bresolin et al. 2012

NGC 3621-Fit of stellar metal lines



Kudritzki et al. 2014

NGC 3621 stellar metallicity



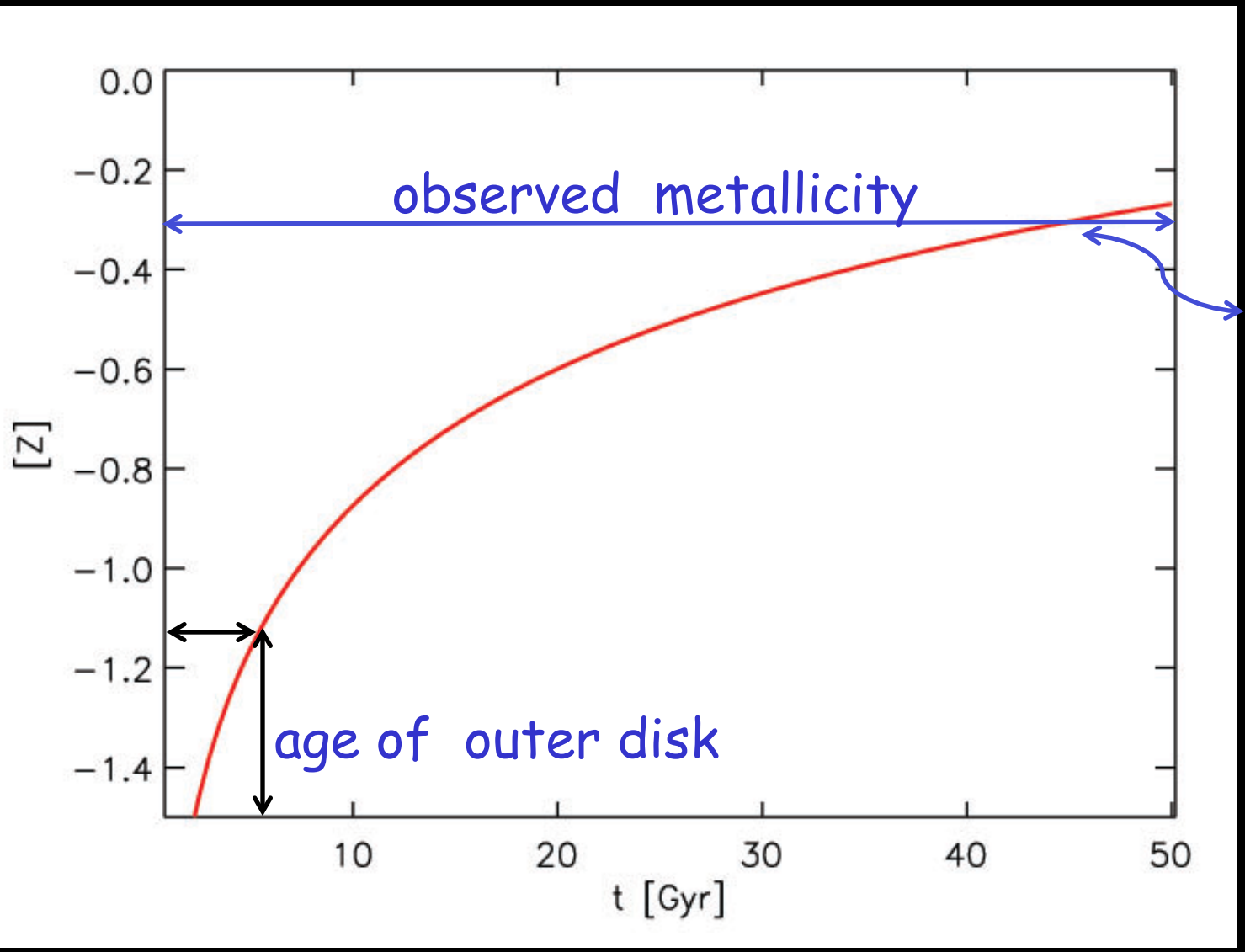
between the two HII strong line methods

~ 0.1 dex higher than auroral line method

confirms outer disk flat metallicity profile

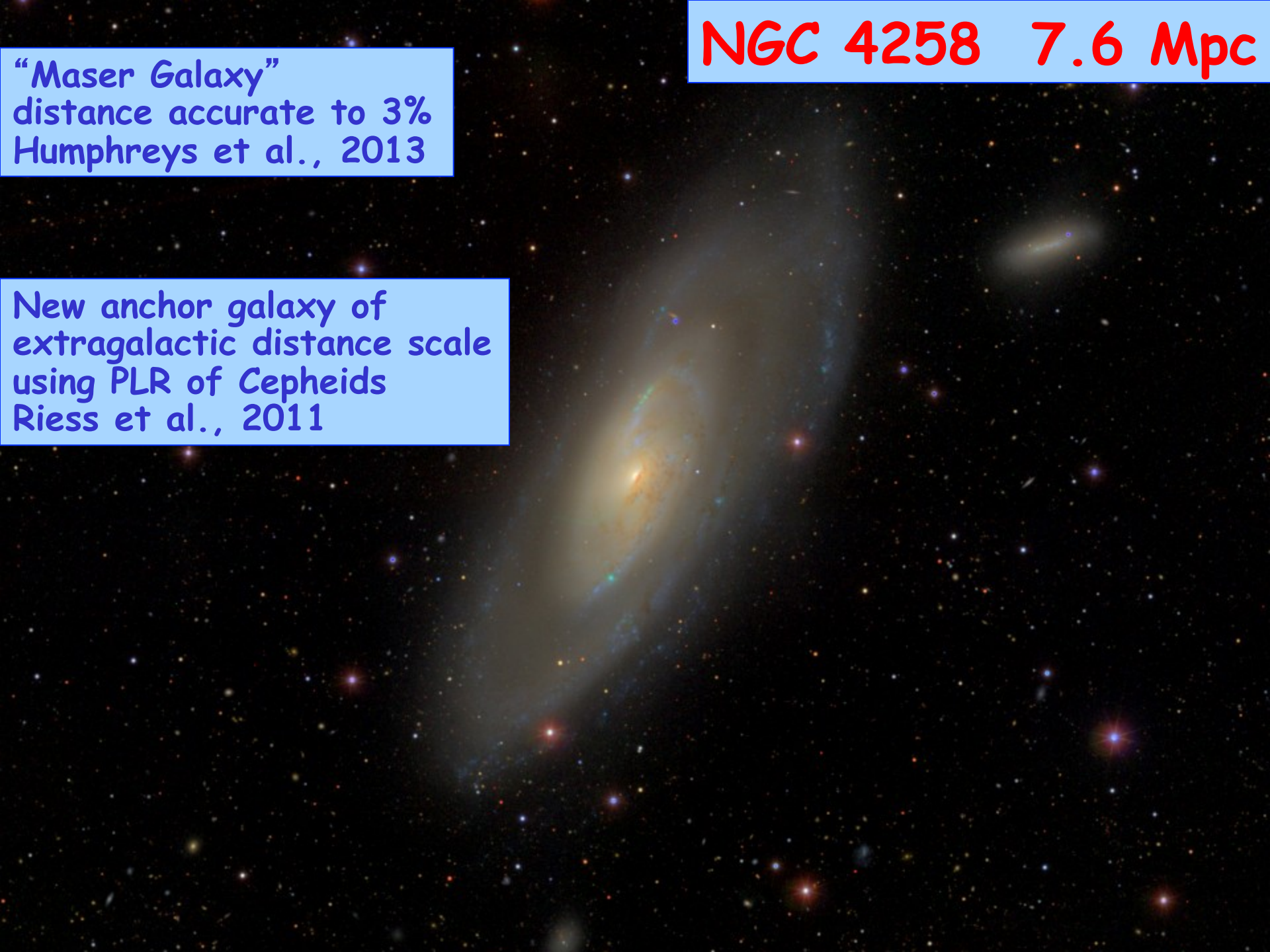
Kudritzki et al. 2014

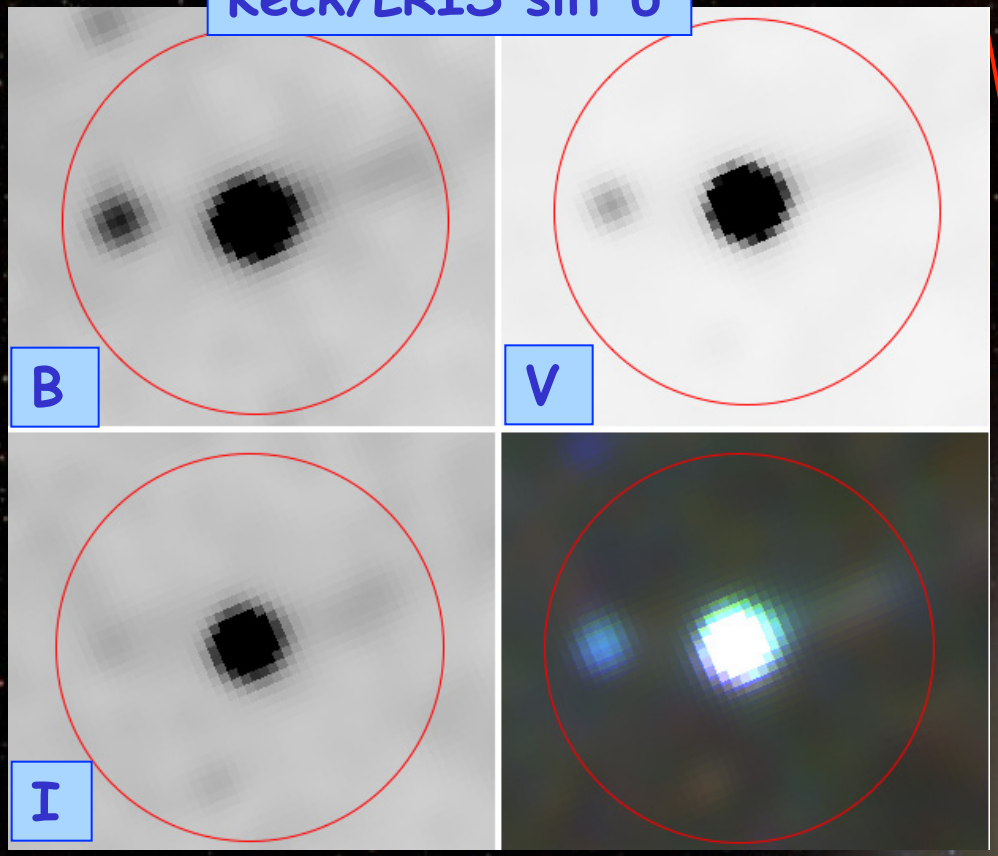
NGC 3621 outer disk chemical evolution



47 Gyr

time needed with in-situ SF and present SFR to produce observed metallicity


NGC 4258 7.6 Mpc
"Maser Galaxy"
distance accurate to 3%
Humphreys et al., 2013
New anchor galaxy of
extragalactic distance scale
using PLR of Cepheids
Riess et al., 2011

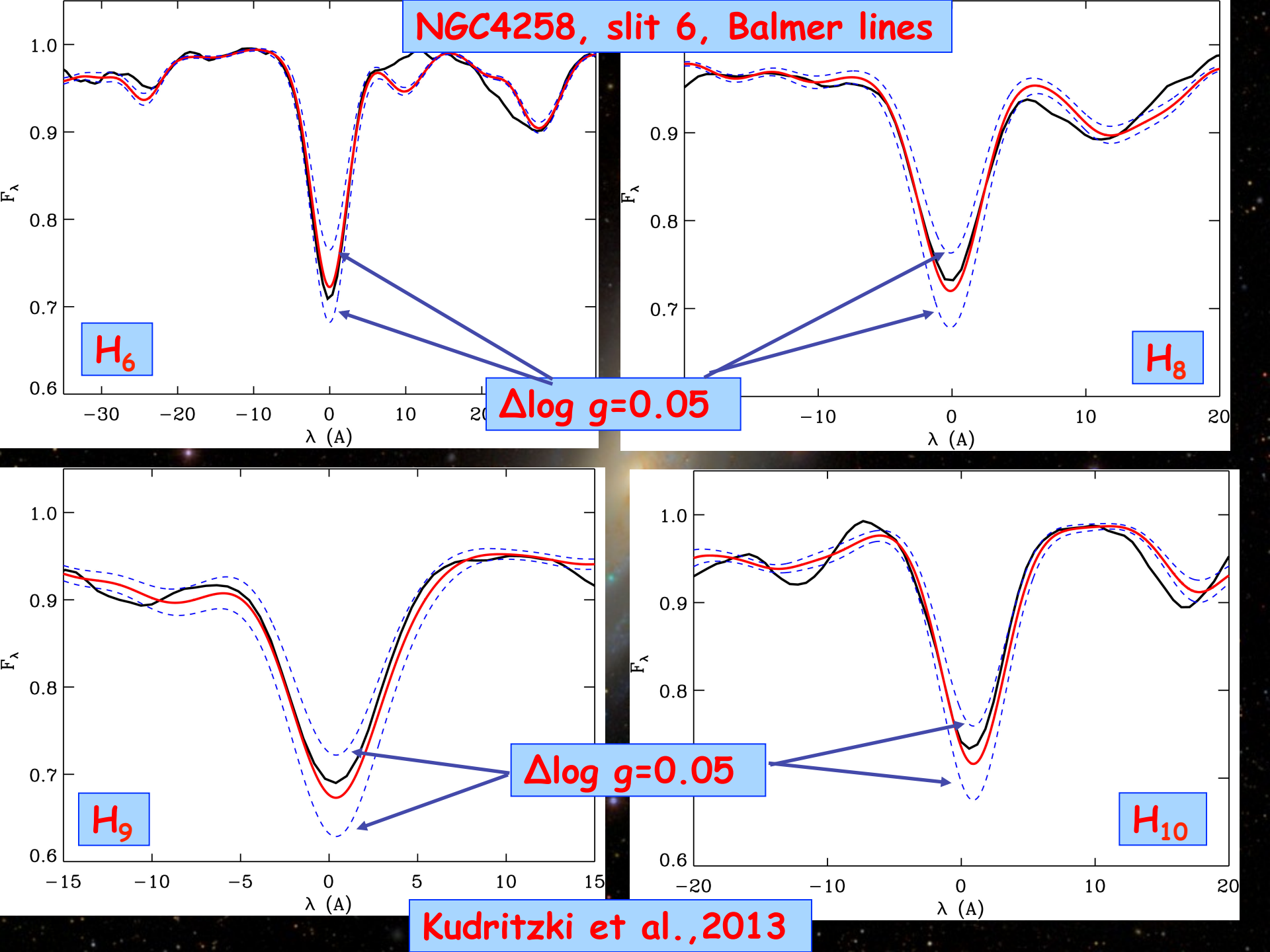


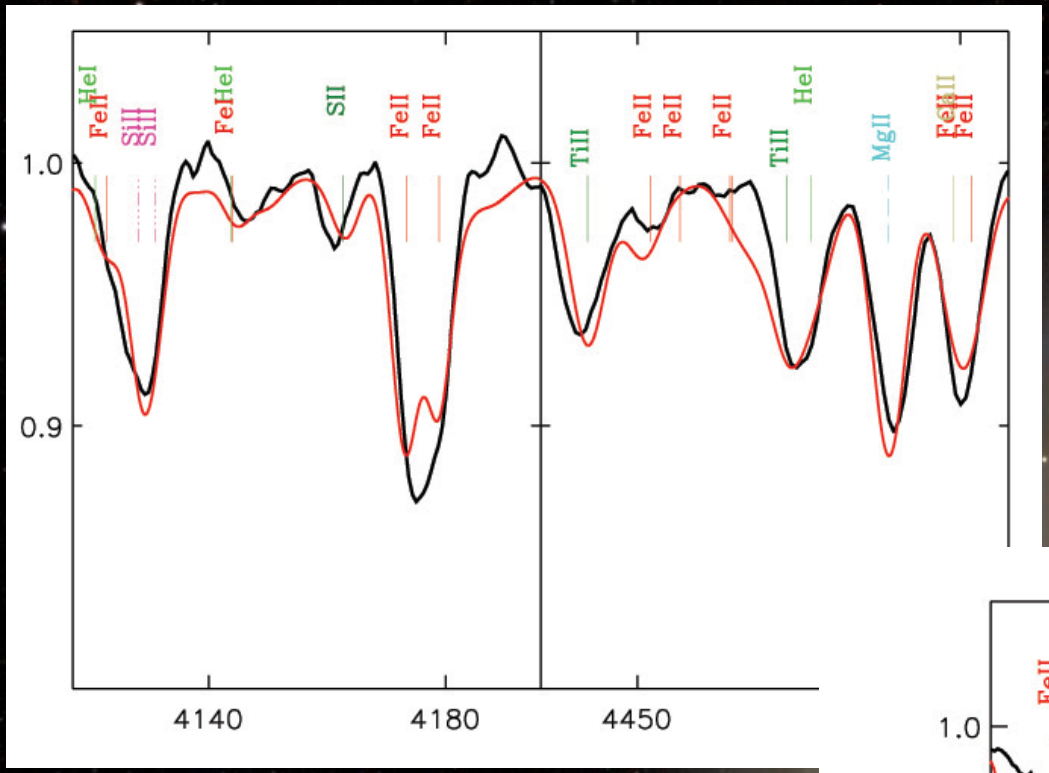
HST ACS 1" radius

NGC 4258 7.6 Mpc

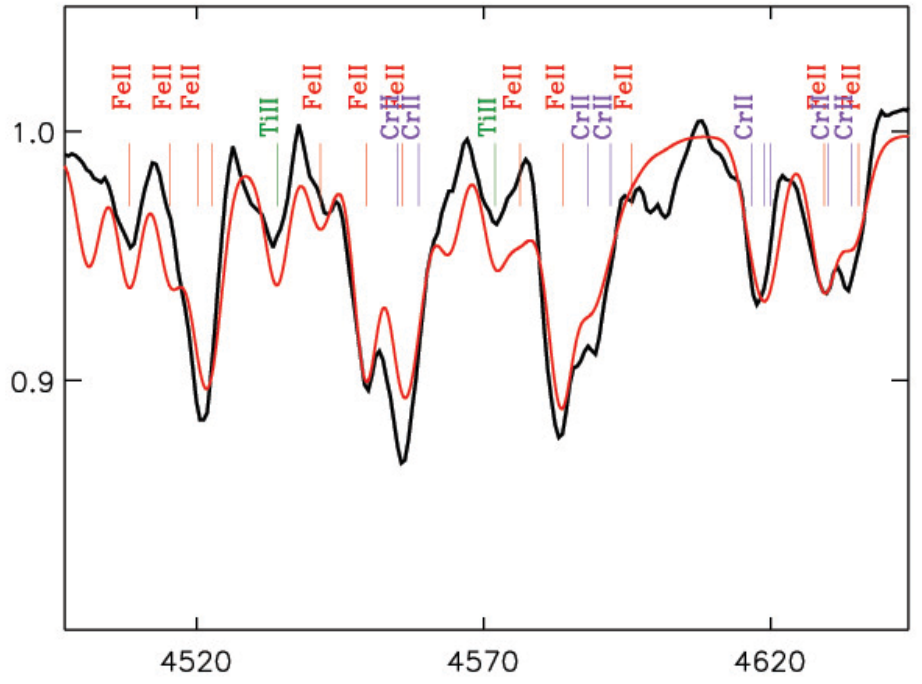
BSG

Kudritzki, Urbaneja, Gazak, Macri, Hosek, Bresolin, Przybilla 2013, ApJ 779, L20


NGC4258, slit 6, Balmer lines
H6
H8
Δlog g=0.05
H9
H10
Δlog g=0.05
Kudritzki et al.,2013
Fλ
λ (A)

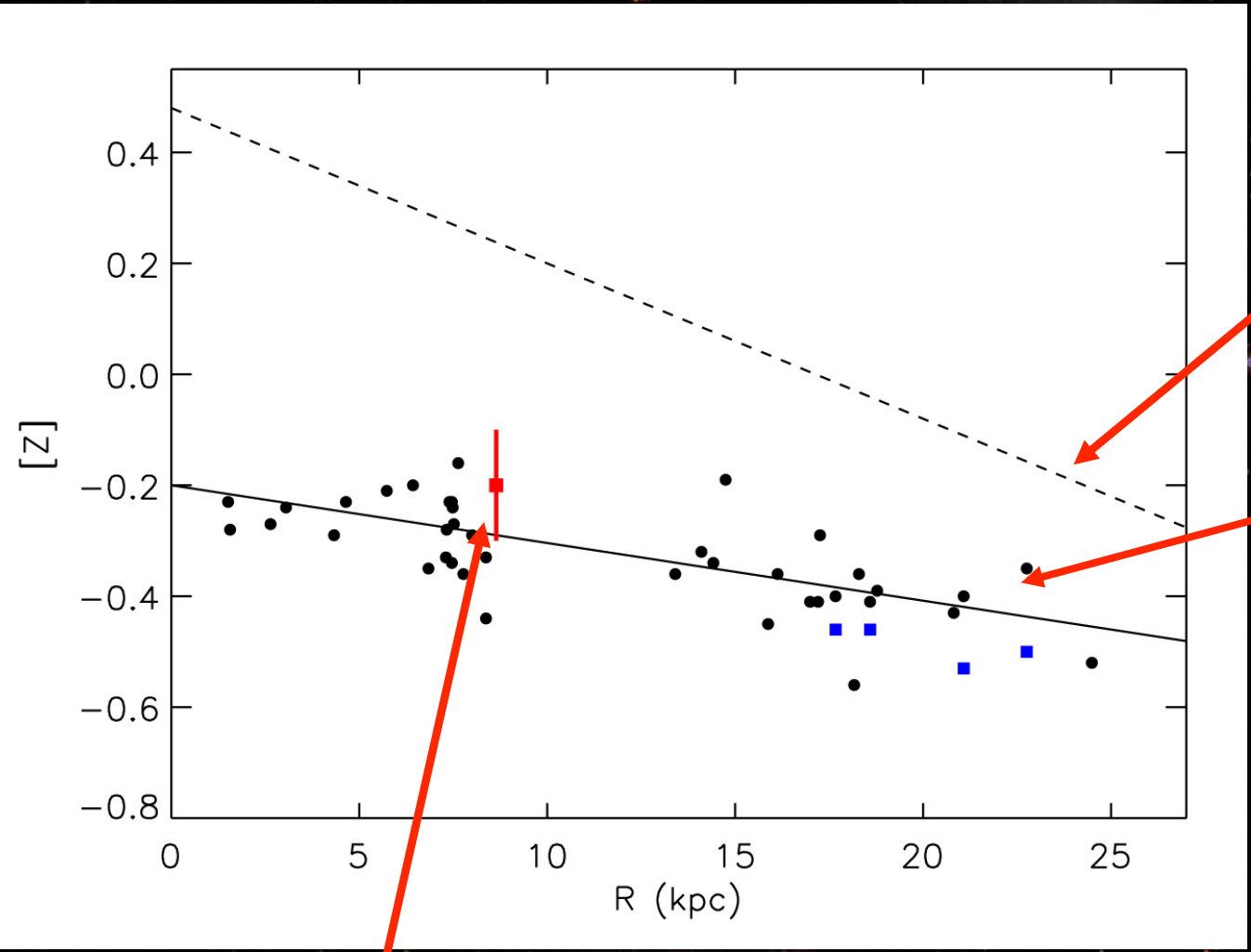


Fit of stellar metal lines



Kudritzki et al.,2013

Metallicity of NGC 4258



Zaritsky et al., 1994

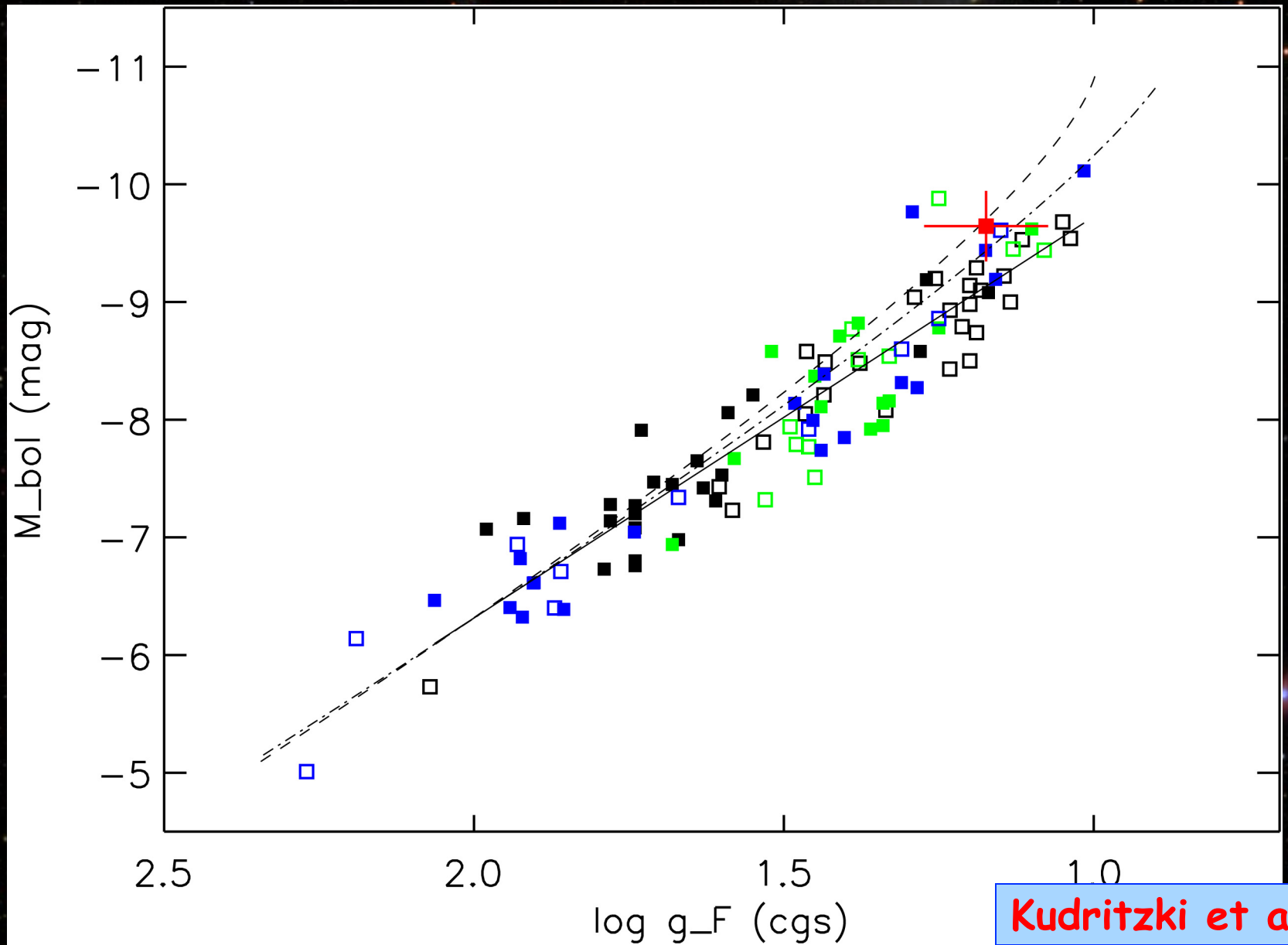
strong lines

Bresolin, 2011

BSG in NGC 4258

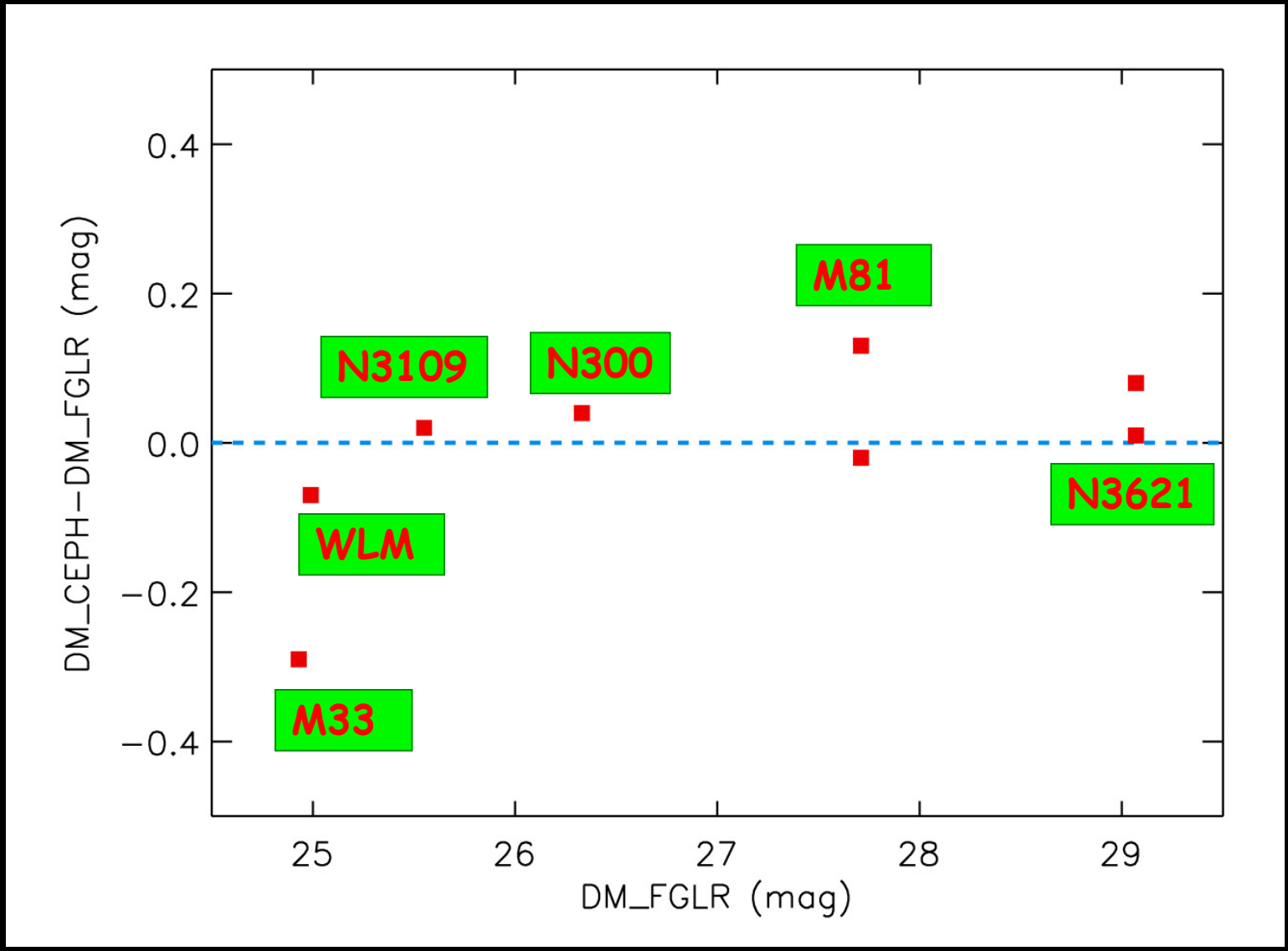
Kudritzki et al.,2013

FGLR of NGC 4258 BSG



Kudritzki et al.,2013

FGLR vs. Cepheid distances



BSGs and TMT/ELT perspectives

WFOS → quantitative spectroscopy
possible down to $m_V \sim 24.5$ 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
→ $\Delta(m-M) \sim 0.1$ mag