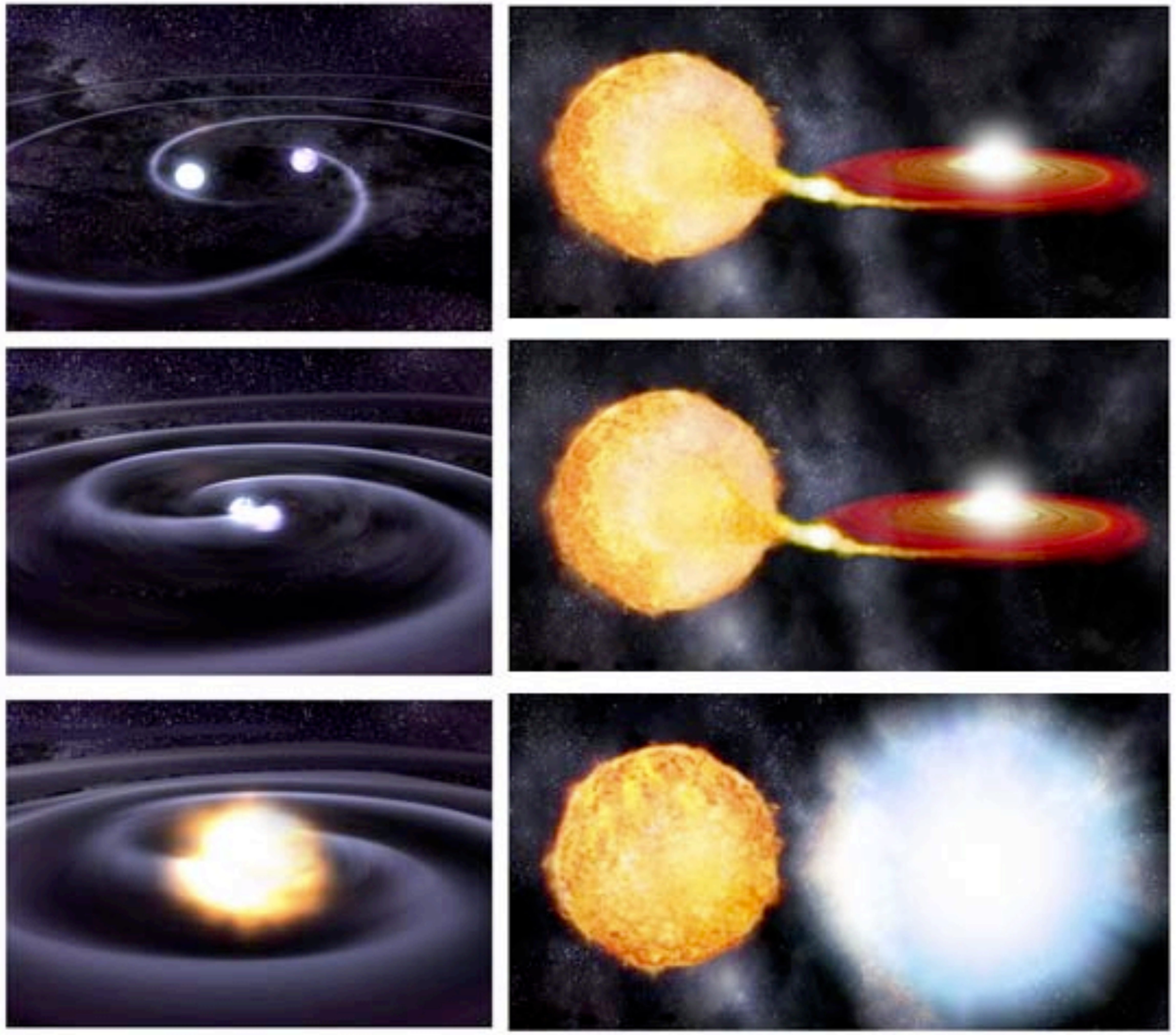
Type Ia supernova peak brightness dependence on progenitor metallicity

Lluís Galbany, RyC fellow, ICE-CSIC (Barcelona)

Institute of Space Sciences
IEEC
CSIC
Consejo Superior de Investigaciones Científicas
Ministerio de Ciencia e Innovación
Unión Europea
Fondo Social Europeo
El FSE invierte en tu futuro
Agencia Estatal de Investigación

Type Ia supernovae



What is exploding?

CO white dwarf (WD) in a binary system
single/double degenerate

How is it exploding?

Merging/compression/He layer burn/collision
Detonation/deflagration/double-detonation
Chandrasekhar/sub-Chandrasekhar mass

Most probably a mixture of scenarios and explosion mechanisms

SNIa cosmology

SNIa are the most precise extragalactic distance indicators (uncert. 5%)

Two empirical correlations:

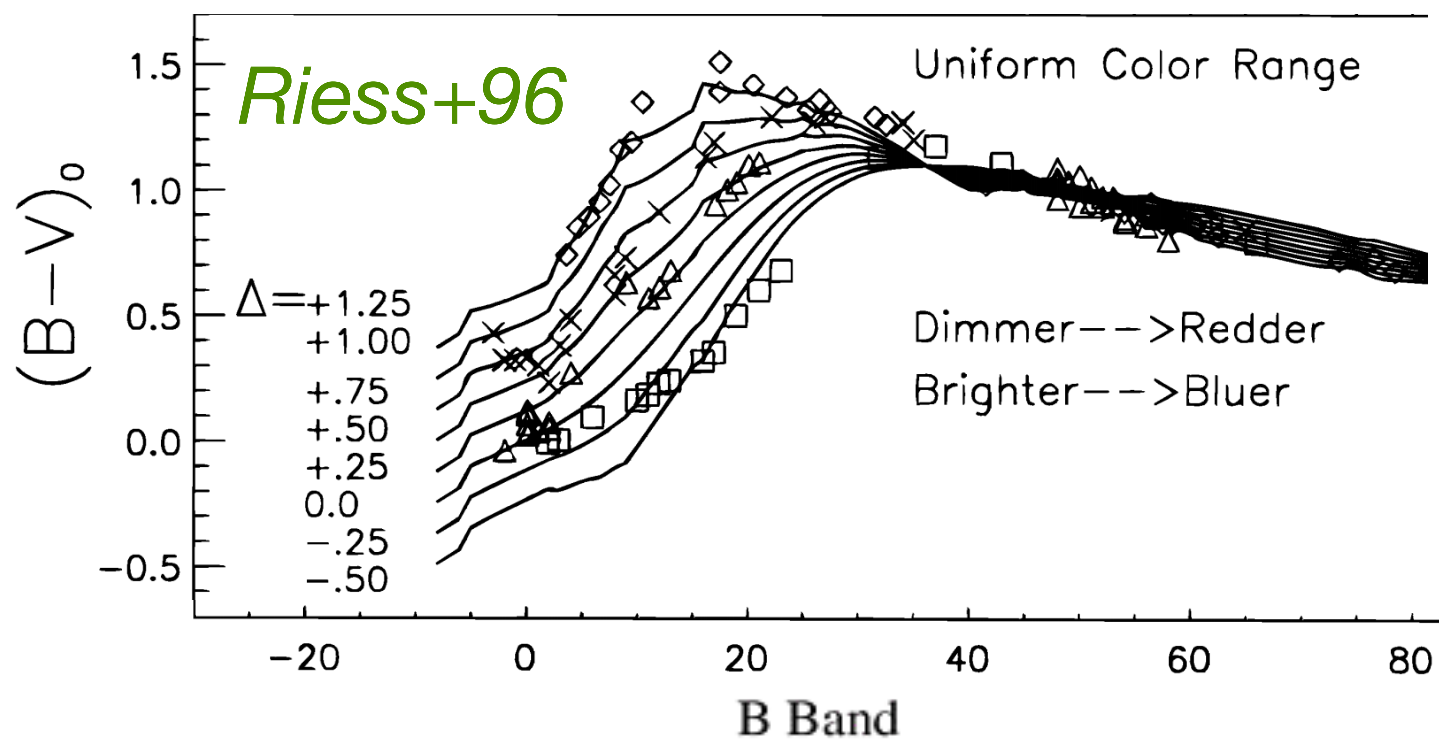
peak brightness vs brightness decay

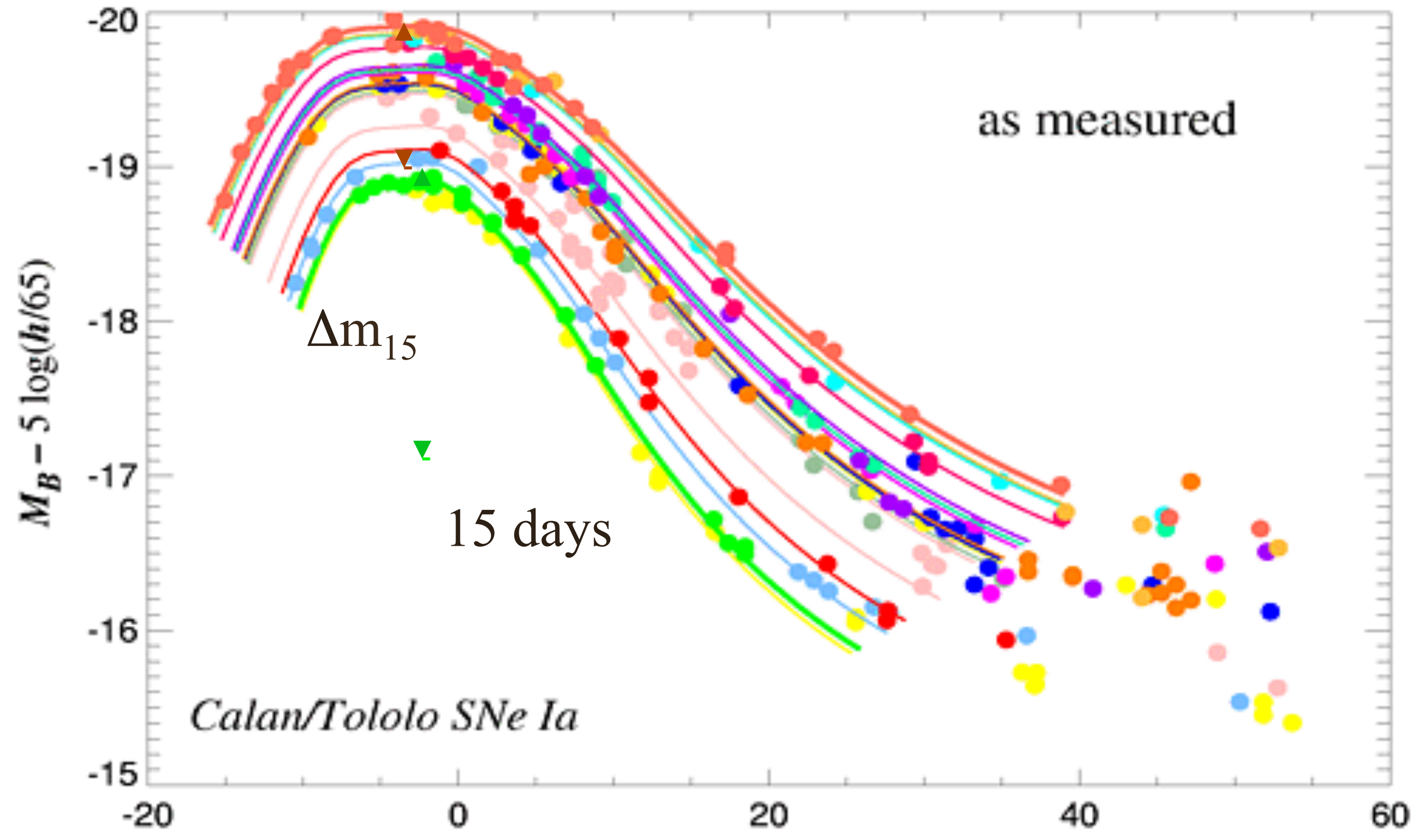
peak brightness vs color

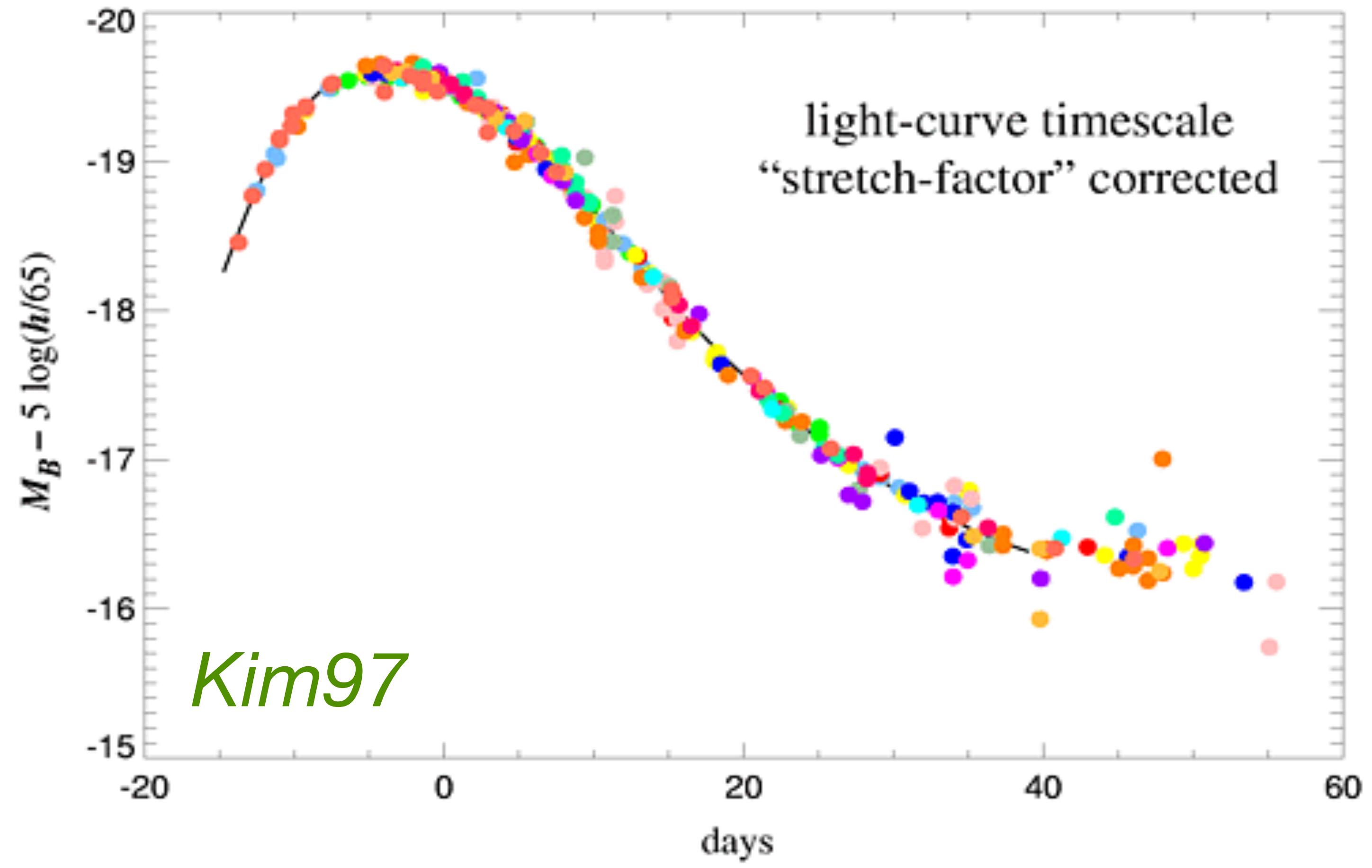
Standardized peak brightness

$$\mu(z)_{\rm SN} = m(z) - M = (m_{\rm obs} + \alpha x1 - \beta c - A_{\rm MW} + K_{x,y}) - M$$

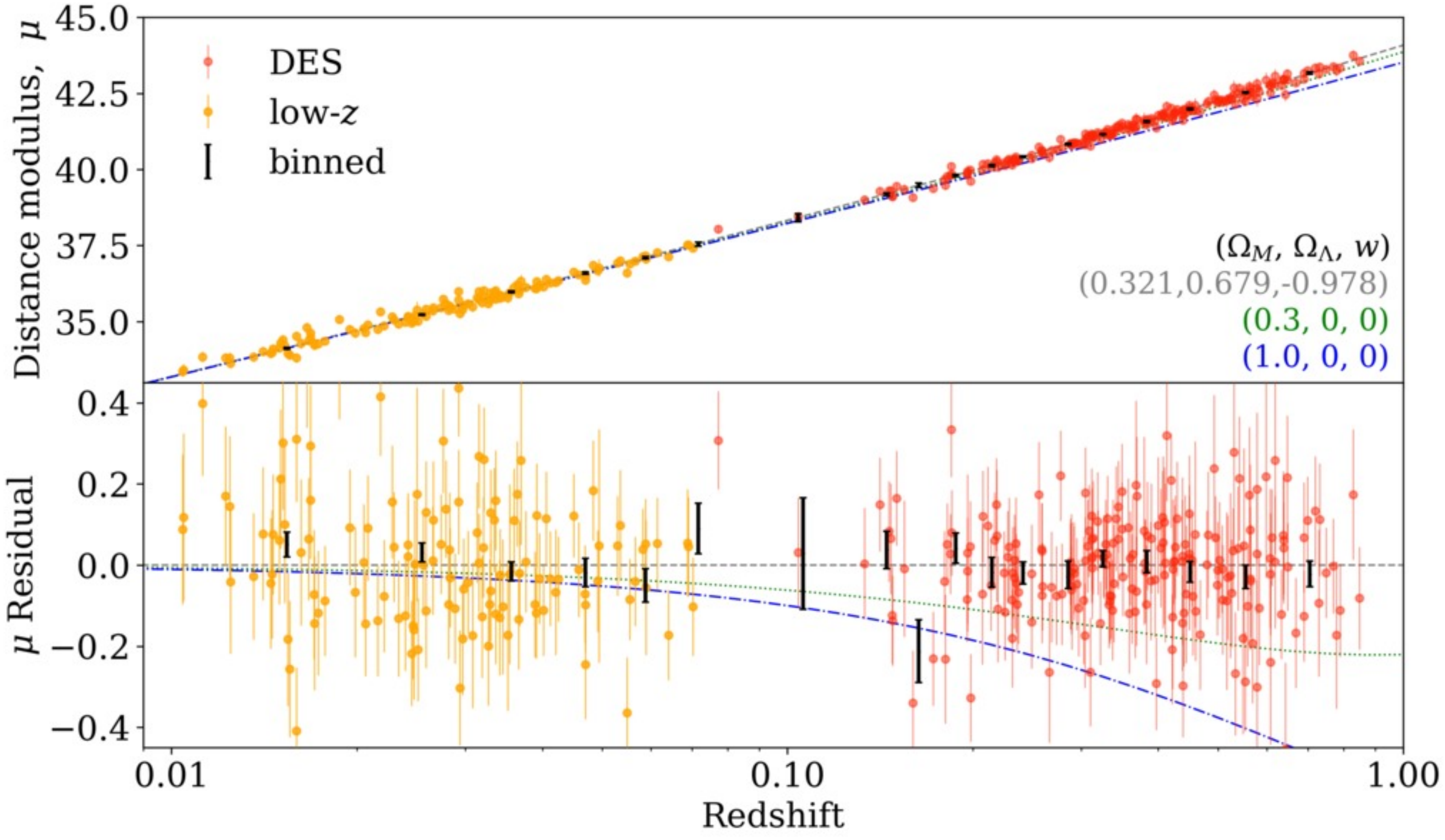
$$\mu(z)_{\rm model} = 5\log_{10}(d_L/10pc) \qquad d_L(z) = (1+z)\frac{c}{H_0}\int_0^z \frac{dz}{\sqrt{\Omega_M(1+z)^3 + \Omega_\Lambda(a+z)^{3(1+w)}}}$$







SNIa cosmology



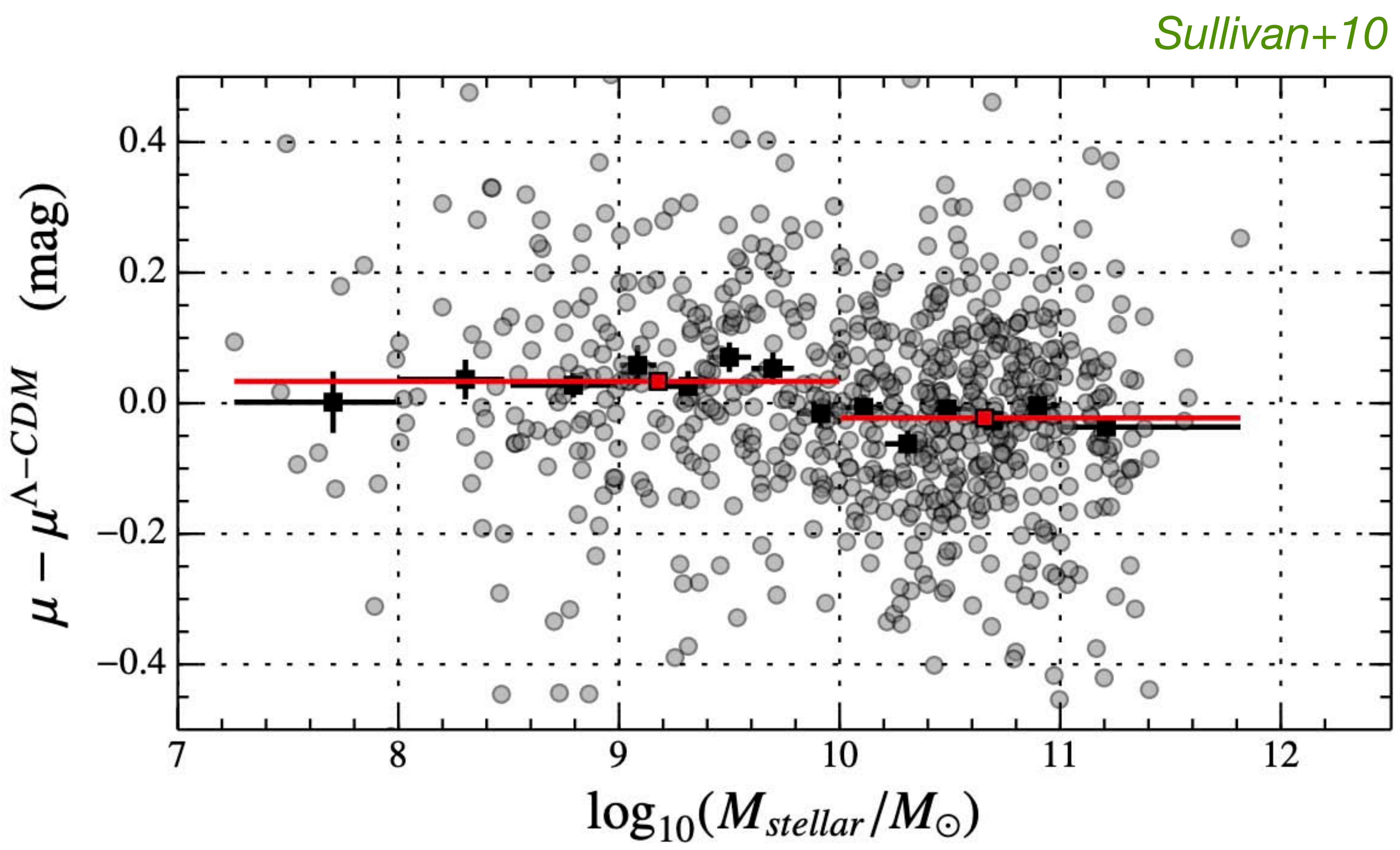
Brout+19

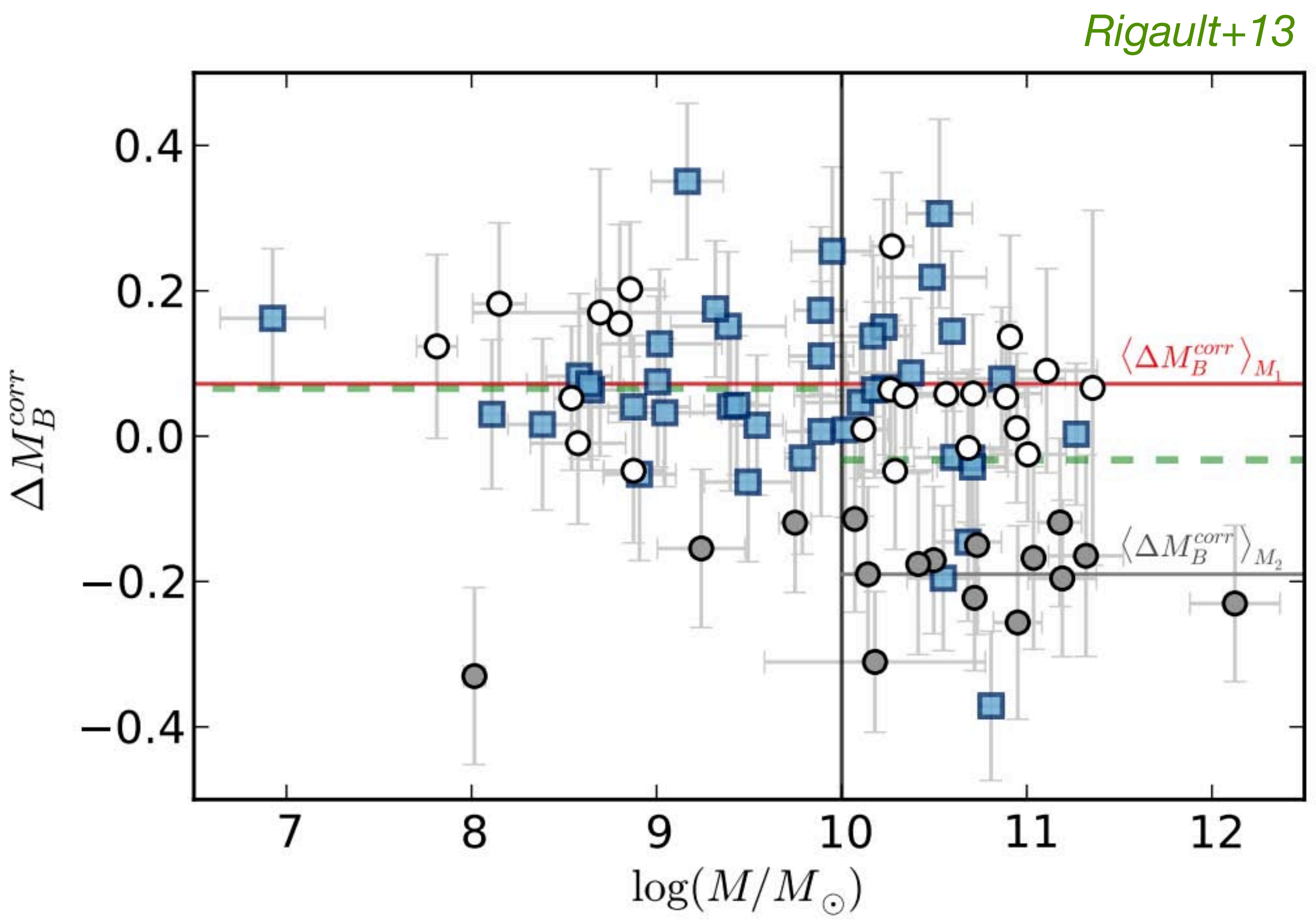
$HR = \mu(z)_{\mathrm{SN}} - \mu(z)_{\mathrm{model}}$

Recent (>2010) cosmological analysis found a dependence between the *Hubble residual and properties of the SN host galaxy**

*deviation between the distance from the best cosmological model and the SN distance

SNIa environment





Two different populations, one associated to young and other to old populations, that evolve with z!

But mass should be just a proxy for another other parameter…

SNIa environment

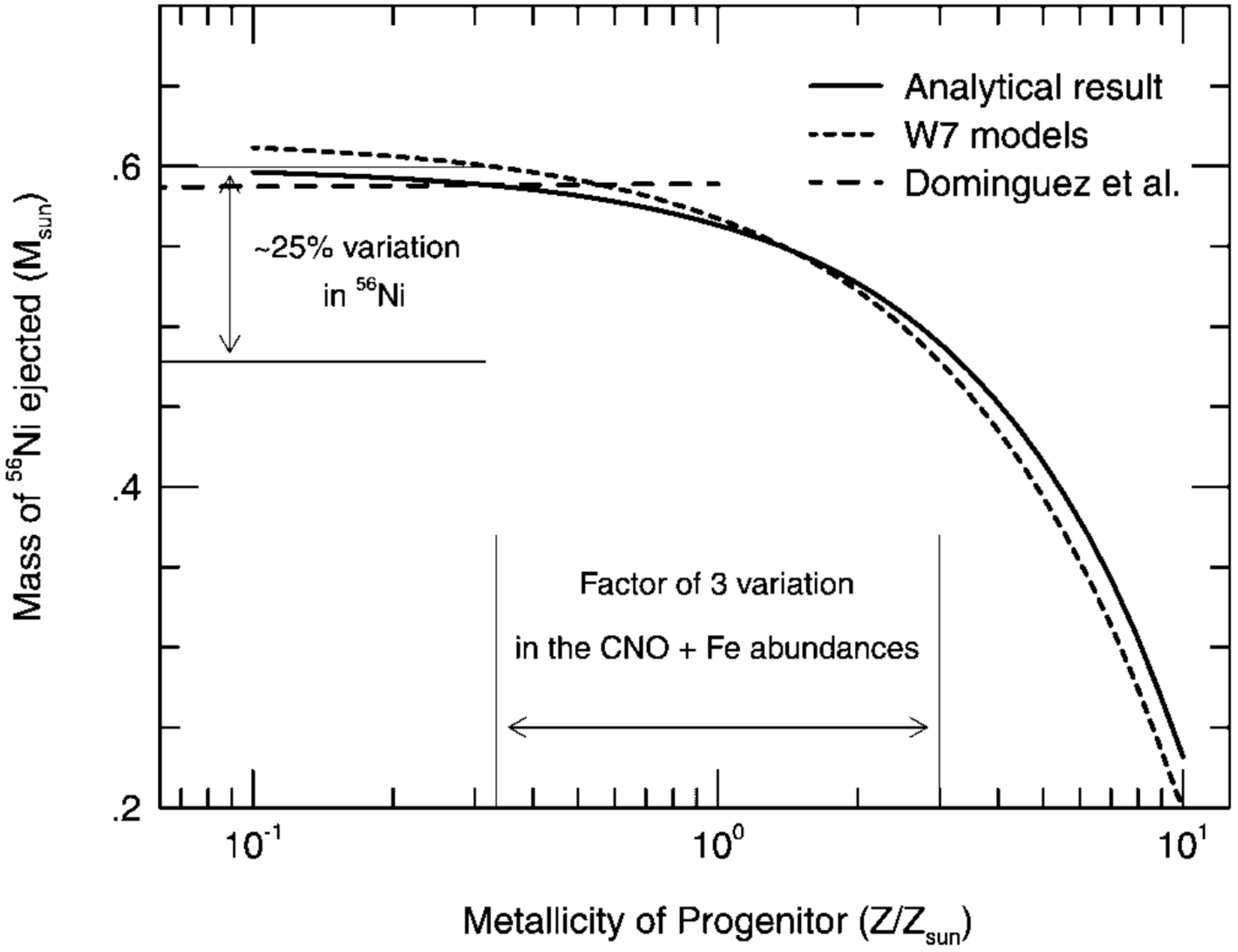
Dependences of the SN parameters on host galaxy properties

As they evolve with redshift, such dependences would impact the cosmological parameters

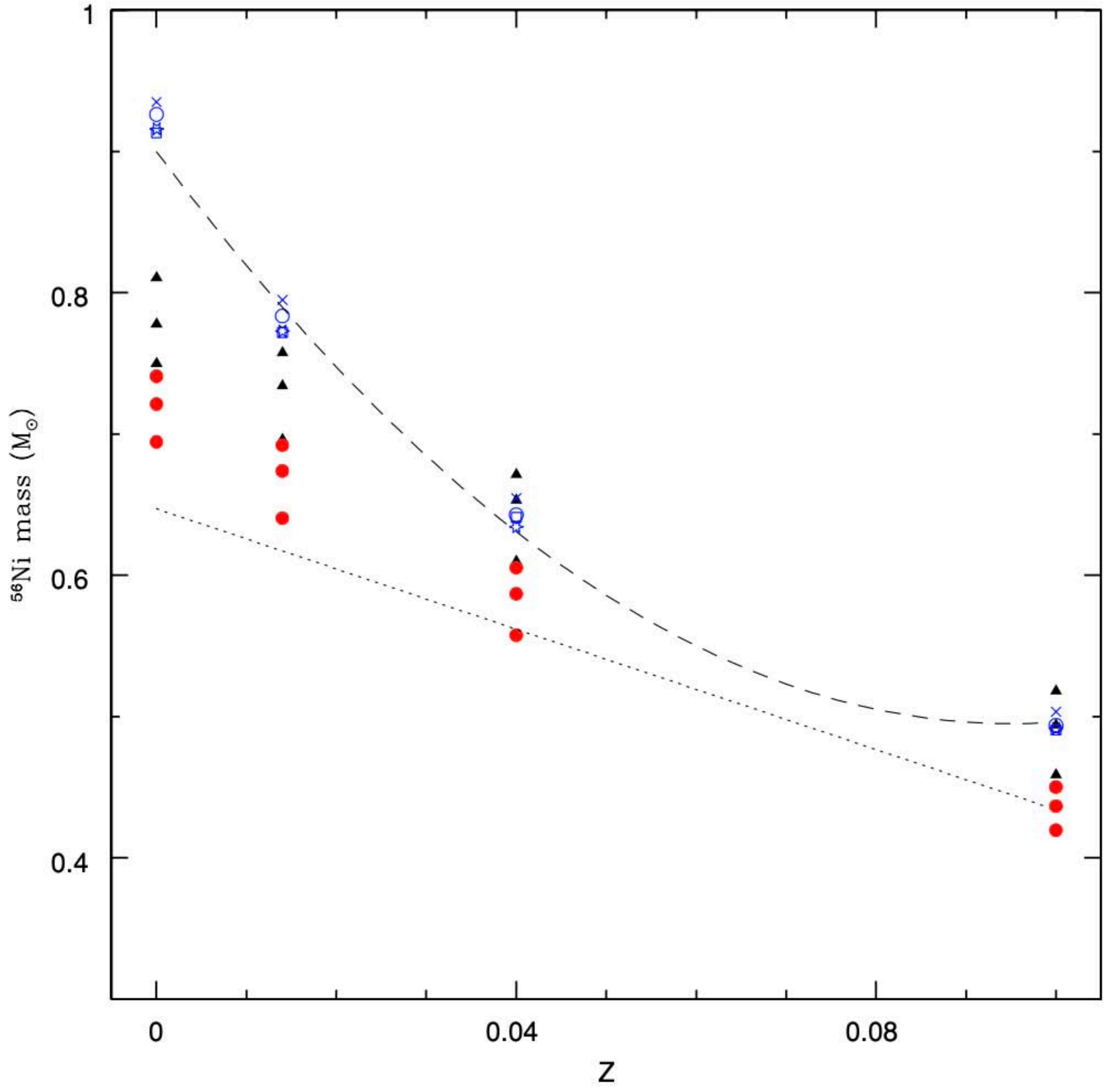
Hamuy et al. (1996)	Bright events occur preferentially in **young** stellar environments.
Hamuy et al. (2000)	Luminous SNe are produced in **metal-poor** neighborhoods
Gallagher et al. (2005)	**high-metallicity** galaxies host SNe Ia with negative HR *(after LC-corr)*
Sullivan et al. (2006)	Brighter events are found in systems with ongoing **star-formation**
Gallagher et al. (2008)	**Progenitor age** primarily determines the peak luminosity
Hicken et al. (2009)	SN Ia in **spiral** hosts are intrinsically fainter *(after LC-corr)*
Howell et al. (2009)	**more massive** progenitors give rise to less luminous explosions
Neill et al. (2009)	**Older** hosts produce less-extincted SNe Ia
Cooper et al. (2009)	SNIa are more luminous or more numerous in **metal-poor** galaxies
Brandt et al. (2010)	Luminous SNe associated with recent **star-formation** and **young** prog.
Sullivan et al. (2010)	SNIa are brighter in **massive** hosts (metal-rich) and with low **SFR** *(after LC-corr)*
Kelly et al. (2010)	SN Ia in physically **larger**, more **massive** hosts are ~10% brighter
Lampeitl et al. (2010)	introduce the stellar **mass** of the host in the parametrization
D'Andrea et al. (2011)	SNe are 0.1 mag brighter in **high-metallicity** hosts after corr.
Gupta et al. (2011)	**older** galaxies host SNe Ia that are brighter
Konishi et al. (2011)	SNe Ia in host galaxies with a higher **star formation** rate show brighter events
Galbany et al. (2012)	SNe that explode **further** are less extinguished, and have **lower metallicity**
Childress et al. (2013)	correlation between SN Ia intrinsic color and host **metallicity**
Johansson et al. (2013)	more luminous SNe Ia appear in **younger** stellar progenitor systems
Rigault et al. (2013)	SNe Ia with **local Hα emission** are redder and drives the HR-**mass** relation
Pan et al. (2014)	fainter, faster declining SNe Ia are hosted by **older**/**massive**/**metal-rich** galaxies
…	

Metallicity dependence predicted

Timmes+03



Bravo, Badenes+10



Observational programme

Local sample

WHT 4.2m telescope

28 SNIa spiral-on host galaxies

Galaxies with independent distances

Slit + metallicity gradients -> local

int-z sample

SDSS SNIa host galaxies

Fiber spectroscopy -> global

high-z sample

KMOS

Iker's talk

A

ON THE DEPENDENCE OF TYPE Ia SNe LUMINOSITIES ON THE METALLICITY OF THEIR HOST GALAXIES

Manuel E. Moreno-Raya[1], Mercedes Mollá[1], Ángel R. López-Sánchez[2,3], Lluís Galbany[4,5], José Manuel Vílchez[6], Aurelio Carnero Rosell[7], and Inmaculada Domínguez[8]

Moreno-Raya+16a

C

Elemental gas-phase abundances of intermediate redshift type Ia supernova star-forming host galaxies

M. E. Moreno-Raya,[1] L. Galbany,[2★] Á.R. López-Sánchez,[3,4] M. Mollá,[5] S. González-Gaitán,[6] J.M. Vílchez[7] and A. Carnero[8,9]

Moreno-Raya+18

B

Using the local gas-phase oxygen abundances to explore a metallicity dependence in SNe Ia luminosities

M. E. Moreno-Raya,[1★] Á. R. López-Sánchez,[2,3★] M. Mollá,[1] L. Galbany,[4,5] J. M. Vílchez[6] and A. Carnero[7,8]

Moreno-Raya+16b

D

Aperture-corrected spectroscopic type Ia supernova host galaxy properties★

Lluís Galbany[1,2], Mat Smith[3], Salvador Duarte Puertas[4,5], Santiago González-Gaitán[6], Ismael Pessa[7], Masao Sako[8], Jorge Iglesias-Páramo[5], A. R. López-Sánchez[9,10,11,12], Mercedes Mollá[13], and José M. Vílchez[5]

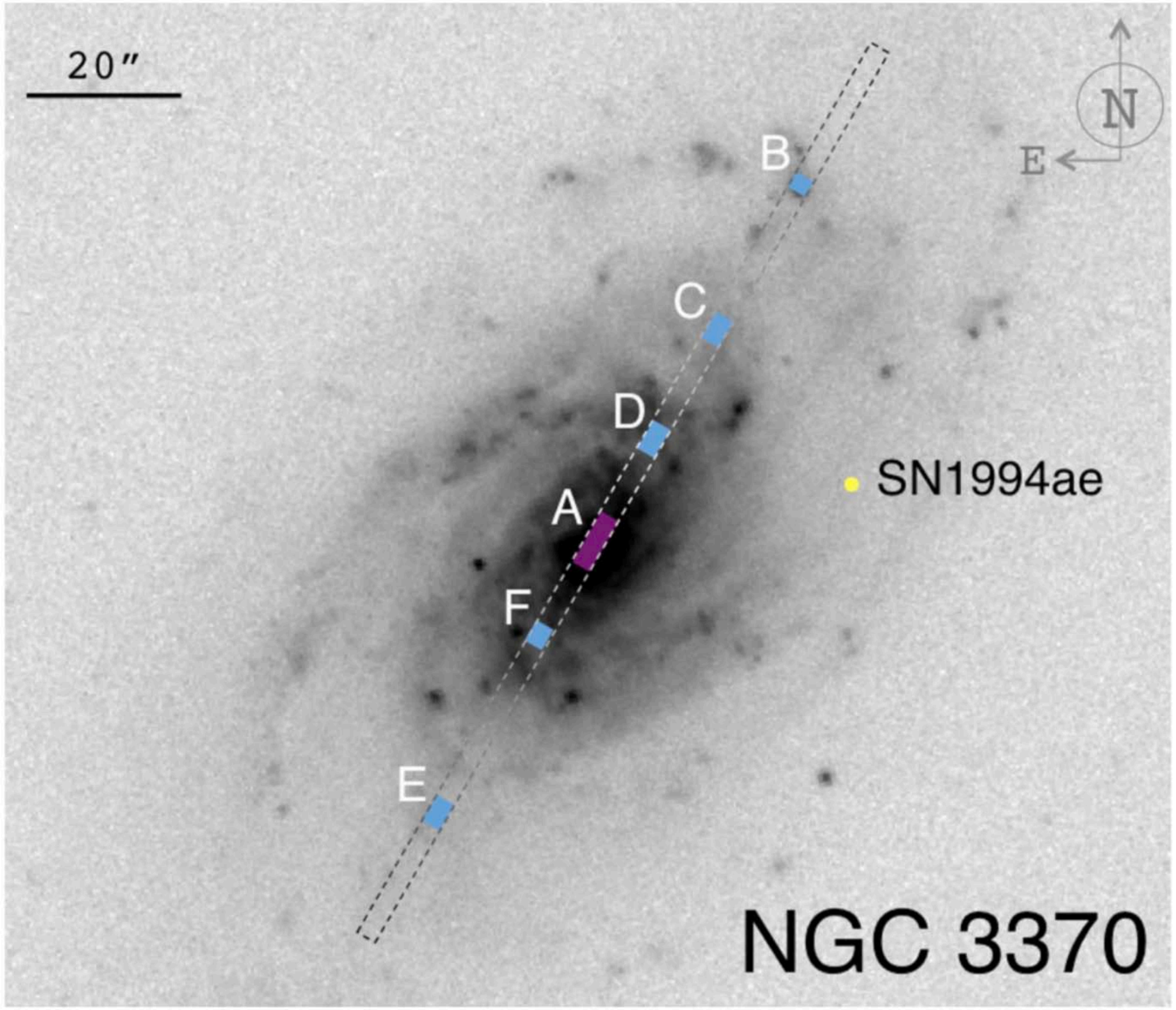
Galbany+22

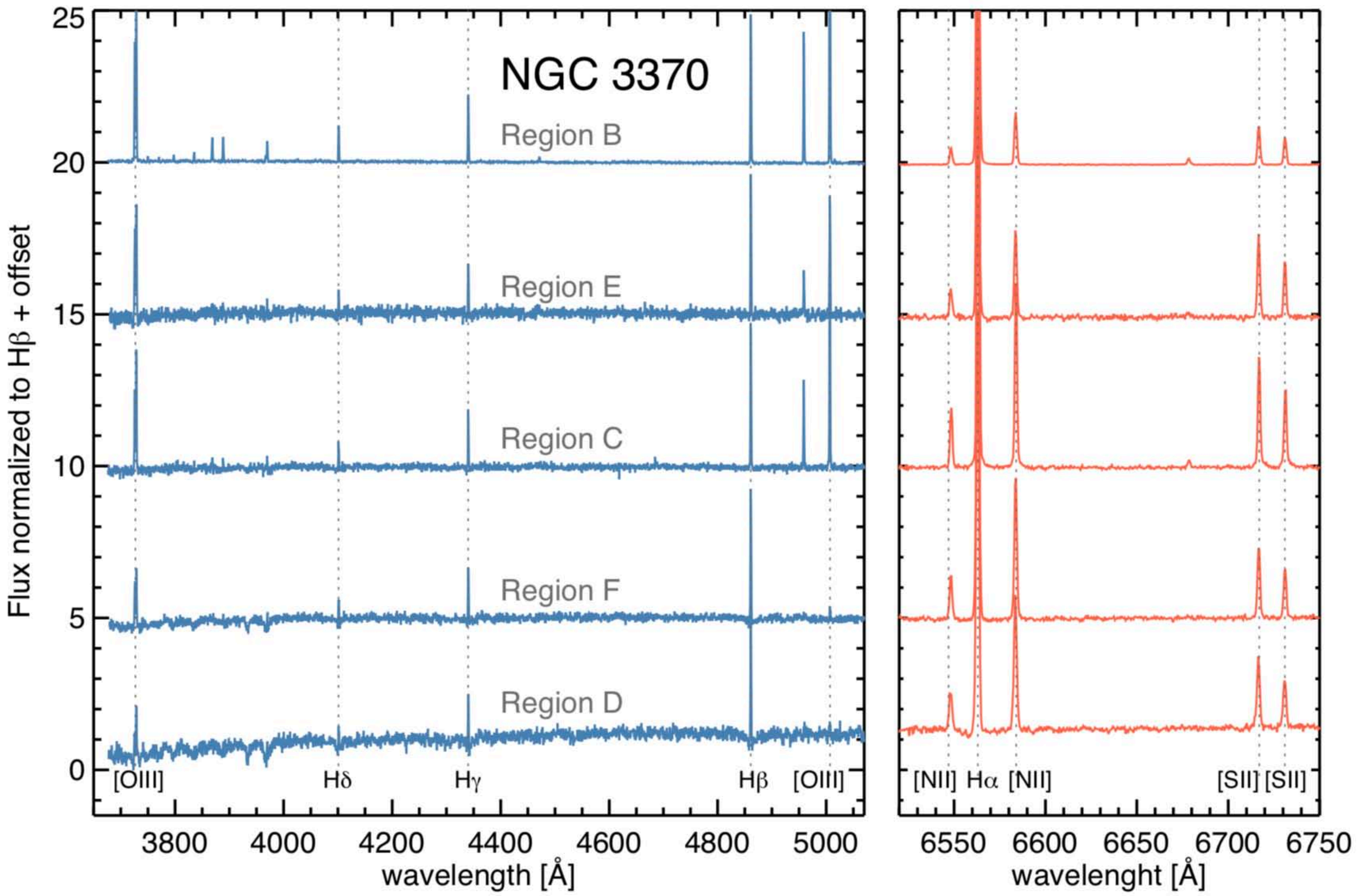
Local sample

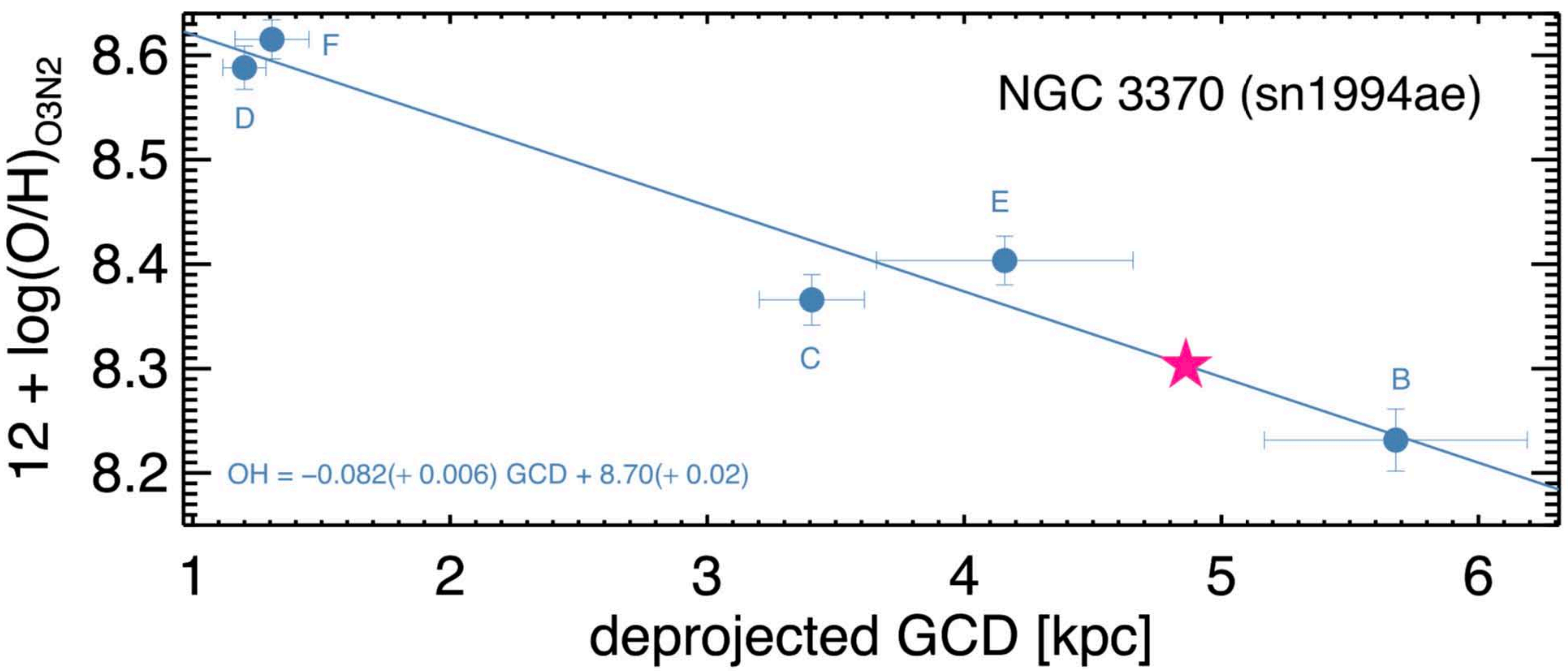
A

MR+16a

28 SNIa hosts with WHT 4.2m telescope





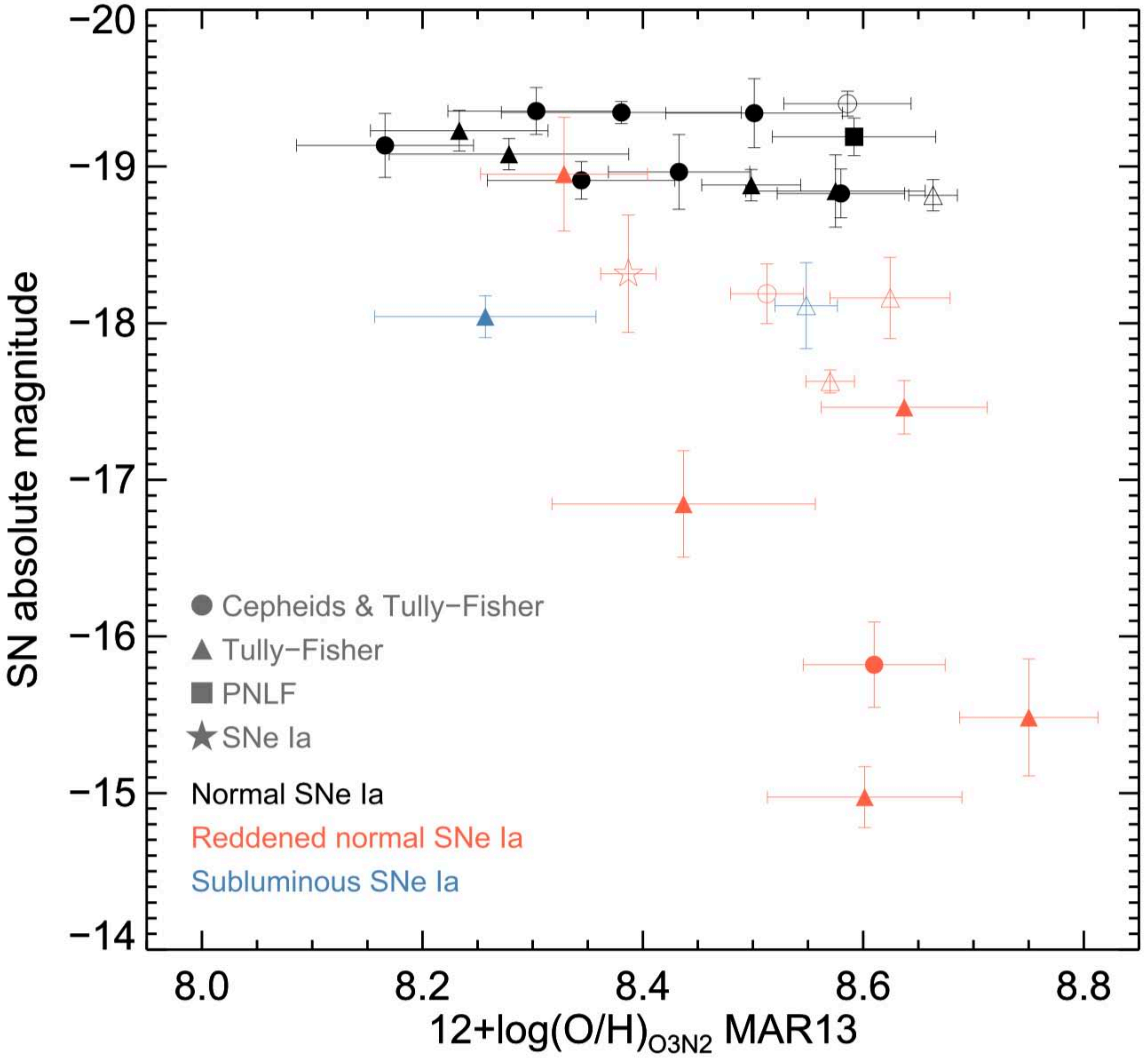


Local sample

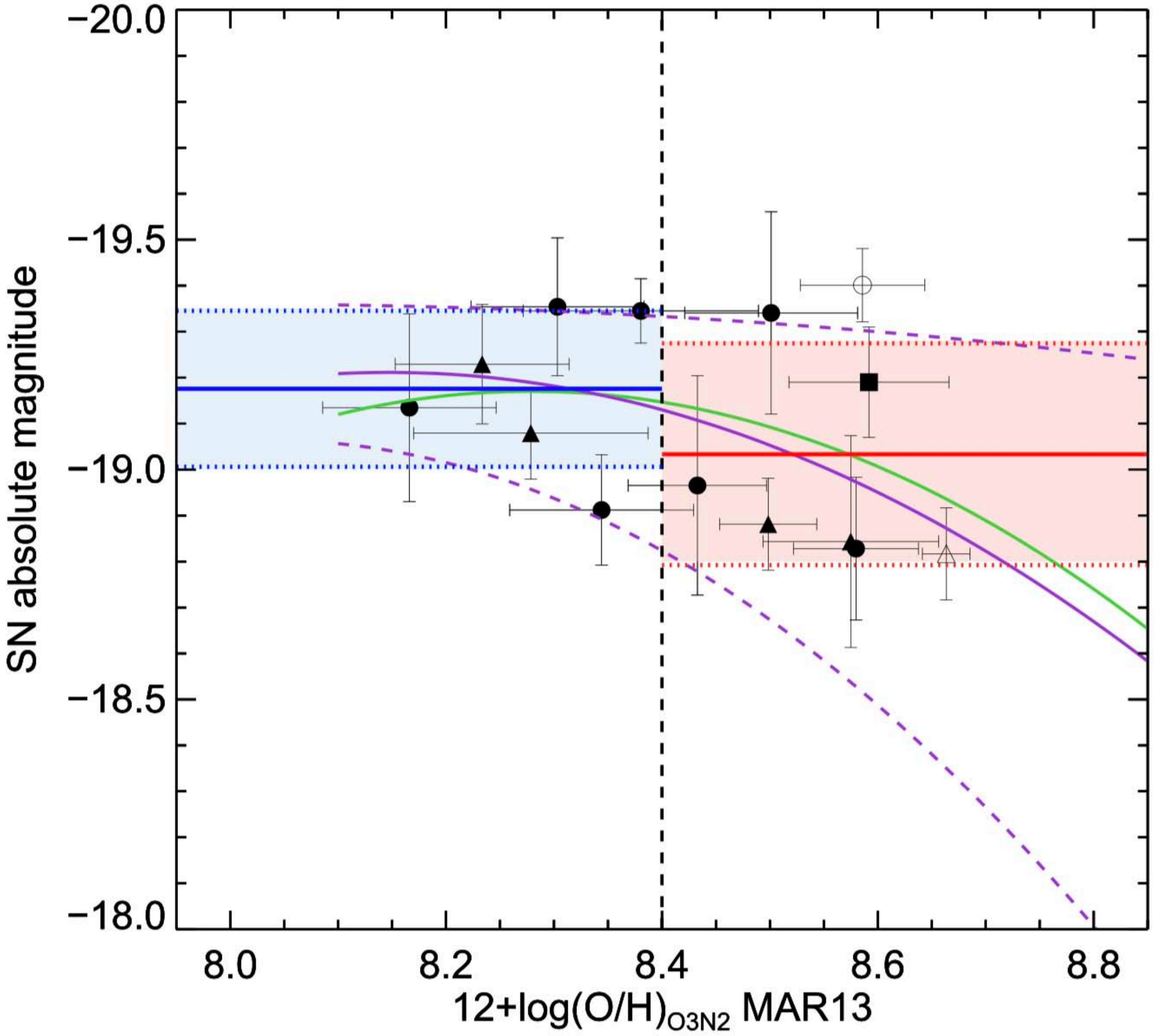
A

MR+16a

Only considering 'Normal' unredeemed SNIa



SNIa apparent peak magnitude +
Independent distance =
SNIa absolute magnitude



0.14±0.10 mag difference

As predicted by Times & Bravo (0.10-0.20 mag)

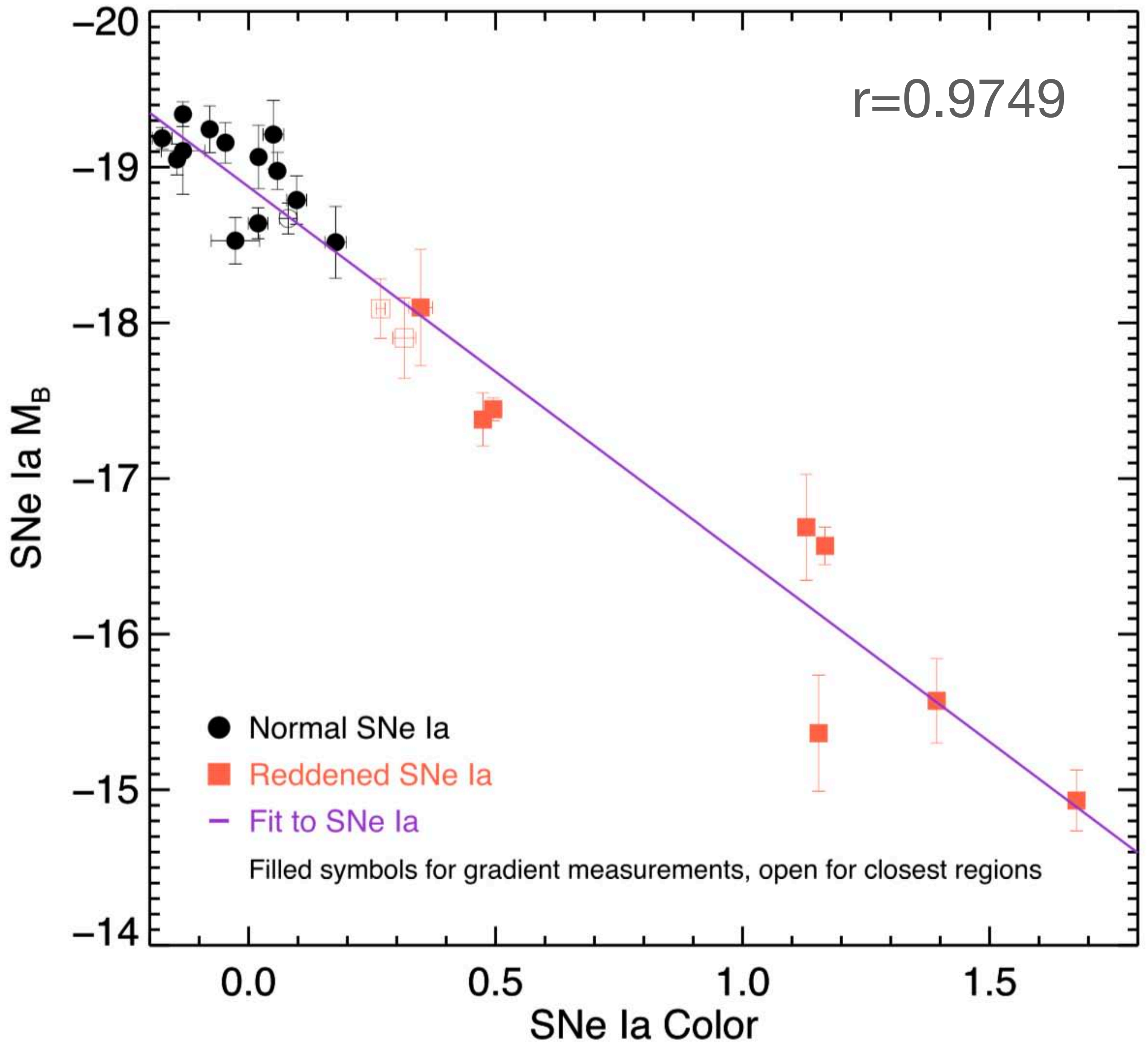
Local sample

PCA of the 4 parameters

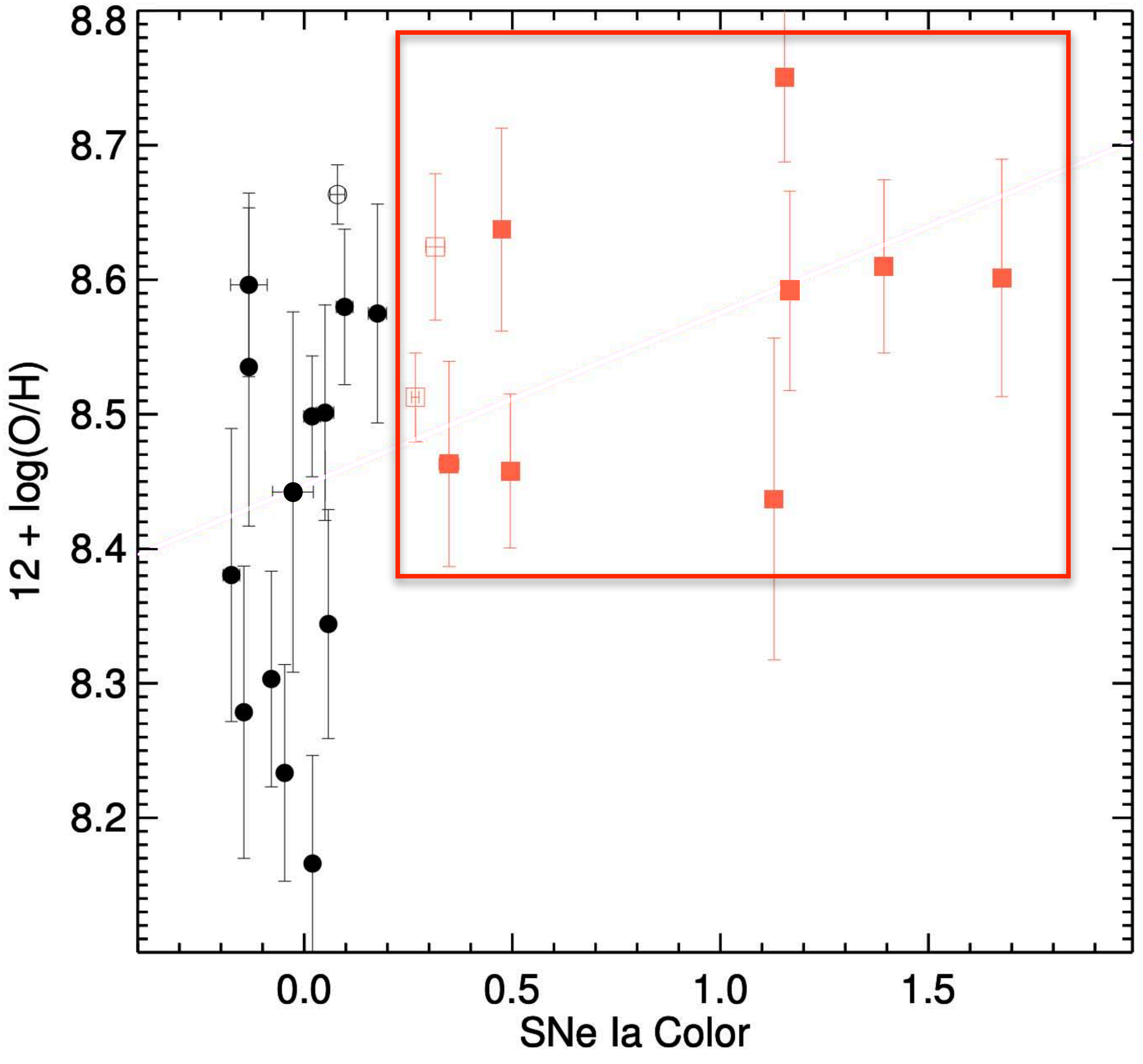
$$\begin{array}{c} \\ \Sigma = \end{array}\begin{array}{c} \begin{array}{cccc} M_B & c & OH & s \end{array} \\ \begin{pmatrix} 1.0 & 0.9749 & 0.5464 & -0.0222 \\ & 1.0 & 0.4780 & 0.0303 \\ & & 1.0 & -0.2251 \\ & & & 1.0 \end{pmatrix} \end{array}$$

Difference of 0.17 mag

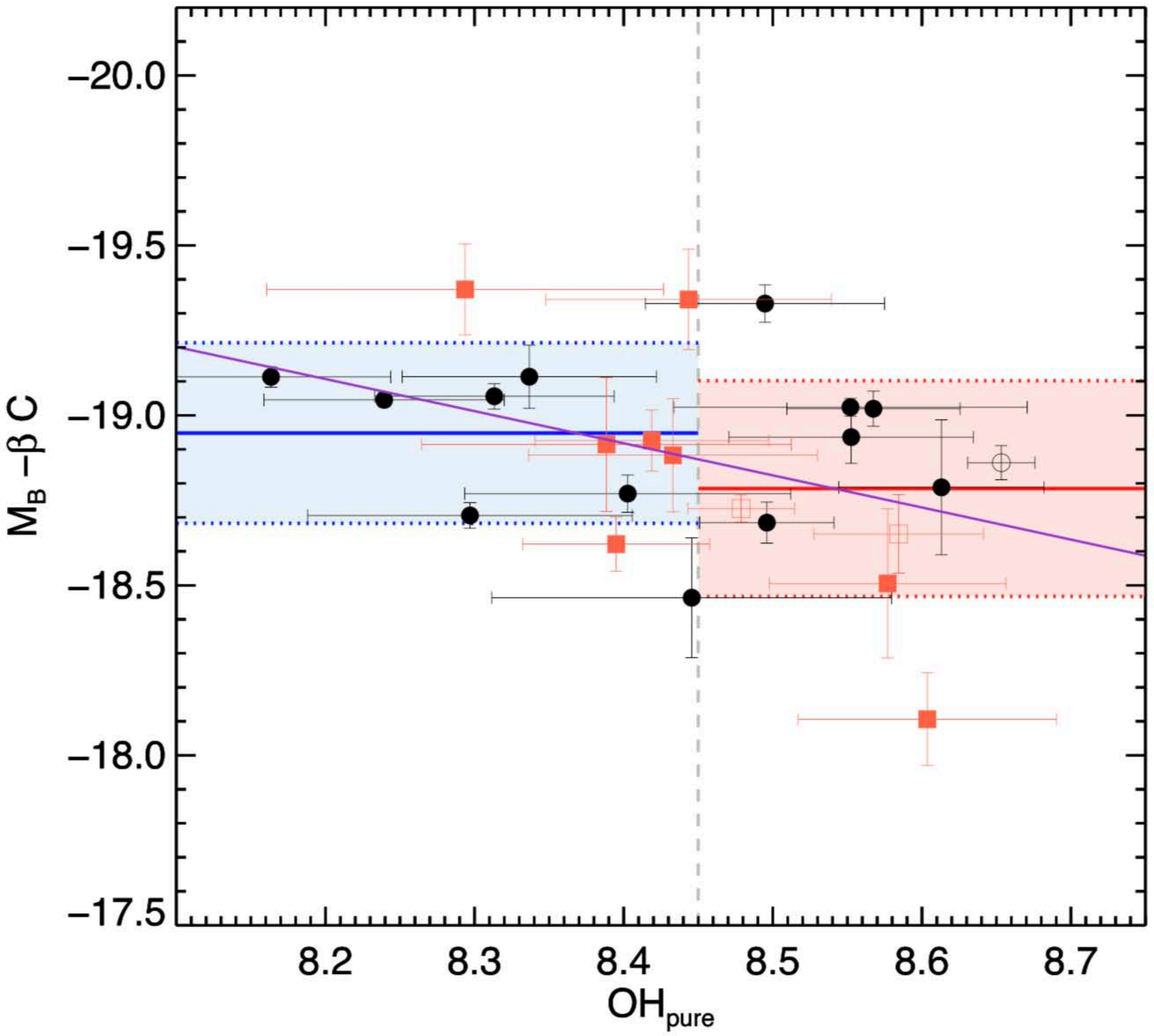
Slope of 0.94 mag/dex



Tight correlation MB-c



Red SNe in metal-rich environments



Int-z sample

c

MR+18

1188 spectra from SDSS and Union2.1

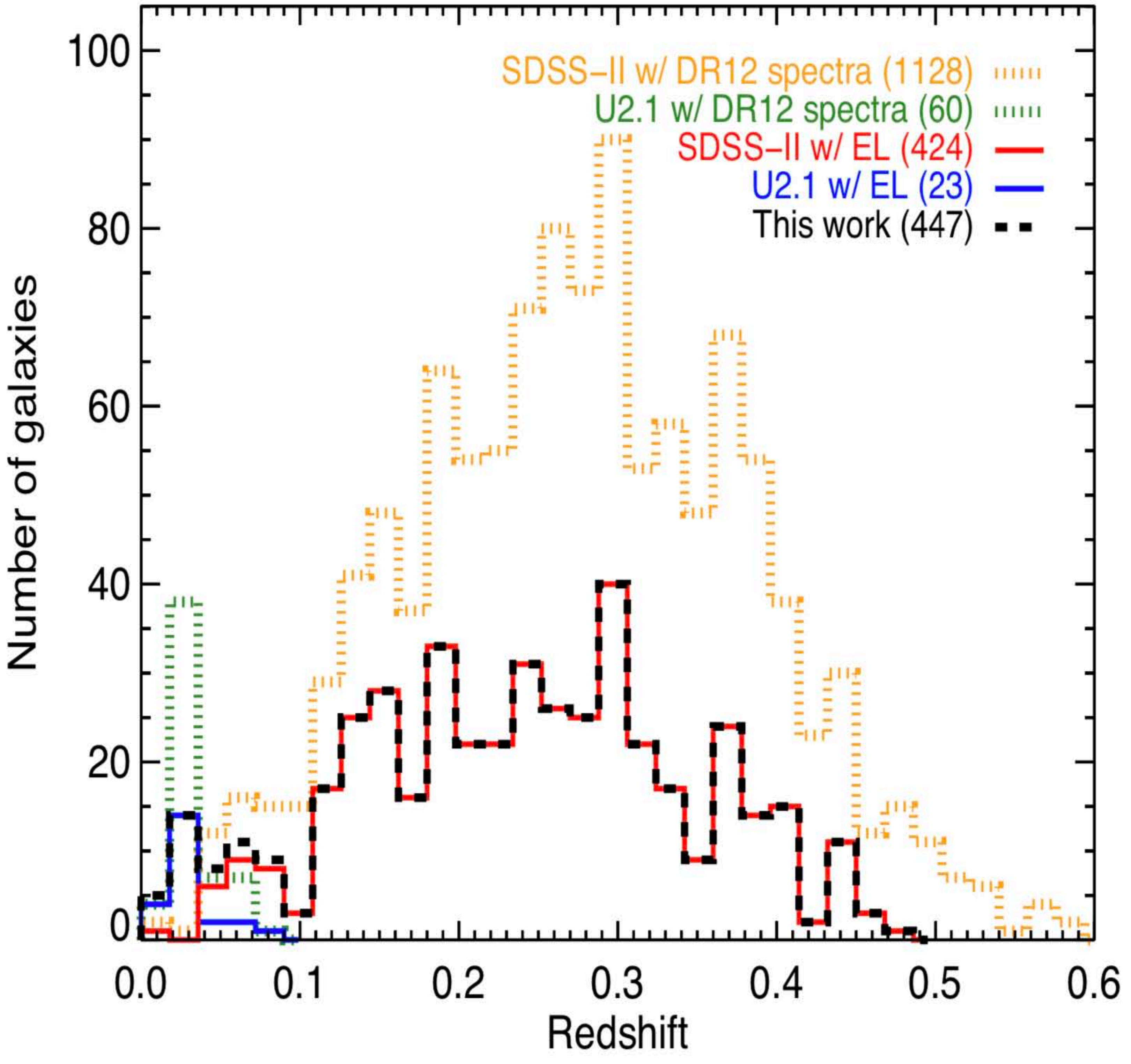
Emissions line measured with IRAF

Kept those with S/N (Ha, Hb, NII) > 5

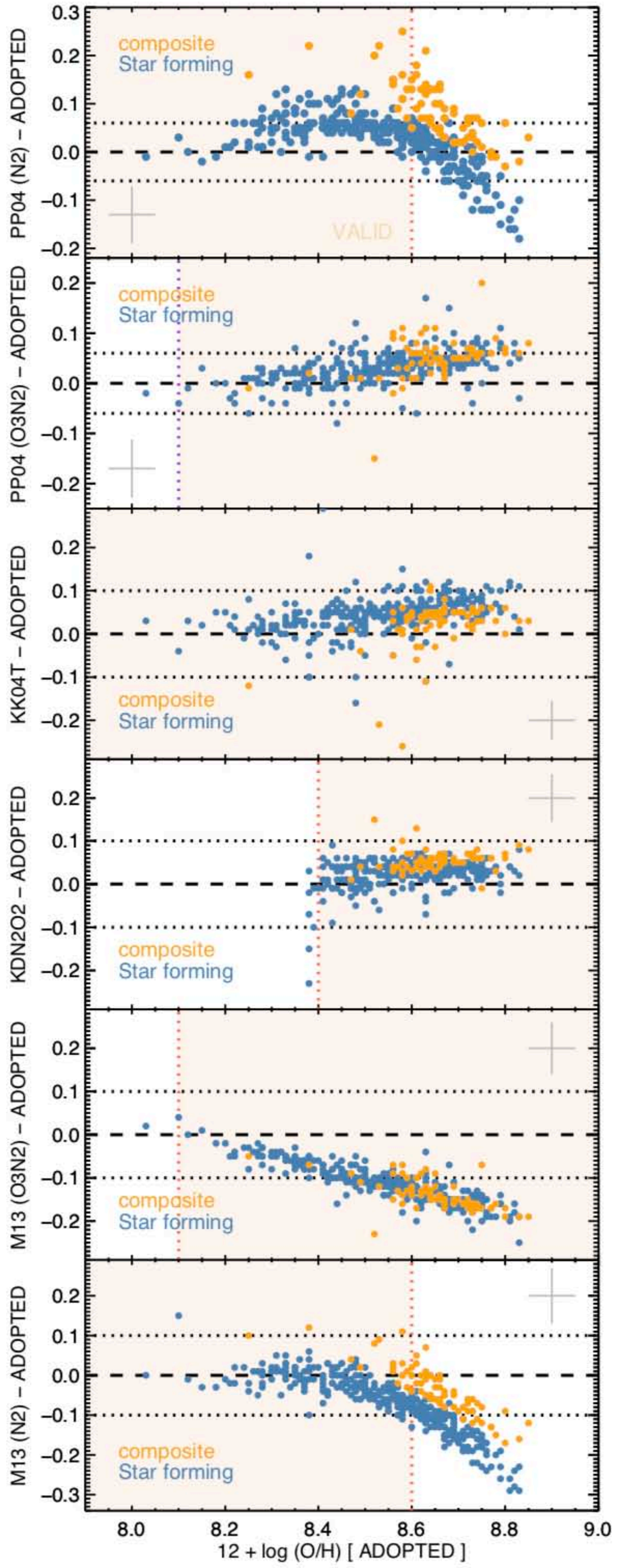
Remove AGN

Extended study on the best calibrator

Fit SNIa light-curves and apply cuts



Step	SDSS	Union2.1	Total
Initial	1466	580	2046
Spectra in DR12	1128	60	1188
Emission-line cuts	424	23	447
SF ionization	397	19	416
LC quality cuts	327	19	346
Stretch/colour cuts	245	18	263

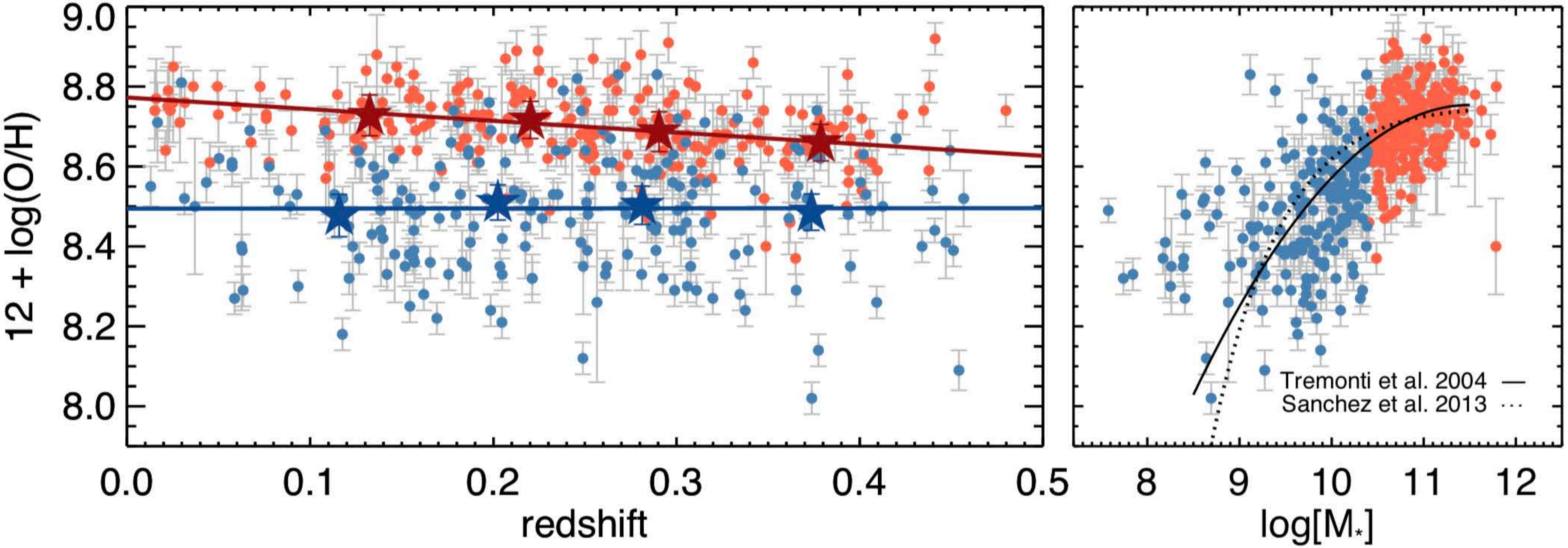


Int-z sample

C
MR+18

$$12 + \log(\mathrm{O/H})_{\text{hi-mass}} = \boxed{-0.29}(\pm 0.26) \times z + 8.77(\pm 0.07),$$

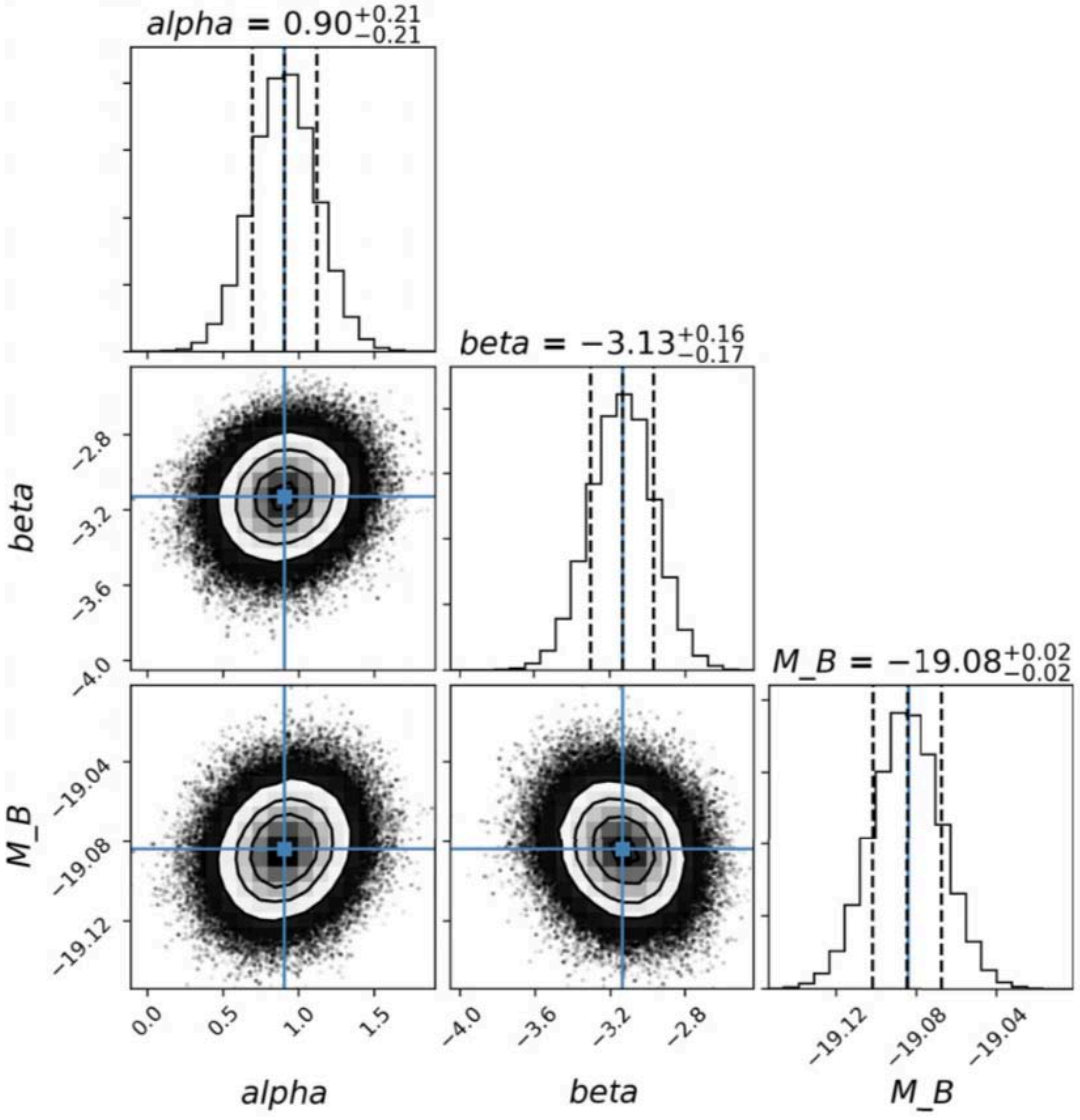
$$12 + \log(\mathrm{O/H})_{\text{lo-mass}} = \boxed{0.002}(\pm 0.253) \times z + 8.49(\pm 0.06).$$



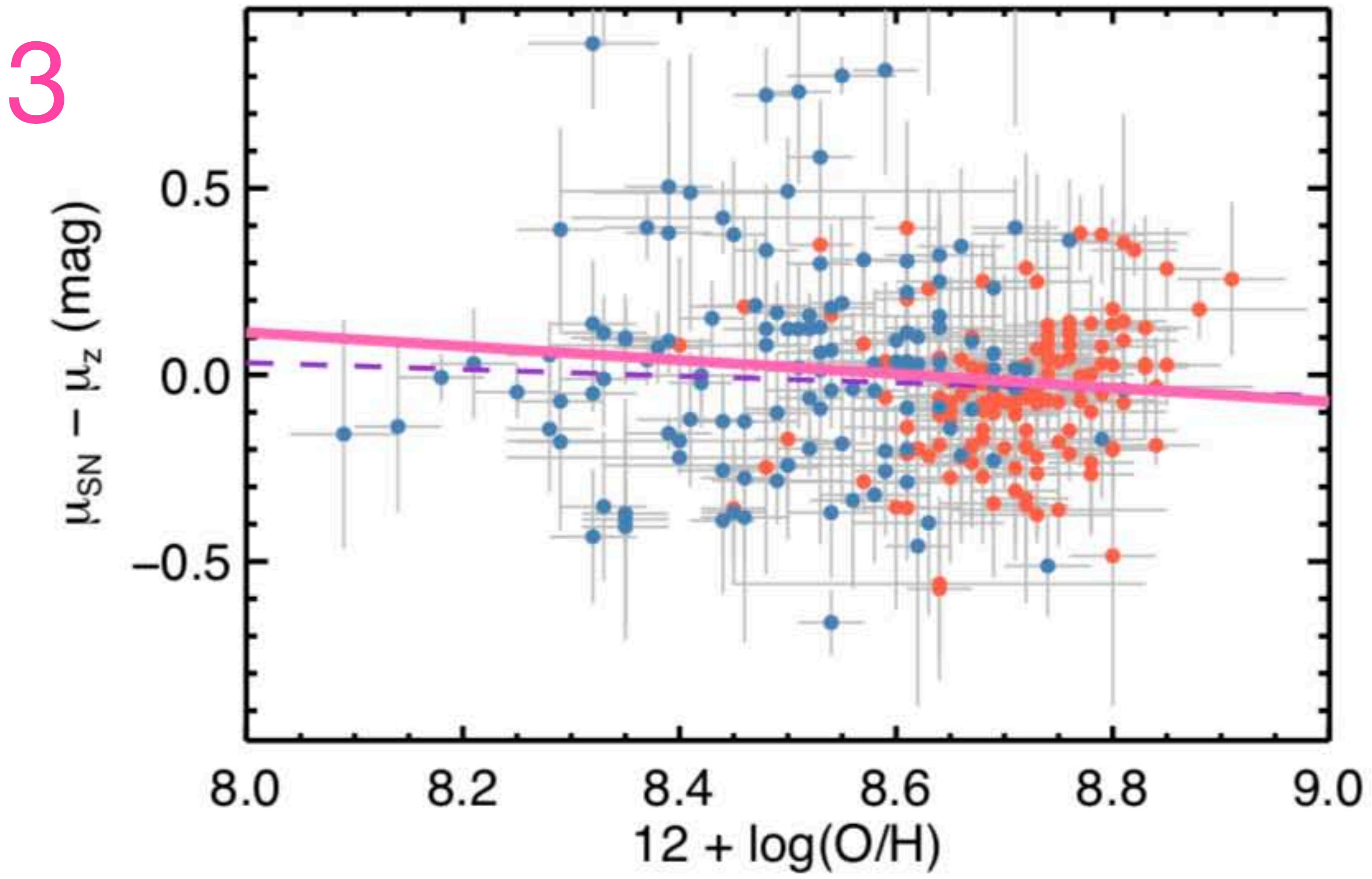
This finding would suggest that SNe in low-mass galaxies are possibly better standard candles

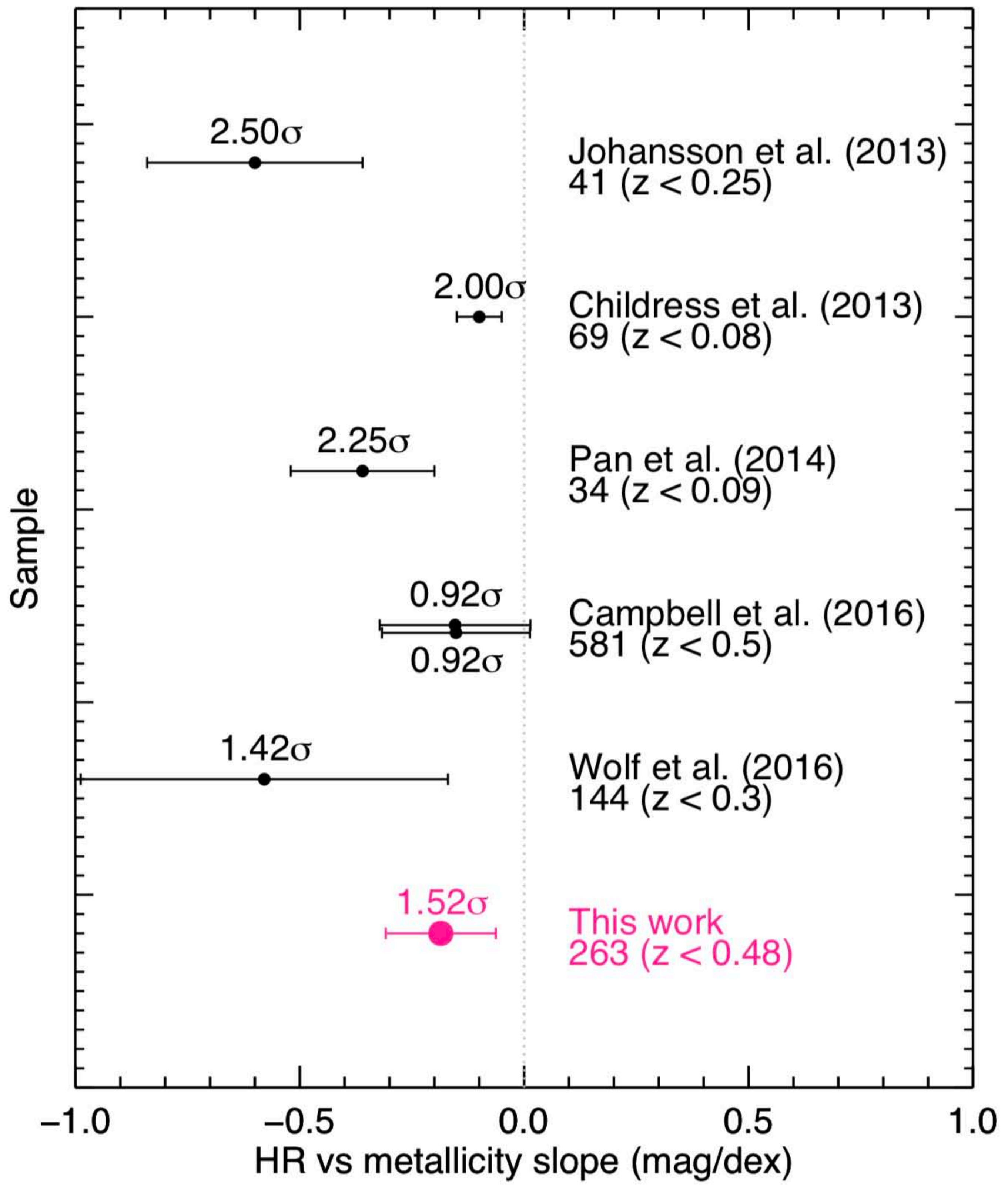
Int-z sample

-0.186 ± 0.123
mag/dex



$$\mu_{SN} = m_B - M_B - \alpha(s-1) - \beta c$$

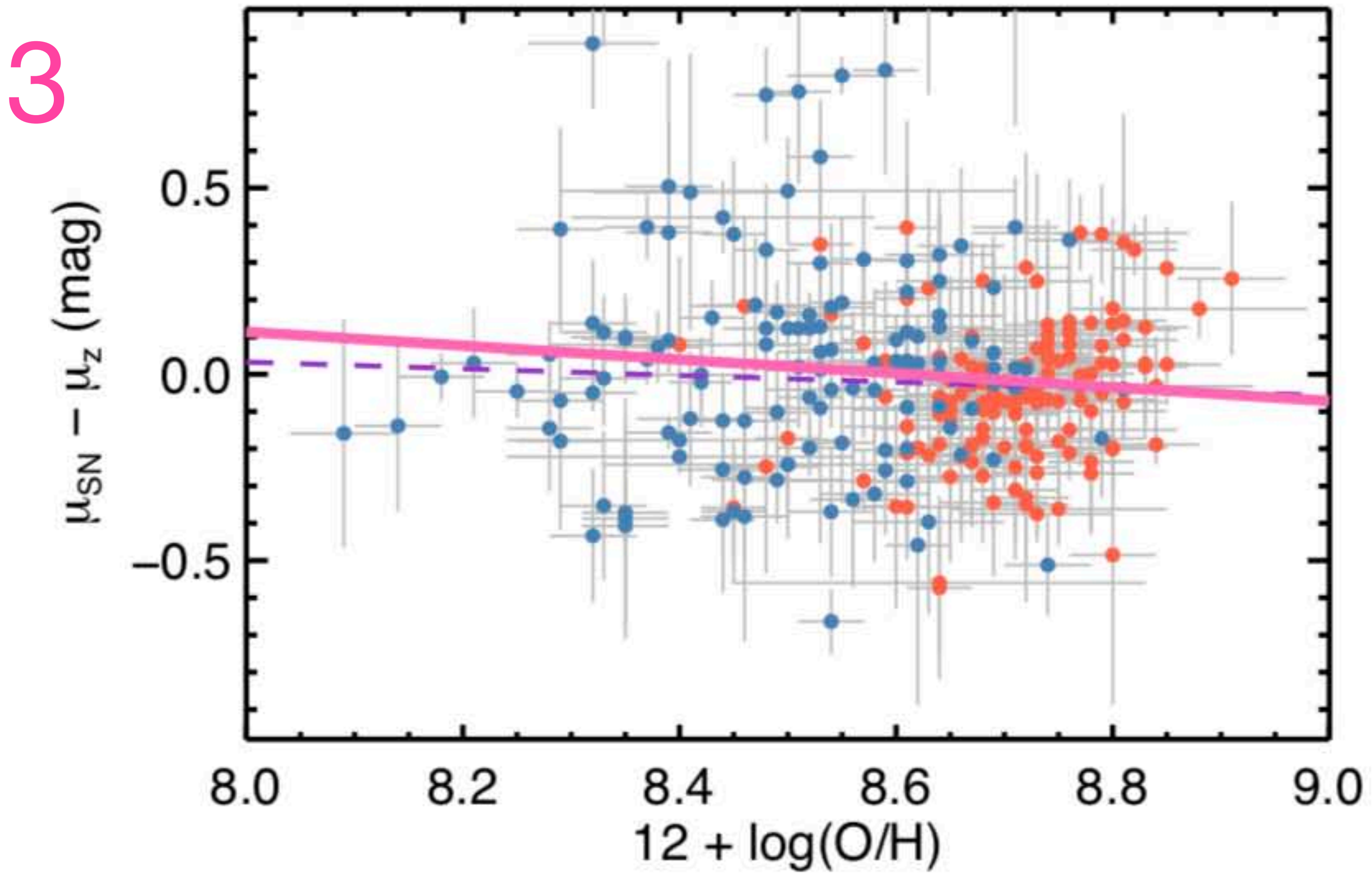




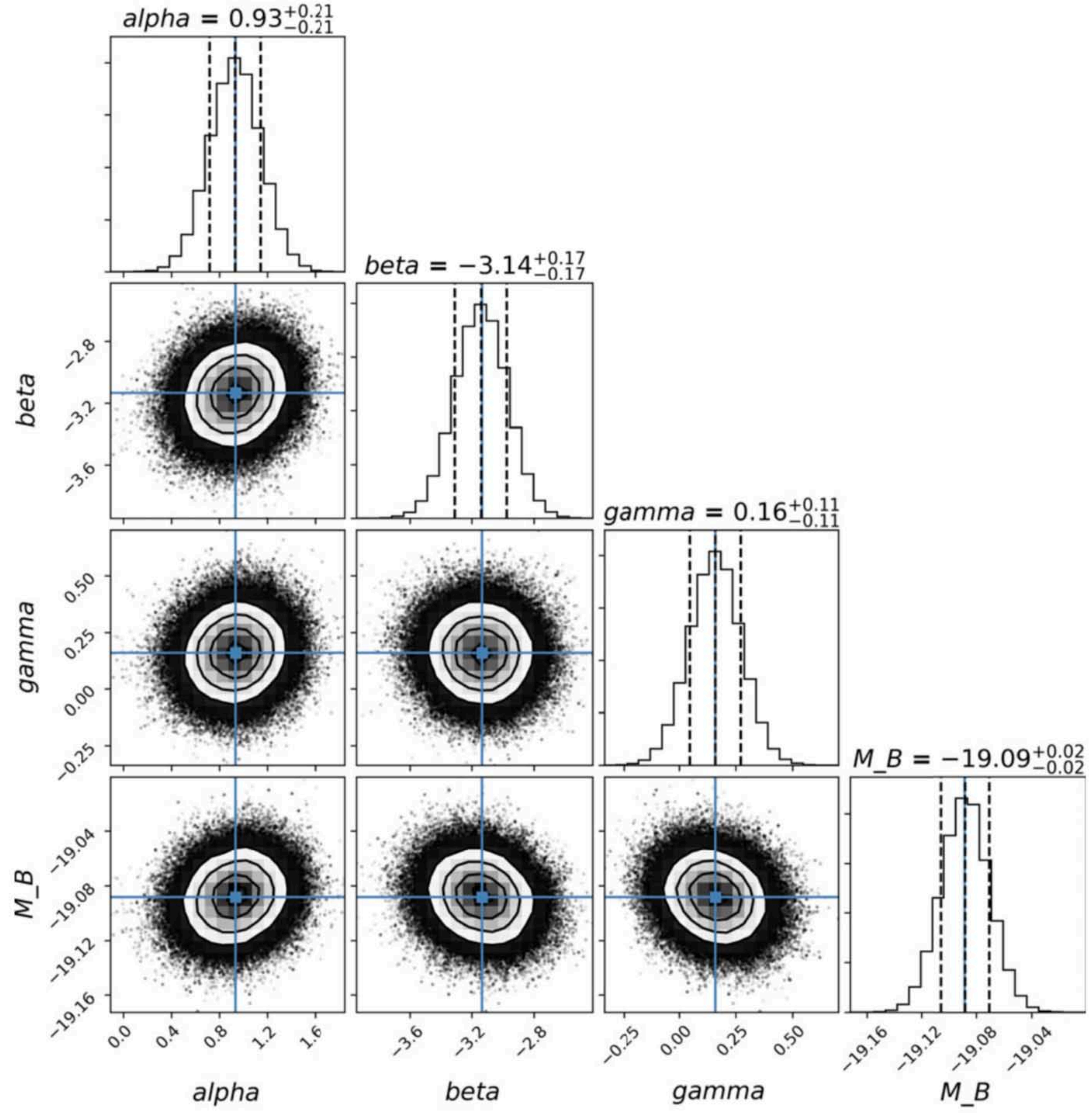
c
MR+18

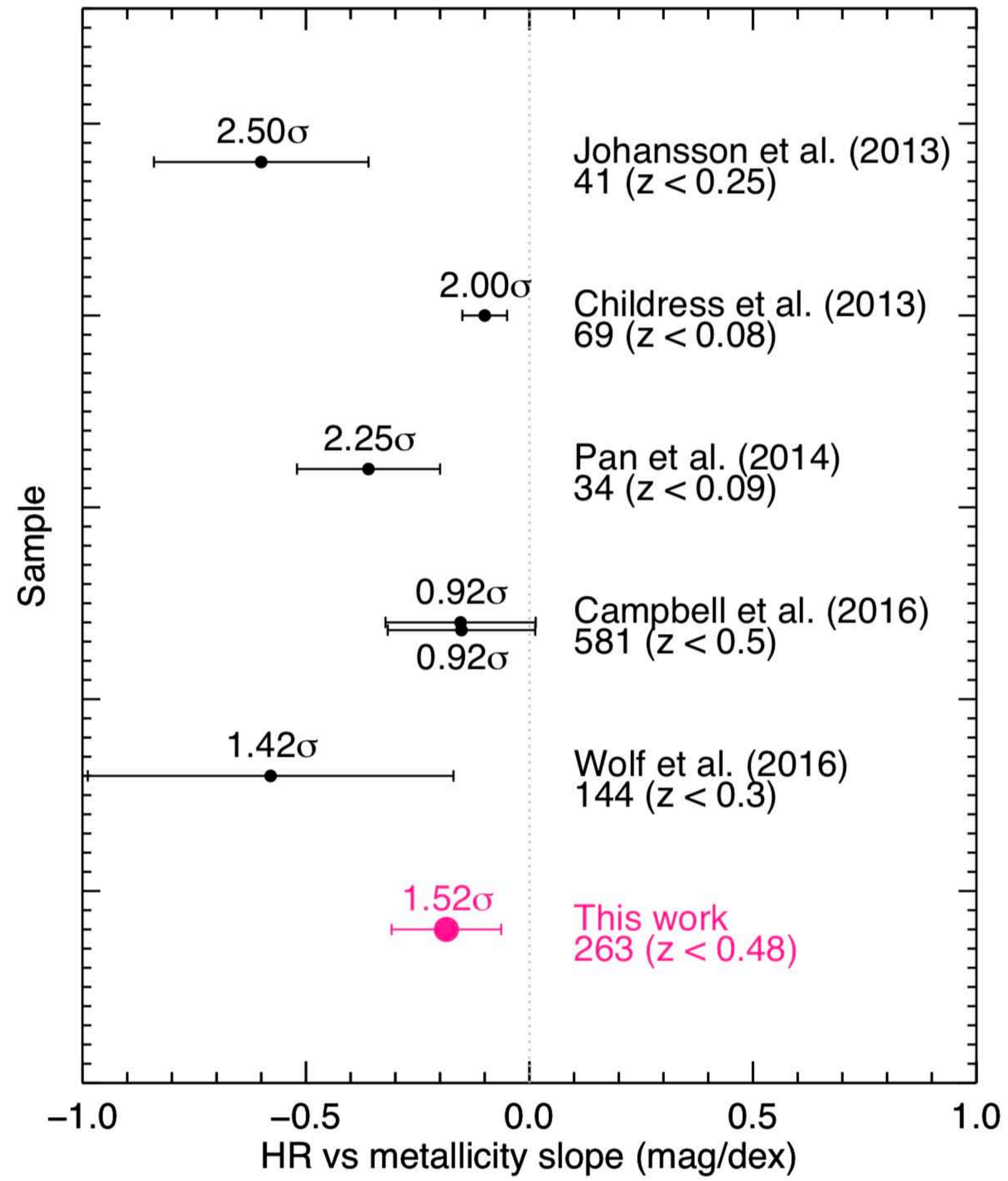
Int-z sample

-0.186 ± 0.123
mag/dex



C
MR+18



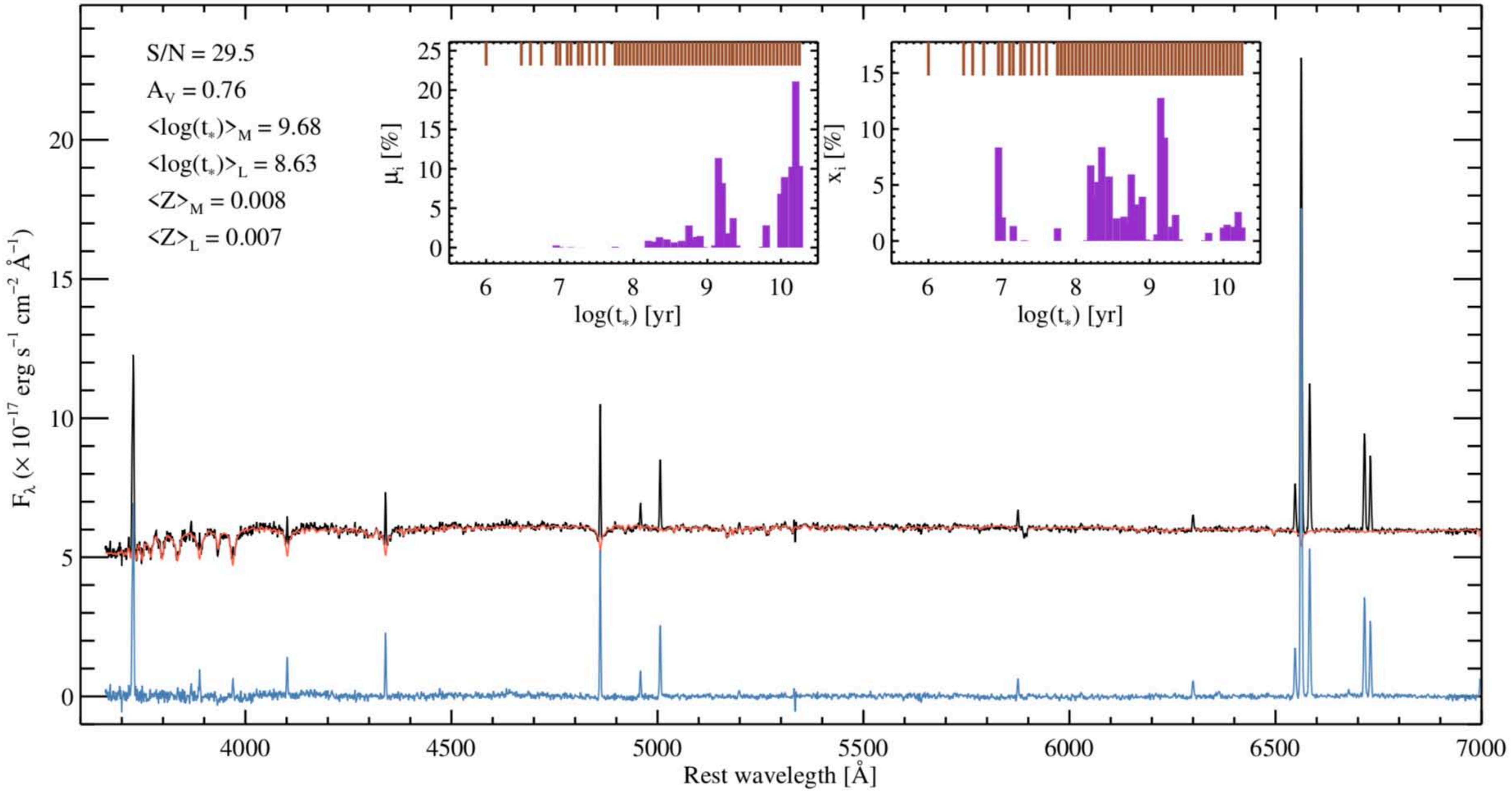


$$\mu_{SN} = m_B - M_B - \alpha(s-1) - \beta c + \gamma OH$$

Int-z sample

D

G+22



SDSS sample

STARLIGHT used to remove continuum

- Stellar mass
- Absorption considered

Emission lines measured with MPFIT

Similar procedure to CALIFA G14,16,18

3 cases studied:

A. As observed

B. Scaled to the photometry

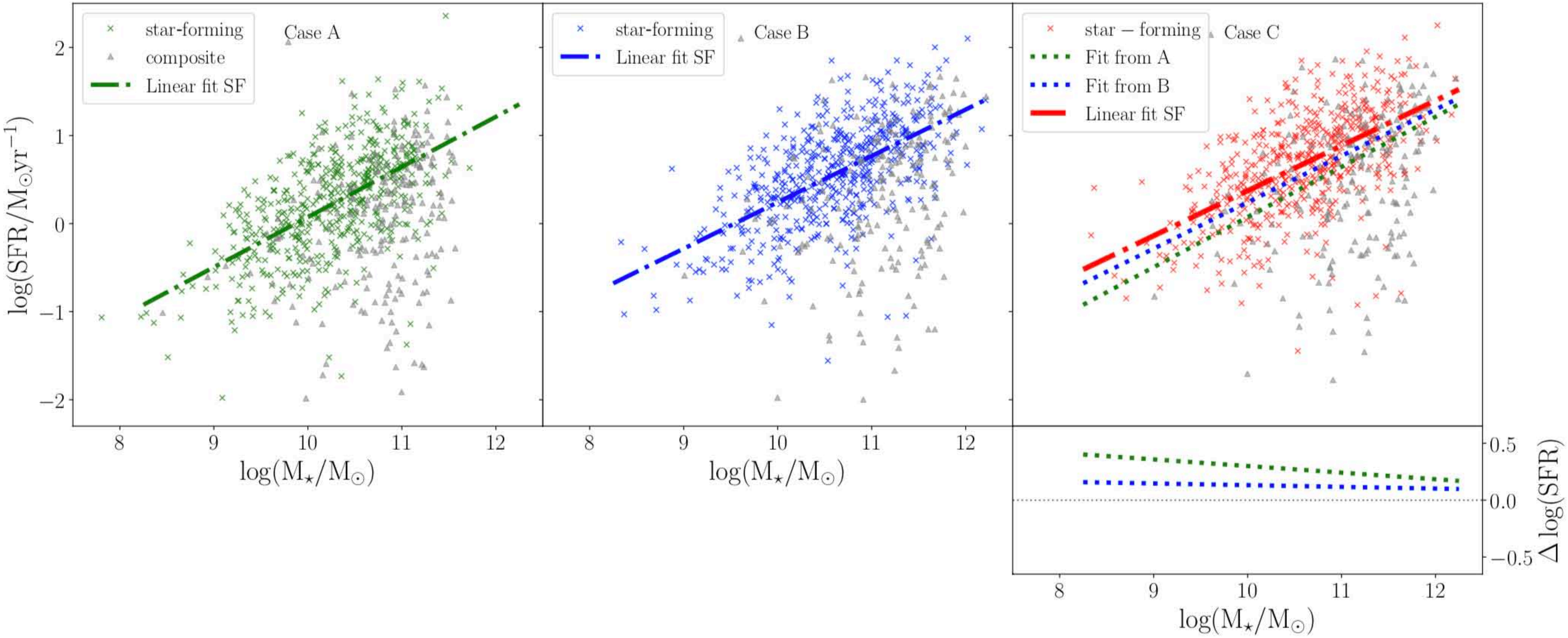
C. Aperture corrected

Iglesias-Páramo+2013
Iglesias-Páramo+2016
Duarte Puertas+2017

Int-z sample

D

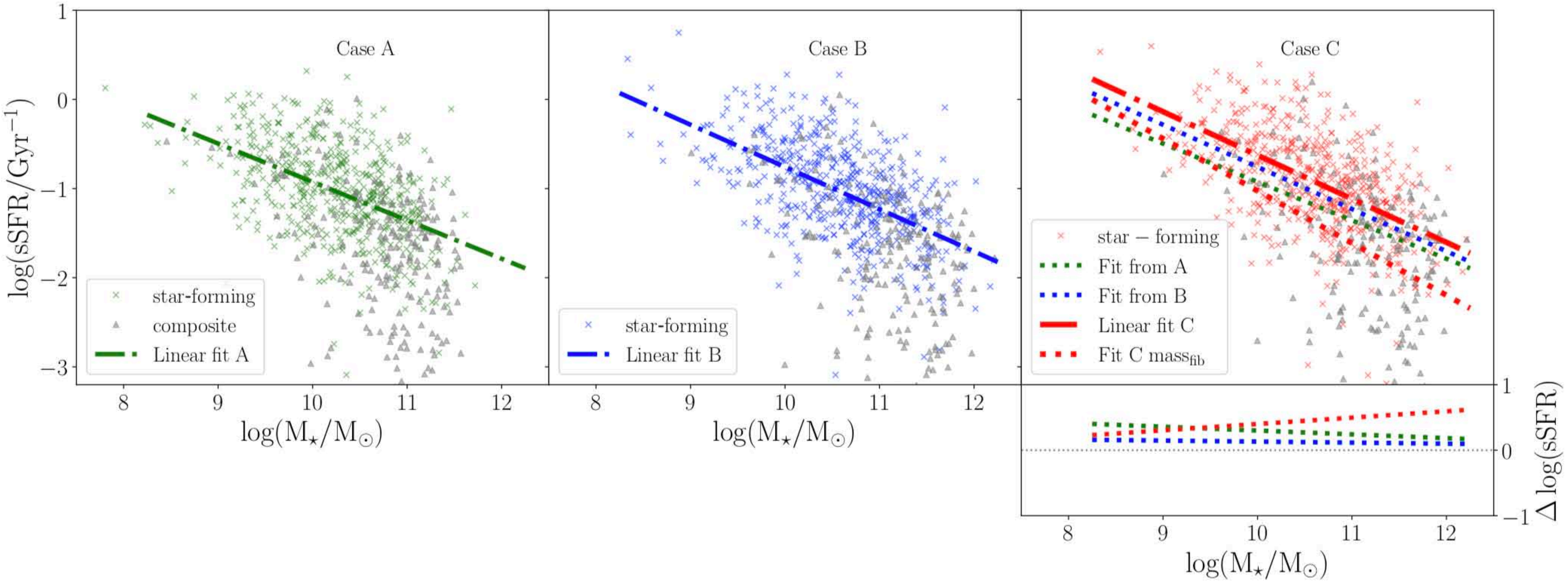
G+22



Int-z sample

D

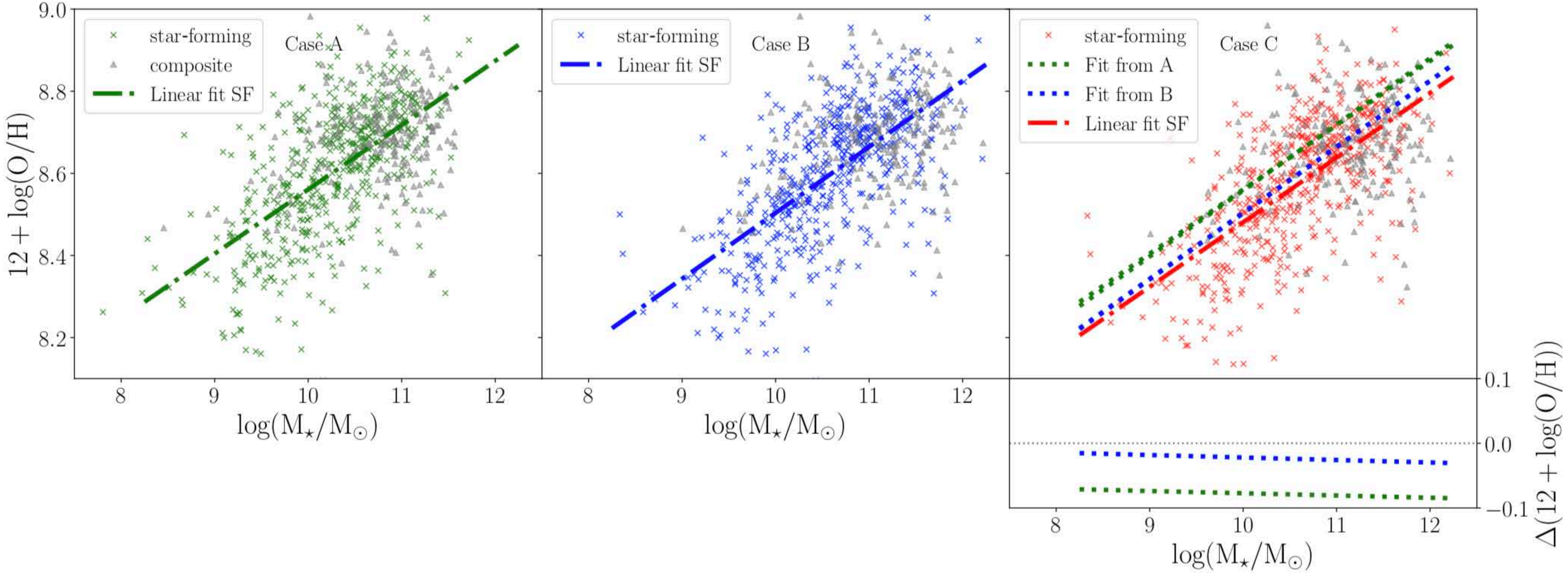
G+22



Int-z sample

D

G+22



Int-z sample

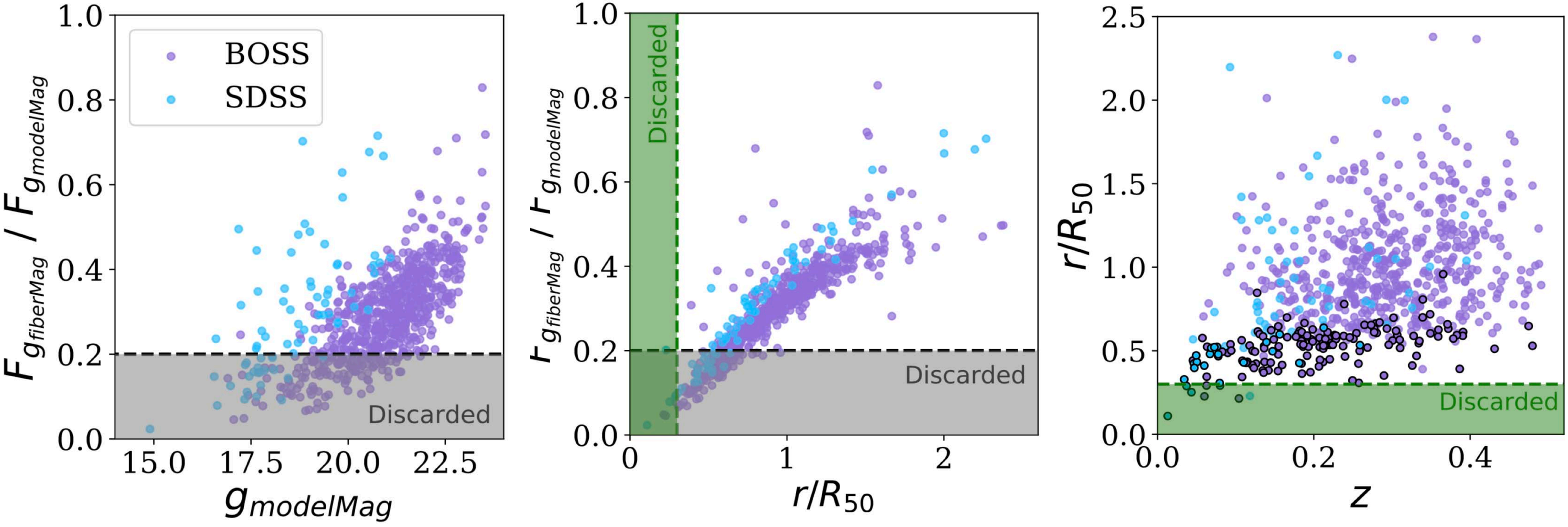
D

G+22

Compared: scaled (Case B) + g-band fraction criterion (Kewley+05+08)

aperture-corrected (Case C)

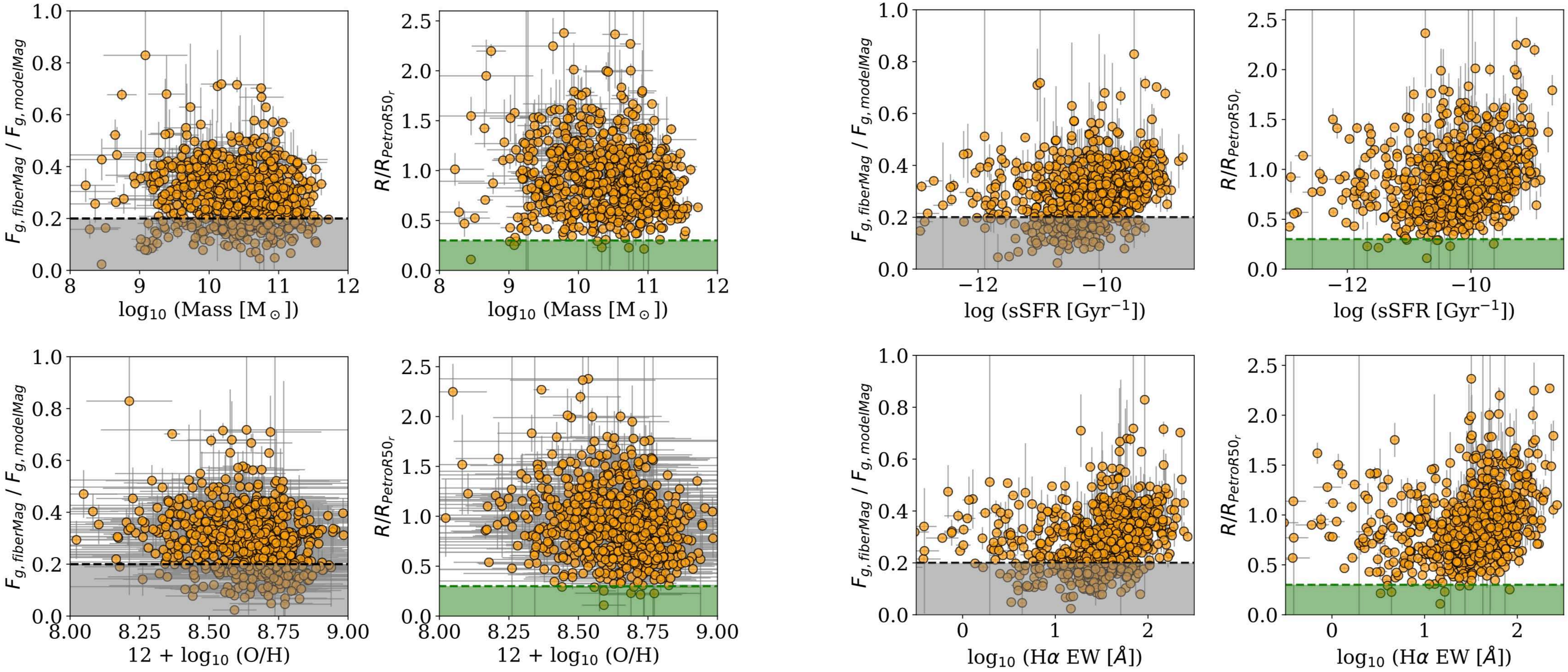
589 vs 475 galaxies



Int-z sample

D

G+22



g-band fraction: Losing High-mass, metal-rich, low sSFR and low HaEW galaxies

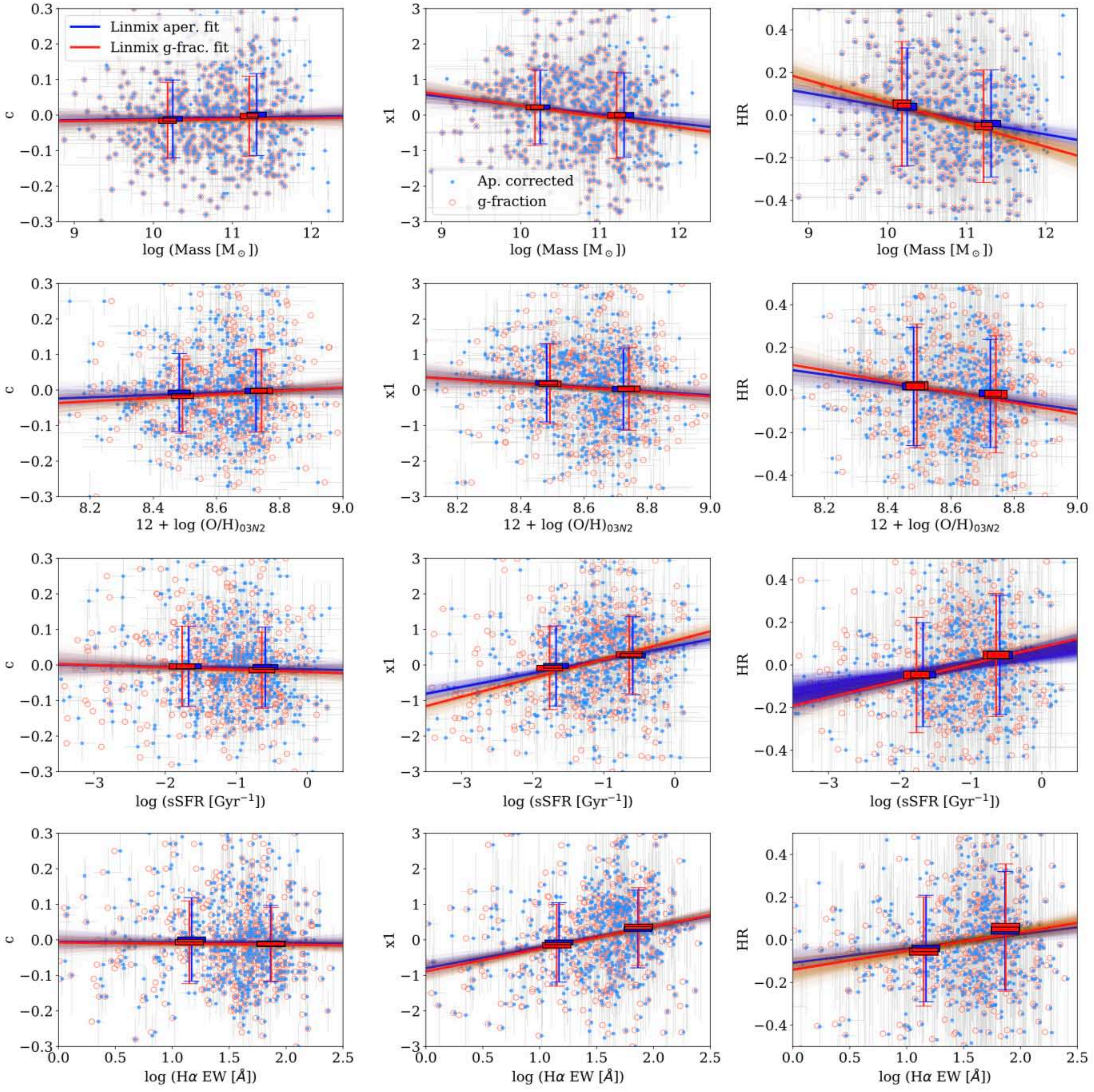
Int-z sample

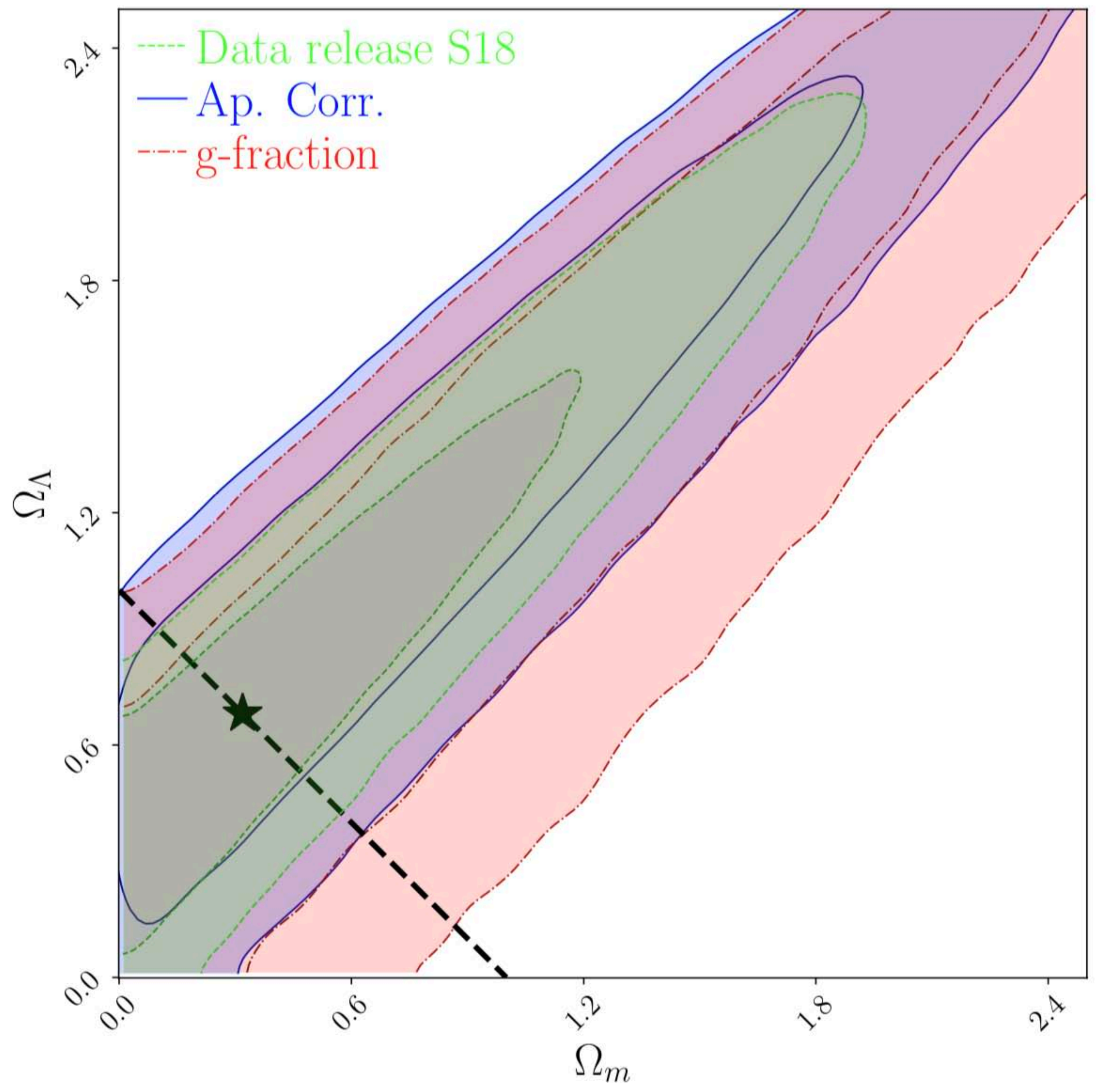
G-band fraction
Aperture-corrected

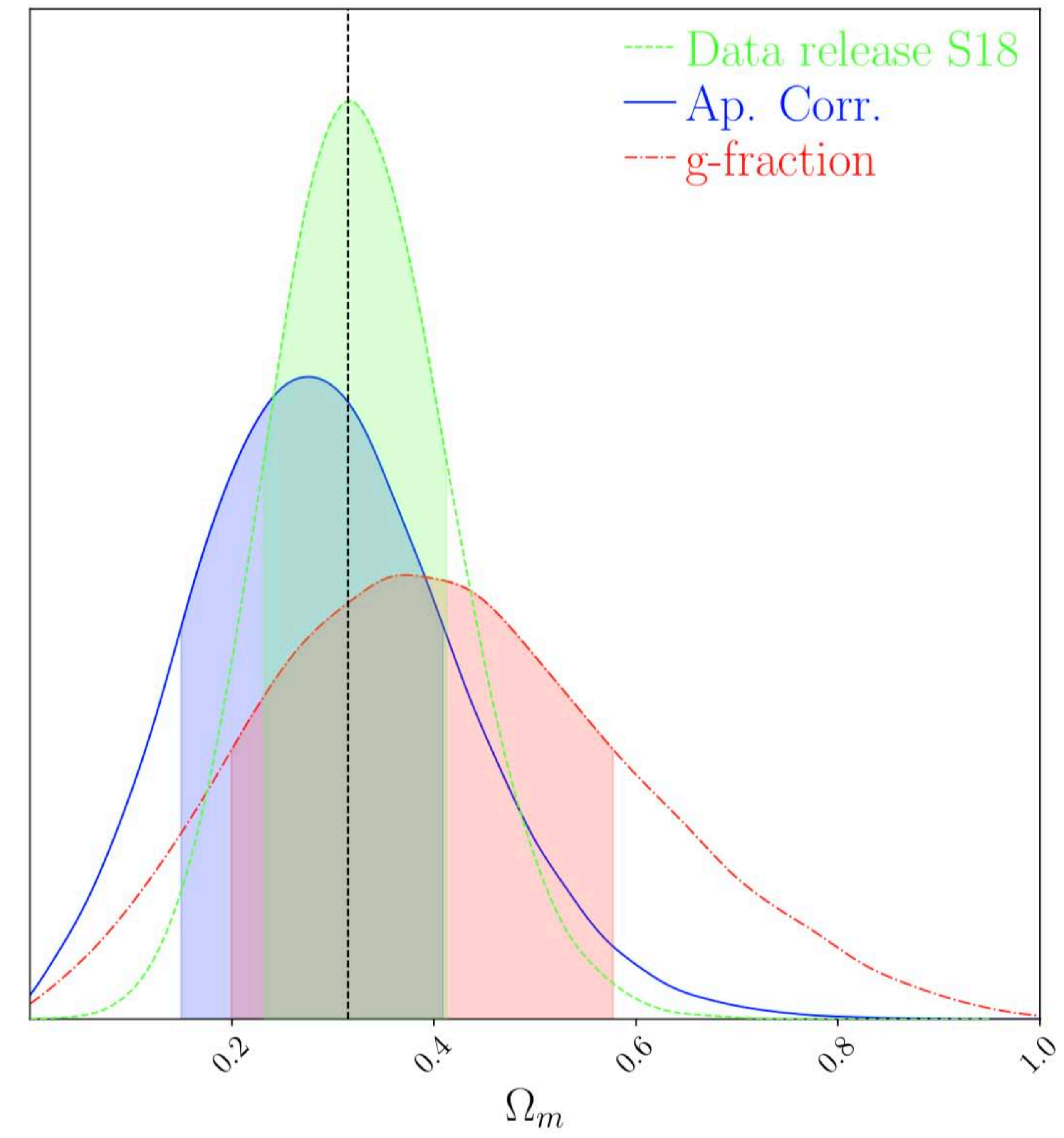
D
G+22

Color | Stretch | Distance

Mass
OH
sSFR
HaEW





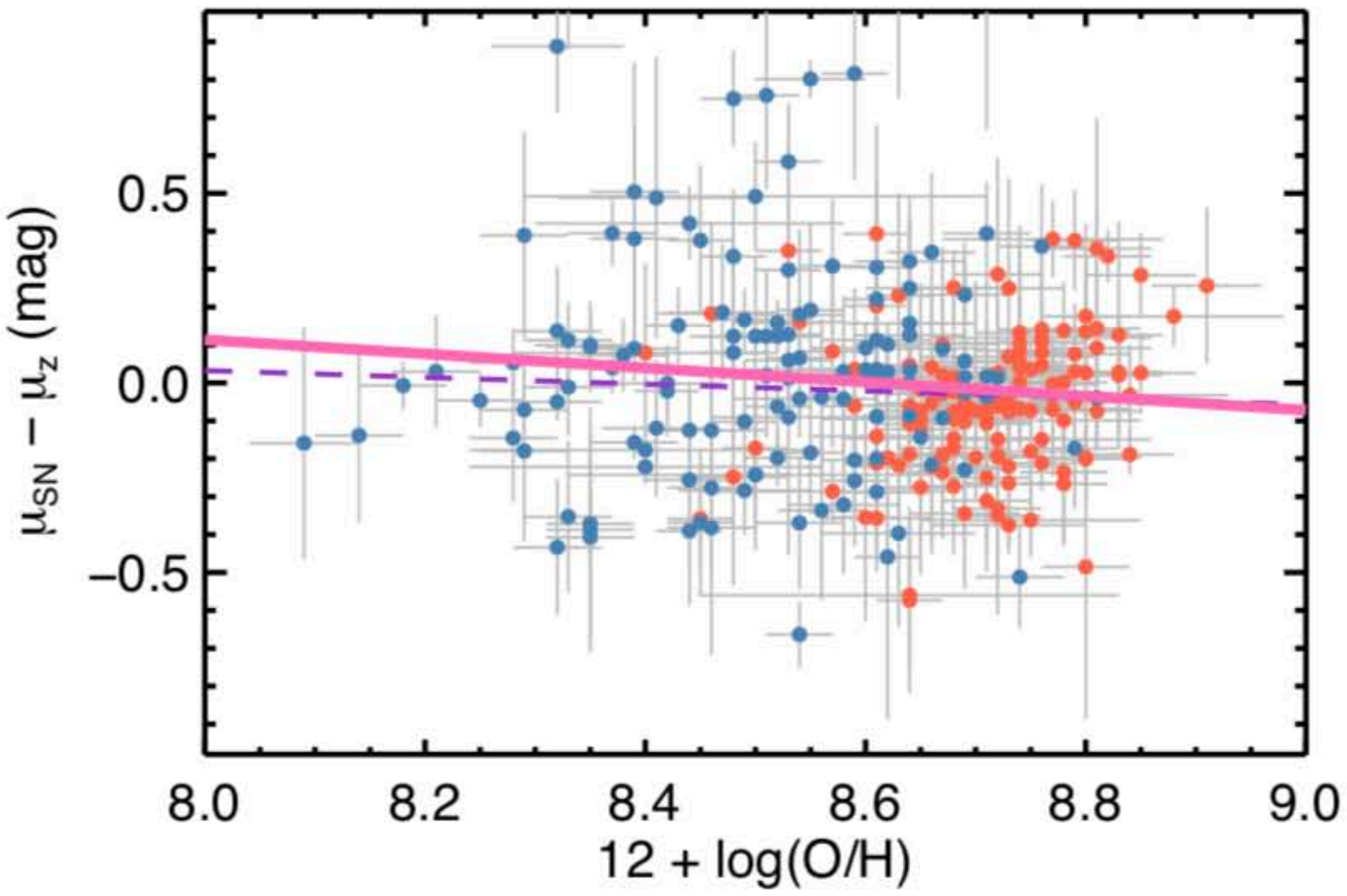


Int-z sample

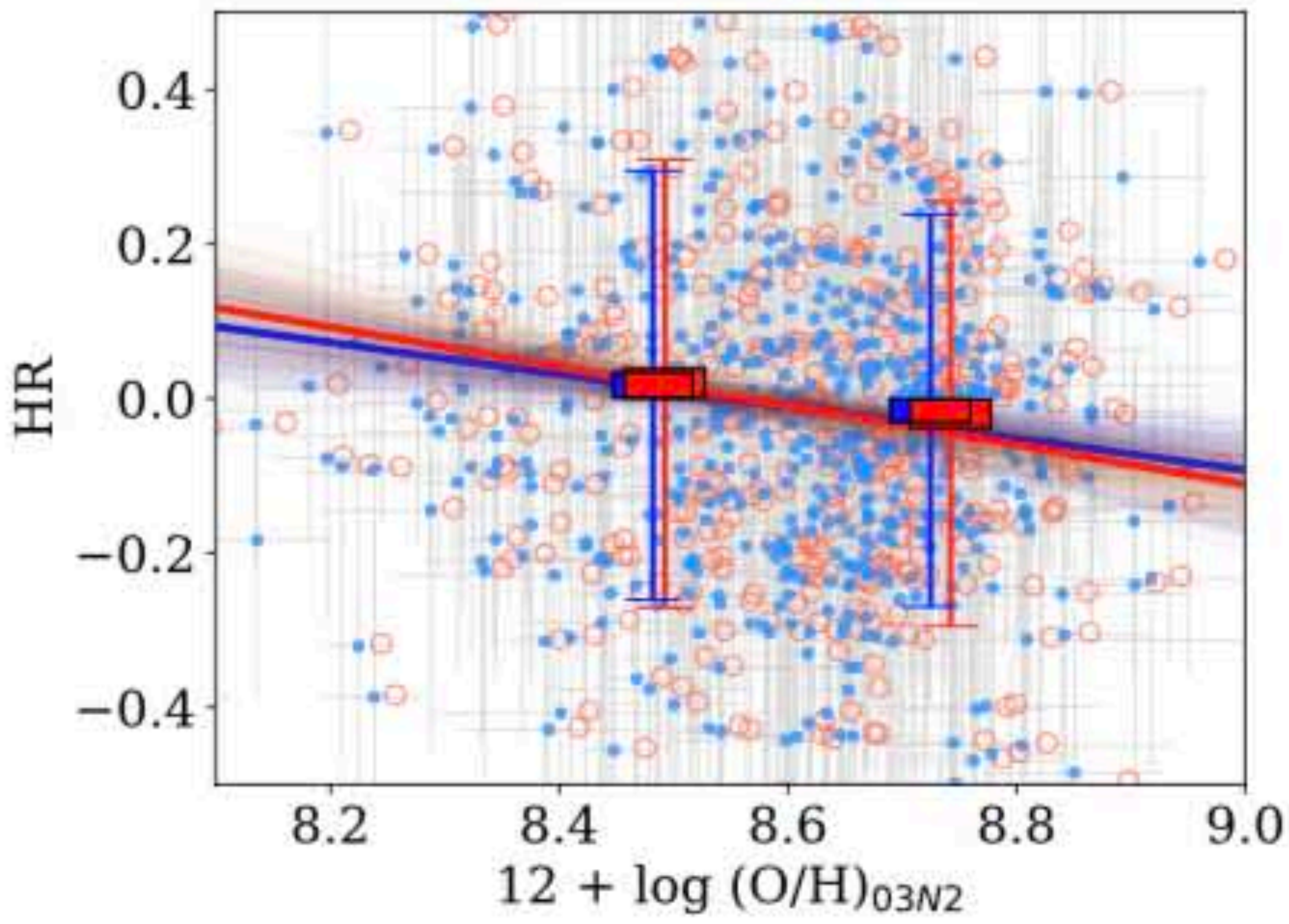
D

G+22

MR+16

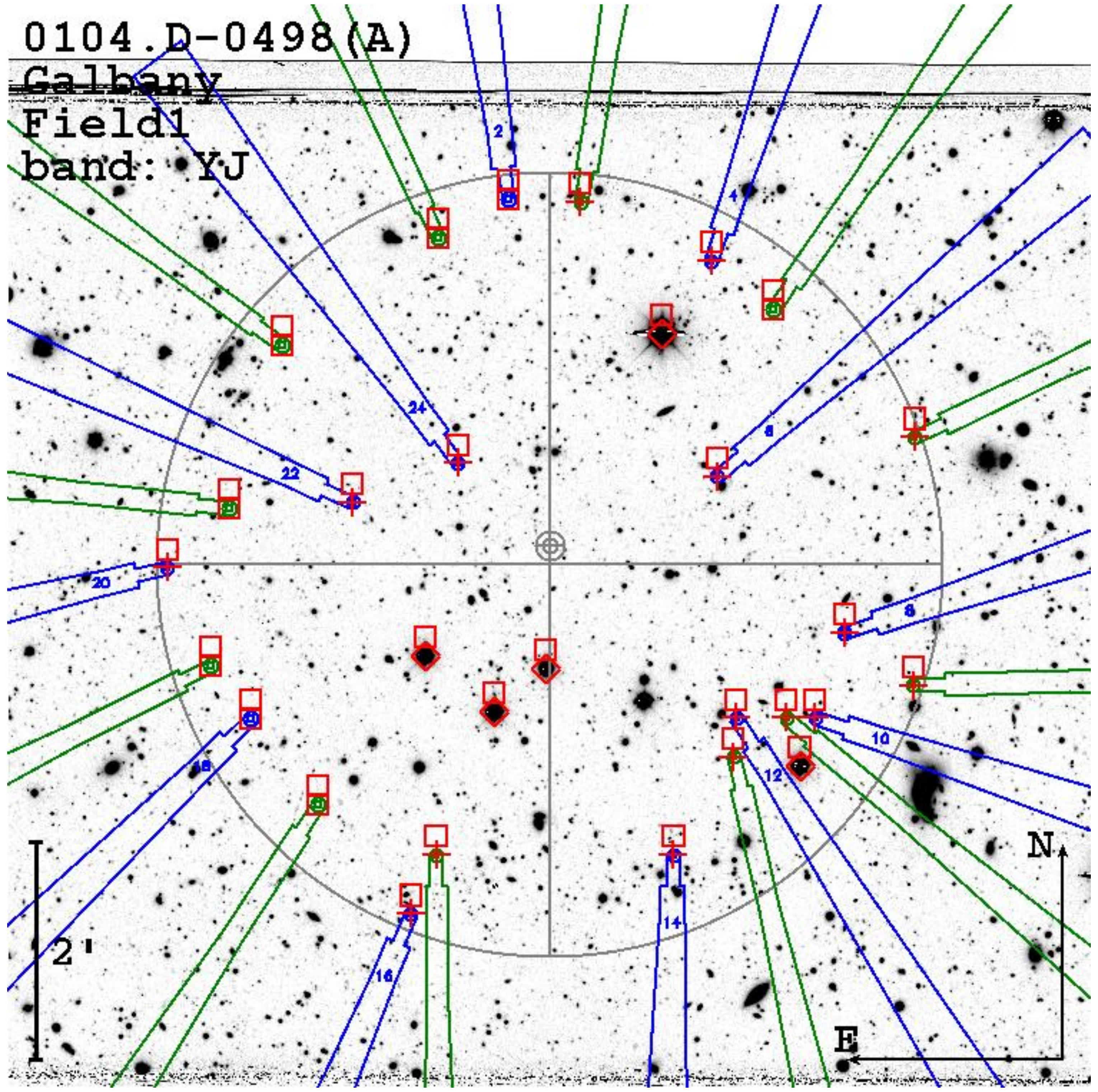


G+22



Slope mag/dex	-0.186 ± 0.123	-0.243 ± 0.082	-0.182 ± 0.076
sig.	1.52	2.96	2.39

High-z sample

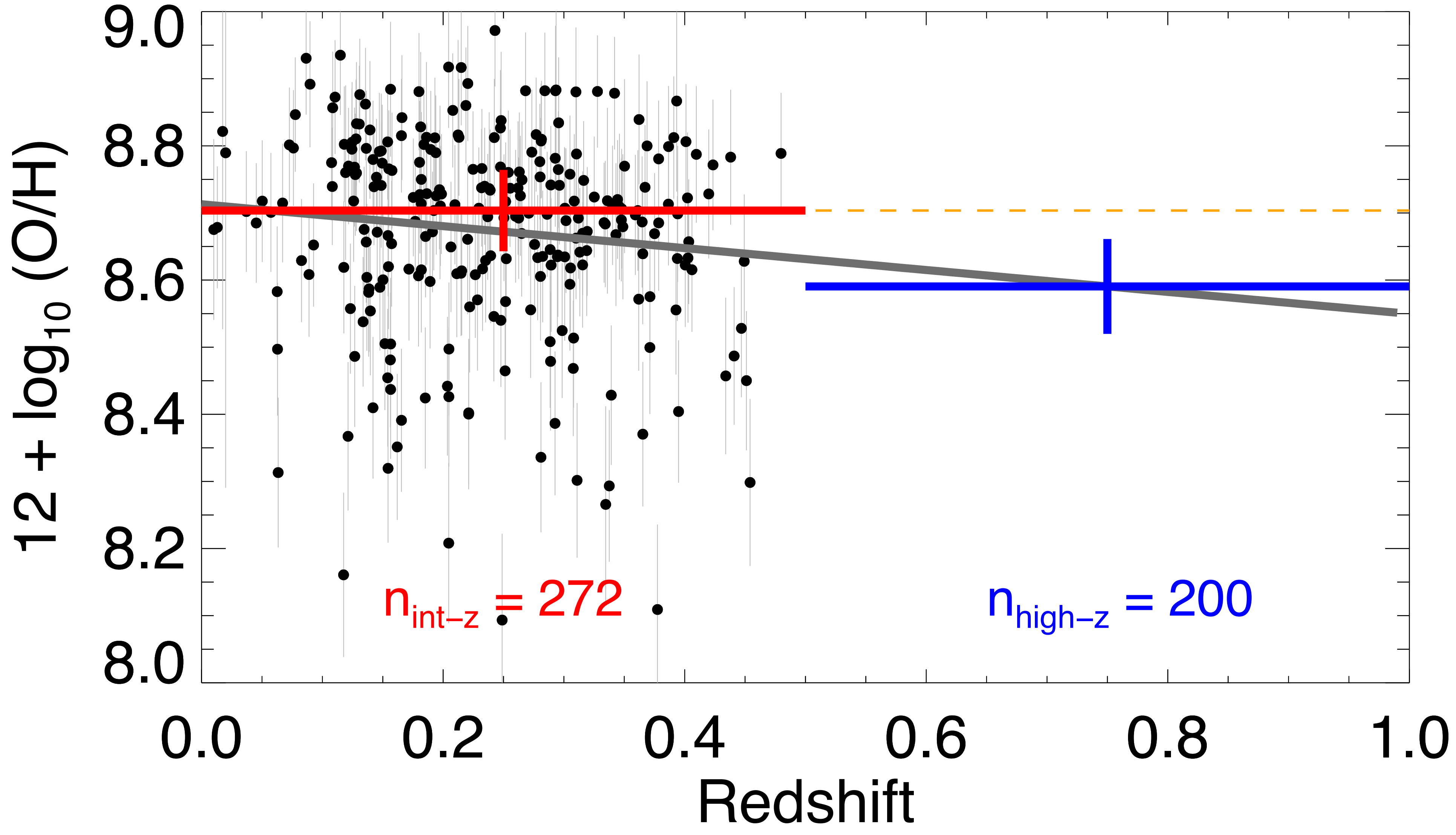


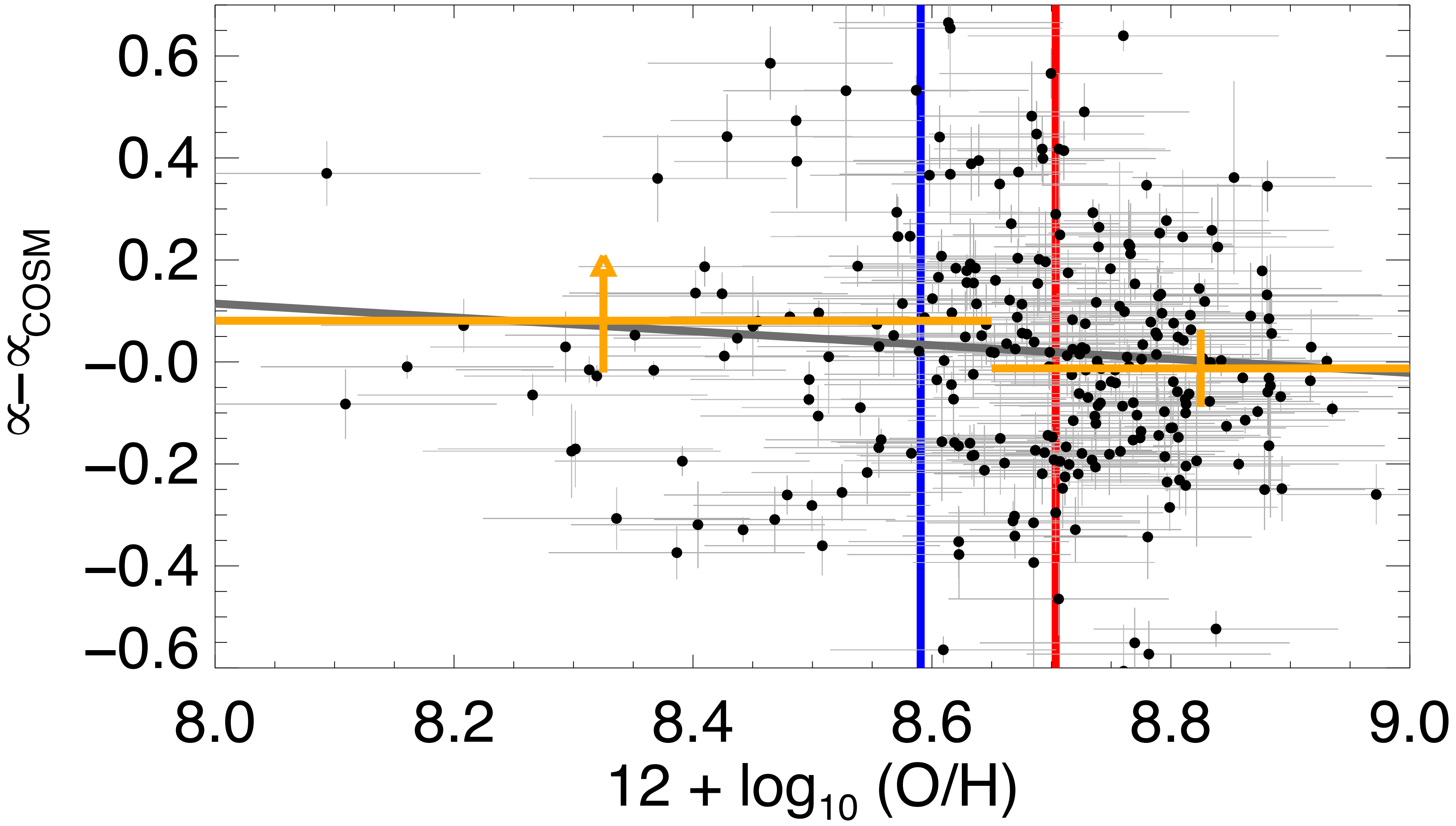
Kmos

@ UT1 Very Large Telescope

DARK ENERGY SURVEY

- 24 arm spectrograph, 7.2’ diameter
- 24 ~3”x3” IFU (0.2” spx)
- >200 SN hosts at z>0.5 from DES





To be continued at Iker’s talk