2405.20965

2406.02072

Type Ia Supernovae standardisation with the ZTF SN Ia DR2 sample

Madeleine Ginolin, Mickaël Rigault

KICC - 11th November 2024

Outline

I. Cosmology with Type Ia supernovae

II. ZTF SN Ia DR2

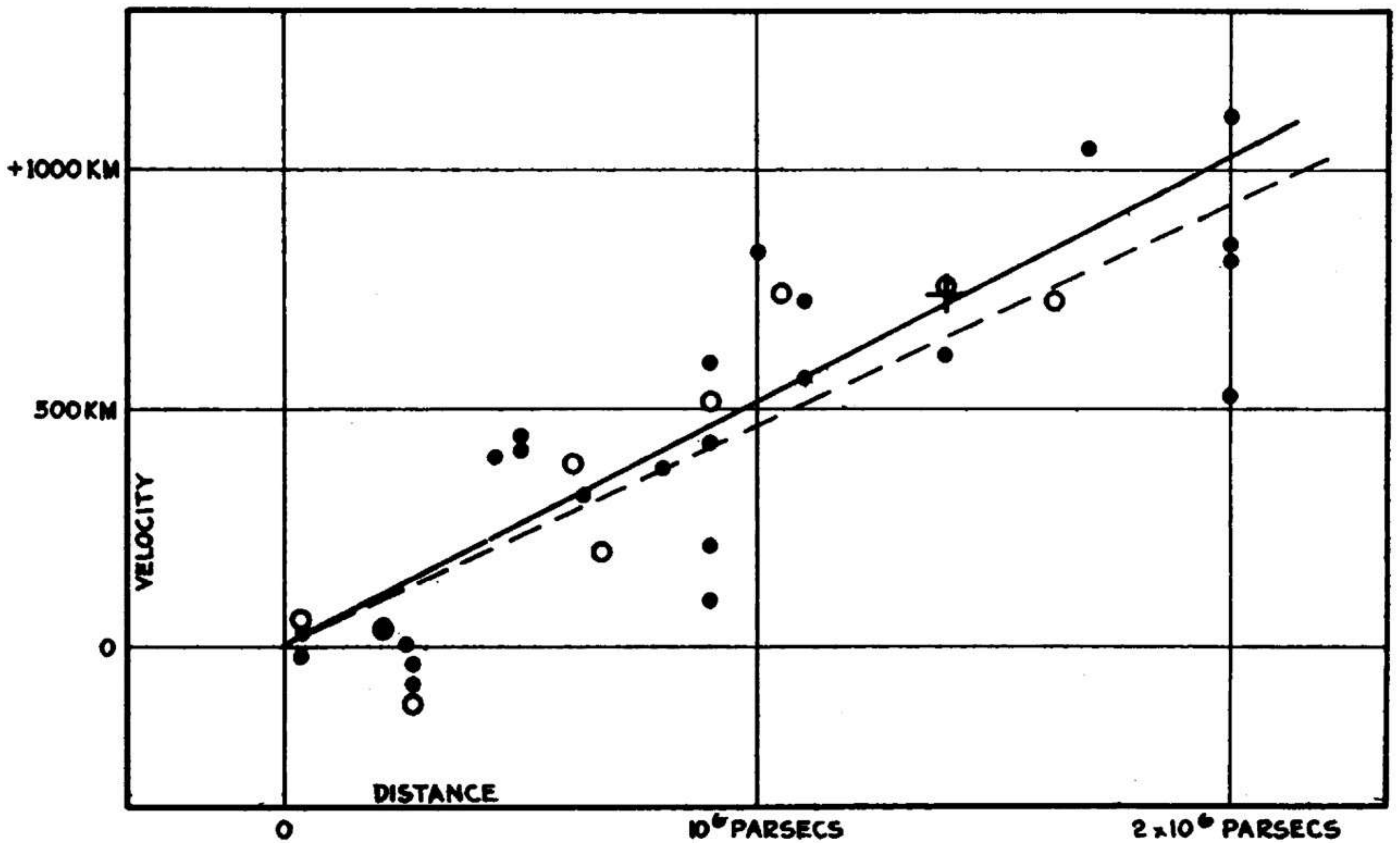
III. SNe Ia standardisation with the ZTF DR2

IV. Next steps

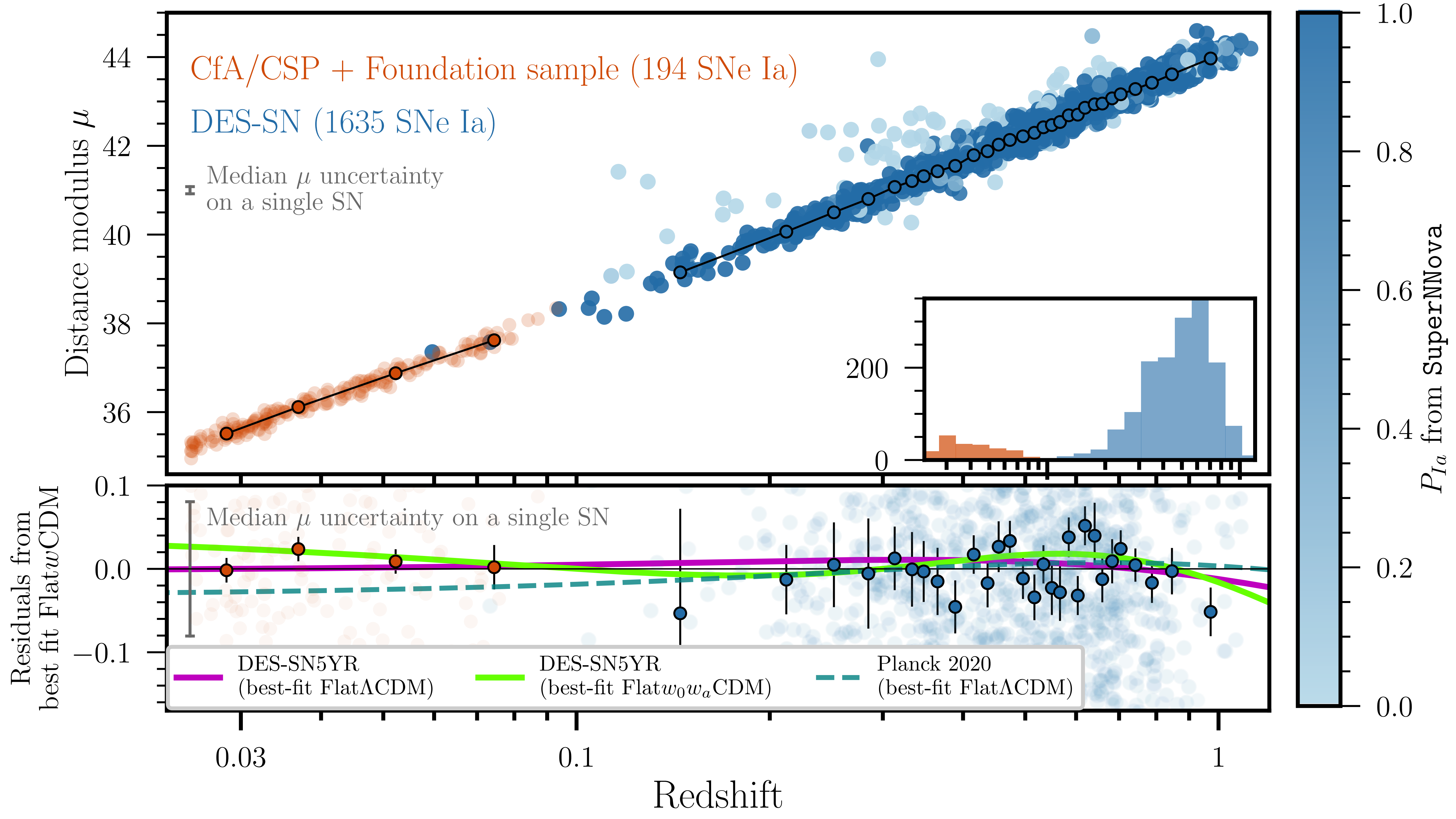
I. Cosmology with Type Ia Supernovae

Cosmology

Hubble diagram



Hubble (1929)

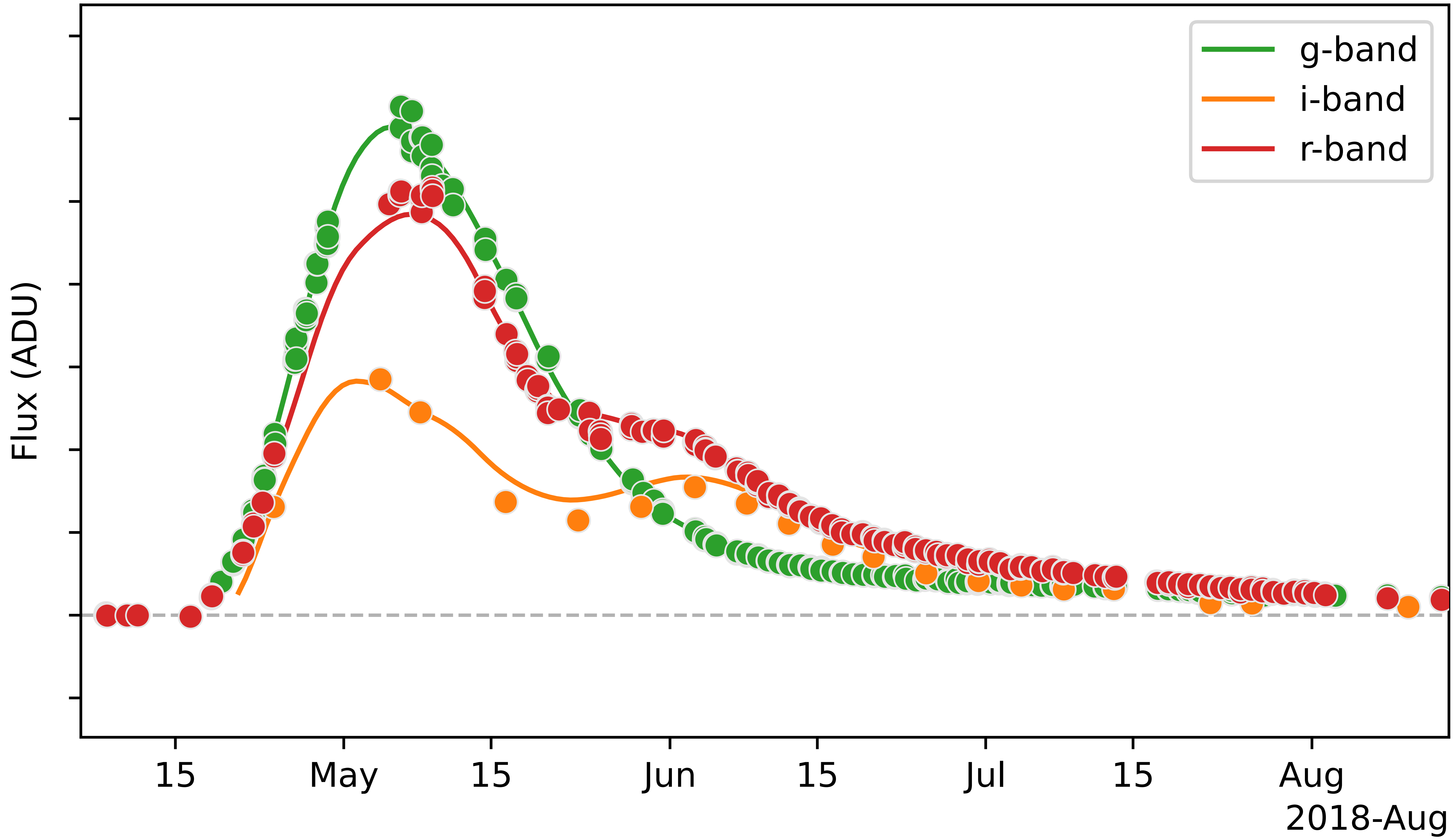


DES-SN5YR

Type Ia Supernovae (SNe Ia)

Lightcurve

Credits: B.J. Fulton/
LCOGT/Caltech



Type Ia Supernovae (SNe Ia)

Lightcurve fitting

Flux of the SN:

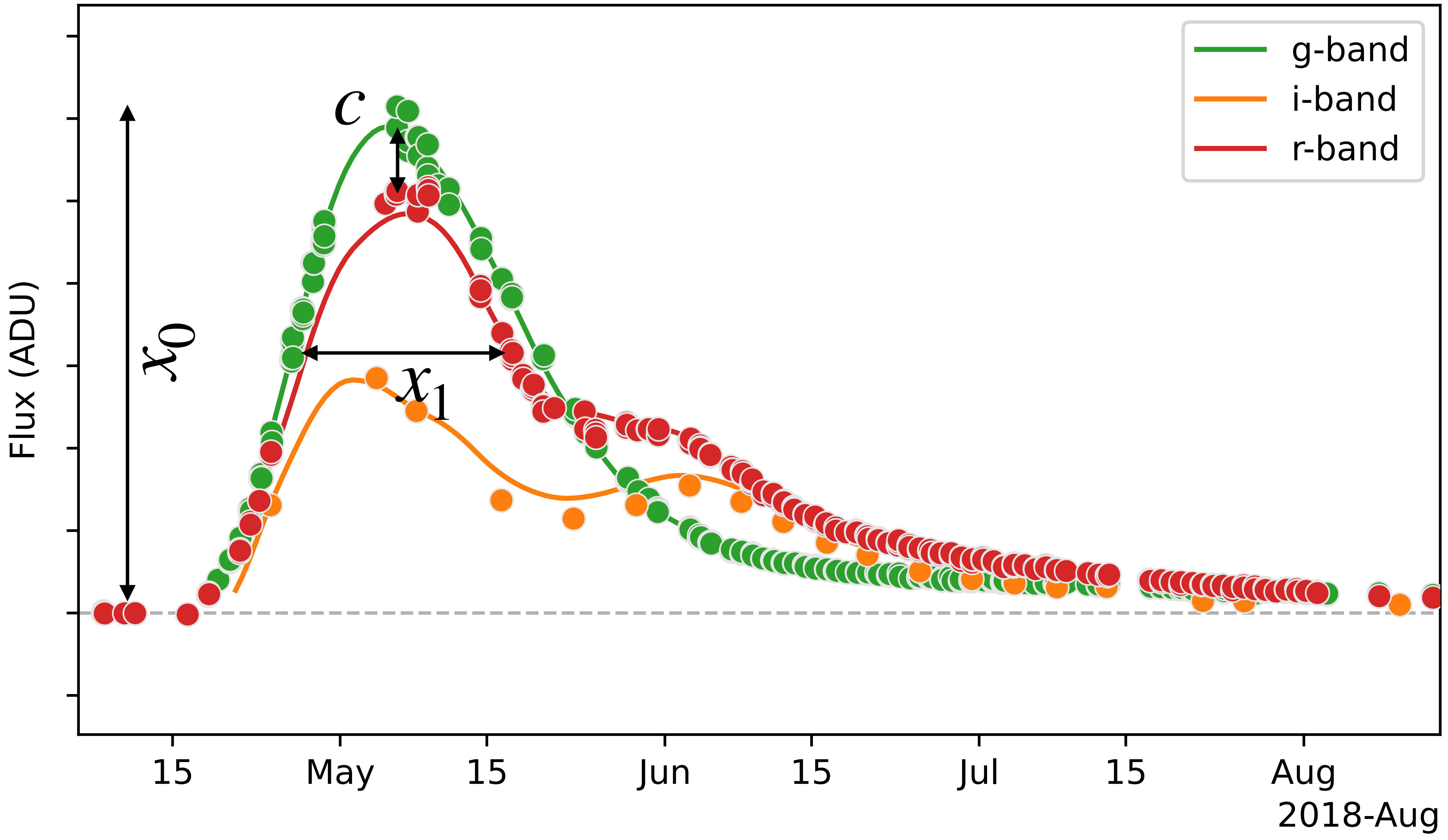
$$F(SN, p, \lambda) = x_0\,[M_0(p,\lambda) + x_1 M_1(p,\lambda)]\exp(cCL(\lambda))$$

Parameters relative to the observation

p: phase of the observation
λ: wavelength

Parameters relative to the SN

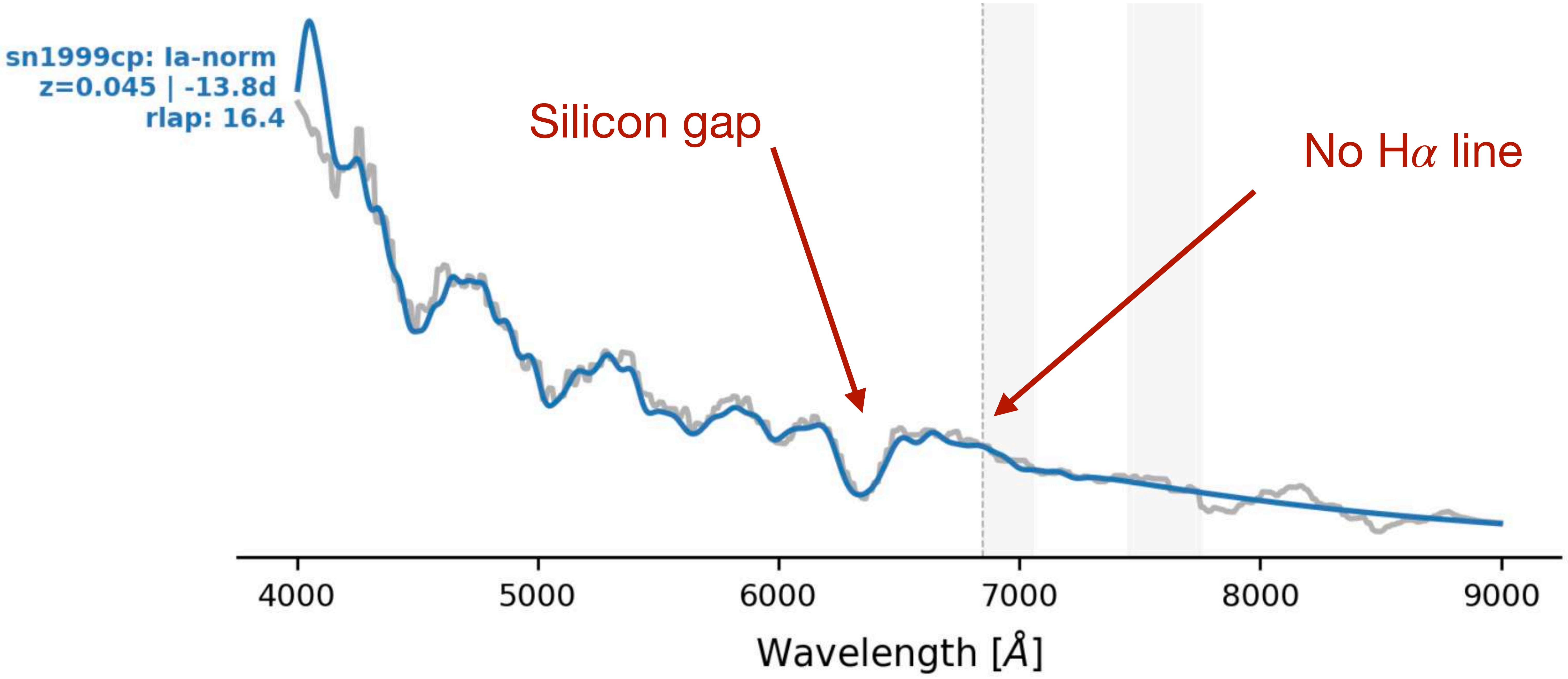
x_0: amplitude
x_1: stretch
c: colour
t_0: time of the peak



SALT2.4 - Guy et al (2007)
SALT3 - Kenworthy et al (2021)

Type Ia Supernovae (SNe Ia)

Spectrum

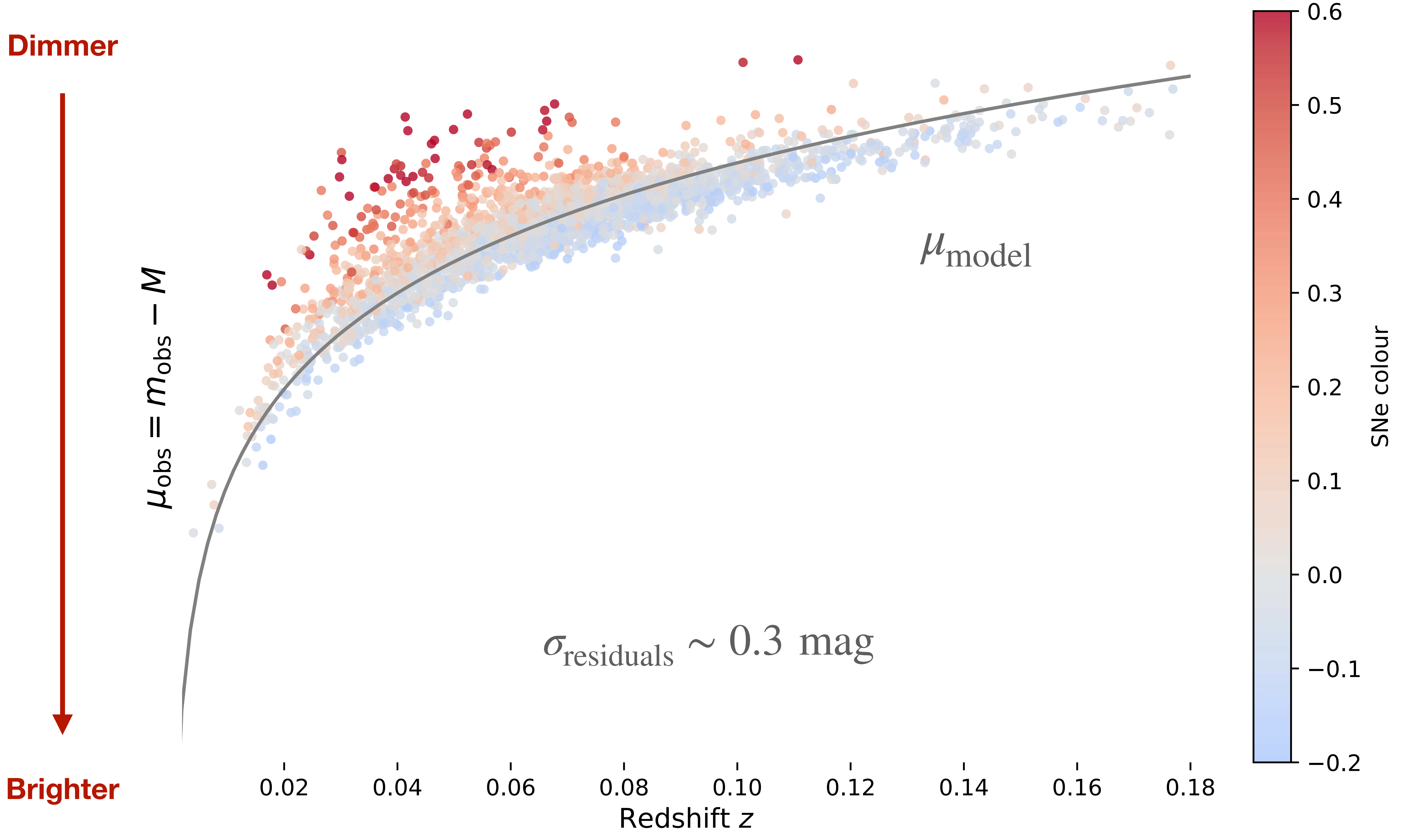


Spectroscopic typing

Redshift information

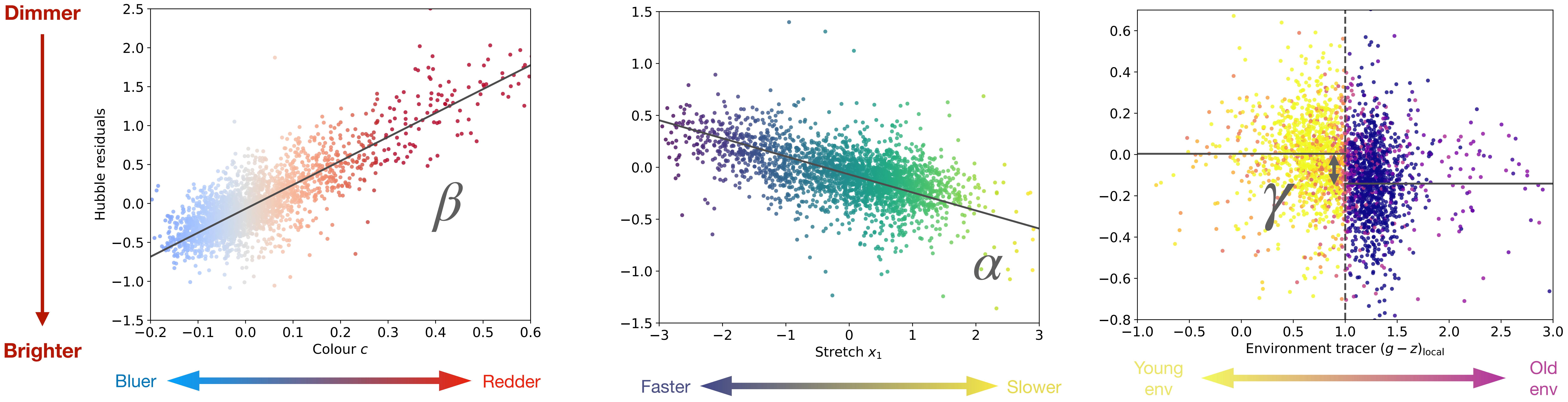
Cosmology with SNe Ia

Supernovae standardisation



Cosmology with SNe Ia

Standardisation



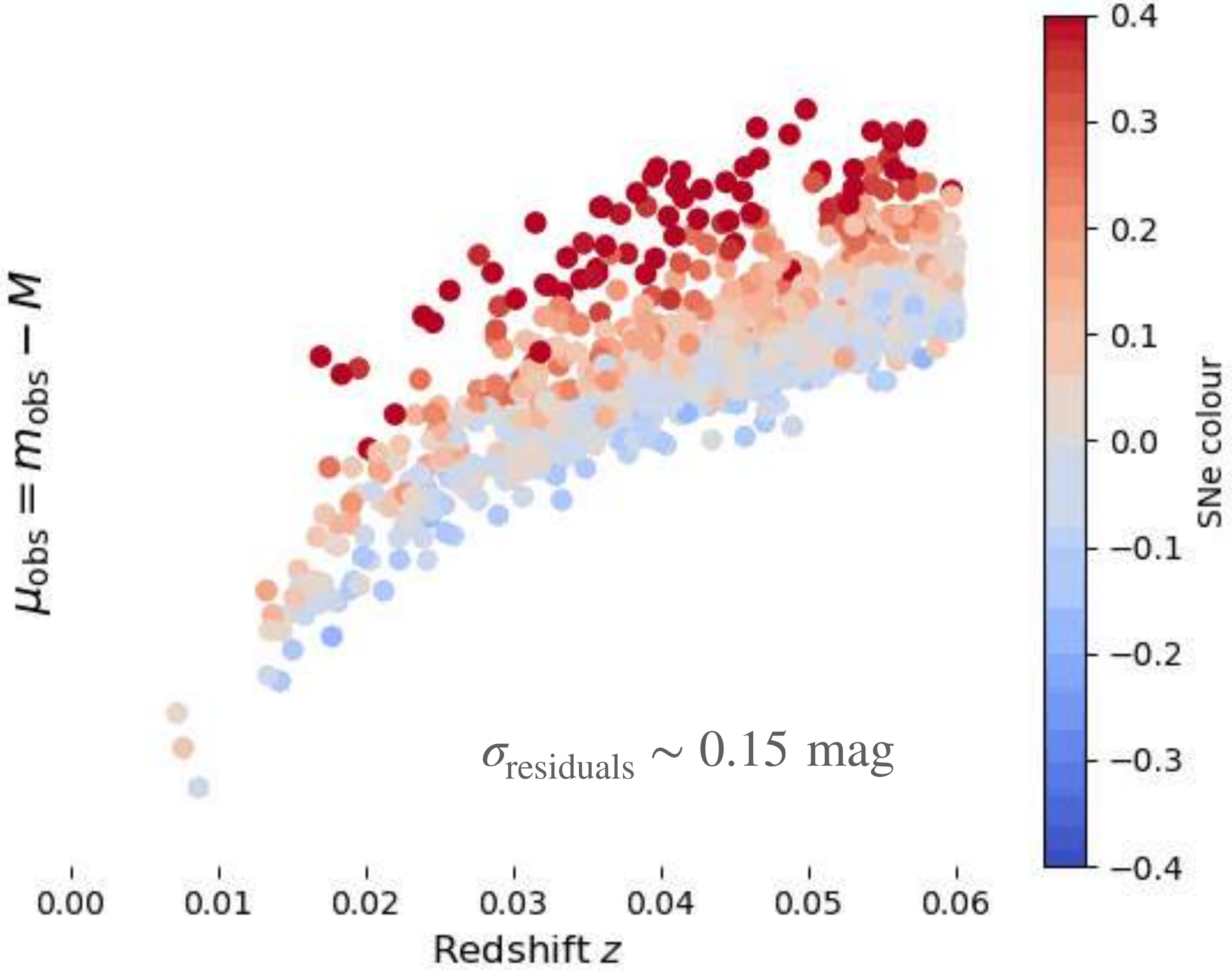
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Cosmology with SNe Ia

Standardisation

$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

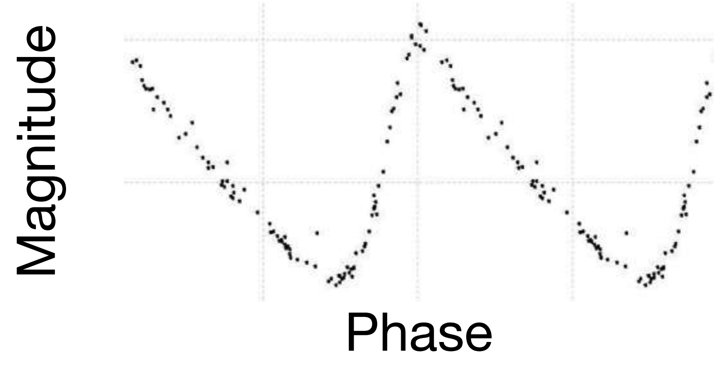
(Tripp 1998)



Cosmology with SNe Ia

Anchoring the Hubble diagram

Cepheids

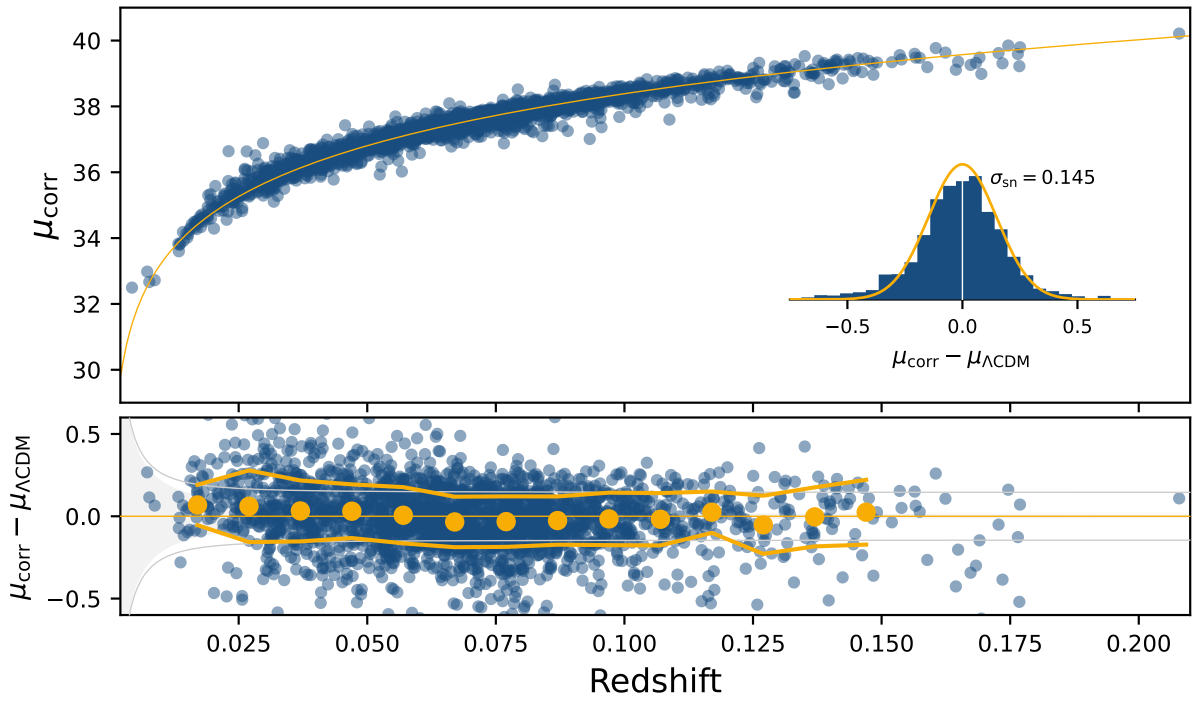


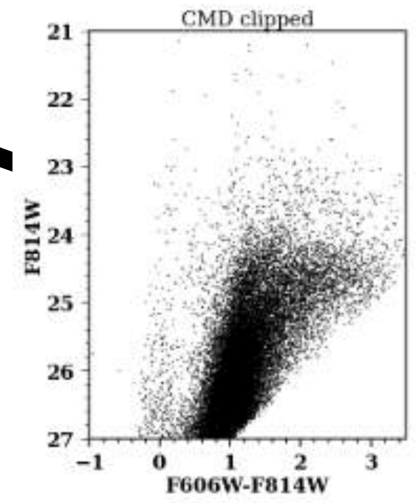
Riess et al (2021)

Geometry

Any standard candles

SNe Ia





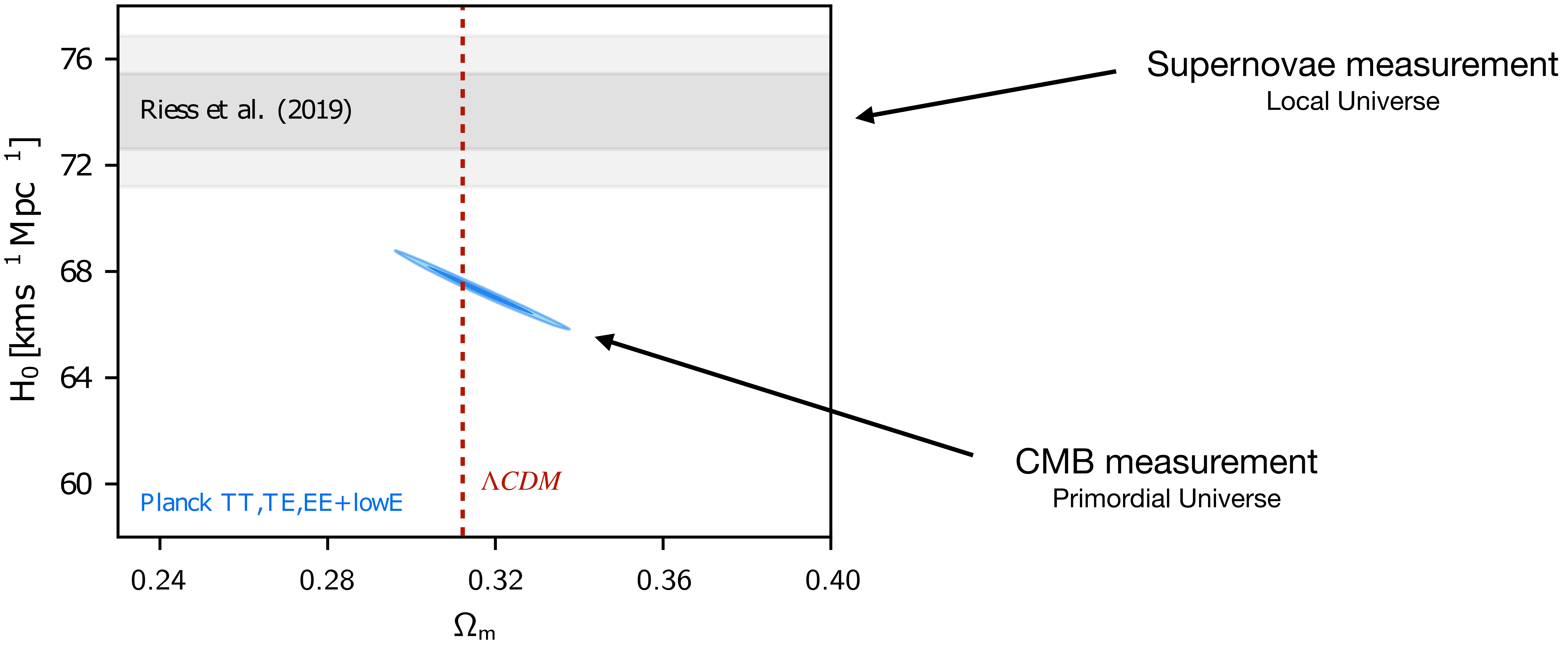
Freedman et al (2019)
Scolnic et al (2023)

TRGB

0 $< 10^{-3}$ $< 10^{-2}$ < 1.1

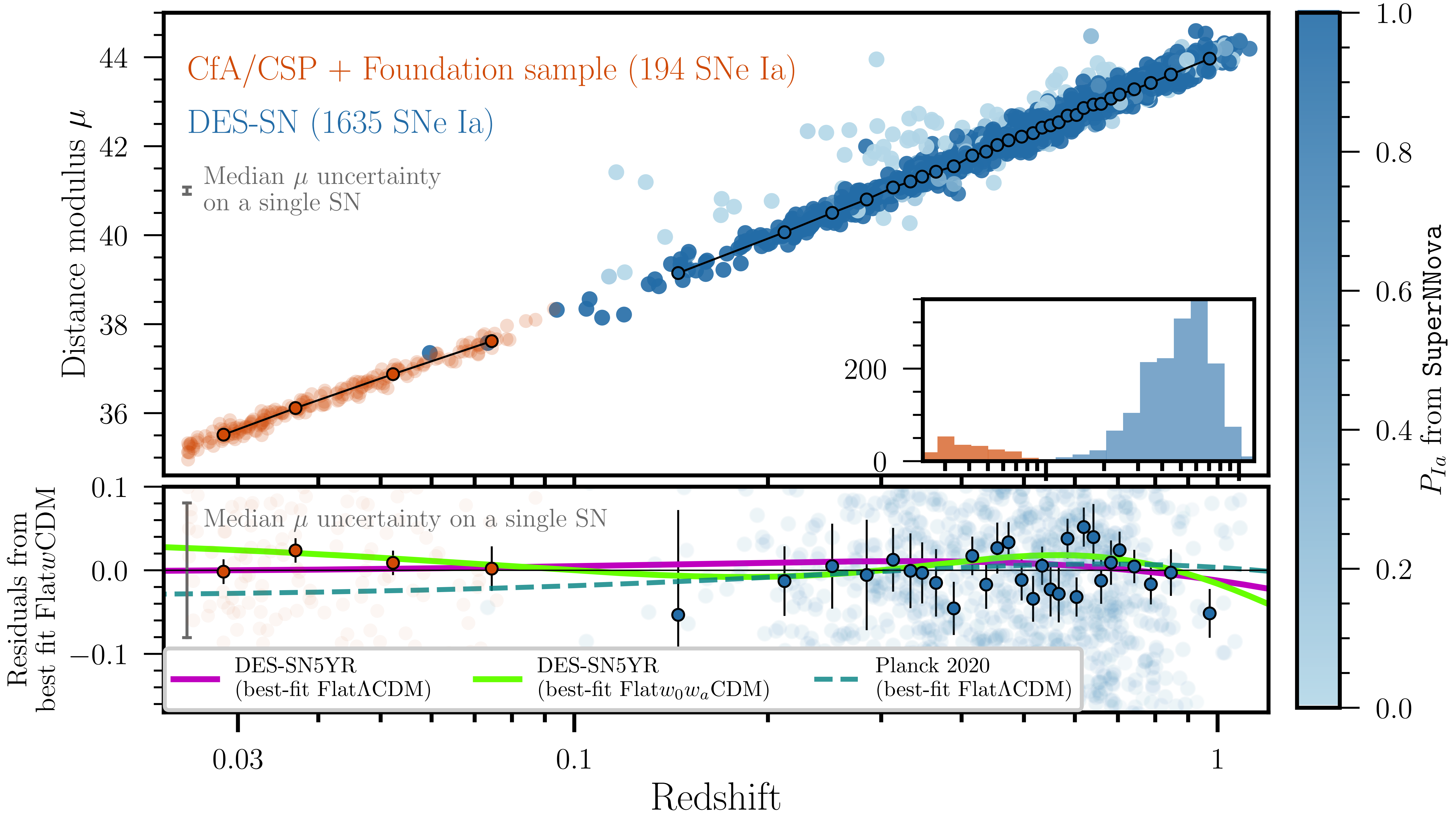
Redshift

Hubble tension

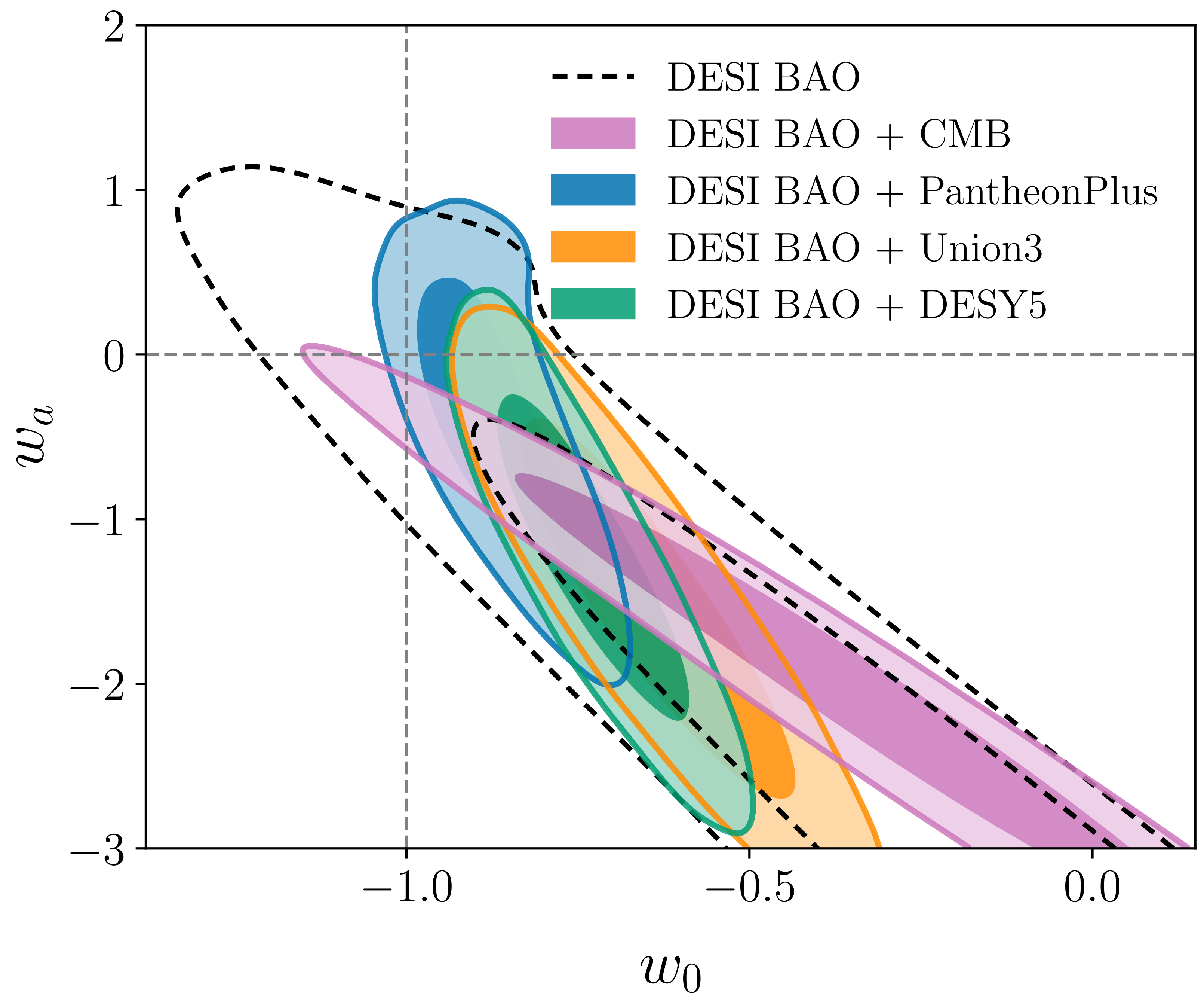


Adapted from Planck collaboration (2020)

Evolving dark energy?



DES-SN5YR



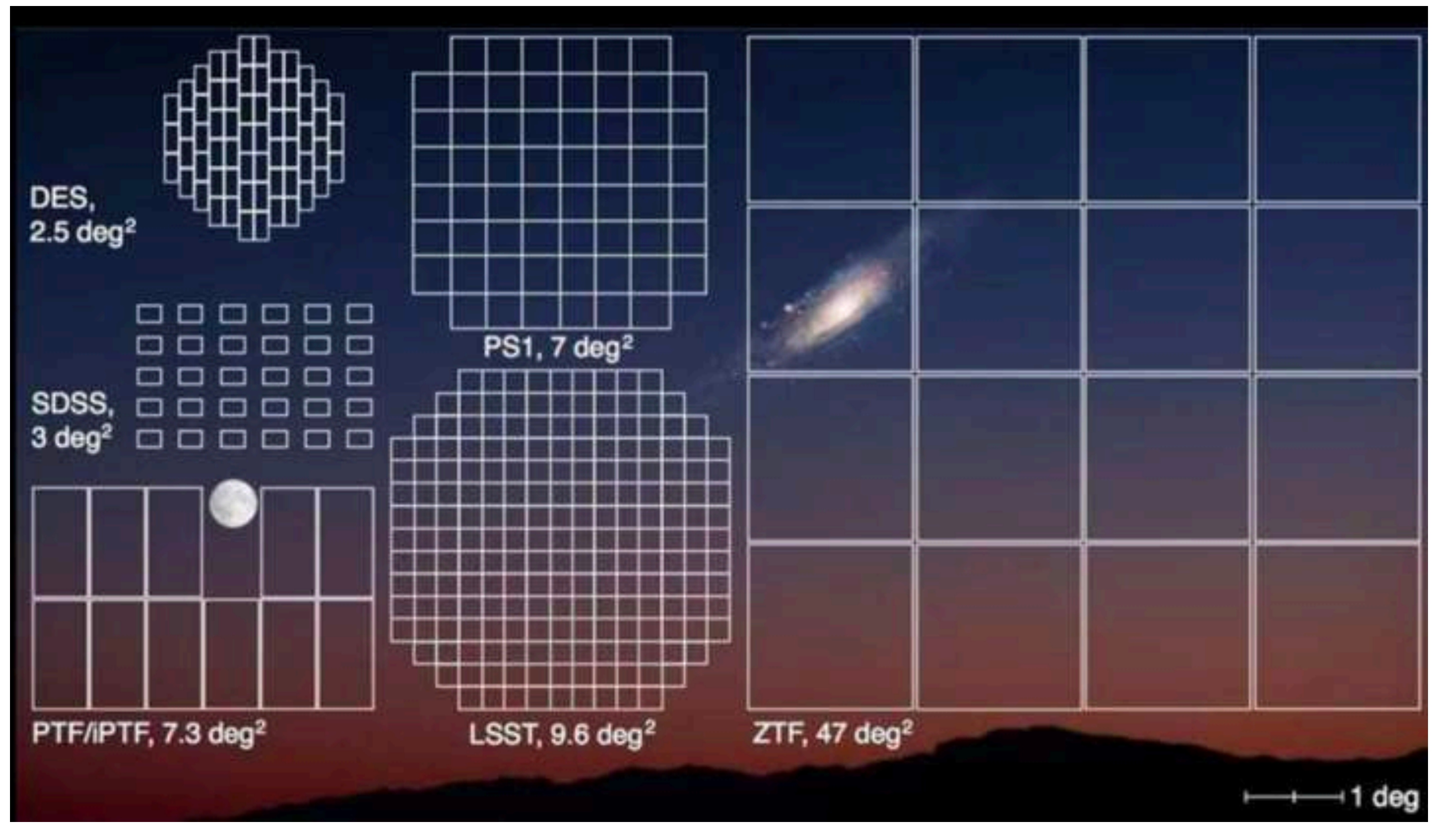
DESI 2024

II. ZTF SN Ia DR2

ZTF

Zwicky Transient Facility

Large FoV
Short exposures
3 bands (g, r, i)
Depth of 20.5 mag in r
(SNe Ia at $z \sim 0.1$)

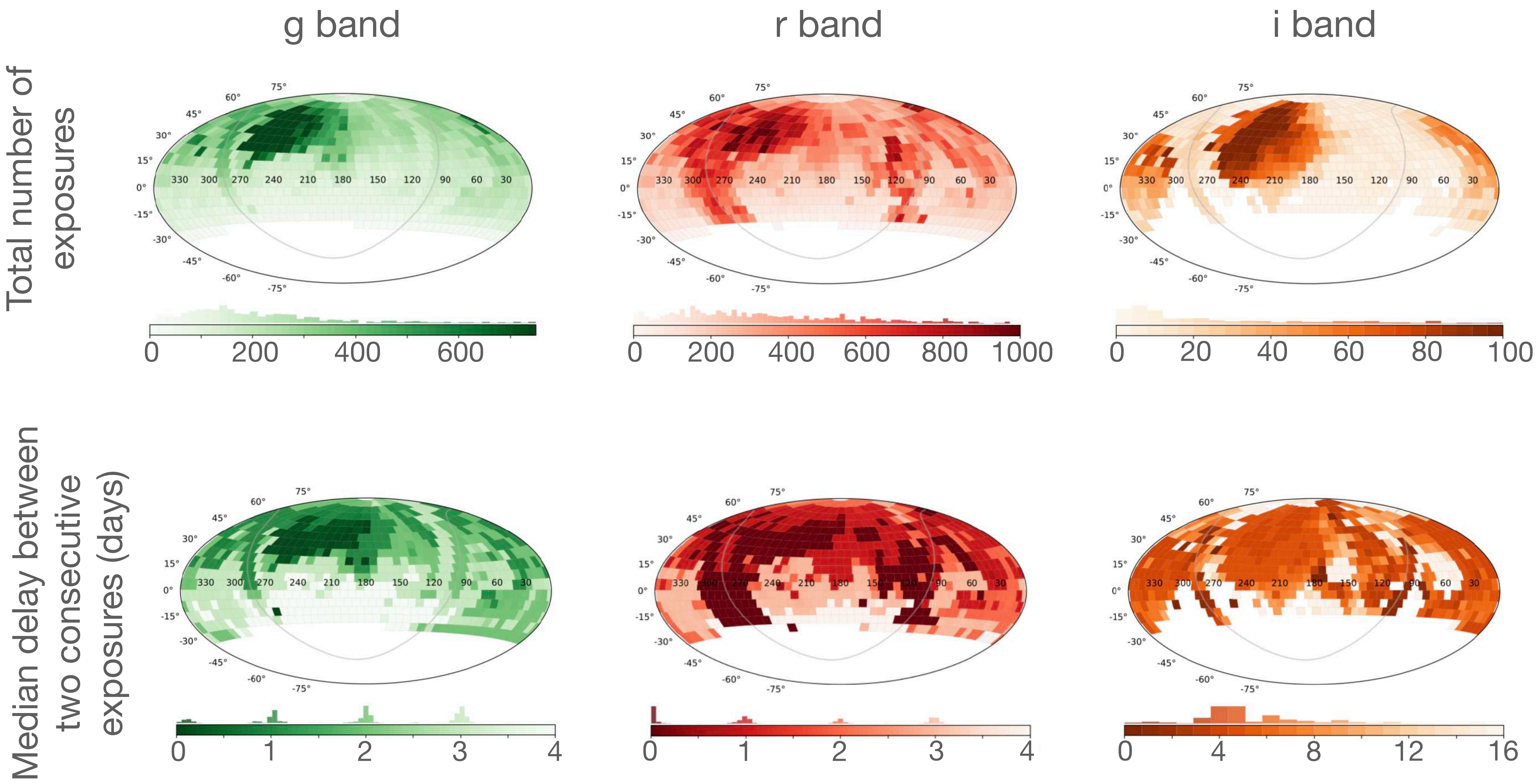


SEDmachine

Low resolution
~1h exposures

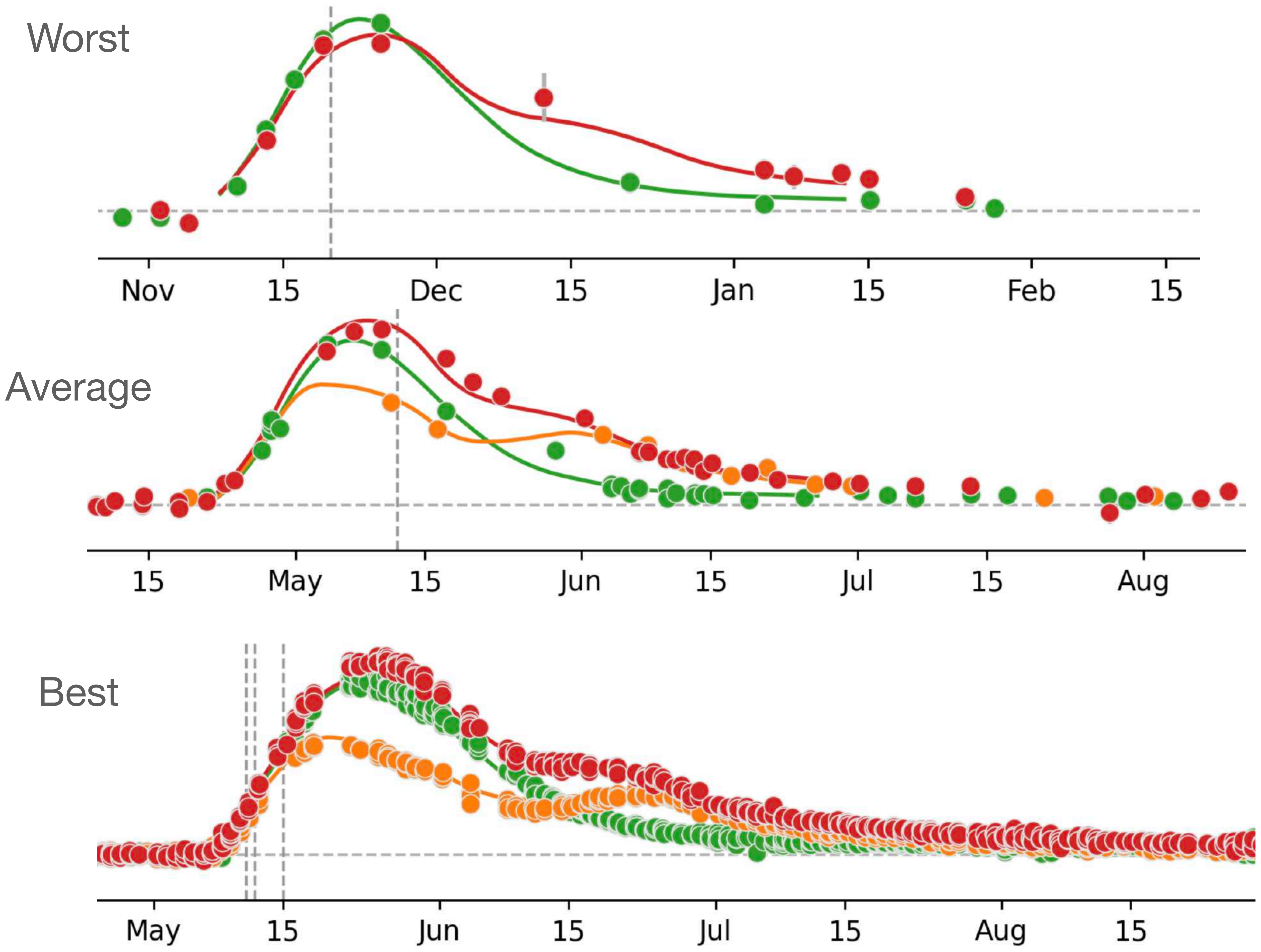
ZTF SN Ia DR2

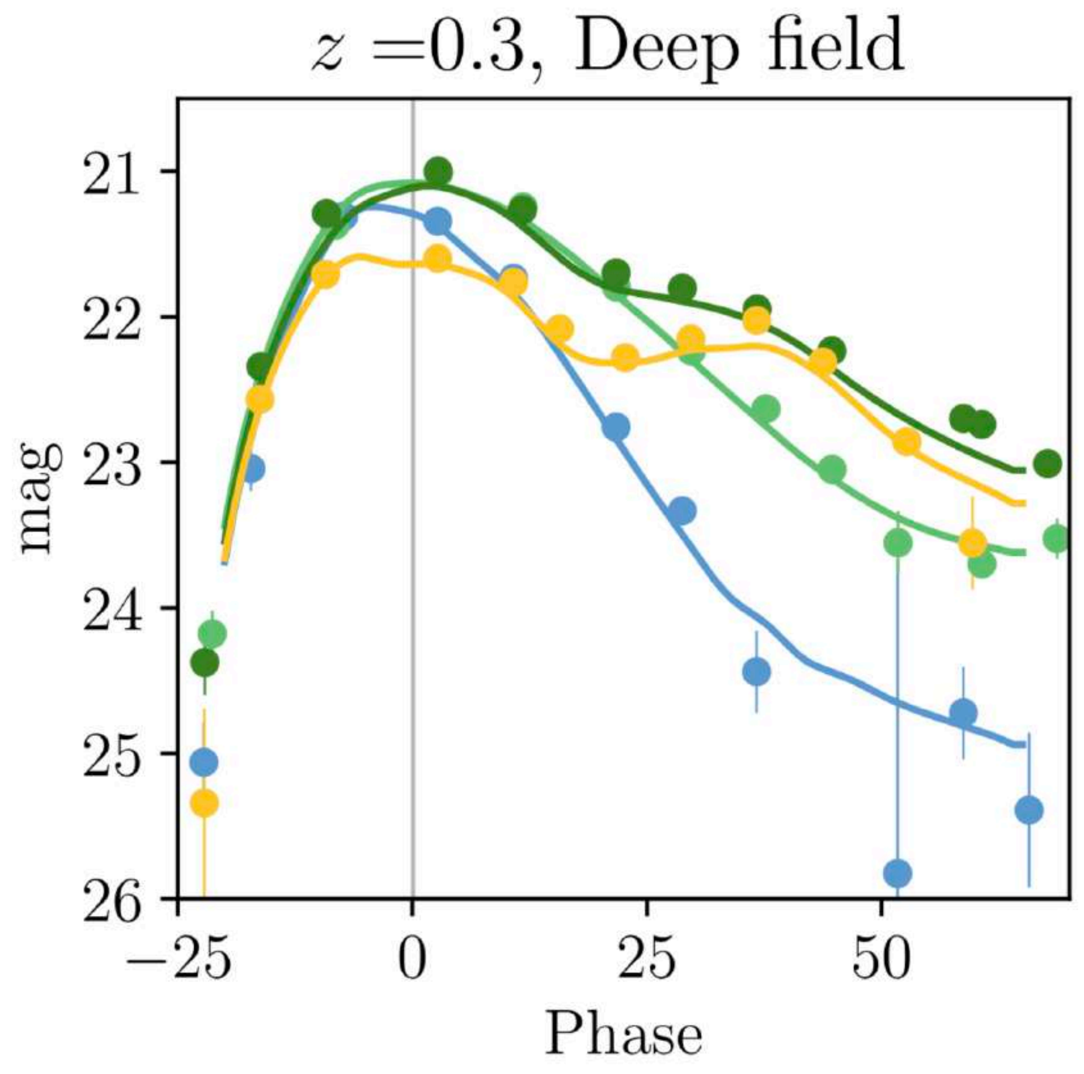
Cadence



ZTF SN Ia DR2

Lightcurves

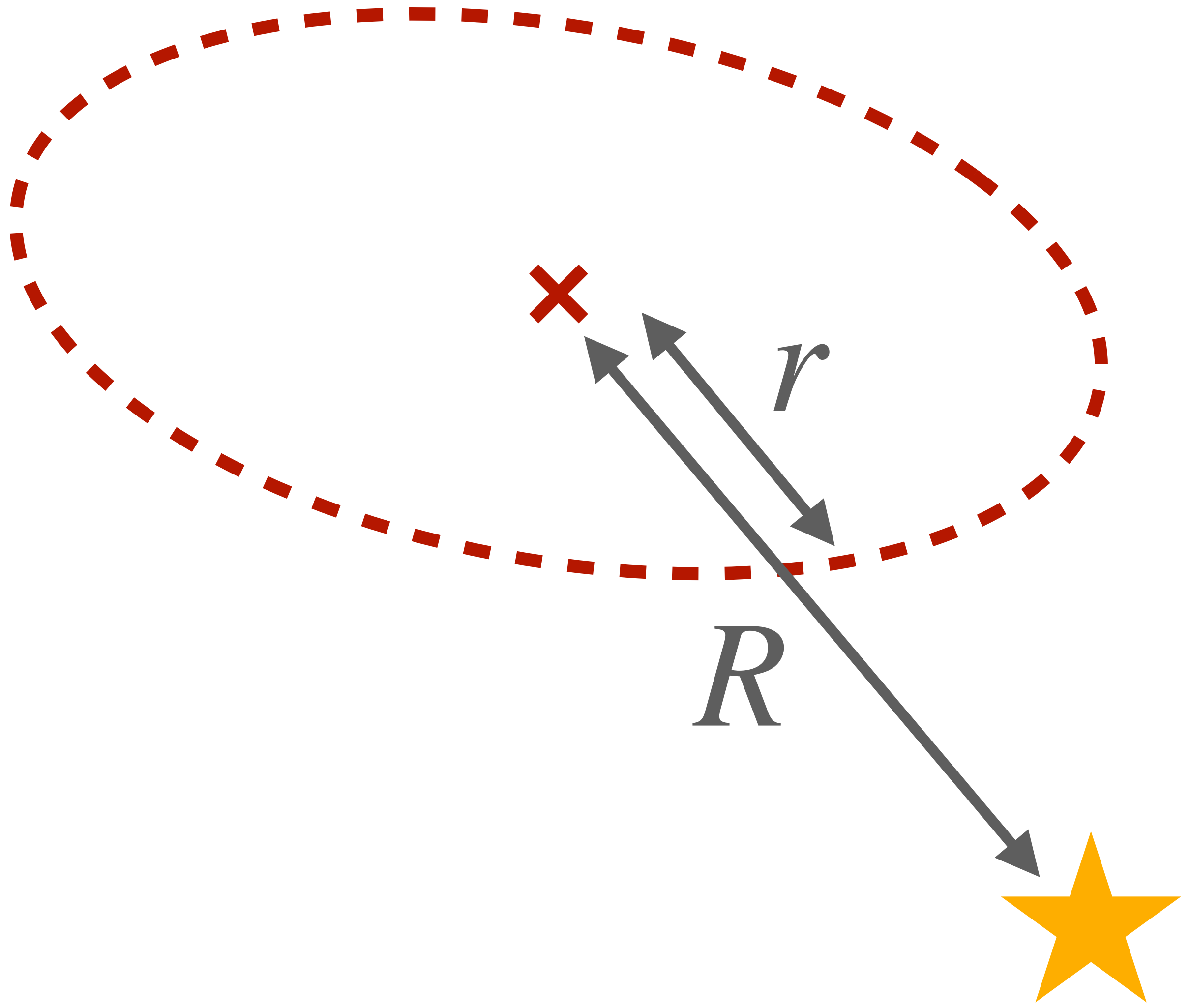




DES-SN5Y
Sanchez et al (2024)

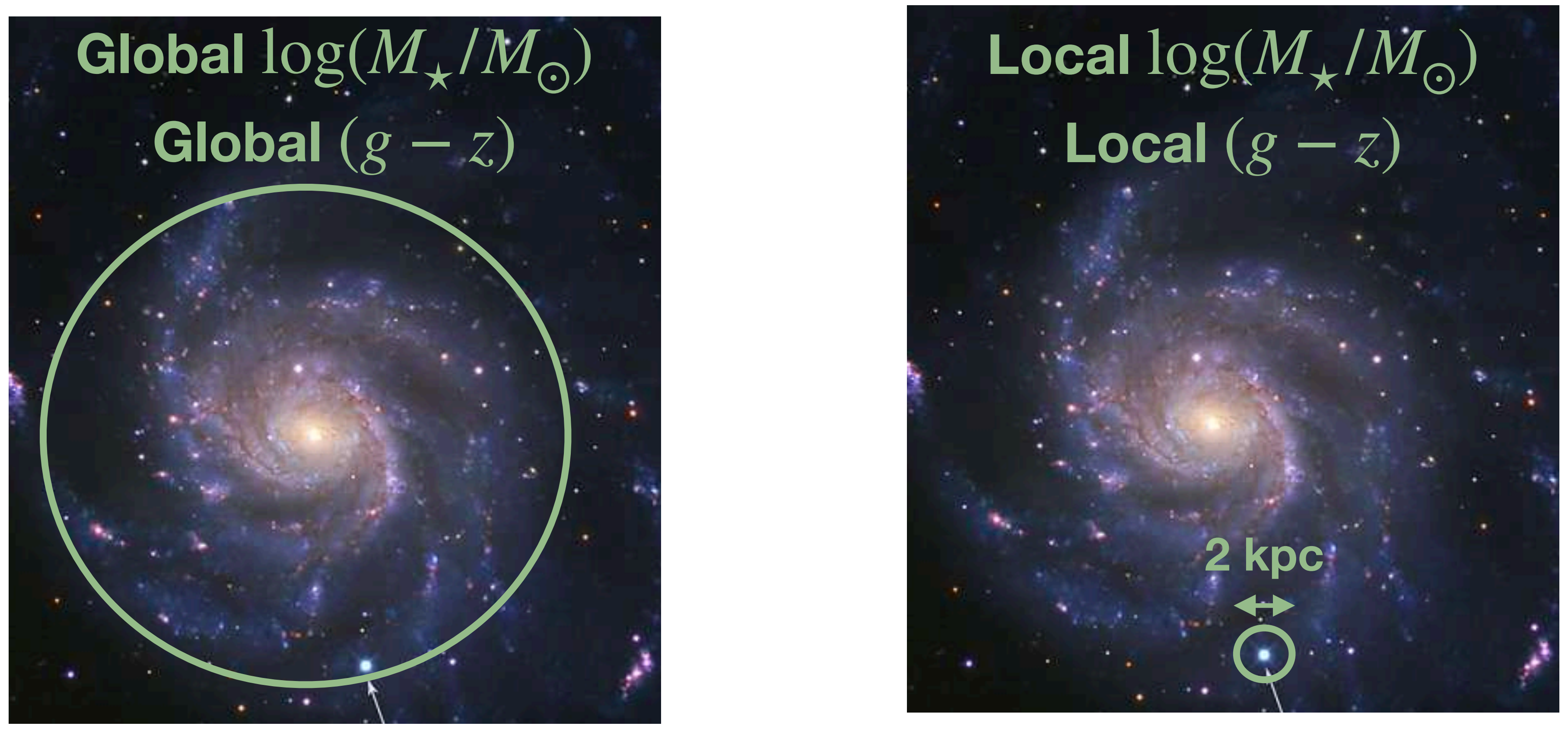
ZTF SN Ia DR2

Environmental properties

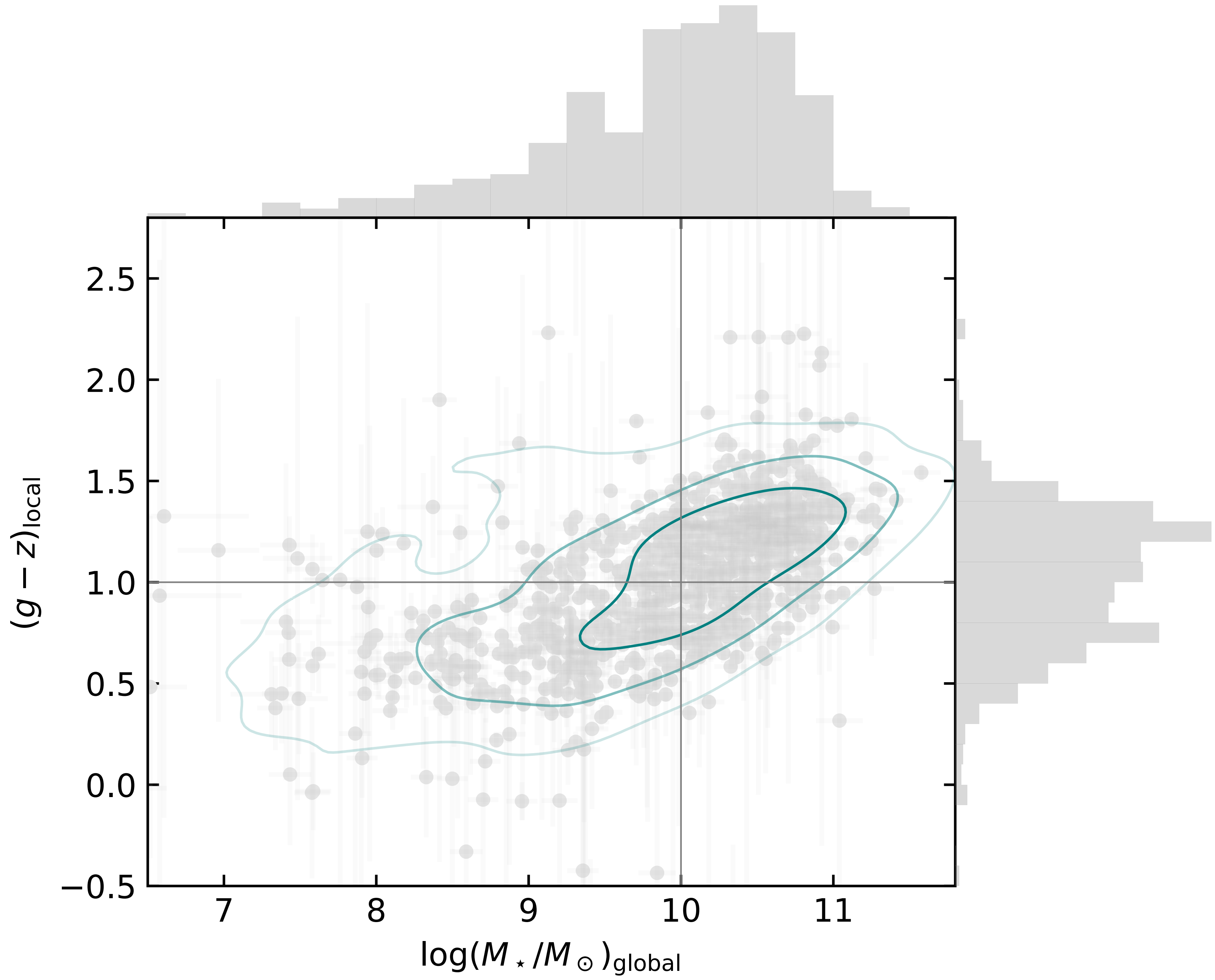


$$\text{dDLR} = \frac{R}{r}$$

Sullivan et al 2006, Gupta et al 2016



Credits: B.J. Fulton/LCOGT/Caltech



ZTF SN Ia DR2

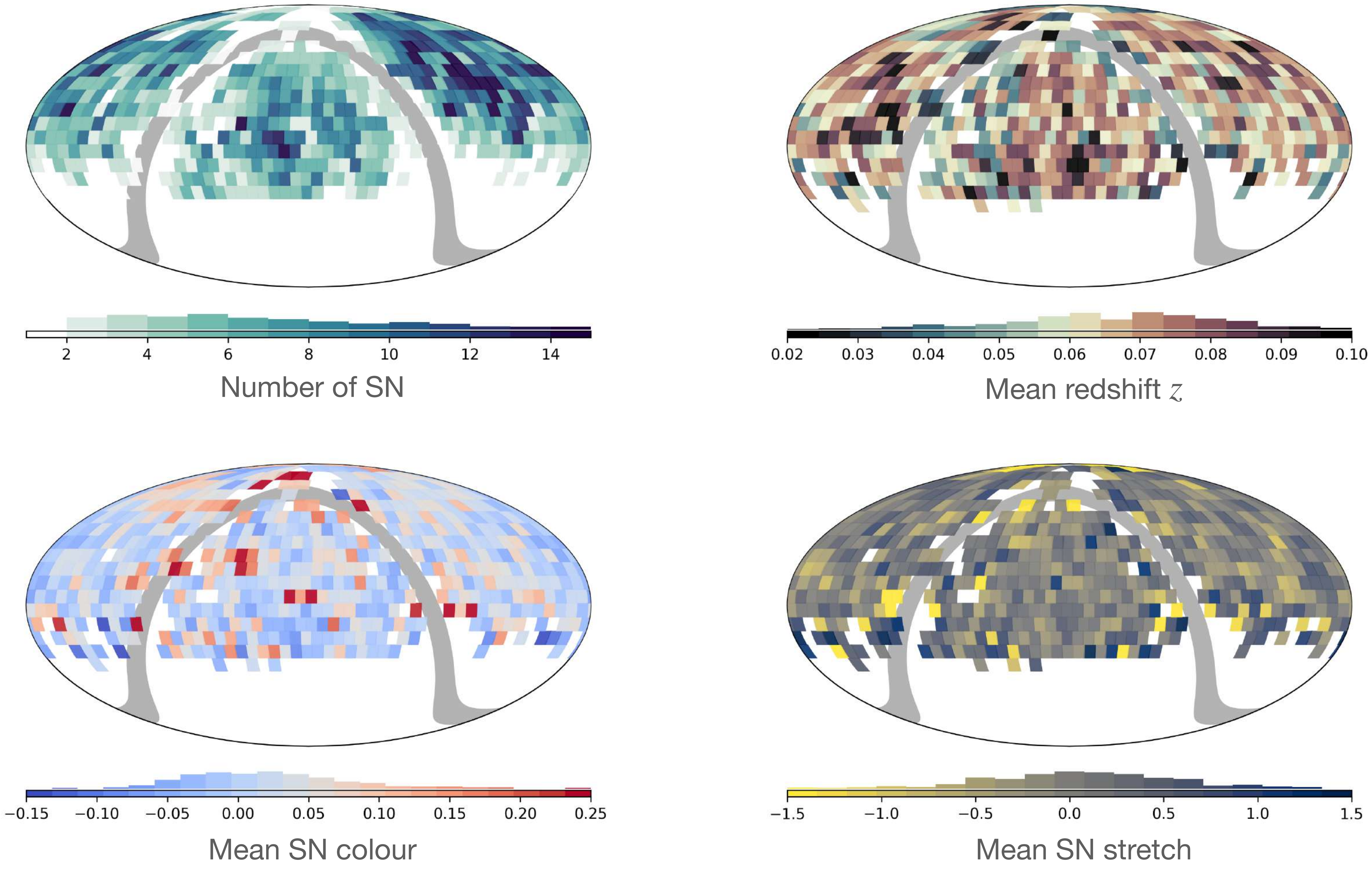
Numbers

2.5 years of data

3628 SNe
Confirmed SNe Ia

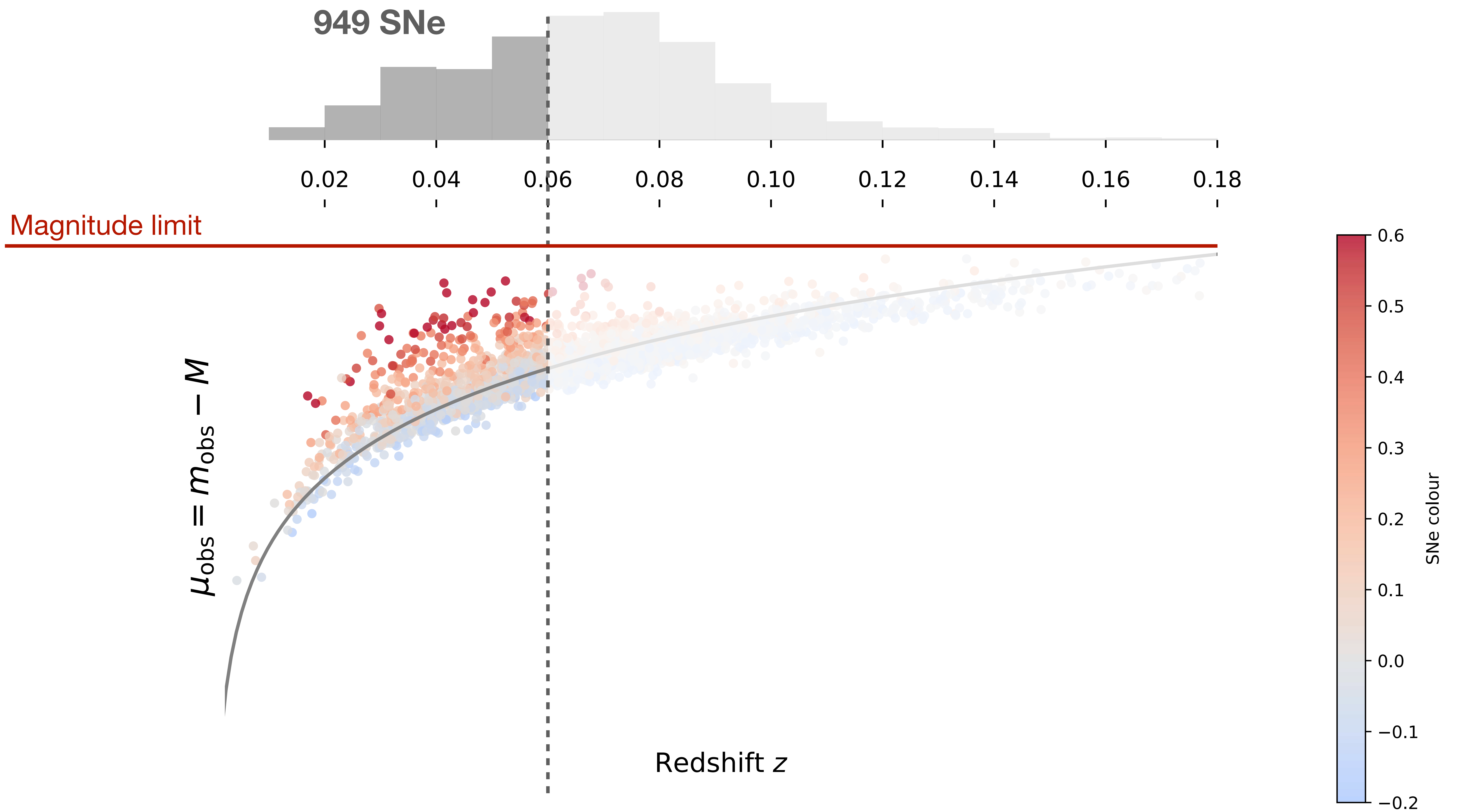
2977 SNe
with well-sampled lightcurves

2628 SNe
usable for cosmology



ZTF SN Ia DR2

Volume limited sample

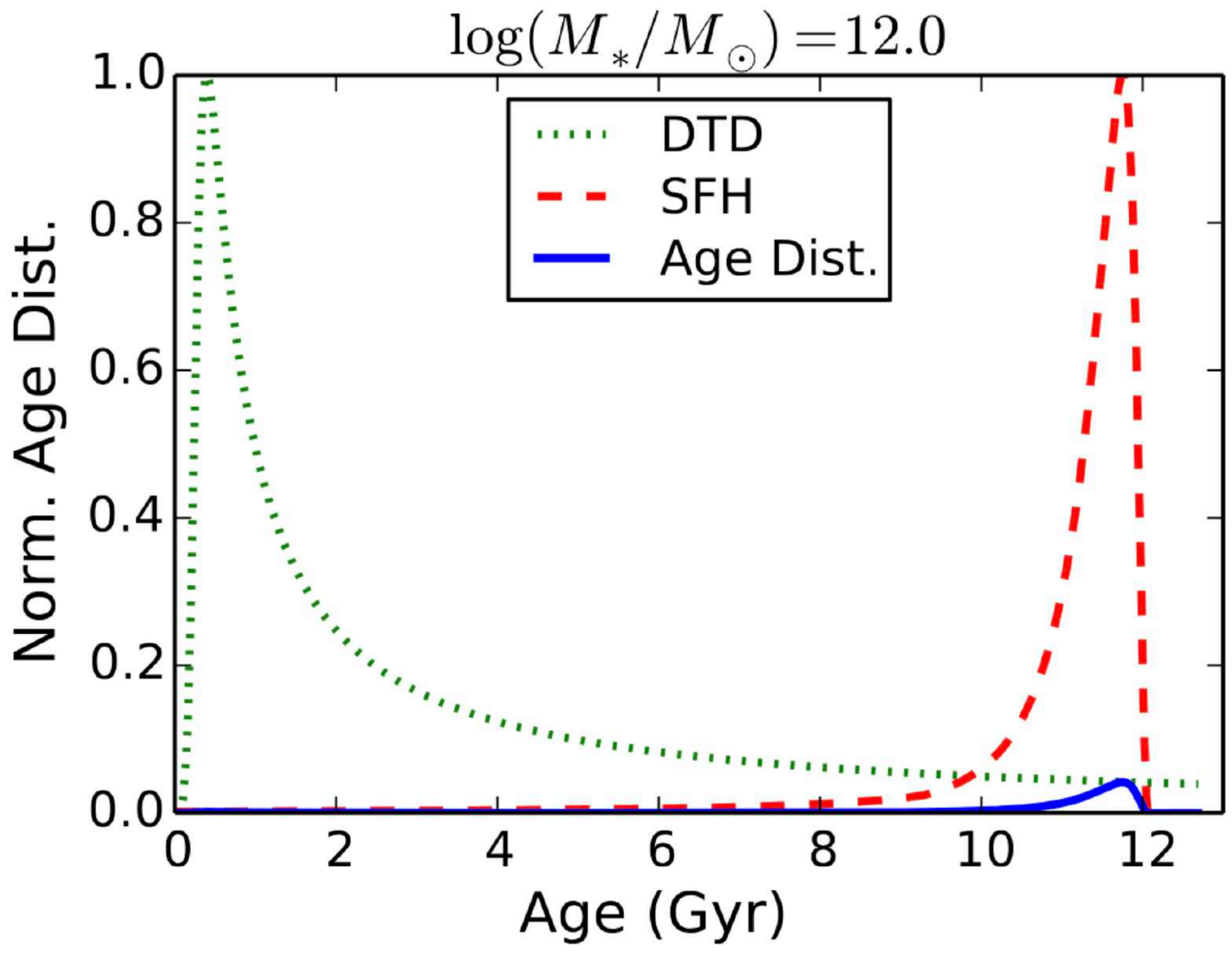


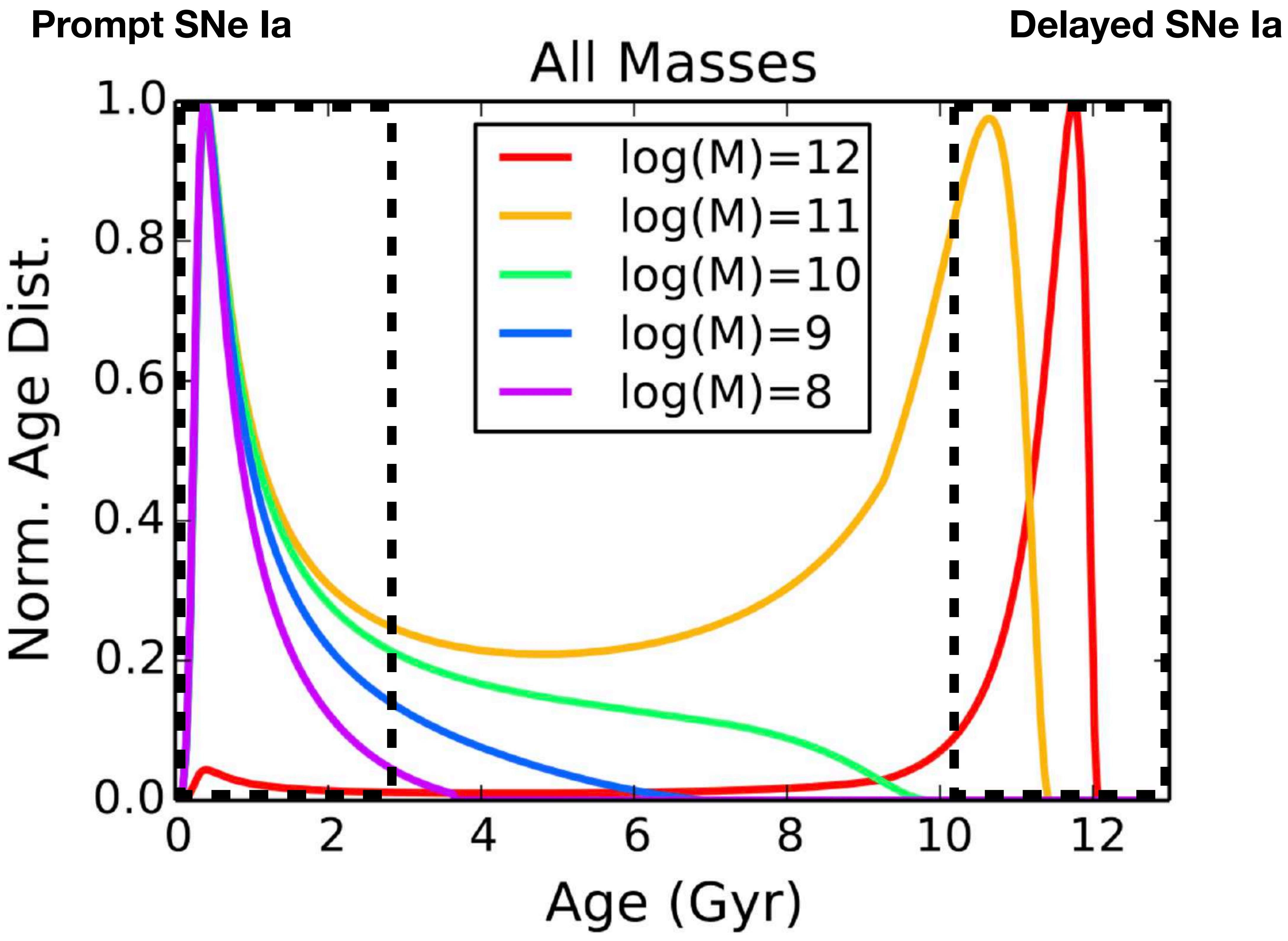
Redshift cut at $z < 0.06$

➡ **No selection biases**

III. SNe Ia standardisation with the ZTF DR2 volume-limited sample

Two population model





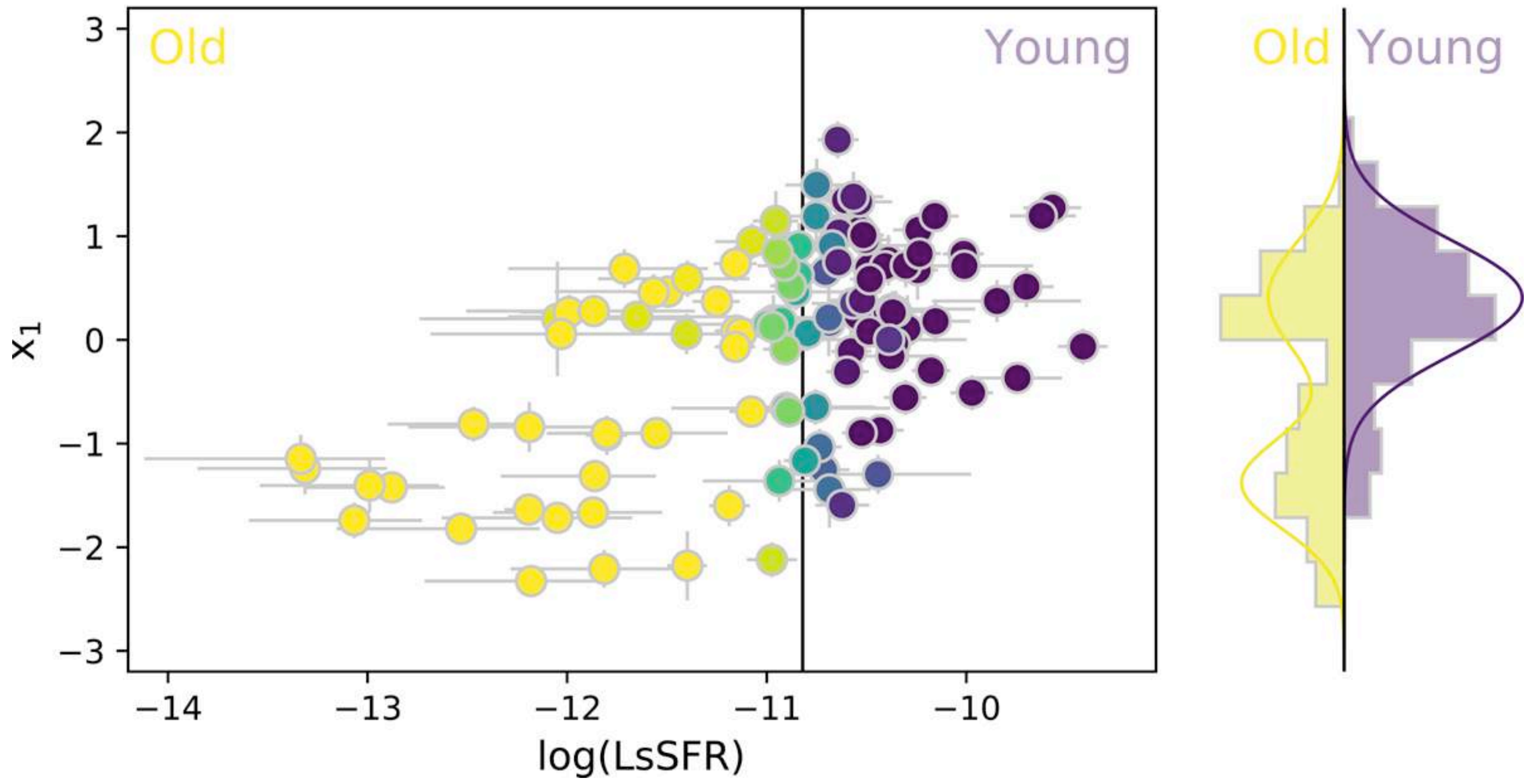
Childress et al (2014)

Mannucci et al (2005)

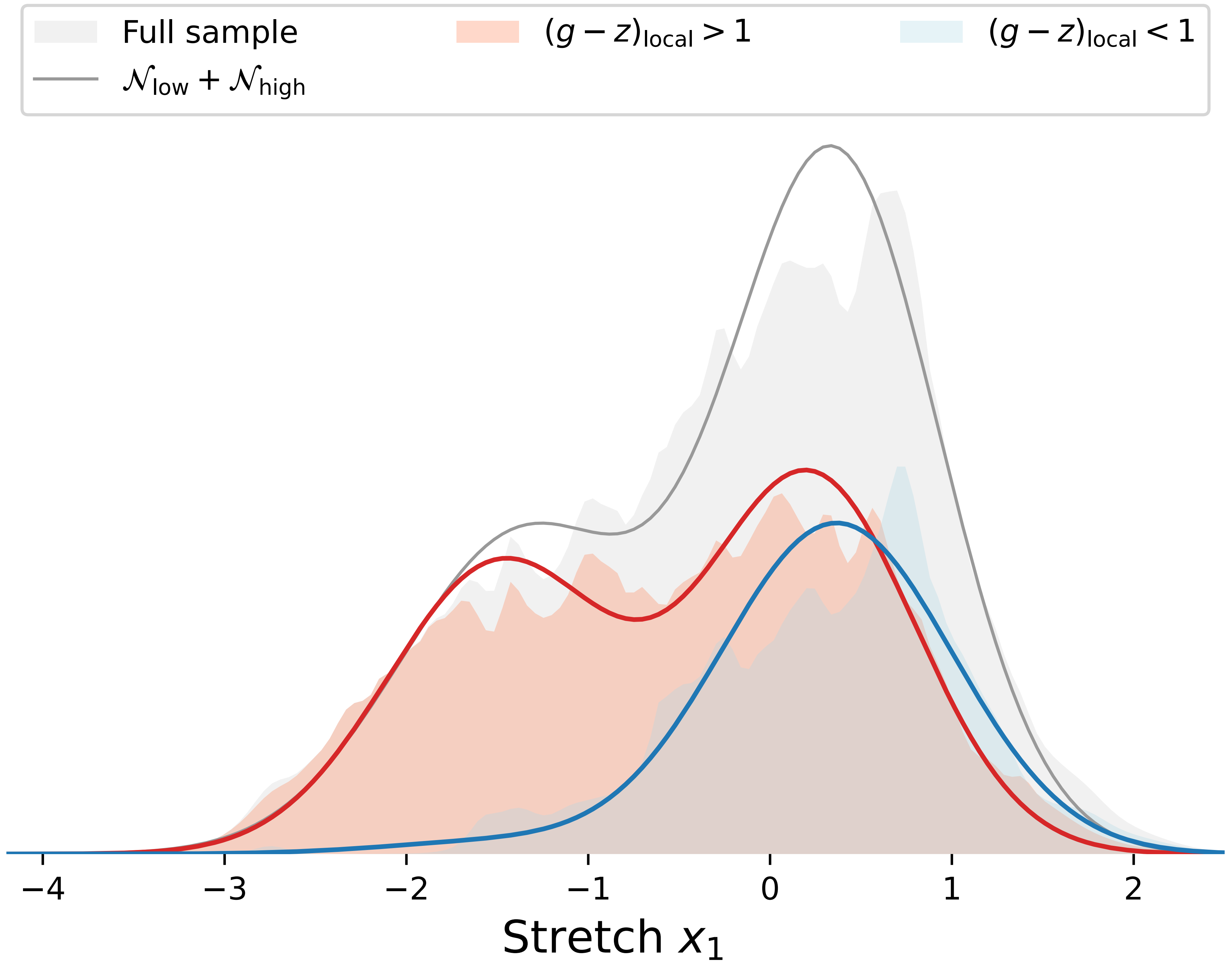
$$\mu_{obs} + M = m_{obs} - \beta c + \alpha x_1 + p\gamma$$

Stretch

Stretch distribution



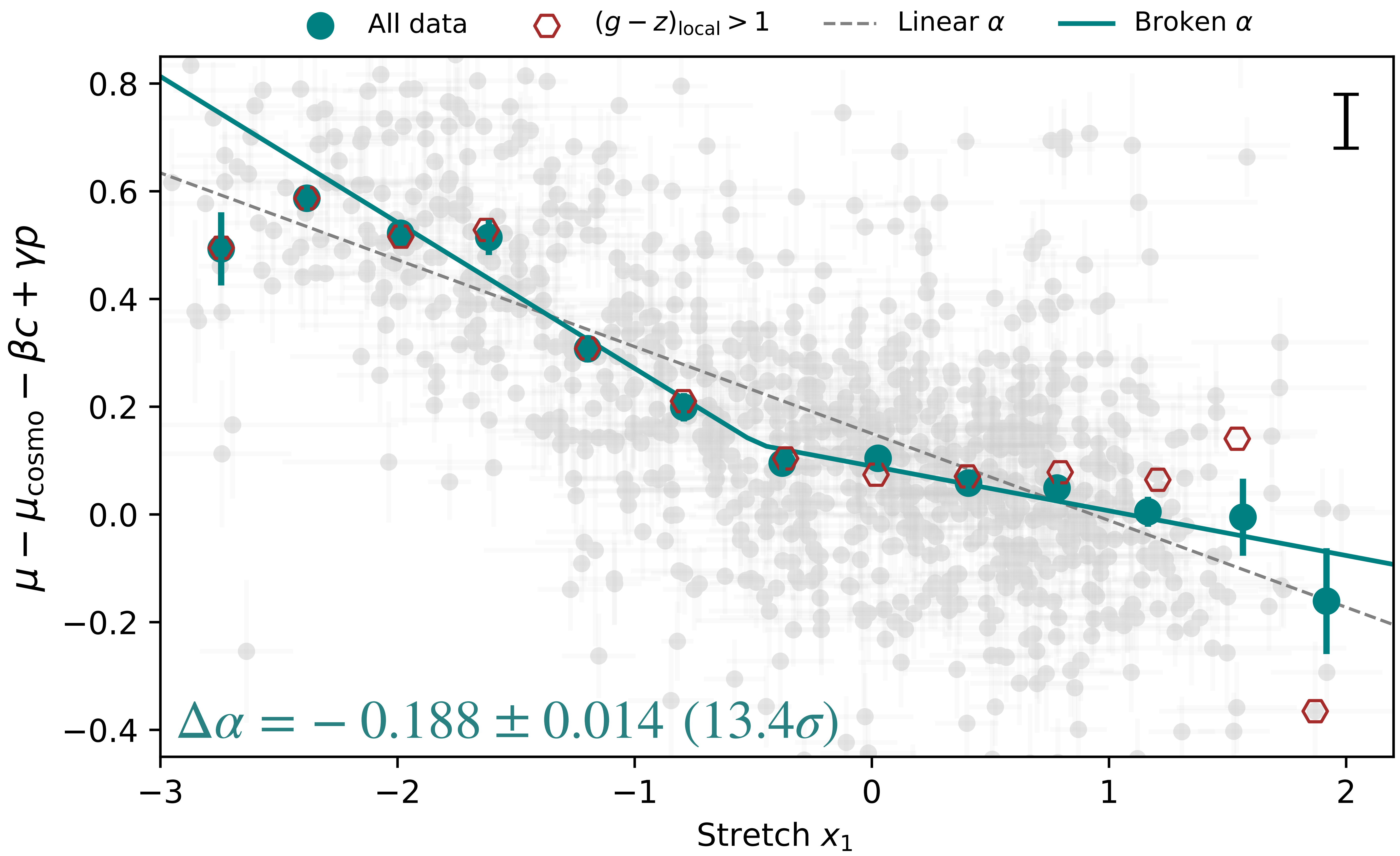
Nicolas et al (2021)
SnFactory - 114 SNe

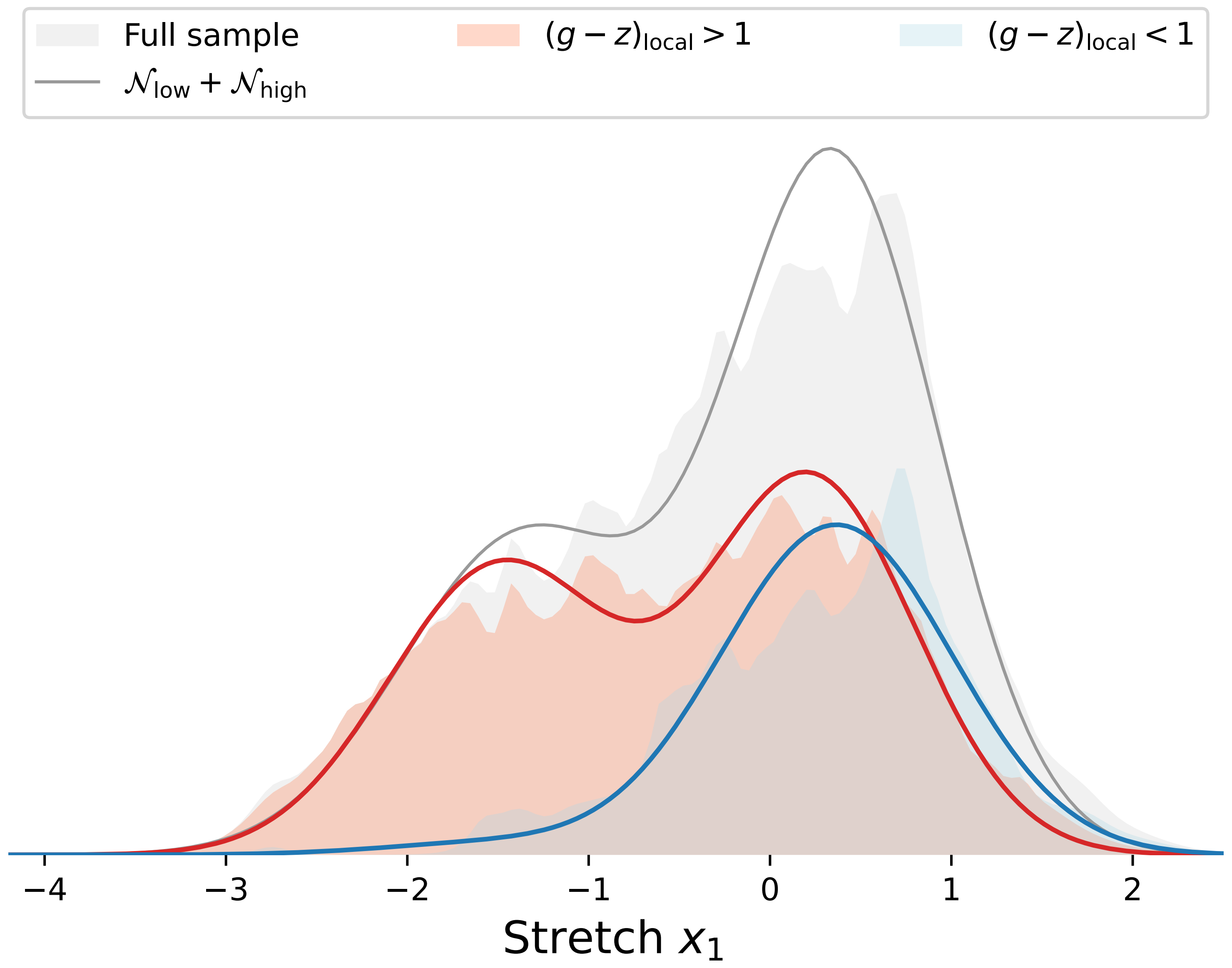


$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

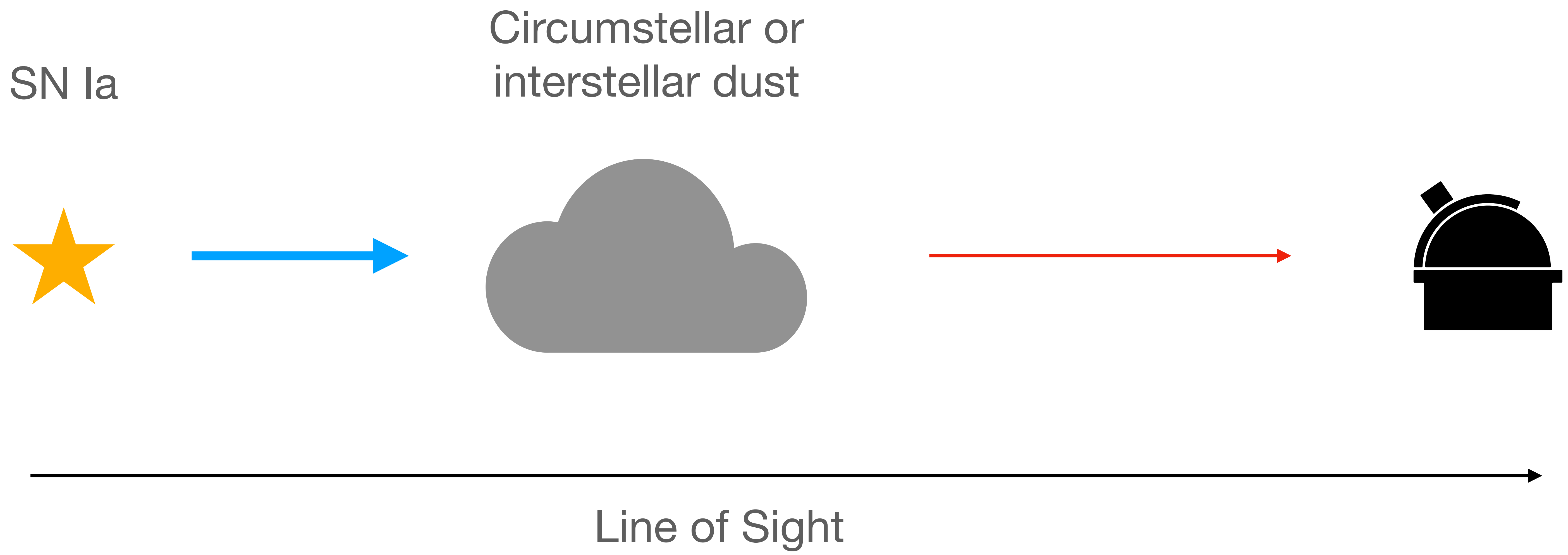
Stretch

Non linearity of the stretch-residuals relation

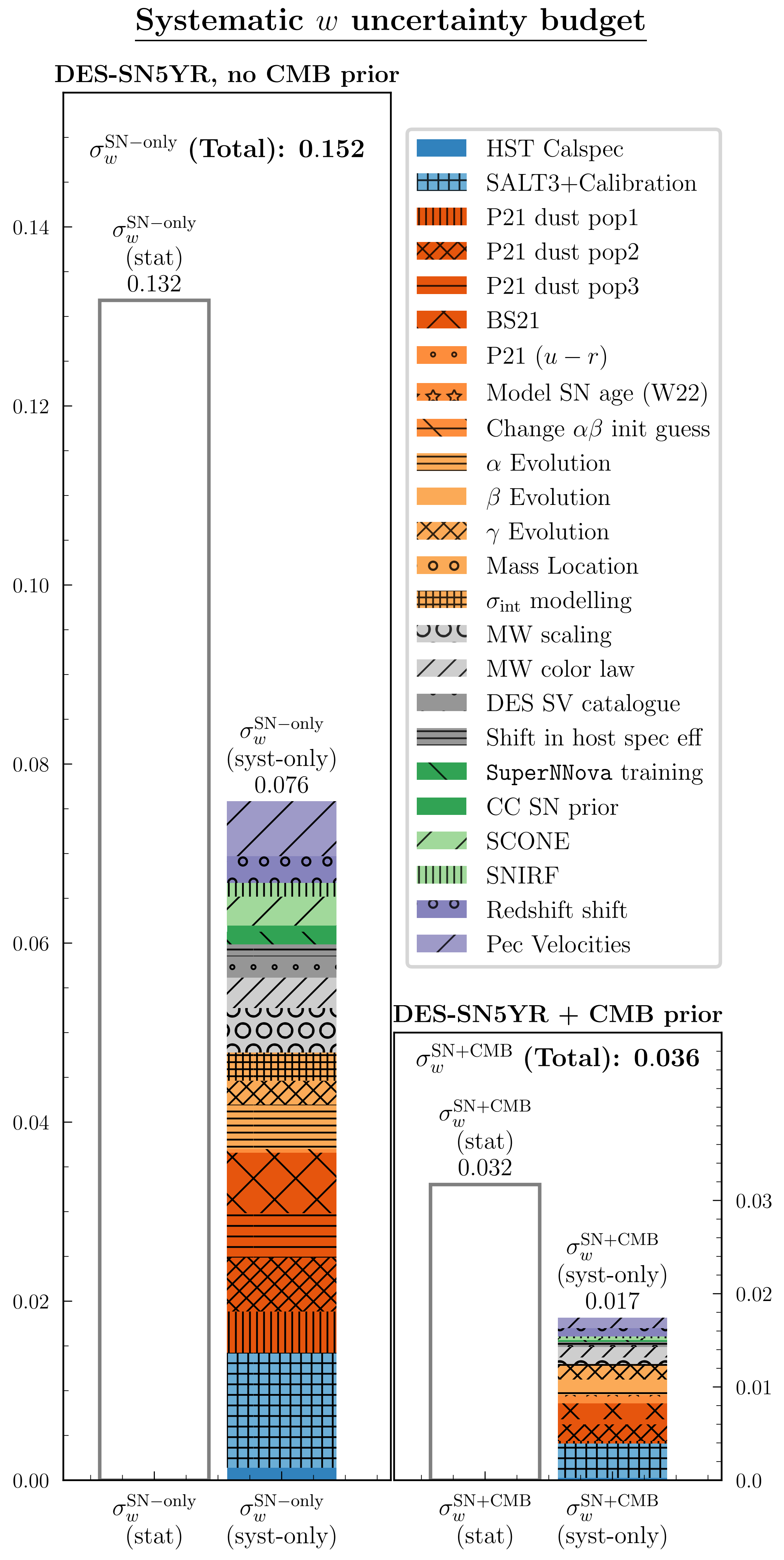




Dust



➡ Reddens the SNe Ia
➡ Dims the SNe



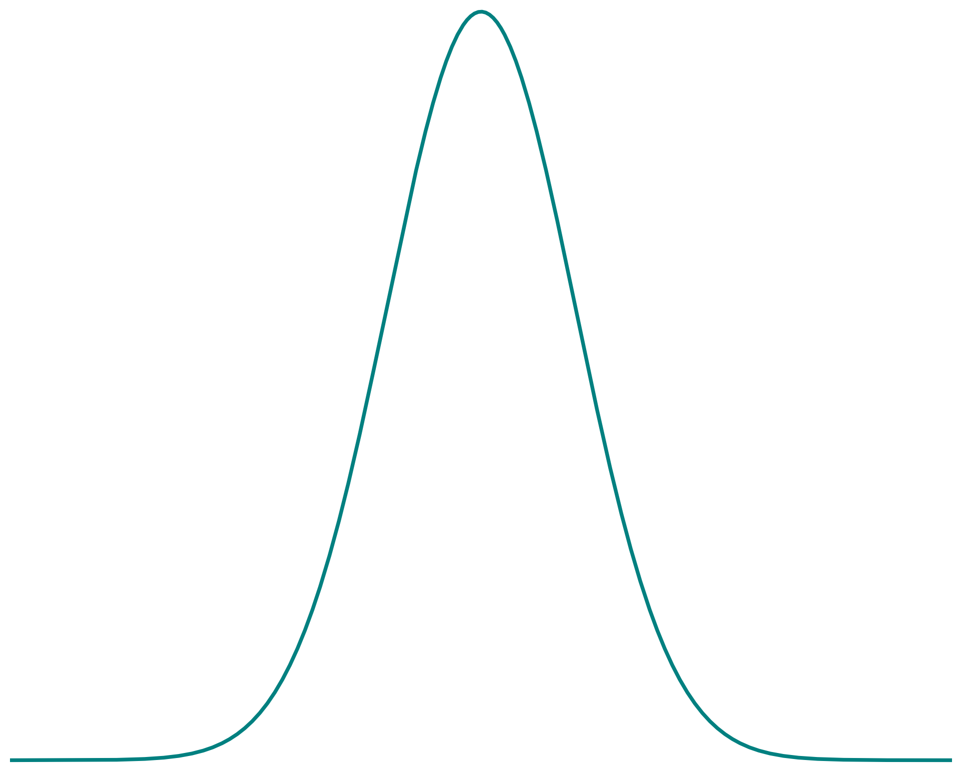
Vincenzi et al (2024)

$$\mu_{obs} + M = m_{obs} - \beta c + \alpha x_1 + p\gamma$$

Colour

Colour distribution

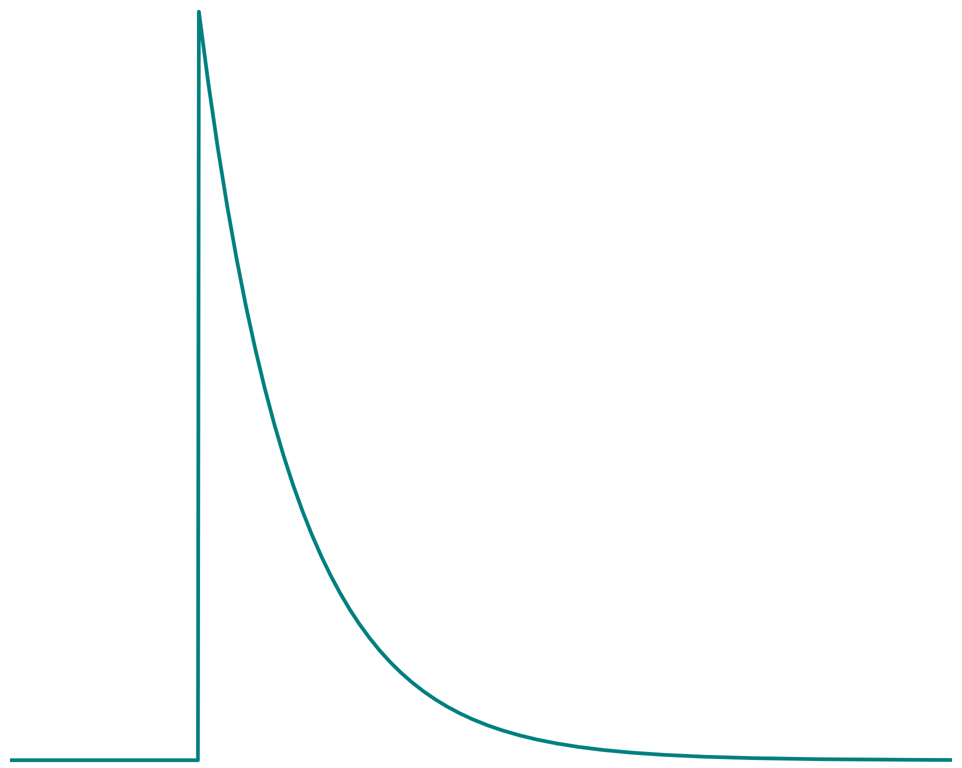
Intrinsic colour



$\mathcal{N}(c, c_{int}, \sigma_c)$

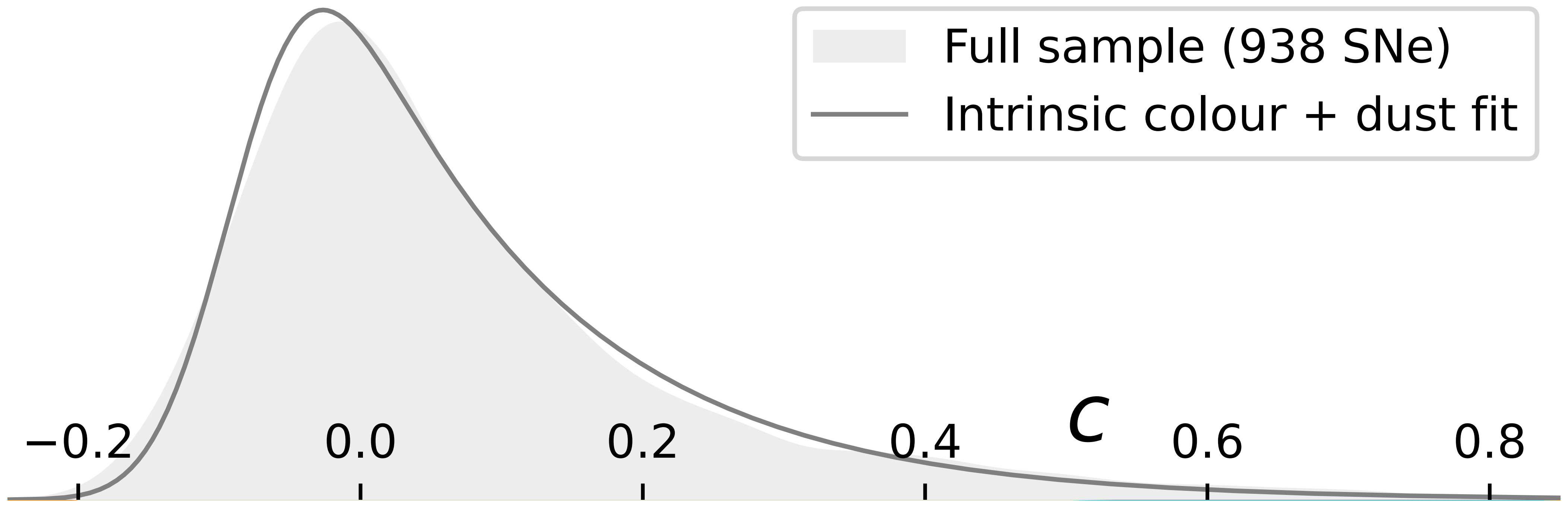
$\otimes$

Dust reddening



$e^{-c\tau}$

$=$

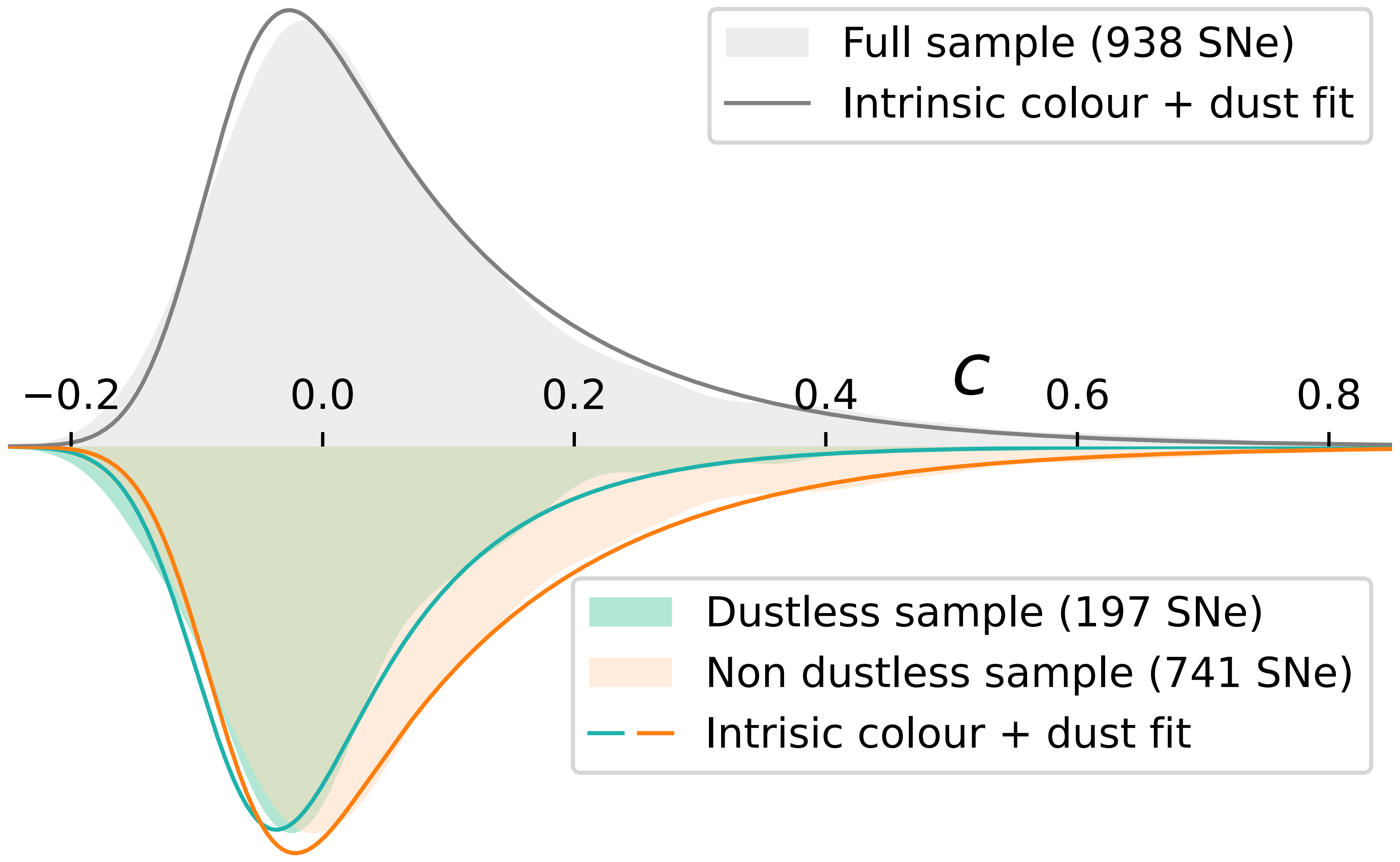


Jha el al. (2007)
Mandel et al. (2011)
Brout & Scolnic (2021)

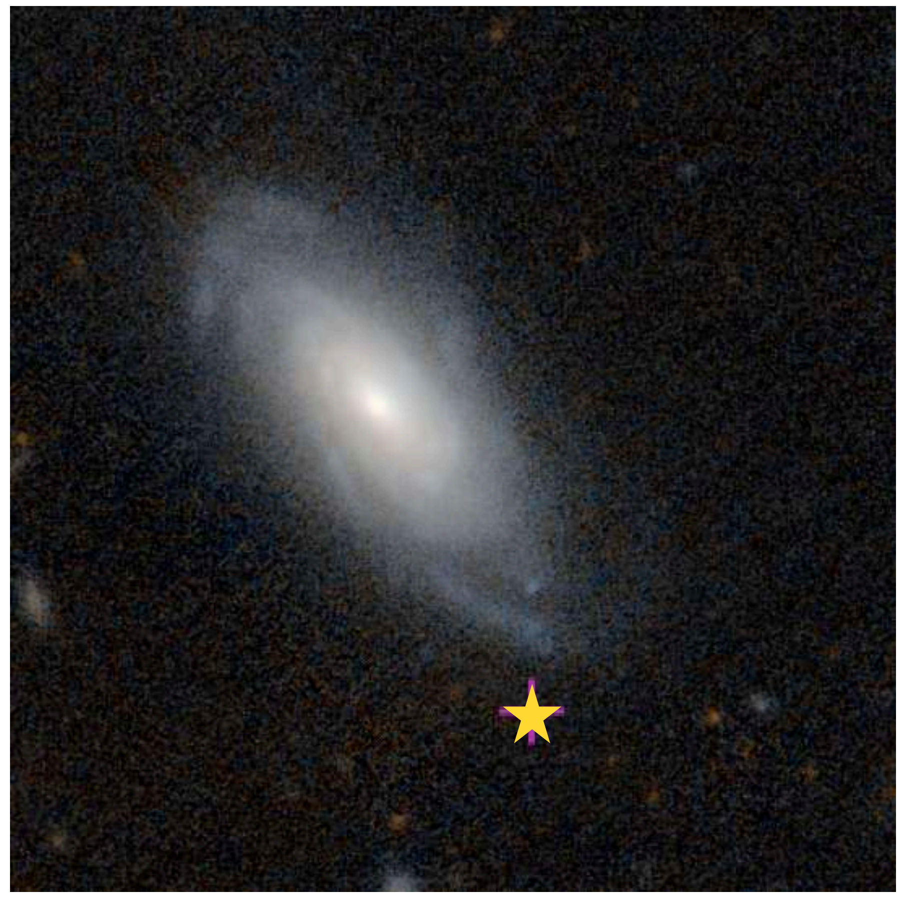
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Colour

Dependence on environment

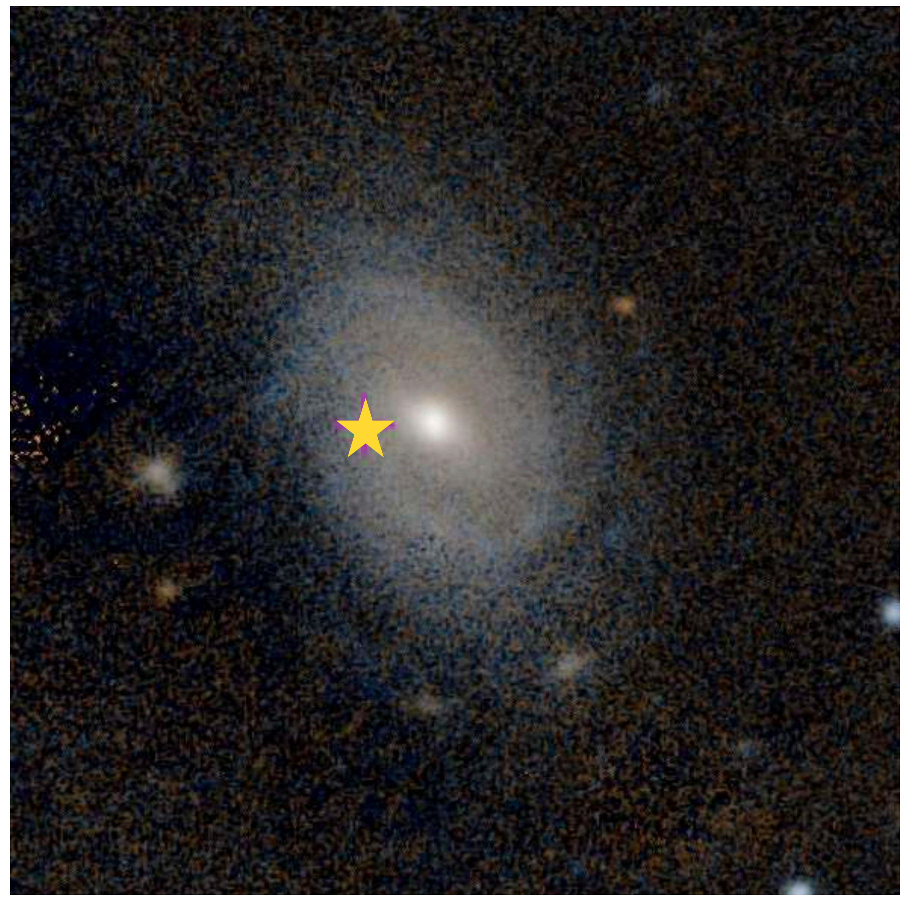


« Dustless » example



ZTF18aahfzea

« Non dustless » example



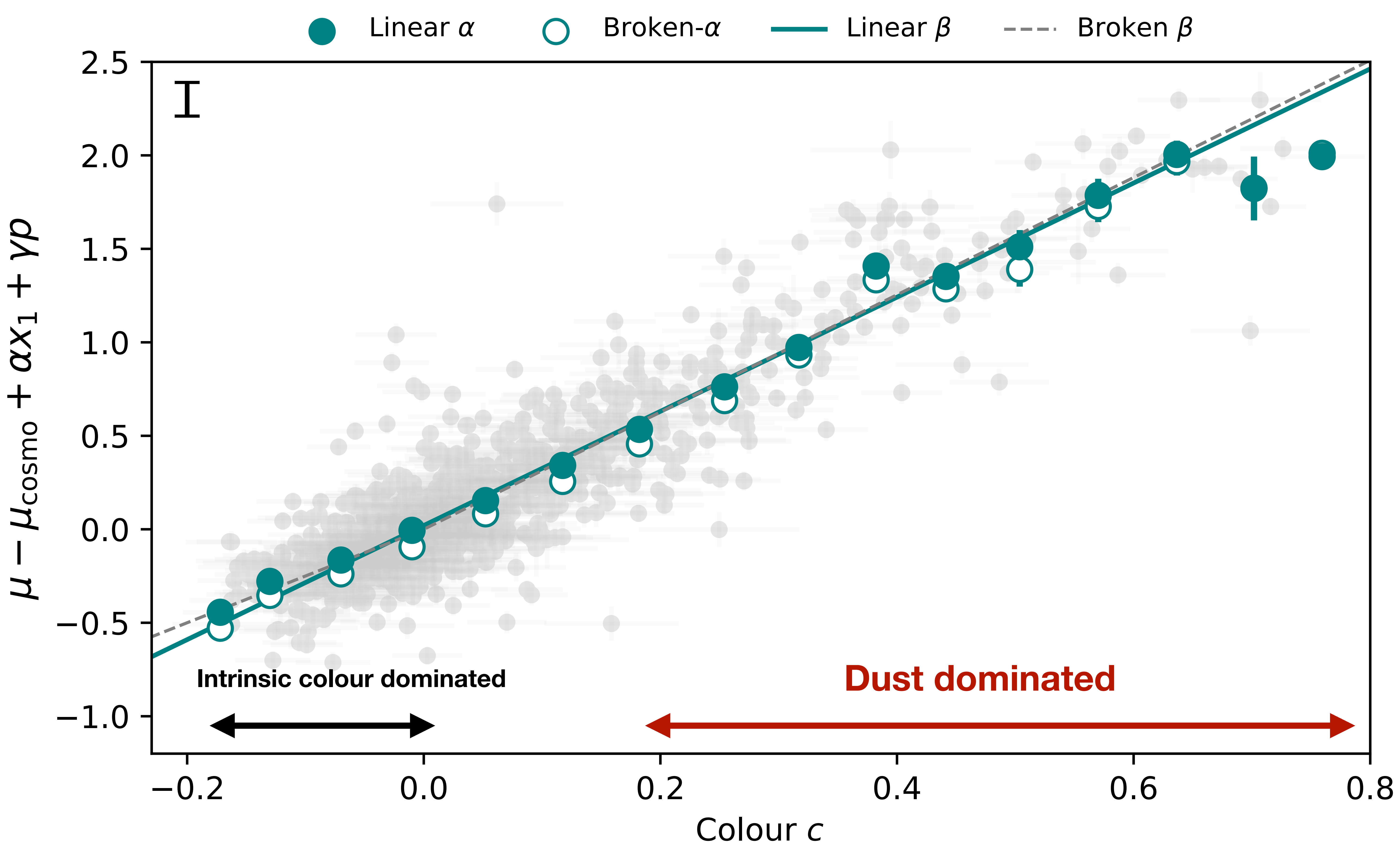
ZTF18aaqfziz

Sample	c_{int}	σ_c	τ
Full sample	-0.085 ± 0.004	0.030 ± 0.005	0.155 ± 0.007
Dustless* sample	-0.087 ± 0.008	0.033 ± 0.008	0.102 ± 0.010
Non dustless sample	-0.082 ± 0.005	0.029 ± 0.006	0.166 ± 0.008

$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Colour

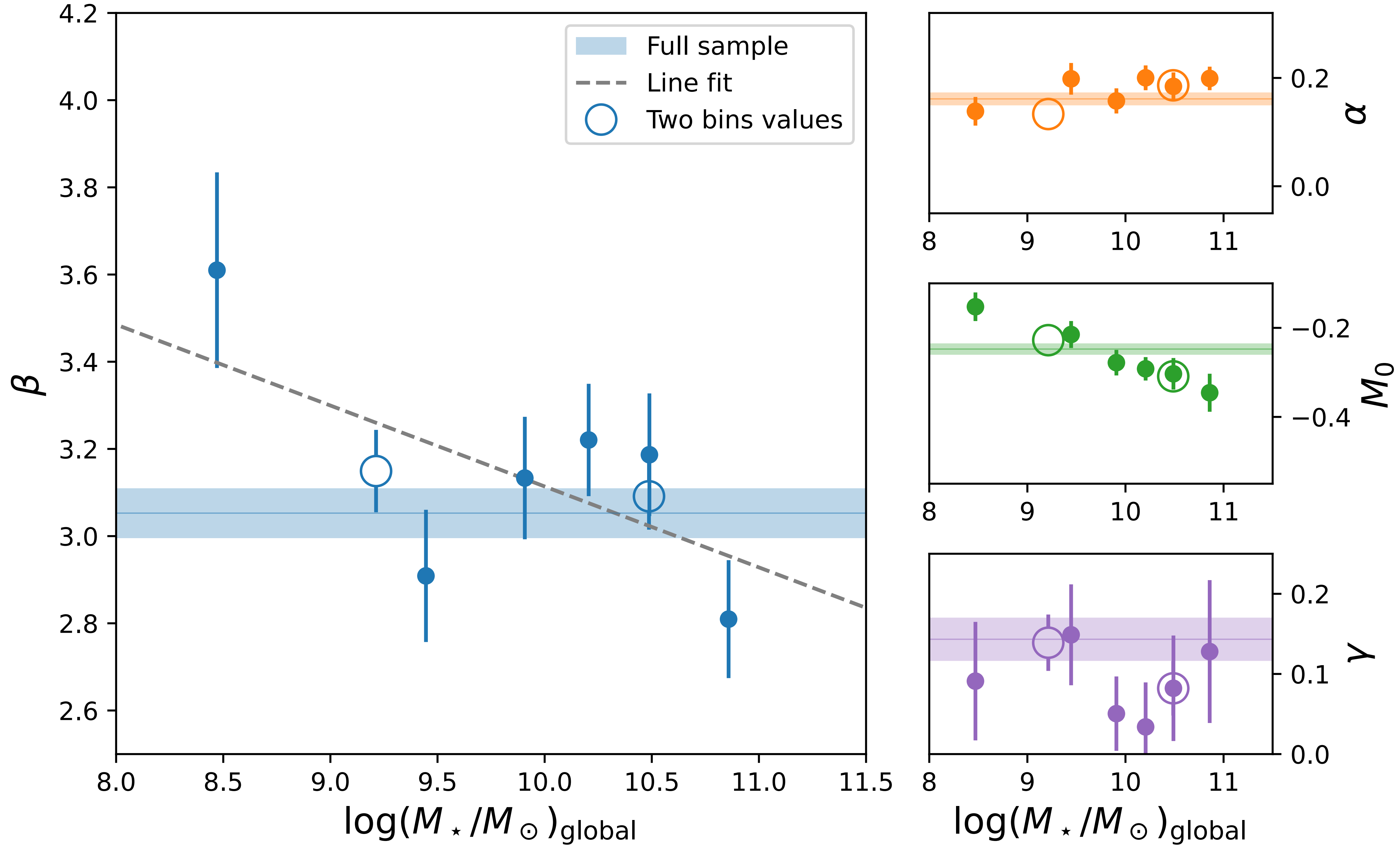
Linearity of the colour-residuals relation

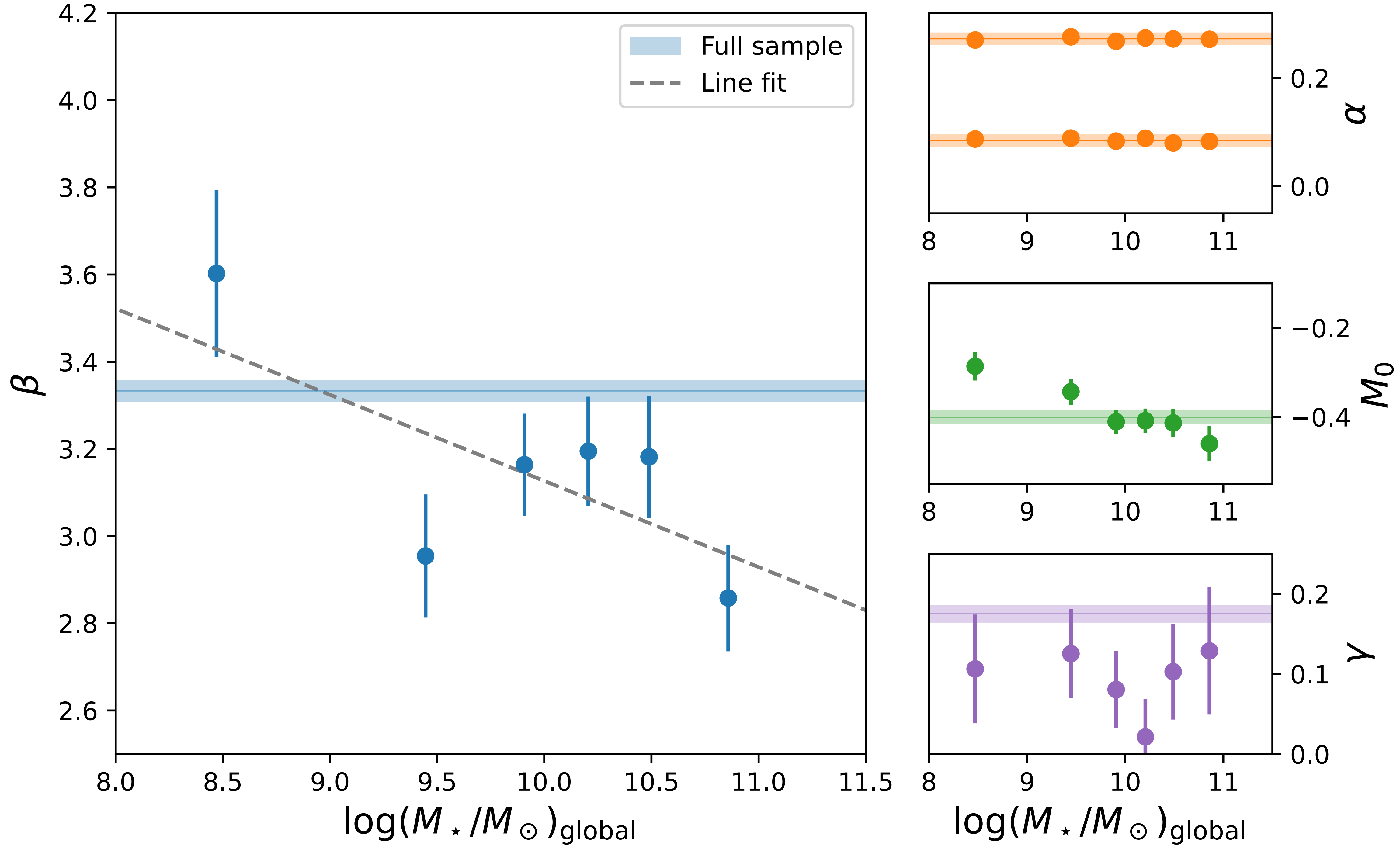


$$\mu_{obs} + M = m_{obs} - \beta c + \alpha x_1 + p\gamma$$

Colour

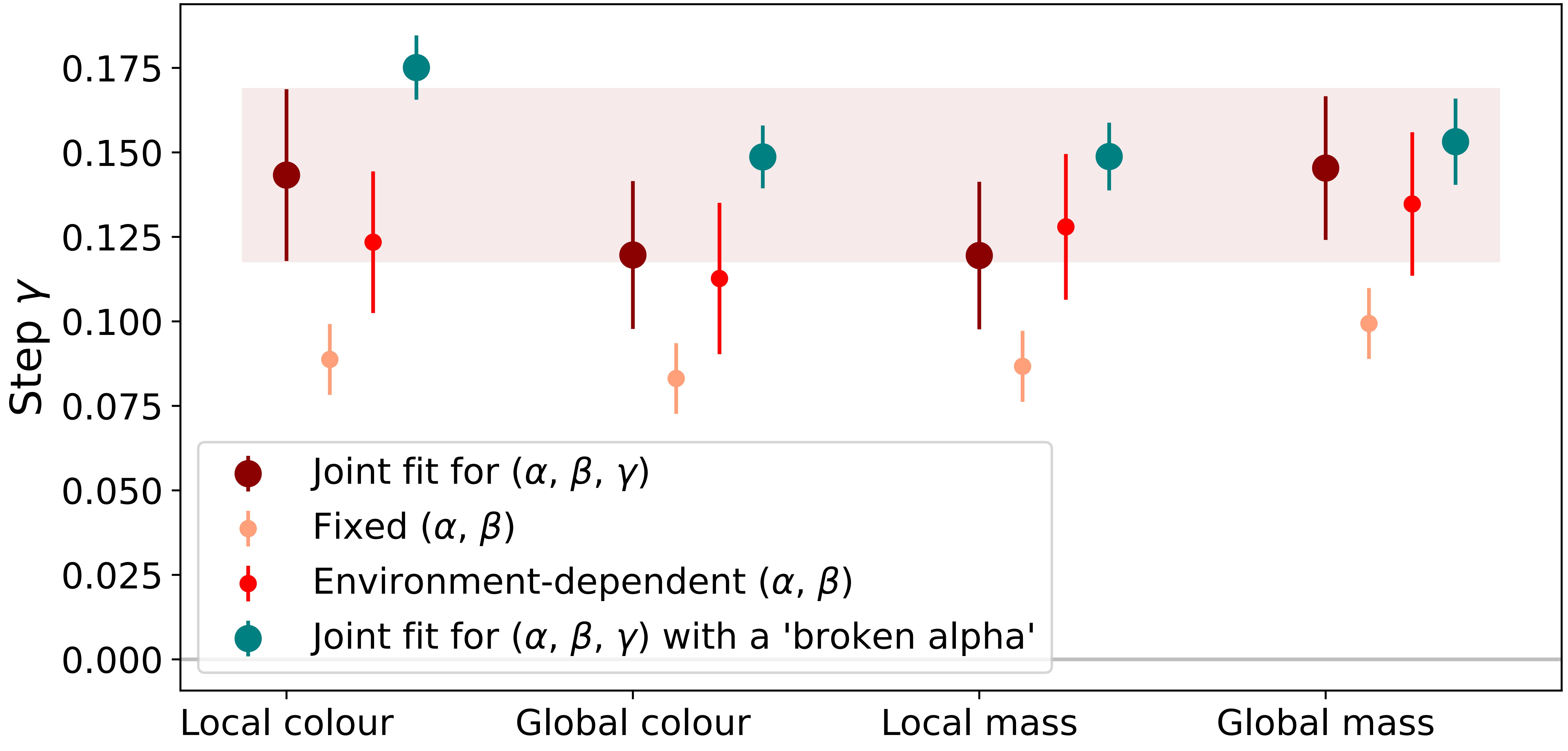
β evolution with environment





$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Environmental step

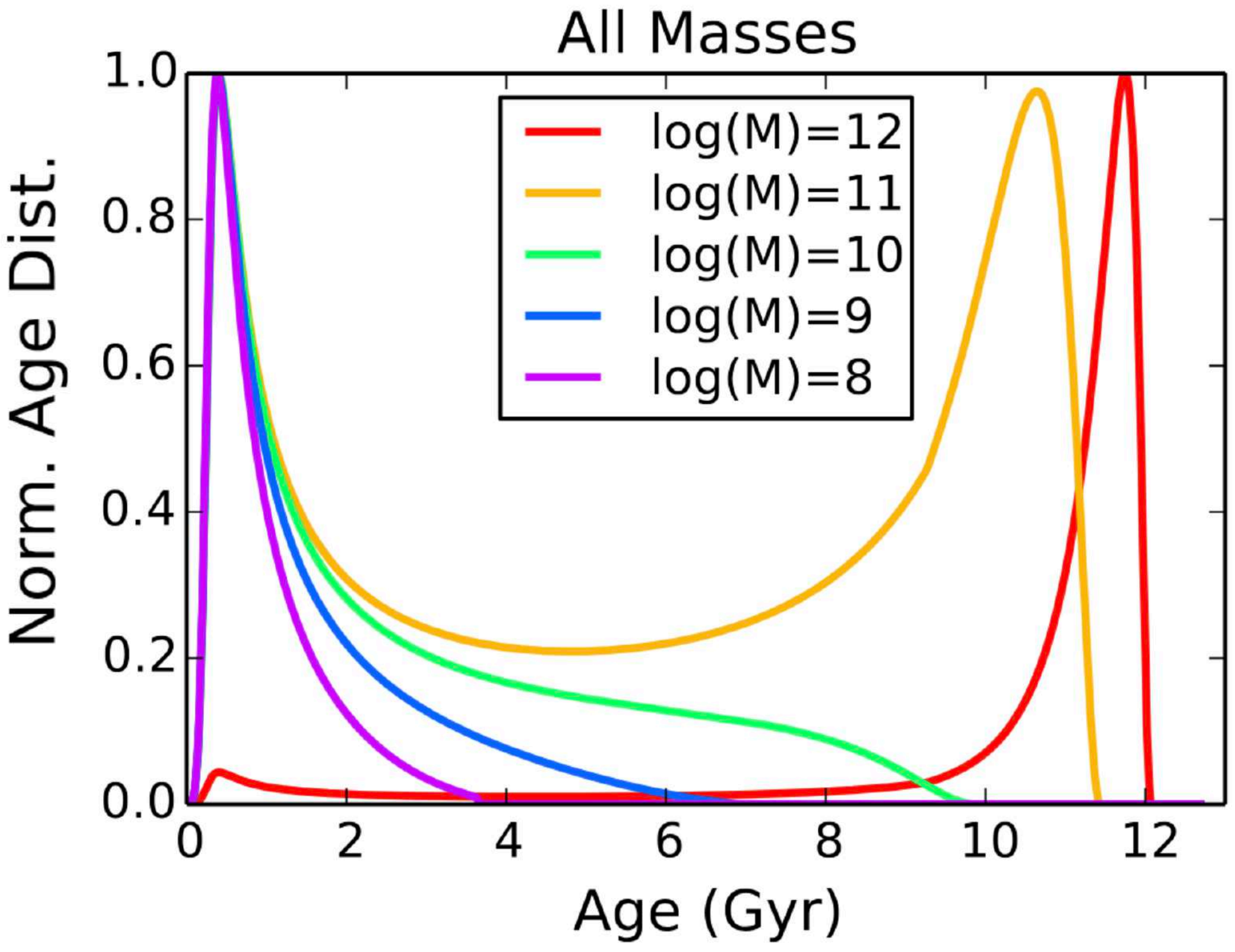


$$\mu_{\mathrm{obs}} + M = m_{\mathrm{obs}} - \beta c + \alpha x_1 + p\gamma$$

Environmental step

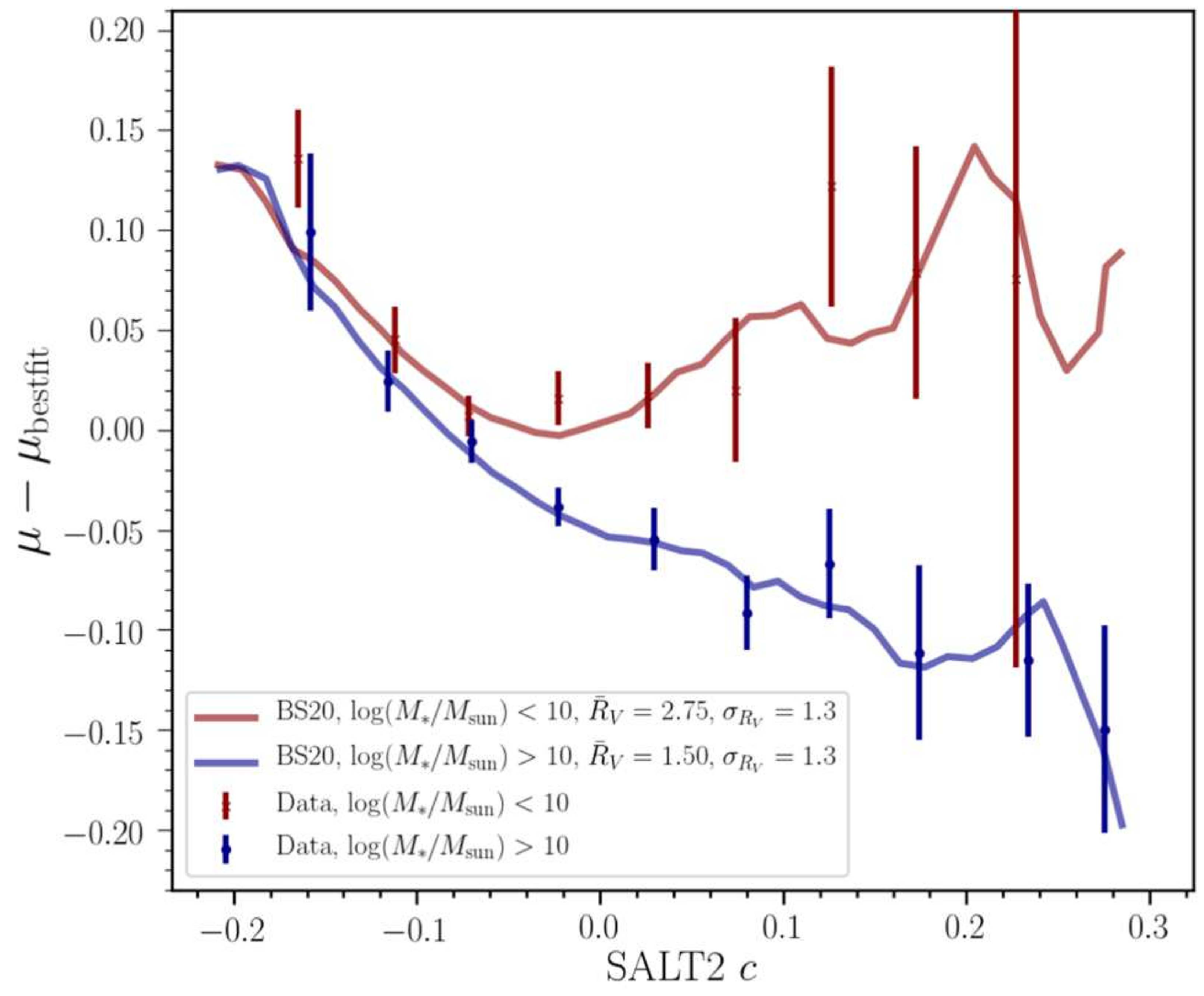
Origin of the step

Two population interpretation



Childress et al (2014)

Dust interpretation

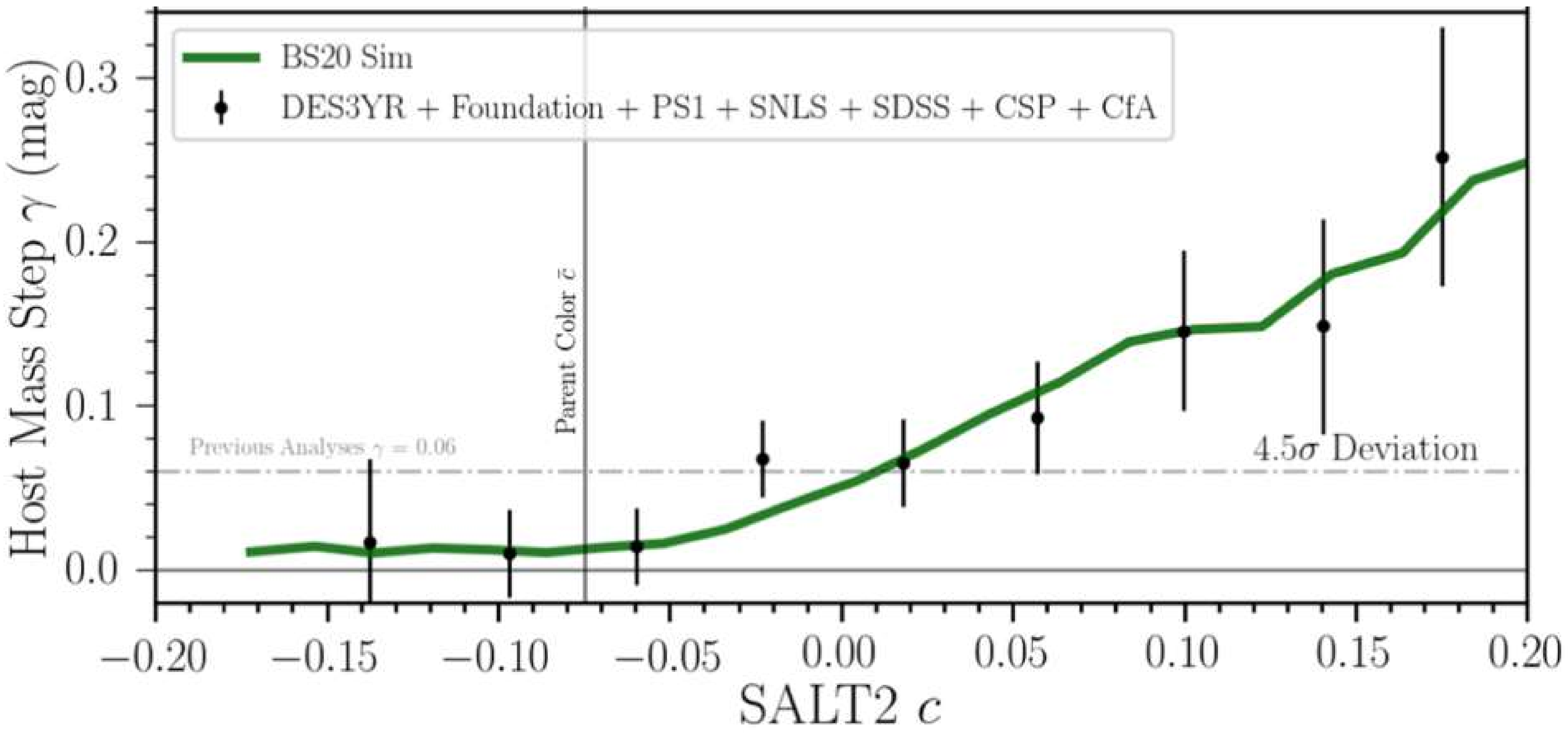


Brout & Scolnic (2021)

$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Environmental step

Colour-dependence of the step



Brout & Scolnic (2021)

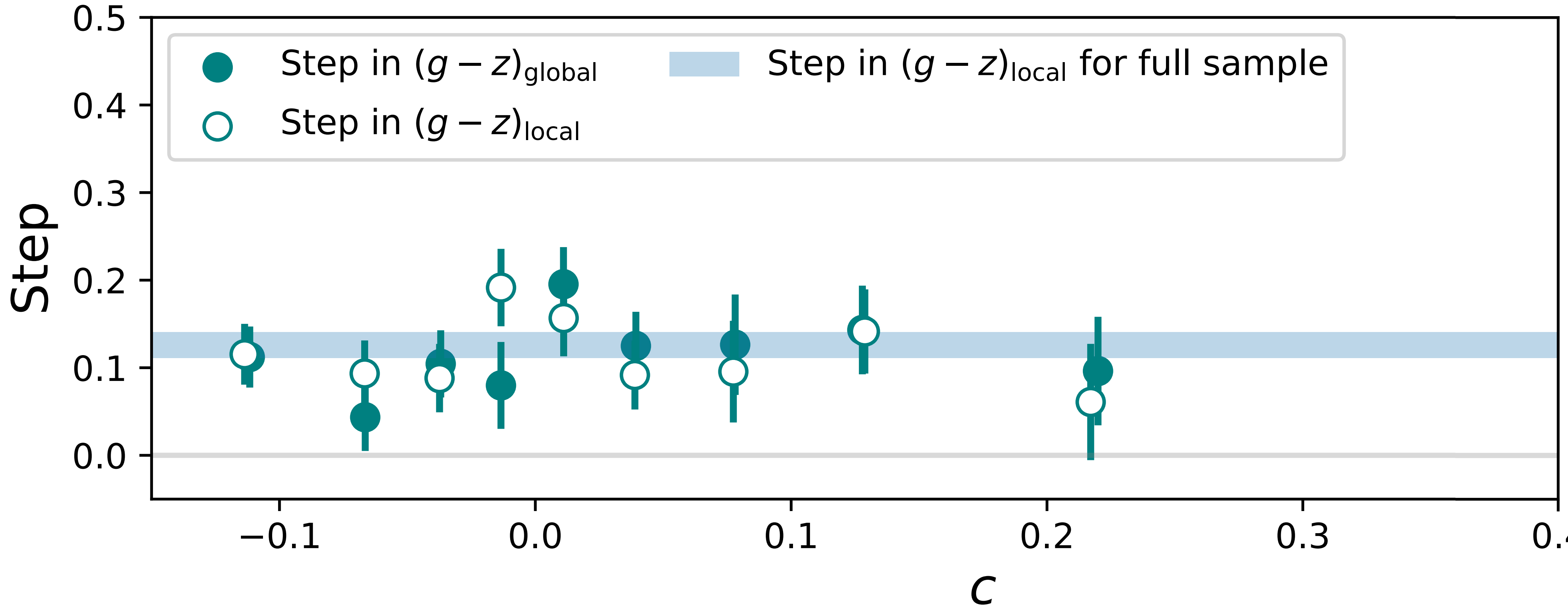


Table 3. Parameters of the step evolution with SN colour: slope of the fit and ΔAIC between an affine function and a constant.

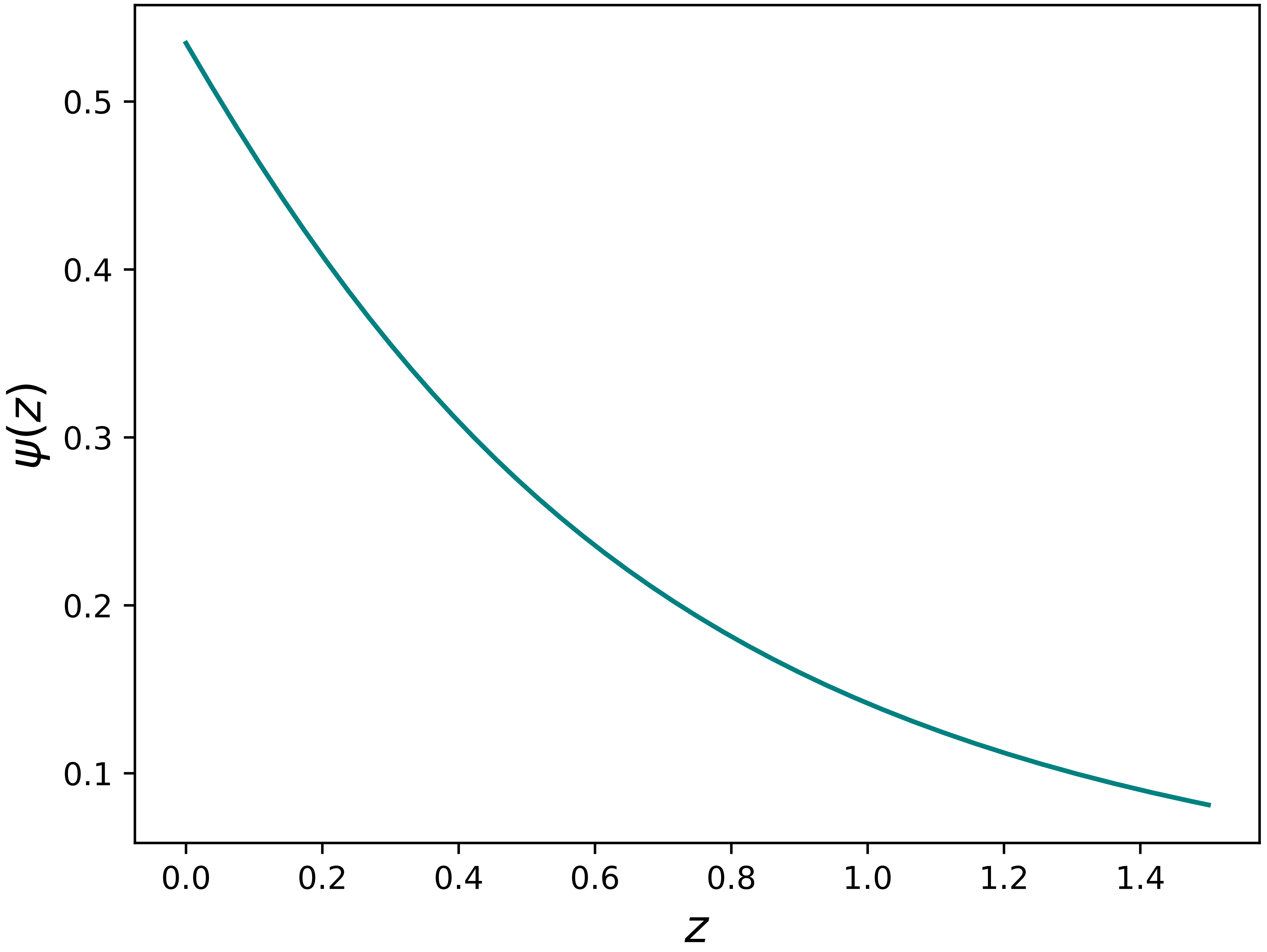
Tracer	Slope	ΔAIC
$(g-z)_{\text{local}}$	0.05 ± 0.11 (0.5σ)	1.8
$(g-z)_{\text{global}}$	0.02 ± 0.12 (0.2σ)	2.0
$\log(M_\star/M_\odot)_{\text{local}}$	-0.11 ± 0.12 (0.9σ)	1.2
$\log(M_\star/M_\odot)_{\text{global}}$	0.02 ± 0.11 (0.1σ)	2.0

IV. Next steps

Redshift evolution

Fraction of old progenitor SNe Ia:

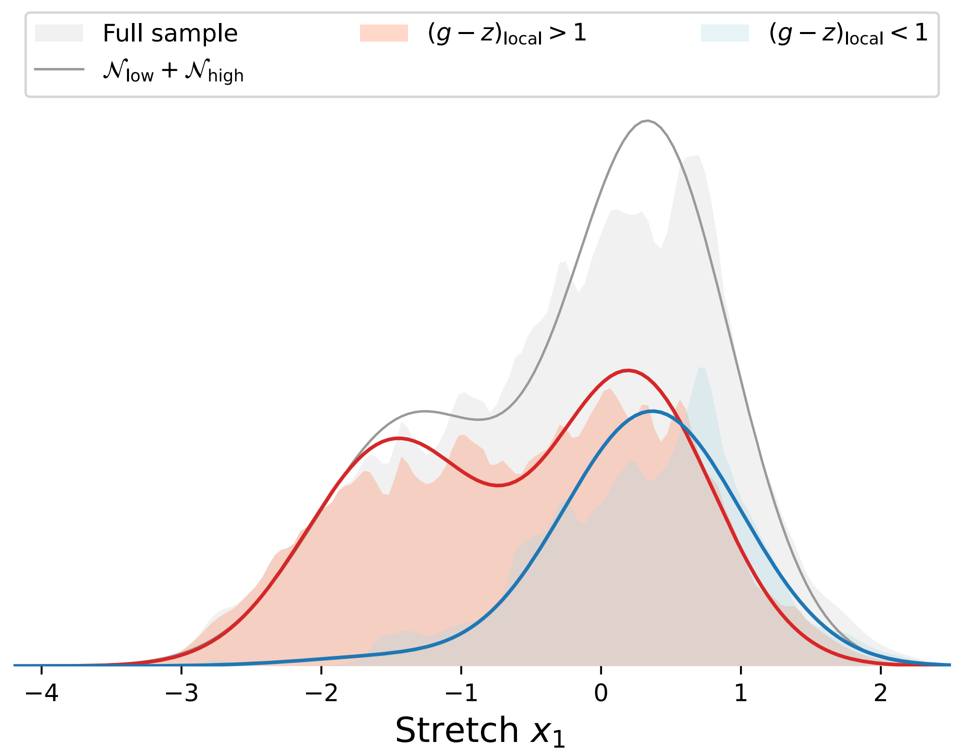
$$\psi(z) = \frac{1}{K(1+z)^{\phi} + 1}$$

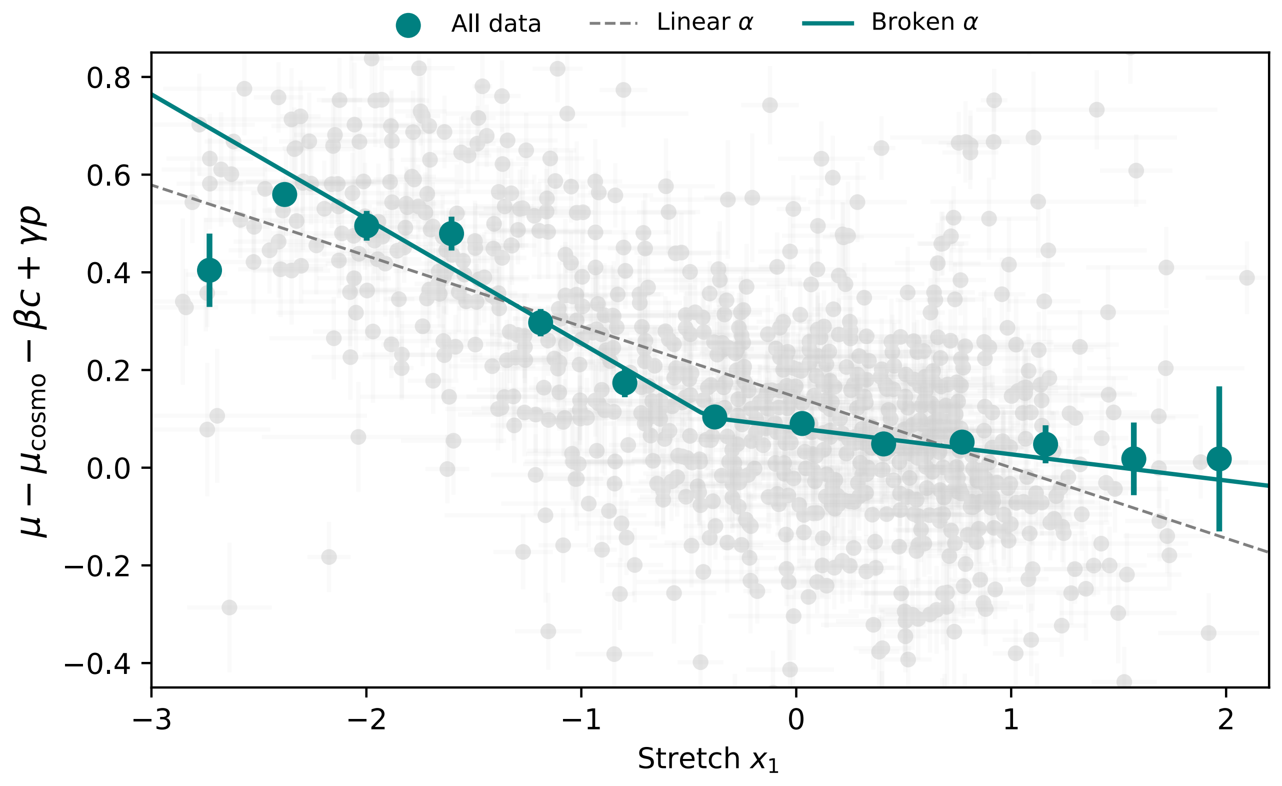


Rigault et al (2020)
Tasca et al (2015)
Mannucci et al (2005)

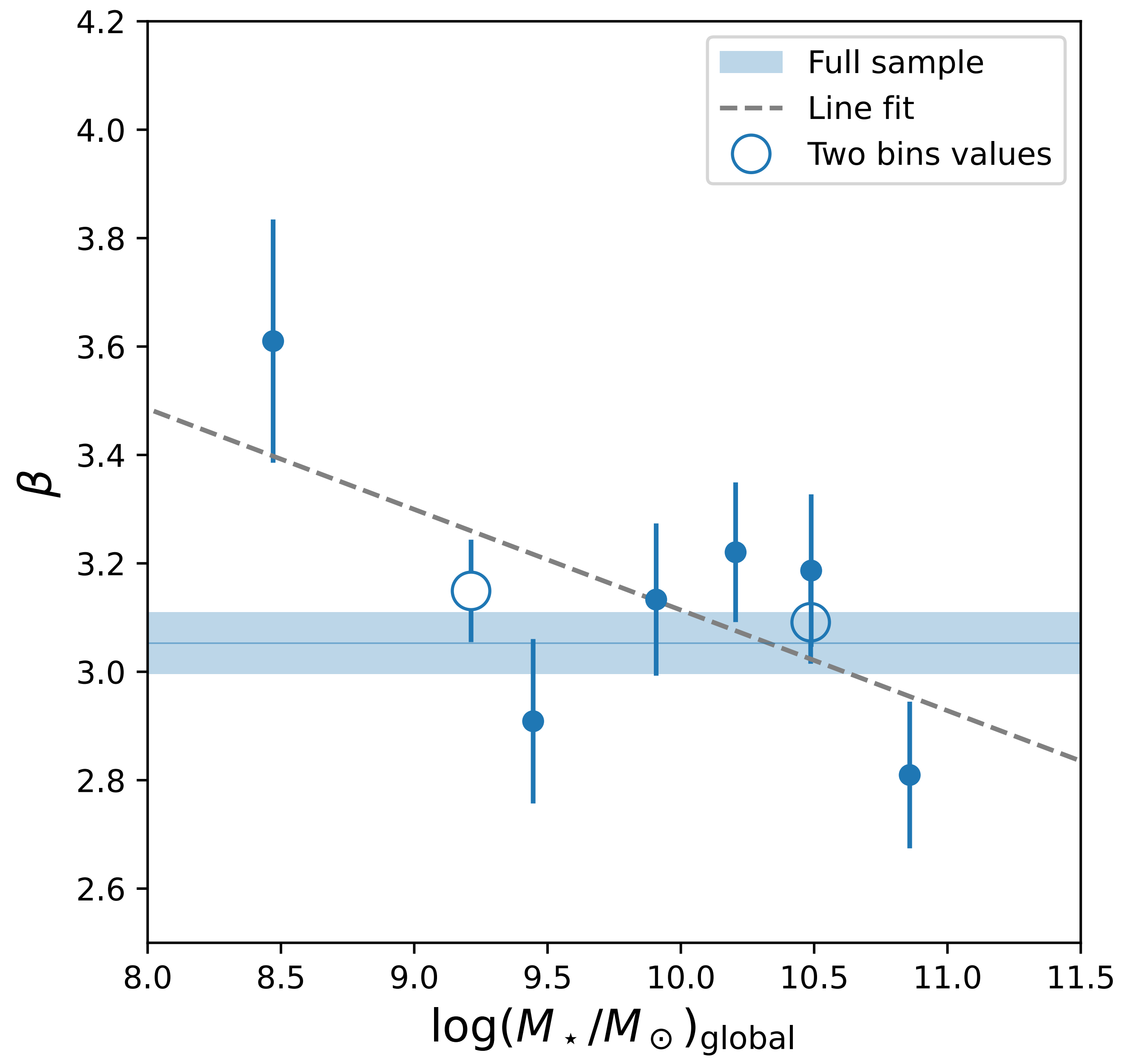
Redshift evolution

α evolution

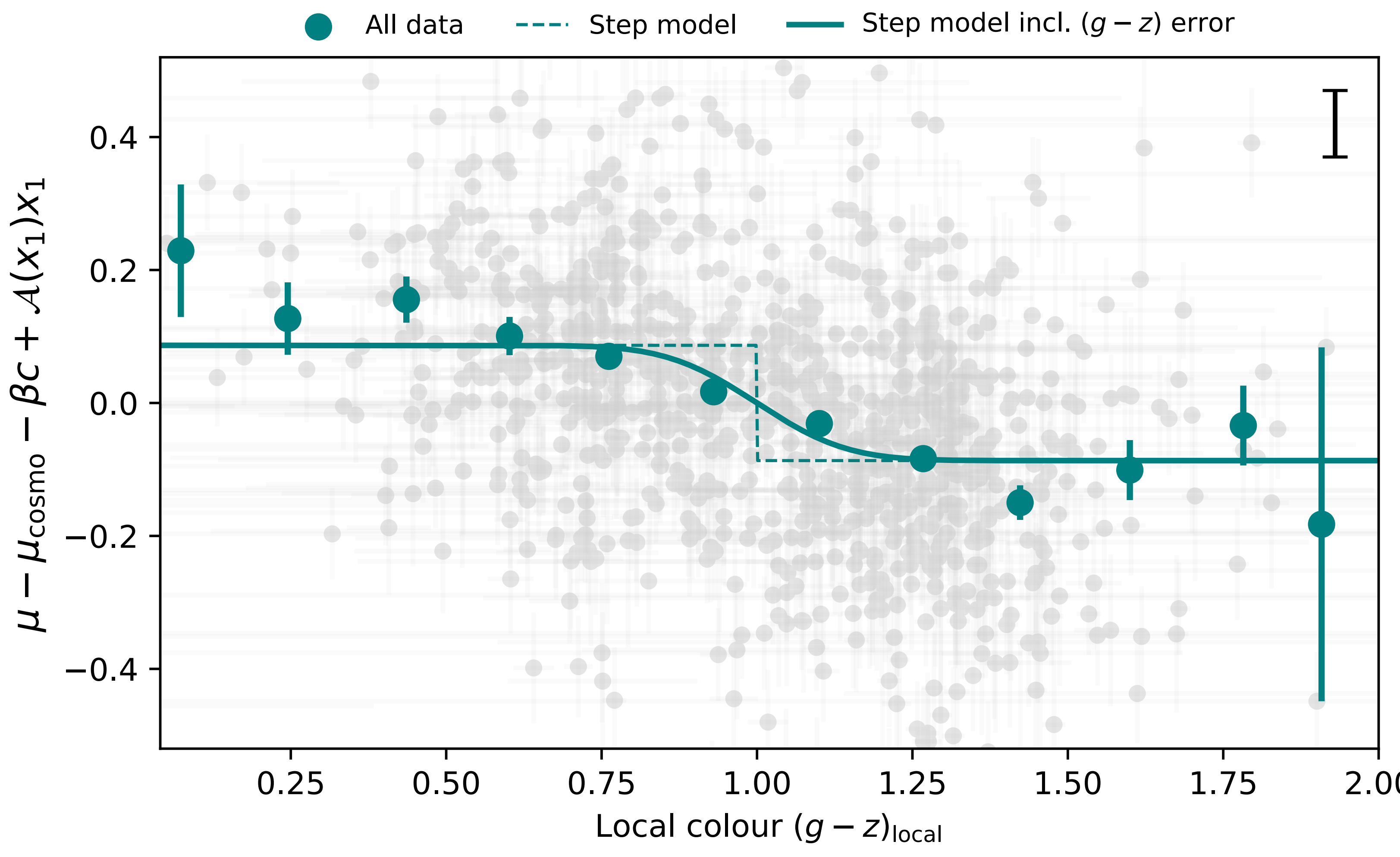




β evolution



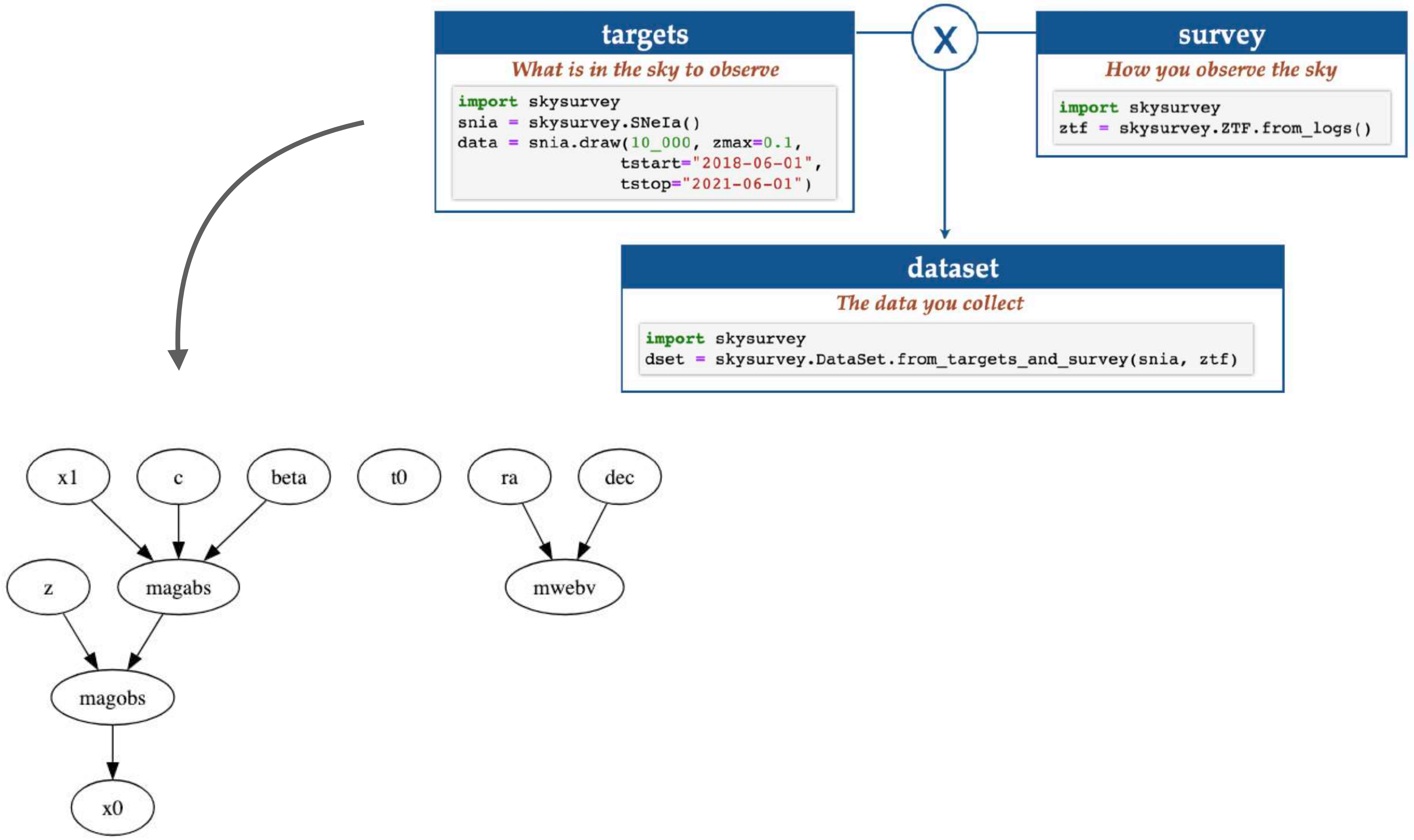
Impact of the environmental step



Next steps

Include these effects in simulations

skysurvey skysurvey.readthedocs.io



Investigate the redshift evolution with high-z data

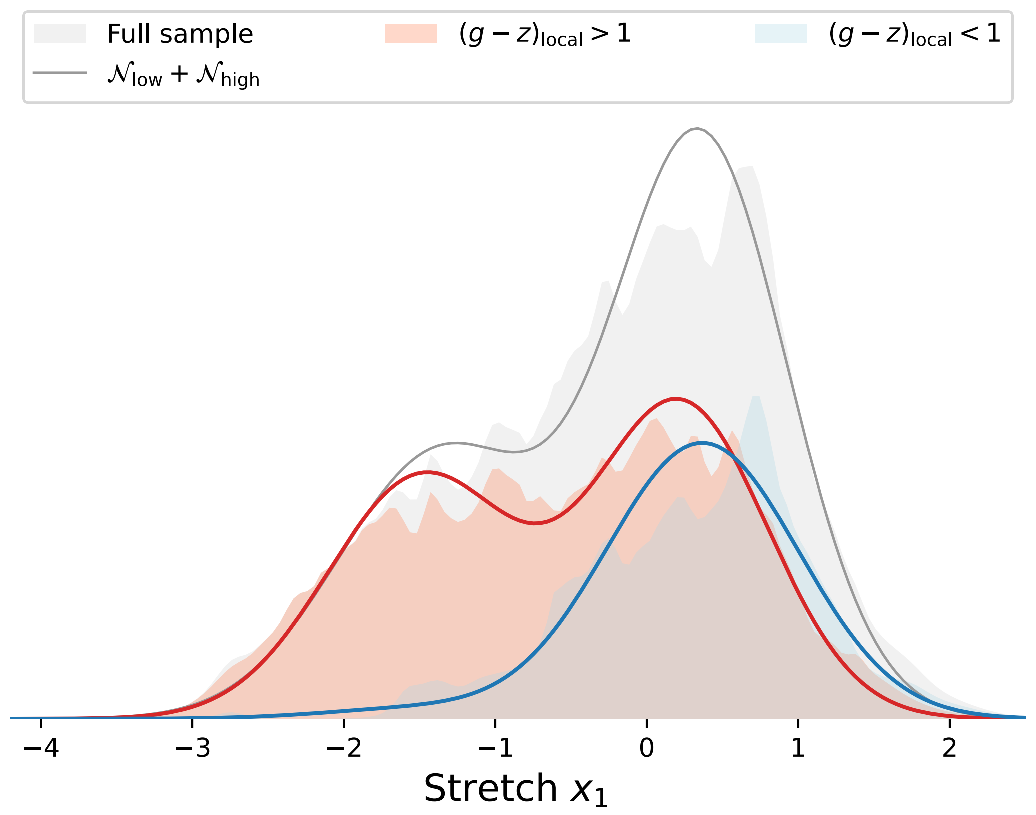
LSST @ Vera C. Rubin Observatory

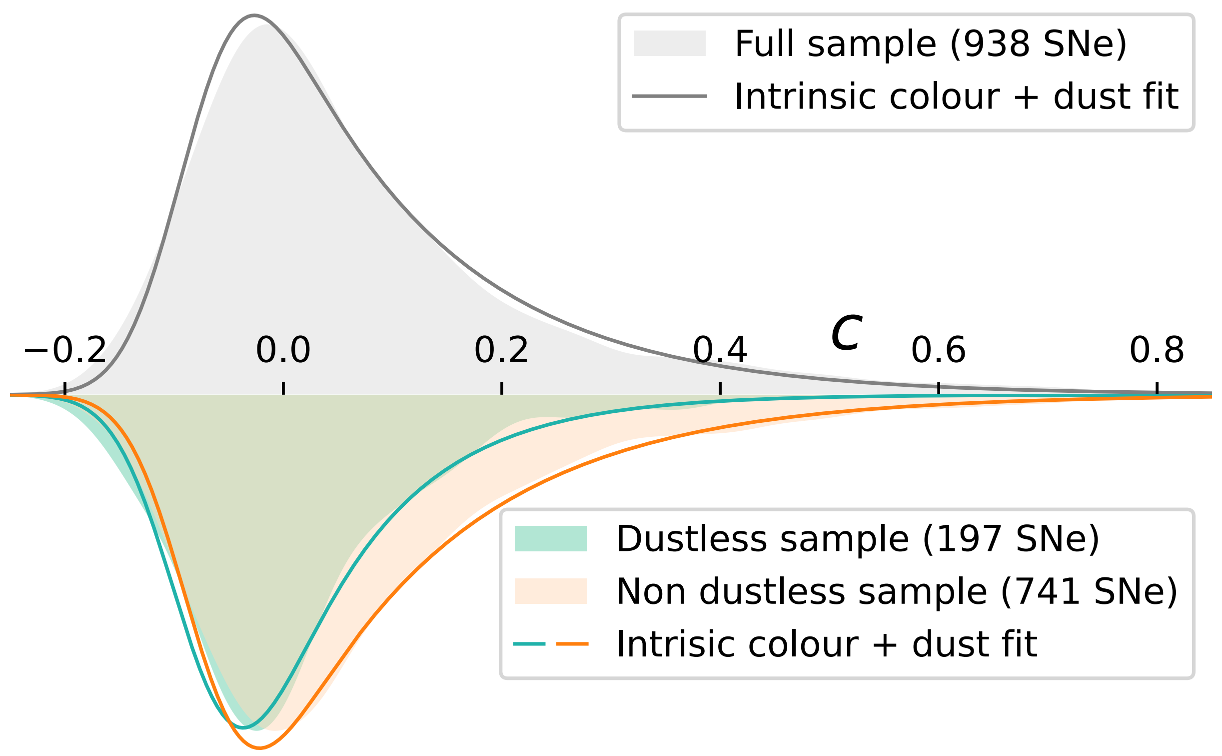
1M SNe Ia over 10 years

Up to $z \sim 1.1$

Conclusion

Type Ia Supernovae properties

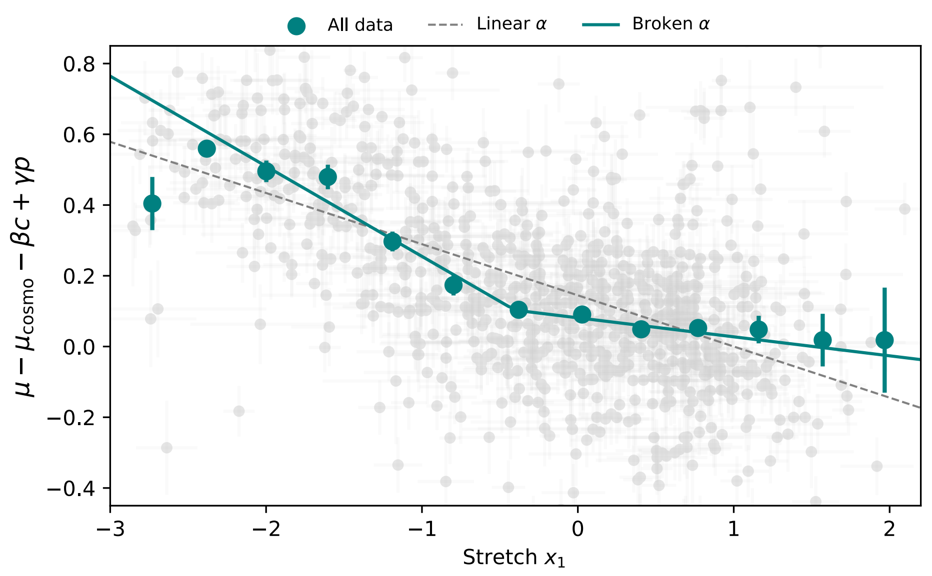


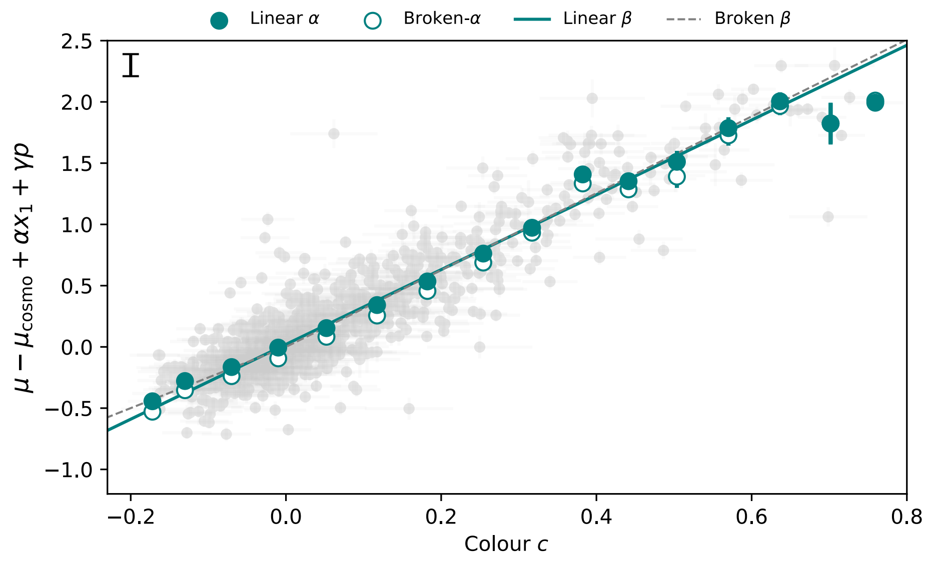


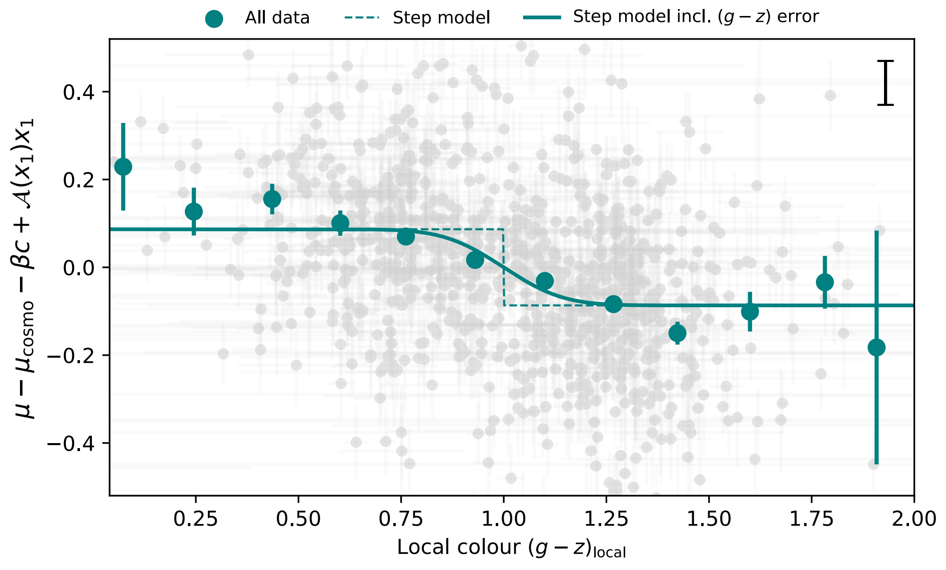
ZTF SN Ia DR2
volume-limited sample

949 SNe Ia
Homogenous
High cadence + spectroscopic

Standardisation dependency on environment







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