

2405.20965

2406.02072



Type Ia Supernovae standardisation with the ZTF SN Ia DR2 sample

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Oxford - 5th November 2024



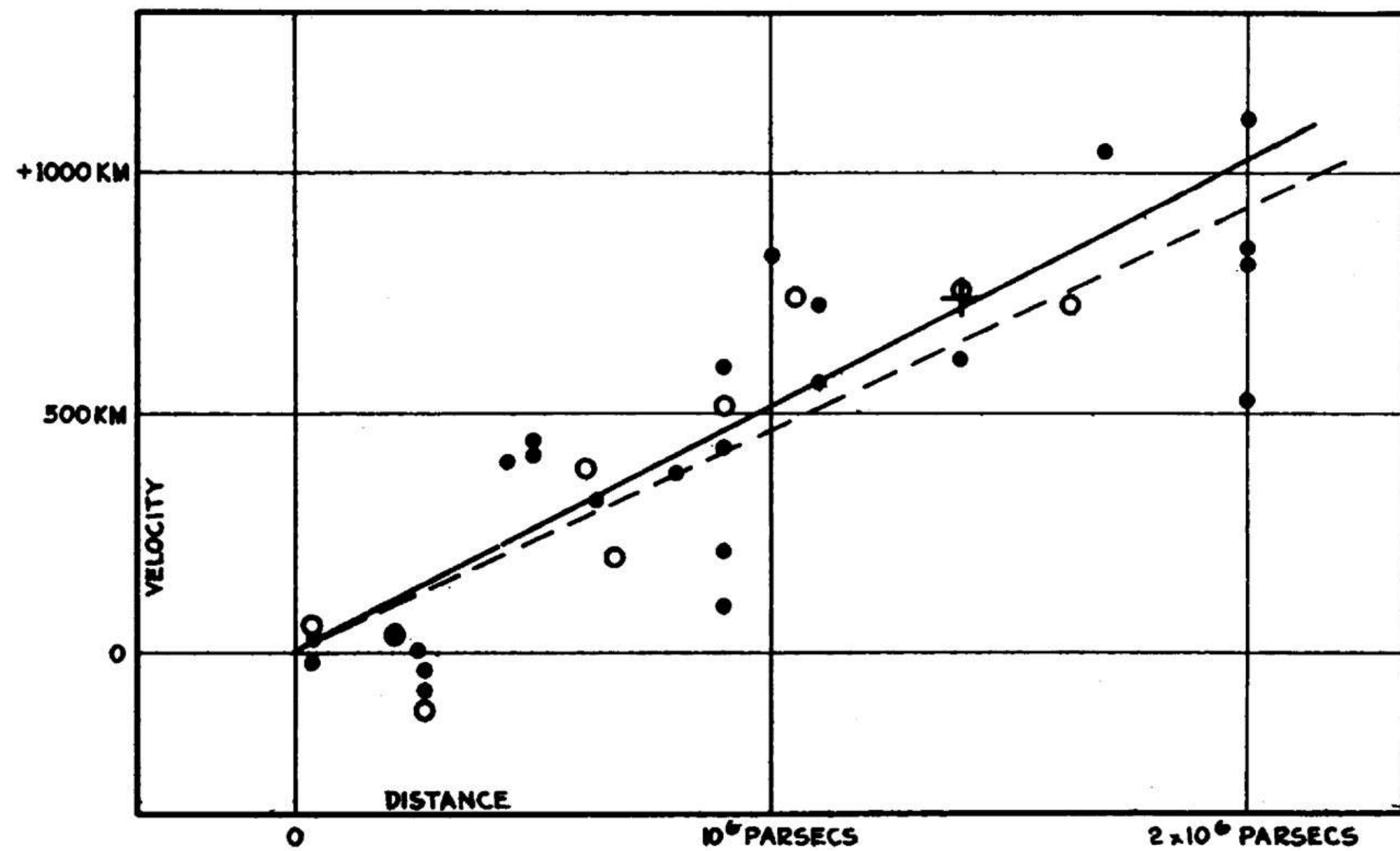
Outline

- I. Cosmology with Type Ia supernovae
- II. ZTF SN Ia DR2
- III. SNe Ia standardisation with the ZTF DR2
- IV. Next steps

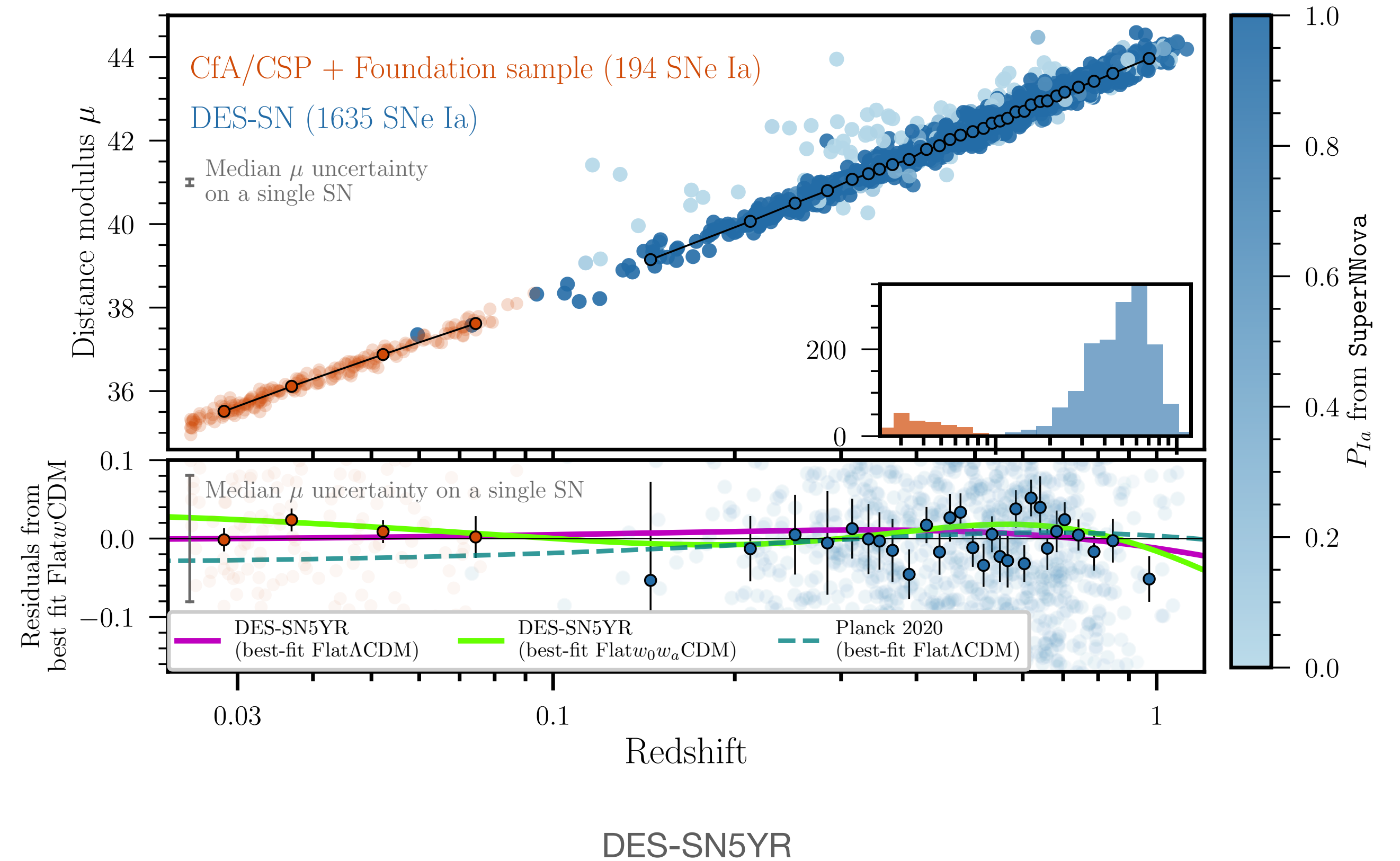
I. Cosmology with Type Ia Supernovae

Cosmology

Hubble diagram



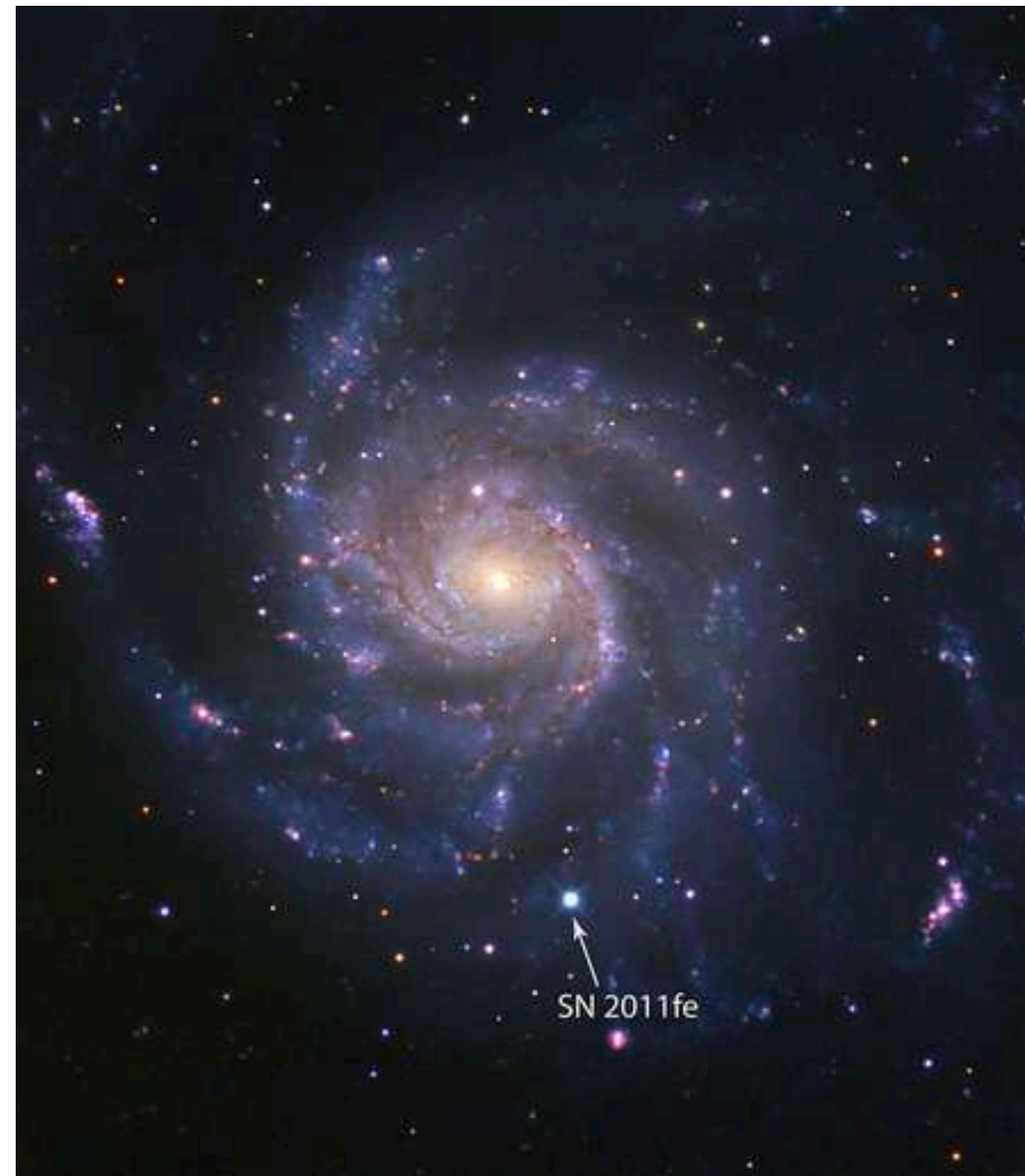
Hubble (1929)



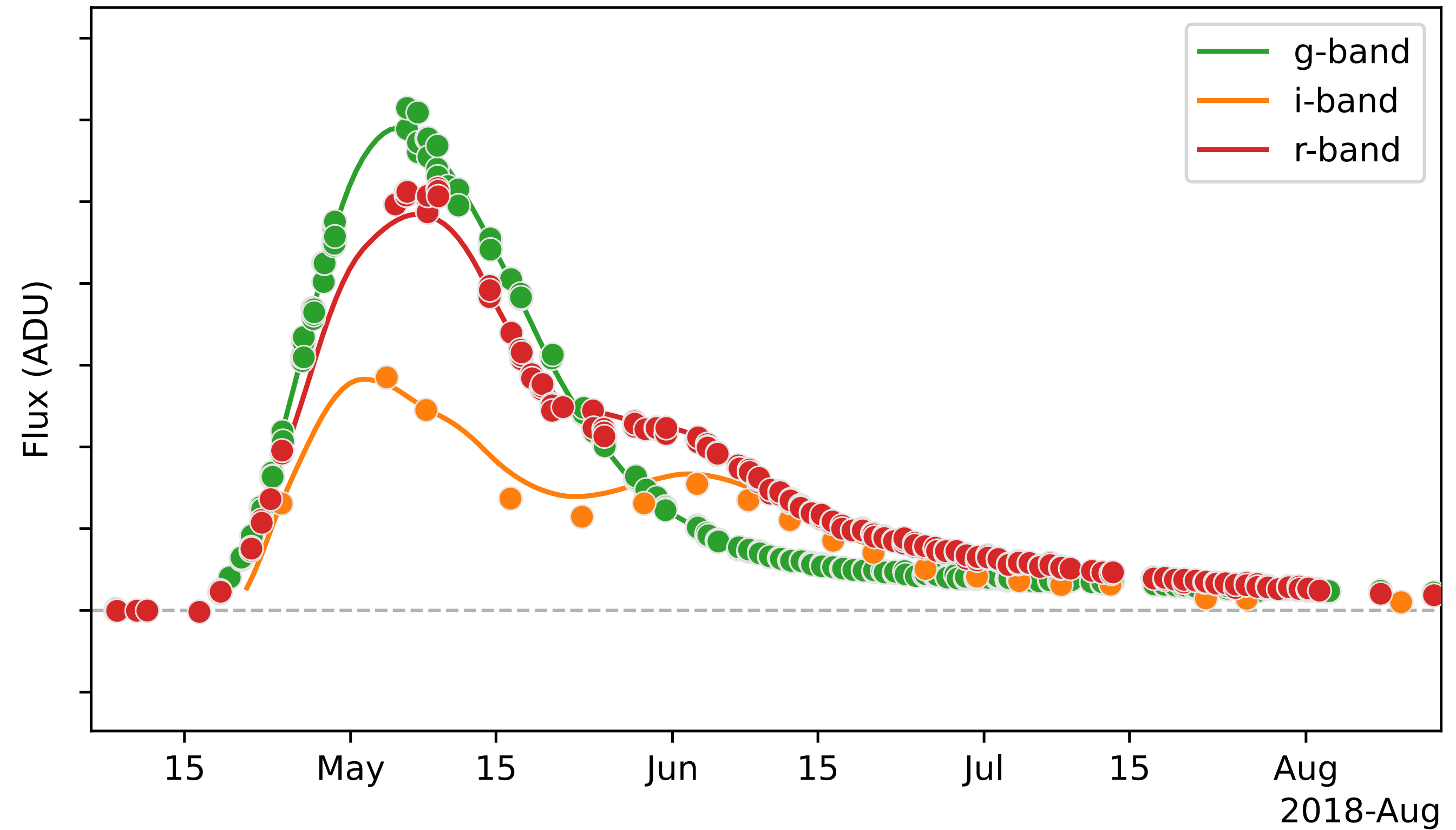
DES-SN5YR

Type Ia Supernovae (SNe Ia)

Lightcurve



Credits: B.J. Fulton/
LCOGT/Caltech



Type Ia Supernovae (SNe Ia)

Lightcurve fitting

Flux of the SN:

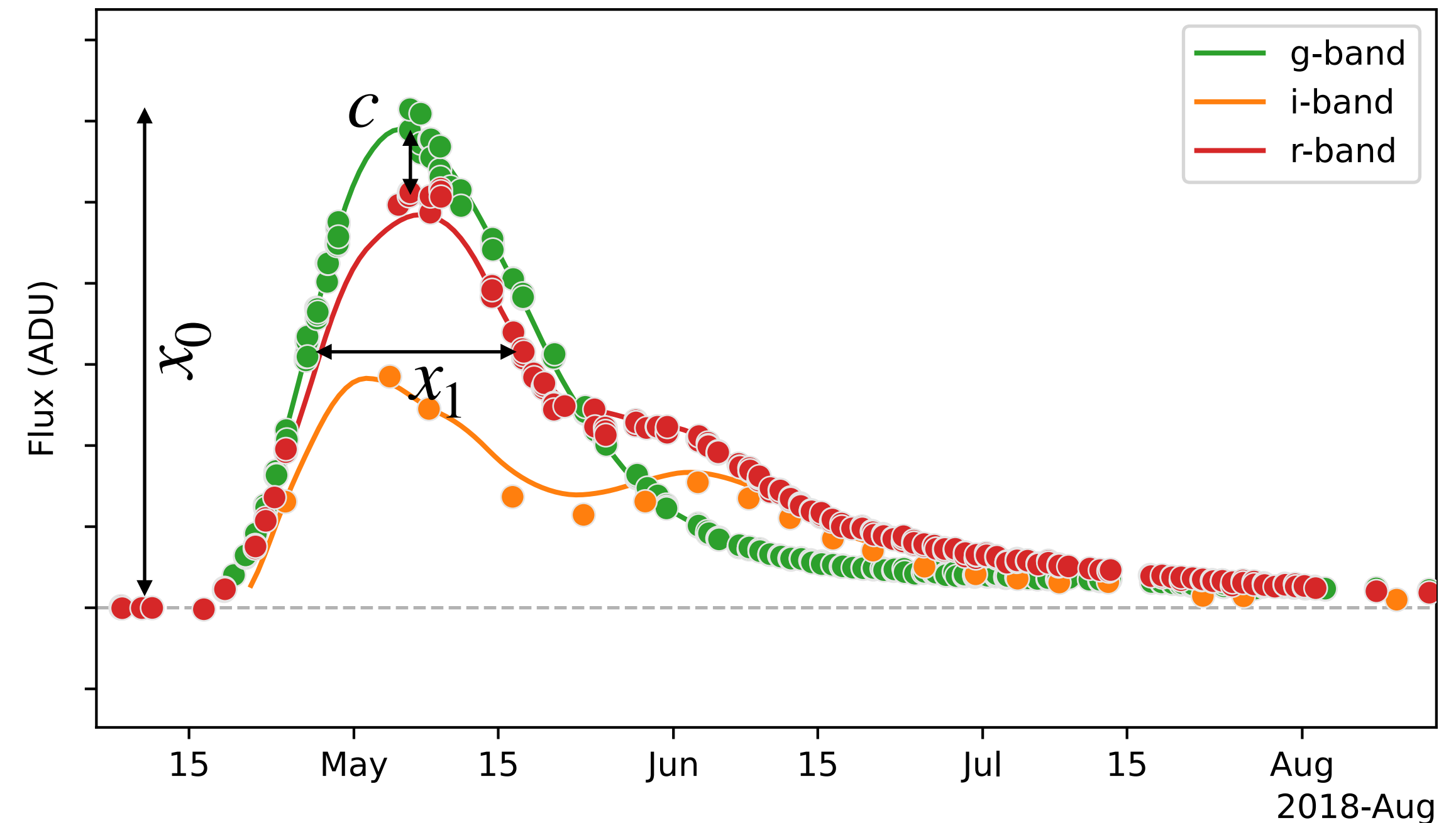
$$F(SN, p, \lambda) = x_0 [M_0(p, \lambda) + x_1 M_1(p, \lambda)] \exp(c CL(\lambda))$$

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

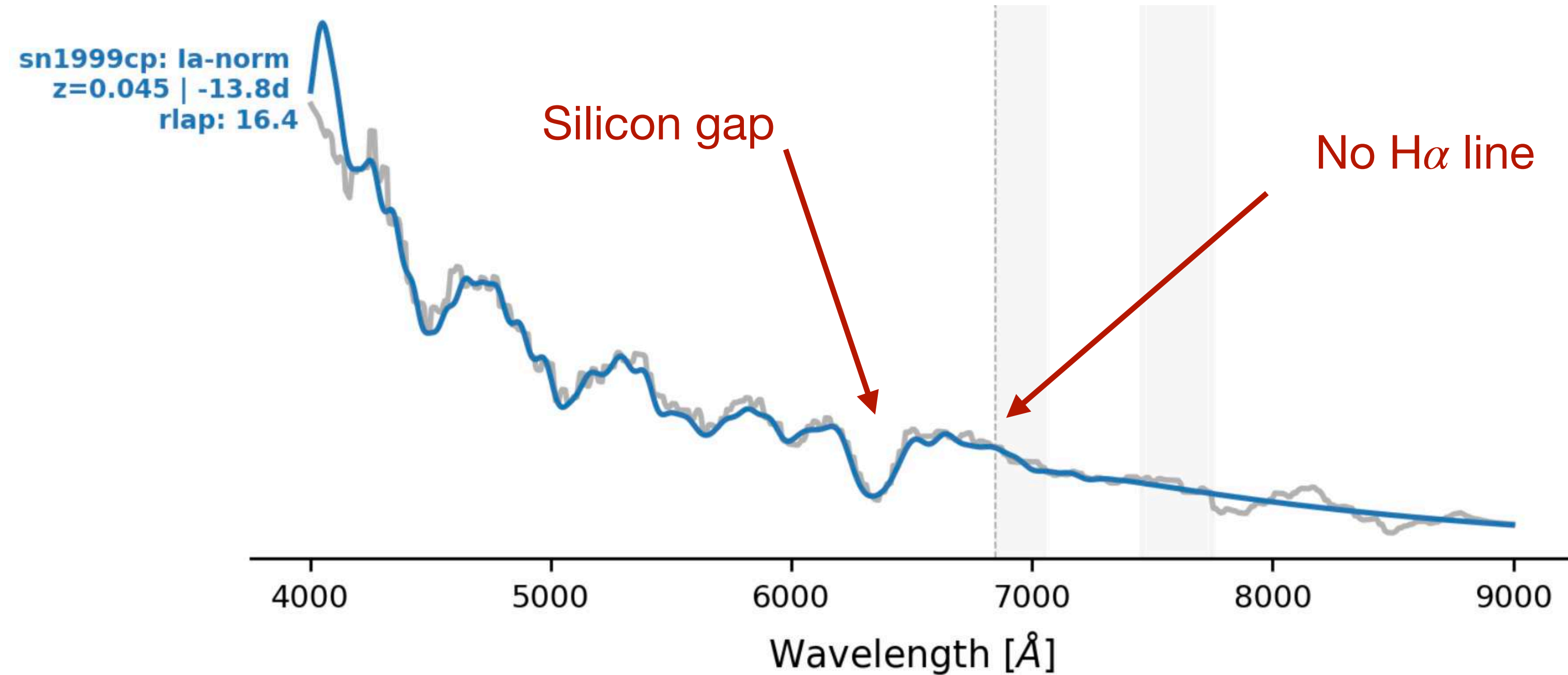


SALT2.4 - Guy et al (2007)
SALT3 - Kenworthy et al (2021)

Type Ia Supernovae (SNe Ia) Spectrum

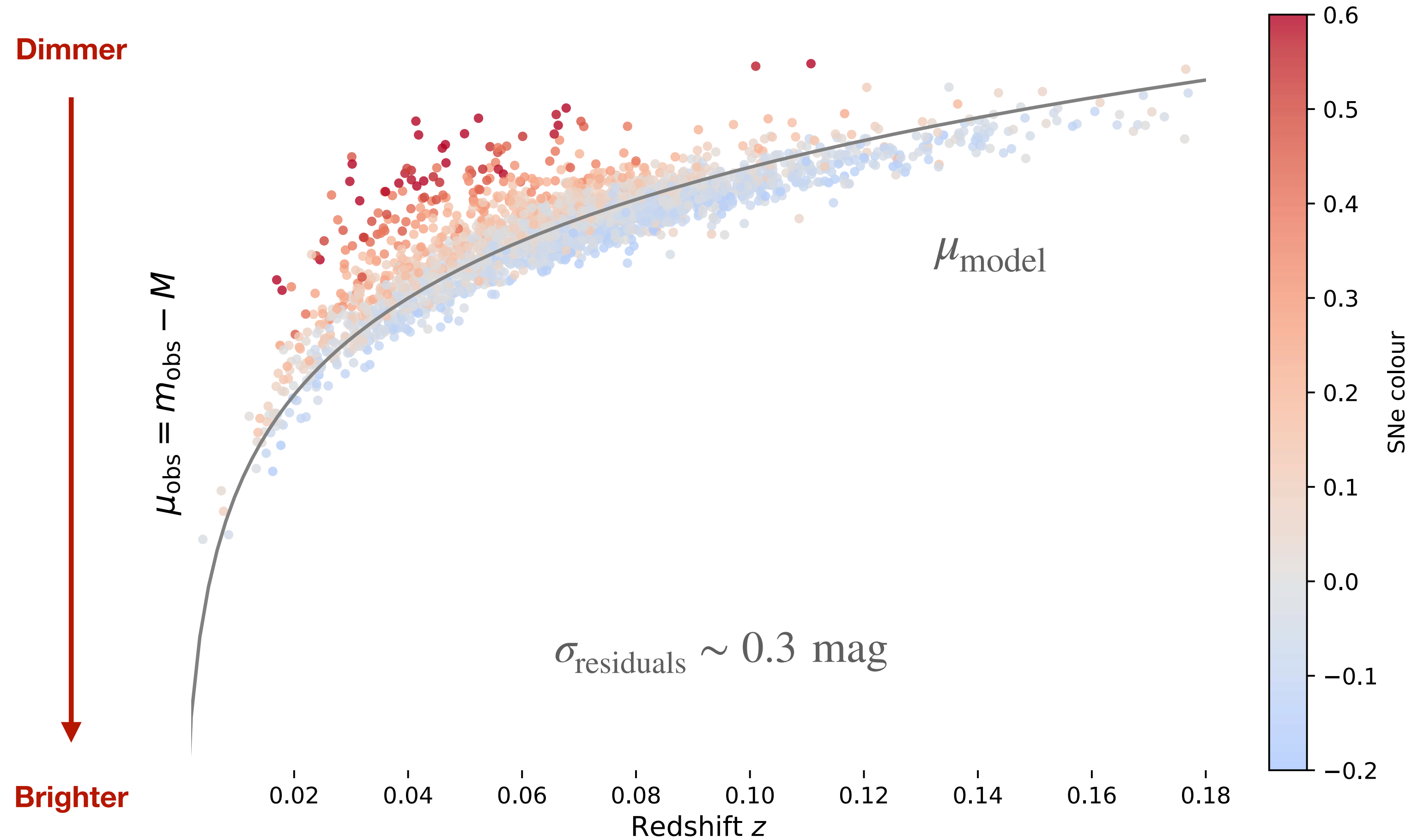
Spectroscopic
typing

Redshift
information



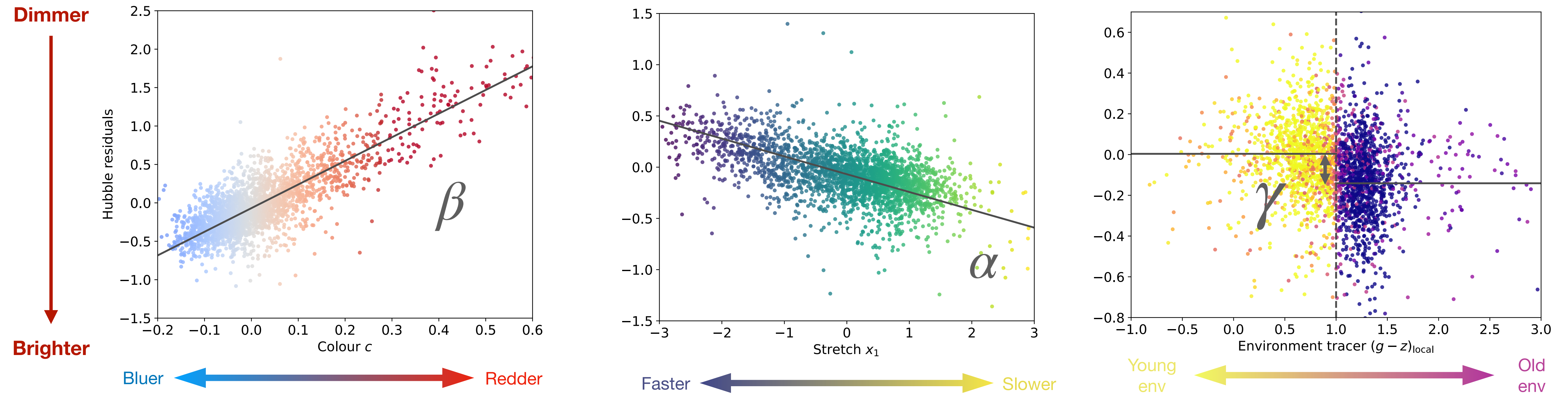
Cosmology with SNe Ia

Supernovae standardisation



Cosmology with SNe Ia

Standardisation



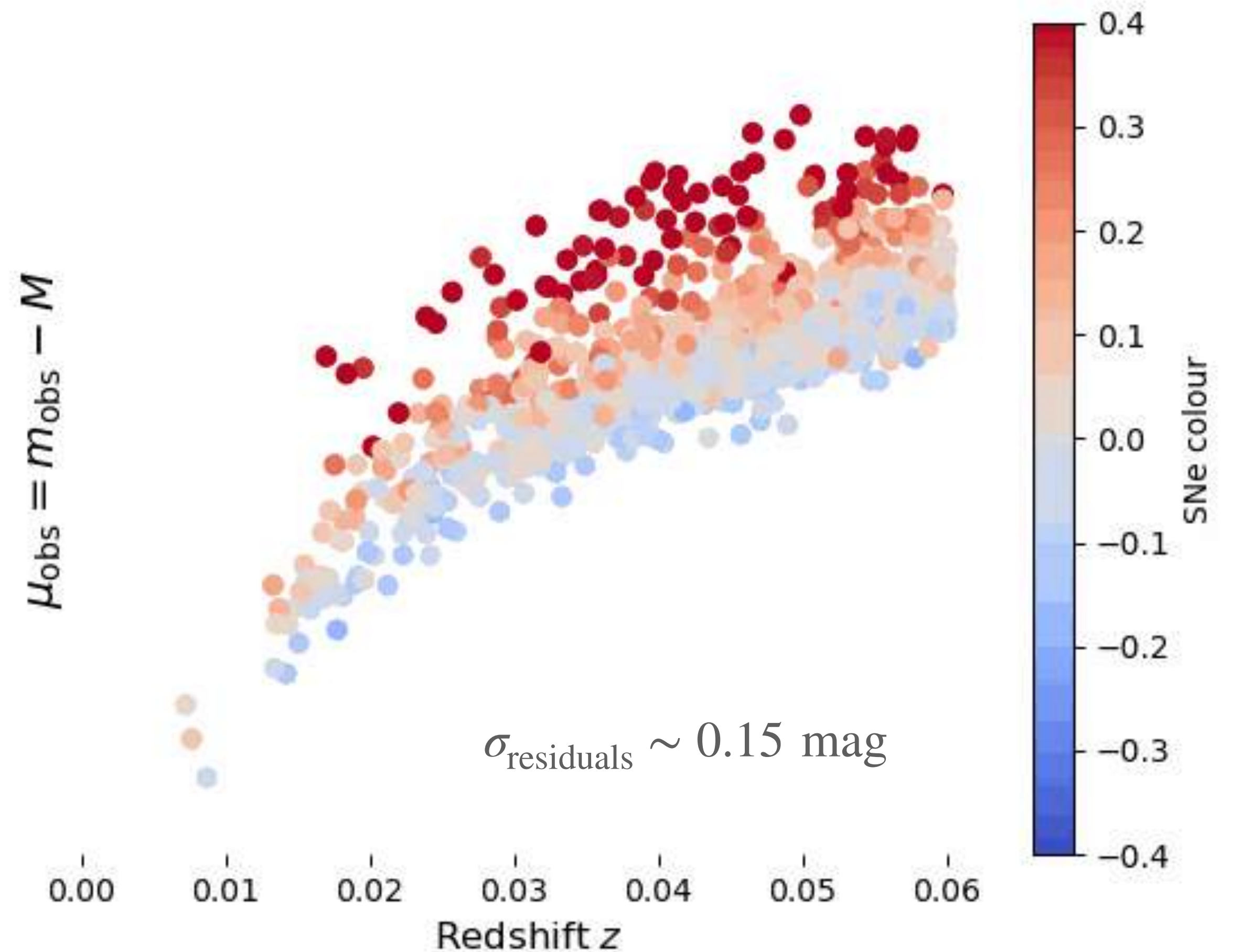
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Cosmology with SNe Ia

Standardisation

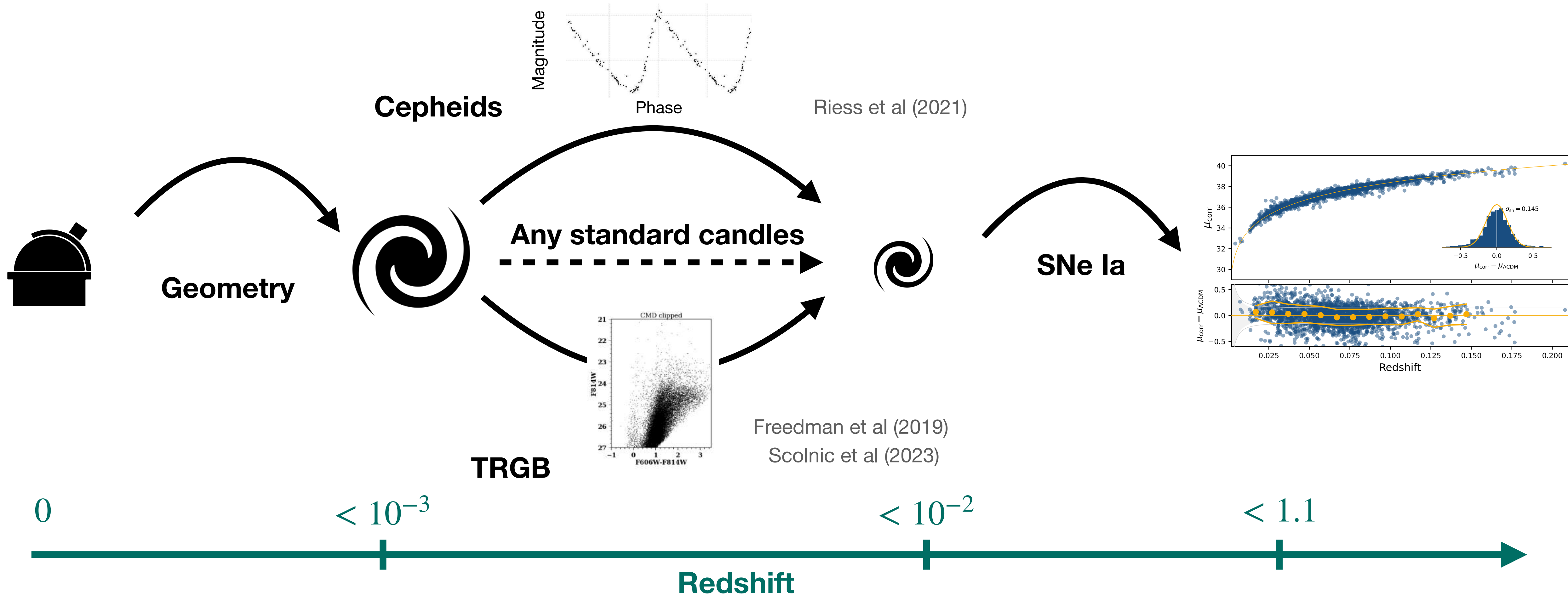
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

(Tripp 1998)

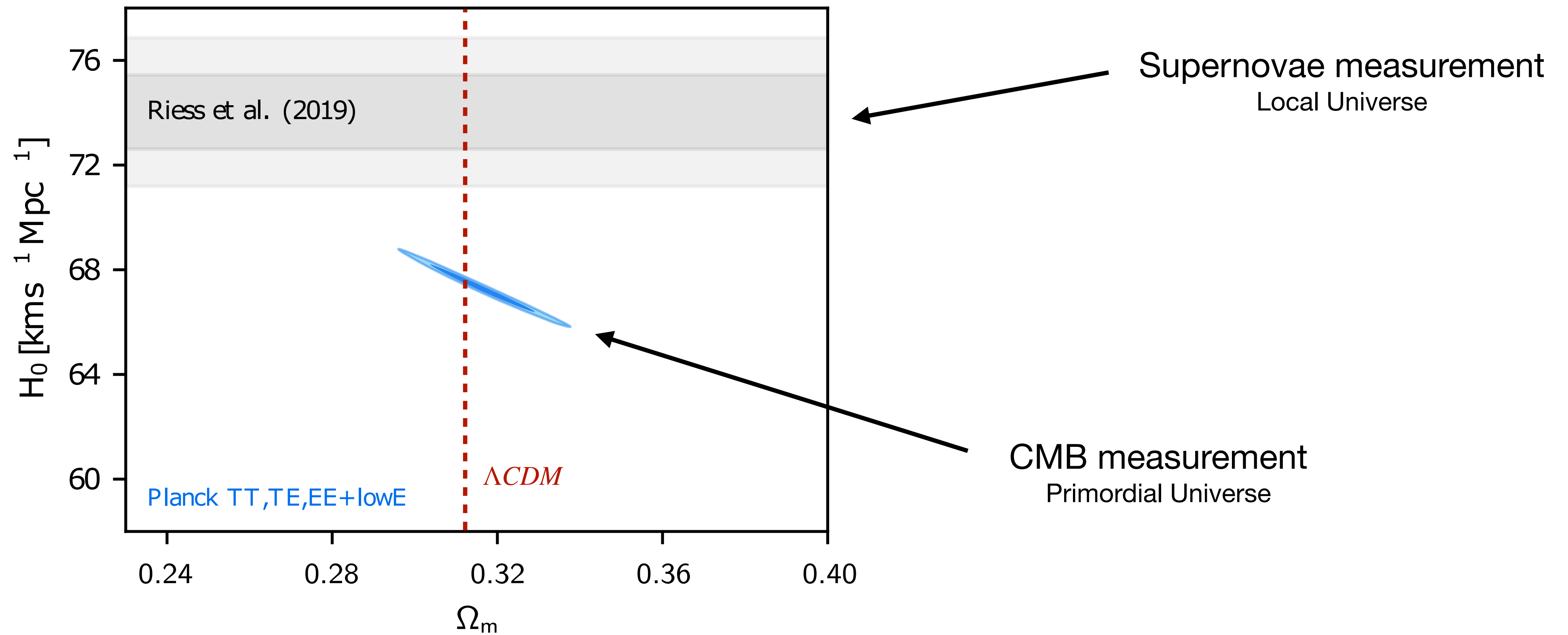


Cosmology with SNe Ia

Anchoring the Hubble diagram

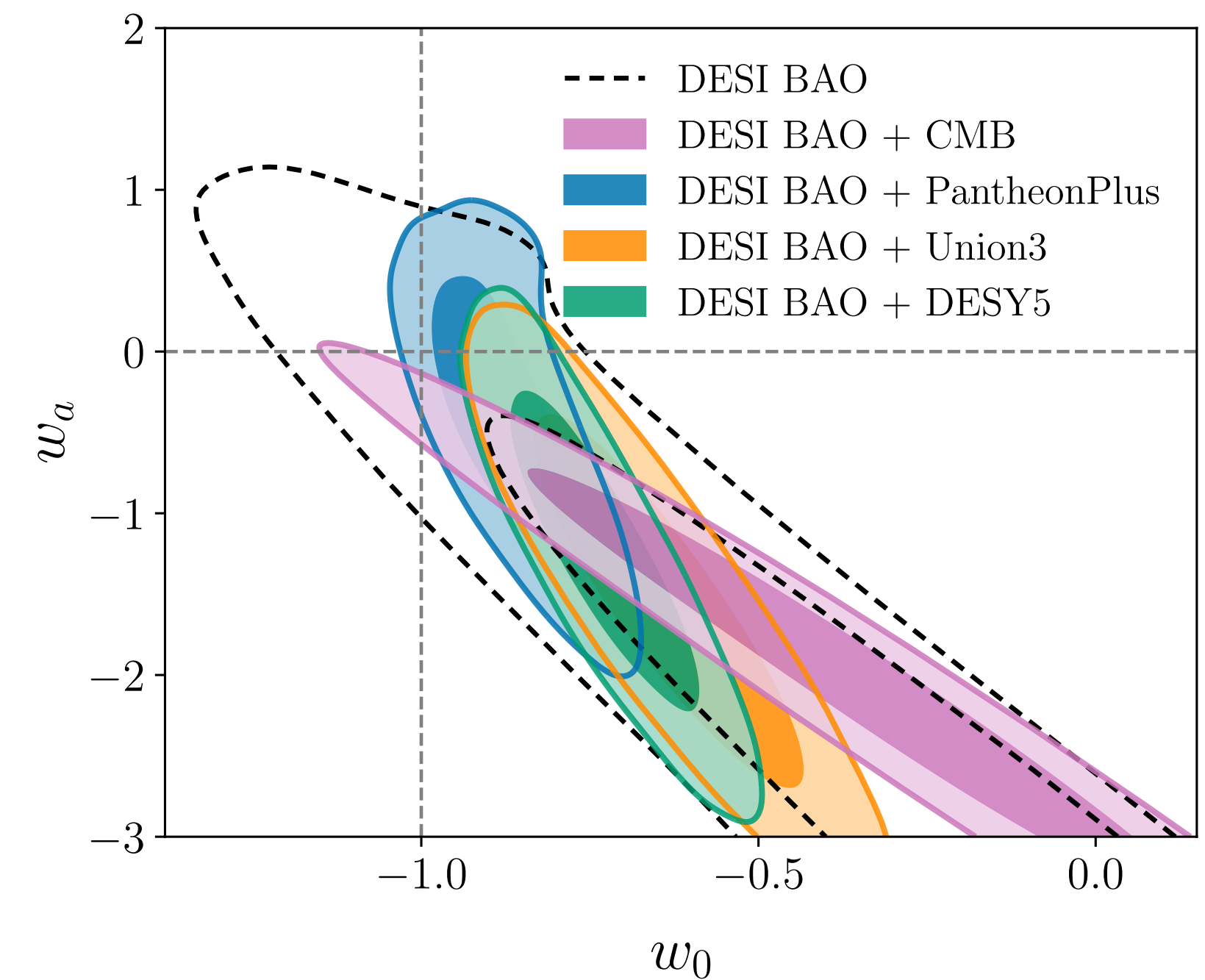
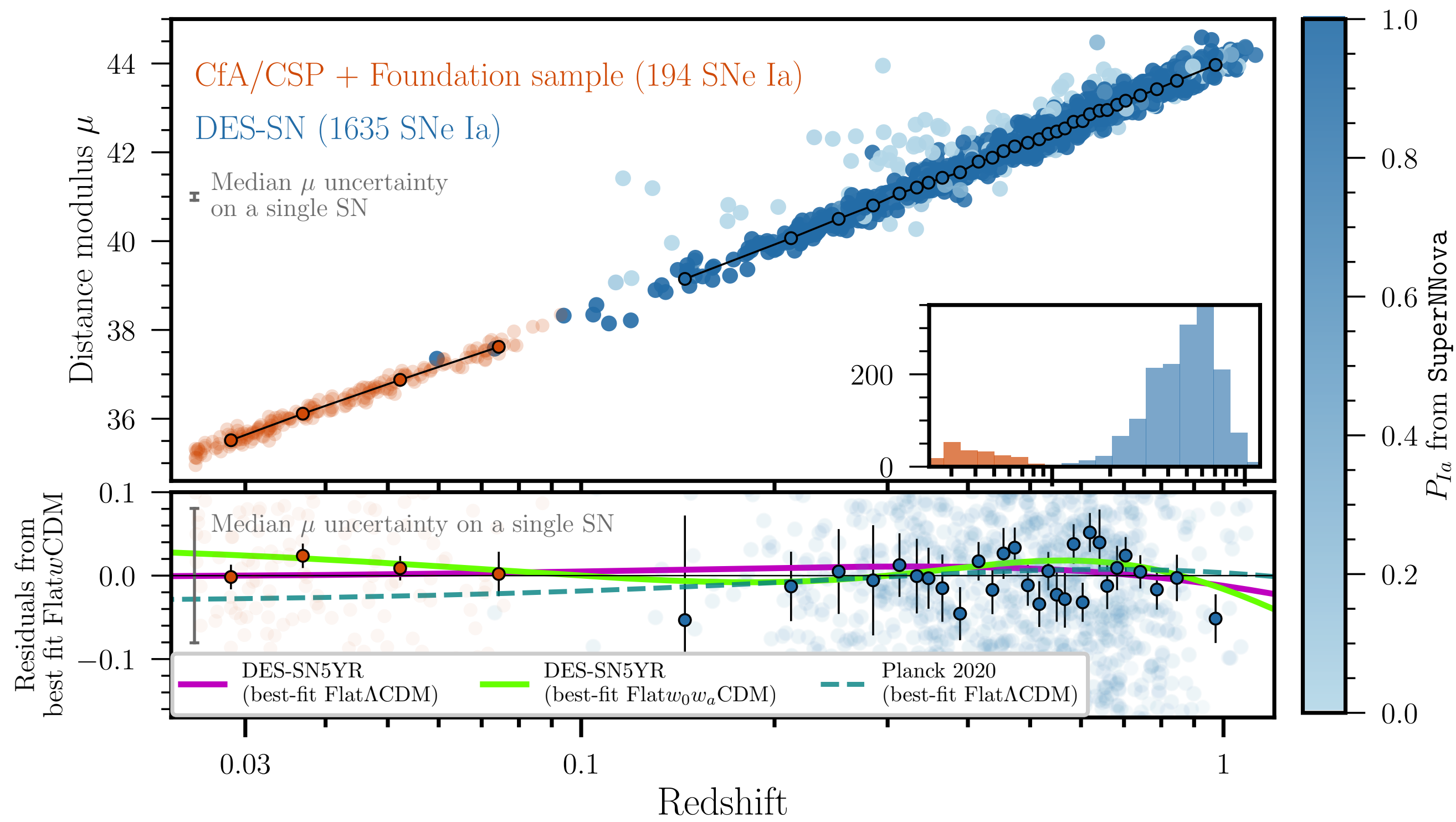


Hubble tension



Adapted from Planck collaboration (2020)

Evolving dark energy?



DESI 2024

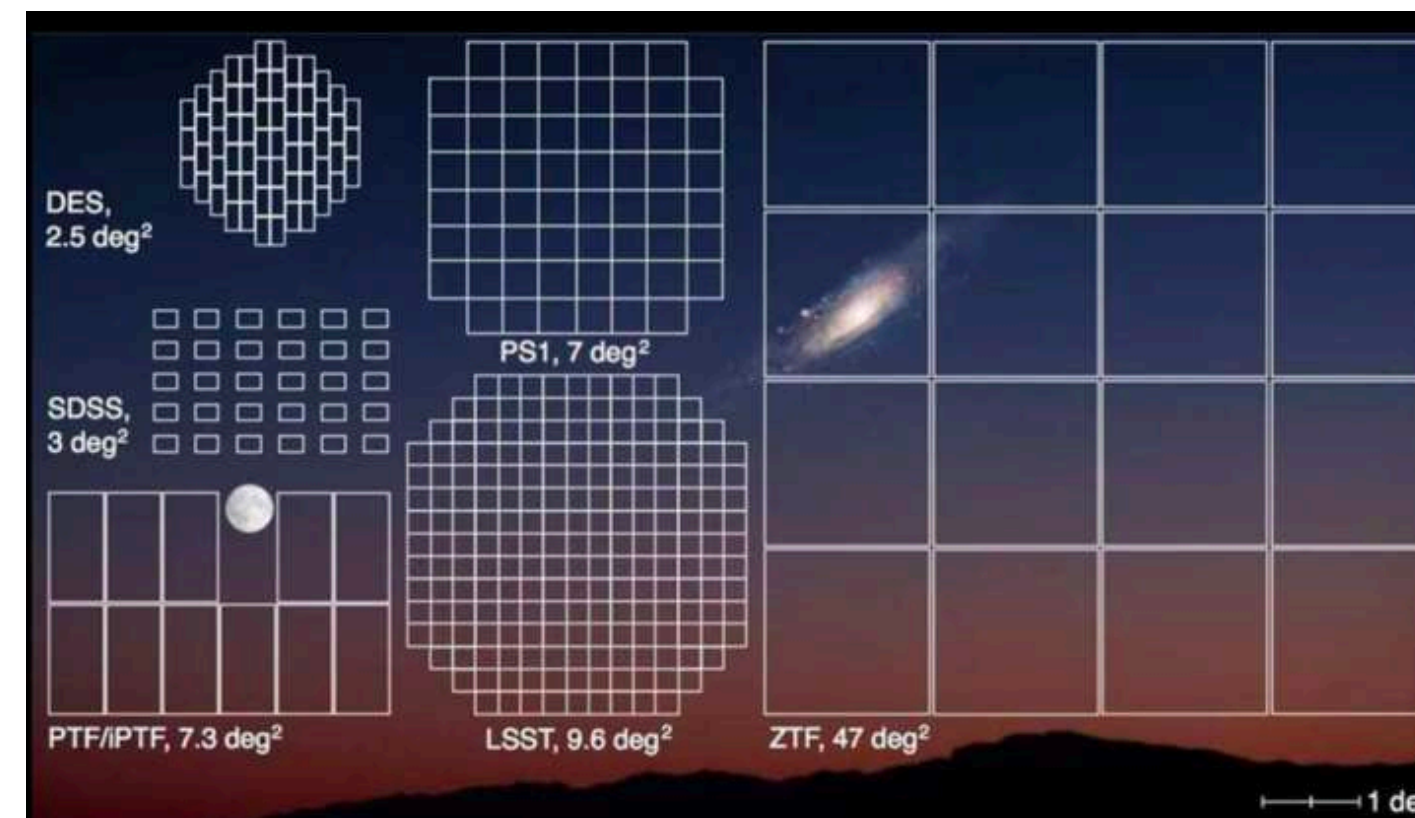
II. ZTF SN Ia DR2

ZTF



Zwicky Transient Facility

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

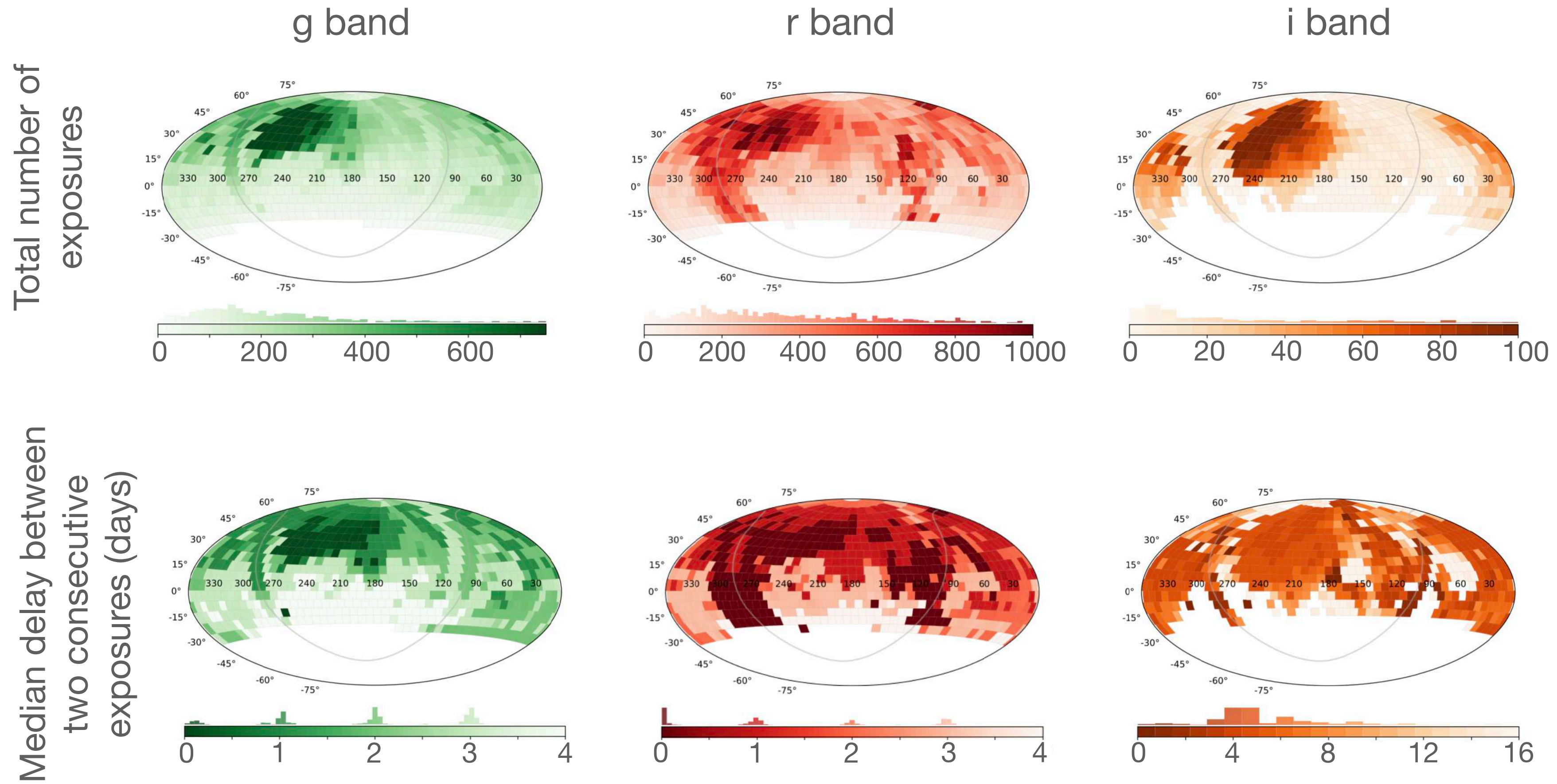


SEDmachine

Low resolution
~1h exposures

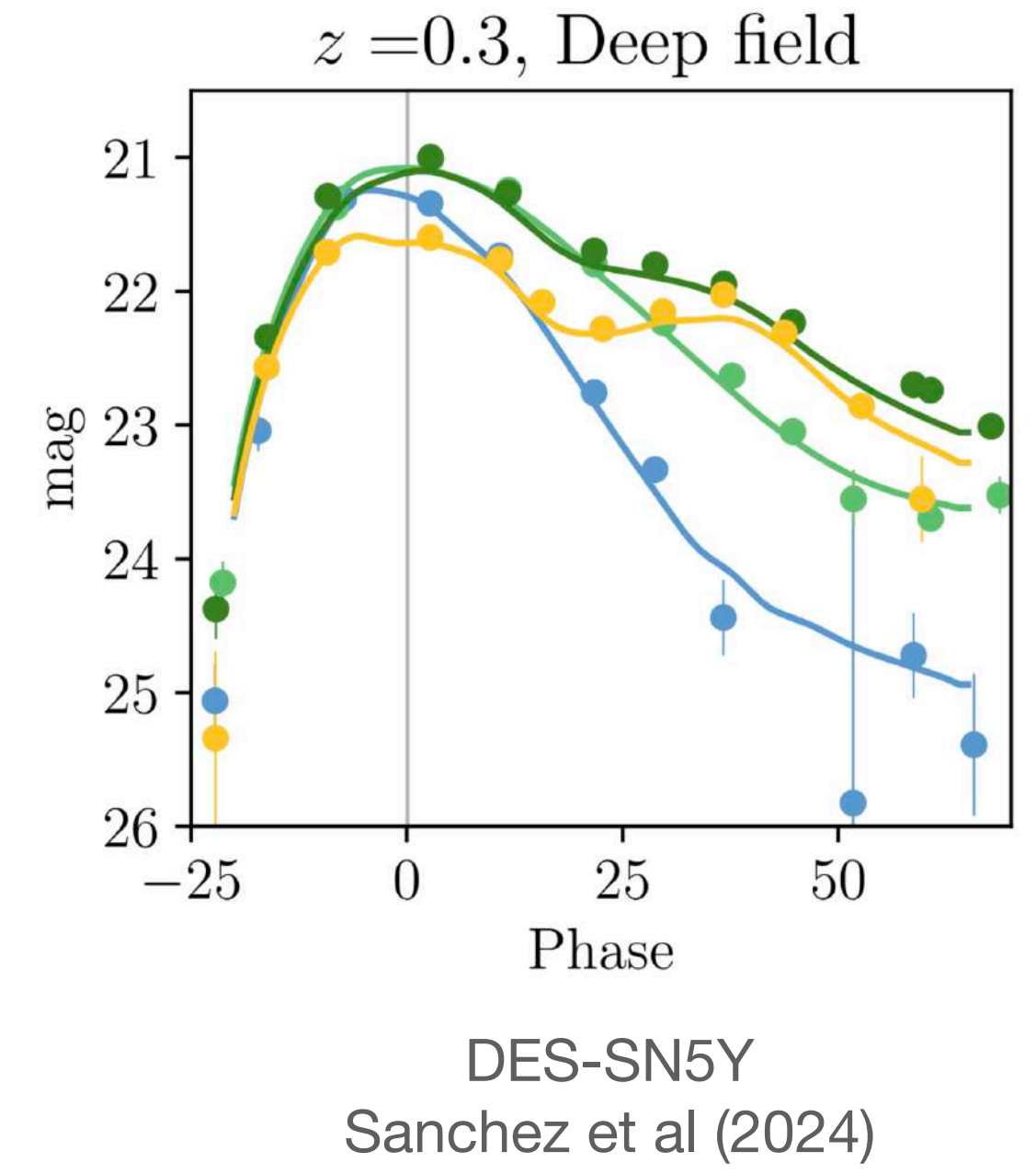
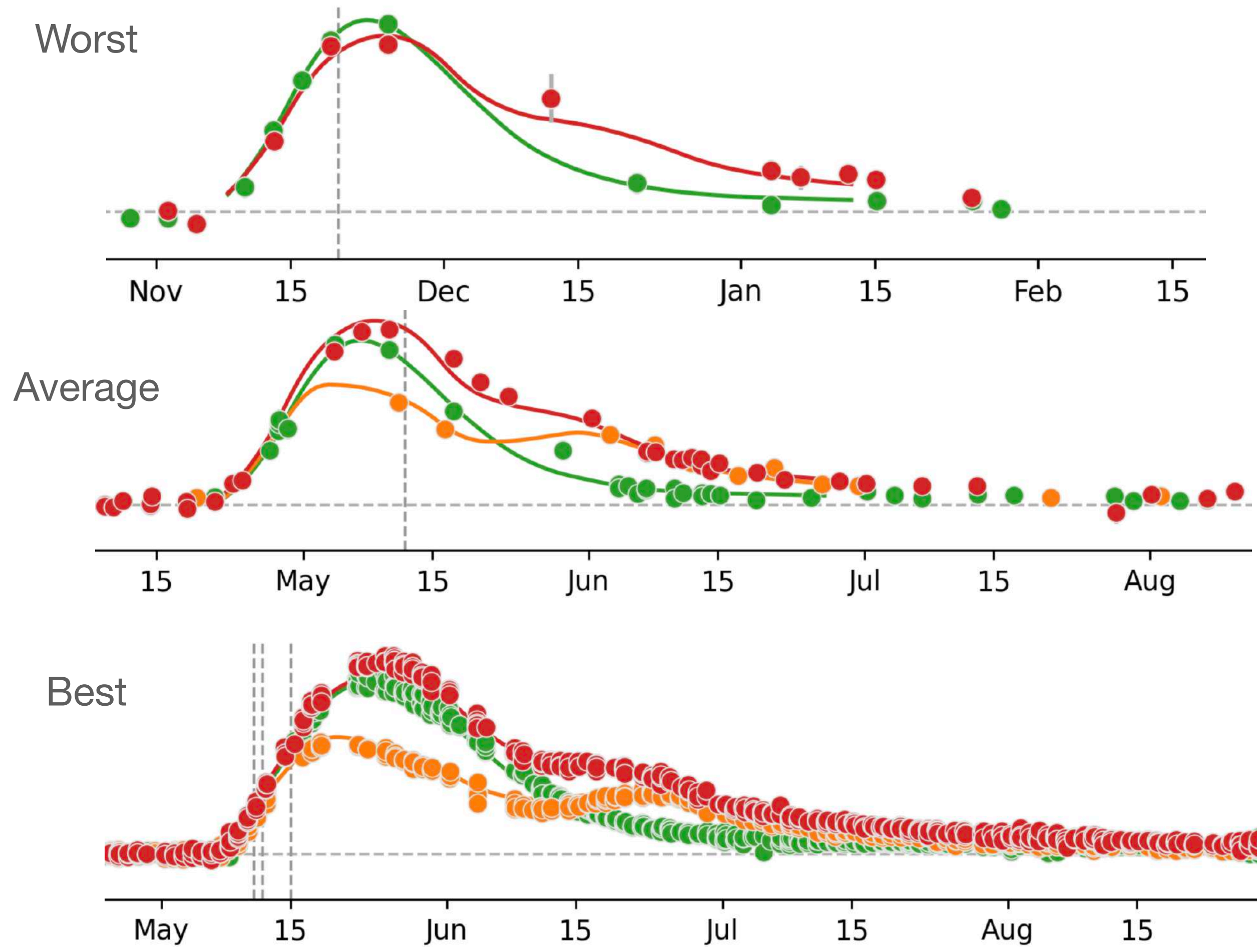
ZTF SN Ia DR2

Cadence



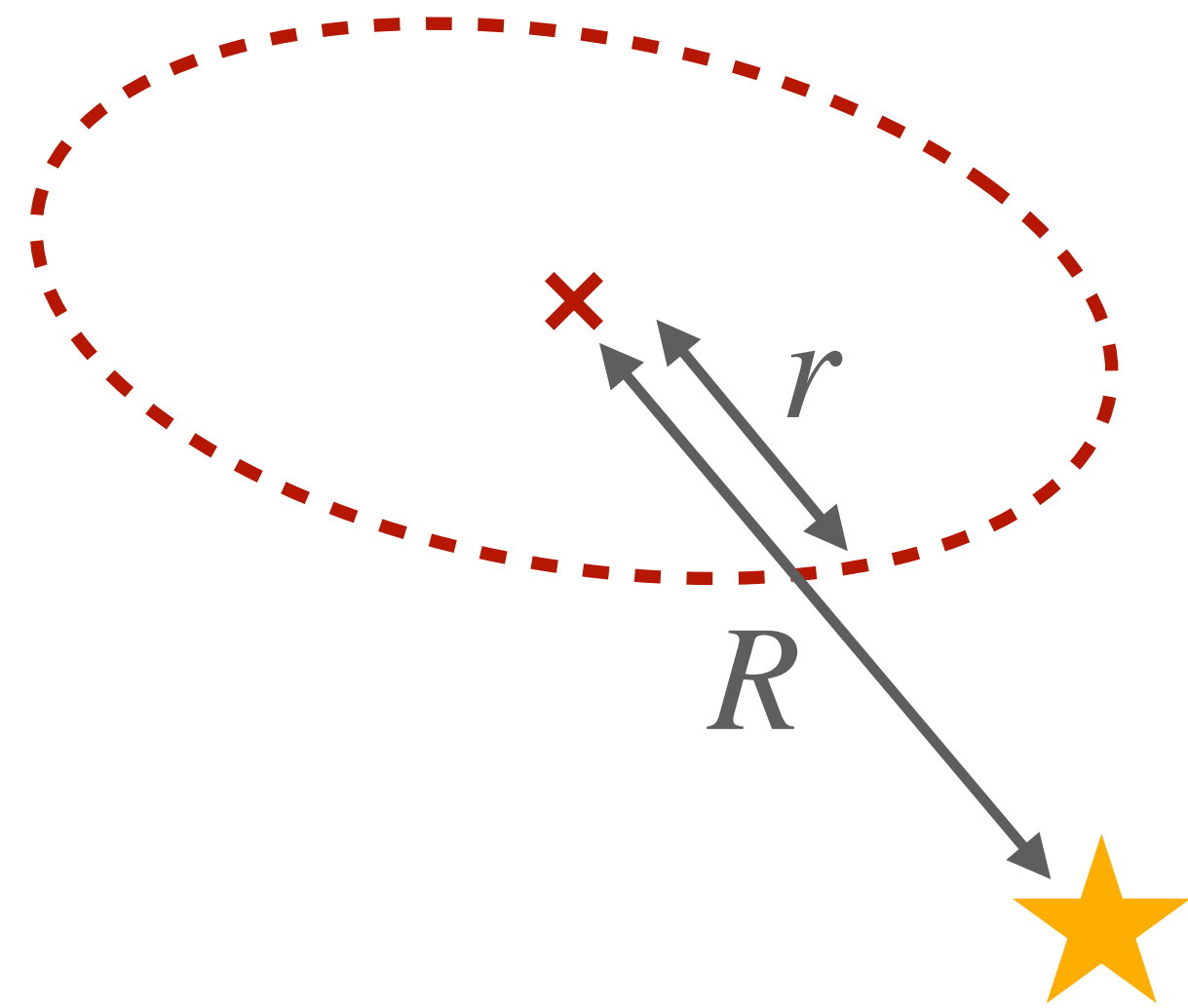
ZTF SN Ia DR2

Lightcurves



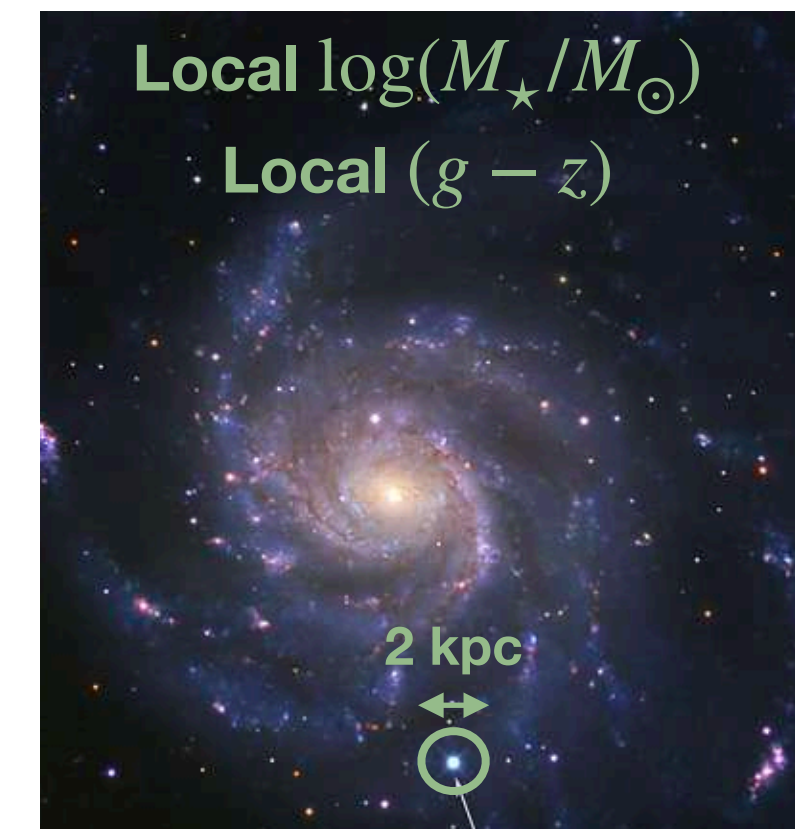
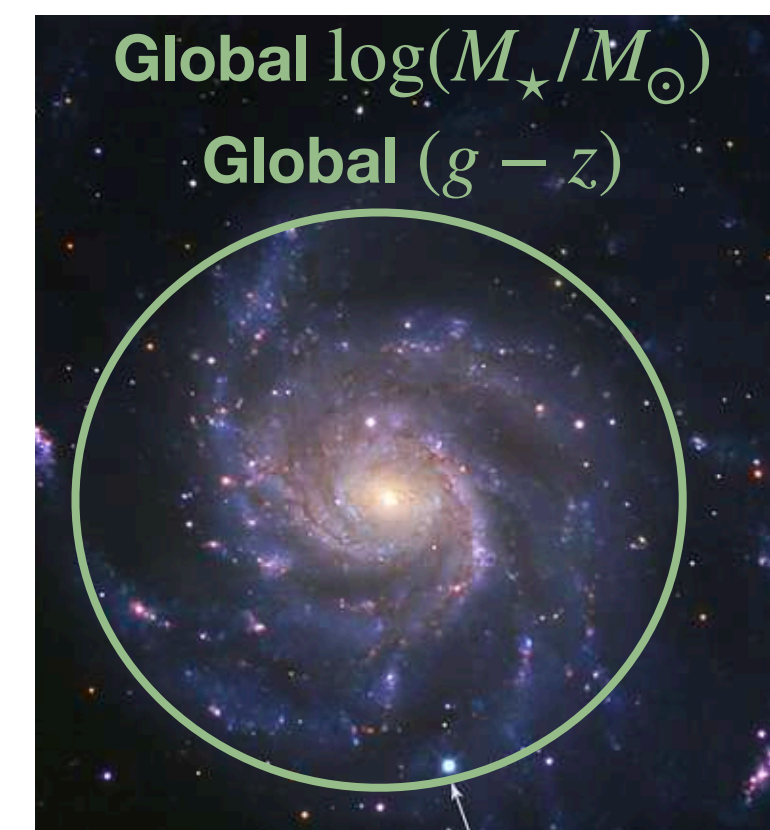
ZTF SN Ia DR2

Environmental properties

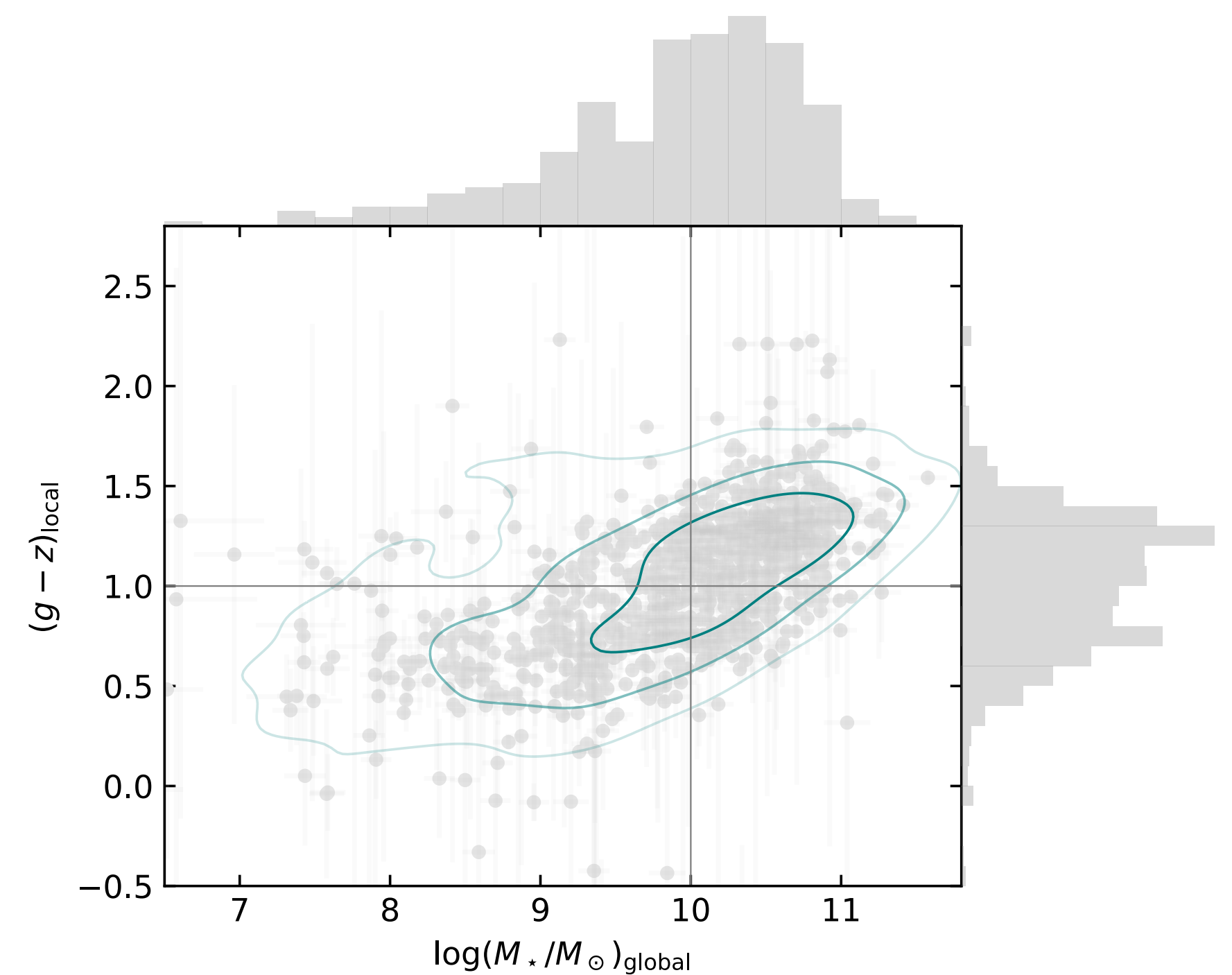


$$dDLR = \frac{R}{r}$$

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

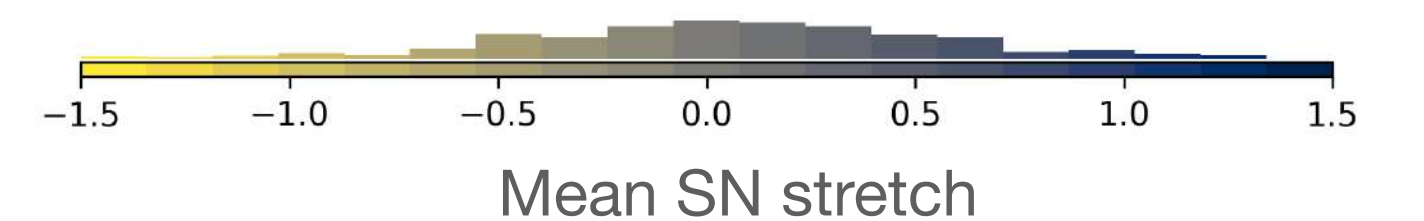
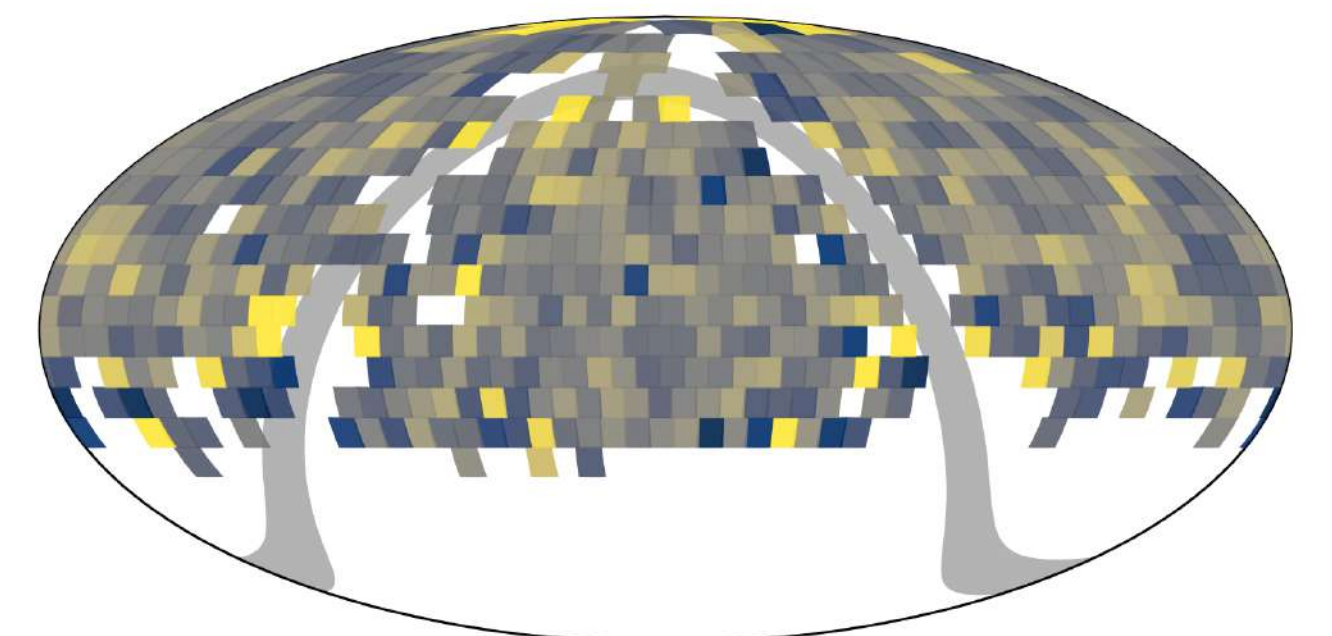
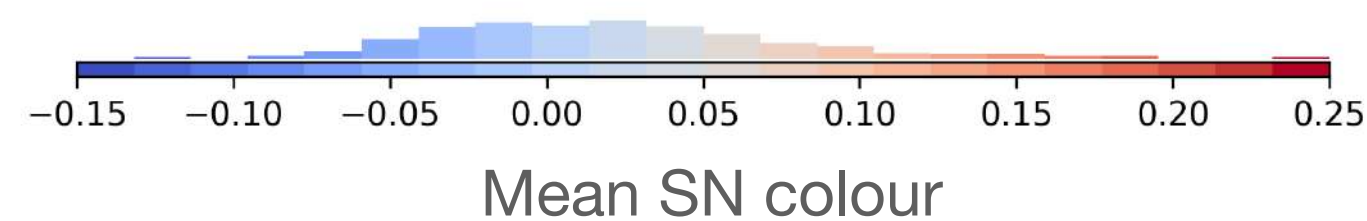
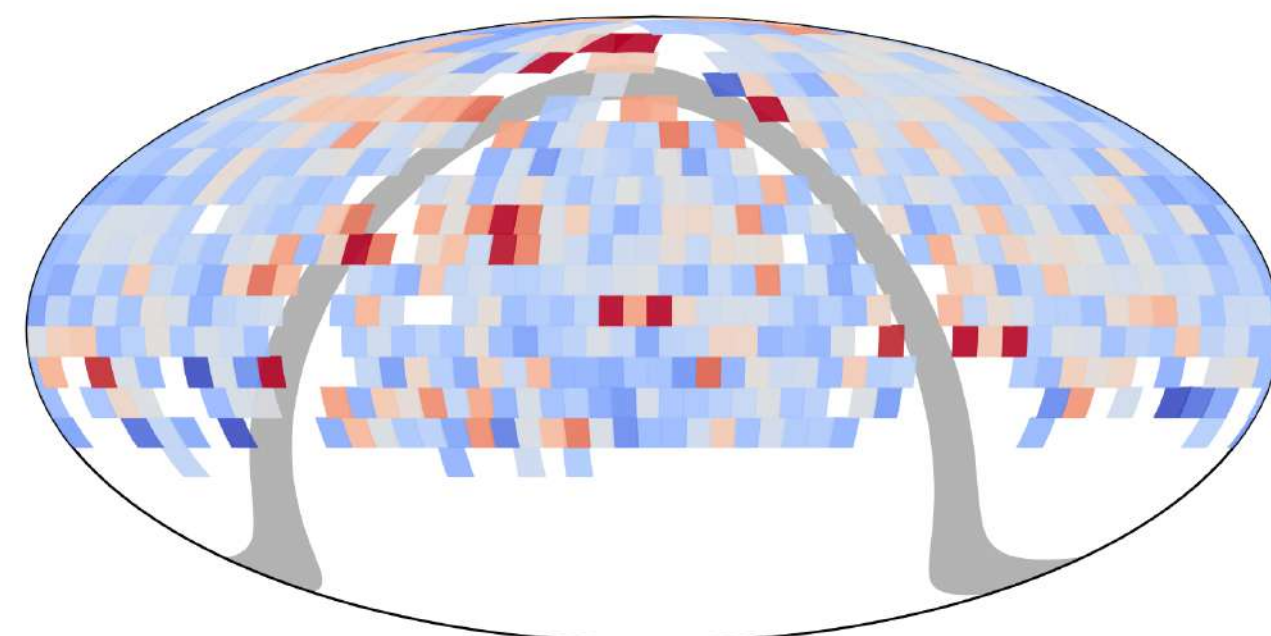
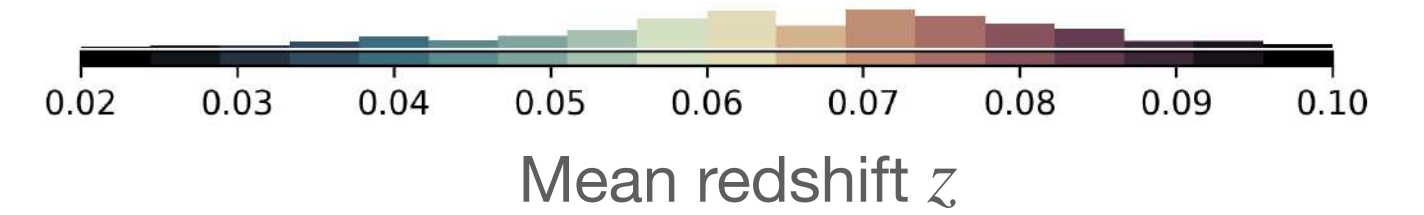
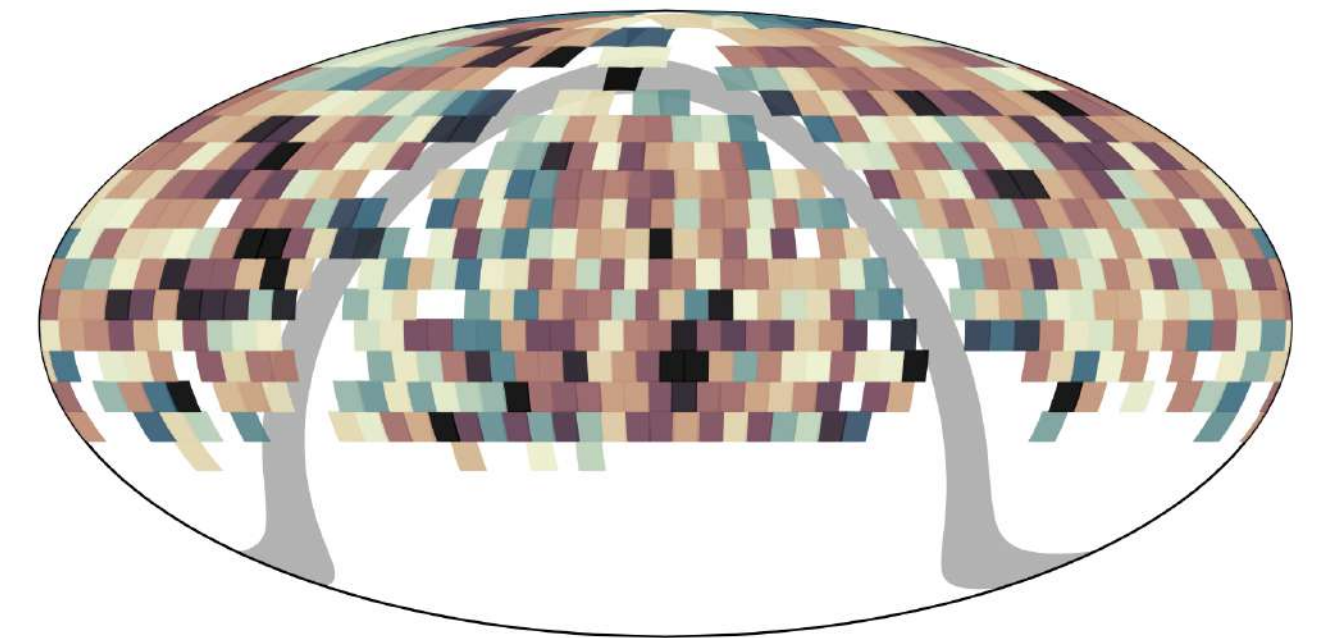
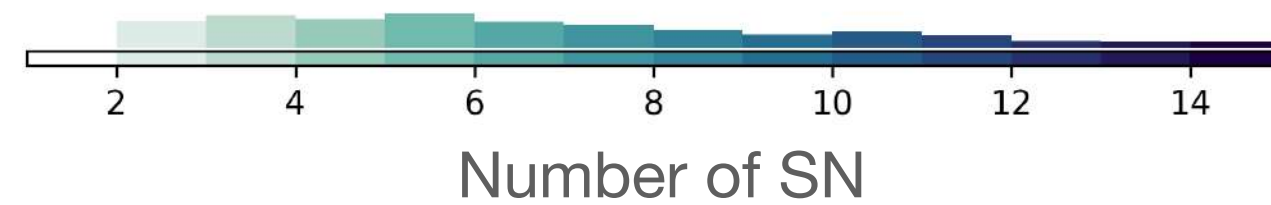
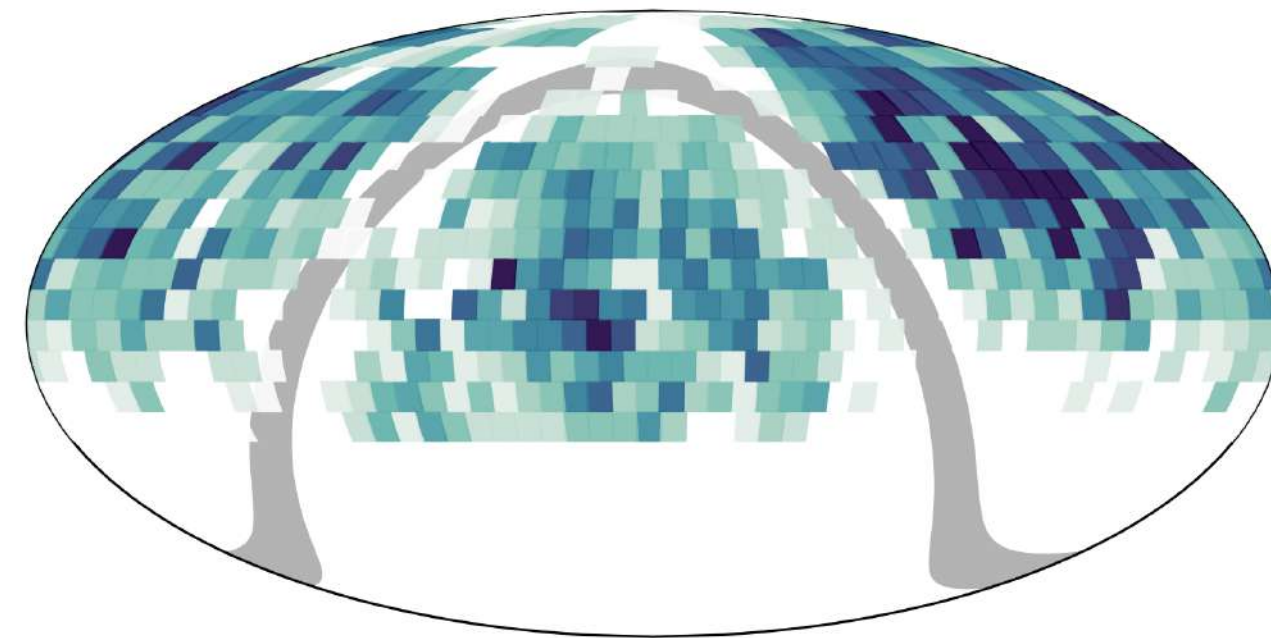
Confirmed SNe Ia

2977 SNe

with well-sampled lightcurves

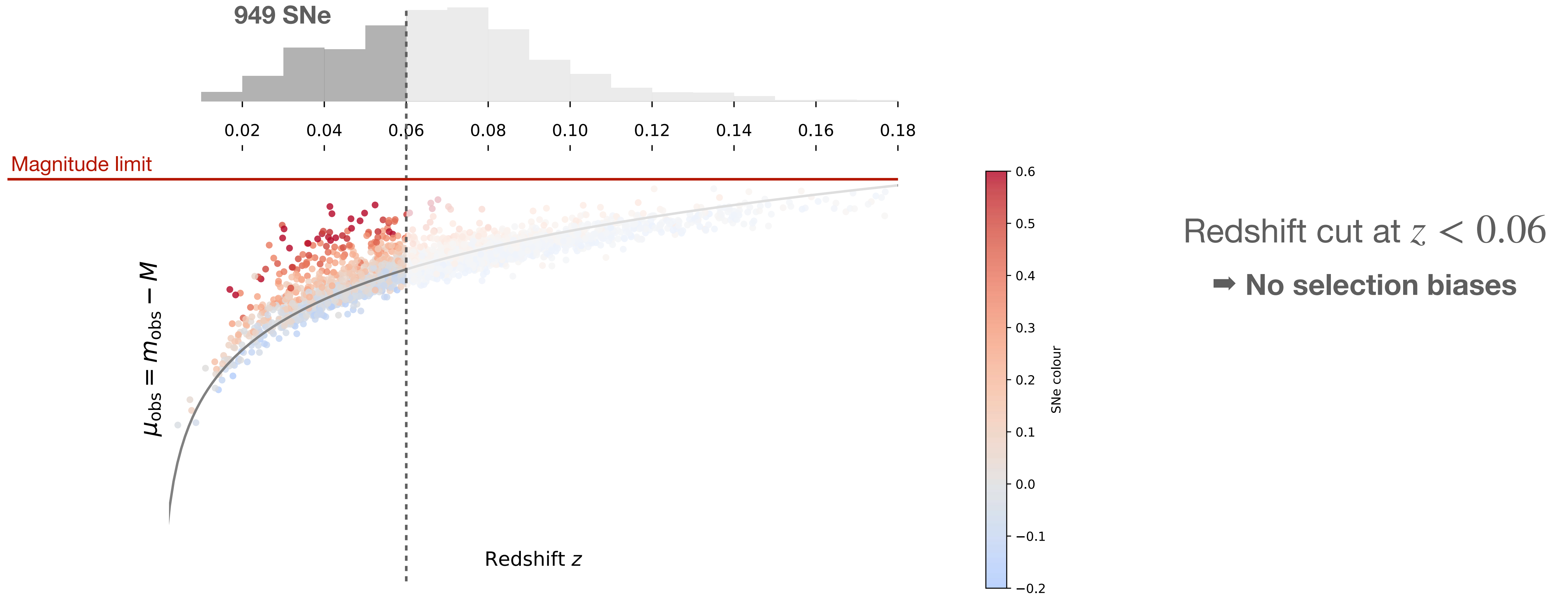
2628 SNe

usable for cosmology



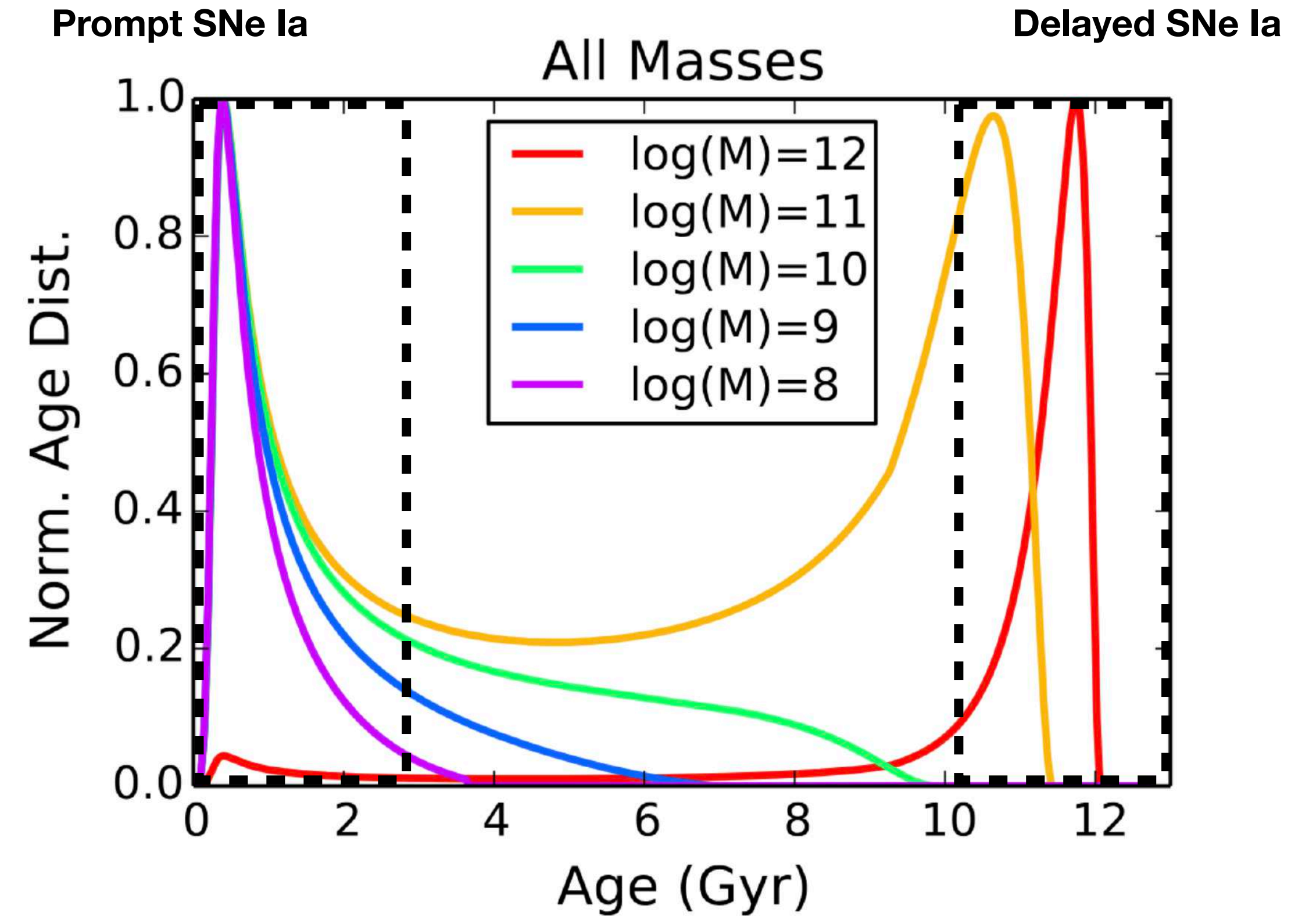
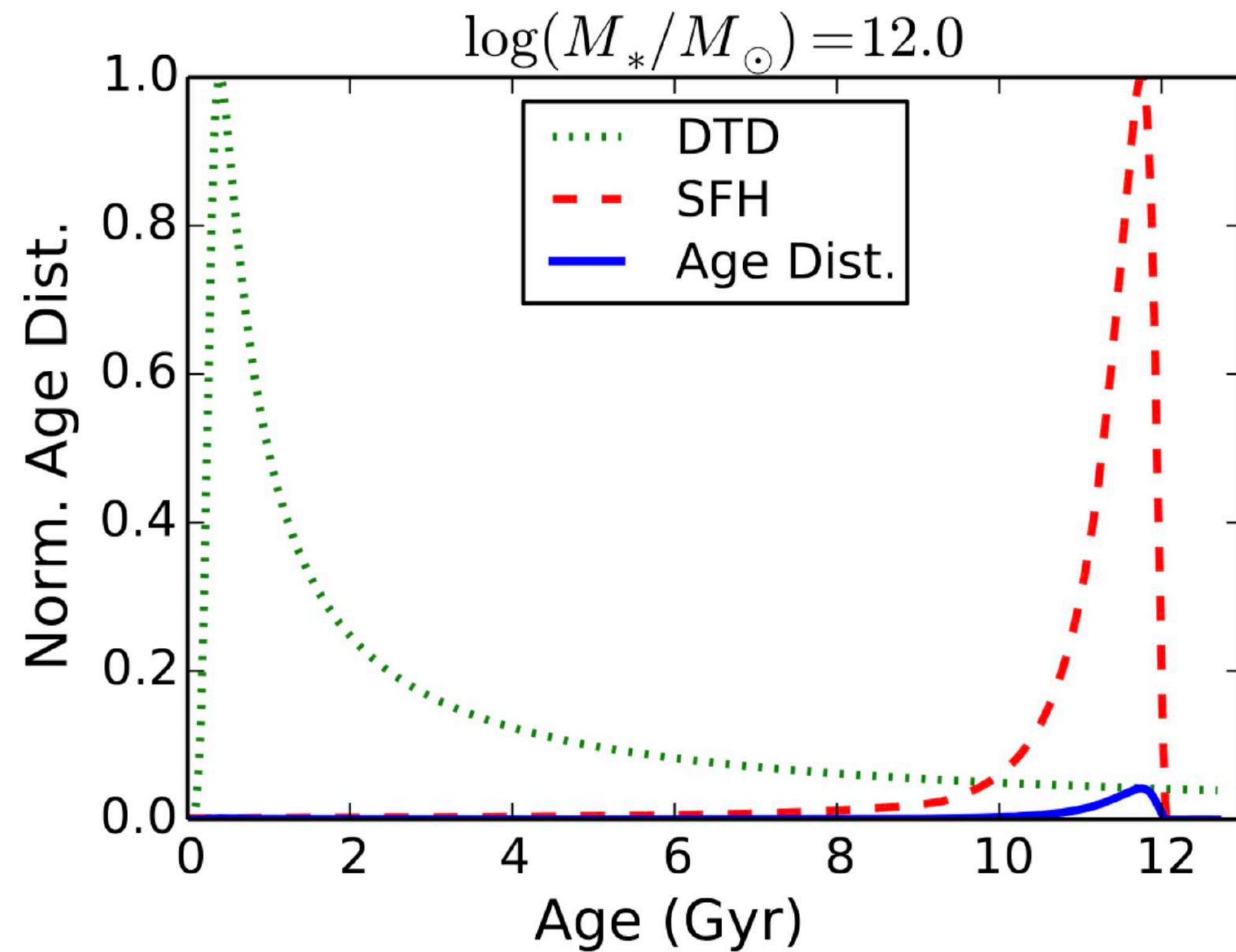
ZTF SN Ia DR2

Volume limited sample



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

Two population model



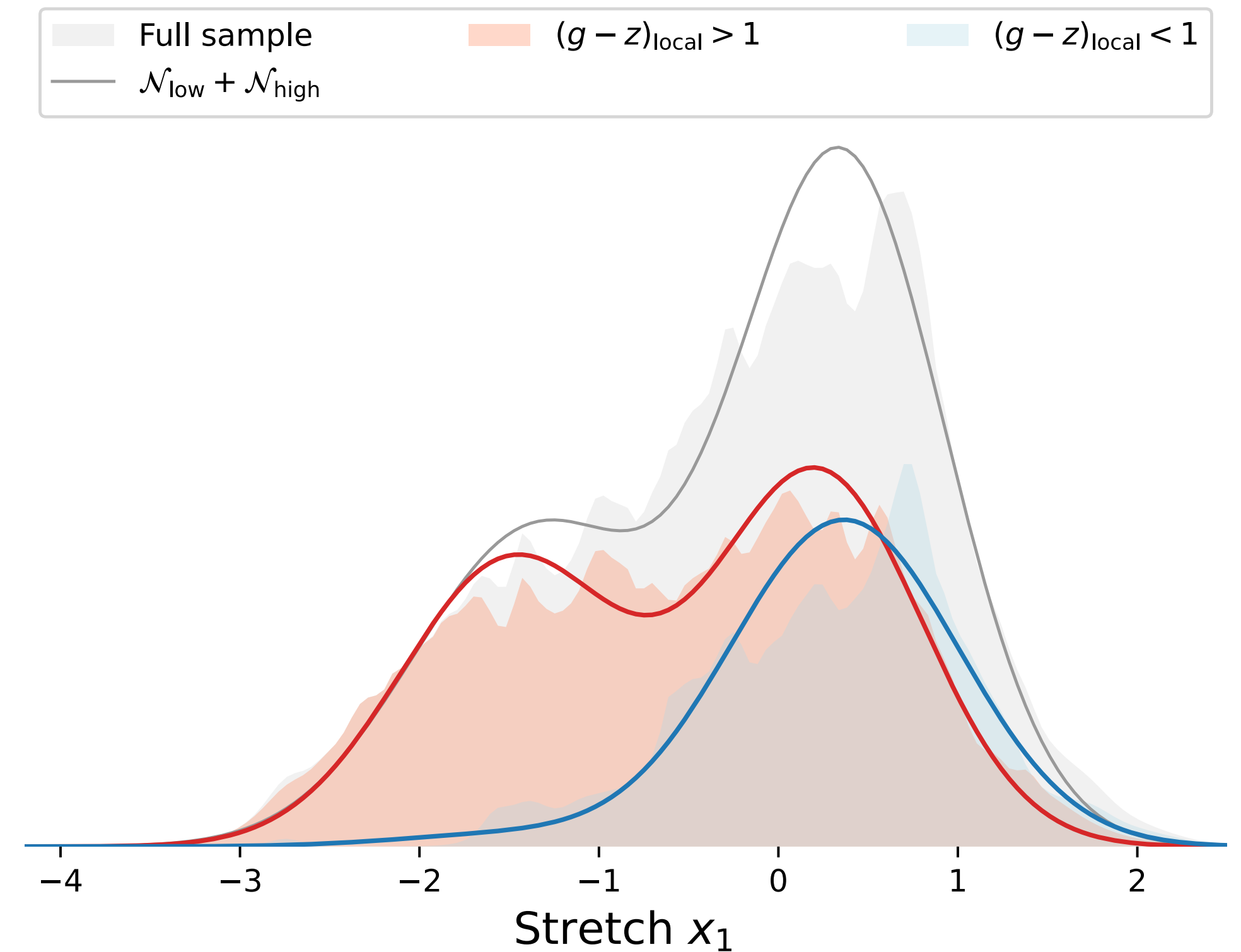
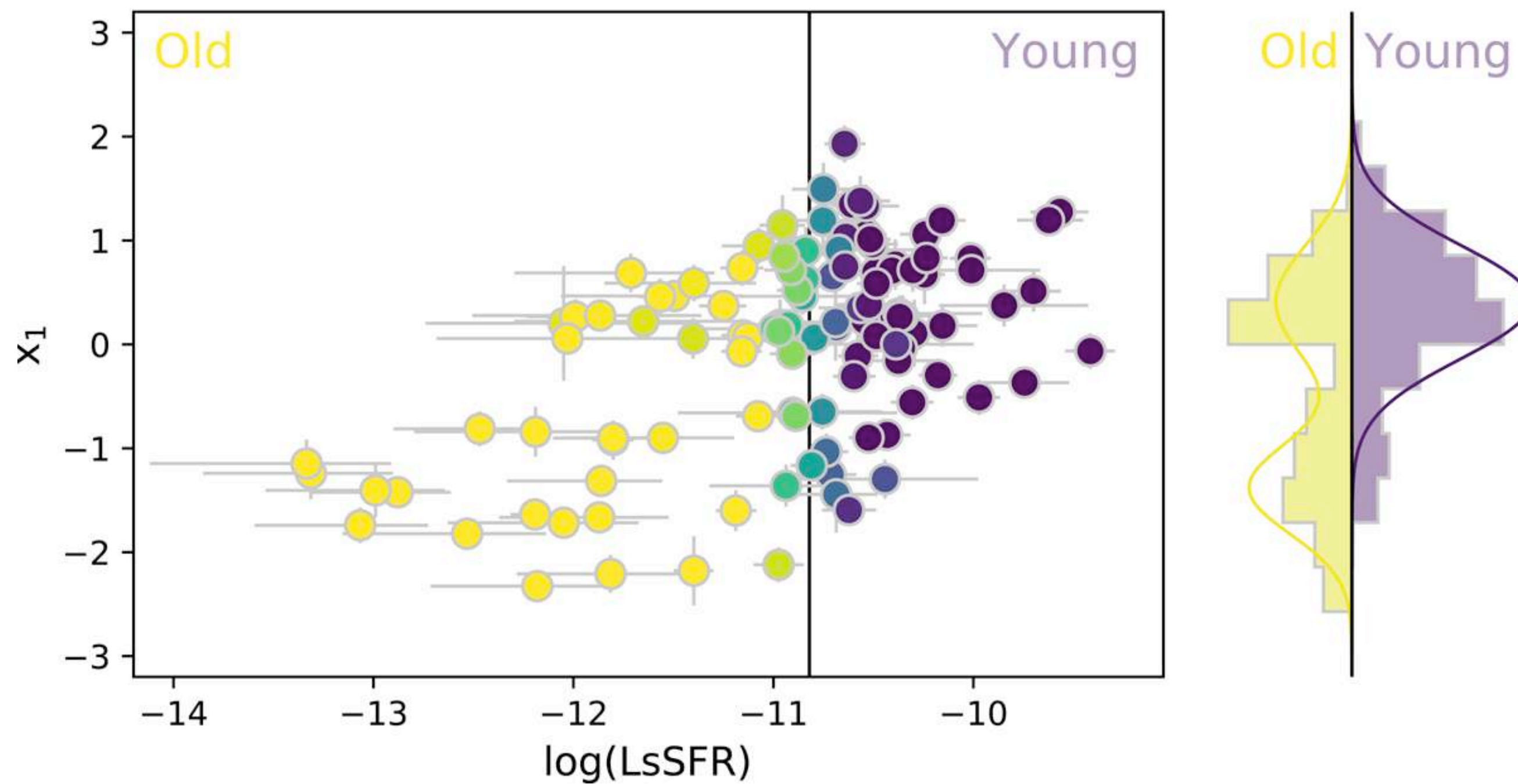
Childress et al (2014)

Mannucci et al (2005)

Stretch

Stretch distribution

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



Nicolas et al (2021)
SnFactory - 114 SNe

Stretch

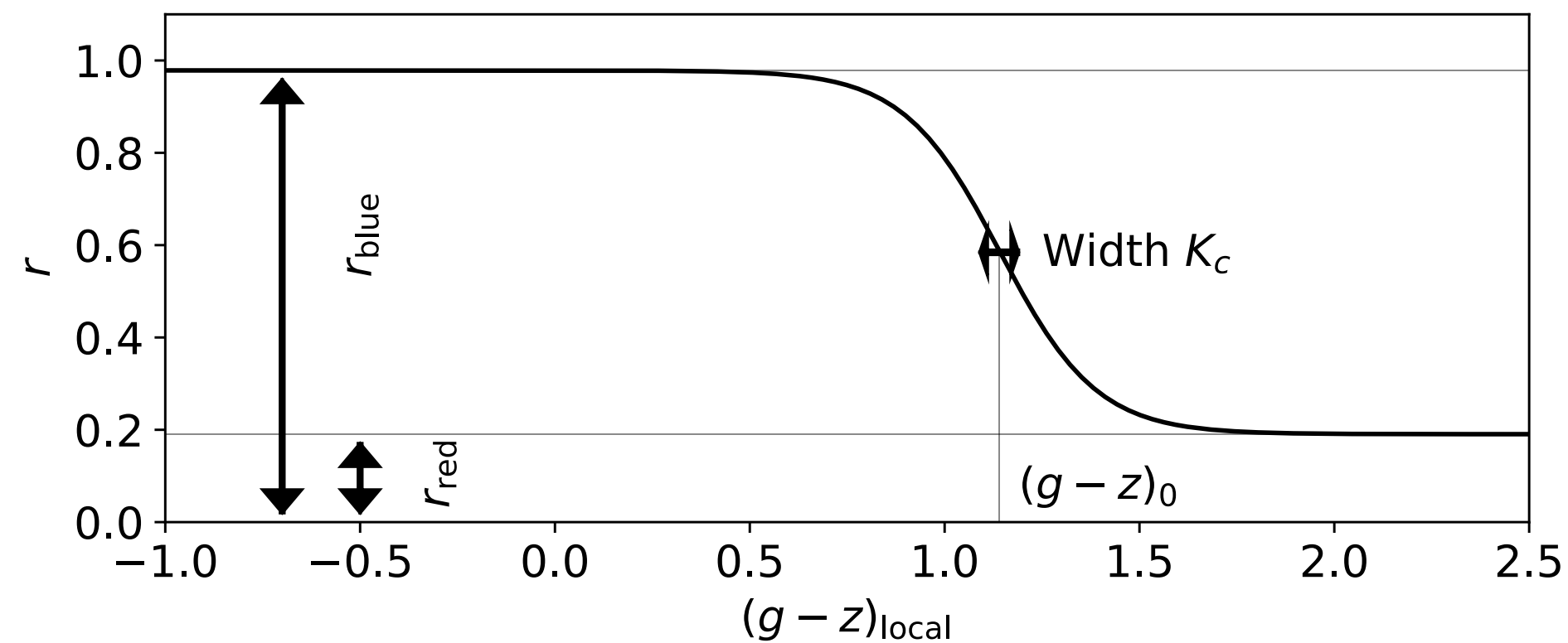
Dependence on environment

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

$$P(x_1 | c_{\text{env}}, M_{\text{env}}) = r(c_{\text{env}}) \mathcal{N}(x_1 | \overline{x_1^{\text{high}}}(M_{\text{env}}), \sigma_{\text{high}}^2) + (1 - r(c_{\text{env}})) \mathcal{N}(x_1 | \overline{x_1^{\text{low}}}(M_{\text{env}}), \sigma_{\text{low}}^2)$$

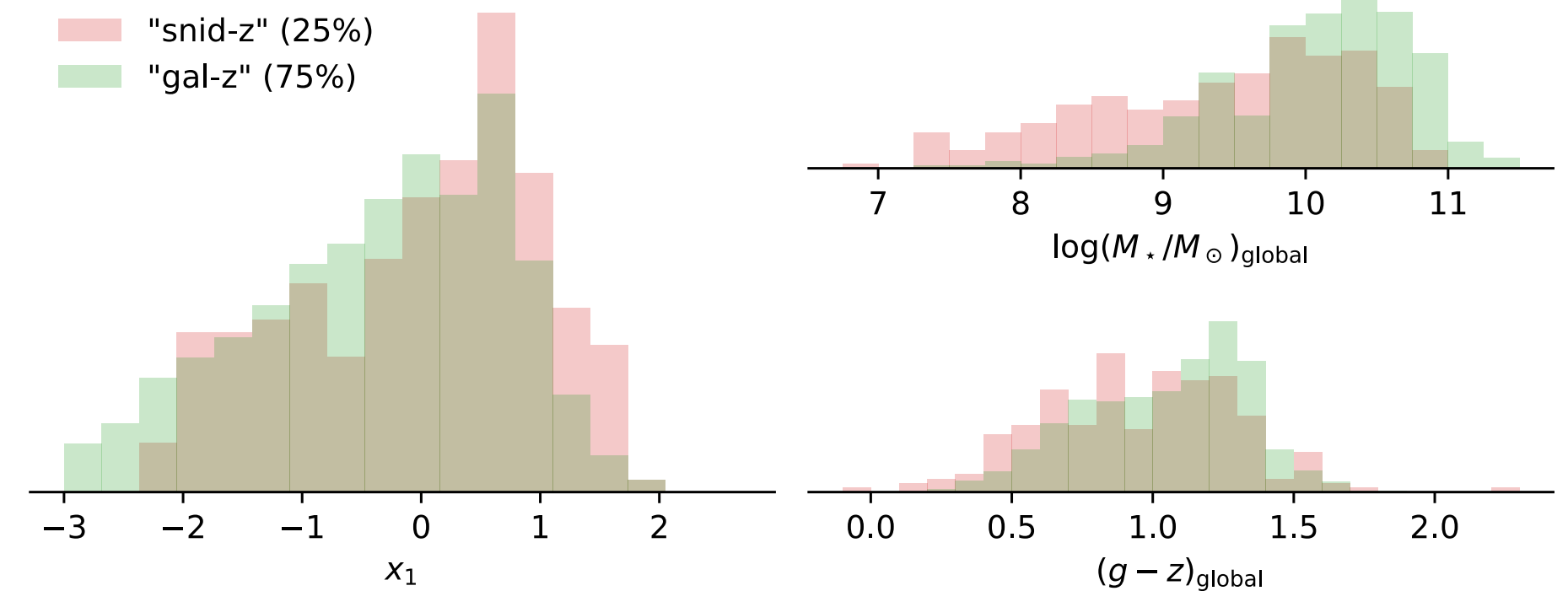
1. Smooth evolution of the fraction of low/high stretch modes with local colour

$$r(c_{\text{env}}) = r_{\text{red}} + (r_{\text{blue}} - r_{\text{red}}) \times \mathcal{S}\left(\frac{1}{K_c} [c_{\text{env}} - c_{\text{env}}^0]\right)$$



2. Dependence of the mean of the stretch with global mass

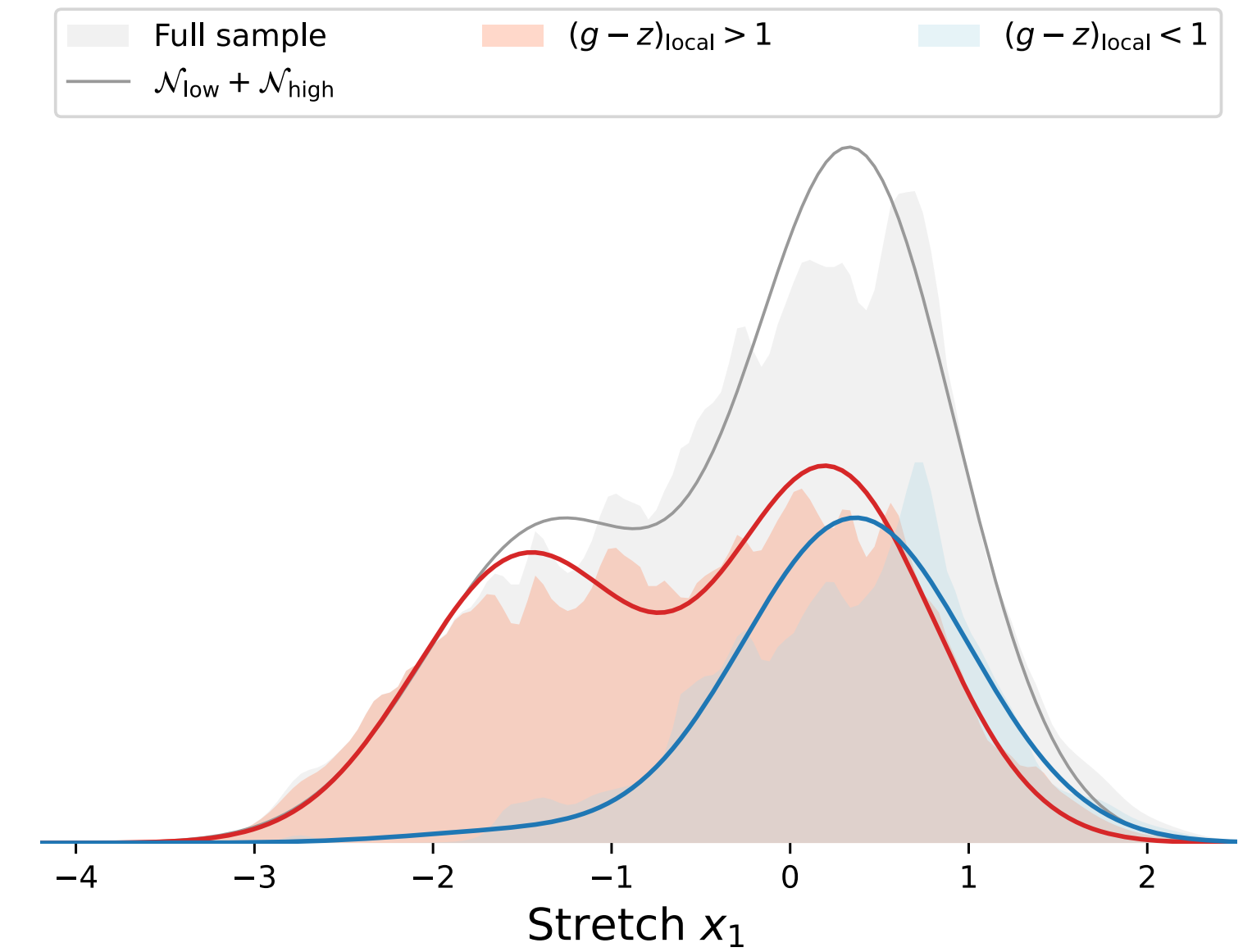
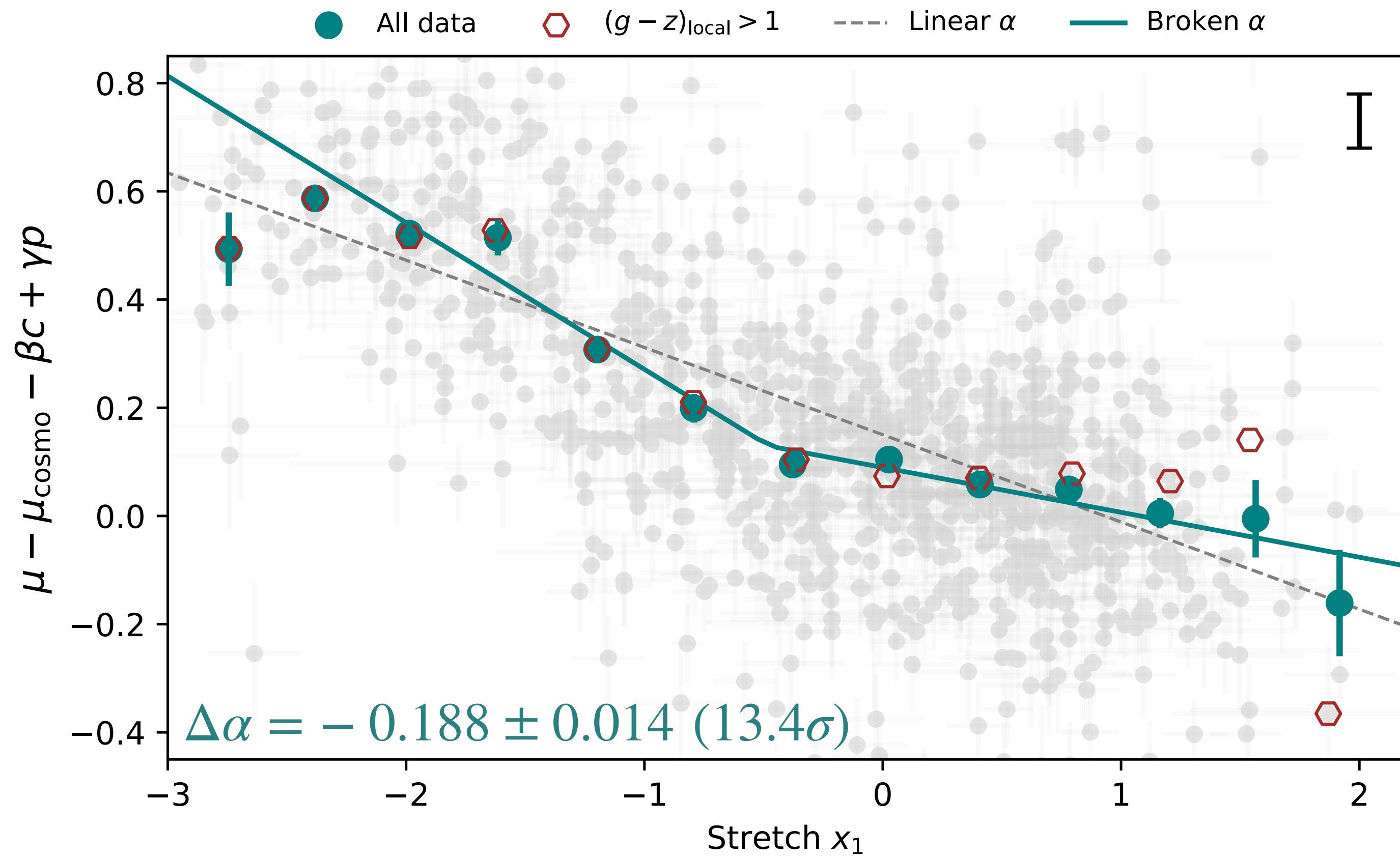
$$\overline{x_1^{\text{high/low}}}(M_{\text{env}}) = K_M \times (M_{\text{env}} - 10) + \overline{x_1^{\text{high/low},0}}$$



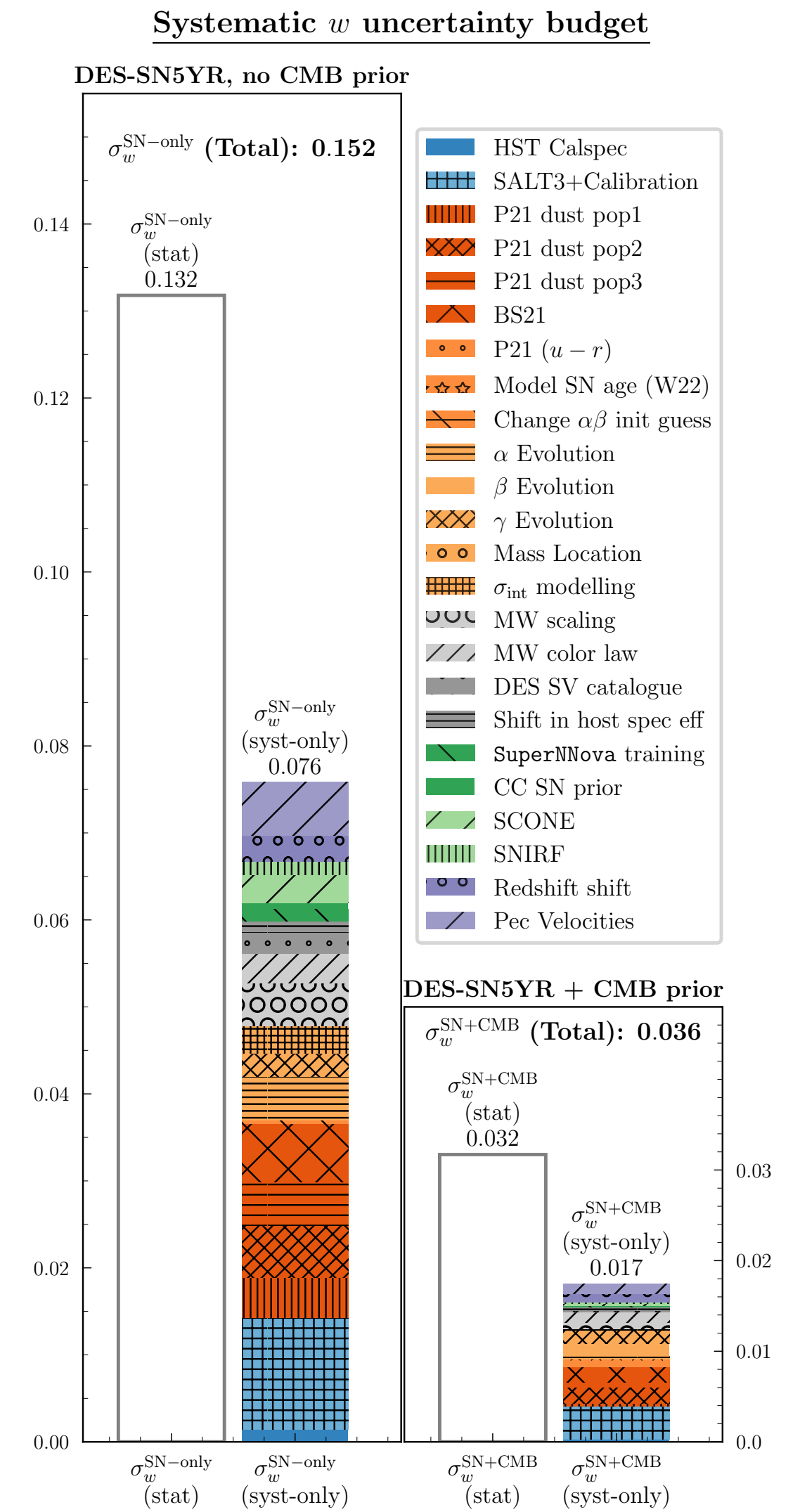
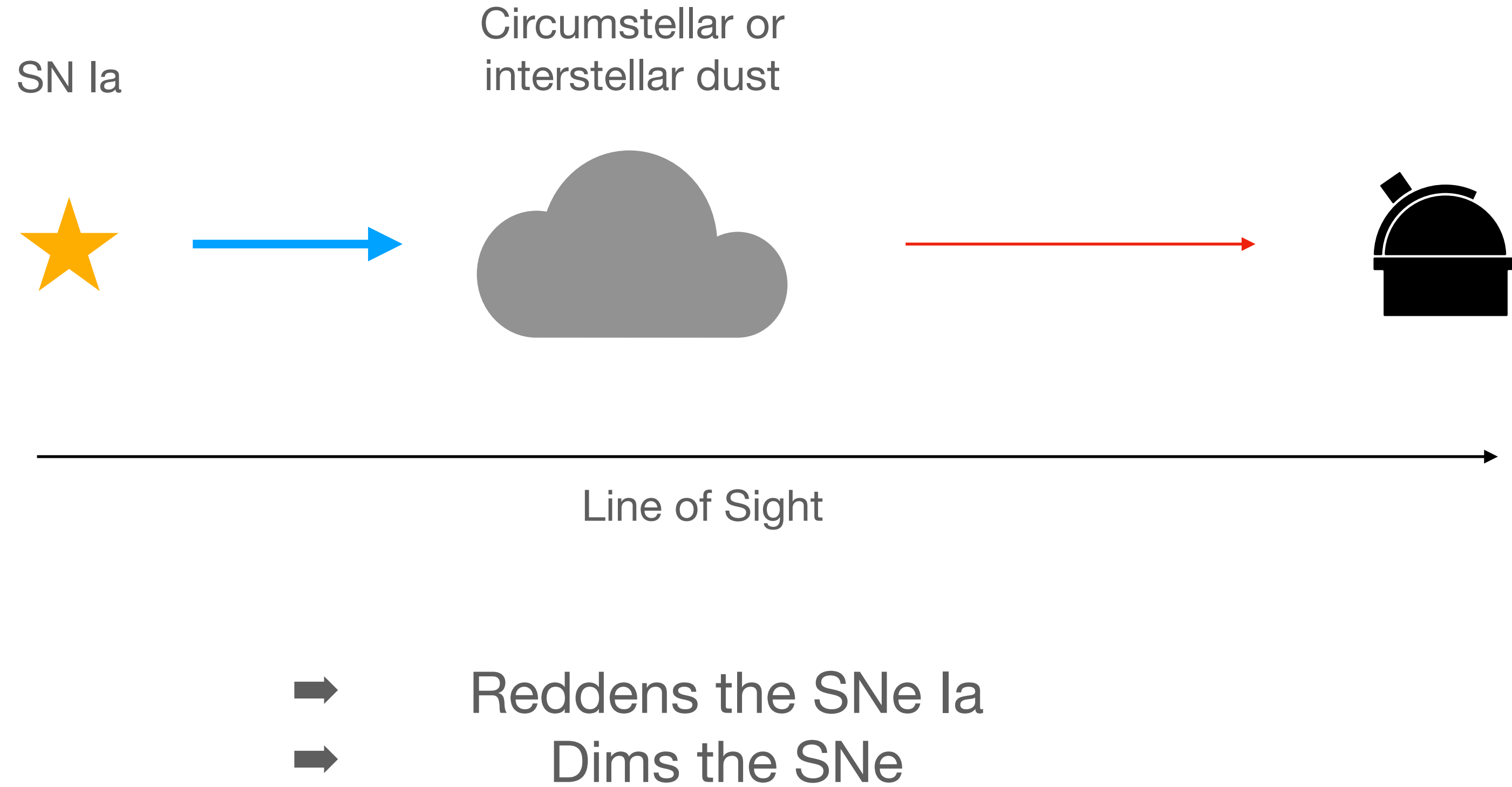
Stretch

Non linearity of the stretch-residuals relation

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



Dust



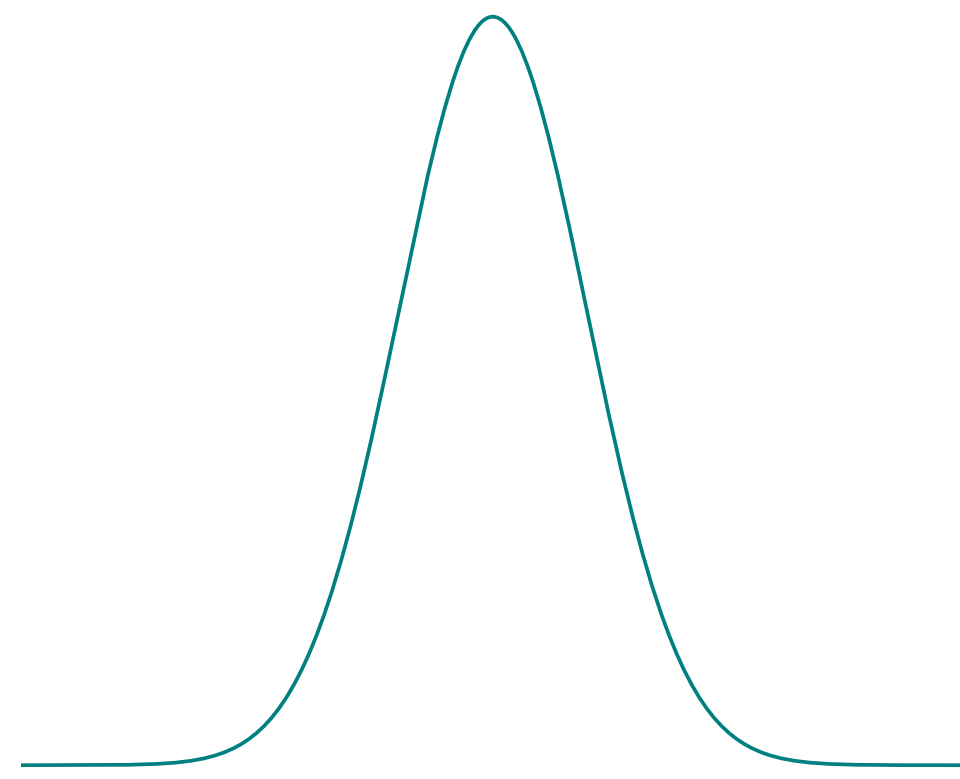
Vincenzi et al (2024)

Colour

Colour distribution

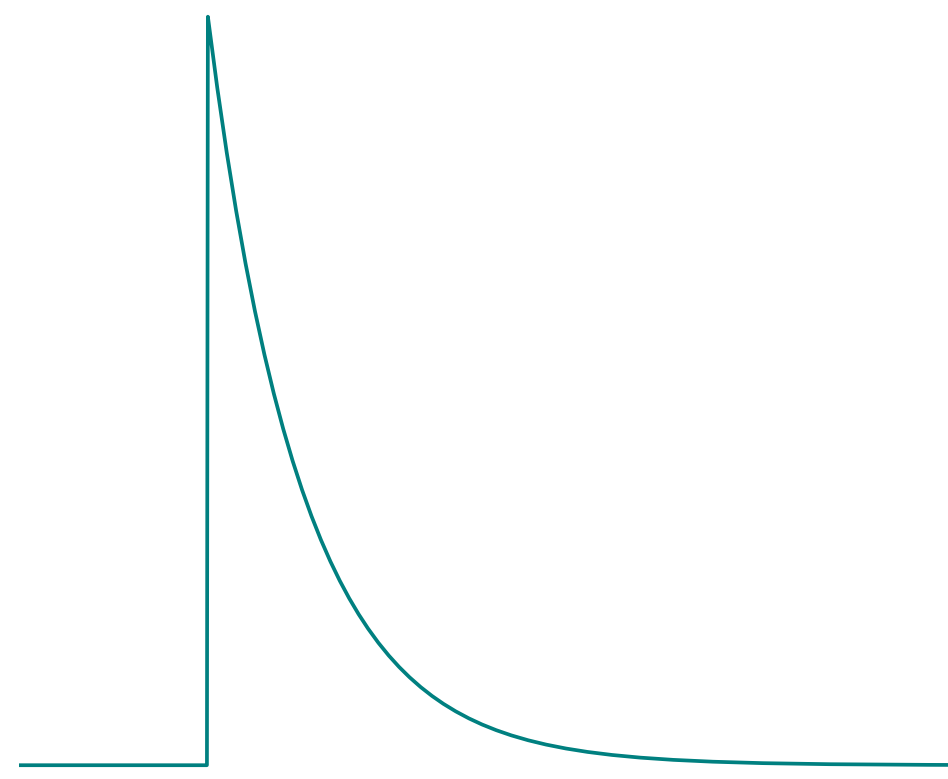
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Intrinsic colour

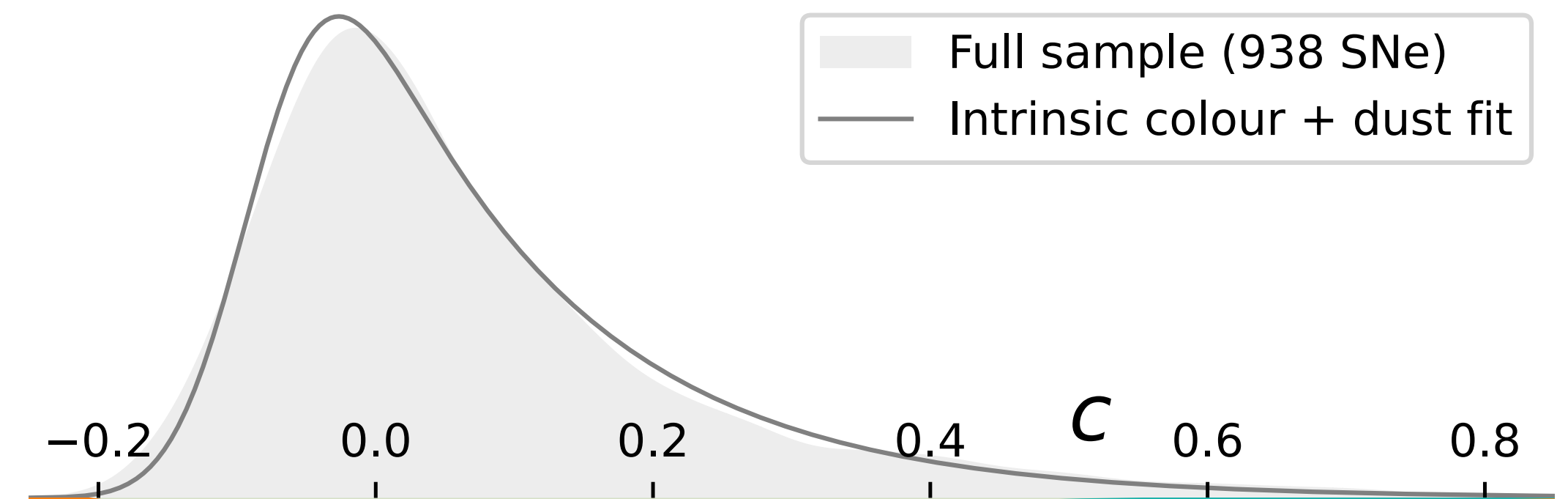


$$\mathcal{N}(c, c_{\text{int}}, \sigma_c)$$

Dust reddening



$$e^{-c\tau}$$

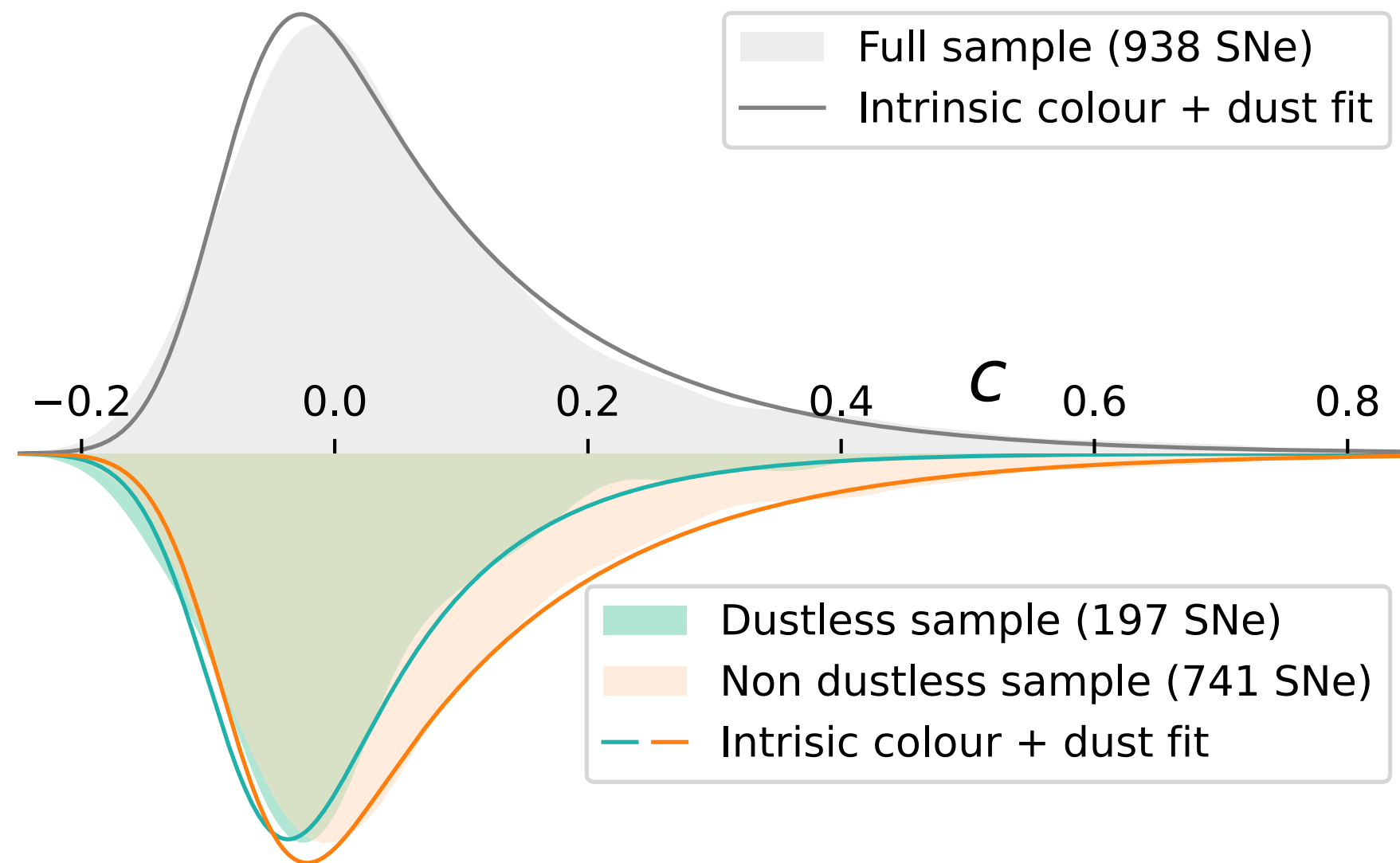


Jha et al. (2007)
Mandel et al. (2011)
Brout & Scolnic (2021)

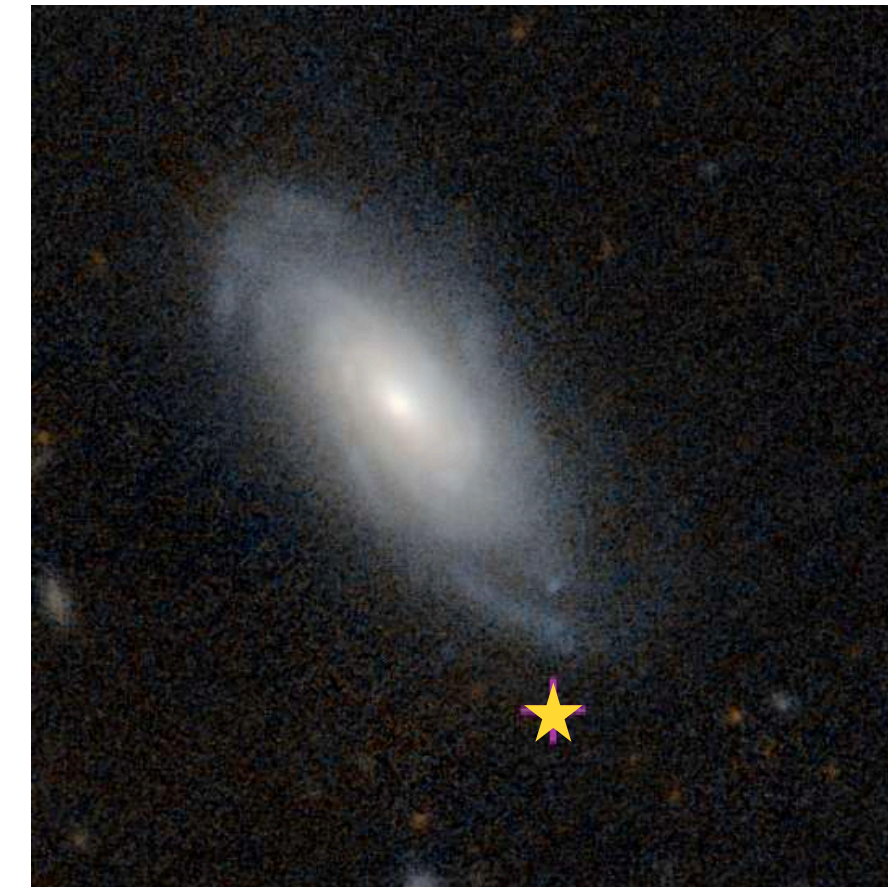
Colour

Dependence on environment

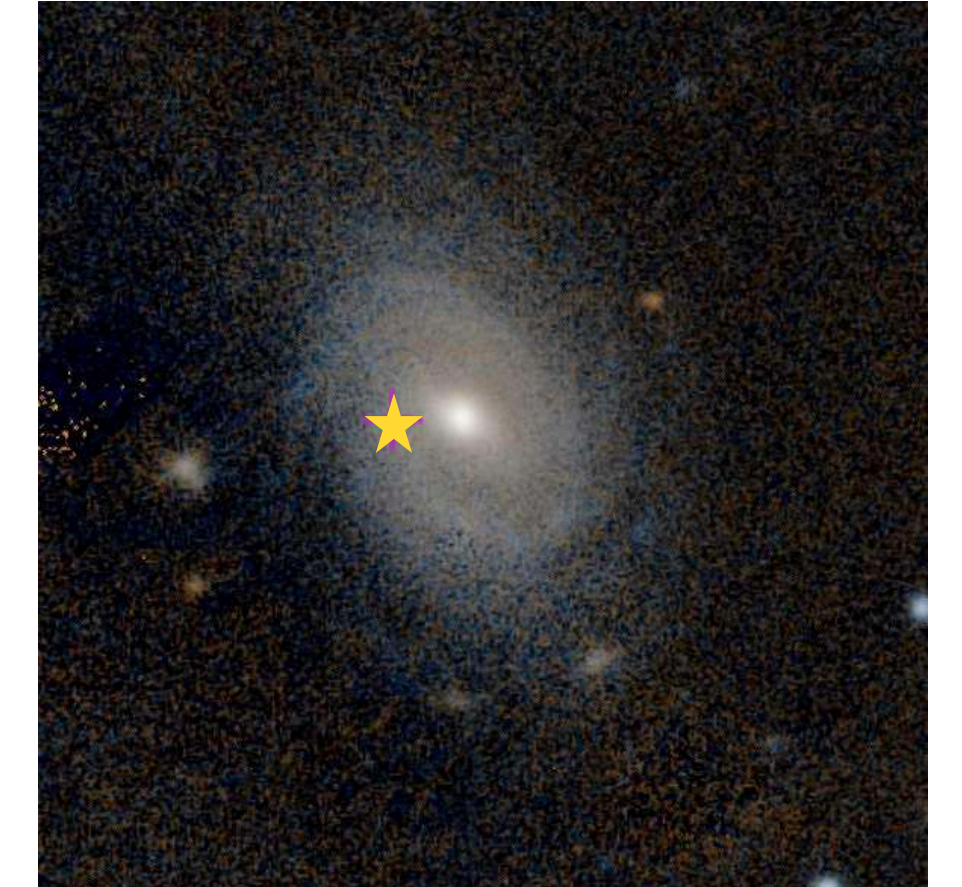
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$



« Dustless » example



« Non dustless » example

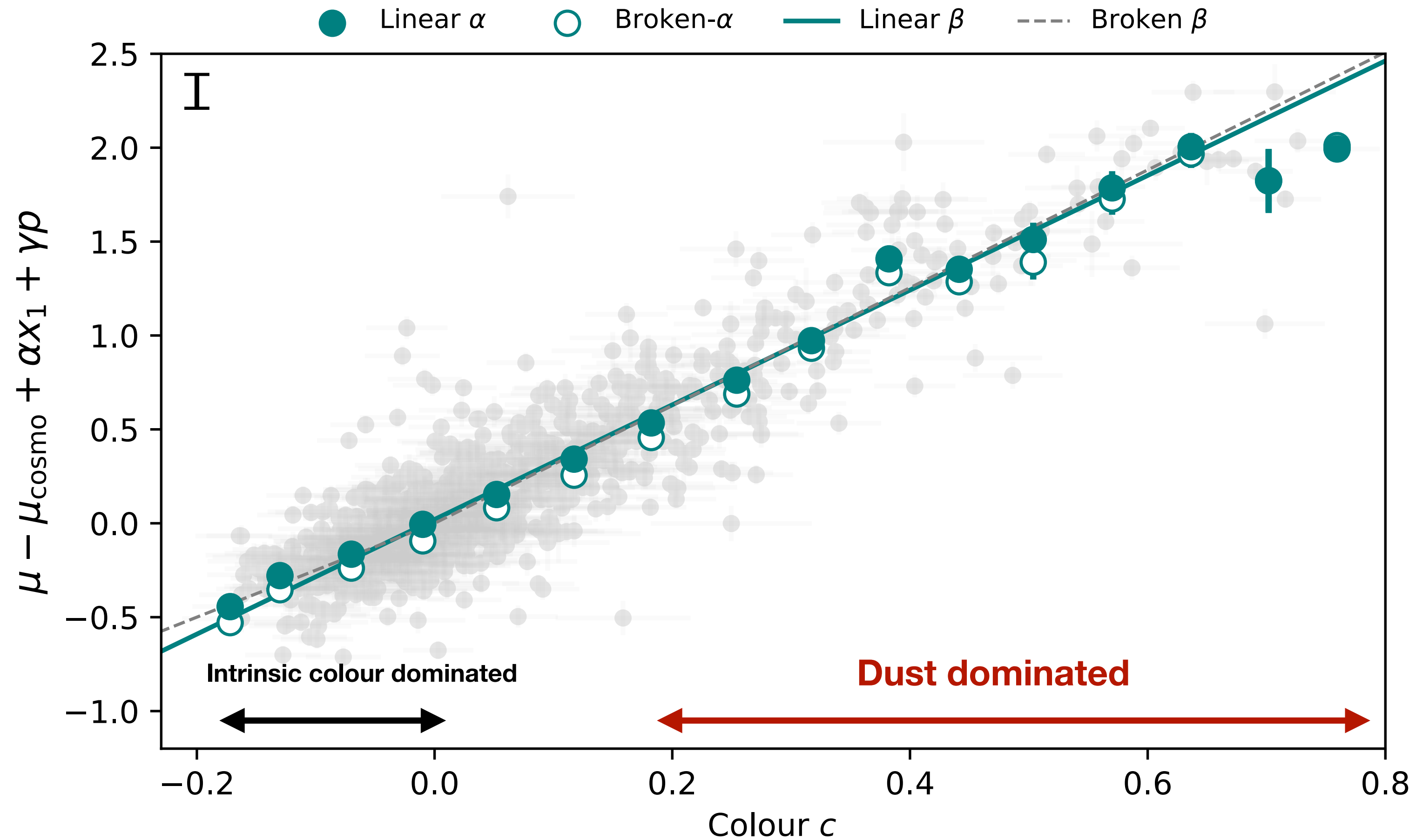


Sample	c_{int}	σ_c	τ
Full sample	-0.085 ± 0.004	0.030 ± 0.005	0.155 ± 0.007
Dustless* sample	-0.087 ± 0.008	0.033 ± 0.008	0.102 ± 0.010
Non dustless sample	-0.082 ± 0.005	0.029 ± 0.006	0.166 ± 0.008

Colour

Linearity of the colour-residuals relation

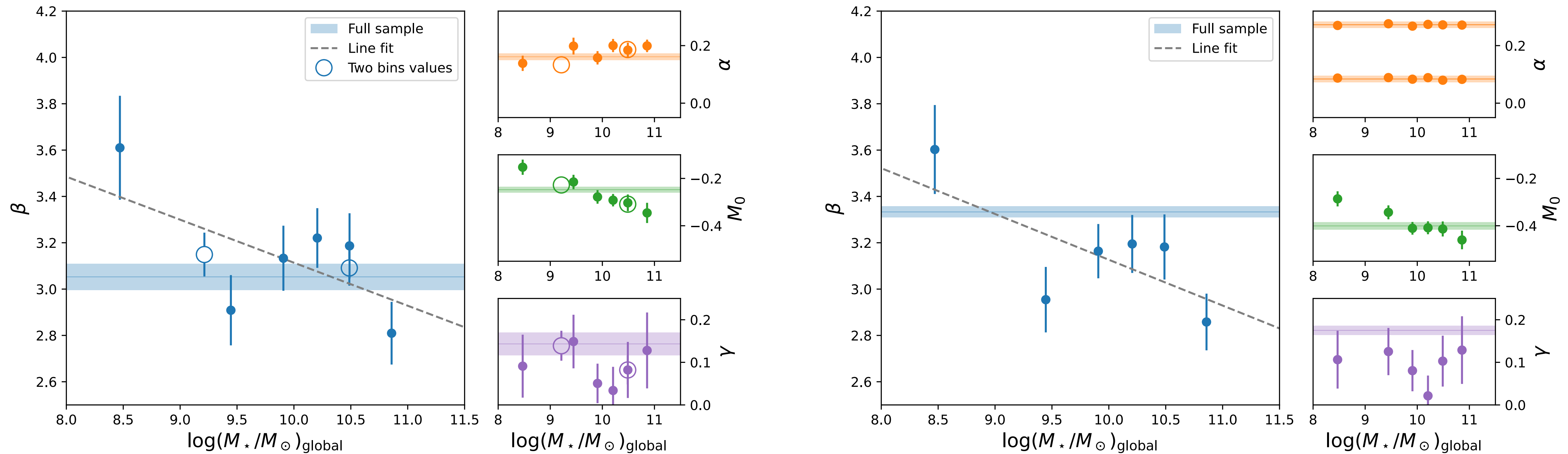
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$



Colour

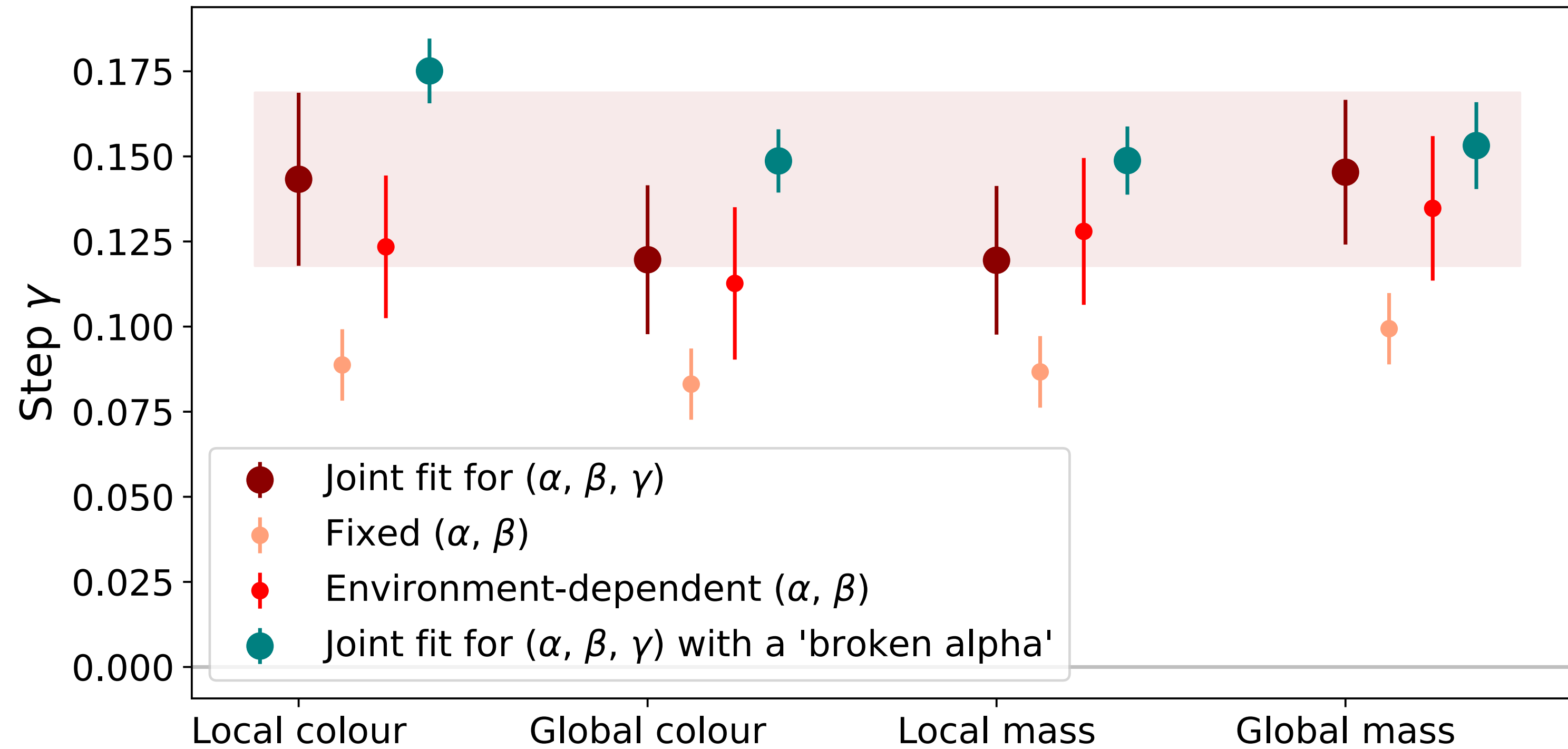
β evolution with environment

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



Environmental step

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

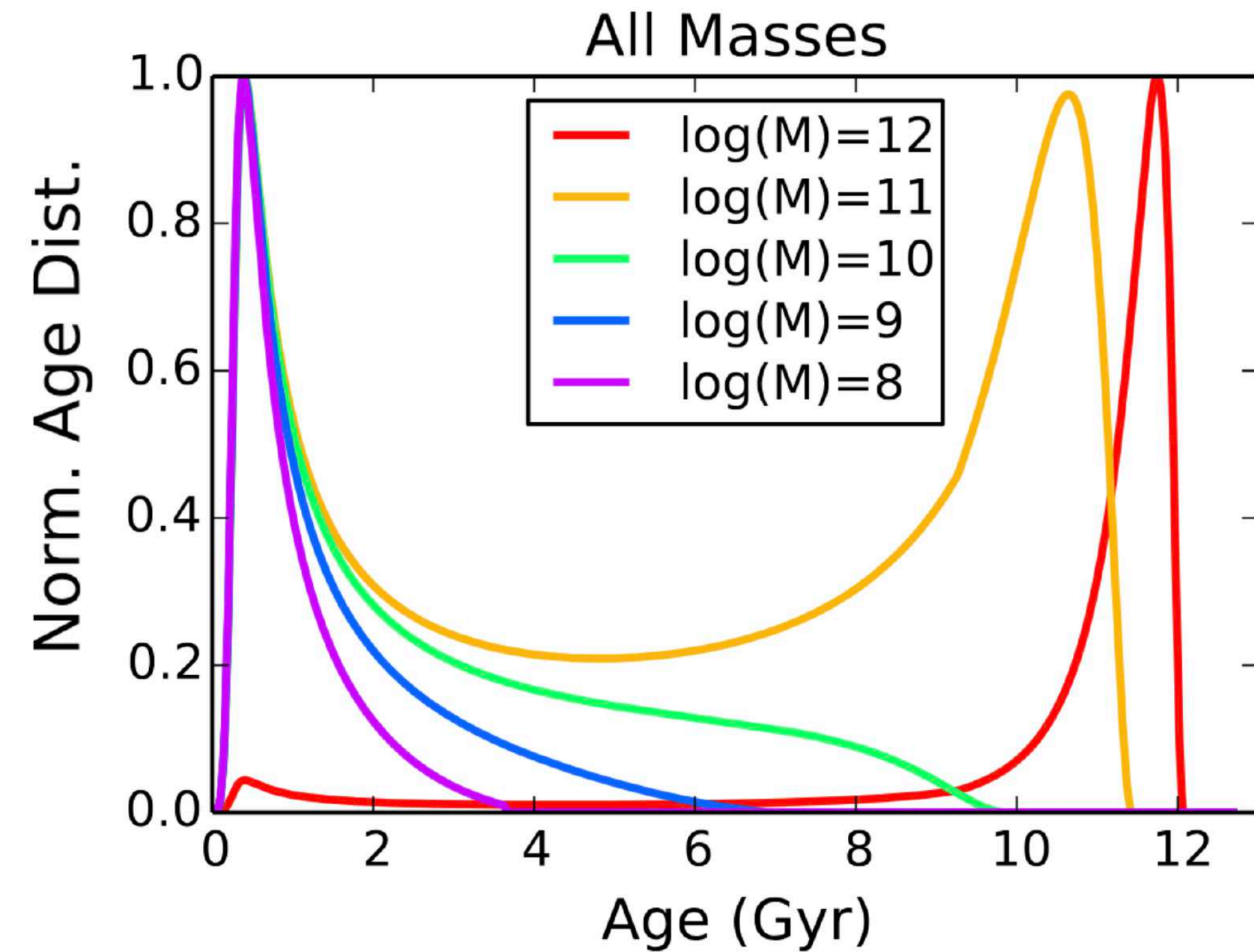


Environmental step

Origin of the step

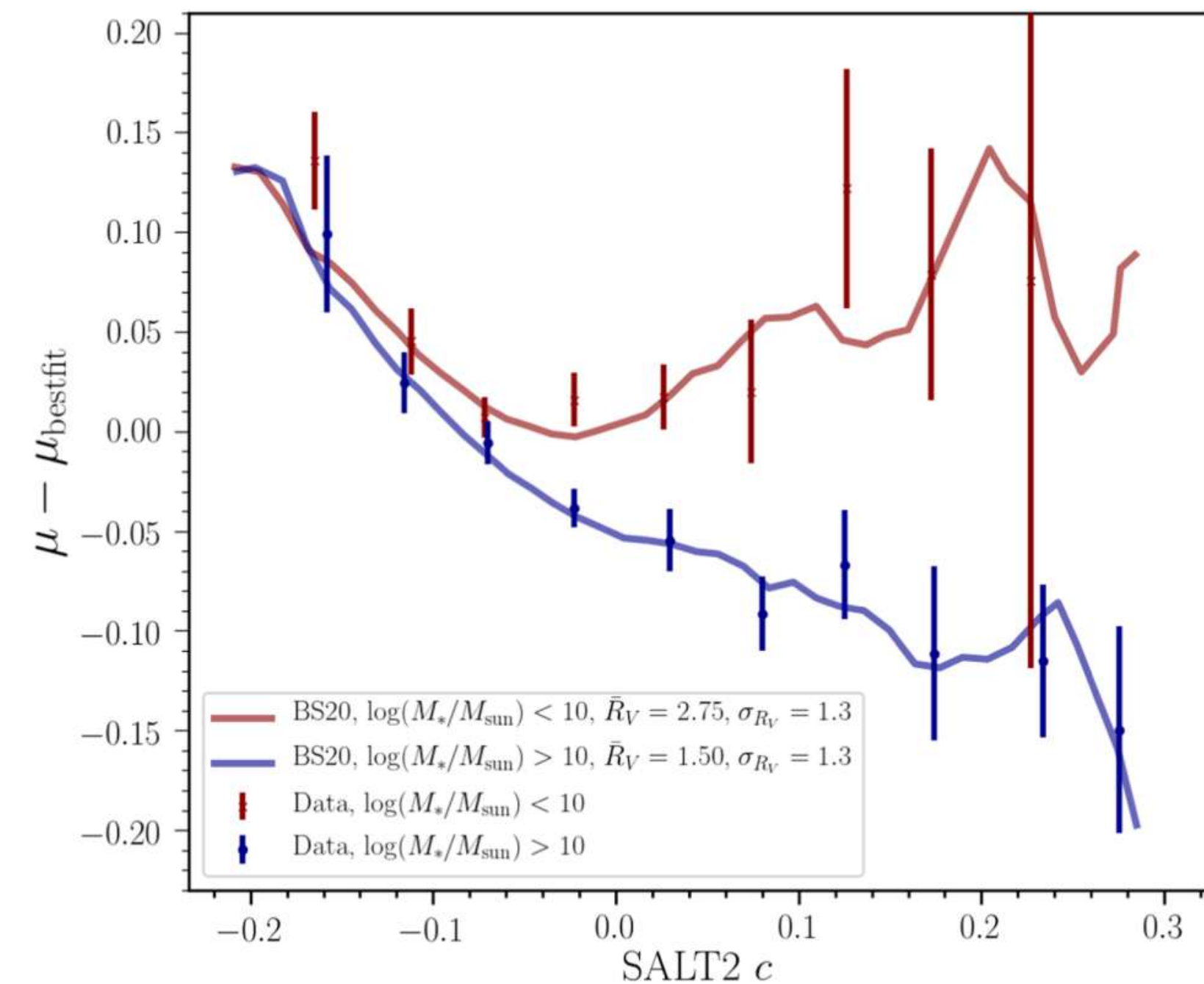
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Two population interpretation



Childress et al (2014)

Dust interpretation

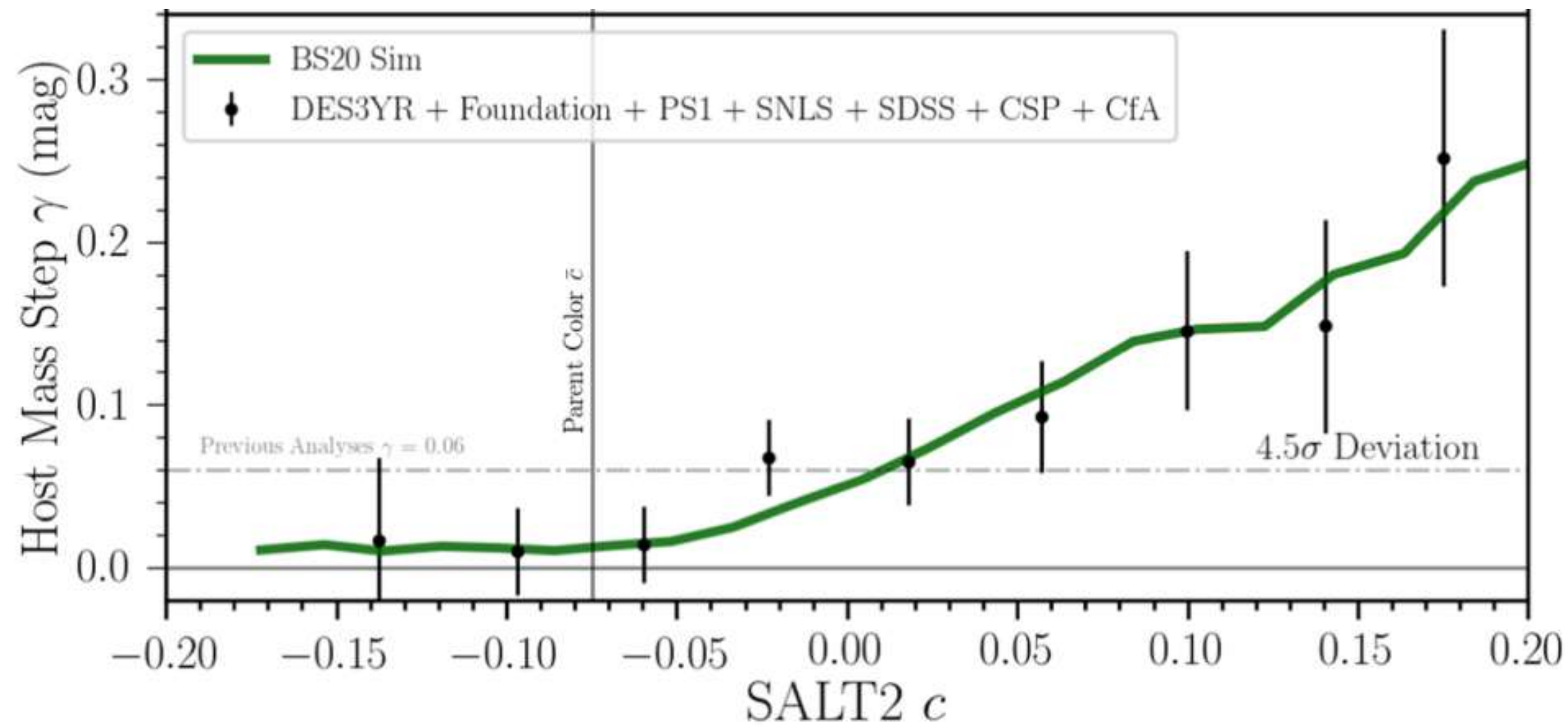


Brout & Scolnic (2021)

Environmental step

Colour-dependence of the step

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



Brout & Scolnic (2021)

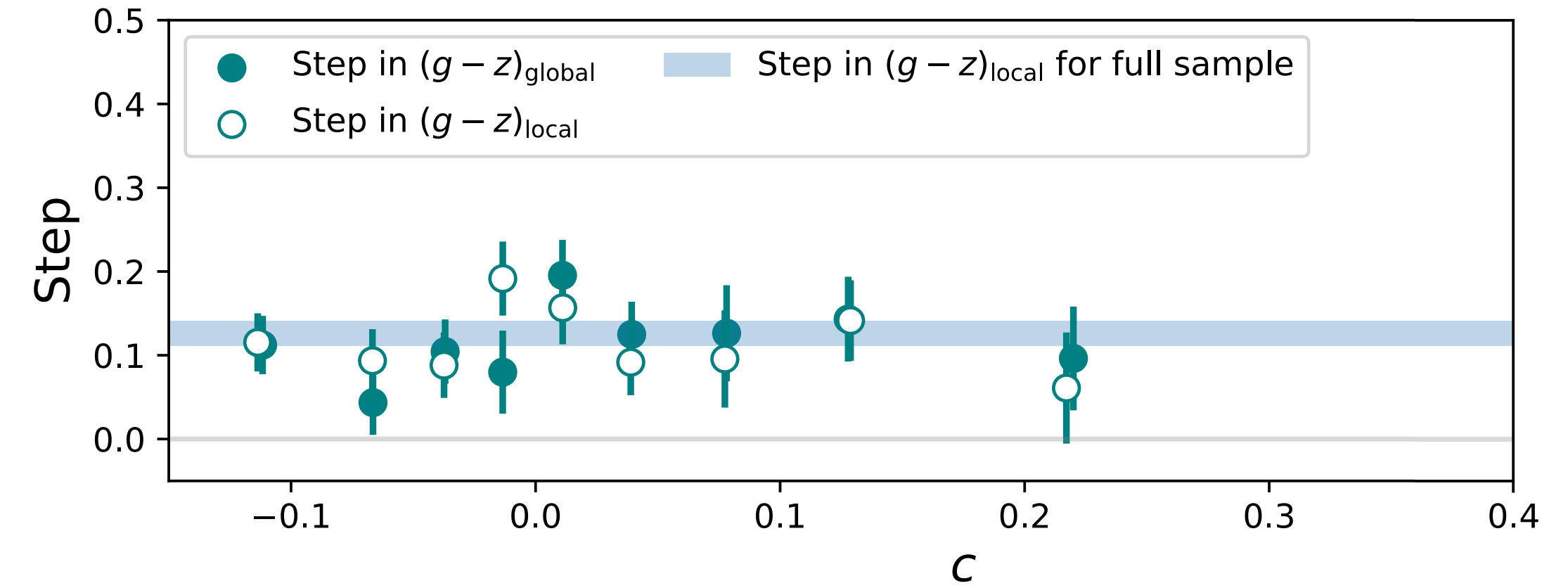


Table 3. Parameters of the step evolution with SN colour: slope of the fit and ΔAIC between an affine function and a constant.

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

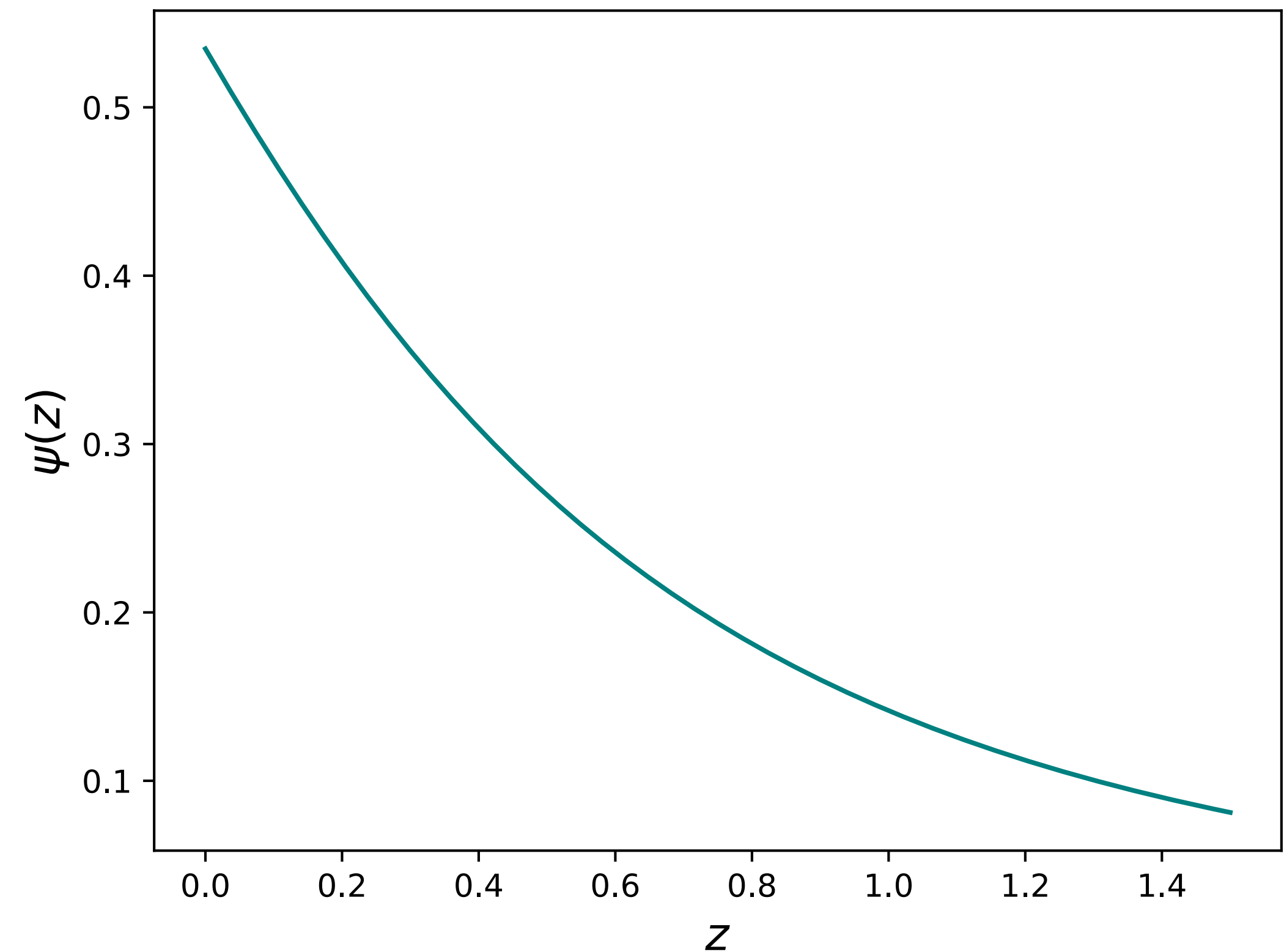
IV. Next steps

Redshift evolution

Fraction of old progenitor SNe Ia:

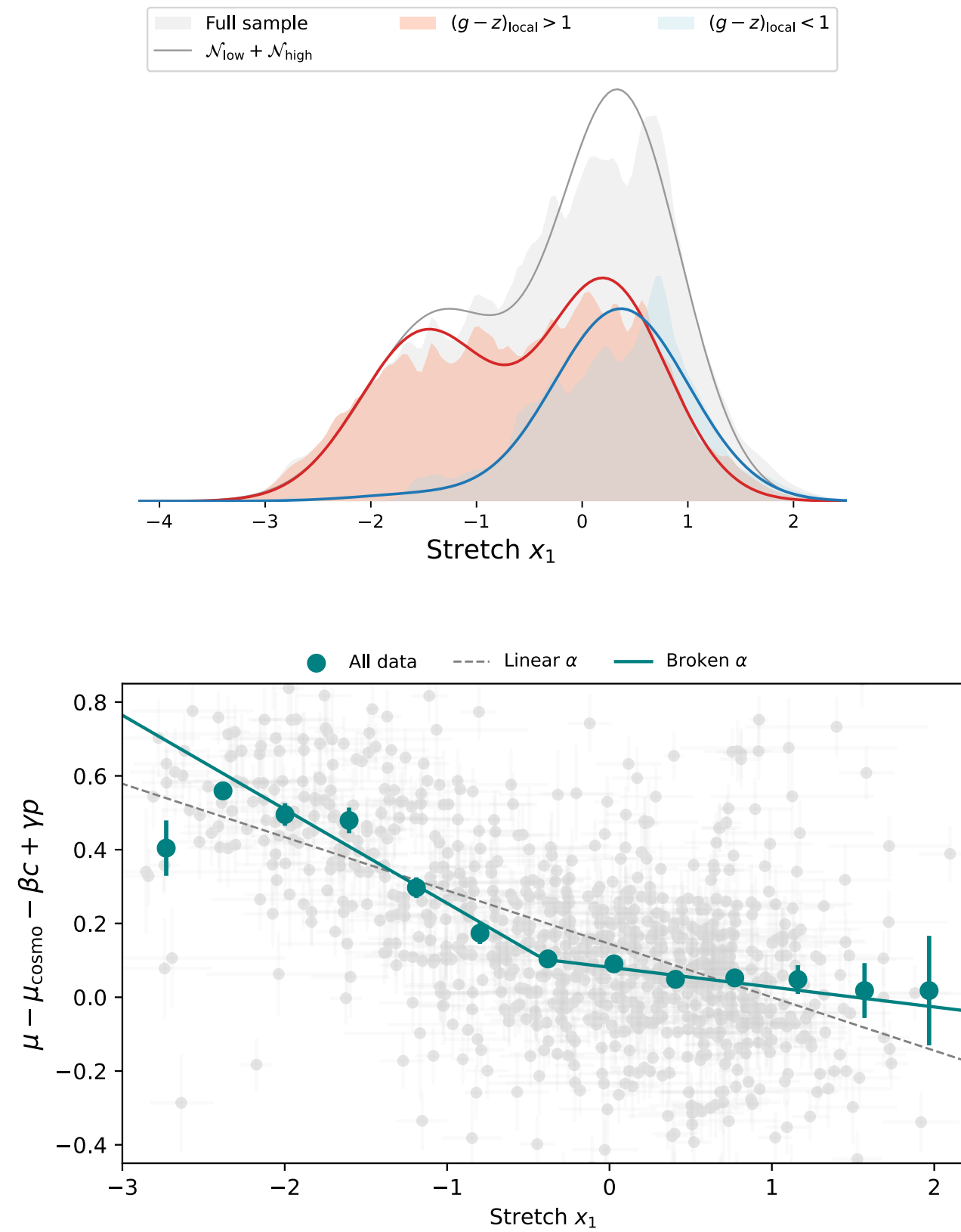
$$\psi(z) = \frac{1}{K(1+z)^\phi + 1}$$

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

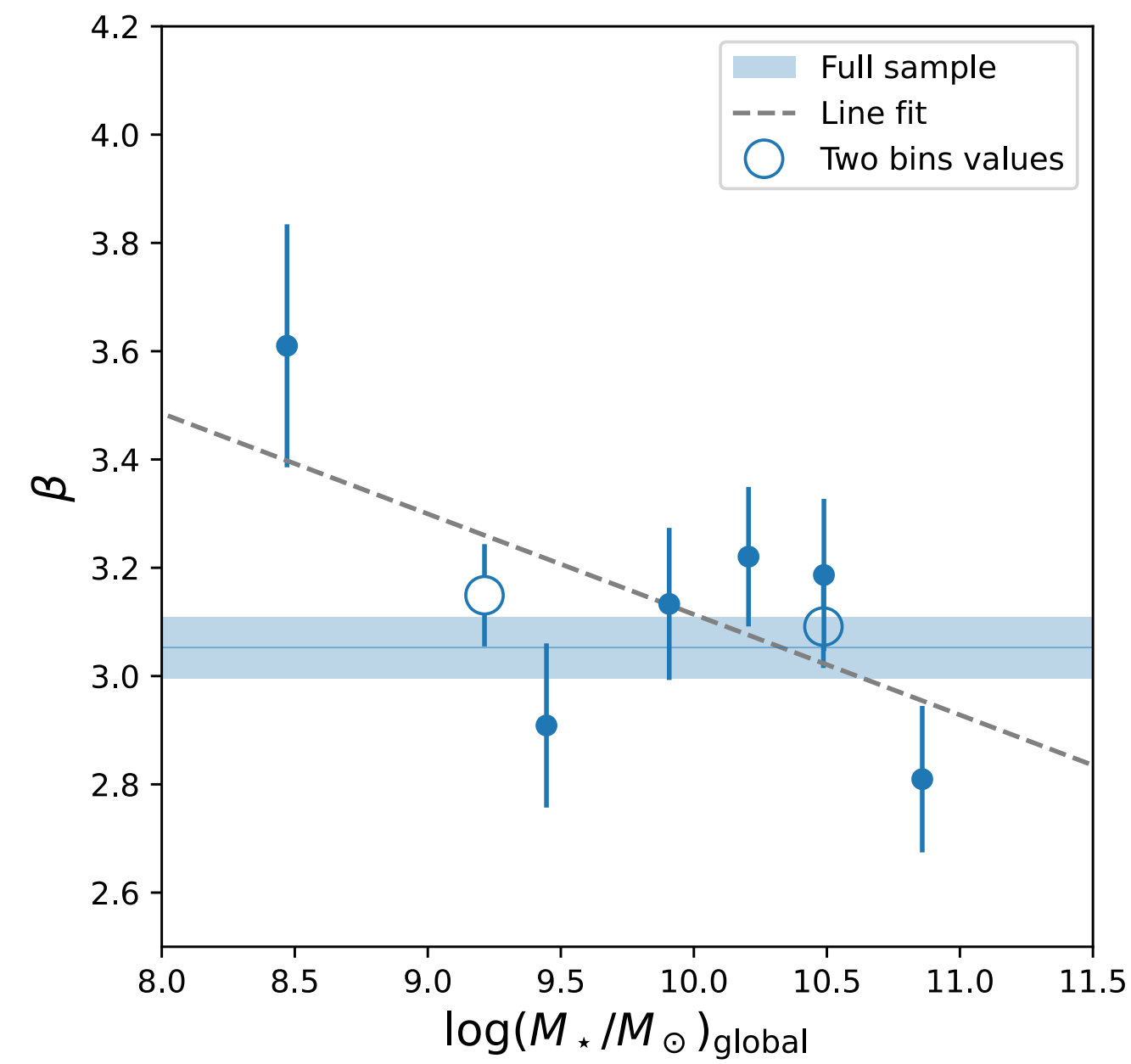


Redshift evolution

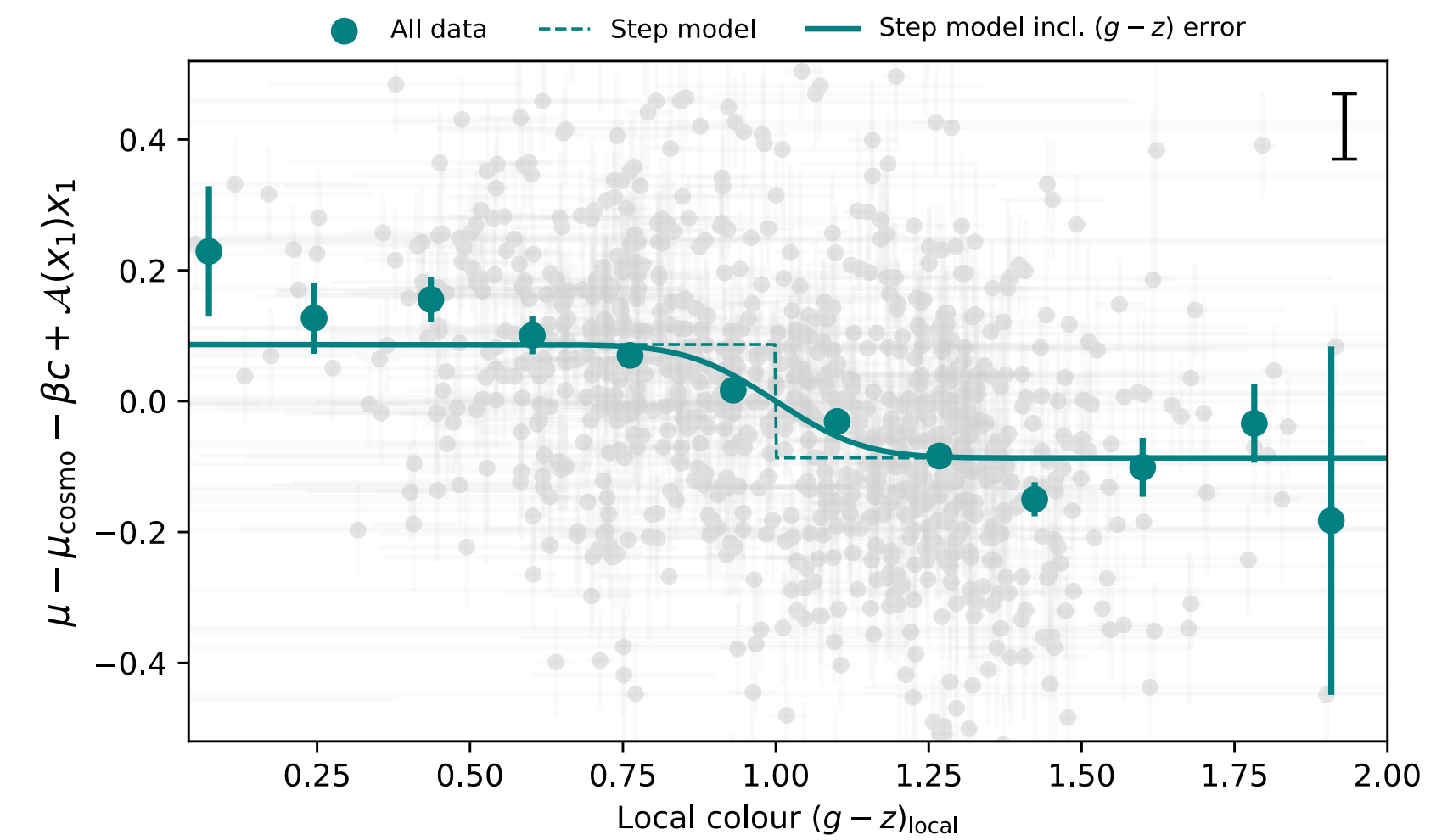
α evolution



β evolution

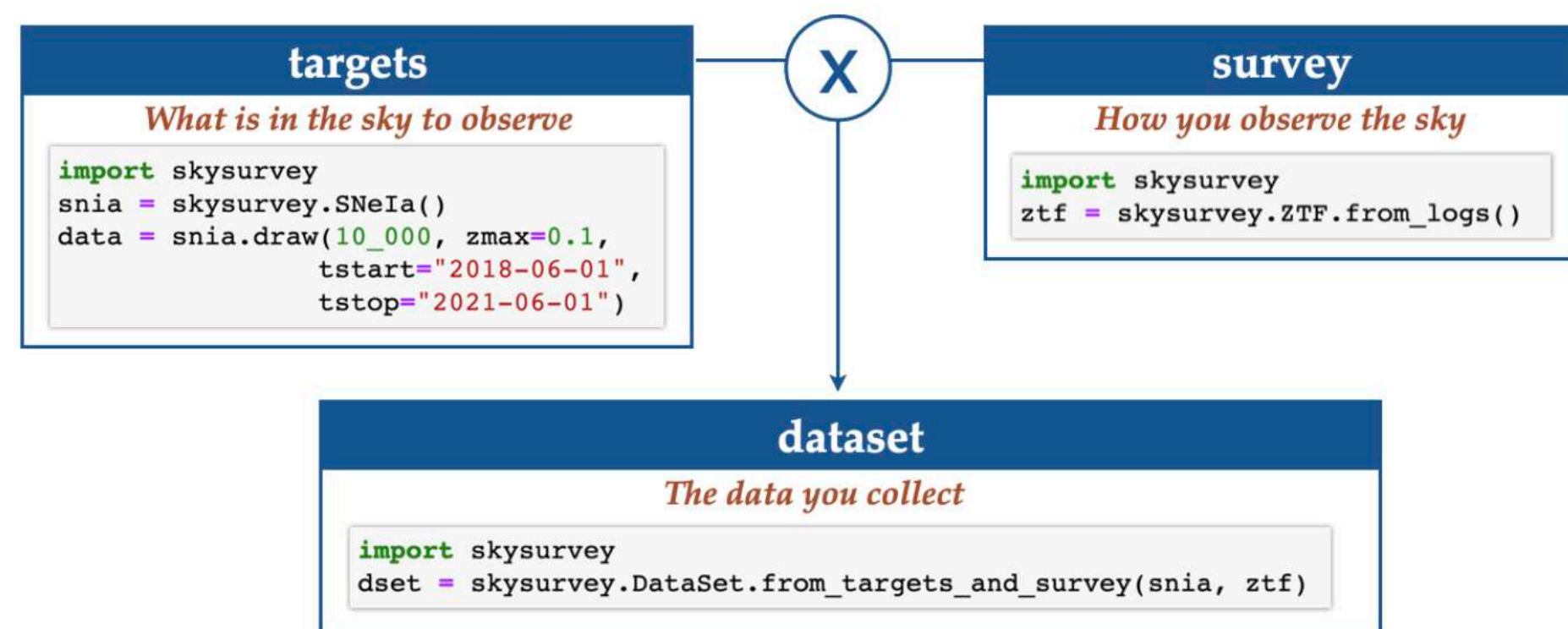


Impact of the environmental step



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

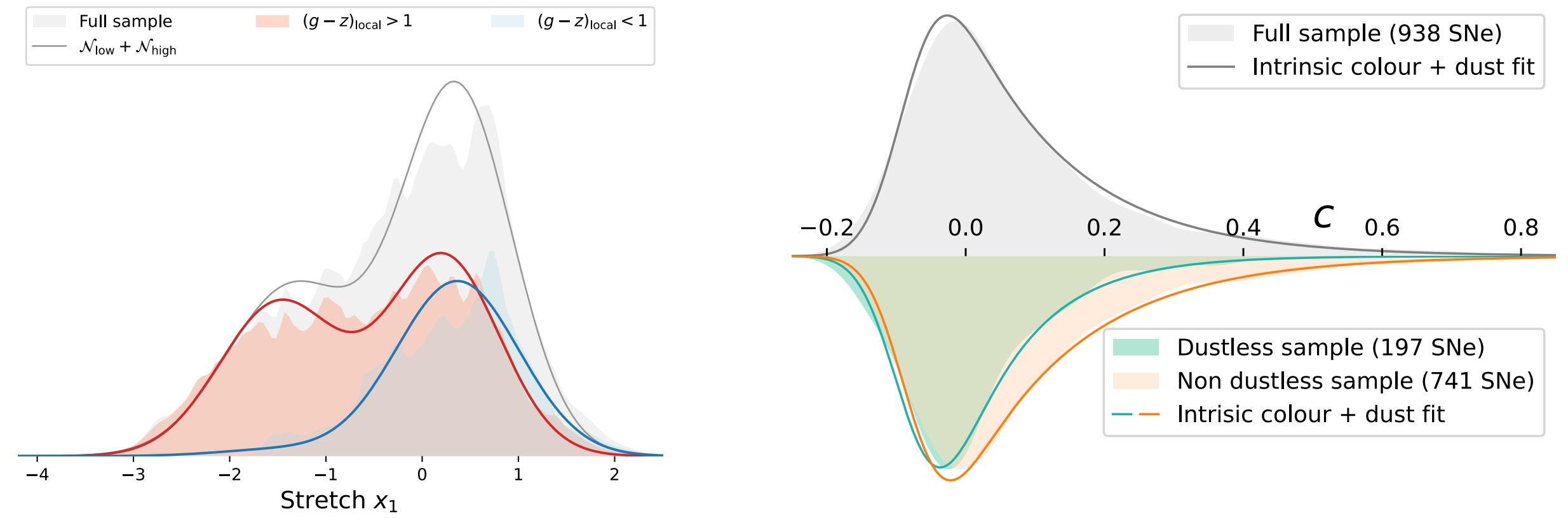
ZTF SN Ia DR2
volume-limited sample

949 SNe Ia
Homogenous
High cadence + spectroscopic

2406.02072

2405.20965

Type Ia Supernovae properties



Standardisation dependency on environment

