

2405.20965

2406.02072



Cosmology with Type Ia Supernovae and the ZTF SN Ia DR2 sample

Madeleine Ginolin, Mickaël Rigault

LPCA - 24th January 2025



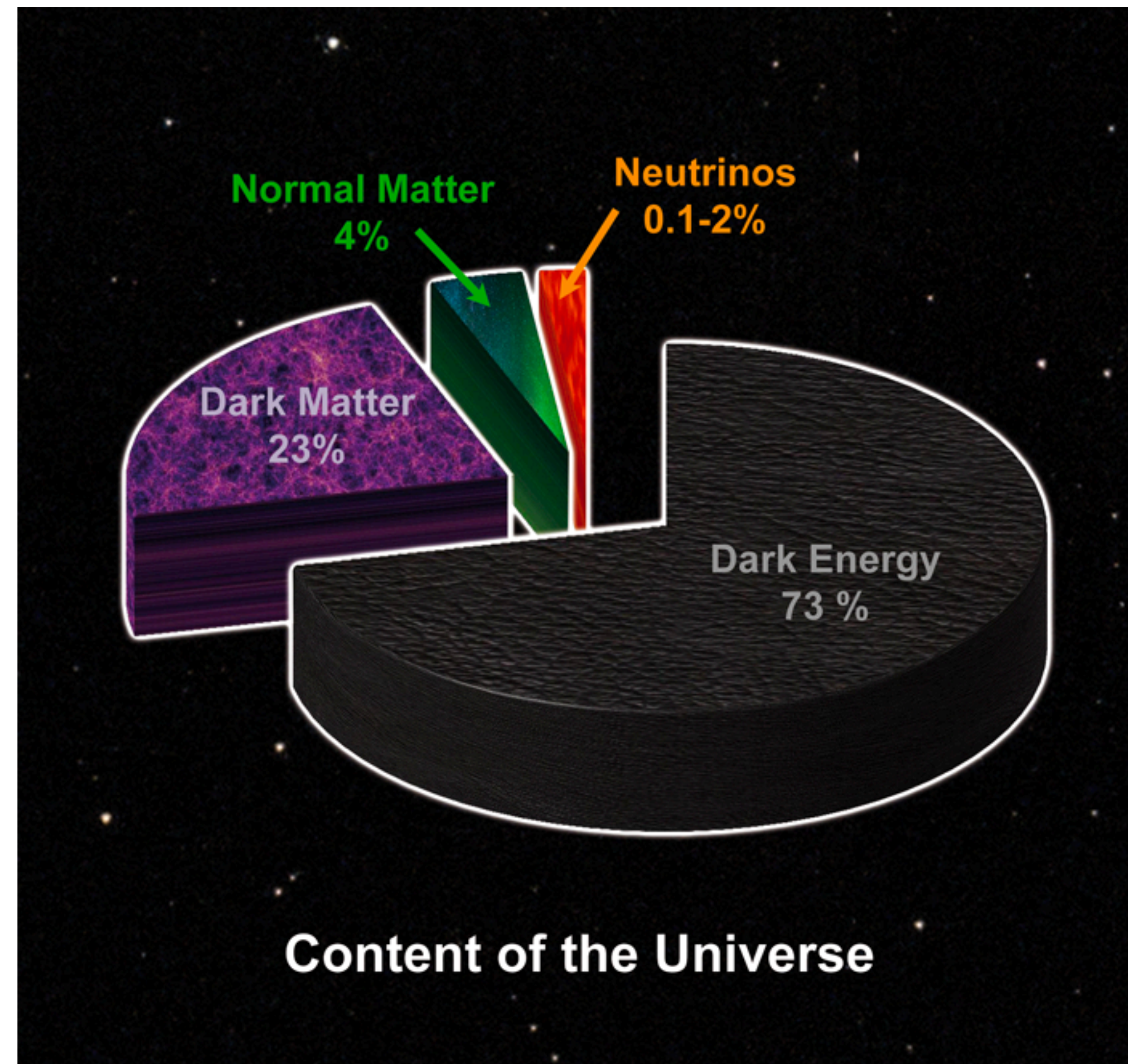
Outline

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

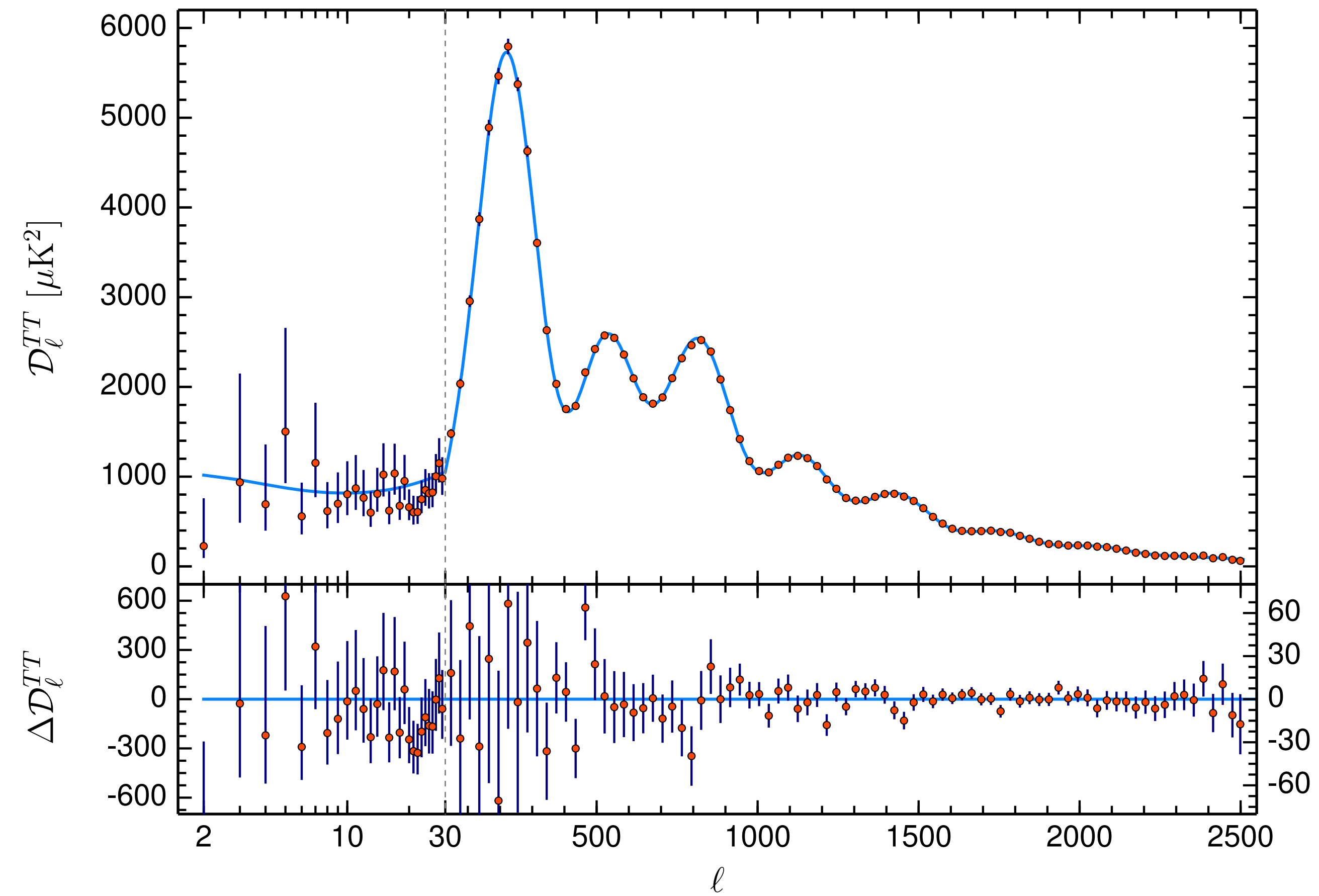
I. Cosmology with Type Ia Supernovae

Cosmology

Λ CDM model



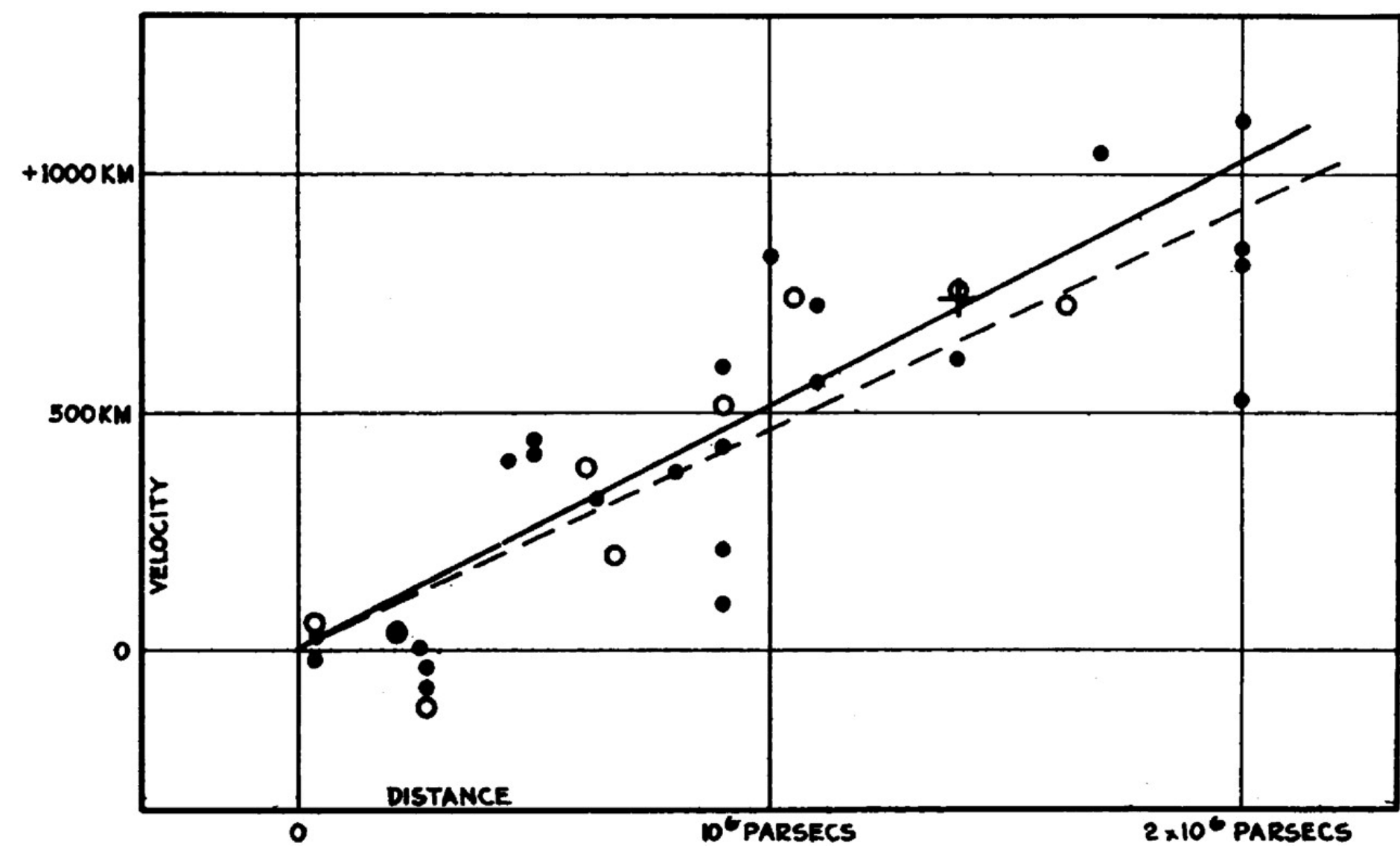
Credits: HAP / A. Chantelauze



Planck 2018

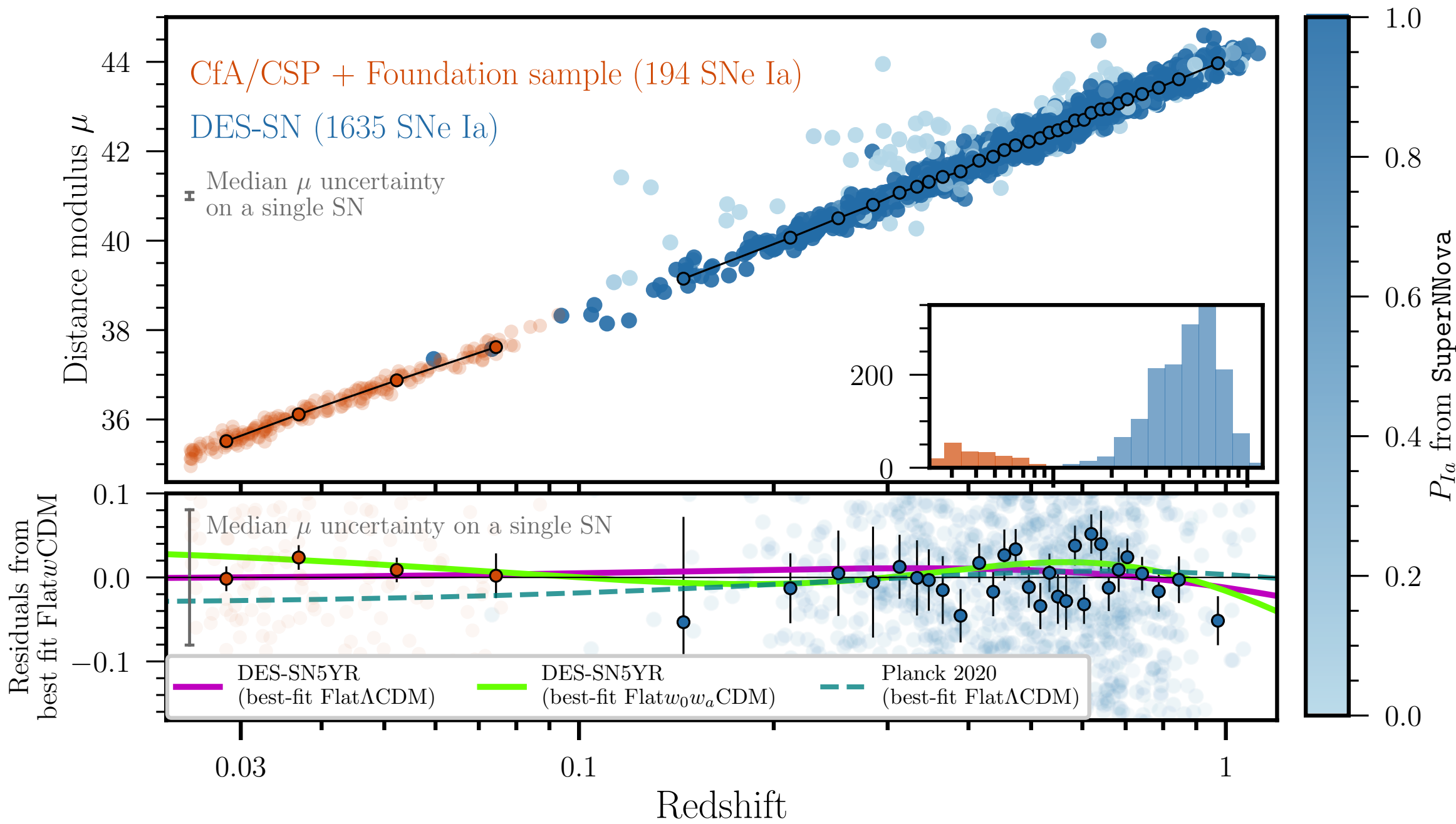
Cosmology

Hubble diagram



Hubble (1929)

H_0

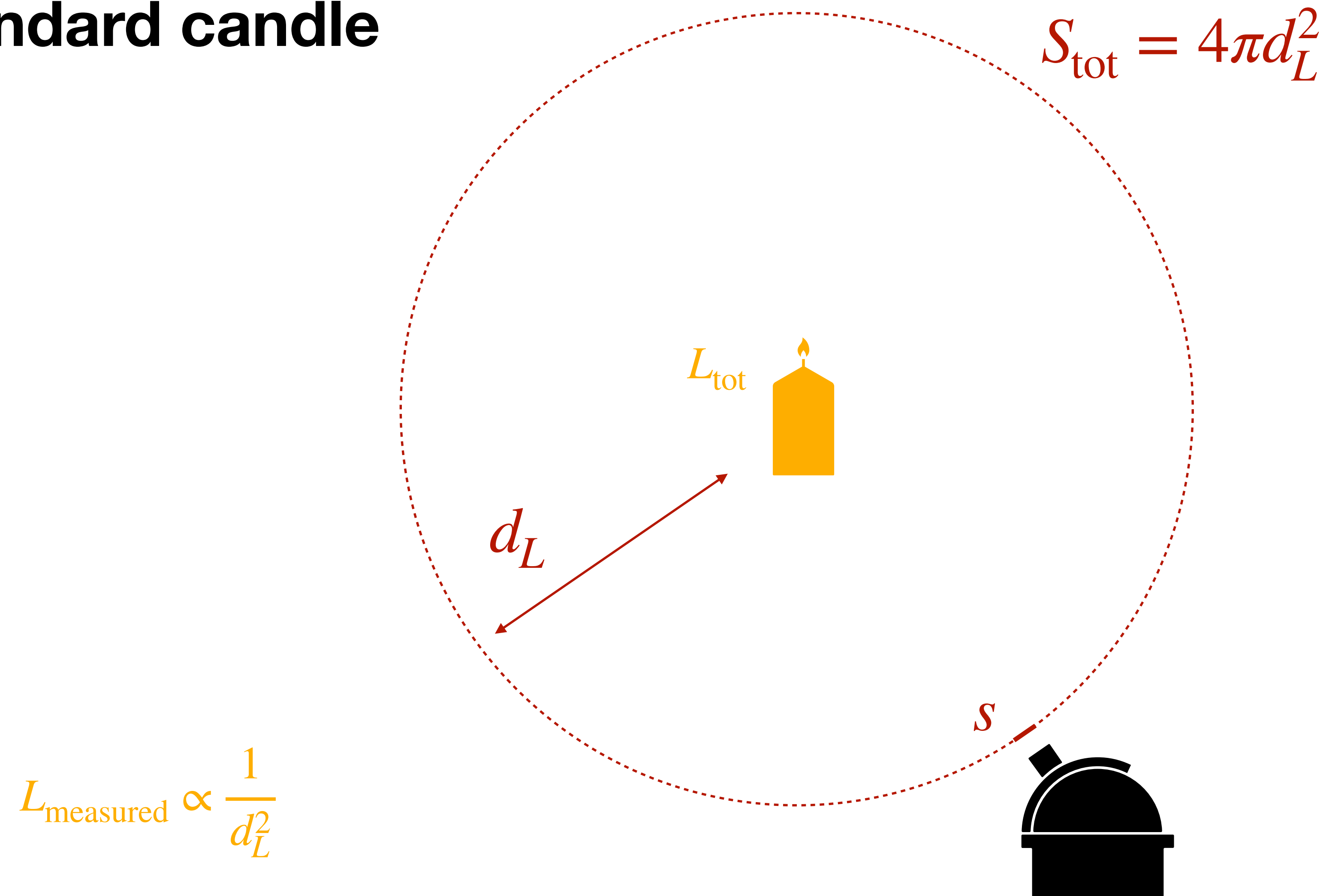


DES-SN5YR

H_0, w, Ω_m

Cosmology

Standard candle

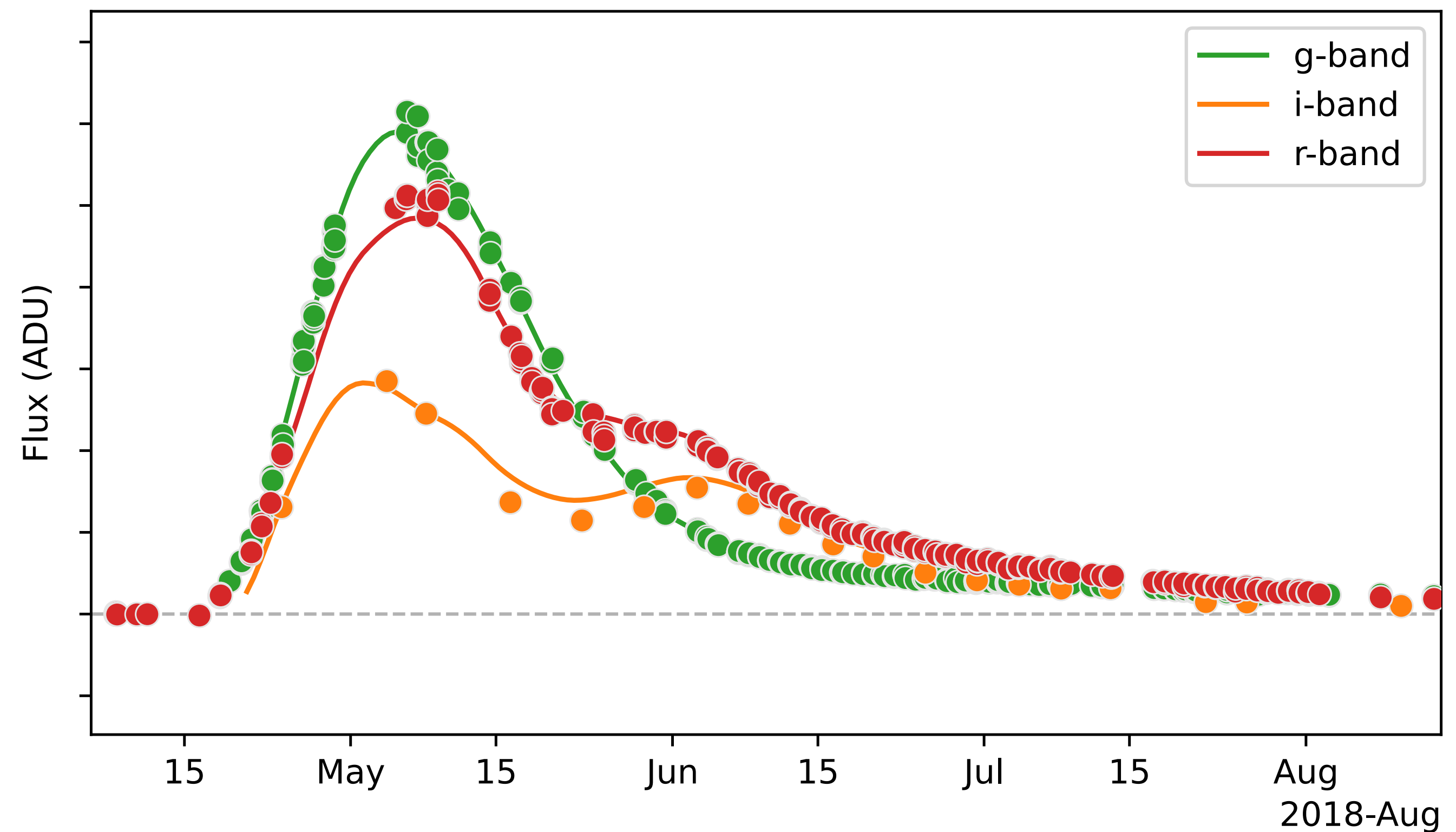


Type Ia Supernovae (SNe Ia)

Lightcurve



Credits: B.J. Fulton/
LCOGT/Caltech



Type Ia Supernovae (SNe Ia)

Lightcurve fitting

Flux of the SN:

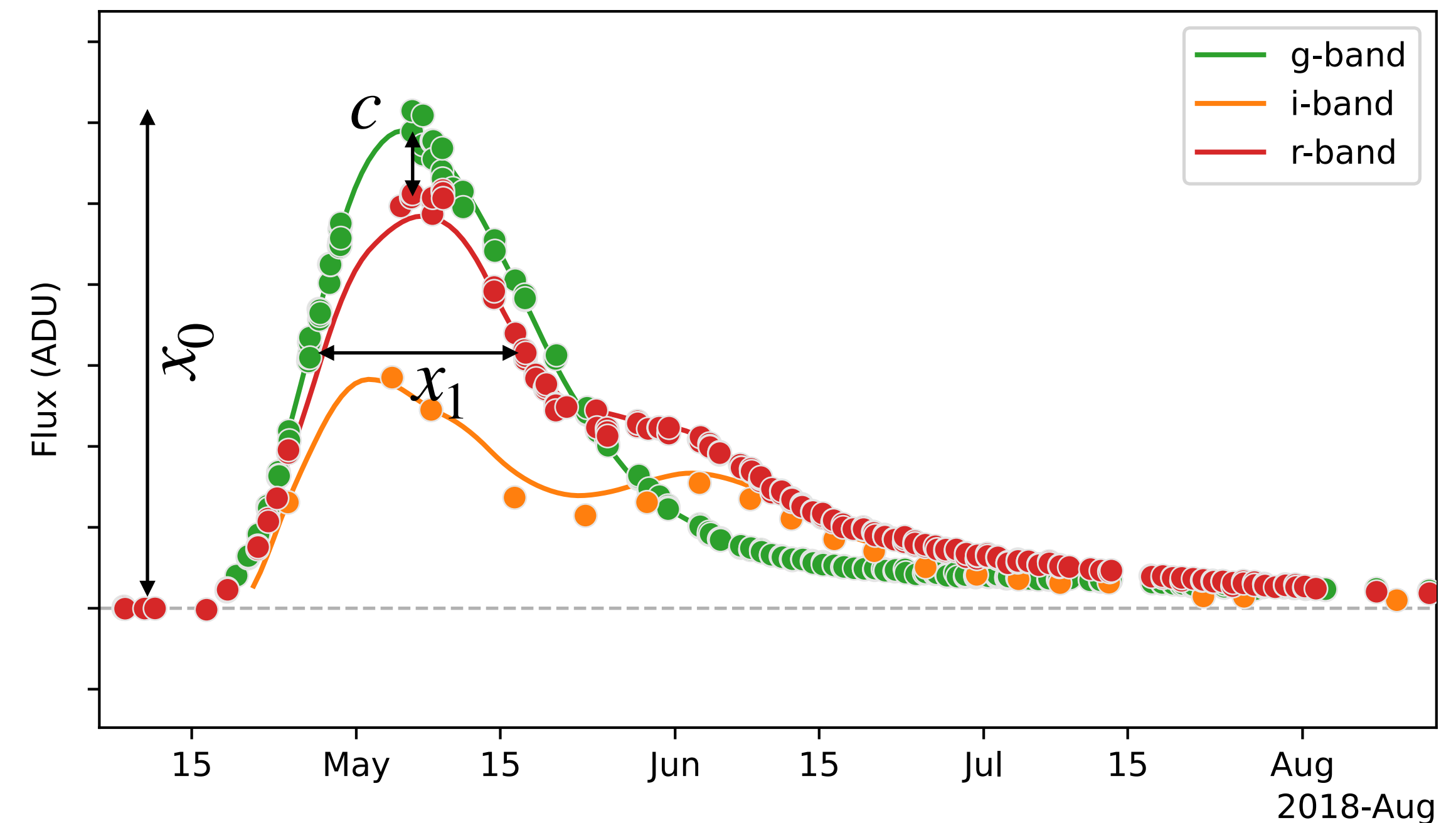
$$F(\text{SN}, p, \lambda) = x_0 [M_0(p, \lambda) + x_1 M_1(p, \lambda)] \exp(c CL(\lambda))$$

Parameters relative to
the observation

p : phase of the
observation
 λ : wavelength

Parameters relative to
the SN

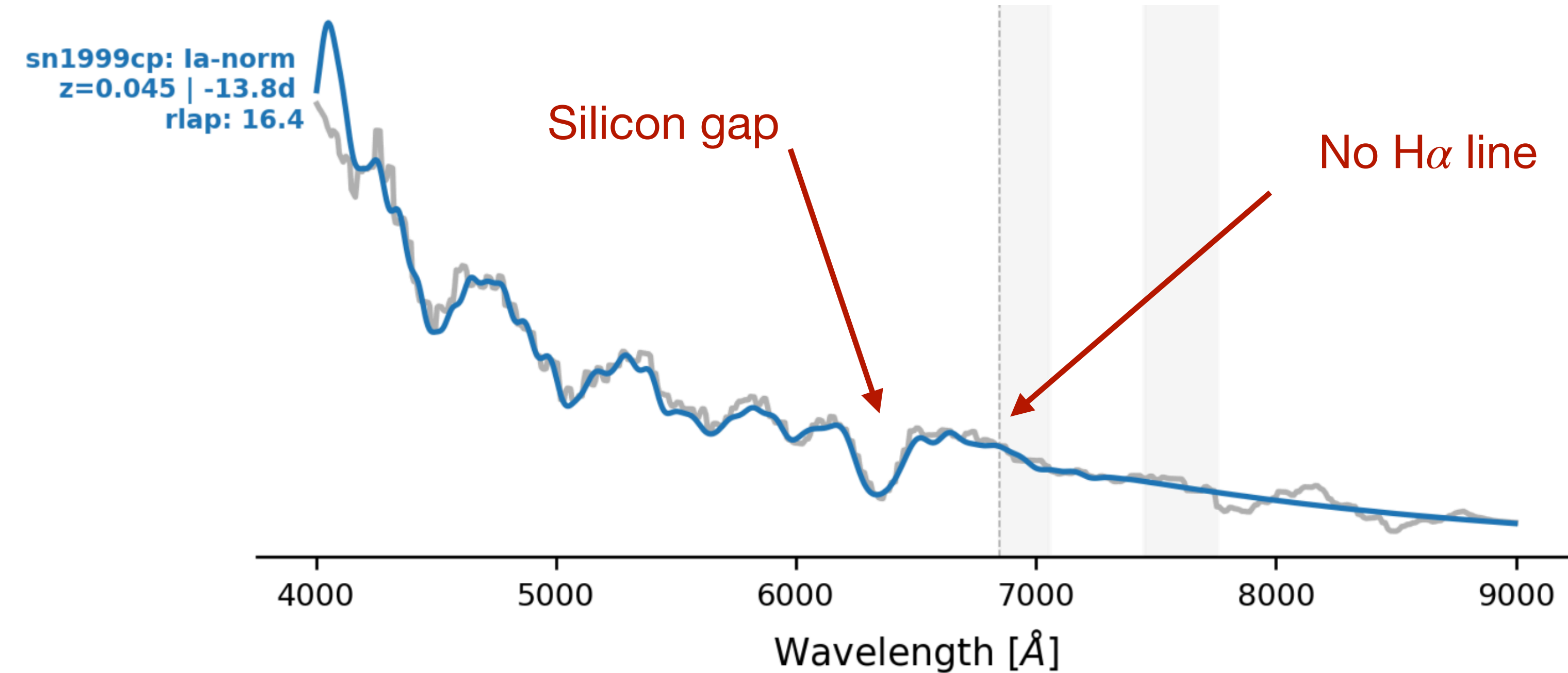
x_0 : amplitude
 x_1 : stretch
 c : colour
 t_0 : time of the peak



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

Type Ia Supernovae (SNe Ia)

Spectrum

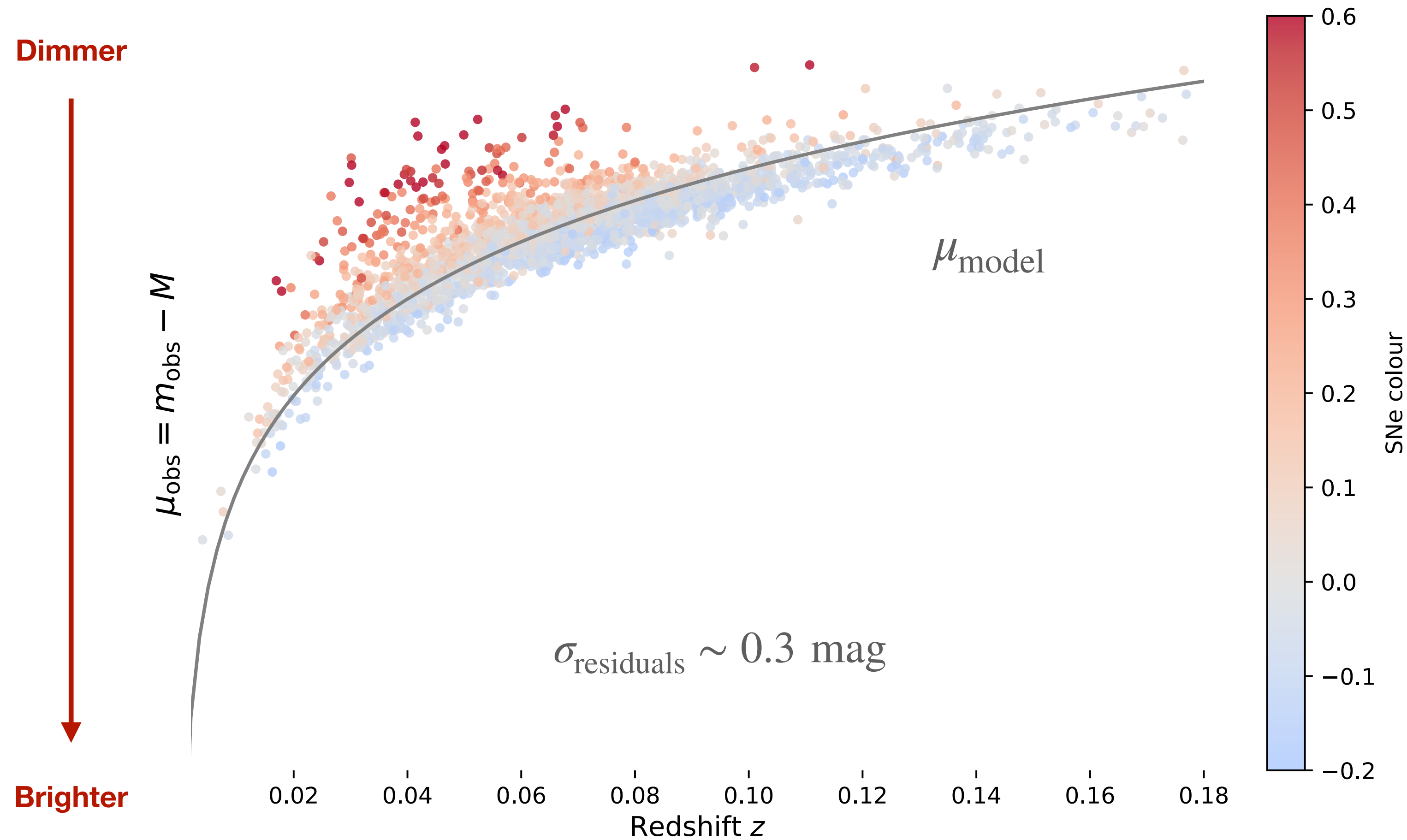


Spectroscopic
typing

Redshift
information

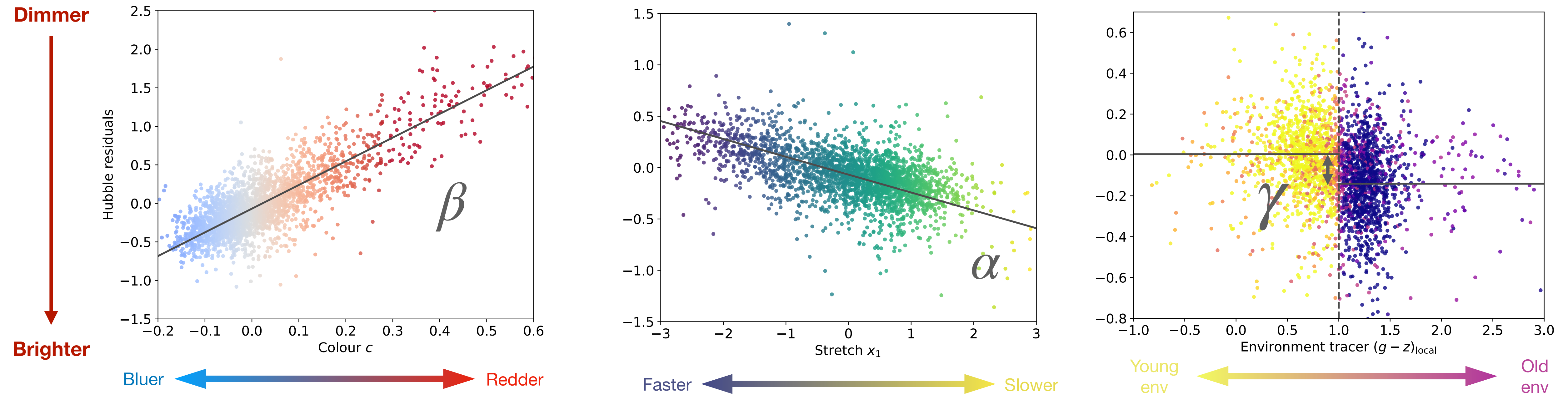
Cosmology with SNe Ia

Supernovae standardisation



Cosmology with SNe Ia

Standardisation



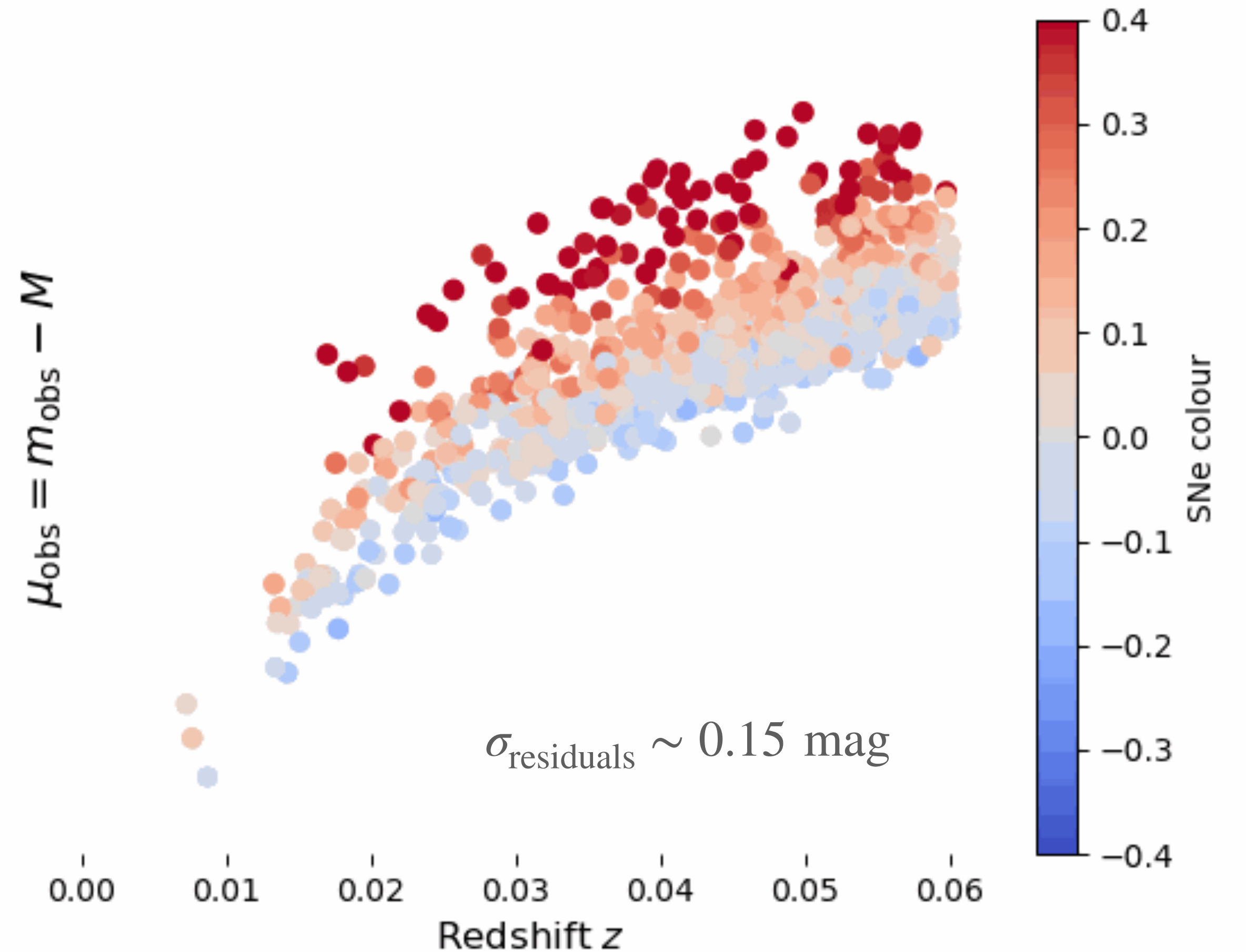
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Cosmology with SNe Ia

Standardisation

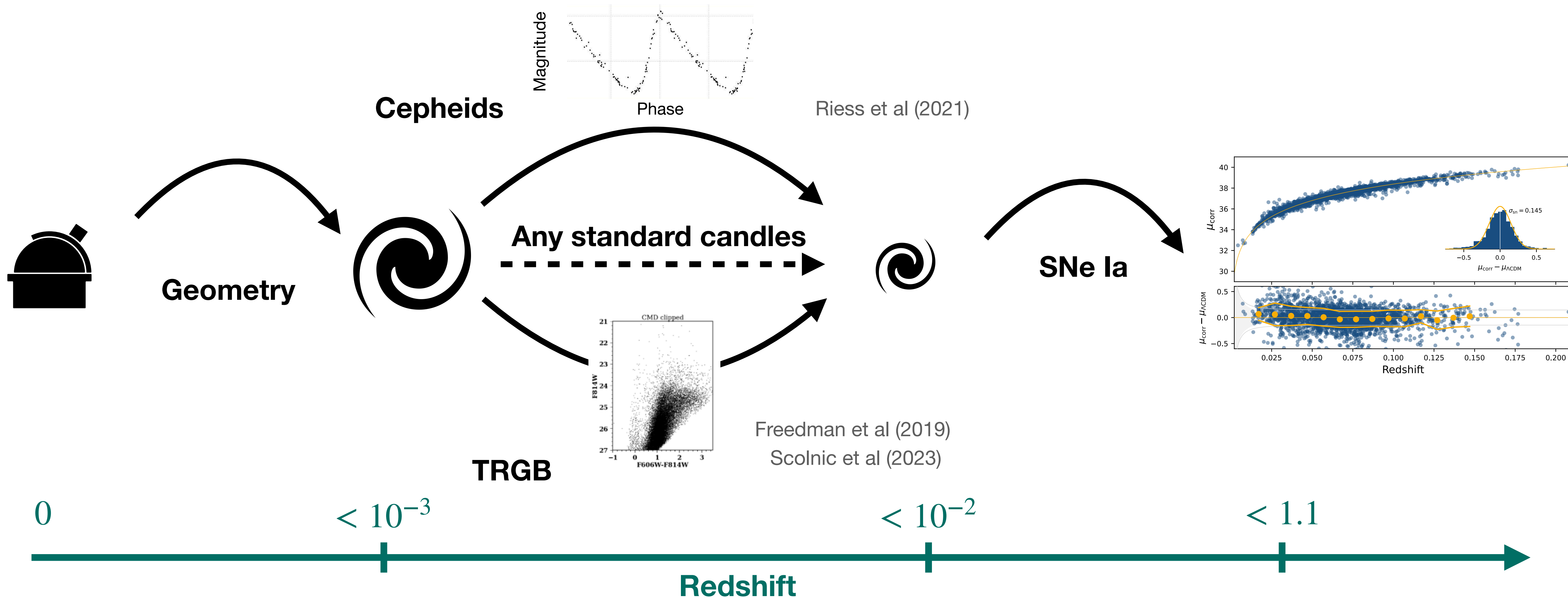
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

(Tripp 1998)

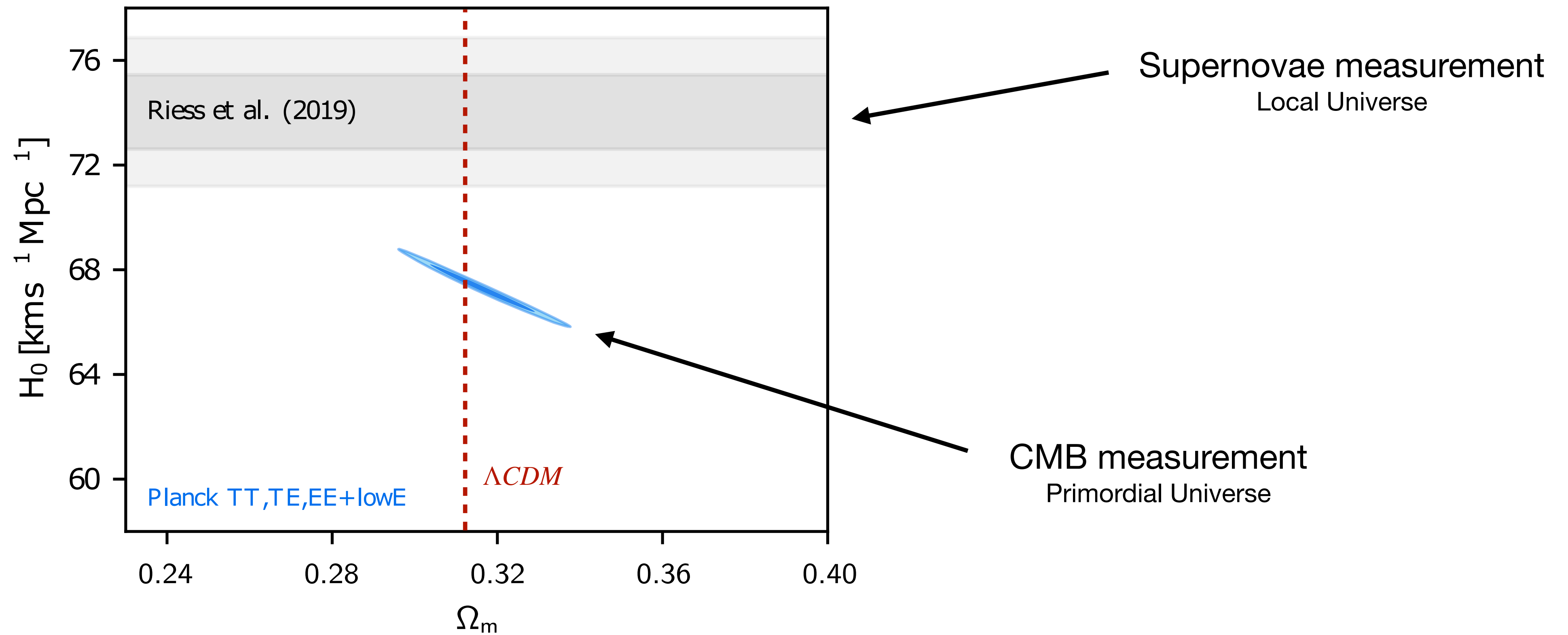


Cosmology with SNe Ia

Anchoring the Hubble diagram

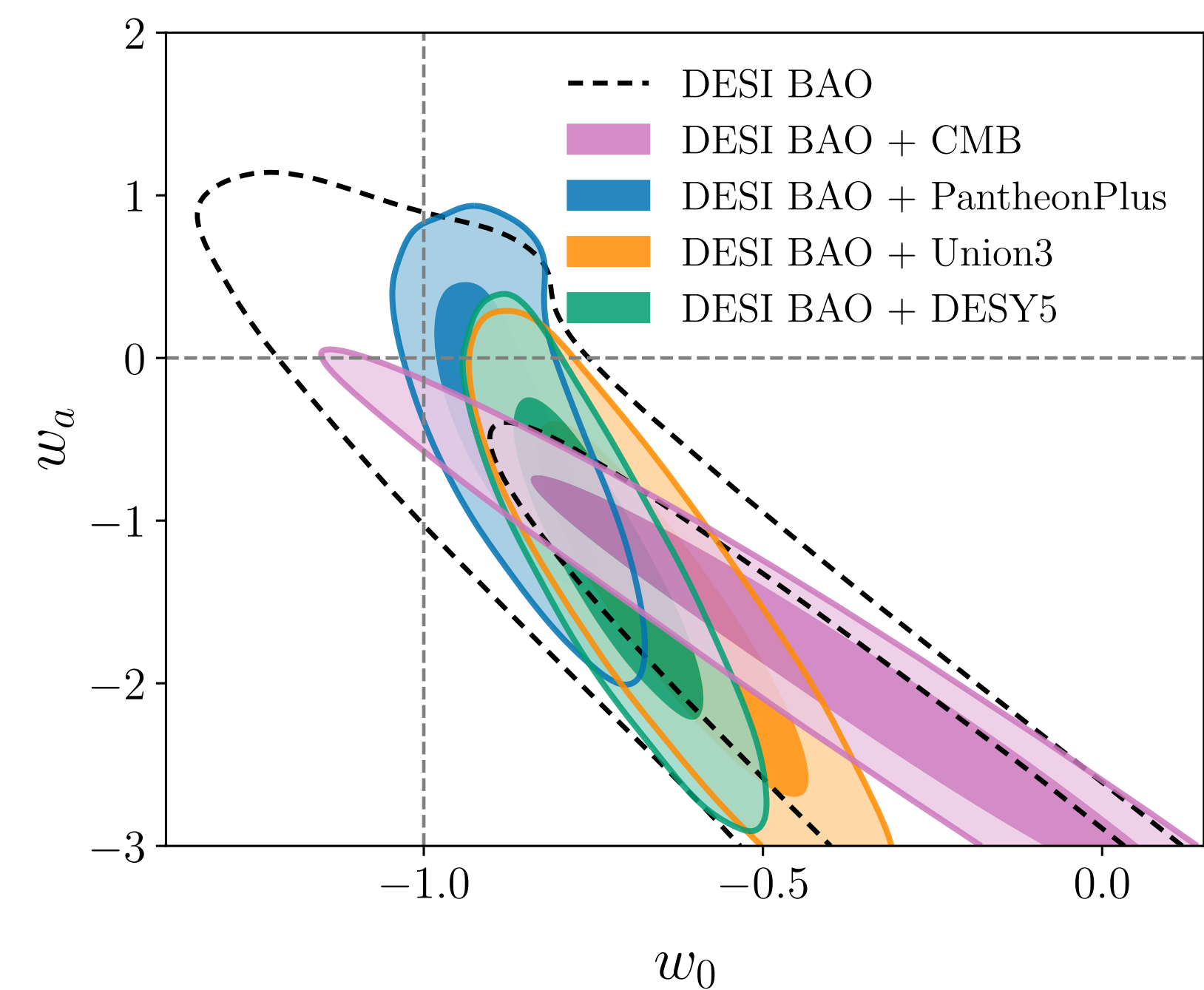
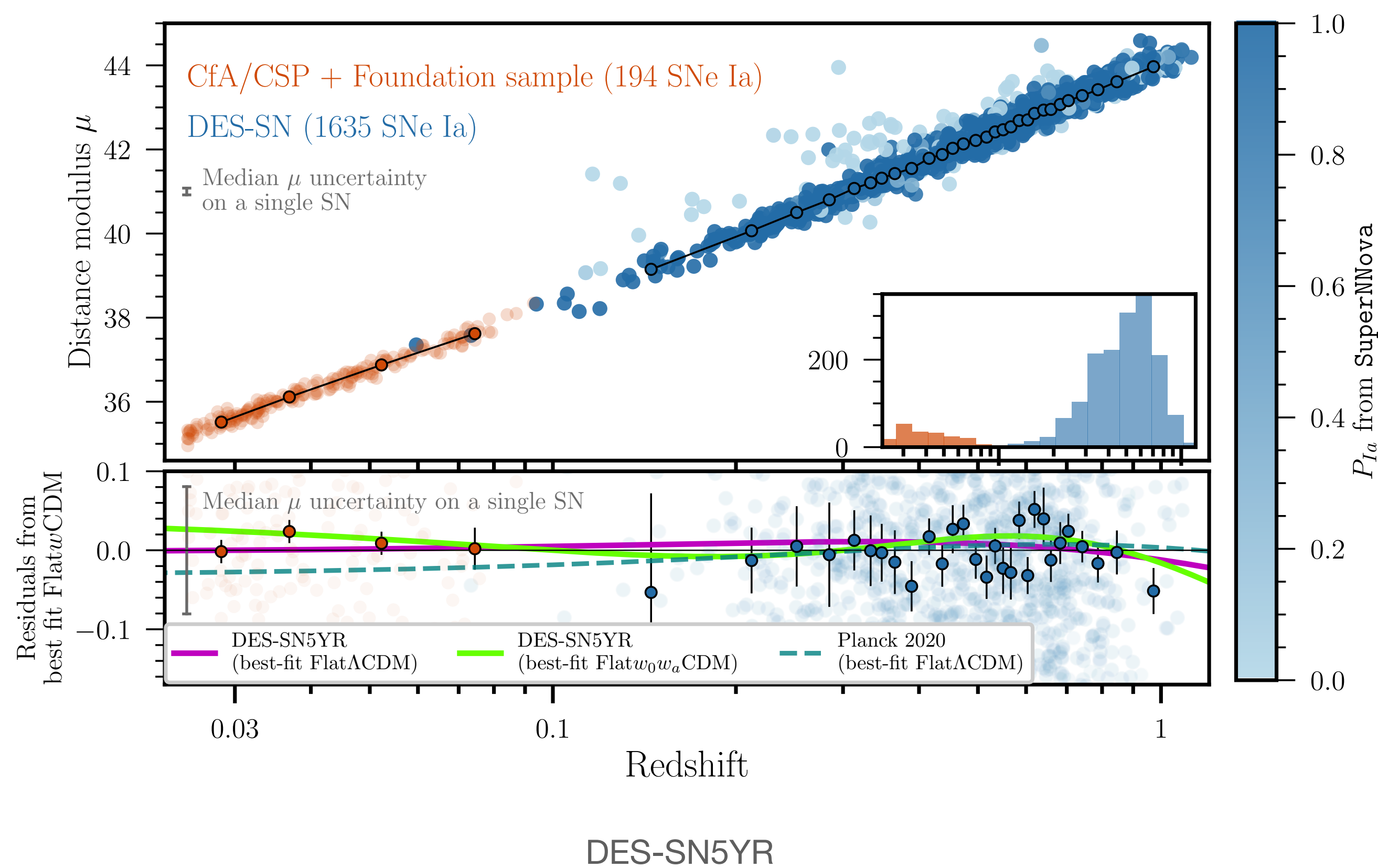


Hubble tension



Adapted from Planck collaboration (2020)

Evolving dark energy?



DESI 2024

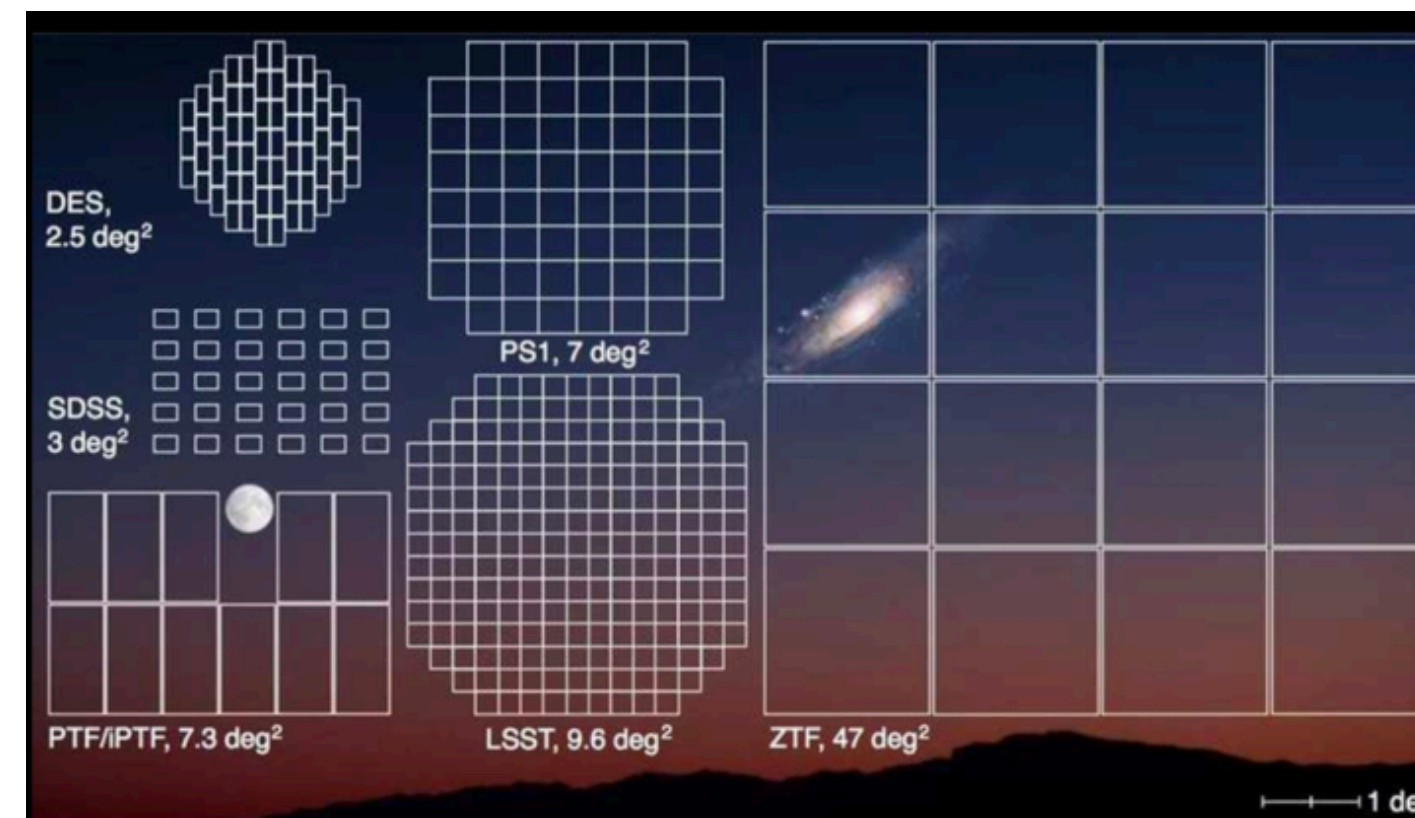
II. ZTF SN Ia DR2

ZTF



Zwicky Transient Facility

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

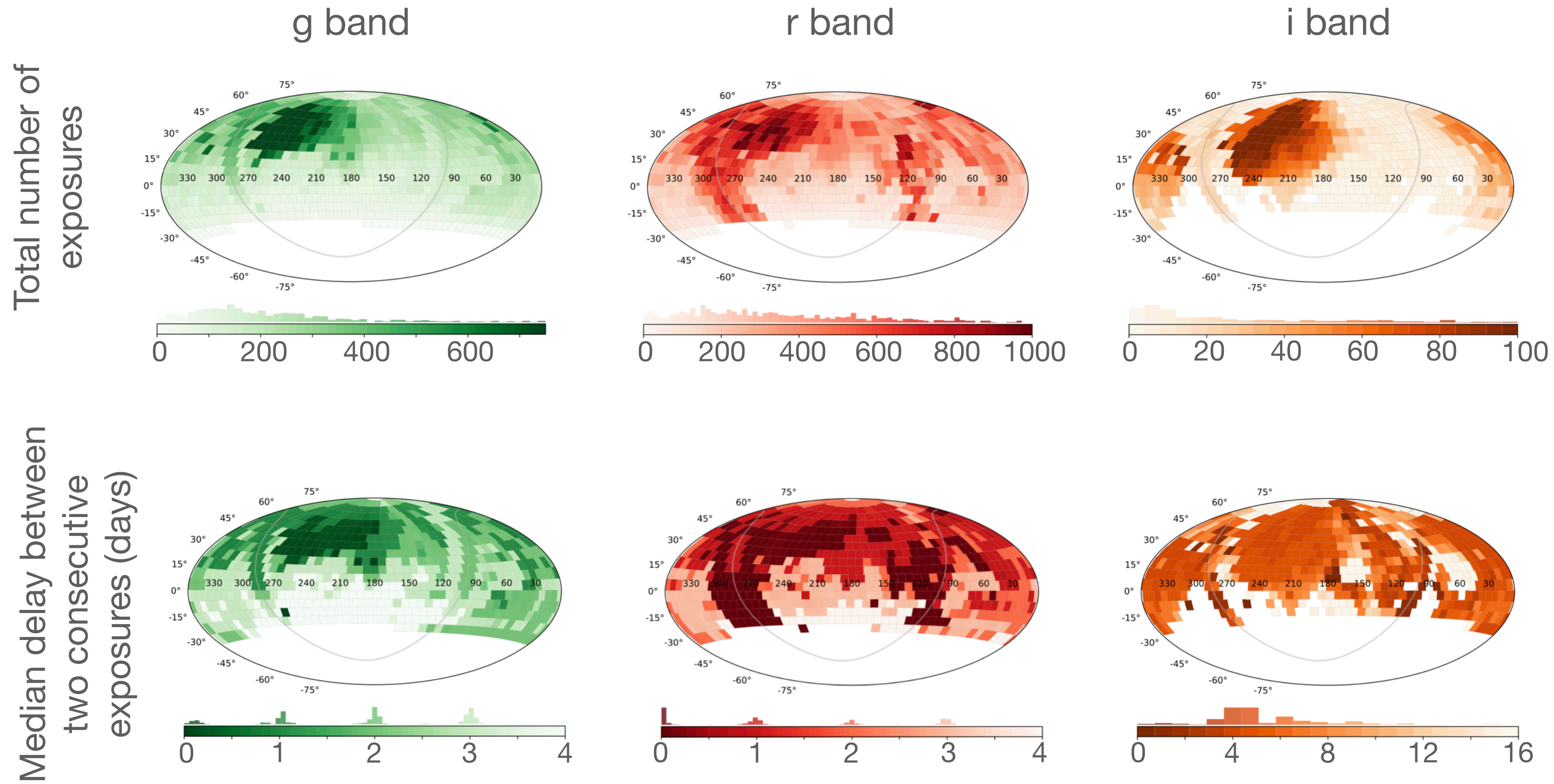


SEDmachine

Low resolution
~1h exposures

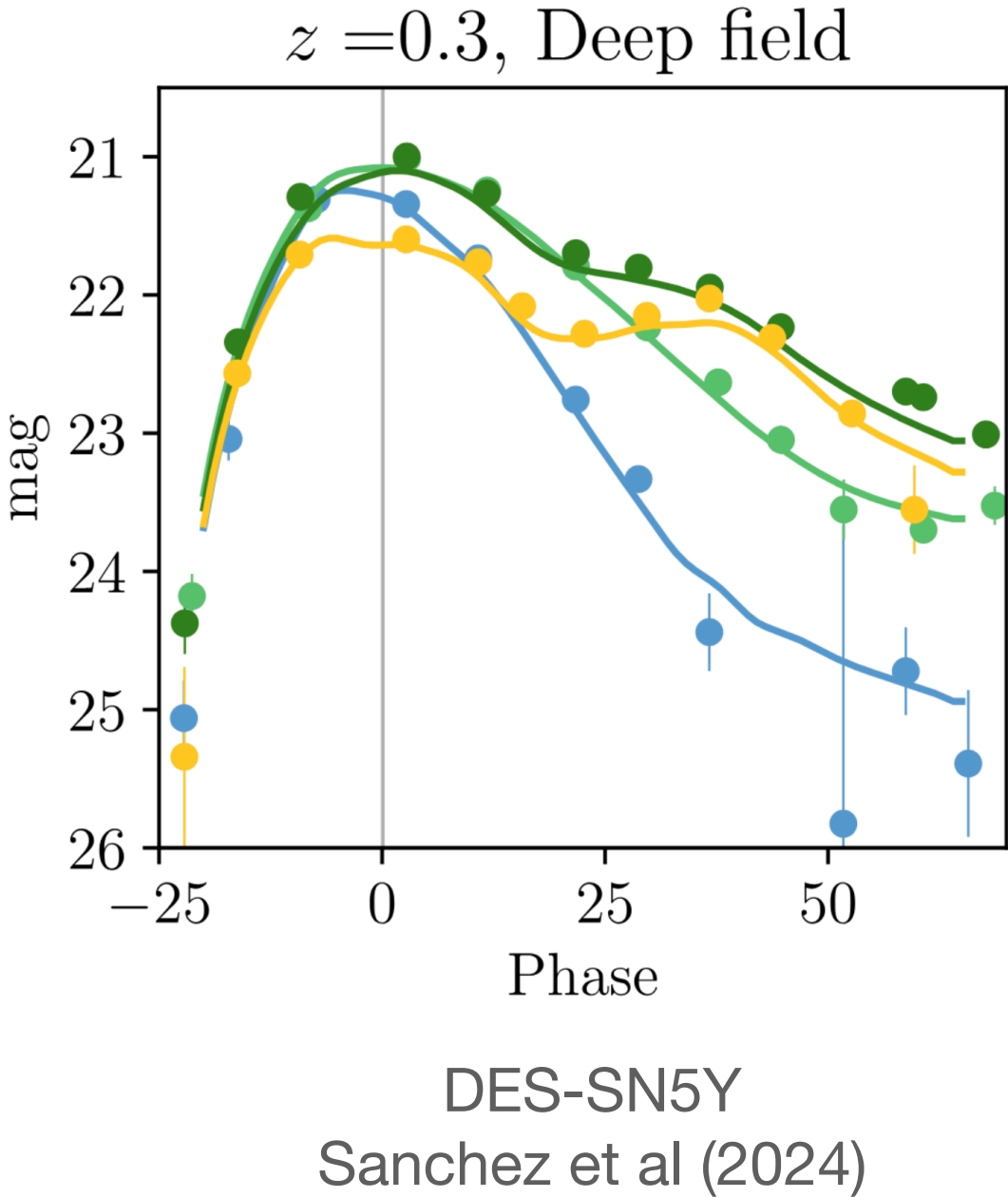
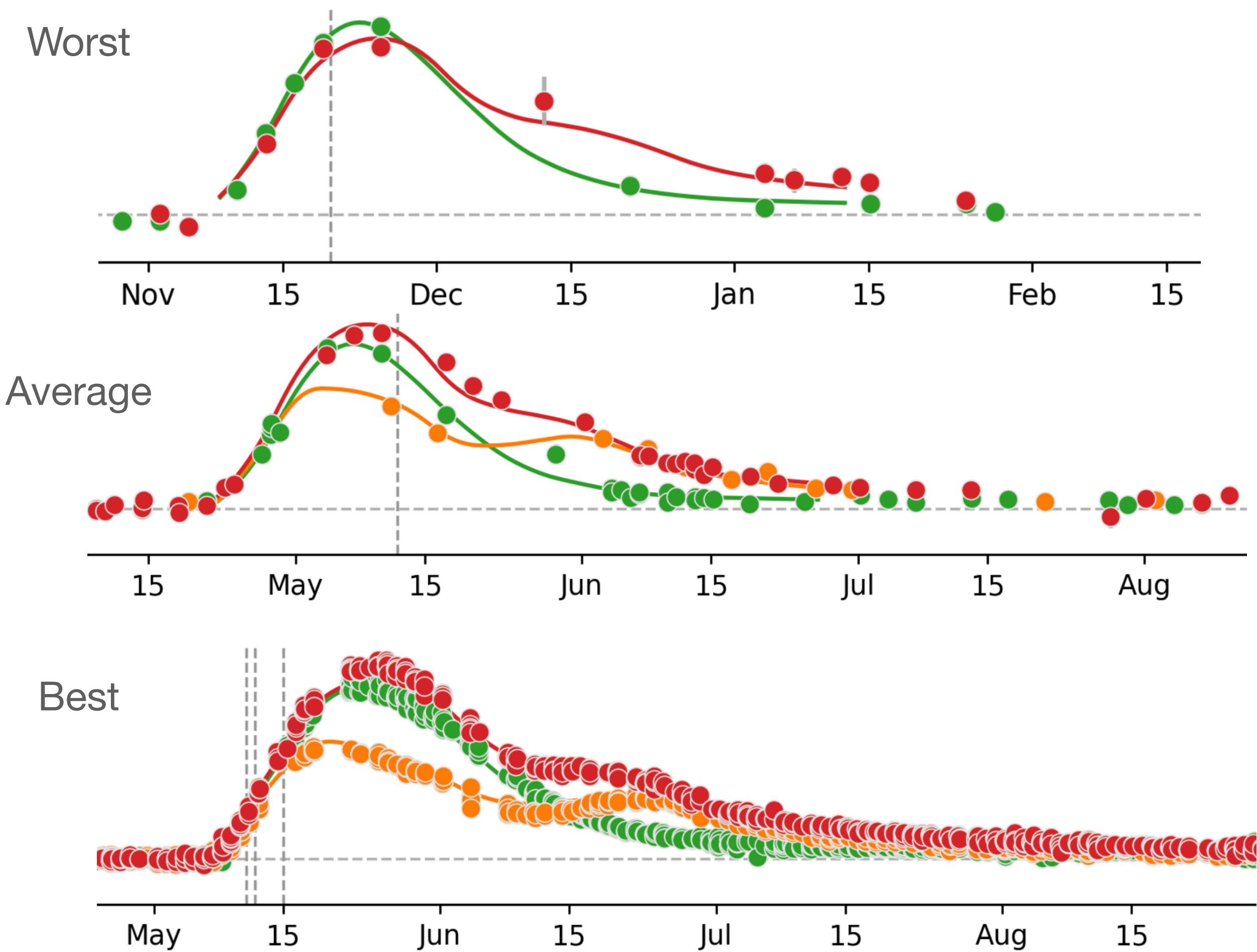
ZTF SN Ia DR2

Cadence



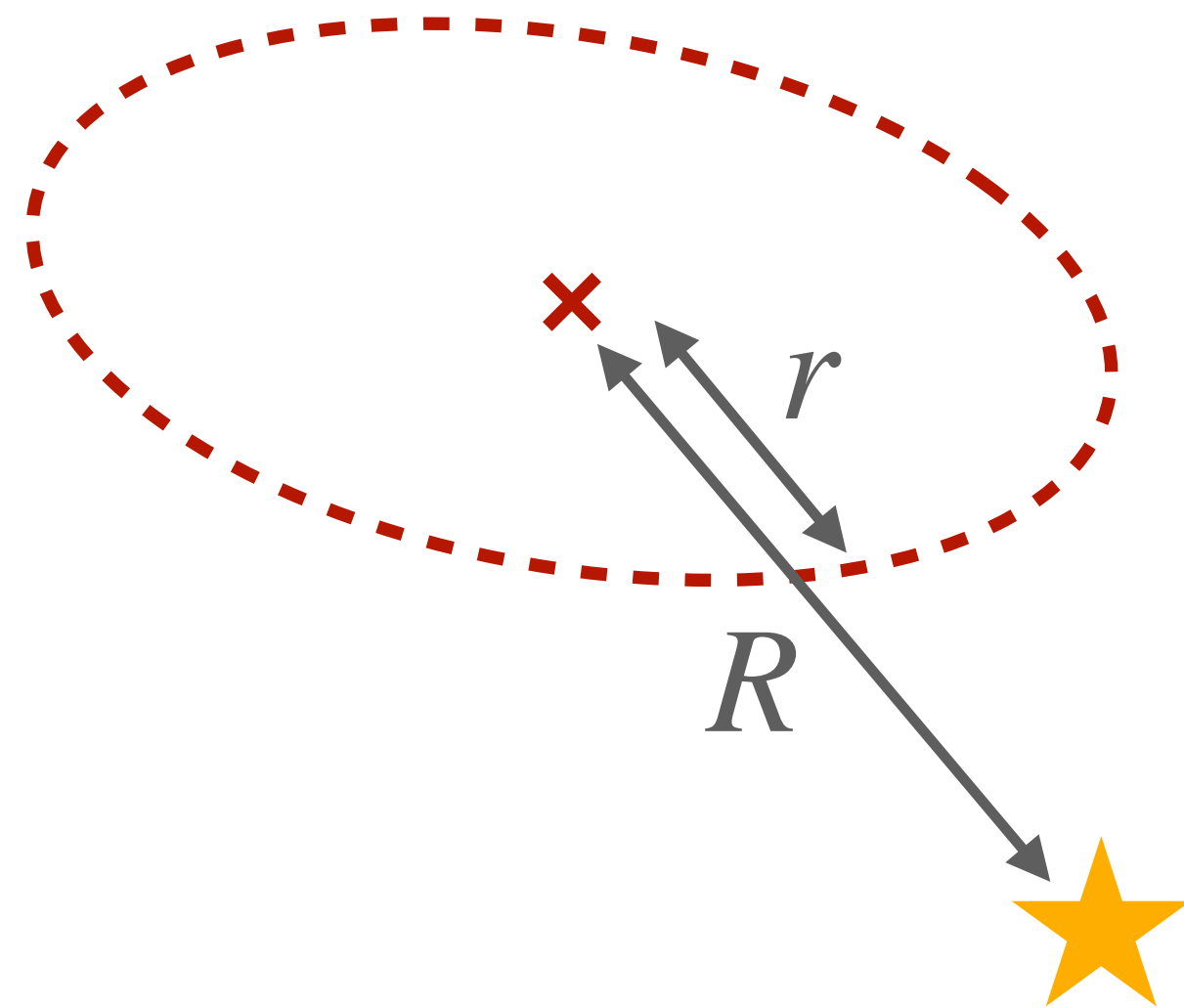
ZTF SN Ia DR2

Lightcurves



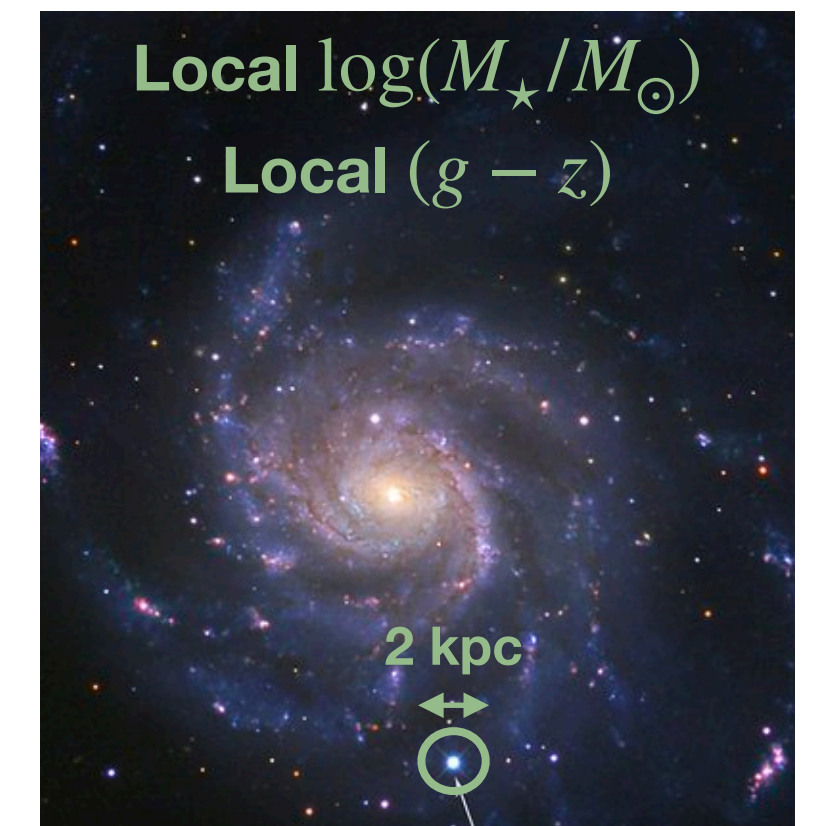
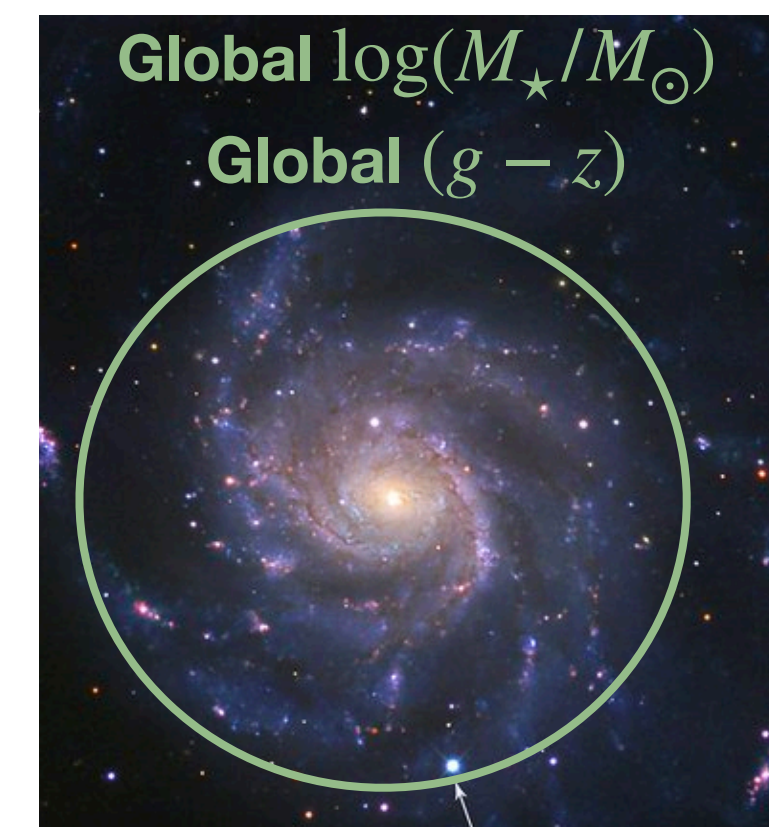
ZTF SN Ia DR2

Environmental properties

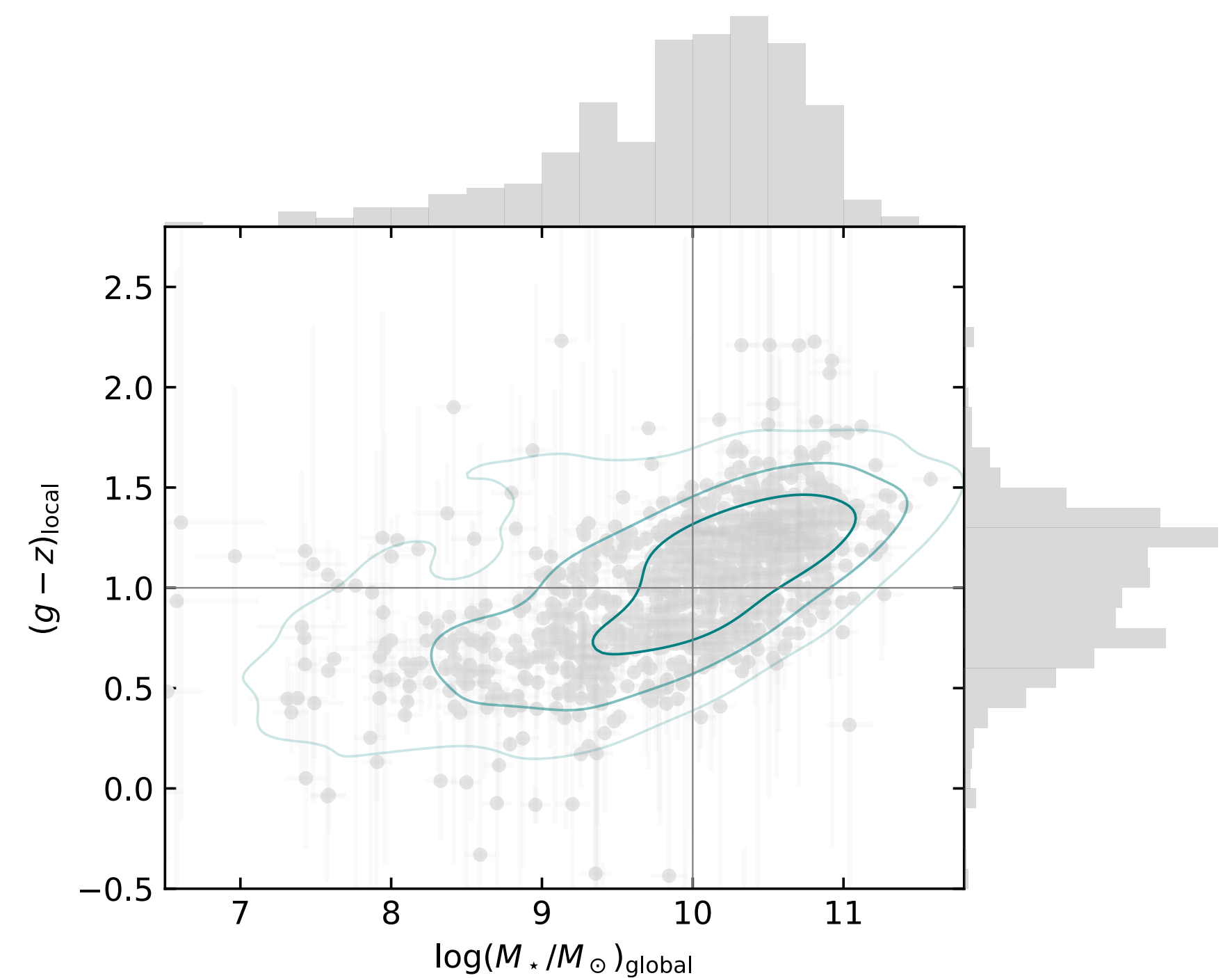


$$\text{dDLR} = \frac{R}{r}$$

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

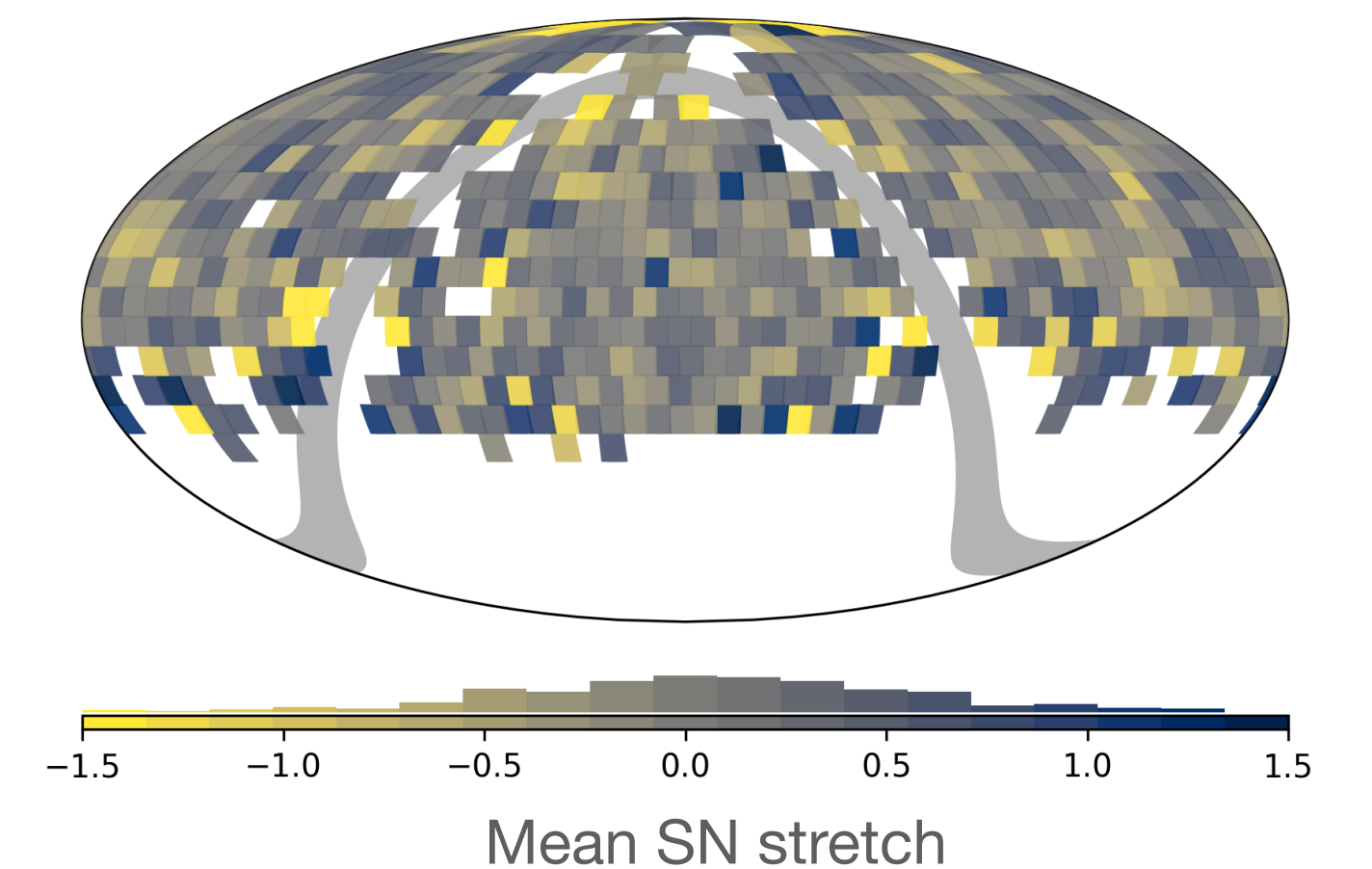
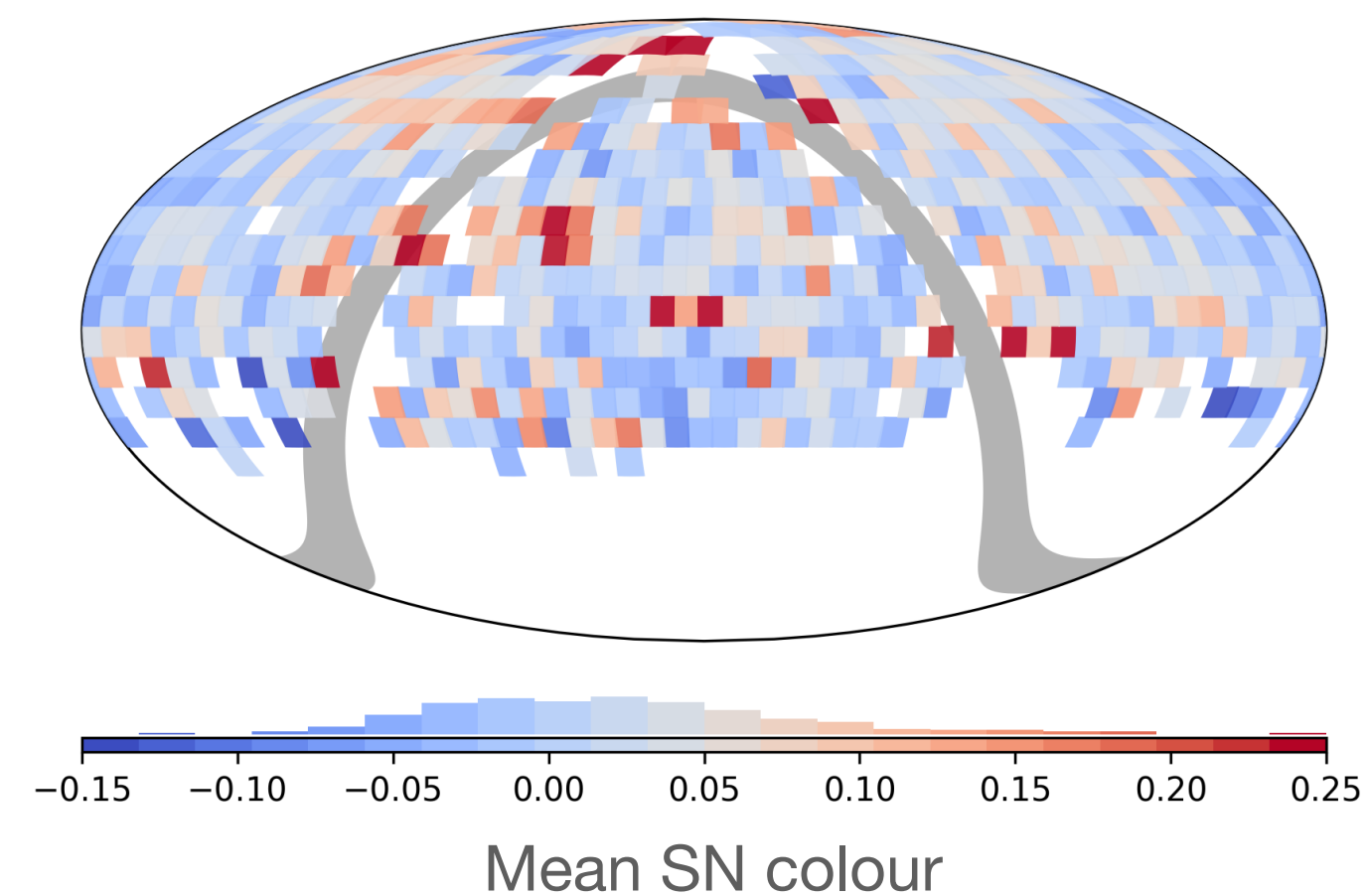
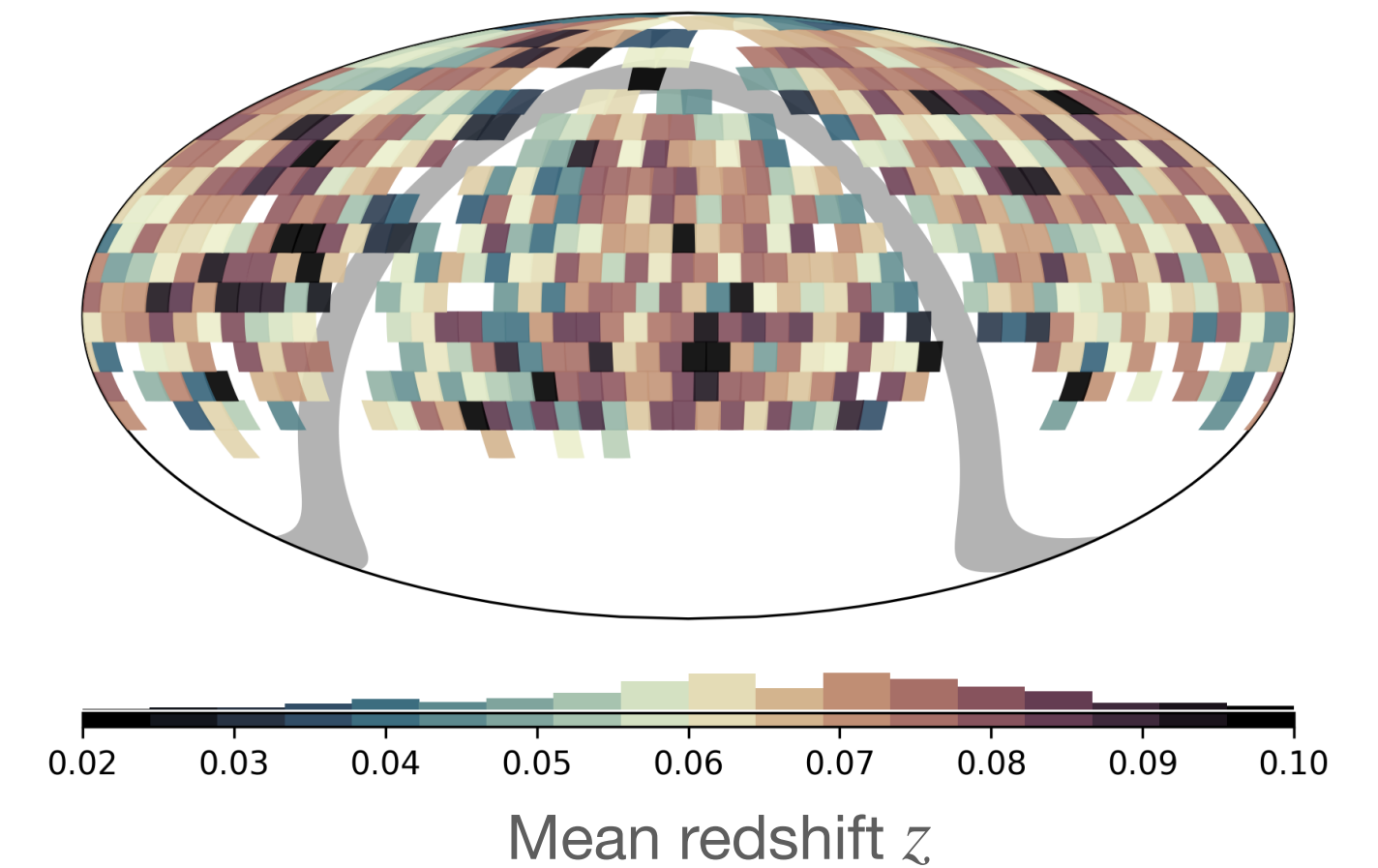
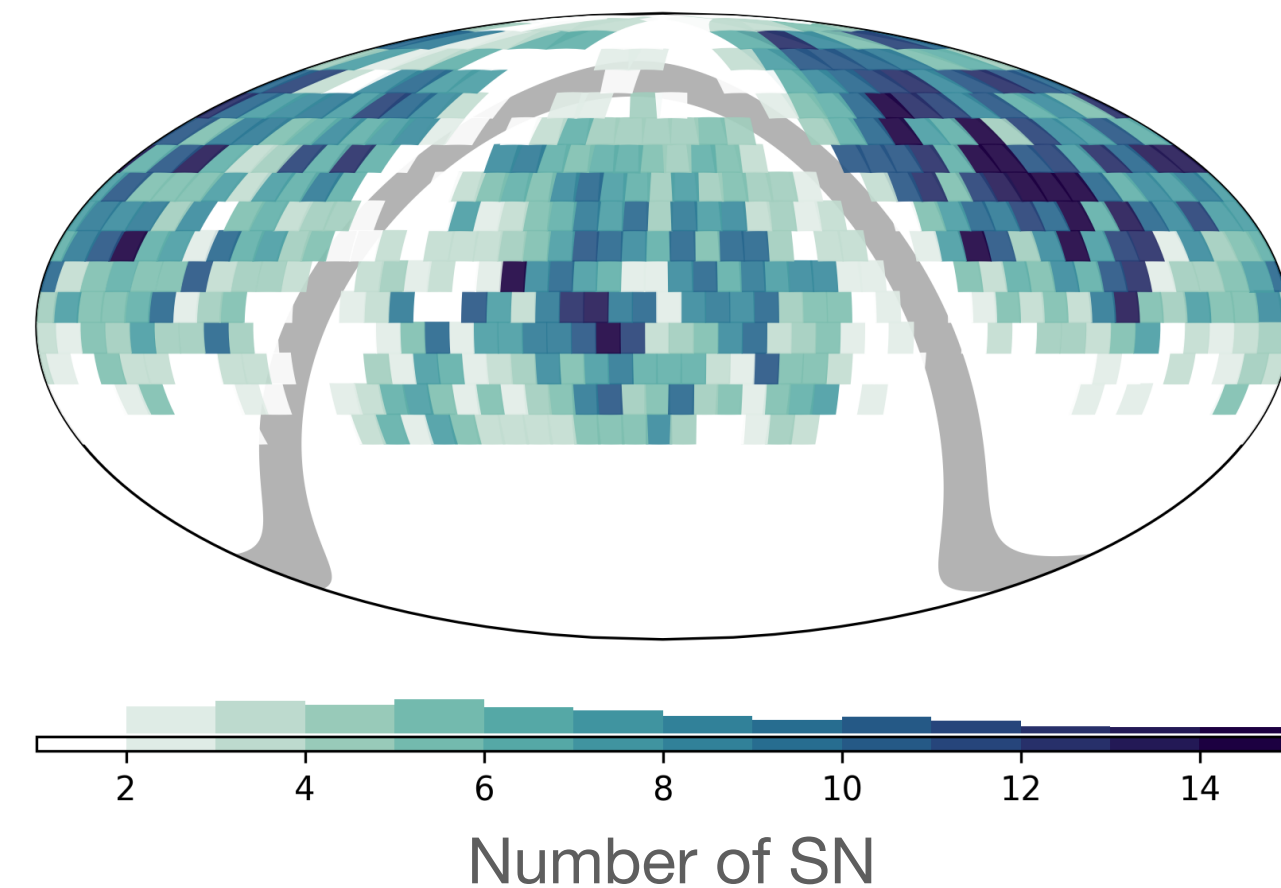
Confirmed SNe Ia

2977 SNe

with well-sampled lightcurves

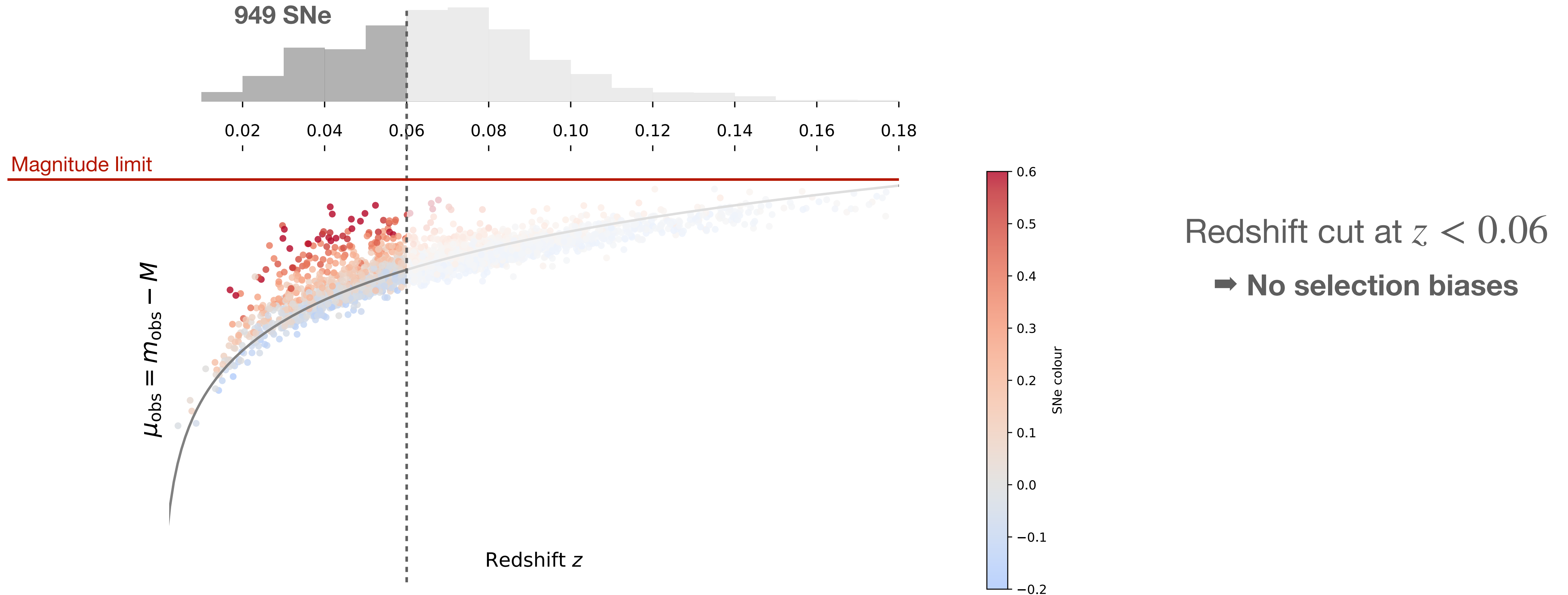
2628 SNe

usable for cosmology



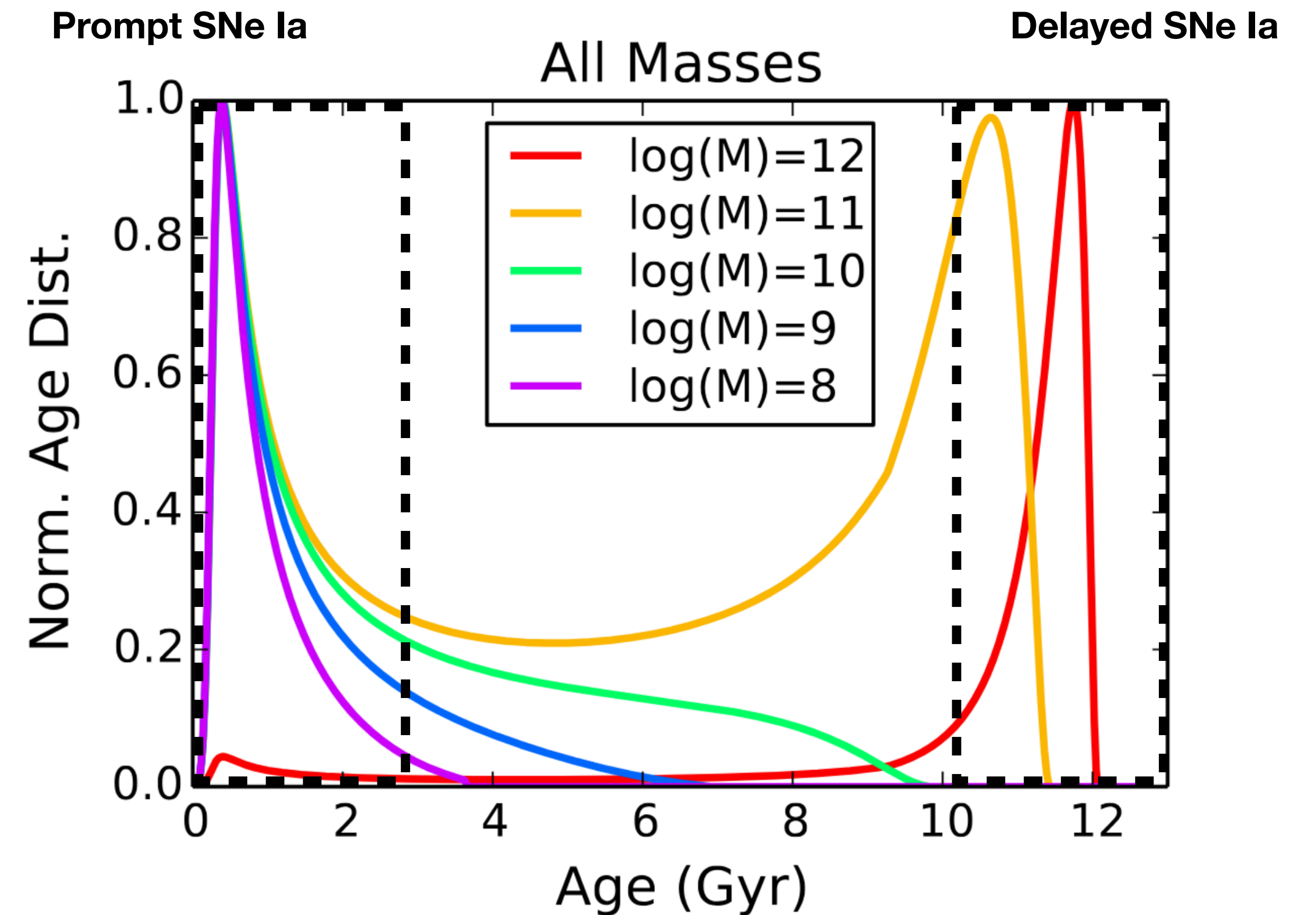
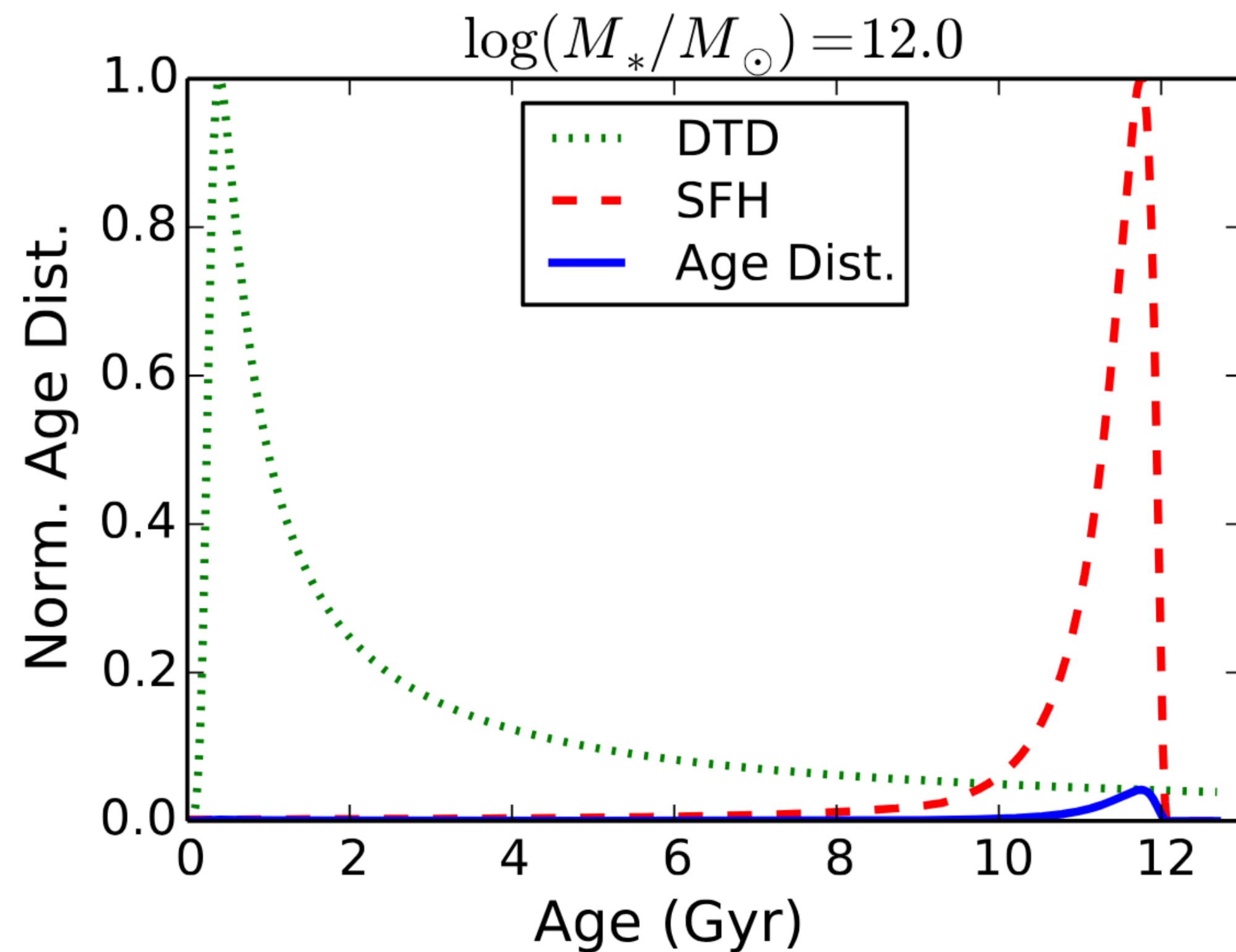
ZTF SN Ia DR2

Volume limited sample



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

Two population model



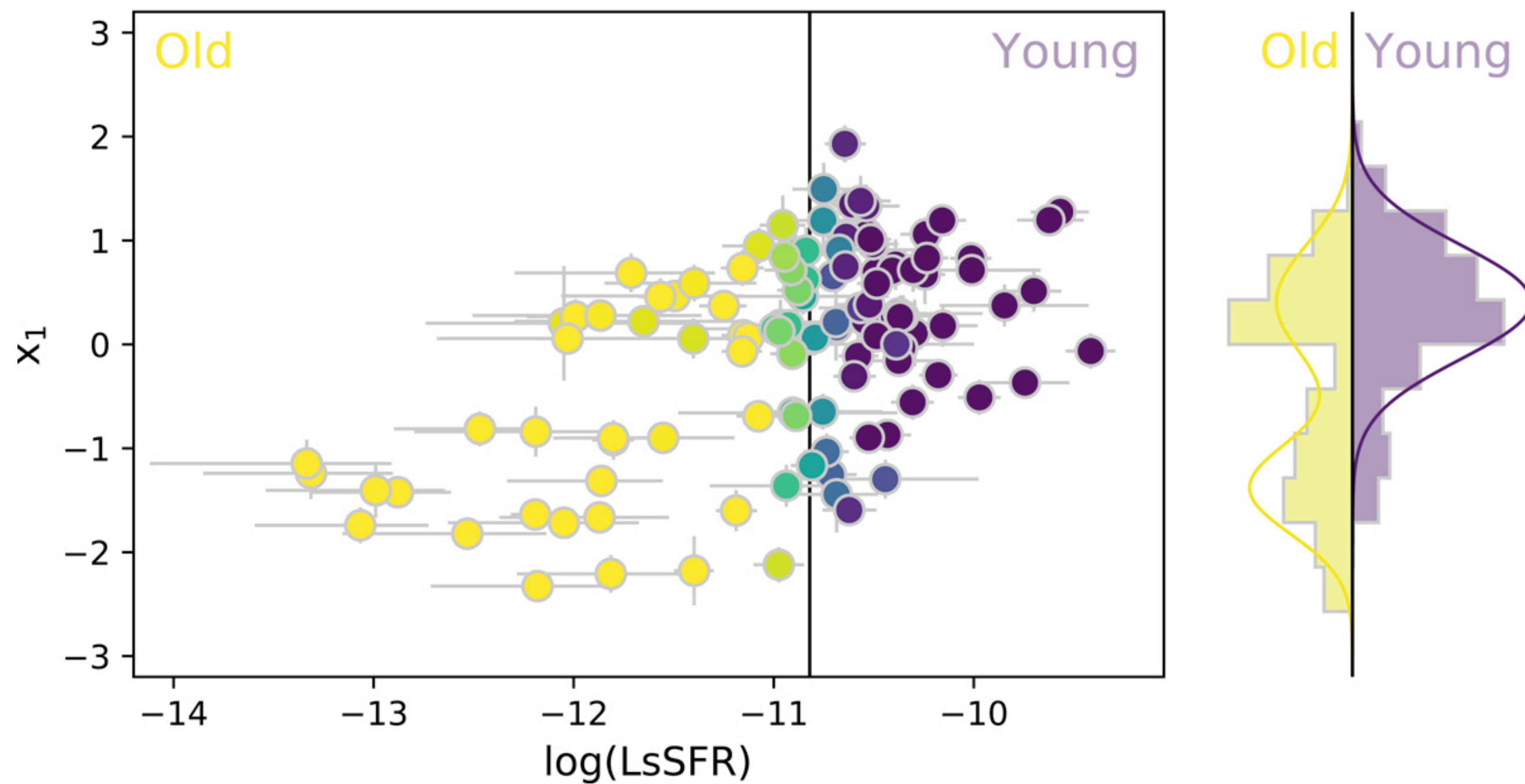
Childress et al (2014)

Mannucci et al (2005)

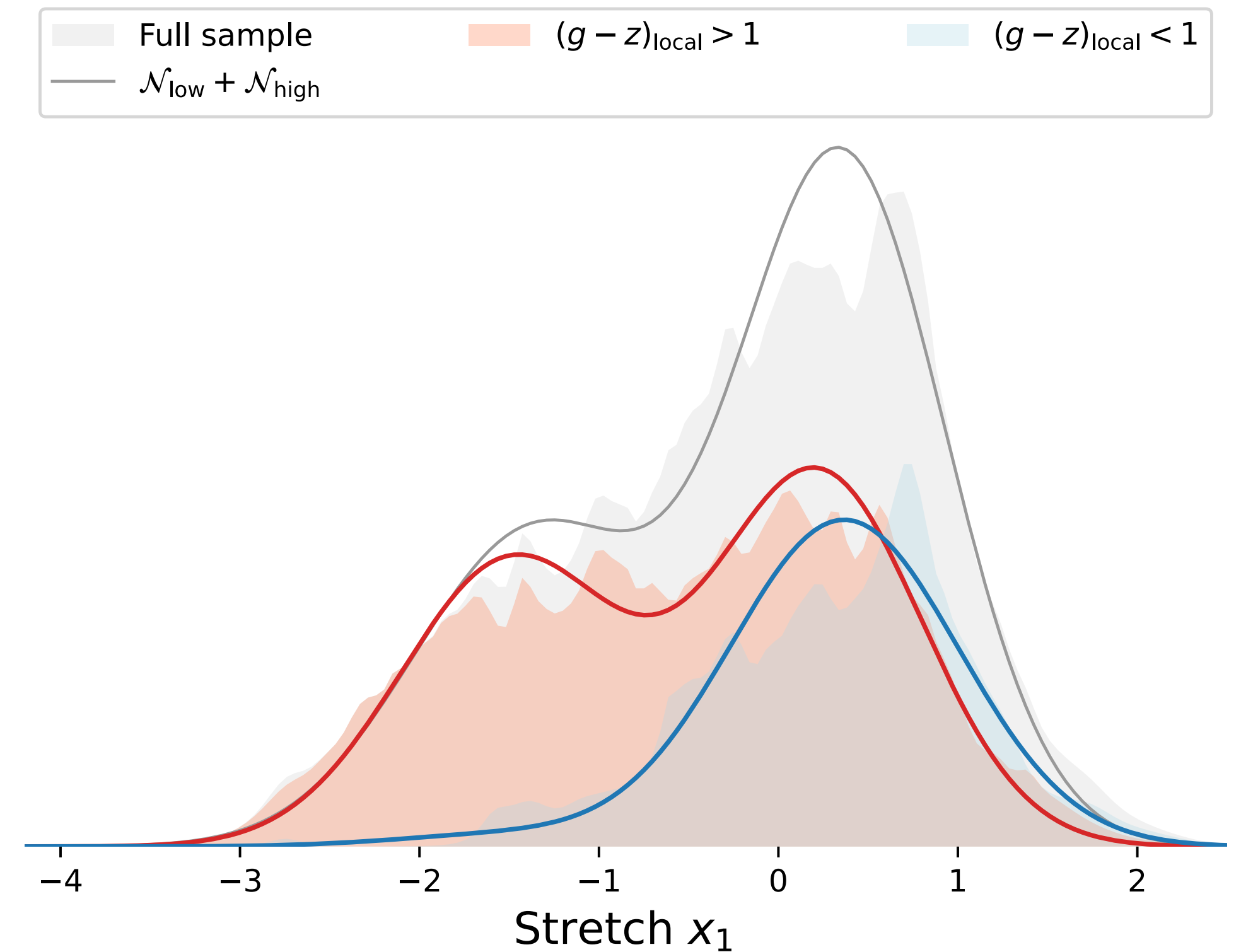
Stretch

Stretch distribution

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



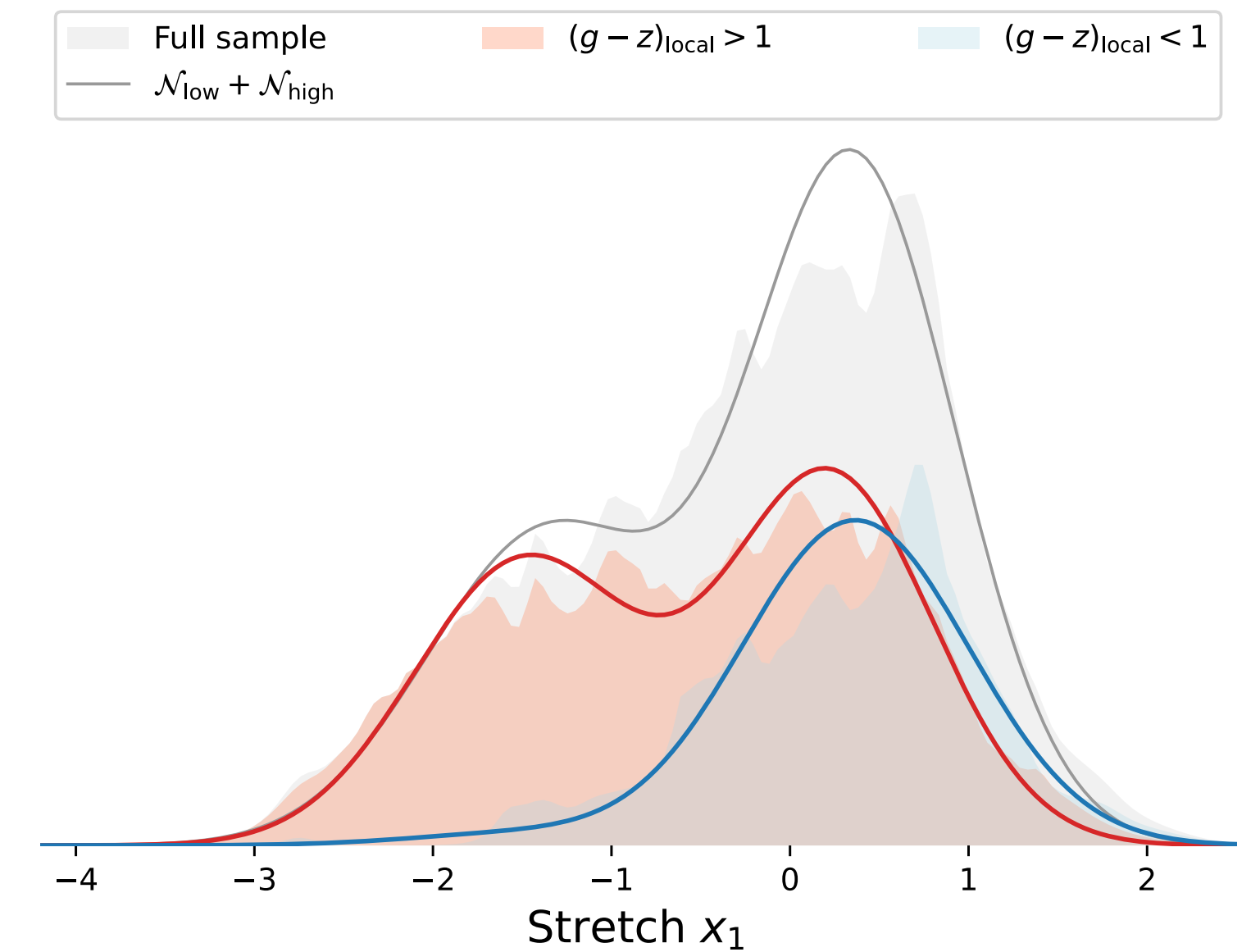
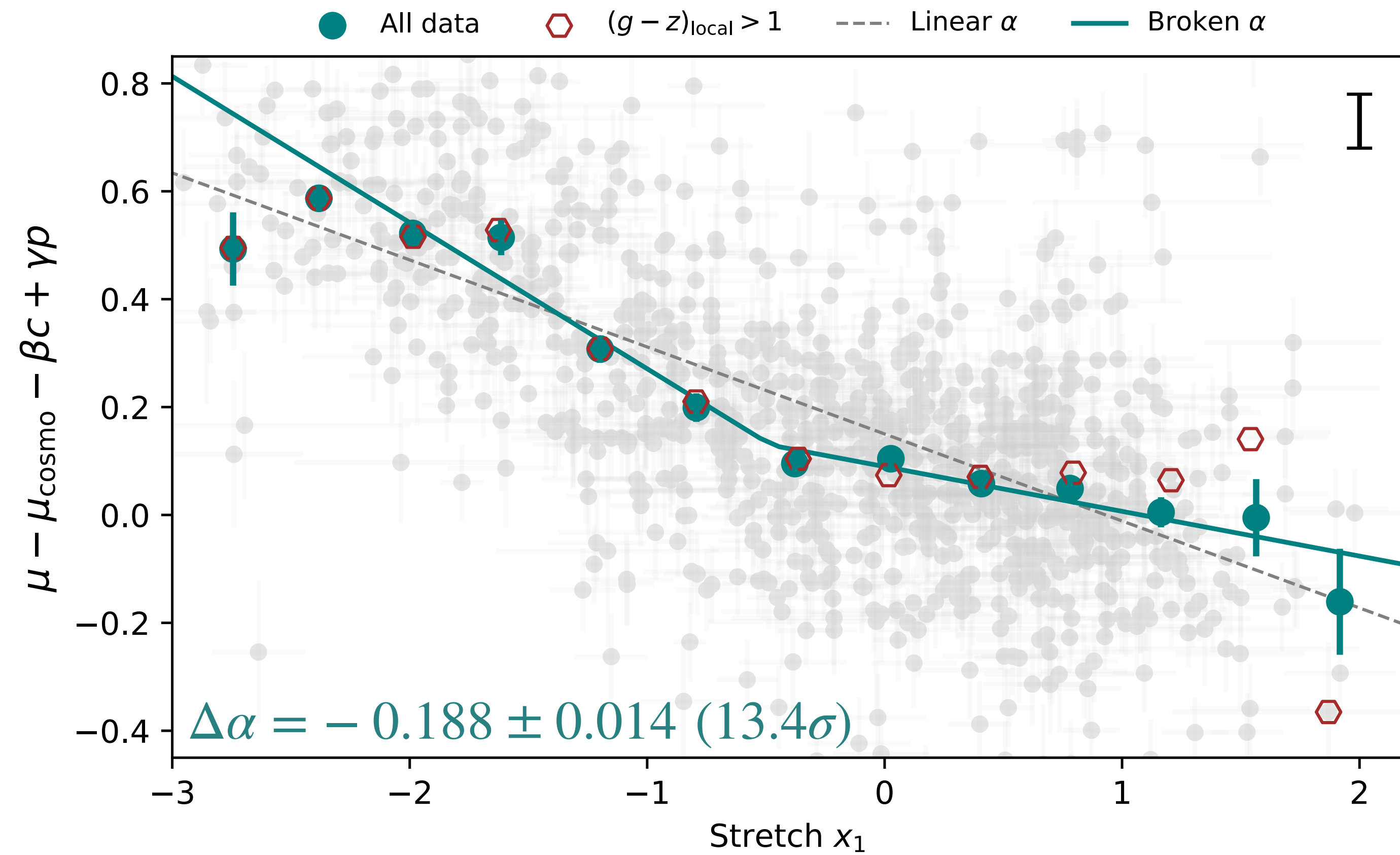
Nicolas et al (2021)
SnFactory - 114 SNe



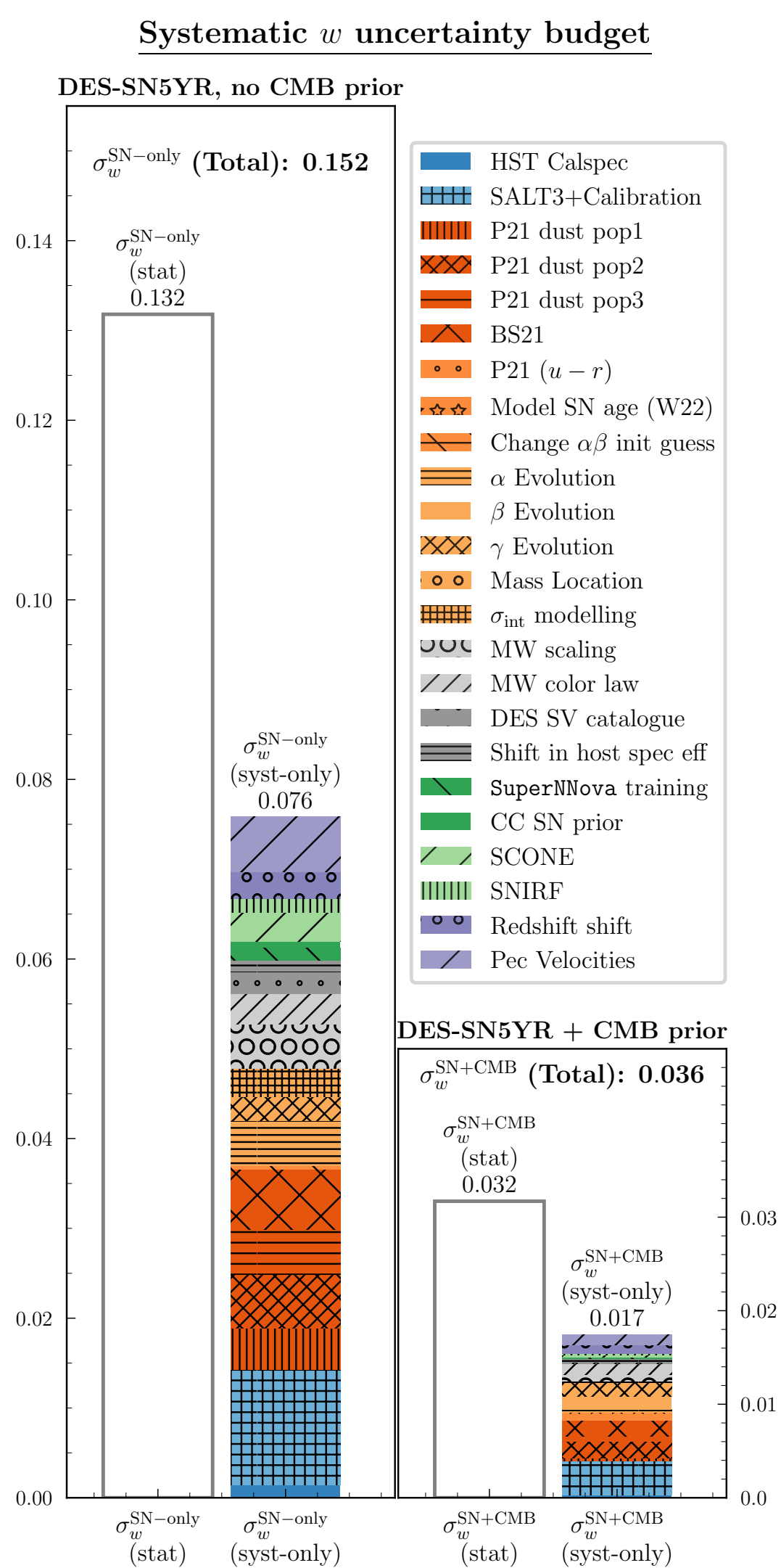
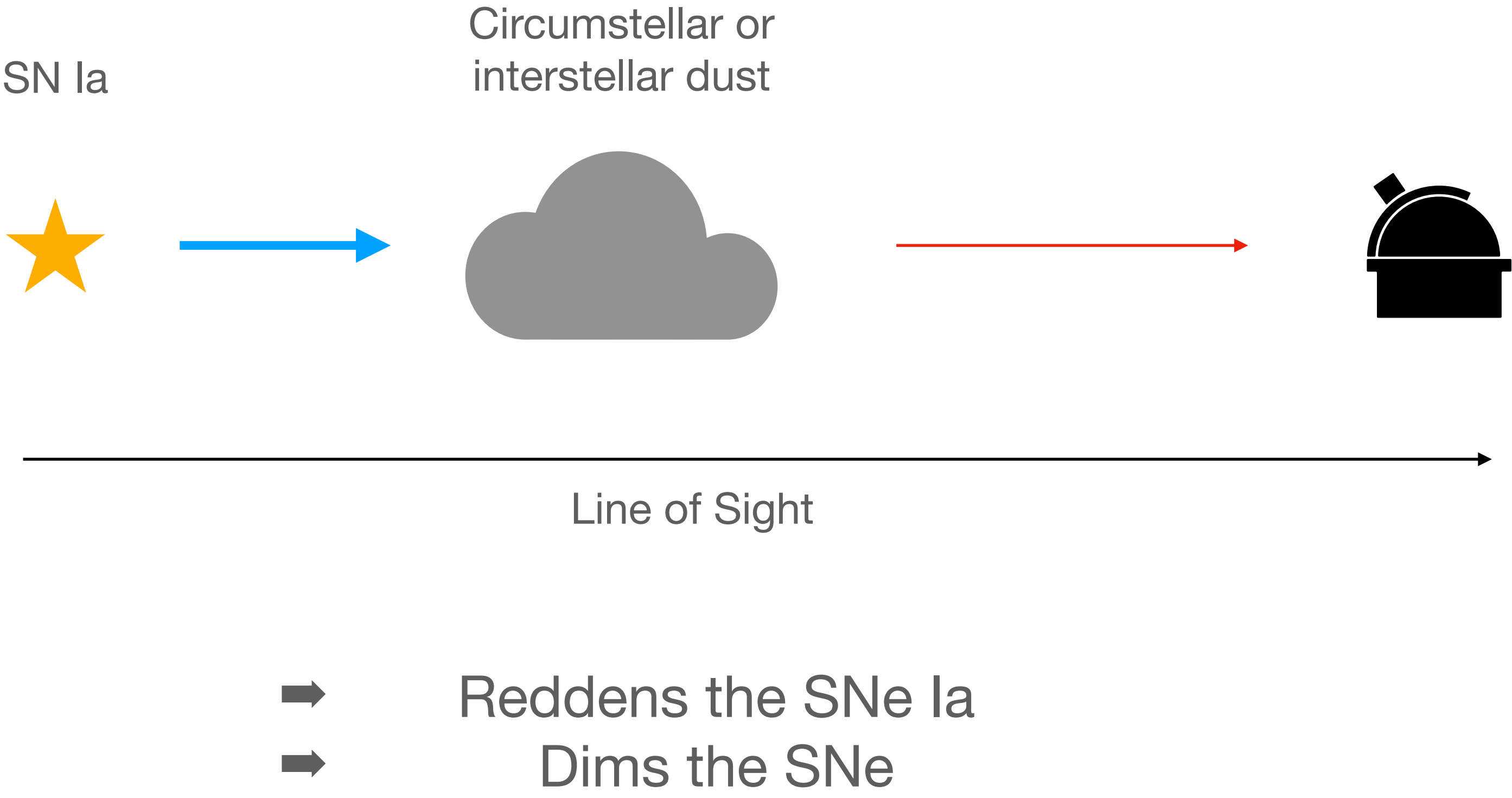
Stretch

Non linearity of the stretch-residuals relation

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



Dust

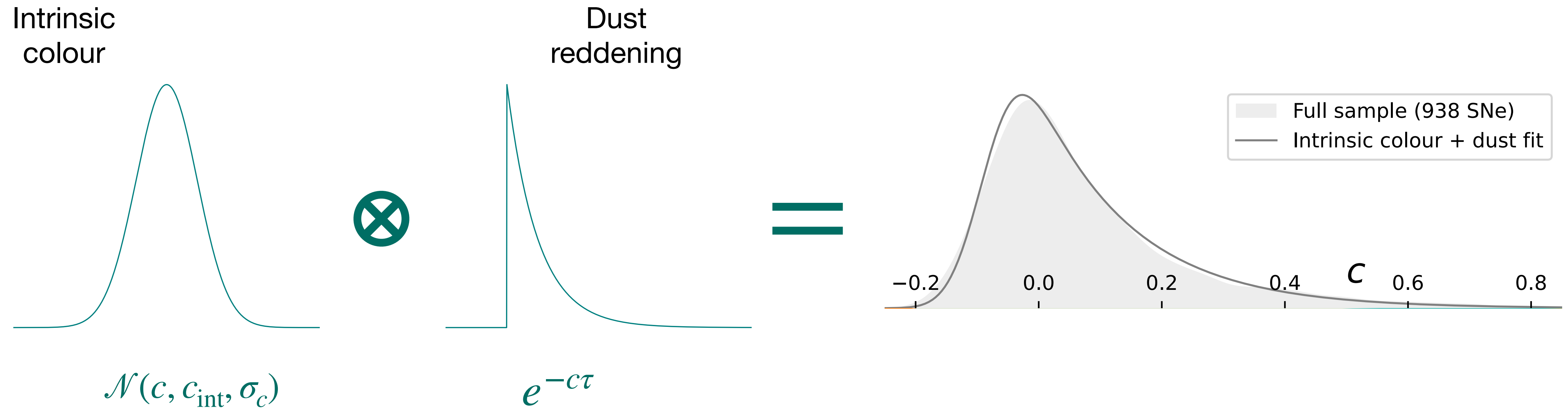


Vincenzi et al (2024)

Colour

Colour distribution

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

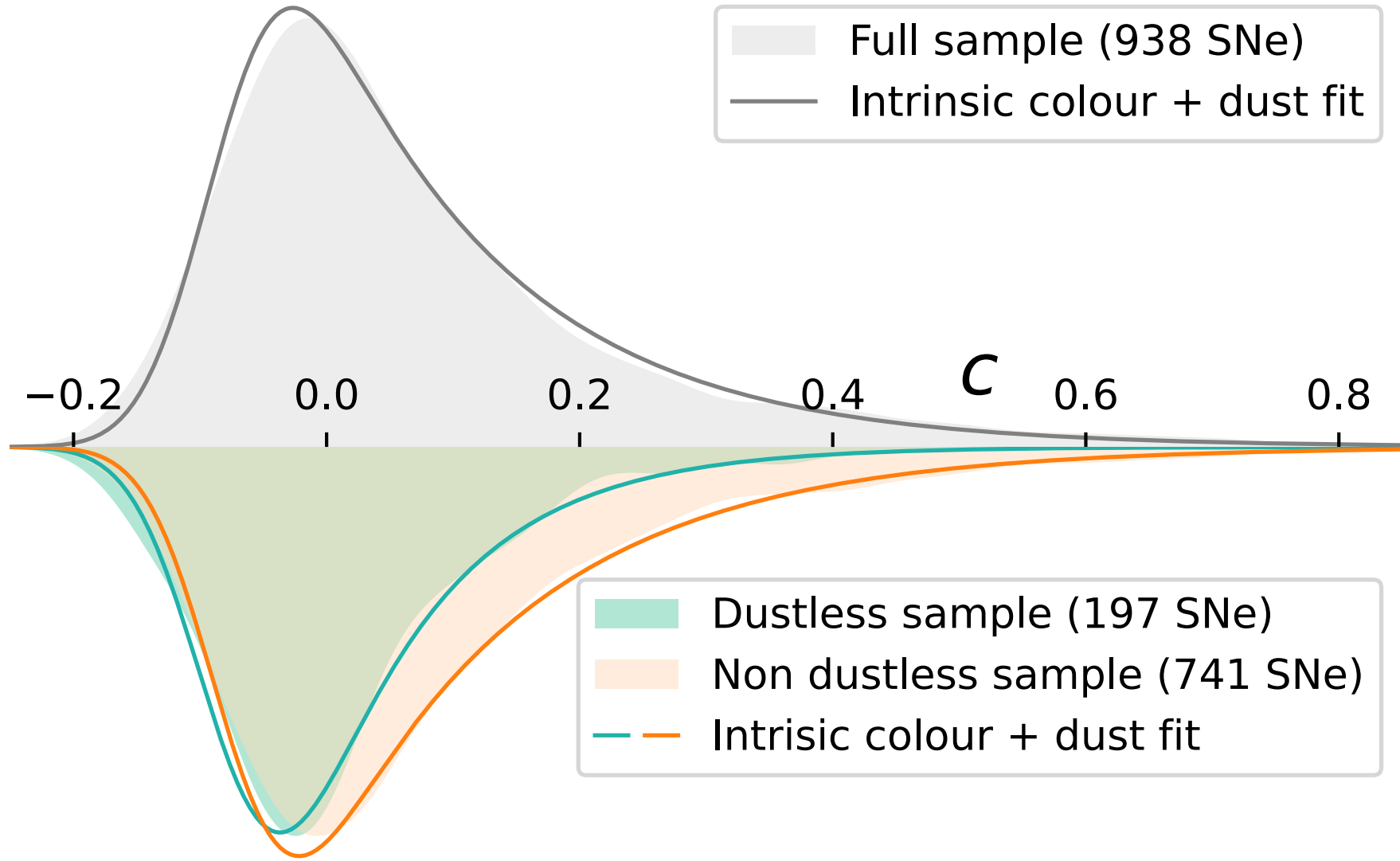


Jha et al. (2007)
Mandel et al. (2011)
Brout & Scolnic (2021)

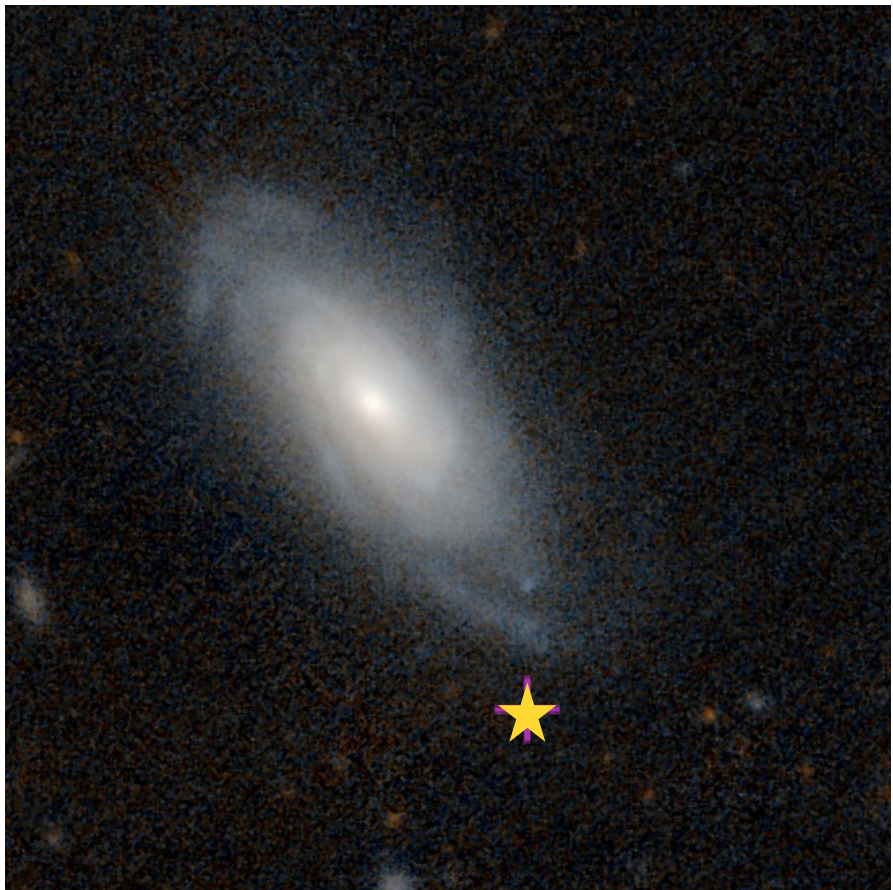
Colour

Dependence on environment

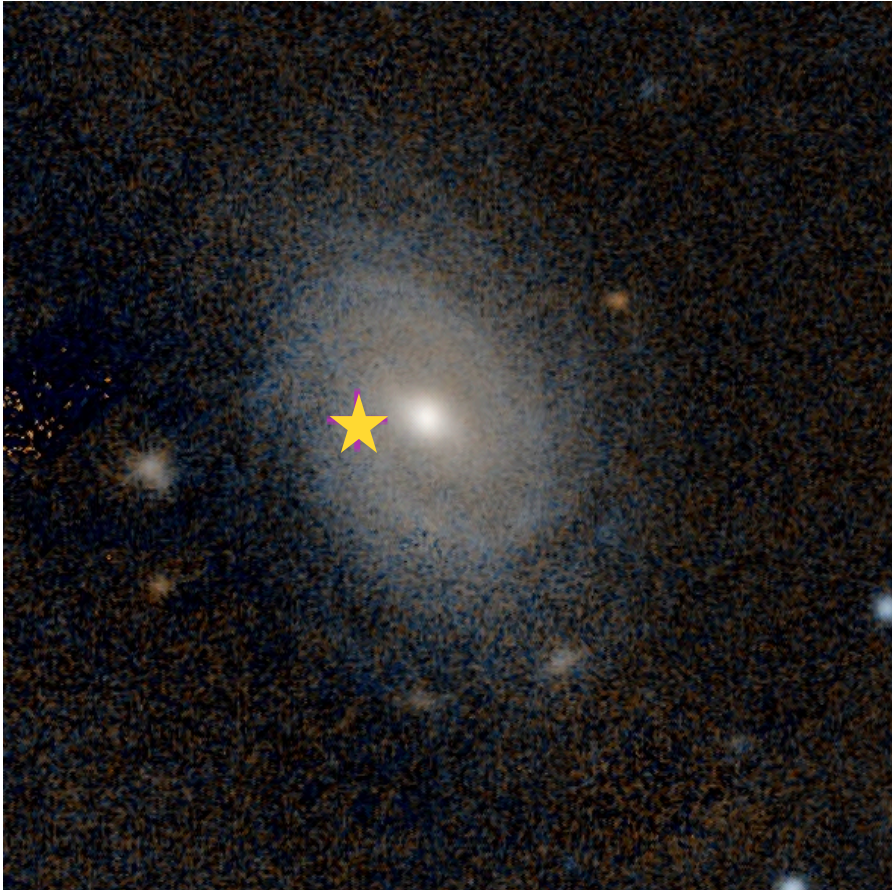
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$



« Dustless » example



« Non dustless » example

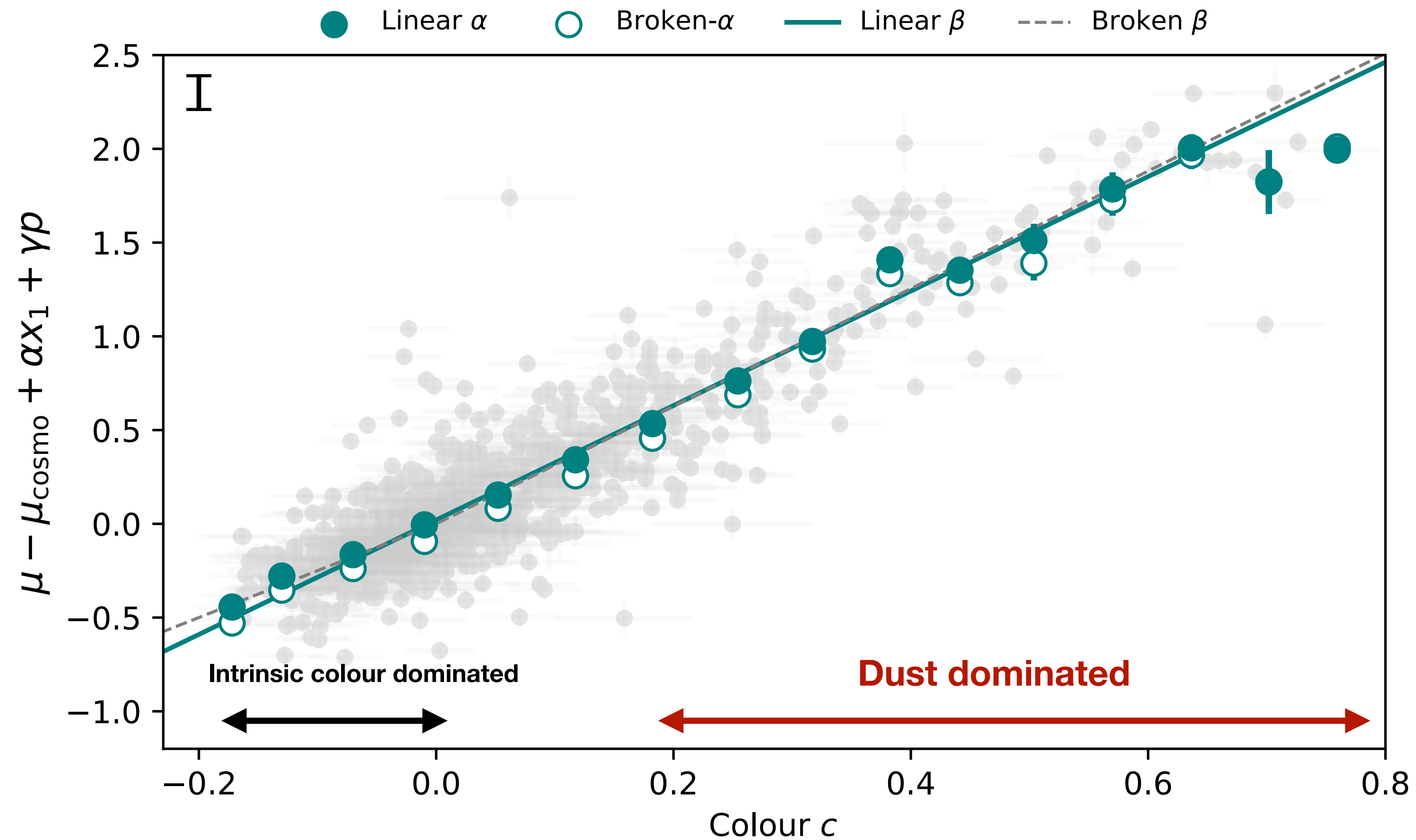


Sample	c_{int}	σ_c	τ
Full sample	-0.085 ± 0.004	0.030 ± 0.005	0.155 ± 0.007
Dustless* sample	-0.087 ± 0.008	0.033 ± 0.008	0.102 ± 0.010
Non dustless sample	-0.082 ± 0.005	0.029 ± 0.006	0.166 ± 0.008

Colour

Linearity of the colour-residuals relation

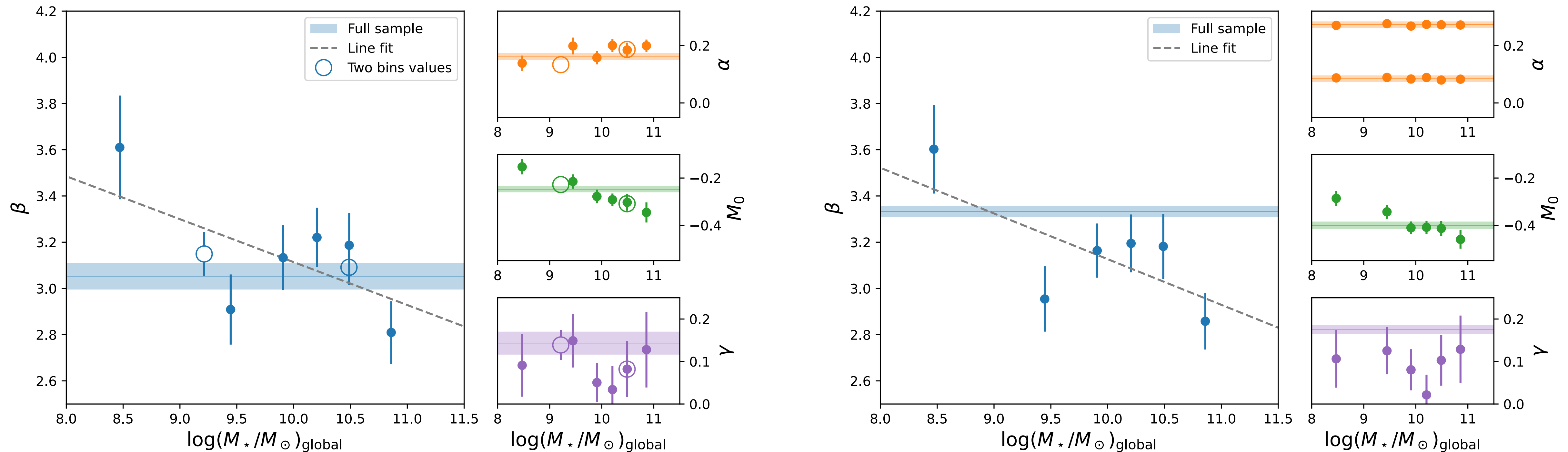
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$



Colour

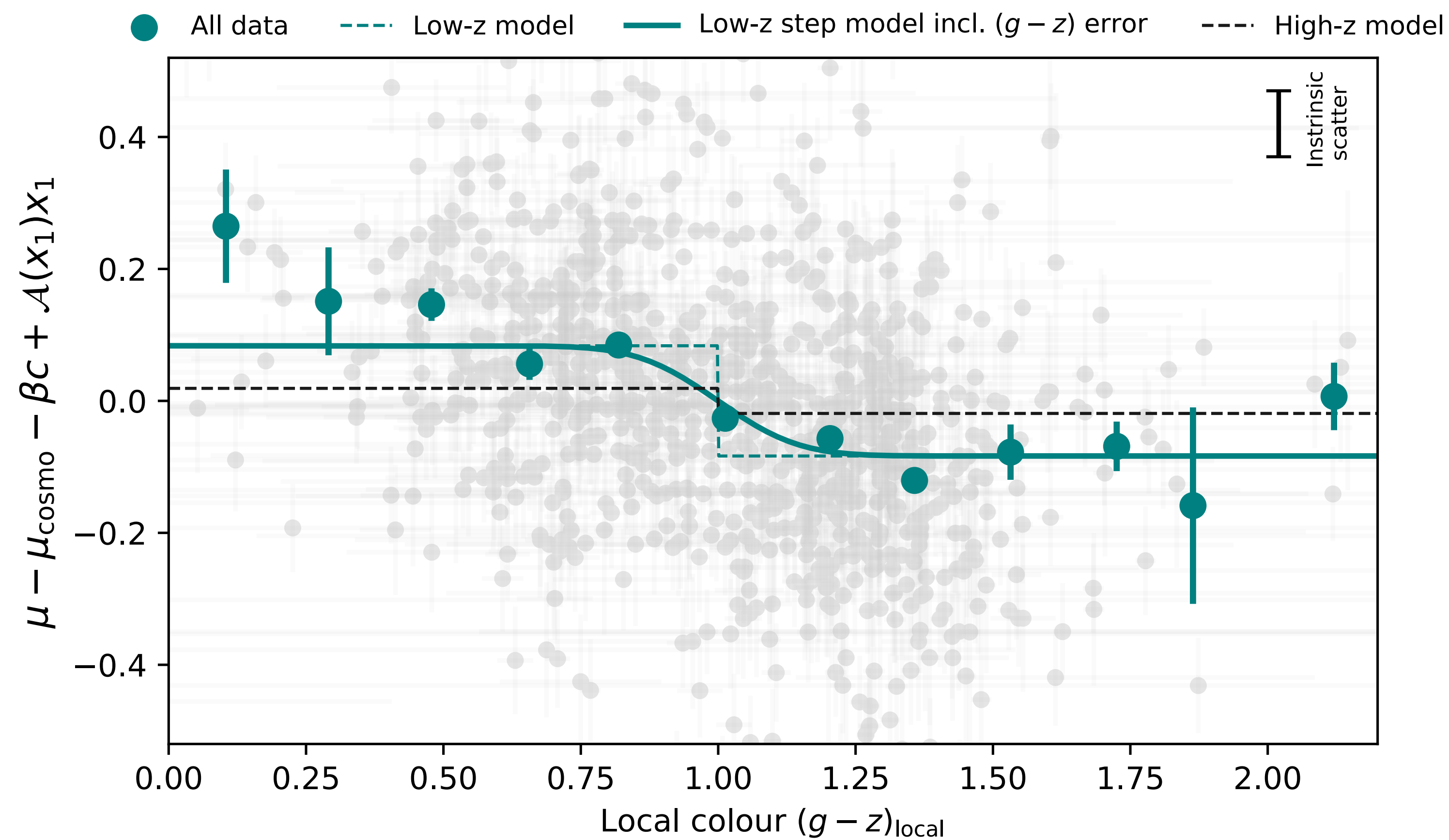
β evolution with environment

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



Environmental step

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

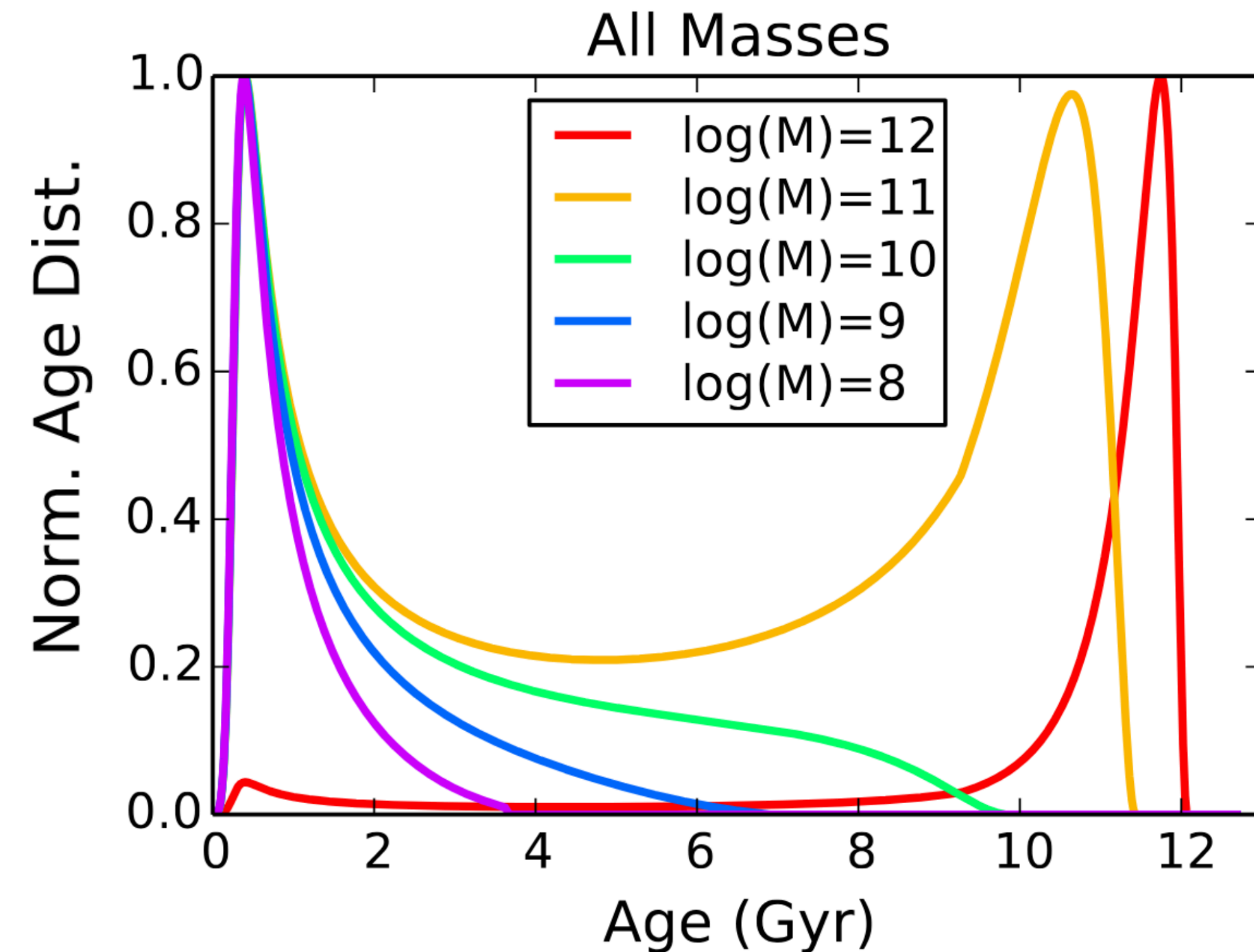


Environmental step

Origin of the step

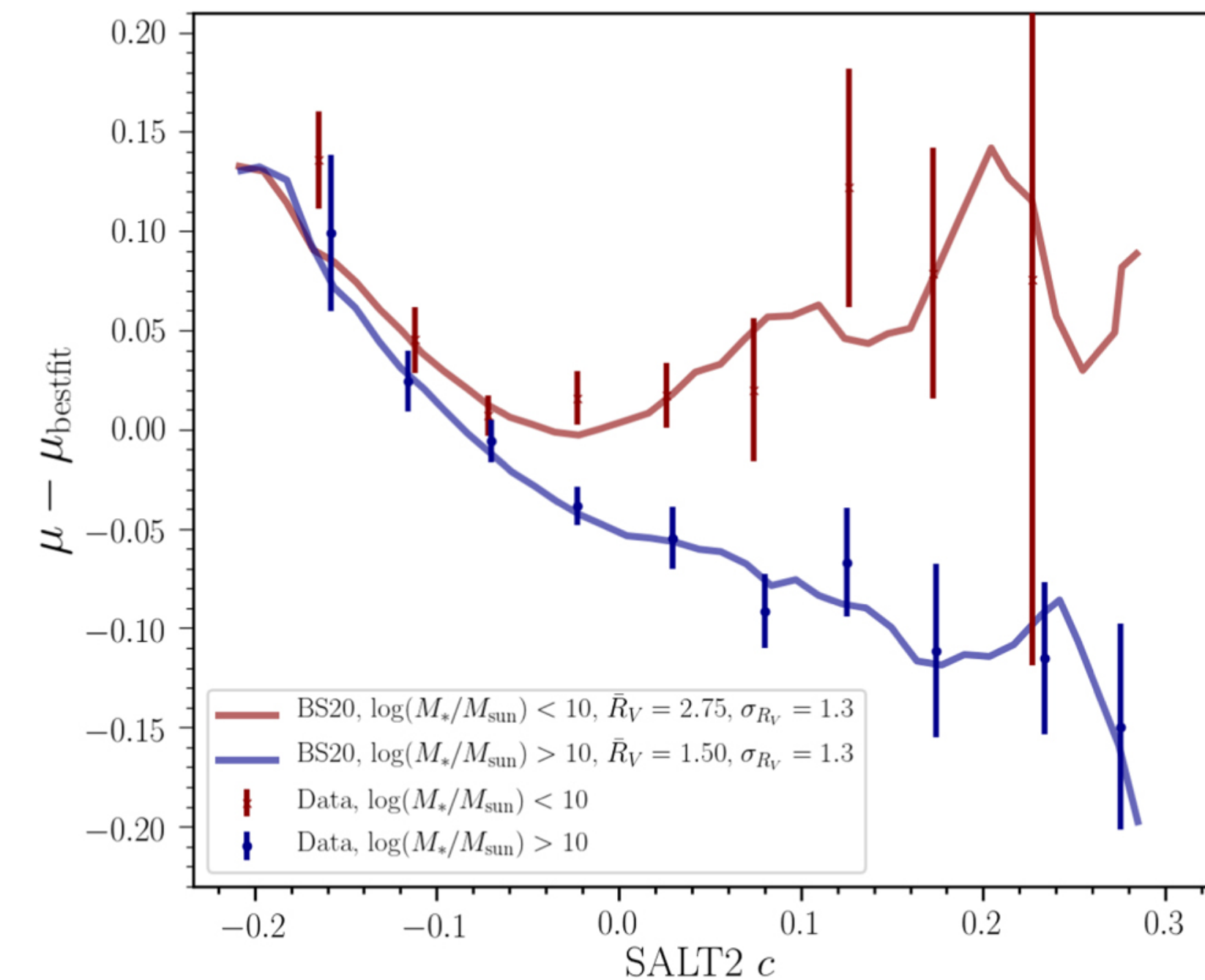
$$\mu_{\text{obs}} + M = m_{\text{obs}} - \beta c + \alpha x_1 + p\gamma$$

Two population interpretation



Childress et al (2014)

Dust interpretation

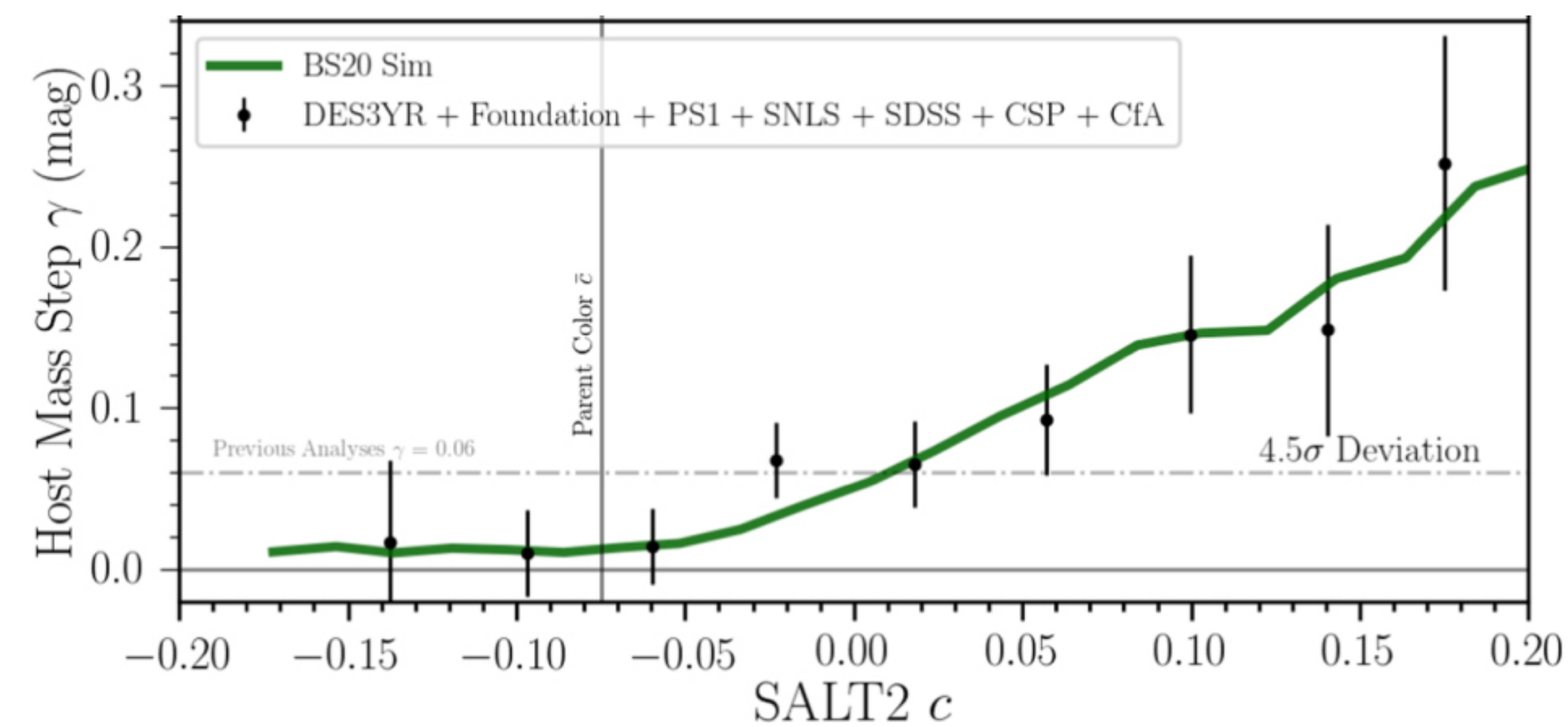


Brout & Scolnic (2021)

Environmental step

Colour-dependence of the step

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



Brout & Scolnic (2021)

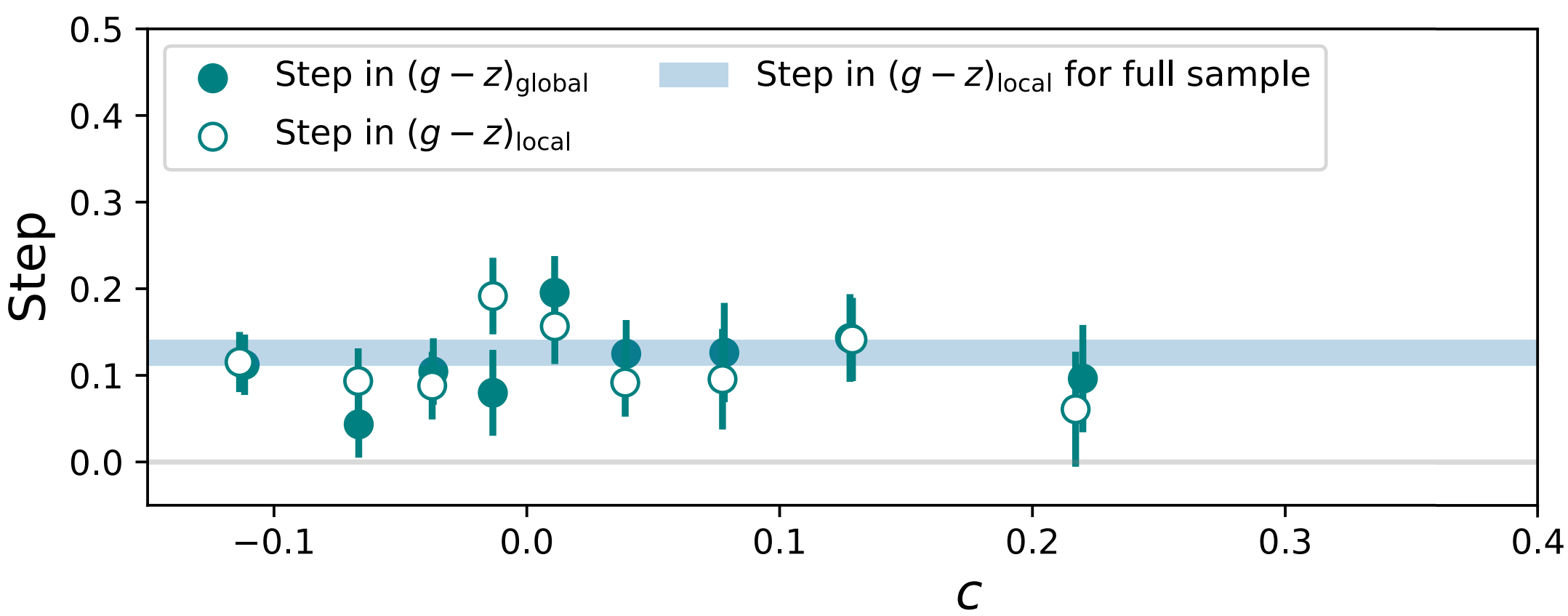


Table 3. Parameters of the step evolution with SN colour: slope of the fit and ΔAIC between an affine function and a constant.

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

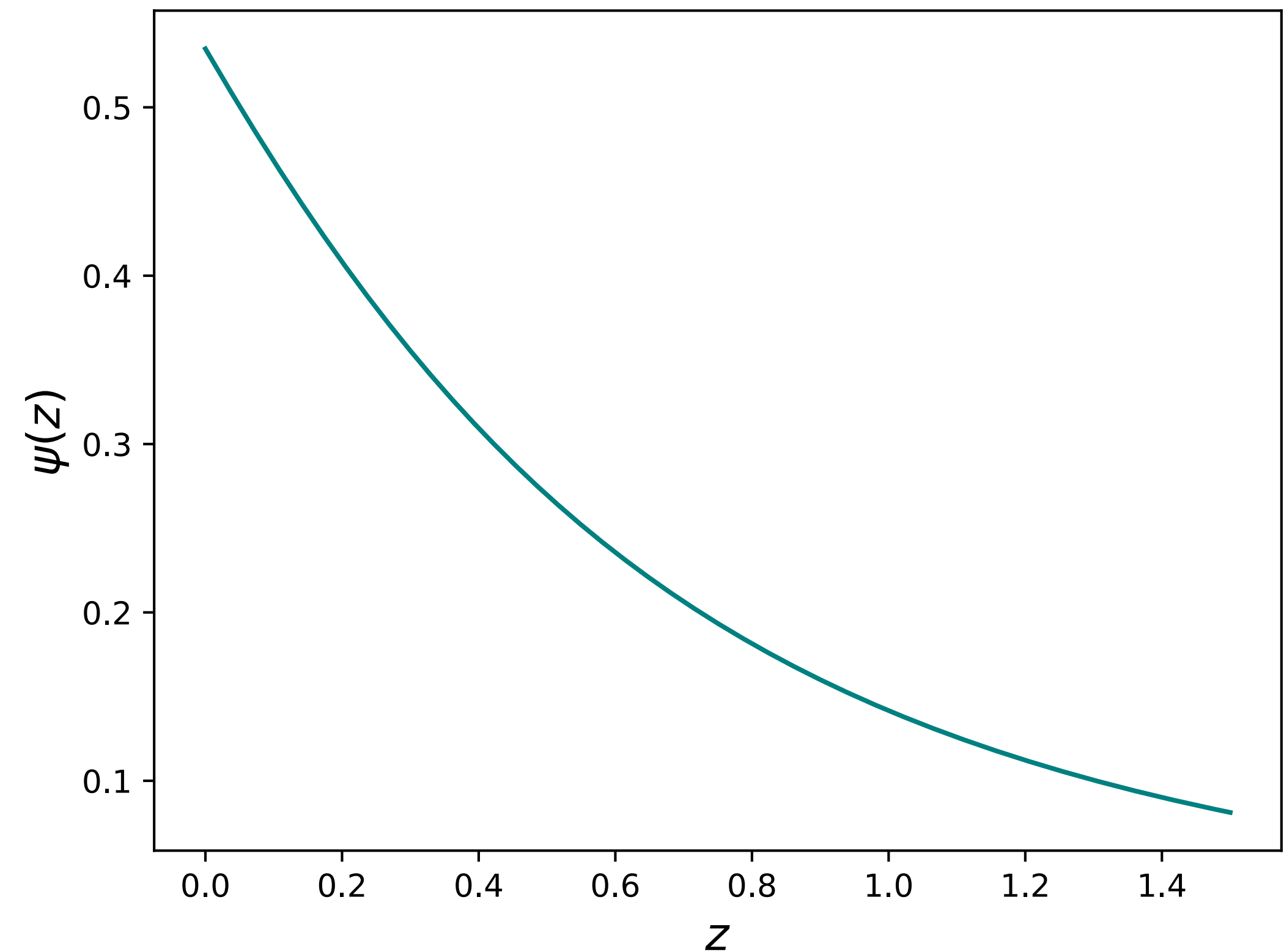
IV. Next steps

Redshift evolution

Fraction of old progenitor SNe Ia:

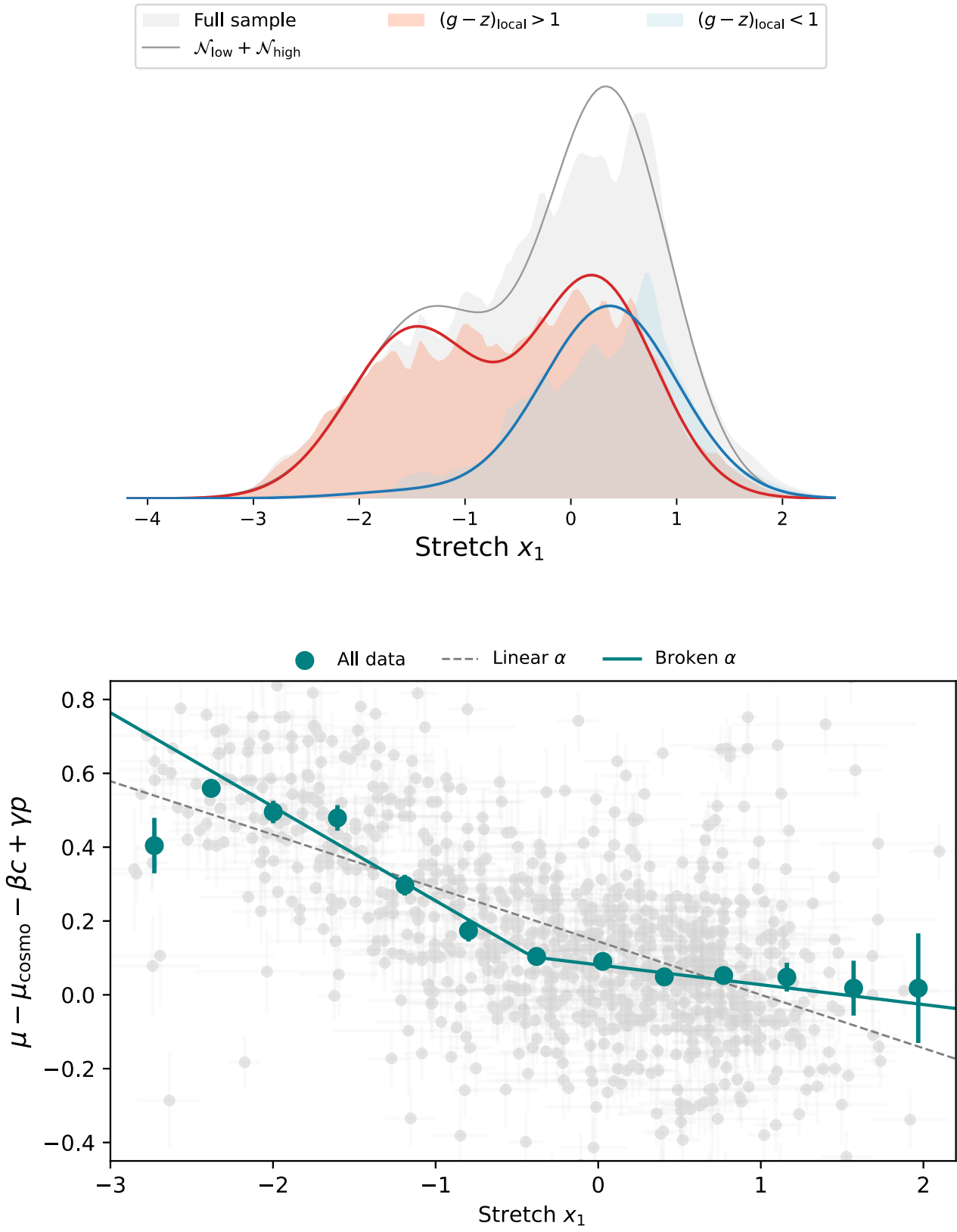
$$\psi(z) = \frac{1}{K(1+z)^\phi + 1}$$

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

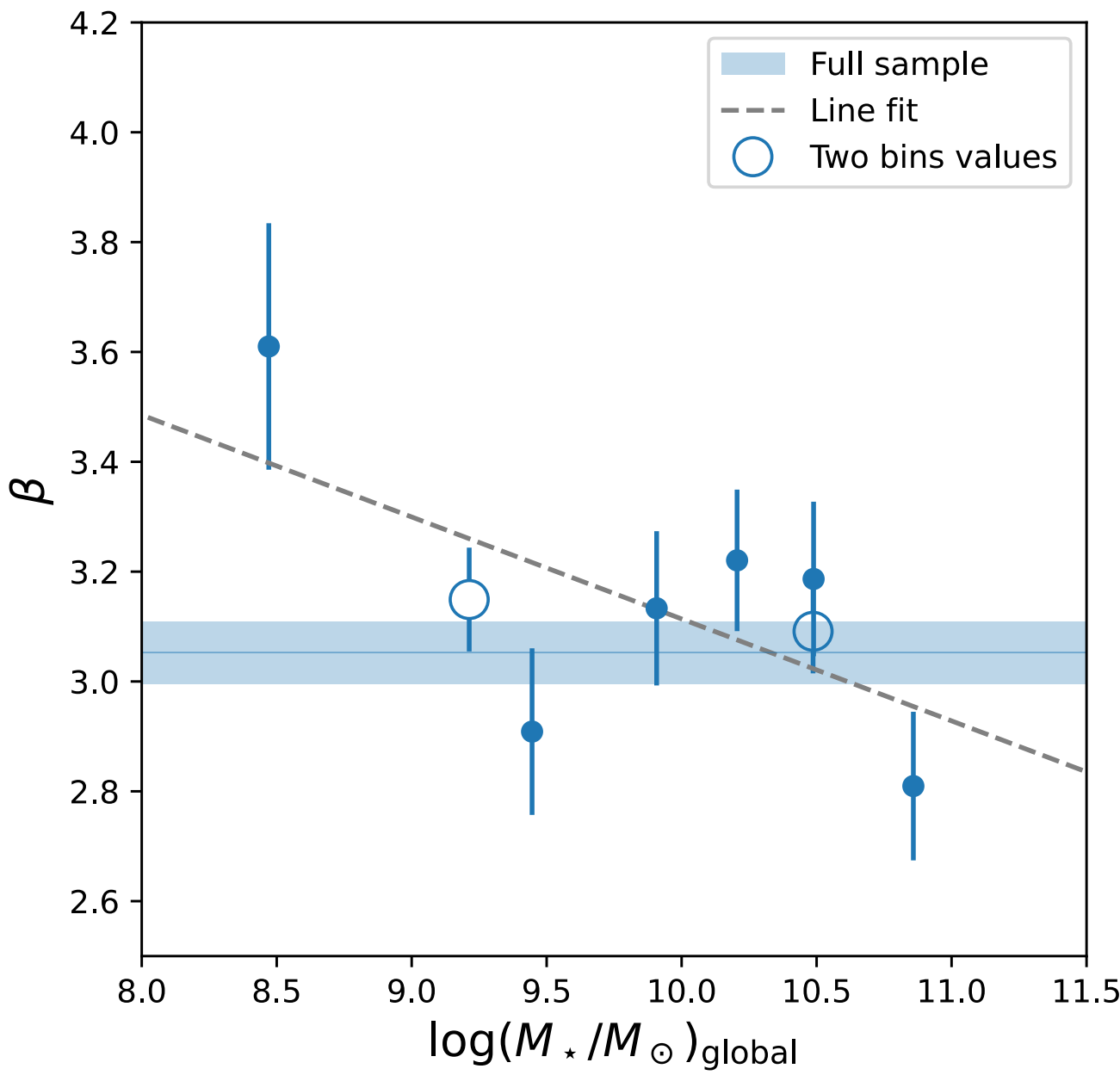


Redshift evolution

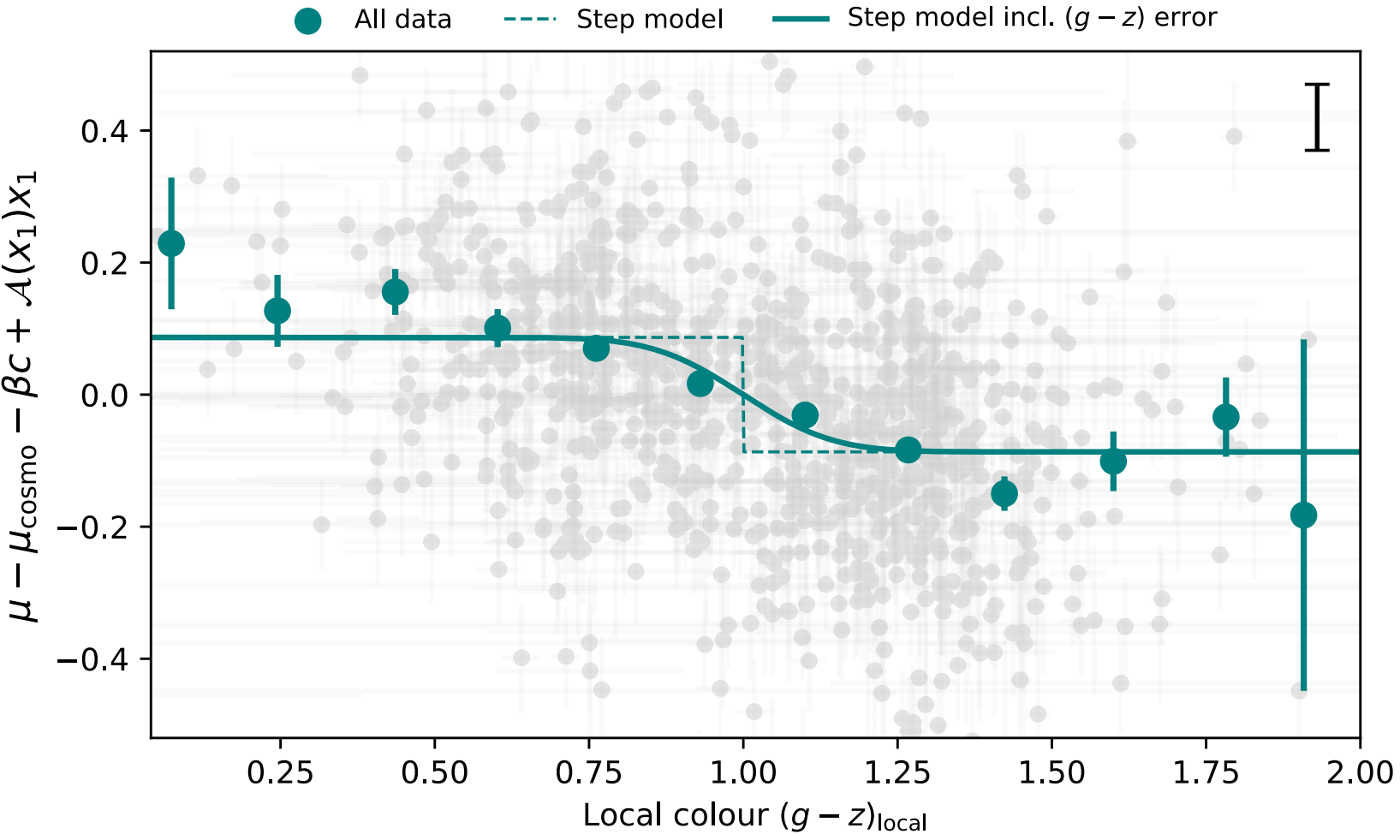
α evolution



β evolution



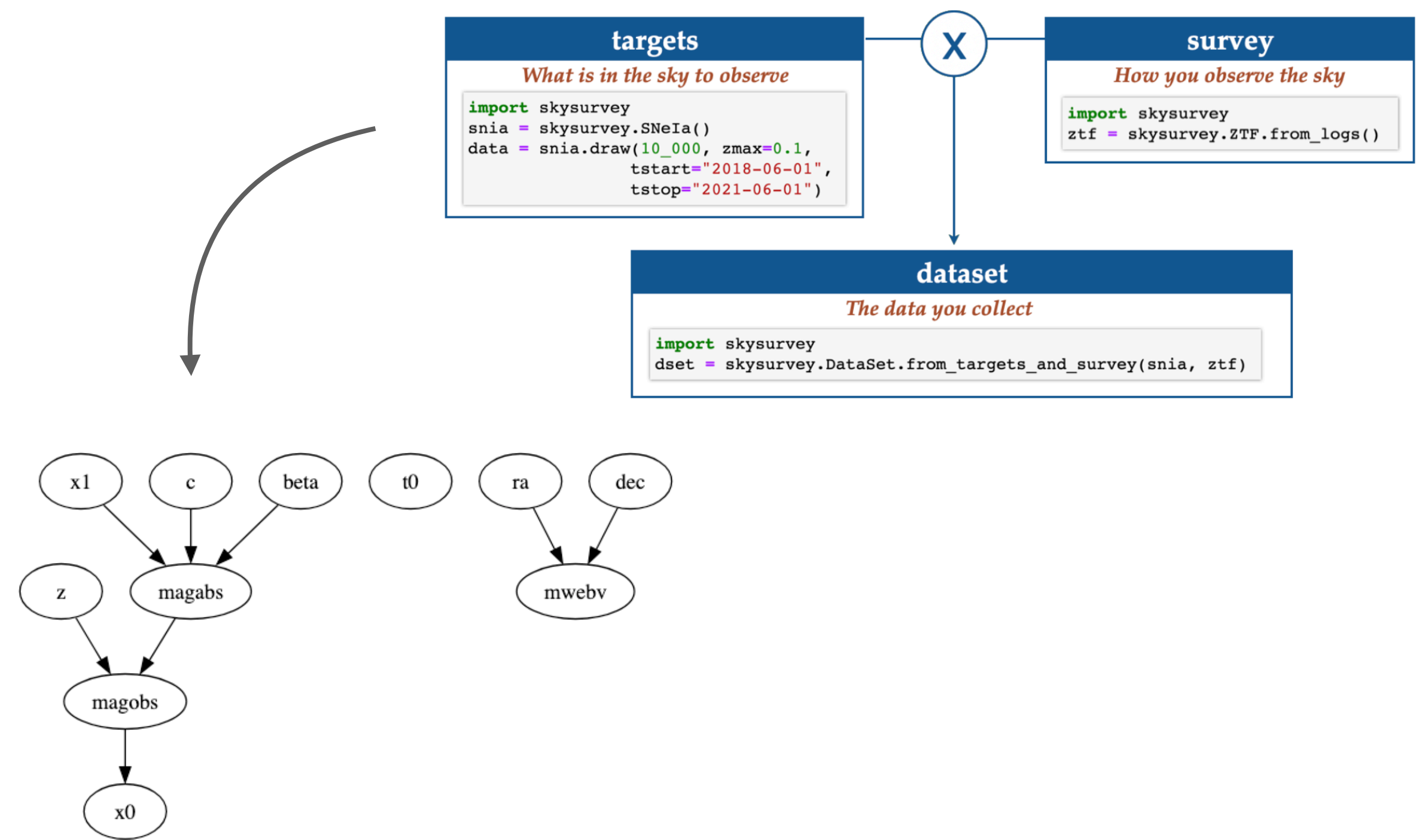
Impact of the environmental step



Next steps

Include these effects in simulations skysurvey

skysurvey.readthedocs.io



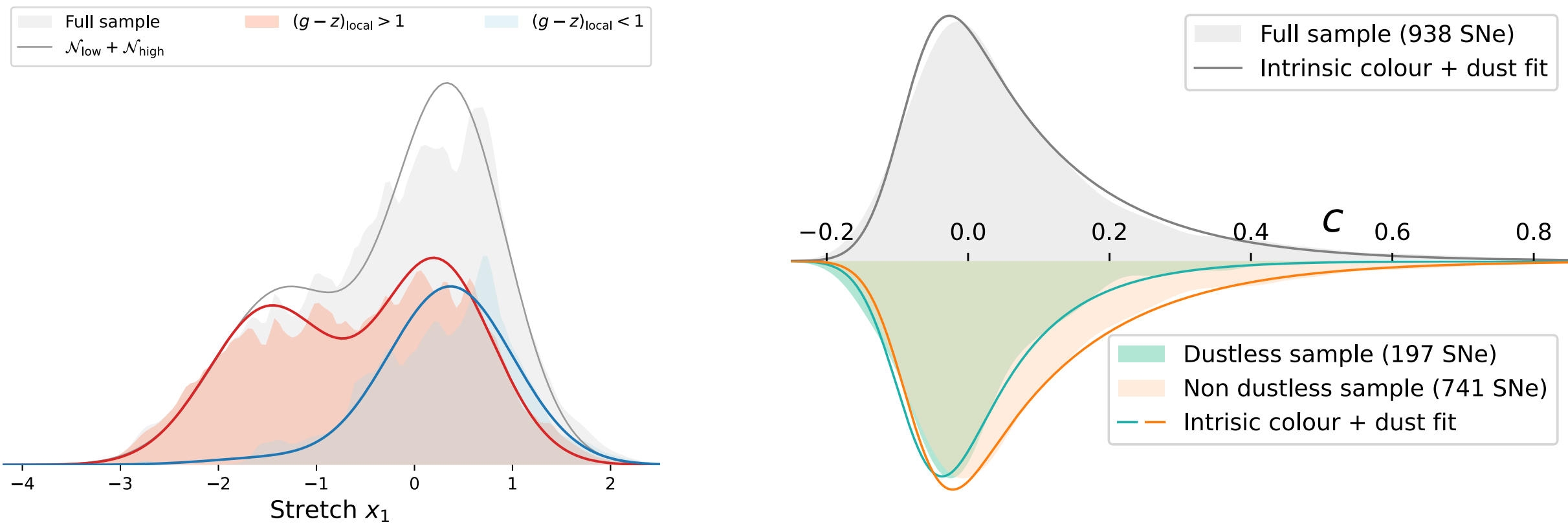
Investigate the redshift evolution with high-z data



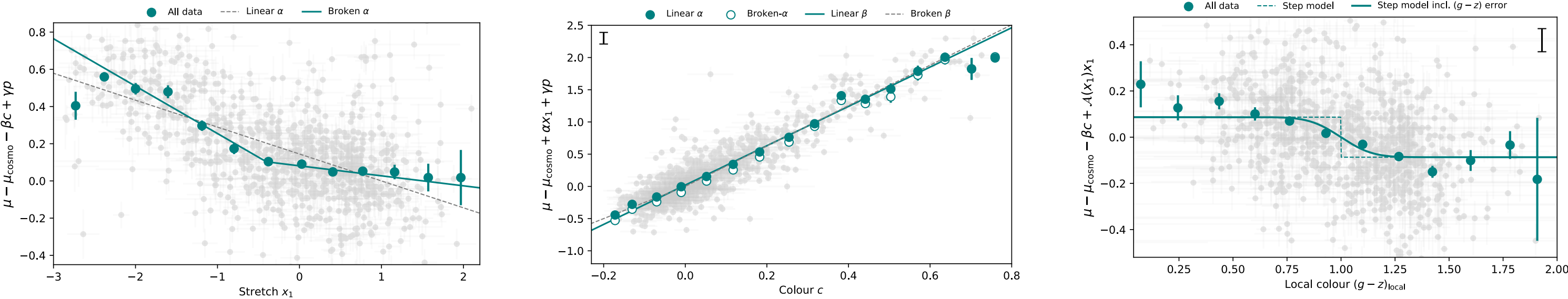
LSST @ Vera C. Rubin Observatory
1M SNe Ia over 10 years
Up to $z \sim 1.1$

Conclusion

Type Ia Supernovae properties



Standardisation dependency on environment



ZTF SN Ia DR2
volume-limited sample

949 SNe Ia
Homogenous
High cadence + spectroscopic

2406.02072

2405.20965