Studying the Environmental Dependence of Type Ia Supernova Luminosities

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Cosmological Synergies in the Upcoming Decade
Paris, Frnace

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Why Environment=Host Galaxy of SNe Ia?

Why Host Galaxy?

host redshift = SN redshift

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host redshift = SN redshift → **Classification of SNe**

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Measuring Host Properties:
Mass and SFR of host galaxy
(which have a correlation with SN Ia luminosity)

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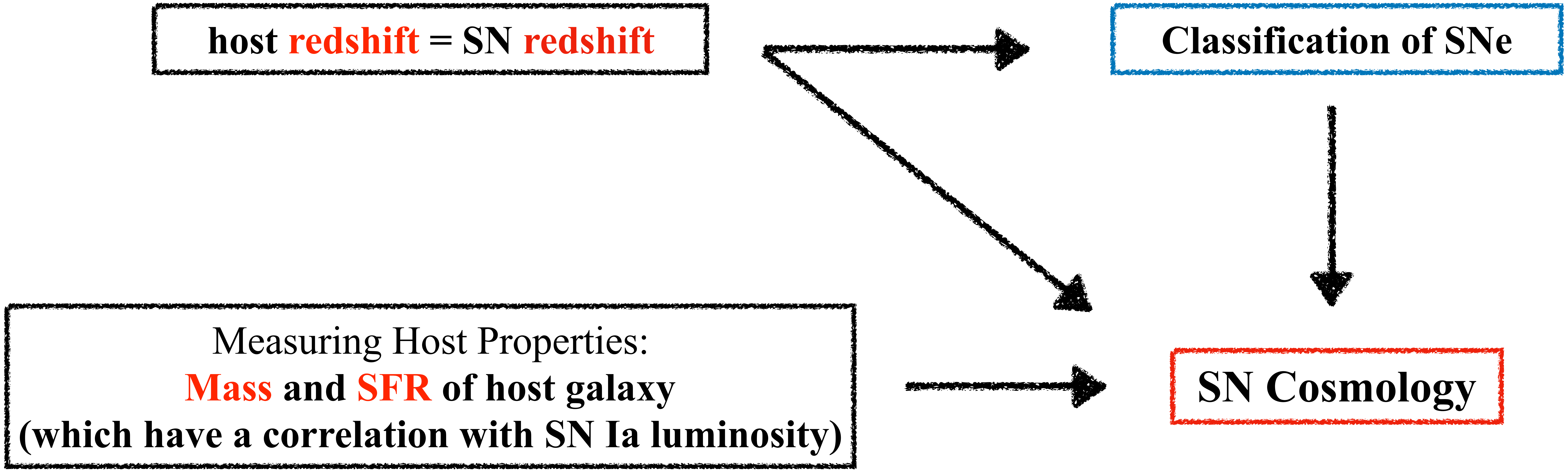

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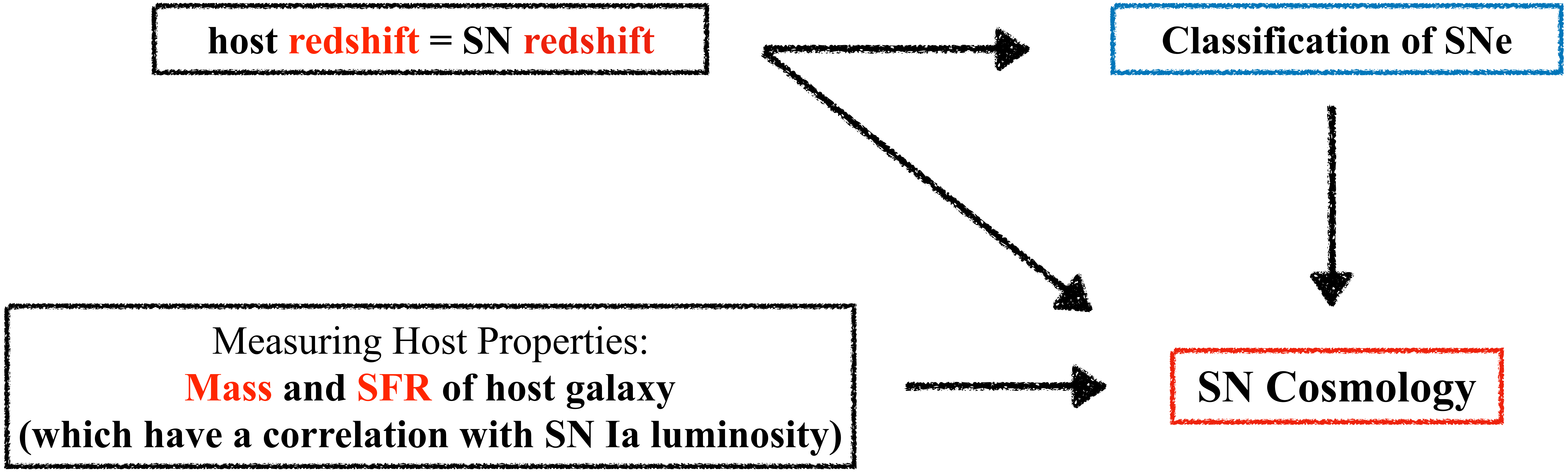

Investigation of host galaxy is crucial for the SN cosmology!

Why Host Galaxy?

host redshift = SN redshift

Classification of SNe

SN Cosmology

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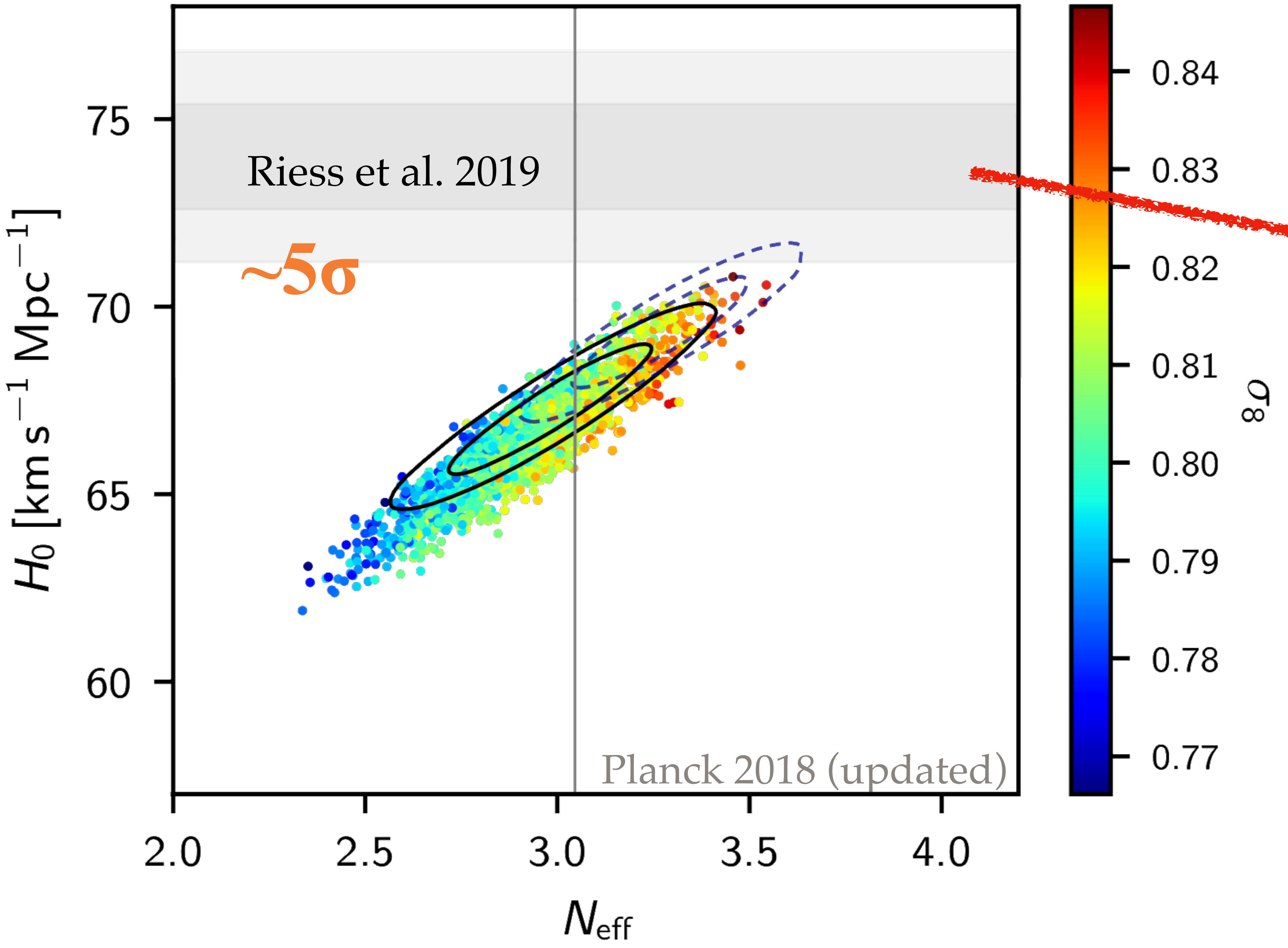
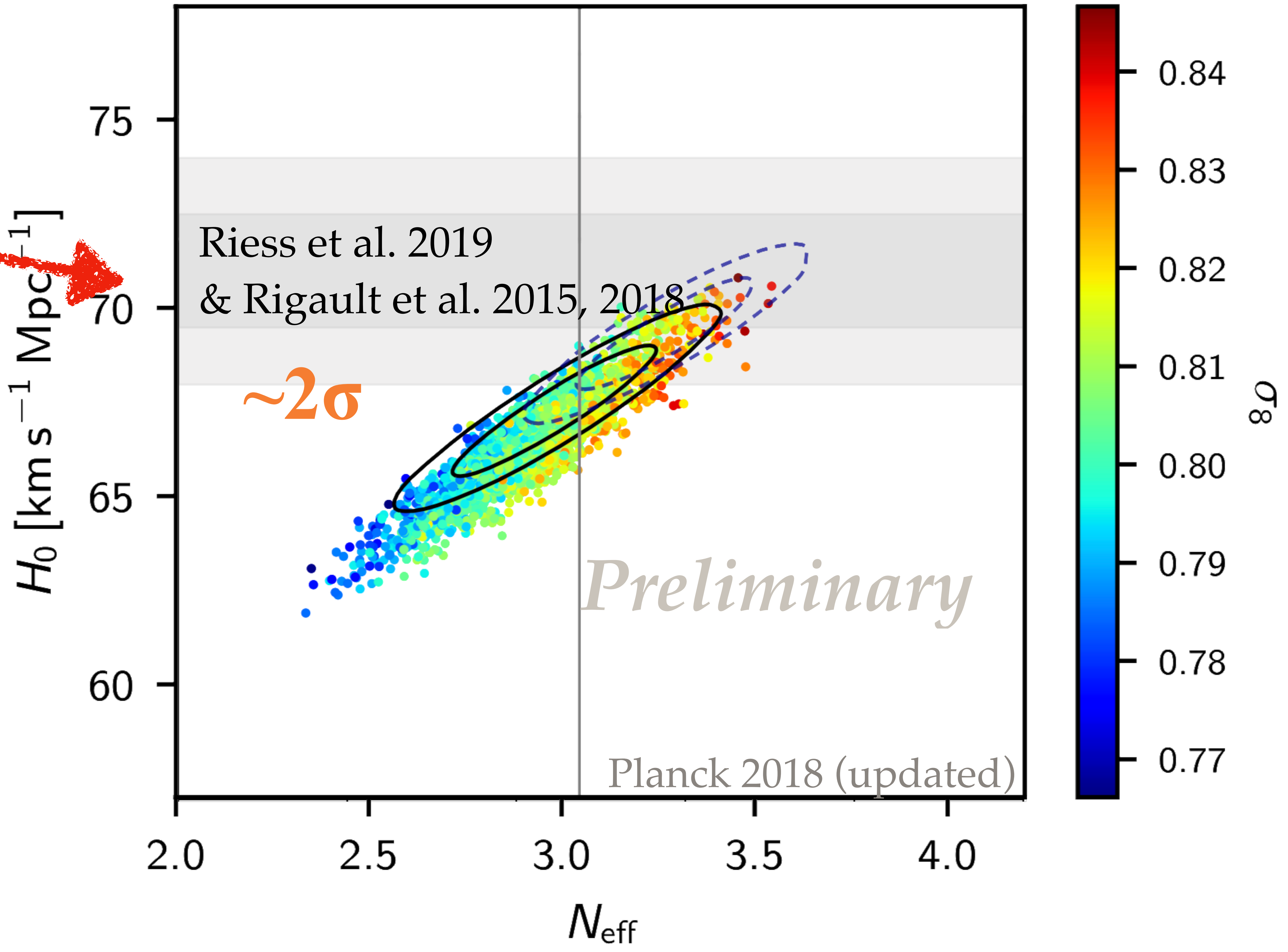
H0 Tension (Mickael's Talk)



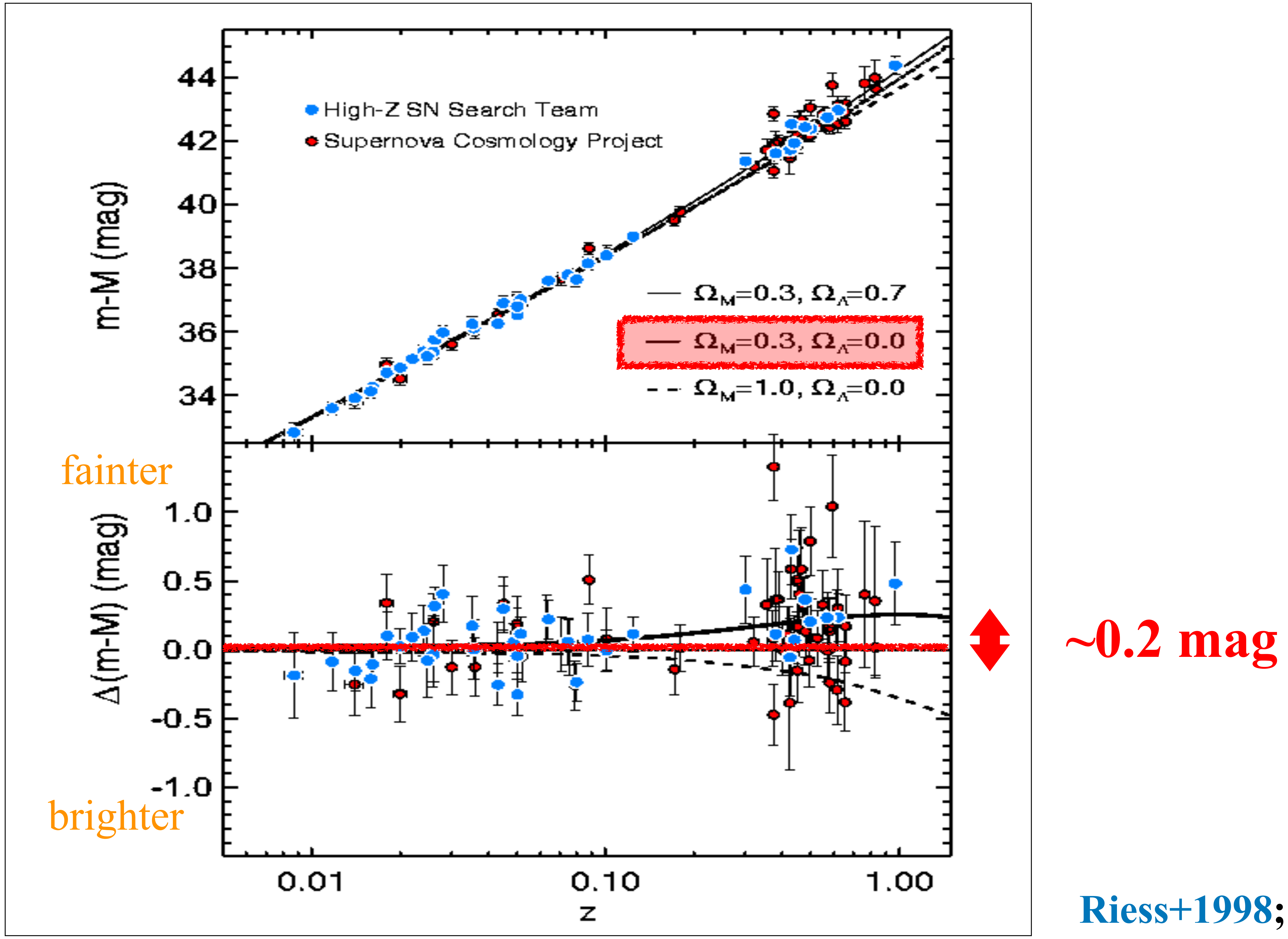


Rigault et al. 2015, 2018, in prep

SN Ia Luminosity and the Accelerating Expansion of the Universe

Distance
(μ_{SN})

Hubble Residual
($HR \equiv \mu_{SN} - \mu_z$)

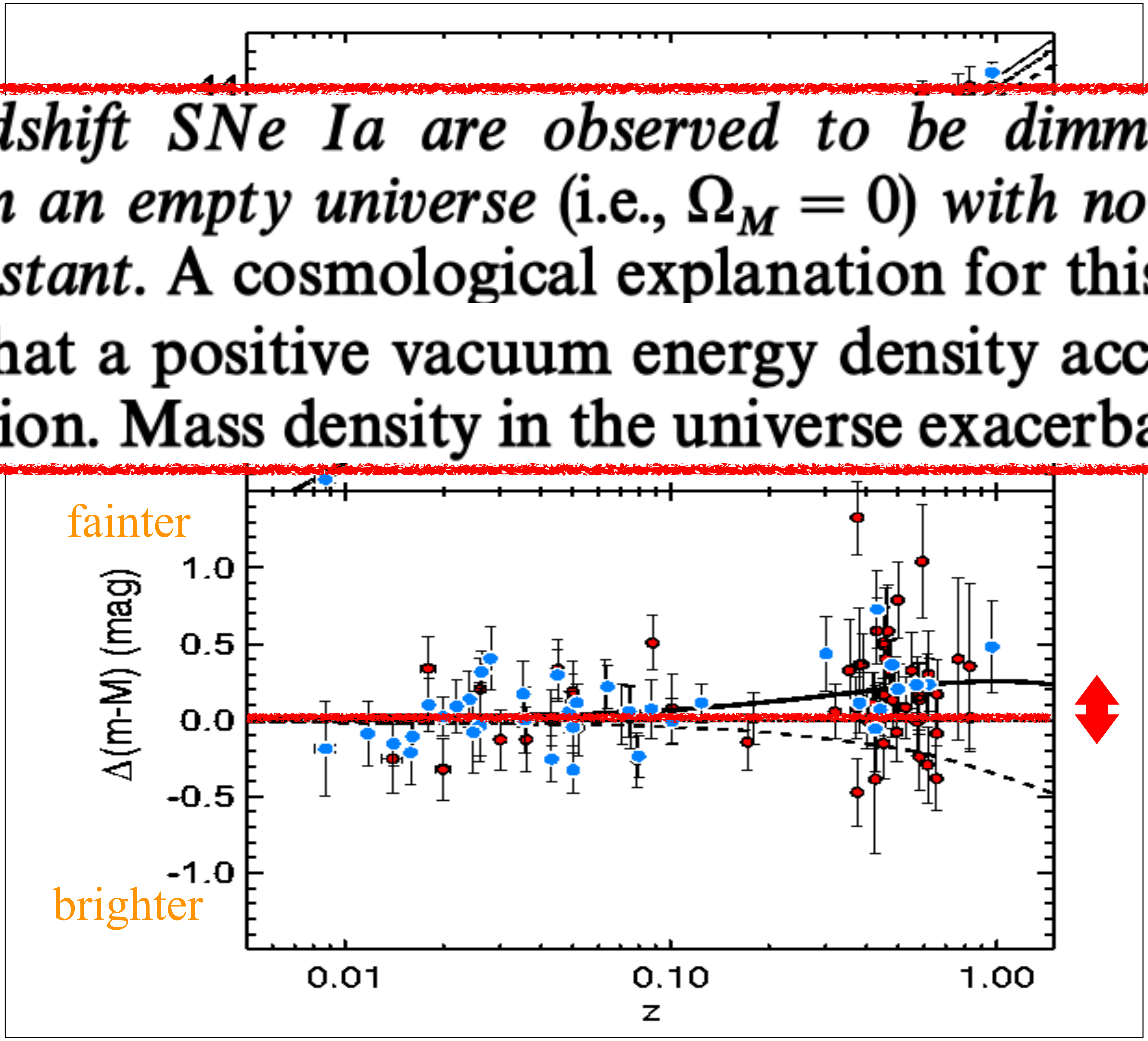


Riess+1998; Perlmutter+1999

SN Ia Luminosity and the Accelerating Expansion of the Universe

High-redshift SNe Ia are observed to be dimmer than expected in an empty universe (i.e., $\Omega_M = 0$) *with no cosmological constant*. A cosmological explanation for this observation is that a positive vacuum energy density accelerates the expansion. Mass density in the universe exacerbates this

Hubble Residual
(HR $\equiv \mu_{SN} - \mu_z$)



Riess+1998; Perlmutter+1999

Luminosity Evolution?

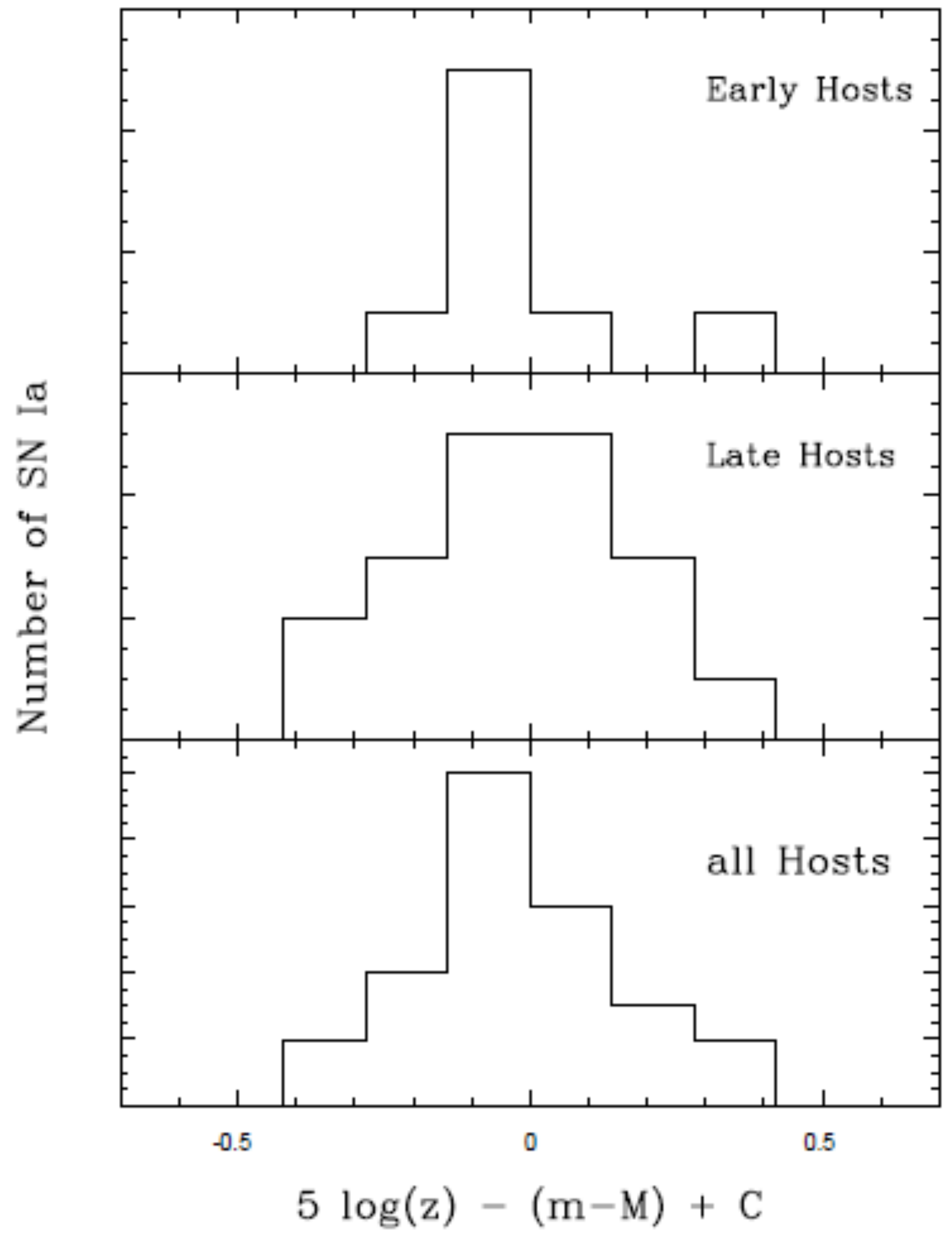


FIG. 3.—Residual of SN Ia distances from RPK96 plotted as a function of galaxy type. The offset between the early-type and late-type galaxies is 0.006 ± 0.07 mag.

Schmidt+1998

Riess+1998

ΔHR = 0.04 ± 0.07 mag
between Early (old; N=8) & Late (young; N=19) type hosts.

> This difference is consistent with zero.

> No Evolution.

Current Status
of Environmental Dependence Studies

Table 9
Comparison of Hubble residual differences between previous studies

Study	SN Data	N_{SN}	Redshift Range	HR Difference (mag)	LC Fitter
Mass					
This Work	YONSEI	648	$0.01 < z < 0.85$	0.057 ± 0.014 (4.1σ)	SALT2
This Work	YONSEI	504	$0.01 < z < 0.85$	0.065 ± 0.015 (4.3σ)	MLCS2k2 ($R_V = 2.2$)
Kelly et al. (2010)	CfA	62	$0.015 < z < 0.08$	0.094 ± 0.045 (2.1σ)	SALT2
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Uddin et al. (2017)	CfA+CSP+SDSS+SNLS	1338[b]	$0.01 < z < 1.1$	0.050 ± 0.009 (5.6σ)	SALT2
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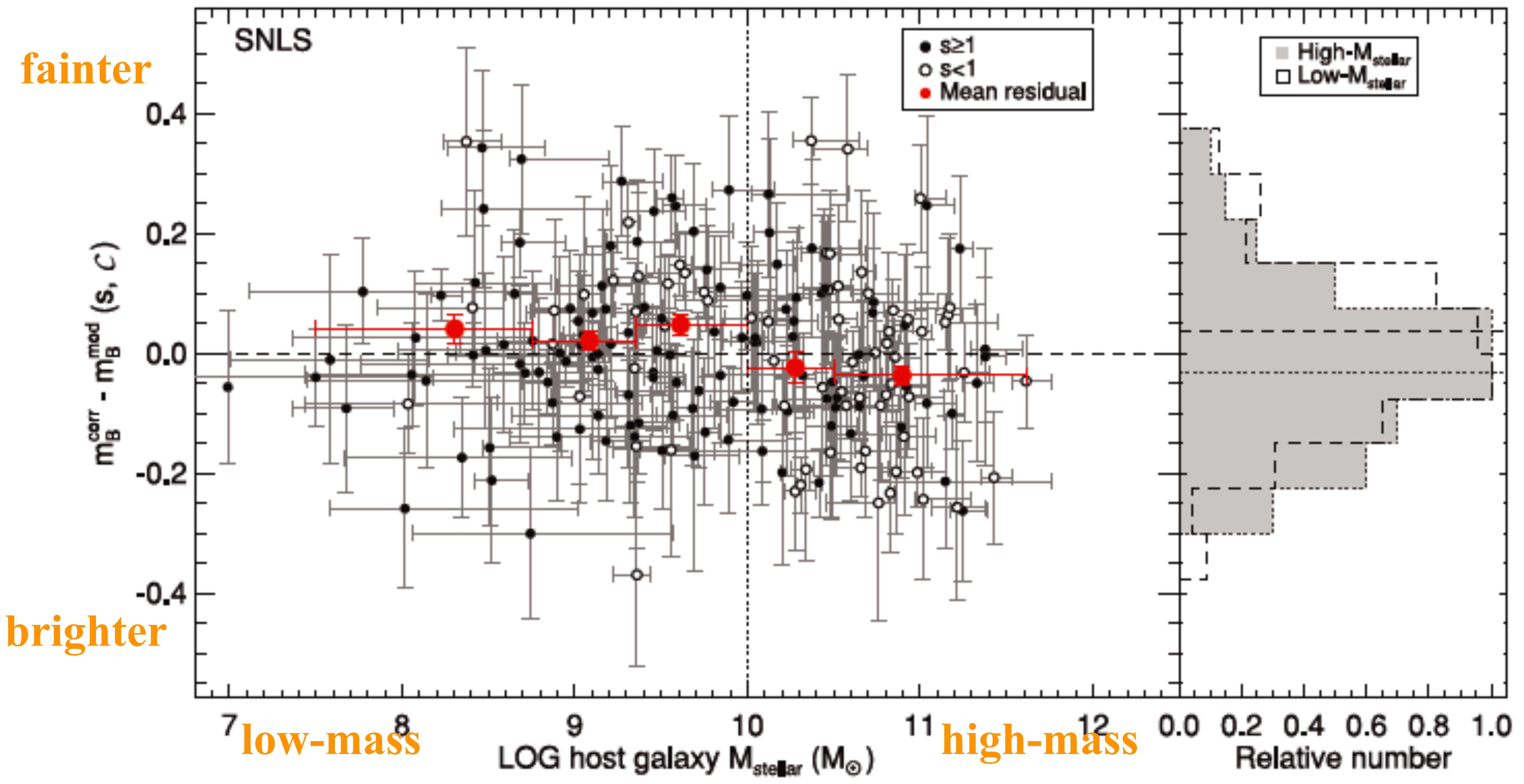
Kim+2019

Well-Established Empirical Correlation between Host Stellar Mass and SN Ia Luminosity

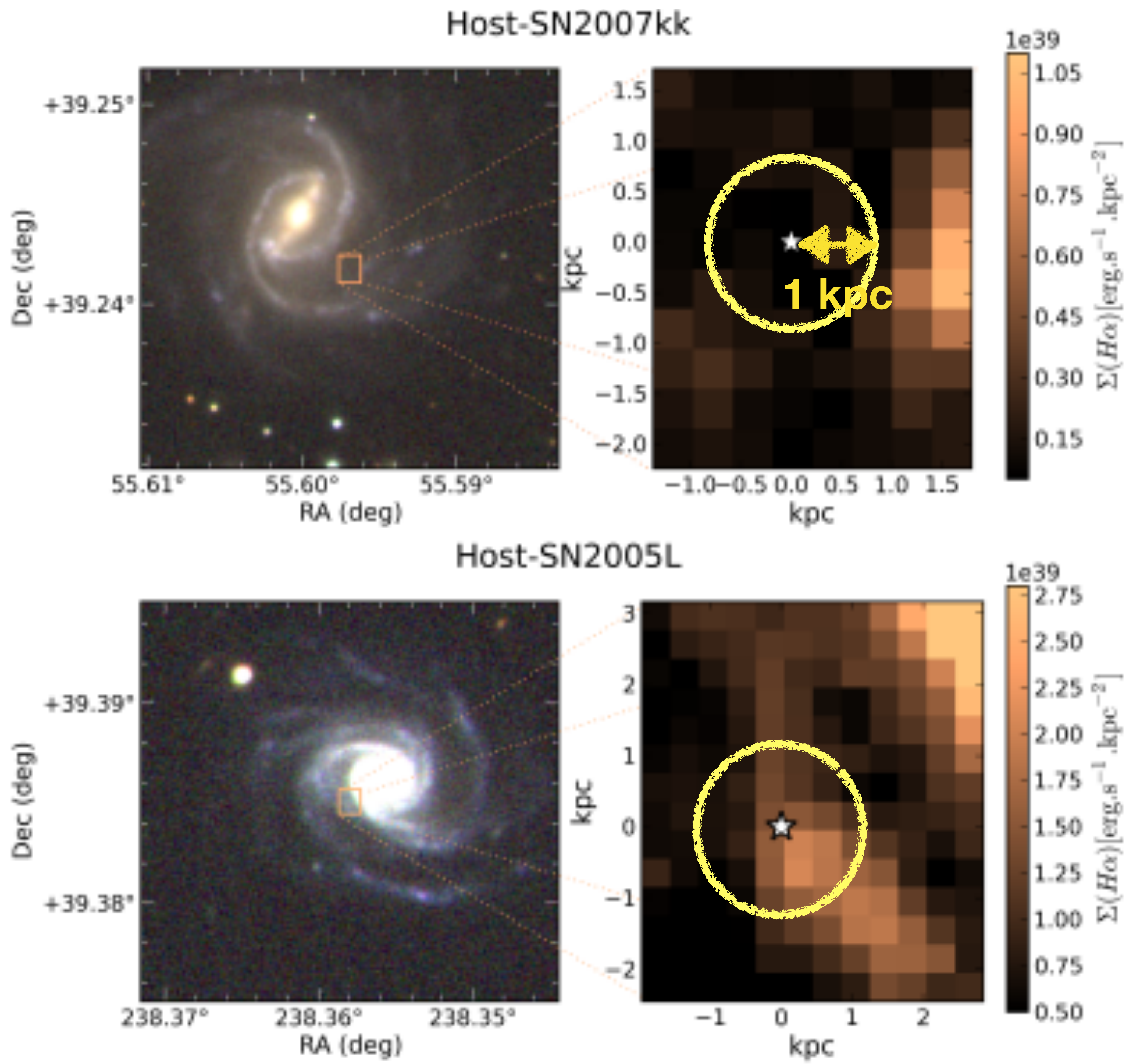


Sullivan+2010

SNe Ia in more massive hosts are brighter by ~0.08 mag (4.0σ)!

(Kelly+2010 (low-z); Lampeitl+2010 (intermediate-z; SDSS); Sullivan+2010 (high-z; SNLS))

Local Environments in SN Ia Study



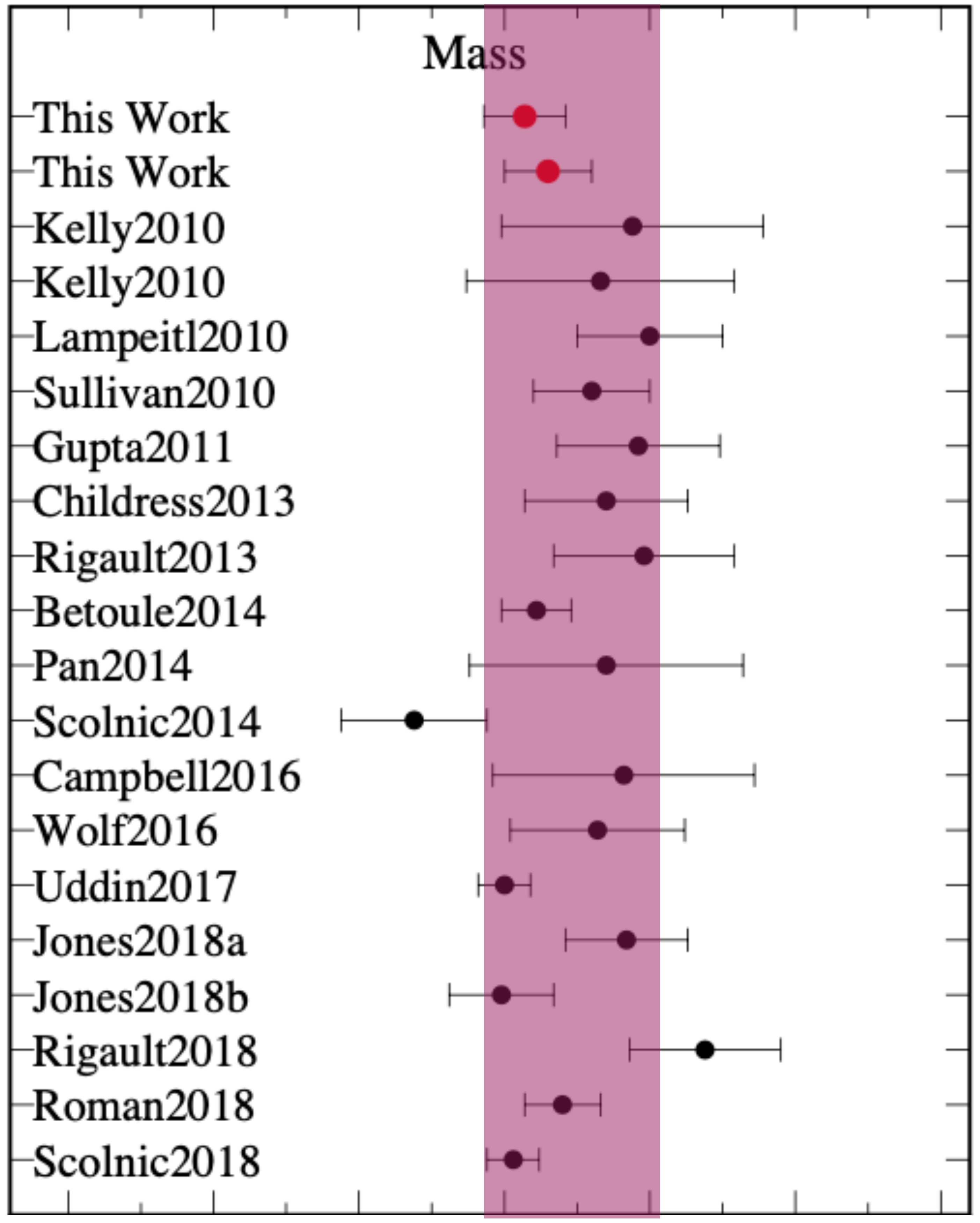
Rigault+2013

Local Environments in SN Ia Study

	Group	N	Mean Residual (mag)	Error (mag)
Local	Locally Passive	194	−0.043	0.013
	Locally Star-forming	174	0.038	0.013
	Diff.		**0.081**	**0.018**
Global	Globally Passive	194	−0.043	0.013
	Globally Star-forming	455	0.006	0.008
	Diff.		**0.049**	**0.015**
	High-mass ($\log M_{\mathrm{stellar}} > 10$)	464	−0.022	0.008
	Low-mass ($\log M_{\mathrm{stellar}} \leqslant 10$)	184	0.035	0.012
	Diff.		**0.057**	**0.014**

Kim+2018

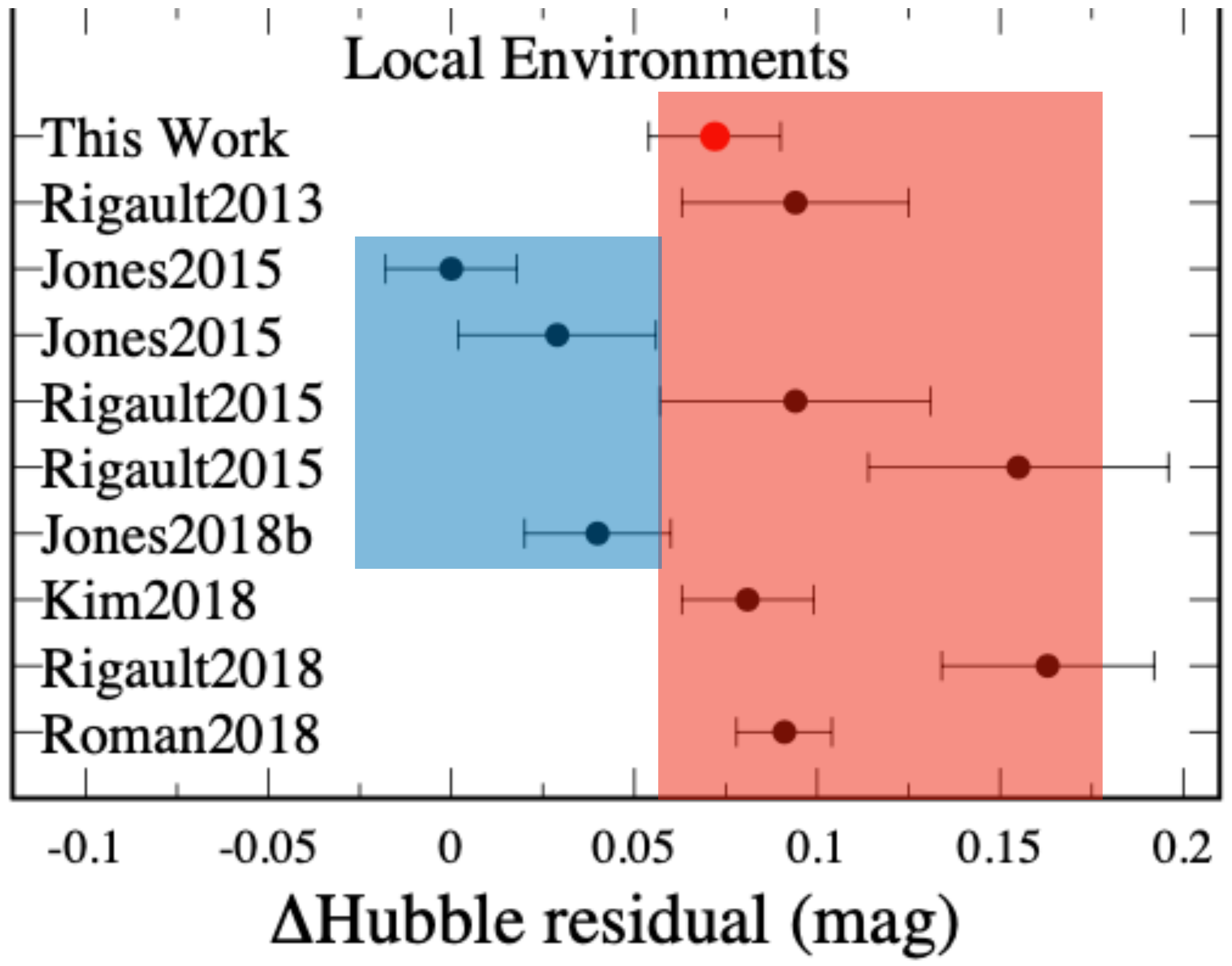
Local Environments Study is GOING ON!



Kim+2019

0.05~0.10 mag

0.00~0.04 mag vs. 0.07~0.16 mag



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Morphology

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SNe Ia in star-forming and low-mass hosts (~younger system) are fainter than SNe Ia in passive and high-mass hosts (~older system), after light-curve corrections!

Kim+2019

Luminosity Evolution?

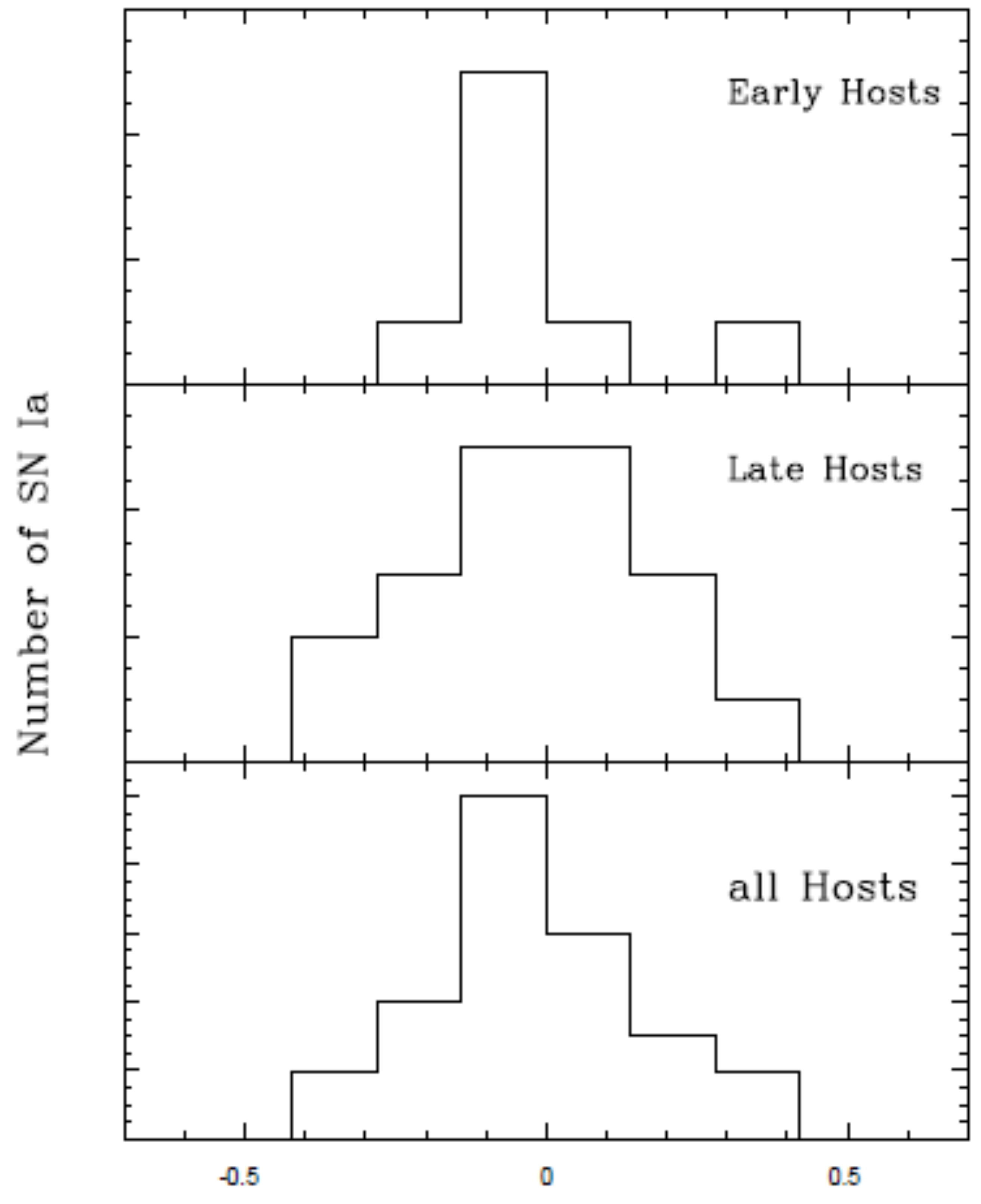


FIG. 3.—Residual of SN Ia distances from RPK96 plotted as a function of galaxy type. The offset between the early-type and late-type galaxies is 0.006 ± 0.07 mag.

Schmidt+1998

Riess+1998

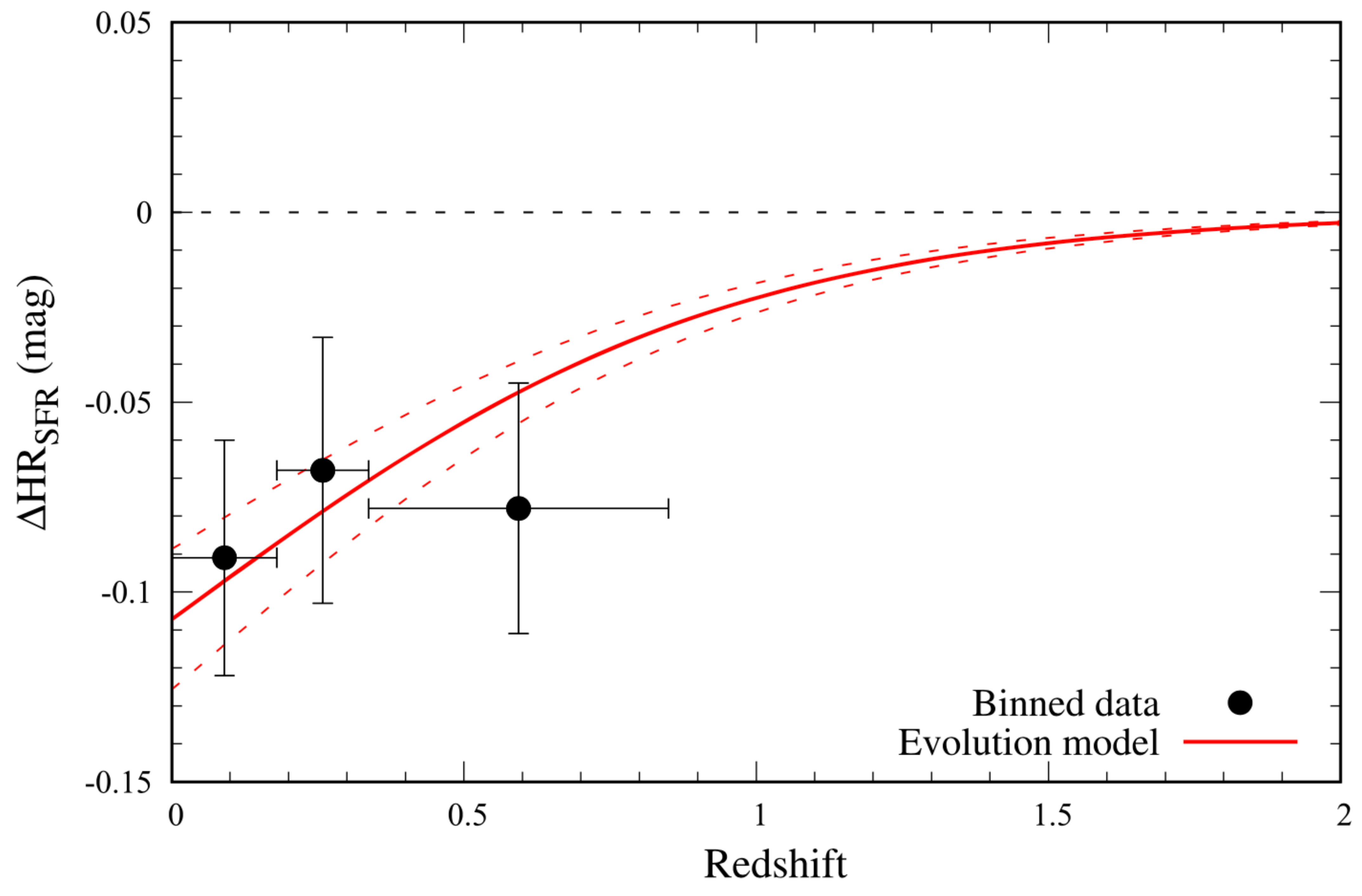
ΔHR = 0.04 ± 0.07 mag

between Early (**old**; N=8) & Late (**young**; N=19) type hosts.

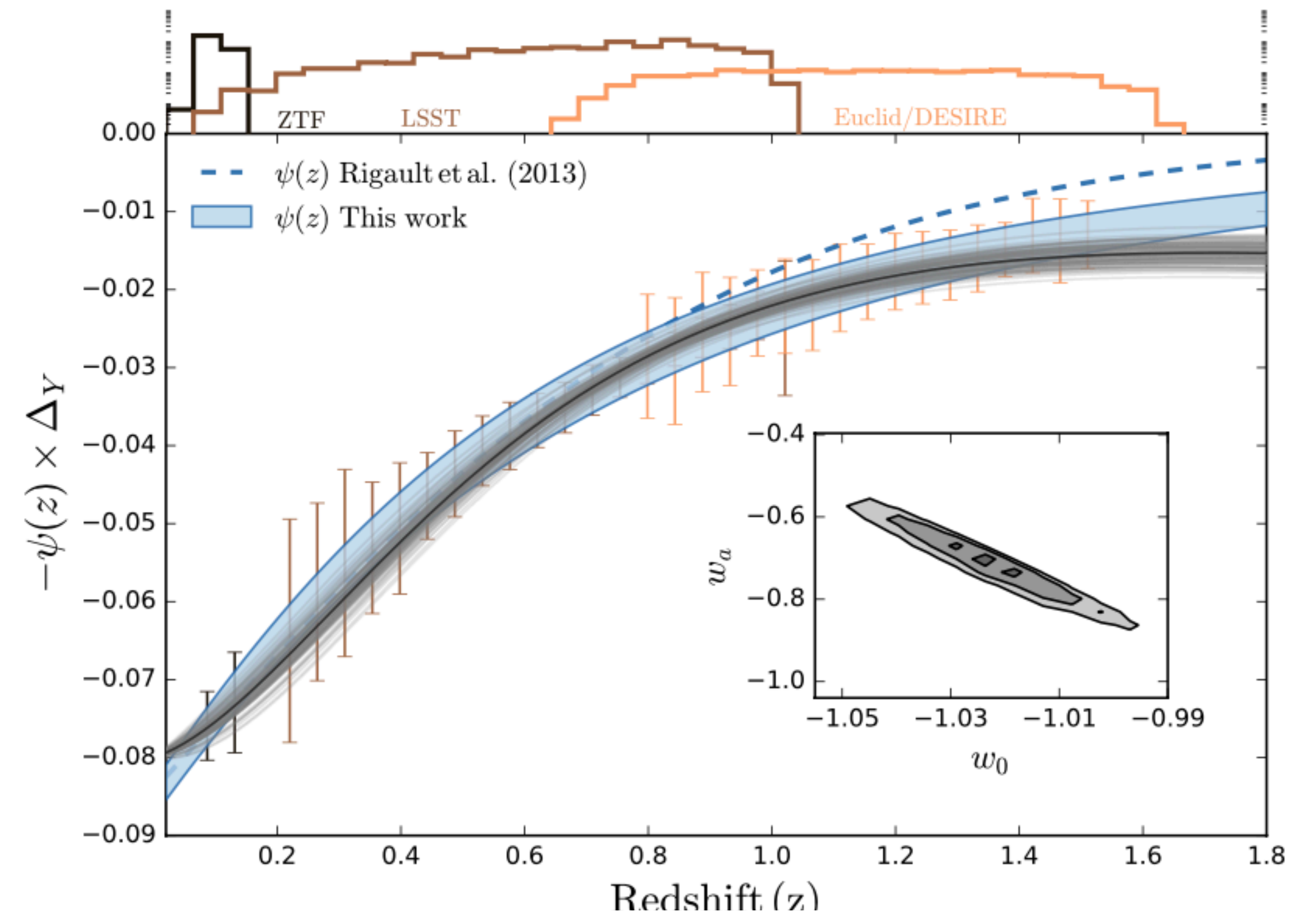
> This difference is consistent with zero.

> No Evolution.

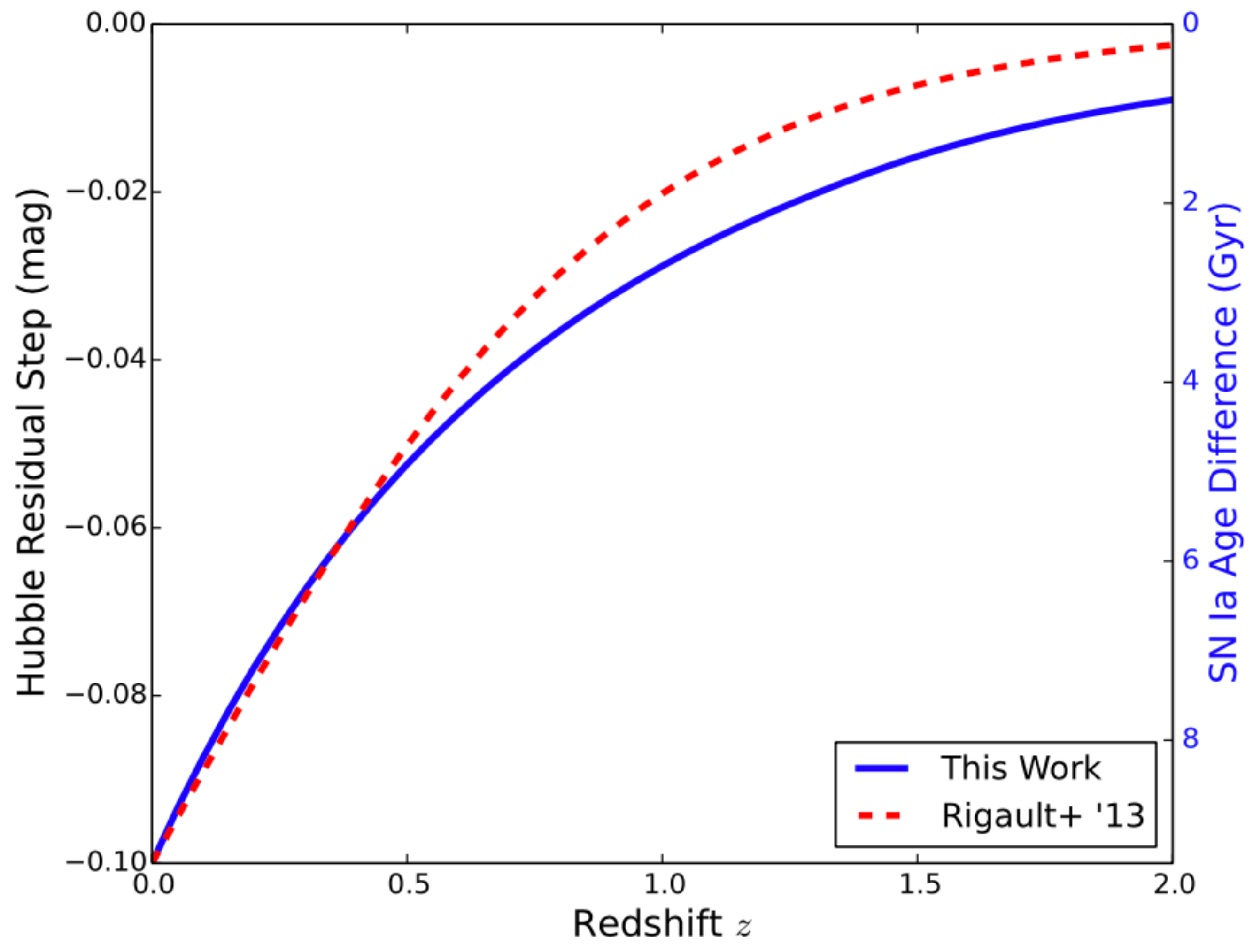
Luminosity Evolution?



Kim+2018



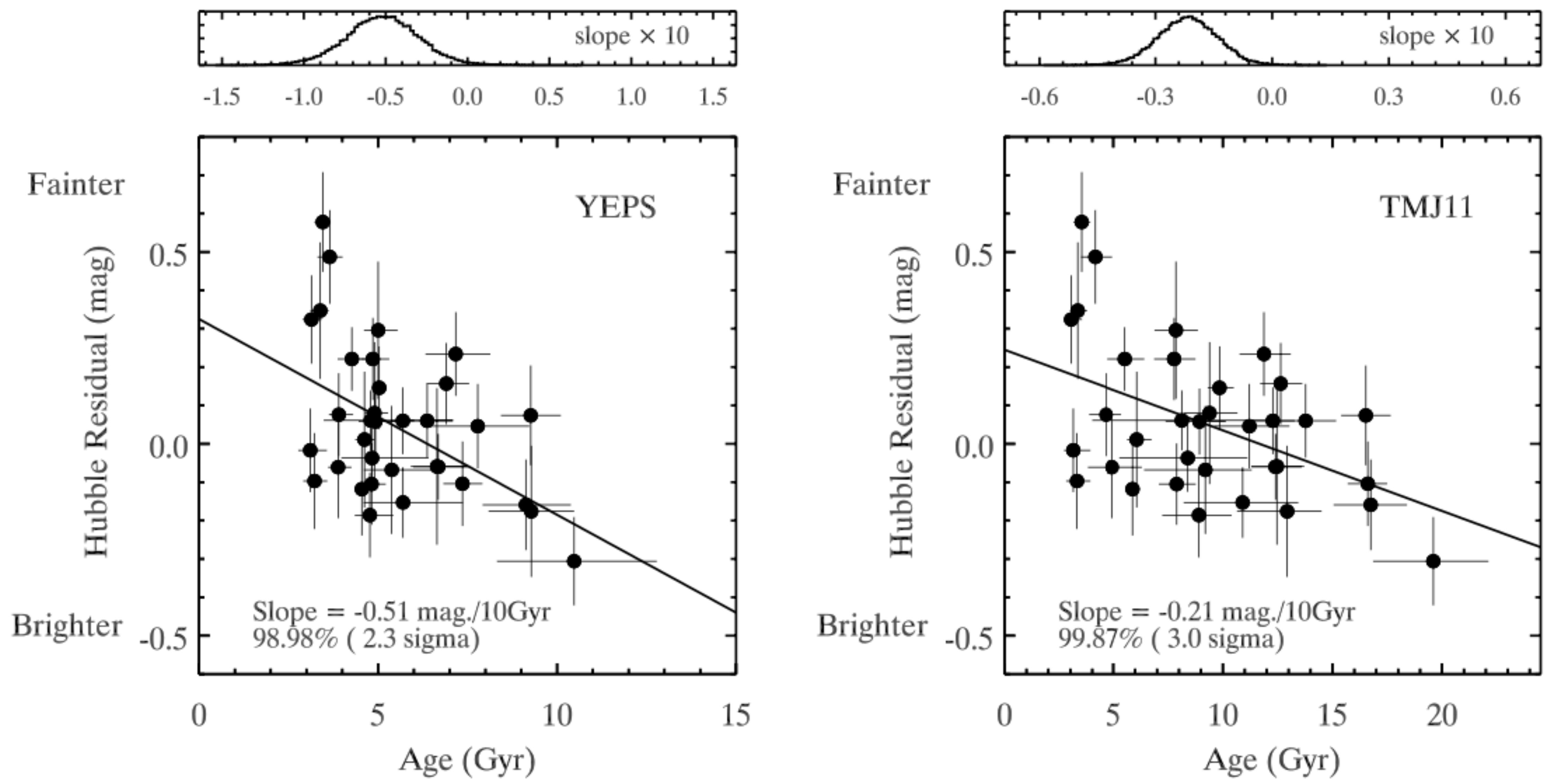
Rigault+2018



Childress+2014

What is the Origin of Environmental Dependence of SNe Ia Luminosity?

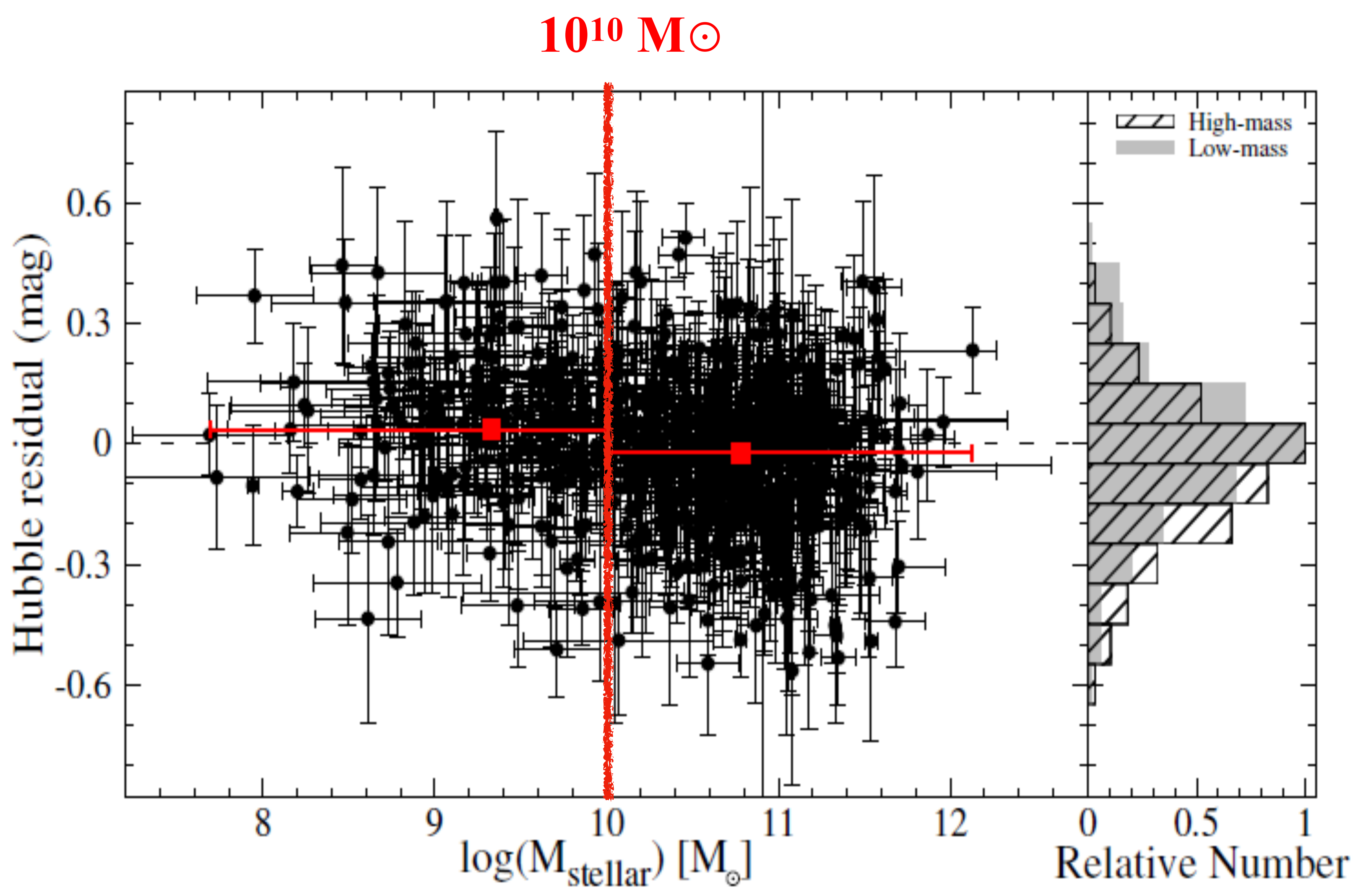
Since **the host mass and SFR cannot directly affect SN luminosity**,
many studies pointed out that this is most likely due to the stellar population properties,
such as **age** and **metallicity**,
empirically (from host observations: Johansson+2013; Pan+2014;Graur+2015; Kang, Kim+2016, 2019)
and
theoretically (from progenitor simulations: Timmes+2003; Kasen+2009; Childress+2014).



Kang, Kim+2016, 2019:
60 Early-type host galaxies
> determine host age from Lick indices with high-quality (S/N ~ 175) spectra
> SN Ia HR vs. host galaxy age.

What is the Origin of Environmental Dependence of SNe Ia Luminosity?

-Unique mass scale of 10^{10} M⊙-



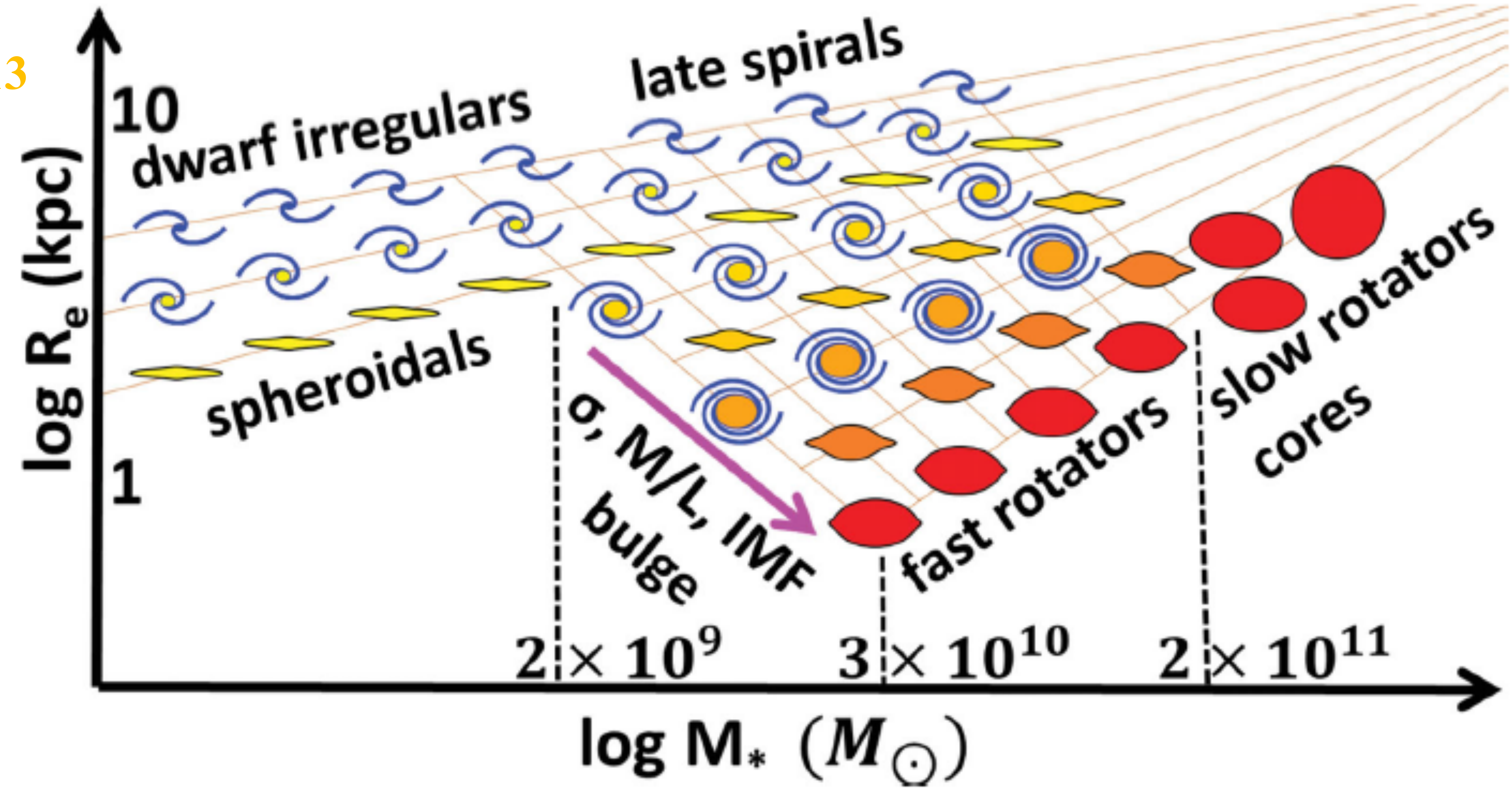
Kim+2019

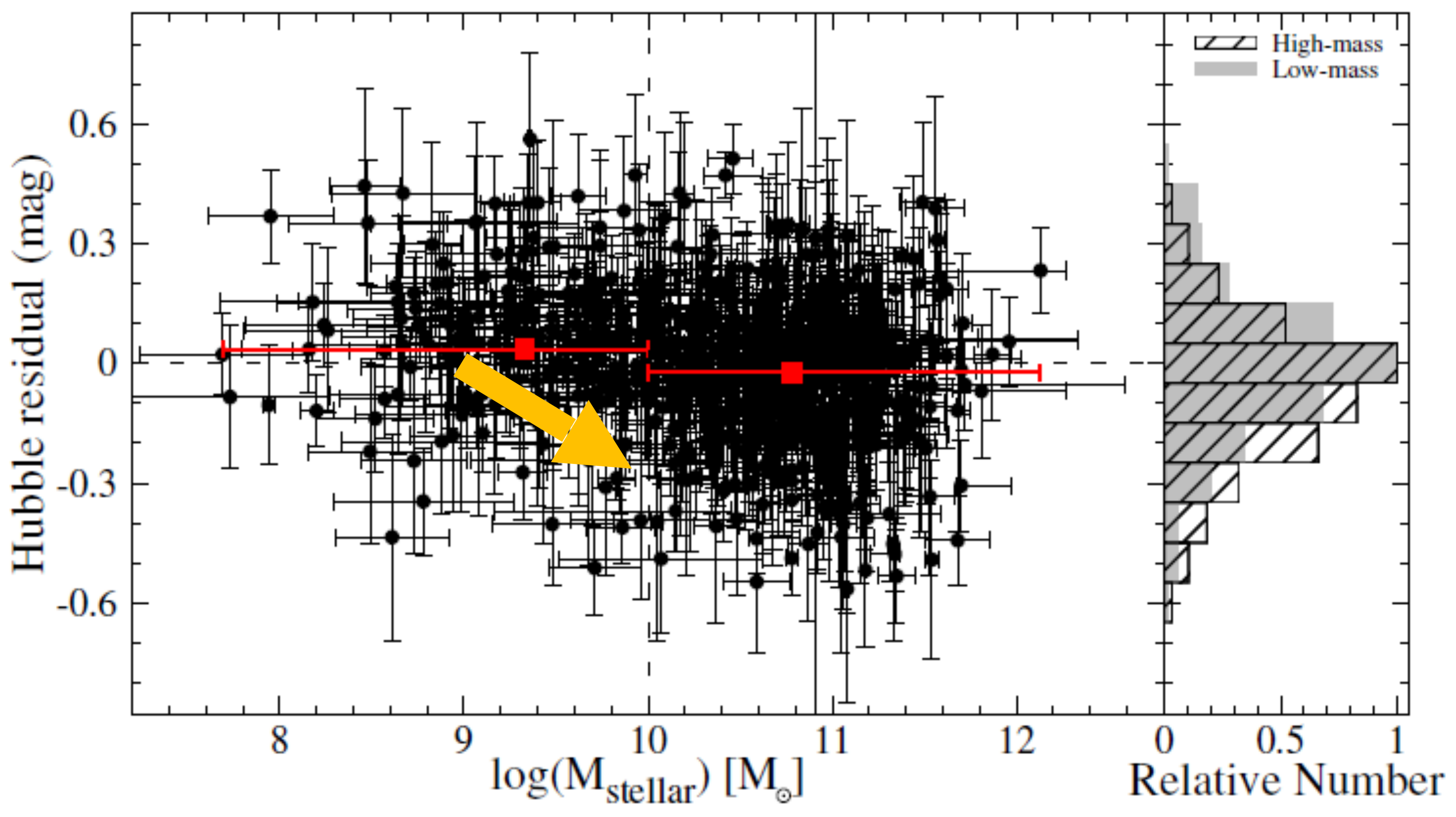
mass-step

What is the Origin of Environmental Dependence of SNe Ia Luminosity?

-Unique mass scale of 10^{10} M☉-

Cappellari+2013



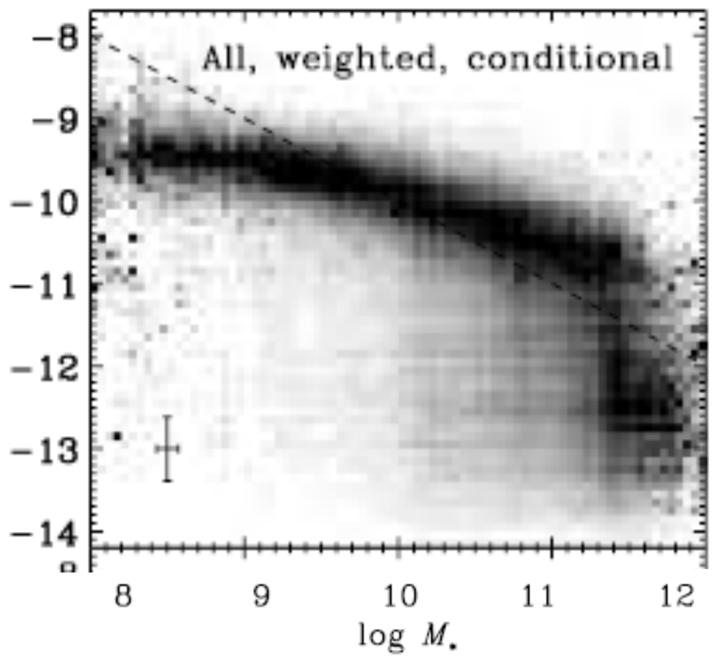


Morphology, mass assembly history, and feedback are changing!

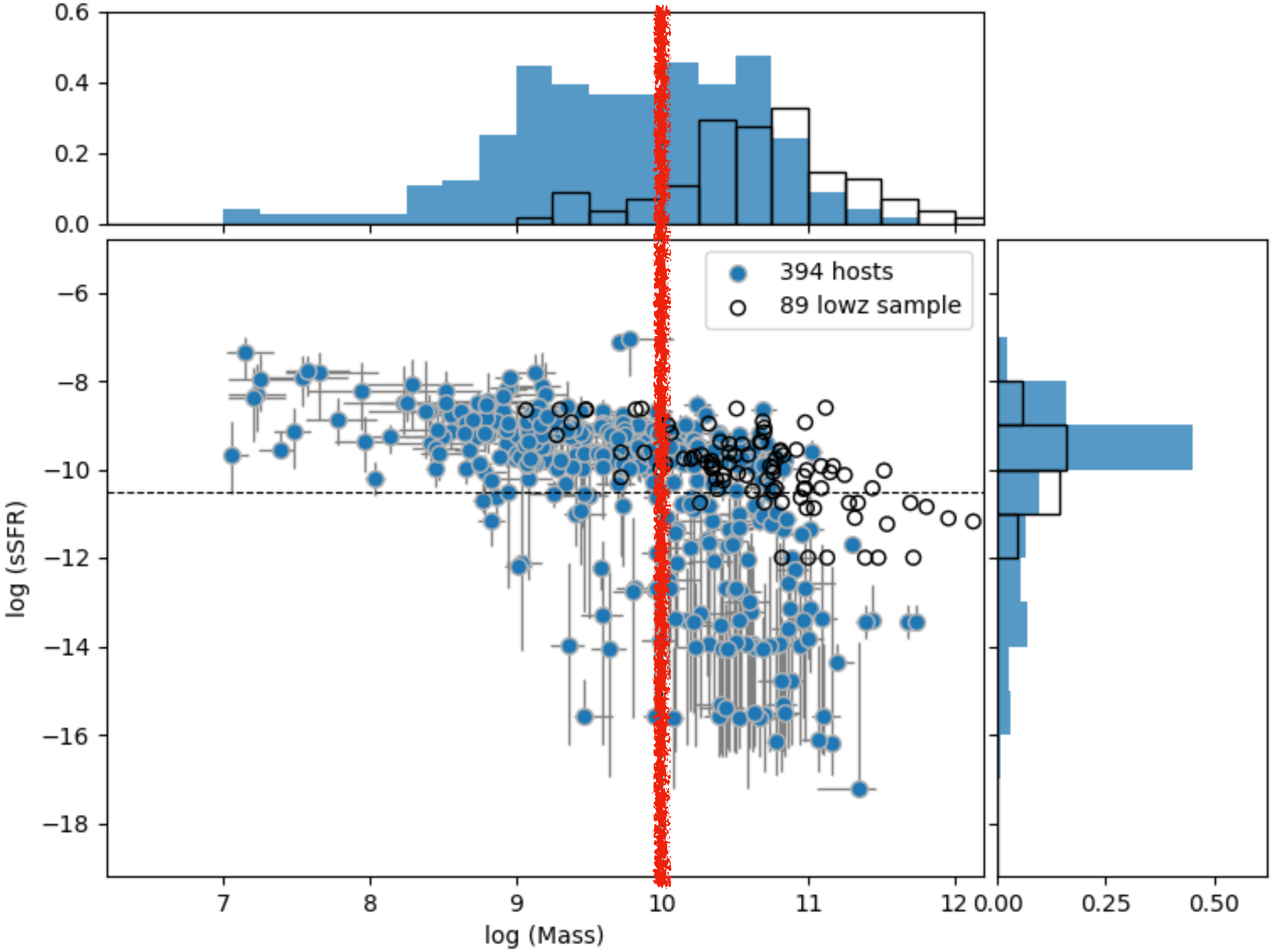
Zwicky Transient Facility

ZTF SN Ia Host Sample

ZTF Year 1 Data: 394 hosts (z < 0.15)

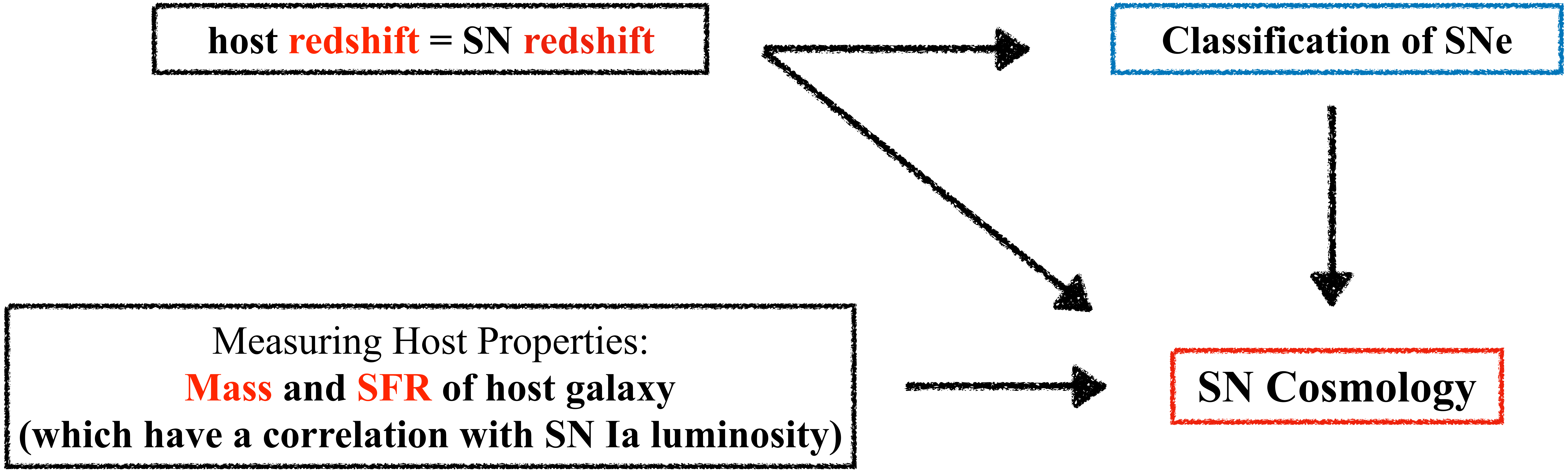


Salim+2007
(~50, 000 galaxies at z~0.1)



Kim et al., in prep

Synergies


host redshift = SN redshift
Classification of SNe
Measuring Host Properties:
Mass and SFR of host galaxy
(which have a correlation with SN Ia luminosity)
SN Cosmology

Synergies

statistical method | **stellar astrophysics**

host redshift = SN redshift

Classification of SNe

Measuring Host Properties:
Mass and SFR of host galaxy
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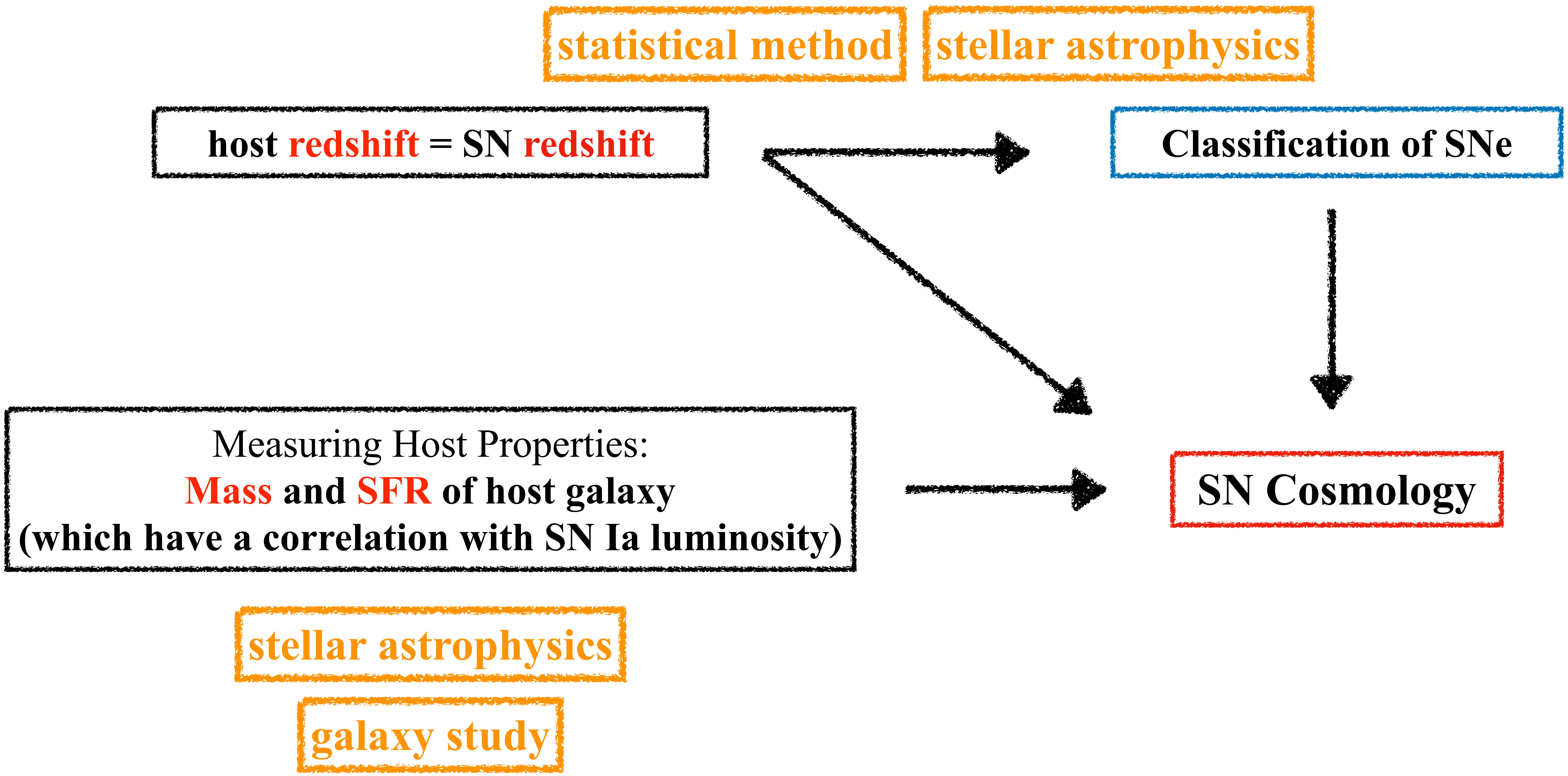
SN Cosmology

Synergies


statistical method
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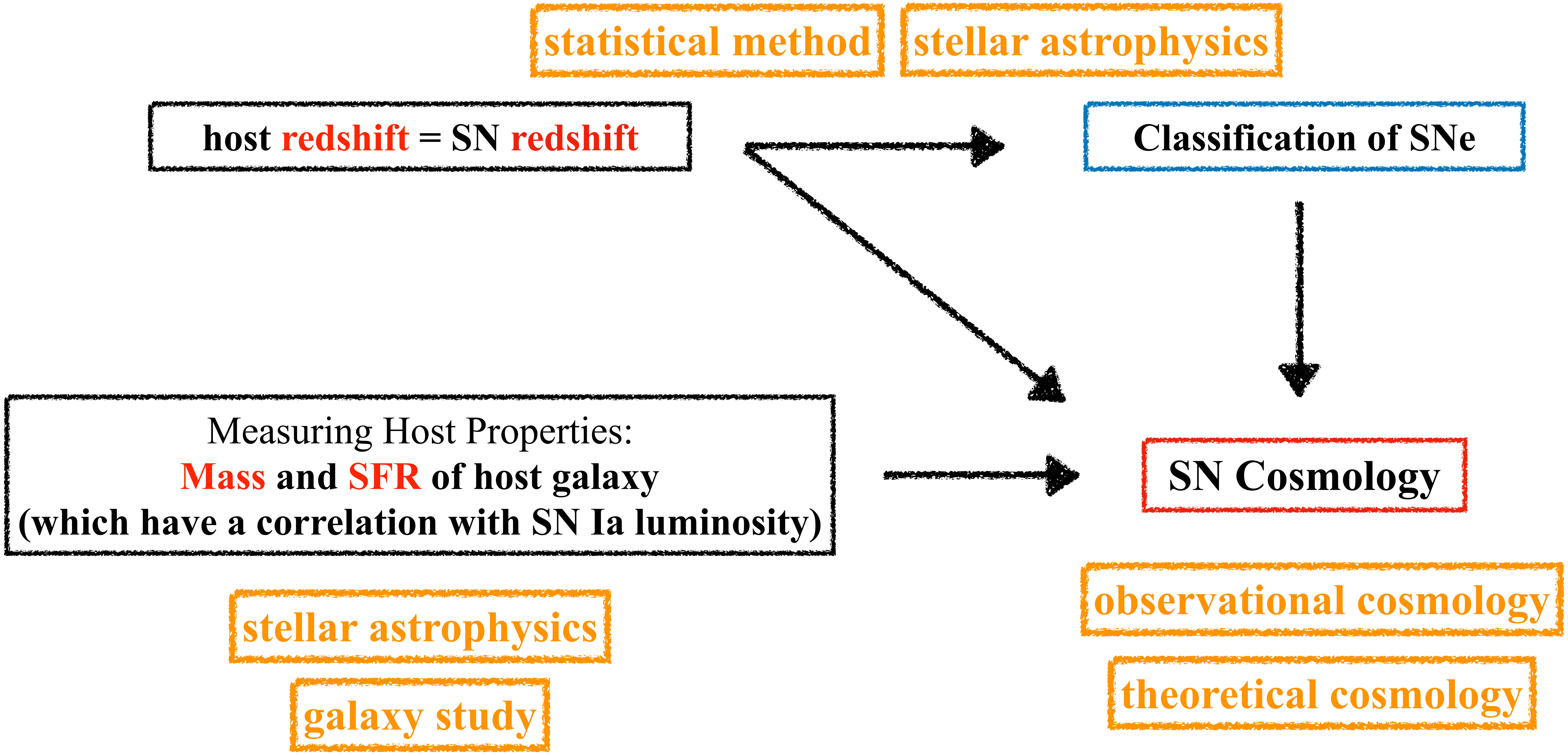
SN Cosmology
stellar astrophysics
galaxy study

Synergies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SN Cosmology
stellar astrophysics
galaxy study
observational cosmology
theoretical cosmology

Thank you!