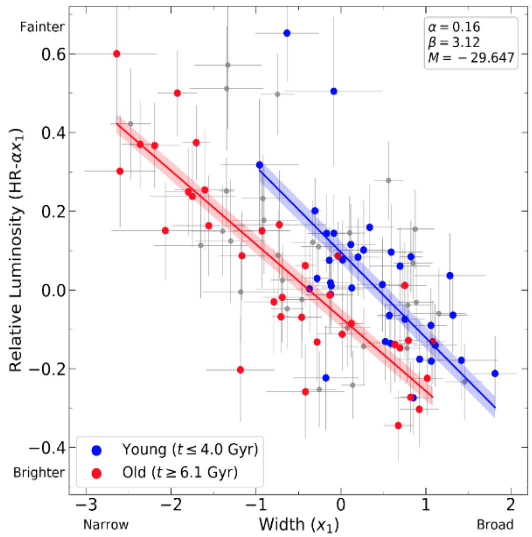
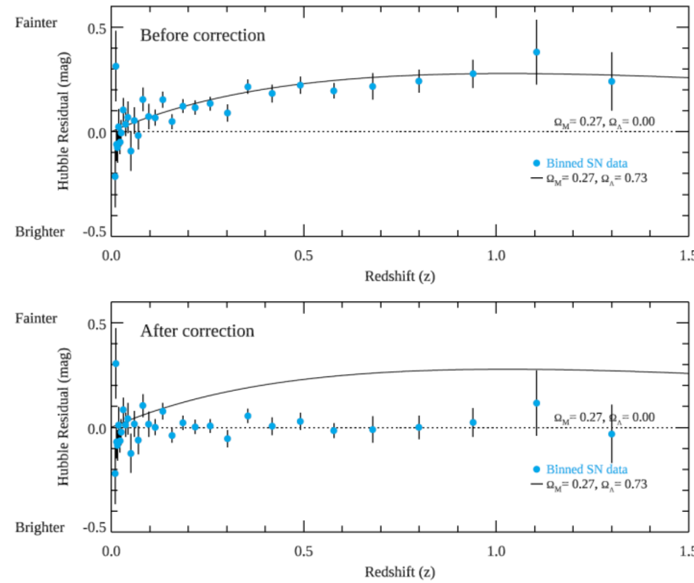
Evidence for strong progenitor age bias in supernova cosmology





Young-Wook Lee (Yonsei), Chul Chung, Hyejeon Cho, Seunghyun Park, Junhyuk Son, Seunghyun An (Yonsei), Pierre Demarque (Yale), Yijung Kang (LSST/SLAC)

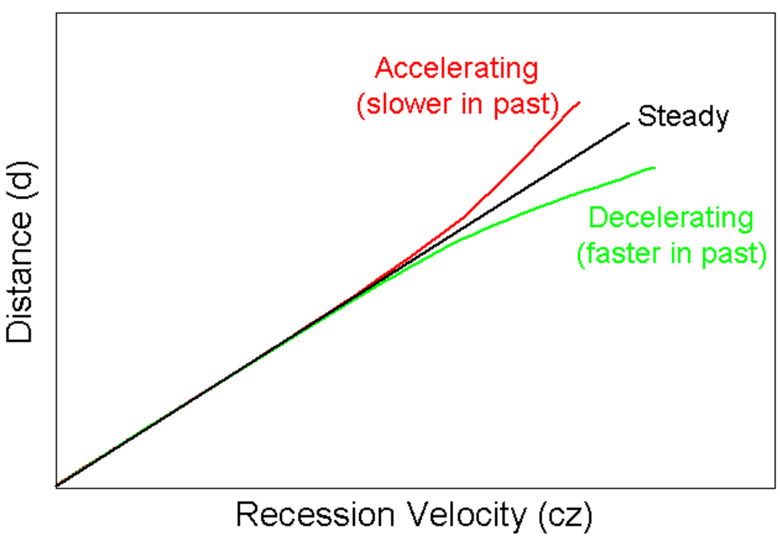
BBU, Romania 20230119

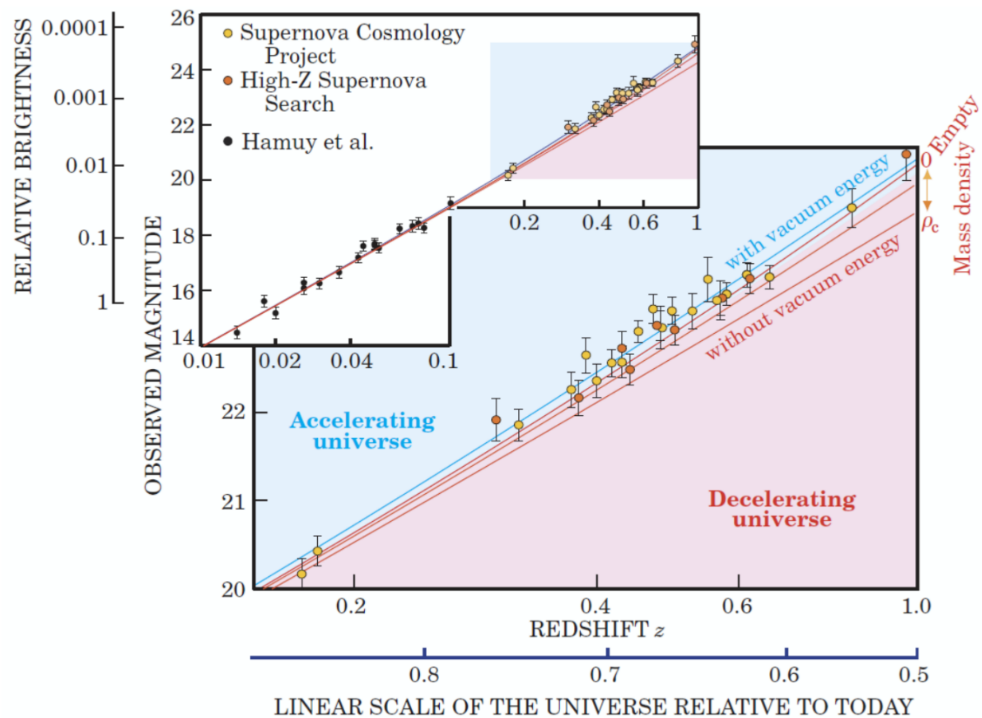
SN cosmology: Most direct evidence for an accelerating universe

"SN cosmology is the most straightforward tool for studying cosmic acceleration..."
(Weinberg, Eisenstein, Riess et al. 2013)

"Independent of GR and based solely upon the SN Hubble diagram…"
(Frieman, Turner, & Huterer 2008, ARAA; Shapiro & Turner 2006; Daly et al. 2008).

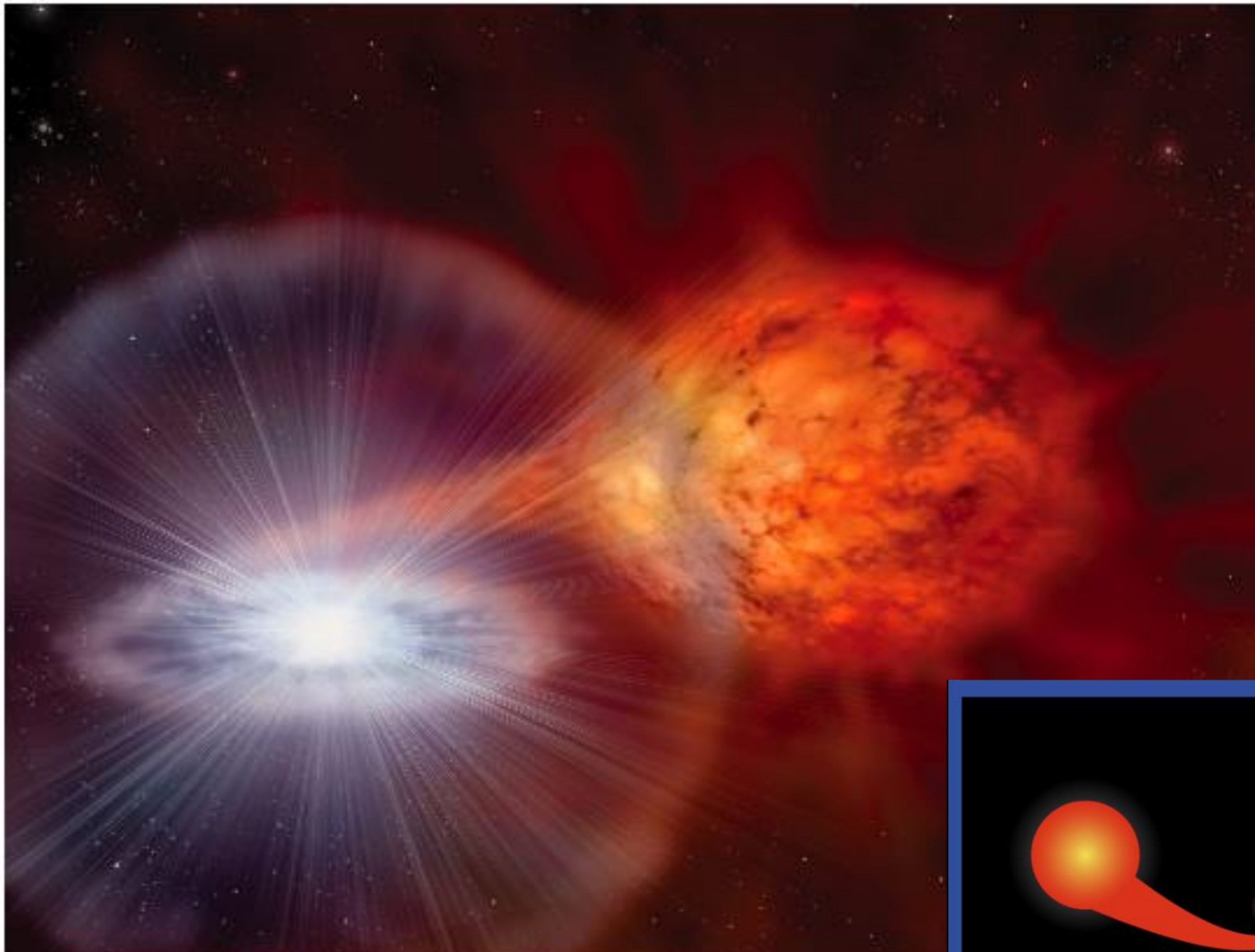
CMB provides crucial constraints on the geometry of the universe, "but it alone provides relatively weak constraints on dark energy." (Planck Collaboration 2020; Frieman et al. 2008)





Type Ia Supernova: "Thermonuclear SN"

(*cf*. Type II SN: "Core-collapse SN")



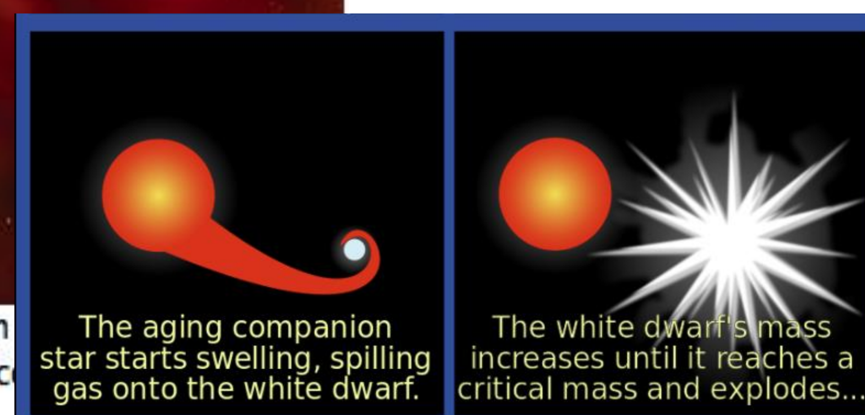
Artist's rendition of a white dwarf accumulating mass from
companion star. This type of progenitor system would be c
degenerate.

Image courtesy of David A. Hardy, © David A. Hardy/www.astroart.org.

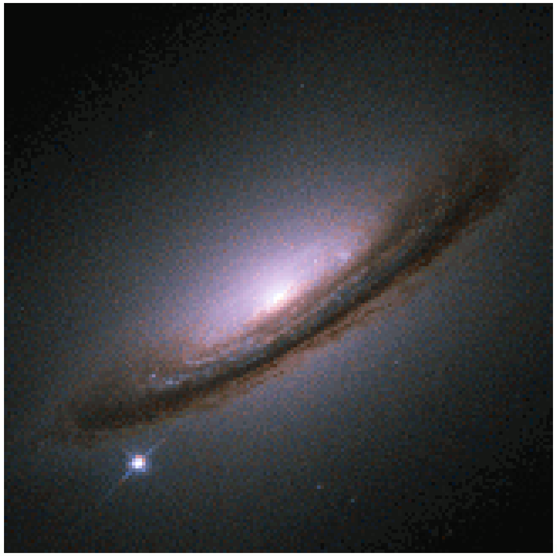
Occurs in a binary system involving at least one white dwarf

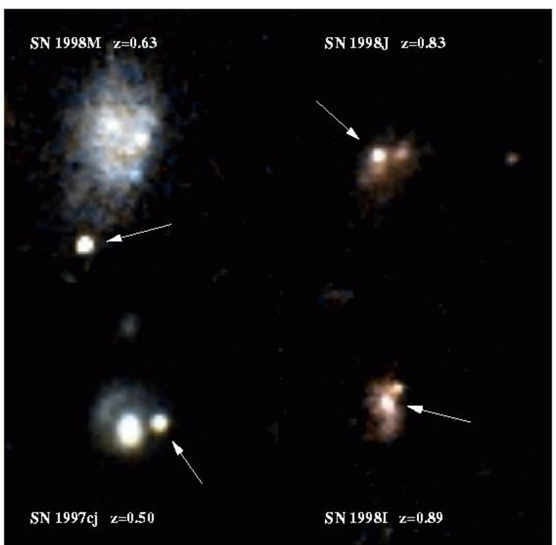
→ Theory is still incomplete (sub-M_{ch} double WD preferred)

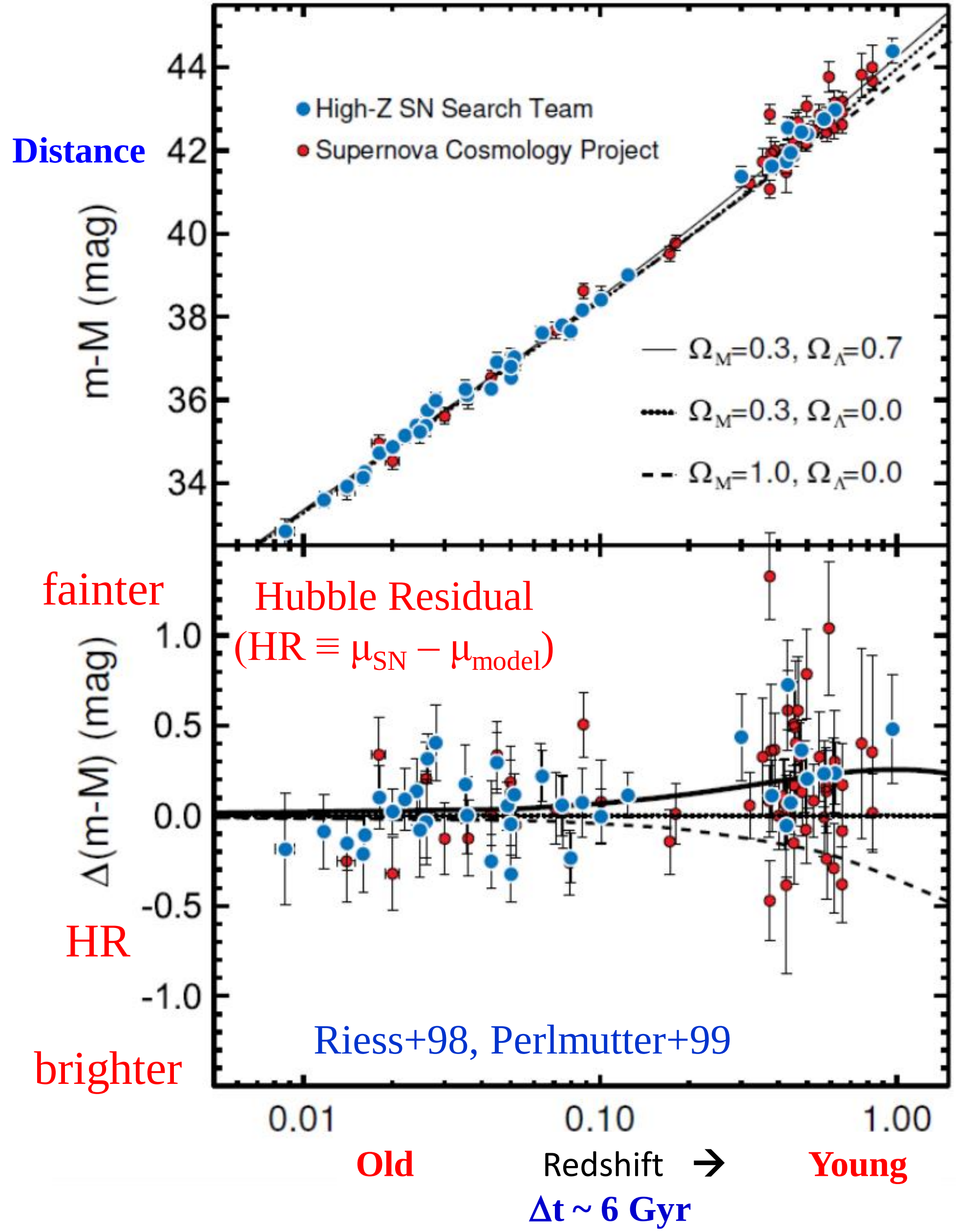
→ Can be used as a standard candle only after the empirical standardization !



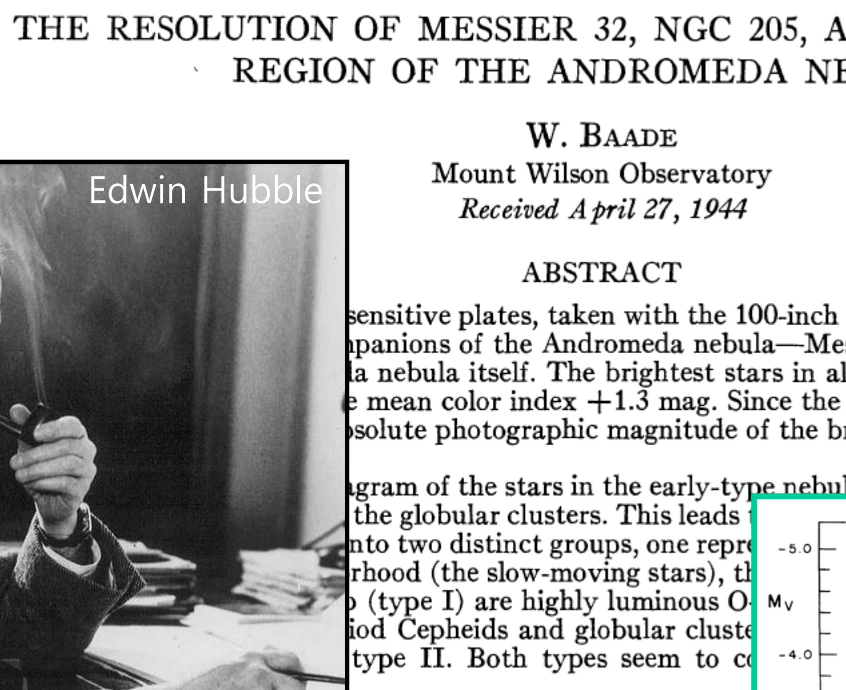
Accelerating Universe or Luminosity Evolution?







Hubble's mistake discovered by Baade

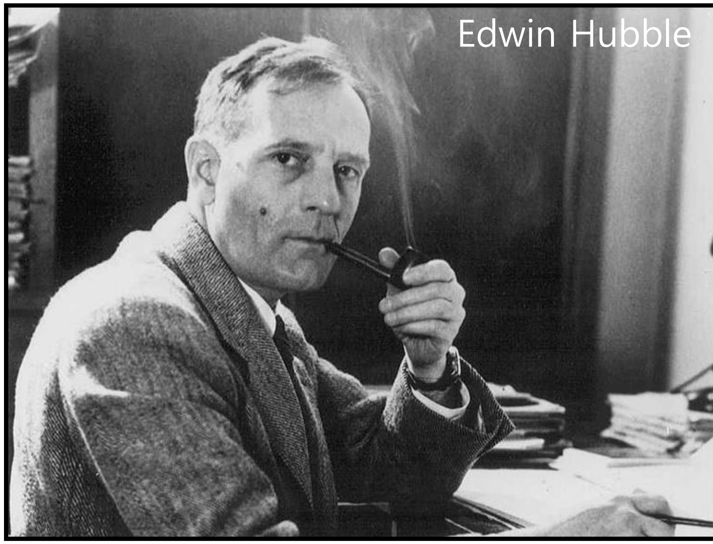

THE RESOLUTION OF MESSIER 32, NGC 205, A
REGION OF THE ANDROMEDA NE

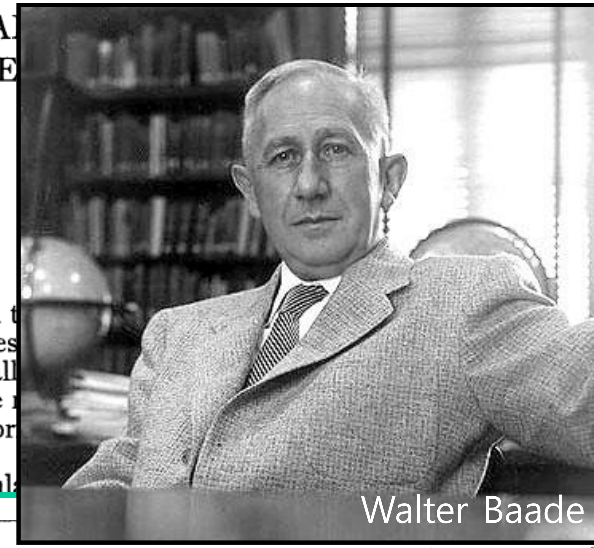
W. Baade
Mount Wilson Observatory
Received April 27, 1944

ABSTRACT

sensitive plates, taken with the 100-inch t
npanions of the Andromeda nebula—Mes
la nebula itself. The brightest stars in all
e mean color index +1.3 mag. Since the
psolute photographic magnitude of the br

agram of the stars in the early-type nebul
the globular clusters. This leads
nto two distinct groups, one repre
rhood (the slow-moving stars), th
o (type I) are highly luminous O-
iod Cepheids and globular cluste
type II. Both types seem to co

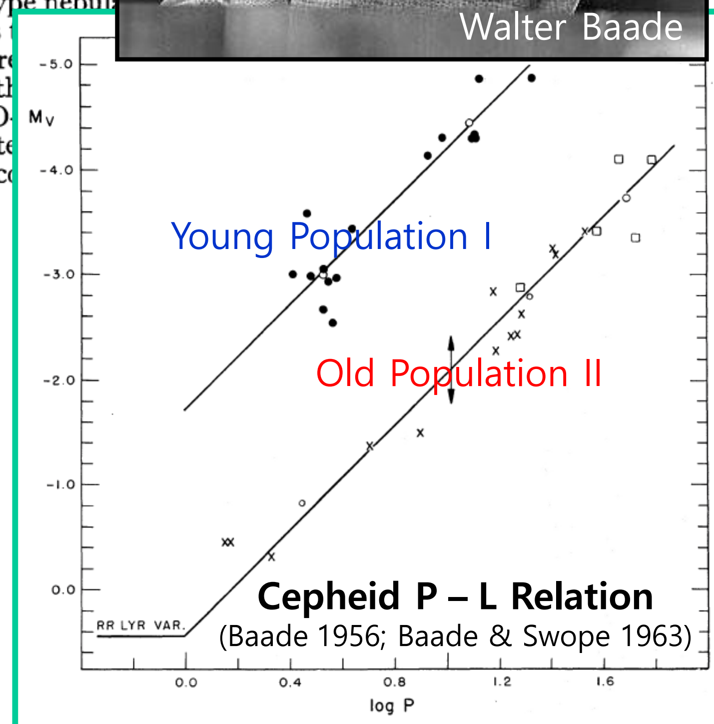




Young population I Cepheids are ~1.5 mag brighter than old population II counterparts

→ M31 distance increased by a factor of 2
→ H_o decreased by a factor of 2 !

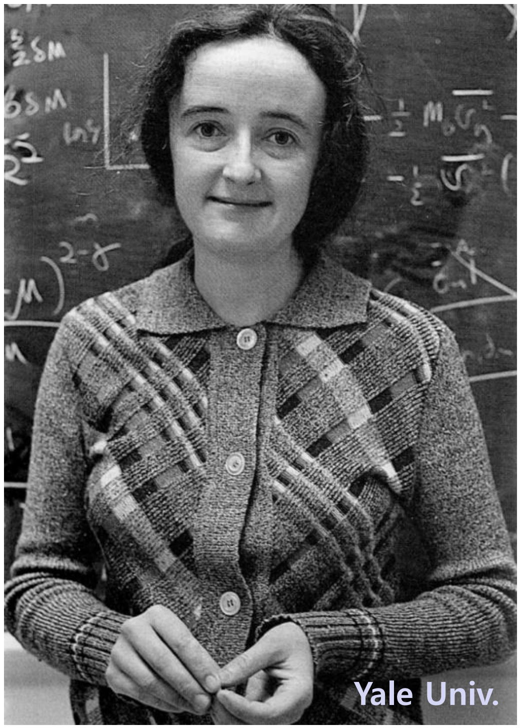
Luminosity of "Standard Candle" can depend on stellar population age (mass)



Cepheid P – L Relation
(Baade 1956; Baade & Swope 1963)

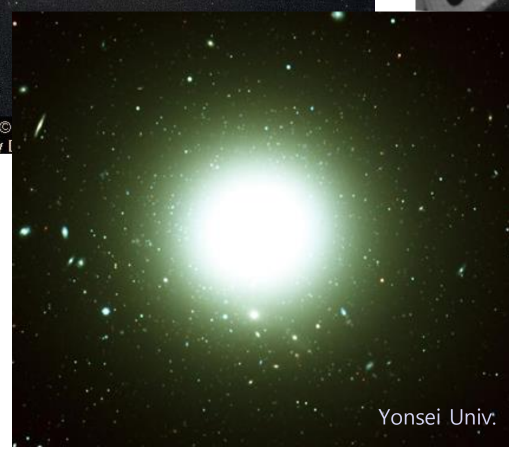
Sandage’s mistake discovered by Tinsley:

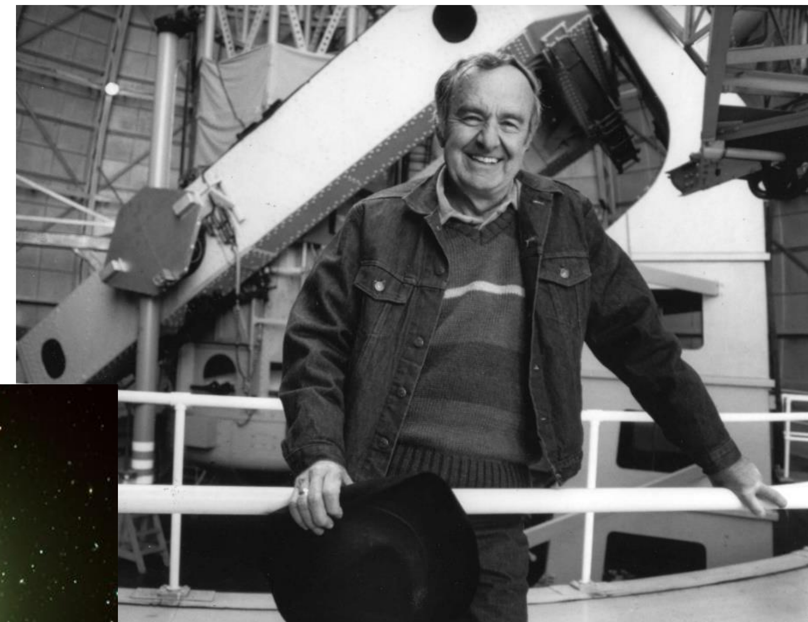
Significant luminosity evolution in observational cosmology



Beatrice Tinsley (1968, 1972)

Theoretical approach



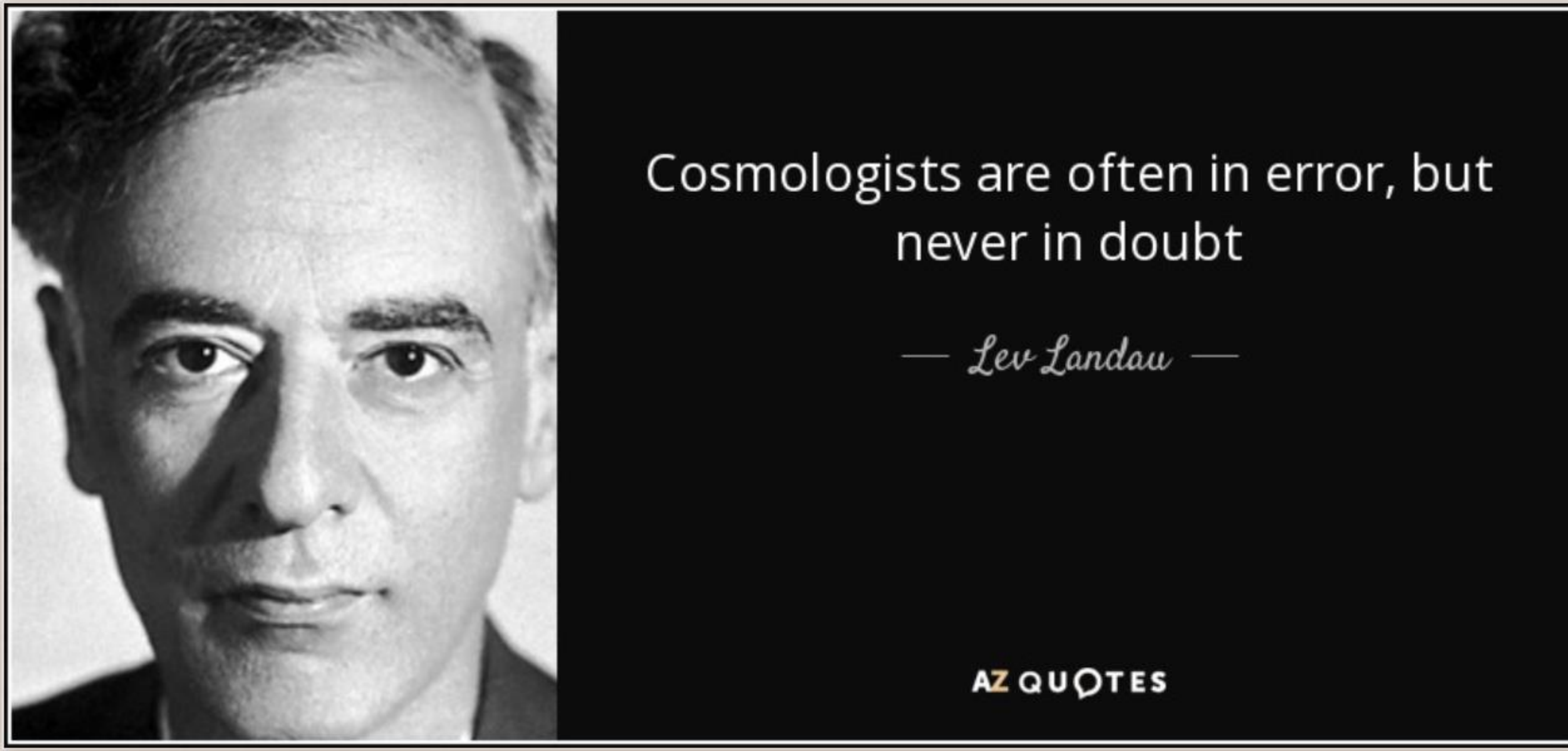


Allan Sandage

Empirical approach

Luminosity evolution underestimated by Sandage →

distance underestimated → incorrect cosmology proposed!



We all make mistakes, and that's the reason why we should make every effort in investigating the possibility of an alternative interpretation in each cosmological probe…

Evidence used to show that there is no luminosity evolution in SN cosmology (Riess+98; Schmidt+98; Perlmutter+99)

→ This key assumption can be best tested *at local universe* by looking for any correlation between population age and HR among host galaxies

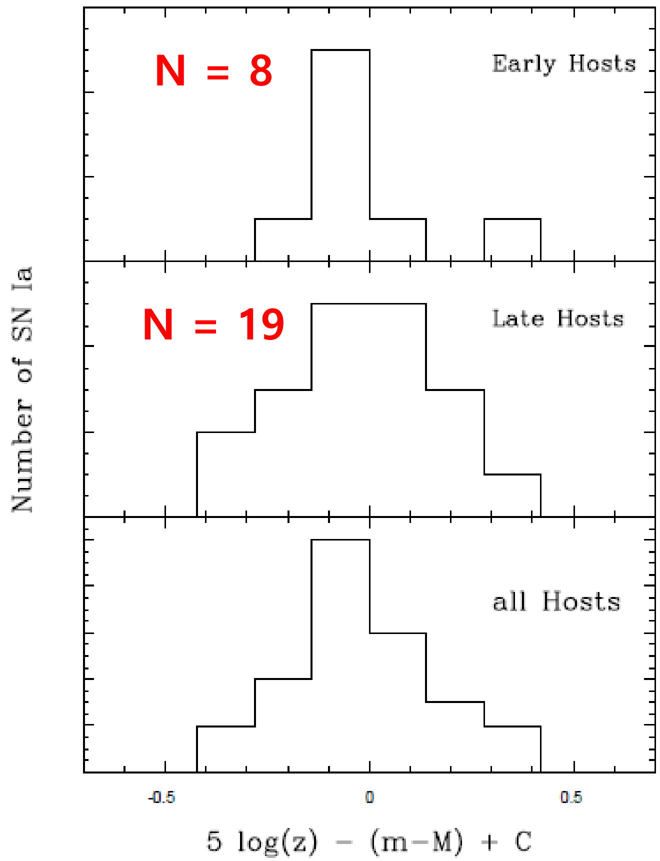


FIG. 3.—Residual of SN Ia distances from RPK96 plotted as a function of galaxy type. The offset between the early-type and late-type galaxies is 0.006 ± 0.07 mag.

Schmidt et al. 1998

Morphology as a proxy for age:

ΔHR = 0.006 +/- 0.07 mag.
Between Early (old) & Late (young) Hosts

→ No Luminosity Evolution

But, more recent & larger CfA dataset shows different result!
(ΔHR = 0.14 +/- 0.07; Hicken+09)

Correlations of SN luminosity (after standardization) with host mass & local SFR

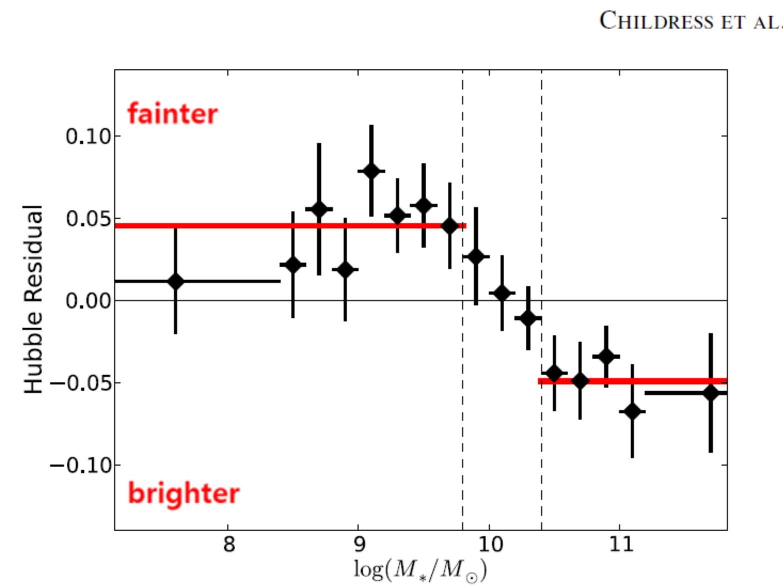
1. SNe Ia in less massive host galaxies are fainter by ~0.1 mag (Sullivan+2010; Kelly+2010; Childress+2013)

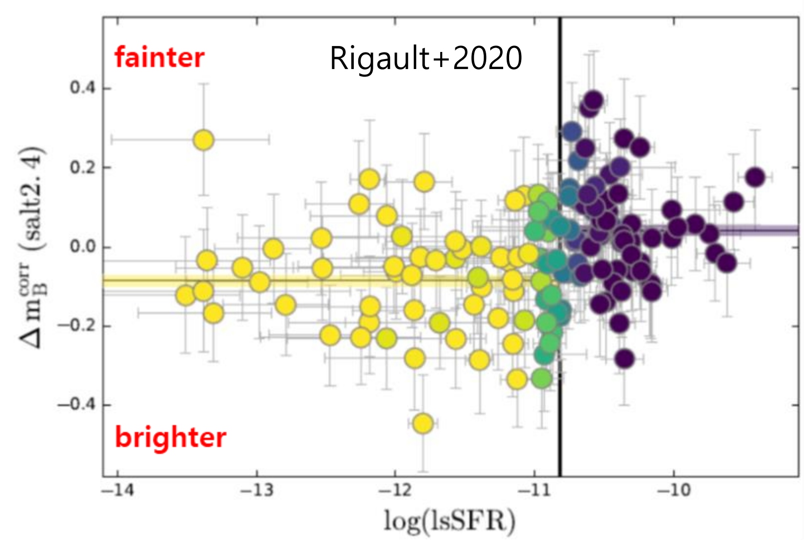
2. SNe Ia in locally star-forming environments are ~0.16 mag fainter than those in passive environments (Rigault+2013, 2020; Kim, Lee+2018)

→ Most likely due to population age...

→ Redshift evolution corrections based on these proxies will mislead!

But reliable population age dating for host galaxies was lacking…





Project YONSEI:

Yonsei Nearby Supernovae Evolution Investigation

(Since 2010)

High S/N (~175) spectra for ~60 nearby early-type host galaxies
($0.01 < z < 0.08$, + many calibration galaxies/stars)

→ 34 nights with LCO 2.5m & MMT 6.5m long-slit spectroscopy

→ Only ETGs because of precision age dating & low extinction

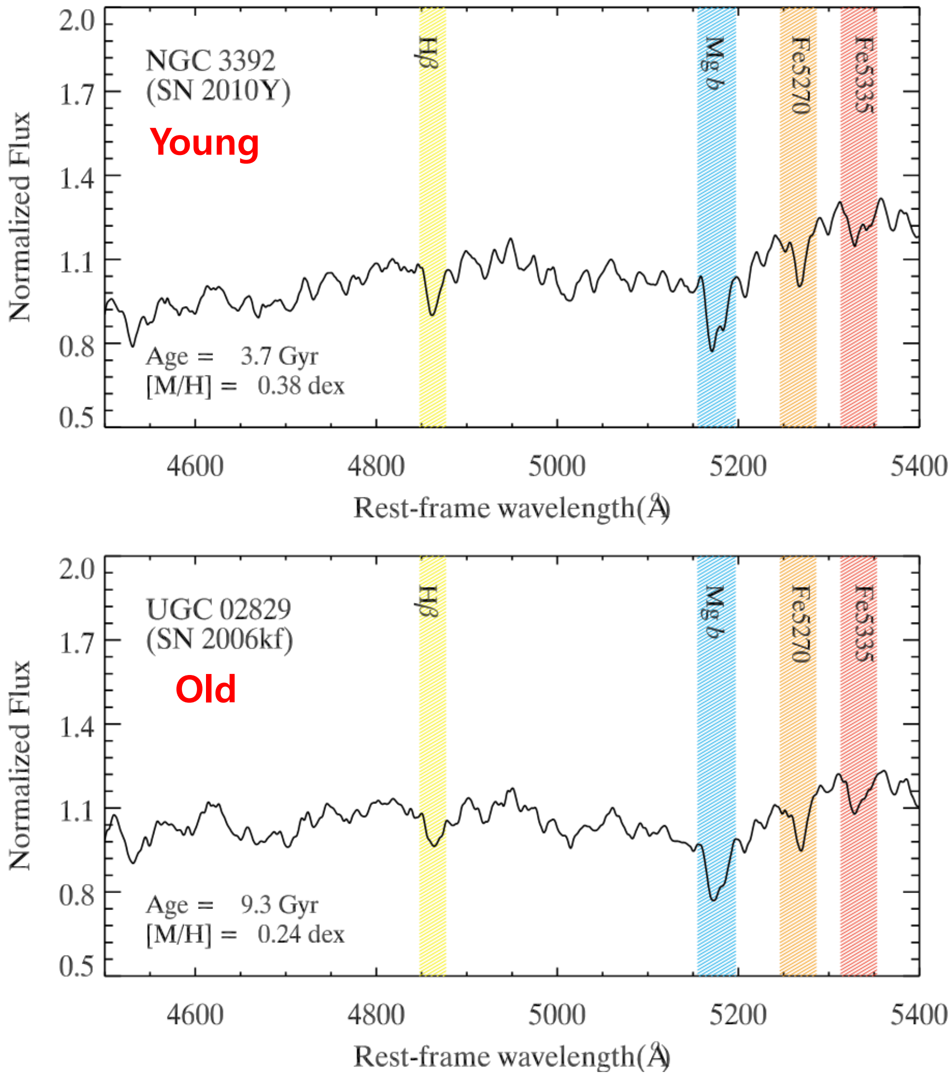
→ For the first time, directly measure reliable population age & metallicity from absorption lines (H_β, Fe, Mgb) & well-established population synthesis models (Yonsei, Thomas, Schiavon)

→ SALT2/SNANA SN LC analysis & standardization (Y.-L. Kim+2018)

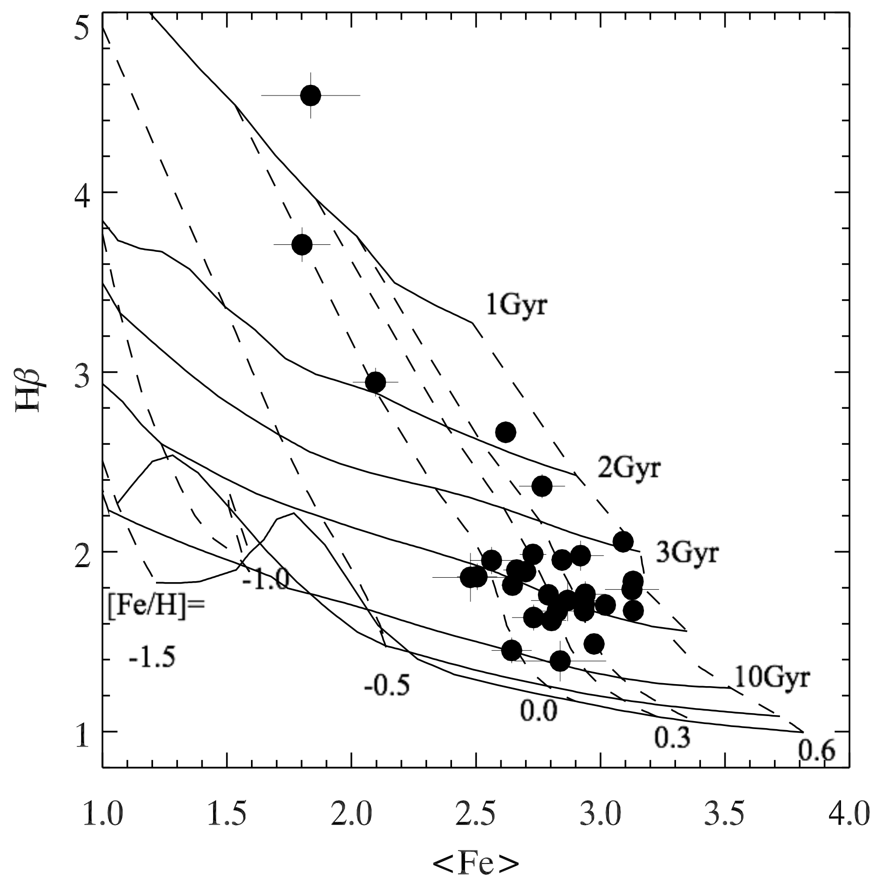
Y. Kang, Y.-W. Lee+2016, 2020

Project YONSEI: Yonsei Nearby Supernovae Evolution Investigation

High Precision (**S/N ~175**) Measurement of Early-type Host Galaxy Ages (since 2010)

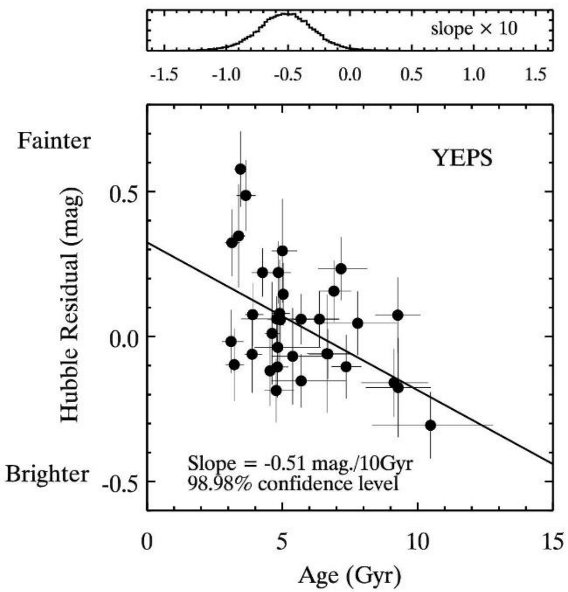


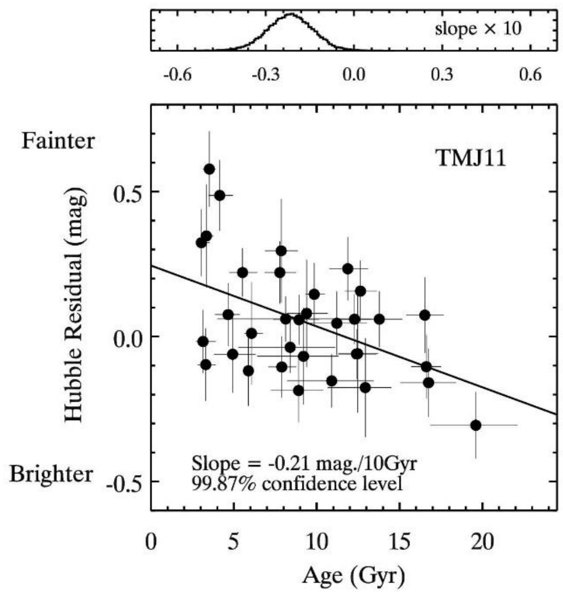
Y. Kang, Y.-W. Lee+2016, 2020



Population Synthesis Models:
Chung+13 (Yonsei); Thomas+11; Schiavon 07

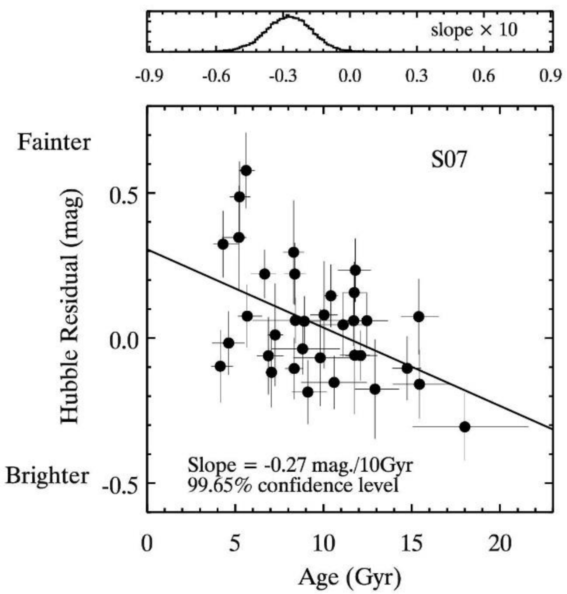
Correlation between SN Luminosity & Population Age





After 9 yrs of hard work, very high S/N (~175) spectra for ~59 (34) normal early-type host galaxies

(Abnormal ETGs with emission lines/recent SF excluded)



3σ Correlation: SNe in younger hosts are fainter (after standardization)

→ high-z SNe should be similarly fainter

0.051 mag/Gyr

This result is not sensitive to the choice of population synthesis model

Y. Kang, Y.-W. Lee+2020, ApJ

Our result from directly measured ages is consistent with previous investigations based on age proxy (host morphology, host mass, local SFR)

Host Property	Reference	Original Correlation	Direction	Converted to Age difference
Morphology	Hicken et al. (2009)	ΔHR / Δmorph.	Fainter in	$\sim$0.19 mag / 5.3 Gyr
		$\approx$0.14 mag / (Scd/Irr-E/S0)	**Later type** galaxy	Fainter in **Younger** galaxy
Mass	Sullivan et al. (2010)	ΔHR /Δmass	Fainter in	$\sim$0.21 mag / 5.3 Gyr
		$\approx$0.08 mag /(Δlog $M_\star \sim 1$)	**Less massive** galaxy	Fainter in **Younger** galaxy
Local SFR	Rigault et al. (2018)	ΔHR /Δlocal SFR	Fainter in	$\sim$0.35 mag /5.3 Gyr
		$\approx$0.16 mag /(Δlog(sSFR$_{>-10.8}$ - sSFR$_{<-10.8}$, yr^{-1} kpc^{-2})	**Higher SFR** environments	Fainter in **Younger** galaxy
Population Age	This work	ΔHR / Δ pop. age	Fainter in	$\sim$0.27 mag /5.3 Gyr
		$\approx$0.051 mag / Gyr (YEPS)	**Younger** galaxy	Fainter in **Younger** galaxy

Y. Kang, Y.-W. Lee+2020, ApJ

When they are converted to age difference
based on our result, Scott et al. 2017, & Galbany et al. 2014

→ *They are all pointing to the same direction!*

→ SNe Ia in younger galaxies (i.e., high-z) are fainter!

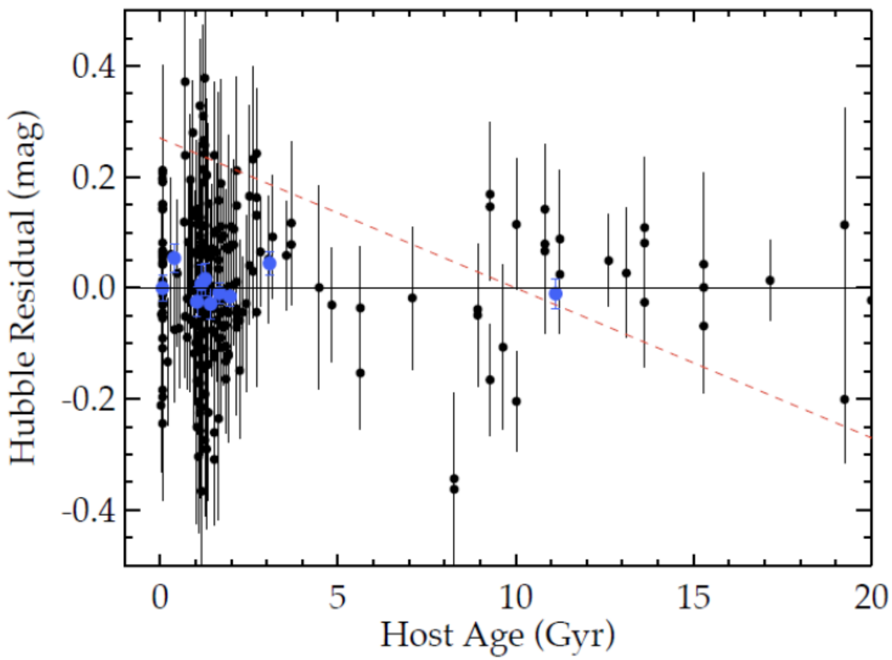
The Astrophysical Journal Letters, 896:L4 (7pp), 2020 June 10 https://doi.org/10.3847/2041-8213/ab94ad

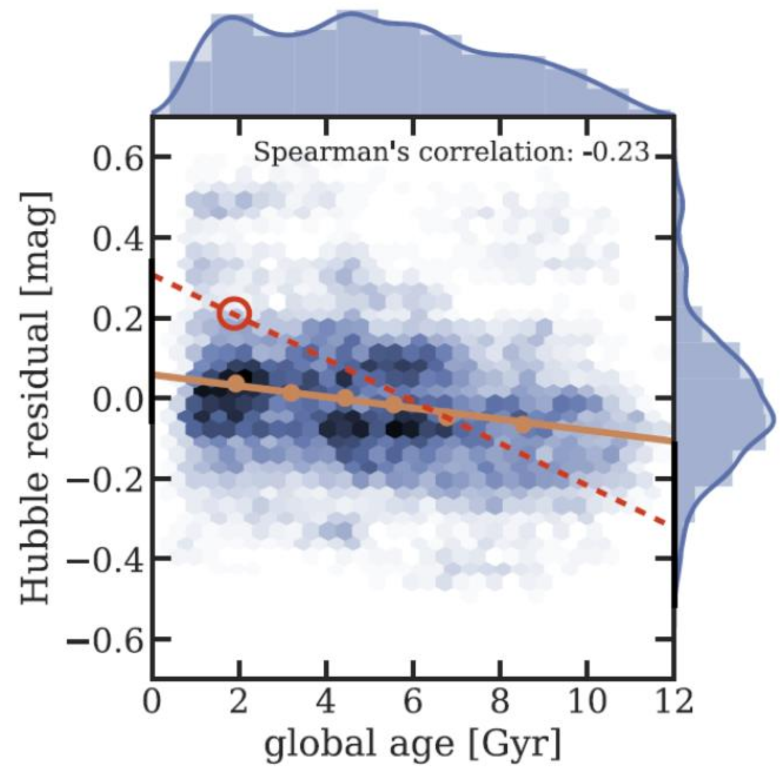
Our result not confirmed from a larger sample of host galaxies of all morphological types??

Evidence for Cosmic Acceleration Is Robust to Observed Correlations between Type Ia Supernova Luminosity and Stellar Age

B. M. Rose[1], D. Rubin[2,3], A. Cikota[3], S. E. Deustua[1], S. Dixon[3,4], A. Fruchter[1], D. O. Jones[5], A. G. Riess[1,6], and D. M. Scolnic[7]

[1] Space Telescope Science Institute, 3700 San Martin Driv
[2] Physics and Astronomy Department, University
[3] Physics Division, E.O. Lawrence Berkeley National Labora
[4] Department of Physics, University of California Berkeley, 36(



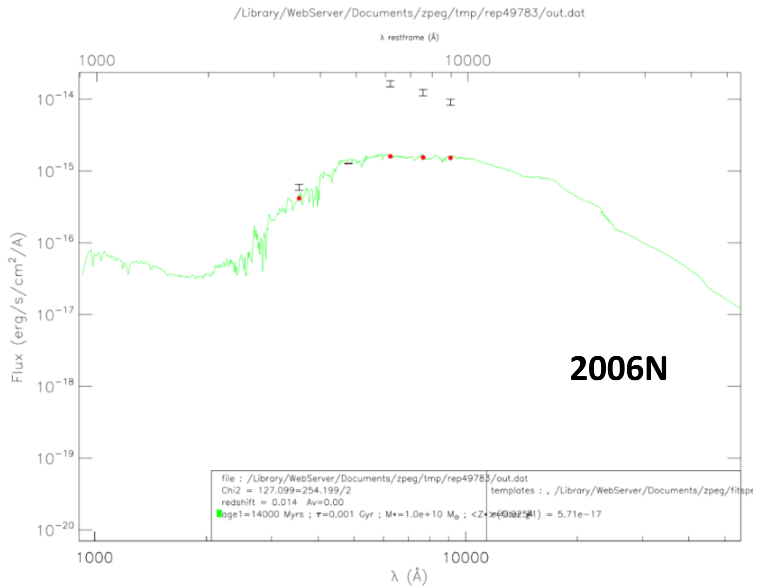


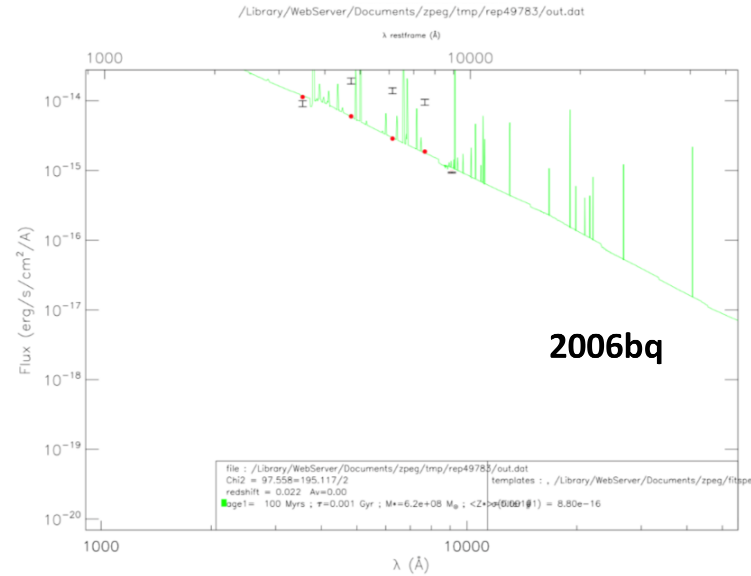
Seriously flawed result based on unqualified, unpublished (Jones+18) **age data without error bar**

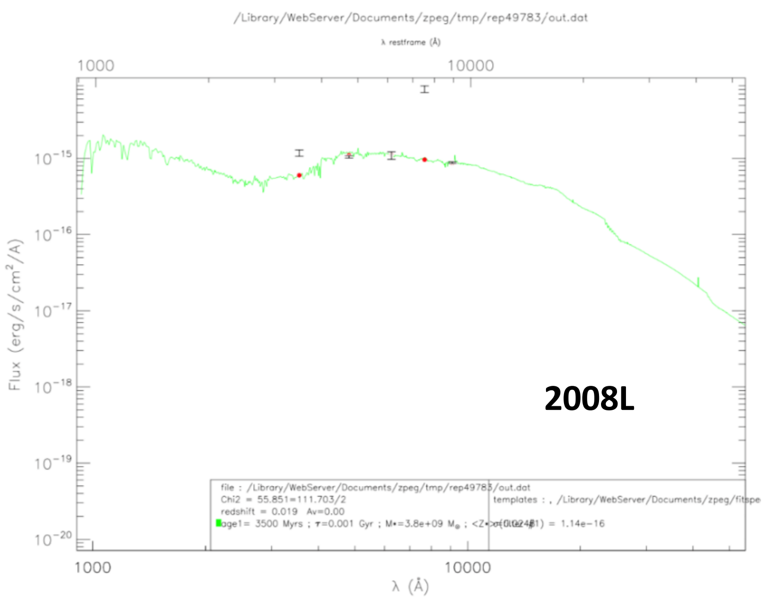
"In science, the data w/o error bar is not even the data"

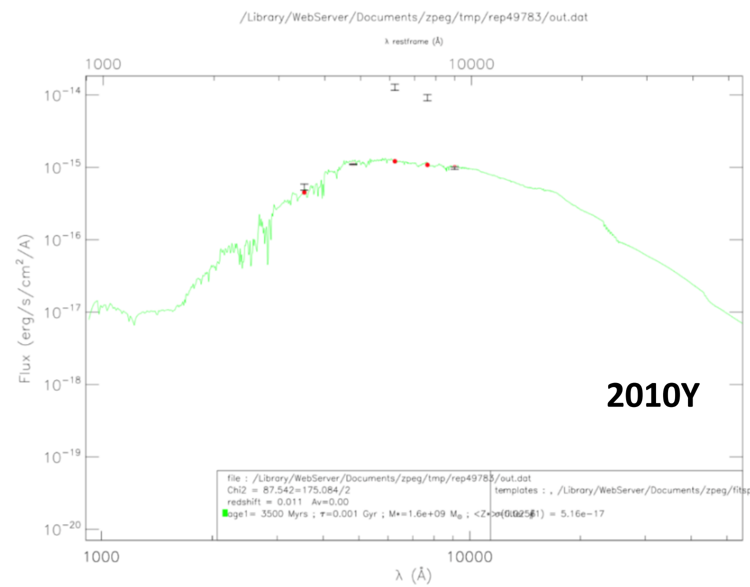
Reliable photometric age dataset (Rose+2019), but serious problem in their statistical analysis (regression dilution bias)

Jones+2018 ages (unpublished): We re-enacted their procedures (Z-PEG) & found that ~50% were derived under serious template mismatch (age error → up to 9.7 Gyr!)

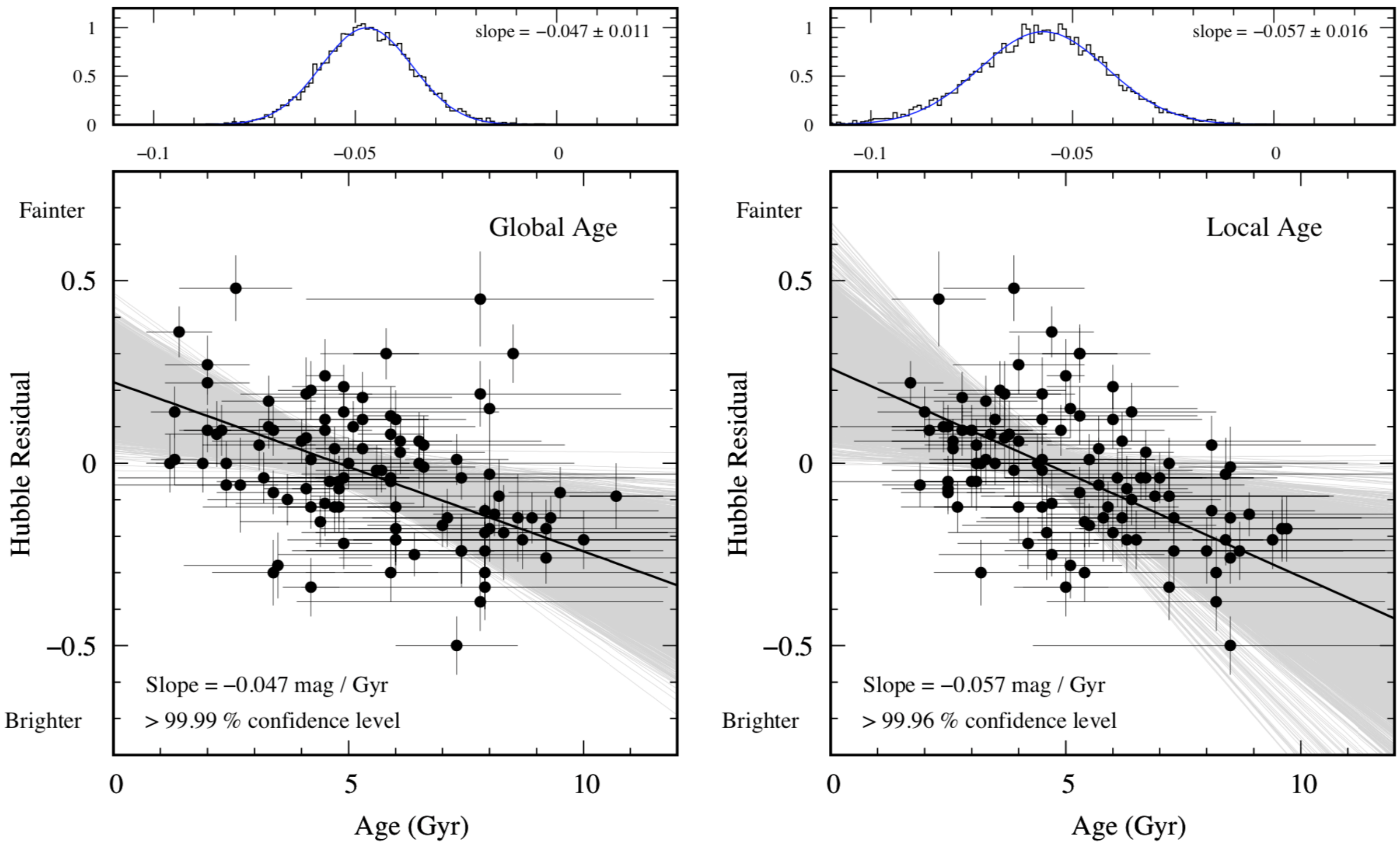








Surprising reversal!: Significant age – HR correlation
from host galaxies comprising all morphological types



Data: Reliable photometric mass-weighted ages (Rose+2019) & HRs (Campbell+2013)
Regression analysis: MCMC posterior sampling method (Kelly 2007)
→ **4.3 sigma (99.99%)** correlation between population age & HR, in excellent agreement with our spectroscopic result from ETGs!

Y.-W. Lee, Chung, Kang, & Jee 2020, ApJ

The Astrophysical Journal, 903:22 (5pp), 2020 November 1
https://doi.org/10.3847/1538-4357/abb3c6

Further Evidence for Significant Luminosity Evolution in Supernova Cosmology

Young-Wook Lee[1,2], Chul Chung[1,2], Yijung Kang[3], and M. James Jee[1,4]
[1] Department of Astronomy, Yonsei University, Seoul 03722, Republic of Korea; ywlee2@yonsei.ac.kr, chulchung@yonsei.ac.kr
[2] Center for Galaxy Evolution Research, Yonsei University, Seoul 03722, Republic of Korea
[3] Gemini Observatory/NSFs NOIRLab, Casilla 603, La Serena, Chile
[4] Department of Physics, University of California, Davis, One Shields Avenue, Davis, CA 95616, USA
Received 2020 June 26; revised 2020 August 21; accepted 2020 August 26; published 2020 October 28

Abstract

Supernova (SN) cosmology is based on the assumption that the corrected luminosity of SNe Ia would not evolve with redshift. Recently, our age dating of stellar populations in early-type host galaxies (ETGs) from high-quality spectra has shown that this key assumption is most likely in error. It has been argued though that the age–Hubble residual (HR) correlation from ETGs is not confirmed from two independent age data sets measured from multiband optical photometry of host galaxies of all morphological types. Here we show, however, that one of the data sets is based on highly uncertain and inappropriate luminosity-weighted ages derived, in many cases, under serious template mismatch. The other data set employs more reliable mass-weighted ages, but the statistical analysis involved is affected by regression dilution bias, severely underestimating both the slope and significance of the age–HR correlation. Remarkably, when we apply regression analysis with a standard posterior sampling method to this data set comprising a large sample ($N = 102$) of host galaxies, very significant (>99.99%) correlation is obtained between the global population age and HR with the slope (-0.047 ± 0.011 mag Gyr^{-1}) highly consistent with our previous spectroscopic result from ETGs. For the local age of the environment around the site of SNe, a similarly significant (>99.96%) correlation is obtained with a steeper slope (-0.057 ± 0.016 mag Gyr^{-1}). Therefore, the SN luminosity evolution is strongly supported by the age dating based on multiband optical photometry and can be a serious systematic bias in SN cosmology.

Even the dataset originally used by Rose, Riess+2020 to oppose our claim is instead strongly supporting our result!!

→ 5σ correlation confirmed by a third party (Zhang+2021)

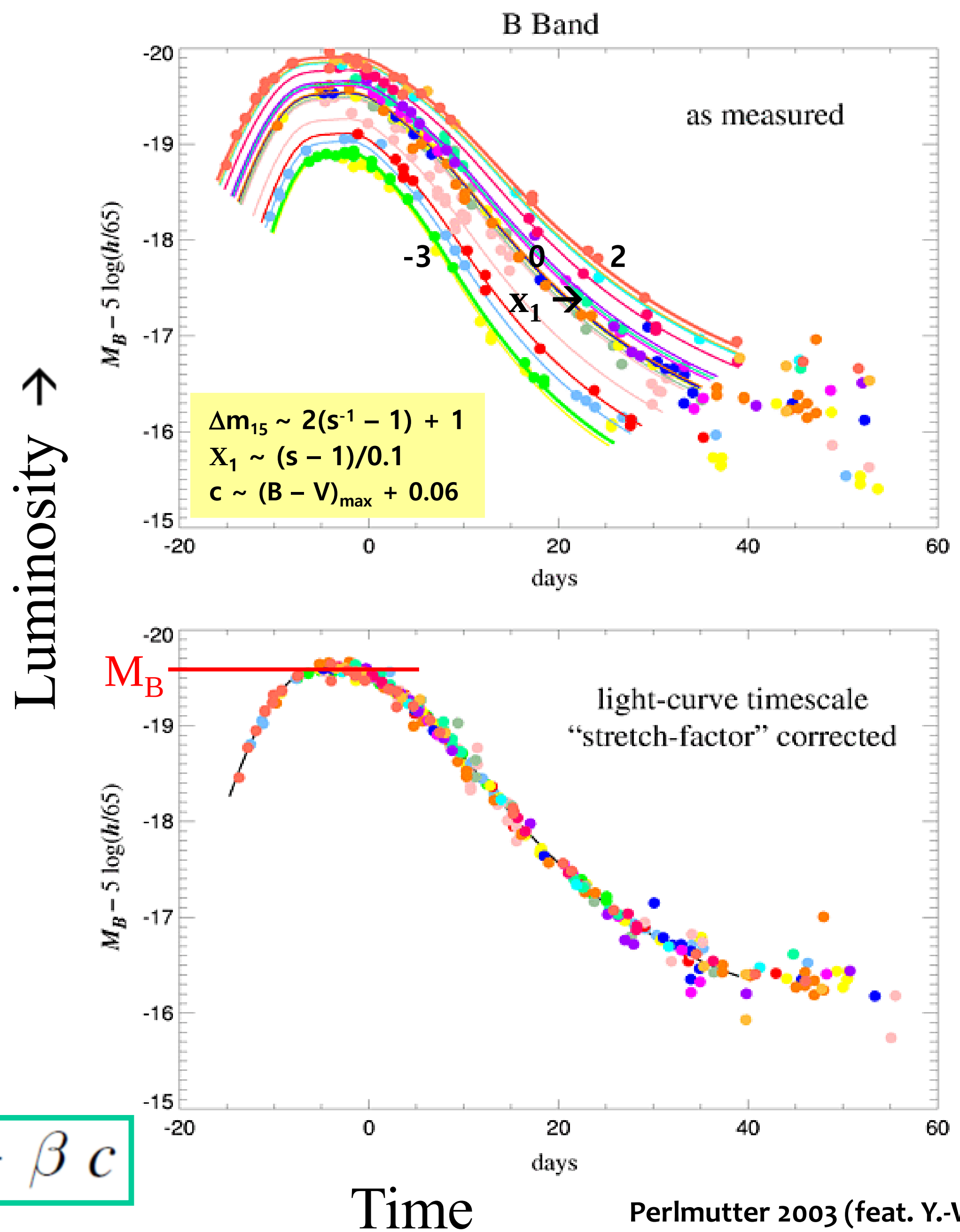
Type Ia SNe

"Standardizable" Candle:
Peak luminosity = f(light-curve width, color)

Width/stretch & color parameters:
$x_1(s, \Delta m_{15})$, c

Assume no evolution with z
(progenitor age)

$$\mu = m_B - M + \alpha\, x_1 - \beta\, c$$



Perlmutter 2003 (feat. Y.-W. Lee)

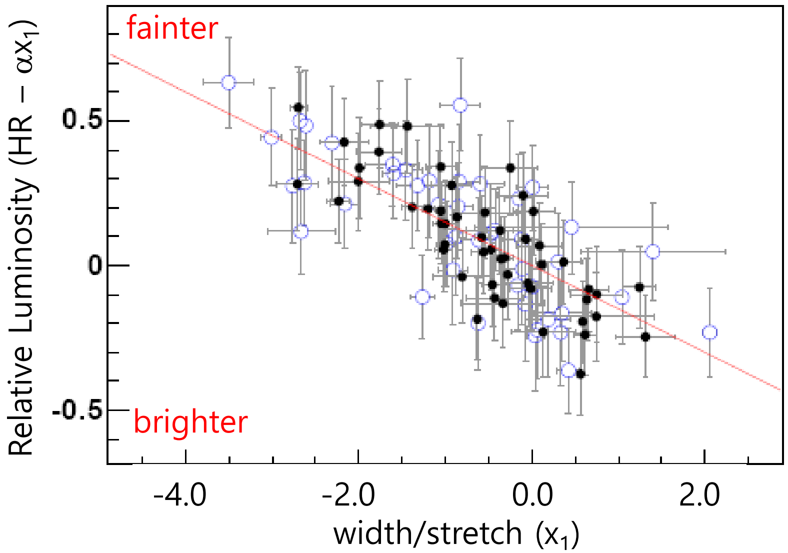
Measuring Luminosity Distances with SNe Ia (SALT2)

Distance modulus $\mu = 5\log_{10} D_L$ estimated using apparent magnitude in a rest-frame (or redshifted) filter + correction factors based on the shape of the SN light curve and its color

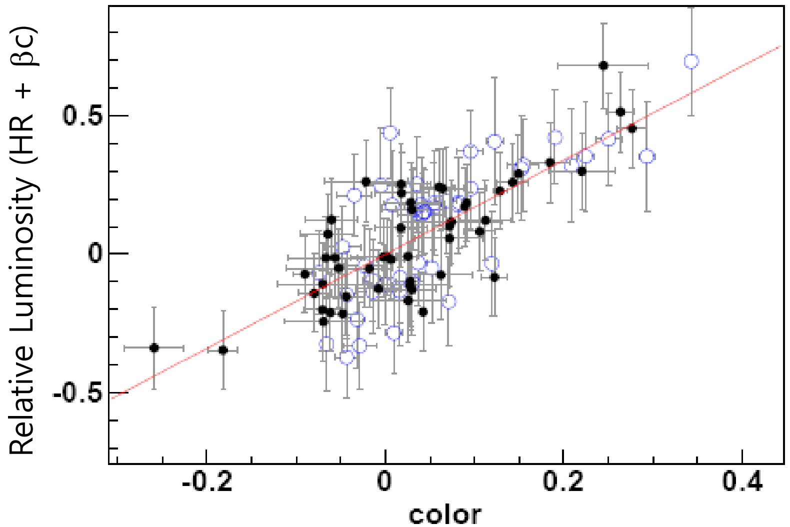
Correction terms

$$\mu_B = m_B^\star - \mathcal{M}_B + \boxed{\alpha \times \underset{x_1}{shape} - \beta \times \underset{c}{color}}$$

$\mathcal{M}_B$, α and β fitted at the same time as cosmology.



Width – Luminosity relation (WLR)



Color – Luminosity relation (CLR)

Credit: J. Guy 2011 (feat. Y.-W. Lee)

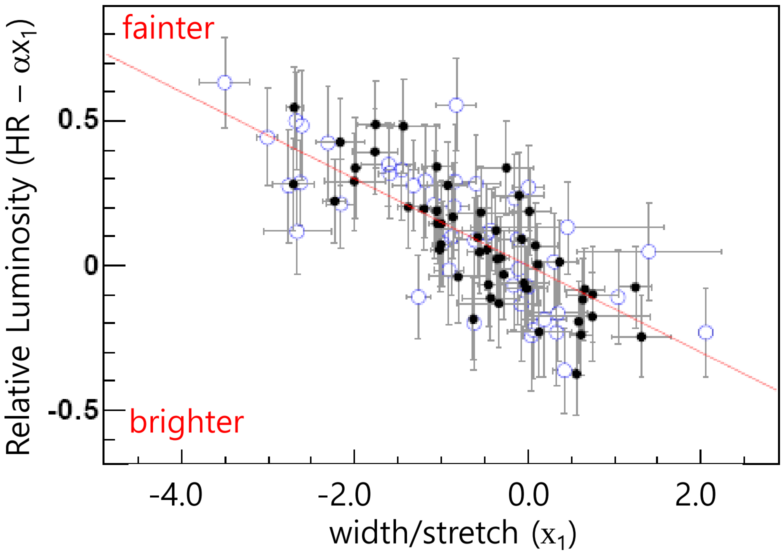
The Key Assumption & Requirement in Supernova Cosmology

"If SNe Ia are to be good standardisable candles over cosmic time, the calibrating relationships between SN luminosity and light-curve shape must be invariant with progenitor age."

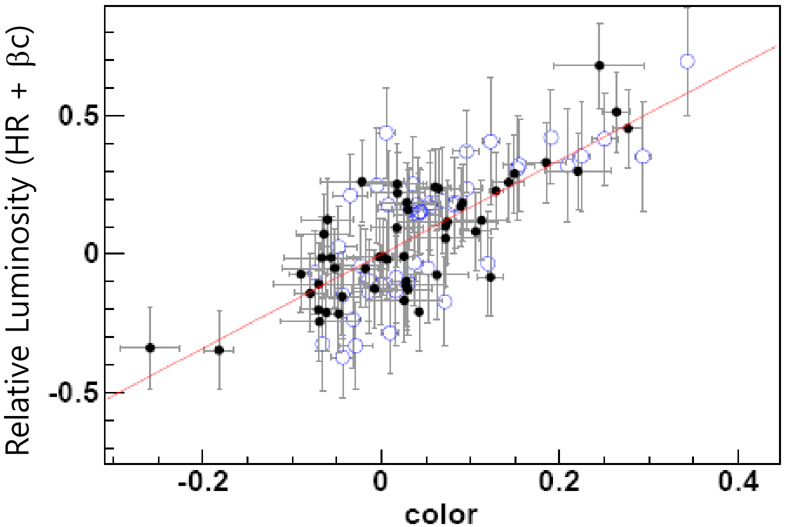
Jha, Maguire, & Sullivan 2019, Nature Astronomy

$$\mu_B = m_B^{\star} - \mathcal{M}_B + \alpha \times \underbrace{shape}_{x_1} - \beta \times \underbrace{color}_{c}$$

$\mathcal{M}_B$, α and β fitted at the same time as cosmology.



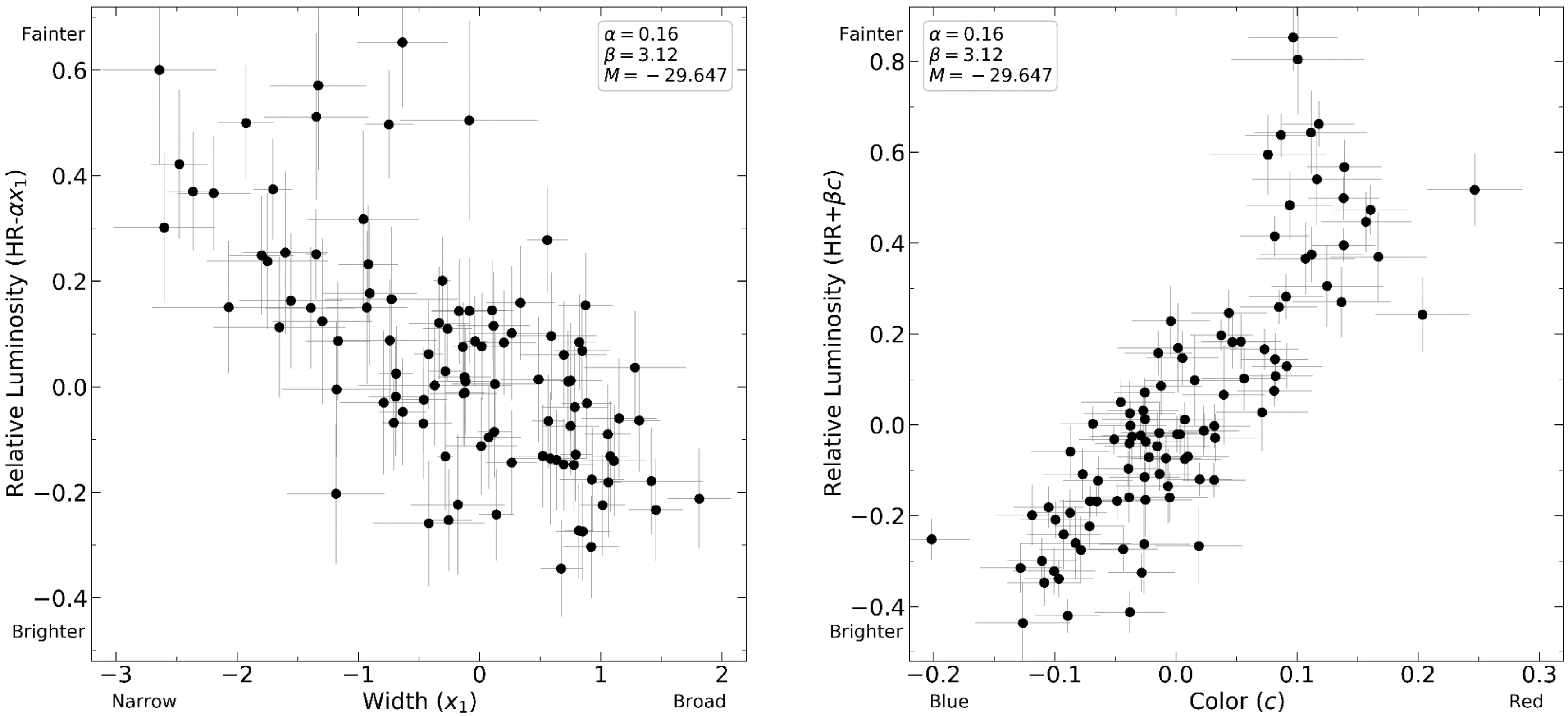
Width – Luminosity relation (WLR)



Color – Luminosity relation (CLR)

Credit: J. Guy 2011 (feat. Y.-W. Lee)

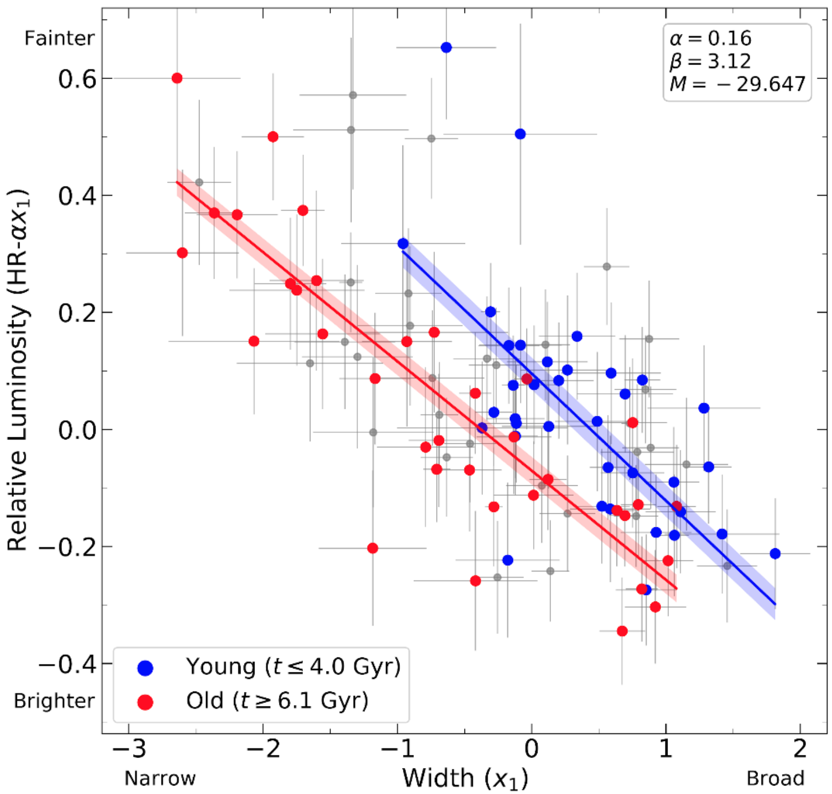
Width – Luminosity Relation & Color – Luminosity Relation of Rose+2019 sample (z ~ 0.14)

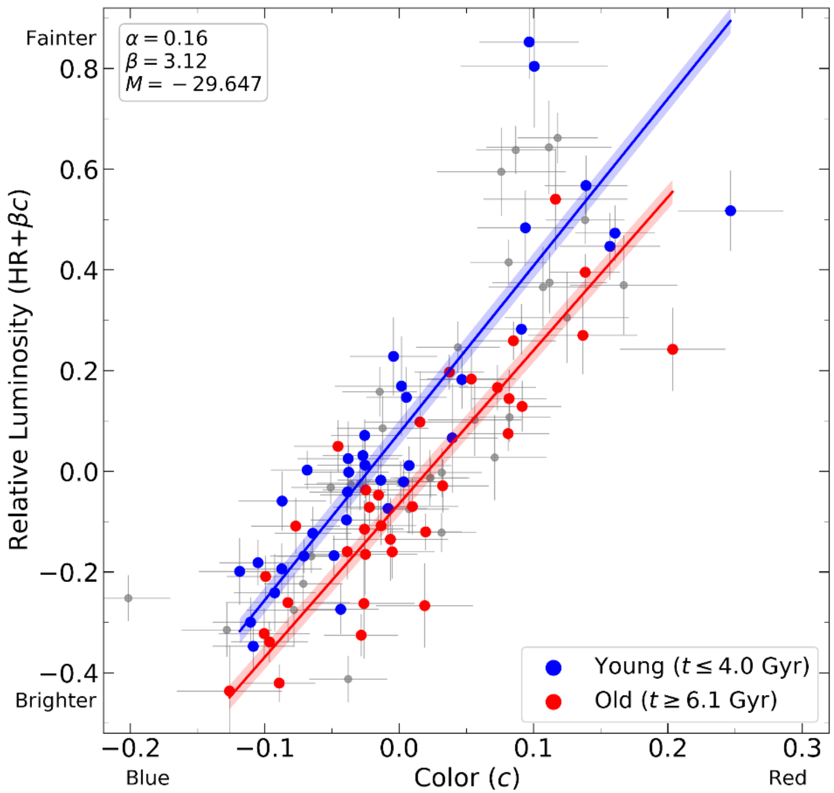


Following Astier, Guy, Sullivan+2006 (previous slide), left panel is corrected only for c, while right panel is corrected only for x_1 to recover WLR & CLR, respectively (x_o, x_1, & c from Campbell+13)

Y.-W. Lee et al. 2022, MNRAS

Surprising Discovery!! Strong progenitor age dependence of Width – Luminosity Relation & Color – Luminosity Relation





SNe from younger progenitors are fainter each at given x_1 and c

→ Reminiscent of Baade's (1956) discovery of two Cepheid P – L relations !!

→ *This* ***4.6 σ*** *result is not sensitive to the choices of (α, β), young/old split, & SN catalog*

(Other host properties show substantially smaller and insignificant offsets) Y.-W. Lee et al. 2022, MNRAS

Hubble's mistake discovered by Baade

THE RESOLUTION OF MESSIER 32, NGC 205, A
REGION OF THE ANDROMEDA NE

W. BAADE
Mount Wilson Observatory
Received April 27, 1944

ABSTRACT

sensitive plates, taken with the 100-inch t
panions of the Andromeda nebula—Mes
a nebula itself. The brightest stars in all
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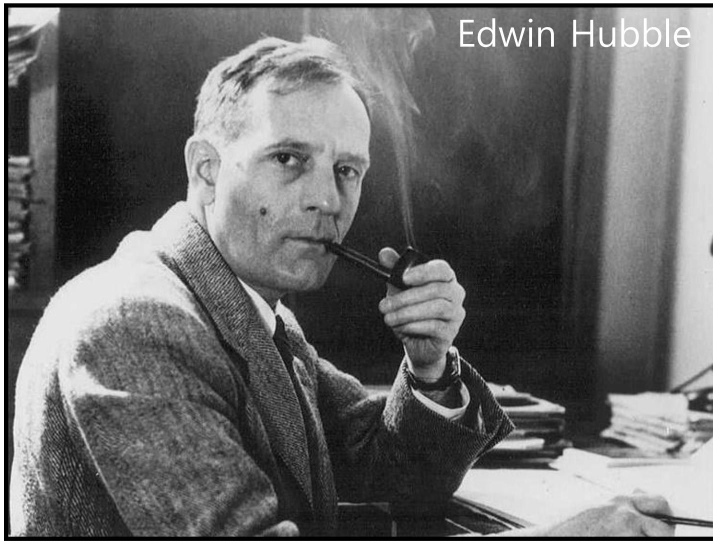
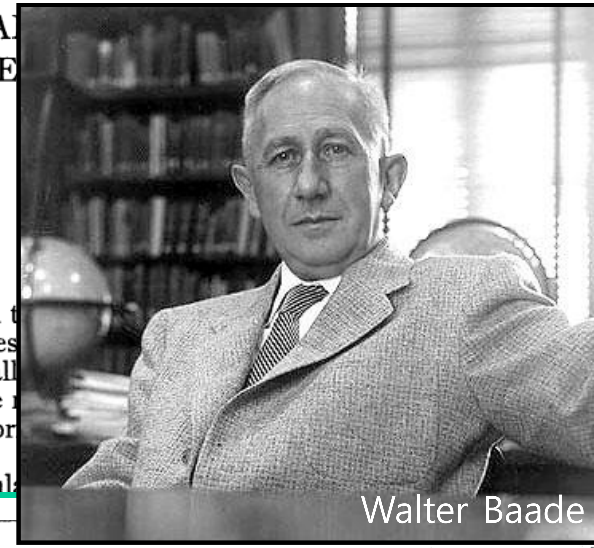
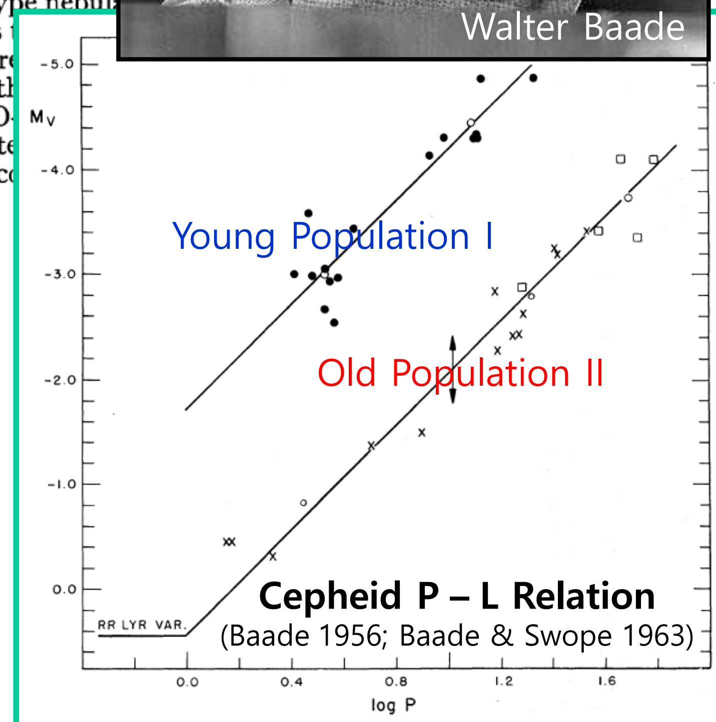
gram of the stars in the early-type nebul
the globular clusters. This leads
nto two distinct groups, one repre
rhood (the slow-moving stars), th
(type I) are highly luminous O-
iod Cepheids and globular cluste
type II. Both types seem to c





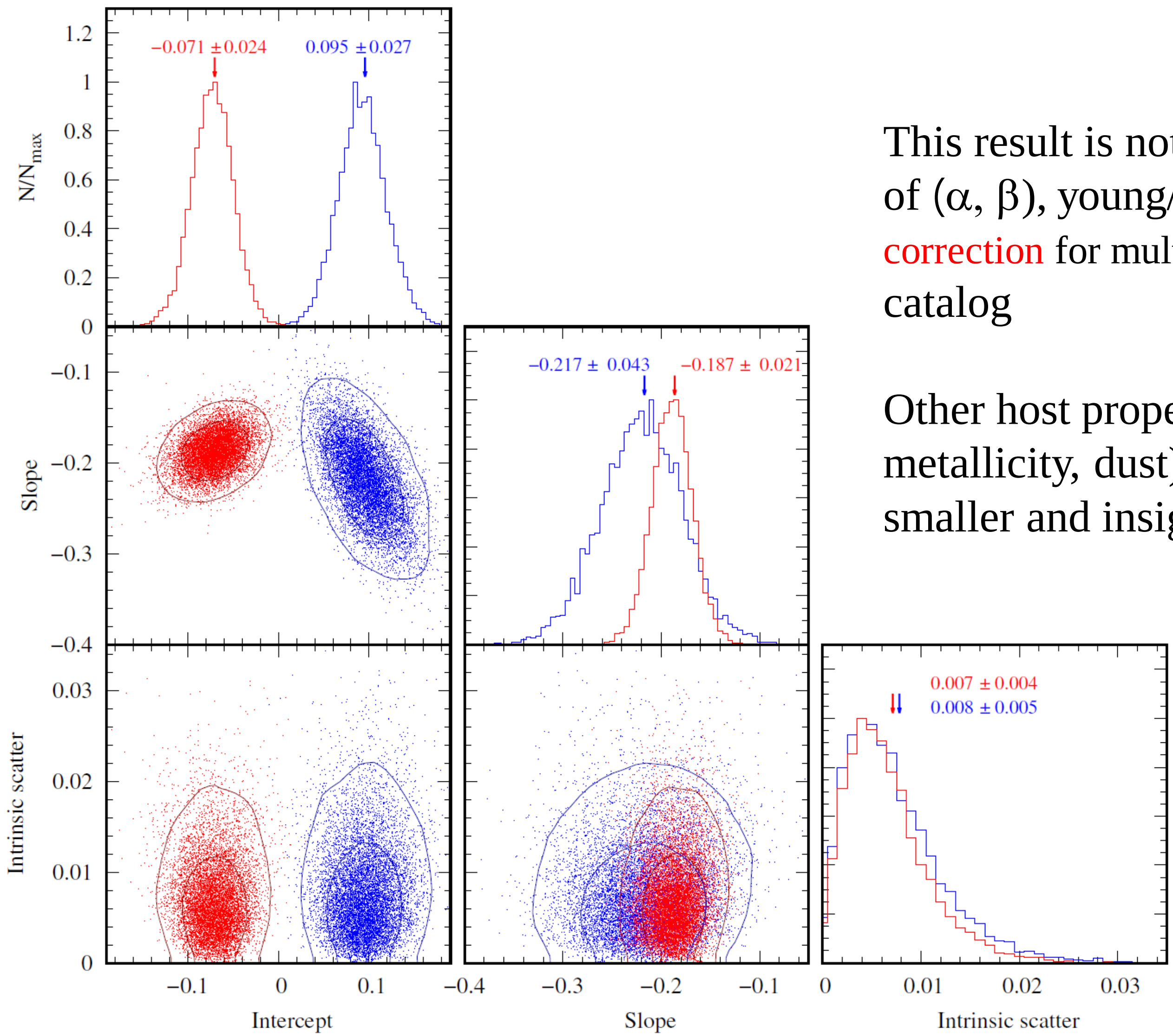


Young population I Cepheids are ~1.5 mag brighter than old population II counterparts

→ M31 distance increased by a factor of 2
→ H_o decreased by a factor of 2 !

<u>Luminosity of "Standard Candle" can depend on stellar population age (mass)</u>

4.6σ difference between the young & old subgroups



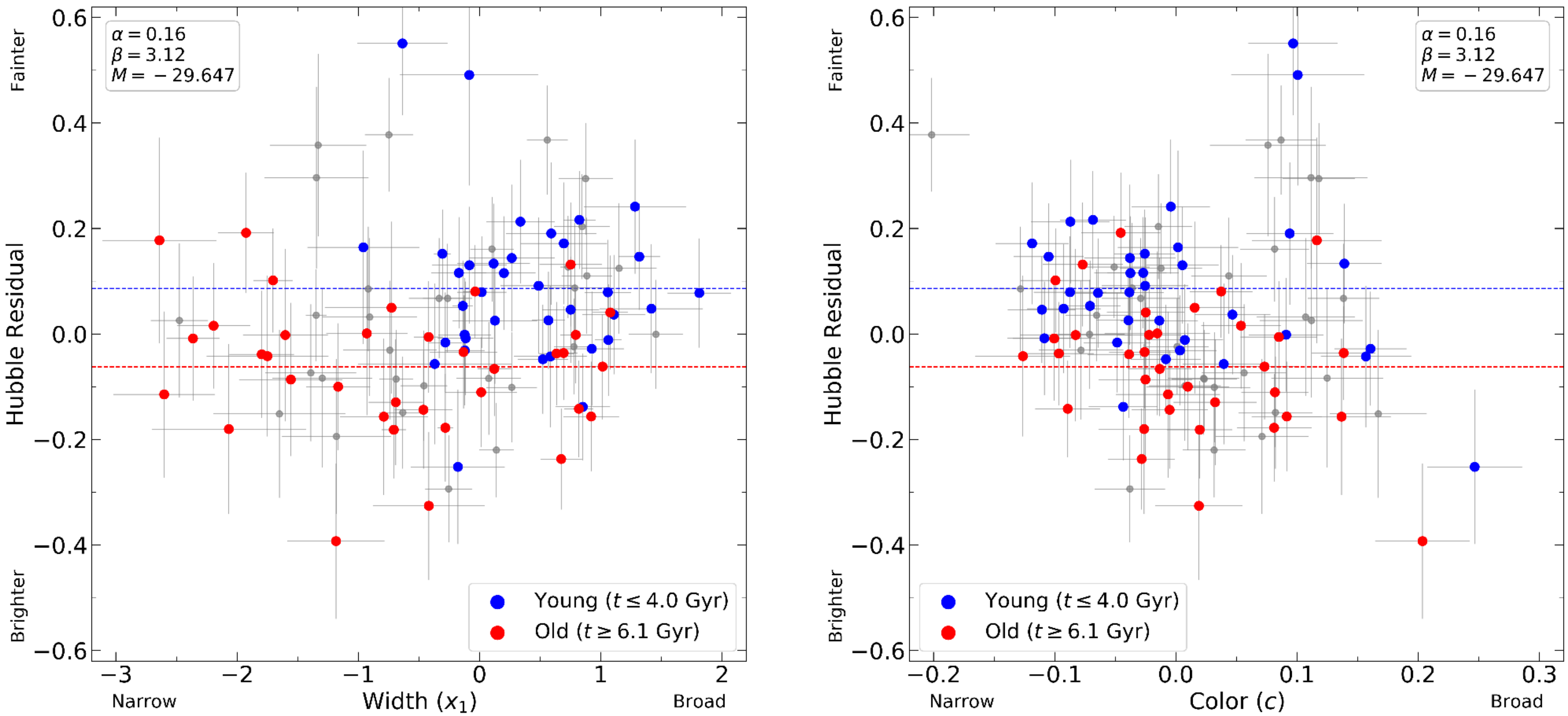
This result is not sensitive to the choices of (α, β), young/old split (Bonferroni correction for multiple testing 4.2σ), & SN catalog

Other host properties (host mass, metallicity, dust) show substantially smaller and insignificant offsets

Y.-W. Lee et al. 2022, MNRAS

After standardization, "young" SNe are over-corrected & fainter!

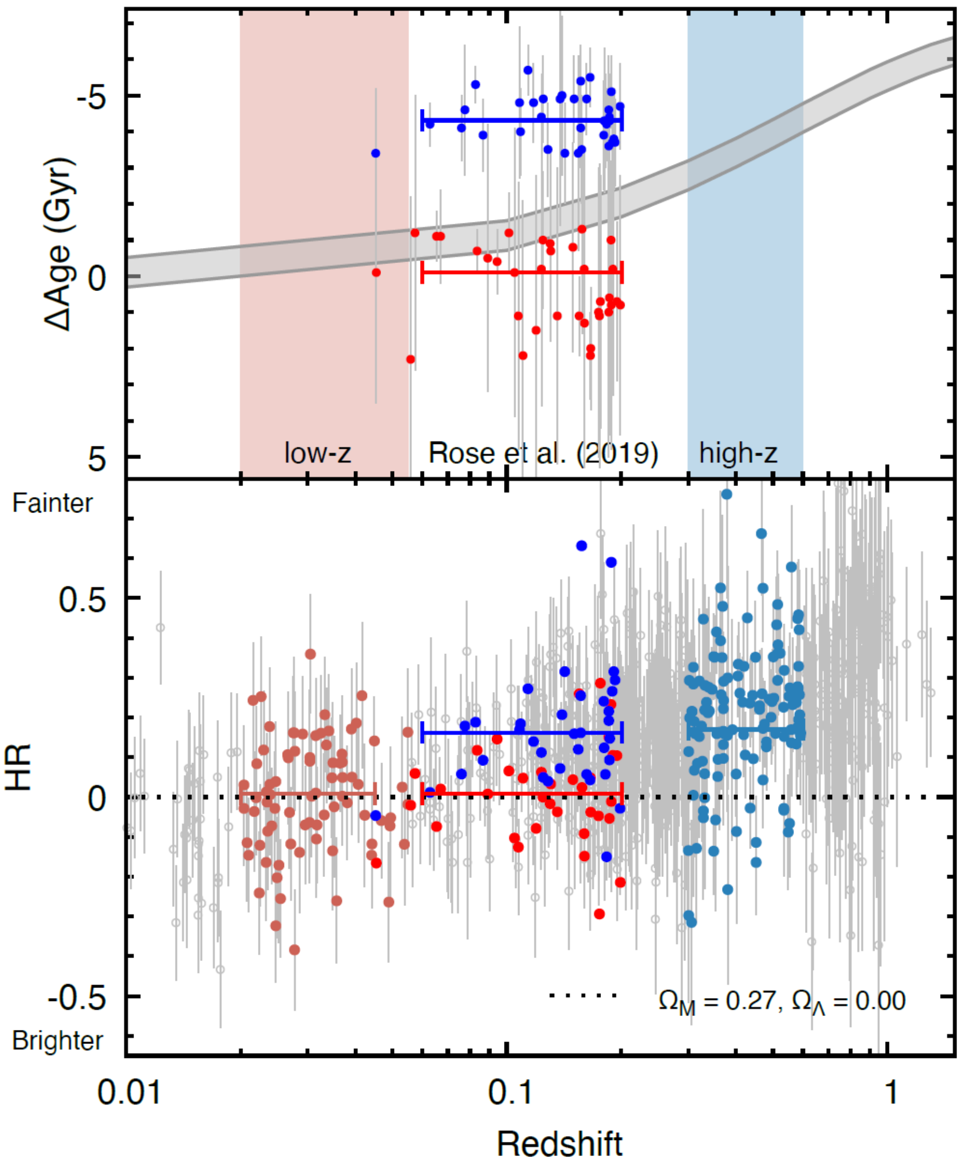
$$\boxed{\mu = m_B - M + \alpha\, x_1 - \beta\, c}$$



High-z SNe are also from younger population, and, therefore, should be equally over-corrected and become similarly fainter!

Y.-W. Lee et al. 2022, MNRAS

Comparison of Rose+19 sample with cosmology sample



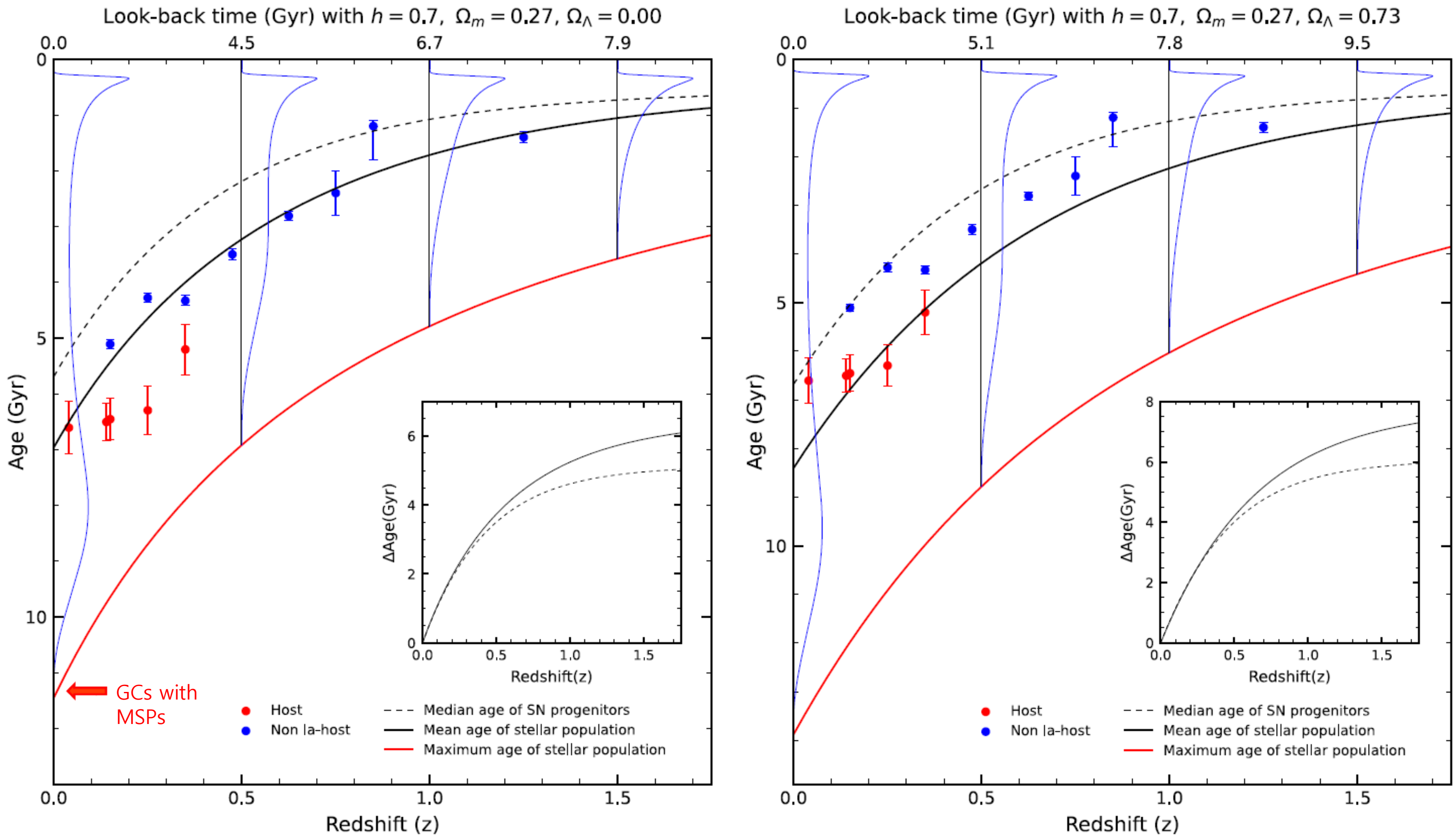
ΔHR between young & old SNe of Rose+19 at z ~ 0.14 is fully consistent with that between similarly young & old SNe at high-z & low-z !

→ *Observed dimming of SNe at high-z ("young") is an artifact of over-correction in the luminosity standardization !*

It is not likely a cosmological effect but a stellar astrophysics effect !

Y.-W. Lee et al. 2022, MNRAS

Redshift Evolution of Supernova Progenitor Age Distribution

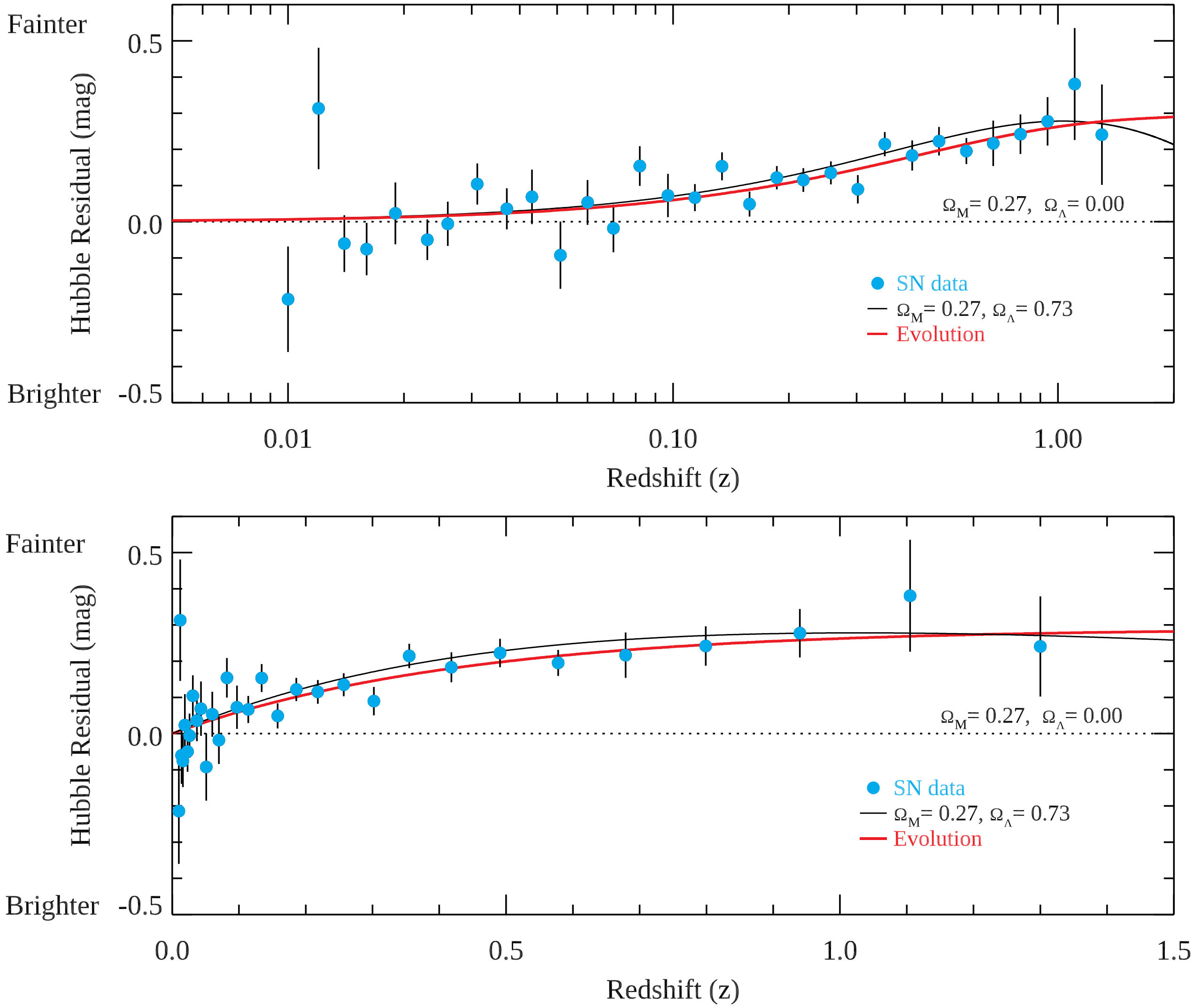


SPAD = Delay Time Distribution (DTD) x Cosmic SFH (Childress+2014; Kang+2020)

Mean population age is getting younger with z: Δt ~ 6 Gyr (0 < z < 1)

Y.-W. Lee et al. 2022, MNRAS (data from Kang+20, Rose+19, Gupta+11, Schiavon+06, Choi, Conroy+14)

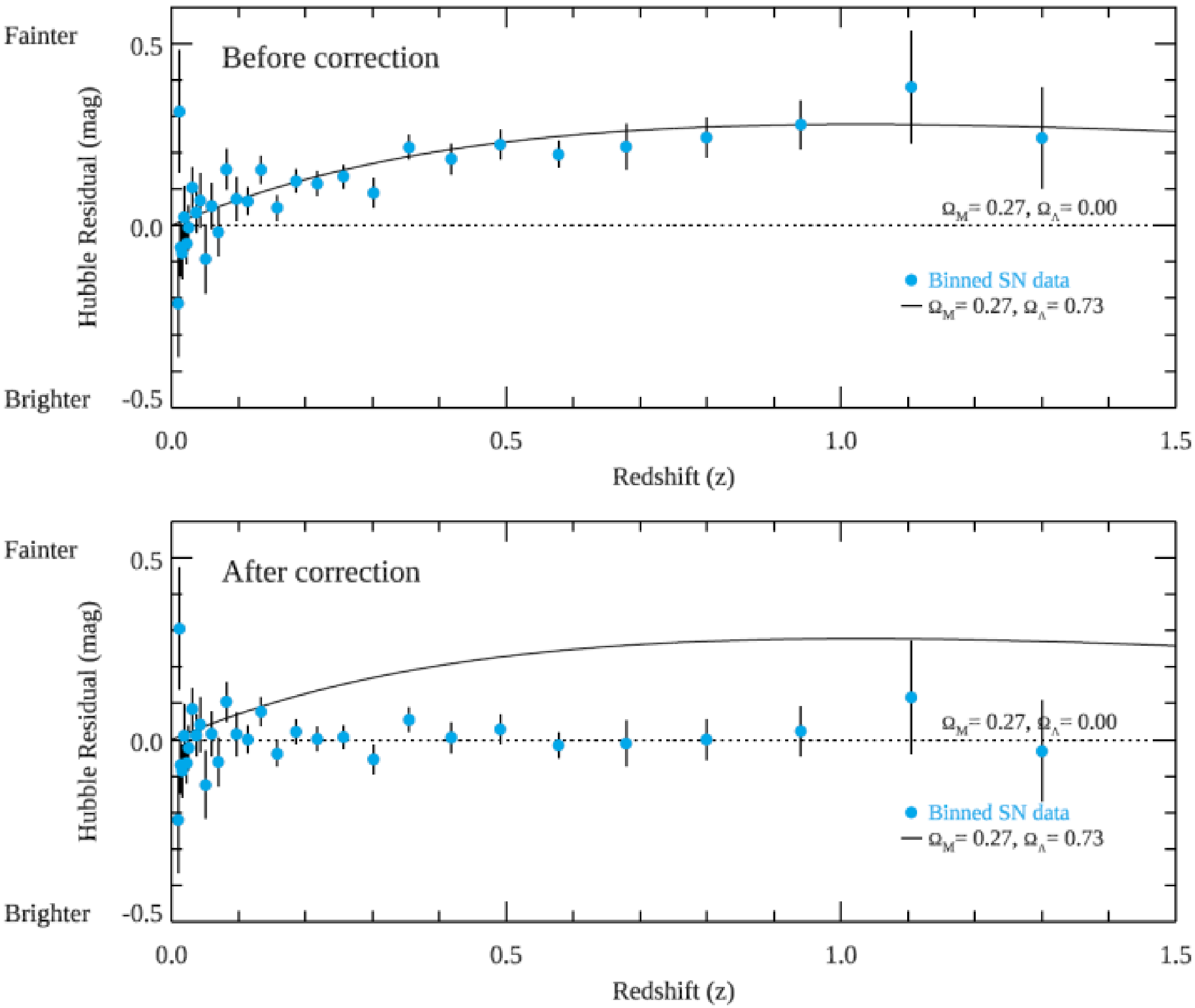
*The progenitor age bias **(~0.05 mag/Gyr)** can mimic accelerating universe with dark energy!*



Red line: Evolution curve (age-bias) from the baseline model without Ω_Λ

Blue circles: Binned SN data (Betoule+14, JLA)

*When the progenitor age bias **(~0.05 mag/Gyr)** is properly taken into account, SN data no longer support an accelerating universe!*



Solid line: LCDM model with Ω_Λ (*accelerating*)

Dotted line: The baseline model without Ω_Λ (*non-accelerating*)

Blue circles: Binned SN data (Betoule+14, JLA)

No evidence left for an accelerating universe !!

Y.-W. Lee et al. 2022, MNRAS

Conclusion

- SN cosmology is based on such a fragile assumption which is not supported by our discovery of strong progenitor age bias in SN luminosity standardization process.
- This result is from Rose, Riess+2020 dataset, but is also consistent with other reliable age datasets (Kang+2020; Gupta+2011) & previous investigations based on age proxy (when converted to age).
- *When this systematic bias is properly taken into account, SN data no longer support an accelerating universe!*
- Our result from SNe is in discordance with CMB (& BAO).
  (in addition to the 'Hubble Tension' between SNe & CMB…)

➔ *Hubble Tension & Discordance in Ω_Λ !!*

To put this result on a firmer refined basis…

an ambitious long-term project is going on..

1. Photometric SED based 'local' age-dating (a' la Rose+2019) for a larger sample of host galaxies at different redshift bins (PS1, SDSS/GALEX, SNLS, DES, LSST, $0.02 < z < 1.0$)

2. Additional high-quality spectroscopic observations for host galaxies → Calibration for photometry based ages

3. "Evolution-free" cosmological fit using only "young" SNe

4. Root cause of host property (host mass, local SFR…) vs. HR correlation?

Welcome collaborations…

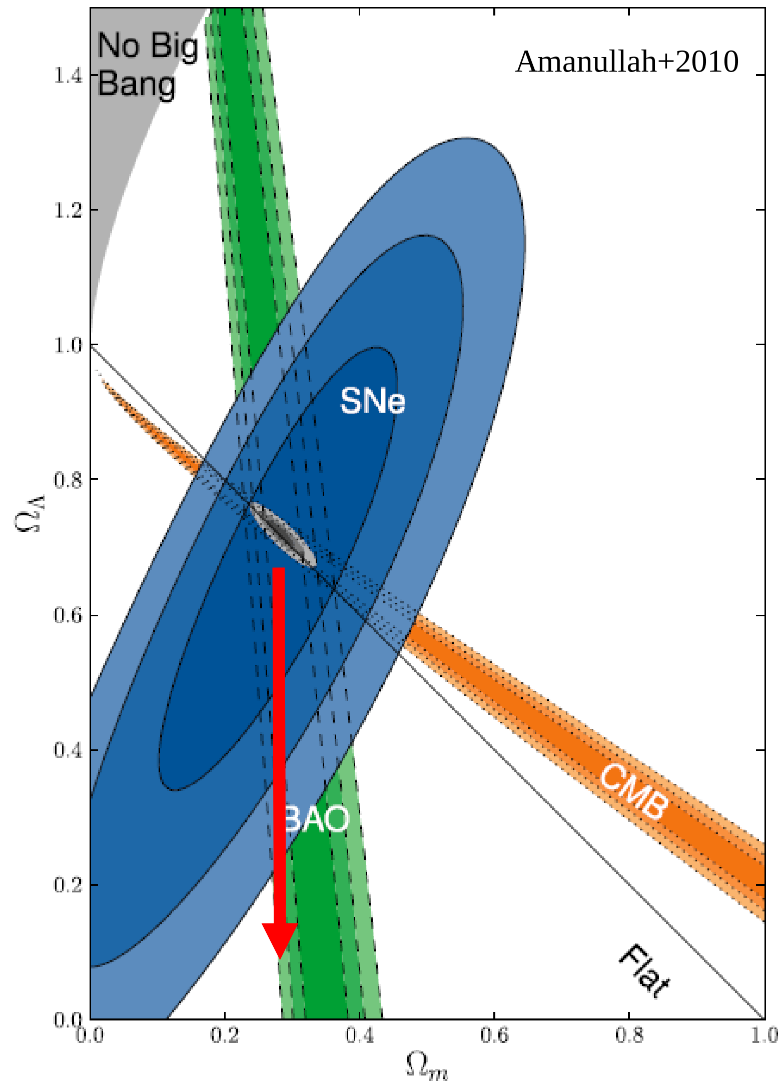
How about other cosmological probes?

Cosmic discordance or "the 1st button fastened wrongly?"

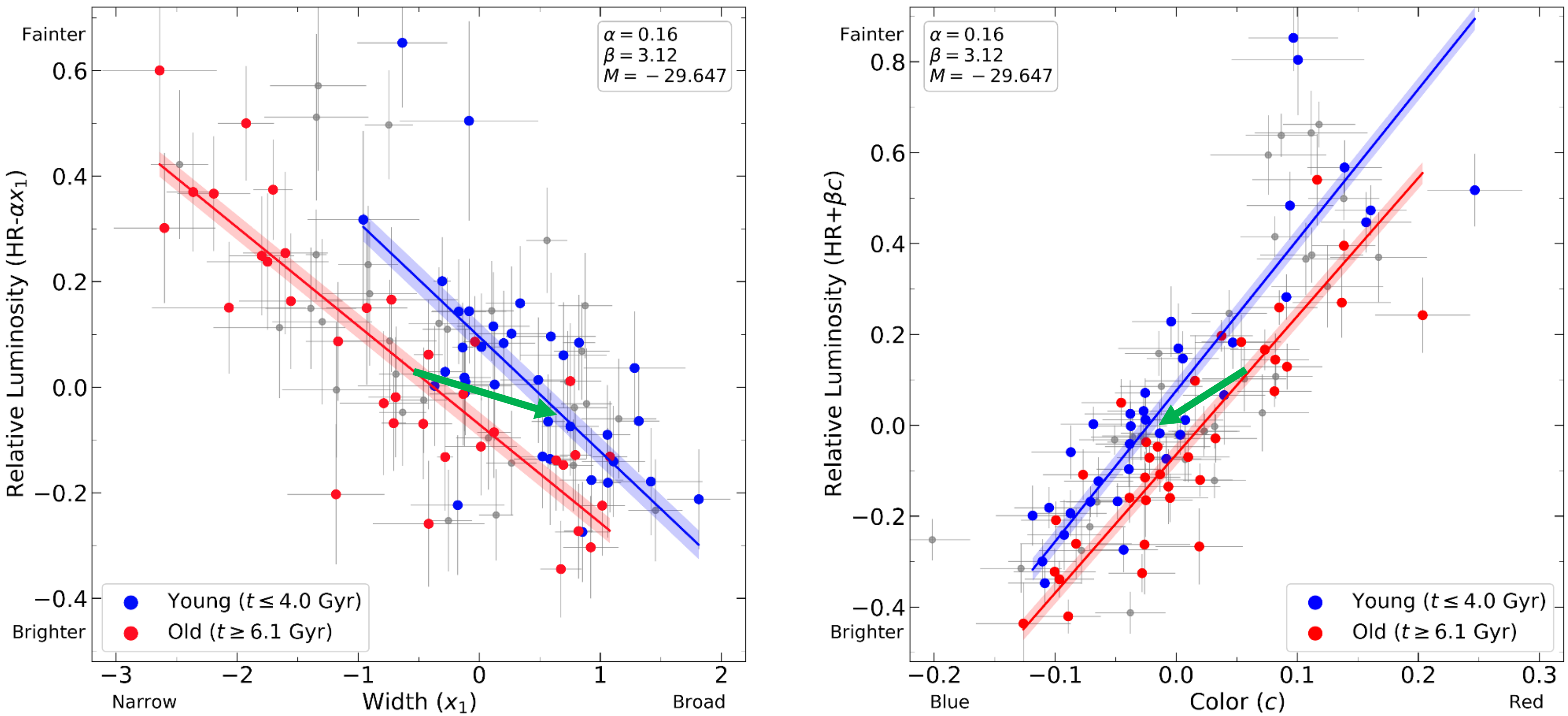
1. SNe Ia: non-accelerating universe?, the most direct (mag & z), independent of Friedmann equation

2. CMB: flat (or close to flat), $\Omega_M \sim 0.3$, not directly sensitive to Dark Energy, only "circumstantial evidence" for Ω_Λ assuming a Friedmann model ($\Omega_{total} \sim 1.0$)

3. BAO & other low-z probes: consistent with LCDM?, but far more complex & model dependent, and <u>systematic errors are yet to be explored</u>



Theoretical models for SNe Ia are qualitatively consistent with our finding



Increasing progenitor mass produces a brighter SN with broader LC & bluer color

(*qualitatively, consistent with model predictions*: Leung+20, Shen+18, Kasen+09,Woosley+07)

→ But, at given x_1 and c, SNe from younger progenitors are fainter!

→ ΔHR = 0.167 +/-0.037 mag @ x_1 = 0 (**4.5 sigma result**) → 0.040 mag/Gyr

Y.-W. Lee et al. 2022, MNRAS