Evidence for Strong Progenitor Age Bias in Supernova Cosmology

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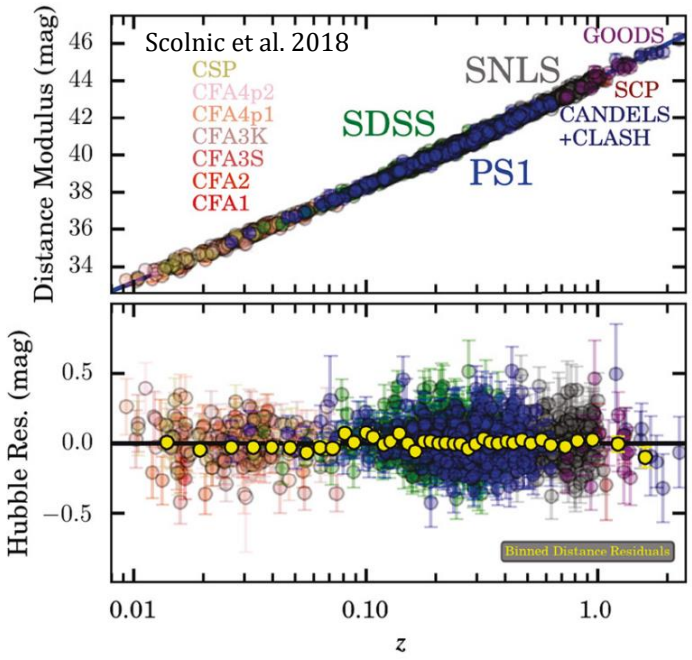
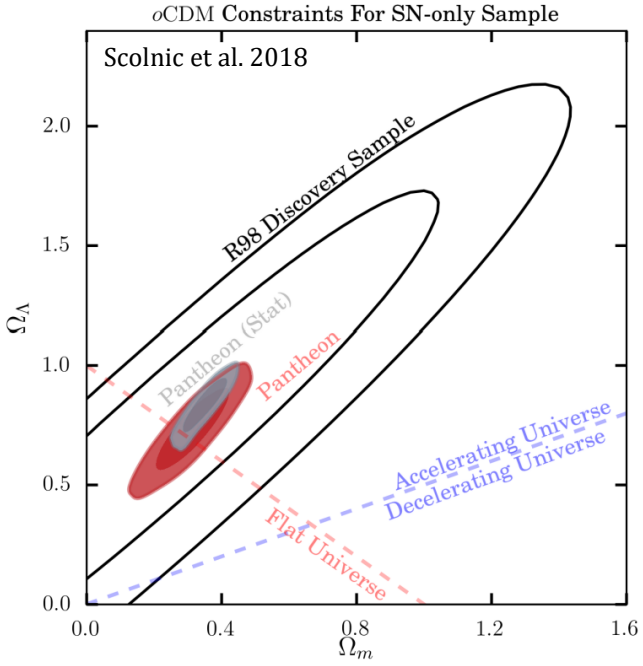
Windows of the Universe at Quy Nhon, Vietnam, 08.08.2023

Type Ia supernovae:
Most direct evidence for an accelerating universe

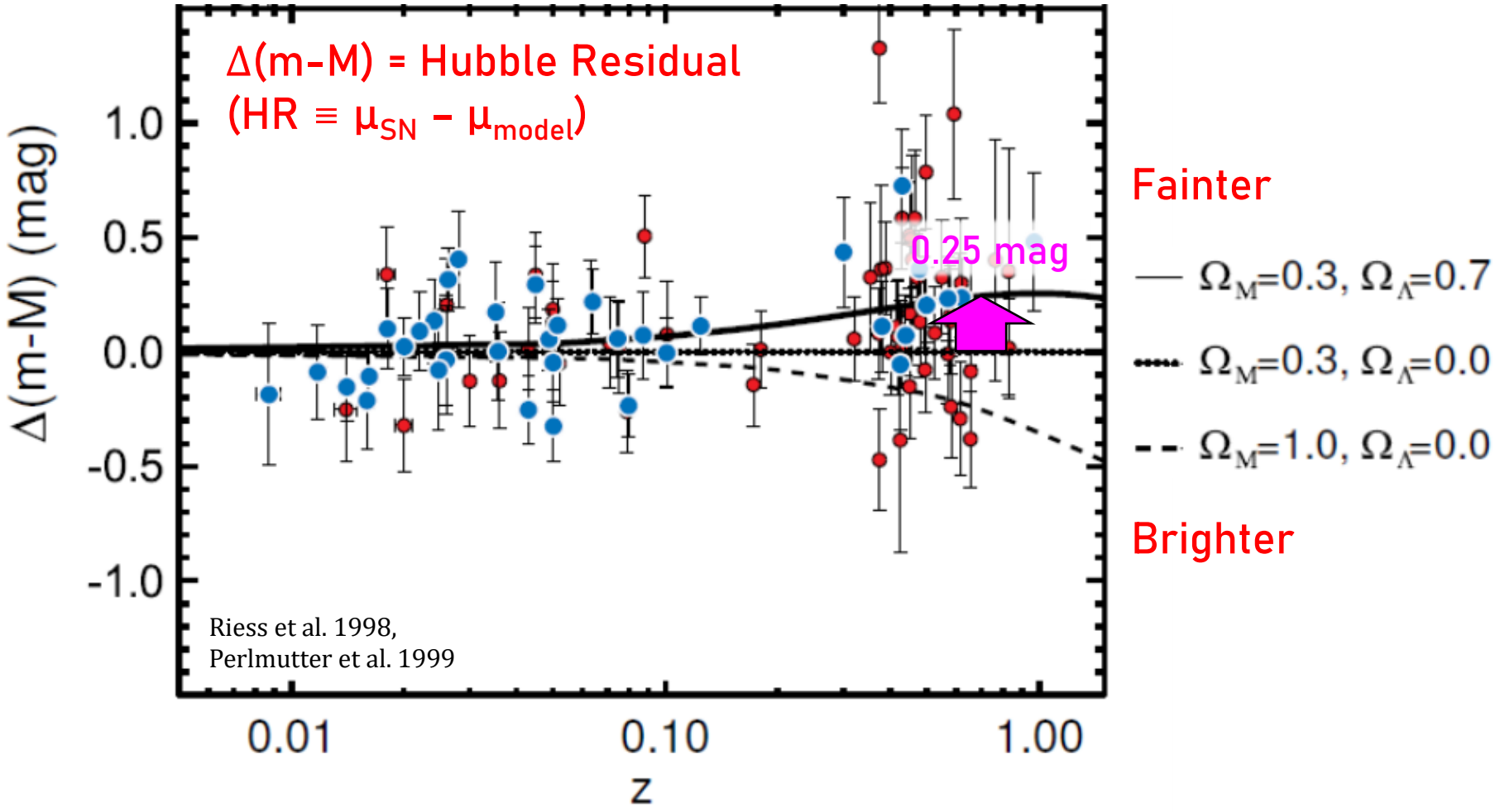
"Supernova cosmology is the most straightforward tool for studying cosmic acceleration…"
(Wienberg, Eisenstein, Riess et al. 2013)

"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)





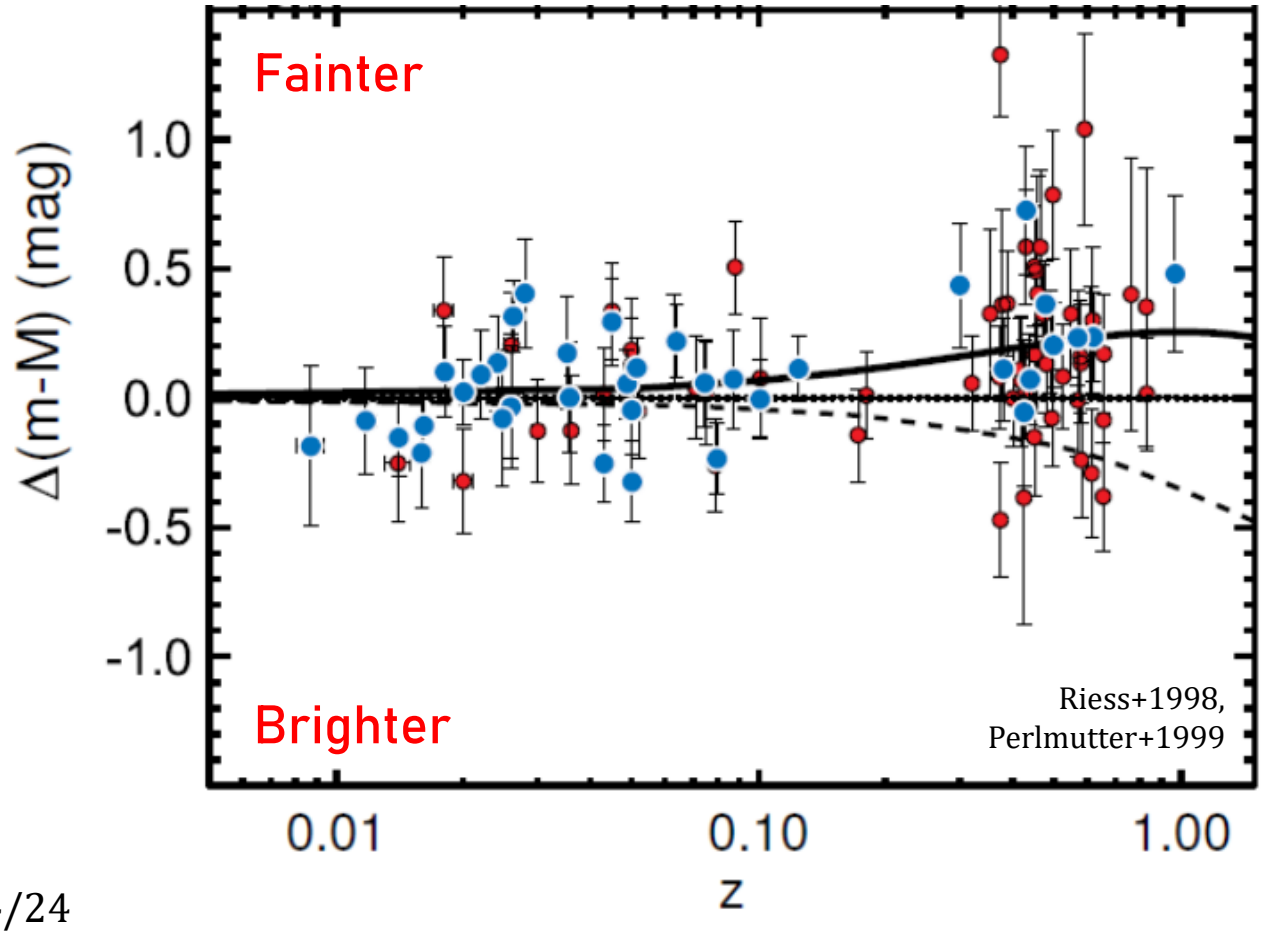
"Accelerating universe" or "Luminosity evolution"?



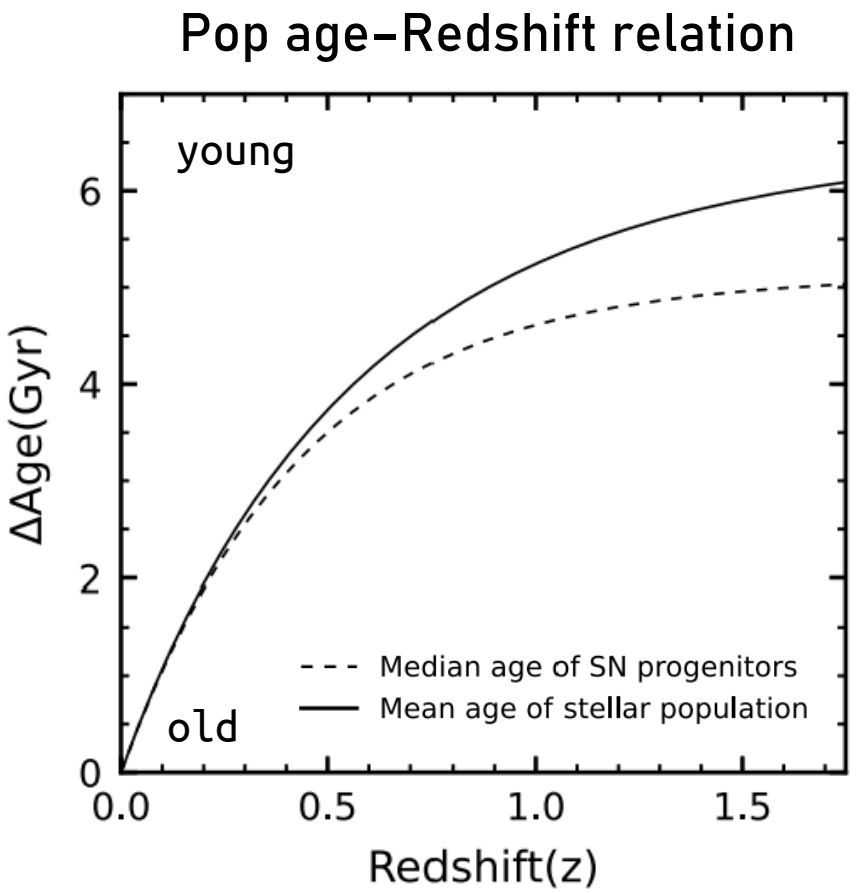
The Key Assumption & Requirement in Supernova Cosmology

"The calibrating relationships between SN luminosity and light-curve shape must be invariant with progenitor age."

(Jha, Maguire, & Sullivan 2019, Nature Astronomy)

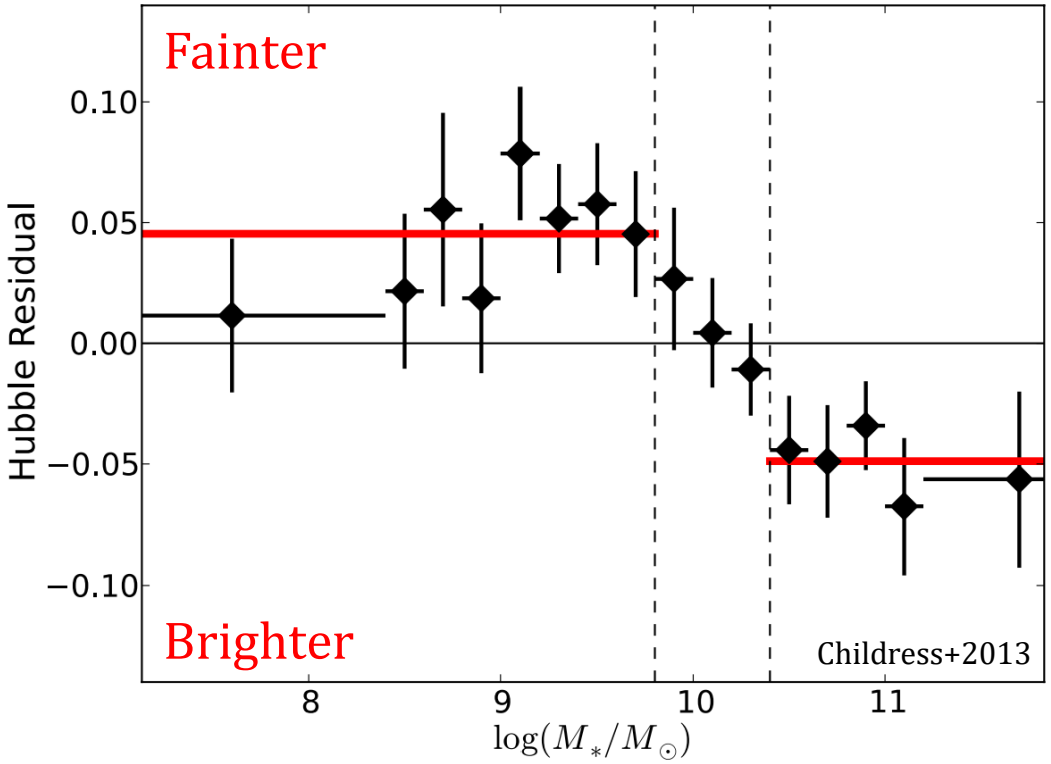


The Key Assumption



Correlations of SN luminosity with Host mass & Local SFR

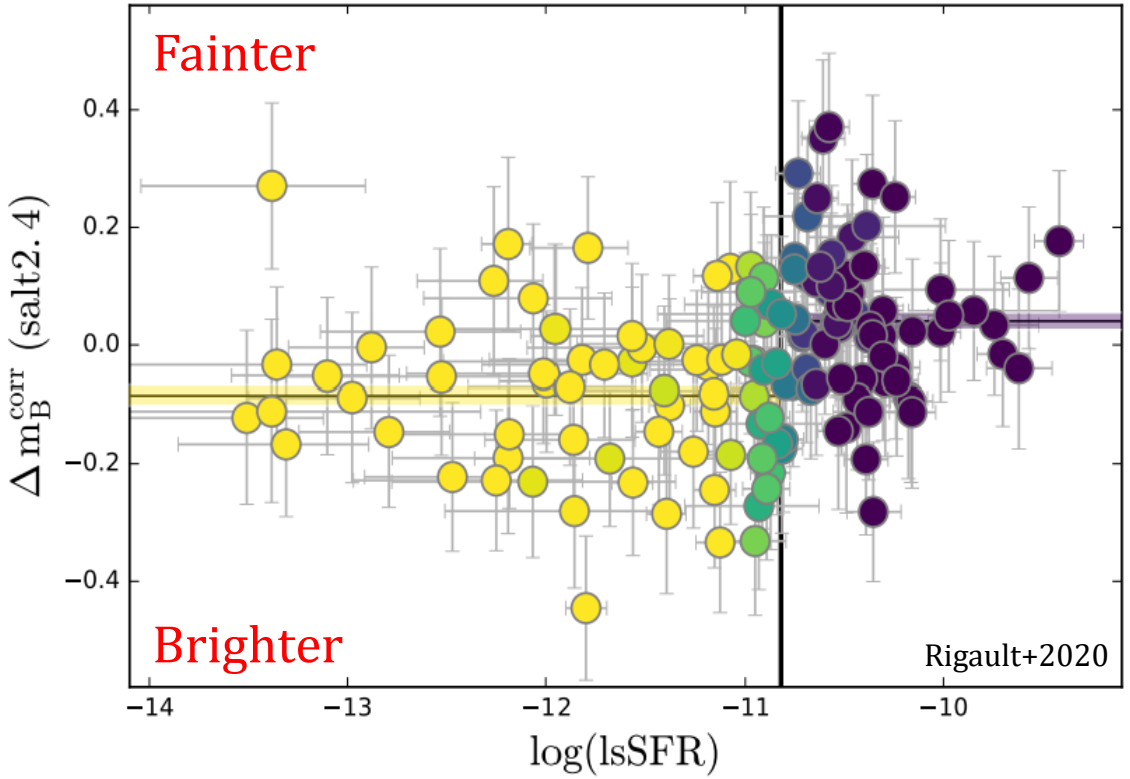
Mass - Luminosity relation



Less massive, more fainter

(Sullivan+2010; Kelly+2010; Childress+2013)

sSFR - Luminosity relation

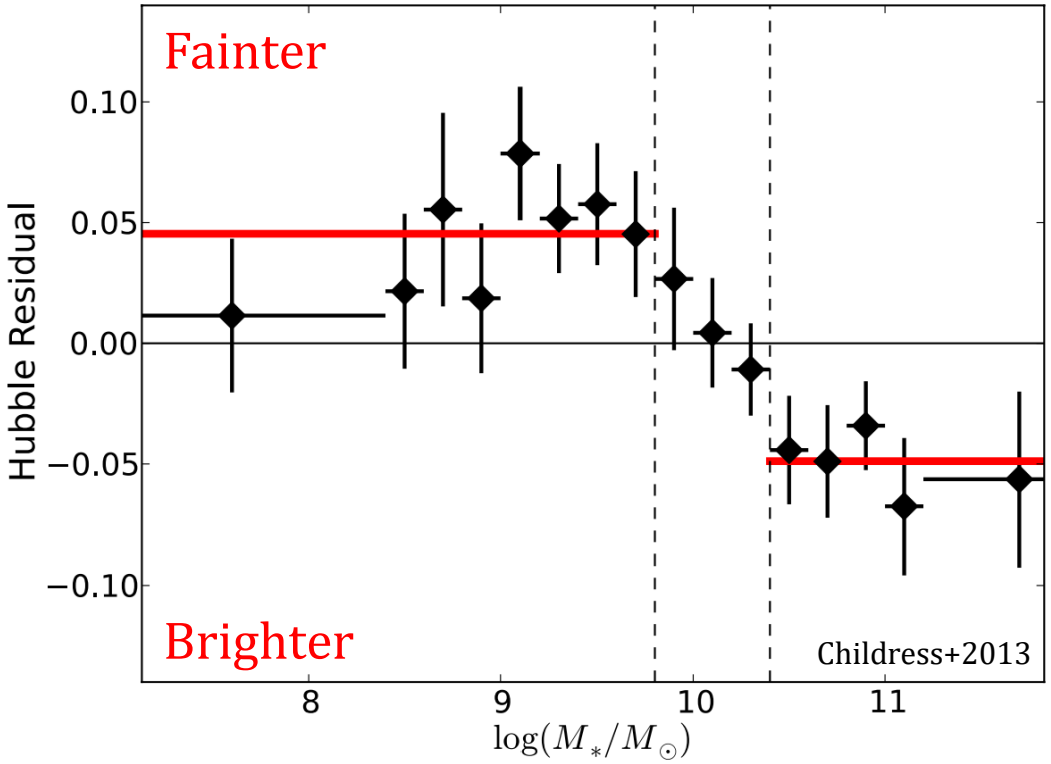


Higher sSFR, more fainter

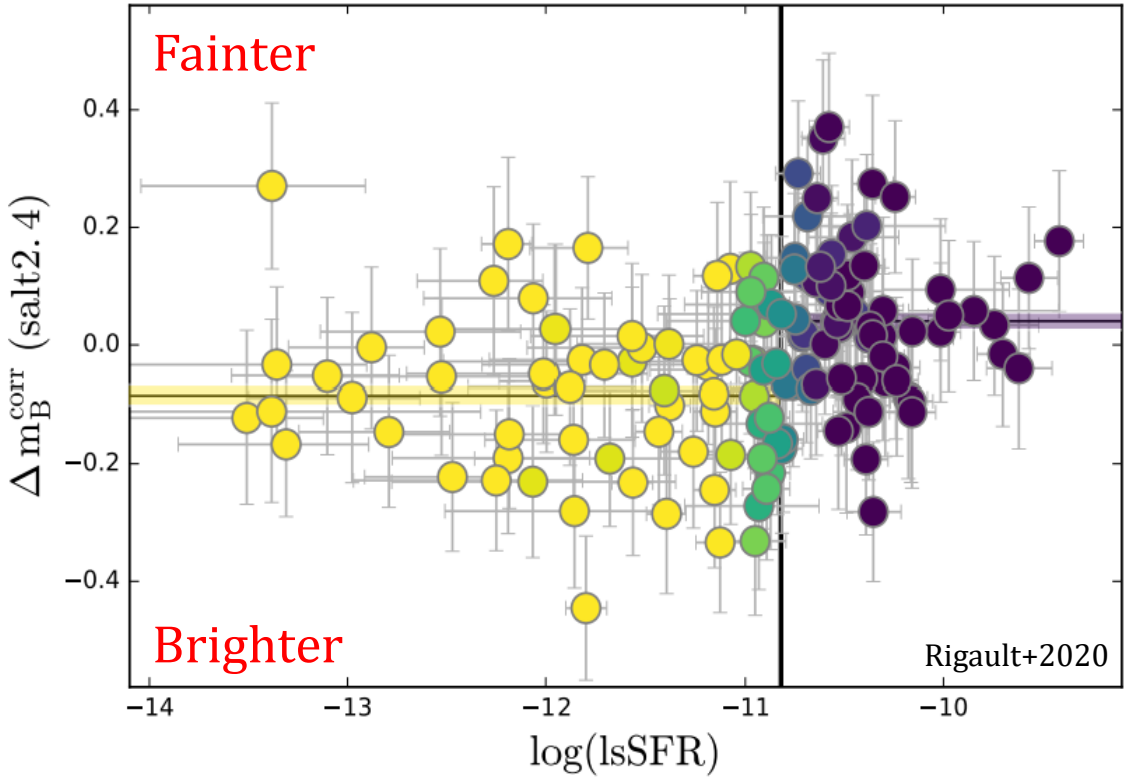
(Rigault+2013, 2020; Kim, Lee+2018)

Correlations of SN luminosity with Host mass & Local SFR

Mass - Luminosity relation



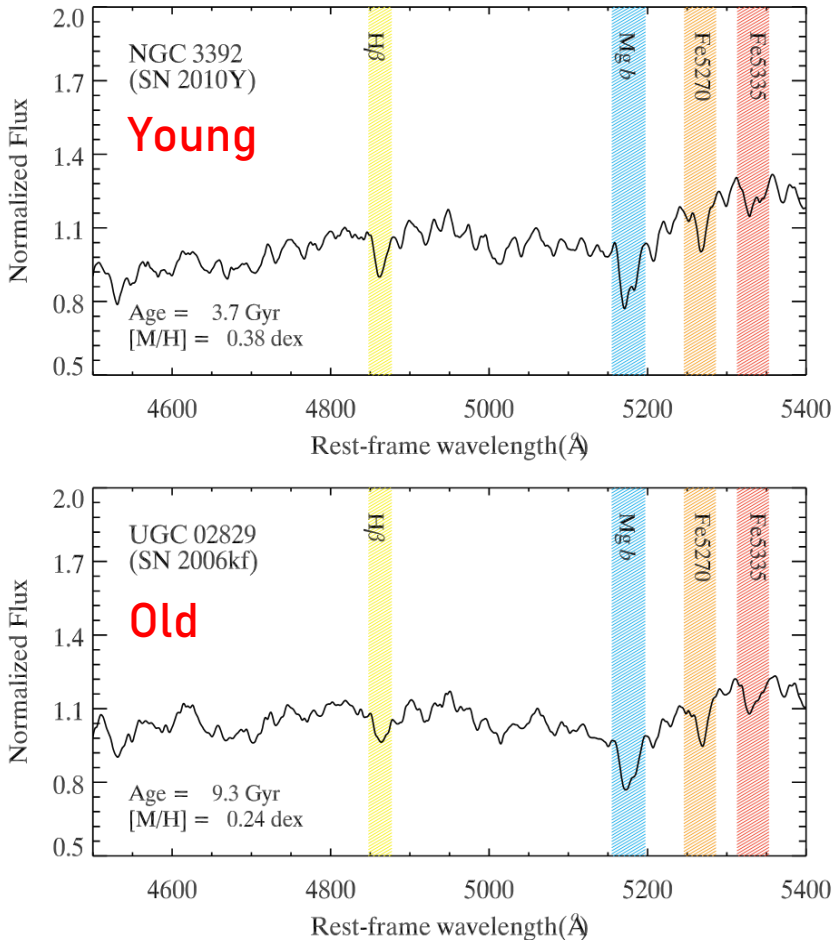
sSFR - Luminosity relation

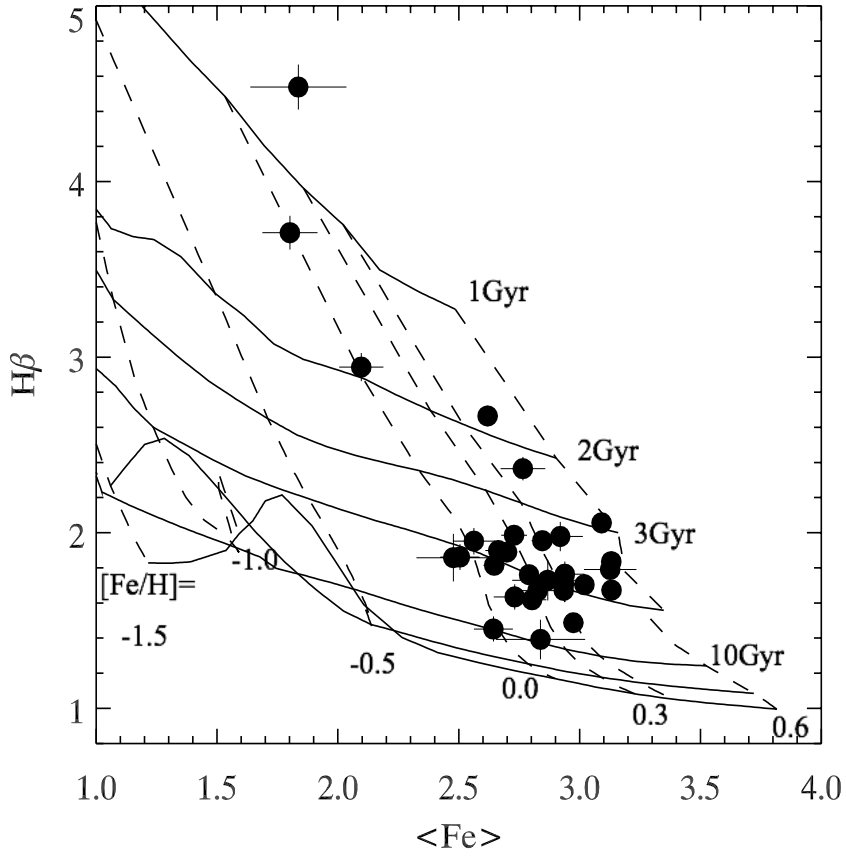


The root cause of these correlations is most likely pop age,
but reliable pop age dating for host galaxies was lacking.

Project **YONSEI**:
YOnsei **N**earby **S**upernovae **E**volution **I**nvestigation

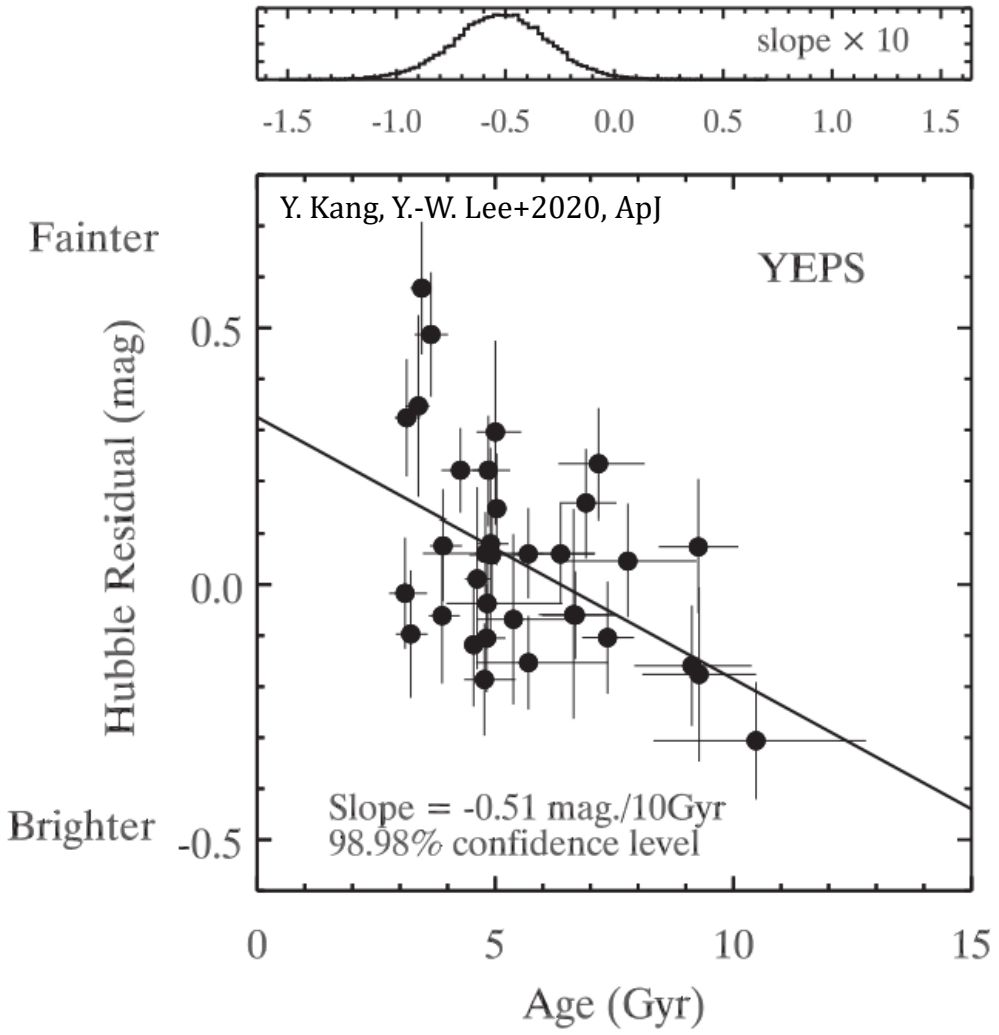
High Precision (S/N ~175) Measurement of Early-type Host Galaxy Ages (since 2010)





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

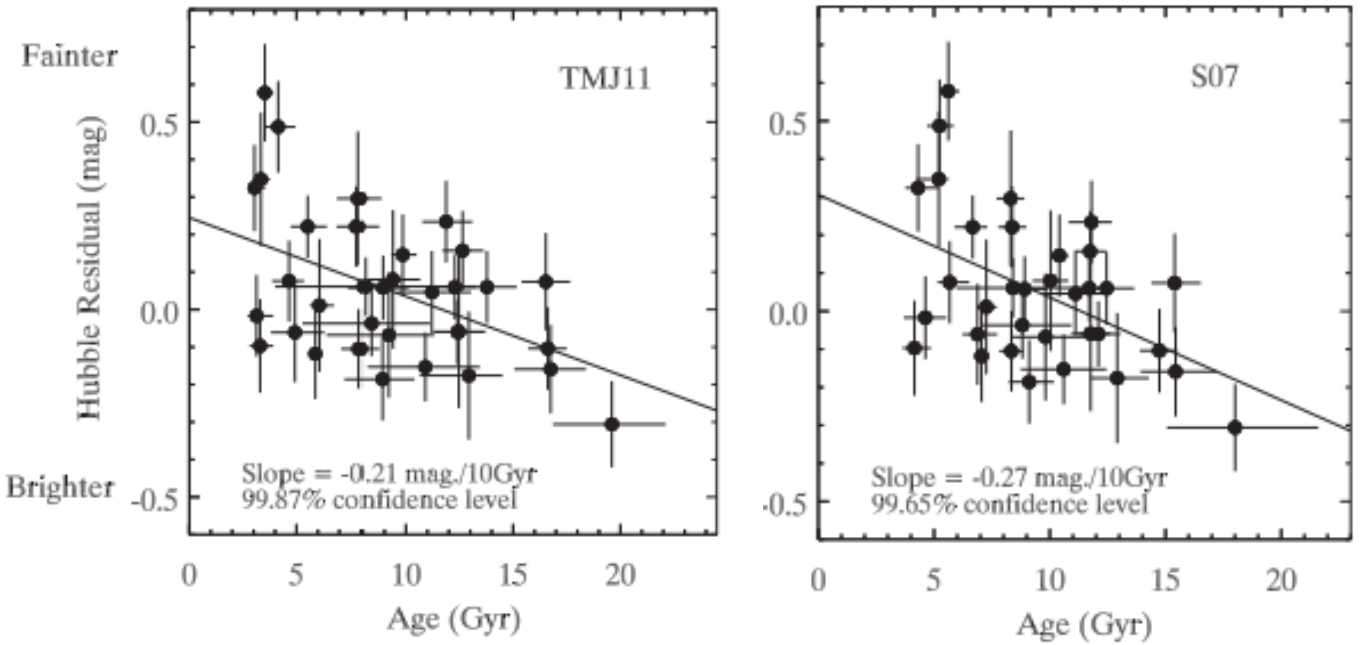
Correlation between SN luminosity & population age



very high S/N (~175) spectra of 34 normal ETGs

SNe in younger hosts are fainter after standardization.
(0.051 mag/Gyr, in 3σ correlation)

not sensitive to the choice of population synthesis model



Population age vs Other proxies

Host property	Converted to Age Difference
Mass (Sullivan et al. 2010)	~0.04 mag / Gyr fainter in younger galaxy
Local SFR (Rigault et al. 2018)	~0.06 mag / Gyr fainter in younger galaxy
Population Age (This work)	~0.05 mag / Gyr fainter in younger galaxy

They are all pointing to the same direction!!

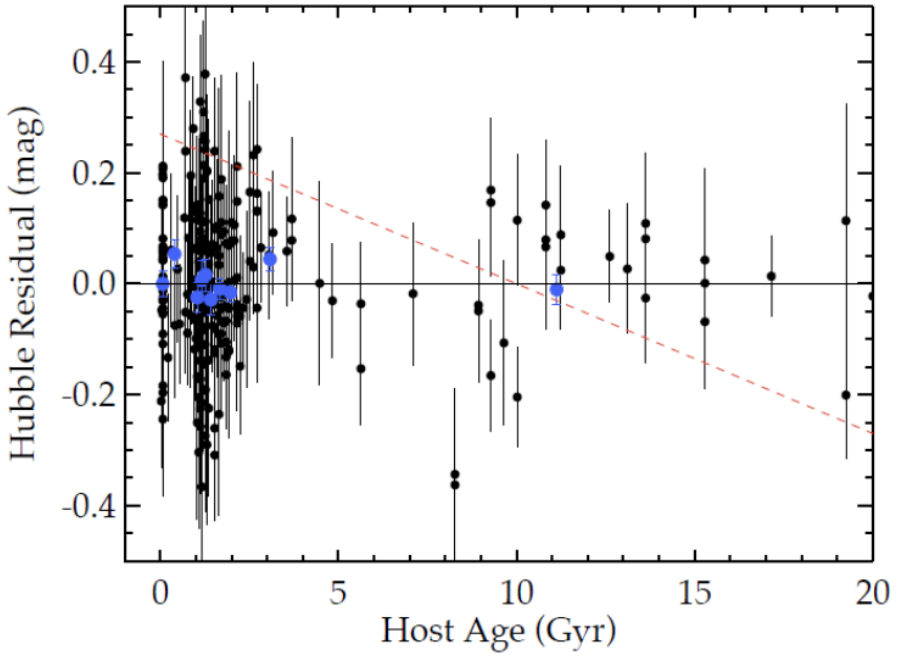
SNe Ia in younger galaxies (high-z) are fainter!!

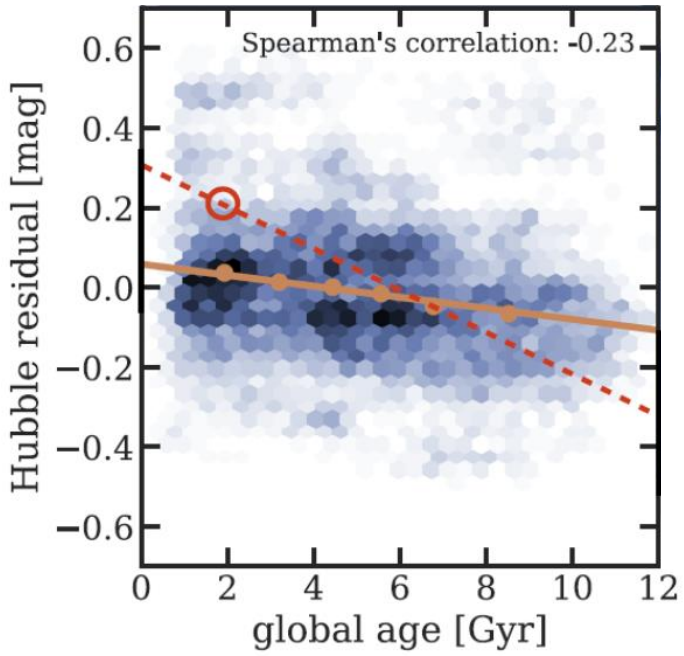
Our result not confirmed from a larger sample of host galaxies of all morphological types??

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

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]



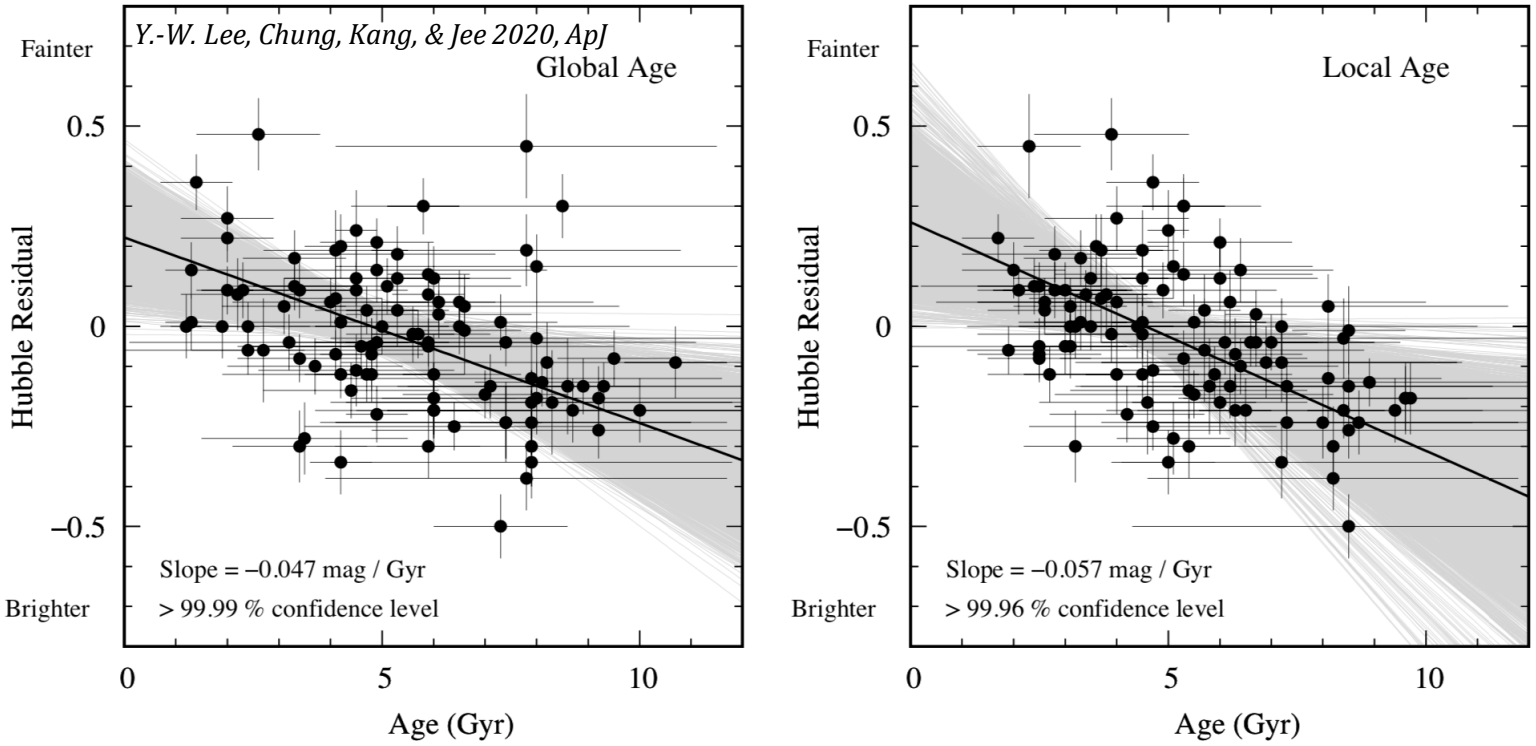


Seriously flawed result based on unqualified, unpublished (Jones+18) age data without error bar

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

Surprising reversal!: Significant age – HR correlation

from host galaxies comprising all morphological types

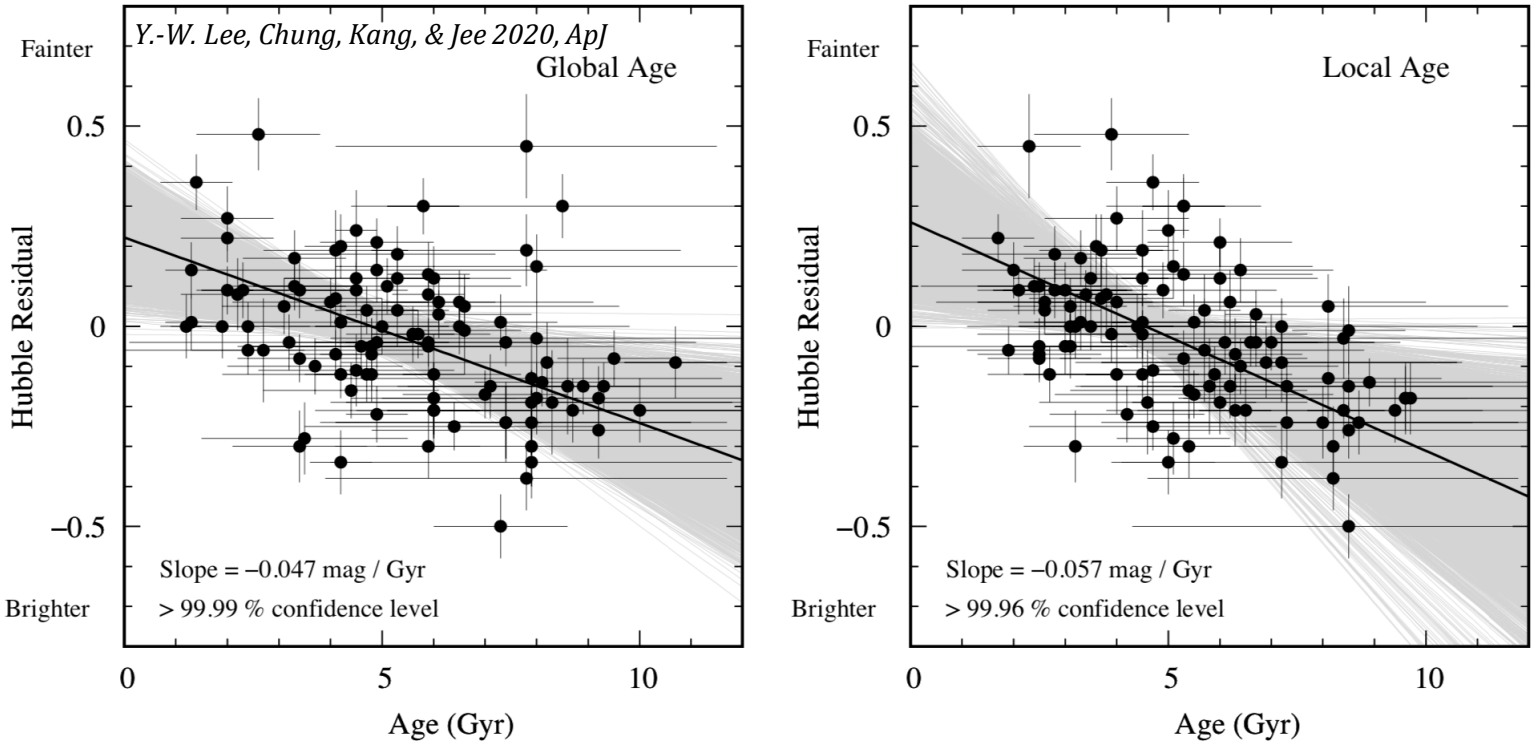


Data: Reliable photometric mass-weighted ages (Rose+2019) & HRs (Campbell+2013)

→ 4.3 sigma (99.99%) correlation between population age & HR,
in excellent agreement with our spectroscopic result from ETGs !

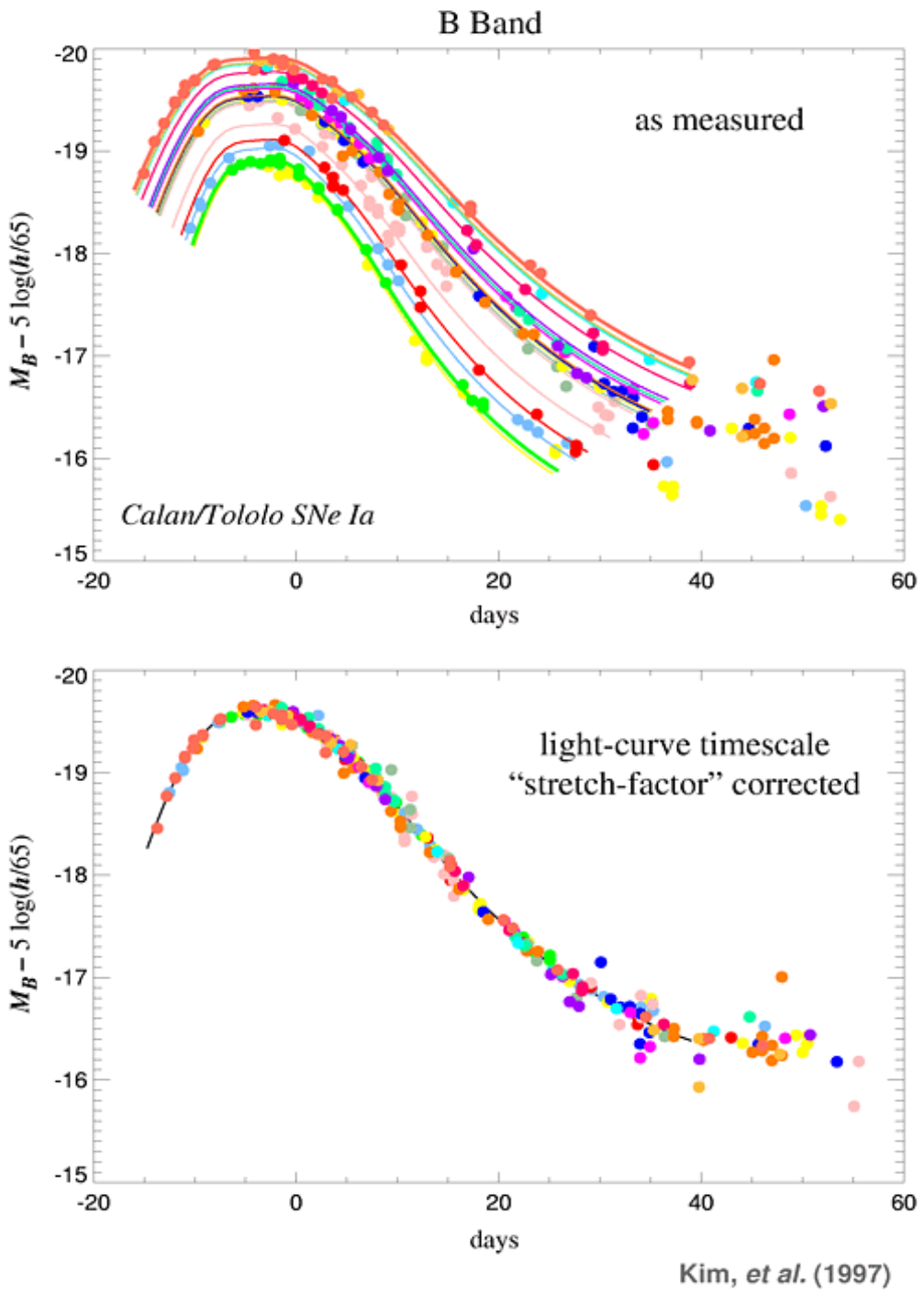
Surprising reversal!: Significant age – HR correlation

from host galaxies comprising all morphological types

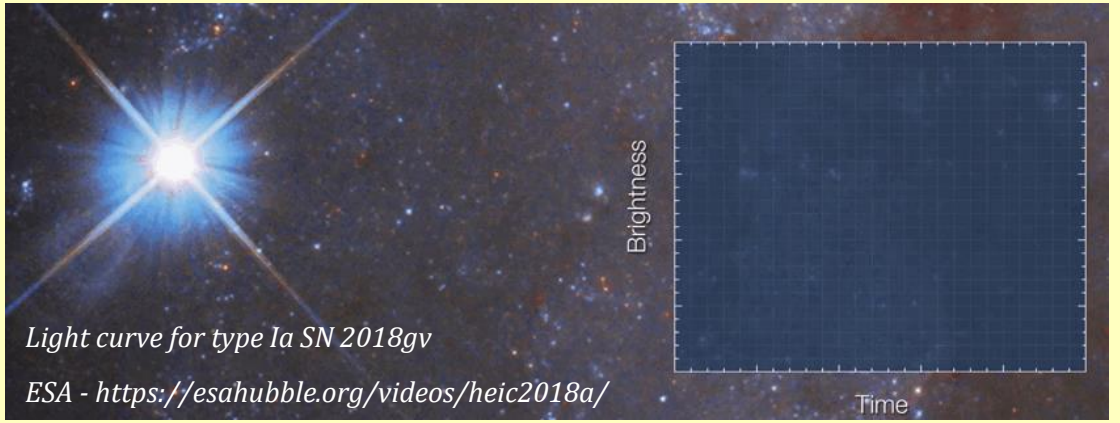


Even the dataset originally used by Rose, Riess+2020 to oppose our claim is instead strongly supports our result !!

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



Type Ia SNe



Light curve for type Ia SN 2018gv

ESA - https://esahubble.org/videos/heic2018a/

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

Width/stretch & color parameters:
x_1 (s, Δm_{15}), C

Assume no evolution with z (progenitor age)

Calibrating Type Ia Supernovae

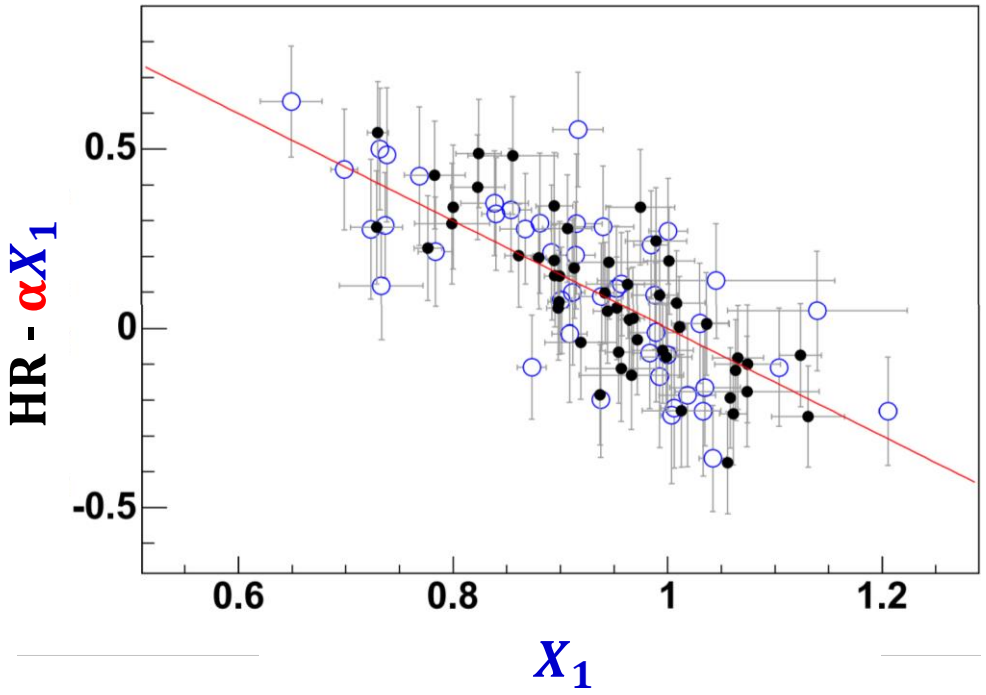
$$HR = \mu_{obs} - \mu_{model}$$

Hubble Residual

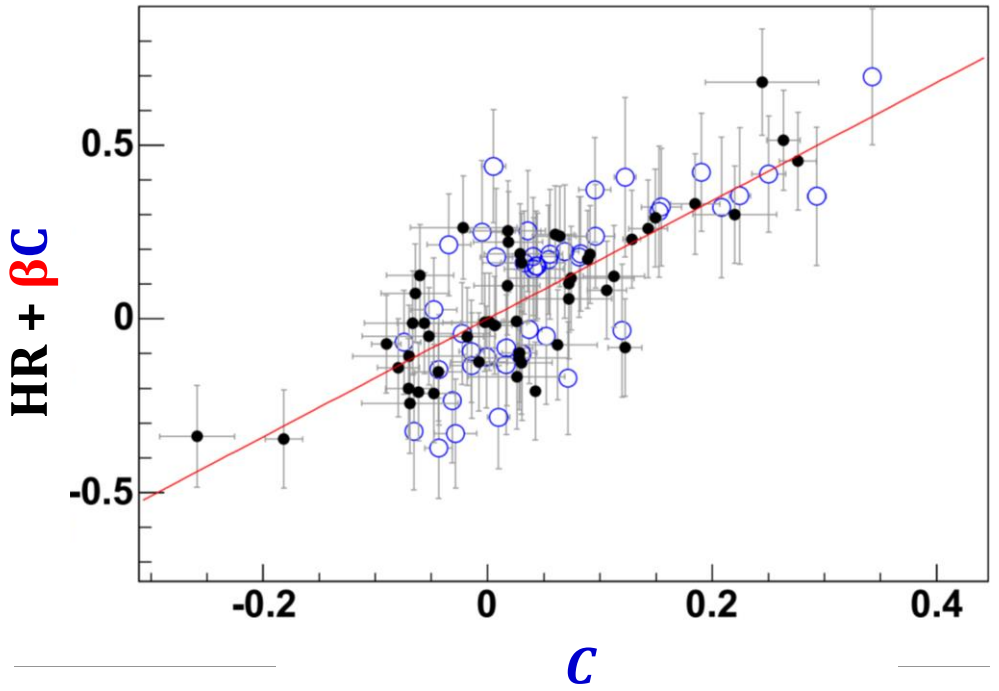
$$\mu_{obs} = m_B + \underbrace{\alpha X_1}_{width} - \underbrace{\beta C}_{color} - M$$

Intrinsic params: $m_B,\ X_1,\ C$
global params: $\alpha,\ \beta,\ M$

Width-Luminosity relation



Color-Luminosity relation



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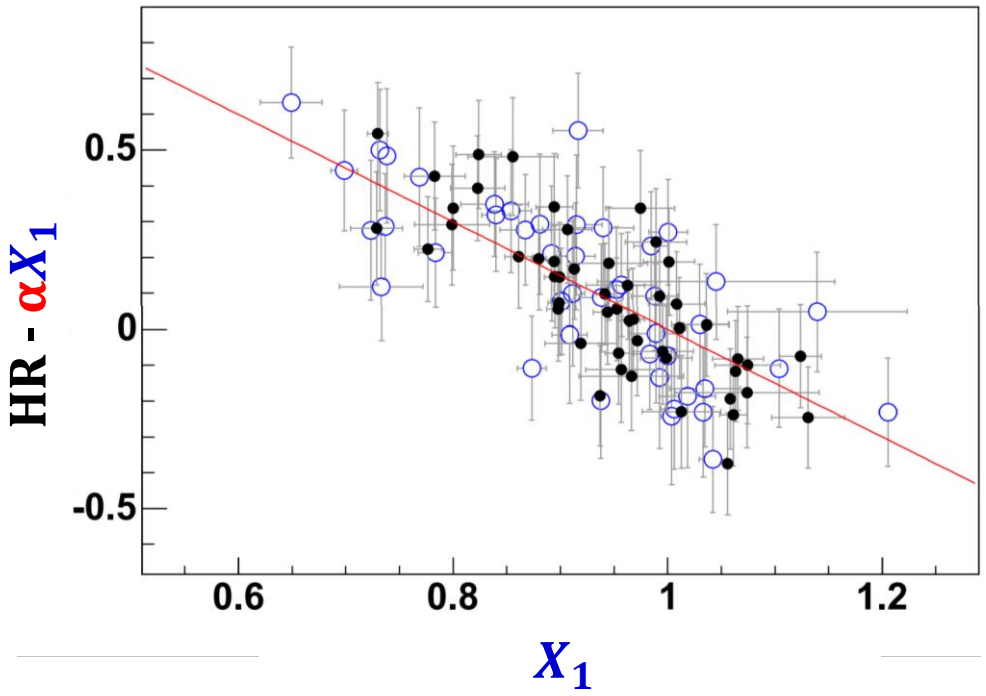

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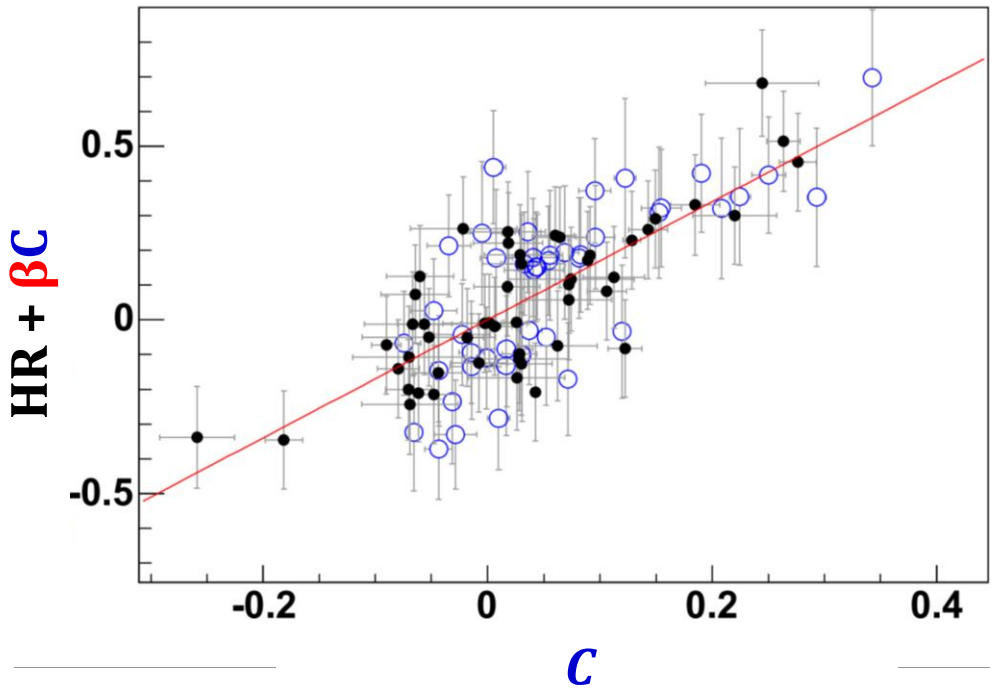
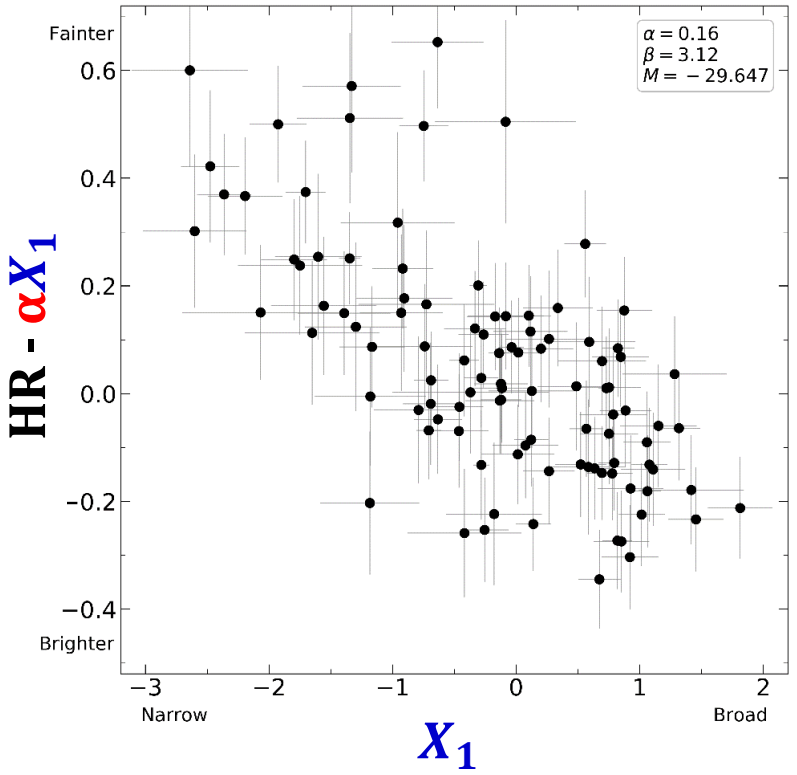


WLR & CLR (Rose+19 data, z~0.14)

Width-Luminosity relation



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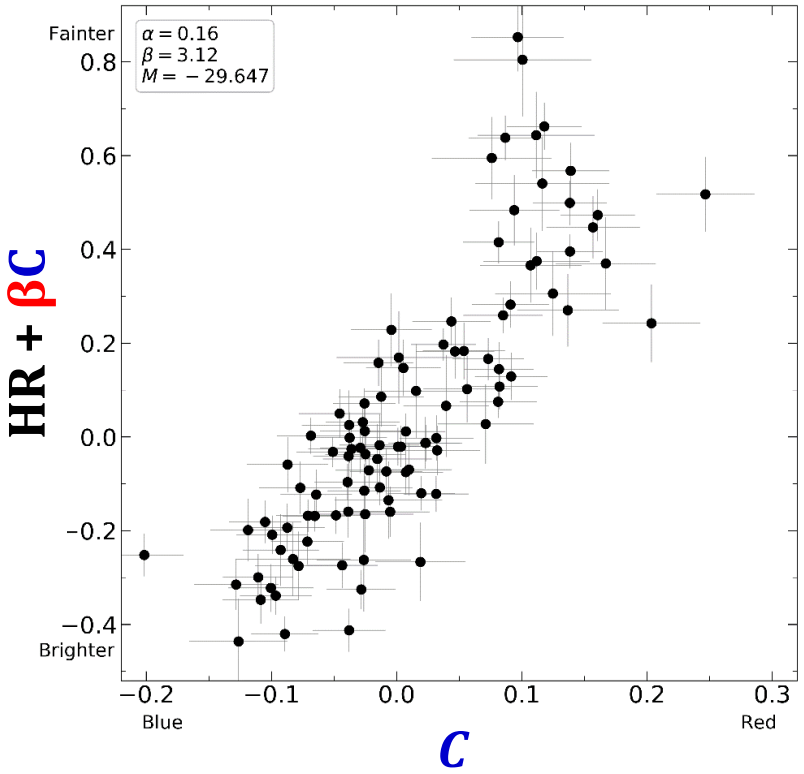
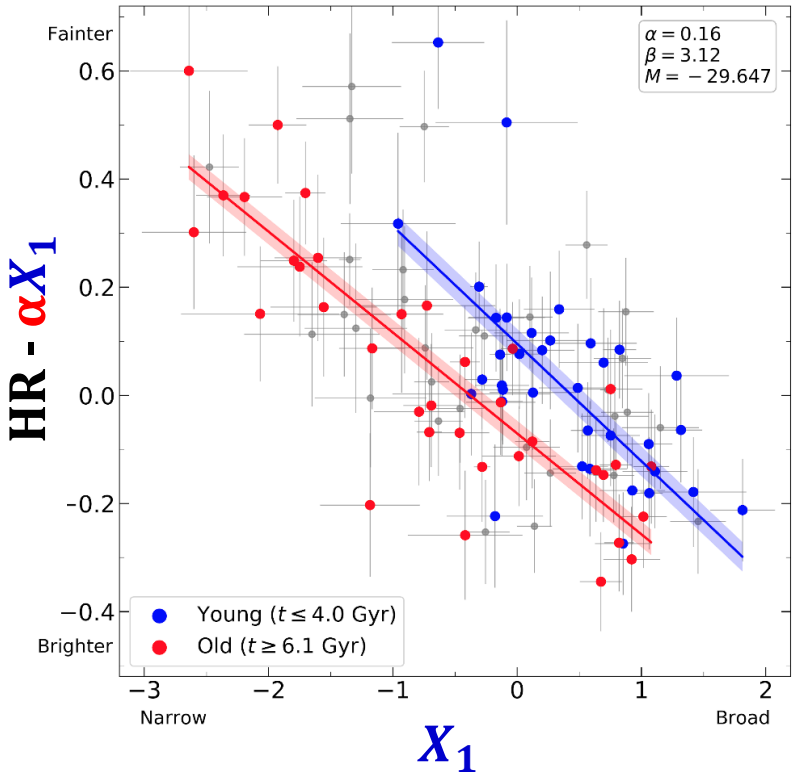


Data: Reliable photometric mass-weighted ages (Rose+2019) & HRs (Campbell+2013)

WLR & CLR (Rose+19 data, z~0.14)

has age-dependence!

Width-Luminosity relation



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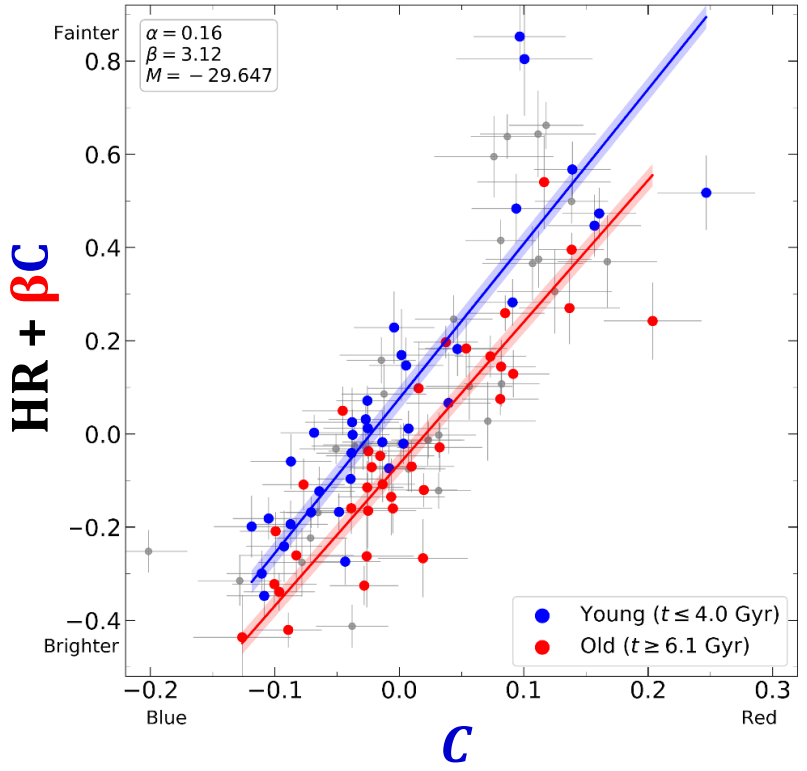


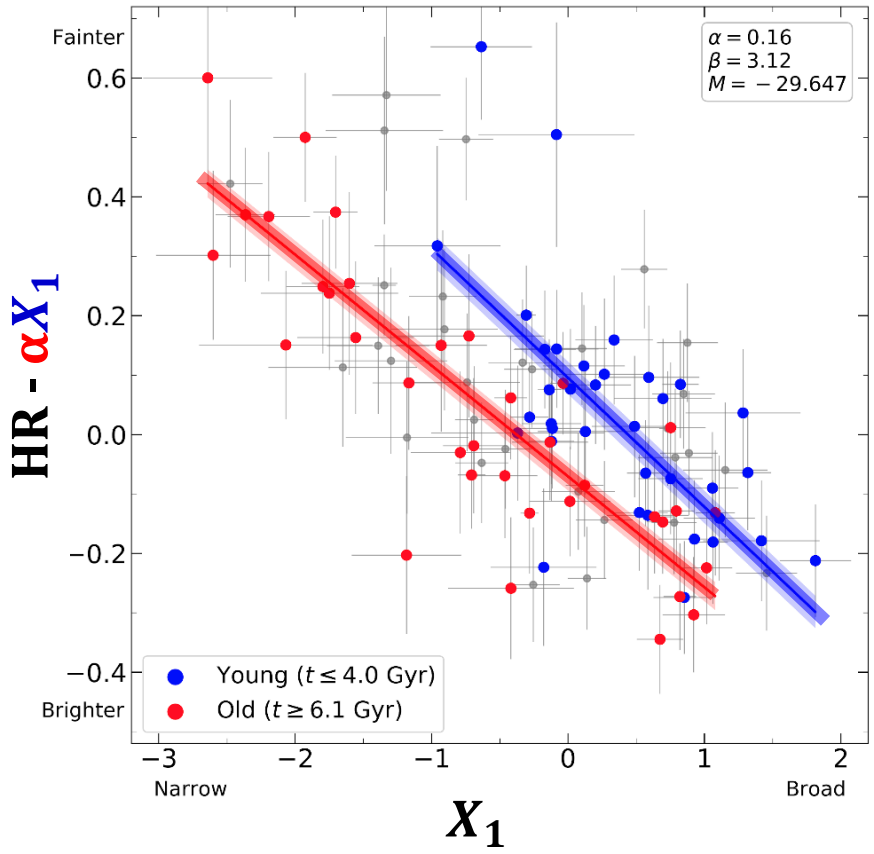
SNe from younger progenitors are fainter for a given X_1 and C

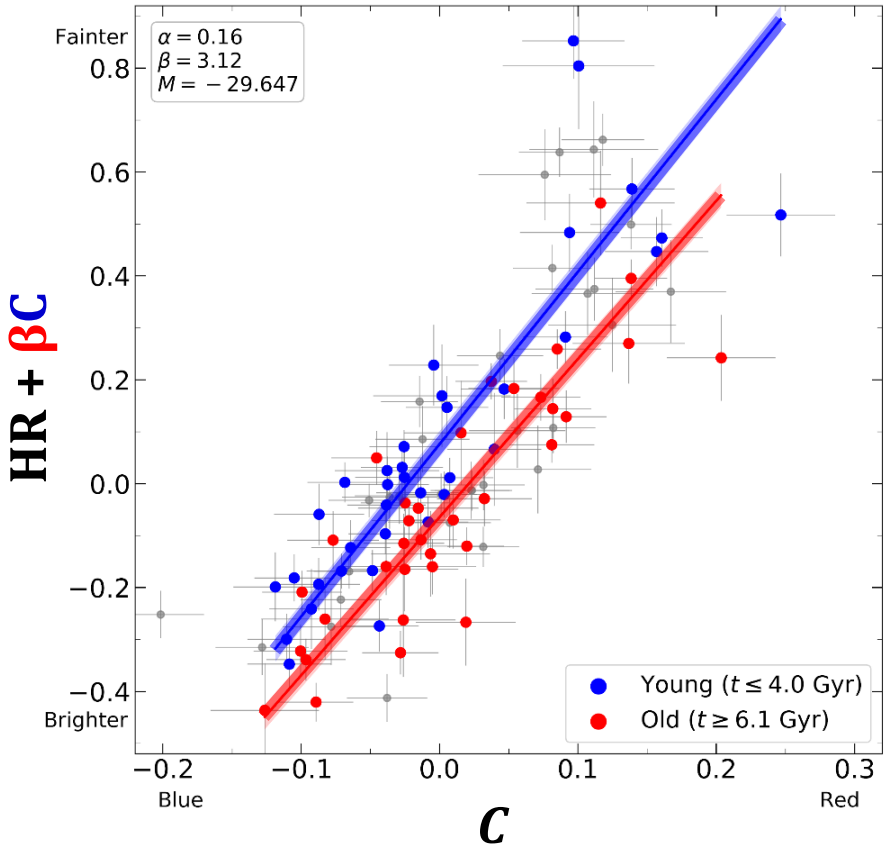
Reminiscent of Baade's (1956) discovery of two Cepheid P – L relations !!

Hubble Residuals (after standardization)

SNe from young population have larger HR

→ SNe at High-redshift have larger HR





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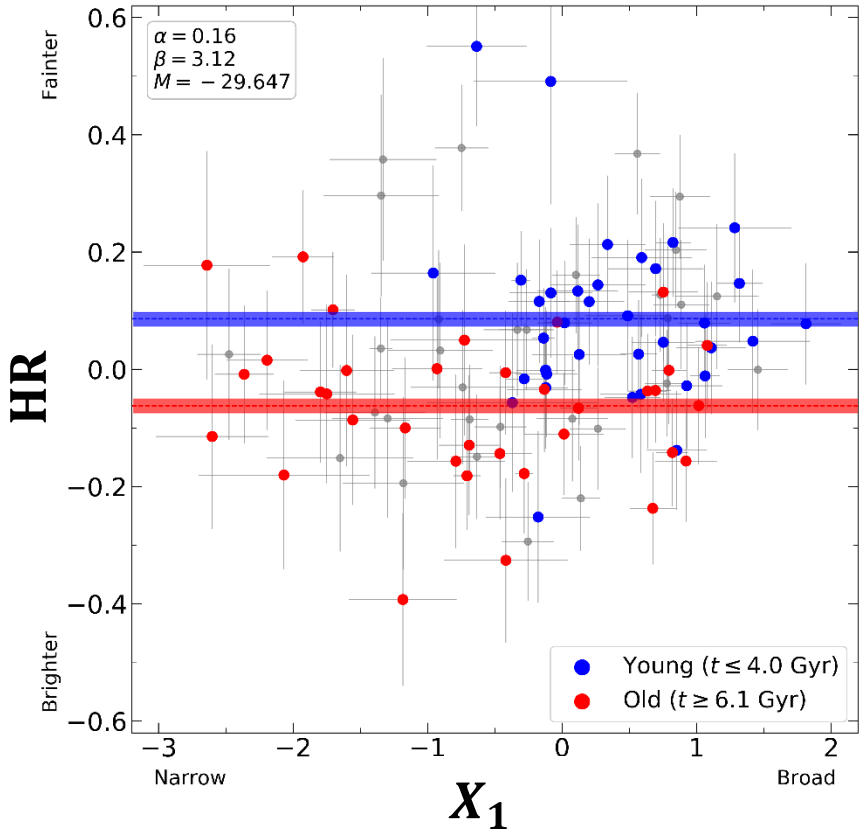
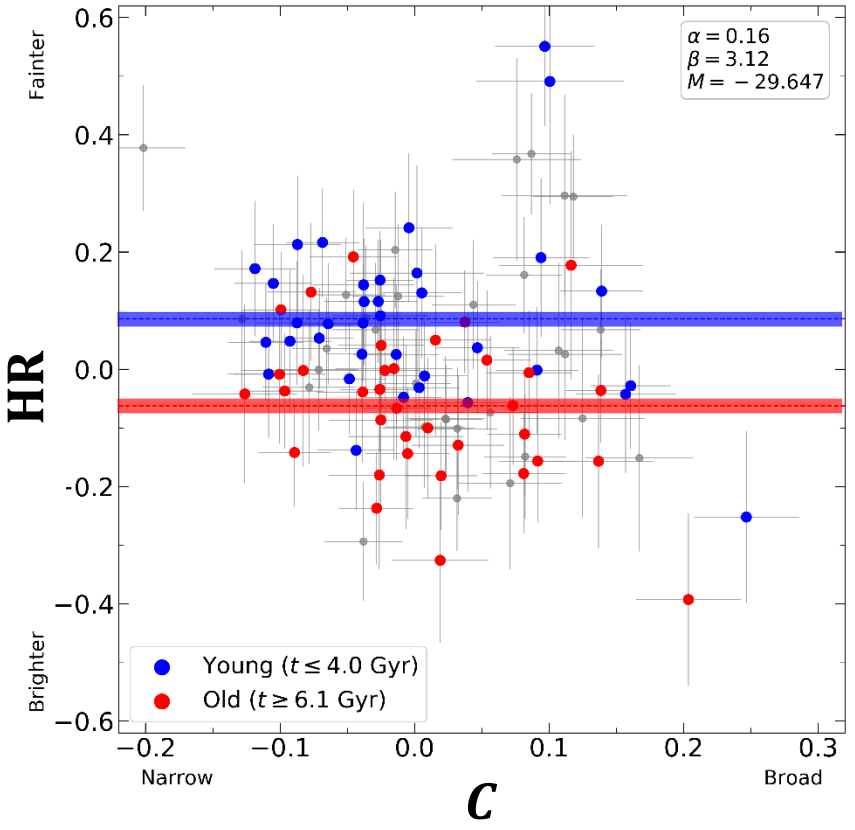
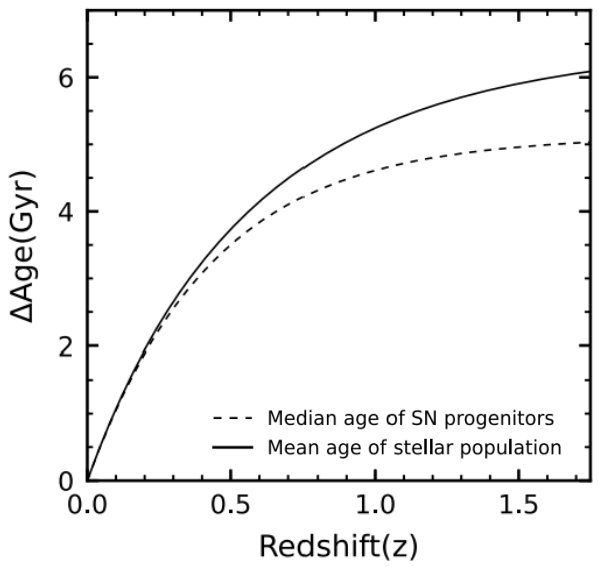
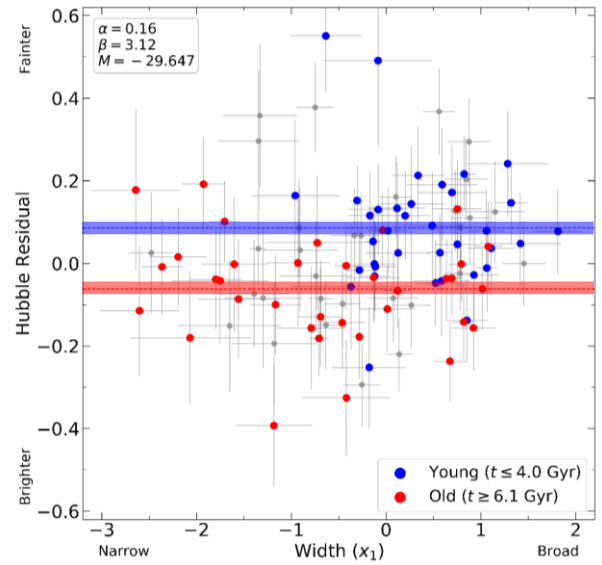




Pop age-Redshift relation
(Δt ~ 6 Gyr, 0 < z < 1.5)



Pop HR-age relation
(-0.04 mag/Gyr)

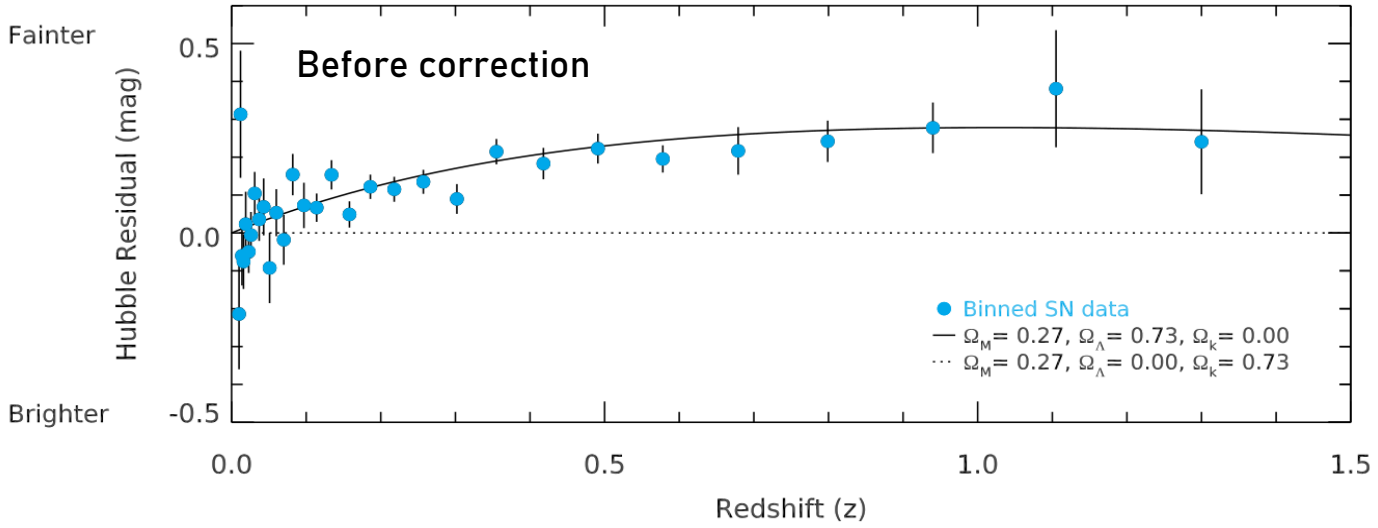


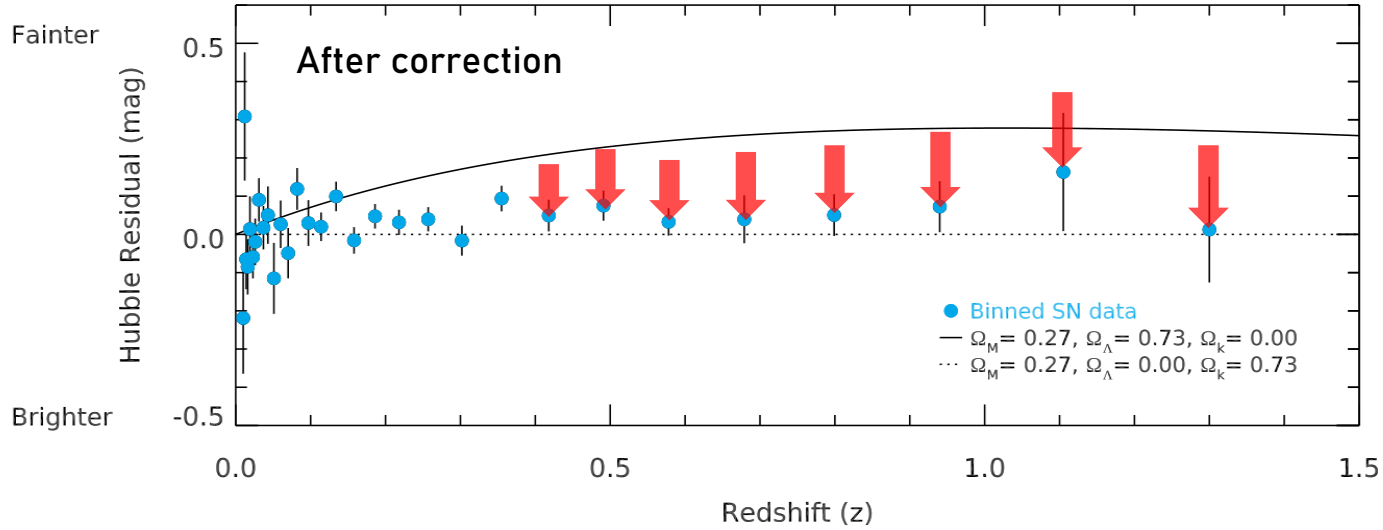
$$\frac{\Delta HR}{\Delta z}$$

The age-bias

Cosmological Parameter Estimation

o-LCDM model, Betoule+14 data





Data prefers non-dark energy after the correction.

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

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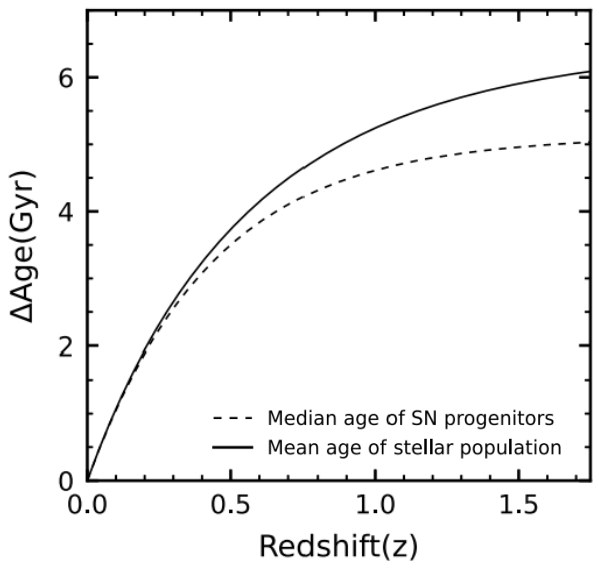

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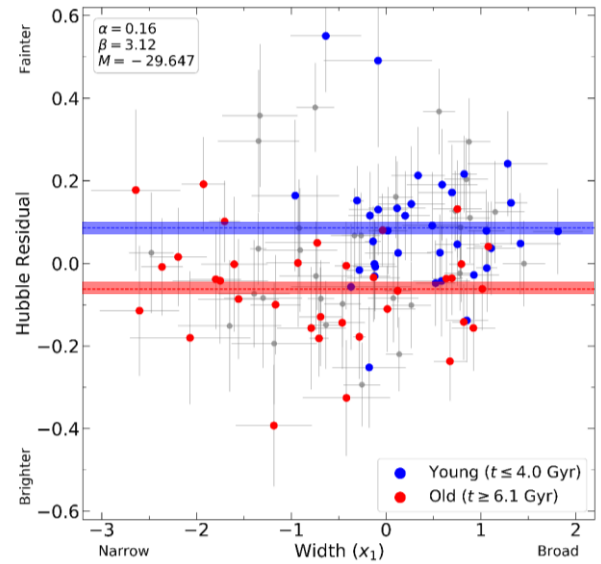
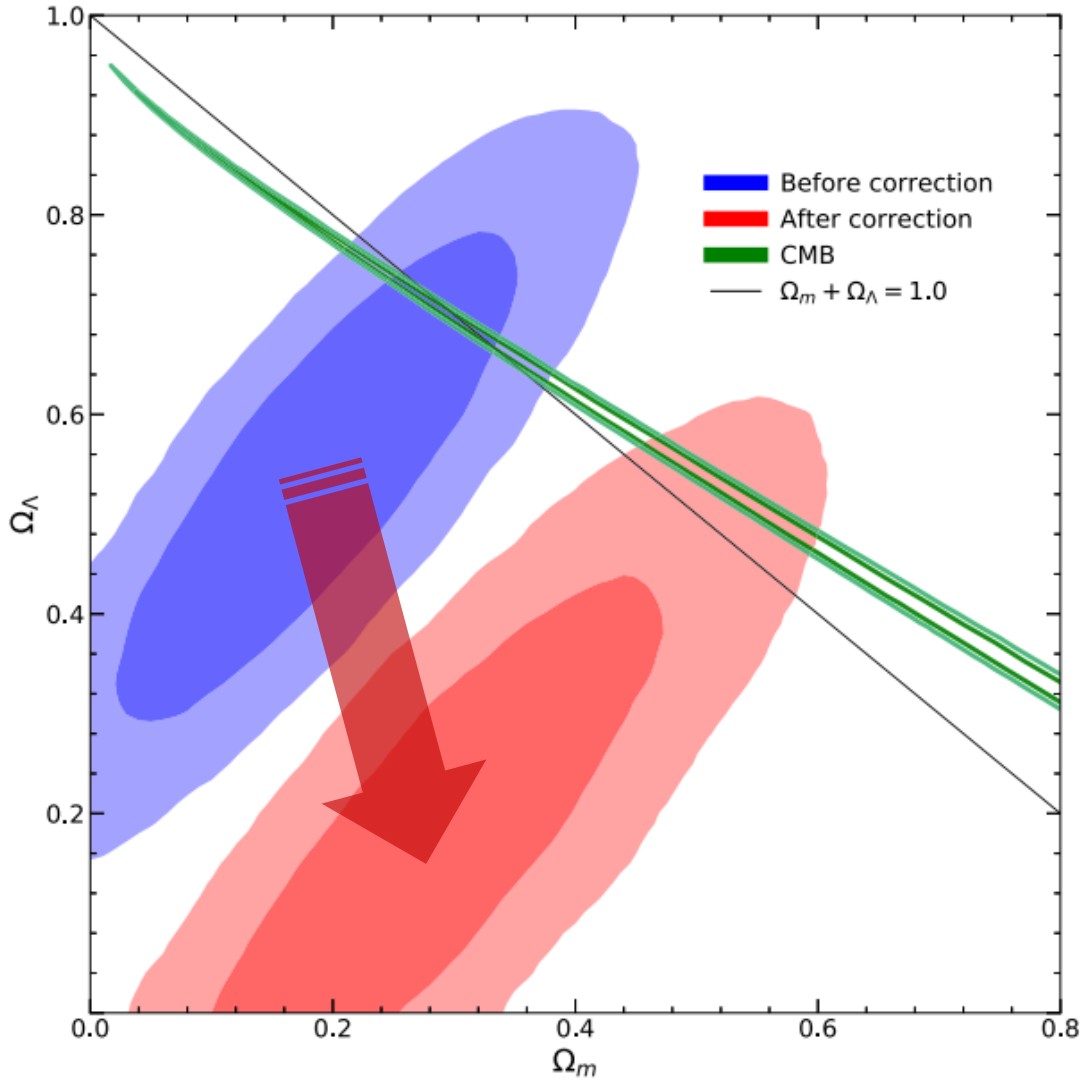


$$\frac{\Delta HR}{\Delta z}$$

The age-bias

Cosmological Parameter Estimation

o-LCDM model, Betoule+14 data

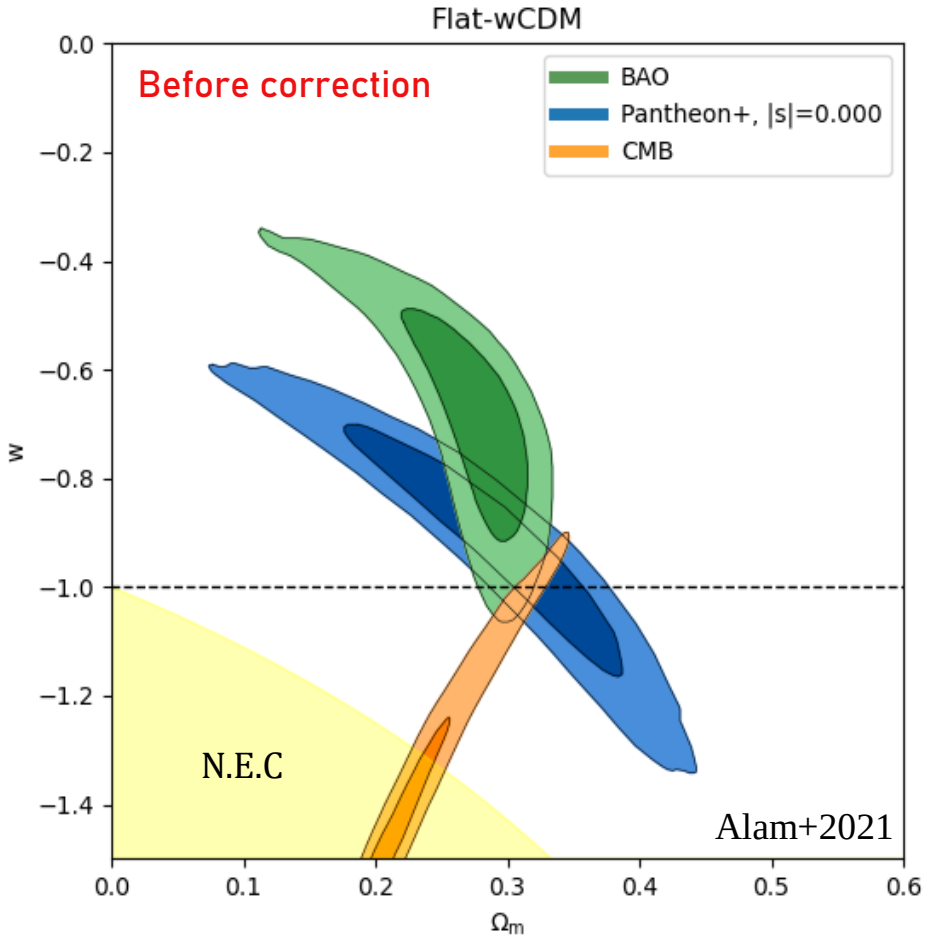


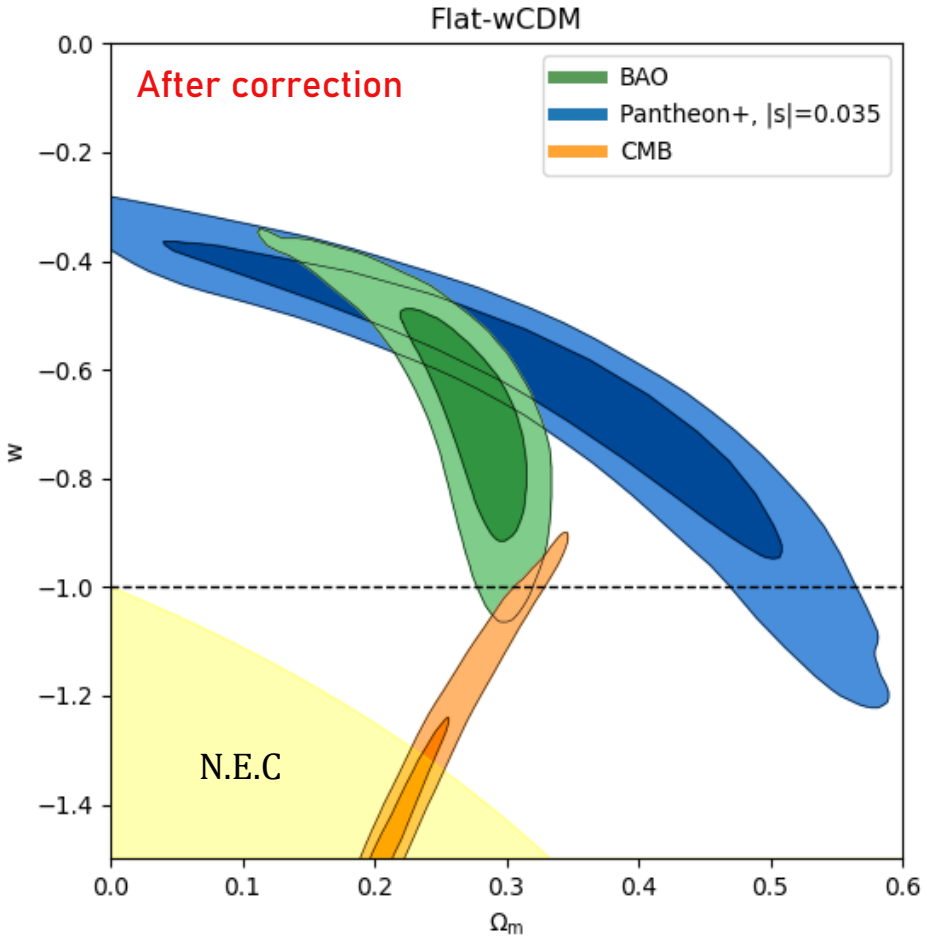
Data prefers non-dark energy after the correction.

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

Cosmological Parameter Estimation

Flat-wCDM model, Pantheon+ data

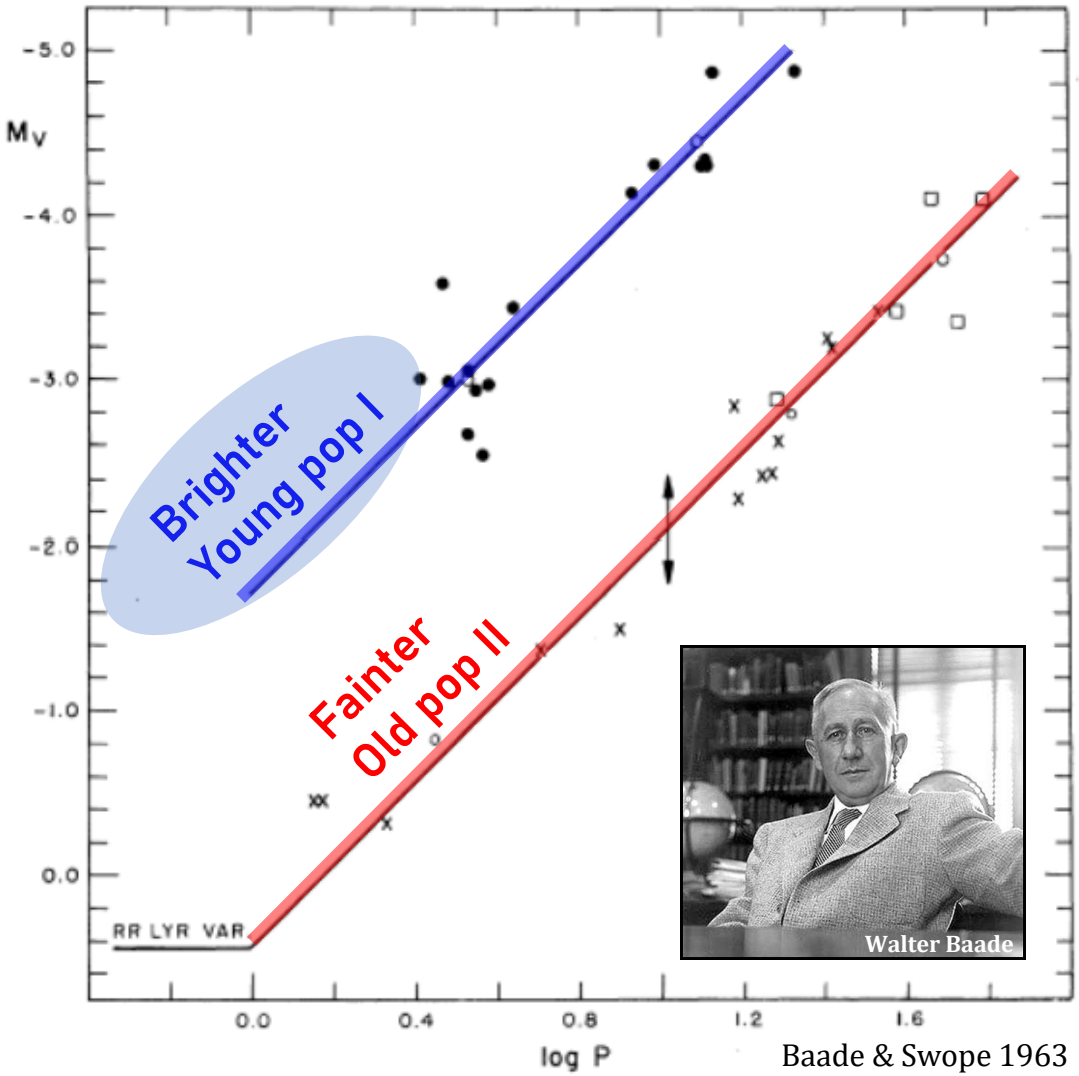




After the age-bias correction, a strong 'w tension (~6.3σ)' between the low-z probes (SNe, BAO) & CMB in flat-wCDM

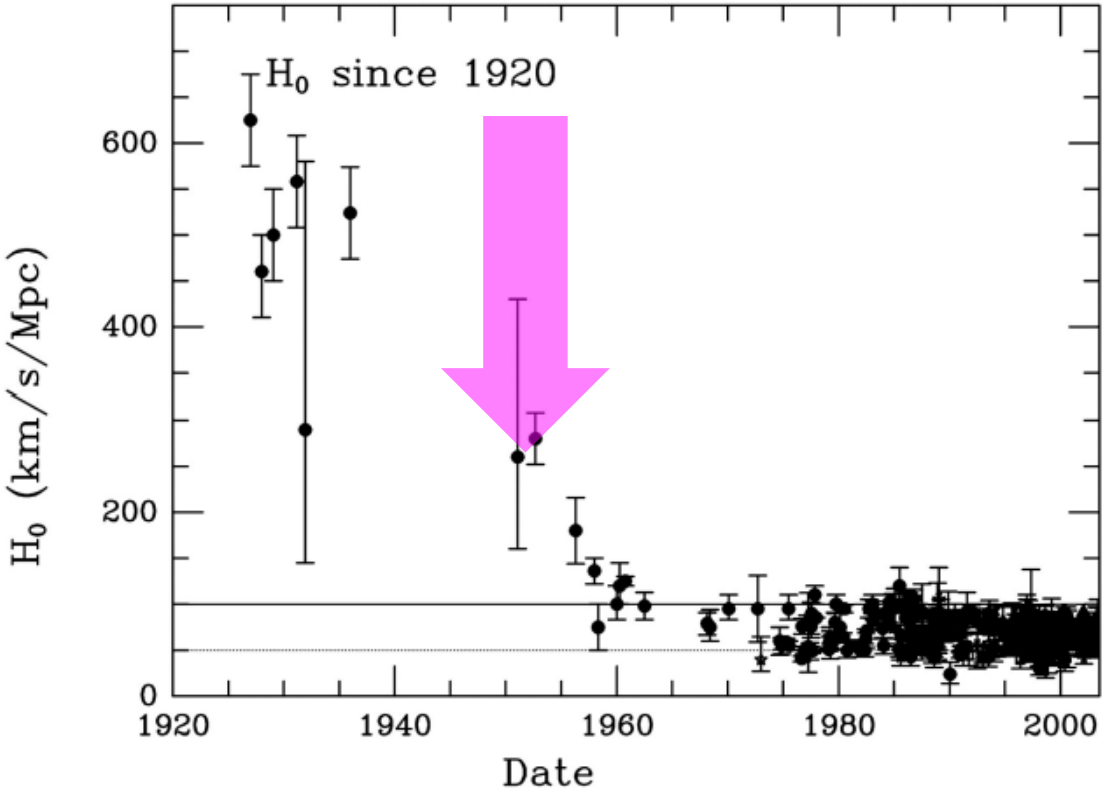
Hubble's mistake discovered by Baade

Cepheid P-L relation



Baade & Swope 1963

The history of H_0



Pop I is 1.5 mag brighter than **Pop II** at a given period.

→ The distance to outer galaxies had doubled.

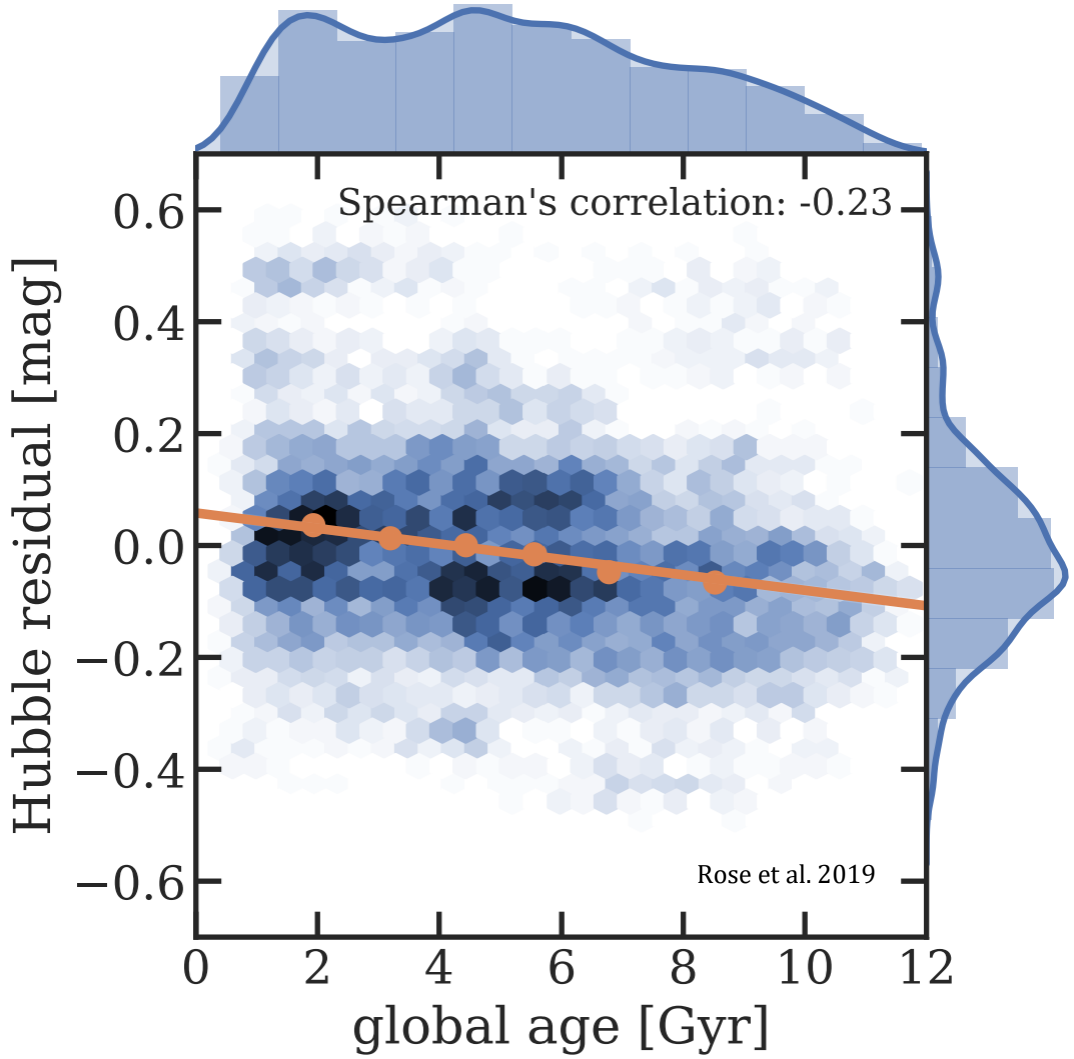
→ **The H_0 had decreased by half!**

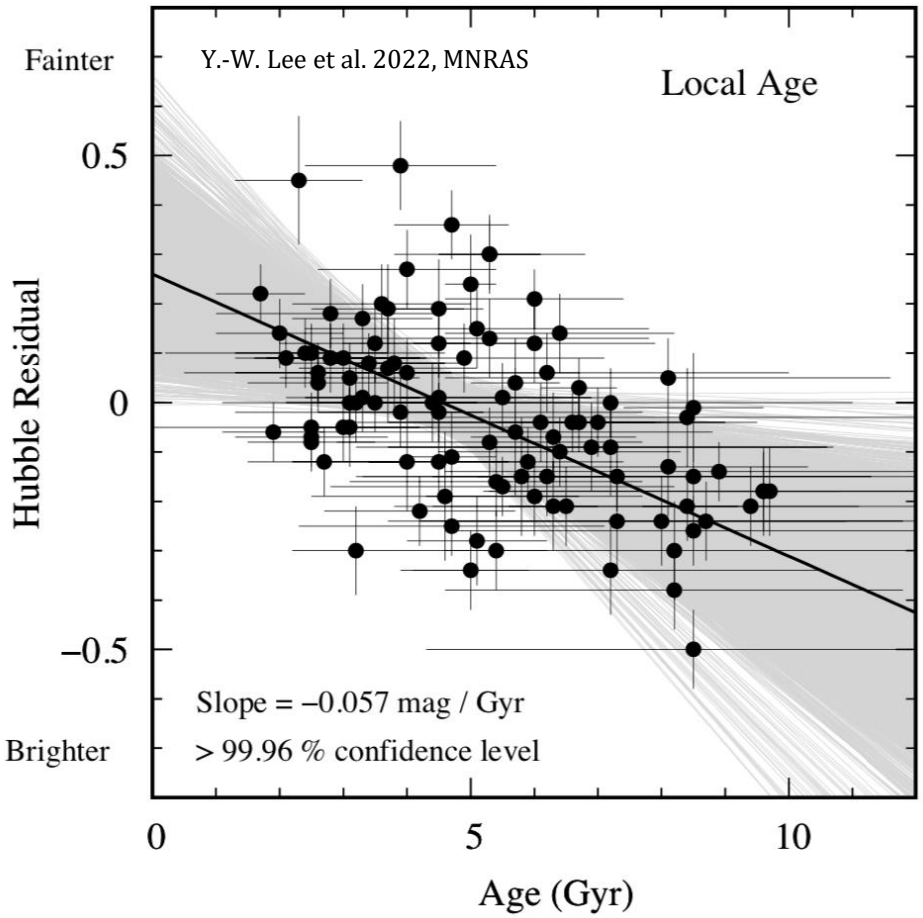
Summary

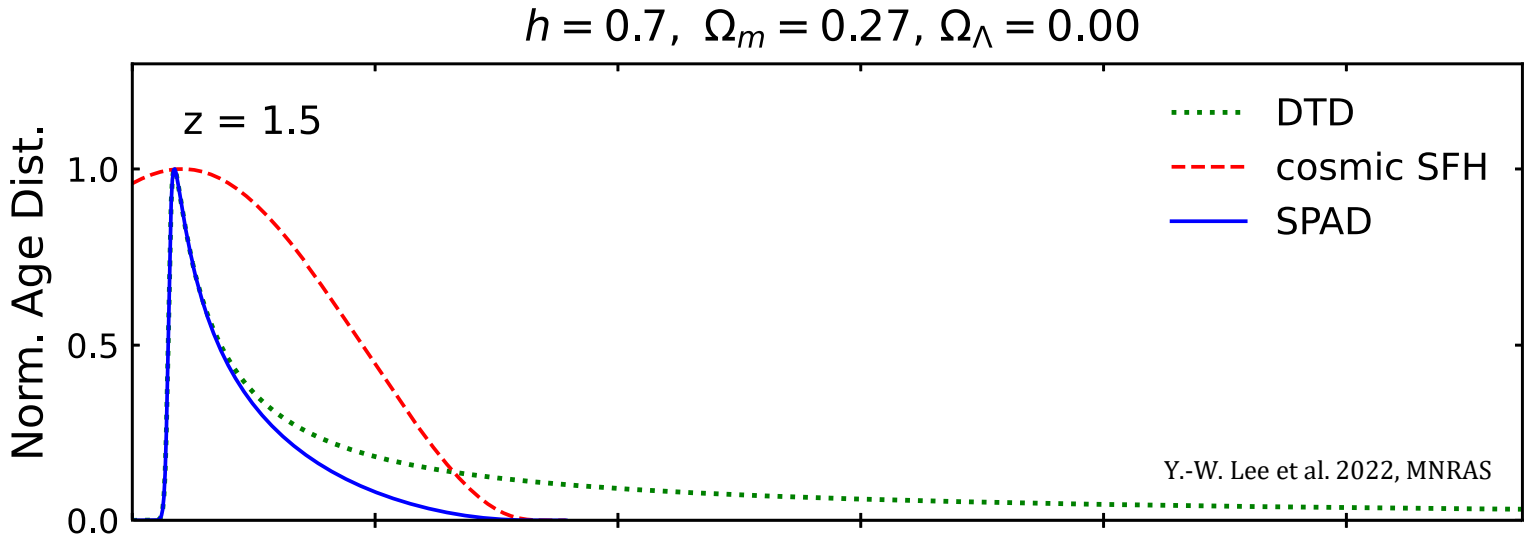
- SN cosmology is based on such a fragile assumption which is not supported by our discovery of strong progenitor age bias in SN luminosity standardization process.

- When this systematic bias is taken into account, we have a strong ‘w tension’ between the low-z probes (SNe, BAO) & CMB in the flat-wCDM model.

- To put this result on a firmer refined basis, follow-up investigations are going on for a larger sample of host galaxies at different redshift bins.


Spearman's correlation: -0.23
Rose et al. 2019
Hubble residual [mag]
global age [Gyr]
0.6
0.4
0.2
0.0
−0.2
−0.4
−0.6
0
2
4
6
8
10
12


Fainter
Brighter
Y.-W. Lee et al. 2022, MNRAS
Local Age
Slope = −0.057 mag / Gyr
> 99.96 % confidence level
Hubble Residual
Age (Gyr)
0.5
0
−0.5
0
5
10



Pop age–Redshift relation