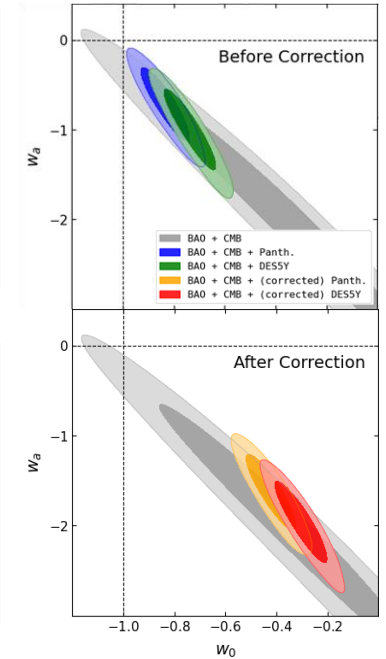
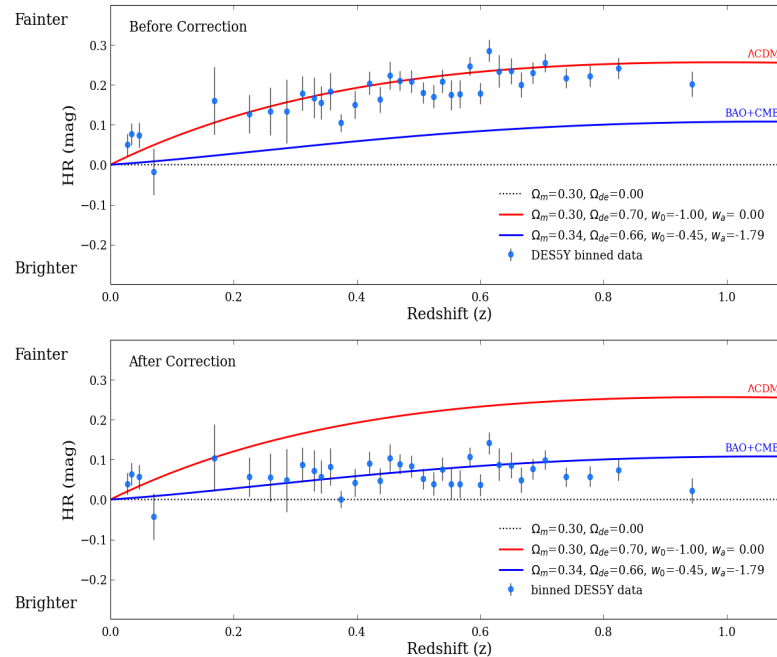


# Strong progenitor age bias in SN distance scale:

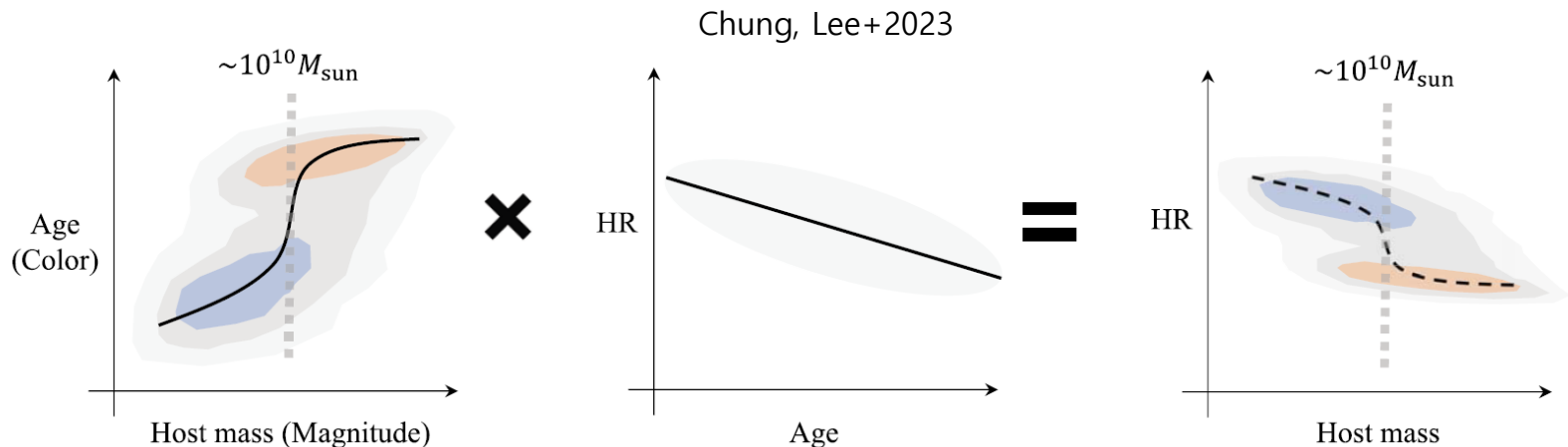
## Revised 'standard candle' (SNe) in alignment with 'standard ruler' (BAO)



**Young-Wook Lee**, Chul Chung, Junhyuk Son,  
Seunghyun Park, Hyejeon Cho, Young-Lo Kim  
**Yonsei University, Seoul, South Korea**

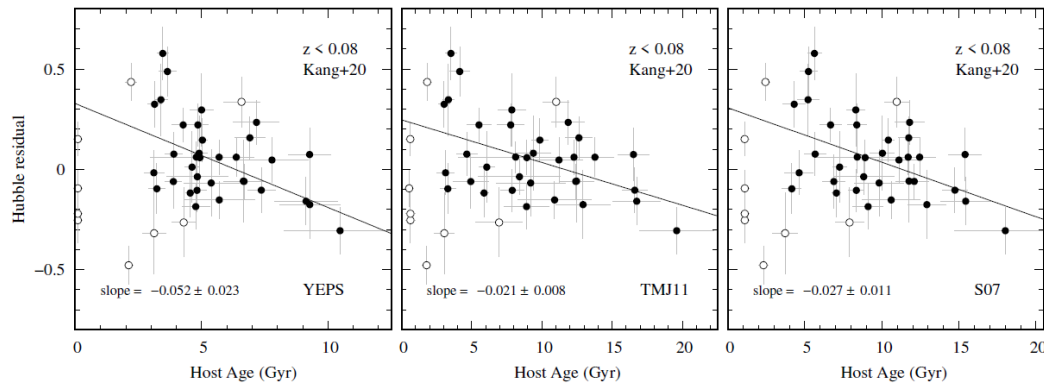
# The root cause of the mass step is most likely the progenitor age

- Host mass step correction is routinely applied to the SN distance scale.
- However, host mass cannot directly affect SN in it, so the root cause of the mass step must be something else closely related to host mass, such as progenitor age (Sullivan+2010; Kelly+2010; Childress+2014; Kang+2016; Rigault+2020; Chung+2023).
- Yet, *reliable & direct* age measurements of stellar populations in host galaxies have been lacking...



# Evidence for progenitor age bias is robust

Repeatedly confirmed by us & third parties ( $\sim 5.5\sigma$ )



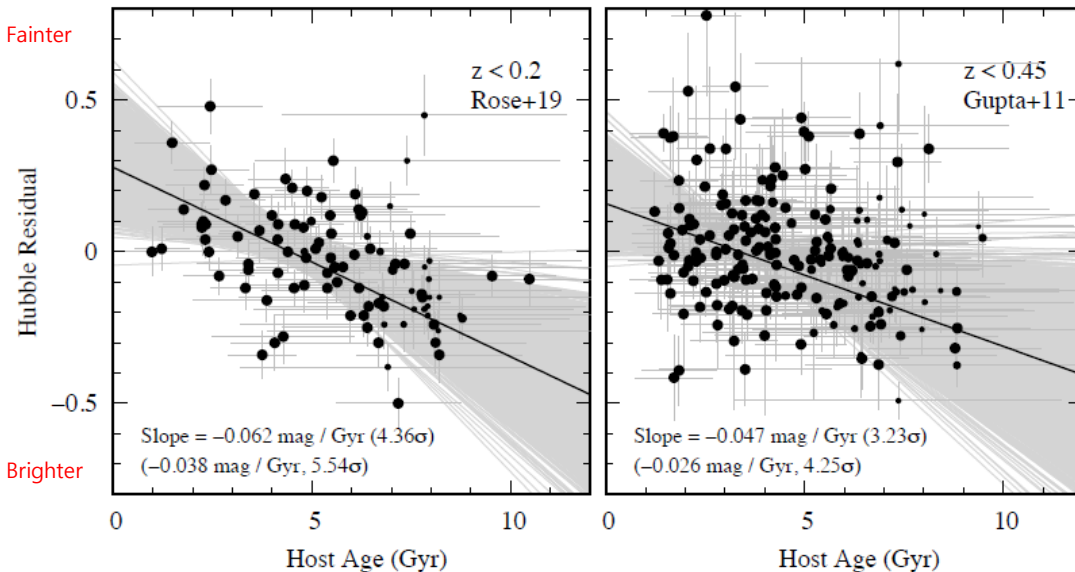
**Spectroscopy:** Kang+20 (ETGs, S/N = 175!,  $3\sigma$ )

**Photometry:** Lee+2020 (Rose+19 sample, LTGs+ETGs,  $4.3\sigma$ )

**Third party confirmation:** Zhang+2021, Wang+2023 ( $5-7\sigma$ )

**New age measurements (Chung+2025):**

Multiband photometry, Conroy & Gunn model with Rose+19 methodology, for a larger sample ( $N \sim 300$ ) of host galaxies in a broader redshift range ( $z < 0.45$ ) confirm the ubiquitous nature of this bias ( $4.3-5.5\sigma$ )



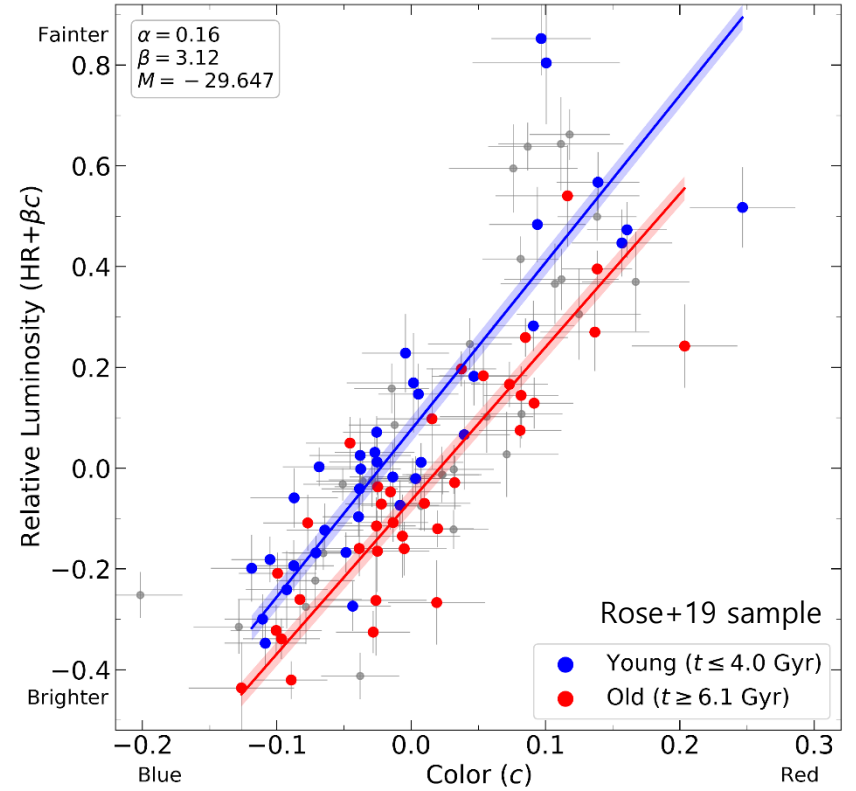
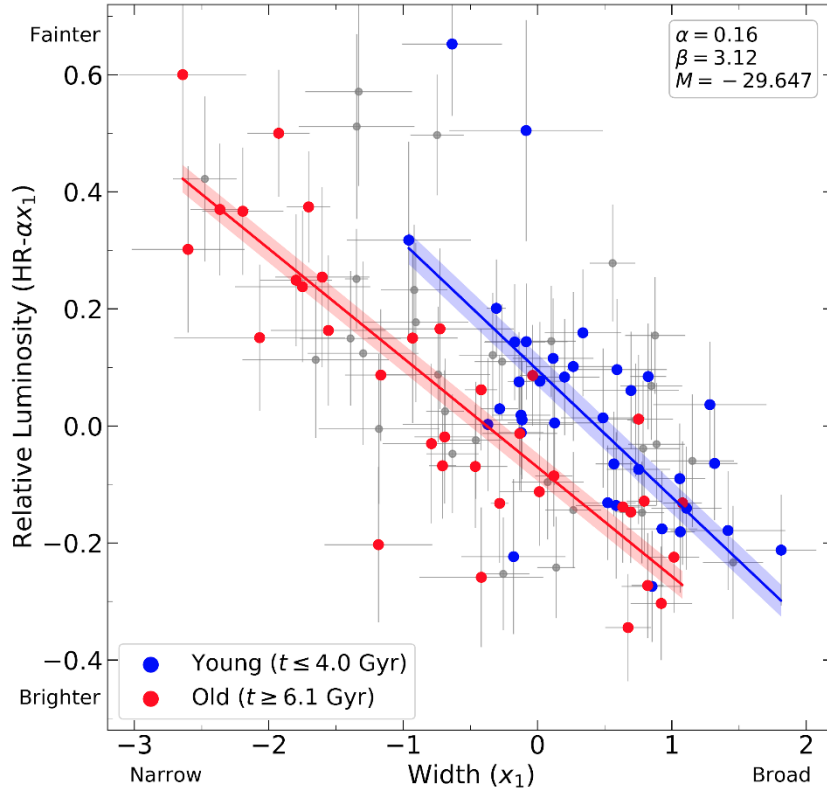
Average of 3 samples

**Slope =  $0.030 \pm 0.004 \text{ mag/Gyr}$**

(utilizing full posterior for age)

# Origin of progenitor age bias:

Progenitor age dependence in SN luminosity standardization process (WLR/CLR)

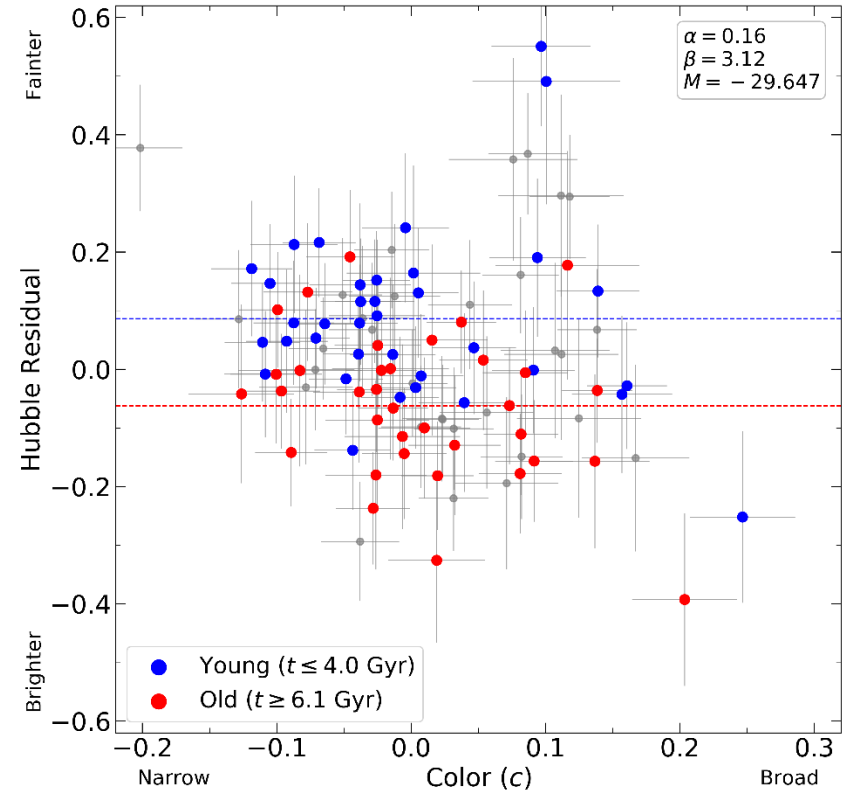
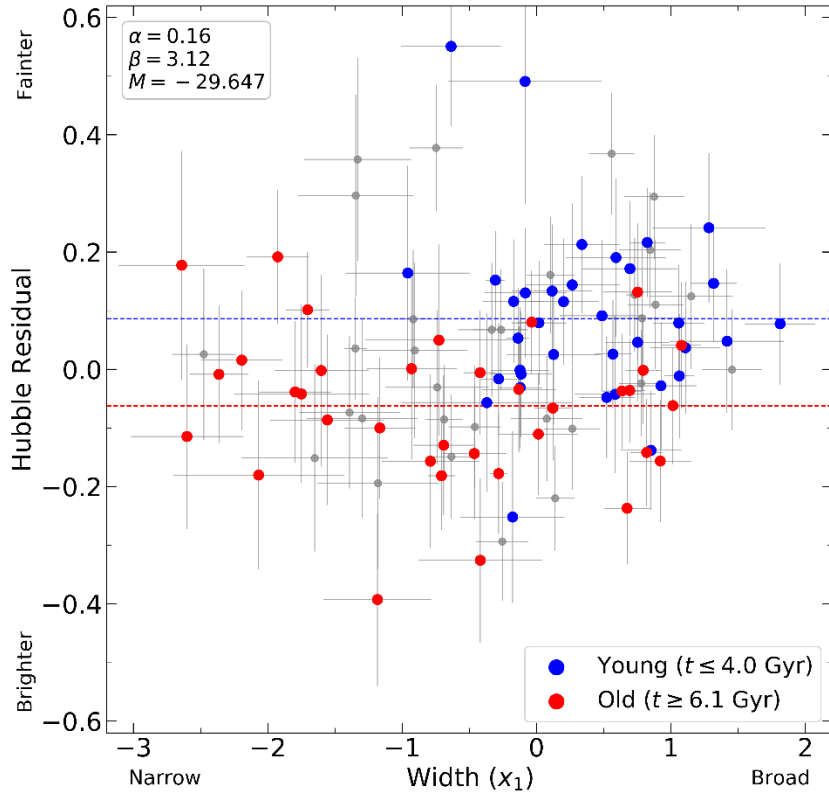


SNe from younger progenitors are fainter each at given  $x_1$  and  $c$  ( $4.6\sigma$  result)

Other host properties, such as host mass, show only insignificant ( $\sim 1\sigma$ ) offsets

After standardization, “young” SNe are *over-corrected* & fainter!

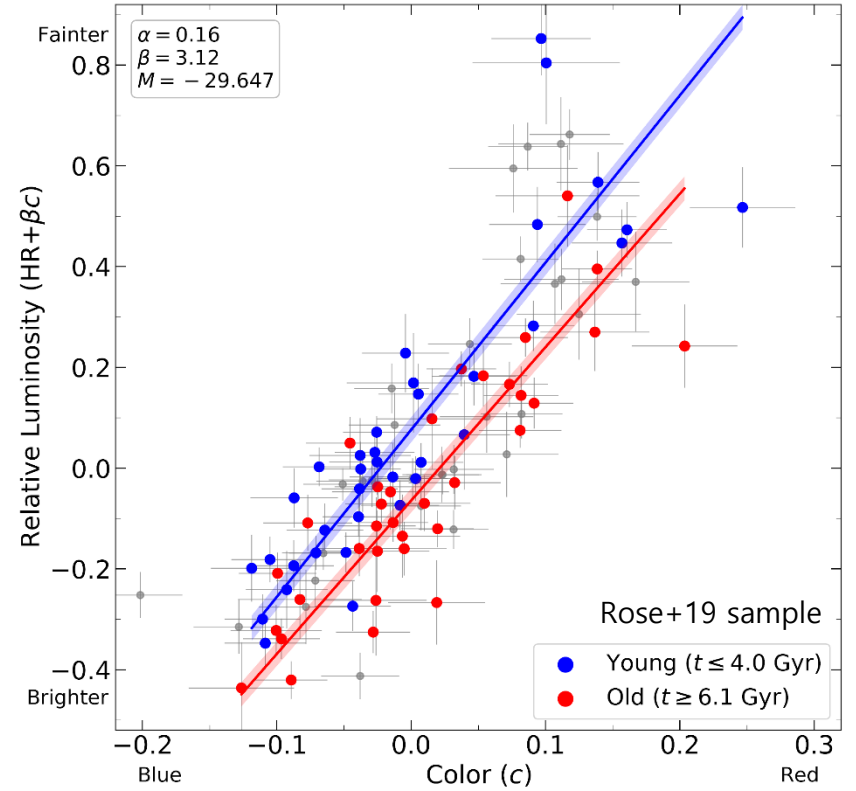
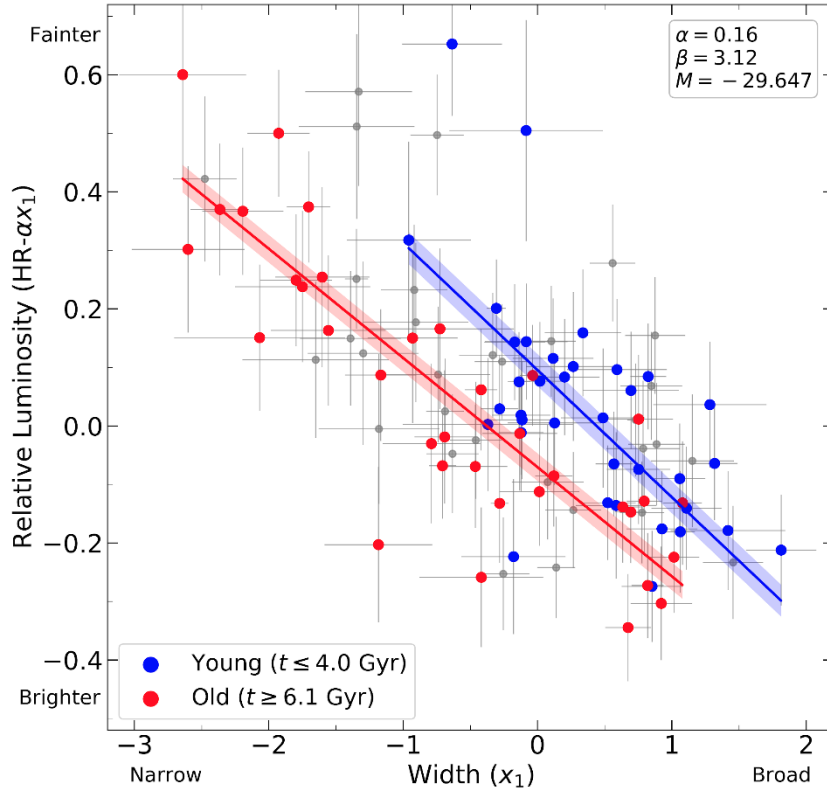
$$\mu = m_B - M + \alpha x_1 - \beta c$$



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

# Origin of progenitor age bias:

Progenitor age dependence in SN luminosity standardization process (WLR/CLR)



SNe from younger progenitors are fainter each at given  $x_1$  and  $c$  ( $4.6\sigma$  result)

Other host properties, such as host mass, show only insignificant ( $\sim 1\sigma$ ) offsets

# Hubble's mistake discovered by Baade

THE RESOLUTION OF MESSIER 32, NGC 205, AND THE  
REGION OF THE ANDROMEDA NEBULA

W. BAADE

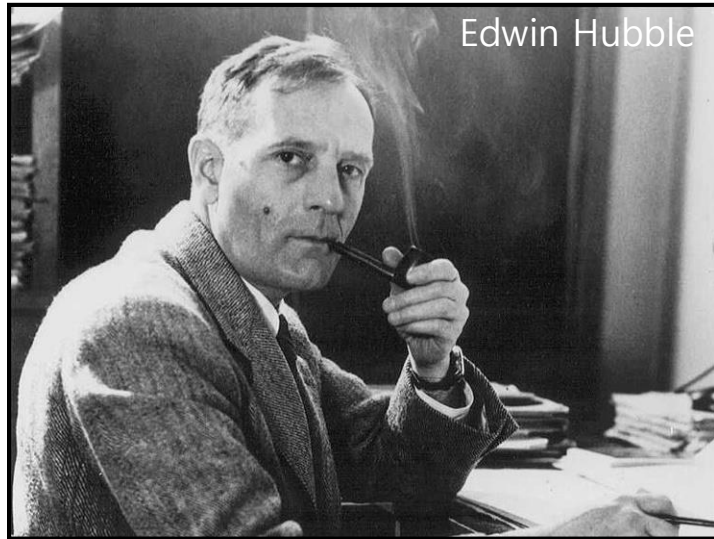
Mount Wilson Observatory

Received April 27, 1944

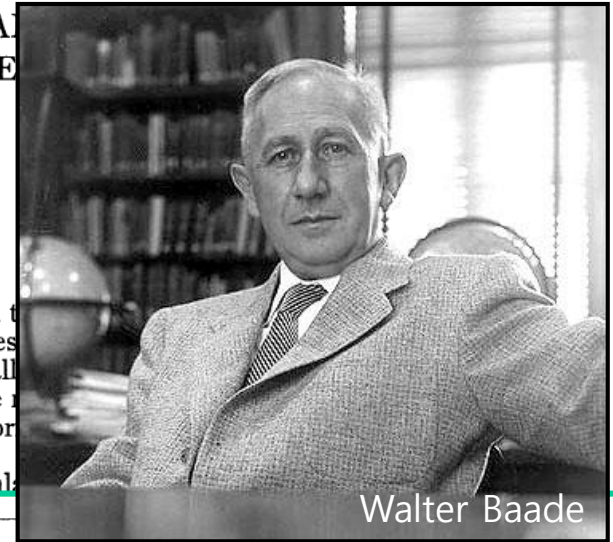
## ABSTRACT

sensitive plates, taken with the 100-inch telescope, show the companions of the Andromeda nebula—Messier 32 and the nebula itself. The brightest stars in all the field have a mean color index  $+1.3$  mag. Since the absolute photographic magnitude of the brightest stars in the field is  $-4.0$  mag, the distance modulus of the nebula is  $1.3 + 4.0 - 4.0 = 1.3$  mag. Since the absolute photographic magnitude of the brightest stars in the field is  $-4.0$  mag, the distance modulus of the nebula is  $1.3 + 4.0 - 4.0 = 1.3$  mag.

Diagram of the stars in the early-type nebulae shows that the globular clusters. This leads to two distinct groups, one representing the slow-moving stars, the other (type I) are highly luminous O-type stars. The Cepheids and globular clusters are of type II. Both types seem to be of the same age.



Edwin Hubble



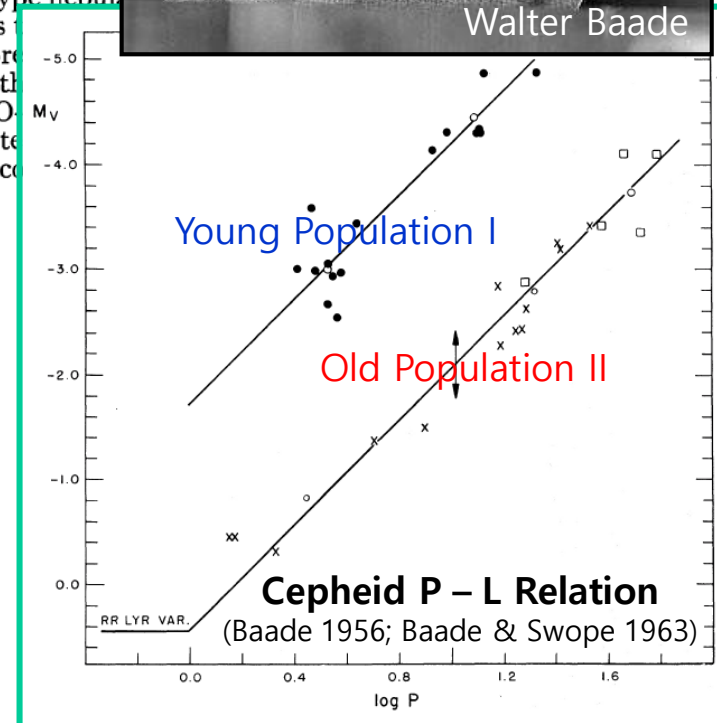
Walter Baade

Young Pop. I Cepheids that Hubble discovered in M31 are brighter than old Pop. II counterparts based on which Hubble mistakenly calibrated his observations.

→ M31 distance increased by a factor of 2

→  $H_0$  decreased by a factor of 2!

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

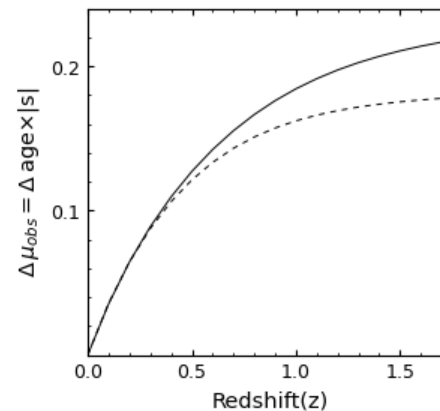
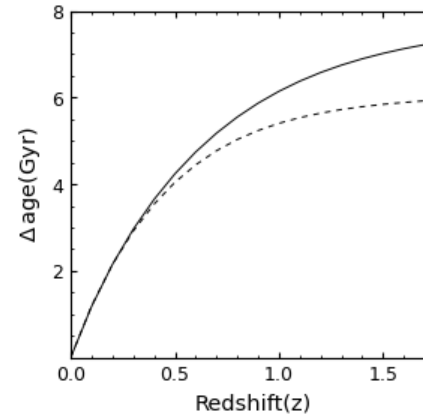
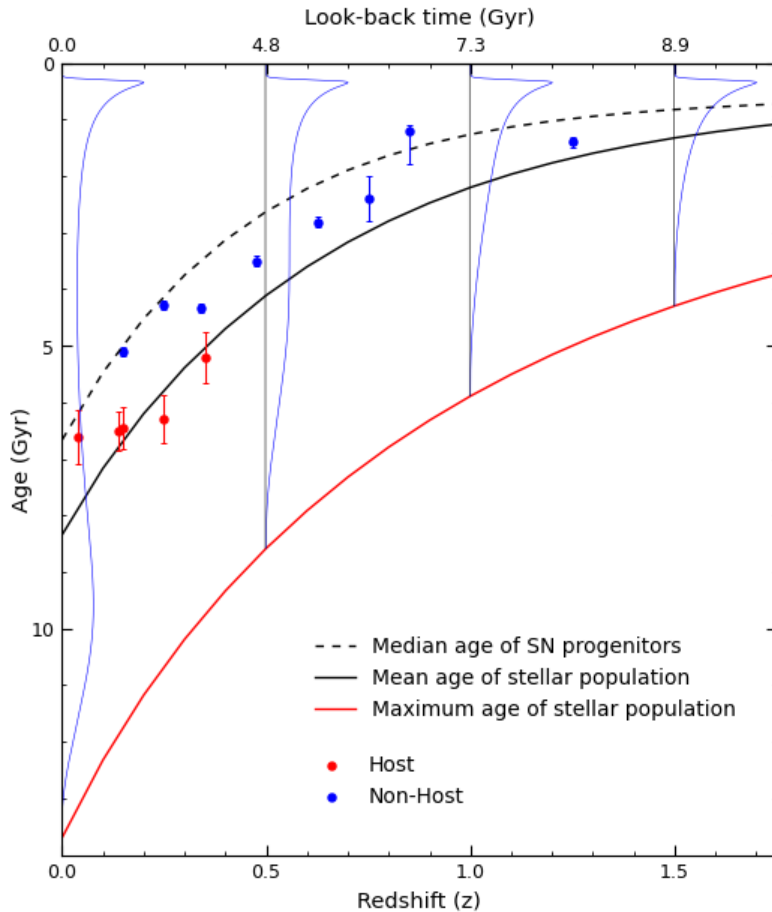




# Redshift Evolution of Supernova Progenitor Age Distribution

DESI BAO + CMB  $\Lambda$ CDM model (Adame et al. 2024):

$$H_0 = 64.7 \text{ km s}^{-1} \text{ Mpc}^{-1}, \Omega_m = 0.344, \Omega_{DE} = 0.656, w_0 = -0.45, w_a = -1.79$$



**SN Progenitor Age Distribution (SPAD)**

**= Delay Time Distribution (DTD) x Cosmic SFH**

(Childress+2014)

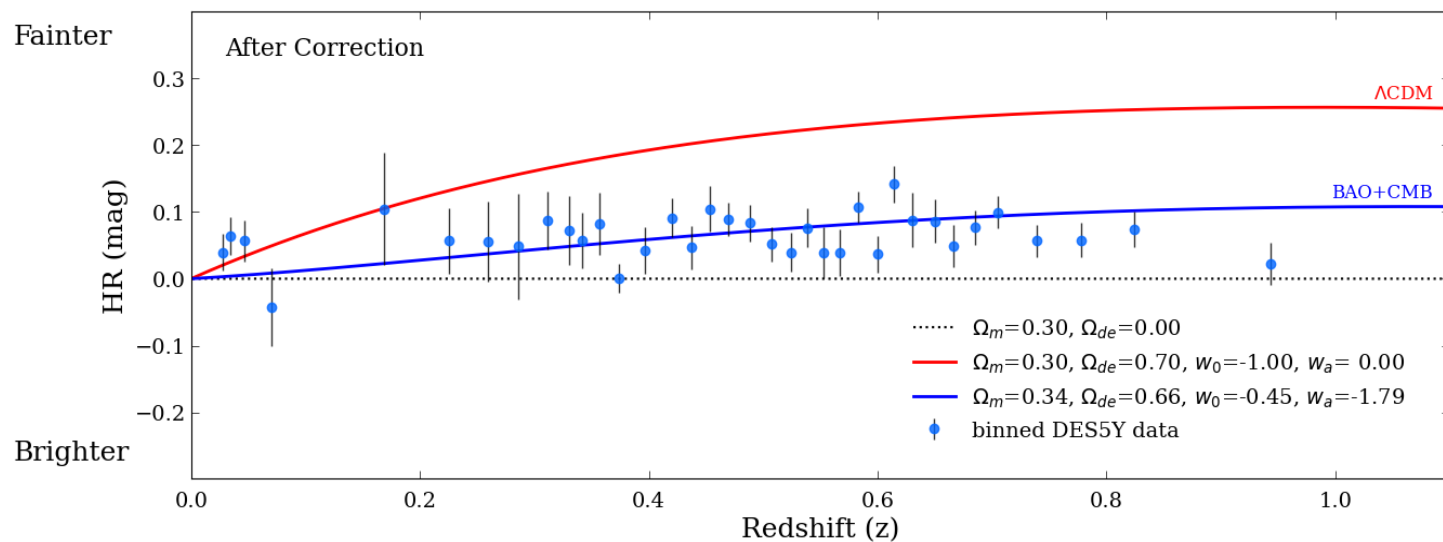
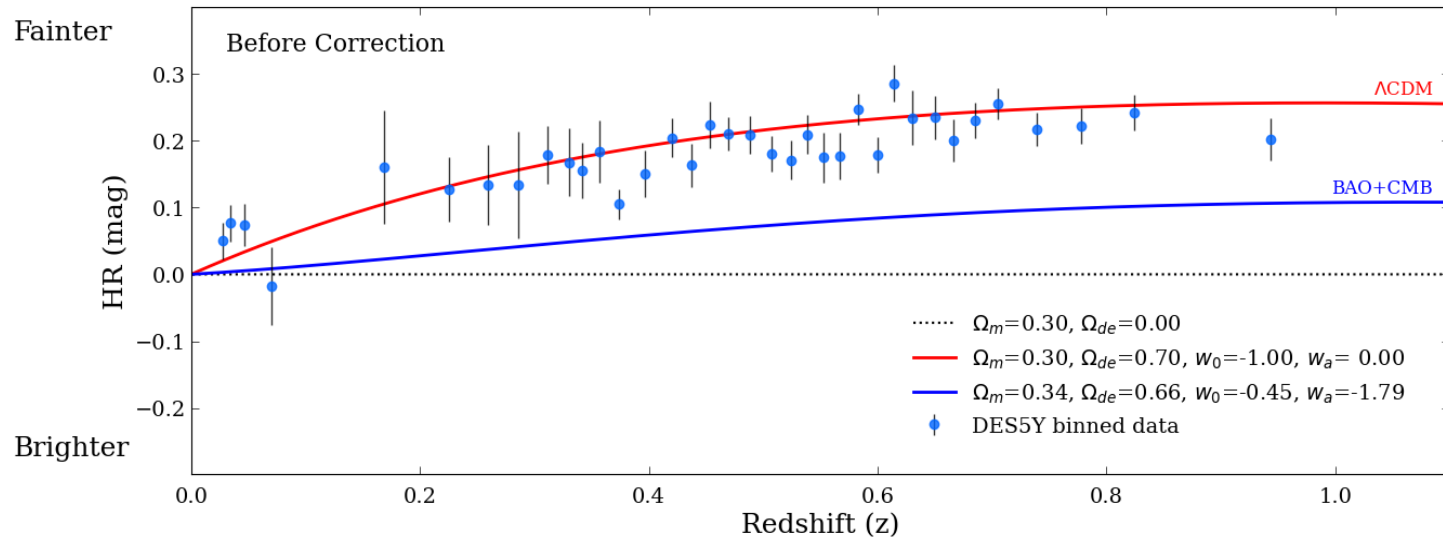
Mean population age & progenitor age are getting younger with z:

**$\Delta t \sim 5 - 6 \text{ Gyr} (0 < z < 1)$**   
 **$\rightarrow \sim 0.15 \text{ mag}$**

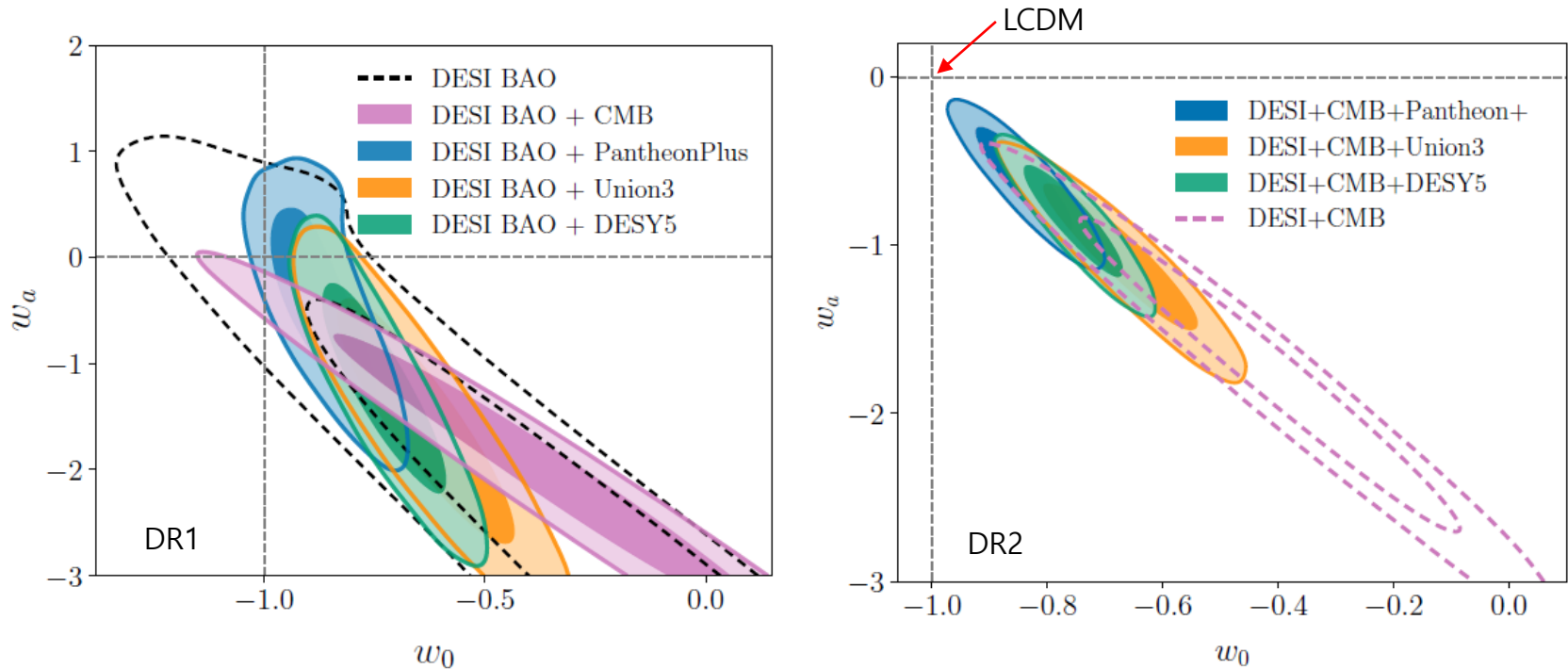
(data from Kang+20, Rose+19, Gupta+11, Schiavon+06, Choi, Conroy+14)



# After correcting for the age bias, SN dataset aligns with a time varying dark energy model suggested by DESI BAO+CMB



# DESI BAO (2024, 2025) suggests $w_0w_a$ CDM model (a time-varying dark energy EoS)



Dark energy equation of state (EoS):

Constant

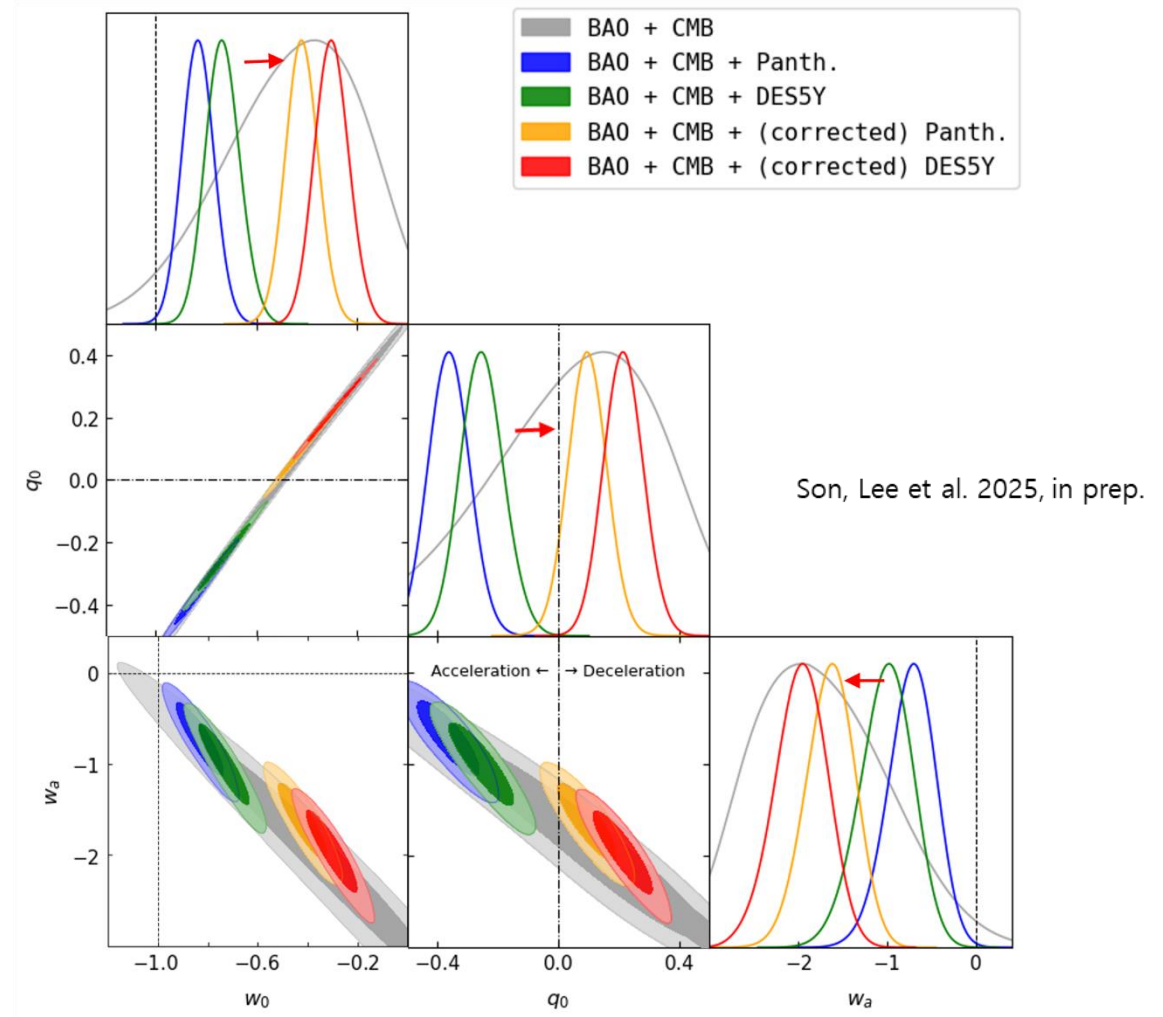
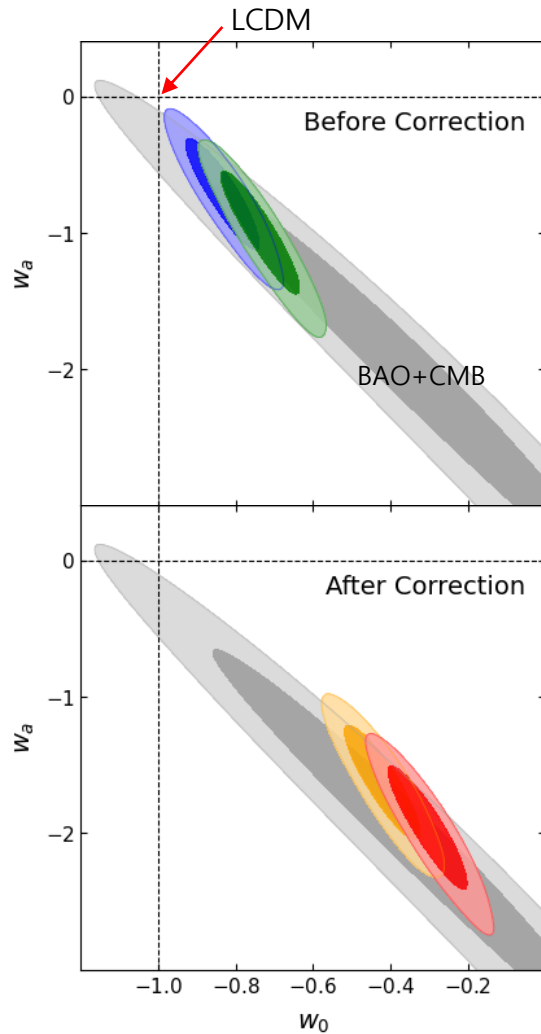
Time-varying

$$w \equiv \frac{p_{\text{de}}}{\rho_{\text{de}}}$$

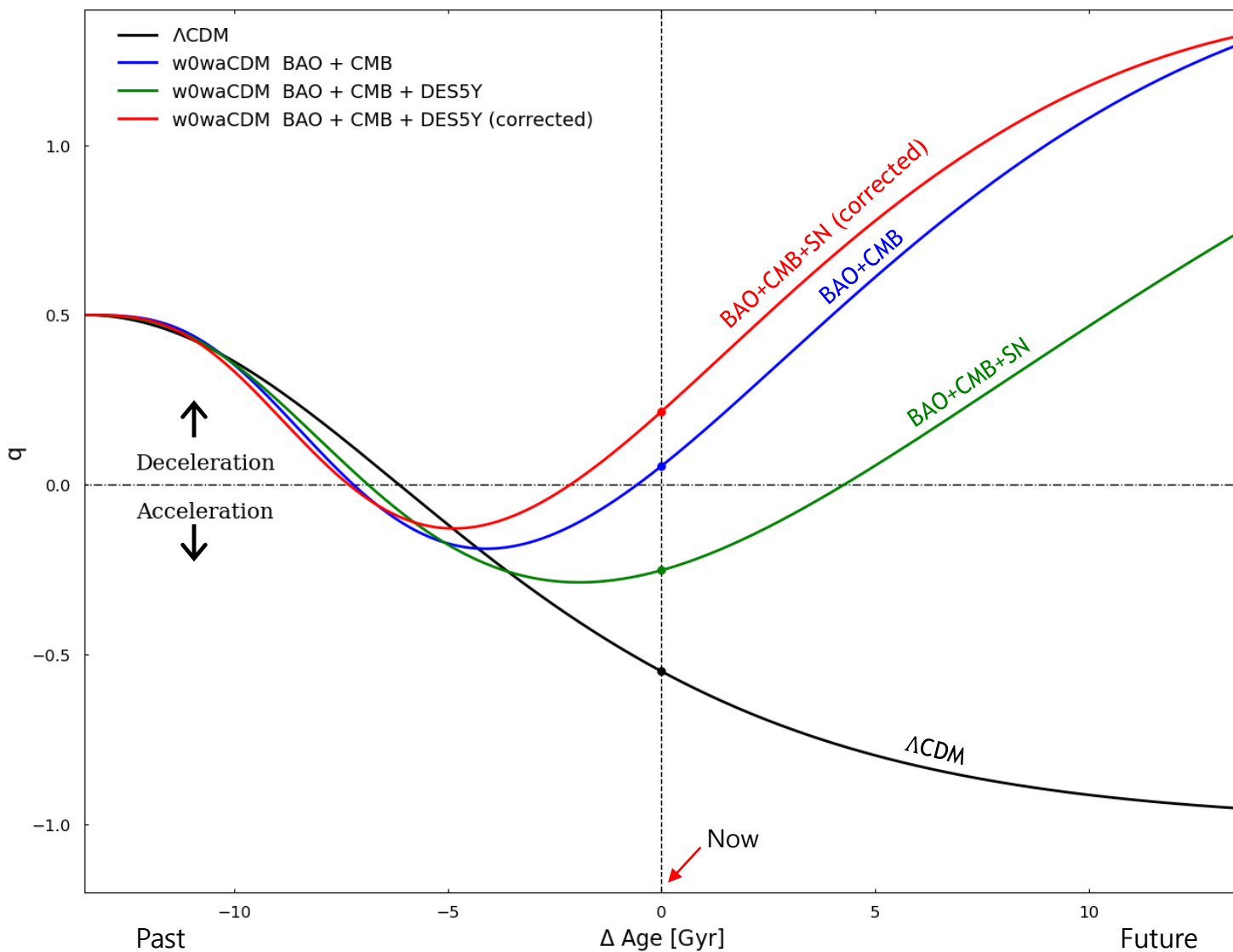
$$w(a) = w_0 + w_a(1 - a) = w_0 + w_a \frac{z}{1 + z}$$

*After correcting for the age bias, SN dataset aligns more closely with the DESI BAO+CMB in the  $w_0w_a$ CDM model*

→  $9\sigma$  discordance with LCDM model, strongly suggesting a time-varying dark energy equation of state



# Evolution of deceleration parameter



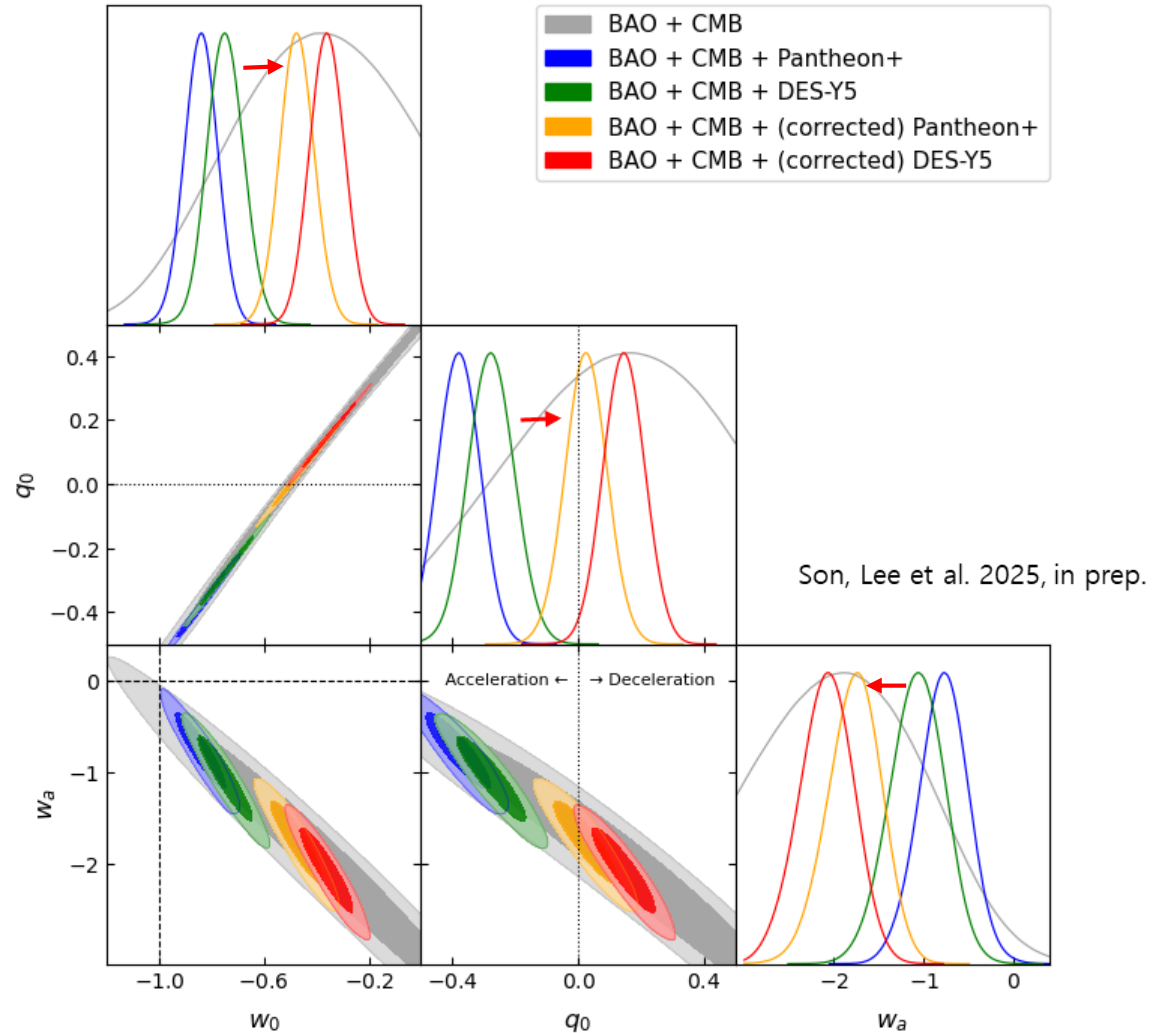
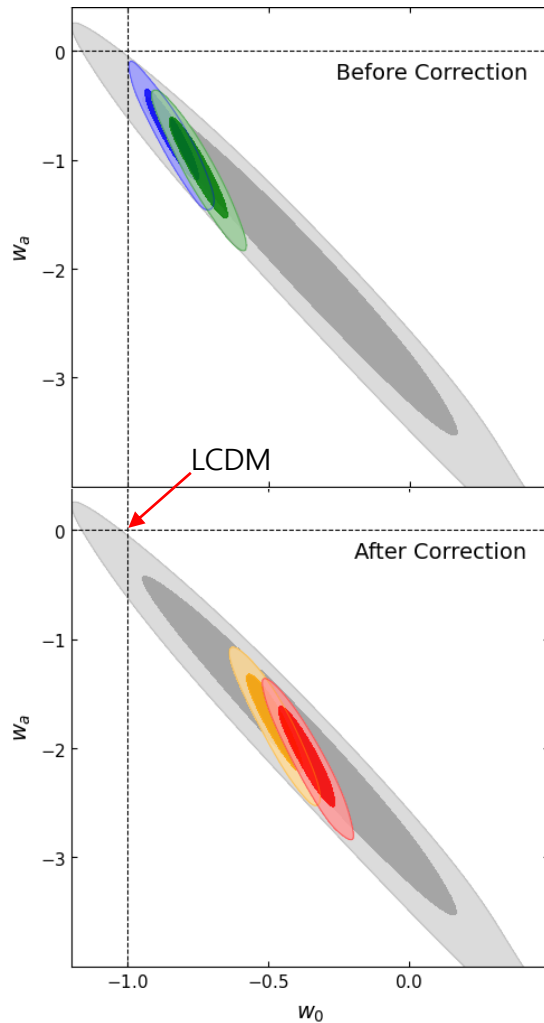
# Conclusion

- Contrary to the key assumption of SN cosmology, there is a growing body of evidence for strong progenitor age bias in SN distance scale.
- After accounting for this systematic bias, SN dataset aligns more closely with the DESI BAO and CMB results in the  $w_0 w_a$ CDM model, bringing the revised 'standard candle' (SNe) into concordance with the 'standard ruler' (BAO).
- When the three cosmological probes (SNe, BAO, CMB) are combined, we find a strong ( $9\sigma$ ) discordance with the LCDM model, suggesting a time-varying dark energy equation of state in a currently non-accelerating universe.



*After correcting for the age bias, SN dataset aligns more closely with the recent DESI BAO and CMB results in the  $w_0w_a$ CDM model*

→  $9\sigma$  discordance with  $\Lambda$ CDM model, indicating a time-varying dark energy equation of state in a currently decelerating universe.

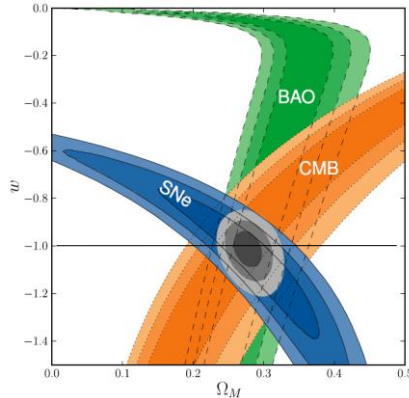




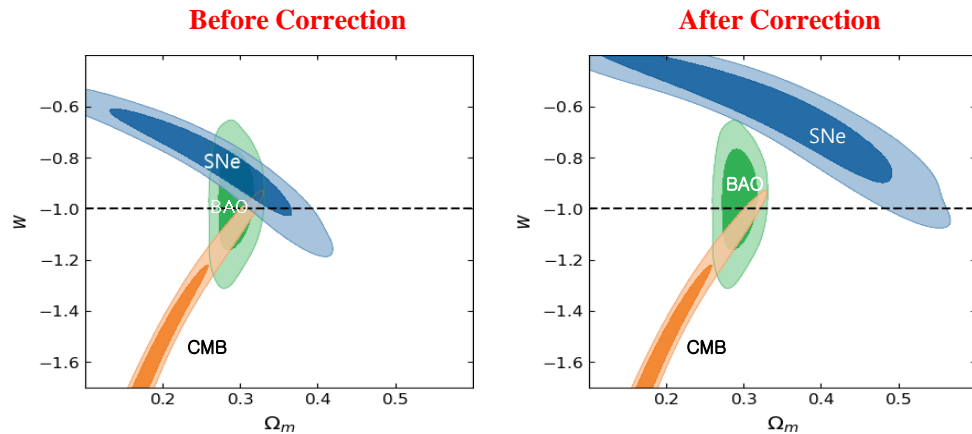
DATA COMBINATION		$\langle w_0 \rangle \pm \text{std}$	$\langle w_a \rangle \pm \text{std}$	$\langle q_0 \rangle \pm \text{std}$
	BAO+CMB	$-0.452 \pm 0.28$	$-1.76 \pm 0.78$	$0.0438 \pm 0.3$
	BAO+CMB+Pantheon+	$-0.831 \pm 0.062$	$-0.724 \pm 0.27$	$-0.362 \pm 0.068$
	BAO+CMB+DES-Y5	$-0.733 \pm 0.068$	$-1.01 \pm 0.3$	$-0.253 \pm 0.71$
	BAO+CMB+Pantheon+ <b>(corrected)</b>	$-0.419 \pm 0.065$	$-1.64 \pm 0.28$	$0.096 \pm 0.065$
	BAO+CMB+DES-Y5 <b>(corrected)</b>	$-0.3 \pm 0.067$	$-1.97 \pm 0.3$	$0.215 \pm 0.065$

# Flat- $w$ CDM model: ‘ $w$ tension’ in cosmology $\rightarrow$ time-varying $w$

2010  
Concordance  
(Amanullah+2010)



2025  
Discordance



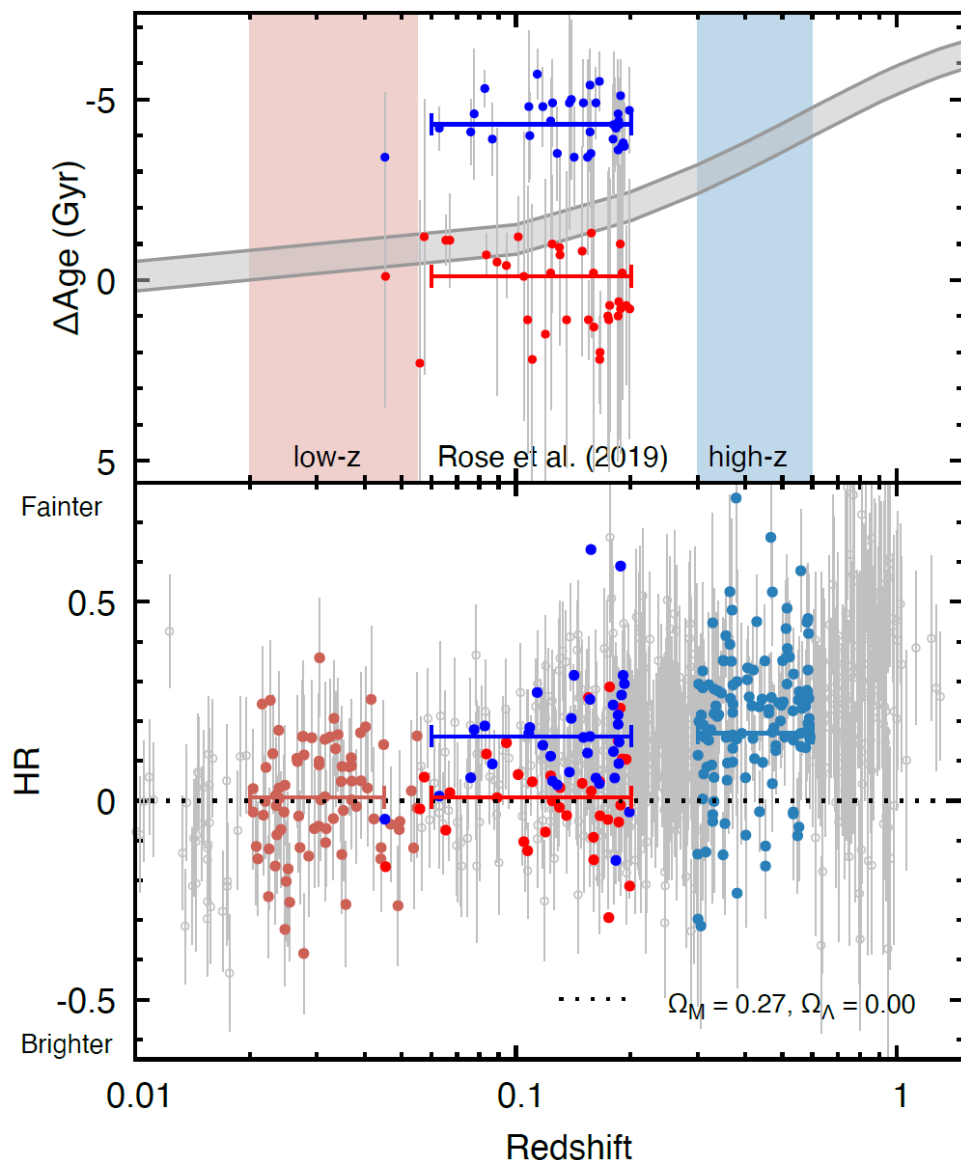
After the age-bias correction, discordance in cosmology!

Dark energy equation of state ( $w = P/\rho$ ) appears increasing from CMB ( $z \sim 1100$ )  $\rightarrow$  BAO ( $0.1 < z < 4$ )

$\rightarrow$  SNe ( $0 < z < 1$ ), **suggesting a time-varying  $w$**

Dark energy equation of state parameter  $w = P/\rho$  (-1 for ‘Cosmological Constant’,  $> -1$  for ‘Quintessence’)  
Data: SNe (DES-Y5 2024), BAO (DESI 2024), CMB (Planck final result 2020)

# Evolution-free cosmological test (use only “young” SNe at low-z)



$\Delta\text{HR}$  between **young** & **old** SNe of Rose+19 at  $z \sim 0.14$  is fully consistent with that between similarly young & old SNe at **high-z** & **low-z**!

→ Observed dimming of SNe with redshift is partially **an artifact of over-correction** in the luminosity standardization for “young” SNe at high- $z$ !

“Evolution-free” test shows no significant dimming!