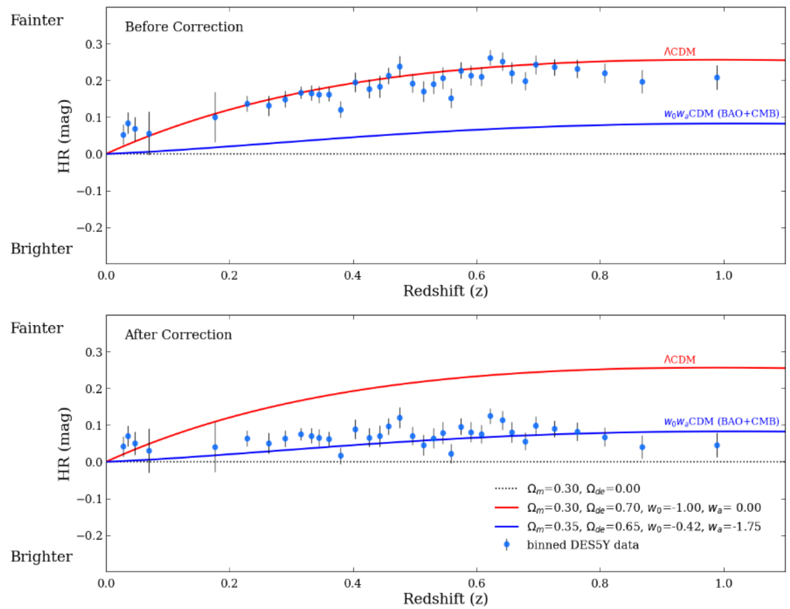
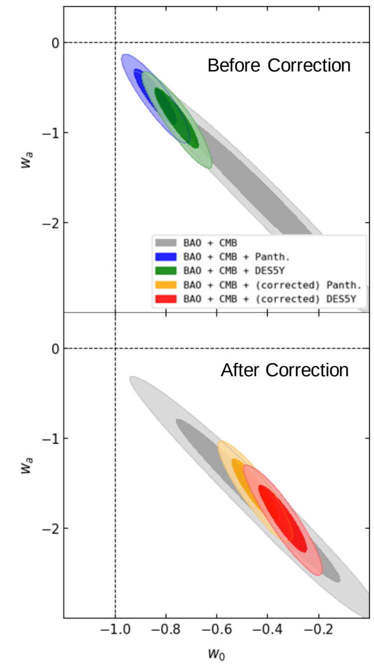
Strong Progenitor Age Bias in Supernova Cosmology:

Alignment with DESI BAO & signs of a non-accelerating universe





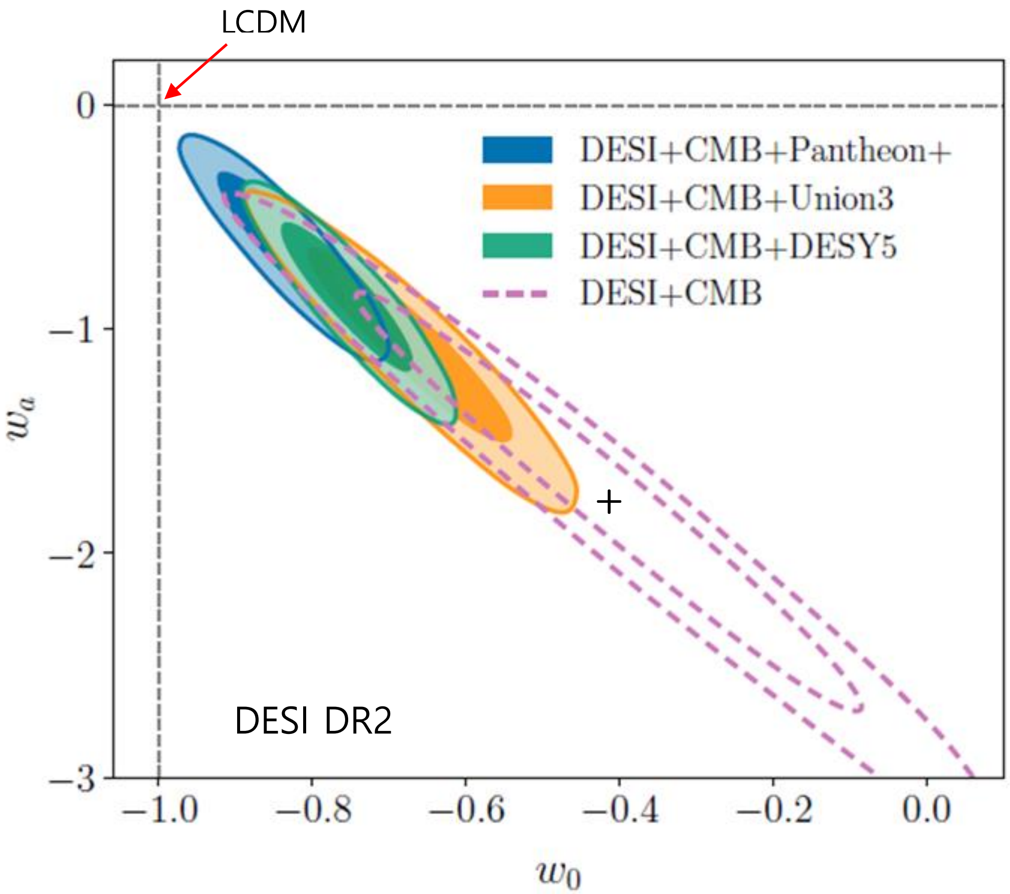
Young-Wook Lee, Chul Chung, Junhyuk Son,
Seunghyun Park, Hyejeon Cho, Young-Lo Kim

Yonsei University, Seoul, South Korea

핵/입자/천체물리 공동 워크샵_20251120

DESI BAO (2024, 2025) suggests $w_o w_a$CDM model

Time-varying dark energy EoS



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

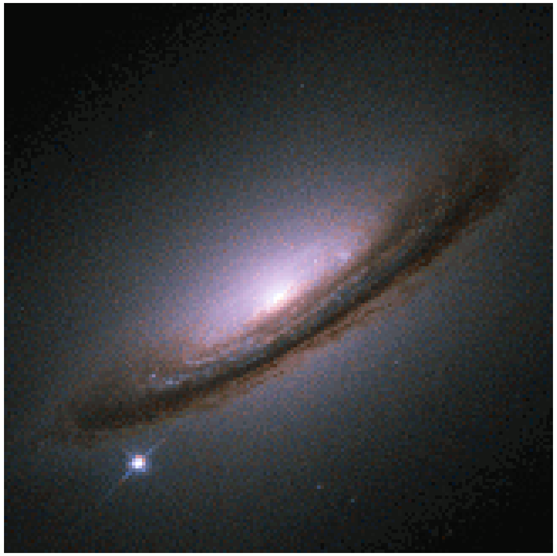
Most extensively discussed model in DESI papers is from a combined analysis of BAO+CMB+SN.

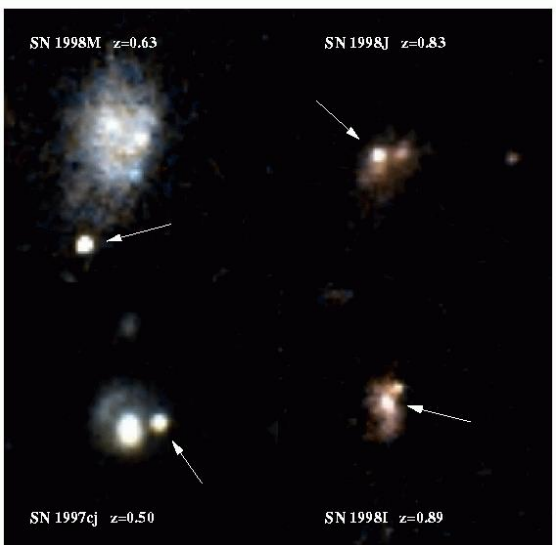
The result from BAO-only or from BAO+CMB alone are significantly different and predict a decelerating Universe! (w_o = -0.42, q_o = +0.092)

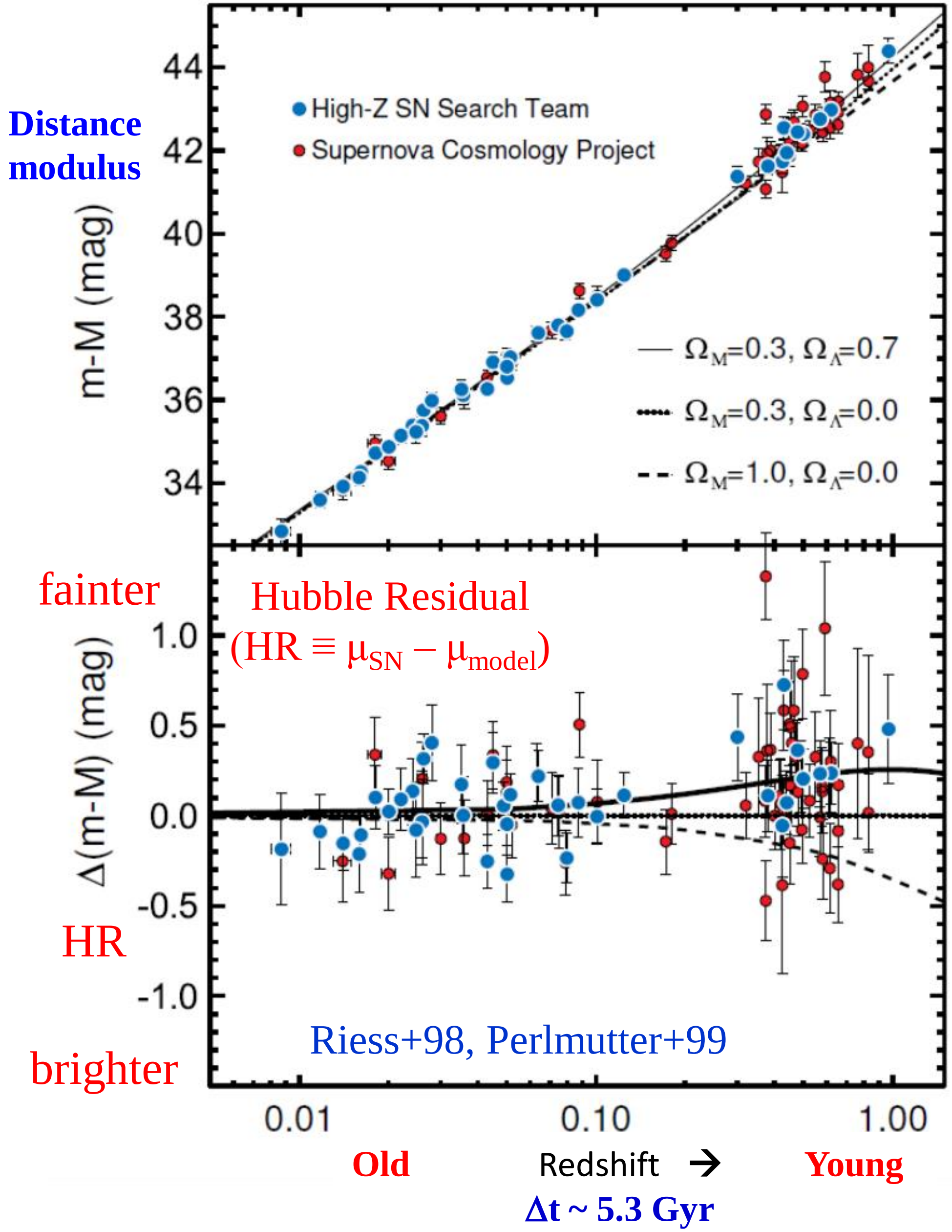
→ a discordance between BAO and SNe

We found that the problem is with SN cosmology!

Accelerating Universe or Luminosity Evolution?

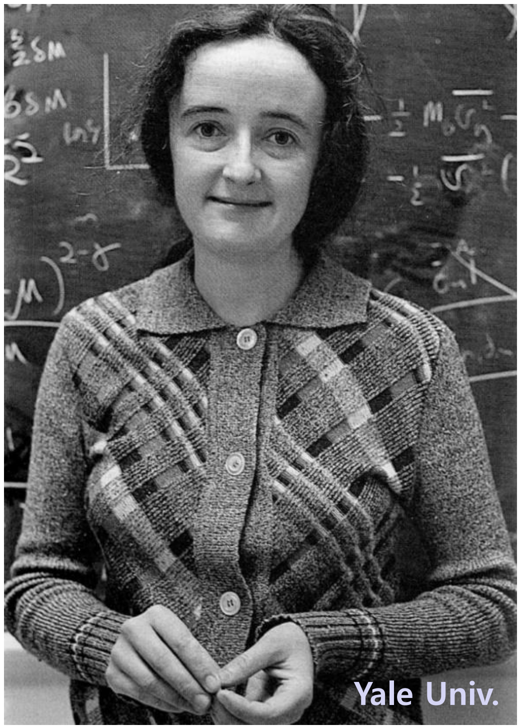






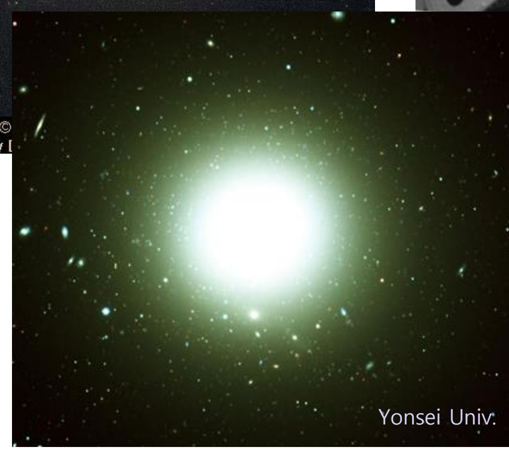
Sandage's mistake discovered by Tinsley:

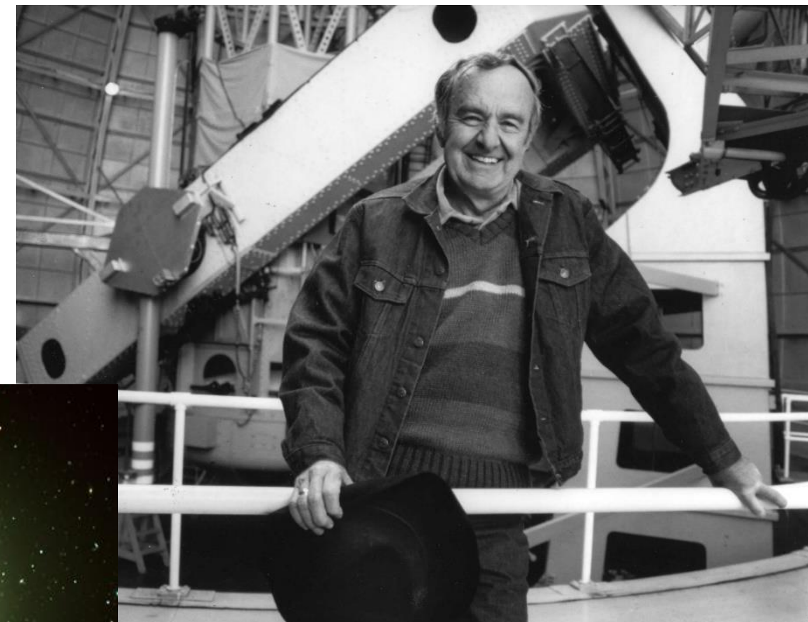
Significant luminosity evolution in observational cosmology



Beatrice Tinsley (1968, 1972)

Theoretical approach





Allan Sandage

Empirical approach

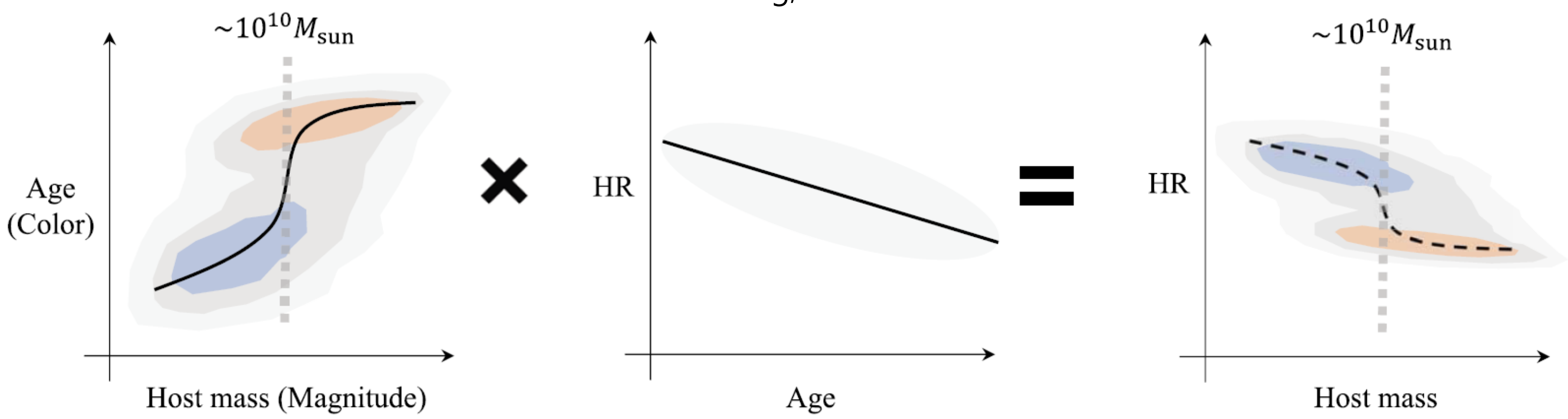
Luminosity evolution underestimated by Sandage →

distance underestimated → incorrect cosmology proposed!

Correlation between SN magnitude and host mass

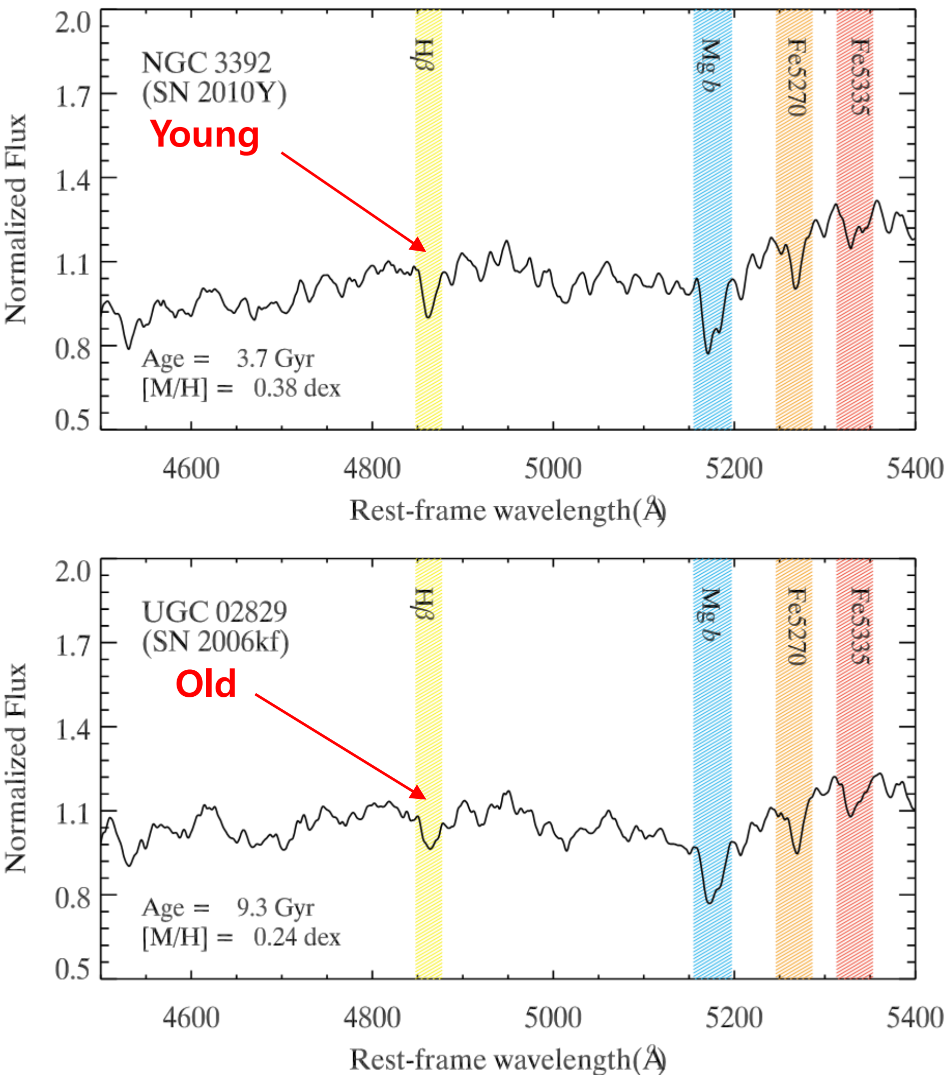
- Host mass step correction is routinely applied to the SN distance scale.
- However, host mass cannot directly affect SN in it, so the root cause of the mass step must be something else closely related to host mass, such as progenitor age (Sullivan+2010; Kelly+2010; Childress+2014; Pan+2014; Kang+2016;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

Chung, Lee+2023

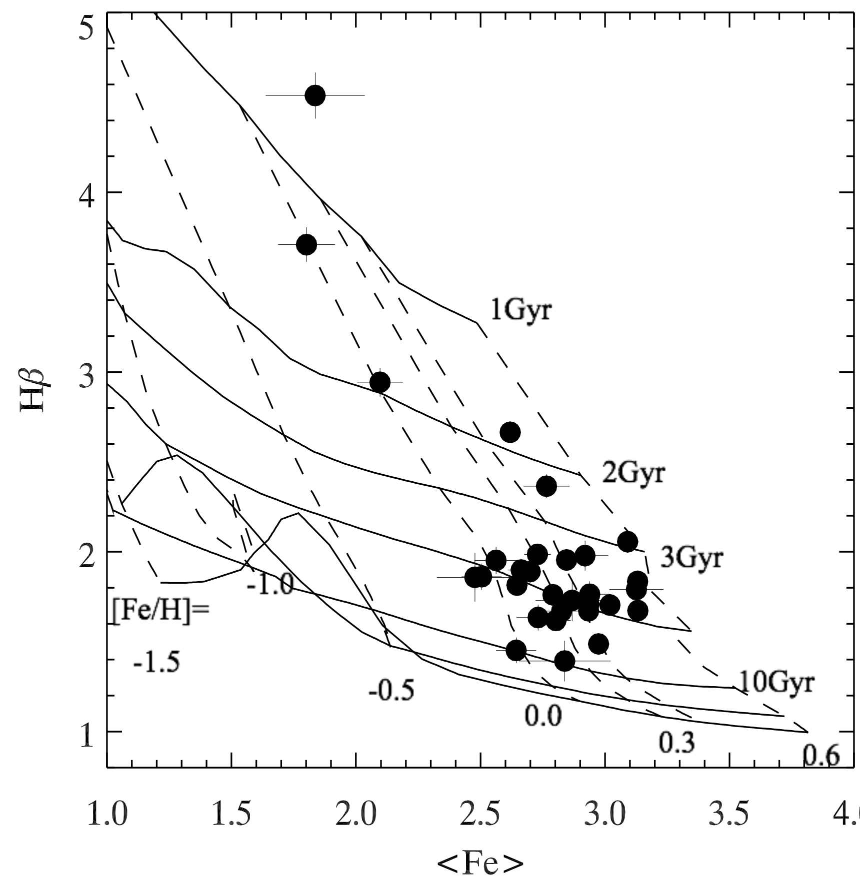


Project YONSEI: Yonsei Nearby Supernovae Evolution Investigation

High Precision (S/N ~175) Spectroscopic Age Measurement of Early-type Host Galaxies & Photometric Age Dating of All Host Galaxies @ All Redshifts (since 2010)



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

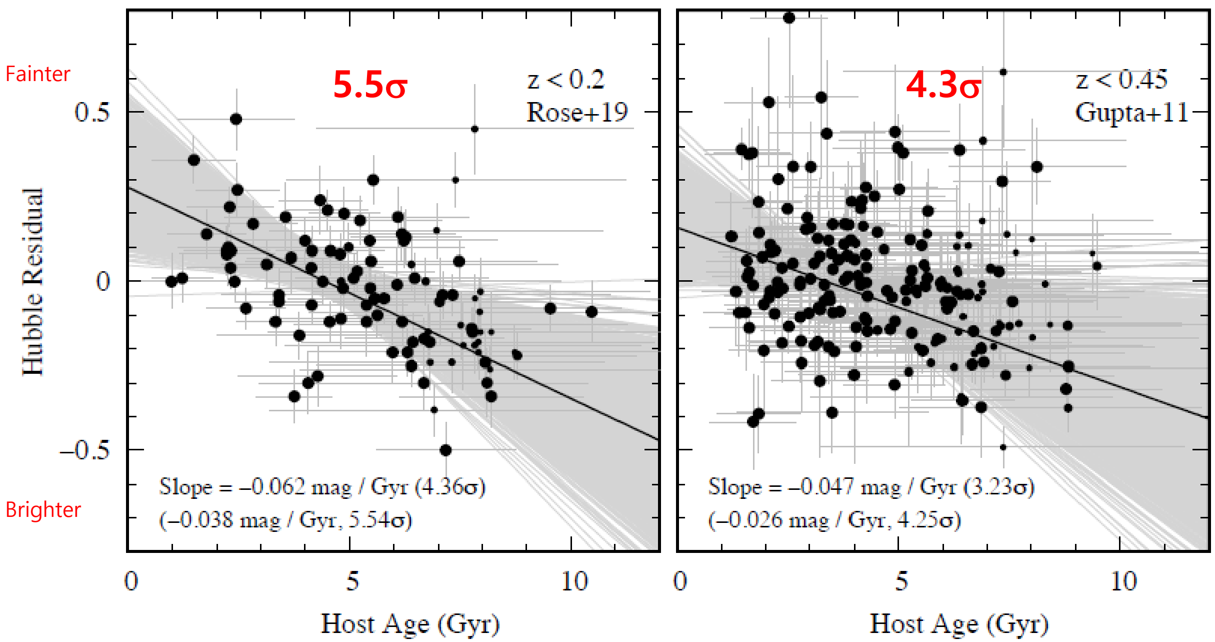


Population Synthesis Models:

Chung+13 (Yonsei); Thomas+11; Schiavon 07

Evidence for progenitor age-bias is robust

Repeatedly confirmed by us & third parties (~7σ)



Spectroscopy: Kang+2020 (ETGs, S/N = 175!, **~3σ**)

Photometry: Lee+2020 (Rose+19 sample, LTGs+ETGs, **4.3σ**)

Third party confirmation: Zhang+2021, Wang+2023 (**5–7σ**)

New age measurements (Chung+2025): a larger sample (N ~ 300) of host galaxies in a broader redshift range (z < 0.45) confirm the ubiquitous nature of this bias (**5.5 & 4.3σ → 7σ**)

Average of 3 samples

Slope = 0.030 +/-0.004 mag/Gyr

(utilizing full posterior for age)

→ 7σ

Type Ia SNe

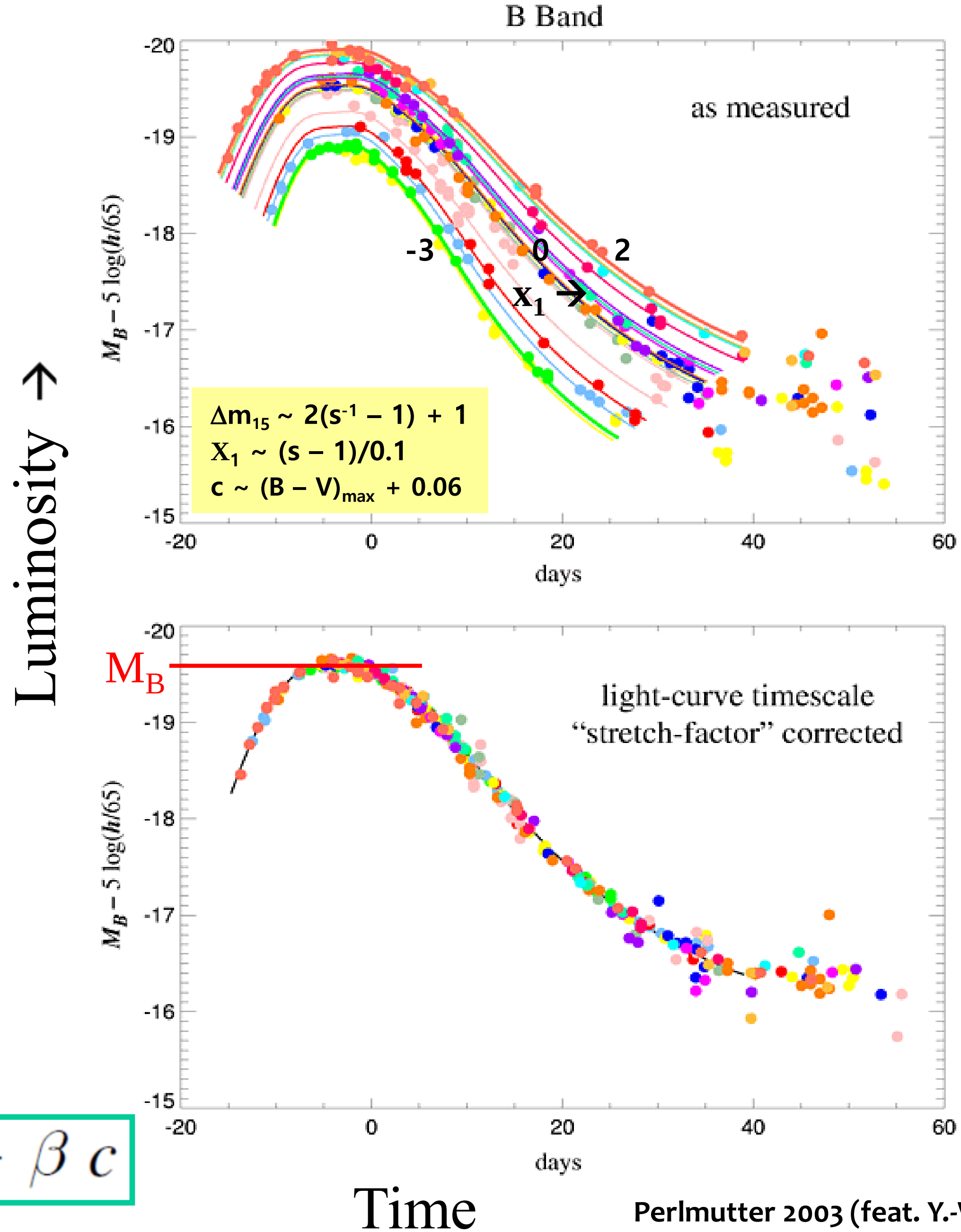
"Standardizable" Candle:

Peak luminosity = f(light-curve width, color)

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

Assume no evolution with z
(progenitor age)

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



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

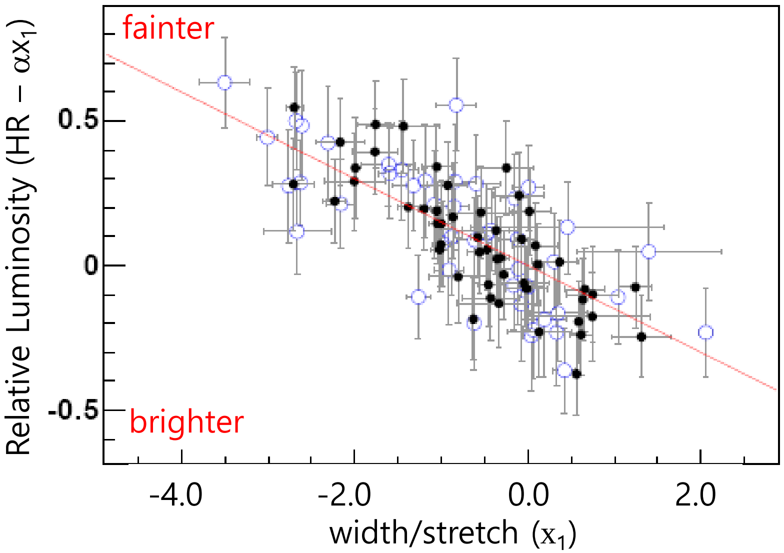
The Key Assumption & Requirement in Supernova Cosmology

"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."

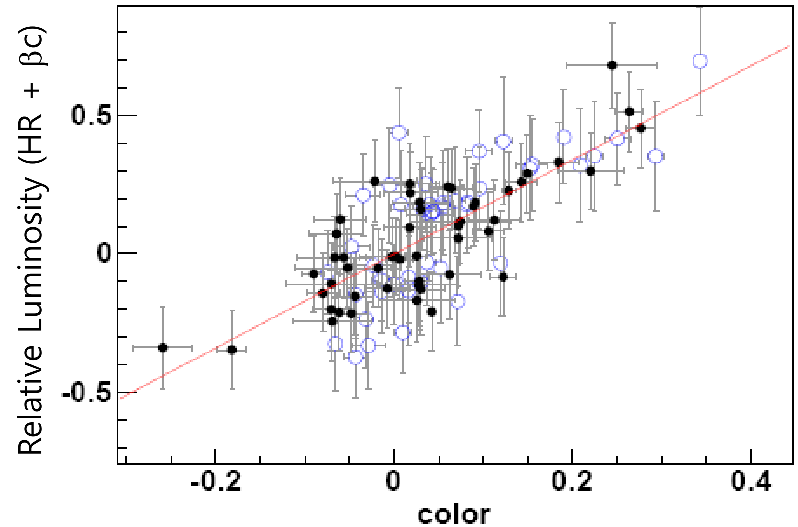
Jha, Maguire, & Sullivan 2019, Nature Astronomy

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

$\boxed{\mathcal{M}_B,\ \alpha \text{ and } \beta \text{ fitted at the same time as cosmology.}}$



Width – Luminosity relation (WLR)
(Phillips relation)

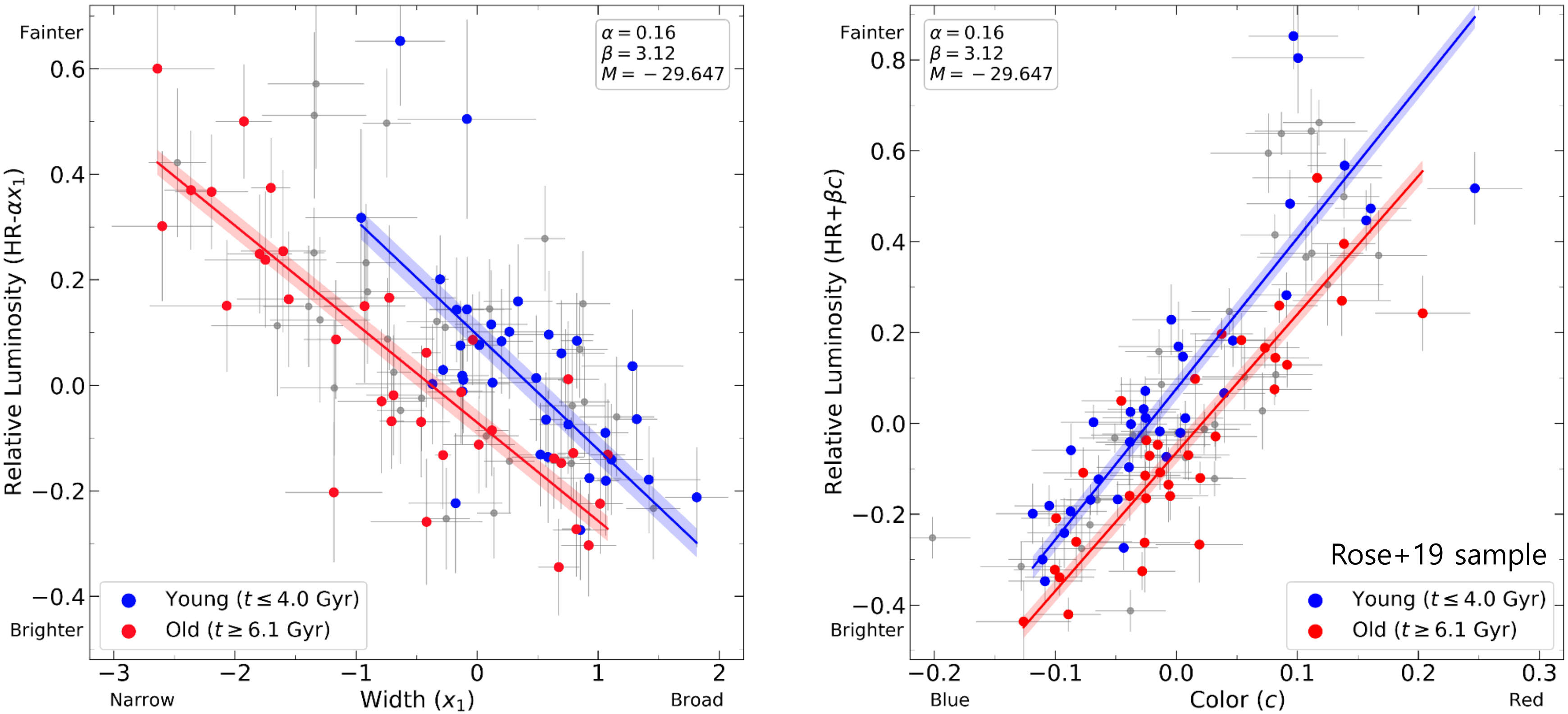


Color – Luminosity relation (CLR)

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

Origin of progenitor age bias:

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



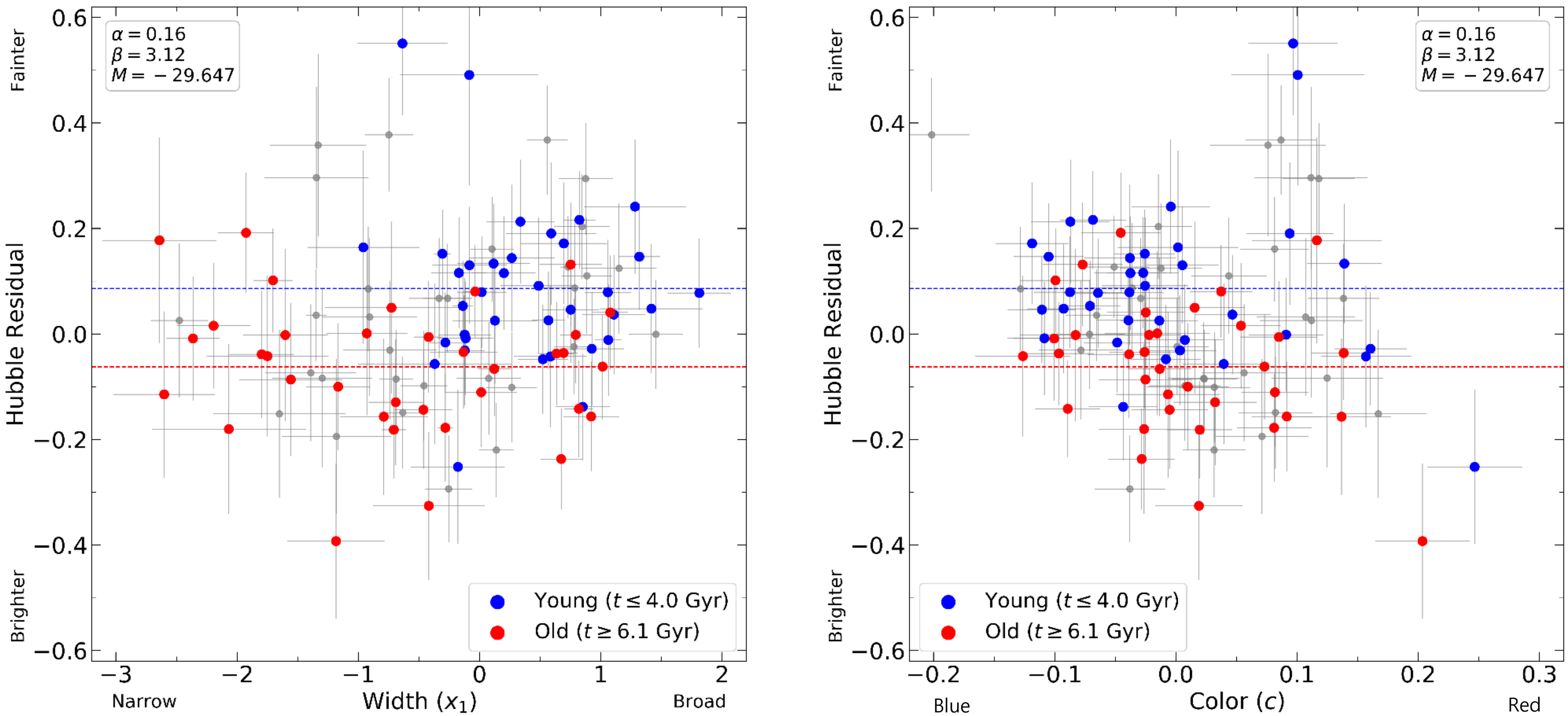
$$\boxed{\mu = m_B - M + \alpha\, x_1 - \beta\, c}$$

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

Other host properties, such as host mass & metallicity, show only insignificant (~1σ) offsets

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

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

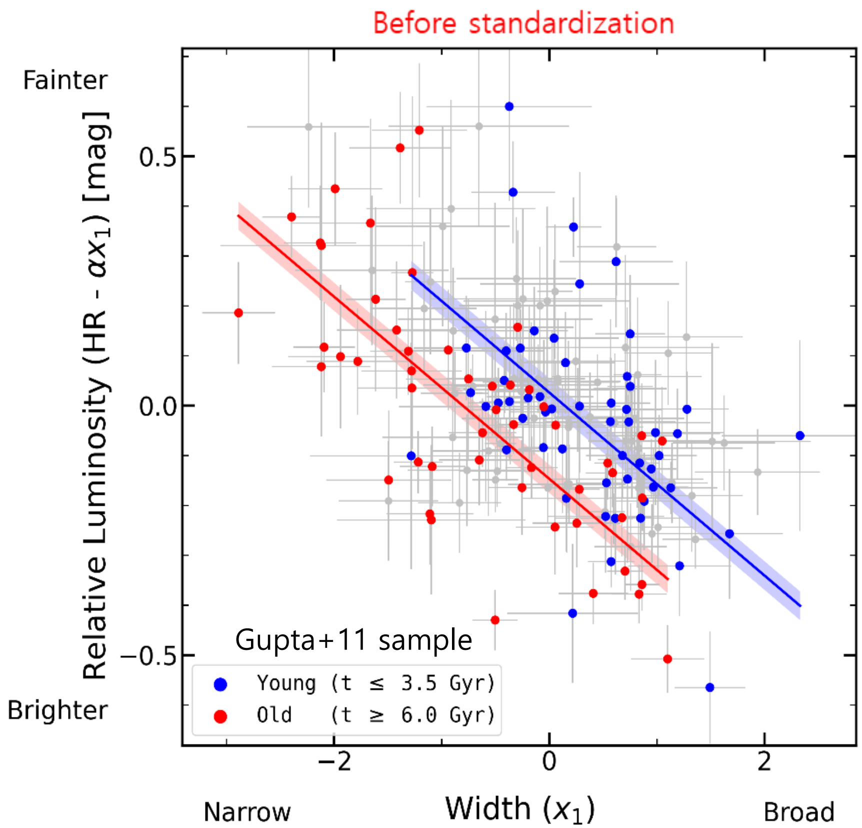


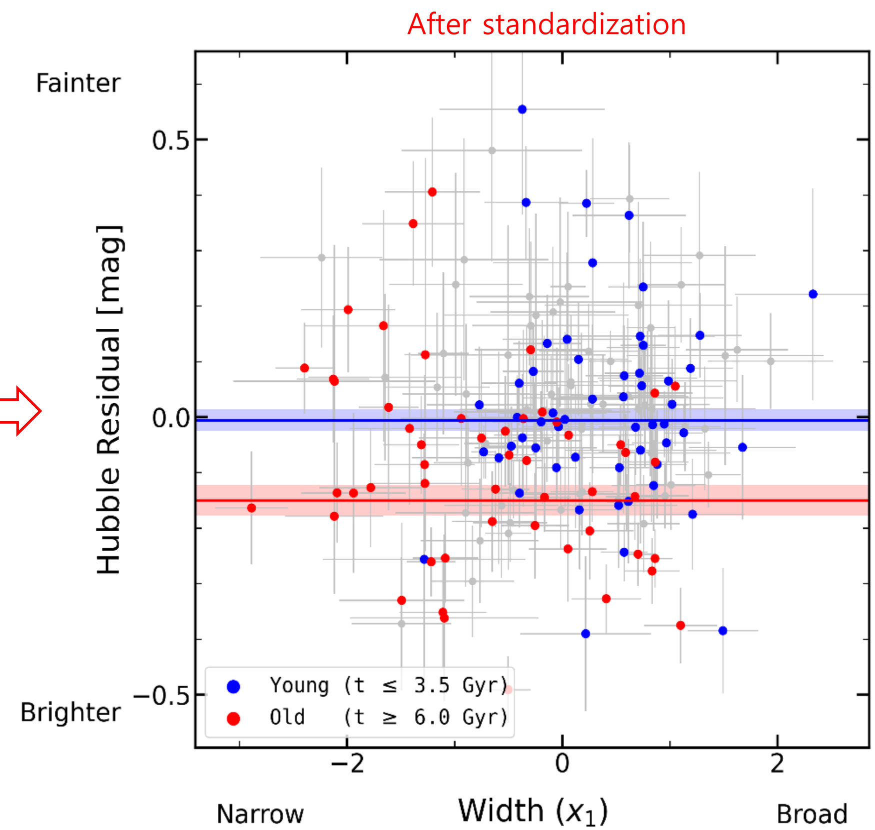
$$\boxed{\mu = m_B - M + \alpha\, x_1 - \beta\, c}$$

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

A similar result from Gupta+2011 sample at z < 0.45





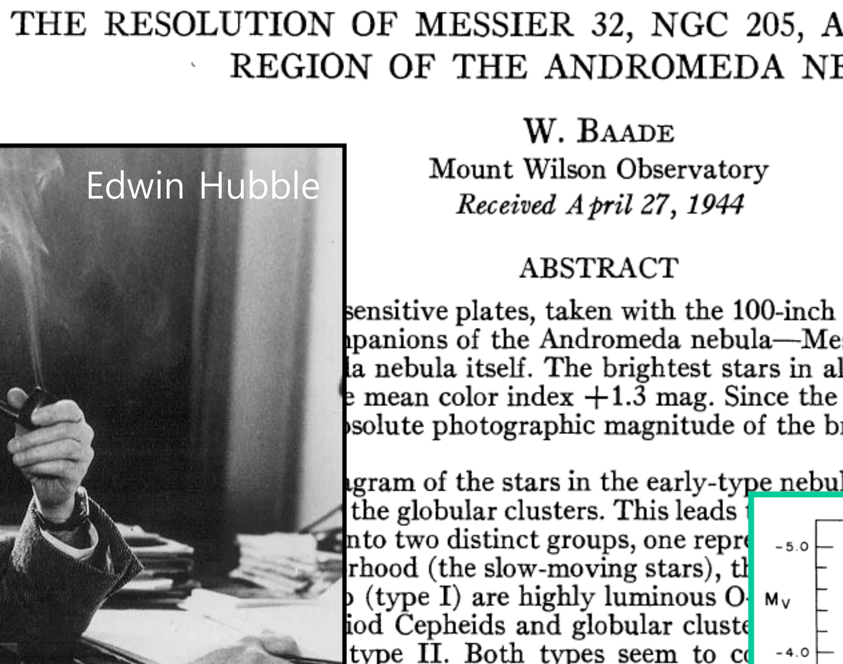
$$\boxed{\mu = m_B - M + \alpha\, x_1 - \beta\, c}$$

SNe from younger progenitors are fainter each at given x_1 and c (4.3σ result)

Other host properties, such as host mass, exhibit less significant ($< 2.9\sigma$) offsets

Park, Lee et al. 2025, in prep.

Hubble's mistake discovered by Baade

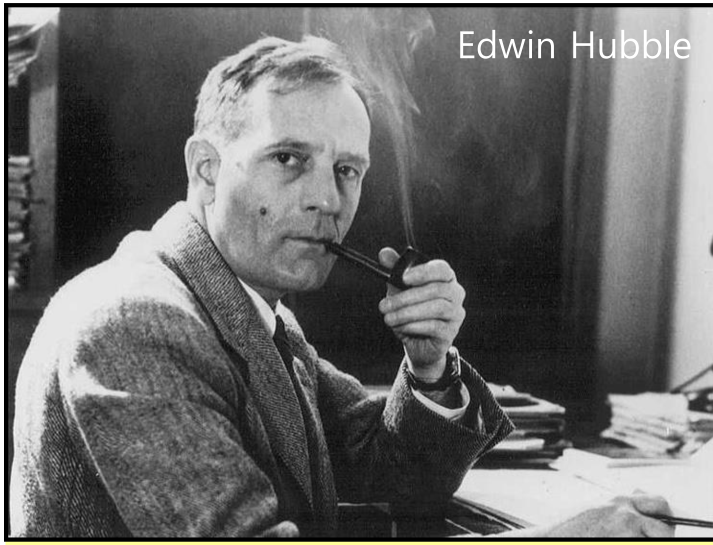

THE RESOLUTION OF MESSIER 32, NGC 205, AI
REGION OF THE ANDROMEDA NE

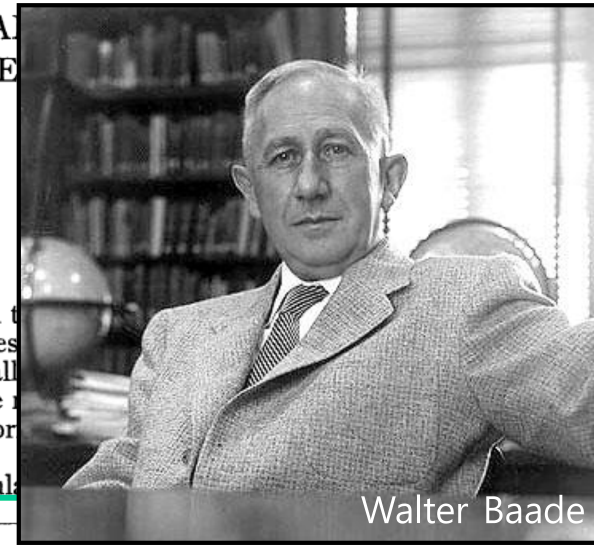
W. BAADE
Mount Wilson Observatory
Received April 27, 1944

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 r
bsolute photographic magnitude of the br

agram of the stars in the early-type nebula
the globular clusters. This leads t
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

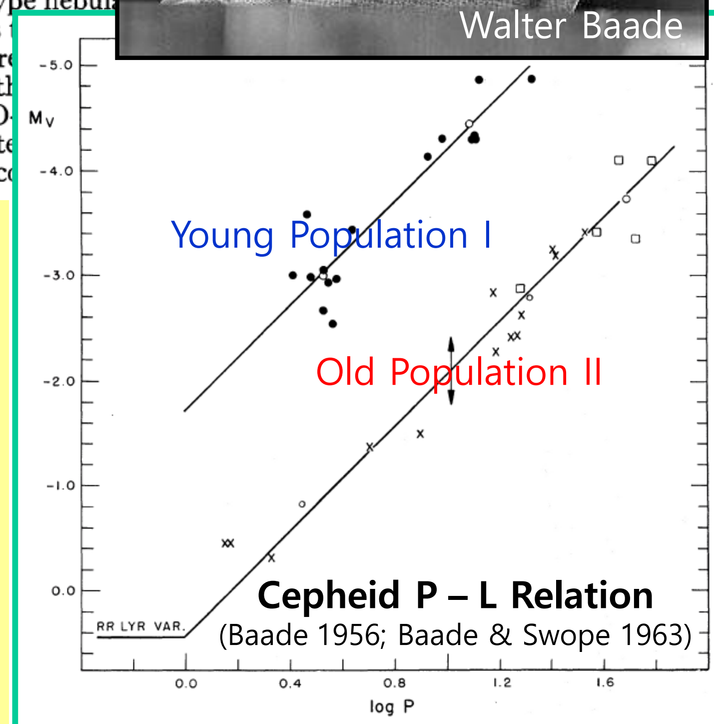




Young Pop. I Cepheids that Hubble discovered in M31 are brighter than old Pop. II counterparts based on which Hubble mistakenly calibrated his observations.

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

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

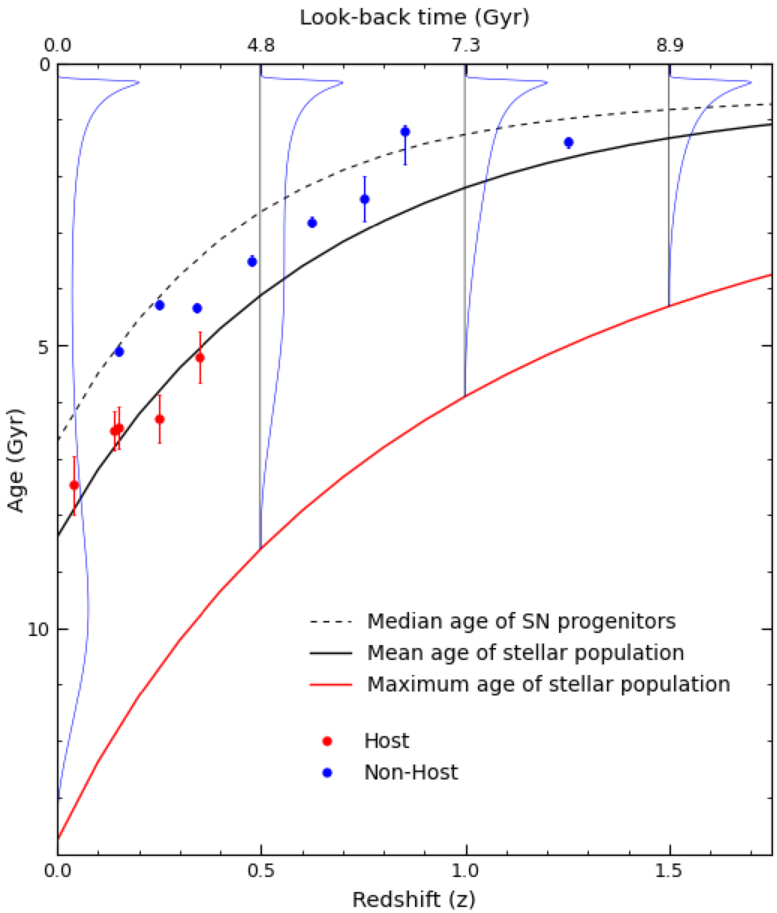


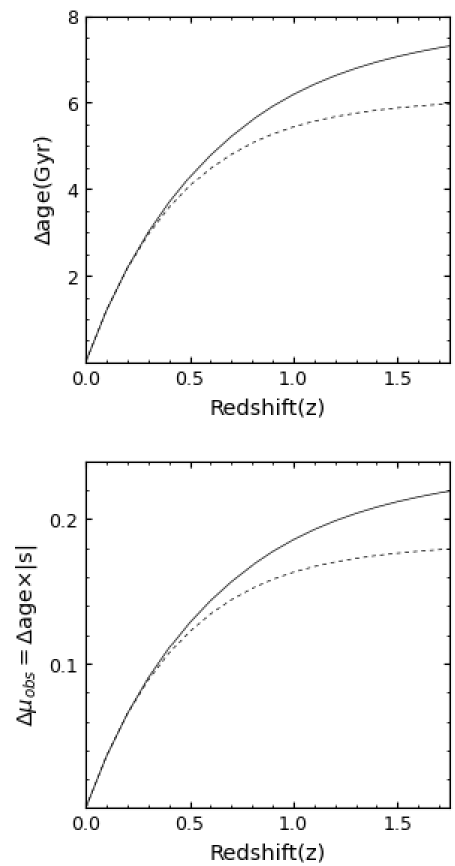
Cepheid P – L Relation
(Baade 1956; Baade & Swope 1963)

Redshift Evolution of Supernova Progenitor Age Distribution

DESI BAO + CMB wowaCDM model (Abdul Karim et al. 2025):

$$H_0 = 64\ \mathrm{kms^{-1}Mpc^{-1}}, \Omega_m = 0.35, \Omega_{DE} = 0.65, w_0 = -0.42, w_a = -1.75$$





SN Progenitor Age Distribution (SPAD)

= Delay Time Distribution (DTD) x Cosmic SFH

(Childress+2014)

Mean population age & progenitor age get younger with z:

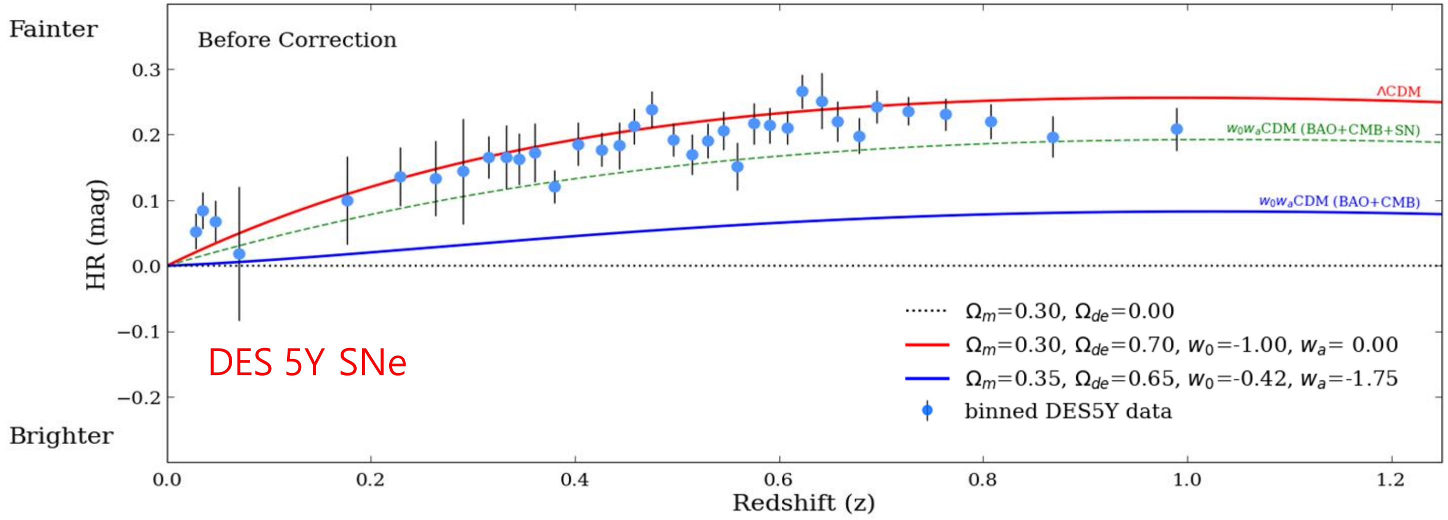
Δt ~ 5.3 Gyr (0 < z < 1)

→ ~0.16 mag

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

Y.-W. Lee et al. 2022, Son et al. 2025

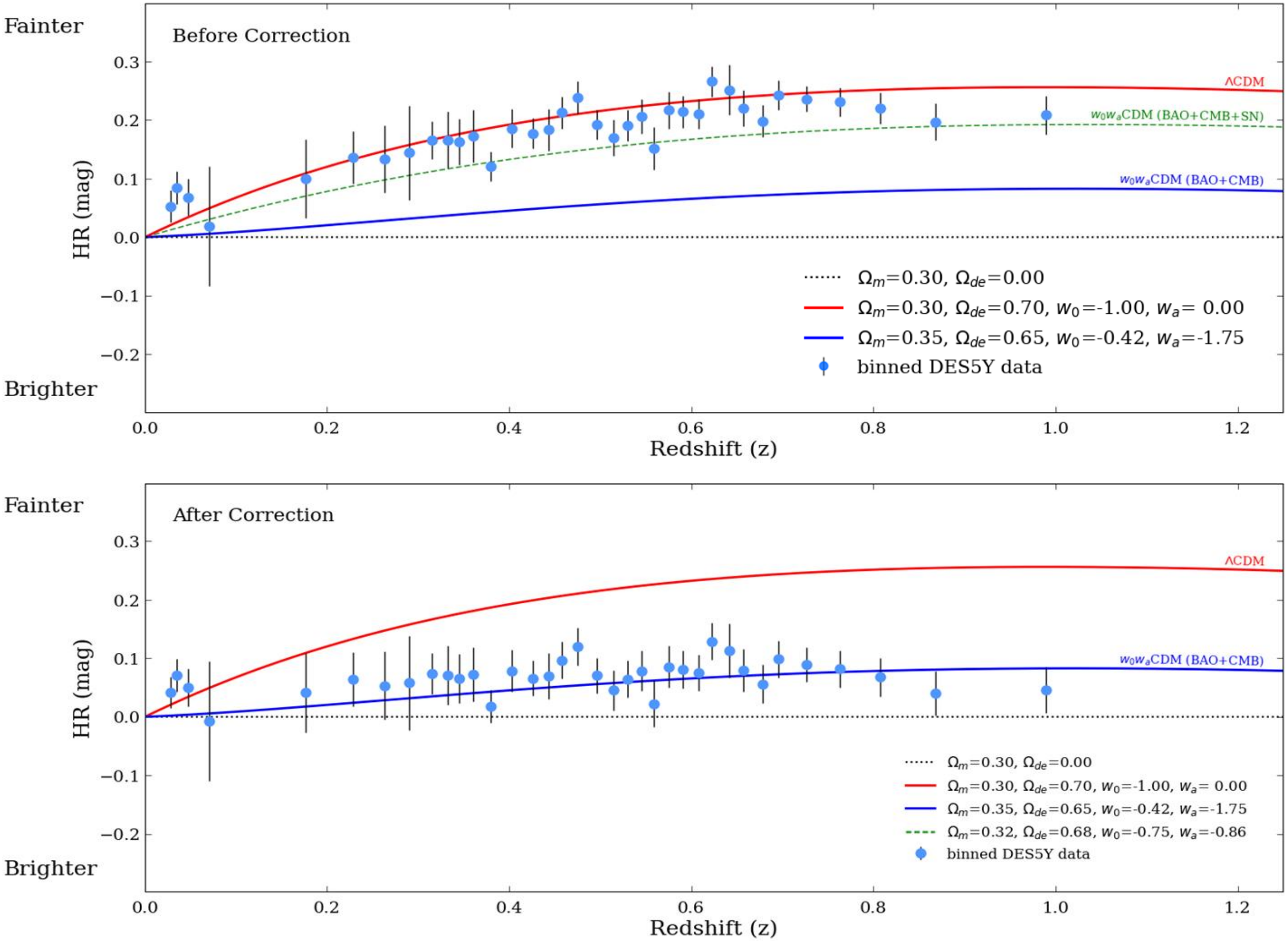
The observed dimming of high-z SNe is partially attributable to the redshift evolution of progenitor age



A correction is required to remove the effect of age bias in order to isolate the purely cosmological signal

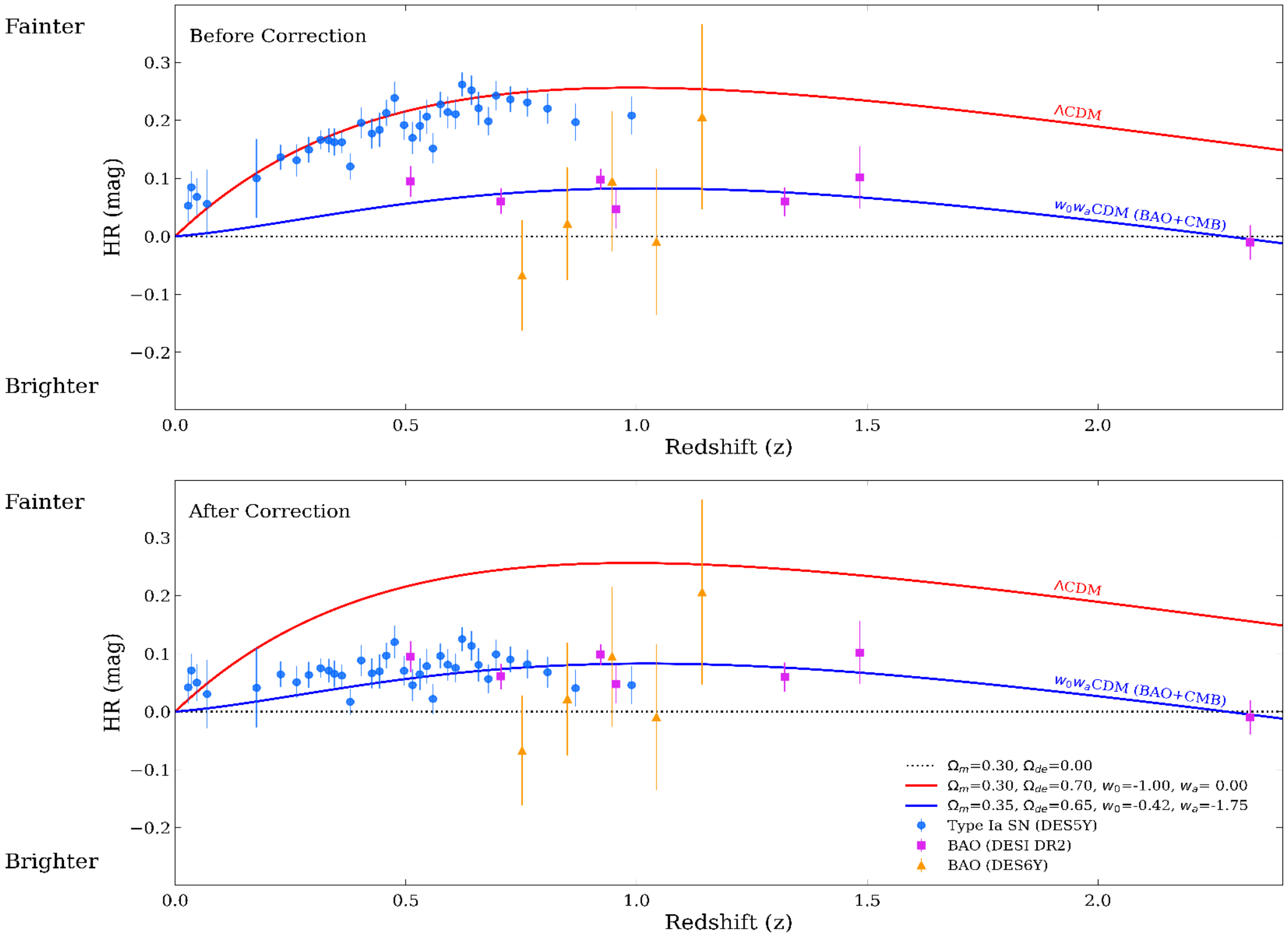
Son, Lee et al. 2025, in press

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



Son, Lee et al. 2025, in press

In the same $w_o w_a$CDM model favored by DESI BAO+CMB alone, corrected SN distances align well with BAO distances



For a self-consistent comparison, we adopt $r_d h$ = 94 Mpc from the same $w_o w_a$CDM model suggested by DESI BAO+CMB (Abdul Karim et al. 2025)

Son, Lee et al. 2025, in press

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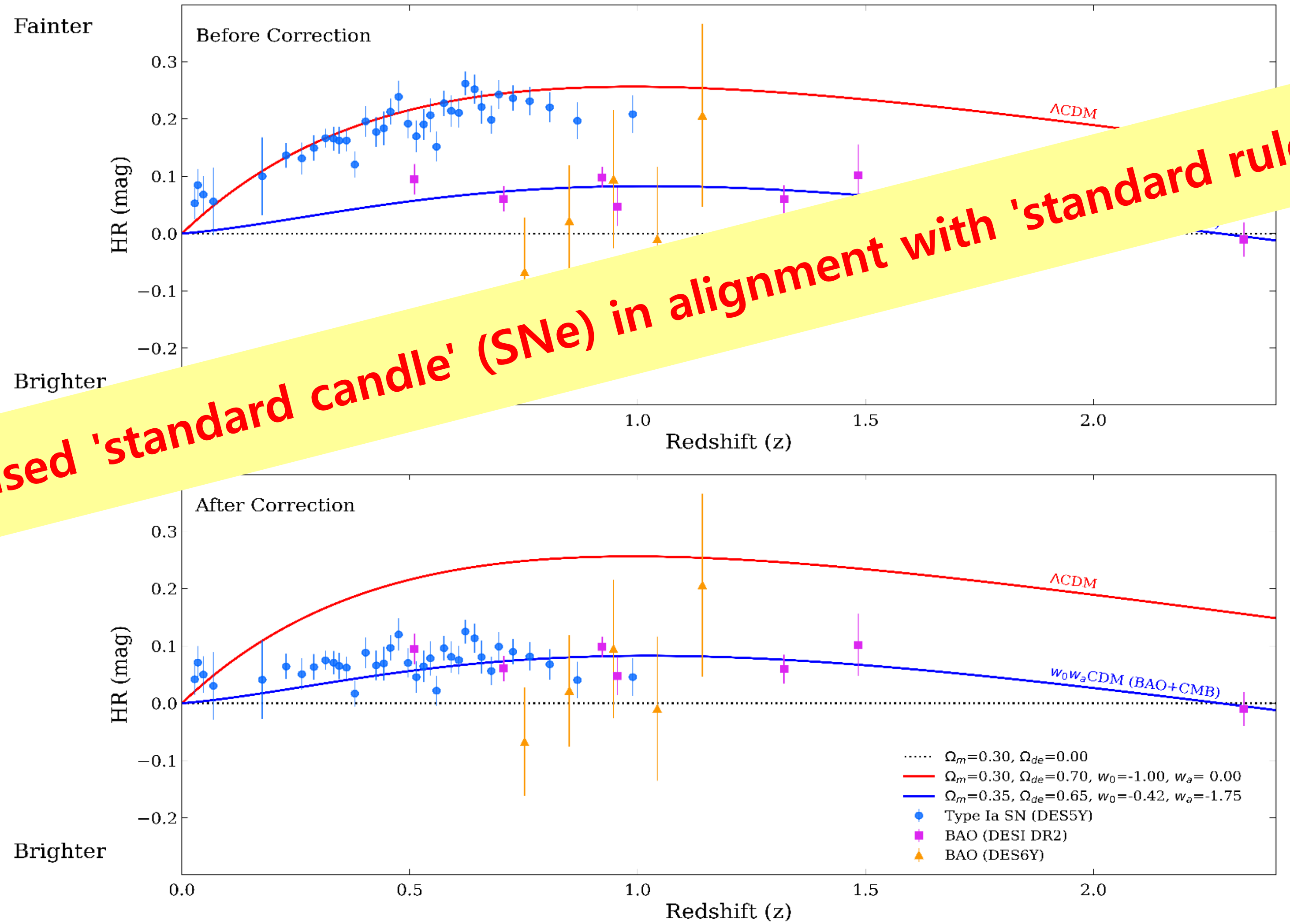


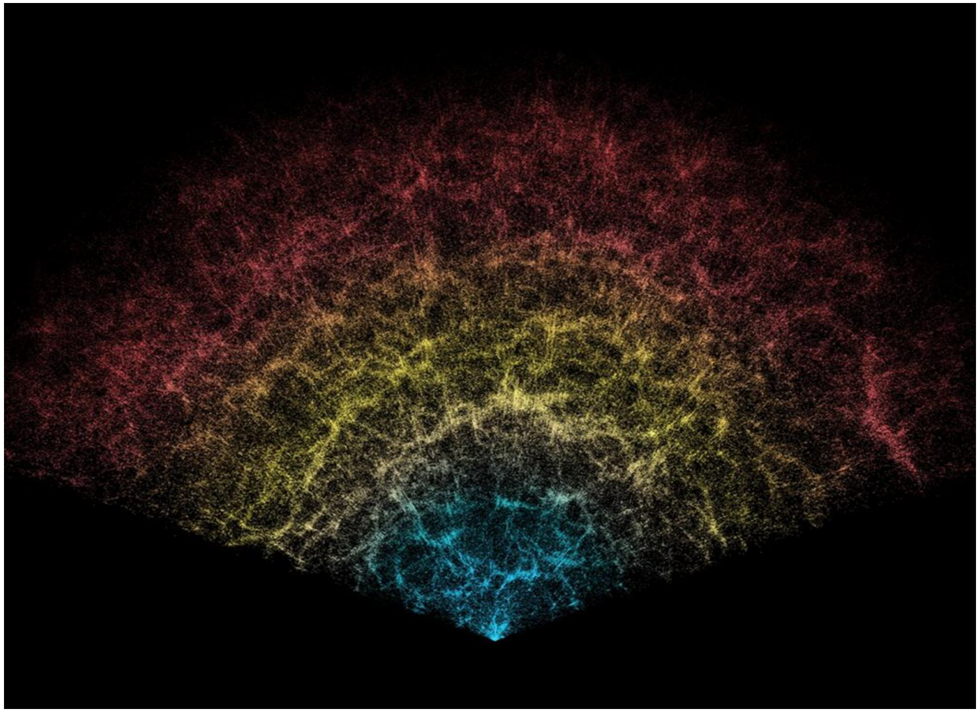
Revised 'standard candle' (SNe) in alignment with 'standard ruler' (BAO)

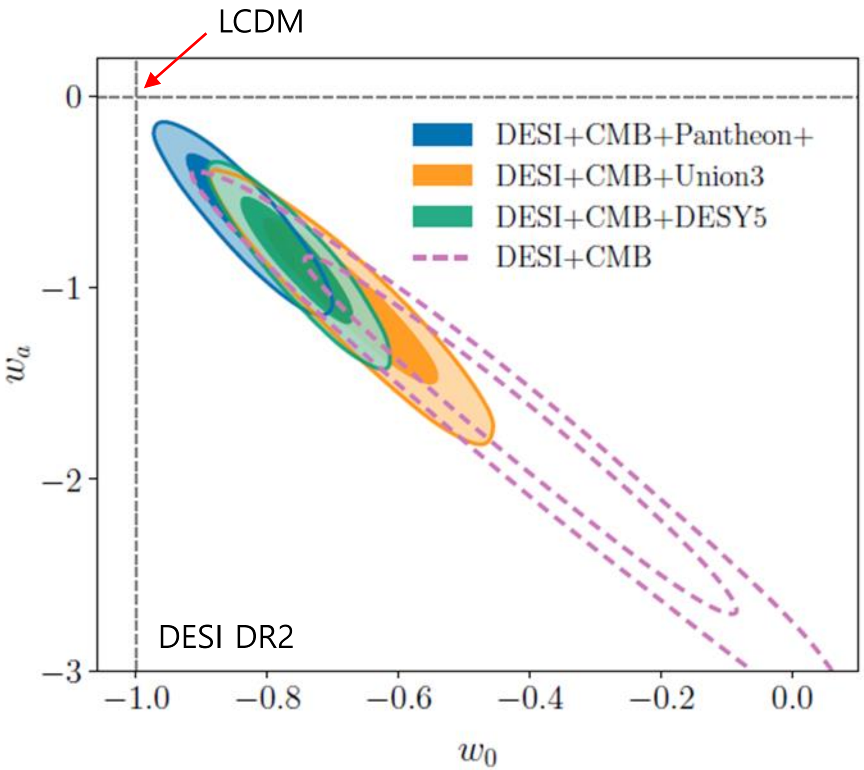
For a self-consistent comparison, we adopt $r_d h$ = 94 Mpc from the same $w_o w_a$CDM model suggested by DESI BAO+CMB (Abdul Karim et al. 2025)

Son, Lee et al. 2025, in press

DESI BAO (2024, 2025) suggests $w_o w_a$CDM model

Time-varying dark energy EoS





Dark energy equation of state (EoS):

Constant

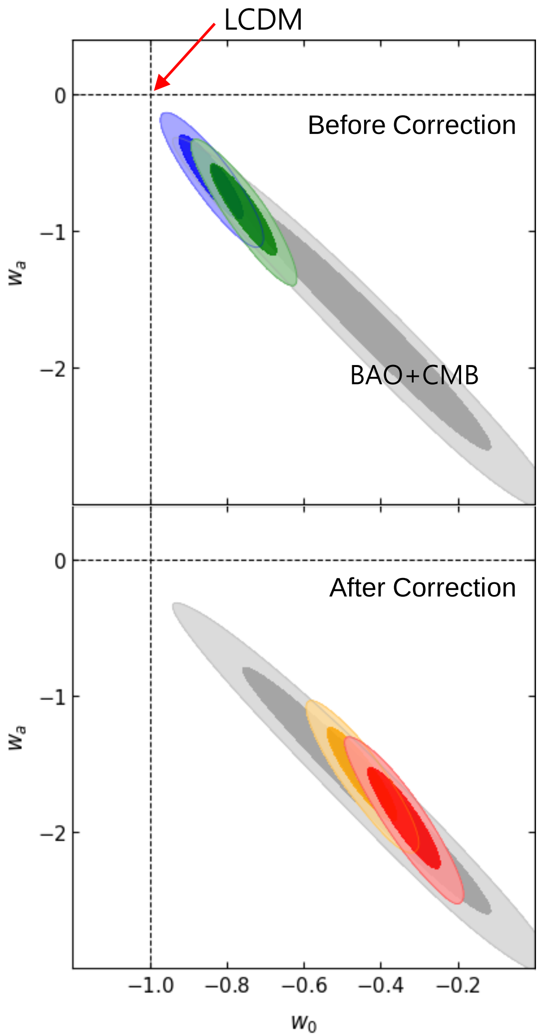
$$\boxed{w \equiv \frac{p_{\rm de}}{\rho_{\rm de}}}$$

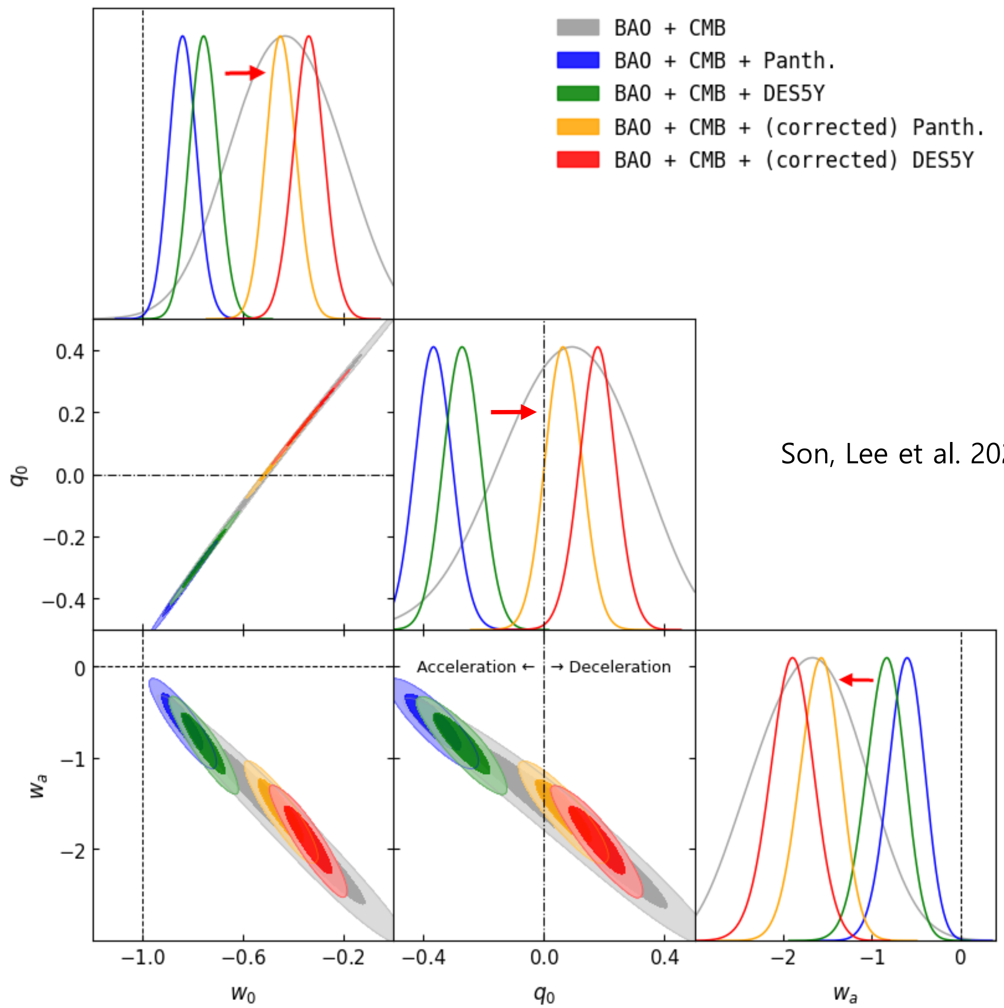
Time-varying

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

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

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





Son, Lee et al. 2025, in press

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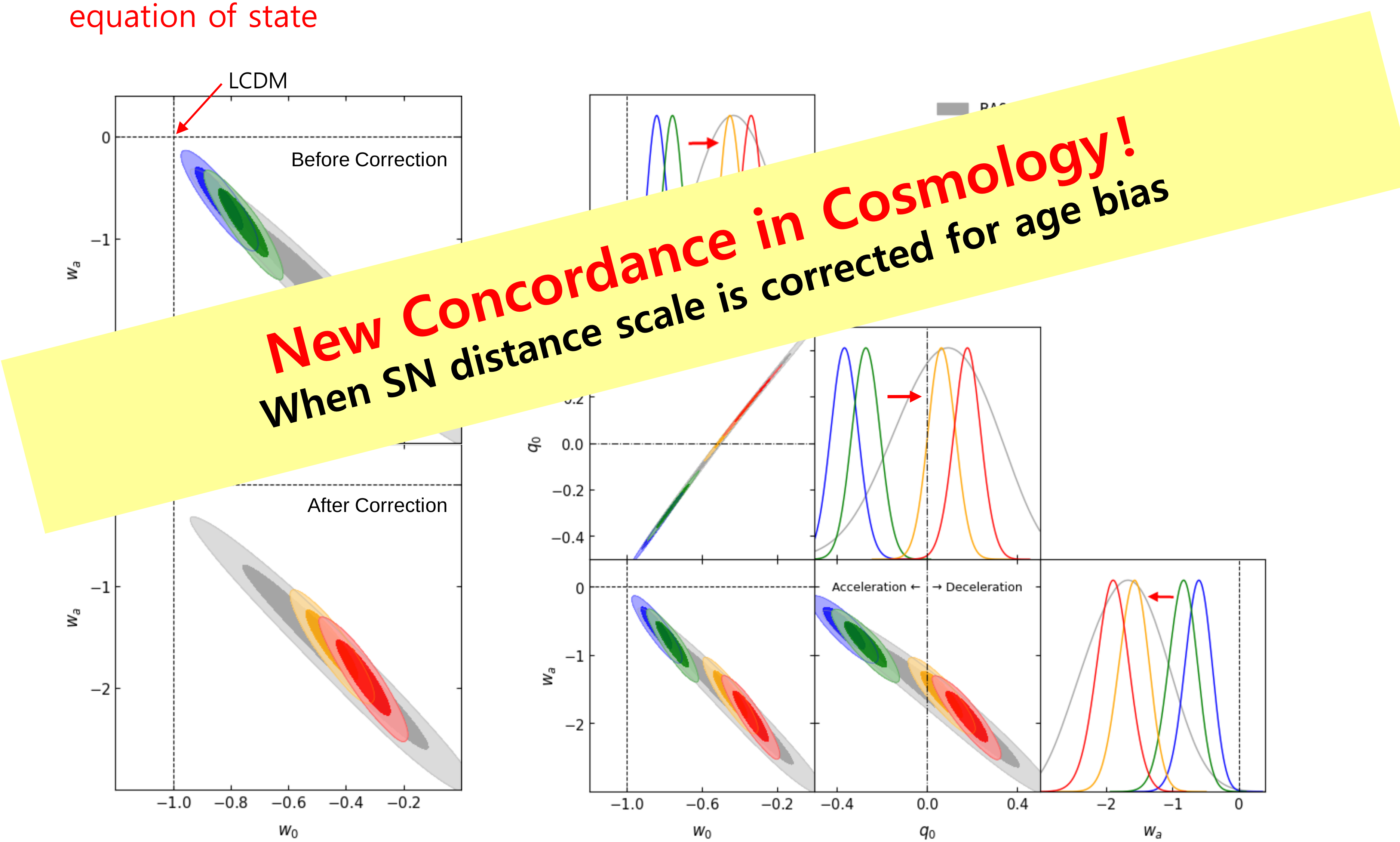
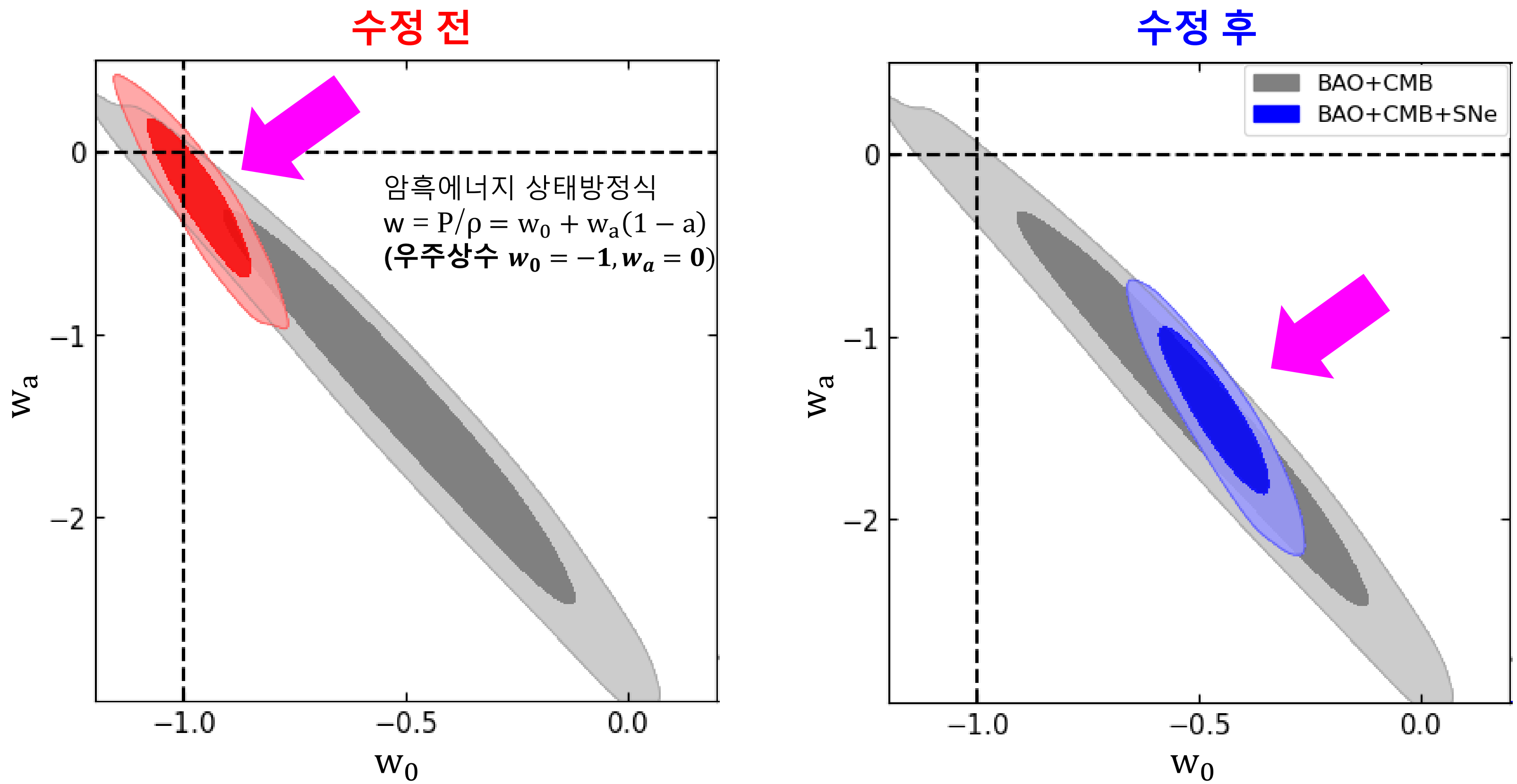


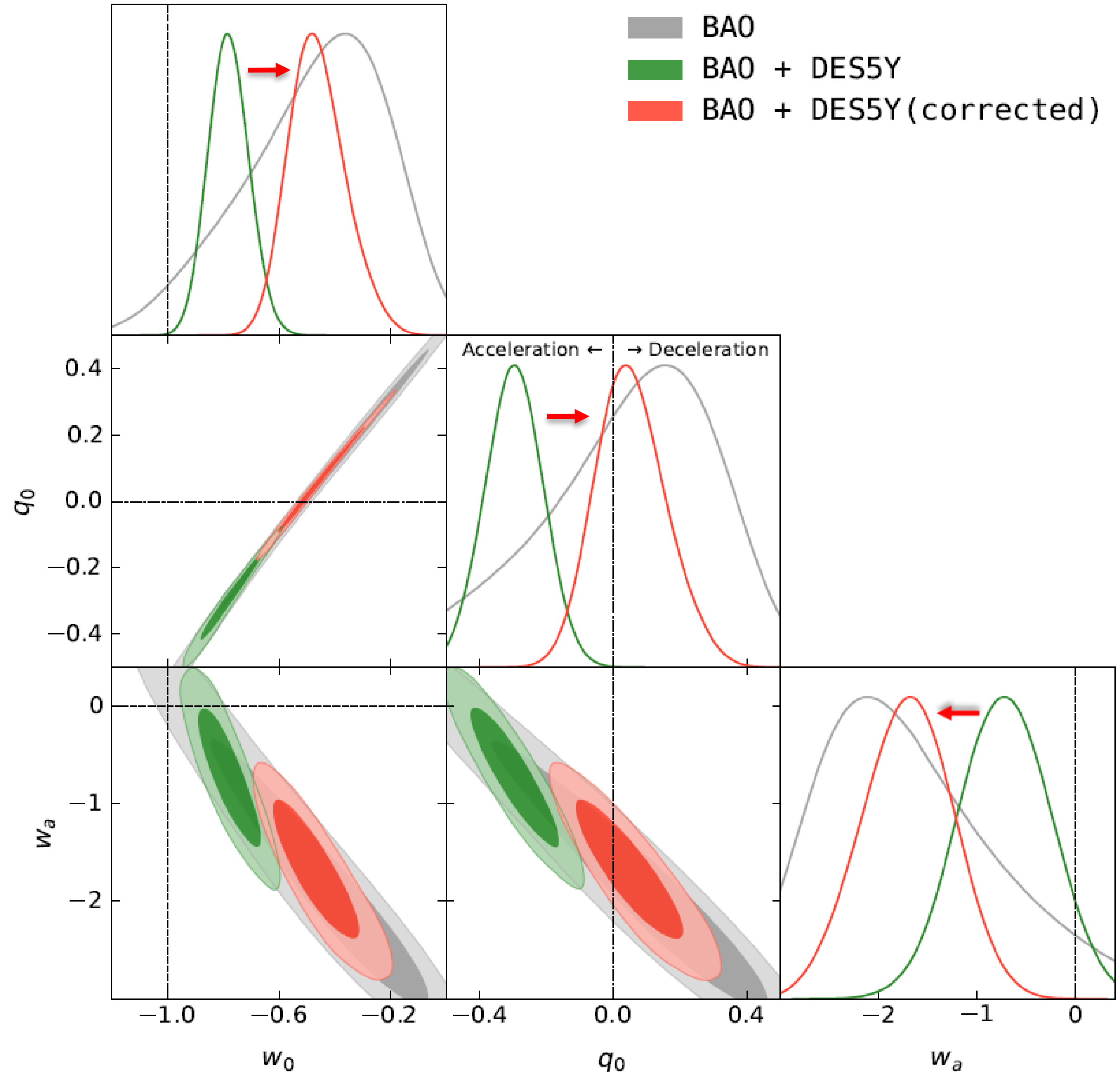
시간에 따라 변하는/약해지는 암흑에너지 모델 ($w_0 w_a$CDM)

SDSS BAO data 도 이미 유사한 결과를 보였음

(DESI BAO 발표 5개월 전, 2023년 12월 손준혁 박사자격시험 발표)

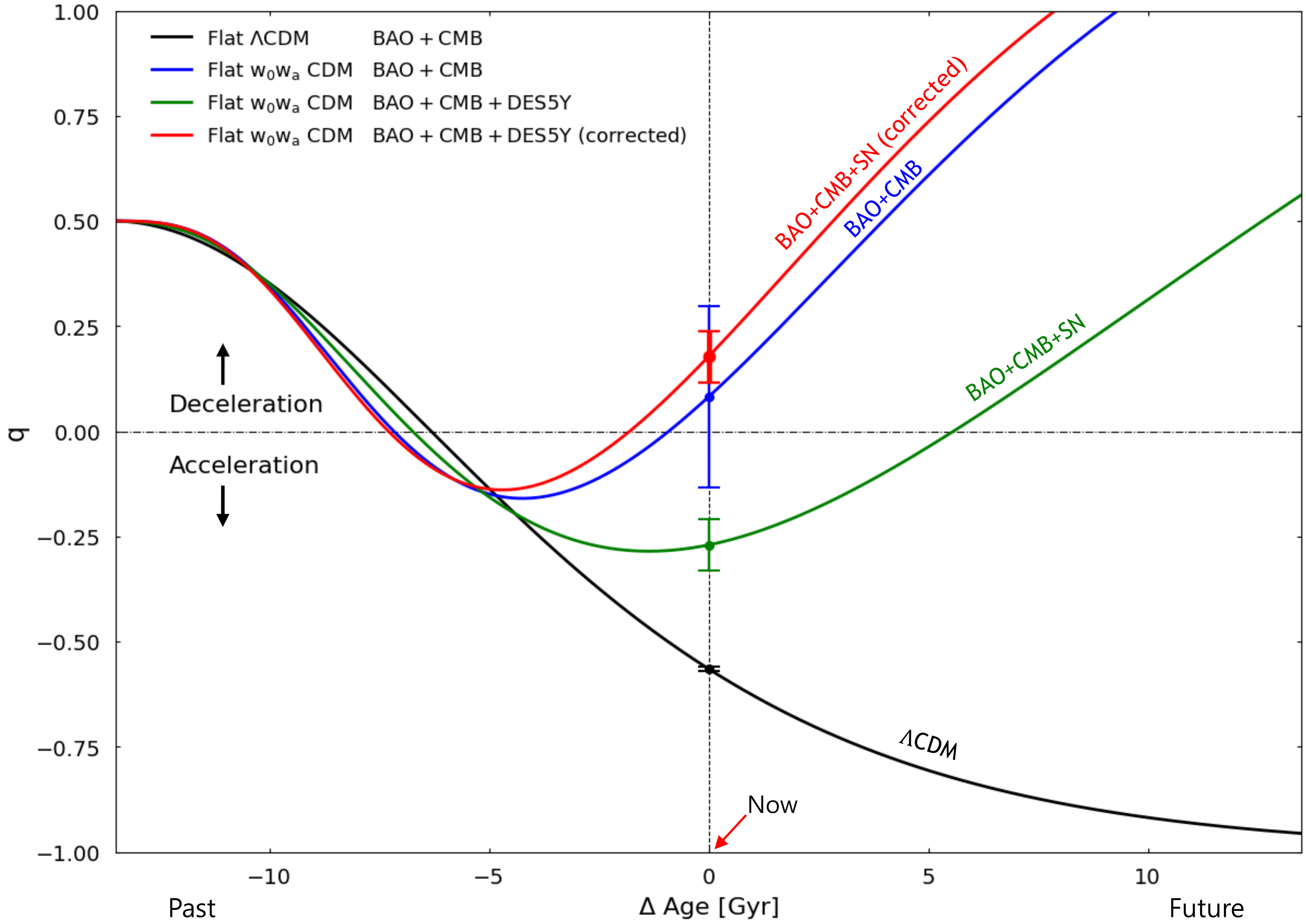


After correcting for the age bias, SN dataset aligns more closely with DESI BAO in the $w_o w_a$CDM model



Evolution of deceleration parameter

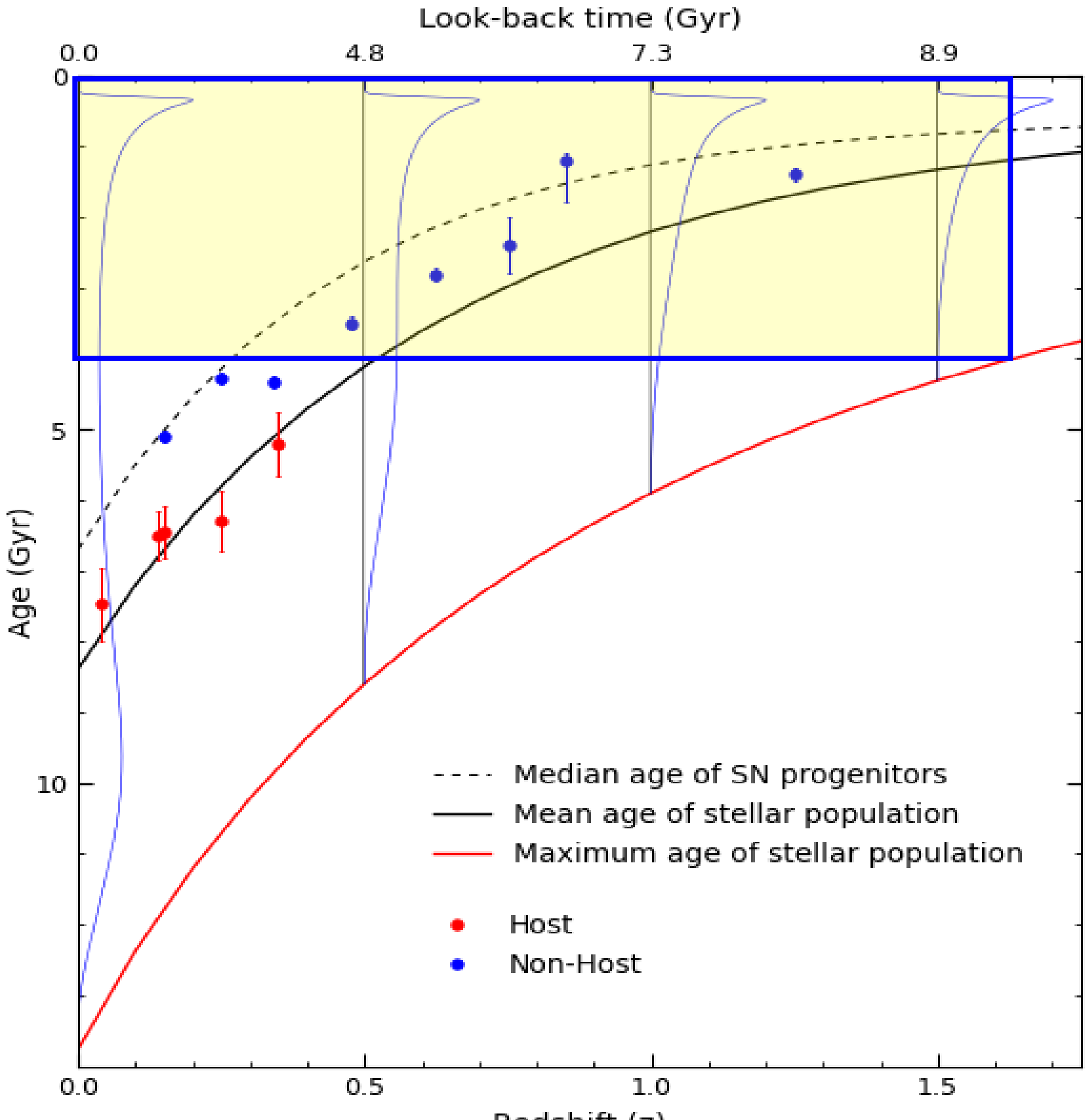
→ The Universe is currently decelerating !



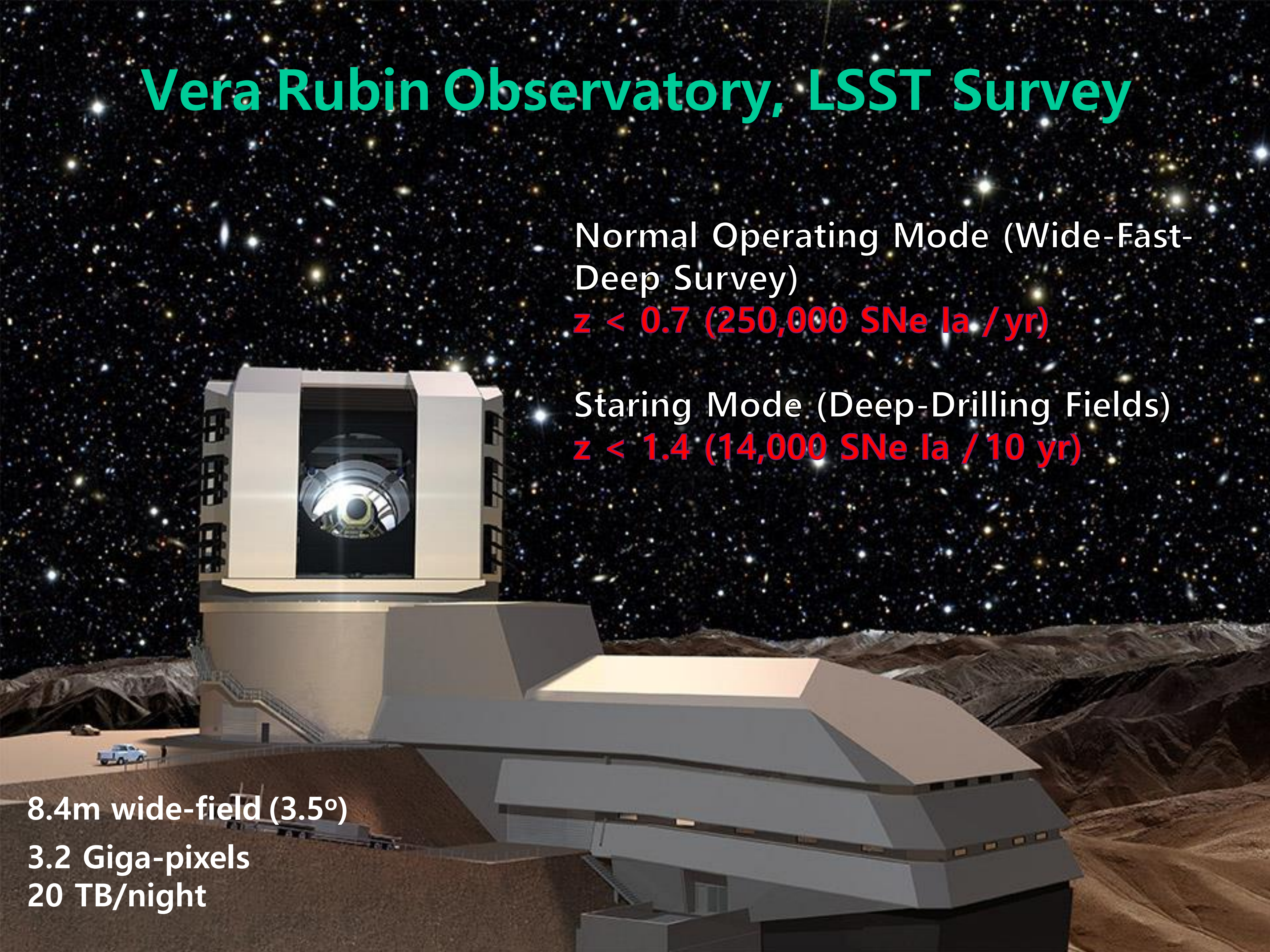
Son, Lee et al. 2025, in press

For more direct test, “Evolution-free” cosmological test

→ Only SNe from young & coeval hosts across full redshift range



Vera Rubin Observatory, LSST Survey



Normal Operating Mode (Wide-Fast-Deep Survey)

$z < 0.7$ (250,000 SNe Ia / yr)

Staring Mode (Deep-Drilling Fields)

$z < 1.4$ (14,000 SNe Ia / 10 yr)

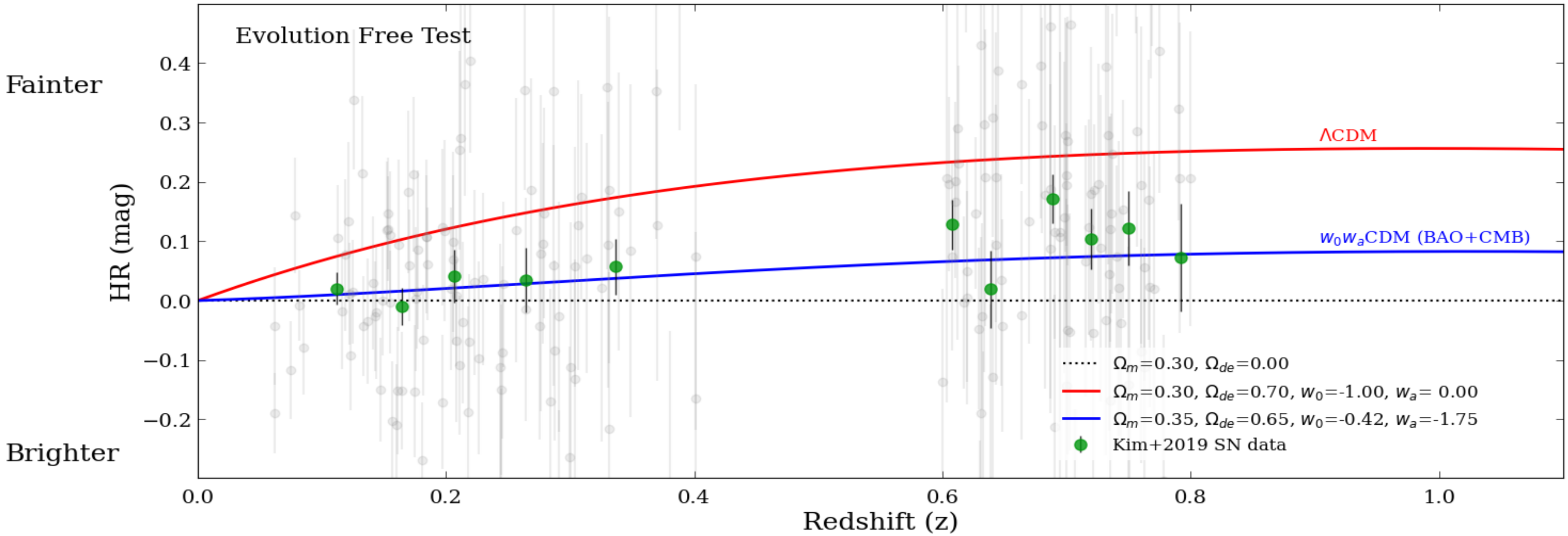
8.4m wide-field (3.5°)

3.2 Giga-pixels

20 TB/night

"Evolution-free" cosmological test (1st result)

→ Only SNe from young & coeval hosts across full redshift range



From cosmic SFH, mean age of host galaxies at z = 0.7 is 3.1 Gyr. We select only equally young (< 4.5 Gyr, mean = 3.1 Gyr) hosts from Rose+19 & Gupta+11 samples at low-z

Son, Lee et al. 2025, in press

Age-bias test & evolution-free test highlighted by Riess et al. 1998 (see also Schmidt et al. 1998 & Perlmutter et al. 1999)

"We can place empirical constraints on the effect that a change in the progenitor age would have on our SN Ia distances by comparing subsamples of low-redshift SNe Ia believed to arise from old and young progenitors."

"Another valuable test would be to compare low redshift distances to starburst and irregular-type galaxies, which presumably are hosts to progenitors that are young and metal poor. Such a nearby sample may yield the closest approximation to the SNe Ia observed at high redshift."

Expected Criticisms

(1) “Host galaxy mass already used as an age proxy”:

Mass cannot replace age. They evolve very differently with redshift. Within the redshift range most relevant to SN cosmology ($0 < z < 1$), galaxy mass evolution is negligible, because most mass assembly was completed before $z \approx 1$–2. However, age changes significantly (by 5–6 Gyr) over this range.

(2) “Today’s Type Ia SNe are found in young star-forming galaxies”:

No. Type Ia SNe are also frequently observed in very old elliptical galaxies with no ongoing star formation (Kang+2020).
Locally SF/Locally passive = 177/196 (Kim+2019).

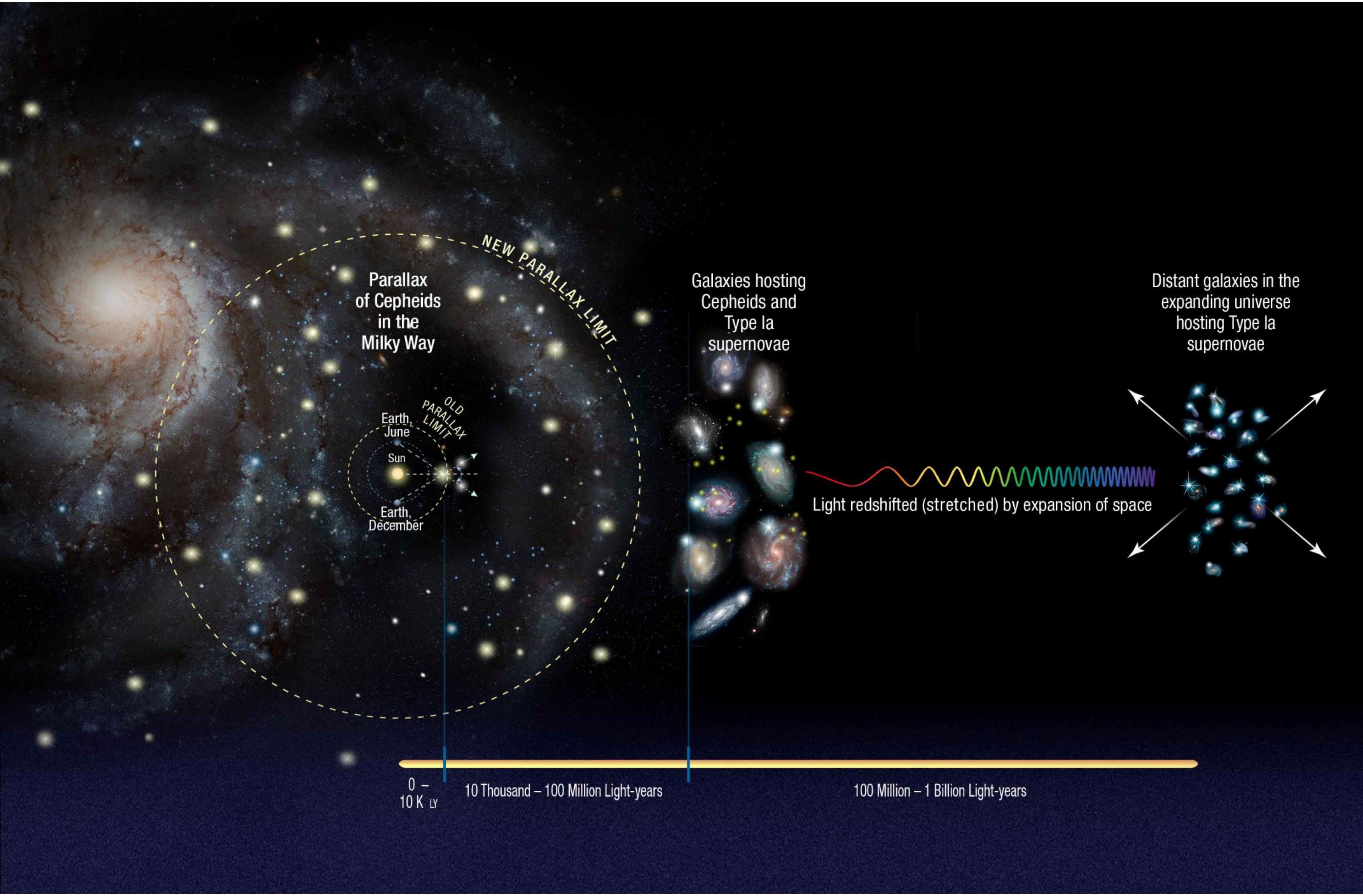
Anticipated Impacts

- **Hubble Tension:** A population mismatch between the calibration sample and the Hubble-flow sample? (+ The R_v problem in Pantheon+) → 천문학적 문제!!

- **JWST massive galaxy tension:** Naturally explained by a 20% increase in Ω_m & a lower H_o in the $w_o w_a$CDM model

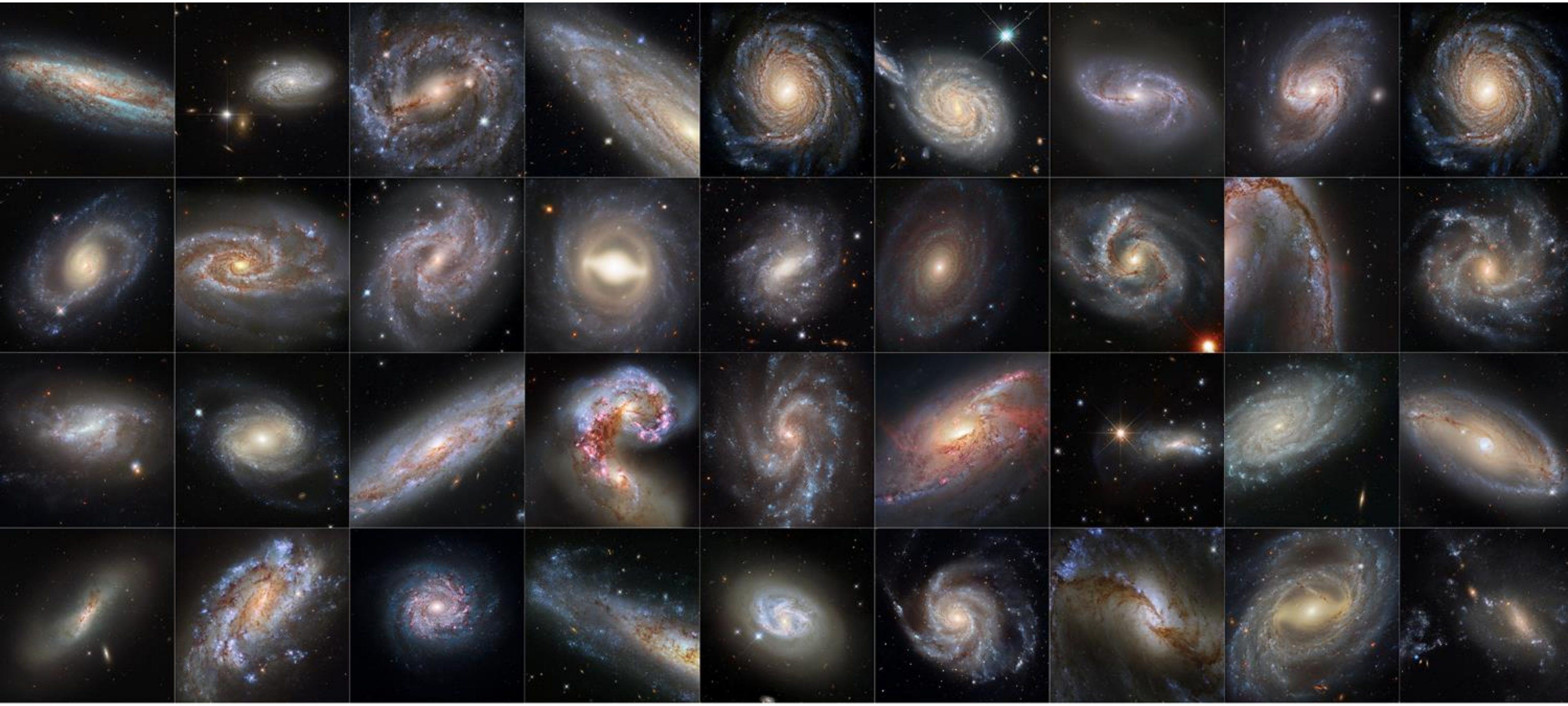
- **Particle physics?**

Hubble Tension: A population mismatch between 2nd & 3rd rungs?



Calibrator Sample (Riess+2022)

Note that they are all late-type galaxies (spirals & irregulars), and,
for most of them, SNe Ia arose on spiral arms (young environments)!



E-mail from Prof. Fred Jegerlehner, Humboldt University & DESY, Germany

Higgs Field as a Source of Time-Varying Dark Energy?

• **The Higgs field is the only scalar field in the Standard Model that couples directly to gravity.**

• **Standard Model parameters (running couplings) vary with the energy scale, the Higgs vacuum energy can therefore evolve in time.**

• **Early universe:** The effective Higgs potential becomes large at high energy, provides enough vacuum energy to **drive inflation.**

• **Late universe:** After cooling and the Higgs phase transition, the vacuum energy drops dramatically, a tiny remnant survives as today’s dark energy.

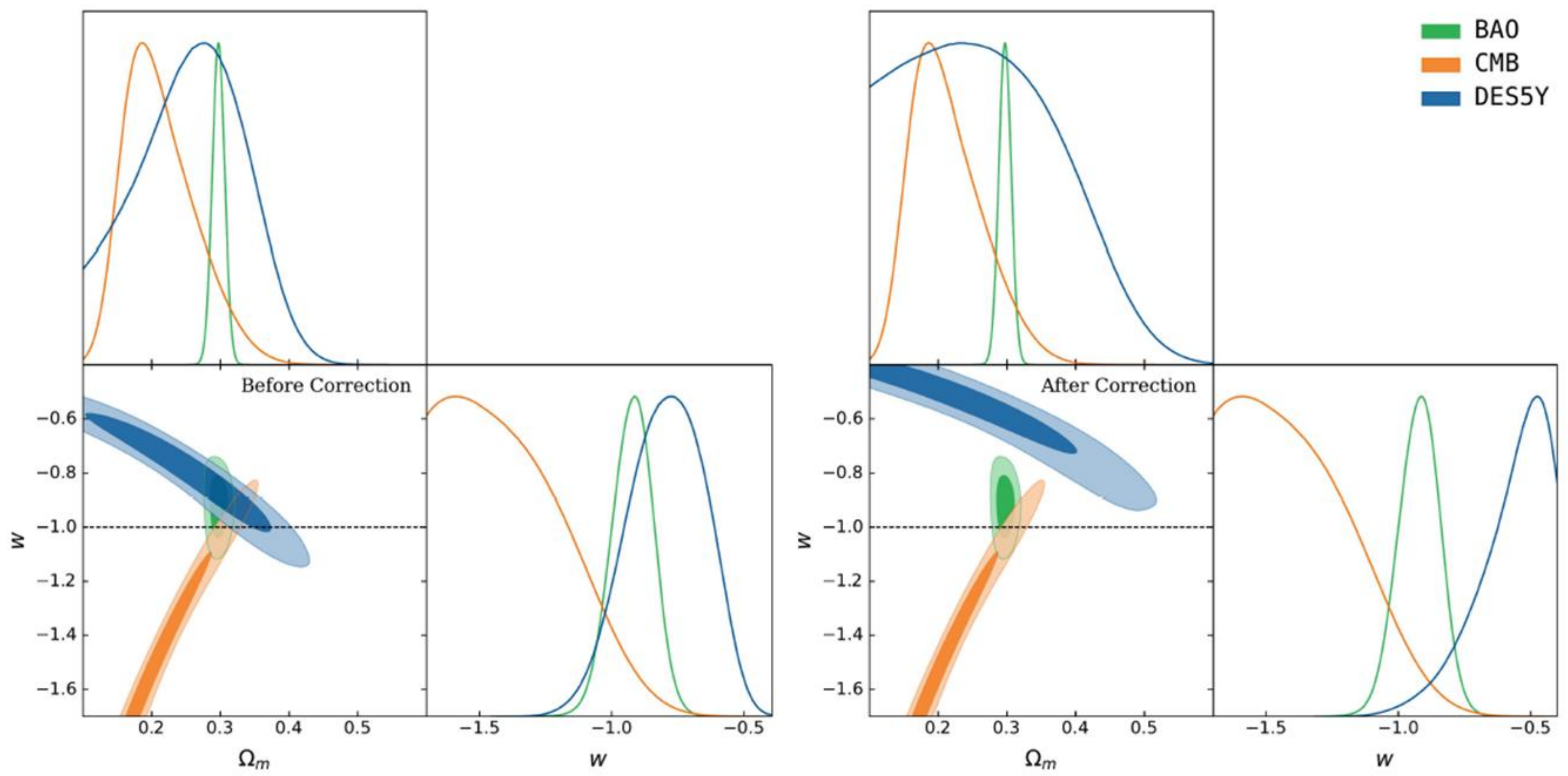
Conclusion

- 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 $w_o w_a$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.
- The same effect could also help alleviate the Hubble Tension.

"History doesn't repeat itself, but it often rhymes."

— *Mark Twain*

Flat-wCDM model: ‘w tension’ in cosmology → time-varying w



After the age-bias correction, discordance in cosmology!
Dark energy equation of state (w = P/ρ) appears increasing from CMB (z ~ 1100) → BAO (0.5 <z < 3) → SNe (0 < z < 1), suggesting a time-varying w

Data: SNe (DES-5Y 2024), BAO (DESI 2025), CMB (Planck final result 2020)

Age-bias correction reduces KL divergence, indicating improved agreement

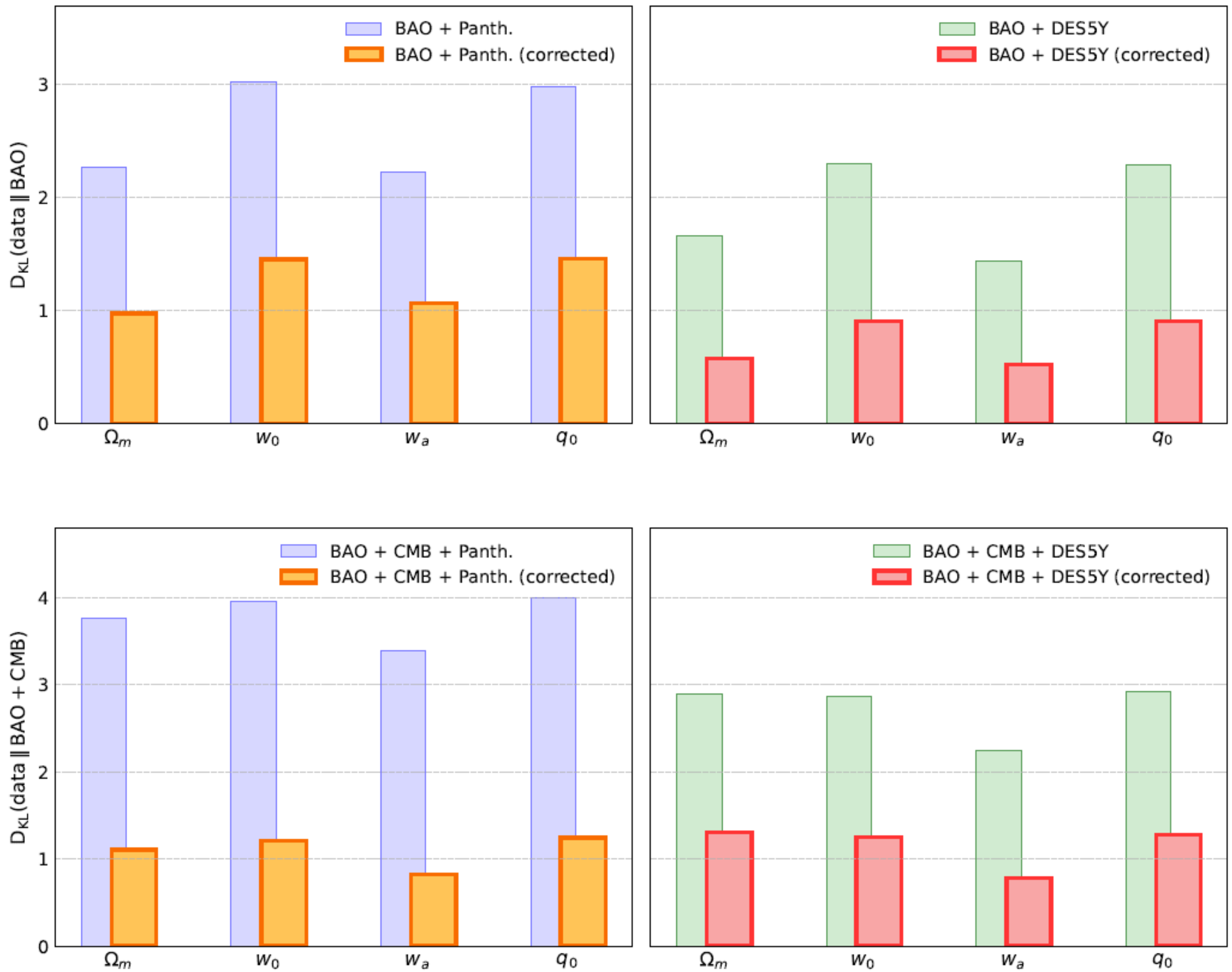
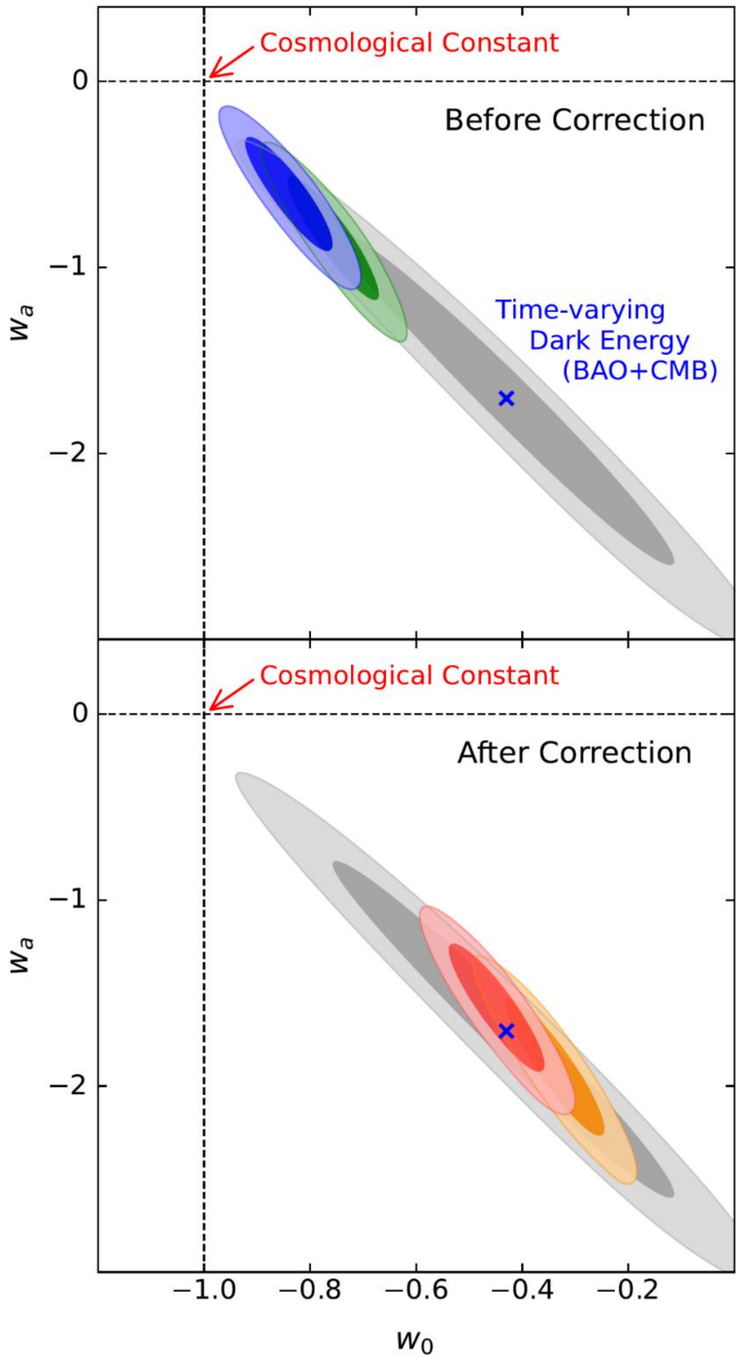


Figure 8. Results of the Kullback–Leibler (KL) divergence analysis. The upper panels show the KL divergence computed from the marginalized posterior distributions of cosmological parameters, using BAO data as the reference. The SN datasets used are PantheonPlus (upper left) and DES5Y (upper right). In both cases, the BAO+SN Ia combinations exhibit lower KL divergence after the age-bias correction, indicating improved consistency with the BAO-only results. The lower panels display the KL divergence relative to the BAO+CMB data, with PantheonPlus (lower left) and DES5Y (lower right) SN data. The application of the age-bias correction consistently reduces the KL divergence for all parameter combinations, indicating improved agreement between the combined probes (BAO+CMB+SN) and the BAO+CMB results.



After correcting for the age-bias, SN-added result aligns more closely with the DESI BAO+CMB in the $w_o w_a$CDM model

>9σ discordance with LCDM

Strongly suggesting a time-varying dark energy equation of state