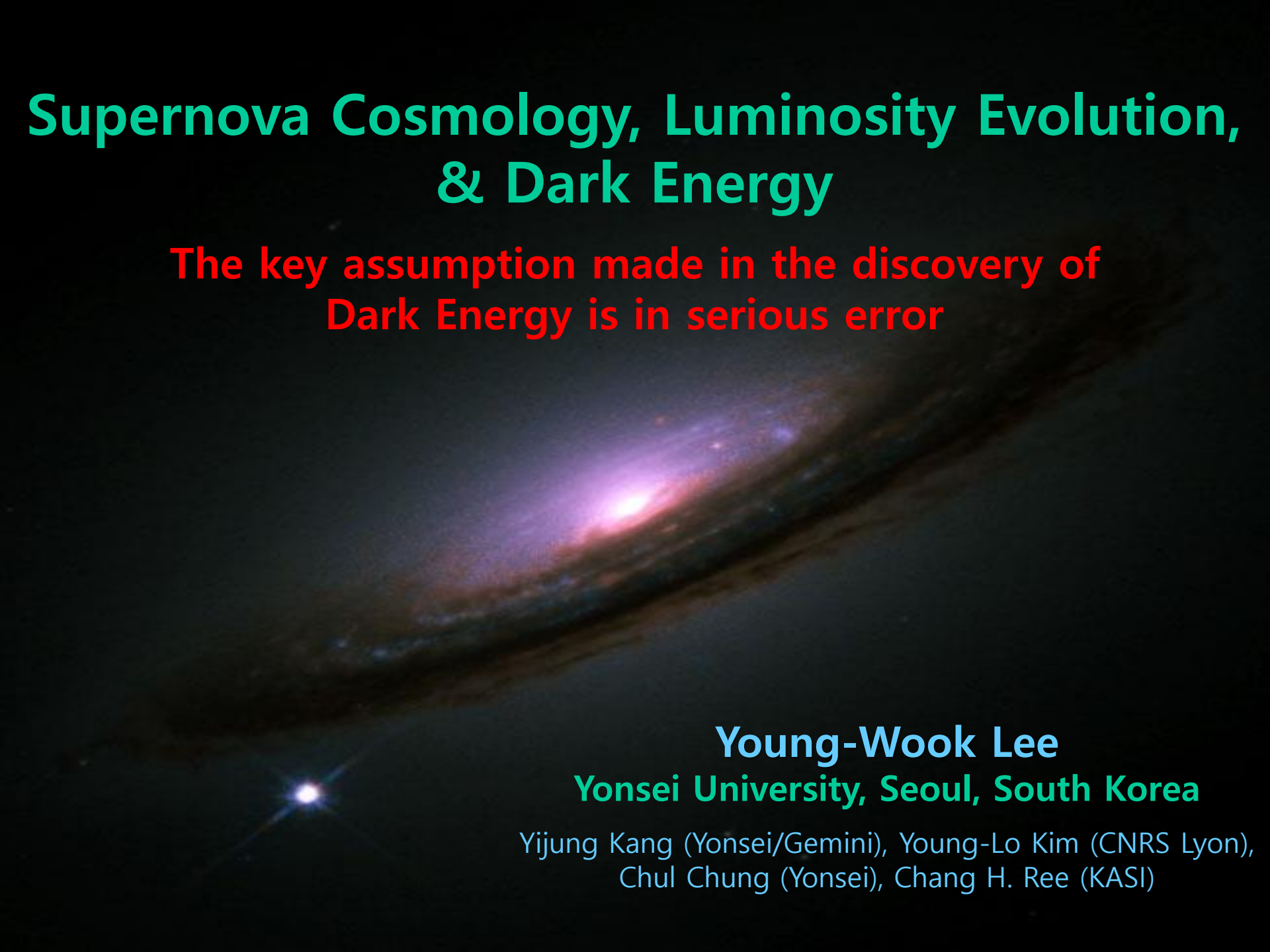
Supernova Cosmology, Luminosity Evolution, & Dark Energy

The key assumption made in the discovery of Dark Energy is in serious error



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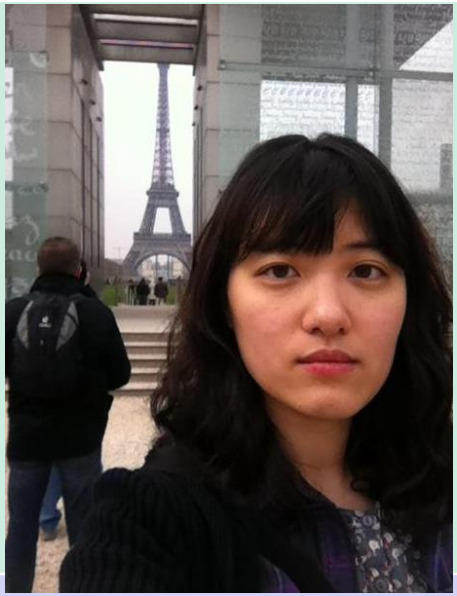
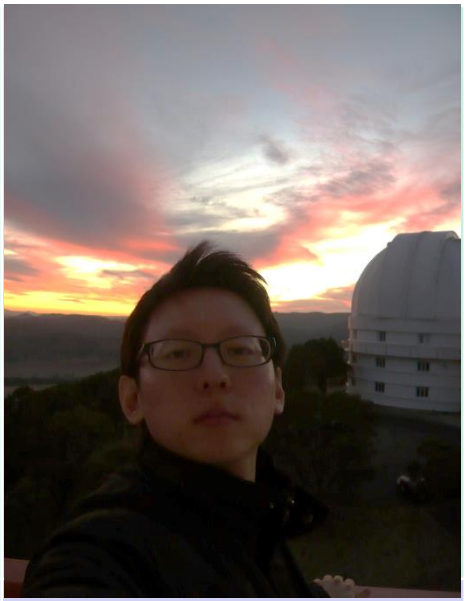
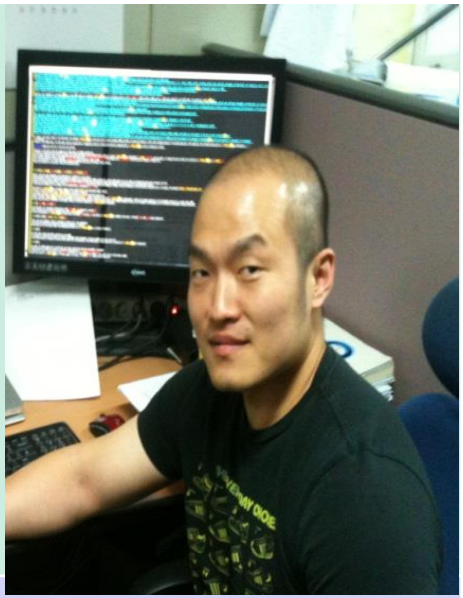
Chul Chung (Yonsei), Chang H. Ree (KASI)

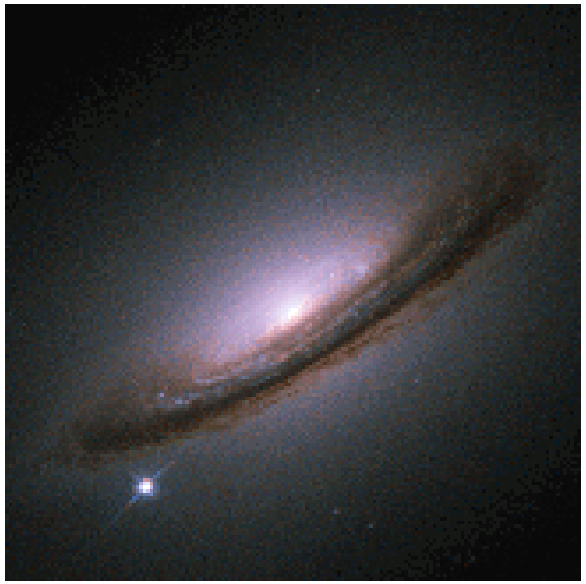
Team YONSEI

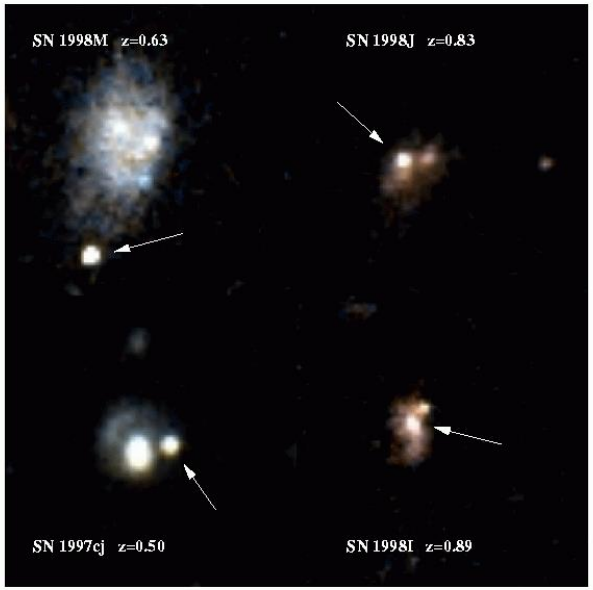
(YOnsei Nearby Supernovae Evolution Investigation: since 2010)

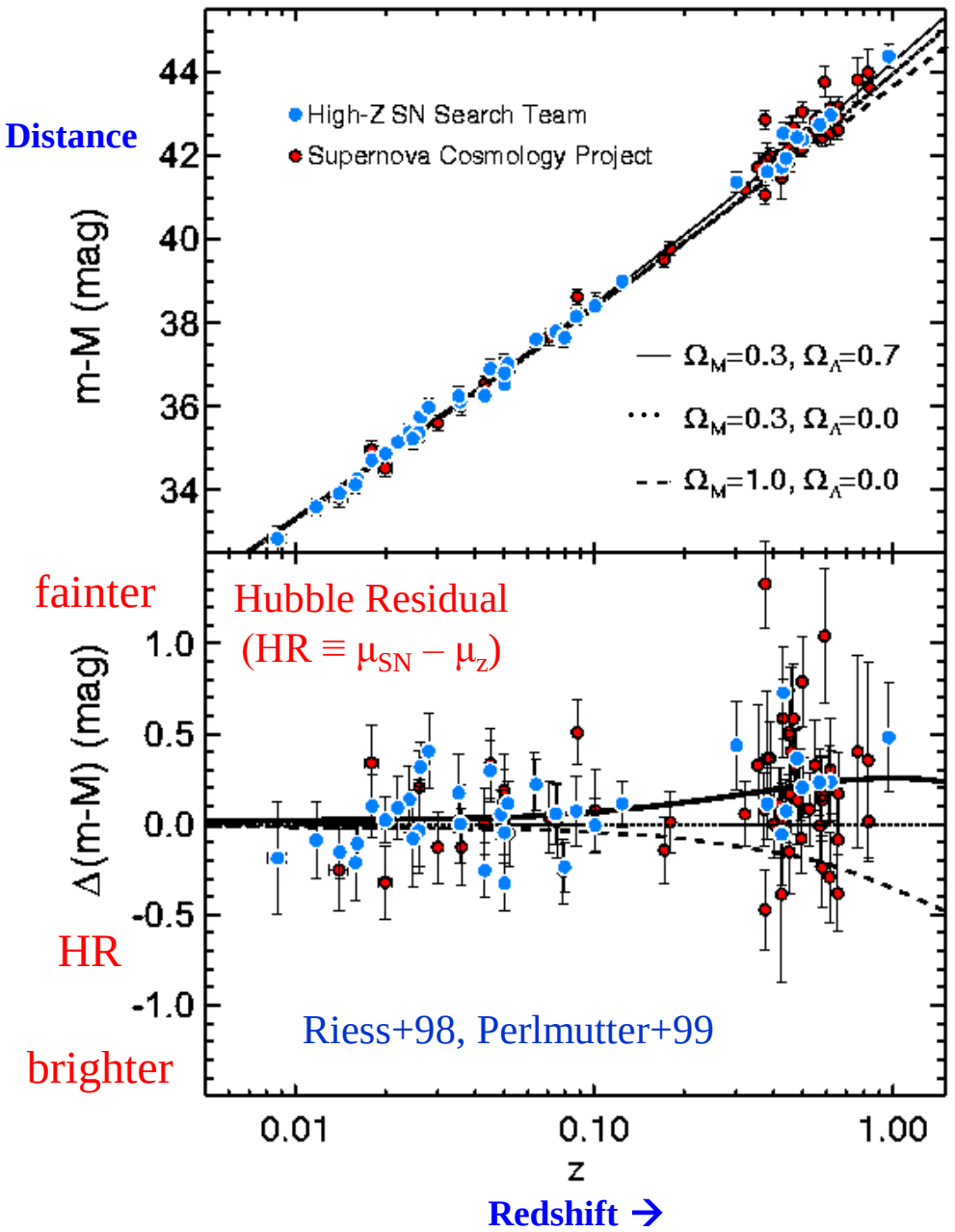
PI : Young-Wook Lee

			
Yijung Kang (Yonsei/Gemini South)	**Young-Lo Kim (Yonsei/CNRS Lyon)**	**Chul Chung (Yonsei)**	**Dongwook Lim (Yonsei/Heidelberg)** **Chang Hee Ree (KASI)**
Spectroscopy of host-galaxies	Light-curve analysis of SNe Ia	Population synthesis models (YEPS)	Spectroscopy, Photometric analysis

Most direct evidence for Dark Energy is still from SN cosmology







Project YONSEI:

Yonsei Nearby Supernovae Evolution Investigation

(Since 2010)

High S/N (~175) spectra for ~70 nearby early-type host galaxies

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

→ Only ETGs because of high-precision age dating & low extinction

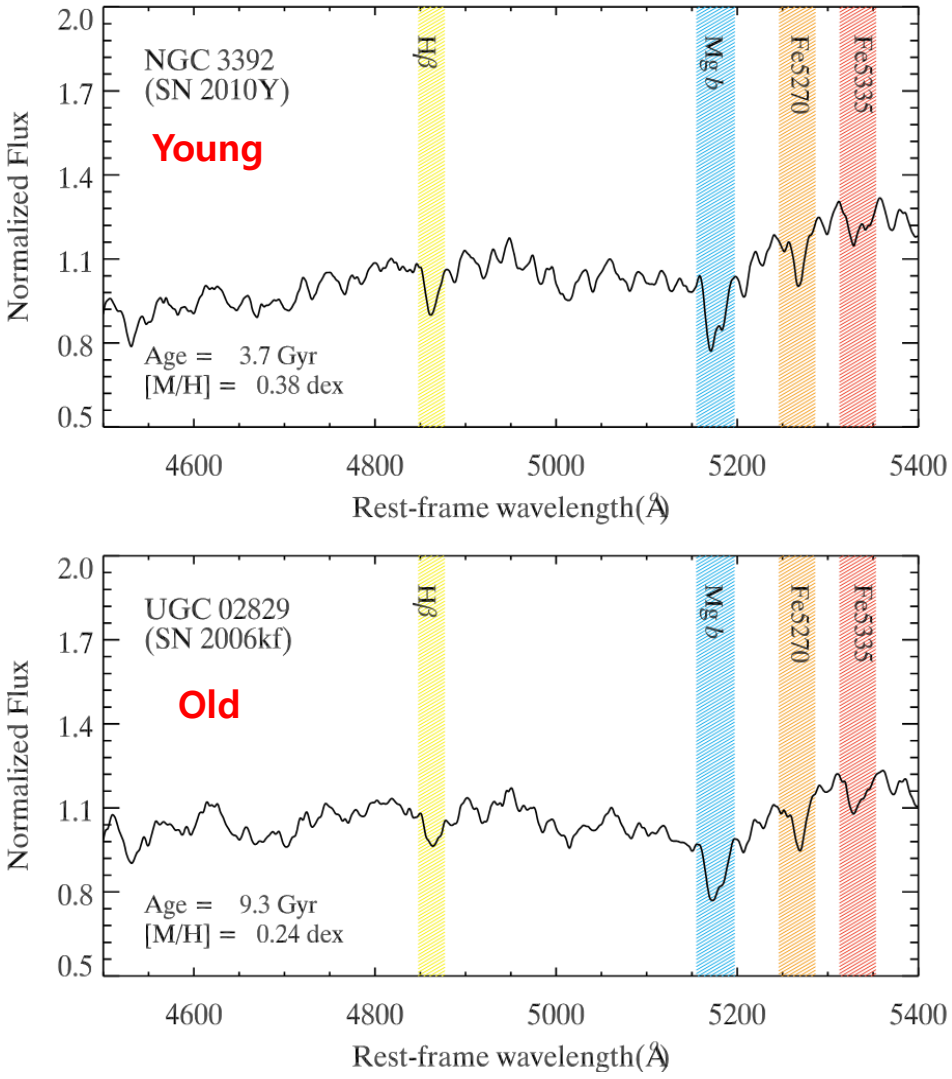
→ For the first time, directly measure population age & metallicity from absorption lines (H_β, Fe, Mgb) & well-established population synthesis models (Yonsei, Thomas, Schiavon)

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

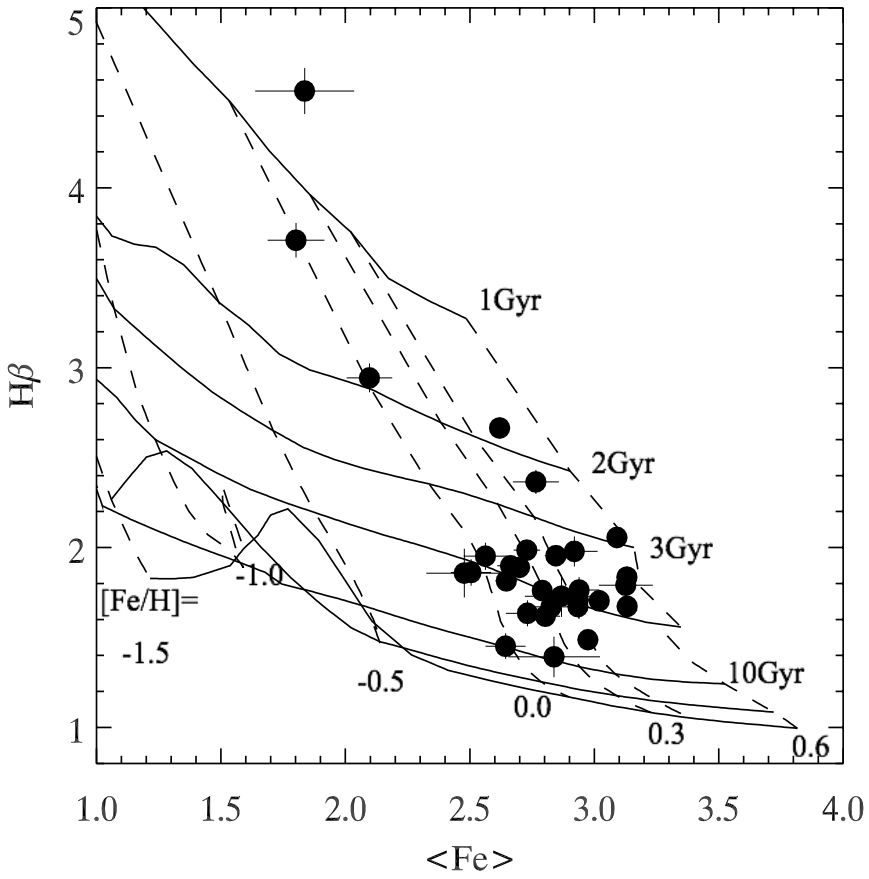
Most direct & stringent test ever made for the luminosity evolution!

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

High Precision Measurement of Host Galaxy Age & Metallicity

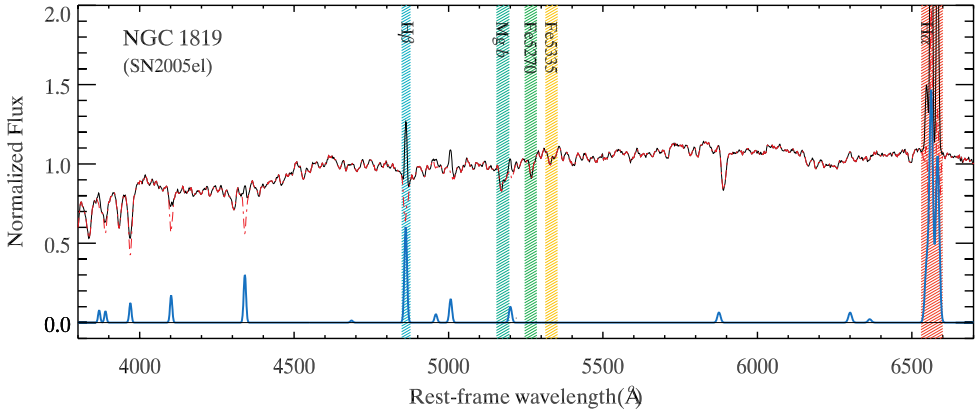


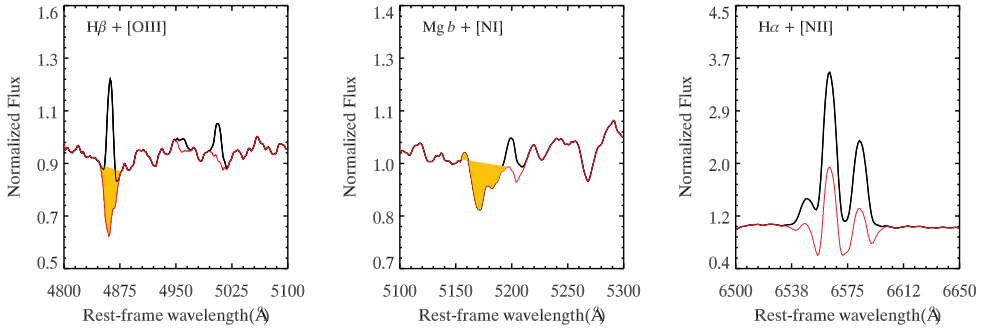
Y. Kang, Y.-W. Lee+2016, 2020

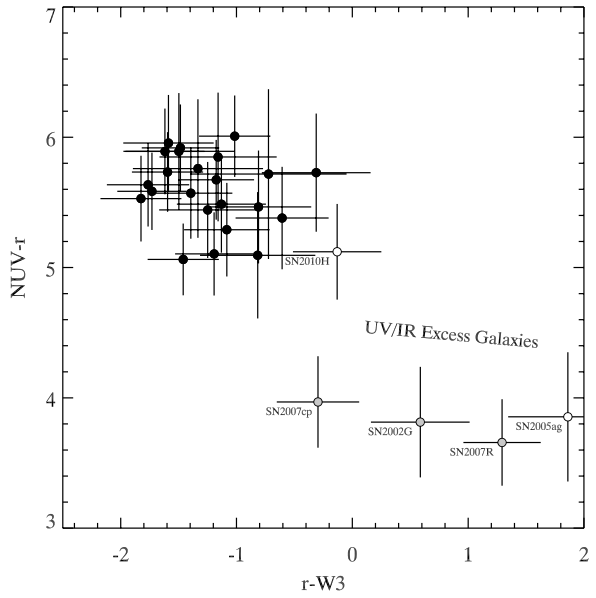


Population Synthesis Models:
Chung+13; Thomas+11; Schiavon 07

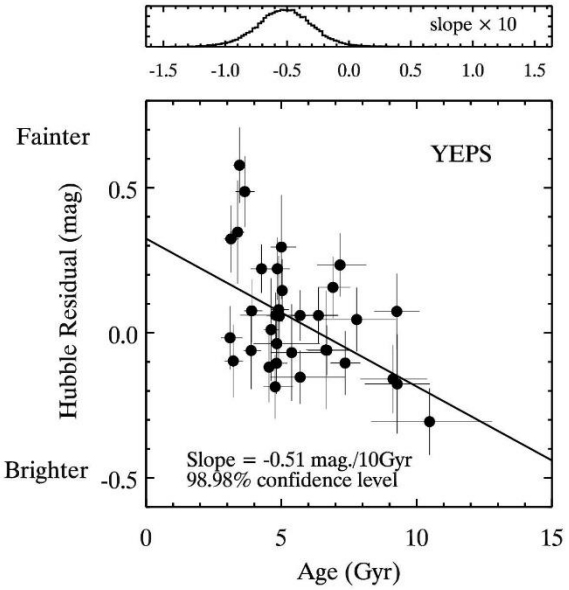
Abnormal (recent star-forming) ETGs were removed based on emission lines and/or UV/IR excess

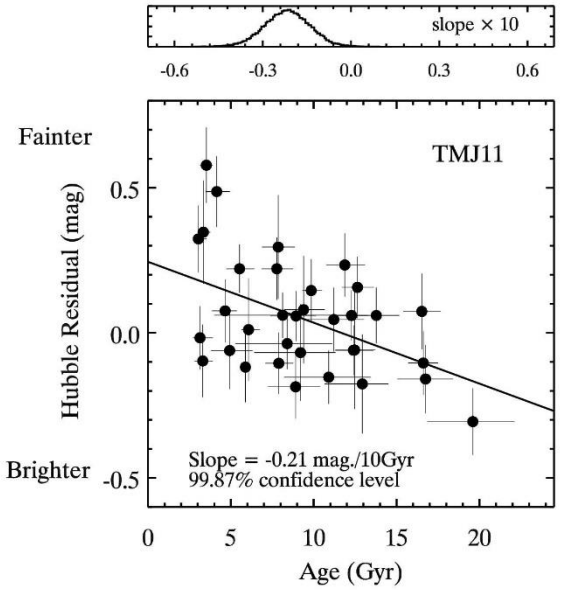


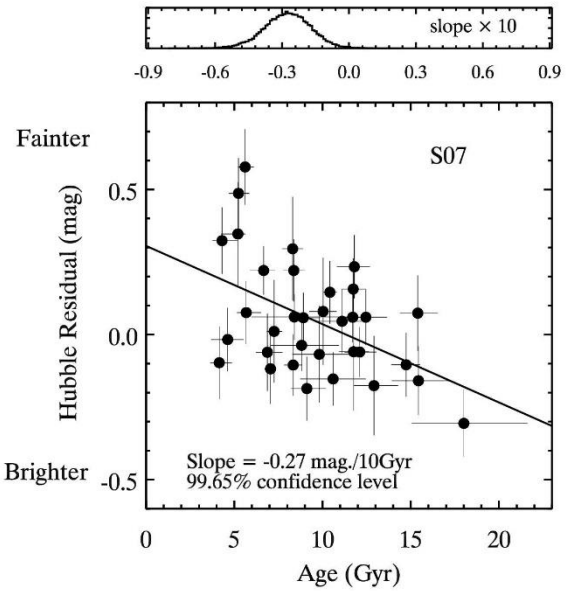




Correlation between SN Luminosity & Population Age







Non-genuine ETGs with recent SF excluded as ages are seriously underestimated or highly uncertain

Correlation is significant at ~99.5% confidence

→ SNe in younger hosts are fainter (after standardization)

→ Evidence for luminosity evolution!

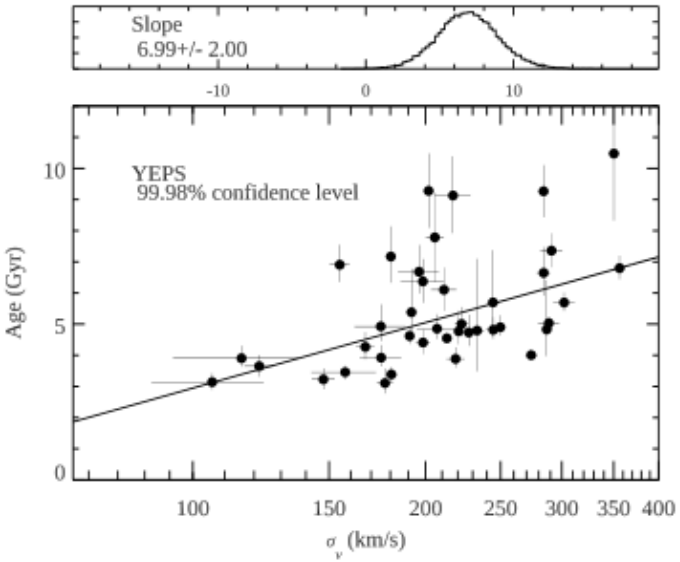
→ ~0.27 mag fainter for dt ~5.3 Gyr

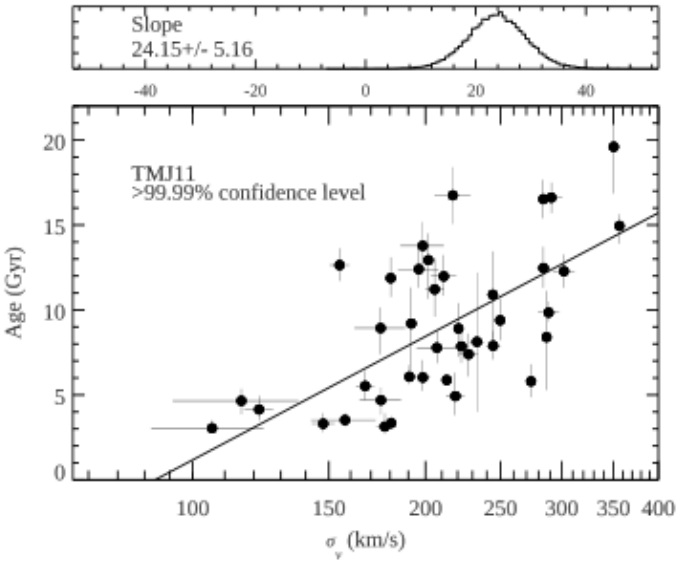
Our result is insensitive to the choice of population synthesis model

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

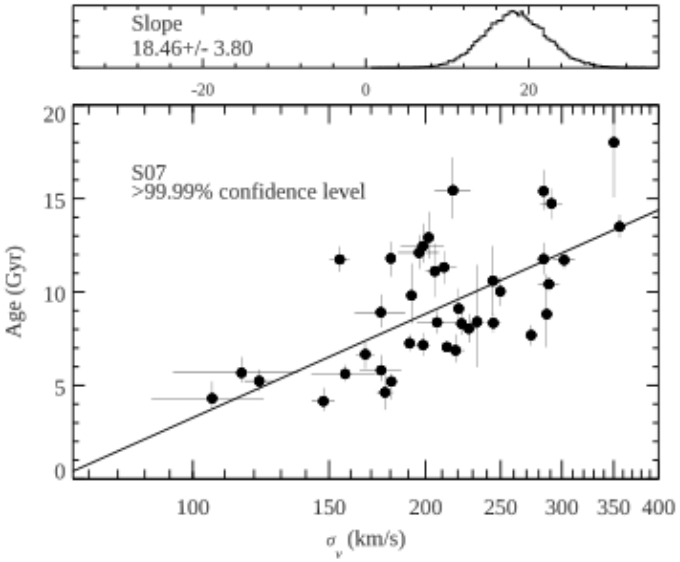
Correlation between Host Mass (σ_v) and Population Age: "Downsizing"

(Kang, Lee+2016, 2020)





Similar results from LTGs (van de Sanda+2018)



MCMC analysis

→ Correlation is significant at 99.99% confidence level!

→ No apparent correlation with metallicity

→ *Host mass – SN luminosity correlation is due to population age difference!*

Other well-established correlations between SN luminosity & host property (related with age)

Host Property	Reference	Original Correlation	Direction	Converted to Age difference
Morphology	Hicken et al. (2009)	ΔHR / Δmorph.	Fainter in	~0.19 mag / 5.3 Gyr
		≈0.14 mag / (Scd/Irr-E/S0)	**Later type** galaxy	Fainter in **Younger** galaxy
Mass	Sullivan et al. (2010)	ΔHR /Δmass	Fainter in	~0.21 mag / 5.3 Gyr
		≈0.08 mag /(Δlog $M_\star$ ~ 1)	**Less massive** galaxy	Fainter in **Younger** galaxy
Local SFR	Rigault et al. (2018)	ΔHR /Δlocal SFR	Fainter in	~0.35 mag /5.3 Gyr
		≈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	~0.27 mag /5.3 Gyr
		≈0.051 mag / Gyr (YEPS)	**Younger** galaxy	Fainter in **Younger** galaxy

When they are converted to age difference

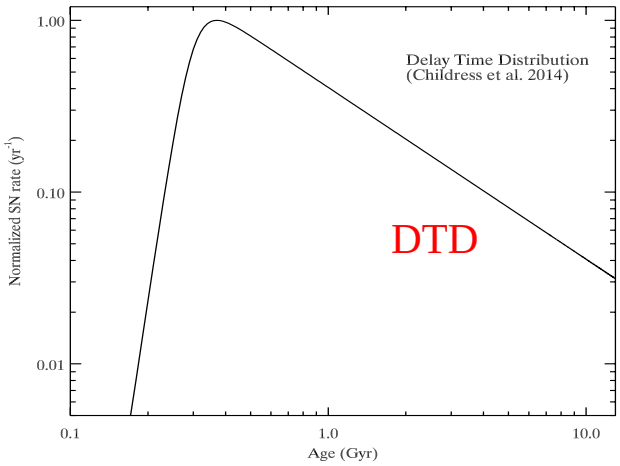
based on our result, Scott et al. 2017, & Galbany et al. 2014

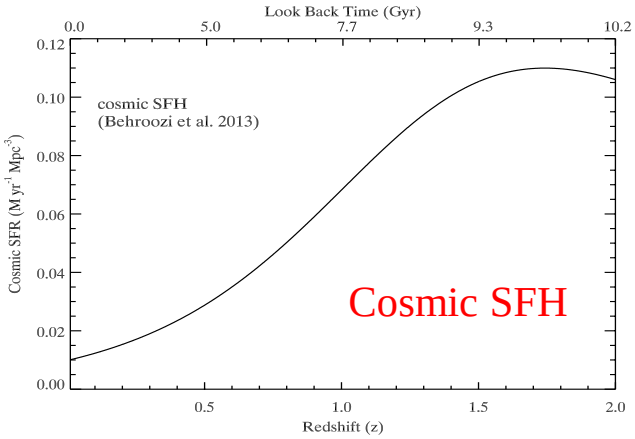
→ *They are all pointing to the same direction!*

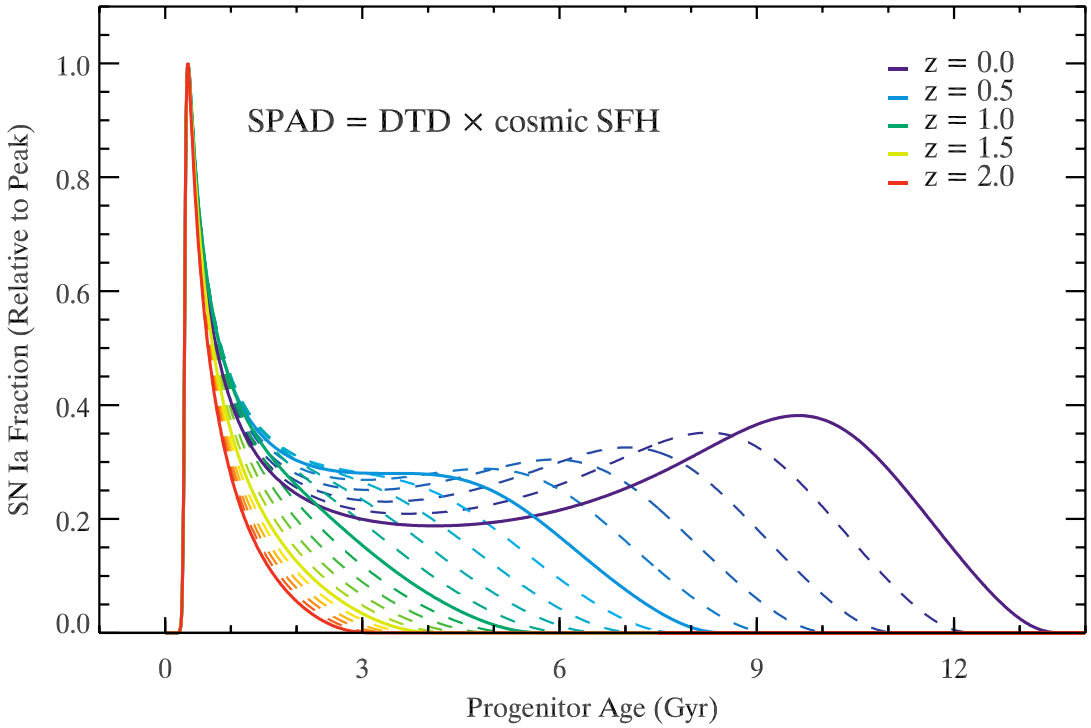
→ SNe Ia in younger galaxies (i.e., high-z) are fainter!

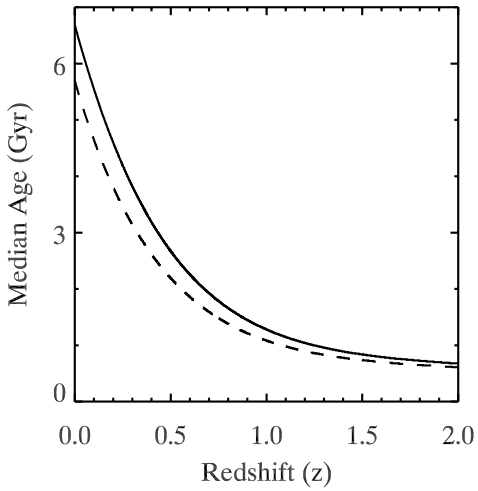
Y. Kang, Y.-W. Lee+2020, ApJ

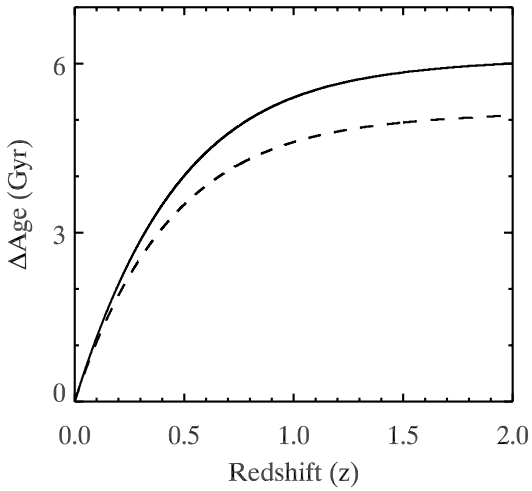
Supernova Progenitor Age Distribution (SPAD): following Childress et al. (2014)





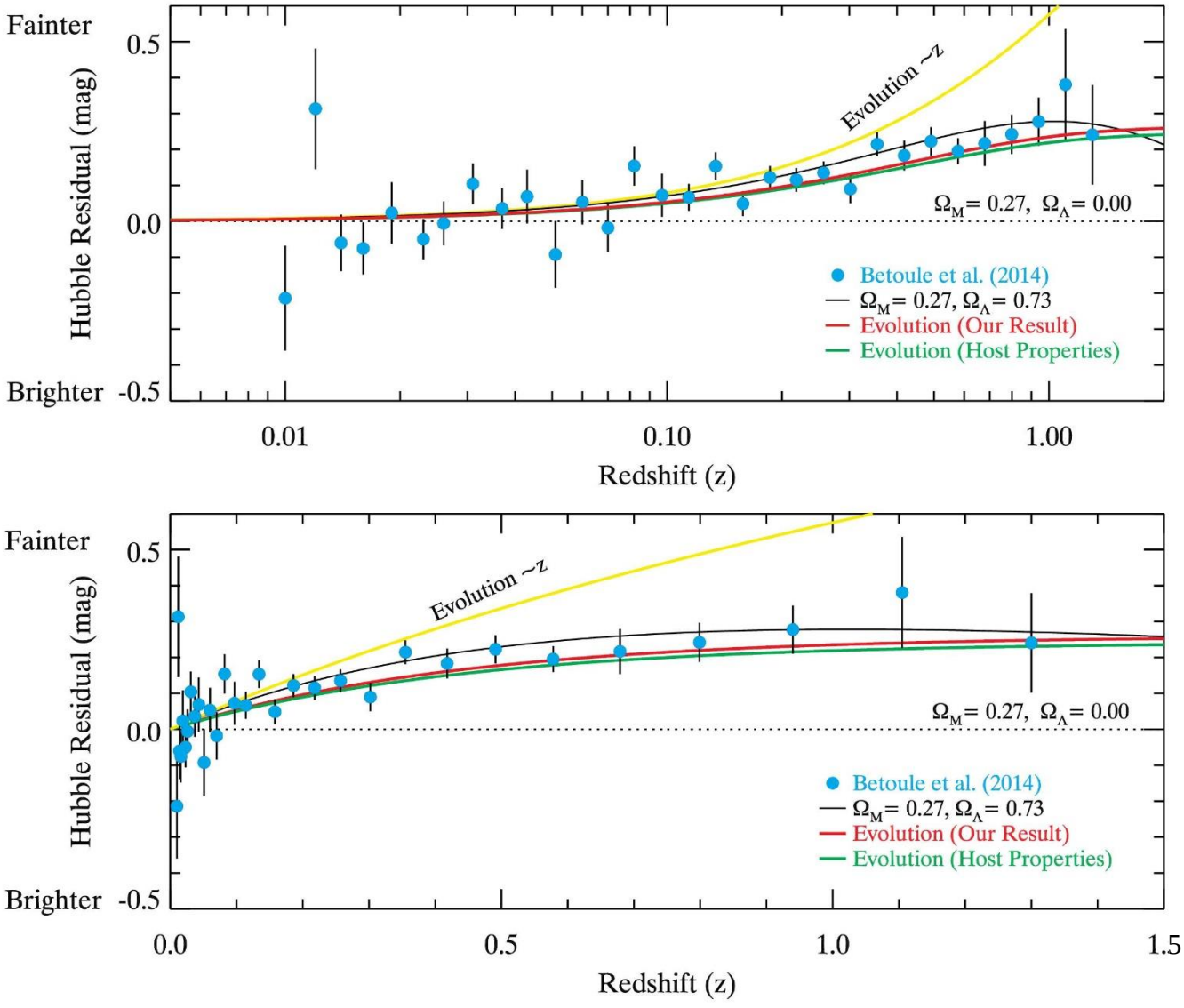






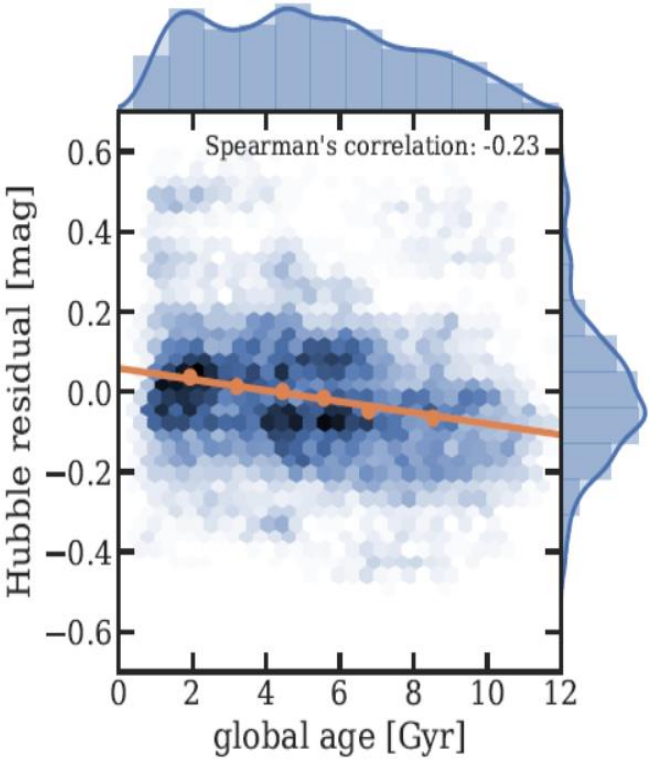
Y. Kang, Y.-W. Lee+2020, ApJ

Luminosity evolution can mimic Hubble residuals used in the discovery of dark energy

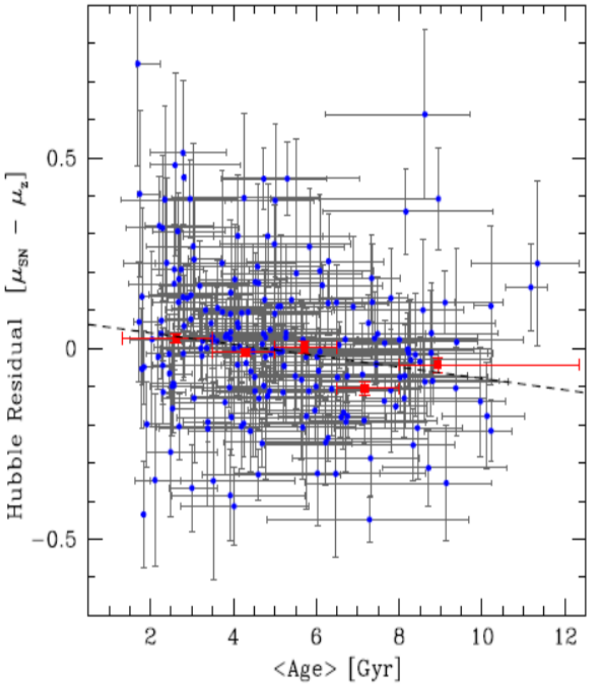


Y. Kang, Y.-W. Lee+2020, ApJ

Secondary Age-dating based on photometry (SED) is also pointing to the same direction (for all galaxy types)



Rose, Garnavich+2019



Gupta+2011

See also Pan, Sullivan+2014 & Neill+2009 for similar correlations

→ 0.08 – 0.11 mag/5.3 Gyr or "step"? → can mimic ~40 % of HR

→ *Still pose a serious problem to the assumption of no L evolution!*

Conclusion

- This is the most direct & stringent test ever made for the luminosity evolution of SNe Ia!
- Our result (based on high-precision ages) and other correlations (based on 2^{ndary} age-dating or age related properties) all indicate that SNe Ia in younger population environments (i.e., high-z) are fainter (after standardization)!
- *Taken at face values*, the luminosity evolution appears to be significant enough to question the very existence of Dark Energy!

"Extraordinary claims require extraordinary evidence"

Carl Sagan

→ *Is the evidence for Dark Energy secure from SN cosmology?*

To put this result on a firmer refined basis, further observations/investigations are definitely required

1. for more ETG host sample (SDSS targets with Gemini/MMT)
2. for the local property at the site of SN (IFU or long-slit)
3. Improve SED based age-dating for all morphological types of host galaxies (GALEX UV to IR)
4. Origin of "over-correction" at younger environment?
5. Better statistical analysis (with sigma_int = 0.0) for SN cosmology
6. BAO, CMB ?…

How about other cosmological probes?

Concordance model from SNe Ia, CMB, & BAO??

1. **CMB from Planck:** no longer supports concordance model? (Di Valentino, Melchiorri, Silk+2019)
2. **BAO & other low-z probes:** shown to be consistent with a non-accelerating universe (Tutusaus, Blanchard+2017)
3. **SNe Ia:** luminosity evolution mimics dark energy (Kang, Lee+2020)

→ The Crisis in Cosmology?