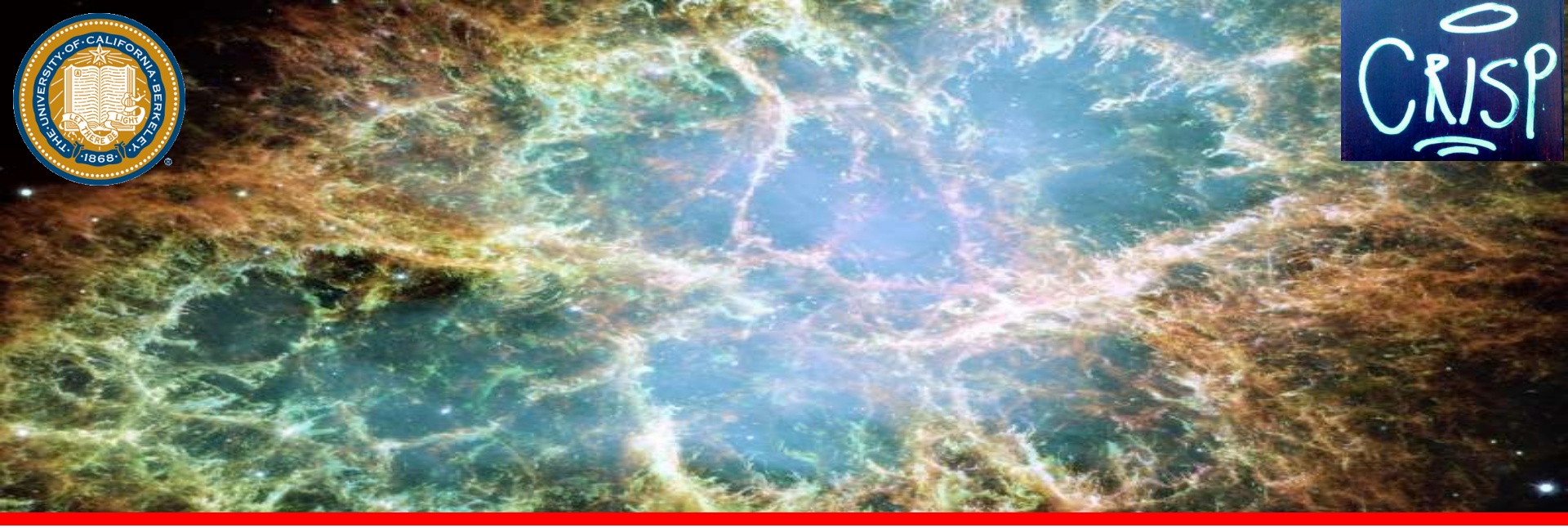


T. de Jaeger (UC Berkeley), S. González-Gaitán (CENTRA), L. Galbany (U Granada)

Implications of varying Rv in cosmology

CRISP meeting July 9th, 2020

Supernovae

- **A supernova (Zwicky 1931) is a stellar explosion that briefly outshines an entire galaxy (10^9–10^{10} L⊙).**

They play an important role in:

→ **Cosmology**

→ **Stellar evolution**

→ **Chemical enrichment of the interstellar medium**

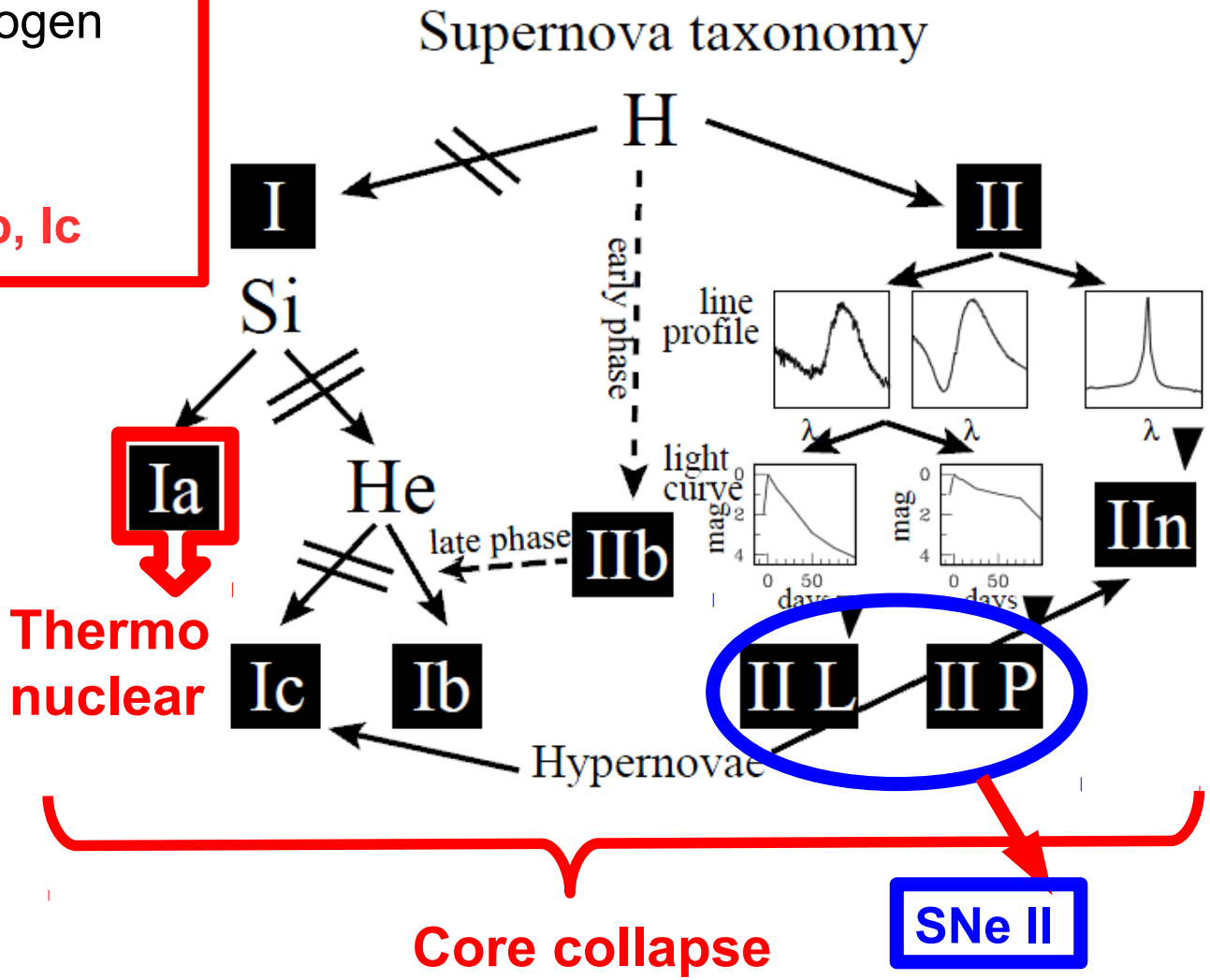
→ **Trigger of star formation**

SN 1987A in LMC

Supernovae

- Spectral classification based on presence of Hydrogen lines:
  - H lines: **II**
  - No H lines: **Ia, Ib, Ic**

Cappellaro & Turatto 2001



Anderson et al. 14

Supernovae (Ia)

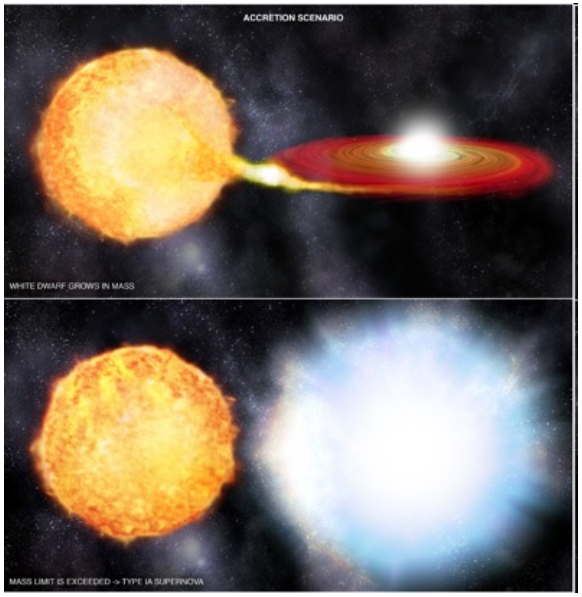
- **White dwarf (WD) of carbon/oxygen C/O** in a **binary system** that undergoes **thermonuclear burning** (Hoyle & Fowler 1960)

Single degenerate scenario :

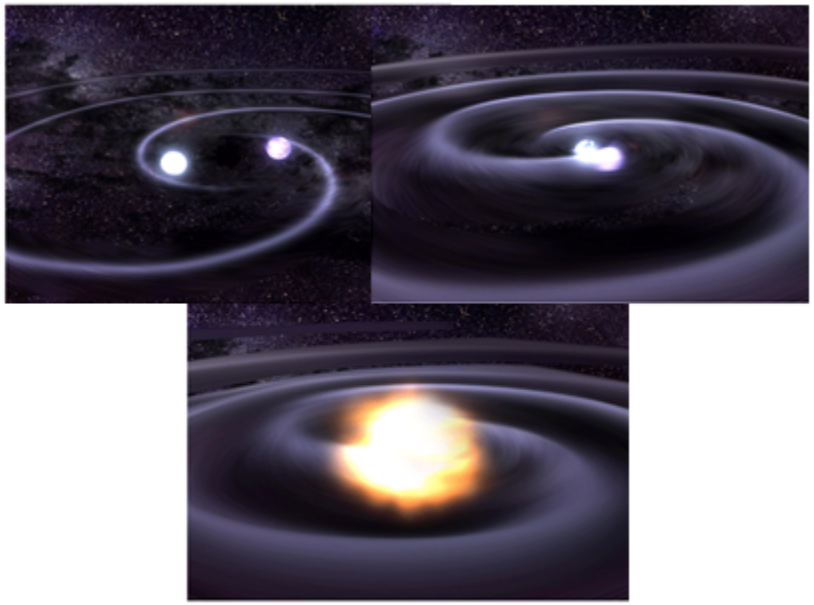
WD exceeds 1.44 M⊙ → electron degenerancy does not support weigth

Double degenerate scenario :

Two WD lose energy due to gravitational waves and collide



NASA/CXC/M Weiss



SNe cosmology

Apparent magnitude

from measurements

$$\mu = m - M =$$

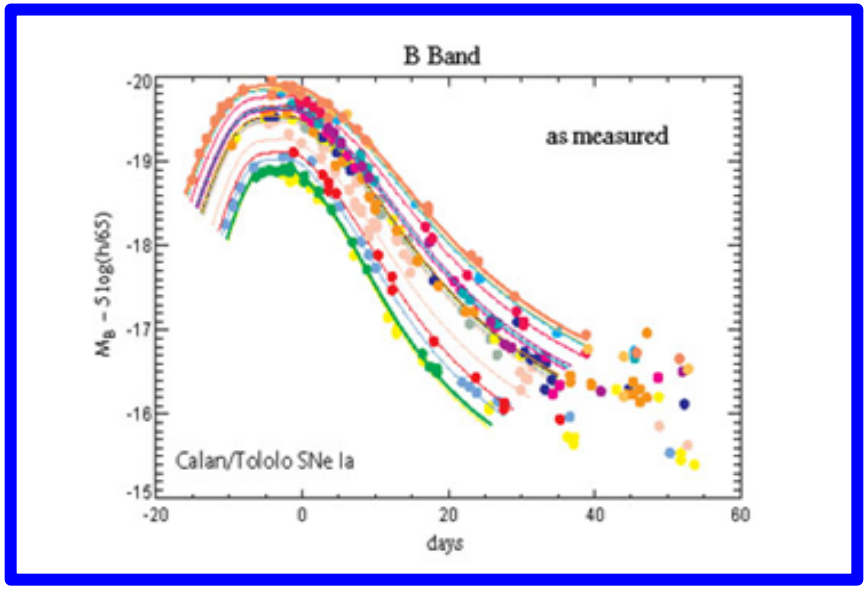
Distance modulus

Absolute magnitude

constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

OBSERVED



SNe cosmology

Apparent magnitude

from measurements

$$\mu = m - M =$$

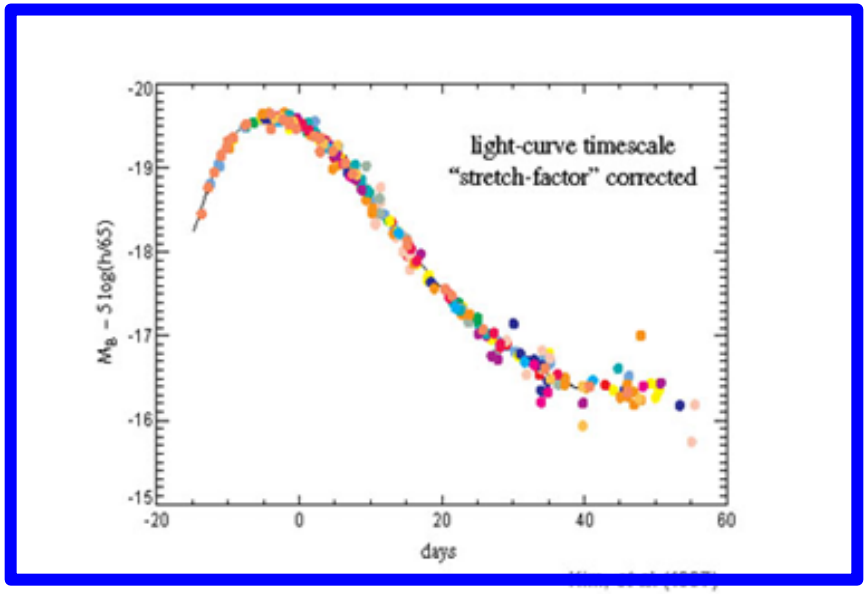
Distance modulus

Absolute magnitude

Unknnow but constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

→ Phillips et al. 93, Brighter SNe decline more slowly



SNe cosmology

Apparent magnitude

from measurements

Redshift
Measured via SN/host galaxy spectrum

Cosmological parameters
Quantities of interest
Ω_m, Ω_Λ, w, H_0

$$\mu = m - M = 5 \log_{10}\left(\frac{D_L(z, C)}{1\,Mpc}\right) + 25$$

Distance modulus

Absolute magnitude

Unknnow but constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

→ Phillips et al. 93, Brighter SNe decline more slowly

Luminosity distance

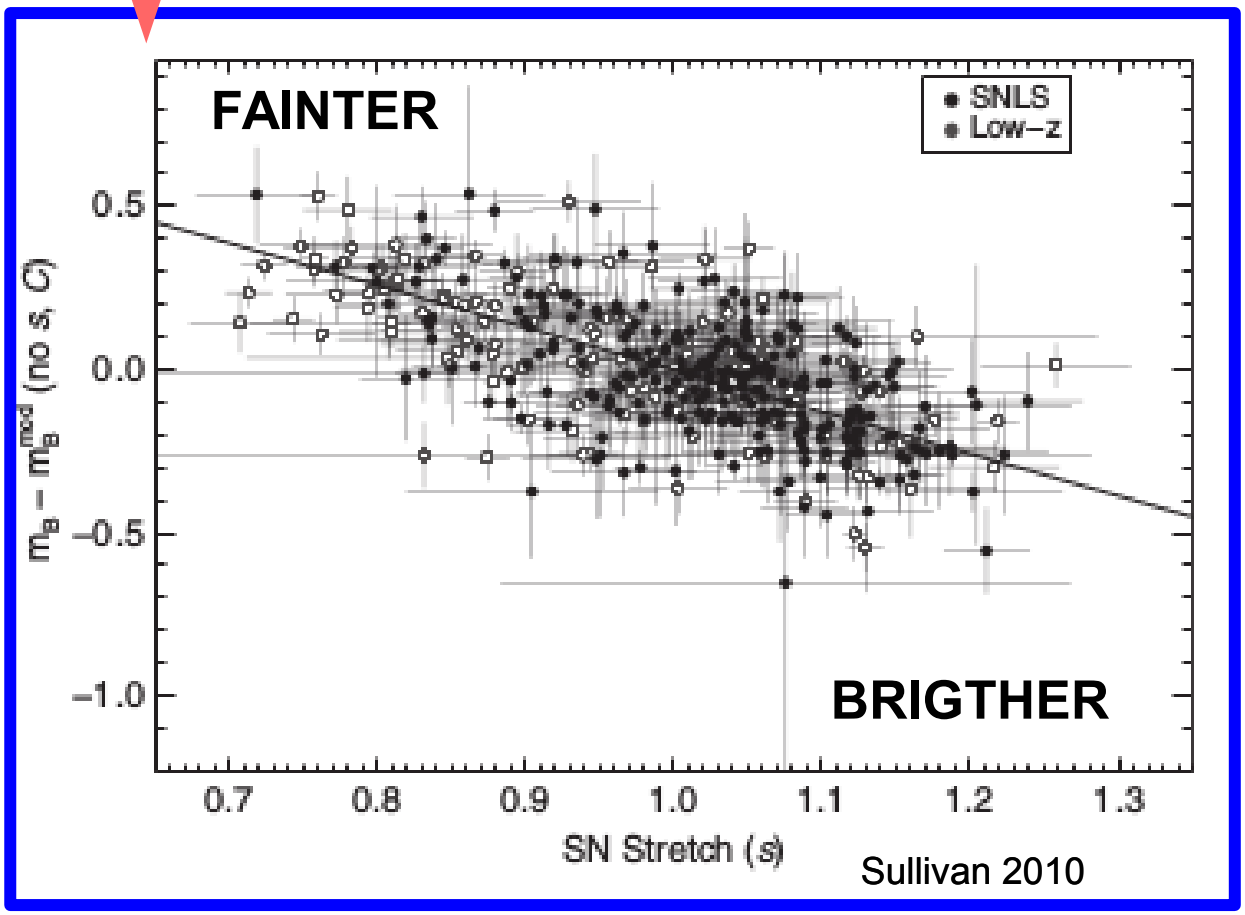
THEORITICAL MODELS

$$d_L = \frac{c(1+z)}{H_0} \int_0^z \frac{dz'}{\sqrt{\Omega_M (1+z')^3 + \Omega_k (1+z')^2 + \Omega_\Lambda (1+z')^{3(1+\omega)}}}$$

Stretch

$$m_{corr} = m_B + \alpha X$$

Fainter SNe Ia → Smaller stretch factor, i.e., narrow LC

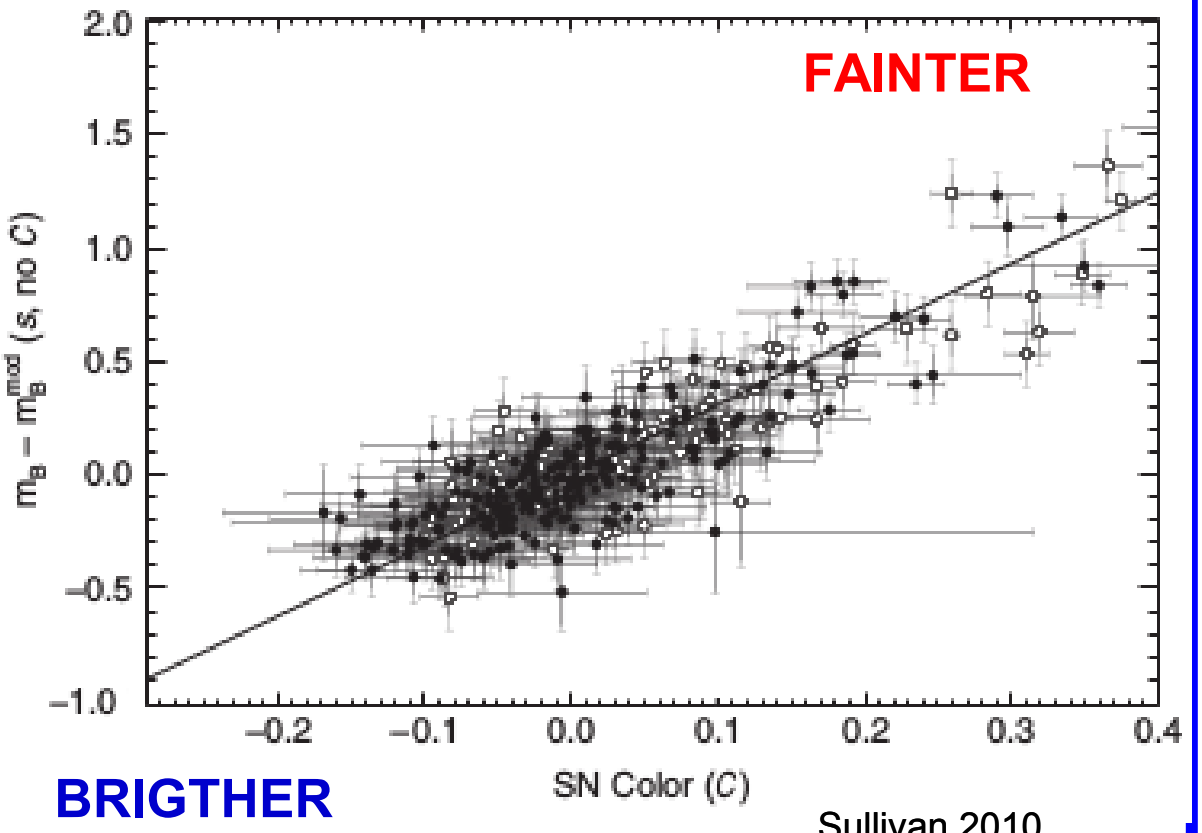


Sullivan 2010

Colour

$$m_{corr} = m_B + \alpha X - \beta C$$

Fainter SNe Ia → Redder



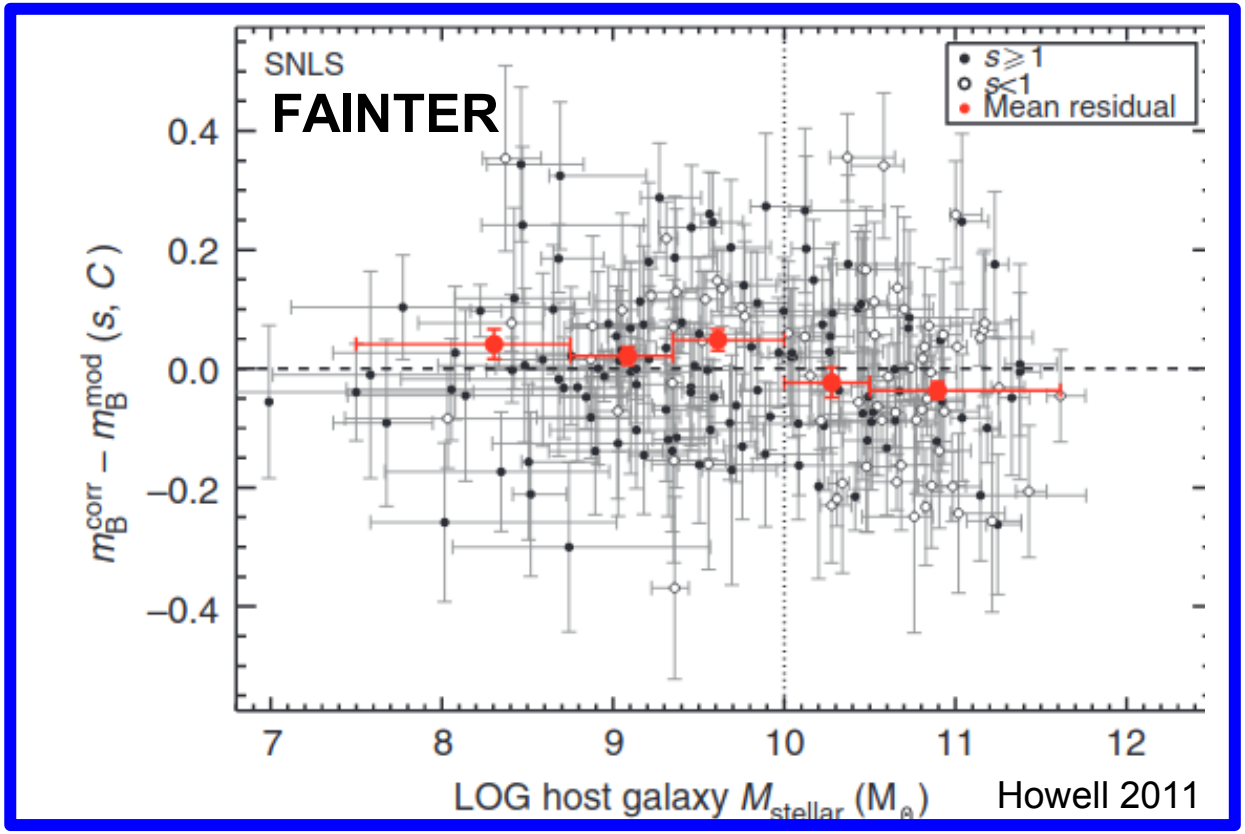
Sullivan 2010

Mass step

$$m_{corr} = m_B + \alpha X - \beta C - \begin{cases} Mb \\ Mb + \delta M \text{ if } M_{stellar} > 10^{10} Msol \end{cases}$$

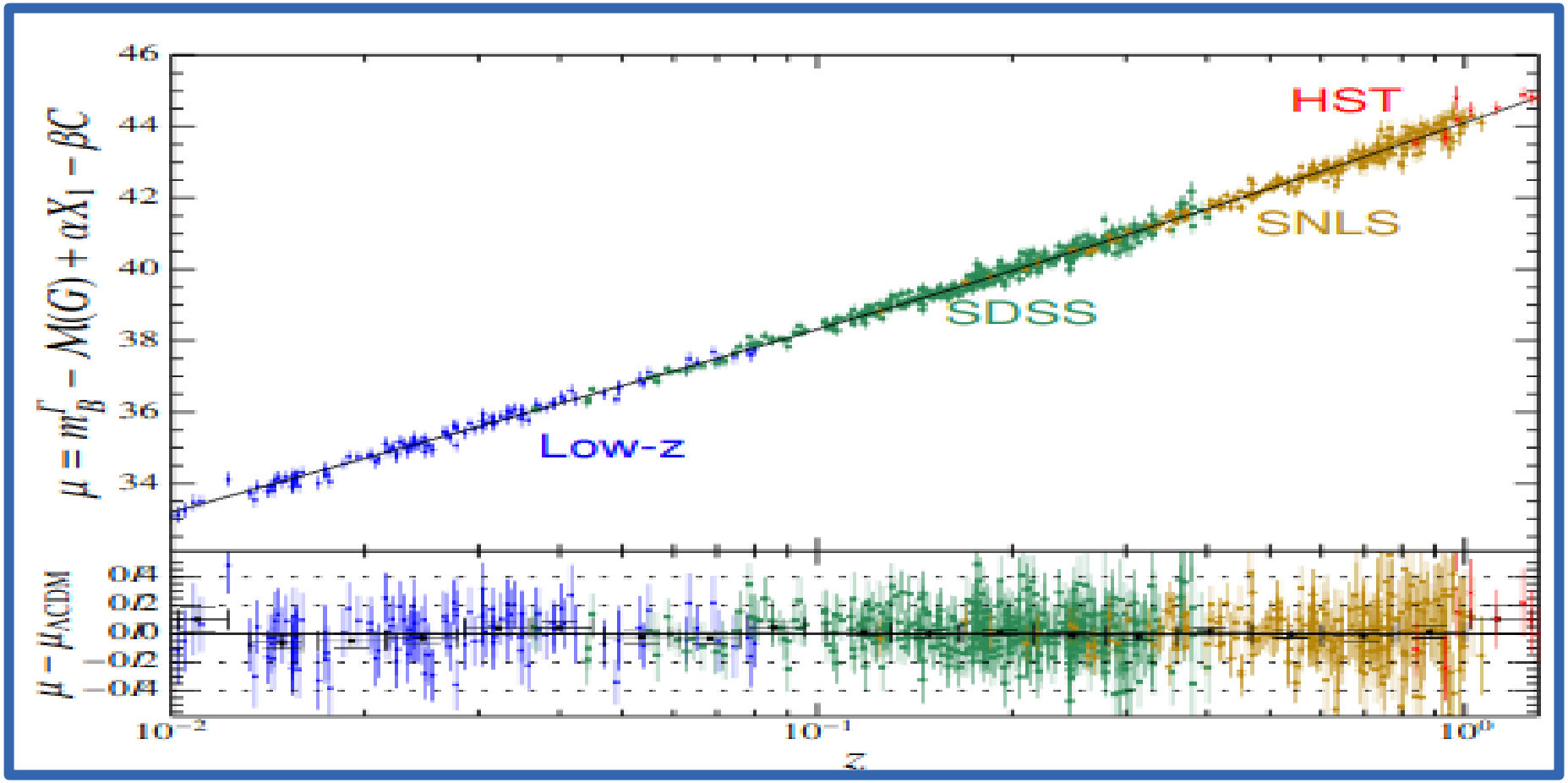
Nuissance parameters

SNe Ia in high mass galaxy → Brighter



Supernova Cosmology

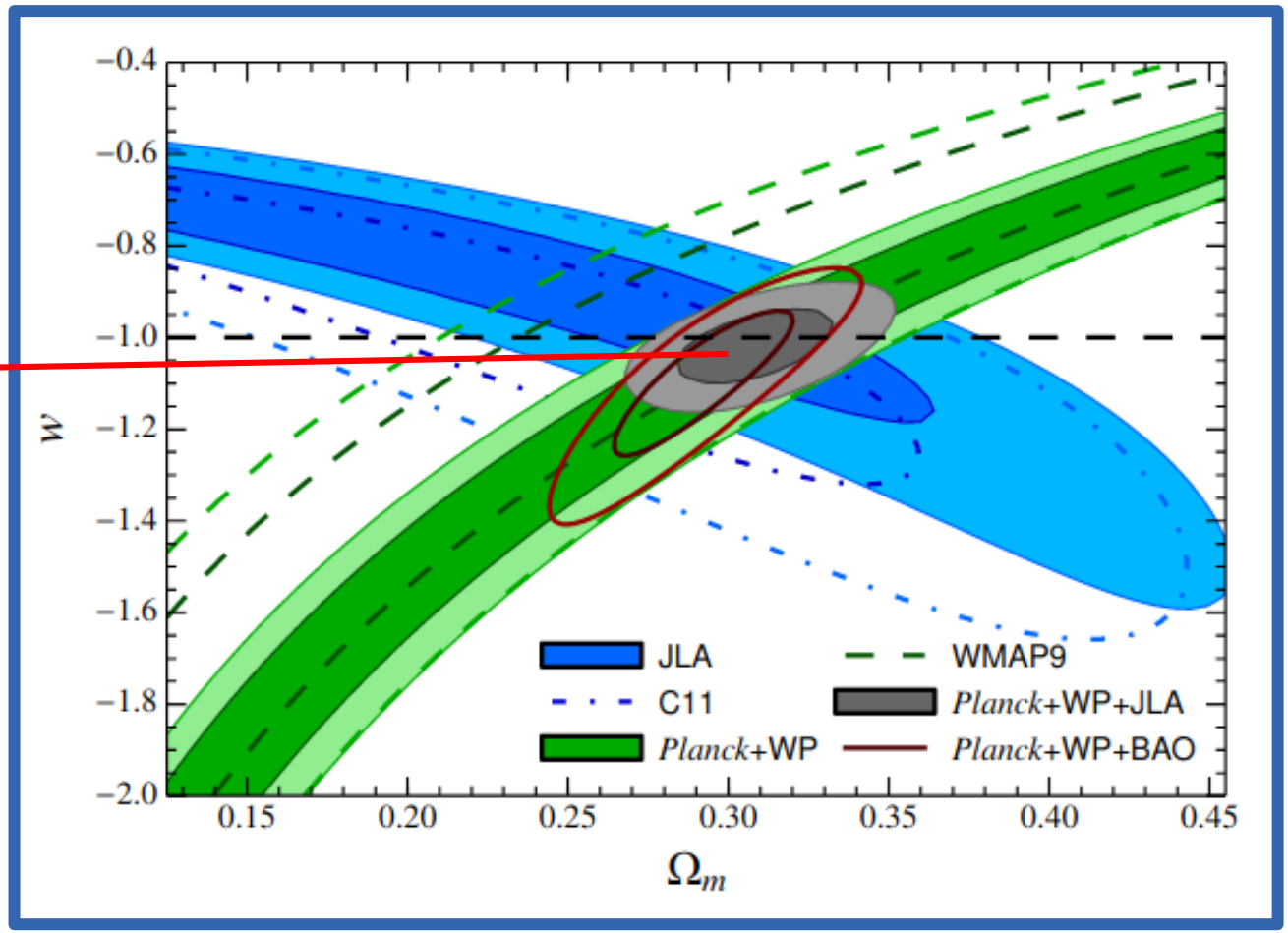
740 SNe Ia (Betoule et al. 2014)



Supernova Cosmology

•SNe Ia + Others probes → Better constraints!!!!

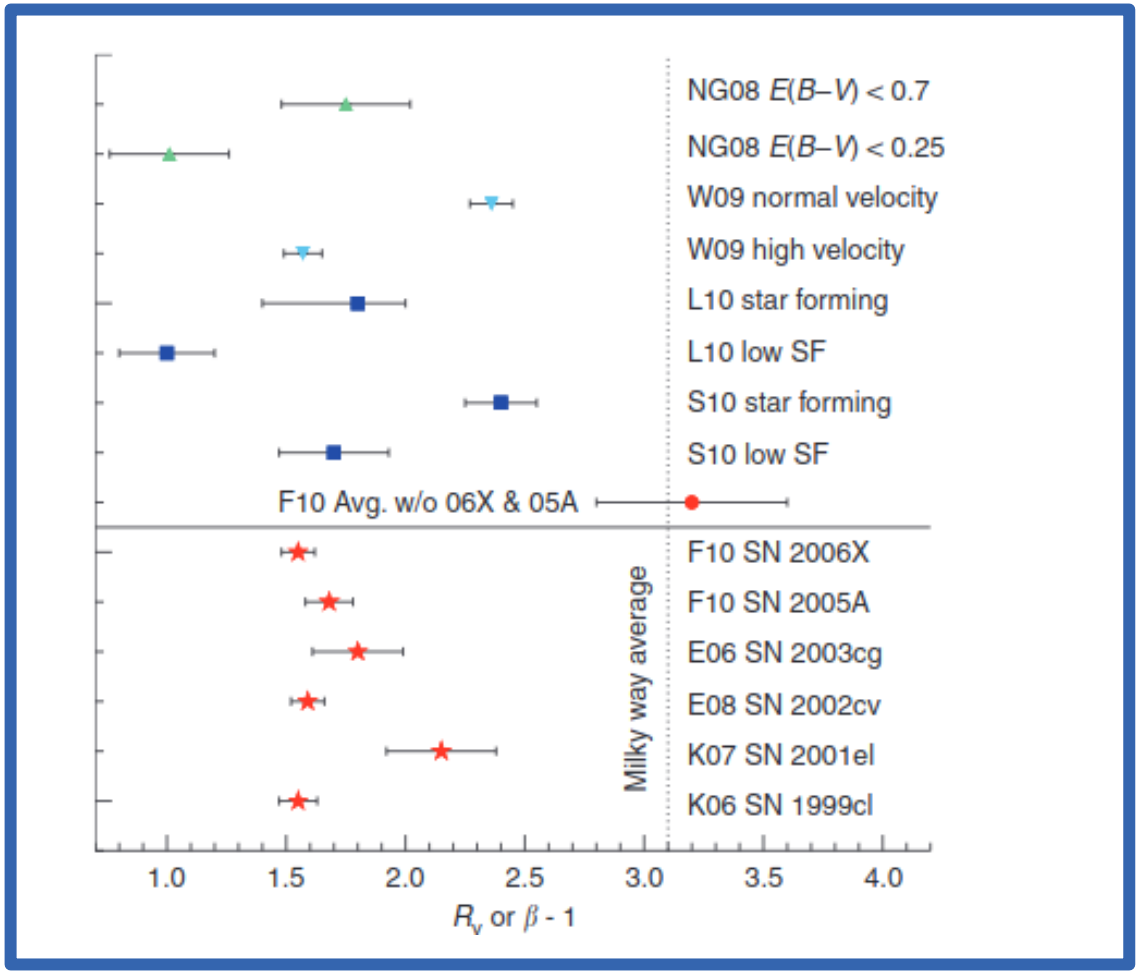
w=-1.018
+/- 0.057



Betoule et al. 2014

Problems

- **If reddening is only due to dust, then $\beta = R_B = R_V + 1$** *(optical total-to-selective extinction)*
- **Same β for all the host galaxies**



Howell 2011

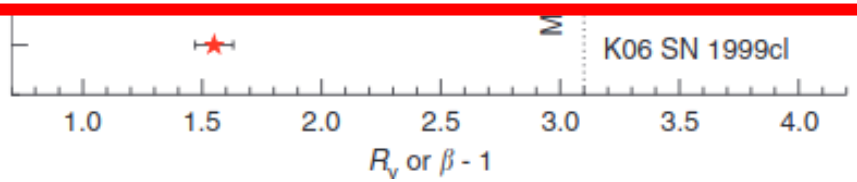
Problems

- **If reddening is only due to dust, then $\beta = R_B = R_V + 1$** *(optical total-to-selective extinction)*
- **Same β for all the host galaxies**

Using individual SNe Ia or sample, **Rv values measured are unsually low**

→ Smaller dust grains in SN Ia host-galaxies….

→ Intrinsic dust….



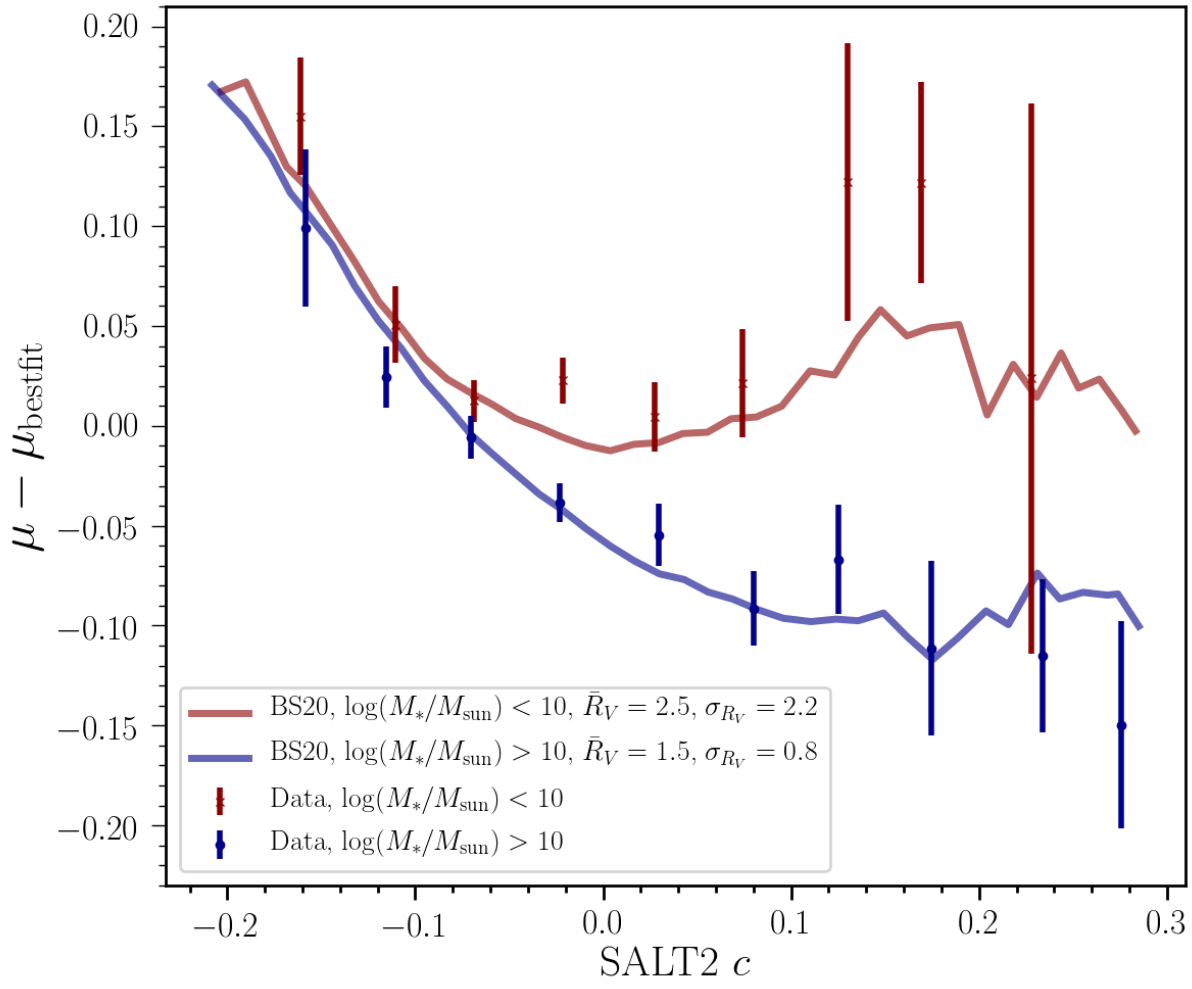
Howell 2011

Problems

Split into high and low host-mass
-> a distinct difference of the color dependence in the biases of Hubble residuals

→ **Small Rv high stellar mass**

→ **Host galaxy stellar mass correlation due to dust.**

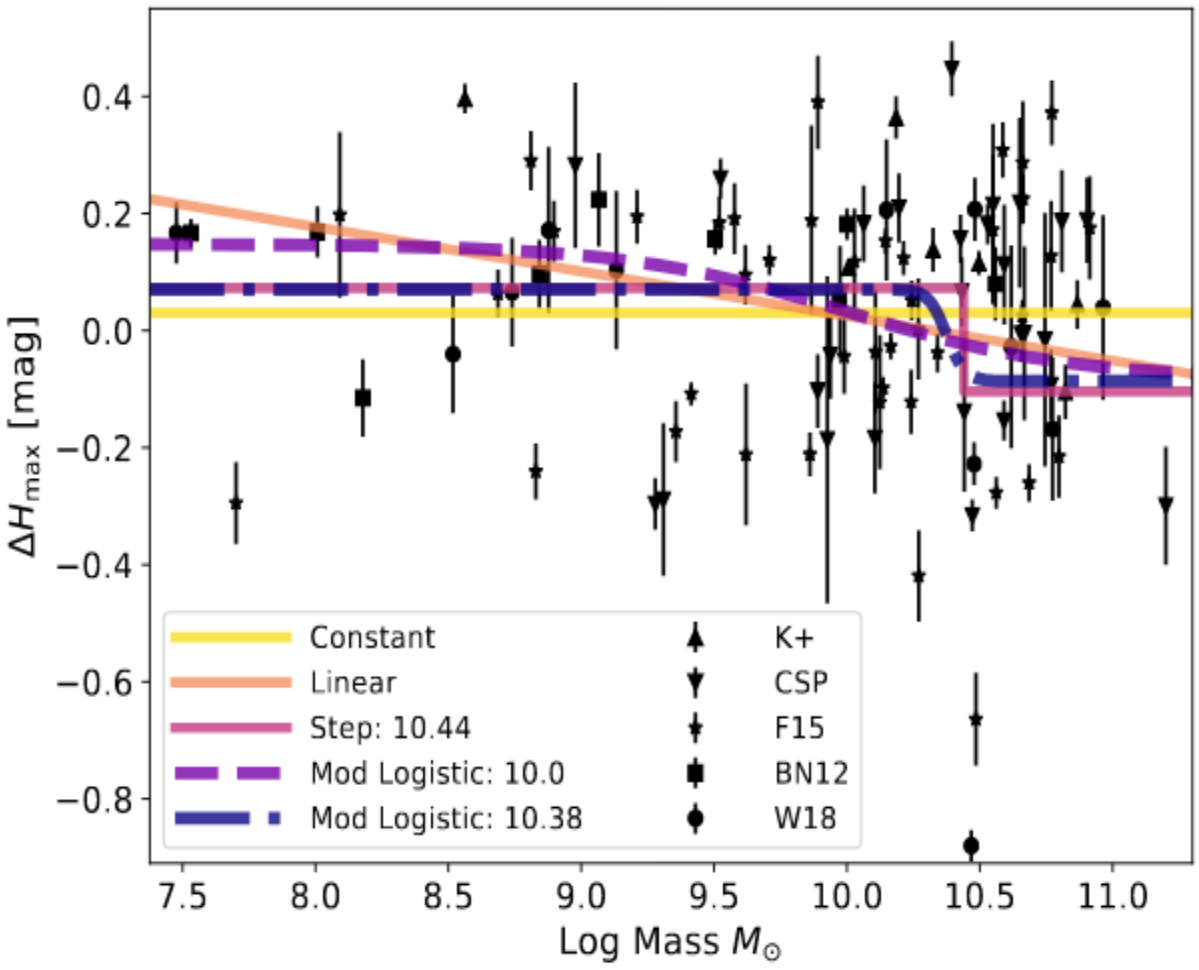


Brout & Scolnic 2020

Problems

BUT correlation is also seen in NIR.

-> some of the correlation may be due to dust but not all of the correlation. (Ponder et al. 2020, Uddin et al. 2020)



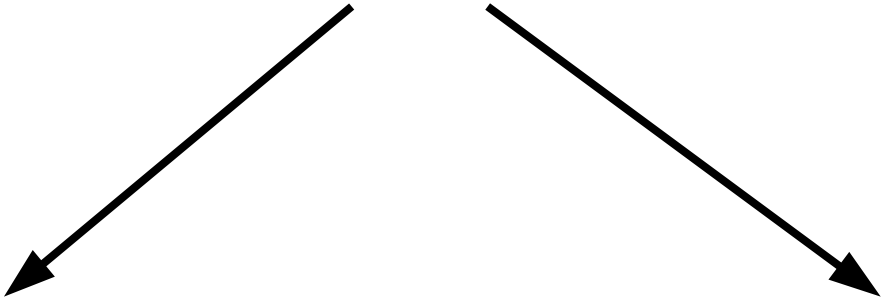
Ponder et al. 2020

Project

Implications of varying Rv in cosmology (w, Ω_m)

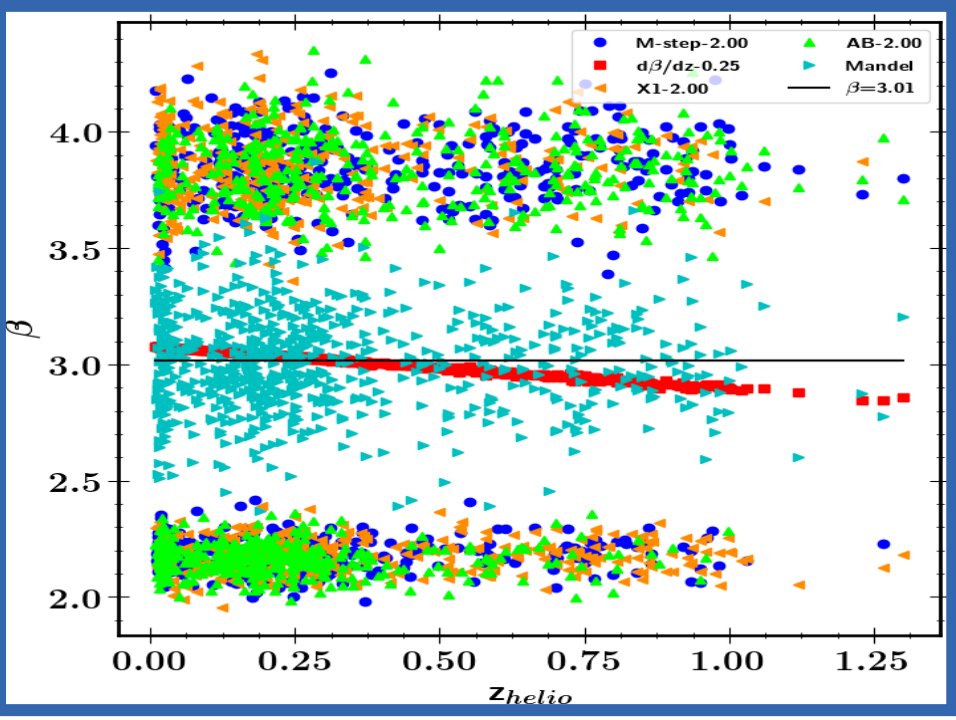
Project

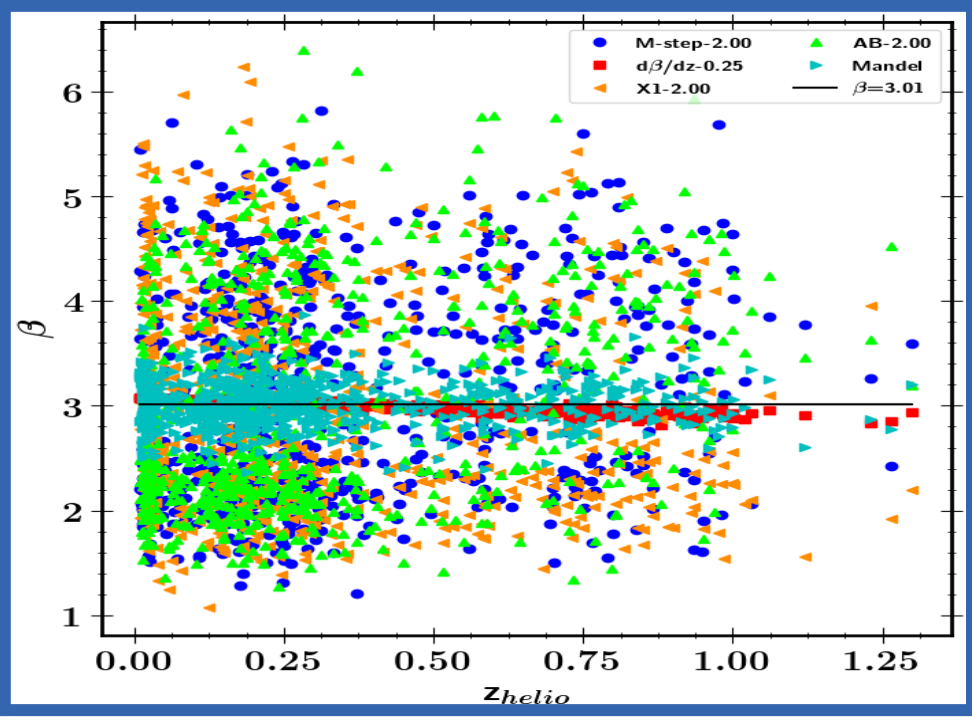
Implications of varying Rv in cosmology (w, Ω_m)

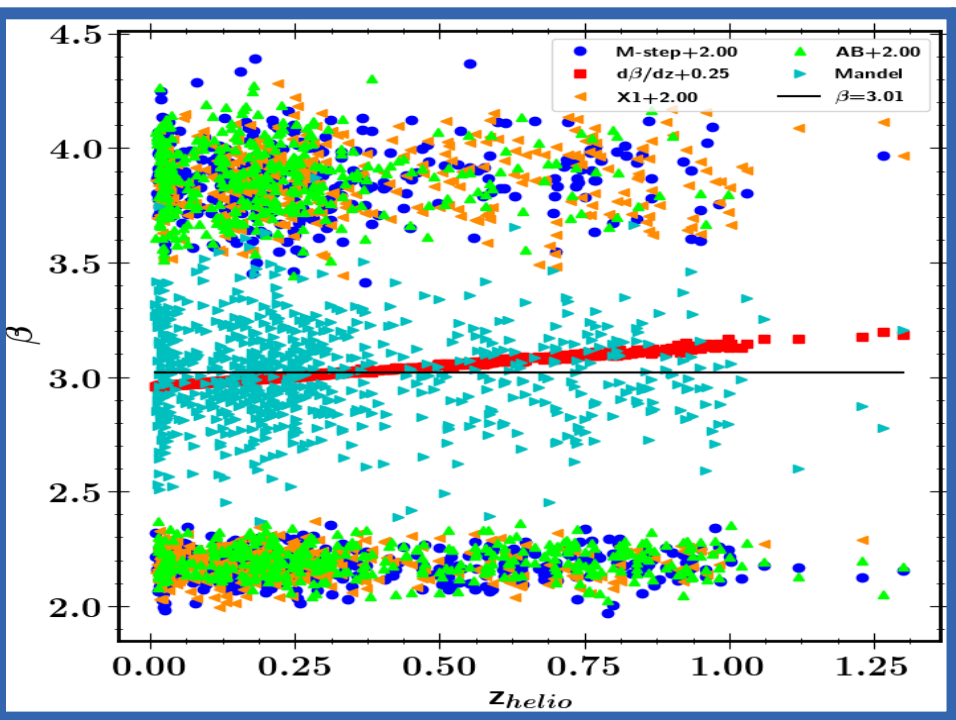


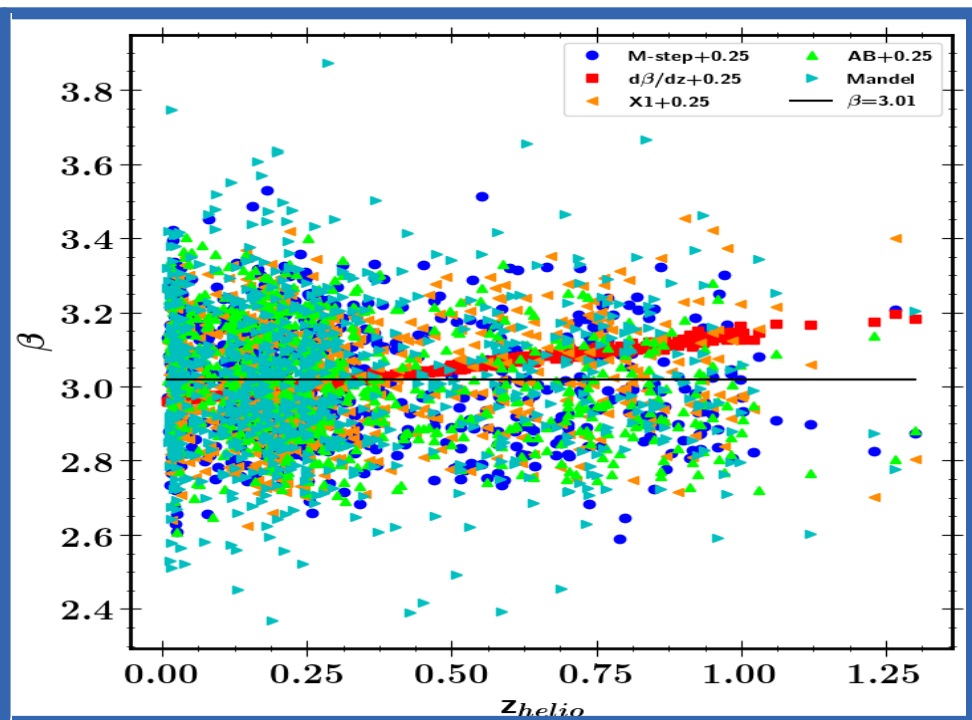
Assign a different β to each SN of the sample of 740 SNe Ia

Effect of using a β step with different observables such as color, stretch, Mstellar, mag and redshift

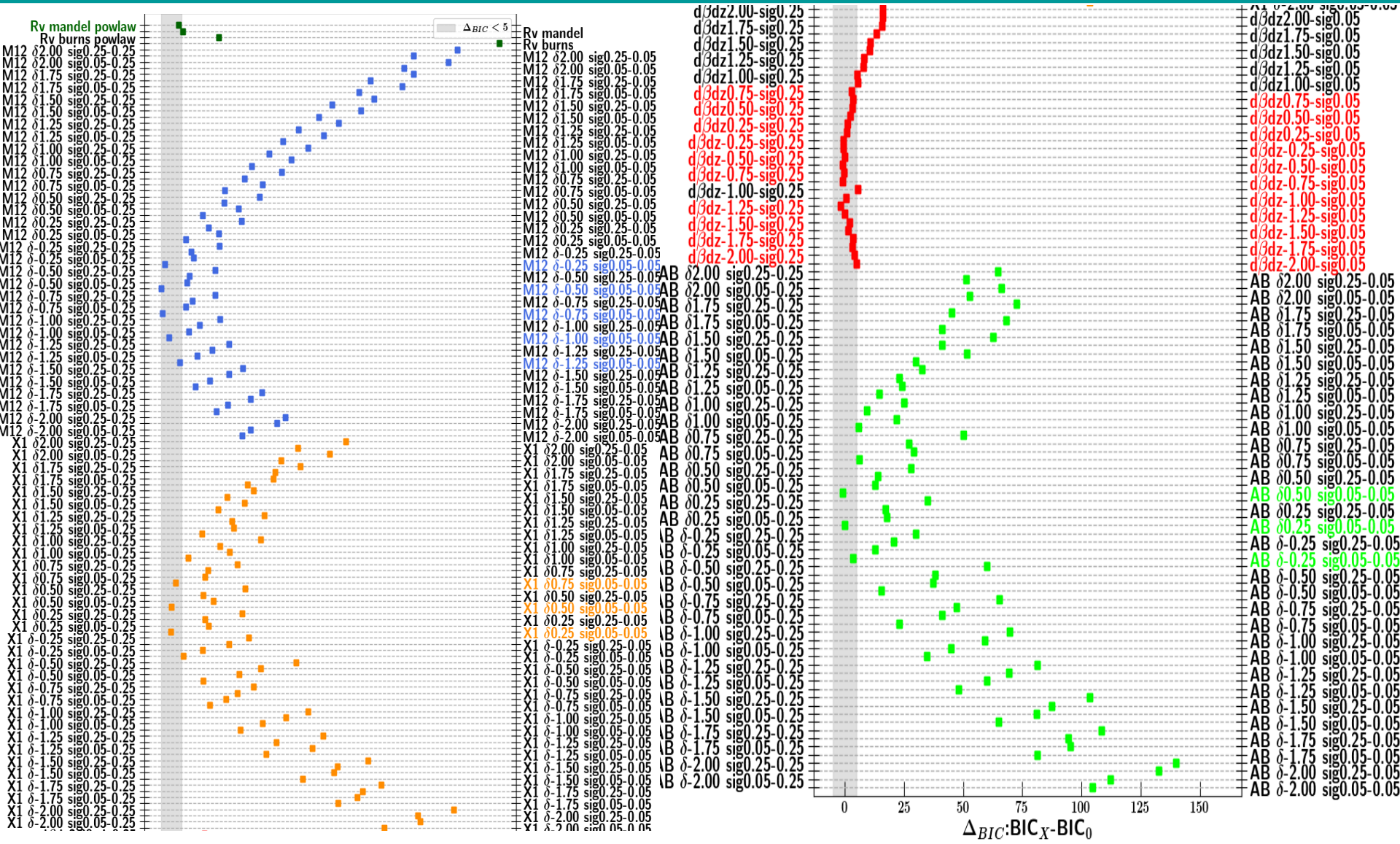

M-step-2.00
dβ/dz-0.25
X1-2.00
AB-2.00
Mandel
β=3.01
β
z_helio

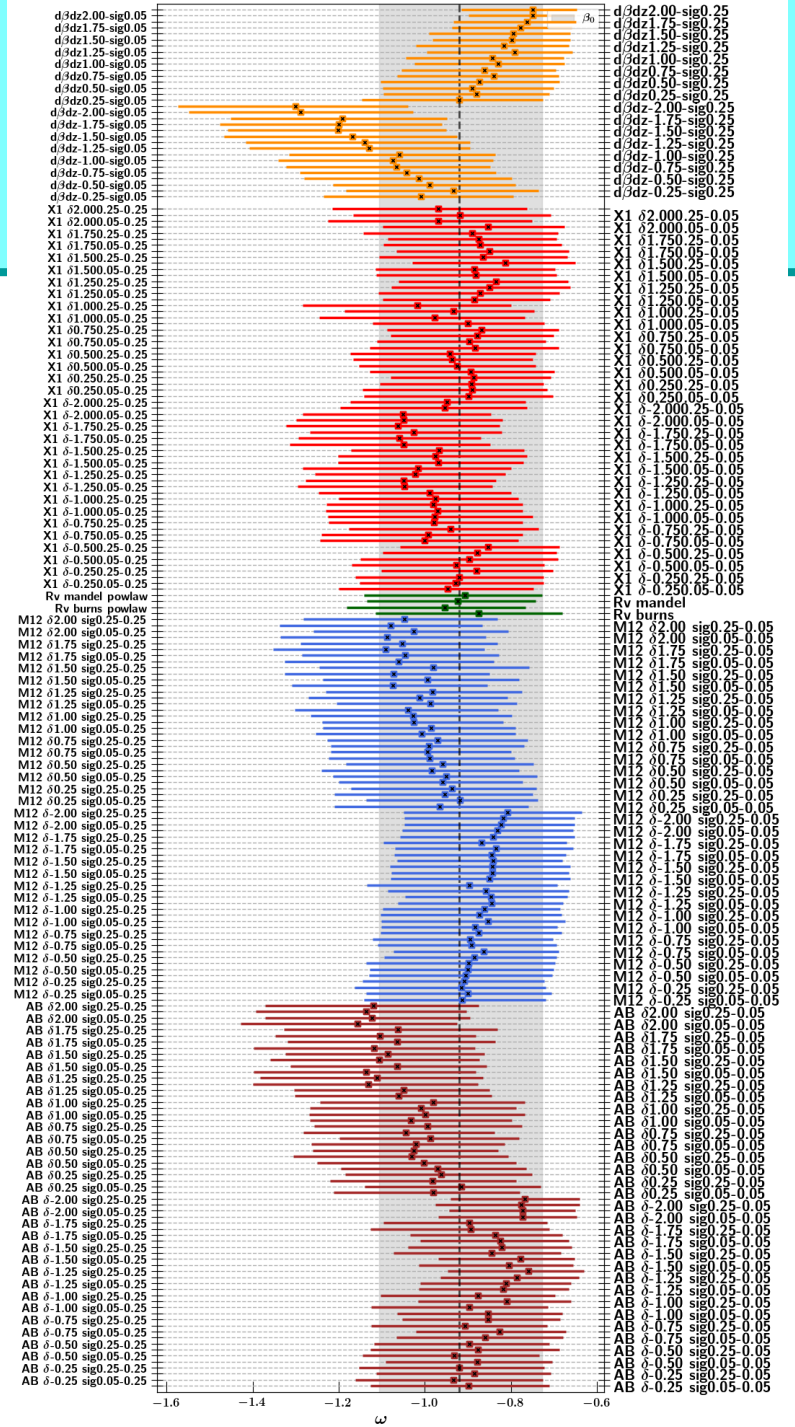

M-step-2.00
dβ/dz-0.25
X1-2.00
AB-2.00
Mandel
β=3.01
β
z_helio


M-step+2.00
dβ/dz+0.25
X1+2.00
AB+2.00
Mandel
β=3.01
β
z_helio


M-step+0.25
dβ/dz+0.25
X1+0.25
AB+0.25
Mandel
β=3.01
β
z_helio

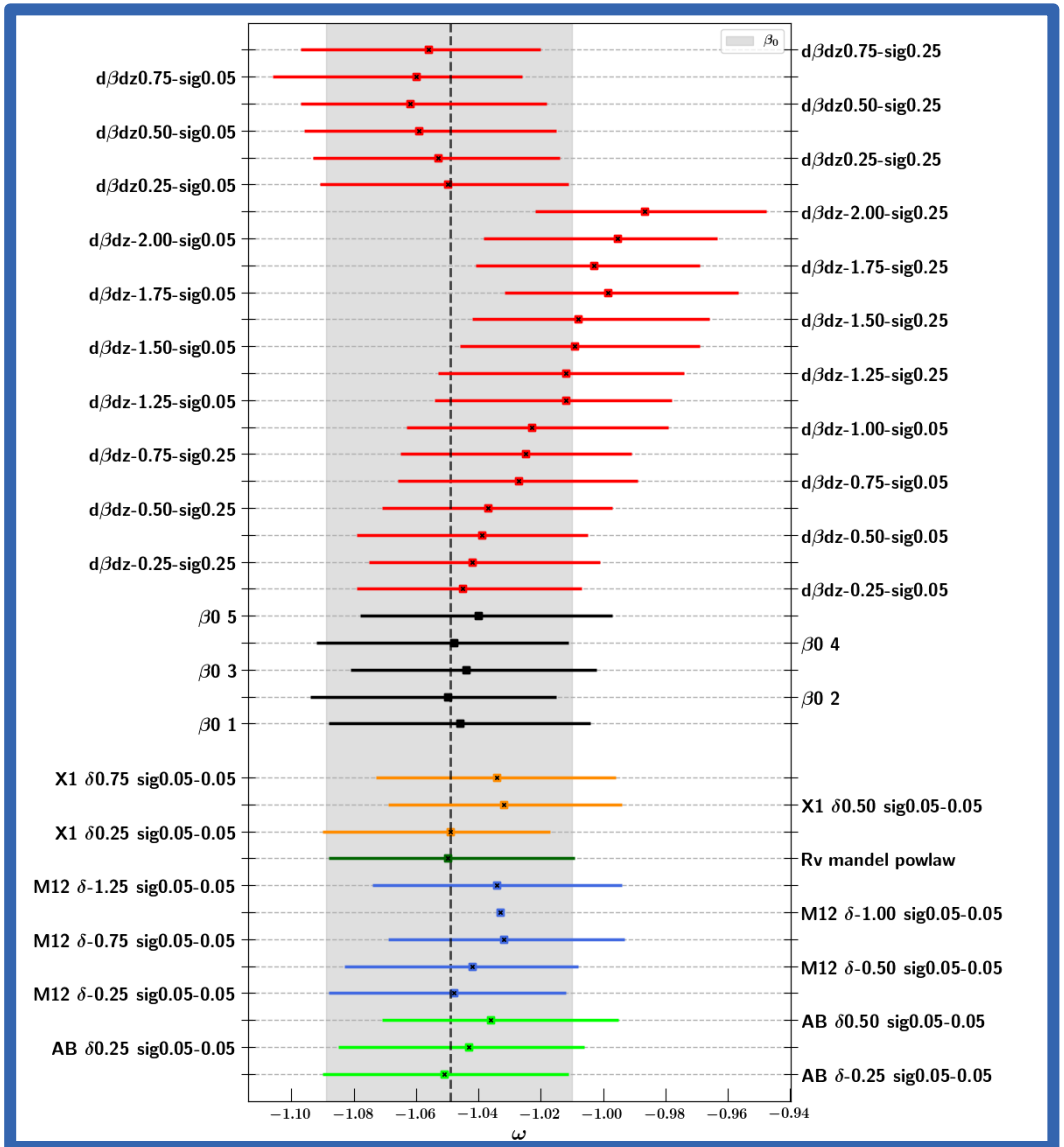
Project: Part 1 (EMCEE)



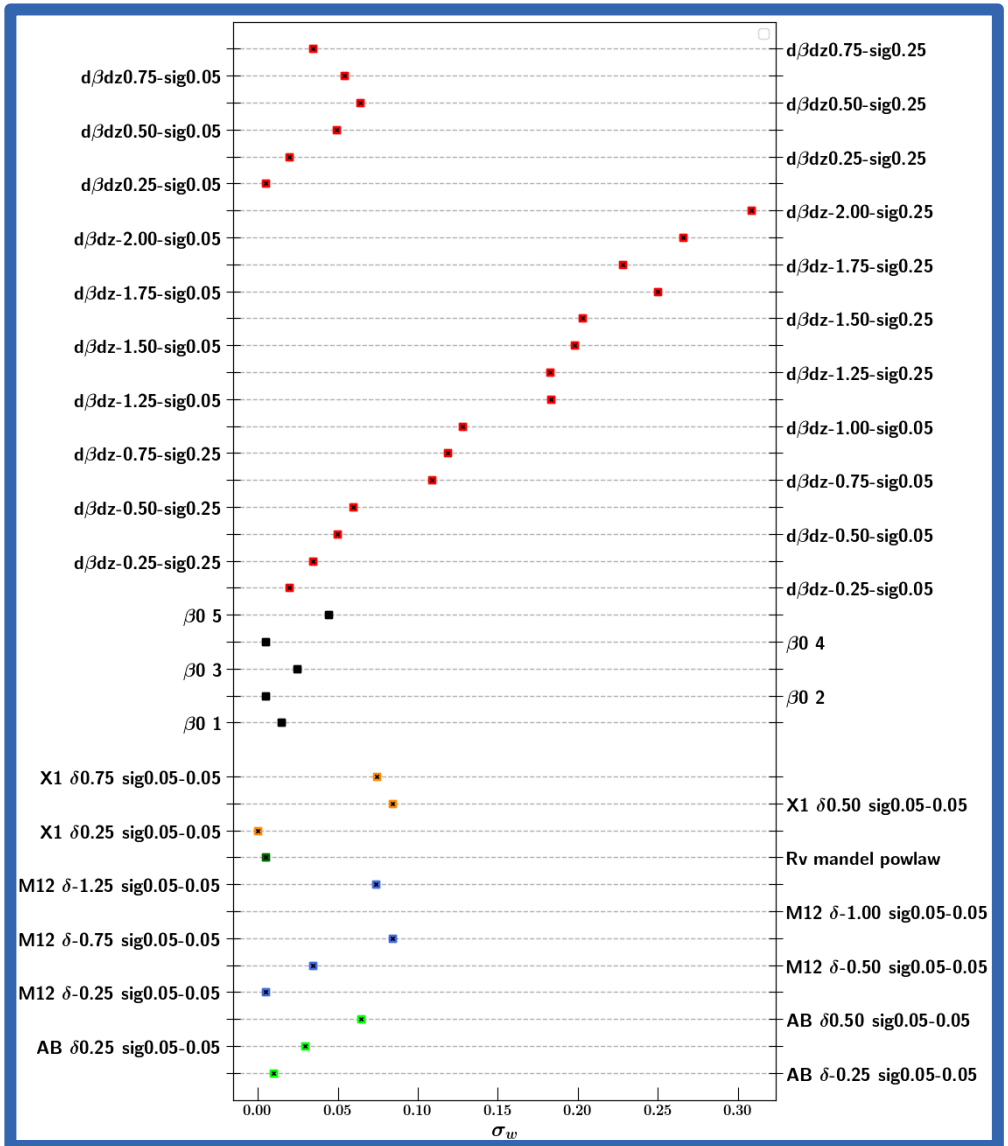

β_0
-1.6
-1.4
-1.2
-1.0
-0.8
-0.6
ω

Project: Part 1 (Montepython)

Add Planck to improve contraints
→ Montepython (~COSMOMC)
→ Model with ΔBIC<5



Project: Part 1 (Montepython)



Difference <0.3 sigma….

Comparison Betoule+14

4chains, 10 000 steps JLA + Planck 2018 **without** covar from Betoule et. 2014.

$$-2\ln(\mathcal{L}) = \sum_{\mathrm{SN}} \left\{ \frac{\left[m_B^{\mathrm{obs}} - (Mb + \delta_M - \alpha X + \beta C) - 5\log_{10}(d_L(z, \Omega_{\mathrm{m}}, \Omega_\Lambda)) - 25\right]^2}{\sigma_{m_B}^2 + (\alpha\sigma_X)^2 + (\beta\sigma_C)^2 + 0.105^2} \right\},$$

Param	best-fit	mean$\pm\sigma$	95% lower	95% upper
w	-1.041	$-1.037^{+0.048}_{-0.045}$	-1.127	-0.9469
α	0.1356	$0.1359^{+0.0088}_{-0.0086}$	0.1183	0.1535
β	3.031	$3.019^{+0.097}_{-0.11}$	2.821	3.221
M	-19.11	$-19.1^{+0.029}_{-0.034}$	-19.16	-19.04
Δ_M	-0.0479	$-0.05348^{+0.015}_{-0.016}$	-0.08449	-0.02221
Ω_m	0.3064	$0.3027^{+0.014}_{-0.012}$	0.2761	0.3298

JLA + Planck 2014 published by Betoule et. 2014:

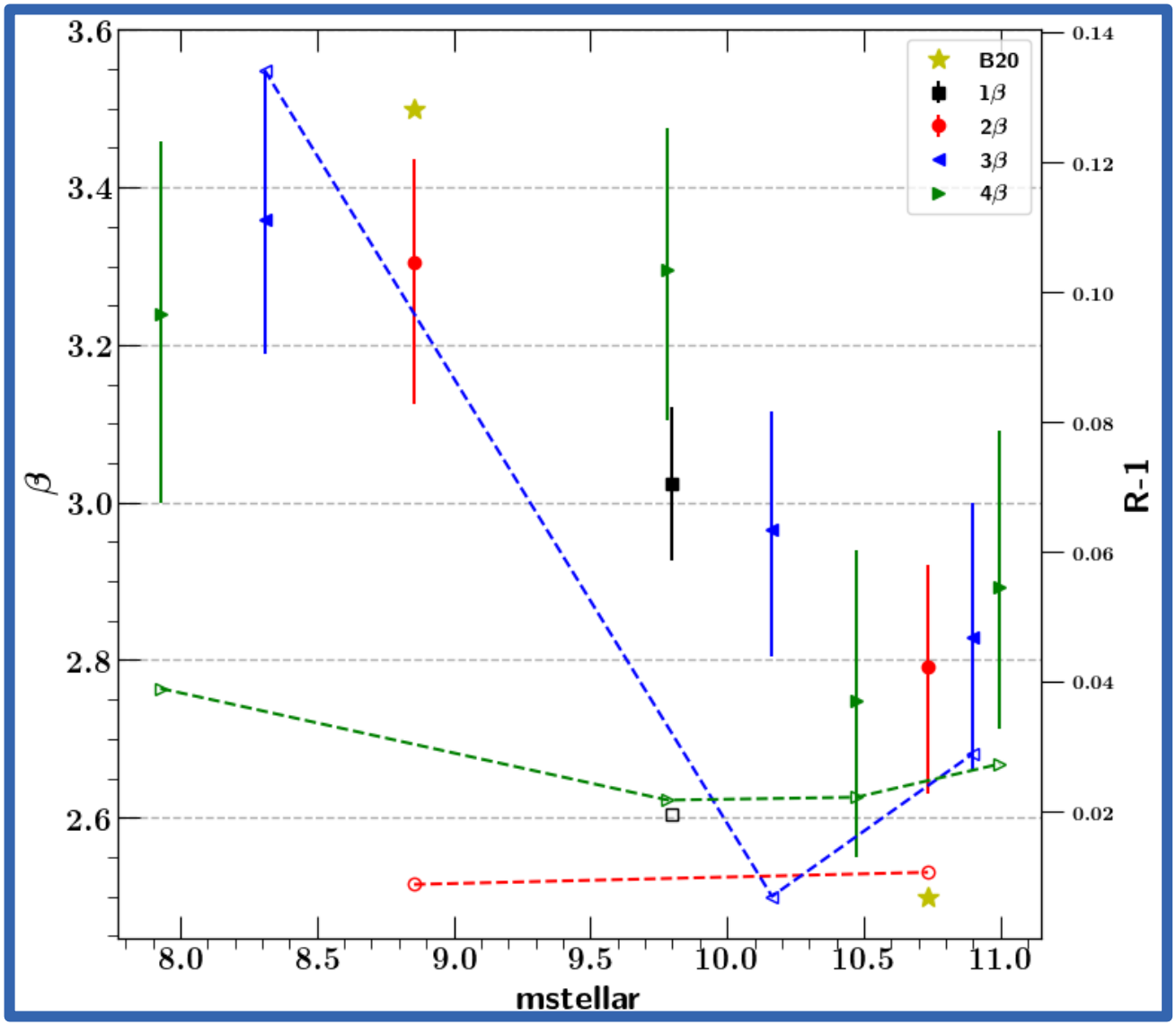
Param	mean$\pm\sigma$
w	-1.018 ± 0.057
α	0.141 ± 0.006
β	3.100 ± 0.075
M	-19.11 ± 0.04
Δ_M	-0.070 ± 0.023
Ω_m	0.307 ± 0.017

Project: Part 2 (β steps)

Fit the cosmology using 1,2,3, or 4β and different observables such as color, stretch, Mstellar, mag and redshift.

→ e.g. Mstellar

R-1=Gelman-Rubin convergence test
Should be **<0.05**



Project: Part 2 (β steps)

Fit the cosmology using 1,2,3, or 4β and different observables such as color, stretch, Mstellar, mag and redshift.

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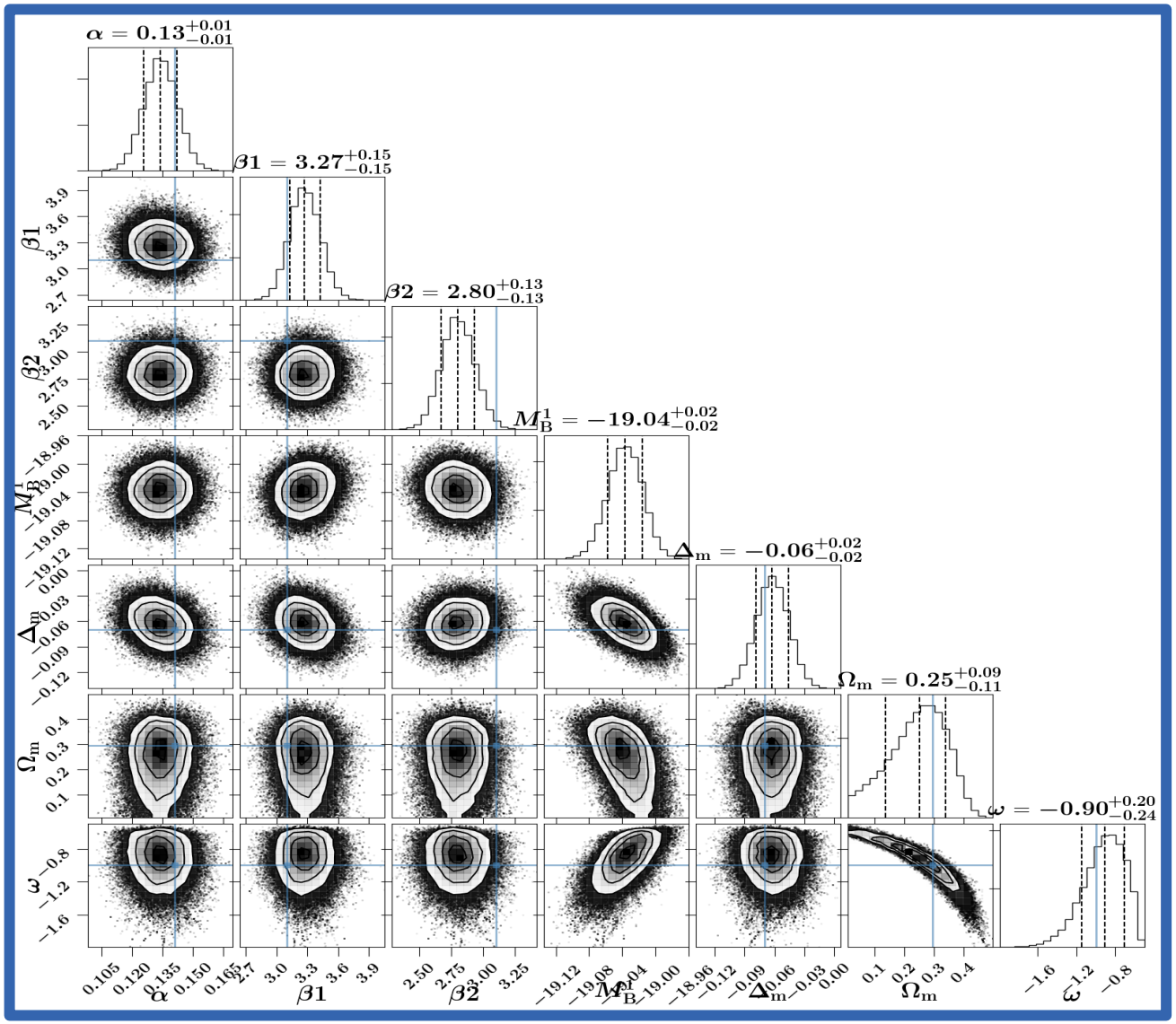
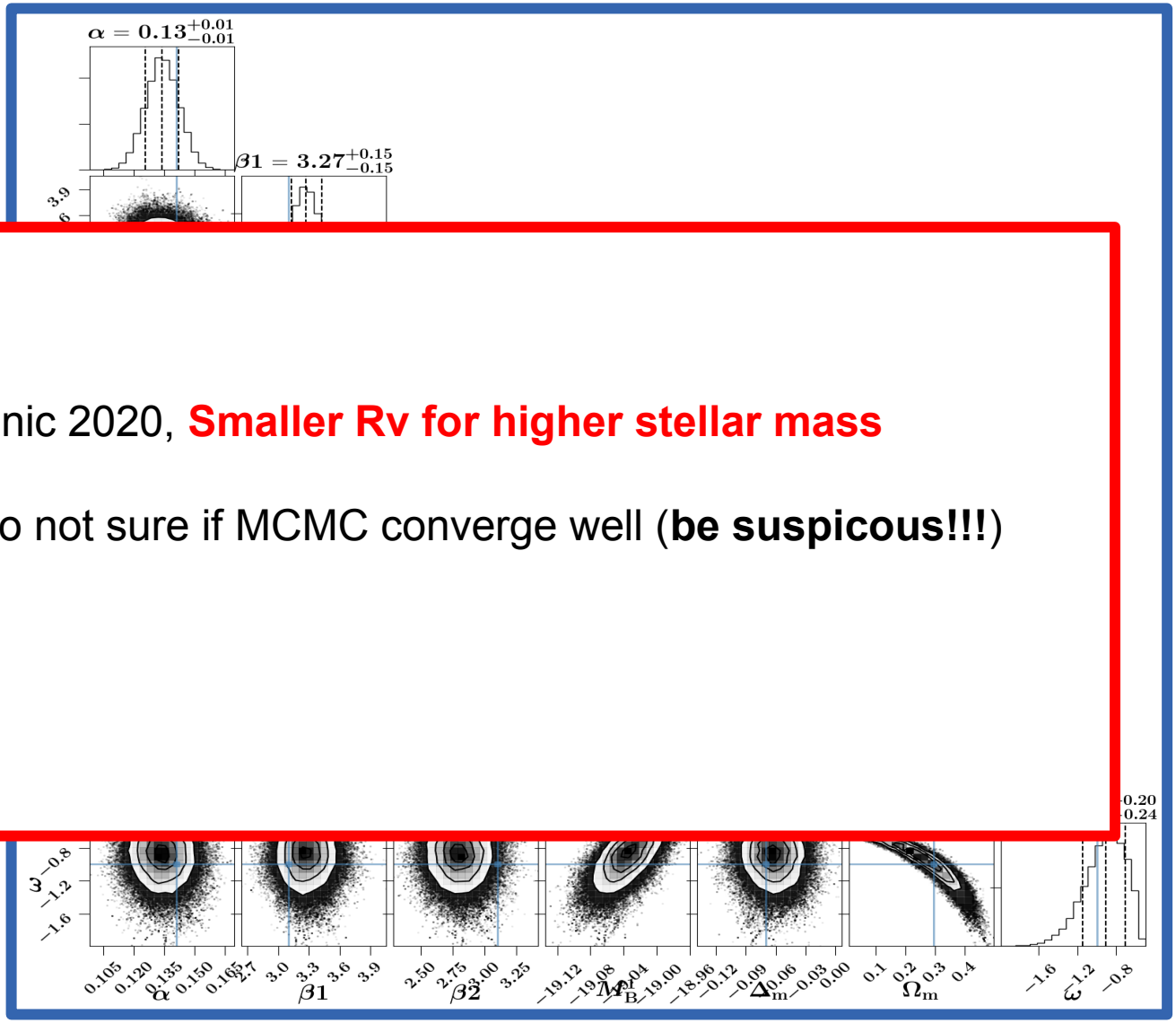


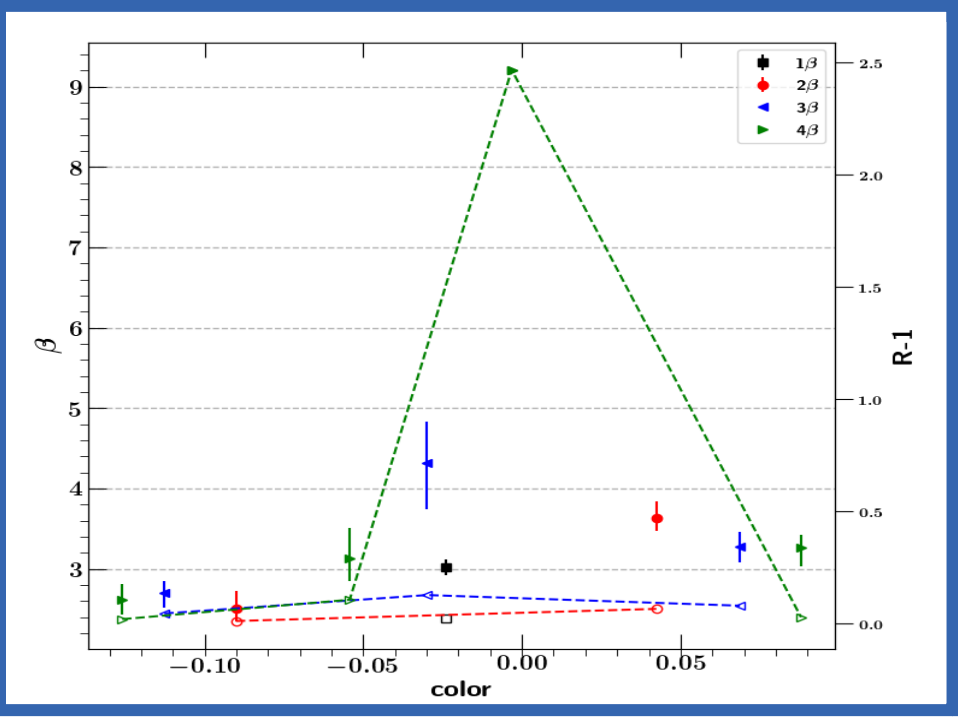
Project: Part 2 (β steps)

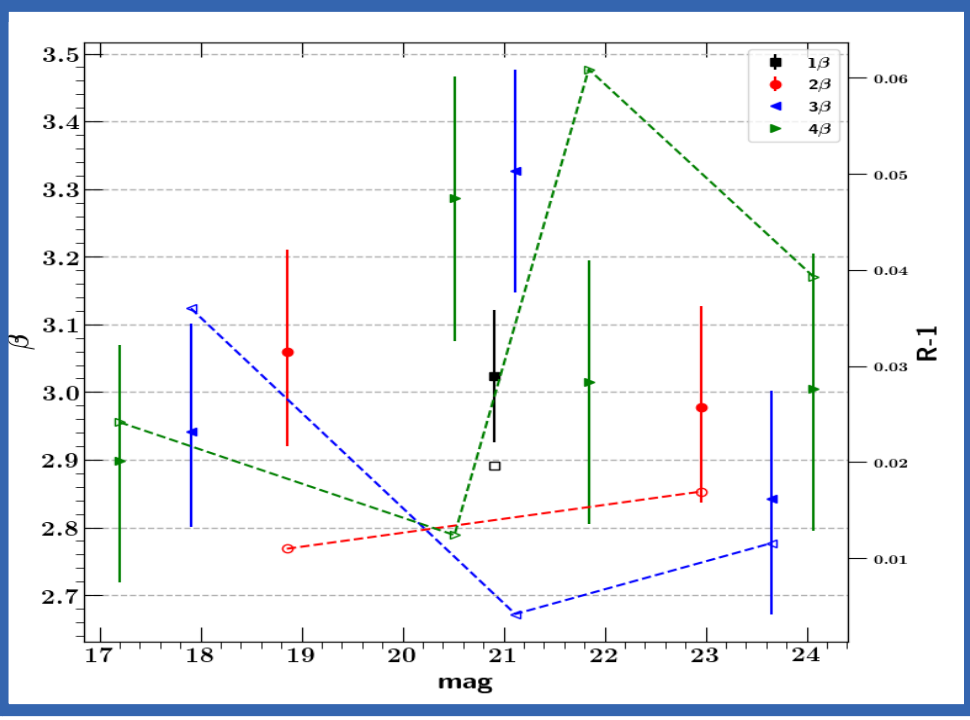
Fit the cosmology using 1,2,3, or 4β and different observables such as color, stretch, Mstellar, mag and r

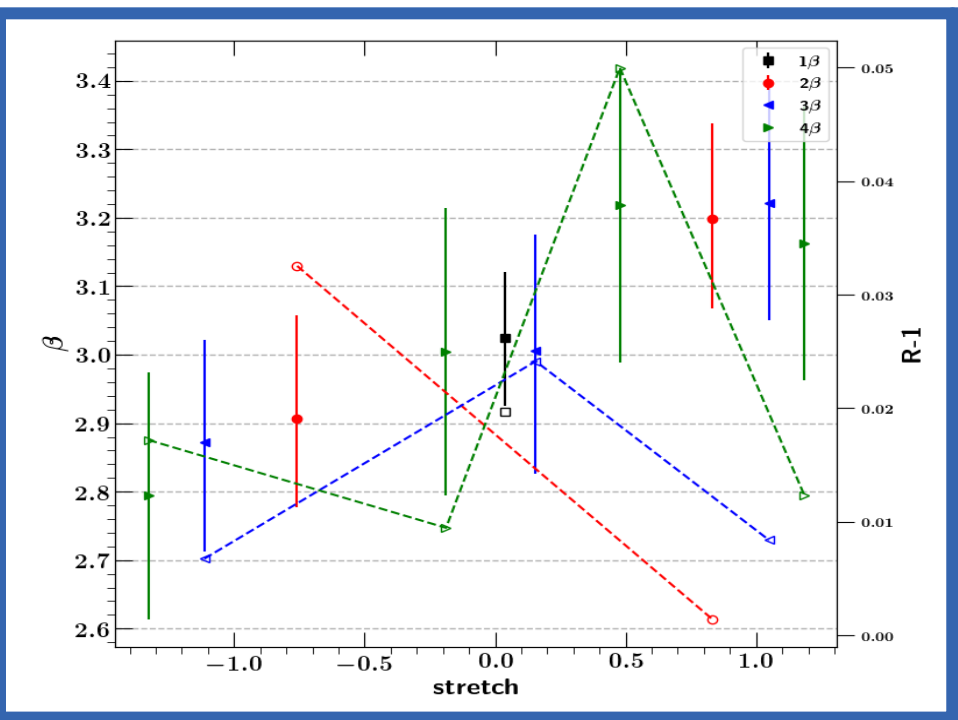
Similar to Brout & Scolnic 2020, **Smaller Rv for higher stellar mass**

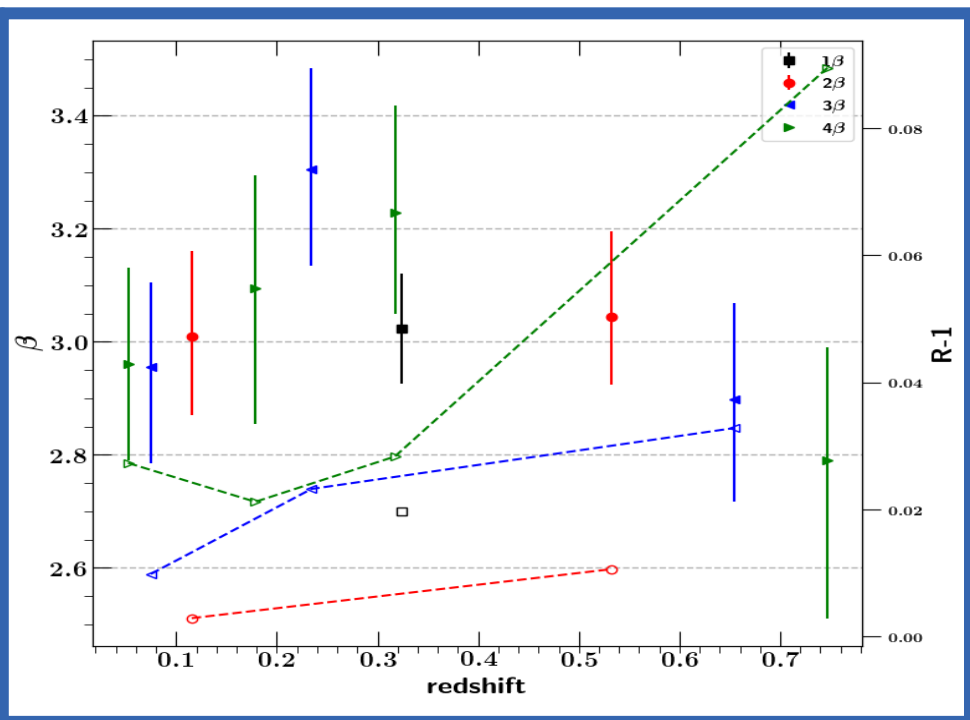
→ **BUT** R-1 are large so not sure if MCMC converge well (**be suspicous!!!**)

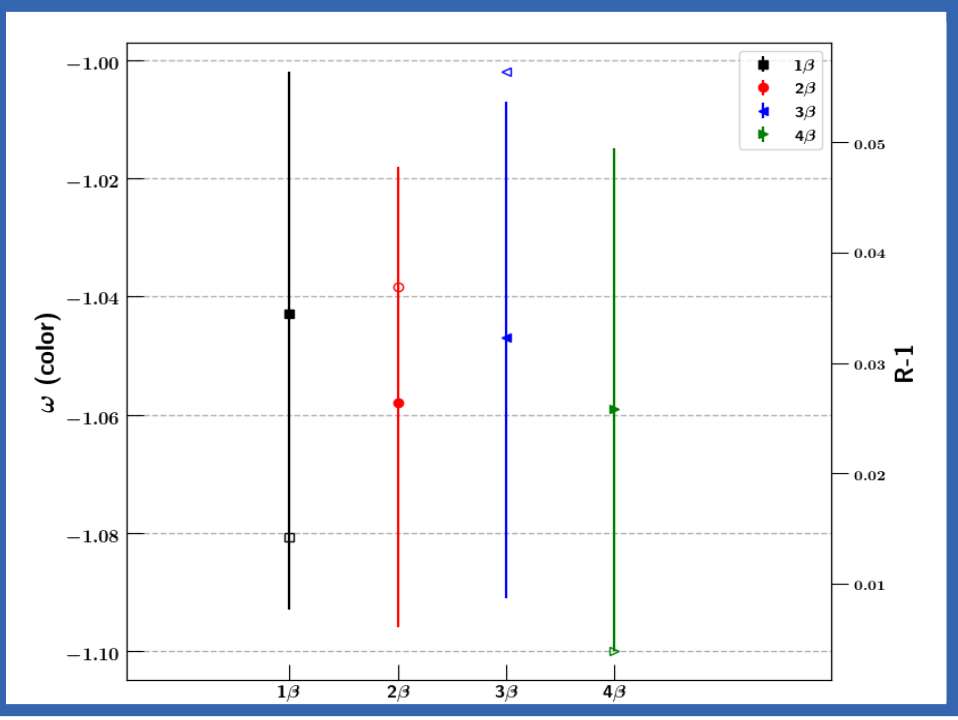


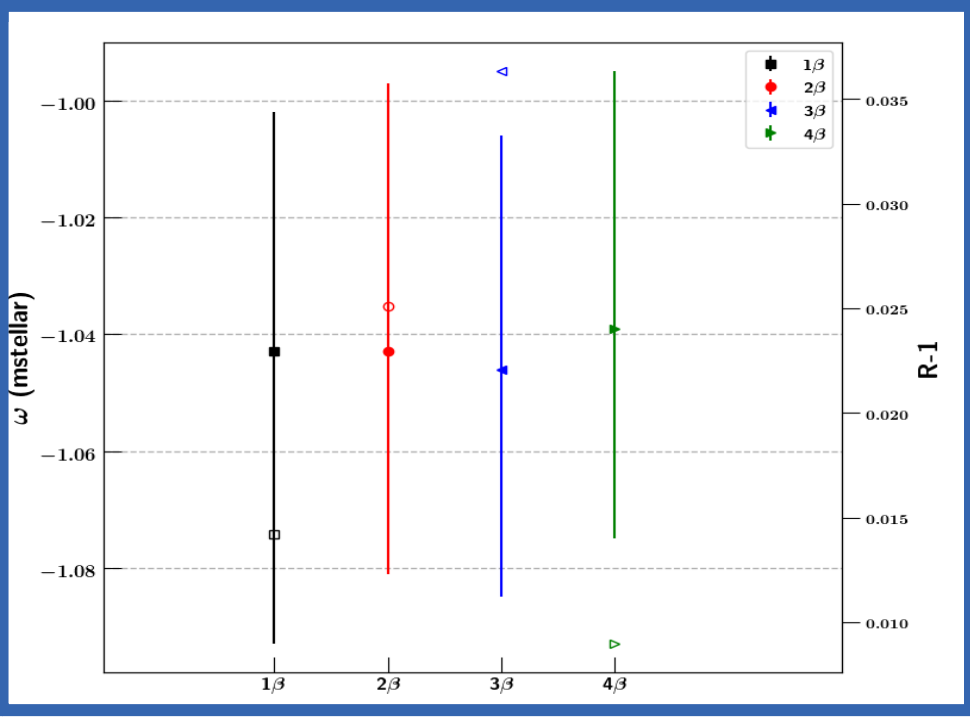

1β
2β
3β
4β
β
R-1
color

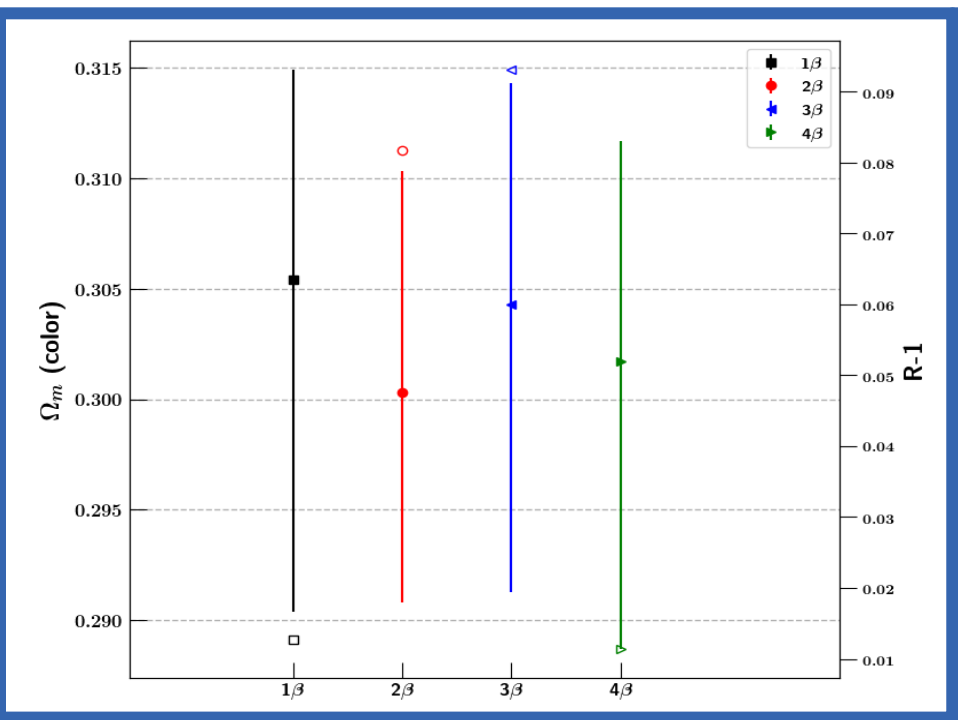

1β
2β
3β
4β
β
R-1
mag

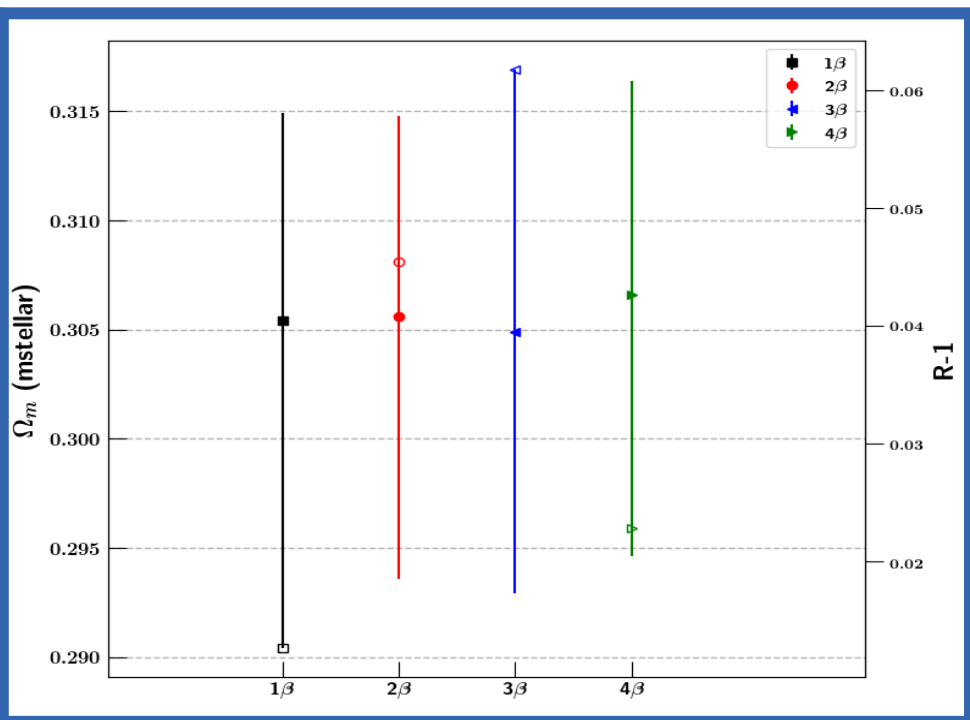

1β
2β
3β
4β
β
R-1
stretch


1β
2β
3β
4β
β
R-1
redshift


ω (color)
R-1
1β
2β
3β
4β


ω (mstellar)
R-1
1β
2β
3β
4β


Ω_m (color)
R-1
1β
2β
3β
4β


Ω_m (mstellar)
R-1
1β
2β
3β
4β

Conclusions

- **Part 1**: Using different β for each SN Ia, no statistical difference is seen on the cosmological parameters

- **Part 2**: SNe Ia in low stellar mass host galaxy have higher Rv. Need to check our MCMC simulation for 3,4 beta.