No Dark Energy is required if we accept a slightly inhomogeneous viewpoint

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Dark Energy is required to explain the SNe m-z relation.

Does we need Dark Energy, really?

We re-analyze
the m-z relation of the observed
SNe Ia and examine an alternative
possibility without Dark Energy.

We find that

no Dark Energy is required

if we accept

the following slightly

inhomogeneous universe:

1) the expansion rate in the nearby ($z \lesssim 0.1$) region is slightly $\sim 10\%$ faster than that in the distant ($z > 0.1$) region.

2) the clumpiness parameter α in the Dyer & Roeder distance is also slightly inhomogeneous; $\alpha \sim 0$ in the nearby region while $\alpha \sim 0.2$ in the distant region.

If we assume that the universe is homogeneous, we need Dark Energy.

What happens
if we accept
the inhomogeneous
universe?

Purpose

- Based on the observational SNe Ia data, we consider the large-scale inhomogeneity and local emptiness of the universe.
- Can we reproduce the observational data without Dark Energy?

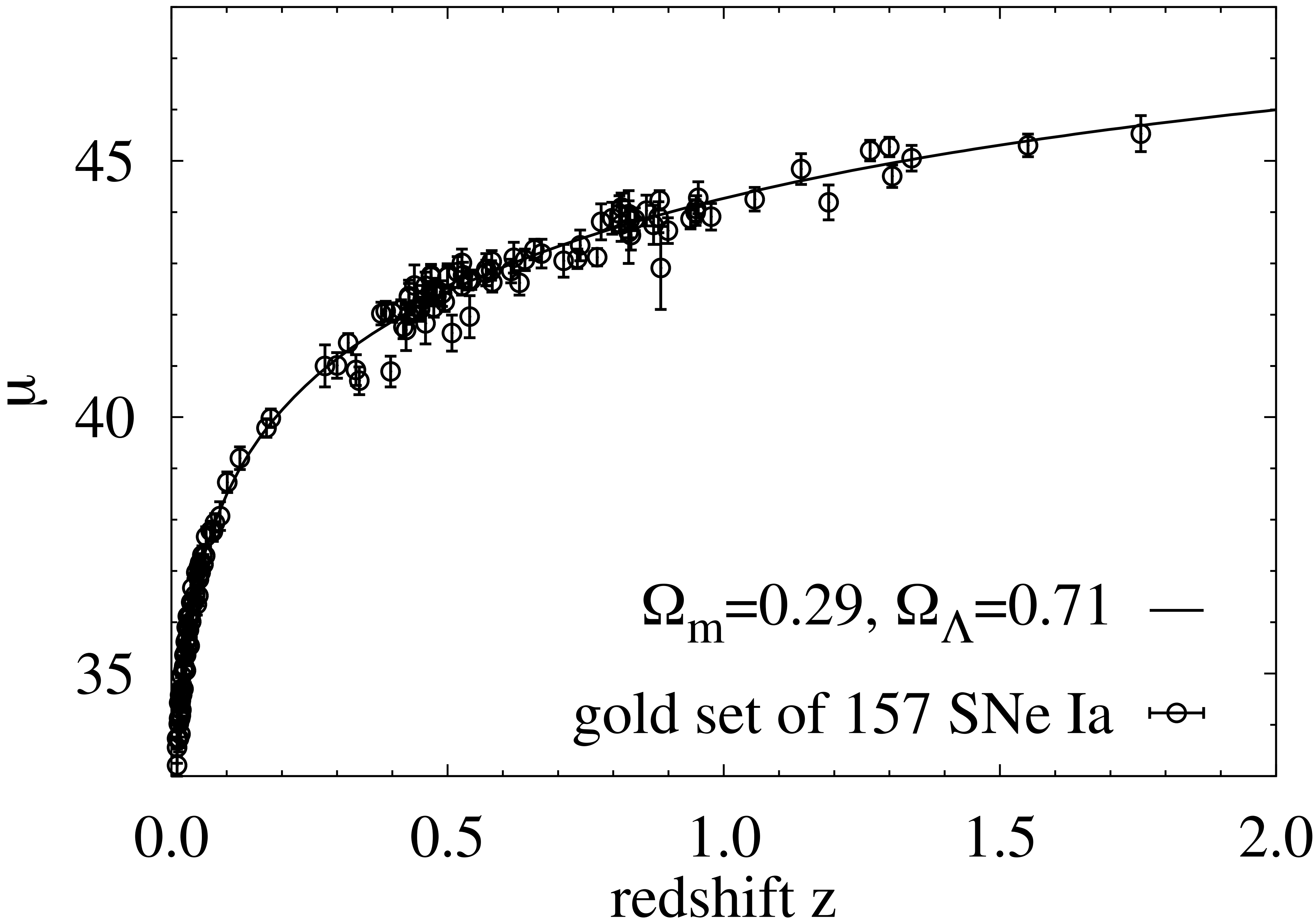
Preceding works

- K. Tomita (2001, 2002)
- M. Kasai (2007)

This works

- We improved the following as compared with M. Kasai (2007).
- We used the gold set data by Riess et al. (2004). $\rightarrow$ The number of data is 157. And these data contain SNe of $z > 1.0$.
- We used the luminosity distance without Ω_Λ , and also the Dyer & Roeder distance as a fitting formula.

Riess et al. (2004)
gold set data



$m - z$ relation

$$m = M_{abs} - 5 + 5\log_{10} D_L(z, \Omega_m, \Omega_\Lambda)$$

$$\therefore M(H_0) \equiv M_{abs} - 5 + 5\log_{10}\frac{c}{H_0}$$

m : apparent magnitude

M_{abs} : absolute magnitude

c : light speed

H_0 : Hubble constant z : red shift

Ω_Λ : Dark Energy Ω_m : density of universe

Luminosity distance

$$D_L(z) = \frac{c(1+z)}{H_0\sqrt{1-\Omega_m-\Omega_\Lambda}}$$

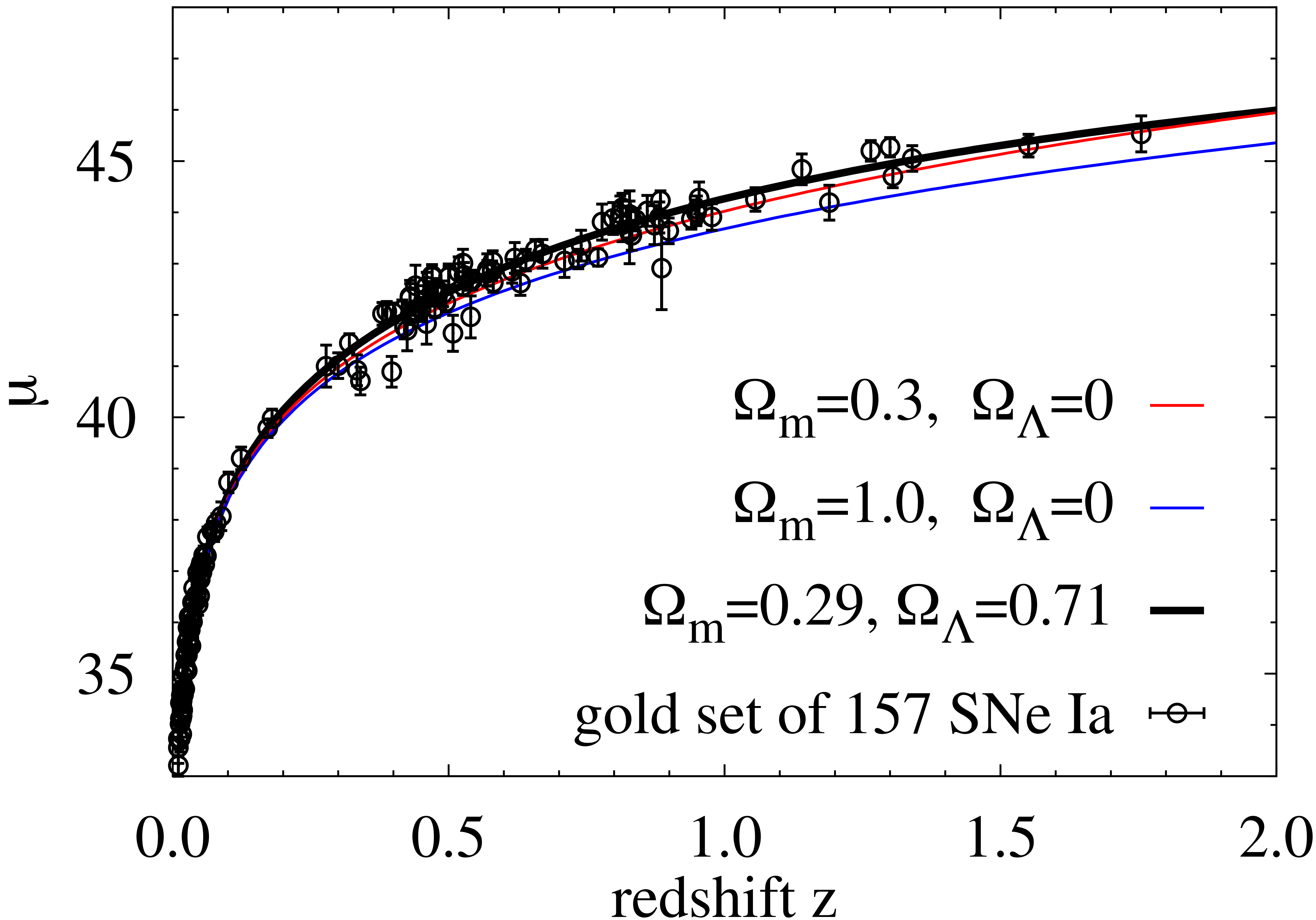
$$\times \sinh\left(\sqrt{1-\Omega_m-\Omega_\Lambda}\int_0^z \frac{dz'}{\sqrt{(1+\Omega_m z')(1+z')^2 - z'(2+z')\Omega_\Lambda}}\right)$$

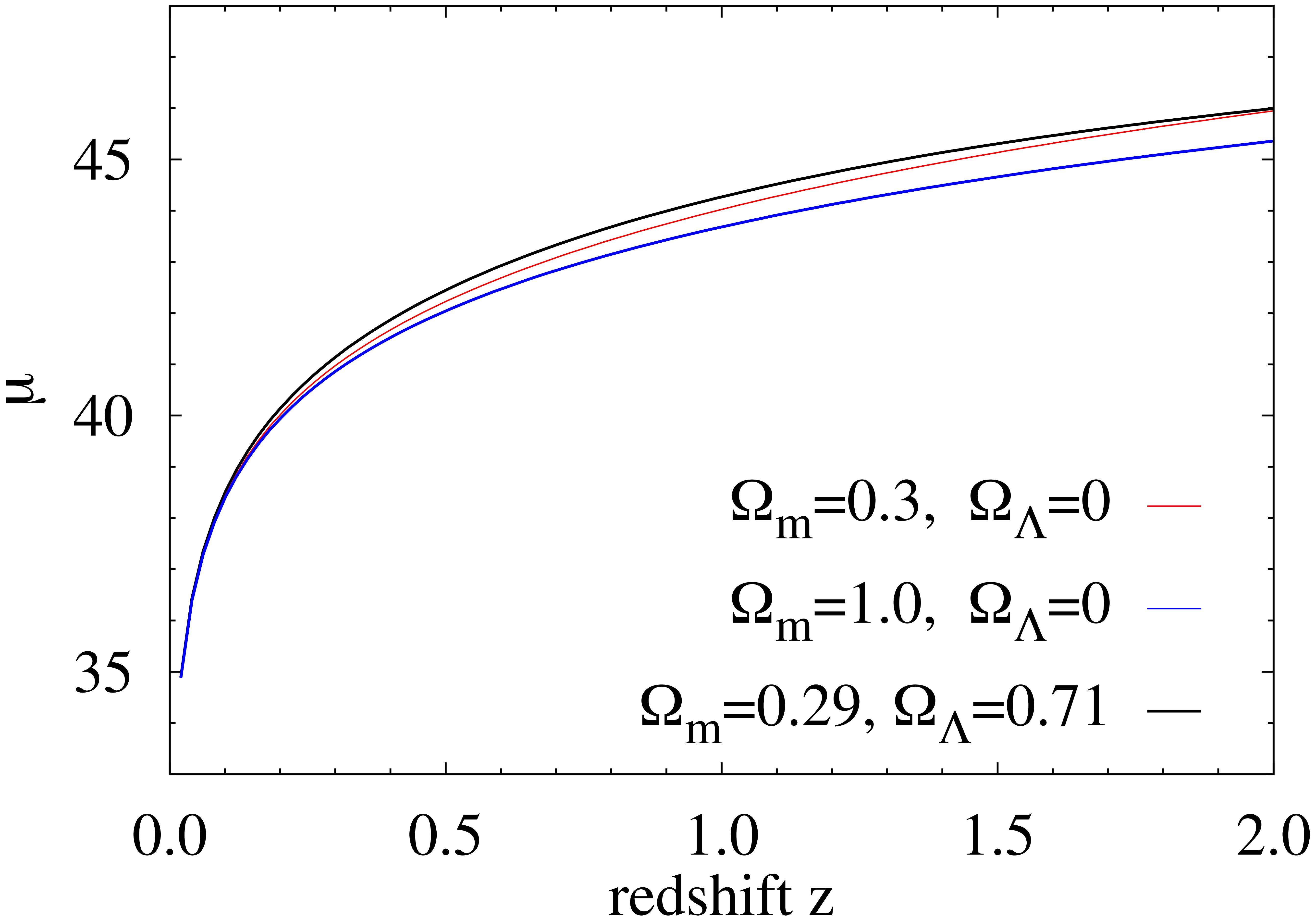
Analytical solution ($\Omega_\Lambda = 0$)

$$D_L(z) = \frac{c}{H_0} d_L(z)$$

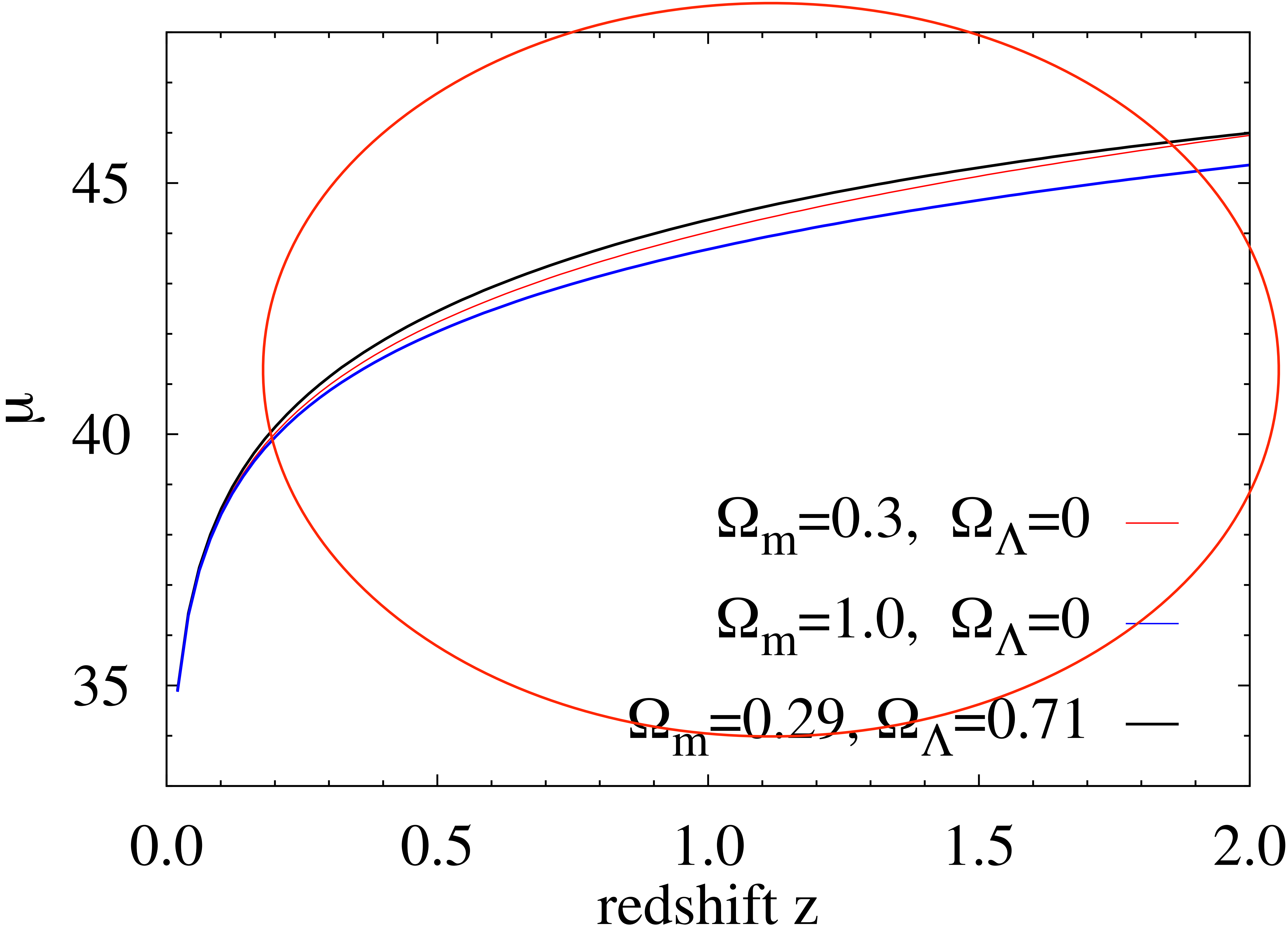
$$d_L(z) = \frac{2}{\mathit{\Omega}_m}\{(2 - \mathit{\Omega}_m + \mathit{\Omega}_m z) - (2 - \mathit{\Omega}_m)\sqrt{1 + \mathit{\Omega}_m z}\}$$

Necessity of Dark Energy




μ
45
40
35
0.0
0.5
1.0
1.5
2.0
redshift z
Ωm=0.3, ΩΛ=0
Ωm=1.0, ΩΛ=0
Ωm=0.29, ΩΛ=0.71

Look at this figure・・・



μ
45
40
35
0.0
0.5
1.0
1.5
2.0
redshift z
Ω_m=0.3, Ω_Λ=0
Ω_m=1.0, Ω_Λ=0
Ω_m=0.29, Ω_Λ=0.71

The effect of cosmological parameter is more remarkable in distant region.

e.g. $z > 0.1$.

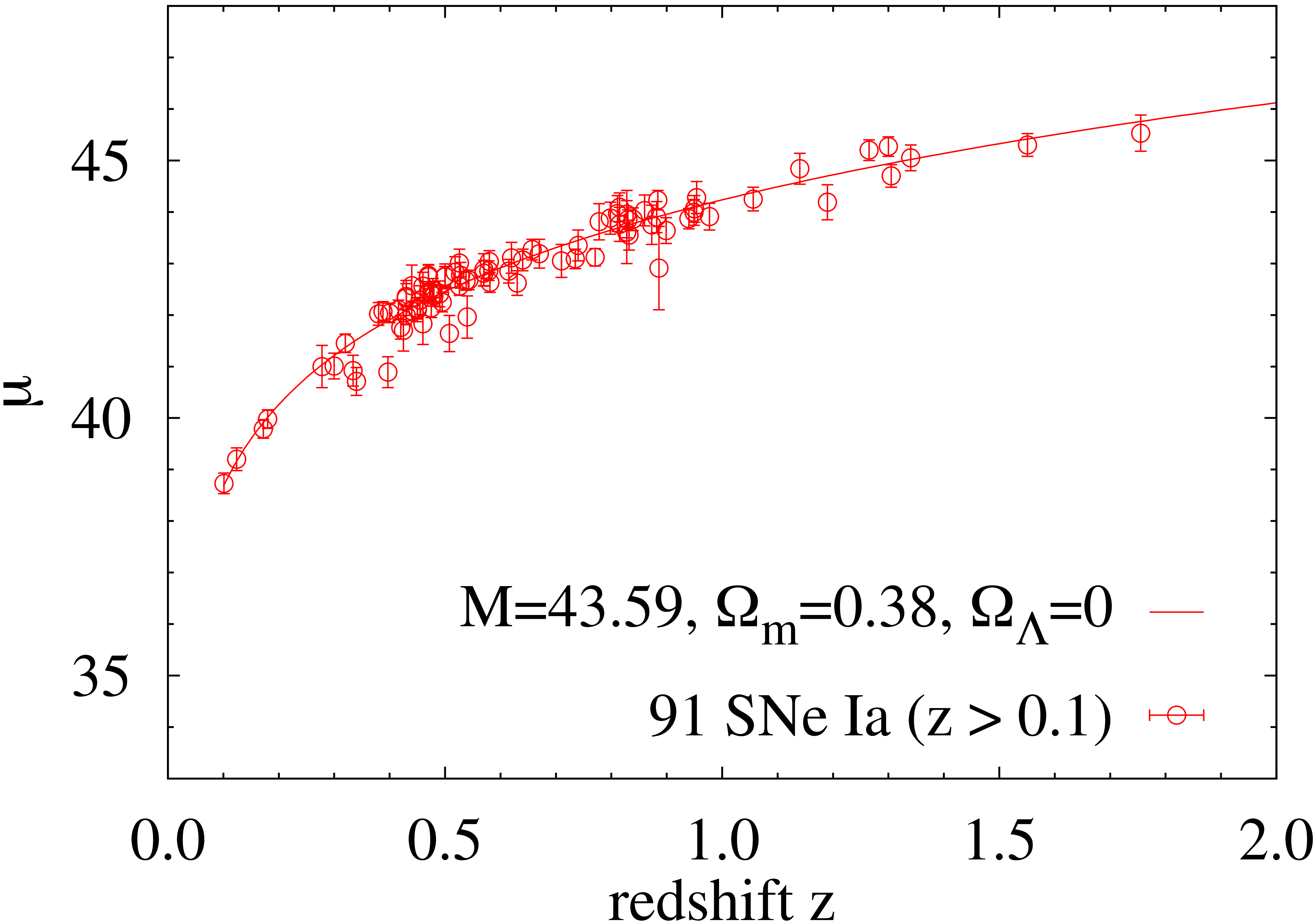
Then,

we consider

only distant data,

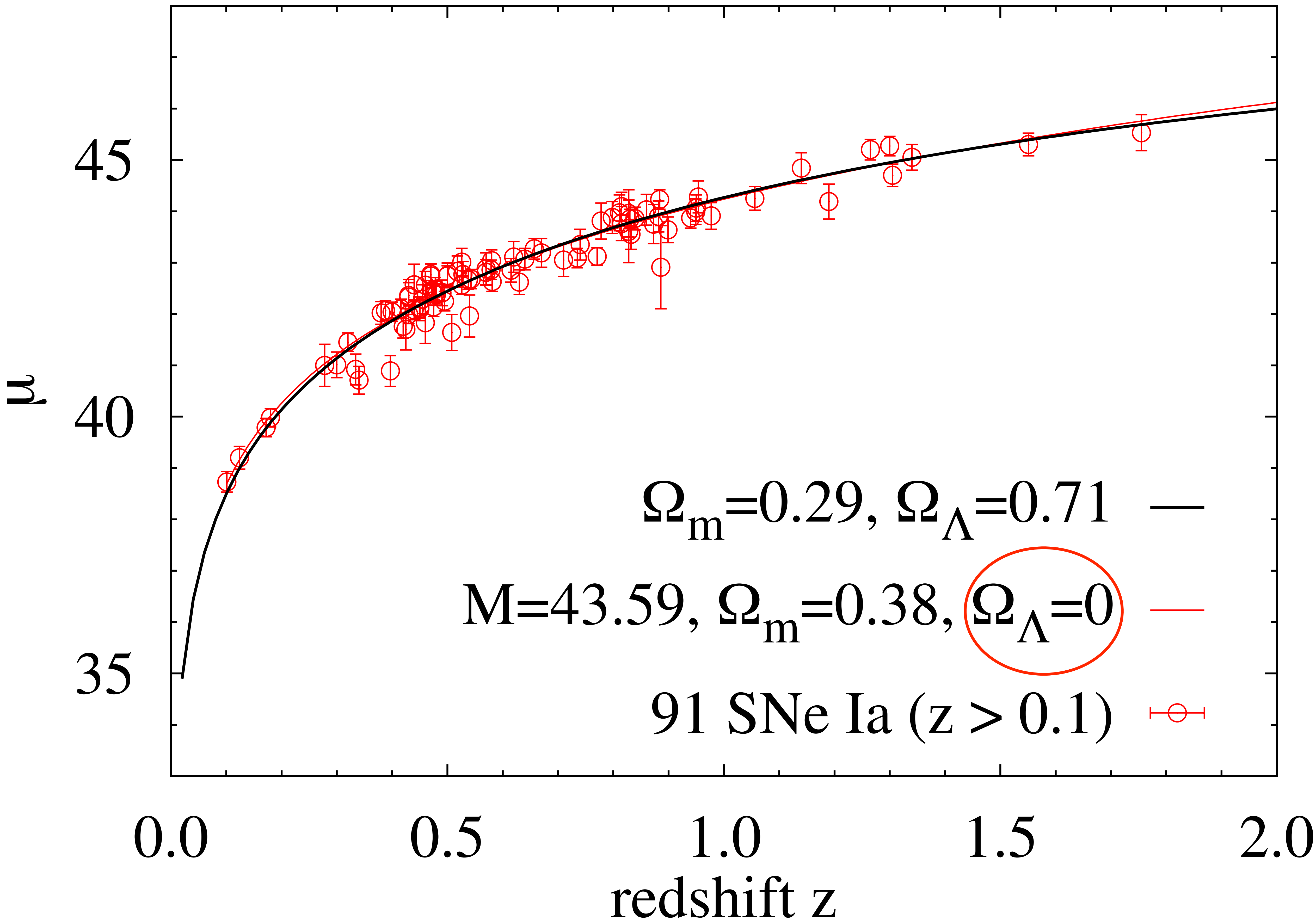
and fit them.

Result of fitting($z > 0.1$)



We compare our result
with that of
gold set data.

Compare to gold set data



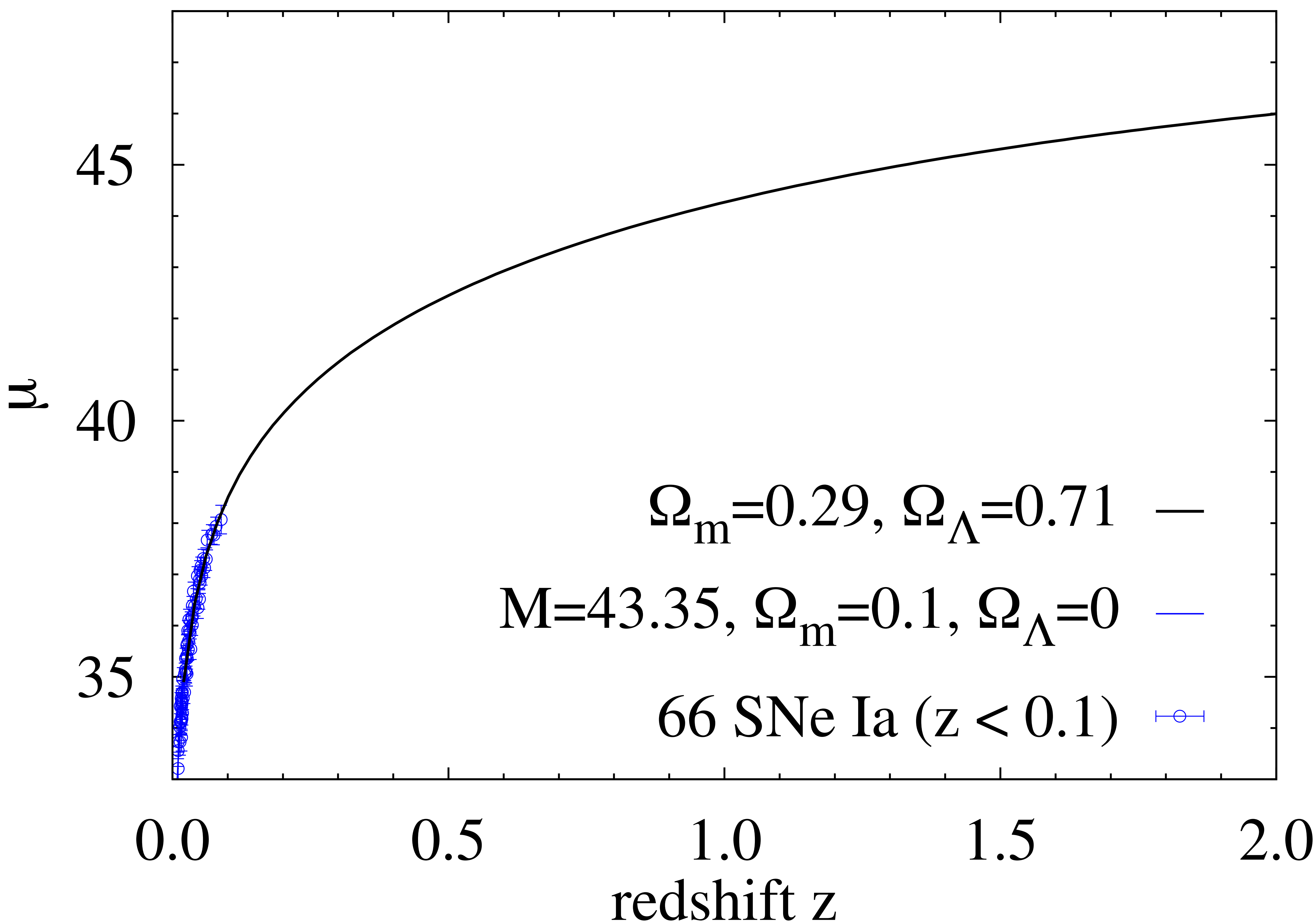
No Dark Energy is necessary to fit the distant data only.

χ^2 comparison

the best fit model for $z > 0.1$	χ^2
Riess et al. $(M = 43.34, \Omega_m = 0.29, \Omega_\Lambda = 0.71)$	110.97
open $(M = 43.59, \Omega_m = 0.38, \Omega_\Lambda = 0)$	108.40

Our model gives slightly better fitting.

Result of fitting ($z < 0.1$) and compare to gold set data



χ^2 comparison

the model for $z < 0.1$	χ^2
$M = 43.34, \Omega_m = 0.29, \Omega_\Lambda = 0.71$	65.30
$M = 43.35, \Omega_m = 0.1, \Omega_\Lambda = 0$	65.75

Again,

no Ω_Λ is required to

fit the nearby data.

Summary

- We can fit each region without Ω_Λ.
- Each best fit parameter is the following:

the best fit model	M	Ω_m	Ω_Λ
Riess et al	43.34	0.29	0.71
Our model (high-z)	43.59	0.38	0
Our model (low-z)	43.35	0.1	0

- If we permit that M of the nearby region and distant region is different, we can fit the observational SNe Ia data without Ω_Λ.

the best fit model	M	Ω_m	Ω_Λ
Riess et al	43.34	0.29	0.71
Our model (high-z)	43.59	0.38	0
Our model (low-z)	43.35	0.1	0

Difference of M is・・・

$$\therefore M(H_0) \equiv M_{abs} - 5 + 5\log_{10}\frac{c}{H_0}$$

i.e., difference of H_0 .

How much is the difference of H_0 ?

difference of H_0 by inhomogeneity

$$\frac{H_0(\mathrm{low})}{H_0\mathrm{high}} = 10^{\frac{M_{\mathrm{high}} - M_{\mathrm{low}}}{5}}$$

$$H_0(\mathrm{low}) = 1.1 H_0(\mathrm{high})$$

Therefore, if we allow that H_0 is larger than 10% in the distant region, we don't need Dark Energy.

Next,

we use

Dyer & Roeder

distance ($\Omega_m = 1, \Omega_\Lambda = 0$).

What's Dyer & Roeder distance？

- The density of inter-galactic space is lower than the average density. Light travels through the low-density space. Dyer & Roeder distance takes such effect into account.
- $\alpha\rho$ ：density of inter-galactic space
- ρ : average density of the universe
- α： $0 \leq \alpha \leq 1$

Dyer & Roeder distance

$$(\Omega_m = 1, \Omega_\Lambda = 0)$$

$$D_{DR}(\alpha, z) \equiv \frac{c}{H_0} d_{DR}(\alpha, z) = \frac{c}{H_0}(1+z)^2 \frac{2}{\beta}(1+z)^{\frac{\beta-5}{4}}\{1-(1+z)^{-\frac{\beta}{2}}\}$$

$$\beta \equiv \sqrt{25-24\alpha}$$

α : clumpiness parameter

- Same as the large-scale inhomogeneity, if we permit that M, α are different in the nearby region and the distant region, we can fit each region without Ω_Λ.

- Each best fit parameter is the following:

th best fit model	M	Ω_m	Ω_Λ	α	χ^2
Riess et al.	43.34	0.29	0.71	-	176.27
our DR model (high+low)	43.68/43.36	1	0	0.19/0	175.81

Conclusion（１）

- No Ω_Λ is required, if we allow the inhomogeneous universe such that:
  - Scale of inhomogeneity is $z = 0.1$.
  - Difference of H_0 is 10%.

Conclusion (2)

- Clumpiness parameter α is also inhomogeneous.
- This trace temporal evolution of the structure formation in the universe.

In the end...

If you stick to the homogeneity,

you also need the Dark Side of Energy.

Vader was seduced by the dark side of the Force...

Don’t be seduced by the Dark Side of Energy!

That's all, thank you.