Determining H_0 and q_0 from Supernova Data

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Abstract

Since 1929 when Edwin Hubble showed that the Universe is expanding, extensive observations of redshifts and relative distances of galaxies have established the form of expansion law. Mapping the kinematics of the expanding universe requires sets of measurements of the relative size and age of the universe at different epochs of its history. There has been decades effort to get precise measurements of two parameters that provide a crucial test for cosmology models. The two key parameters are the rate of expansion, i.e., the Hubble constant (H_0) and the deceleration in expansion (q_0). These two parameters have been studied from the exceedingly distant clusters where redshift is large. It is indicated that the universe is made up by roughly 73% of dark energy, 23% of dark matter, and 4% of normal luminous matter; and the universe is currently accelerating. Recently, however, the unexpected faintness of the Type Ia supernovae (SNe) at low redshifts ($z<1$) provides unique information to the study of the expansion behavior of the universe and the determination of the Hubble constant. In this work, We present a method based upon the distance modulus redshift relation and use the recent supernova Ia data to determine the parameters H_0 and q_0 simultaneously. Preliminary results will be presented and some intriguing questions to current theories are also raised.

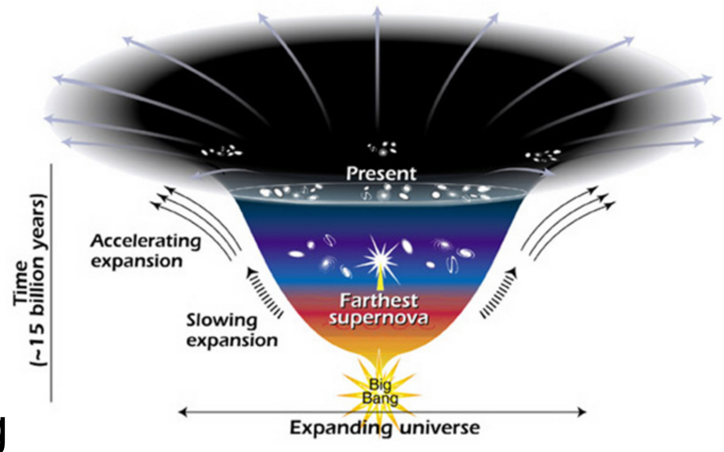
Outline

1. Introduction
2. Model and data analysis
3. Discussion

1. Introduction

Cosmology:

the search for two numbers:

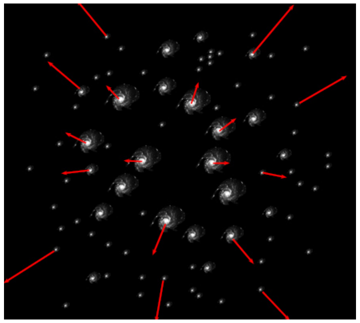


- **The Hubble constant H_0** ---
  describing how fast the universe is expanding

$$H(t) = \frac{\dot{a}(t)}{a(t)},$$

$a(t)$ = the cosmic scale factor

- **The deceleration parameter q_0** --- measuring the fate and age of the universe



$$q(t) = -\frac{\ddot{a}(t)/a(t)}{H^2} = -(1+\frac{\dot{H}}{H^2}) = \frac{1}{2}(1+3w)$$

$w=p/\rho$ is the equation of state of the universe

The search for the two numbers is based upon an unwarranted assumption: **redshift = distance**

The value of Hubble parameter changes over time --- either increasing or decreasing --- depending on the sign of *q*.

$q_0 > 0$, $w < -1/3$, $t < 1/H$ the expansion is slowing down.

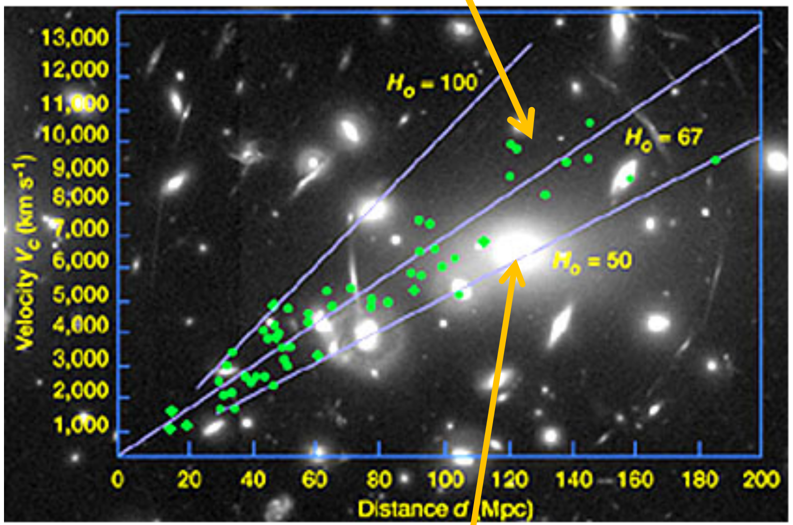
$q_0 = 0$, $w = -1/3$, $t = 1/H$ the expansion rate is a constant.

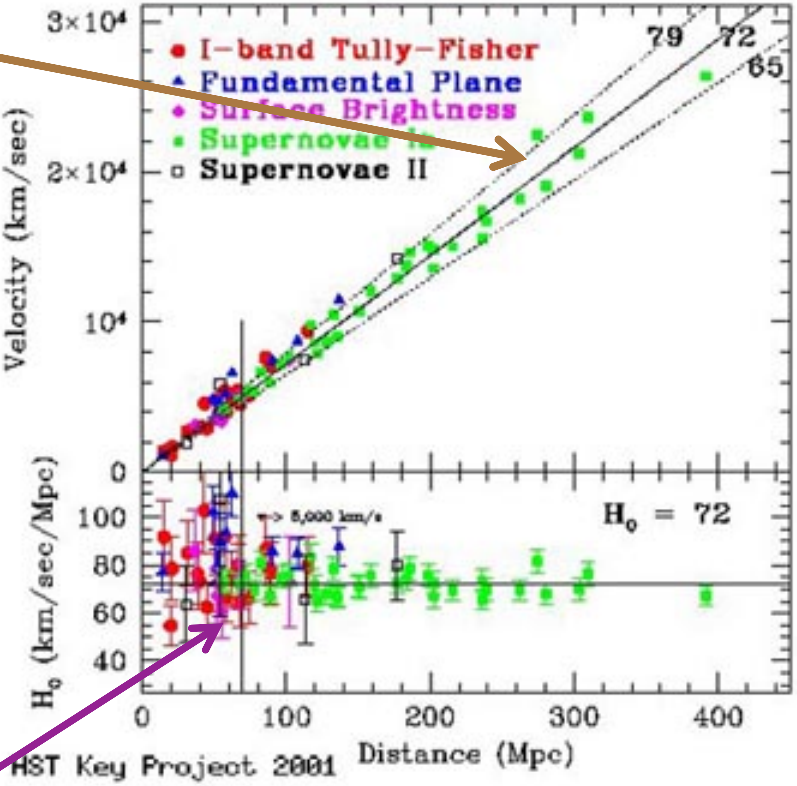
$q_0 < 0$, $w < -1/3$, $t > 1/H$ the expansion is accelerating.

Is our universe expansion accelerating or decelerating?

The value of H_0

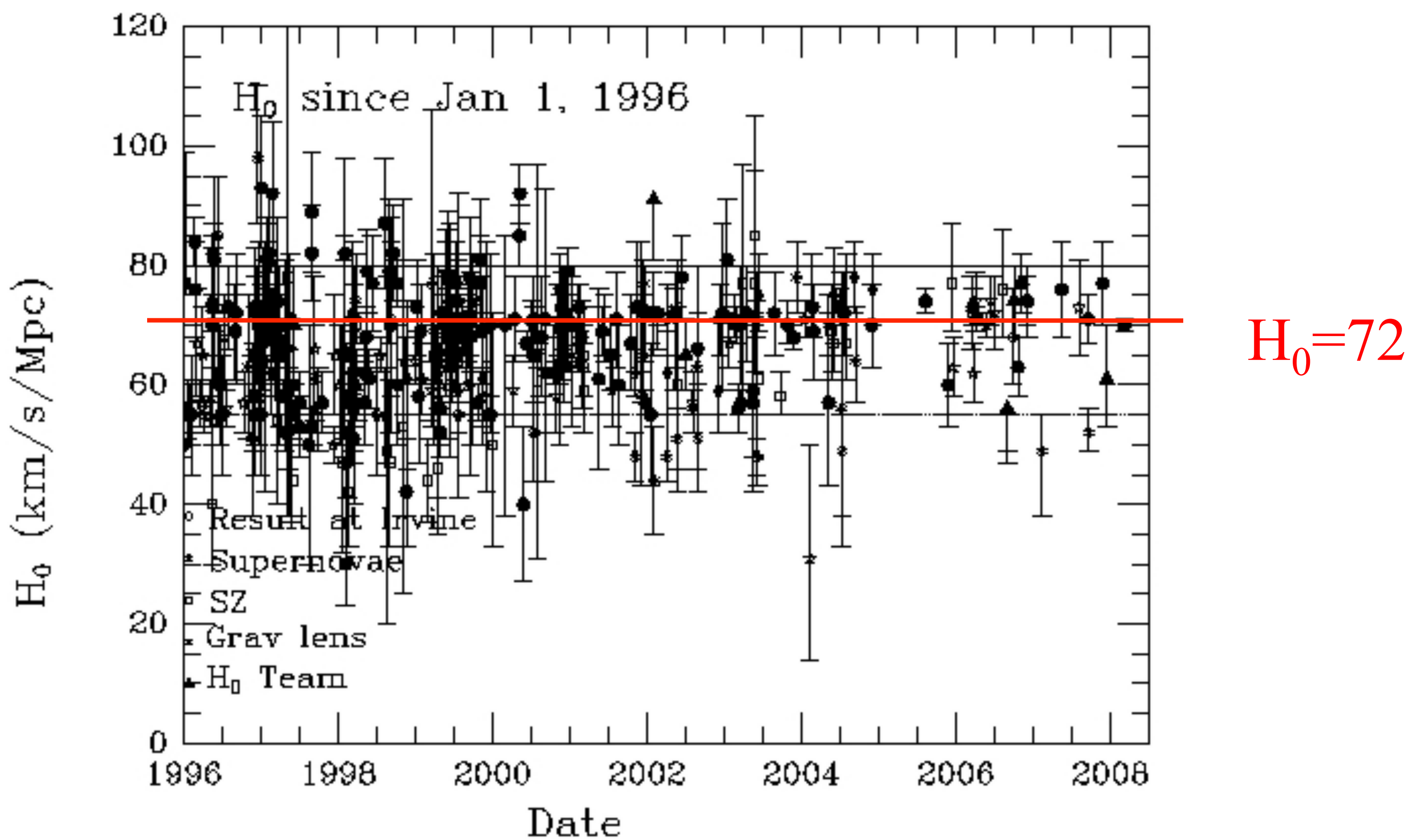
$q_0 < 0$, the expansion is accelerating.





$q_0 > 0$, the expansion is decelerating.

The history of H_0 value since 1996



$$\dot{H} > 0 \Rightarrow q_0 < 0$$

The universe expansion is accelerating!

2. Our model and data analysis

The luminosity distance to SNe Ia through the solution to Freidmann equation is

$$\boxed{d_L(z) = \frac{c(1+z)}{H_0} \int_0^z \frac{dz'}{E(z')}.}$$

$$\boxed{E(z) \equiv \left(\Omega_m (1+z)^3 + (1-\Omega_m) \times exp\left[3 \int_0^z \frac{dz'}{1+z'}(1+w(z'))\right]\right)^{1/2}}$$

$\Omega_m = 8\pi\rho_m/3H^2$ is the dimensionless matter density.

Taylor expanding the equation of state around the current epoch

$$p = p_0 + \kappa_0(\rho - \rho_0) + \frac{1}{2}\left.\frac{\mathrm{d}^2 p}{\mathrm{d}\rho^2}\right|_0 (\rho - \rho_0)^2 + O[(\rho - \rho_0)^3],$$

The scale factor *a(t)* with Taylor expansion around t_0

$$a(t) = a_0\left(1 + H_0(t - t_0) - \frac{1}{2}q_0 H_0^2(t - t_0)^2 + \frac{1}{3!}j_0 H_0^3(t - t_0)^3 + O((t - t_0)^4)\right)$$

Thus, the distance

$$\boxed{d_L(z) = \frac{cz}{H_0}\left(1 + \frac{1}{2}(1 - q_0)z - \frac{1}{6}(1 - q_0 - 3q_0^2 + j_0)z^2 + O(z^3)\right)}$$

$j(t) = (\dddot{a}/a)/(\dot{a}/a)^3$ is the jerk parameter

The absolute magnitude

$$\boxed{M = m - 5log_{10}\frac{d_L}{10pc} = m - 5log_{10}(10^5 d_L(Mpc)),}$$

m is the apparent magnitude.

The distance modulus – redshift relation becomes

$$\boxed{\mu \equiv m - M = 25 - 5log_{10}H_0 + 5log_{10}(cz) + 5log_{10}[1 + \frac{1-q_0}{2}z - \frac{1-q_0-3q_0^2+j_0}{6}z^2].}$$

Remark: for given sets of μ and *z* of the supernovae, the above equation would become the equations of parameters (H_0, q_0, j_0), each equation would define a surface in the (H_0, q_0, j_0) space. The intersection of any three surfaces would give a set of solution for (H_0, q_0, j_0) of the present universe.

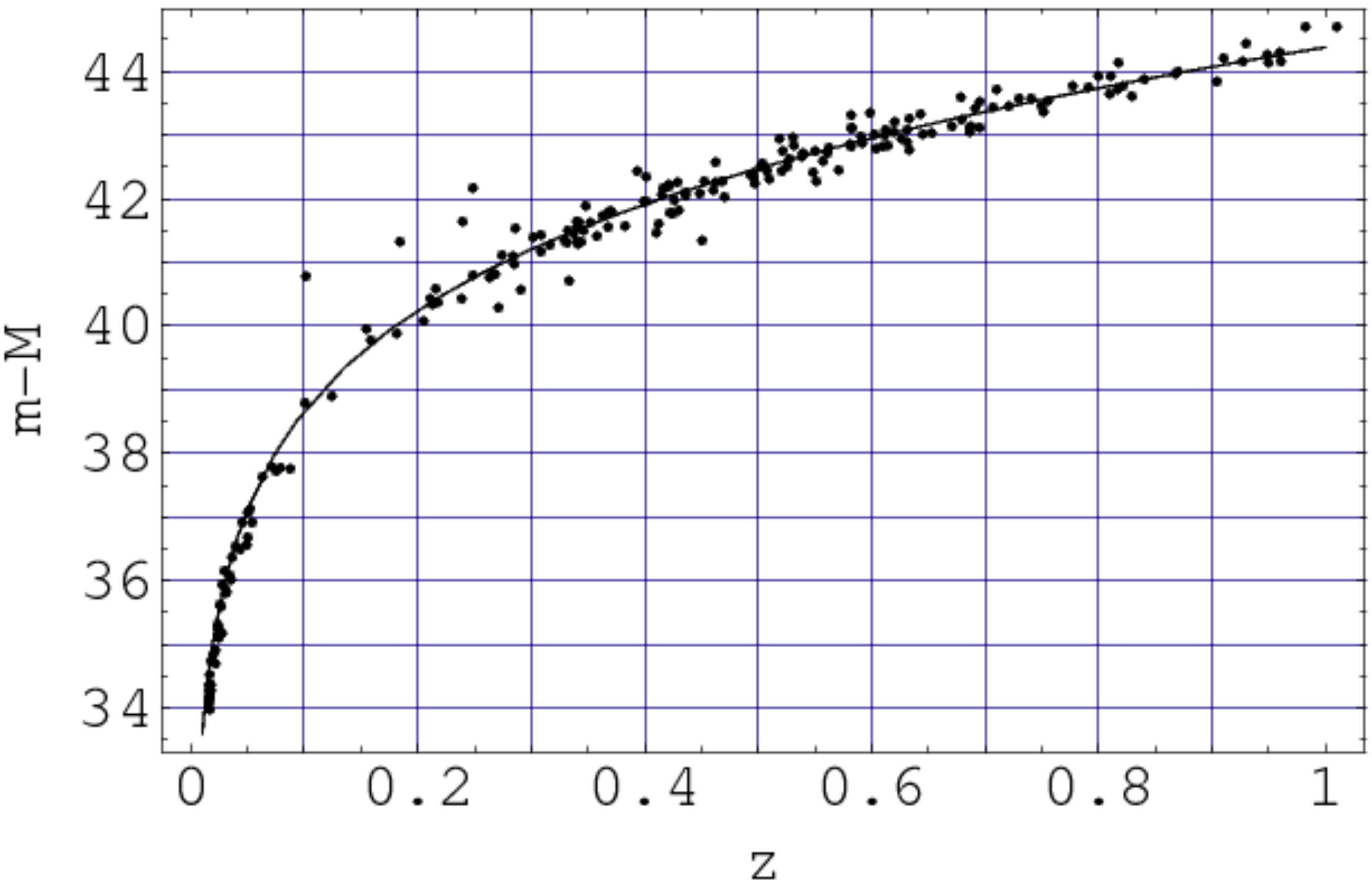
For small *z* *(z< 0.3)*, neglecting $O(z^2)$ and using the approximation *log(1+x) ~ x*, the previous equation successfully reduces to the Weinberg formula

$$\boxed{m - M = 25 - 5log_{10}H_0 + 5log_{10}(cz) + 1.086(1 - q_0)z.}$$

Applying to data of MLCS2k2 which contains 206 SNe Ia ranging from *z=0.0154 to z=1.01,* yield fitting curve

$$\boxed{\mu = 43.4622 - 0.0121094\, z^{-1} + 0.938887\, z + 2.07606\, ln\, z.}$$

***μ-z* plot** of data **MLCS2k2** (206 SNe Ia) and fitting curve $\mu=43.4622-0.0121094z^{-1}+0.938887z+2.07606\ln z$



Preliminary results

The solutions (H_0, q_0, j_0) calculated from the fitting function of data **MLCS2k2**

No.	z	μ	(H_0, q_0, j_0)
1	0.2	40.2481	57.27, 0.338, -0.888 *
2	0.3	41.2040	57.03, 0.390, -0.930
3	0.4	41.9052	57.02, 0.391, -0.930
4	0.5	42.4684	57.01, 0.393, -0.928
5	0.6	42.9448	57.17, 0.374, -0.953
6	0.7	43.3616	$*$ This row is calculated from z=0.2, 0.3 and 0.4.
7	0.8	43.7347	

Average values:

$$\boxed{H_0 = 57.12\,km/sec/Mpc, \quad q_0 = 0.377, \quad j_0 = -0.926.}$$

Similarly, applying to the **SALT** data, the fitting curve is

$$\mu = 43.749 - 0.00654325\, z^{-1} + 0.719647\, z + 2.17426\, ln\, z,$$

The average values from this fitting are

$$H_0 = 54.46\, km/sec/Mpc, \quad q_0 = 0.270, \quad j_0 = -0.778.$$

Then the **average result from two fittings** is

$$\boxed{H_0 = 55.8 \pm 1.4\, km/sec/Mpc, \quad q_0 = 0.32 \pm 0.06.}$$

$\Rightarrow$

Data MLCS2k2 indicates

$H_0 < 60$ km/sec/Mpc, $q_0 > 0$

3. Discussion

A. H_0, q_0

This analysis on data **MLCS2k2** gives ***H_0< 60, q_0>0,*** which is **inconsistent** with the current quoted values

H_0~ 72, q_0< 0

Is the expansion at present time accelerating or decelerating?

B. *w?*

Substituting $q_0 \sim 0.32$ into w gives

$$w \sim -0.12$$

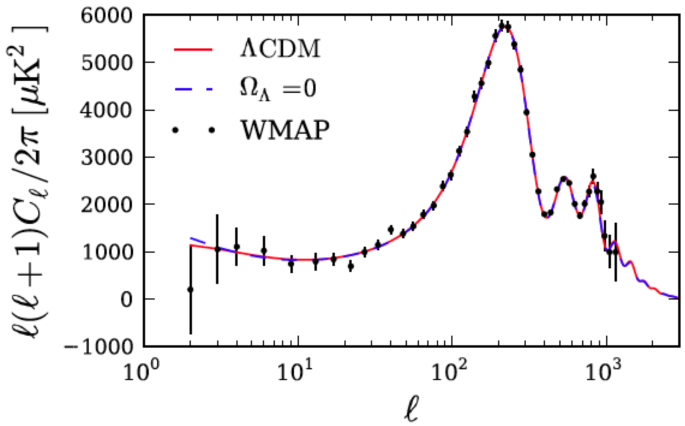
Implication: there is only 12% dark energy in present universe – **inconsistent** with current ΛCDM model ($w < -0.7$). What makes the rest in a nearly flat universe ($w = -1$)?

What and where are wrong here?

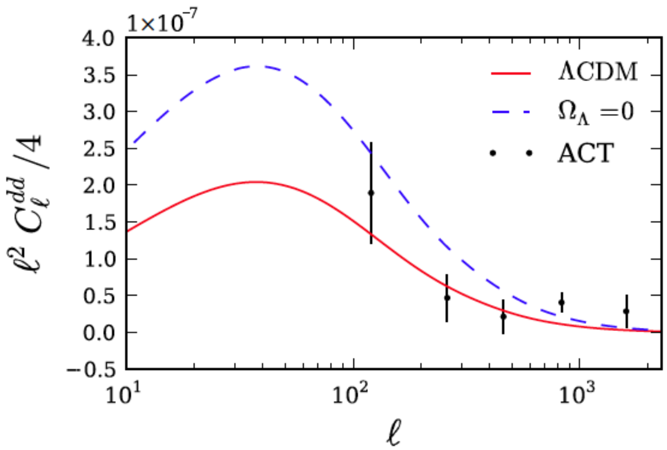
Recent data and future plan

ACT data and models,

Sherwin et al, PRL 107, 8 July, 2011



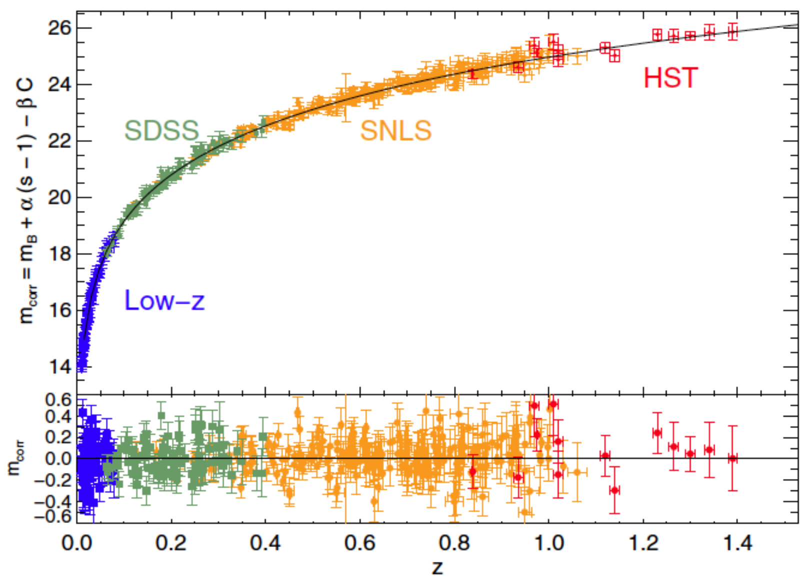
Angular power spectra of CMB temperature fluctuations



The CMB lensing deflection power spectra

Conley et al, APJS 192, 10, 1088/0067-0049, 2011

$$m_{\rm mod} = 5\log_{10}\mathcal{D}_L(z_{\rm hel}, z_{\rm cmb}, w, \Omega_m, \Omega_{DE}) - \alpha(s-1) + \beta\mathcal{C} + \mathcal{M},$$



W=-0.91$^{+0.16}_{-0.20}$

To Include more data: SDSS, SNLS, SiFTO, SALT2,…in our analysis

Thank YOU!