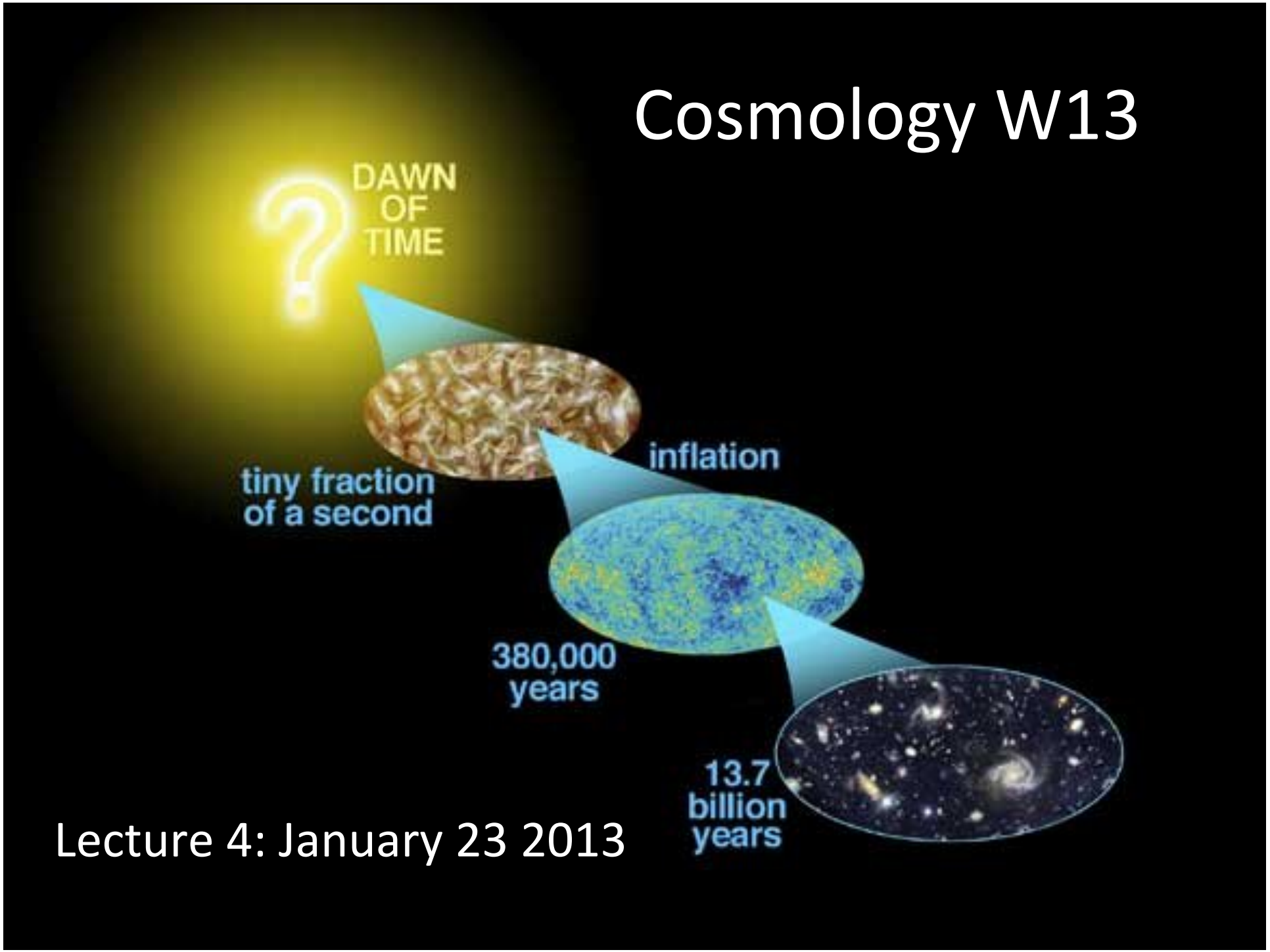
Cosmology W13



Lecture 4: January 23 2013

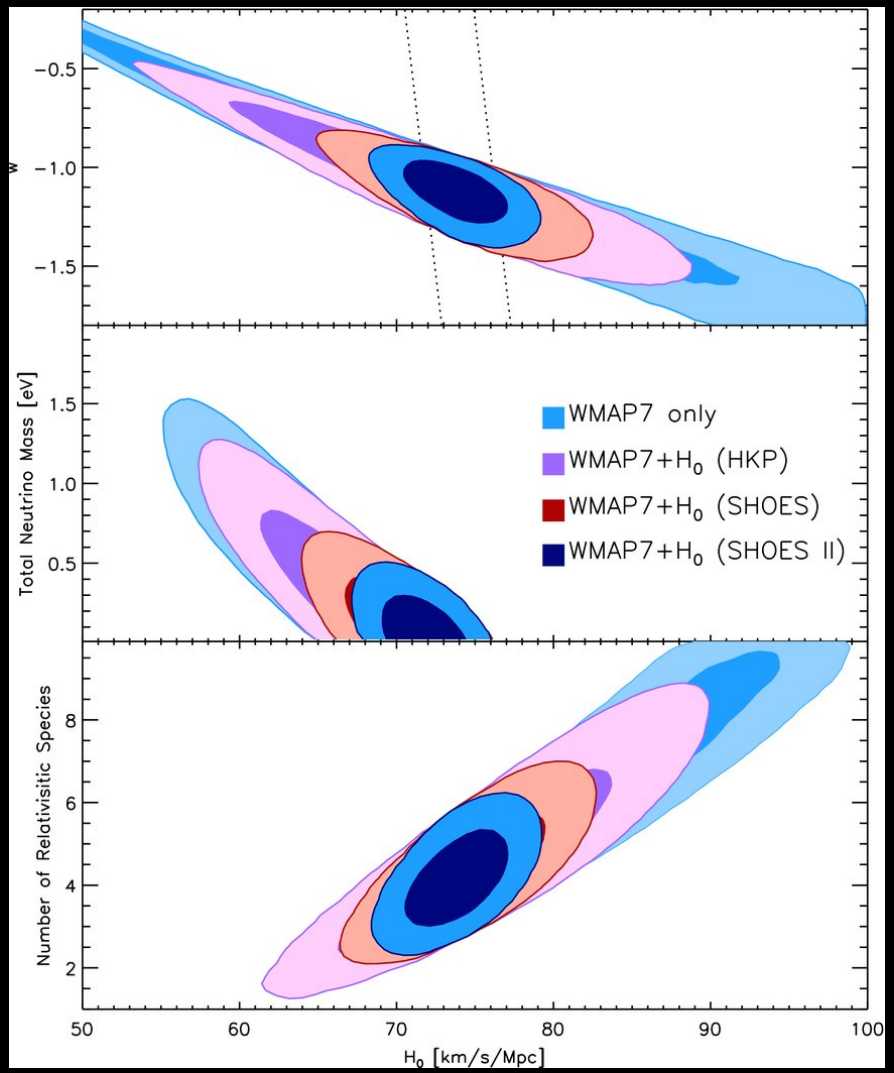
Cosmography I

- The local distance ladder – the quest for H0
- Standard candles (SN Ia)
- Age of the universe - Cosmic Chronometers
- other methods will be discussed later

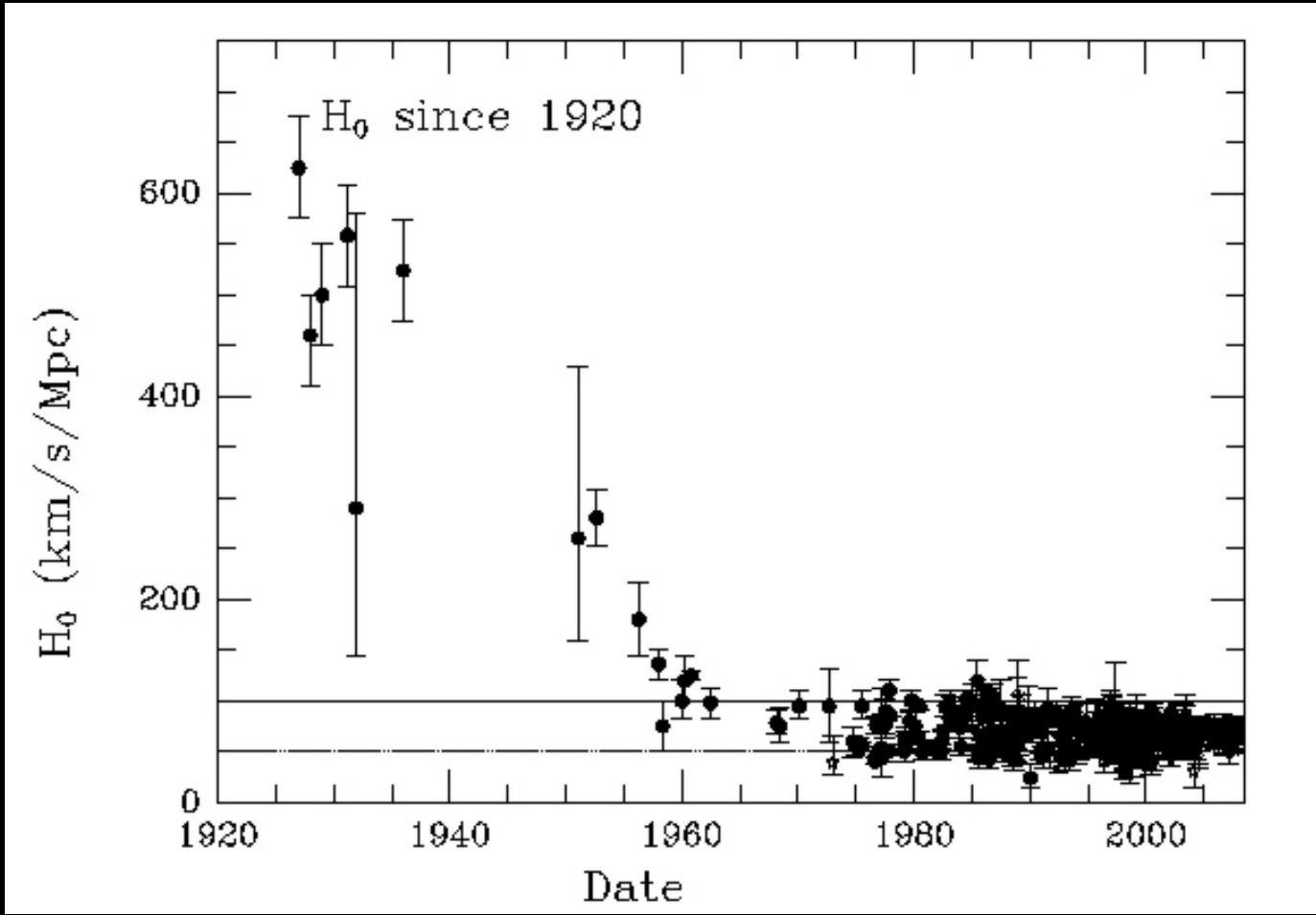
References

- History
  - https://www.cfa.harvard.edu/~dfabricant/huchra/hubble/
- General
  - Frieman, Turner, Huterer, ARA&A, 46, 385
- H0 – distance ladder
  - Freedman et al. 2001, ApJ, 553, 47
  - Freedman & Madore 2010, ARA&A, 48, 673
  - Riess et al. 2011, ApJ, 730, 119
  - Freedman et al. 2012, ApJ, 758, 24
- Ia
  - Perlmutter et al. 1999, ApJ, 517, 565
  - Riess et al. 1998, AJ, 116, 1009
- Cosmic Chronometers

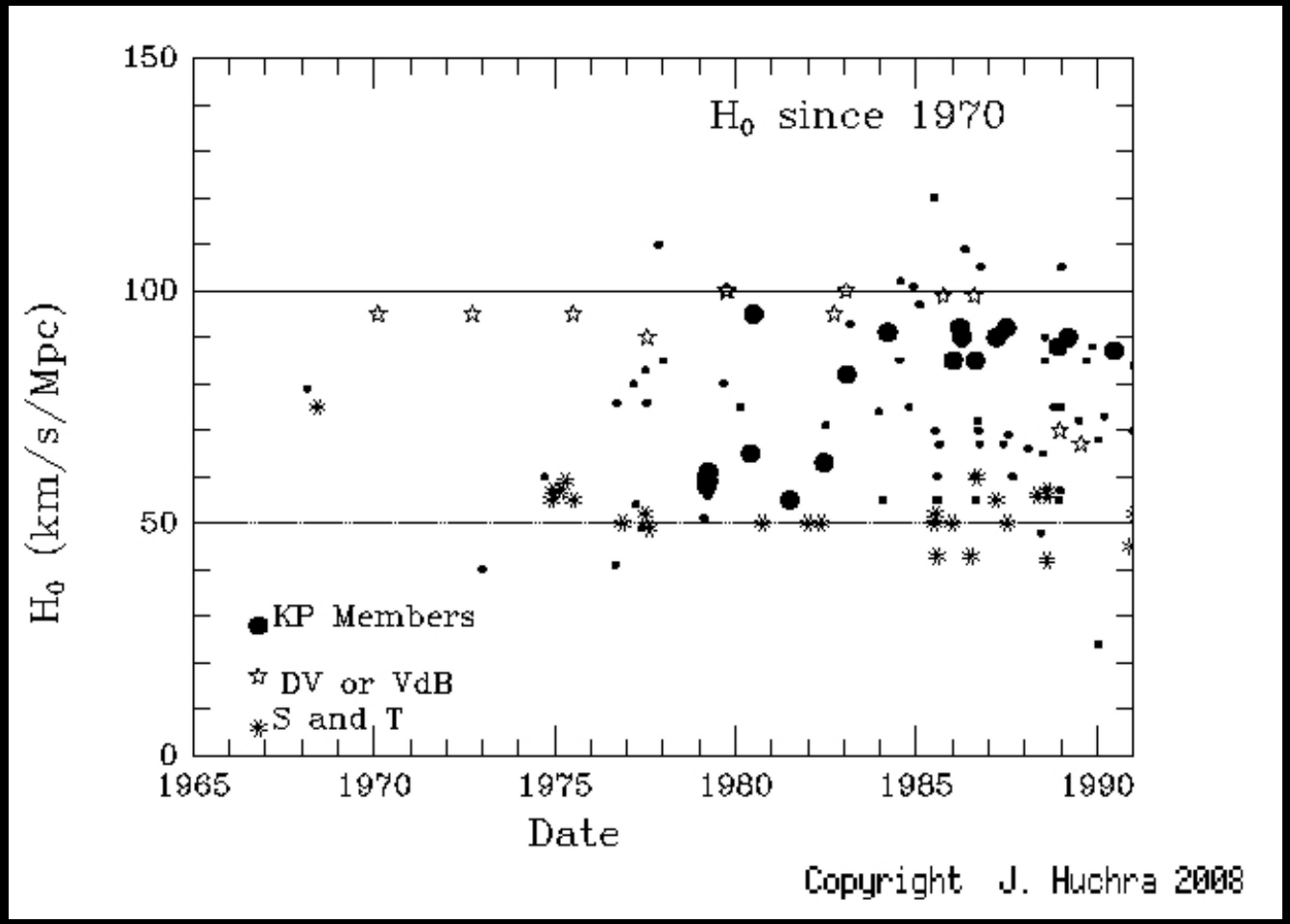
Why H_0?


w
−0.5
−1.0
−1.5
Total Neutrino Mass [eV]
1.5
1.0
0.5
WMAP7 only
WMAP7+H0 (HKP)
WMAP7+H0 (SHOES)
WMAP7+H0 (SHOES II)
Number of Relativisitic Species
8
6
4
2
50
60
70
80
90
100
H0 [km/s/Mpc]

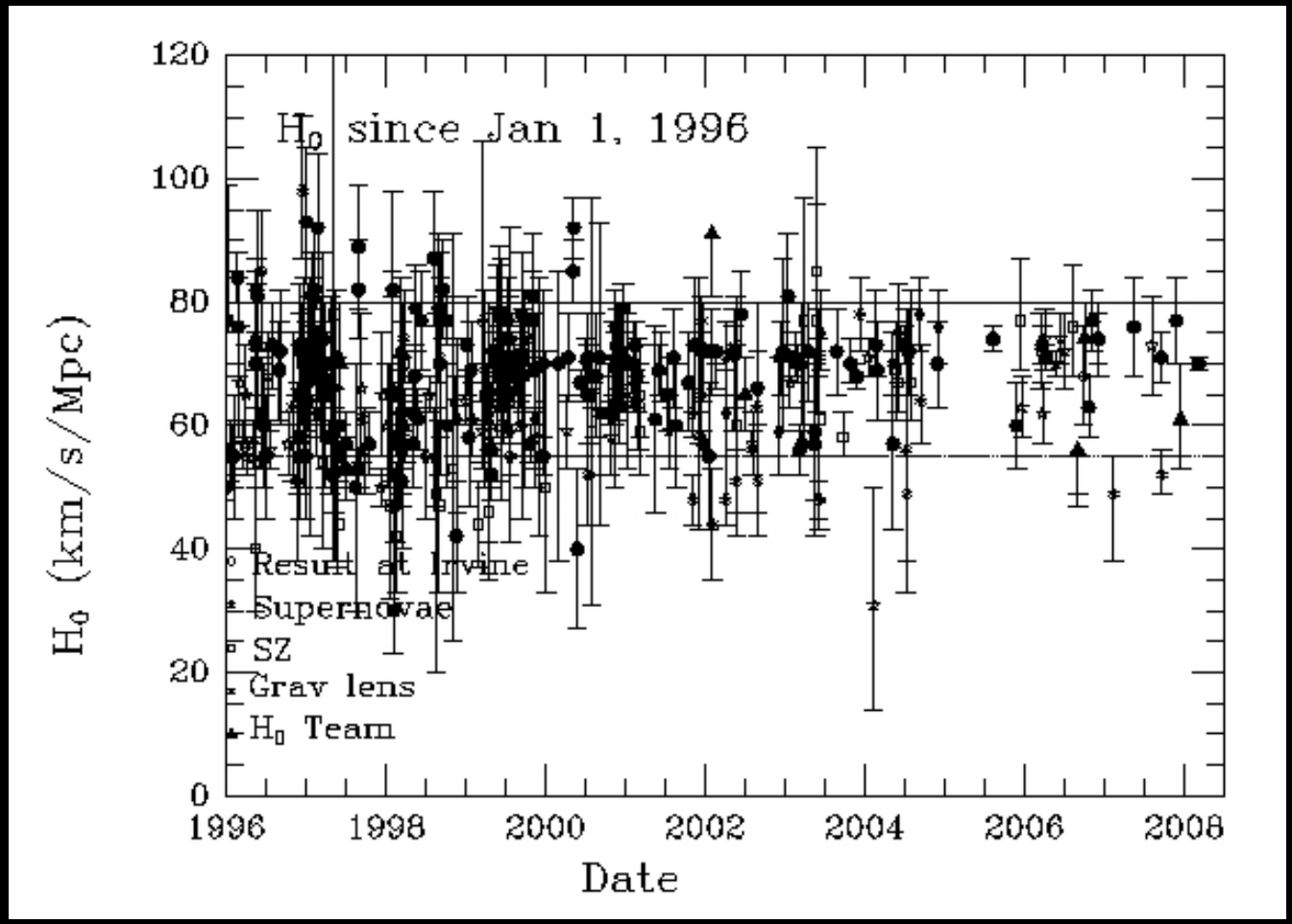
H_0 History


H₀ since 1920
H₀ (km/s/Mpc)
0
200
400
600
1920
1940
1960
1980
2000
Date

History


H_0 since 1970
150
100
50
0
H_0 (km/s/Mpc)
1965
1970
1975
1980
1985
1990
Date
KP Members
DV or VdB
S and T
Copyright J. Huchra 2008

History


H_0 since Jan 1, 1996
Result at Irvine
Supernovae
SZ
Grav lens
H_0 Team
H_0 (km/s/Mpc)
Date
0
20
40
60
80
100
120
1996
1998
2000
2002
2004
2006
2008

History – the ladder

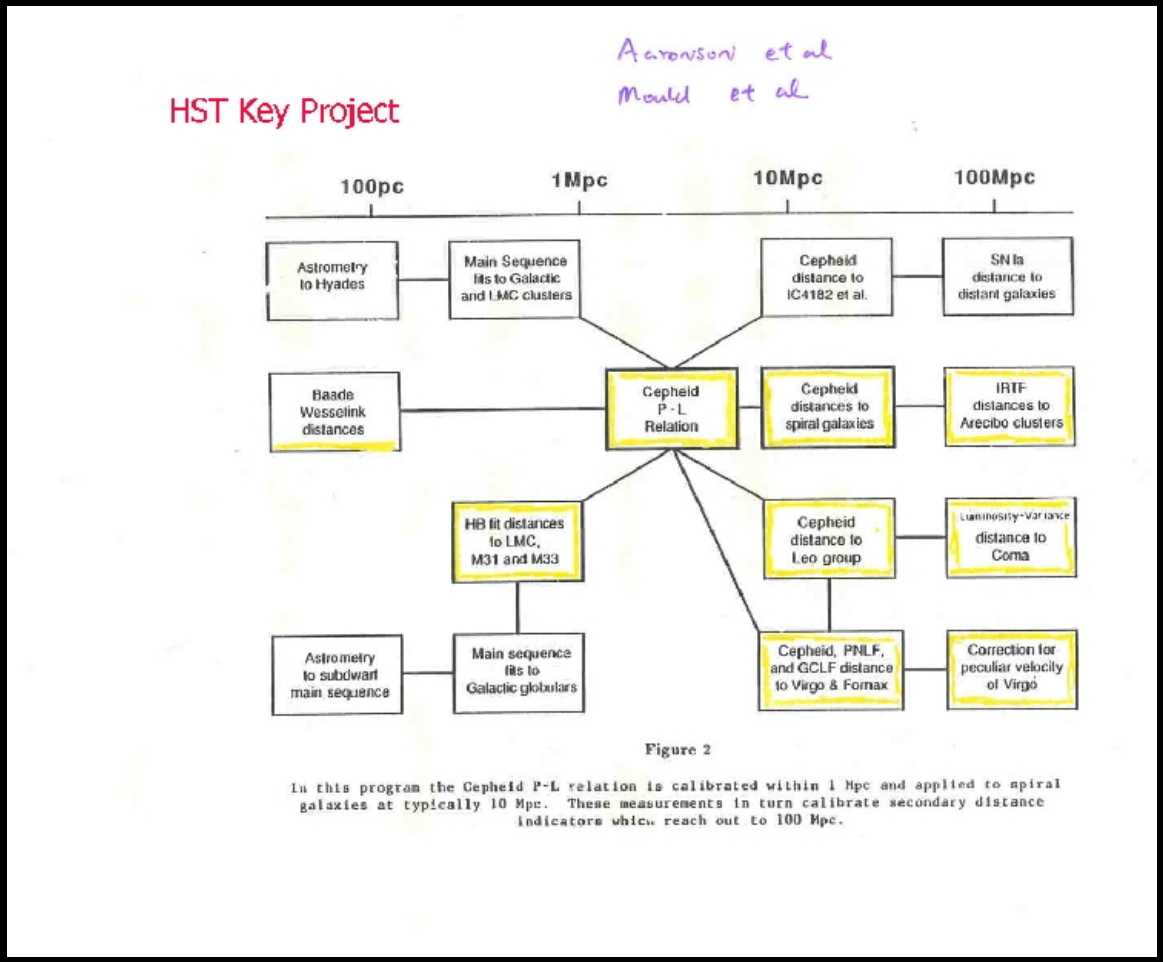
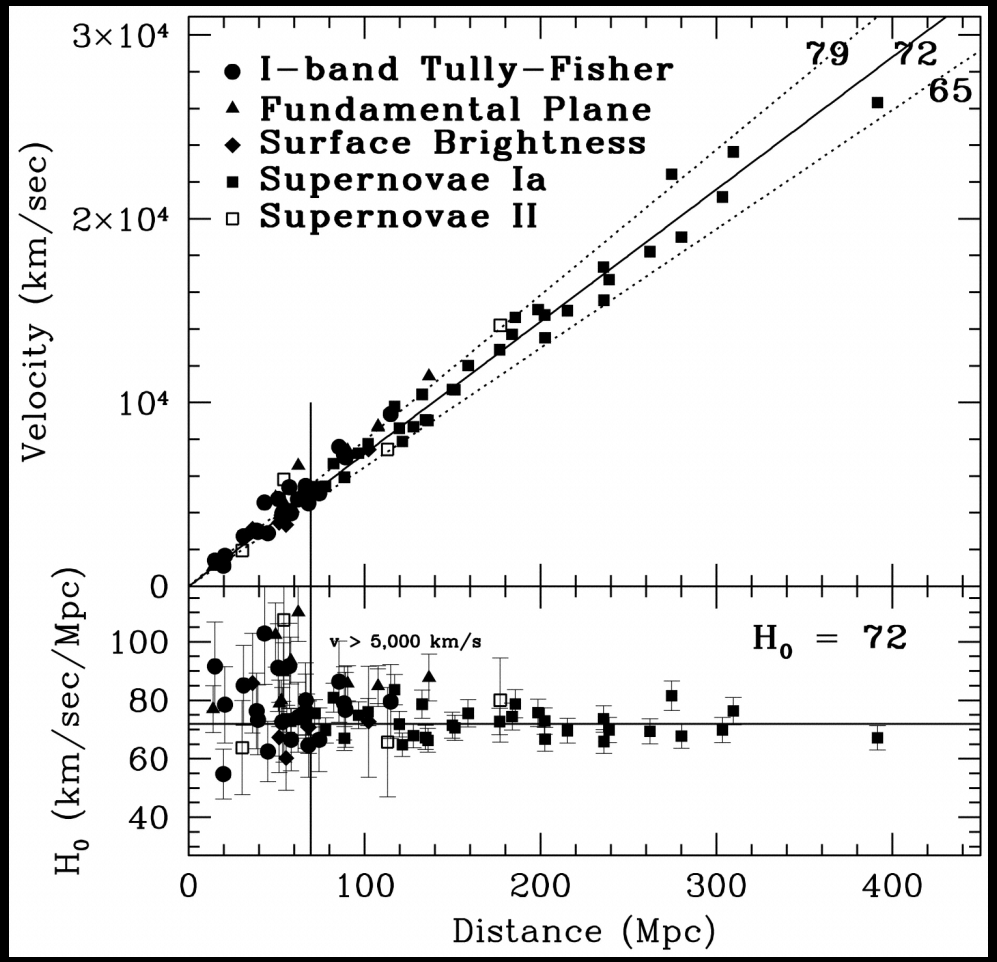


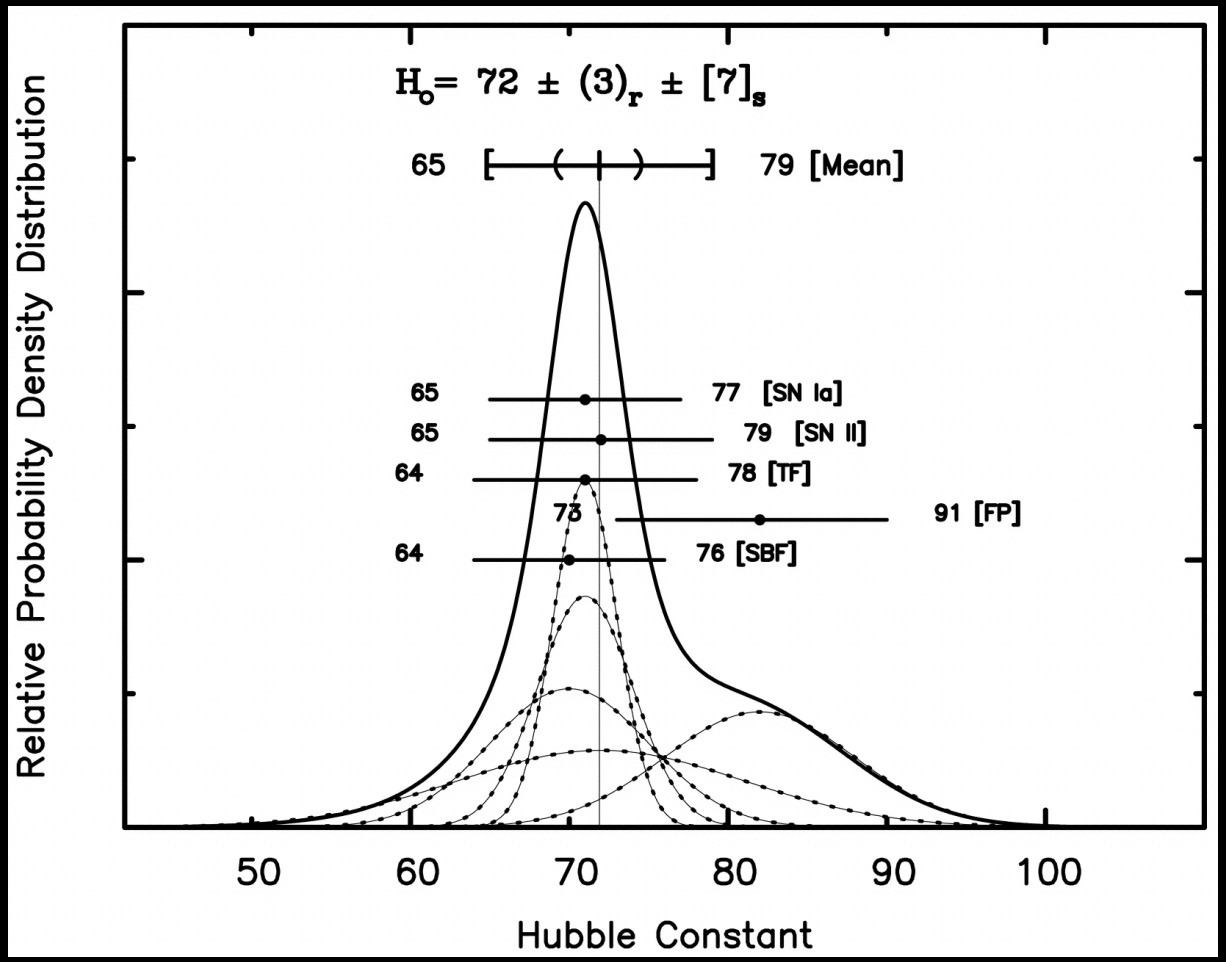
Figure 2

In this program the Cepheid P-L relation is calibrated within 1 Mpc and applied to spiral galaxies at typically 10 Mpc. These measurements in turn calibrate secondary distance indicators which reach out to 100 Mpc.

Key Project


3×10⁴
2×10⁴
10⁴
0
Velocity (km/sec)
I−band Tully−Fisher
Fundamental Plane
Surface Brightness
Supernovae Ia
Supernovae II
79
72
65
100
80
60
40
H₀ (km/sec/Mpc)
v > 5,000 km/s
H₀ = 72
0
100
200
300
400
Distance (Mpc)

Key Project


$H_o = 72 \pm (3)_r \pm [7]_s$
65
79 [Mean]
65
77 [SN Ia]
65
79 [SN II]
64
78 [TF]
73
91 [FP]
64
76 [SBF]
Relative Probability Density Distribution
50
60
70
80
90
100
Hubble Constant

From Key Project to SHOES

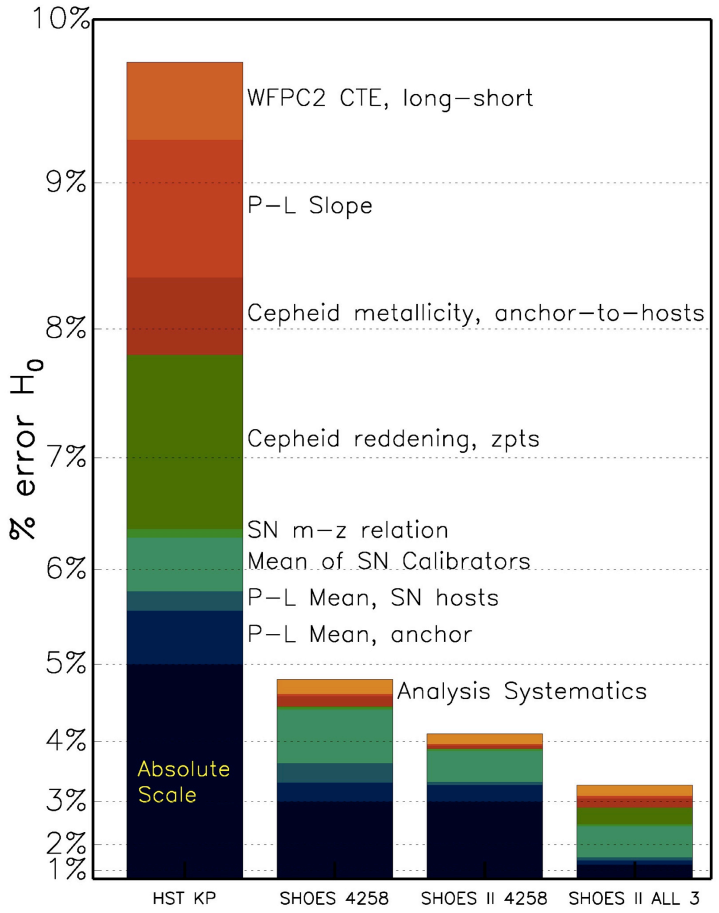
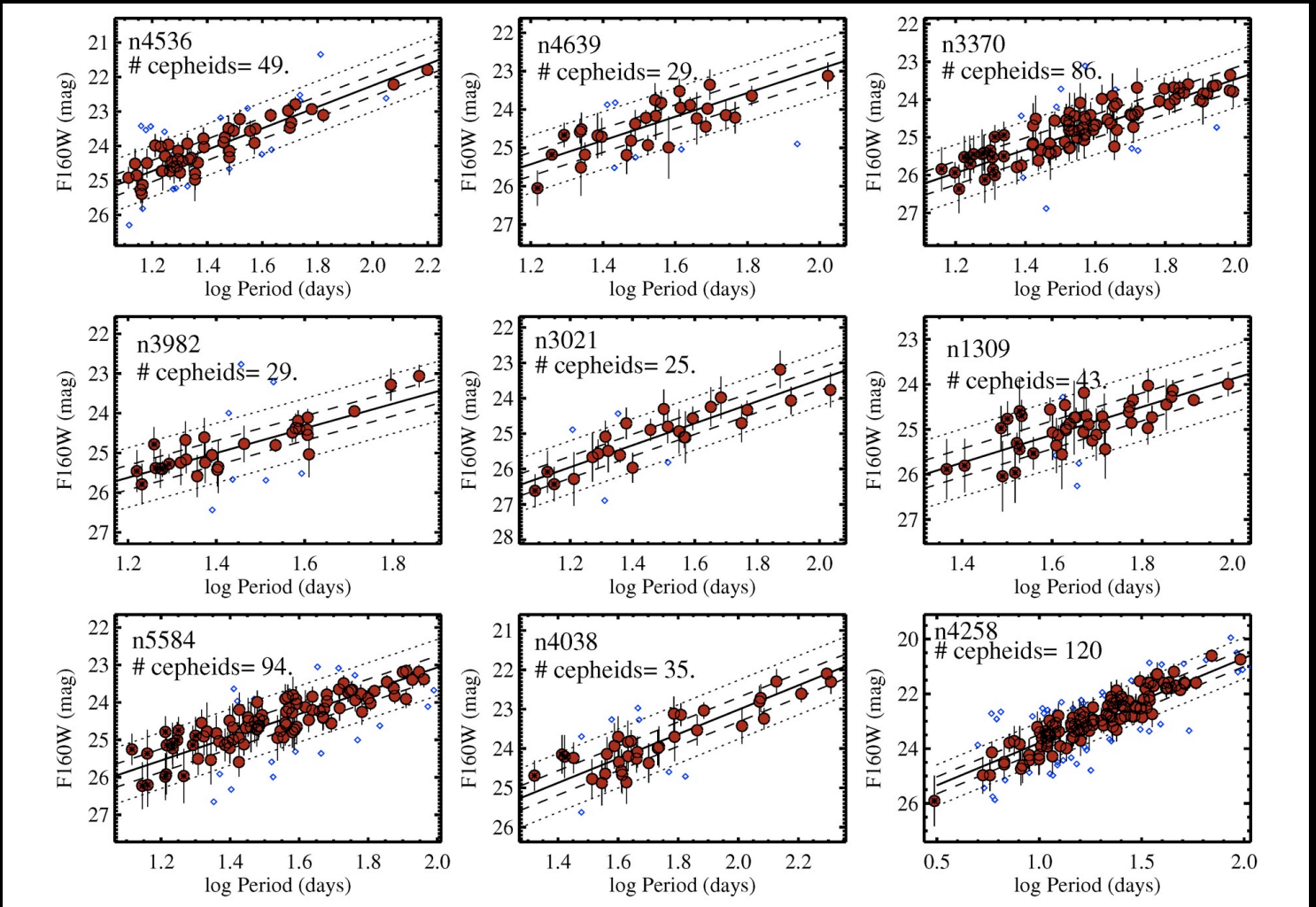
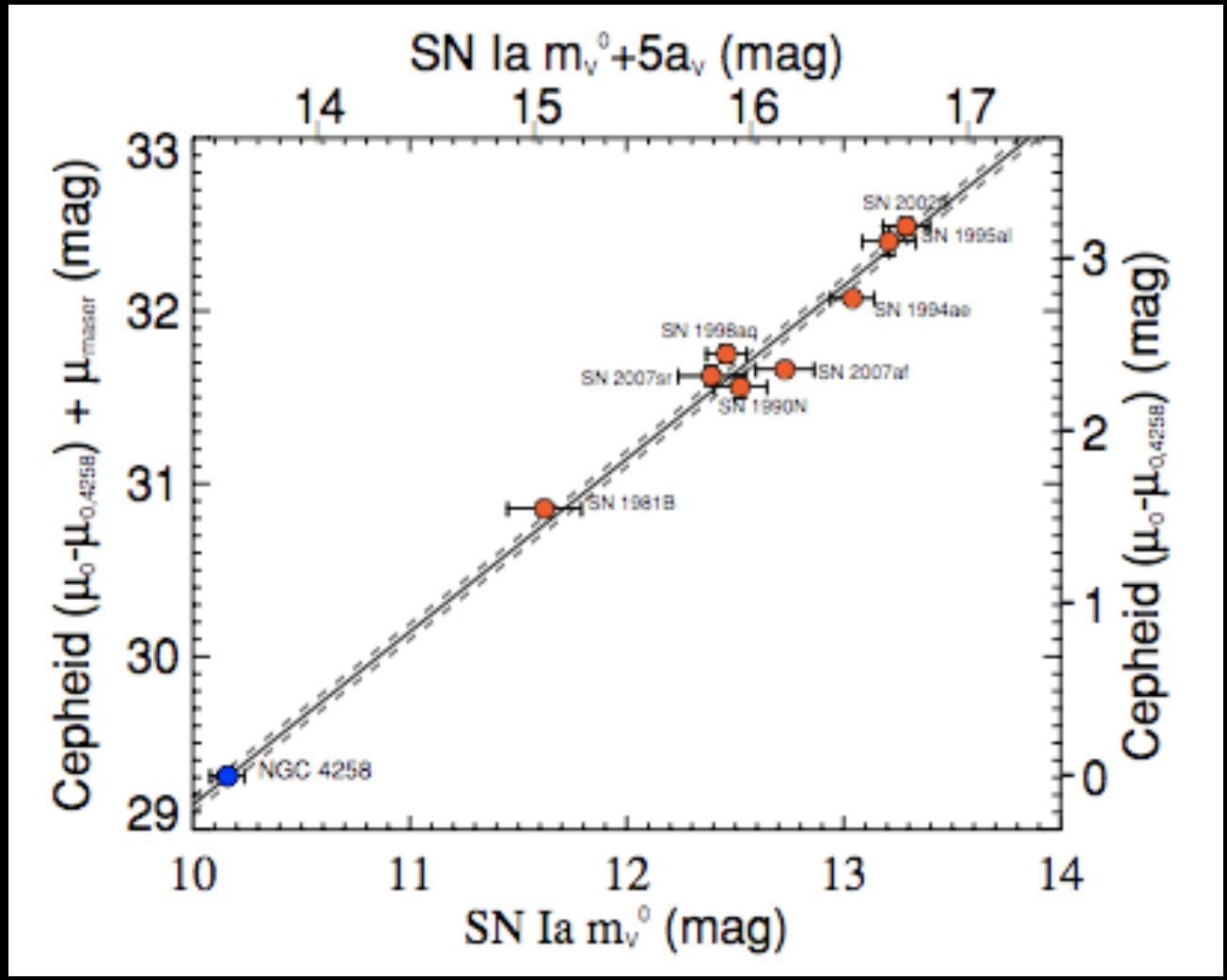


Figure 9. Uncertainties in the determination of the Hubble constant. Uncertainties are squared to show their contribution to the quadrature sum. These terms are given in Table 5.

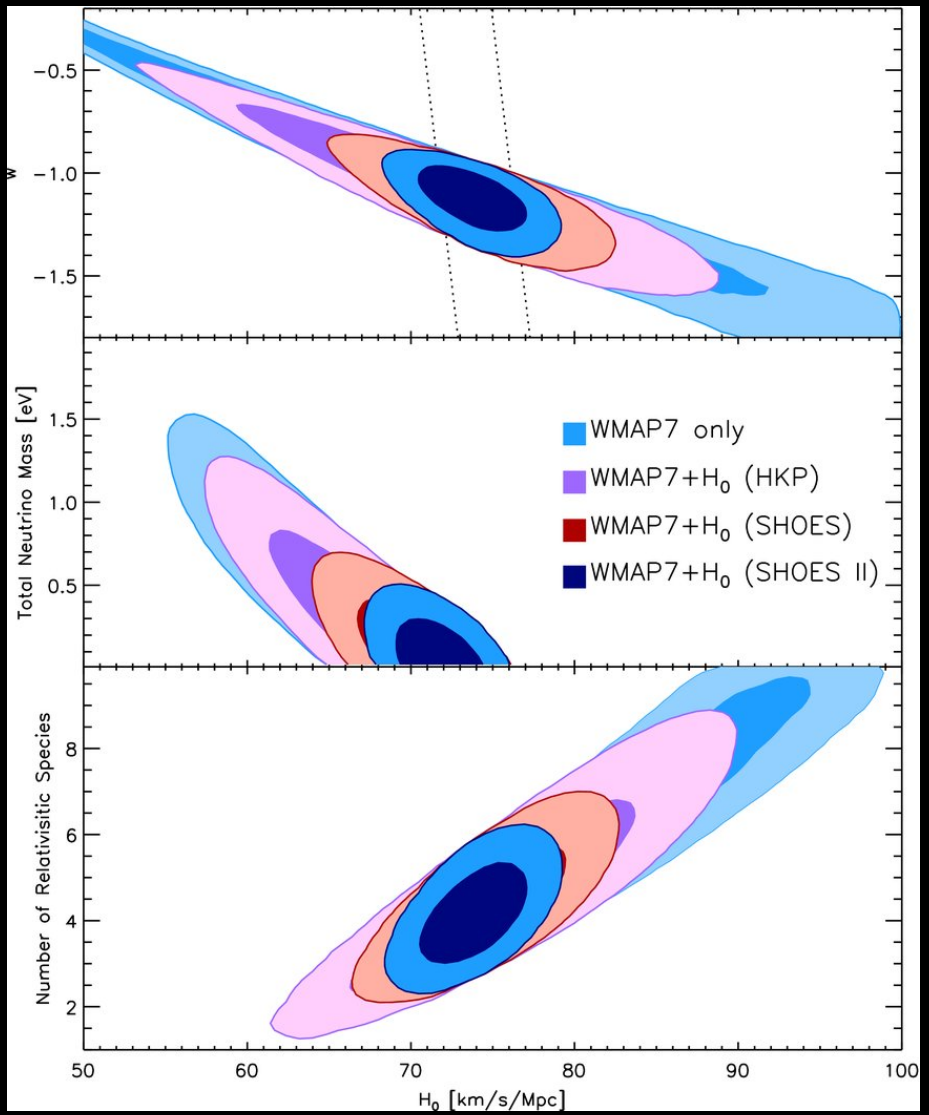
SHOES


n4536
cepheids= 49.
n4639
cepheids= 29.
n3370
cepheids= 86.
n3982
cepheids= 29.
n3021
cepheids= 25.
n1309
cepheids= 43.
n5584
cepheids= 94.
n4038
cepheids= 35.
n4258
cepheids= 120
F160W (mag)
log Period (days)

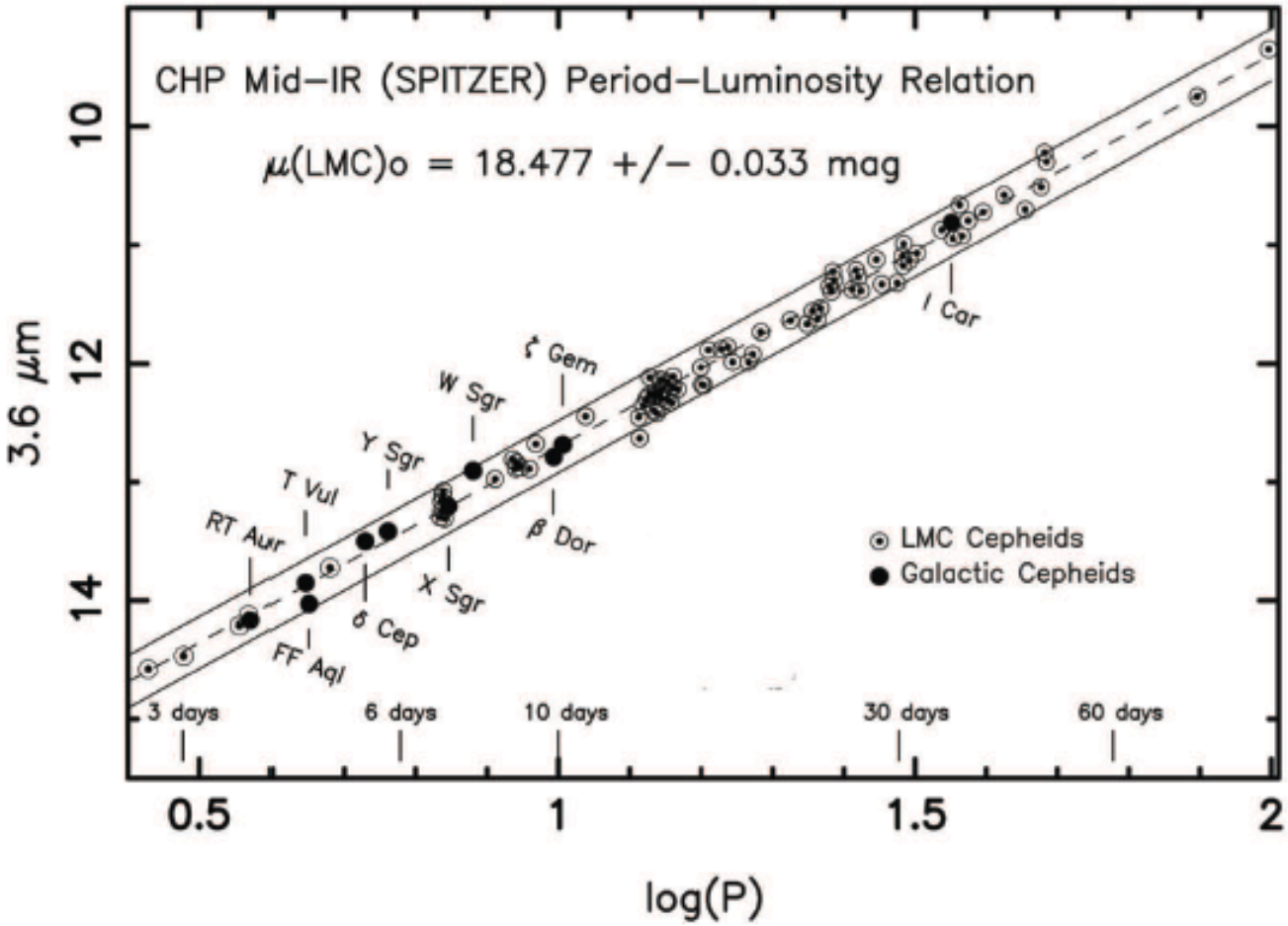
SHOES


SN Ia m_v^0+5a_v (mag)
14
15
16
17
33
32
31
30
29
Cepheid (μ_0-$\mu_{0,4258}$) + μ_{maser} (mag)
SN 2002fk
SN 1995al
SN 1994ae
SN 1998aq
SN 2007af
SN 2007sr
SN 1990N
SN 1981B
NGC 4258
3
2
1
0
Cepheid (μ_0-$\mu_{0,4258}$) (mag)
10
11
12
13
14
SN Ia m_v^0 (mag)

SHOES


w
−0.5
−1.0
−1.5
Total Neutrino Mass [eV]
1.5
1.0
0.5
WMAP7 only
WMAP7+H0 (HKP)
WMAP7+H0 (SHOES)
WMAP7+H0 (SHOES II)
Number of Relativisitic Species
8
6
4
2
50
60
70
80
90
100
H0 [km/s/Mpc]

CHP


CHP Mid–IR (SPITZER) Period–Luminosity Relation
μ(LMC)o = 18.477 +/– 0.033 mag
3.6 μm
10
12
14
0.5
1
1.5
2
log(P)
3 days
6 days
10 days
30 days
60 days
RT Aur
T Vul
Y Sgr
W Sgr
ζ Gem
δ Cep
FF Aql
X Sgr
β Dor
l Car
LMC Cepheids
Galactic Cepheids

Ia as standard candles

$$D_L = (1+z)D$$

$$D = \frac{c}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_m(1+z')^3 + (1-\Omega_m-\Omega_{de})(1+z')^2 + \Omega_{de}(1+z')^{3(1+w)} + \Omega_\gamma(1+z')^4}}$$

$$D_A = D/(1+z)$$

Sn Ia as standard candles

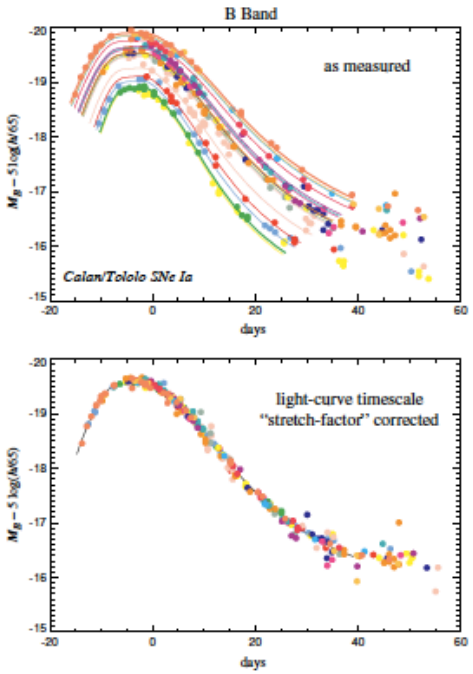


Figure 12: *Top panel:* B-band light curves for low-redshift SNe Ia from the Calan-Tololo survey (Hamuy et al. 1996) show an intrinsic scatter of ~ 0.3 mag in peak luminosity. *Bottom panel:* After a one-parameter correction for the brightness-decline correlation, the light curves show an intrinsic dispersion of only ~ 0.15 mag. From Kim (2004).

Ia as standard candles

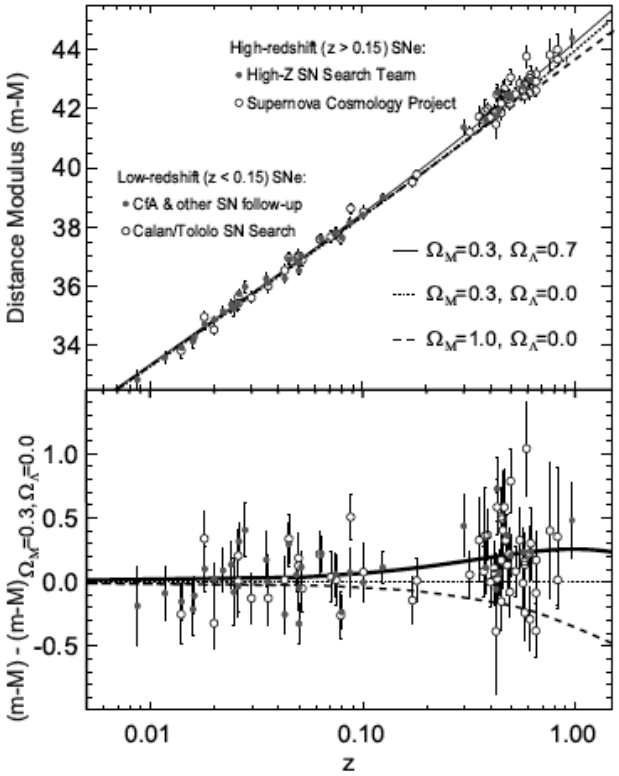
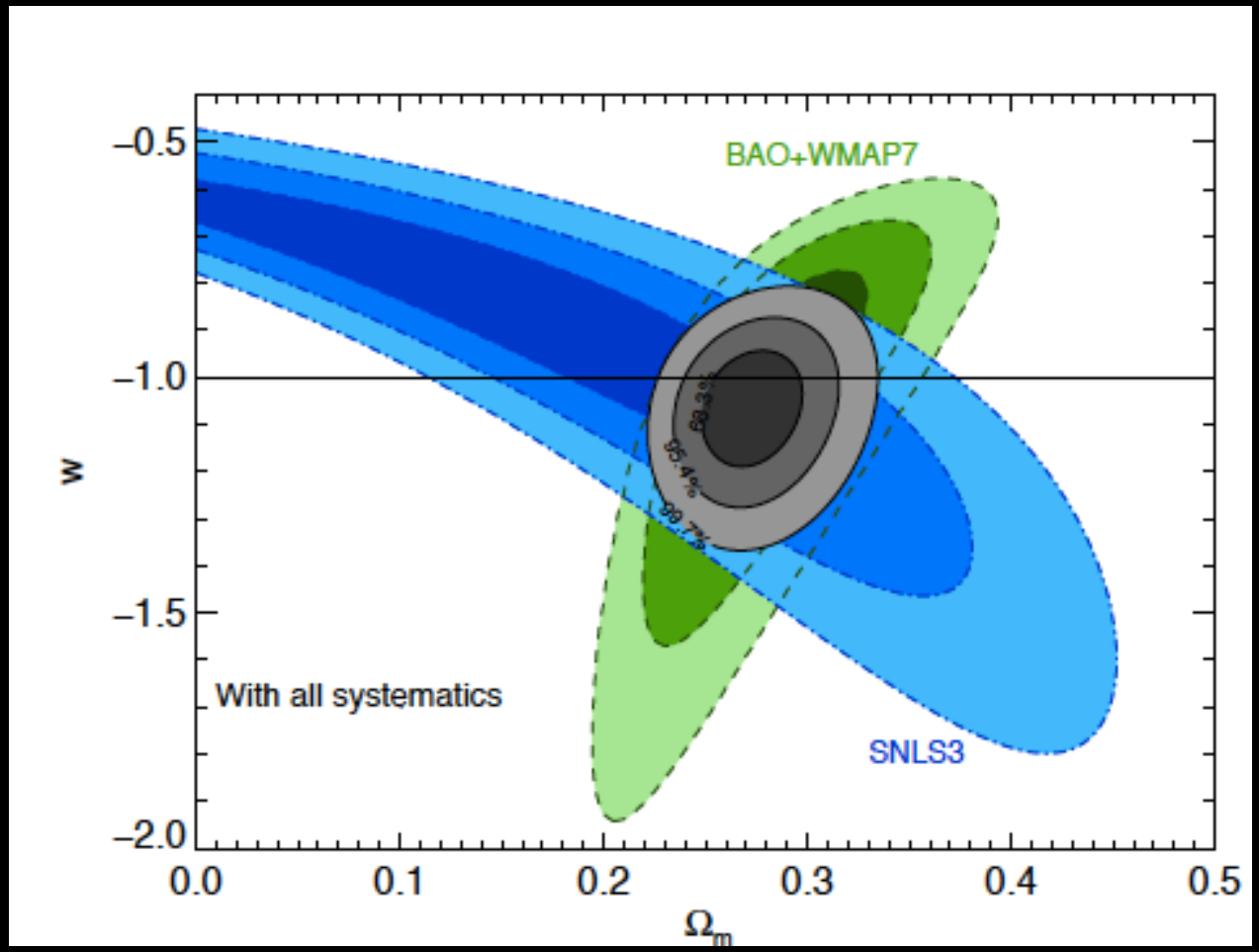


Figure 4: Discovery data: Hubble diagram of SNe Ia measured by the Supernova Cosmology Project and the High-z Supernova Team. Bottom panel shows residuals in distance modulus relative to an open universe with $\Omega_0 = \Omega_M = 0.3$. Figure adapted from Perlmutter & Schmidt (2003), Riess (2000), based on Perlmutter et al. (1999), Riess et al. (1998).

Recent SN results

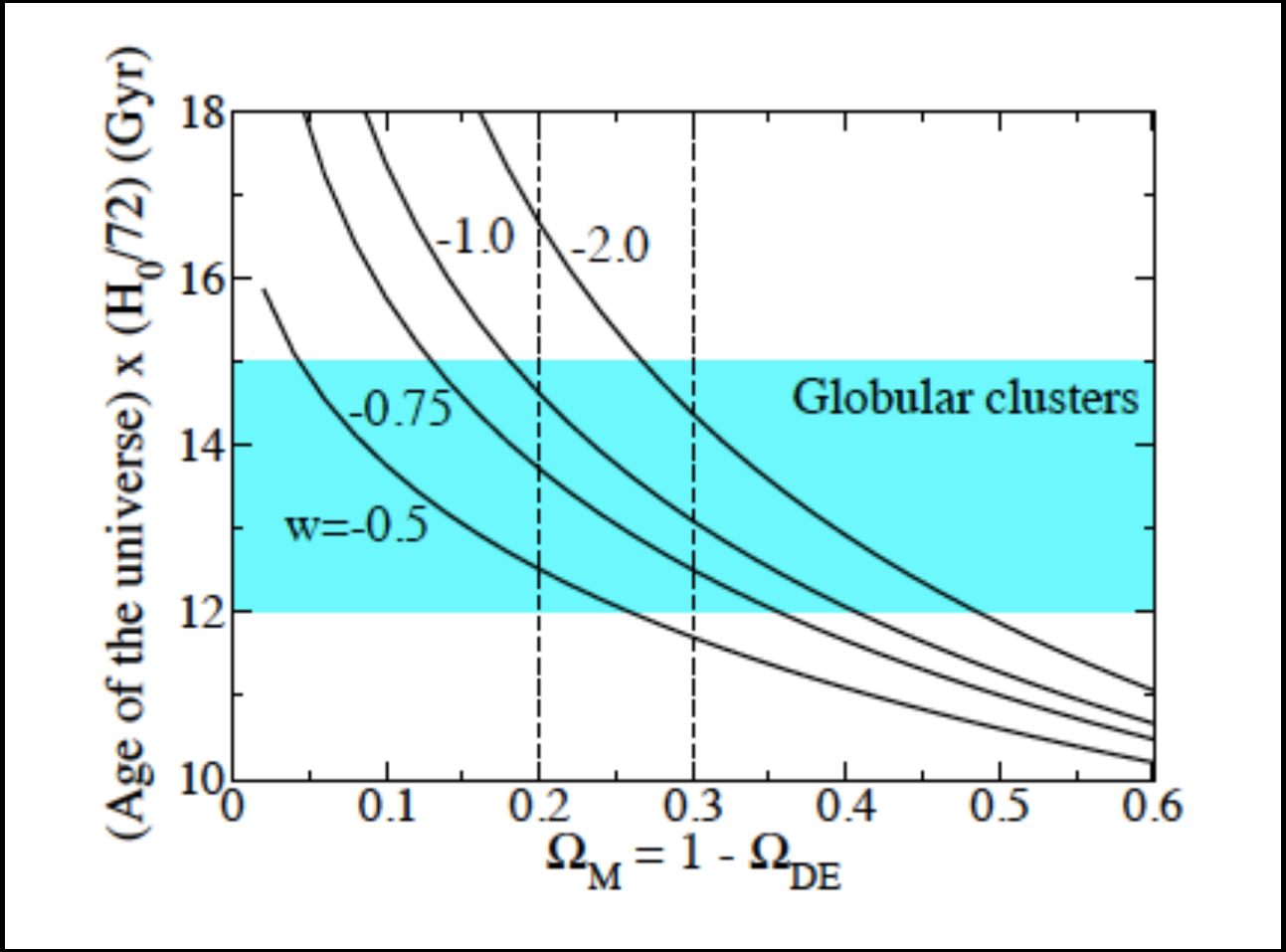


Sullivan et al. 2012

SN Ia challenges

- Poorly understood physics
- Selection effects (brightness and lensing)
- Dust
- Photometric calibration is hard at extreme levels of precision

Cosmic Chronometers



Cosmic Chronometers – H(z)

$$H(z) = -\frac{1}{(1+z)}\frac{dz}{dt}.$$

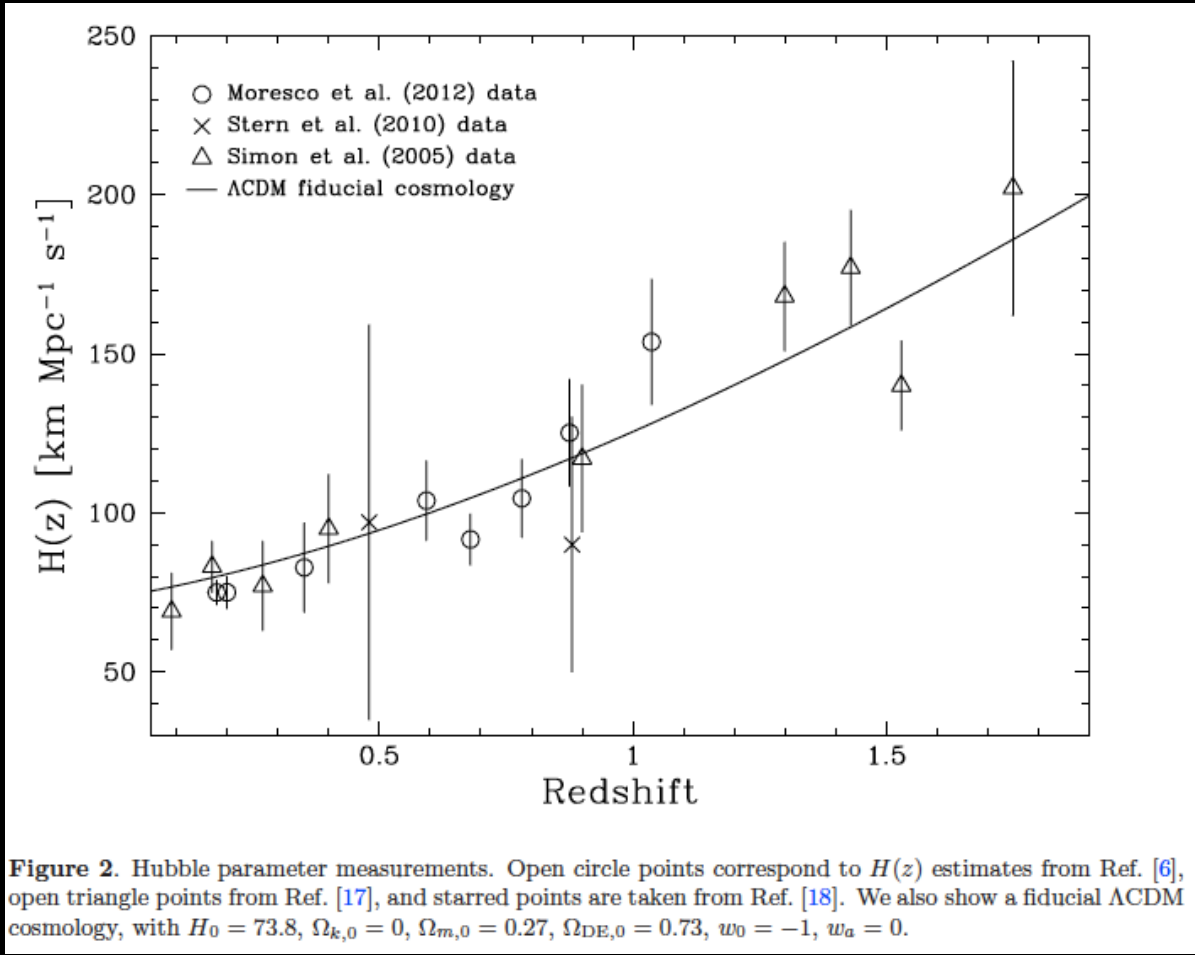


Figure 2. Hubble parameter measurements. Open circle points correspond to $H(z)$ estimates from Ref. [6], open triangle points from Ref. [17], and starred points are taken from Ref. [18]. We also show a fiducial ΛCDM cosmology, with $H_0 = 73.8$, $\Omega_{k,0} = 0$, $\Omega_{m,0} = 0.27$, $\Omega_{\rm DE,0} = 0.73$, $w_0 = -1$, $w_a = 0$.

Jimenez & Loeb 2002; Moresco et al. 2012

Chronometers challenges

- Hard to measure stellar ages with high precision
- Progenitor bias: galaxies evolve
- Edge effects

Homework for 1/28

- See web page

The end