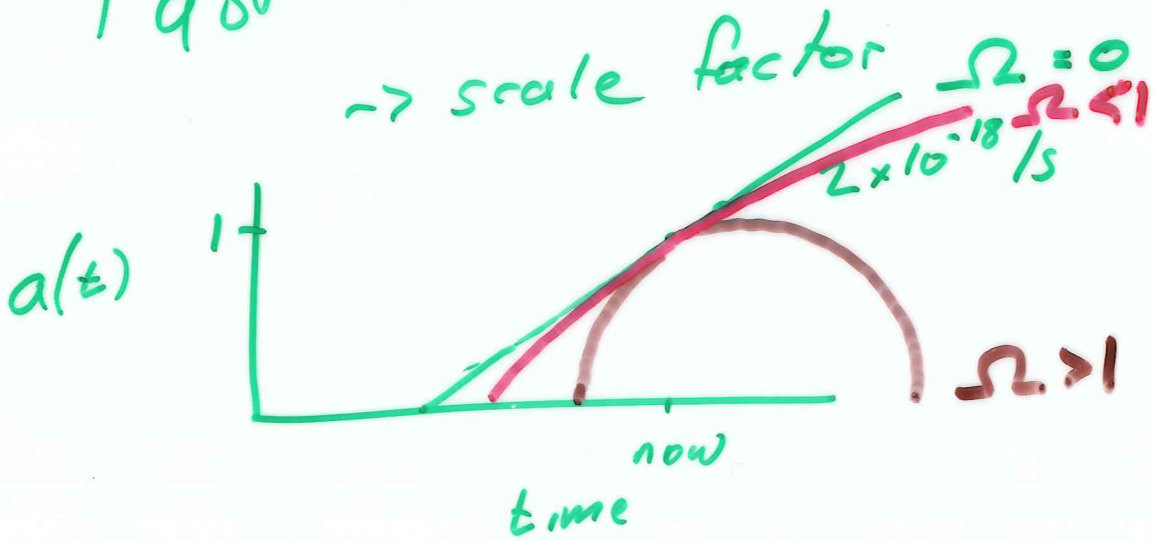
P/S had in PS #7

(PS #8 posted tomorrow)

names & staples greatly appreciated!

Past & Future of Universe

-> scale factor



define current scale factor to be unity

$\Omega = \rho/\rho_{CRIT}$

in 10^6 years there are

$3\times10^7\times10^6\ s = 3\times10^{13}\ s$

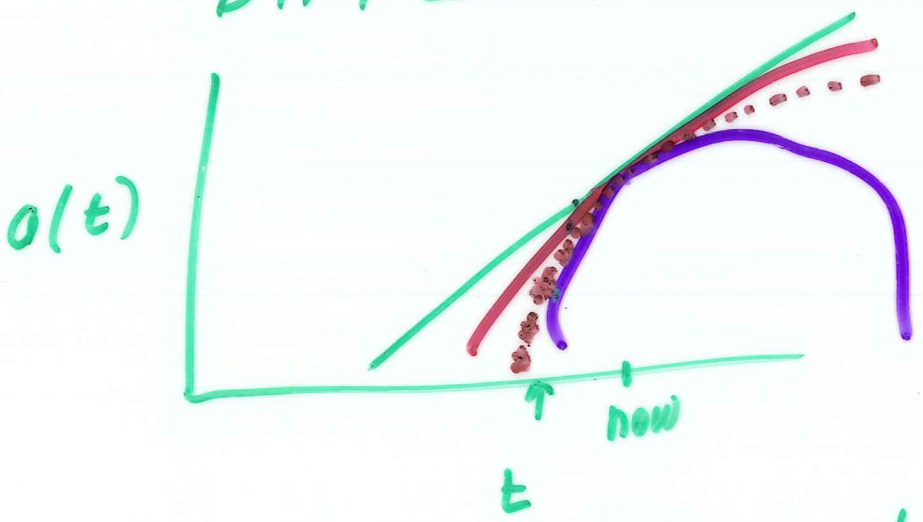
scale factor increases by $3\times10^{13}\times2\times10^{-18} = 6\times10^{-5}$

Direct measurement of Ω

→ Dark Matter

Mass in galaxies → $\Omega \sim 1/3$

DIFFERENT APPROACH



look into past (light travel time)

measure distance

time in past: $\frac{D}{c}$

determine scale factor at that time

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a different view of redshift

one view: redshift → velocity

cosmological redshift is not same as velocity

another view: wavelengths of light expand along with Universe

so when we observe distant object λ is longer than when it was emitted

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distance = $m - M = 5 \log(D/10\,pc)$

time = distance/c

$$\frac{a_{now}}{a_{then}} = \frac{\lambda_{obs}}{\lambda_{emit}} = \frac{\lambda_{emit} + \Delta\lambda}{\lambda_{emit}}$$

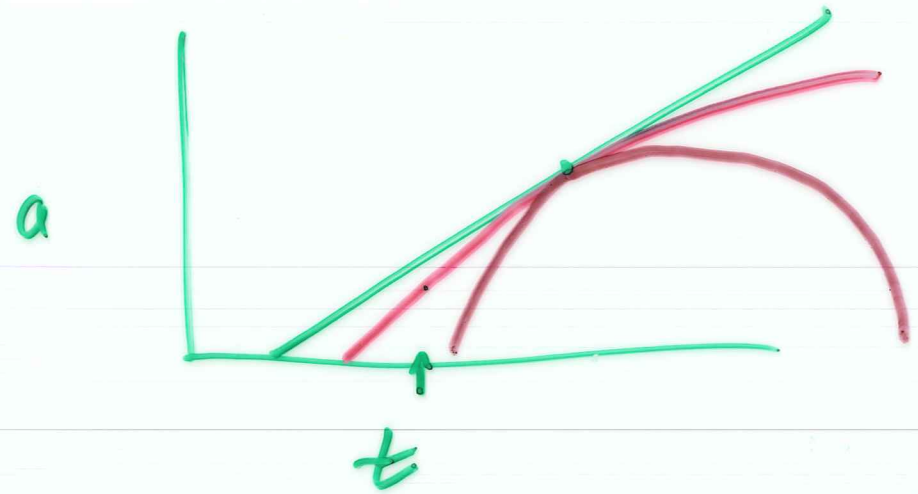
$$= 1 + z$$

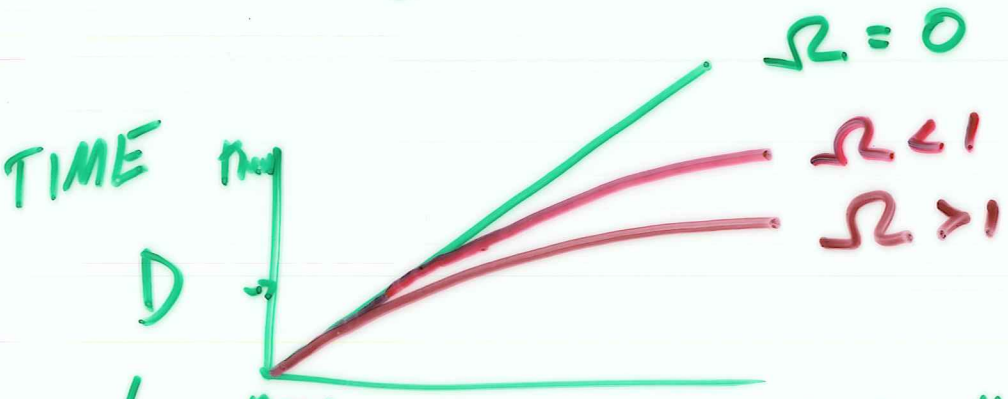
$\downarrow \Delta\lambda / \lambda_{emitted}$

$a_{now} \equiv 1$

$$\frac{1}{a} = 1 + z \quad \text{or} \quad a = \frac{1}{1+z}$$

← measure





z — $\frac{1}{1+z} = a$ $\quad \frac{1}{a} = 1+z$

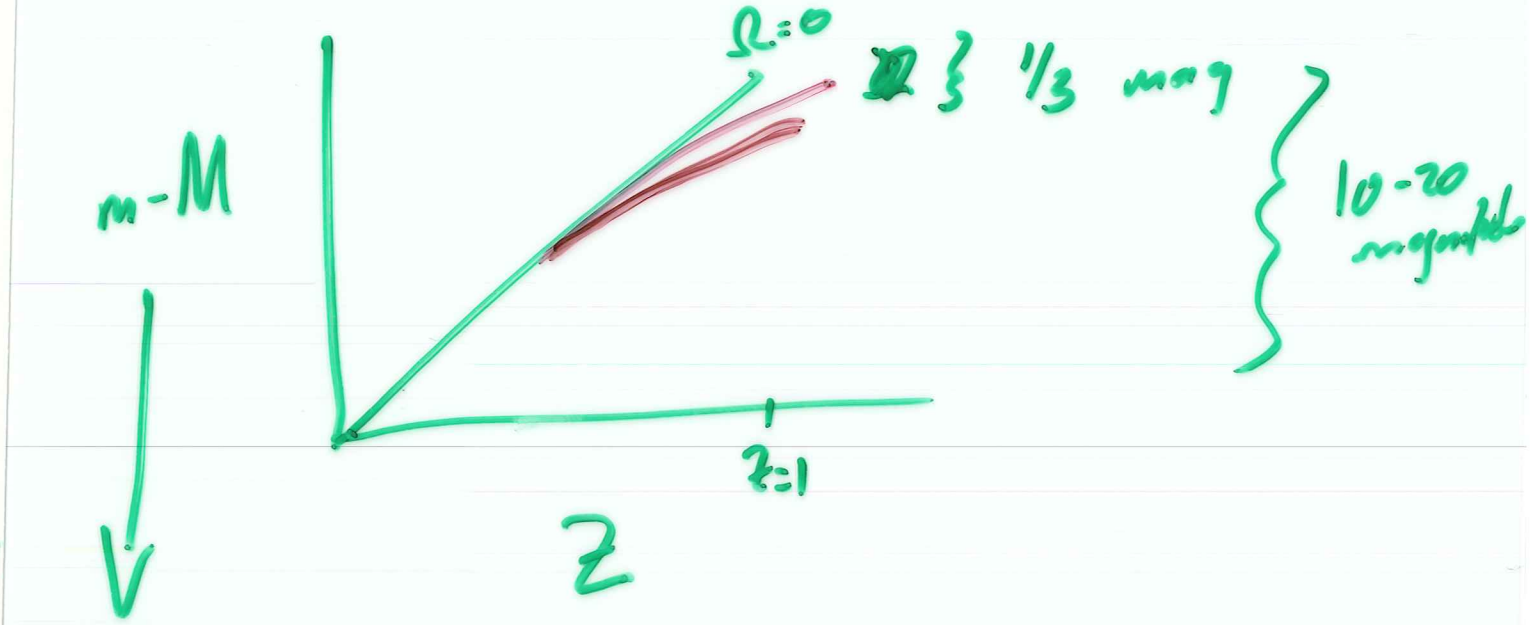
$\frac{1-a}{a} = z$

$m - M = 5 \log (D/10\,pc)$

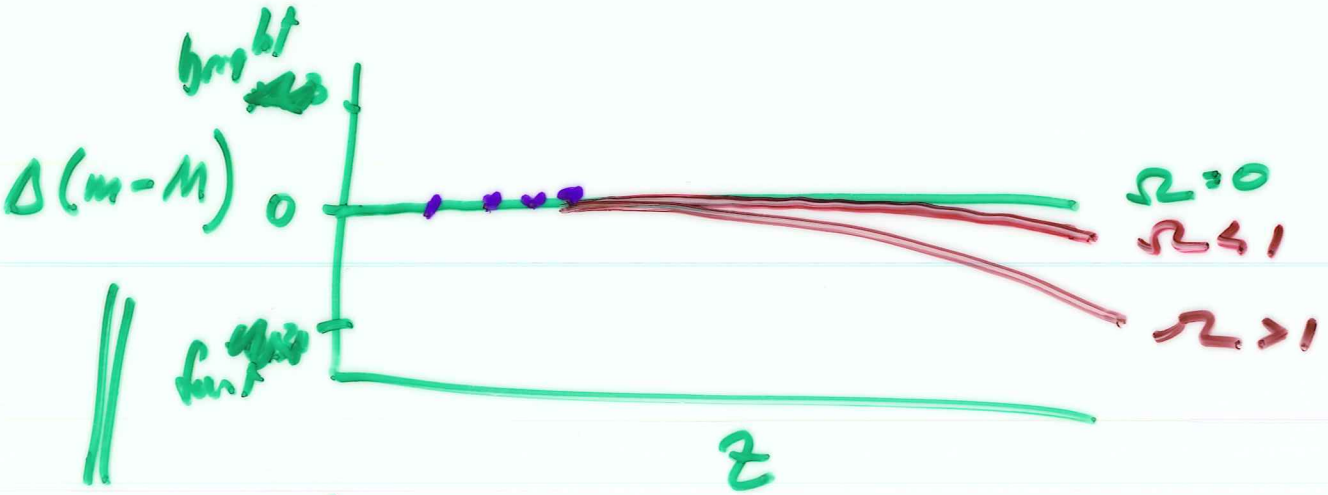
SCALE FACTOR

REALLY BRIGHT STANDARD CANDLE

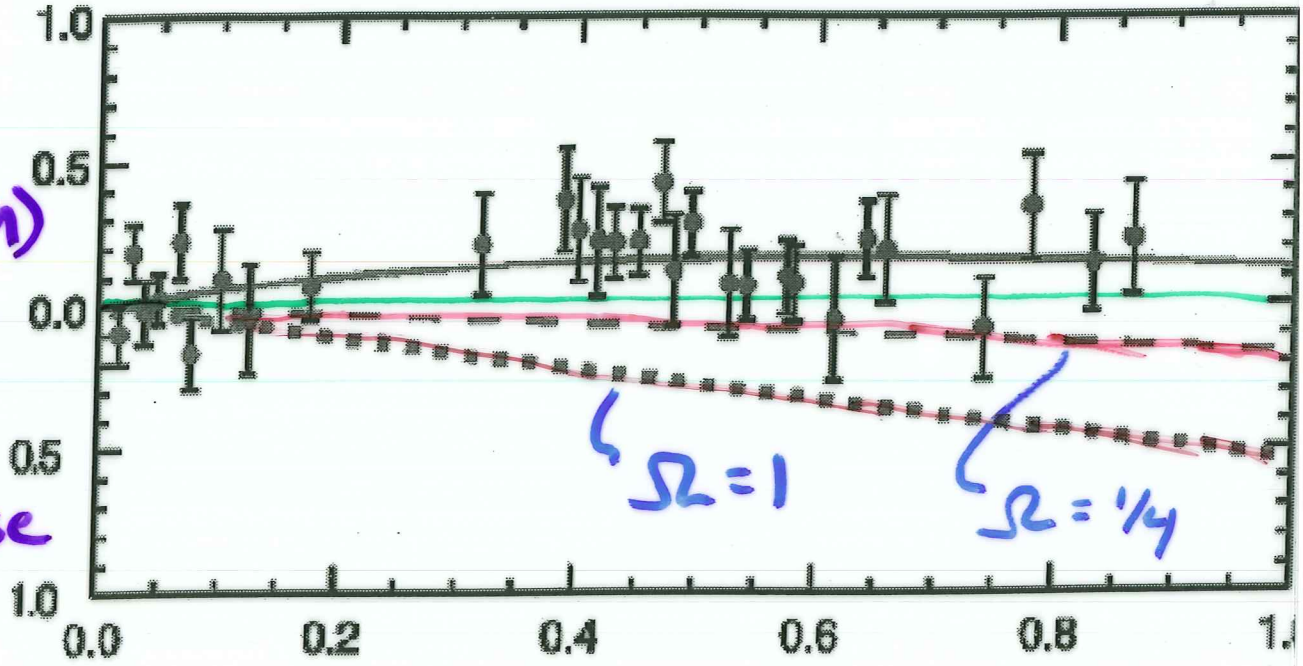
⇒ see it at large distances



"distance modulus"



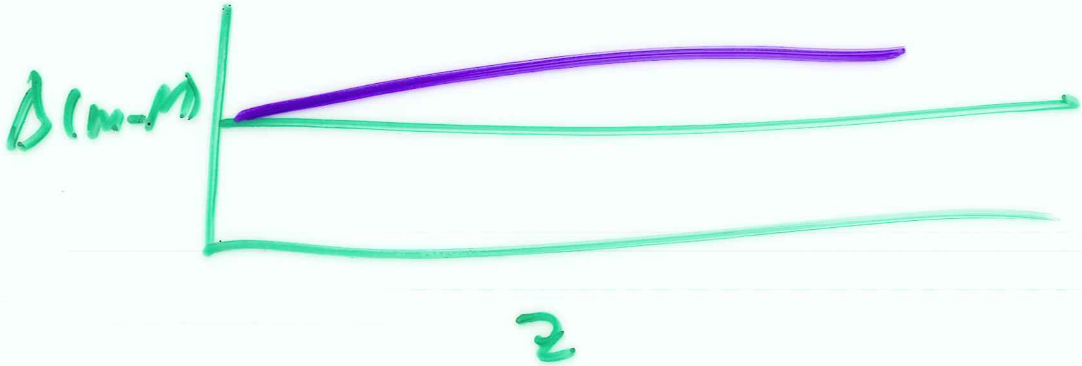
difference between measured m-M and m-M that given z in empty universe

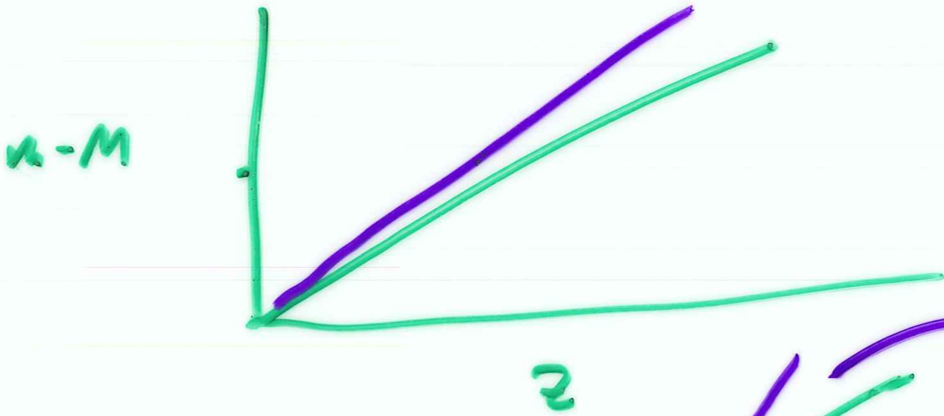


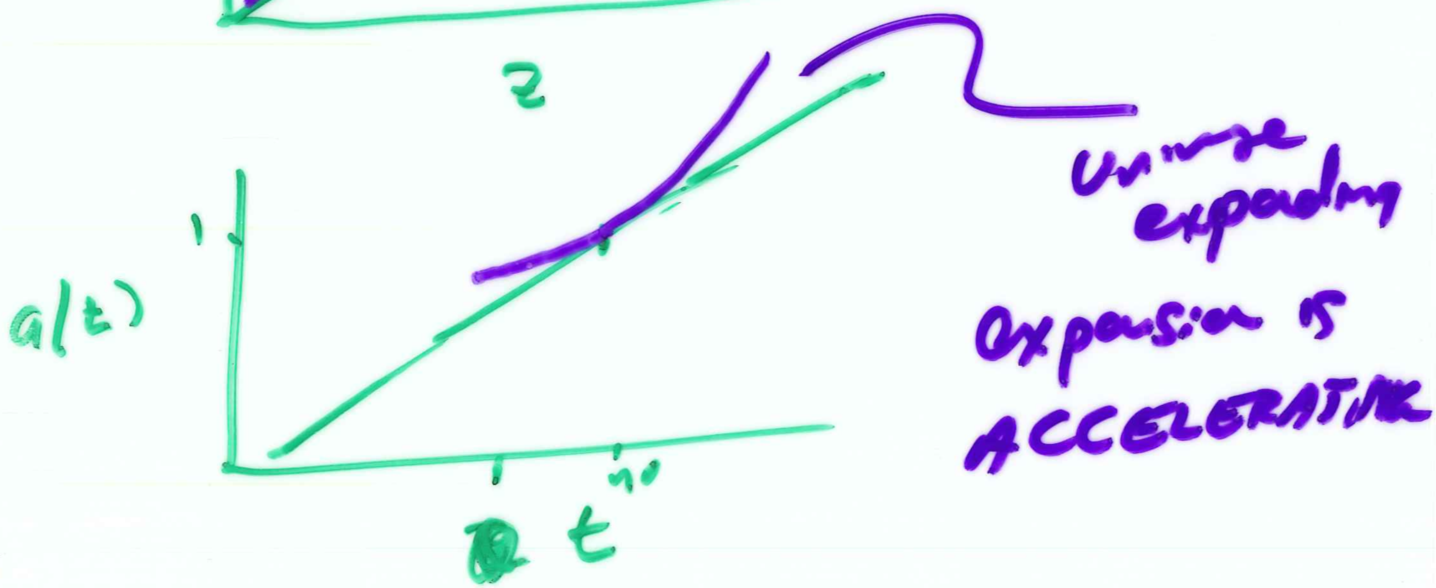
z

from Supernova Cosmology Project, Knop et al. 2003 Astrophysical Journal

two errors: measurement error (m)
accuracy of standard candle (M)







Universe is being pushed outward
by repulsive gravity

"Dark Energy"

What is density of Dark Energy
compared to matter?

every $1\ m^3$ $\Rightarrow$ $\frac{E/c^2}{m^3}$

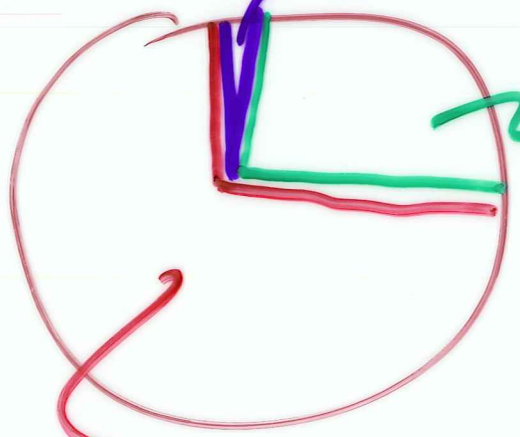
$\Omega_m = 1/4$

$\Omega_{DE} = 3 \times \Omega_m$

$\Omega = \rho/\rho_{CRIT}$

FEC 2007

PIE CHART OF UNIVERSE



ordinary matter energy

ordinary matter

Ω Dark Matter

Dark Energy

Einstein wanted a static Universe

invented an additional term

Λ "Cosmological constant"

force balance gravity

$\Rightarrow$ static universe

Then Hubble discovers expansion

E: "Λ was my biggest mistake"

FABLE: Einstein's biggest "mistake"

MORAL: "... terrific ideas can turn up in other contexts"

$\Omega_\Lambda \sim 10^{120}$ (particle physics)

$\Omega_\Lambda = 3/4$