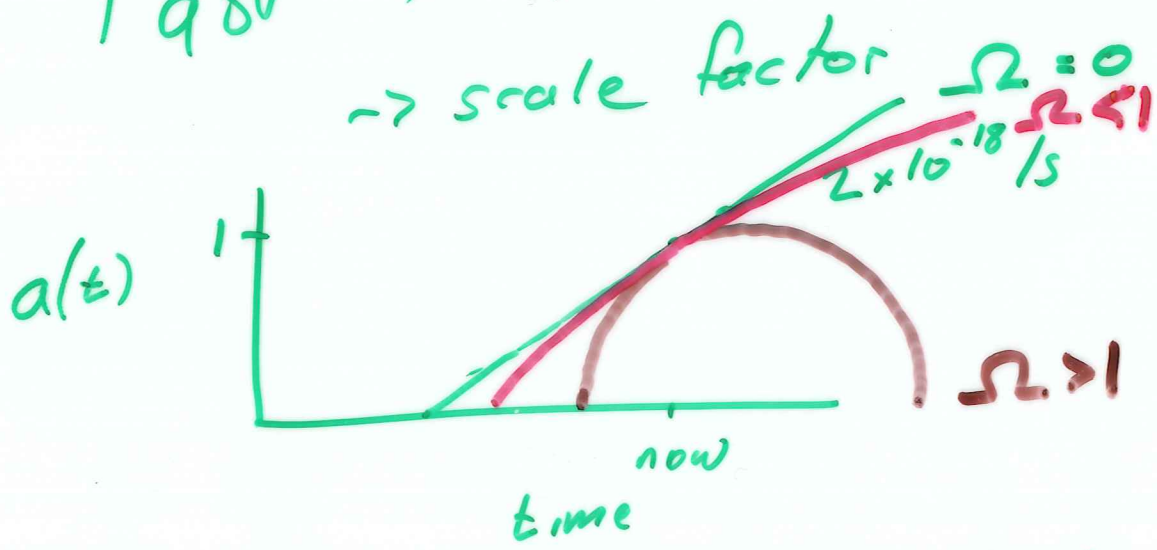
P/s had in PS #7

(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

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

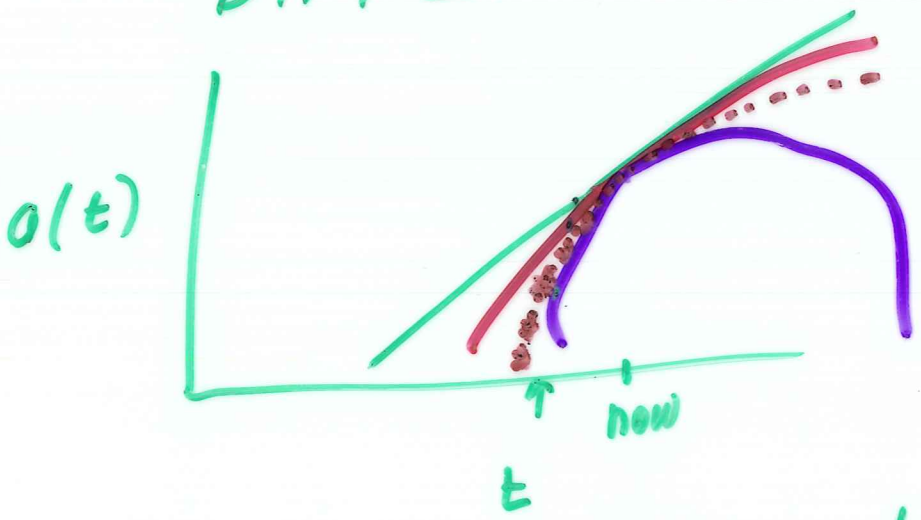
scale factor increases by $3\times10^{13}\times2\times10^{-18} = 6\times10^{-5}$

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 ordinary 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

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

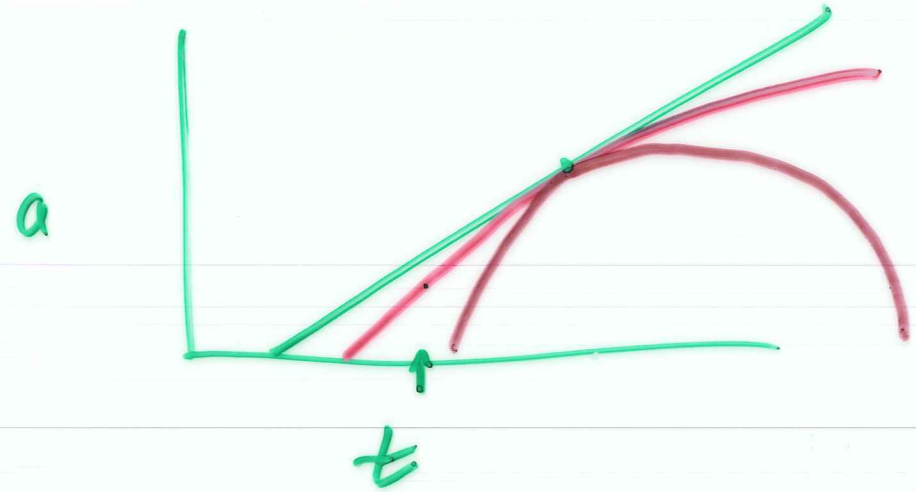
$$= 1 + z$$

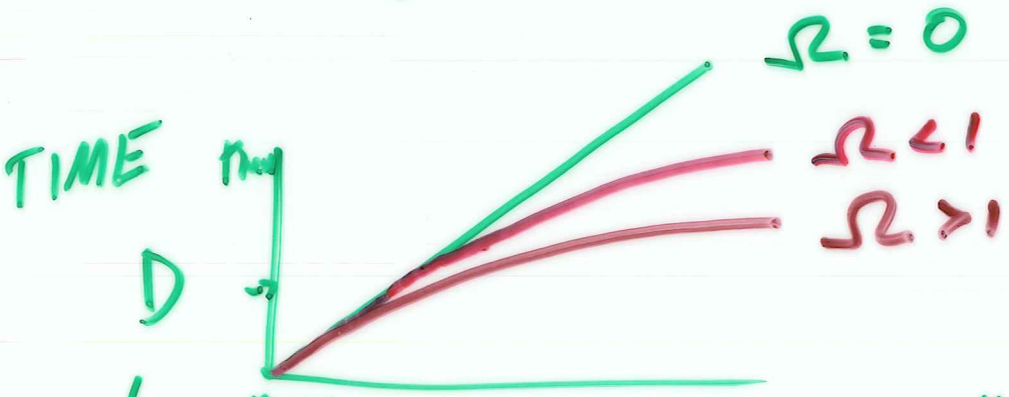
$\Delta\lambda$ / $\lambda_{emitted}$

$a_{now} \equiv 1$

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

measure





$z \sim \frac{1}{1+z} = a$

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

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

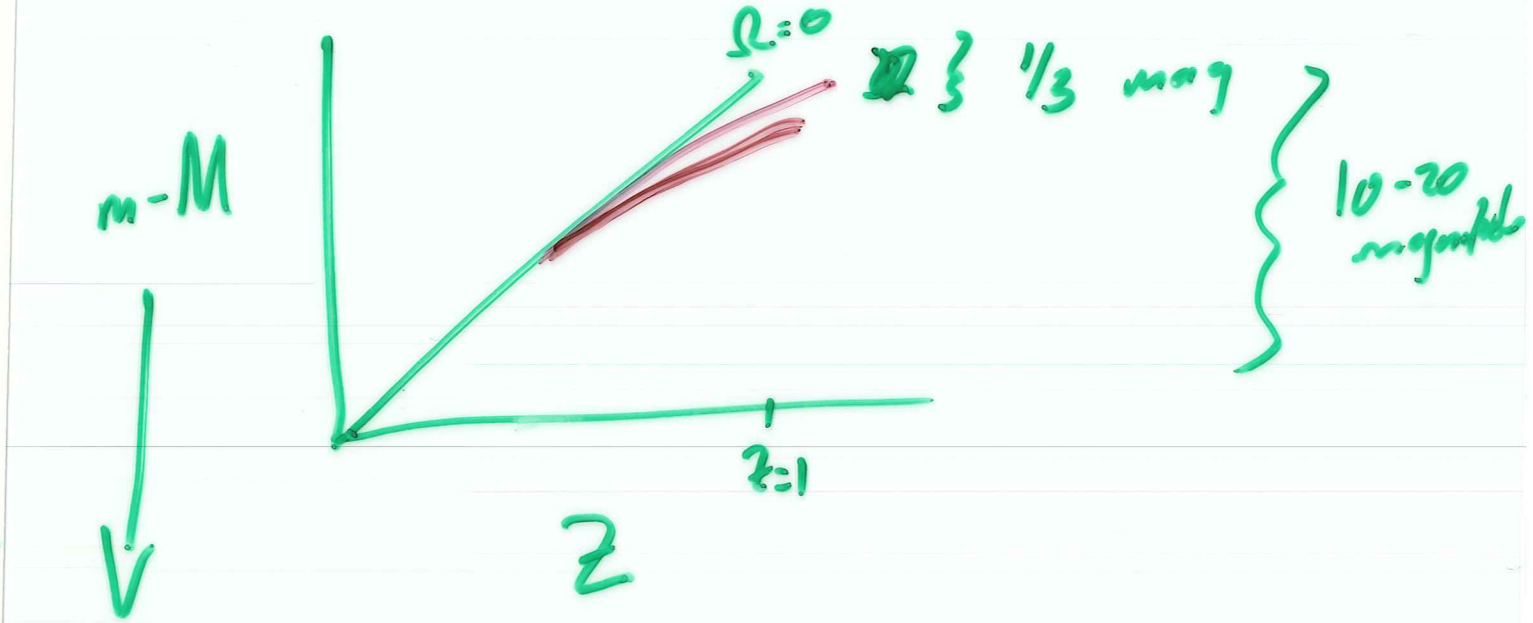
$m - M = 5 \log (D/10\,pc)$

SCALE FACTOR

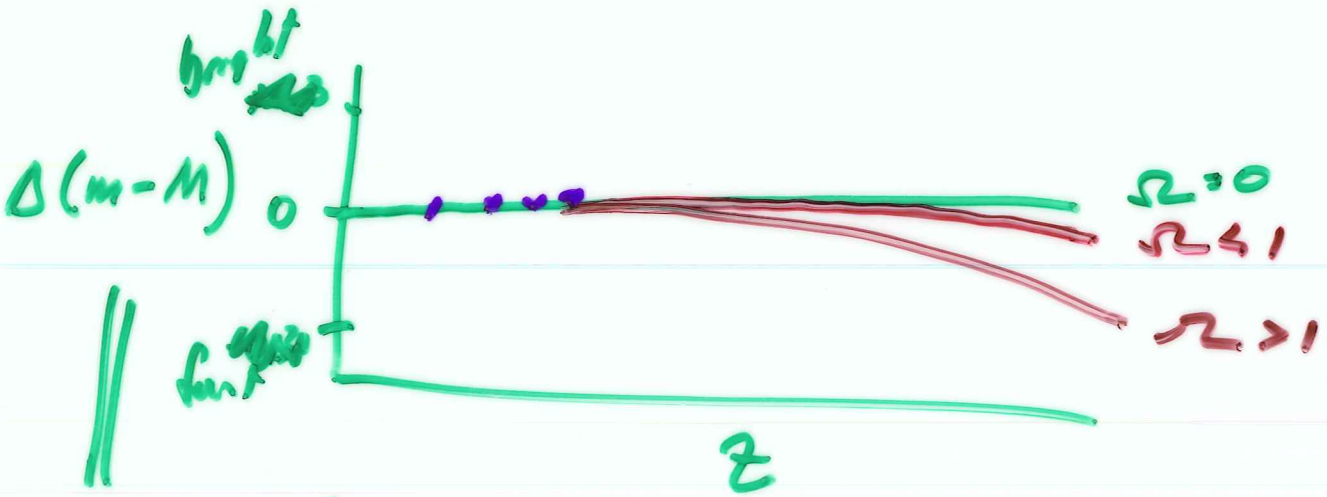
REALLY BRIGHT STANDARD CANDLE

⇒ see it at large distances

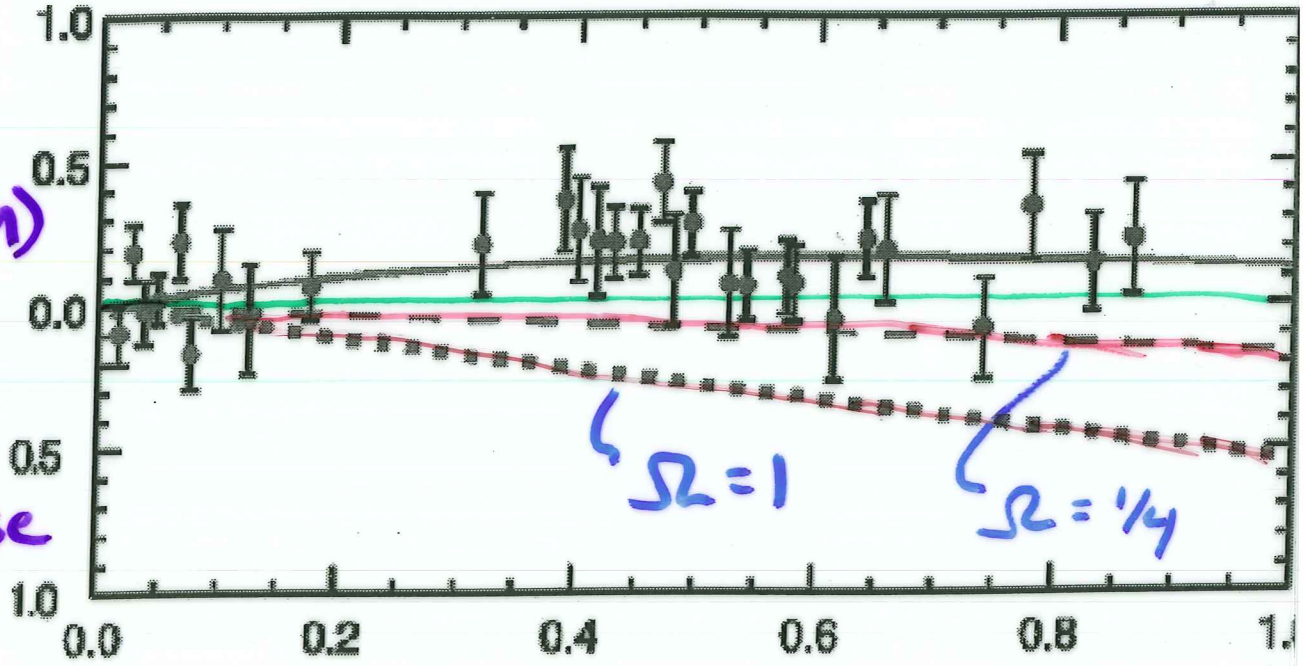
Type Ia Supernovae



"distance modulus"

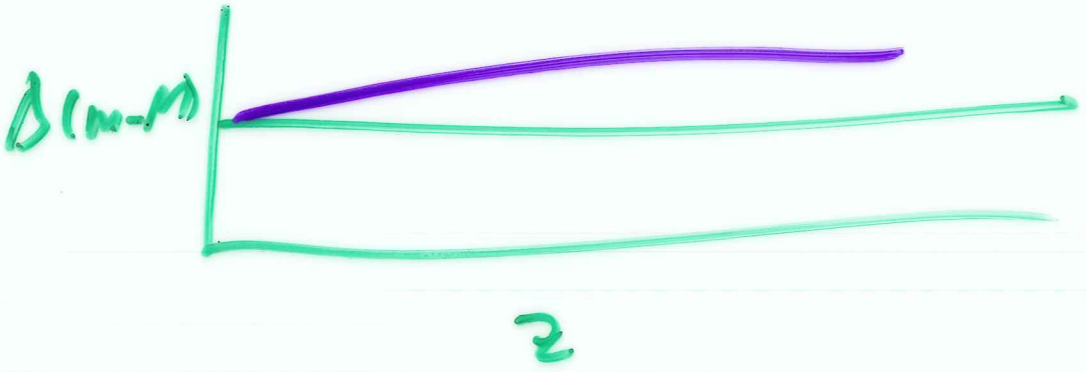


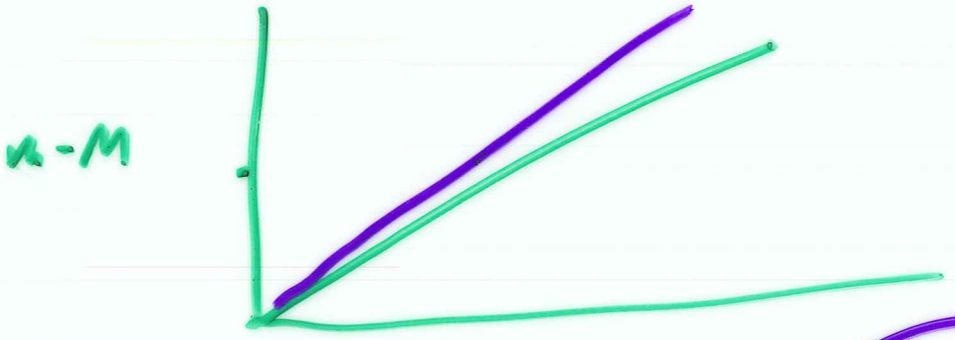
difference between measured m-M and m-M that given z in empty universe

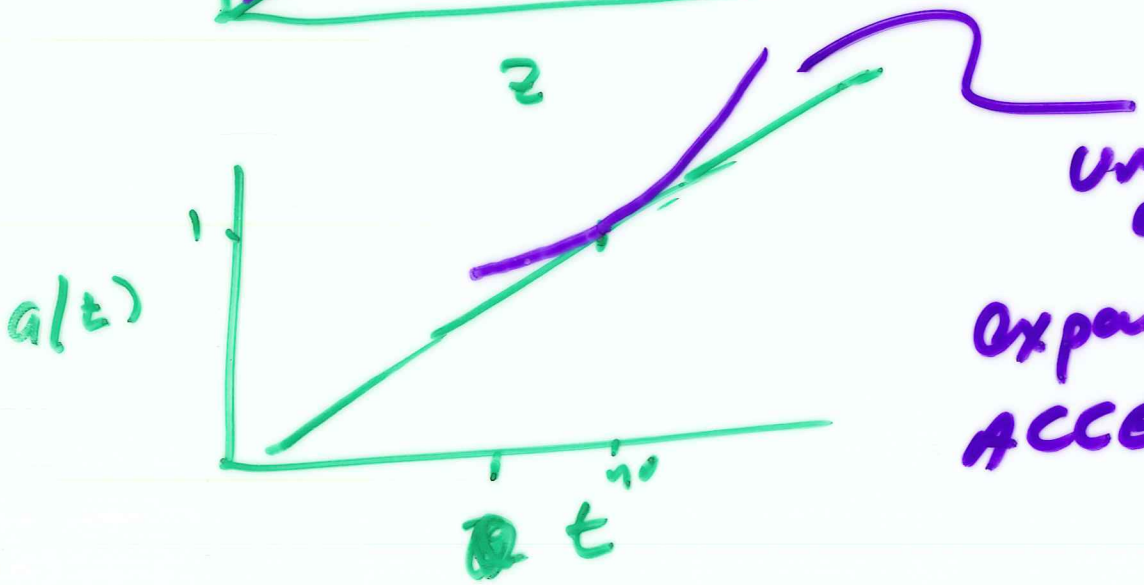


from Supernova Cosmology Project, Knop et al. 2003 Astrophysical Journal

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







Universe expanding

Expansion is ACCELERATING

Universe is being pushed ahead by repulsive gravity

"Dark Energy"

What is density of Dark Energy compared to matter?

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

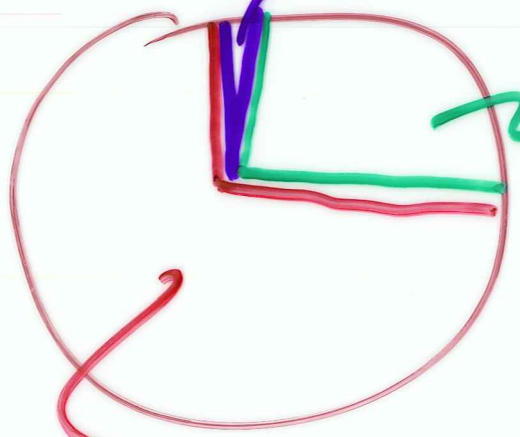
$\Omega_m = 1/4$

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

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

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"

$\Rightarrow$ repulsive force balance gravity

$\rightarrow$ static universe

Then Hubble discovers expansion

E: "Λ was my biggest mistake"

FABLE: Einstein's biggest "mistake"

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

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

$\Omega_\Lambda = 3/4$