Type II supernova cosmology: past and future

T. de Jaeger (UC Berkeley)

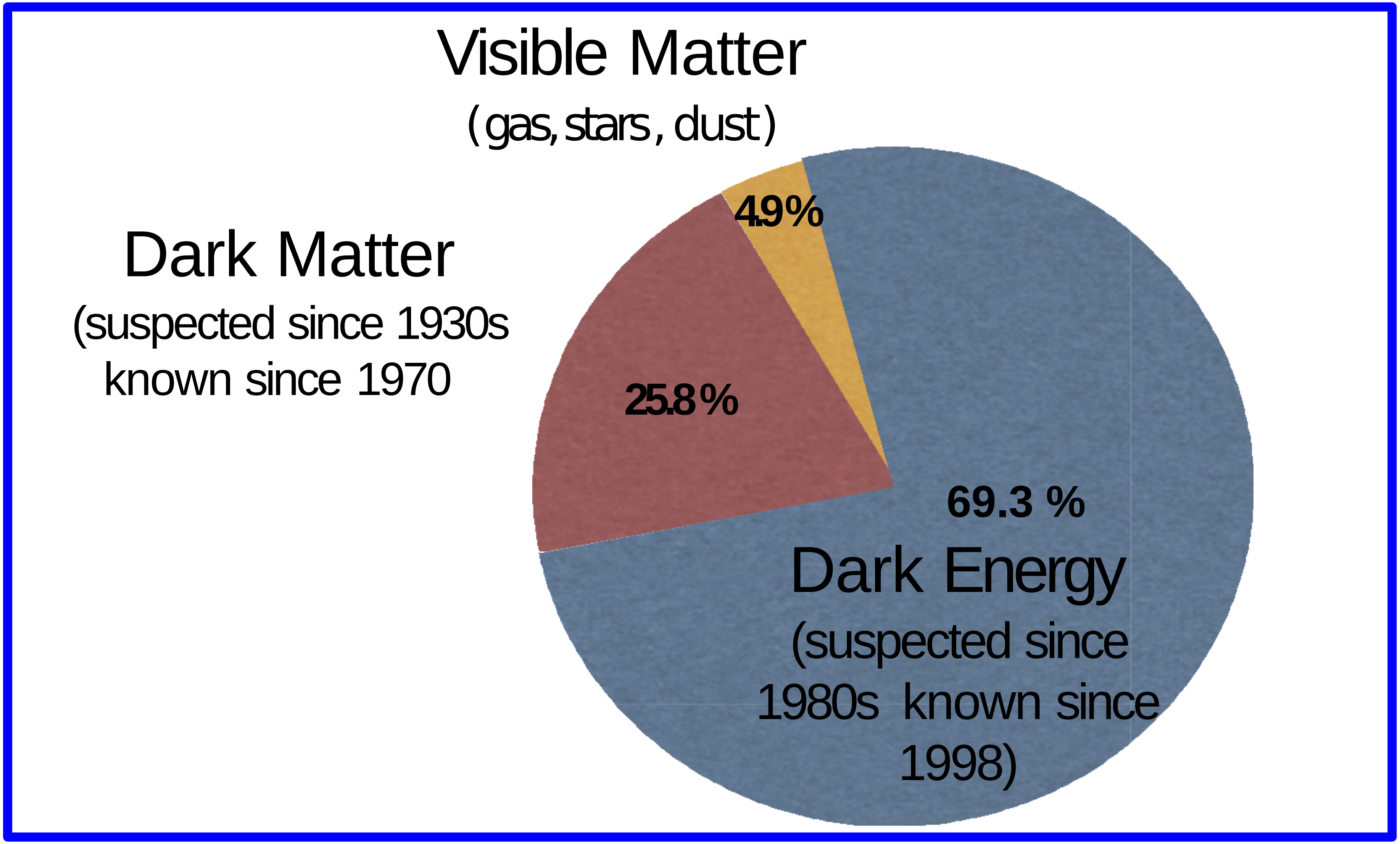
17/01/2019
Lisboa

Cosmology

<u>Cosmology :</u> from the Greek κόσμος, kosmos "world" and -λογία, -logia "study of"

→ study of the origin, evolution, composition and dynamics of the Universe

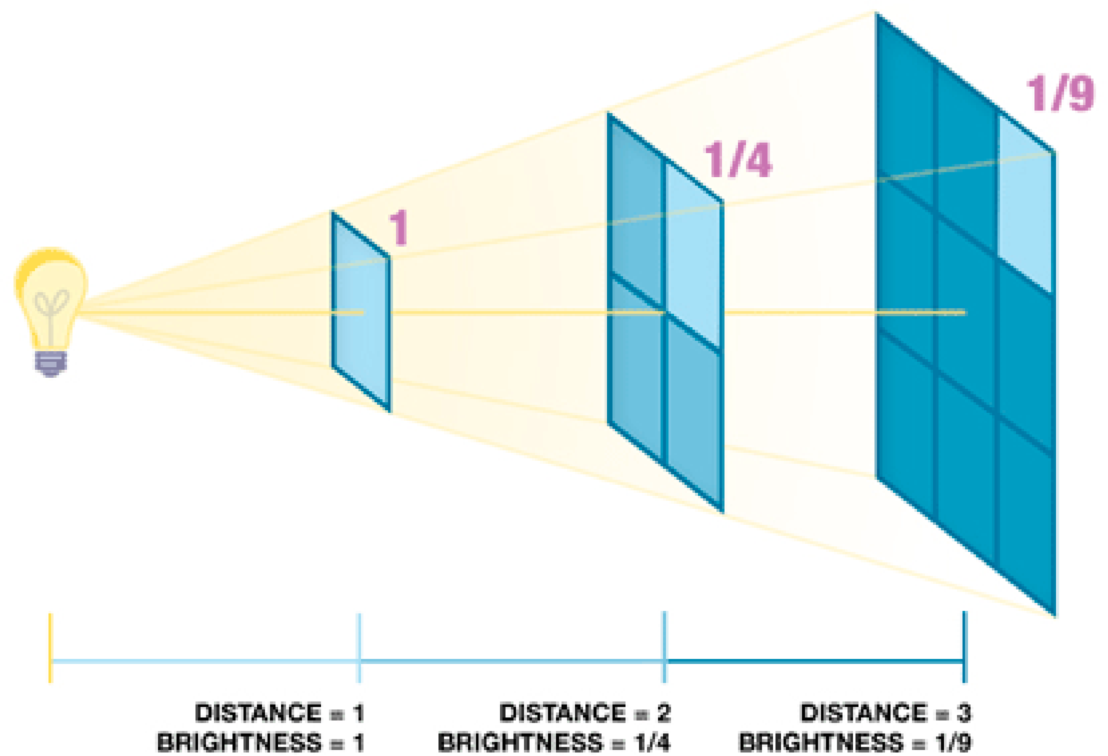
Cosmology



Visible Matter
(gas, stars, dust)
4.9%
Dark Matter
(suspected since 1930s
known since 1970
25.8%
69.3 %
Dark Energy
(suspected since
1980s known since
1998)

Distances

Inverse square law



Distances

Distances

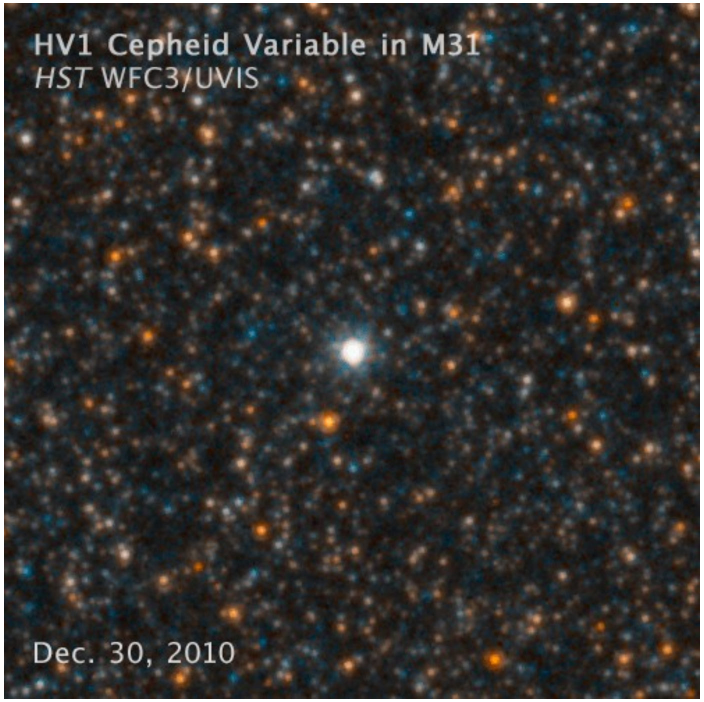
Distances

Need to know the intrinsic brightness of the object

→ **STANDARD CANDLES**

Distances

Cepheids : period-luminosity relation



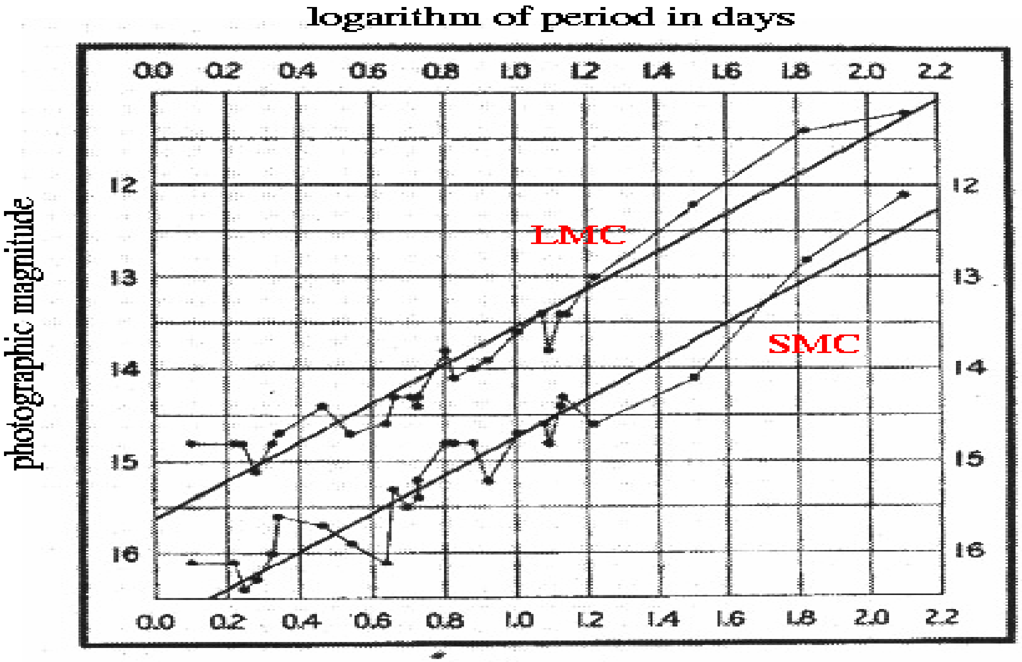
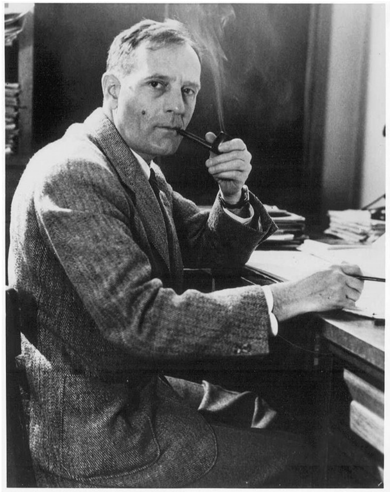


FIG. 2.

Leavitt et al. 1908

Expansion of the Universe



<u>Hubble 1929 :</u> **UNIVERSE IS EXPANDING!!!**

→ **More distant galaxies are moving faster away from us!!!**

Velocities measured by Slipher

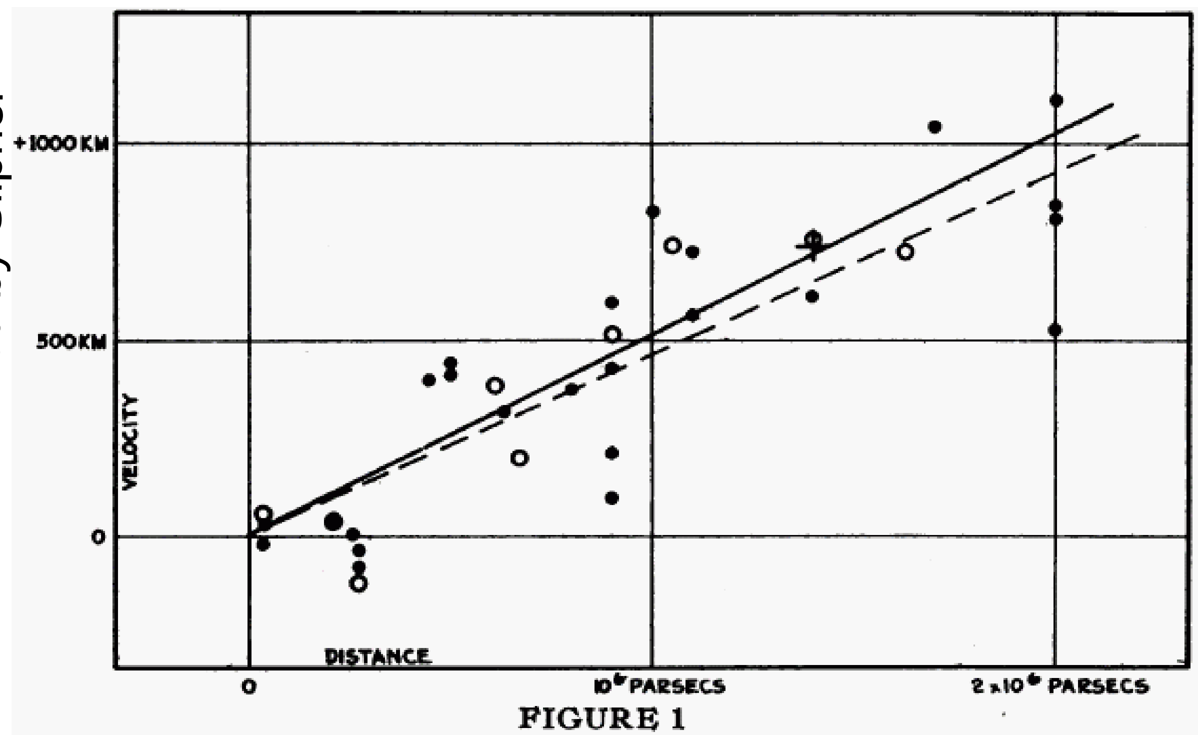


FIGURE 1

Velocity-Distance Relation among Extra-Galactic Nebulae.

Distance measured with Cepheids by Hubble

Oops… sorry Hubble

In **1927** : Annales de la Société Scientifique de Bruxelles, A47, p. 49-59

6. CONCLUSION.

Nous avons obtenu une solution qui vérifie les conditions suivantes :

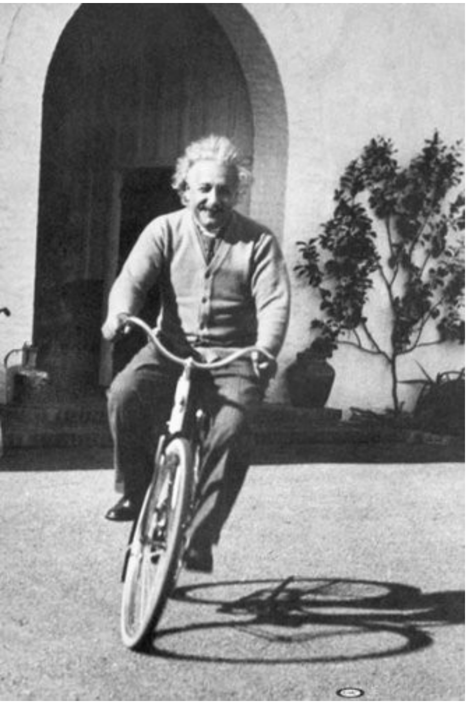
1. La masse de l'univers est constante et est liée à la constante cosmologique par la relation d'Einstein

$$\sqrt{\lambda} = \frac{2\pi^2}{\kappa M} = \frac{1}{R_0}$$

2. Le rayon de l'univers croît sans cesse depuis une valeur asymptotique R_0 pour $t = -\infty$.

3. L'éloignement des nébuleuses extra-galactiques est un effet cosmique dû à l'expansion de l'espace et permettant de calculer le rayon R_0 par les

Big surprise (1915)

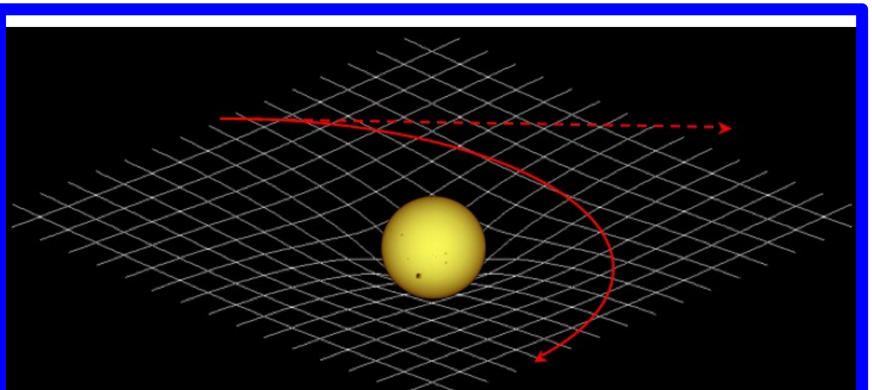


Curvature of spacetime

$$R_{\mu\nu} - \frac{1}{2} R \, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

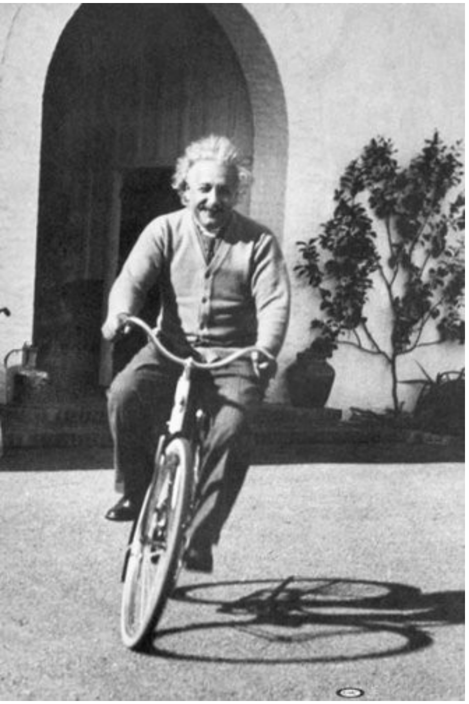
Matter/ energy

Only two solutions for Universe : contraction or expansion



Static Universe

Cosmological constant



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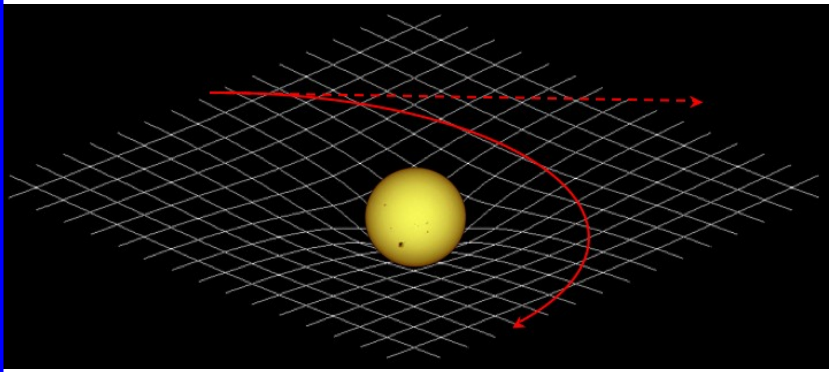
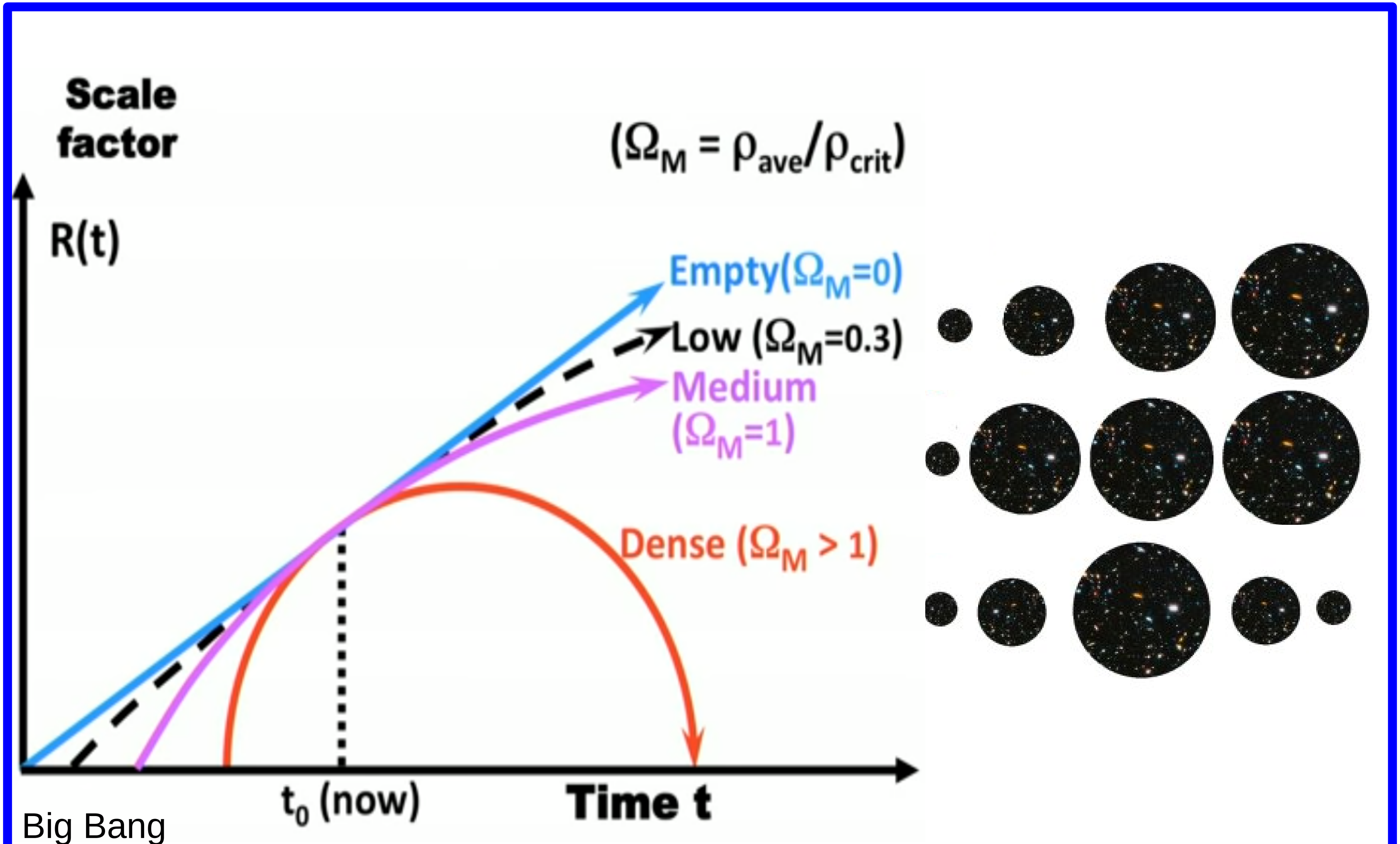


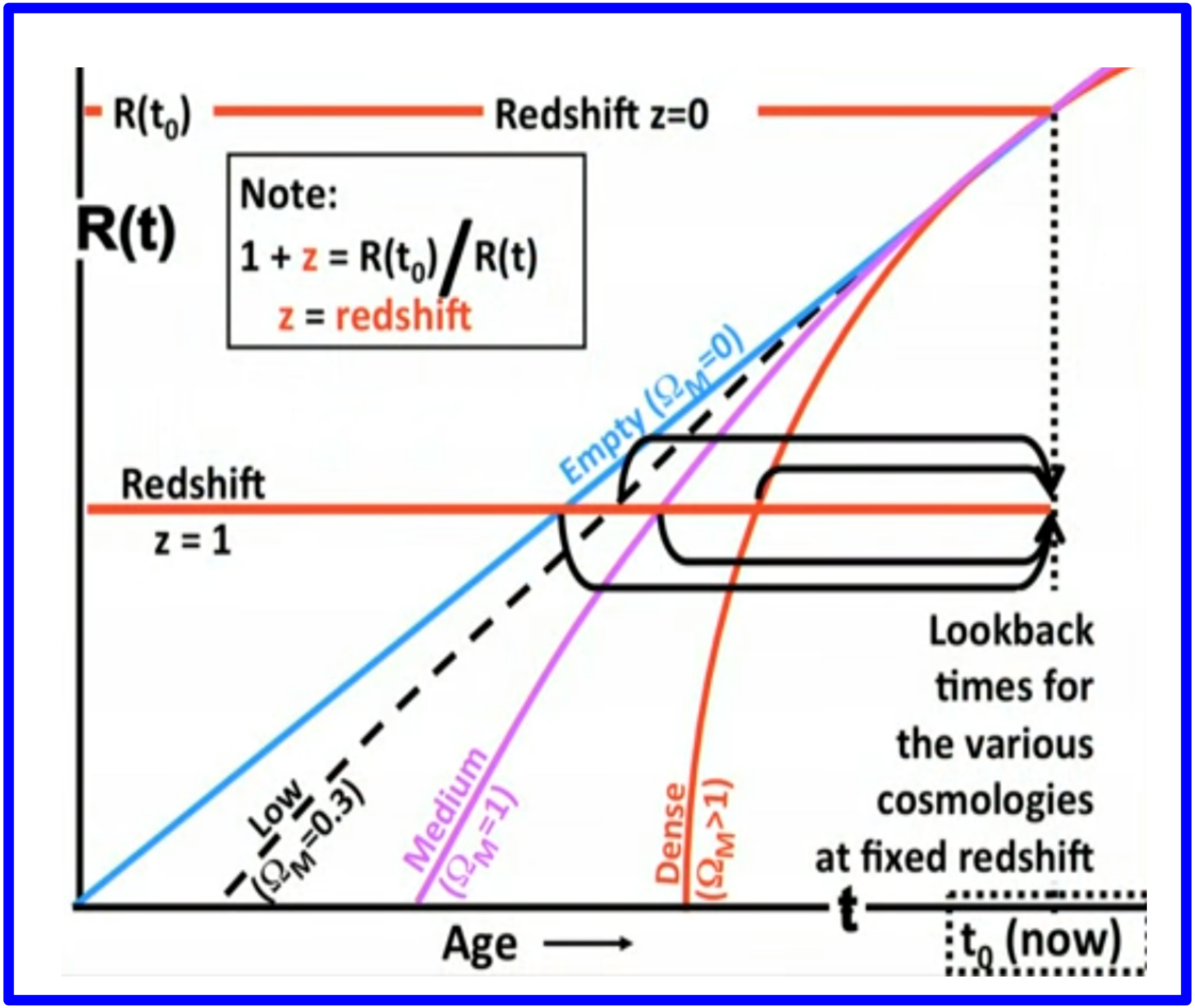
Cosmological constant

$$R_{\mu\nu} - \frac{1}{2} R\, g_{\mu\nu} + \Lambda\, g_{\mu\nu} = \frac{8\pi G}{c^4} T_{\mu\nu}$$

Universe destiny?

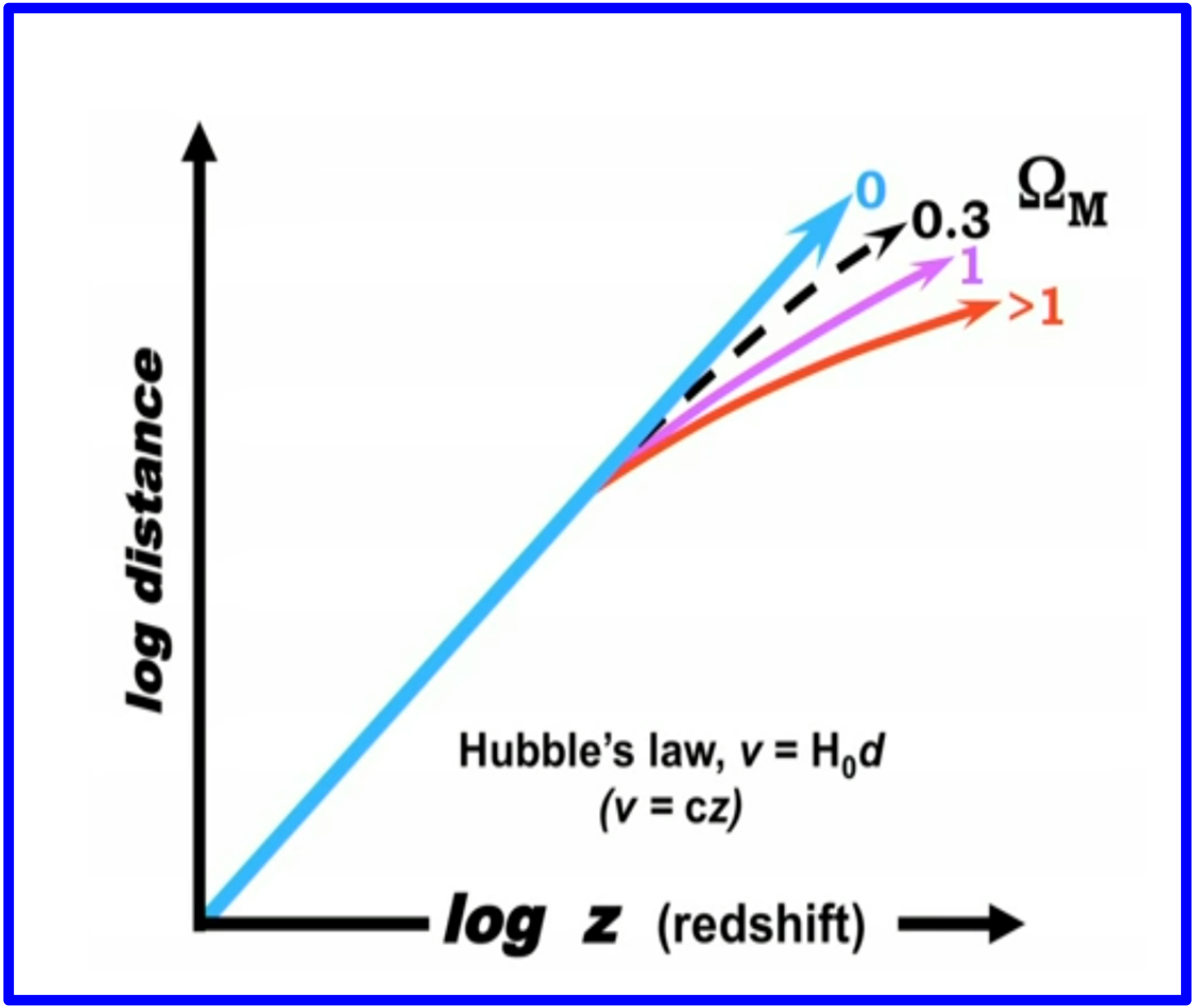


Universe destiny?



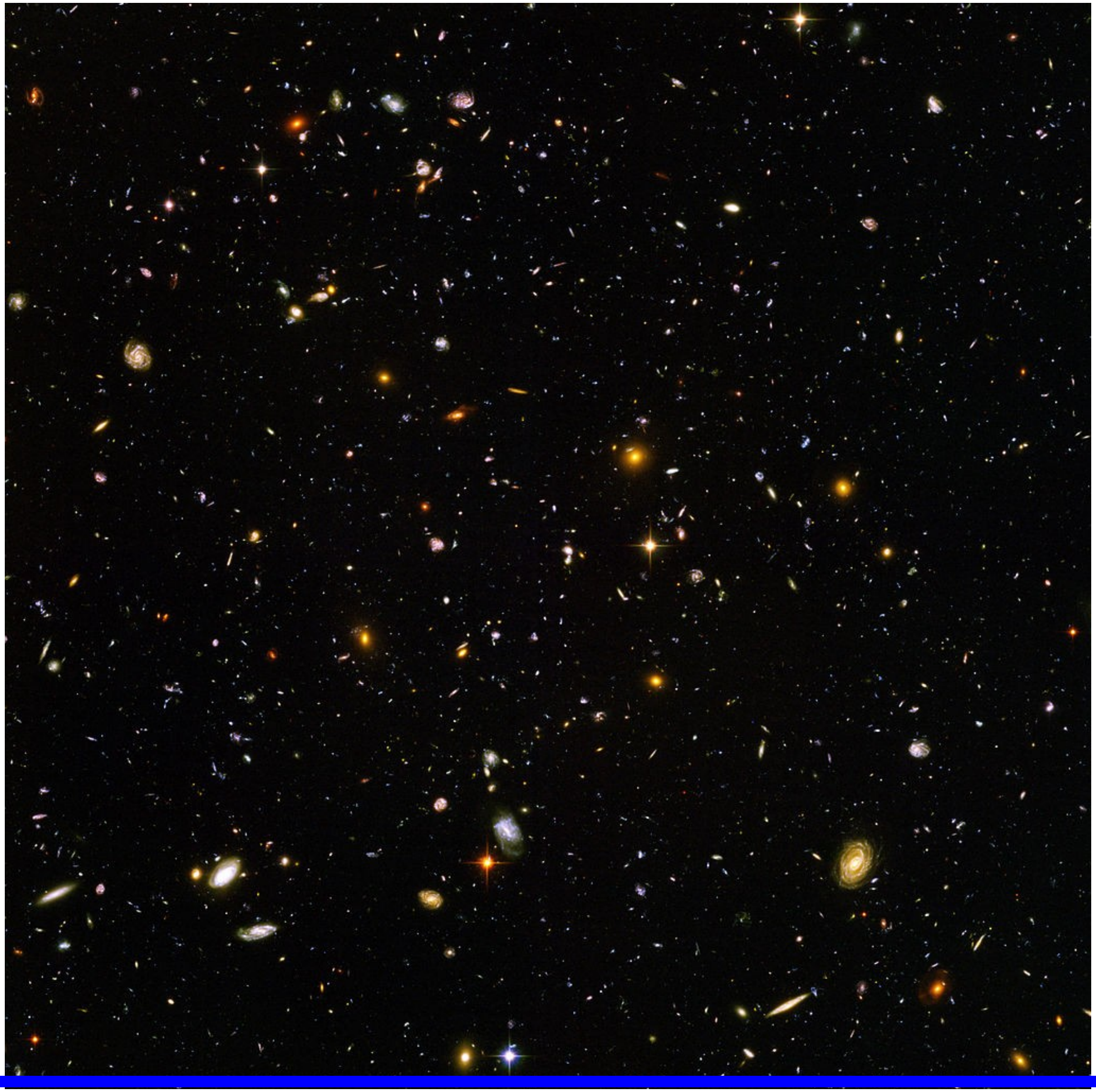
Credit : Alex Filippenko

Universe destiny?



Credit : Alex Filippenko

Measuring great distances



Credit : HST

Supernovae

- **A supernova (Zwicky 1931) is a stellar explosion that briefly outshines an entire galaxy (10^9–10^{10} $L_\odot$).**

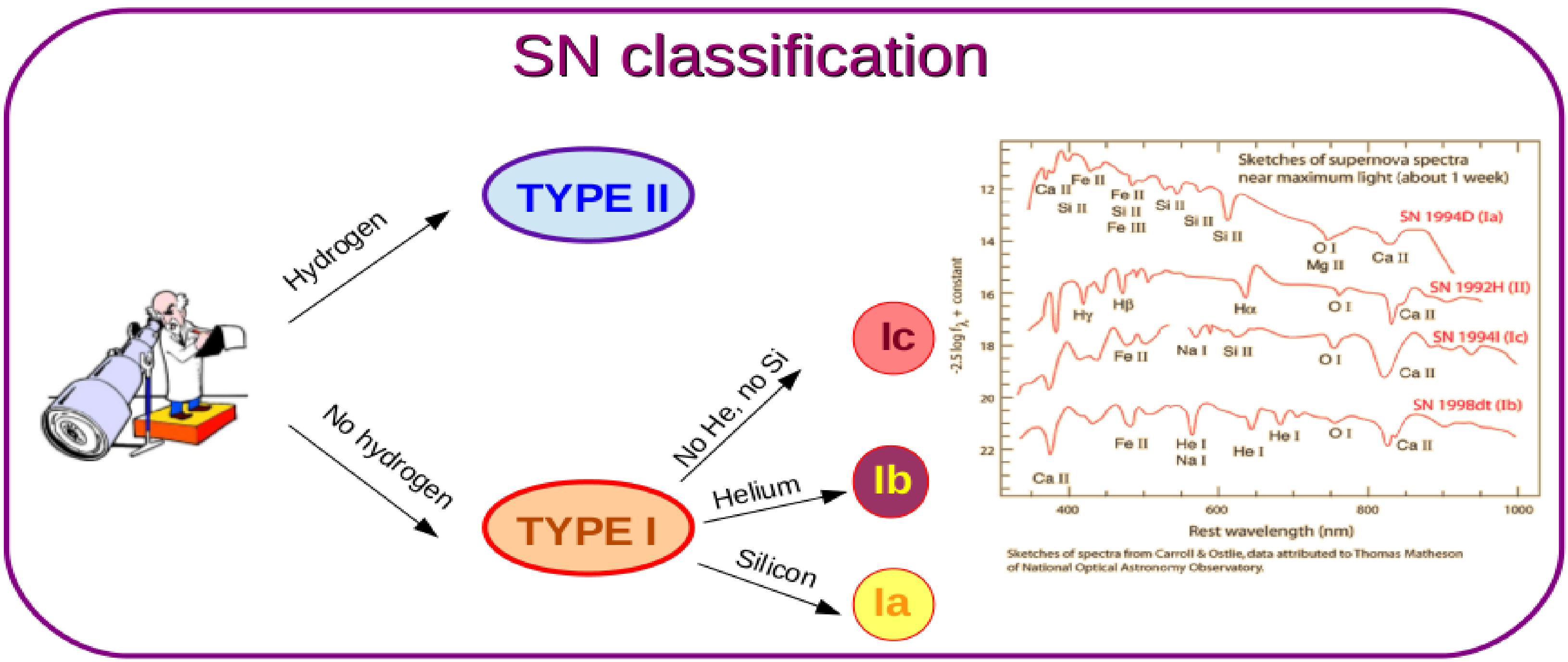
SN 1987A in LMC

Supernovae

Credit :LCOGT BJ Fulton

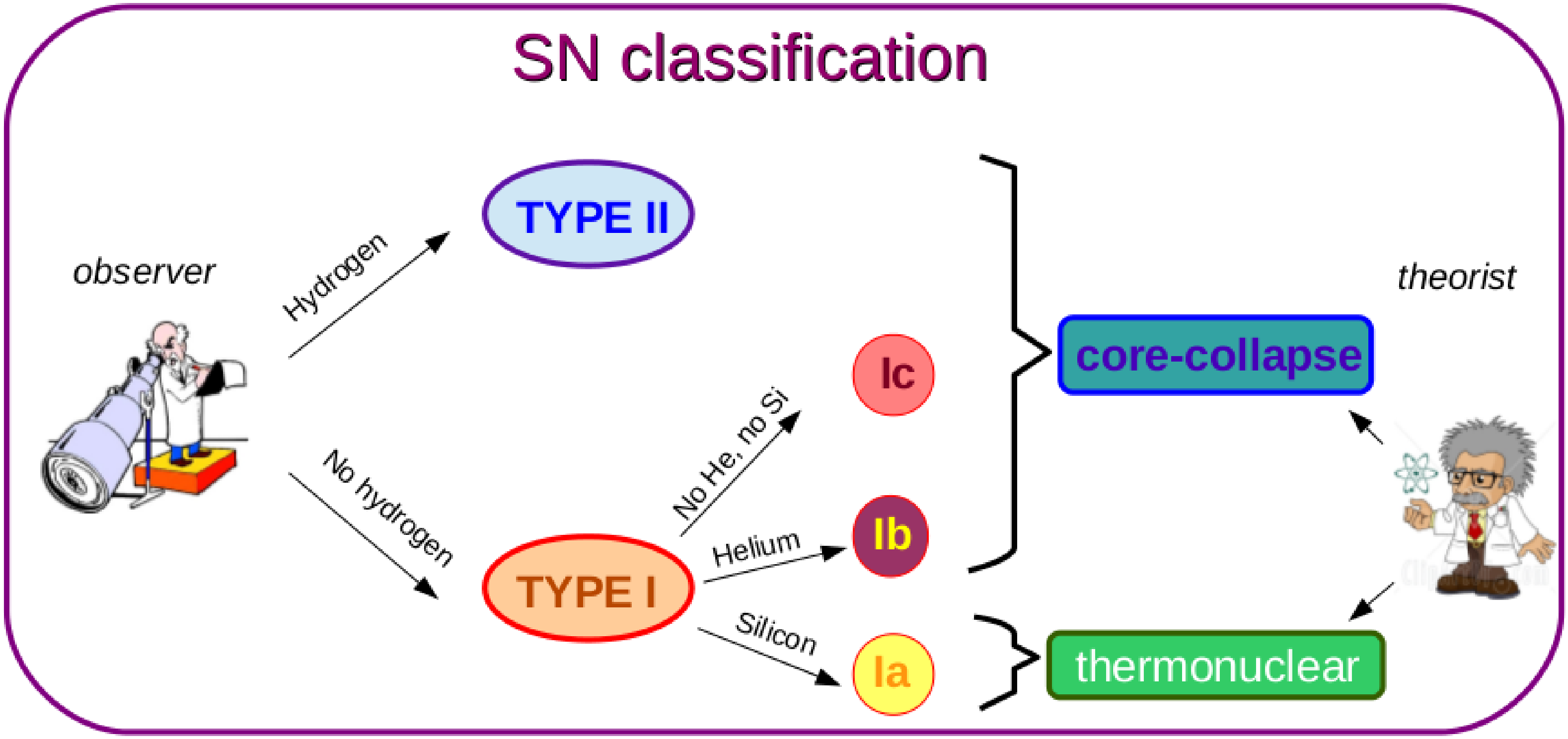
Supernovae

- First SN spectral classification by R. Minkowski in 1941: two SN types based on presence of Hydrogen lines:
  - Presence of Hydrogen lines: **II**
  - Absence of Hydrogen lines: **Ia, Ib, Ic**



Supernovae

- Two different types of progenitors:
  - thermal burning of a white dwarf binary, **Ia**
  - core collapse of massive stars type **Ib, Ic and II**

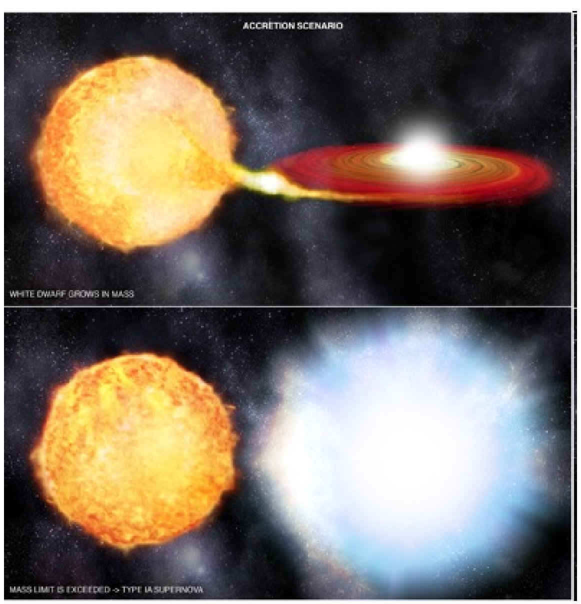


SNe Ia

- White dwarf (WD) of carbon/oxygen C/O composition in a binary system that undergoes thermonuclear burning (Hoyle & Fowler 1960)

Single degenerate scenario :

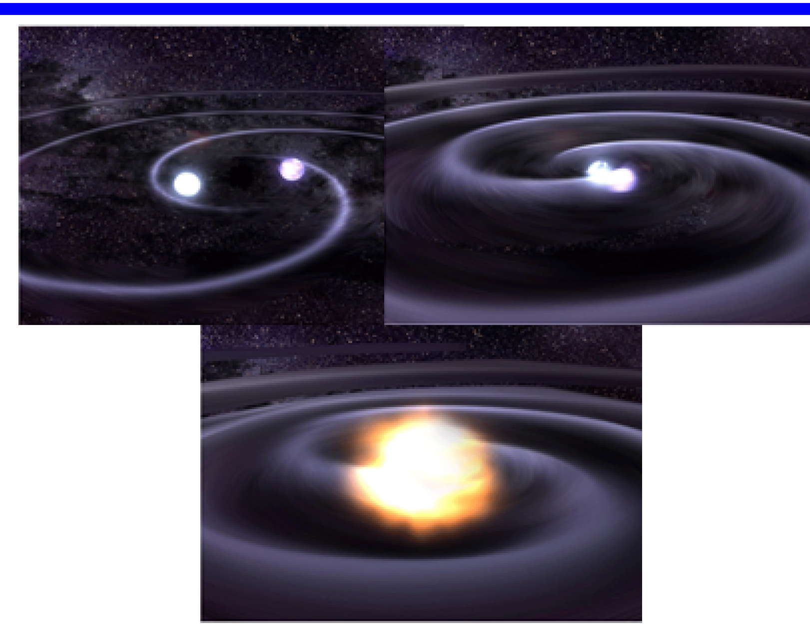
WD exceeds 1.44 M☉ → electron degenerancy does not support weigth



NASA/CXC/M Weiss

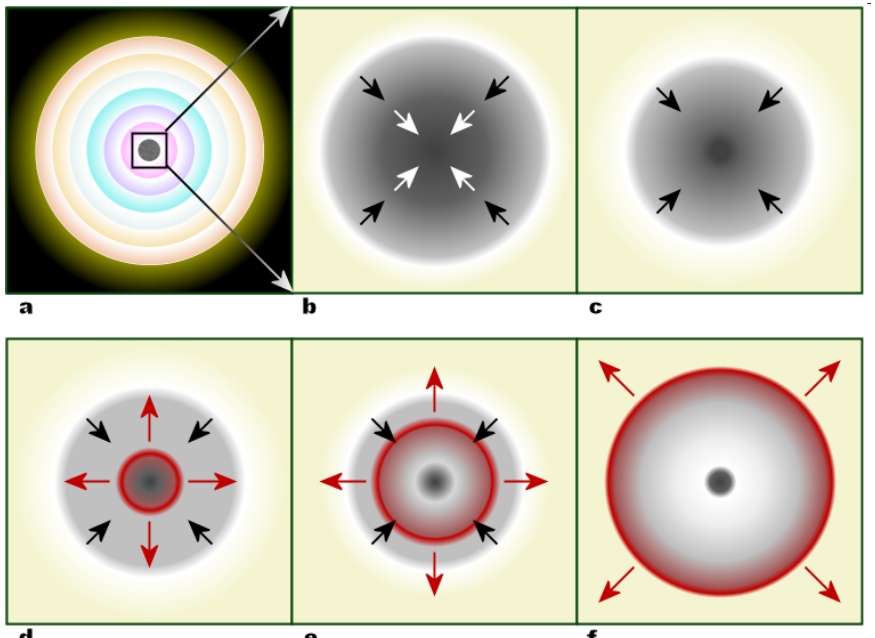
Double degenerate scenario :

Two WD lose energy due to gravitational waves and collide

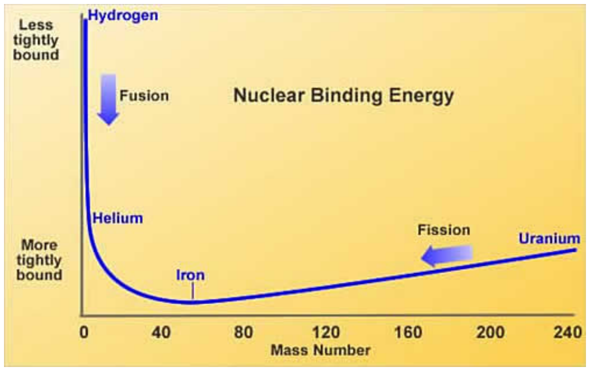


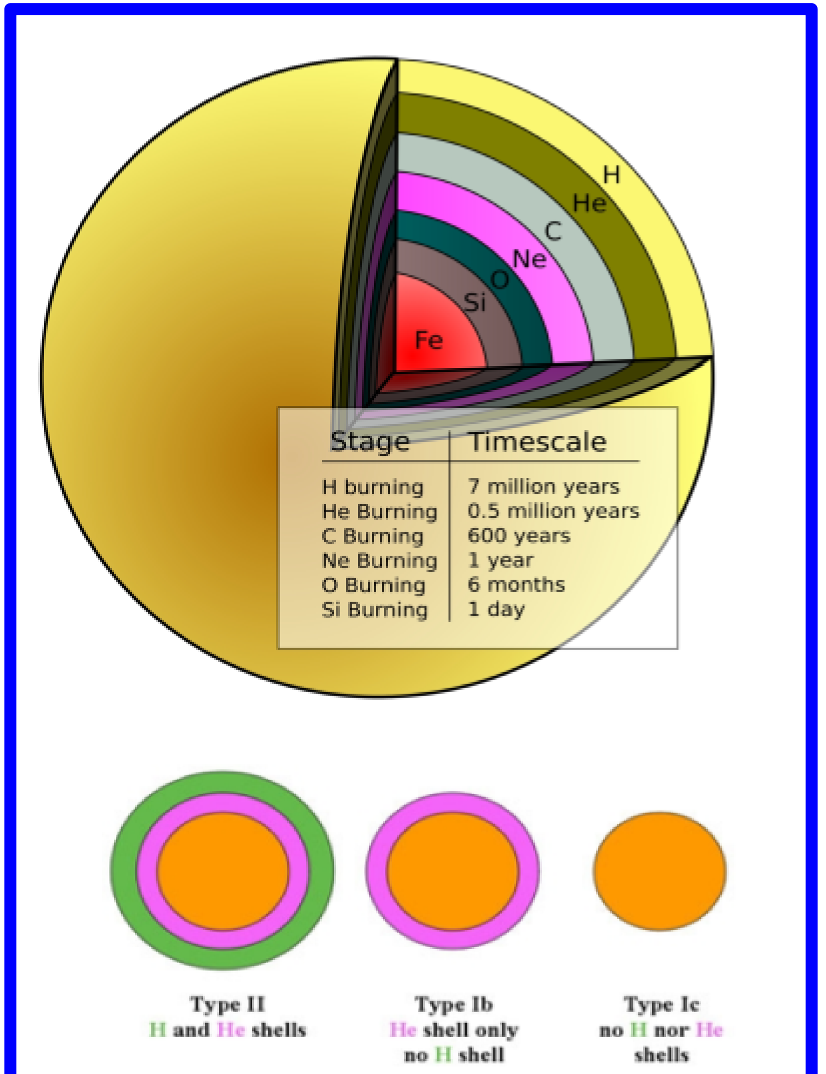
CCSNe

core collapse of massive stars M>8Msol:



R.J. Hall

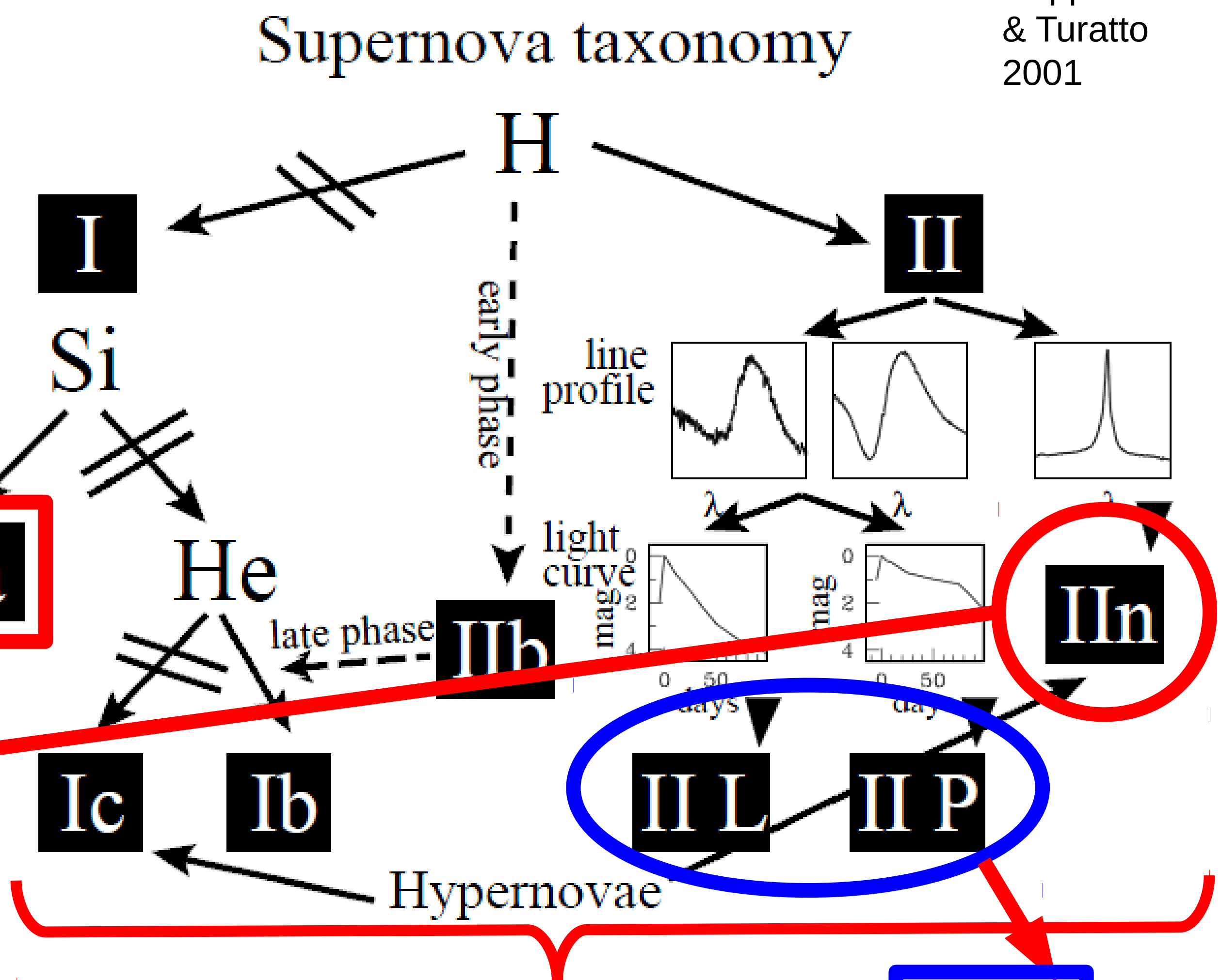




Stage	Timescale
H burning	7 million years
He Burning	0.5 million years
C Burning	600 years
Ne Burning	1 year
O Burning	6 months
Si Burning	1 day

Supernovae

Cappellaro & Turatto 2001



Thermonuclear

SN Impostor : looks like SNe IIn, but the link to a definitive SN event is questionable.
e.g. 2011A (de Jaeger et al. 15)

Core collapse

SNe II

Anderson et al. 14, Sanders et al. 15

SNe cosmology

$$\mu =$$

Distance modulus

OBSERVED

SNe cosmology

Apparent magnitude

from measurements

$$\underbrace{\mu = m -}_{\text{OBSERVED}}$$

Distance modulus

SNe cosmology

Apparent magnitude

from measurements

$$\mu = m - M =$$

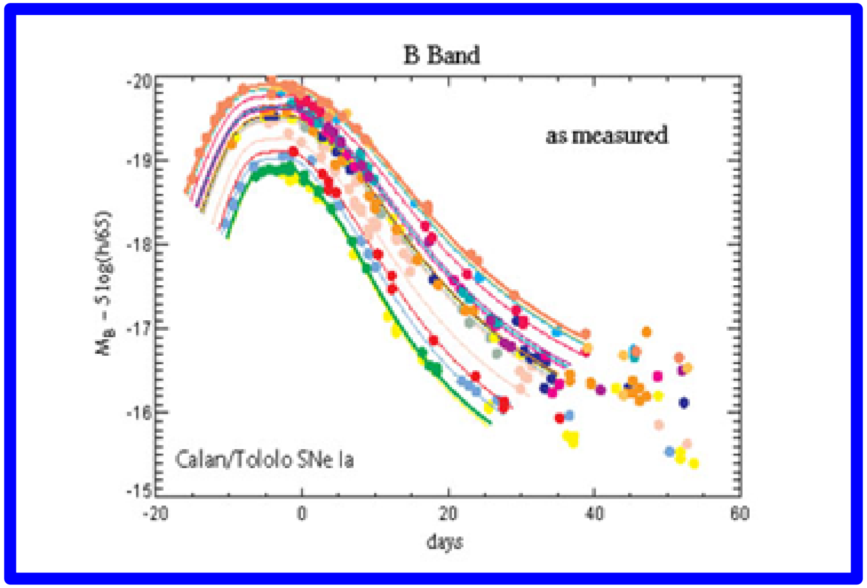
Distance modulus

Absolute magnitude

constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

OBSERVED



SNe cosmology

Apparent magnitude

from measurements

$$\mu = m - M =$$

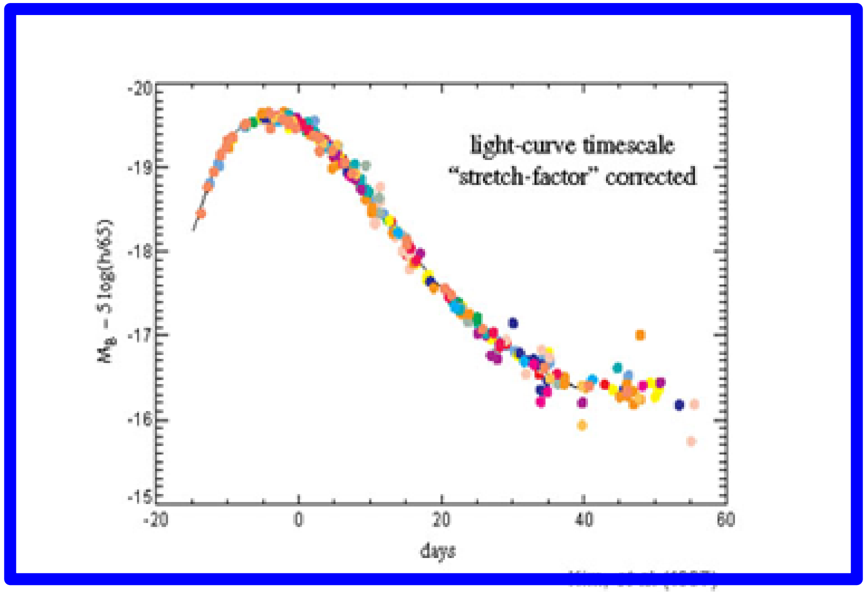
Distance modulus

Absolute magnitude

Unknnow but constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

→ Phillips et al. 93, Brighter SNe decline more slowly



SNe cosmology

Apparent magnitude

from measurements

Redshift
Measured via SN/host galaxy spectrum

Cosmological parameters
Quantities of interest
Ω_m, Ω_Λ, w, H_0

$$\mu = m - M = 5 \log_{10}\left(\frac{D_L(z, C)}{1\,Mpc}\right) + 25$$

Distance modulus

Absolute magnitude

Unknnow but constant for standard candles.

SNe are not perfect standard candles and need to be corrected using relations

→ Phillips et al. 93, Brighter SNe decline more slowly

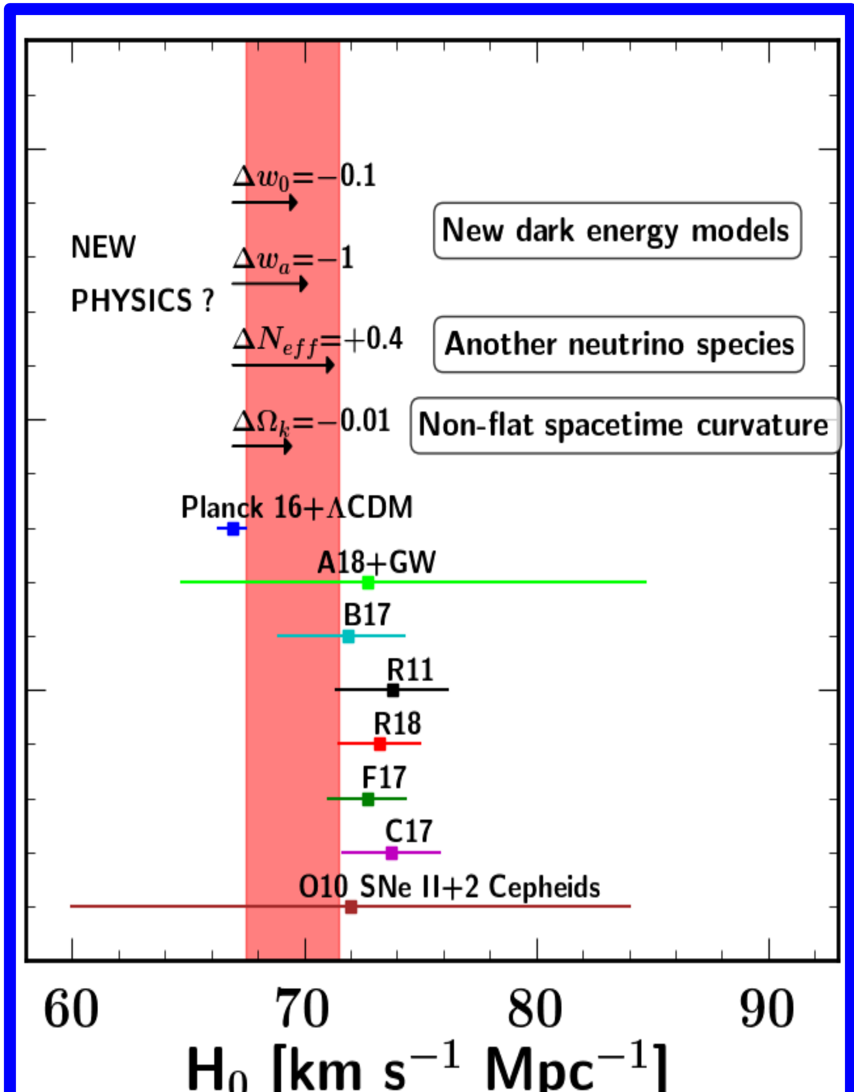
Luminosity distance

THEORITICAL MODELS

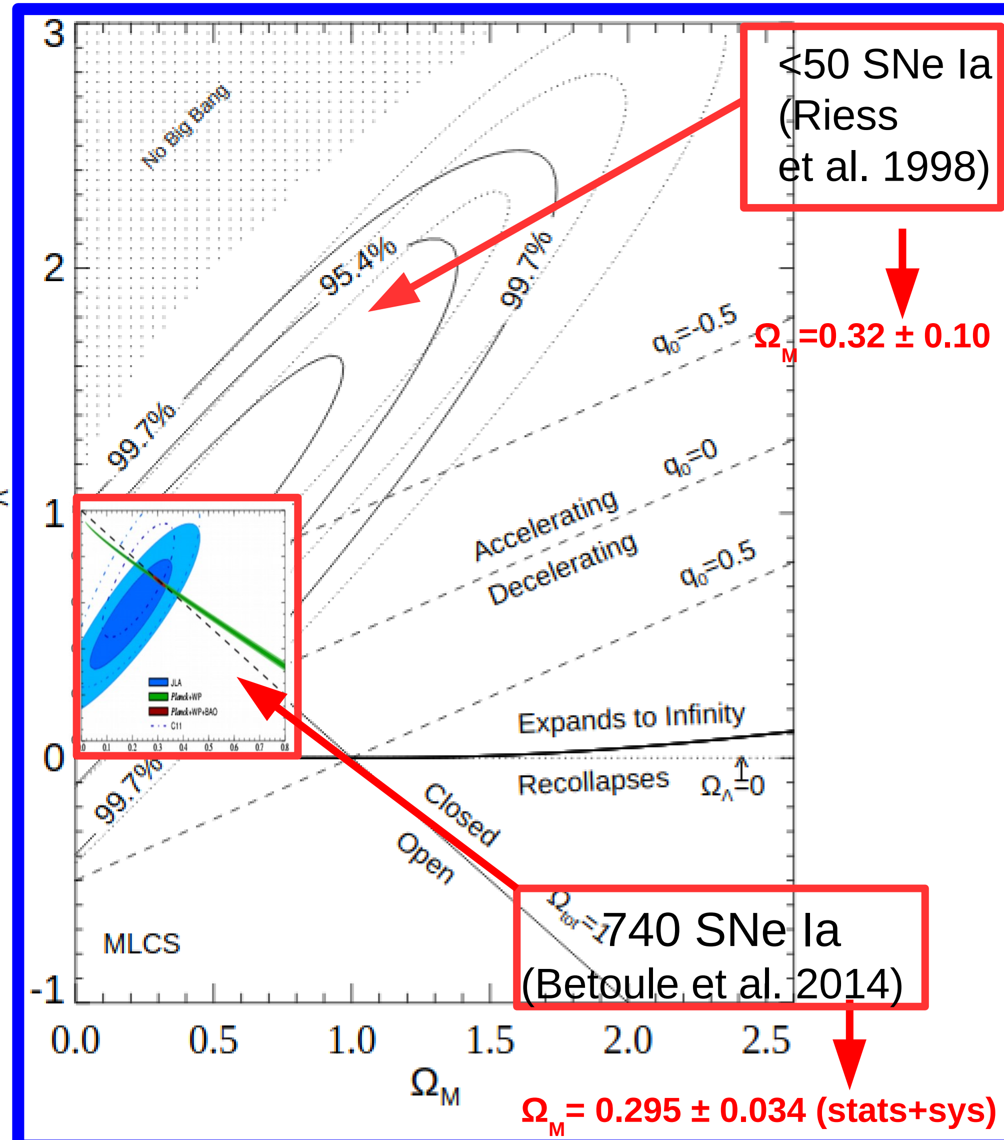
$$d_L = \frac{c(1+z)}{H_0}\int_0^z \frac{dz'}{\sqrt{\Omega_M(1+z')^3 + \Omega_k(1+z')^2 + \Omega_\Lambda(1+z')^{3(1+\omega)}}}$$

SNe cosmology

Perlmutter et al. 1999
Schmidt et al. 1998



Riess et al. 2016



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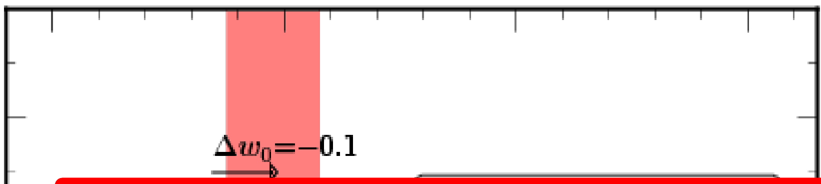
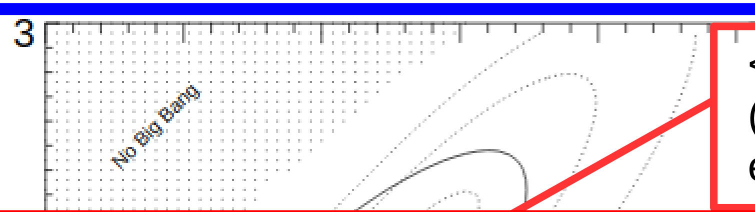




<50 SNe Ia (Riess et al. 1998)

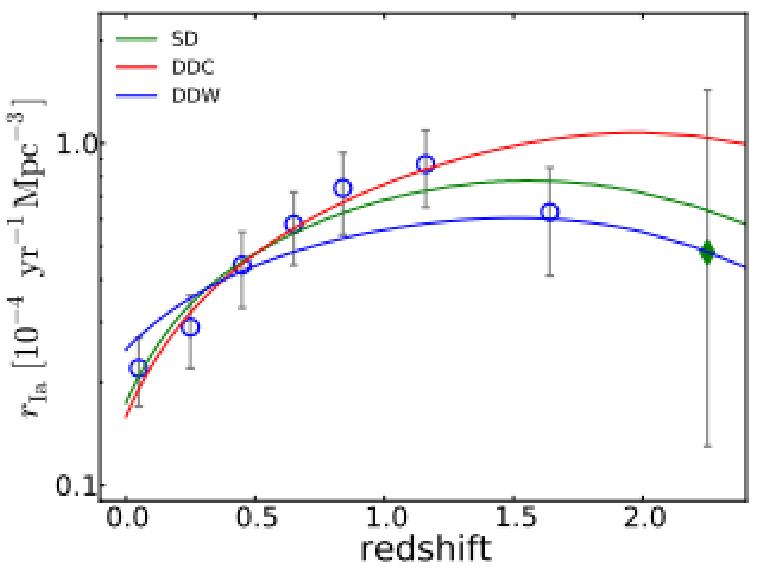
Even though SNe Ia remain the most mature and well-exploited method measuring the acceleration, further improvement to constrain the nature of dark energy requires developing as many independent methods as possible.

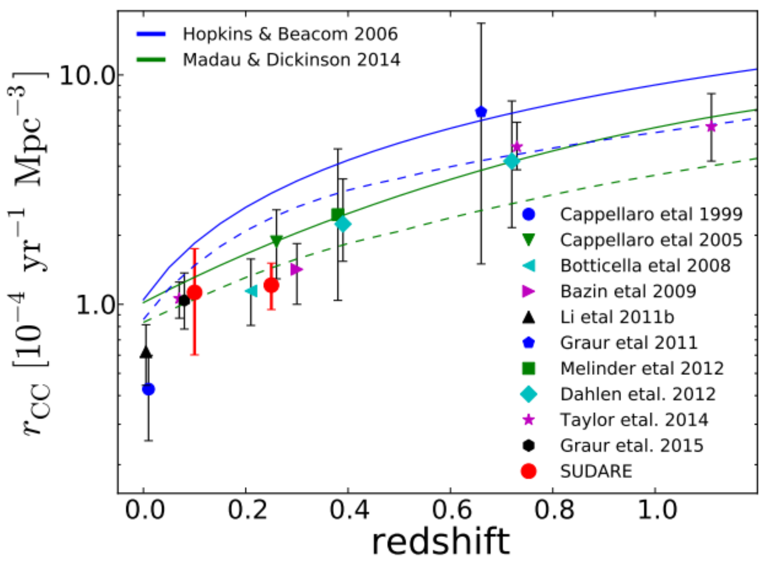
- **CMB** (Fixsen et al. 1996; Jaffe et al. 2001; Spergel et al. 2007; Bennett et al. 2003; Planck Collaboration et al. 2013)
- **BAO** (Blake & Glazebrook 2003; Seo & Eisenstein 2003)
- **X-ray clusters** (White et al. 1993; Schuecker et al. 2003)
- **SLSNe / SNeII** (Inserra & Smartt 2014; Hamuy & Pinto et al. 2002)

Riess et al. 2016

Why SNe II?

•Their rate is expected to peak at higher redshifts than SNe Ia (Cappellaro et al. 15)

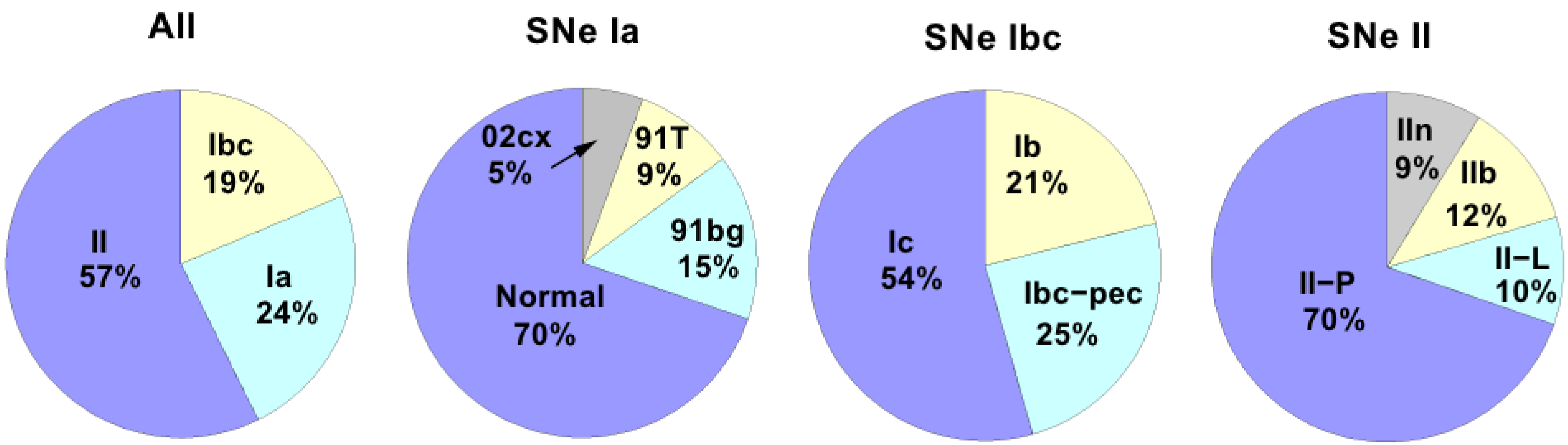




Why SNe II?

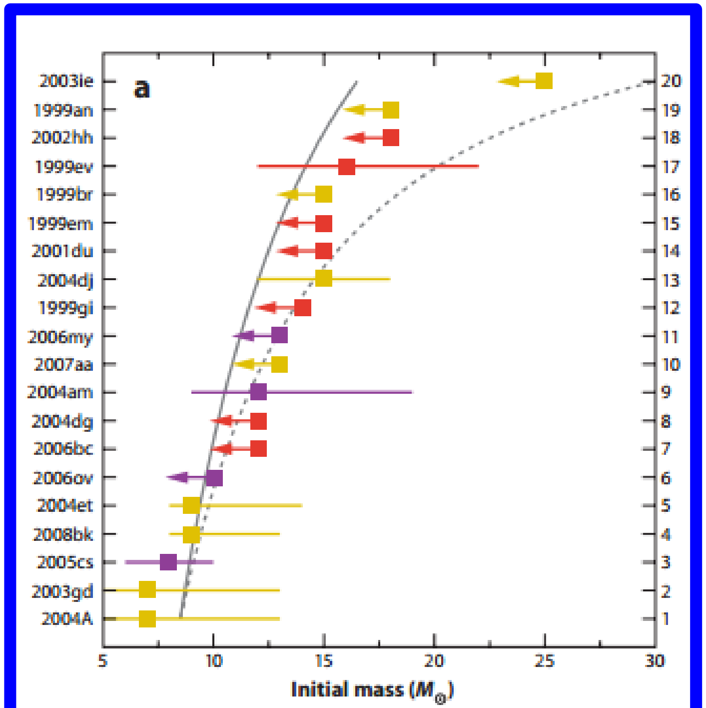
- Their rate is expected to peak at higher redshifts than SNe Ia (Cappellaro et al. 15)

- They are more abundant than the SNe Ia (Li et al. 11)



Why SNe II?

- Their rate is expected to peak at higher redshifts than SNe Ia (Cappellaro et al.15)
- They are more abundant than the SNe Ia (Li et al. 11)
- **Their progenitors and environments (only late-type galaxies) are better understood than those of SNe~Ia**

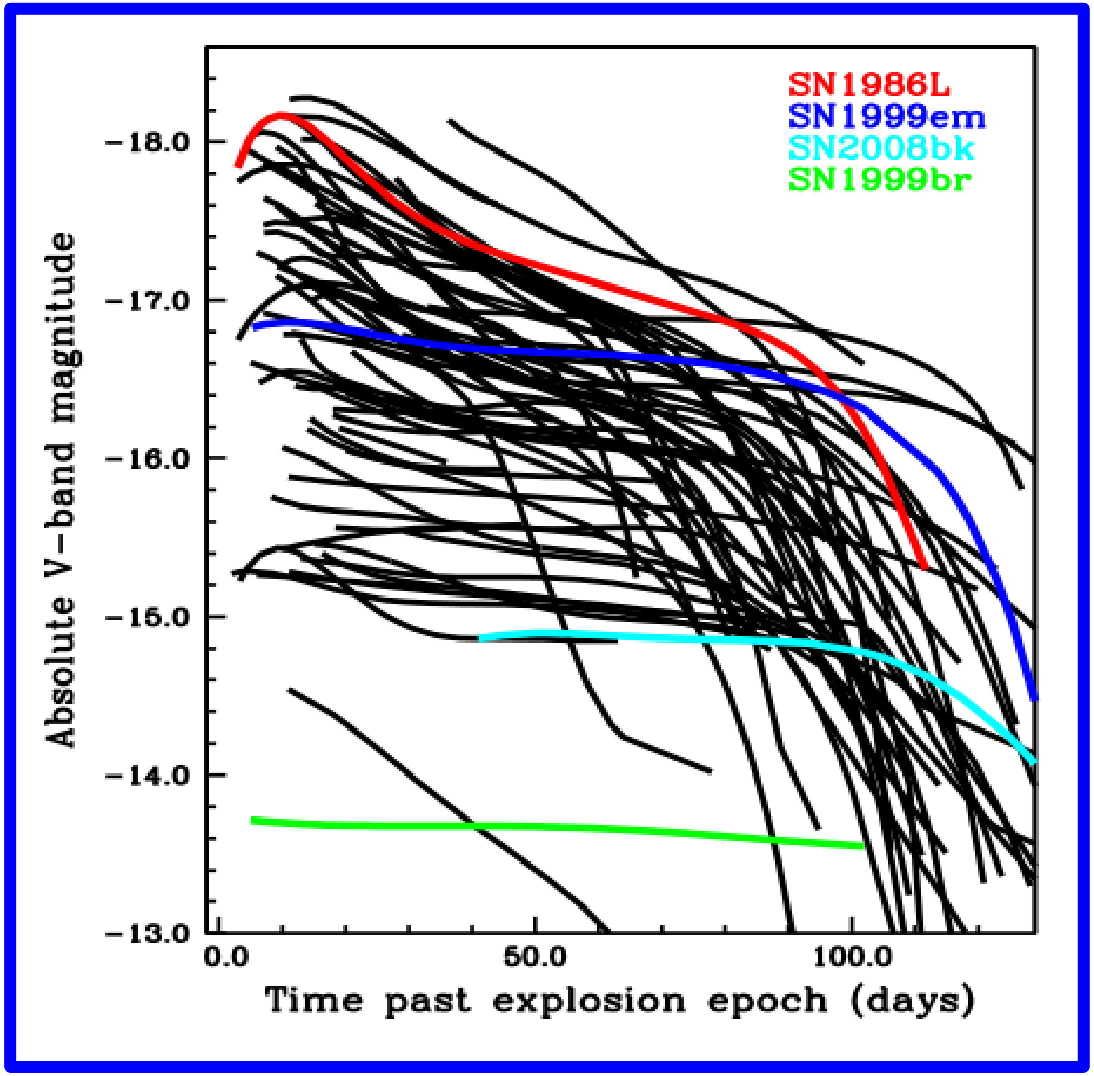


RSG (Smartt 09)

Pre-explosion SN 2008bk ~1000d after

Matilla et al. 2010

Are SNe II standard candles?

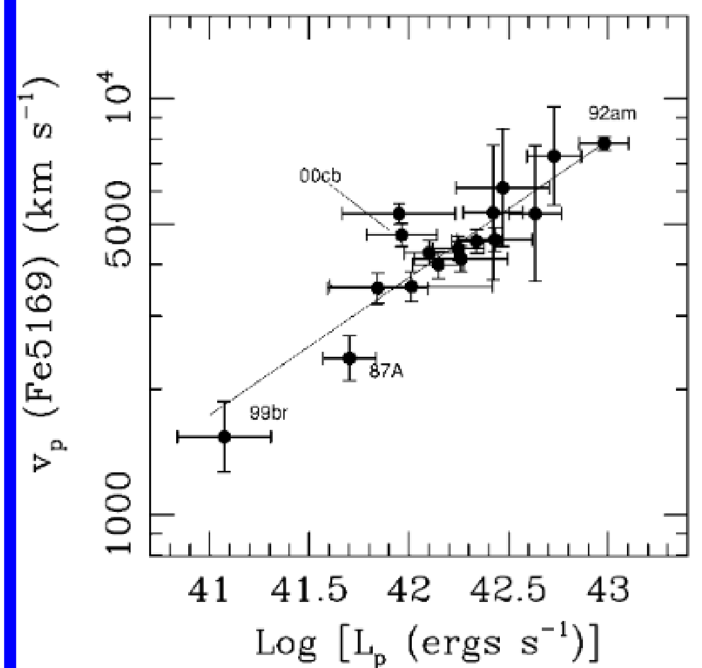


Anderson et al. 2014

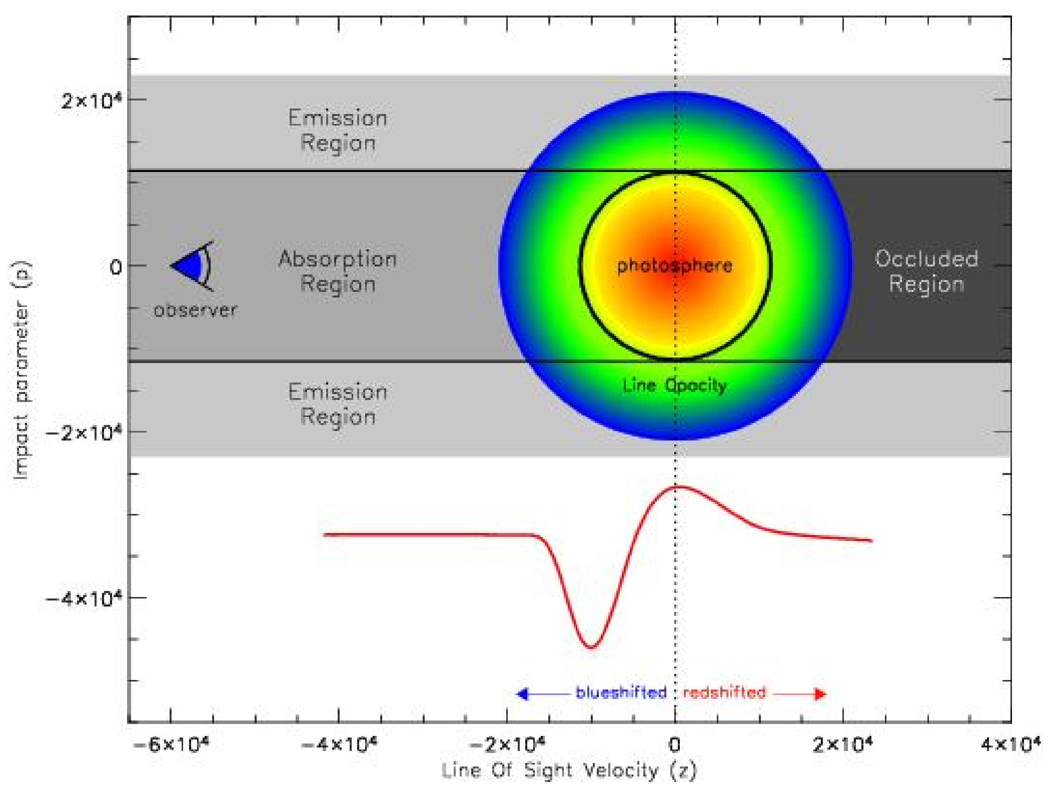
SNe II are standardisable!!! (SCM)

Expansion velocities of the ejecta: More luminous SN have faster ejecta

P-Cygni profile: A redshifted emission from the expanding shell moving away. A blueshifted absorption feature due to the cooler material expanding towards the observer



Hamuy & Pinto 2002



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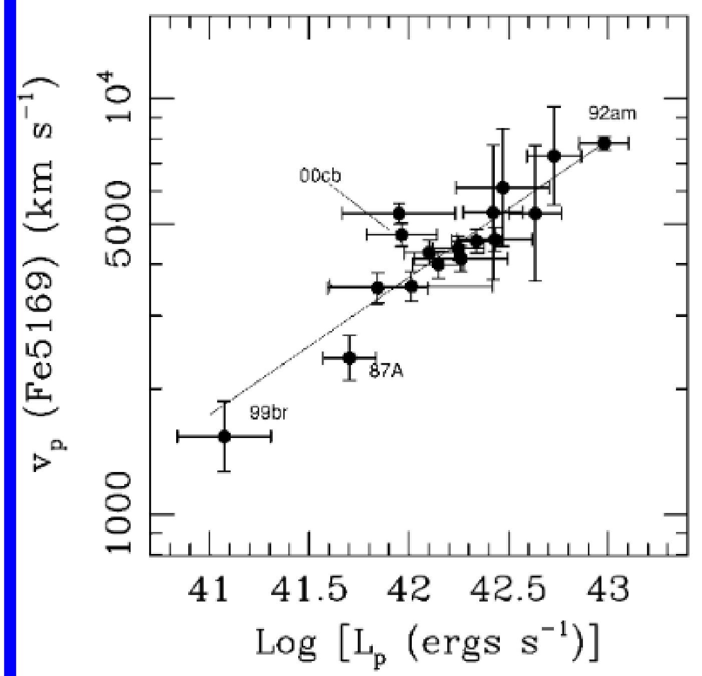
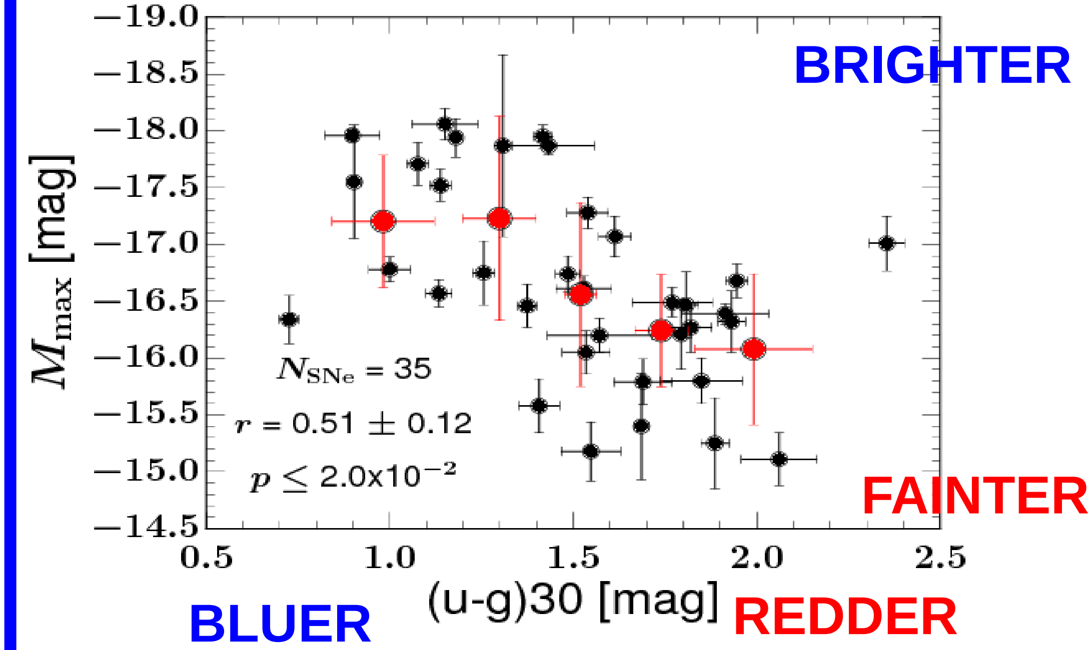
Expansion velocities of the ejecta: More luminous SN have faster ejecta

Colour: Brigther SN are bluer (~ to SNe Ia) → Nugent et al. 06

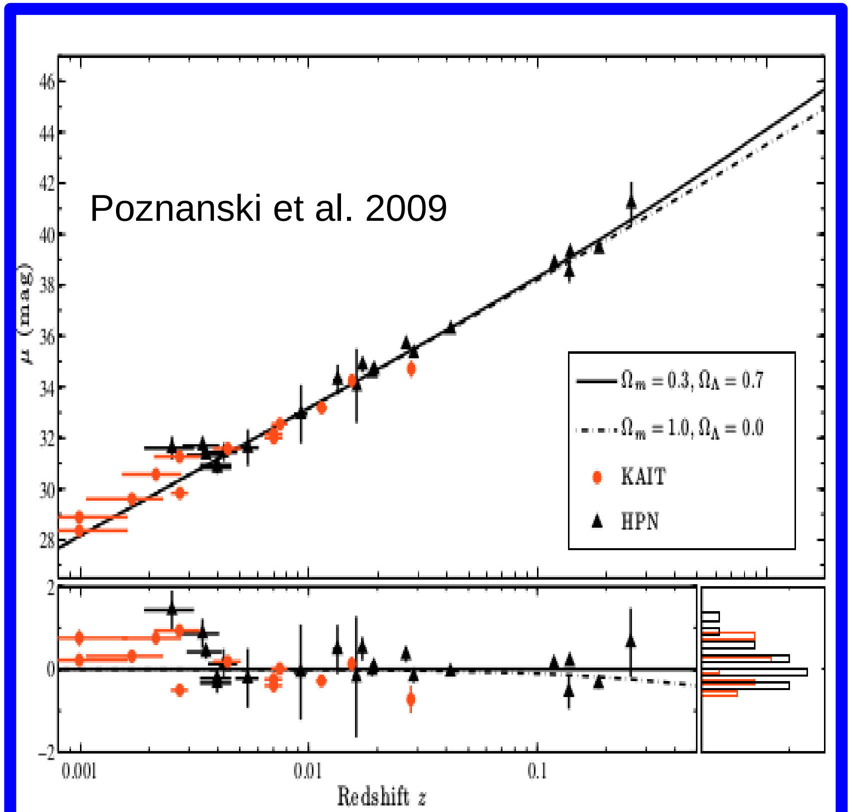


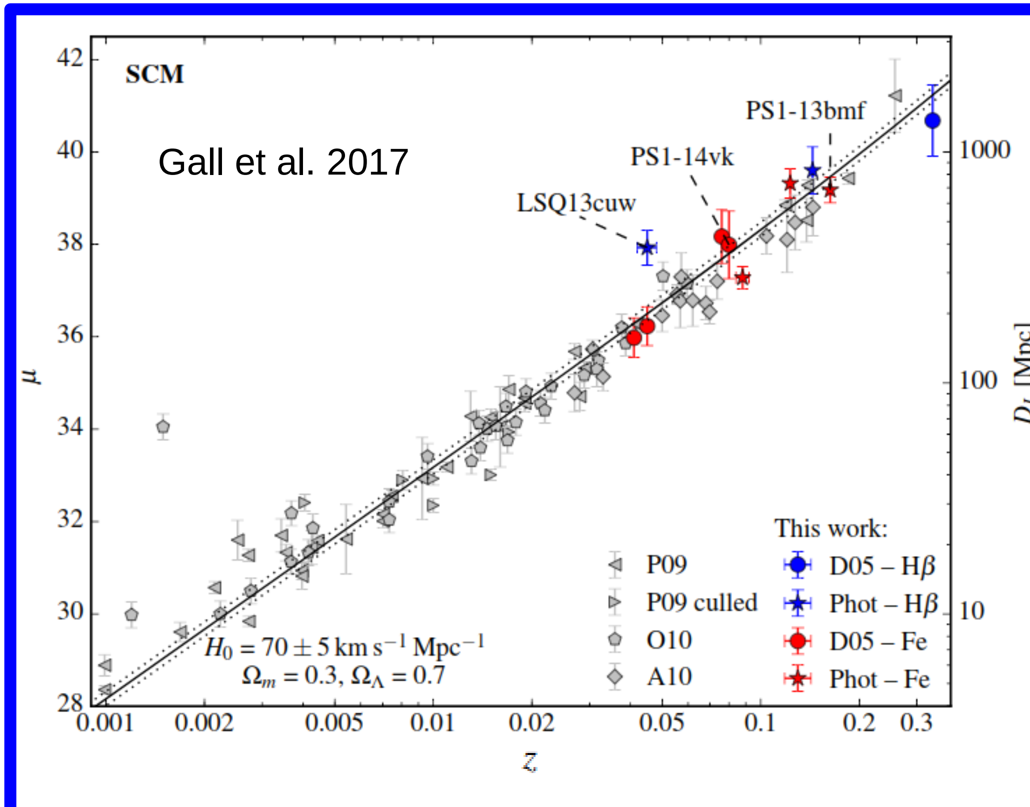
Hamuy & Pinto 2002



de Jaeger et al. 18a

Standard Candle Method





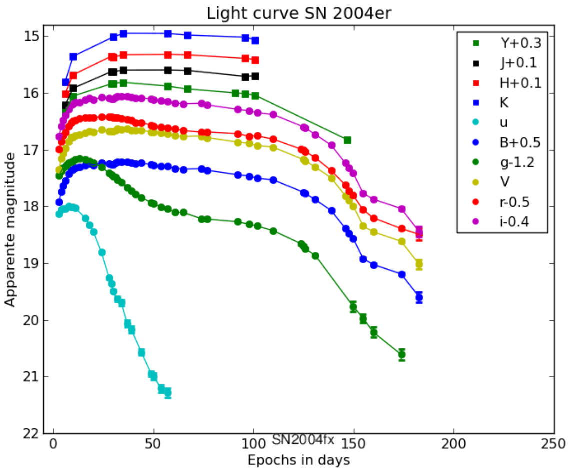
Dispersion~ 0.25-0.3 mag
(10-14 % en distances)

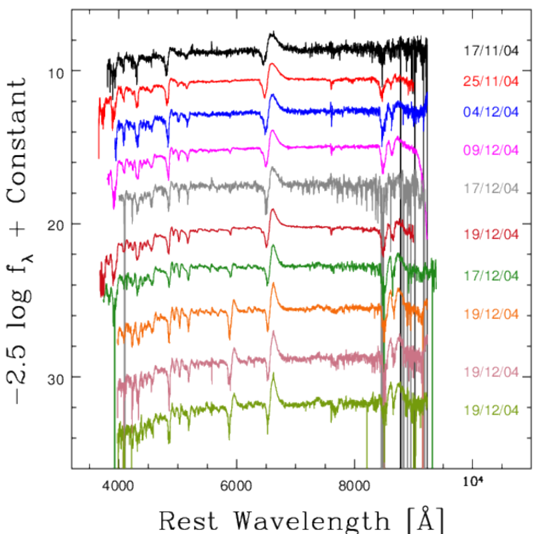
Hamuy & Pinto 02	Nugent et al. 06
Poznanski et al. 09/10	D'Andrea et al. 10
Olivares et al. 10	Maguire et al. 10
Emilio Enriquez et al. 14	Rodríguez et al. 14
de Jaeger et al. 15a,b,17a	Gall et al. 17

Data

CSP-I (Hamuy et al 06)

(**39** SNe II 0.01<z<0.05)

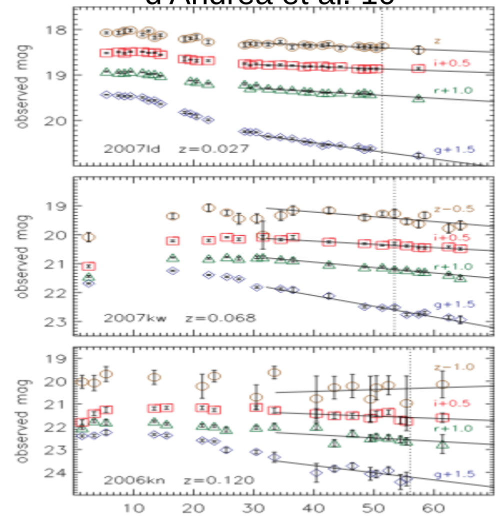


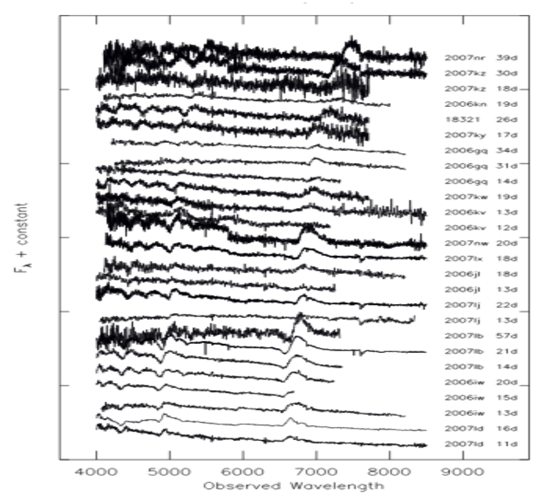


SDSS-SN (Frieman et al 08)

(**16** SNe II 0.03<z<0.14)

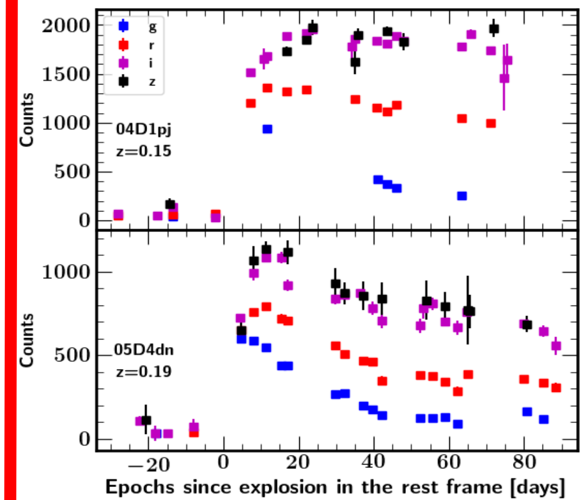
d'Andrea et al. 10

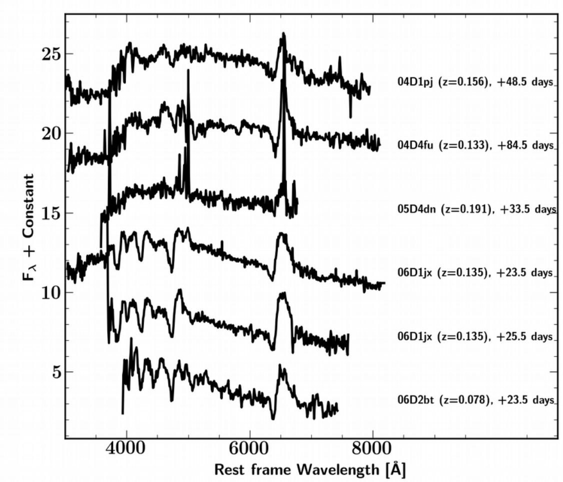




SNLS (Astier et al 06)

(**5** SNe II 0.08<z<0.19)

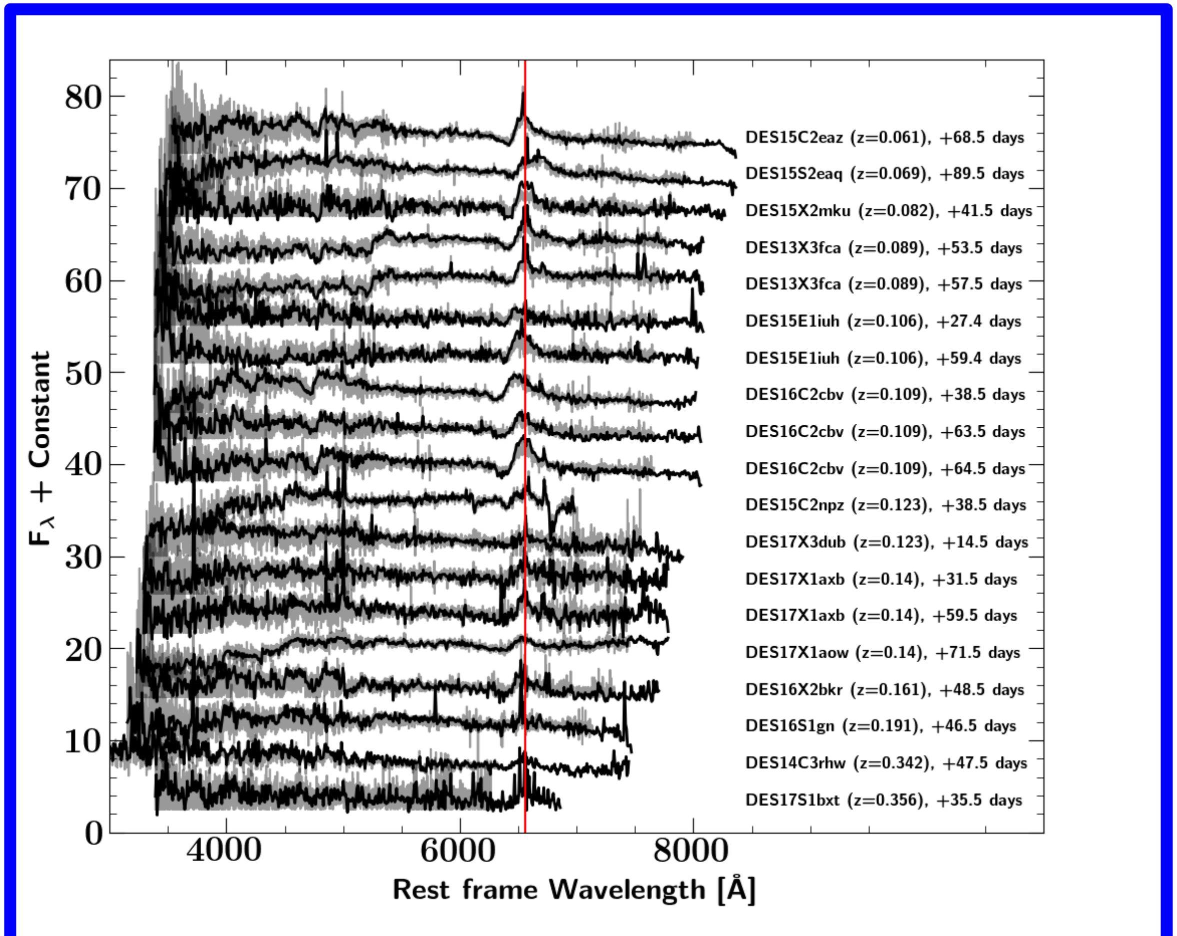


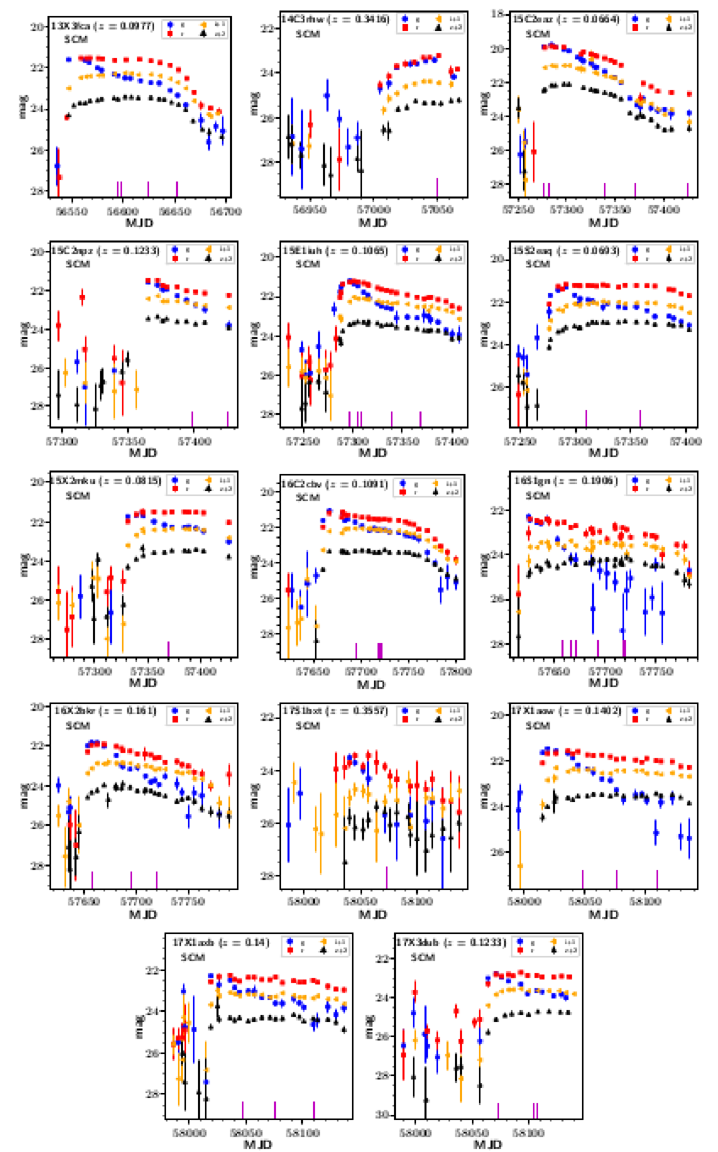


Data (DES en prep.)

- **56** SNe II spectroscopique confirmées:

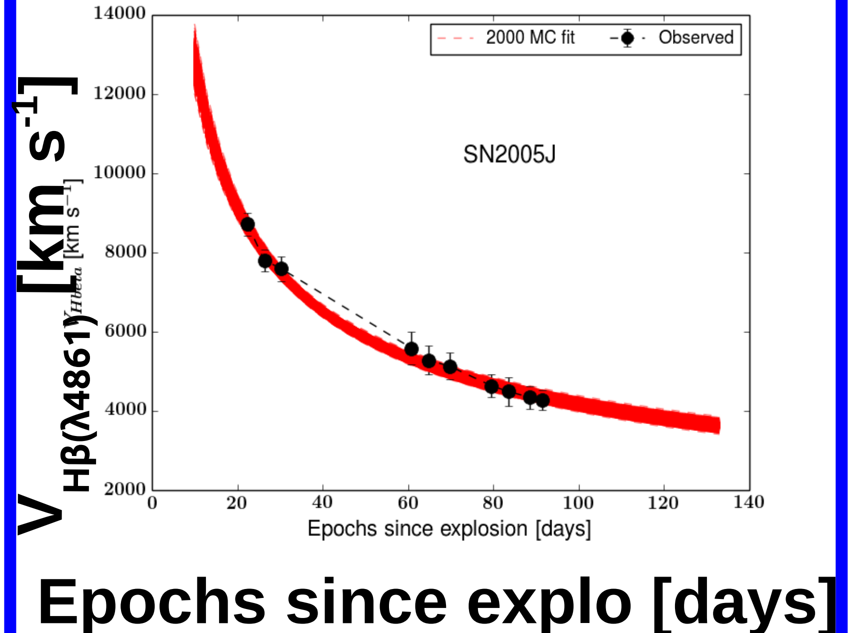
→ **14** SNe II sont utiles pour SCM



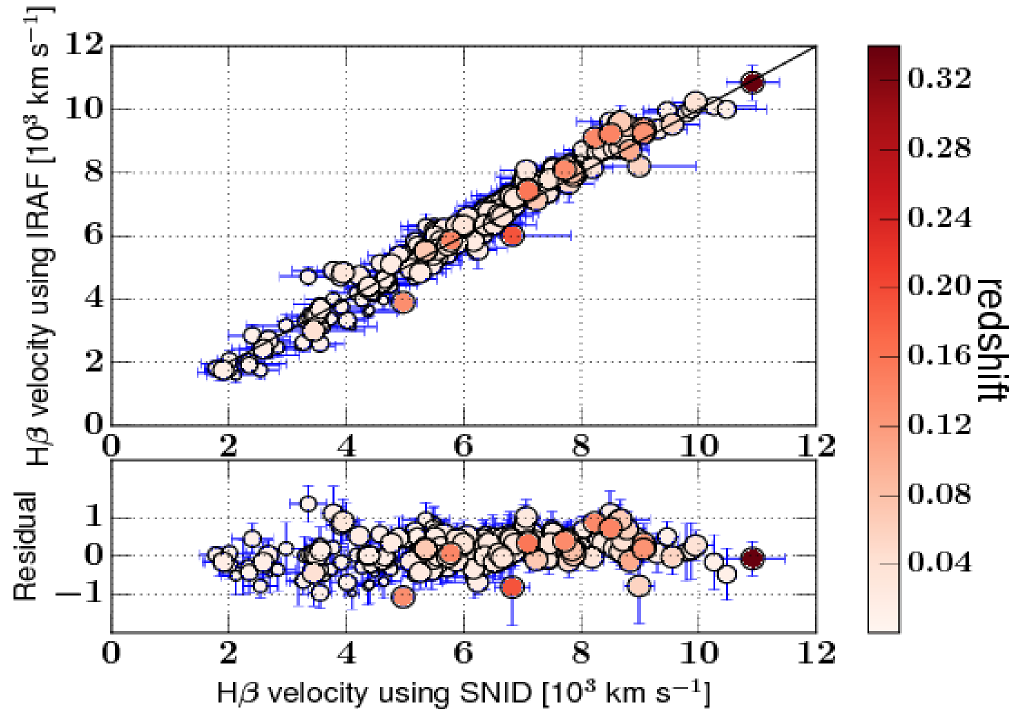


Velocity

Power law fit



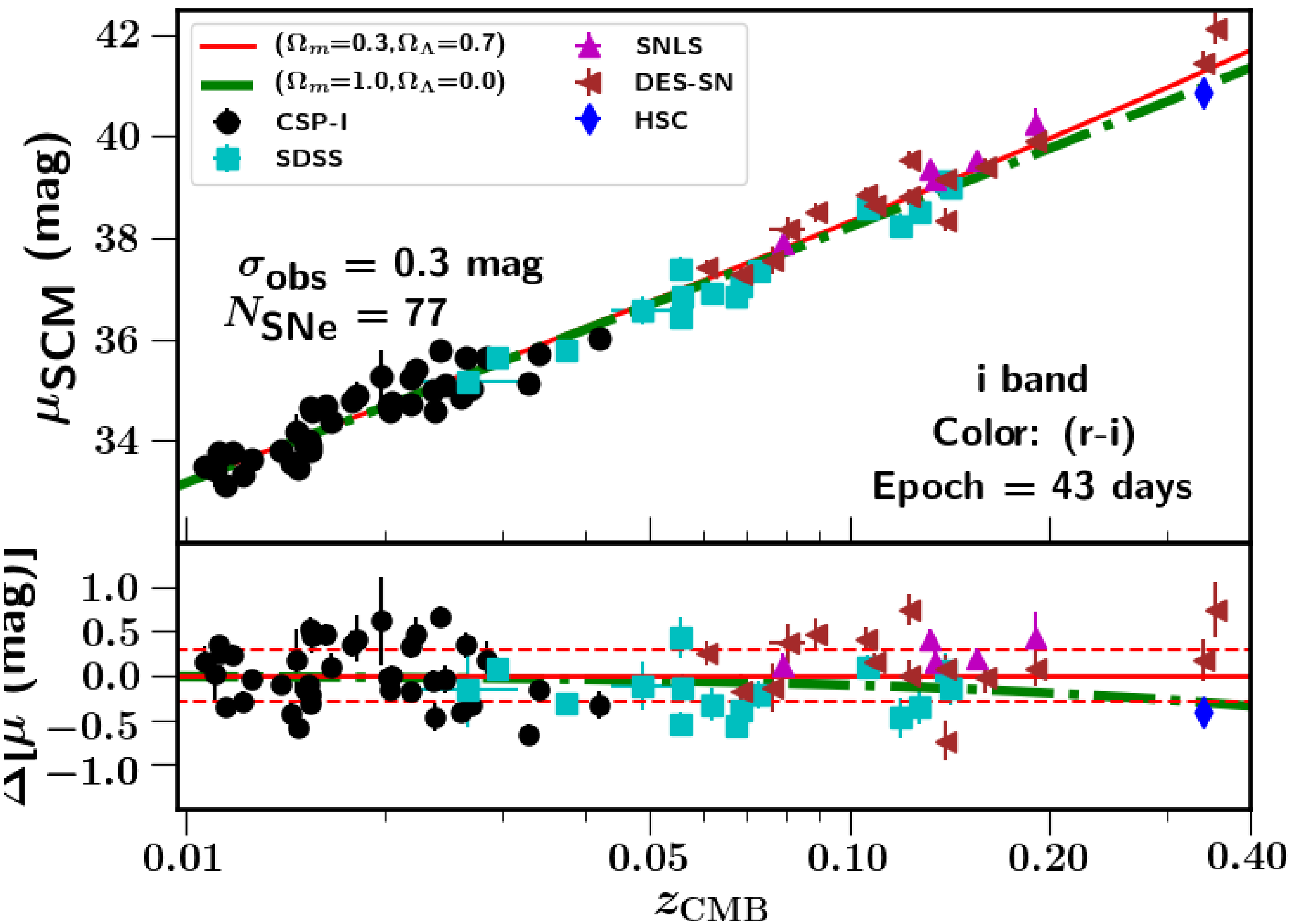
SNID vs IRAF



de Jaeger et al. 2017b

SCM

$$m_i^{\text{model}} = \mathcal{M}_i - \alpha \log_{10}\left(\frac{v_{\mathrm{H}\beta}}{< v_{\mathrm{H}\beta} > \ \ \mathrm{km\ s^{-1}}}\right) + \beta(r-i) + 5\log_{10}(\mathcal{D}_L(z_{\mathrm{CMB}}|\Omega_{\mathrm{m}},\Omega_\Lambda))$$

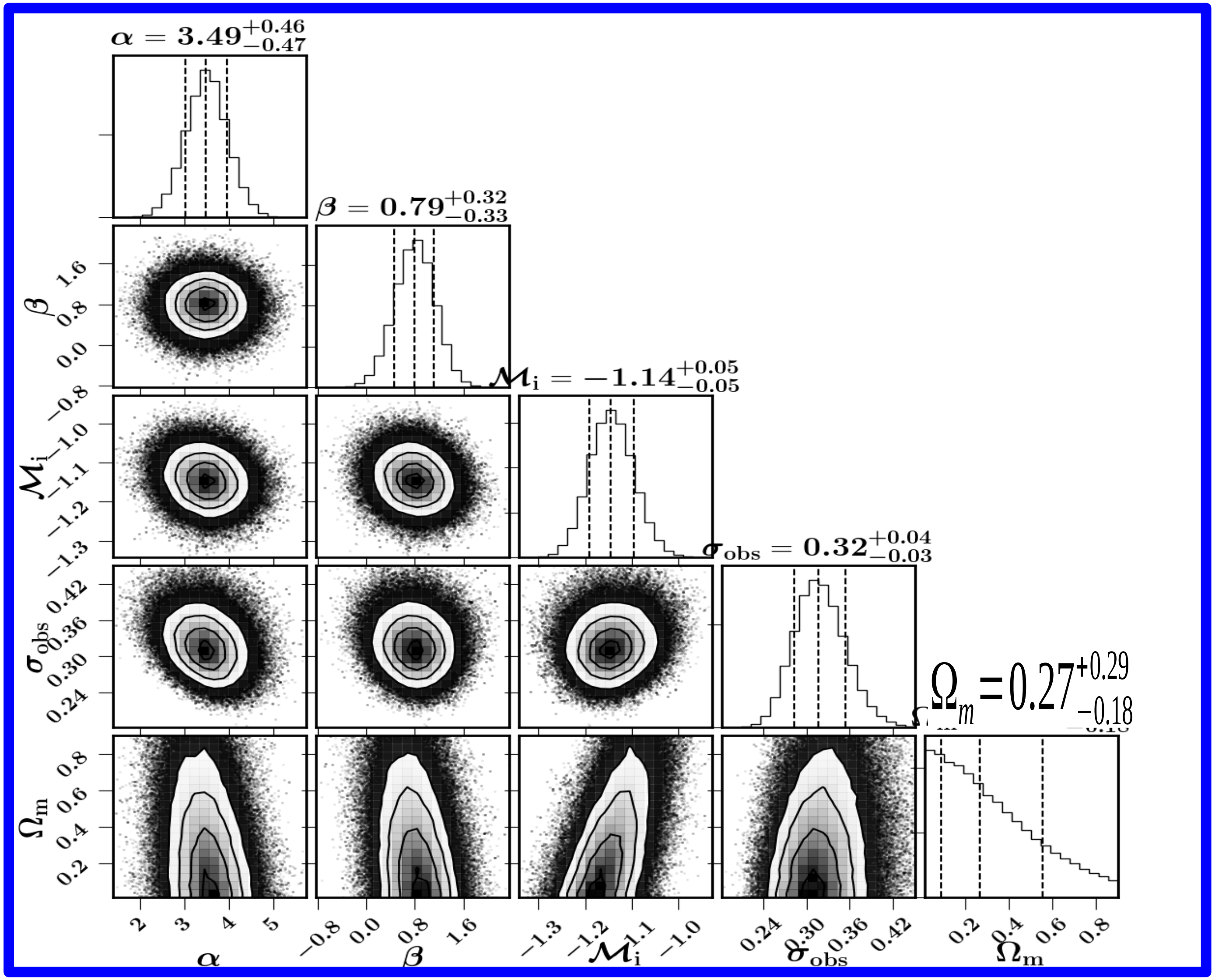


SCM

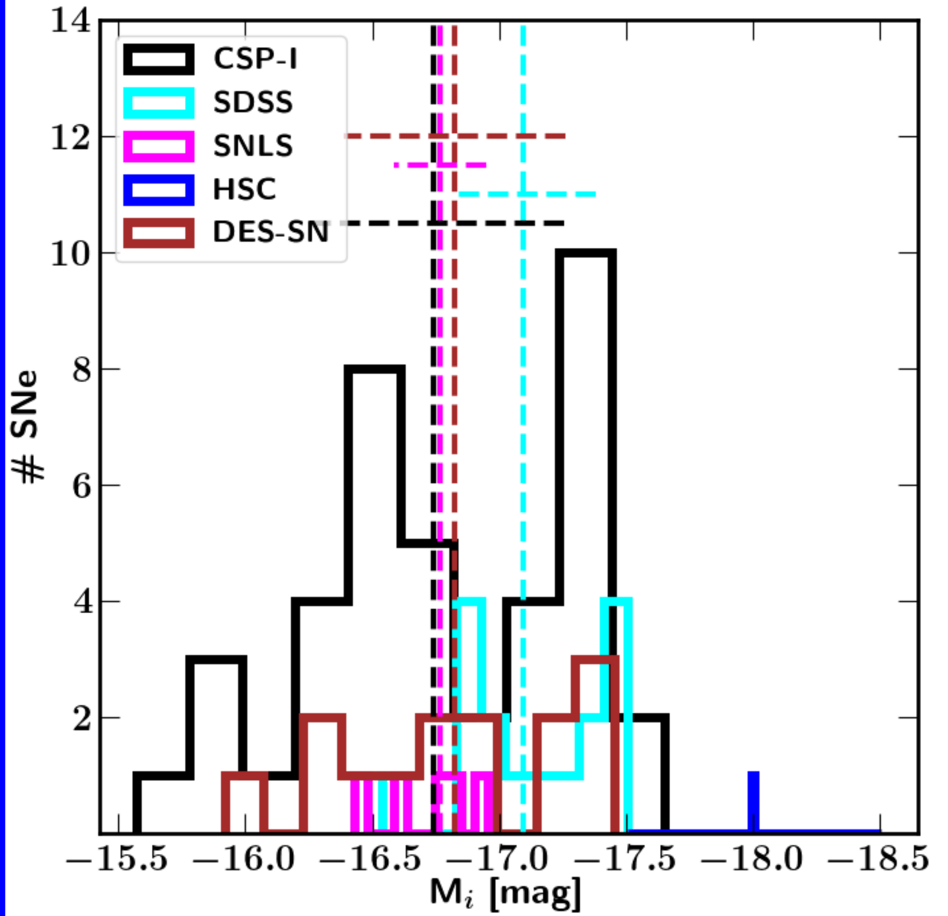
Assuming a flat Universe

$\Omega_m + \Omega_\Lambda = 1$

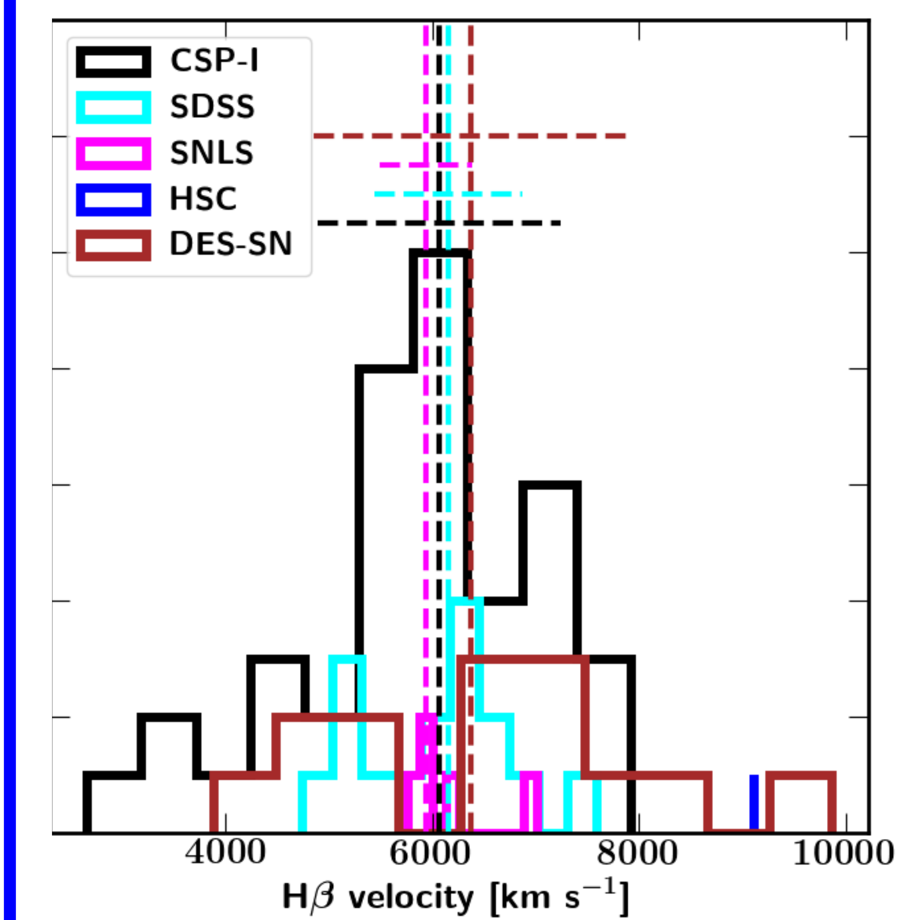
Ω_m as a free parameter



Samples



CSP-I
SDSS
SNLS
HSC
DES-SN
SNe
M$_i$ [mag]



CSP-I
SDSS
SNLS
HSC
DES-SN
Hβ velocity [km s^{-1}]

Samples

Redshift evolution?

Table 2. SCM-fit Parameters.

Data Set	α	β	M_i	σ_{int}	SNe
CSP-I	$3.72^{+0.64}_{-0.61}$	$1.11^{+0.46}_{-0.46}$	$-16.85^{+0.06}_{-0.06}$	$0.32^{+0.05}_{-0.04}$	40
CSP-I+SDSS-II	$3.72^{+0.56}_{-0.55}$	$1.04^{+0.34}_{-0.33}$	$-16.93^{+0.05}_{-0.05}$	$0.30^{+0.04}_{-0.04}$	56
CSP-I+SNLS	$3.61^{+0.61}_{-0.59}$	$0.93^{+0.44}_{-0.44}$	$-16.83^{+0.05}_{-0.05}$	$0.31^{+0.05}_{-0.04}$	45
CSP-I+DES-SN	$3.36^{+0.53}_{-0.52}$	$0.64^{+0.43}_{-0.41}$	$-16.85^{+0.05}_{-0.05}$	$0.34^{+0.04}_{-0.04}$	54
CSP-I+SDSS-II+SNLS	$3.65^{+0.55}_{-0.54}$	$0.95^{+0.33}_{-0.33}$	$-16.91^{+0.04}_{-0.04}$	$0.30^{+0.04}_{-0.03}$	61
CSP-I+SDSS-II+SNLS+HSC	$3.78^{+0.53}_{-0.52}$	$0.97^{+0.33}_{-0.32}$	$-16.94^{+0.04}_{-0.04}$	$0.30^{+0.04}_{-0.03}$	62
de Jaeger et al. (2017a)	$3.57^{+0.52}_{-0.50}$	$0.95^{+0.29}_{-0.29}$	$-16.93^{+0.04}_{-0.04}$	$0.28^{+0.04}_{-0.03}$	61
CSP-I+SDSS-II+DES-SN	$3.35^{+0.49}_{-0.48}$	$0.80^{+0.33}_{-0.32}$	$-16.91^{+0.04}_{-0.04}$	$0.32^{+0.04}_{-0.03}$	70
CSP-I+SNLS+DES-SN	$3.33^{+0.51}_{-0.50}$	$0.55^{+0.39}_{-0.38}$	$-16.84^{+0.05}_{-0.05}$	$0.32^{+0.04}_{-0.04}$	59
CSP-I+SDSS+SNLS+DES-SN+HSC	$3.48^{+0.47}_{-0.47}$	$0.78^{+0.32}_{-0.32}$	$-16.92^{+0.04}_{-0.04}$	$0.32^{+0.04}_{-0.03}$	76
SDSS-II	$3.21^{+1.50}_{-1.62}$	$0.36^{+0.54}_{-0.51}$	$-17.15^{+0.08}_{-0.08}$	$0.24^{+0.09}_{-0.07}$	16
SDSS-II+SNLS	$2.76^{+1.81}_{-1.68}$	$0.44^{+0.61}_{-0.61}$	$-17.04^{+0.08}_{-0.08}$	$0.30^{+0.08}_{-0.06}$	21
SDSS-II+DES-SN	$2.57^{+0.92}_{-0.93}$	$0.41^{+0.51}_{-0.50}$	$-17.01^{+0.07}_{-0.07}$	$0.36^{+0.07}_{-0.06}$	30
SDSS-II+SNLS+DES	$2.64^{+0.86}_{-0.88}$	$0.39^{+0.49}_{-0.47}$	$-16.96^{+0.06}_{-0.06}$	$0.34^{+0.06}_{-0.05}$	35
SDSS-II+SNLS+HSC+DES	$3.15^{+0.81}_{-0.83}$	$0.47^{+0.50}_{-0.49}$	$-16.99^{+0.06}_{-0.06}$	$0.34^{+0.06}_{-0.05}$	36
SNLS+DES-SN	$3.34^{+0.83}_{-0.88}$	$-0.06^{+0.60}_{-0.64}$	$-16.80^{+0.07}_{-0.07}$	$0.26^{+0.09}_{-0.07}$	19
DES-SN	$3.22^{+1.08}_{-1.12}$	$-0.05^{+0.74}_{-0.76}$	$-16.83^{+0.11}_{-0.11}$	$0.35^{+0.12}_{-0.10}$	14

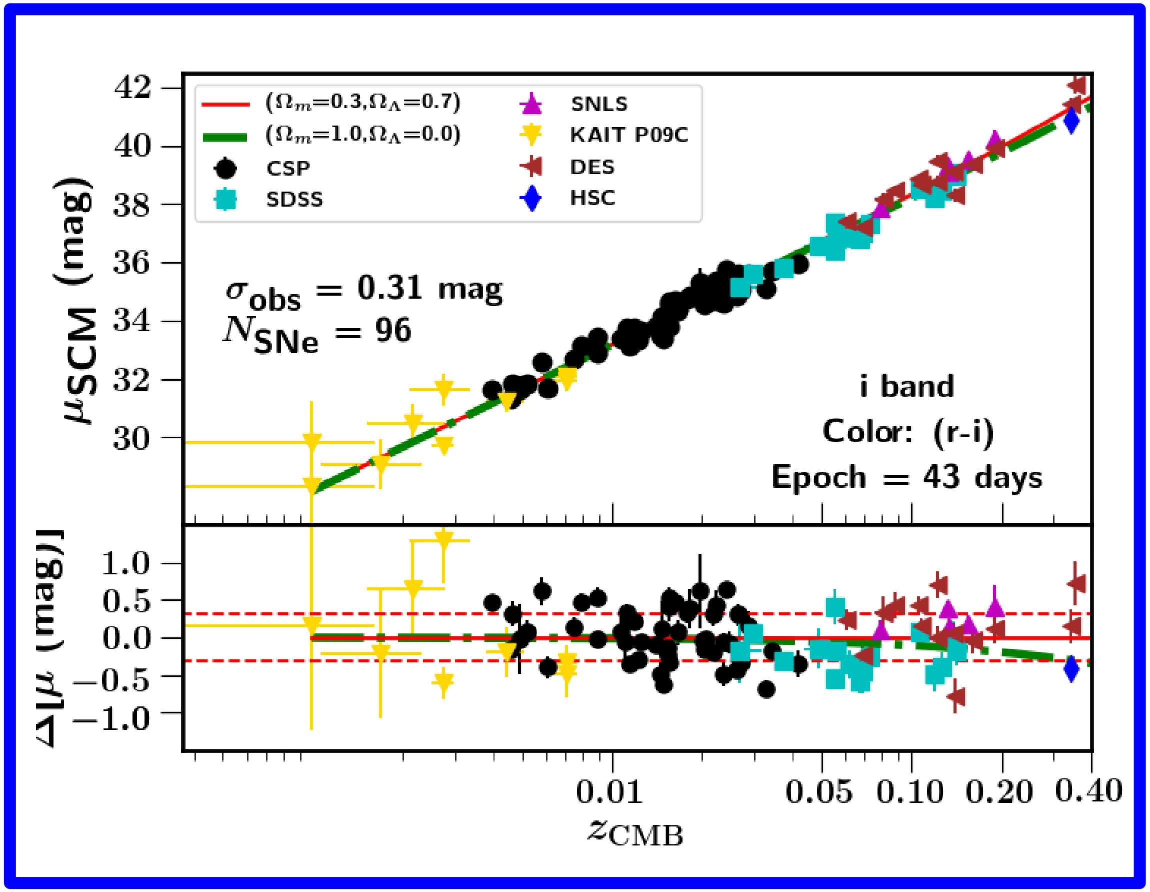
best-fitting values and the associated errors for each parameter of the SCM fit at 43 days after the explosion and using different samples.

Host galaxy extinction?

→ Two sub-samples. The bluest color sample (38 SNe II) a dispersion of 0.29 mag while for the reddest sub-sample we derive 0.31 mag. If β=0, only the scatter of the reddest sub-sample slightly increases (0.33 mag)

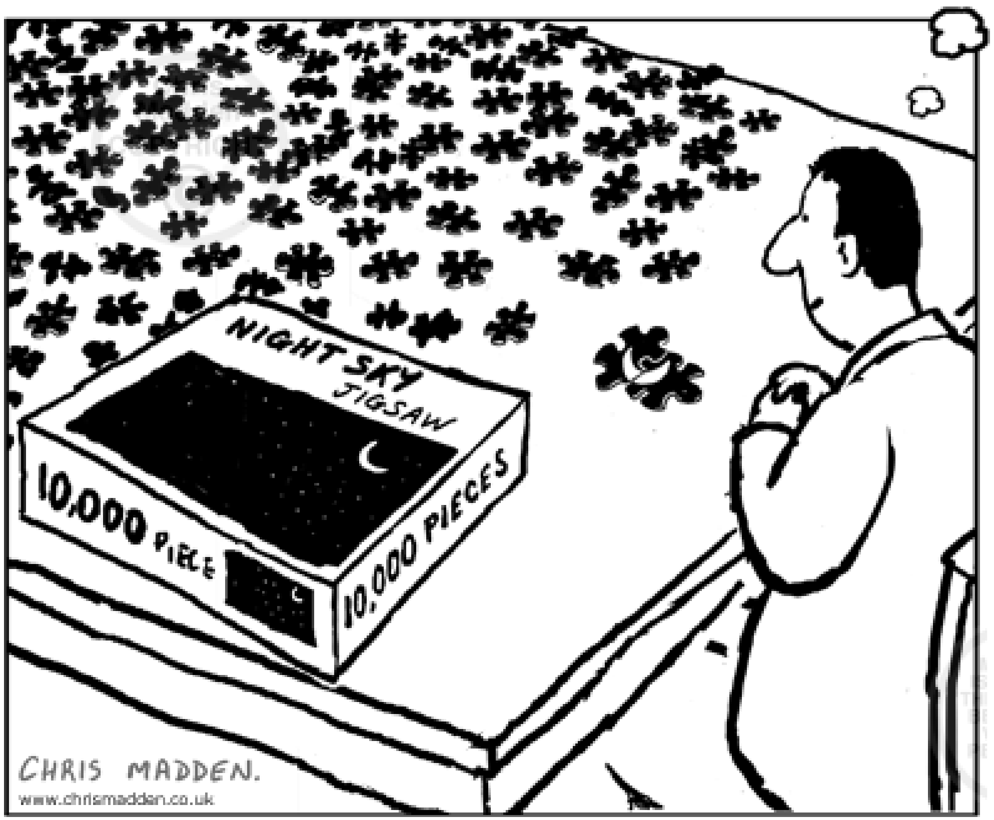
H0

Adding KAIT sample: SN1999em, SN1999gi, SN2005ay with Cepheid measurements



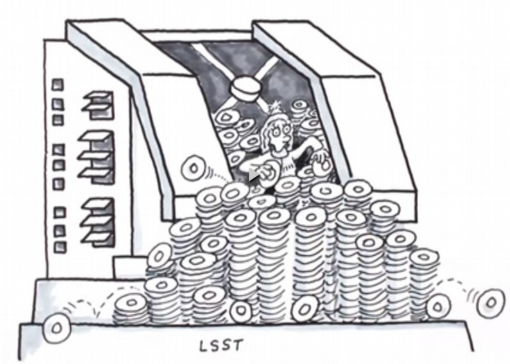
$$\log_{10} H_0 = 0.2 \times \left[m_{SN} + \alpha \log_{10}\left(\frac{v_{H\beta}}{< v_{H\beta} > \ \mathrm{km\ s^{-1}}} \right) - \beta(r-i) - \mu_{SN} - M_i + 25 \right],$$

H0=65 ± 7 km/s/Mpc

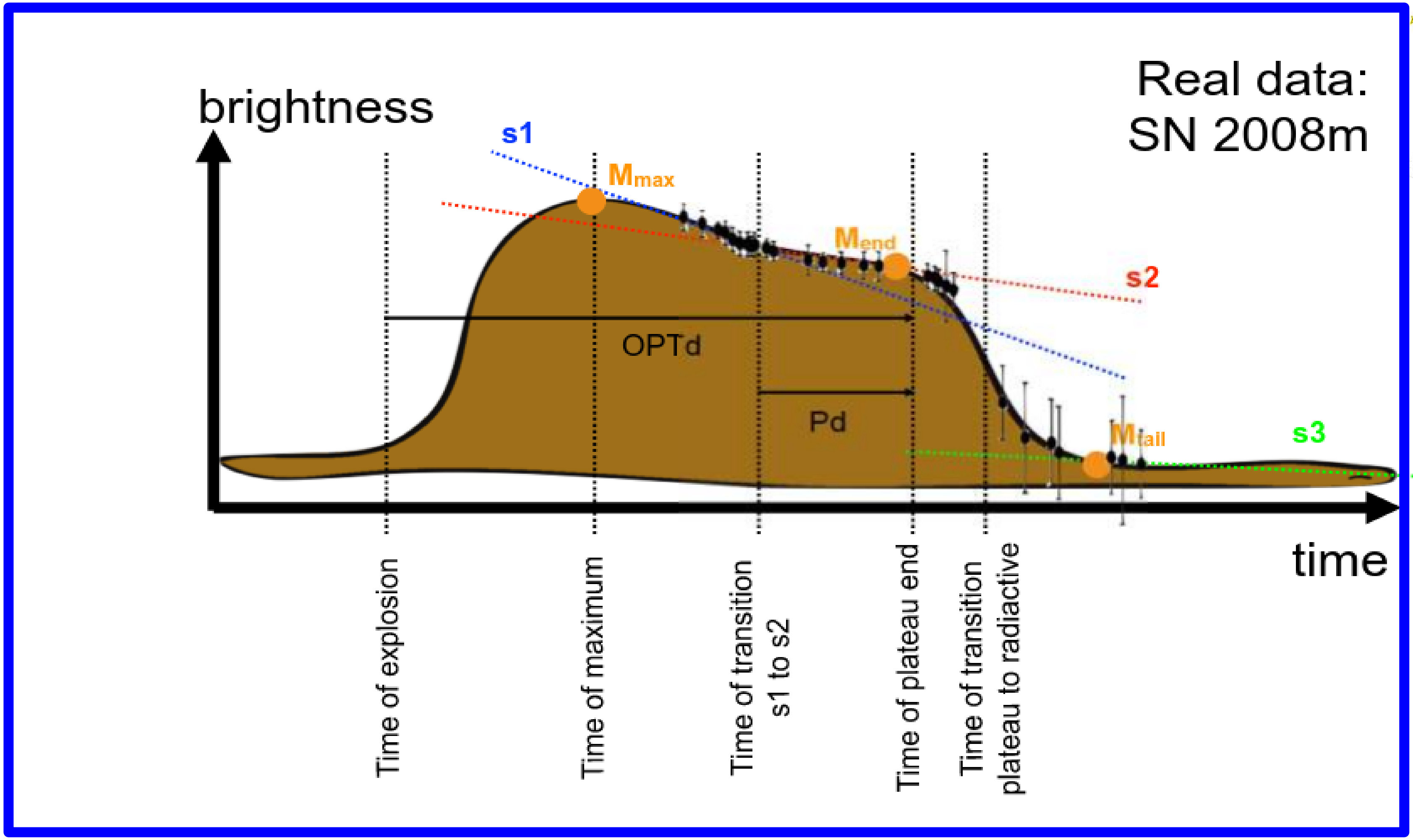


BUT If we did not have spectroscopic information?

Can we come up with a method solely based on photometry?



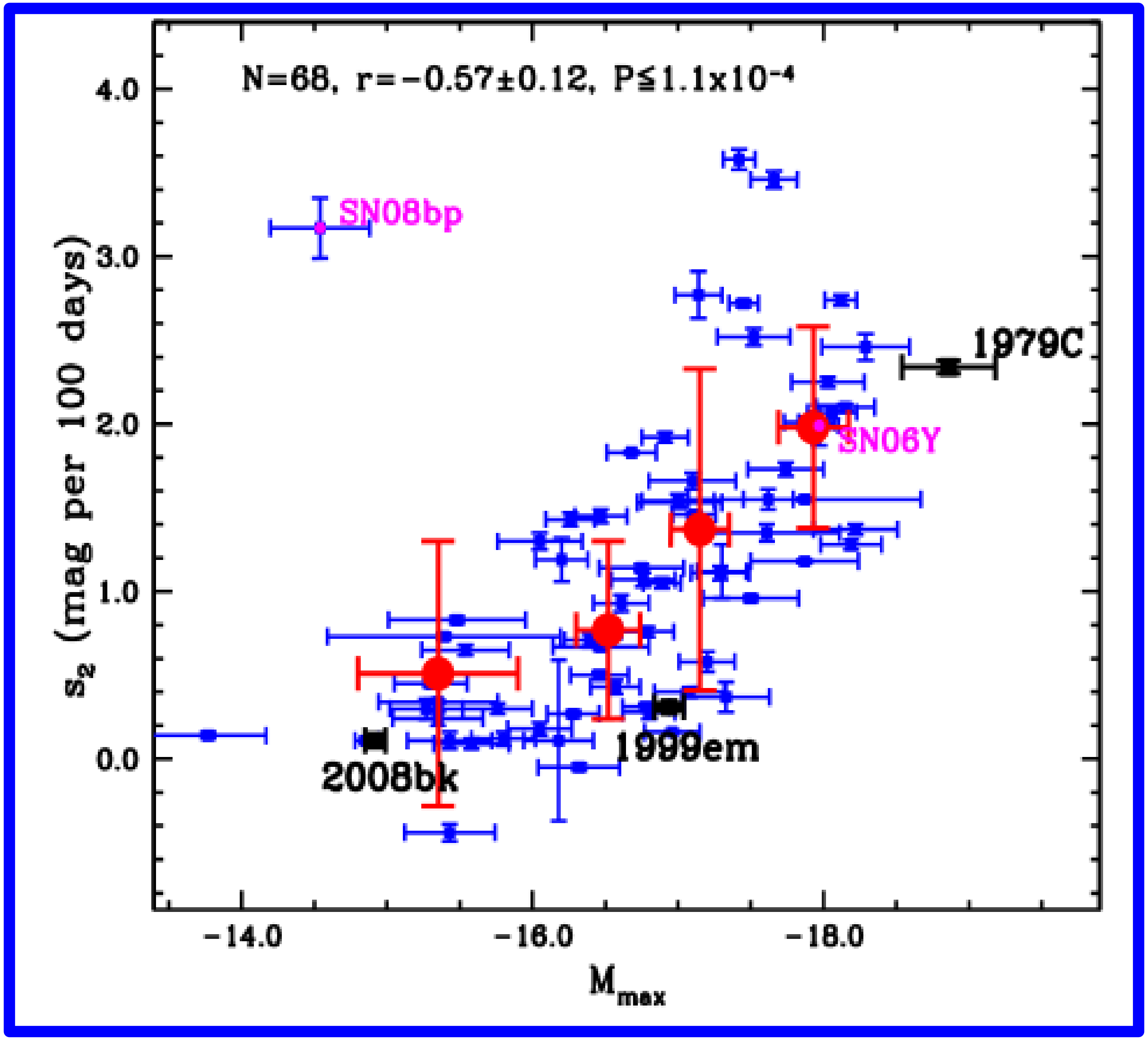
PCM



Courtesy Lluis Galbany

PCM

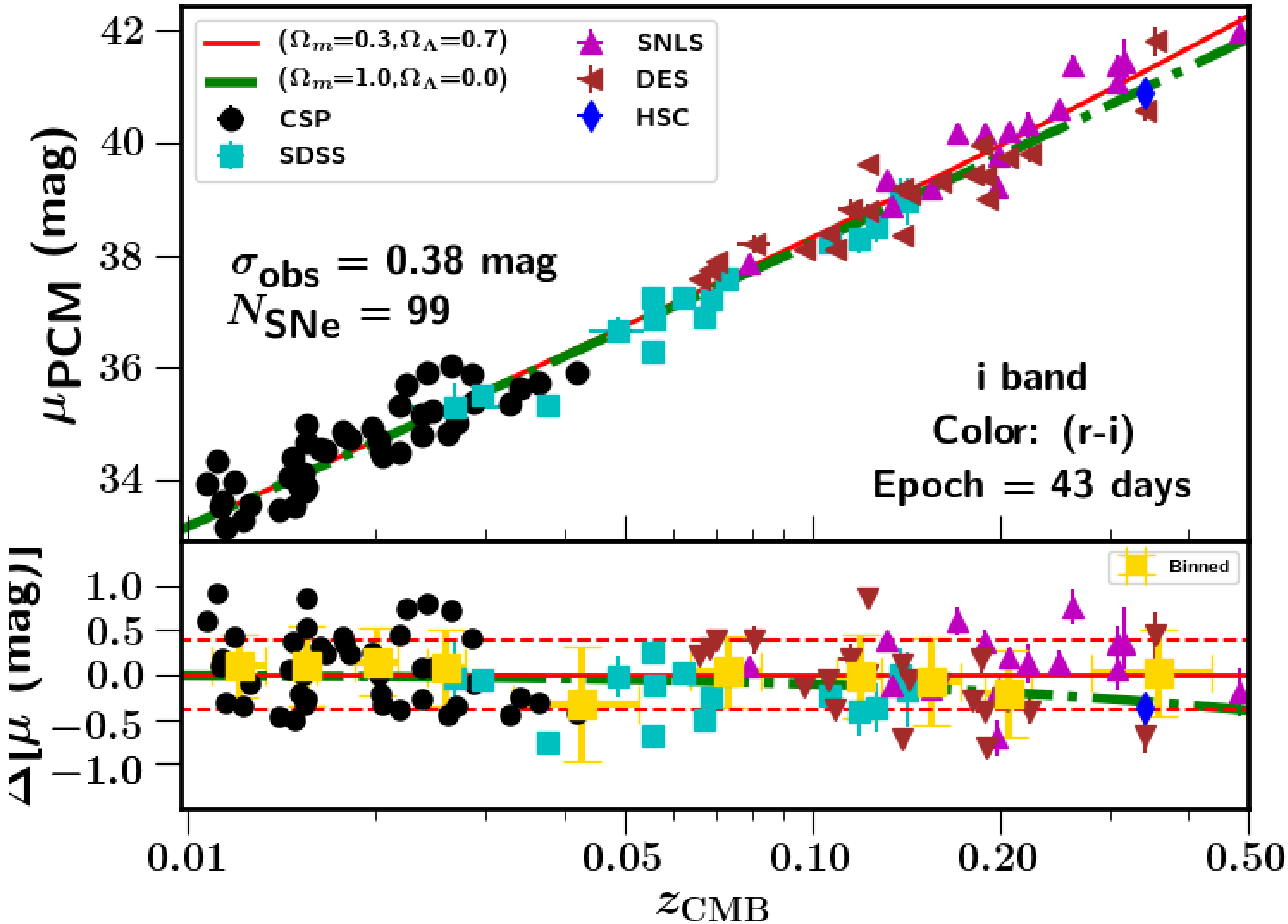
Plateau slope (s_2): **Brighter** SNe have **steeper** plateau



Anderson et al. 2014

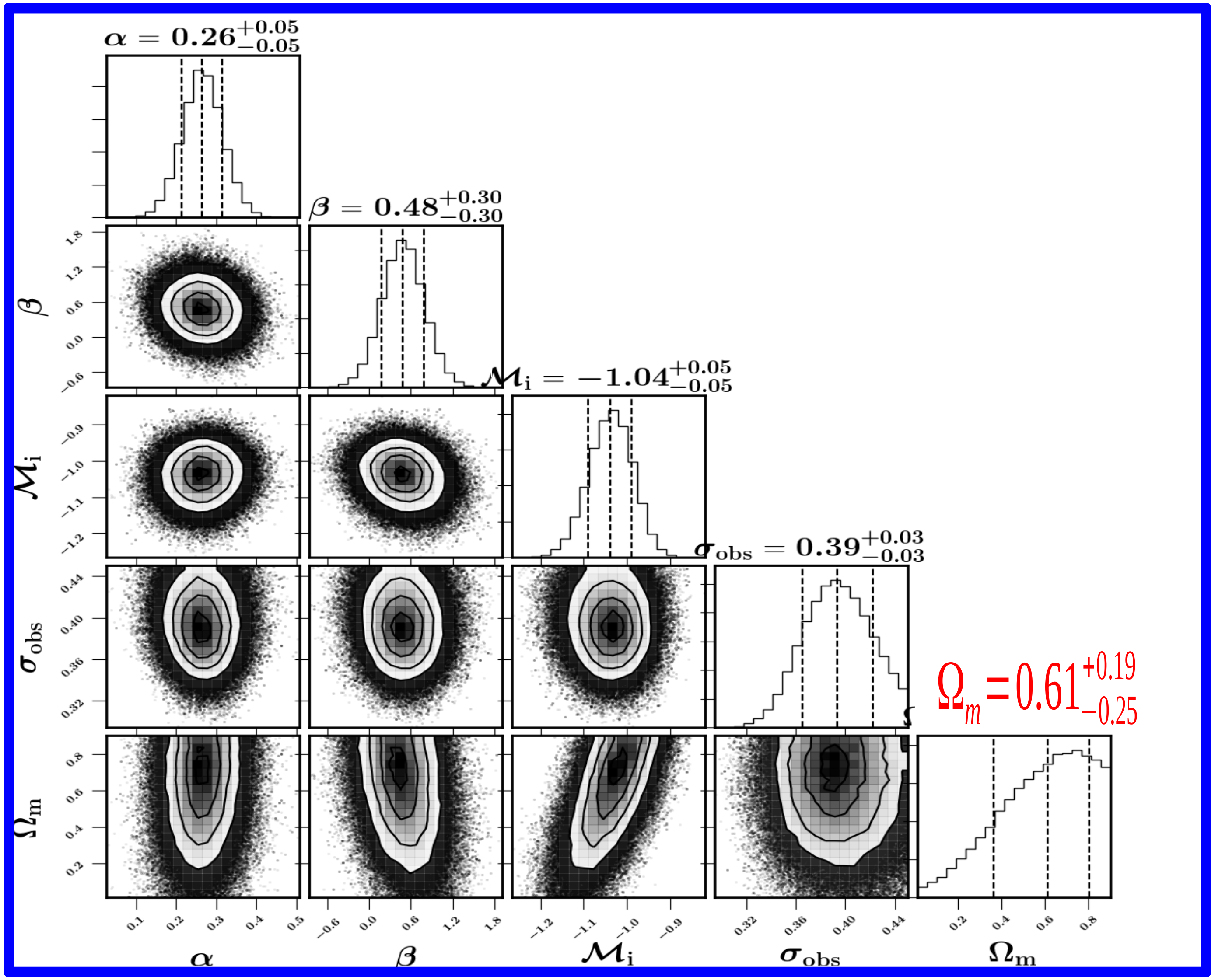
PCM

$$m_i^{\mathrm{model}} = \mathcal{M}_i - \alpha s_2 + \beta(r-i) + 5\log_{10}(\mathcal{D}_L(z_{\mathrm{CMB}}|\Omega_{\mathrm{m}}, \Omega_\Lambda))$$



PCM

Assuming a flat Universe
$\Omega_m + \Omega_\Lambda = 1$
Ω_m as a free parameter



Others methods

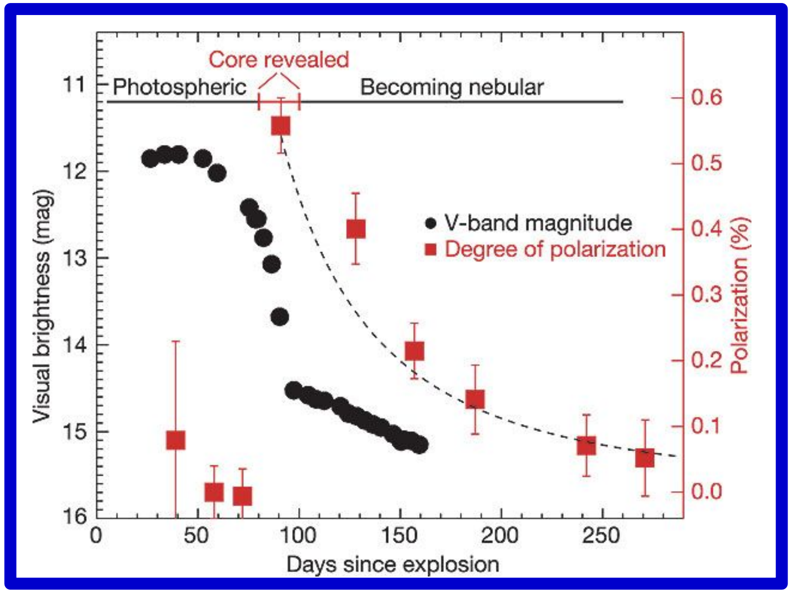
Expanding Photosphere Method: relation physical and angular radius → Θ=R/D

Assuming:

- **Homologus expansion**: R(t)= Ro + v (t-to)
- **Spherical symmetry** (Leonard et al. 02)
- **SN ~ Black body**

$$\Theta=\sqrt{\frac{f_\lambda}{\zeta_\lambda^2 \pi B_\lambda(T) 10^{-0.4 A(\lambda)}}}$$

t= to + D (Θ/v)



Pros:

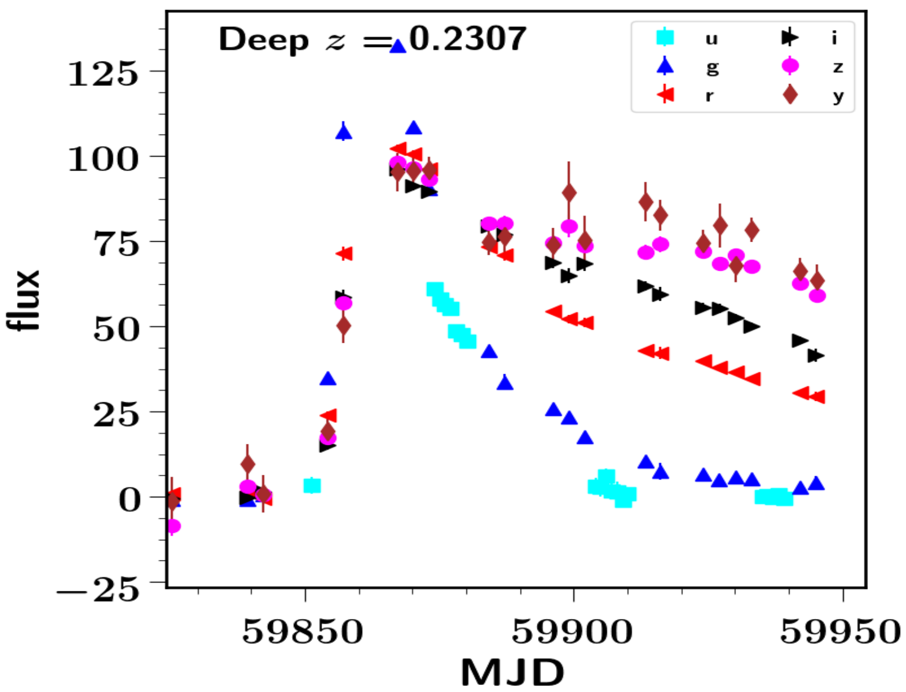
- **Independant from calibration (Cepheids)**
  → H0

Cons:

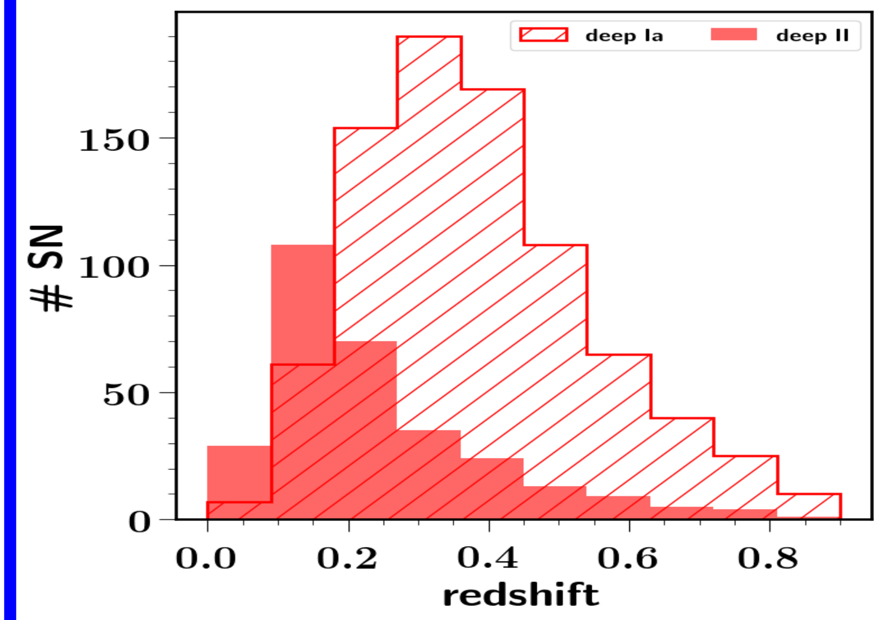
- **Besoin d’au moins 2 spectres**
- **Needs models for dilution factors**
- **Not easy at high z**

LSST

Light curve



Redshift



PLASTICC challenge

Conclusions

- Precision of SNe Ia : 0.15 mag (7% in distance)
- Precision of SCM : 0.30 mag (14% in distance)
- Precision of PCM: 0.38 mag (17% in distance)

Next steps

- Measuring H0 :

  → Cepheid calibrations via HST images (Riess et al .2009,2011)

- Expand the sample to high-z supernovae :

  → Dark Energy Survey (DES) supernovae (de Jaeger et al. in prep)

  → LSST

  → Gemini + Magellan + Keck spectroscopic followup

- New SNe II template :

  → Type II light-curve fitter?

  → Improve K-corrections

- SNe II environnments

  → SNe II les plus brillantes ont un environnement peu métallique

  → IFU/MUSE