Supernovae Ia, Énergie Noire et Galaxies

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habilitation à diriger des recherches

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LPNHE PARIS

UPMC SORBONNE UNIVERSITÉS

Supernovae Ia, Énergie Noire et Galaxies

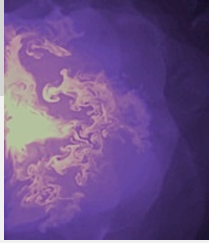
1. Supernovae Ia and Dark Energy

2. From EROS to the Supernova Legacy Survey
   SNLS : measuring the dark energy equation of state parameter *w*

3. SNLS galaxies :
   SNLS SNe Ia gravitational magnification
   host galaxies and cosmology

4. Perspectives

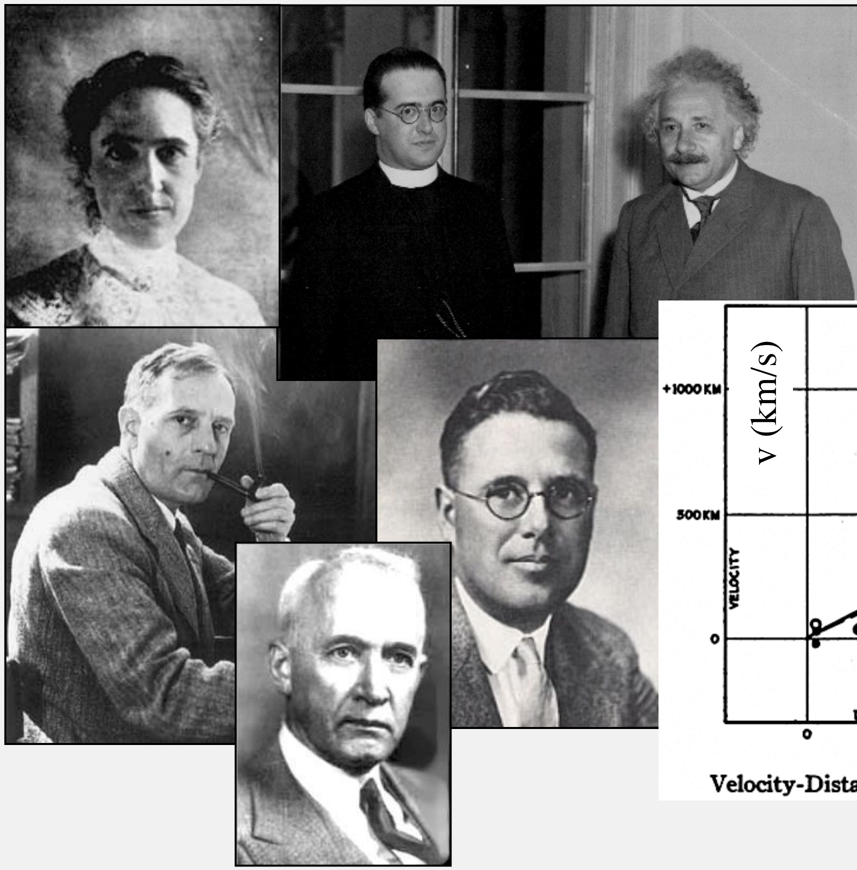
1. Supernovae Ia and Dark Energy



1930's : the Universe is in expansion

Lemaître (1927), Hubble(-Humason) (1929) : $v = c\,z = H_0\, d$

recent measurement : $H_0 \approx 70$ km.s^{-1}.Mpc^{-1}



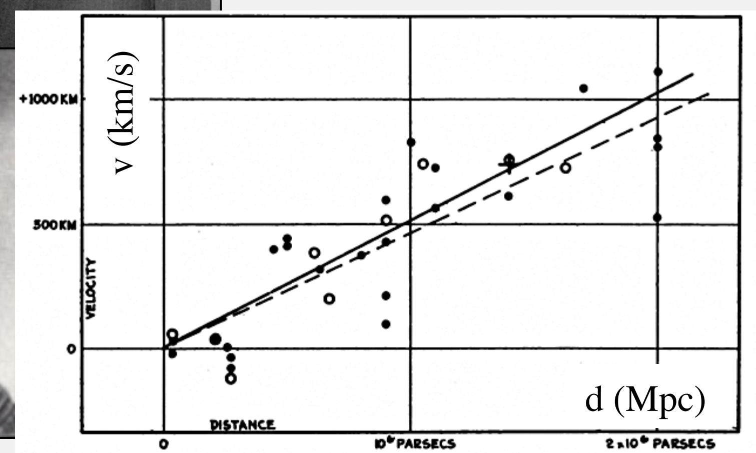
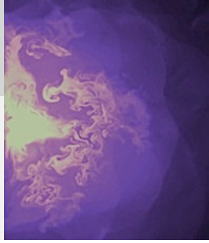


FIGURE 1
Velocity-Distance Relation among Extra-Galactic Nebulae.

<u>matter decelerates expansion</u> : measuring today's matter density with expansion history

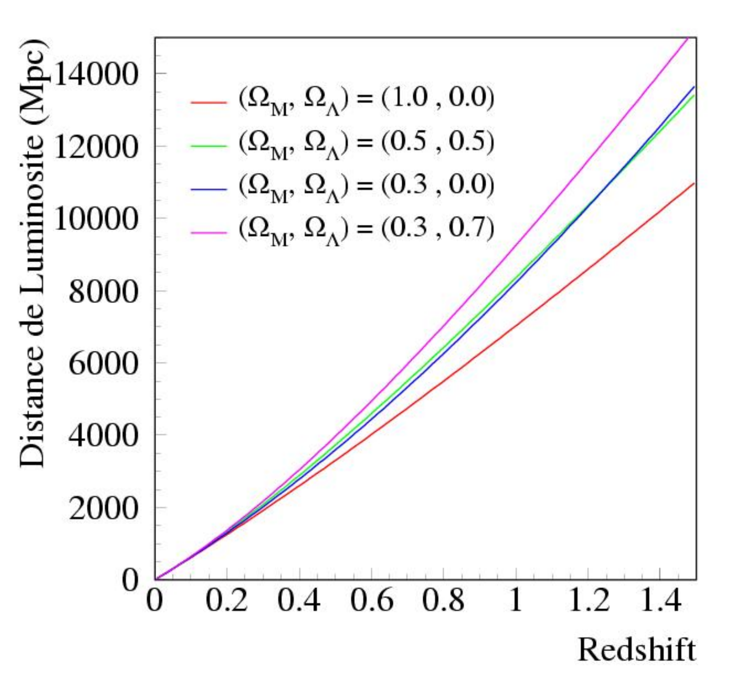
1. Supernovae Ia and Dark Energy



homogeneous & isotropic Universe in expansion :

d ∝ expansion factor **a(t)**

Hubble factor : $H = \dot{a}/a$



<u>when observing a luminous source, we measure</u> :

- **redshift z** : $1+z = \lambda_{\text{réception}} / \lambda_{\text{émission}} = a_0 / a(t_{\text{emission}})$
- **luminosity distance :**

$$D_L = (L / 4\pi F)^{1/2}$$

measuring the flux F,
providing the **Luminosity L** is known

$$D_L(z) = a_0 \, (1+z) \mathcal{S}_k \left(\frac{c}{a_0} \int_0^z \frac{dz'}{H(z')} \right)$$

Friedman-Lemaître equations relates **H(z)** to Universe contents :

$$D_L(z) = \frac{cz}{H_0} f_D(z; \Omega_m, \Omega_{DE}, w)$$

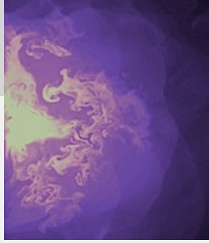
Hubble Diagram : $D_L(z)$

- **matter** $\Omega_m = \rho_{m\,0} / \rho_{crit\,0}$

with today's critical density $\rho_{crit\,0} = 3 H_0^2/(8\pi G)$

+ Dark Energy ?

1. Supernovae Ia and Dark Energy

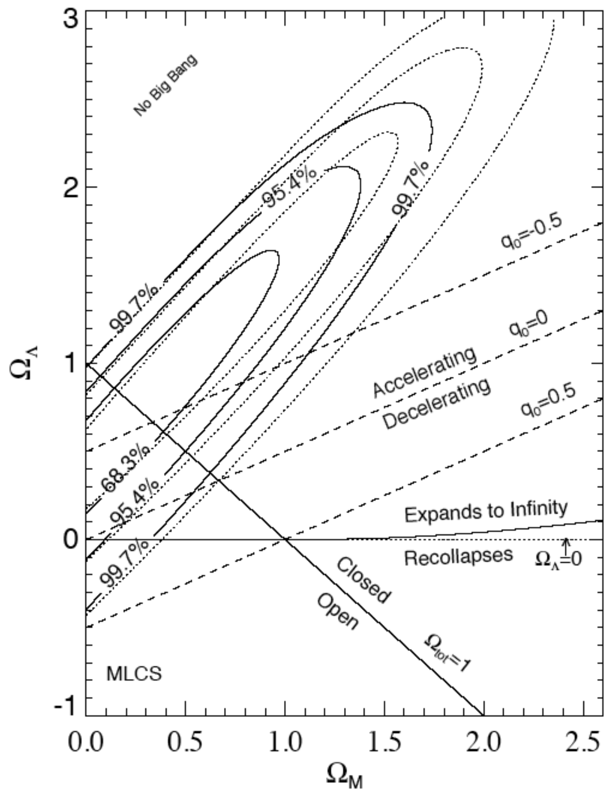


1998 : expansion is accelerating !

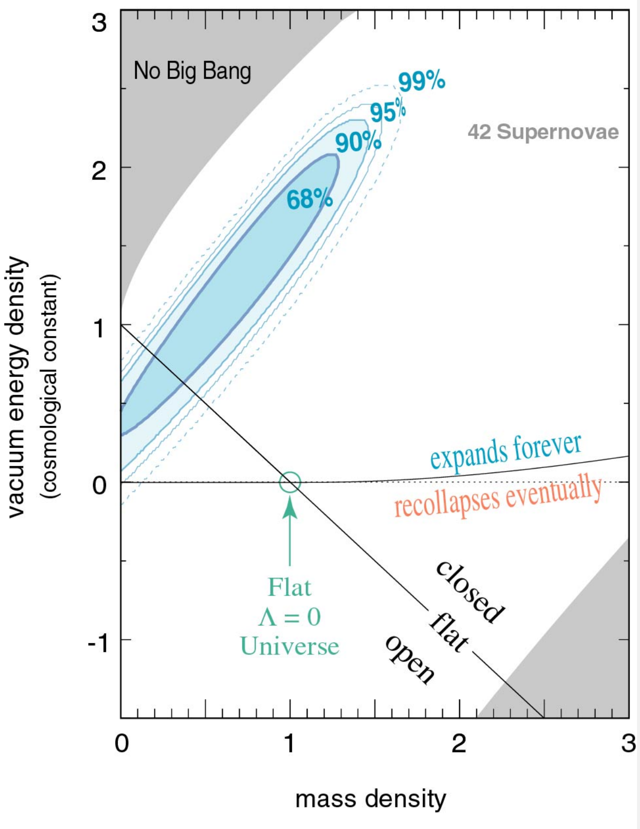
luminosity distances D_L and redshifts z of :
Calàn-Tololo : ~ 30 nearby type Ia supernova explosions &
The Supernova Cosmology Project, The High-Z Team : ~50 distant type Ia supernovae

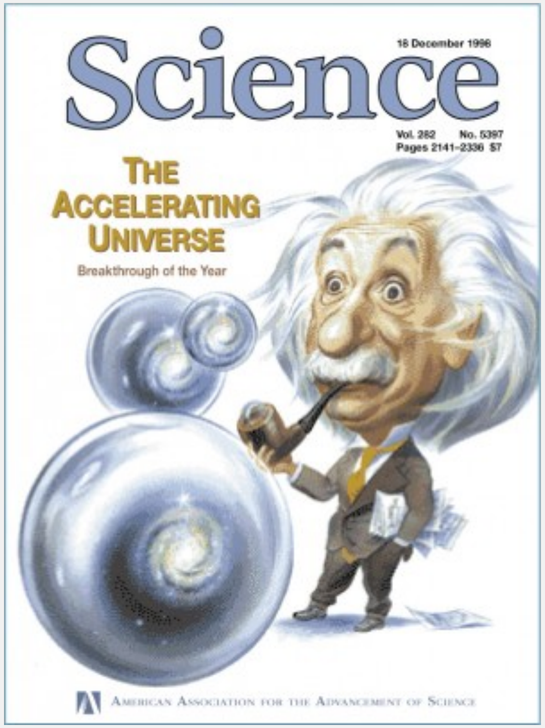
Something else besides matter ? Cosmological constant Λ ? Dark Energy ?

High-Z Team,
Riess *et al.* (1998)



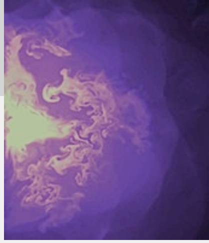
Supernova Cosmology Project,
Perlmutter *et al.* (1999)





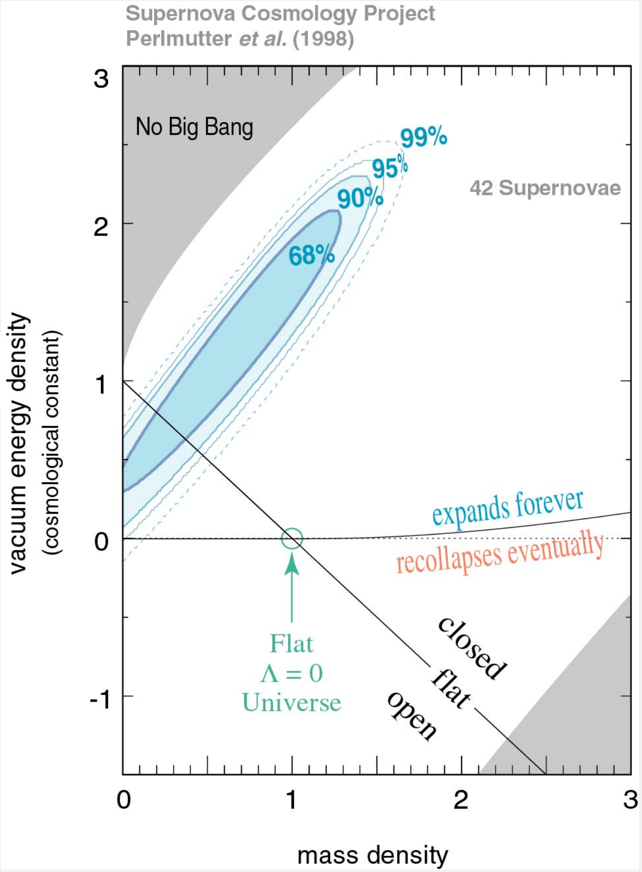
1. Supernovae Ia and Dark Energy

Confirmation by other cosmological probes during the last decade :



- **Concordance Model** :
  - flat universe
  - ~30% matter
  - ~70% of unknown dark energy behaving as Einstein's cosmological constant Λ

- $\Omega_{tot} = \Omega_m + \Omega_\Lambda \approx 1$,
- $\Omega_m \approx 0.3$,
- $\Omega_\Lambda \approx 0.7$ *with a precision of ~ 0.02*



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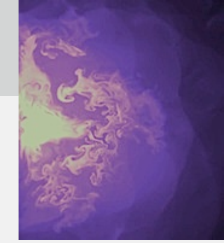

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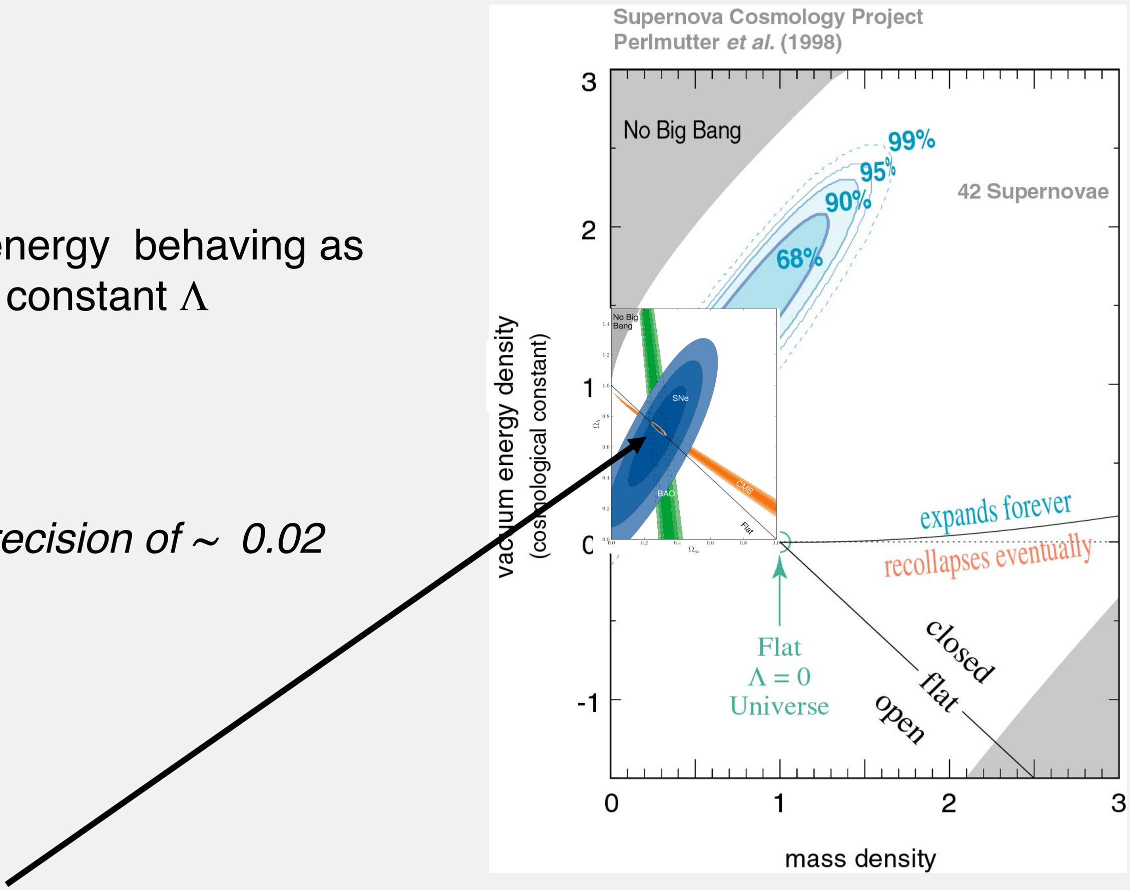

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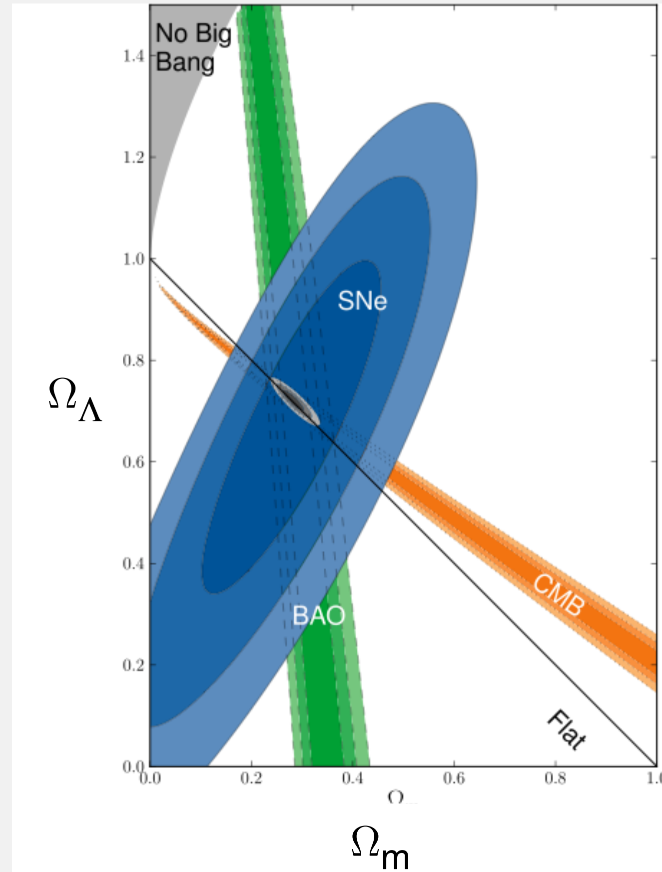


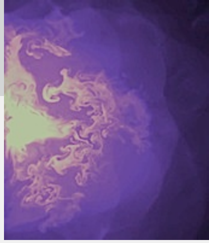
Suzuki *et al.*, 2012



Saul Perlmutter, Brian P. Schmidt, Adam G. Riess

The Nobel Prize in Physics 2011 was divided, one half awarded to Saul Perlmutter, the other half jointly to Brian P. Schmidt and Adam G. Riess "for the discovery of the accelerating expansion of the Universe through observations of distant supernovae".

1. Supernovae Ia and Dark Energy



Dark Energy ?

some fluid X (« **dark energy** »), density Ω_{DE} and equation of state $\mathbf{p = w\,\rho}$

- *accelerates the expansion for w <-1/3*

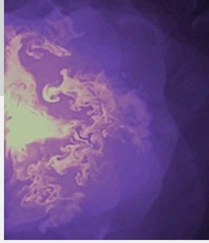
- *cosmological constant* Λ :
  formally equivalent to fluid with $\Omega_\Lambda = \Lambda / 3H_0^2$ *and* $w_\Lambda = -1$

- *vacuum energy :* ρ_{vac} = cste … mathematically equivalent to Λ (**Zel' dovich,1968**)
  $w_{vac} = -1$

- **DE :** w **= cste** or $w(z) = w_0 + w_a (1 - a/a_0)$

To measure *w* precisely :
- **low-z and high-z D_L**
- **high precision on D_L**
- **Ω_m prior or constraint increases precision**
- **tight systematics control**

1. Supernovae Ia and Dark Energy



$$D_L = (L / 4\pi F)^{1/2}$$

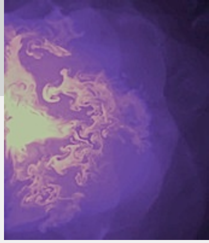
Problem : we measure the flux **F**, how do we know the luminosity **L** ????

STANDARD CANDLES : **L ≈ cste**

➜ compare the fluxes of 2 standard candles at z_1 and z_2

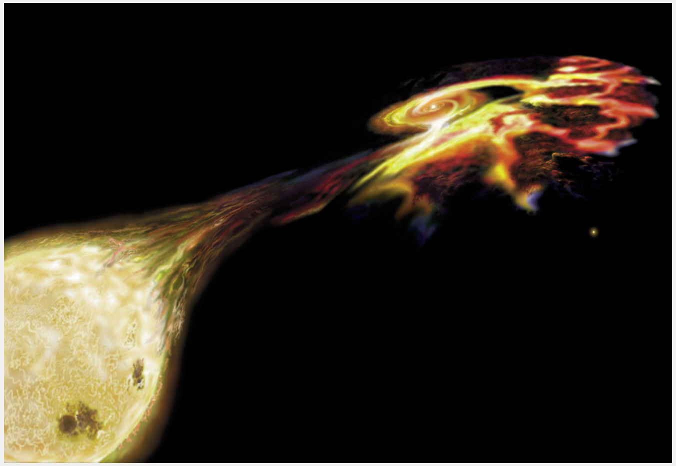
$$\frac{d_L(z_1)}{d_L(z_2)} = \left(\frac{F_2}{F_1}\right)^{1/2} = \mathcal{F}(z_i; \Omega_M, \Omega_X, w)$$

1. Supernovae Ia as cosmological tools



- thermonuclear explosion of a white dwarf : bright events (~10^{11} $L_\odot$)
- rare (<1 / galaxy / century)
- identified by their **spectra**
- show little (40%) **B-band peak luminosity L_{peak}** dispersion

…… they are **standard candles**

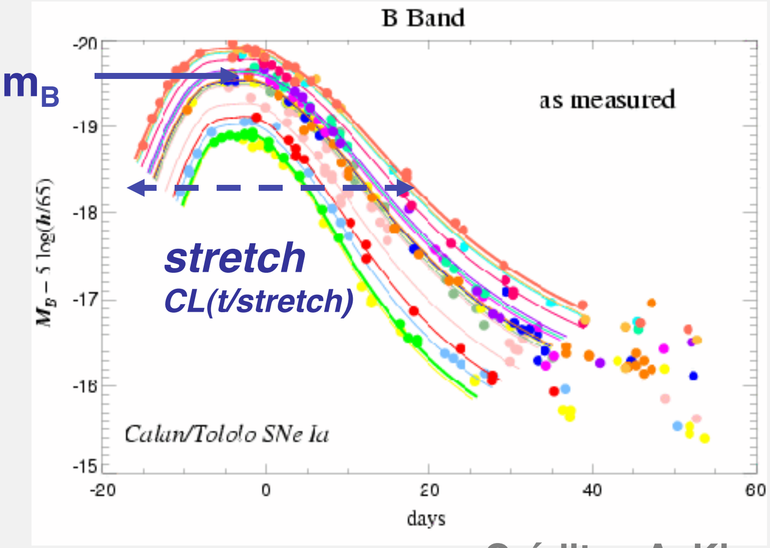


- light curve shape-luminosity relation :
  brighter - slower
- color-luminosity relation :
  brighter-bluer

Standardisation : after empirical correction :

➡ **~16%** dispersion on L_{peak}

➡ **8%** precision on distance D_L



Crédits : A. Kim

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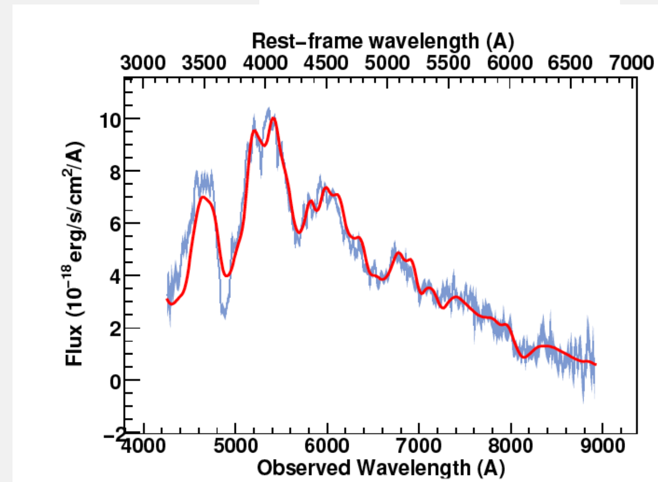
Balland et al. 2009



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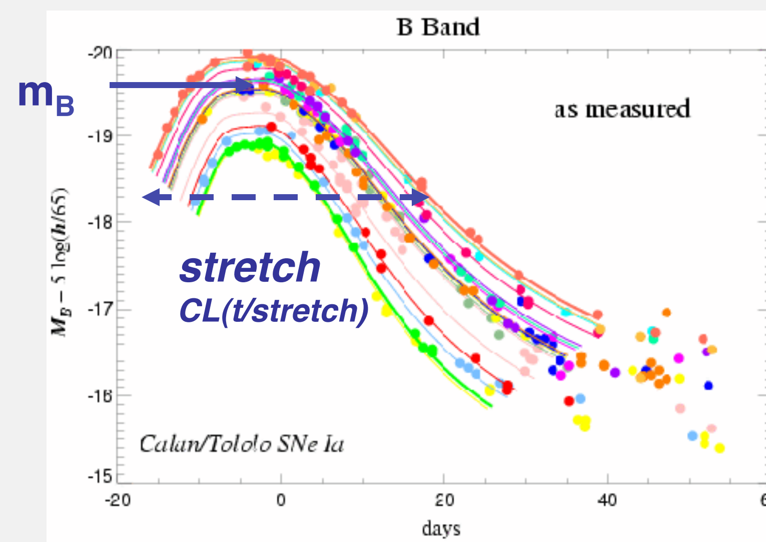

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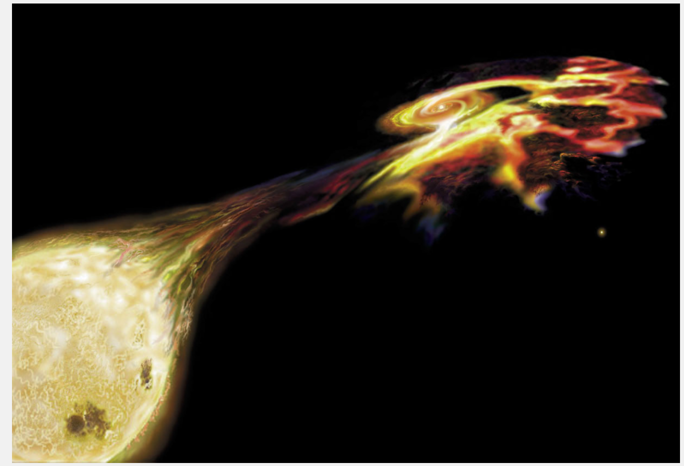

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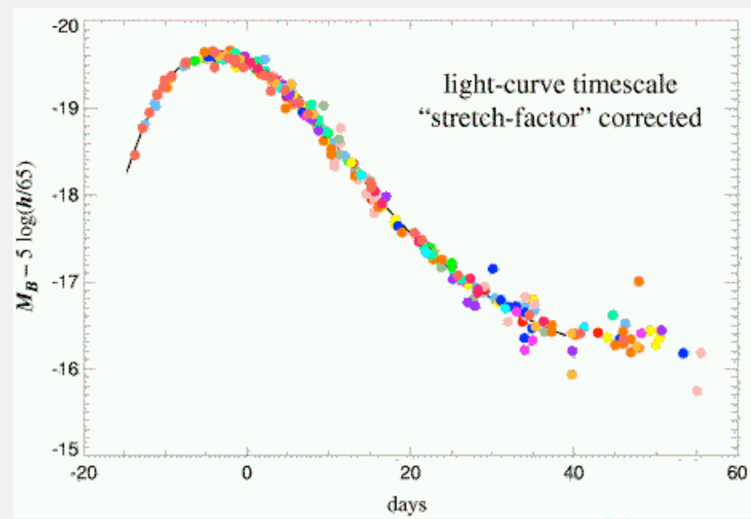

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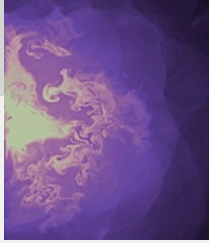

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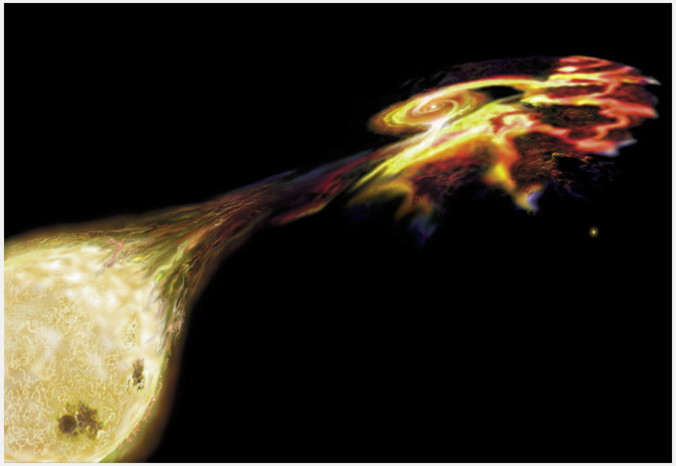

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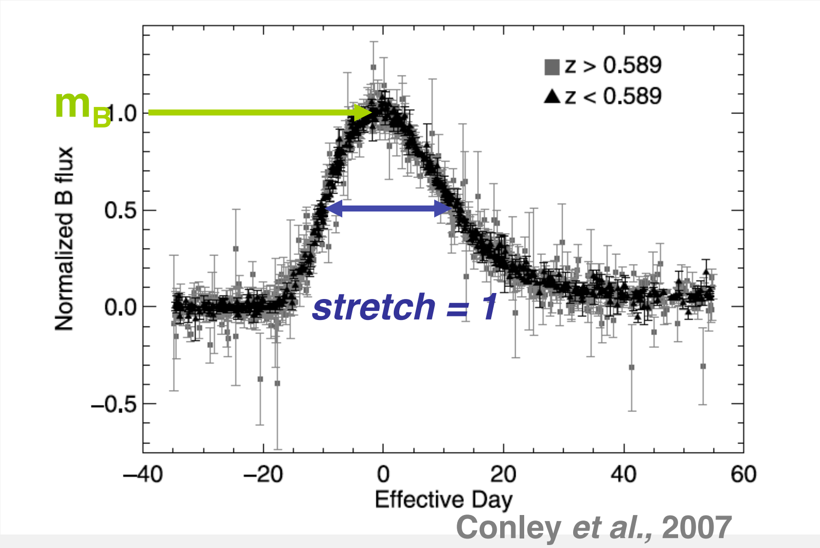
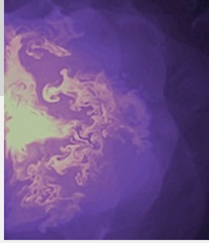


Conley *et al.*, 2007

1. Supernovae Ia as cosmological tools

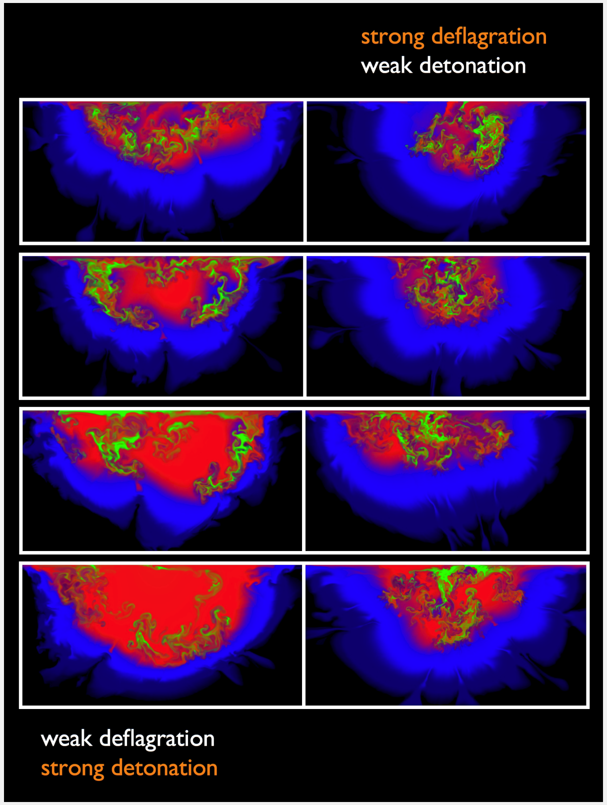


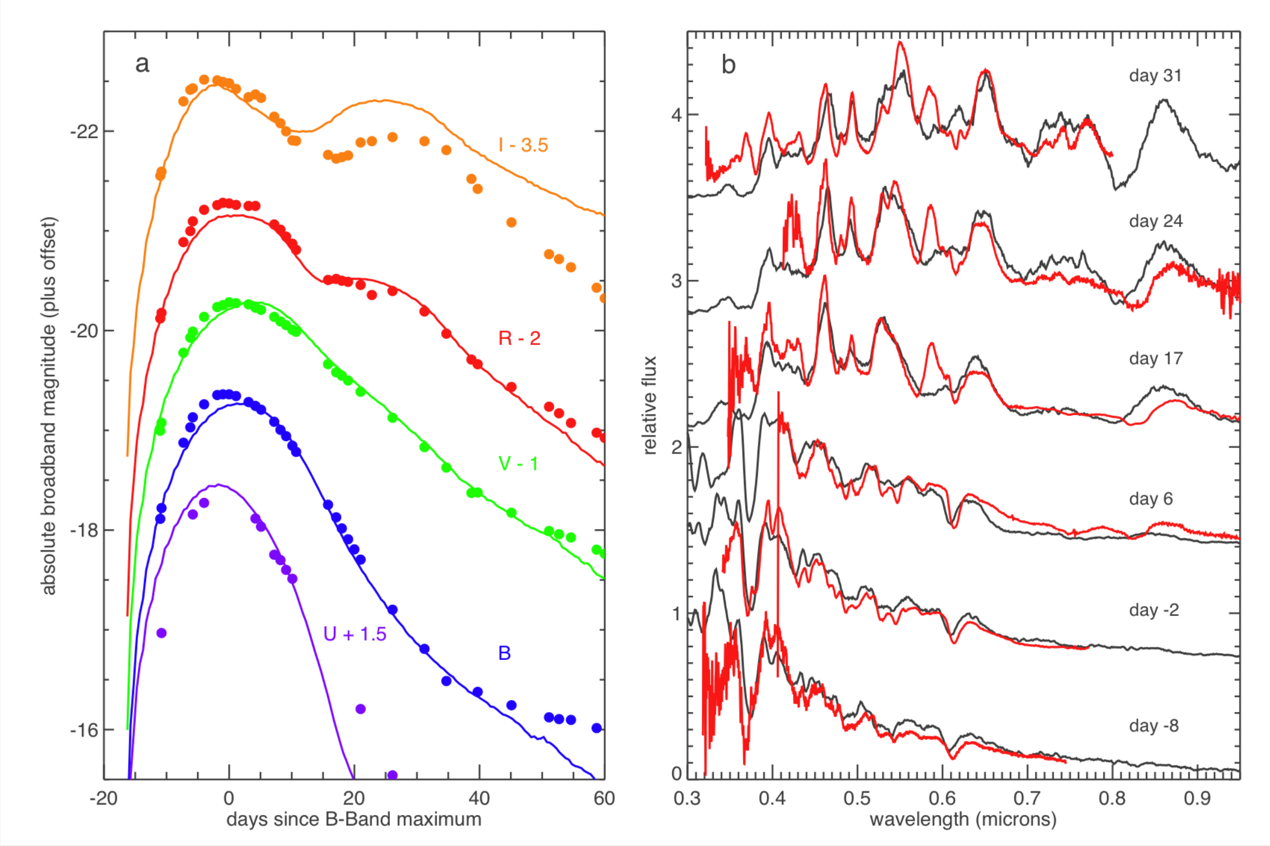
supernovae Ia modelisation : e.g. **Kasen, 2009**

- carbon-oxygen white dwarf in binary systems accreting mass from companion star
- multi-dimensional modelling of the explosion physics and radiative transfer

reproduces global light-curve & spectra behavior, brighter-slower & brighter-bluer relations

… but not precise enough to avoid resorting to empirical modeling for peak luminosity, stretch and color measurement





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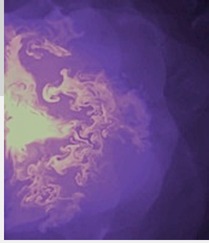
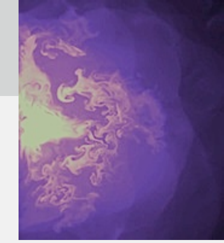


An empirical approach :

- comparing fluxes at different redshifts

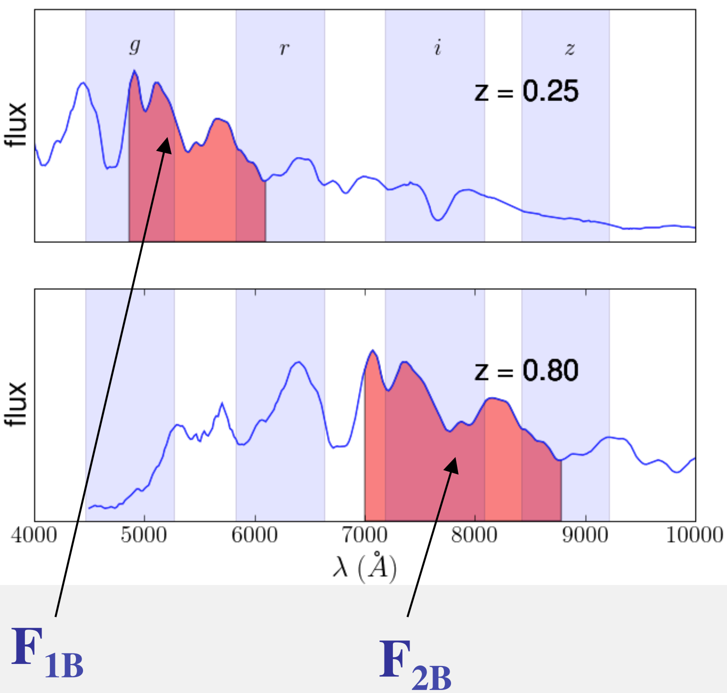
- standardisation and distance estimator

1. Supernovae Ia as cosmological tools



comparing fluxes at different redshift

$$D_L = \left(\frac{L}{4\pi F}\right)^{1/2} = \frac{cz}{H_0} f_D(z; \Omega_m, \Omega_{DE}, w)$$



F_B is the **restframe B band flux (m_B magnitude)** measured at ≠ redshifts
→ in ≠ obs. frame filters
→ flux inter-calibration of passbands

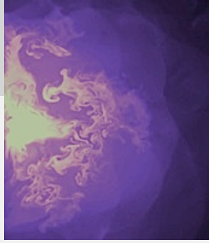
Calibration is crucial : dominant systematics in survey

to get **m_B at peak, *stretch* & *color* :**

→ empirical **spectro-photometric modeling** **$\phi(\lambda, t)$** to interpolate between photometric measurements

→ trained on a set of nearby & distant SNe

1. Supernovae Ia as cosmological tools



standardisation & distance estimator

distance — flux (magnitude) — luminosity (absolute magnitude)

$$\mu(z\,;\Omega_m,\Omega_{DE},w) = m_B - (M_B - \alpha\,(\mathit{stretch}-1) + \beta\,\mathit{color})$$

- m_B: measured peak magnitude in restframe B filter
- M_B: absolute B (peak) magnitude for the « standard » SN (*stretch*=1, *color*=0)
- $\alpha\,(\mathit{stretch}-1)$: light-curve shape correction
- $\beta\,\mathit{color}$: color correction

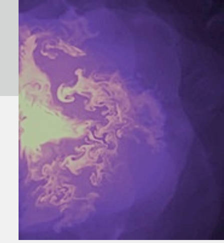
• **z** & $\mathbf{m_B}$, ***stretch***, ***color*** measured on each SN

• $\mathbf{M_B}$, α, β fitted on Hubble diagram $\mu(\mathbf{z})$ along with cosmology

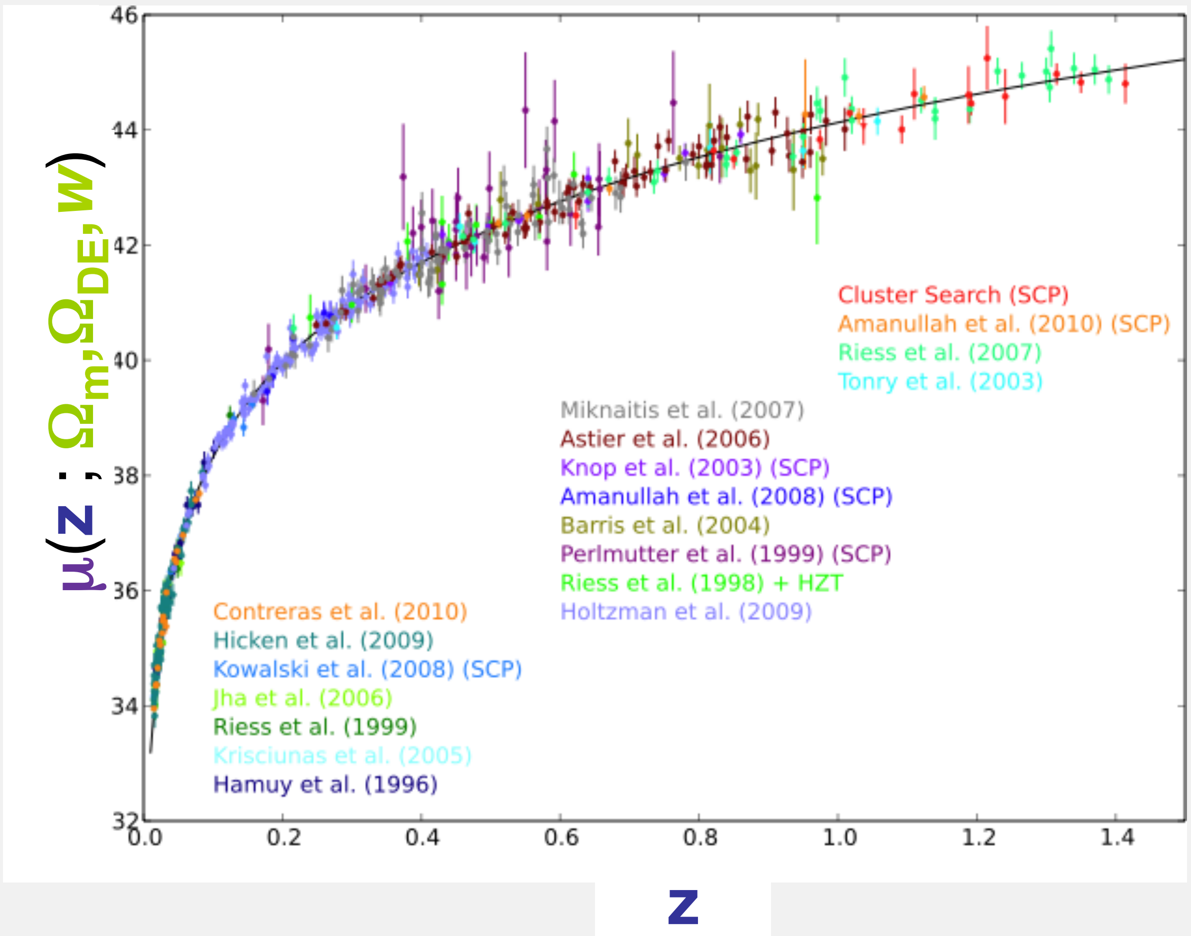
α : brighter-slower relation

β : brighter-bluer relation -- no assumption whether intrinsic or due to extinction by dust

1. Supernovae Ia as cosmological tools



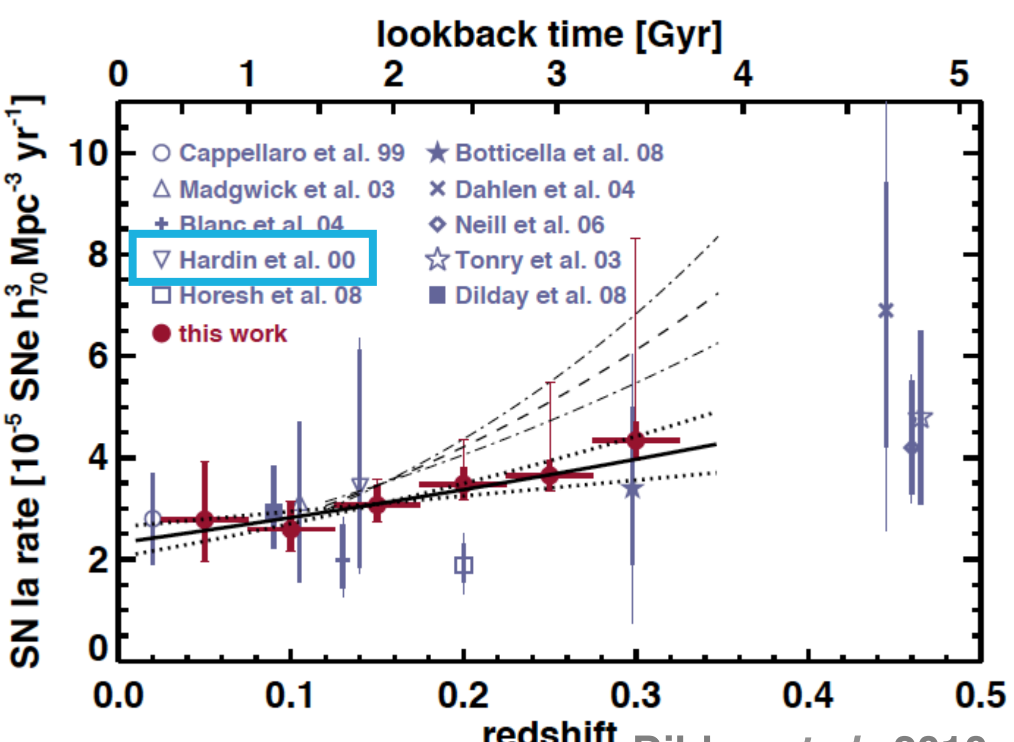
recent Hubble diagram : cosmological constraints **Suzuki *et al.*, 2012**
Union 2 compilation : SNe from various teams, Calàn-Tololo, SDSS, HZTeam, Essence, ….
and the **Supernova Cosmology Project, the Supernova Legacy Survey**



2. From EROS to the Supernova Legacy Survey

Mon parcours :

- EROS (Expérience de Recherche d'Objets Sombres): nearby supernova search (PhD thesis, 1998 : SN search & explosion rate measurement)



Dilday *et al.*, 2010

2. From EROS to the Supernova Legacy Survey

Mon parcours :

Now and since 1999 : Maître de Conférence at Univ. Pierre et Marie Curie, in the Laboratoire de Physique Nucléaire et des Hautes Energies Cosmology Group

• **The Supernova Cosmology Project**
search & observing runs for SNe Ia at intermediate redshifts (redshift desert) at the Isaac Newton Group telescopes

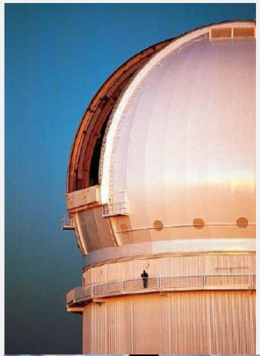
• *since 2003* : **The Supernova Legacy Survey**
measuring w with distant SNe Ia up to z ~ 1. at the Canada-France-Hawaii telescope

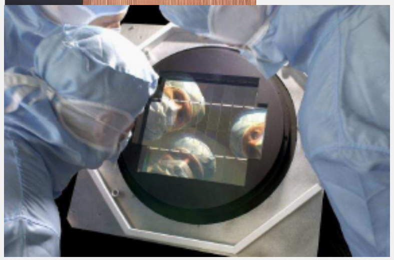
- **SNLS supernovae photometry**
  (developped in the frame of Nicolas Fourmanoit's PhD)

- **SNLS galaxies** : constructing a 3-D catalog for :
  gravitationnal lensing, SN environment impact on cosmology

2. The Supernova Legacy Survey

Measuring w at precision better than 0.1
systematics control is fundamental to the design of SNLS





Deep CFHT Legacy Survey : 4 square degrees
40 nights /year during 5 years (end : 08/2009)

- detection & follow-up with 1 instrument :
  3.6-m telescope @ Hawaii (Mauna Kea, 4200m),
  Megacam (CEA/IRFU), 36 CCDs, 3.4 10^8 pixels, 1 sq. degree

→ calibration at < 1%
→ deep survey (Malmquist bias)

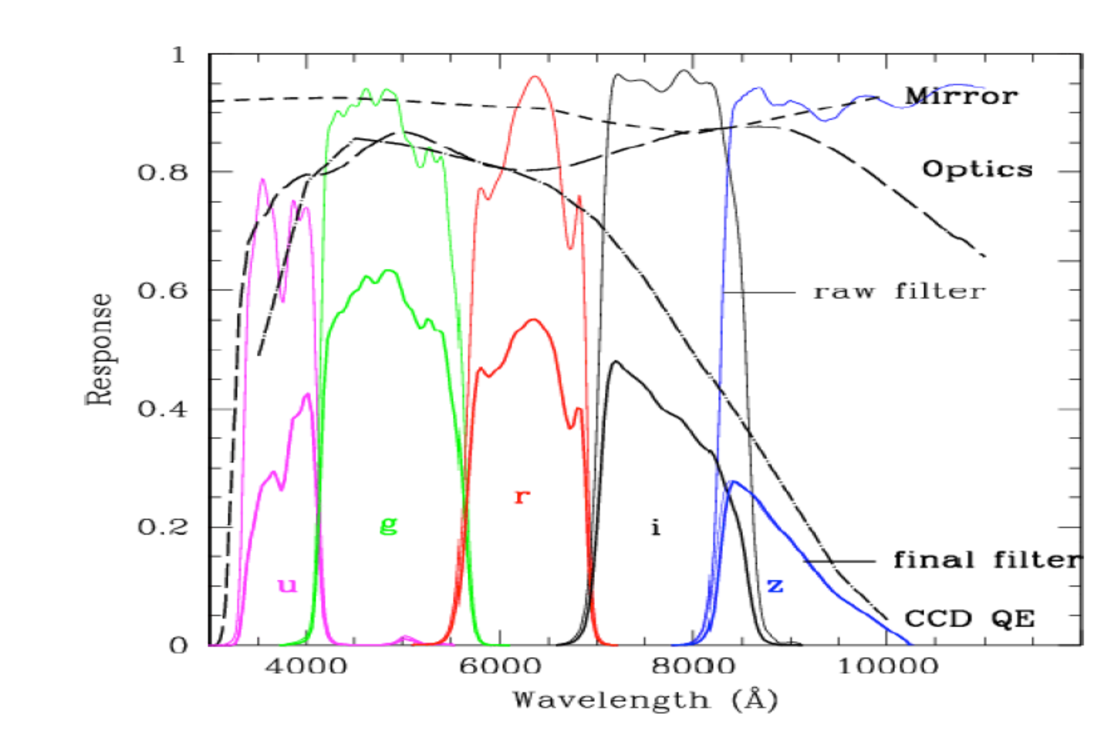
- spectroscopic follow-up : ~ 450 SNe Ia (**SNLS5**)
  10-m class telescopes @ Hawaii, Chile

- 4 filters griz : → $\mathbf{m_B}$ at ≠ z, B-V or U-B ***colors*** for all SNe

- ***rolling search*** **: repeated observations of 4 fields**
  detection & follow-up at the same time
  → well sampled & well measured lightcurve : $\mathbf{m_B}$, ***stretch & color***

→ deep SN-free images : **photometric study of SNe host galaxies**

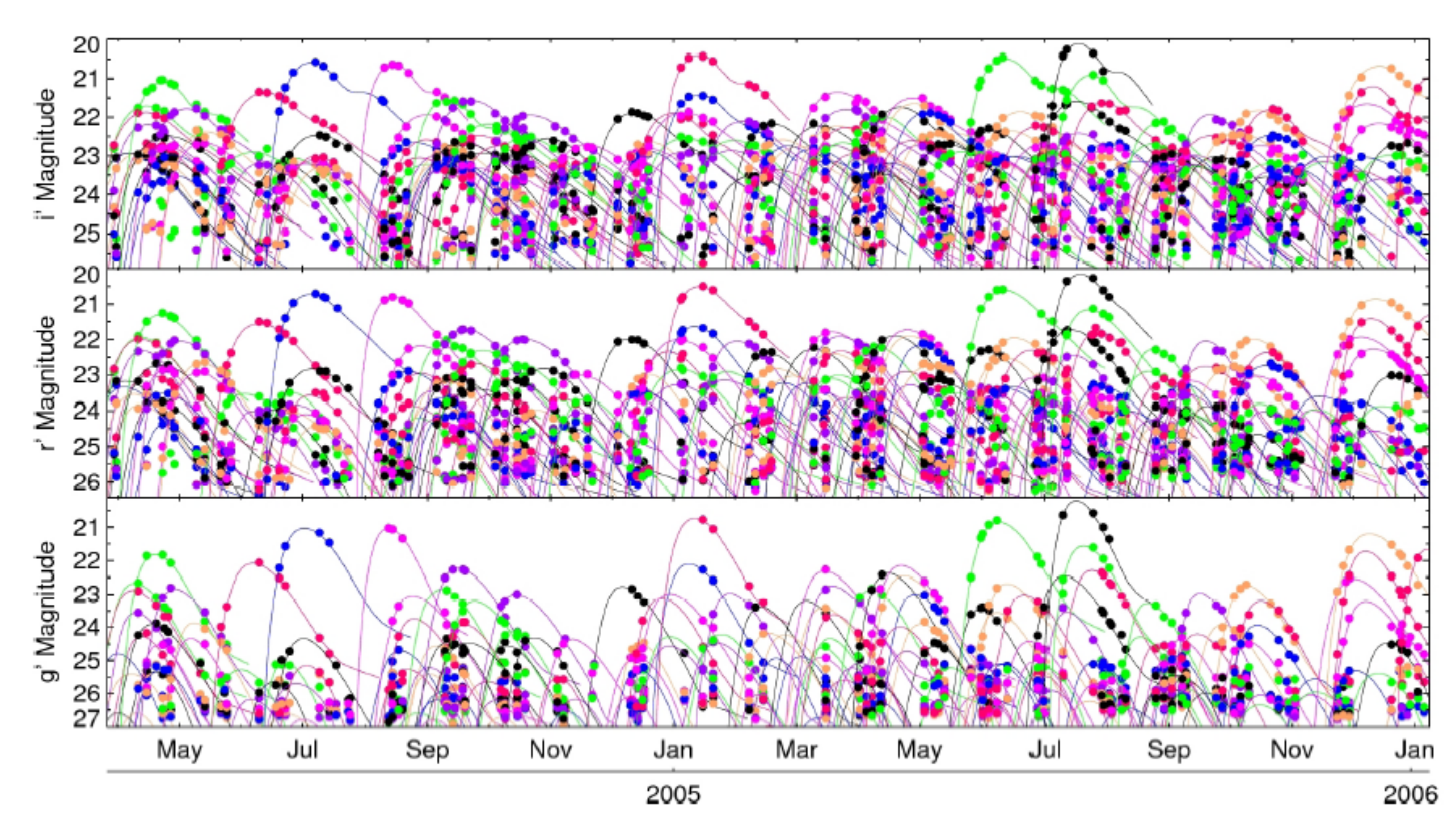
Filters



Mirror
Optics
raw filter
final filter
CCD QE
u
g
r
i
z
Response
Wavelength (Å)
0
0.2
0.4
0.6
0.8
1
4000
6000
8000
10000

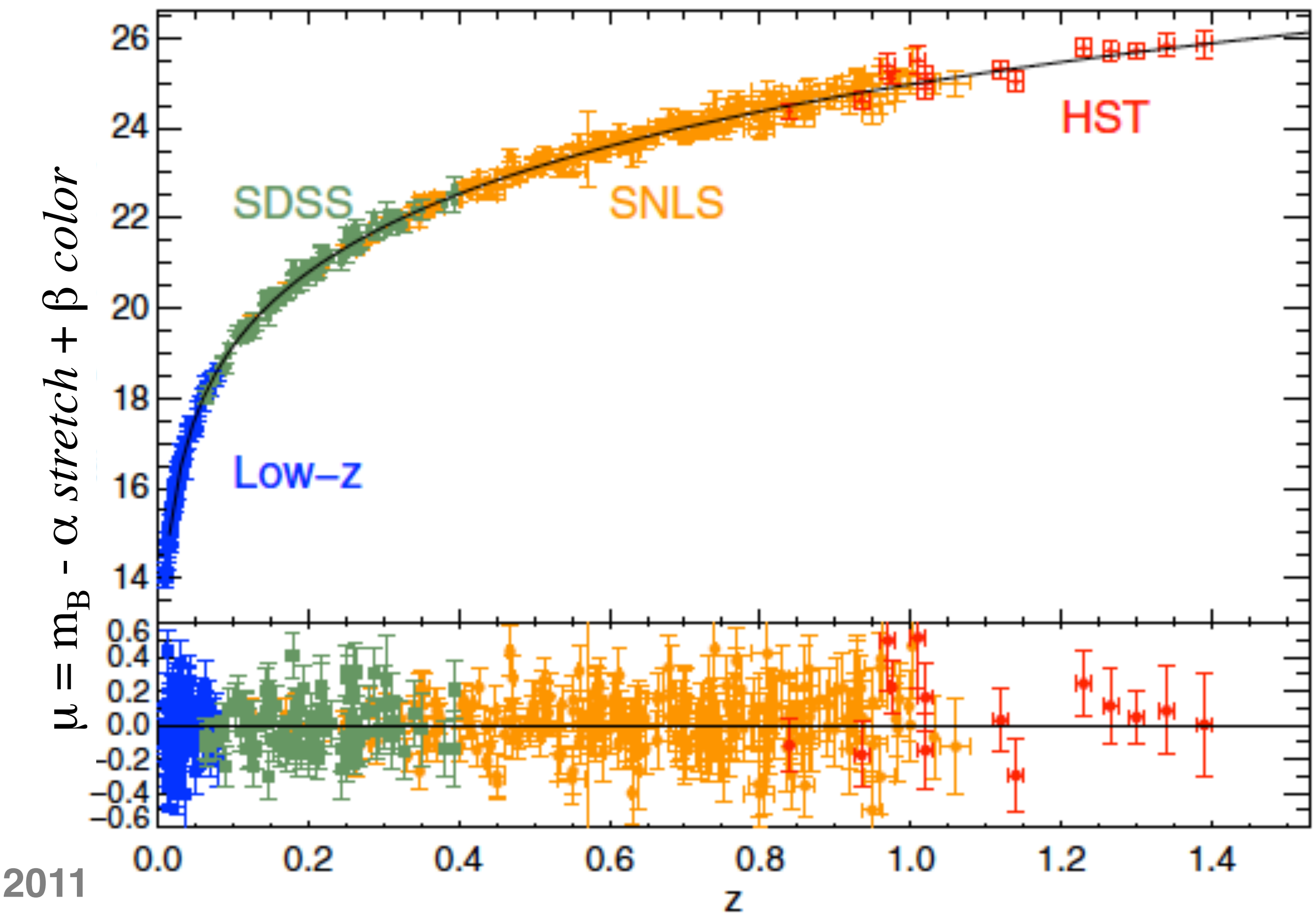
2. The Supernova Legacy Survey

Rolling Search Mode



SNLS-3 extended Hubble Diagram

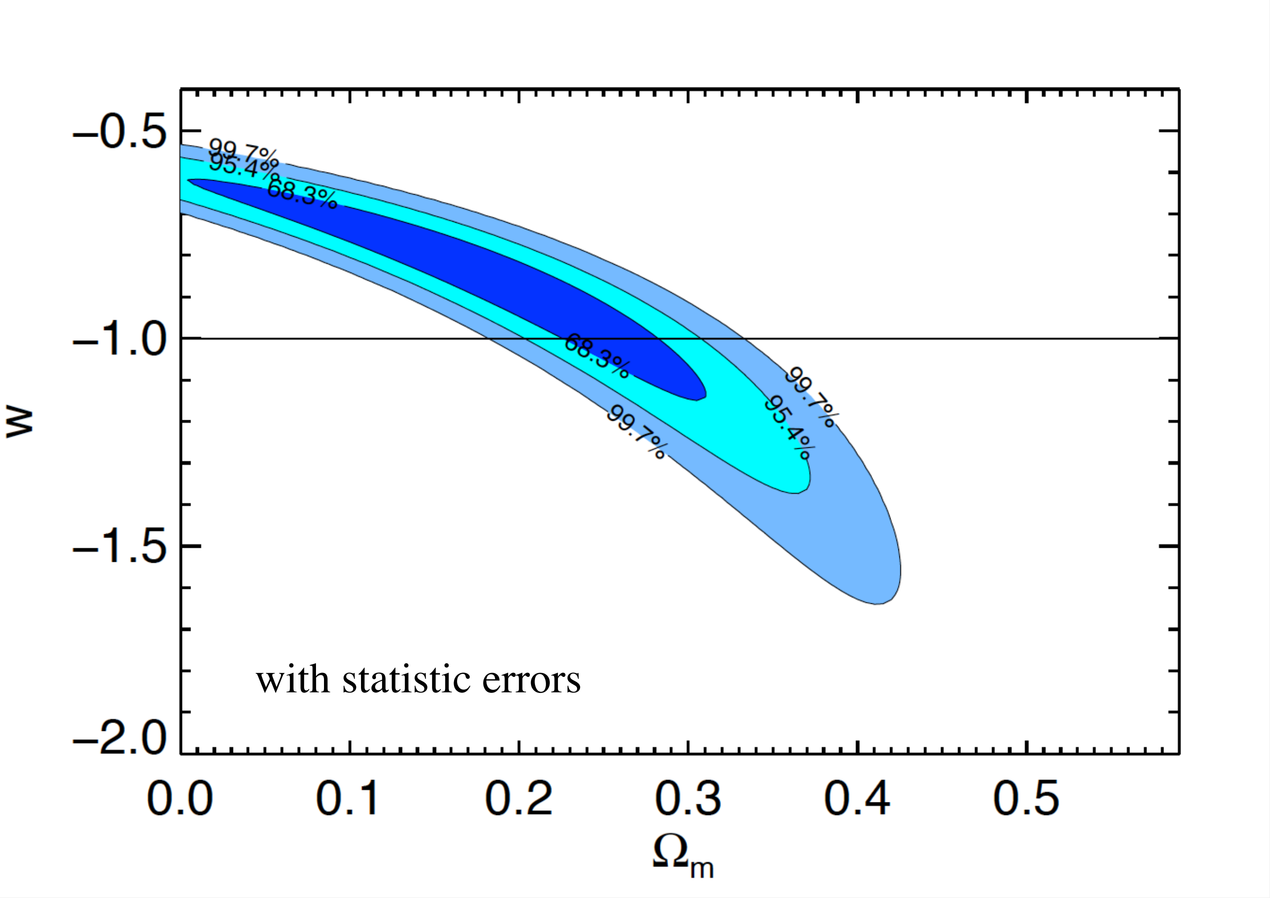
123 nearby (z ~ 0.05) & 93 SDSS-II (z~ 0.1-0.4)
& 242 SNLS (z ~ 0.2-1.) & 14 HST (z ~ 0.7-1.4) SNe Ia



Conley *et al.*, 2011

2. The Supernova Legacy Survey

SNLS-3 + flat universe (SN only):
statistical uncertainties

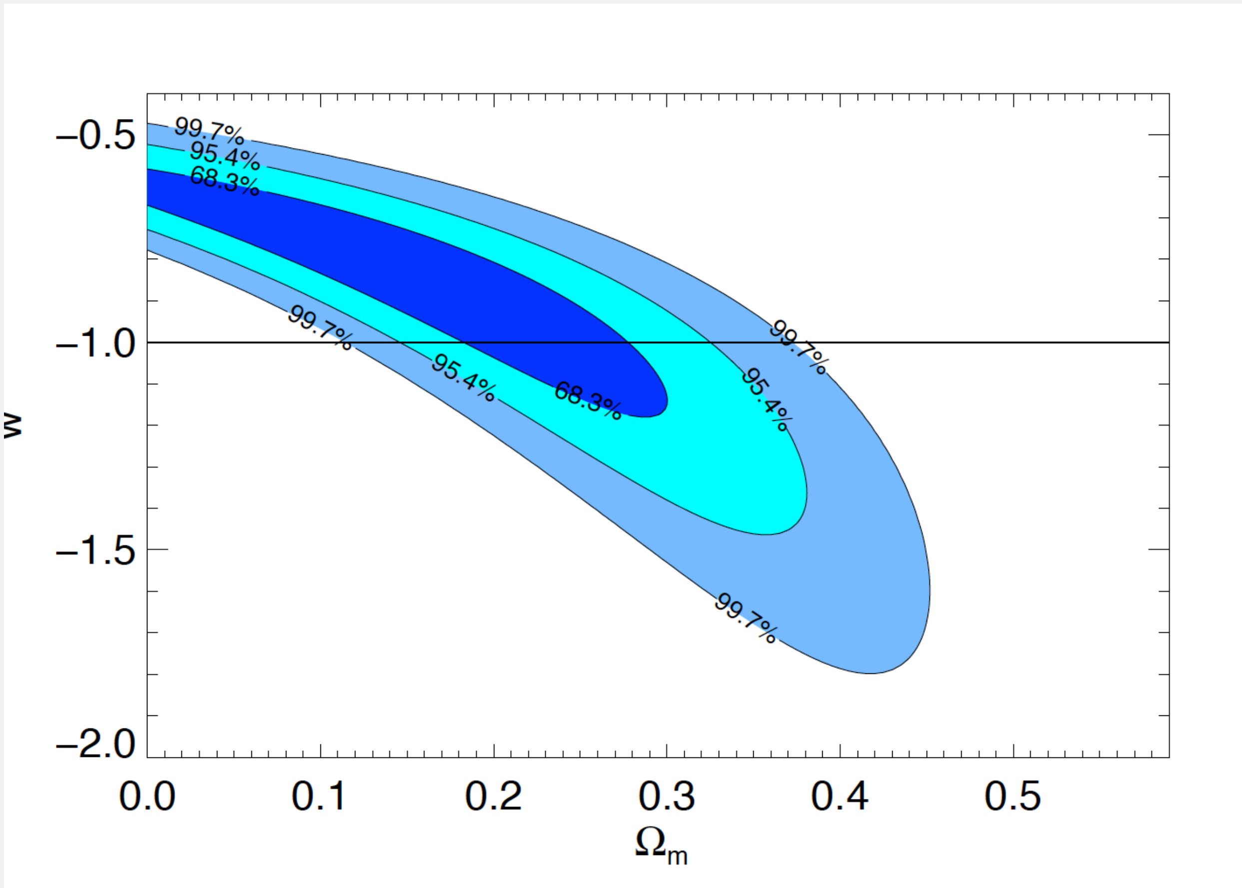


Conley *et al.*, 2011

2. The Supernova Legacy Survey

SNLS-3 + flat universe (SN only):

Taking thoroughly acount of **systematic** uncertainties

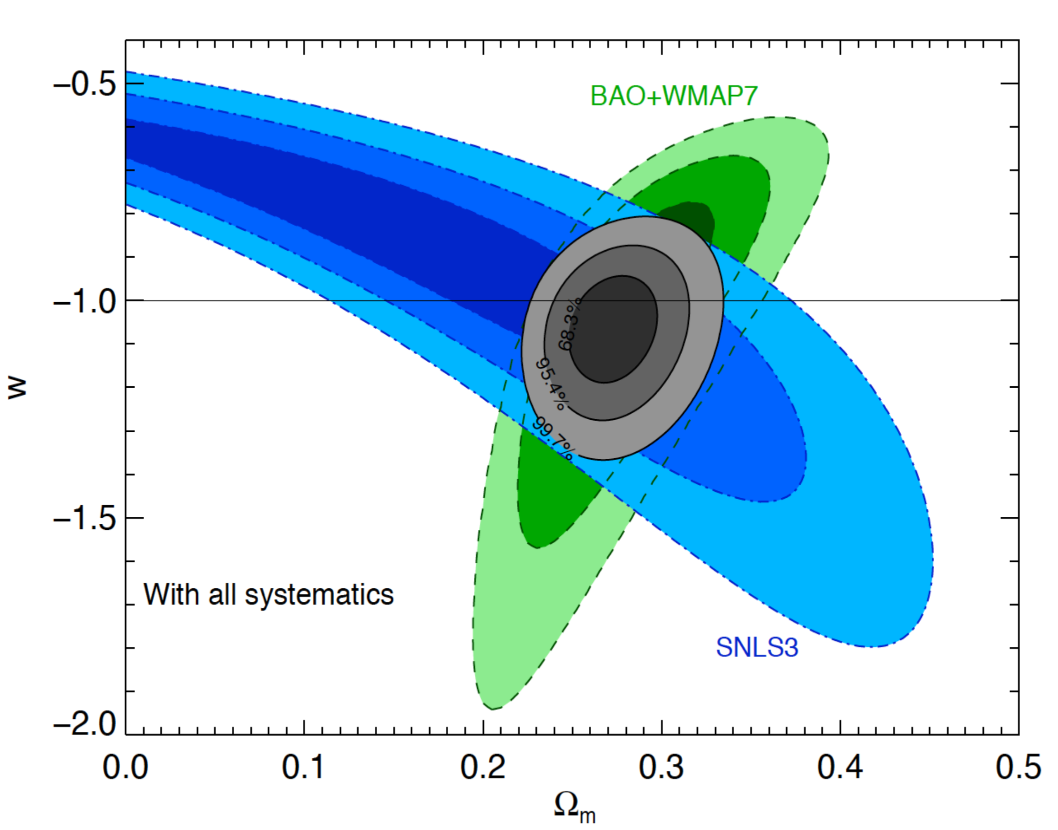


$$\Omega_M = 0.18 \pm 0.1, w = -0.91^{+0.17}_{-0.24} \text{ (syst. + stat.)}$$

2. The Supernova Legacy Survey

SNLS-3 + flat universe+ other probes : BAO + WMAP7

Sullivan *et al.*, 2011



$$\Omega_M = 0.274^{+0.019}_{-0.015}, w = -1.068^{+0.08}_{-0.082} \text{ (syst. + stat.)}$$

2. The Supernova Legacy Survey

Main contributions in the Supernova Legacy Survey :

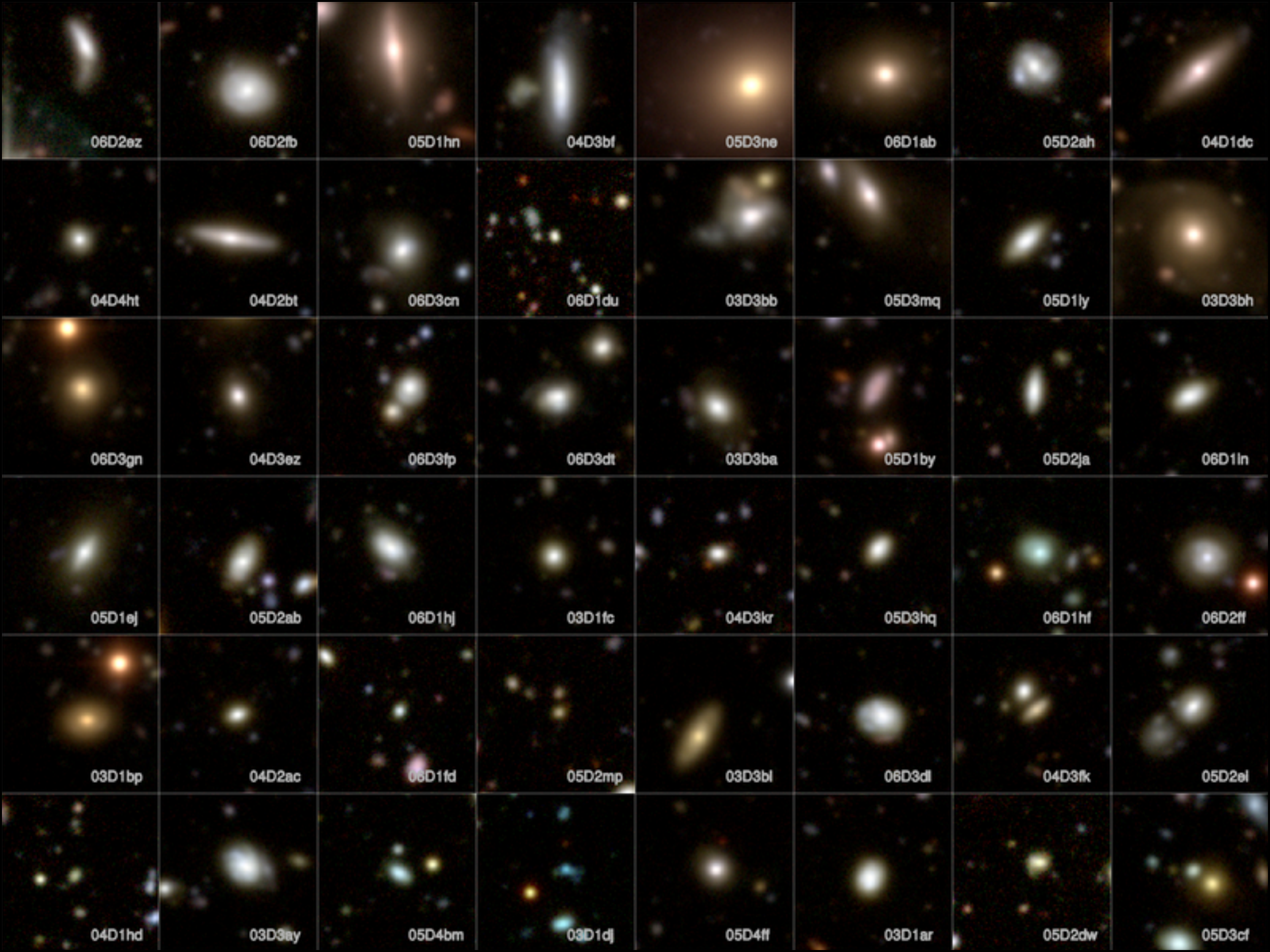
• the photometry of SNL5 supernovae

(developped in the frame of Nicolas Fourmanoit PhD)

• SNLS galaxies : SNLS SNe gravitational magnification

(Taia Kronborg PhD, supervisor: J. Guy)

host galaxies & SN as a distance indicator : a 3rd relation



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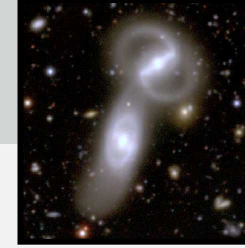
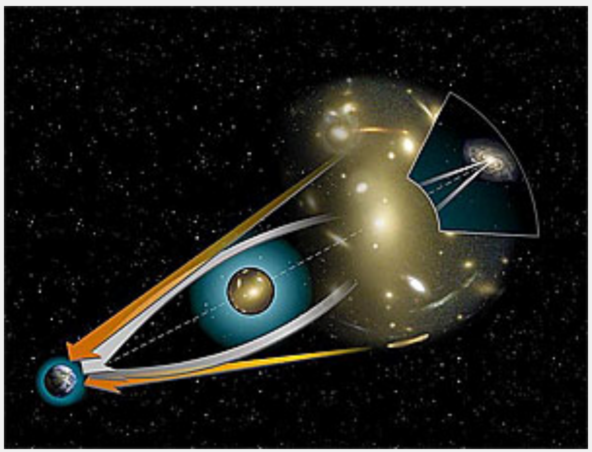
3. Supernova Legacy Survey Galaxies : *scientific context*

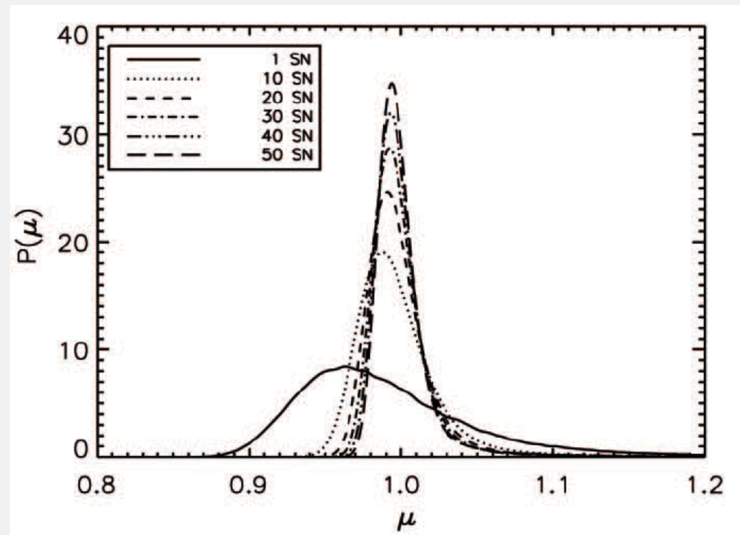


(1) SNe gravitational magnification:

→ inhomogeneities along the SNe line of sight :

SNe light magnification : **F(lensed) = $\mu \times$ F(true)**



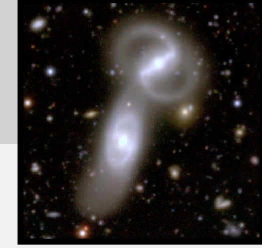


Holz & Linder 2005

- increase dispersion of Hubble Diagram (e.g. **Frieman1996, Holz & Linder 2005** …)

- taken into account in SNLS3 cosmology fit statistical error matrix :
  $\sigma_{lensing} \approx$ **0.055 × z**

3. Supernova Legacy Survey Galaxies : *scientific context*



(1) SNe gravitational lensing :

→ **magnification of distant SNe Ia : probe of foreground galaxies dark mattter halo**

• detection method : **Gunnarson2006, Jonsson2006**

Hubble residual: r = μ_L(SN) - μ_L(z; cosmologie) , μ_L(SN) estimated with SN mags.

expected magnification μ : using Q-LET code **Gunnarson2004**

3-D positions (α, δ, **photometric redshift**) of foreground galaxies

+ DM halo model (scaling laws: $M_{halo} \propto L_{gal}^{\alpha}$, α **spiral/elliptical**)

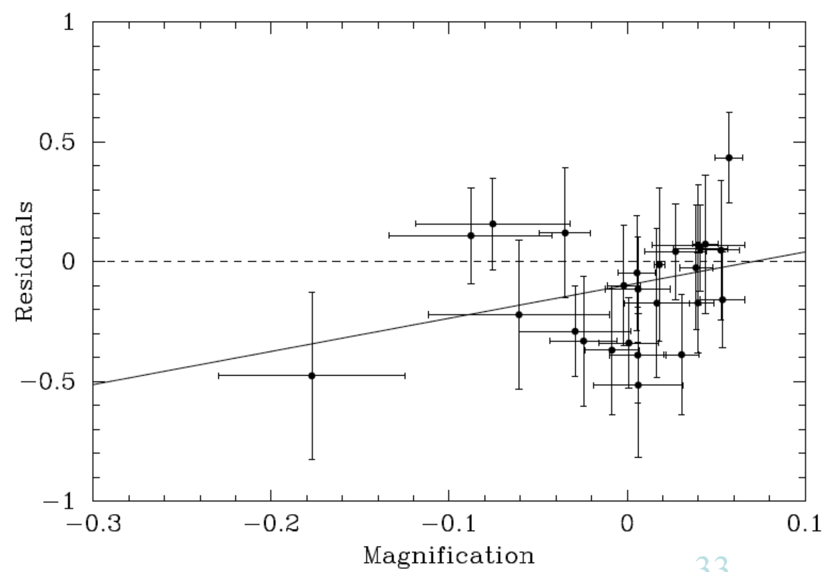
correlation between : μ_m= -2.5 $\log_{10}(\mu)$ **& r**

• weak signal

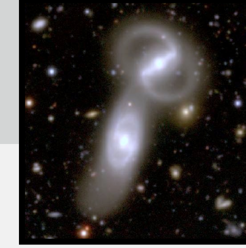
• tentative detection:

Jonsson2007 with 27 SNe from GOODs survey : evidence of a positive correlation at 91%

Jonsson et al. 2007



3. Supernova Legacy Survey Galaxies : *scientific context*



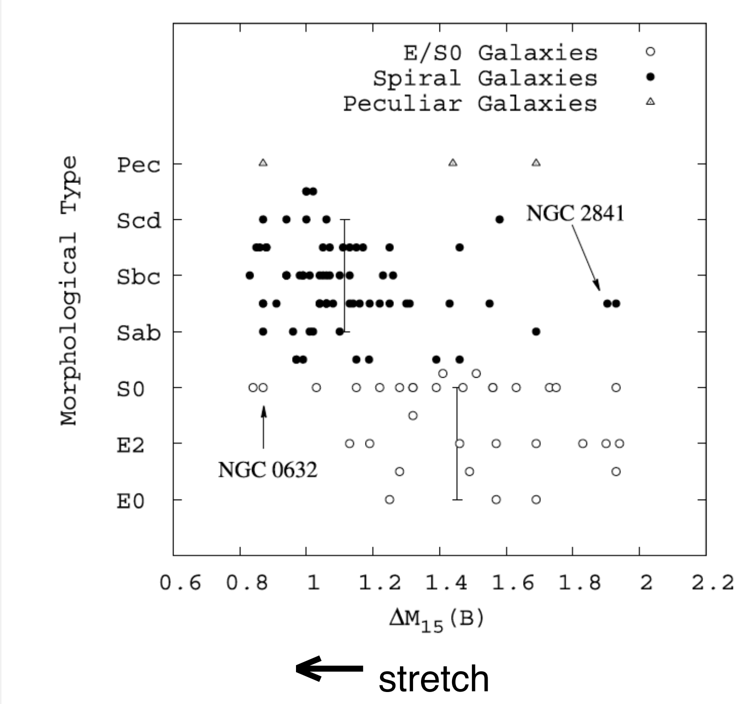
(2) Does the cosmology measurement depends on the SN environment ?

→ SN **stretch** : segregation according host galaxy caracteristics

SN **stretch** is on average smaller (SN fainter) in :

elliptical / passive (sSFR) / red / massive (stellar mass) / evolved (mean stellar age) / more metallic galaxies

Filipenko1989, Hamuy1996,2000, Gallagher2005,2008 etc.
Sullivan2006 : SNLS SNe

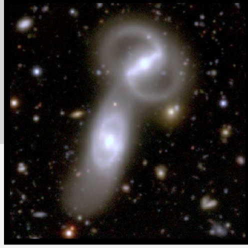


Gallagher *et al.* 2008

→ SN color : no clear dependance
Hicken2009, Smith2011, Sullivan2010, Galbany2012

3. Supernova Legacy Survey Galaxies : *scientific context*

4. galaxies : context scientifique



(2) Does the cosmology measurement depends on the SN environment ?

→ SNe Ia rate : dependance on galaxy specific Star Formation Rate

explosion rate = SN/yr/$M_{\odot}$ in **active** galaxies (sSFR) ~ 10 × **passive** galaxies
(Manucci2005, Sullivan2006)

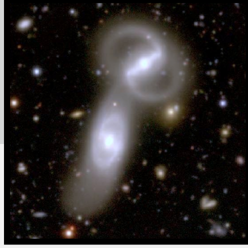
demographic shift : SN % in star-forming host galaxies (⇒ greater stretch, brighter) **increases with redshift z**

→ Fully corrected by the brighter-slower relation ?
demographic shift : potential bias (z) in Hubble diagram

→ **Does M_B, α, β depends on the environment ?**

3. Supernova Legacy Survey Galaxies : *a 3-D photometric catalog*

4. Cartographie des galaxies : simple

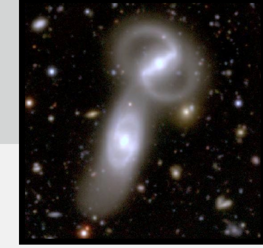


Photometric catalog construction : **Hardin *et al*., in prep.**
positions, size, magnitudes in ugriz filters, …

→ measuring **ugriz** galaxies magnitudes on deep stacked images
excluding images when SN is on

→ limiting mag at S/N=5: **i(Vega) ≈ 25.3**, **~200 000** galaxies/field
bias less than ~ 2%

3. Supernova Legacy Survey Galaxies : *a 3-D photometric catalog*



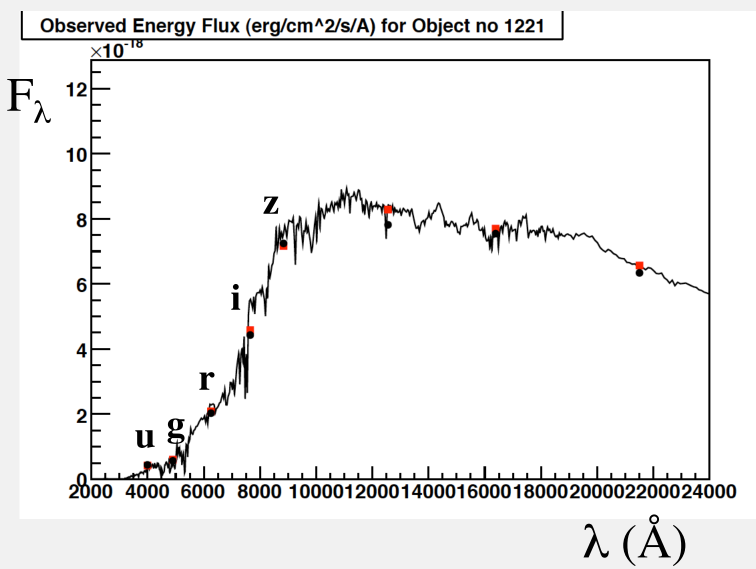
Galaxy Photometric Modeling : Kronborg *et al.*, 2010

→ **photometric redshift technique** (Baum1957) :

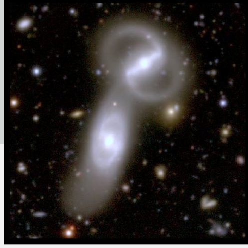
• spectral template library : $S(\lambda, M)$ for galaxy model M. *M discrete or continuous*
vary the model normalisation $\mathcal{A}$ and the redshift z

• ugriz mags fit with spectral template library :
photometric redshift z & absolute magnitude, intrinsic colors
• error propagation from obs. mags to computed caracteristics

• *SED* $S(\lambda, M)$ optimized using galaxies with spectro. redshifts :
so that < z spectro - z photometric > = 0 : un-bias photo-z's



3. Supernova Legacy Survey Galaxies :
a 3-D photometric catalog



Galaxy Photometric Modeling : Kronborg *et al.*, 2010

→ **which photo-z's ?**

- published photo-z's : **Ilbert2006, Coupon2009** on Deep (SNLS) fields

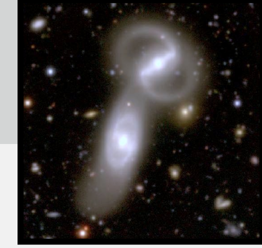
Ilbert2009 **COSMOS 30-bands data (overlap SNLS field D2)**

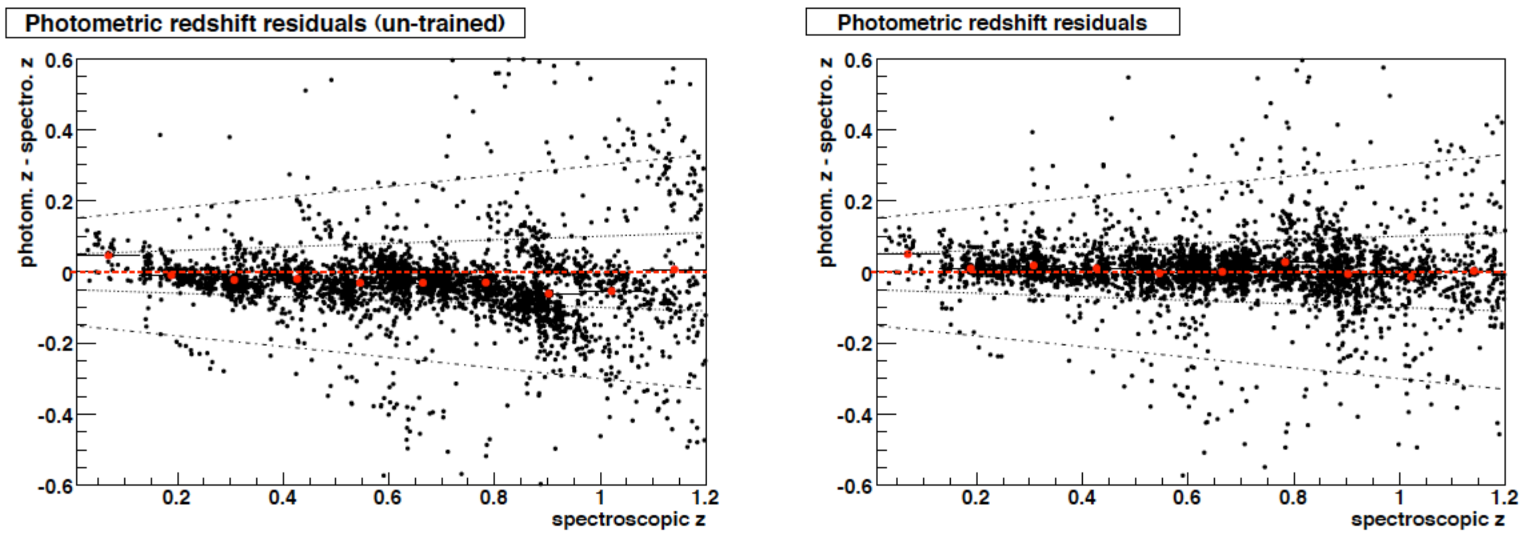
empirical template library « optimized »
error propagation from obs. mags. to absolute mags, colors and photo-z ?

- stellar population synthesis code : PEGASE.2 **Fioc1999** ; ZPEG, **LeBorgne2002**.
 --> star formation history, recent star formation, stellar mass
 ….. but not optimized

- **optimized own template library (Expo) :** <10 simple (PEGASE.2) templates trained on data : D3 field for ~ 6300 galaxies (0.1<z<1.5) from DEEP-2 survey **(Davis2003,2007)**.

3. Supernova Legacy Survey Galaxies :
a 3-D photometric catalog





→performance :

- estimated on ~3600 galaxies with spectro. redshifts on D1 field from VVDS Deep Survey **(LeFevre2004)**.
- **catastrophic errors** i.e. $|\Delta z| /(1+z) > 0.15$: **6.6%**
- **precision** i.e. $\sigma_z = \sigma(\Delta z /(1+z))$: $\sigma_z = 0.038$
- published photo-z on Deep fields **(Ilbert2006, Coupon2009)** : $\sigma_z = 0.03$, cat. error : 3.6%

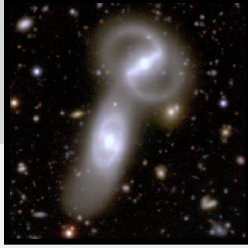
- used for **photometric-z, absolute magnitudes** and **rest-frame colors** estimation

  error propagation with Monte-Carlo
- but optimization correction :

  original PEGASE.2 templates used when the redshift is fixed : recent SFR rate, stellar mass etc.

3. Supernova Legacy Survey Galaxies :
a 3-D photometric catalog

4. Host galaxies ID



Host galaxies identification:

→ **distance criteria** & **identification of problematic situations :**

~85% of SNe with well identified host

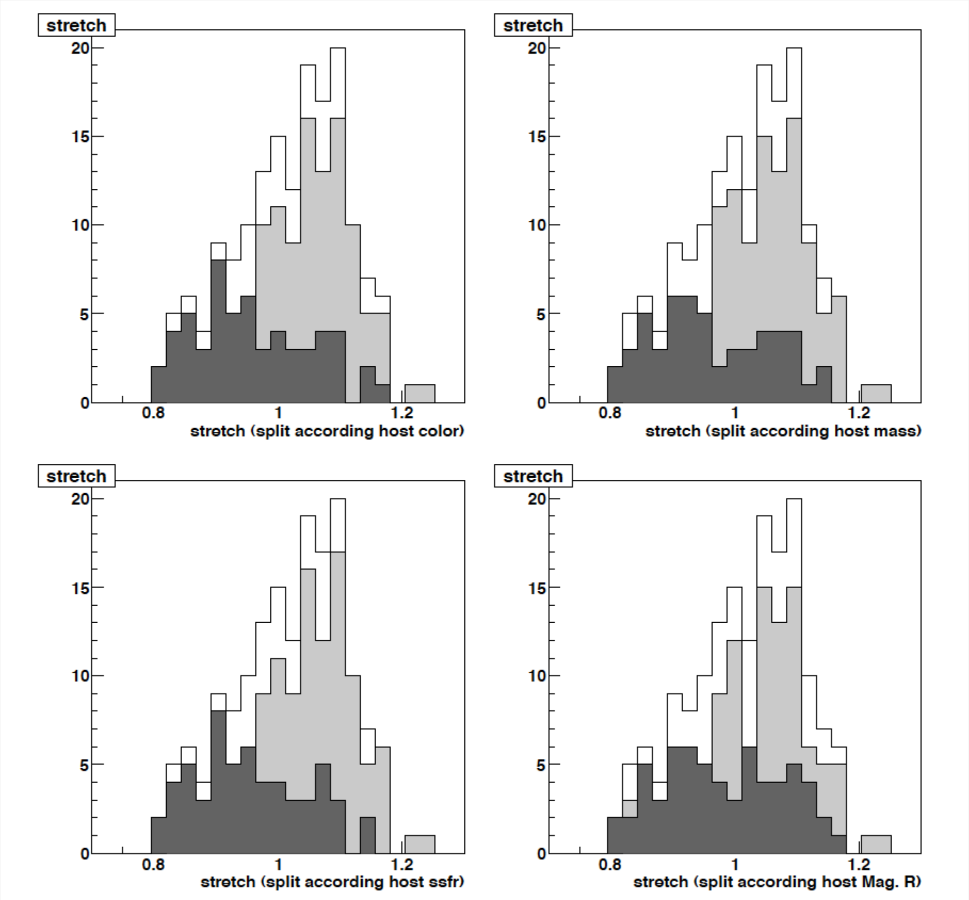
→ **SNe stretch vs host caracteristics :**

red/blue hosts (U-V)

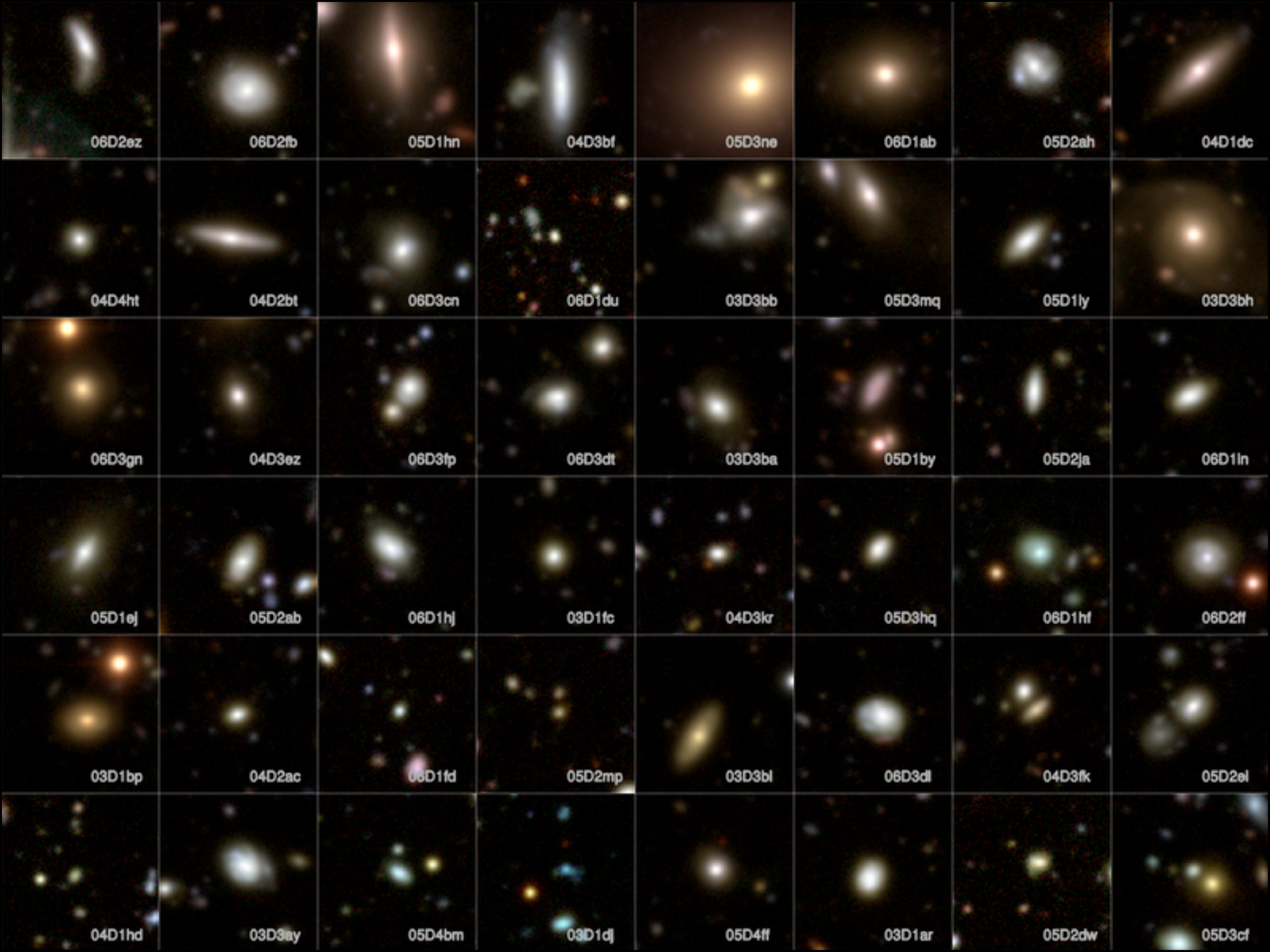
massive/or not hosts

passive/active hosts (sSFR)

bright/faint hosts (R abs. mag)



stretch segregation according to host caracteristics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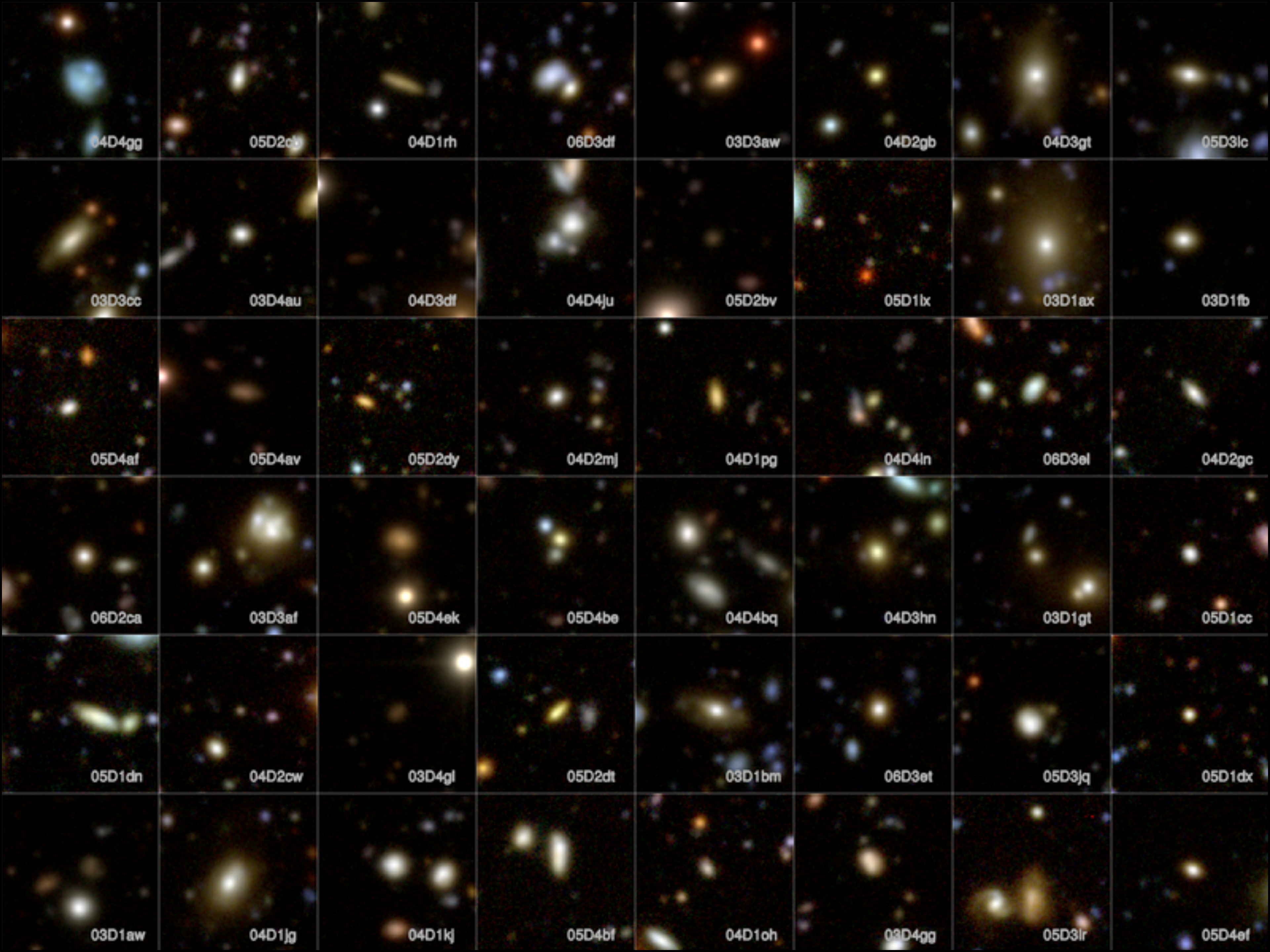

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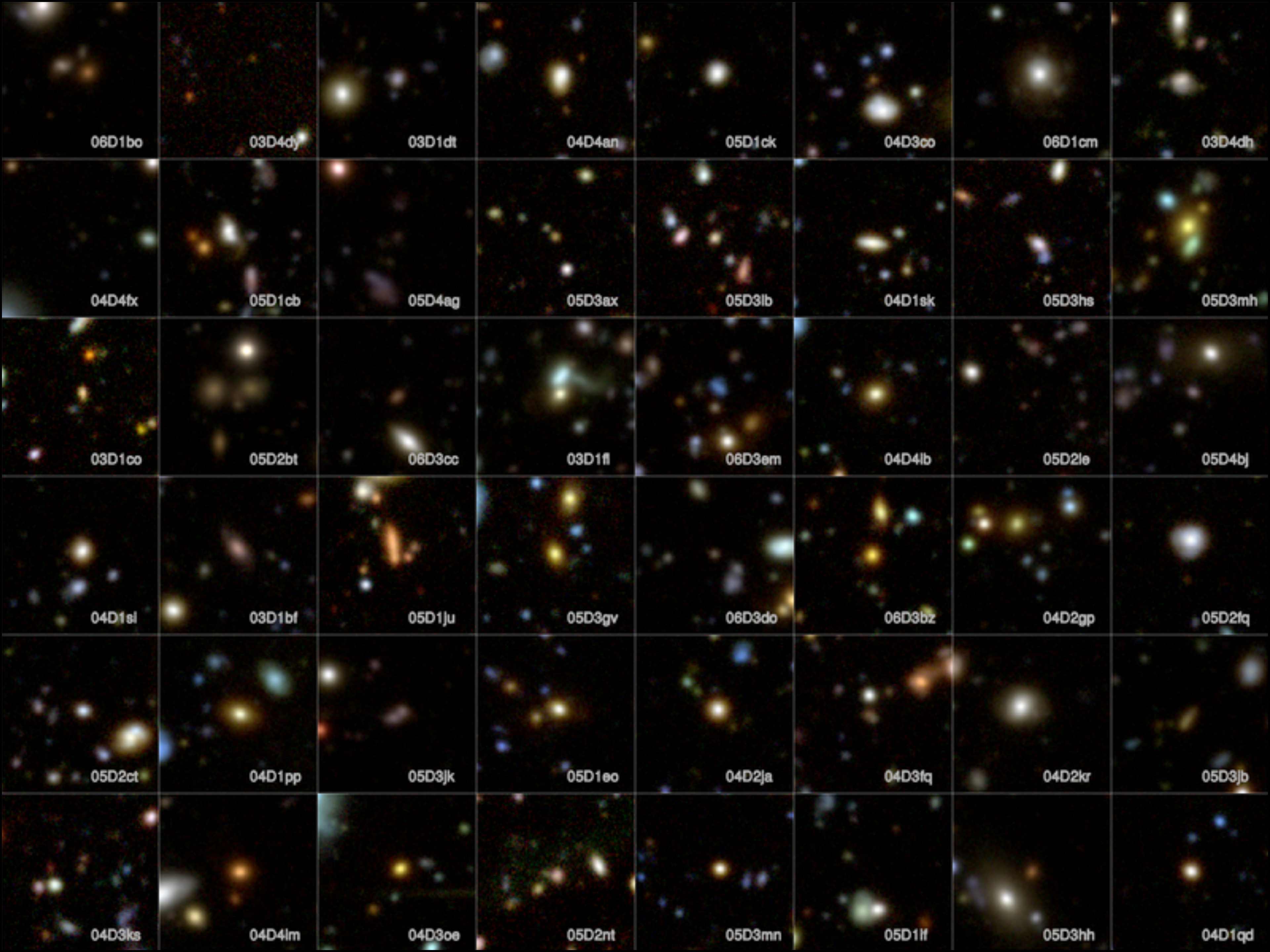
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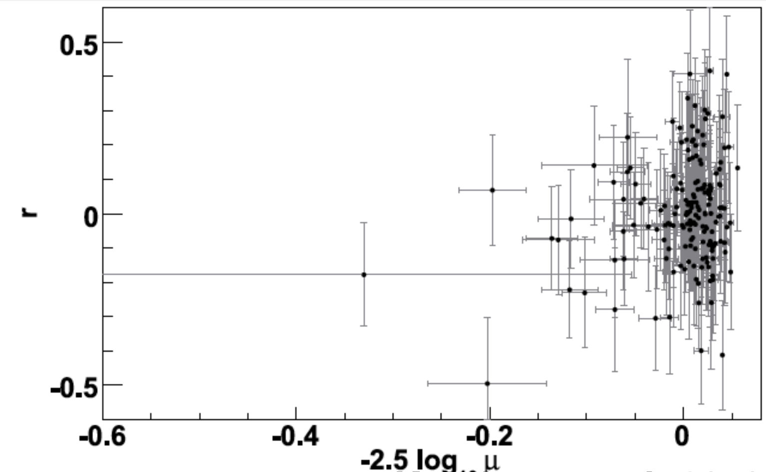
04D1qd

3. Supernova Legacy Survey Galaxies : *SNLS3 SNe gravitational magnification*

Kronborg *et al.*, 2010

→ **correlation between expected magnification** $\mu_m = -2.5 \log_{10}(\mu)$ **& Hubble residual r** for SNLS3 SNe Ia sample (171 SNe Ia)

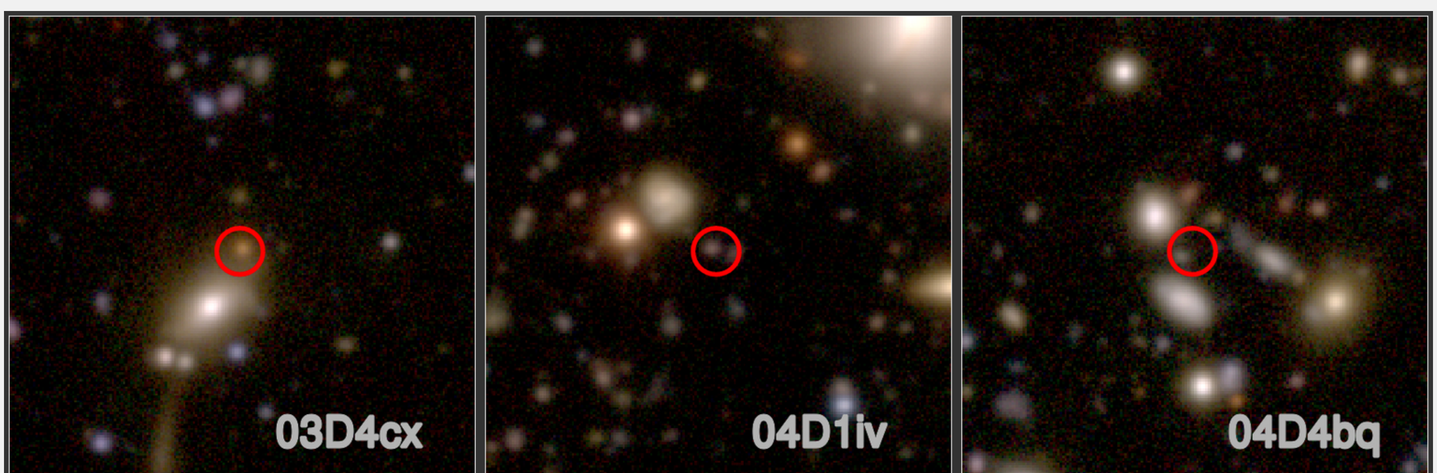


Kronborg *et al.*, 2010

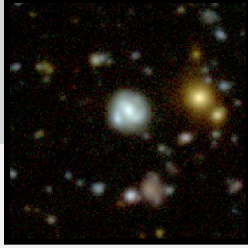
- correlation coefficient : 0.18

- significance estimated shuffling data : **detection at 2.3-σ level**

- galaxy classification elliptical/spiral with restframe U-V
  if random, the detection drops to 1.4-σ



3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



→ **differing M_B values according to host stellar mass :** **Sullivan *et al.*, 2010**

• the **average** SNe Ia is fainter in massive galaxies : taken into account by the brighter-slower relation

• **the "standard"(*) SNe Ia is brighter (~ 4-σ) in massive galaxies**

(*i.e. *stretch*=1 *color*=0)

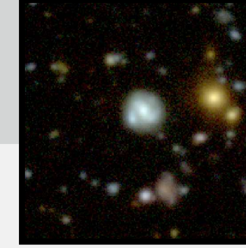
• **subtle effect – 0.08mag** : smaller than stretch and color corrections

$$\mu_B = m_B - M_B^1 + \alpha\,(stretch-1) - \beta\,color \quad \text{when } M_{host} < M_{split}$$

$$\mu_B = m_B - M_B^2 + \alpha\,(stretch-1) - \beta\,color \quad \text{when } M_{host} > M_{split}$$

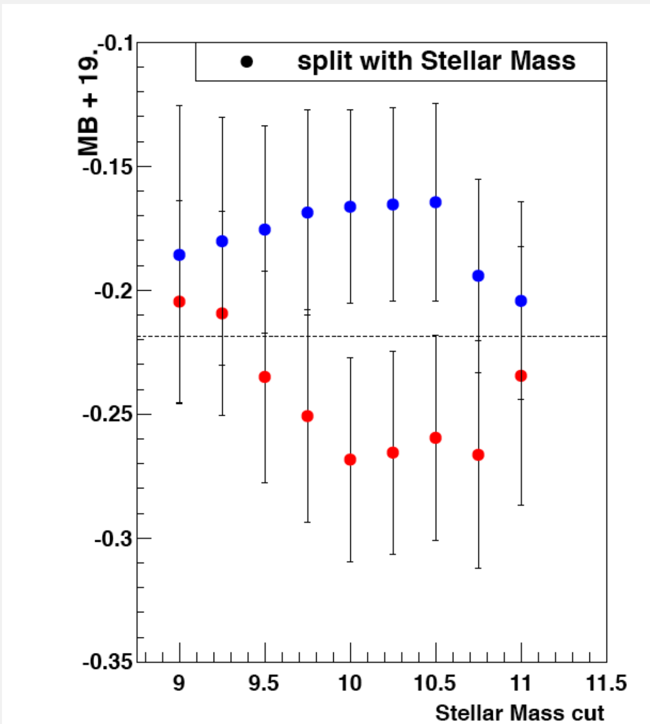
• Hubble diagram fit with 2 different M_B's value, one for the low and one for the high mass pop. + a common cosmology Ω_Λ

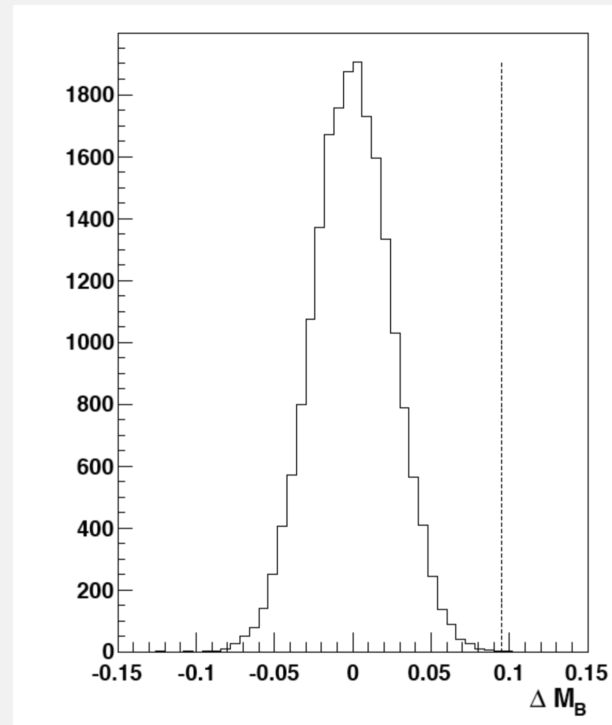
3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



$\mu_B = m_B - M_B^1 + \alpha\,(stretch\text{-}1) - \beta\; color$ when $M_{host} < M_{split}$

$\mu_B = m_B - M_B^2 + \alpha\,(stretch\text{-}1) - \beta\; color$ when $M_{host} > M_{split}$

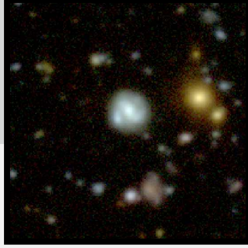




SN population split with a varying threshold in host stellar mass
for this study : SNLS SNe at z<0.85

Statistical significance
threshold : stellar mass = $10^{10.5}$ M⊙,
$\Delta M_B \neq 0$ at 3.7-σ

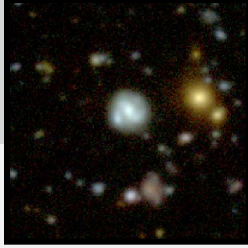
3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



- also at a lesser significance with : **sSFR, U-V color, abs. R Mag**
- also detected in nearby and intermediate-z samples :
e.g. SDSS **Lampeitl2010, Kelly2010, Gupta2011** (206 SNe, 3-σ)
- no significative difference in α, significative difference in β depending on sample

→ besides SN stretch & color, **host stellar mass as a 3rd parameter ?**

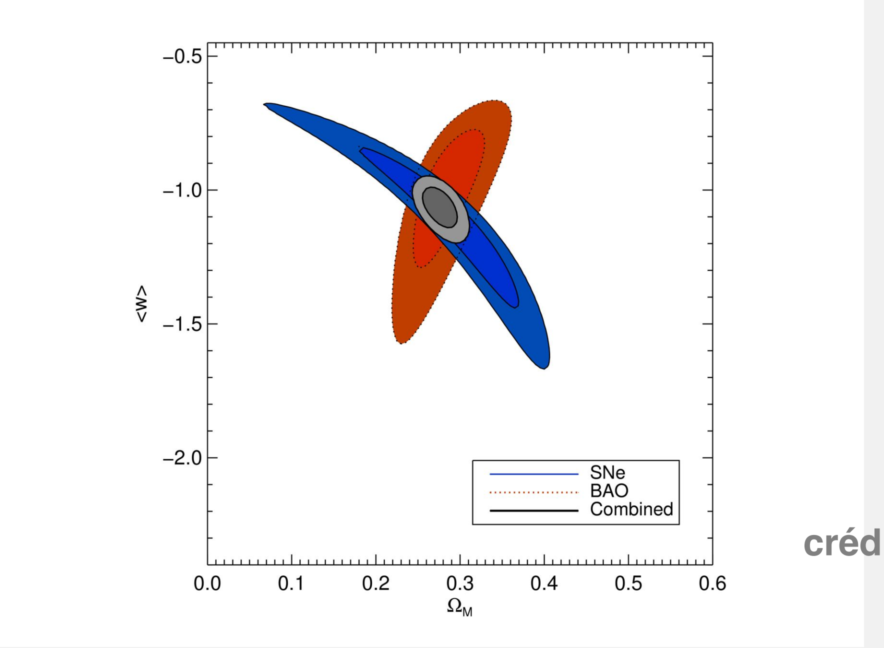
3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



→ besides SN stretch & color, **host stellar mass as a 3rd parameter ?** **Sullivan *et al.*, 2011**

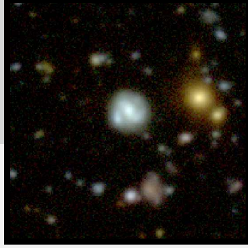
use two M_B – one for high-mass galaxies and one for low-mass host galaxies
$M_{split} = 10^{10}\ M_\odot$

$\mu_B = m_B - M_B^1 + \alpha\ (stretch-1) - \beta\ color$	when $M_{host} < M_{split}$
$\mu_B = m_B - M_B^2 + \alpha\ (stretch-1) - \beta\ color$	when $M_{host} > M_{split}$



crédits: M. Sullivan

3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



→ besides SN stretch & color, **host stellar mass as a 3rd parameter ?** **Sullivan *et al.*, 2011**

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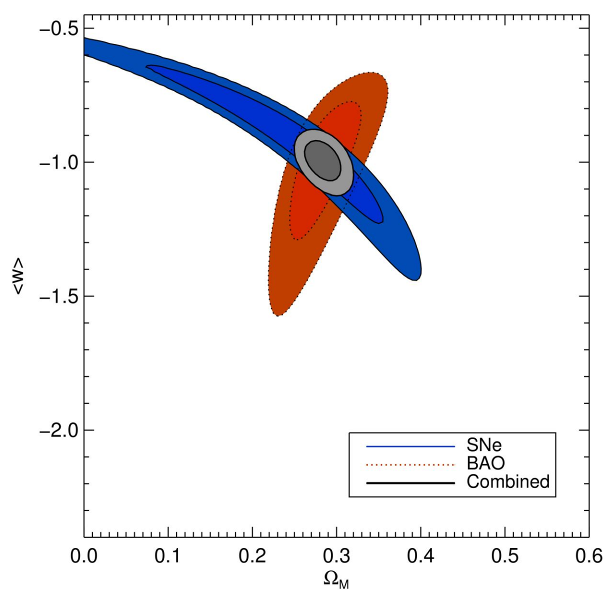
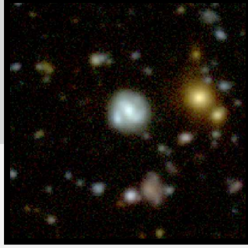


χ^2 reduced at 5-σ

$\delta w \sim \sigma(w)$

crédits: M. Sullivan

3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*



→ besides SN stretch & color, **host stellar mass as a 3rd parameter ?** **Sullivan *et al.*, 2011**

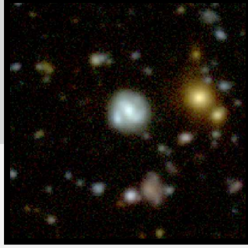
use two M_B – one for high-mass galaxies and one for low-mass host galaxies
$M_{split} = 10^{10}\ M_\odot$

$$\mu_B = m_B - M_B^1 + \alpha\ (stretch-1) - \beta\ color \quad \text{when } M_{host} < M_{split}$$

$$\mu_B = m_B - M_B^2 + \alpha\ (stretch-1) - \beta\ color \quad \text{when } M_{host} > M_{split}$$

And two β's ?
χ^2 reduced, but $\delta w \sim 0$ and $\delta\Omega \sim 0$
→ only 1 β, but δw taken into account in systematics

3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*

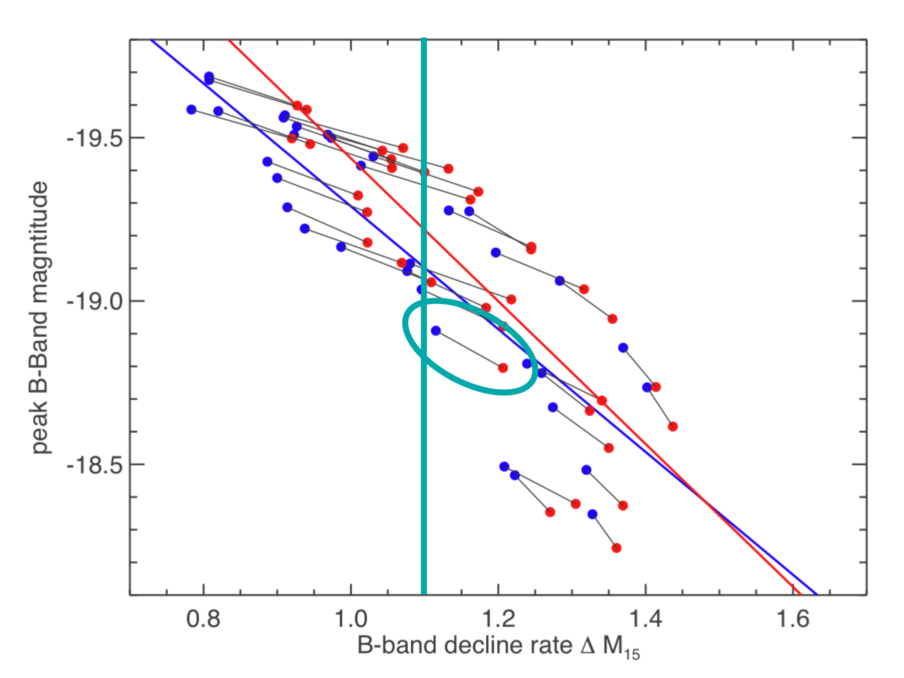


interpretation as metallicity ?

→ Tremonti *et al.* 2004 : stellar mass - metallicity relation
+ Gallagher *et al.*, 2008 ; Konishi *et al.* 2011, D' Andrea *et al.* 2011 (SDSS) : standard SN brighter in (spectroscopic) high-metallicity hosts

→ Timmes *et al.* 2003 : higher metallicity white dwarf → neutron-rich SN Ia
→ explosion produces more stable ^{58}Ni and less ^{56}Ni
→ fainter SN

→ Kasen *et al.* 2009 : ^{56}Ni mass and metal abundances as an input of radiative transfer code

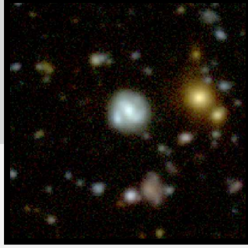


→ for higher metallicity ie higher ^{56}Ni mass, SN is fainter but also faster (brighter-slower relation)
→ but slope & normalisation differ :

higher metallicity *standard SN* is brighter !

3. Supernova Legacy Survey Galaxies : *host galaxies and cosmology*

4. hote et cosmo: results



→**host stellar mass as a 3rd parameter**

→**host galaxies studies mandatory for SNe Ia surveys**

4. Perspectives

SNLS galaxies catalog :

• publication of photometry in preparation

• better modelisation: including dust (improve galaxy classifcation), JHK photometry from WIRcam Deep Survey

SNLS SNe Ia magnification : *PhD thesis starting this winter*

• expected detection level with **SNLS-5 yrs** : 400 SNe Ia + 200 photometric SNe Ia : **detection at a 3-σ level at 80%**

• constraints on σ_v **(halo)** ?
comparaison with galaxy-galaxy lensing measurements from CFHTLens : M_{200} measurement for blue and red galaxies on Wide fields
M. Velander in prep.

4. Perspectives

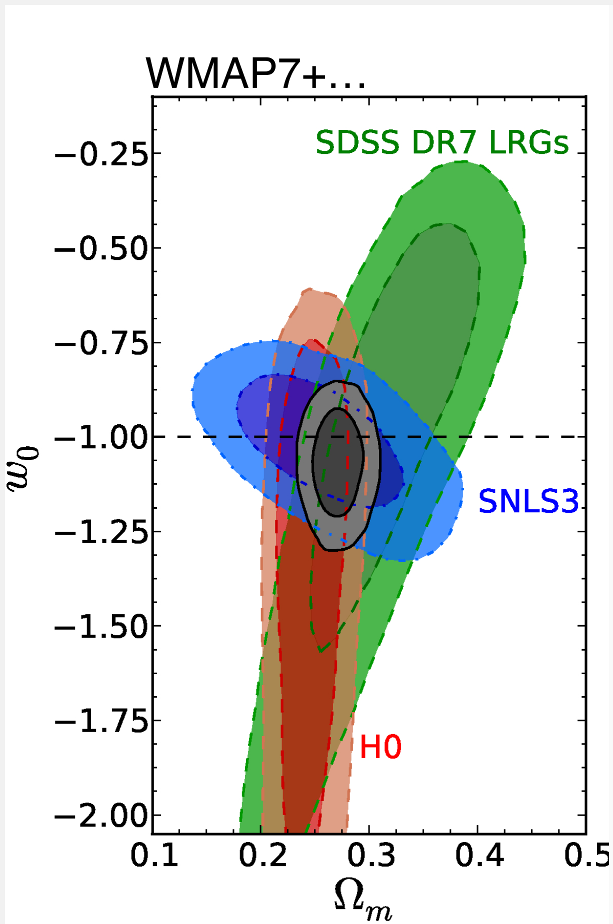
Photometric SNLS SNe Ia Hubble diagram :

- photometric SNe Ia SNLS-3 yrs : **Bazin2011,** SNLS-5 yrs underway
- spectroscopic redshift program with AAOmega at the 4-m Anglo-Australian-Telescope : **Lidman2012**
  already 80 SNe Ia redshifts
- host masses: **Hardin *et al.* in prep**

prefigures future SN surveys such as Dark Energy Survey (2012), Large Synoptic Survey Telescope (2020)

4. Perspectives

SNLS+WMAP7+BAO/DR7+H_0



Flat
w = -1.061 ± 0.069
Ωm = 0.269 ± 0.015

non Flat
w = -1.069 ± 0.091
Ωm = 0.271 ± 0.015
Ωk = -0.002 ± 0.006

minus SNe
w = -1.412 ± 0.333
Ωm = 0.259 ± 0.030
Ωk = -0.009 ± 0.008

minus BAO
w = -1.018 ± 0.111
Ωm = 0.259 ± 0.049
Ωk = 0.001 ± 0.015

DES: Dark Energy Survey

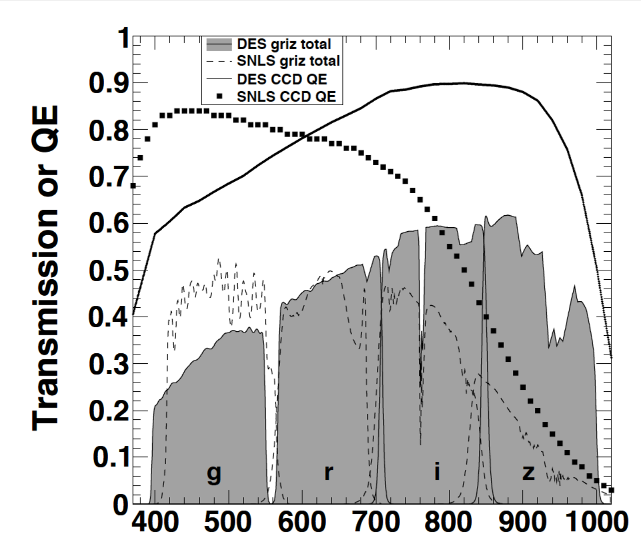
complementarity of SNe Ia as a probe for DE with lensing:

15 sq. deg.
~ 4000 SNe Ia z~ 0.05 to z~1.2
20% spectroscopic id.
photometric Ia + host spectro
Bernstein *et al.* 2012

Instrument :
- Bianco 4-m @ Chile
- camera 5.2 10^8 pixels (62 CCDs)
- 2.2 deg^2

Survey:
- 5 years
- 5 000 deg^2, 8 bands survey grizY + JHK from VHS
- > 10^8 galaxies with photo-z

Schedule: now !



LSST : Large Synoptic Survey Telescope

<u>a wide and deep field survey</u>

nature of dark energy
- falsifiate w=-1 ?

- a time variating w ?
  $w(a) = w_0 + w_a (1-a/a_0)$

Figure of Merit : $[\text{Det Cov}(w_0,w_a)]^{-1/2}$

complementarity of SNe Ia probe for DE with lensing/BAO:

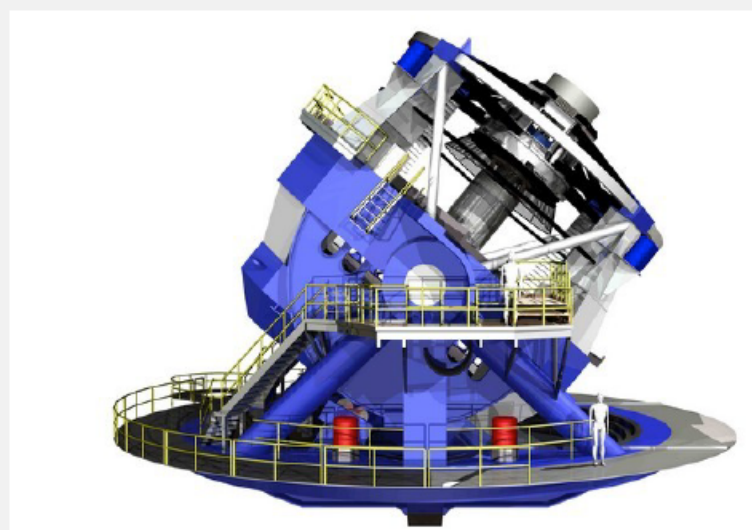
e.g. : 2 complementary programs at z~ 0.2 and z <1
O(10 000) SNe Ia, photometry only

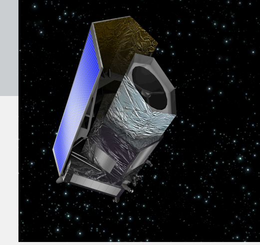
joint survey with **Euclid spatial mission ?**

<u>Instrument :</u>
- primary mirror 8.4-m @ Chile
- camera 3.2 10^9 pixels (189 CCDs)
- 9.6 deg^2

<u>Survey:</u>
- 10 years, 5 10^6 images
- 20 000 deg^2, 6 filters UV - NIR
- > 3 10^9 galaxies with photo-z

<u>Schedule:</u> first priority by NAS in 2010, funding NSF/DOE in 2014, first light 2020

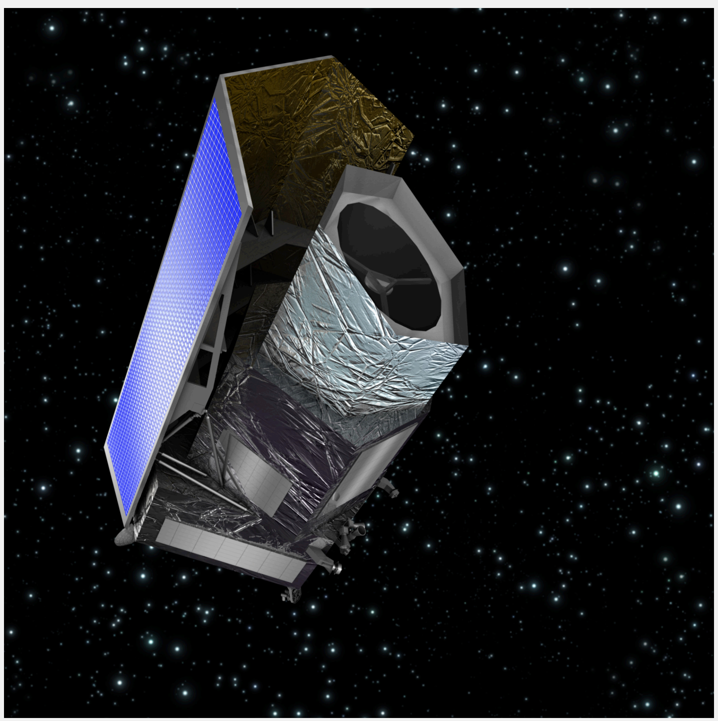




Euclid : Spatial Mission

SNe Ia as complementary probe for DE with lensing/BAO

joint program with **LSST**
SNe Ia at z ~ 0.75 to z ~ 1.5 **?**



Instrument :
- 1.2-m
- 0.5 deg^2
- dichroic visble/NIR YJH
- slitless spectrograph
- 6 years

Schedule:
ESA Cosmic Vision 2020-2025, launched in 2020

- SNe Ia efficient probe for w measurement :
  key for future Dark Energy Programs

- SNLS SNe Ia distance estimator improved
and systematics thorougly studied

- **SNLS indeed a Legacy Survey**