June, 24h, 2014

Ayan Mitra

Supernovae Ia, Gravitational Lensing with Supernovae Legacy Survey (SNLS)

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Outline

- Introduction : Gravitational Lensing and Supernova Ia
- Data and techniques
- Results of SNLS 3 data
- Present and Future works

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,</u>
<u>we measure</u> :

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

- **luminosity distance :** $D_L = (L / 4\pi F)^{1/2}$
  measuring the flux F, provided 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 :

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

$$H(t)^2 = \frac{8\pi G}{3c^2}\varepsilon(t) - \frac{\kappa c^2}{R_0^2 a(t)^2}\,.$$

Friedmann Equation

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

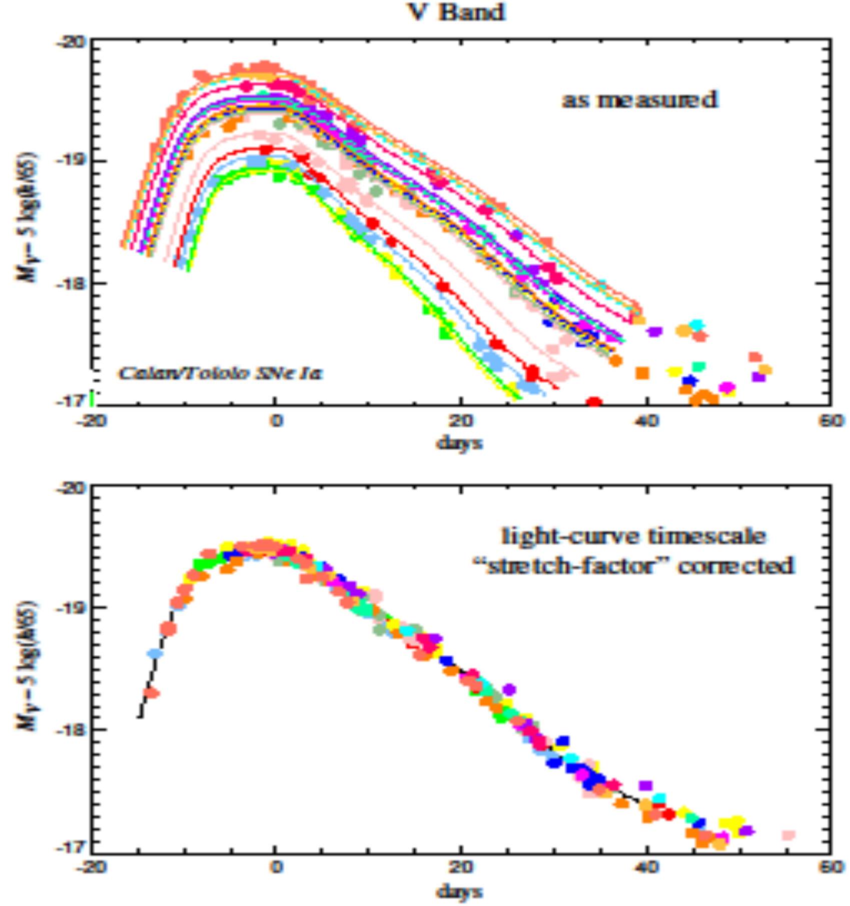
+ Dark Energy ?

Defining *w = p/rho*

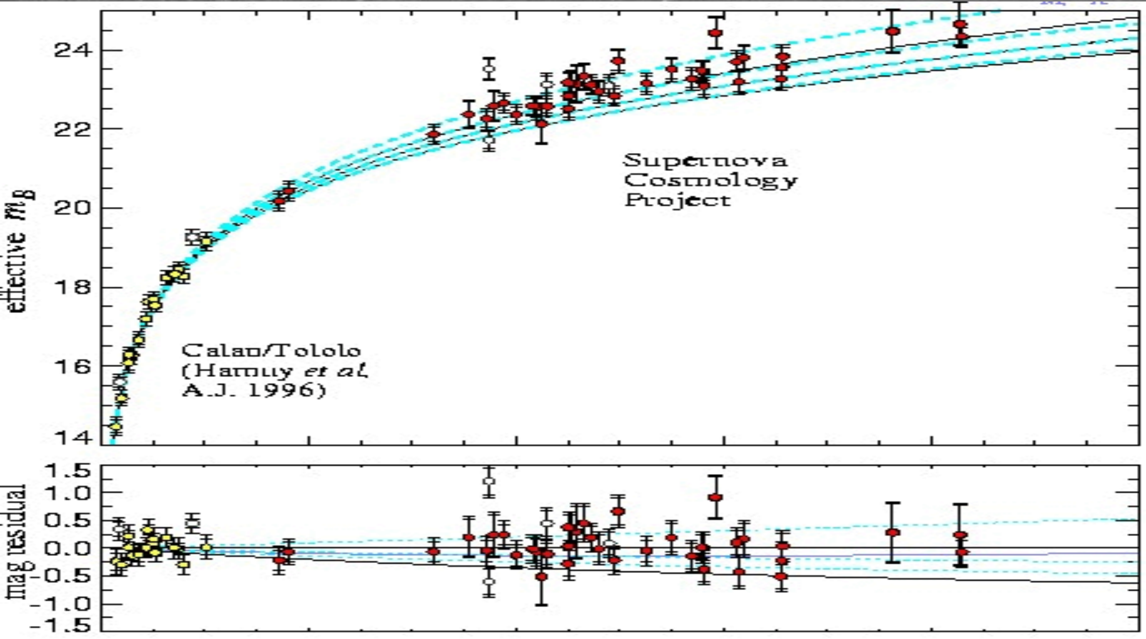
w = Equation of state parameter.

- Sn Ia are believed to be result of an explosion of a white dwarf accreting matter and reaching Chandrasekhar mass.
- Supernovae type I lack H emission or absorption lines. Type Ia shows a clear Si absorption line at 6700 angströms.

- $\mathbf{D_L} = (\mathbf{L} / 4\pi\ \mathbf{F})^{1/2}$;
- if L≈ cste, then we can measure **relative** distances without knowing L.

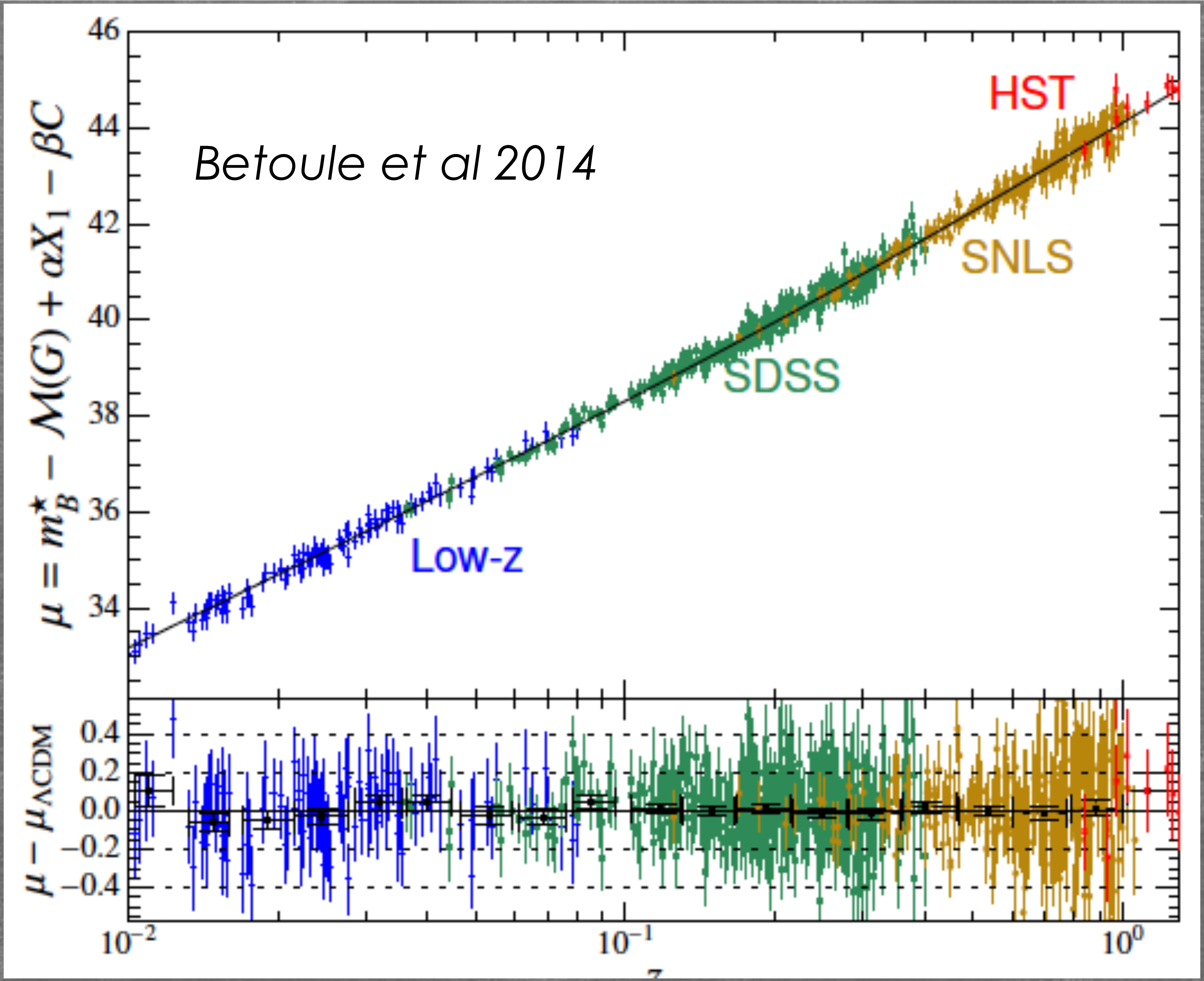


By fitting for one parameter, the "stretch" (Perlmutter 1997; Perlmutter et al. 1997; Goldhaber et al. 2001), the observed variation in Type Ia SNe can be reduced to $\sigma_M = 0.15$.



Sne Ia exhibit remarkable homogeneous light curves when corrected for the stretch factor parameter. Enabling them to be used as standard candles.

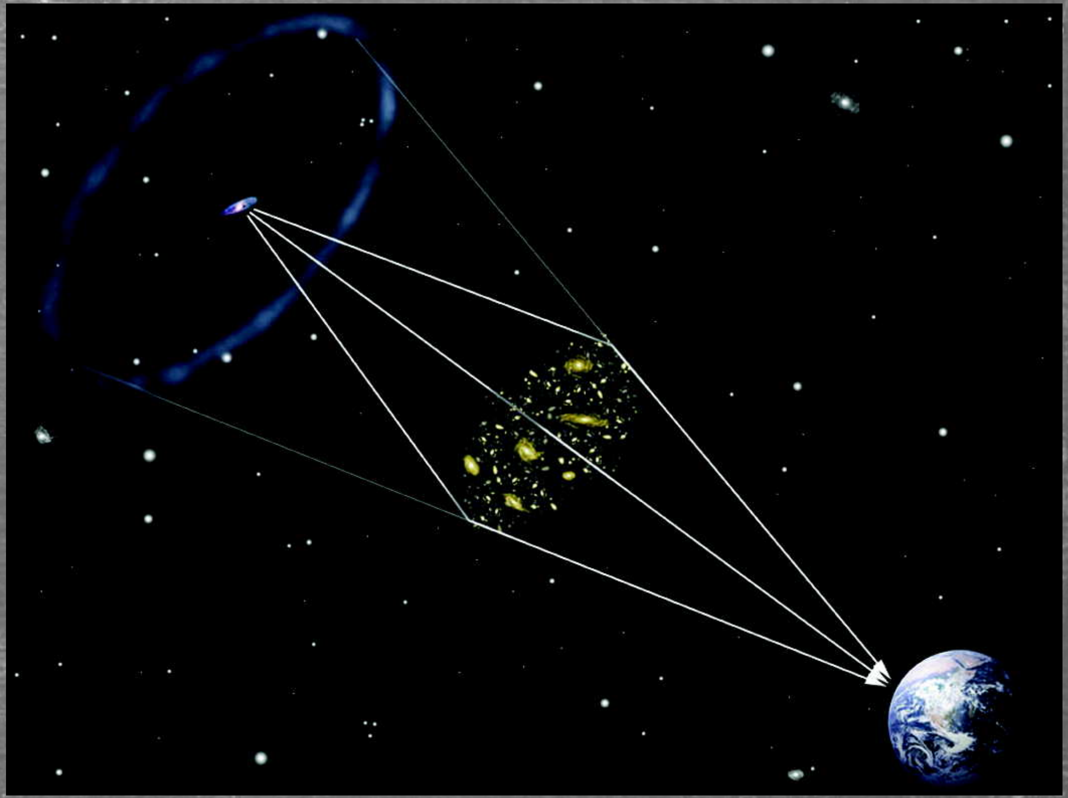
L≈ cste, at 16%.



http://arxiv.org/pdf/1401.4064.pdf

Gravitational Lensing

- It is the bending of light rays in the presence of massive object .
- The angle of deflection caused by an object of mass *M* for rays of light passing at a distance of *r* is : $\alpha = \frac{4GM}{rc^2}$



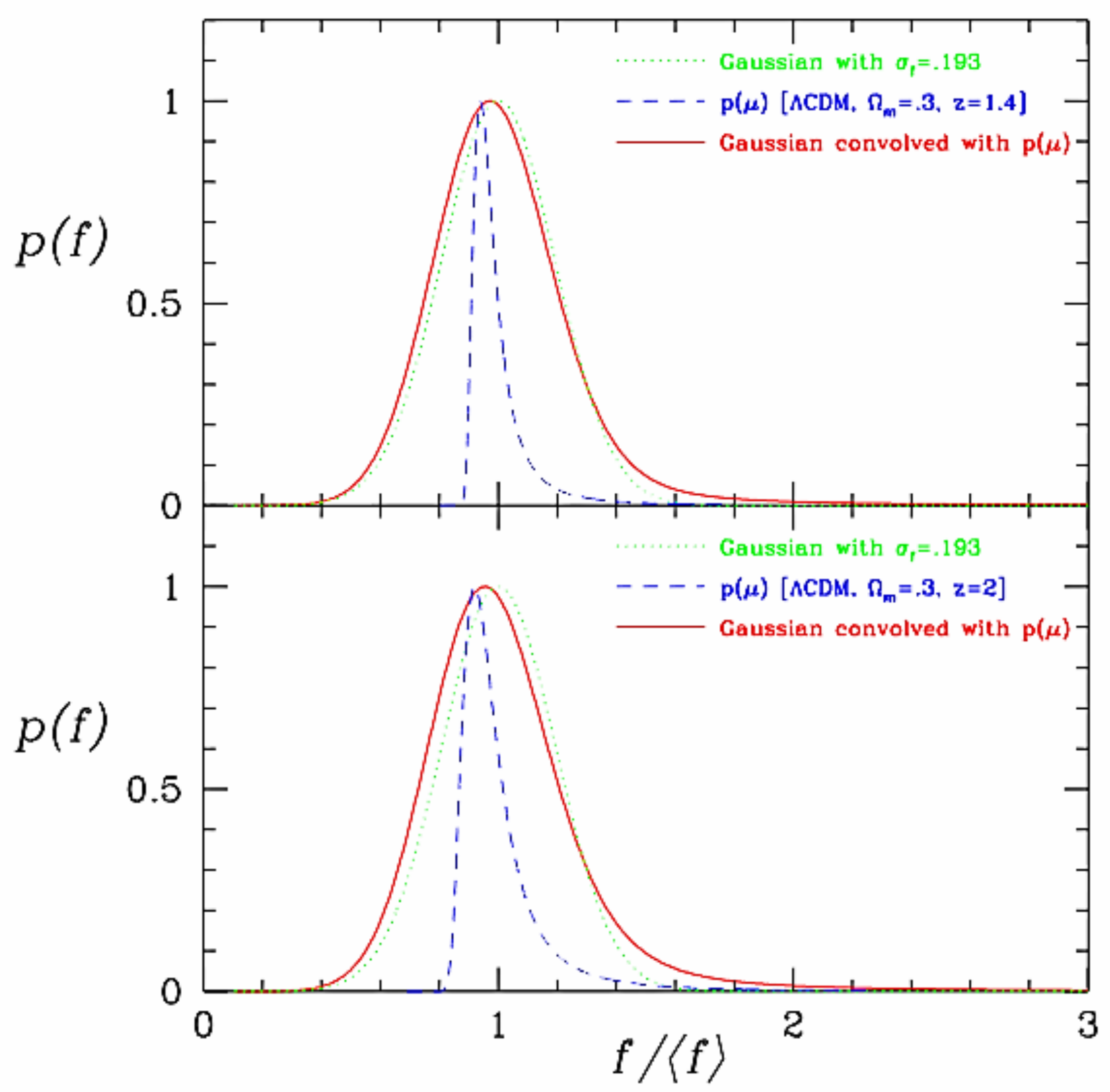
- weak lensing requires studying a lot of sources statistically to infer information about the foreground mass.

SNe Ia as Lensing Tool

Lensing affects the SNe brightness distribution.

- Longer non-Gaussian tail at the bright end
- Shift of the peak towards faint end

But we will be studying the magnification of the SNe by underlying dark matter haloes of the foreground galaxies along the line of sight of the Sne.



(Y.Wang 2005)

SNLS -The SuperNova Legacy Survey

http://www.cfht.hawaii.edu/SNLS

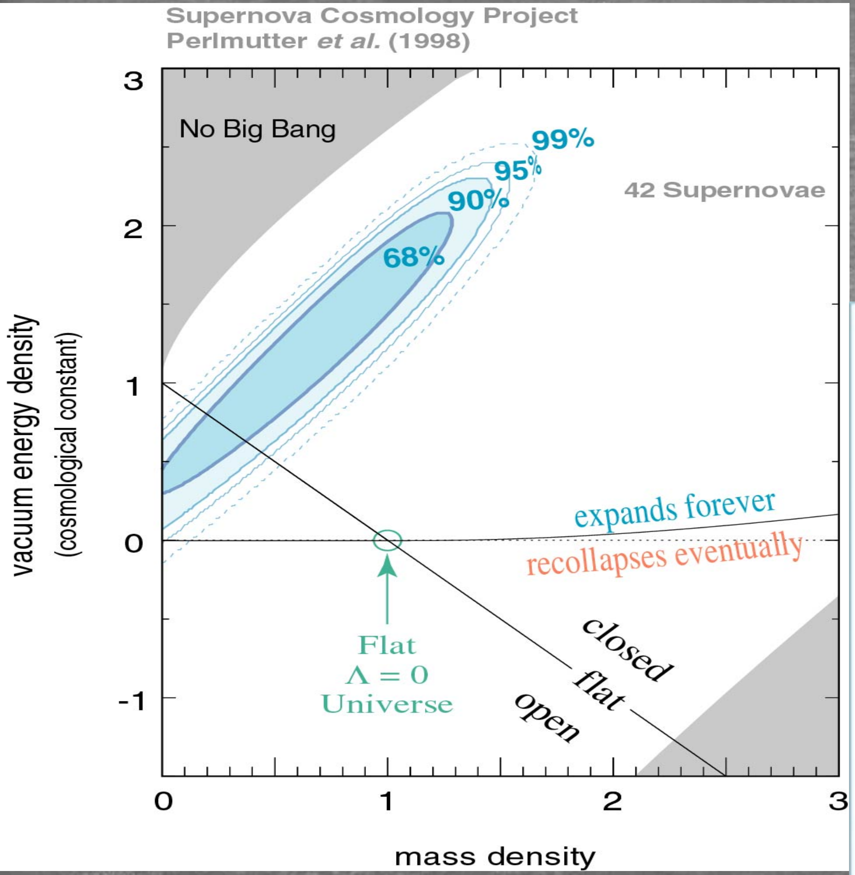
Victoria
Sébastien Fabbro, Chris Pritchet

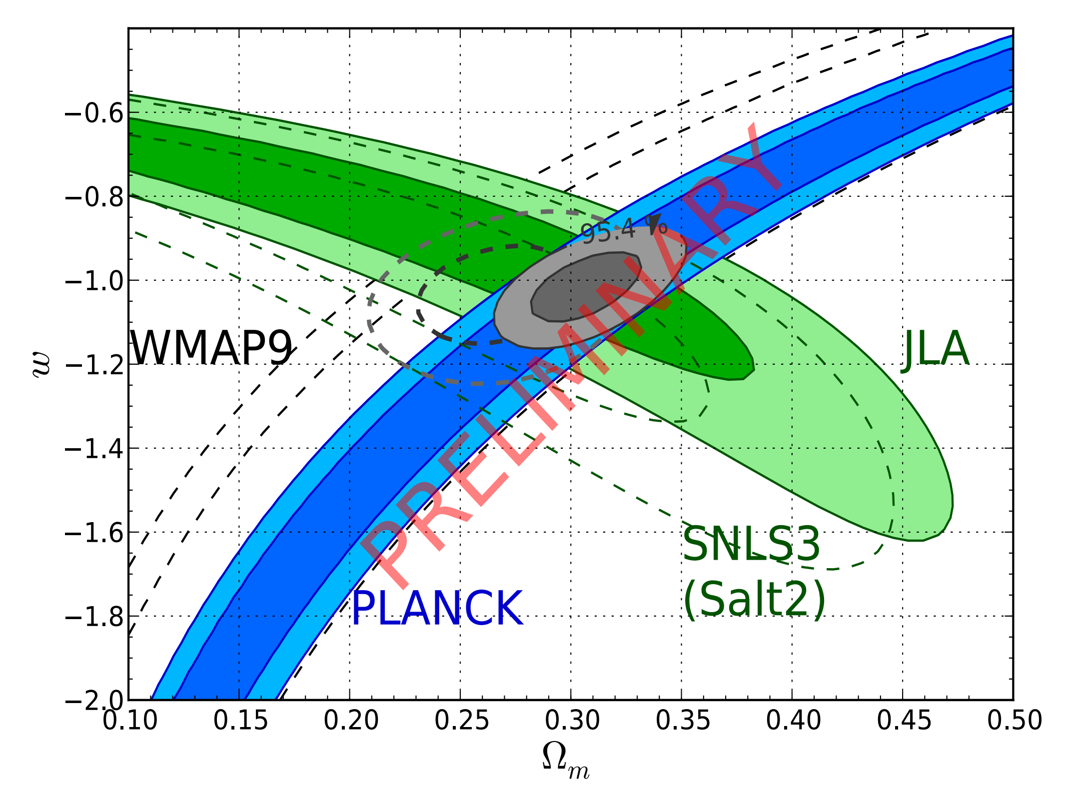
Toronto
Ray Carlberg, Kathy Perrett

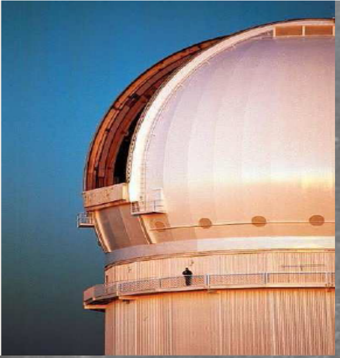
Paris/Saclay
Pierre Astier, Christophe Balland, Marc Betoule, Patrick El-Hage, Julien Guy, Delphine Hardin, Reynald Pain, Nicolas Regnault, N. Palanques, J. Rich, V. Ruhlman

Marseille
Stéphane Basa, Dominique Fouchez

Supernovae Ia and Dark Energy







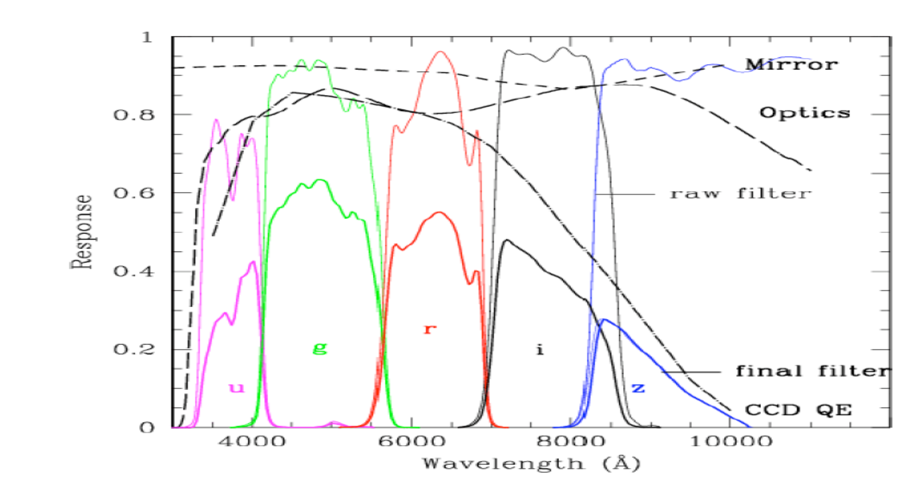
2. The Supernova Legacy Survey

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

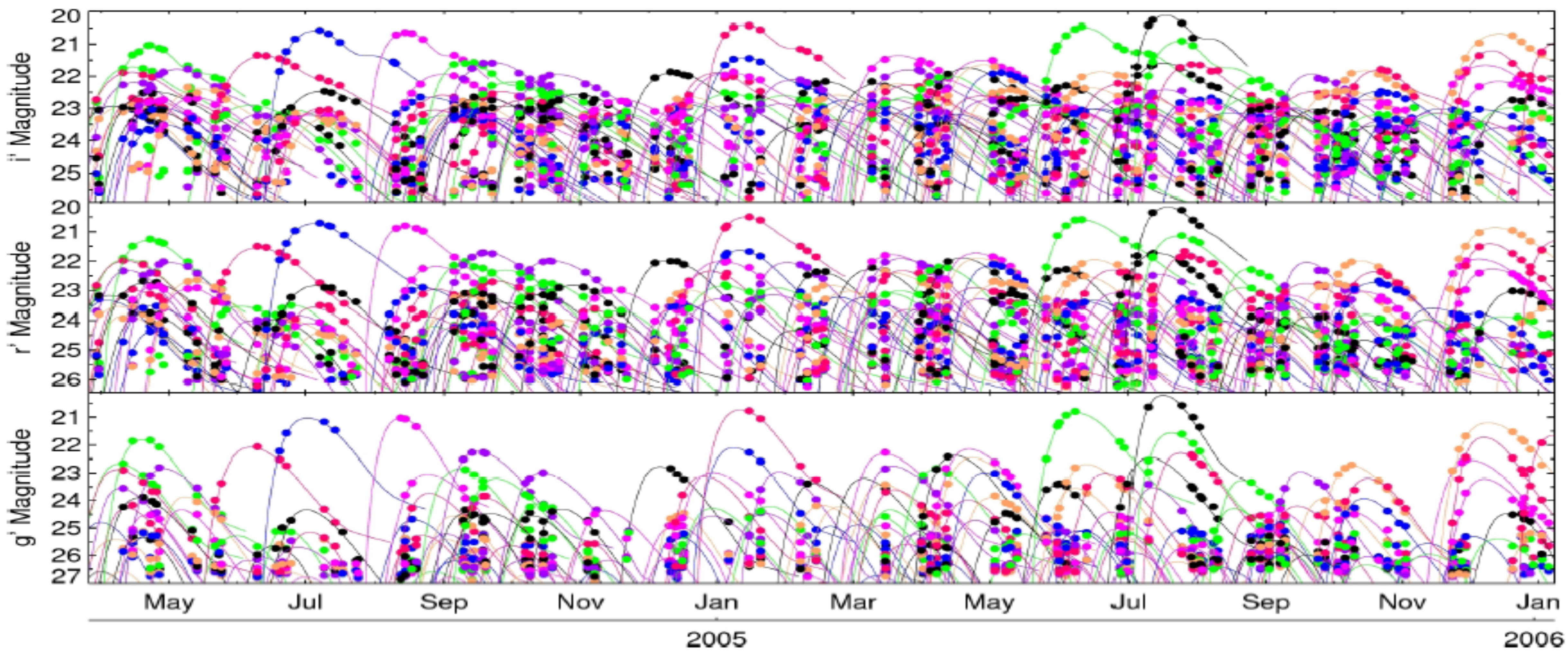
- spectroscopic follow-up : ~ 450 SNe Ia (**SNLS5**)
10-m class telescopes @ Hawaii, Chile
4 filters griz : → $\mathbf{m_B}$ at ≠ z, B-V or U-B ***colors*** for all SNe



- ***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**

2. The Supernova Legacy Survey

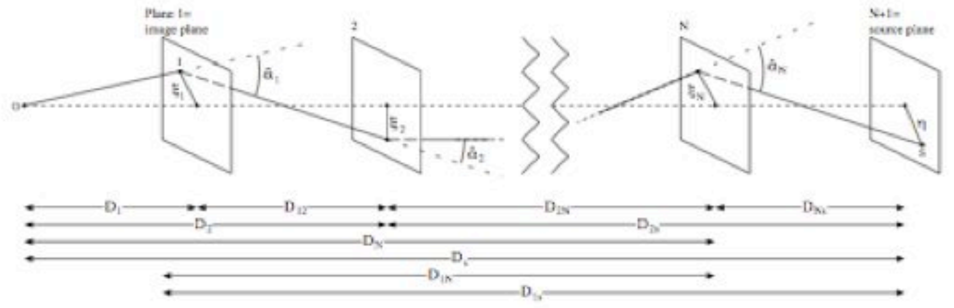
Rolling Search Mode



Gravitational Magnification Computation

- SNLS-3 : Lensing Analysis
- Qlet
- Ray tracing algorithm

Gunnarsson et al. 2003



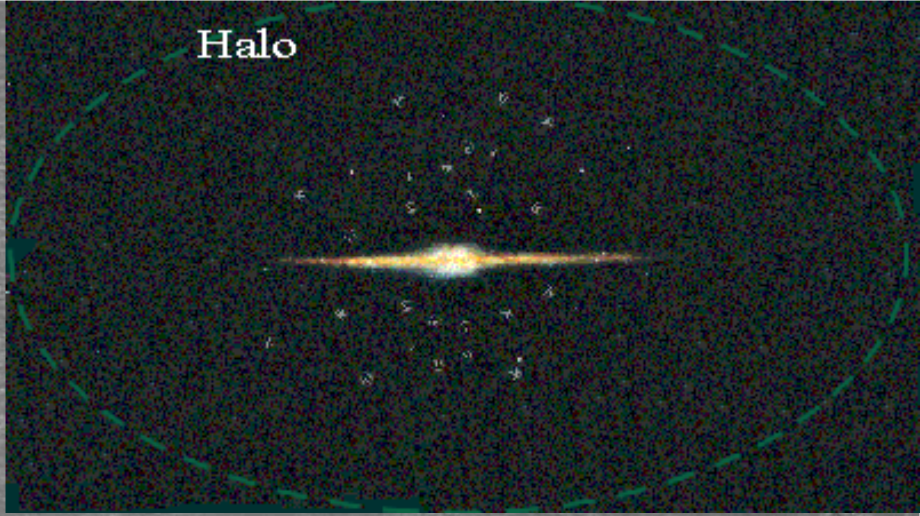
Multiple lens-plane method

- SNLS-5 : Lensing Analysis
- Get_magnification
- Weak Lensing approximation

$$\Delta m_{\mathrm{lens}} \simeq -2.17\kappa$$

- Ray tracing vs weak approx. : Deviation in value < 5% (*jonssonet.al. 2010*)

Halo modeling



Halo Models

NFW

Navarro et.al.1997

Numerical simulations show that NFW profiles are better suited for halo modeling

$$\rho(r) = \frac{\delta_c \rho_c}{(r/r_s)(1 + r/r_s)^2}$$

SIS

Modelled as ideal gas in thermal equilibrium trapped in gravitational potential .

$$\rho(r) = \frac{\sigma_v^2}{2\pi G} \frac{1}{r^2}$$

$$\mu(\theta) = \frac{|\theta|}{|\theta| - \theta_E}$$

$$\theta_E = 4\pi \left(\frac{\sigma_v}{c}\right)^2 \frac{D_{ds}}{D_s}$$

Scaling Laws

- Halo Types : NFW / SIS M_{200} / Sigma →

$$\frac{\sigma}{\sigma_*} = \left(\frac{L}{L_*}\right)^{\alpha}$$

$$\frac{M}{M_*} = \left(\frac{L}{L_*}\right)^{\beta}$$

- Galaxy type : Elliptical / Red and Spiral / Blue →

$$L \propto \sigma^{\eta}$$

$$L \propto V_{max}^{\gamma}$$

e.g. : Faber Jackson (Tully Fisher)

$$(\sigma_\star, L_\star, \alpha) = (156^{+18}_{-24}\mathrm{km.s}^{-1}, 10^{10}L_{r\odot}, 0.286^{+0.12}_{-0.09})$$

(Kleinheinrich et.al. 2004)

$$\log V_{\mathrm{max}} = -0.134(M_B + 3.61 + 1.22z)$$

Tully Fisher. *(Bohm et.al. (2004))*

$$\log \sigma = 2.2 - 0.091(M_r + 20.79 + 0.85z)$$

Faber Jackson. *(Mitchell et.al. (2005))*

η = 4.4

$$M_{0,L} = 1.26^{+0.07}_{-0.06} \times 10^{13}\, h_{70}^{-1}\, M_\odot$$

$$\beta_L = 1.56^{+0.04}_{-0.06},$$

$$M_{0,L} = 0.16 \pm 0.03 \times 10^{13}\, h_{70}^{-1}\, M_\odot$$

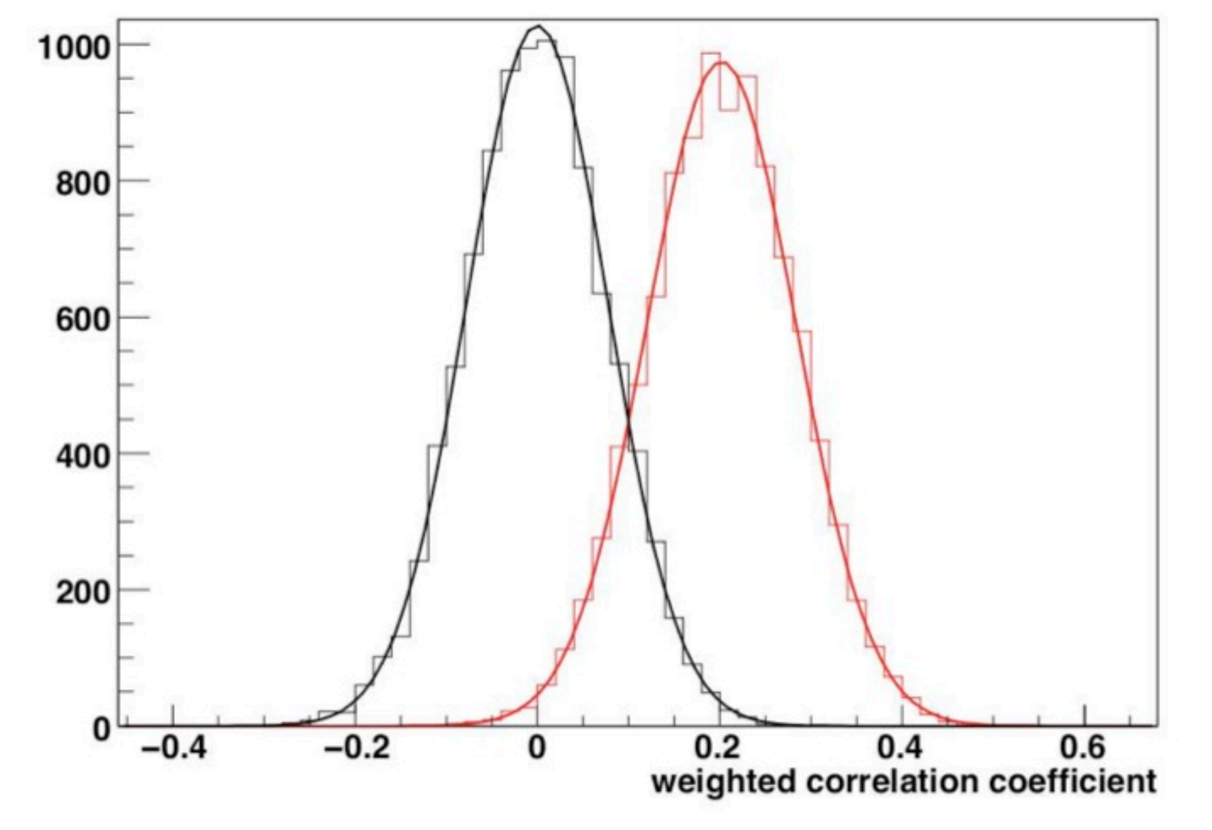
$$\beta_L = 0.73^{+0.09}_{-0.08}.$$

Velander et.al. 2013

Recent works: Scaling laws with stellar mass.*(Velander et.al. 2013,van Uitert et.al. 2011)*

Previous results

- *Kronborg et. al. 2010*
  - SNLS 3 sample analysis
  - 171 SNe Ia selected out of 233 total SNe
  - Ray tracing algorithm used.
  - Detection of 3σ lensing signal at 35% chance
- *Jonsson et.al. 2006*
  - GOODS sample Sne
  - 32 SNe analyzed
  - No strong signs , *<μ>=1*
  - Zero correlation within 68%
- *Jonsson et. al. 2010*
  - SNLS 3 sample analysis
  - Application of weak lensing approximation
  - Result within 5% deviation with ray tracing algorithm

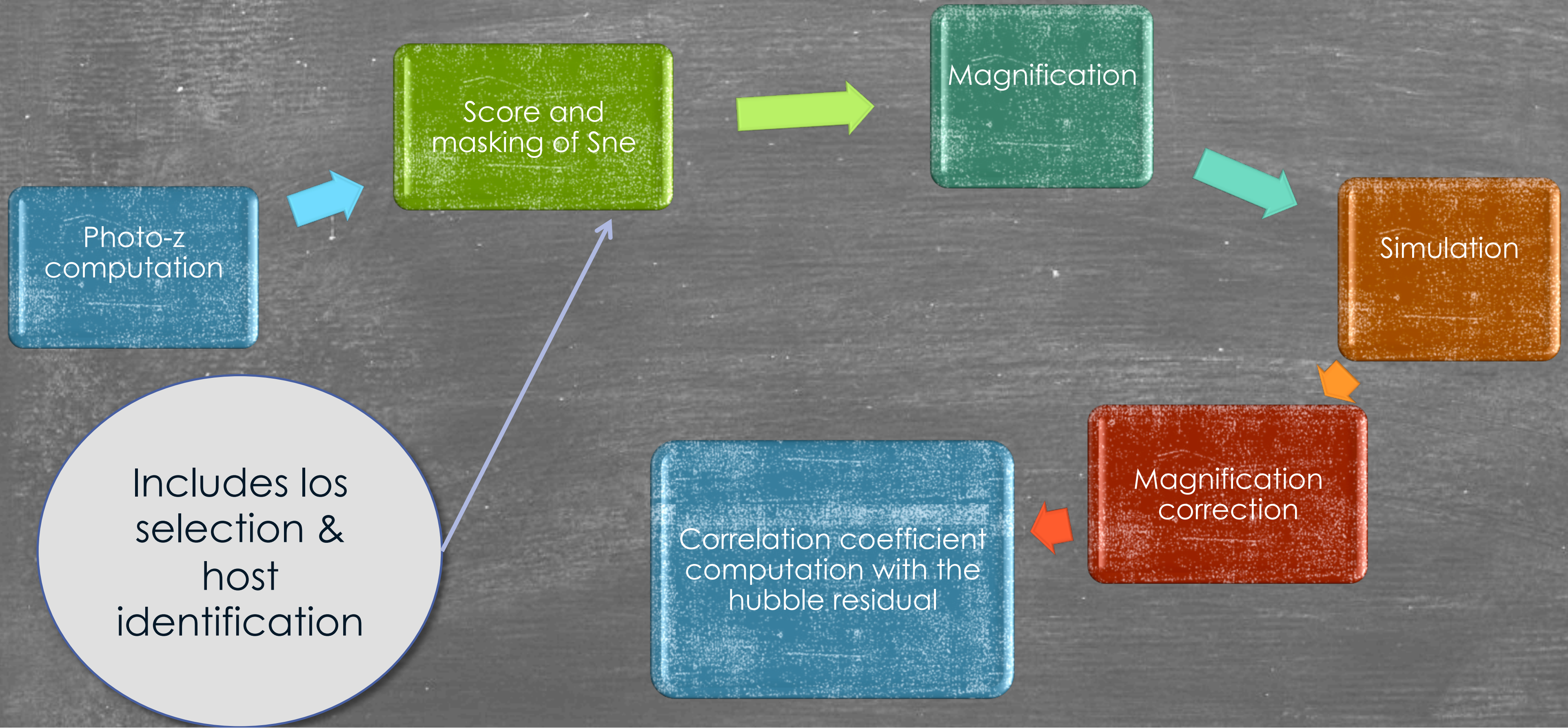


Kronborg et.al. 2010

Techniques

Anlaysis Chain

The lensing computation chain is ready

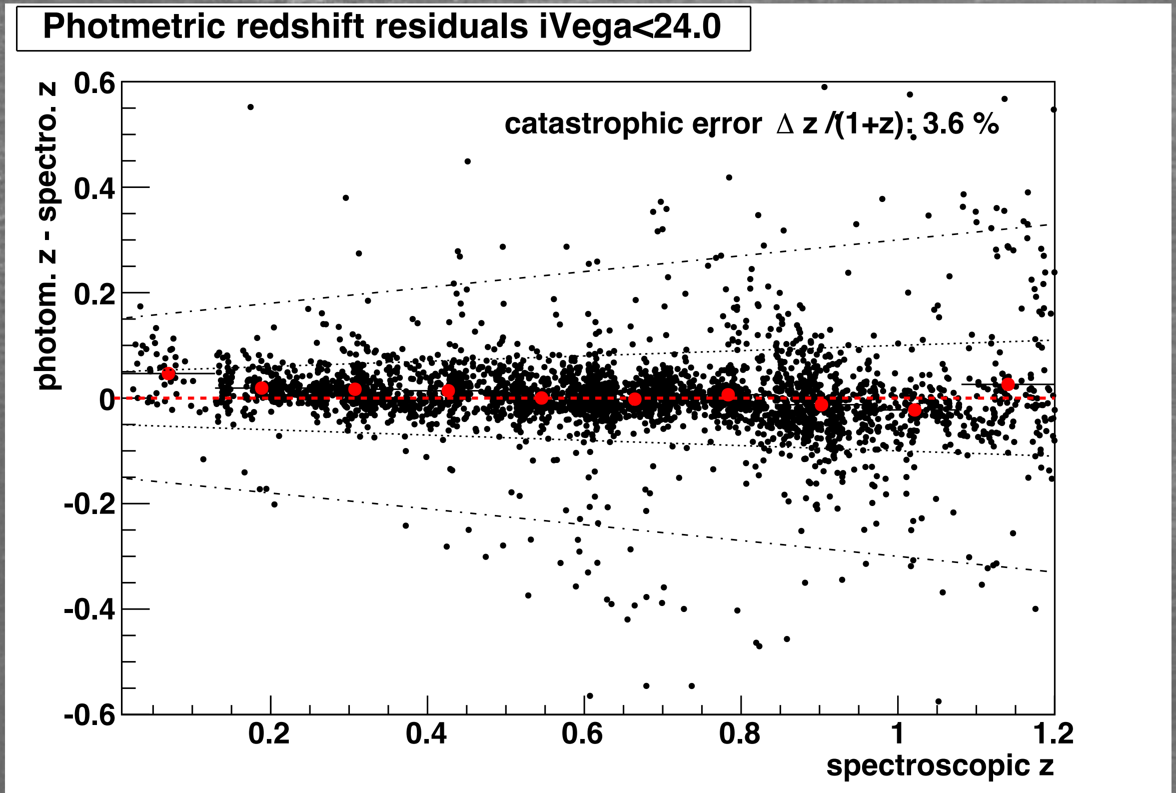


Photometric redshift

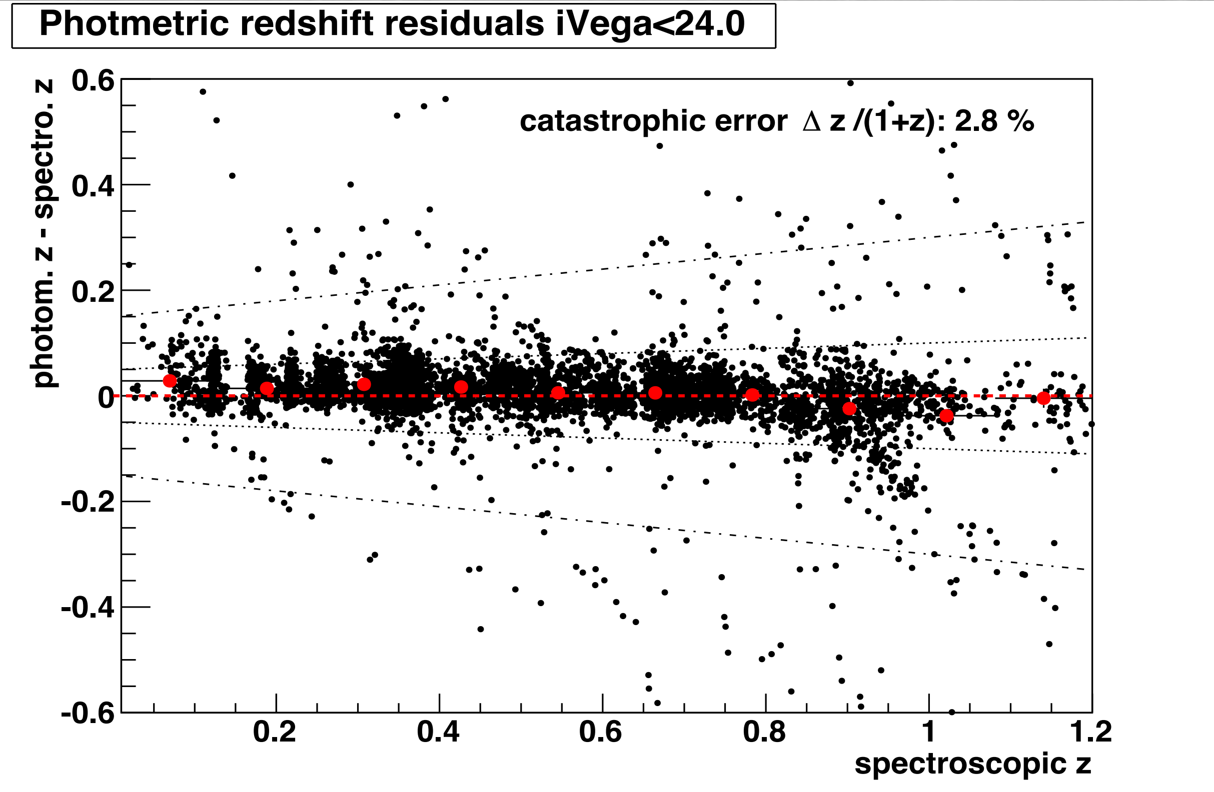
On Redshift accuracy

- Photometric redshift error :
- Total number of galaxies used i <24 : 3513
- catastrophic errors at 0.1 : 5.84%
- catastrophic errors at : 0.15 : 3.62%
- precision zp - z : mean= 0.0035 sigma= 0.05515 →
- 5.5 % of précision on (zp – z)
- precision (zp - z)/(1+z) : mean = 0.00329 sigma= 0.03228 →
- 3.3% of précision on (zp - z)/(1+z)

D1 and D2 fields :

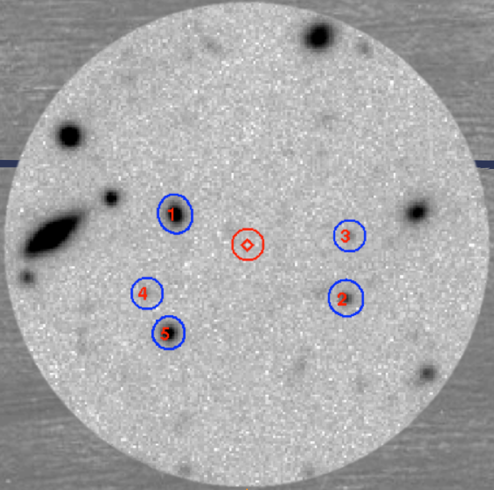


D1



D2

Host Galaxy Detection

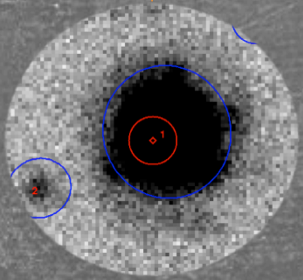


Various cut-offs

Broadly :

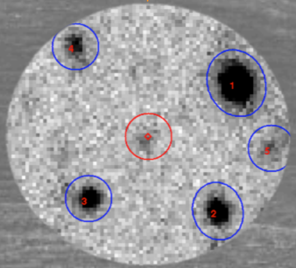
Distance $d=\sqrt{(ax^2+bxy+cy^2)}/KRON\ factor$

Redshift and photometric redshift comparison



Host Detected :

Isolating the best galaxy from other galaxies as the 1st host



Not Detected : faint hosts

or

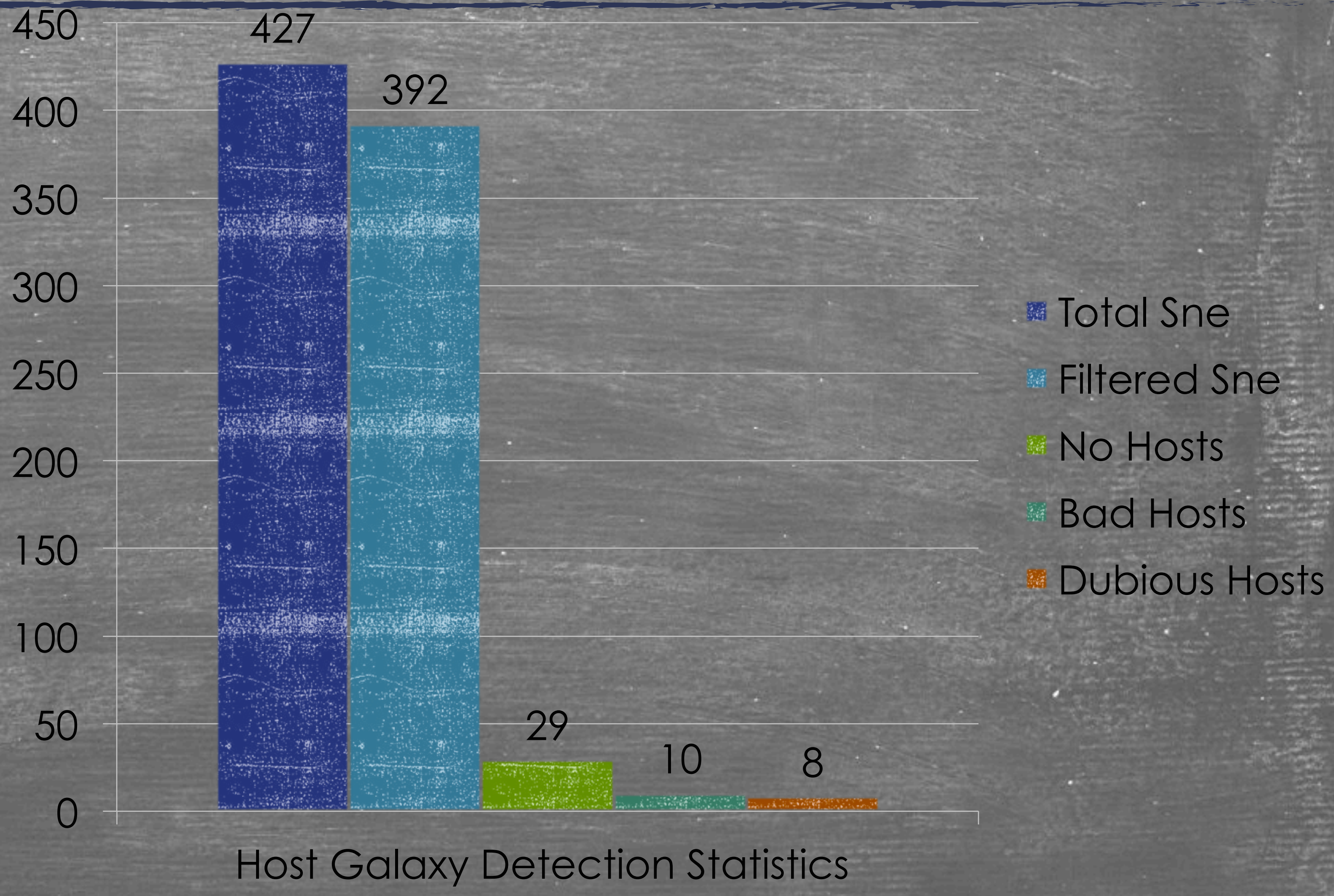
Bad cases due to polluted image / Dubious cases

Also detection of background/foreground galaxies.

Latest Status

Tentative Detection results :

- Number of SNe : 439
- SNe with hosts OK : 392
- SNe with no hosts : 29
- SNe with bad images : 10
- SNe with dubious hosts : 8



NO_HOST

e.g. : 04D2iu z=0.700

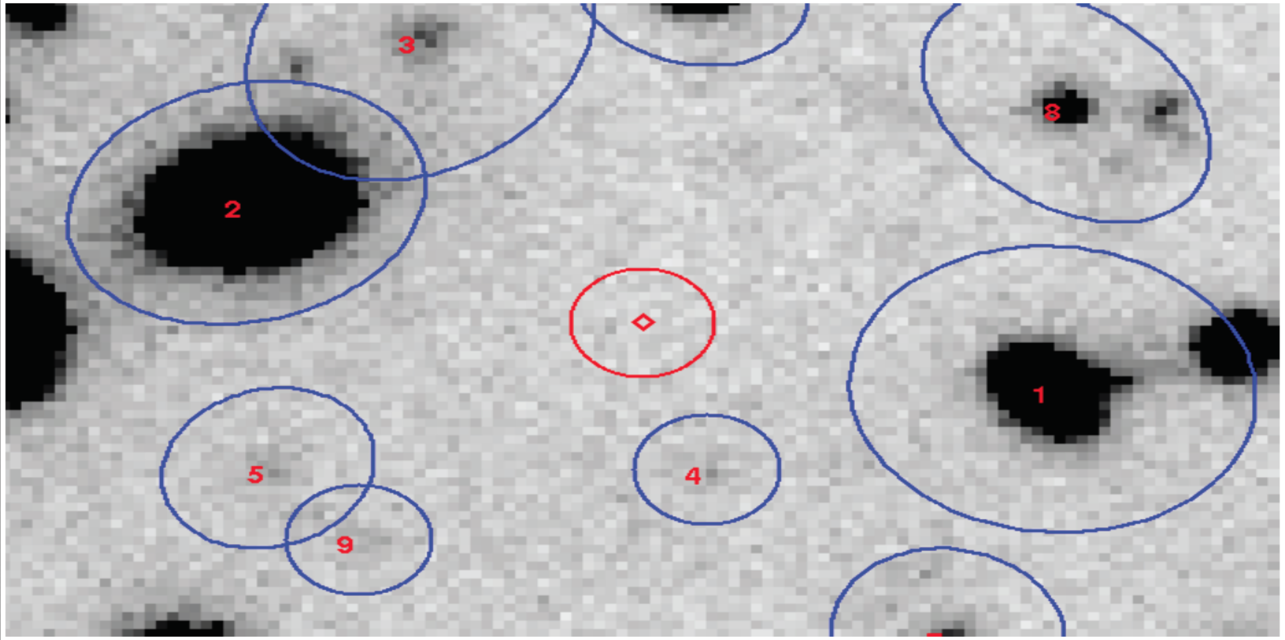
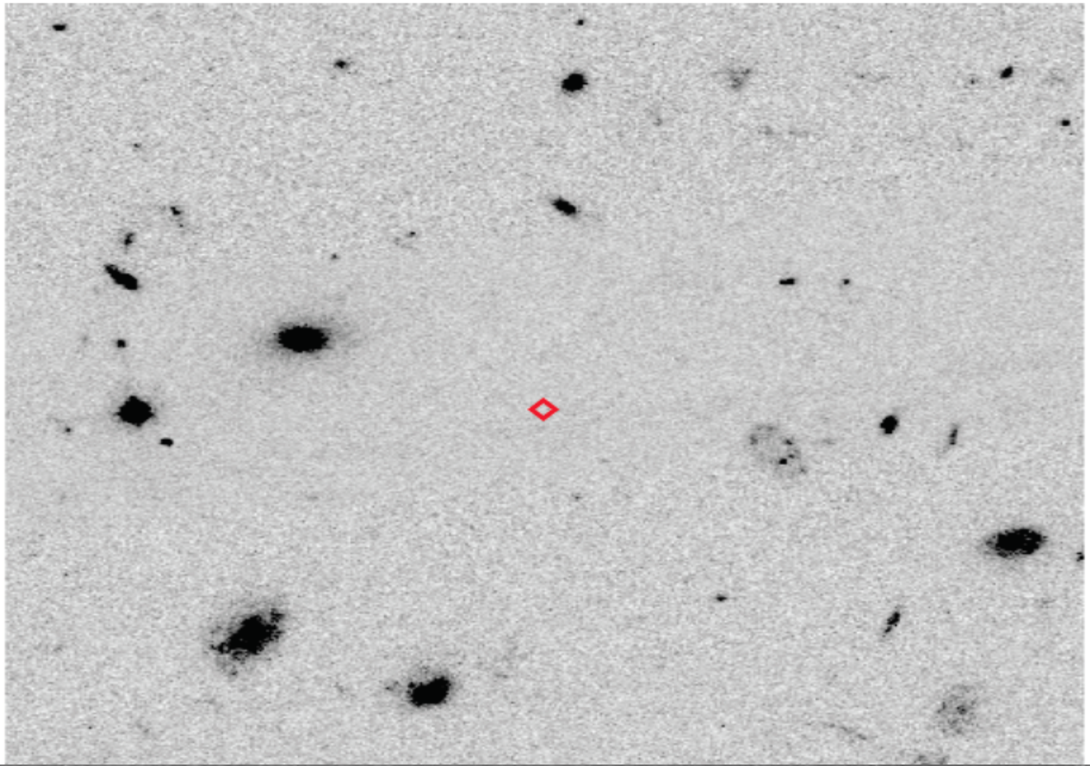


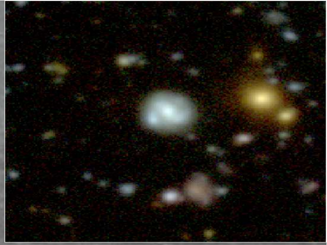
Figure 58: Zoom on SN 04D2iu (z = 0.700)

CFHTLS image



HST image

05D3mx



- 06D3mx z=0.470 : host is the 2nd closest galaxy
- reduced elliptical distance galaxy 1 : d = 1.63
- reduced elliptical distance galaxy 2 : d = 1.63

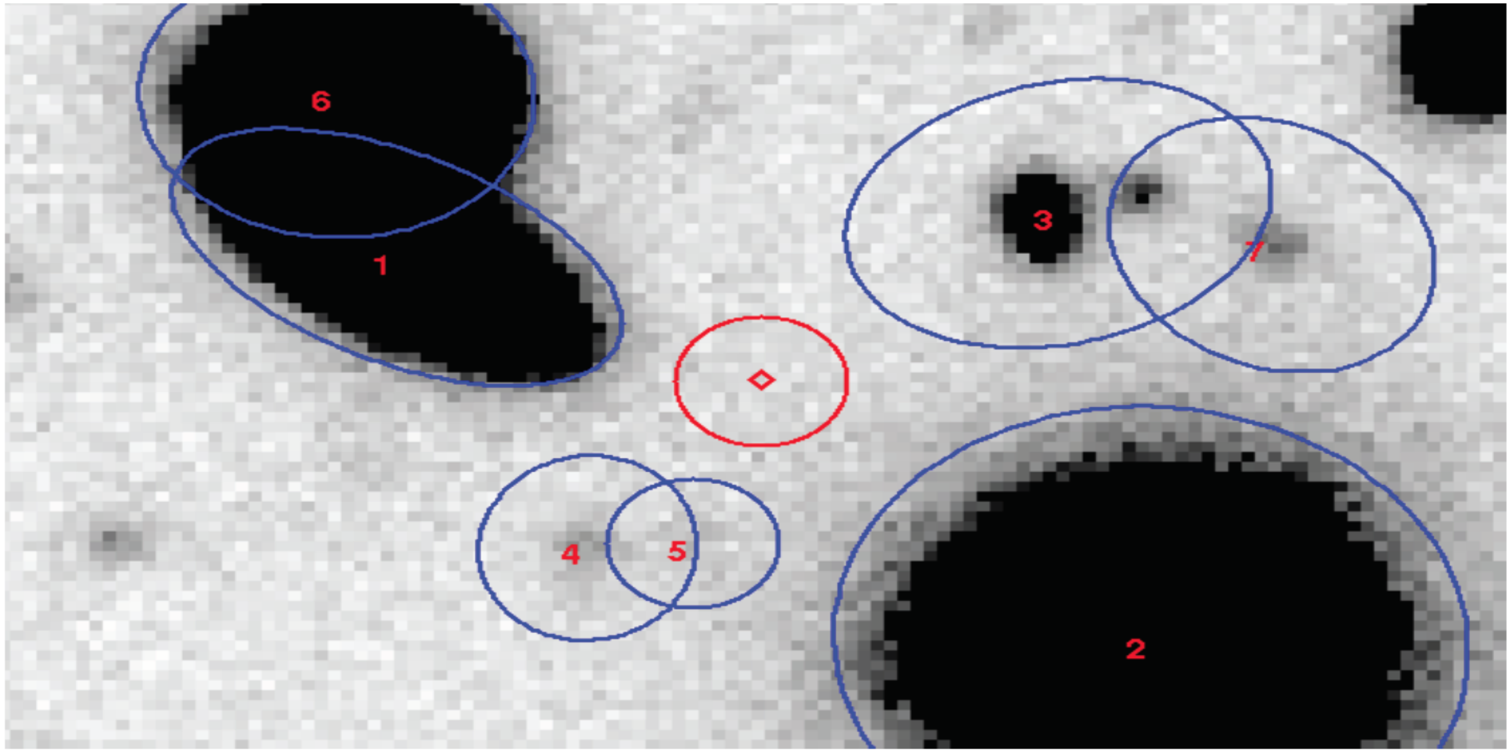


Figure 64: Zoom on SN 05D3mx (z = 0.470)

SN infos (database & and host dist.)								
	RA	Dec	type	z spec.	host dist. (")	ell. dist.	normalized ell. dist.	normalized ell. dist. to 2nd and 3d host
SN	14:22:09.101	52:13:09.04	SNIaqm	0.470	5.60	4.55	1.63	1.63, 1.72

05D3mx

- 06D3mx z=0.470 : host is the 2nd closest galaxy

Z SN = 0.470
ZP galaxy 1 : 0.52 (expo) templates) ; 0.55 Coupon 2009
ZP galaxy 2 : 0.46 (expo) templates) ; 0.46 Coupon 2009

For all hosts : comparison with T0004 photoz (Coupon et al. 2009)																
EXPO					PEGASE (age cstr)						C09					
No gal.	z ph.	template	e(b-v)	chi2	z ph.	template	age (Myr)	stell. M.	e(b-v)	chi2	RA	Dec	dist. in "	z ph.	template	e(b-v)
1	0.52	1865	0.00	4.28	0.48	S0	5235	10.83	0.00	1.05	14:22:09.665	52:13:11.32	0.072	0.55	Ell	0.01
2	0.46	841	0.00	3.88	0.45	S0	6503	11.32	0.00	1.28	14:22:08.503	52:13:04.19	0.096	0.46	Ell	0.01

05D3km : dubious host

- 05D3km z=0.960 -- galaxy in front at z~0.45

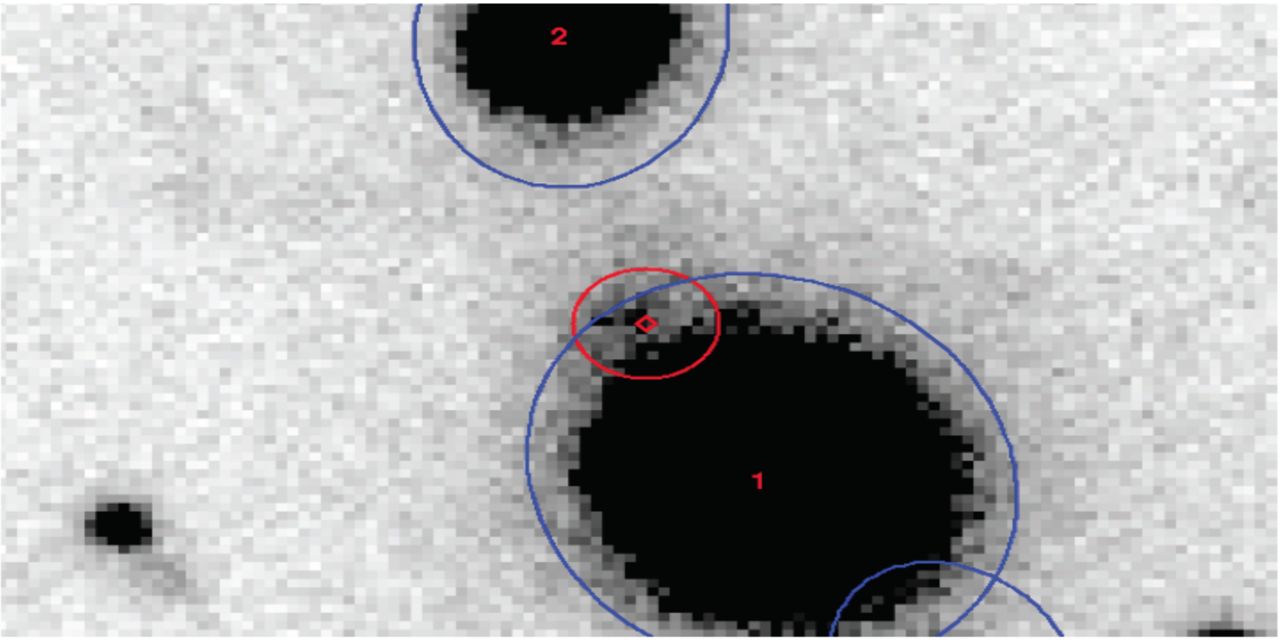


Figure 42: Zoom on SN 05D3km (z = 0.960)

For 1st host : comparison with Coupon et al. (09)															
SNLS + EXPO					SNLS + PEGASE age cstr.					C09					
No gal.	z ph.	tau	e(b-v)	chi2	z ph.	template	age (Myr)	e(b-v)	chi2	RA	Dec	dist. in "	z ph.	template	e(b-v)
1	0.44 (0.01)	934	0.00	7.38	0.43 (0.01)	S0	6474	0.00	2.04	14:22:38.035	53:03:57.82	0.05	0.42	Ell	0.01

Simulation

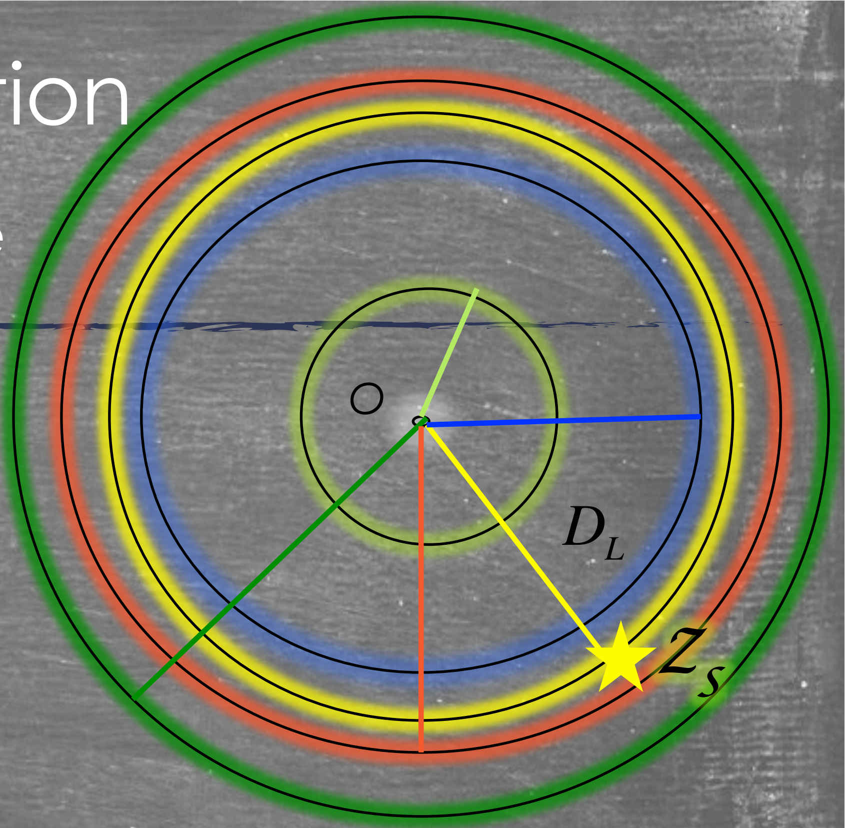
Magnification Normalization

$$\mu = \frac{F}{F_0}$$

F = Flux in inhomogeneous universe

F_0 = Flux in homogeneous universe

where, $F_0 = \frac{1}{4\pi}\frac{L_S}{D_L^2}$



with D_L the luminosity distance in a homogeneous universe that fits the cosmological data : FLCDM model with Ω_m=0.27

So that (mean over sphere at redshift zs) : $\langle \mu \rangle = 1$

But in our case we estimate F using : homogenous FLCDM Ω_m universe + DM haloes around line-of-sight galaxies so that : $\langle \mu \rangle > 1$

-> need for normalization.

Simulation

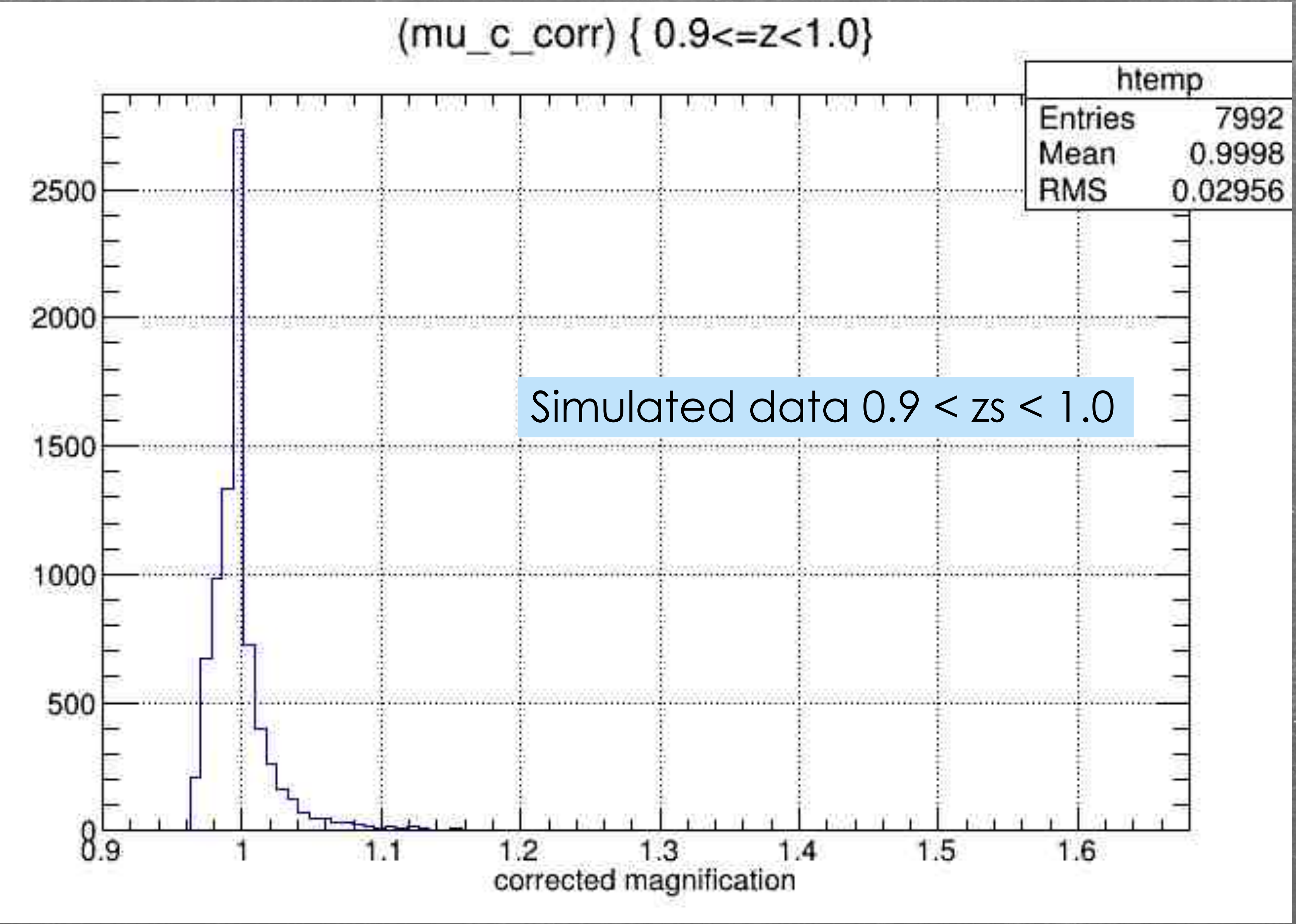
Total 12000 SNe
With 12 bins divided into redshift

Z=0.1	Z=0.2	Z=0.3	Z=0.4	Z=0.5	Z=0.6	Z=0.7	Z=0.8	Z=0.9	Z=1.0	Z=1.1	Z=1.2
1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe	1000 SNe

- Random SNe positions
- True galaxy catalog

Magnification Normalization procedure

- Mean magnification computation in 12 redshift (zs) bins
- Polynomial Fitting(3rd order) in zs
- All SNe magnification values corrected

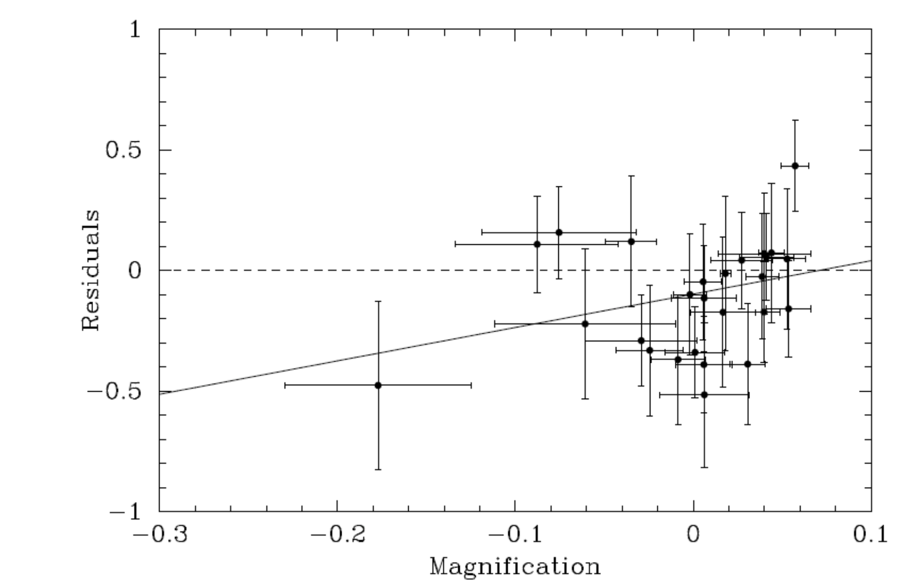

(mu_c_corr) { 0.9<=z<1.0}
htemp
Entries 7992
Mean 0.9998
RMS 0.02956
0
500
1000
1500
2000
2500
0.9
1
1.1
1.2
1.3
1.4
1.5
1.6
corrected magnification
Simulated data 0.9 < zs < 1.0

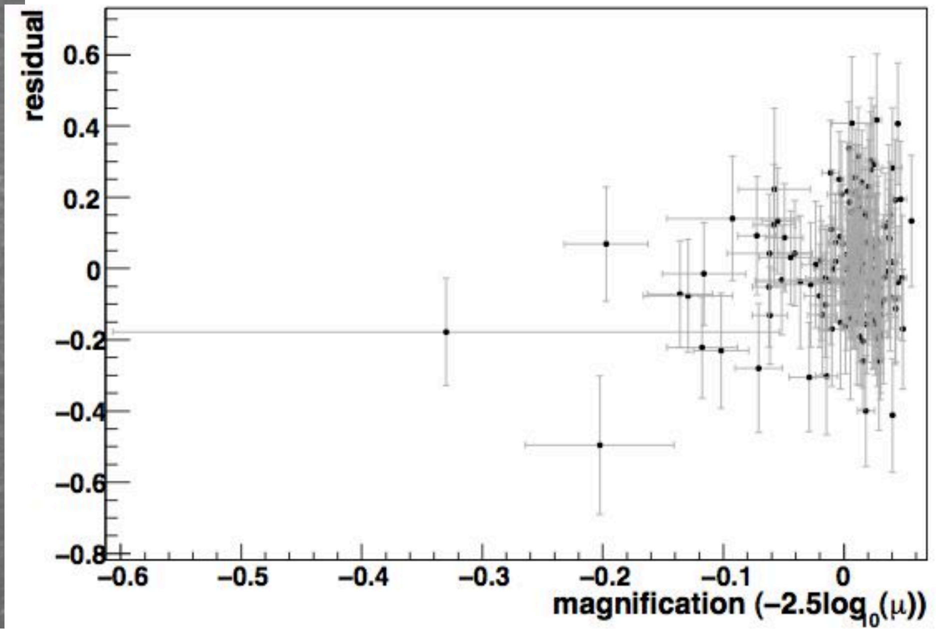
Signal Detection

Hubble residual: r = μ_L(SN) - μ_L(z; cosmologie), μ_L(SN) estimated with SN mags and SN host 3rd variable.

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

Tentative detection:**(Jonsson2007)** with 27 SNe from GOODs survey : evidence of a positive correlation at 91%





- correlation coefficient : 0.18 for SNLS3 Kronborg 2010
- r = (0.65 ± 0.30) × μ_m
- weak signal

Towards SNLS 5

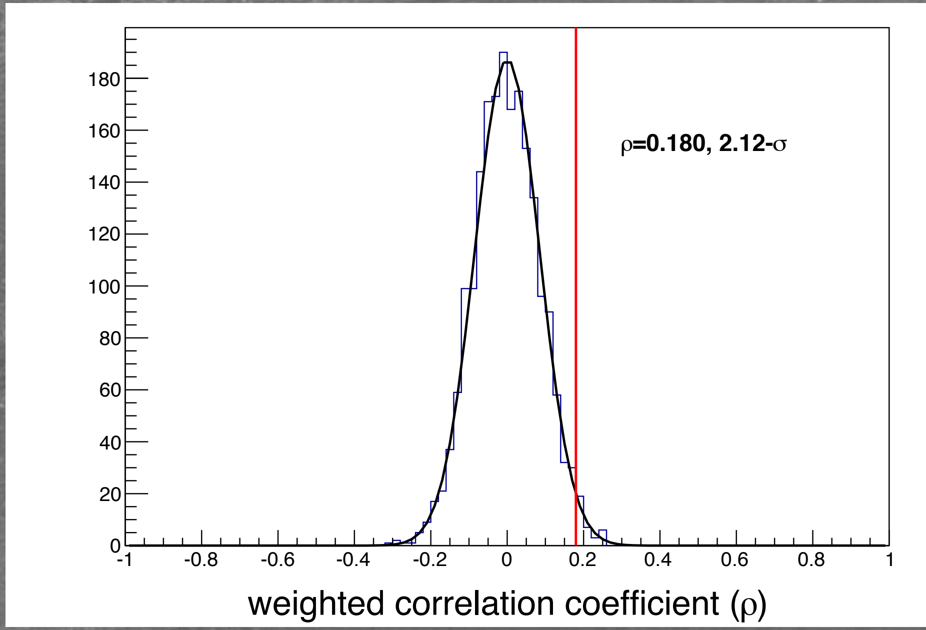
Correlation computation

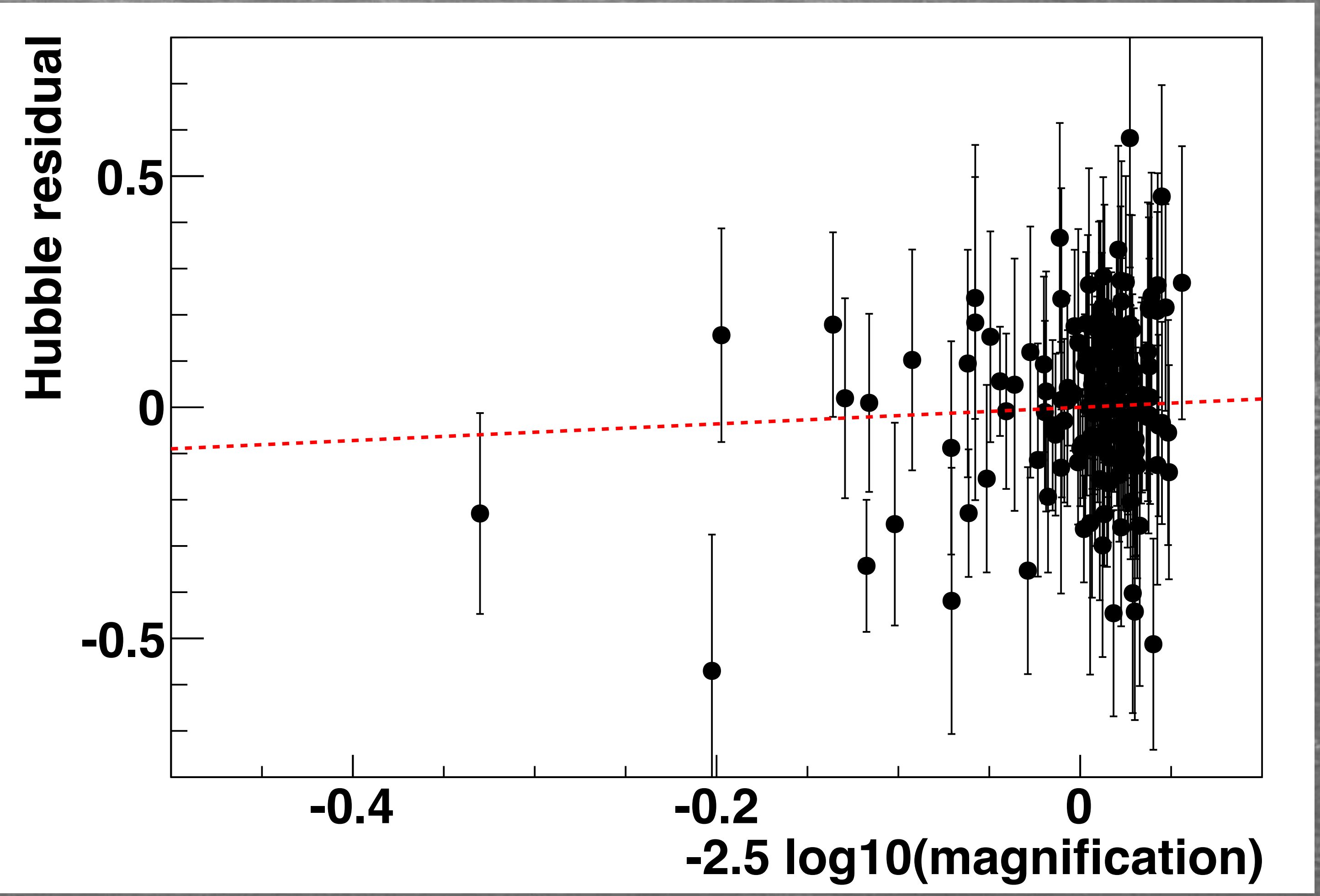
- Correlation coefficient signal is being compared between the previous magnification value and the **new residuals** (JLA)
- The new line of sight magnification values and the new JLA residuals

Magnification	Correlation
SNLS-3 qlet magnification values	0.179 98.25%
New Los qlet value	0.177 98.30%
New Los getmag value	0.195 98.94%

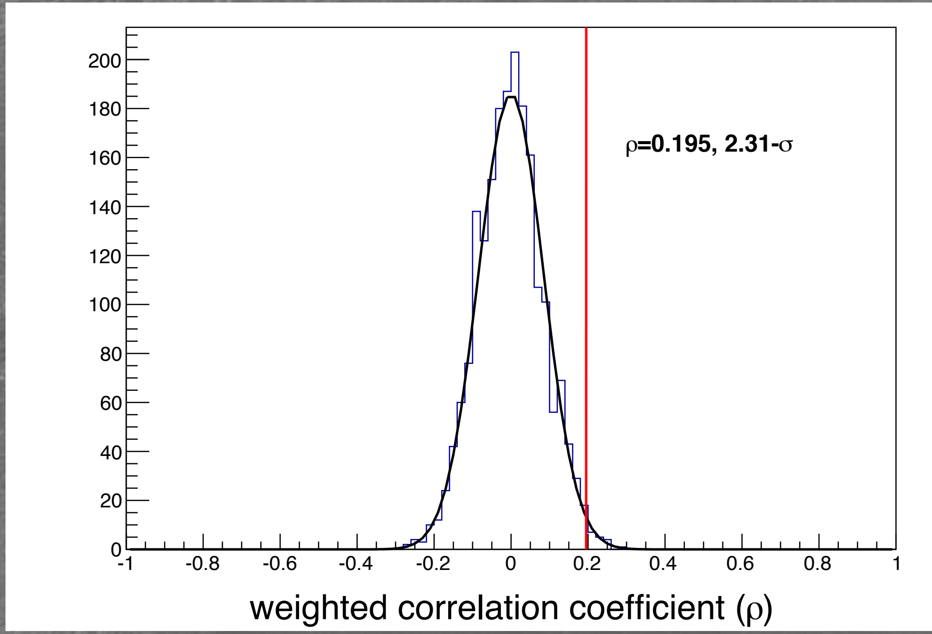
With SNLS3 magnification values

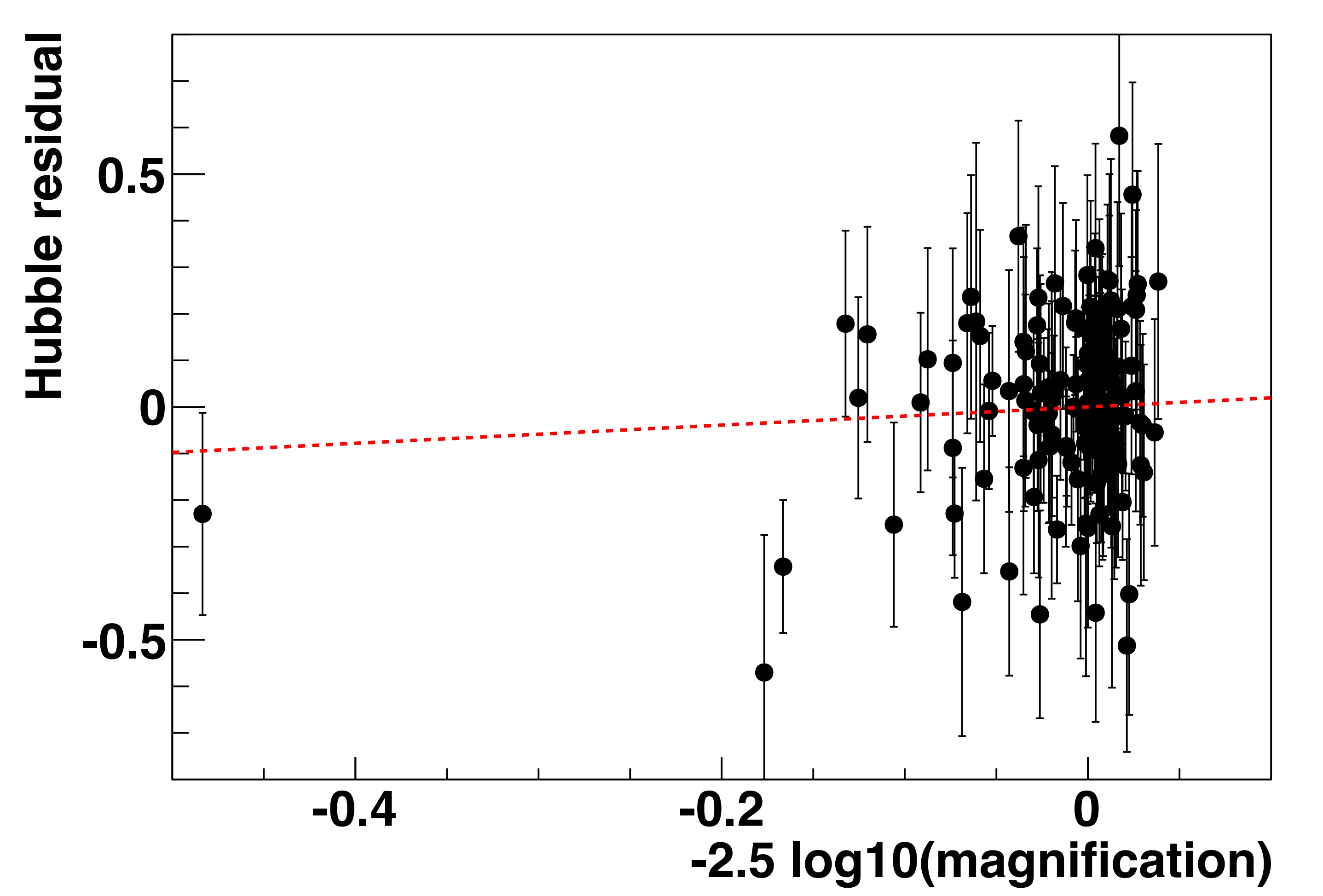
Around 20 Sne are missing in the JLA so the signal was found with 155 Sne





With SNLS3 new los magnification values using approximation formula

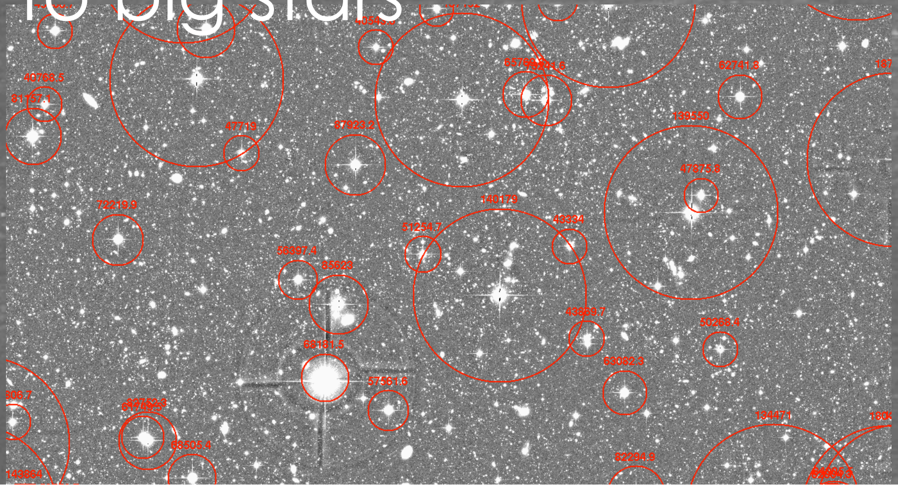


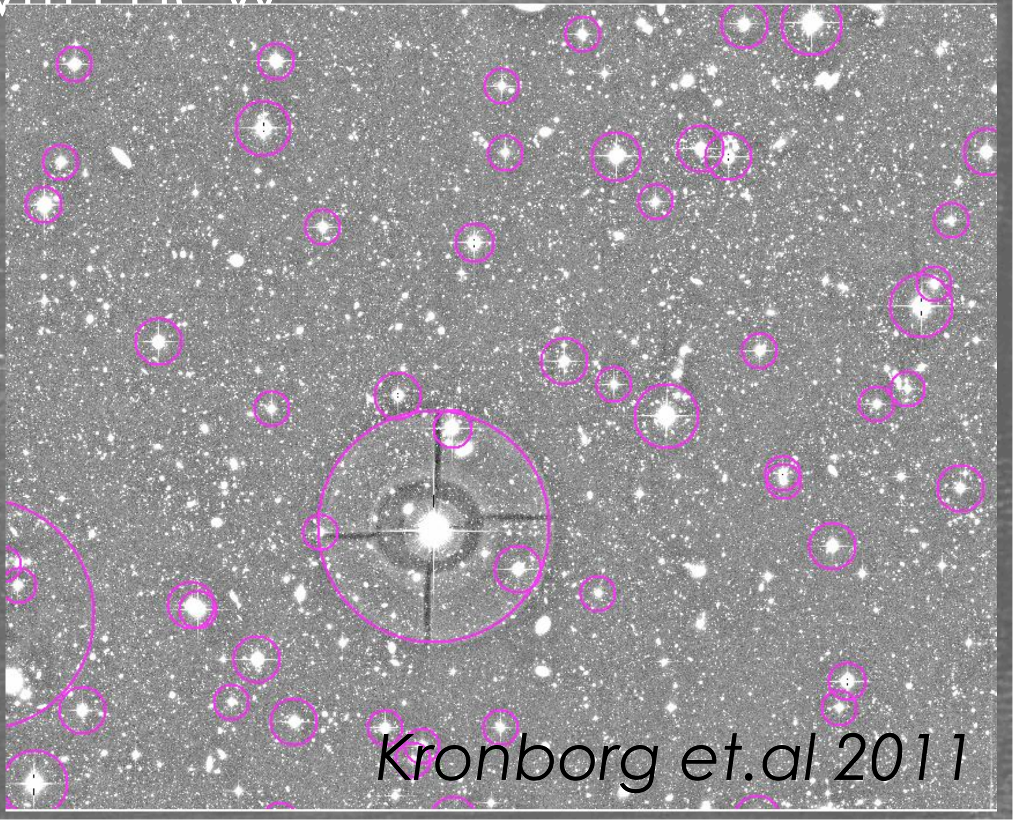


Present and future works :

- Scoring of full spectroscopic SNLS5 sample ✓
- Scoring of photometric sample : to be done
- Need for a new mask ? To be checked with new star catalogue
- Maybe Apply new cuts ? Like
- Distance of Sne to big stars

Masking not so good as old one



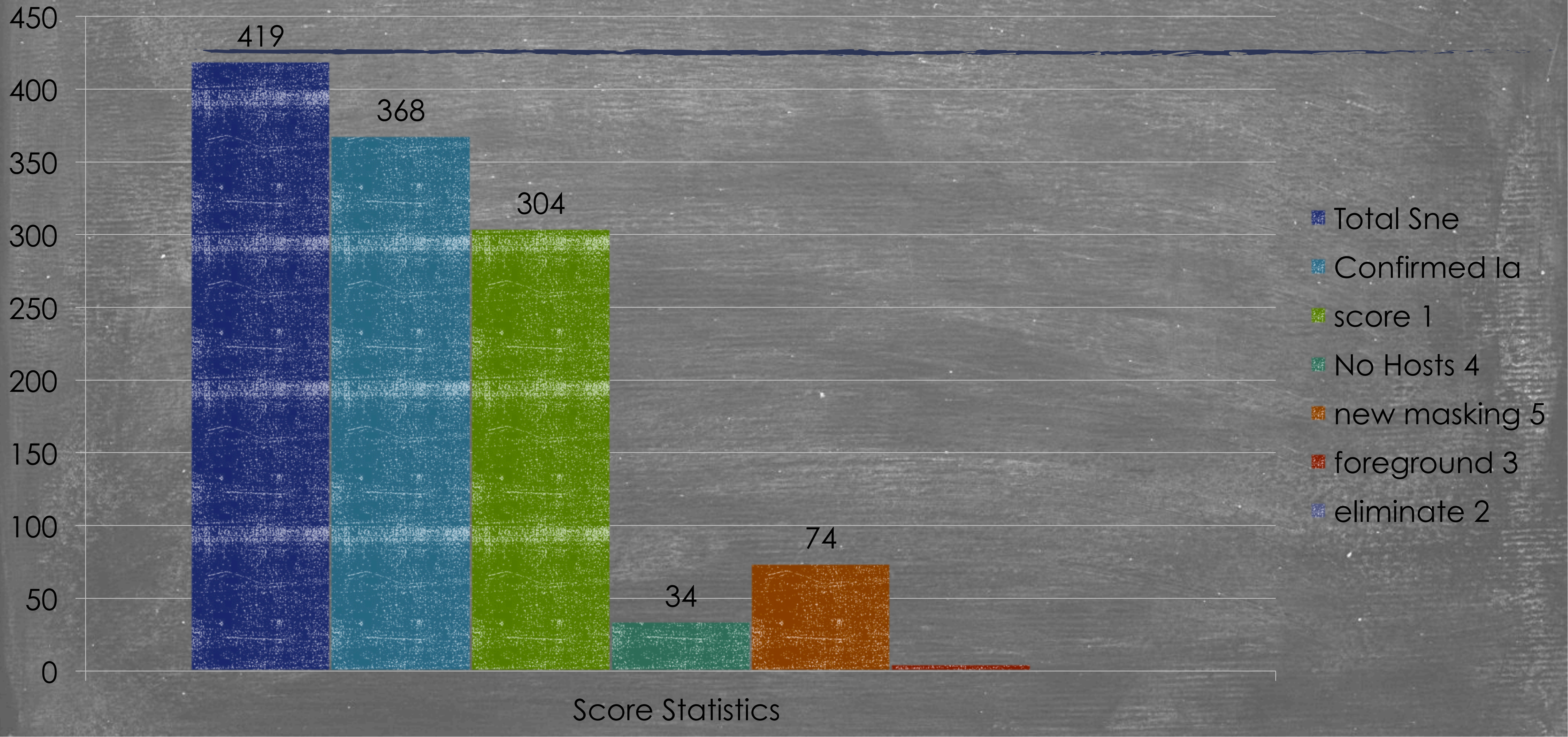


Kronborg et.al 2011

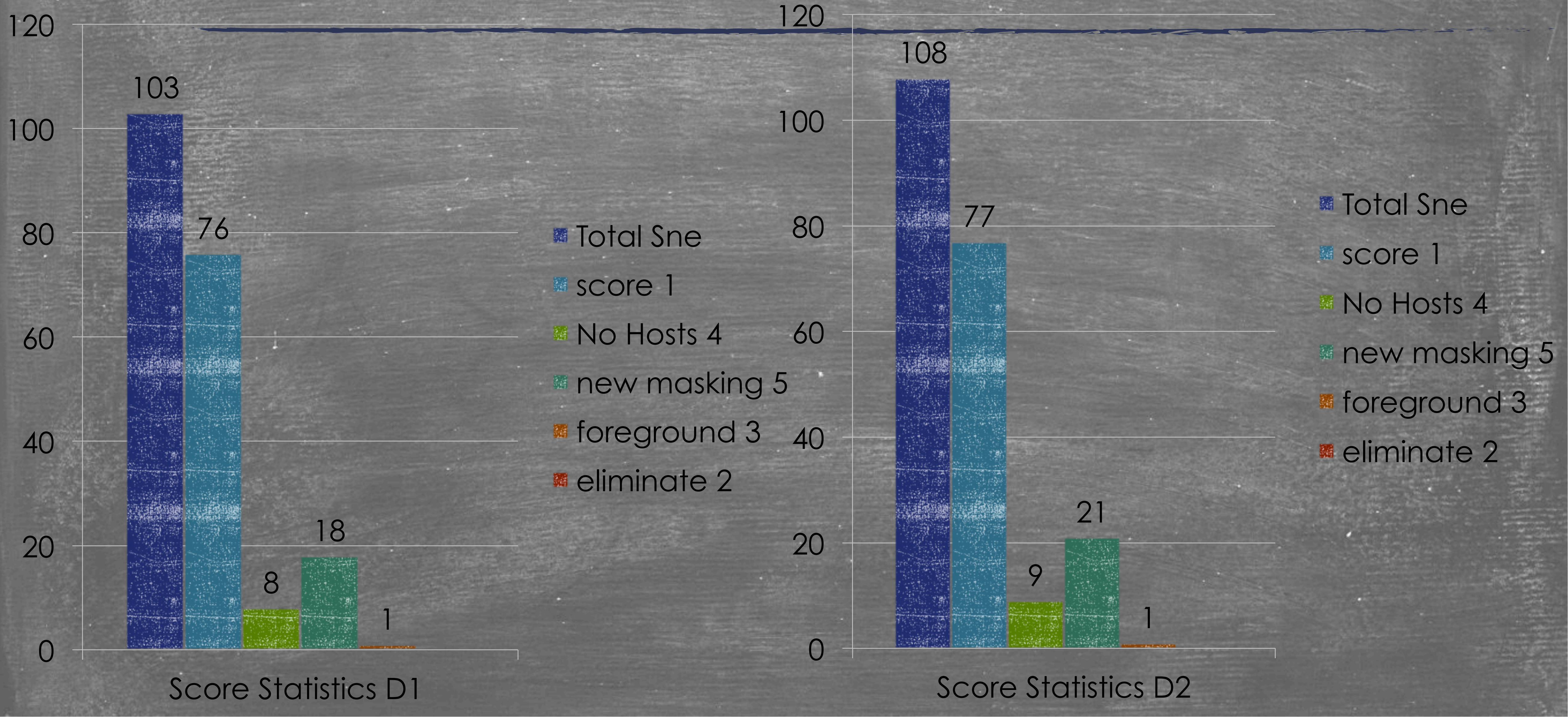
Score

- Different scores are given to the Supernova based on some characteristics on identification, example : presence/absence of host, masking not proper, host galaxy blocked by foreground galaxy or whether to be eliminated.
- Some statistics after scoring of the final spectroscopic sample:

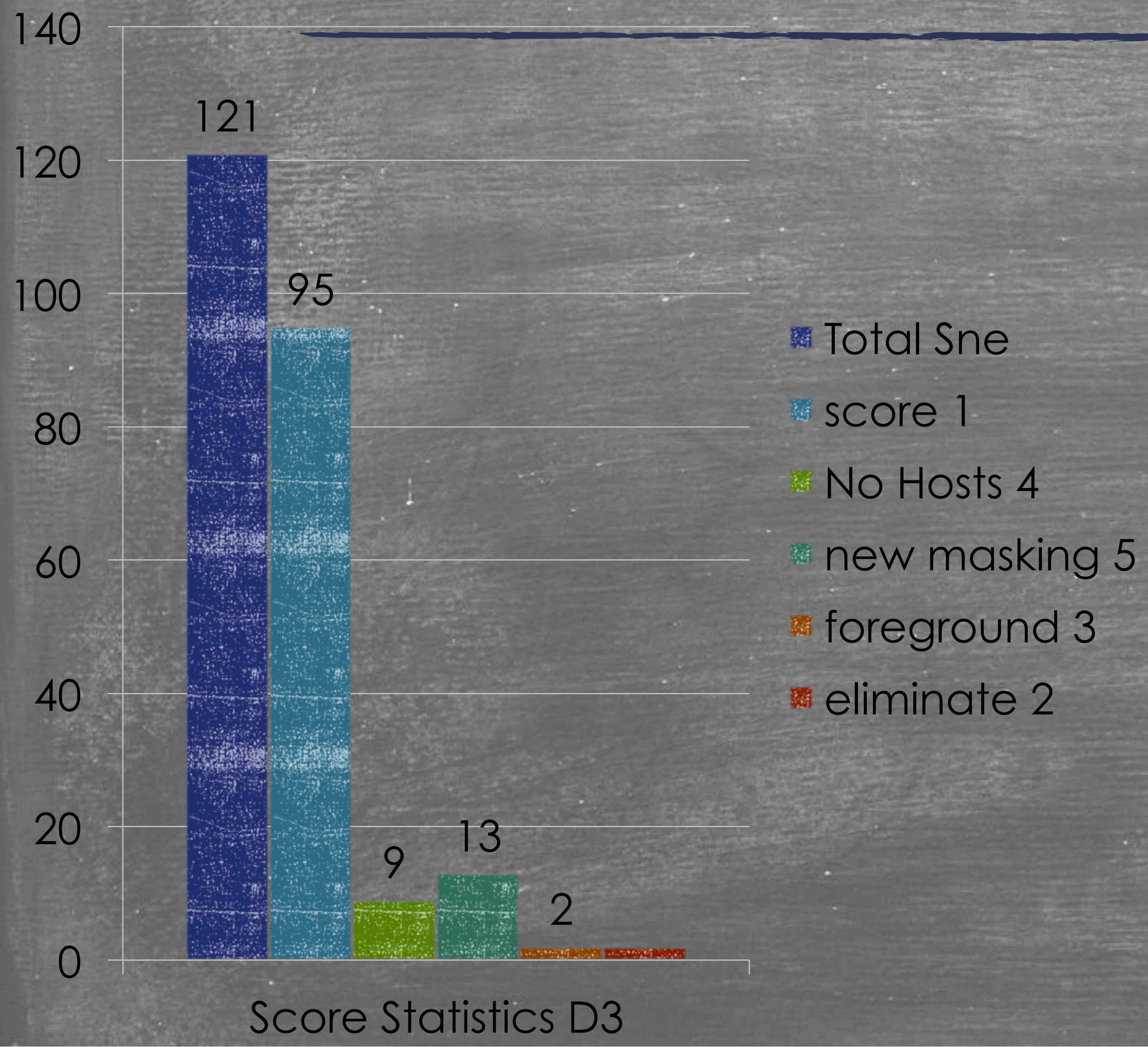
Spectroscopic SNLS 5 Sample Score :



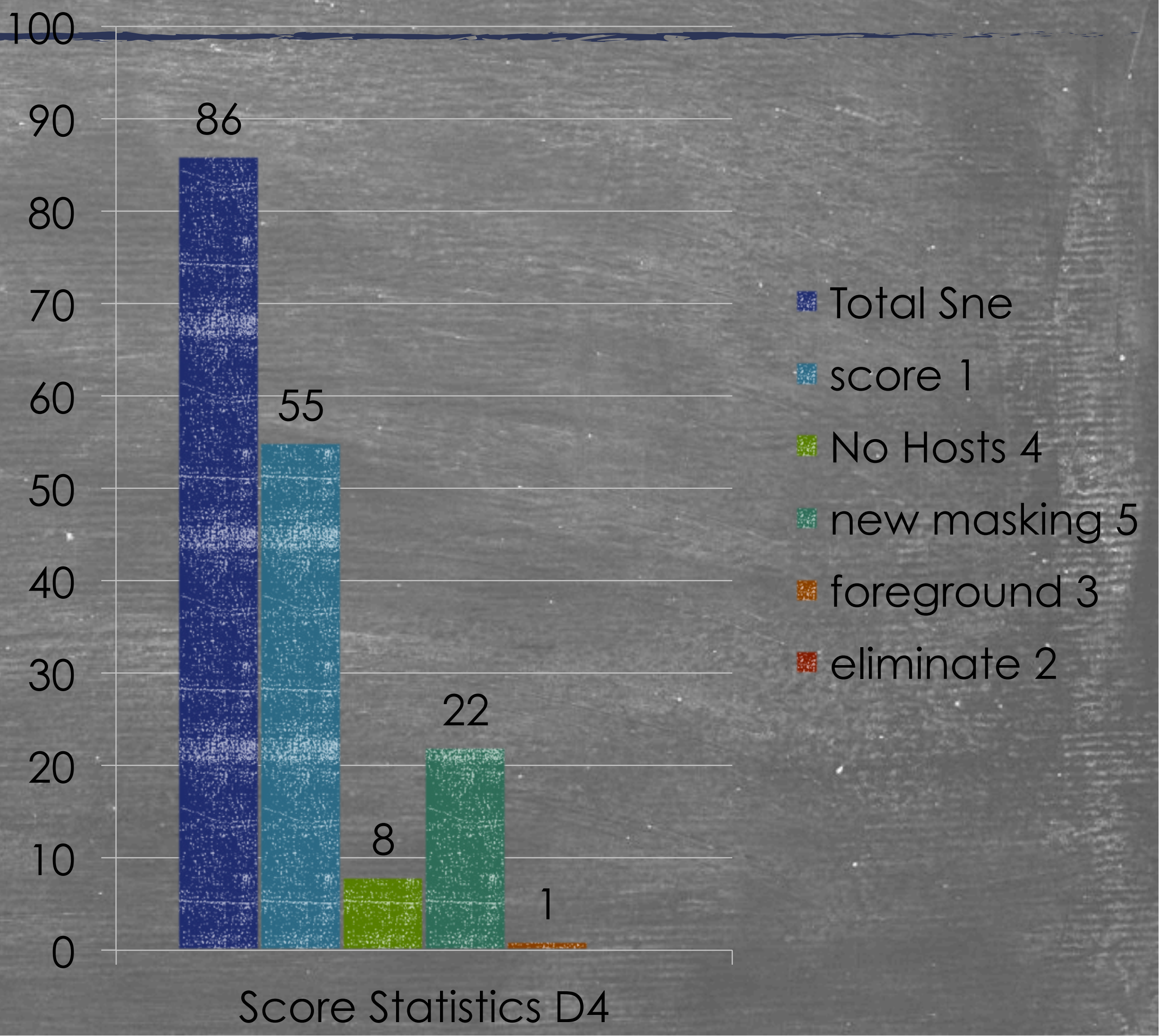
D1 and D2 statistics



D3 and D4

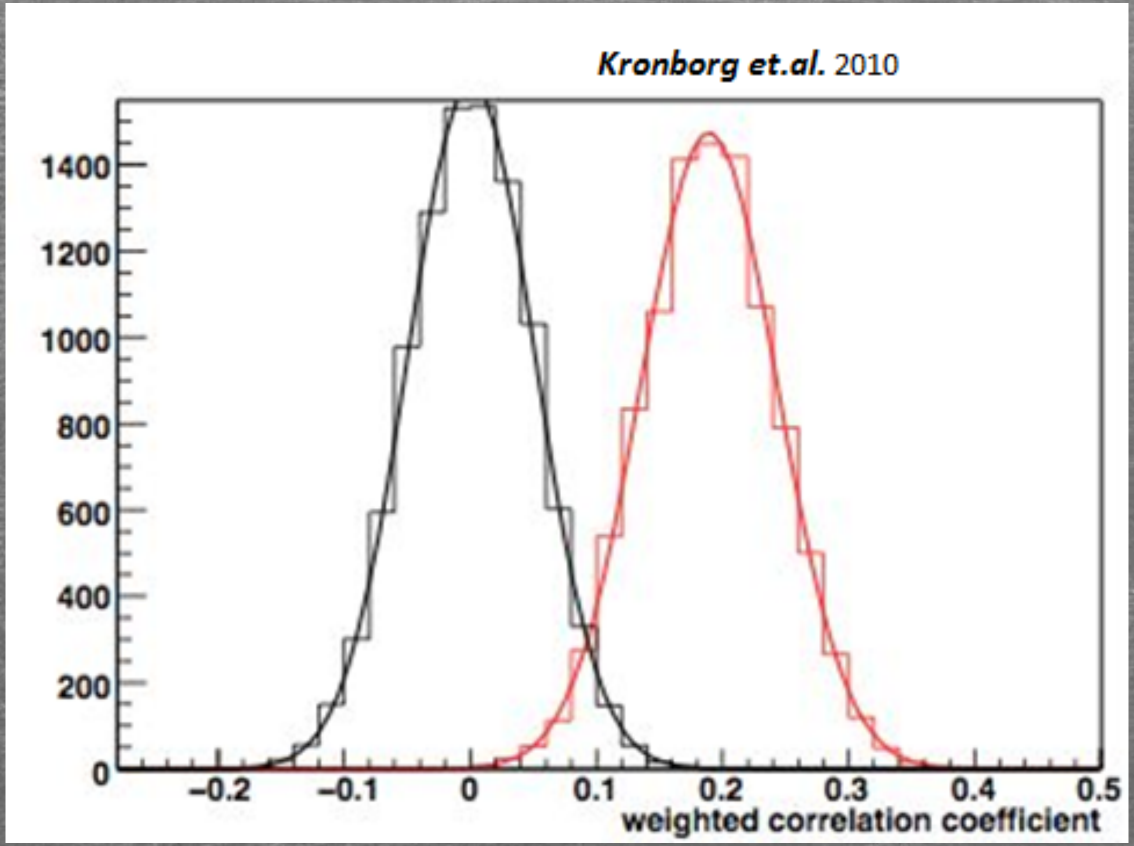


140
120
100
80
60
40
20
0
121
95
9
13
2
Total Sne
score 1
No Hosts 4
new masking 5
foreground 3
eliminate 2
Score Statistics D3



100
90
80
70
60
50
40
30
20
10
0
86
55
8
22
1
Total Sne
score 1
No Hosts 4
new masking 5
foreground 3
eliminate 2
Score Statistics D4

Expected Results (Kronborg 2010)



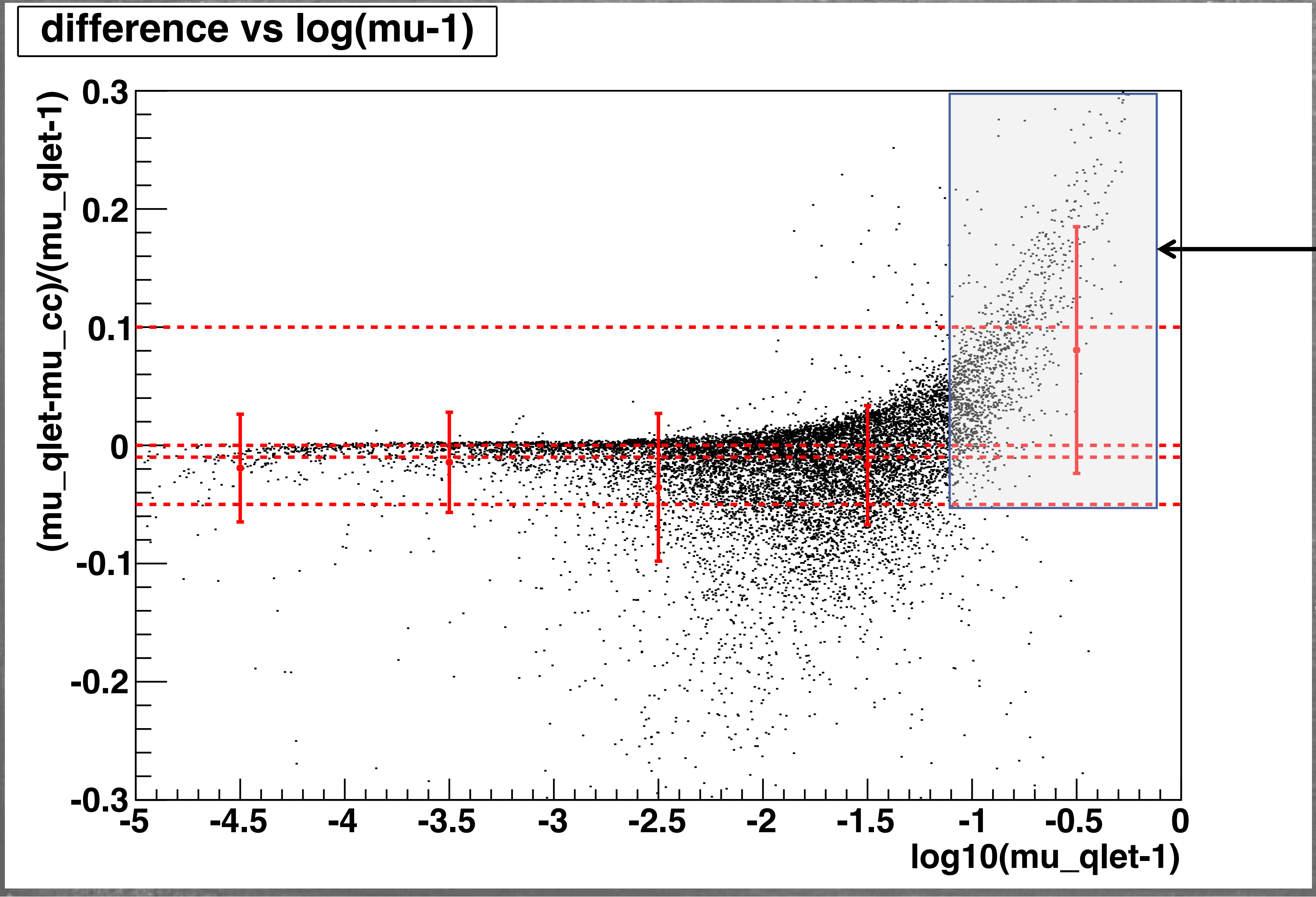
- More the data(more SNe) better the lensing signal detection chances.
- More high-z *SNe*.
- Hubble diagram residual scatter.

- A 3 σ signal is expected in the final sample of the survey. Which is 5 years of SNLS data consisting of around 500 SNe.


06D2ez
06D2fb
05D1hn
04D3bf
05D3ne
06D1ab
05D2ah
04D1dc
04D4ht
04D2bt
06D3cn
06D1du
03D3bb
05D3mq
05D1ly
03D3bh
06D3gn
04D3ez
06D3fp
06D3dt
03D3ba
05D1by
05D2ja
06D1ln
05D1ej
05D2ab
06D1hj
03D1fc
04D3kr
05D3hq
06D1hf
06D2ff
03D1bp
04D2ac
06D1fd
05D2mp
03D3bl
06D3dl
04D3fk
05D2el
04D1hd
03D3ay
05D4bm
03D1dj
05D4ff
03D1ar
05D2dw
05D3cf

End

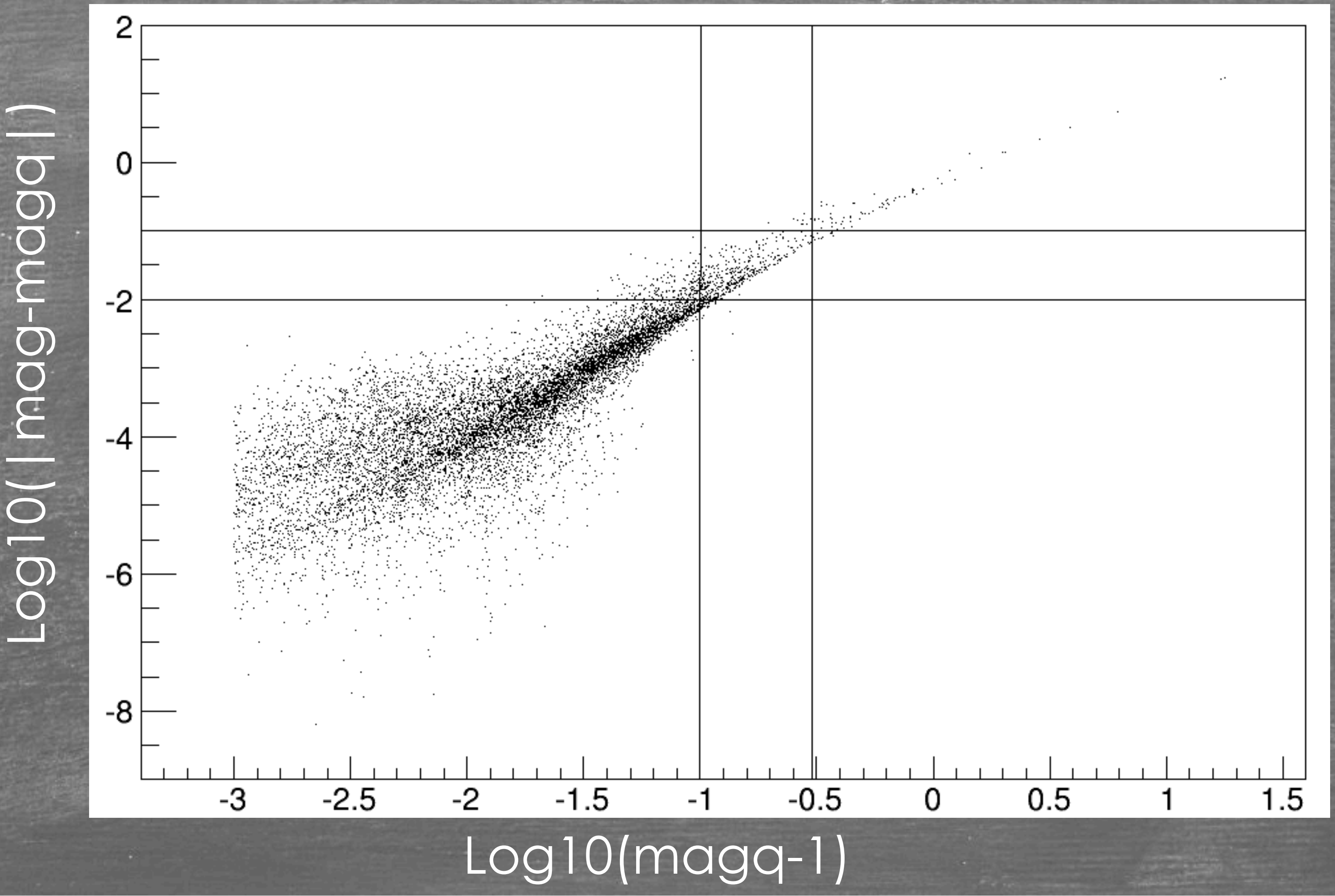
Plots on difference of qlet and getmag



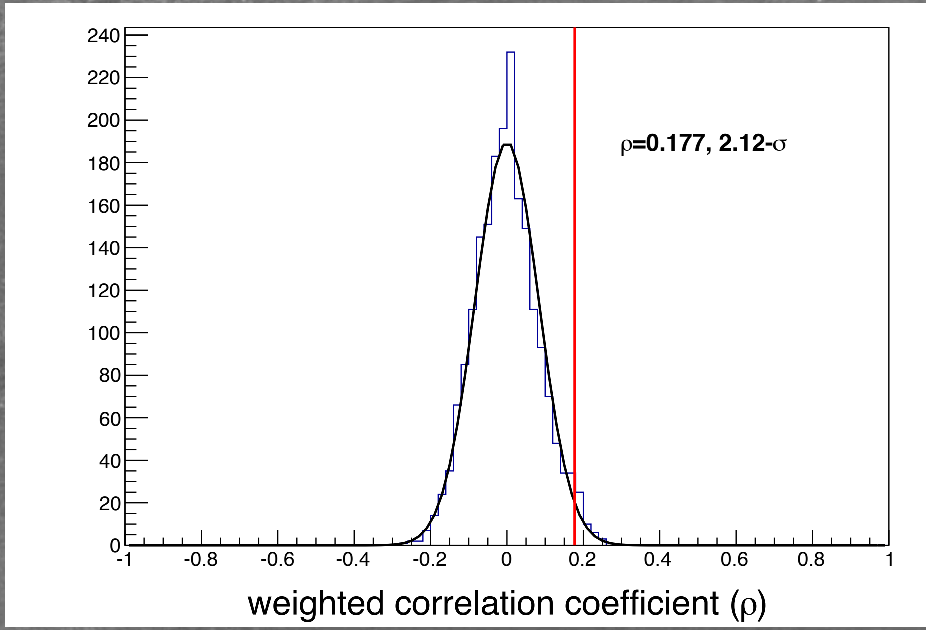
This is the business part and 1st order approximation is loosing out on some higher orders which matters.
Higher correlation is obtained here

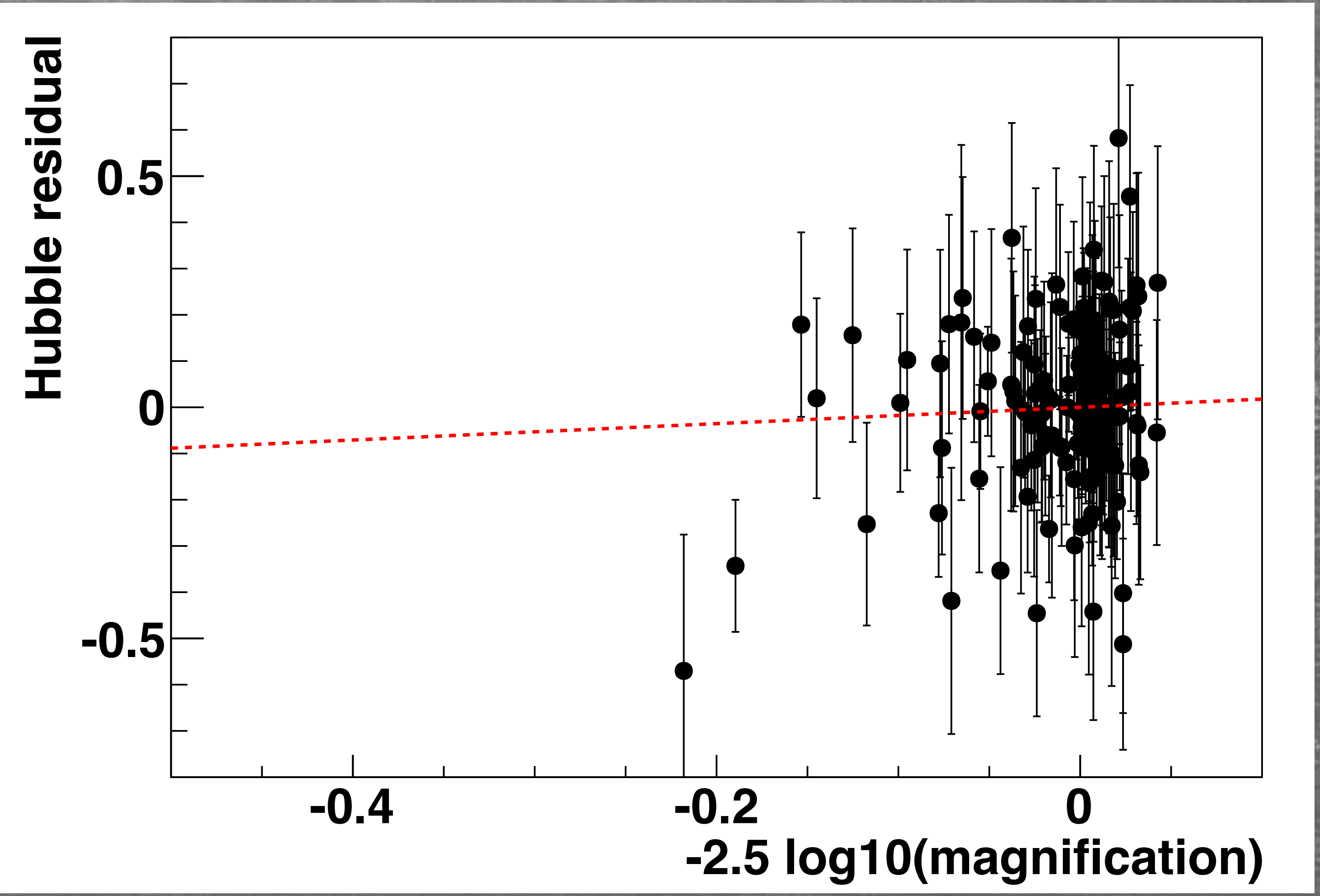
The result of Jonsson et.al 2010 ie deviation in value < 5% is good in "weak lensing regime"

Plots on difference of qlet and getmag



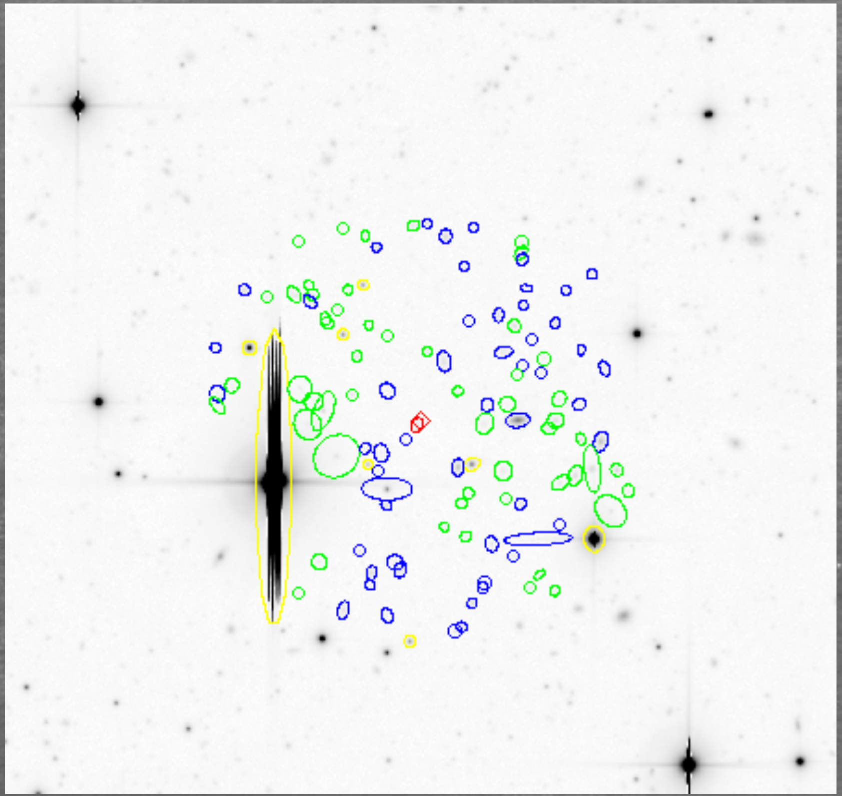
With SNLS3 new Line of sight magnification values

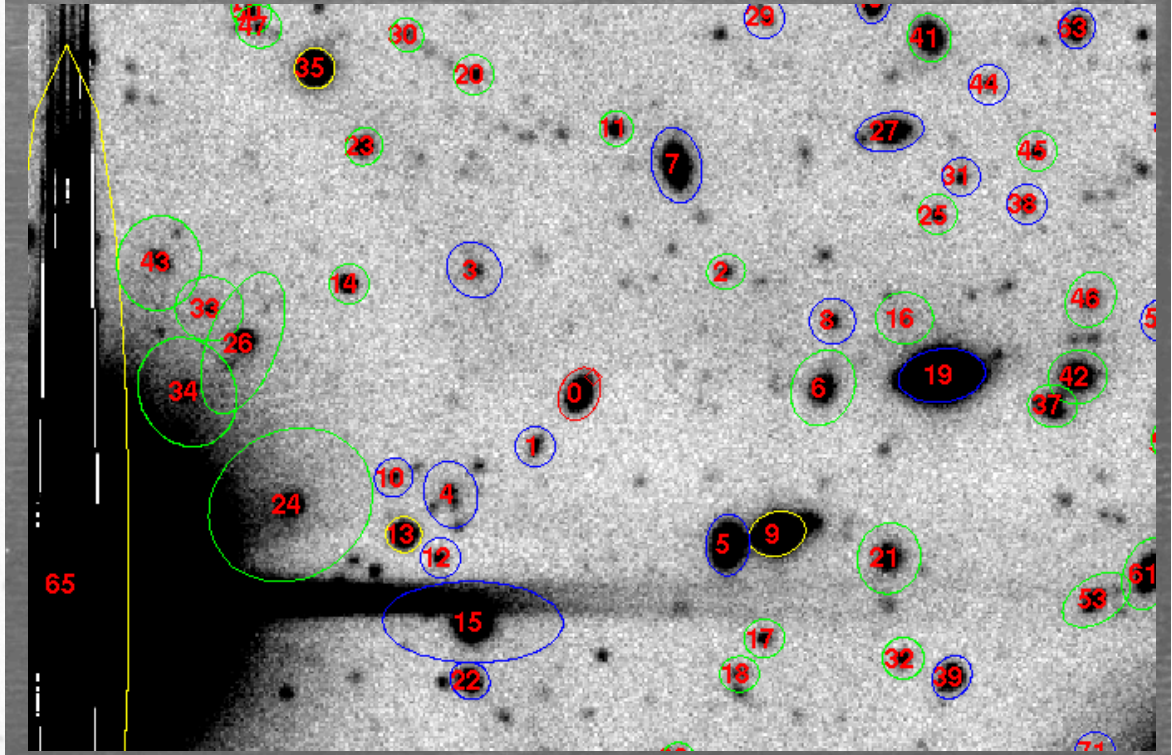




Masking

- Masking : it is the process of identifying and masking the regions with excessive brightness/flux that otherwise affect the surroundings. For example : secluding regions with very bright stars





SN 03D4cy (z = 0.927)