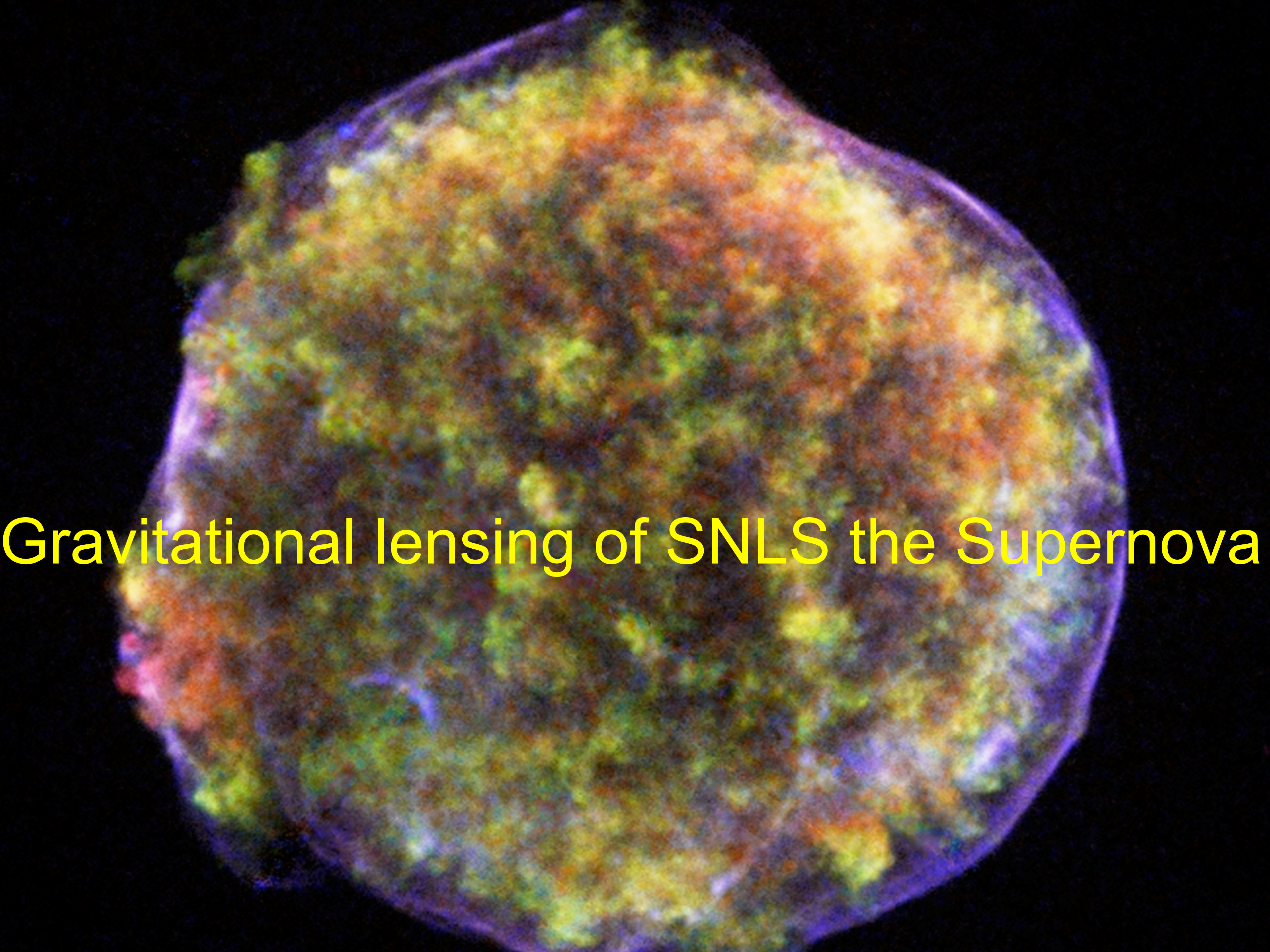
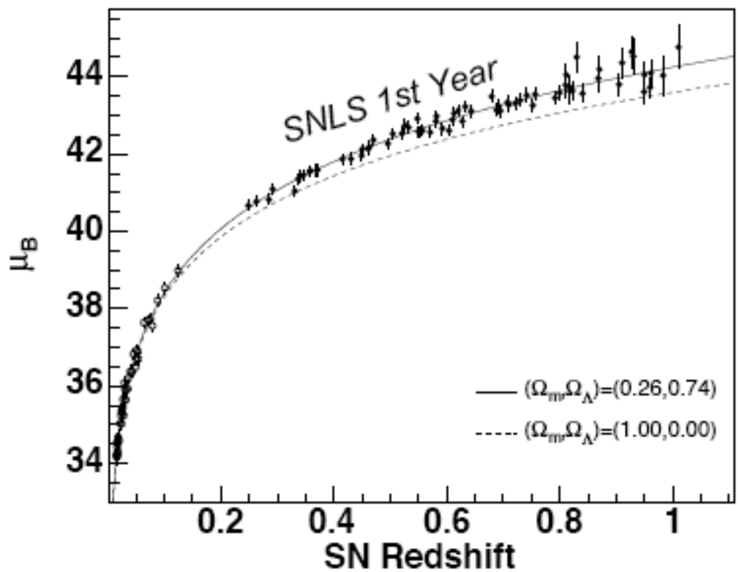
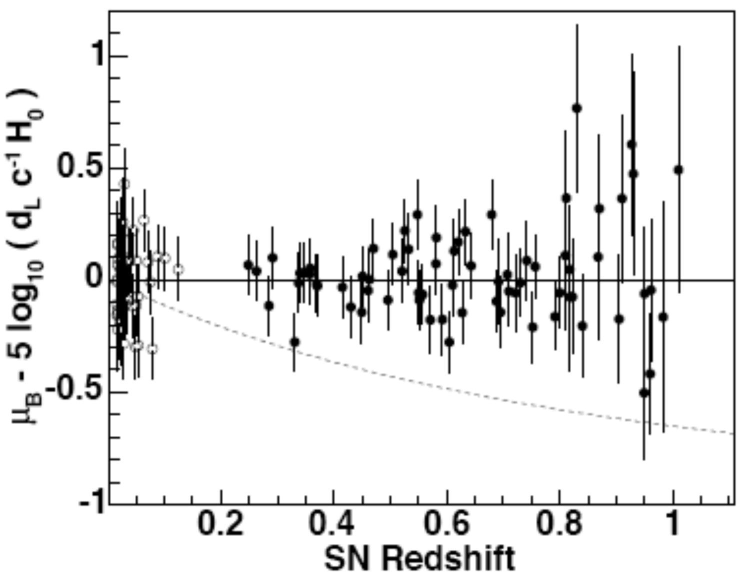
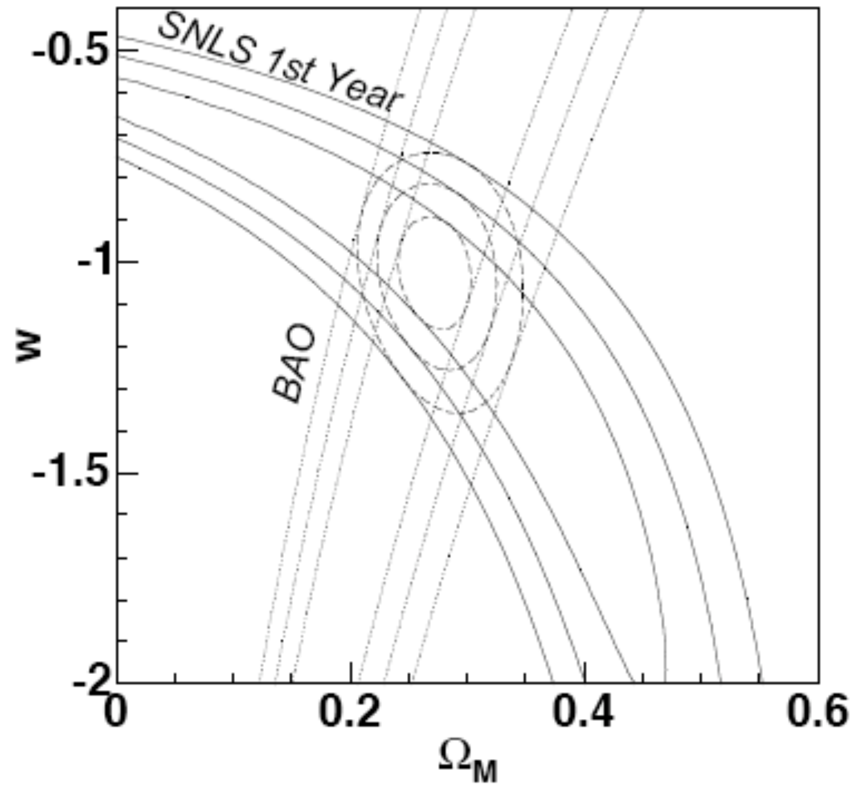

Gravitational lensing of SNLS the Supernova

First Year Results from CFHT SNLS

Astier et al (astro-ph/0510447)







Goal: measure the dark energy equation of state

71 homogenously studied SNe Ia

w = -1.023 ± 0.090

Gravitational lensing

One of the consequences of GR is that light rays are deflected by gravity

Gravitational lensing depends solely on the projected, two-dimensional mass distribution of the lens, and is independent of the luminosity and the composition of the lens.

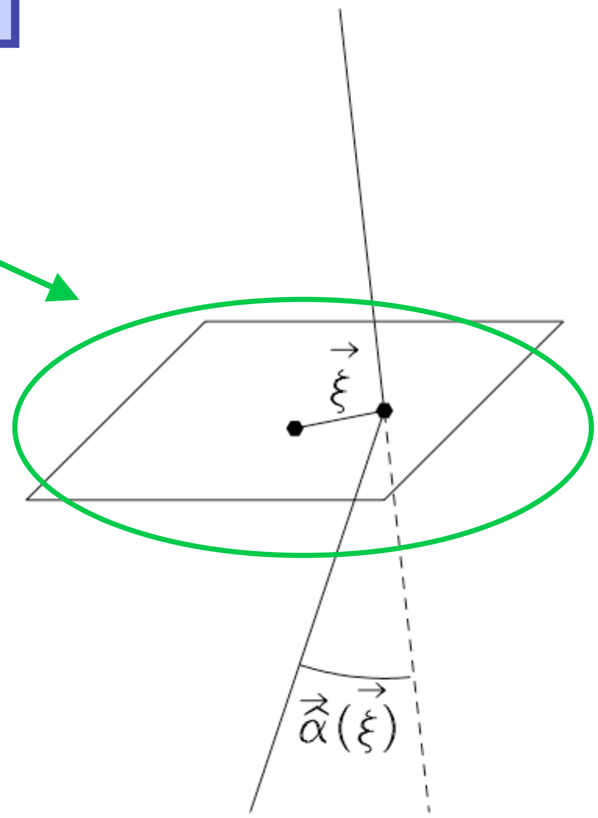
⇒ Ideal way to detect and study dark matter

The thin screen approximation

Valid when the distance between observer and lens and lens and source is much bigger than the size of the lens

The mass of the lens is projected onto a mass sheet orthogonal to the line-of-sight

= lens plane



Surface mass density

$$\Sigma(\vec{\xi}) = \int \rho(\vec{\xi}, z)\, dz$$

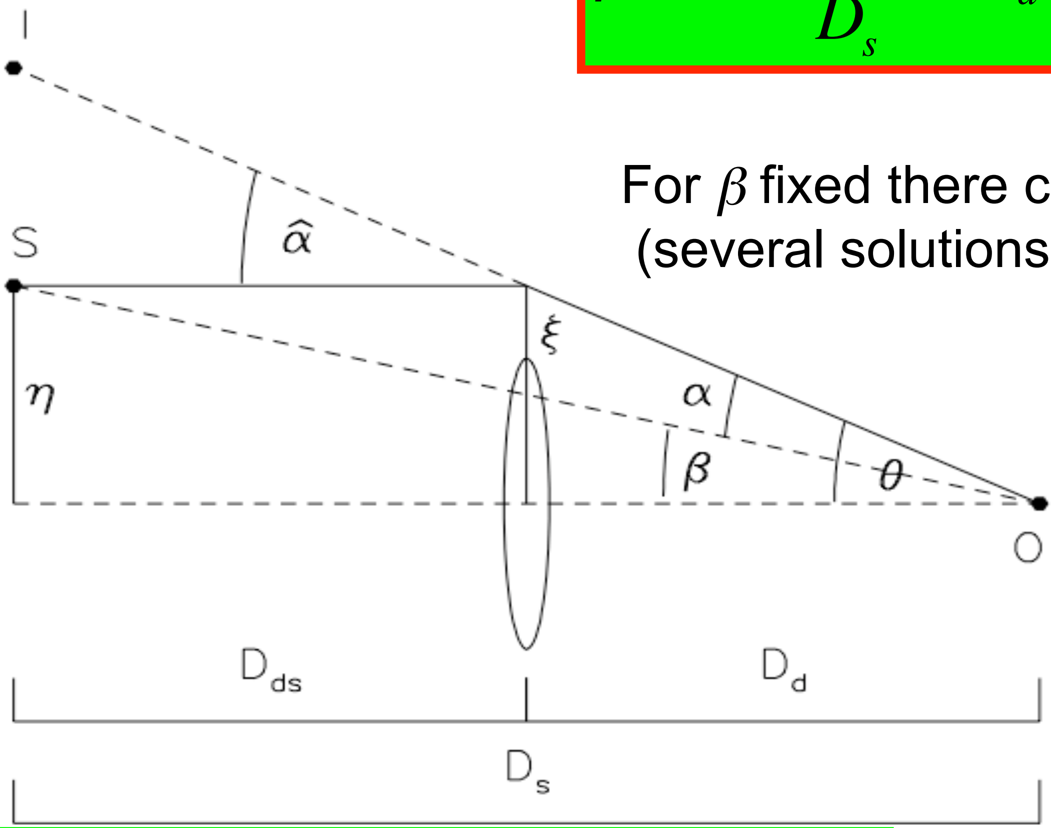
Sum of deflection angles due to all mass elements in the plane

$$\vec{\hat{\alpha}} = \frac{4G}{c^2} \int d^2\xi' \, \Sigma(\vec{\xi}') \frac{\vec{\xi} - \vec{\xi}'}{\left|\vec{\xi} - \vec{\xi}'\right|^2}$$

The lens equation

$$\vec{\xi} = D_d \vec{\theta}$$
$$\vec{\eta} = D_s \vec{\beta}$$

$$\vec{\beta} = \vec{\theta} - \frac{D_{ds}}{D_s} \vec{\hat{\alpha}}(D_d \vec{\theta}) = \vec{\theta} - \vec{\alpha}(\vec{\theta})$$



For β fixed there can be several positions in the sky (several solutions)

→ Multiple images

Jacobien matrix of the lens equation

$$A(\vec{\theta}) = \frac{\partial \vec{\beta}}{\partial \vec{\theta}}$$

→

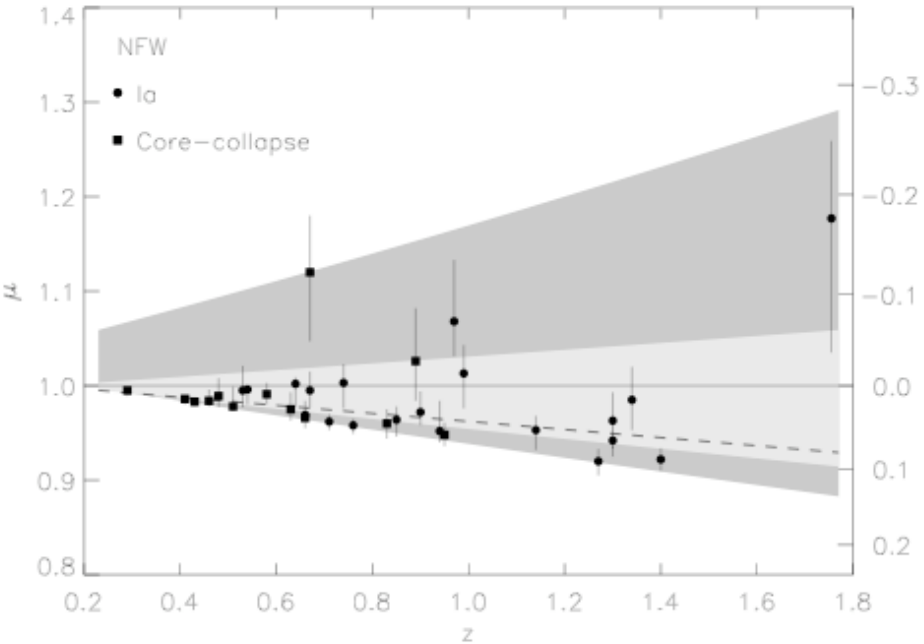
Magnification factor

$$\mu = \frac{1}{\det A}$$

Why is this interesting for us?

The light from a supernova will experience gravitational lensing due to galaxies, clusters or other matter densities in the line-of-sight and this will cause an additional dispersion in the observed source luminosities

Most of the Sne are demagnified and some are significantly magnified



Jonsson et al. 2006

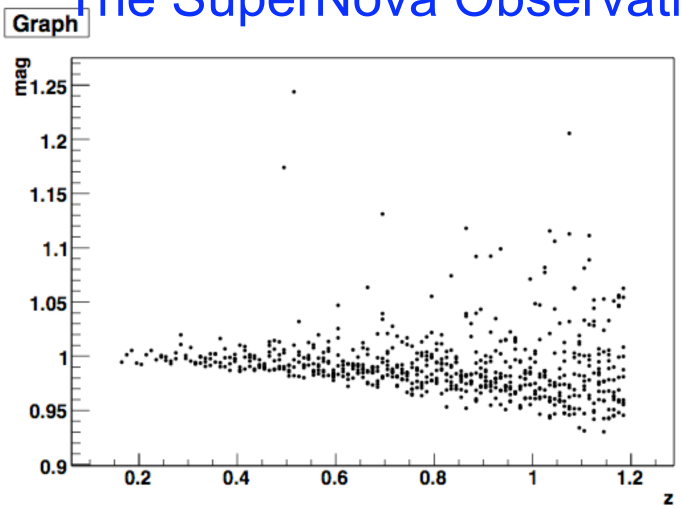
Questions to be addressed:

-Can the intrinsic scatter in the Hubble diagram be further reduced?
-Is it possible to detect a correlation between residuals and magnification?
-Is it possible to say something about the dark matter distribution of the galaxies?

First estimate (a feasibility check)

700 simulated type Ia Sne using SNLS Sne observations
(Astier et al 2006)

Magnification of each supernova is estimated using SNOC
The SuperNova Observation Calculator *Goobar et al (astro-ph/0206409)*



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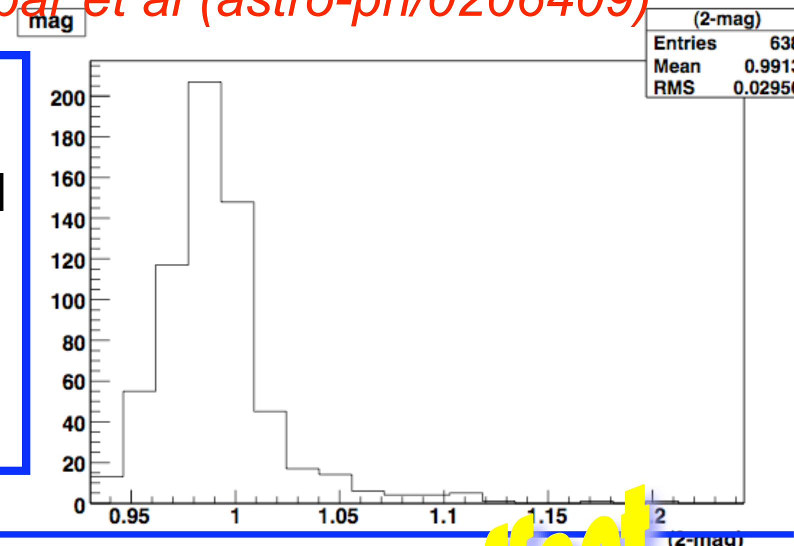


Cosmological results

$\delta\Omega_M$ and δw due to lensing ~ 2-3 %
Uncertainties due to lensing ~ 1-2%

small effect

$$w = w_0 + w'(a - a_0)$$

Lensing accounts for **7.5%** of the dark energy task force figure of merit

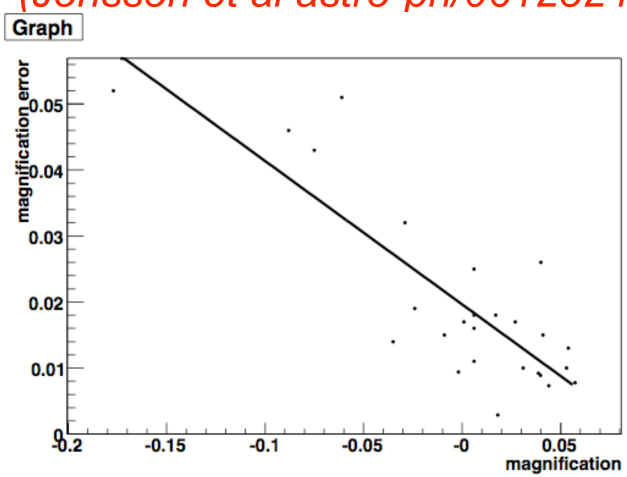
Is it possible to detect a signal ?

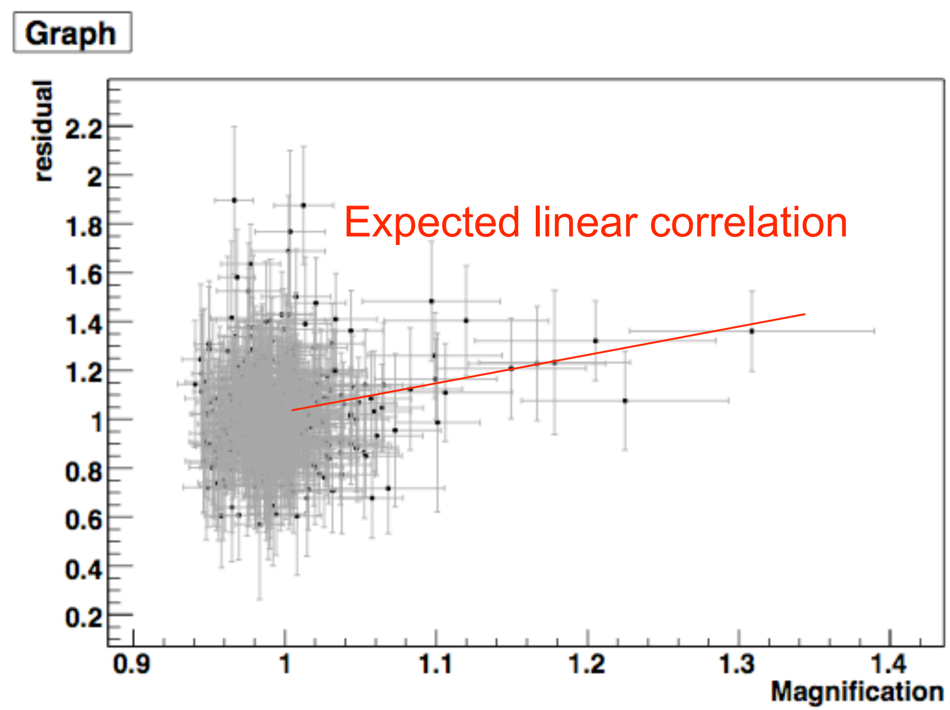
Expected standard candle brightness
(calculated from a cosmological model)

Correlation ⟷ Magnification

→ **Plots of residuals vs magnification**

For estimations of the magnification errors, a work on the GOODs fields has been used
(Jonsson et al astro-ph/0612324)





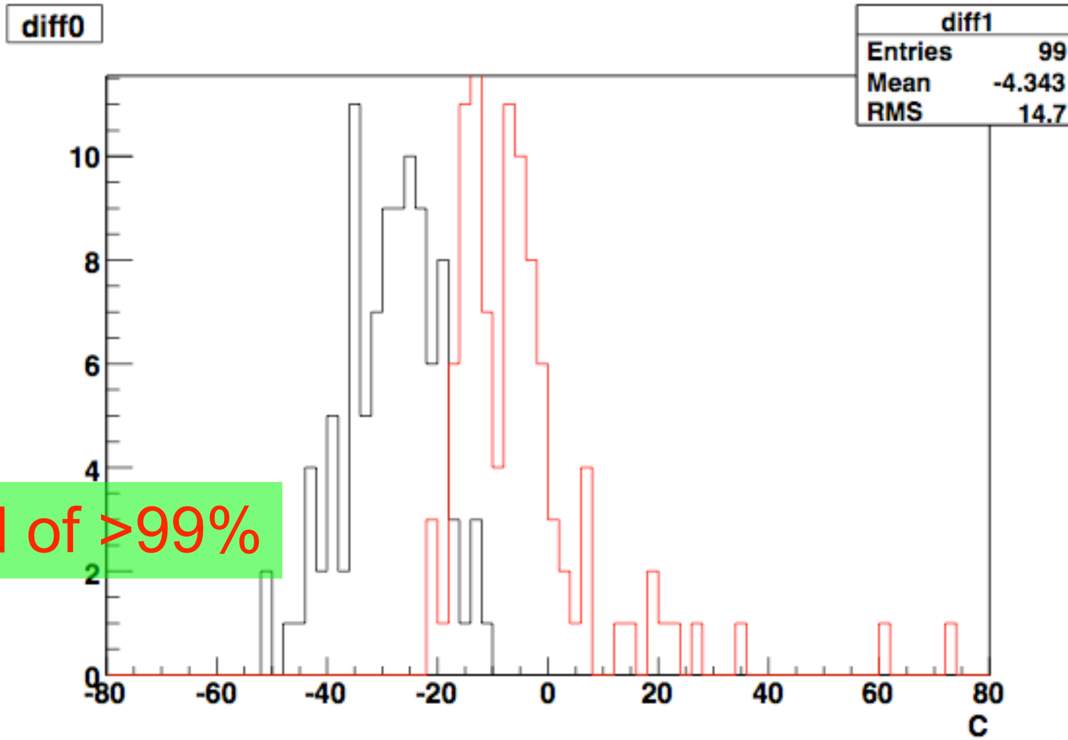
Likelihood ratio

$$C = \chi^2(\text{no correlation}) - \chi^2(\text{linear correlation})$$

2 different samples:

-with lensing effects

-without lensing effects



Confidence level of >99%

ANALYSIS OF THE SNLS DATASET

Analysis chain

Actual data
Galaxy catalogue including magnitudes in the g r i (u) and z - bands + photometric redshift

Using PEGASE : a UV to NIR spectral evolution model of galaxies
- → type
- → absolute magnitudes
- → all sorts of things

Galaxy type + B-band absolute magnitude

Conversion of luminosity into velocity dispersions or virial masses using results based on galaxy-galaxy lensing or the Faber-Jackson / Tully-Fisher relations.

Estimation of the mass of the galaxy using galaxy models like SIS or NFW
Estimation of the eta-parameter

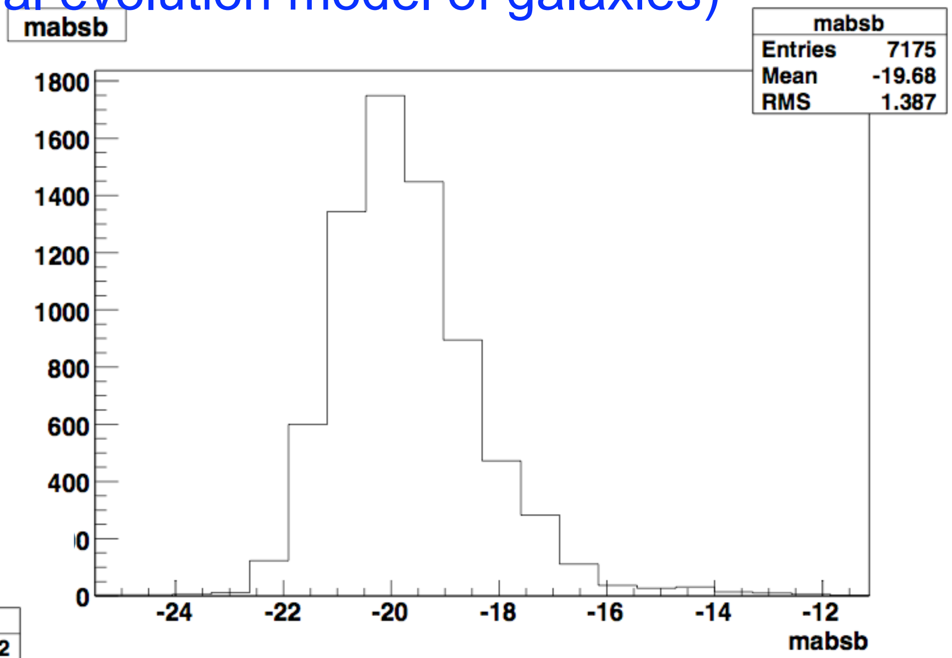
Using Q-LET, a multiple lens plane algorithm which calculates the magnification with respect to a homogeneous universe

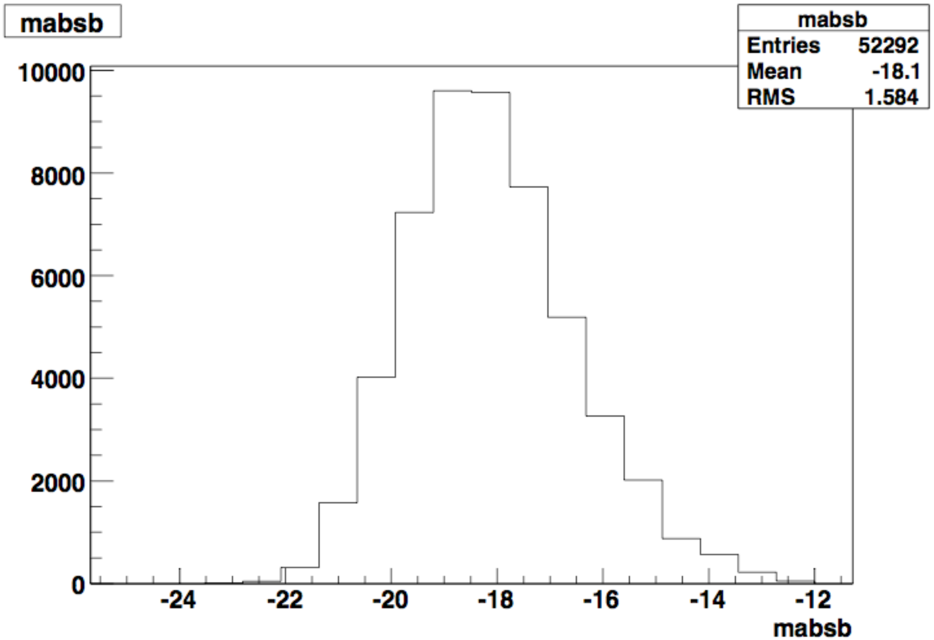
Estimation of the magnifi-cation of each SNe

Pegase (a UV to NIR spectral evolution model of galaxies)

-Photometric redshift code

-Fits redshifted spectral templates





→ templates

→ Absolute B-band magnitudes

Conversion of luminosity into velocity dispersion or virial mass

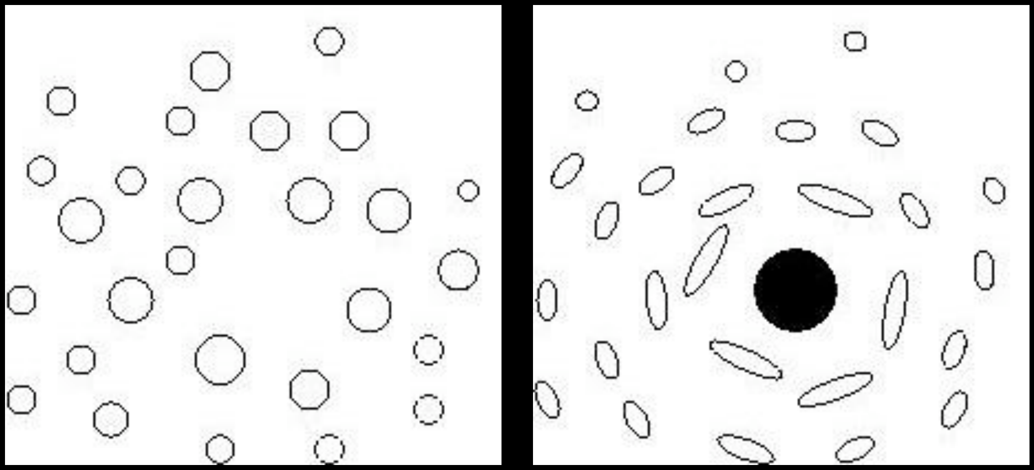
2 promising methods:	
Galaxy-galaxy lensing	Faber-Jackson / Tully-Fisher relations

Investigation of 5 different papers and their results
(3 galaxy-galaxy lensing papers and 2 FJ/TF papers)

Hoekstra et al. 2004/2005 RCS	Bohm et al. (2004) FORS Deep Field
Kleinheinrich et al. 2005 COMBO-17	Mitchell et al. (2005) SDSS

Galaxy-galaxy lensing

Images of background galaxies are distorted by foreground galaxies.



Tangential ellipticity is proportional to tangential shear, γ_t

$$\gamma_t = \varepsilon_t$$

Shear is a measure of the total mass (dark and luminous)

$$\gamma_t (r) \sim \Sigma(<r) - \Sigma(r)$$

BUT

One can only study ensemble averaged properties, because the weak lensing signal induced by an individual galaxy is too low to be detected.

Measured quantity = the **mean** tangential shear divided into angular bins.

Fit the signal with an assumed halo model

NFW

SIS

Extraction of physical properties of the halo such as velocity dispersion and masses.

Halo models

SIS Isothermal Sphere

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

$$\gamma_T = \frac{2\pi\sigma_v^2}{c^2\theta}\beta$$

Velocity dispersion

NFW Navarro Frenk White

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

$$M_{vir} = \frac{800\pi}{3}\rho_c r_{vir}^3$$

Virial mass/radius

Scaling relations

The lensing signal depends on the angular diameter distance between observer, lens and source which is different for each survey.

What to do?

Answer:

Scale the results to a fiducial luminosity L*

$\frac{\sigma}{\sigma_*} = \left(\frac{L}{L_*}\right)^{\alpha}$	$\frac{M}{M_*} = \left(\frac{L}{L_*}\right)^{\beta}$	$L_* = 10^{10} h^{-2} L_{B\oplus}$

Difficulties

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Selection and contamination	Contamination by groups or clusters Different color splits	

The Faber-Jackson/Tully-Fisher relations

The Faber-Jackson or Tully-Fisher relations relates the velocity dispersion and the Luminosity of the galaxy.

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

F-J relation (ellipticals)
Mitchell et al. (2005)

$$\log_{10}\sigma = -0.091(M_B - 4.74 + 0.85z)$$

30,000 galaxies

T-F relation (spirals)
Bohm et al. (2004)

$$\log_{10}V_{\max} = -0.134(M_B + 3.61 + 1.22z)$$

$$\sigma = V_{\max}/\sqrt{2}$$

77 galaxies

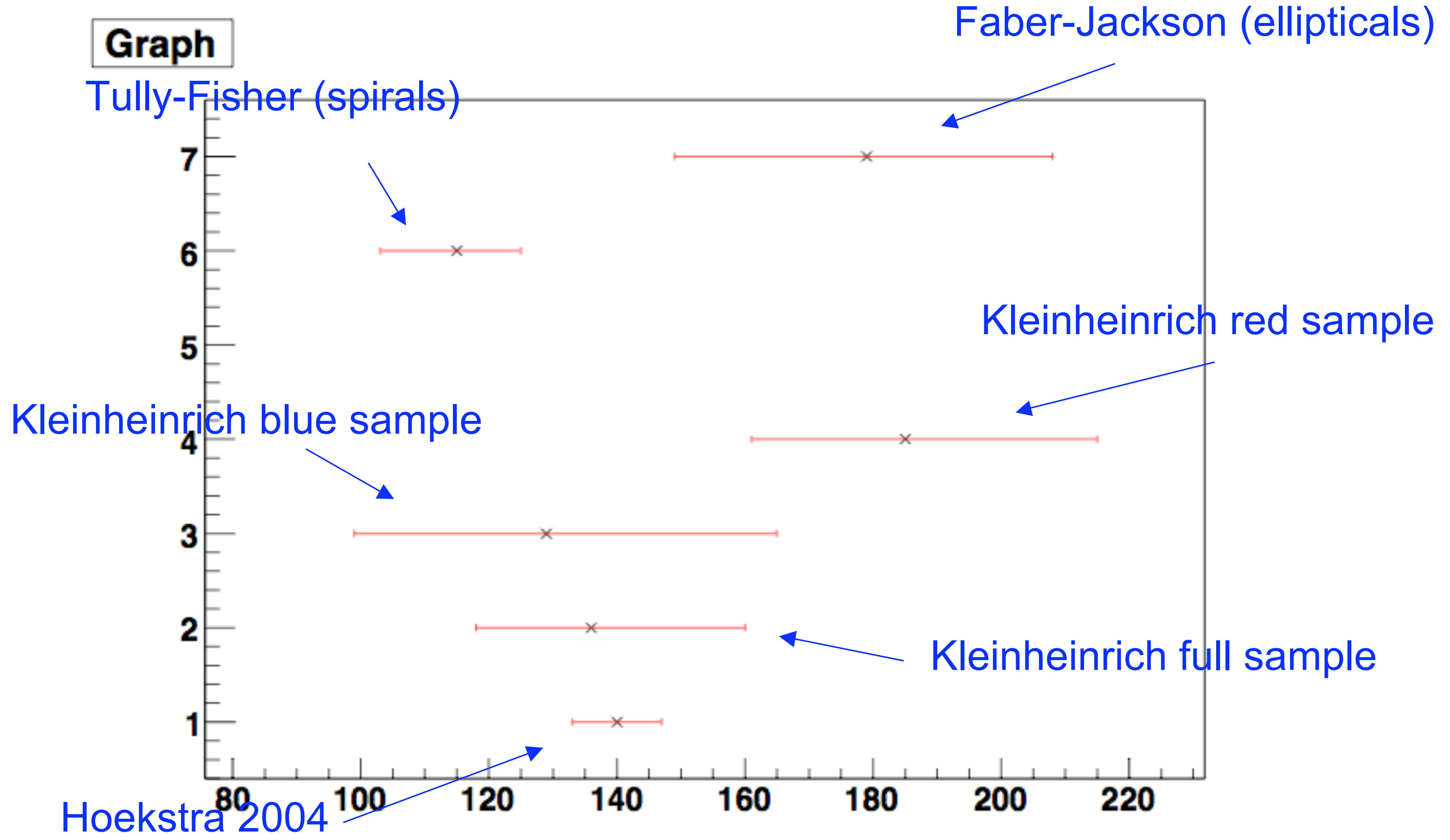
paper	scaling parameter α	σ_* km/s
Hoekstra et al. 2004	0.3	$140 \pm 4 \pm 3$
Kleinheinrich et al. full sample blue sample (but scale = $150h^{-2}$kpc) red sample (but scale = $150h^{-2}$kpc)	$0.28^{+0.12}_{-0.09}$ $0.22^{+0.15}_{-0.15}$ $0.28^{+0.15}_{-0.12}$	136^{+18}_{-24} 130^{+30}_{-36} 185^{+24}_{-30}
Tully-Ficher relation (spirals)	0.33	115^{+12}_{-10}
Faber-Jackson relation (ellipticals)	0.23	149^{+30}_{-29}

Table 1: Results for the SIS model.

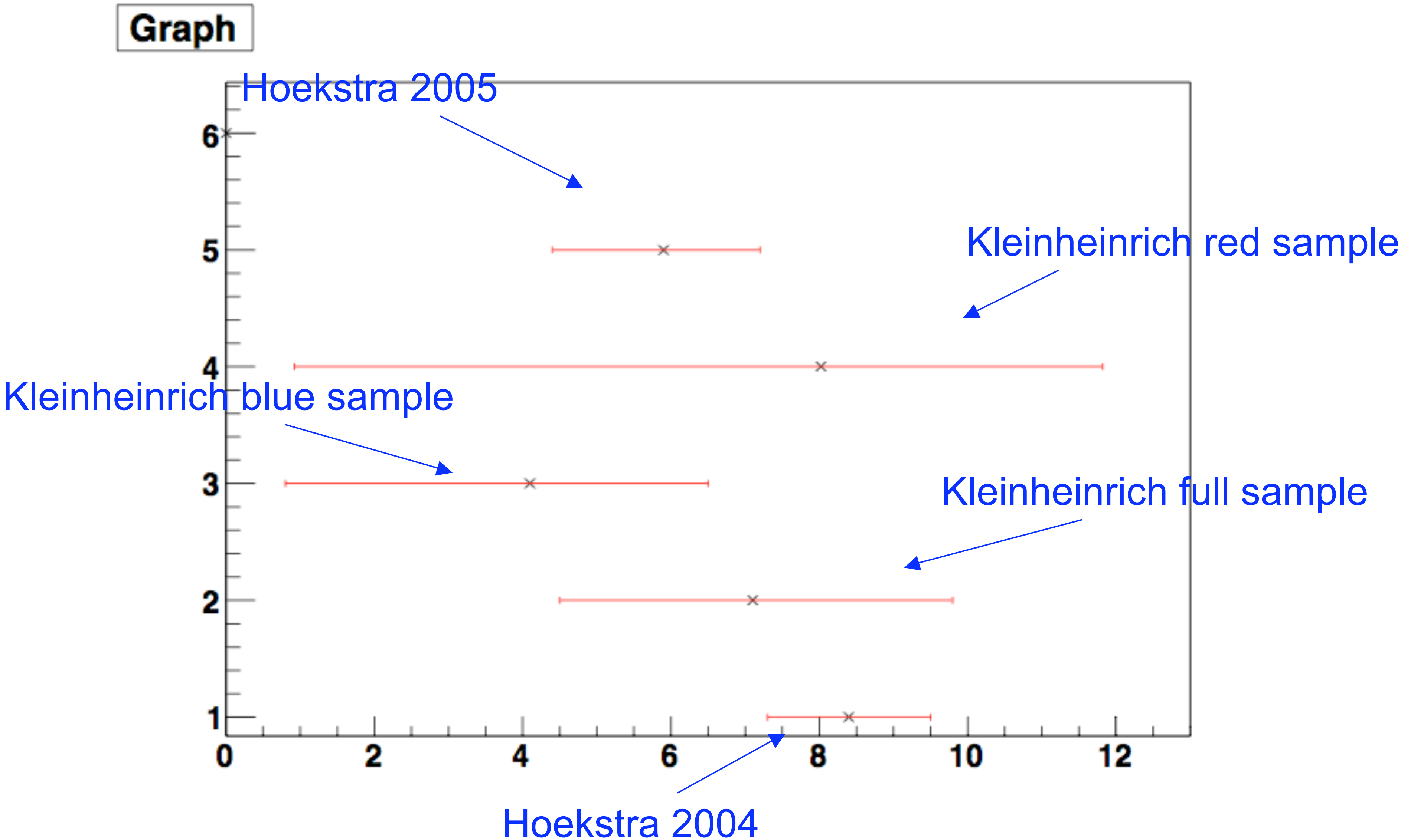
paper	scaling parameter β	M_{vir} $10^{11}h^{-1}M\odot$
Hoekstra et al. 2005	1.5±0.3	$5.9^{+1.5}_{-1.3}$
Kleinheinrich et al. full sample blue sample red sample	$0.9^{+0.36}_{-0.48}$ $0.54^{+0.60}_{-0.36}$ $1.26^{+0.48}_{-0.60}$	$7.1^{+2.6}_{-2.7}$ $4.1^{+3.3}_{-2.4}$ $8.02^{+7.1}_{-3.8}$
Hoekstra et al. 2004	1.2	$8.4 \pm 0.7 \pm 0.4$

Table 2: Results for the NFW model.

Velocity dispersions



Virial mass


Graph
Hoekstra 2005
Kleinheinrich red sample
Kleinheinrich blue sample
Kleinheinrich full sample
Hoekstra 2004
1
2
3
4
5
6
0
2
4
6
8
10
12

η The smoothness parameter

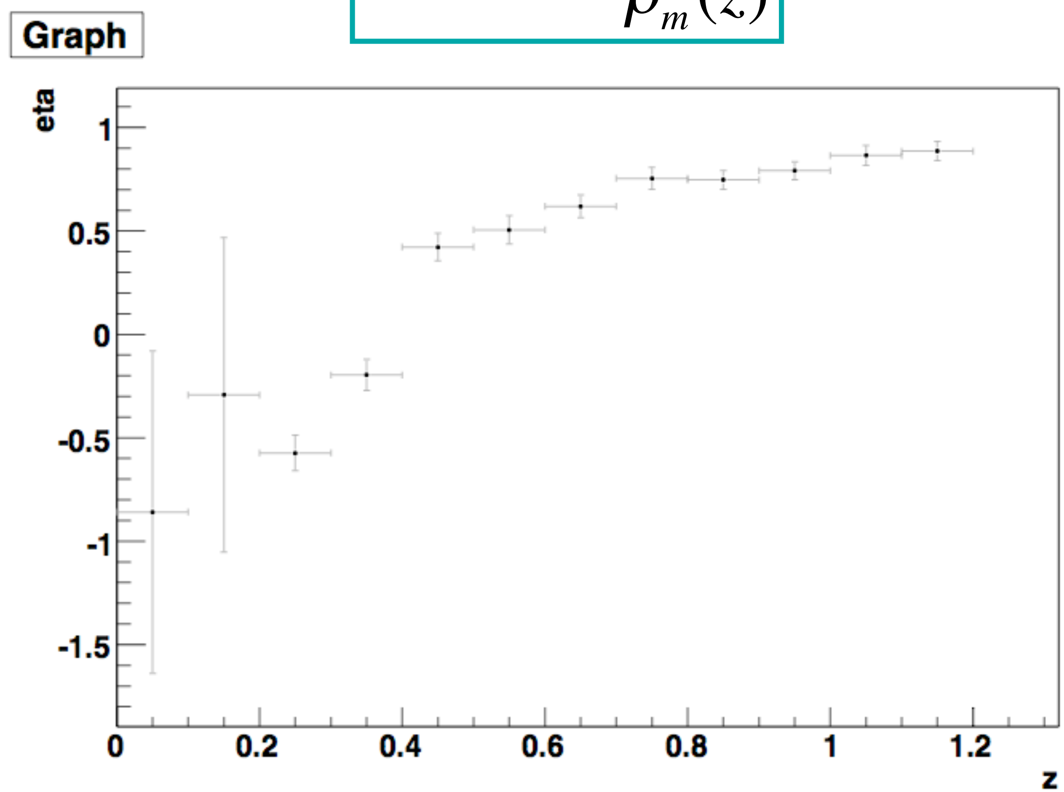
All “unobserved” matter is put into a smoothly distributed component.

$$\eta(z) = 1 - \frac{\rho_g(z)}{\rho_m(z)}$$

Difficulty:

How to infer the “correct” total mass of each galaxy?

Results from SIS and NFW give different mass



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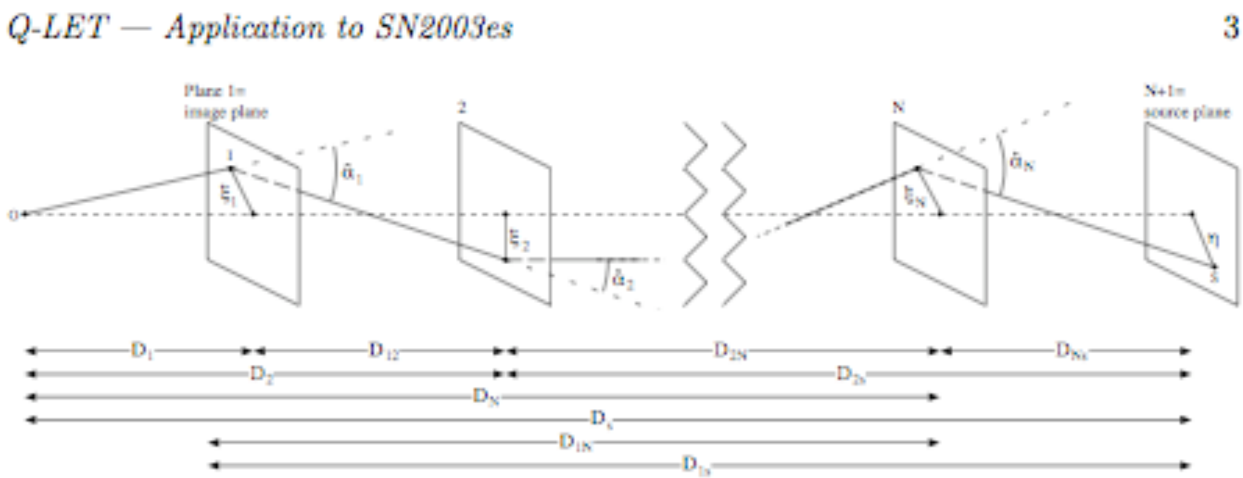
Q-LET

Q-LET is a program that enables a quick estimate of the gravitational lensing effects on a point source



Multiple lens-plane method

Input	Output
-Cosmological parameters + z of the sn -List of redshifts, distances to the line of sight, mass or velocity dispersions, halo models for all the galaxies in the line of sight	The magnification factor

Future work

- Estimation of the magnification of the 500 final Sne
- Look for the lensing signal (a correlation between the residuals in the Hubble diagram and the magnification)
- See wheather it is possible to constrain the halo masses of the galaxies


"That's all Folks!"