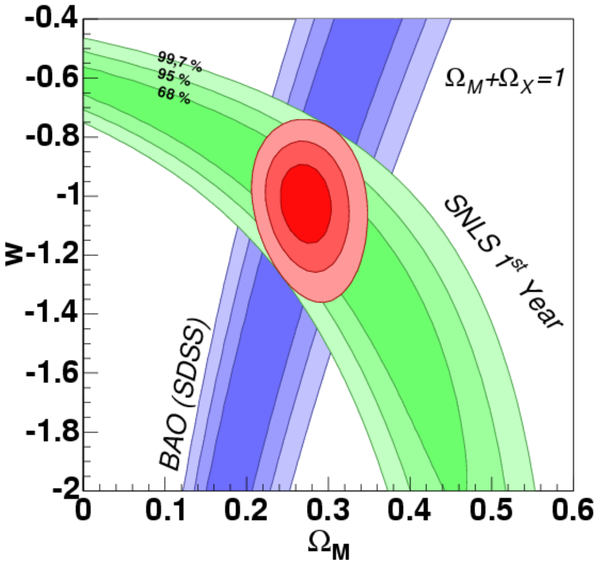
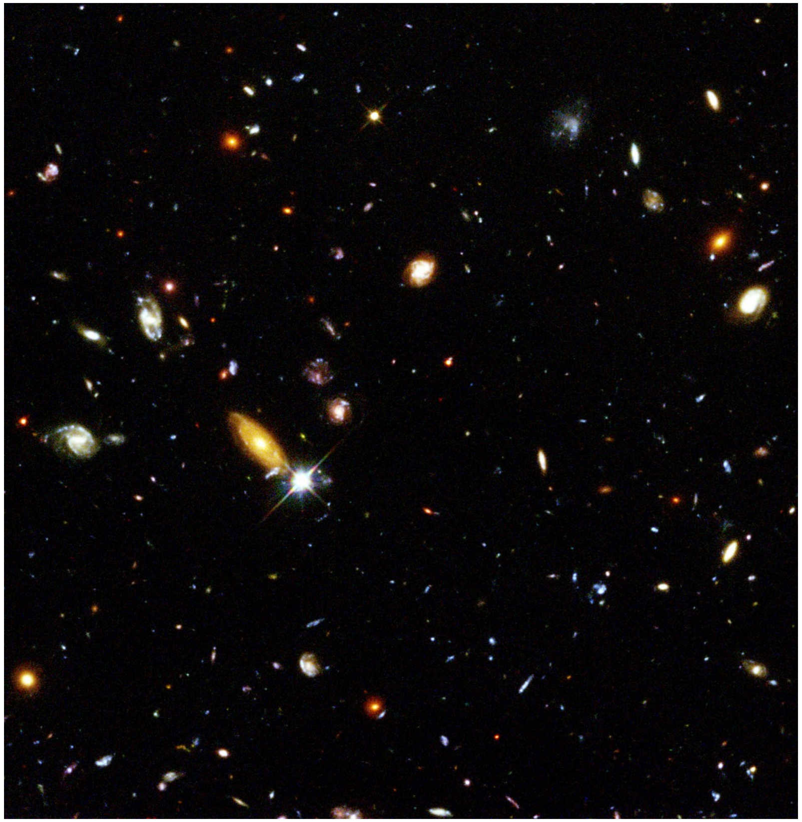
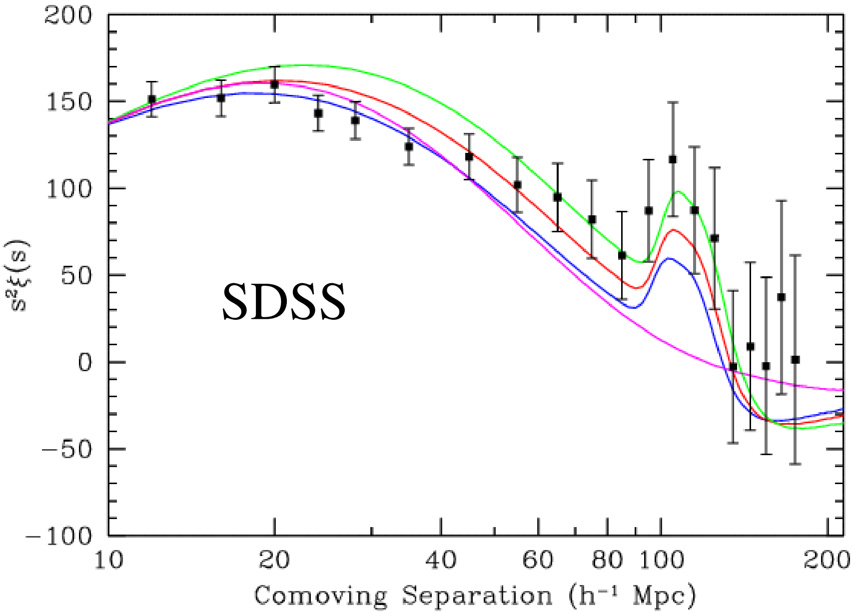
Large surveys







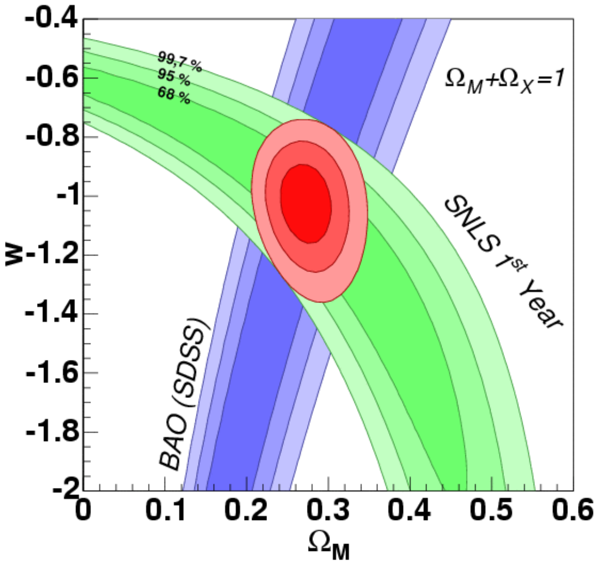
Pierre Astier
LPNHE/IN2P3/CNRS
Universités Paris VI&VII

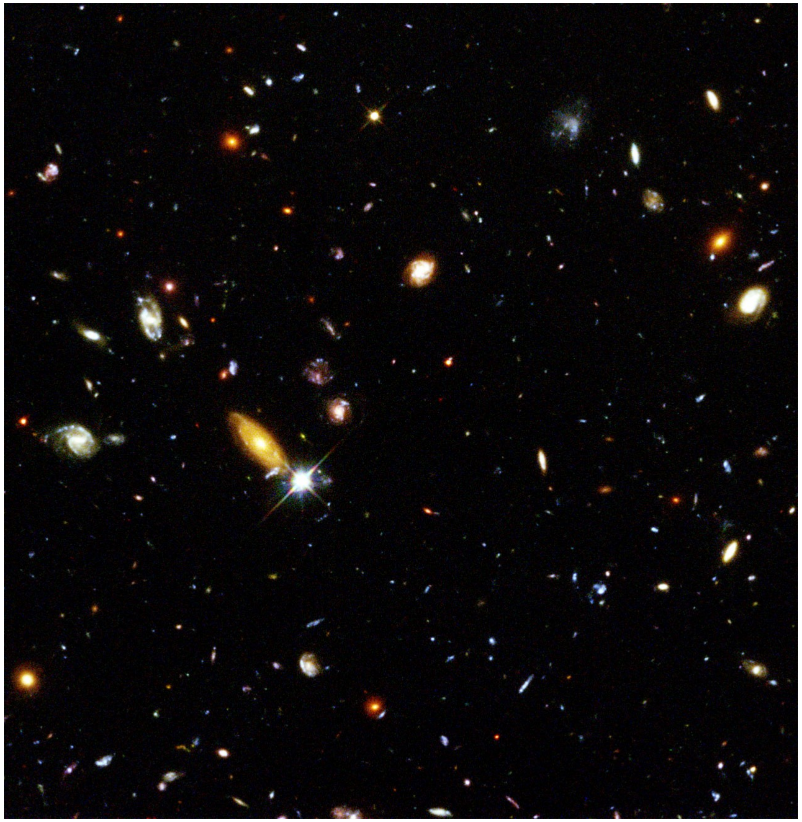
Rencontres de Blois
May 22nd 2008

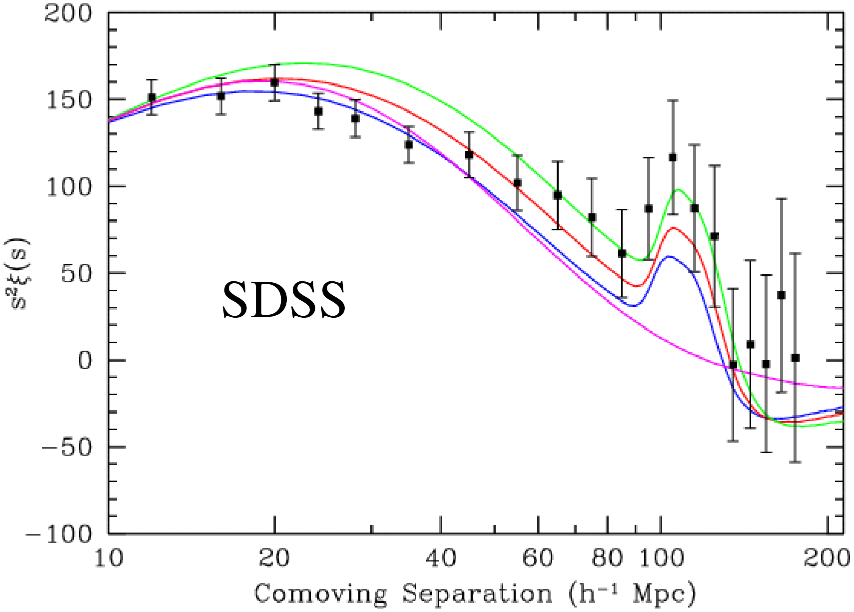
A biased sampling about

Large surveys

related to cosmological parameters







Pierre Astier
LPNHE/IN2P3/CNRS
Universités Paris VI&VII

Rencontres de Blois
May 22nd 2008

Outline

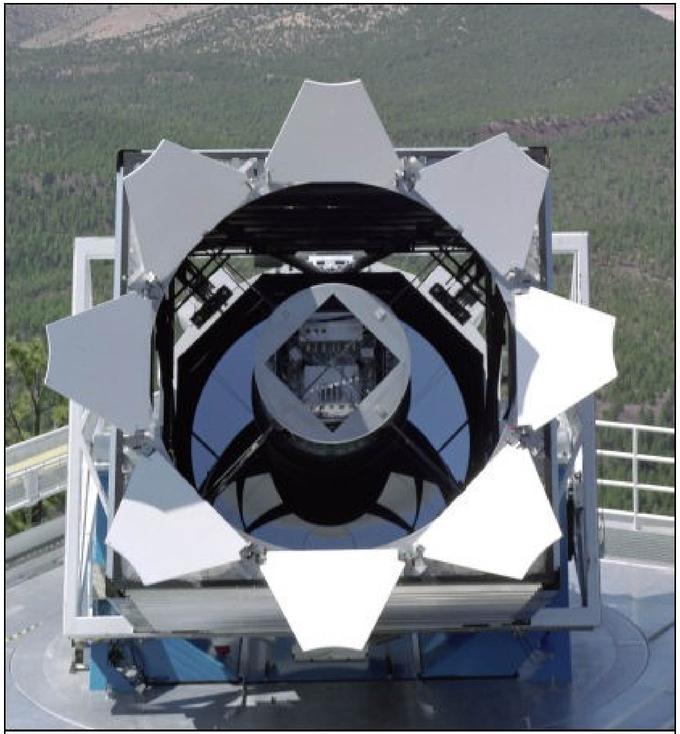
- The SDSS
  - A flavour of SDSS-I, II
- The CFHT Legacy survey
  - Instrument, survey operations
  - Weak lensing results
- Supernova surveys
  - SNLS, ESSENCE, SDSS-III
- Projects
  - Ground and space, photo-z

SDSS

(Sloan Digital Sky survey)

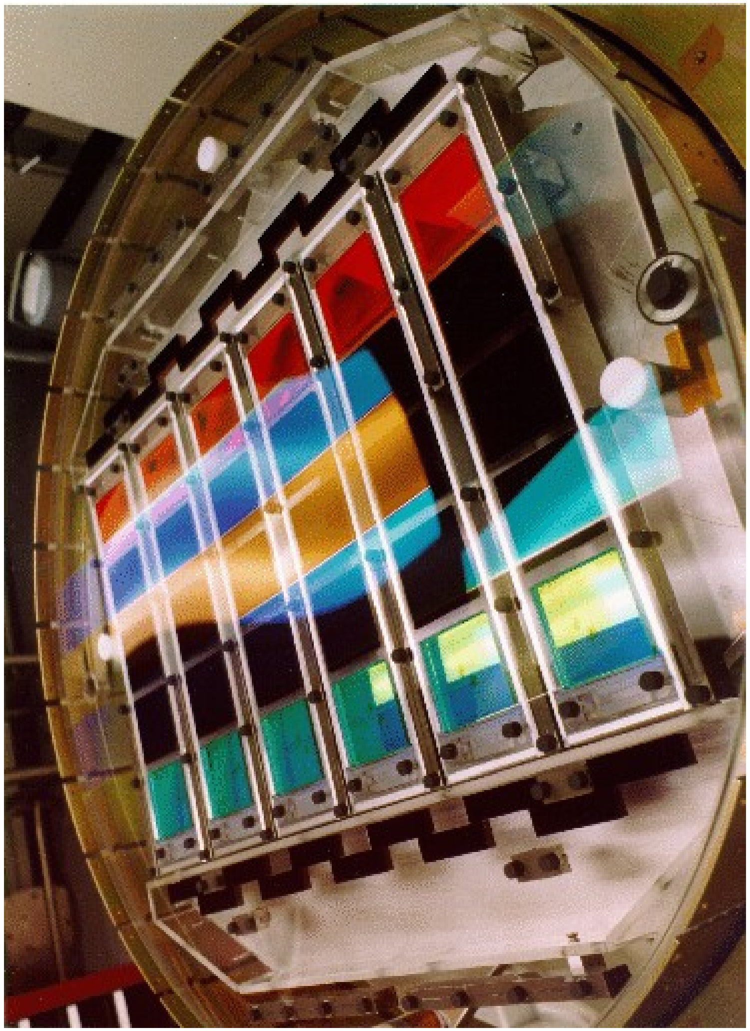
SDSS-I : 2000-5
SDSS-II : 2005-8
SDSS-III : 2008-14

- Imaging and spectroscopic survey
- Now reaching 8000 deg^2
  ~700,000 galaxy spectra
  + quasars, stars, ...
- Dedicated 2.5 m telescope
  (Apache Point, New Mexico)
- Images, spectra & catalogs
  released ~ once a year



SDSS SURVEY TELESCOPE

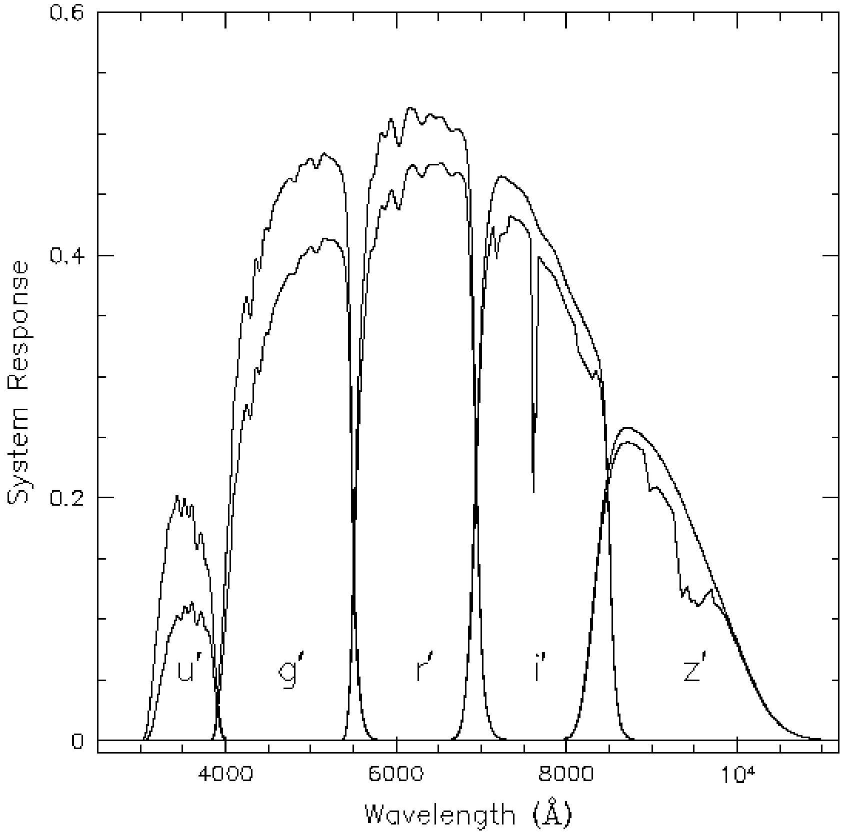
SDSS imaging camera



Drift scanning (56 s/band)

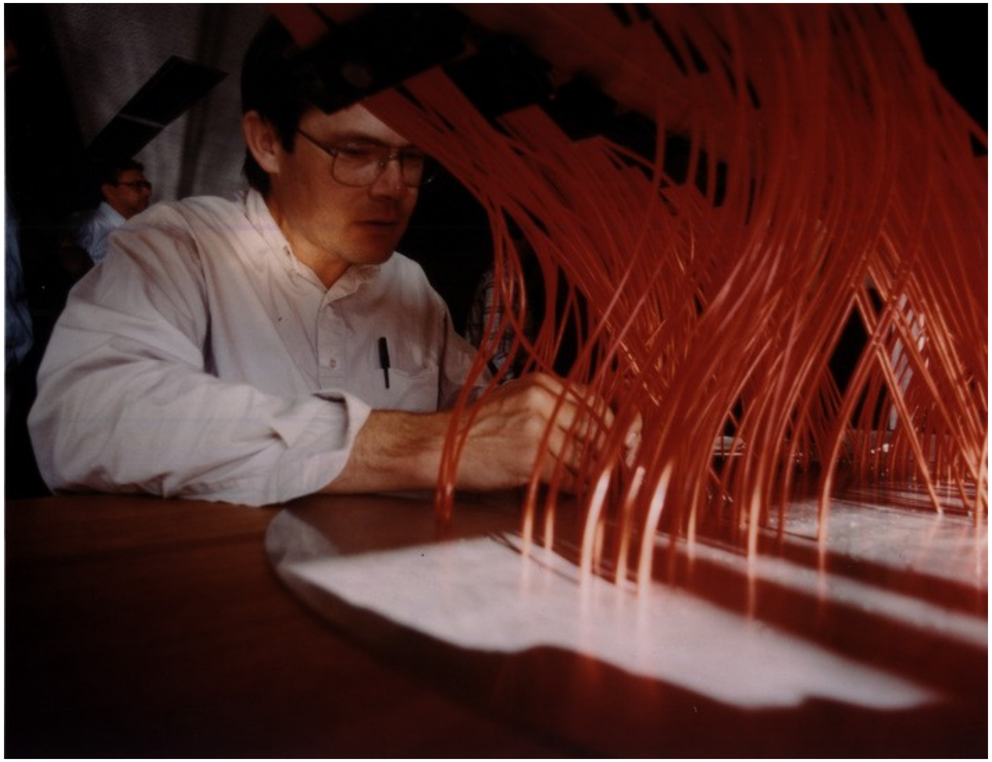
5 bands per visit

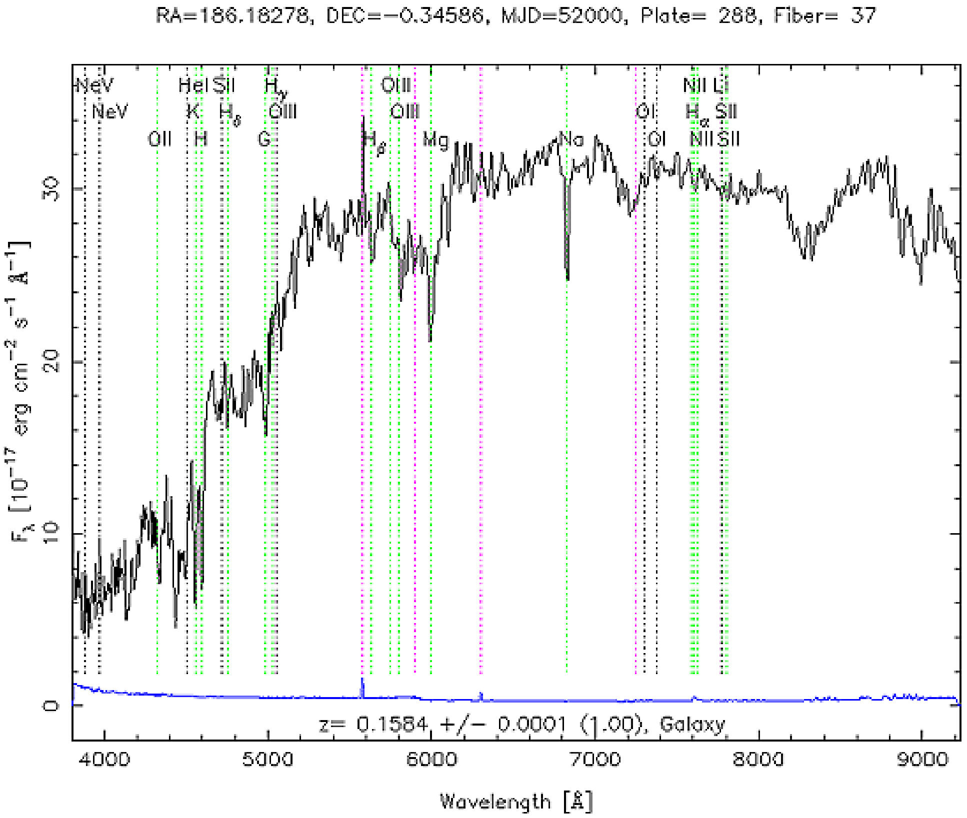
~ 225 deg^2 per night



SDSS spectroscopy

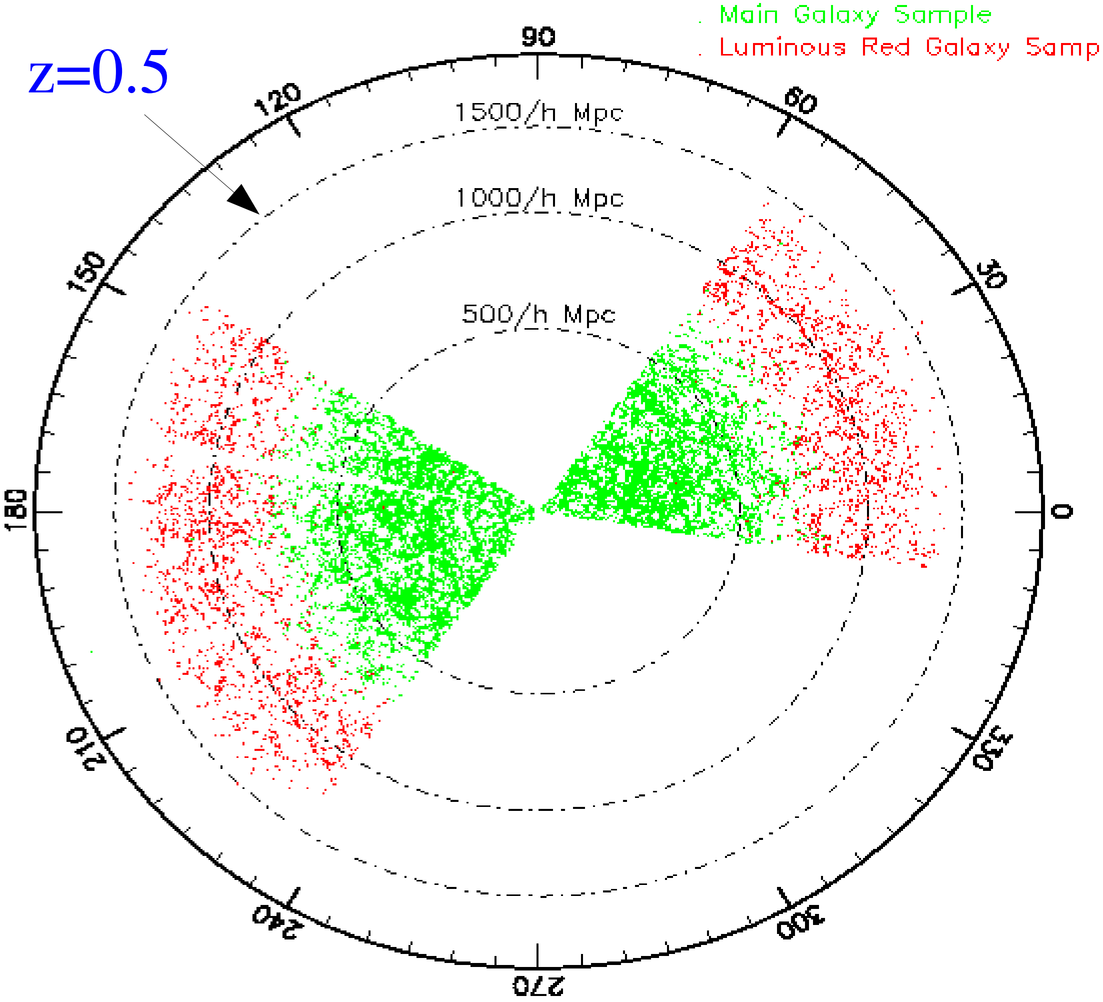
- Fiber-fed spectrograph :
  - ~ 600 objects per pointing
  - 7 deg^2 field-of-view.
- Fibers (manually) plugged in precision-drilled plates
- Up to 9 plates/night





P. Astier (Blois 22/05/08)

SDSS galaxy samples



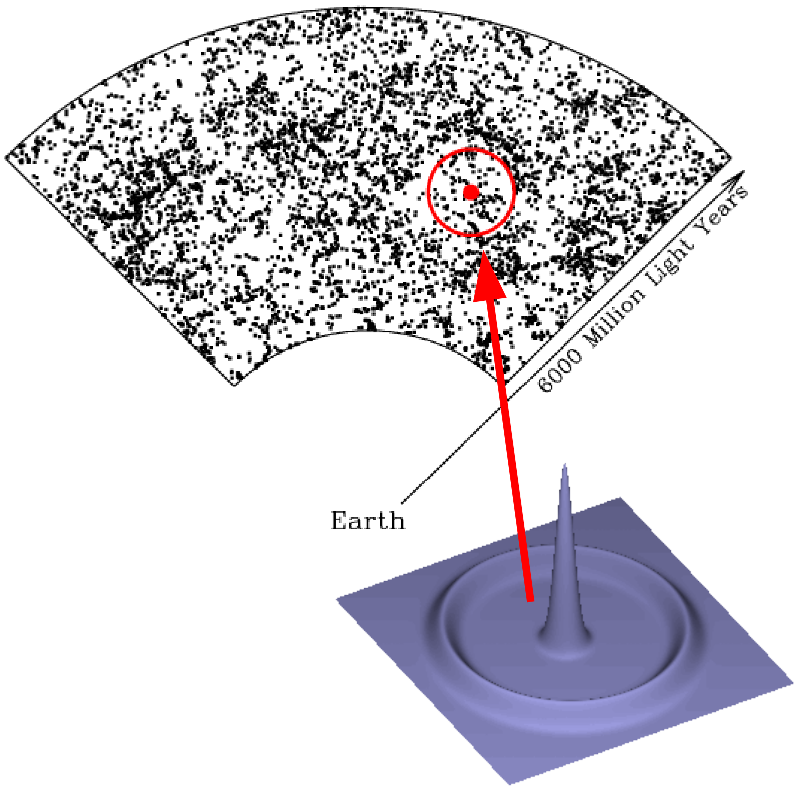
Luminous Red
Galaxies
$0<z<\sim 0.5$
coarse sampling

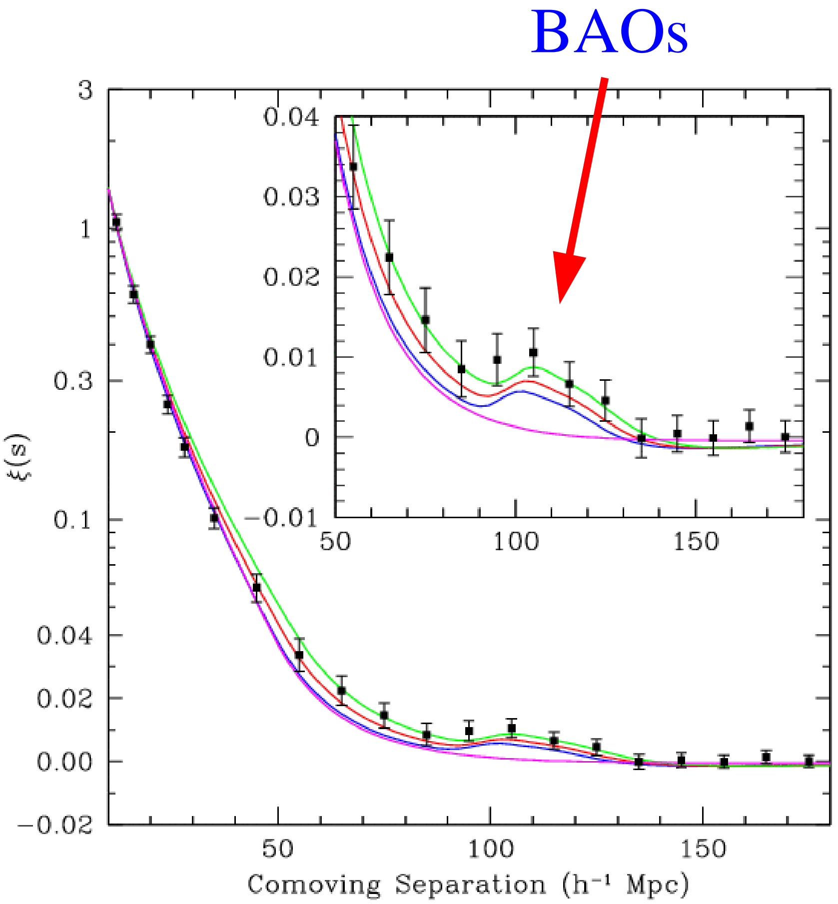
Main sample
$z<\sim 0.2$
dense sampling

SDSS : correlation function of LRGs

- 55000 Luminous Red Galaxies
- Over 4000 deg^2 up to z~0.48
- <z> = 0.35

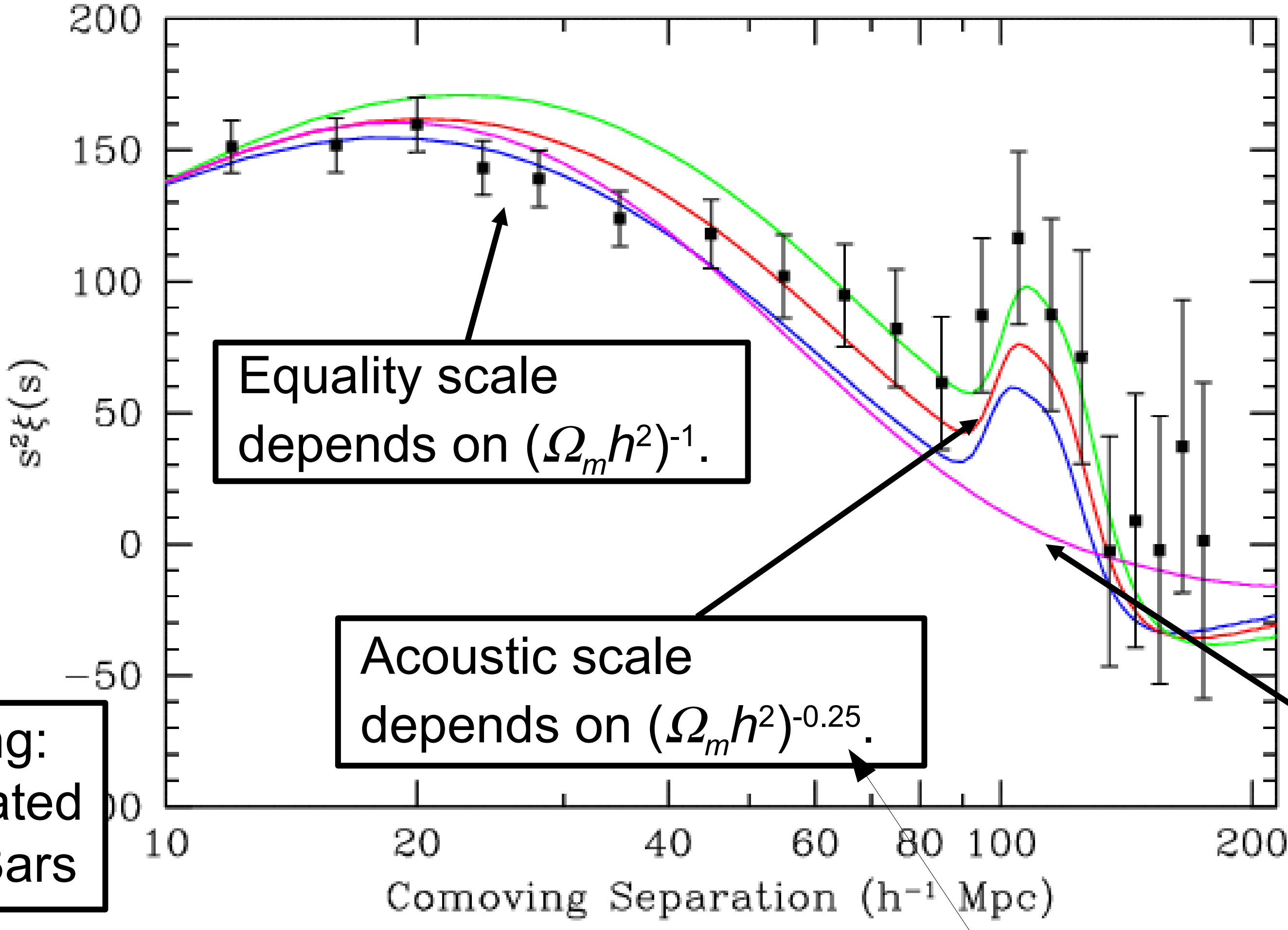
(D.Eisenstein et al [SDSS Collab.] 2005)





Two key features

(D.Eisenstein et al [SDSS Collab.] 2005)



$\Omega_m h^2$ = 0.12

$\Omega_m h^2$ = 0.13

$\Omega_m h^2$ = 0.14

Equality scale depends on $(\Omega_m h^2)^{-1}$.

Acoustic scale depends on $(\Omega_m h^2)^{-0.25}$.

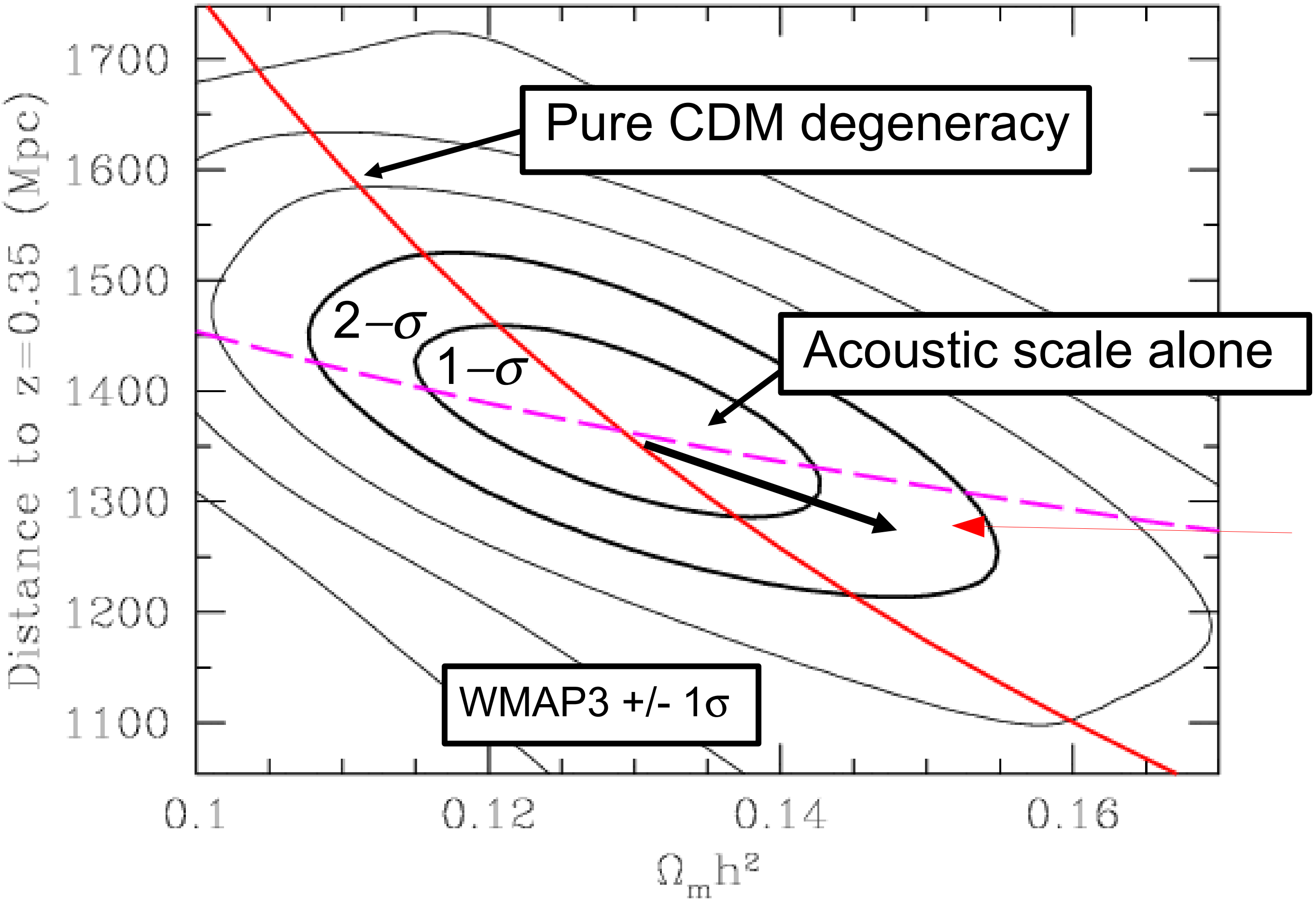
Pure CDM model has no peak.

Warning: Correlated Error Bars

not a consequence of first principles

See Hu, 0407158

Cosmological Constraints



The uncertainty in $\Omega_m h^2$ makes it better to measure$(\Omega_m h^2)^{1/2} D$. This is independent of H_0.

$$\Omega_m = 0.273 \pm 0.025 + 0.123(1+w_0) + 0.137\Omega_K.$$

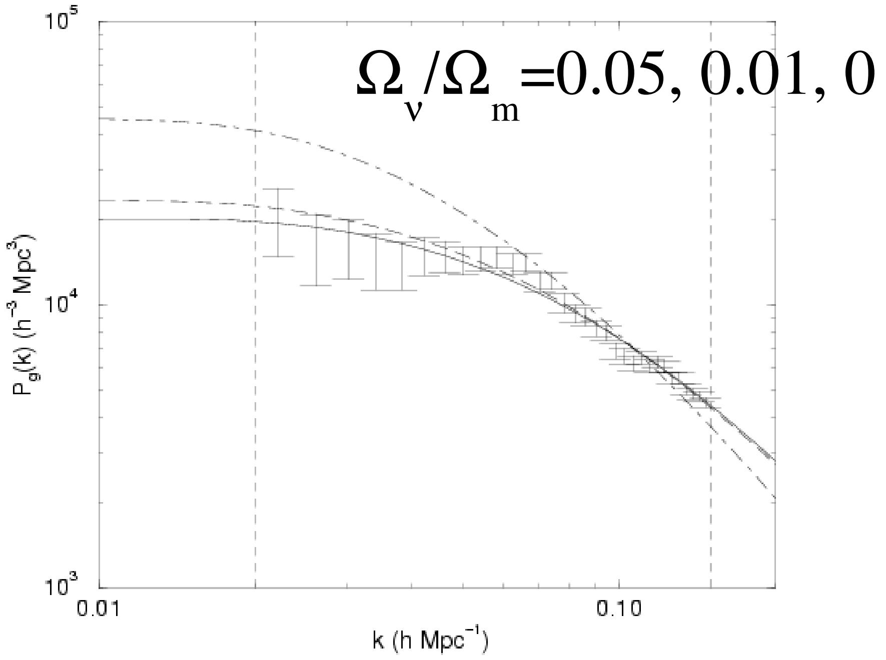
Eisenstein et al [SDSS], ApJ (2005)

Neutrino mass in the 2dfGRS (2002)

(from the galaxy power spectrum)

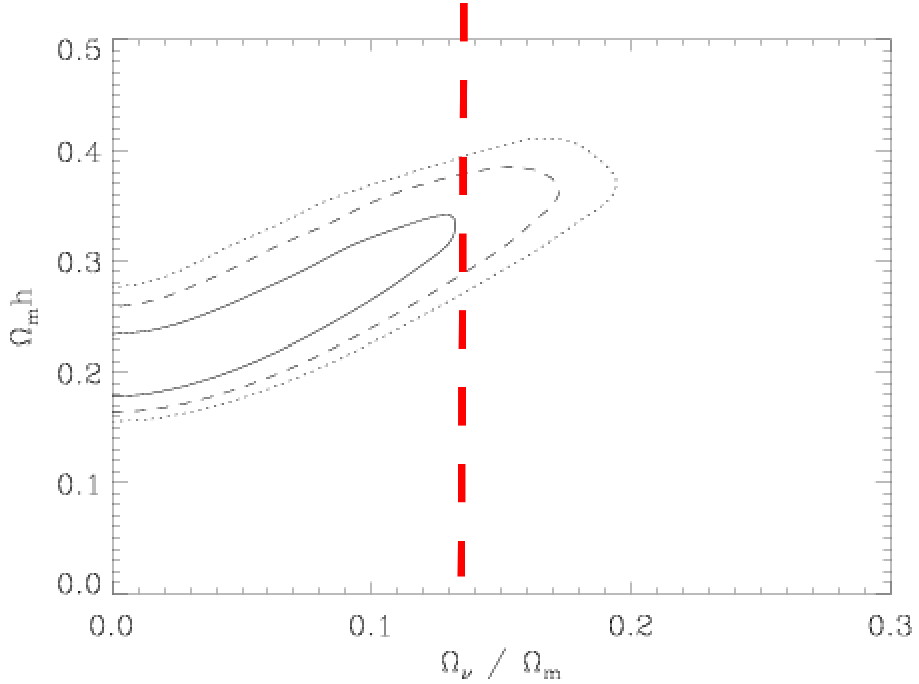
2dfGRS : similar to the SDSS (earlier and shallower)

(astro-ph/0204152)



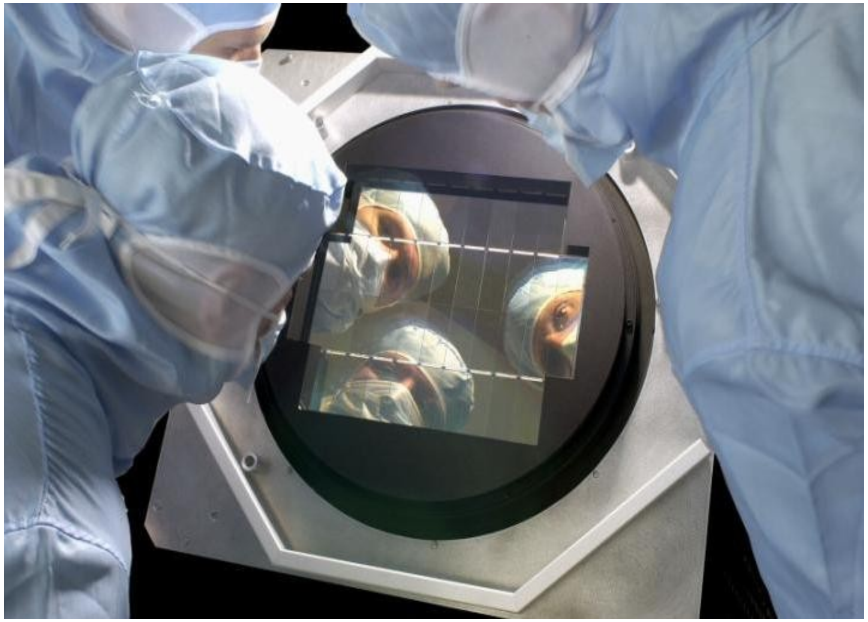
Ω_ν/Ω_m=0.05, 0.01, 0

m_ν= 1.8 eV



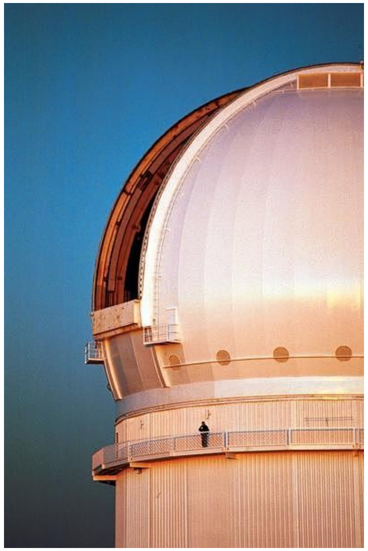
Current limits are of course more stringent

Higher z : the CFHT Legacy Survey



CFHT / Megacam

- 3.6 m telescope on Mauna Kea (Hawaii)
- Megacam : 1 deg^2 imager (320 Mpix)
- Typical image quality : 0.8”



CFHTLS :

~500 nights over 5 years (1/3 of the observing time)

Defined by the community of CFHT users:

- Deep survey (& SNe) : 4 deg^2
- Wide survey (weak lensing) ~170 deg^2 (5 bands)
- Data open to the community, then world wide.

The CFHTLS observations

Wide survey : main goal is weak shear

~ 170 deg^2 in total

over 3 patches (eventually) in 5 bands (for photo-z)

~1 hour per band and filter -> ~1 night/deg^2

z distribution of galaxies peaks at z~0.8

July 2003
to
July 2008

Deep survey : study of galaxies and SNe

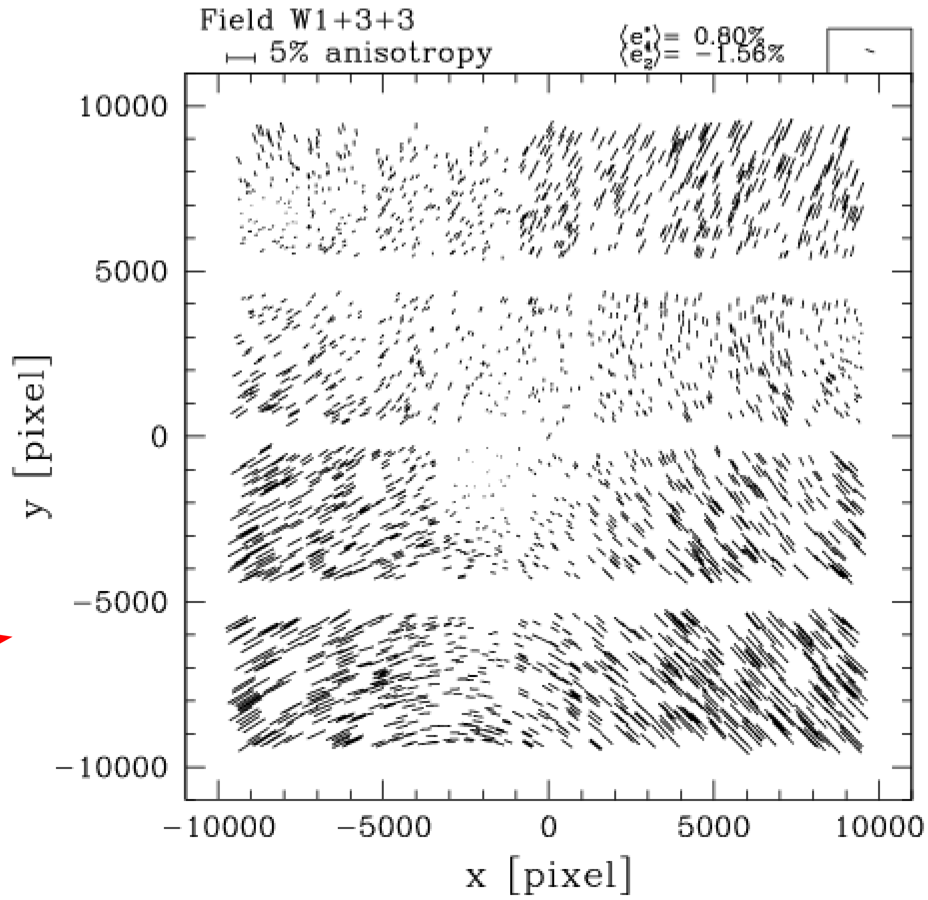
- 4 deg^2 in total
- Images in g,r,i,z taken every 4 night, 5 times a month.
- Depth and sequence adequate for type Ia SNe at z~1
- final stack depth : i~27

Weak shear measurements

Weak shear signal : correlations of ellipticities of distant galaxies (as a function of angular separation)

Sources of ellipticity:

- Natural galaxy ellipticity : ~ 30%
  - -> average over many galaxies
- Imaging system : 0 – 10 %
  - -> measure ellipticity of stars
- Cosmological signal : ~ 1%

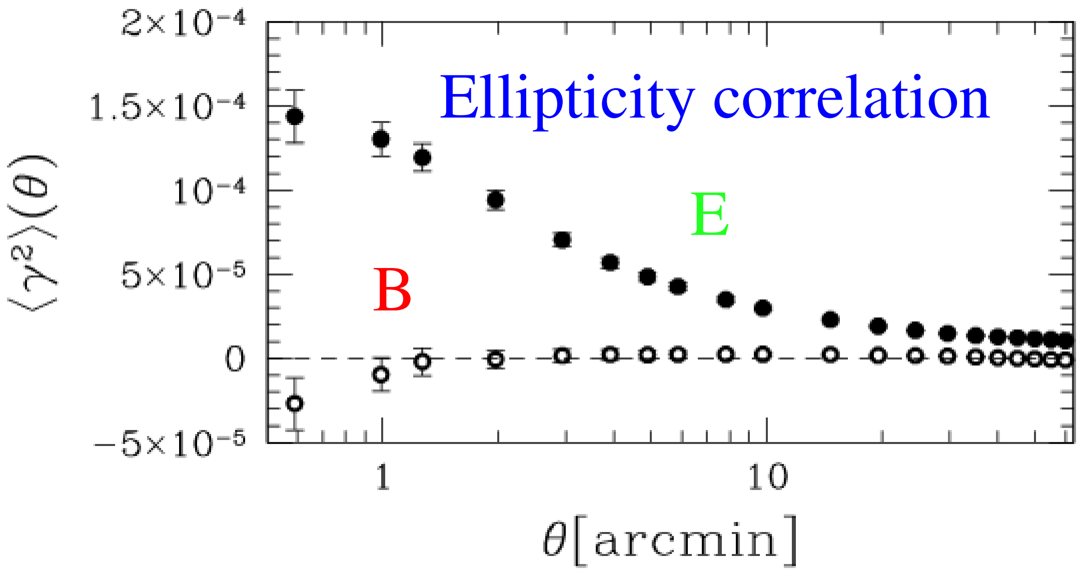


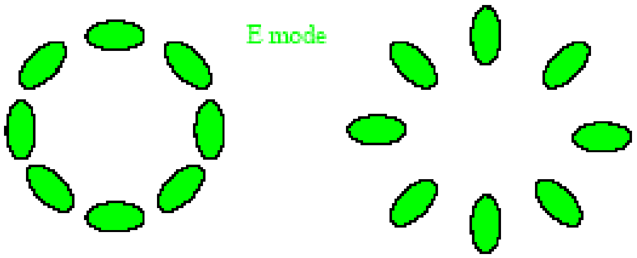
Measured ellipticity of stars

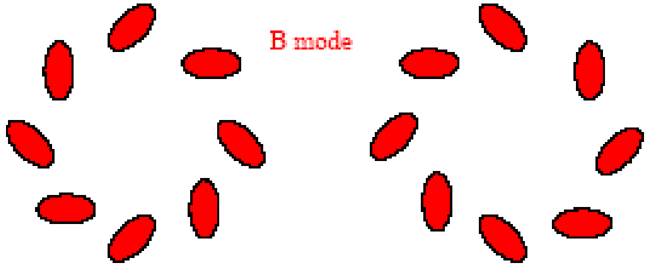
(CFHT/Megacam) Hoekstra et al 2005

CFHTLS wide first results (1)

Hoekstra et al,
Semboloni et al 2005
22 deg^2 median $z = 0.8$





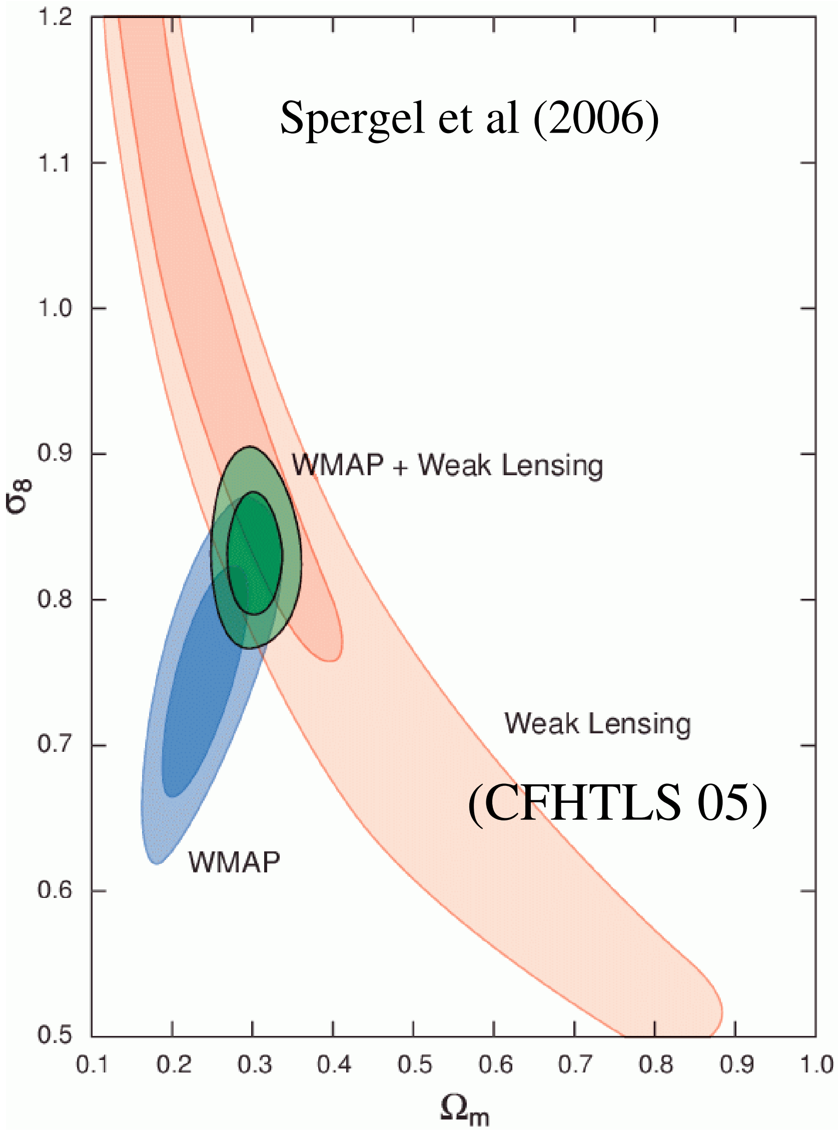


- Lensing : (scalar) gravitational potential.
- Ellipticity field is 2d

Constraint : shear B-modes = 0

powerful check of the optical distortions removal

CFHTLS wide first results (2)



Comparison with WMAP (3 years):
some (moderate) tension

But:

The z distribution of CFHTLS galaxies has been derived from the Hubble Deep Field
--> sample variance

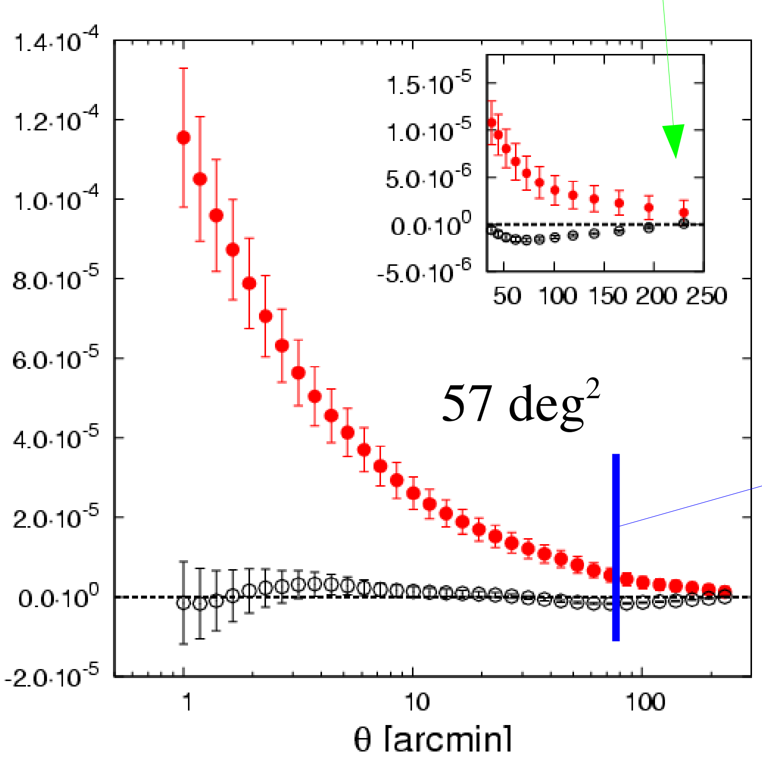
==> need accurate (average) redshifts for weak shear interpretation

CFHTLS new lensing results

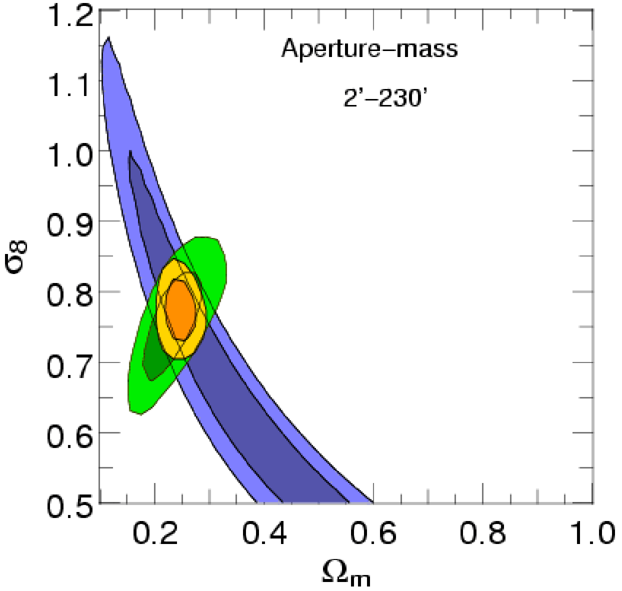
(Fu et al, 0712.0884)

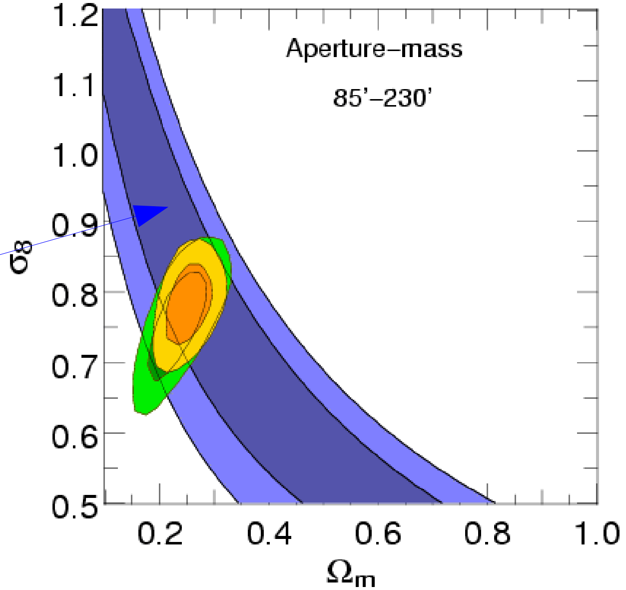
Redshift distribution now measured
in the same fields (from the deep parts)

Correlations are detected up to 4 degrees



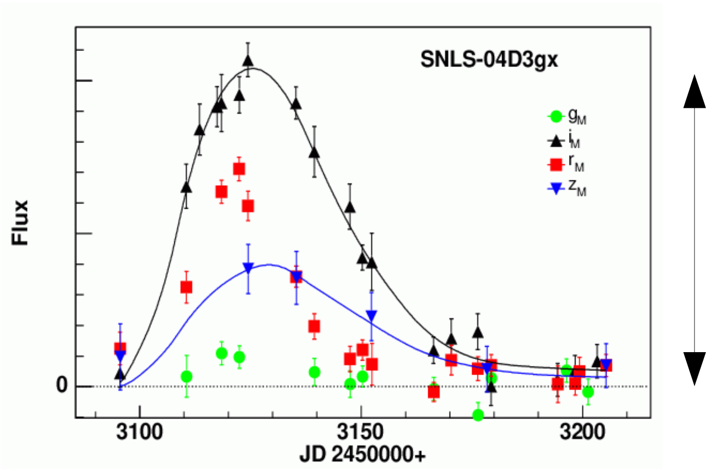
57 deg^2



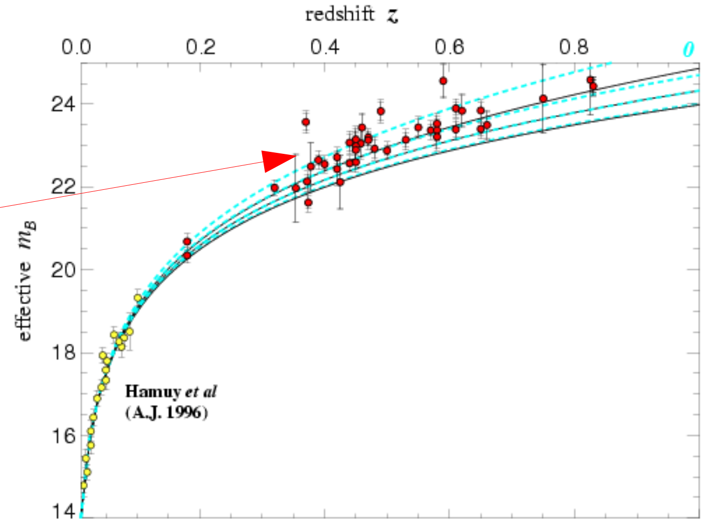


~3 times more to come, with more bands...

Measuring distances to SNe Ia



peak flux



Sne Ia are observed to exhibit reproducible peak luminosities

- Dispersion ~ 40 % caused by luminosity variations.

--> Have to use intrinsic luminosity indicators:

- decline rate (or light curve width)
  -> fair time sampling of light curves
- color (i.e. ratio of fluxes in different bands)
  -> measurements in several bands

P. Astier (Blois 22/05/08)

Supernova (Ia) surveys

SNe surveys require(d) 3 types of observations:

1) search : differential imaging
2) spectroscopic identification of candidates (and z measurement)
3) multi-band (>=2) photometry of light curves (over >1 month restframe)

With wide-field imagers, steps 1 and 3 can be merged :

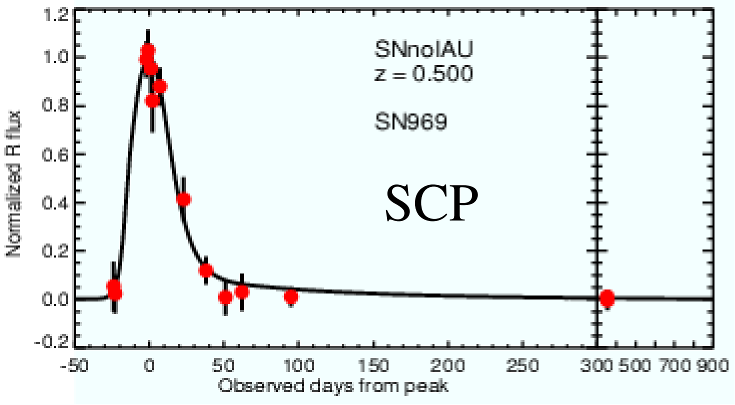
repeated imaging of the same fields : astro-movie or “rolling search”

Yield (Ia):

$z<1$: 5 Sne/month/deg^2 4-m telescope
$z<0.4$: 0.3 Sne/month/deg^2 2-m telescope
$z<0.1$: 0.01 Sne/month/deg^2 1-m telescope

SNe Ia surveys: from workshops to factories

Rolling search is THE way to go for SNe surveys



Three ~~ongoing~~ finishing projects:

- Essence@CTIO

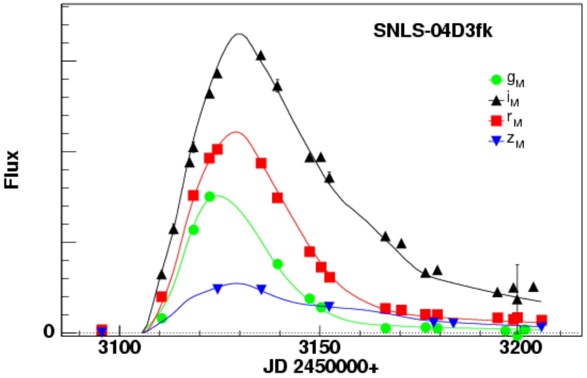
  ~8 deg^2, RI bands, 0.2<z<0.8, 5 years from 2002.

- SNLS@CFHT (within the CFHTLS)

  4 deg^2, griz bands, 0.2<z<1, 5 years from 2003.

- SNe in SDSS-II

  300 deg^2, ugriz bands, z<~0.35, 3 years from fall 2005.



Rolling searches become increasingly difficult as z decreases

- Requires very wide field imaging ~10 deg^2
- Large area -> Large data volume.

SNLS SuperNova Legacy Survey

French-Canadian led Collaboration to discover, identify and measure SNe Ia in the CFHT Legacy Survey (DEEP). About 40 persons.

Targets 500 well measured SNe Ia at $0.2<z<1$

Same amount of telescope time for imaging and spectroscopy

Rolling search over four 1 deg^2 fields
in 4 bands (griz): ~250 hours/year at CFHT.

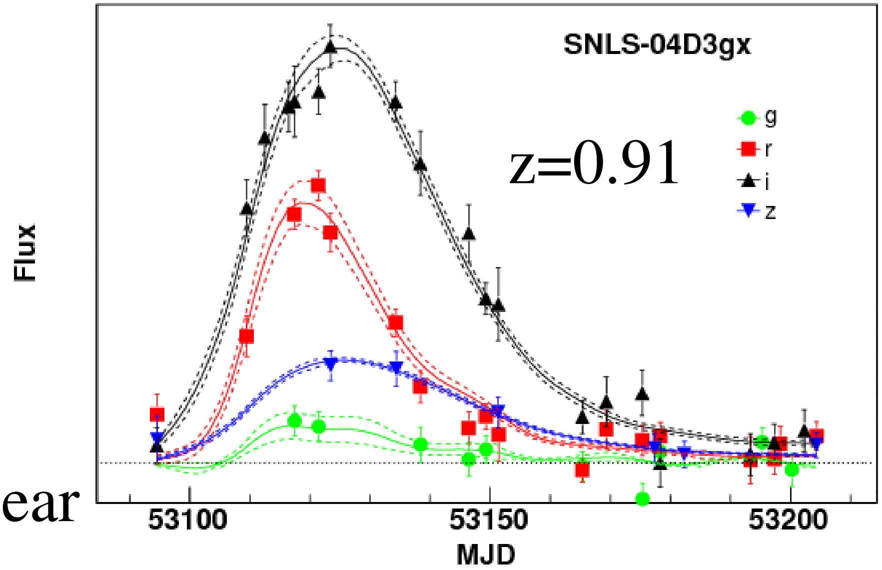
Spectroscopy : ~ 250 h/year on 8m-class (!!)

- VLT (Europe 120 h/y), Gemini (US/UK/Can 120 h/y), Keck (US 30 h/y).

http://snls.in2p3.fr

CFHTLS/Deep : Observing mode

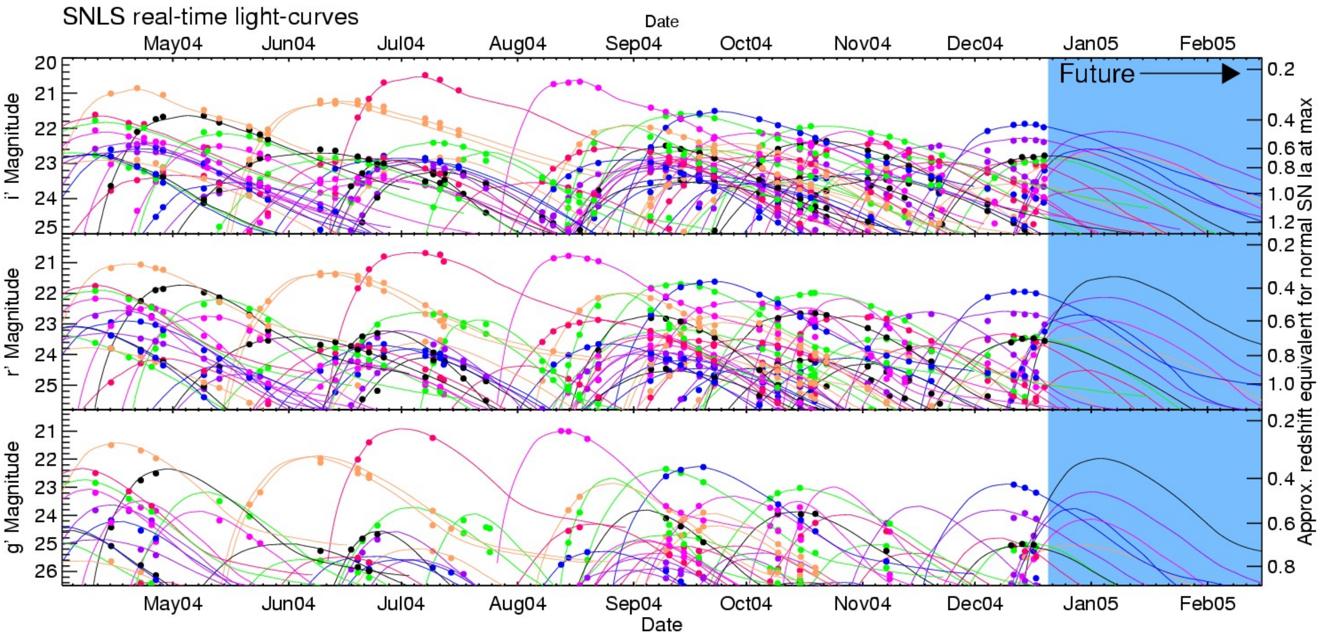
- 40 nights/year for 5 years.
- Repeated observations every ~4 night ("rolling search"), service mode
- 4 bands g,r,i,z
- 4 one deg^2 fields monitored ~ 6 month/year



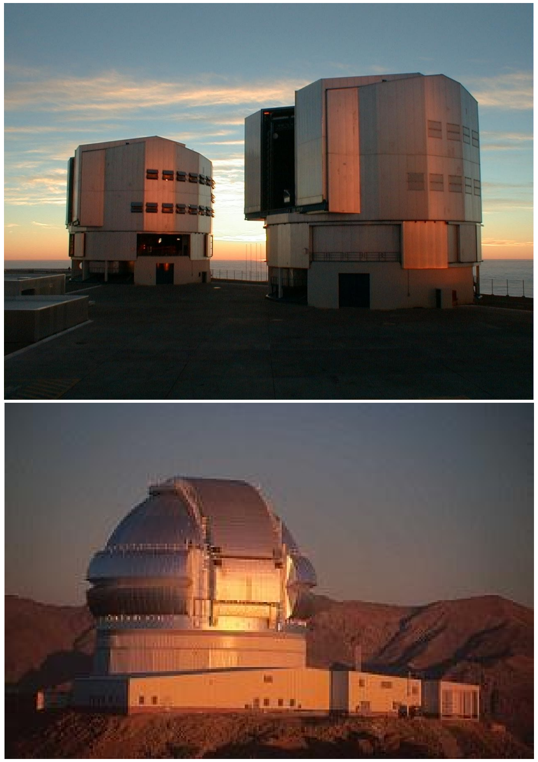
-> Photometric data **before** objects are detected

-> Multiplexing : several SNe per field in a single exposure

-> Repeated calibration of field stars



SNLS Spectroscopy



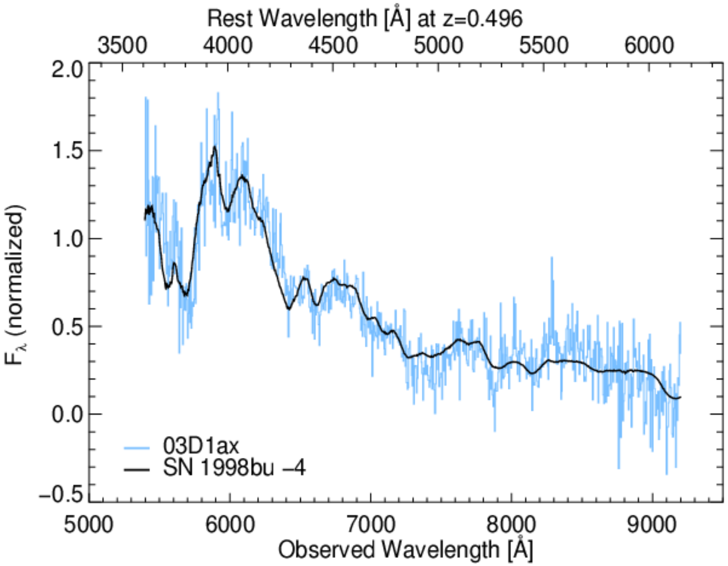
Identification of SNe Ia

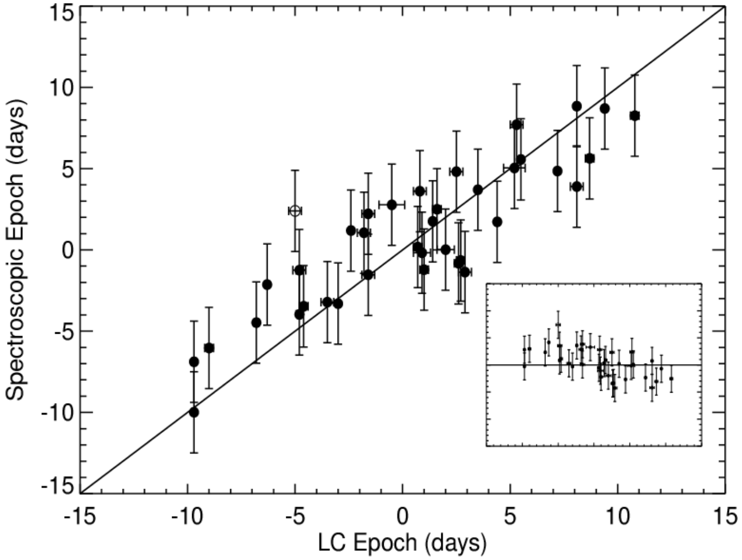
Redshift (usually of the host galaxy)

Detailed studies of a (small) sample of SNe Ia/II

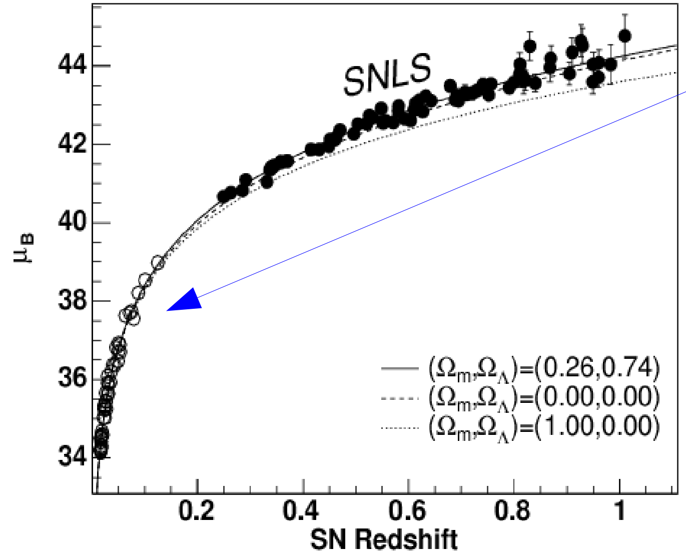
Telescopes

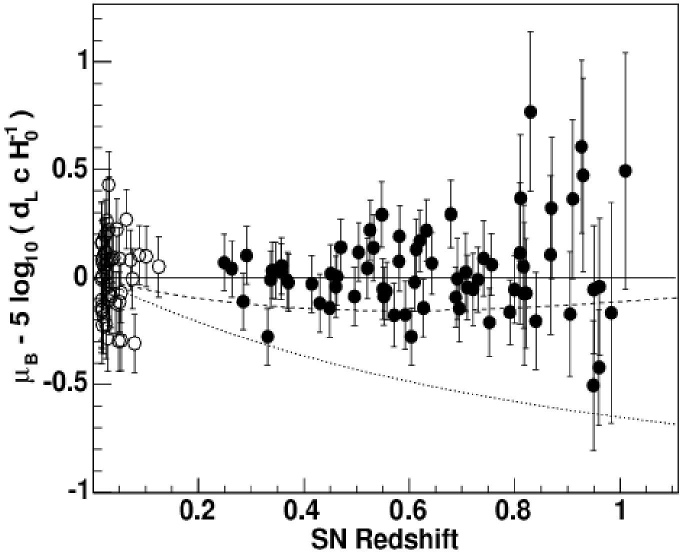
- VLT Large program (service)
  240h in 2003+2004, idem 2005+2006
- Gemini : 60h/semestre
  (Howell 2005, astro-ph/0509195)
- Keck : 30h/year (spring semester)





Hubble Diagram of SNLS (first year)





Final sample :

45 nearby SNe from literature

+71 SNLS SNe

(2 events lightcurves are badly fitted,

2 are strong Hubble Diagram outliers)

Distance estimator:

$$\mu_B = m_B^* - \mathcal{M} + \alpha(s-1) - \beta c$$

brighter-slower

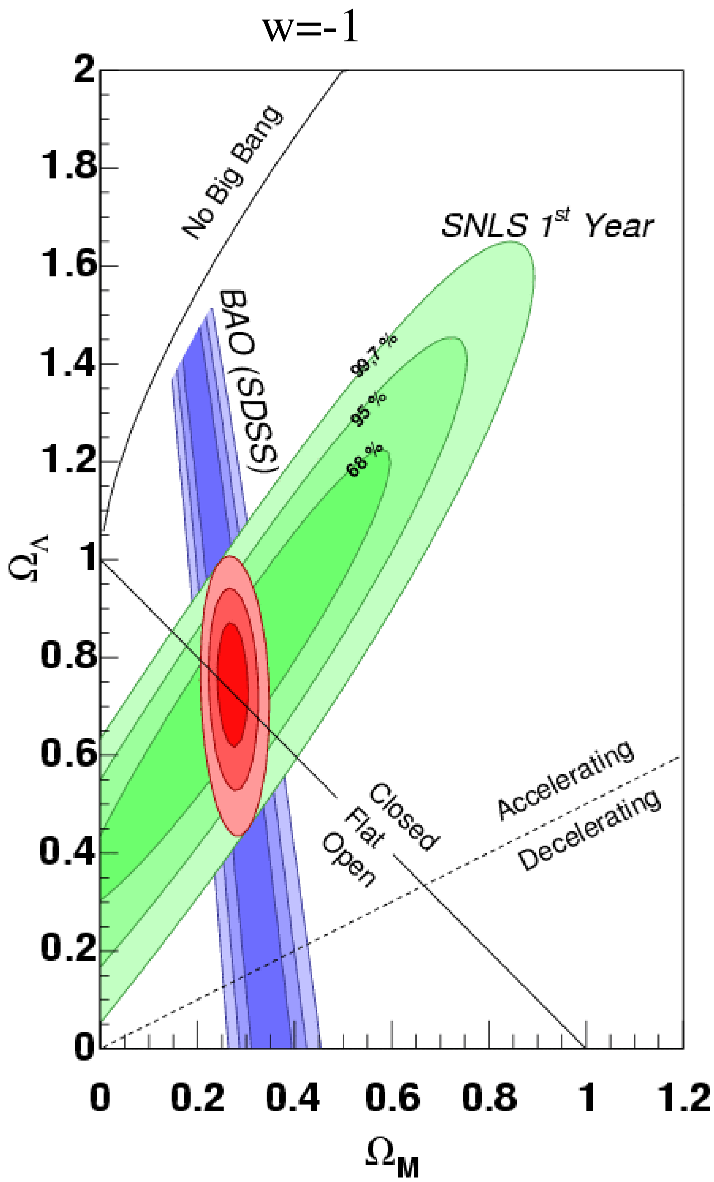
brighter-bluer

$$\chi^2 = \sum_{objects} \frac{\left(\mu_B - 5\log_{10}(d_L(\theta,z)/10pc)\right)^2}{\sigma^2(\mu_B) + \sigma^2_{int}}$$

- minimize w.r.t θ, ***M***, α ,β
- compute σ_{int} so that $\chi^2 = N_{dof}$ ($\sigma_{int} = 0.13$)
- marginalize over ***M***, α ,β to draw contours

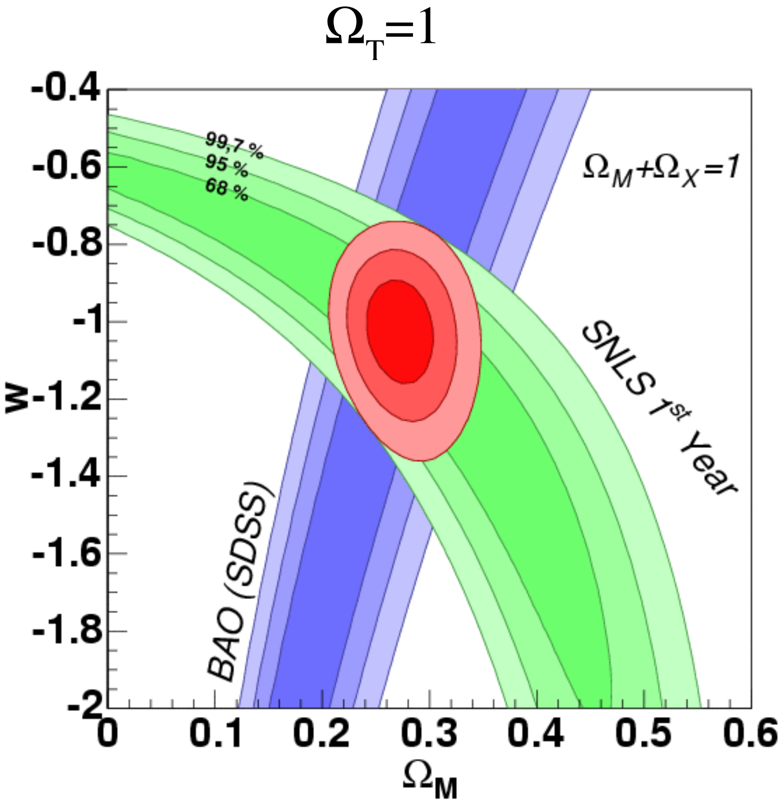
(astro-ph/0510447)

SNLS (1 year) confidence Contours



w=-1

68.3, 95.5 et 99.7% CL



Ω_T=1

<-- Λ

BAO: Baryon Acoustic Oscillations

(Eisenstein et al 2005, SDSS)

SNLS SNe + nearby SNe + BAOs :

$$\boxed{\begin{aligned} \Omega_M &= 0.271 \pm 0.021\ (stat) \pm 0.007\ (sys) \\ w &= -1.02 \pm 0.09\ (stat) \pm 0.054\ (sys) \end{aligned}}$$

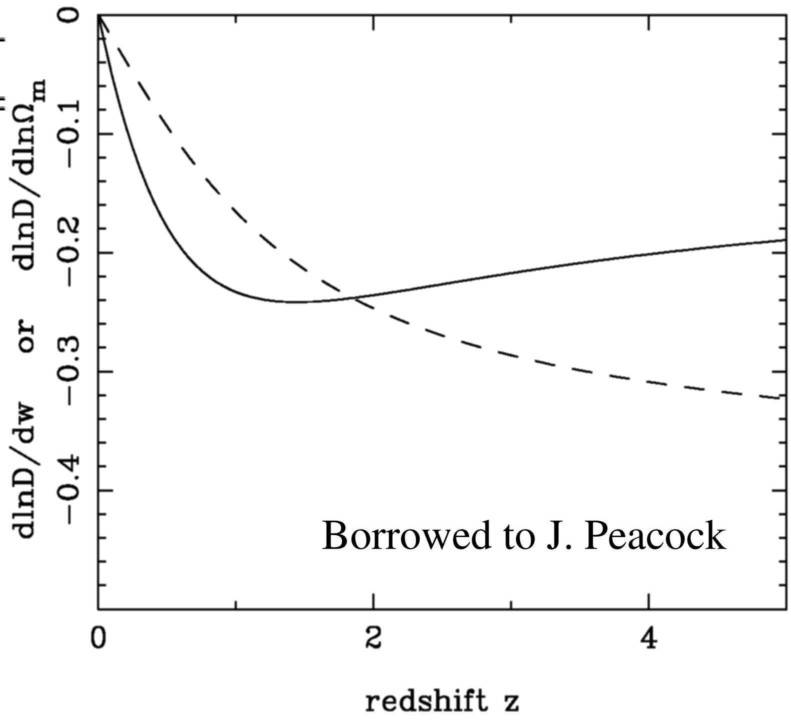
SNLS (1 year) systematics

Source	$\sigma(\Omega_M)$	$\sigma(\Omega_{tot})$	$\sigma(w)$	$\sigma(\Omega_M)$	$\sigma(w)$
	(flat)			(with BAO)	
Zero-points	0.024	0.51	0.05	0.004	0.040
Vega spectrum	0.012	0.02	0.03	0.003	0.024
Filter bandpasses	0.007	0.01	0.02	0.002	0.013
Malmquist bias	0.016	0.22	0.03	0.004	0.025
Sum (sys)	0.032	0.55	0.07	0.007	0.054
Meas. errors	0.037	0.52	0.09	0.020	0.087
U-B color(stat)	0.020	0.10	0.05	0.003	0.021
Sum (stat)	0.042	0.53	0.10	0.021	0.090

Photometric Calibration

Rule of 5 :

shifting distances by 1% shifts w by 0.05



Borrowed to J. Peacock

ESSENCE (very short summary)

ESSENCE is a ground-based SNe rolling search survey

- running at CTIO-4m, imager 0.4 sq. deg.
- only 2 (observer) bands : R I
- imaging time : ~ 1/3 of SNLS

Data set (astro-ph/0701041):

60 supernovae (z<~0.7, over 3 years)

Noisy distance estimator

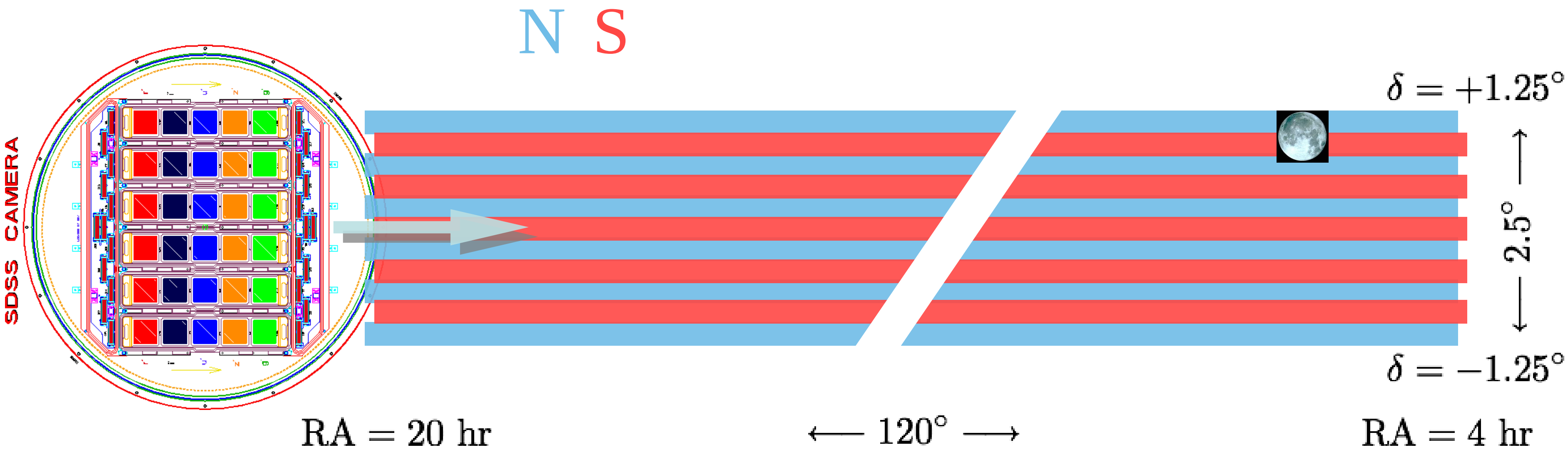
Priors used to reduce scatter. Only 2 bands

Results :

Essence + nearby SNe + B.A.O w = -1.05 +/- 0.12 +/- 0.13

SNLS+Essence + nearby SNe + B.A.O w = -1.07 +/- 0.09 +/- 0.13

Supernovae in SDSS-II



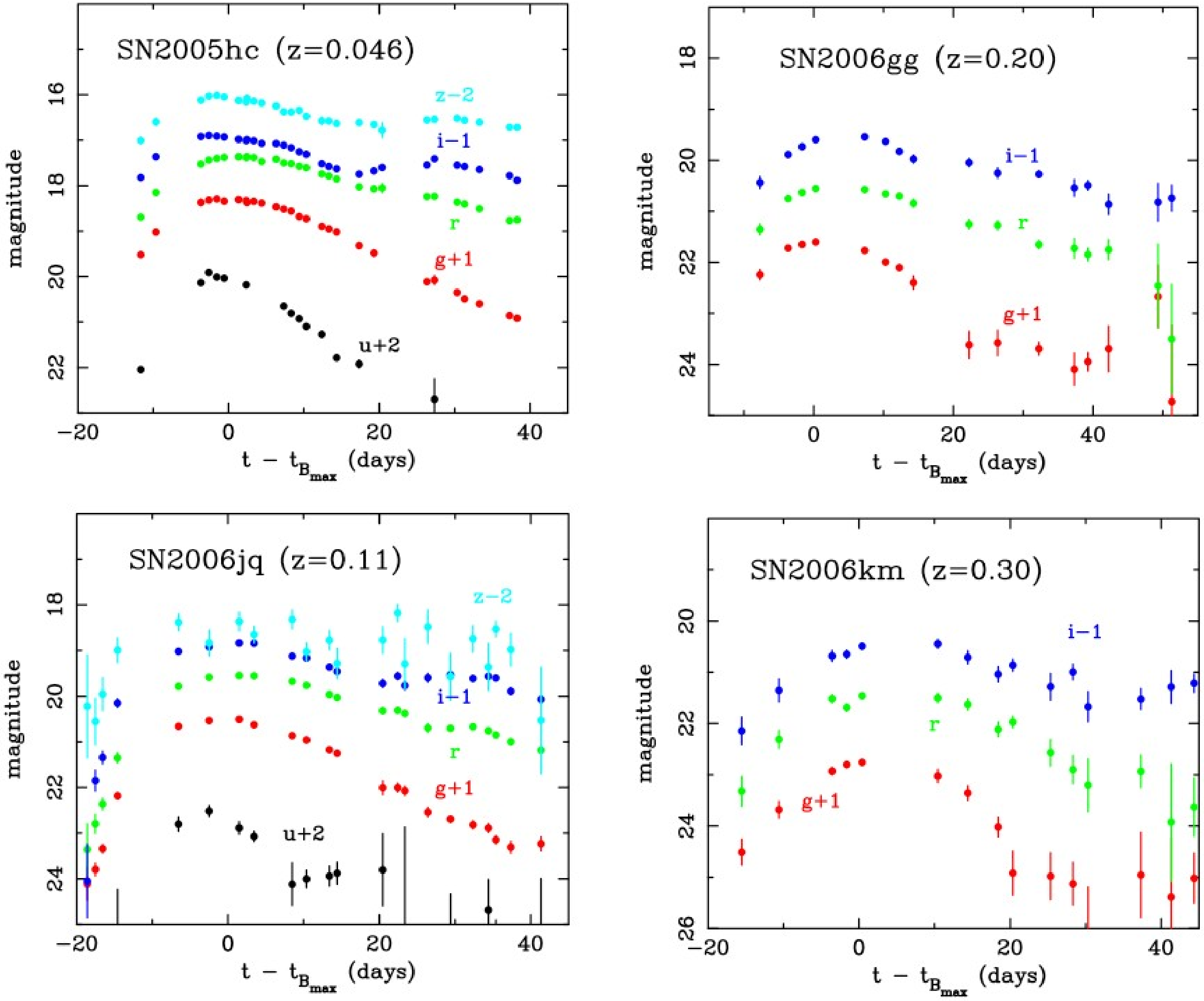
Imaging with the SDSS 2.5m telescope

- September 1 - November 30 of 2005-2007
- Scan 300 square degrees of the sky every 2 day

Spectroscopy using mainly 4m-class telescopes

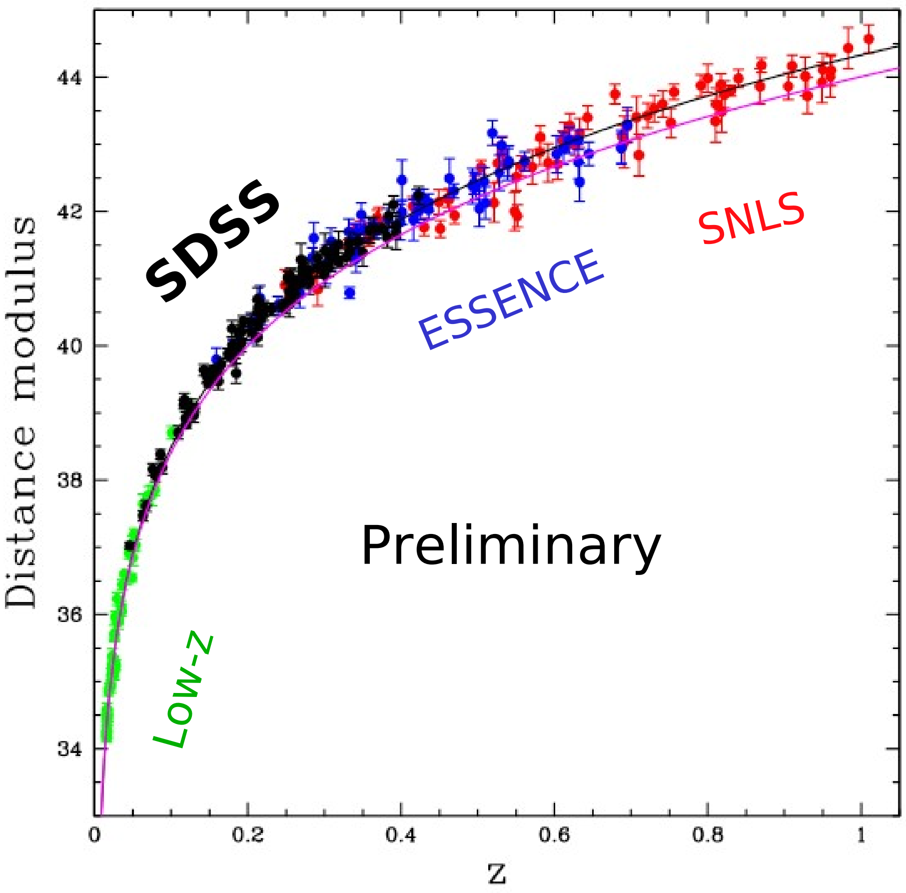
(see astro-ph/0708.2749)

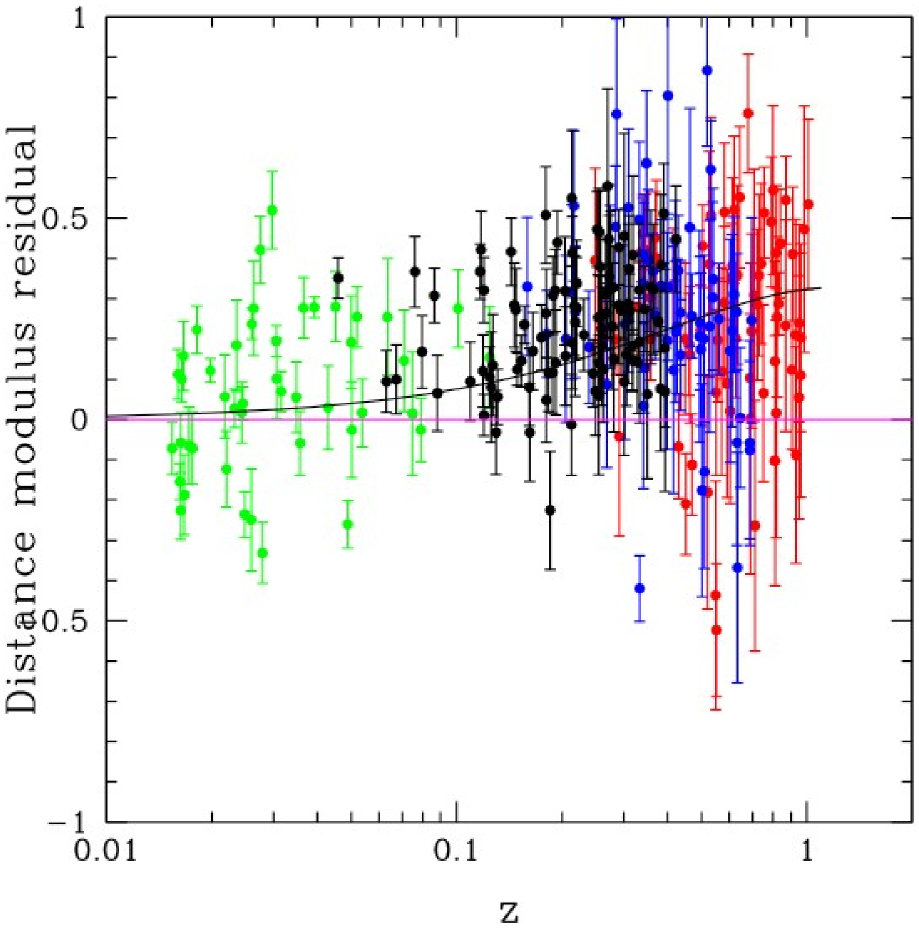
SDSS-II SN lightcurves



SDSS SN Photometry: Holtzman et al. (2007) submitted

Hubble Diagram(s)

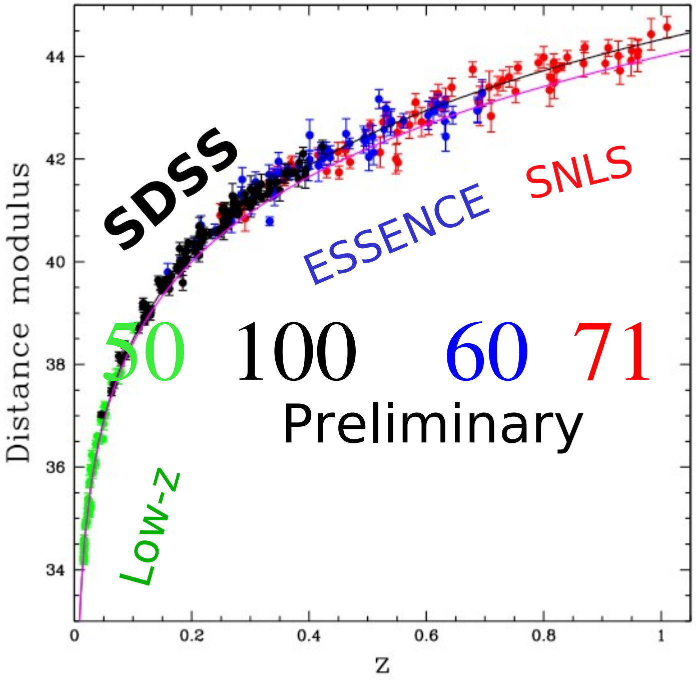




- SDSS 2005 Data only
  - 130 SNe Ia
  - 99 after quality cuts
  - Kessler et al (2008) to appear

(From J. Frieman)

Supernovae status



Statistics of "published" samples :

- much better photometry than historical samples
- multi-band

Statistics on disk : ~ at least 3 times more.

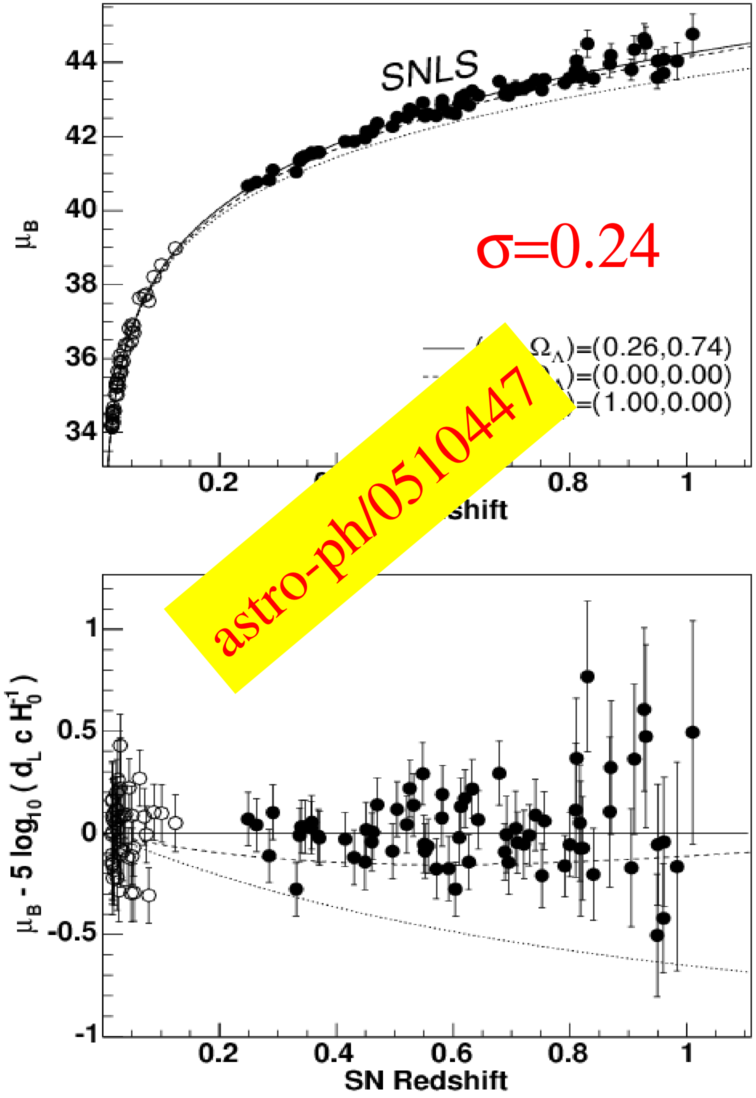
Work under way:

- improve distance estimators
- improve photometric calibration techniques
- collect more and better nearby events (e.g. SuperNova Factory)

Plausible precision for a constant equation of state:

0.05 (stat) and 0.05 (sys)

Improving distances to SNe

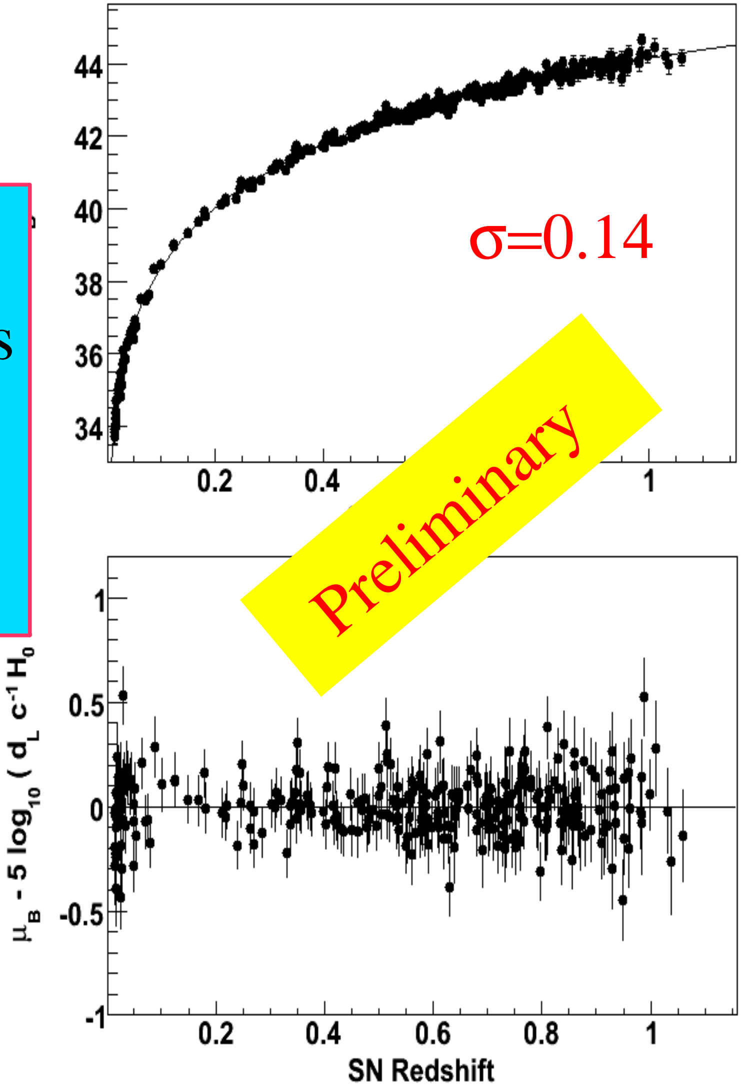


astro-ph/0510447

σ=0.24

improvements:

- Lightcurve fits
- Instrument Calibration
- Algorithms



σ=0.14

Preliminary

Future

Large survey projects : instruments

		FOV	diameter	first light	status	who/where
ground	SDSS-III	7 deg2	2.5m	2008	funded	Apache Point
	VST @ ESO	1 deg2	2.6 m	2008	funded	ESO/Paranal
	DARKCam	2 deg2	3.6 m	??	refused at ESO	UK+...
	HyperSuprimeCam	2-3 deg2	8 m	2012	funded	Japan/Subaru
	Dark Energy Survey	2 deg2	CTIO-4m	2012	funded	Fermilab/CTIO
	Pan StarsS	7 deg2	1.8 m	2007	funded	Univ. Hawaii
	Pan StarsS 4	7 deg2	1.8 m x 4	2009 (+)	not funded	Univ. Hawaii
	LSST	10 deg2	8 m	2015	not funded	DOE/NSF
space	SNAP	0.7 deg2	2 m	2016(+)	competing	DOE/NASA
	ADEPT	?	?	same as SNAP	competing	DOE/NASA
	DUNE	~1 deg2	1.2 m	2017(+)	competing	ESA
	SPACE	0.4 deg2	1.5m	2017(+)	competing	ESA

Being merged into a single mission : “Euclid”

Large survey projects : plans

Physics:

- Dark energy/Dark matter : Weak Lensing, BAO's, SNe, Clusters
- galaxy studies, ...

		Area (deg2)	bands	depth (lim. Mag)
ground	SDSS-III	10000	spectroscopy	~18
	VST @ ESO	1500	4 (vis)	~25
	HyperSuprimeCam	2000	5 (vis)	~26
	Dark Energy Survey	5000	5 (vis)	~24
	Pan StarsS	1200	4 (vis)	24
	Pan StarsS 4	20000	4 (vis)	23.5
	LSST	20000	6 (vis)	26.5
space	SNAP	3000	6 (vis) +3 (NIR)	26
	ADEPT	30000	spectroscopy	H=22
	DUNE	20000	1 vis + 2 NIR	24.5
	SPACE	20000	spectroscopy	H=23

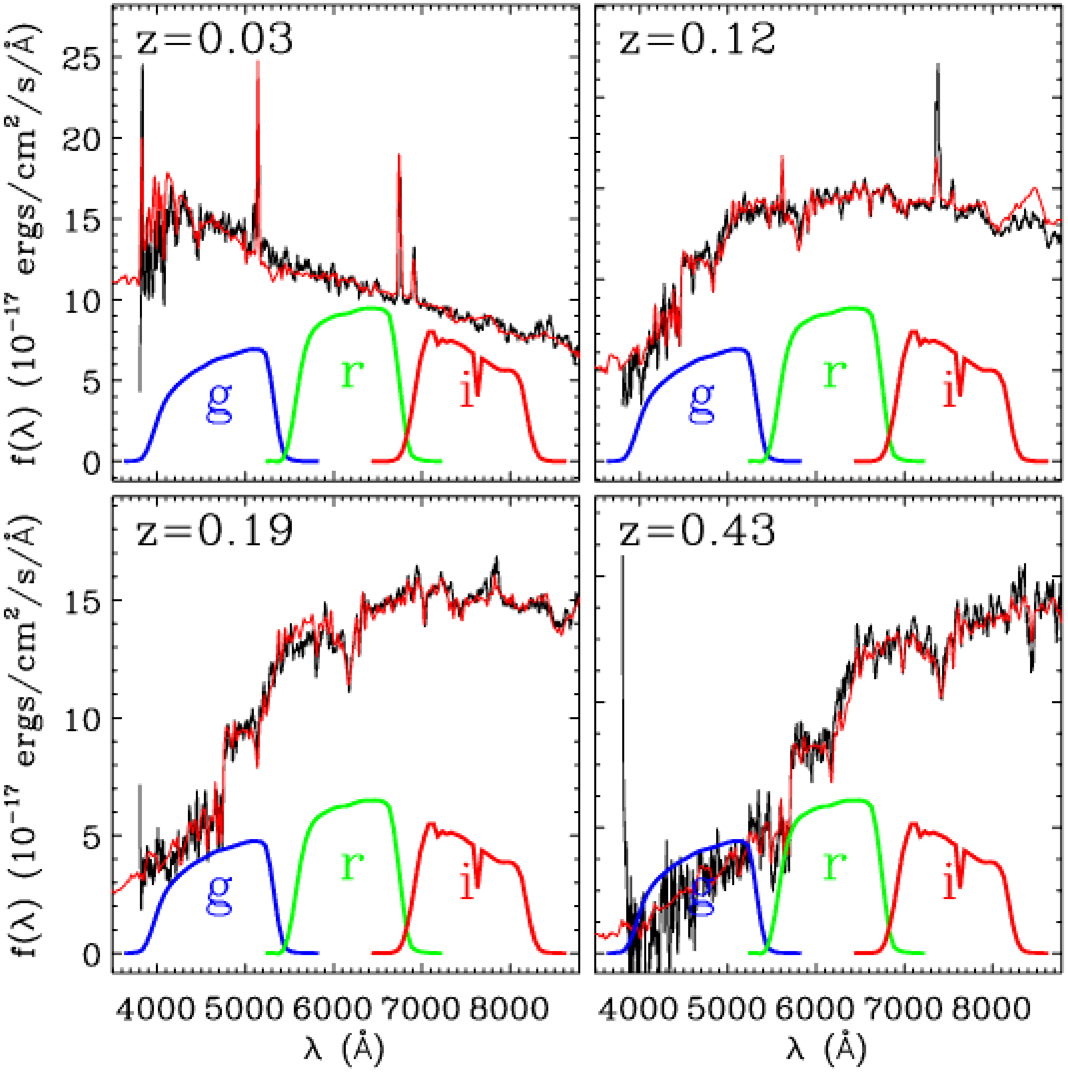
Photometric redshifts

Currently, photometric galaxy samples are more than 10 times larger than spectroscopic galaxy samples.
They extend much further in z.

Do do cosmology with only imaging, one has to guess redshifts from multiband photometry
(with a small spectroscopic training subsample)

Unfortunately, no second generation massive spectroscopic instrument is secured.

Photo-z : poor man's spectroscopy



(http://howdy.physics.nyu.edu/index.php/Kcorrect)

From fluxes in broad bands,
guess a galaxy type
and a redshift

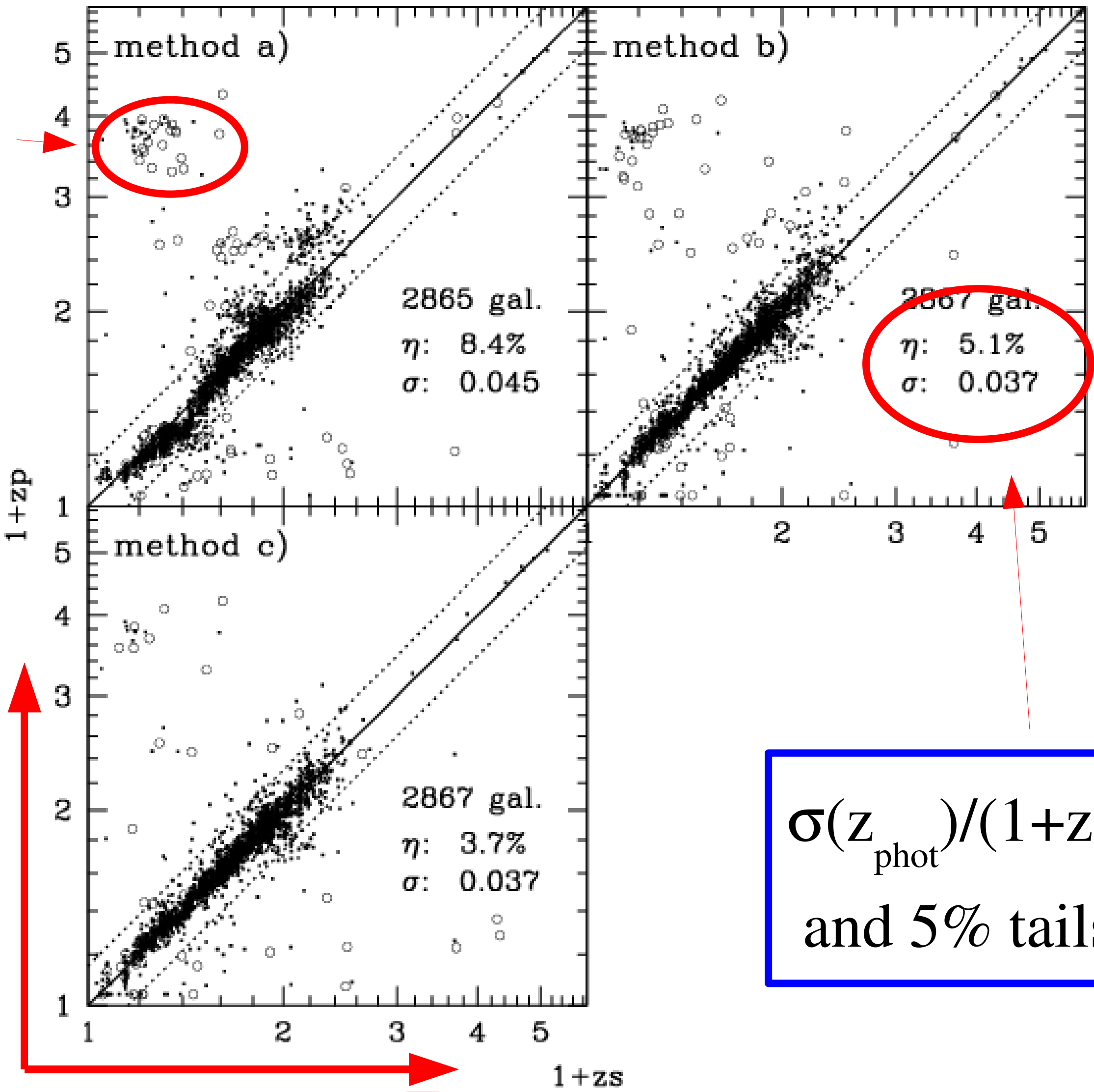
Issues:

- S/N
- which bands ?
- how many ?
- ambiguities

CFHTLS photo-z

Adjust spectral templates and calibration

Confusion between Lyman break (91 nm) and the “400 nm break”



Z_{phot}
(CFHTLS ugriz imaging)

Z_{spec} (VVDS spectroscopy)

$\sigma(z_{phot})/(1+z) = 0.04$
and 5% tails (> 0.15)

Ilbert et al, astro-ph/0603217

Photo-z precision

Issues

1) Large photometric surveys require large training samples
   - 100,000+ galaxy spectra for 20,000 sq deg surveys.
   - no sizable spectroscopic training set beyond m~25

2) Systematic photo-z shifts (~0.01) are a killer for precise estimates of cosmological parameters.

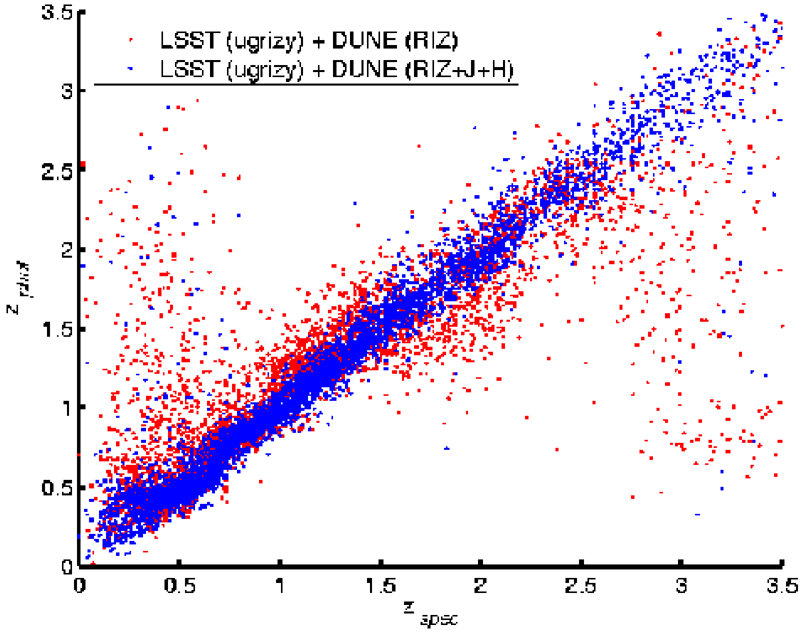
   Should target biases <~ 0.001

3) Which bands are mandatory?

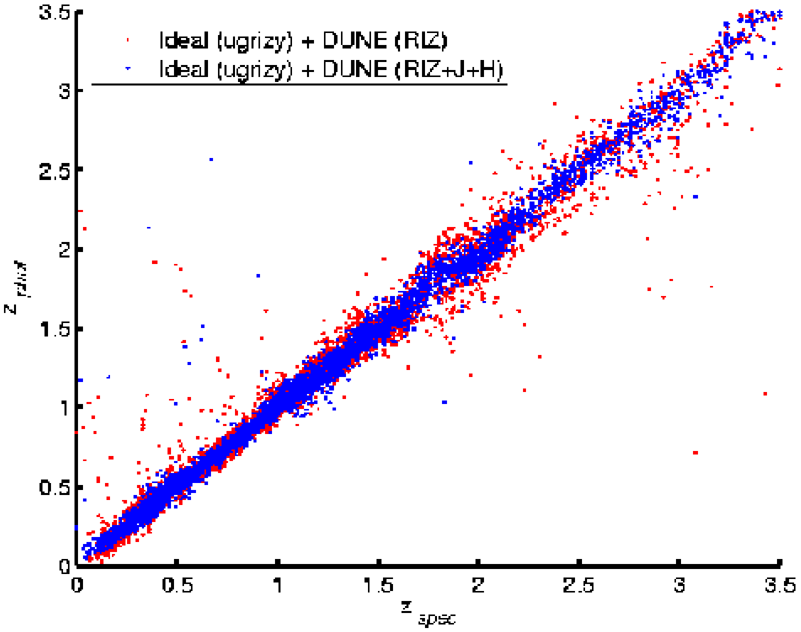
Photo-z precision

Simulations from 0705.1437
(F. Abdalla et al)

LSST(ugrizy)+IR
LSST(ugrizy)



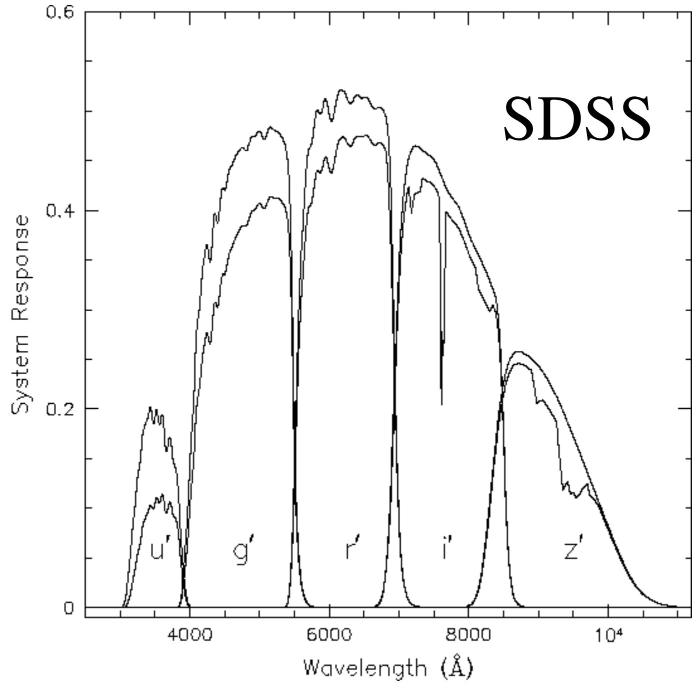
Same with much
deeper u band



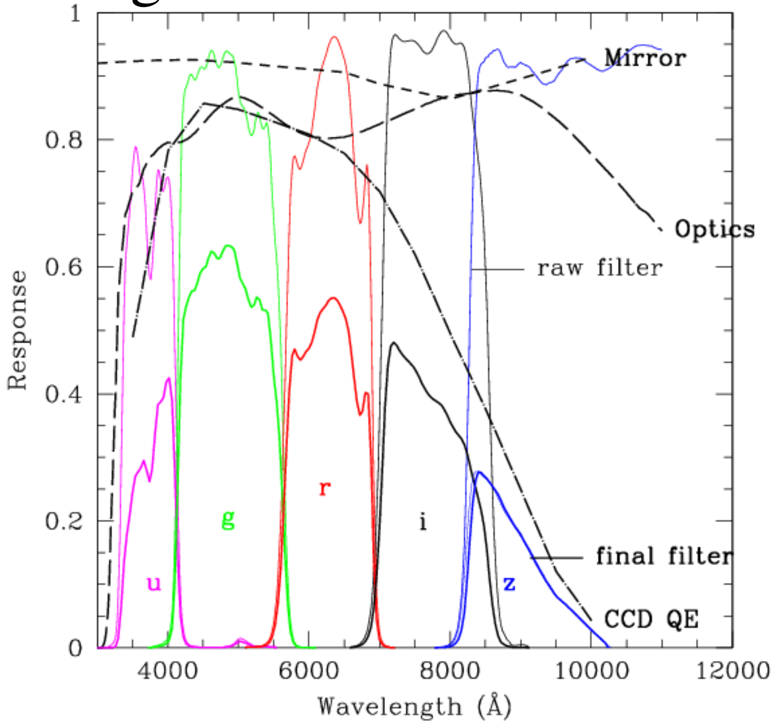
For photo-z,
IR (space based) photometry may perhaps
be replaced by deep u (ground based)

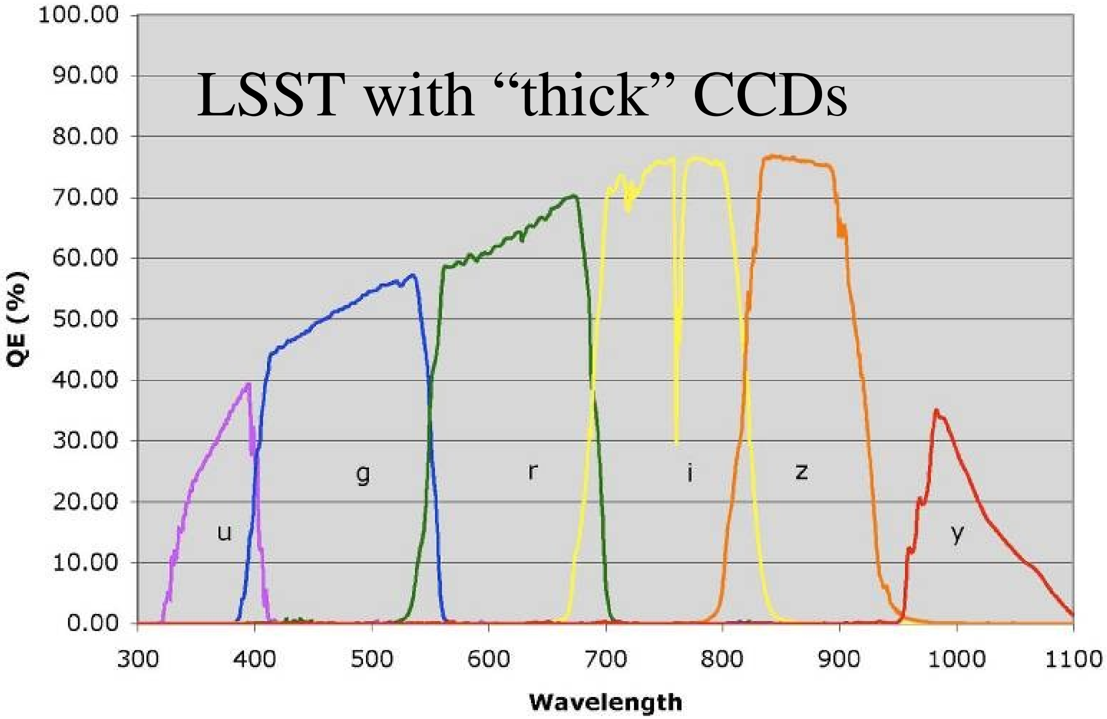
Overall transmissions do improve

CCDs, but also mirrors, filters, coatings

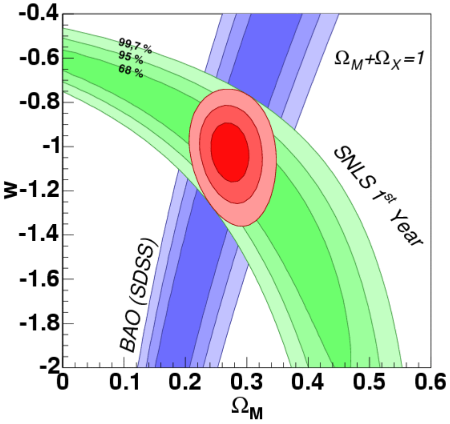


Megacam : thin CCDs





Summary



- Large surveys have already produced a large set of measurements
- Dedicated or semi-dedicated facilities
- Many imaging projects but very few spectroscopic projects
- Serious “technical issues” for next round(s)
  - Photometric precision
  - Scatter and bias of photometric redshifts
  - Ellipticity measurements
  - ... NIR ?
- There are several 500+ M$ projects in the landscape
- Most future cosmological measurements assume Planck-like CMB measurements

SNLS Cosmological results

(SNLS collaboration, A&A 2006, astro-ph/0510447)

For a flat ΛCDM cosmology:

(SNLS alone) $\boxed{\Omega_M = 0.264 \pm 0.042\ (stat) \pm 0.032\ (sys)}$

For a flat Ω_M,w cosmology :

SNLS + Baryon Acoustic Oscillations (Eisenstein et al, 2005):

$$\boxed{\begin{aligned} \Omega_M &= 0.271 \pm 0.021\ (stat) \pm 0.007\ (sys) \\ w &= -1.02 \pm 0.09\ (stat) \pm 0.054\ (sys) \end{aligned}}$$

- **Confirmation of acceleration of expansion** with 71 (new!) distant SNe Ia.
- Use **color-corrected distance estimate without prior** on color.
- Careful study of systematics
- Photometric calibration will improve with specific measurements at CFHT

Dark Energy : observational handles

$$\left(\frac{\dot{R}}{R}\right)^2 = \frac{8\pi G}{3}\rho_M + \frac{\Lambda}{3} - \frac{k}{R^2}$$

Expansion history H(z) constrains
the RHS of Friedmann's equation

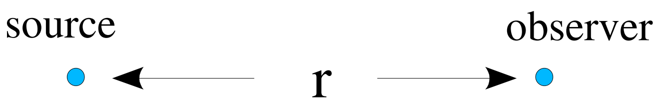
- Distances to standard candles as a function of z (SNe Ia)
- Angular size of a standard rod as a function of z
  (Baryon Acoustic Oscillation , BAO)

Growth of (matter) structures

$$\ddot{\delta} + 2\left(\frac{\dot{R}}{R}\right)\dot{\delta} = 4\pi G \rho_{\mathrm{M}} \delta$$

- Large scale matter power spectrum
  evolution with z (weak shear)
- Galaxy cluster statistics

Distances and cosmological parameters



$$ds^2 = dt^2 - R^2(t)\left(\frac{dr^2}{1-kr^2} + r^2(d\theta^2 + sin^2\theta\, d\phi^2)\right)$$

r(z) =(comobile) distance to a source at a redshift z.

Source and observer are themselves comobile

Messenger : light -> ds = 0. With the Friedmann equation:

$$r(z) = \frac{c}{H_0\sqrt{|\Omega_k|}} S\left(\sqrt{|\Omega_k|}\int_0^z \frac{dz'}{\sqrt{(1+z')^2(1+\Omega_M z') - z'(2+z')\Omega_\Lambda}}\right)$$

$$S(x) = \begin{cases} sin(x) & \text{si} \quad k=1 \\ x & \text{si} \quad k=0 \\ sinh(x) & \text{si} \quad k=-1 \end{cases}$$

How to measure cosmological distances ?

- luminosity distance $d_L = (1+z)\, r(z)$
  - -> observed flux of an object of known (or reproducible) luminosity
- angular distance $d_A = r(z)/(1+z)$
  - -> angle that sustains a known length
    - Correlations of CMB anisotropies.
    - Correlations of galaxies.

Degeneracies from distance data

$$\underset{\substack{\uparrow\\ \text{defines r(z)}}}{\left(\frac{H(z)}{H_0}\right)^2} = \underset{\substack{\uparrow\\ \text{Matter}}}{\Omega_{\mathrm{M}}(1+z)^3} + \Omega_{\mathrm{X}}\ \underset{\substack{\uparrow\\ \text{Dark Energy}}}{\exp}\left(3\int_0^z \frac{1+w(z')}{\underset{\substack{\uparrow\\ \text{E.O.S}}}{1+z'}}dz'\right) + \underset{\substack{\uparrow\\ \text{Curvature}}}{\Omega_{\mathrm{k}}(1+z)^2}$$

The expansion history depends on the sum of 3 terms.

The equation of state only enters in one of them.

--> exact or quasi degeneracies from fits of r(z)

1) need to know Ω_k (from C.M.B + something)

2) if w(z) is arbitrary, the expansion history (via r(z)) constrains a relation between Ω_M and w(z), not both of them independently.

3) even assuming a constant w, there remain a strong (although not exact) degeneracy.

--> distance data alone does not fix unambiguously the E.O.S

Observing Dark Energy(!)

Dark energy plays an important role in the recent universe ($z <\sim 1$).

Its effect decreases (vanishes?) with increasing z.

Particularly sensitive methods (for $z < \sim 1$):

	measures combinations of
- Supernovae Ia Optical (and IR) telescopes, imaging and spectroscopy Figure of merit : number of SNe, z span	$r(z)$
- Weak gravitational shear Optical telescopes, imaging Figure of merit : surveyed area on the sky (up to $z\sim1$)	$r(z)$ $r(z_{lens},z_{source})$ $P(k;z)$
- Baryon Acoustic Oscillations Optical telescopes, imaging and spectroscopy. Figure of merit : surveyed universe volume	$r(z)$, $H(z)$ $\Omega_m h^2$ (via z_{eq} and c_{sound})

DE probes : current development

Type Ia supernovae (distances to standard candles):

Established acceleration/Dark Energy (1998)

Now in a second round of observing programs.

BAO (primordial peak in the galaxy correlation function):

Signal detected in the SDSS and 2dF (at a single redshift) (2005)

Second round programs planned or under way.

Weak Lensing (galaxy shear correlations due to DM):

Signal detected in 2000.

z dependence of the signal to be quantified soon.

Galaxy clusters (counting)

Feasibility unclear: efficiency & modeling issues

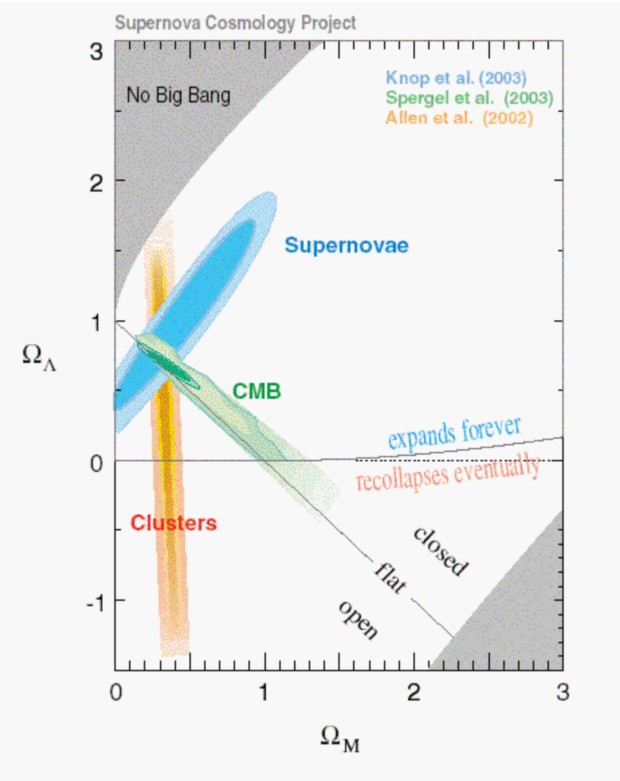
Distances to SNe Ia : some history

Early days:

- Riess et al 1998 (10(+6) SNe Ia)
- Perlmutter et al 1999 (42 SNe Ia)

=> Acceleration of expansion

=> Gruber prize to the ~50 authors of these 2 papers !



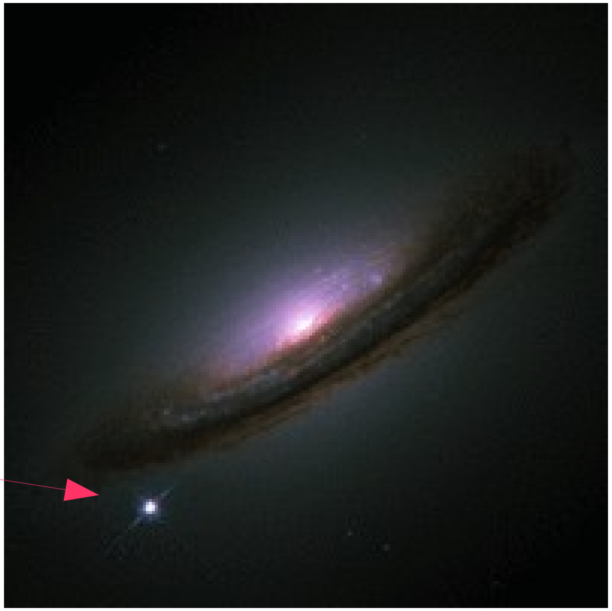
Later on:

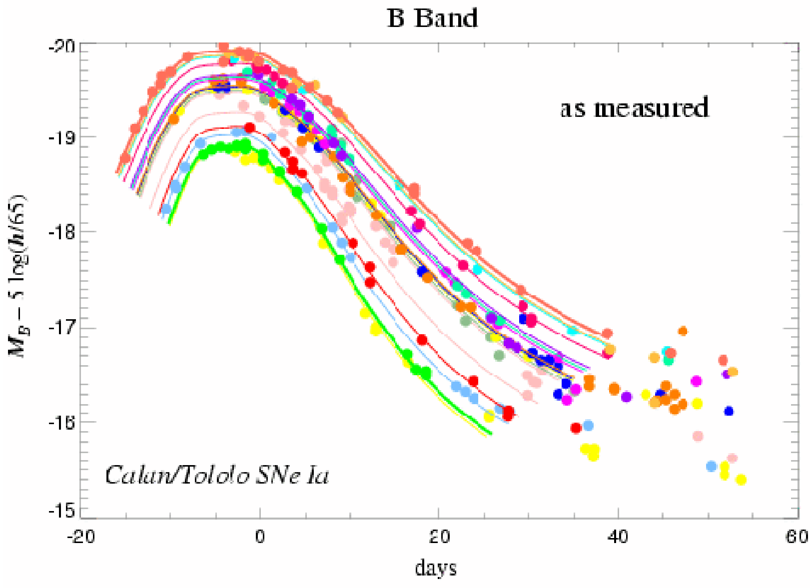
- Sullivan et al 2002 Hubble diagrams by galaxy types
  (non-evolution test)
- Tonry et al 2003 (+8)
- Barris et al 2003 (+23 SNe Ia, z<1)
- Knop et al 2003 (+11 SNe Ia measured with HST)
- Riess et al 2004: (+16 SNe Ia found and measured with HST) up to z~1.6
- Riess et al 2006: (+17 SNe Ia found and measured with HST) up to z~1.6

Supernovae Ia

Thermonuclear explosions of stars
which appear to be reproducible

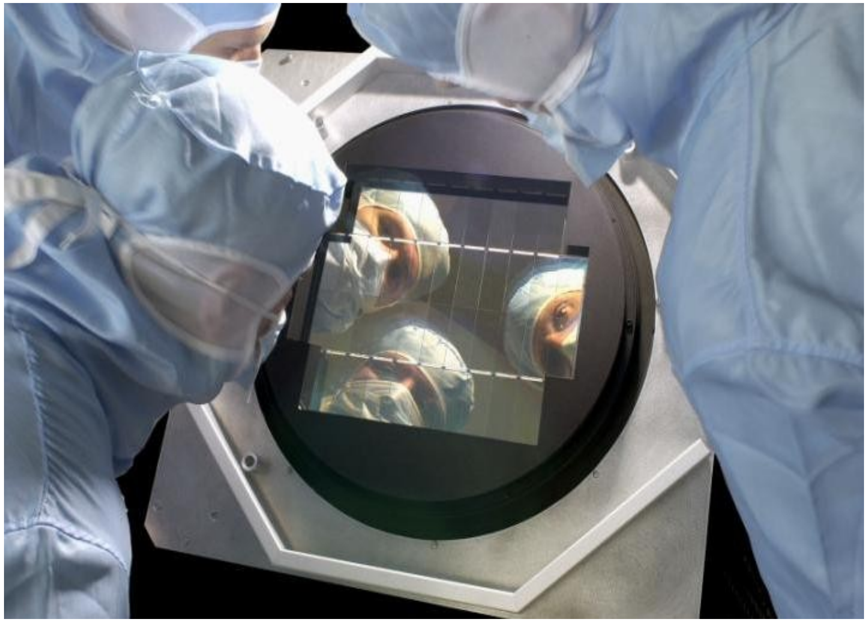
- Very luminous
- Can be identified (spectroscopy)
- Transient
  (rise ~ 20 days)
- Scarce (~1 /galaxy/millenium)
- Fluctuations of the peak
  luminosity : 40 %
- Can be improved to ~14 %



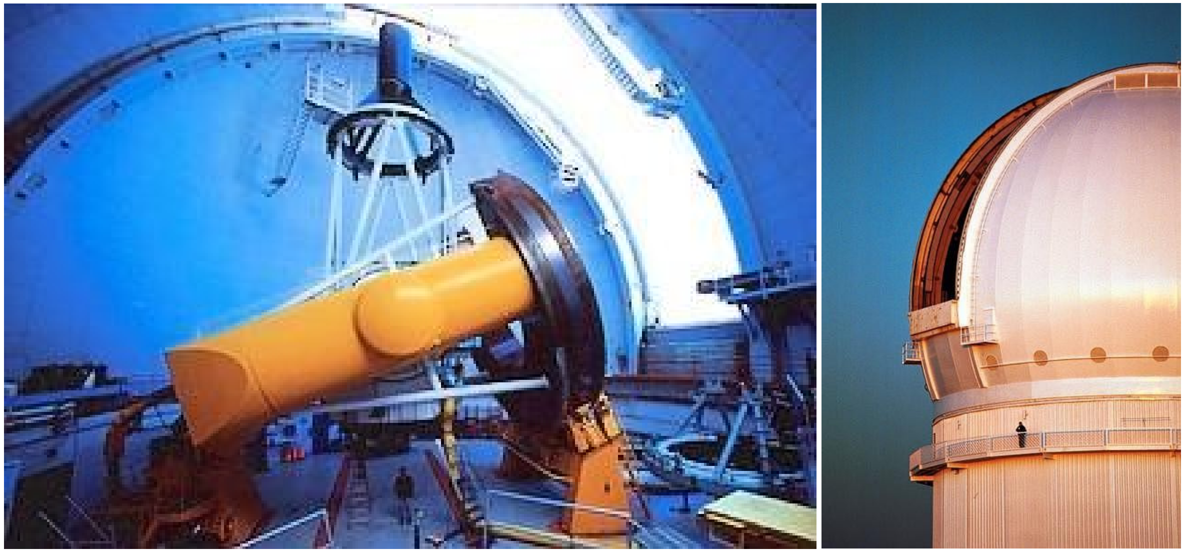


MegaCam at CFHT

MegaCam:
- 36 CCDs 2k x 4.5k pixels
- 1 pixel = 0.185"
- field of view : 1 deg^2
- 1^{rst} light at end of 2002.



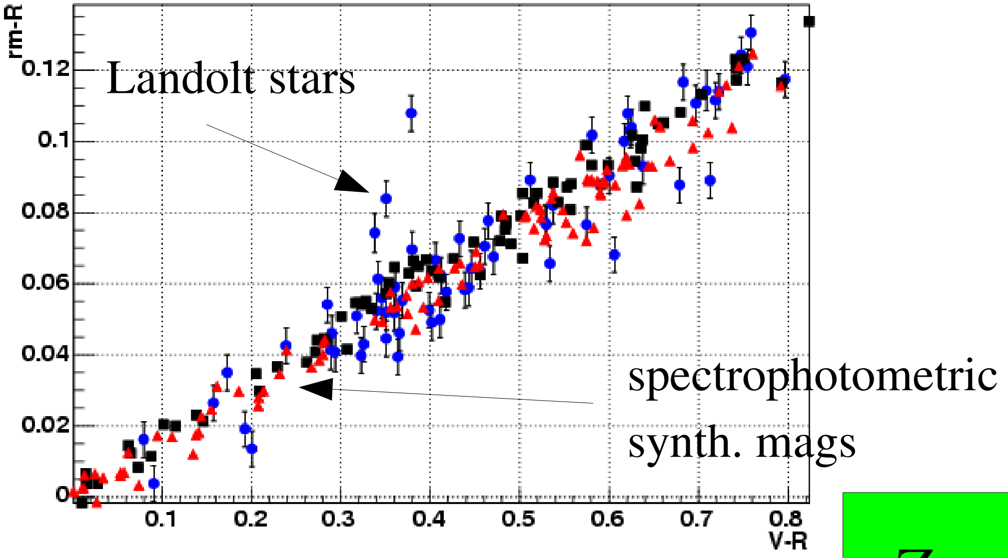
CFHT:
- diametre 3.6m
- Mauna Kea, Hawaii
- 4200 m
- <seeing> = 0.8"

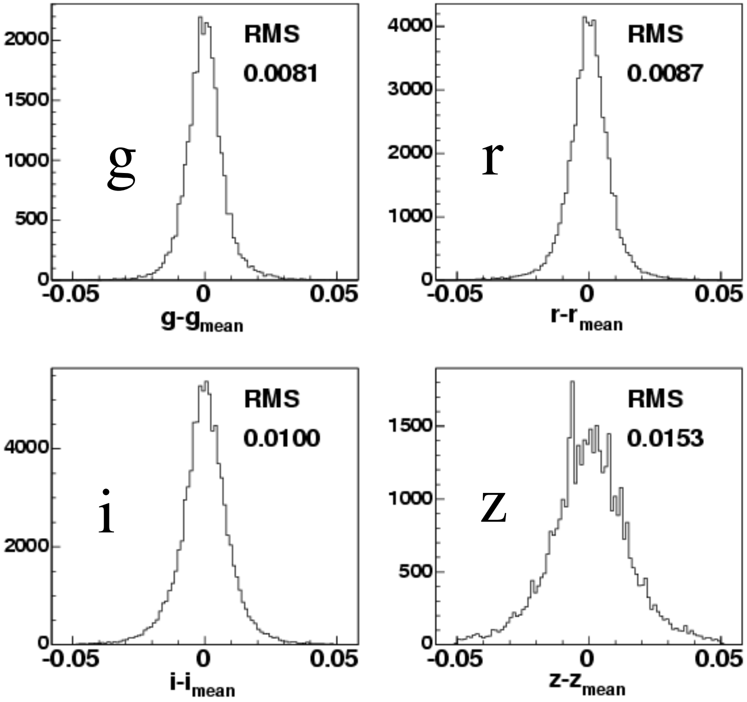


Photometric calibration

- Relies on repeated observations of Landolt standard stars.
- Calibration in “Landolt” (Vega) magnitudes because nearby SNe are calibrated this way
- Produces calibrated star catalogs in the CFHTLS Deep fields, in natural Megacam magnitudes.

Comparison of synthetic and observed color terms (Megacam/Landolt & Megacam SDSS 2.5m)



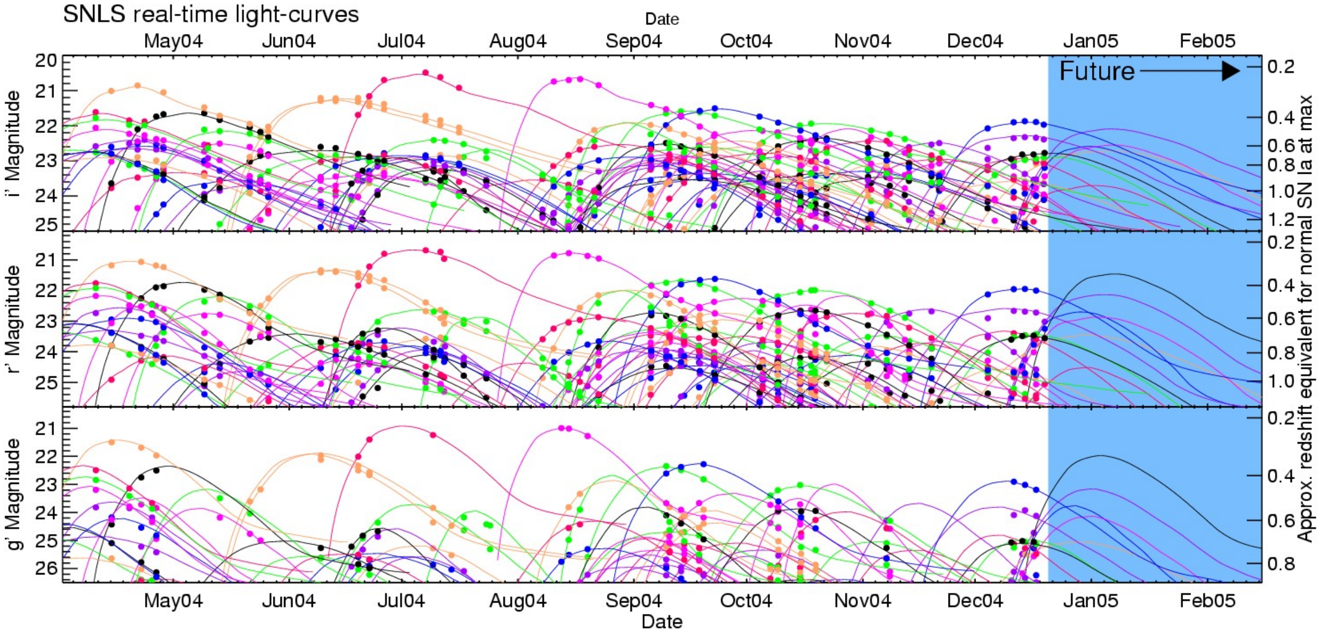


-Zero points @ 0.01 (0.03 in z)

-Repeatability better than 0.01 (0.015 in z)

First year SNLS data set

(up to July 2004)



142 acquired spectra:

- 20 Type II SNe
- 9 AGN/QSO
- 4 SN Ib/c
- 91 SNe Ia

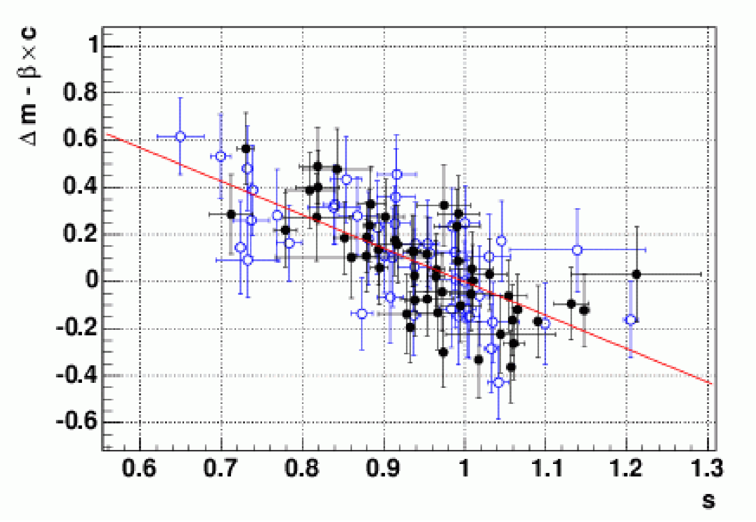
-10 missed references (are now usable)

- 6 only have 1 band (lost)

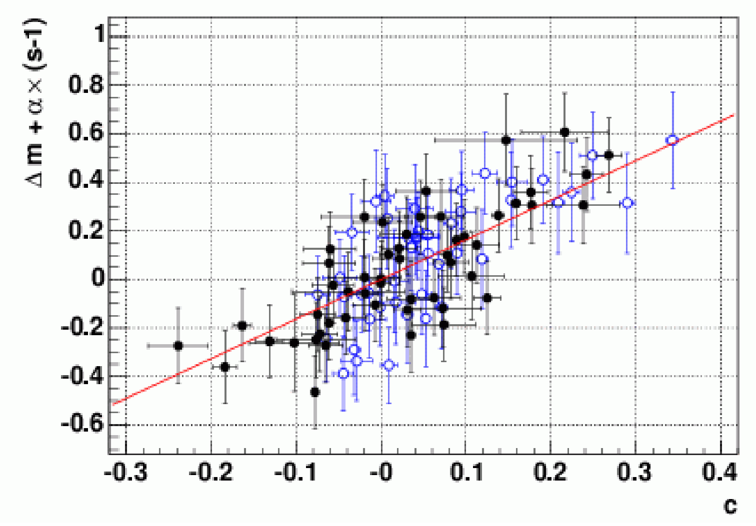
75 usable Ia events

Evolution test: comparing distant (z<0.8) and nearby SNe

Brighter - slower

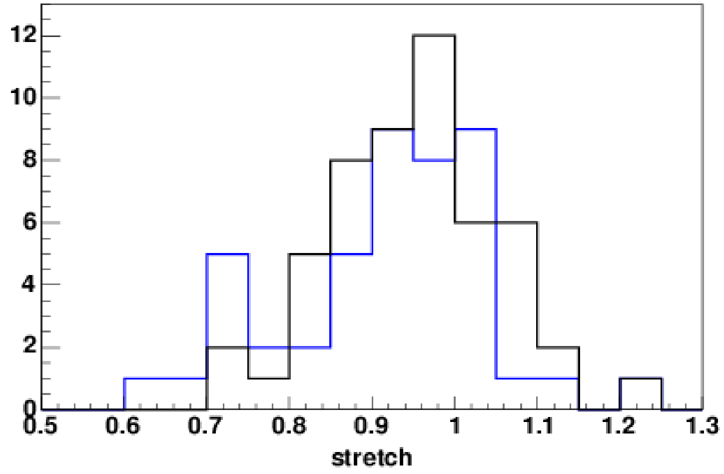


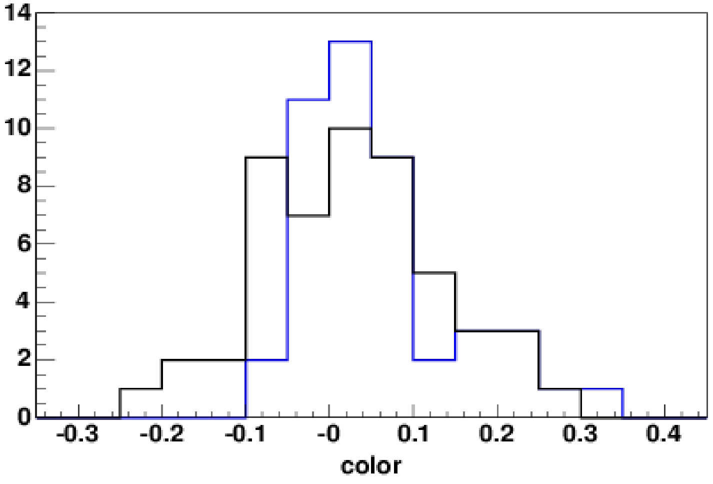
Brighter - bluer



Blue: nearby SNe

Black: SNLS SNe



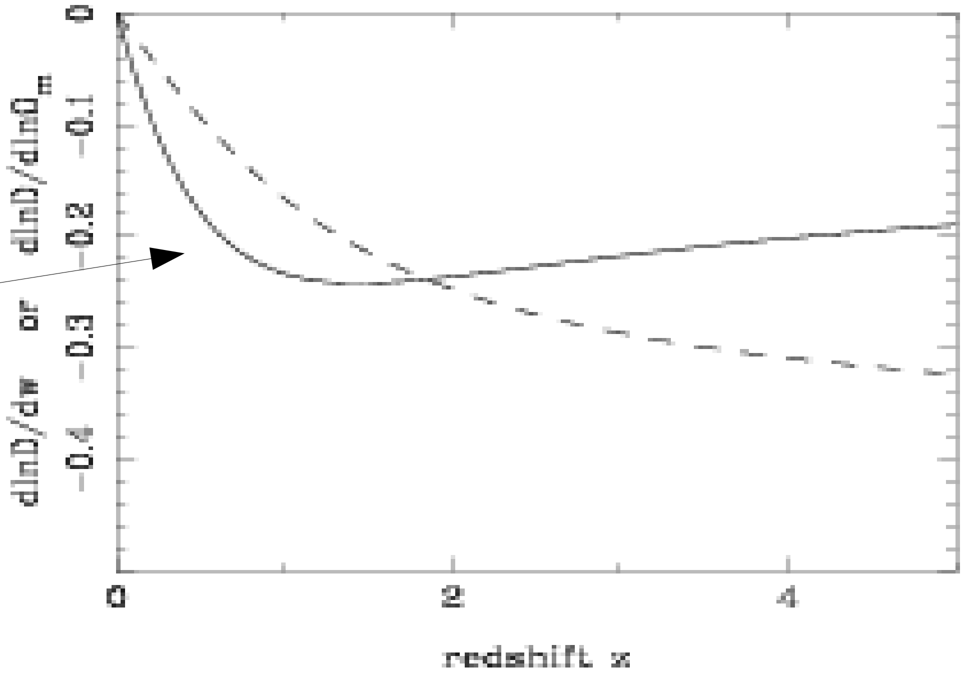


Stretch, color and relations with luminosity are essentially compatible between nearby and distant events.

Photometric calibration and EOS accuracy

For a constant EOS:

d log(d)/ dw <~ 0.2



(from astro-ph/0610906)

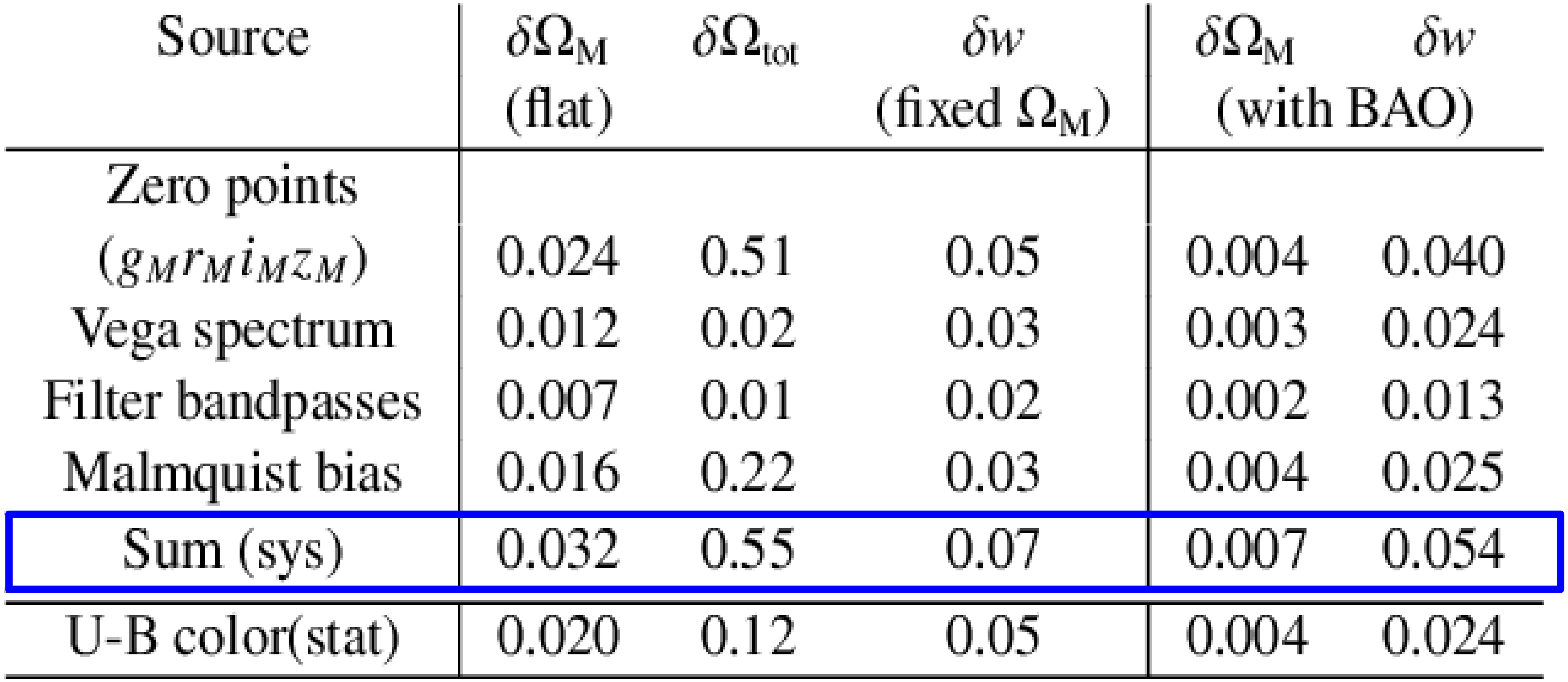
Hence:

a 2% uncertainty on flux translates to

- a 1% uncertainty on distance
- a 0.05 uncertainty on w

SNLS Systematic uncertainties

Summary:



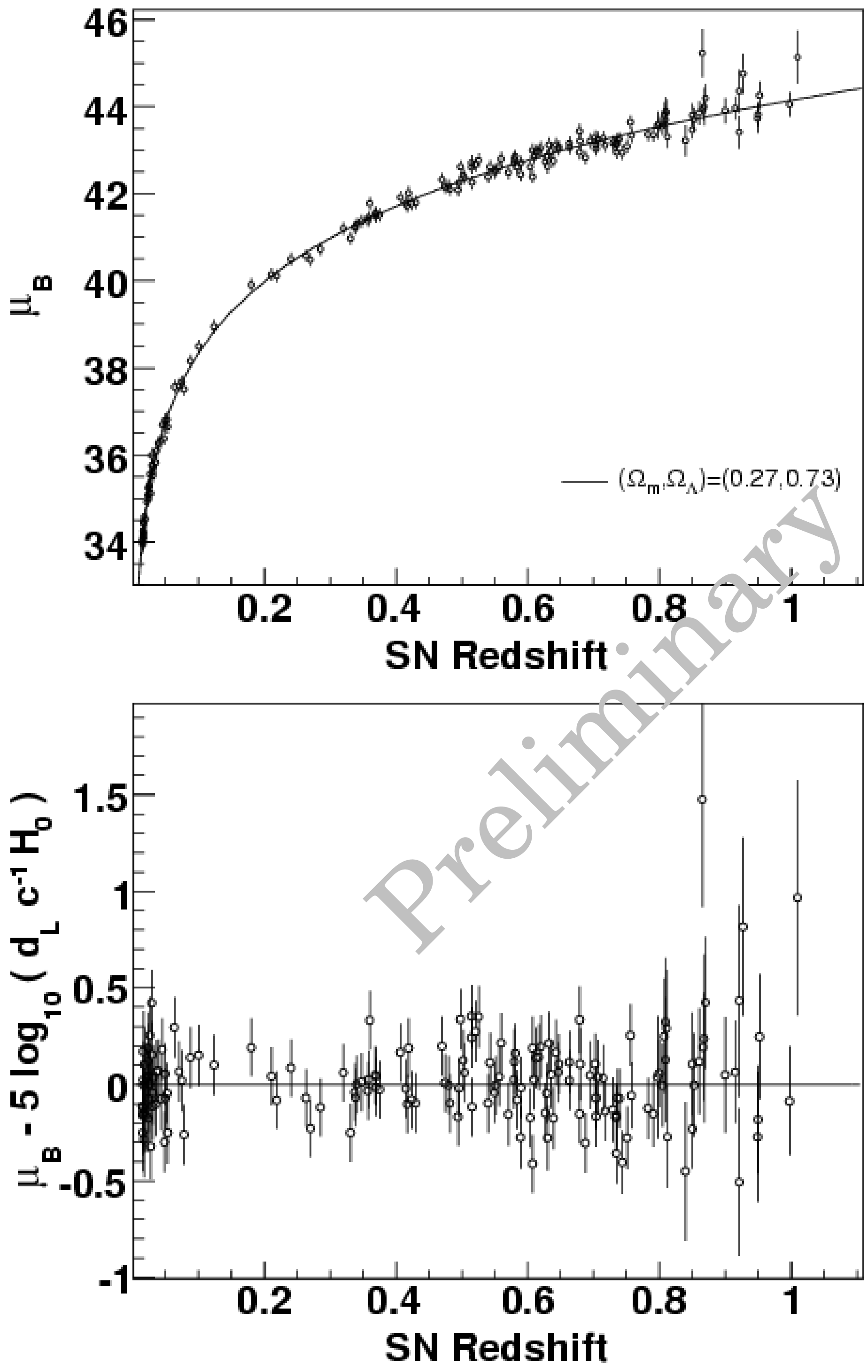
Source	$\delta\Omega_M$ (flat)	$\delta\Omega_{tot}$	δw (fixed Ω_M)	$\delta\Omega_M$ (with BAO)	δw (with BAO)
Zero points ($g_M r_M i_M z_M$)	0.024	0.51	0.05	0.004	0.040
Vega spectrum	0.012	0.02	0.03	0.003	0.024
Filter bandpasses	0.007	0.01	0.02	0.002	0.013
Malmquist bias	0.016	0.22	0.03	0.004	0.025
Sum (sys)	0.032	0.55	0.07	0.007	0.054
U-B color(stat)	0.020	0.12	0.05	0.004	0.024

Improvements foreseen on z calibration and Malmquist bias

SNLS 2.5 years
Hubble Diagram

Up to March 2006,

~230 distant SNe Ia

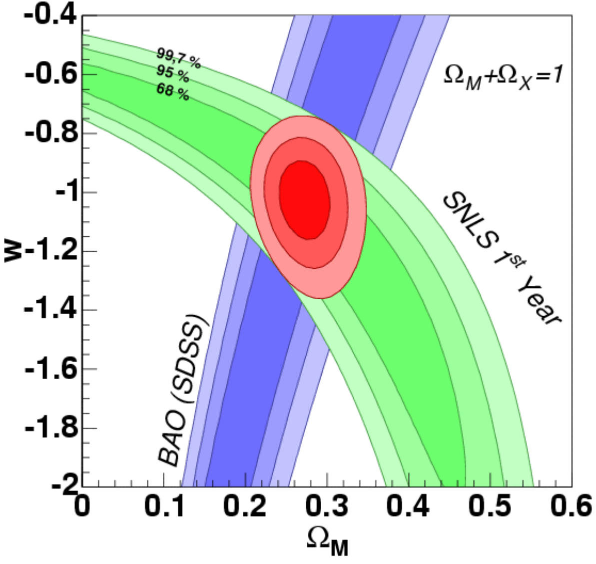


More Data Coming Soon

- High-z Supernovae ($z>0.3$)
  - SNLS, Essence, SCP, PANS(HST)
- Medium-z Supernovae ($0.05<z<0.3$)
  - SDSS
- Local Supernovae
  - CfA, KAIT, CSP, SNFactory,...

SNe+BAO:Short term forecasts for w

(SNLS Collab., 2005)

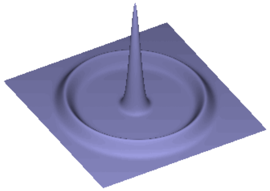


Expected "realistic" statistical improvements of the (Ω_M,w) constraints.

SNfactory
SDSS SNe
SNLS SNe

	Nearby SNe	44	inf.	44	132	132	250
	Distant SNe	71	71	213	213	500	500
with current	$\sigma(\Omega_M)$	0.023	0.019	0.019	0.019	0.018	0.018
BAO accuracy	$\sigma(w_0)$	0.088	0.073	0.076	0.064	0.060	0.055
BAO x 2	$\sigma(\Omega_M)$	0.016	0.014	0.014	0.013	0.013	0.013
(4000->8000 deg^2)	$\sigma(w_0)$	0.081	0.062	0.067	0.054	0.049	0.044

Material from D. Eisenstein (et al).
I added mistakes on my own.

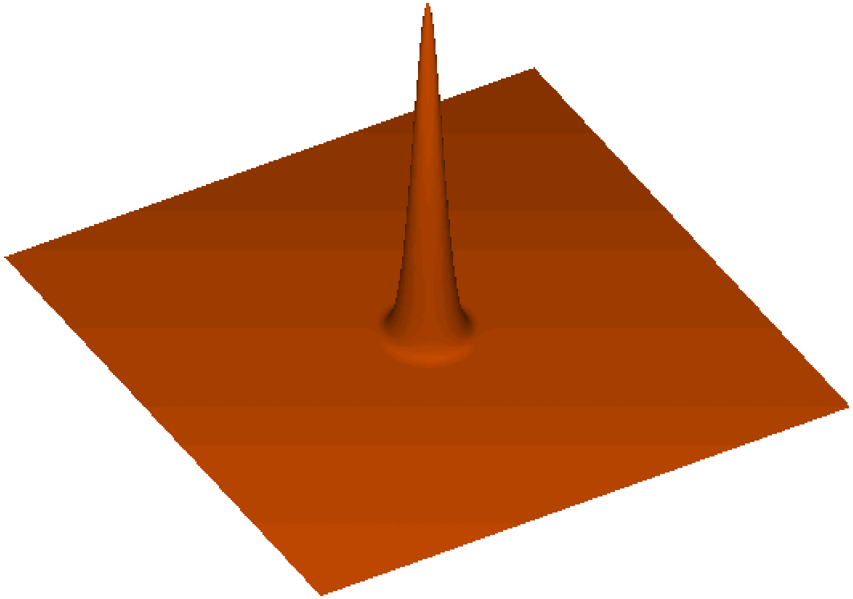


Baryon Acoustic Oscillations

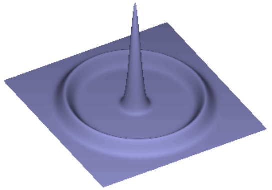
- Before recombination, sound waves propagate in the universe.

- Acoustic oscillations are seen in the CMB
Look for the the same waves in the galaxy correlations.

- Typical CMB fluctuations are ~10^{-5}...
... expect 1% signal today in galaxy correlations

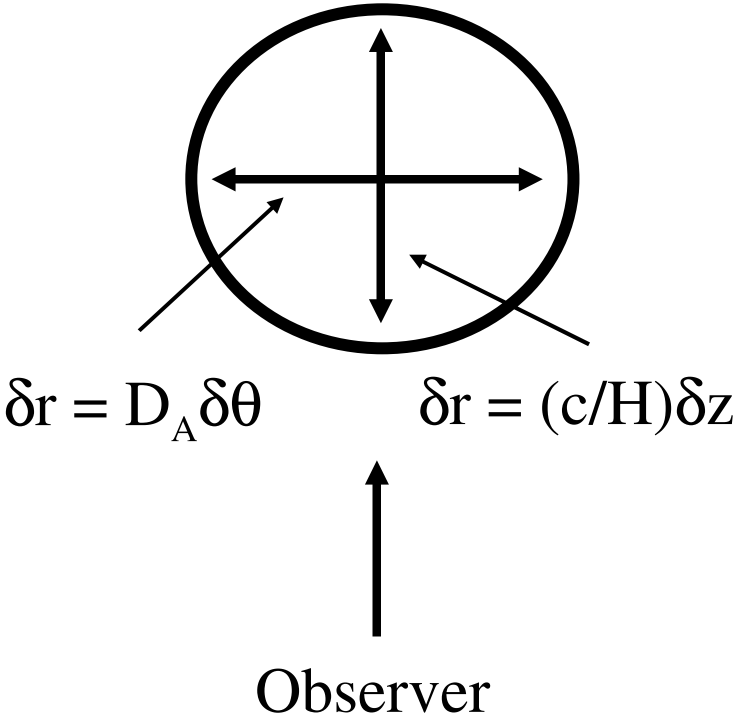


propagation of a fluctuation
from BB to recombination



A Standard Ruler

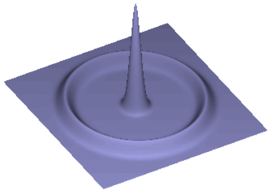
- The acoustic oscillation scale depends on the sound speed and the propagation time.
  - These depend on the matter-to-radiation ratio ($\Omega_m h^2$) and the baryon-to-photon ratio ($\Omega_b h^2$).
- The CMB anisotropies measure these and fix the oscillation scale.
- In a spectroscopic galaxy redshift survey, we can measure this along and across the line of sight.
- Yields $H(z)$ and $D_A(z)$!



$\delta r = D_A \delta\theta$

$\delta r = (c/H)\delta z$

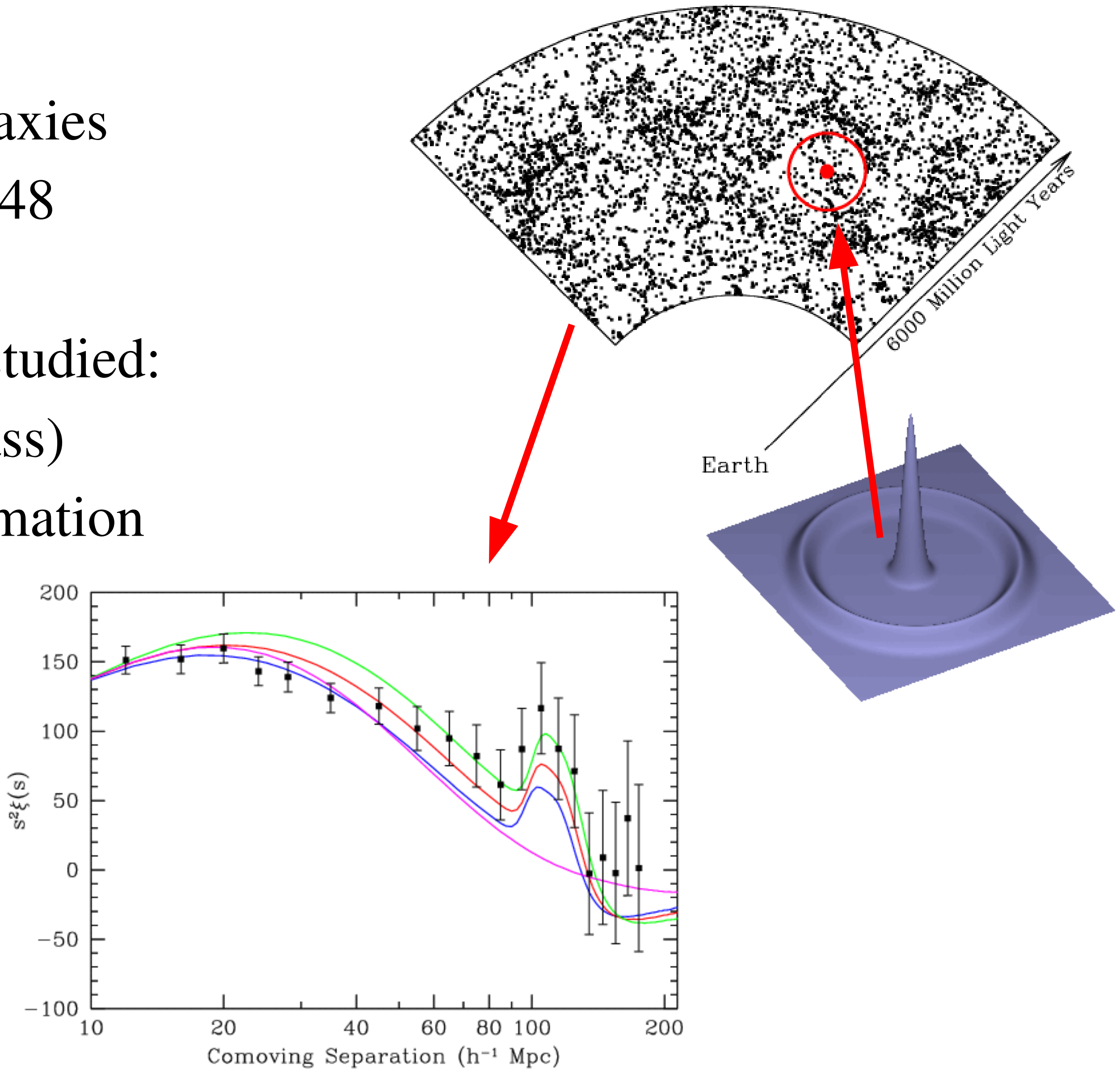
Observer



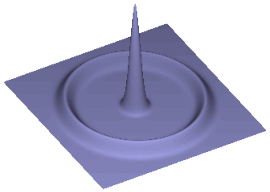
Detection in the SDSS

(D.Eisenstein et al [SDSS Collab.] 2005)

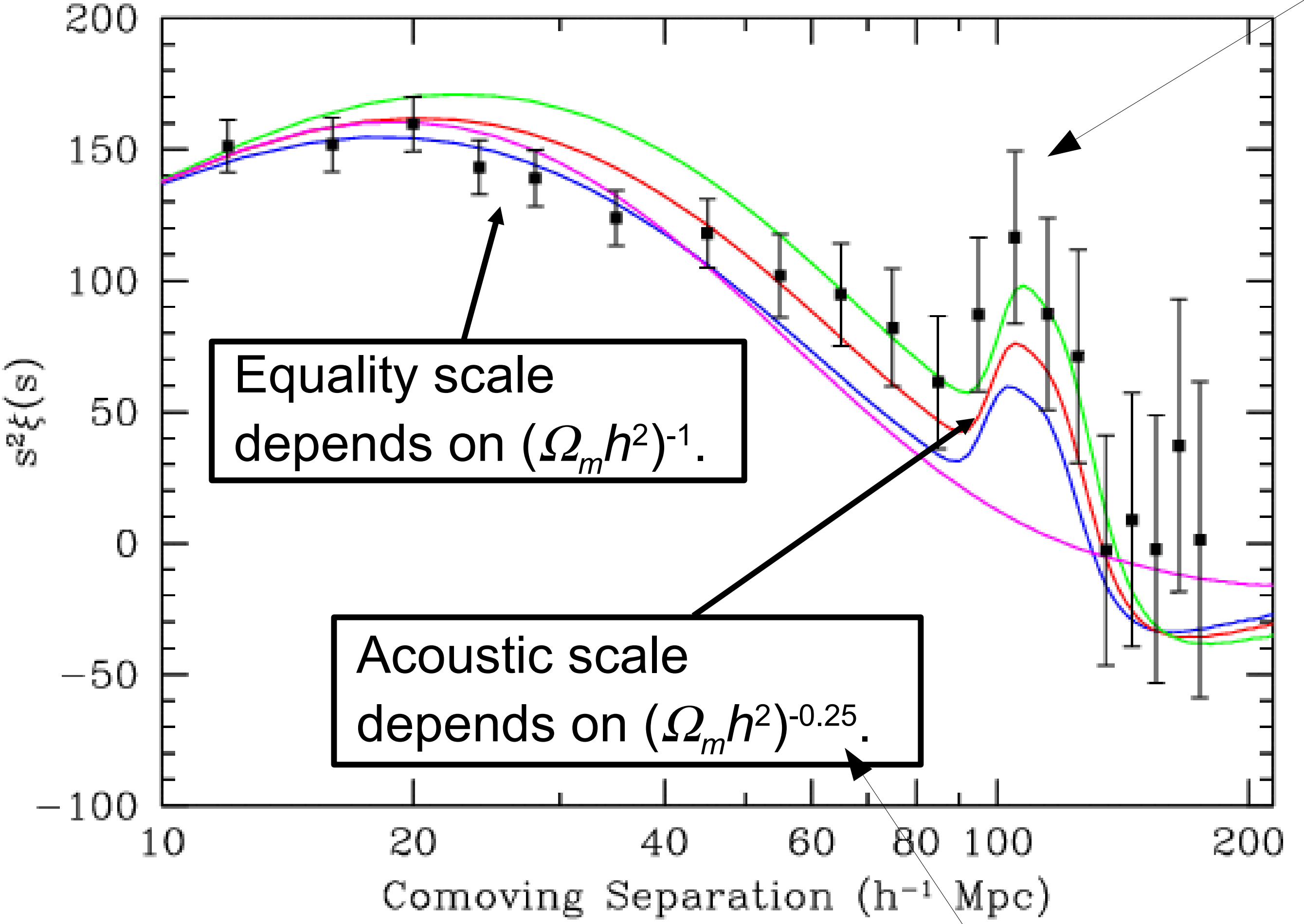
- 55000 Luminous Red Galaxies
- Over 4000 deg^2 up to z~0.48
- <z> = 0.35
- Sources of bias carefully studied:
  - galaxy bias (light vs mass)
  - non-linear structure formation
  - redshift distortions



Two Scales in Action



Correlated error bars



Equality scale depends on $(\Omega_m h^2)^{-1}$.

Acoustic scale depends on $(\Omega_m h^2)^{-0.25}$.

$\Omega_m h^2 = 0.12$

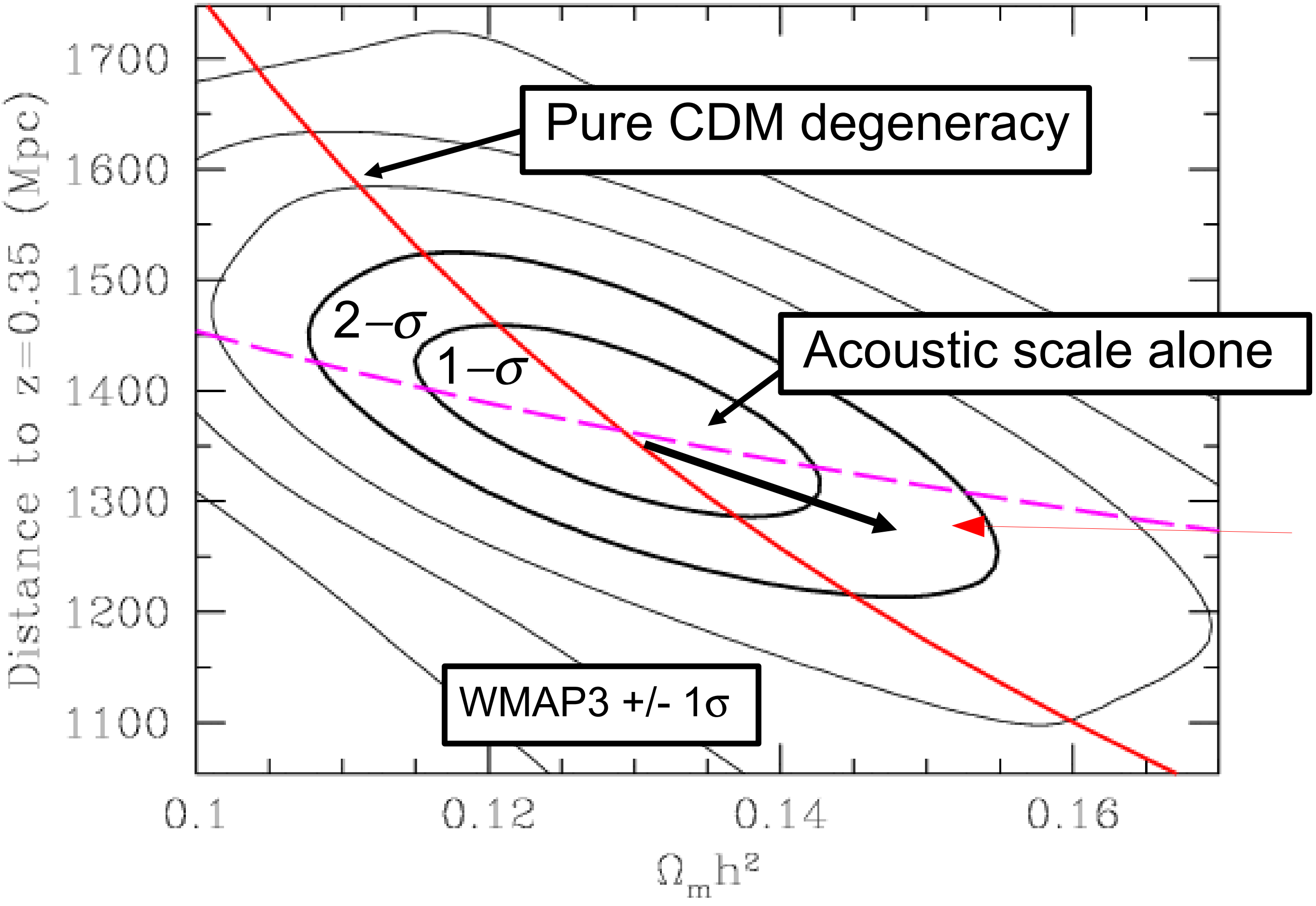
$\Omega_m h^2 = 0.13$

$\Omega_m h^2 = 0.14$

not a consequence of first principles

See Hu, 0407158

Cosmological Constraints



The uncertainty in $\Omega_m h^2$ makes it better to measure $(\Omega_m h^2)^{1/2} D$. This is independent of H_0.

$$\Omega_m = 0.273 \pm 0.025 + 0.123(1+w_0) + 0.137\Omega_K.$$

Eisenstein et al [SDSS], ApJ (2005) (astro-ph/0501171)

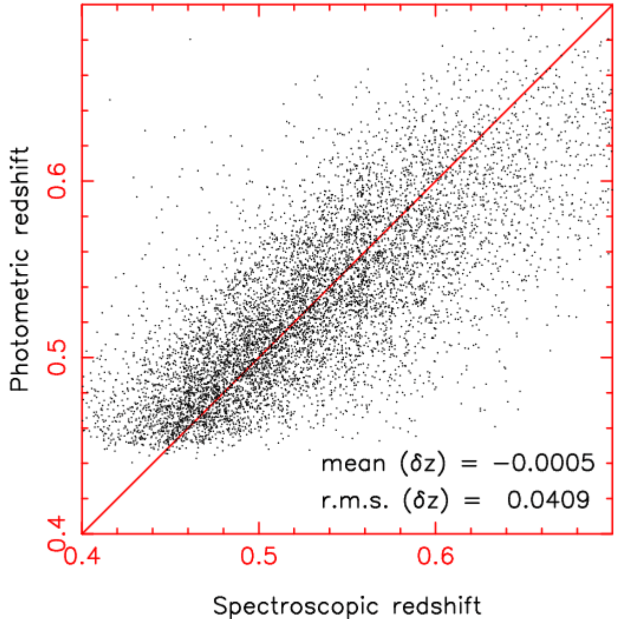
BAO : future

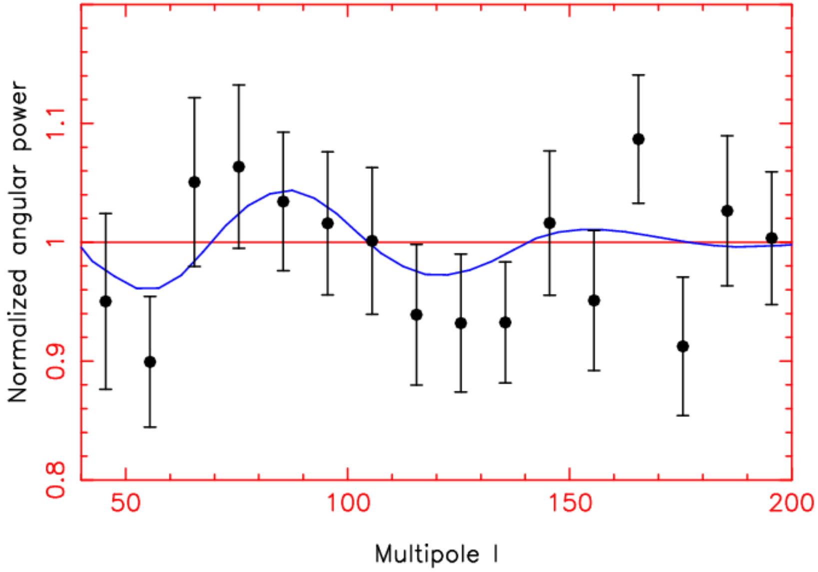
- SDSS is currently doubling its surveyed area (4000->8000 deg^2)
- The BOSS project : reach z ~ =0.8 over 10 000 deg^2 (2011?)
- The AAOmega project: reach z=0.7 over 3000 deg^2 (running)
- Next generation typically requires :
  - 8m-class telescope
  - wide-field spectrograph (~2 deg FOV)
  - Get ~5000 spectra in a single shoot
  - No project approved yet....
- What about BAO using photometric redshifts?

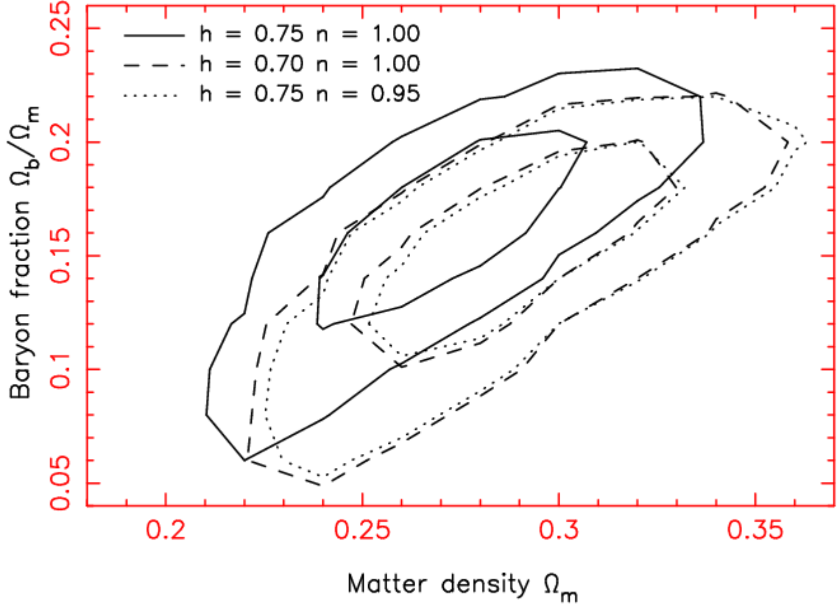
BAO with photometric redshifts

astro-ph/0605303 : 600 000 Luminous Red Galaxies
from SDSS at 0.4<z<0.7, using photo-z
(see also 0605302: same data, different analysis)

-> ~ < 3 sigma detection of BAOs
-> comparable to Eisenstein et al (2005)
-> 10 photo-z ~ 1 spectroscopic z
-> ..... and we just loose H(z)





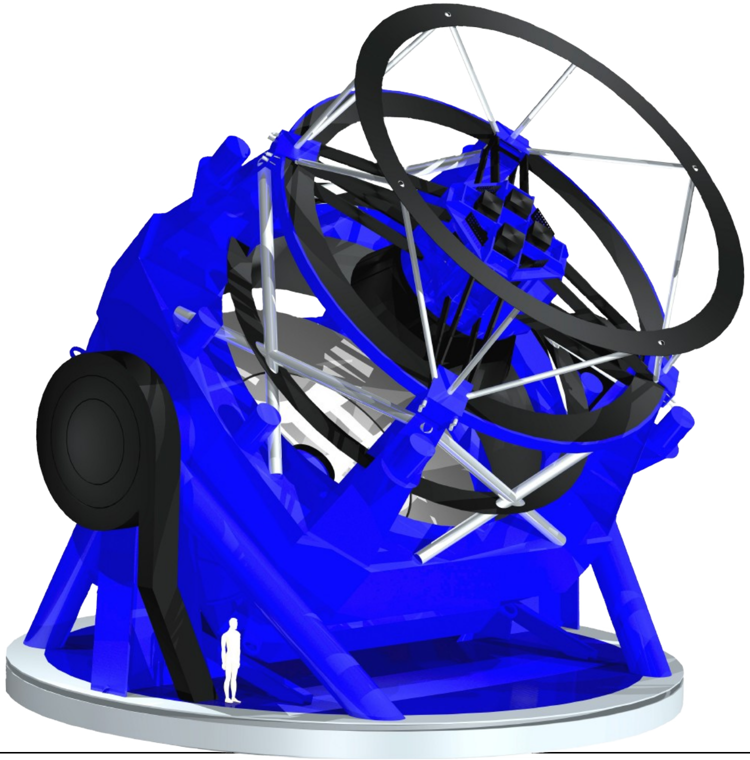


Wide field imaging projects

	FOV	diameter	first light	status	who/where
VST @ ESO	1 deg2	2.6 m	2008	funded	ESO/Paranal
DARKCam	2 deg2	3.6 m	??	refused at ESO	UK+...
HyperSuprimeCam	2-3 deg2	8 m	2012	~funded	Japan/Subaru
Dark Energy Survey	2 deg2	CTIO-4m	2012	not funded	Fermilab/CTIO
Pan StarsS	7 deg2	1.8 m	2007	funded	Univ. Hawaii
Pan StarsS 4	7 deg2	1.8 m x 4	2009 (+)	not funded	Univ. Hawaii
LSST	10 deg2	8 m	2014	not funded	DOE/NSF
SNAP	0.7 deg2	2 m	2017(+)	competing	DOE/NASA
DUNE	~1 deg2	1.2 m	2017(+)	competing	ESA

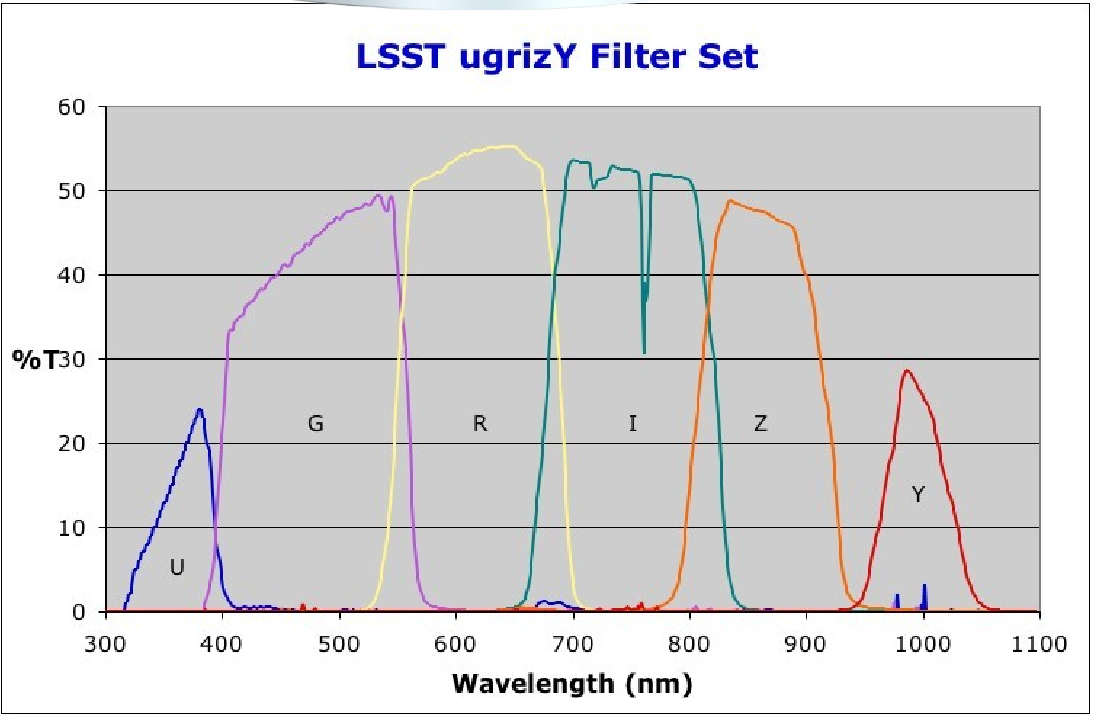
- Can target all DE probes : WL, SNe, BAOs, galaxy clusters
- Ground based : visible From space : near IR (+visible)

LSST concept

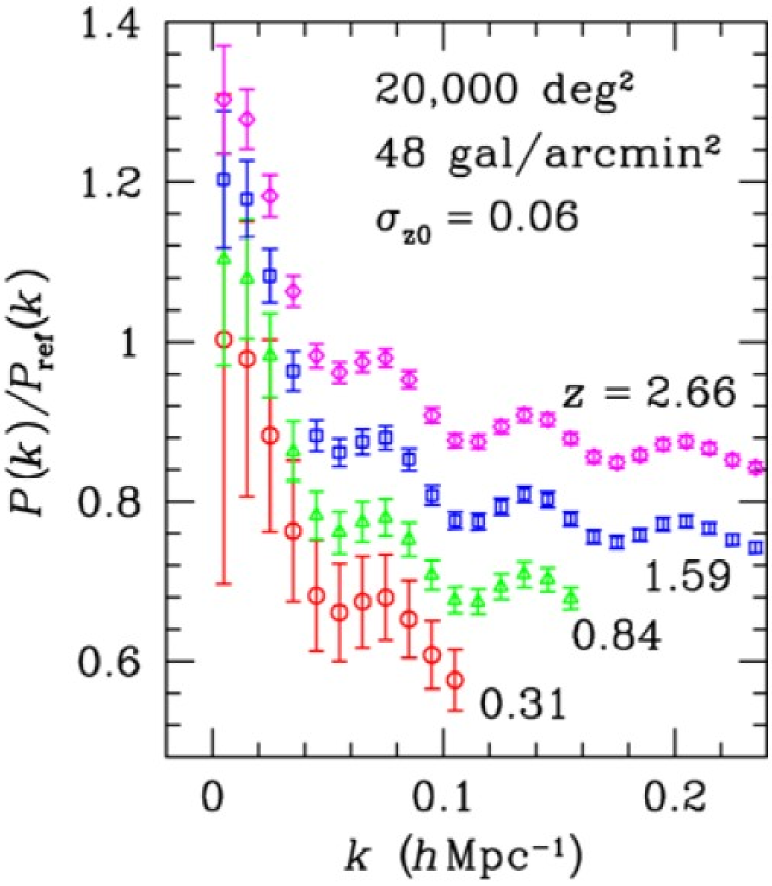


- Primary mirror :~ 8m
- Single instrument : imager
- with Field Of View~ 10 deg^2
- 6 bands from 330 to 1050 nm.
- Visits the whole dark sky

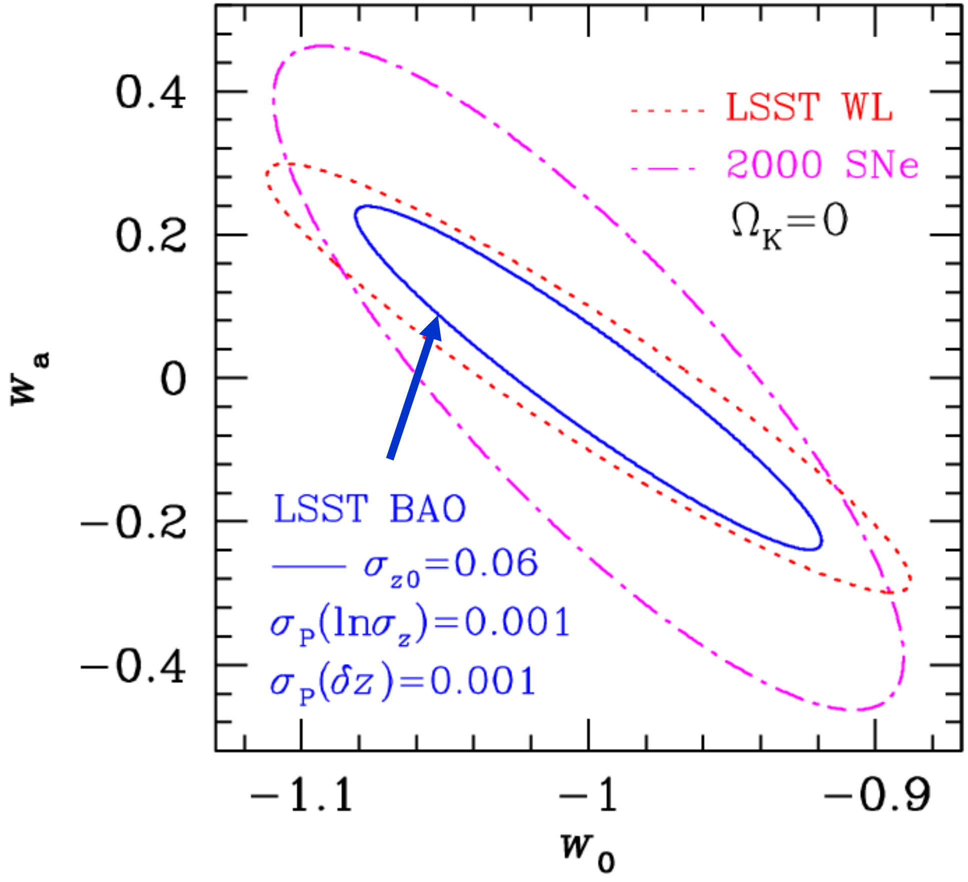
  in 2 bands within less than a week
- 20 Tb/night
- Science:
  - DM & DE through lensing
  - SNe, BAO
  - .....
- First light anticipated in 2014



LSST forecast : BAO Power Spectra



Two-dimensions on the sky.
3 billion galaxies.



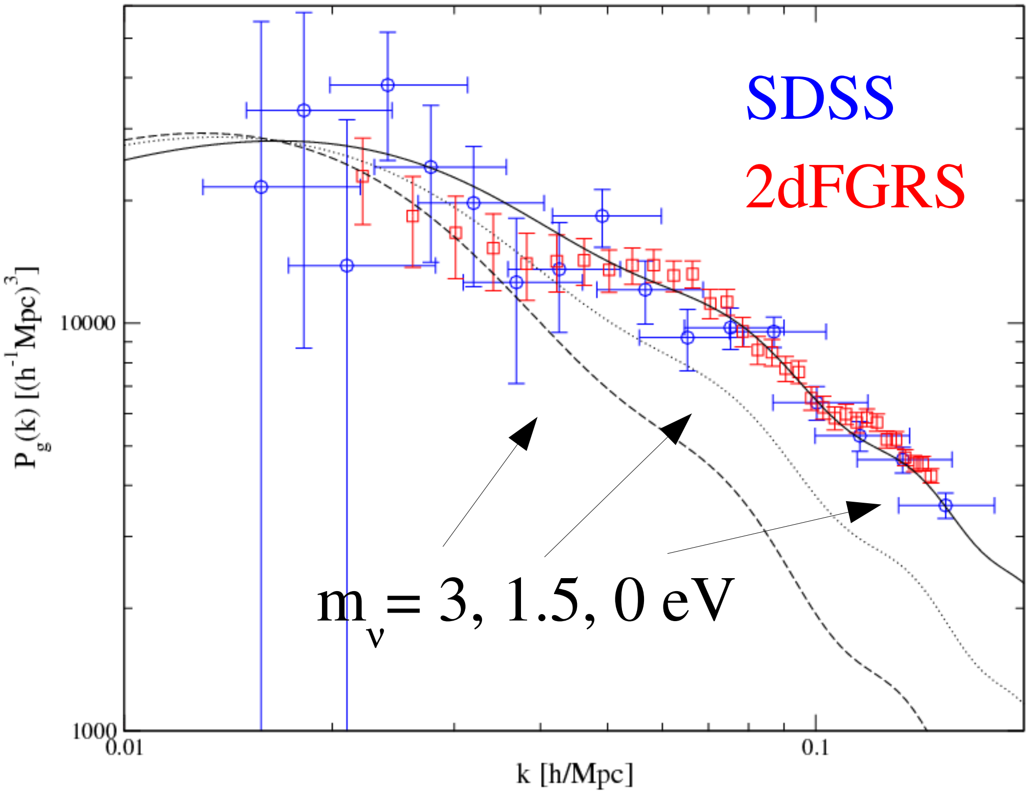
Combination yields accuracy ~ 2 % on constant w

Neutrino mass(es) from telescopes

Neutrino number density is known precisely from CMB temperature
-> m_ν translates to a physical density.

- Since neutrinos are light, they slow down the growth of structures on small scales (large k).

-> Impact correlations of galaxies



Neutrino mass(es) : limits

No positive detection yet, only upper limits.

Strongly dependent on the allowed parameter space and data samples

astro-ph/0602155 :

CMB, LSS, BAO and SNIa , reasonably open parameter space

---> $m_\nu < 0.62$ eV (95 % CL)

astro-ph /0604335:

CMB, LSS,BAO, SNIa and Ly alpha , narrower parameter space:

---> $m_\nu < 0.17$ eV (95 % CL)

Neutrino mass(es) : outlook

Weaknesses of this approach to neutrino mass detection:

(1) There are interesting degeneracies :
e.g: dark energy equation of state ~~is~~ was degenenerate with m_ν

(2) We now have to use a lot of probes to lift degeneracies
systematic uncertainties of probes are mainly ignored

(3) We measure galaxy correlations, we compute matter correlations
(general problem referred to as the bias)

==> Expecting simpler and safer analyses using matter power spectrum
measured via lensing (weak shear or CMB lensing)

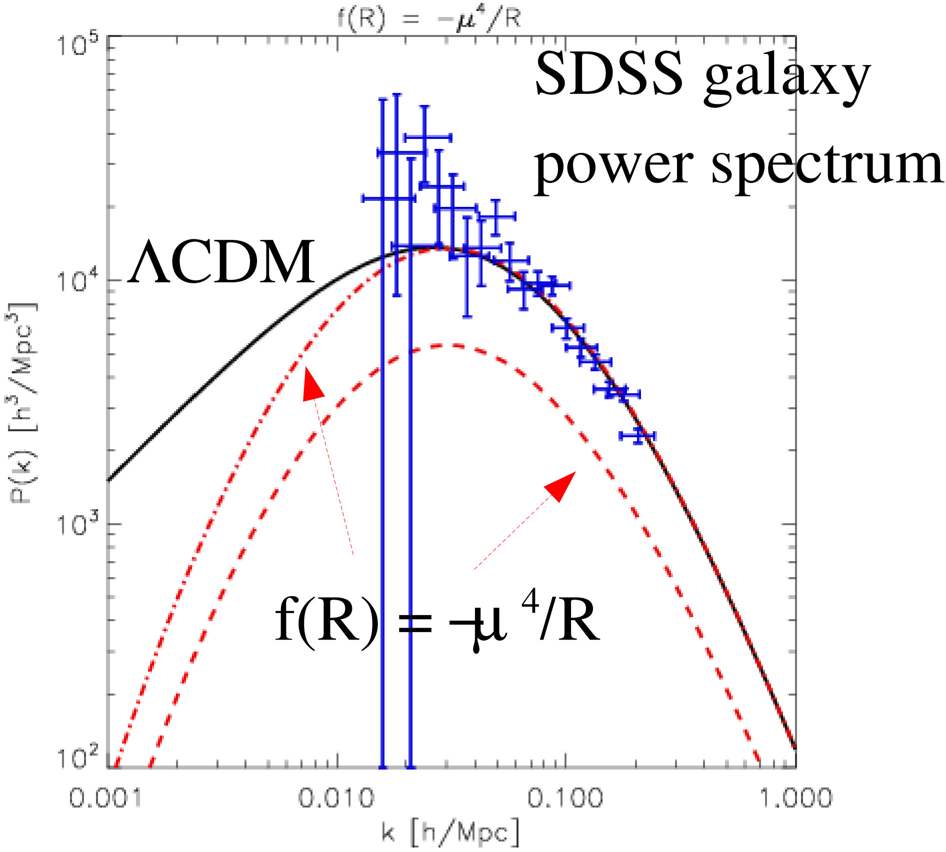
Modified gravity : non-minimal couplings

(R. Bean & al astro-ph/0611321)

$$S = \frac{1}{2\kappa^2}\int d^4x\sqrt{-g}\,\left[R + f(R)\right] + \int d^4x\sqrt{-g}\,\mathcal{L}_{\rm m}[\chi_i, g_{\mu\nu}]$$

Choose f so that it only impacts on large scales and preserves small scales

-> Cannot get CMB and galaxies power spectra with the observed ratio (as in ΛCDM)

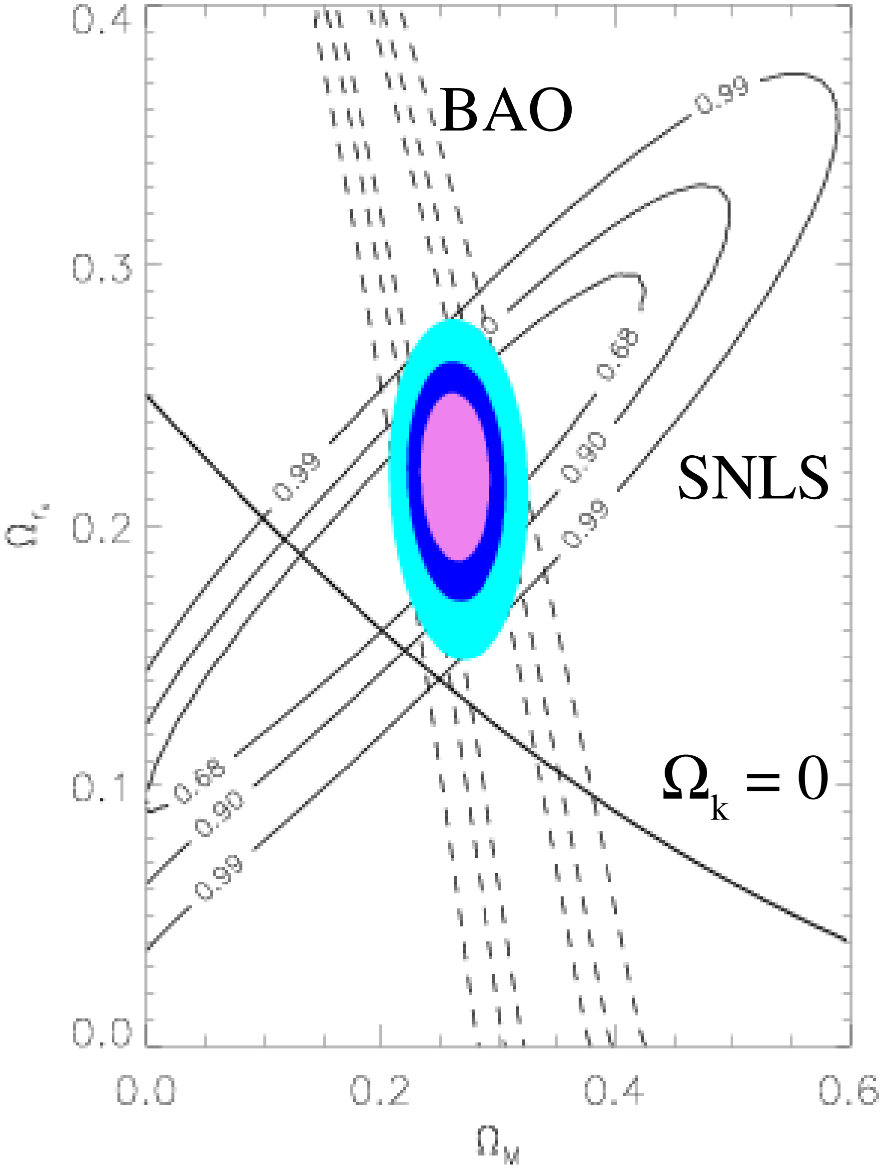


Extra dimension(s)

DGP model of 5D gravity :
(3+1)D brane in a (4+1)D bulk.

At odds with recent constraints assuming a flat universe.

Fairnbairn & Goobar (astro-ph/0511029)



Conclusions/summary

- Dark Energy looks like a cosmological constant:
    - w = ~ -1 +/- 0.09 (down to 0.07 using SNe, BAO, CMB)
    - improvements down to 0.05 are expected within ~ 2 years
    - drastic improvements will come from wide field imaging facilities ground- or space- based.

- Expected data for the coming years:
    - First results from second round spectroscopic BAO (AAOmega)
    - Final results from the CFHTLS weak shear analysis
    - Final results from the SNLS
    - Planck maps and power spectra
    - ....

More slides

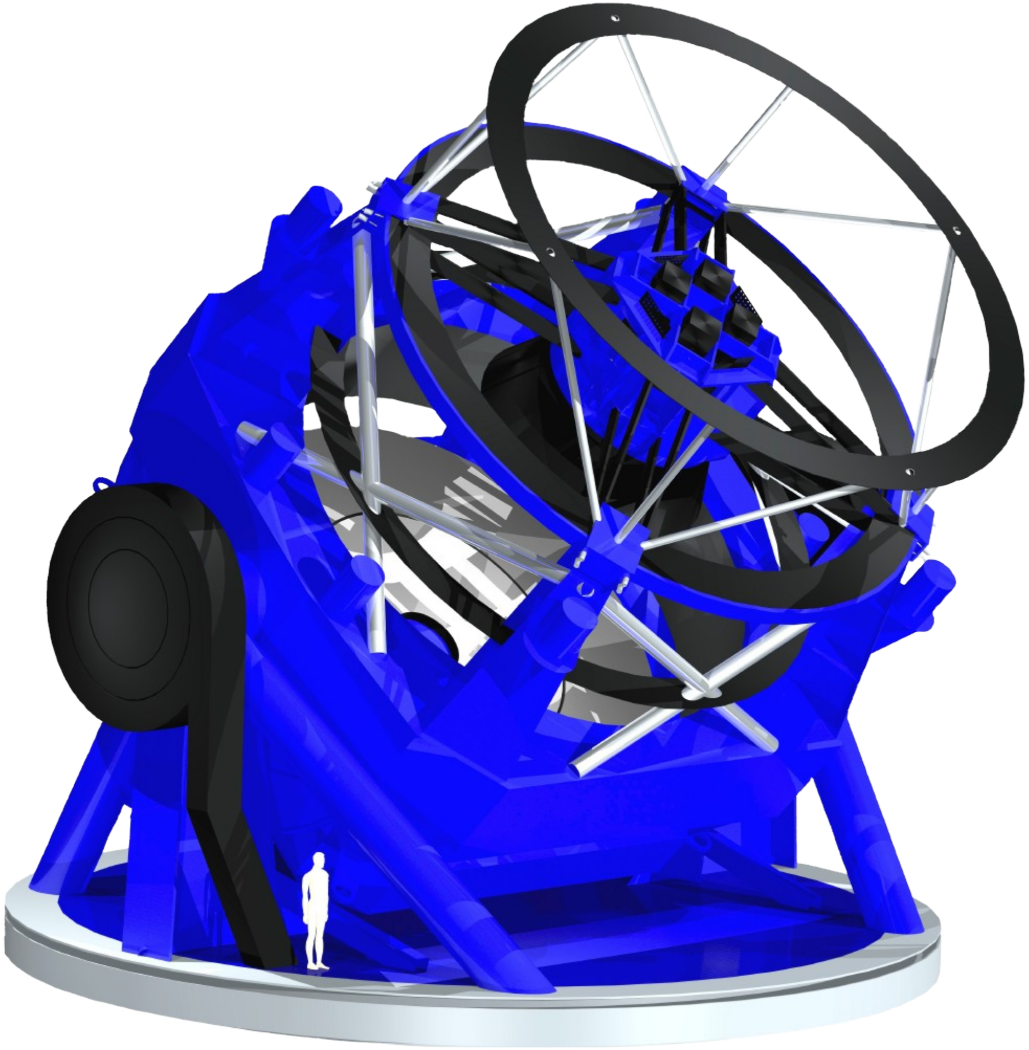
Backreaction

Idea:

- Friedmann's equation is derived assuming that universe is homogeneous
- Universe is not homogeneous.
- Inhomogeneities do add extra terms to Friedmann equation

LSST Concept

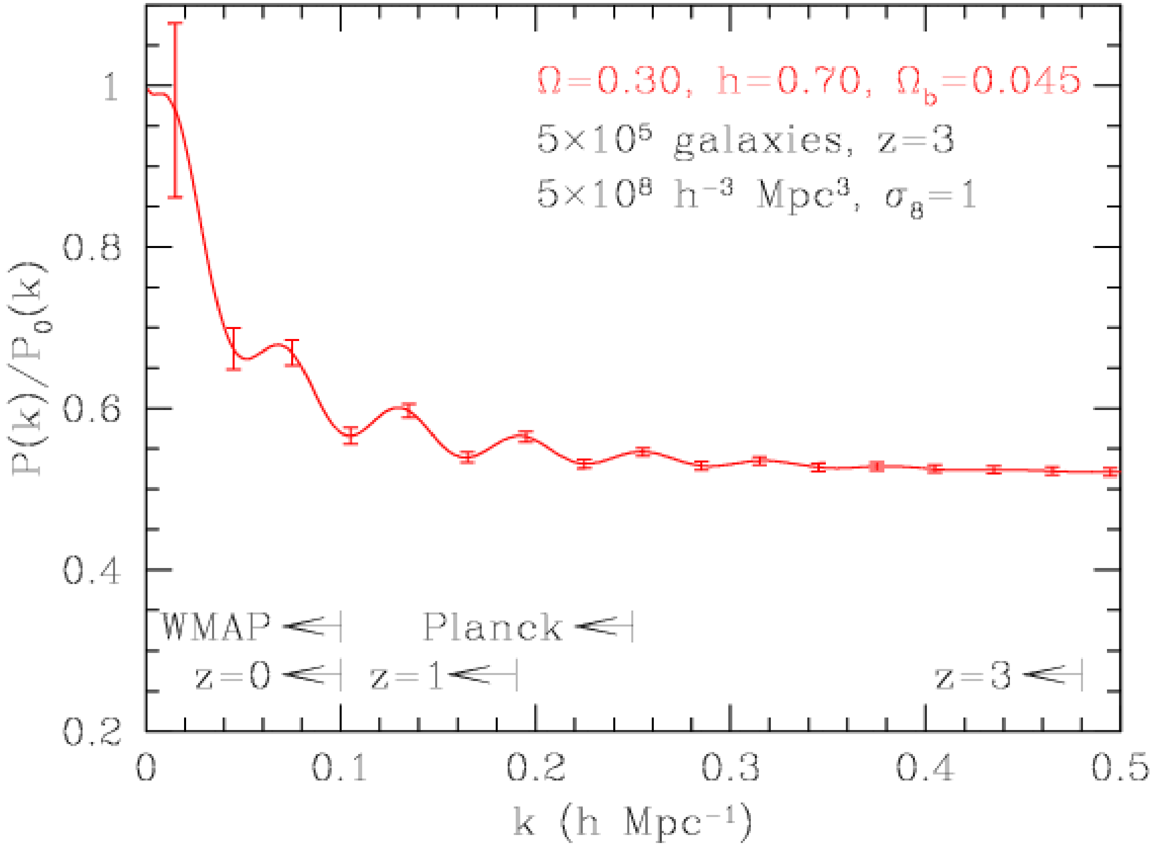
Design Telescope and Camera as a Single Instrument



- 8.4 Meter Primary Aperture
  - 3.4 M Secondary
  - 5.0 M Tertiary
- 3.5 degree Field Of View
- 3.2 Gigapixel Camera
  - 4k x 4k CCD Baseline
  - ~200 detectors
  - 65 cm Diameter
  - Six Filters
- 30 Second Cadence
  - Highly Dynamic Structure
  - Highly Parallel Readout
- Accumulated depth ~27 mag. in each filter over 10y (20000 deg^2)
- Data Storage and Pipelines ~ 18Tb/night!

- Etendue = 270 m^2 deg^2

A Baseline Survey at $z = 3$

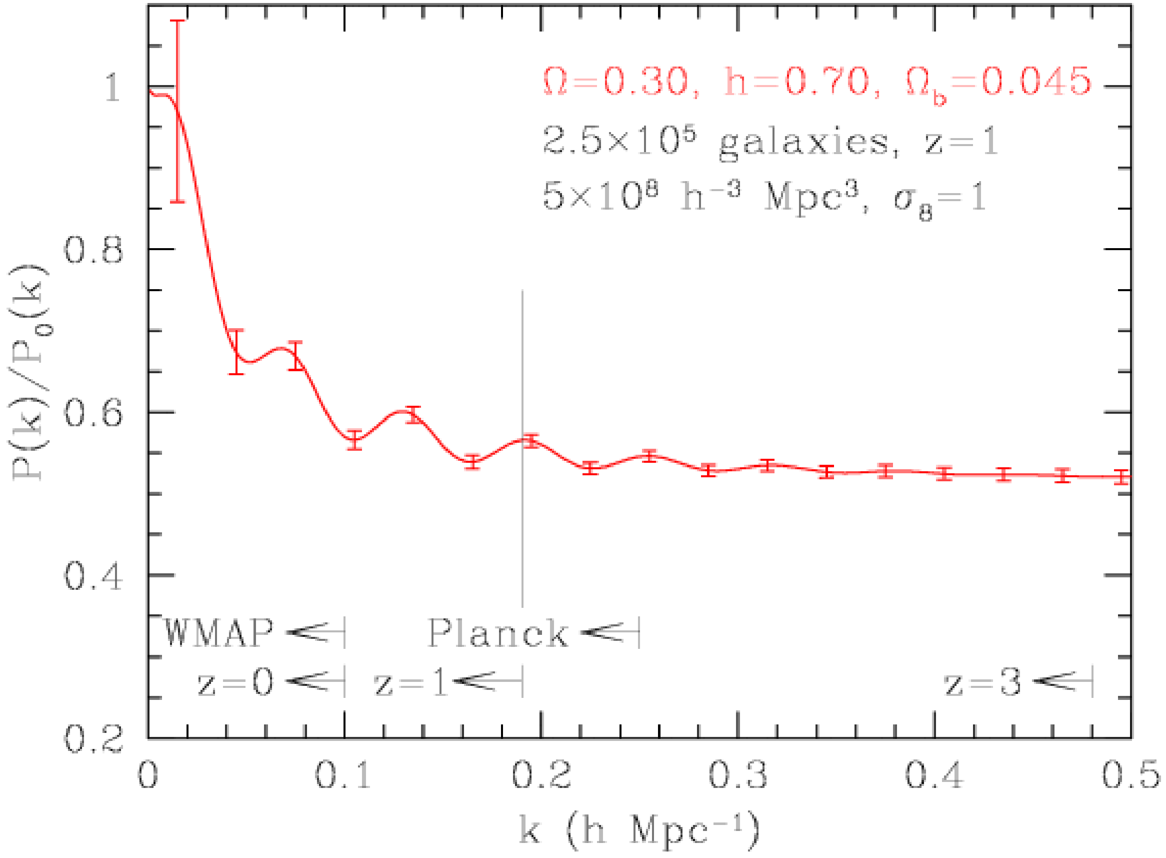


Statistical Errors from the z=3 Survey

- 600,000 gal.
- ~300 sq. deg.
- 10^9 Mpc^3
- 0.6/sq. arcmin

- Linear regime $k<0.3$h Mpc^{-1}
- 4 oscillations

A Baseline Survey at $z = 1$

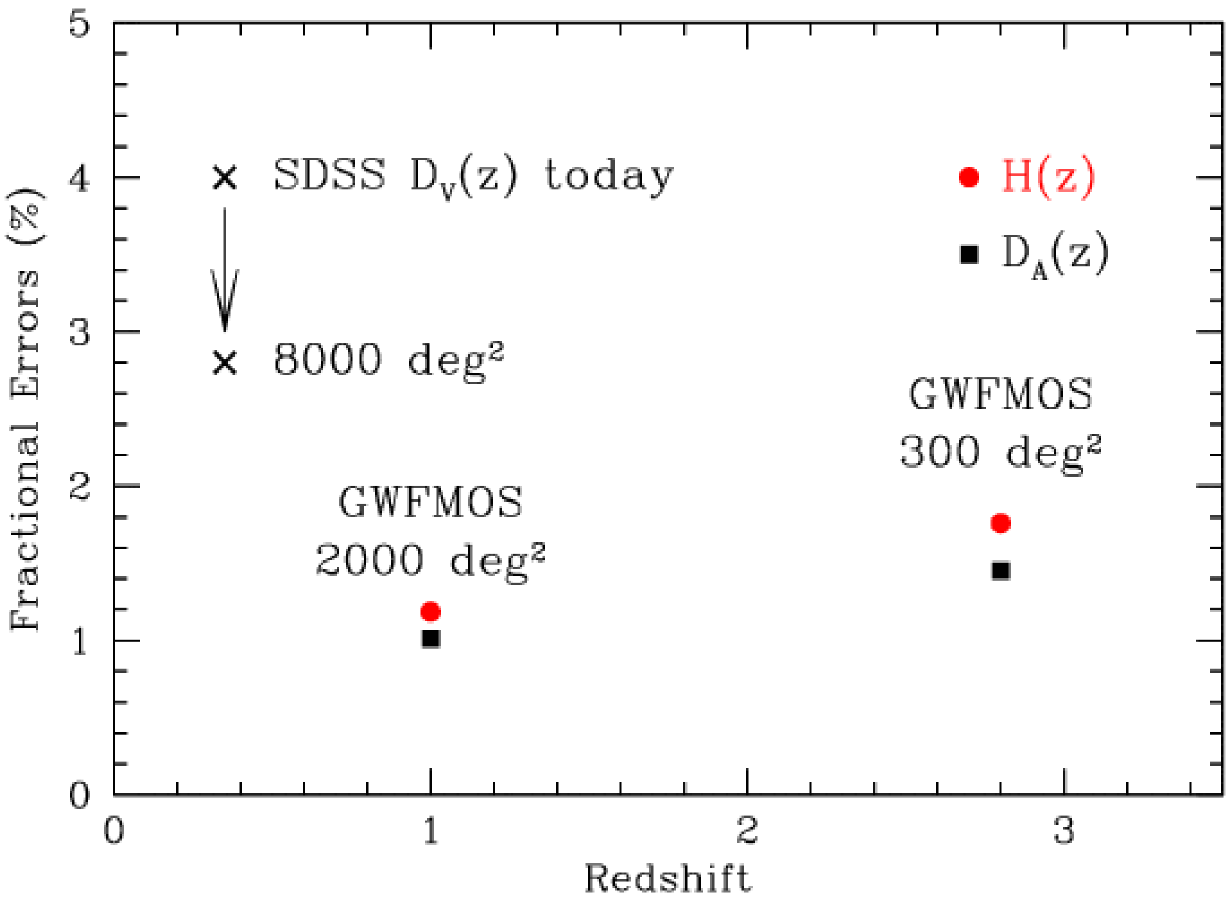


Statistical Errors from the z=1 Survey

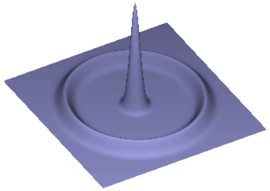
- 2,000,000 gal.,
  z = 0.5 to 1.3
- 2000 sq. deg.
- 4x10^{9} Mpc^{3}
- 0.3/sq. arcmin

- Linear regime
  k<0.2h Mpc^{-1}
- 2-3 oscillations

Baseline Performance



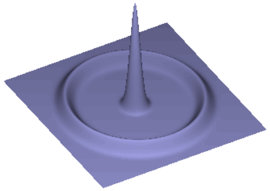
Distance Errors versus Redshift



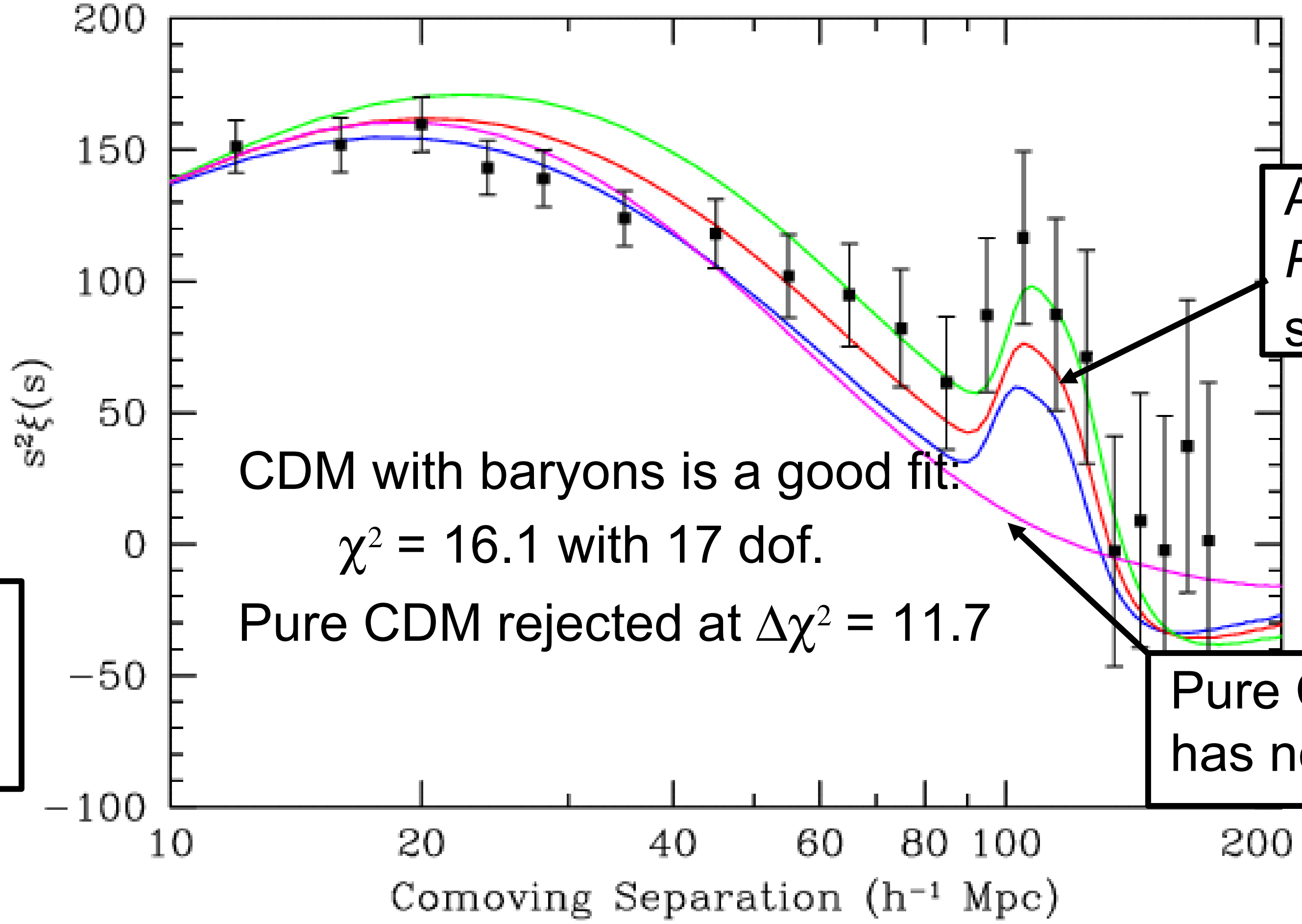
BAO forecast Methodology

Hee-Jong Seo & D. Eisenstein (2003)

- Fisher matrix treatment of statistical errors.
  - Full three-dimensional modes including redshift and cosmological distortions.
  - Flat-sky and Tegmark (1997) approximations.
  - Large CDM parameter space: $\Omega_m h^2$, $\Omega_b h^2$, n, T/S, Ω_m, plus separate distances, growth functions, β, and anomalous shot noises for all redshift slices.
- Planck-level CMB data
- Combine data to predict statistical errors on $w(z) = w_0 + w_1 z$.



Large scale correlations



$\Omega_m h^2 = 0.12$

$\Omega_m h^2 = 0.13$

$\Omega_m h^2 = 0.14$

Acoustic series in $P(k)$ becomes a single peak in $\xi(r)$

CDM with baryons is a good fit: $\chi^2 = 16.1$ with 17 dof.

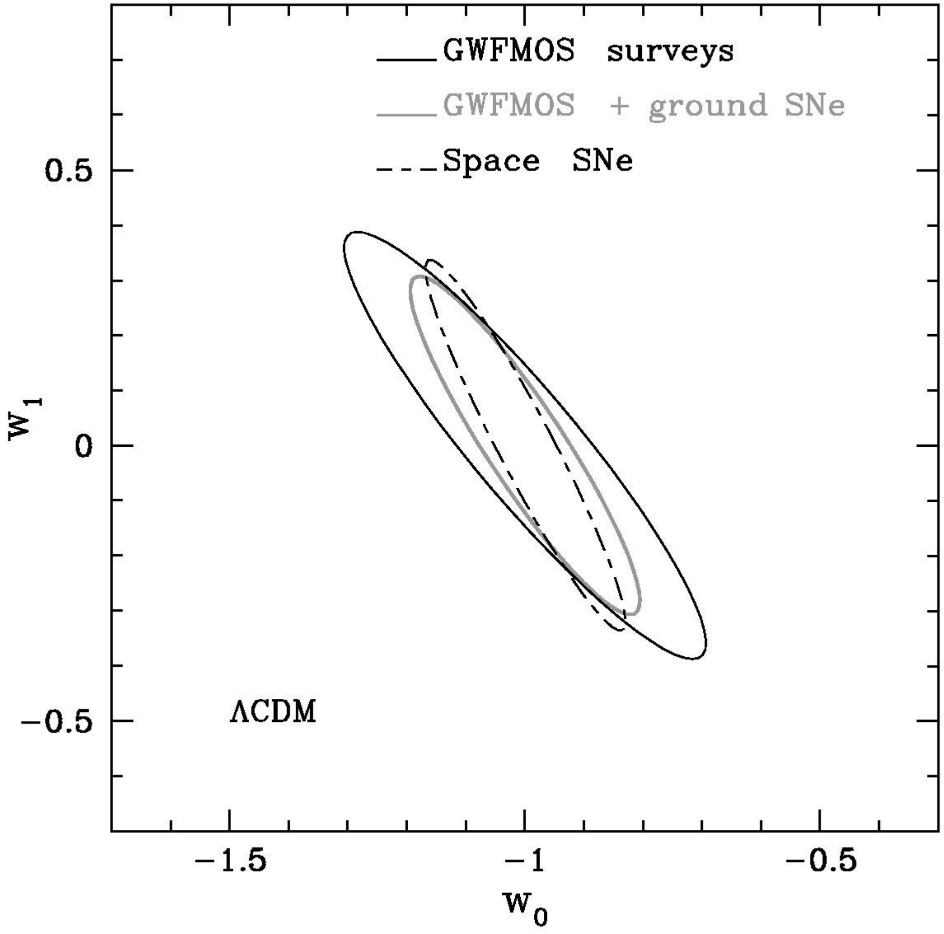
Pure CDM rejected at $\Delta\chi^2 = 11.7$

Pure CDM model has no peak.

Warning: Correlated Error Bars

Results for ΛCDM

- Data sets:
  - CMB (*Planck*)
  - SDSS LRG (z=0.35)
  - Baseline *z*=1
  - Baseline *z*=3
  - SNe (1% in Δz=0.1 bins to *z*=1 for ground, 1.7 for space)
- $\sigma(\Omega_m) = 0.027$
  $\sigma(w)$= 0.08 at *z*=0.7
  $\sigma(dw/dz) = 0.26$
- $\sigma(w)$= 0.05 with ground SNe



Dark Energy Constraints in ΛCDM

6-band Survey: *ugrizy* 320–1050 nm

- Sky area covered: 20,000 deg^2 0.2 arcsec / pixel
- Each 9.6 sq.deg FOV revisited >300 times/band
- Time resolution: >20 sec
- Limiting magnitude: 26.5 AB magnitude @10σ (24.5 in u)
  24 AB mag in 15 seconds
- Photometry precision: 0.01 mag requirement, 0.005 mag goal
- Galaxy density: 50 galaxies/sq.arcmin
- 3 billion galaxies with color redshifts
- Time domain: Log sampling, seconds – years

Massively Parallel Astrophysics

- Dark matter/dark energy via weak lensing
- Dark matter/dark energy via supernovae
- Dark Energy via Baryon Acoustic Oscillations
- Galactic Structure encompassing local group
- Dense astrometry over 20000 sq.deg: rare moving objects
- Gamma Ray Bursts and transients to high redshift
- Gravitational micro-lensing
- Strong galaxy & cluster lensing: physics of dark matter
- Multi-image lensed SN time delays: separate test of cosmology
- Variable stars/galaxies: black hole accretion
- QSO time delays vs z: independent test of dark energy
- Optical bursters to 25 mag: the unknown
- 6-band 27 mag photometric survey
- Solar System Probes: Earth-crossing asteroids, Comets
- Extragalactic stars

LSST Dark Energy Highlights

- Weak lensing of galaxies to $z = 3$.

  Two and three-point shear correlations in linear and non-linear gravitational regimes.

- Supernovae to $z = 1$.

  Discovery of lensed supernovae and measurement of time delays.

- Galaxies and cluster number densities as function of z.

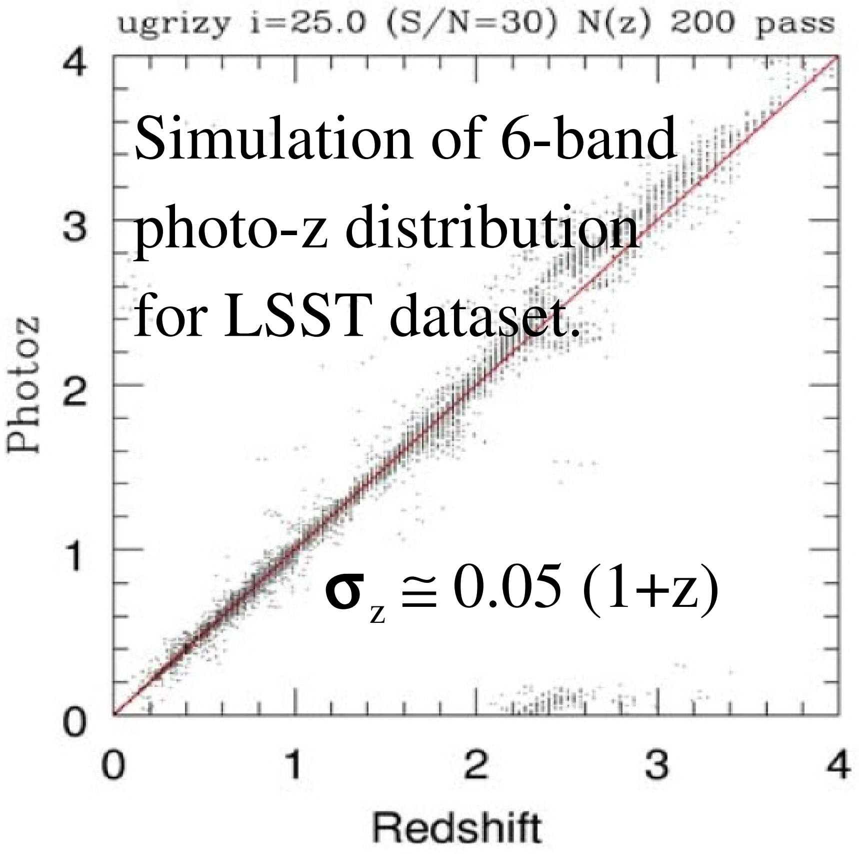
  Power spectra on very large scales $k \sim 10^{-3}\ h\ \mathrm{Mpc}^{-1}$.

- Baryon acoustic oscillations.

  Power spectra on scales $k \sim 10^{-1}\ h\ \mathrm{Mpc}^{-1}$.

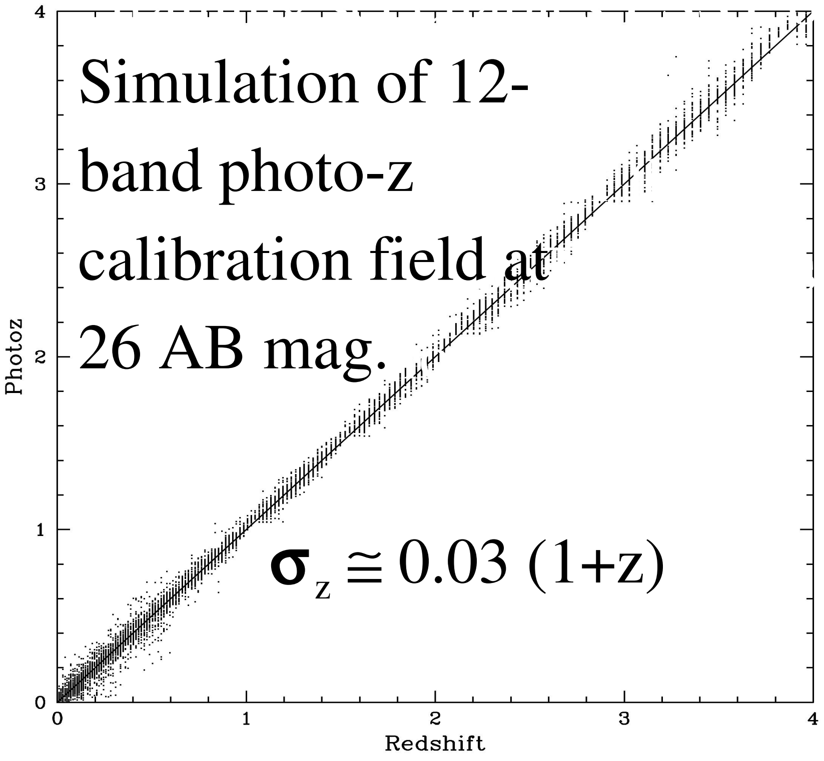
Photo-z Calibration Campaign

- Transfer fields - 200,000 galaxies with 12-band photo-z redshifts.
- Calibrate 12-band photo-z with subset of 20,000 spectroscopic redshifts.



Simulation of 6-band photo-z distribution for LSST dataset.

$\sigma_z \cong 0.05\,(1+z)$



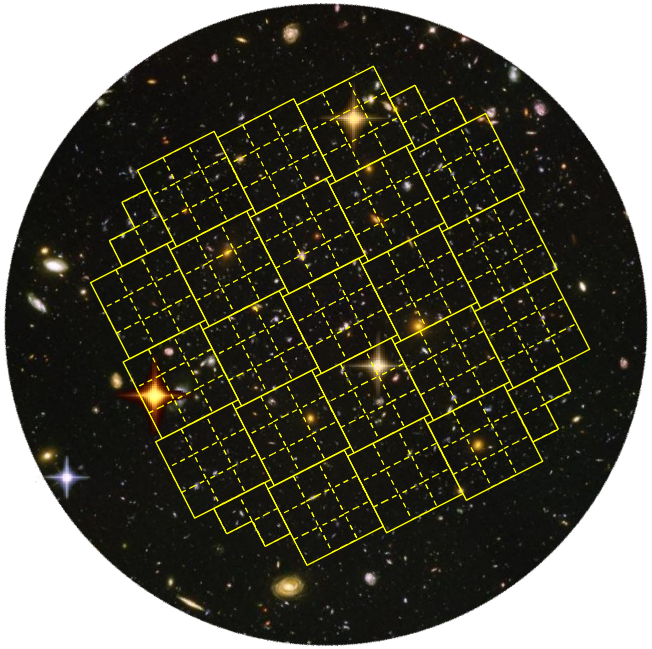
Simulation of 12-band photo-z calibration field at 26 AB mag.

$\sigma_z \cong 0.03\,(1+z)$

Need to calibrate transfer photo-z to 10% accuracy to reach desired precision

Multi-Epoch Data Archive

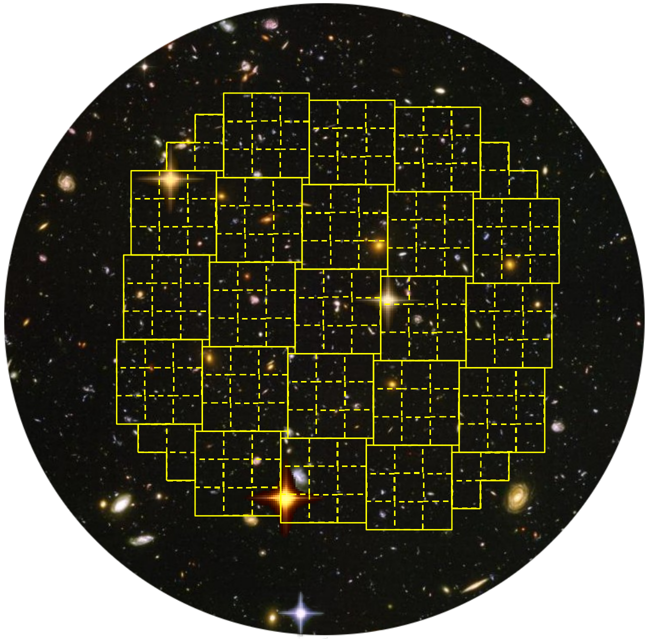
Average down instrumental and atmospheric statistical variations.



Large dataset allows systematic errors to be addressed by subdivision.

Multi-Epoch Data Archive

Average down instrumental and atmospheric statistical variations.



Large dataset allows systematic errors to be addressed by subdivision.

Repeating observation

LSST is designed to repeat short (~30 s) exposures

==> each object is measured several hundred times

This averages :

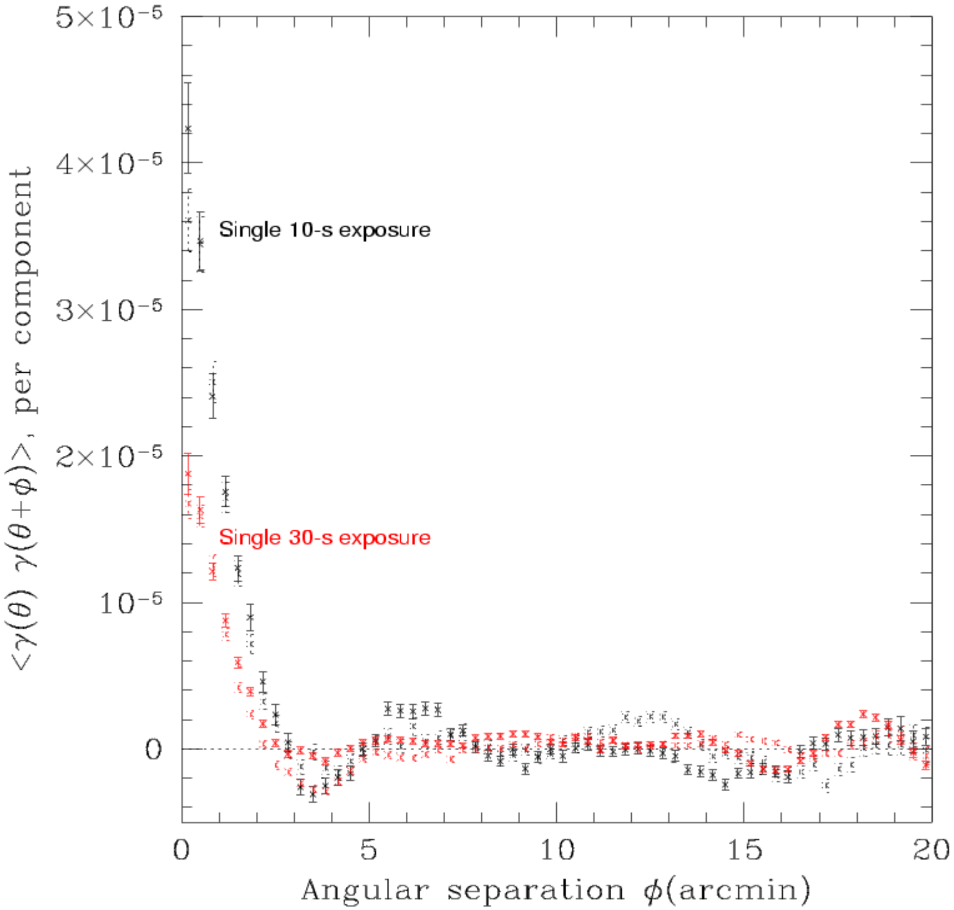
- systematics related to the position and orientation of focal plane.
- atmospheric conditions
- noise in the PSF modeling (lensing)

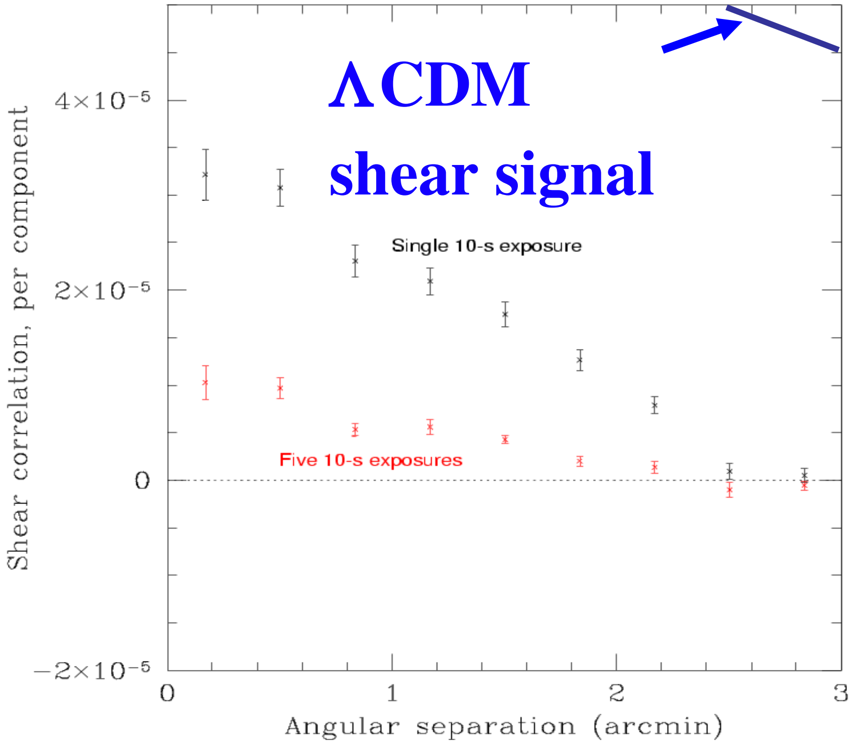
Important advantage for:

- ellipticity measurements.
- photometric calibration.

Residual 2-Point Shear Correlations

LSST multi-epoch survey provides sensitivity well below target signal.





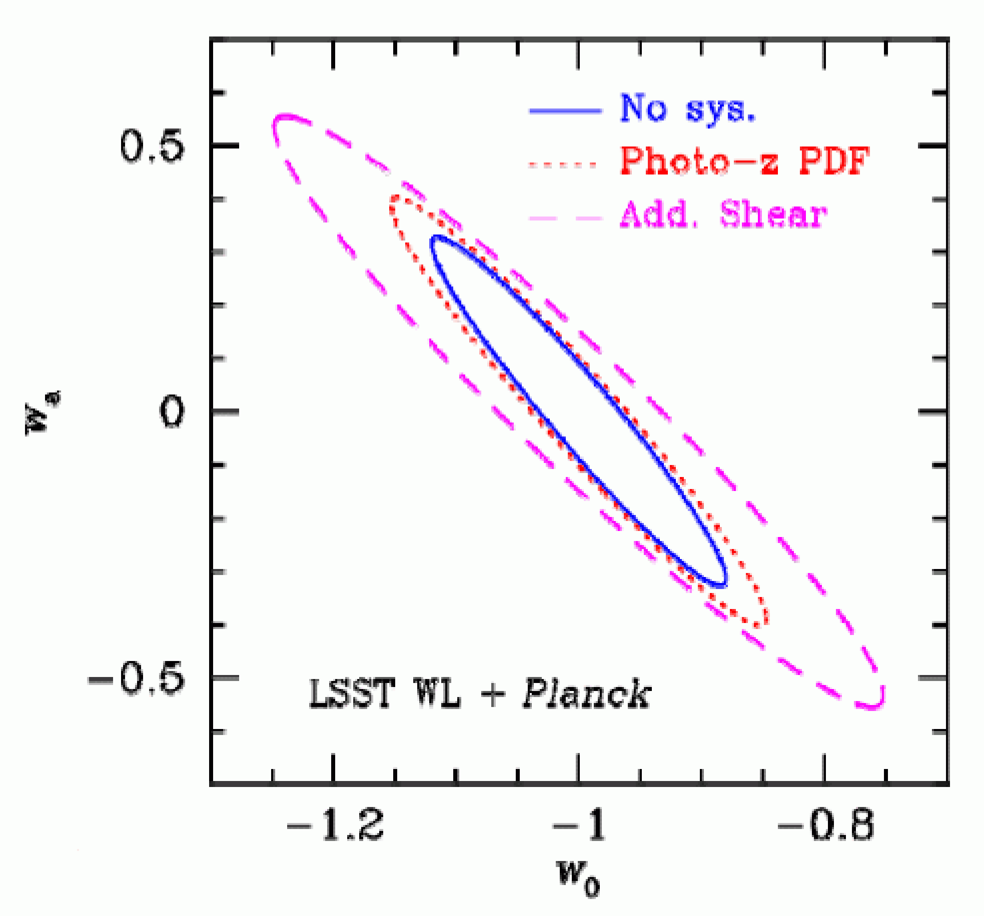
ΛCDM shear signal

Typical separation of reference stars in LSST exposures.

P. Astier (Blois 22/05/08)

LSST-Lensing

2-point correlation tomography



10 z bins (0<z<3.5)

uncertainties on photo-z :
  per galaxy: 0.05(1+z)
  per redshift slice :
    bias : 0.0025(1+z)
    scatter : 0.0035(1+z)

Shear residuals:
  10^{-8} per C_l “bin”

P. Astier (Blois 22/05/08)

The LSST Collaboration

Brookhaven National Laboratory

Harvard-Smithsonian Center for Astrophysics

Johns Hopkins University

Las Cumbres Observatory

Lawrence Livermore National Laboratory

National Optical Astronomy Observatory

Ohio State University

Pennsylvania State University

Research Corporation

Stanford Linear Accelerator Center

Stanford University

University of Arizona

University of California, Davis

University of Illinois

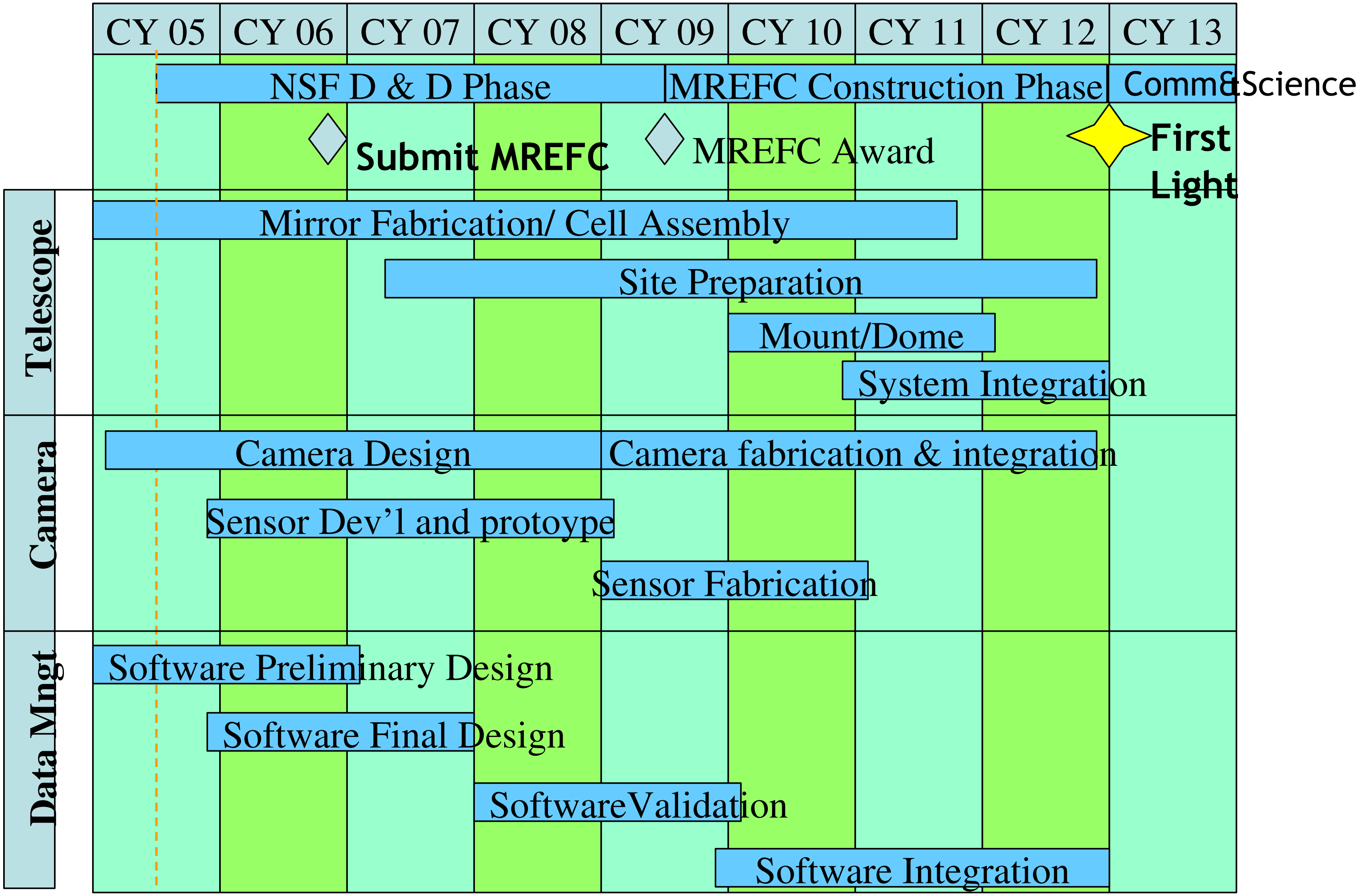
University of Pennsylvania

University of Washington

Astronomes (NSF) & Physiciens (DOE)

Project Baseline Schedule Plans

Large Synoptic Survey Telescope


CY 05 | CY 06 | CY 07 | CY 08 | CY 09 | CY 10 | CY 11 | CY 12 | CY 13

NSF D & D Phase

MREFC Construction Phase

Comm&Science

Submit MREFC

MREFC Award

First Light

Telescope

Mirror Fabrication/ Cell Assembly

Site Preparation

Mount/Dome

System Integration

Camera

Camera Design

Camera fabrication & integration

Sensor Dev'l and protoype

Sensor Fabrication

Data Mngt

Software Preliminary Design

Software Final Design

SoftwareValidation

Software Integration

more realistic : first light expected by 2014, if funded

Space based DE projects

The JDEM (Joint Dark Energy Mission) framework :
3 mission concepts

- ADEPT (BAO and Sne, all spectroscopic)
- Destiny (SNe and BAO, all spectroscopic)
- SNAP (SNe and WL) Imaging and spectroscopy

In Europe:
- DUNE (mainly WL) -> see Y. Mellier's talk

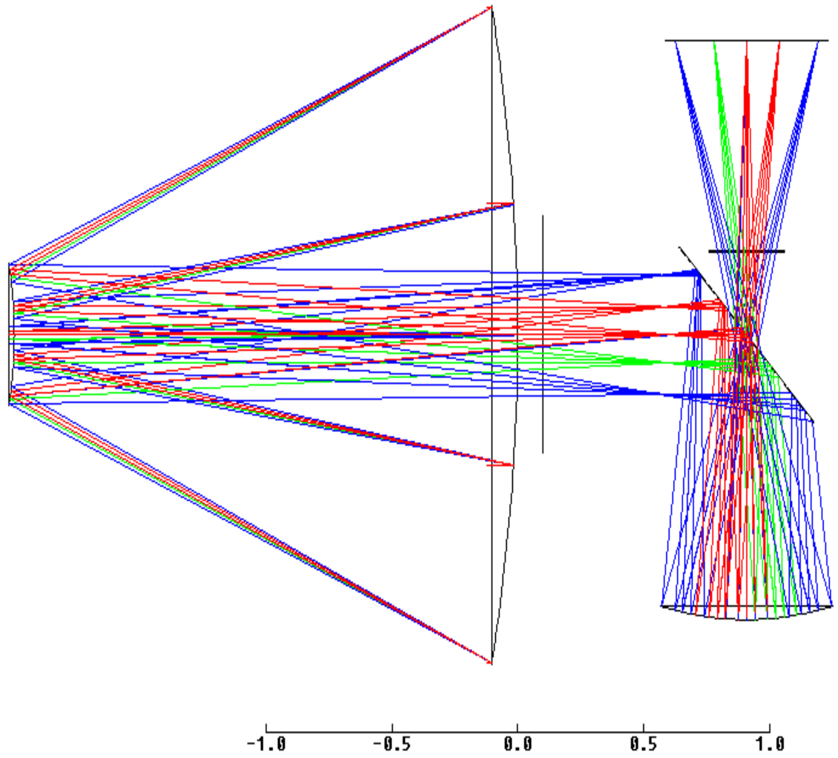
SNAP Concept

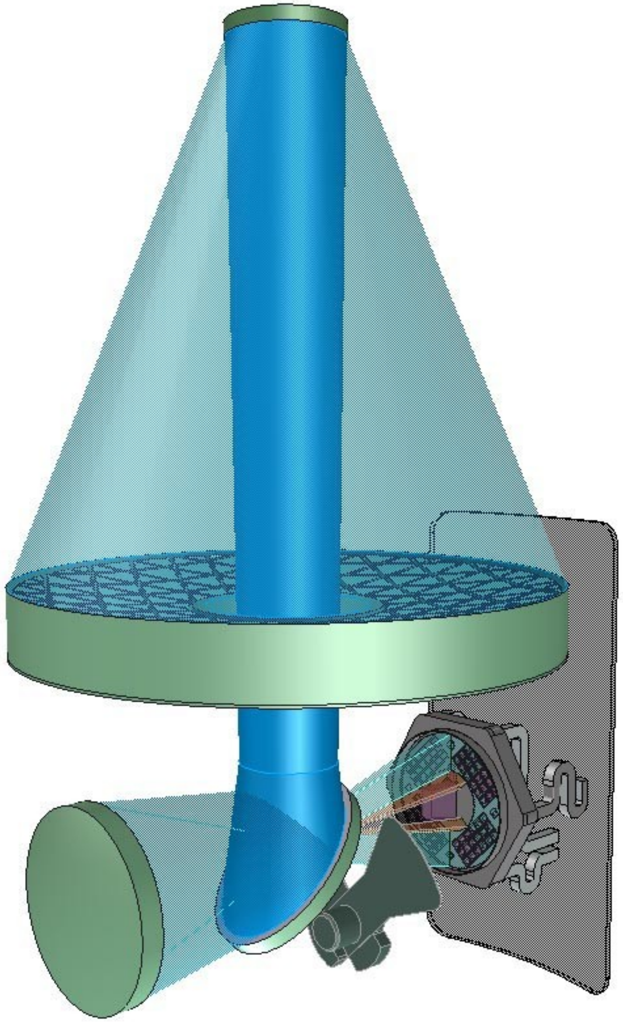
- Build a SNe Ia Hubble diagram up to z=1.7
  High S/N multiband photometry
  Identify all SNe spectroscopically
  -> onboard spectrograph

- moderate size very accurate WL survey,
  with excellent photo-z's

SNAP Telescope

- 2-m primary aperture, 3-mirror anastigmatic
- Provides a wide-field flat focal plane.





SNAP Imager : visible + NIR

- *A large solid-angle camera (0.7 square degrees) provides multiplexed supernova discovery and followup.*
- *Covers wavelength region of interest, 0.35-1.7 microns.*
- *Fixed filter mosaic on top of the imager sensors.*

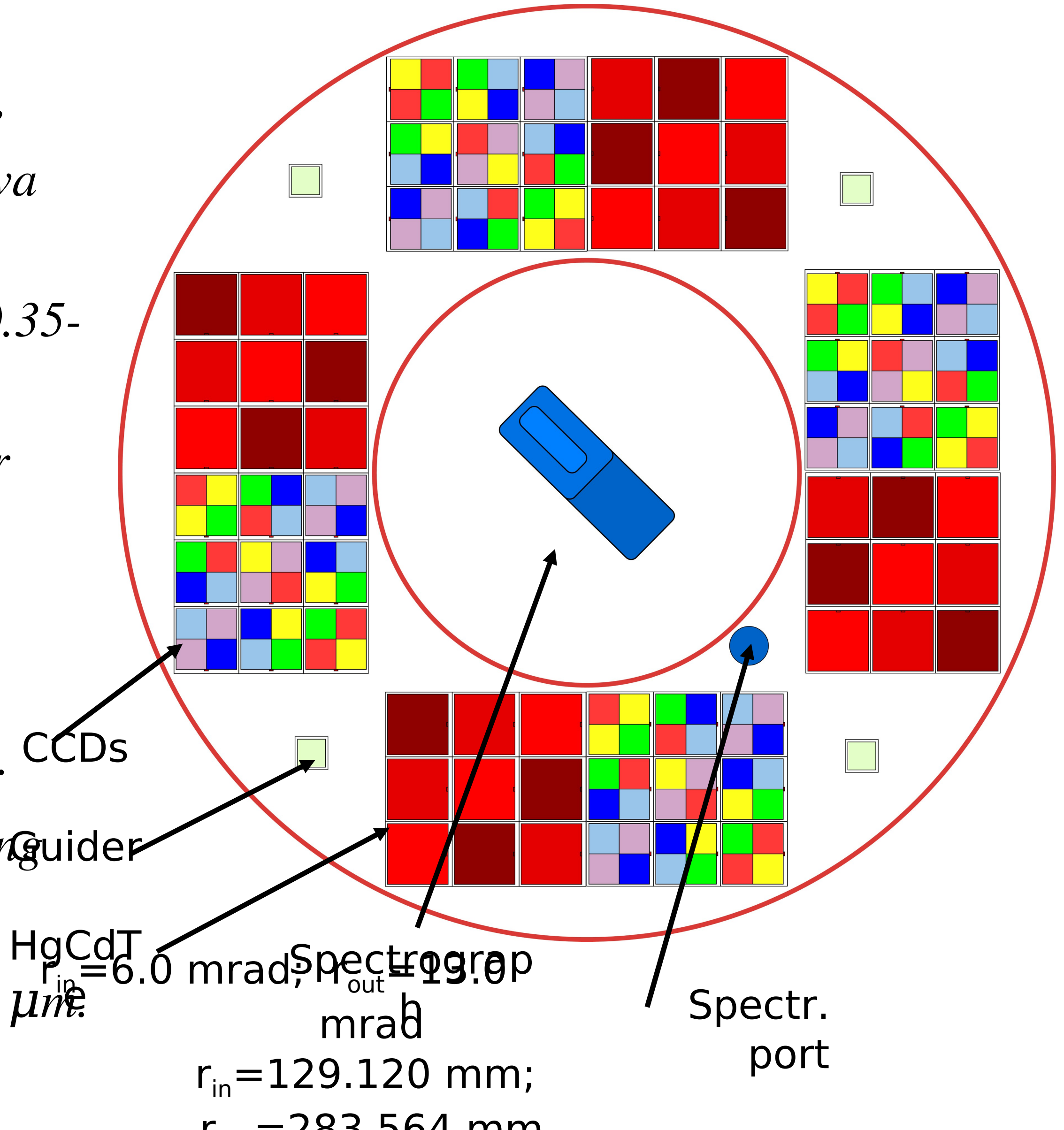
— *3 NIR bandpasses.*

— *6 visible bandpasses.*

- *Coalesce all sensors at one focal plane.*

— *36 2k x 2k HgCdTe NIR sensors covering 0.9-1.7 µm.*

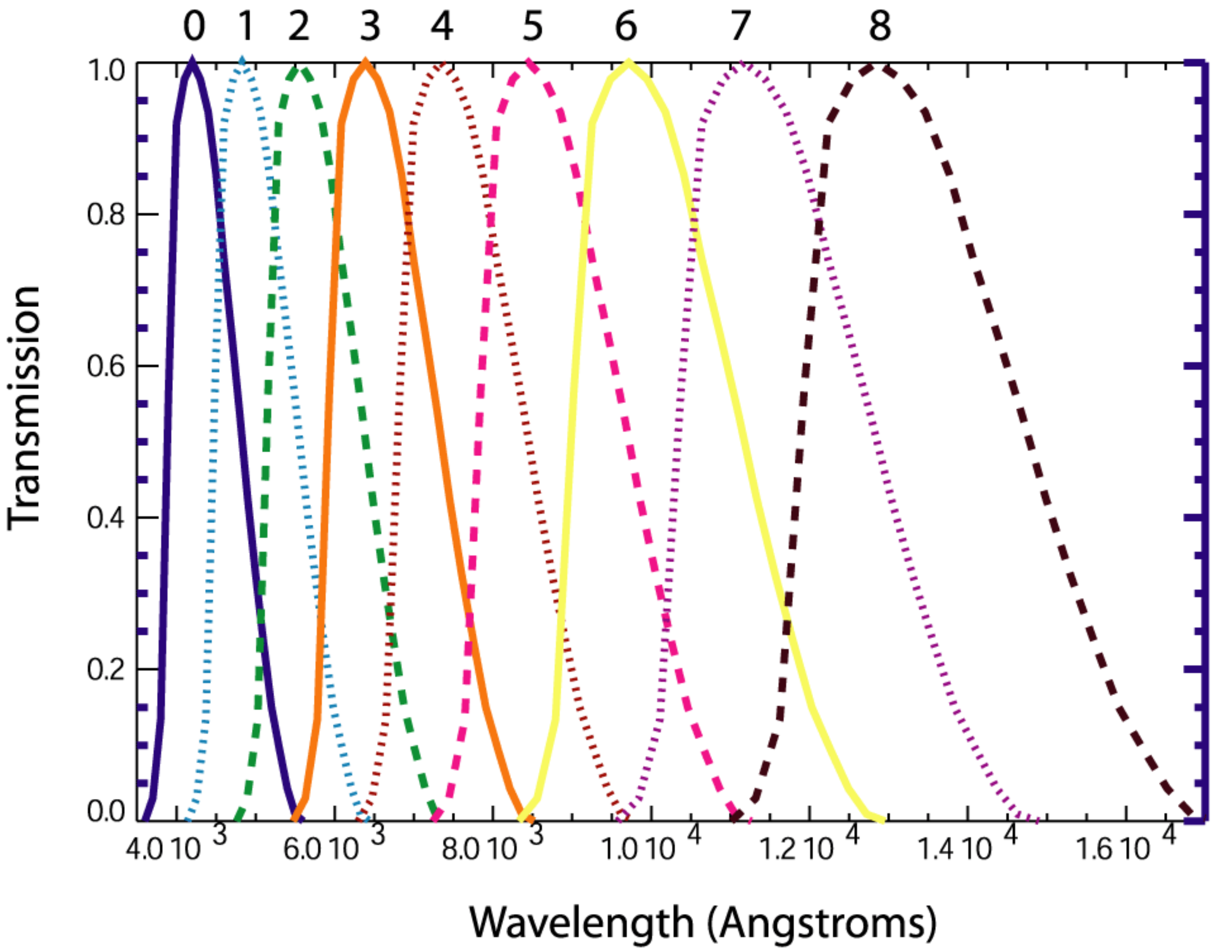
— *36 3.5k x 3.5k CCDs covering 0.35-1.0 µm.*



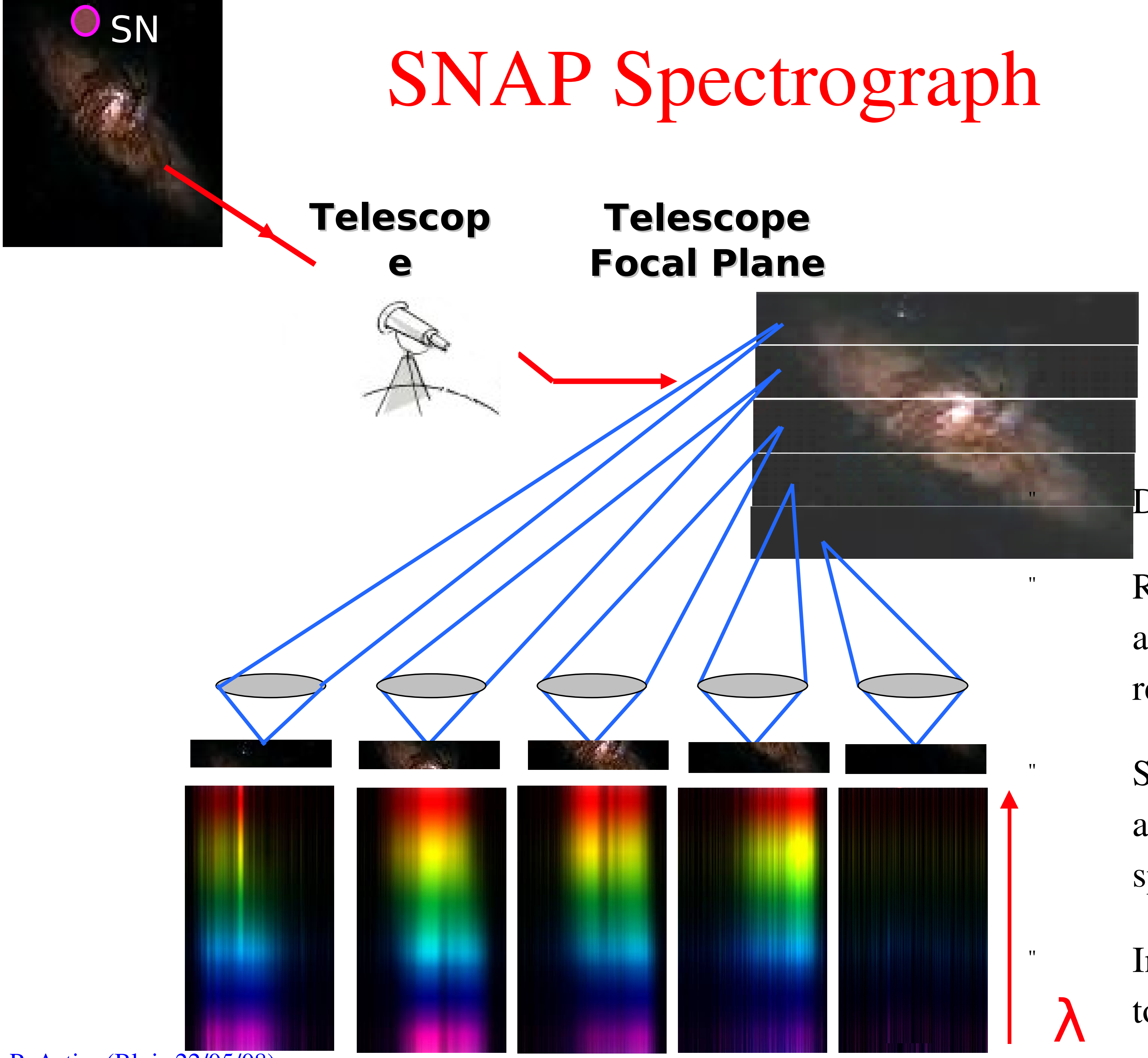
P. Astier (Blois 22/05/08)

SNAP filters

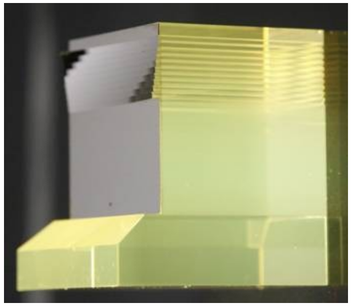
9 redshifted B-band filters distributed logarithmically.



SNAP Spectrograph



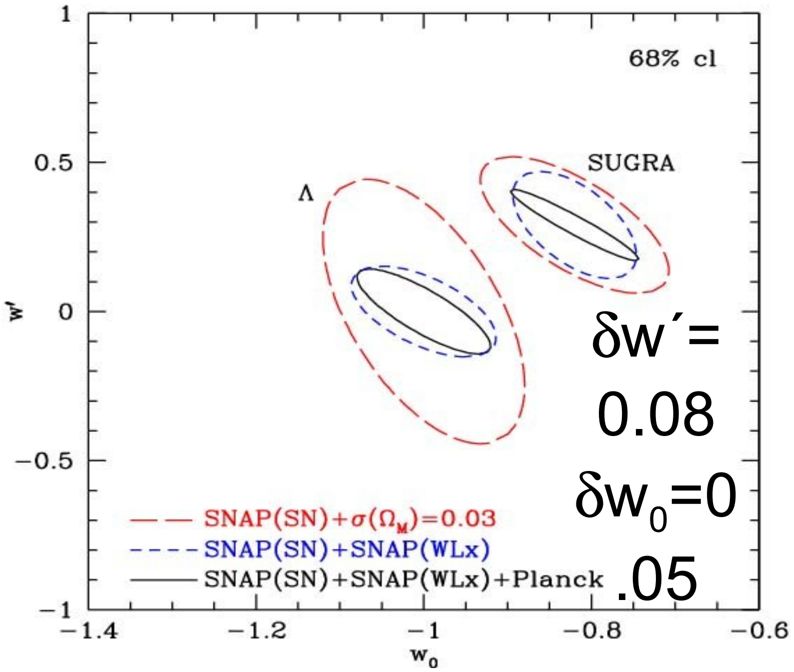
Slicer Mirror Array



- Data cube
- Reduces pointing accuracy requirement
- Simultaneous SNe and host galaxy spectra
- Internal beam split to visible and NIR.

SNAP Data Products

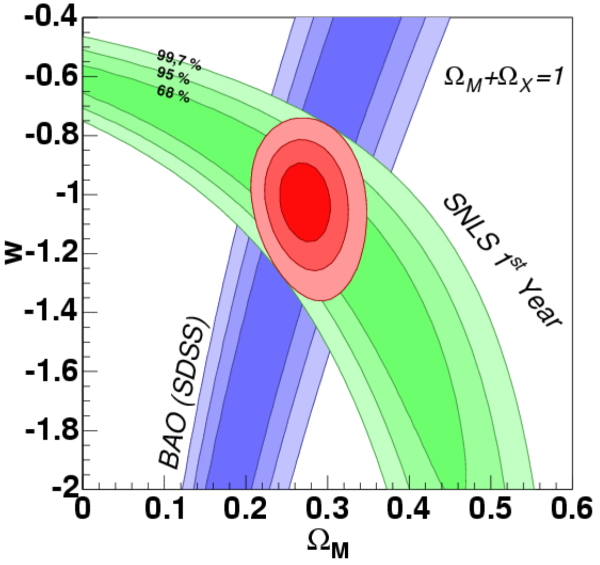
- Supernovae
  - ~2000 SNe Ia @ 0.1<z<1.7
  - 9-band light curves with 4-day cadence
  - Spectrum near maximum (triggered)
- Weak Lensing
  - 1000 (+?) square degrees
  - 100 resolved galaxies per square arcmin
  - 9-band photo-z determination



$\delta w' = 0.08$

$\delta w_0 = 0.05$

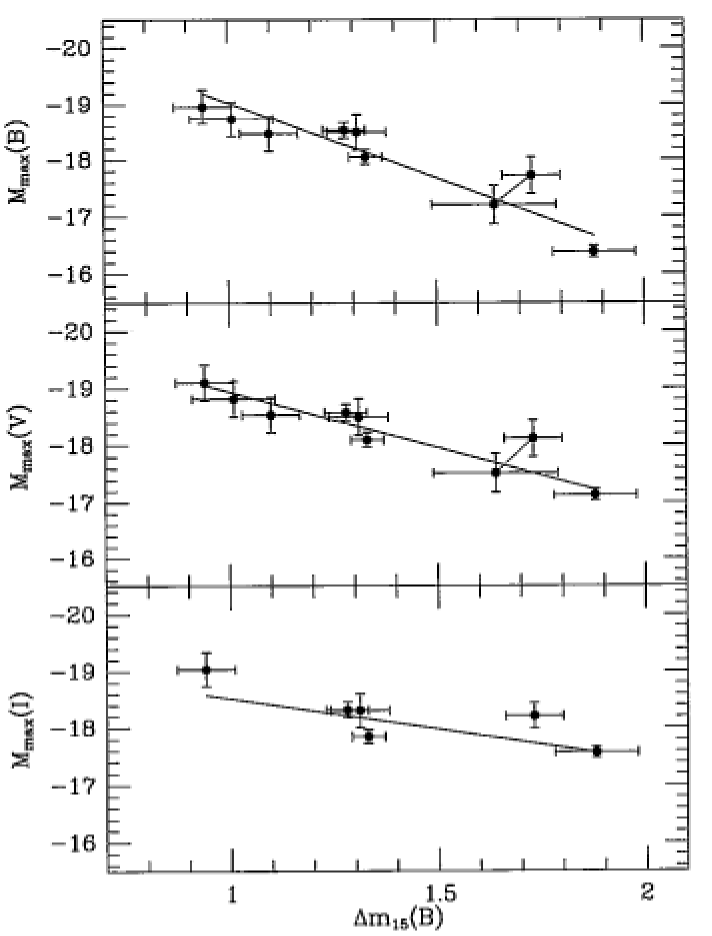
Conclusions

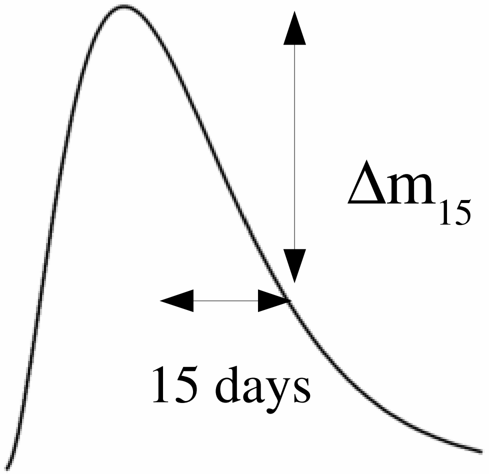


- Dark Energy looks like a cosmological constan
- Current ground-based efforts could reach <w> to 0.05
- Many expensive space projects in the landscape :
  - Agencies recognize the importance of DE science
  - Competitions are finally beginning, but it is not clear that a DE mission will come out.
  - Results (if any) by 2020+

- DE science will be ground-based during the next decade.

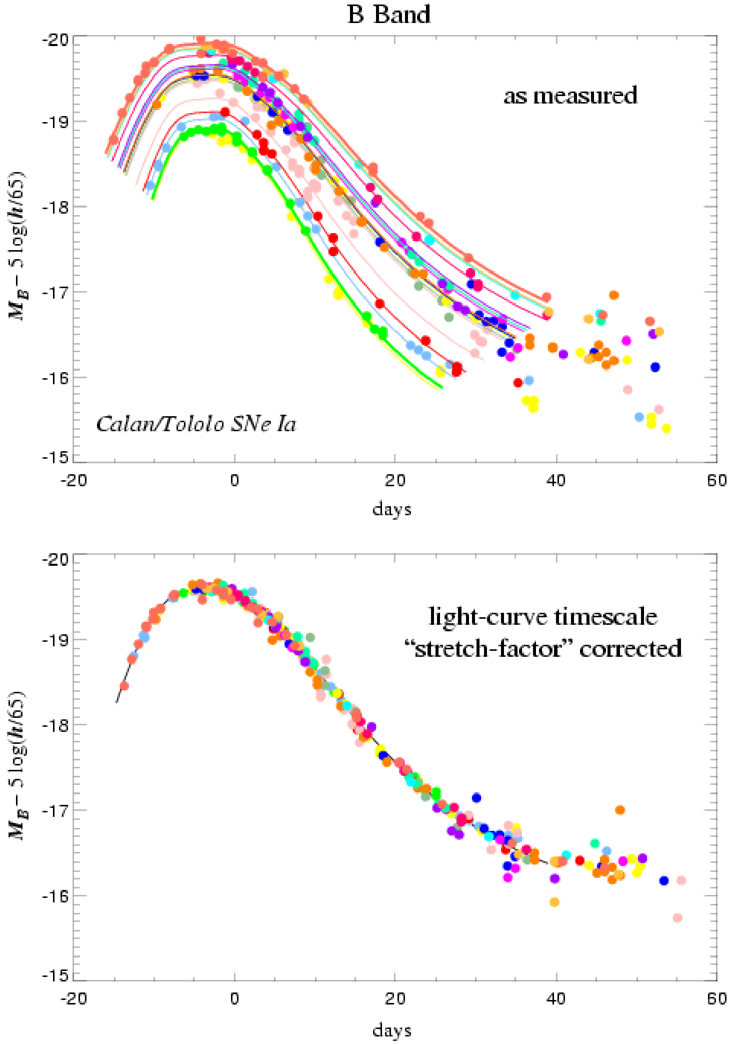
Brighter-Slower





Δm_{15}

15 days



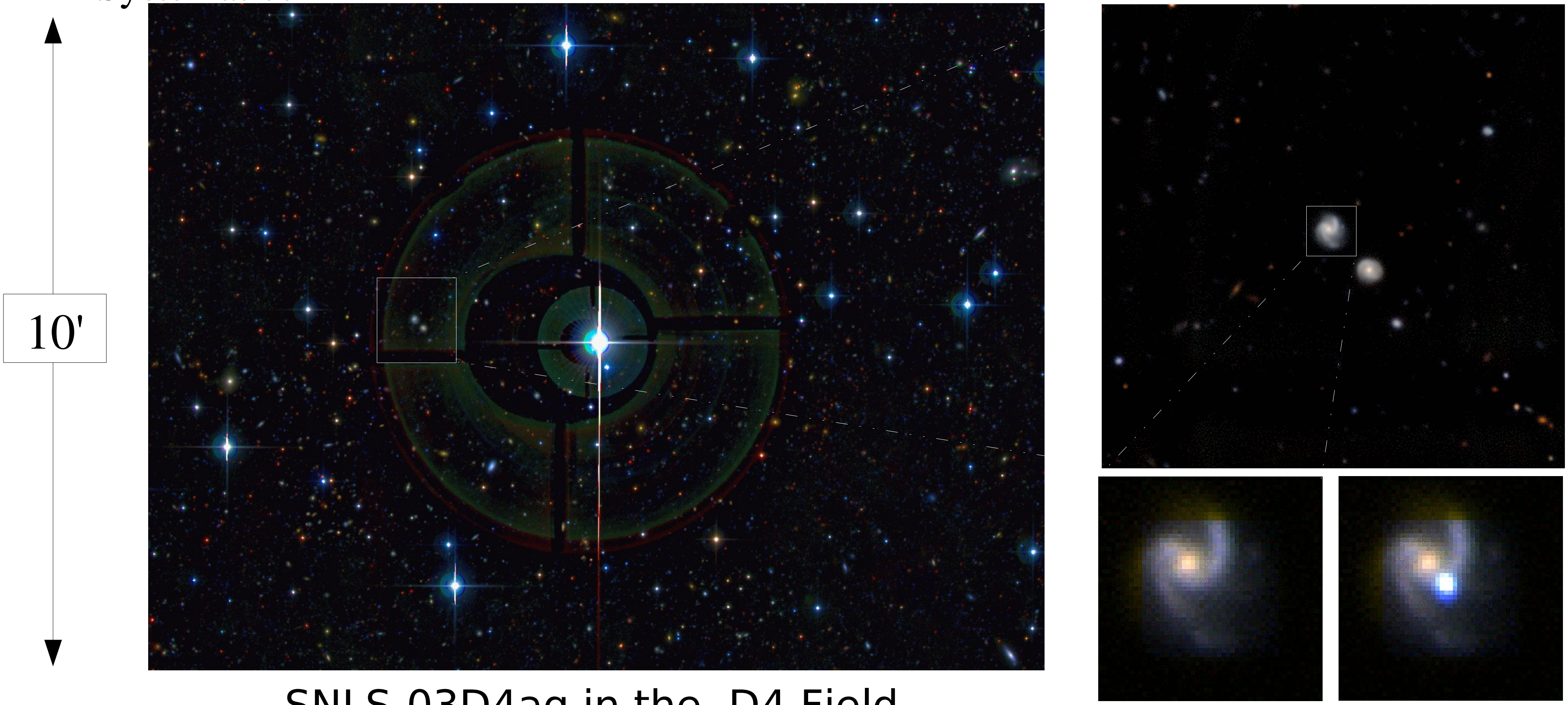
Kim, *et al.* (1997)

Δm_{15} : Phillips (1993)

Timescale stretch factor

Analysis for cosmology of the SNLS first year data sample August 2003 – July 2004

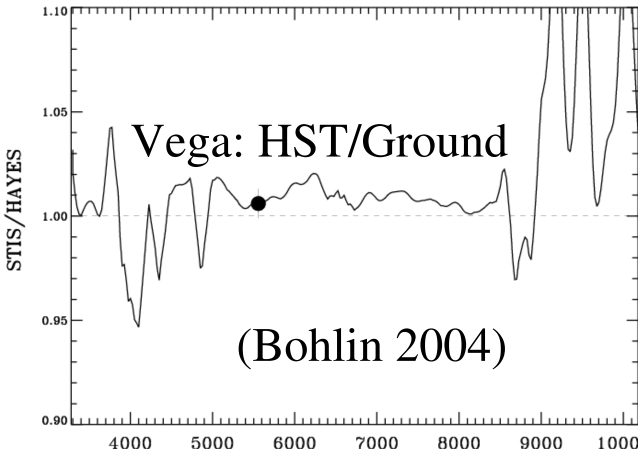
- Differential photometry
- Photometric calibration
- Fitting lightcurves
- Fitting cosmology
- Systematics

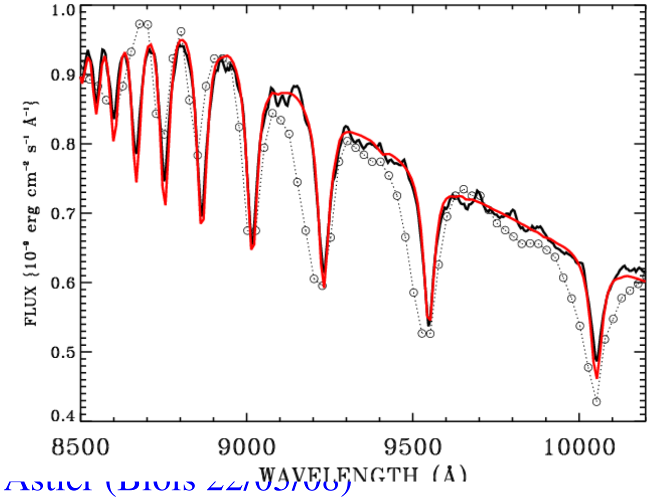


SNLS-03D4ag in the D4 Field

Current issues : Photometric calibration

SNe cosmology requires ratio of fluxes measured in different spectral bands
Magnitudes provide ratio of fluxes measured in the same band.
Hence magnitudes have to be converted into fluxes...
... which requires the spectrum of standard stars.
- Vega spectrum known to ~ 1% (Hayes 1985, Bohlin 2004)





- SNe cosmology forecasts usually assume ~1 % systematic uncertainty of relative (distant/nearby = red/blue) flux scales.
This is realistic but may become pessimistic.

- Could we calibrate instruments against lab standards rather than sky standards ?
- Essence has such a project underway (@CTIO)
- SNLS is in the implemetation phase.

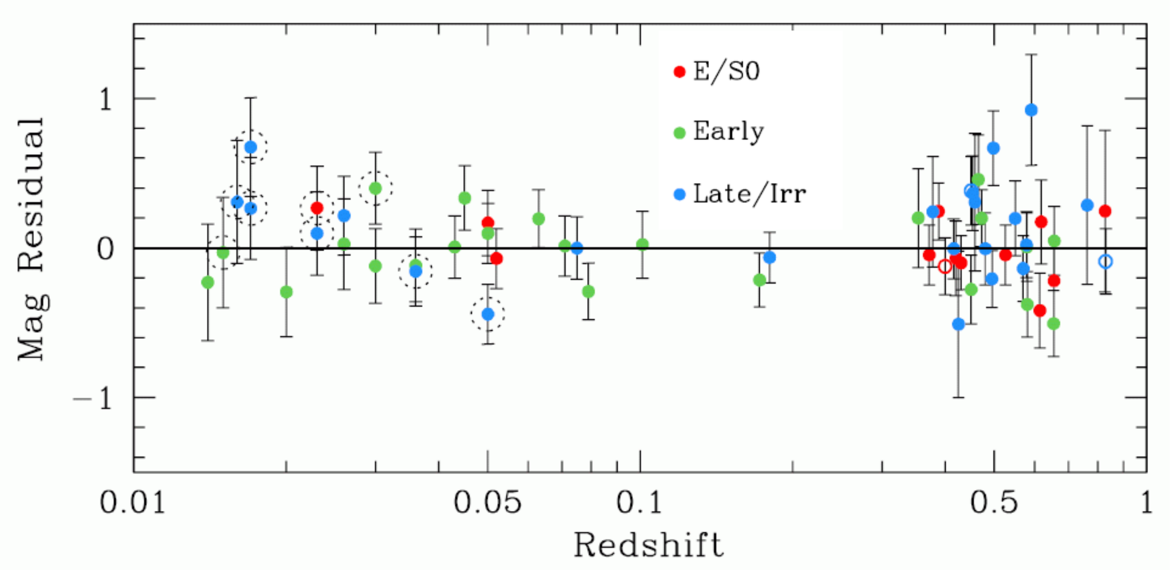
Current issues : SN properties vs galaxy types

Host galaxy types should evolve with redshift. However:

- No evolution of SNe Ia observables yet
  (marginal demographic evolutions compatible with selection biases)

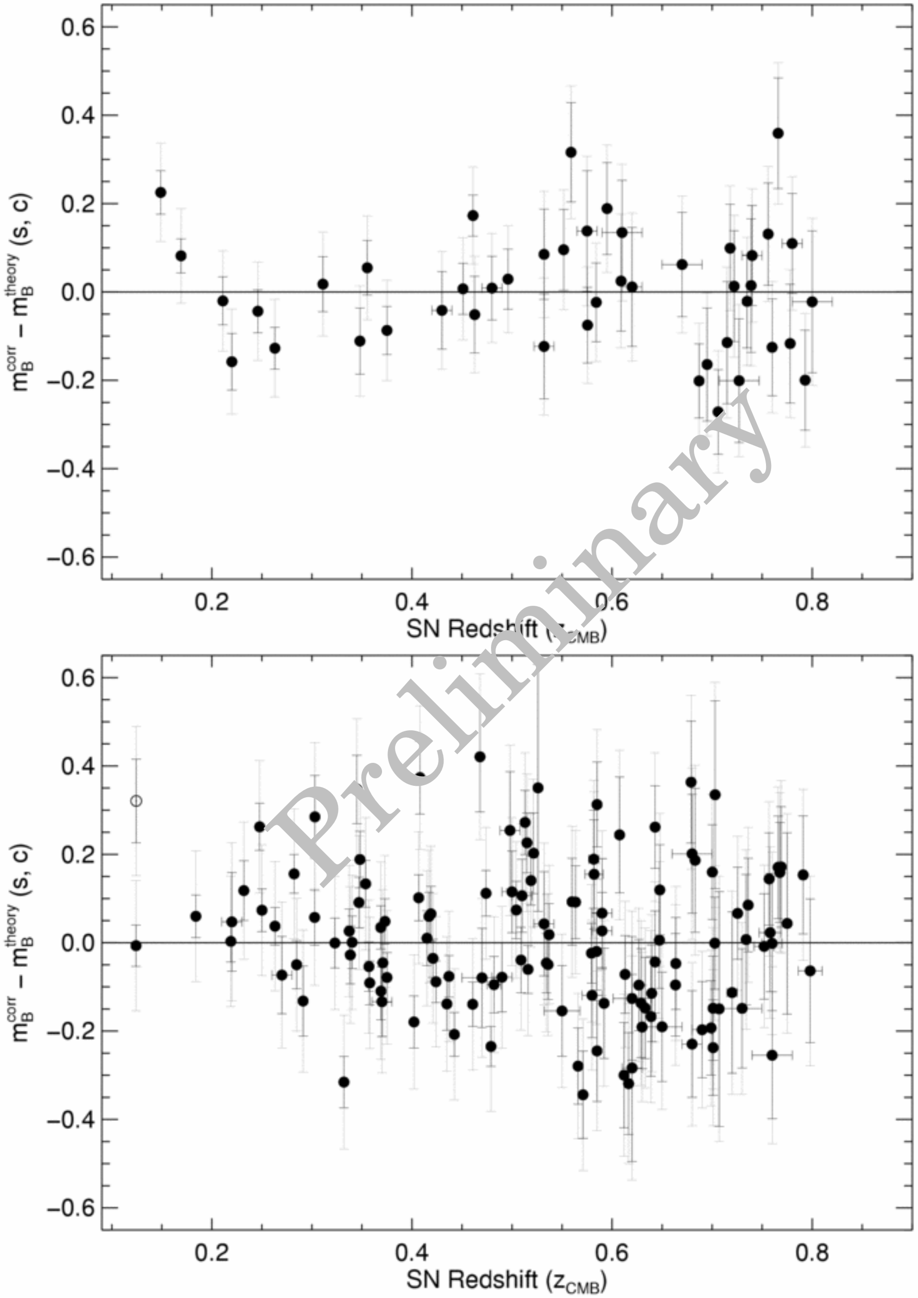
Strategy :

- Identify host galaxy type from colors (at known redshift) or spectrum.
- Compare SNe properties and brighter-bluer and brighter-redder correlations separately.
- Build separate Hubble diagrams if incompatible
- Obvious



Residuals to Hubble diagram of Perlmutter et all 99 with host galaxy types
Sullivan et al (2003)
astro-ph/0211444

Split by host galaxy type



Passive

α=1.34 ± 0.24

β=2.52 ± 0.16

σ~0.10 mag

Star-forming

α=1.19 ± 0.15

β=2.71 ± 0.17

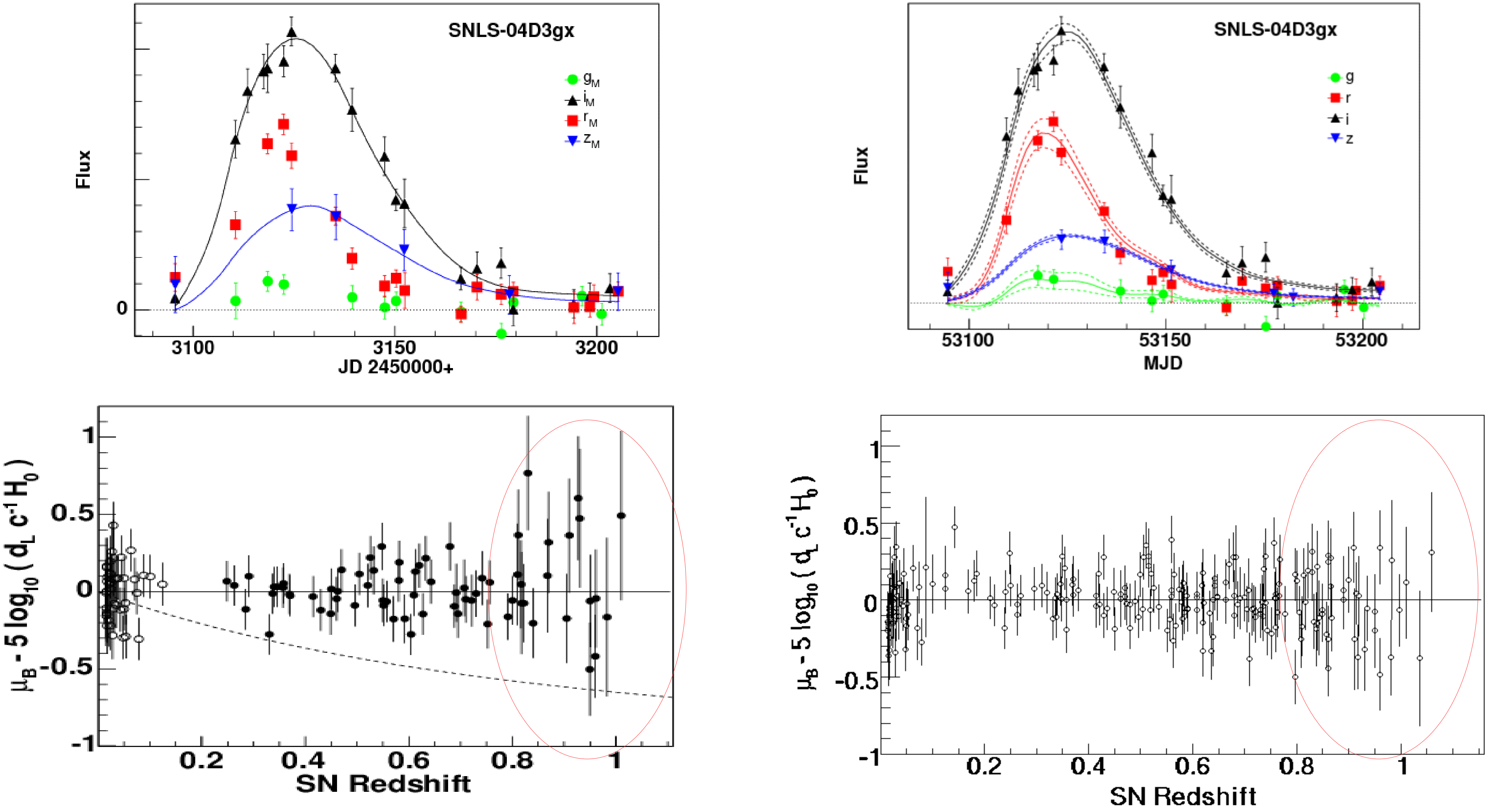
σ~0.14 mag

compatible
brighter-slower
and
brighter-bluer
relations

preliminary results by Sullivan et al, following Sullivan et al (2006)

Improving distances at high redshift

By modelling the UV behavior of SNe, we improve high z distance estimates



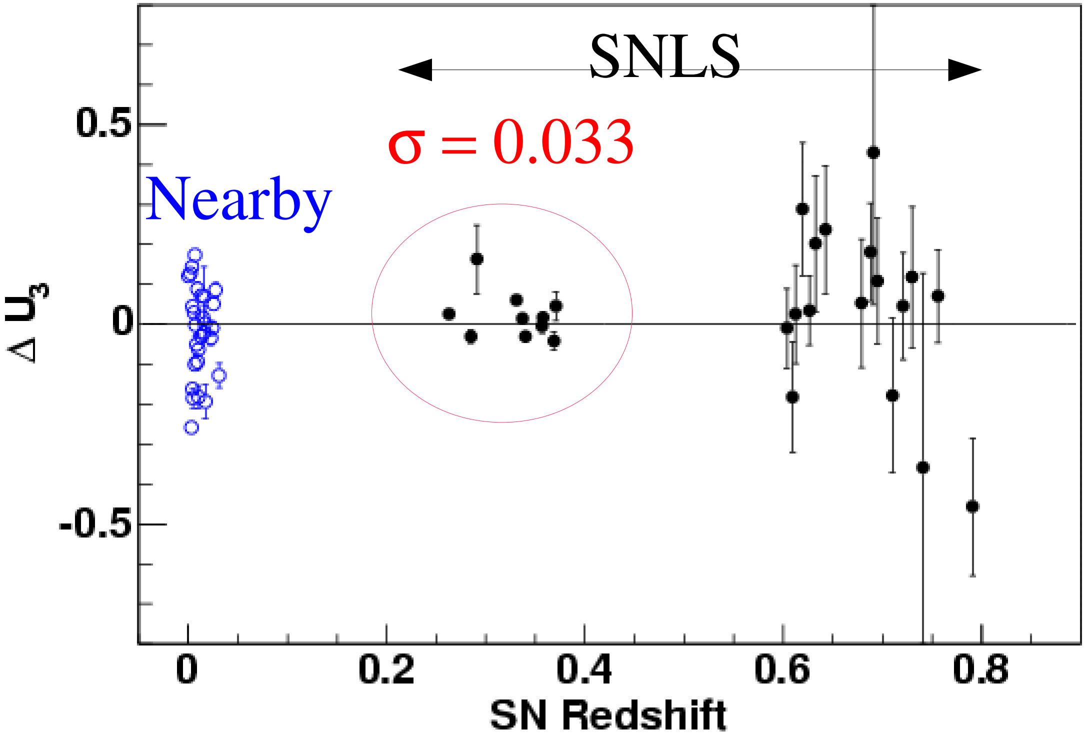
(Guy et al, astro-ph/0701828)

Three-band measurements: color compatibility of Sne Ia

Compare restframe peak U, guessed from B and V, and measured U

ΔU_3 = U(measured) – U(guessed from B and V)

SN Ia restframe UBV relations are very reproducible: U&B are sufficient to measure a distance



SNe Ia cosmology : HST searches

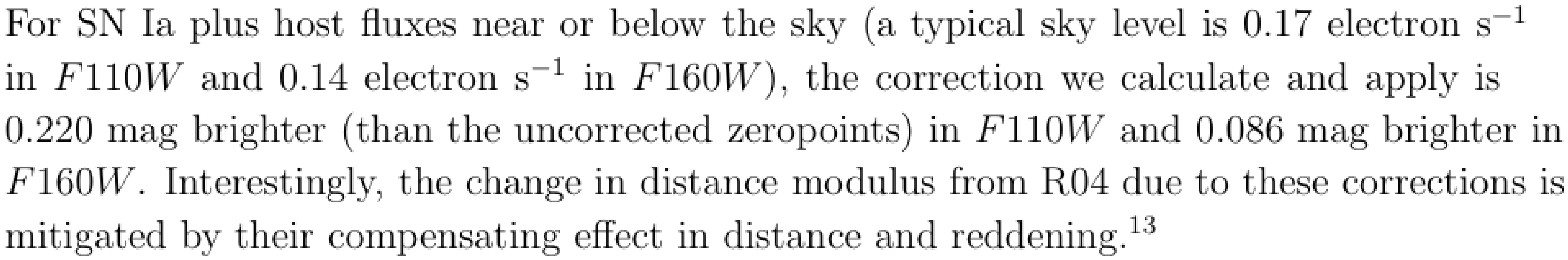
PANS survey : an HST based survey

- HST/ACS search (imaging in the visible)
- HST/ACS grism spectroscopy (resolution $\delta\lambda/\lambda \sim 1/100$)
- HST follow-up with ACS (visible) and/or NICMOS (near IR) according to z.

Two published papers : Riess et al (2004, 2006):

- Statistical accuracy comparable to SNLS first year, despite larger statistics and a larger z span : due to a less accurate distance estimator (known as MLCS).
- The analysis applies a prior on measured color (!).
- HST/NICMOS photometric calibration uncertain : $z>1$ SNe distances are uncertain by at best 4% ($\delta w \sim 0.1$)

Recalibrated SN HST Magnitudes



For SN Ia plus host fluxes near or below the sky (a typical sky level is 0.17 electron s^{-1} in $F110W$ and 0.14 electron s^{-1} in $F160W$), the correction we calculate and apply is 0.220 mag brighter (than the uncorrected zeropoints) in $F110W$ and 0.086 mag brighter in $F160W$. Interestingly, the change in distance modulus from R04 due to these corrections is mitigated by their compensating effect in distance and reddening.[13]

Riess et al. (2006) astro-ph 0611572

Calibration uncertainty not included in any previous HST SN cosmology paper!

(nor in Riess et al (2006) ...)

SNe Ia cosmology : ESSENCE result

ESSENCE is a ground-based rolling search running at CTIO-4m.

First cosmology paper :astro-ph 0701041

Data set :

60 supernovae (over 3 years) measured in only 2 observer bands (R & I)

--> measured restframe bands change a lot across the sample

Analysis :

- prior on measured colors
  (depends on z to compensate for selection biases ?!)
- noisy distance estimator

causes large
“systematic”
errors

Results :

Essence + nearby SNe + B.A.O w = -1.05 +/- 0.12 +/- 0.13

SNLS+Essence + nearby SNe + B.A.O w = -1.07 +/- 0.09 +/- 0.13

Dark Energy EOS : current status

Dark Energy looks like Λ (SNe+BAO)

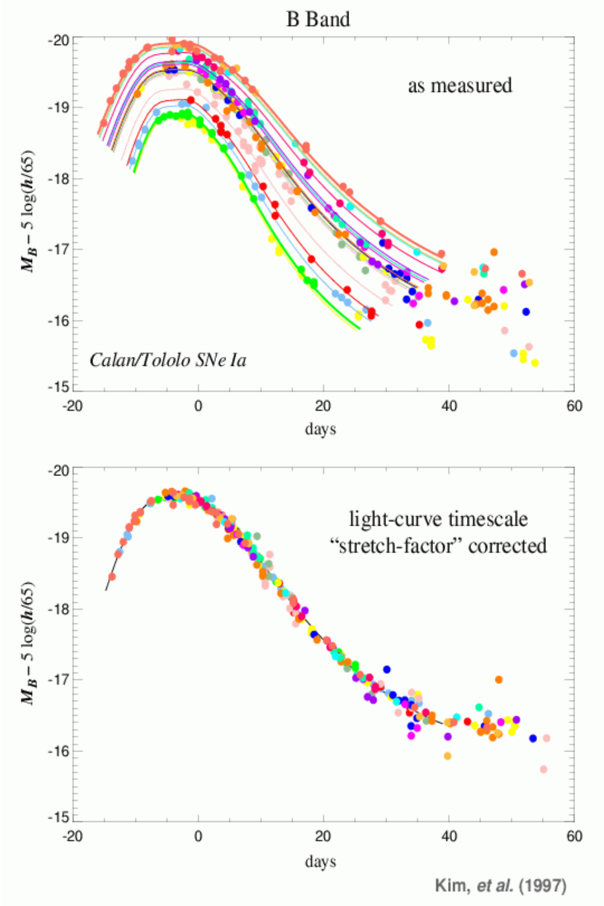
$$\boxed{\begin{aligned} \Omega_M &= 0.271 \pm 0.021\ (stat) \pm 0.007\ (sys) \\ w &= -1.02 \pm 0.09\ (stat) \pm 0.054\ (sys) \end{aligned}}$$

(astro-ph/0510447)

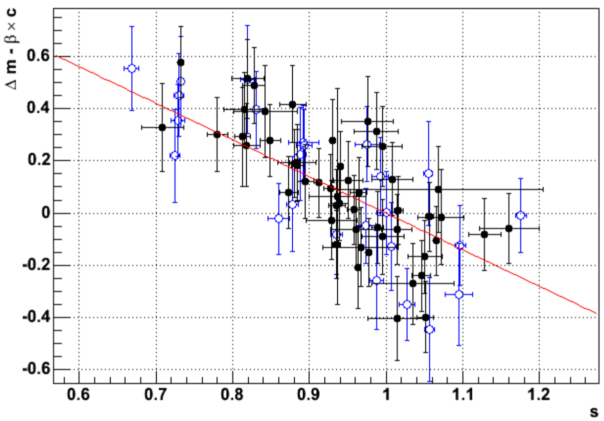
- w @ 0.05 within reach of current efforts
- Only next generation surveys will tackle dw/dz
  - SNe
  - BAO
  - Weak lensing
  - more probably a mixture of these

Intrinsic luminosity indicators (for Ia's)

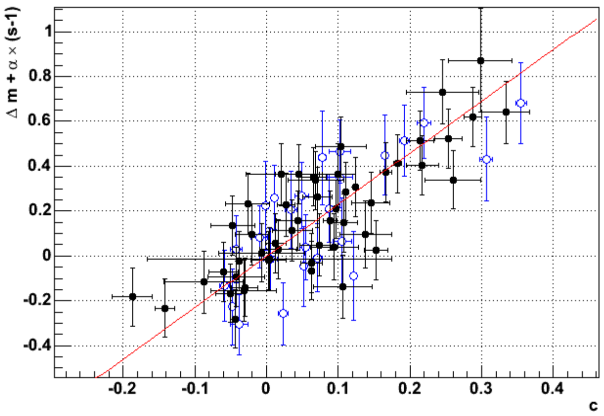
Brighter - slower



Kim, *et al.* (1997)



Brighter - bluer



stretch: time-scale parameter of the (B) lightcurve, corrected for (1+z)

or

decline rate:

decrease of flux at 15 (RF) days from max

color (e.g B-V)

(rest frame) at peak.

Color = Log(flux(V)/flux(B))

B ~ [400,500] nm

V ~ [500,650] nm

=> enable to reduce brightness scatter to ~13 % (0.13 mag)

SNe Ia surveys: from workshops to factories

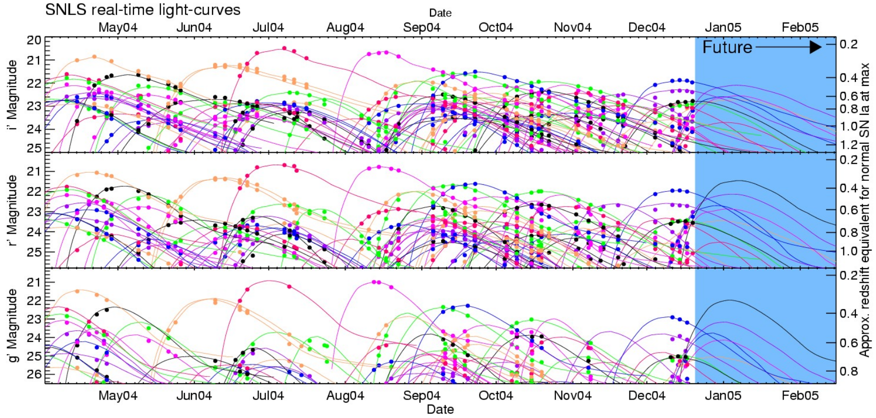
Old observing way is a many-step process:

- search: imaging at two epochs, ~3 weeks apart
- spectroscopy of candidates found

Photometry of identified Ia's

Drawbacks:

- Extremely vulnerable to bad weather
  - poor yield of observations
- Many telescopes involved
  - proposals/scheduling issues
  - Photometric calibration issues



Rolling search mode:

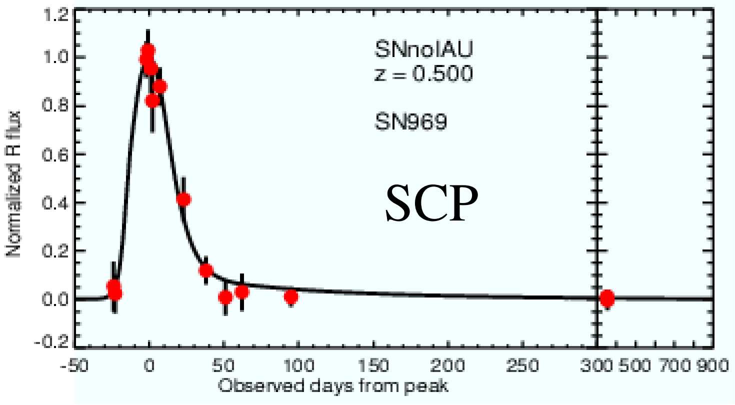
- Repeated imaging of the same fields
- Spectroscopy near peak
- Built-in photometric follow-up

Bonuses:

- Mutiplex: many measurements/exposure
- Detection on a time sequence
- LC sampling independent of phase
- Imaging robust to bad weather
- Spectroscopy in service mode possible
- Only one imaging telescope to calibrate
- Deep stack at the end of the survey
- .....

SNe Ia surveys: from workshops to factories (2)

Rolling search is THE way to go for SNe surveys



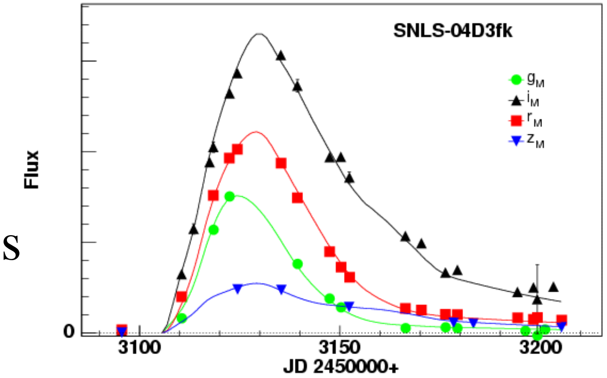
Three ongoing projects:

- Essence@CTIO

  ~8 deg^2, RI bands, 0.2<z<0.8, 5 years from 2002.
- SNLS@CFHT (within the CFHTLS)

  4 deg^2, griz bands, 0.2<z<1, 5 years from 2003.
- SNe in SDSS-II

  300 deg^2, ugriz bands, z<~0.35, 3 years from fall 2005.



Rolling searches become increasingly difficult as z decreases

- Requires very wide field imaging ~10 deg^2
- Large area -> Large data volume.

- Many ground-based wide-field imaging projects are in the landscape:

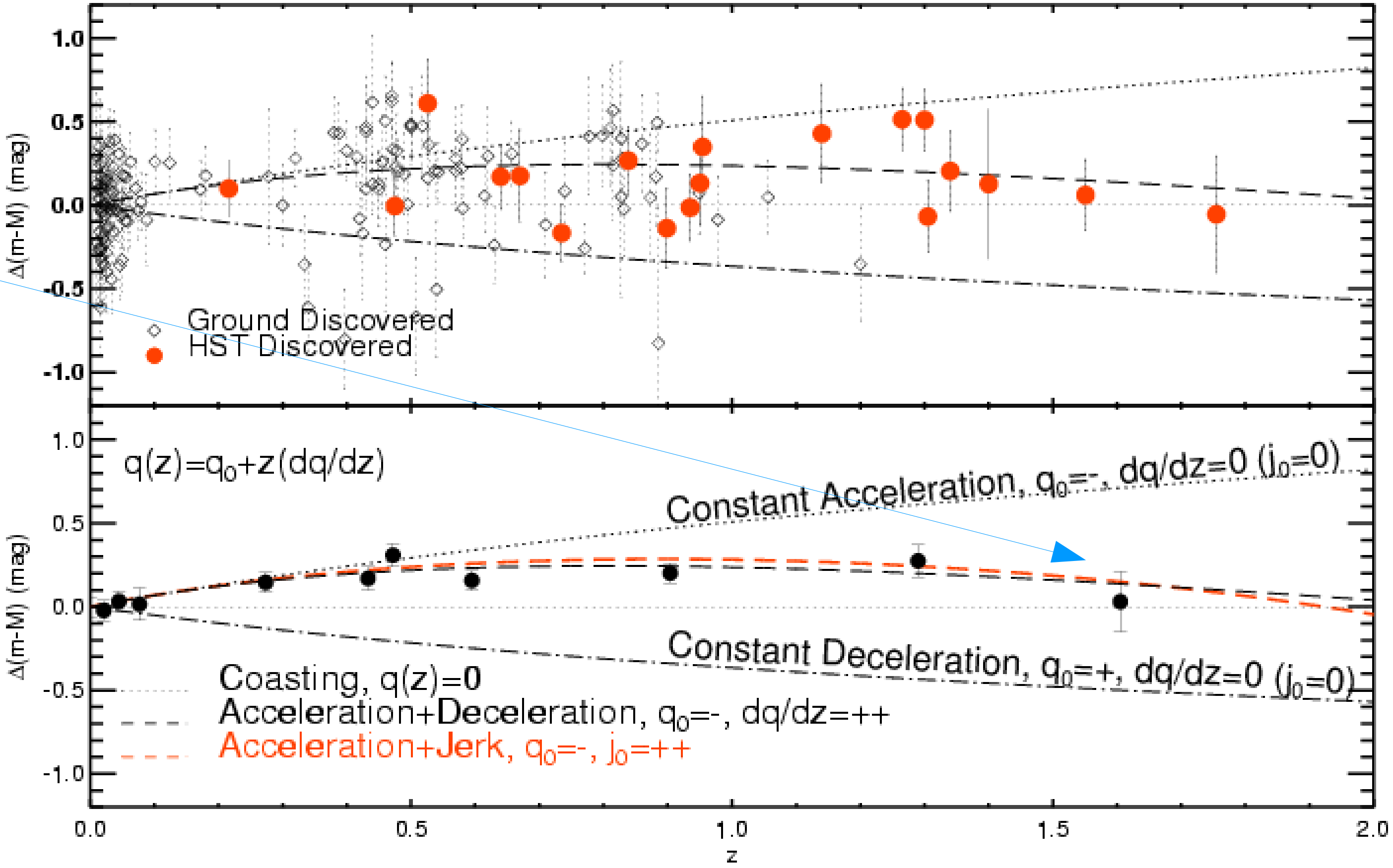
  Pan-Starss, DES (@CTIO), LSST, Hyper Suprime Cam, ...

Acceleration ?

We need a recent acceleration, but only recent.

The expansion was decelerating in the past:

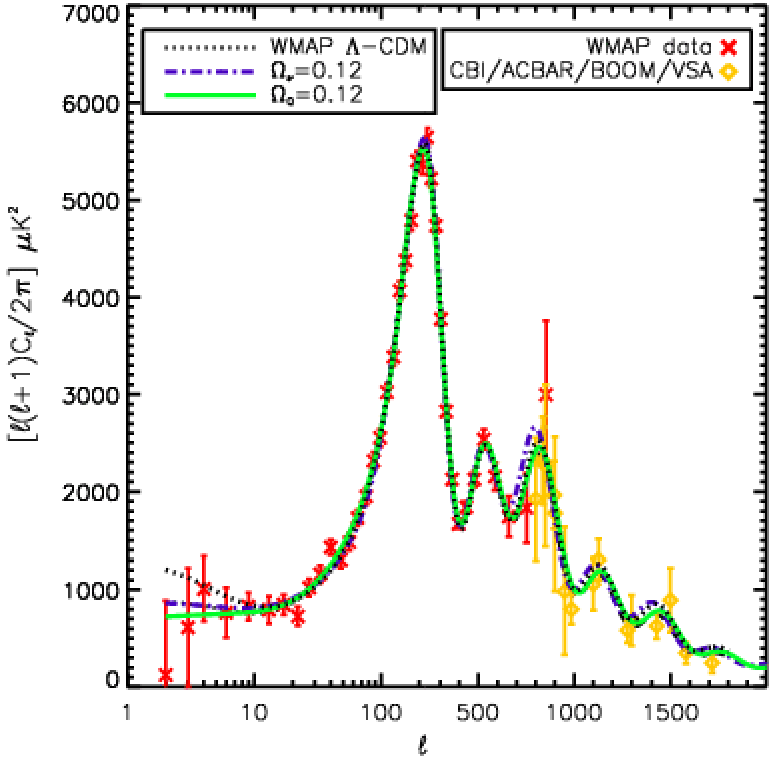
Λ does the job.



SNe Ia, Riess et al, 2004

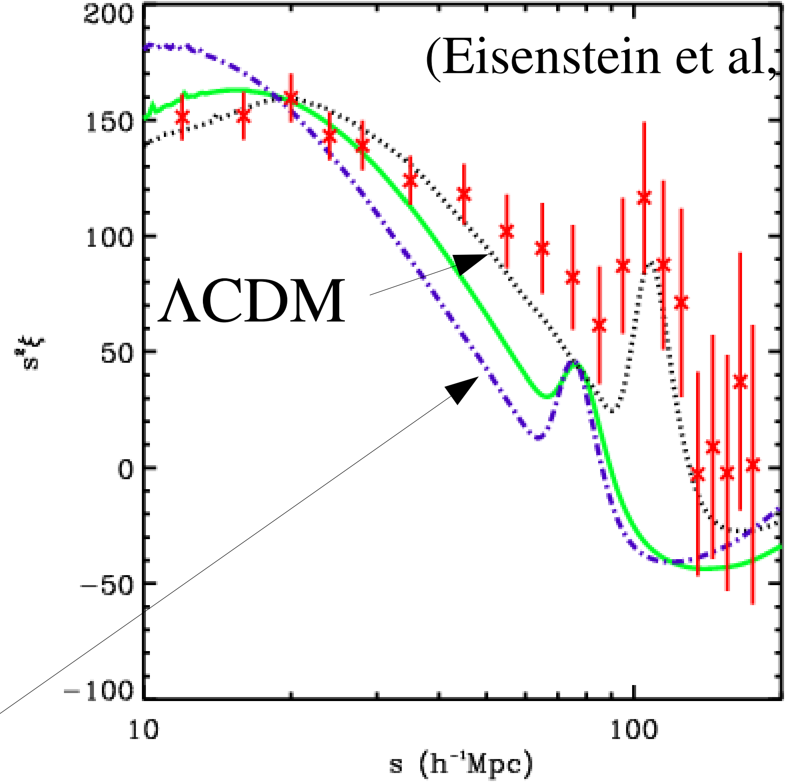
Do we really need Dark Energy ?

NO



YES

SDSS LRG
correlation function
(Eisenstein et al, 2005)



ΛCDM

Blanchard et al 2003,

$\Omega_M = 0.88$, $\Omega_v = 0.12$, $H_0 = 46$

SNe ignored.

Blanchard et al 2005,
cannot accommodate
Λ=0 with baryon acoustic peak.

$\Omega_{DE}(z)$

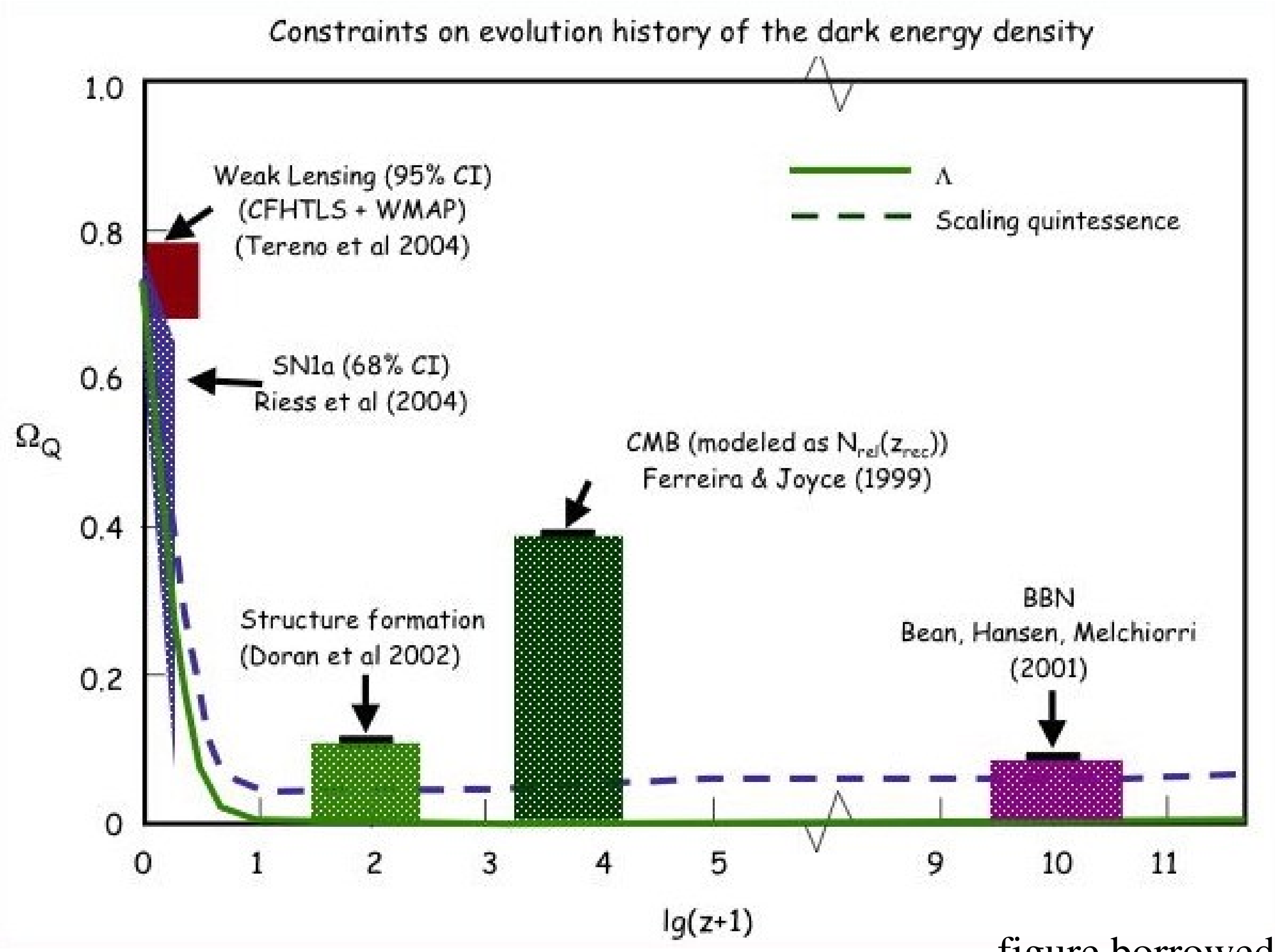
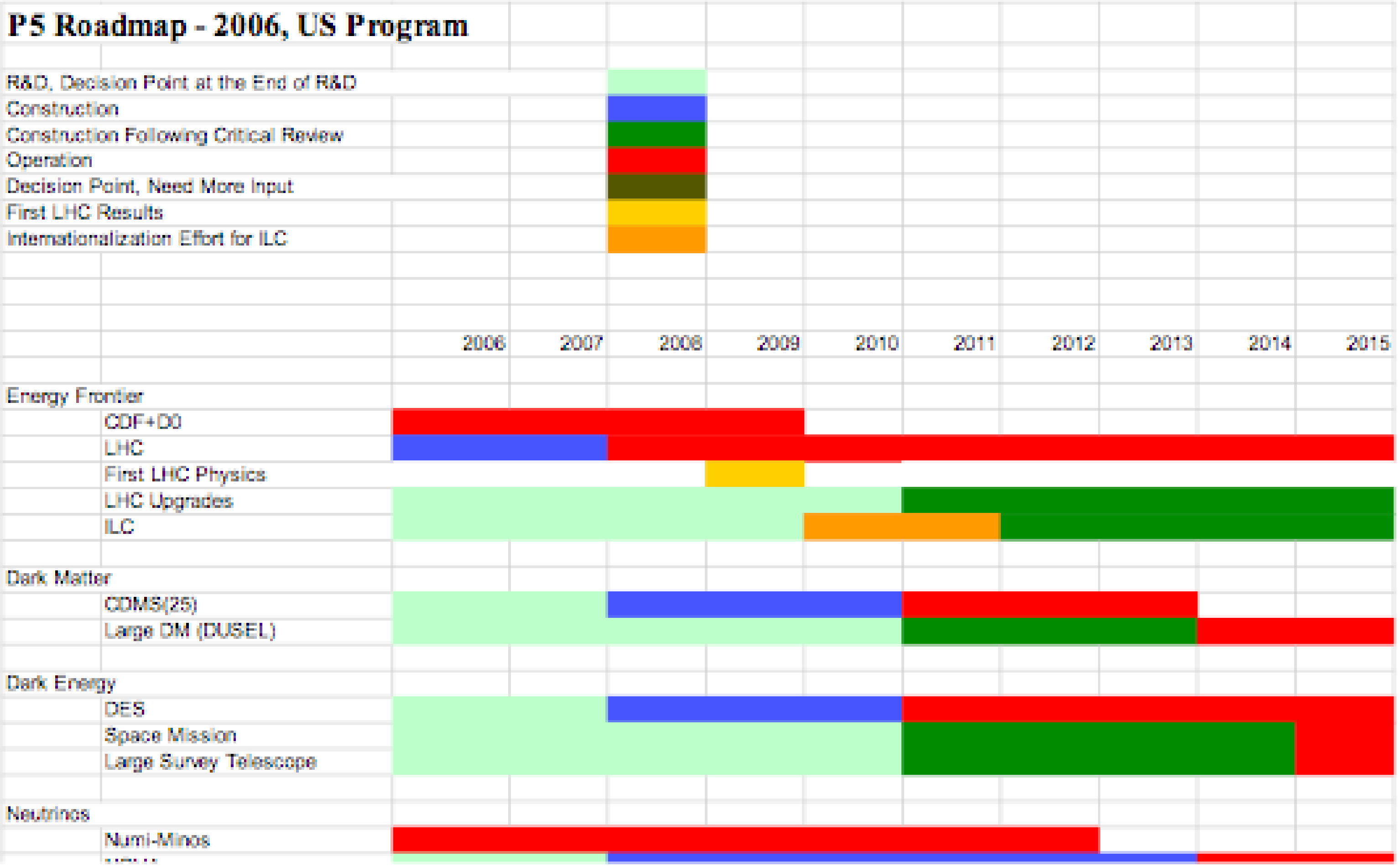


figure borrowed from R. Bean

Calendrier immédiat (DOE)



P5 Roadmap - 2006, US Program

▧ R&D, Decision Point at the End of R&D
🟦 Construction
🟩 Construction Following Critical Review
🟥 Operation
🟫 Decision Point, Need More Input
🟨 First LHC Results
🟧 Internationalization Effort for ILC

		2006	2007	2008	2009	2010	2011	2012	2013	2014	2015
Energy Frontier											
	CDF+D0	🟥	🟥	🟥	🟥						
	LHC	🟦	🟦	🟥	🟥	🟥	🟥	🟥	🟥	🟥	🟥
	First LHC Physics				🟨						
	LHC Upgrades	▧	▧	▧	▧	▧	🟩	🟩	🟩	🟩	🟩
	ILC	▧	▧	▧	▧	🟧	🟧	🟩	🟩	🟩	🟩
Dark Matter											
	CDMS(25)	▧	▧	🟦	🟦	🟦	🟥	🟥	🟥		
	Large DM (DUSEL)	▧	▧	▧	▧	▧	🟩	🟩	🟩	🟥	🟥
Dark Energy											
	DES	▧	▧	🟦	🟦	🟦	🟥	🟥	🟥	🟥	🟥
	Space Mission	▧	▧	▧	▧	▧	🟩	🟩	🟩	🟩	🟥
	Large Survey Telescope	▧	▧	▧	▧	▧	🟩	🟩	🟩	🟩	🟥
Neutrinos											
	Numi-Minos	🟥	🟥	🟥	🟥	🟥	🟥	🟥			
		▧	▧	🟦	🟦	🟦	🟦	🟦	🟦	🟥	🟥

SNAP

LSST

=> LSST (&SNAP) in R&D until 2010

Opinions personnelles

- Projet bien avancé techniquement
- Presque auto-contenu : il lui manque les z spectro (comme à tous)
- Projet au sol qui domine ce champ de physique.
- Pas de verrou technologique majeur.
- photo-z sans IR ?
- Ellipticités du sol?
- Financement hybride envisagé : NSF et DOE

  source d'embrouilles ?
- Quelle date de premiere lumière ?
- 4000 Tb de données par an...

Et la France ?

Visite des chefs en France a l'automne 2006 :

- Sollicitation explicite pour joindre la collaboration
- Ne demandent pas d'argent...
- .... tout de suite

Tickets d'entrée considérés:

- Contributions en nature a la camera.
- Participation/fourniture d'un telescope auxiliaire de calibration.
- Savoir-faire acquis avec le CFHTLS.

Politique :

- Discussions LSST/ESO au sujet des z spectroscopiques.

Summary

- The LSST will be a significant step in survey capability.

  Optical throughput ~ 100 times that of any existing facility.

- The LSST is designed to control systematic errors.

  We know how to make precise observations from the ground.

  We know how to accurately calibrate photo-z measurements.

  Multi-epoch with rapid return to each field on the sky – advantages likely not yet fully appreciated.

- The LSST will enable multiple simultaneous studies of dark energy.

  Complementary measurements to address degeneracy and theoretical uncertainty in a single survey.

- The LSST technology is ready.

SNe Ia surveys: from workshops to factories (3)

Discovery and photometry of SNe will become easier and easier...

Even for nearby SNe :

typically requires 2000 deg^2 in 3-4 bands twice a week to $m_{AB} = 21.5$

Within reach of Pan StarSS, LSST goes deeper, smaller telescopes would suffice.

What about spectroscopy?

- SNLS uses ~250 h/year on 8m-class telescopes :VLT, Gemini and Keck for ~140 SNe Ia/year.

- Multiply that by 10 ?
  - more than one dedicated 8m telescope
  -> (extremely) unlikely to happen shortly

Mandatory improvements for O(10000) cosmology/SNe surveys:

- Photometric identification of Ia's, from lightcurve shapes and colors

Characterizing Dark energy

from distance data

At least 4 mathematically equivalent descriptions (flat):

- $d_L(z)$ or $r(z)$ & Ω_M
- $\Omega_{DE}(z)$
- $w_{DE}(z) = w(z)$ & $\Omega_{DE}(0)$
- $V(\phi)$ for a scalar field ϕ (+ initial conditions)

Related via identities such as:

$$\rho_X(z) = \rho_X(0) \exp 3 \int_0^z \frac{1 + w_X(z')}{1+z'} dz'.$$

$$d_L(z) = (1+z)\frac{c}{H_0} \int dz' \left(\Omega_M (1+z')^{-3} + (1-\Omega_M) \frac{\rho_X(z')}{\rho_X(0)} \right)^{-1/2}$$

$$1 + w_X(z) = \frac{1+z}{3} \frac{3H_0^2\,\Omega_M(1+z)^2 + 2r''/r'^3}{H_0^2\,\Omega_M(1+z)^3 - r'^{-2}}.$$

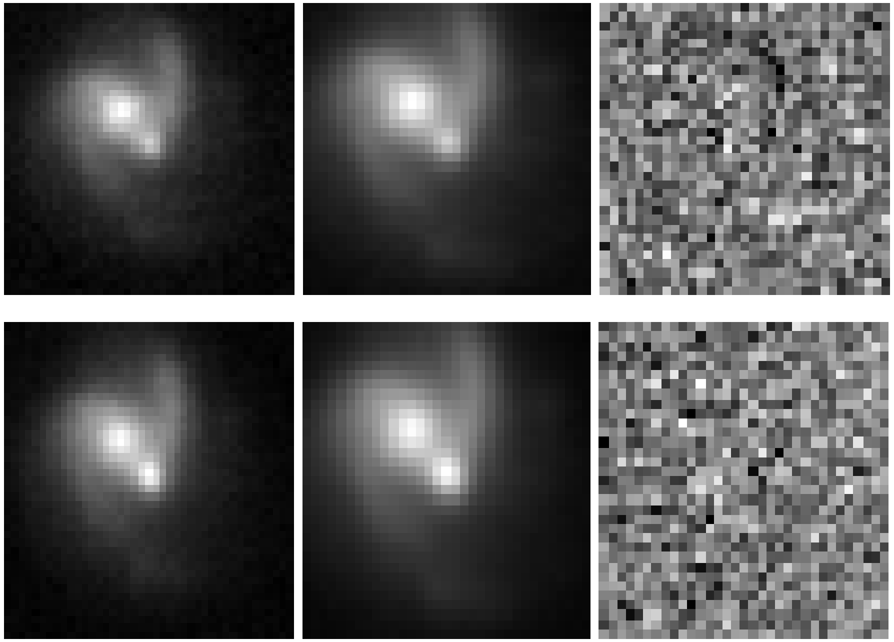
comparable size
but opposite signs.
Same for denominator.

No way to get precise w(z) measurements from distance data without some "external" Ω_M constraint.

Differential photometry

Image model: constant galaxy + varying point source + flat sky

$$\begin{aligned} I(x,y) &= \text{Flux} \times \left[\text{Kernel} \otimes \text{PSF}_{\text{best}}\right](x - x_{sn}, y - y_{sn}) \\ &+ \left[\text{Kernel} \otimes \text{Galaxy}_{\text{best}}\right](x,y) + \text{Sky} \end{aligned}$$

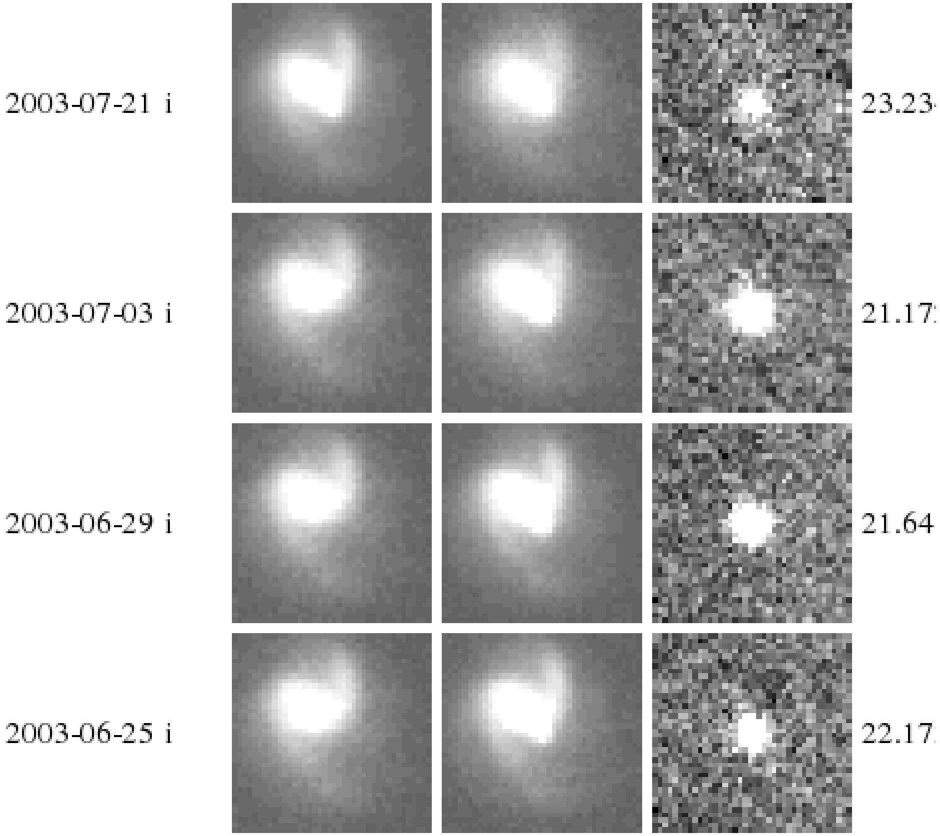


Data model residuals

- Fit galaxy on a stamp
- Same SN position in all images
- Incorporate images without SN
- Fit independently exposures from the same night (errors = observed scatter).

Detecting Supernovae

- New images (of the previous night) are subtracted off a reference image of the field (e.g. a stack of last year images)
  - before subtraction one has to “align” images:
    - geometrically
    - photometrically
    - PSF (bring to the same star shape).



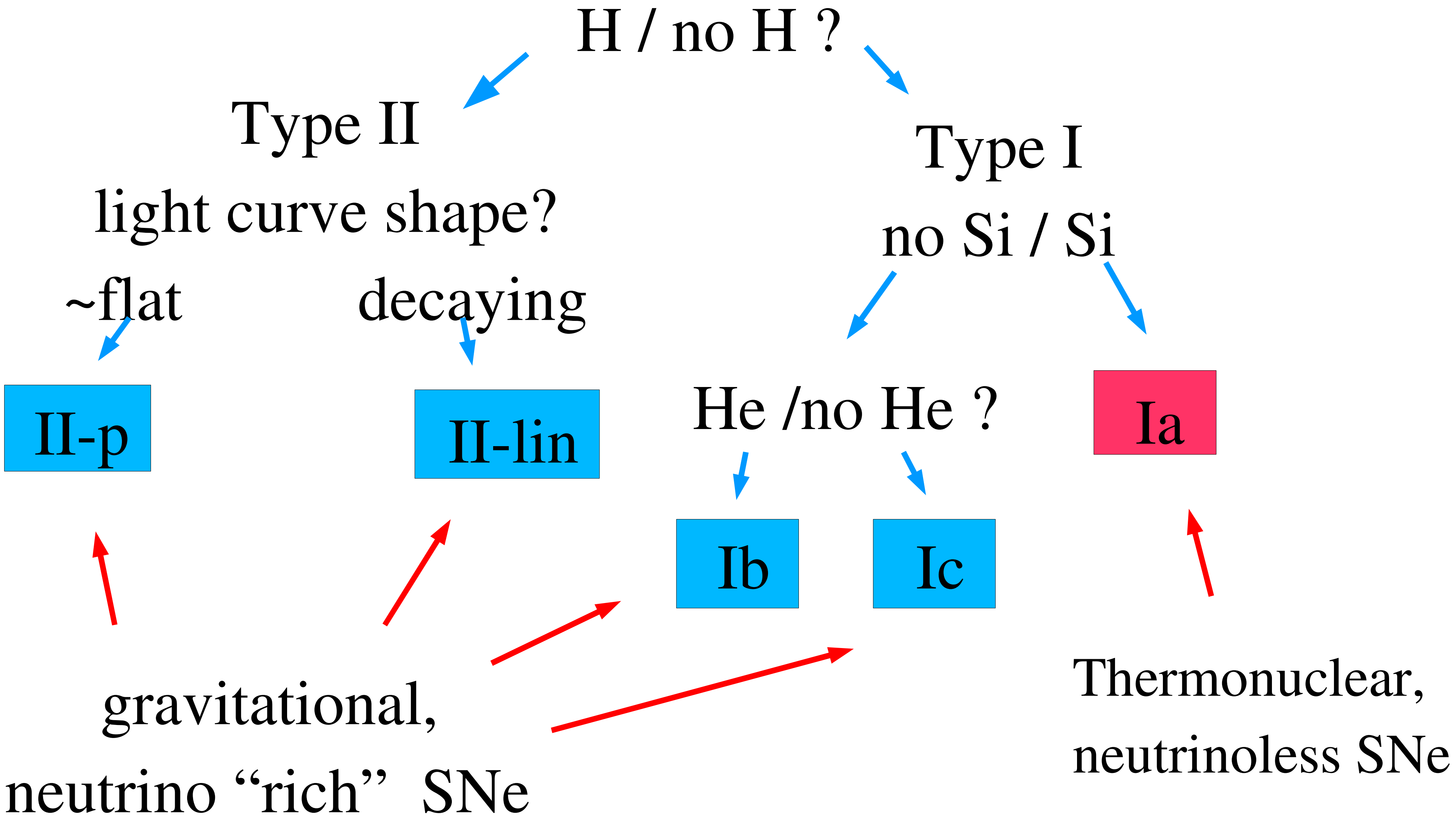
- Detection of (positive) excesses (typically above 3 σ)

-> Association of detections over nights/bands to reach ~ 8σ

–> Lightcurves are fit to a SNe Ia template to evaluate a “Ia likelihood”

-> Spectroscopy.

Supernovae: present classification scheme



H / no H ?

Type II

light curve shape?

~flat

decaying

II-p

II-lin

Type I

no Si / Si

He /no He ?

Ia

Ib

Ic

gravitational,
neutrino “rich” SNe

Thermonuclear,
neutrinoless SNe

Redder-Fainter (4)

Latest R (also known as β) news :

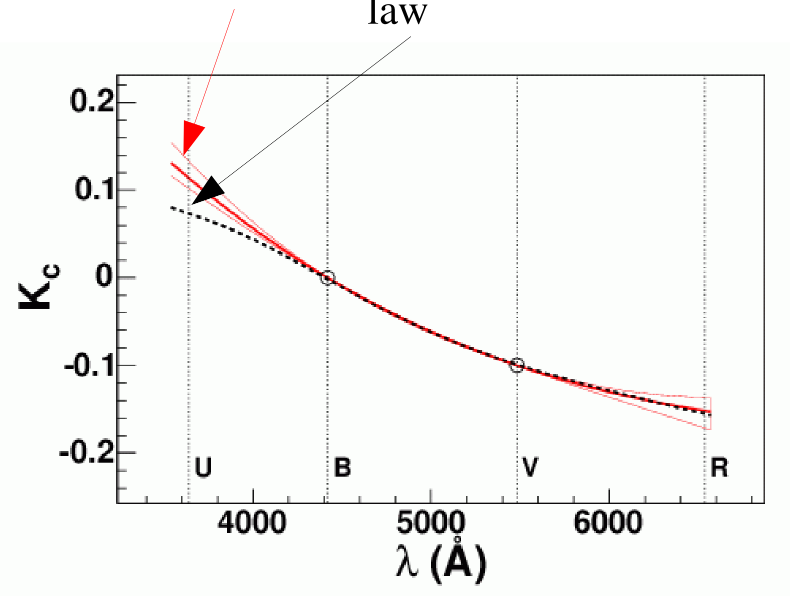
- Lifan Wang et al (2005) find 2.59.
- Guy et al (2005) find about 2.
- Xiaofeng Wang et al (2006) find 3.3

(typical uncertainty : 0.2-0.3)

Tentative conclusions:

- Empirical brightness-color relations of SNe Ia are odd, but favorable for distance measurements.
- These relations should be fitted together with the brighter-slower relation, because color and decline rate are (slightly) correlated.
- If one assumes a specific redder-fainter relation, this impacts on the observed brighter-slower relation (Leibungut 2000).

color relations measurement

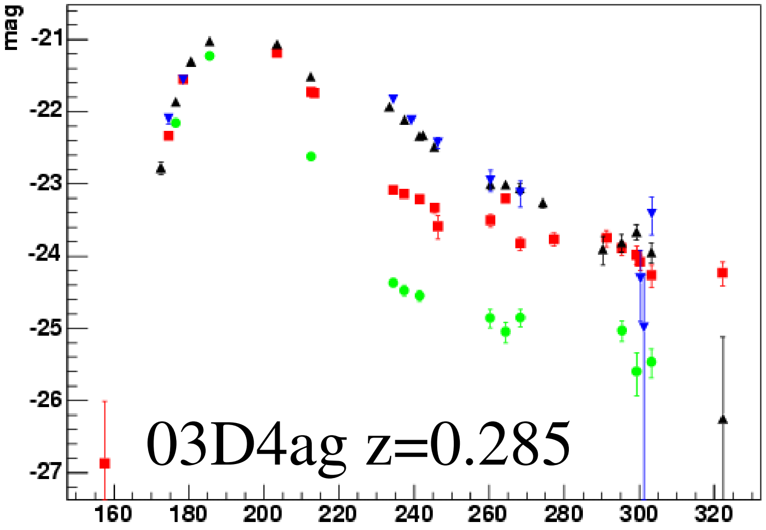


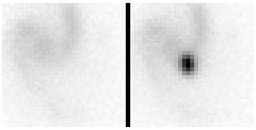
SNe

Cardelli Extinction law

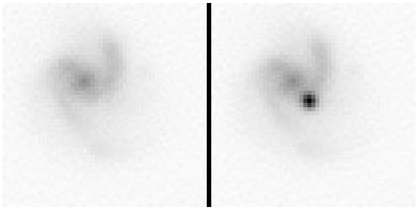
A-A(B) for E(B-V)=0.1:
color relations are compatible with MW dust, but in U band (Guy et al 2005)

Lightcurve examples

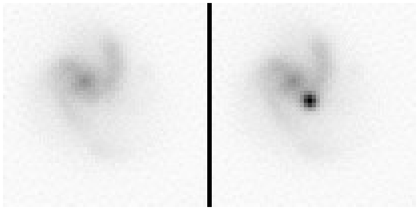




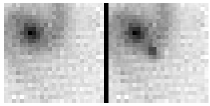
g



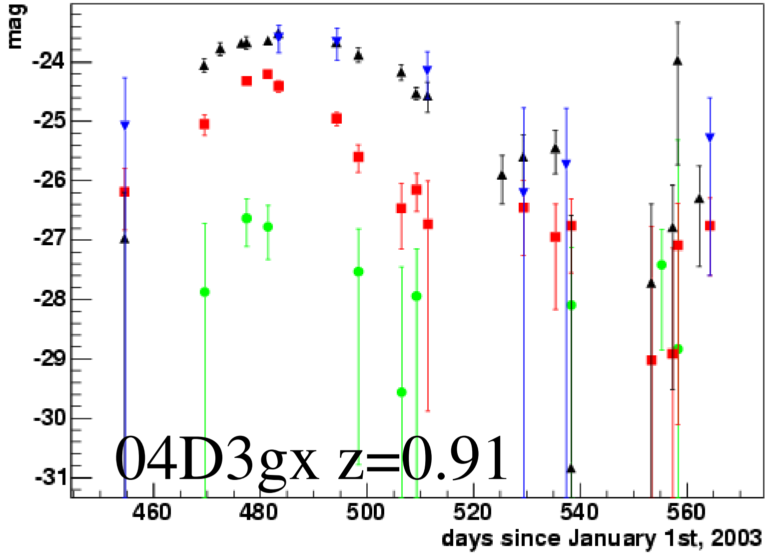
r

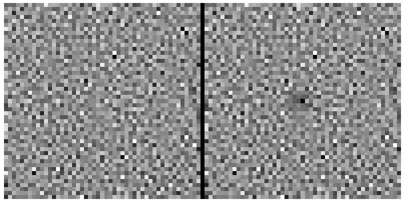


i

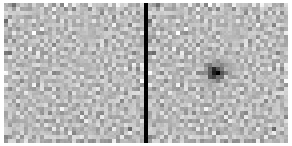


z

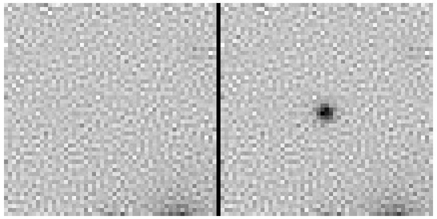




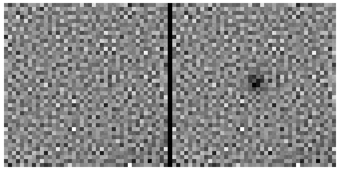
g



r



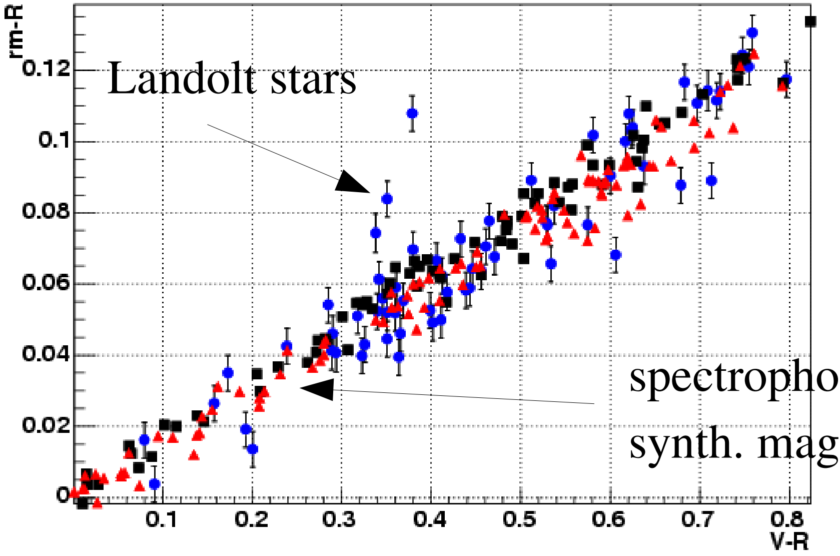
i



z

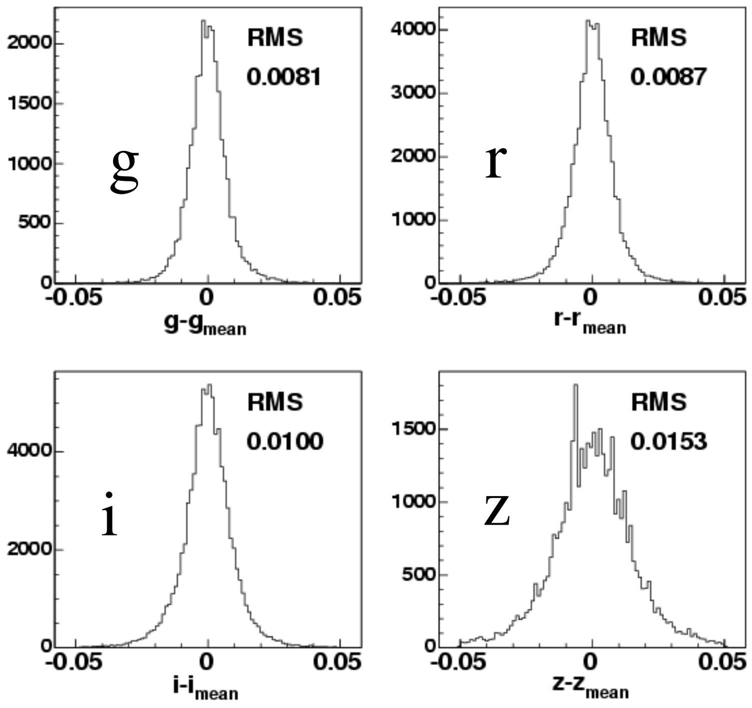
Photometric calibration

- Based on repeated observations of Landolt standards
- Carried out in “Landolt” magnitudes since nearby SNe are calibrated this way
- Produce calibrated star catalogs in the SN fields, in Megacam natural magnitudes
- Checked synthetic vs observed color terms (Megacam/Landolt & Megacam SDSS 2.5m)



Landolt stars

spectrophotometric synth. mags



-Zero points at the 0.01 level (0.03 in z)

-Repeatability better than 0.01 (0.015 in z)

Multi-color lightcurve fits

SALT :Spectral Adaptive Lightcurve Template

(Guy *et al* 2005, A&A, in press)

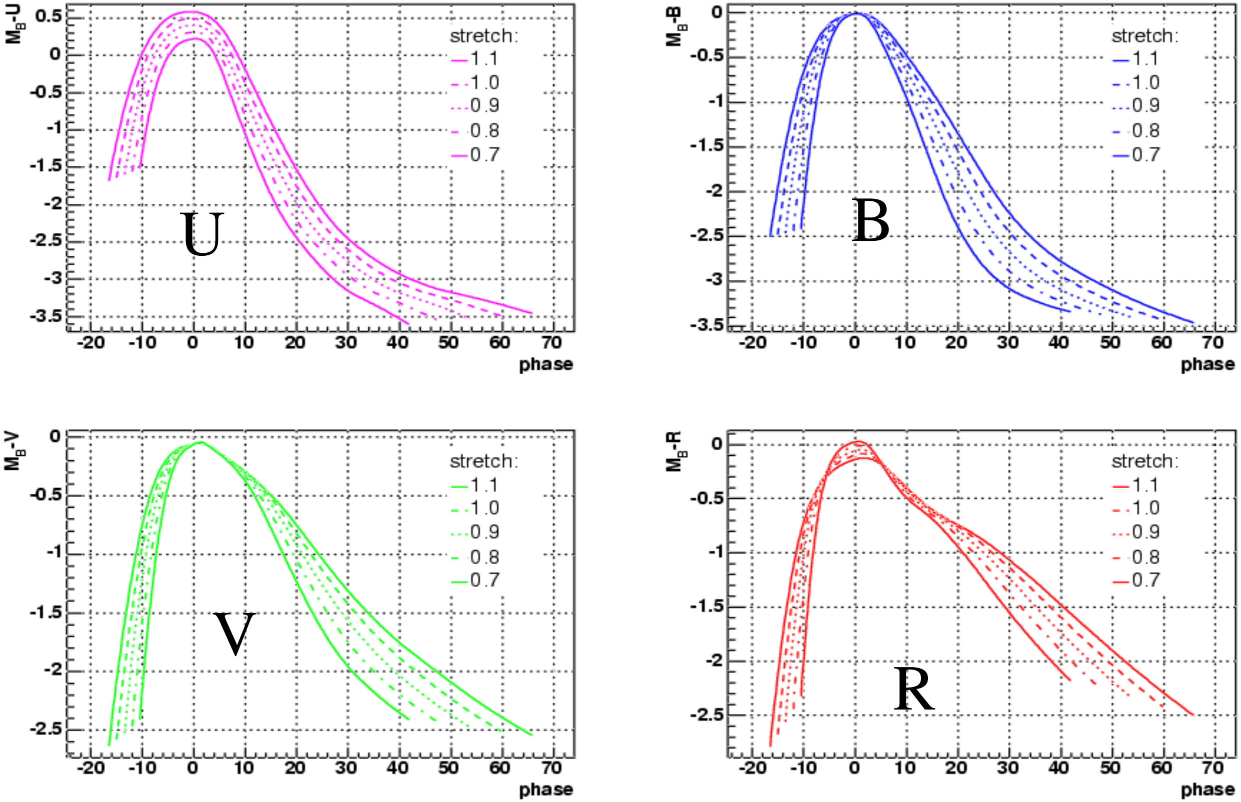
Model SNe Ia SED as a function of:

- phase (date with respect to B-band maximum)
- lambda (rest-frame wavelength)
- stretch (=s)
  (dilatation of phase axis in B-band)
- color =E(B-V) (= c)
  at B-band maximum

Train the model on a local sample, in UBVR.

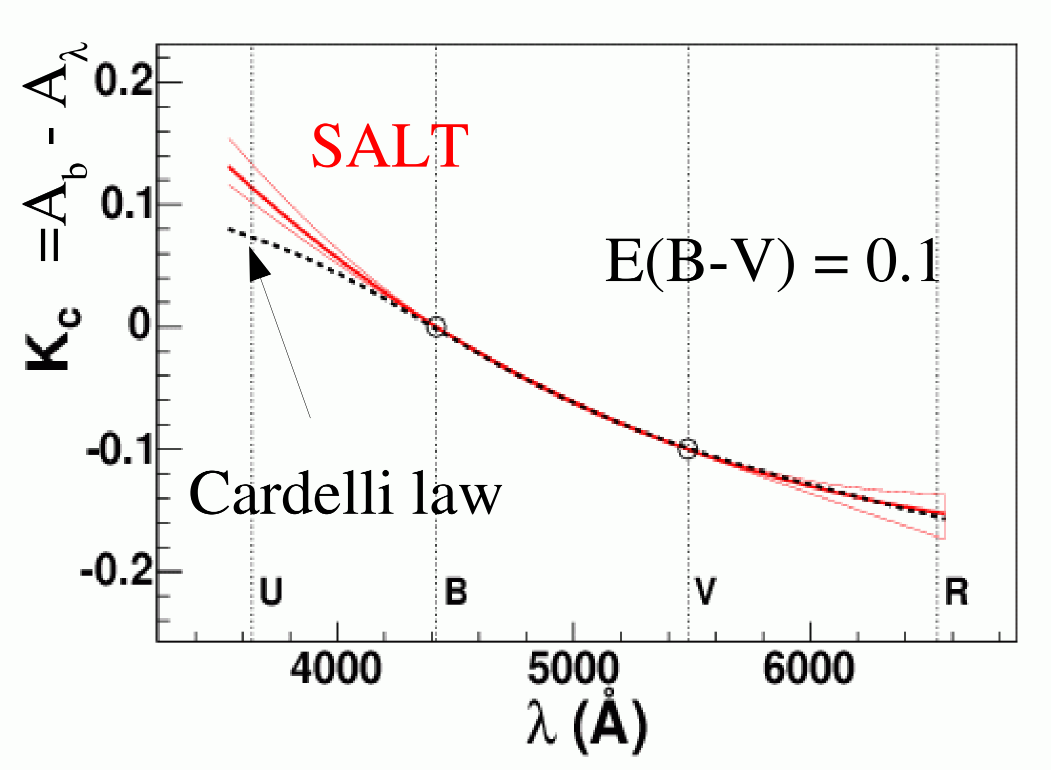
coverage: 3460 to 6500 Ang.

lightcurve for various stretches and color=0



Color relations with SALT

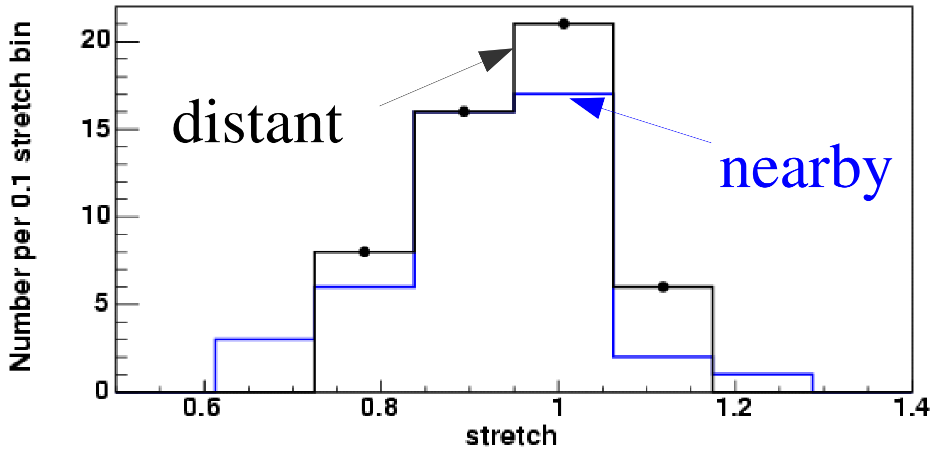
(Given B and V, what about U and R?)



SNe Ia color <u>relations</u> seem compatible with extinction <u>but for U band</u>

Comparisons SNLS/nearby

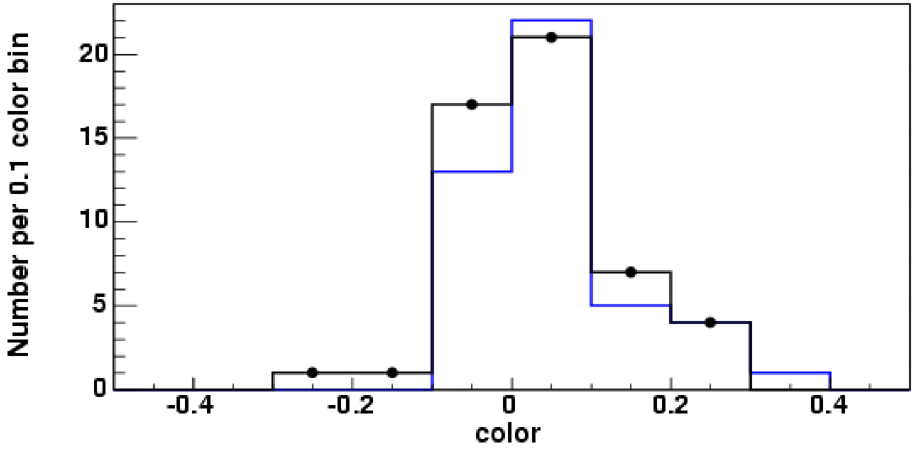
stretch



mean values within 1 σ

Kolmogorov prob = 0.99

color



mean values within 1.5 σ

Kolmogorov prob = 0.99

Compatible distributions

Malmquist bias of SNLS sample

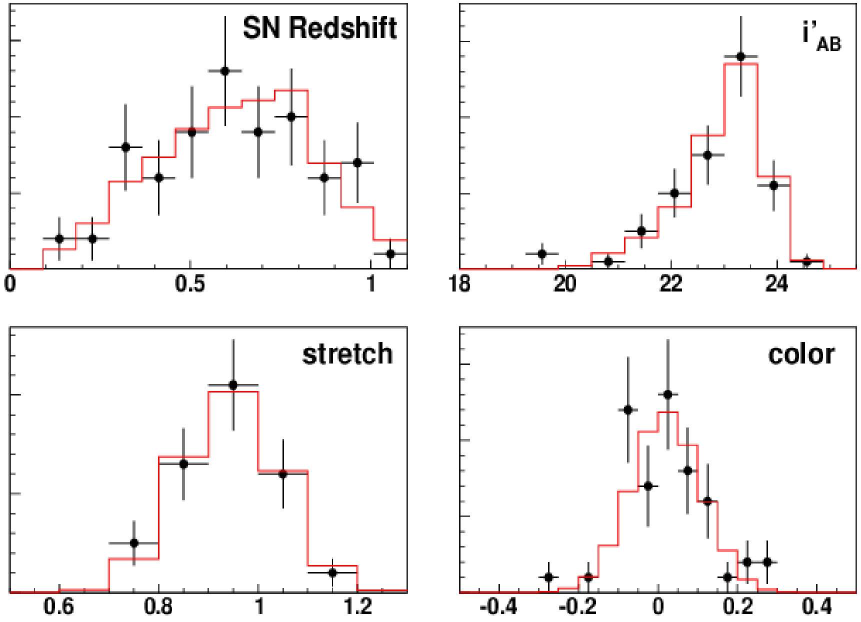
- Distributions of stretch and color
- Take into account brighter-slower, brighter-bluer (from best fit)
- Add intrinsic dispersion (from best fit)
- Apply cut on i' magnitude @ date of spectroscopy (assume a dist. of spectro. phases)
- Constant SN rate per comobile volume

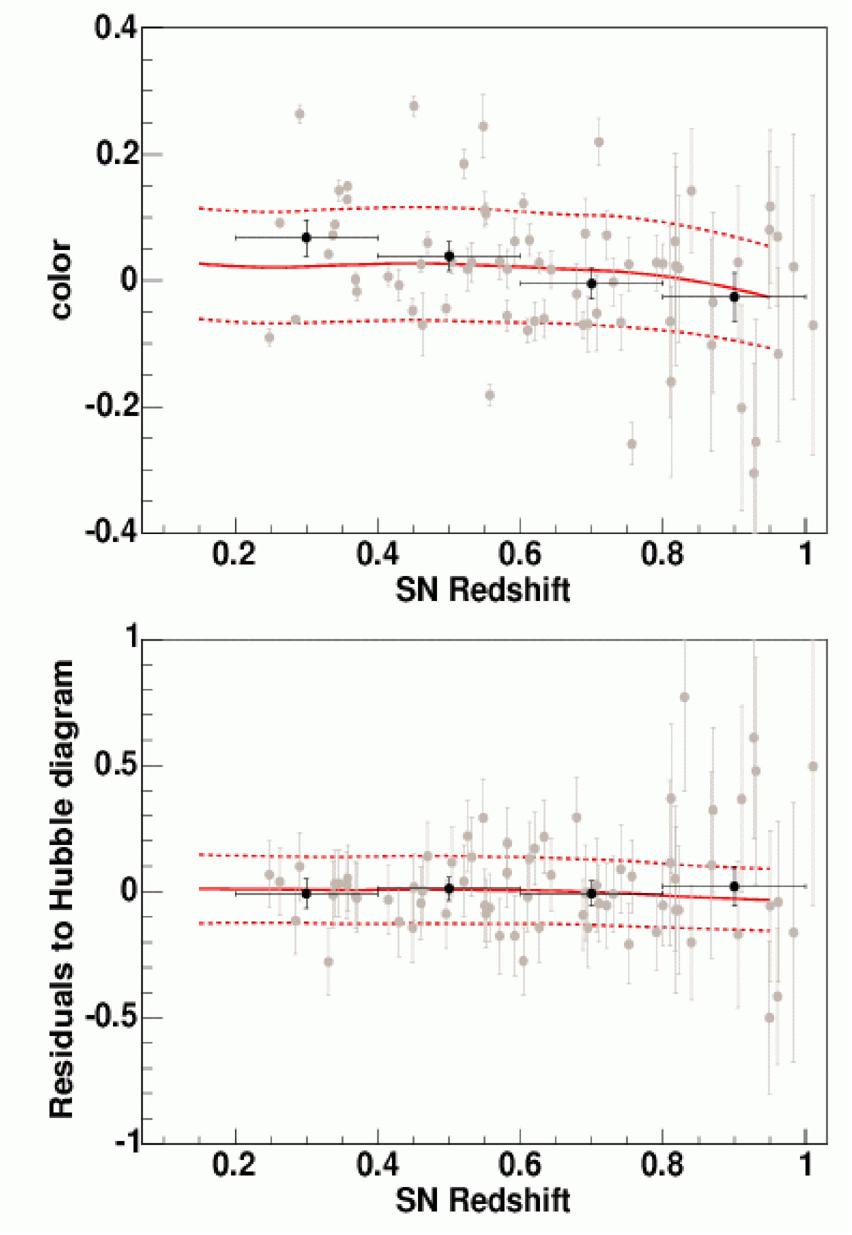
Try to reproduce distributions of :

- redshifts
- i' mag at maximum
- stretch
- color

Check bias for distance moduli

Malmquist Bias





Impact on Ω_m (flat ΛCDM):

Nearby SNe	+0.019 ± 0.012
SNLS SNe	-0.020 ± 0.010

Conclusions/perspectives

- We have built a Hubble Diagram with 45+71 SNe Ia

$$\boxed{\begin{aligned} \Omega_M &= 0.271 \pm 0.021\ (stat) \pm 0.007\ (sys) \\ w &= -1.02 \pm 0.09\ (stat) \pm 0.054\ (sys) \end{aligned}}$$

- All have 1 measured color, 50 have 2 or more.
- We have almost 200 identified Ia's of excellent quality on disk, all measured with the same instrument.
- The Rolling Search approach is effective both for quality and quantity.
- 700 SNe by the end of the survey remains our target.
- Photometric calibration will likely improve.
- Many precision tests are now becoming possible