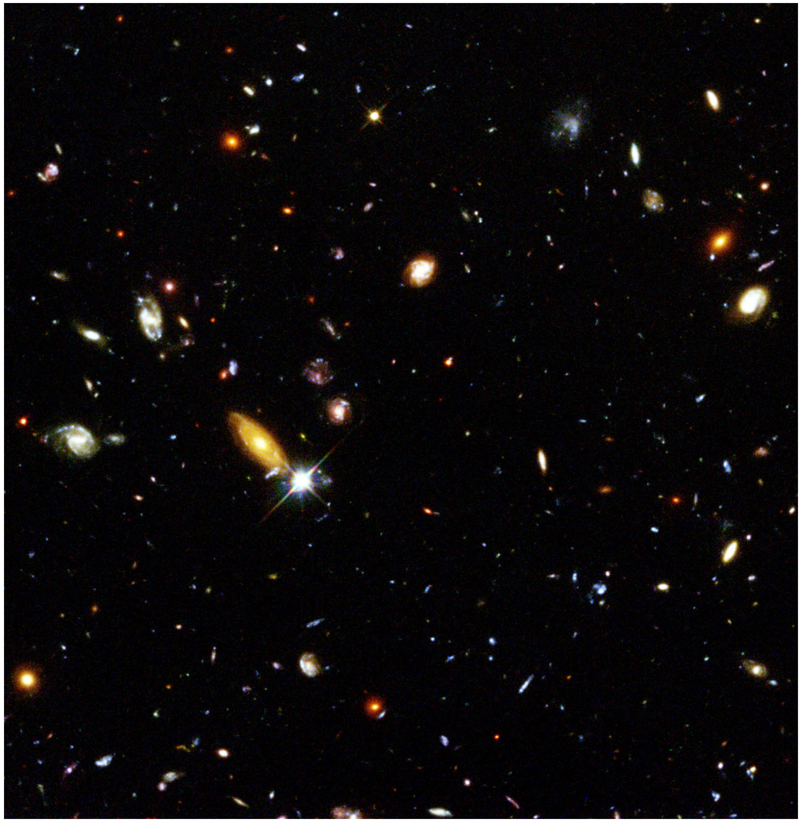
Supernovae from space



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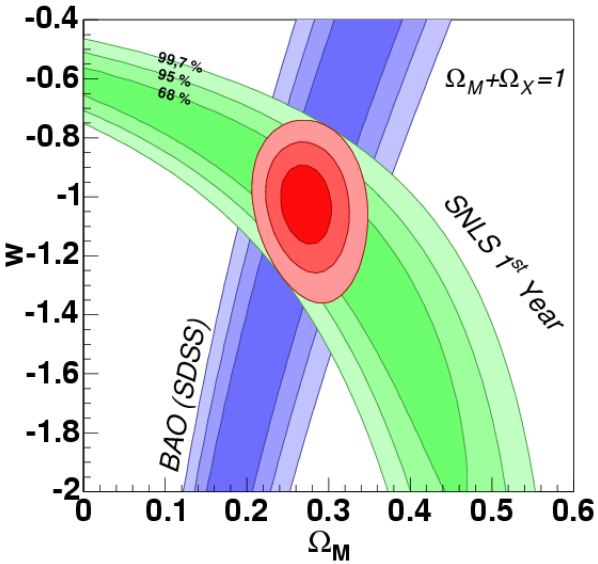
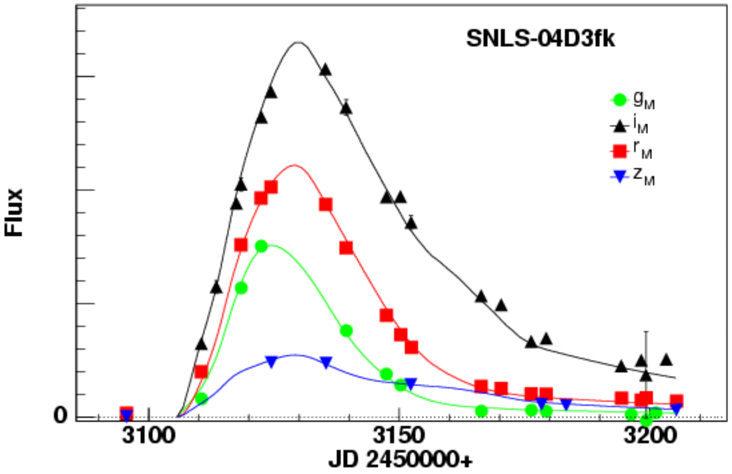




Paris-Berkeley workshop
September 2009

Political framework

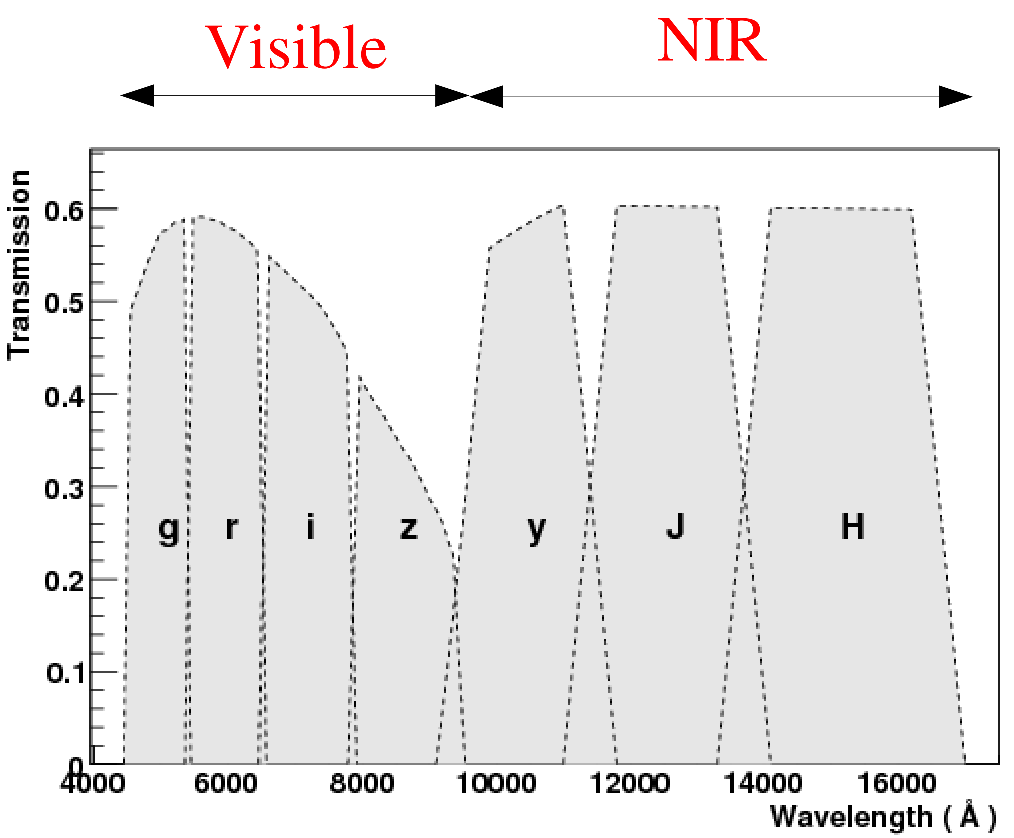
Political framework

Too complicated. Null slide.

Instrumental Framework

Hypotheses :

- Telescope diameter 1.2 m (or more !) with central occultation
- Dual channel imaging system : visible (CCDs) and NIR (HgCdTe) which operate simultaneously
- 0.5 deg^2 in each channel with filter wheels
- ~ logarithmic filters Example : 450->1650 nm



Imaging performance

- Image sampling : 0.1” in the visible and 0.3” in NIR.
  NIR : RO noise = 20 el, dark current = 0.1 el/sec.
- Image quality : 0.17” FWHM from spacecraft + diffraction
  -> 0.2“ at 500 nm to 0.35” at 1500 nm
- Sky background : from Leinert (1998) at 30 degrees from the ecliptic pole

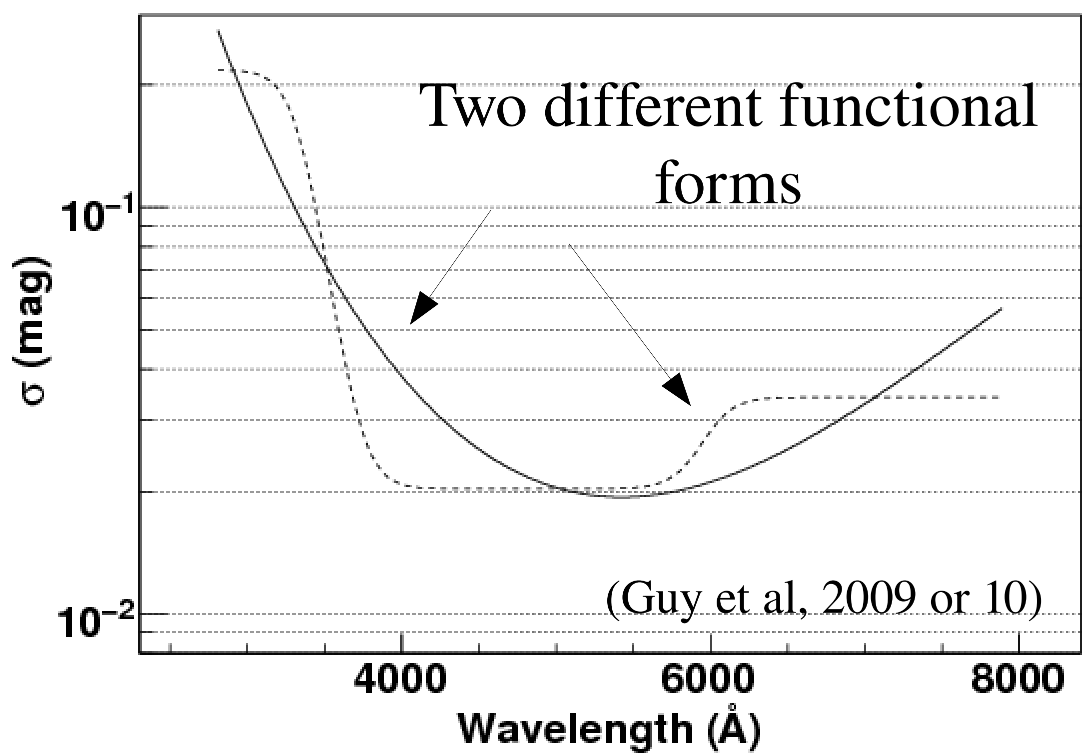
AB mags. Sensitivity for point sources and PSF photometry

band	sky	zp (e^-/s)	10σ (600s, ps)
g	23.19	24.27	25.1
r	22.89	24.32	25.1
i	22.68	24.18	24.9
z	22.60	23.72	24.4
y	22.47	24.32	24.4
J	22.44	24.37	24.4
H	22.31	24.41	24.4

Supernova survey requirements

- Common restframe bands observed at all redshifts
- Three common bands : B,V,R . U at z>0.4.
- Accuracy of a single band LC amplitude better than 2.5 %

  -> implies distances better than 0.14
- Redshift-limited survey -> no Malmquist bias.



Residual scatter
of lightcurve amplitudes
to SALT2 color relations
-> assume 2.5 % noise

Rate and model

SNLS SNe Ia rate measurements borrowed from Pascal Ripoche (Moriond cosmo 2008)

Rate = star formation rate (SFR) (Hopkins et Beacom 2006])
*
dela

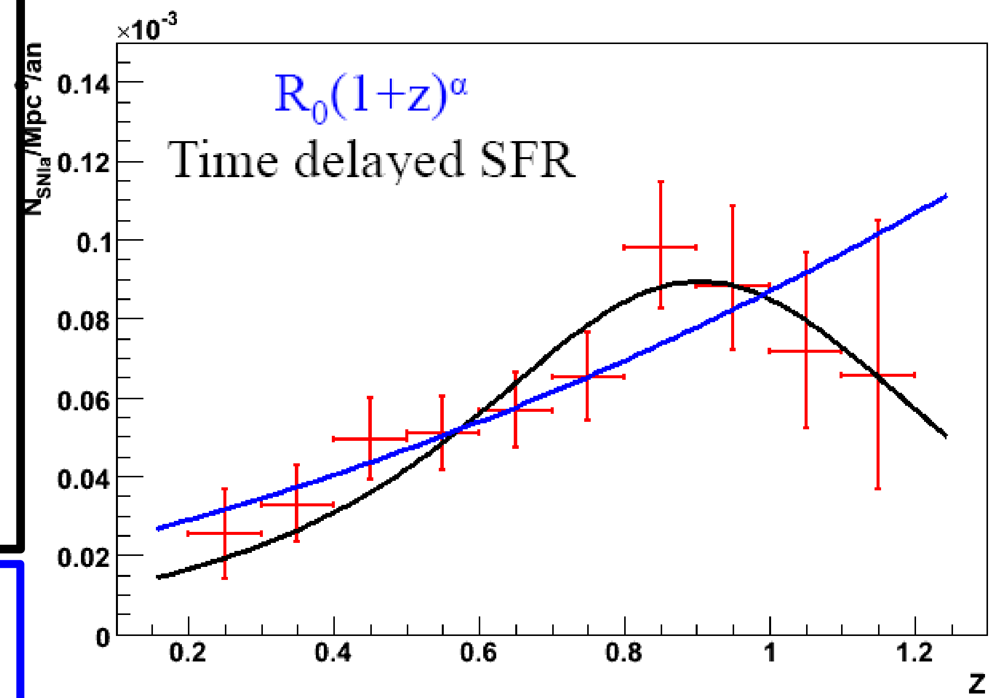
$$Rate(t) = k\int_{tF}^{t} SFR(t')\times\phi(t-t')dt'$$

$$\phi(t) = \frac{1}{\sqrt{2\pi\sigma^2}} e^{-\frac{1}{2}\left(\frac{t-\tau}{\sigma}\right)^2}$$

$\sigma/\tau=0.2$ $\tau=3.7\pm0.25$ Gyr $\chi^2=3.75$

- Slope measurement
- $$Rate(z) = R_0\,(1+z)^{\alpha}$$
-
- $\alpha=2.14\pm0.51\ 10^{-5}$ Sn/Mpc^3/yr
- $R_0=2.0\pm0.54$

$\chi^2=4.77$



Imaging survey fiducial parameters

- "Rolling search" in a single cone ?
  - -> too small volume at low redshift
  - -> Two cones : a deep survey (10 deg^2) and a "wide" survey (50 deg^2)

- SN rates: they seem to significantly increase with redshift.

  Assumed rate:

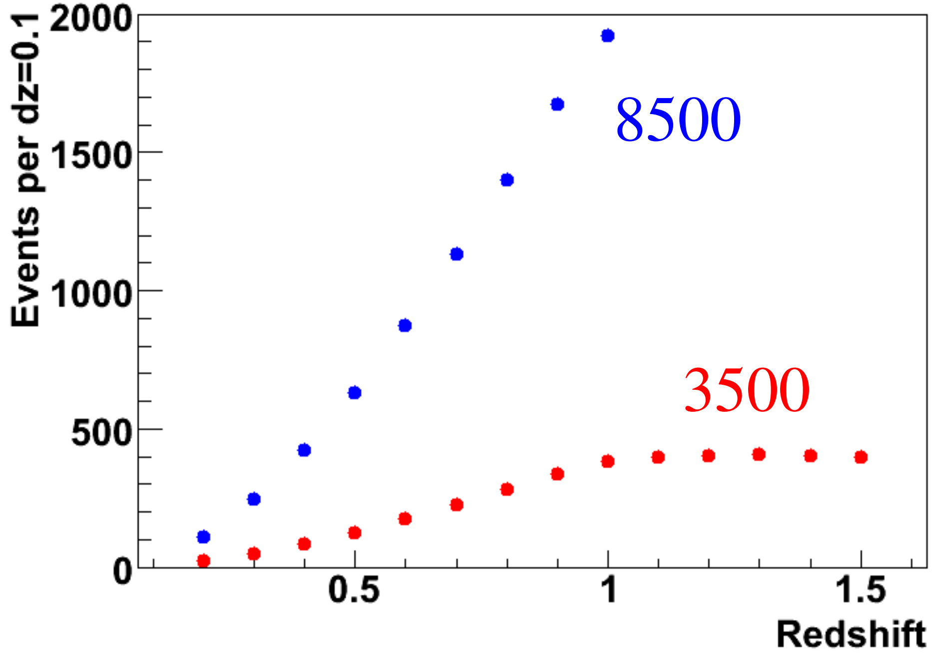
  z<=1 : $R(z) = 1.53\ 10^{-4}\,[(1+z)/1.5]^{2.14}\,h_{70}^3\,Mpc^{-3}\,y^{-1}$

  z > 1 : R(z>1) = R(z=1)

  (smaller yield than Mannucci et al (2007))

- Survey duration : 1.4 year
- Cadence : 5 (observer) days (could be less with shorter exposures)

Fiducial sample



Exposure time per visit
every 5 days

	wide	deep
g	400	1600
r	400	1600
I	500	1600
z	700	2400
y	650	1800
J	650	2400
H	650	3000
total	2000	7200

Exposure times provide average S/N>=40 (in BVR for LC amplitude) at highest redshifts for the deep and the wide.

Deep : 20*2h = 40 hours
Wide : 100*5.5h = 55 hours
left : 120 - 95 = 25 hours

~ 100 epochs in total

Saul's question : multiplex advantage ?

What is the benefit of rolling search w.r.t pointed observations?

Wide survey :

- 100 epochs
- 100 pointings (footprint)
- 8500 events , 8*(1+z) light curve points per event (and band)
  - -> 120 000 lc points

Number of lightcurve points per image :

120 000 / 10 000 = 12

I find a significant multiplex advantage

This (only) depends on 2 figures:

- the SNe Ia rate
- the imager area

Why Space

- Stability of the instruments (PSF, calibration)
- No other practical route to precision distances to SNe at z>~1
- NIR coverage with high sensitivity :
  - Large wavelength coverage at all redshifts
    (mandatory to sort out color variation sources)
  - High redshifts in BVR (as small redshifts)
  - Restframe I band to z=0.9 !! with more than 5000 events
    & "standard" distances to the SAME events.
  - Precise NIR host galaxy colors for SN physics
- No need to tackle restframe U-band

(See talks by Julien Guy and Rick Kessler)

Types and redshifts

Redshifts :

- galactic photo-z : degrades cosmology, requires training.
- SN photo-z : better accuracy, but correlated with distance estimate.
- "after the fact" host redshifts
  - -> with a BigBoss like instrument, requires O(500) hours
  - -> will assume 80 % efficiency in getting host z.
- If wide-field slit spectroscopy were available on board.... think about it

Typing :

7 bands : LC shapes, color relations (which are tight)

+ 2nd maximum in restframe I at $z<1$

+ drop out at 300 nm at $z>0.7$

Encouraging results on SNLS with:

- host galaxy photo-z
- 4 bands (only!)
- poorer S/N

Colors and distances

- We cannot assume that any Cardelli law describes the brighter-bluer relation of SNe Ia
- Even if it is true, we'd better prove it
  - ==> measure the color relations (don't assume Cardelli)
  - ==> measure the total to selective extinction (and don't assume any link with color relations)
  - ==> check that color variations are compatible with extinction (by some exotic stuff)
- We should obviously avoid any prior on color. BTW, even if color variations are only due to extinction, negative extinction estimates are unbiased.
- We all would like to know what causes color variations, but it has to come from the data.
- Measure many colors precisely !

Considered uncertainty sources

- Photometric noise
- Photometric calibration : 1% in all bands (independent)
- Lightcurve model uncertainty :
  - Statistical accuracy
  - Color noise floor (2.5 % on amplitude per band)
  - Photometric calibration of the training sample
  - Self-training
    - colors of a fiducial supernova
    - color law (à la SALT2)
- Tripp distance estimator : $\mu_B = m_B - M + \alpha(s-1) - \beta c$
- Intrinsic brightness drift $M(z) = M_0 + s_M z$ with s_M constrained (0.01)
- Intrinsic dispersion : 0.15 (pessimistic by now)

Parameters & Fit

- Event parameters (4 per event : T_0, m_B, X_1, color)
- Zero points : 1 per band
- SN model (to be determined from data) :
  - colors of a fiducial supernova. (14 parameters)
  - color law (à la SALT2). (9 parameters)
  - account for "color noise" (2.5 % all bands)
  - use all events for LC fitter training
- M,α,β and $M(z) = M_0 + s_M z$ with $\sigma(s_M) = 0.01$
- Intrinsic scatter : 0.15
- Cosmological parameters

Technique : fit lightcurves and cosmology together, all events and parameters at once and marginalise over everything but cosmology. (~ 50,000 parameters)

Cosmo priors ?

- Let us count cosmological parameters :
  - SNe Ia Hubble diagram nowadays constrains 1 combination
  - .... perhaps 1.5 when considering high redshift events
  - Assume that our high precision forecast constrains two parameters
  - Cosmological models with matter (Ω_M), DE (Ω_X, 2 e.o.s param) have 4 parameters
- Need a 2-d prior
- Using the geometrical constraints from CMB yields a 1-d constraint in this four-parameter space (Ω_M,Ω_X, 2 e.o.s param)

==> either need to invoke some other probe (BAO) or assume flatness.

Use geometrical Planck priors and flatness

Results

Calibration

M drift

Color noise

Sn Model

label	N_1	N_2	zp	σ_c	$\sigma(s_M)$	$\sigma(w_a)$	z_w	$\sigma(w(z_w))$	Area
A	0	0	0	0	0	0.30	0.44	0.022	0.657
B	14	0	0	0	0	0.30	0.44	0.022	0.660
C	0	9	0	0	0	0.30	0.44	0.022	0.657
D	0	0	0.01	0	0	0.30	0.44	0.022	0.663
E	0	0	0	0.025	0	0.30	0.44	0.022	0.673
F	0	0	0	0	0.01	0.34	0.39	0.027	0.905
G	0	0	0	0.025	0.01	0.34	0.39	0.027	0.926
H	14	0	0	0.025	0.01	0.34	0.39	0.027	0.934
I	0	9	0	0.025	0.01	0.34	0.39	0.027	0.926
J	14	9	0	0.025	0.01	0.34	0.39	0.027	0.935
K	0	0	0.01	0.025	0.01	0.35	0.39	0.027	0.940
L	14	0	0.01	0.025	0.01	0.37	0.37	0.030	1.107
M	0	9	0.01	0.025	0.01	0.35	0.39	0.027	0.941
N	14	9	0.01	0.025	0	0.33	0.40	0.027	0.909
Y	14	9	0.005	0.025	0.01	0.36	0.38	0.029	1.032
Z	14	9	0.01	0.025	0.01	0.37	0.37	0.030	1.110
Z*0.5	14	9	0.01	0.025	0.01	0.48	0.40	0.036	1.745

What matters

- A redshift dependent M drift (not a surprise)
- zp uncertainties together with a SN model training
  -> calibration badly hurts via SN model training.

- Statistics : with half the sample, the ellipse size increases by 60 %
- Getting host redshifts. Hopefully, there are plenty of other reasons to carry out a spectroscopic follow-up.

What does not matter

- α,β binned in redshift.
- Several event classes with different M,α,β and SN models.

Summary

- 7 bands dual-cone rolling search imaging survey for SN out to z= 1.5 with a 1.2 m mirror. No real optimization work done.
- Avoids the shortcomings of ground-space cross-calibration.
- With however decent capabilities for DE e.o.s
- “BVR” restframe-bands survey. Trivial to add restframe U-band.
- Built-in restframe I-band Hubble diagram to z~0.9.

- Improves over a proven approach to measure distances to SNe.
- This sketch for a SN survey was conceived in a framework where the instrumentation is designed for other probes...
- Assumed instrument : ~ Euclid with a filter wheel in the visible.
- Regarding statistics, the main concern is the étendue of the imagers.
- Deep multi-band VIS+NIR imaging has a lot of non-DE applications

  The dual-cone approach even increases the science possibilities

  (= the number of potential supporters)