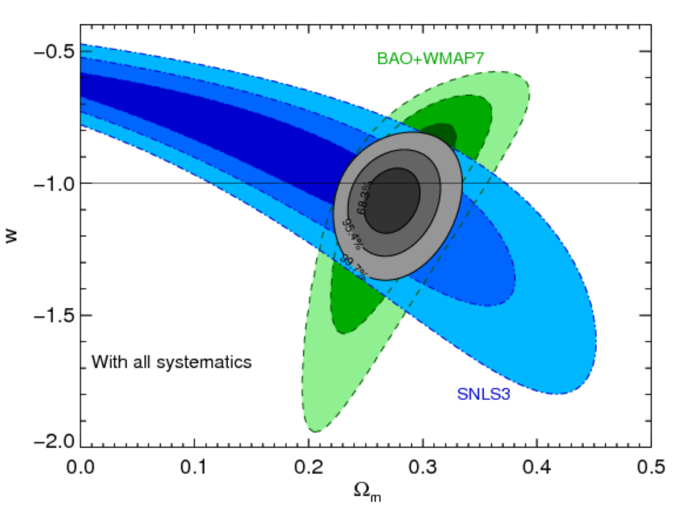
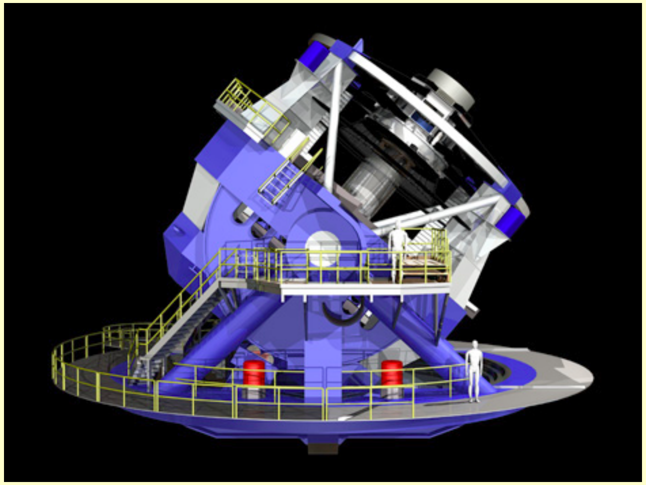
Distances to supernovae : present and future



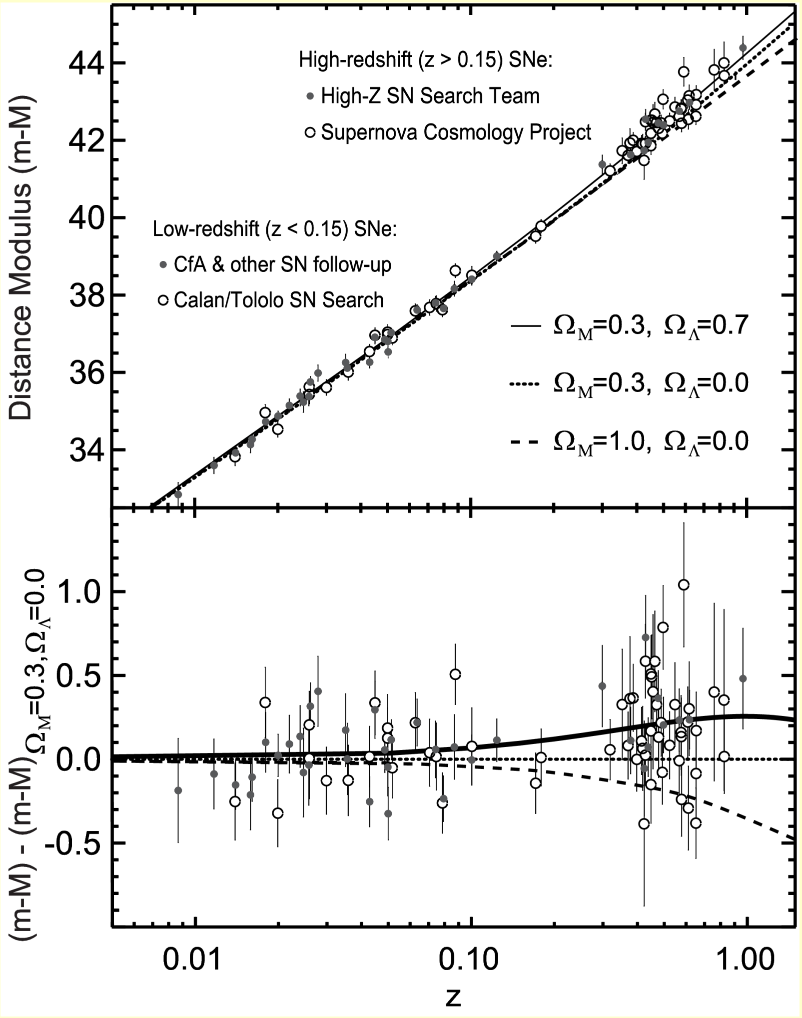


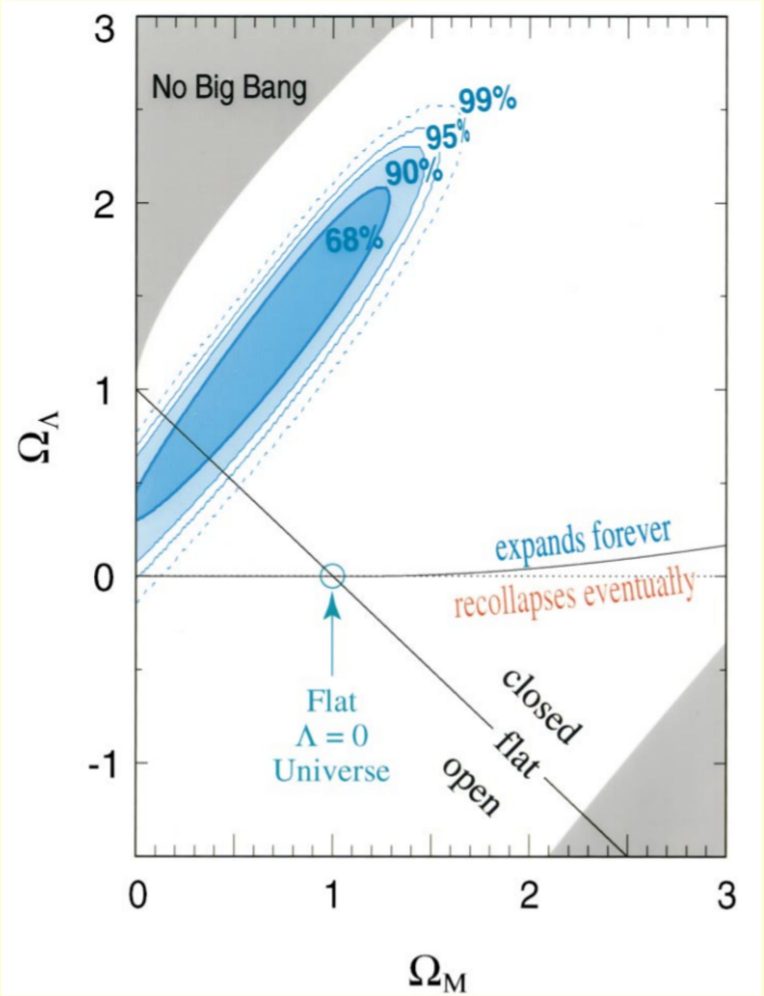
Itzykson Conference, June 2012

Pierre Astier

LPNHE / IN2P3 / CNRS , Universités Paris 6&7.

About 13 years ago





Perlmutter et al (1999)

Last fall

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

Photo: U. Montan

Saul Perlmutter

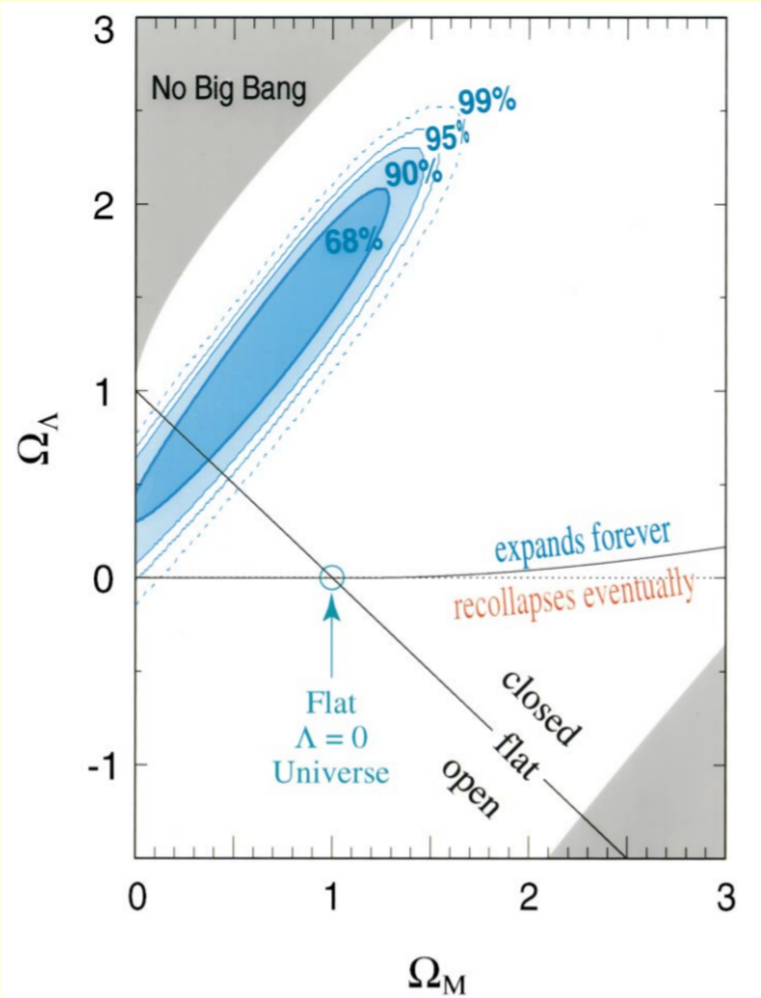
Photo: U. Montan

Brian P. Schmidt

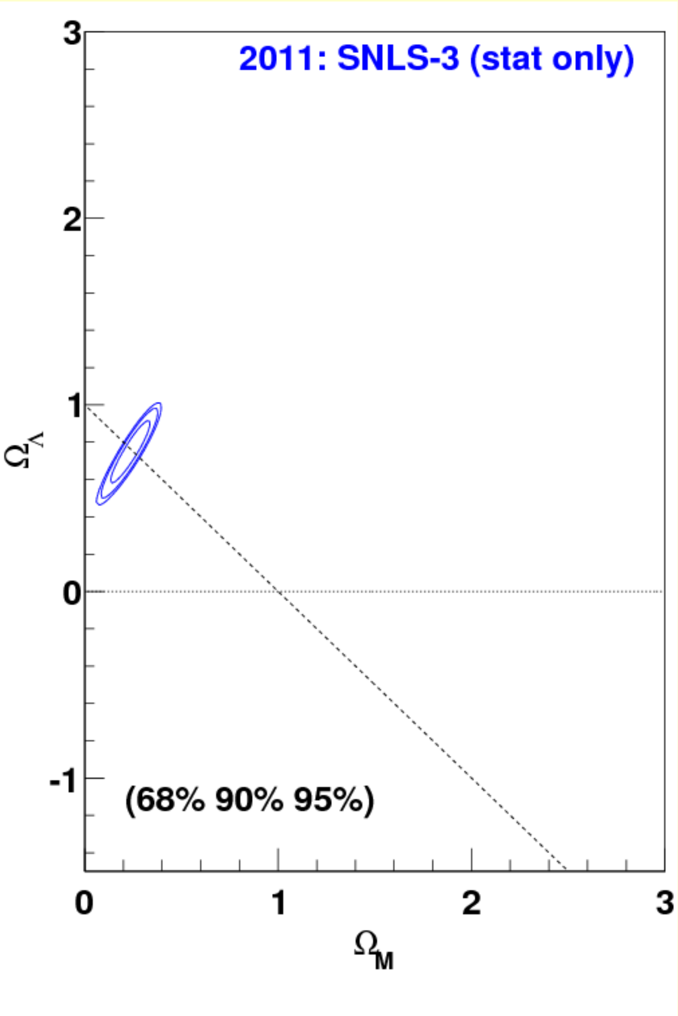
Photo: U. Montan

Adam G. Riess

In between



Perlmutter et al (1999)

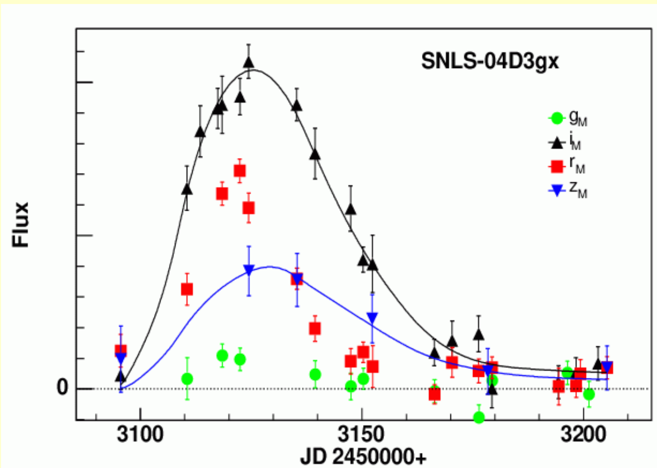


Guy et al (2010), Conley et al (2011), Sullivan et al (2011)

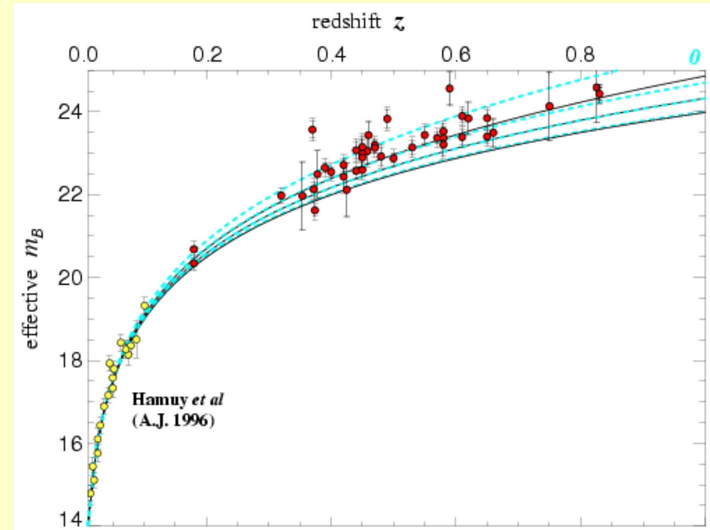
Outline

- How have we improved measurements?
- What are the real uncertainties ?
- How do we move forward ?

Measuring supernovae



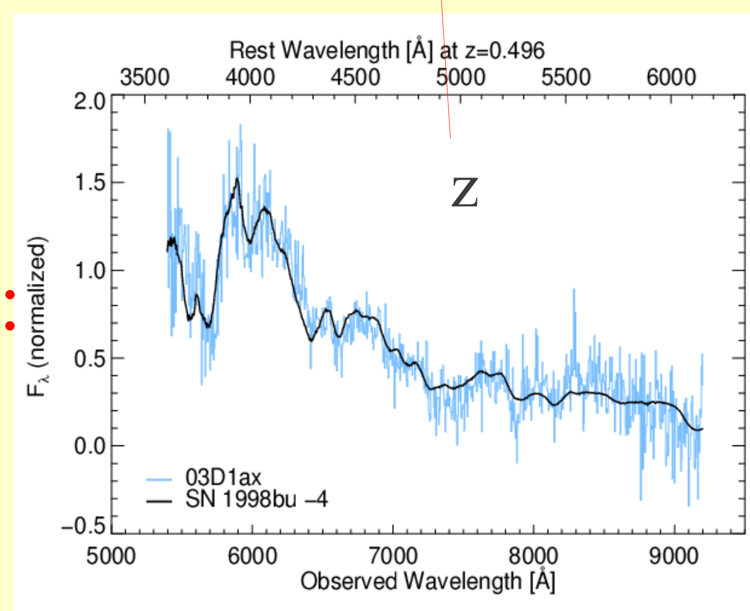
peak flux



multi-band photometry

=> distance

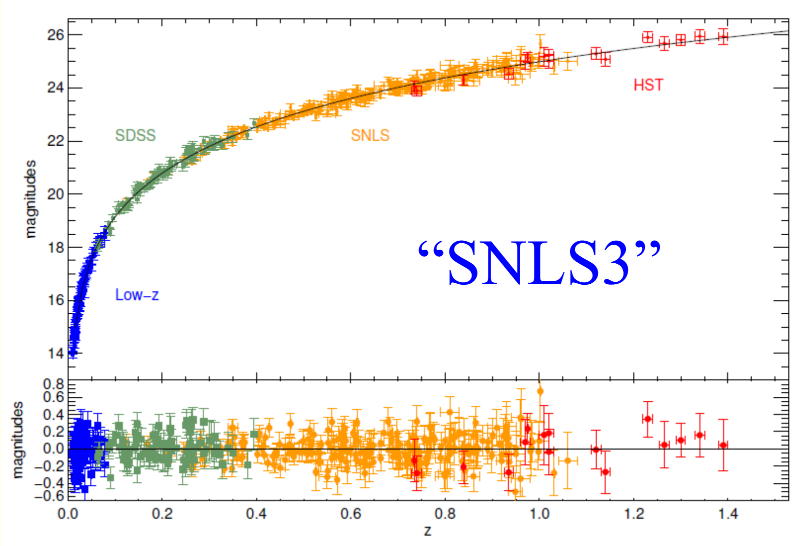
z

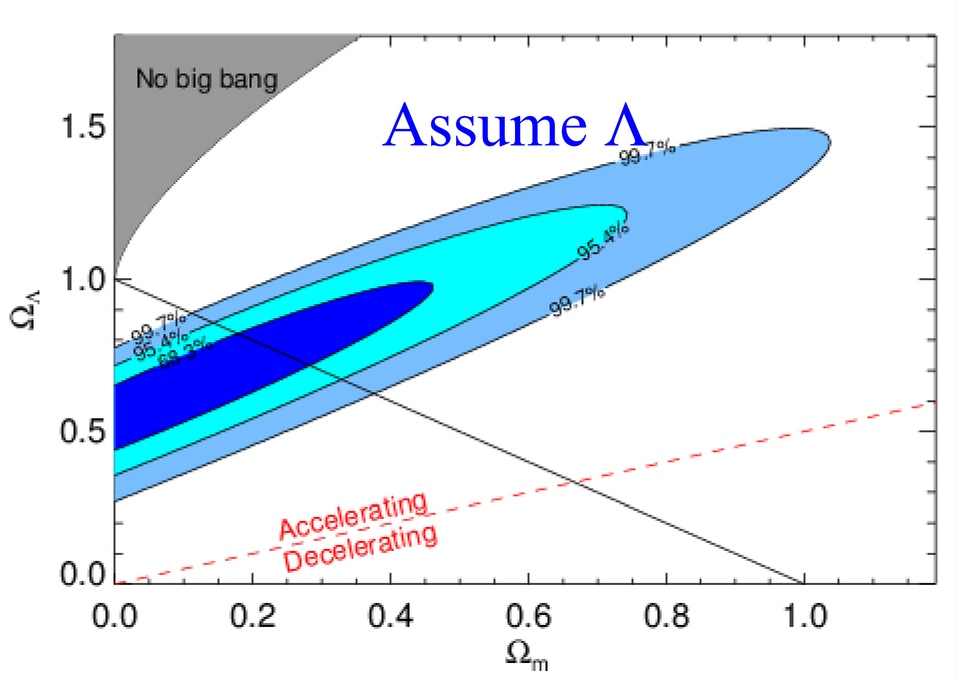


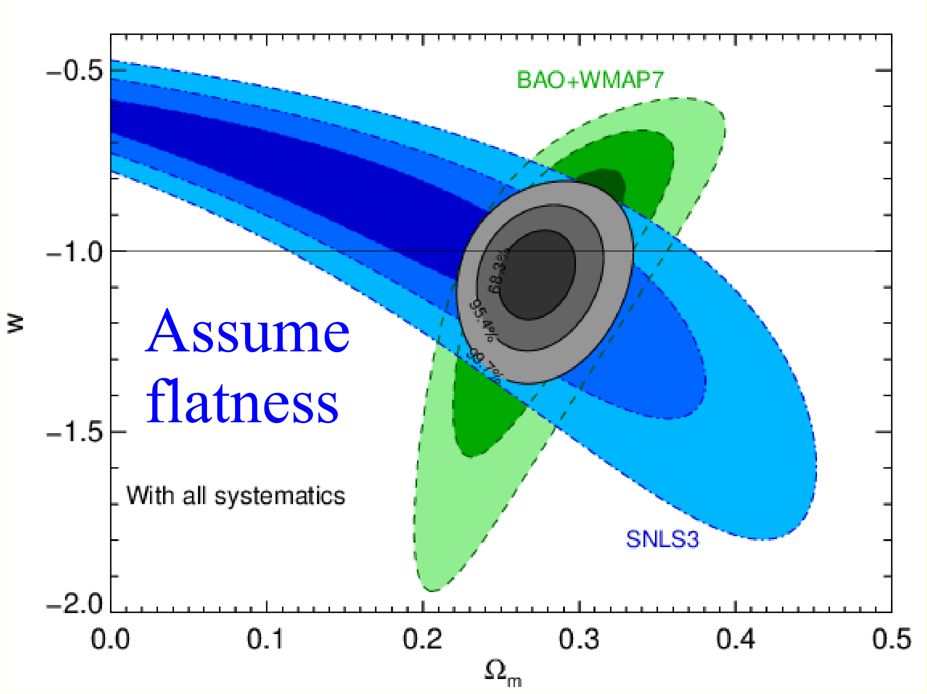
spectroscopy:

- identification
- redshift

Current results





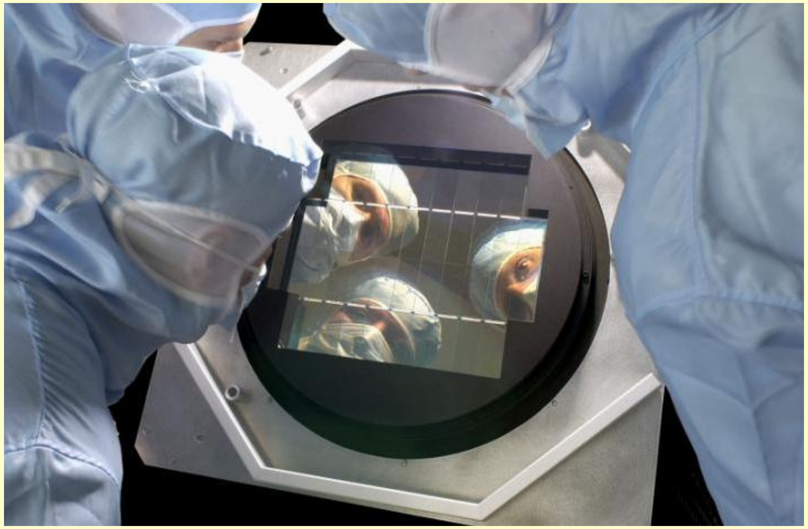


- Contours include systematics
- Covariance matrix of distances (stats and sys) is provided.

Conley et al, Sullivan et al (2011)

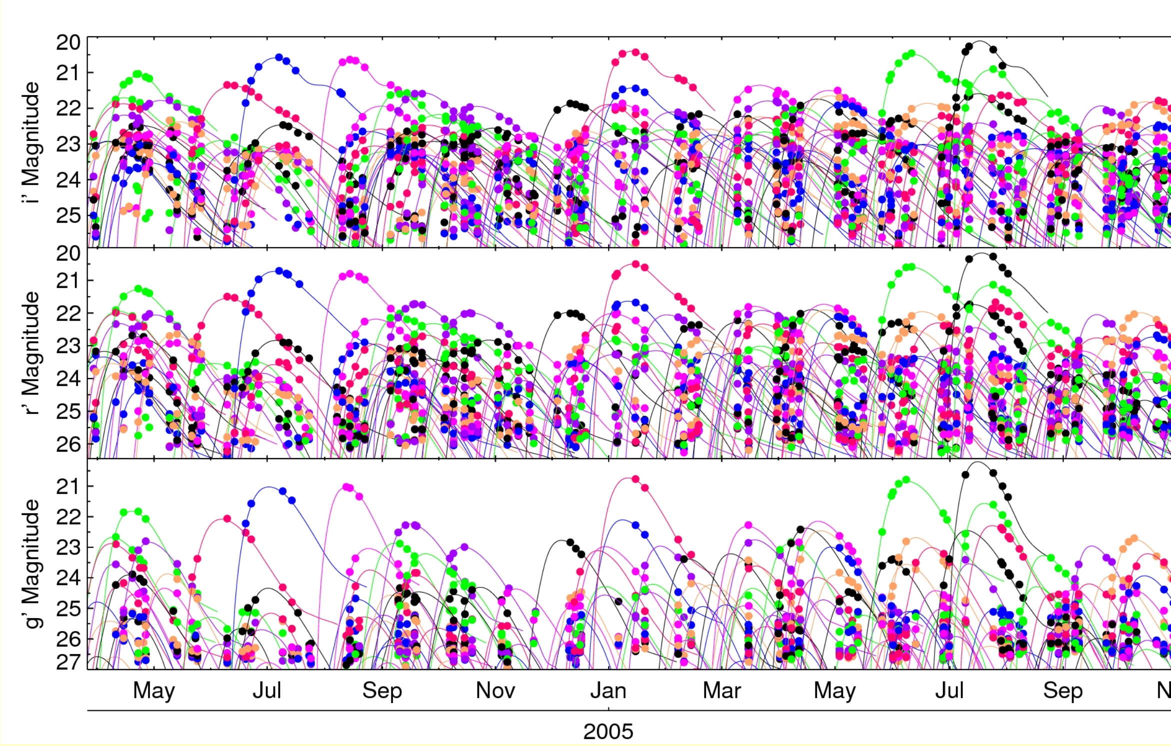
SNLS in a nutshell

- 5 year "rolling" SN survey (within CFHTLS) 2003-2008.
- Goal: ~500 high-z SNe to measure "w"
- Uses 1 deg ^{2} "Megacam" imager on CFHT. griz bands every ~4 nights
- Spectroscopy on VLT,Gemini & Keck.



- SN Survey ended (June 2008)
- ~ 450 confirmed z>0.1 SNe Ia
- ~1000 SN detections in total
- Used ~1200 h for imaging

  and ~1200 h for spectroscopy



What has changed since 1998 ?

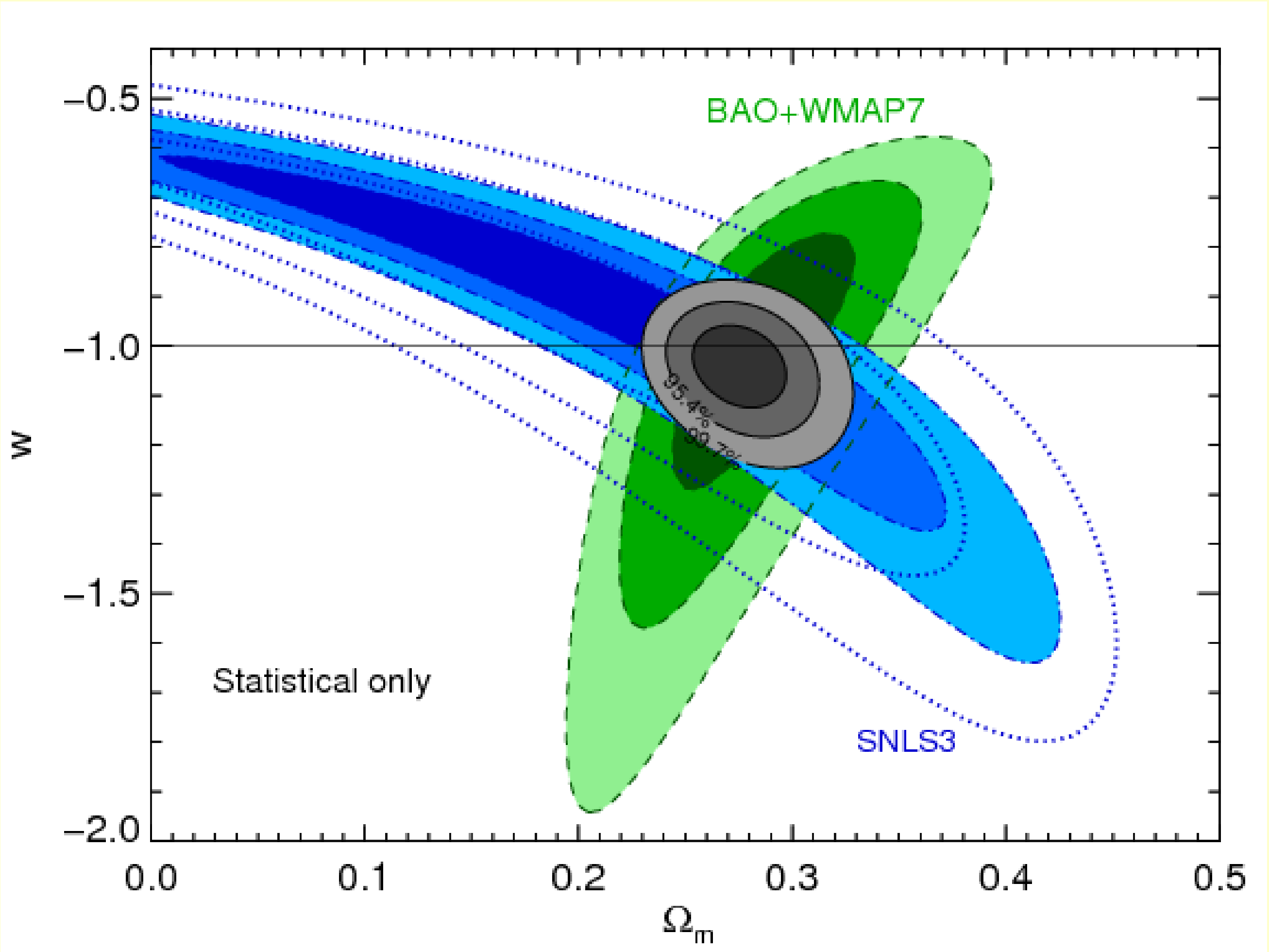
- Wide-field imaging on large telescopes

  Megacam : 1 deg^2 on a 4-m.

- Time-allocation committees willing to allocate

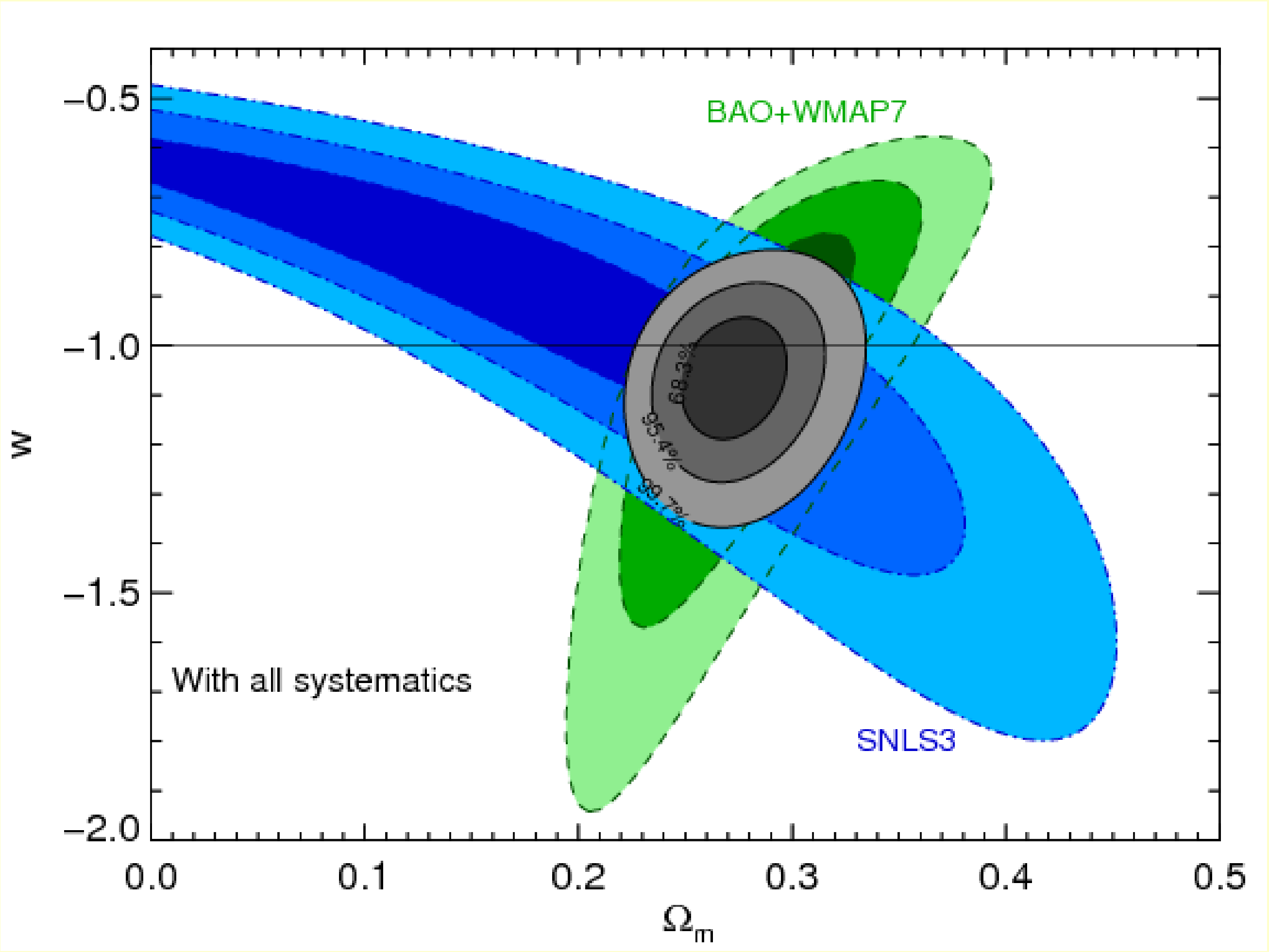
  O(100-1000) h programs.

SNLS3 contours (1)



w= -1.06 +/- 0.05 (stat) +/- 0.06 (sys)

SNLS3 contours (2)



w= -1.06 +/- 0.08 (stat+sys)

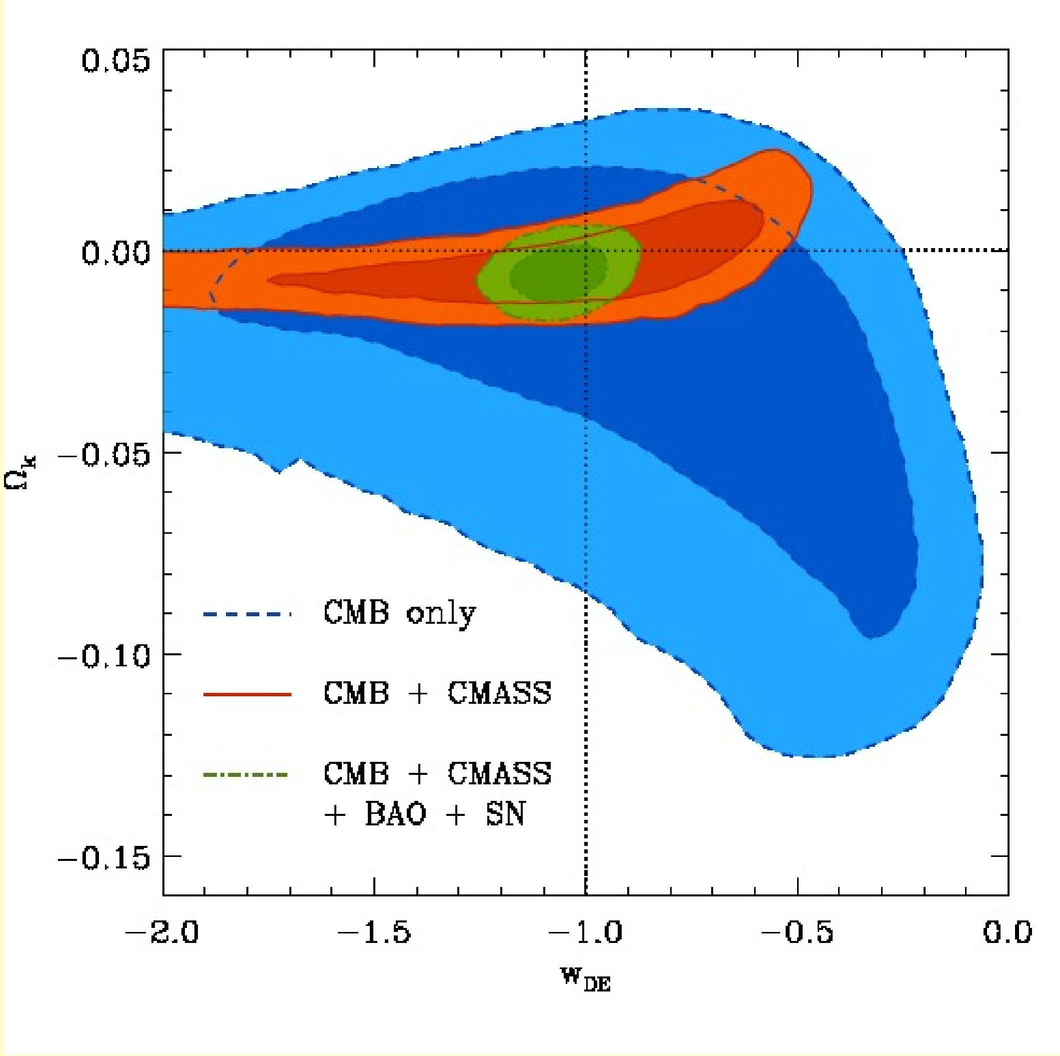
Competition

1203.6616

CMASS : two-point correlation Function from SDSS DR9 (BOSS)

SN : SNLS3 (with systematics)

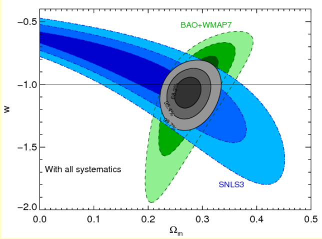
→ You still need SNe to constrain the equation of state.



SNSL3 systematic uncertainties

Table 7: Identified systematic uncertainties

Description	Ω_m	w	Rel. Area [a]	w for Ω_m=0.27
Stat only	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058
All systematics	0.18 ± 0.10	$-0.91^{+0.17}_{-0.24}$	1.85	$-1.08^{+0.10}_{-0.11}$
Calibration	$0.191^{+0.095}_{-0.104}$	$-0.92^{+0.17}_{-0.23}$	1.79	-1.06 ± 0.10
SN model	$0.195^{+0.086}_{-0.101}$	$-0.90^{+0.16}_{-0.20}$	1.02	-1.027 ± 0.059
Peculiar velocities	$0.197^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.03	-1.034 ± 0.059
Malmquist bias	$0.198^{+0.084}_{-0.100}$	$-0.91^{+0.16}_{-0.20}$	1.07	-1.037 ± 0.060
non-Ia contamination	$0.19^{+0.08}_{-0.10}$	$-0.90^{+0.16}_{-0.20}$	1	-1.031 ± 0.058
MW extinction correction	$0.196^{+0.084}_{-0.100}$	$-0.90^{+0.16}_{-0.20}$	1.05	-1.032 ± 0.060
SN evolution	$0.185^{+0.088}_{-0.099}$	$-0.88^{+0.15}_{-0.20}$	1.02	-1.028 ± 0.059
Host relation	$0.198^{+0.085}_{-0.102}$	$-0.91^{+0.16}_{-0.21}$	1.08	-1.034 ± 0.061



(Conley et al 2011)

Photometric calibration dominates by far

P. Astier Itzykson conf.

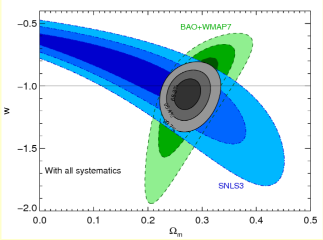
SNLS3 calibration uncertainties

Description	w for Ω_m=0.27	Rel area
Stat only	-1.031 ± 0.058	1
All calibration	-1.06 ± 0.10	1.79
Colors of BD 17° 4708	-1.075 ± 0.075	1.31
SED of BD 17° 4708	-1.026 ± 0.073	1.23
SNLS Zero Points	-1.030 ± 0.069	1.21
low-z Zero Points	-1.044 ± 0.065	1.13
SDSS Zero Points	-1.028 ± 0.060	1.02
MegaCam Bandpasses	-1.017 ± 0.066	1.20
low-z Bandpasses	-1.027 ± 0.059	1.04
SDSS Bandpasses	-1.026 ± 0.059	1.02
HST Zero Points	-1.027 ± 0.058	1.03
NICMOS Nonlinearity	-1.029 ± 0.059	1.05

(Conley et al 2011)

Spectrum of the primary calibrator

Transfer to Field stars and supernovae



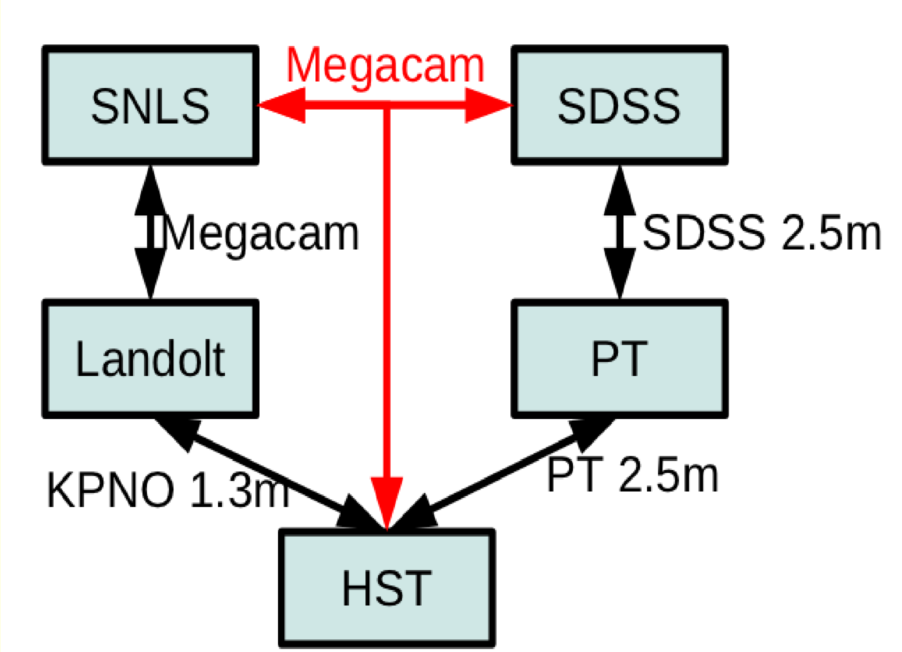
SNLS5 : 5-year SNLS sample

Full SNLS sample :~450 events

(Betoule et al 2012, in prep)

Major improvements in calibration:

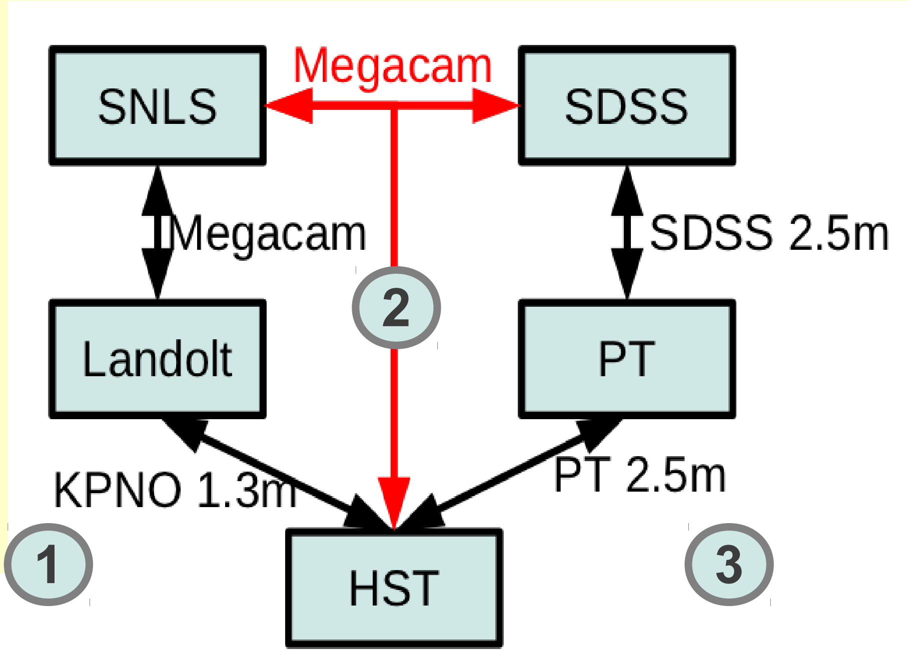
- Direct cross-calibration to the SDSS SN fields
- Shortcut
- Redundancy



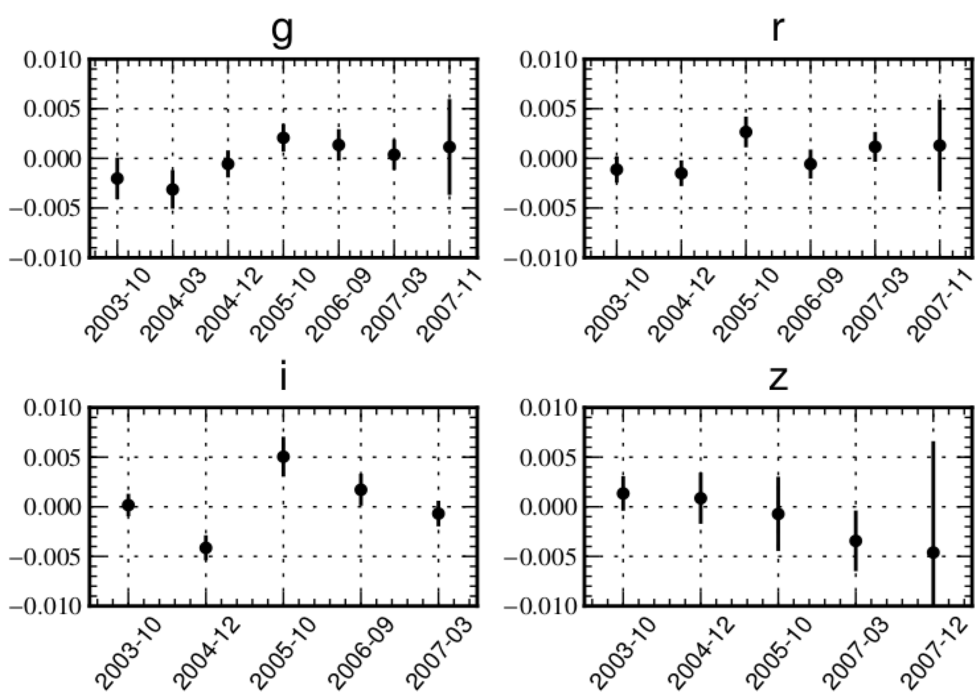
Primary standards, calibrated to stellar models

SNLS5 calibration (1)

Calibrate science fields over 5 or 6 seasons independently



epochs agree with *rms* < .3% in all bands



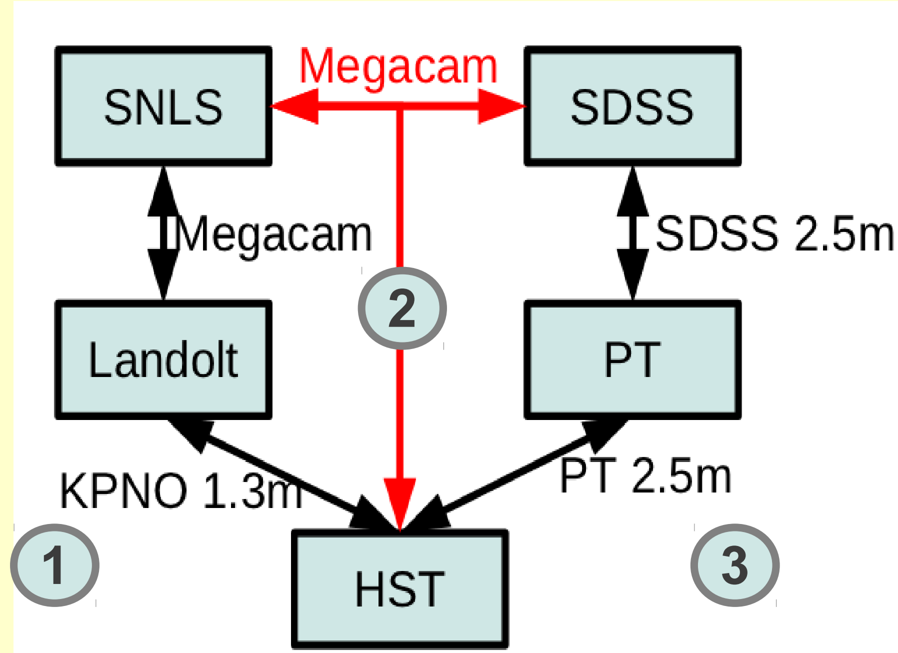
Compatible to 0.3 % r.m.s

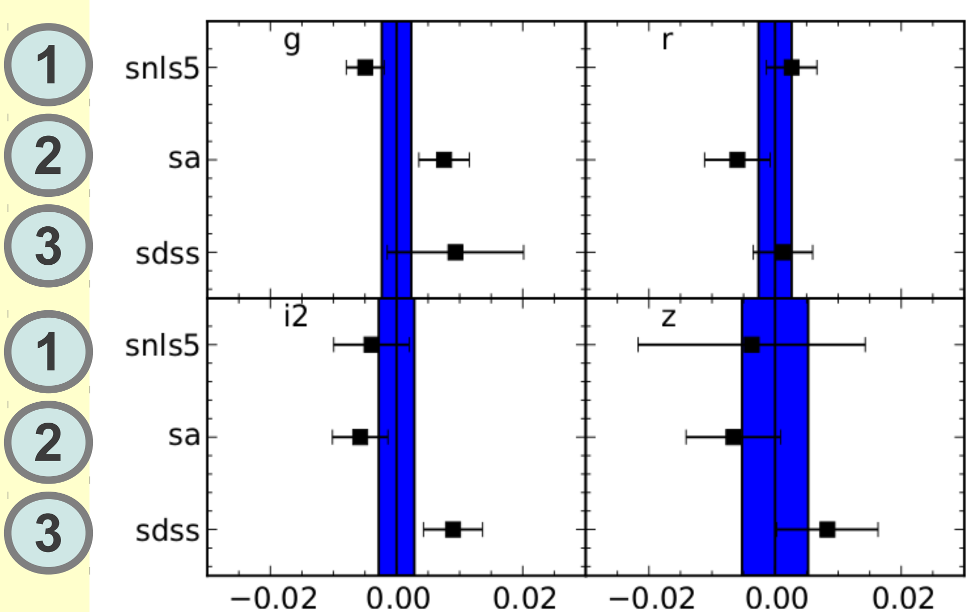
Betoule et al , 2012
In prep

P. Astier Itzykson conf.

SNLS5 calibration

Compare three paths for SNLS fields calibration:
1 – classical
2 – direct (faint standards)
3 – cross-calibrate with SDSS
→ compatible within uncertainties





band	combined uncertainties
g	0.002
r	0.003
i2	0.003
z	0.006

Betoule et al , 2012
In prep

LPNHE
PARIS

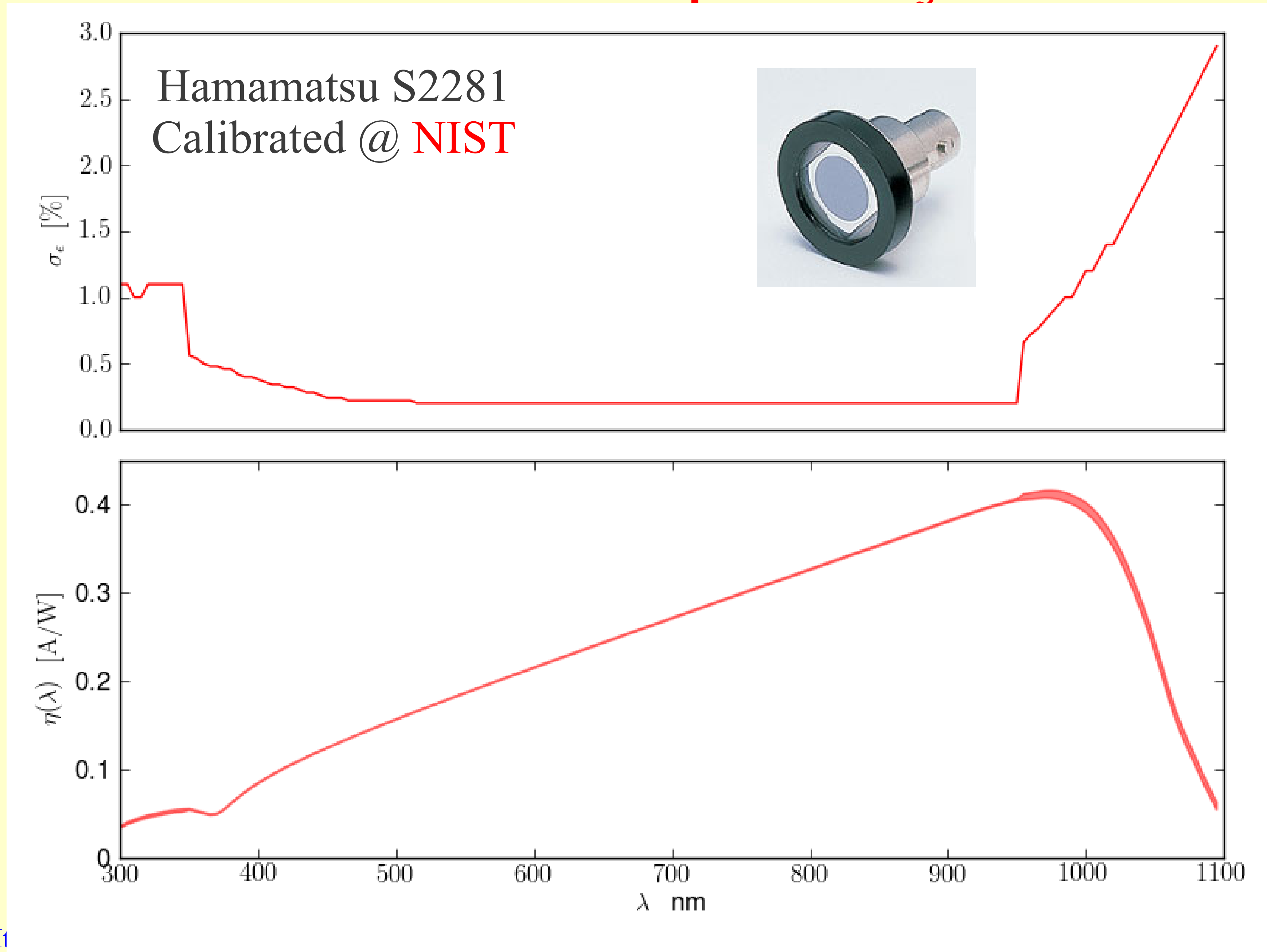
Stellar photometric calibration

On the way to better than 0.5 % for the
"calibration transfer chains" (SN to primary standards)

→ Physical flux of primary standards is
the next bottleneck

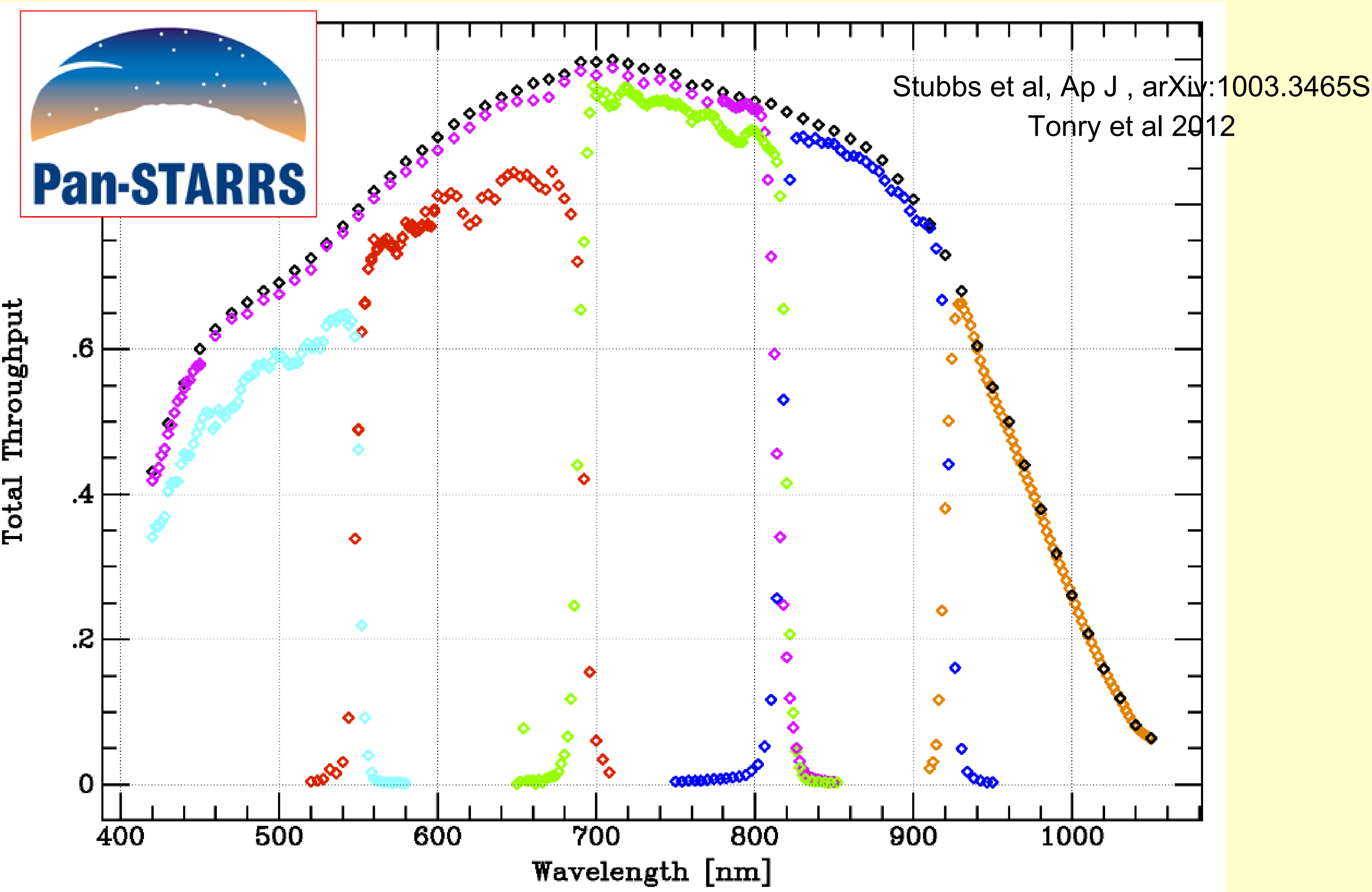
Why not lab standards ?

Some other kind of primary standard



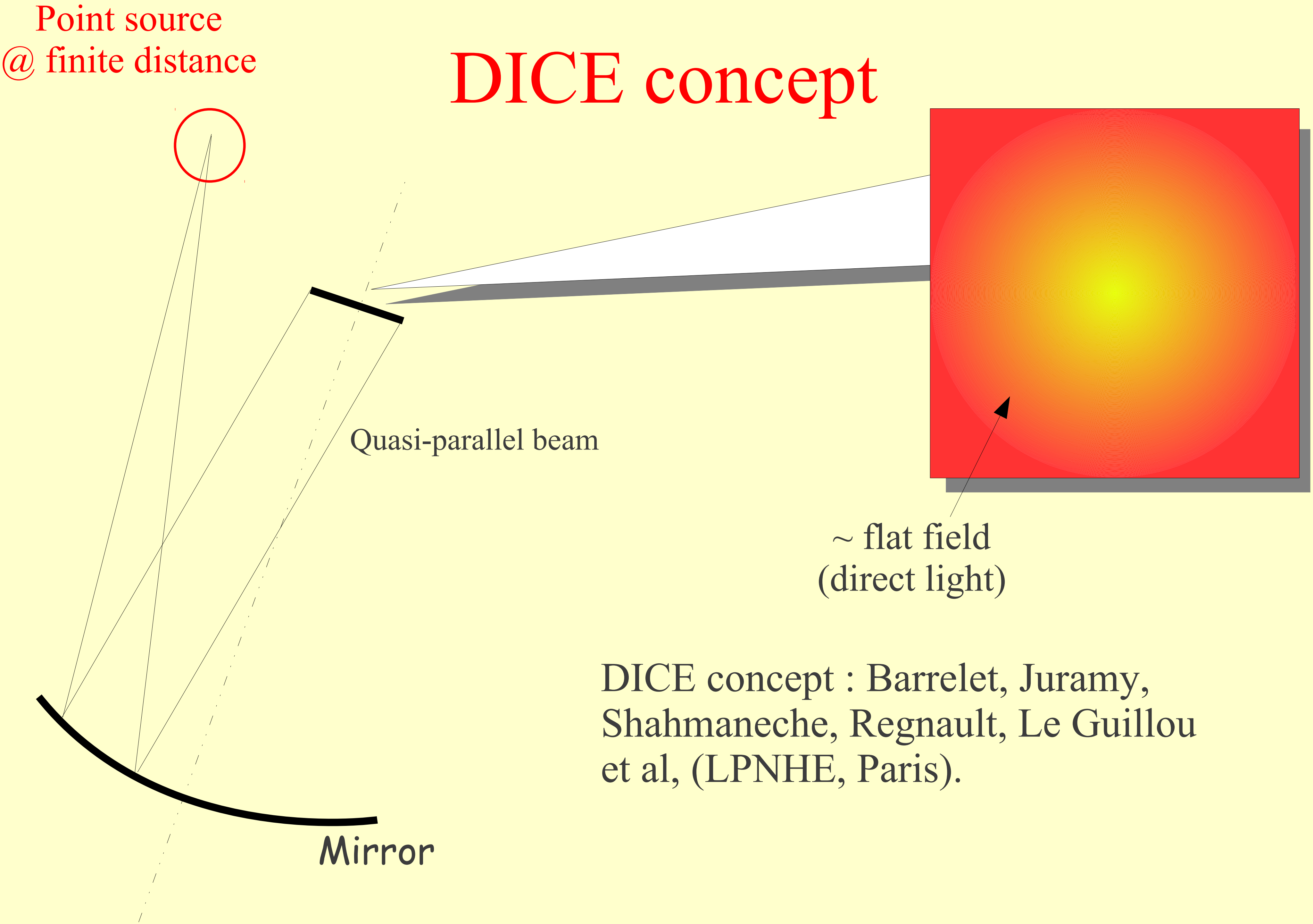
Artificial calibration sources are fashionable these days

- Stubbs et al (ESSENCE, PanSTARRS)
- Marshall et al (DECal/DES)
- Fagin et al (ALTAIR: balloon)
- Regnault et al (snDICE/SNLS SkyDice/SkyMapper)
- Cramer et al (NIST stuff)
- Jones et al (LSST)
- ….



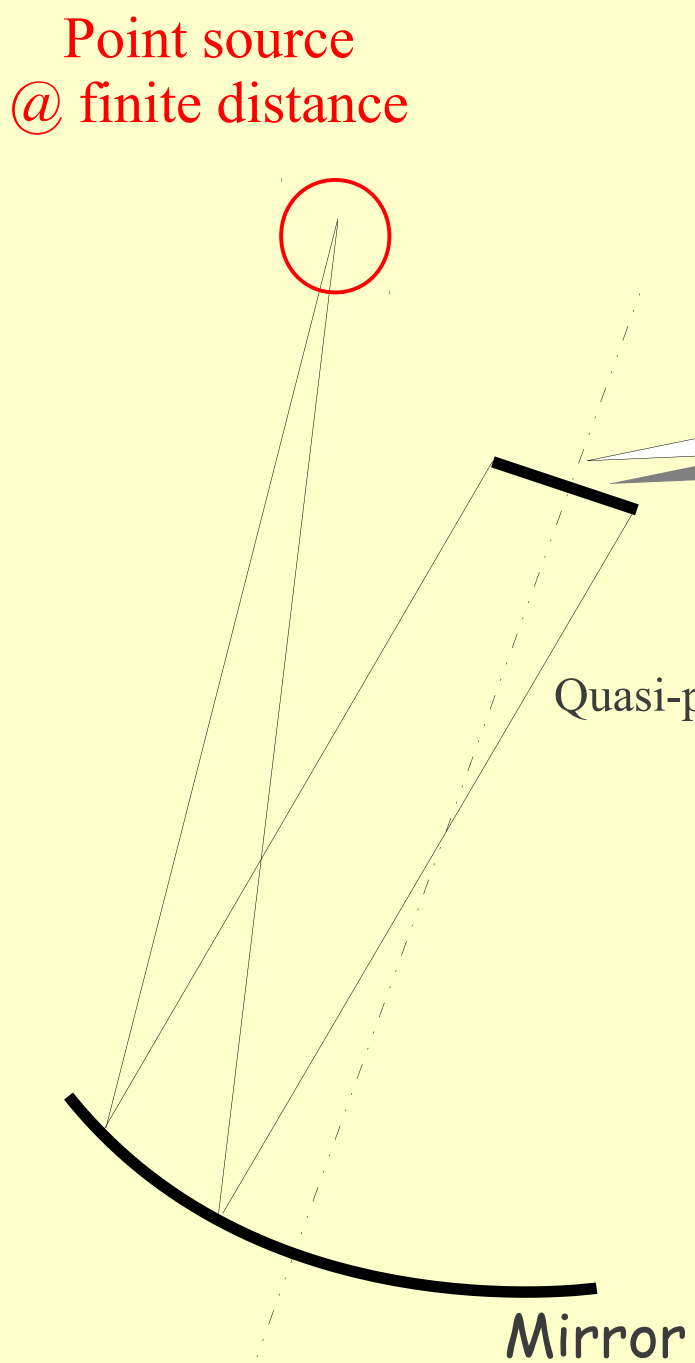
Measure bandpass transmissions and compare to stellar calibration
→ mismatch at a few % level.

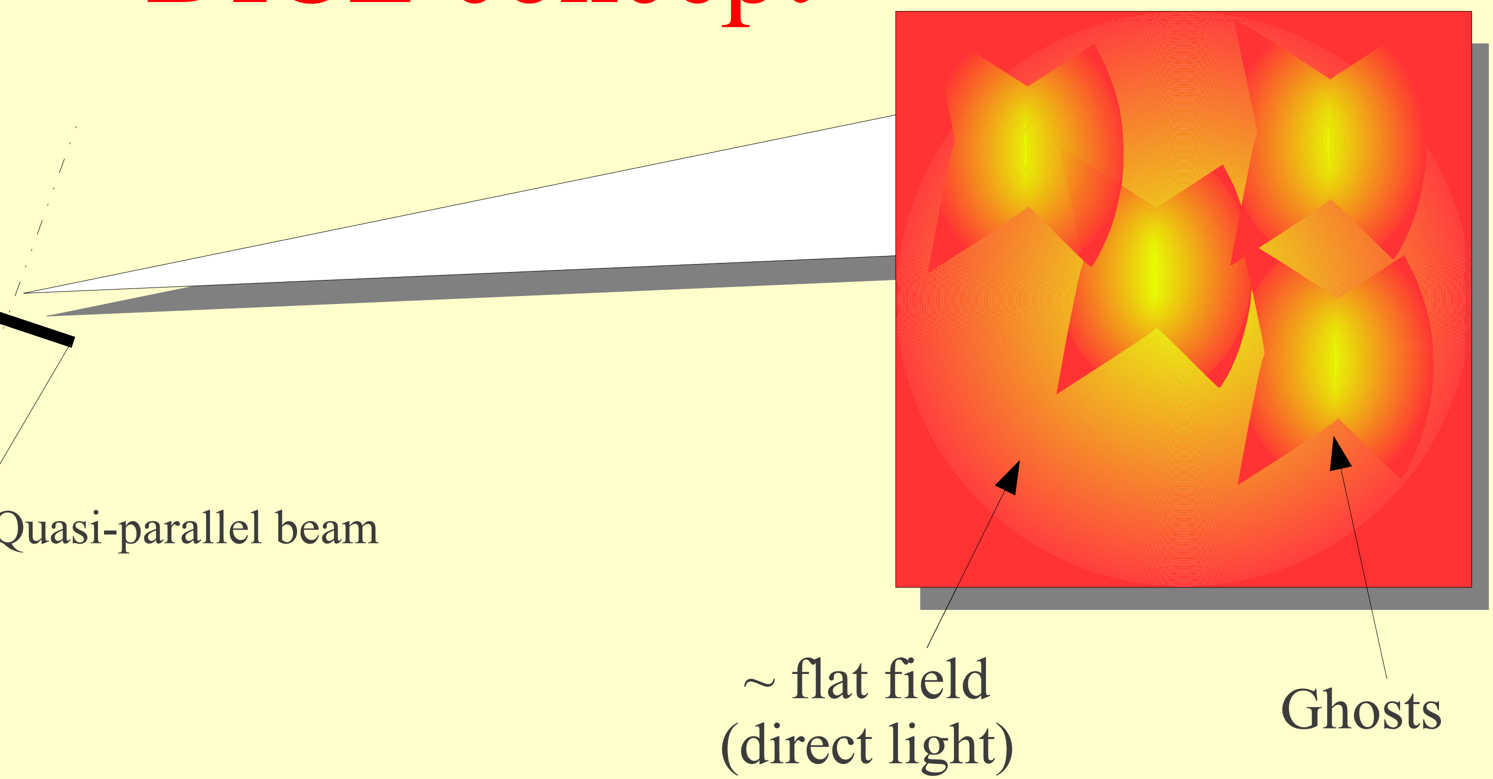
DICE concept



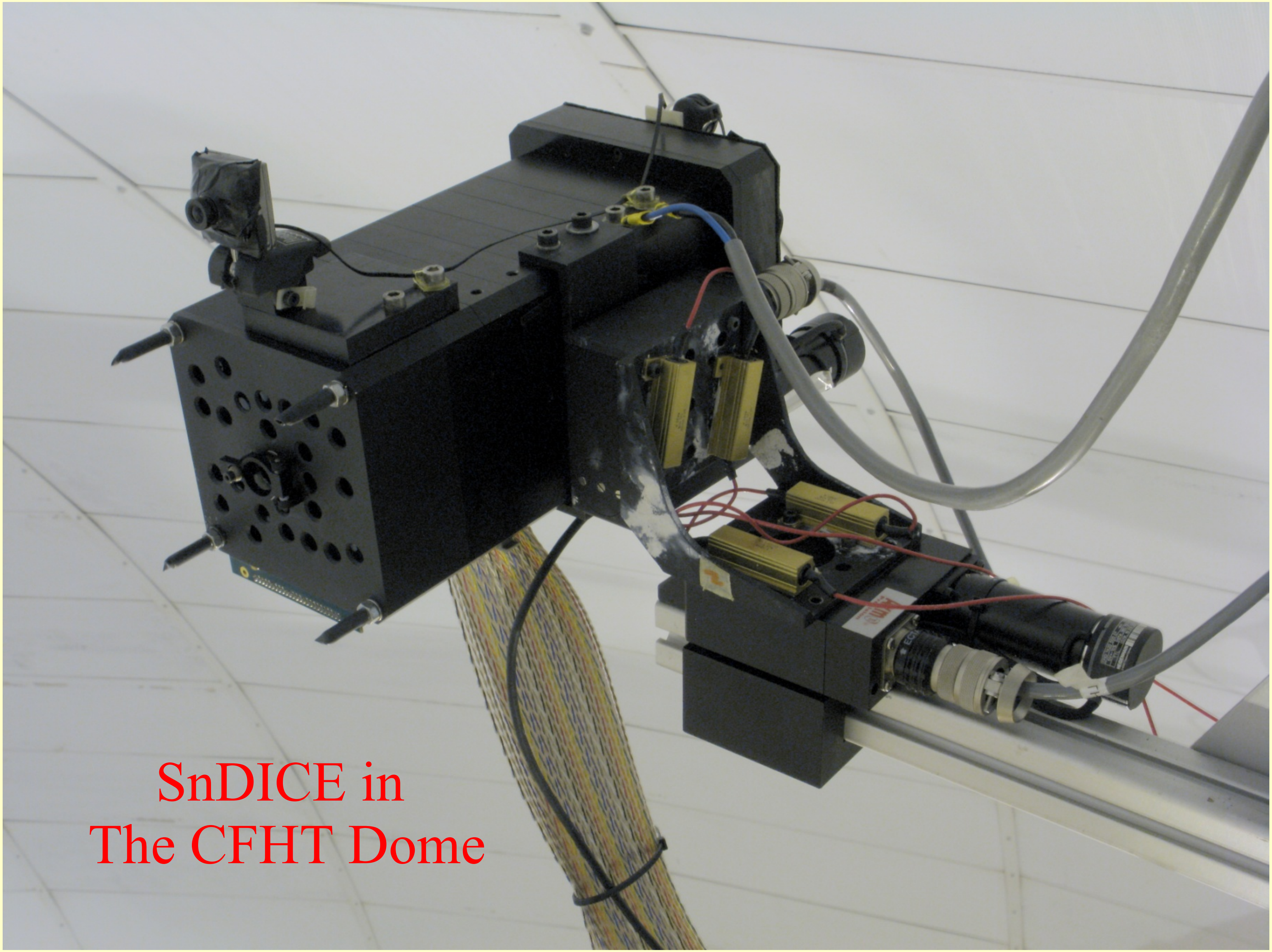
DICE concept : Barrelet, Juramy, Shahmaneche, Regnault, Le Guillou et al, (LPNHE, Paris).

DICE concept





DICE concept : Barrelet, Juramy, Shahmaneche, Regnault, Le Guillou et al, (LPNHE, Paris).


SnDICE in
The CFHT Dome

Megacam@CFHT
Illuminated by
SnDICE

Ghost, to be
subtracted

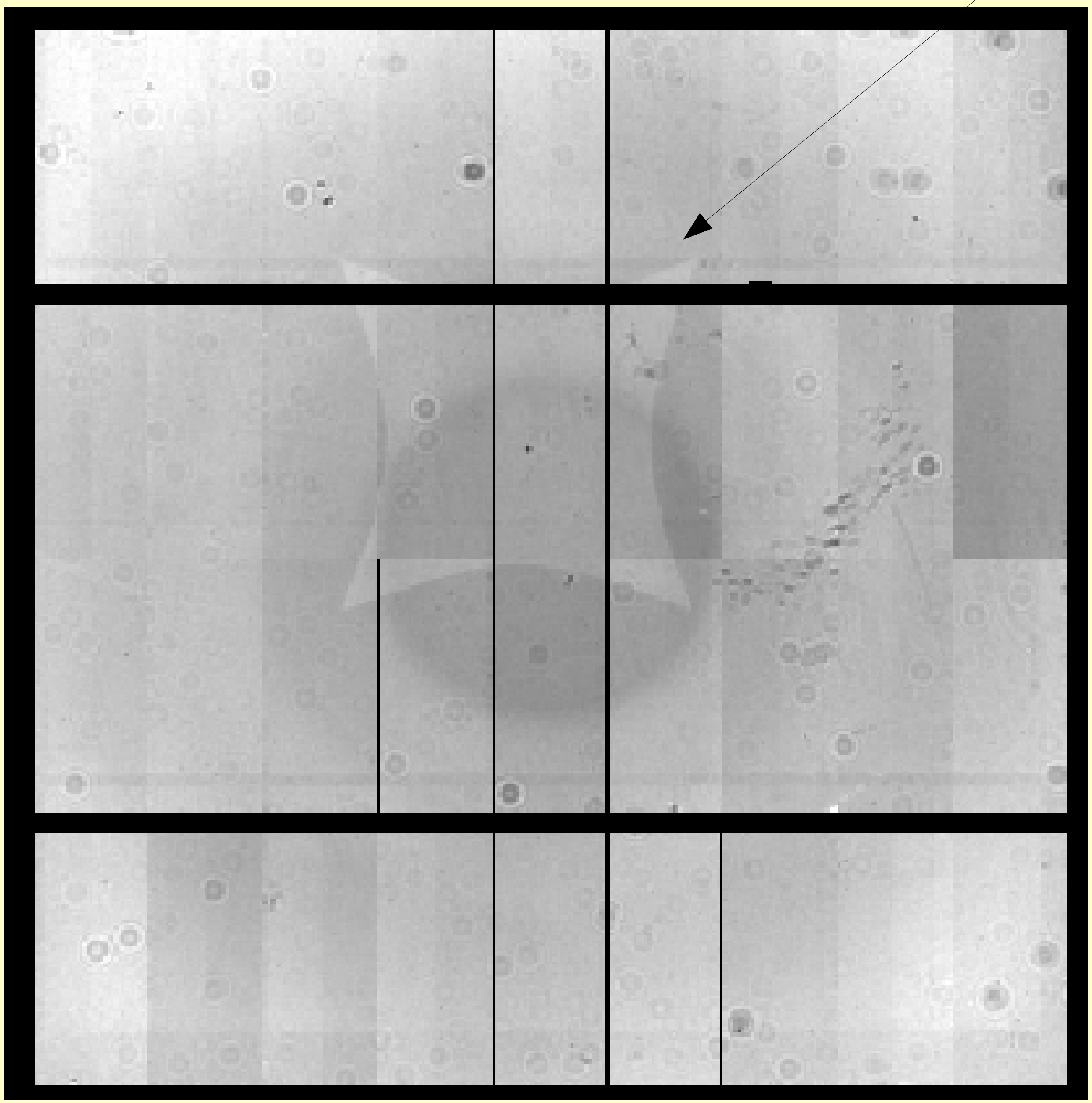
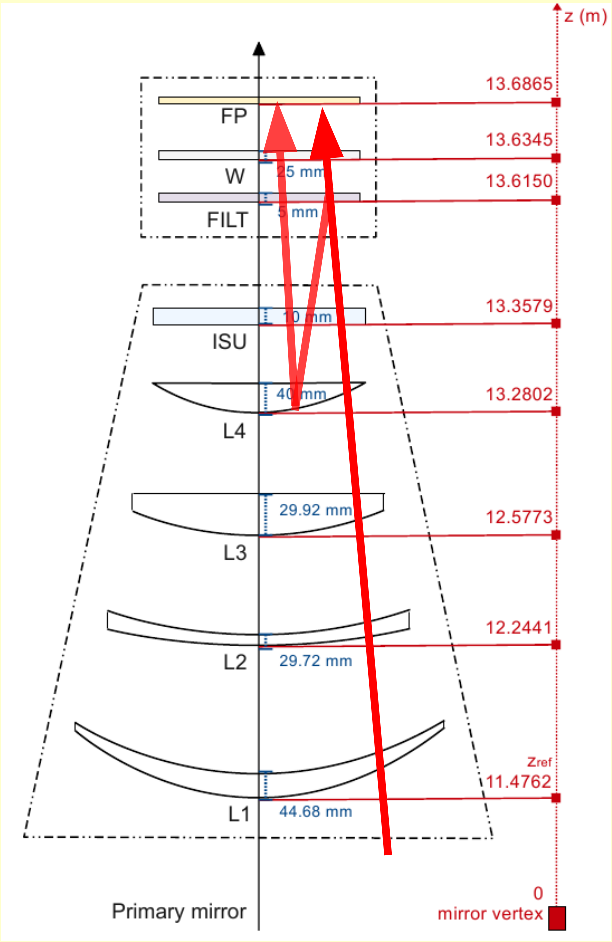


Image corrector:



P.

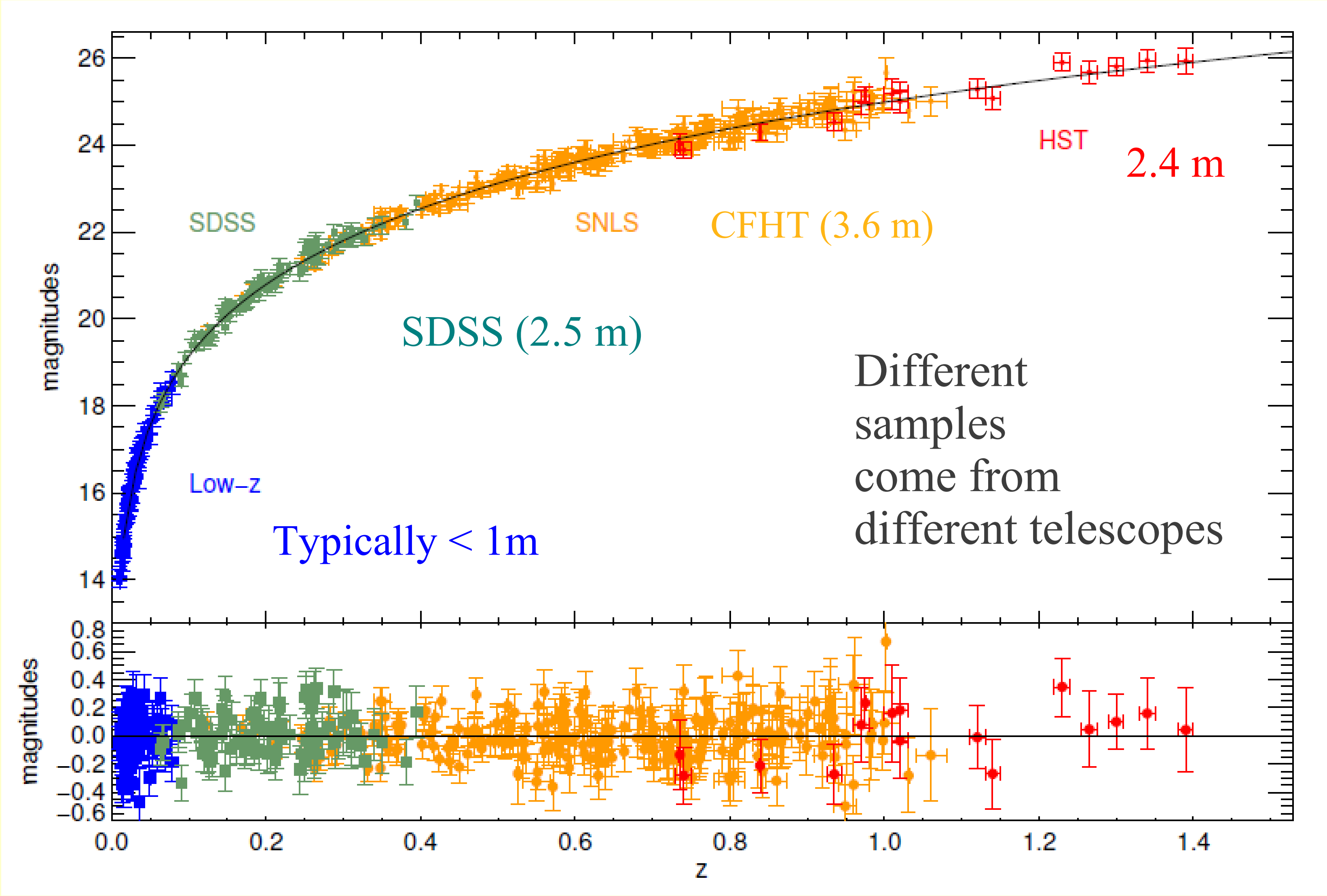
Photometric calibration: summary

- SN cosmology is probably the most demanding field of astronomy regarding photometric calibration

- Stellar calibration is improving :
  - Accurate transfers from primary standards to science targets
  - Redundancy : uncertainties are no longer hand waving.
  - The next bottleneck is primary standards.

- Artificial sources :
  - A lot of ingenuity is being invested in the field
  - not yet competitive
  - these devices will at least improve the daily monitoring of wide-field instruments
  - stay tuned.

Current main SN datasets



Conley et al (2011)

P. Astier Itzykson conf.

Some SNe surveys over the last 10 years

Increasing redshift

Low z : ($z<0.1$ -- 0.01 SN/deg^2/month)

SN Factory ($0.03<z<0.08$ analysis underway)
CFA
Carnegie
PTF

Intermediate ($z<0.4$ -- 0.5 SN/deg^2/month)

SDSS — Rolling search on ~300 deg^2, 5 bands, 2005-07

High z : ($z<1$ 5 SN/deg^2/month)

ESSENCE — Rolling search on ~8 deg^2, 2 bands, 2002-07
SN Legacy Survey — Rolling search on ~4 deg^2, 4 bands, 2003-08

Very high z with HST: ($z>1$, > 15 SN/deg^2/month)

PANS/GOODS — Rolling search on GOODS, 1 band
SCP SN search in clusters — Rolling search, 2 bands

Event statistics

Nearby :

- CfA : ~ 270 events (Hicken et al, 2009, 2012)
- CSP : ~ 85 events (Contreras et al, 2010, Stritzinger et al 2011)
- Others : a few tens.

→ about 50 % pass strict quality cuts (mainly phase coverage)

Distant :

- Essence : 60 events (Wood-Vasey et al, 1987)
- SNLS : 250 events (Astier et al, 2006, Guy et al 2010)
- SDSS : 103 events (Kessler et al, 2008)

>90% enter the Hubble diagram

To come : SNLS5 450 SDSS5 : 500

HST:

- PANS/GOODS : ~ 30 events (half at z>1) (Riess et al, 2004,2007)
- Cluster Supernova Survey : 20 events (Suzuki et al, 2012)

Current best quality sample : O(1000) events.

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	2011	funded	ESO/Paranal
	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 2	7 deg2	1.8 m x 2	2013	funded	Univ. Hawaii
	BigBoss (spectro)	7 deg2	4m	?	not funded	DOE/NOAO
	LSST	10 deg2	8 m	2019	funded	DOE/NSF
space	WFIRST	0.7 deg2	1.3 m	2020(+ ?)	??	NASA
	Euclid	0.5 deg2	1.2 m	2019	approved	ESA

Large or very large projects which can address more than just dark energy !

Euclid's adoption
vote tomorrow

Distances to SNe: where will we stand around 2020 ?

- SNLS : done
- PanStars : limited to z ~ 0.6 ?
- DES : much better than SNLS ?
- Nearby samples:
  - PFT
  - SkyMapper
  - Others ???
- Subaru/HSC : time allocations ?
- ???

Key features for a SN survey

Redshift range:

- High resistivity CCDs help a little bit (efficient z band)
- NIR from space ($z \rightarrow \sim 2$, sensitivity permitting)

Lightcurve quality :

- At least SNLS !
- Full sample spectroscopic ID is over : extra load on photometry.

Calibration :

- On the way to 0.5 % or better (Regnault et al 09, Betoule et al 12)
- Self-calibration (Kim & Miquel, 06)

Statistics : O(10000)

Required measurement quality for distances to SNe Ia.

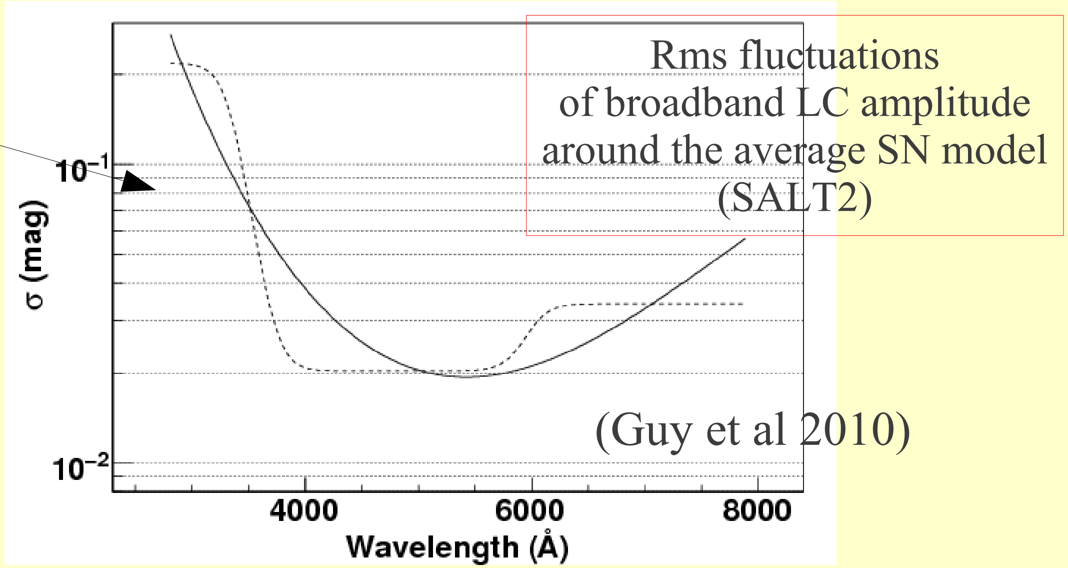
- Quality of luminosity distances depend on S/N of light curve amplitudes :
  - Directly
  - Through color (← usually dominates)

$$\text{Log(distance)} = m_B + \alpha * \text{Shape} - \beta * \text{color}$$

- Resolution of light curve amplitudes (or restframe color) summarises the quality of a given observing plan regarding distance measurements.

- Intrinsic limit : >~2.0% for broadband Measurements.

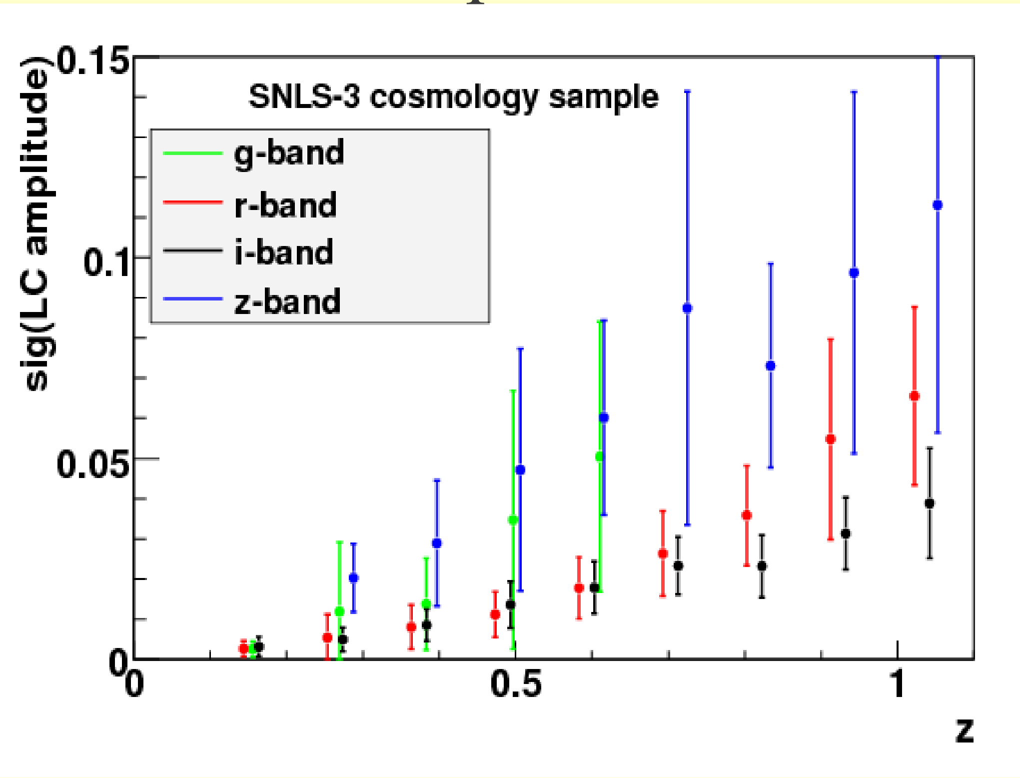
.



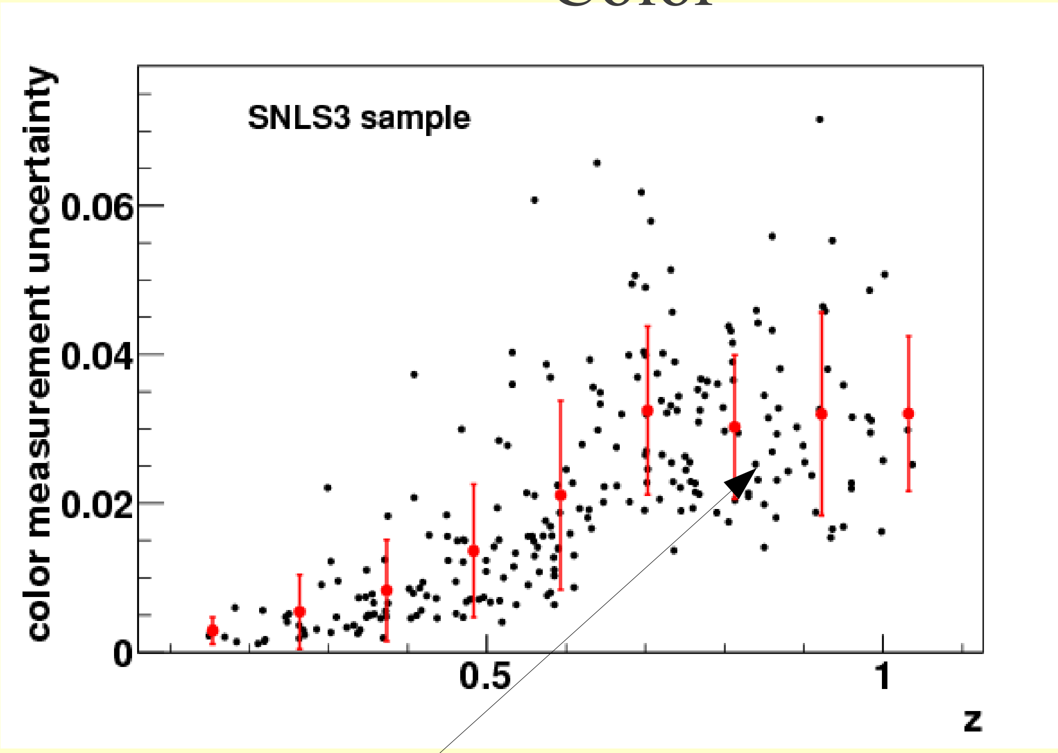
SNLS (3 year)

Measurement uncertainties (shot noise)

Amplitude



Color



0.03 at z=1 is possible !

Measuring color in the restframe UV is efficient
Unfortunately the intrinsic scatter is very large
→ not a model to be followed.

P. Astier Itzykson conf.

Not worse than SNLS:

- Amplitudes measured to ~ 3% or better at the highest redshift
  → Contribution to distance uncertainty below intrinsic scatter
  → Same luminosity bounds at all redshifts.

- Lightcurves measured over [-10,+30] restframe days
  → get stretch and shape.

- We need 2 bands to measure distance. 3 bands are better.

- Do not go deep into the UV
  Poor reproducibility, suspicions of evolution (Maguire 2012).
  central wavelength > 380 nm

- Similar restframe wavelengths at all redshifts.
  Failing to do so severely degrades cosmological constraints if they account for lightcurve fitter training and calibration uncertainties

SNe at z>1 → NIR → Go to space

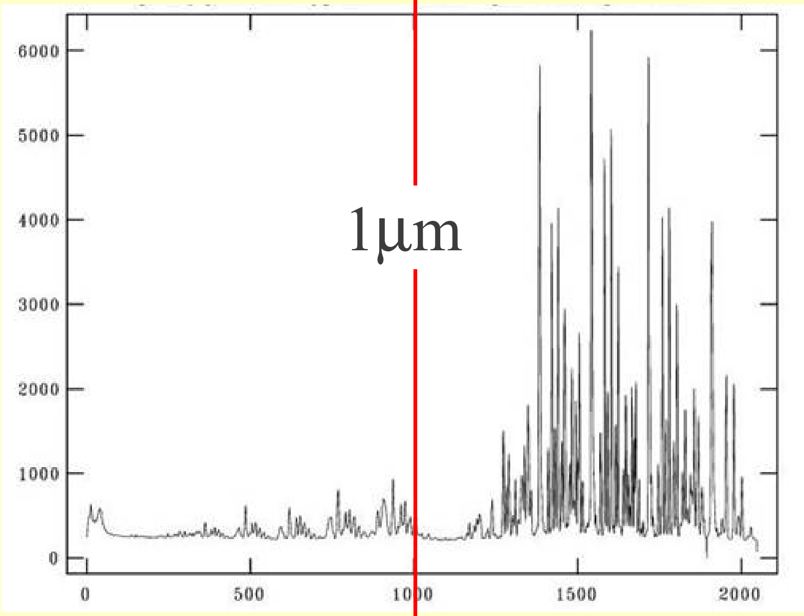
There

Is

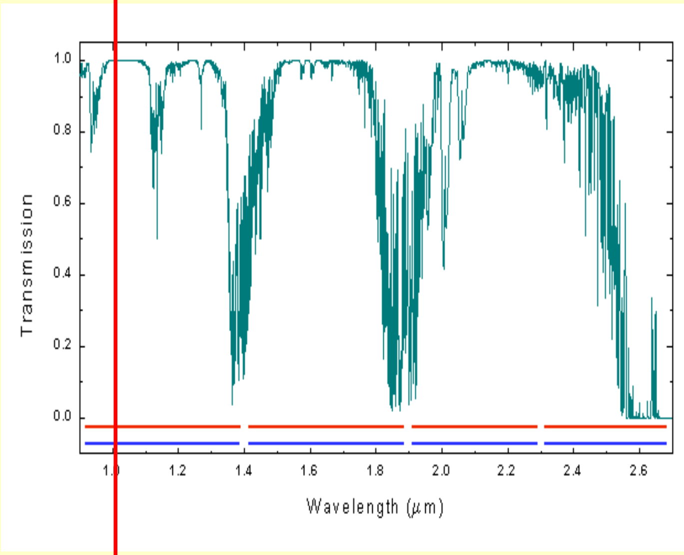
No

Alternative

Atmospheric
emission

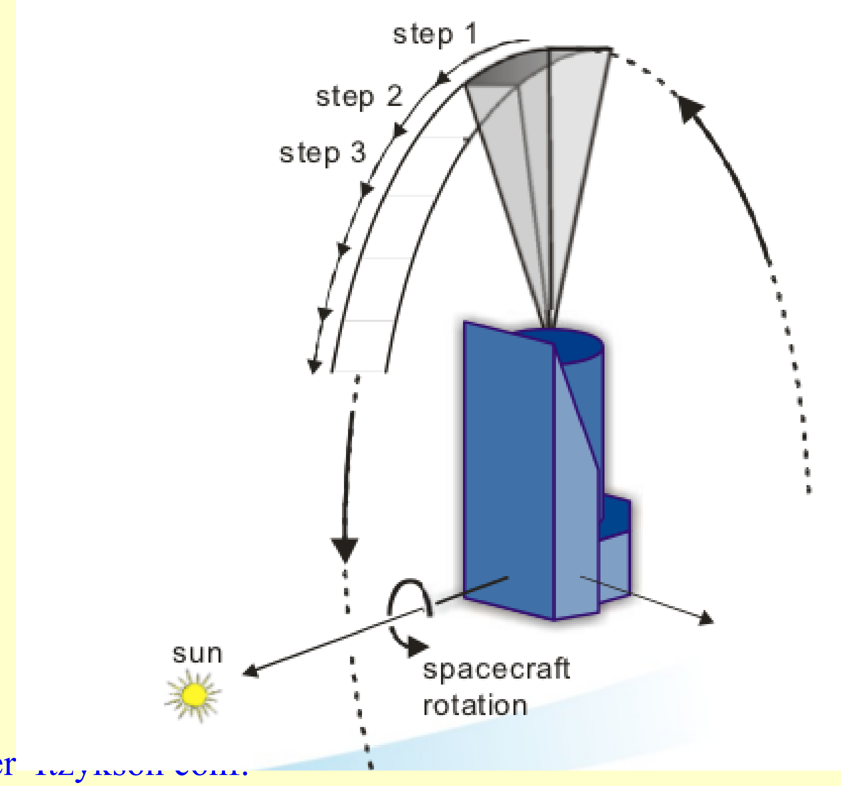


Atmospheric
Absorption



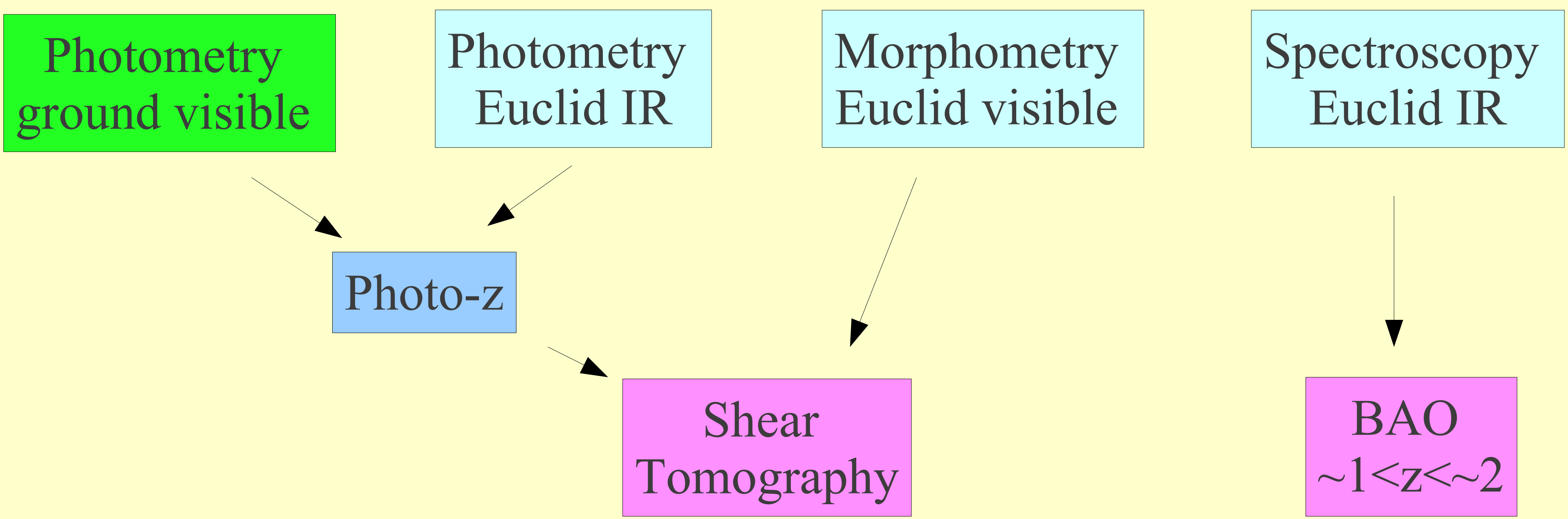
Euclid

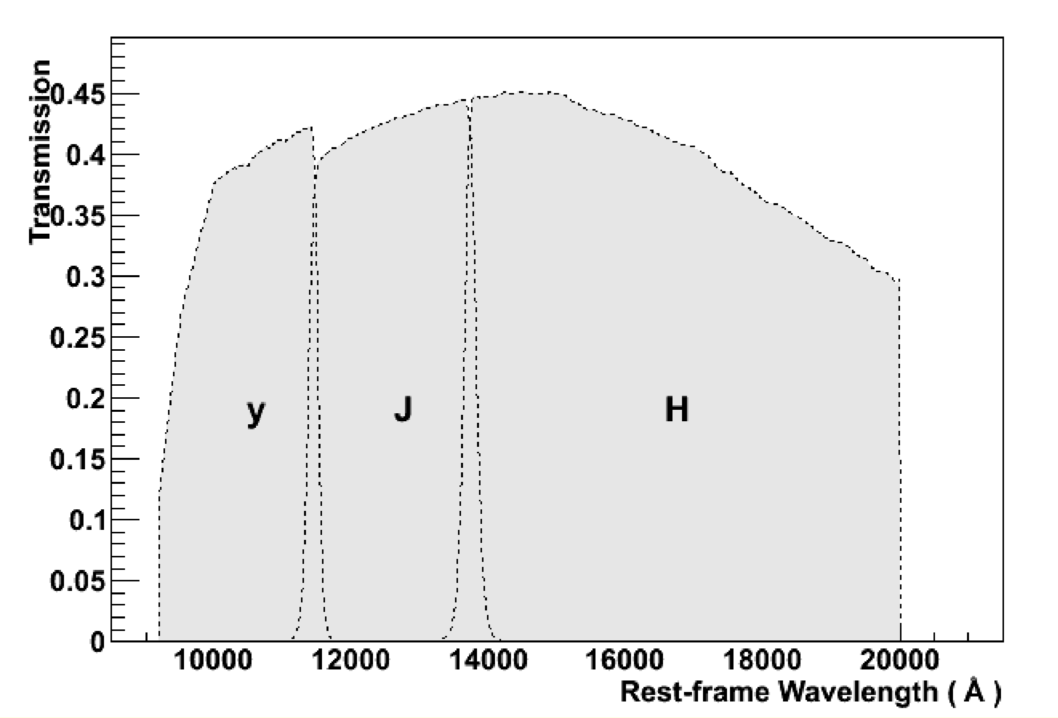
- ESA mission (M class)
- Phase B
- Launch dec 2019
- “whole” sky survey
- Adopted tomorrow (!)



Euclid core science

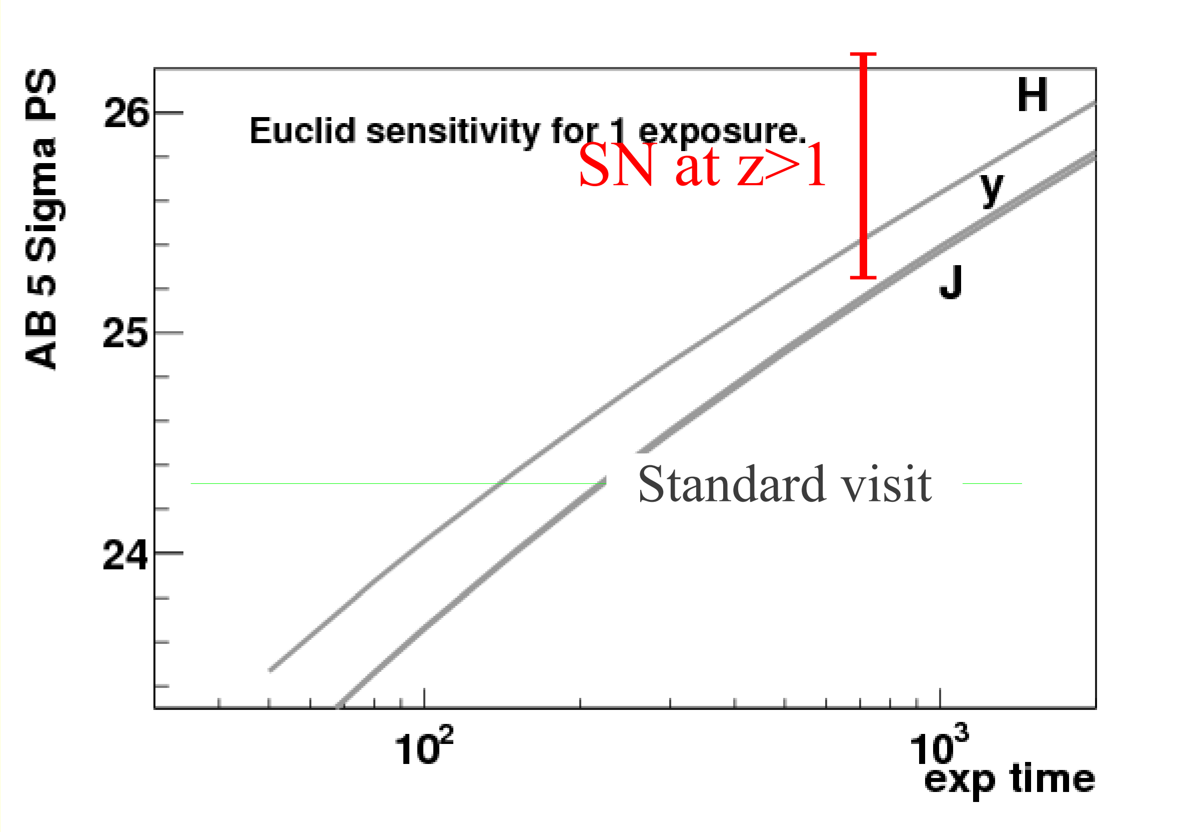
- 1.2m , 2 simultaneous channels, Visible & NIR, 0.5 deg^2
- Visible→ morphology of galaxies, ~~photometry~~
- IR → Photometry and spectroscopy.





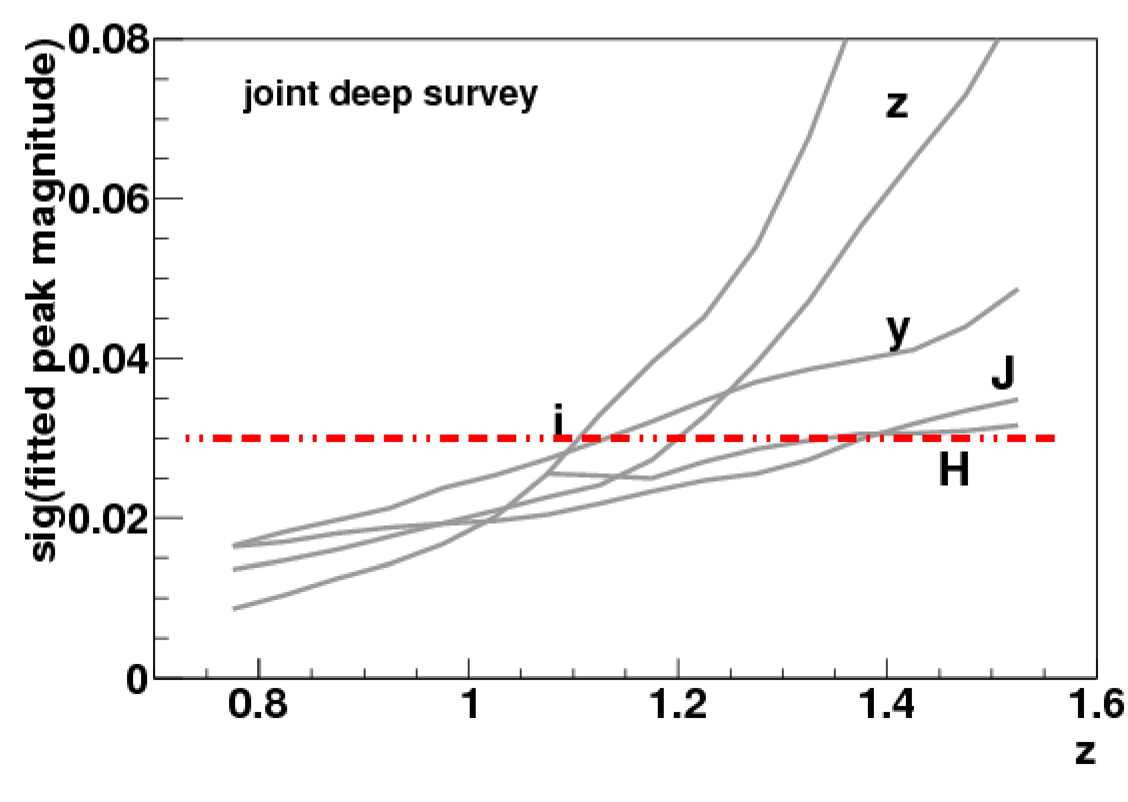
SNe NIR imaging with Euclid

To measure distances to a sizable SN sample, we need longer exposures than in the standard visit.



Measuring Ia at high z with Euclid + X

We need visible photometry → consider e.g. LSST



Hypotheses :

4-day cadence

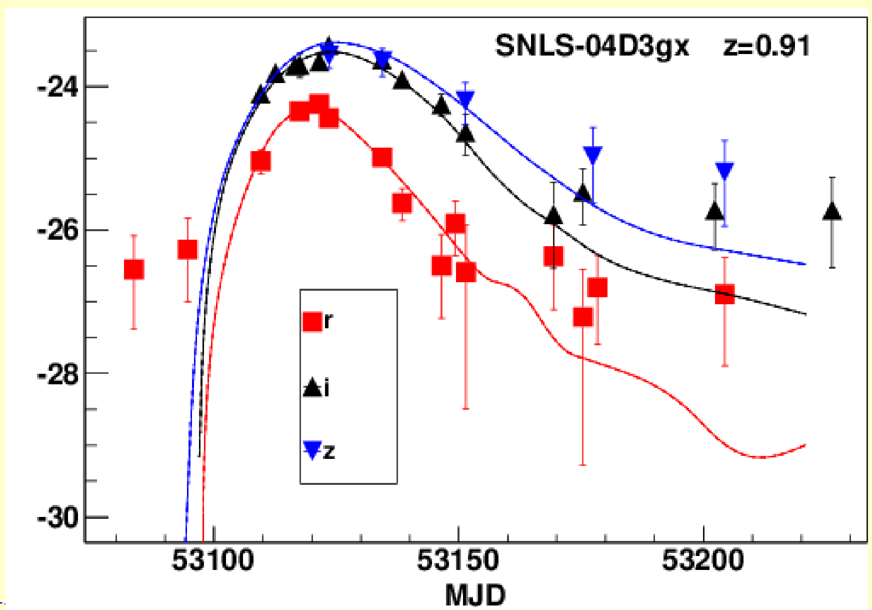
Joint LSST – Euclid survey

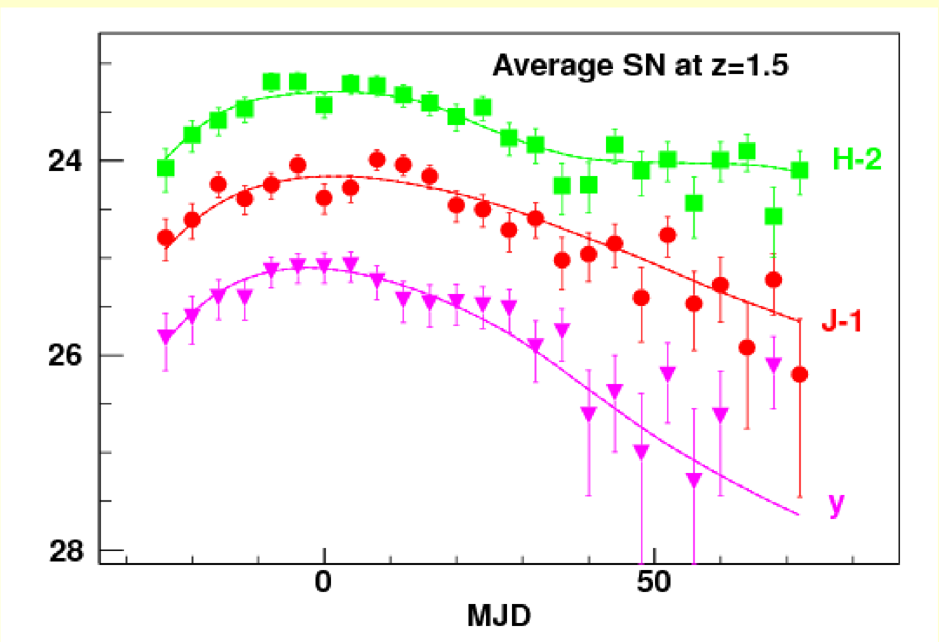
LSST	i	700 s
LSST	z	1000 s
Euclid	Y	1200 s
Euclid	J	2100 s
Euclid	H	2100 s

- The wavelength coverage is larger than the redshift coverage :
  i at z=0.8 → 420 nm H at z=1.5 → 660 nm
- I made up the LSST integration times : going deeper is conceivable
- LSST is just an example. HSC/Subaru would do as well.

Euclid & LSST

LSST wide Survey	LSST Deep fields	Euclid IR Photometry
0.05<z<0.35 (~8000)	0.15<z<0.95 (8800)	0.75<z<1.55 (1750)





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Simulation Results

Summary :

	z min	z max	area	duration	statistics
Hi-z	0.75	1.55	20	6	1740
Mid-z	0.15	1.05	50	18	8800
Low-z	0.05	0.35	3000	6	8000

All surveys are redshift limited !

Cosmological constraints with “geometrical” Planck priors + flatness.

	sig(w_0)	sig(w_a)	FOM
3 surveys	0.022	0.25	204
low+mid	0.026	0.22	137
mid+high	0.030	0.40	82

$$\sigma(w_0) = 0.022$$

- Euclid's contribution is sizable although not dominant.
  Can be made larger with more observing time …
- Final Euclid stack reaches ~28th mag (point-source, 5 sigma)

Euclid+X : status

- This is the only SN project proposed so far for SNe in the next decade relying on hardware "on track to the sky".
- Politically tricky (2 collaborations) ...

… but Euclid is not stand-alone by construction.

EUCLID :

- The survey project was adopted by the Euclid SN WG.
- Currently being transferred to upper levels.

→ stay tuned

LSST :

- Provision for a Euclid-compatible deep field was made.
- Observing cadence will remain flexible.
- Working groups currently in reconfiguration.

Summary/conclusions

- SN are still in business to constrain EoS of DE
- We are now at an uncertainty of ~0.07.
- On track to reach 0.05 with acquired data.
- Developments of artificial light sources underway
- Large scale SN survey sketch relying on

  Euclid + X (e.g. LSST)
- Stay tuned.