Hubble Diagram

N. Regnault et al

LSST DESC
Dark Energy Science Collaboration

Outline

- State of the art
- Ingredients
  - Calibration
  - Precision photometry
- The Hubble diagram in 2022
  - Combining ZTF, JLA++, Subaru …
- What can (should) do in the early days of LSST ?
  - Nearby SNe
  - ZTF

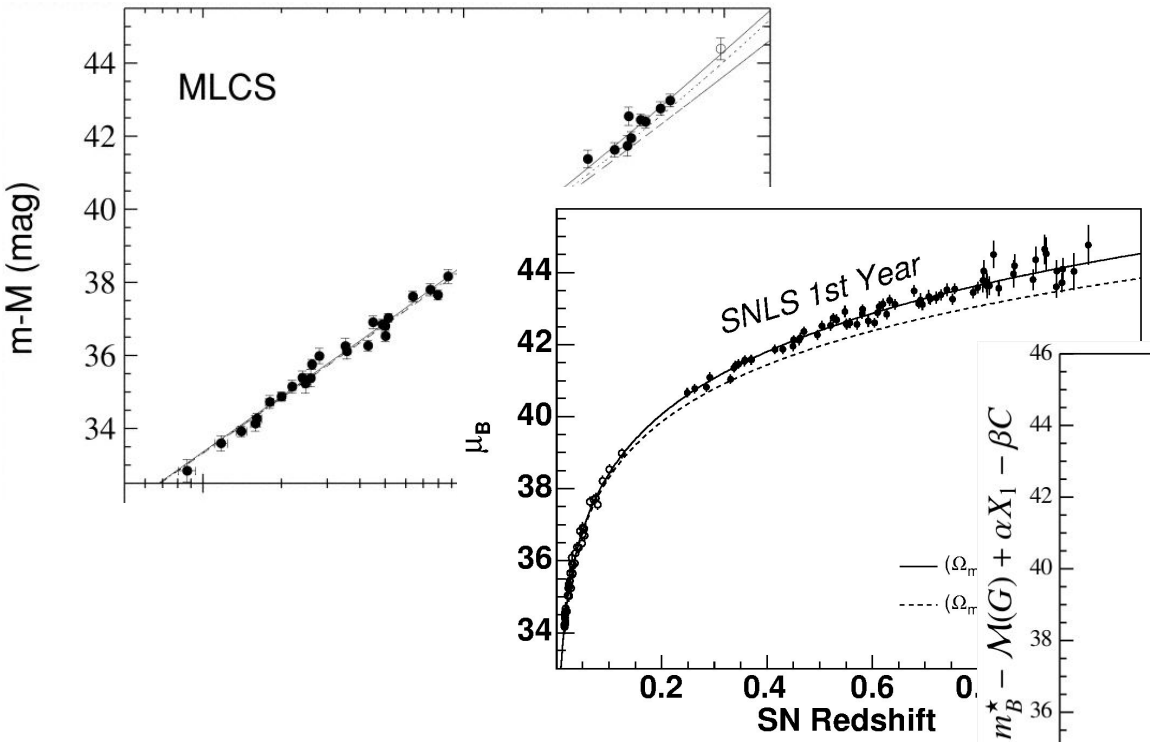
http://supernovae.in2p3.fr/~nrl/lsst_sn_cadence/2019/

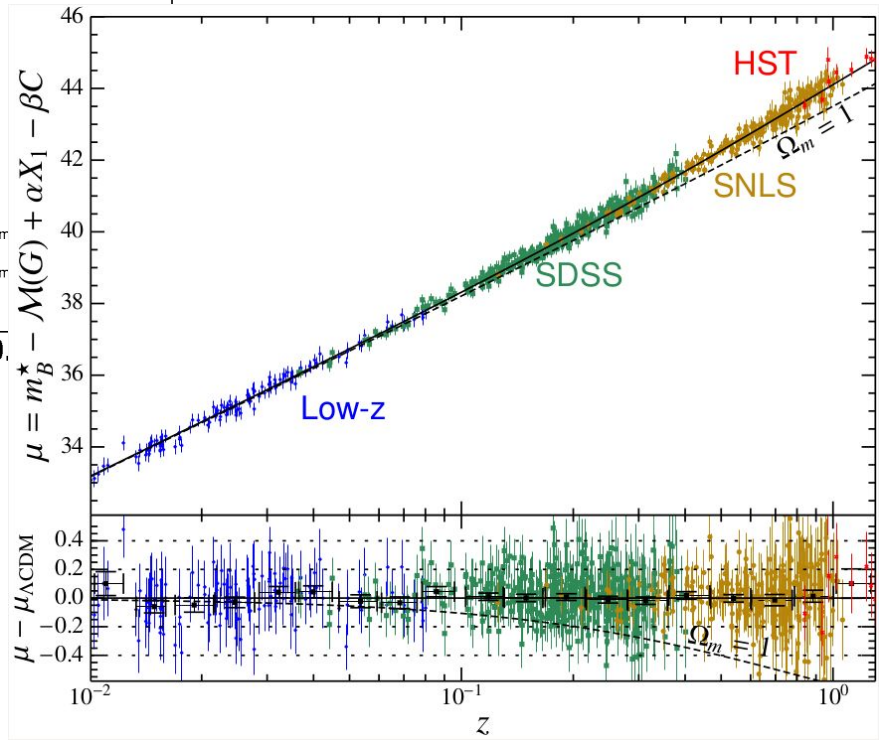
SN Hubble diagram

State of the art (still today):
Betoule et al, 2014)

Key ingredients:

- Standardization
- LC fitter
- Precision photometry
- Calibration
- Calibration
- Calibration...



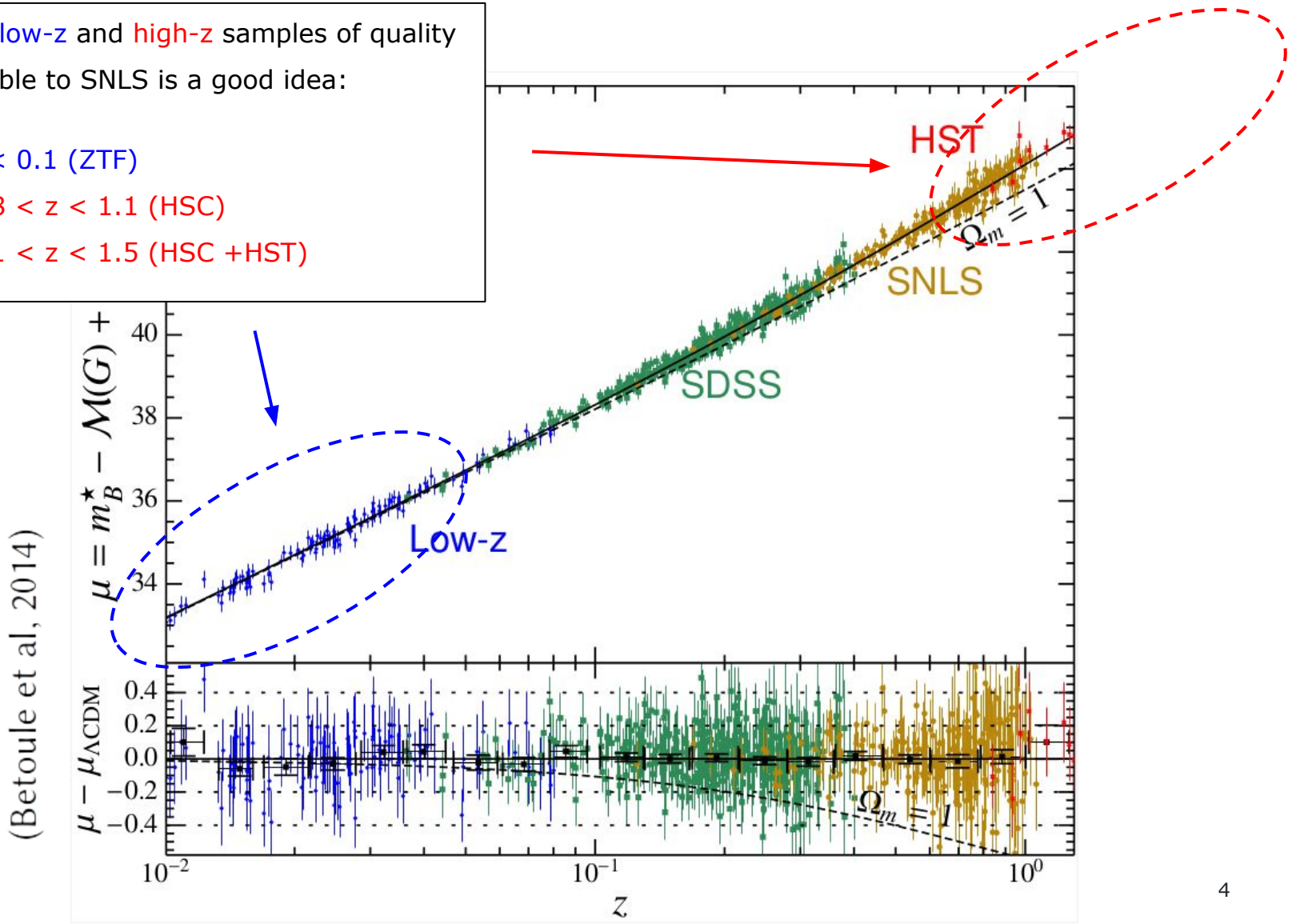


- 1998 : O(50) SNe
- 2005 : O(100) SNe
- 2014 : O(1000) SNe

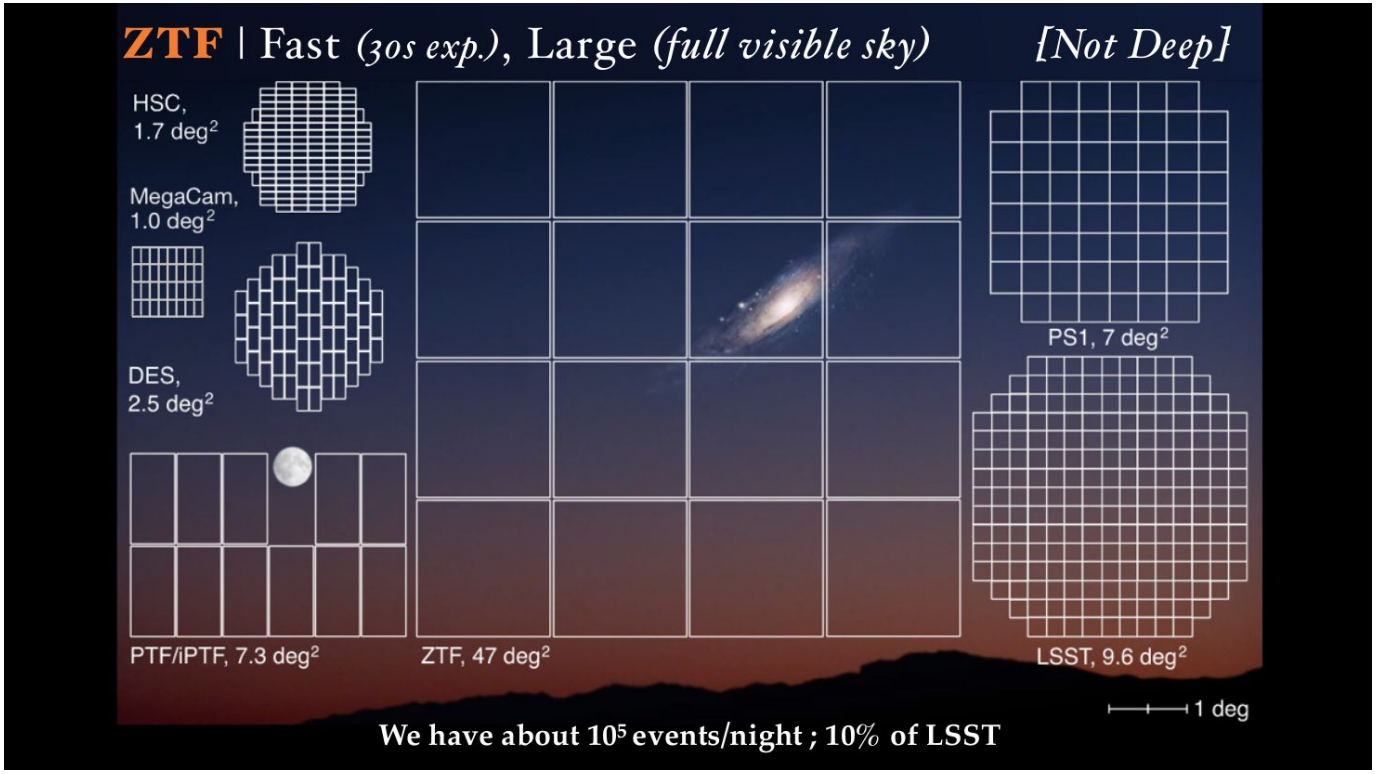
Under-constrained regions

To build low-z and high-z samples of quality comparable to SNLS is a good idea:

- z < 0.1 (ZTF)
- 0.8 < z < 1.1 (HSC)
- 1.1 < z < 1.5 (HSC +HST)

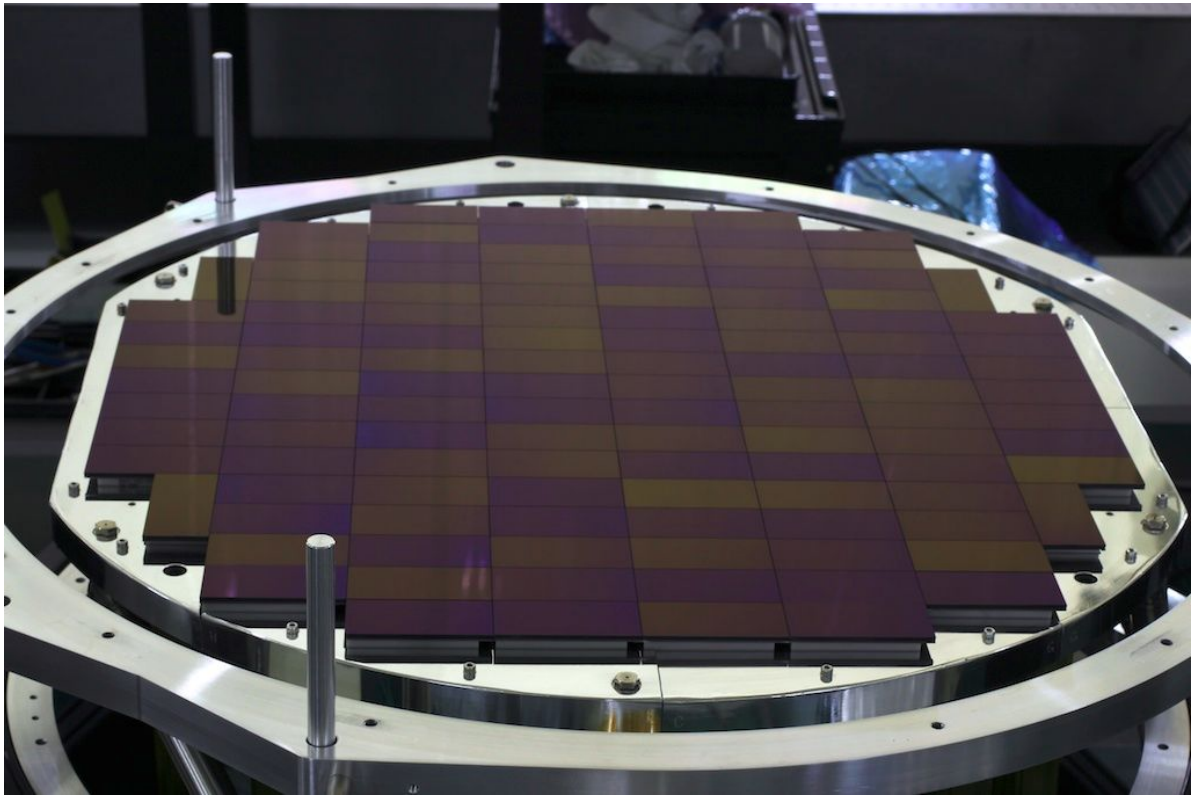


ZTF



- O(1000) SNe up to z < 0.1
- 4-day cadence (g,r) + 6 day cadence (i-band, private)
- 10% of sample with a higher cadence (1 day ?)

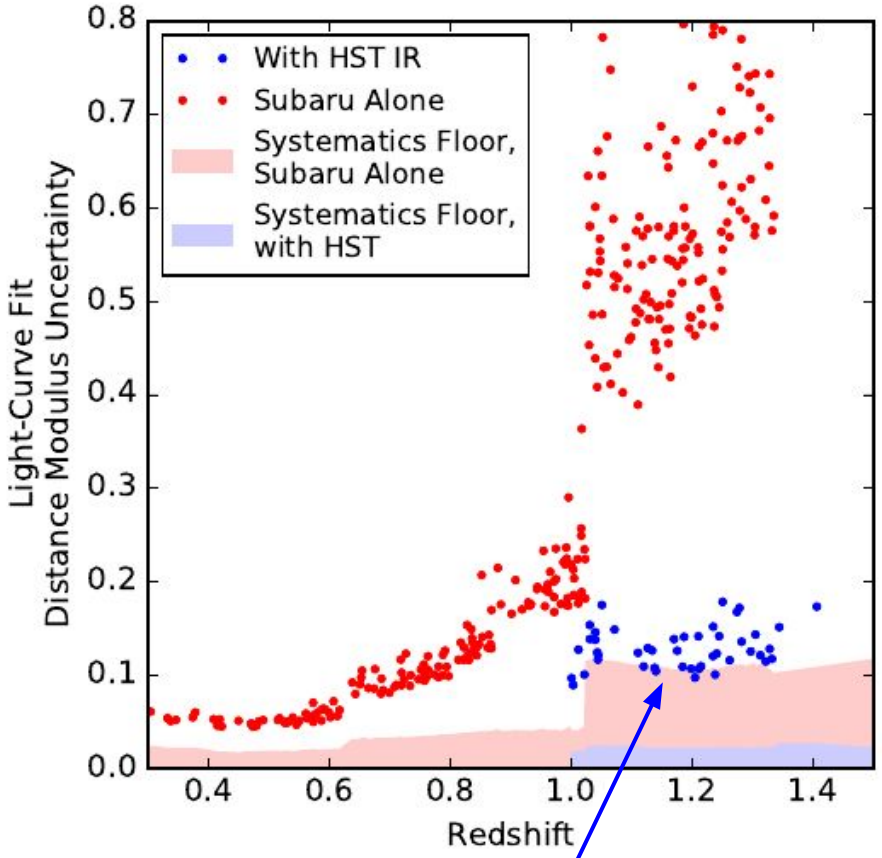
Subaru Strategic Program



- 1.8 deg^2 camera
- 116 CCD à haute résistivité
- Télescope Subaru (8.2-m)

Subaru + HST

- 2 seasons
- ~ 240 SNe
  - ~ 80 @ z < 0.8
  - ~ 80 @ 0.8 < z < 1.1
  - ~ 80 @ 1.1 < z < 1.5
- Subaru/HSC alone can measure distances up to z<1.1
- Beyond that, we need IR photometry (e.g. HST observations)



With one single HST visit (2 orbits per SN), One can measure a distance

Forecasts & scenarios

- Question:
  - How is the Hubble diagram going to look like, before the first light of LSST ?
  - What cosmological constraints can we expect from it ?
- More precisely: is is worth trying to build a consistent analysis of
  - ZTF,
  - SSP (HSC+HST),
  - JLA++ (recalibrated SNLS-5)
- And combine it (later) with the existing (published) datasets
    - PanSTARRS, CSP, Pantheon, SeeChange, ...

?

Method

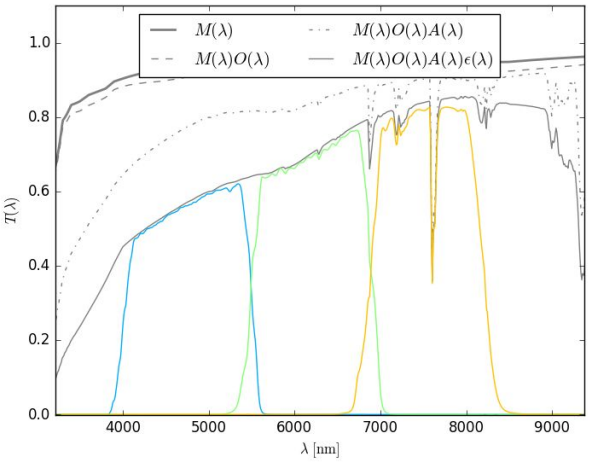
- Derived from forecasting method developed for (Astier et al, 2014)
  - Simulated light curves (SALT2 + instrument model)
  - Emulation of full analysis
    - LC fits
    - Standardization
    - Fitter retraining
    - Cosmology
  - with calibration uncertainties folded in

See Astier et al, (2014) A&A
Hazenberg et al, 2018 (DESC note)
saunerie.snsim (Regnault, undocumented)

ZTF

- ~ 880 SNe Ia @ z < 0.1
  - 4 day cadence in g,r, 6 day cadence in i
  - High cadence for ~ 10% of the sample
- Rough instrument model

band	leff (AA)	ZP (AB)	msky (m/"^2)	fsky (e/px/s)	FWHM (")	NEA (px^2)	gFWHM (")	m5
ZTF::g	4794.50	23.45	21.26	2.97	2.31	20.88	0.00	20.58
ZTF::r	6221.85	23.34	20.20	7.19	2.08	17.24	0.00	20.21
ZTF::i	7540.40	23.19	19.47	12.26	2.17	18.67	0.00	19.76



tuned

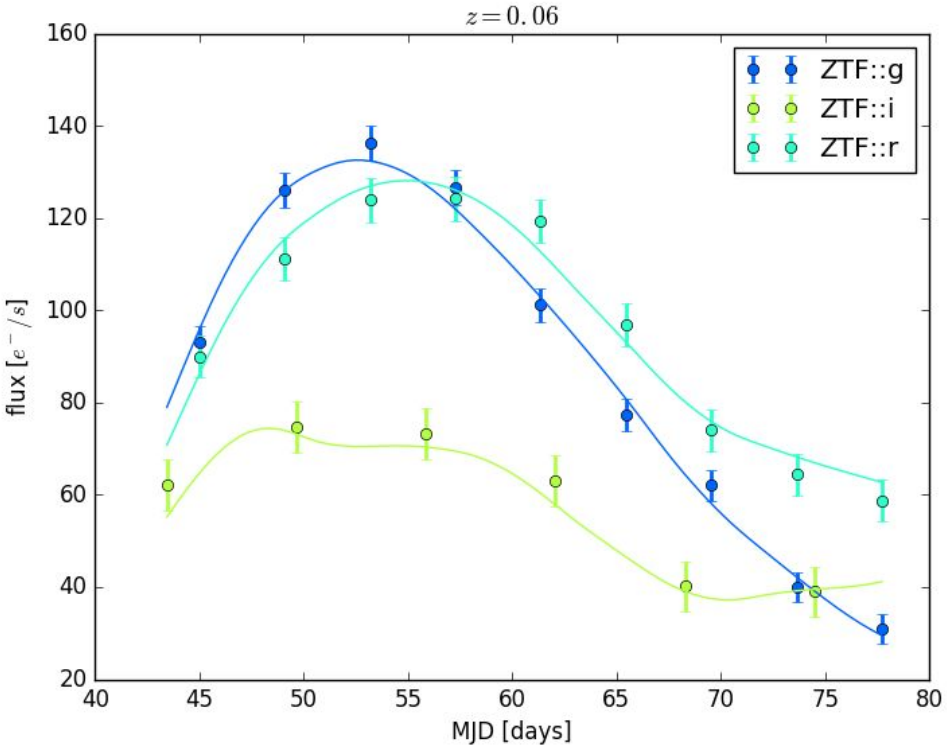
Wild guess

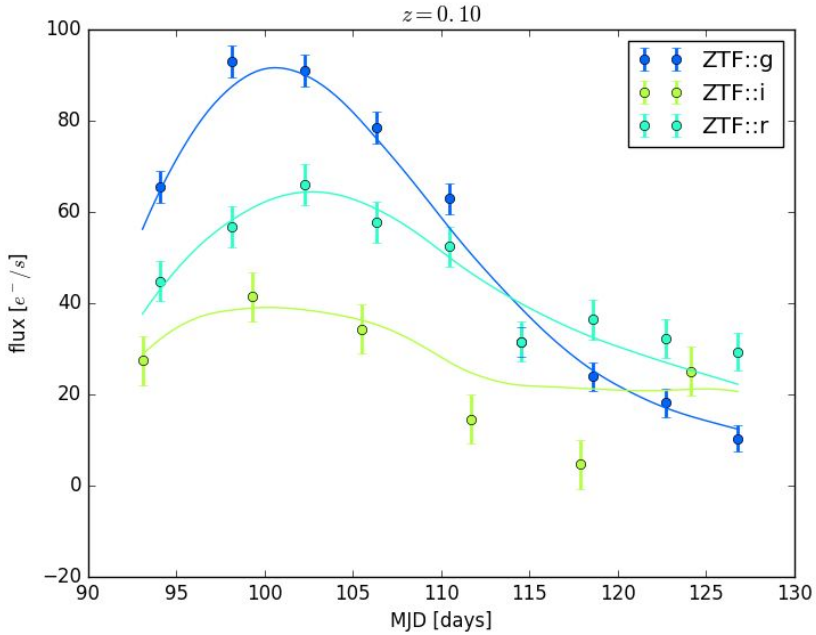
M. Rigault (private comm)

PSF dependent

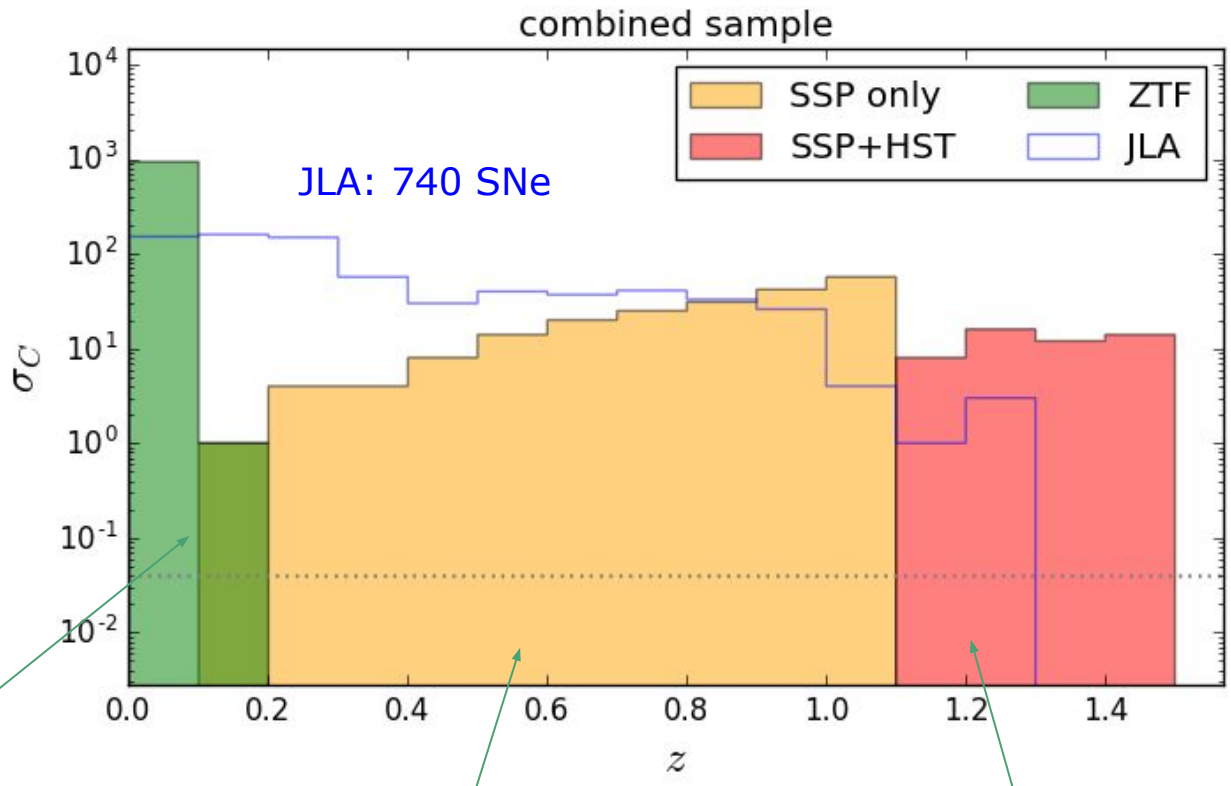
Seems to match what MR tells me

Simulated ZTF light curves





A look at the JLA+ZTF+HSC/HST SN sample

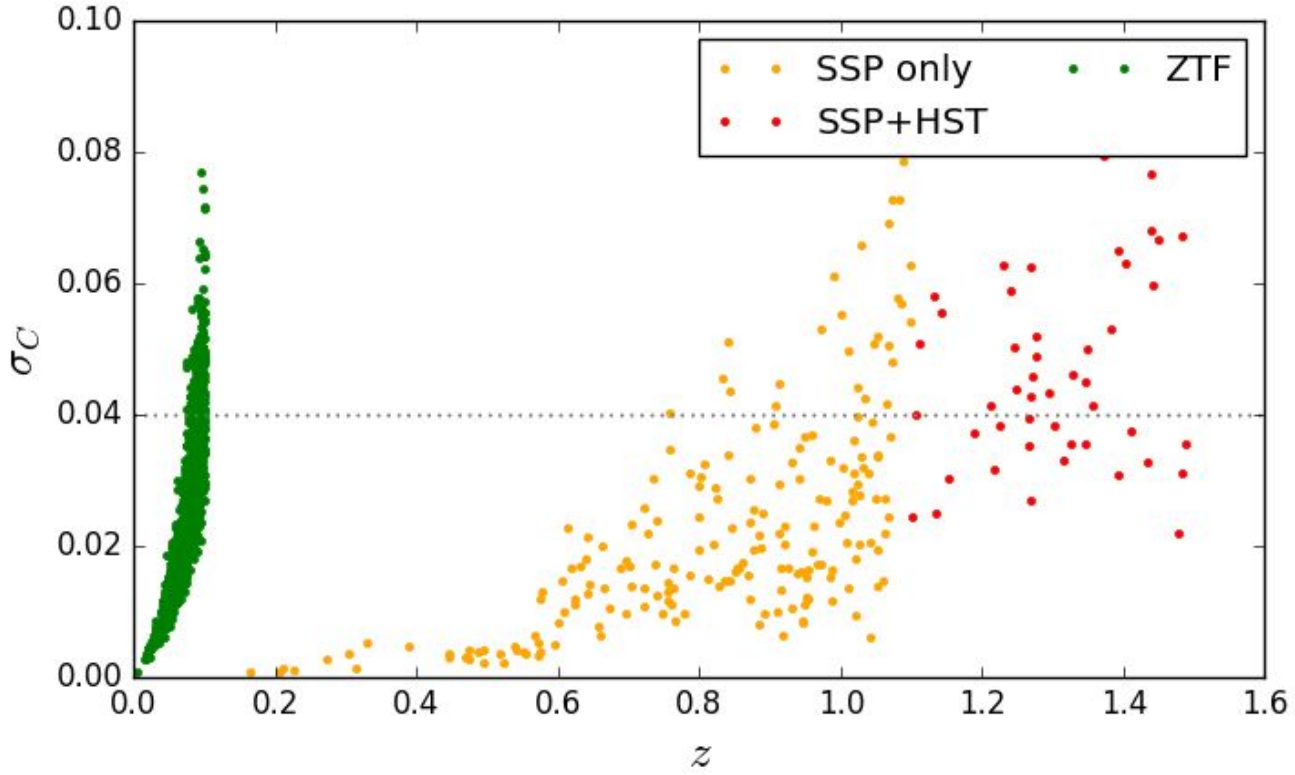


O(800)

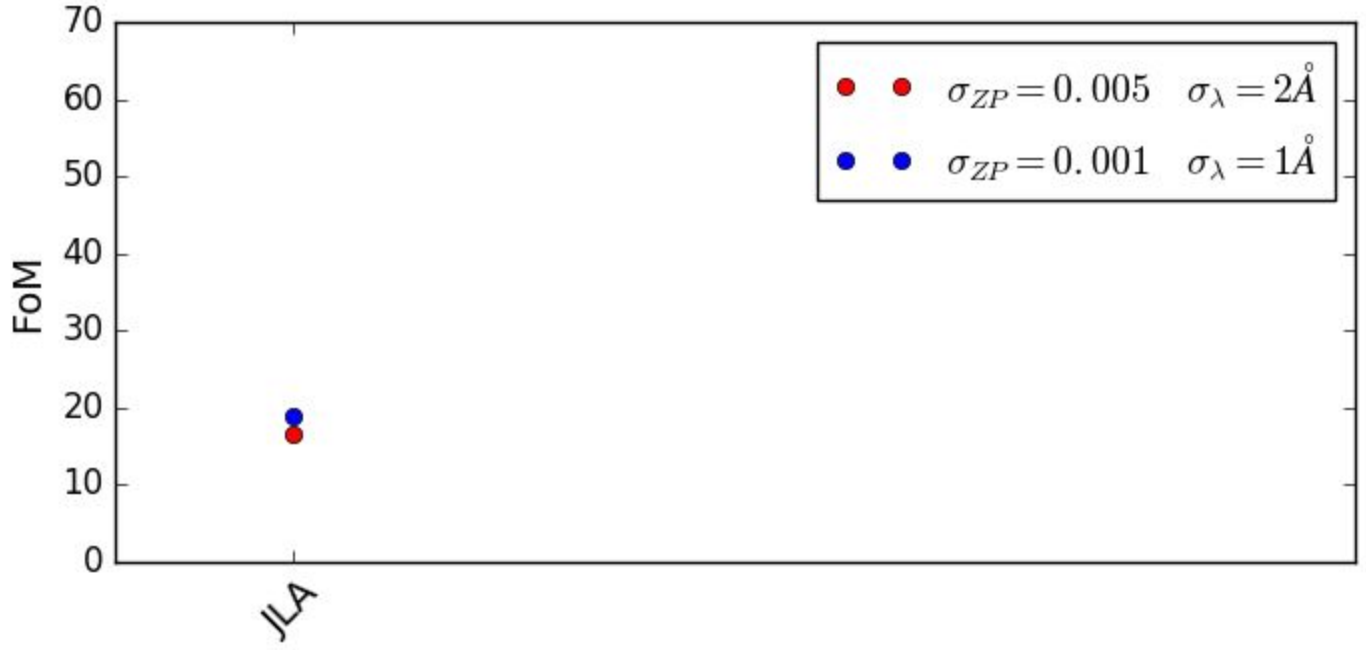
O(250)

~50

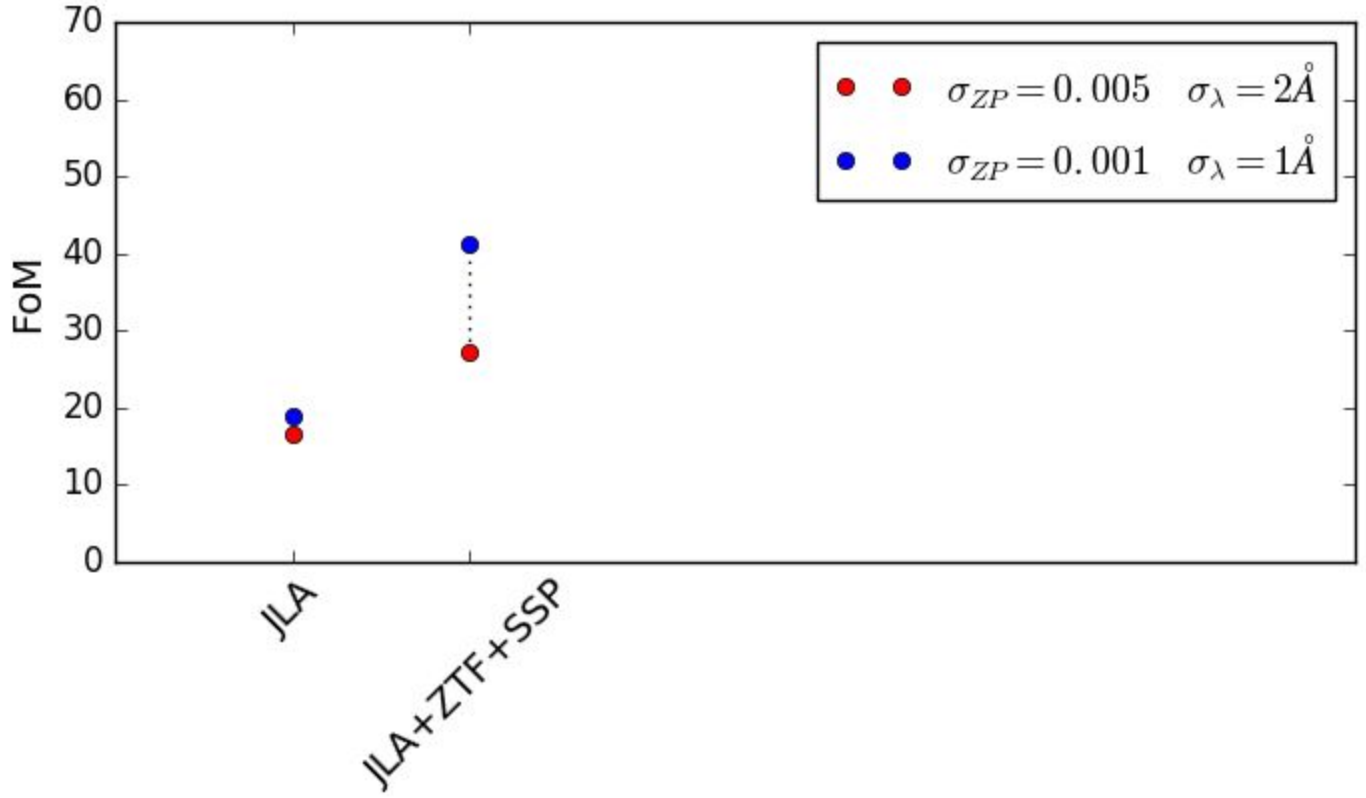
A look at the JLA+ZTF+HSC/HST SN sample



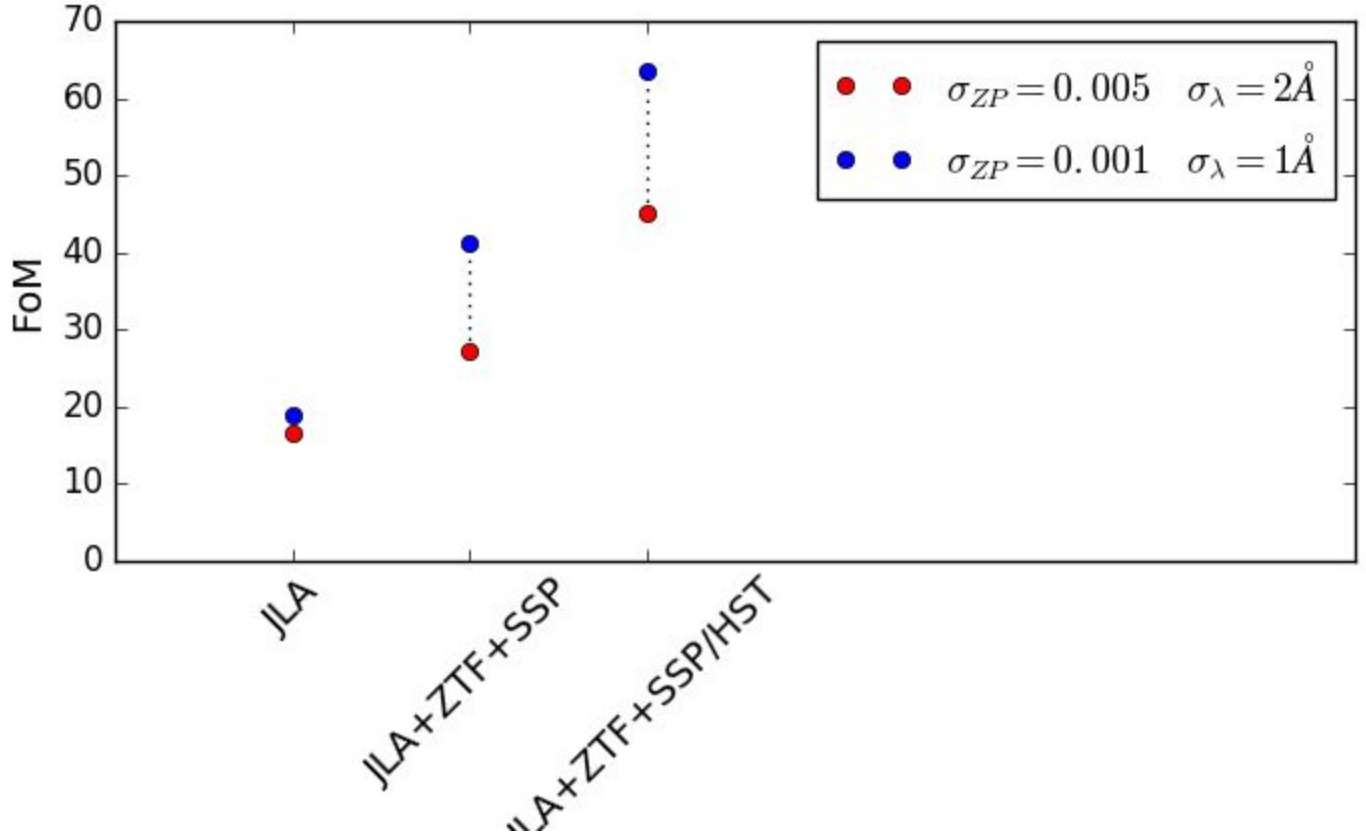
Figures of merit



Figures of merit



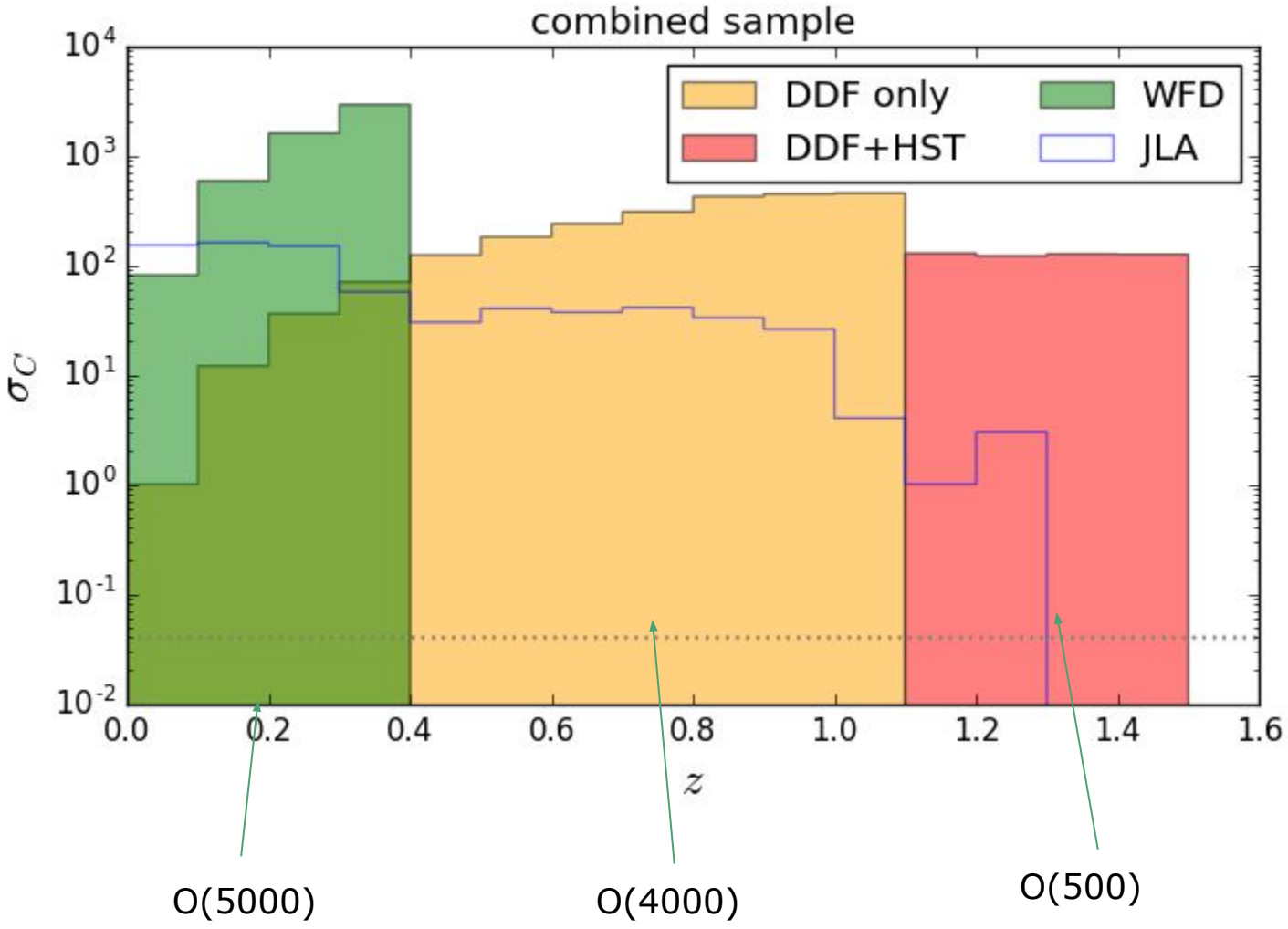
Figures of merit



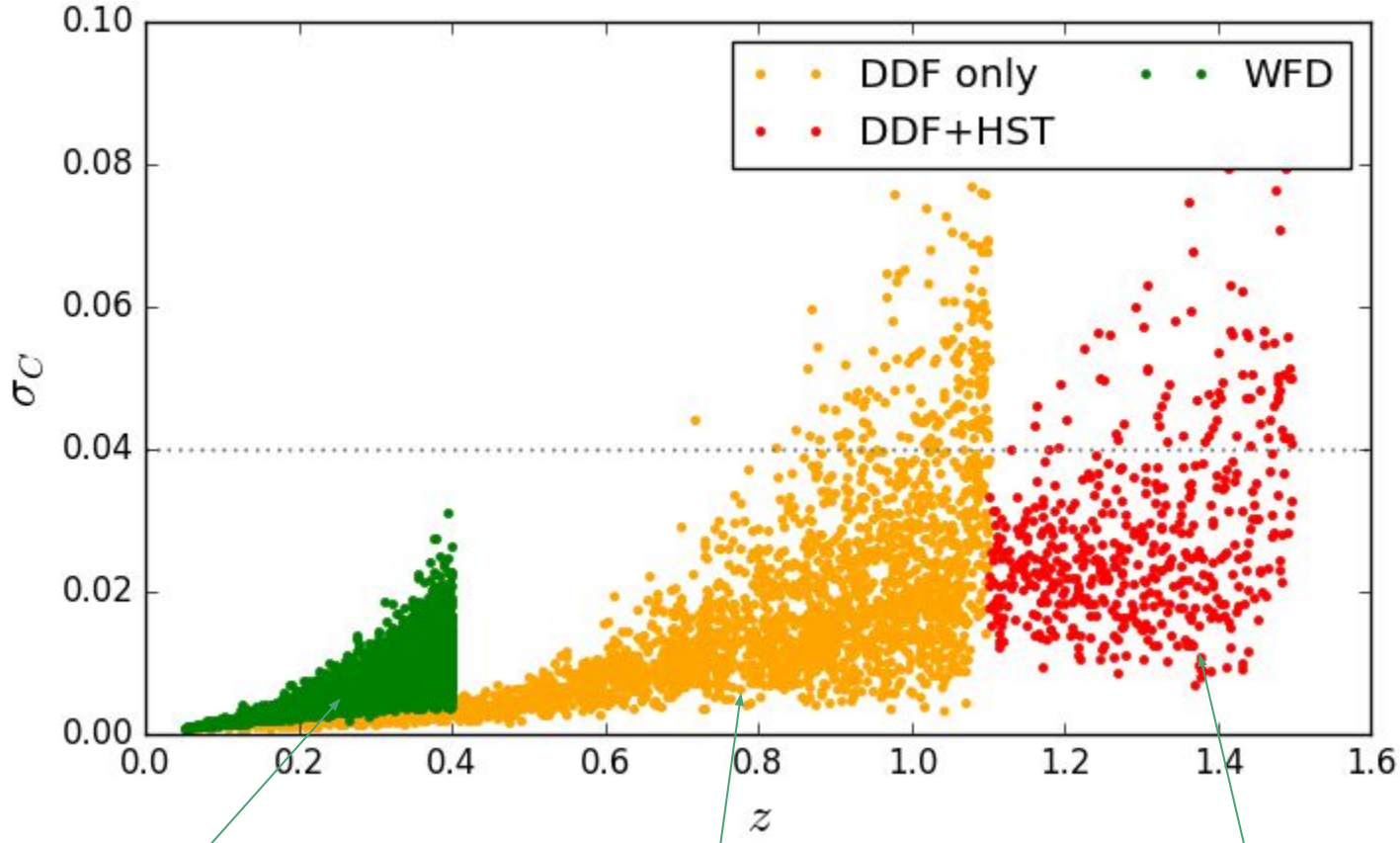
What can we do in the early days of LSST ?

- Explore what we get from 1(2) years of LSST and
  - A small (1000 deg^2), well cadenced nearby survey
    - Cadence of 3 days, gri, 30-s
  - a very good cadence on two DDF pointings
    - Cadence of 2 days, riz, 600-s
    - (lower cadence but deeper visits is also an option)
  - Choose equatorial DDF's so that Subaru/PFS can observe them
  - Consortium to gather HST follow-up time
  - (subaru-like strategy)

An early LSST SN sample



An early LSST SN sample

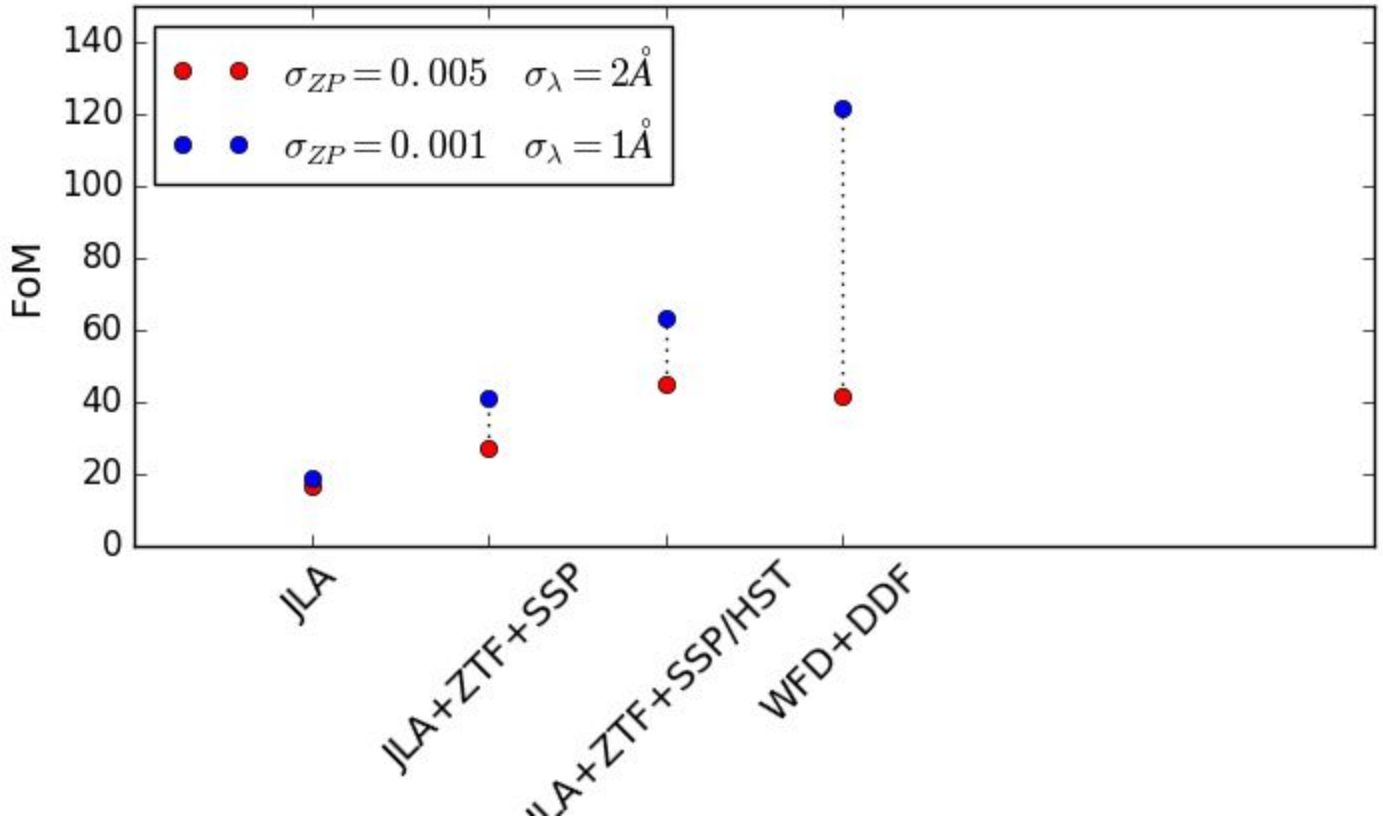


Slightly optimistic

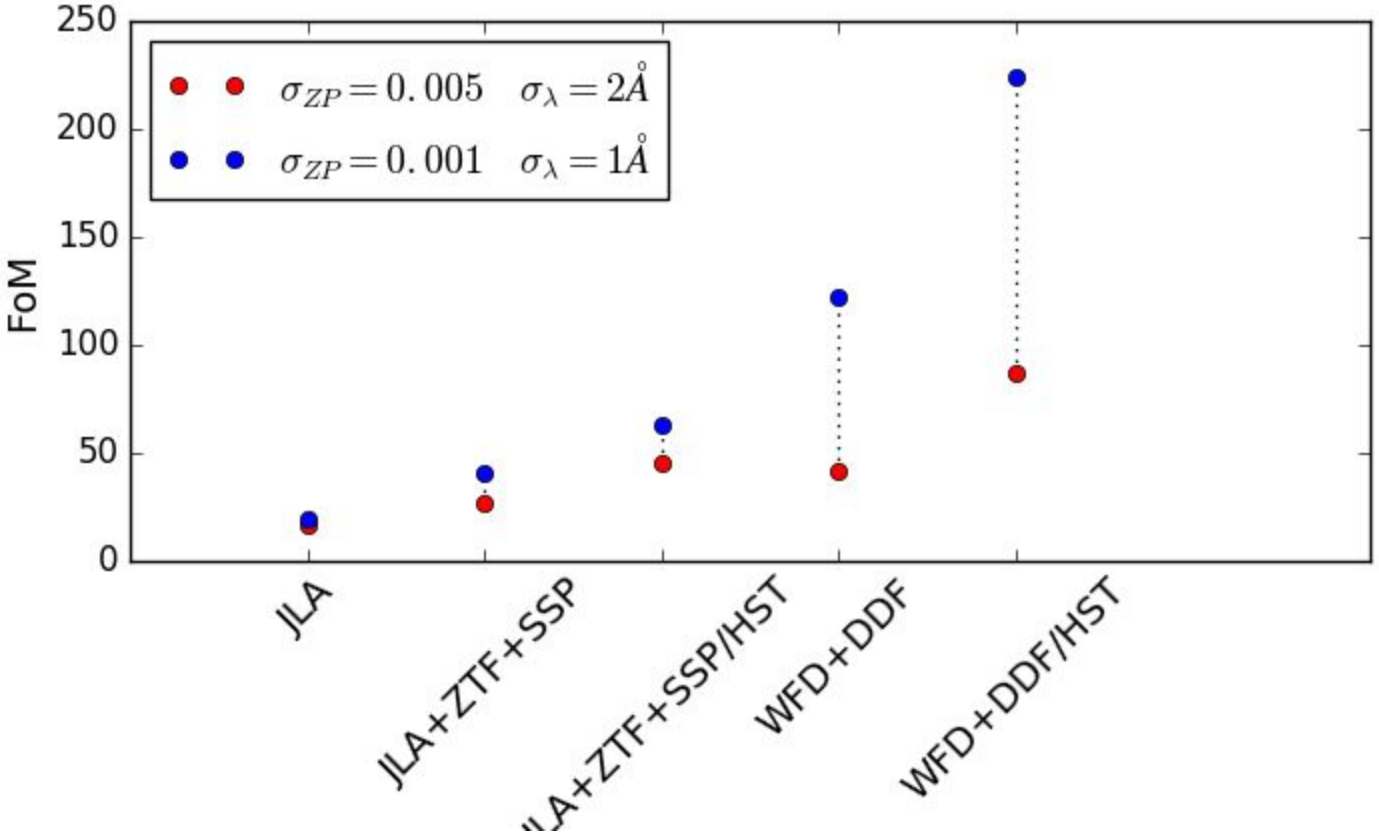
Because very good cadence

1 HST visit per SN (+1 for the refs)

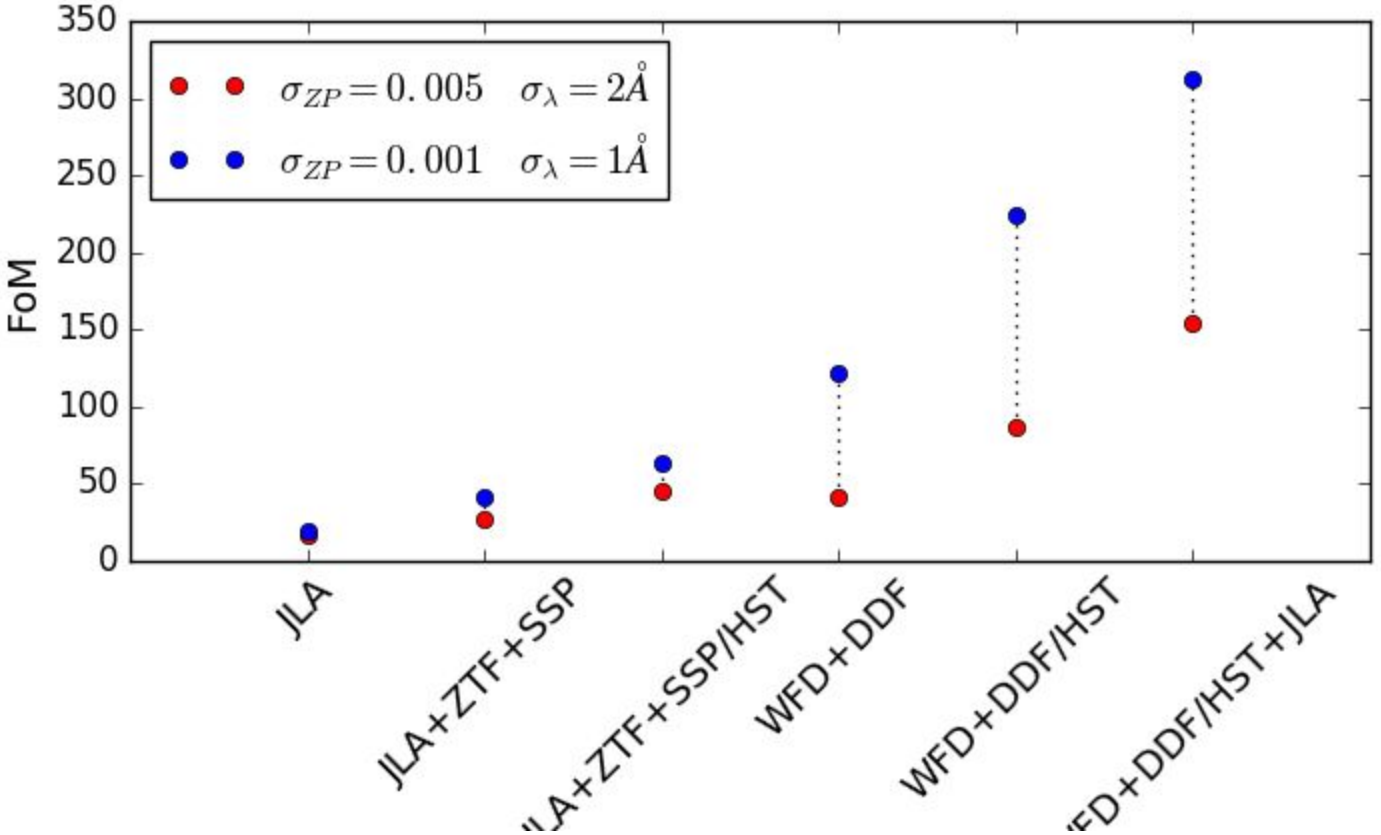
Forecasts


$\sigma_{ZP} = 0.005 \quad \sigma_\lambda = 2\mathring{A}$
$\sigma_{ZP} = 0.001 \quad \sigma_\lambda = 1\mathring{A}$
FoM
0
20
40
60
80
100
120
140
JLA
JLA+ZTF+SSP
JLA+ZTF+SSP/HST
WFD+DDF

Forecasts


250
200
150
100
50
0
FoM
$\sigma_{ZP} = 0.005 \quad \sigma_\lambda = 2\mathring{A}$
$\sigma_{ZP} = 0.001 \quad \sigma_\lambda = 1\mathring{A}$
JLA
JLA+ZTF+SSP
JLA+ZTF+SSP/HST
WFD+DDF
WFD+DDF/HST

Forecasts


350
300
250
200
150
100
50
0
FoM
$\sigma_{ZP} = 0.005 \quad \sigma_\lambda = 2\mathring{A}$
$\sigma_{ZP} = 0.001 \quad \sigma_\lambda = 1\mathring{A}$
JLA
JLA+ZTF+SSP
WFD+DDF
WFD+DDF/HST

Conclusion

- Potential to reach a FoM of ~ 70 or more,
  - before LSST first light
- … by combining
  - large upcoming nearby datasets (ZTF)
  - JLA++
  - subaru/HSC + HST
  - … analyzed in a consistent way (photometry, calibration)
- Potential to reach FoM of ~ 200+
  - In the early days of LSST
  - If excellent cadence (dedicated DDF survey)
  - And if can exploit space-ground complementarity
- Need to get organized
  - Science case, common analysis effort/framework,
  - HST+PFS time