Calibration of the Hubble diagram

Marc Betoule (LPNHE)
Journées LSST france
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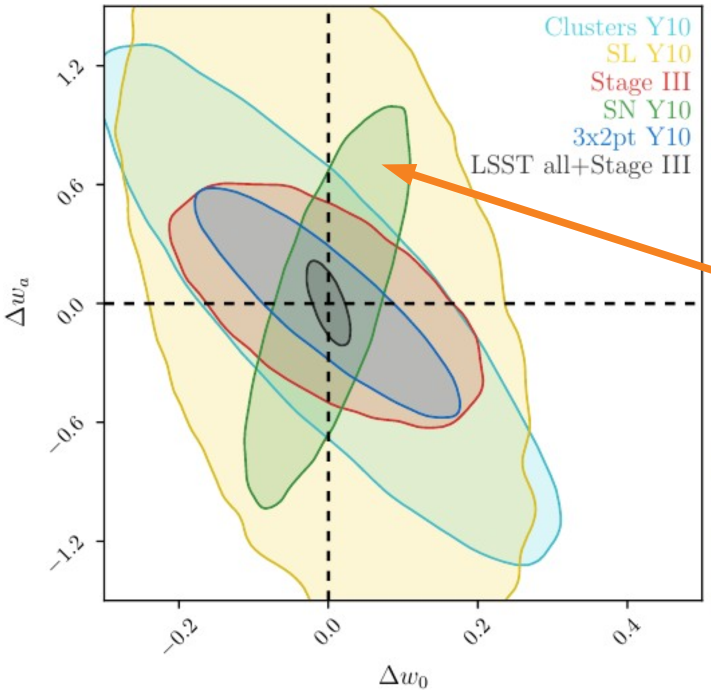
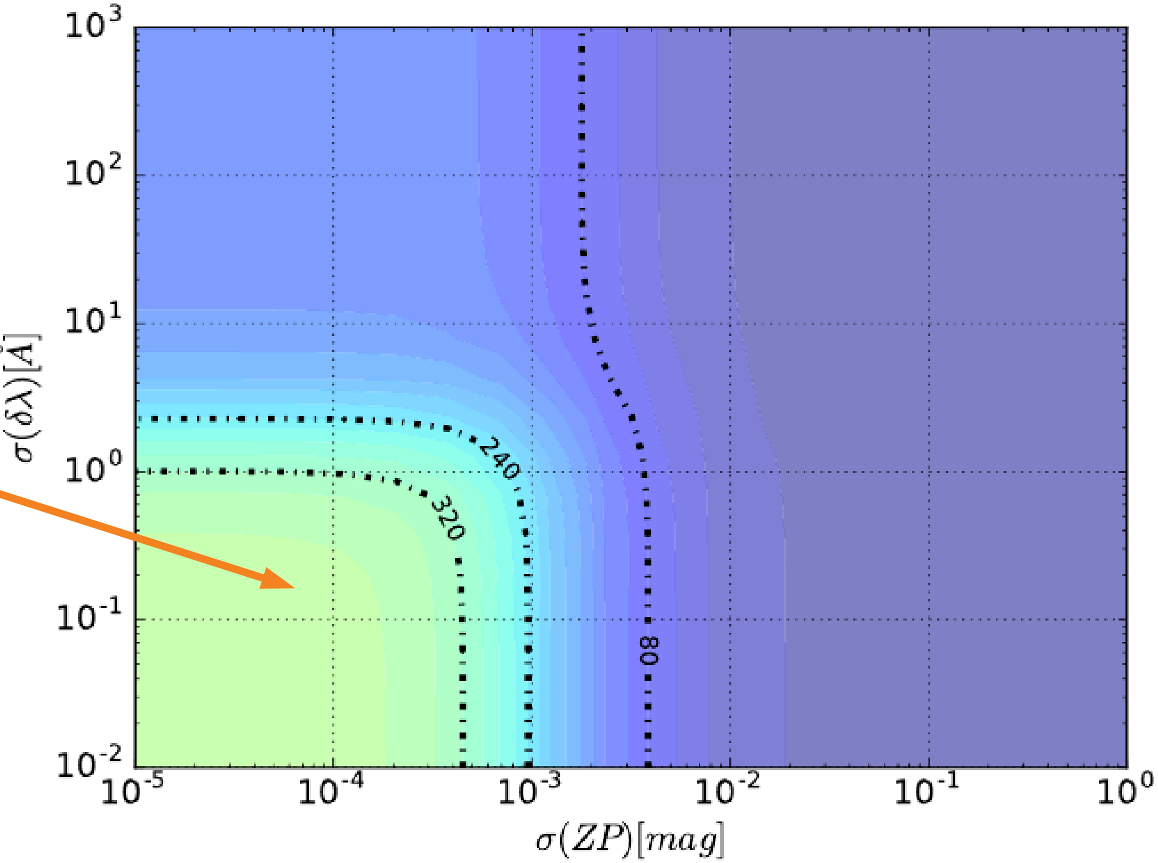
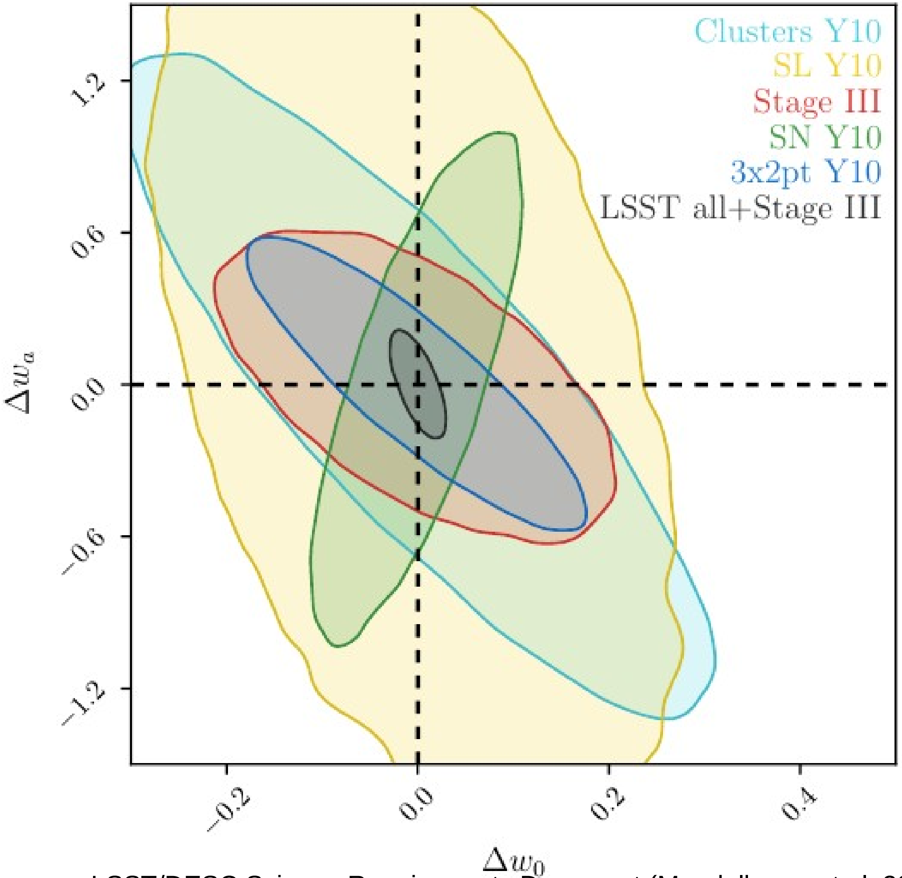




LSST and Dark Energy

- 2 complementary pillars
  - Weak lensing probes the growth of structure through the evolution of matter distribution
  - SNe Ia probes the expansion rate through the distance-redshift relation
- Substantial metrology challenges associated to both



LSST/DESC Science Requirements Document (Mandelbaum et al. 2018)

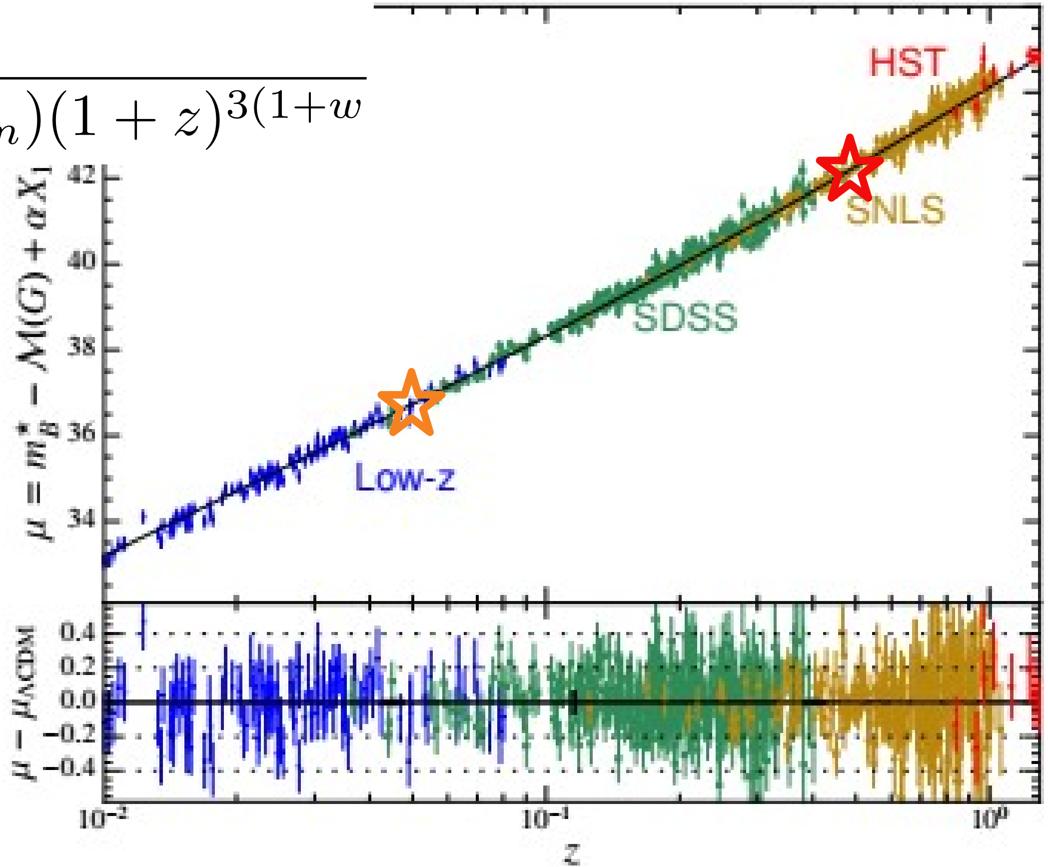
Cosmological constraints from the Hubble diagram

$$d_l(z) = \frac{c}{H_0}\int\sqrt{\frac{dz}{\Omega_m(1+z)^3+(1-\Omega_m)(1+z)^{3(1+w}}}$$

$$f \sim \frac{1}{d_l^2}$$

$$R = \frac{f(z=0.05)}{f(z=0.6)}$$

$$\frac{1}{R}\frac{dR}{dw} = 0.3$$

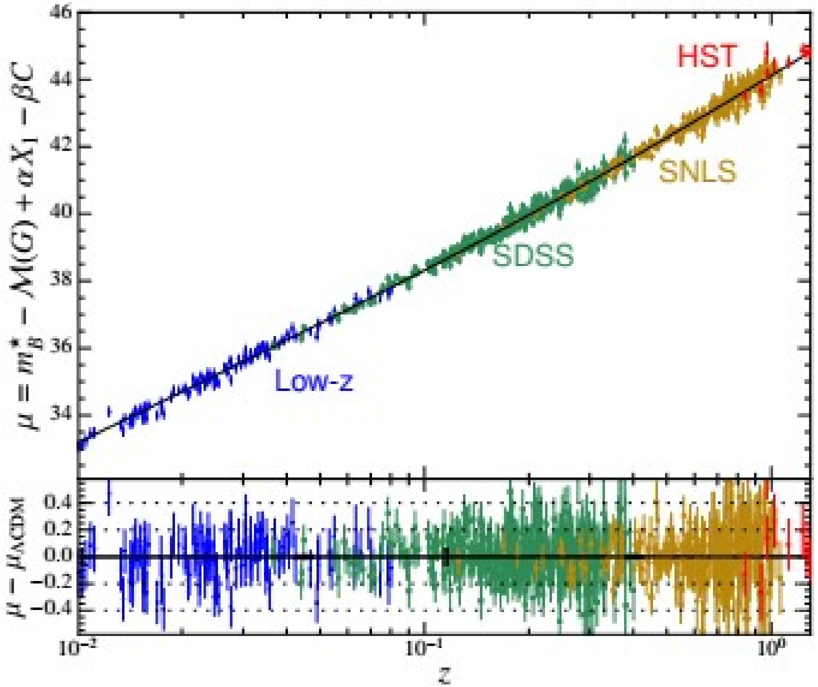


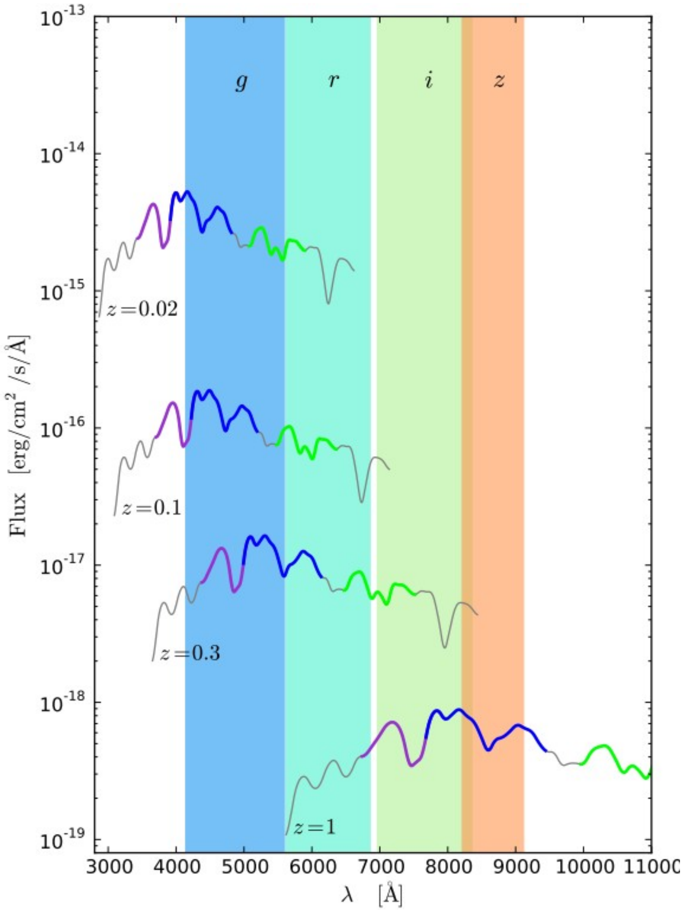
Supernovae need accurate broadband flux calibration

The Hubble diagram

- Comparison of flux at different redshifts
- **Color** is an important correction
- M ~ B - 3 * (B-V)

Error in relative distance modulus is roughly:
2g - 3r - 2i + 3z
(Dependent on redshift repartition, SN model...)

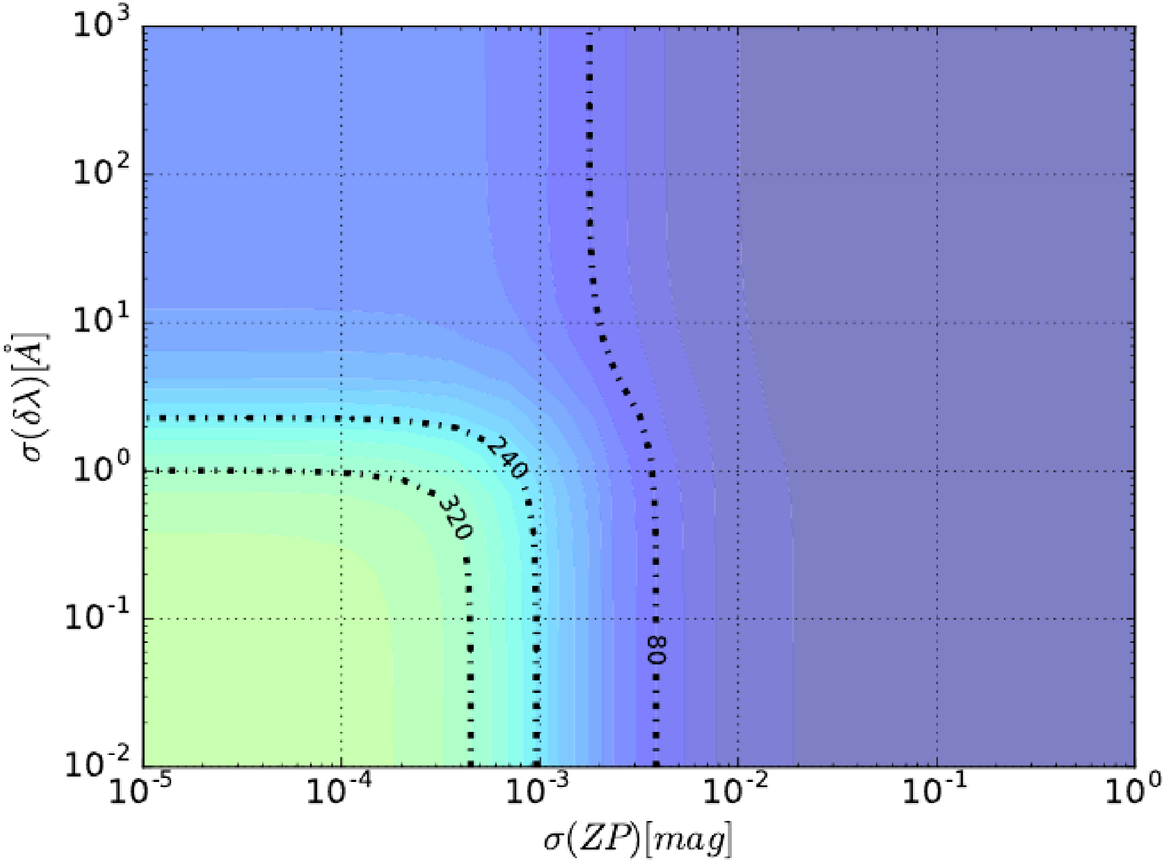




Another factor ~3 between error on relative distance modulus and systematic error on w (Dark energy equation of state parameters)

1 mmag on flux → 1% on w

Supernovae in LSST need mmag accuracy in color



Full computation of the expected Dark Energy Figure of Merit (**FoM**)
As a function of uncertainties on **filters** and **flux calibration**
for a **realistic LSST** survey

- At 1% calibration the supernovae survey does not bring much to cosmology
- 1 mmag required to extract most of the statistical power of LSST

F. Hazenberg et al. 2018 (DESC note)

Broadband fluxes in varying passbands

$$f = \int T(\lambda) S(\lambda) d\lambda$$

Composite Transmission (contribution from atmosphere, instrument, filters, detector …) :

$$T(\lambda) = A(\lambda) F(\lambda) O(\lambda) \epsilon(\lambda)$$

To some level, everything moves. The passband can be parametrized by its moments:

At zeroth order the zero point

$$Z = \int T(\lambda) d\lambda$$

At first order the central wavelength

$$\bar{\lambda} = \int \lambda T(\lambda) d\lambda$$

At second order the passband width

$$\Delta\lambda = \int (\lambda - \bar{\lambda})^2 T(\lambda) d\lambda$$

...

Old-School strategy (SNLS)

- Assume something about the wavelength shape of the passbands
- Homogenize zero point across focal plane using specific observation
- Transfer zero point to science fields using specific observations

3 major shifts : I

- Data redundancy and statistics in modern survey is sufficient to infer part of the calibration parameters from the science data themselves:
  - SDSS: Padmanaban 2008 (2%)
  - Pan-Starrs: Schlafly et al. 2012 (.7%)
  - DES: Burke et al. 2018 (.3%)
  - Gaia, ZTF LSST
- Solve at least uniformity and transfer
- Solve chromatic variations due to atmosphere in last version

3 major shifts : II

- Most modern surveys have serious hardware to measure the integrated passband
  - SNLS: DICE
  - SDSS: Doi et al. 2010
  - Pan-Starrs: Tonry et al. 2012
  - DES: Lasker et al. 2019
  - LSST CBP (ZTF, GAIA)

Major shifts number 3

- Switching to a laboratory flux standard
  - SCALA (POWER)
  - NISTSTAR (?)
  - STARDICE (POWER)
  - CBP (POWER)