Calibration impact on the performances of a LSST SN survey

F. Hazenberg
LPNHE-Paris
LSST-France (CPPM)

Draft version January 8, 2018
Typeset using LaTeX **twocolumn** style in AASTeX61

IMPACT OF THE CALIBRATION ON THE PERFORMANCES OF THE LSST SN SURVEY

F. Hazenberg,[1] M. Betoule,[1] S. Bongard,[1] L. Le Guillou,[1] N. Regnault,[1] P. Gris,[2] and ...[3]
(LSST Dark Energy Science Collaboration)

[1] *LPNHE, CNRS-IN2P3 and Universités Paris 6 & 7, 4 place Jussieu, F-75252 Paris Cedex 05, France*
[2] *LPC Clermont*
[3]

ABSTRACT

We study the impact of the LSST SN survey calibration, parametrized on one side as random errors in the zeropoint of each filter (δ_{zp}'s) and on the other as shifts in wavelength of each filter (δ_λ's), on the accuracy of the cosmological constraints we will extract from LSST. We perform a set of simulation of a typical LSST SNe Ia survey. The standardization of the SNe Ia, their spectrophotometric evolution, the cosmology and the calibration parameters are fitted at the same time to capture all possible interactions between the parameters. We show that, when all parameters are left free, a nearly complete degeneracy remains between zero points and cosmology, so that accurate external constraints on the flux scale is required. We show that an accuracy of $\leqslant 1mmag$ is required to extract most of the statistical information LSST will bring.

Goals of this study

I. Evaluate the impact of calibration uncertainties on the performances of a LSST SN survey
   A. zeropoints
   B. filter knowledge
II. Formulate requirements for these quantities

Challenges

- Account for ***all*** free parameters in the analysis:
  - Cosmology (***w***, w_a) # 2
  - Standardization (brighter bluer, brighter slower, …) # 2
  - SN properties (color, stretch, …) # 2 x N_{SN}
  - SN spectrophotometric model (aka SALT2 or ..) # 10 000
- Simulation + analysis should work for $N_{SN} = O(10^5)$:
  - fast simulation (many cadences to explore)
  - fast analysis (many calibration hypotheses to test)
  - tractable (single step analysis to ease error propagation)

Method

I. Simulation using snsim package
   A. SALT2
   B. Cadence
   C. Instrument model
II. Single step analysis
   A. Cosmo fit
   B. Standardization : brighter bluer only
   C. SN properties : color
   D. Spectrophotometric model : mean spectrum + color law

Simulation

- Outcome : SN peak magnitudes **and uncertainties** in each observed filter
  - wide : ***griz***
  - deep : ***rizy***
- Speed :
  - 50 SN/s/core
  - This work : 20k SNe, 7 minutes
  - Typical LSST full sample : 100k SNe, 35 minutes (one core)

Analysis model

The magnitude at day max of a supernova at a redshift ***z*** in a band ***b*** expressed as follows:

$$m_b = M_X + P(\frac{\bar{\lambda}_b}{1+z}) + cQ(\frac{\bar{\lambda}_b}{1+z}) + \beta c + \mu(z, \theta_{\mathrm{cosmo}}) + \mathcal{Z}_b$$

Analysis model

The magnitude at day max of a supernova at a redshift ***z*** in a band ***b*** expressed as follows:

Standardization

$$m_b = M_X + P\left(\frac{\bar{\lambda}_b}{1+z}\right) + cQ\left(\frac{\bar{\lambda}_b}{1+z}\right) + \beta c + \mu(z, \theta_{\mathrm{cosmo}}) + \mathcal{Z}_b$$

Spectrophotometric model

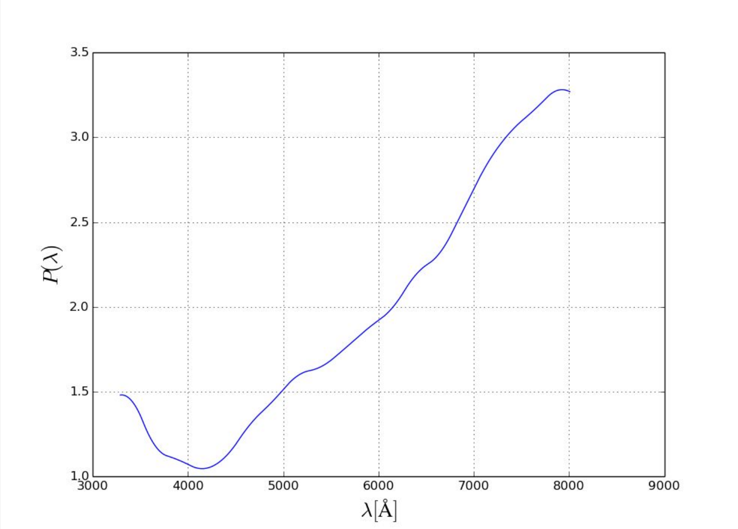
Cosmology

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

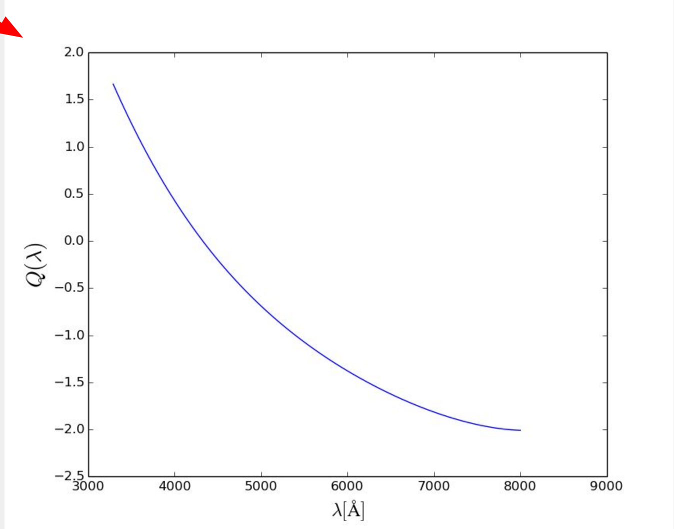
Analysis model

The magnitude at day max of a supernova at a redshift ***z*** in a band ***b*** expressed as follows:

$$m_b = M_X + P(\frac{\bar{\lambda}_b}{1+z}) + cQ(\frac{\bar{\lambda}_b}{1+z}) + \beta c + \mu(z, \theta_{\mathrm{cosmo}}) + \mathcal{Z}_b$$



SN Ia SED : developped over a B-spline basis of order 3

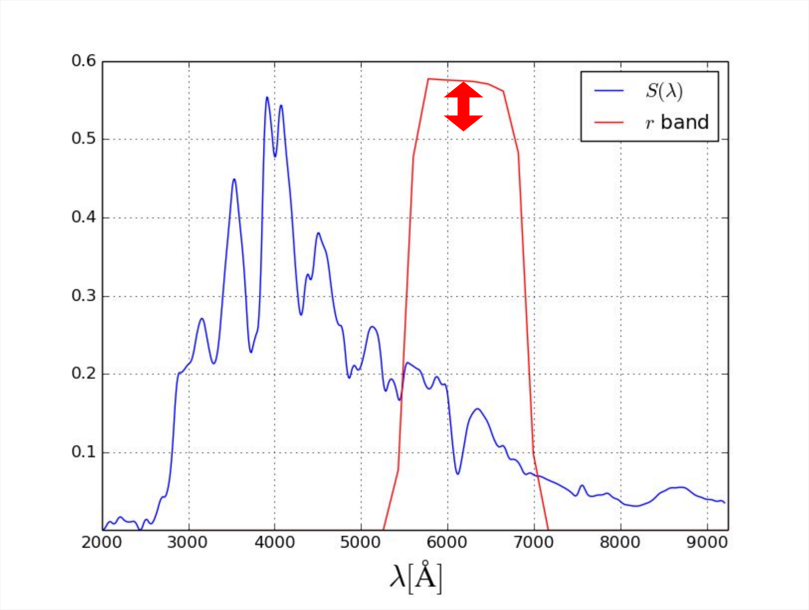


SN Ia Color law: Polynomial of order 4

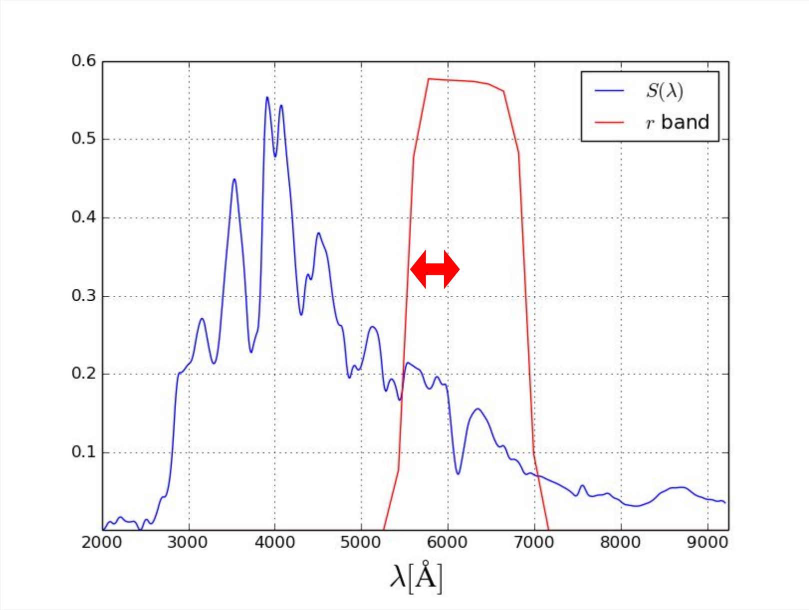
Calibration parameters

Our calibration parameters are (for each band):

Error on the instrument zeropoint: $\boldsymbol{\delta zp}$



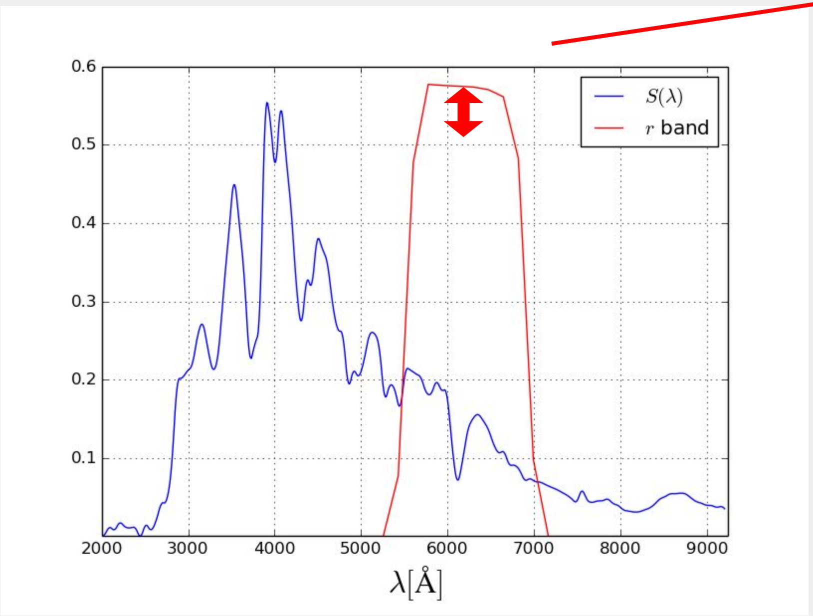
Error on filter mean wavelength: $\boldsymbol{\delta\lambda}$

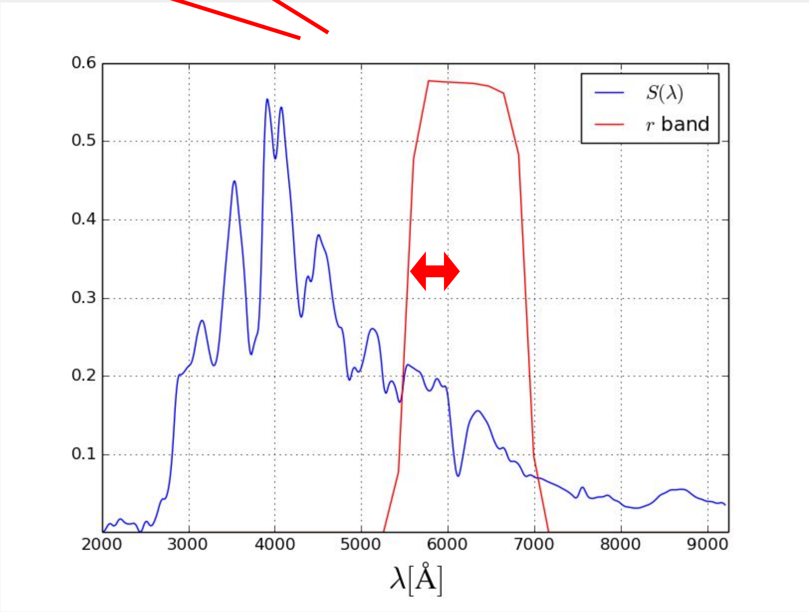


Calibration parameters

If we add calibration uncertainties as parameters, our model becomes:

$$m_b = M_X + P\left(\frac{\bar{\lambda}_b + \delta\lambda_b}{1+z}\right) + cQ\left(\frac{\bar{\lambda}_b + \delta\lambda_b}{1+z}\right) + \beta c + \mu(z, \theta_{\mathrm{cosmo}}) + \mathcal{Z}_b + \delta z p_b$$





Propagation of uncertainties

We compute the uncertainties on the fit parameters from the inverse of the Fisher information matrix ***F***

$$F = J^T C^{-1} J$$

Jacobian matrix :our model derivatives wrt free parameters (including calibration parameters)

We only compute the block of $\boldsymbol{F^{-1}}$ corresponding to cosmology parameters (much faster)

We add prior information on calibration parameters representative of actual calibration uncertainties:

$$C_s = \begin{pmatrix} cov(\delta zp, \delta zp) & cov(\delta zp, \delta\lambda) \\ cov(\delta\lambda, \delta zp) & cov(\delta\lambda, \delta\lambda) \end{pmatrix}$$

Ongoing validation of the framework

Crude simulation of a dataset representative of the JLA sample:

- **740** well sampled SNe Ia
- From **SNLS + SDSS + HST + low z**
- 32 different bands
- $\longrightarrow$ 64 x 64 calibration covariance matrix

Our simulation + analysis reproduces:

- roughly the statistical uncertainty of Betoule et al. (2014)
- exactly the scaling due to calibration errors

Forecast on a typical LSST SN survey data sample

Simulated data sample

- A wide ($z < 0.4$) and a deep ($0.1 < z < 0.9$) layer
- "***griz***" bands for Wide, "***rizy***" for Deep
- 30s exposure for Wide, 1200-1800s for Deep
- cadence of 3 days both
- ~ 10k SNe Ia in each → **20k** well sampled SNe Ia in total
- SNR always > 20

Calibration covariance matrix (zp and filters position)

Non-diagonal terms from the calibration strategy

Variation of the flux integration of a CALSPEC standard with a 1Å shift of the filter

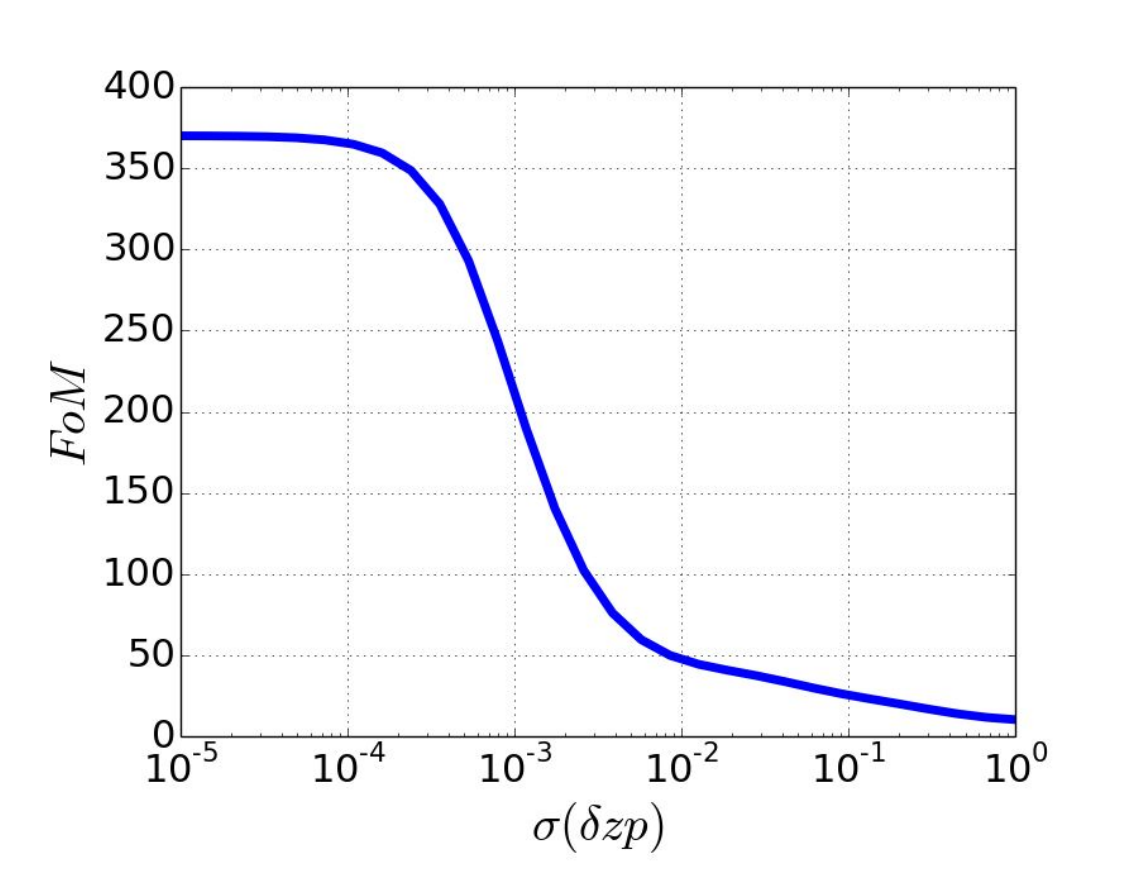
ZP cov

$$C_s = \begin{pmatrix} \sigma^2_{zp_g} + (\sigma_{\lambda_g} \frac{\partial zp_g}{d\lambda_g})^2 & 0 & \frac{\partial zp_g}{\partial \lambda_g}\sigma^2_{\lambda_g} & 0 \\ 0 & \ddots & 0 & \ddots \\ \frac{\partial zp_g}{\partial \lambda_g}\sigma^2_{\lambda_g} & 0 & \sigma^2_{\lambda_g} & 0 \\ 0 & \ddots & 0 & \ddots \end{pmatrix}$$

δλ cov

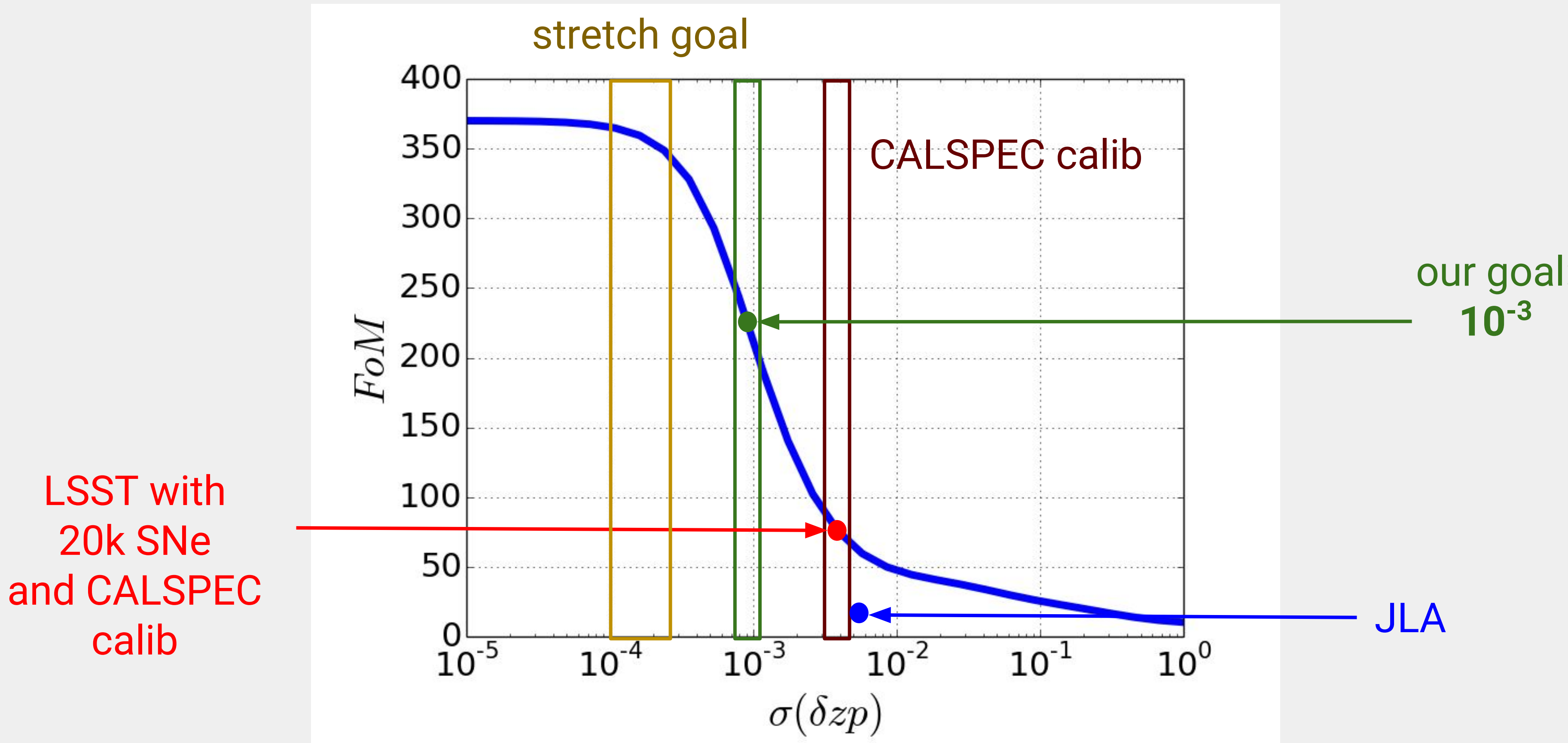
FoM (fixed filter position)

We compute the FoM from the covariance matrix for 2×10^4 SNe Ia :

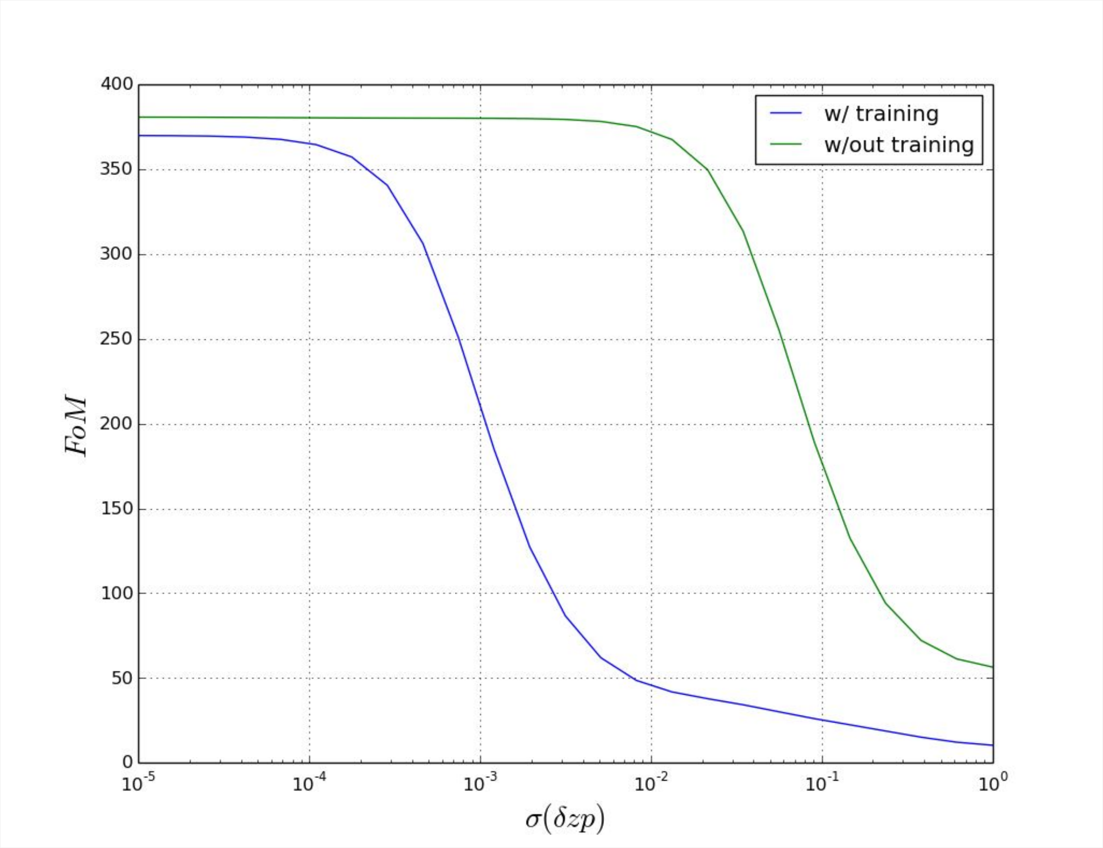


FoM (fixed filter position)

We compute the FoM from the covariance matrix for 2x10^4 SNe Ia :



Without training



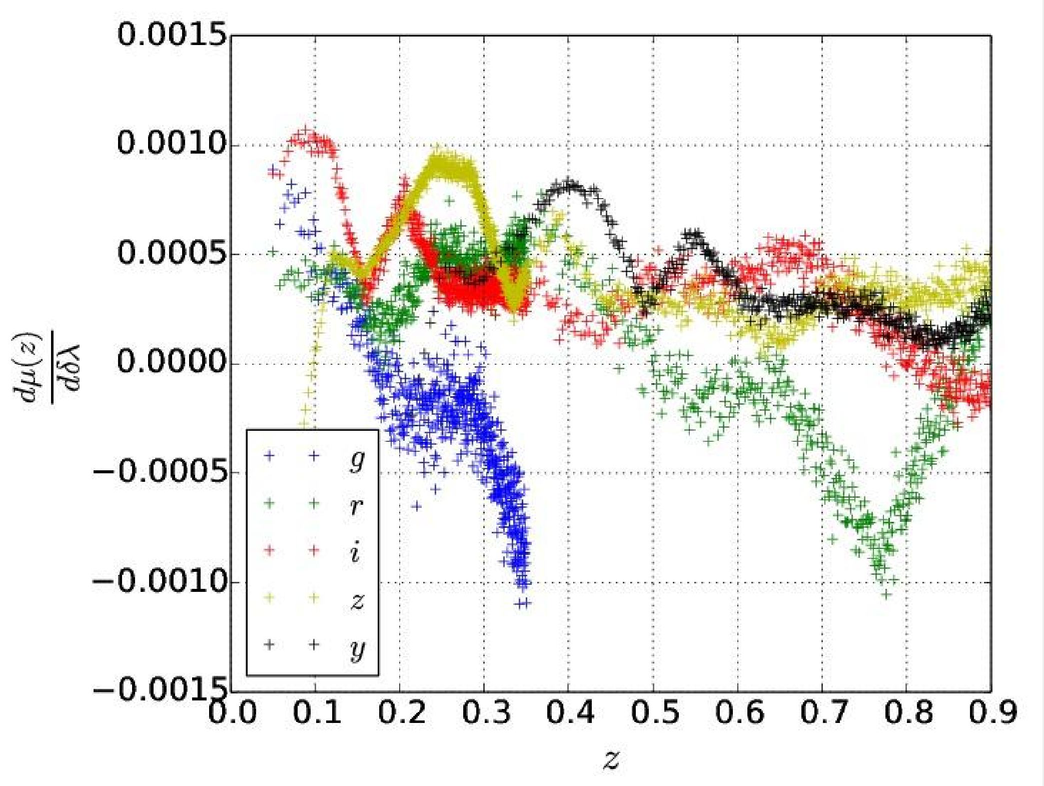
If we do not train the spectrophotometric model : conclusions completely different

→ large overestimation of the performances

Concerning the filters position uncertainties

- Redshift is a fixed parameter
- No SN evolution with redshift
- All SNe Ia are supposed to have the same spectral shape

Model derivatives wrt filter position error



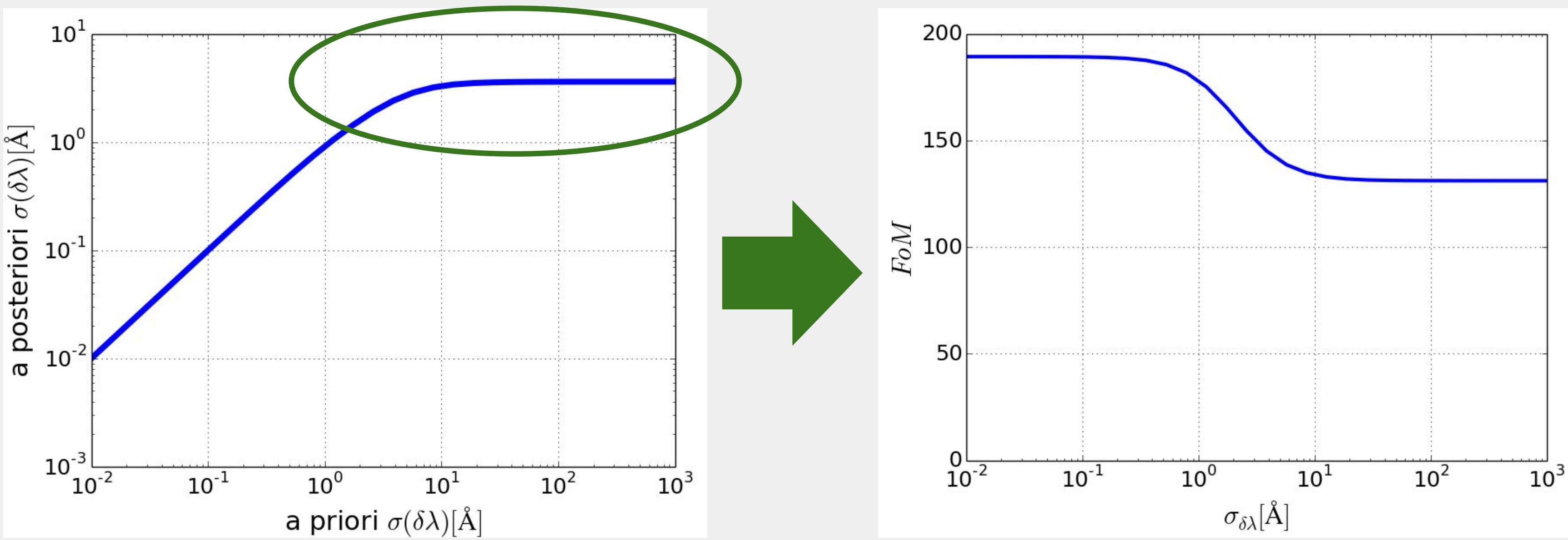
Wiggles introduced in the Hubble Diagram by filter shifts:

→ Spotted and erased by the fit of a smooth cosmology

Concerning the filters position uncertainties

So filter position uncertainty has very little effect on the performances.

uncertainty on filter position constrained by the SNe



This auto-calibration will weaken as we refine the training of the model

Conclusion

- Code to simulate $O(10^5)$ SNe analysis including training in less than 1 hour
- Training has to be taken into account
- Requirements on the ZP of 1 mmag
- A note detailing this work will be distributed soon

Perspectives

- Use a more realistic observation cadence
- Add SN spectral diversity
- Add the phase dimension to the model
- Study the impact of the cadence on the performances
- Make the code available to the collaboration