Calibration impact on the performances of a LSST SN survey

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

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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 ($\boldsymbol{w}$, $\boldsymbol{w_a}$) — # 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 $N_{SN} = O(10^4)$:
  - 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 : 35k SNe → ~15 minutes

Analysis model

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

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

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Spectrophotometric model

Cosmology

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

Calibration parameters

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

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

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: analysis = **1s** for a 35k SNe Ia dataset)

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

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

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
- → 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

Wide layer (z<0.4)	g	r	i	z
T_{exp}	30	30	30	30
$m_{5\sigma}$	24.83	24.35	23.88	23.30
cadence [days]	7.7 / 13.6	2.9 / 5.6	4.3 / 8.2	3.3 / 6.7
Target amplitude SNR	> 30	> 40	> 30	> 20

2000 spectroscopically confirmed SNe Ia per year

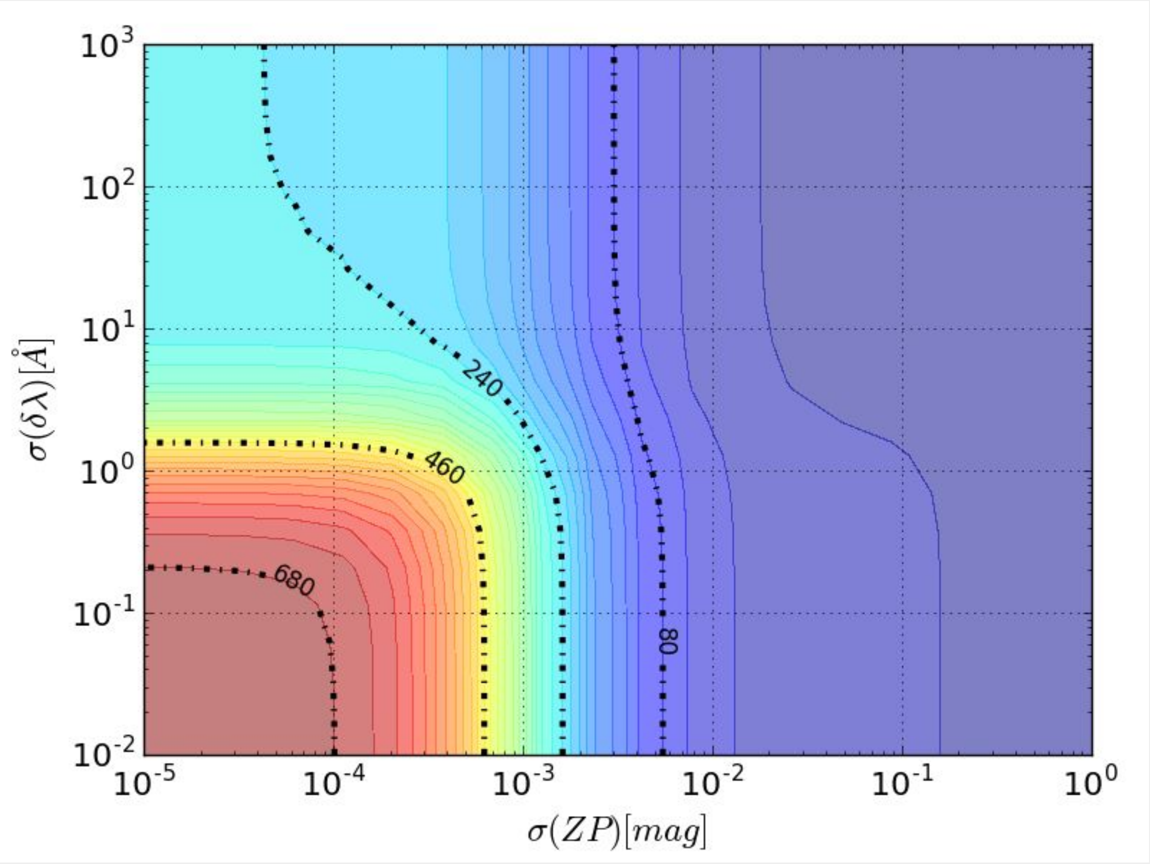
Deep layer (z<0.9)	r	i	z	y
T_{exp}	600	600	720	600
$m_{5\sigma}$	26.43	26.16	25.56	24.68
cadence [days]	5 days			
Target amplitude SNR	> 25	> 60	> 35	> 20

1500 spectroscopically confirmed SNe Ia per year

Total of **3500 SNe/year** (dataset size used by Dan Scolnic and Renée Hložek)

Results on the FoM

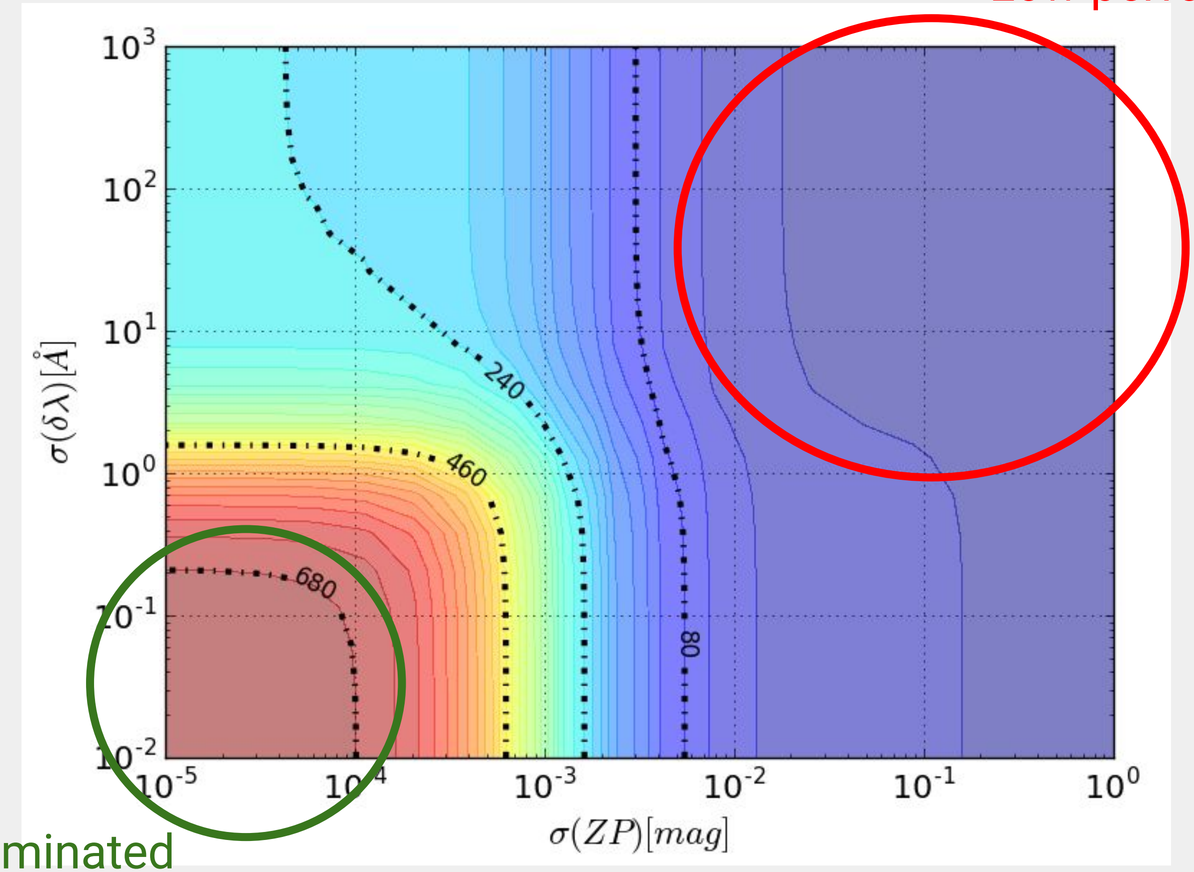
FoM isocontours computed for the ten years survey (35k SNe) with 400 different combinations of a priori knowledge on the **filter zeropoint**, and **mean wavelength position**.



Results on the FoM

FoM isocontours computed for the ten years survey (35k SNe) with 400 different combinations of a priori knowledge on the **filter zeropoint**, and **mean wavelength position**.

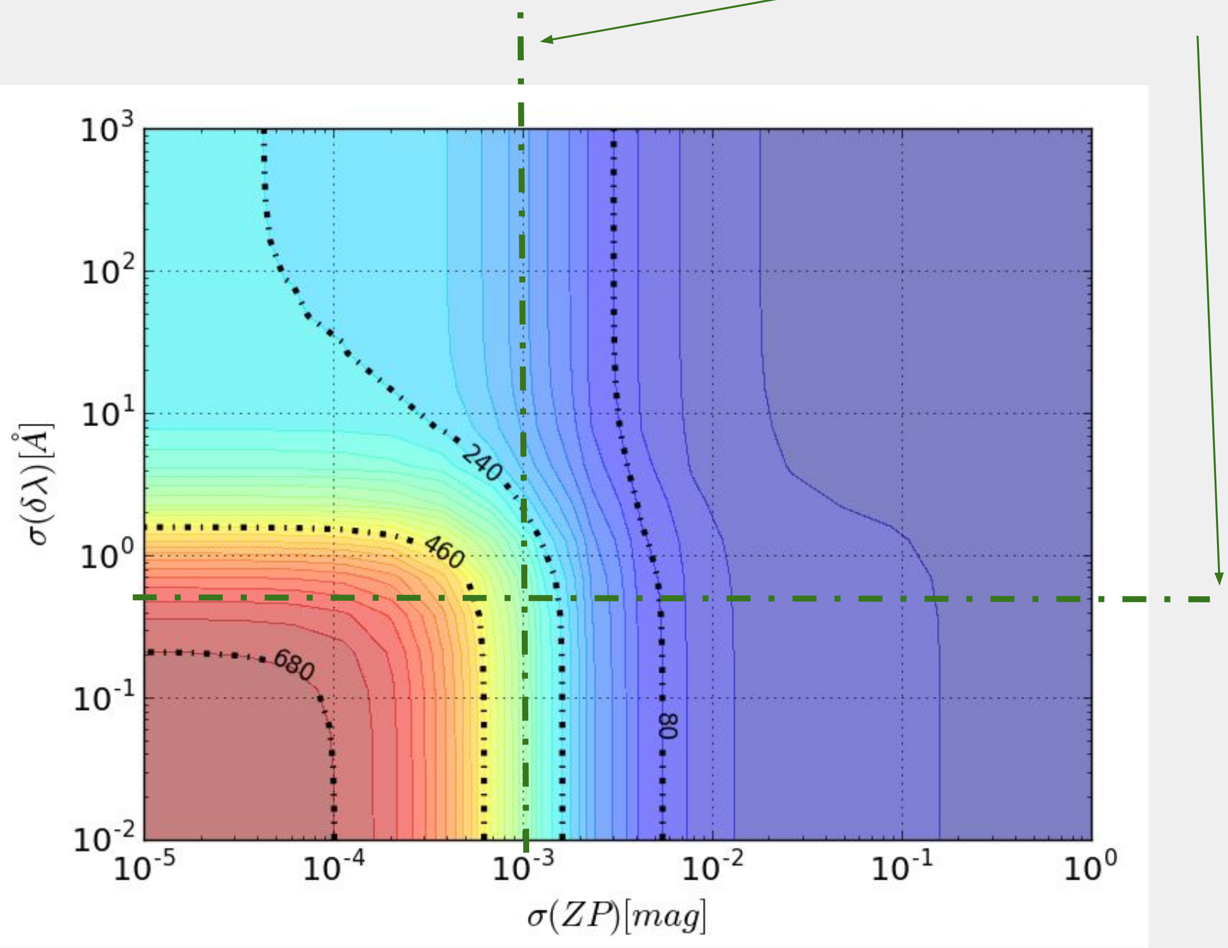
Low performances



Statistics dominated

Results on the FoM

DESC SRD v0.9 requirements



SRD requirements → 0.5 x max FoM

Conclusion

- Code to simulate $O(10^5)$ SNe analysis including training in less than 1 hour
- Stage IV - like analysis, including at the same time calibration parameters
- Requirements in agreement with DESC SRD v0.9
- Currently distributing a note detailing this work

Backup

Calibration covariance matrix (zp and filters position)

Non-diagonal terms from the calibration strategy

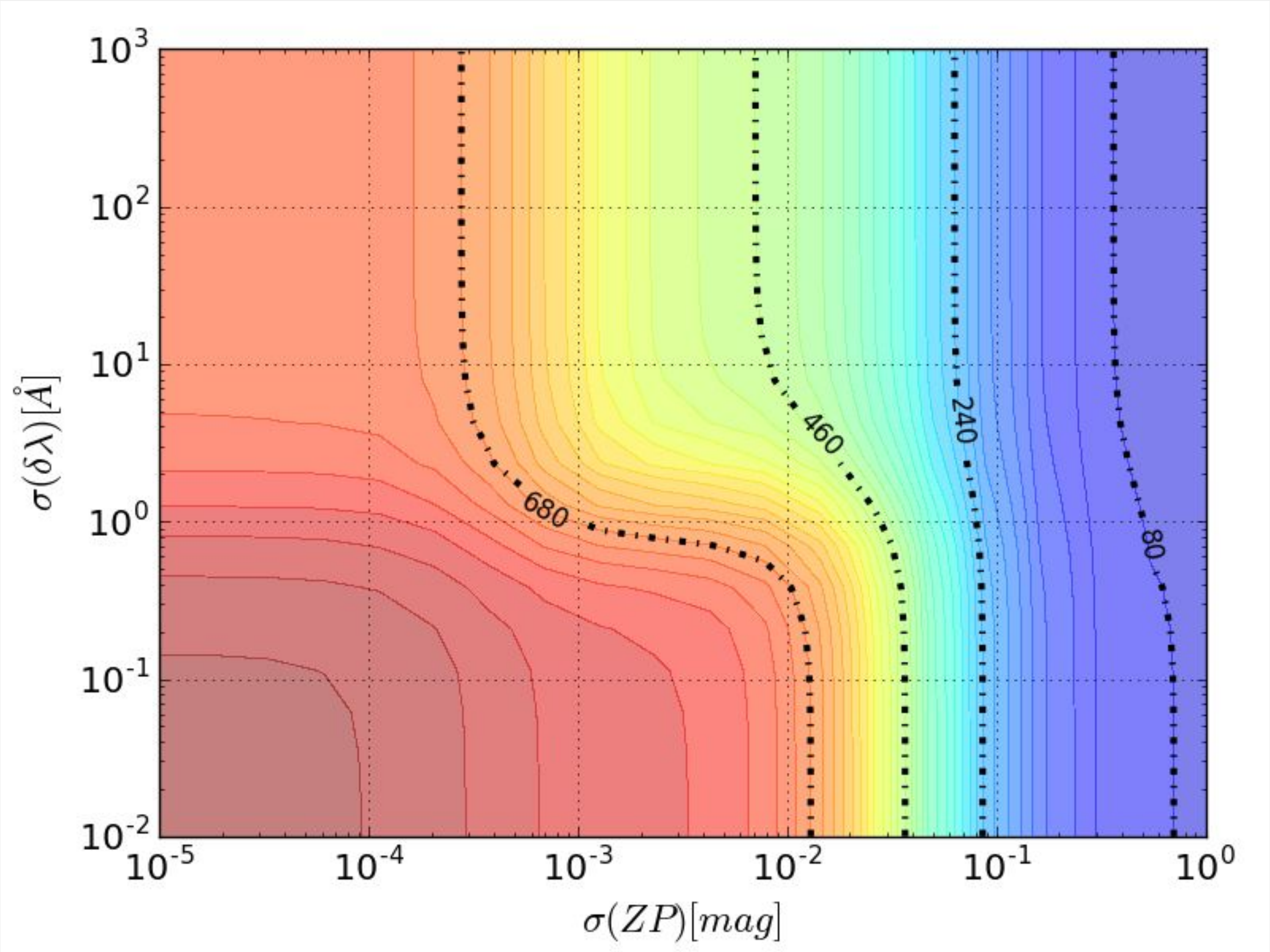
Variation of the flux integration of a CALSPEC standard with a 1Å shift of the filter

ZP cov

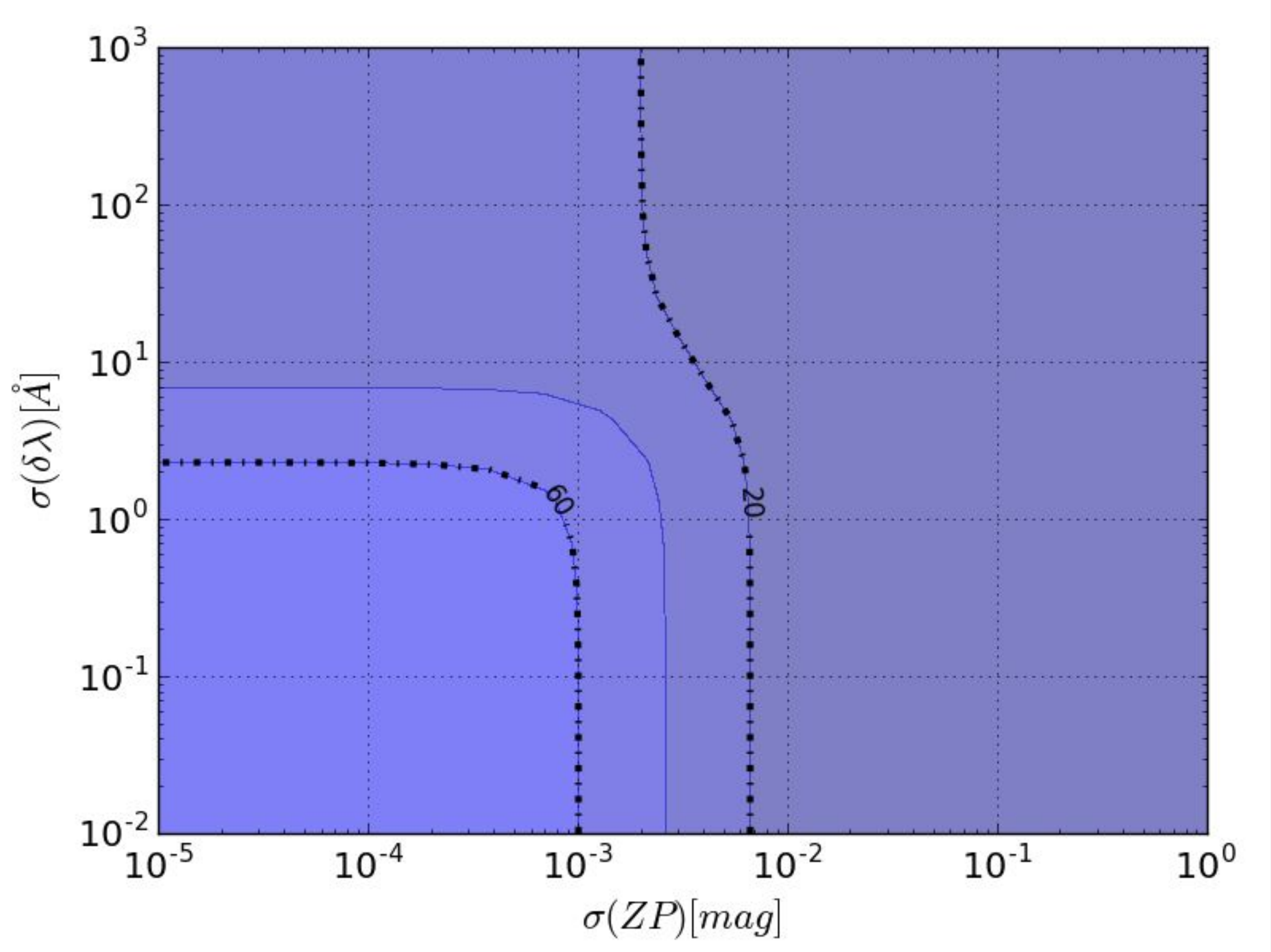
$$C_s = \begin{pmatrix} \sigma^2_{zp_g} + (\sigma_{\lambda_g} \frac{\partial zp_g}{d\lambda_g})^2 & 0 & \frac{\partial zp_g}{\partial \lambda_g}\sigma^2_{\lambda_g} & 0 \\ 0 & \ddots & 0 & \ddots \\ \frac{\partial zp_g}{\partial \lambda_g}\sigma^2_{\lambda_g} & 0 & \sigma^2_{\lambda_g} & 0 \\ 0 & \ddots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

δλ cov

Training of the model



FoM at 1 year



10^3
10^2
10^1
10^0
10^{-1}
10^{-2}
$\sigma(\delta\lambda)[\mathring{A}]$
60
20
10^{-5}
10^{-4}
10^{-3}
10^{-2}
10^{-1}
10^0
$\sigma(ZP)[mag]$

FoM at 5 years