NaCl : what is it?

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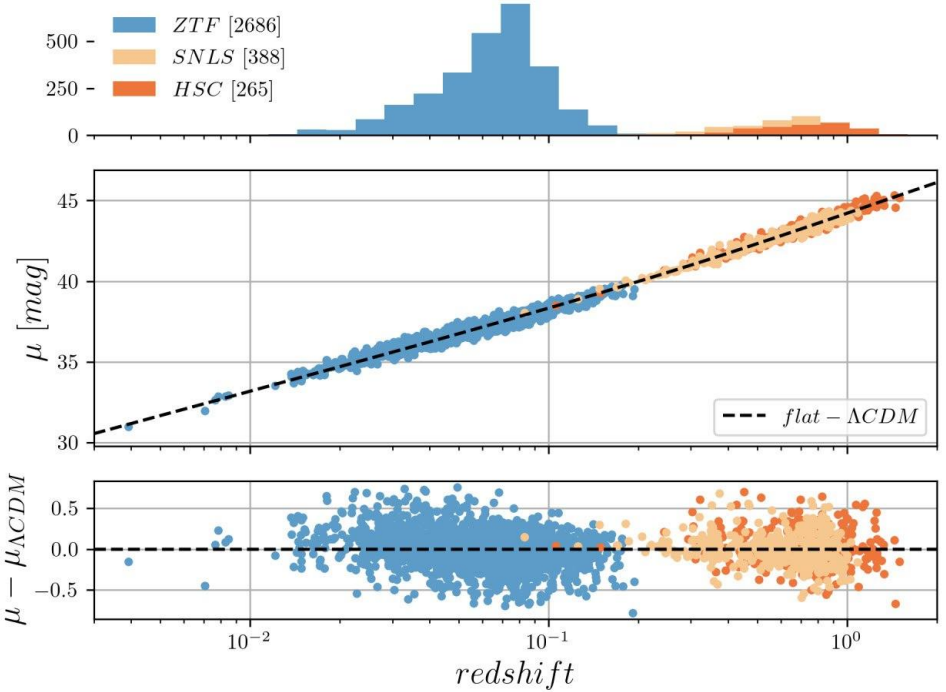
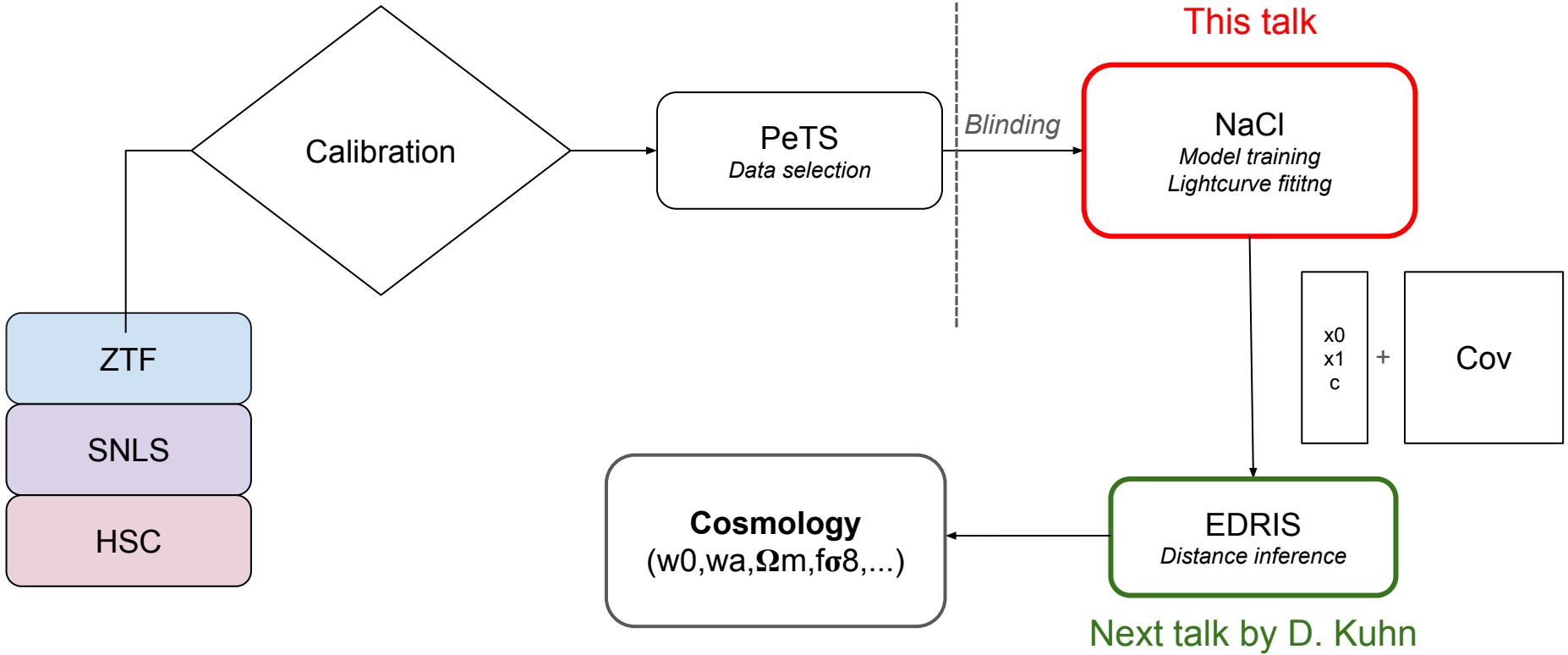
LEMAîTRE (Latest Extensive Mapping of Acceleration with Independent Troves of Redshifted Explosions)

- The LEMAîTRE project aims at constructing a new and independent Hubble-Lemaitre diagram
- It contains its own **new analysis pipeline** from extracting SN Ia lightcurves from pixels to the cosmological analysis
- This allows us to tackle multiple known issues that were previously complicated to address

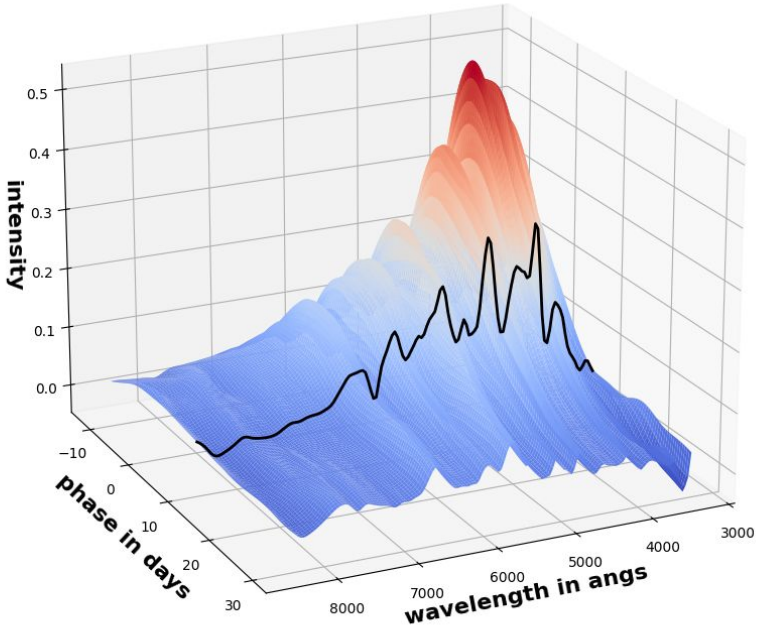


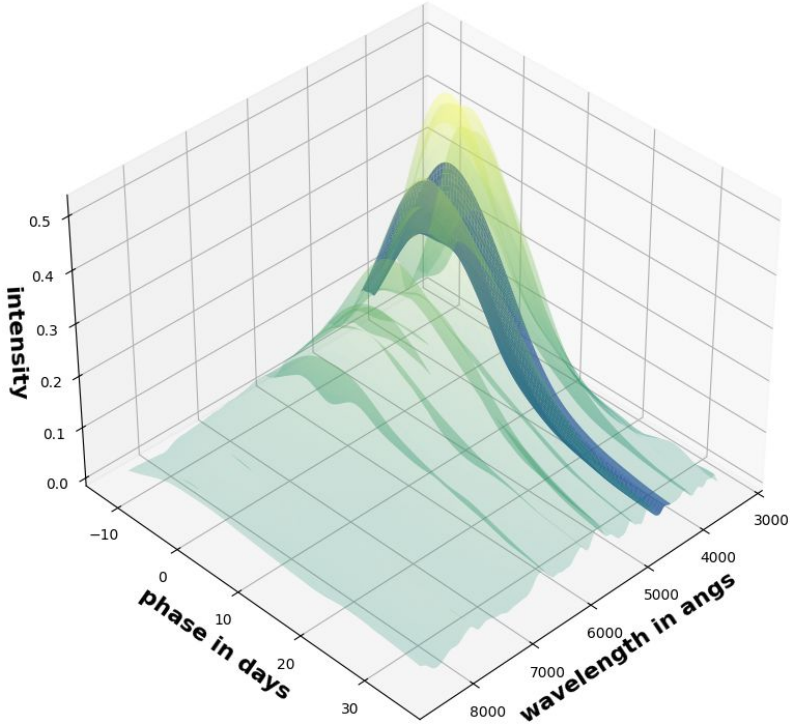
LEMAÎTRE pipeline



SN Ia spectrophotometric modelling

- We interpolate the SN Ia flux from a spectrophotometric model : slice in phase





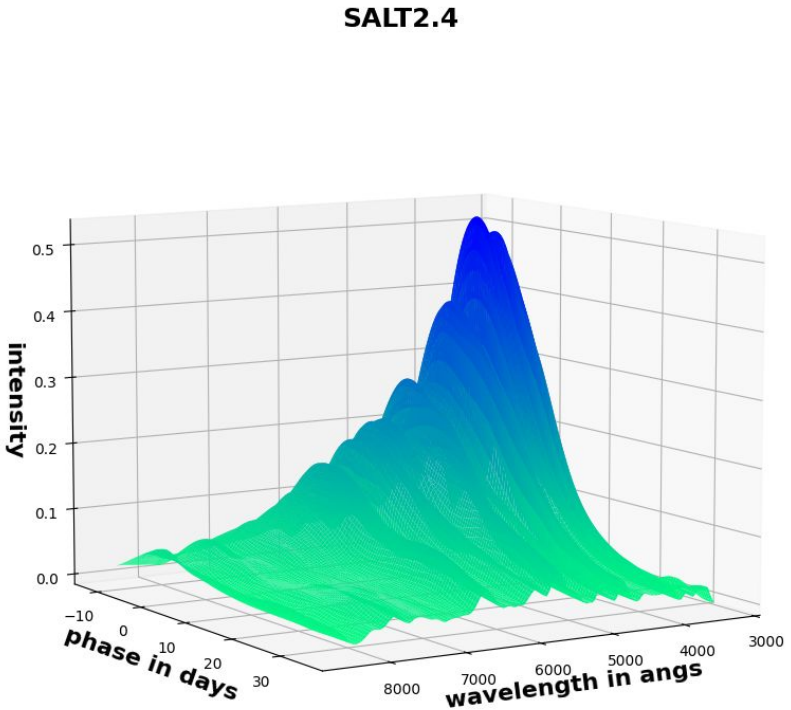
SN Ia spectrophotometric modelling

- To describe SNe diversity we use spectrophotometric models like SALT2

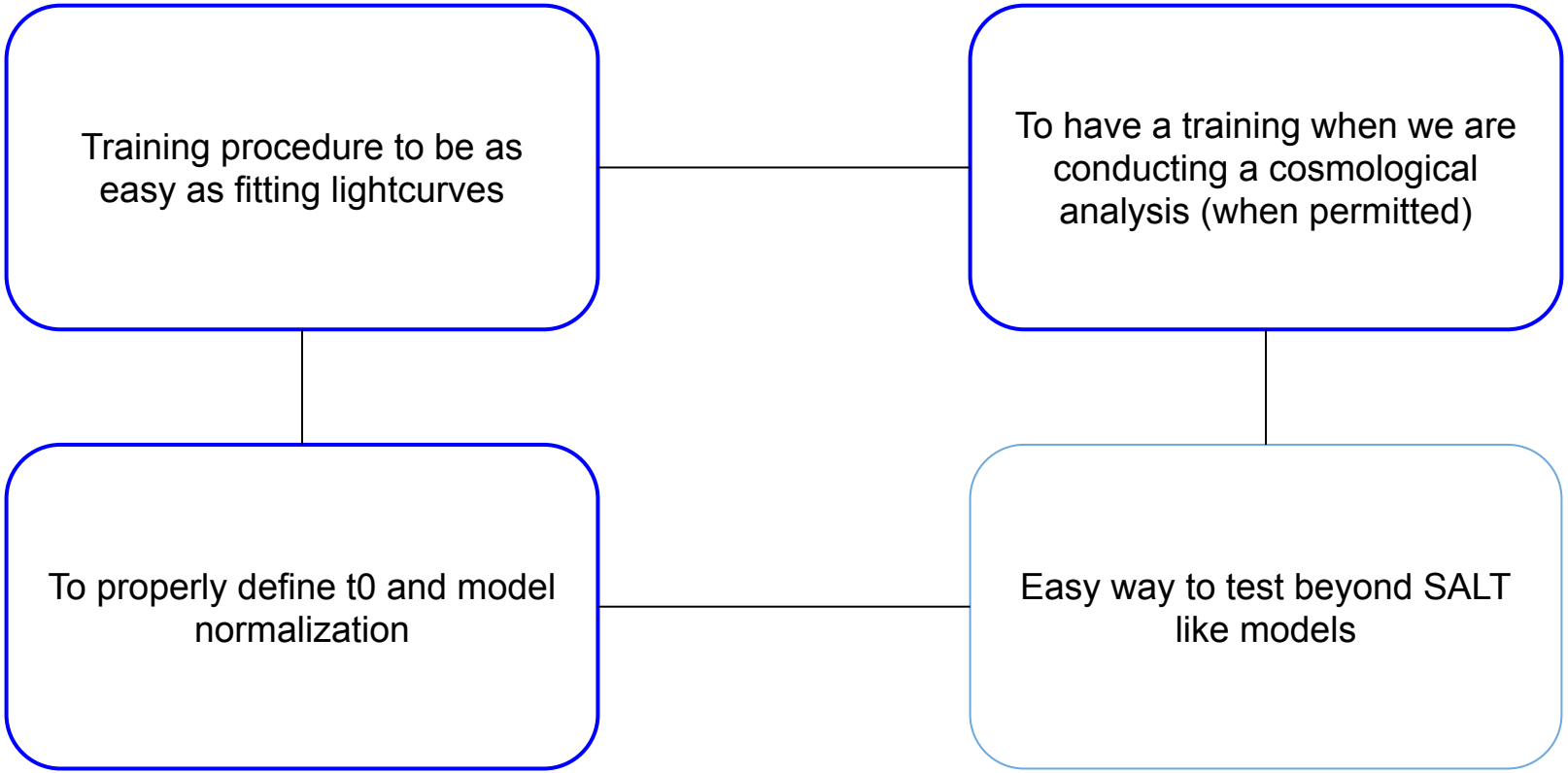
Model

$$S(\lambda, \mathrm{p}) = X_0 \times \left[M_0(\lambda, \mathrm{p}) + X_1 \times M_1(\lambda, \mathrm{p}) \right] \, 10^{0.4cCL(\lambda)}$$

Amplitude Stretch Color



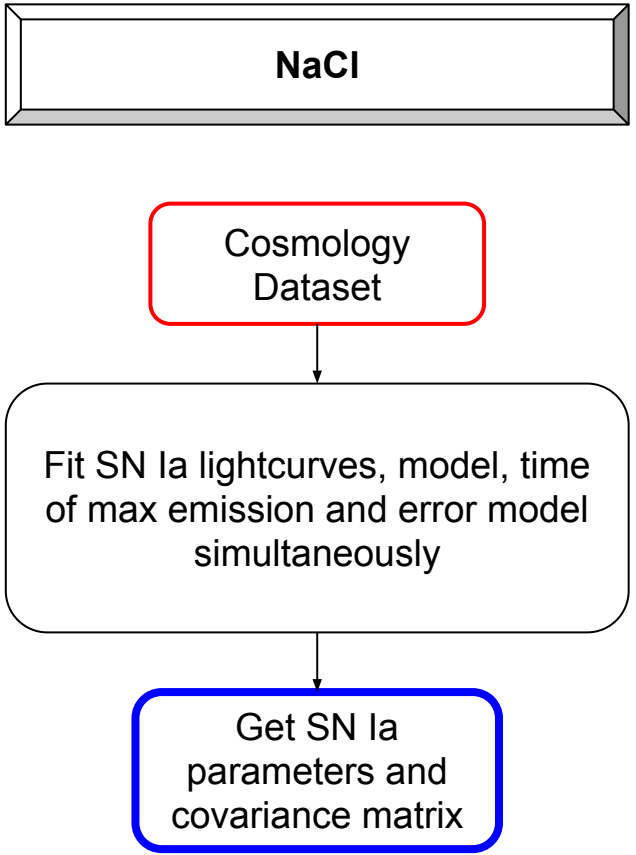
The idea behind NaCl



NaCl : a new framework for training spectrophotometric models

- The training procedure is **simplified into one log likelihood minimisation** which encapsulates the **propagation of measurement, model and calibration uncertainties**

- NaCl is **user friendly**, **fast** for training models and can be easily **reparameterized** to train more sophisticated models



NaCl : Requirements for such a framework

1. Error model fitted during training
2. Fitting t0 and having constraints on model
3. Regularize model
4. Include calibration during training
5. Include color scatter

NaCl : Requirements for such a framework

Error model (error snake) : To capture the variabilities from one SN to another we fit an error snake model

$$-2\log\left(\mathscr{L}(\beta)\right) = N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R}$$

$$\mathbf{V}^{-1} = (\mathbf{V}_{\text{meas}} + \mathbf{V}_{\text{model}})^{-1}$$

Where

$$\mathbf{V}_{\text{model}} = \begin{cases} \left(\sigma(\lambda, p) \times \gamma_{\text{SN}} \times \text{flux}\right)^2 \\ \dots \\ \left(\gamma \times \text{flux}\right)^2 \end{cases}$$

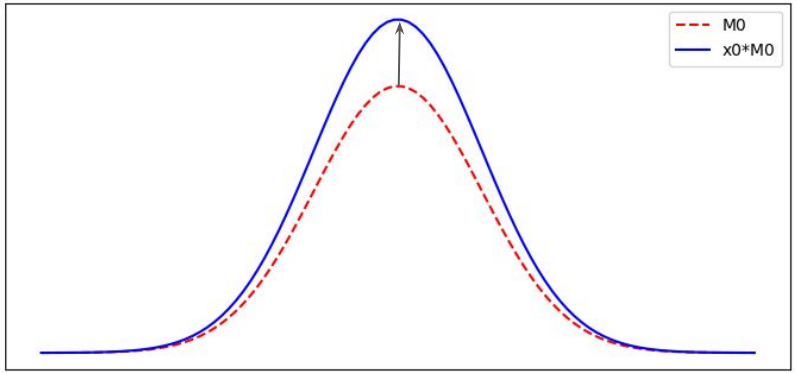
NaCl : Requirements for such a framework

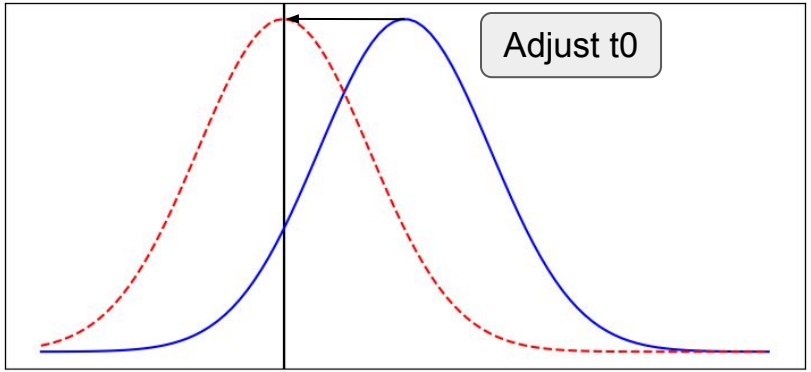
Model constraints and tmax fit : The model contains degeneracies between the model parameters and SN parameters when it comes to the definition of **color**, **normalization** and **time of maximum emission in the B band**

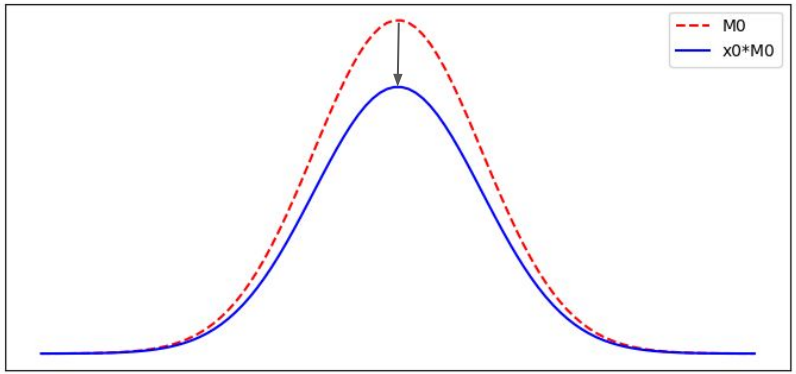
$$-2\log\big(\mathscr{L}(\beta)\big) = N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R}$$
$$+ \mu_{cons}\mathbf{C}(\beta)^T\mathbf{C}(\beta)$$

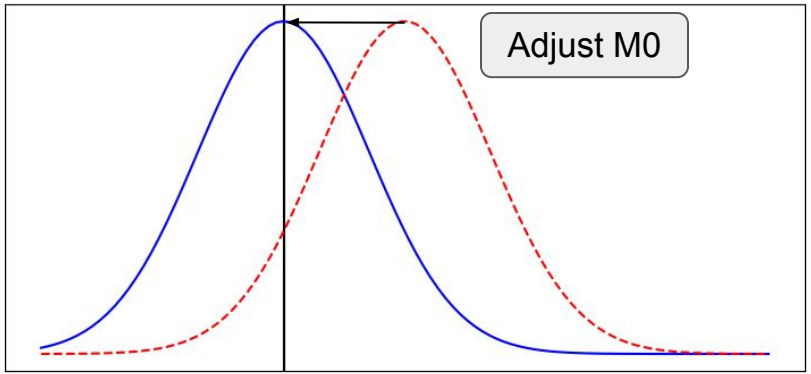
NaCl : Requirements for such a framework

Model constraints and tmax fit : examples









NaCl : Requirements for such a framework

Model constraints and tmax fit : The constraints in NaCl are different to what we have in SALT

$$\int M_0(\lambda, p=0)\, T_B(\lambda) \frac{\lambda}{hc} d\lambda = 1 \qquad \int \frac{\partial M_0(\lambda, p=0)}{\partial t}|_{t=t_B} = 0$$

$$\int M_1(\lambda, p=0)\, T_B(\lambda) \frac{\lambda}{hc} d\lambda = 0 \qquad \int \frac{\partial M_1(\lambda, p=0)}{\partial t}|_{t=t_B} = 0$$

The constraints in NaCl are evolving to be fully independent of the dataset

$$< (X_1 - < X_1 >)^2 >= 1 \rightarrow \int M_1(\lambda, p=15)\, T_B(\lambda) \frac{\lambda}{hc} d\lambda = 1$$

NaCl : Requirements for such a framework

Model regularization : Parts of the model won't be constrained by any data so we add a penalty term, model regularization, to adjust the model in those areas

$$-2\log\left(\mathscr{L}(\beta)\right) = N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R} + \mu_{cons}\mathbf{C}(\beta)^T\mathbf{C}(\beta) + \mu_{reg}\beta^T\mathbf{P}\beta$$

NaCl : Requirements for such a framework

Calibration uncertainties : We take into account the calibration uncertainties by fitting **a parameter per band** which are held by **prior** calculated with the **predetermined covariance matrix of the filters**

$$-2\log\left(\mathscr{L}(\beta)\right) = N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R} + \mu_{cons}\mathbf{C}(\beta)^T\mathbf{C}(\beta) + \mu_{reg}\beta^T\mathbf{P}\beta + \eta^T\mathbf{V}_\eta^{-1}\eta$$

NaCl : Requirements for such a framework

Color scatter : We take into account the intrinsic variation of the color of each SN

Currently we fit **a parameter per lightcurve** held by **prior** that is fitted during the training

This current implementation will change due to the fact that we have SNe measured in **only 2 bands** with ZTF

$$
\begin{aligned}
-2\log\left(\mathscr{L}(\beta)\right) = {} & N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R} \\
& + \mu_{cons}\mathbf{C}(\beta)^T\mathbf{C}(\beta) + \mu_{reg}\beta^T\mathbf{P}\beta \\
& + \eta^T\mathbf{V}_\eta^{-1}\eta + \log(|\mathbf{V}_\kappa(\sigma_\kappa)|) + \kappa^T\mathbf{V}_\kappa^{-1}(\sigma_\kappa)\kappa
\end{aligned}
$$

Nacl : Likelihood

Model constraints

Classic likelihood with

$$\mathbf{V}^{-1} = (\mathbf{V}_{\text{meas}} + \mathbf{V}_{\text{model}})^{-1}$$

$$-2\log(\mathscr{L}(\beta)) = N\log(2\pi) + \log(|\mathbf{V}|) + \mathbf{R}^T\mathbf{V}^{-1}\mathbf{R}$$
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Calibration uncertainty

Color scatter

Model regularization

Nacl : Likelihood

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& + \eta^T\mathbf{V}_\eta^{-1}\eta + \log(|\mathbf{V}_\kappa(\sigma_\kappa)|) + \kappa^T\mathbf{V}_\kappa^{-1}(\sigma_\kappa)\kappa
\end{aligned}
$$

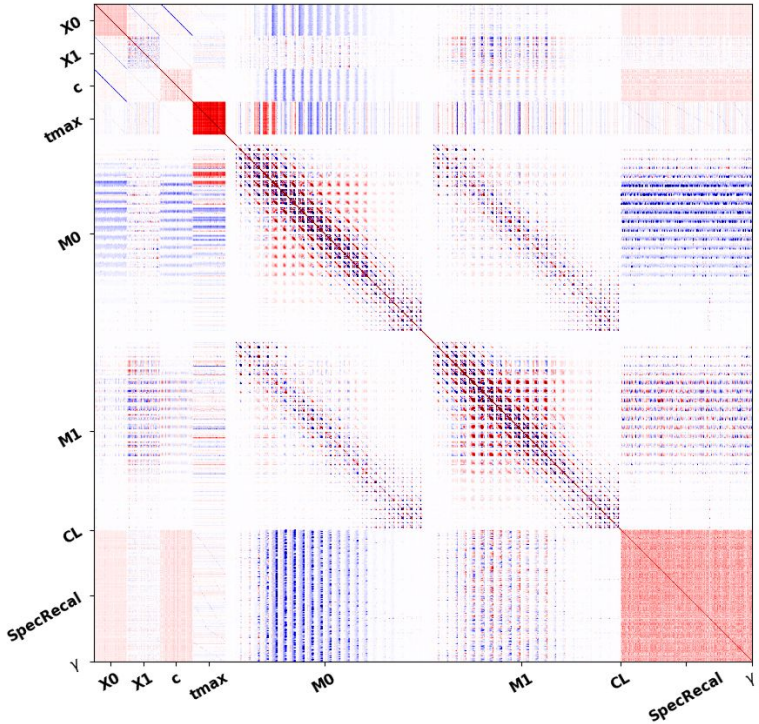
NaCl : a new framework for training spectrophotometric models

- After a training NaCl marginalises over the model parameters and **only keeps the SN parameters used in the cosmological analysis** and their **covariance matrix**

One parameter per SN

A few thousand parameter

$$\begin{bmatrix} X_0 \\ X_1 \\ c \\ t_0 \\ M_0 \\ M_1 \\ CL \\ \dots \end{bmatrix}$$



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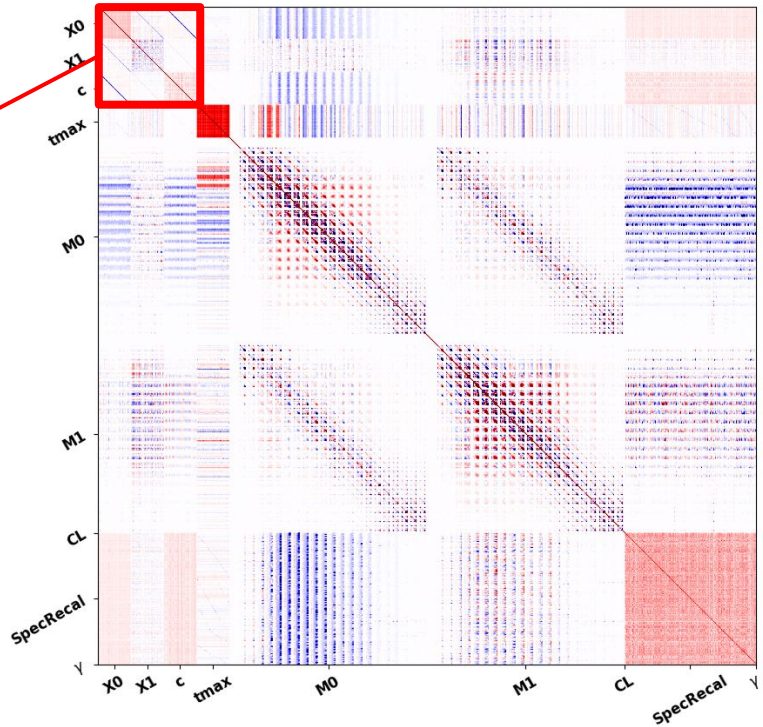


Important technical notes on NaCl

NaCl contains 2 hyper-parameters managing the constraints and regularization

$$\chi^2_{reg} = \mu_{reg} \beta^T \mathbf{P} \beta$$

$$\chi^2_{cons} = \mu_{cons} \mathbf{C}(\beta)^T \mathbf{C}(\beta)$$

- If **μ_reg**'s value is too high the model becomes attenuated and the distances are biased
- If **μ_cons** is too small the constraints are poorly respected in the training and degeneracies appear

We have a heuristic with simulations that allows us to find the correct values of the hyper-parameters

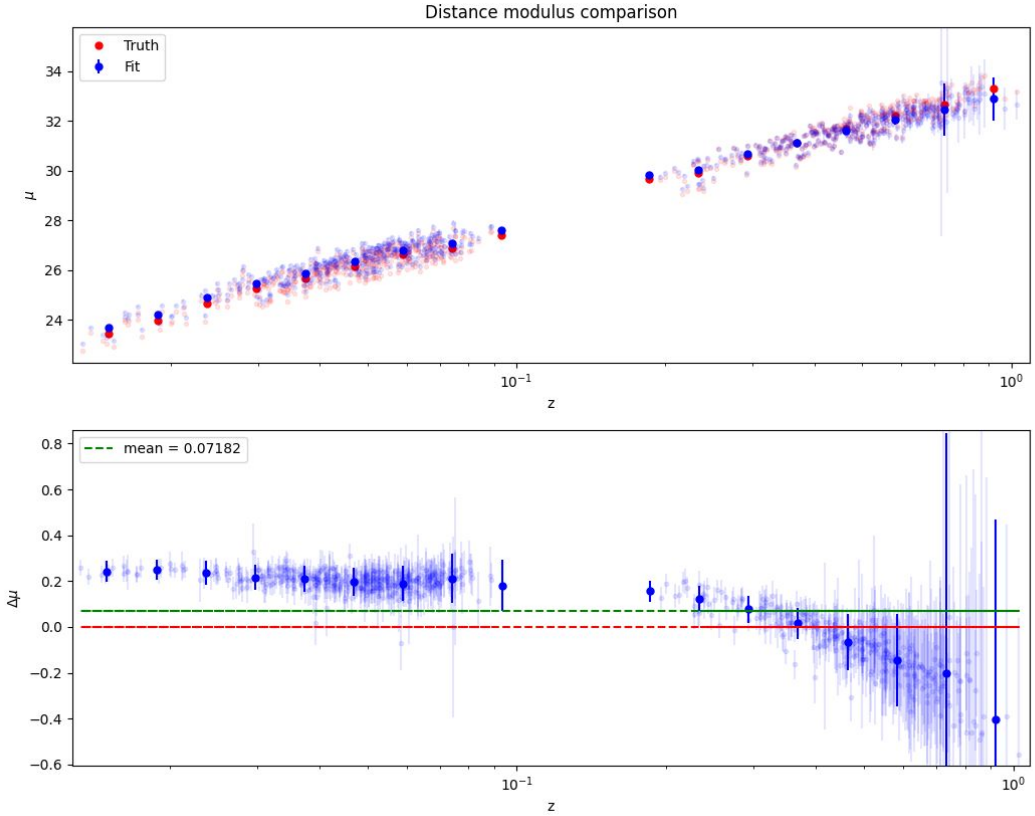
Important technical note on NaCl

- The hyperparameters’ exact values doesn’t need to be known for NaCl to be able to properly train a model

- We noticed issues when we change our hyperparameters by multiple orders of magnitude

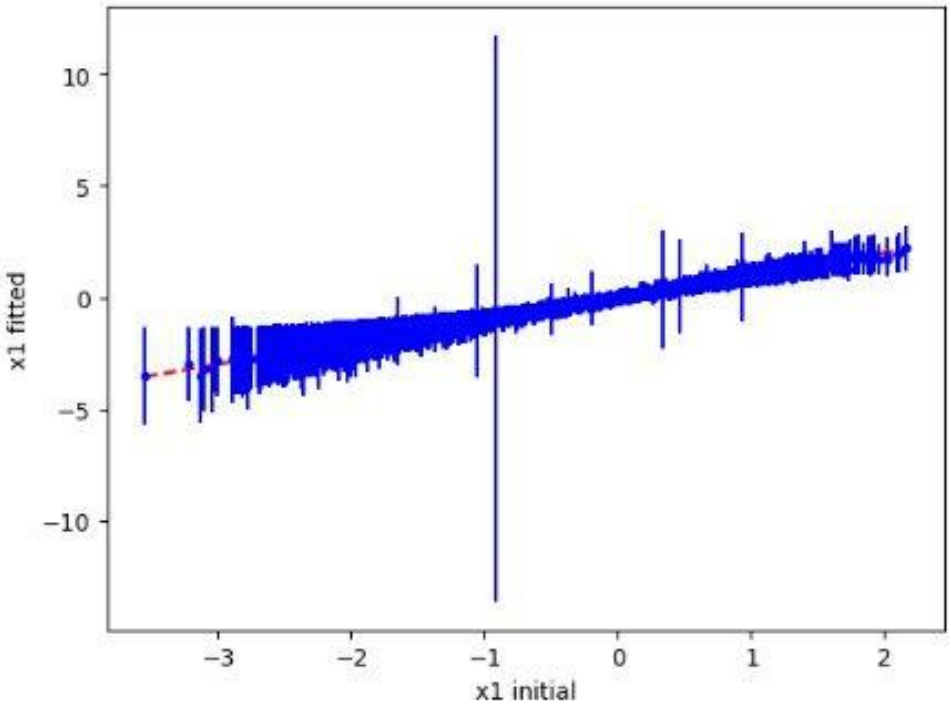
Examples

μ_reg
increased by
1e+4



Examples

μ_cons
decreased by
1e+12



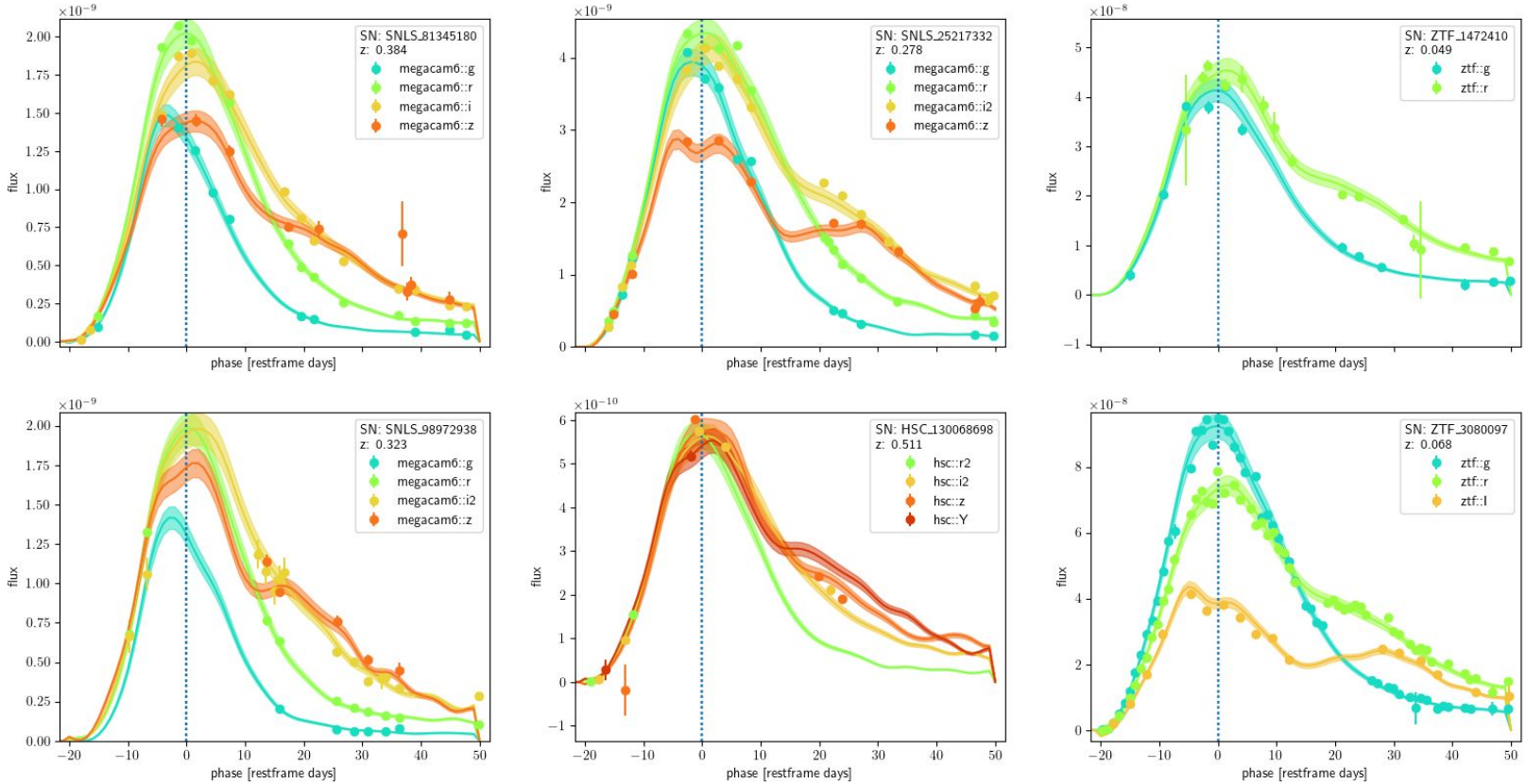
Current developments in NaCl

- Color scatter needs to be reworked due to the current method not being able to work for ZTF SNe measured in only 2 bands (DC3)

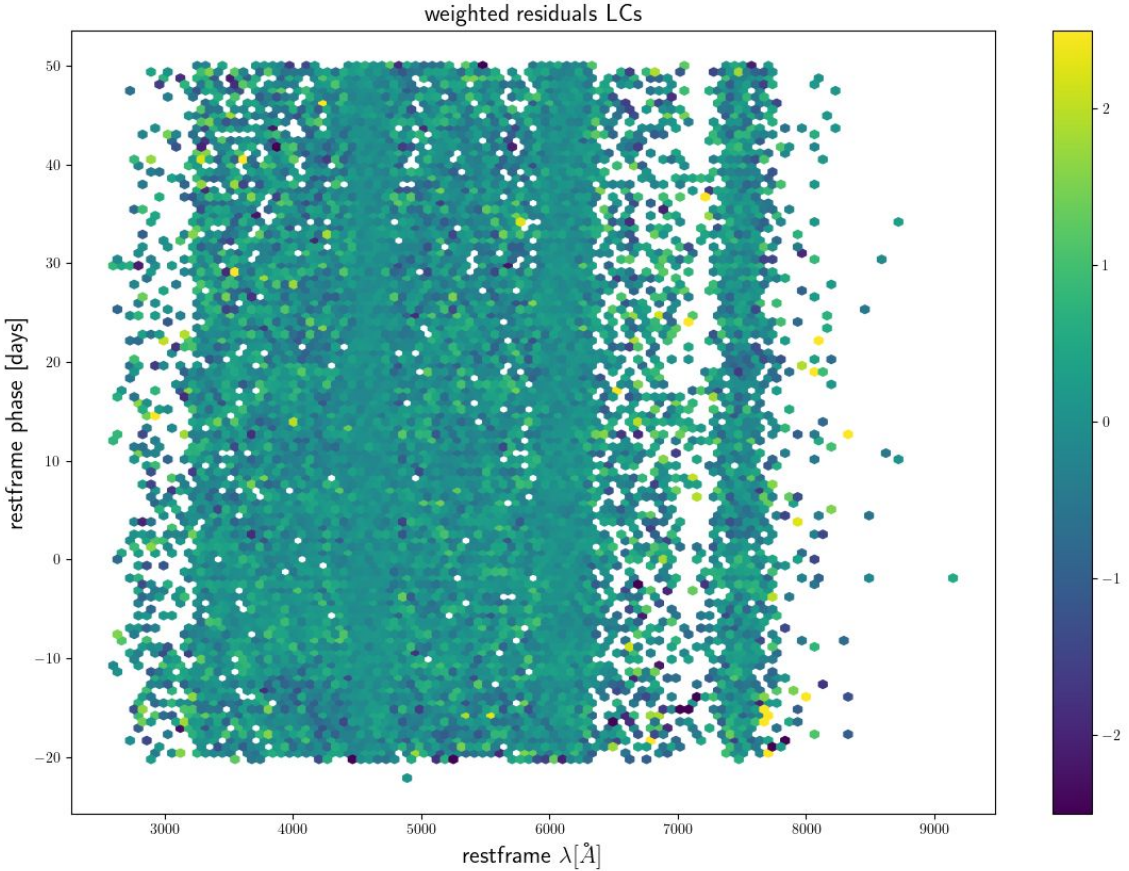
- Account for the calibration mean wavelength uncertainties (DC3)

- Improving what we call the “training recipe” to build a robust starting point to the training

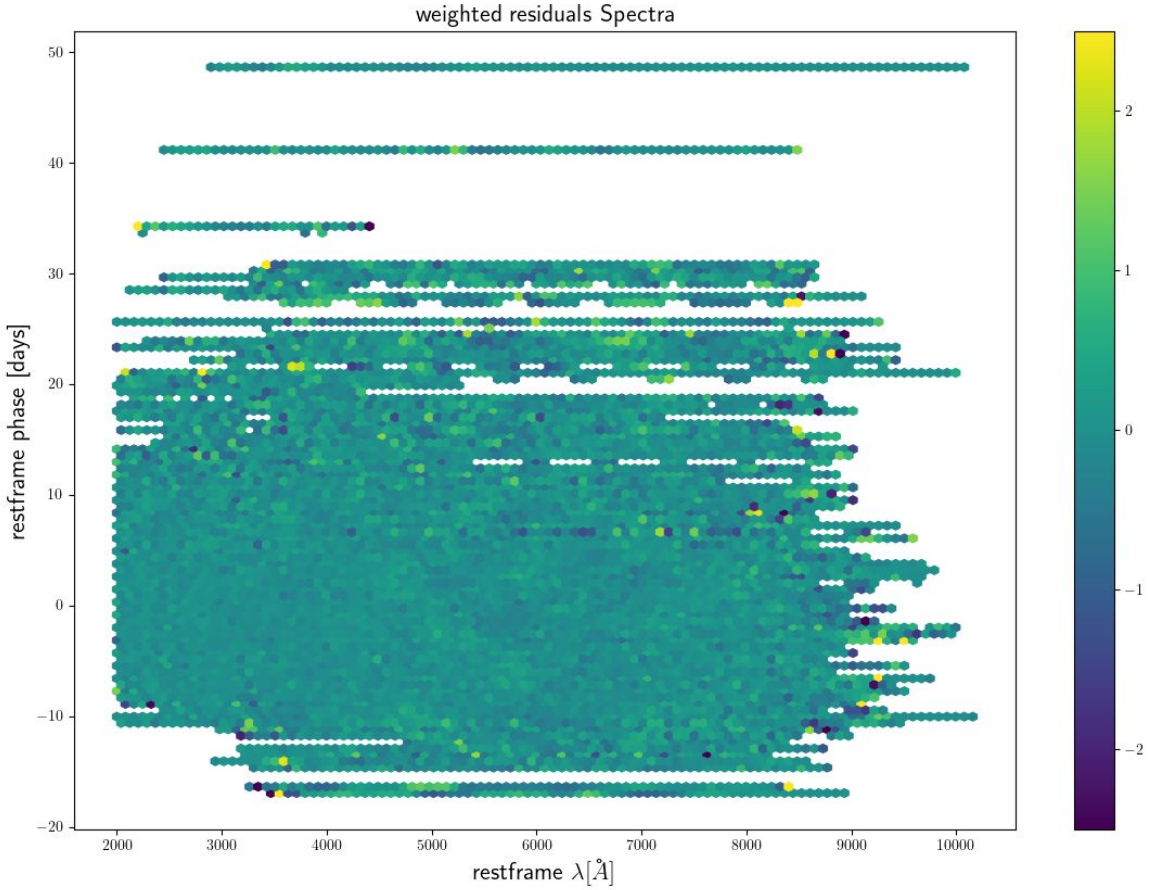
NaCl output with DC1



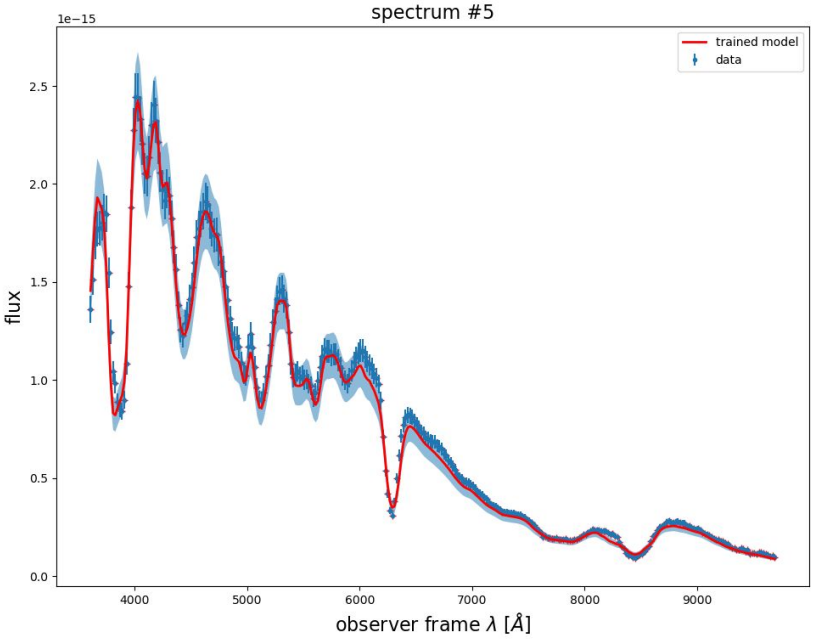
NaCl output with DC1

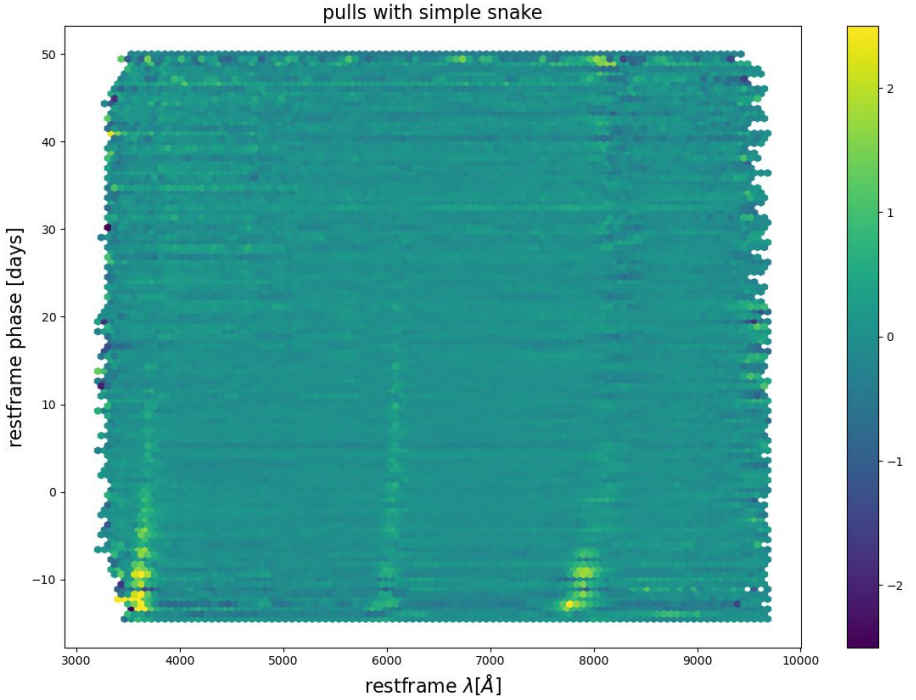


NaCl output with DC1



NaCl output on SNFactory data





NaCl

In short, NaCl is **a framework that trains a spectrophotometric model** on a **cosmological dataset** to ensure an accurate **propagation of measurement, model and calibration uncertainties**

We will show NaCl applied on simulations in the next presentation with the DC1 results…

Important technical notes on NaCl

- NaCl's constraints on the model are different than we have in SALT
- We are working on a set of constraints that do not depend on the dataset, only the model

- If we are working with simulations then **we don't** necessarily **expect** to **reconstruct the same SN parameters** but we do expect to obtain the **same distances**