ZTF-IN2P3
Paris, LPNHE
"NaCl"

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PhD student

Introducing myself

Mahmoud Osman

1st year PhD student at LPNHE (ZTF x DESI)

Under the supervision of Nicolas Regnault (ZTF) and Pauline Zarrouk (DESI)

Part of my work involves looking at a **new way to improve the standardization of type Ia supernova light curves**

Introduction : standardising supernova lightcurves

- Cosmological information can be inferred from supernova **lightcurves** (distances) with the distance luminosity
- For that we need to **reconstruct the restframe flux** from the measured flux
- Type Ia Supernovae can be **standardised** due to the low natural dispersion between light curves
- This is done by training an empirical model

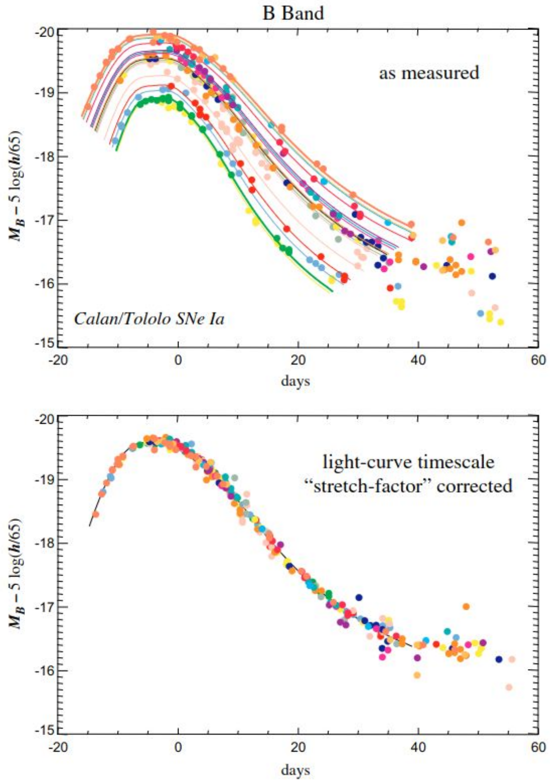


Illustration of light curves before and after stretch-factor corrections
Source : Huterer & Shafer (2017)

The NaCl framework

- Framework developed at LPNHE by Guy Augarde (Augarde 2022)
- Simplifies the training process of SN Ia models
  - **One single iteration** that encapsulate the full training into **a single minimisation**
  - **Propagates the calibration uncertainties** (used to necessitate many parallel trainings) by going into the likelihood
  - Much faster than before and can be used by anyone
- Model **independent :** Easy to plug in another model (SUGAR, SNEMO, etc…). Currently uses the SALT2 model

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

- Goal : train the full model (doesn’t distinguish light curve fitting and training)

Merging training and light curve fit

Start with a certain model

Light curves

$$\phi_{phot} = X_0(1+z)\int S(\lambda,p)\frac{\lambda}{hc}T((1+z)\lambda)\mathrm{d}\lambda$$

Spectra

$$\phi_{spec} = R_{spec}(\lambda)\frac{1}{1+z}S(\lambda,p)$$

Spectra with cosmological information

$$\phi_{spectrophoto} = X_0\frac{1}{1+z}S(\lambda,p)$$

Model parameters to be fitted

$$\begin{bmatrix} X_0 \\ X_1 \\ c \end{bmatrix}$$

One parameter for each SN

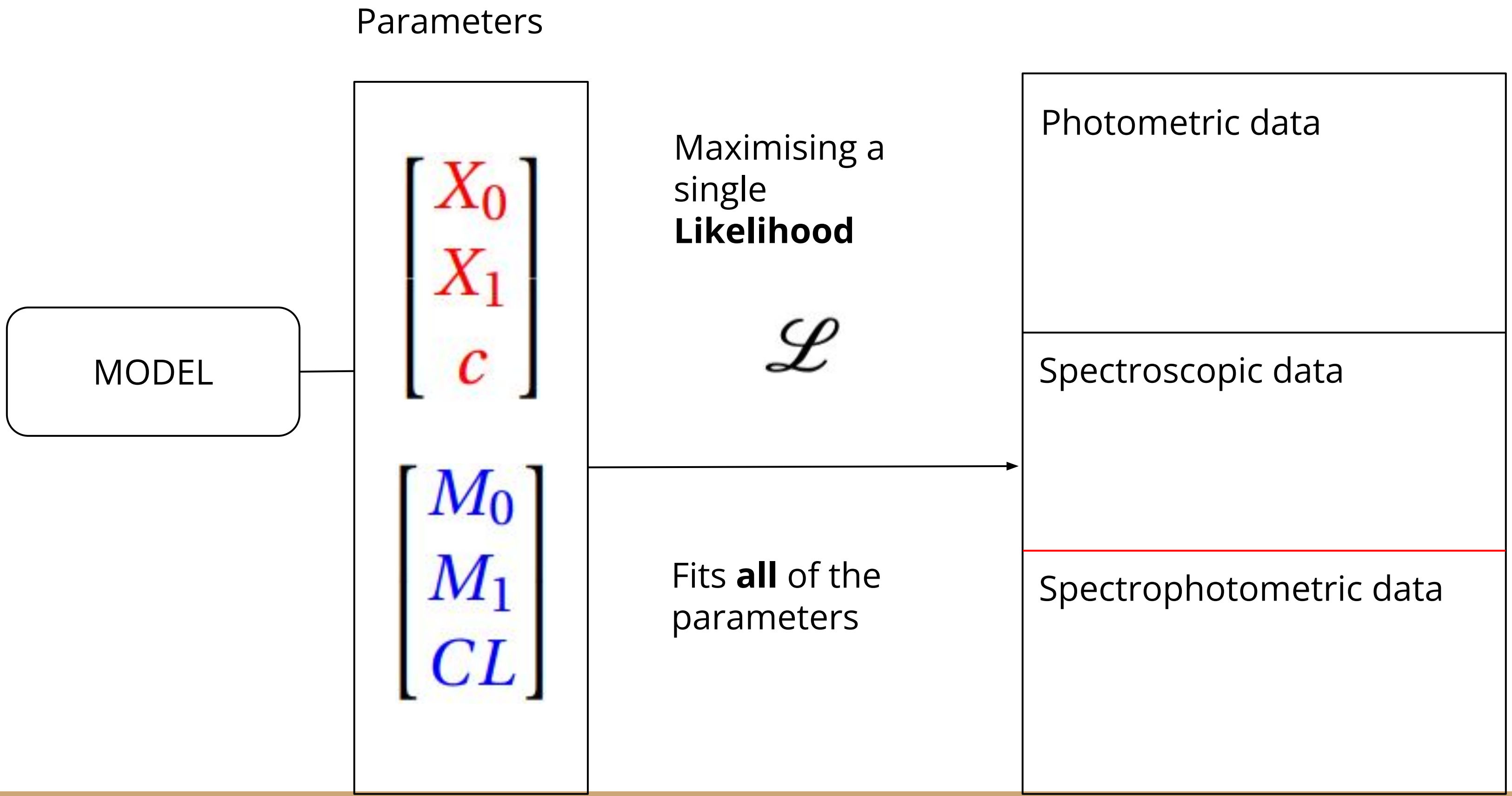
$$\begin{bmatrix} M_0 \\ M_1 \\ CL \end{bmatrix}$$

Global parameters (currently around 9 000)

Plus nuisance parameters

TOTAL : Around 10 000 parameters to be fitted for 200 SNe

Merging training and light curve fit



Training done on the **SNfactory data** by directly fitting the spectra

↓

Now we must train on the **ZTF + SNLS + HSC + SNfactory data**

Merging training and light curve fit

After the fit we can only keep the parameters belonging to each SN which encodes the **cosmology** and we keep the **covariance matrix**

$$\begin{bmatrix} X_0 \\ X_1 \\ c \end{bmatrix}$$

$$\begin{bmatrix} M_0 \\ M_1 \\ CL \end{bmatrix}$$

Data selection

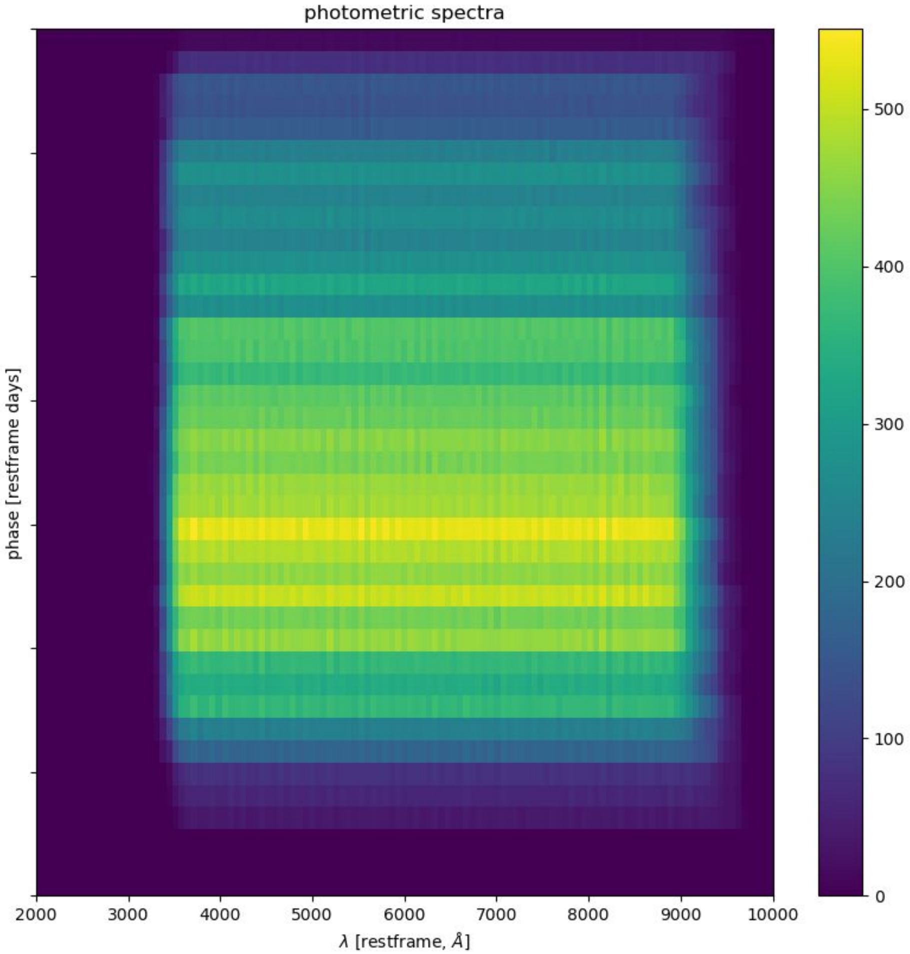
SNFactory dataset used contains :

224 SNe

3135 spectra

Coverage

Coverage of the data points in the dataset



Fit : bases of the model

- Wavelength and phase are defined on a basis of spline of order 4.
  - Each basis contains a number of **knots** on which are projected the model surfaces.

$$M_{0|1} = \sum_i \sum_j \theta_{i,j}^{0|1} \mathscr{B}(p)_i \mathscr{B}(\lambda)_j$$

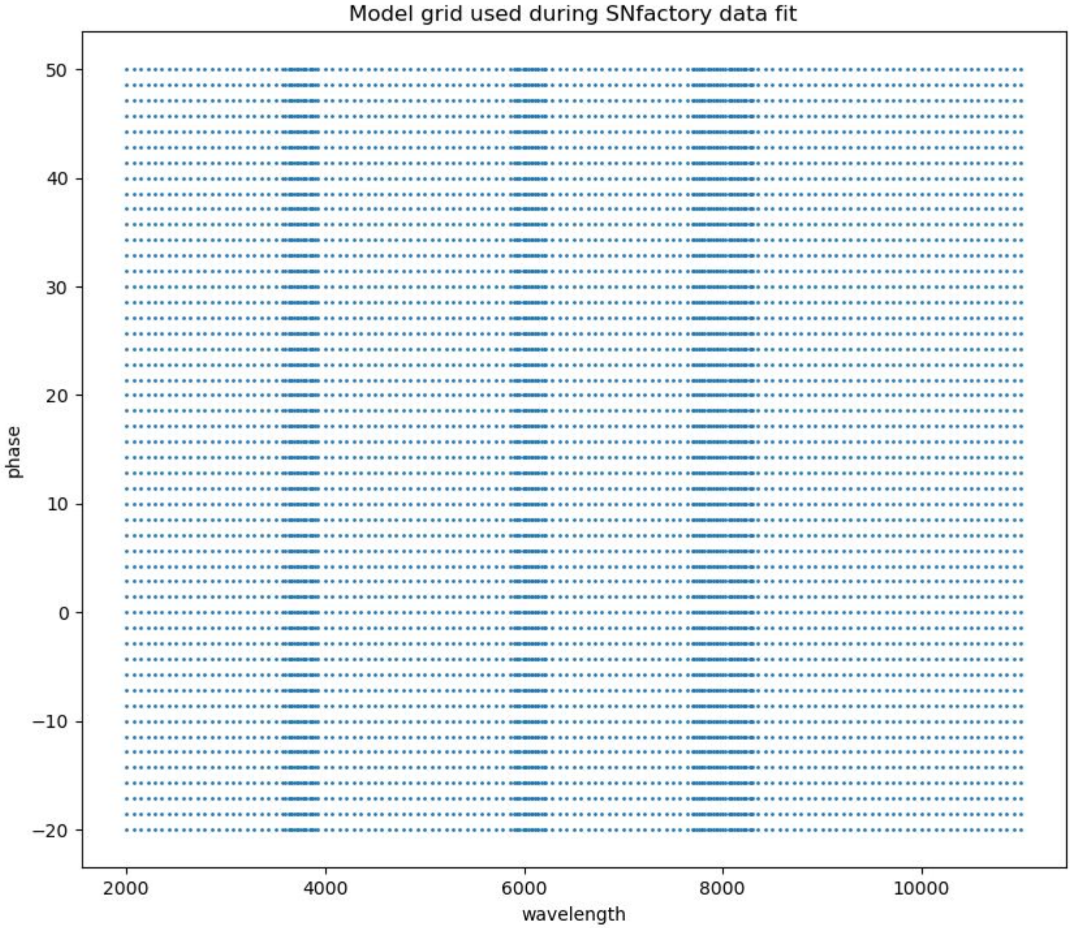
Where $M_{0|1}$ the model surfaces, $\theta_{i,j}^{0|1}$ the projections of the surfaces on each knot, $\mathscr{B}(p)_i$ and $\mathscr{B}(\lambda)_j$ are the spline basis.

Fit : technicalities

Fitting the previously mentioned data on :

- Wavelength basis :
  - Range = (2000.0A - 11000.0A)
  - Knots = 55A
  - Adapted basis = (3500A - 3800A), (5900A - 6200A), (7700A, 8300A) with knots every 30A
- Phase :
  - Range = (-20, 50)
  - Knots = 3.5 days

Fit : grid



Model grid used during SNfactory data fit
phase
wavelength
50
40
30
20
10
0
−10
−20
2000
4000
6000
8000
10000

Fit : Error model

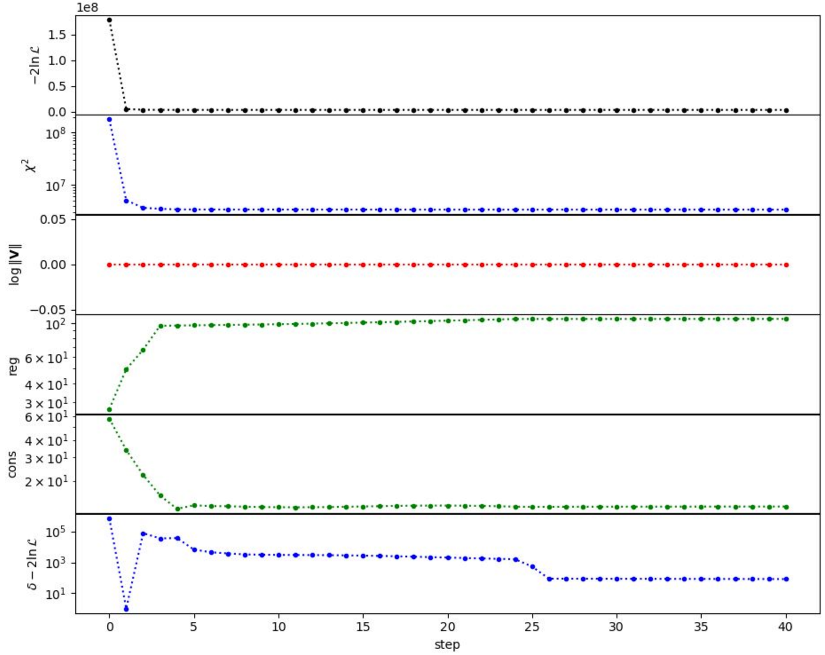
- Currently for the SNfactory data fit we've added an error snake to the variance of the model :

$$\mathbf{V}_{ii}^{\text{snake}} = (\gamma \times \text{flux})^2$$

- After the fit we get γ = 0.103
- It's important to note that it is to plug in another error model in NaCl

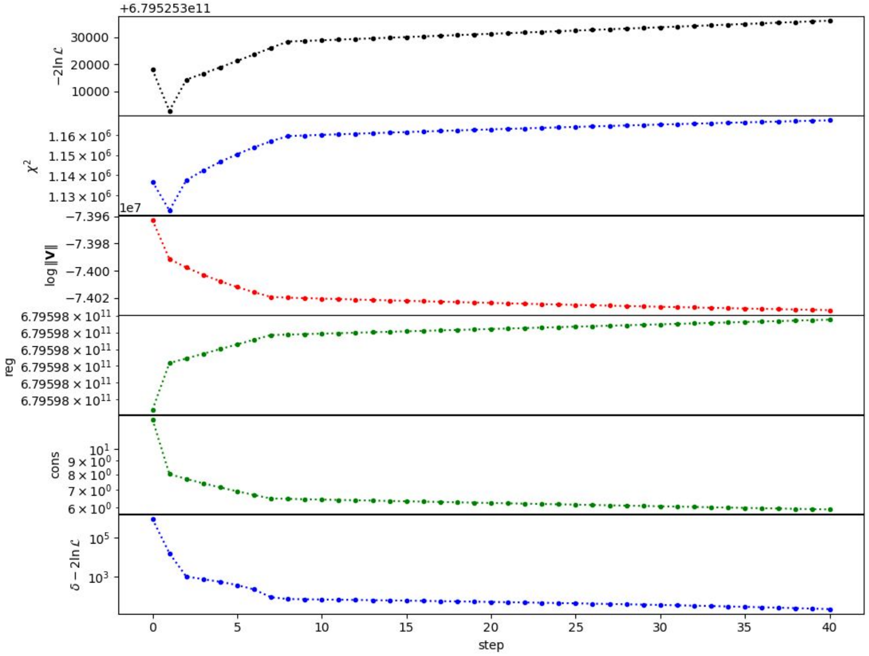
Minimization steps

First fit without error snake



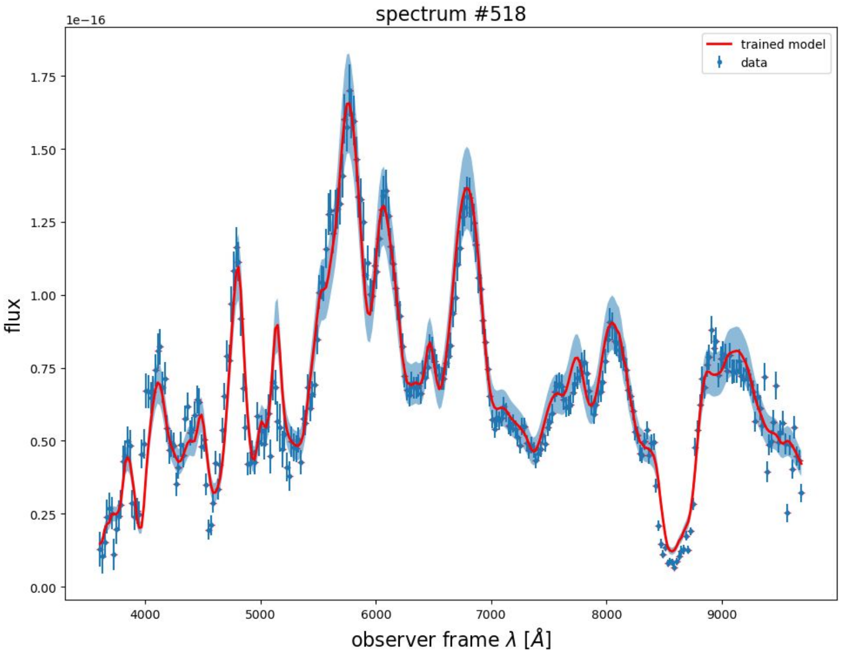
Around 11 mins

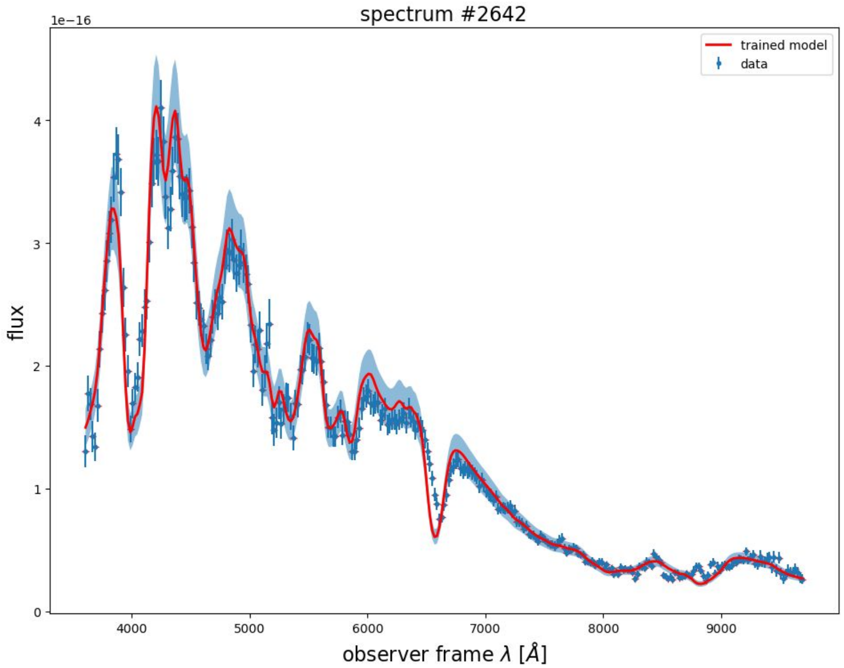
Second fit with error snake



Around 18 mins

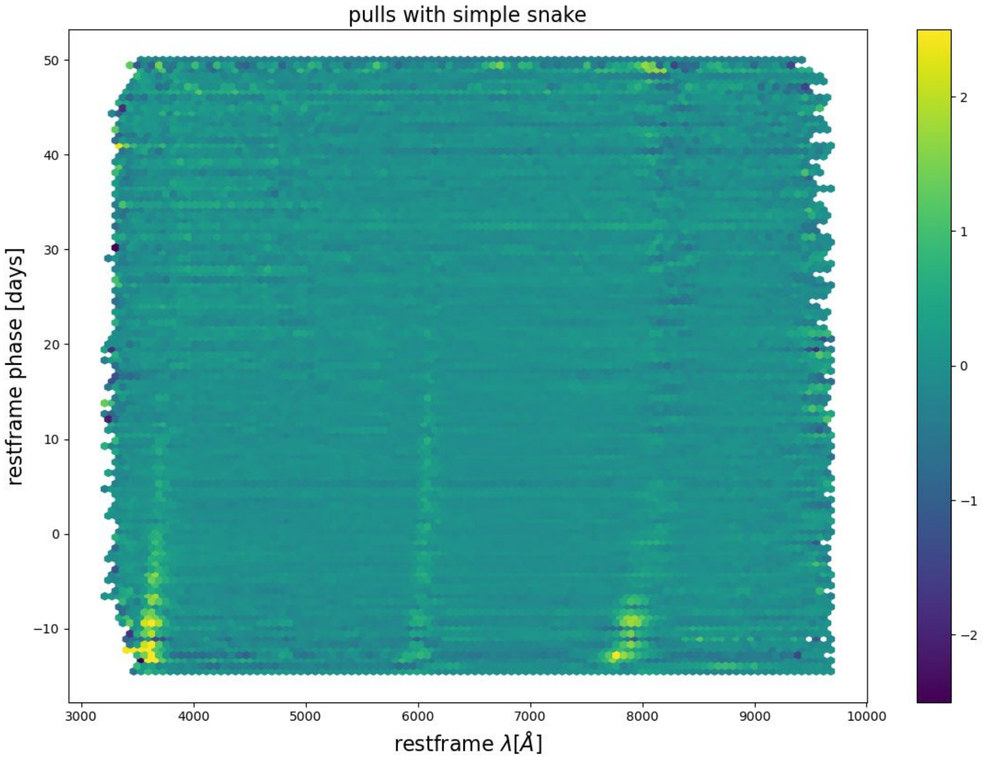
Examples of some fits done with NaCl



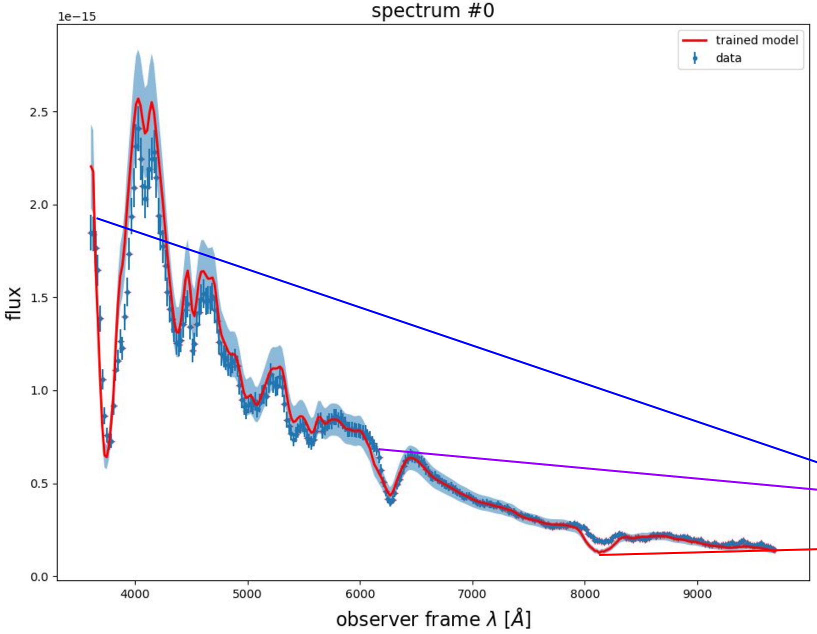


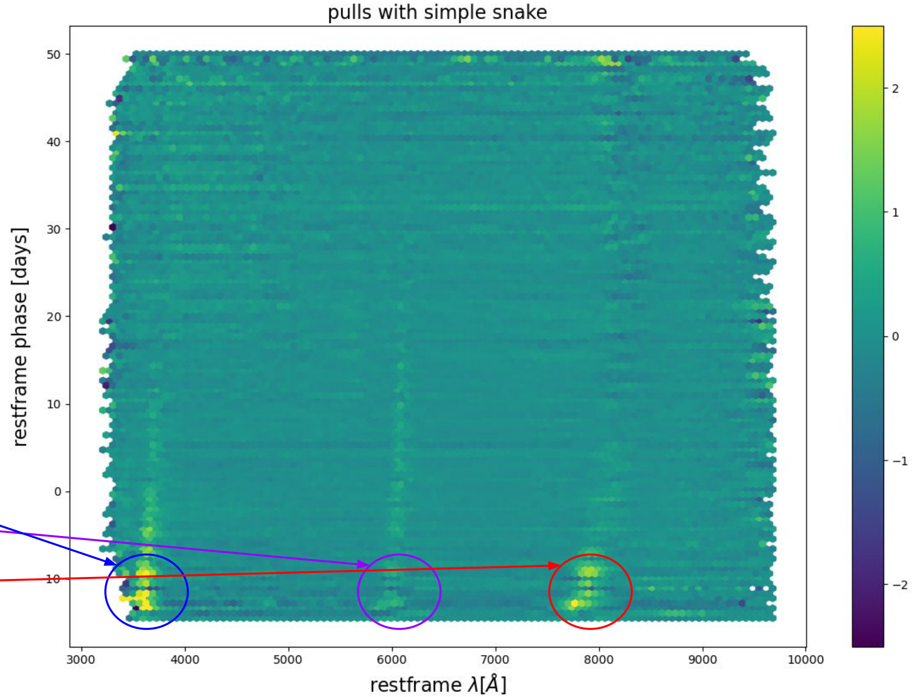
Residuals and x2

- Weighted residuals after fitting the model
- Noticed the areas where the fit doesn't describe the data very well
  - Early phase region
  - High phase region
- Spectral features
  - Ca peak
  - Si II peak
  - UV area
- Model doesn't capture the variability in those areas



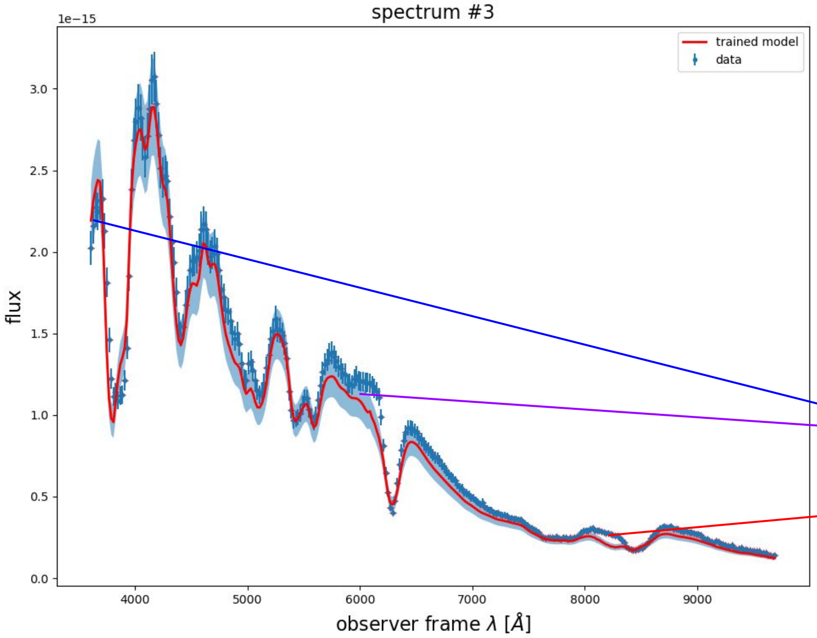
Fitted spectra and pulls

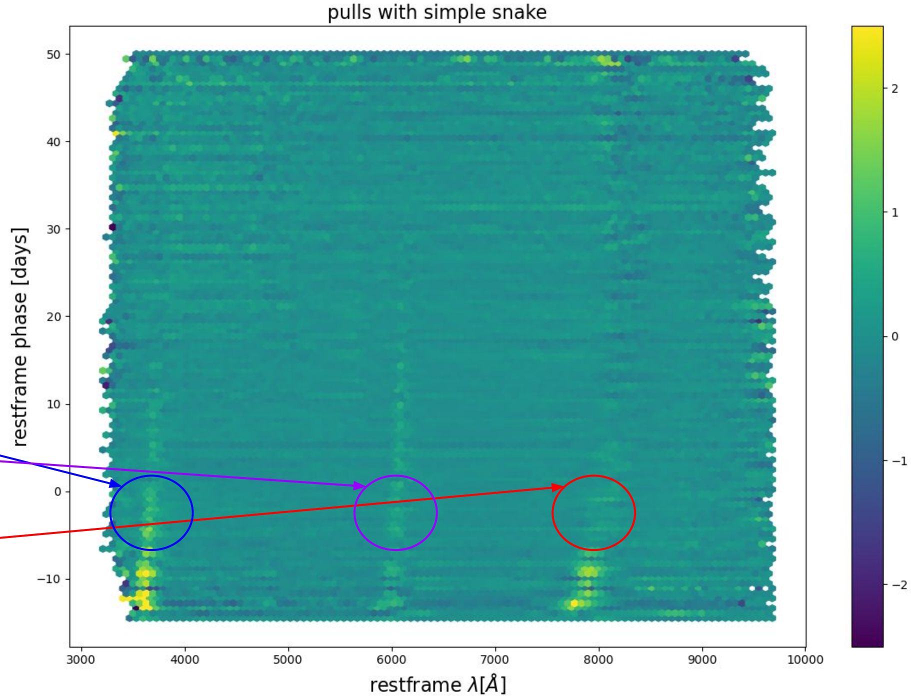




SN:CSS110918_01 at p=-7

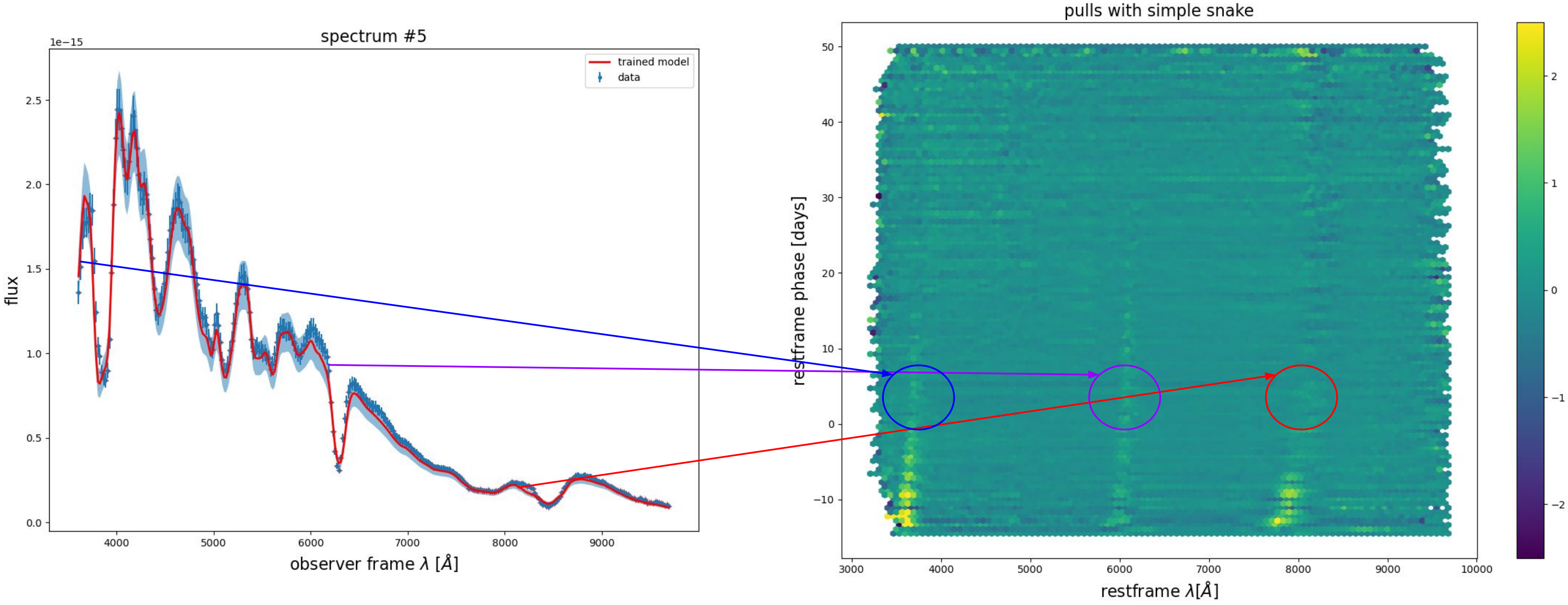
Fitted spectra and pulls





SN:CSS110918_01 at p=1

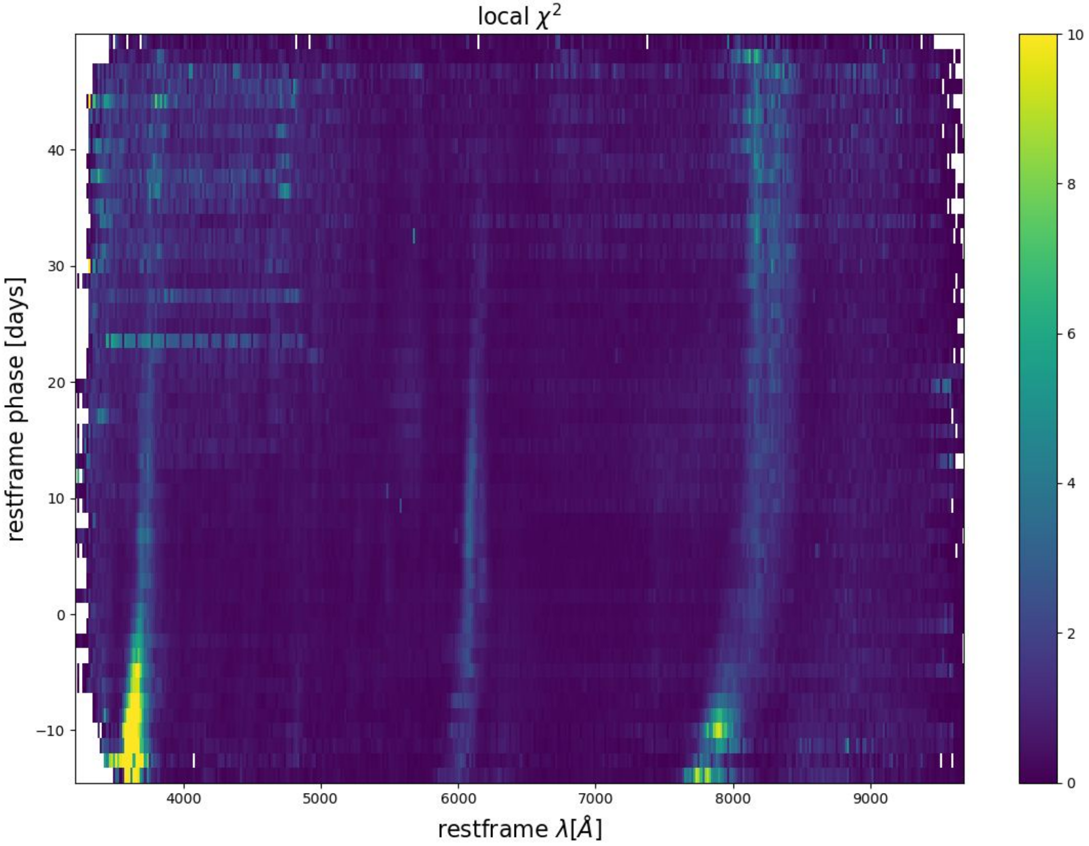
Fitted spectra and pulls



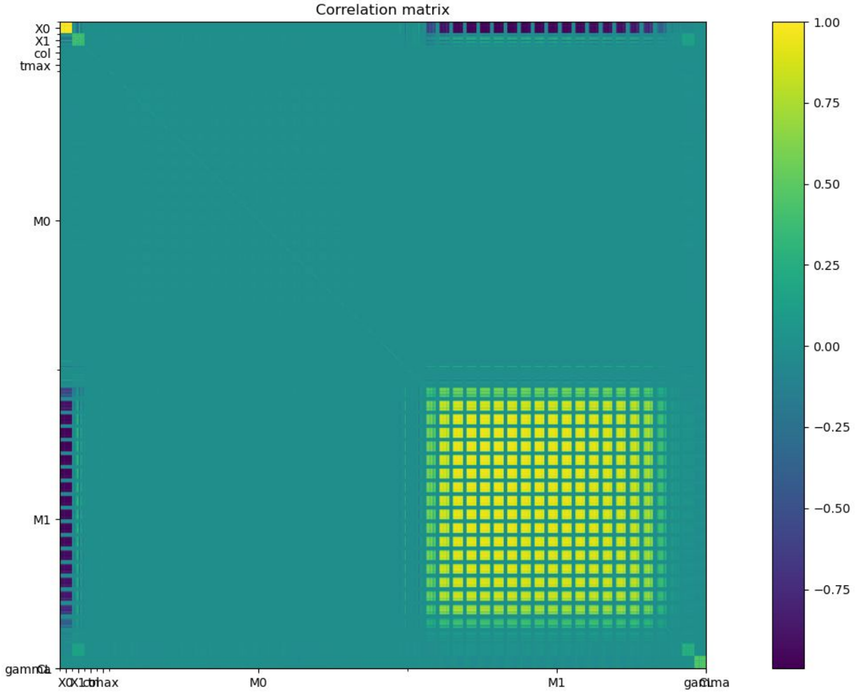
SN:CSS110918_01 at p=6

Local χ^2

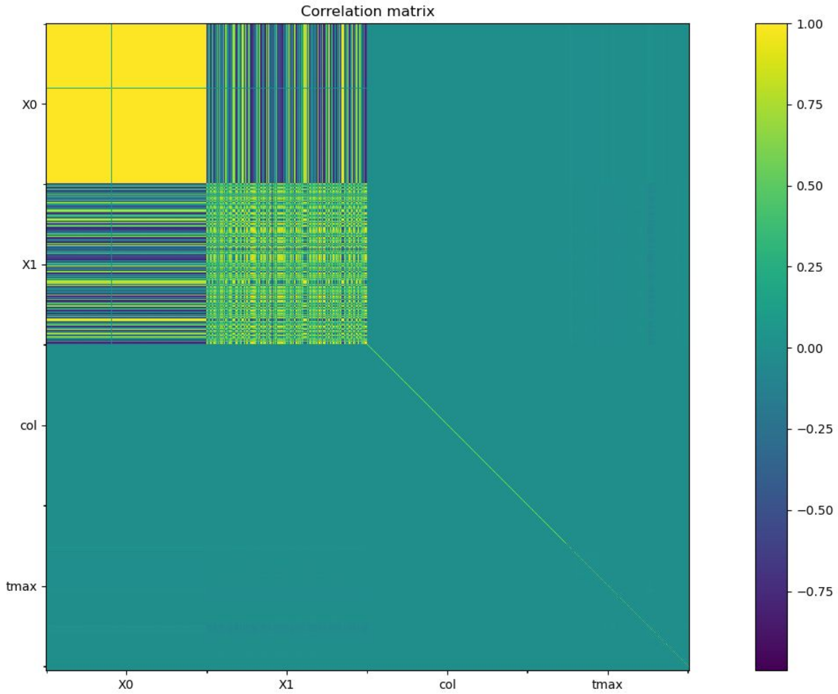
Here we have the values of χ^2 calculated for different regions of the model



Correlation matrix



Correlation matrix



Future work

- NaCl :
    - Have the basspands loaded directly from sncosmo
    - Find an error model that is more adapted
- Use the ZTF data & SNFactory in a training
- Finish the integration in LEMAITRE
- Beyond SALT:
    - We would also like to see if we can **extend the SALT model** in order to describe the areas that haven't been captured well during the fit. This will be inspired by the Stein et al. (2023) **Probabilistic AutoEncoder** model

Thank you for your attention!!

Backup slides

Regularization

- Adding a penalty to the Chi2 for regions for which we do not have data
- Having a simple penalty on the 1st derivative of the model isn't enough
- Having a constant penalty is also not enough

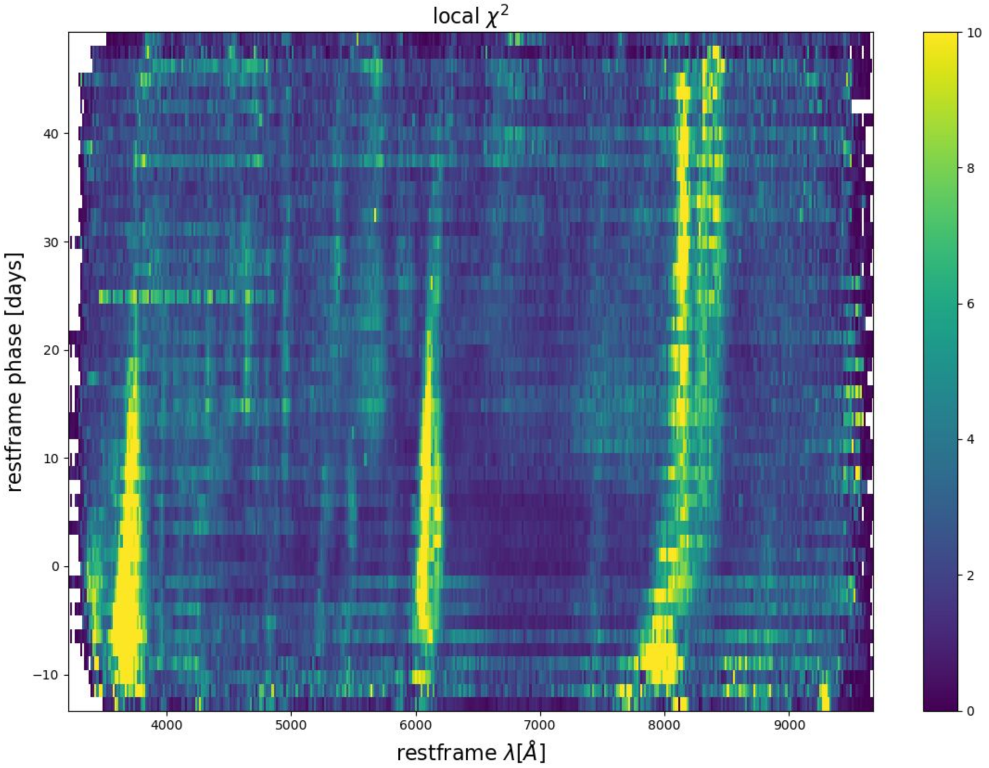
$$\chi^2_{reg} = \sum_i \mu_0 \theta_i^2 + \mu_1 (\theta_{i+1} - \theta_i)^2$$

- We found that having an adaptive regularization works best
- The overall penalty is multiplied by a certain factor for it to be relevant and that factor can bias the results if too high

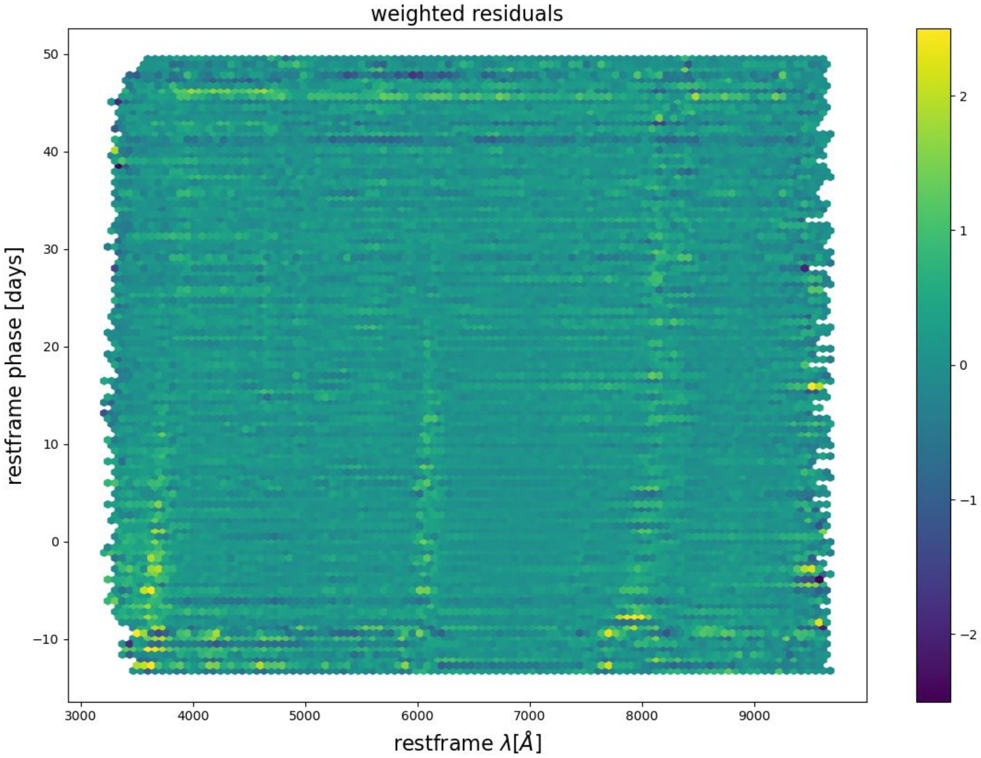
$$\chi^2_{reg} = (\mathbf{MD})^T (\mathbf{MD}) \Theta$$

$$M_i = \max(\mu - s_i, 0)$$

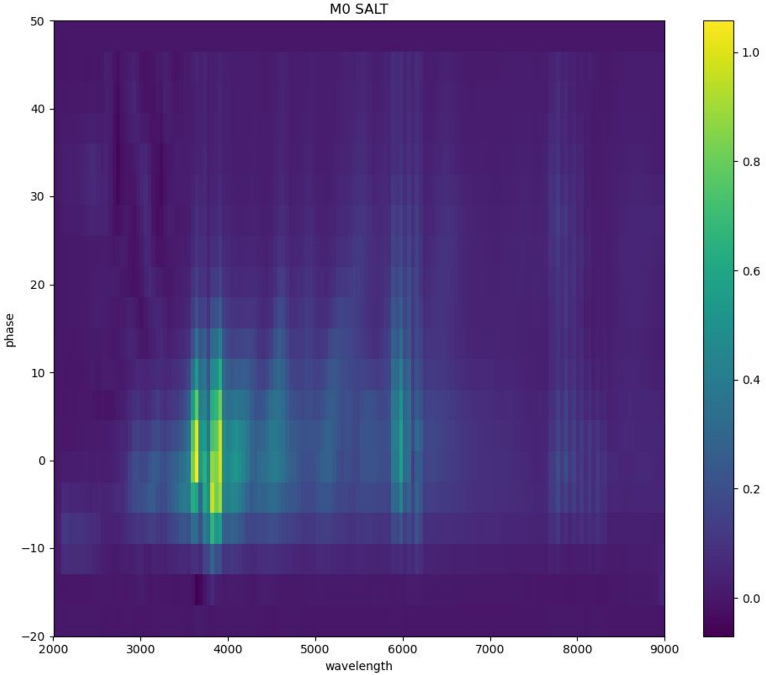
No snake

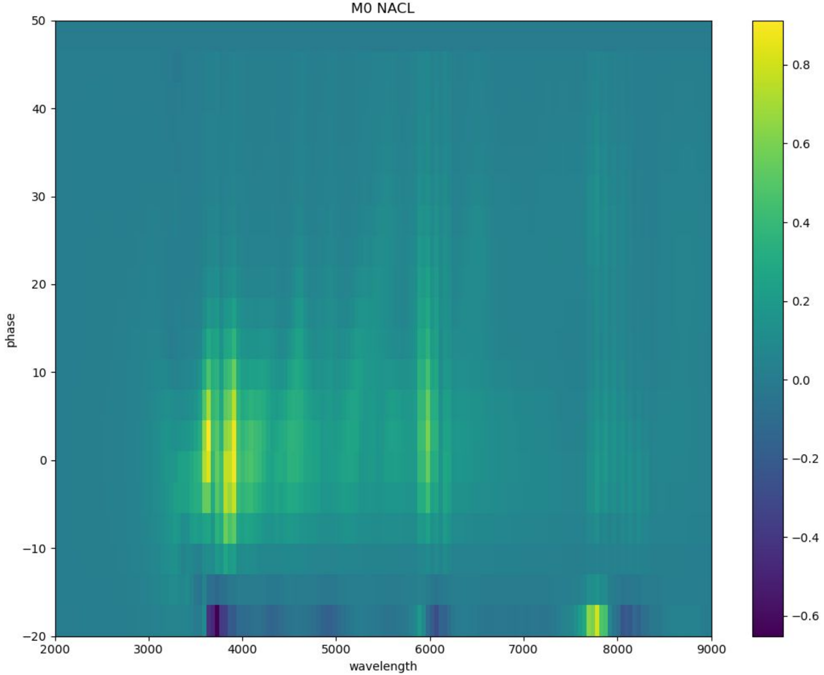

local χ^2
restframe phase [days]
restframe $\lambda [\AA]$
40
30
20
10
0
−10
4000
5000
6000
7000
8000
9000
10
8
6
4
2
0

No snake

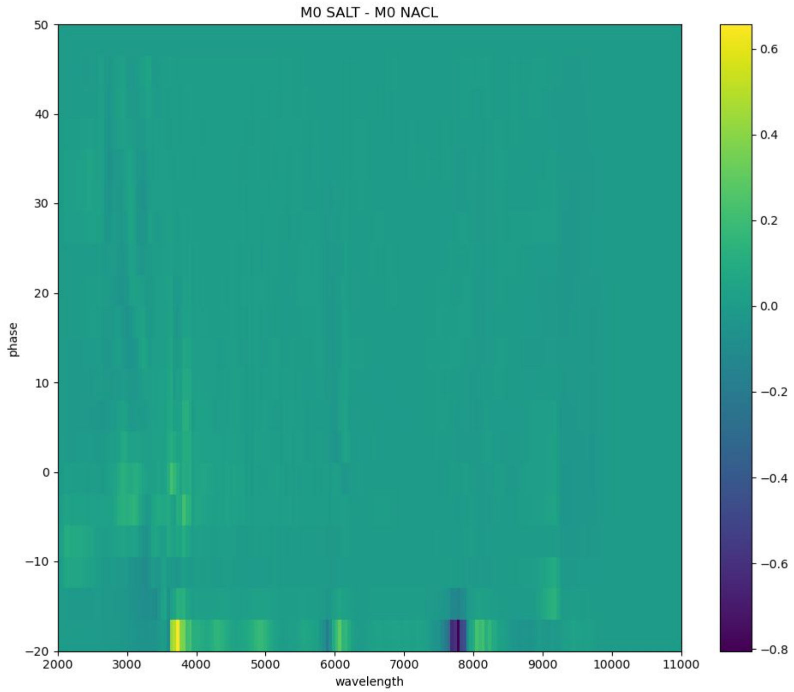

weighted residuals
restframe phase [days]
restframe $\lambda[\AA]$
50
40
30
20
10
0
−10
3000
4000
5000
6000
7000
8000
9000
2
1
0
−1
−2

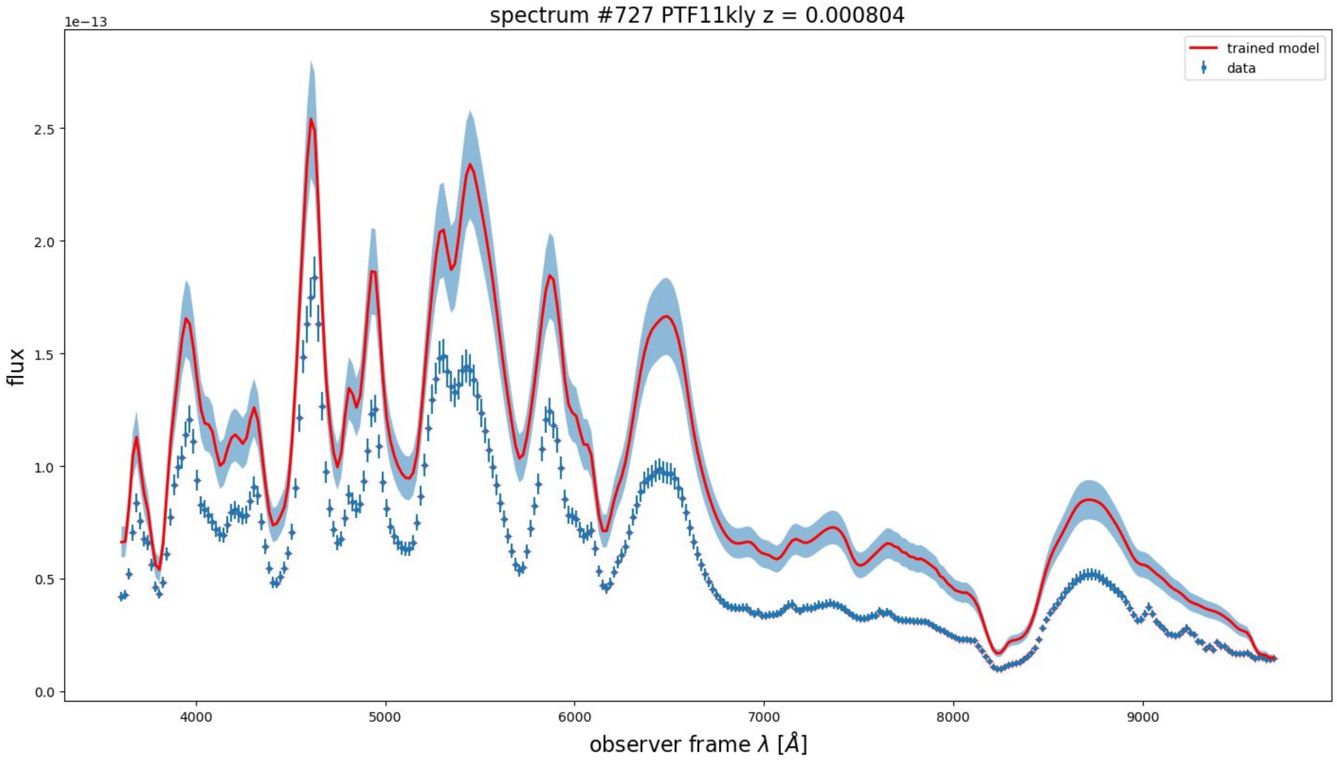
SALT2 surfaces

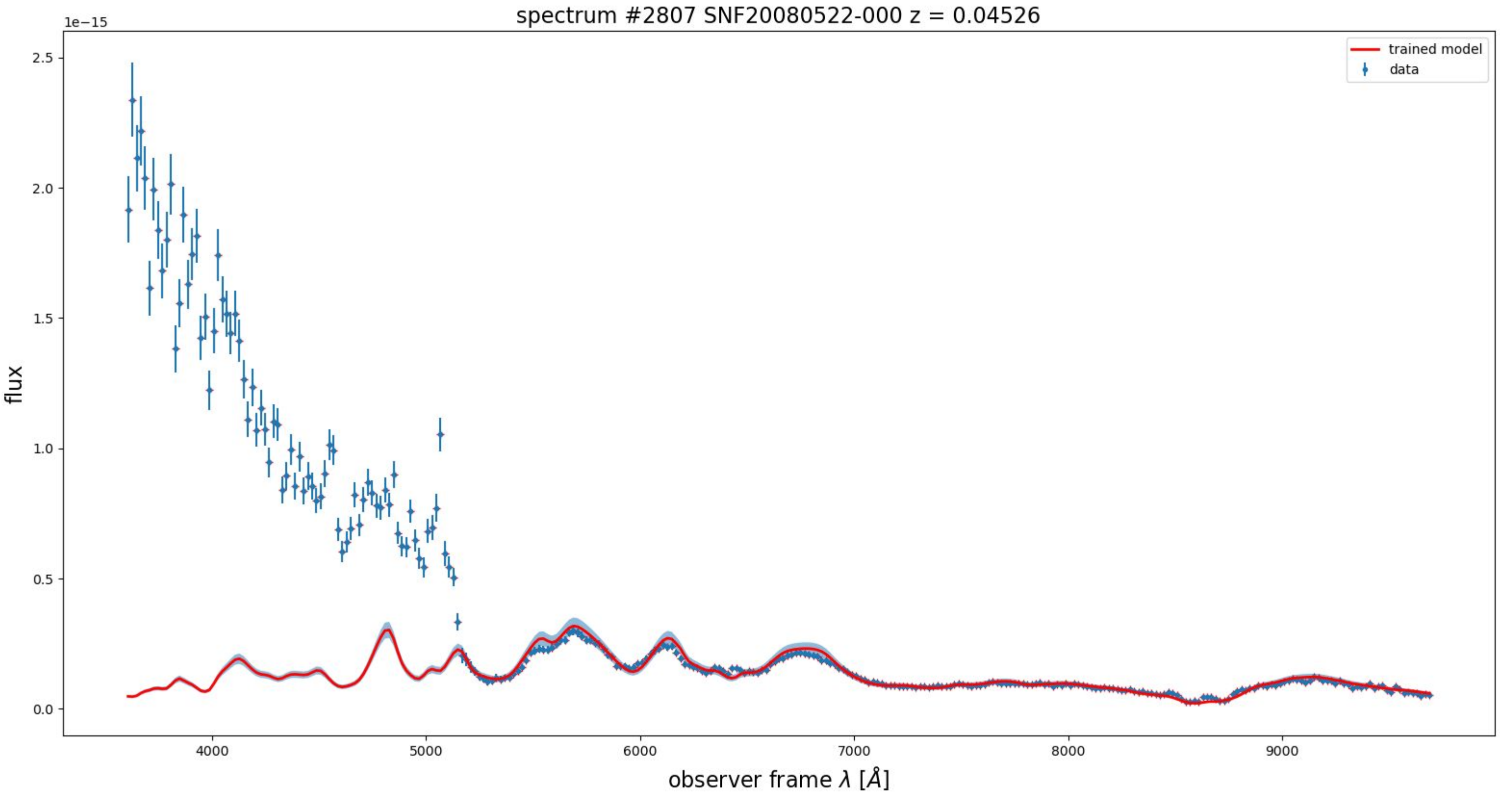




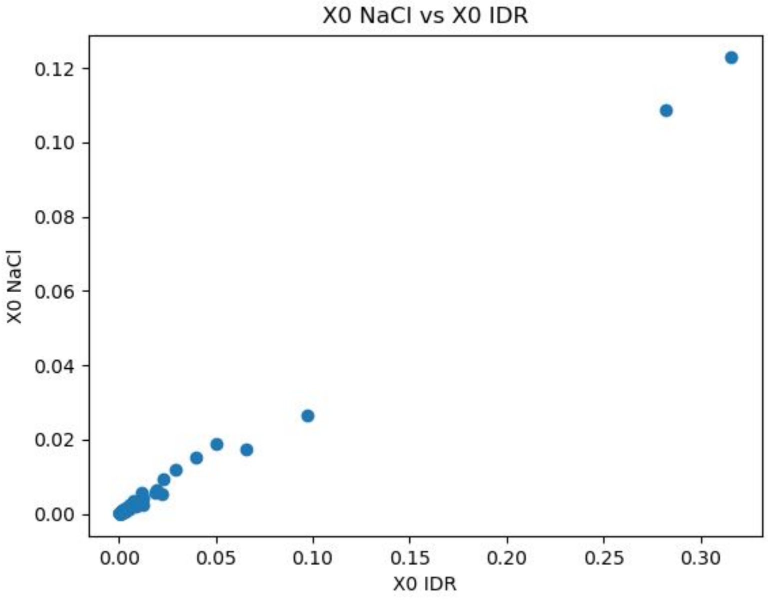
SALT2 surfaces

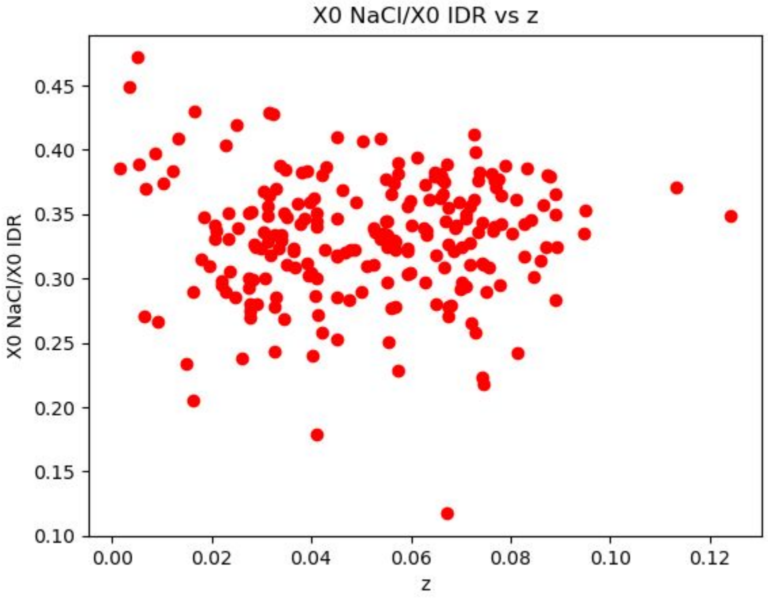


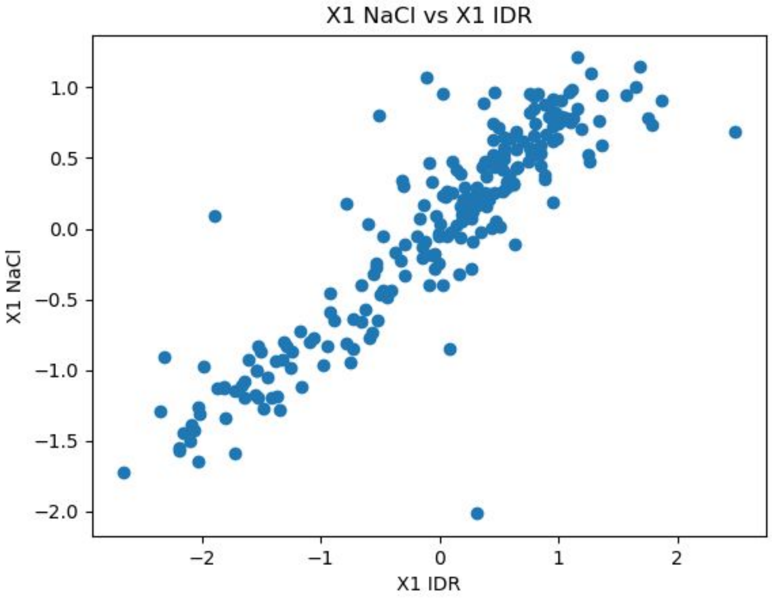

spectrum #727 PTF11kly z = 0.000804
1e−13
trained model
data
flux
2.5
2.0
1.5
1.0
0.5
0.0
4000
5000
6000
7000
8000
9000
observer frame λ [$\AA$]

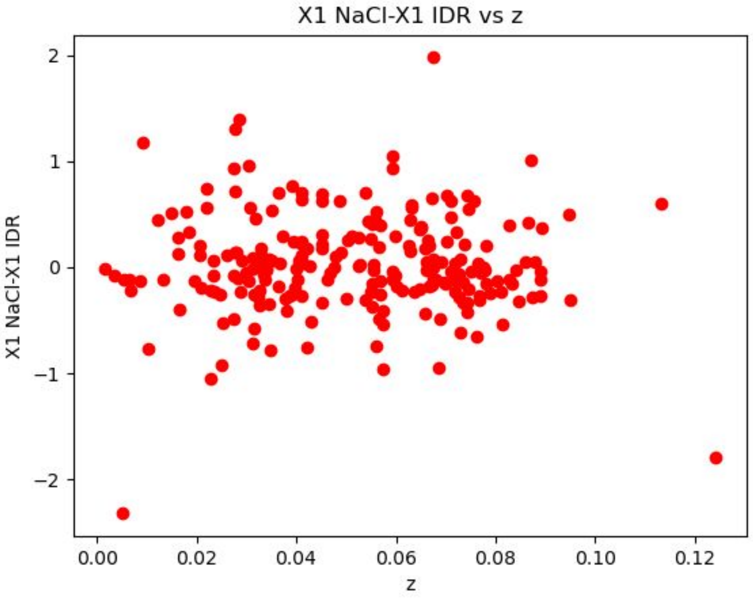


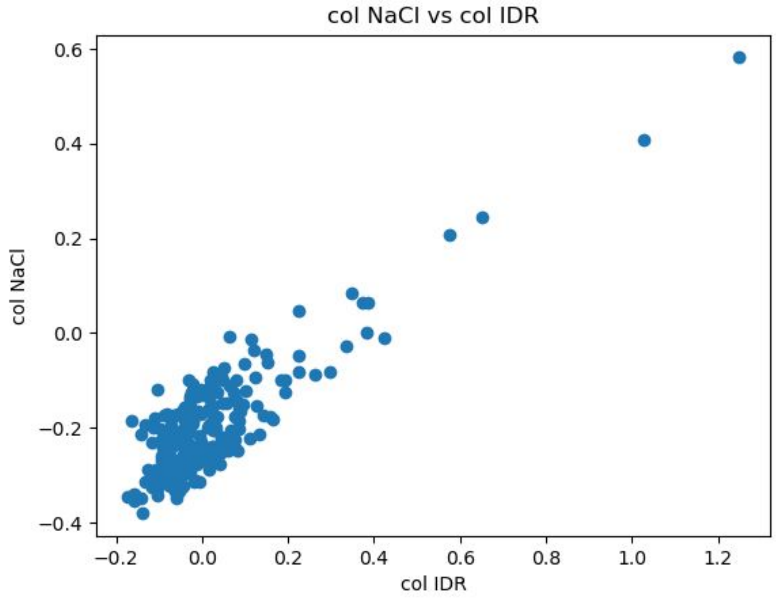
spectrum #2807 SNF20080522-000 z = 0.04526
1e−15
2.5
2.0
1.5
1.0
0.5
0.0
flux
4000
5000
6000
7000
8000
9000
observer frame λ [$\AA$]
trained model
data

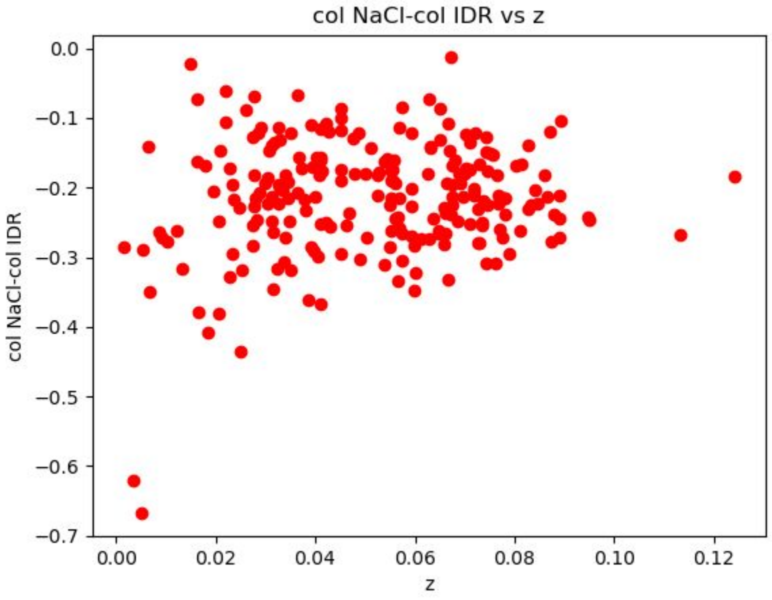

X0 NaCl vs X0 IDR
X0 NaCl
X0 IDR
0.12
0.10
0.08
0.06
0.04
0.02
0.00
0.00
0.05
0.10
0.15
0.20
0.25
0.30


X0 NaCl/X0 IDR vs z
X0 NaCl/X0 IDR
z
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.00
0.02
0.04
0.06
0.08
0.10
0.12


X1 NaCl vs X1 IDR
X1 NaCl
X1 IDR
1.0
0.5
0.0
−0.5
−1.0
−1.5
−2.0
−2
−1
0
1
2


X1 NaCl-X1 IDR vs z
X1 NaCl-X1 IDR
z
2
1
0
−1
−2
0.00
0.02
0.04
0.06
0.08
0.10
0.12


col NaCl vs col IDR
0.6
0.4
0.2
0.0
−0.2
−0.4
col NaCl
−0.2
0.0
0.2
0.4
0.6
0.8
1.0
1.2
col IDR


col NaCl-col IDR vs z
0.0
−0.1
−0.2
−0.3
−0.4
−0.5
−0.6
−0.7
col NaCl-col IDR
0.00
0.02
0.04
0.06
0.08
0.10
0.12
z