# LEMAîTRE : An independent measurement of the dark energy equation of state from a new set of SNe Ia : **Dataset and Lightcurve model**

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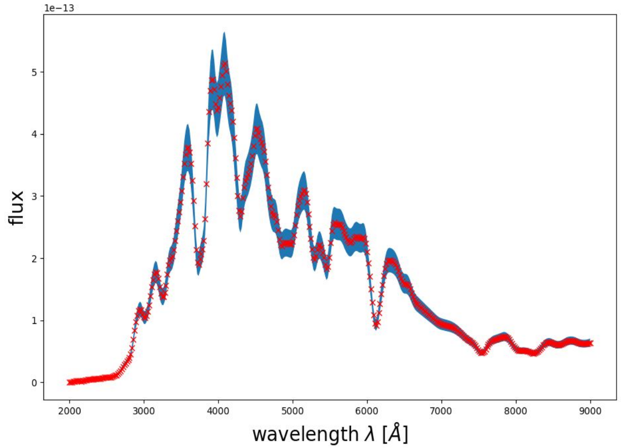
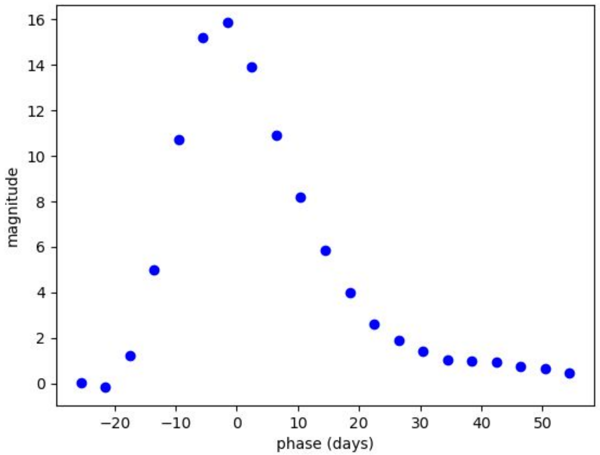
Supervised by Nicolas Regnault & Pauline Zarrouk

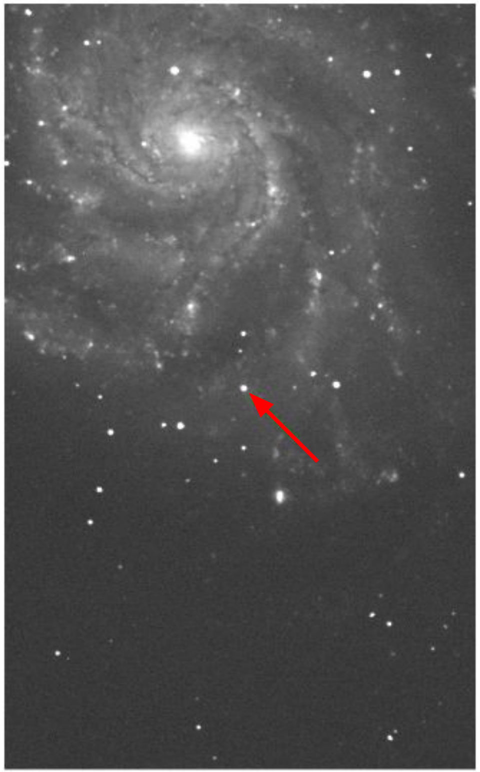
# Supernova Ia (SN Ia)

- Thermonuclear explosion of a white dwarf star
- Measure spectra lightcurves




*Simulations*



SN 2011fe

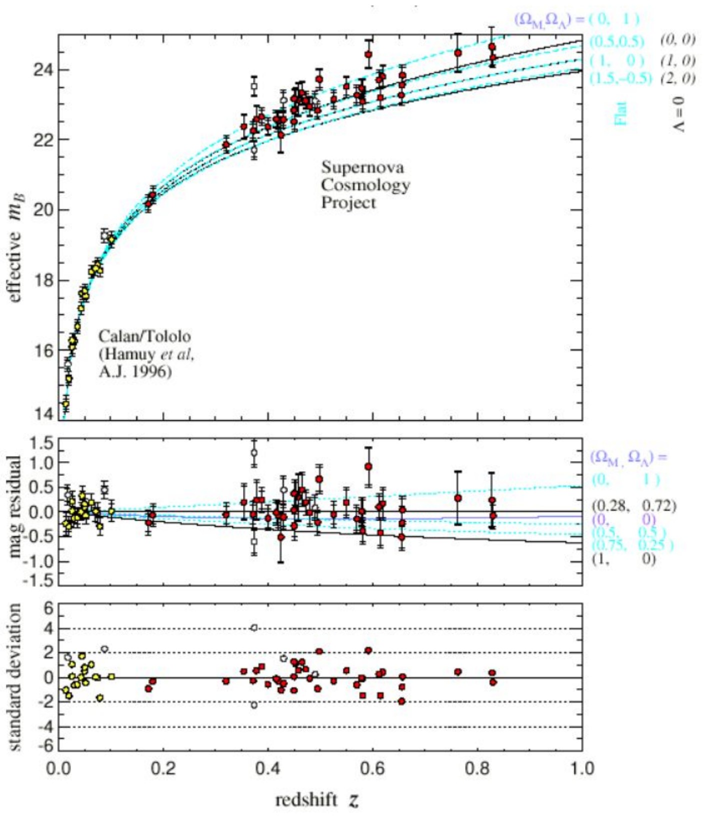
*Source : Nugent, P.E. et al. arXiv : 1110.6201*

# SN Ia cosmology

- We can use SN Ia to map the **expansion history** of the Universe since they are standardisable candles

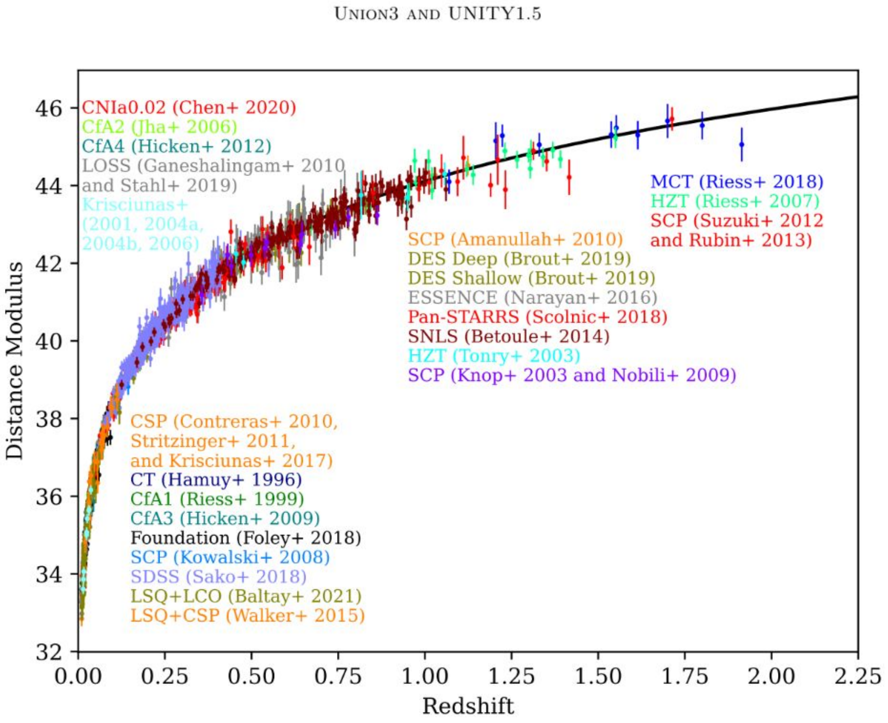
- Historically, first time we've measured the **accelerated expansion**

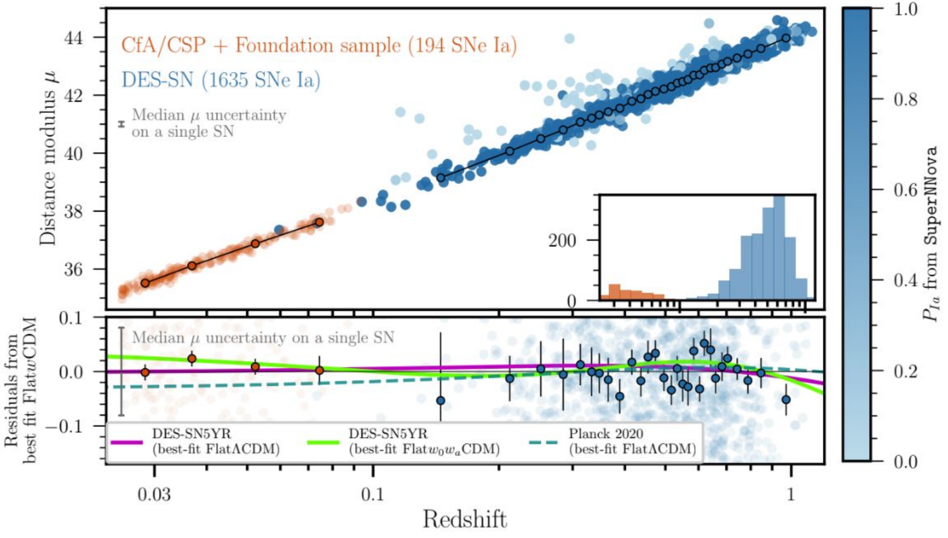
- This was done with ~ 40 SN Ia




*Hubble Diagram of Type Ia Supernovae (Supernova Cosmology Project 1998)*

# Recent cosmological results with SN Ia (20 years later…)




Same low z sample

Union3 : 2087 SNe
arXiv:2311.12098

DES year 5 : 1829 SNe
arXiv:2401.02929

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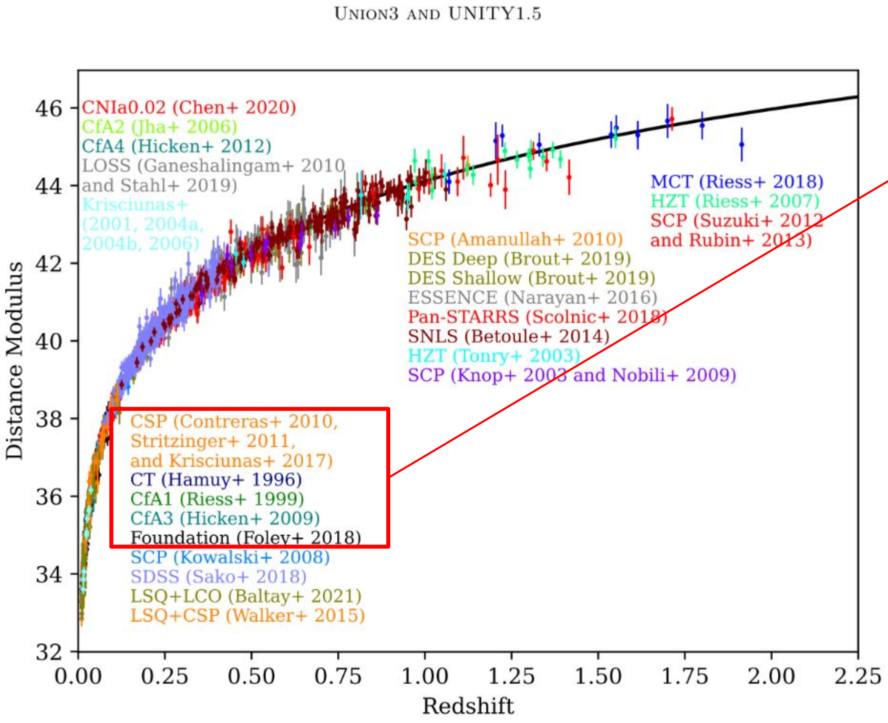


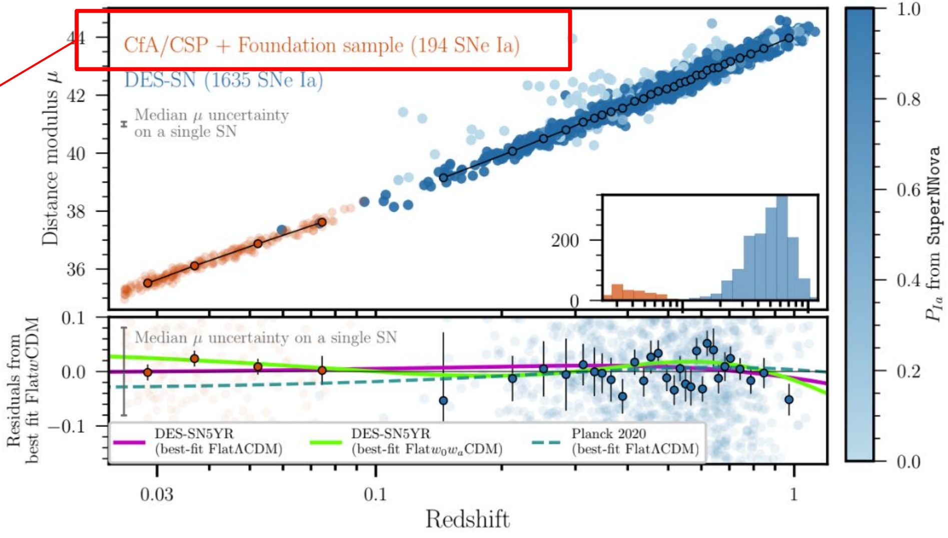


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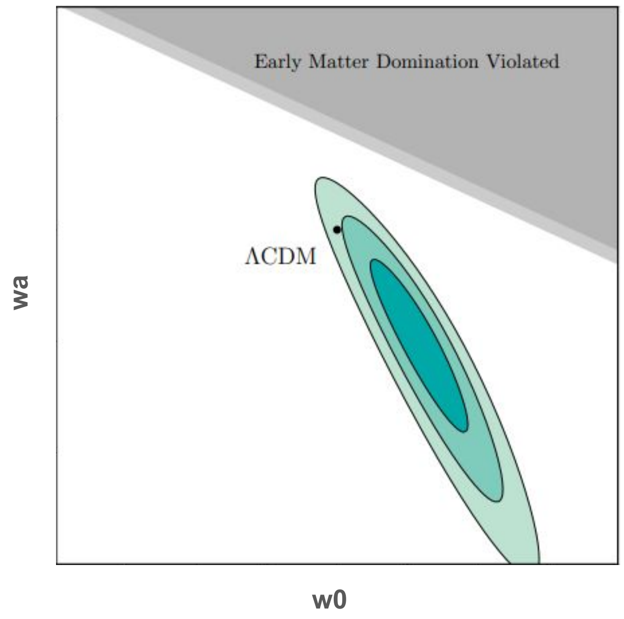
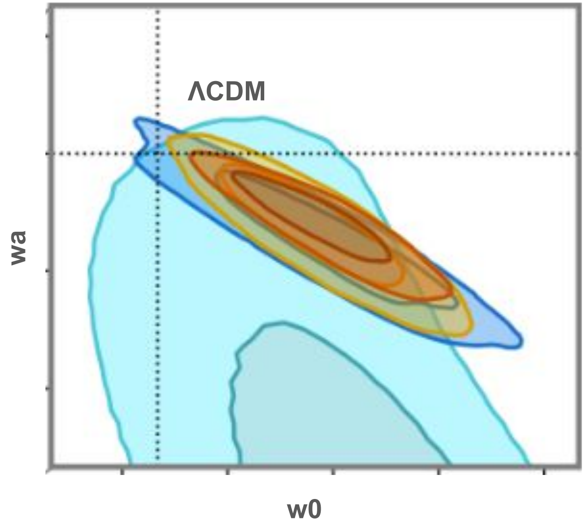


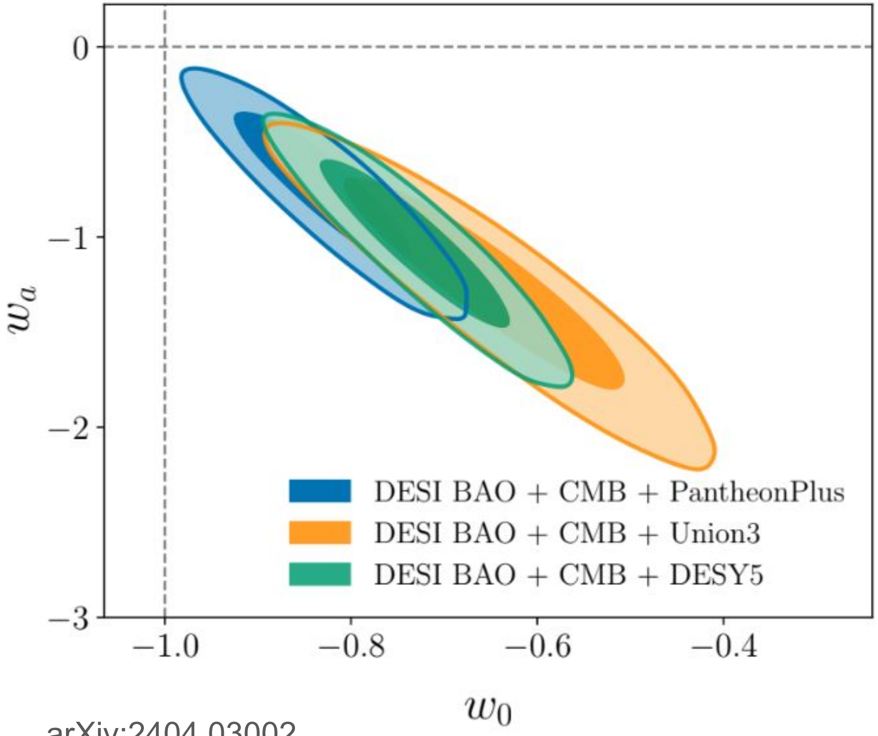

**> 2 σ**




Union3 : 2087 SNe
arXiv:2311.12098

DES year 5 : 1829 SNe
arXiv:2401.02929

# Recent cosmological results with SN Ia and DESI



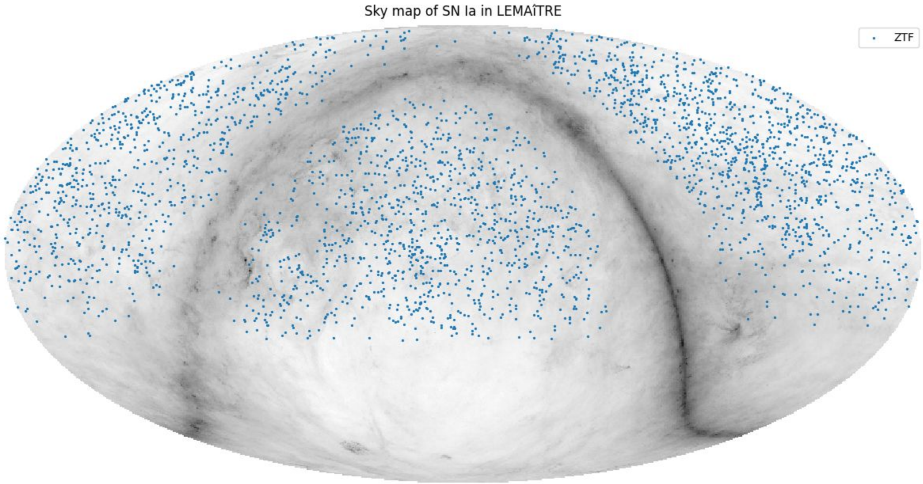

arXiv:2404.03002

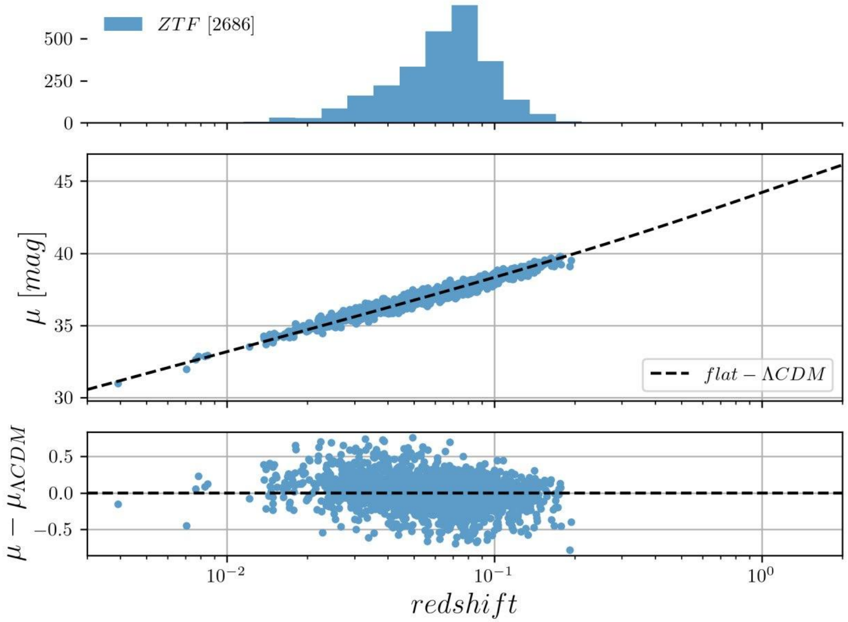
**> 3σ**
**Strongly driven by SN Ia**

# **LEMAîTRE**
# (**L**atest **E**xtensive **M**apping of **A**cceleration with **I**ndependent **T**roves of **R**edshifted **E**xplosions)

A Hubble-Lemaître diagram containing a completely **independent SN Ia dataset** which allow us to properly tackle the w-wa tension with ΛCDM

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

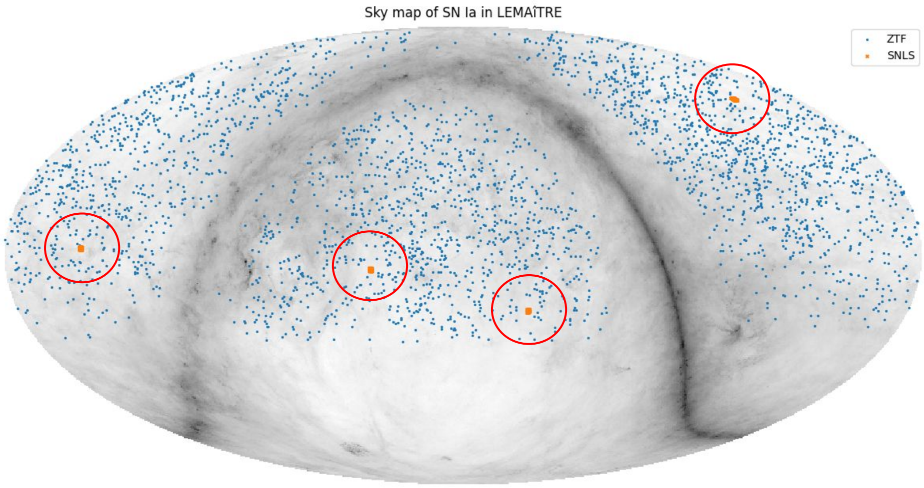


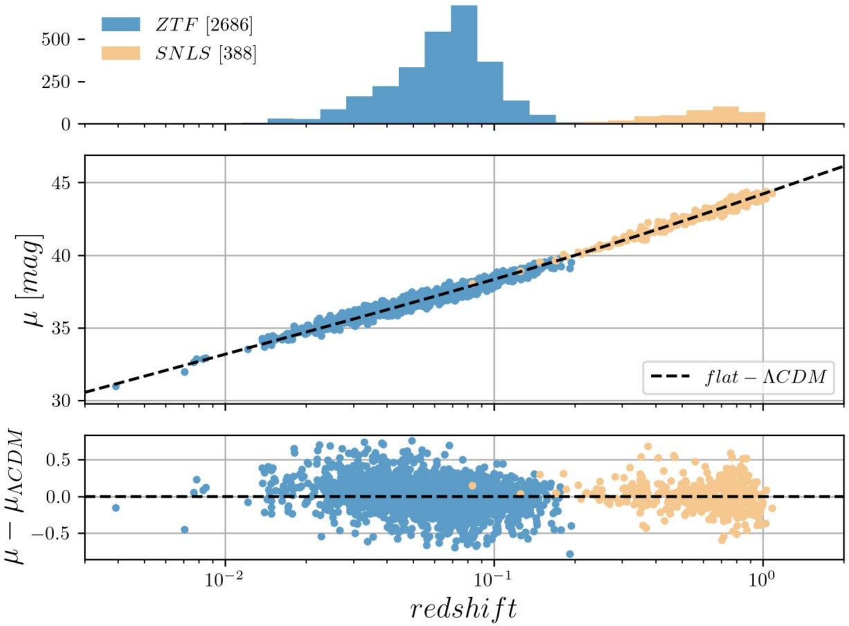




3 bands : g, r, I

- A Hubble-Lemaître diagram containing a completely **independent SN Ia dataset**:
  - **ZTF** (~3000 SN) *at z<0.1*

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

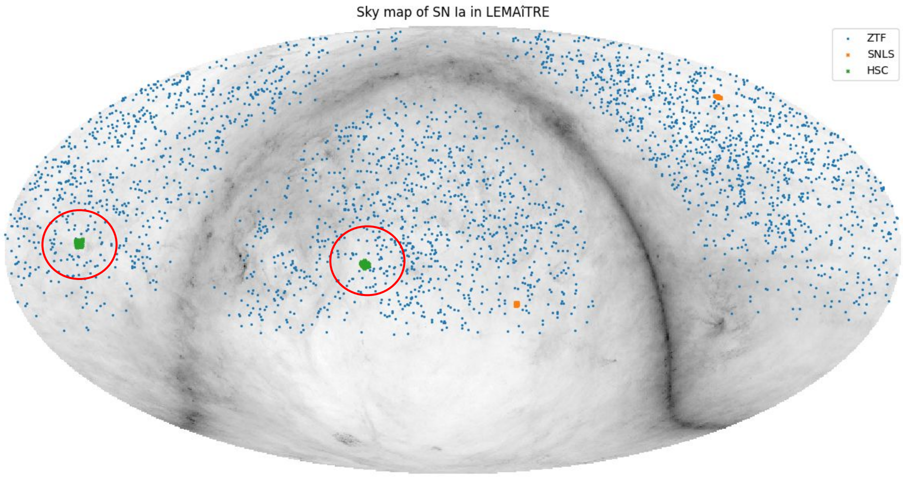


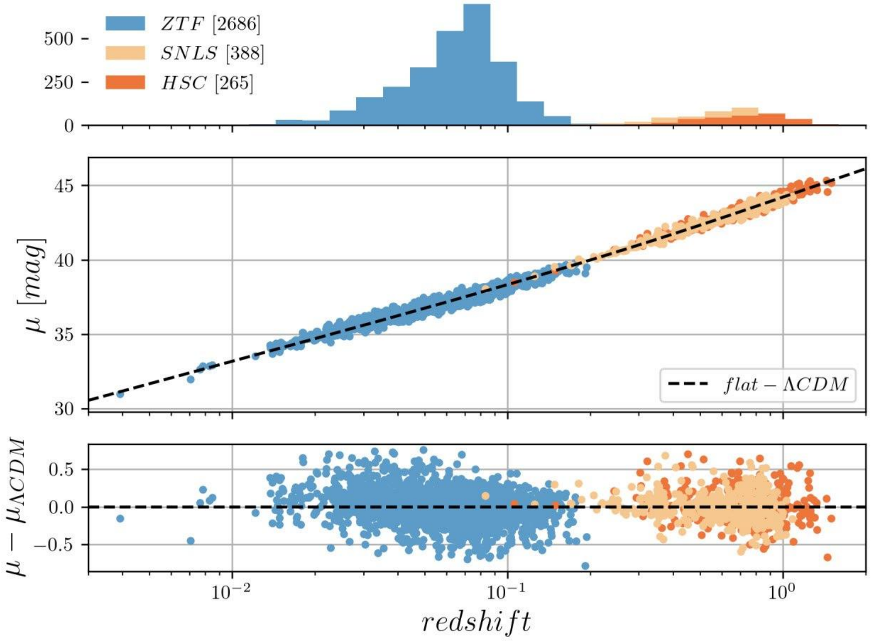




7 bands (3+4) : g, r, i, z

- A Hubble-Lemaître diagram containing a completely **independent SN Ia dataset**:
  - **ZTF** (~3000 SN) *at z<0.1*
  - **SNLS** y5 (~400 SN)

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



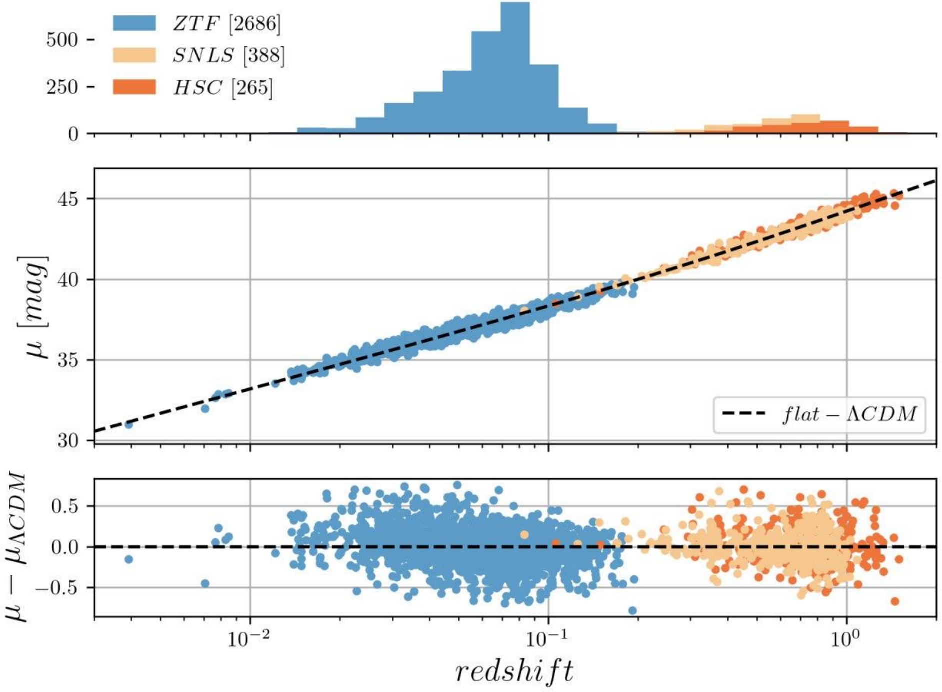

- A Hubble-Lemaître diagram containing a completely **independent SN Ia dataset**:
    - **ZTF** (~3000 SN) *at z<0.1*
    - **SNLS** y5 (~400 SN)
    - **HSC** (~300 SN)

12 bands (7+5) : g, r2, i2, Y, z

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

- The LEMAîTRE project also contains its own **new analysis pipeline** from extracting SN Ia lightcurves from pixels to the cosmological analysis

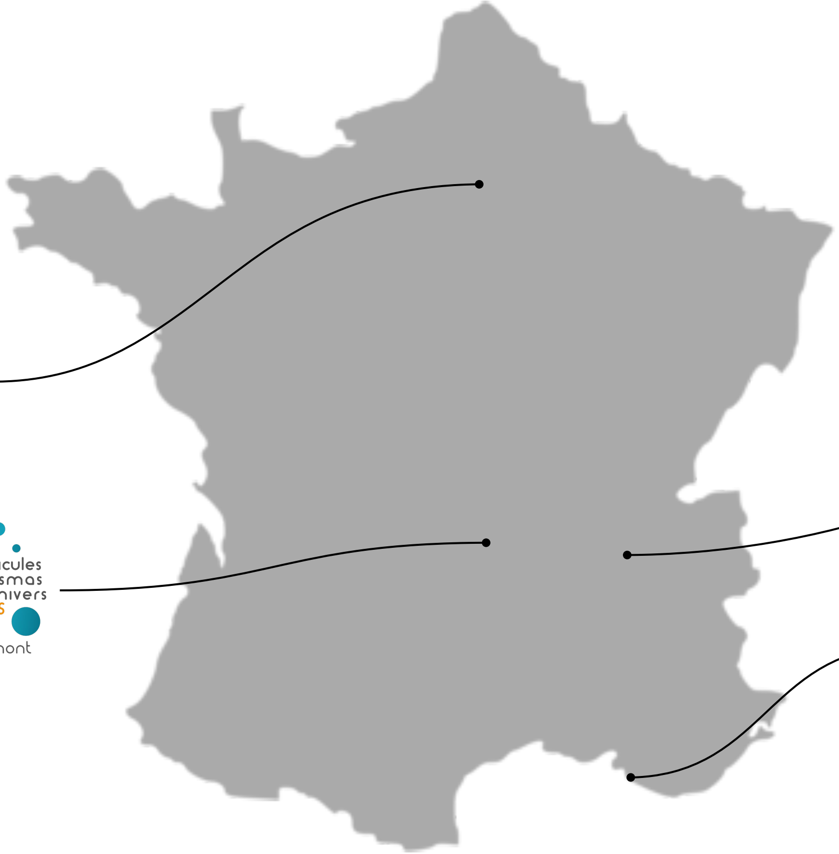
- This allows us to tackle known issues such as the **selection effects** previously fitted with simulations



# People working on the LEMAÎTRE project

LPNHE
PARIS

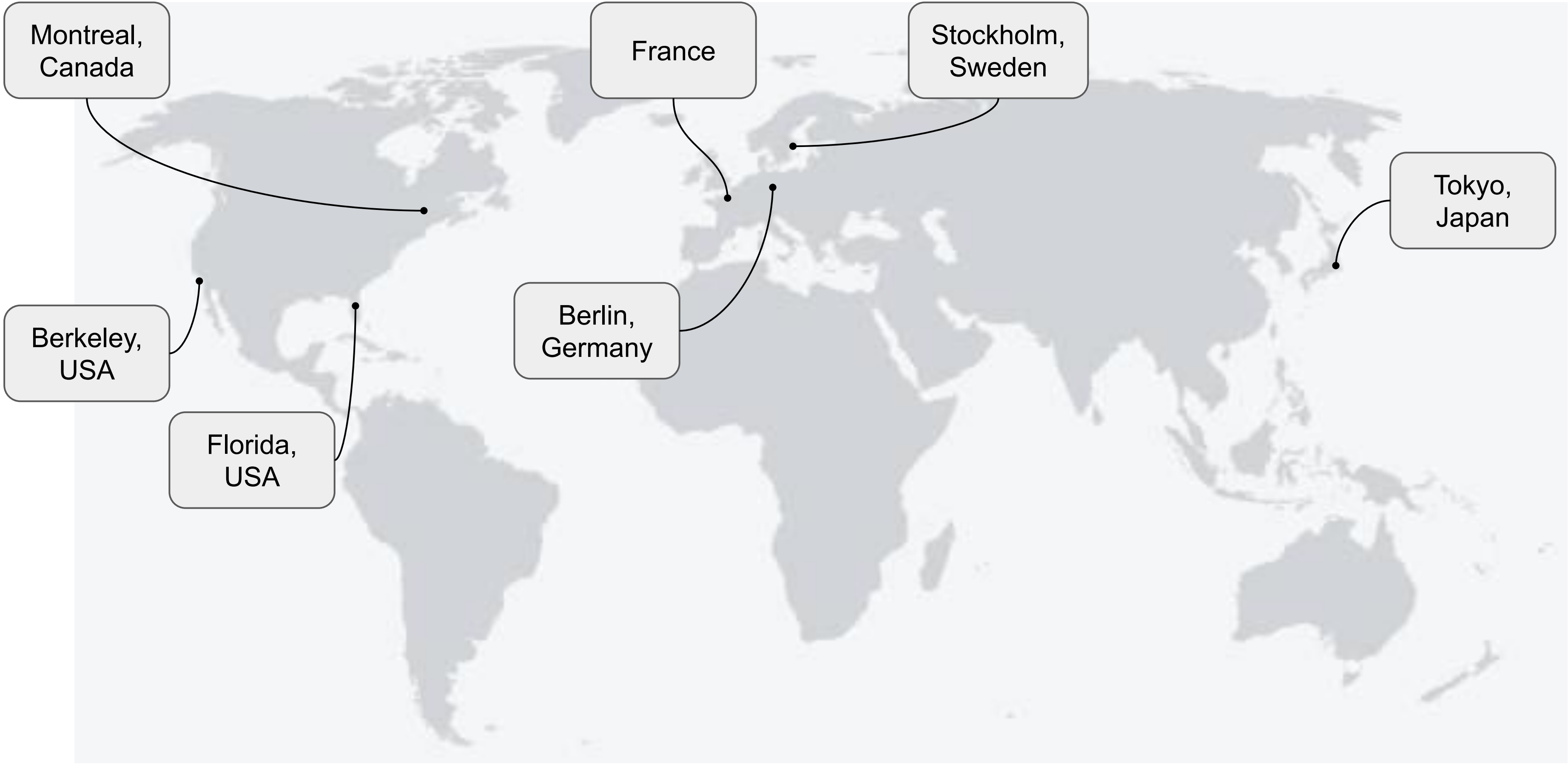
LPC
Particules
pLasmas
Univers
applicationS
Laboratoire de Physique de Clermont



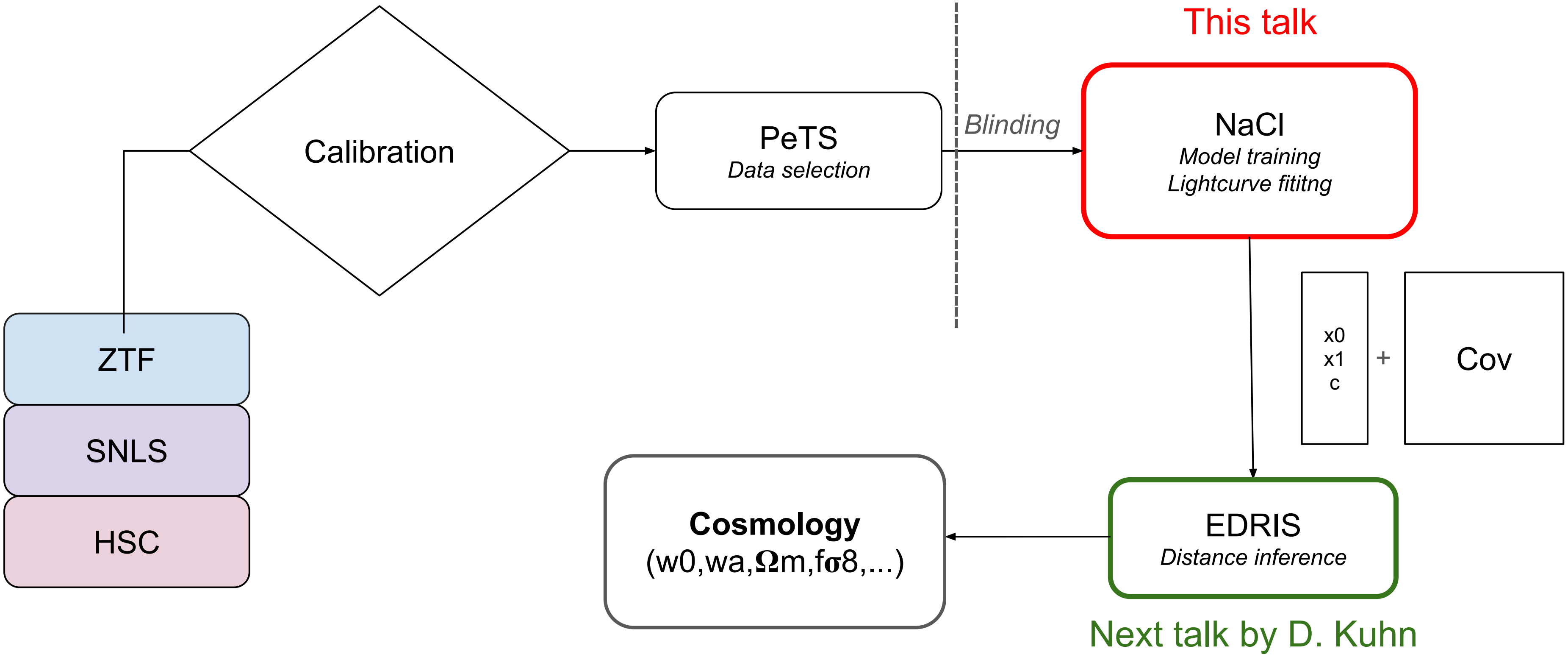
iP2i
LES 2 INFINIS
LYON

CENTRE DE PHYSIQUE DES PARTICULES DE MARSEILLE
CPPM

# People working on the LEMAîTRE project

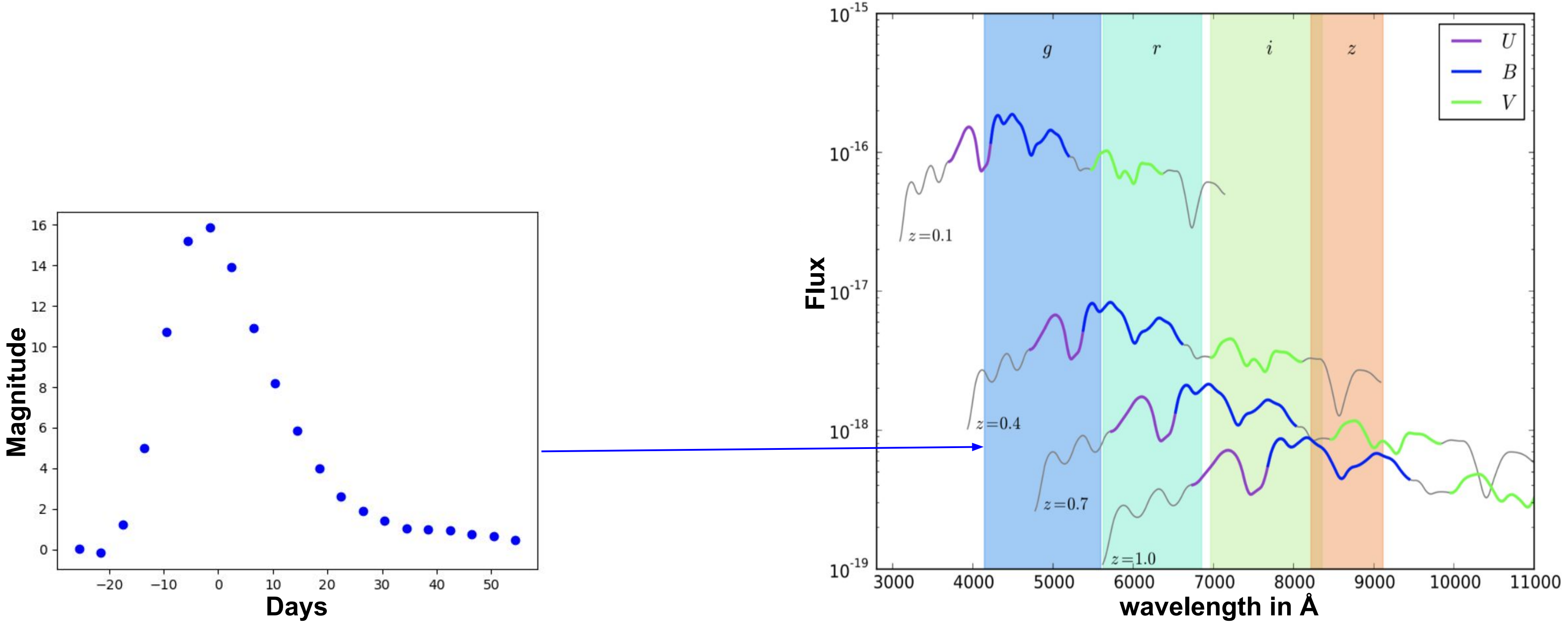


# LEMAîTRE pipeline



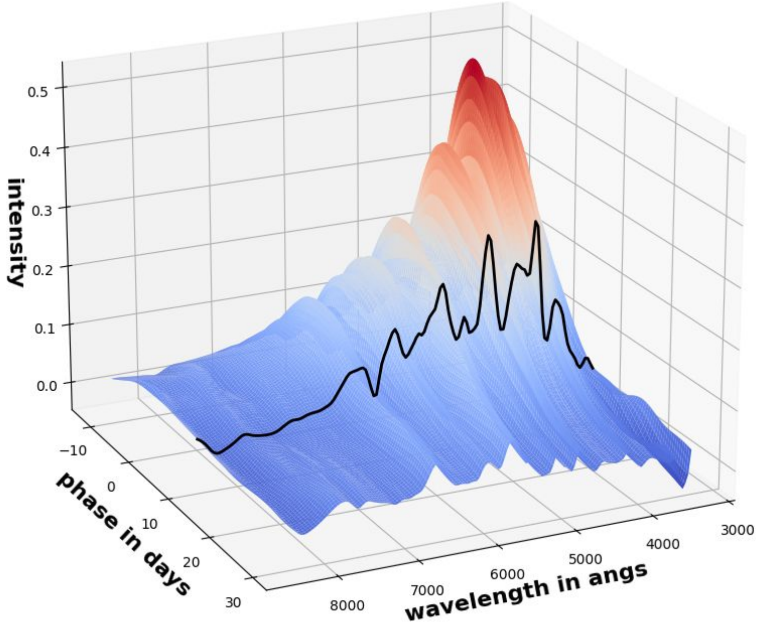
# SN Ia spectrophotometric modelling

- In order to measure SN Ia distances we need to reconstruct its **restframe flux**



# SN Ia spectrophotometric modelling

- For that we interpolate the SN Ia flux from a spectrophotometric model



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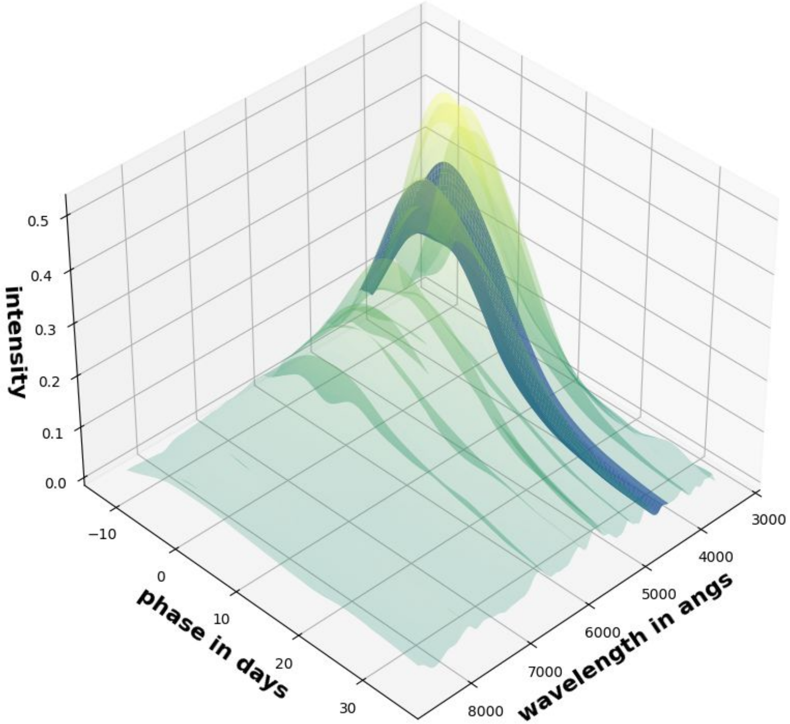


# SN Ia spectrophotometric modelling

- Natural dispersion in SN Ia
- Standardizable with 2 parameters : **color** and **stretch**

*Tripp (98) relation :*

$$-2.5\log_{10}(f) = m_{meas} = m_{std} + \alpha X_1 + \beta c$$

Measured magnitude ($m_{meas}$)

Model magnitude ($m_{std}$)

Stretch parameter ($X_1$)

Color factor ($c$)

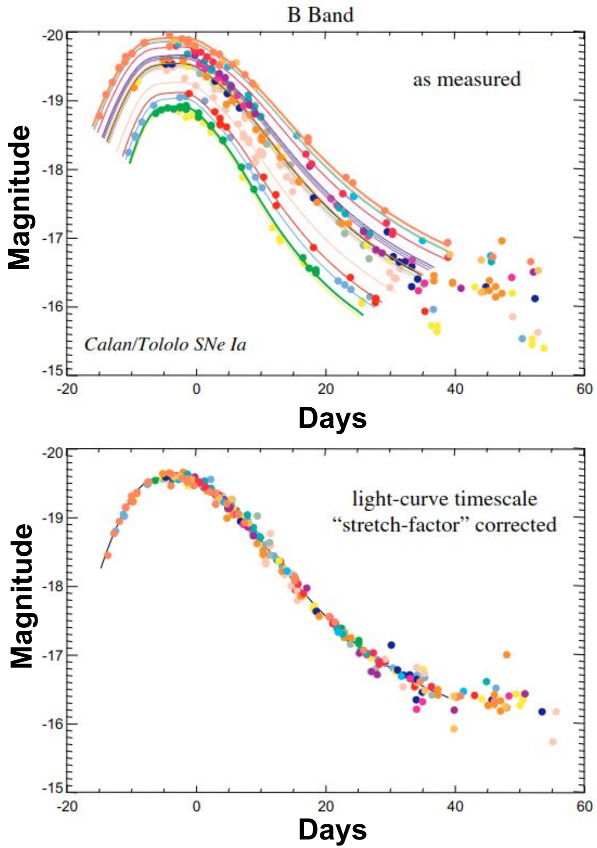



Illustration of light curves before and after stretch-factor corrections

*Source : Huterer & Shafer (2017) based on A. G. Kim (1997)*

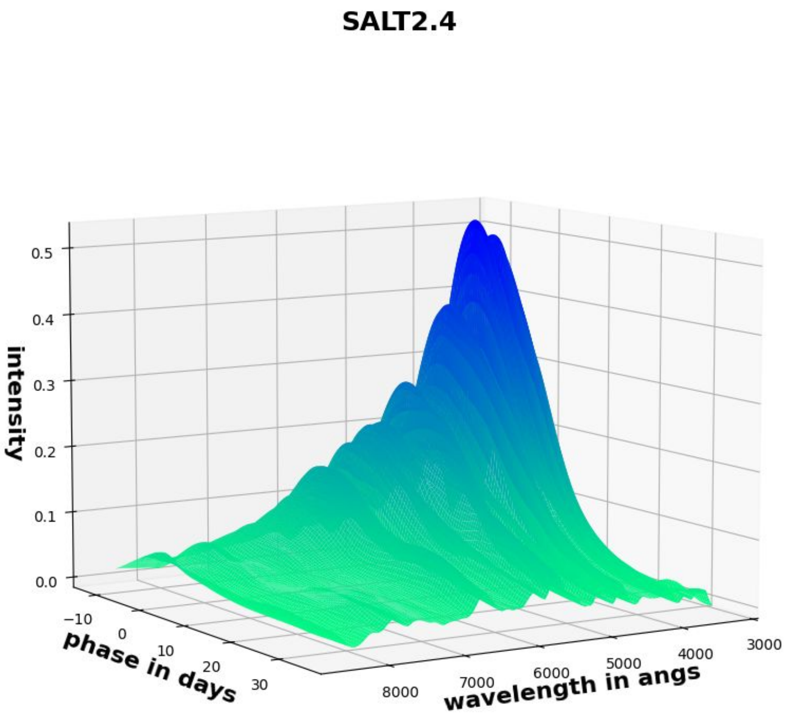
# SN Ia spectrophotometric modelling

- To describe all of this we use spectrophotometric models like SALT2

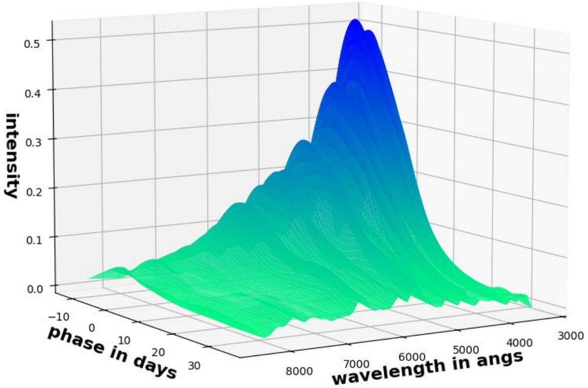
Model

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

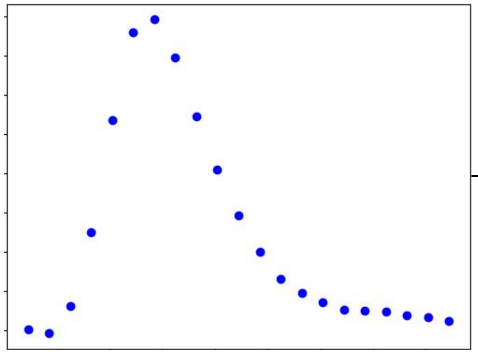
Amplitude Stretch Color



# SN Ia spectrophotometric modelling



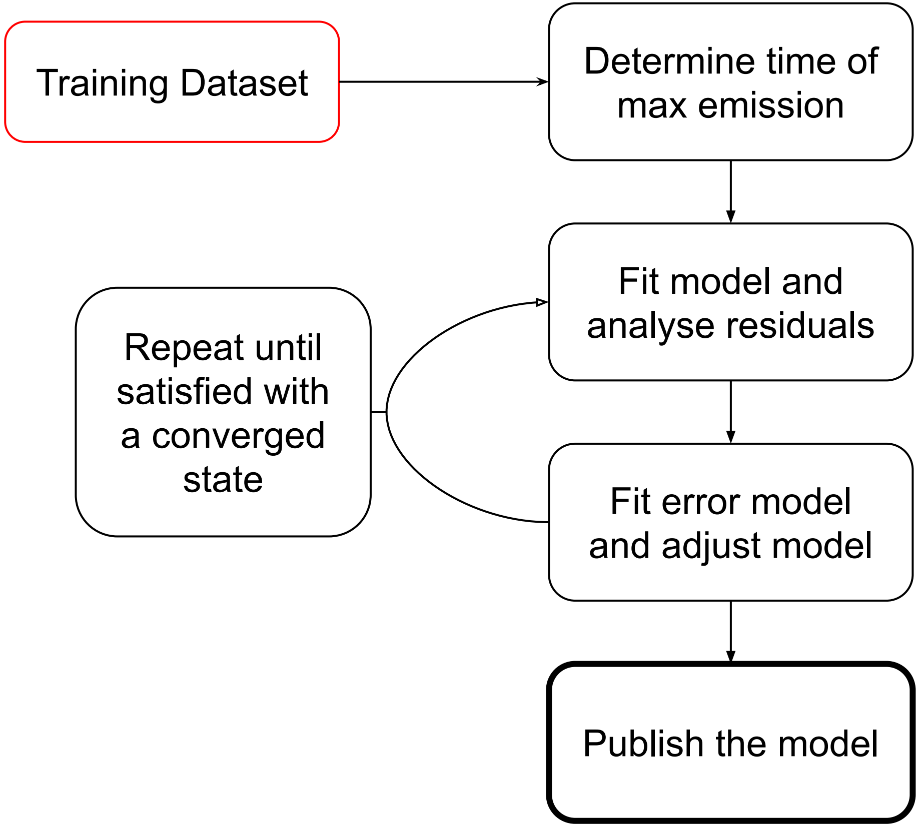

+



Compressed

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

# SN Ia spectrophotometric modelling : why not use one of the SALT models?



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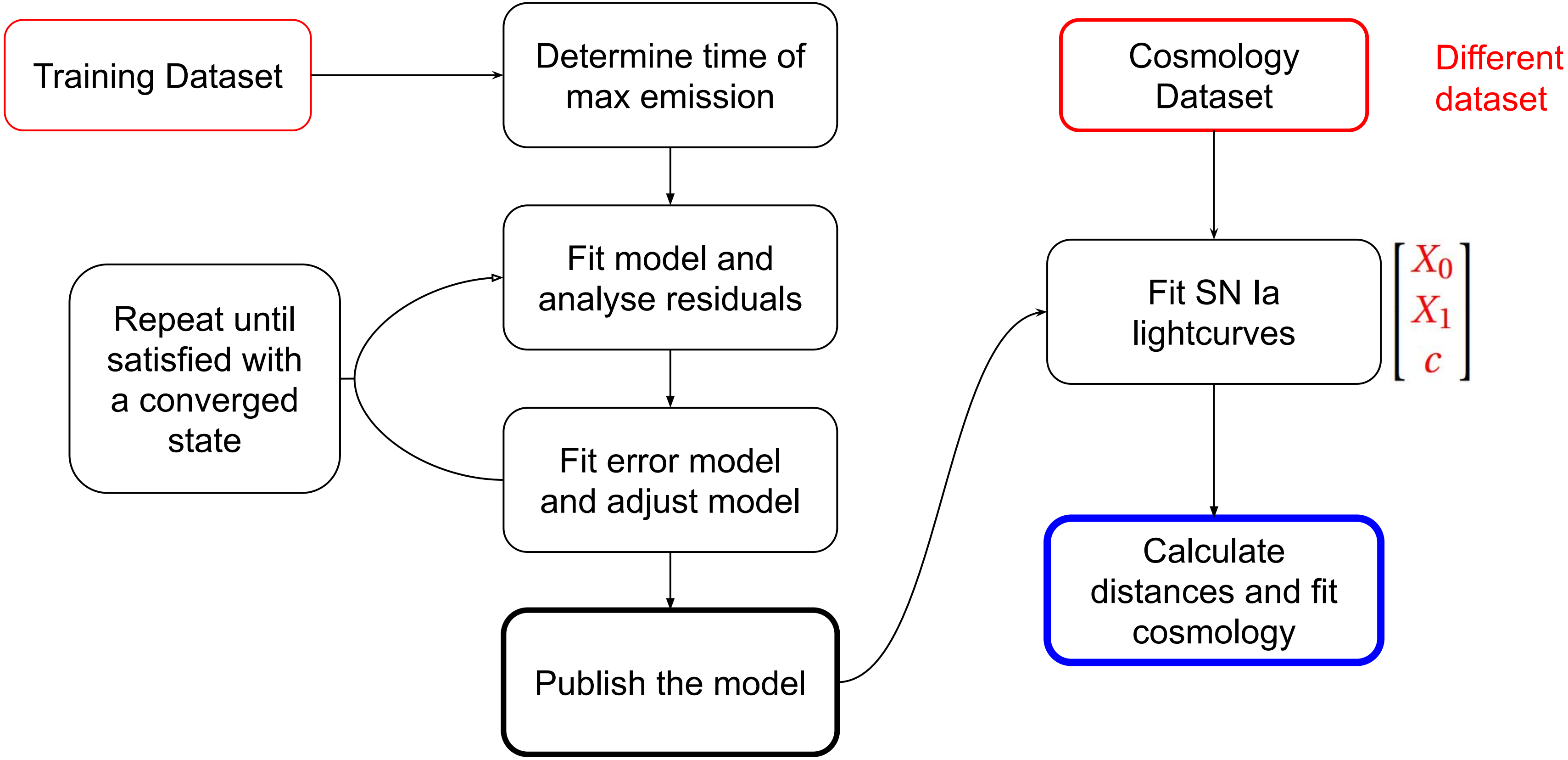
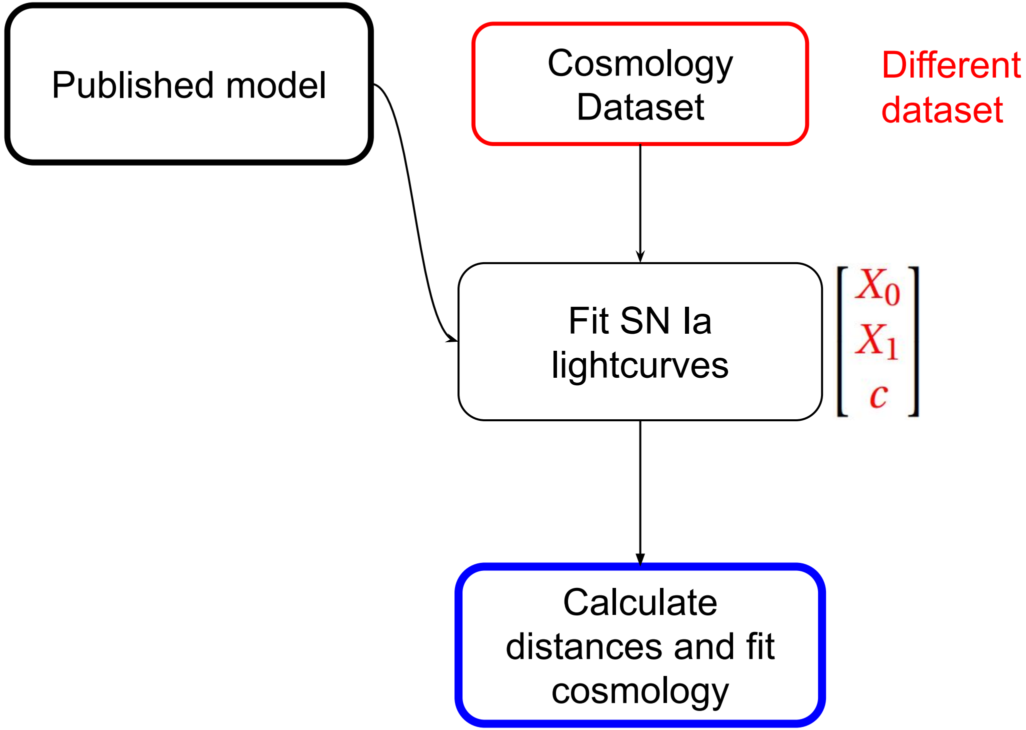


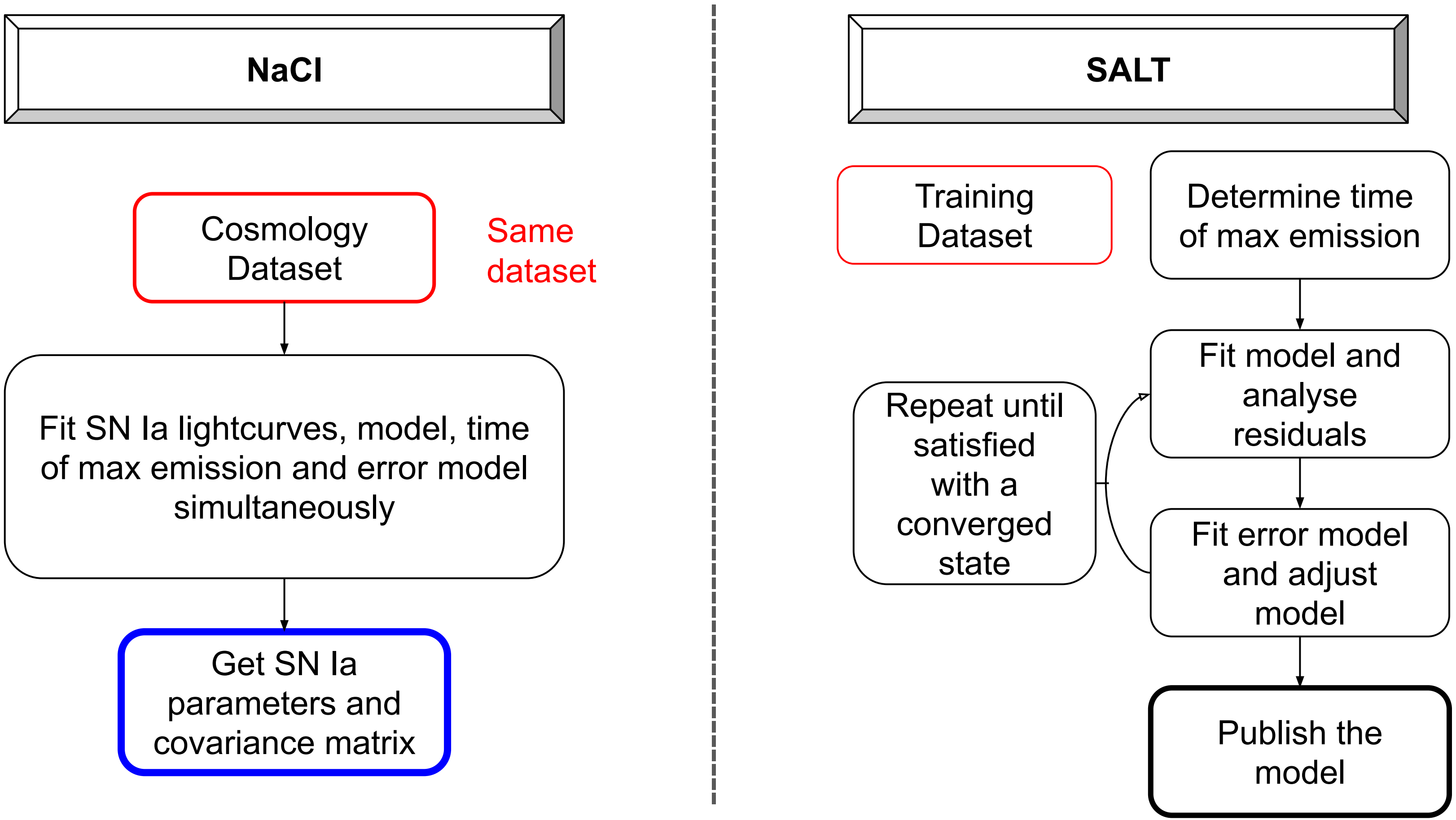
# SN Ia spectrophotometric modelling : why not use one of the SALT models?

- **Complicates propagation** of model and calibration uncertainties which turn into **systematics**

- SALT calibration systematics are one of the leading sources of uncertainties



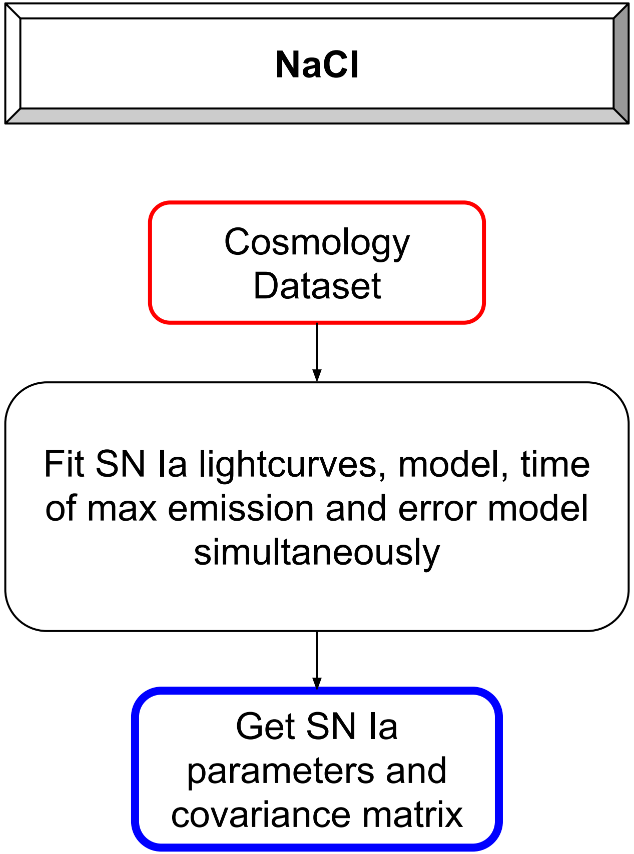
# **NaCl** : a new framework for training spectrophotometric models



# **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 **easy** to use, **fast** for training models and can be easily **reparameterized** to train more sophisticated models



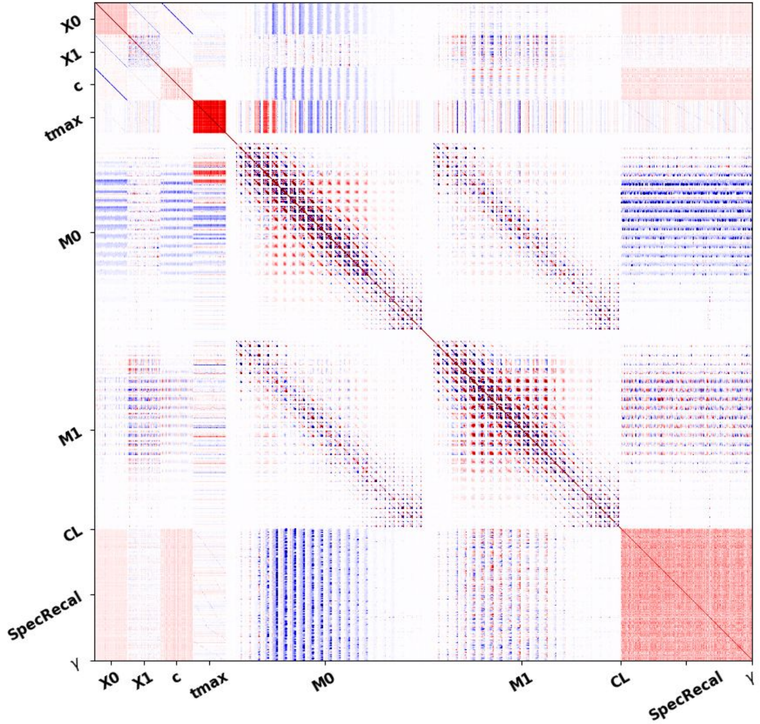
# NaCl : a new framework for training spectrophotometric models

- 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**

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



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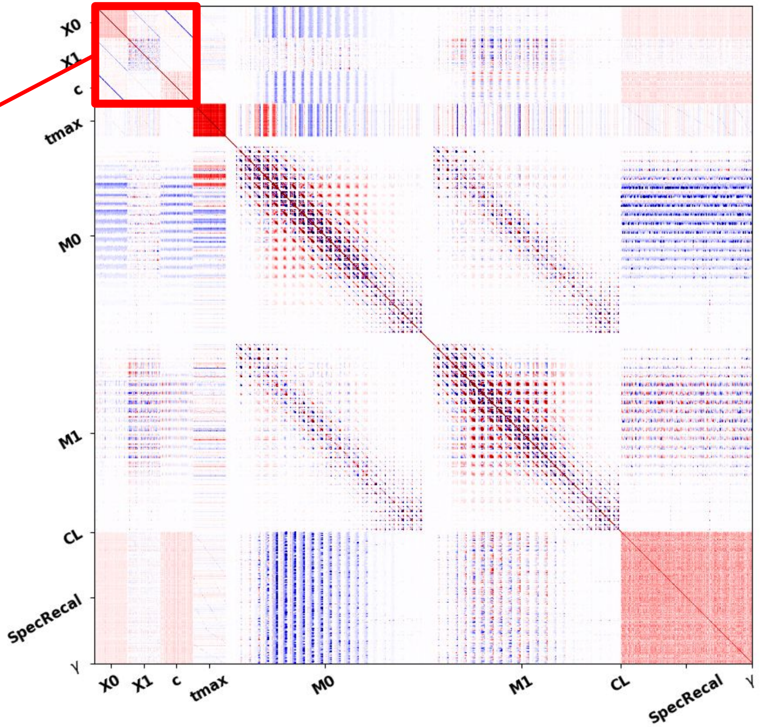
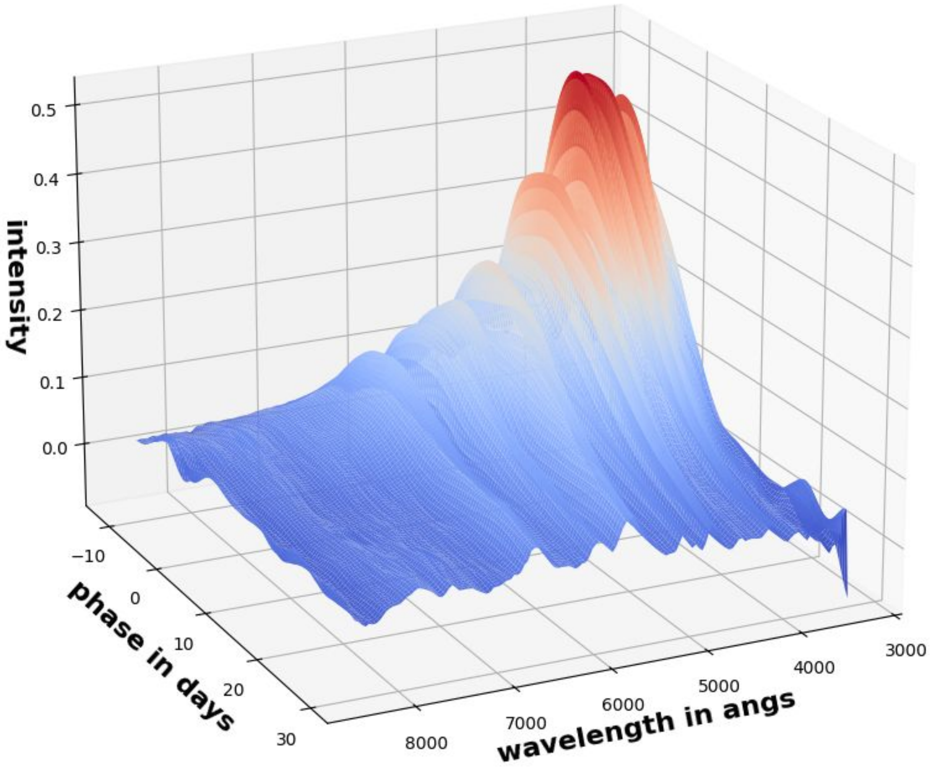


# Results of NaCl training : simulations

- Results of NaCl trainings on LEMAîTRE-like simulations

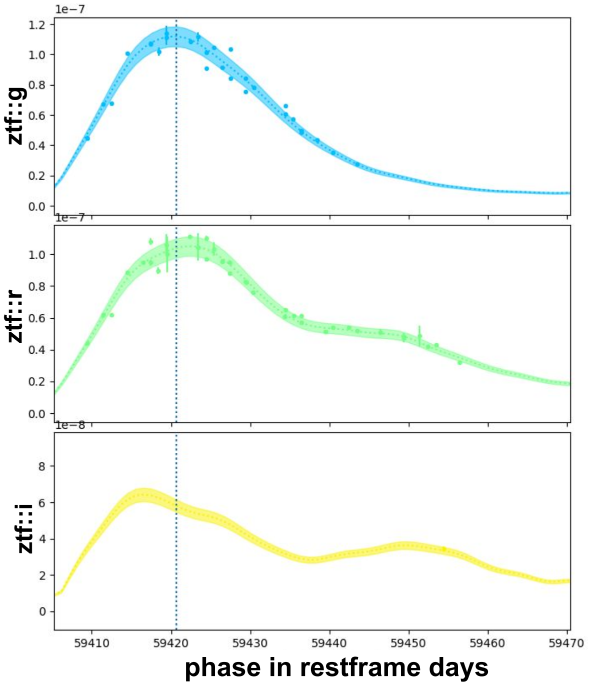
- We show here the trained model

- Time it took ~ 30 mins



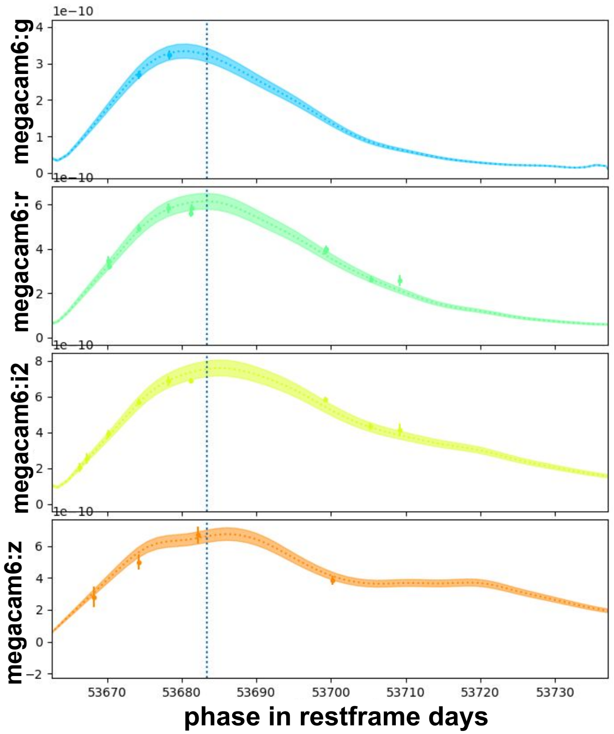
# Results of NaCl training : simulations

861 @ z=0.0358



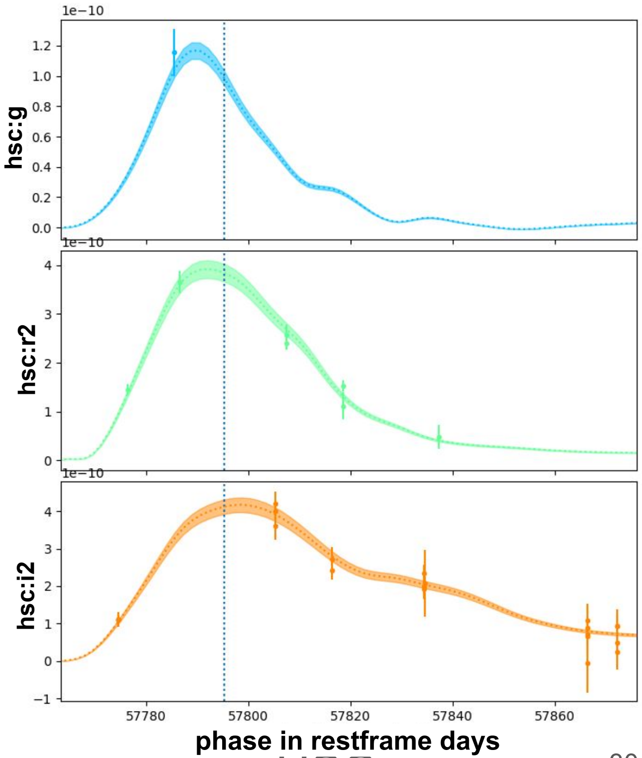

ZTF

14023 @ z=0.335



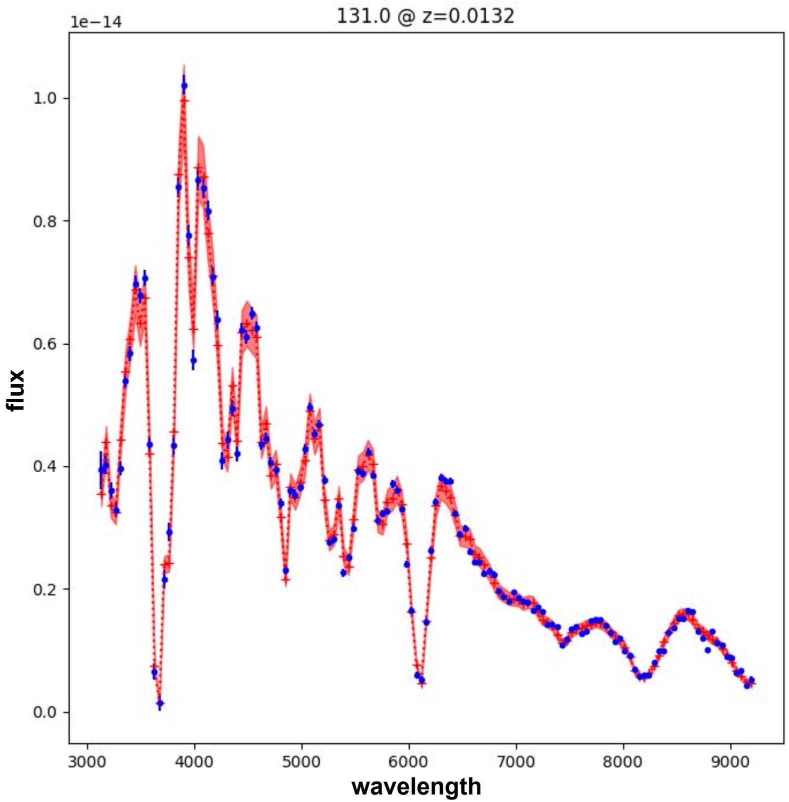

SNLS

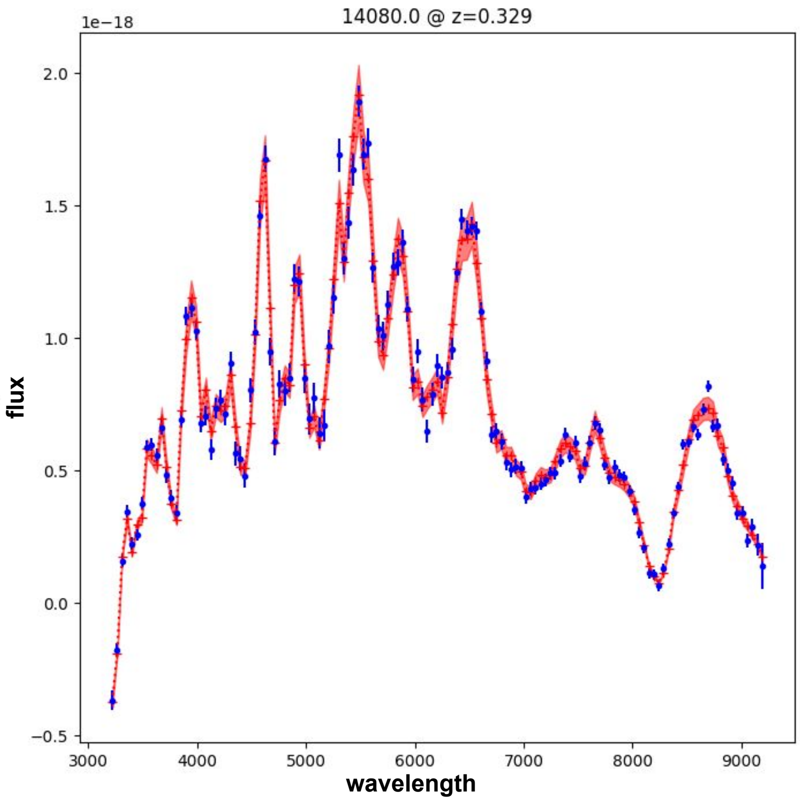
33088 @ z=0.618




HSC

# Results of NaCl training : simulations



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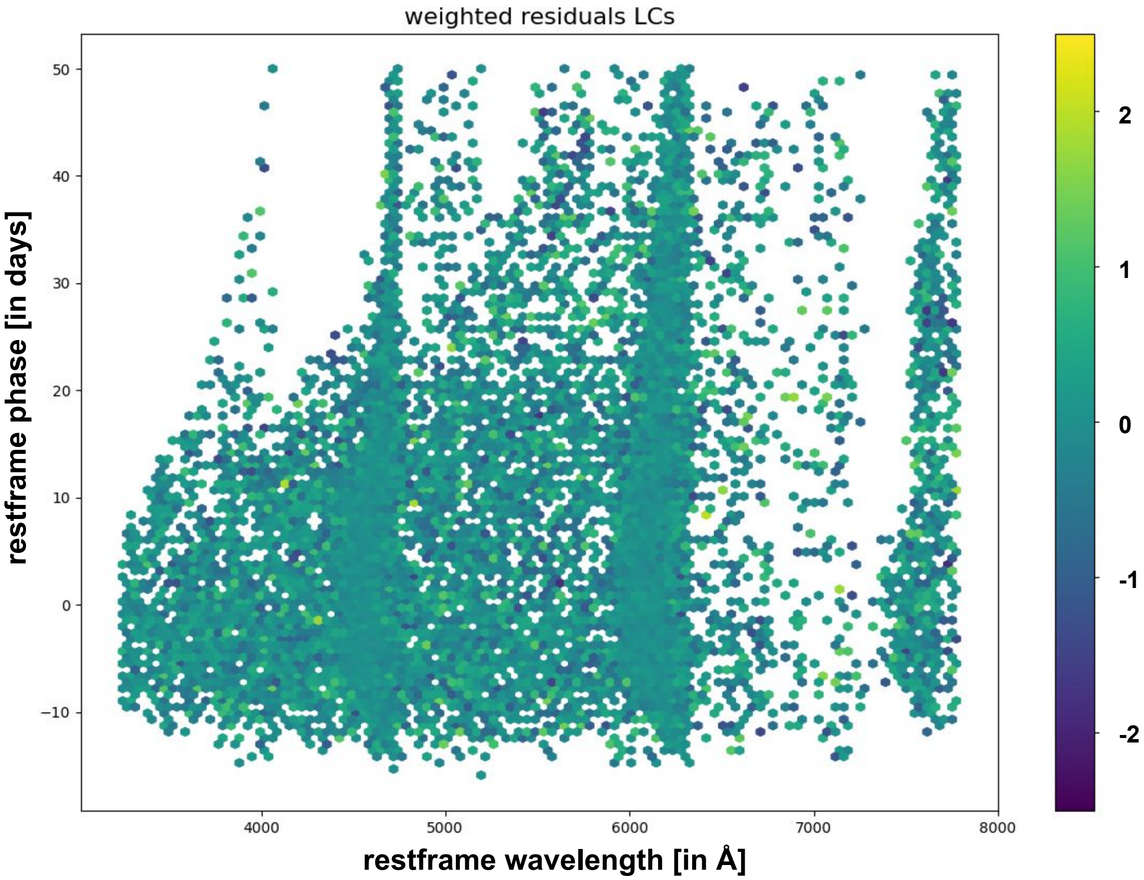
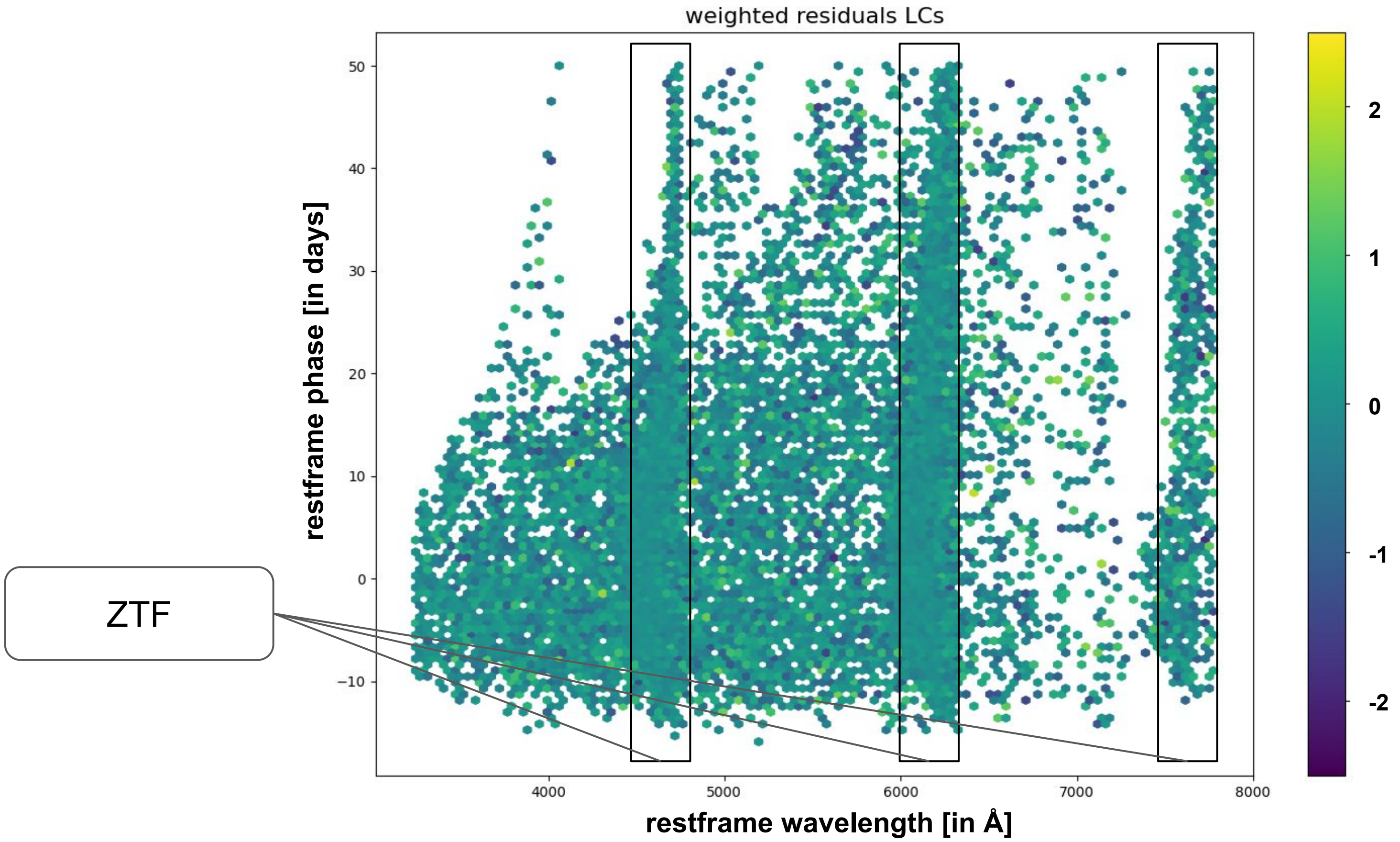


# Photometric residuals



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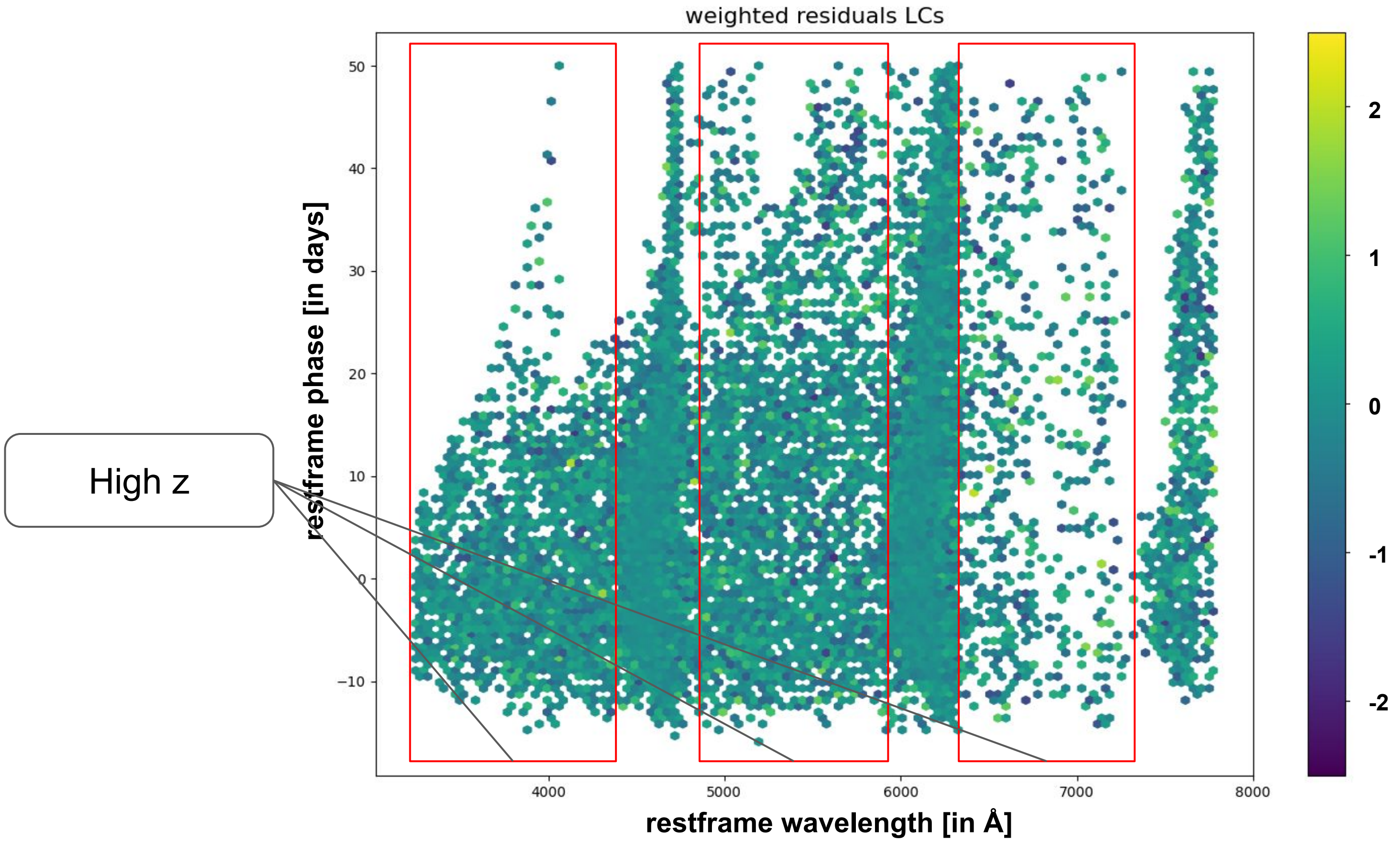
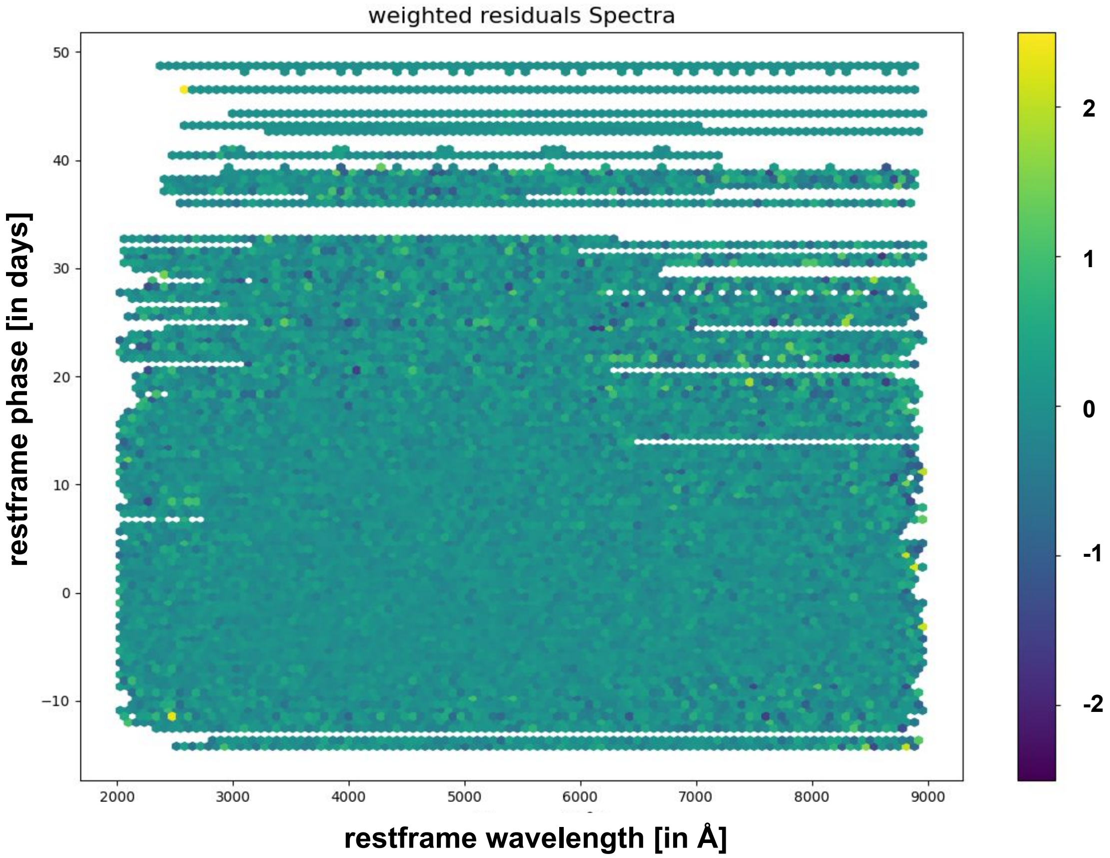
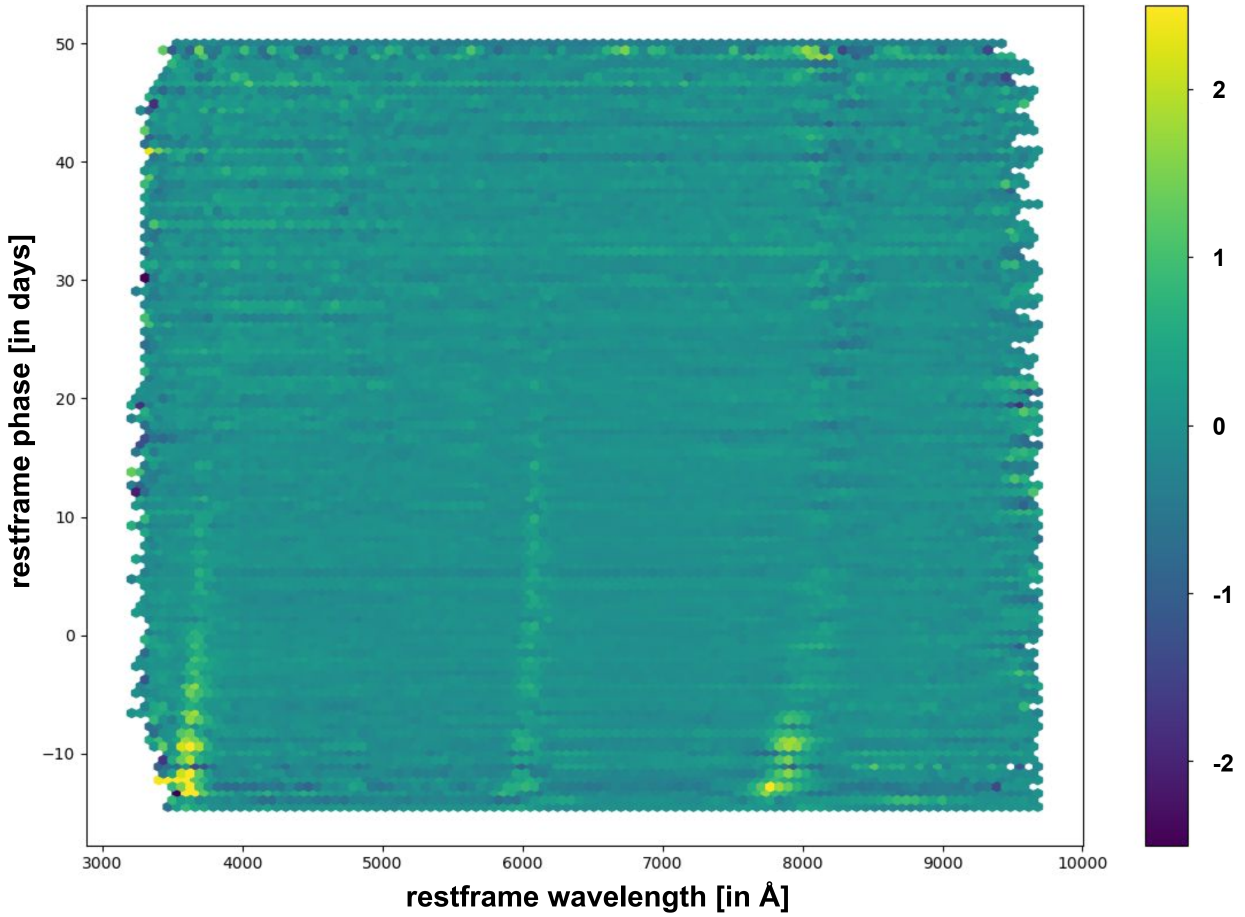


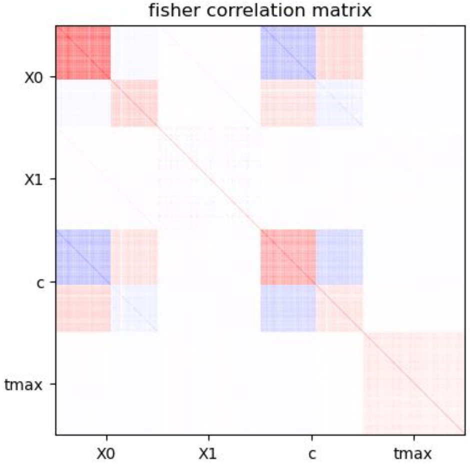
# Spectroscopic residuals

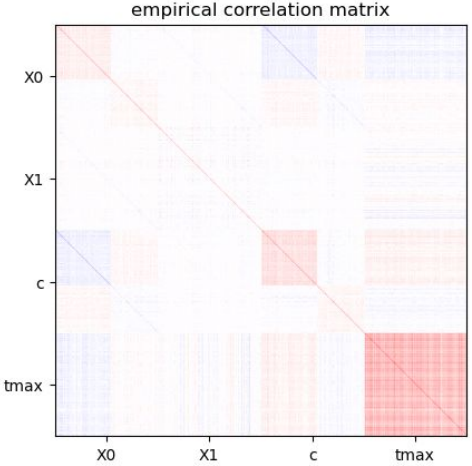


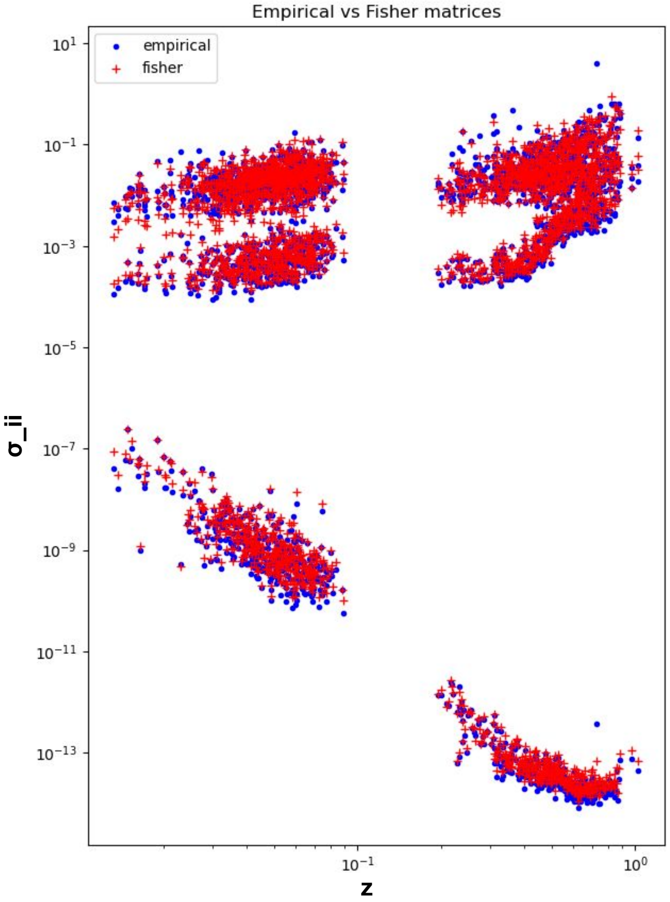
# Spectroscopic residuals : real data



# Results of NaCl training : Covariance matrix Fisher vs Empirical

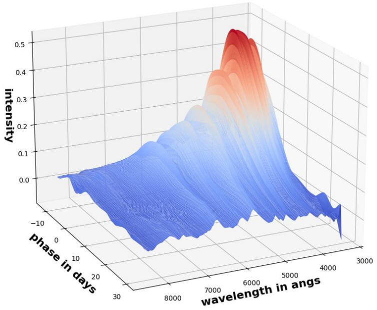


# Conclusion

**Next talk, stay tuned!!**




**NaCl**
*SN Ia modelling*

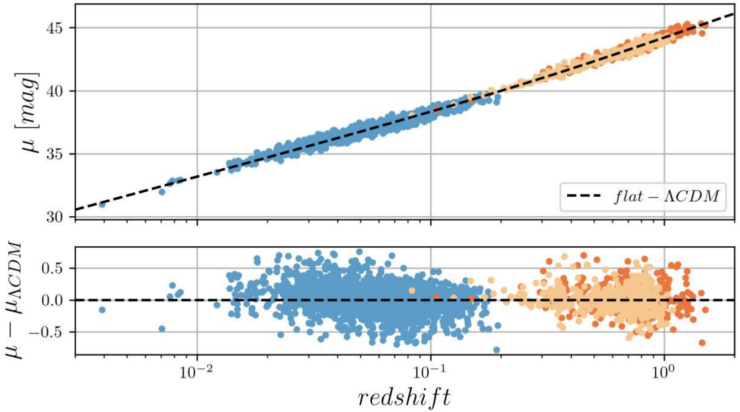
**EDRIS**
*Distance inference*

ZTF

SNLS

HSC

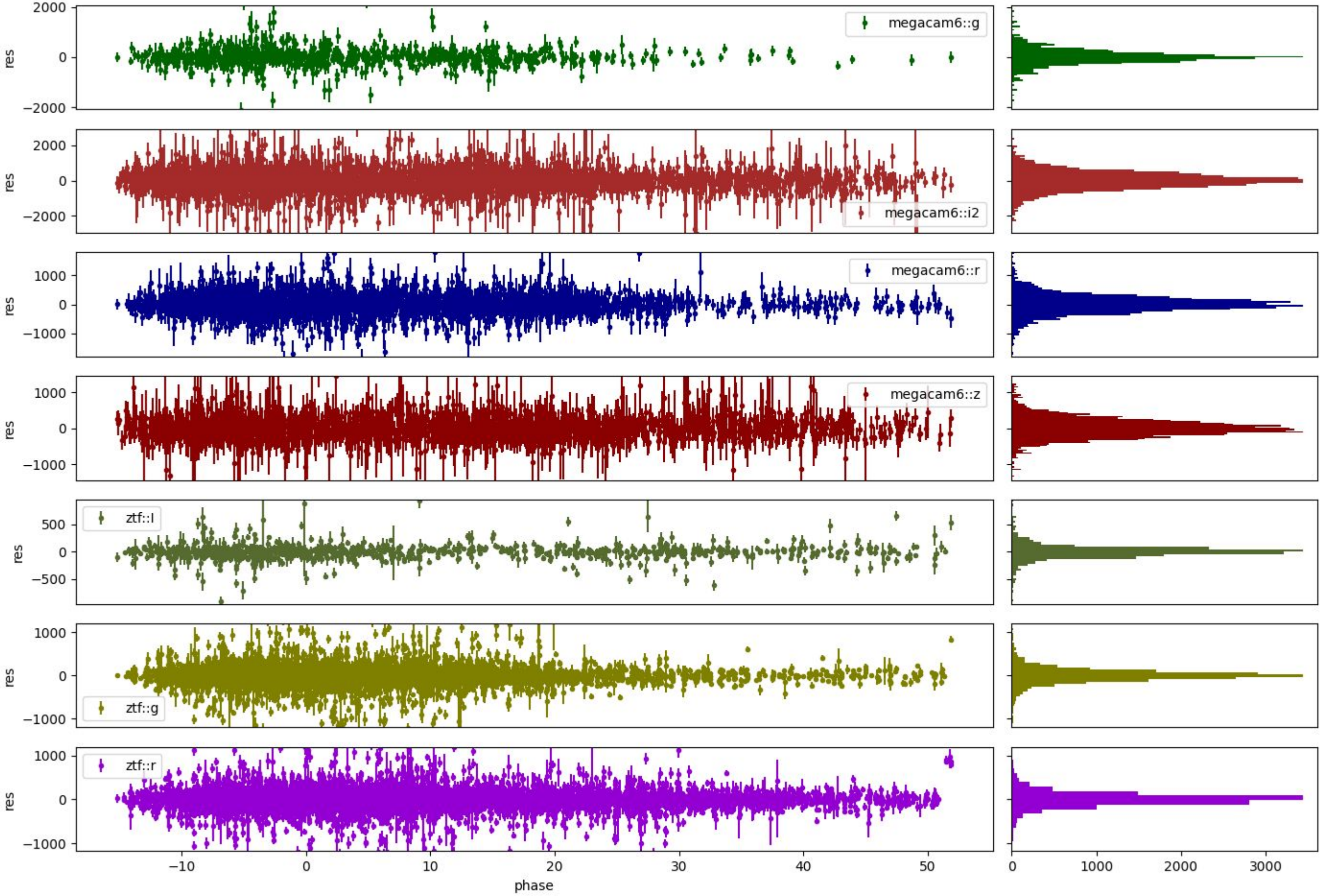
Calibration
&
Data selection



# Thank you!

# Backup

# Results of NaCl training : Residuals



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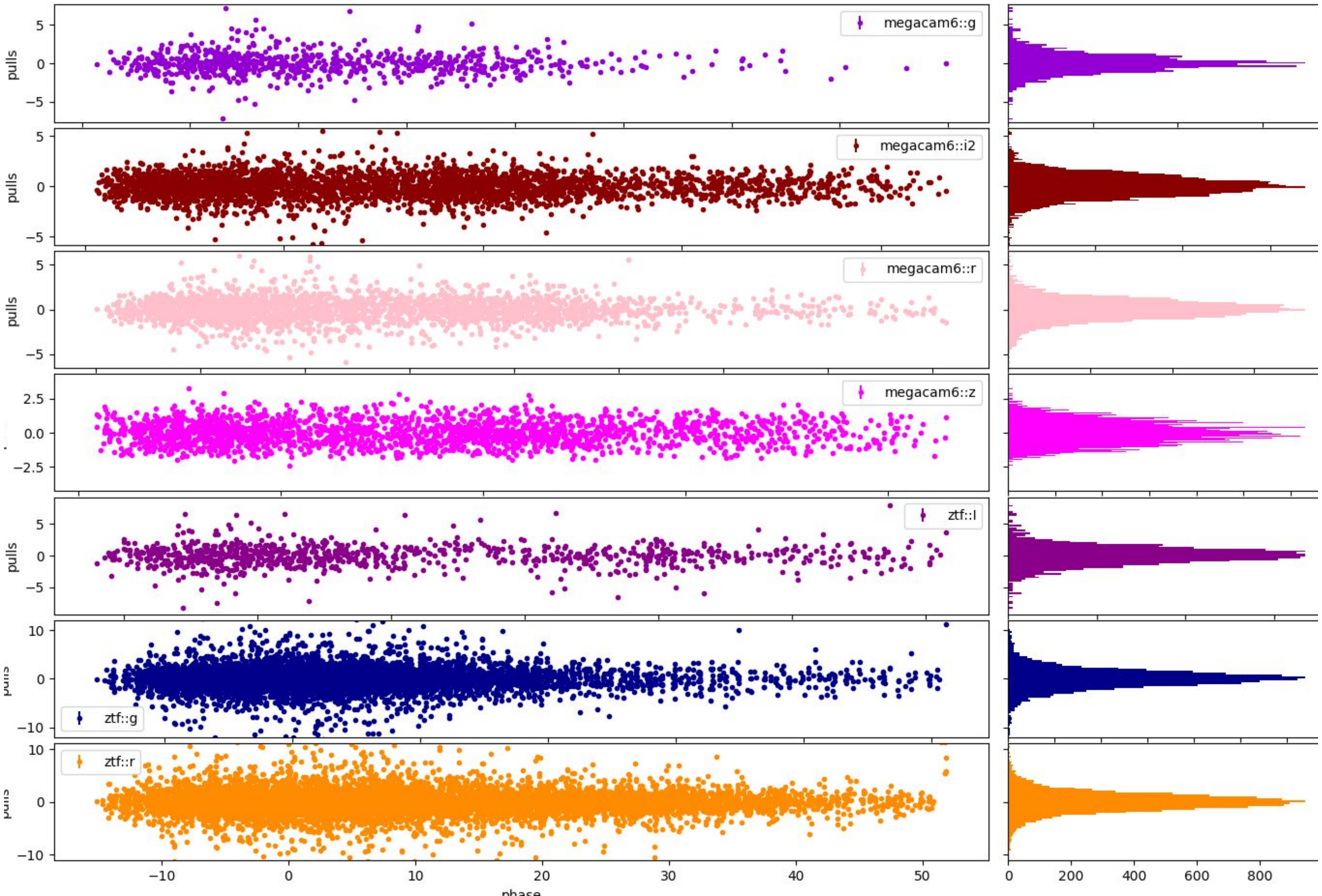
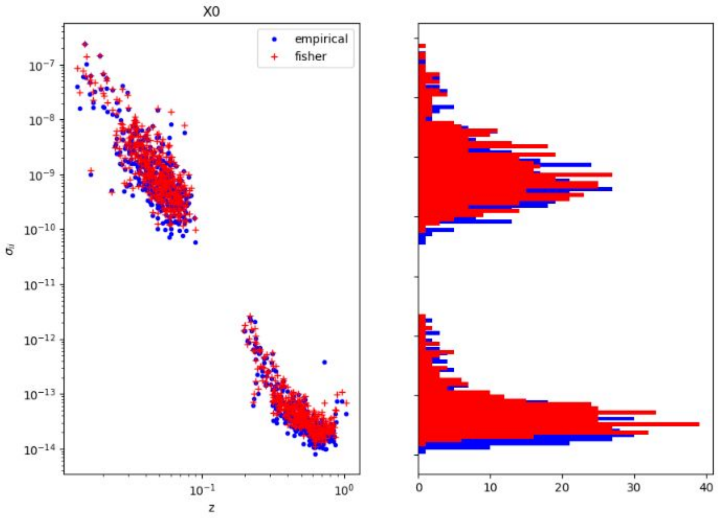
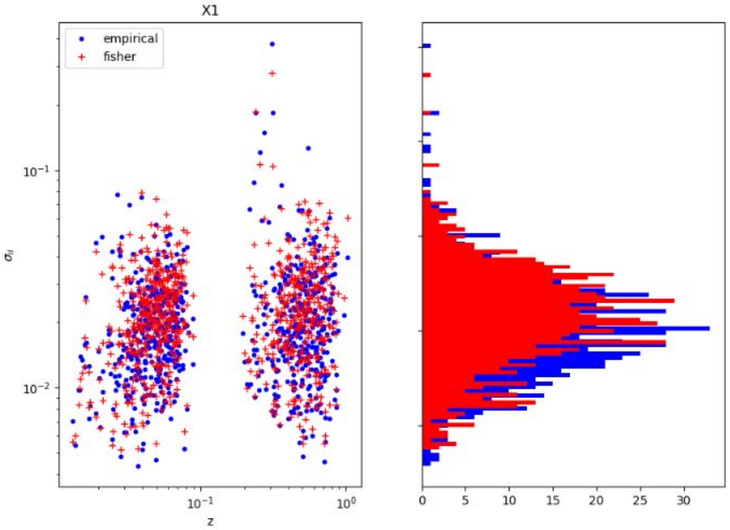
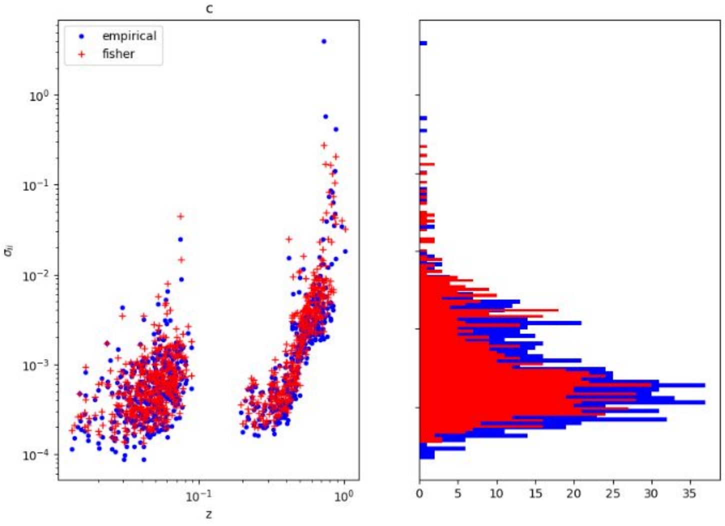
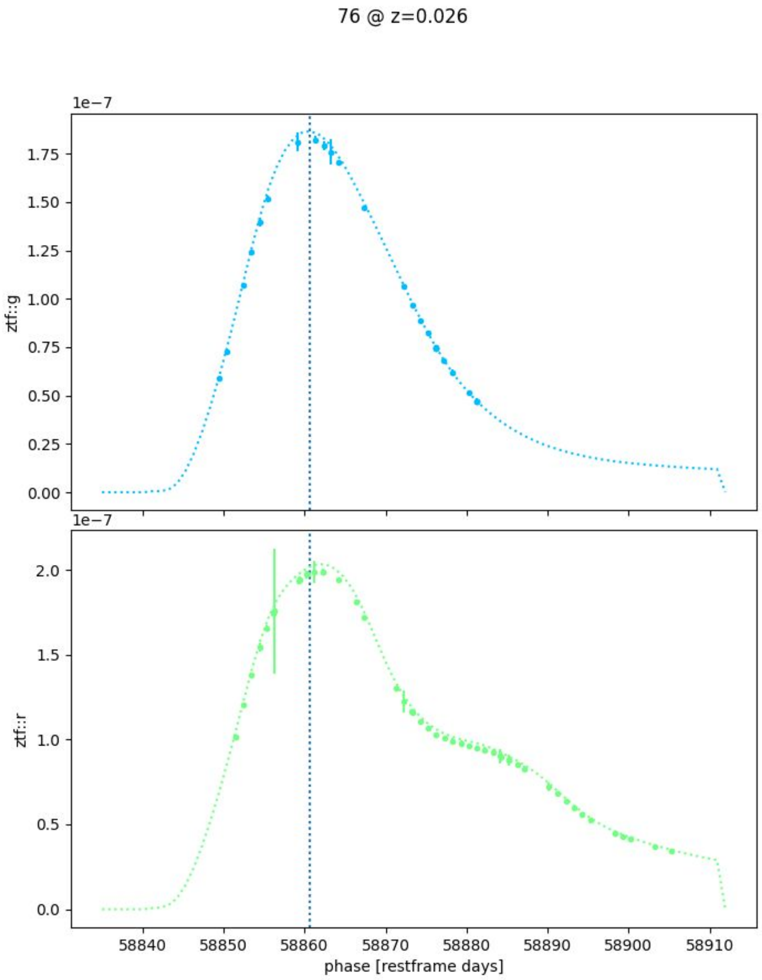


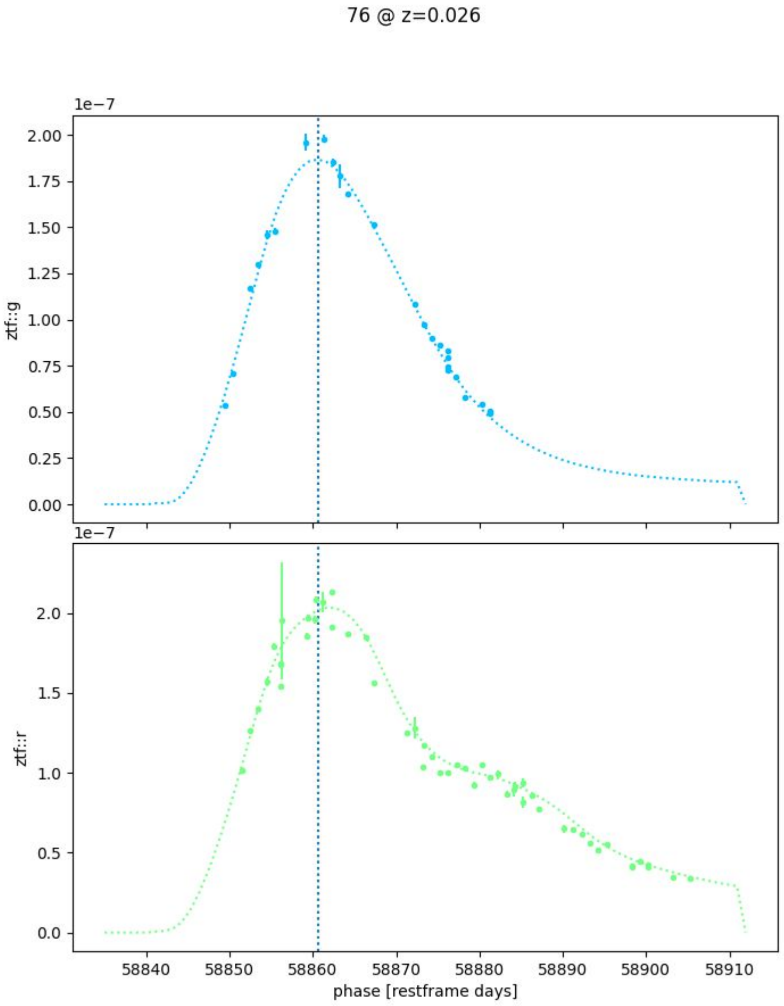
# Results of NaCl training : Covariance matrix Fisher vs Empirical

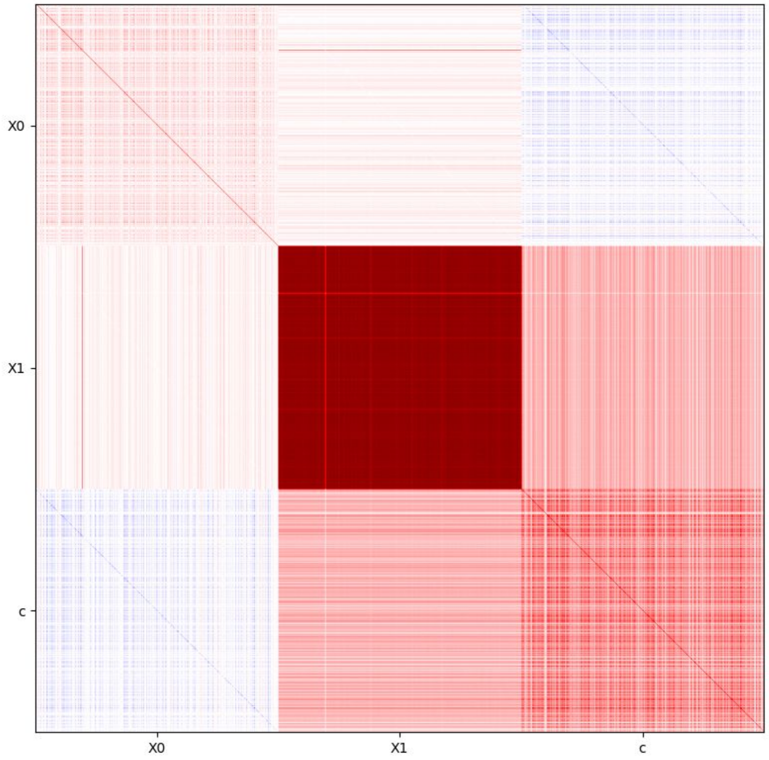


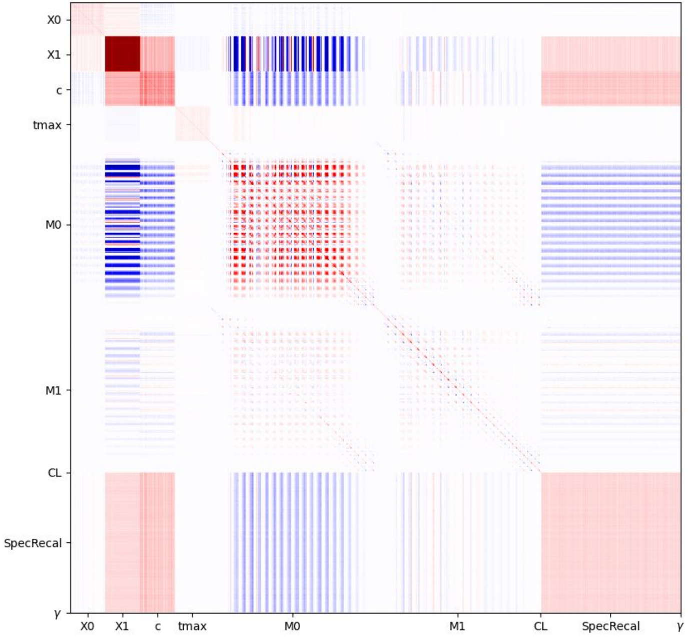




76 @ z=0.026
1e−7
ztf::g
1e−7
ztf::r
58840
58850
58860
58870
58880
58890
58900
58910
phase [restframe days]


76 @ z=0.026
1e−7
ztf::g
1e−7
ztf::r
58840
58850
58860
58870
58880
58890
58900
58910
phase [restframe days]



X0
X1
c
X0
X1
c

X0
X1
c
tmax
M0
M1
CL
SpecRecal
γ
X0
X1
c
tmax
M0
M1
CL
SpecRecal
γ