Black Swans Challenge Week

Collaboration B Structure

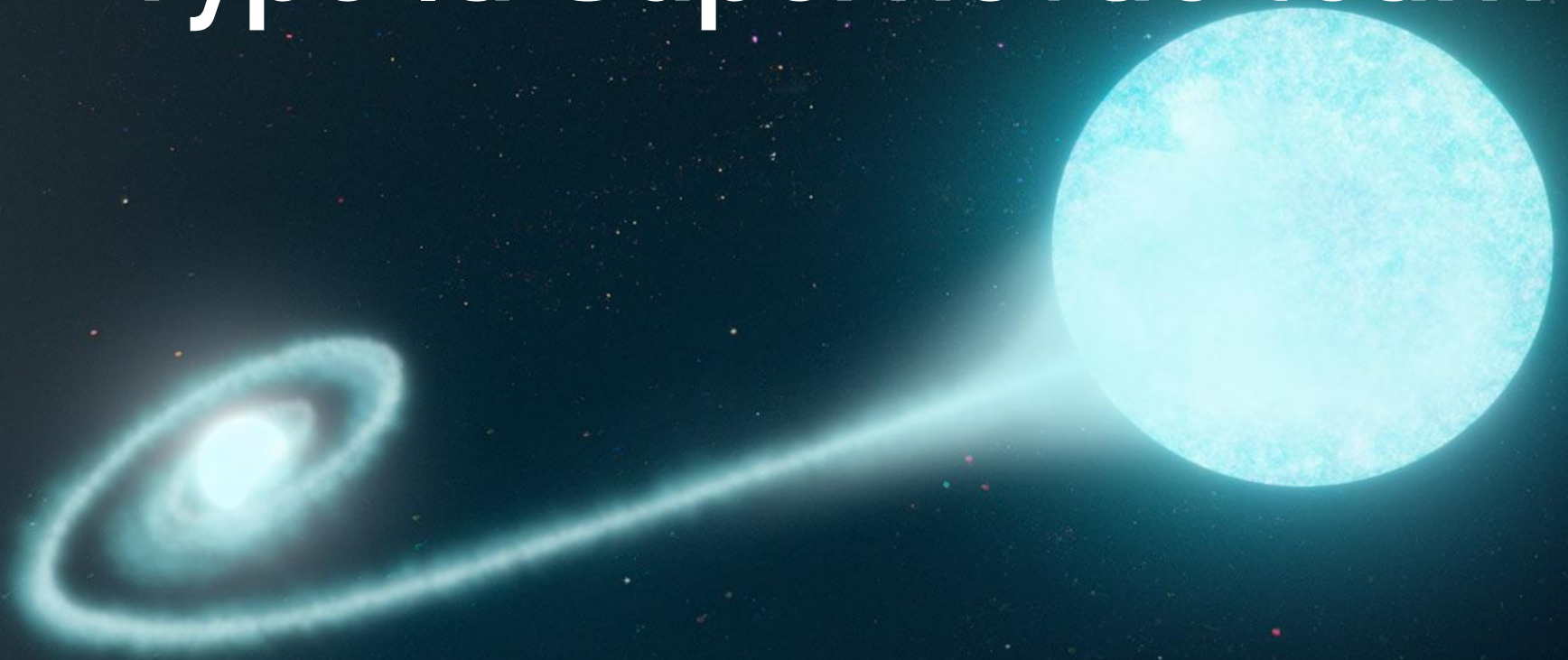
Type Ia Supernovae team

- WP-SN-1 :
- WP-SN-2 :
- WP-SN-3

Cosmic Microwave Background team

- WP-CMB-1 :
- WP-CMB-2 :
- WP-CMB-3

Challenge Week – Group B – Type Ia Supernovae team



Black Swans Detection in Particle Physics and Cosmology

The Work Packages

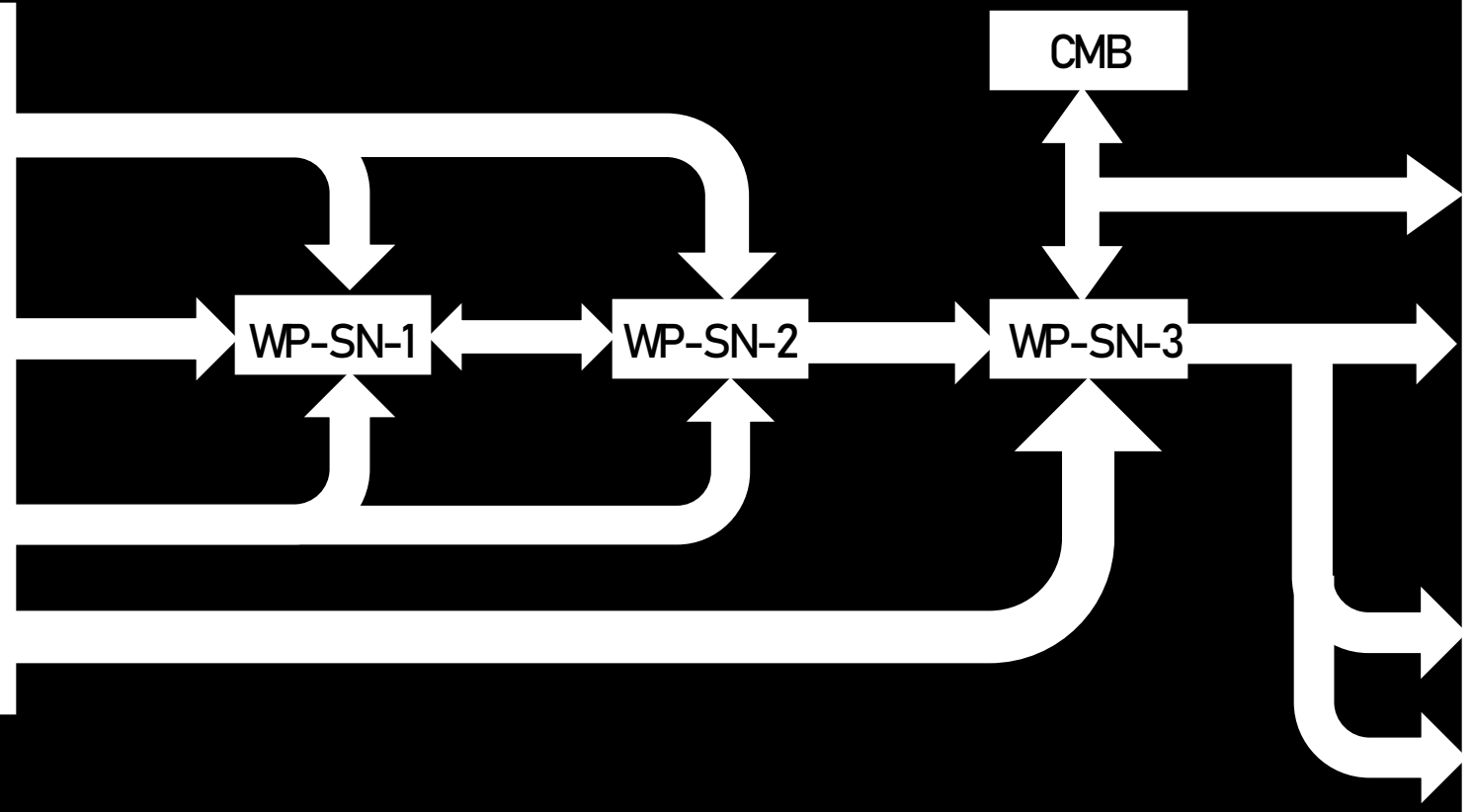
- Work Package SN-1 : Supernova detection on images
- Work Package SN-2 : Photometry of supernovae candidates
- Work Package SN-3 : Light Curve Fitting and cosmological constraints

Our general objective : extracting relevant cosmological information from a dataset concerning Type Ia supernovae

How each group relates to one another

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model



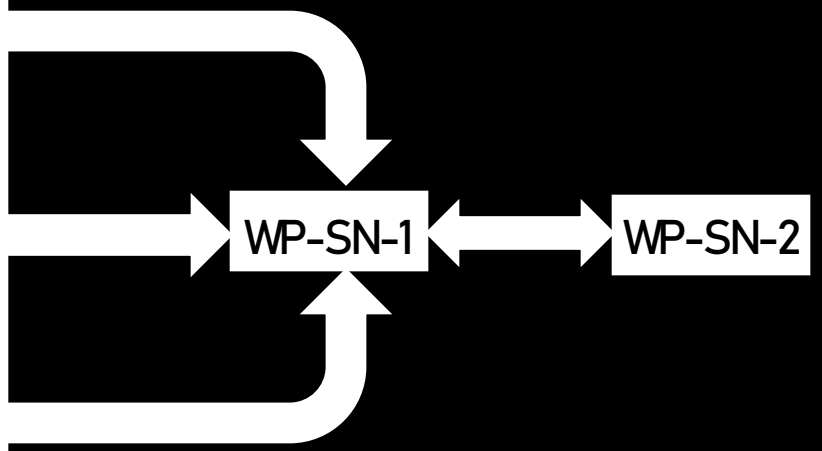
Output data

- Adjustments of CMB+SNIa dataset for values and errors of cosmological parameters
- Adjustments of SNIa dataset for values and errors of cosmological parameters.
- Apparent magnitude of supernovae
- Distance and redshift of supernovae

WP-SN-1 : Supernovae detection on images

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model

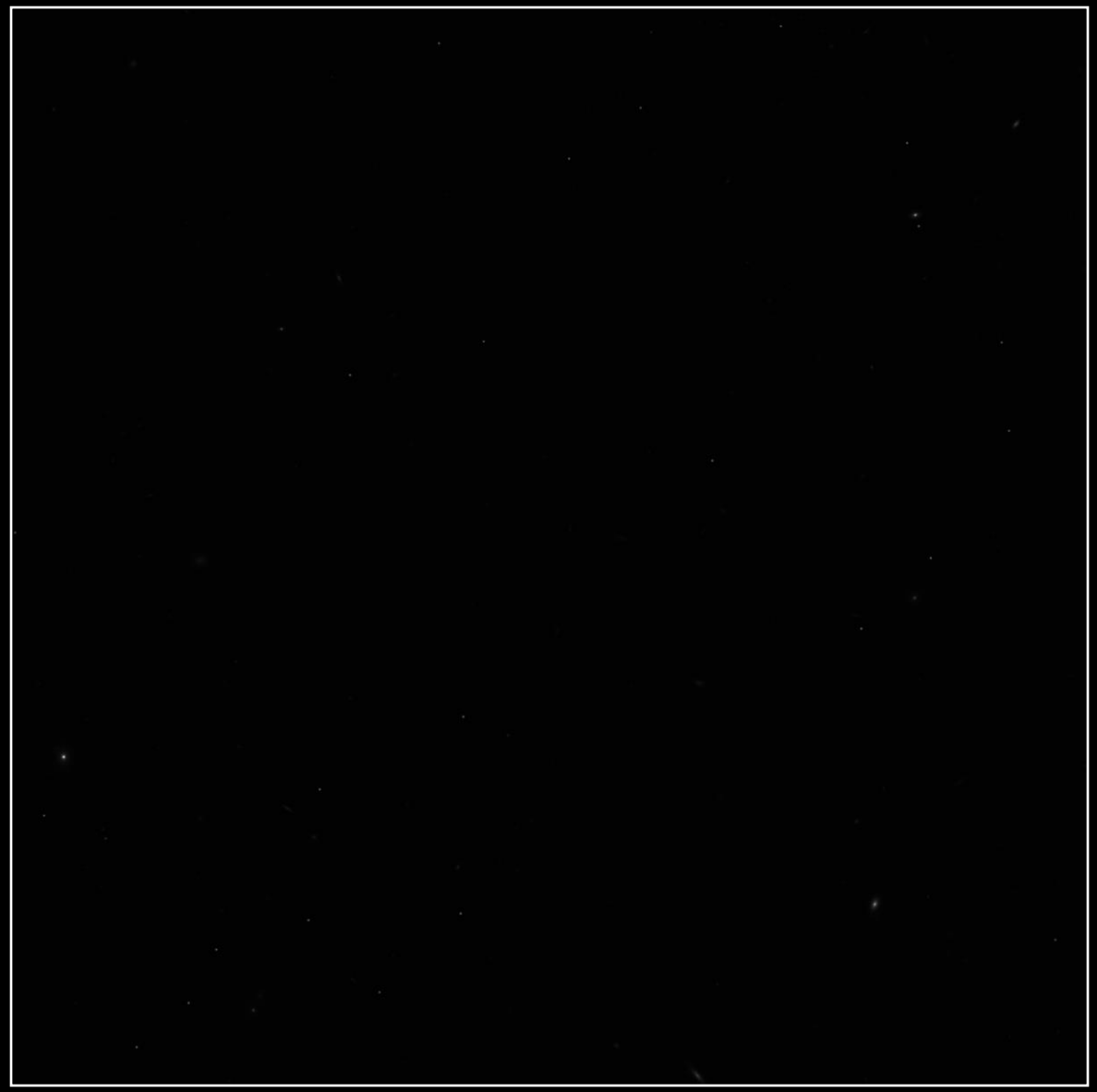


The input data

Data for five different sky fields.

For each field :

- Images taken at different epochs (common to each field)



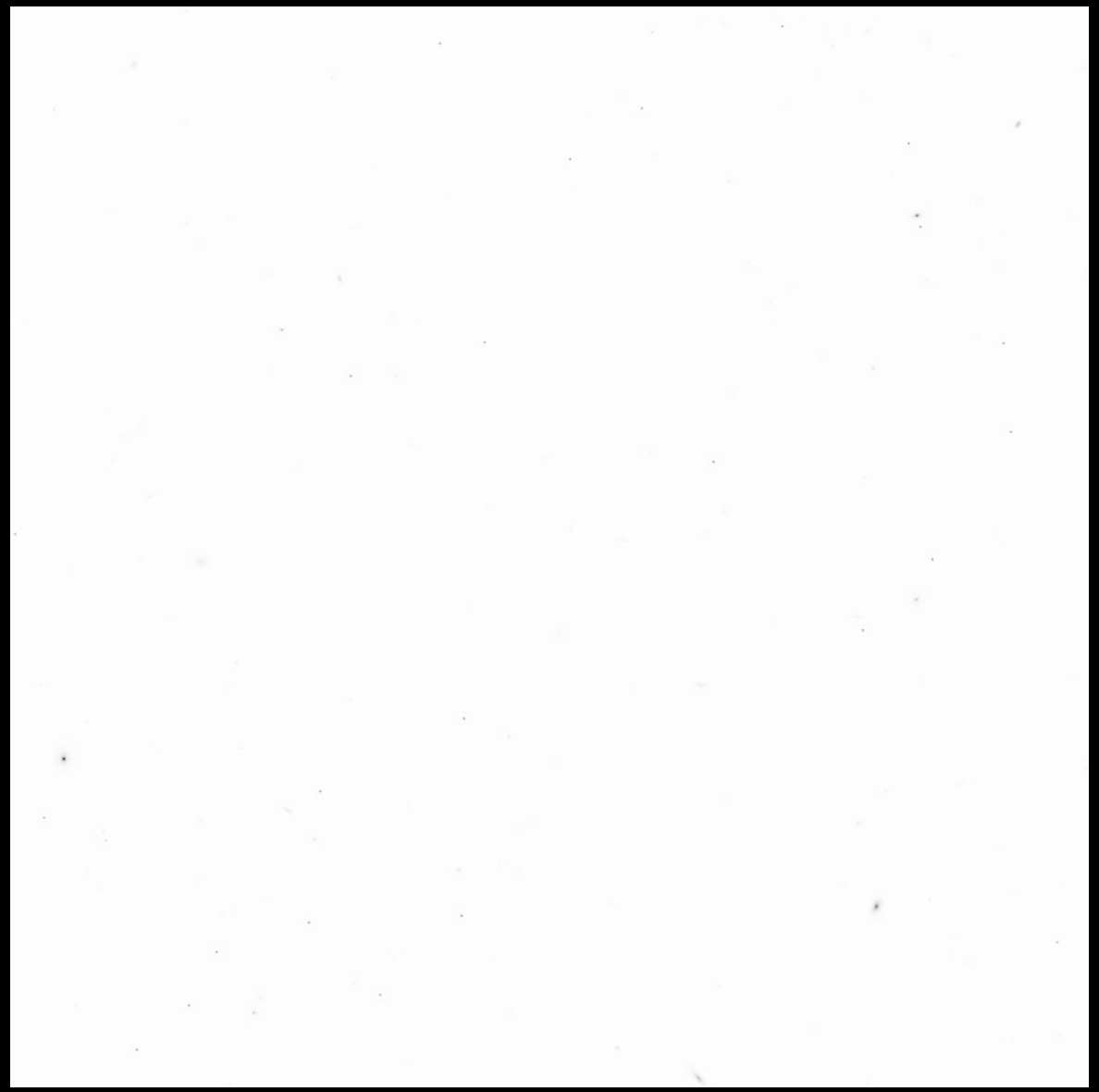
The input data

Data for five different sky fields.

For each field :

- Images taken at different epochs (common to each field)

With inverted grayscale, as we cannot see much...



The input data

- Information on galaxies and stars on the reference image (epoch - 100)

	Unnamed: 0	magnitudes	redshift	x	y
0	galaxie 1	26.56	1.21	1,460.45	1,305.45
1	galaxie 2	26.68	0.33	430.00	1,488.05
2	galaxie 3	27.73	2.27	65.51	997.74
3	galaxie 4	27.79	0.82	1,644.35	508.90
4	galaxie 5	26.84	1.38	1,772.20	1,117.38
...	...	...	...	...	...
220	galaxie 221	27.01	2.47	571.89	368.31
221	galaxie 222	29.38	1.46	957.48	1,389.70
222	galaxie 223	27.27	1.10	1,658.57	380.69
223	galaxie 224	26.83	0.72	366.67	1,795.23
224	galaxie 225	28.01	0.92	1,082.95	933.43

225 rows × 5 columns

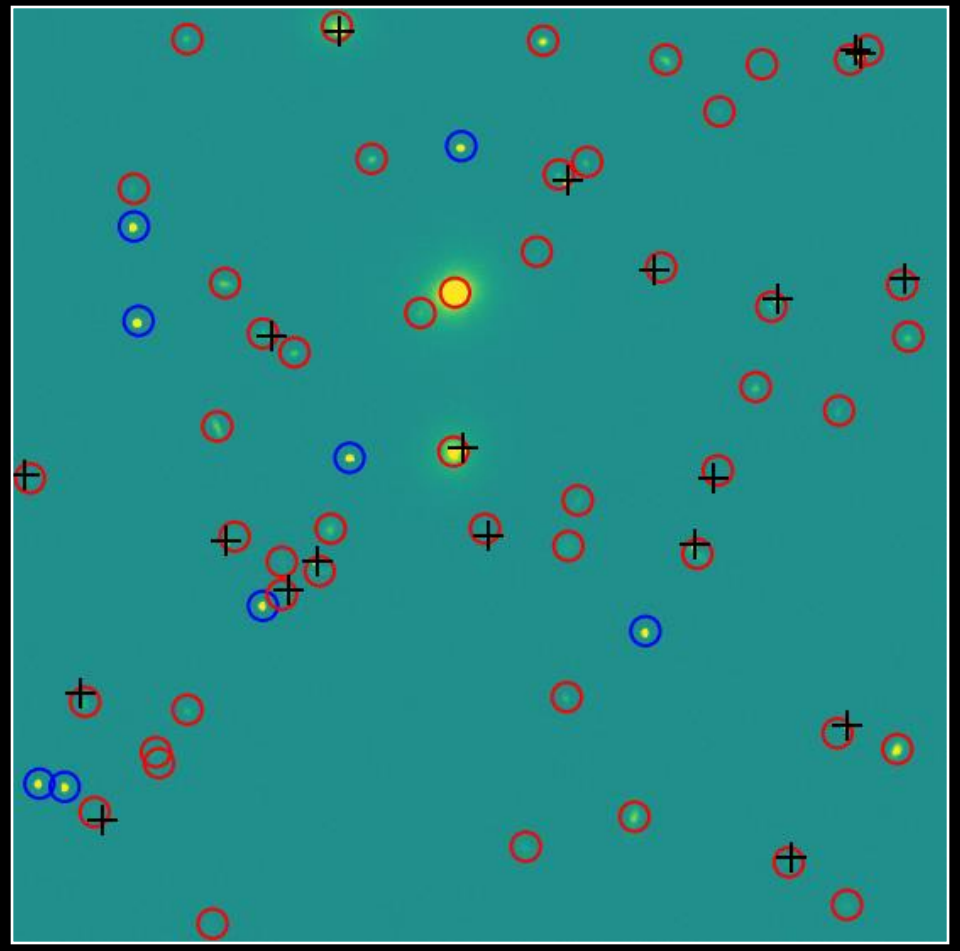
The input data

- A PSF.txt file containing Full-Width-Half-Maximum for each image

$$\boxed{\mathrm{FWHM} = 2\sqrt{2\ln(2)}\,\sigma}$$

```
2.43753869835907355 2e-01
3.50499234043720575 6e-01
2.21375916878713829 8e-01
3.48920648155112145 3e-01
2.93957058688098904 5e-01
3.19651134255821867 1e-01
2.29524038457059542 7e-01
2.36806964418630250 3e-01
3.29014425293648382 6e-01
2.09725601252681137 5e-01
2.49722501560553894 5e-01
3.08481703245600869 0e-01
2.45354668654001850 7e-01
2.76282306980926428 7e-01
3.84446557380709264 0e-01
3.85071374573555391 7e-01
3.13349984914999990 5e-01
3.06694176997800549 4e-01
2.02972004926645632 8e-01
3.95579852680401022 9e-01
```

WP-SN-1 Objective : develop and algorithm that detects supernovae on images



How do we detect supernovae ?

It isn't quite that simple...

- The images need to be intercalibrated for the fluxes to be the same.
- Turbulence in the Earth's atmosphere isn't the same on each image. The images need to have the same seeing conditions.

The Calibration

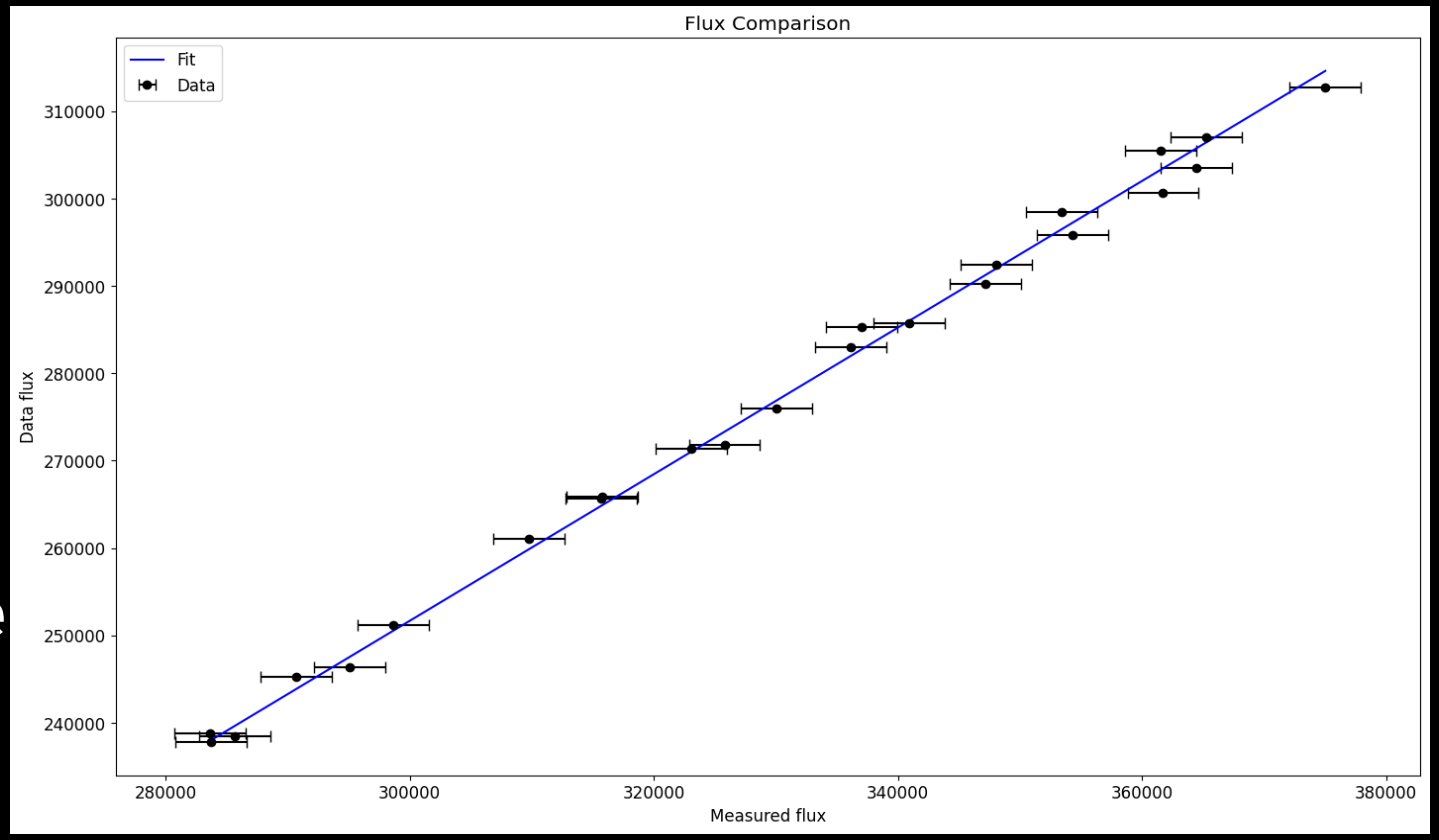
- Equivalent of the exposure in photography
- A same integrated flux on different images will not correspond to the same physical flux
- Reminder: we want to substract images to remove "constant" objects
- Consequence: We need to make sure a same integrated flux on different images represents the same physical quantity

$$\begin{cases} M = -2{,}5 * \log_{10}(I) + C \\ I_{data} = 10^{-\frac{c}{2{,}5}} I_{measured} \end{cases}$$

The Calibration 2

$$\begin{cases} M = -2{,}5 * \log_{10}(I) + C \\ I_{data} = 10^{-\frac{c}{2{,}5}} I_{measured} \end{cases}$$

- We can do a linear regression to determine the coefficients C
- We use Scipy ODR for the uncertainties (Covariance matrix)
- Reminder: we want to <u>substract</u> images to remove "constant" objects
- Consequence: We then normalize the images using the calculated coefficients!



The seeing correction

- Each star is characterized by a PSF (Point Spread Function)
- The PSF varies depending on atmospheric conditions
- Reminder: we want to substract images to remove "constant" objects
- Consequence: we need to make the different stars' PSF the same on two different epochs

The seeing correction-2

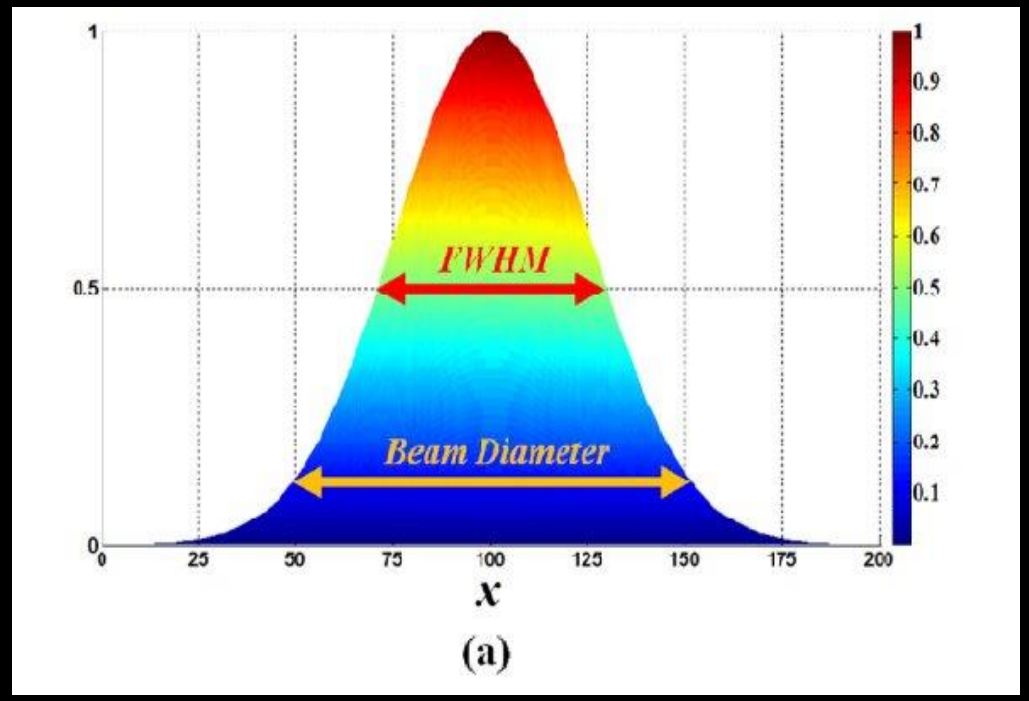
- We assume PSF to be symmetrical-gaussians
- We assume an epoch has the same PSF for all stars
- We calculate a correction filter
- Mathematical hypothesis suggest searching for a gaussian function
- And apply it
- Physical problem: we can't just improve an image, so correction will have to degrade all images to the worst:
  - We choose to make a local correction for each image difference

The seeing correction-3

- Some maths led to:

$$\begin{cases} \mu = \mu_A - \mu_B \\ \sigma^2 = \sigma_A^2 - \sigma_B^2 \end{cases}$$

- Where A denotes the image with the worst sigma, and B the other image we wish to substract
  - NB: we can now see the physical problem as a mathematical one



The seeing correction-4

- The algorithm: takes a directory and epoch name to read the PSF file, the list of normalized images, and the number of the epochs we want to correct (2 numbers)
- Finds the worst image
- Calculates the coefficient of correction
- Applies it
- Returns corrected image and the number of corrected image

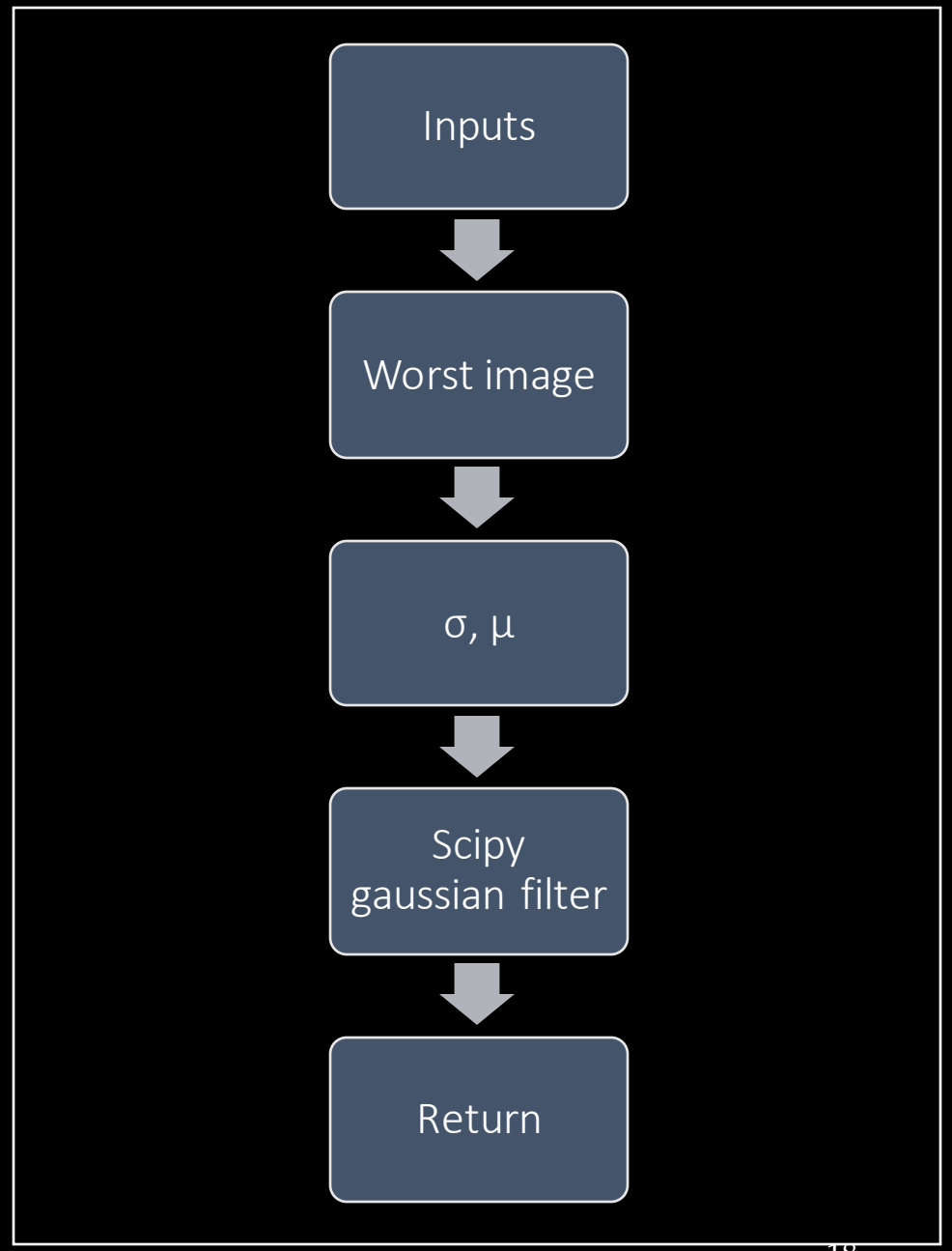
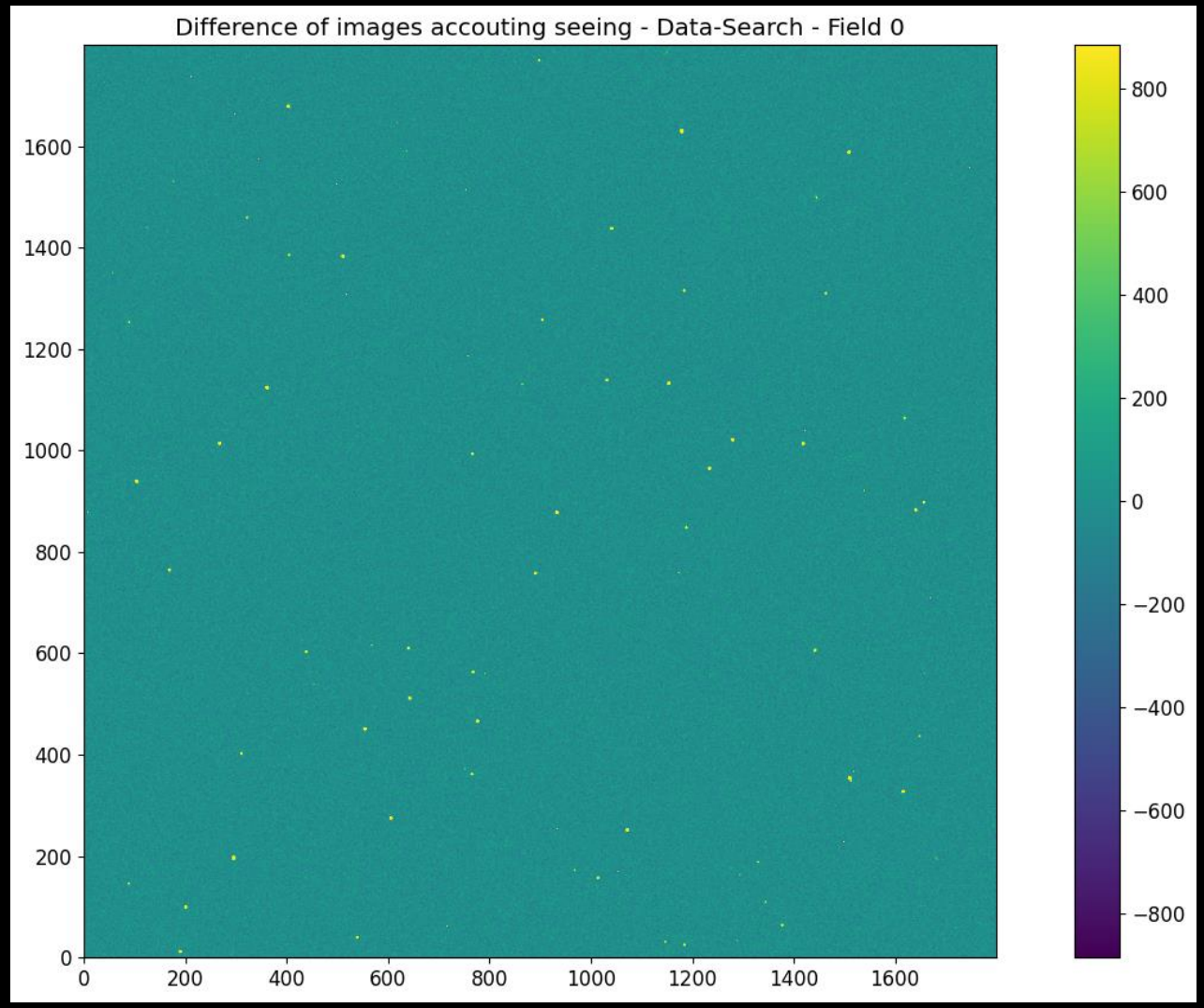


Image differencing

- The algorithm: takes a directory and epoch name, the list of normalized images, and the number of the epochs we want to substract (2 numbers)
- Calls the seeing correction function, which returns a corrected image and the number of the corrected image (basically, which one was modified)
- Returns the correct difference (depends on which image was corrected)

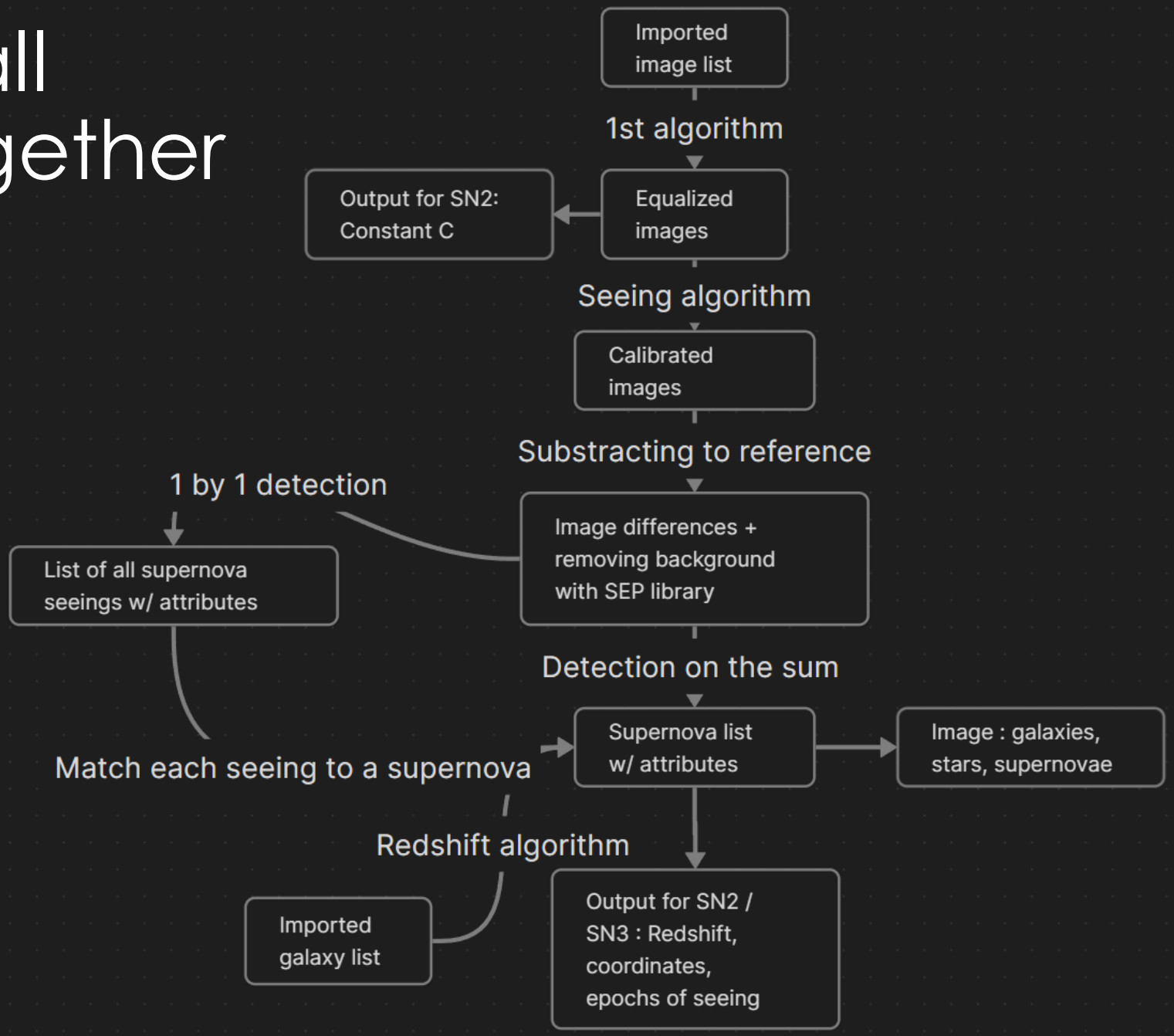


Calculating redshifts

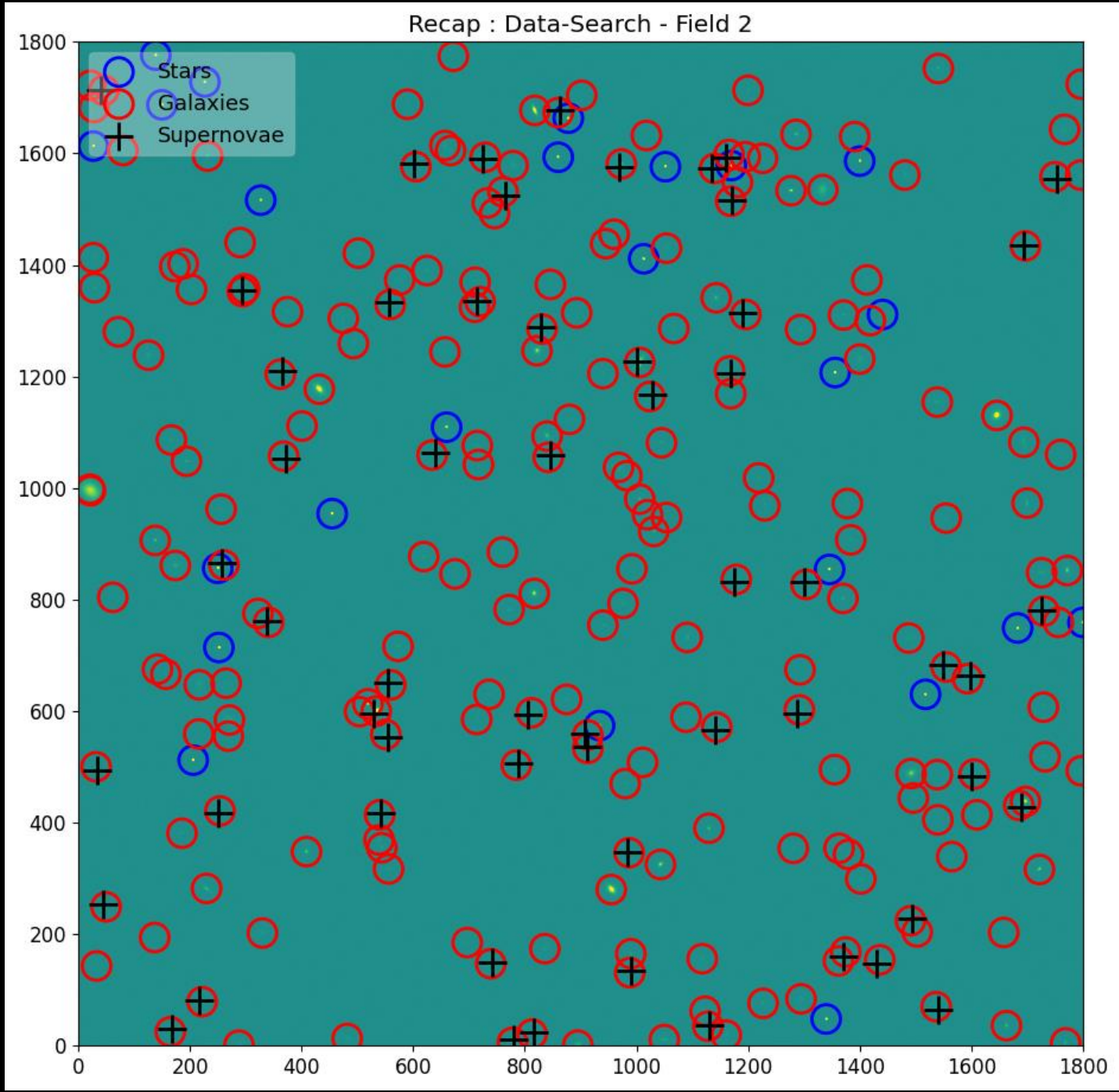
For each supernova :

- Find nearest galaxy
- Use its id and redshift

How it all gets together



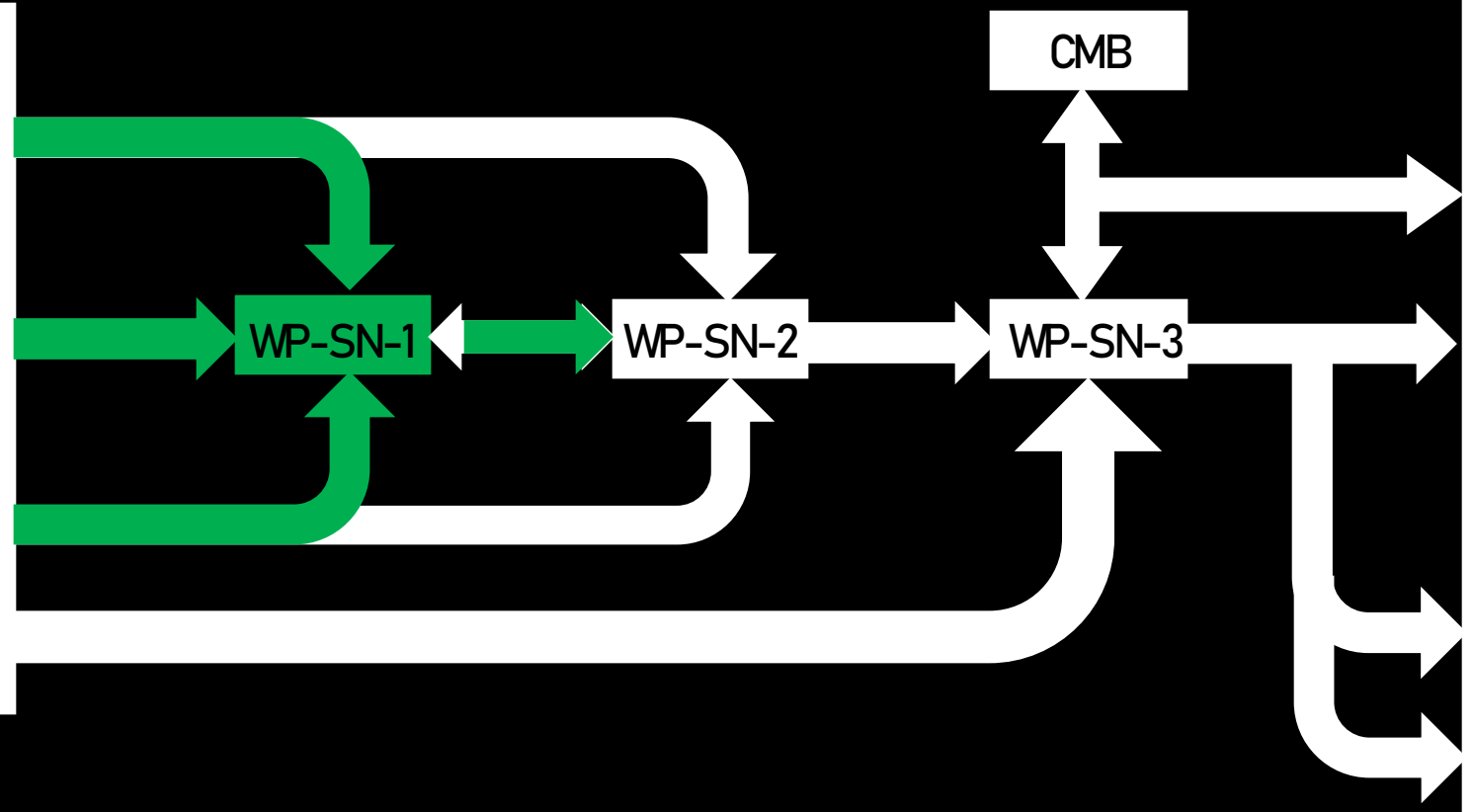
Results !


Recap : Data-Search - Field 2
Stars
Galaxies
Supernovae
0
200
400
600
800
1000
1200
1400
1600
1800

Progress Recap

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model



Output data

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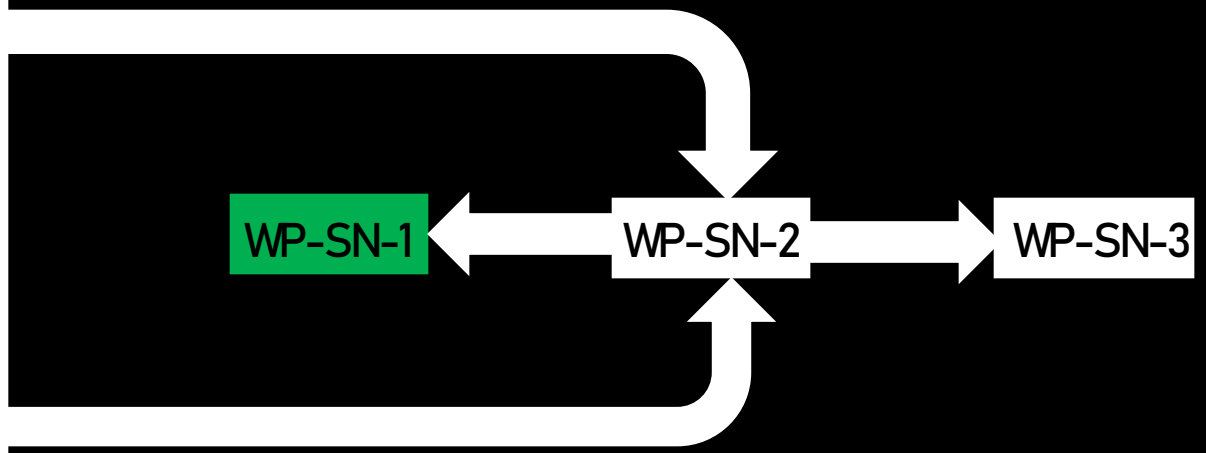
- Adjustments of SNIa dataset for values and errors of cosmological parameters.
- Apparent magnitude of supernovae
- Distance and redshift of supernovae

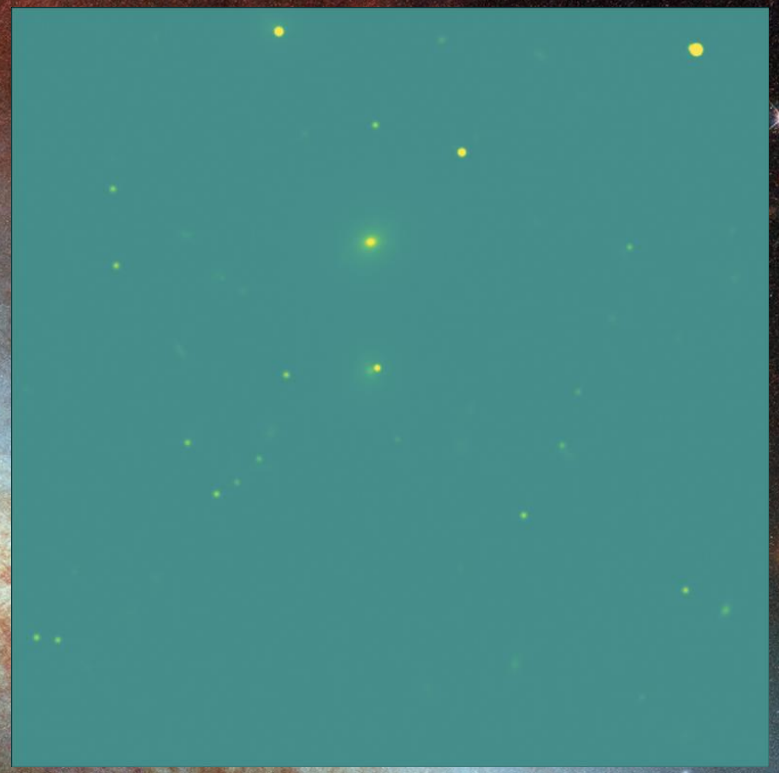
WP-SN-2 : Photometry of Supernova candidates

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model



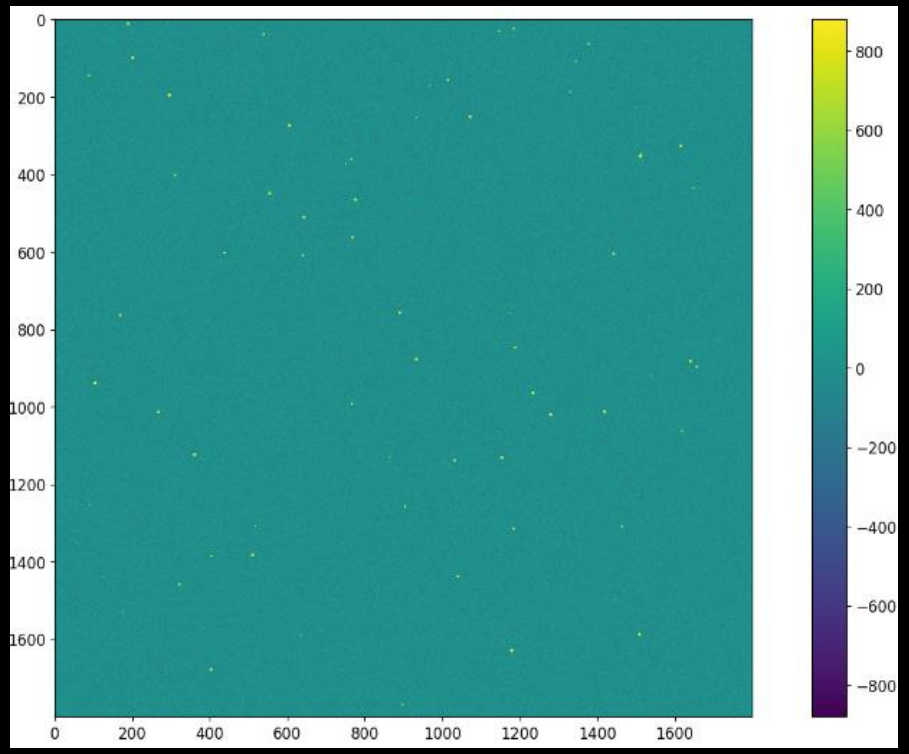
Our objectives:



- Displaying the light curves of supernovae
- Compute the photometry of images
- Estimate the uncertainties on the magnitude

Quick reminder of SN2's entry data

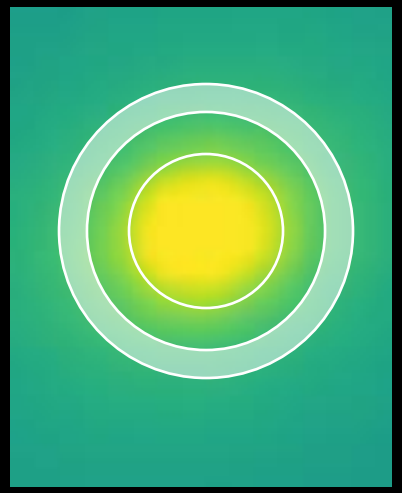
- Calibrated images at different epochs
- Coordinates of Supernovae
- Program from SN1 : Difference of two images



Define concepts:

- Aperture mask: The aperture mask is the set of pixel in a defined aperture radius around the center of the supernova
- Flux: Flux is the sum of the intensities on the aperture mask
- Magnitude: $M = -2{,}5 \log_{10}\left(\frac{I}{c}\right)$, with I the flux and c a calibration factor to be determined
- Light curves: A light curve is a display of the magnitude as a function of time

Theory



- To measure the aperture radius:

$$aperture_{radius} = \frac{3PSF}{2\sqrt{2\ln(2)}}$$

$$annulus_{inner_radius} = 1{,}5 * aperture_{radius}$$

$$annulus_{outer_radius} = 2 * aperture_{radius}$$

- To calculate the magnitude:

$$M = -2{,}5\log_{10}(I) + C$$

- To plot the light curves:

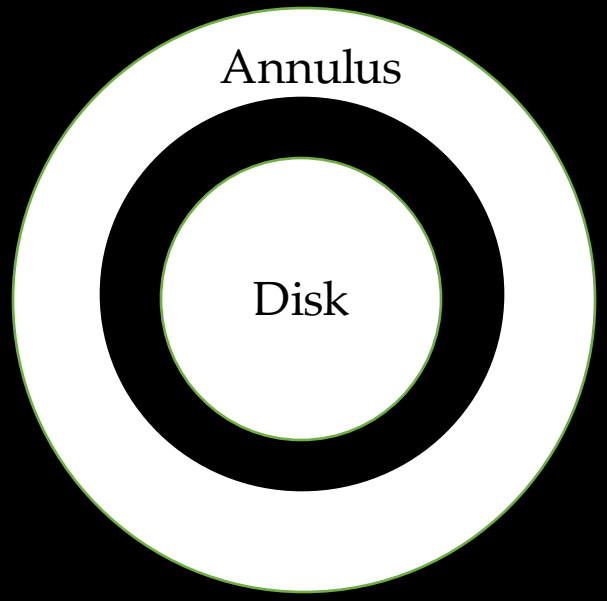
$$-M = f(t)$$

Algorithms

- def aperture_radius(psf):
  #...
  return radius
- def photometry_function(image, x, y, aperture_radius,C=0):
  #...
  return [-magnitude,sigma_m]
- dico={0: [[epoch1, m1, i1]
  [epoch2, m2, i2]
  ...
  [epoch18, m18, i18]],
  1: [[epoch1, m1, i1]
  etc...

Calculation and propagation of uncertainties

Origin of uncertainties : measurement and variance of pixel's intensity



Notations : $Intensity\ of\ pixel\ (i,j) = (x_{i,j})$

Number of pixels in

- the disk :$|D|$
- the annulus :$|A|$

Calculation and propagation of uncertainties

Subtracted flux in disk : $I = \sum_D x_{i,j} - \frac{|D|}{|A|} \sum_A x_{i,j}$

Uncertainties on I : $\boxed{\sigma_I^2 = |D|\sigma_x^2 + \frac{|D|^2}{|A|}\sigma_x^2}$

Where σ_x^2 is the variance on the image calculated with numpy library

Calculation and propagation of uncertainties

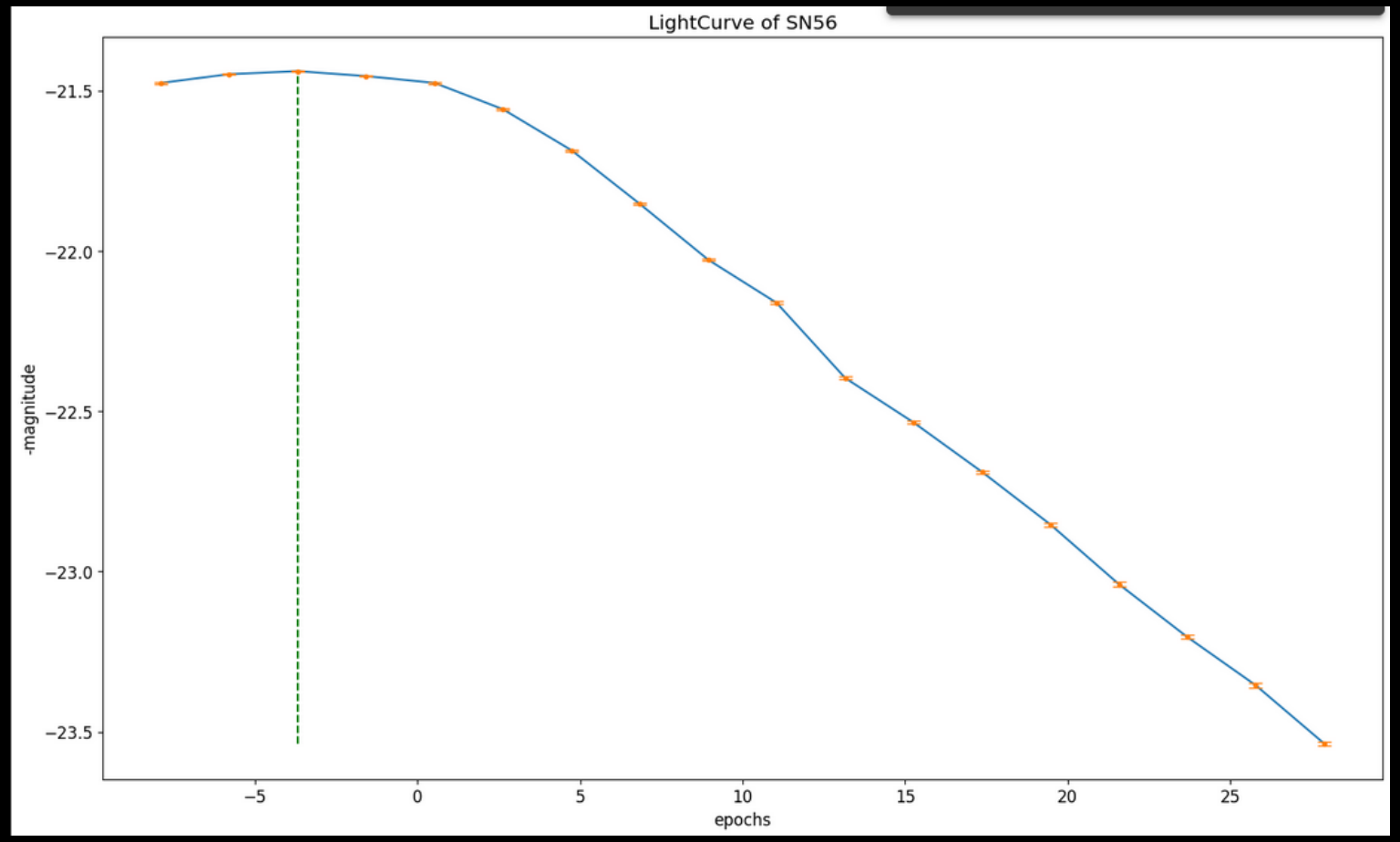
Magnitude : $\mathrm{M} = -2{,}5 \log_{10}(I) + C$

Where C directly linked to the calibration factor given by SN1

Uncertainties on M : $\boxed{\sigma_M^2 = \left(\frac{-2{,}5}{I * \ln(10)}\right)^2 \sigma_I^2 + \sigma_C^2}$

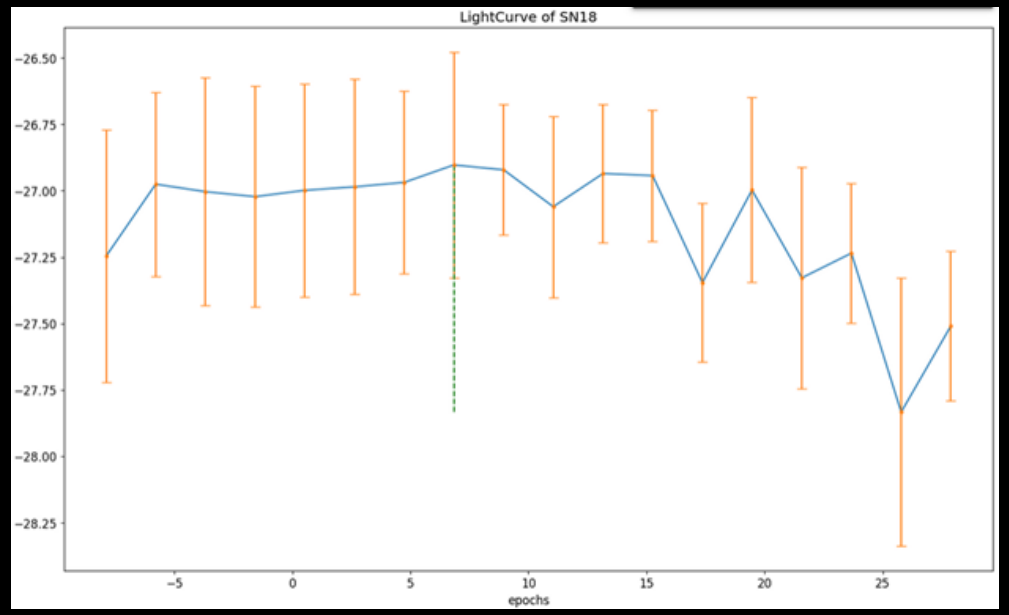
We chose to neglect σ_C^2 to simplify calculations

Results : detection of supernovae

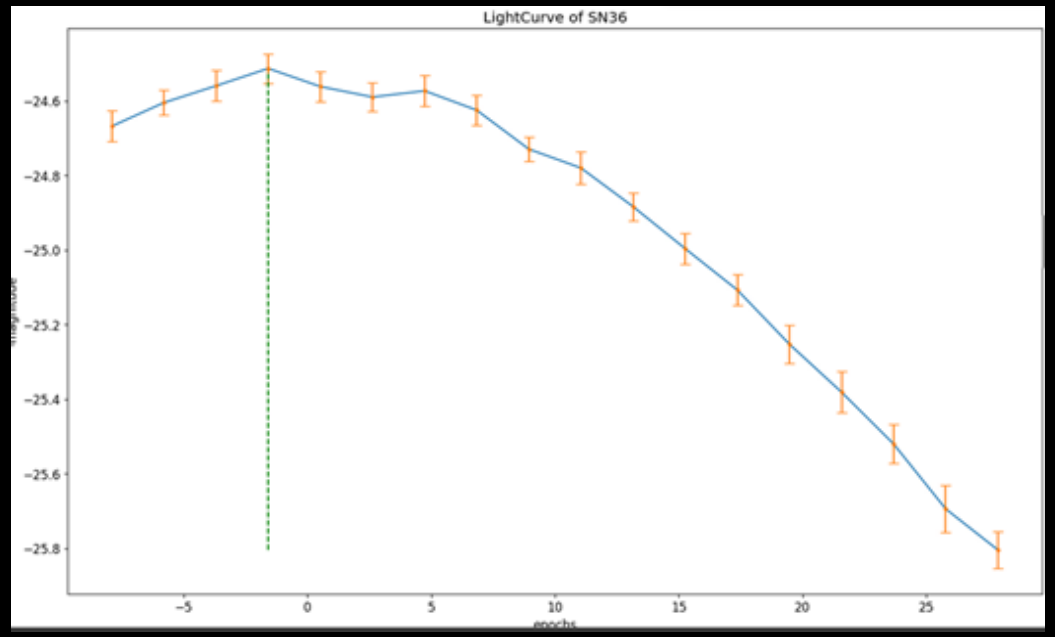


Detection of a supernova with lower uncertainties on the magnitude

Results : detection of supernovae



Very high uncertainties on a quasi-constant magnitude : not a supernova

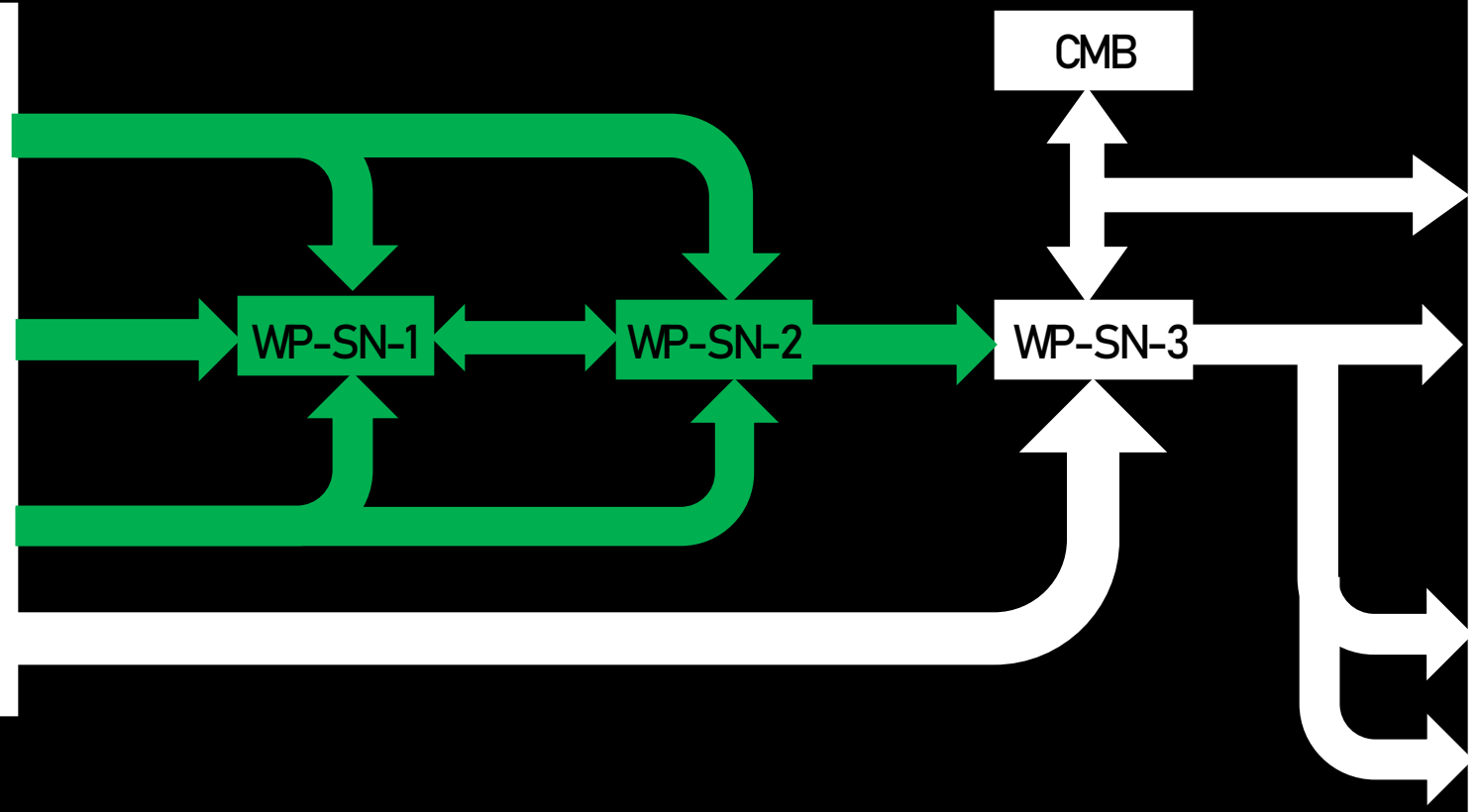


Detection of a supernova with higher uncertainties on the magnitude

Progress Recap

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model



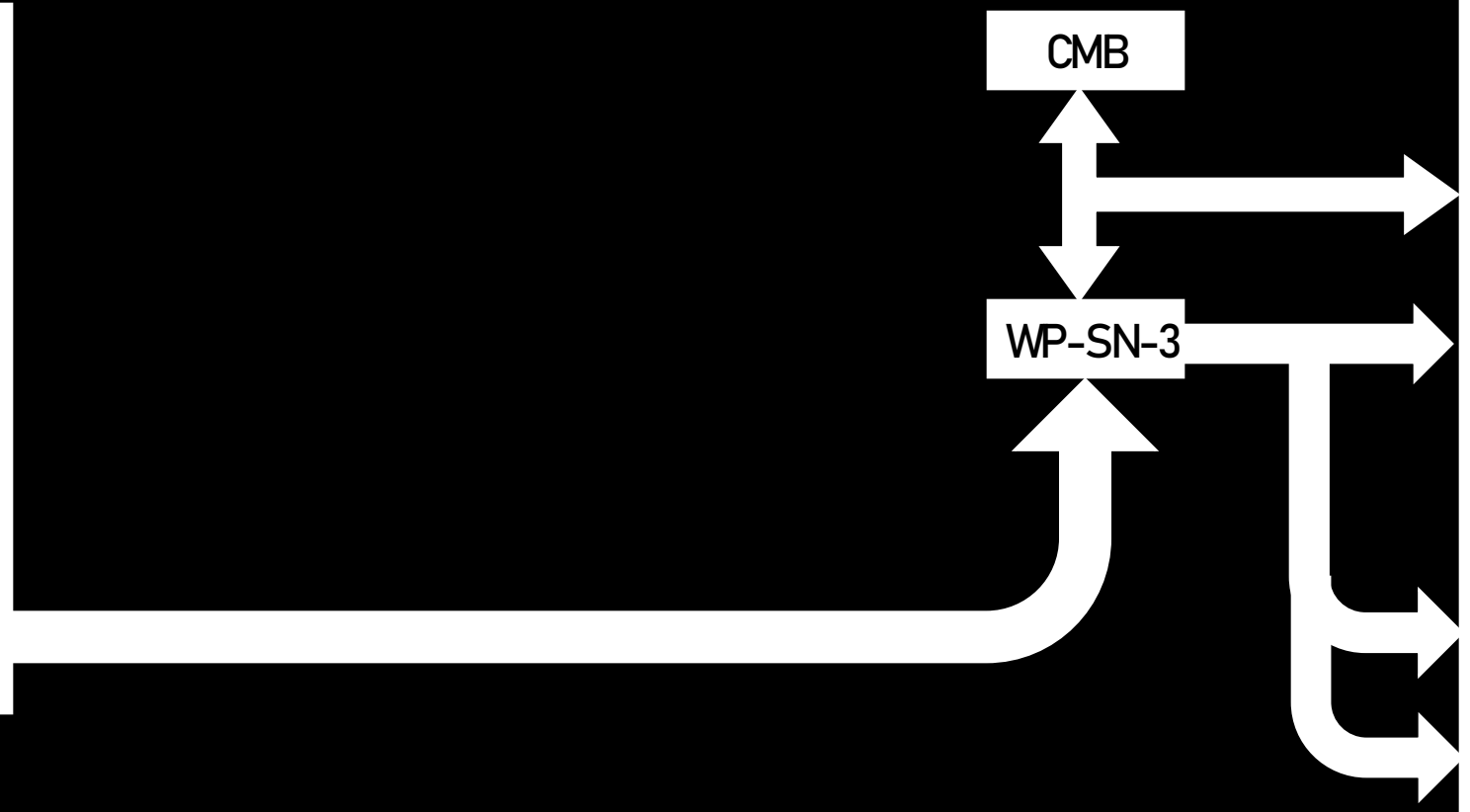
Output data

- Adjustments of CMB+SNIa dataset for values and errors of cosmological parameters
- Adjustments of SNIa dataset for values and errors of cosmological parameters.
- Apparent magnitude of supernovae
- Distance and redshift of supernovae

WP-SN-3 : Light Curve Fitting and cosmological constraints

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
- Cosmological seeing of each image
- Type Ia supernova light curve model



Output data

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- Apparent magnitude of supernovae
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WP-SN-3 Presentation

Input data :

Time, observed magnitudes of each supernova and their uncertainties

Output Data :

Distance modulus with its uncertainties from each supernova.

Hubble diagram

Cosmological parameters

First Approach : False leads

- **Relativistic track** : We wanted to link supernova time and our own time using a relativistic approach.

- To find s and mu, we first wanted to **fix s and then deduce mu** (but in doing so, we don't get the optimum (s,mu) pair).

- We were **missing a parameter :** the time of maximum of the light curves

Distance Modulus of each Supernovae using a fit

- Model used for the fit accounting for redshift and brighter slower effect (stretch factor) :

$$m_{th} = \mu + M_{th}((t - t_0)(1 + z) * s) - 1,52(s - 1)$$

'Fitted apparent Magnitude'

Distance Modulus (Parameter)

Parameter which accounts for the location of the maximum

Effect of the redshift

Brighter Slower Effect (s is the stretch Factor)

- Errorbars :

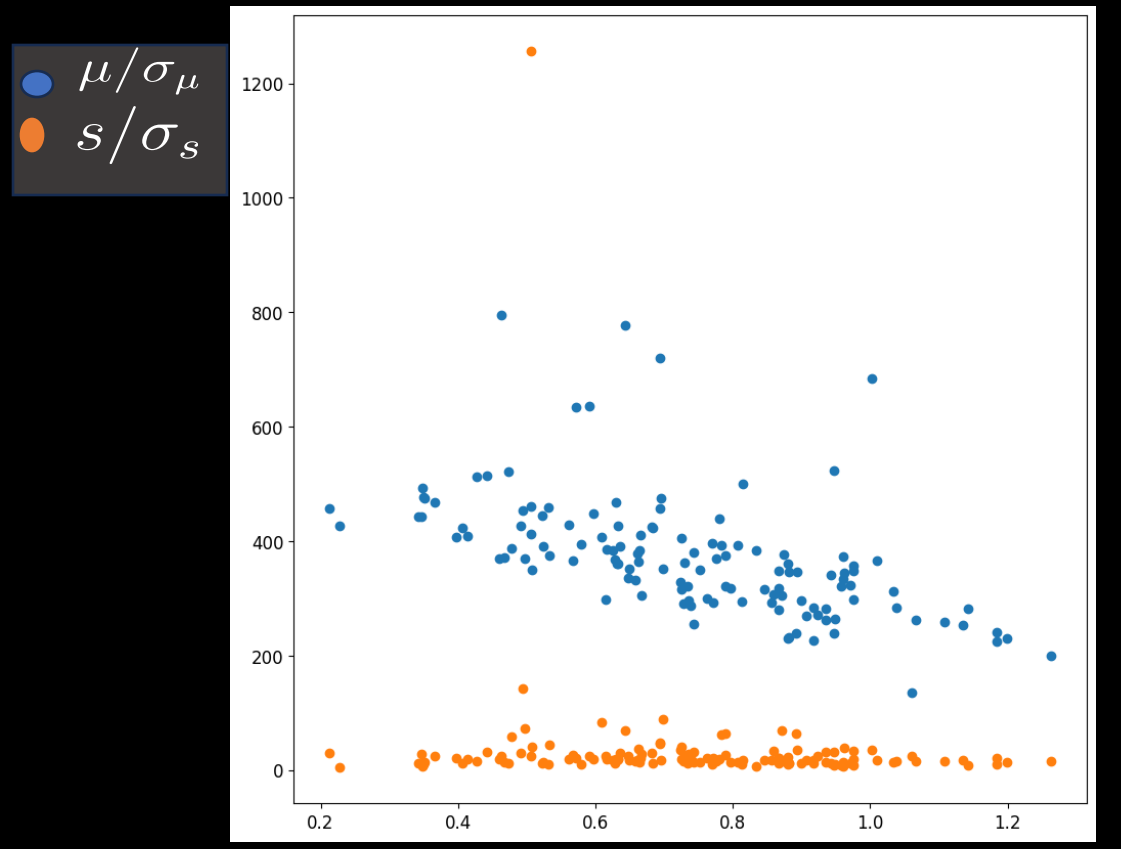
$$\sigma_\mu = \sqrt{\sigma_{Mth}^2 + \sigma_{mobs}{}^2}$$

Distance modulus of each supernovae using a fit (minuit)

With Minuit :

- **Guess of the parameters**
- **Entries** : time scale + apparent magnitud (obs) and errorbars (obs magnitud)

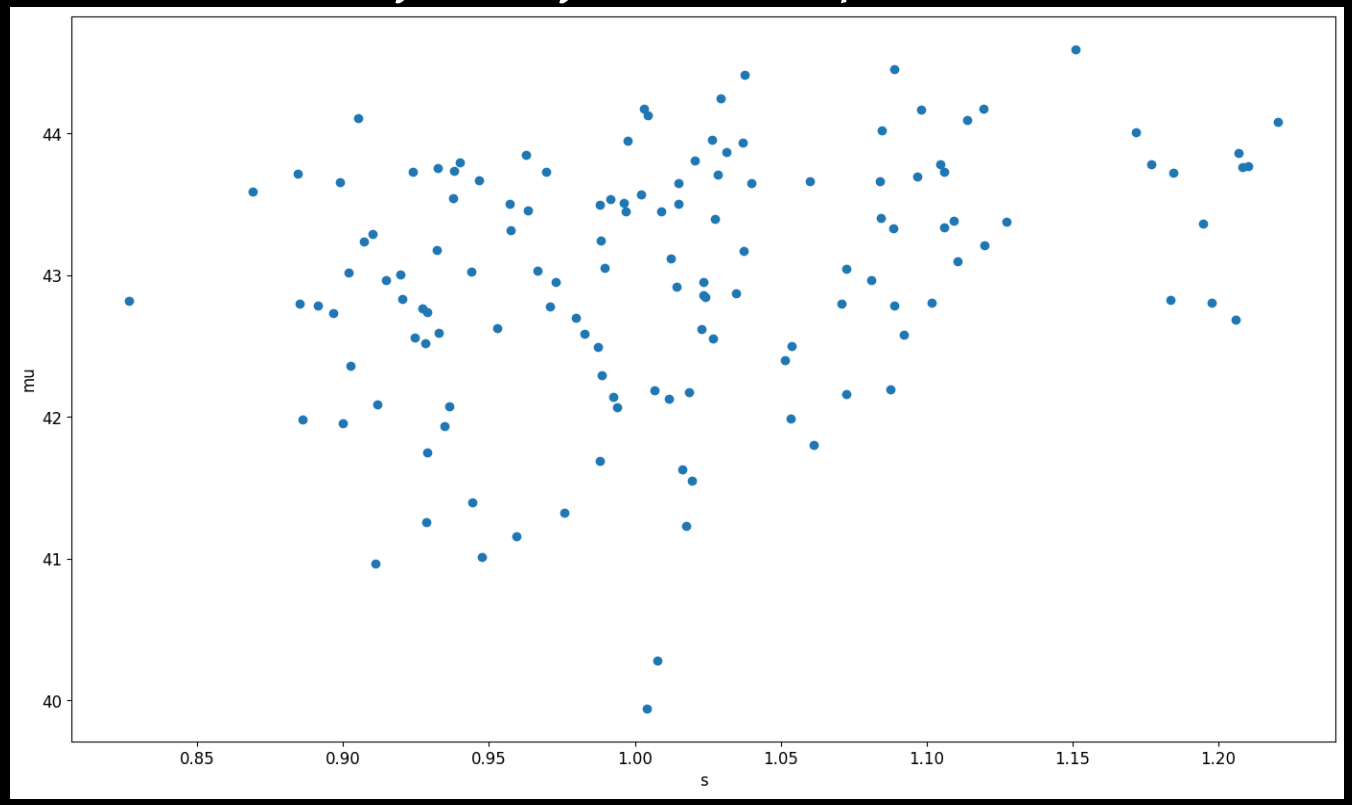
To sum it up : Adjust μ, s and t0 to fit as well as possible with the observed magnitud.



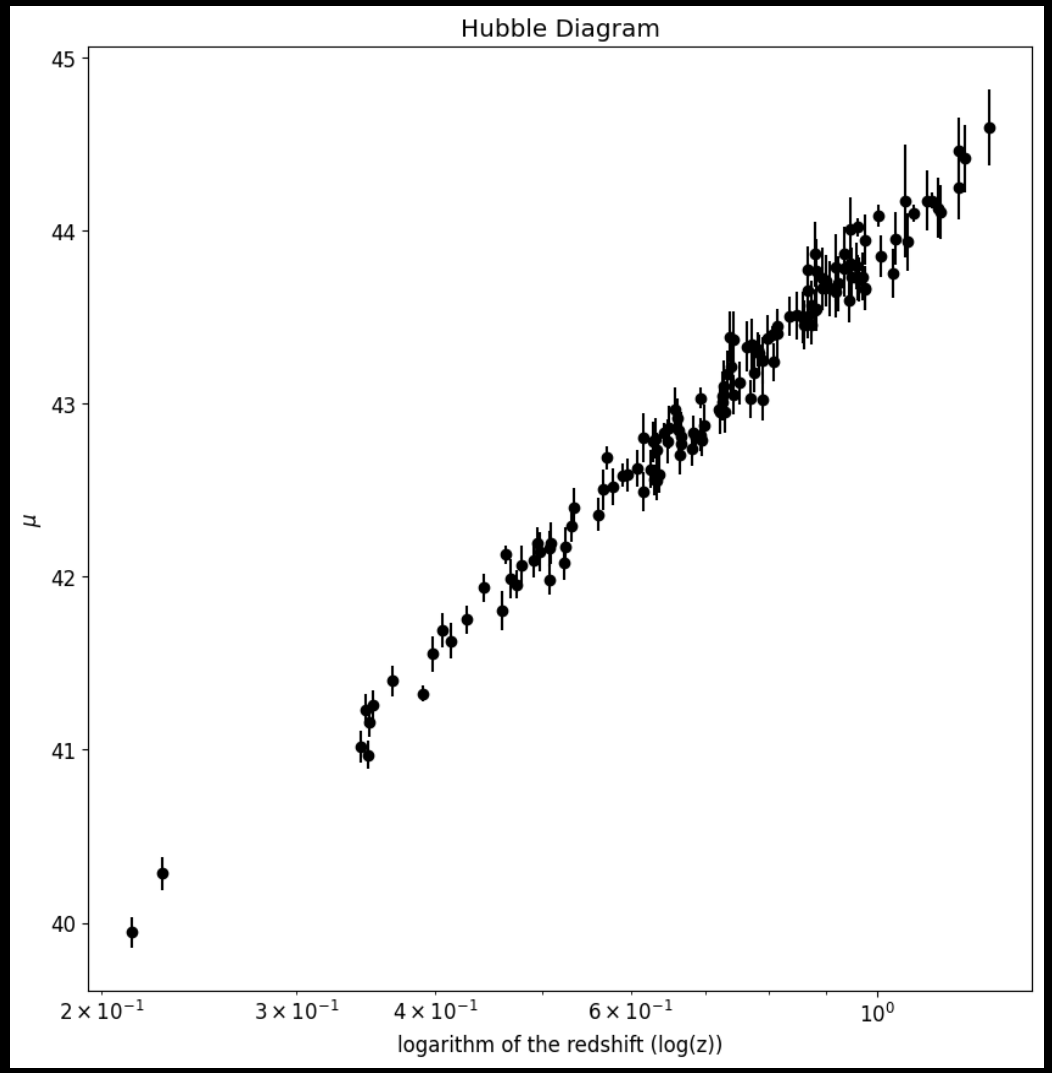
Distance modulus and stretch factor as a function of z

Hubble diagram with Minuit

Distance modulus as a function of the stretch factor for each supernovae



-> No correlation between mu and s : good news !



Distance modulus as a function of log(z) (Hubble diagram)

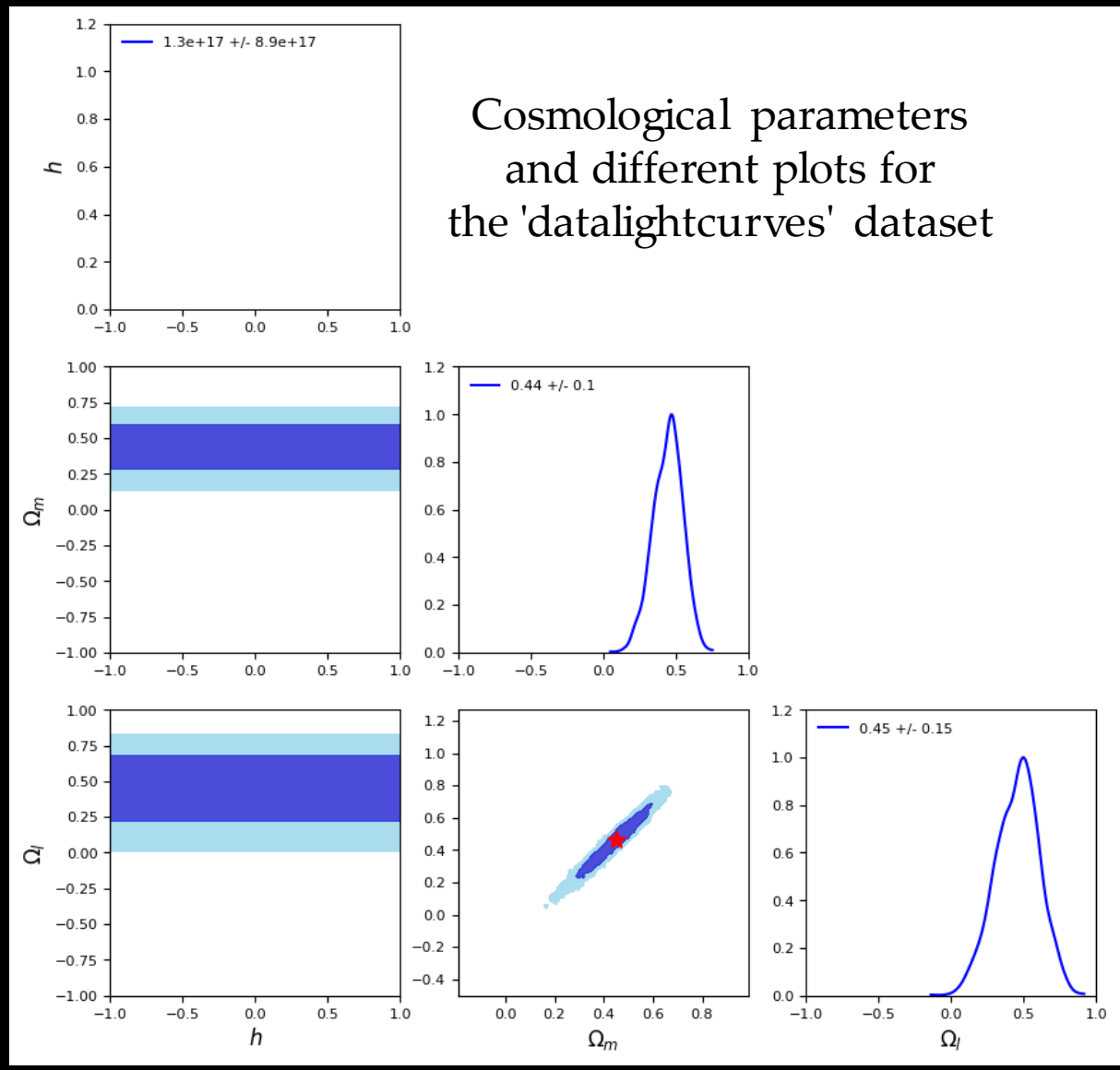
Fit for cosmological parameters

- MCMC :
  - Based on the following equation :

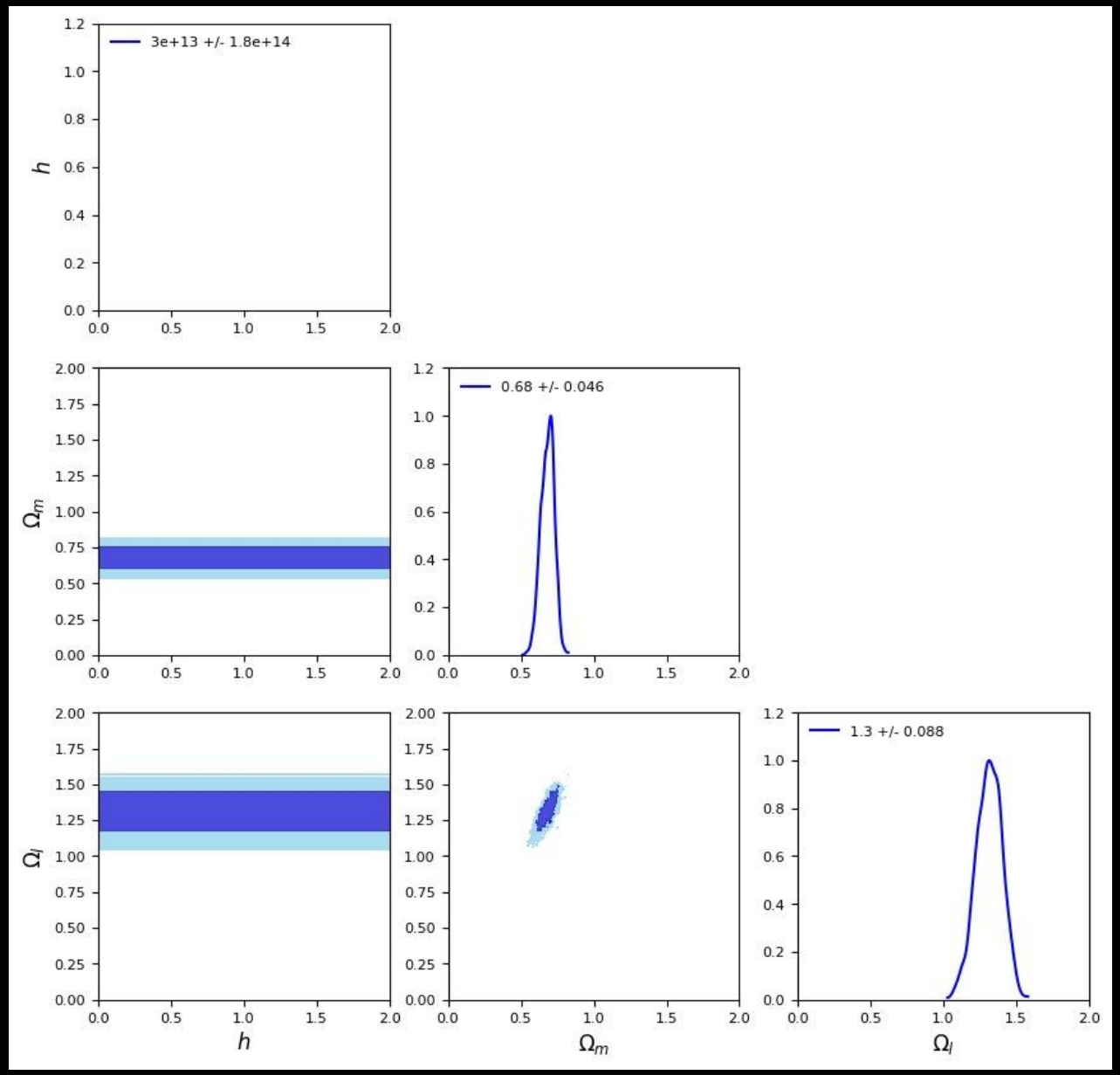
$$\mu = 5 * \log\left(D_l(z)\right) - 5$$

  - Entry : the distance modulus μ, the related uncertainties σμ, the redshift z

  - State equation of dark matter : we fix w at –1
  - We fit the cosmological parameters h, Ωl and Ωm
  - Supernovaes measurments do not constraint h



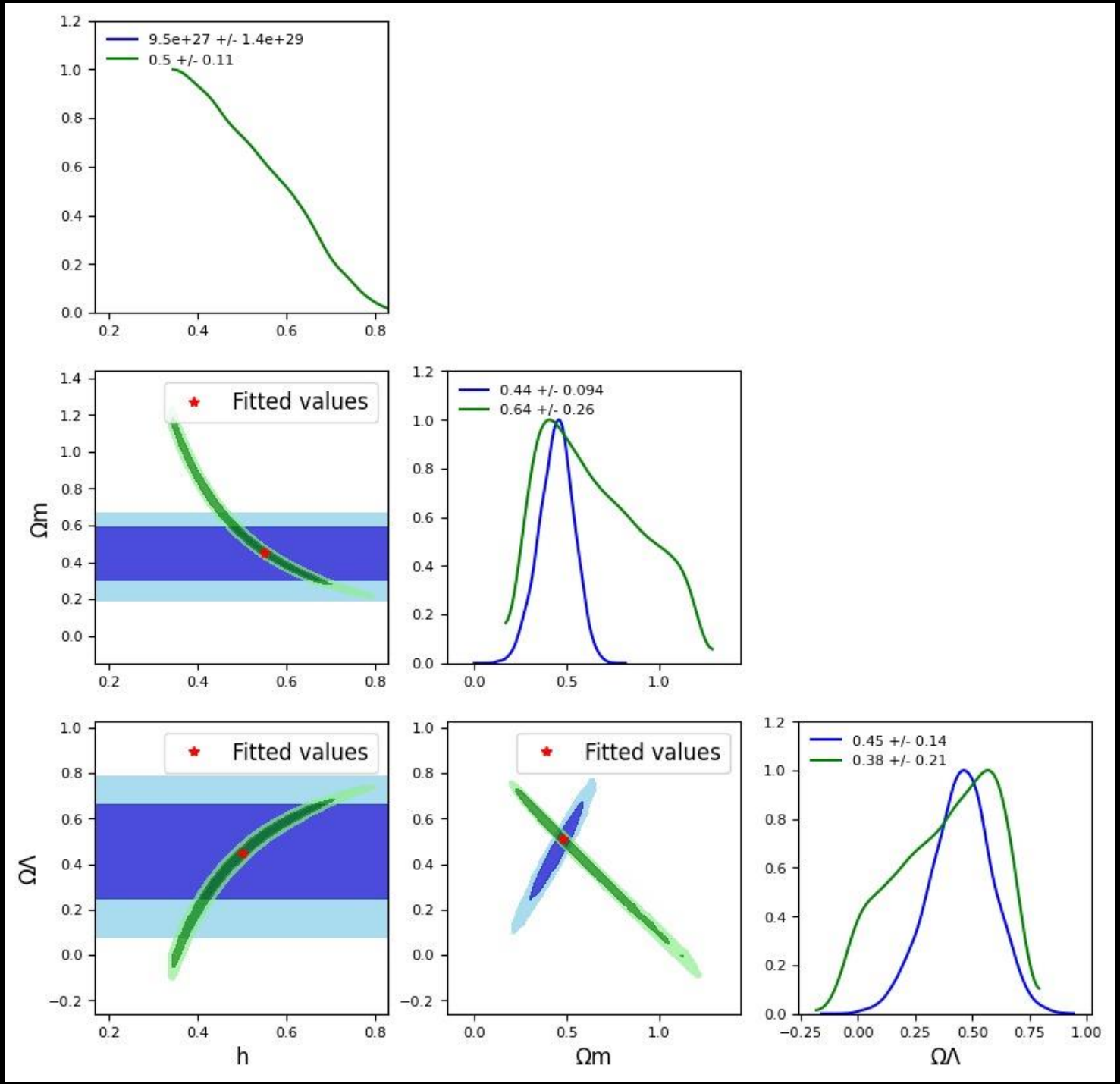
Cosmological parameters and different plots for the 'datalightcurves' dataset



Results with data from SN2

Different data, different results

Fitted cosmological parameters (with CMB3)



Final Progress Recap

Input data

- Images (various fields and epochs)
- List of information on galaxies and stars (location, magnitude, redshift,...)
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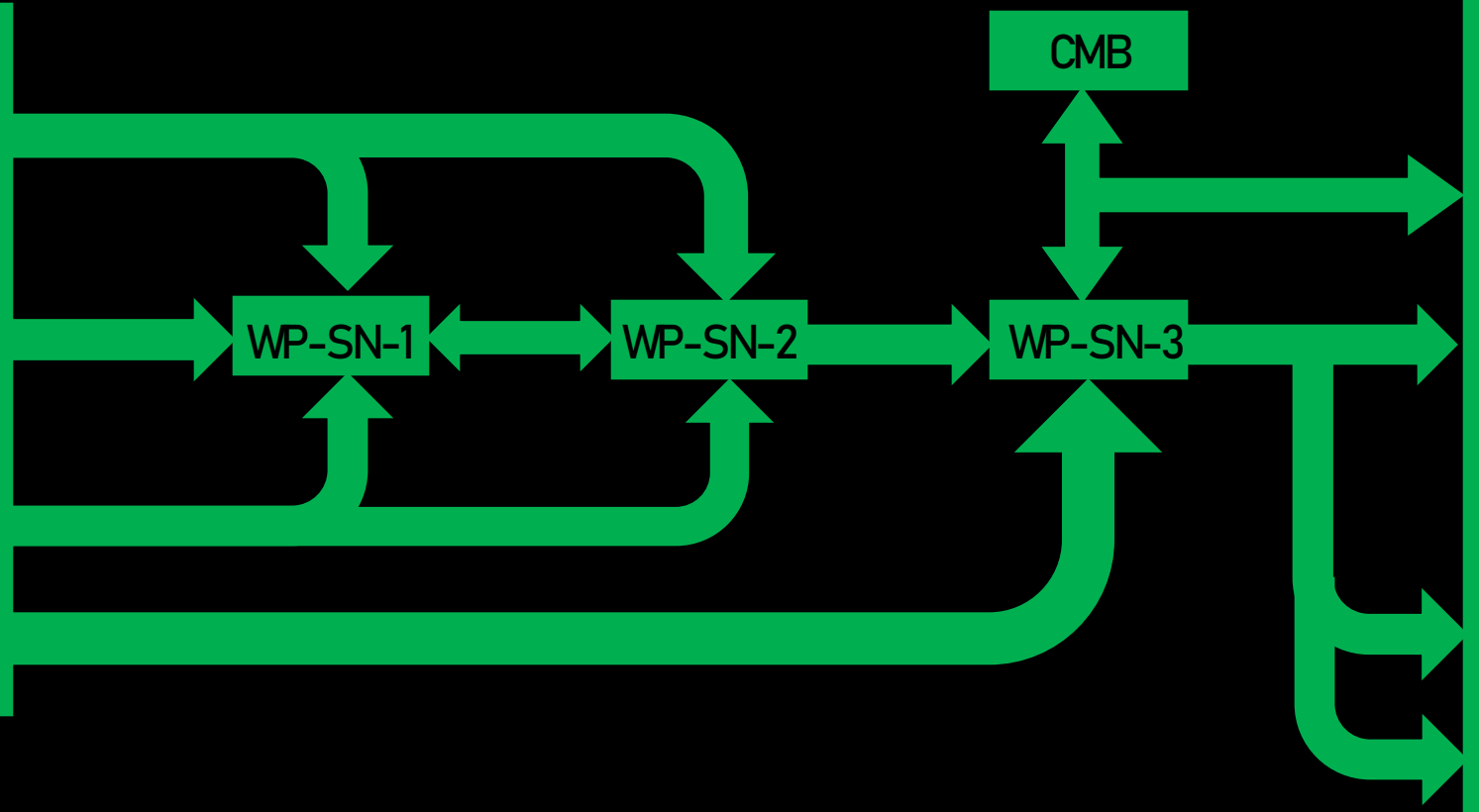
- Type Ia supernova light curve model



Output data

- Adjustments of CMB+SNIa dataset for values and errors of cosmological parameters
- Adjustments of SNIa dataset for values and errors of cosmological parameters.
- Apparent magnitude of supernovae
- Distance and redshift of supernovae

Cosmology

B

CMB-1 : Time domain filtering and Map-making

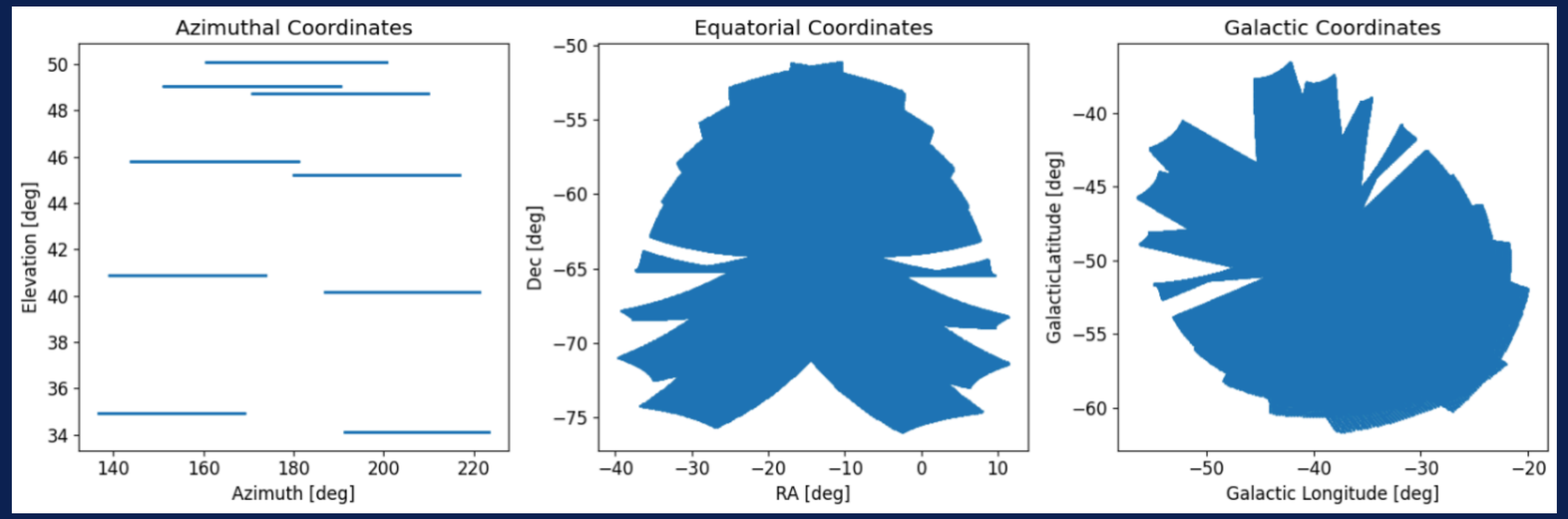
Goal

Input :

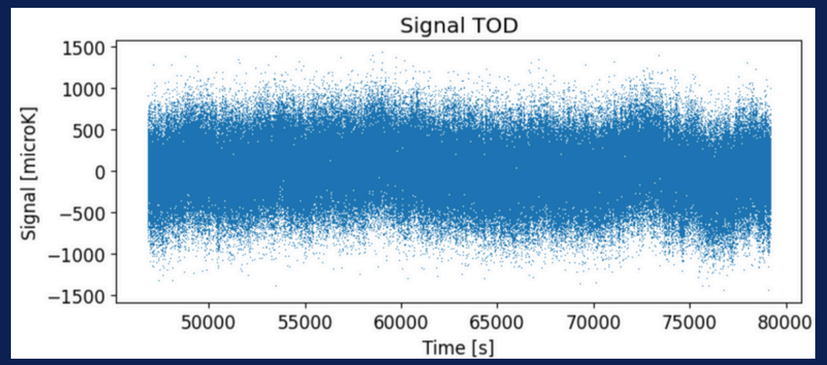
- Measures of variation of temperature
- 9 days
- Different coordinates

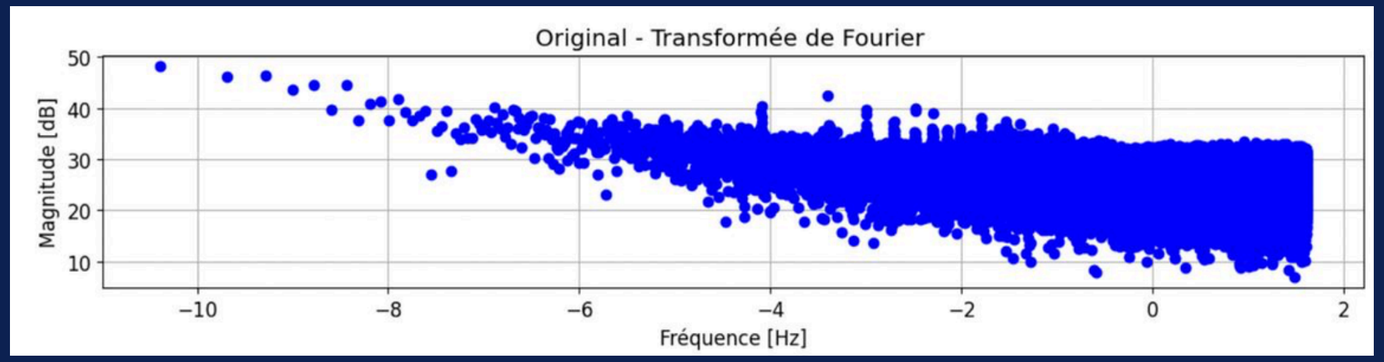
Deliverables :

- Maps of the CMB for each days
- Maps of the CMB over the whole dataset



Analyse of the signal





Noise

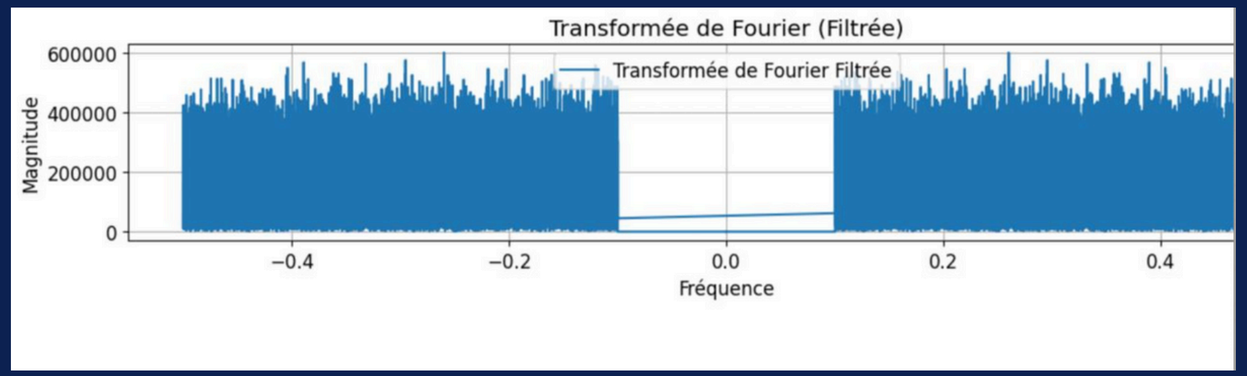
- 1/f noise due to natural phenomenons:
  - atmosphere
  - cryogenics
  - eletronics

Filters

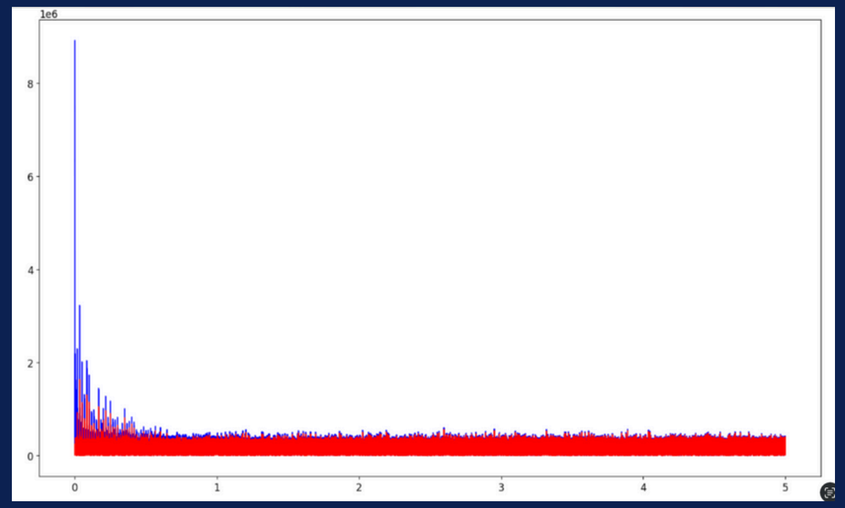
- High-passed filter
- Bumped filter
- Whitened filter

Different filters

High-Passed Filter



Whitened Filter



TF’ = Tf’/(sqrt(Pfit/W0))

W0 amplitude du bruit blanc

Pfit= sigma^2 * (1 + (f0/f)alpha)

Model of the Temperature

$$\vec{d} = A \cdot \vec{T} + \vec{n}$$

Data Samples (N_d)	Pointing Matrix (N_d x N_{pix})	True Sky (N_{pix})	Noise (N_d)

$$\hat{T} = \left(A^t \cdot N^{-1} \cdot A\right)^{-1} \cdot A^t \cdot N^{-1} \cdot \vec{d}$$

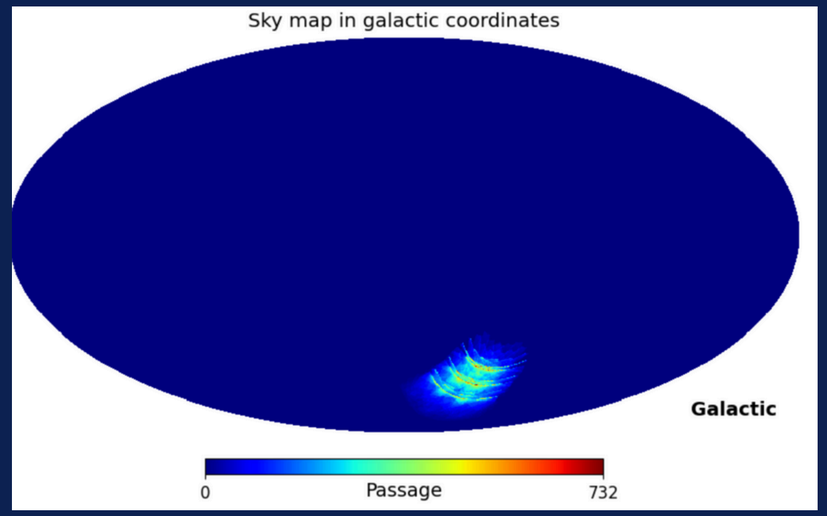
Approximation : White Noise

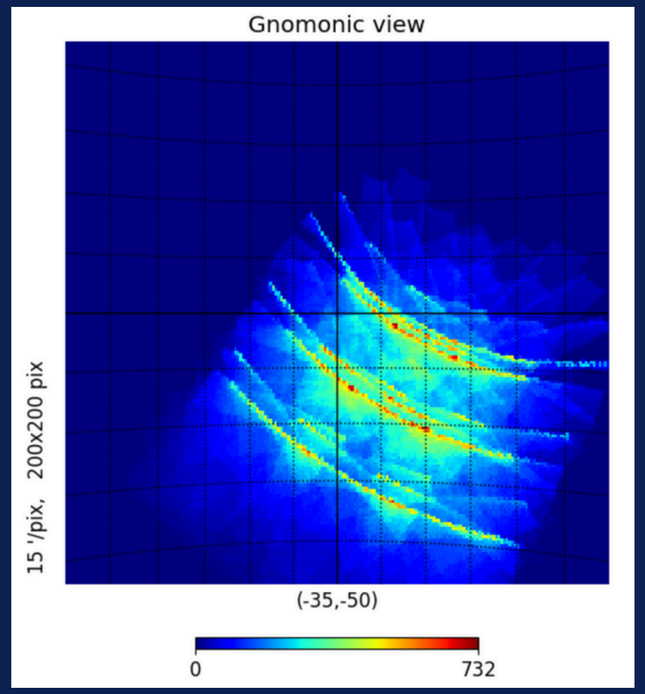
$$\hat{T} = \underbrace{\left(A^t \cdot A\right)^{-1}}_{\text{Inverse of passage on each pixel}} \cdot \underbrace{A^t \cdot \vec{d}}_{\text{Sum of data on each pixel}}$$

=> T is the vector of the average temperature on each pixel

Difficulties

Multiple data on single place

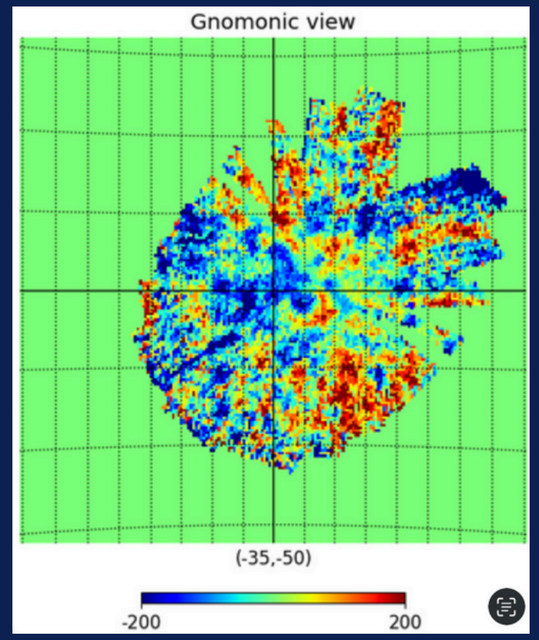




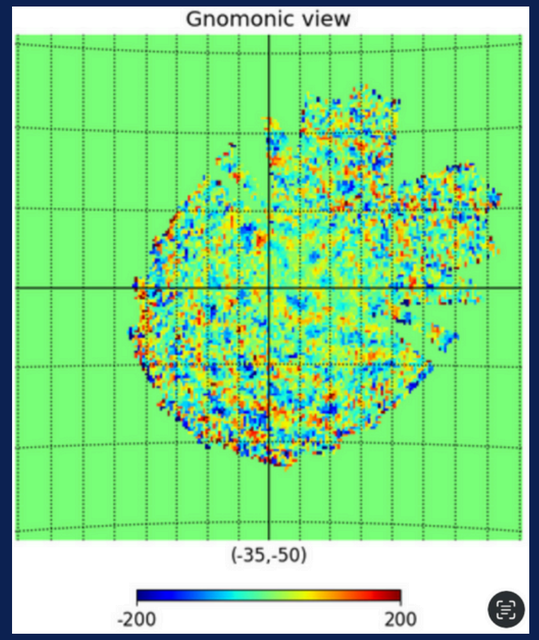
Multiple days

Different filters for day 0

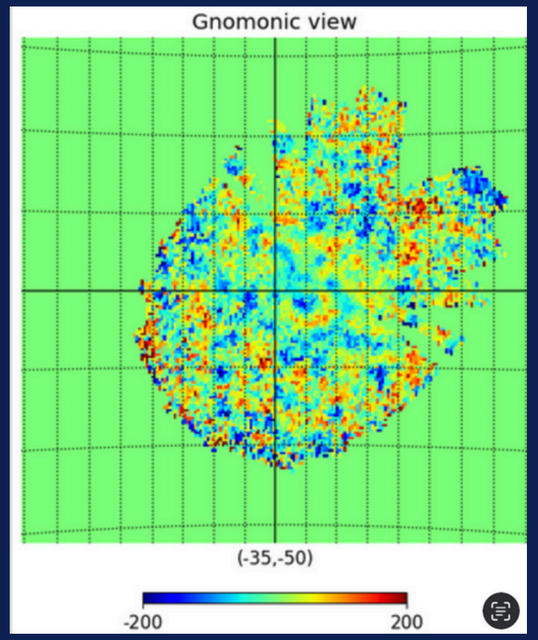
Without Filter



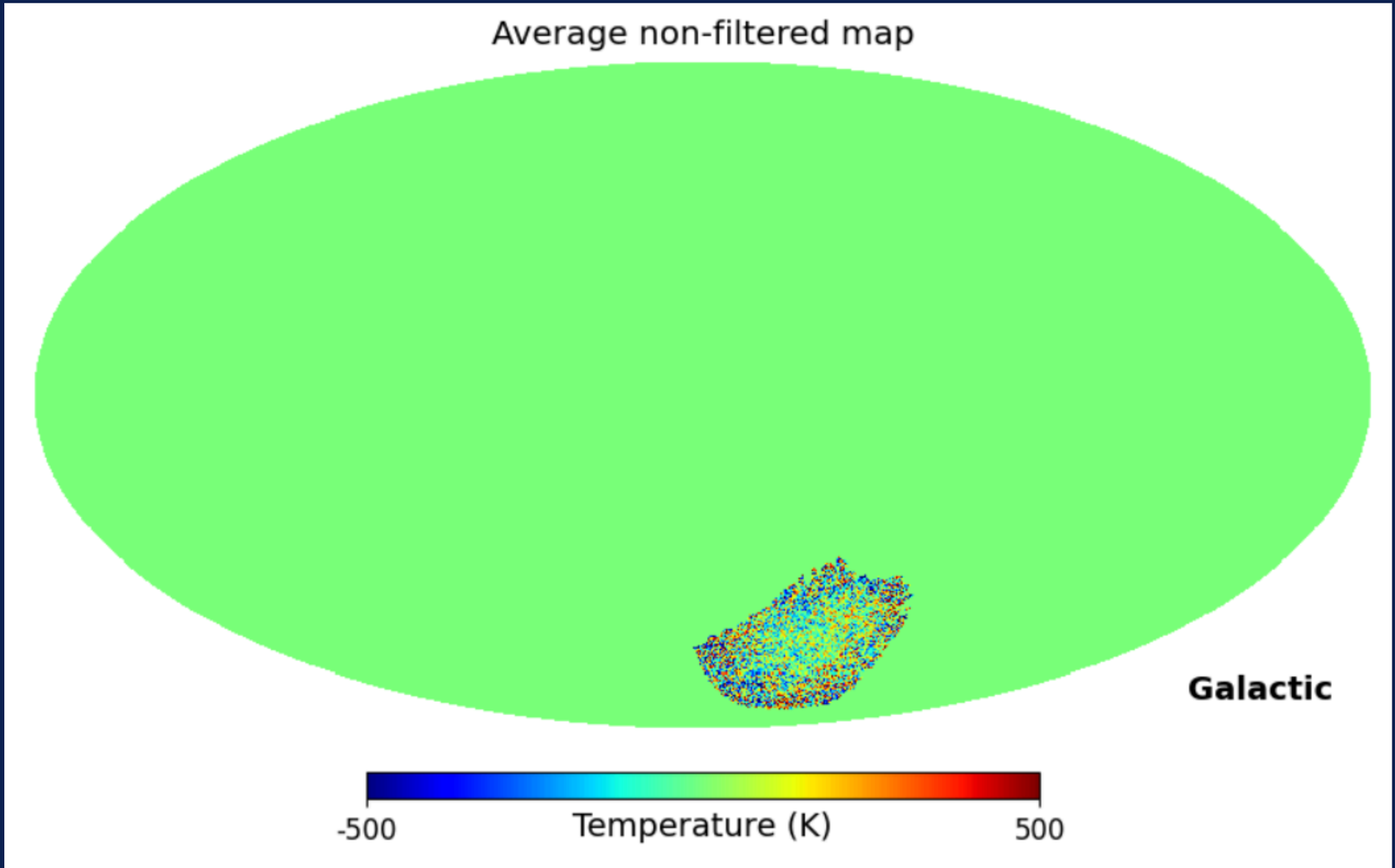
High-Passed Filter



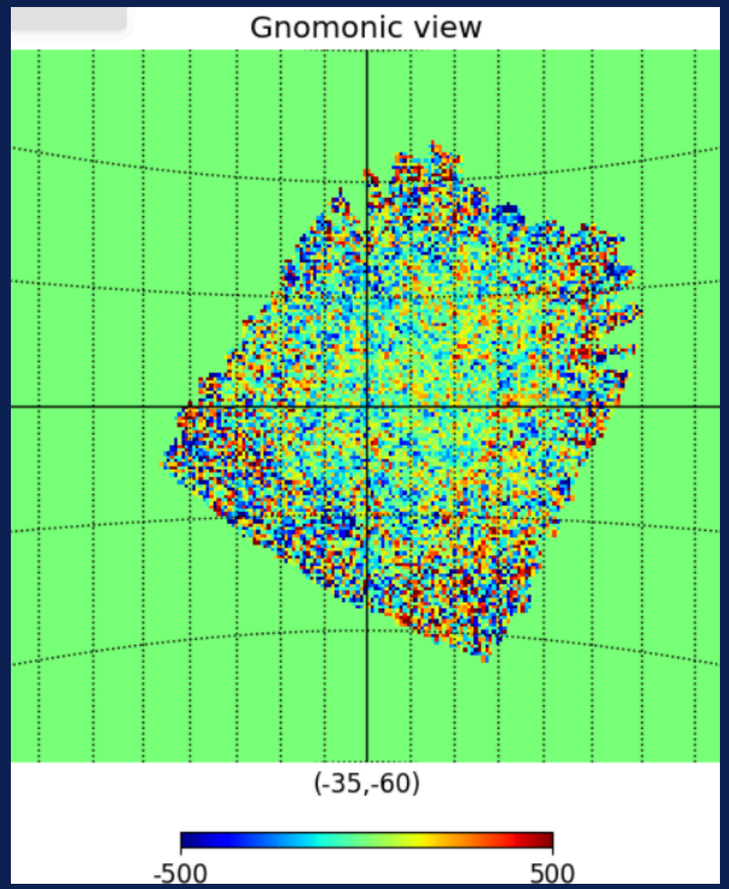
Whitened Filter



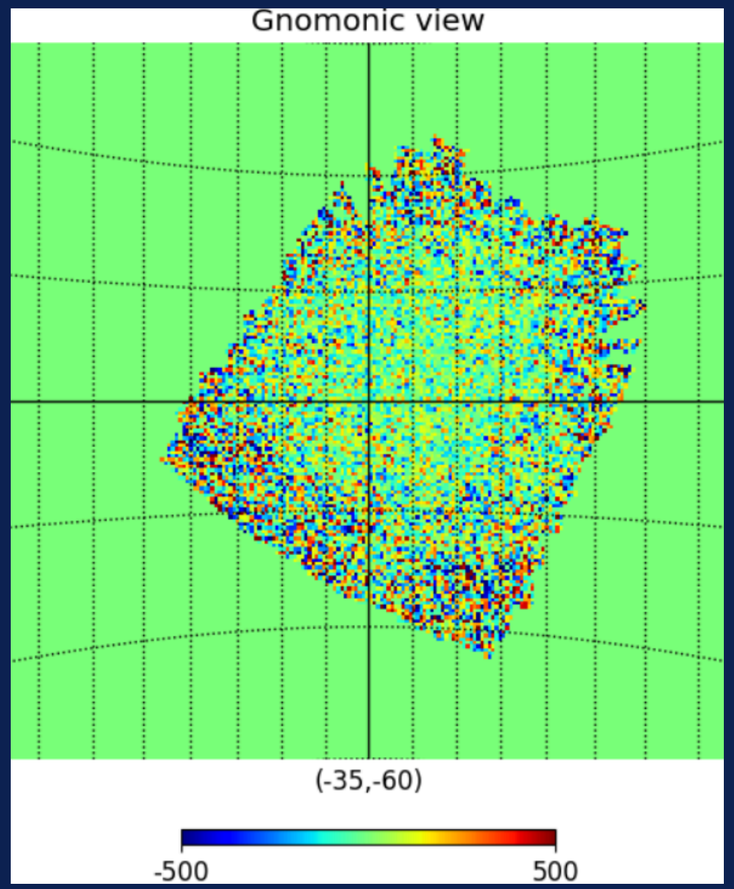
Average maps



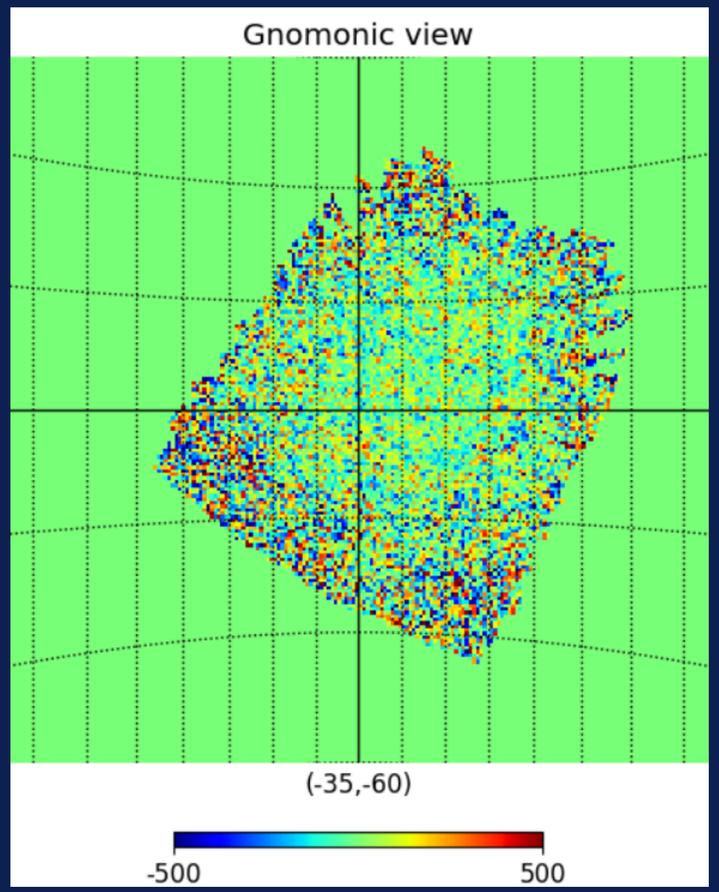
Average maps



Non-filtered



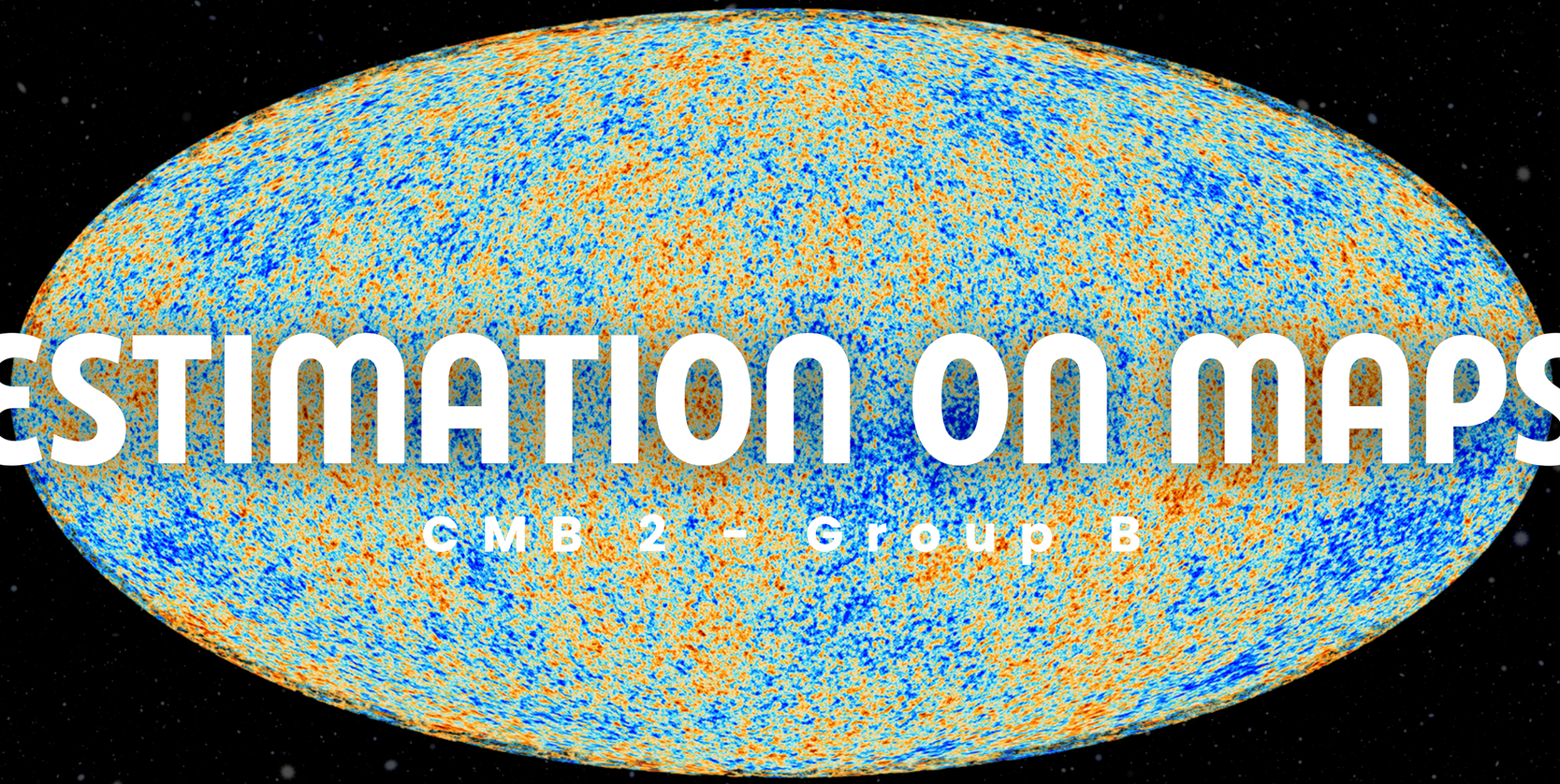
High-pass filtered



Prewhitened

EI - PNT - BLACK SWANS

> *Every individual collaborates with the entirety of the cosmos,*
> Nietzsche



ESTIMATION ON MAPS

CMB 2 - Group B

BOZZARELI Dorian
BOBANT Jean-Baptiste
ALBANEL Jean

LEGOFF Benoit
AMEVET Baptiste

1. Our Goals

> Extract the **angular power spectrum**

WHAT IS ANGULAR POWER SPECTRUM

- C_l : variance of the distribution of CMB temperature fluctuations
- at a given angular scale l

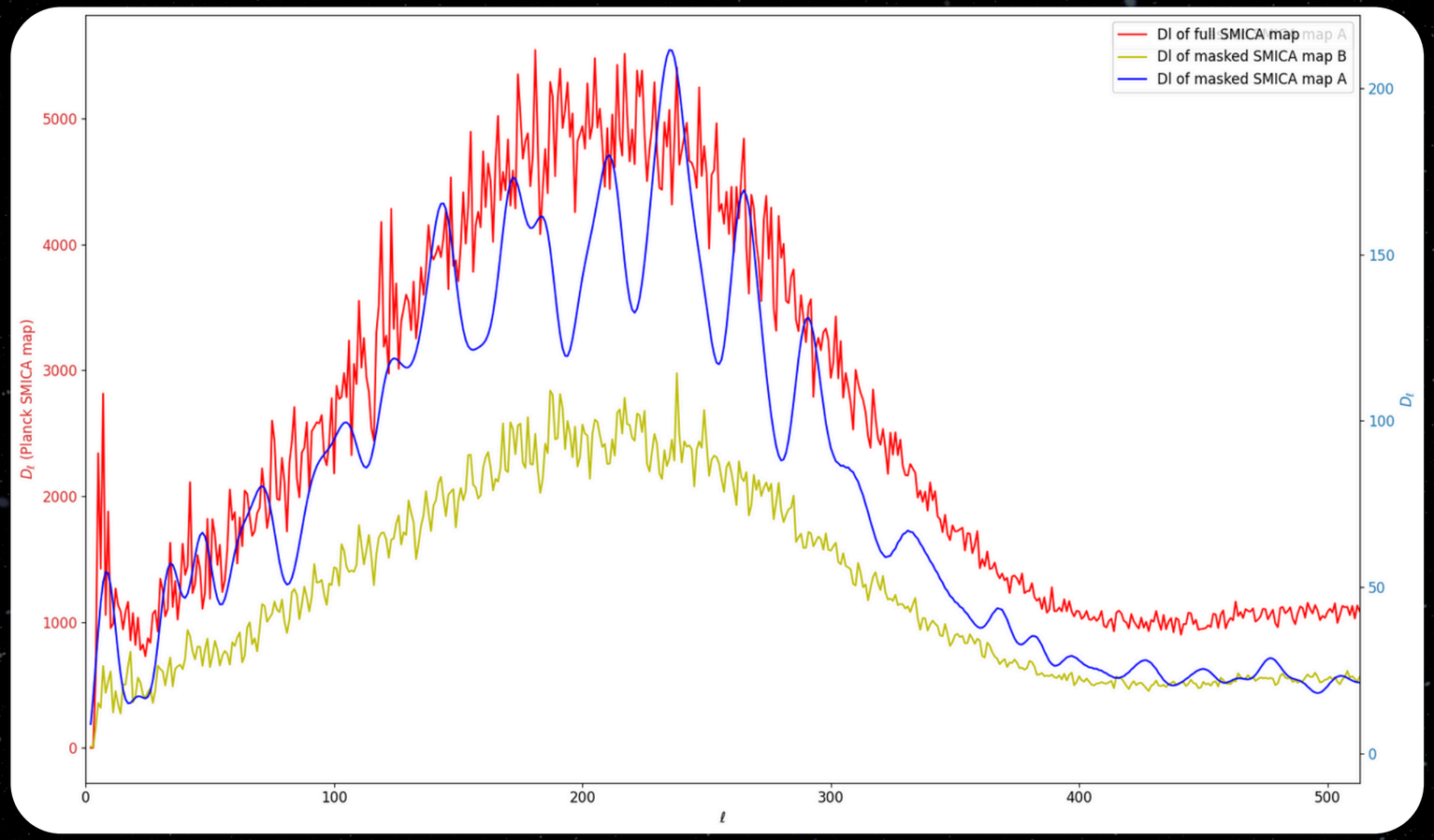
THINGS TO TAKE INTO ACCOUNT

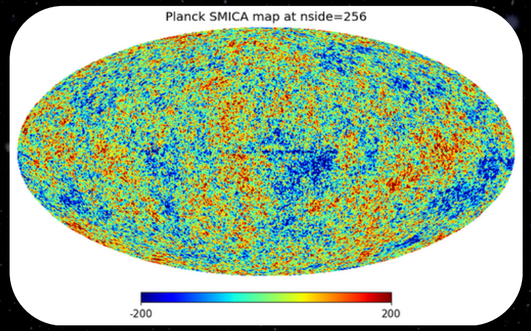
- Noise
- Beam of the instrument
- Influence of the mask *(please see next slide)*

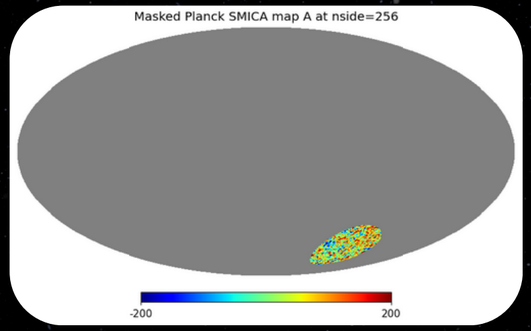
$$\frac{\Delta T}{T}(\theta,\phi) = \sum_{l=0}^{\infty}\sum_{m=-l}^{l} a_{l,m} Y_{l,m}(\theta,\phi)$$

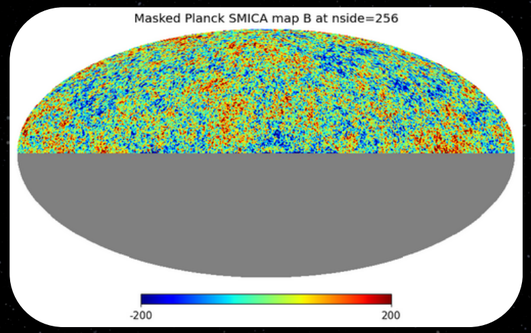
$$C_l = \frac{1}{2l+1}\sum_{m=-l}^{l} |a_{l,m}|^2$$

2. Influence of the mask

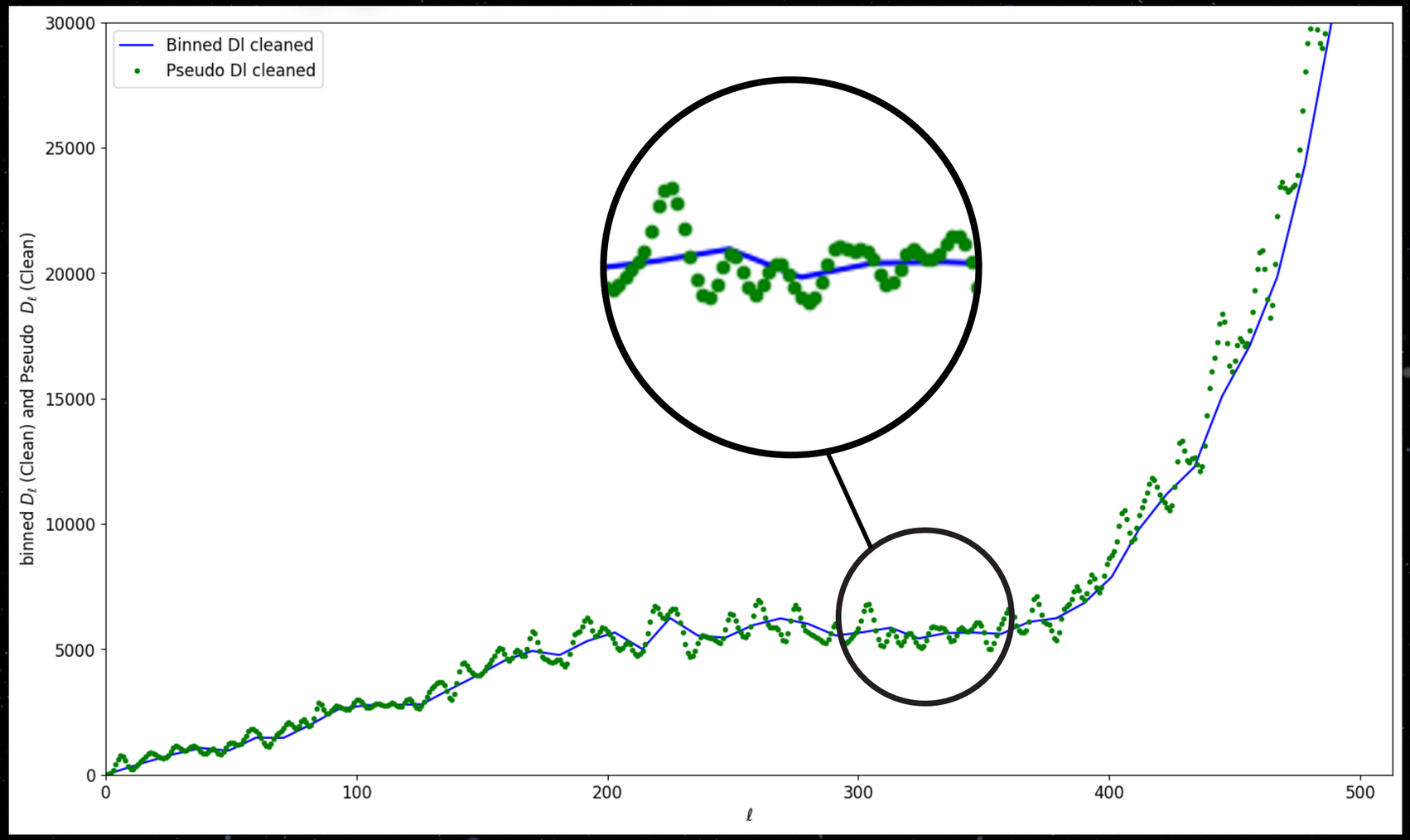








3. Binning process



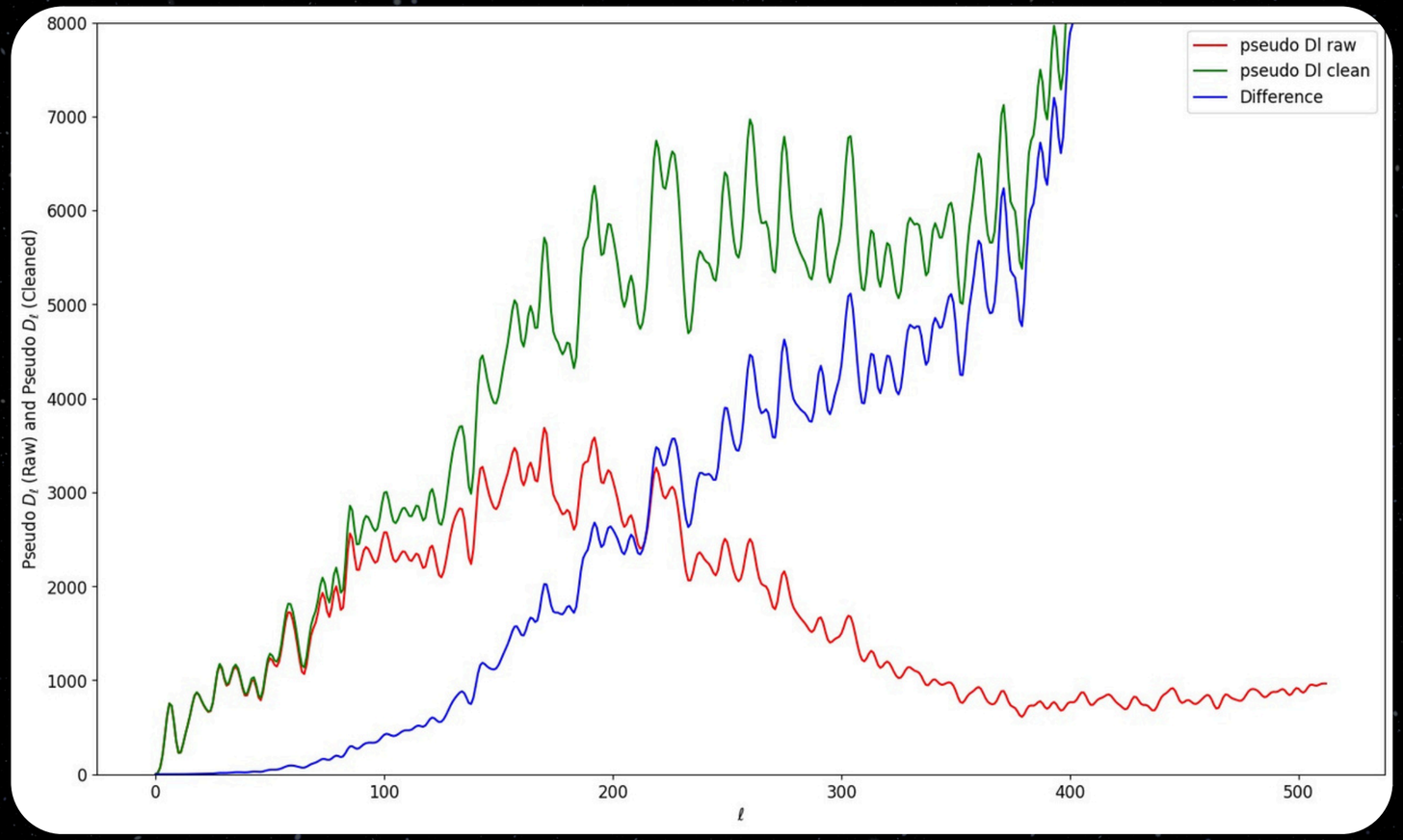
4. Sources of uncertainties

ANGULAR RESOLUTION

$$FWHM = 30 arcminutes$$
$$FWHM = 2.5 \times \sigma^2$$
$$B_l = exp\left(-\frac{1}{2} l^2 \sigma^2\right)$$

HEALPIX MAPS

- Pixel window fonction
- Smooth the sky by averaging the pixels



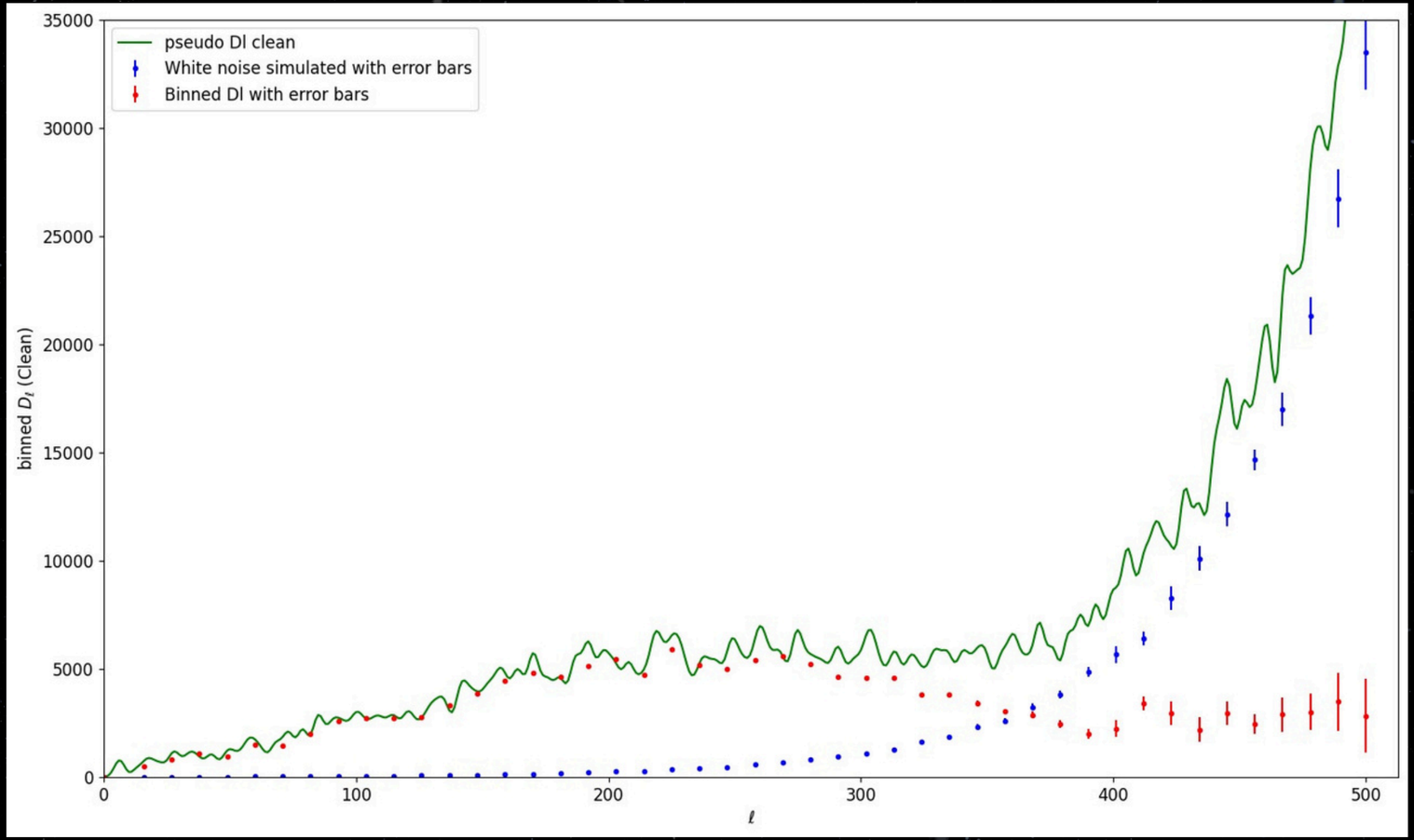
5. Noise effects

NOISE EFFECTS

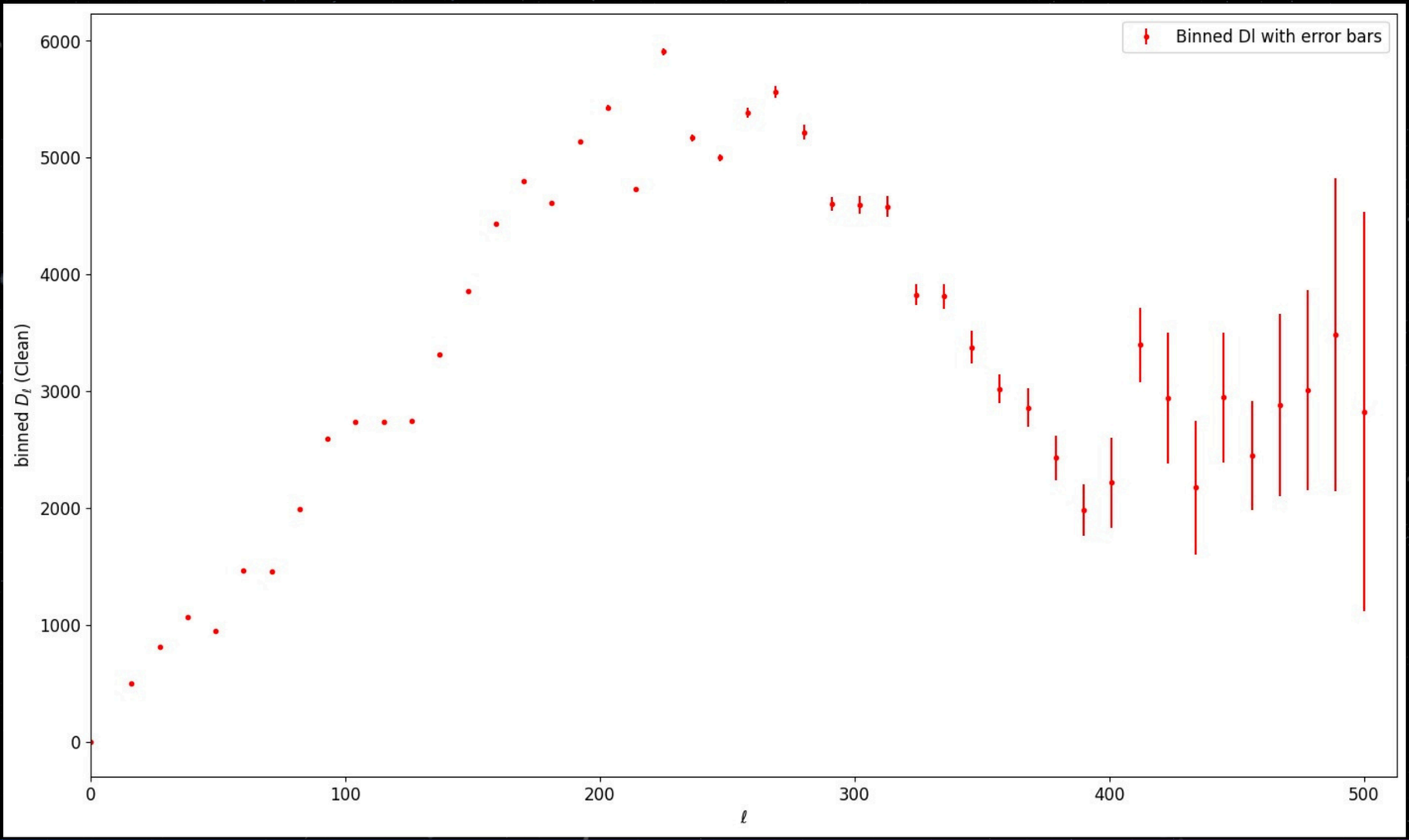
- Create measure uncertainties
- Need to estimate these errors

MONTE CARLO TREATMENT

- Noise simulation
- Generation of white noise
- Estimation of the noise variance



6. Conclusion



Cosmology

CMB 3 Group B

Stéfan Cohen - Victor Kang - Nino Massenet - Mathieu Robin - Martin Debacker

CMB Overview :

CMB 1

time ordered data

maps involving realistic noise and filtering

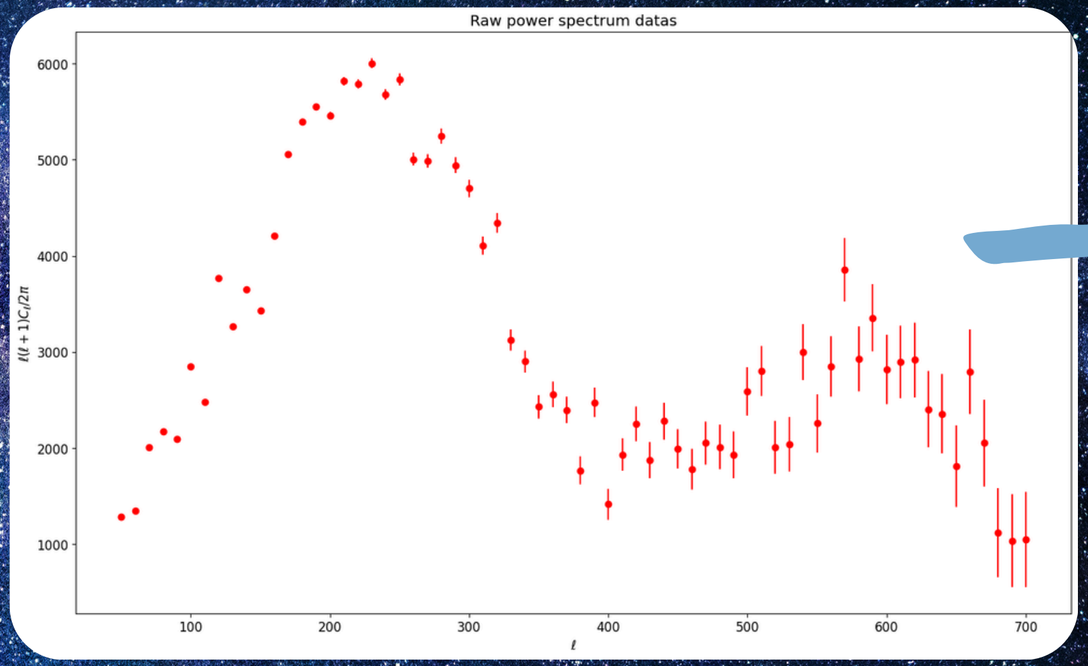
CMB 2

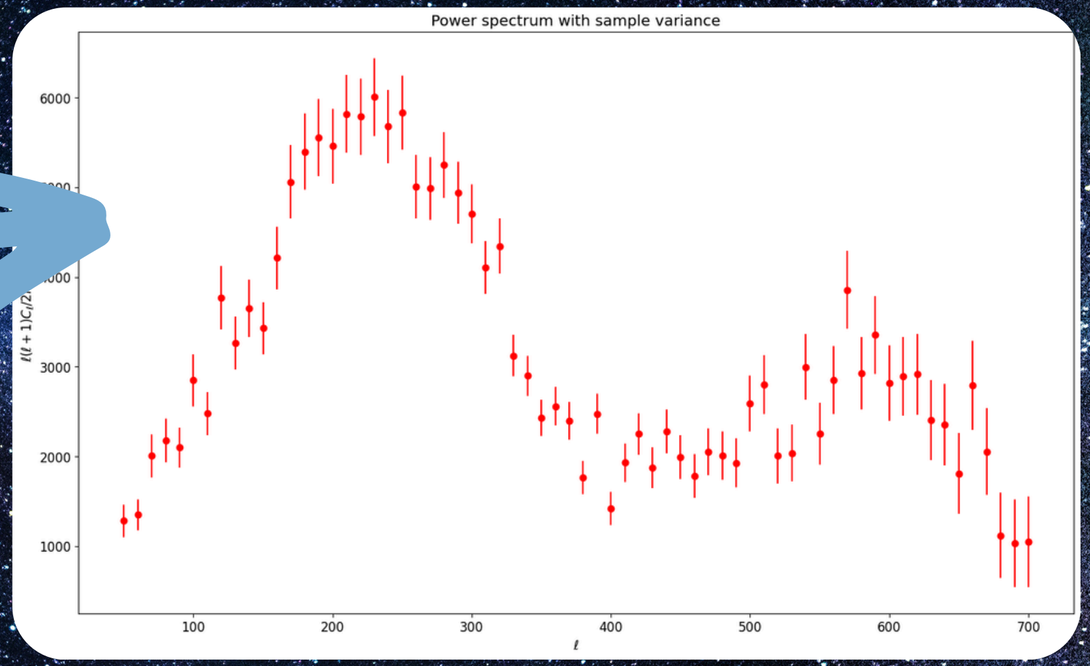
angular power spectrum involving realistic effects

CMB 3

cosmological parameters

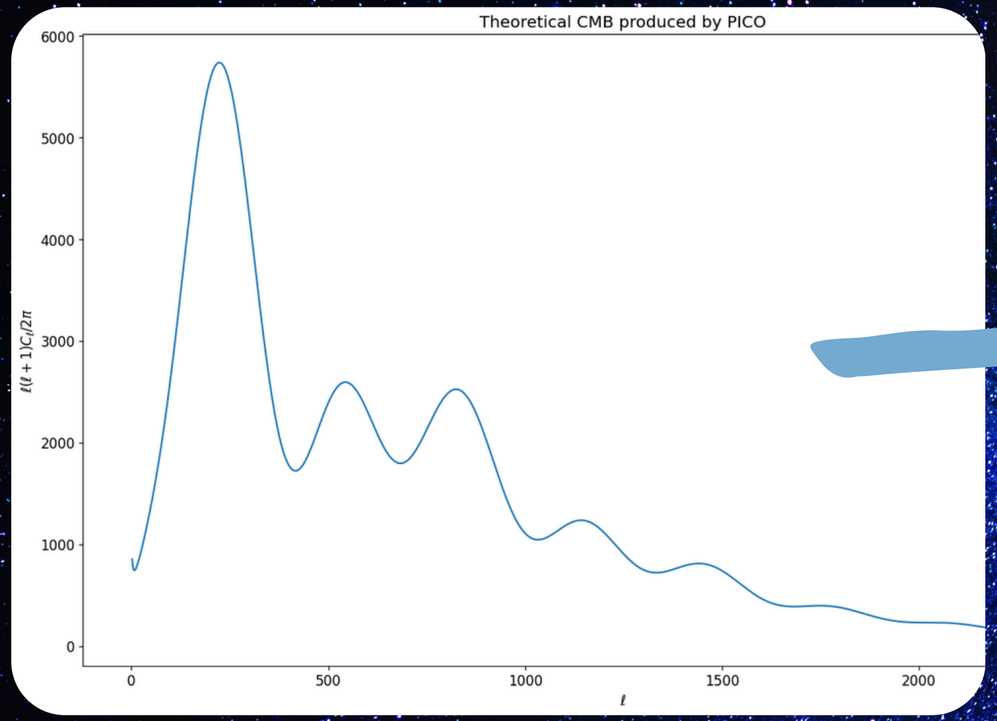
1) Sample Variance

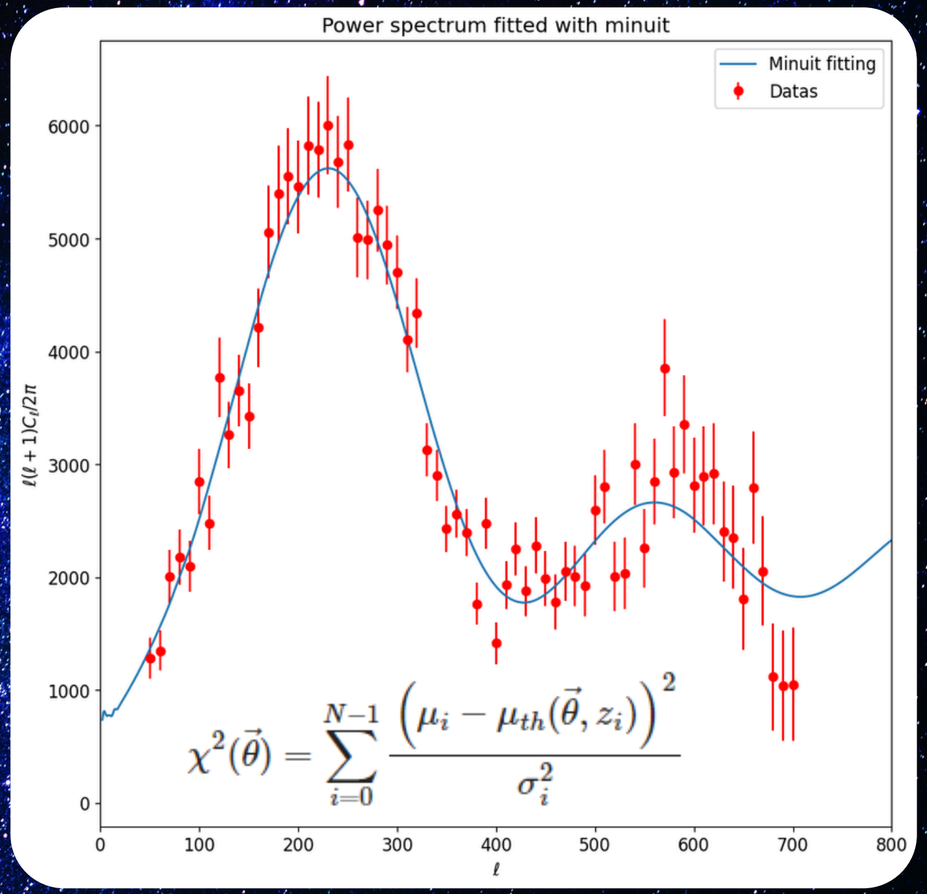




$$RMS = \sqrt{\frac{2}{((2l+1) \times sky_{fraction} \times \triangle l)}} \times Cl$$

2) Minuit fit





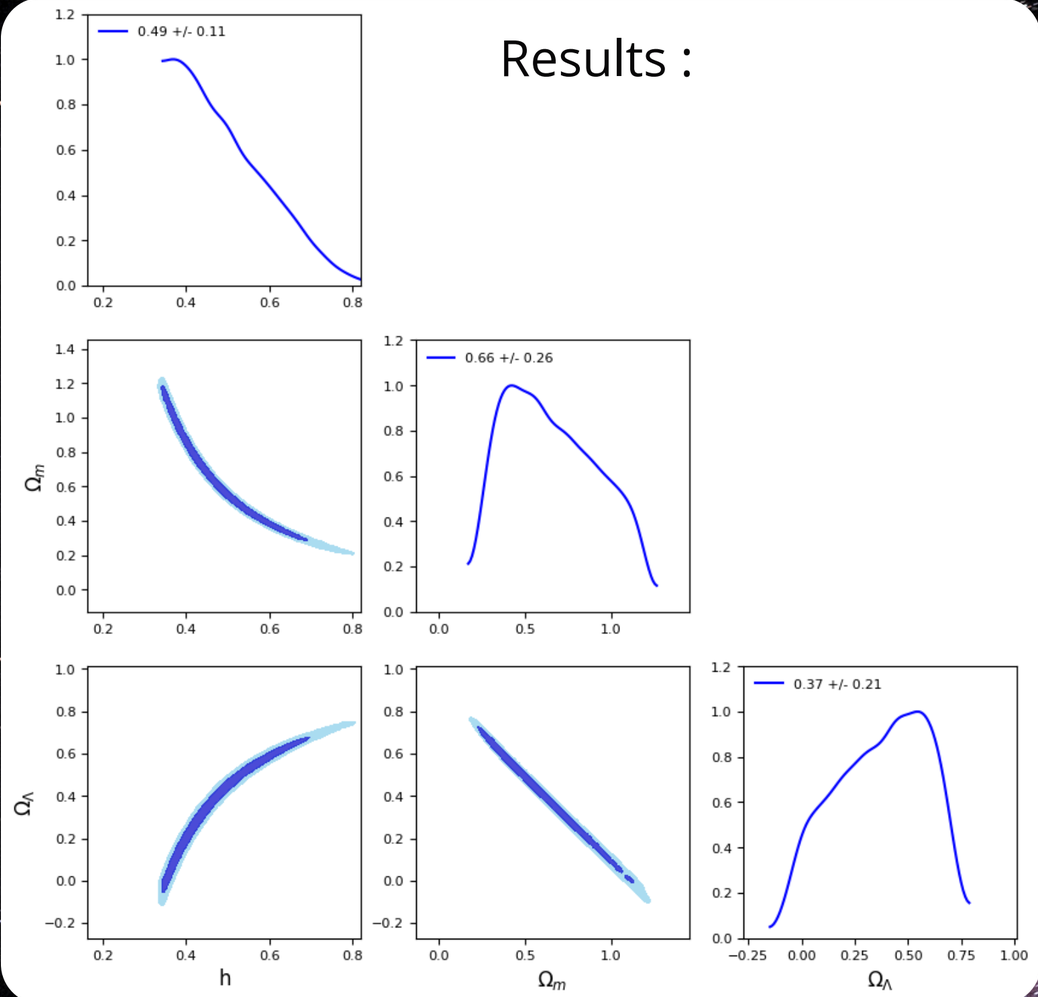
Minuit method = **Least Squares** method
-> gave a probable minimizer for the loss function, usuable as a starting point for the more rigourous **MCMC method**

Results :
$\Omega\Lambda = 0.361 \pm 0.114$
$h = 0.459 \pm 0.196$
$\Omega m = 0.668 \pm 0.013$

$h = H0/100$
$\Omega m = (\Omega bh^2 + \Omega ch^2)/h^2$
$\Omega\Lambda = 1 - \Omega m - \Omega k$

3) mcmc fit

Results :



Likelihood of the data and the model :

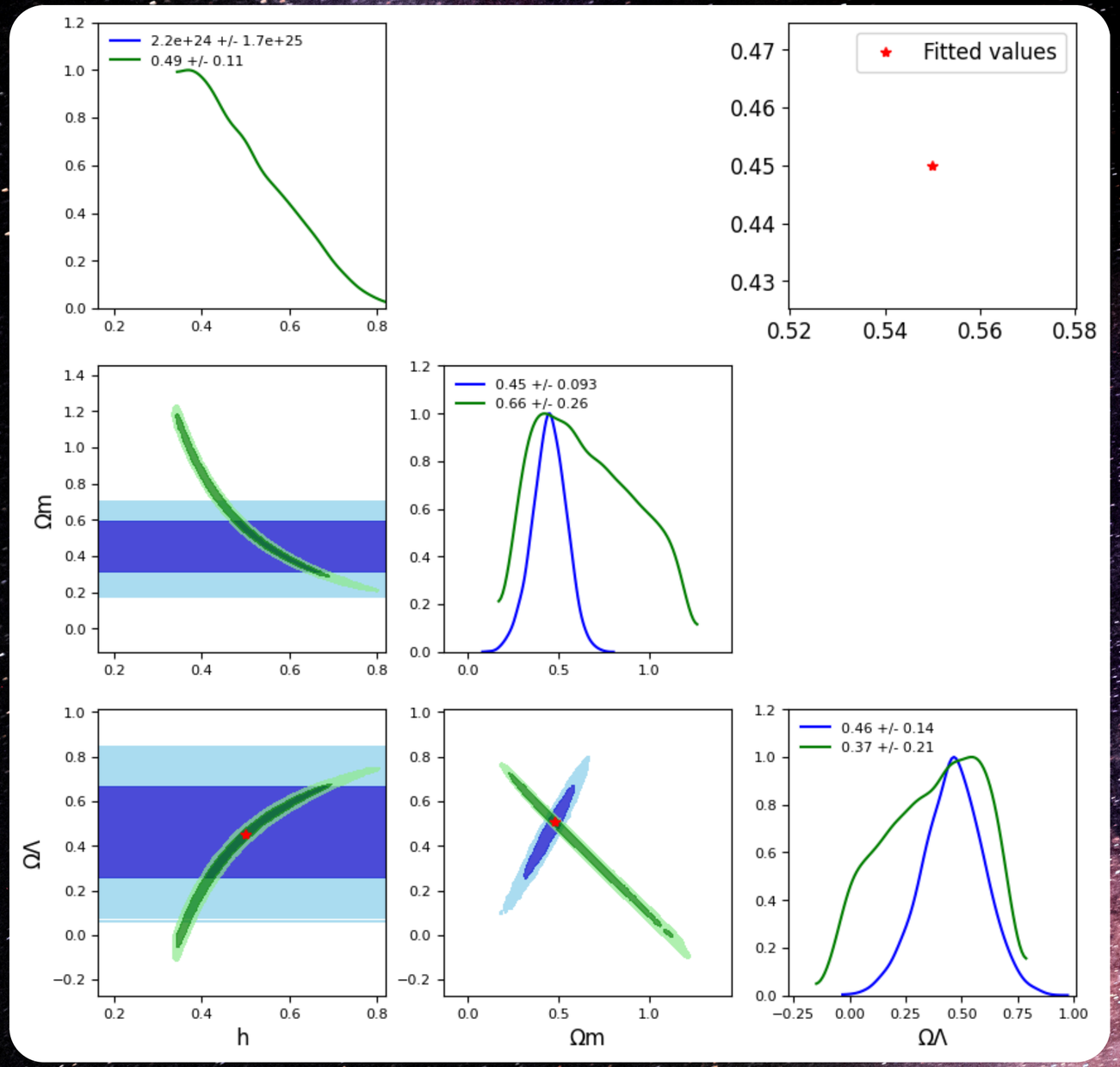
$$\mathcal{L}(\vec{d} \mid \vec{\theta}) = \frac{1}{\prod_{i=0}^{N-1} \sqrt{2\pi\sigma_i^2}} \exp\left(\sum_{i=0}^{N-1} - \frac{\left(y_i - f(x_i, \vec{\theta})\right)^2}{2\sigma_i^2} \right)$$

The quantity to minimize :

$$\begin{aligned} A(\vec{d} \mid \vec{\theta}) &= -2\log\left(\mathcal{L}(\vec{d} \mid \vec{\theta})\right) \\ &= -2\log\left(\frac{1}{\prod_{i=0}^{N-1} \sqrt{2\pi\sigma_i^2}}\right) + \sum_{i=0}^{N-1} \frac{\left(y_i - f(x_i, \vec{\theta})\right)^2}{\sigma_i^2} \end{aligned}$$

Results :
$\Omega\Lambda = 0.440 \pm 0.054$
$h = 0.487 \pm 0.112$
$\Omega m = 0.595 \pm 0.012$

4) Merged MCMC fit w/ SN3



Approximated Results

:

ΩΛ = 0.45
h = 0.50
Ωm = 0.48

Project Conclusion

Almost all of the work packages’ objectives have been reached