Data post-processing

Thomas Martin

Supervisors: Laurent Drissen & Gilles Joncas

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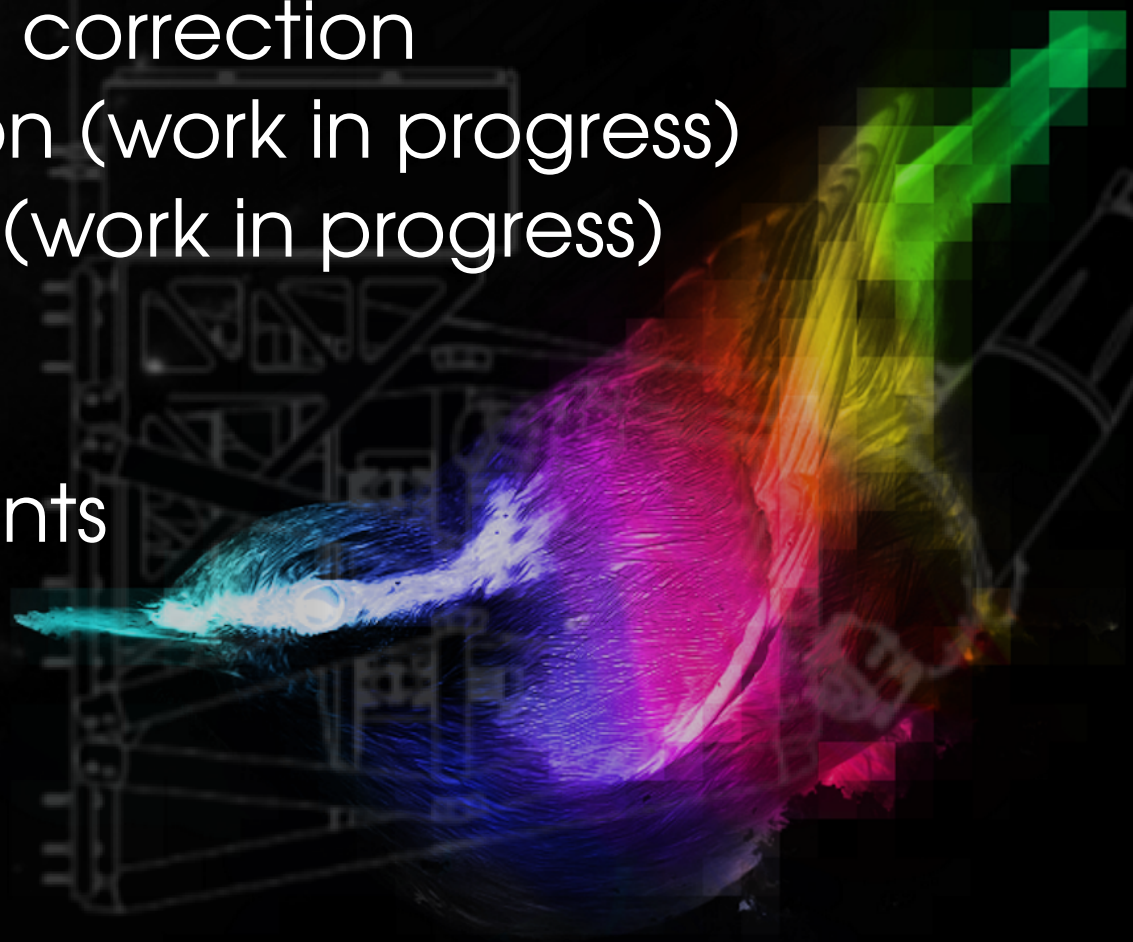
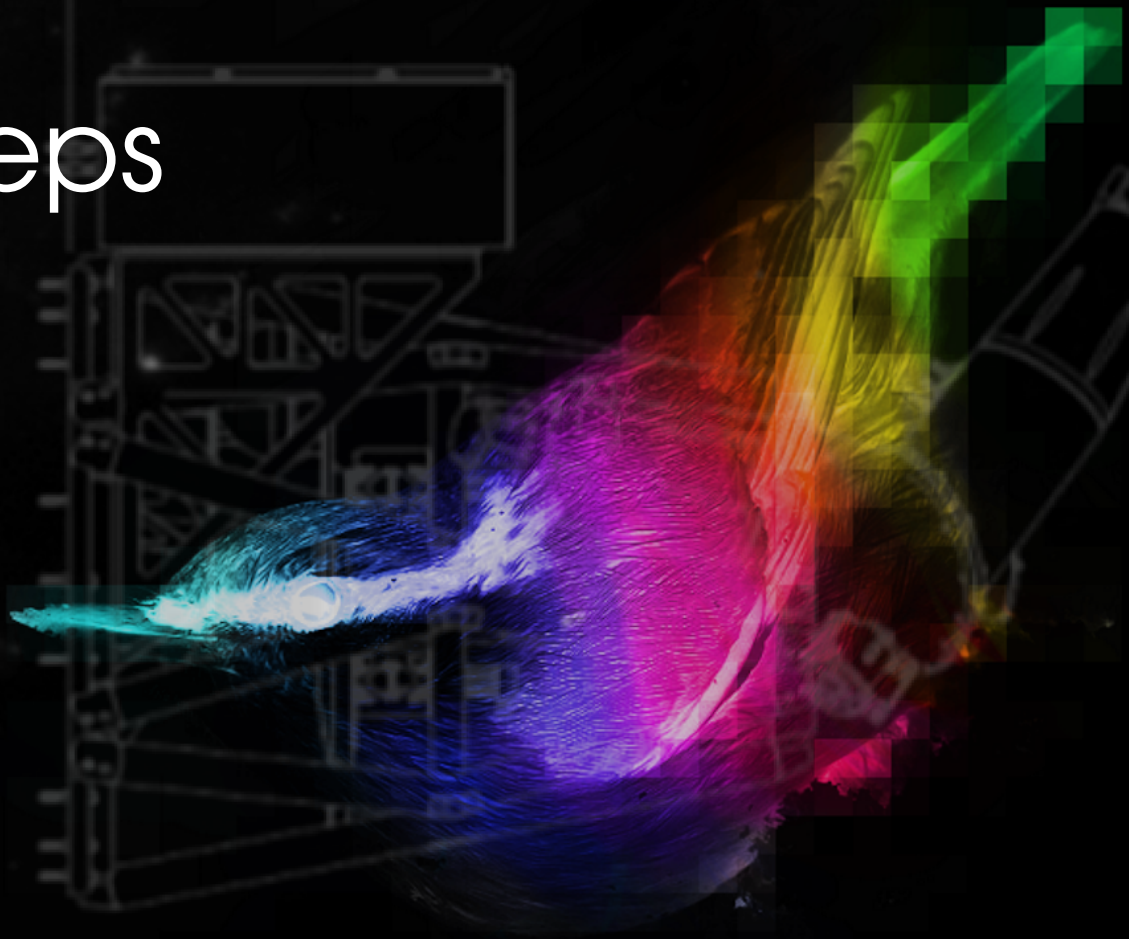
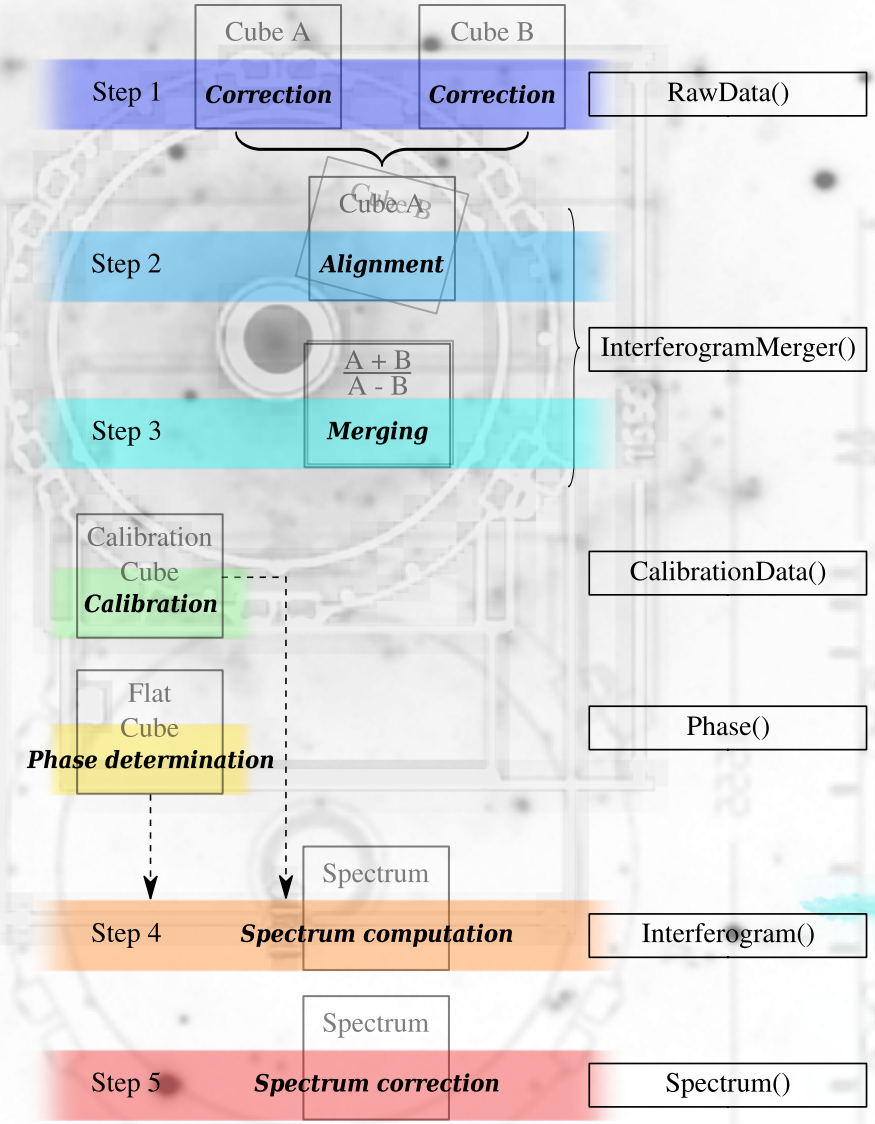


Reduction steps



Reduction steps



1. Correction of frames and alignment
2. Alignment of the cubes
3. Merging
4. Spectrum calculation
5. Spectrum correction (e.g. filter, flux calibration)

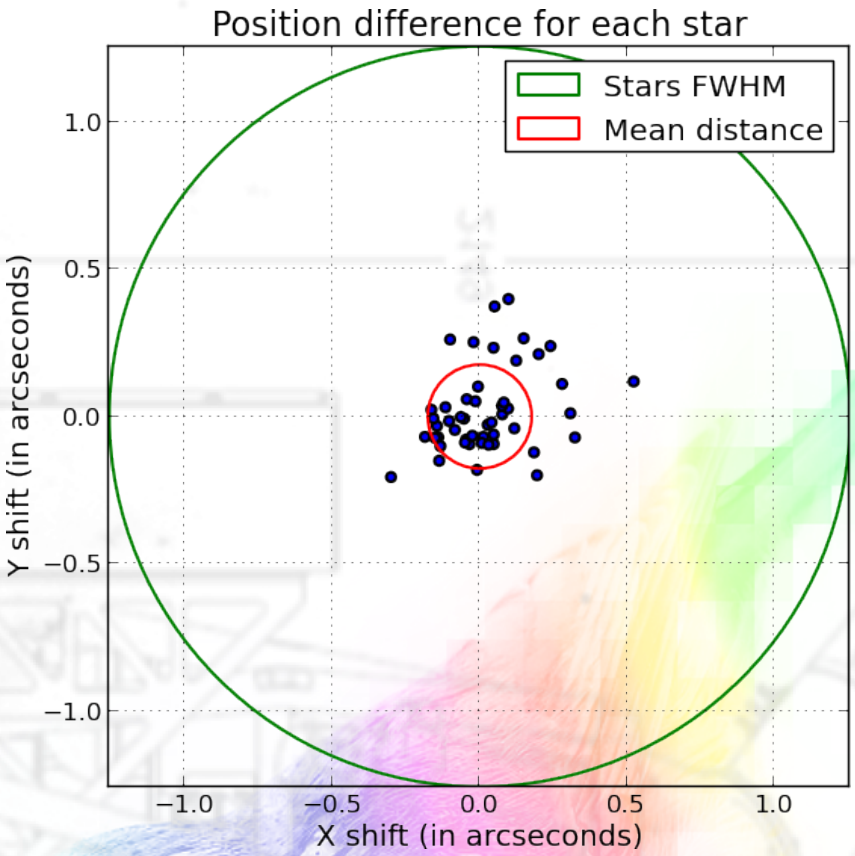
Cubes alignment

5 parameters

X and Y, rotation, tip and tilt

Automated process

- **Detection** of the best stars
- **Optimisation** of the alignement parameters



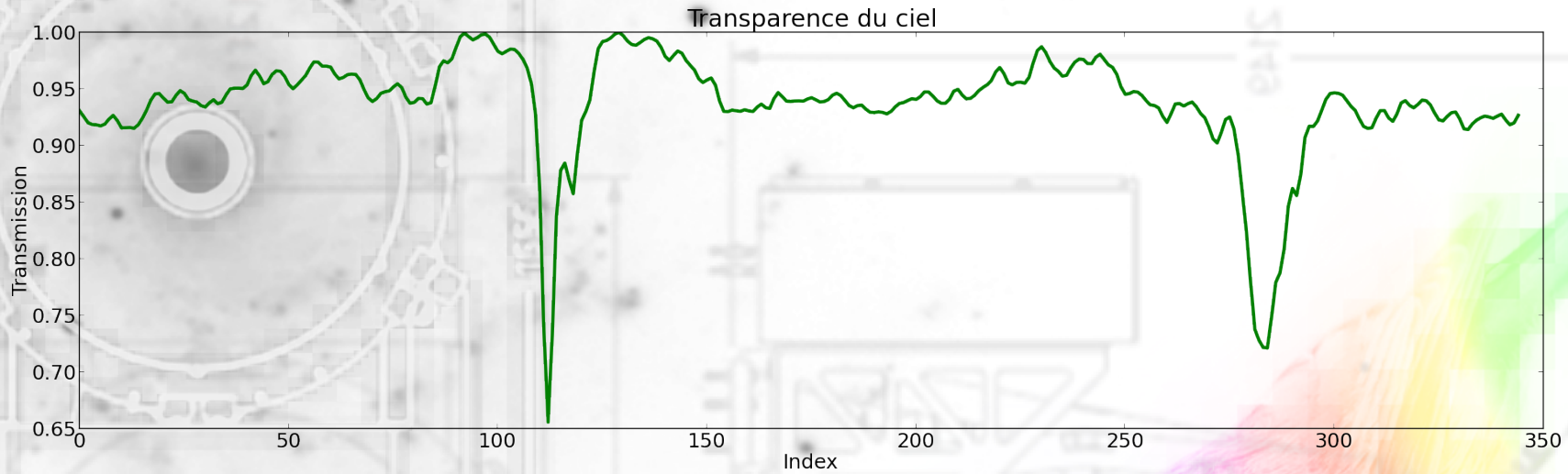
Alignment precision

Computed over the stars position in each cube $\sim$ **0.2”**
(stars FWHM $\sim$ 2.4”, pixel size $\sim$ 1.6”)

Sky transmission correction

Sky transmission variations (airmass, clouds)

$I_{\mathrm{CCD}}(t) = I_{\mathrm{star}} \times f_{\mathrm{transmission}}(t)$

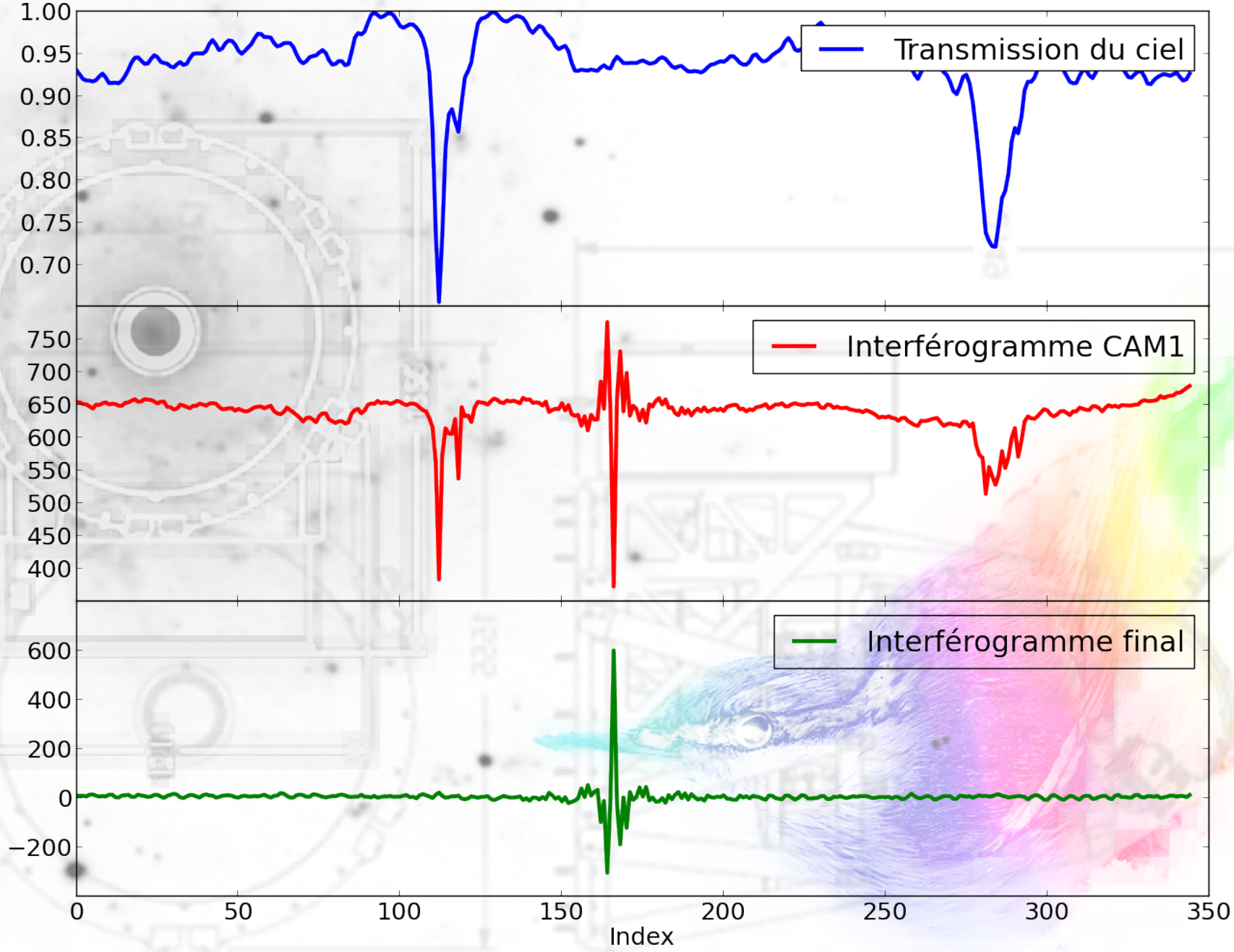


Correction

$I_{\mathrm{CAM1}} + I_{\mathrm{CAM2}} = \mathrm{constant}$

$\Rightarrow$ We use **stars photometry** to get a high SNR (assuming that the transmission variation is the same for the whole frame).

Correction example for sky transparency



Phase correction (work in progress)

Phase

$$\text{Interferogram} \xrightarrow{\text{TF}} \left\{ \begin{array}{c} \text{Re} \\ \text{Im} \end{array} \right\} \rightarrow \left\{ \begin{array}{l} \text{Amplitude} = \sqrt{\text{Re}^2 + \text{Im}^2} \\ \textbf{Phase} = \arctan\left(\frac{\text{Im}}{\text{Re}}\right) \end{array} \right.$$

Complex spectrum

$$\left\{ \begin{array}{l} S(\nu) = R(\nu) + i \times I(\nu) \\ S(\nu) = A(\nu)\exp(i\phi(\nu)) \end{array} \right.$$

Perfect spectrum

$$\phi(\nu) = 0 \implies S(\nu) = A(\nu)$$

Phase correction

$$A(\nu) = \text{Re}(S(\nu)\exp(-i\phi(\nu)))$$

An observed interferogram contains **noise**.

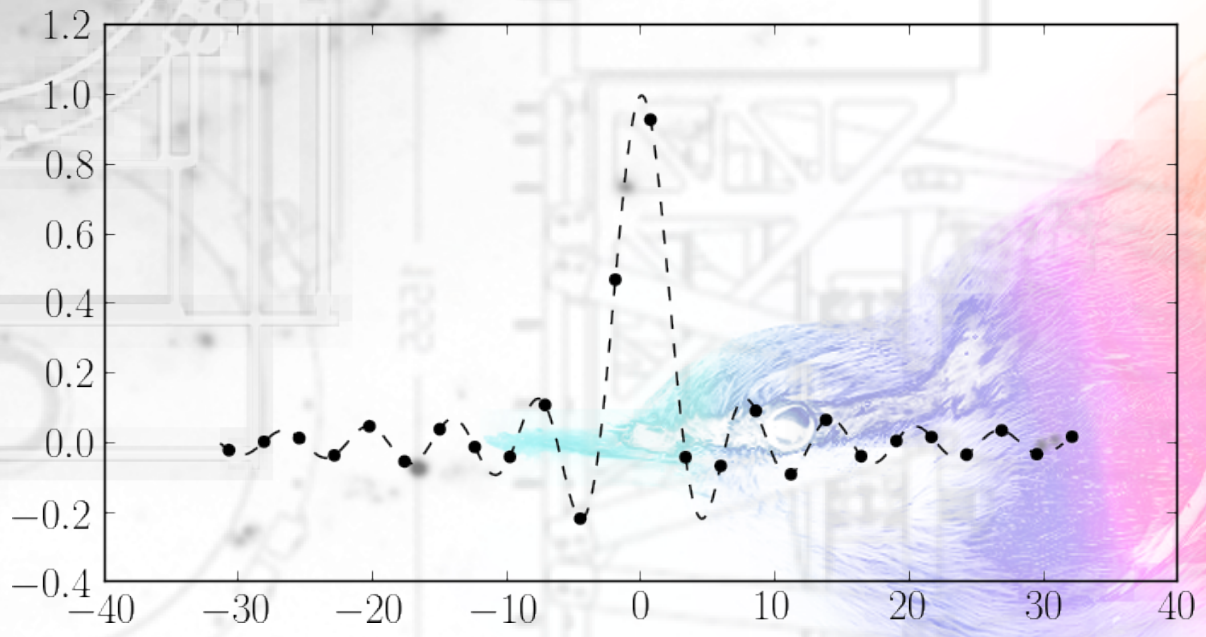
$\implies$ Noisy (Im, Re) or **noisy (Amplitude, Phase)**. But phase is assumed to be a **slowly varying function** .

$\implies$ **Phase can be smoothed** (replaced by a **polynomial fit**).

Phase errors origin

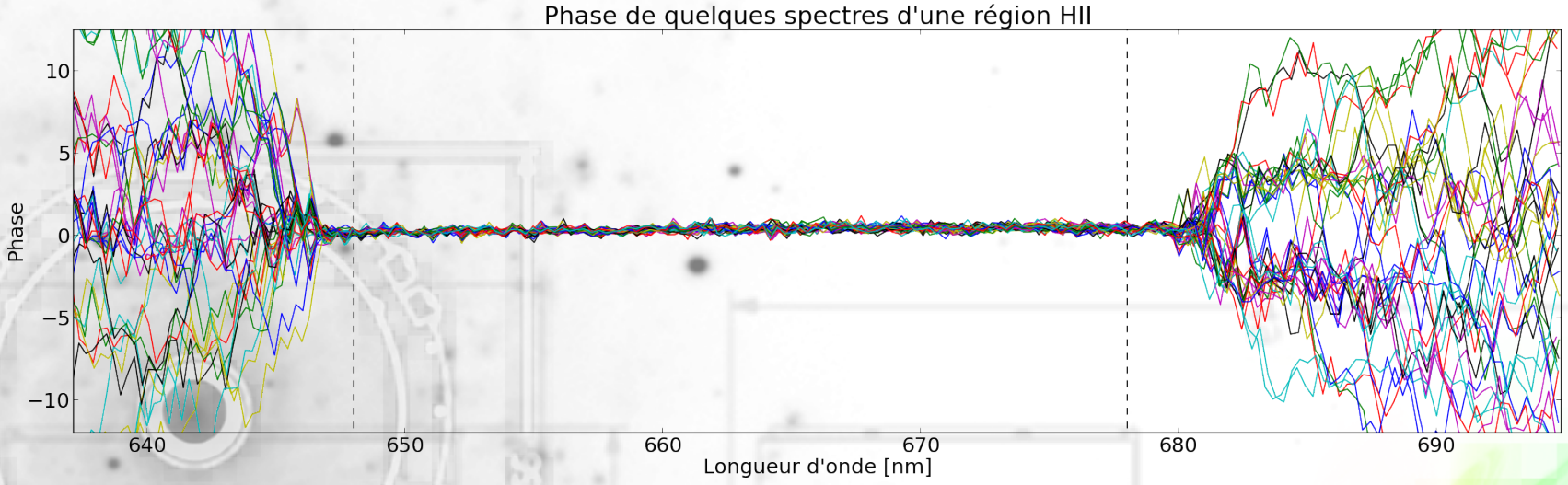
Interferogram asymmetry (Learner et al. 95)

- Non perfectly centered ZPD (always : order 1)
- Wavelegth dependant effects (e.g. beamsplitter, order > 1)
- Irregular sampling (e.g. error on the mirror position, can give an irregular phase function)

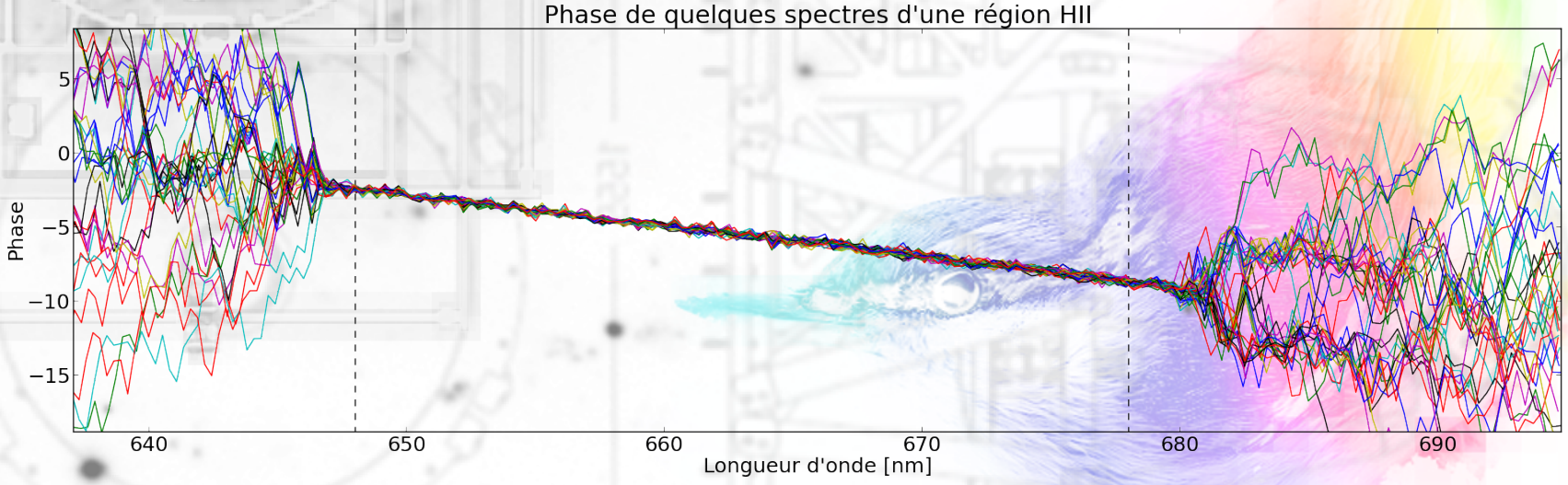


Effect of a non centered ZPD

Effect of a ZPD shift

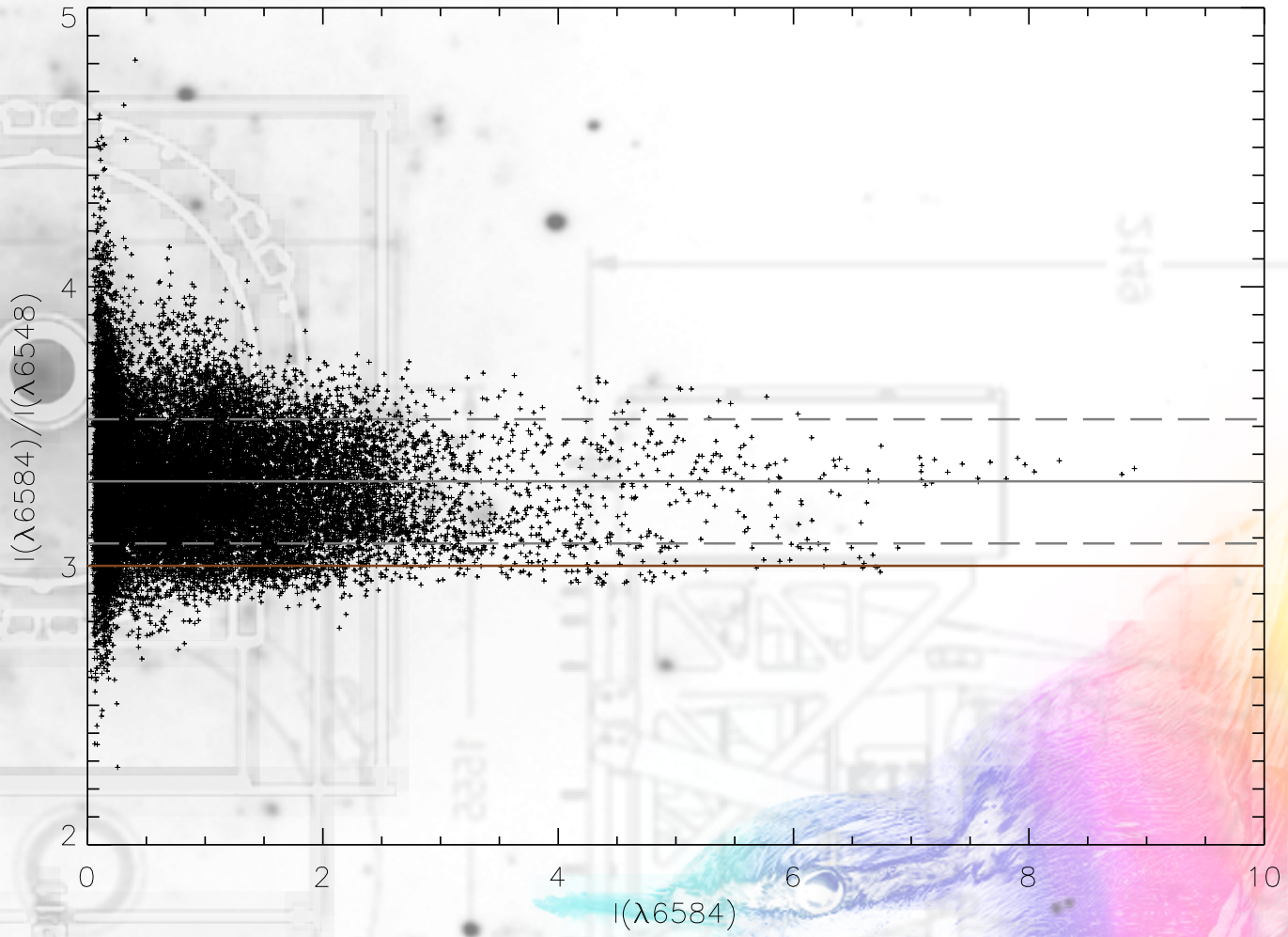


ZPD well centered



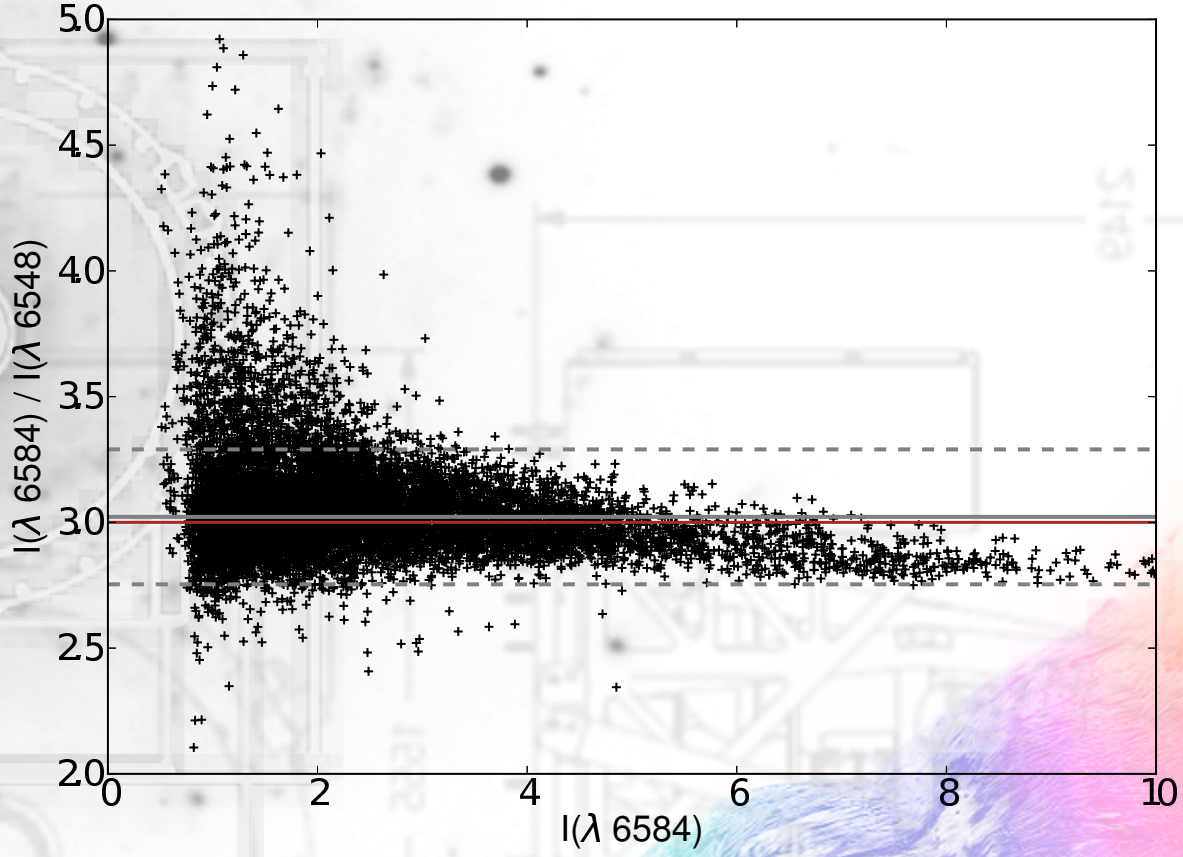
ZPD non-centered

N II emission lines ratio



N II ratio vs intensity **without phase correction** (M27, Dominic Lagrois).

N II emission lines ratio



N II ratio vs intensity **with a basic phase correction** (M27).
Still a lot of work has to be done, better results will come !

Flux calibration (work in progress)

Flux calibration

Correction of the **Instrumental function** (filter + optics) + detectors **quantum efficiency**

- **Mission start** : Spectrum of a standard for each filter in **photometrical conditions**
- **For each cube** : An image of the same standard star is taken at the beginning and the end of the observation

ORBS for SITELLE

ORBS users

ORBS users

ORBS must be used to reduce SITELLE's data

- **CFHT** Team
- Astronomers who would like to tune data reduction (e.g. apodization, phase correction)

$\Longrightarrow$ **Constraints** on software quality

- Completely **automated**
- Optimized computing time (Fully **parallelized**)
- Big data cubes (68 Go) can be processed on personal computers
- Data reduction quality must be validated
- Spectral data must be easy to extract

Automatization

Automatization

- **No action required during data reduction**
- $\Longrightarrow$ No parameter to tune
- Oddities are controlled
- Informations are genetrated to help checking : **log**, data produced at each step is kept.

*logfile.log

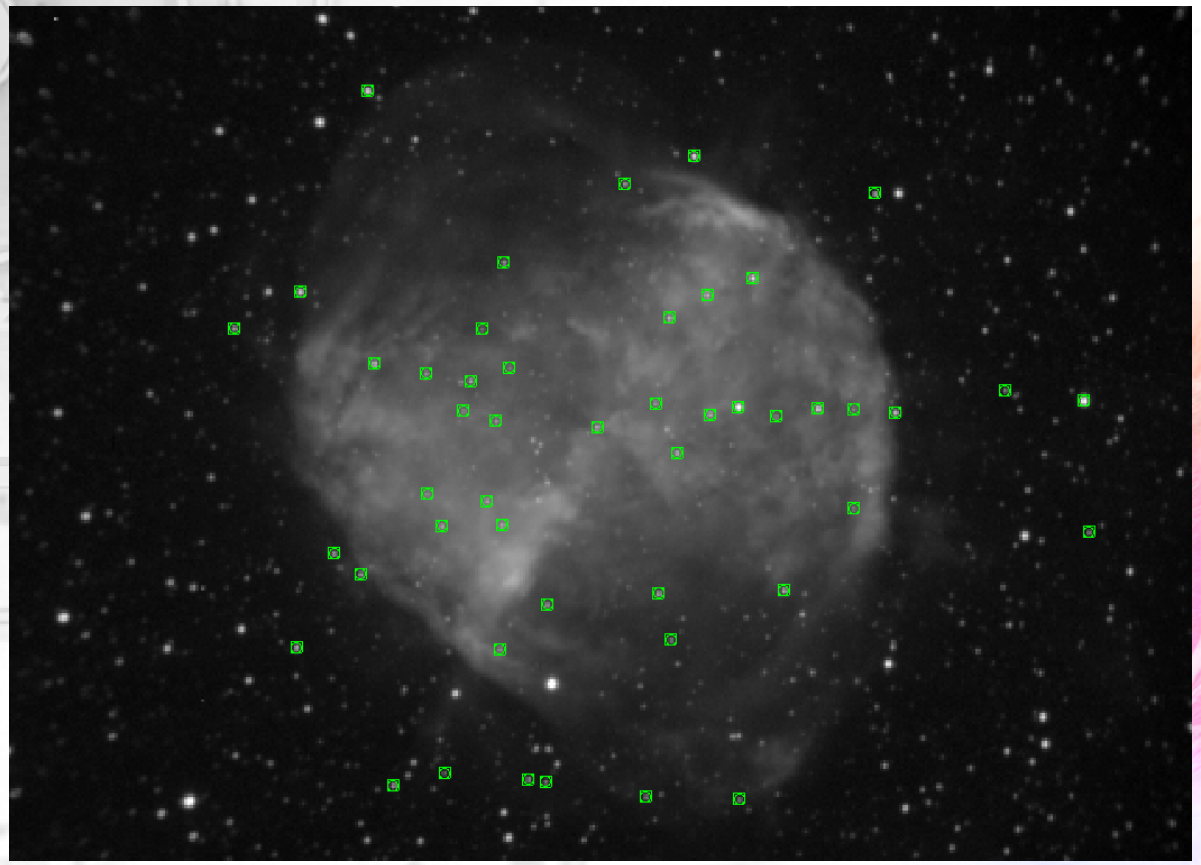
```
13-02-27|13:43:32 # Tools : main > ** ORBS reduction process **
13-02-27|13:43:32 # Tools : main > Passed arguments :
13-02-27|13:43:32 # Tools : main >  -b 227,252
13-02-27|13:43:32 # Tools : main >  -a 1.5
13-02-27|13:43:32 # Tools : main > Bad frames : [227 252]
13-02-27|13:43:32 # Tools : main > Apodization function : 1.5
13-02-27|13:43:32 # Tools : main > Option file : R.opt
13-02-27|13:43:32 # Tools : main > Full reduction started at : Wed Feb 27 13:43:32 2013
13-02-27|13:43:32 # RawData : __init__ > Data shape : (446, 433, 345)
13-02-27|13:43:32 __init__ > Alignment vector computation started for camera 1
13-02-27|13:43:32 # RawData : detect_stars > Detecting stars
13-02-27|13:43:34 # RawData : detect_stars > 15 stars detected
13-02-27|13:43:34 # RawData : create_dxdy_vector > Creating alignment vector
13-02-27|13:43:34 # RawData : _load_star_list > Star list of 15 stars loaded
13-02-27|13:45:57 # RawData : _write_fits > data written as : ./M27_SPIOMM_R/CAM1/M27_SPIO
13-02-27|13:45:57 print_stats > Alignment vector computation performance stats:
 > Camera number: 1
 > Data cube size: 446 x 433 x 345
 > Number of quadrants: 9
 > Computation time: 144 s
 > Max memory used: 57 Mb
 > Efficiency: 2.174e-06 s/pixel

13-02-27|13:45:57 # RawData : __init__ > Data shape : (511, 511, 345)
13-02-27|13:45:57 __init__ > Alignment vector computation started for camera 2
```

Star detection

How to choose good stars ?

- **Most luminous stars** that never saturate.
- Must not be too near from another star
- FWHM selected to avoid most luminous HII regions



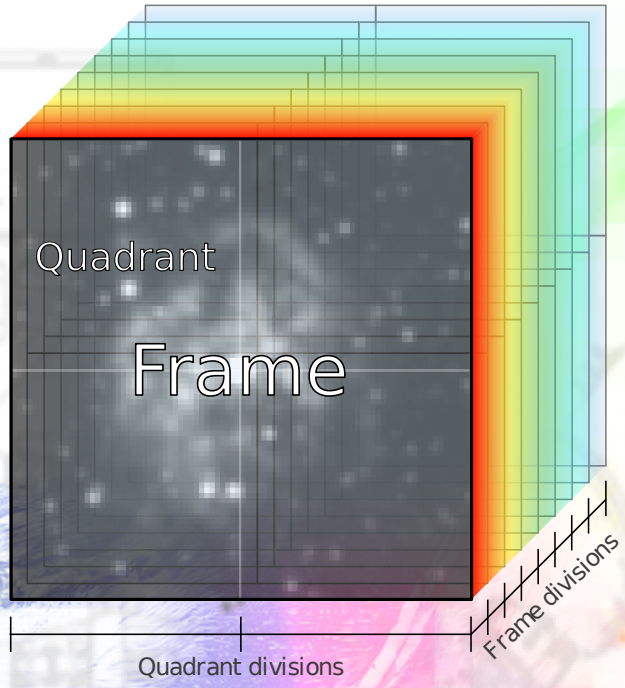
Performances

Computing time optimization

Parallelization of **all** the processes

Data size

- Maximum size of one cube: **34 Go** ($2048 \times 2048 \times 1000$ floats of 64 bits)
- $\Longrightarrow$ Cubes are divided in quadrants and frames
  $\Longrightarrow$ facilitate parallelization
- A cube is never stored as one big file but splitted in frames.



Post-reduction softwares

IRIS *Interface rapide d'information et de synthèse*

- **Fast checking of the reduction quality**
- **Normalized information** synthesis.

ORCS *Outils de réduction de cubes spectraux*

- **Extraction of spectral data** (e.g. spectral images, velocity maps ...)
- Automated processes (e.g. heliocentric radial velocity correction ...)