

Integral Field Spectroscopy

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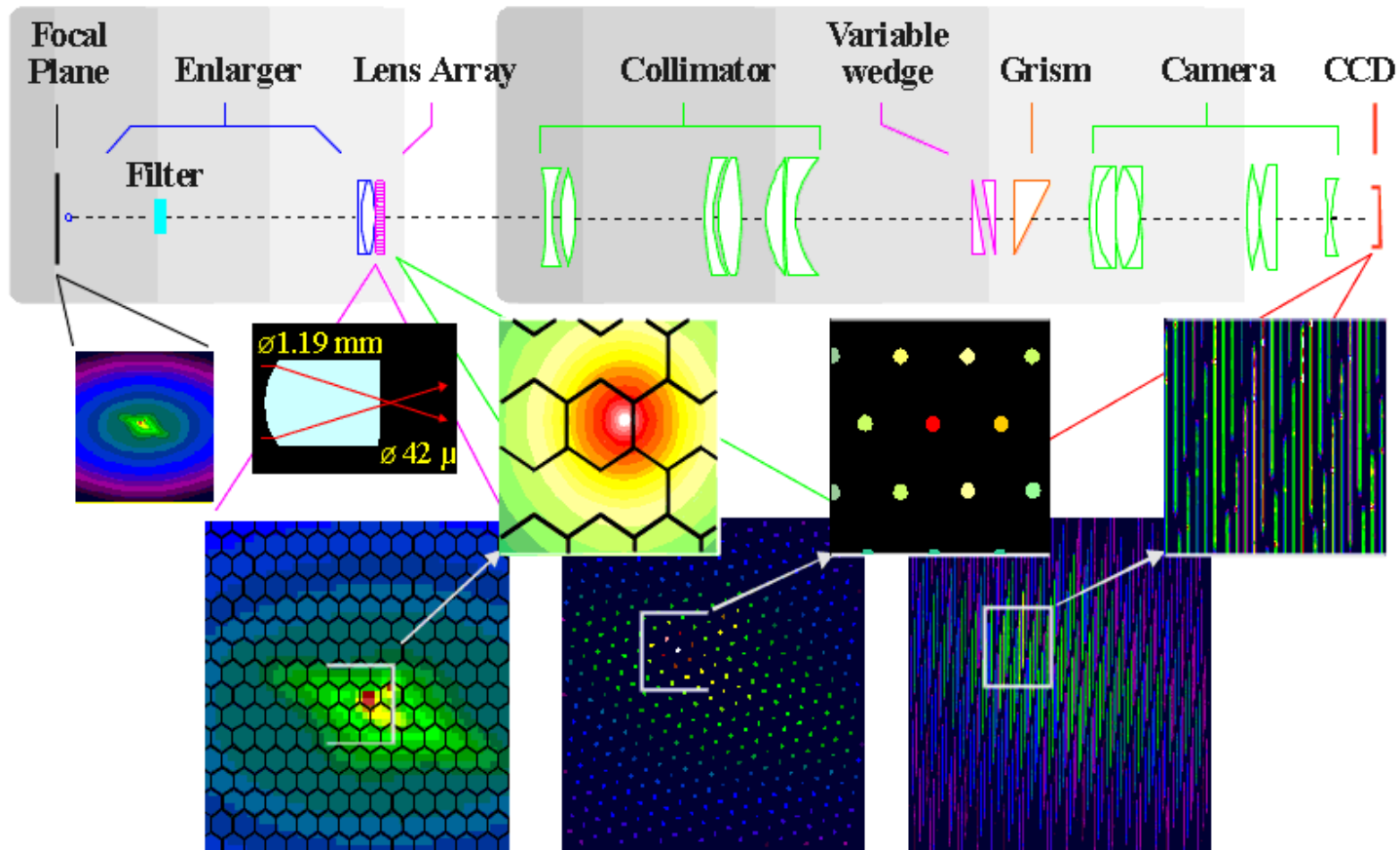
Integral Field Spectroscopy

1.) Integral Field Spectroscopy : **What is it ?**
2.) IFS for SN : **Why ? *Why not ?***
3.) IFS data reduction : **an example**

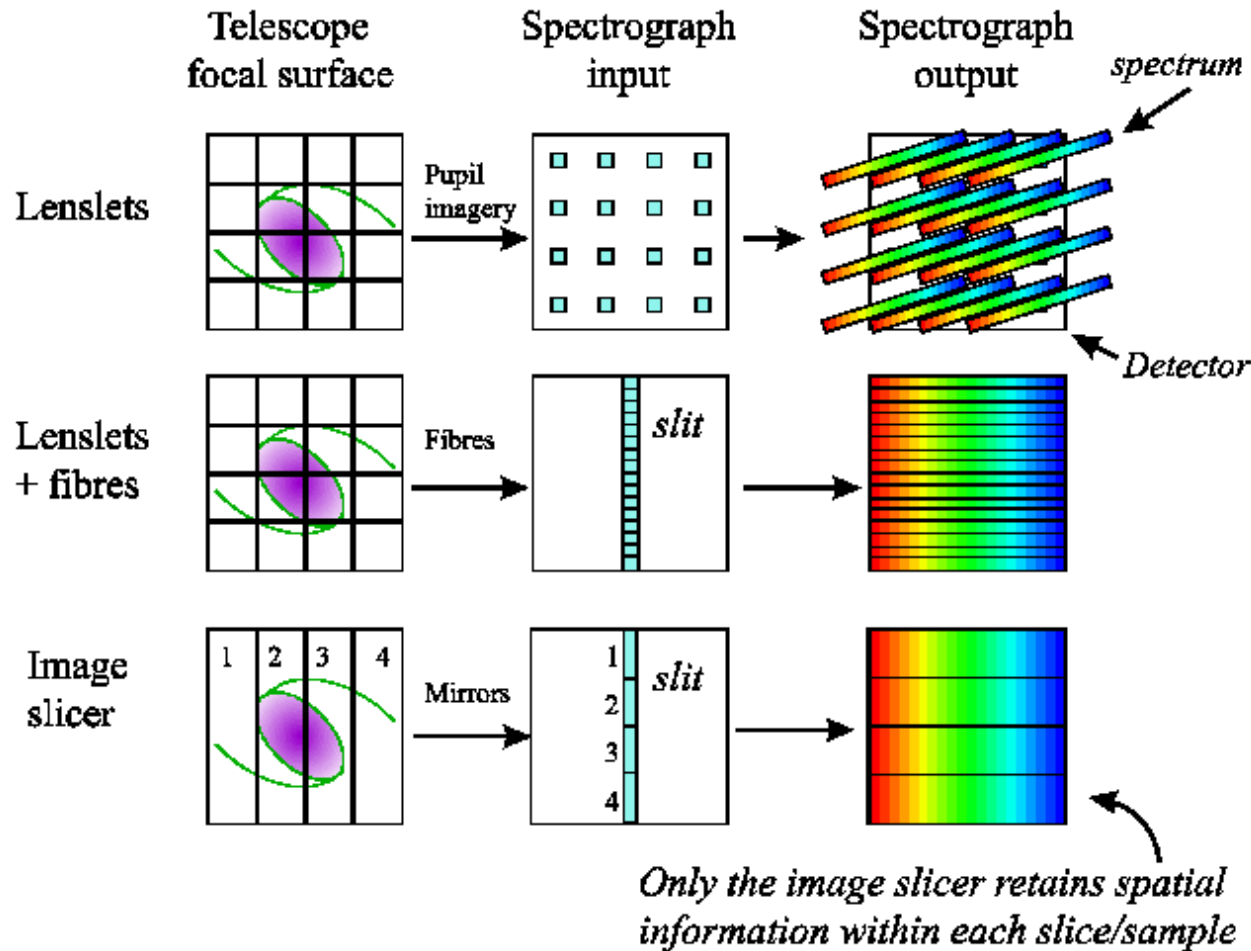
Integral Field Spectroscopy : What is it ?

IFS : an example OASIS

 **TIGER MODE OPTICAL LAYOUT**

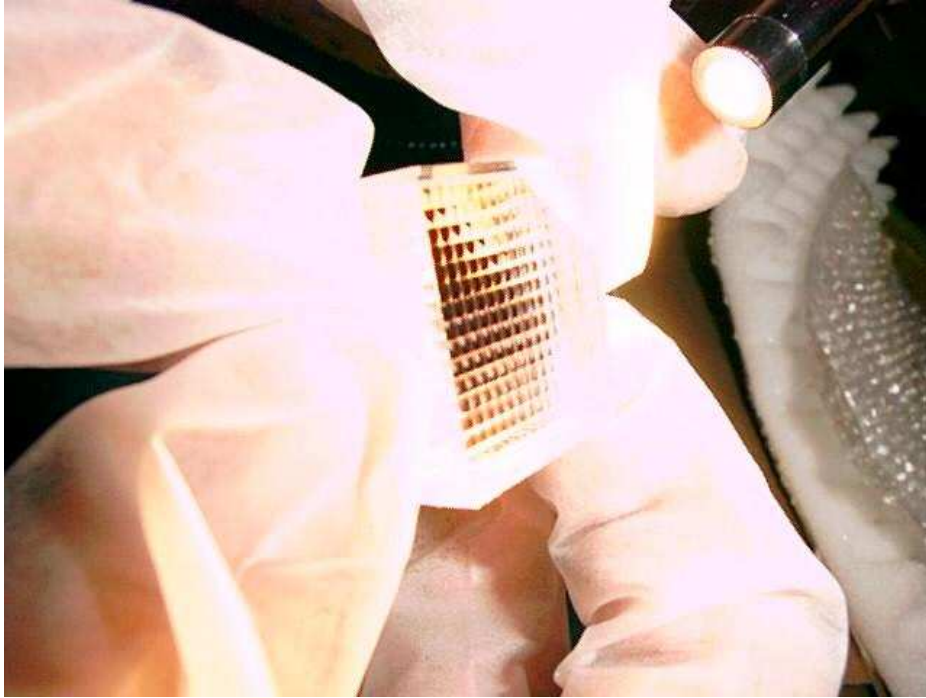


IFS : 3 types (ground telescope)



Durham University AIG

IFS : μ -lens array (1)



SNIFS (on UH)
 μ -lens array
15x15 lenses , 6"x6"
1 lens = 1.5 mm

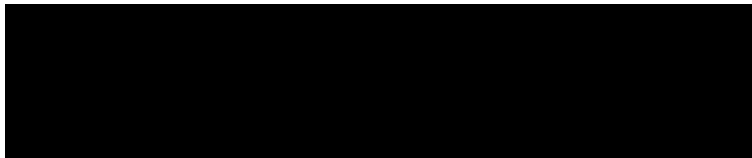
raw SNIFS exposure



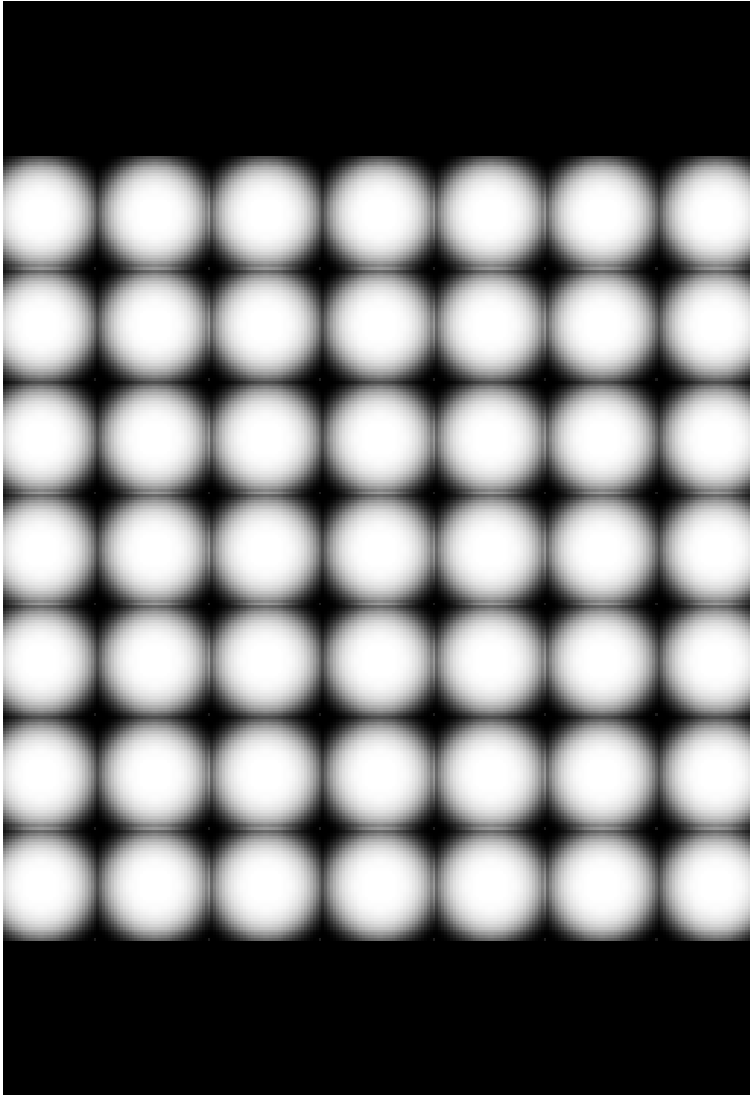
IFS : Micro-lens array (2)



Uniform light on the array



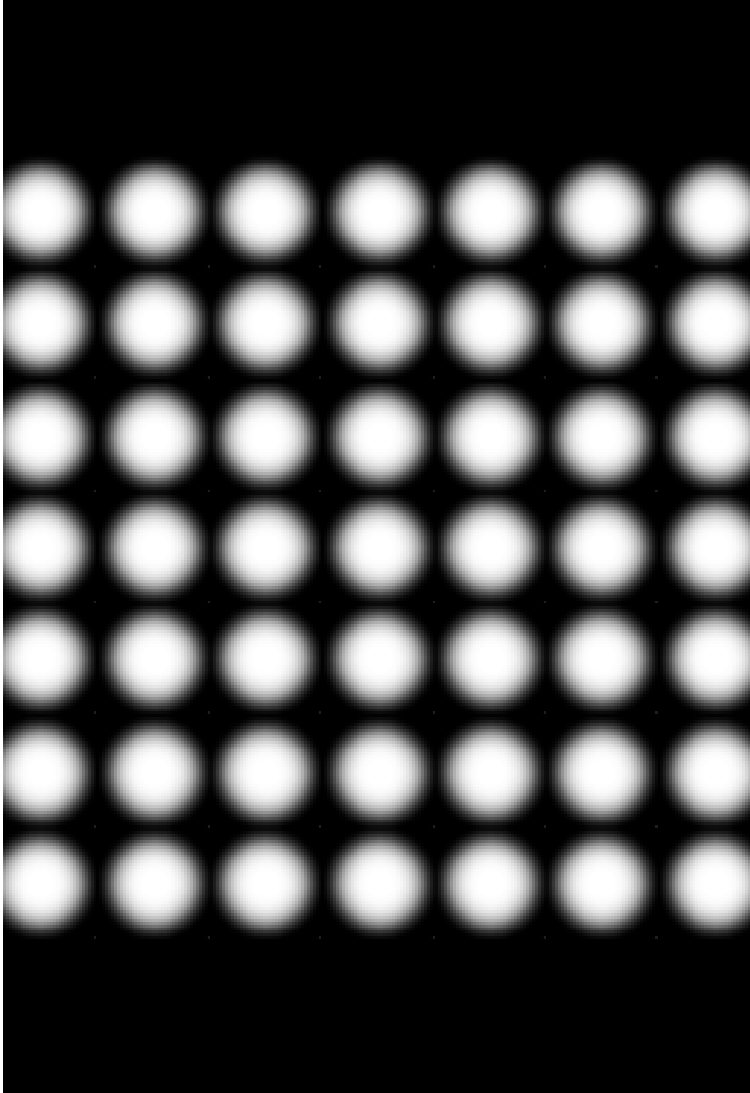
IFS : Micro-lens array (2)



Uniform light on the array

- focus of the light in small spots

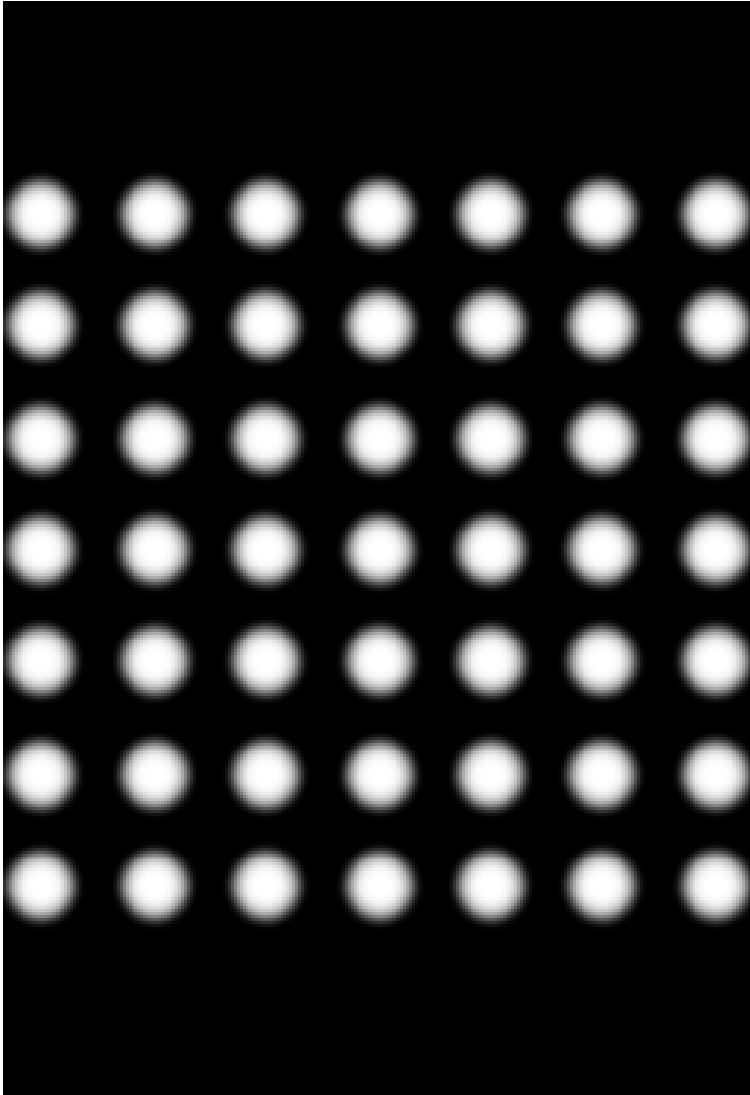
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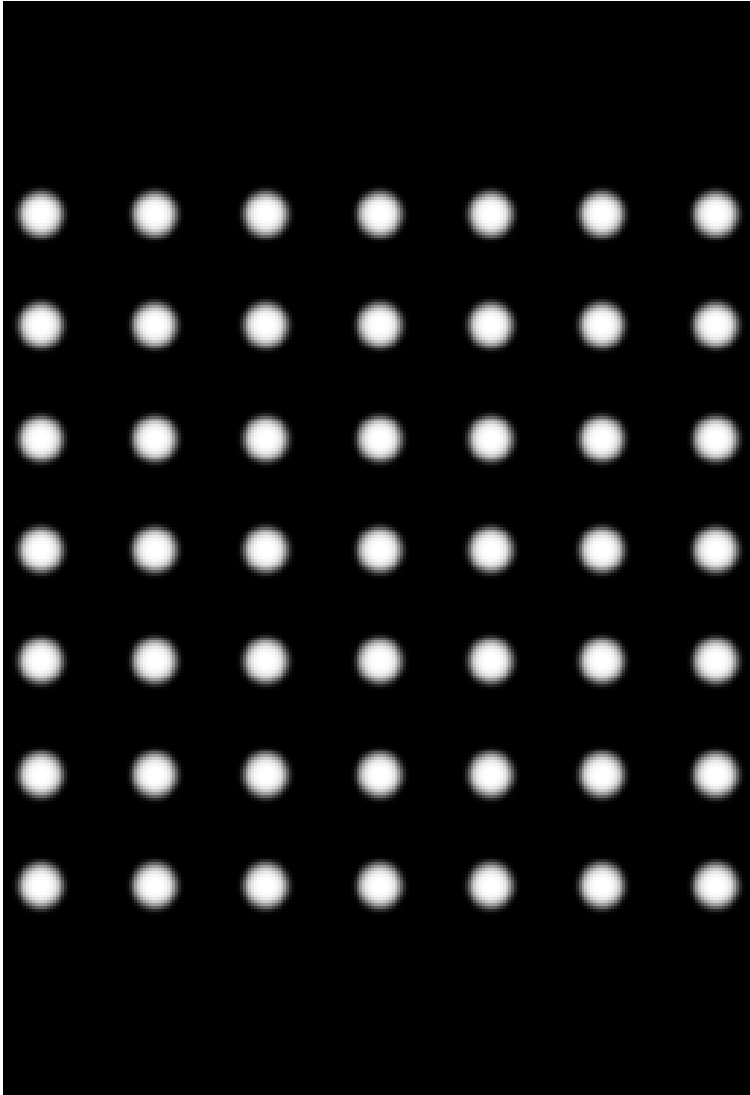
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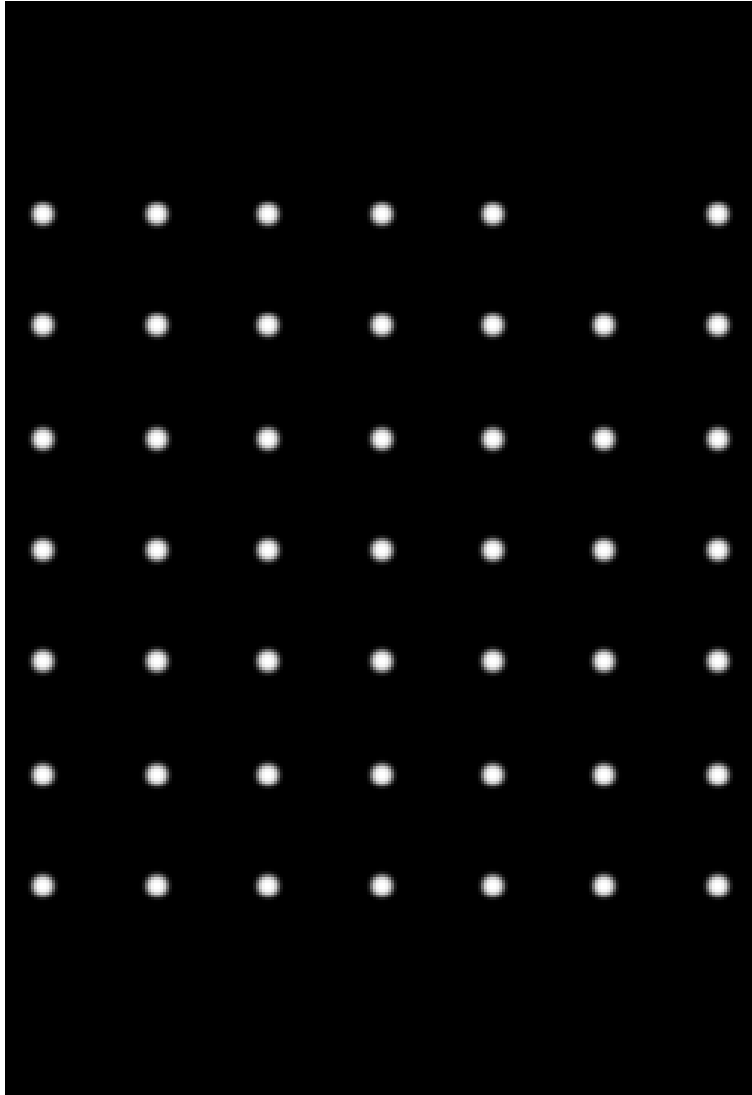
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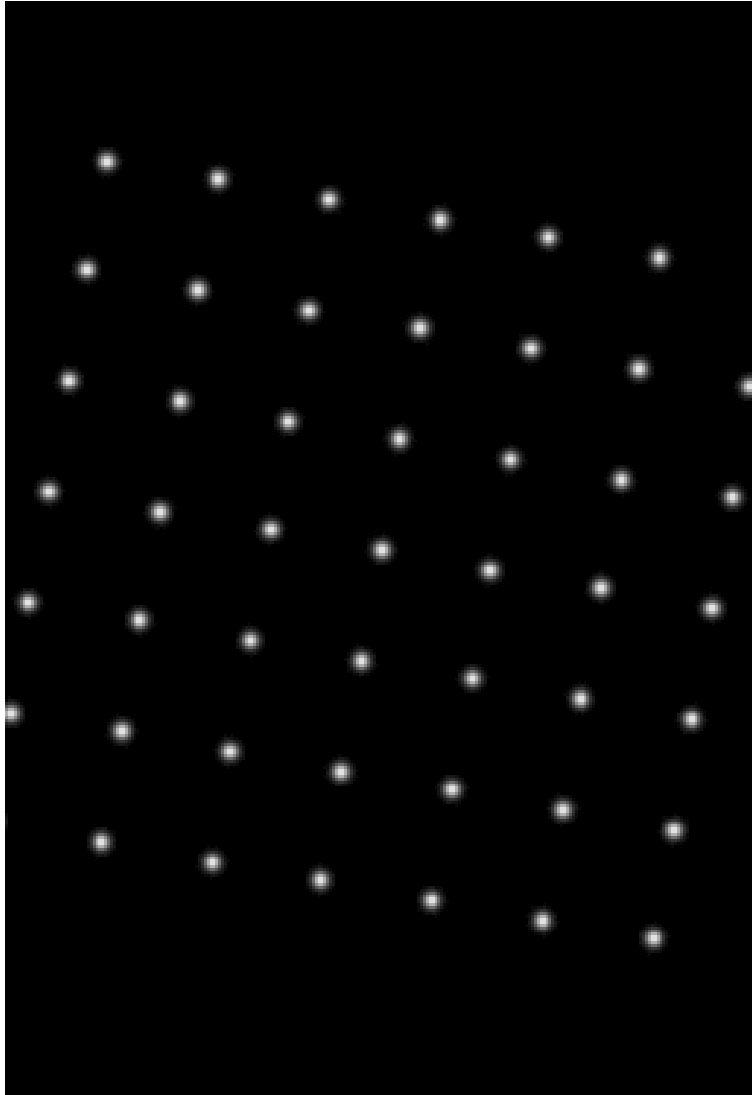
IFS : Micro-lens array (2)



Uniform light on the array

- focus of the light in small spots

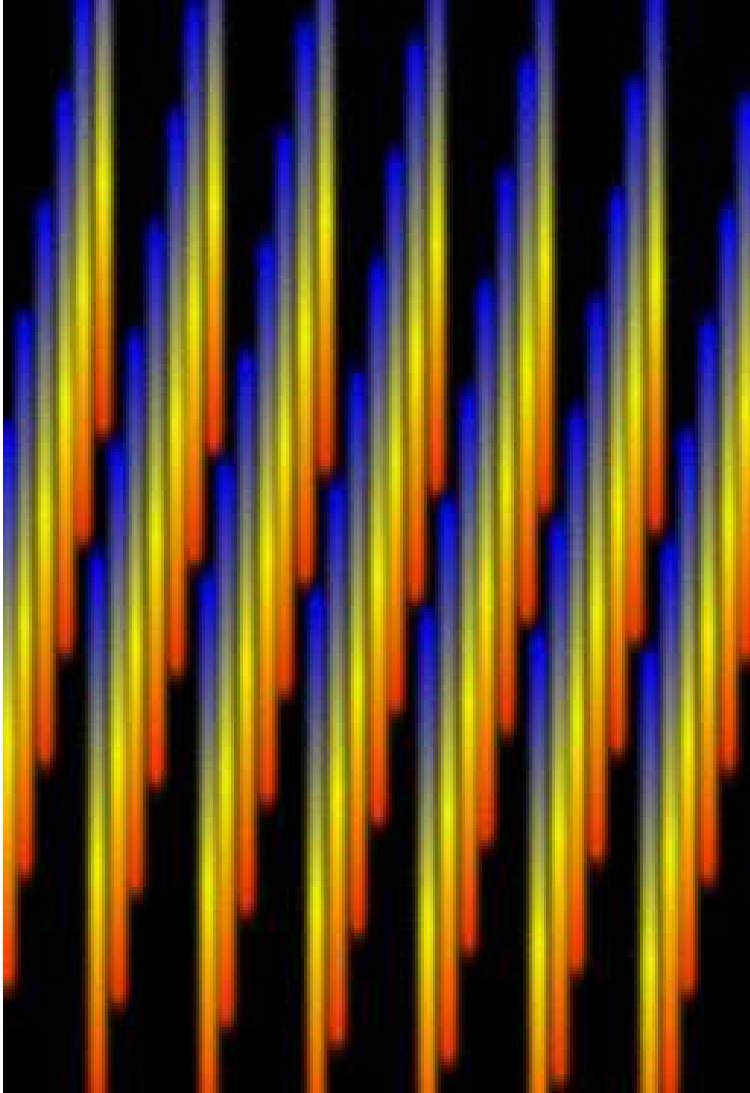
IFS : Micro-lens array (2)



Uniform light on the array

- focus of the light in small spots
- μ -lens array and grism are rotated

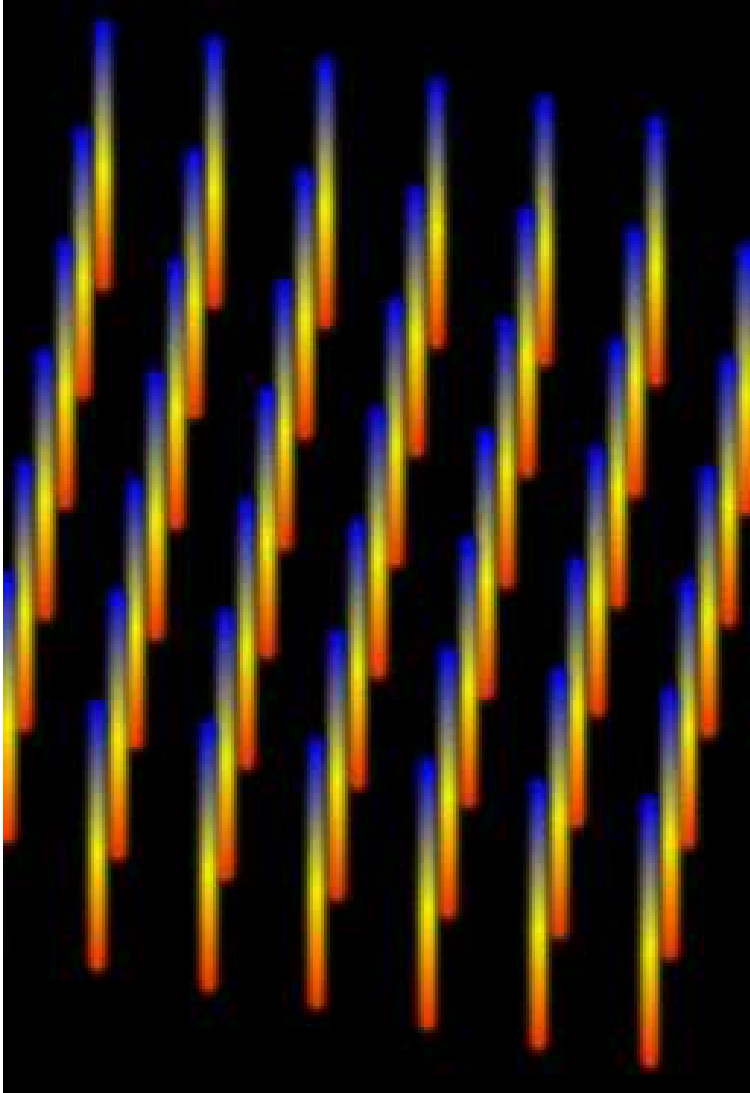
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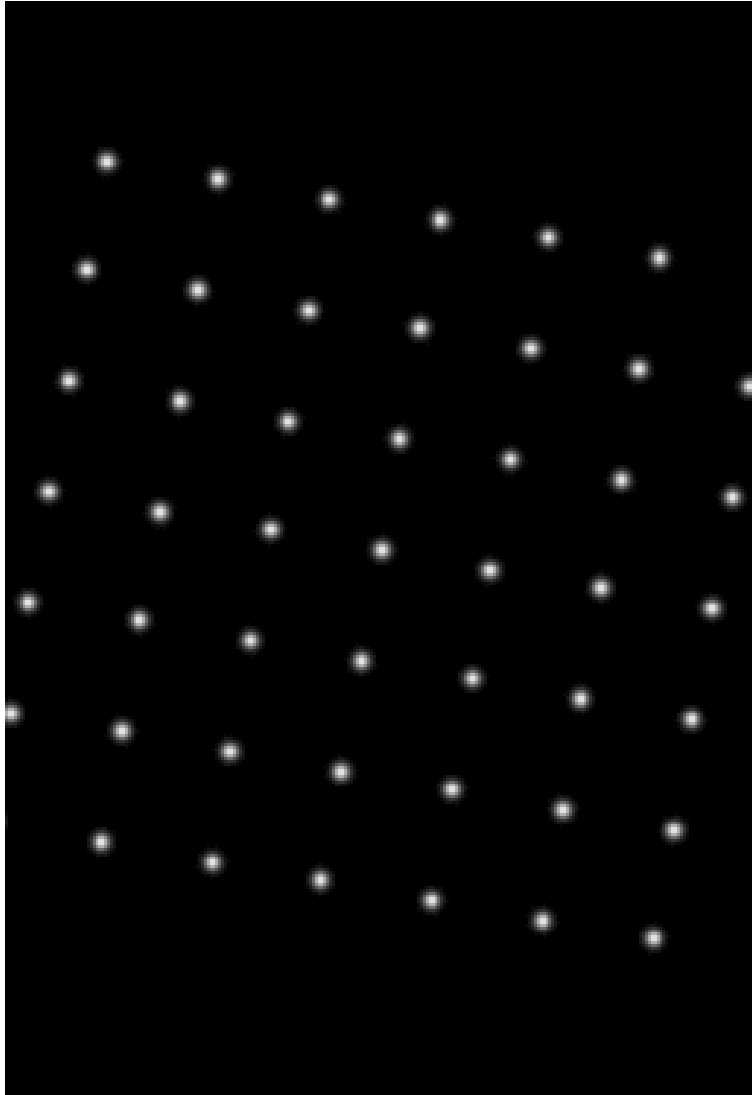
IFS : Micro-lens array (2)



Uniform light on the array

- focus of the light in small spots
- μ -lens array and grism are rotated
- filter can be added to avoid spectra overlap

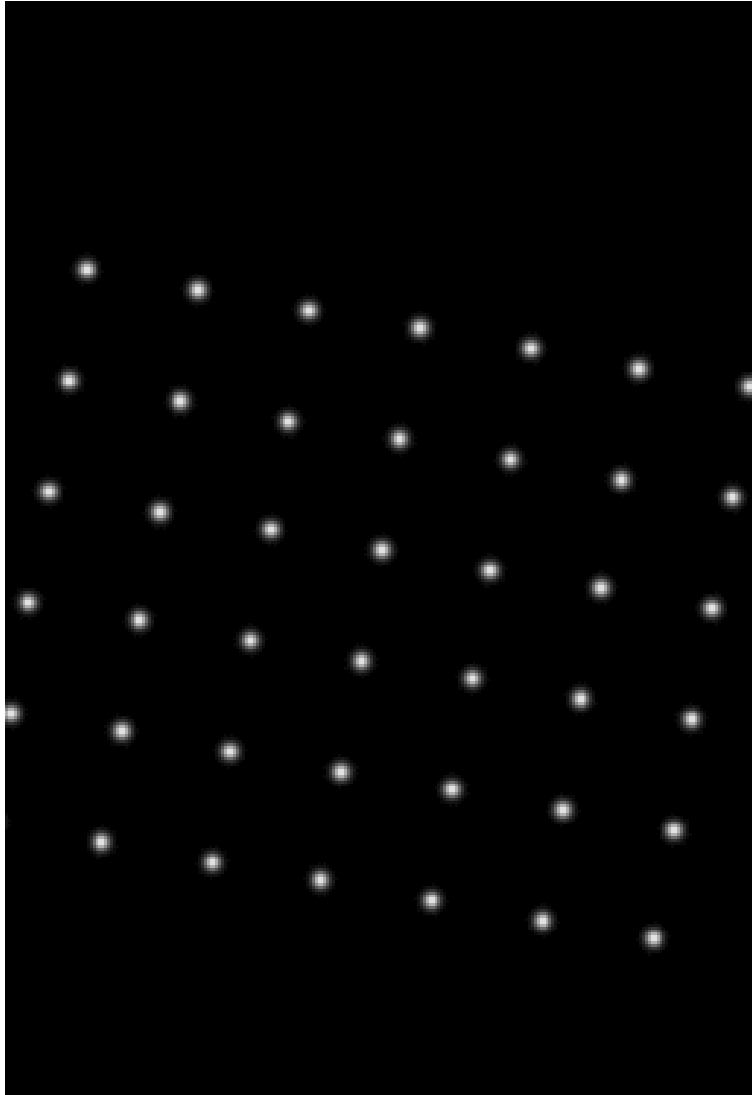
IFS : Micro-lens array (2)



Uniform light on the array

- focus of the light in small spots
- μ -lens array and grism are rotated
- filter can be added to avoid spectra overlap
- or the number of raw reduced to increase the spectral coverage

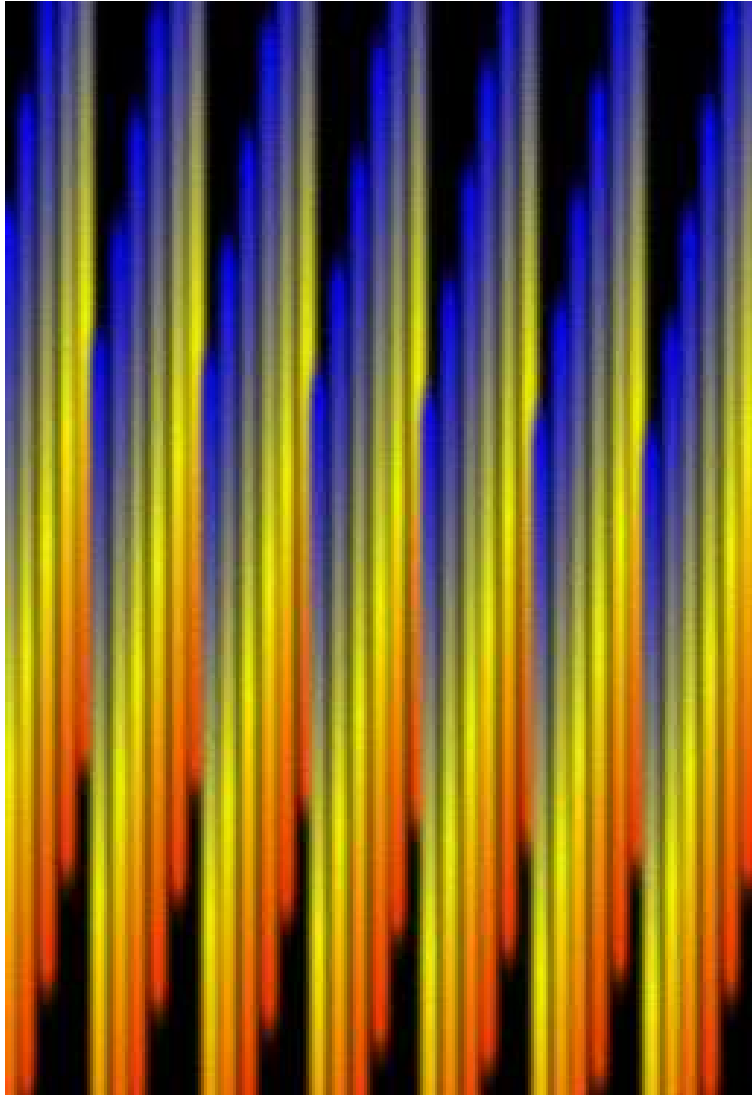
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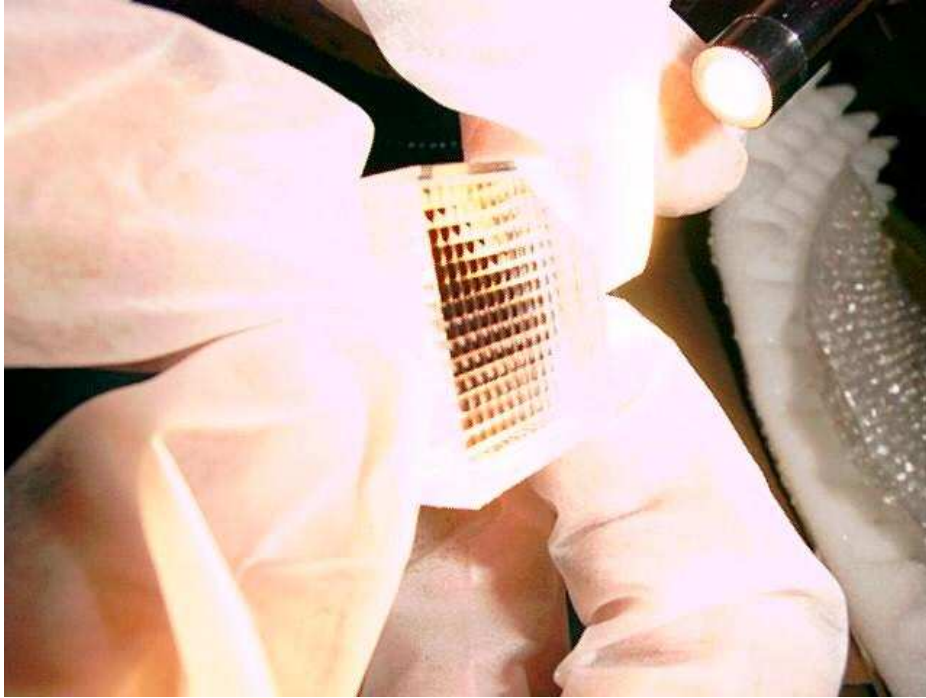
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Uniform light on the array

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IFS : μ -lens array (3)

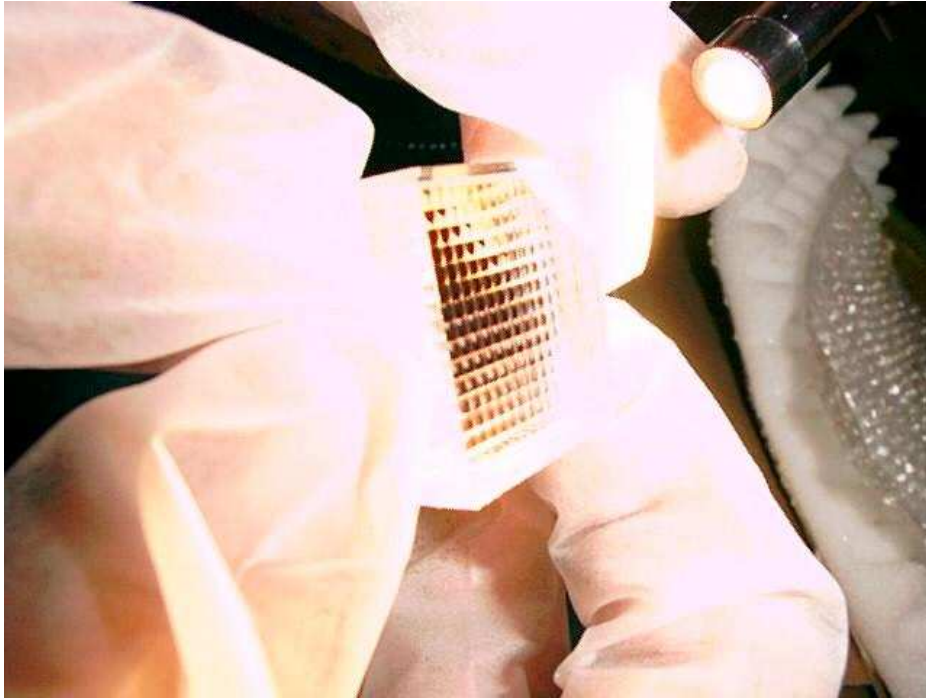


SNIFS (on UH)
 μ -lens array
15x15 lenses , 6"x6"
1 lens = 1.5 mm

raw SNIFS exposure



IFS : μ -lens array (3)

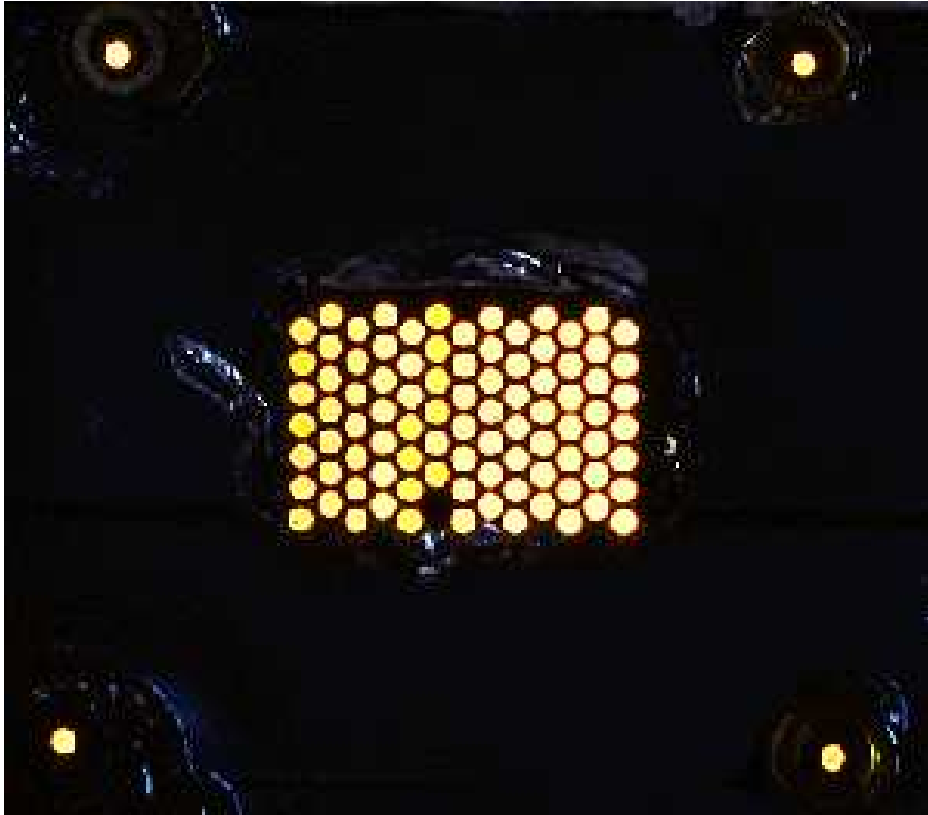


SNIFS (on UH)
 μ -lens array
15x15 lenses , 6"x6"
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μ -lens array :

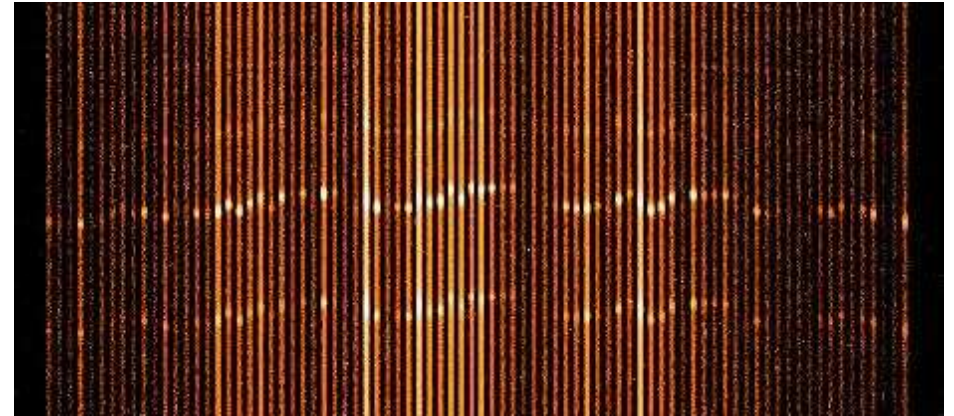
- contiguous **coverage** of a field
- no **spatial-spectro** mix
- **psf sampling** / “photometric” grade
- limited field/number of ***lenses***
- complex image ***reconstruction***

IFS : fibers

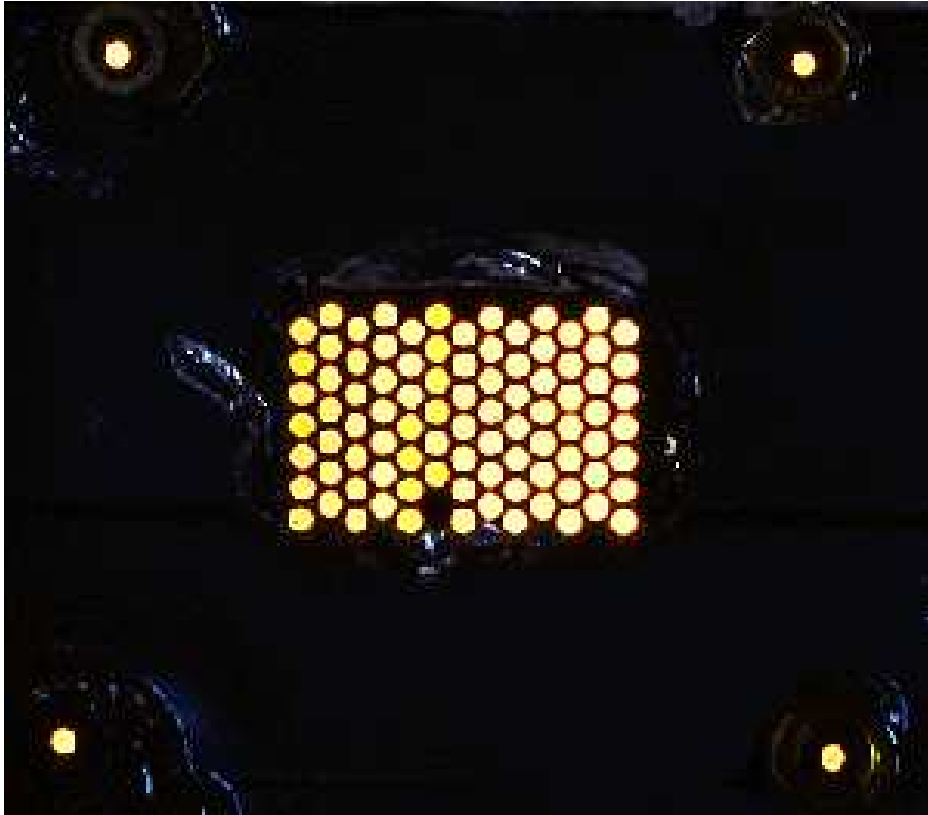


SparsePak (on WIYN)
IFS fibers end
(fibers for object + sky)

SparsePak raw exposure



75 (+ 7 sky) fibers , 80"x80"
1 fiber 500 micron

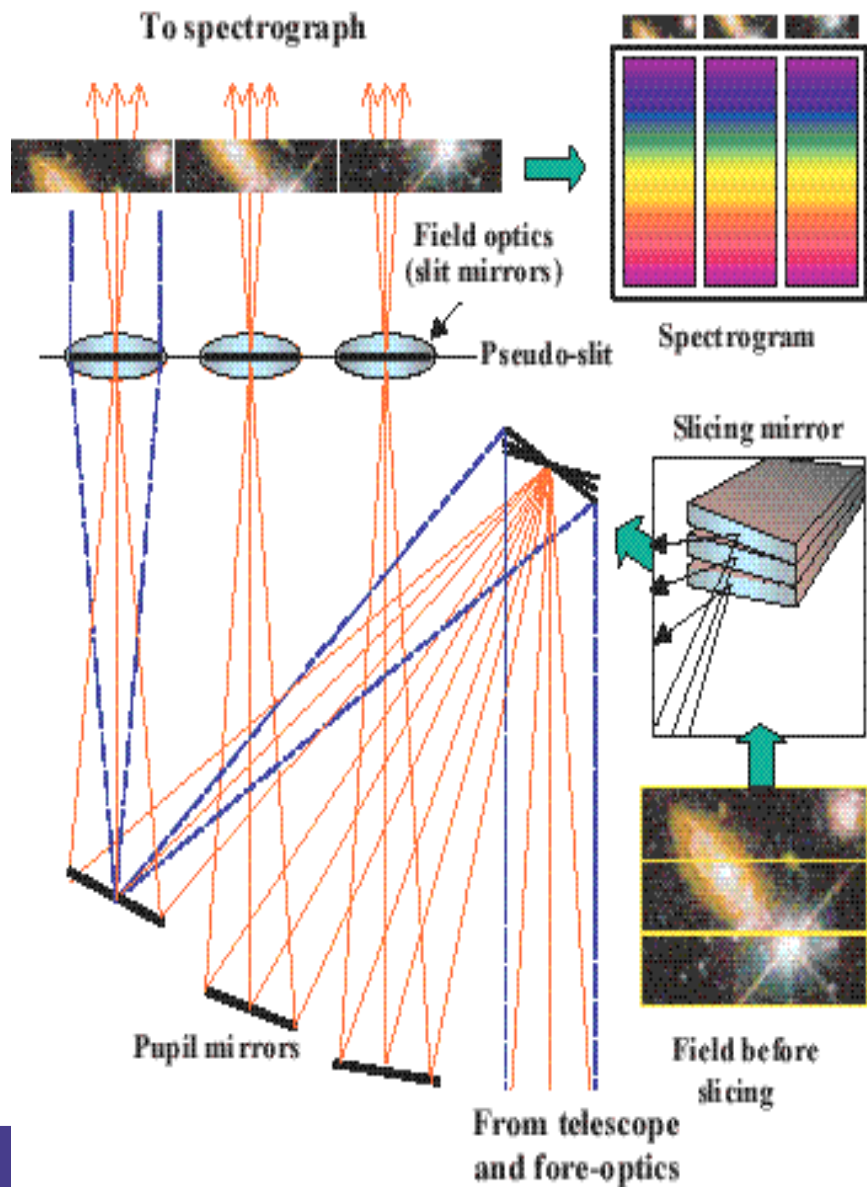


SparsePak (on WIYN)
IFS fibers end
(fibers for object + sky)

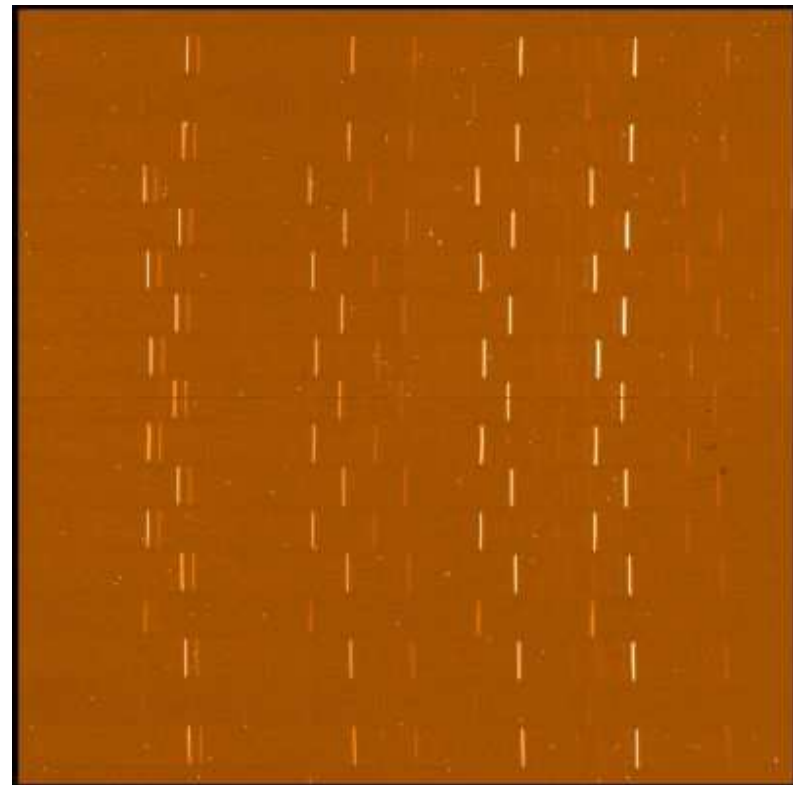
Fiber bundles :

- high freedom in **field mapping on ccd('s)**
- “easiest” IFU to **build**
- sampling of the sky ***not contiguous***
- ***not “photometric”*** grade
- issues in ***fiber - telescope interface***

IFS : slicer



UIST on UKIRT
raw exposure



21 slices, 5" x 5"

IFS : slicer

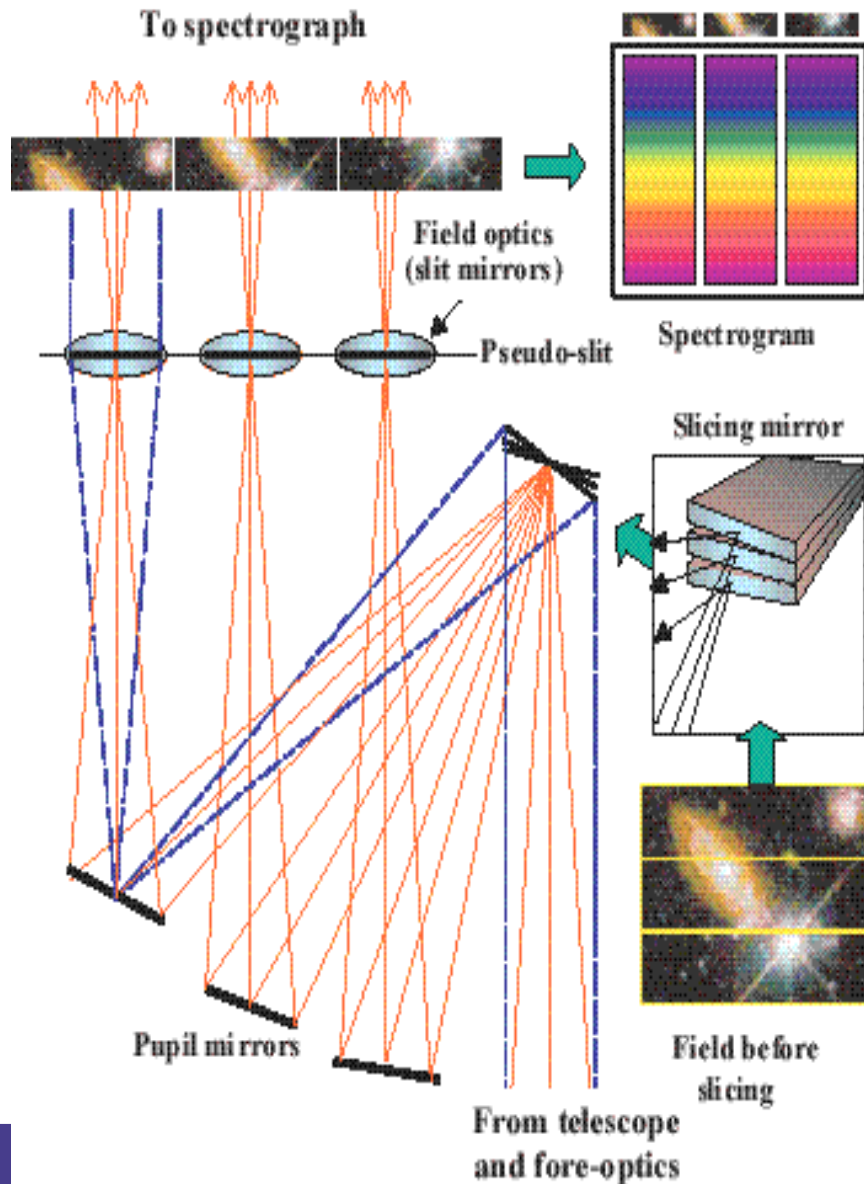


Image slicers :

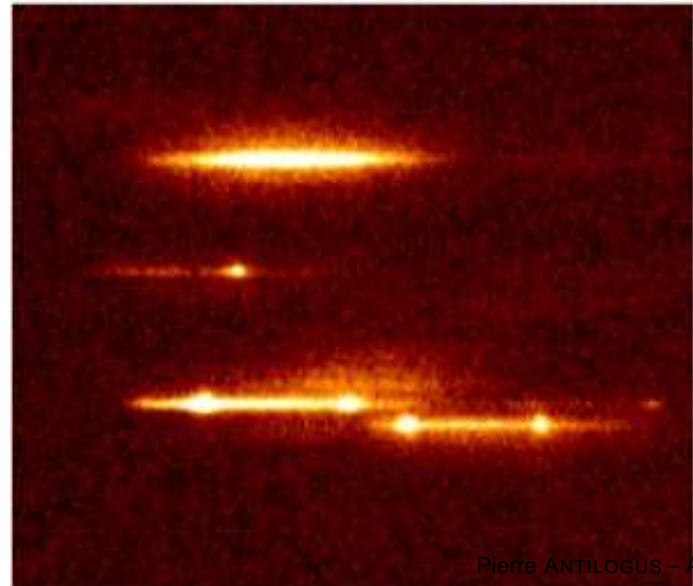
- uniform/contiguous coverage of a field
- psf sampling / “photometric” grade
- **limited field** (...but solution MUSE)
- difficult device to **build**

IFS : 1 extra solution for space

HST ACS instrument :
raw **grism slitless** mode.



Point source target :
clear 0th, 1st, 2nd orders



IFS : 1 extra solution for space

HST ACS instrument :
raw **grism slitless** mode.



Point source target :
clear 0th, 1st, 2nd orders

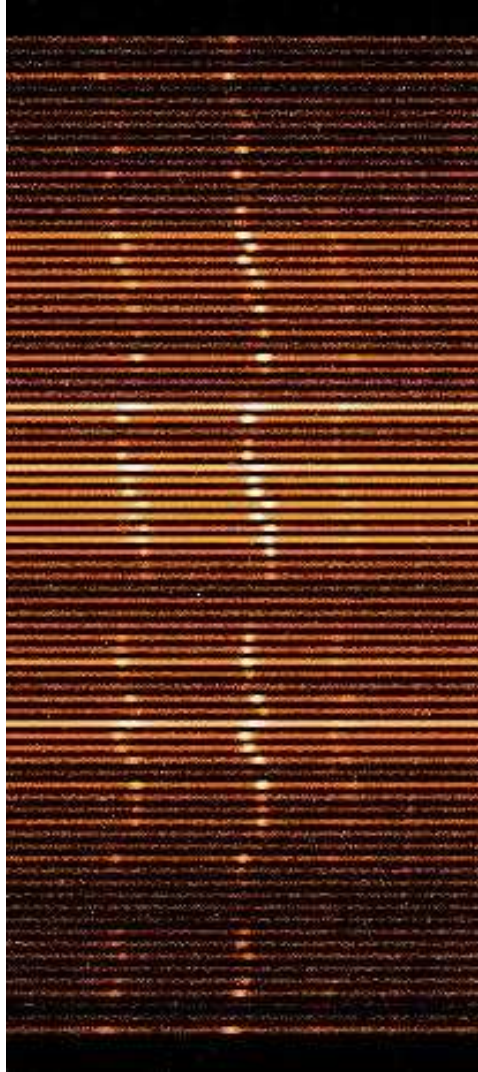
- **simple** and high throughput
- **sky subtraction** (blue) issue
- **resolution + isolation** issues
- ... **but so simple**

IFS : summary

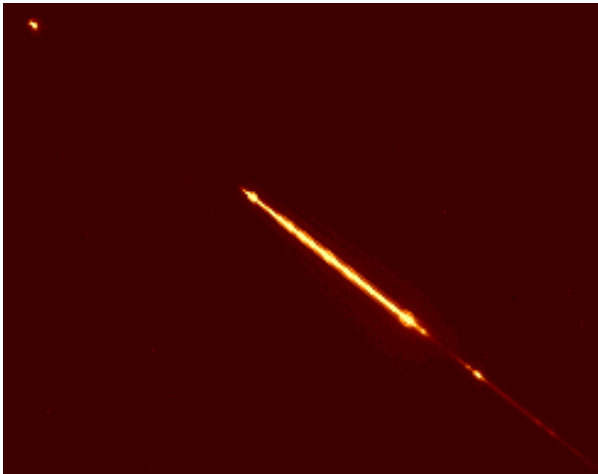
μ -lens array



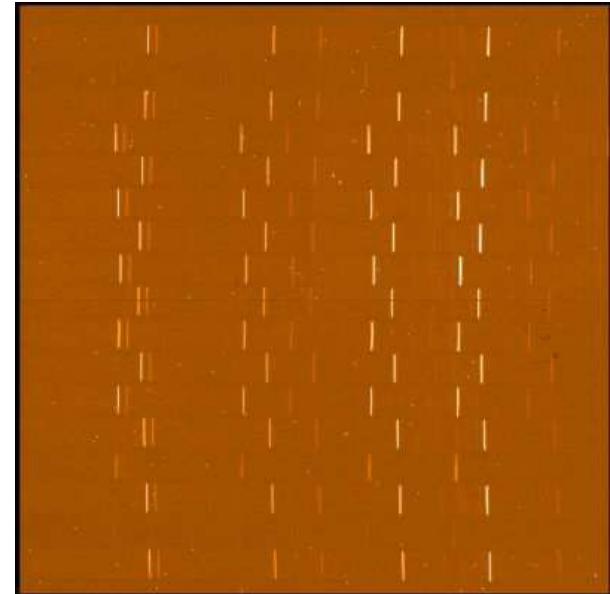
lens+fibers



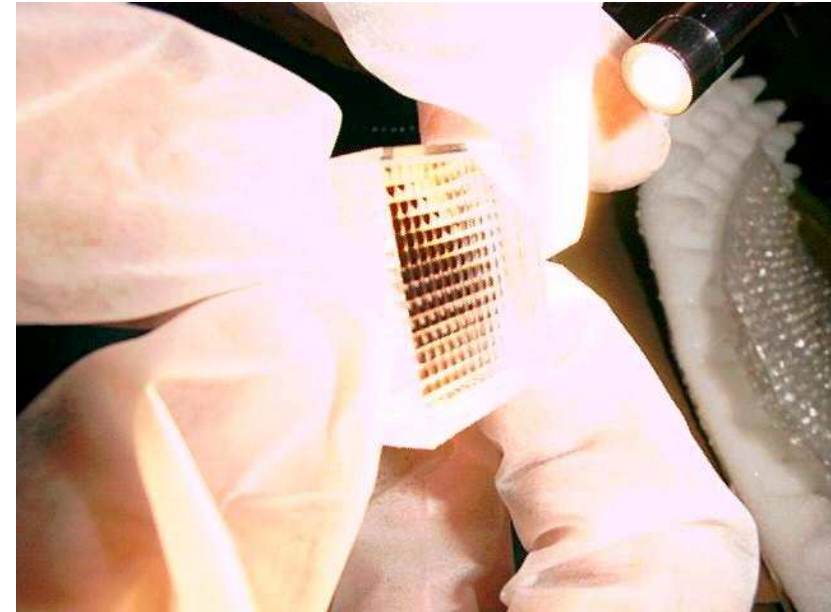
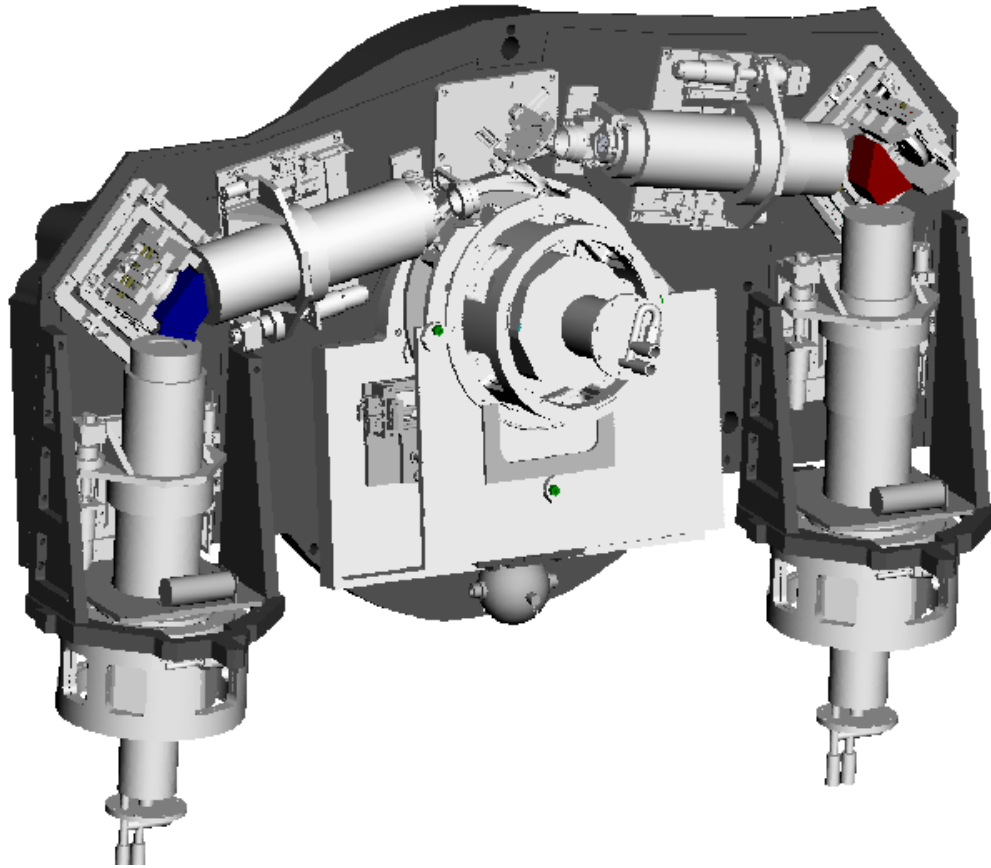
Slitless grism



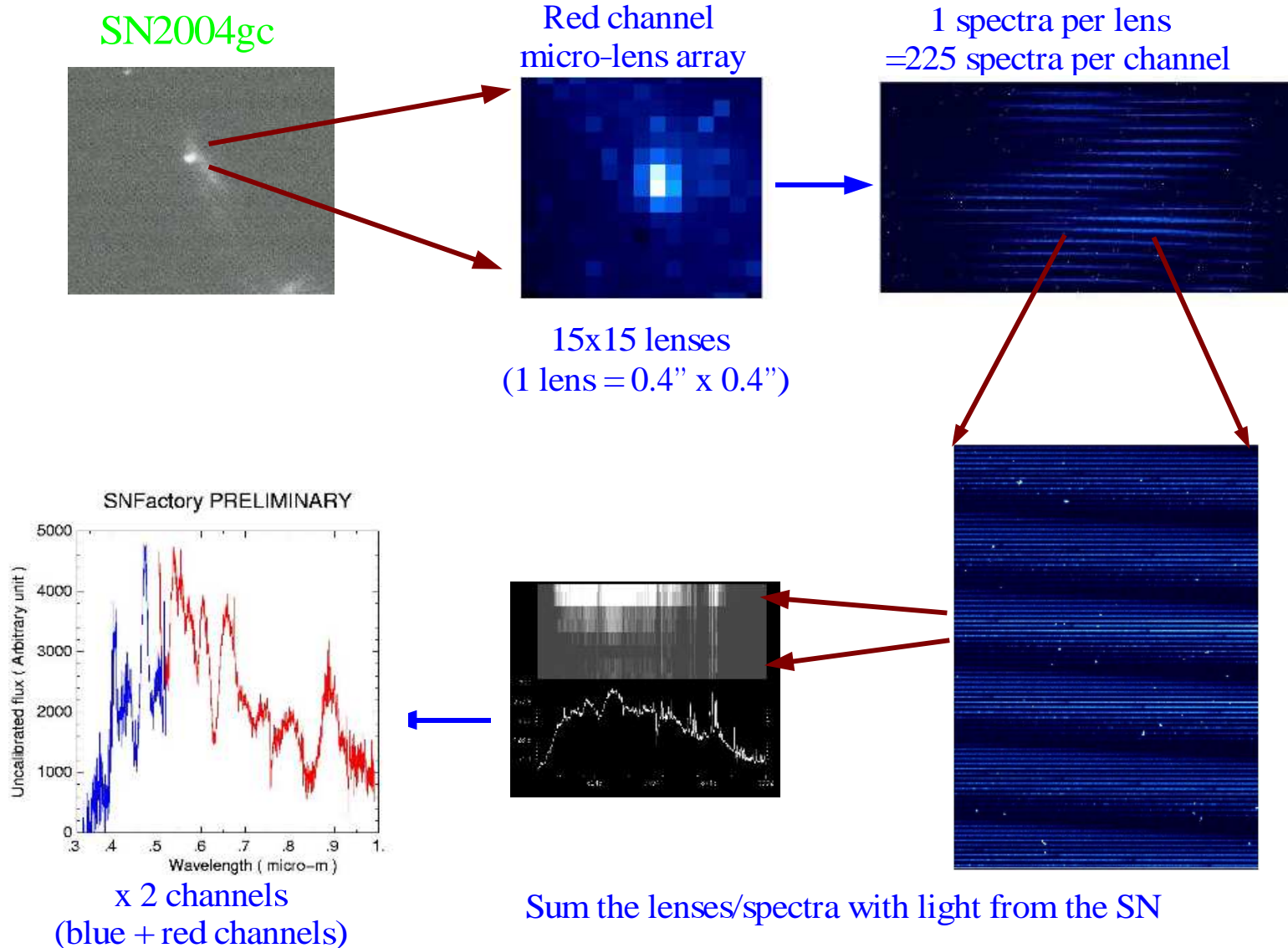
slicer



SN Ia exposure : SNIFS example (1)



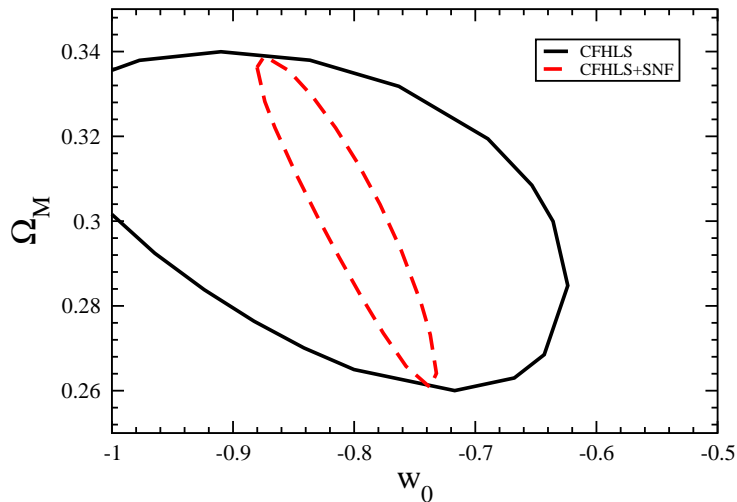
SN Ia exposure : SNIFS example (2)



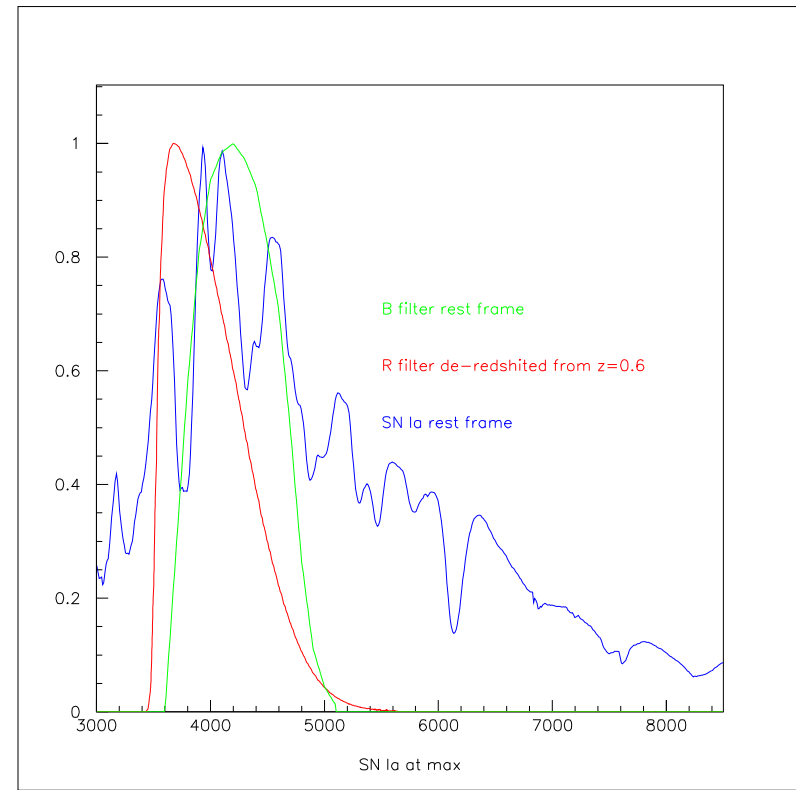
IFS for SN : Why ? Why not ?

Photometry of SN : spectra issue

SN in cosmology :
compare SN flux for the same spectra rest frame at
different $z \rightarrow$ K corrections

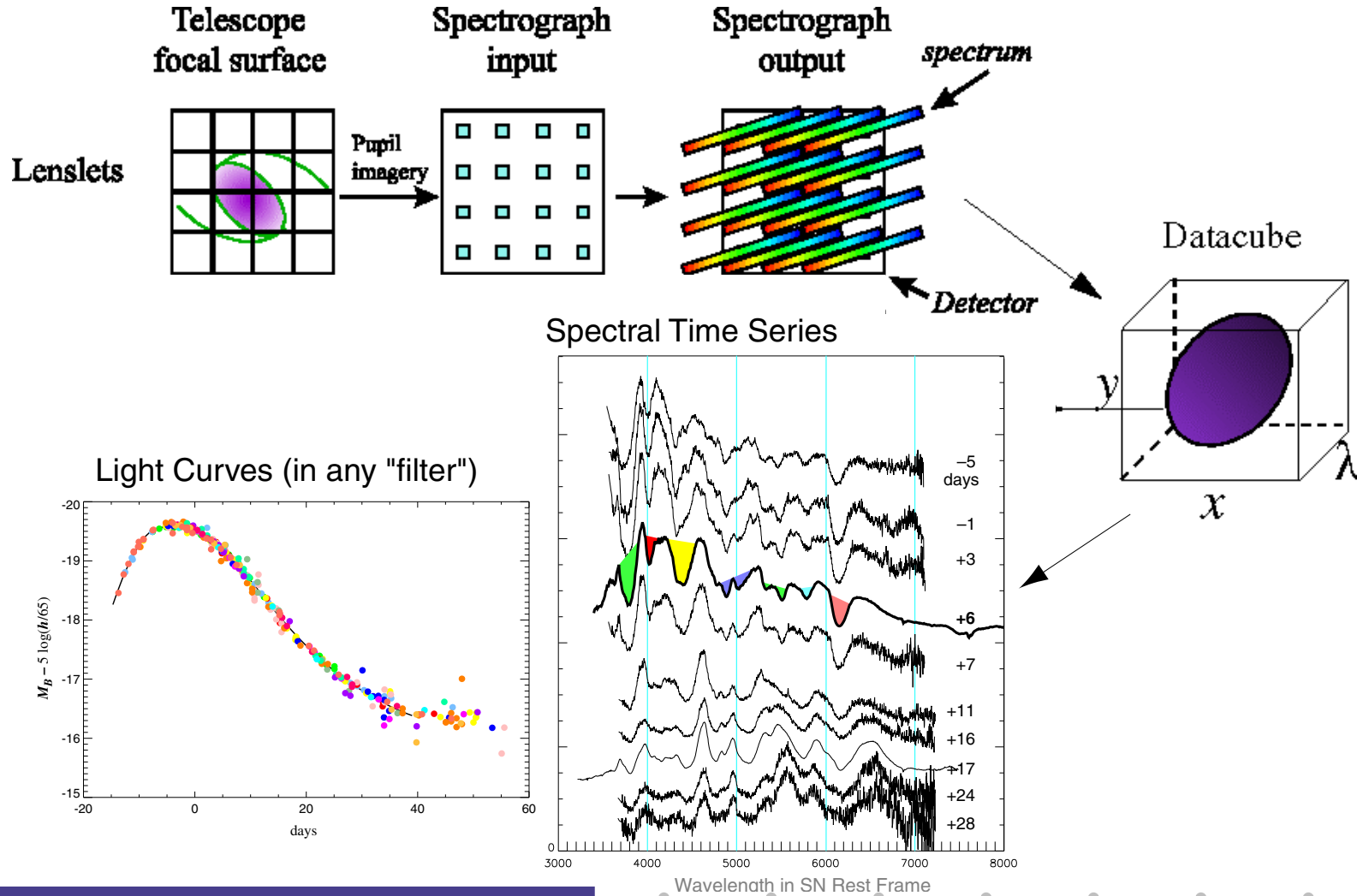


prior $\Omega_M = 0.28 \pm 0.03$

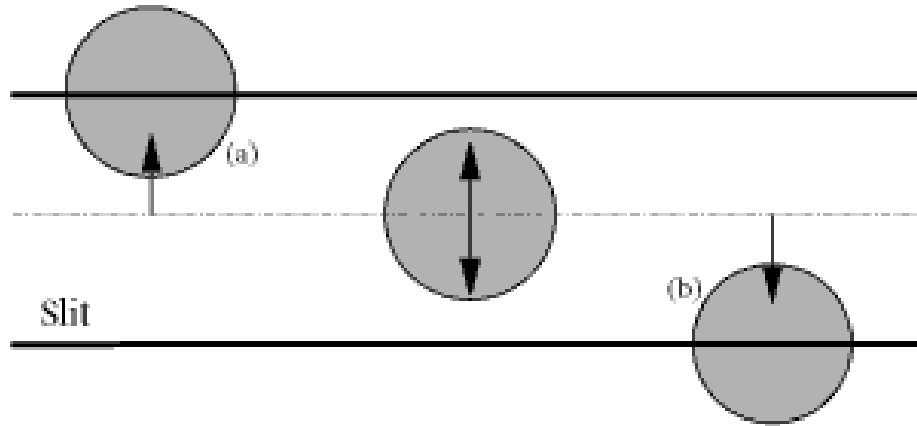


SNFactory spectro-photometry goal

"Integral Field Unit" Spectrograph



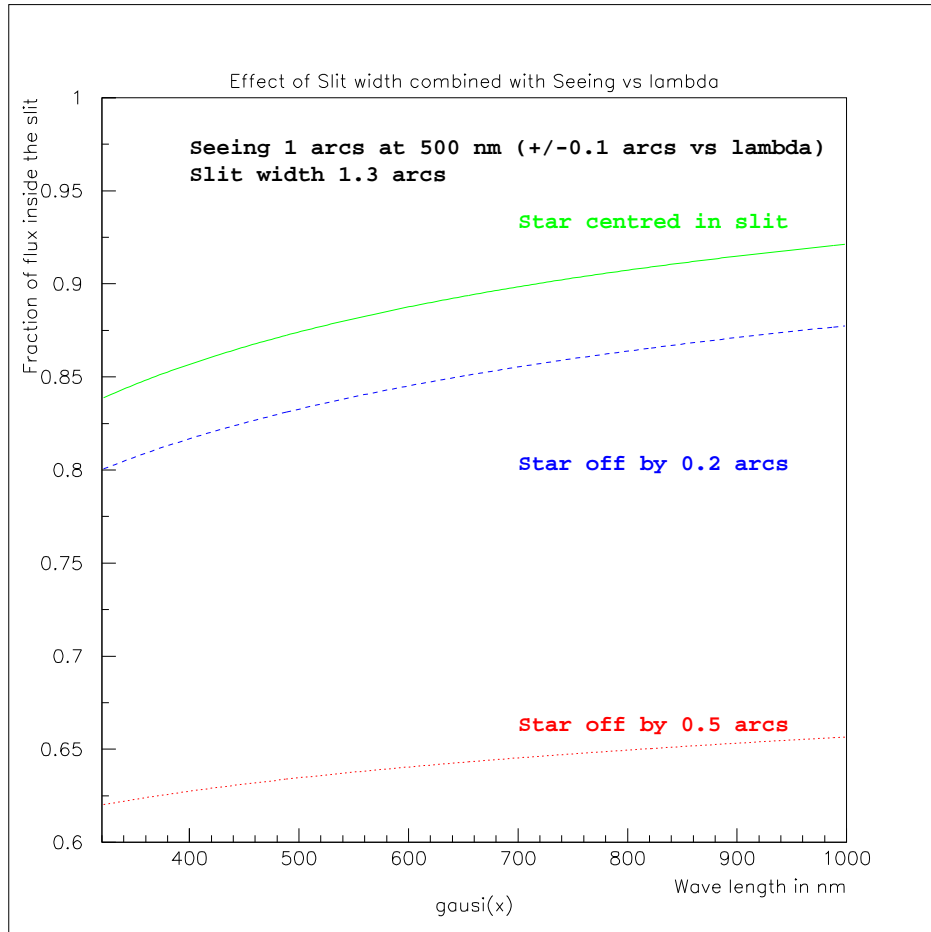
Slit width and spectra shift



Mix of spectral-spatial information:

- the width of the slit directly contribute to the **wavelength resolution**
- un-centered non uniform target will end-up to an overall **shift** of its spectra.

Slit transmission



- no way to do photometry with a slit
- no precisely relative flux over a “large” wavelength range (Seeing $\sim \lambda^{-0.2}$)

Slit setup

The listed slit issues, imply a **precise acquisition** of the target to have it well centered in the slit.

This is in general the dominant **overhead** to any spectra acquisition.

The ratio between the spectra exposure time to the acquisition time, can end to a quite **low efficiency**, in practice this can become killing for low z SN survey.

→ **IFS may** speed up the acquisition... and for sure **relax the required precision** on the target acquisition.

IFS : Spectro-Photometry (1)

Photometry requires **calibration** on standard .

This can only be done in photometric night, when the **atmospheric transparency** is constant over a “long” period of time.

For a SN light curve between -10Day→+20Day only a small fraction of the data will be taken in such condition ($\sim 20\%$)

The **stars around** the SN are used to inter-calibrate the exposures.

How to do that with IFS when only a small number (~ 1) of object(s) is seen ?

IFS : Spectro-Photometry (2)

To perform an optimum Photometry, you should know the **PSF** :

- this will give you the **best** out of **the collected signal**.
- give you a chance to **separate** the SN from the ***underlying galaxy***.

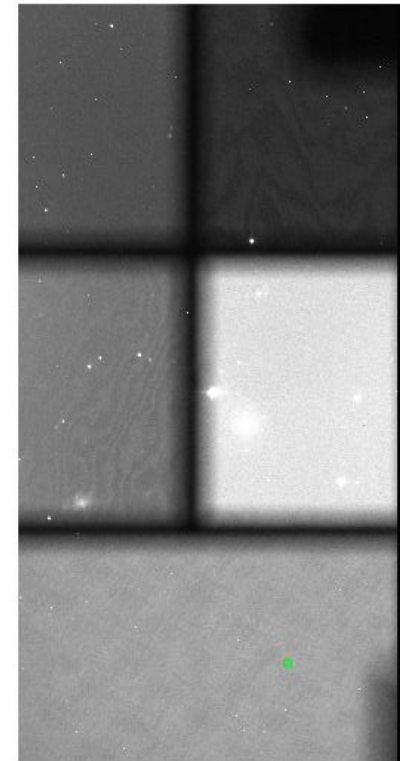
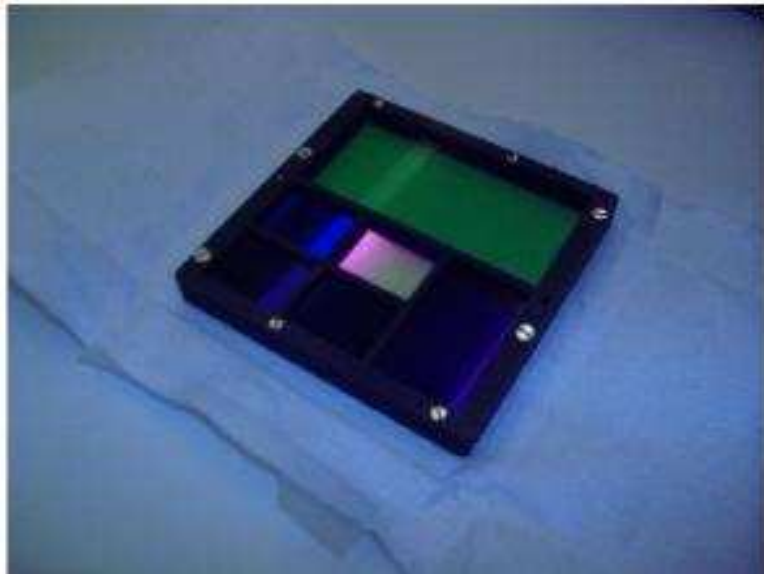
Here also, on a photometric exposure, the **stars around the SN** can be used to obtain a precise model of the **SN PSF**.

But how to do that with an IFS ?

IFS : Spectro-Photometry (3)

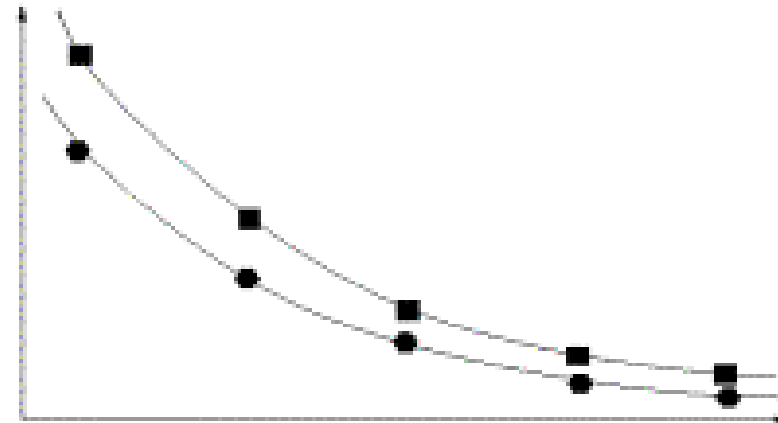
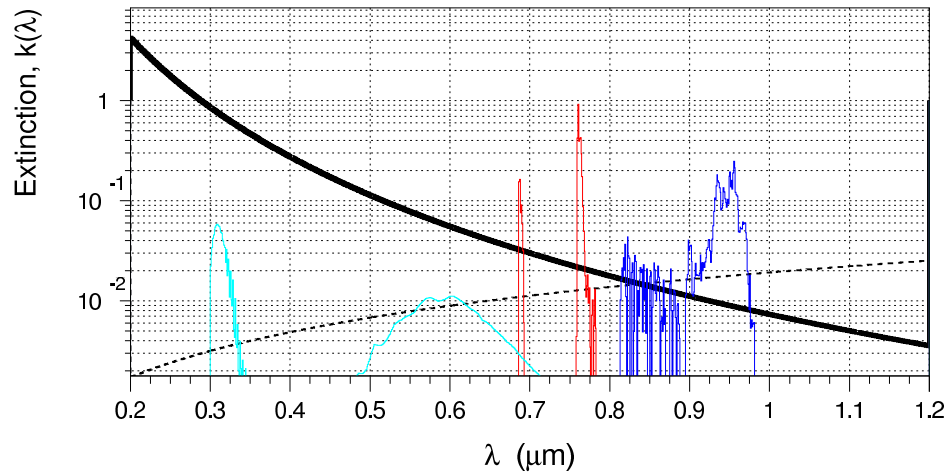
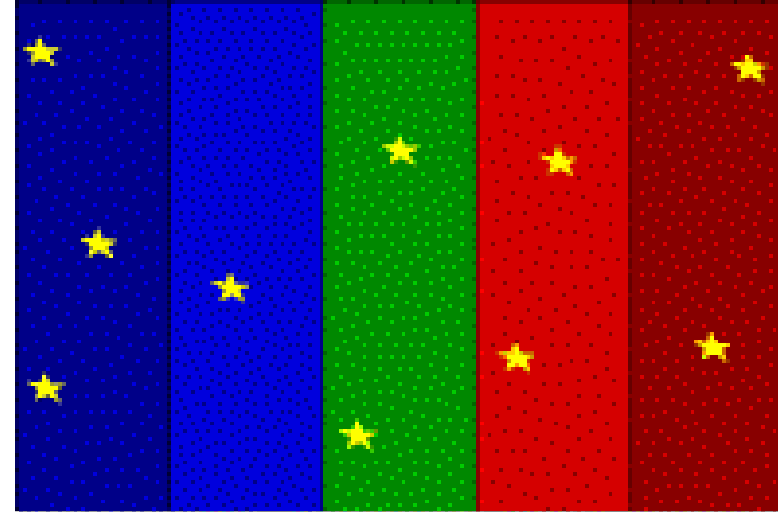
SNIFS proposed solution :

a photometric channel for atmospheric condition monitoring

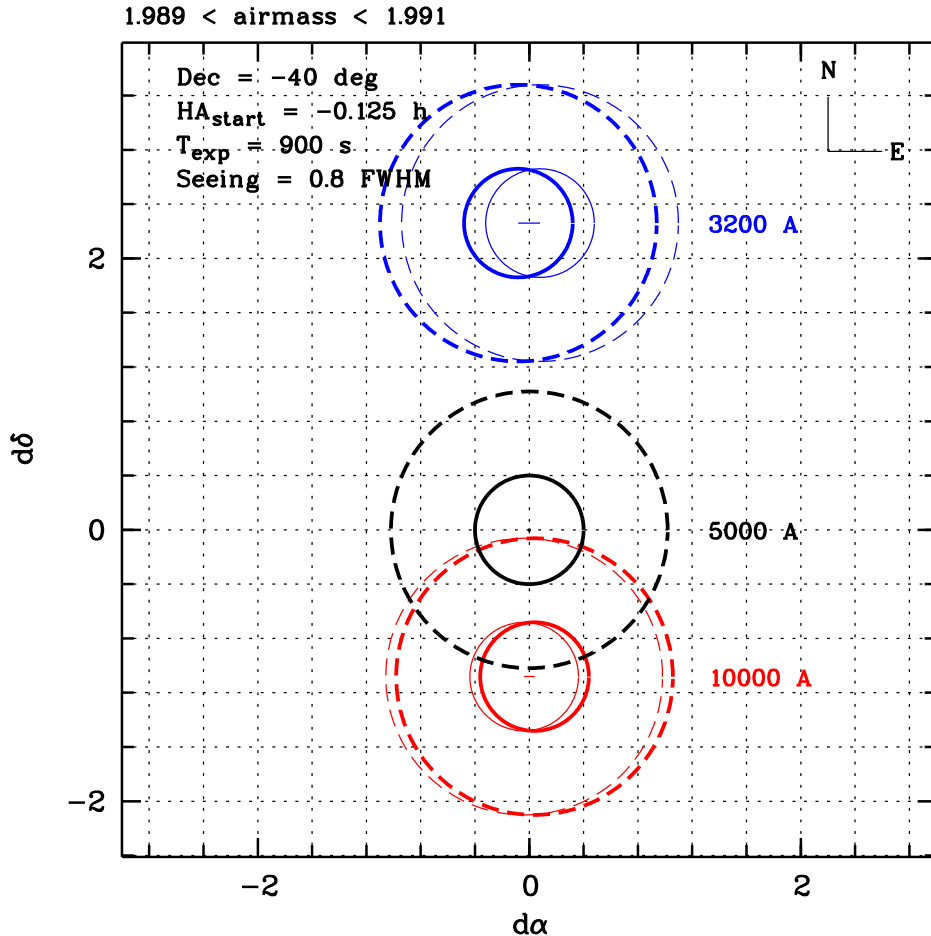


IFS : Spectro-Photometry (4)

The idea: With a "right" set of filters, you can monitor the flux of stars between different SN exposure and estimate the atmosphere changes.



Atmospheric refraction



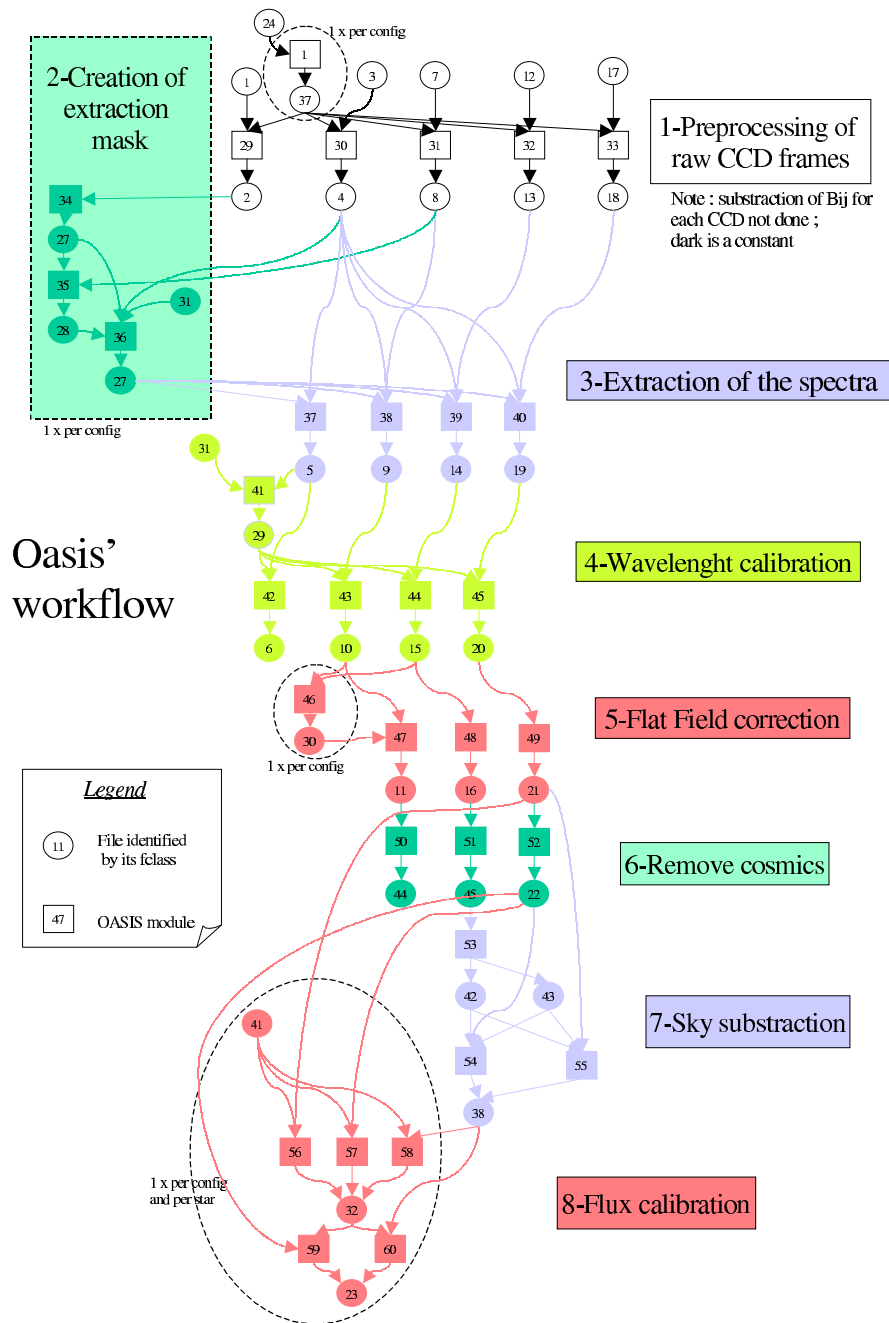
Atmospheric refraction :

- limit the **airmass** you can go down .
- good model of the refraction effect for the SN **extraction**.

IFS data reduction

The text in this section is mainly based on
Y.Copin (IPN-Lyon)
documents on the SNIFS data reduction software

IFS data reduction : work flow



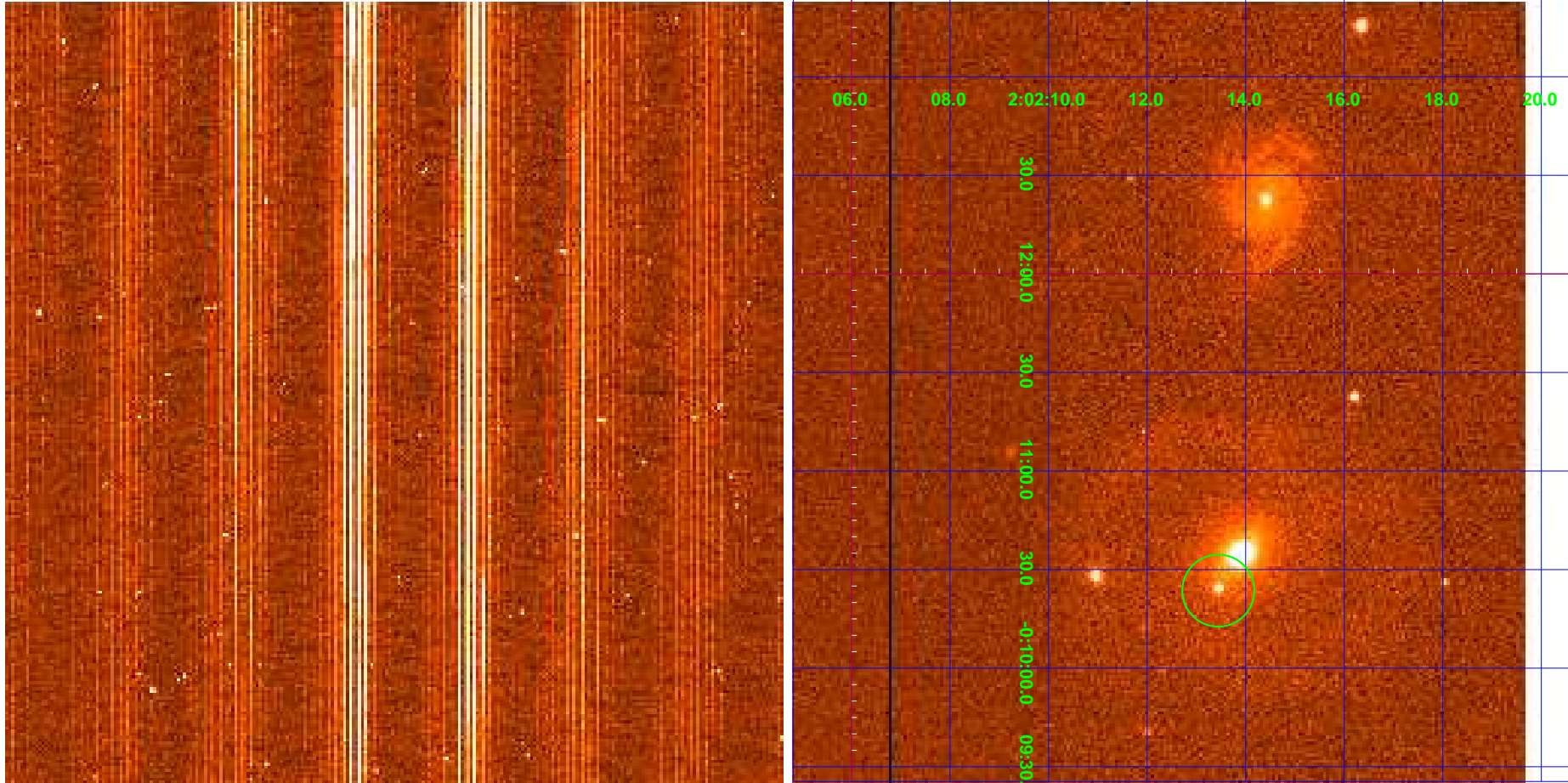
IFS and slit spectra data reduction are **comparable**, except for :

- the **extraction/location of the spectra** on the CCD prior to any further step in the data reduction.
- flat field.**
- the **object extraction** itself is closer to photometry technique.

IFS data reduction : exposures

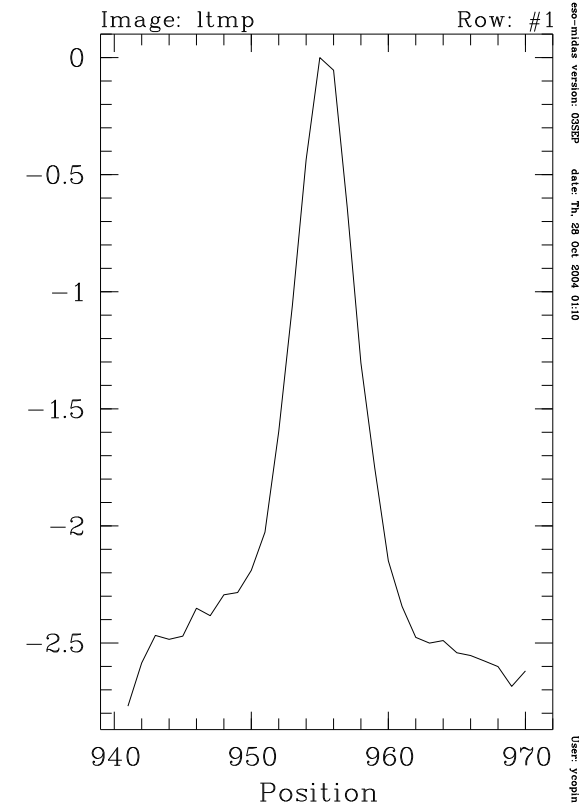
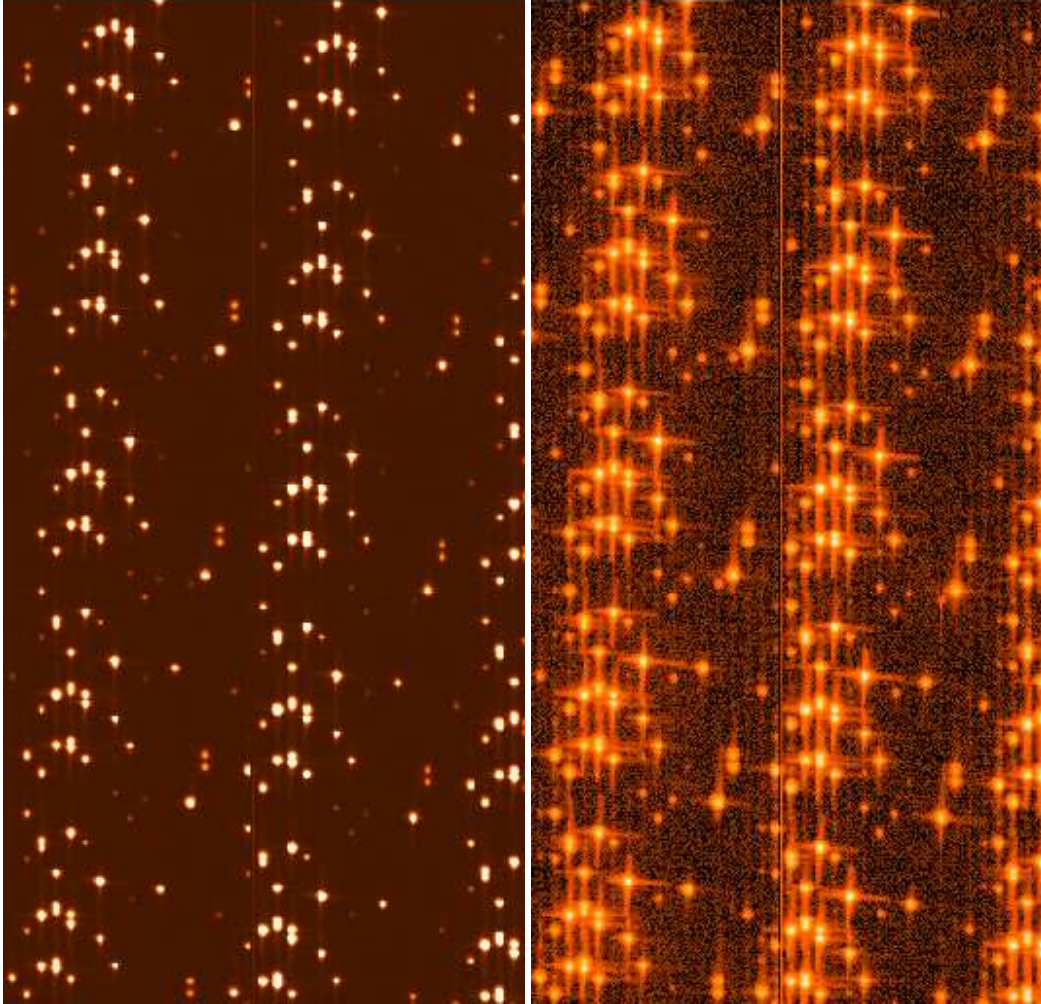
- Object exposures
- Arc exposures
 1. once in a while for mask extraction
 2. for each object to correct for flexure
- Continuum exposures
 1. once in a while for mask extraction
 2. once a night for HF and LF flat

Object exposure



SN2004dt, Sept. 06, 2004 (R+P_V)

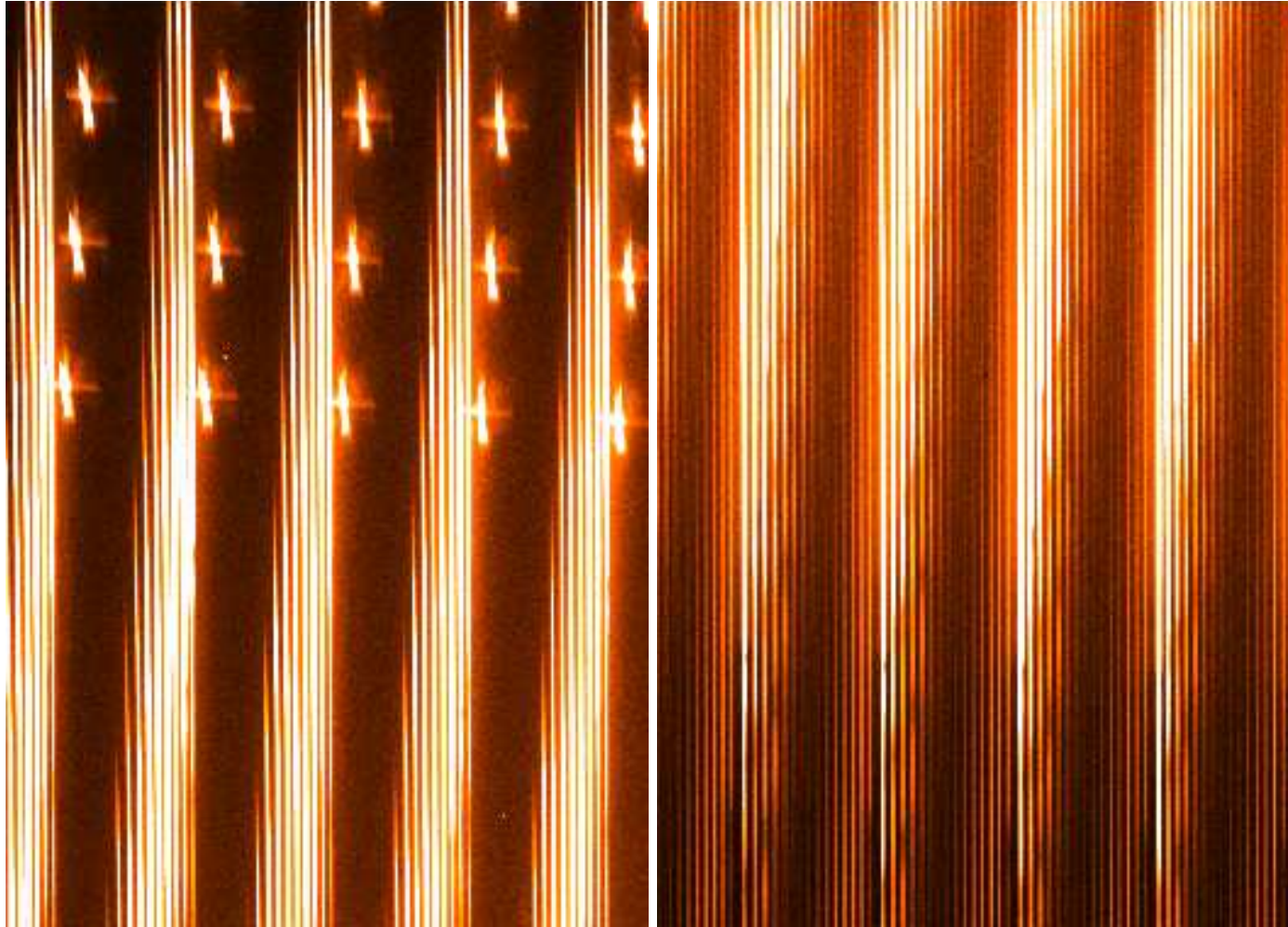
Arc exposure



1st-order
Low cross-talks

Red arc (Hg + Cd + Ar)

Continuum exposure



0th-orders

Blue continuum

2nd-orders

IFS Data reduction : Goal

- Deliver a **Flux**(x, y, λ)-datacube (x, y = lens id) from the $I(i, j)$ on the CCD (i, j = pixel id)
SNIFS :
 - 15×15 spectra, 3200-6000 + 5000-10000 Å
 - Collected on 2 CCD 2kx4k (one per channel)
- Remove the spectrograph **instrumental signature**

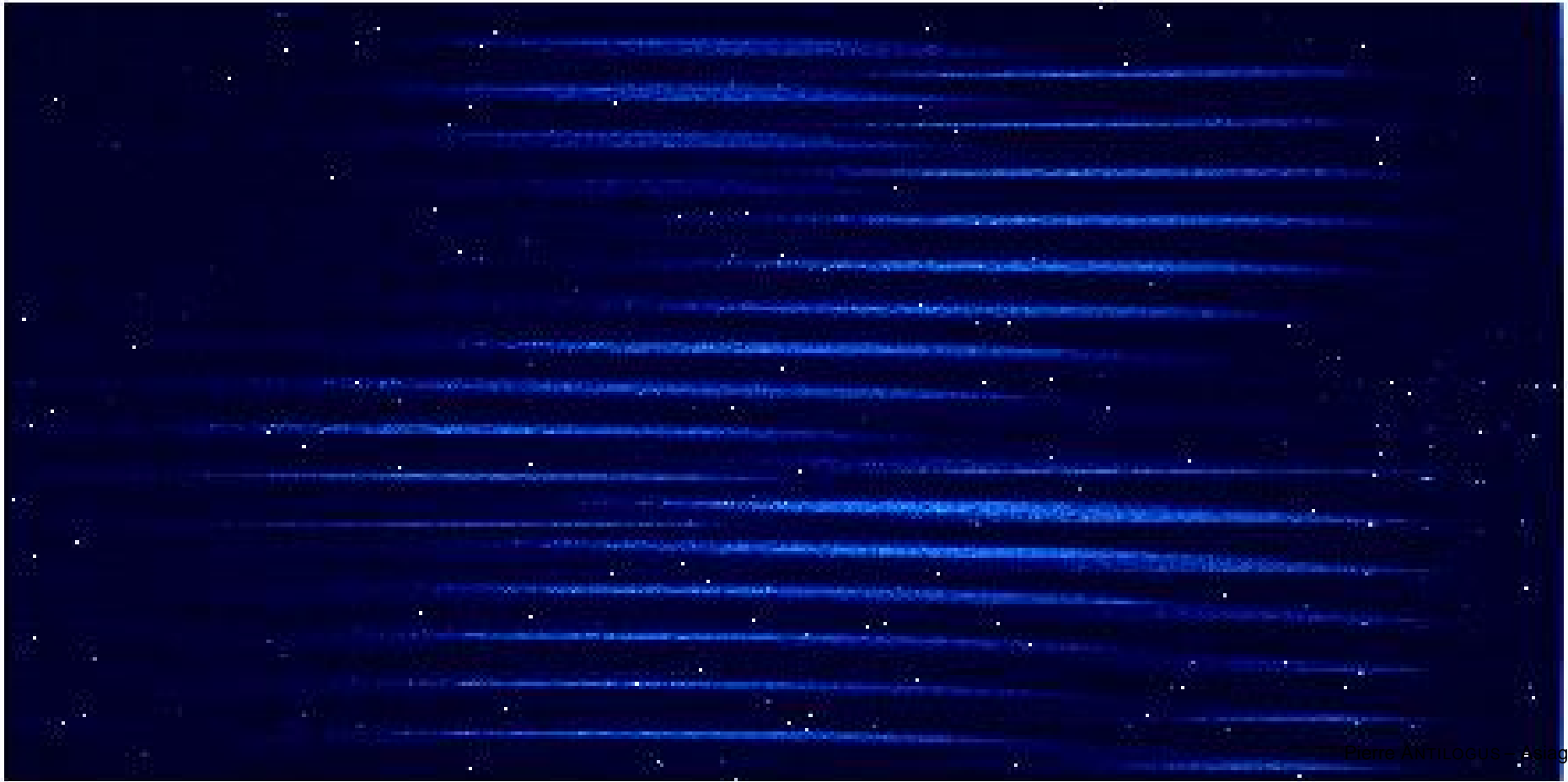
IFS Data reduction : Tools

- C-code, based upon the IFU-libs developed in Lyon
- Spectral processing:
 - **IFS-specific** (x, y, λ) cube extraction
 - 1st step: compute the extraction “mask”
 - 2nd step: extract the signal
 - **Standard** spectral calibration
 - λ -calibration
 - Spectro-spatial flat-field (LFFF \neq HFFF)
 - Cosmics cleaning
 - *Sky (+background) subtraction* (external)
 - *Flux calibration* (external)
 - **Variance** spectrum propagation

Cube extraction / extraction mask (1)

Optical model :

Goal \Rightarrow found+associate each spectra to a μ -lens

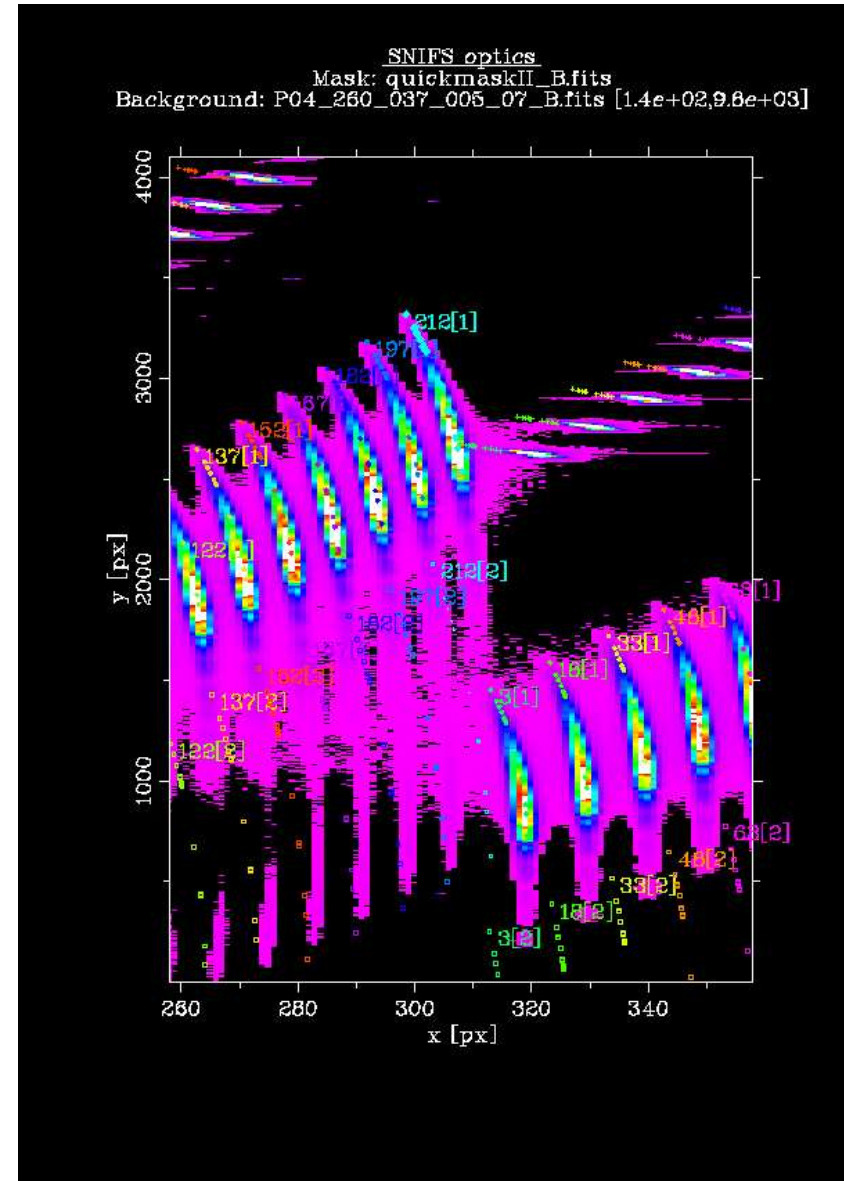
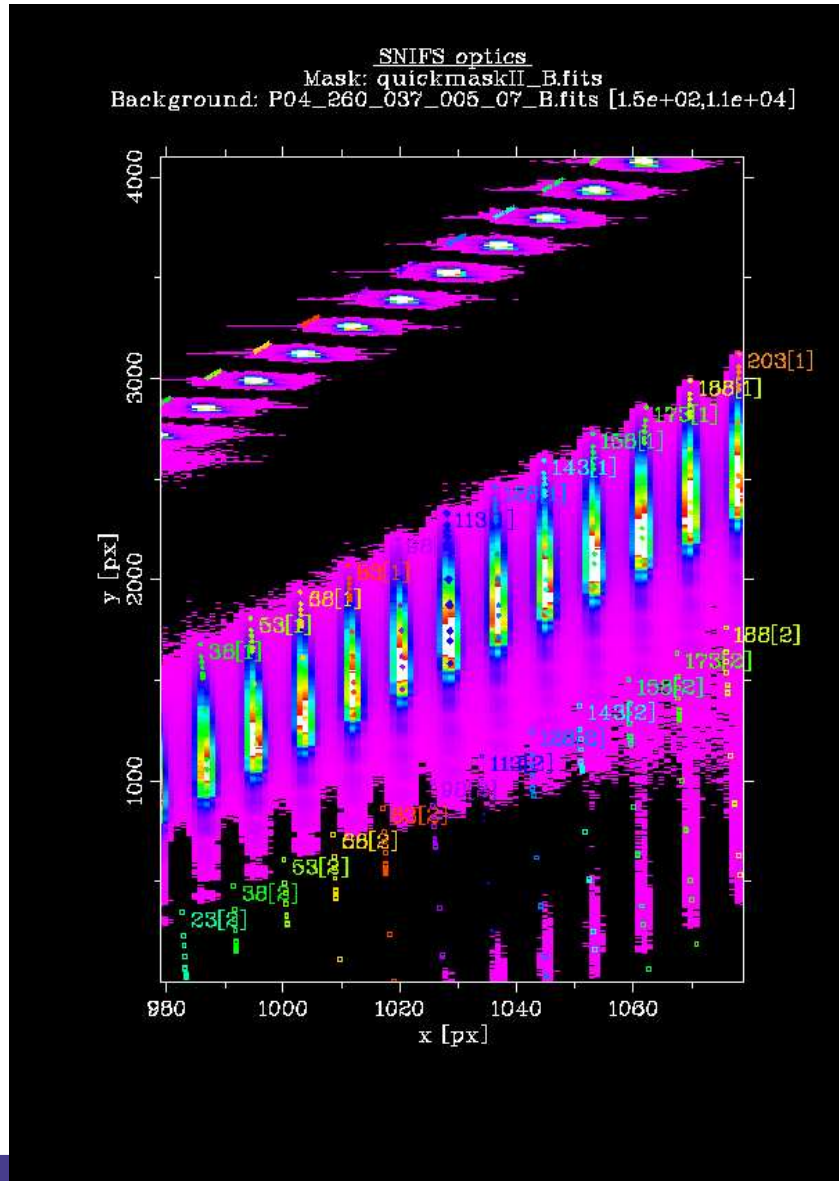


Cube extraction / extraction mask (1)

Optical model :

- $I(i, j)_{ccd} \leftrightarrow F(x, y)_{\mu-lens}$
- based on (Collimator + Grism + Camera)
- 10 **physical** parameters (focals & dist. parameters, center of dist., grism angles)
- Model simultaneously adjusted on 1st-order **continuum crests** (spectra positions) and associated **arc** (λ)
 1. $\text{RMS}(\delta x)_B \rightarrow 0.04 \text{ px}$
 2. $\text{RMS}(\delta x)_R \rightarrow 0.02 \text{ px}$

Cube extraction / extraction mask (2)



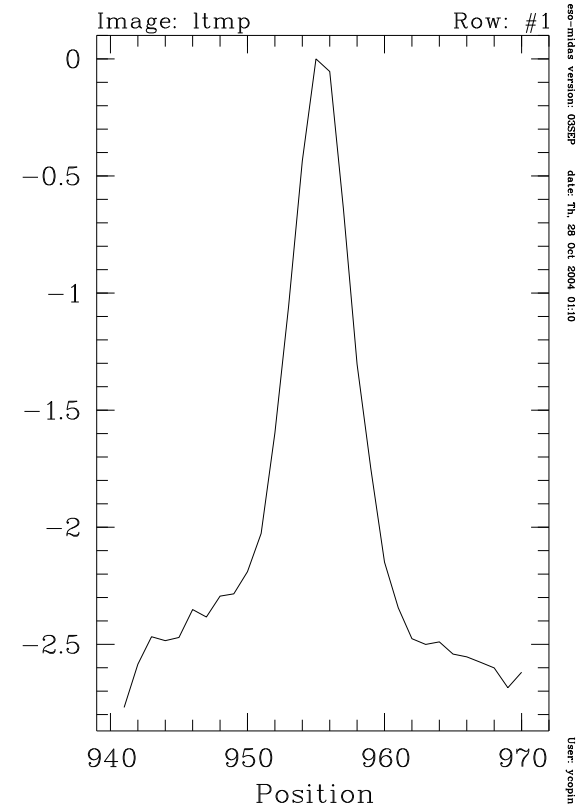
Spectra extraction (1)

Cross-dispersion **profile model**:

Goal



extraction of the identified
spectra



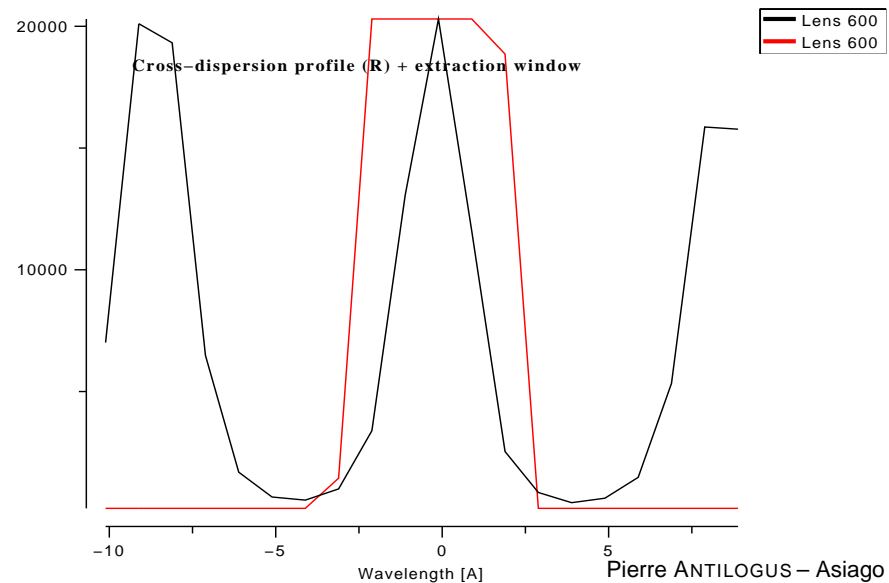
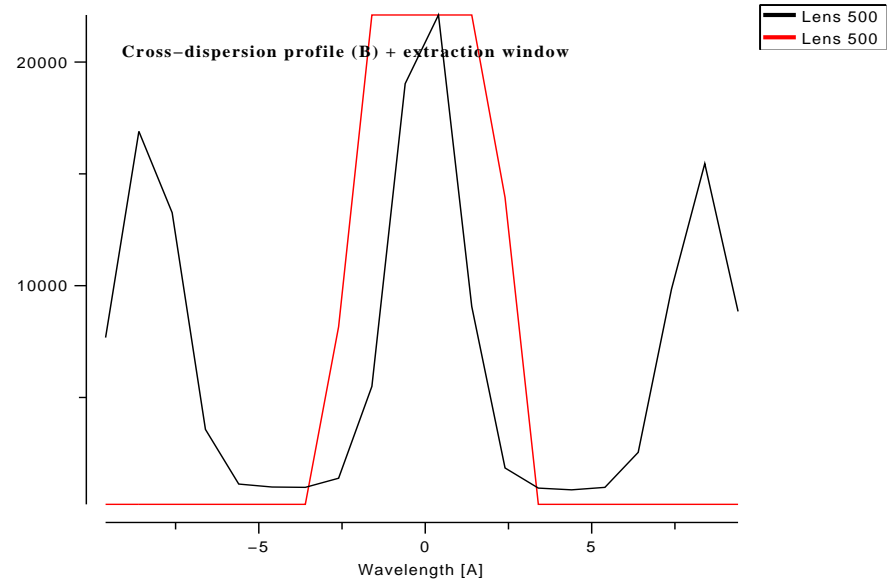
Spectra extraction (1)

Cross-dispersion **profile model**:

- Needed for optimal extraction
- Three components:
geometrical pupil \otimes global PSF \otimes local PSF
(spixel, λ)
 - **Geometrical pupil**: analytic approx. from optical parameters
 - **Global PSF**: 2-gaussian fit from arc analysis
 - **Local PSF**: 1-gaussian fit from continuum analysis

Spectra extraction (2)

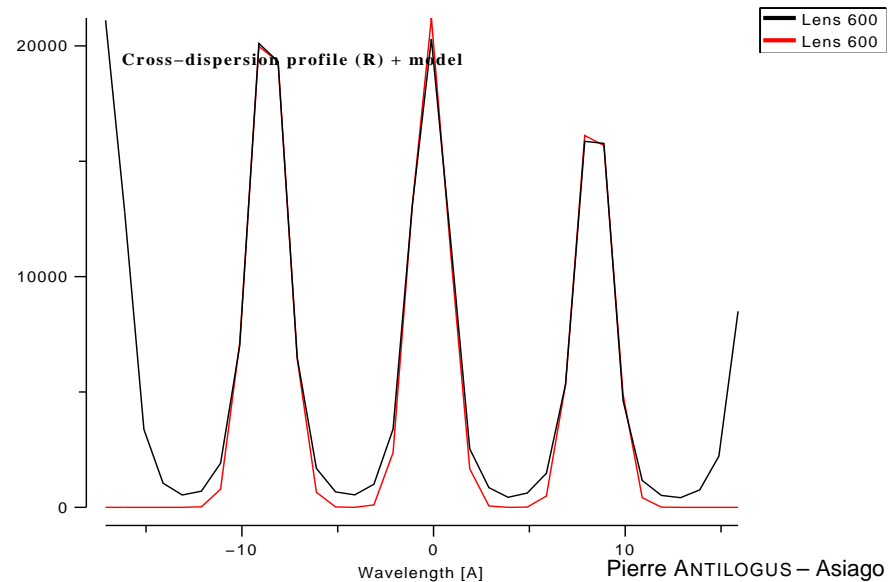
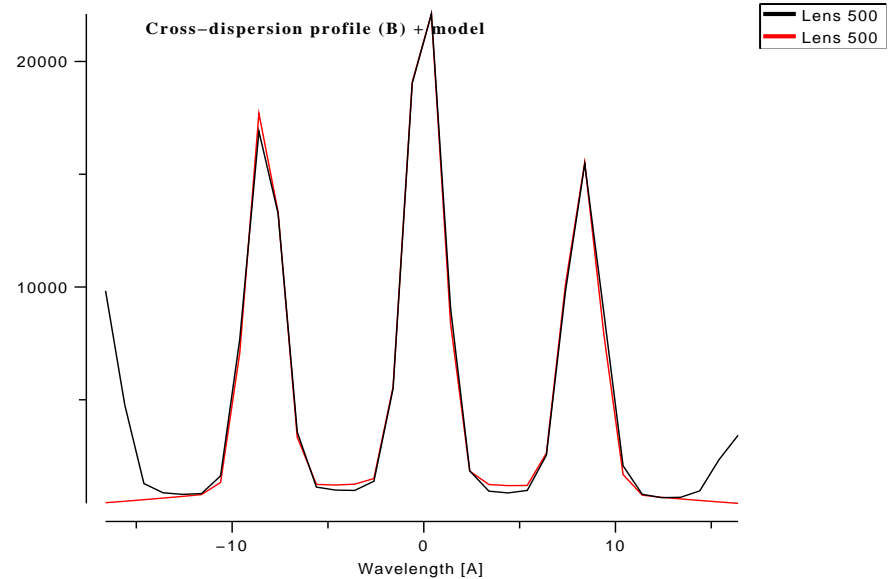
- Well-separated spectra
 - Inter-spectra: ~ 8.4 px
 - X-disp. FWHM: ~ 2.2 px
- **Raw extraction:** pure summation around the mask position
- **Optimal extraction:** includes cross-talk correction + optimal summation



Spectra extraction (3)

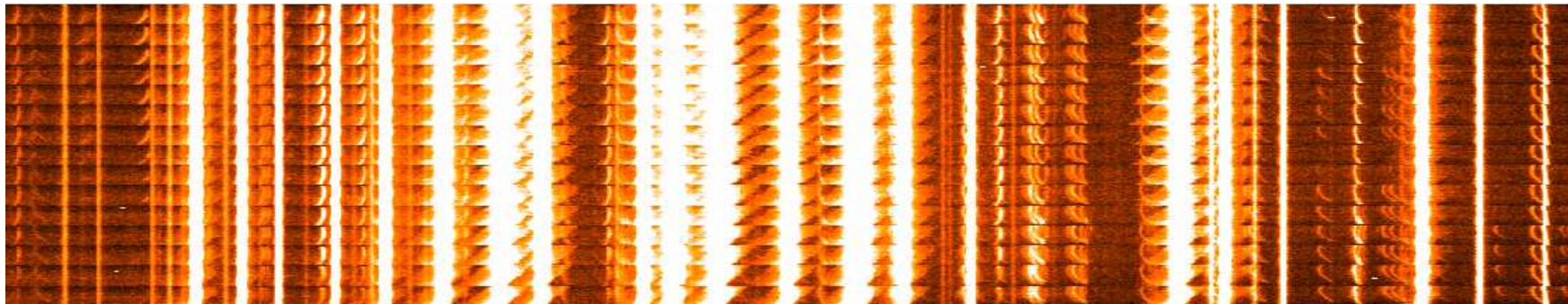
Optimal extraction requires :

- Cross-dispersion profile
- 1st-order only
- Diffuse/remnant light subtraction



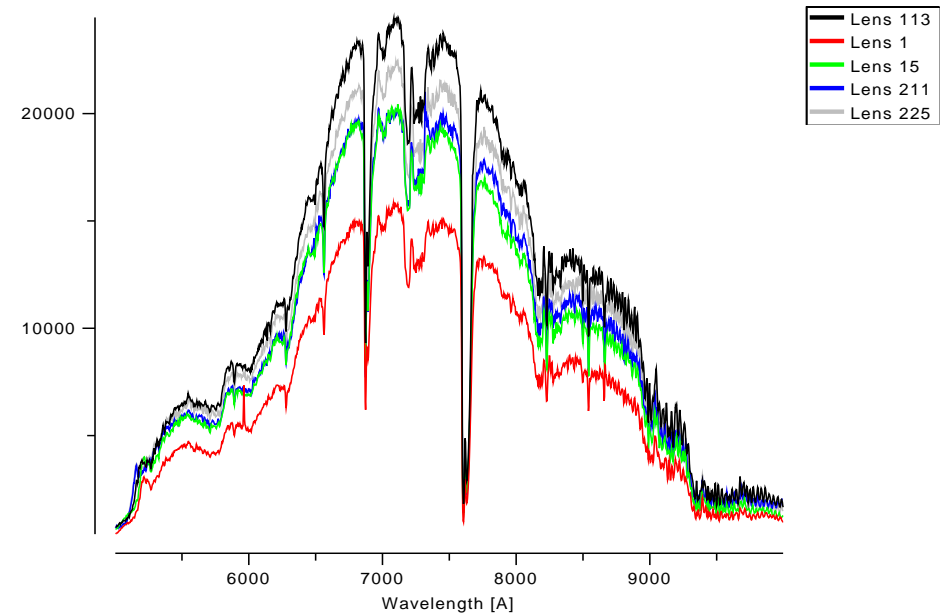
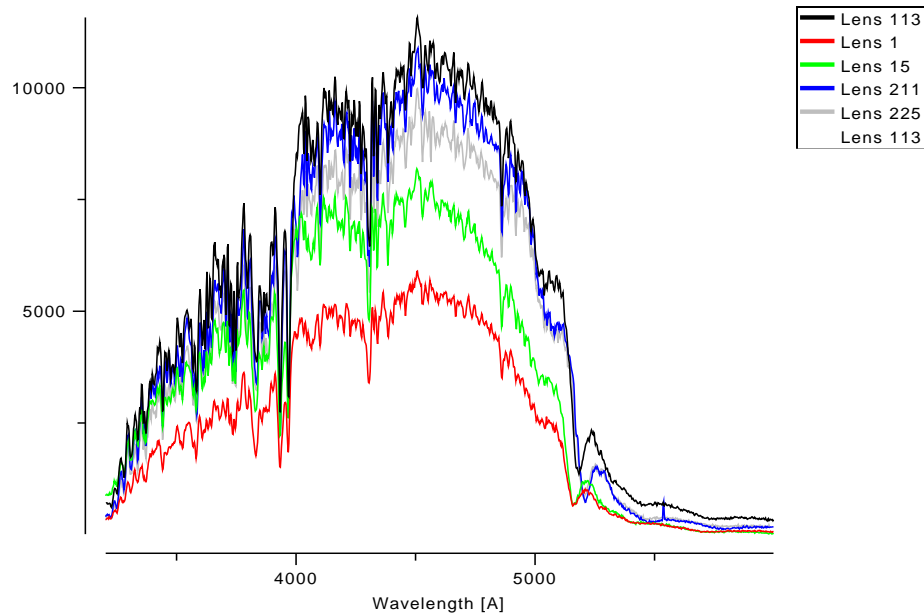
Spectra / wavelength calibration

- Pre-calibration from optical model (px-precision)
 - Blue: $\Delta\lambda = 2.38 \text{ \AA}$
 - Red: $\Delta\lambda = 2.93 \text{ \AA}$
- then Polynomial calibration from Hg+Cd+Ar lamps ($< .1$ px-precision)
- High accuracy requires optimal extraction to disentangle between weak lines and ghosts



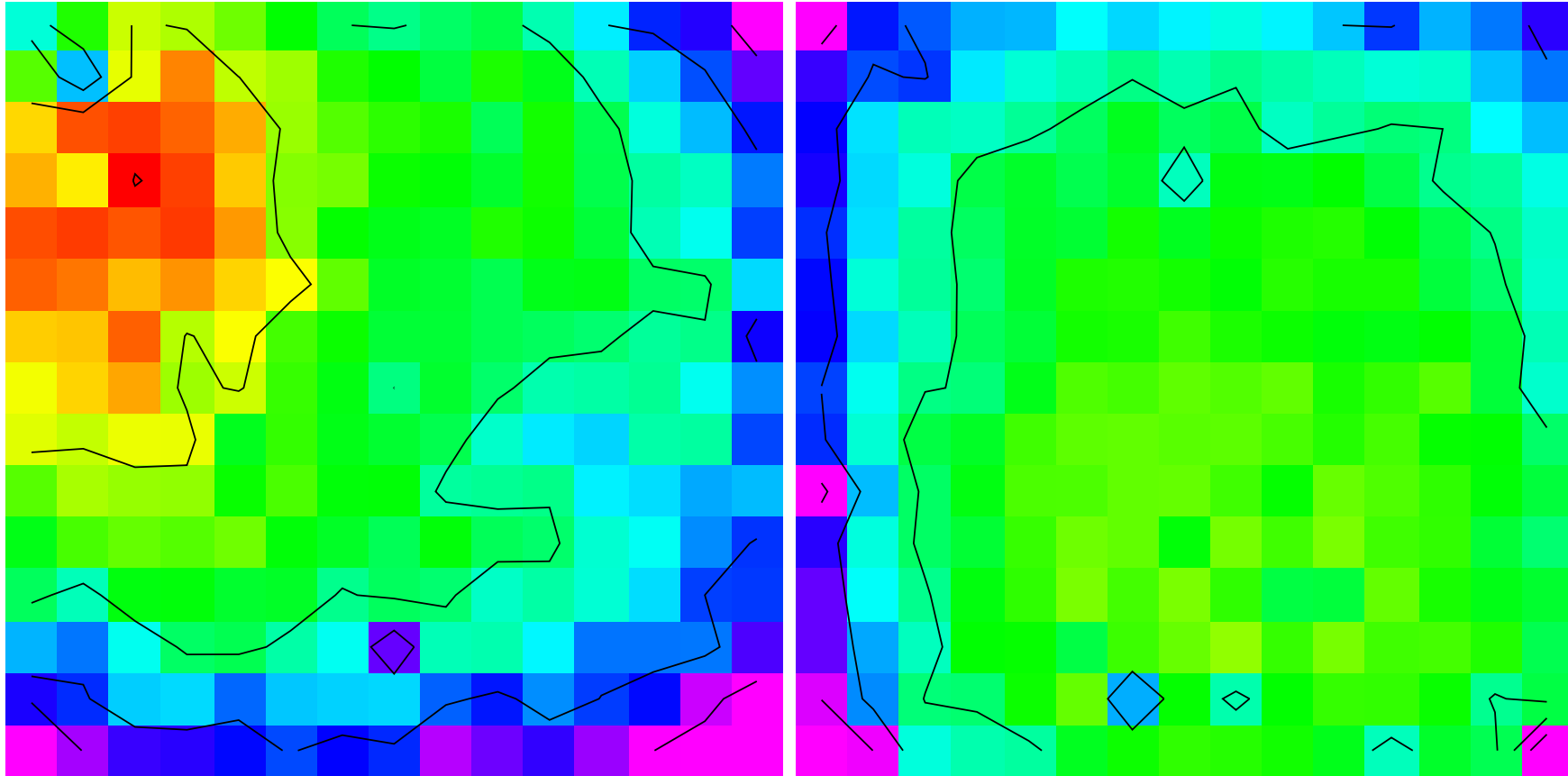
spectro-spatial flat field

Continuum lamp are used to correct the dispersion observed lens to lens (spatial correction) and versus lambda (spectral correction):



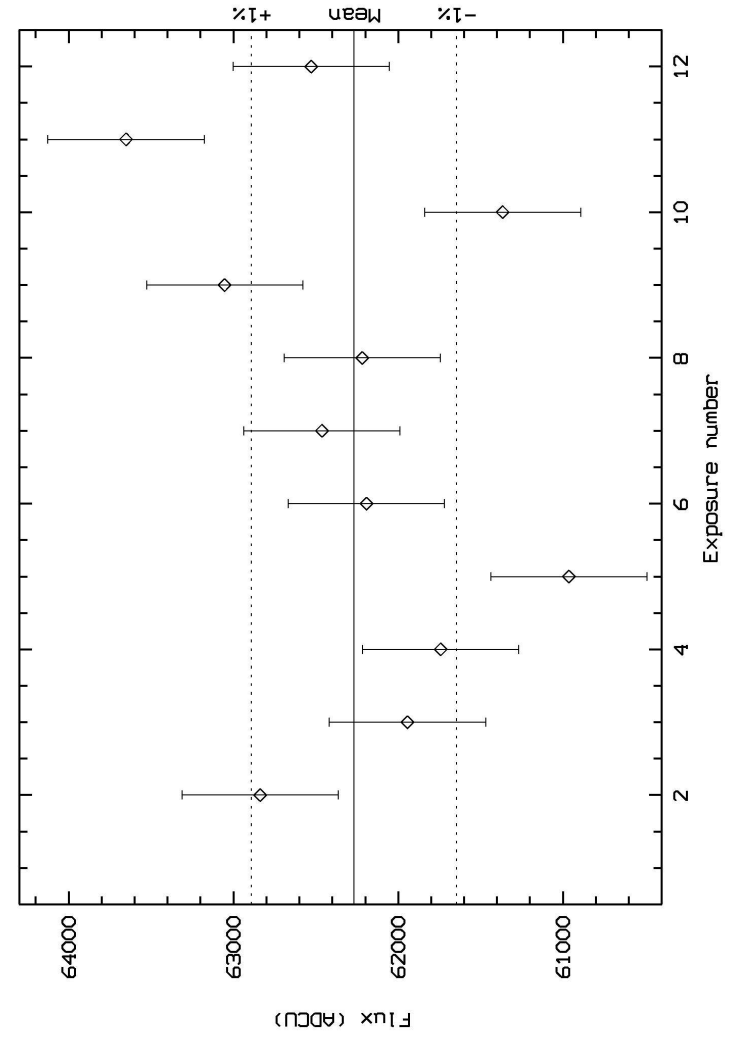
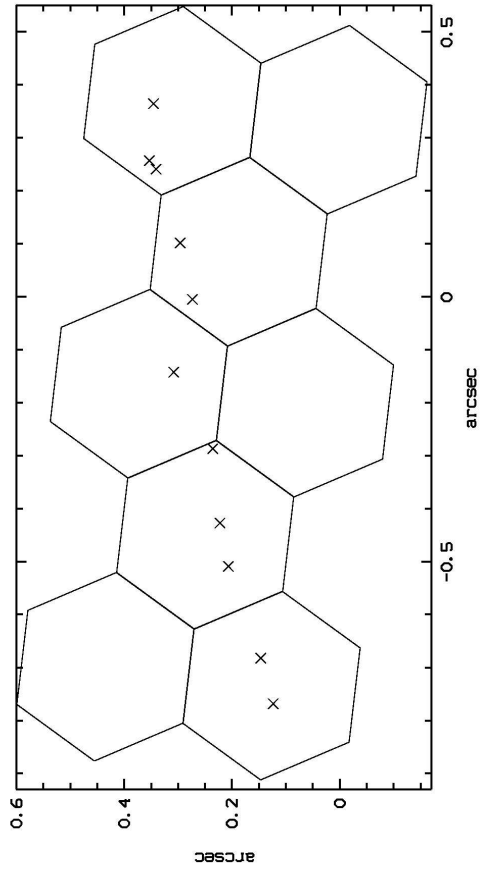
Spatial correction

Before: (Range: 0.9-1.1, contours: 5%)



After: below 1 %

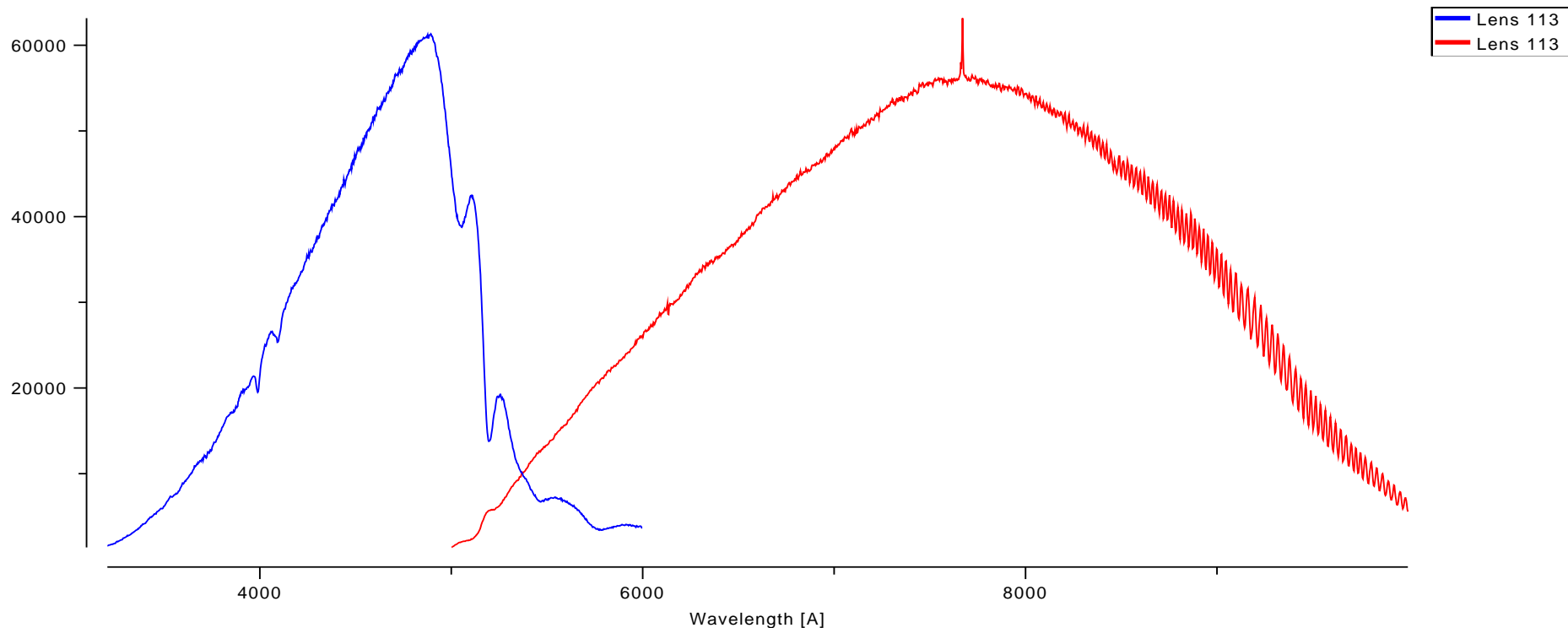
Spatial responses : intra-lens variation ?



Spectral correction

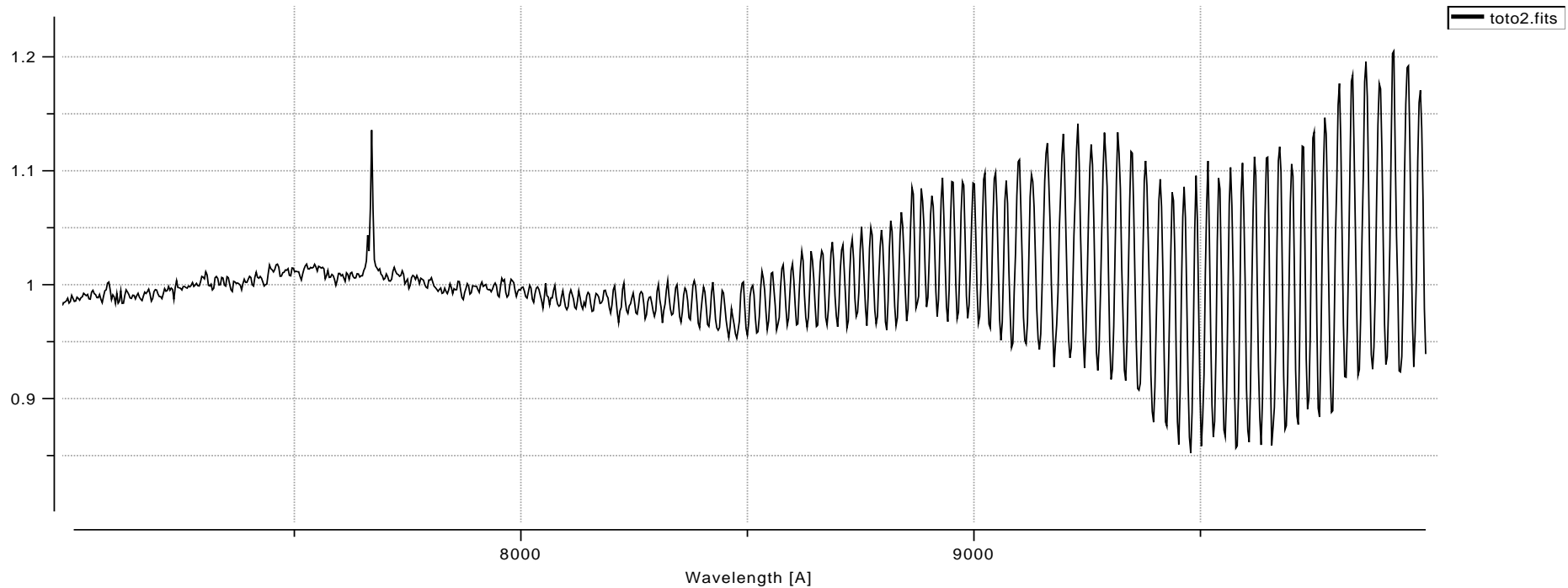
Take-out the spectrograph transmission

Low Frequency response dispersion of the spectrographe are corrected using continuum variation from spectra (=lens) to spectra. Global response correction is done at flux-calibration stage.



Spectral correction : fringes

Fringes are left after a simple LF flat :



Could be absorbed in PSF modeling...

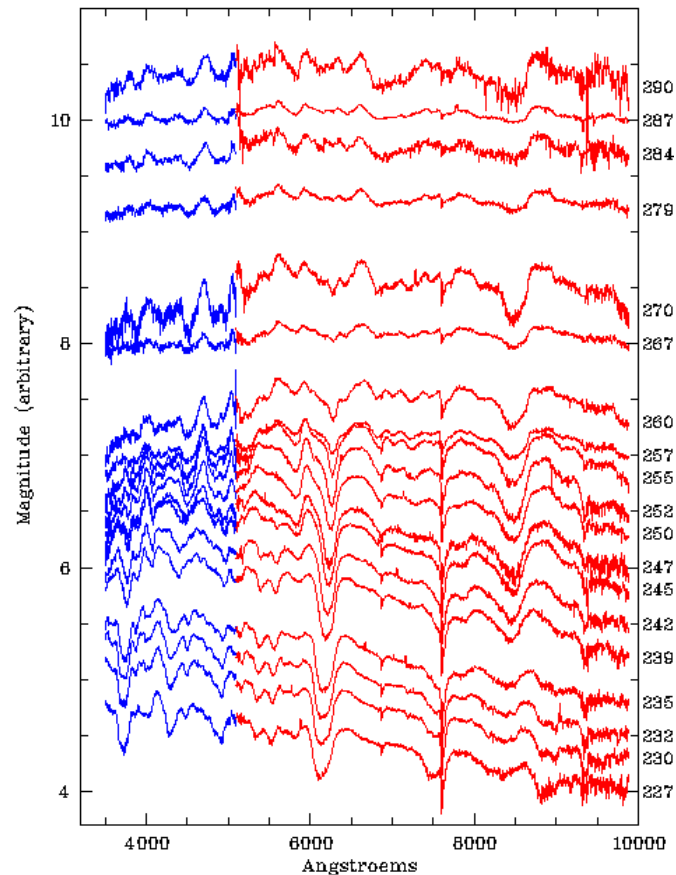
but with IFS better to get a **thicker** CCD .

Conclusion

Spectro-photometry with IFS of point source & variable objects is new.

Conclusion

Spectro-photometry with IFS of point source & variable objects is **new**.



SN2004dt
SNFactory
Time serie of spectra
PRELIMINARY
(uncalibrated)

Conclusion

Spectro-photometry with IFS of point source & variable objects is **new**.

How far we can go with the existing instrument(s) ?

Let's wait a year ...