# Reduction of VLT spectra .2.

# IFU Data

**Alessandra Zanichelli**

Istituto di Radioastronomia- INAF Bologna

# Outline

- What is Integral Field Spectroscopy
- Overview of existing VLT IFUs
- Main topics on IFU data reduction
- Available pipelines
- What next? Scientific analysis

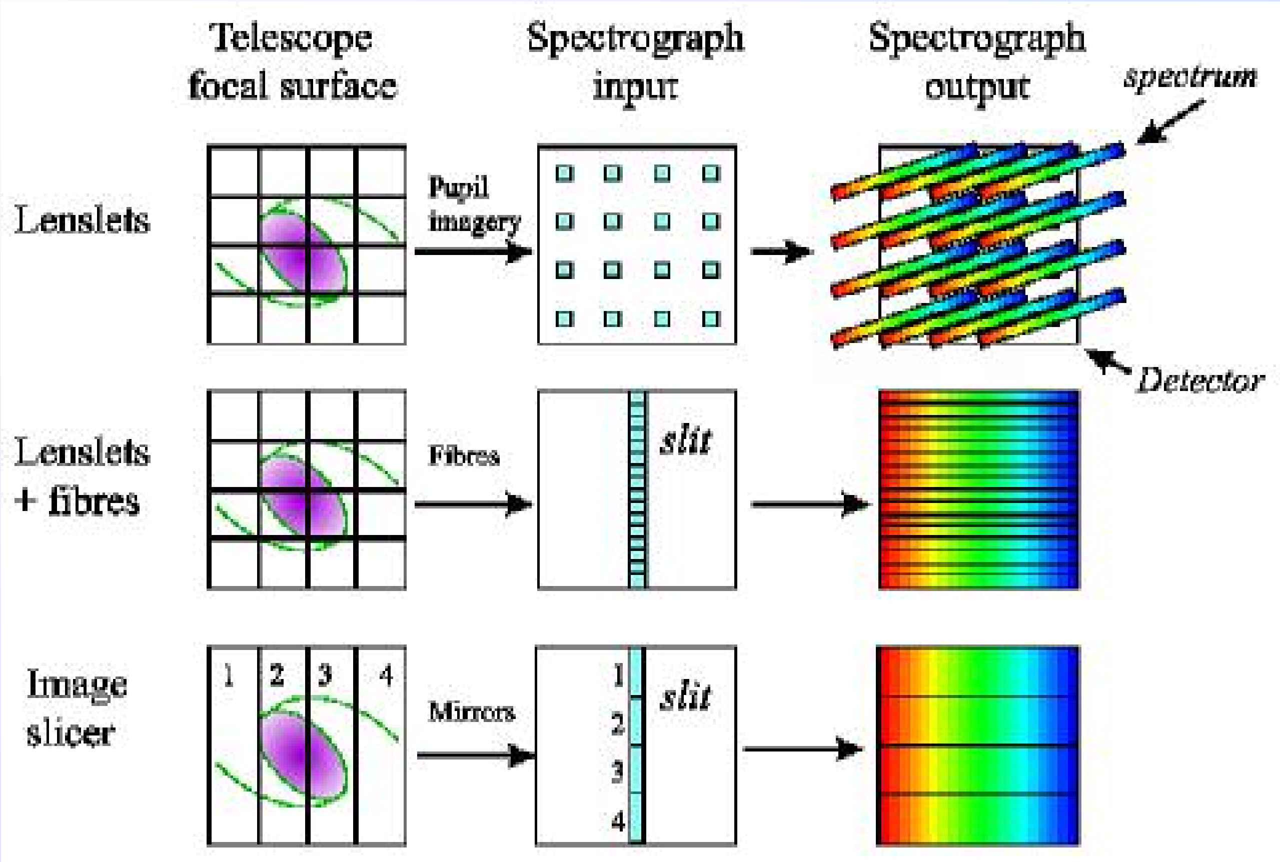
# What is Integral Field Spectroscopy

Traditional spectroscopy is based on dispersing the image of a slit (single or multiple), capturing a fraction of the light from an object. Inefficient if object is extended or crowded field.

Techniques which record spectra from each part of an object/field simultaneously are termed Integral Field Spectroscopy, a.k.a. two-dimensional spectroscopy or three-dimensional imaging

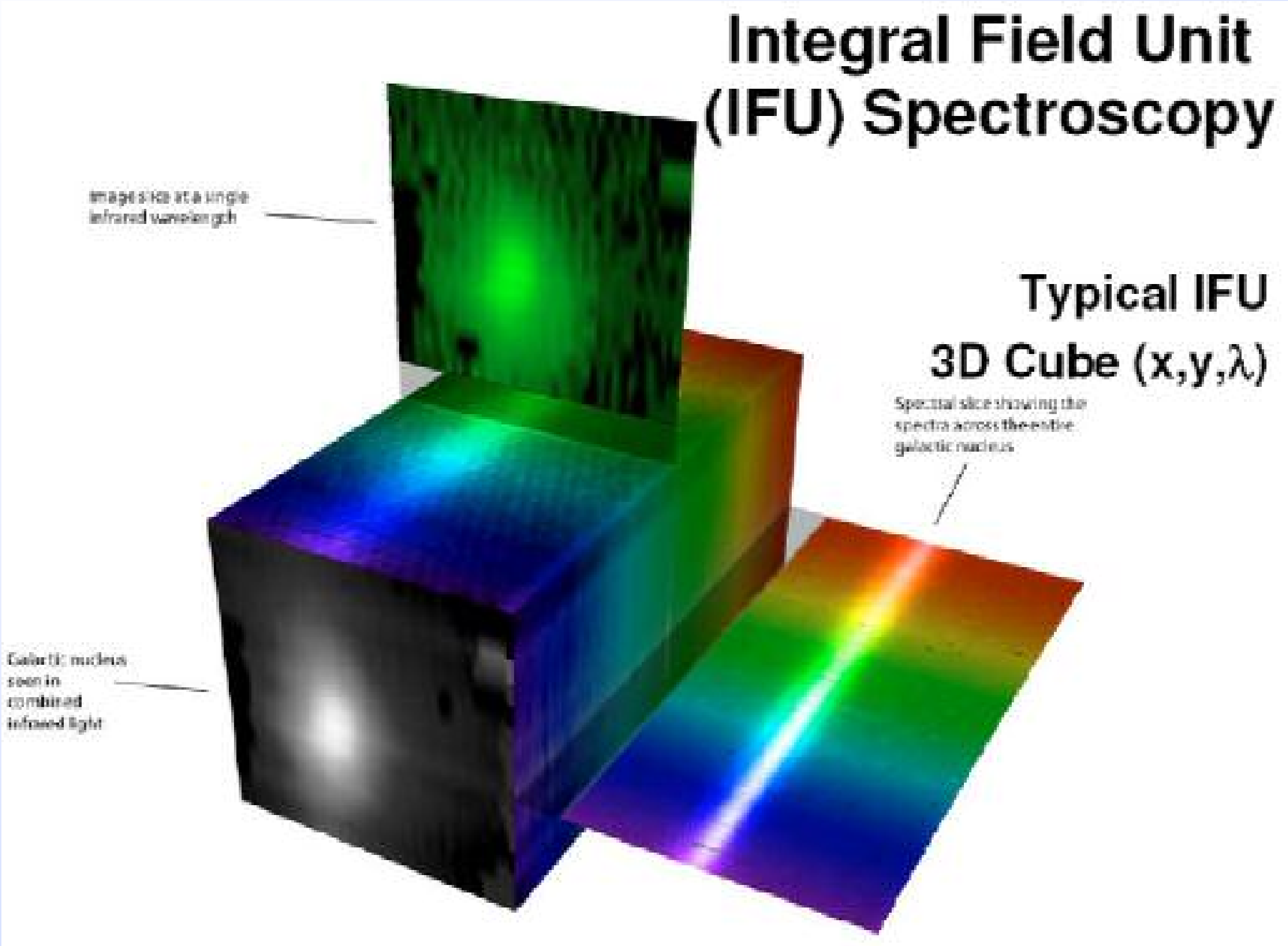
Can use: lenslets, lenslet+fiber, image slicers

# IFU techniques



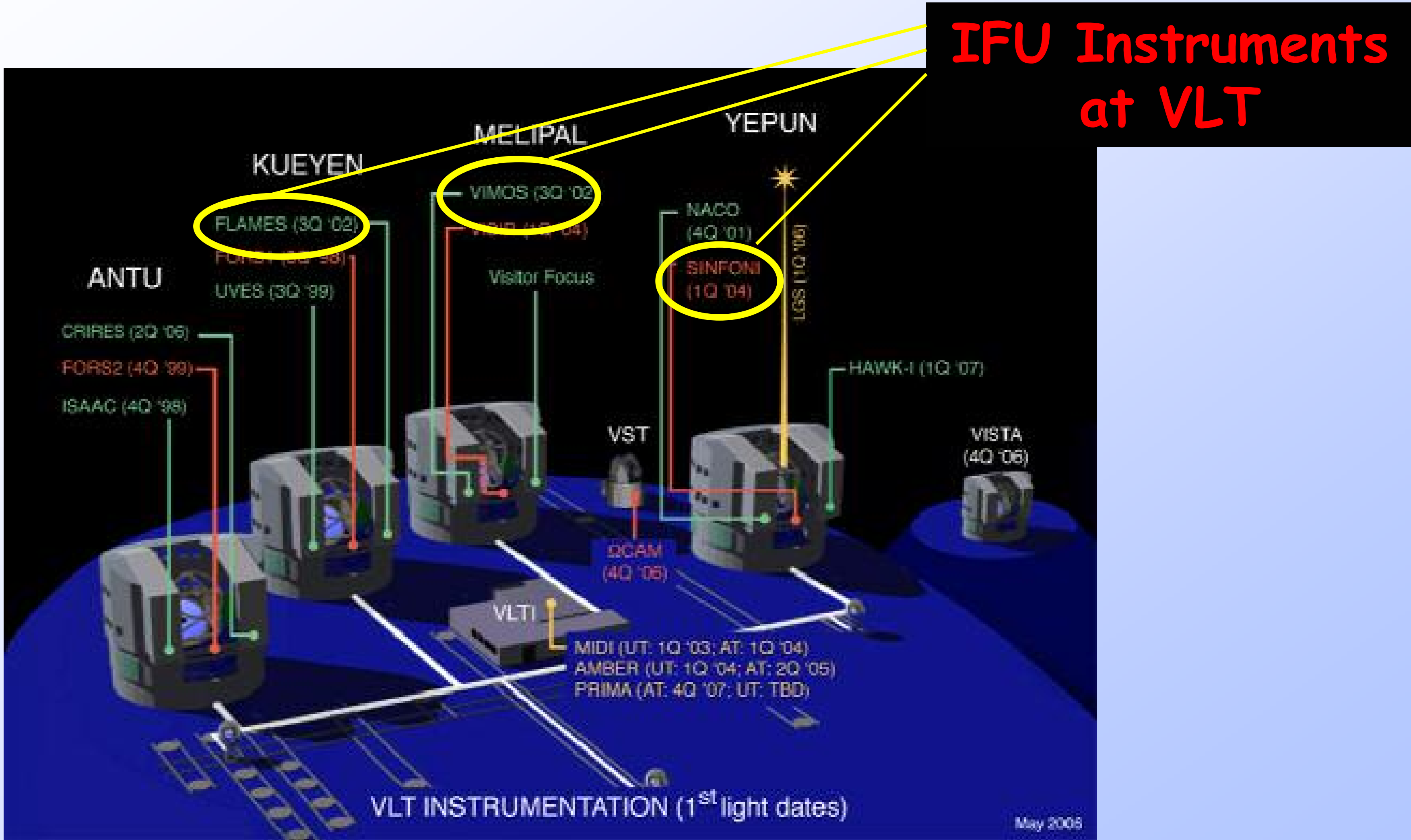

Allington-Smith, 1998

# IFU datacube



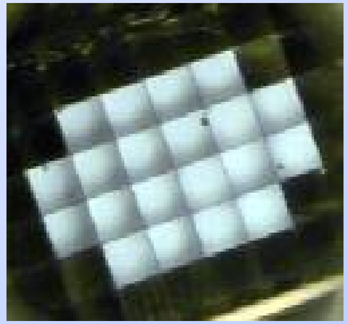

Dolensky, 2006

# What is available at ESO-VLT?

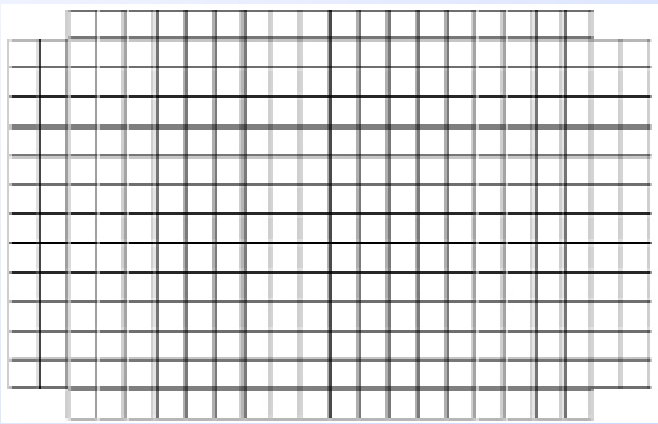


# FLAMES/GIRAFFE

Lenslet+fiber IFU, optical, R=10000-25000



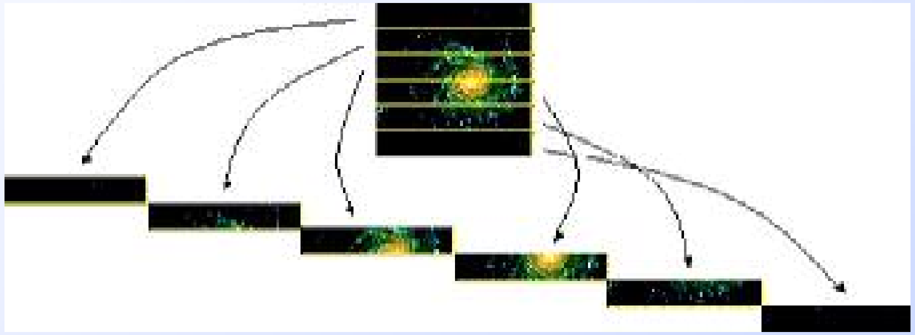
IFU MODE: rect. array of 20 microlenses 0.52" each, FoV 2"x3". Rearranged on subslits.
15 movable IFU units dedicated to objects, 15 to sky.

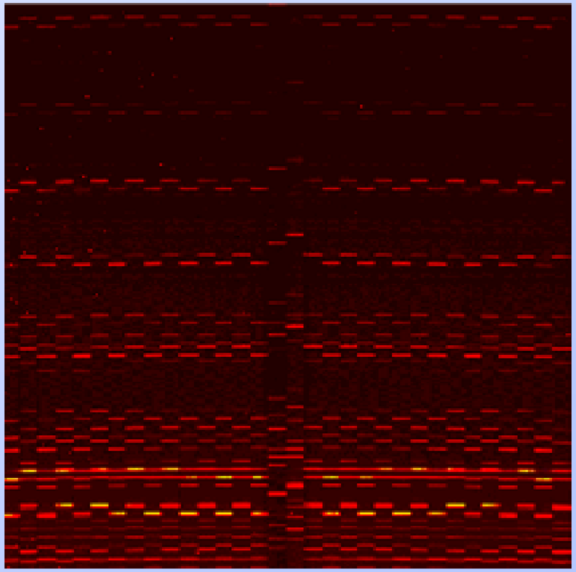


ARGUS MODE: 22x14=308 lenses.
Sampling 0.52"/lens, FoV 11.5" x 7.3"
Sampling 0.3"/microlens, FoV 6.6" x 4.2"
Rearranged on subslits.

# SINFONI/SPIFFI

Image slicer + AO IFU, near-IR, R=1500-4000.
32 slices, variable size. FoVs: 8"x8", 3"x3", 0.8"x0.8".
Each slice re-imaged over 64 CCD pixels, total of 32x64=2048 spectra.





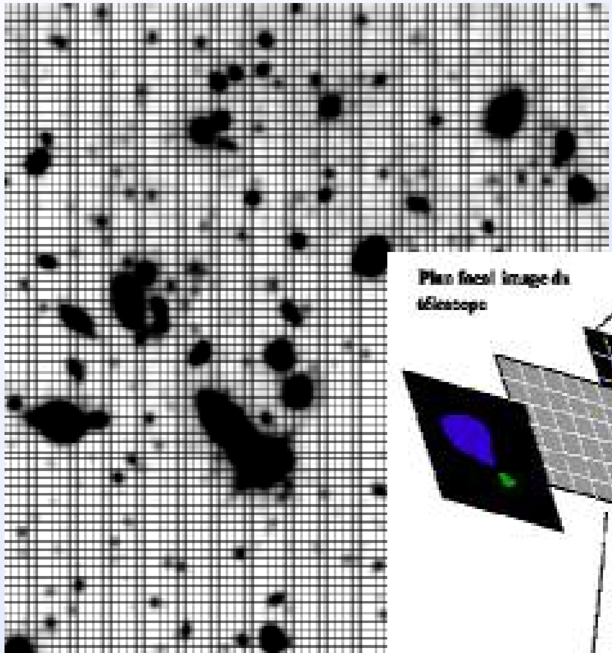
SINFONI calibration lamp. Brick-wall pattern due to slicer.
(Schreiber 2003)

# VIMOS Integral Field Unit

Lenslet+fiber IFU, optical, R=200-2500, 6400 spectra

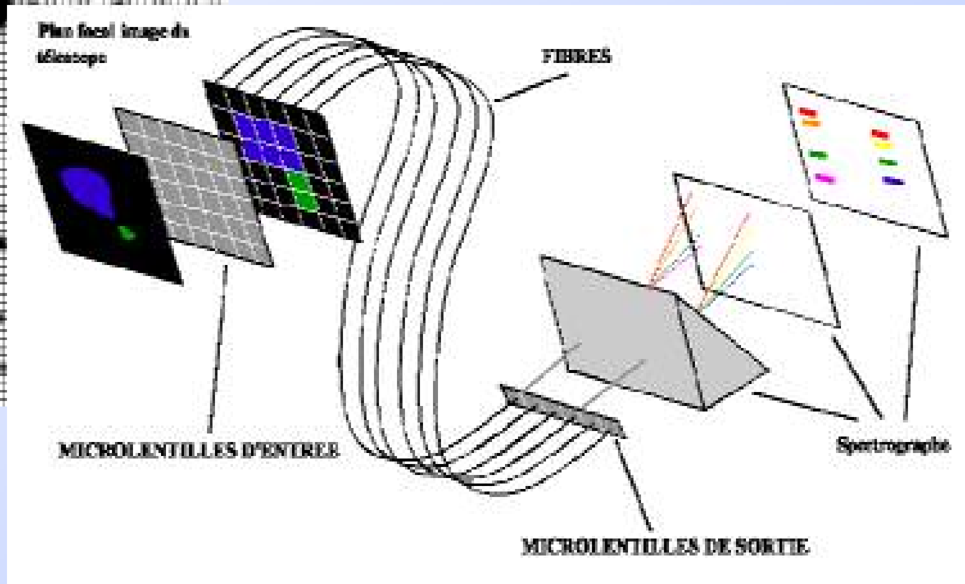
80 lenses

80 lenses



IFU head

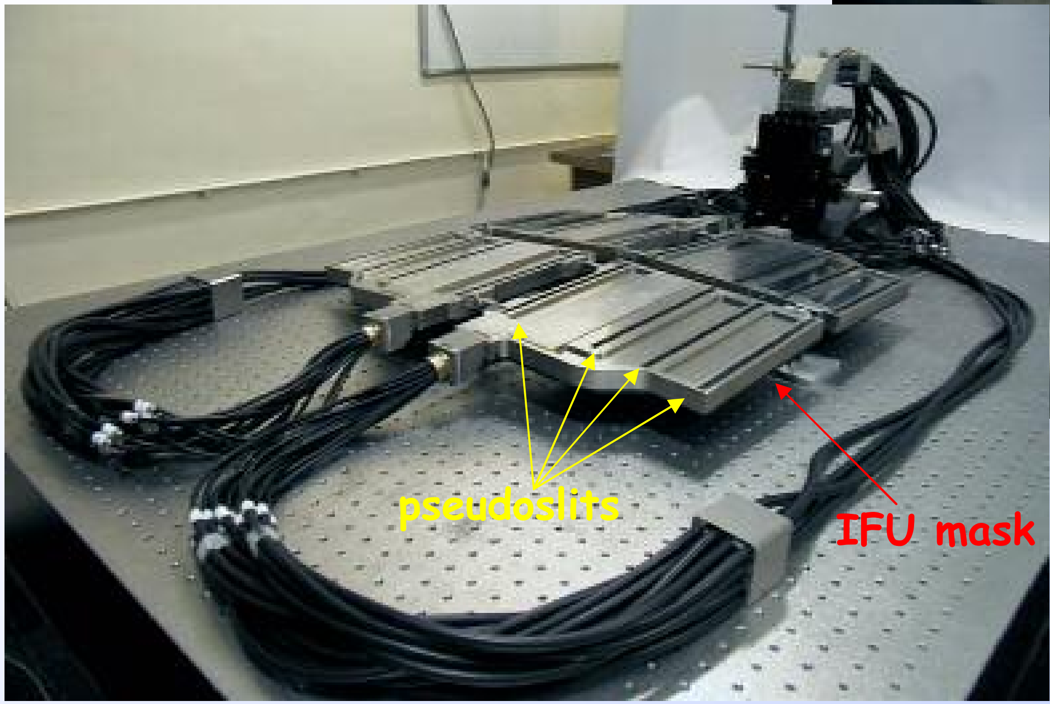
IFU FoV feeds 4 masks (one per CCD). Each mask has 4 pseudoslits hosting 400 fibers/spectra each.

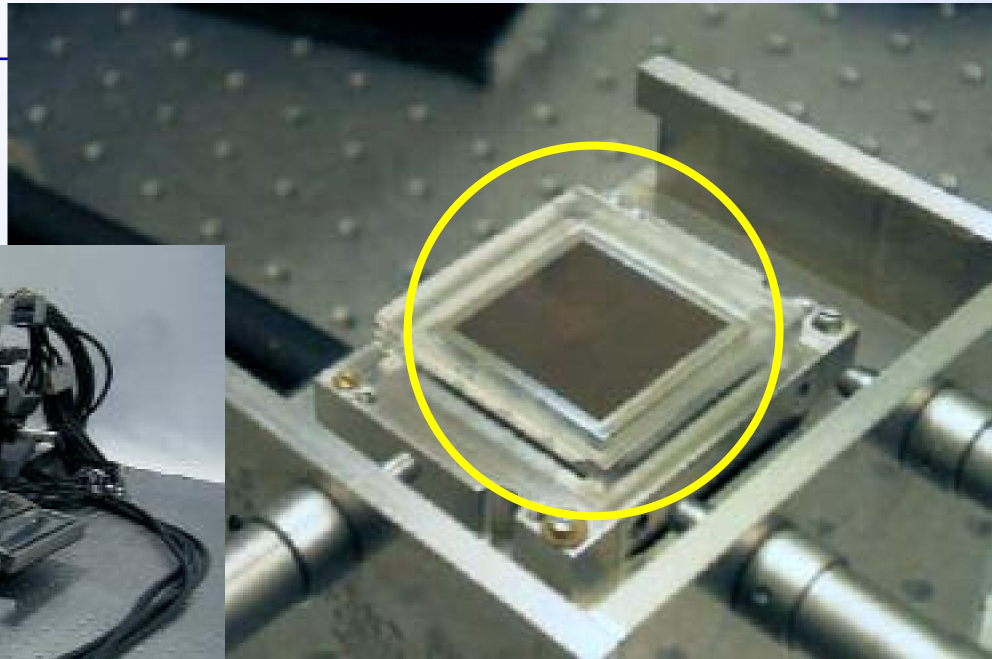



Max. FoV:

54" x 54"

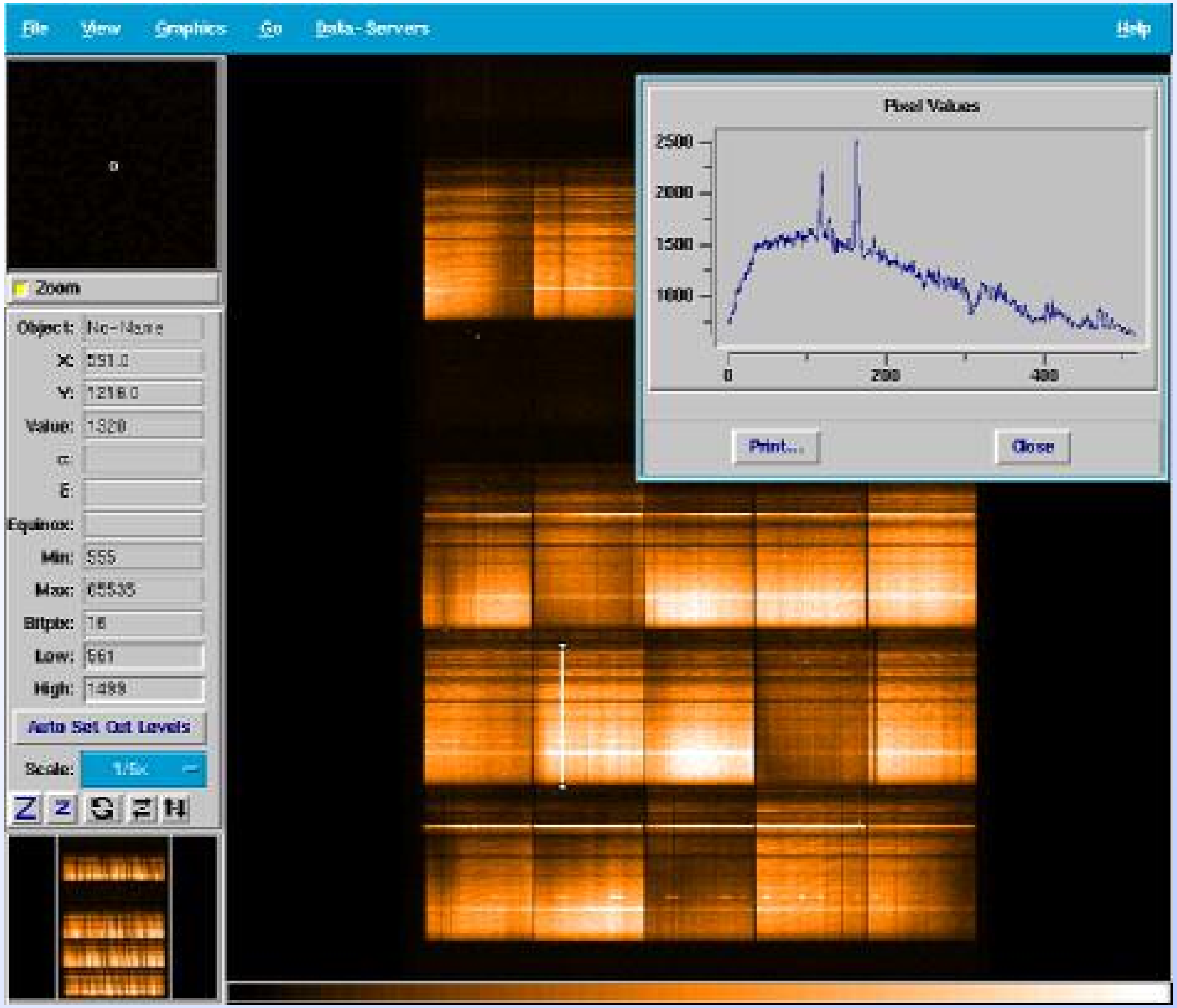
# VIMOS Integral Field Unit



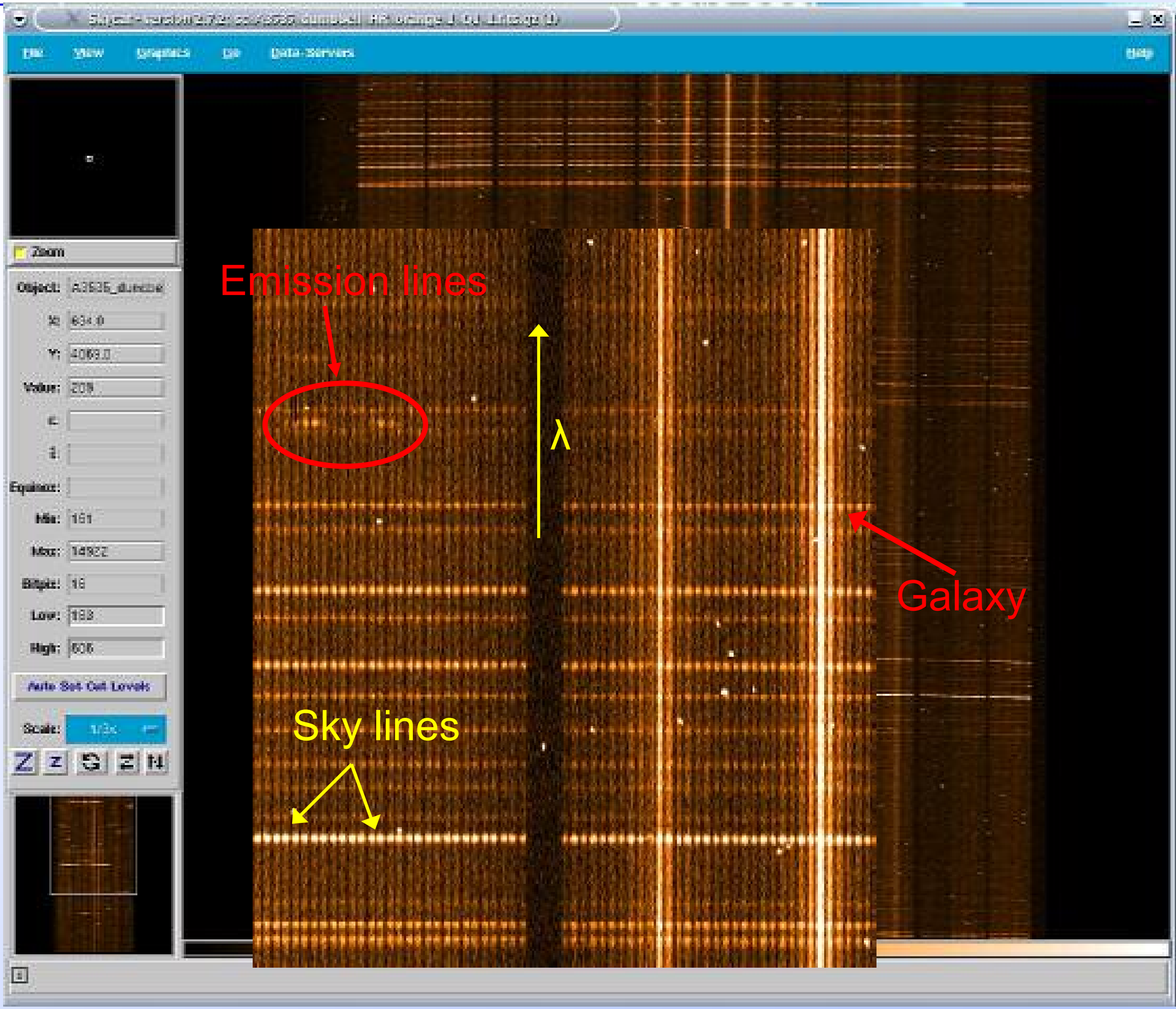
IFU head:
80x80
microlenses

| Spectral Resolution | FoV | Spatial Resolution | N. of spectra |
|---|---|---|---|
| High (R~2500) | 27"x27" | 0.67"/fiber | 1600 |
| High (R~2500) | 13"x13" | 0.33"/fiber | 1600 |
| Low (R~200) | 54"x54" | 0.67"/fiber | 6400 |
| Low (R~200) | 27"x27" | 0.33"/fiber | 6400 |




- IFU First Light
- one quadrant
- 4 pseudoslits
- 400 spectra per pseudoslit

Antennae Galaxy, LR Red 5 min. exposure,
0.67 "/fiber.


Emission lines
λ
Galaxy
Sky lines

# Principles of Data Reduction

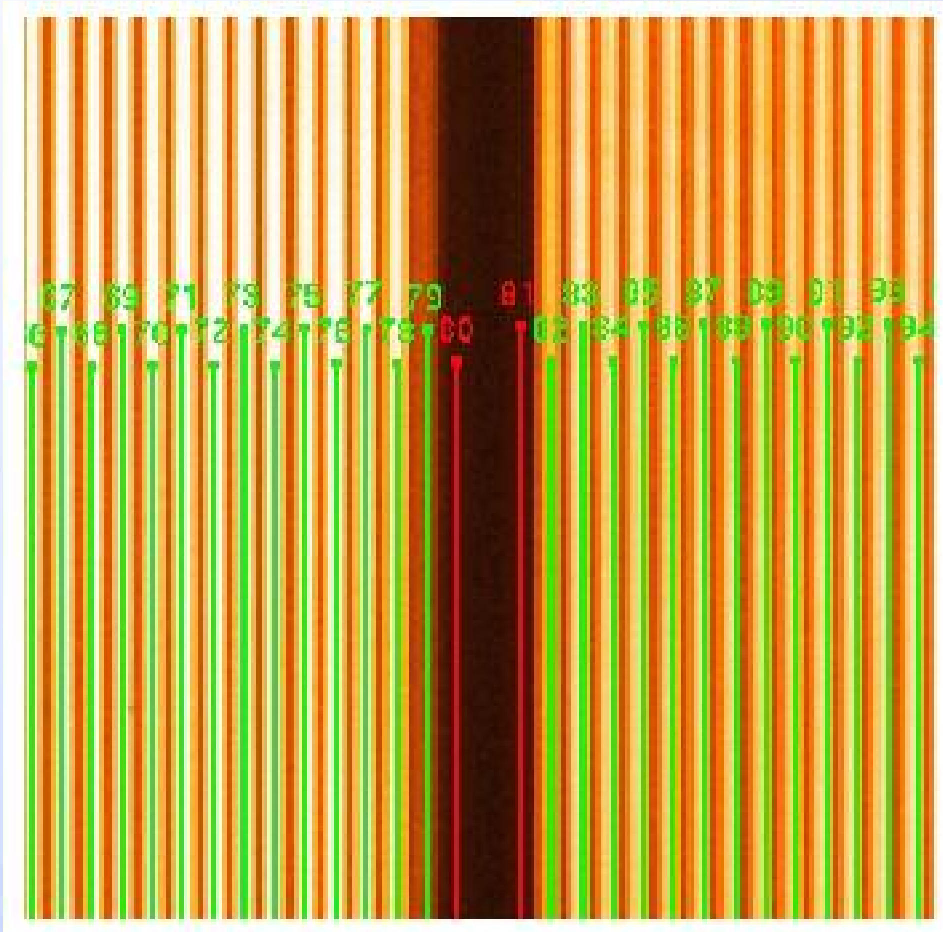
- Tracing spectra location
- Wavelength calibration
- Relative transmission calibration
- Sky subtraction

…

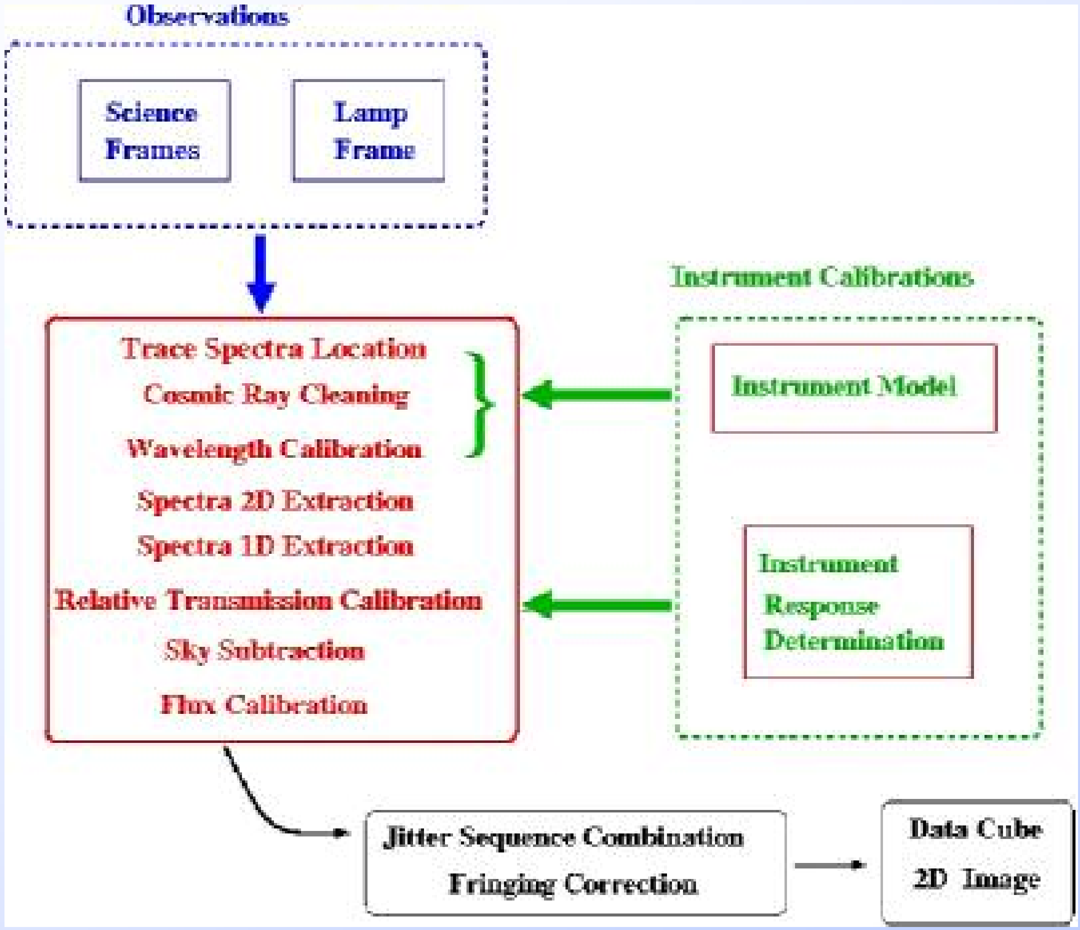
Problems that are common to all VLT IFS, but worse for VIMOS IFU, due to FoV size and crowding of spectra on the CCDs.

## Spectral packing:

**VIMOS IFU spectra are approx. 5 pixels wide across dispersion direction (distance between two contiguous green lines)**



# VIPGI: VIMOS Interactive Pipeline and Graphical Interface




+ Large CCD/FoV
+ Closely packed spectra (5 pixels wide across disp.)

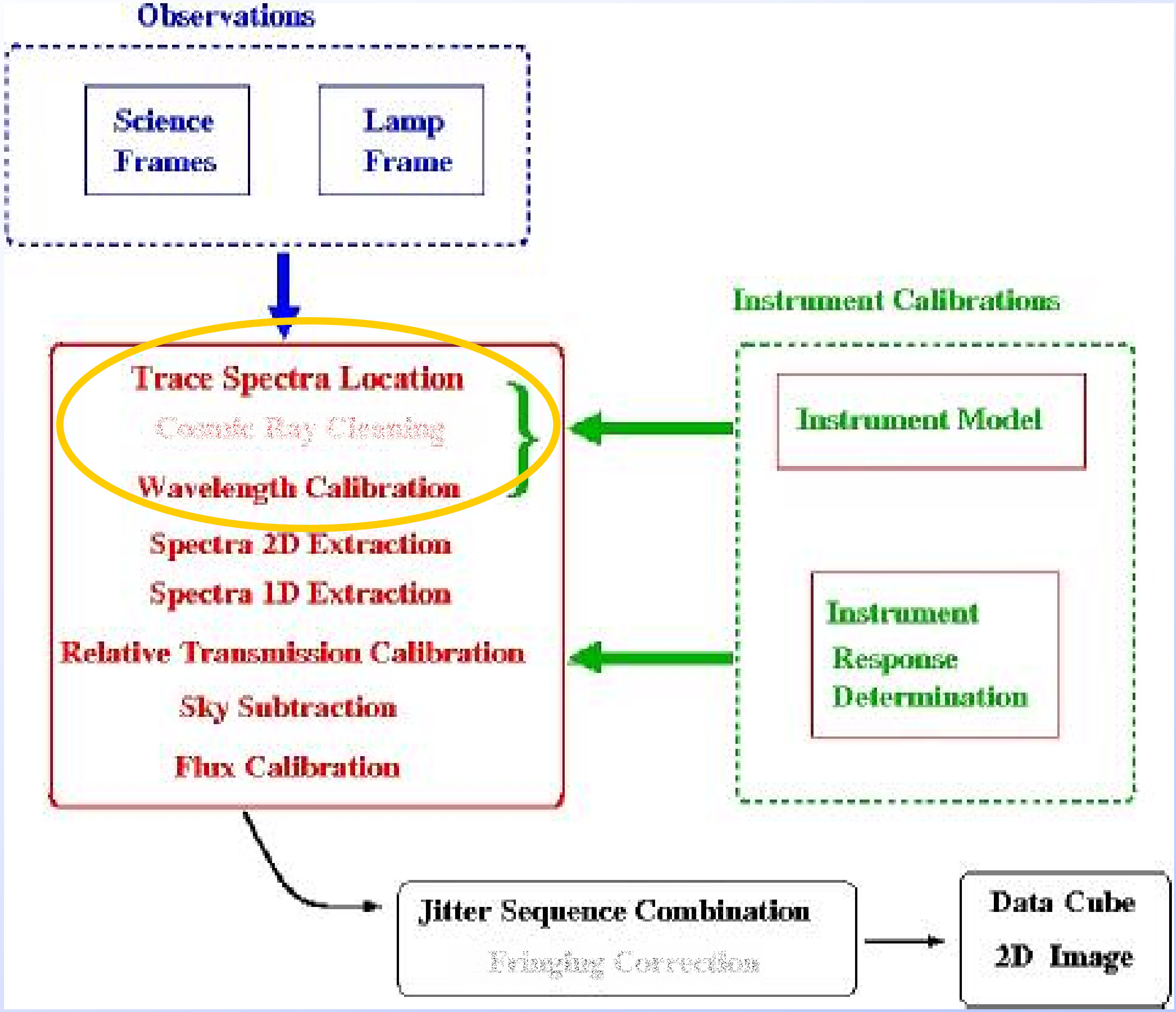
Complex Instrument Calibrations

# Instrument Model (IM)

- Optical distortion model + curvature model (correspondence between position on sky and on CCD)

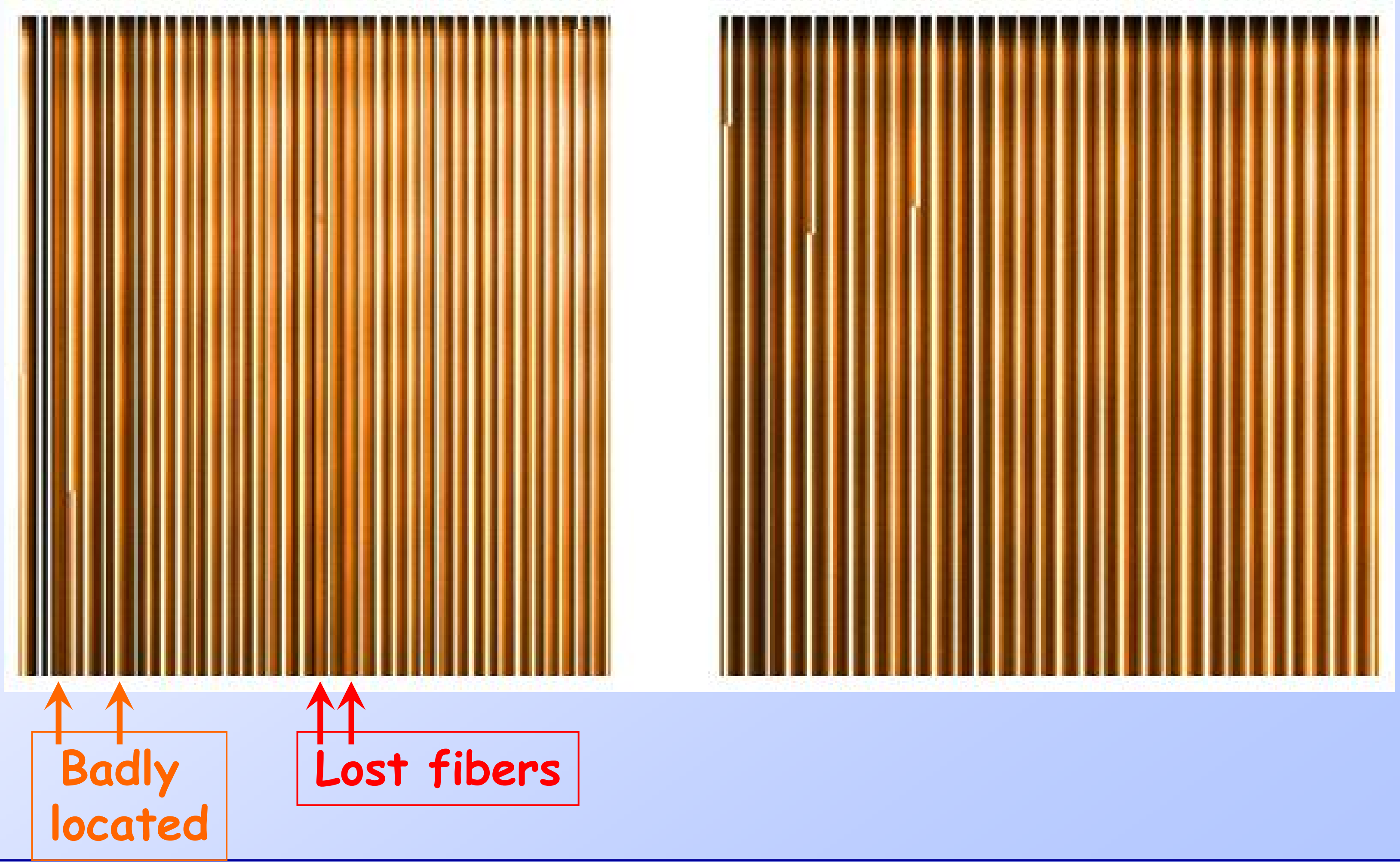
- Inverse dispersion solution (correspondence between wavelength and pixel coordinates on CCD)

Polynomials, given as first guesses in image headers. May change (f.i. instrument maintenance) and must be checked: Adjust First Guesses (interactive task).

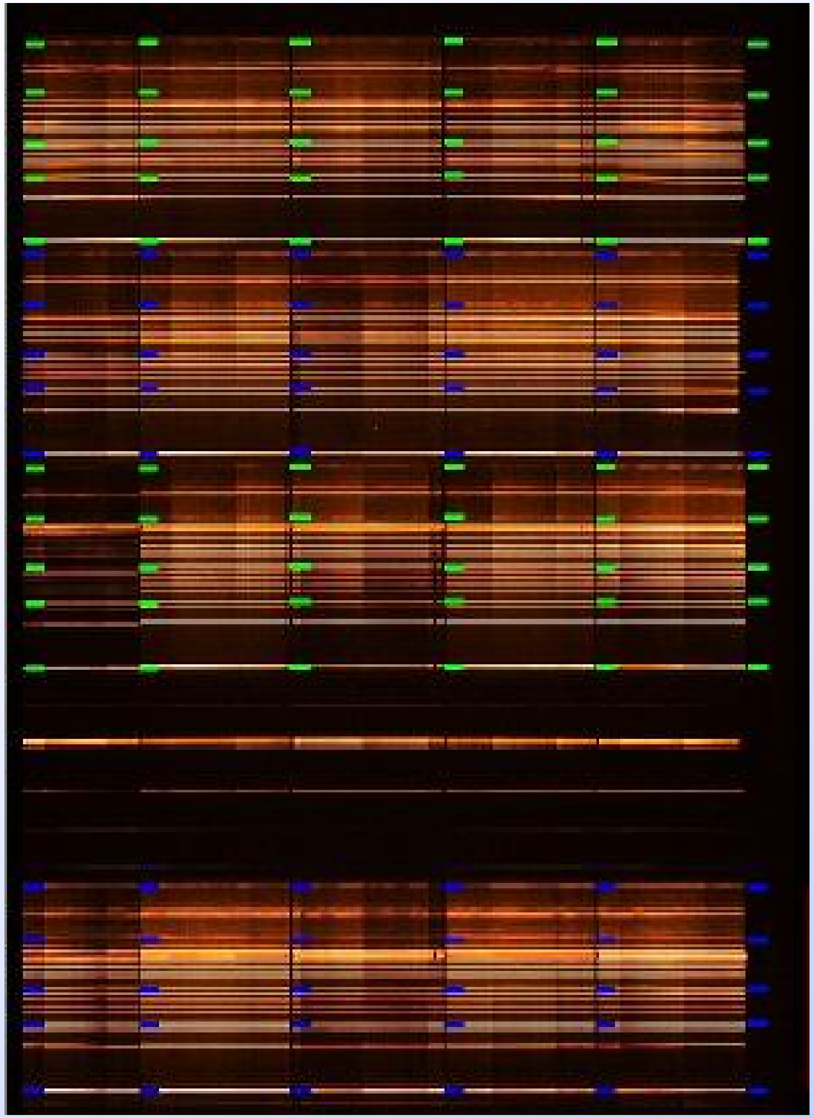

Observations
Science Frames
Lamp Frame
Instrument Calibrations
Trace Spectra Location
Cosmic Ray Cleaning
Wavelength Calibration
Spectra 2D Extraction
Spectra 1D Extraction
Relative Transmission Calibration
Sky Subtraction
Flux Calibration
Instrument Model
Instrument Response Determination
Jitter Sequence Combination
Fringing Correction
Data Cube
2D Image

# IM I: Trace Spectra Location

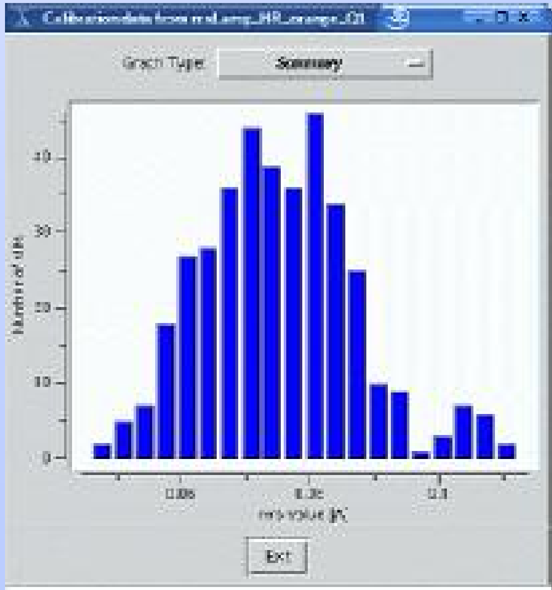
The BAD and GOOD spectra location (white lines must be on peaks)

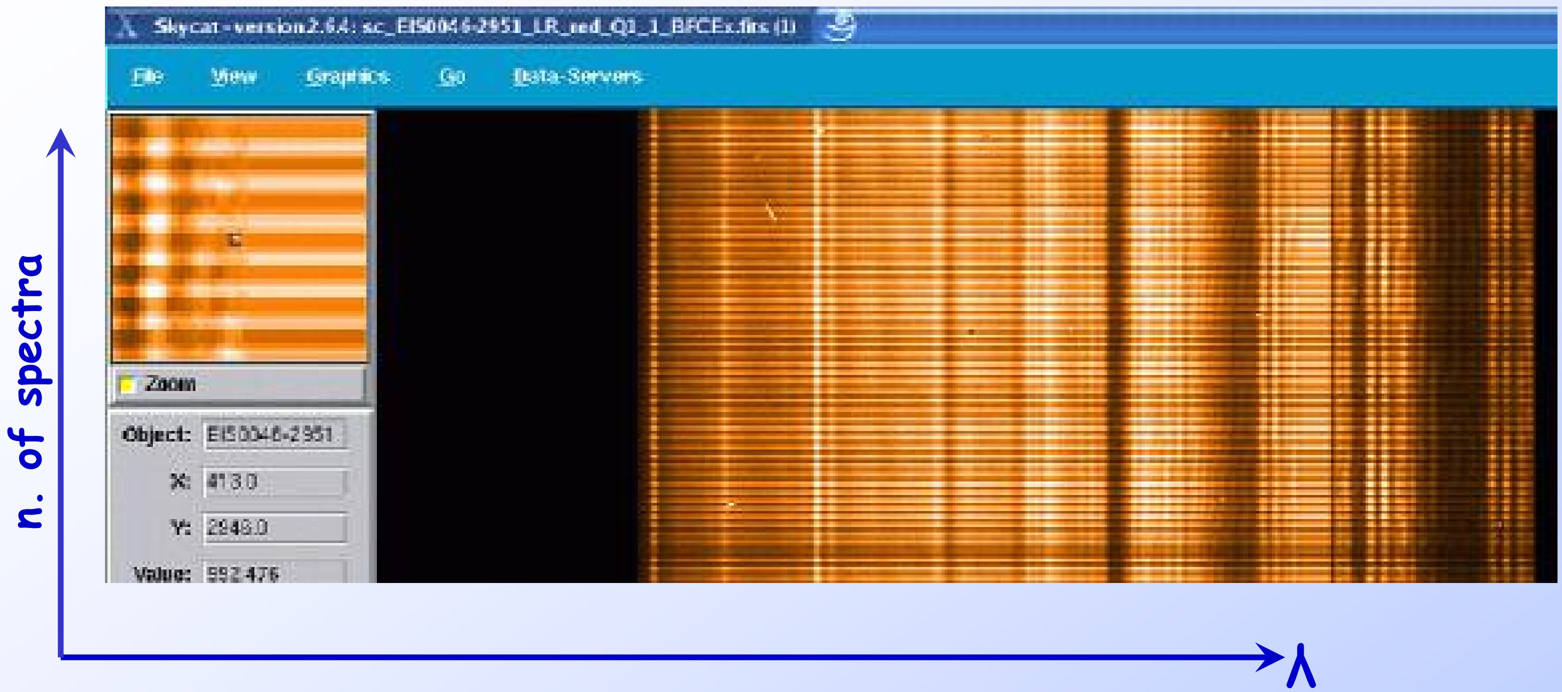


# IM II: Wavelength calibration

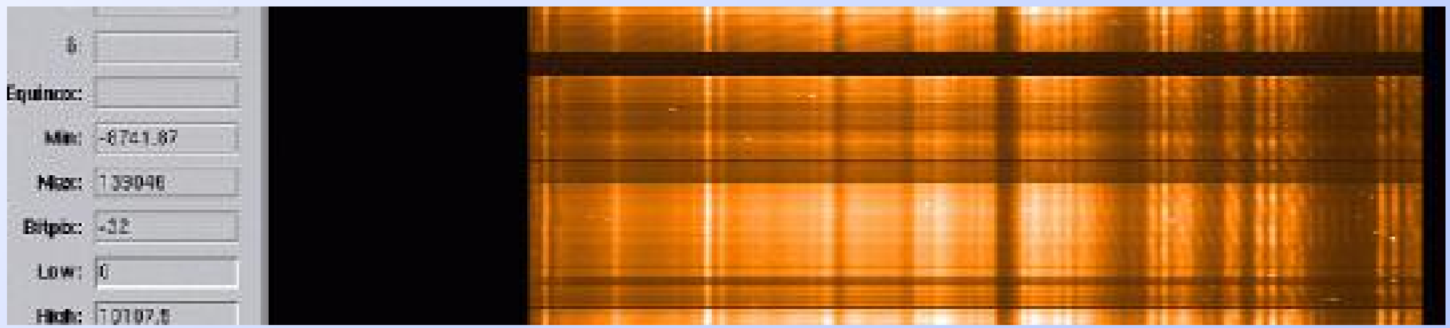


Spectra almost fill all the available CCD area: need a very precise correspondence between wavelength and pixel positions

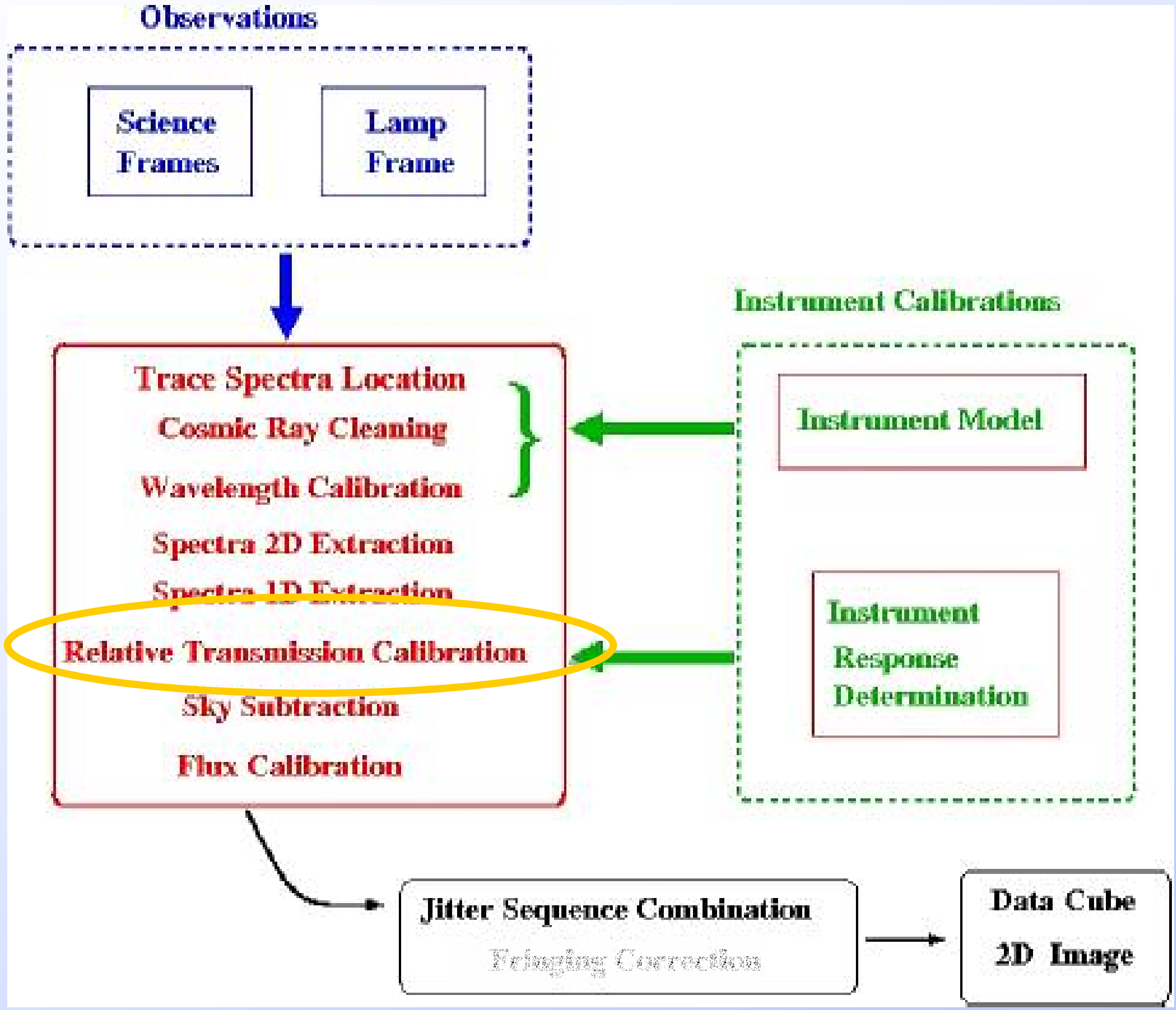





2D extraction




1D extraction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# Instrument Response: fiber transmission calibration

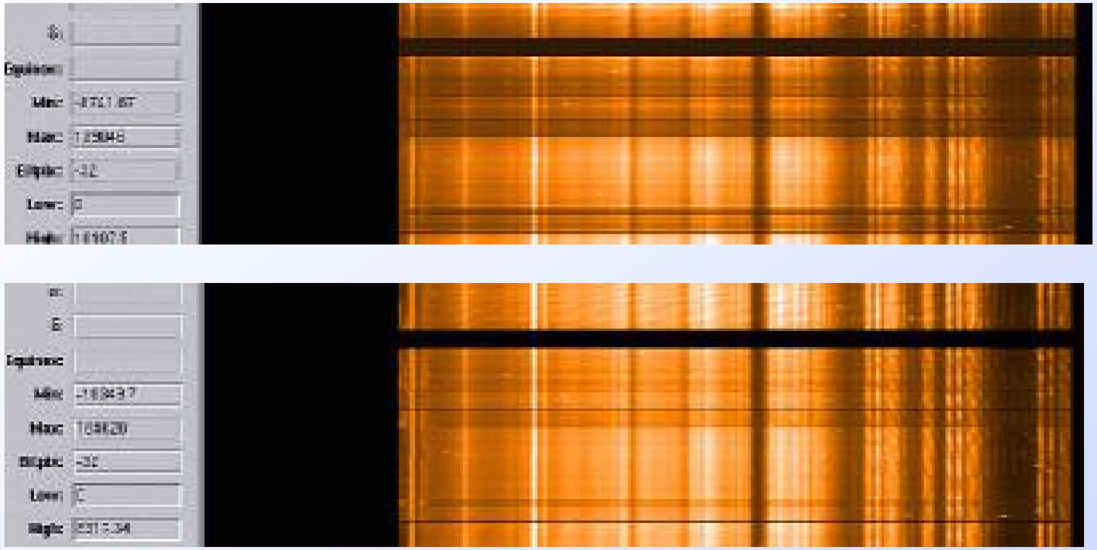
Transmission is different from fiber to fiber: standard "laboratory" coefficients.

Transmission changes over time and with instrument position: finer calibration, *ad hoc* values from real data.

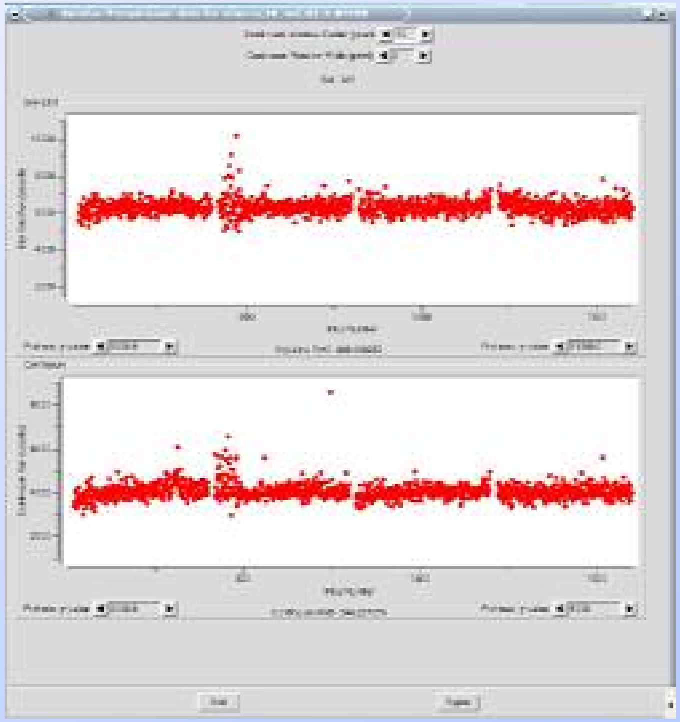
Assumption: flux of sky lines (like 5892) must be constant for all fibers.

**Select a sky line and use its flux to determine transmission coefficients w.r.t. a reference fiber.**

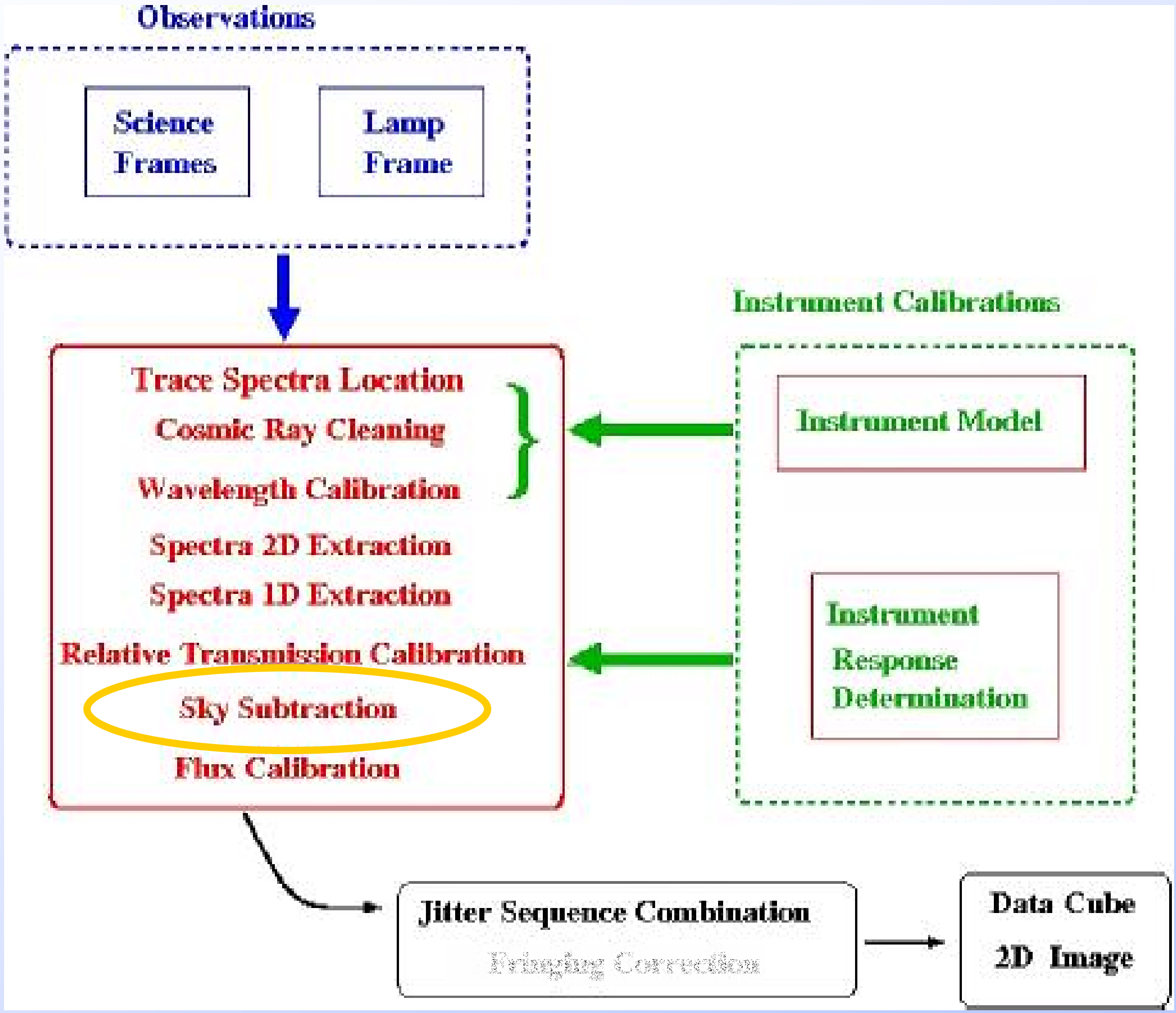
# VIPGI fiber transmission calibration



Top: 1D extracted, before relative transmission calibration.
Bottom: same, but after relative transmission calibration.



Top: intensity of the 5892 A skyline for 1600 spectra.
Bottom: intensity over continuum @ 6000A.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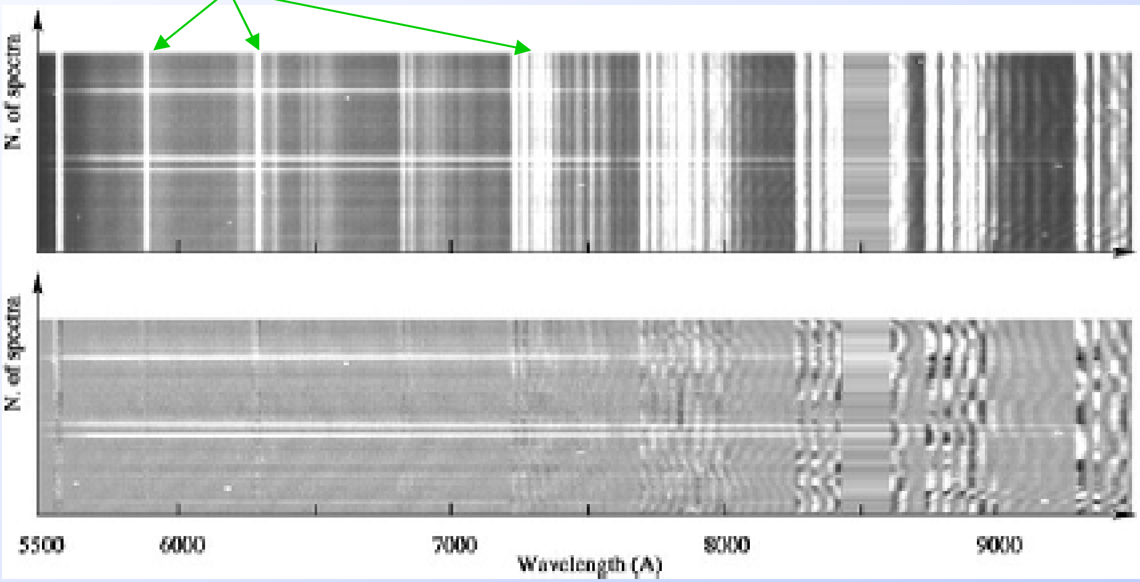
# IFU sky subtraction

When light enters a fiber the information on its spatial distribution is lost.

VIMOS IFU *does not* have sky dedicated fibers.

IFU spectra: object+sky or only sky.

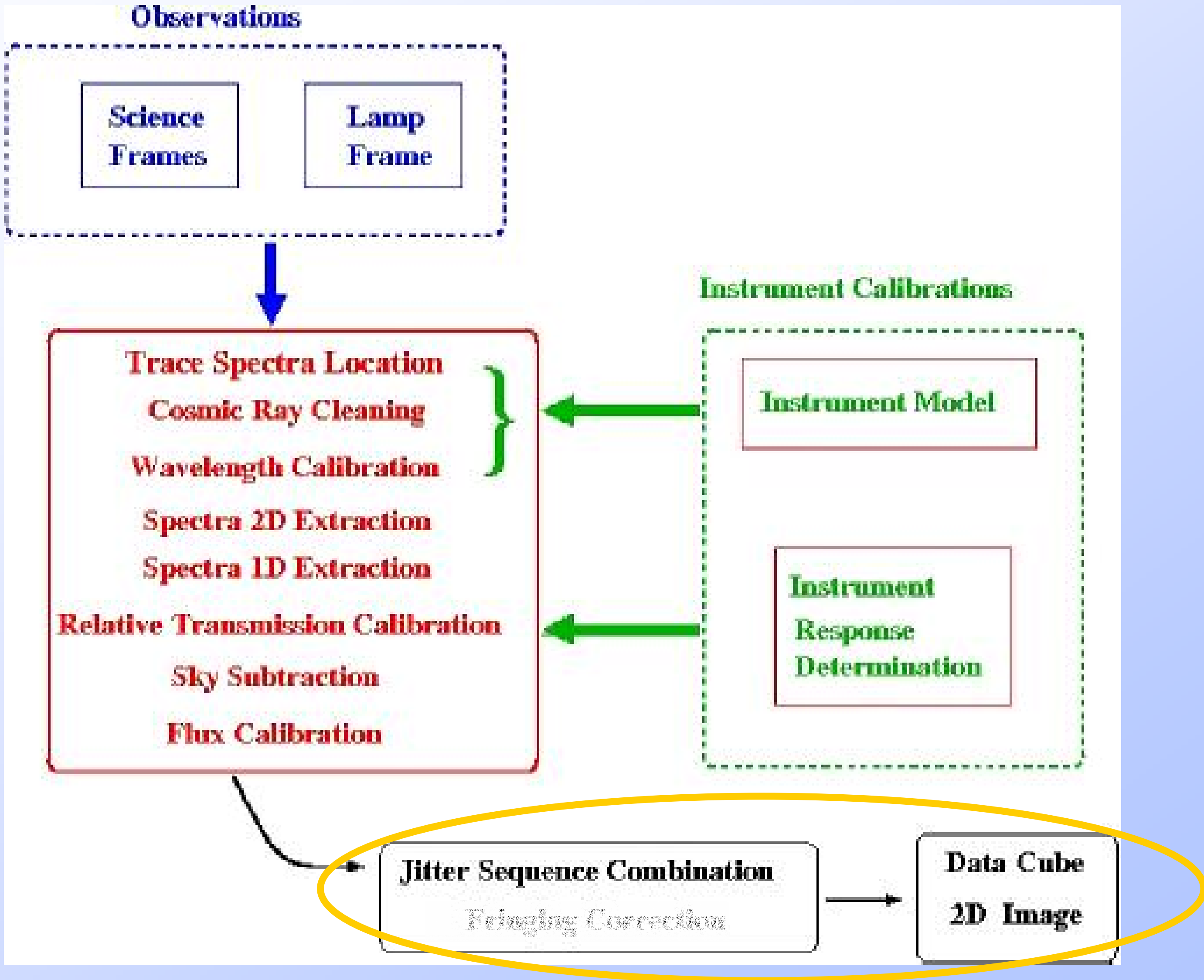
Sky lines on 1D spectra




VIPGI: select pure-sky spectra from distribution of spectral intensities: peak (sky) + tail (sky+obj) @ high fluxes.

Top: before sky subtraction.
Bottom: after sky subtraction

# Final steps...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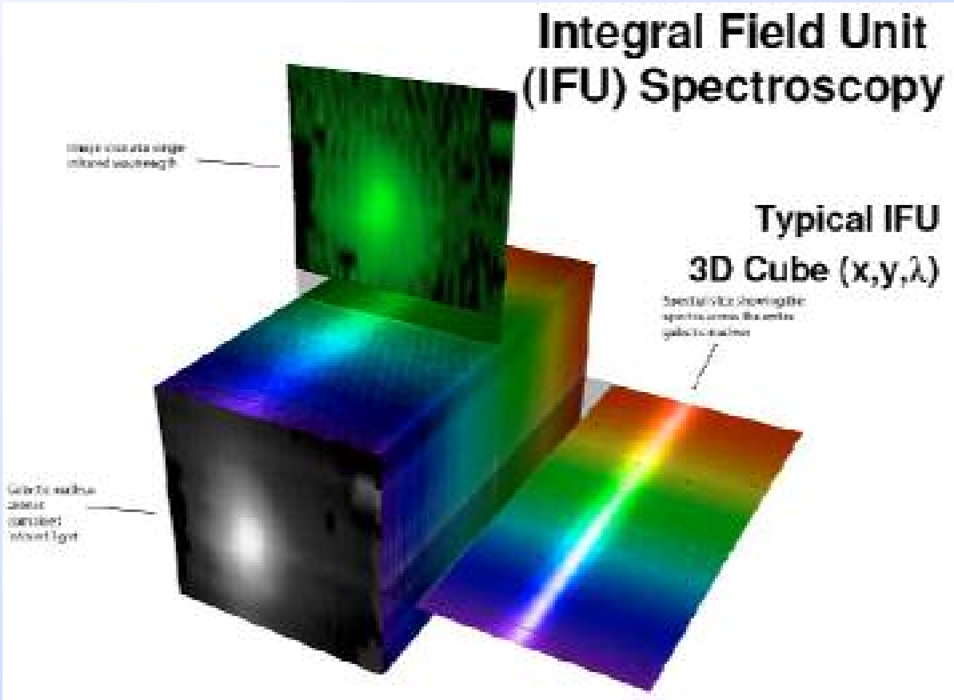
# Jitter sequence: the datacube…

**Jittering quite commonly used: stack exposures by using position offsets (warning!) and get final datacube.**



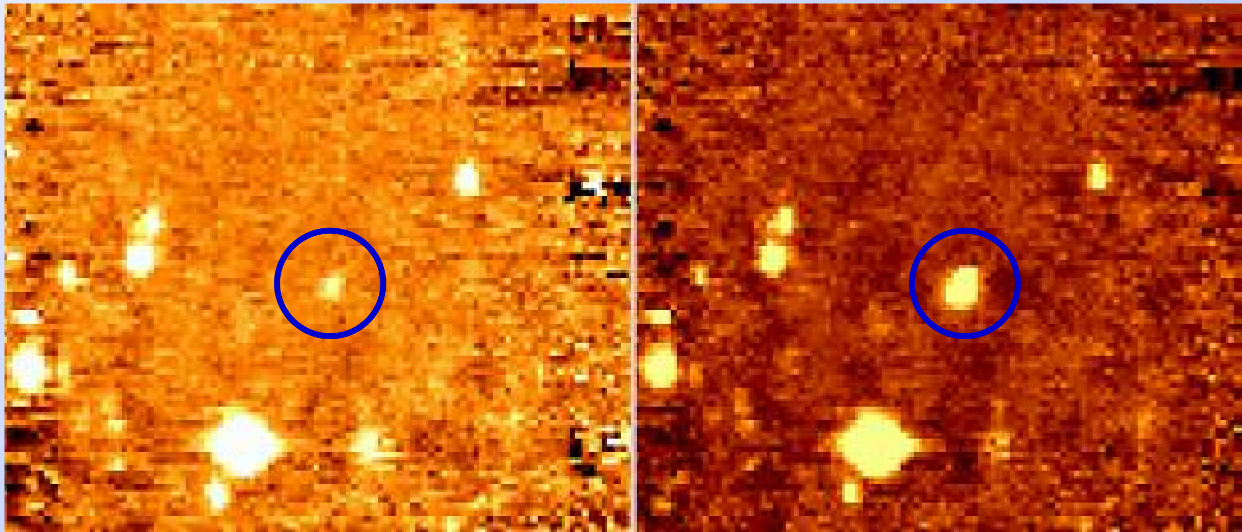
# ...and the 2D reconstructed image

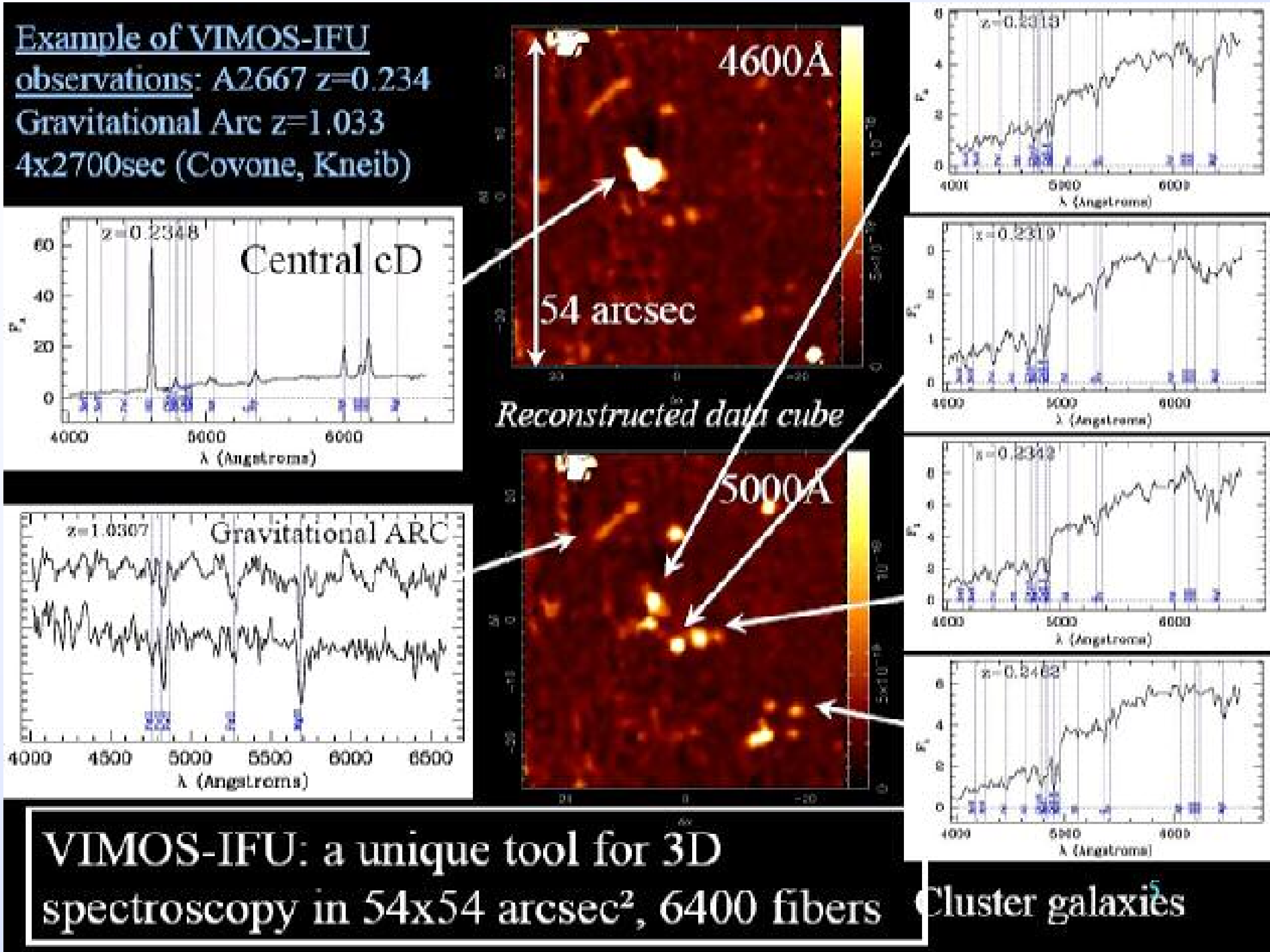
Integrate the datacube in wavelength to get 2D images.

Example: a radio galaxy at z~3 observed with VIMOS IFU, blue grism (courtesy of Matt Jarvis, University of Oxford).

**Left:** 2D image integrated over the full grism range.

**Right:** 2D image integrated over 50A around the Lya emission. The extended Lya halo is clearly visible.




Example of VIMOS-IFU observations: A2667 z=0.234
Gravitational Arc z=1.033
4x2700sec (Covone, Kneib)
z=0.2348
Central cD
λ (Angstroms)
z=1.0307
Gravitational ARC
λ (Angstroms)
4600Å
54 arcsec
Reconstructed data cube
5000Å
z=0.2313
z=0.2319
z=0.2342
z=0.2462
VIMOS-IFU: a unique tool for 3D spectroscopy in 54x54 arcsec², 6400 fibers
Cluster galaxies

# Available pipelines

ESO pipelines for VLT IFUs are available at:

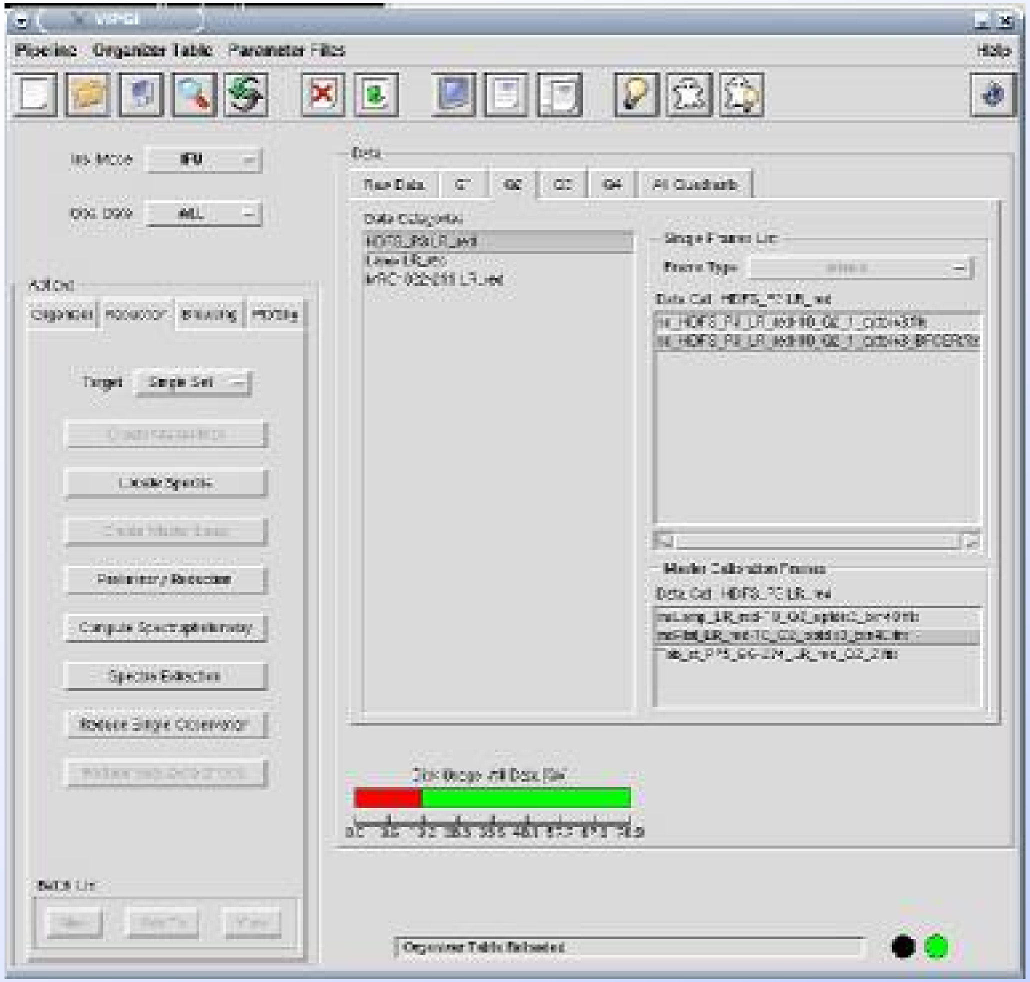
http://www.eso.org/observing/dfo/quality/pipeline-status.html

- Create master calibration data
- Reduce science frames
- Extract quality control information from the data

FLAMES/GIRAFFE: no sky subtraction supported.

VIMOS IFU: sky subtraction, jitter mode and fringing correction not supported. Master flux calib. only.

# VIPGI pipeline




Developed by the VIRMOS Consortium.

Supports all VIMOS observing modes and all reduction steps.

http://cosmos.iasf-milano.inaf.it/pandora/vipgi.html

# What next? Scientific analysis

No “official” tools for data visualization and analysis.

Existing analysis tools for IFU data:

GIPSY (Groeningen Image Processing System)

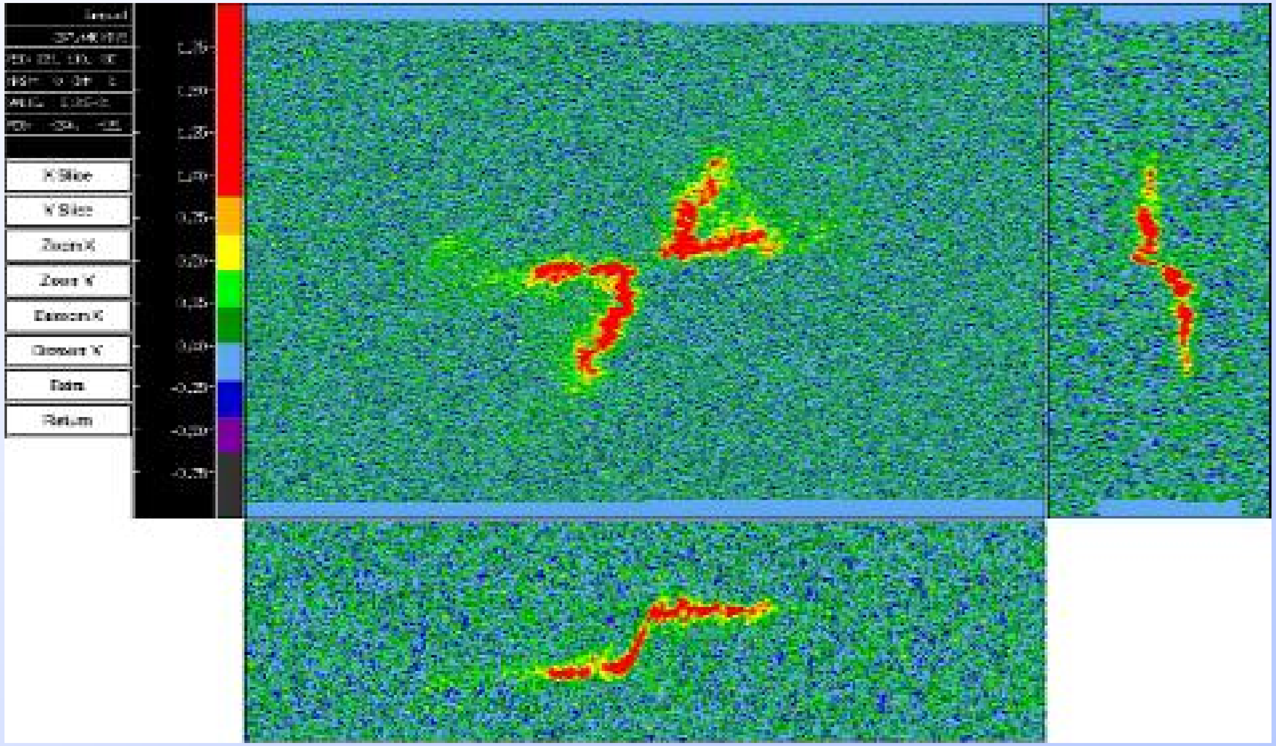
QFitsView (Thomas Ott, MPE)

Karma (ATNF)

...

# GIPSY

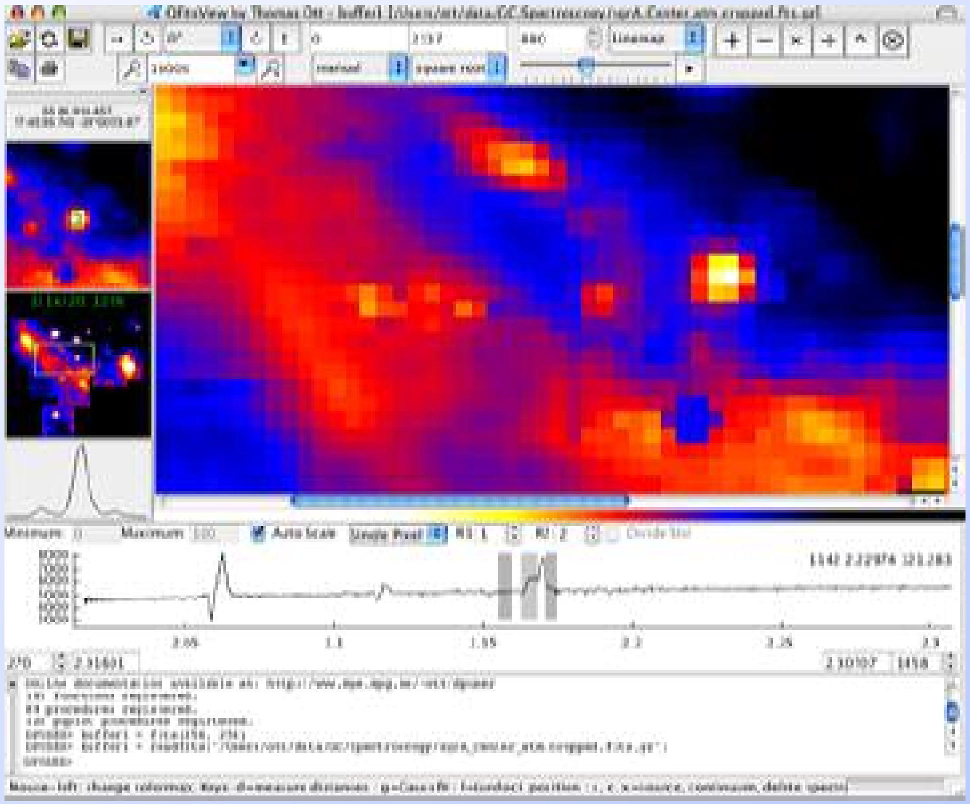
**Highly interactive, supports Python scripts, designed for WSRT data reduction and analysis.**



http://www.astro.rug.nl/~gipsy/

# QFitsView

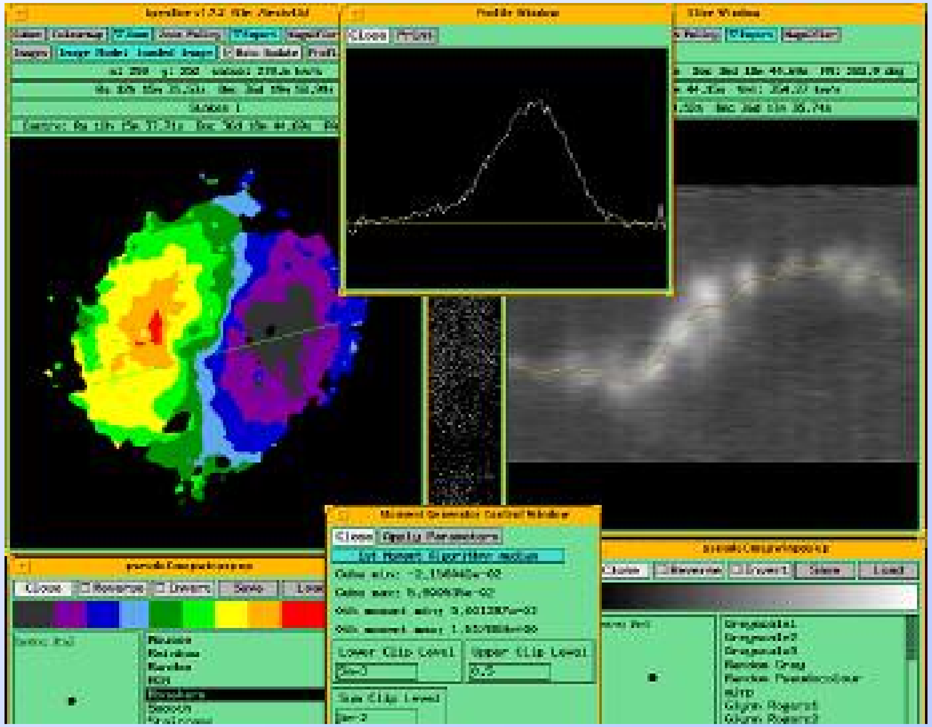
**Powerful visualization tool with analysis capabilities.**



http://www.mpe.mpg.de/~ott/QFitsView

# KARMA

**Highly interactive, powerful visualization tool.
Analysis tasks available.**



http://www.atnf.csiro.au/computing/software/karma/

# Conclusions

Integral Field Spectrographs are very powerful tools for a number of scientific investigations.

Data reduction quite complex w.r.t. classical (multi)slit spectroscopy, very careful calibration needed.

Pipelines and science analysis tools now available.

Don't hesitate: try them!