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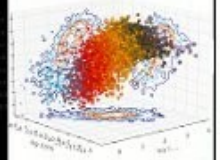
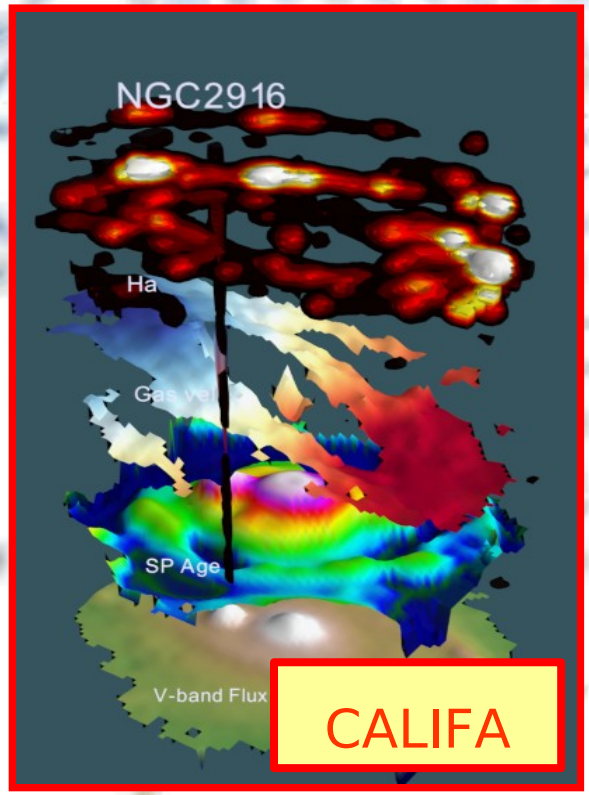
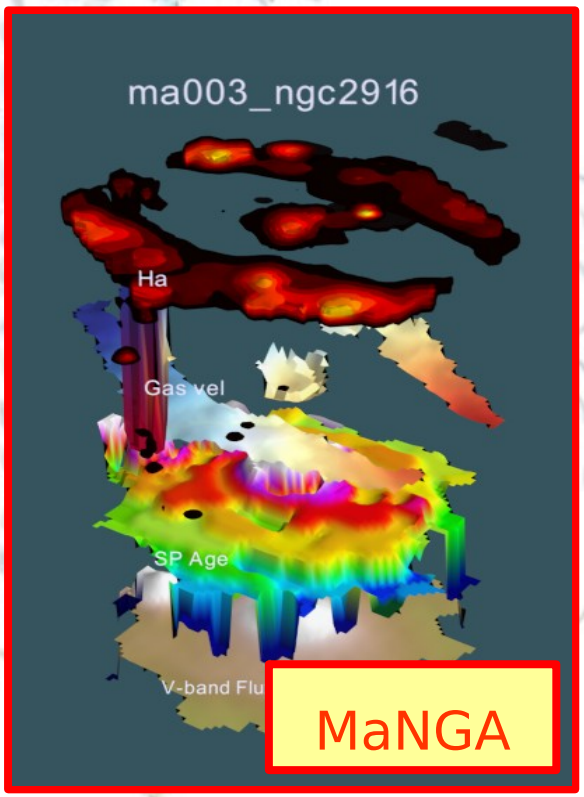


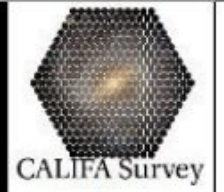
Notes on Integral Field Spectroscopy (IFS/3D)

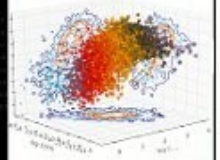
Sebastián F. Sánchez / IA-UNAM





- GH2014, IFS School, INAOE -





IFS or 3D Spectroscopy

- Is the spectroscopic technique that samples a quasi-continous area in the sky (FOV).
- The FOV is sampled by small aperture elements named spaxels, which correspond to pixels of an image.
- Light coming through each spaxel is transported to the entrance of an spectrograph.
- The image/plane and focal/plane are completely decoupled: Lot of software is required to reconstruct the orginal spatial shape at each wavelength

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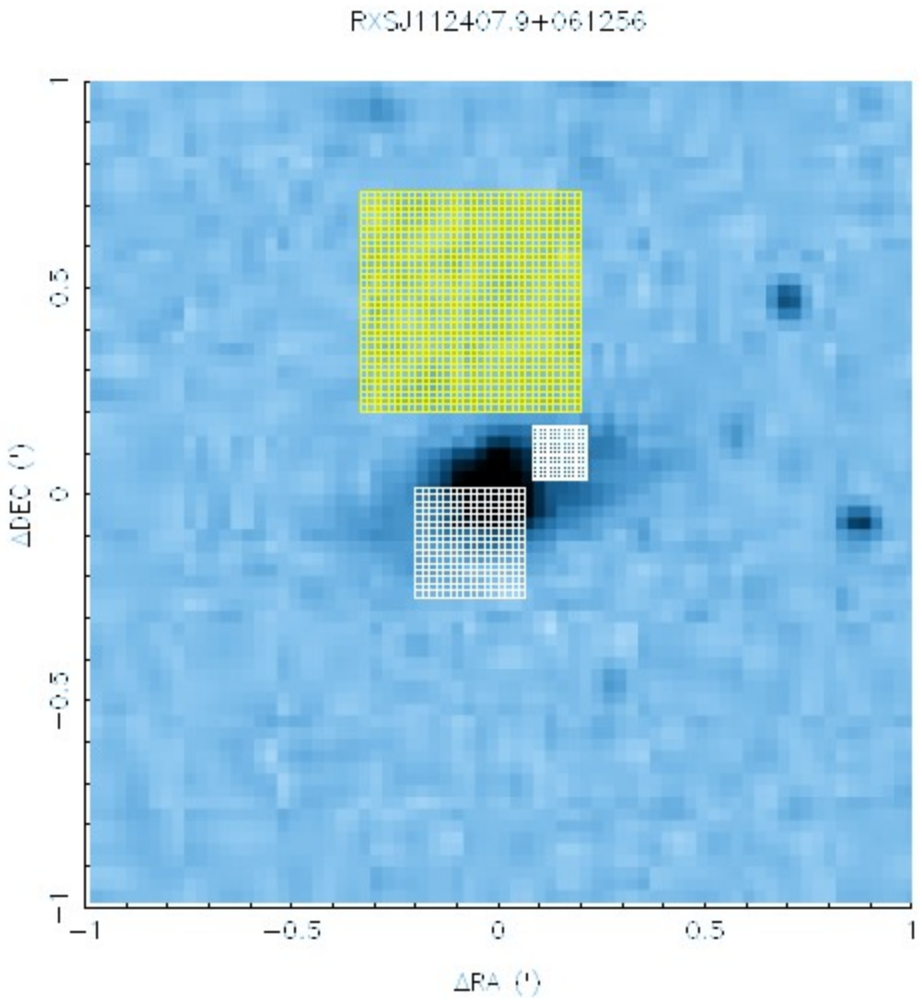
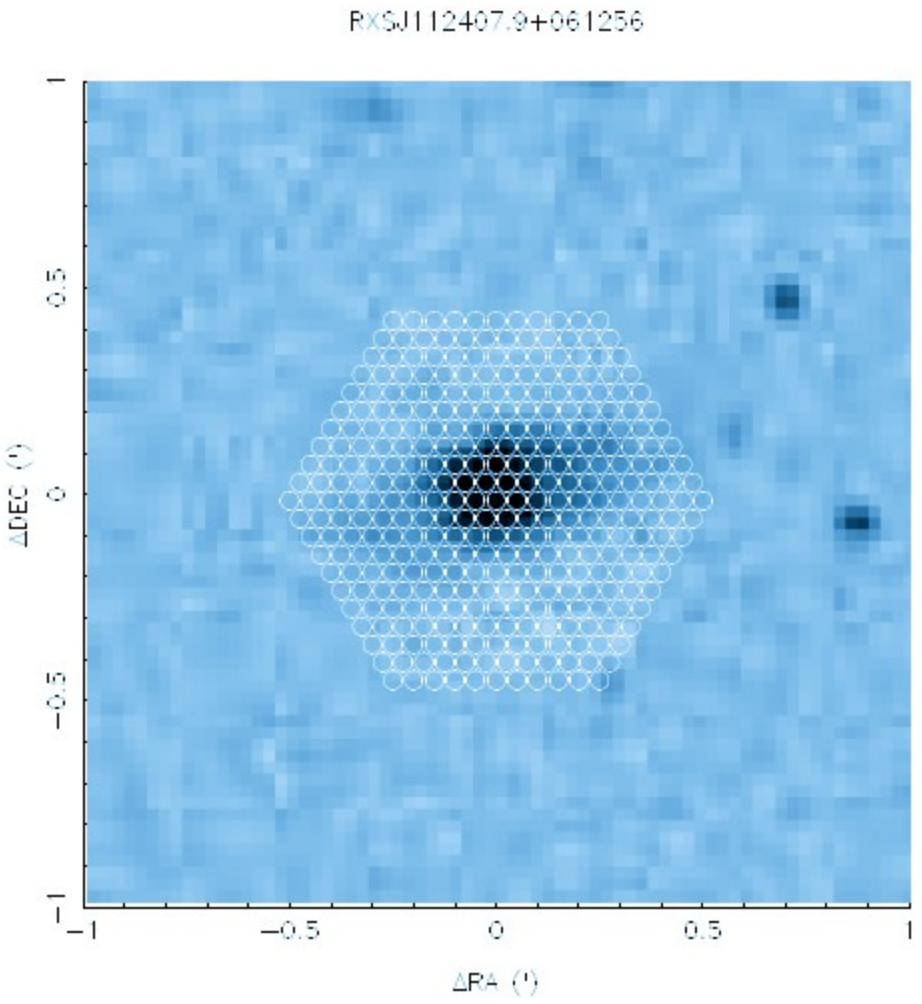
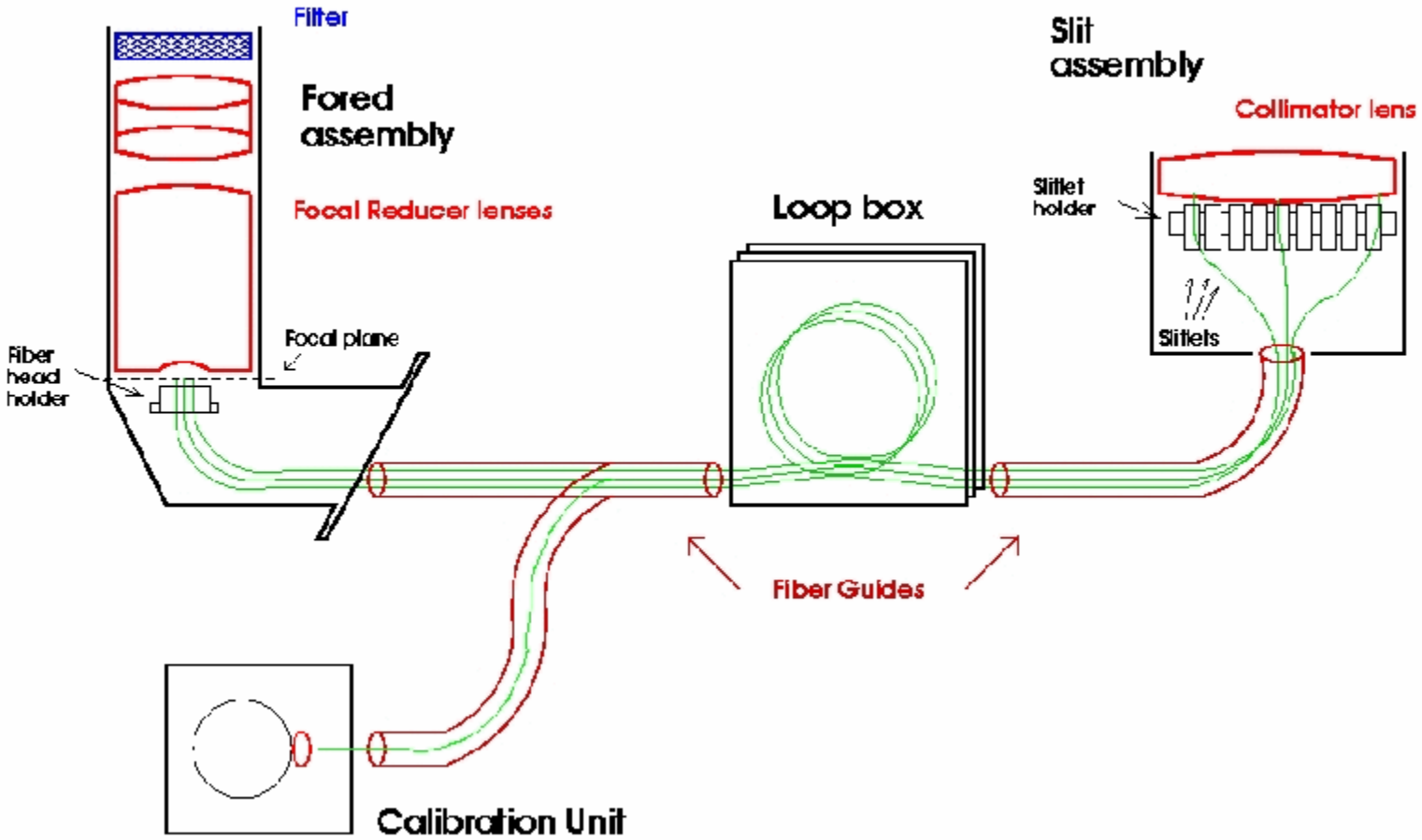
Different kind of spaxels.





PPAK schematics



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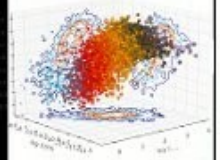
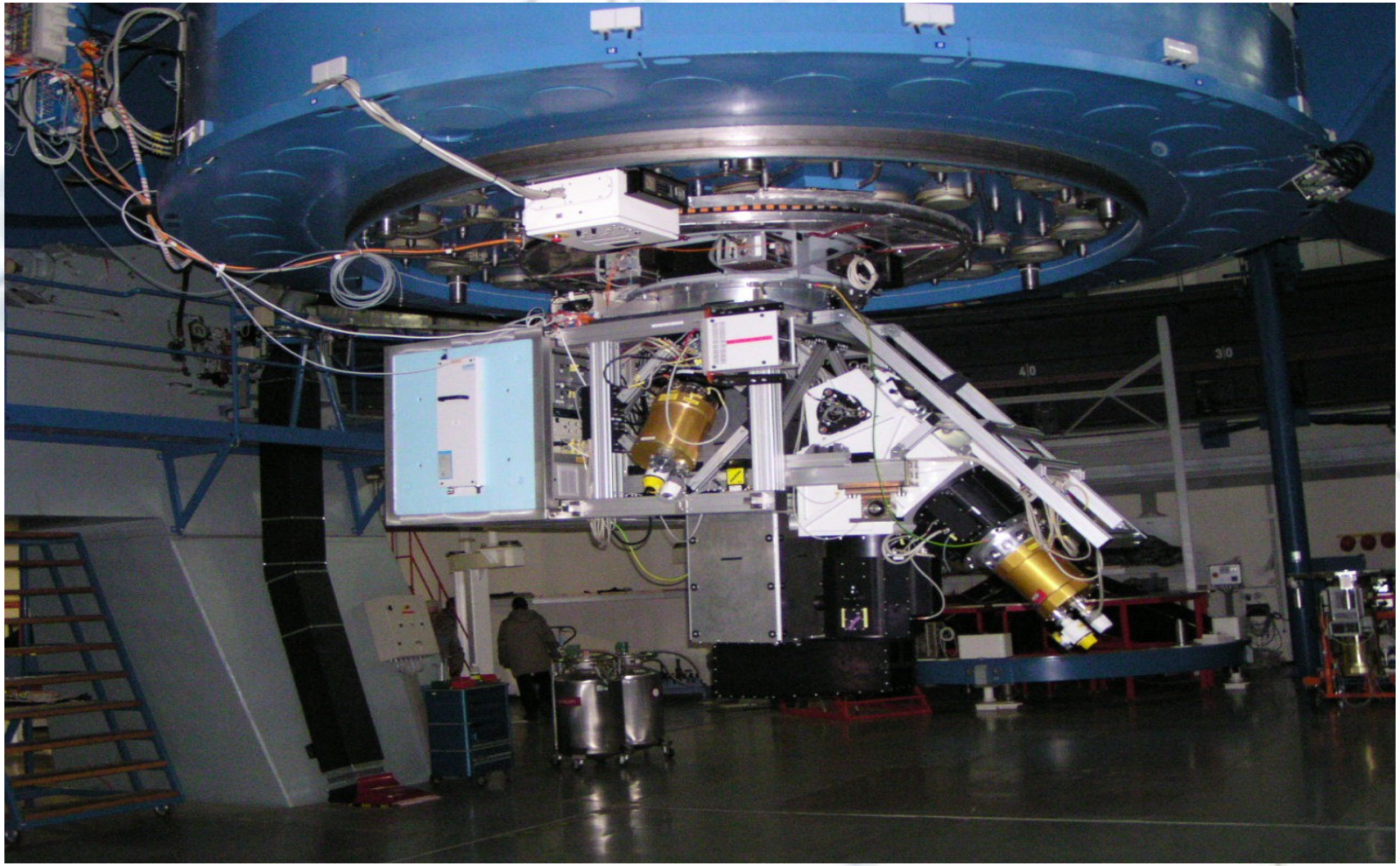


Fiber Feed IFS technique: Raw Data and Reduction



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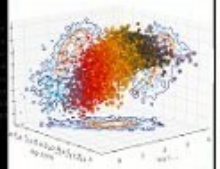
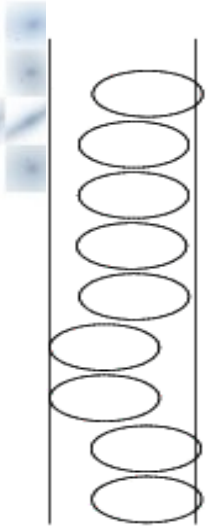
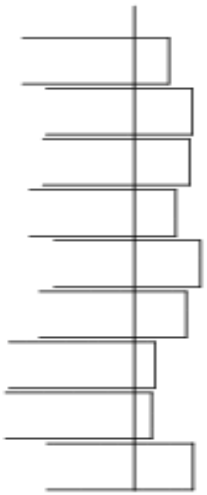
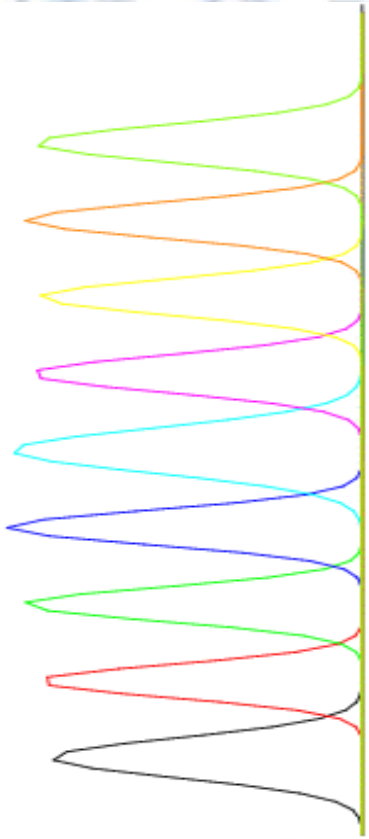
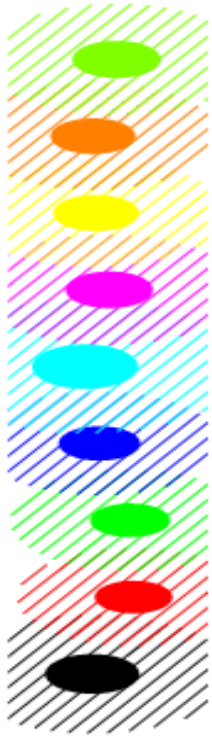
The Raw data of FF IFUs











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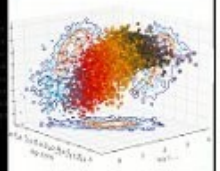
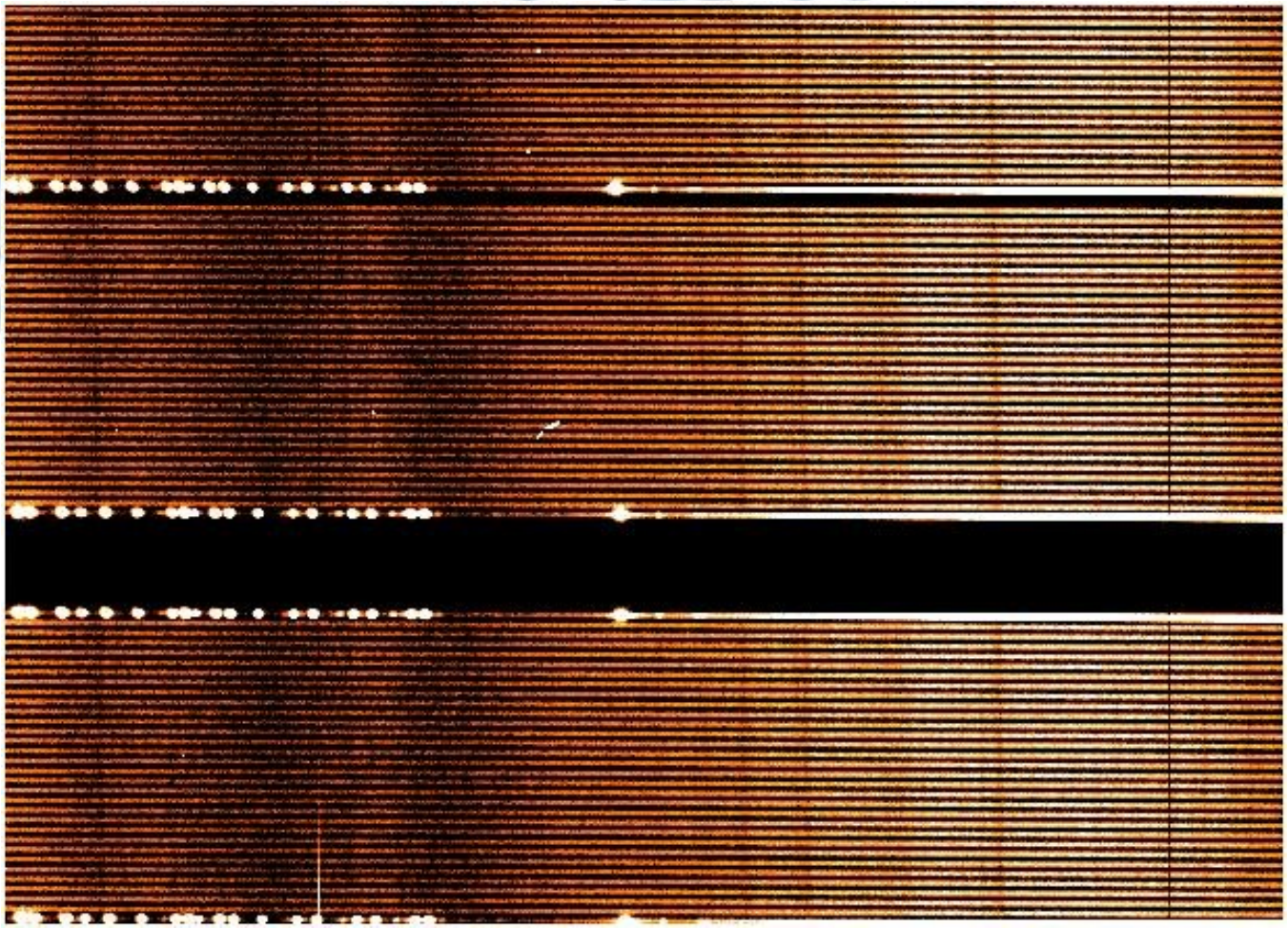
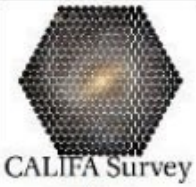
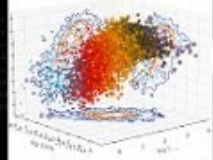


The Raw data of FF IFUs







FF IFU: Data Reduction

- IRAF / Hydra package.
- P3D: IDL, stand-alone (@aip).
- R3D: Perl/C (@caha).
- Py3D: Python (@aip/ESO).
- Your own tool!

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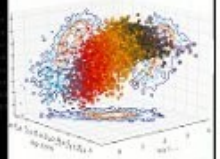

FF IFU: Data Reduction (I)

- Continuum exposure used to find and trace the location of the spectra in the CCD.
- Bias substraction. CCD flat performed.
- Straylight corrected.
- The FWHM of the spectra projected in the cross-dispersion axis determined.
- Gaussian extraction performed.
- Comparison Arc used to determine the distorsion correction and wavelength solution, latter applied to the data.

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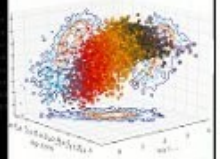

FF IFU: Data Reduction (II)

- Sky-frames taken during the twilight used to correct for the differentical transmission fiber to fiber (wavelength dependent).
- Spectrophotometric calibration standard star exposure used to determine the flux calibration, applied to the science frames.
- Science (331), Sky (36) and calibration spectra (15) are separated in different frames, once reduced.
- Sky spectrum is derived for each frae (median+3sigma clipping of the 36 sky-spectra) and the subtracted to the data.

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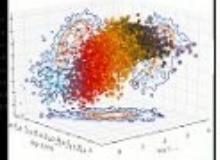

FF IFU: Data Reduction (III)

- Re-arrange the dithered pointings in a single RSS frame, plus the complementary Position Table.
- Mask the spectral pixel strongly affected by the vignetting.
- Interpolate the final Mosaic into a common grid datacube of 1”/pixel.
- Correct for the Differential Atmospheric refraction
- If needed, perform a flux recalibration based on broad-band photometry.

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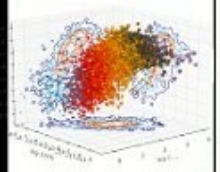
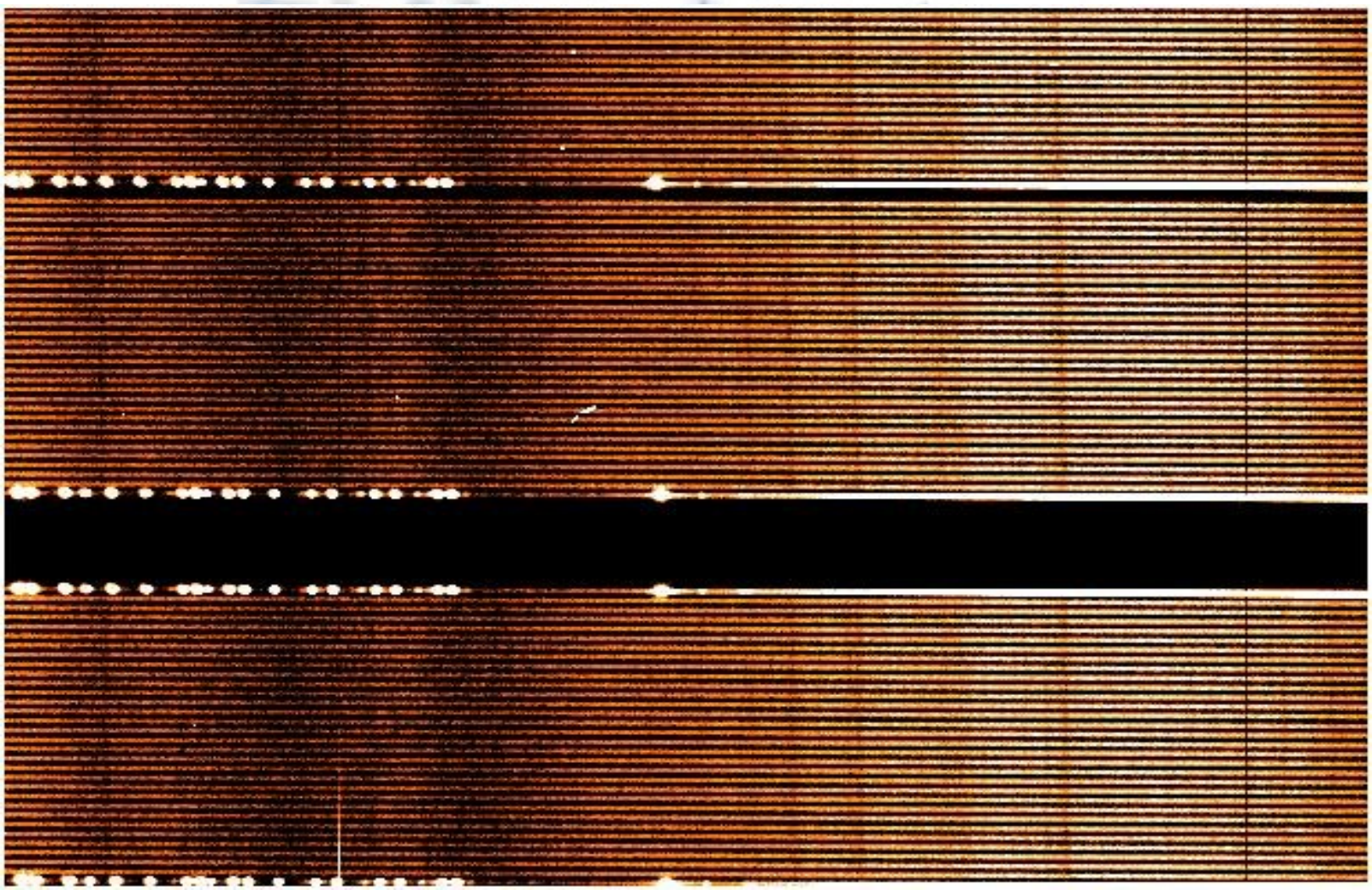


The Raw data of FF IFUs



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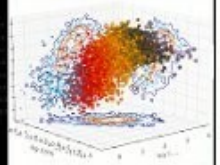
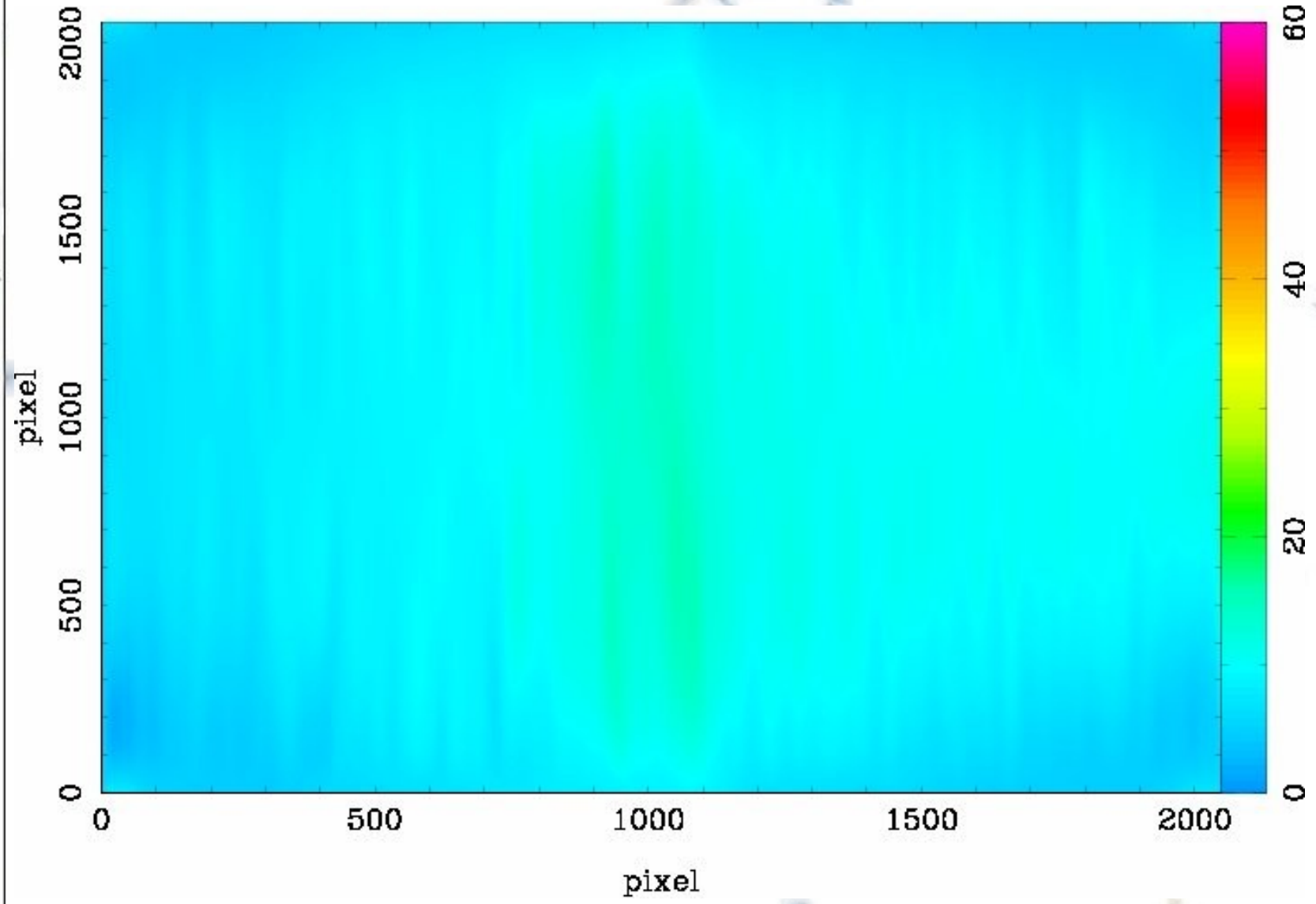


Stray-Light



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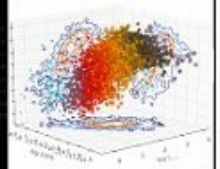
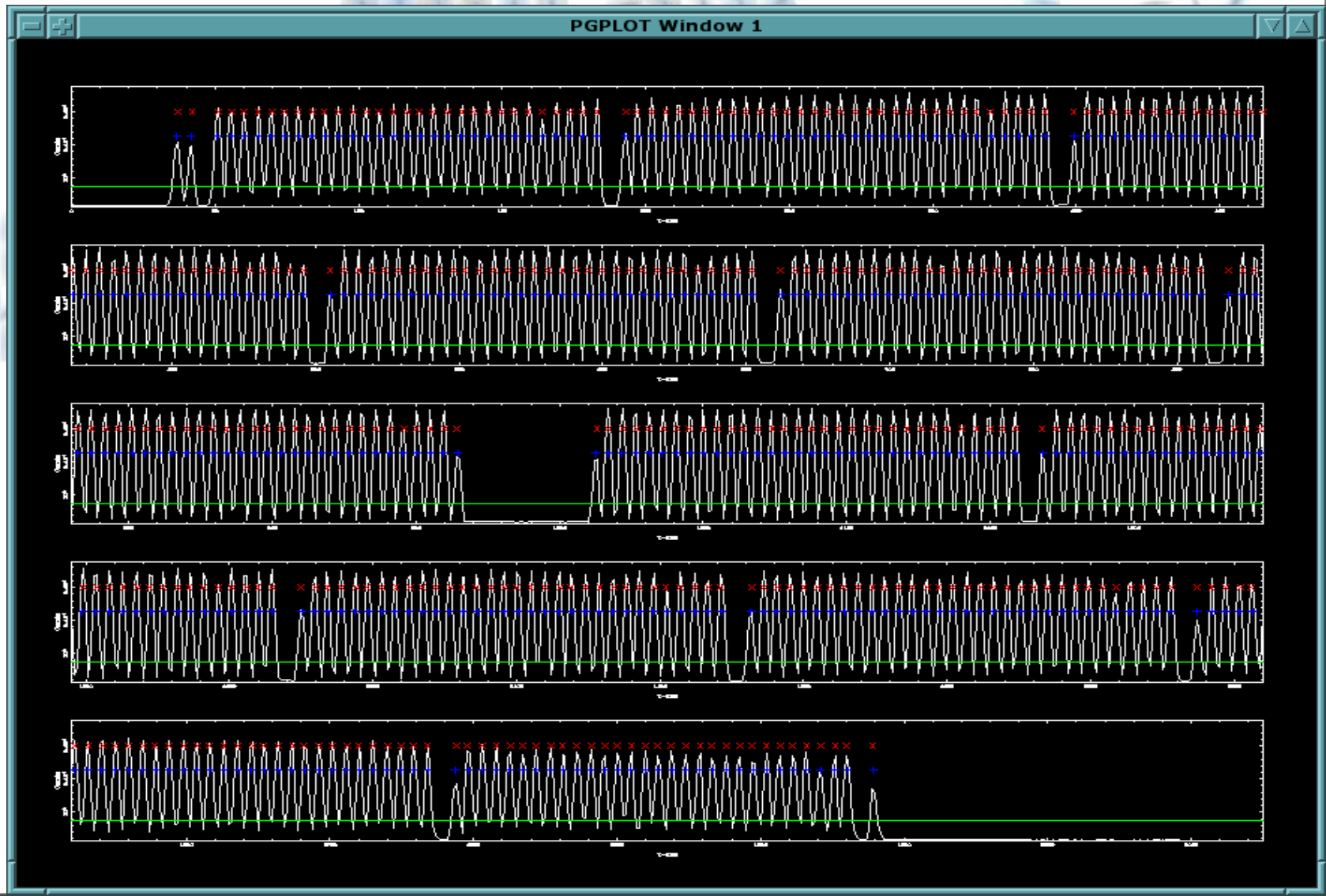


Tracing process (I)



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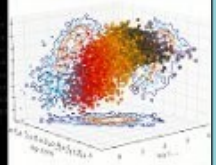
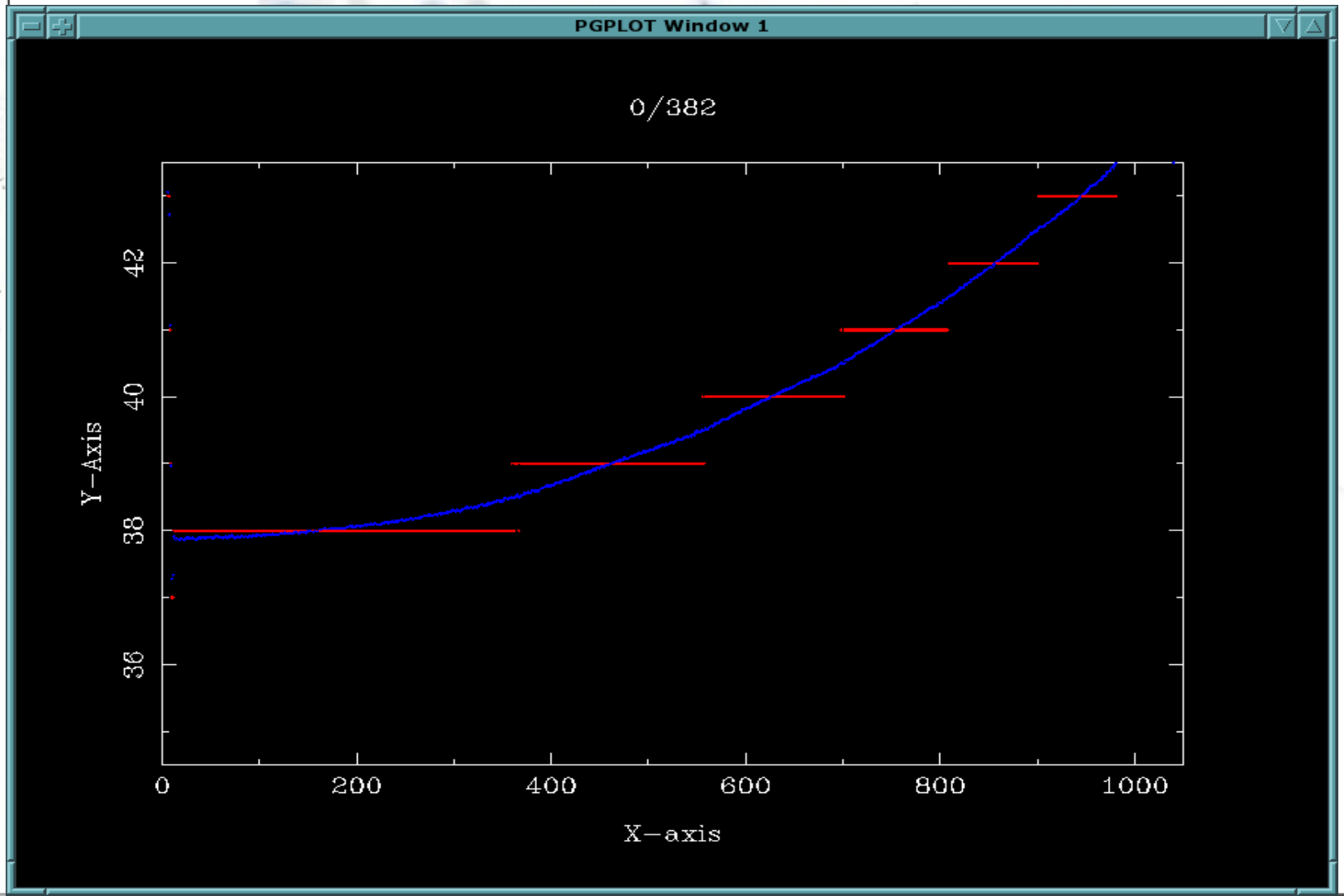


Tracing process (II)



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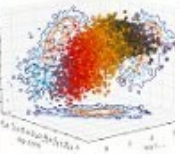
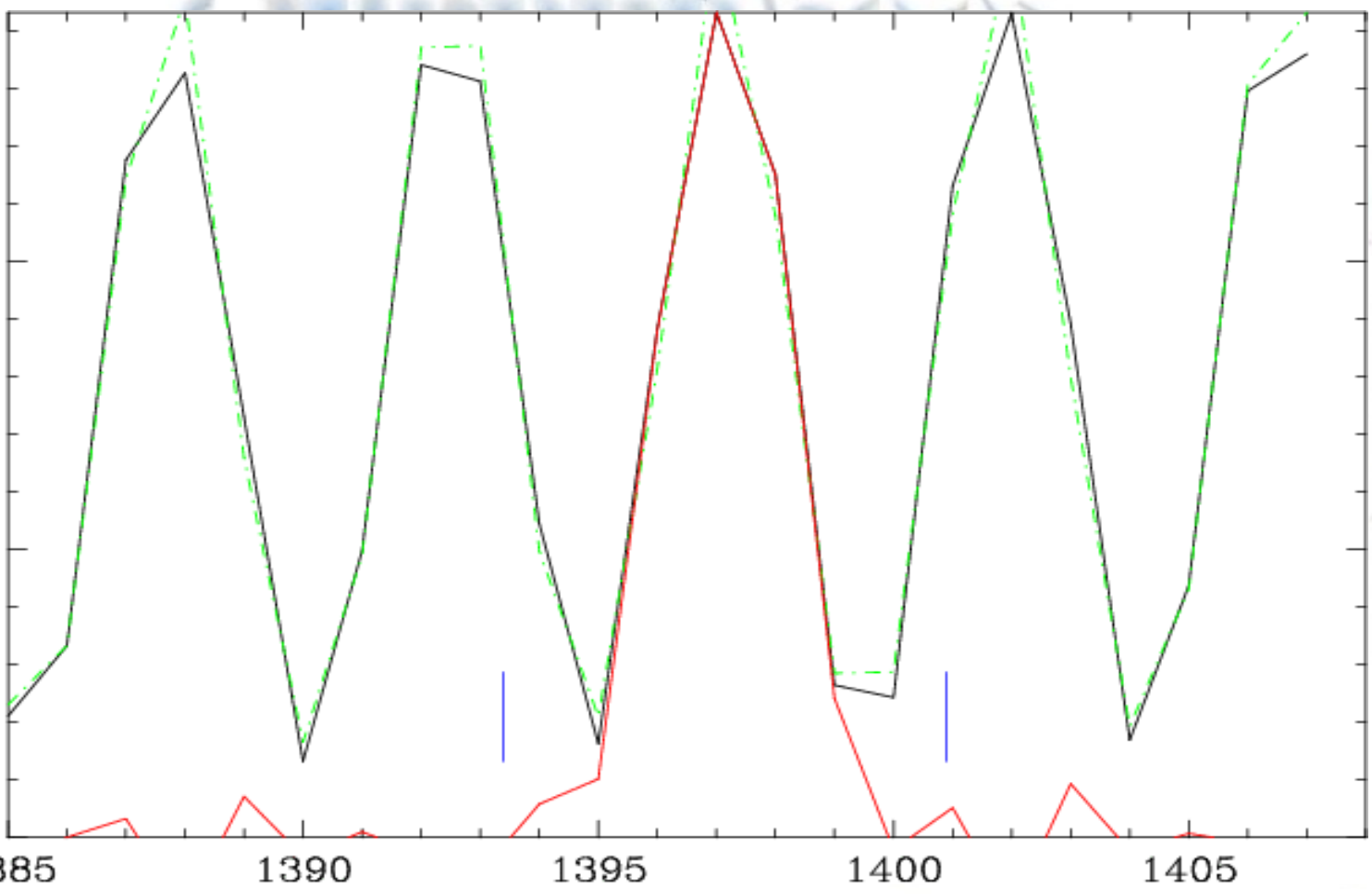
Extraction & Cross-Talk: How to Add flux?





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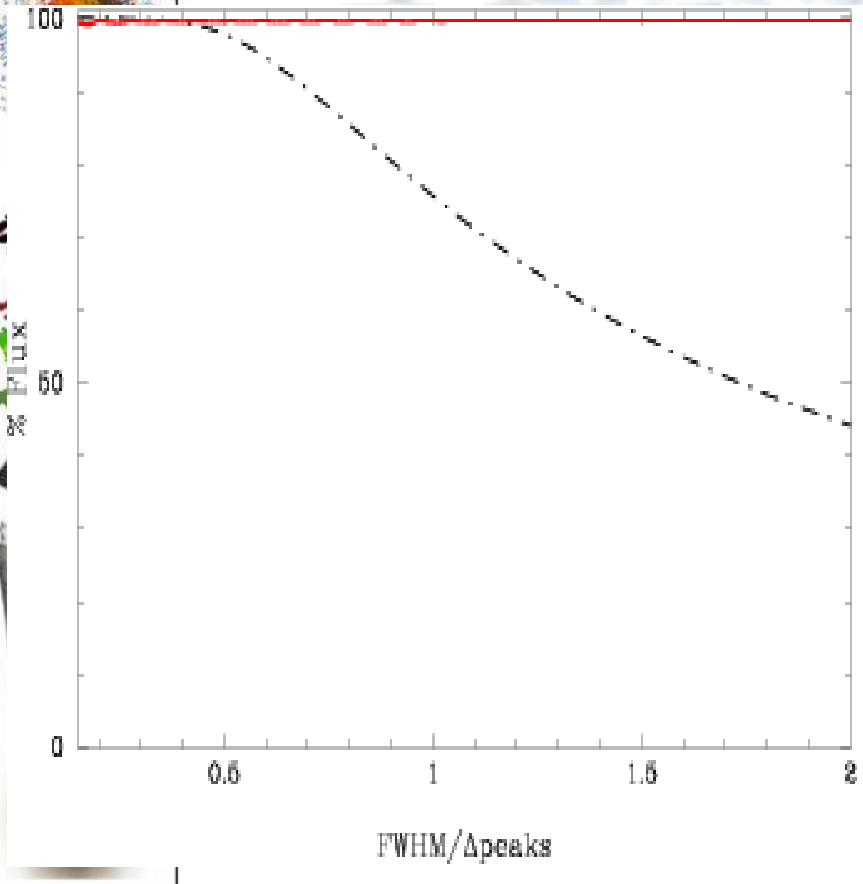
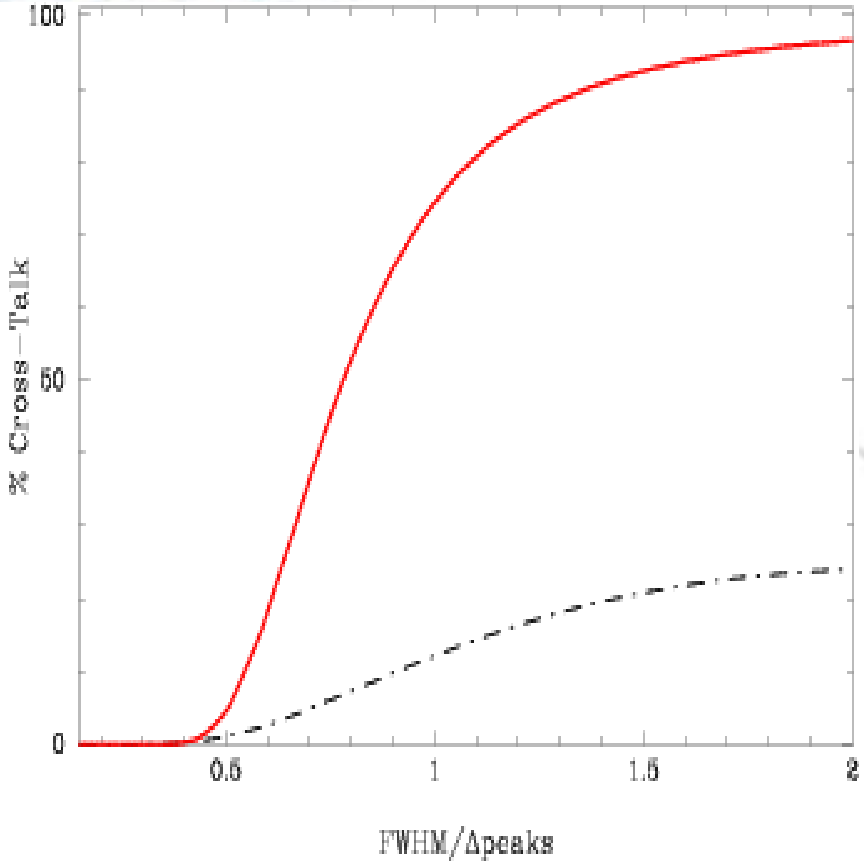
Extraction: cross-talk?





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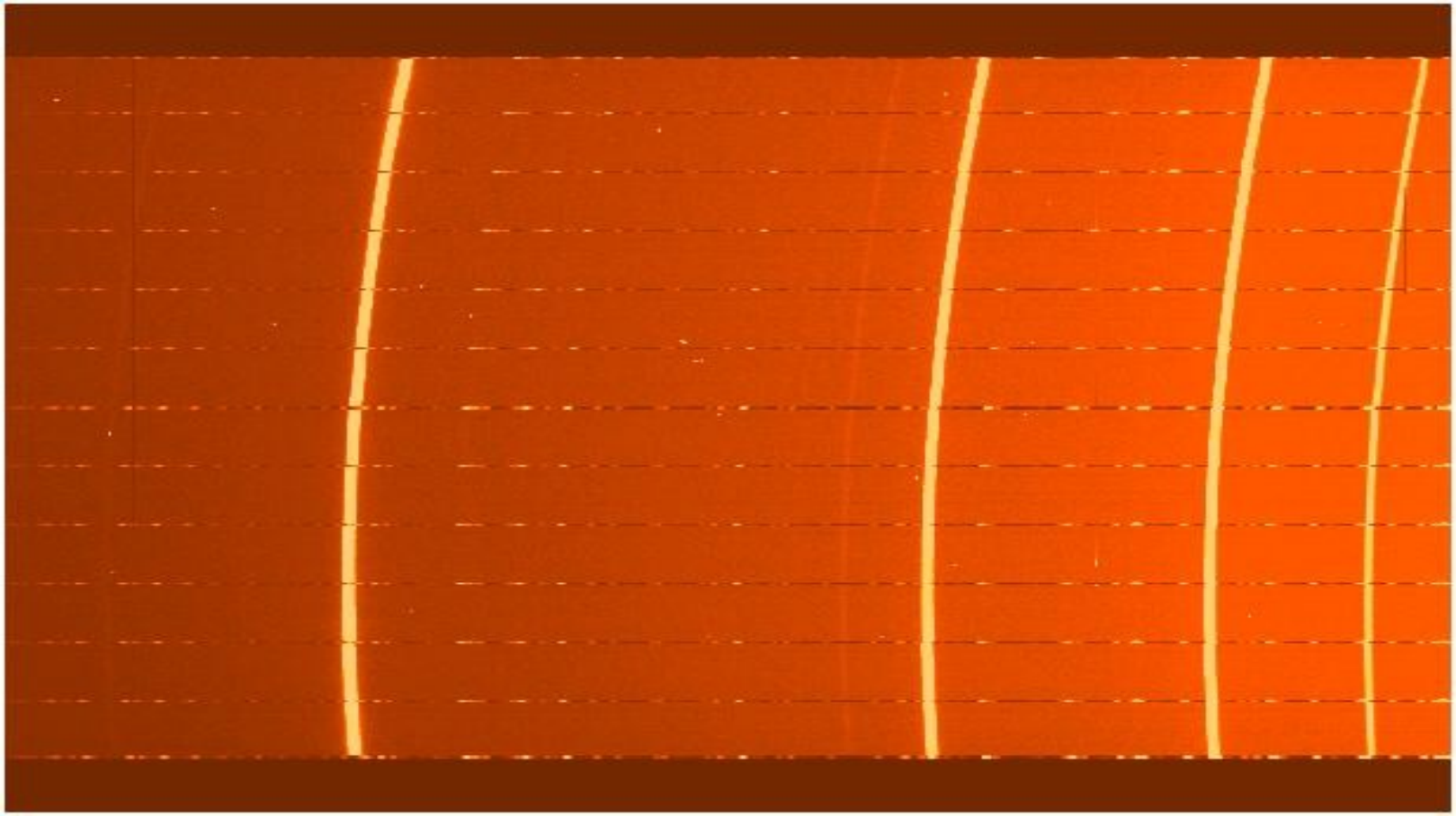
Extraction: The final product



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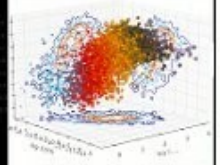
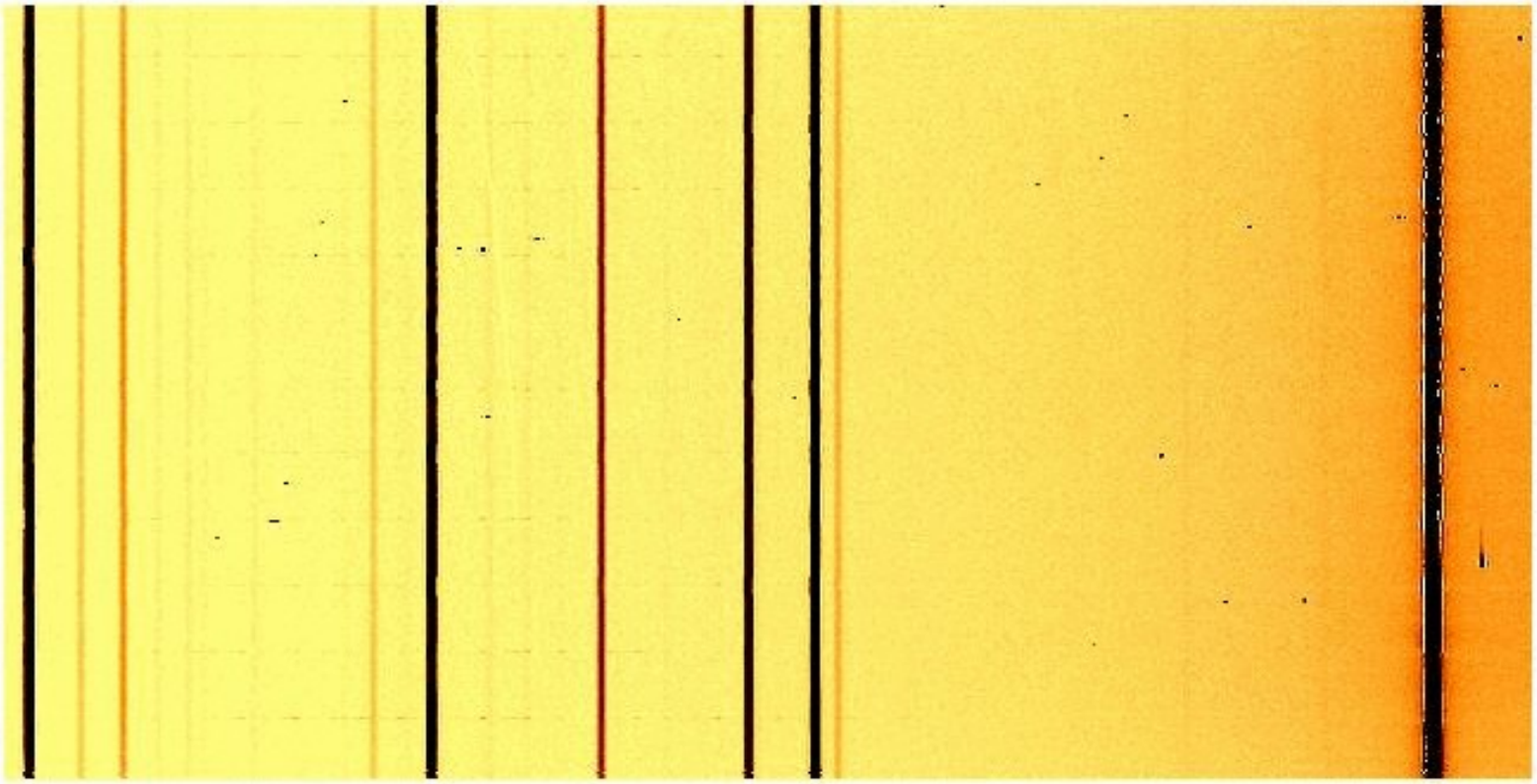


Distorsions: Shifting lines.



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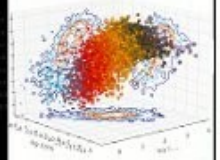
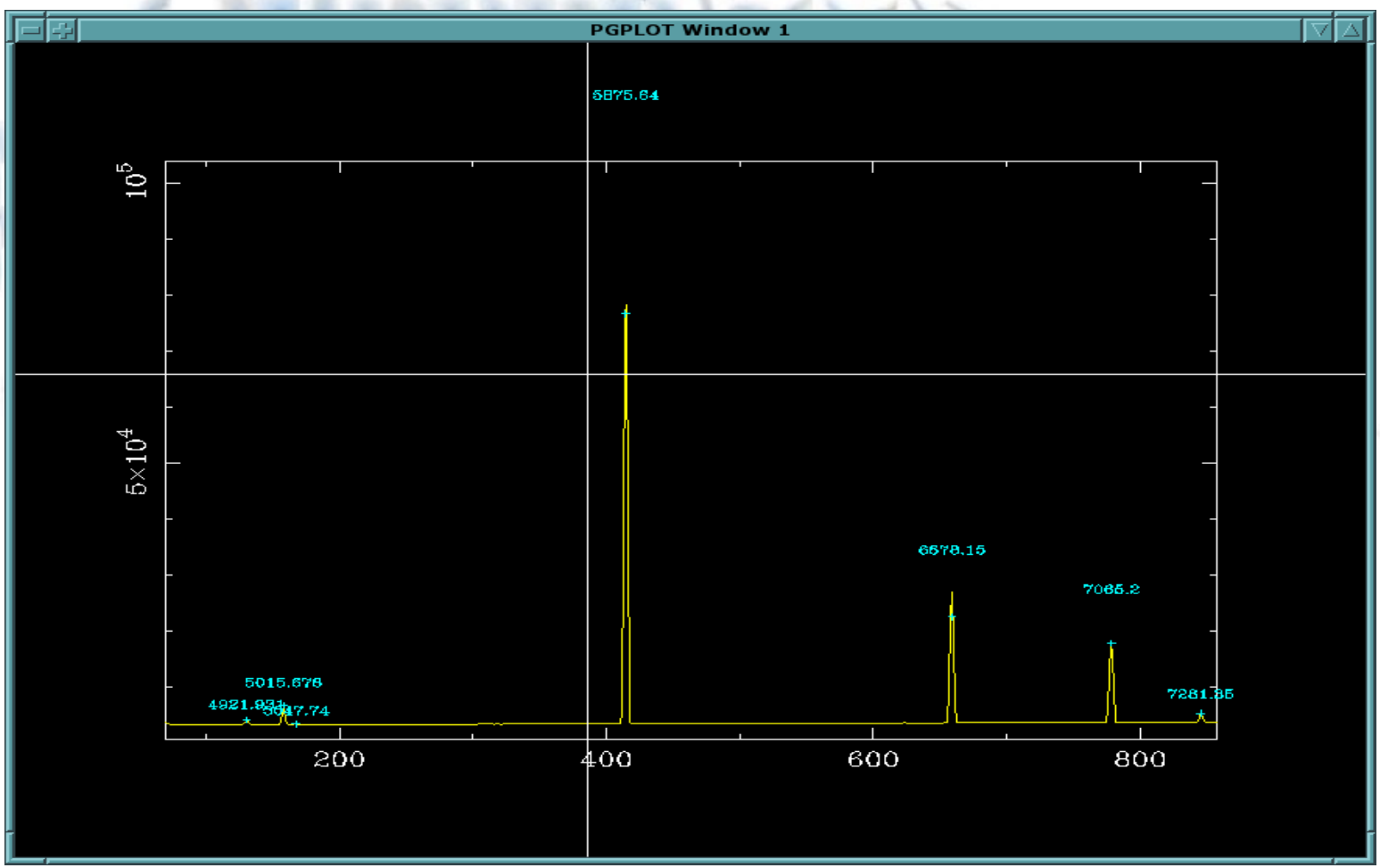


Dispersion:Which line are you?



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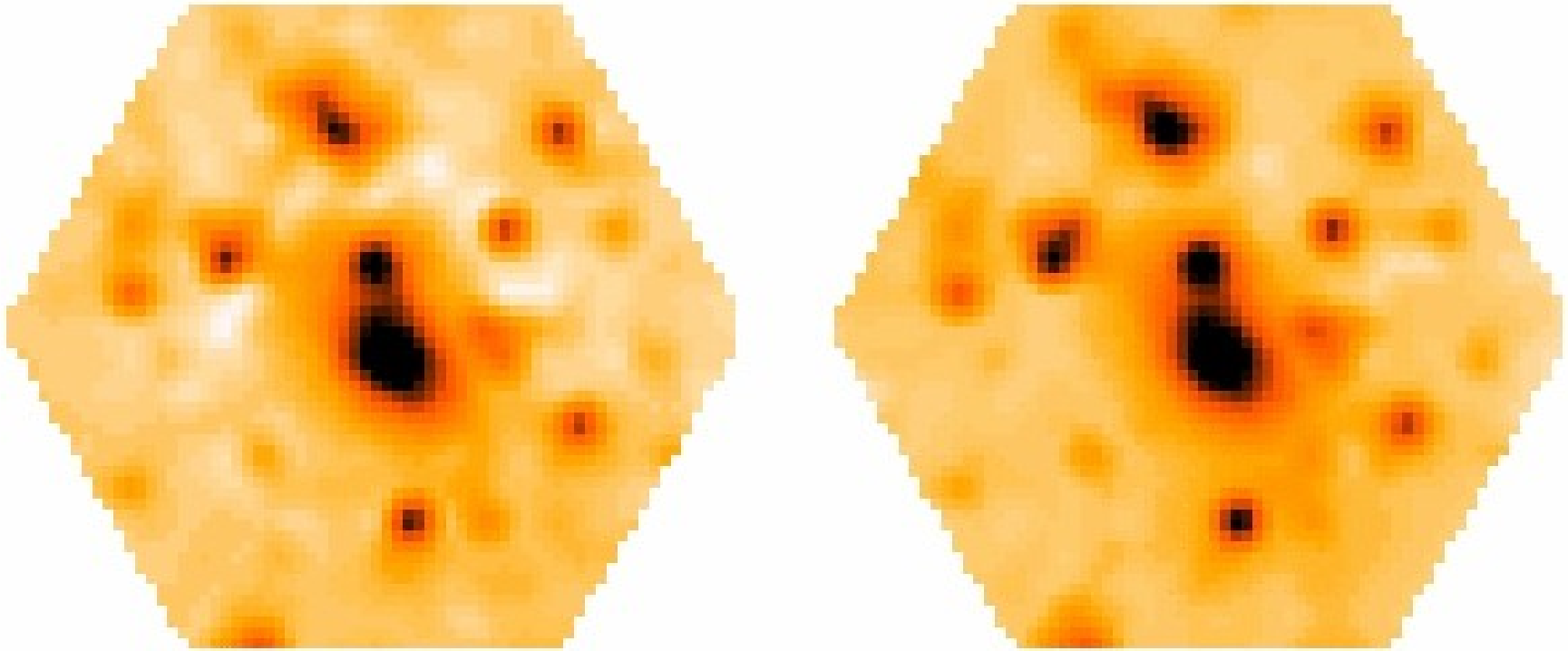
Fiber-to-Fiber transmission



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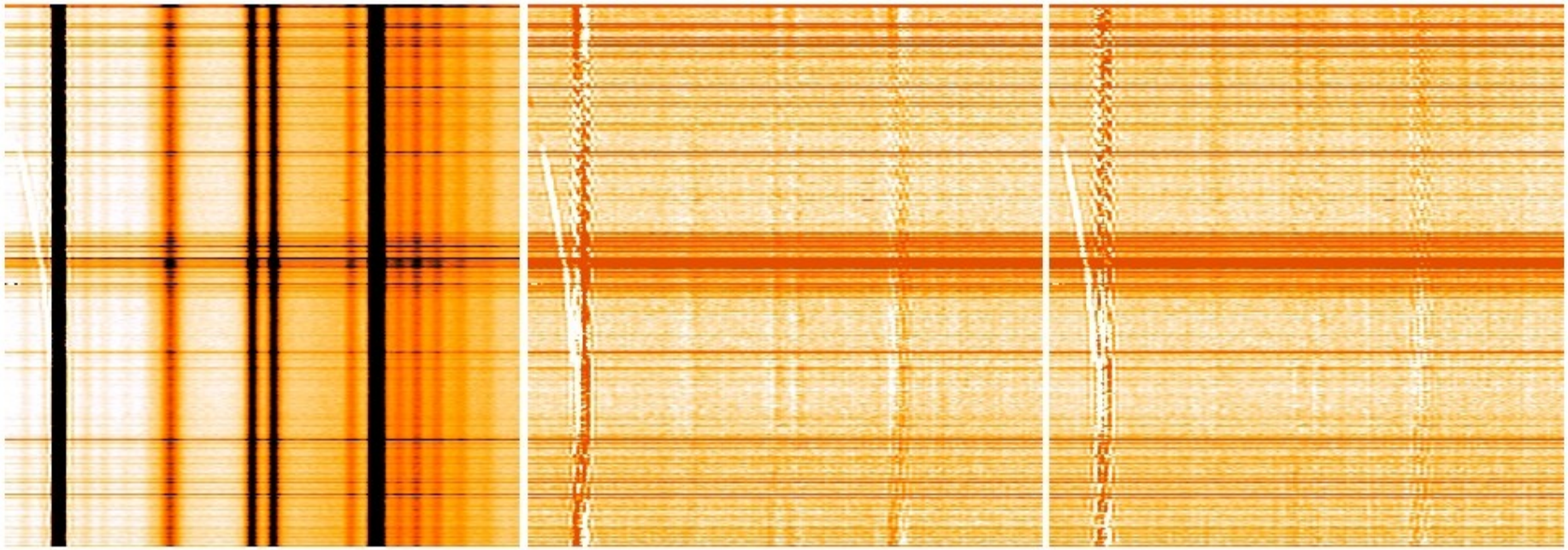
Sky subtraction... If possible.



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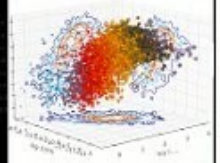
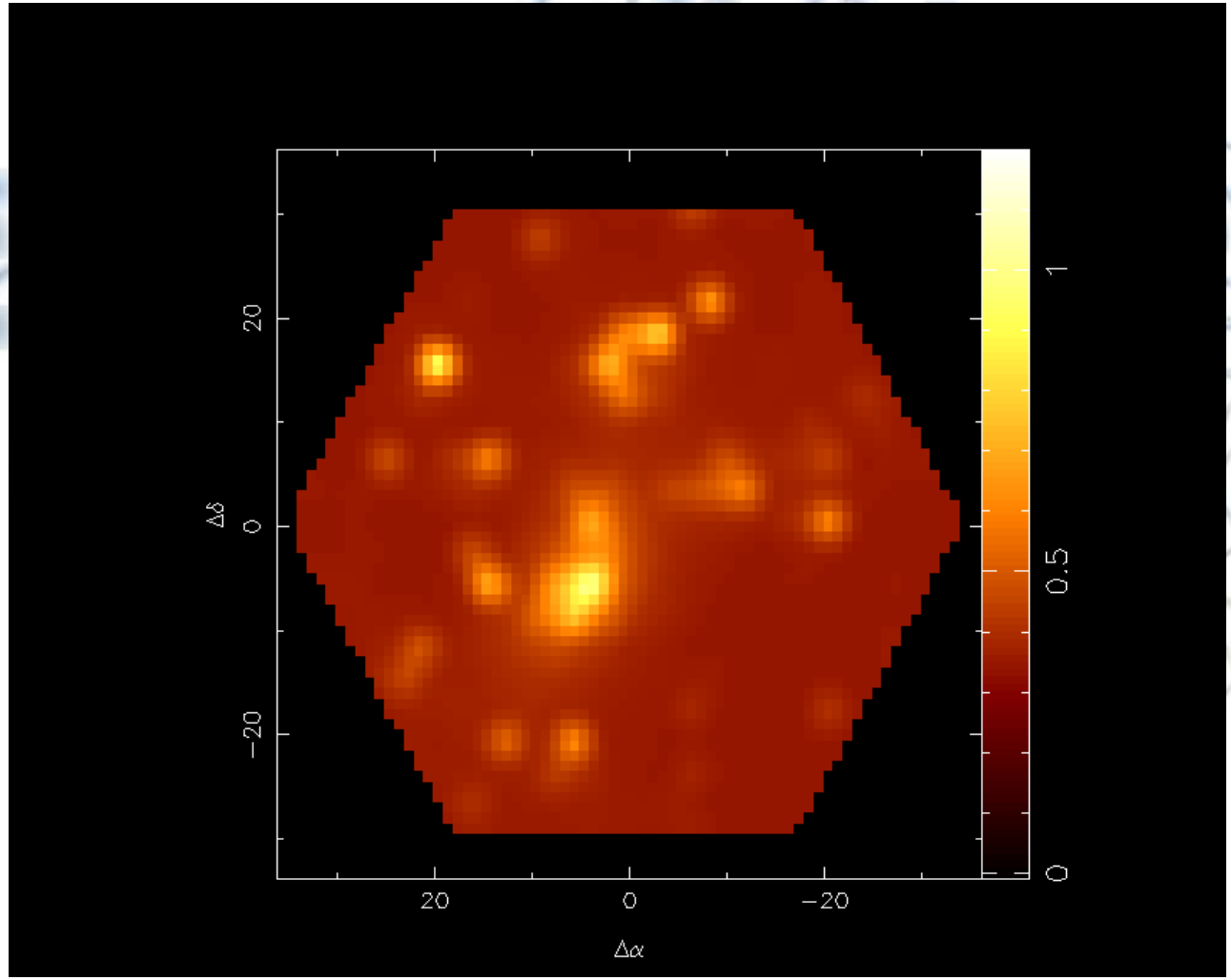


Where my spectra comes from?.



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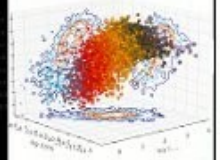
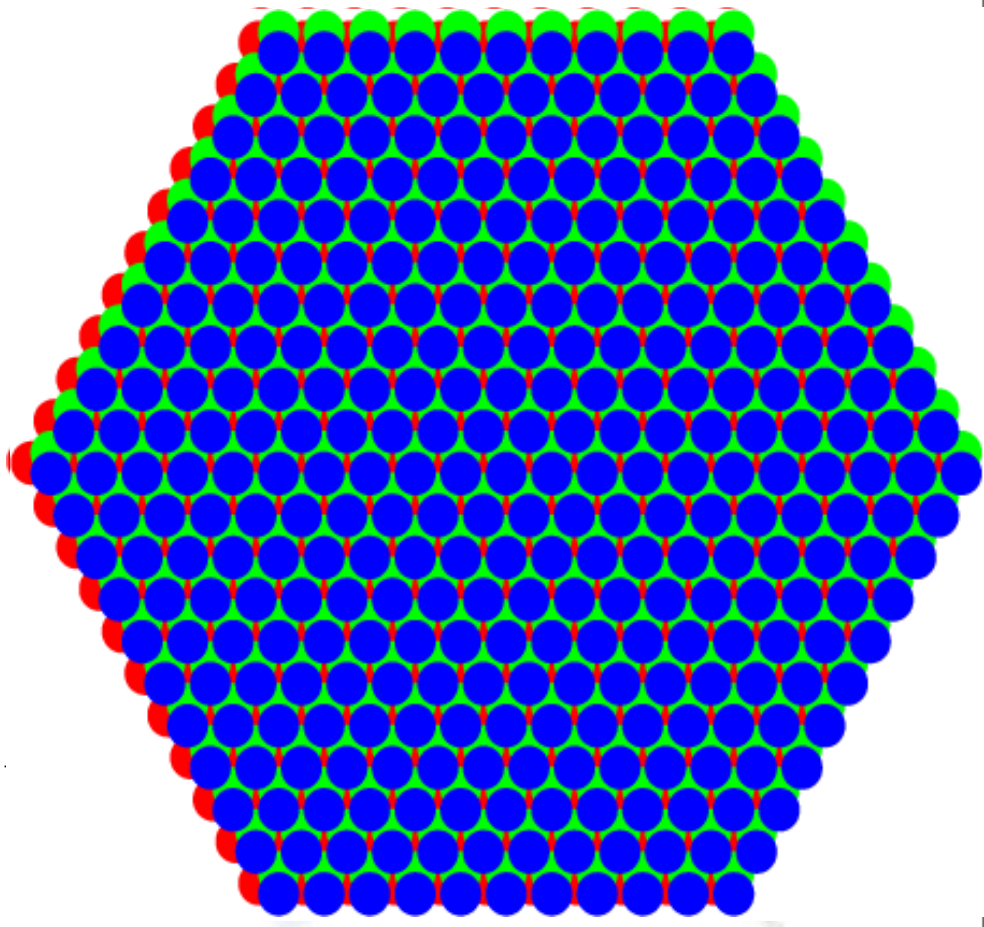
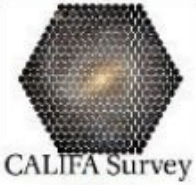
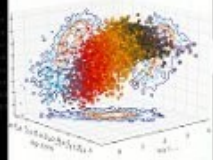


Dithering to complete the FoV

- 3 position dither pattern per pointing.
- Complete spatial covering of the FOV.
- Increase of the spatial resolution.
- Interpolation/image reconstruction scheme.







Dithering to complete the FoV

- Required to correct the continuum for the DAR.
- Implies a spatial co-variance between adjacent spaxels.
- Lots of simulations: Take care of the exotic procedures!!!

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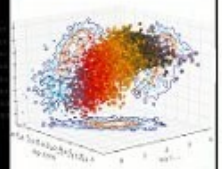
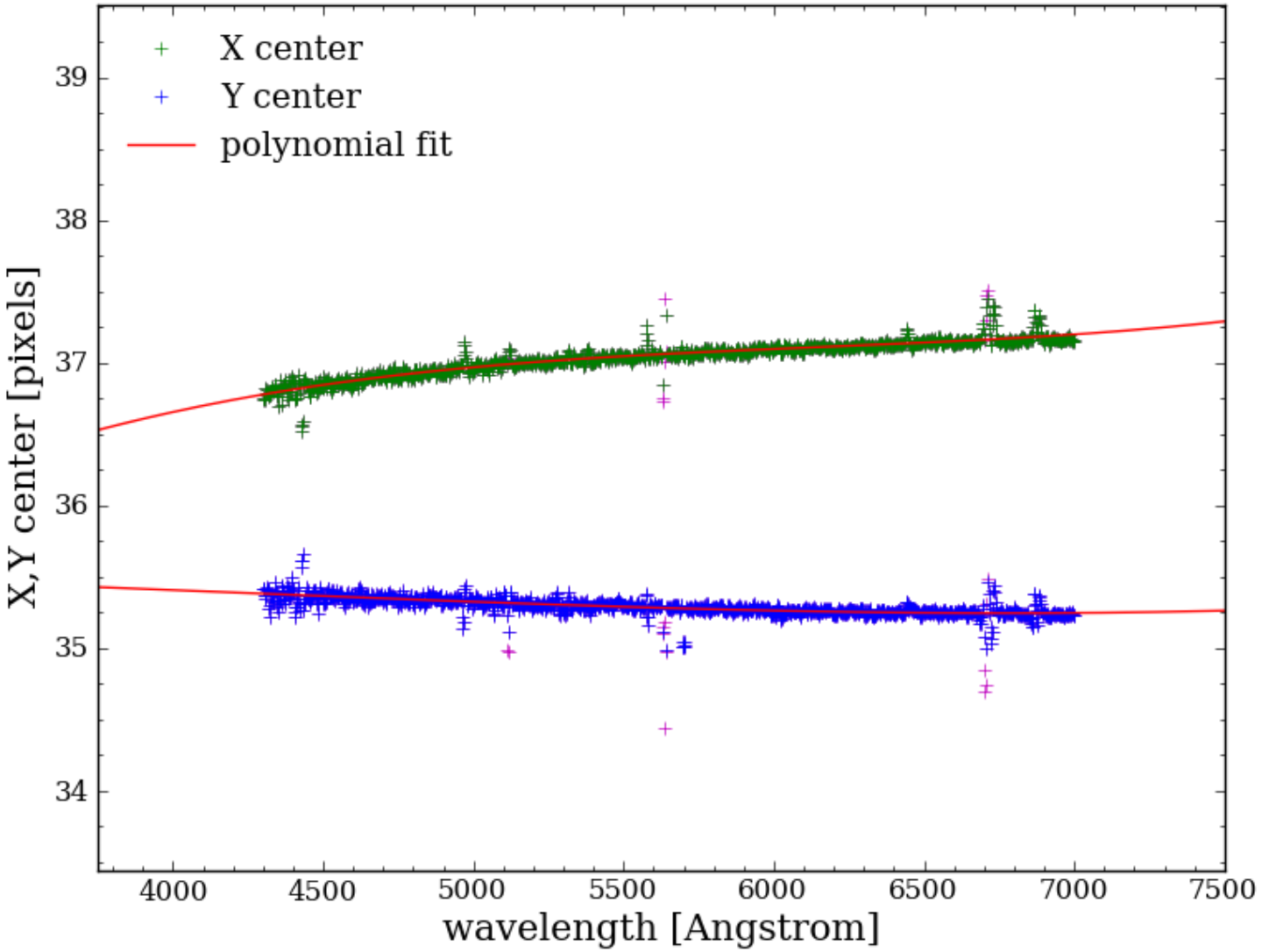
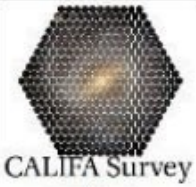
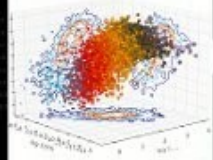


Dithering to correct DAR



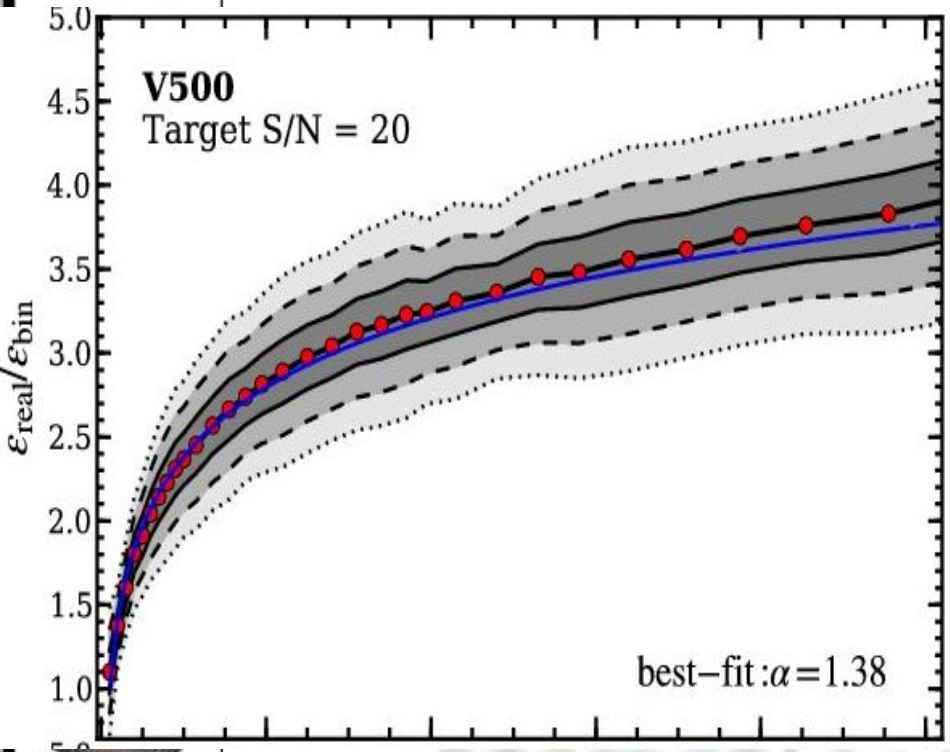


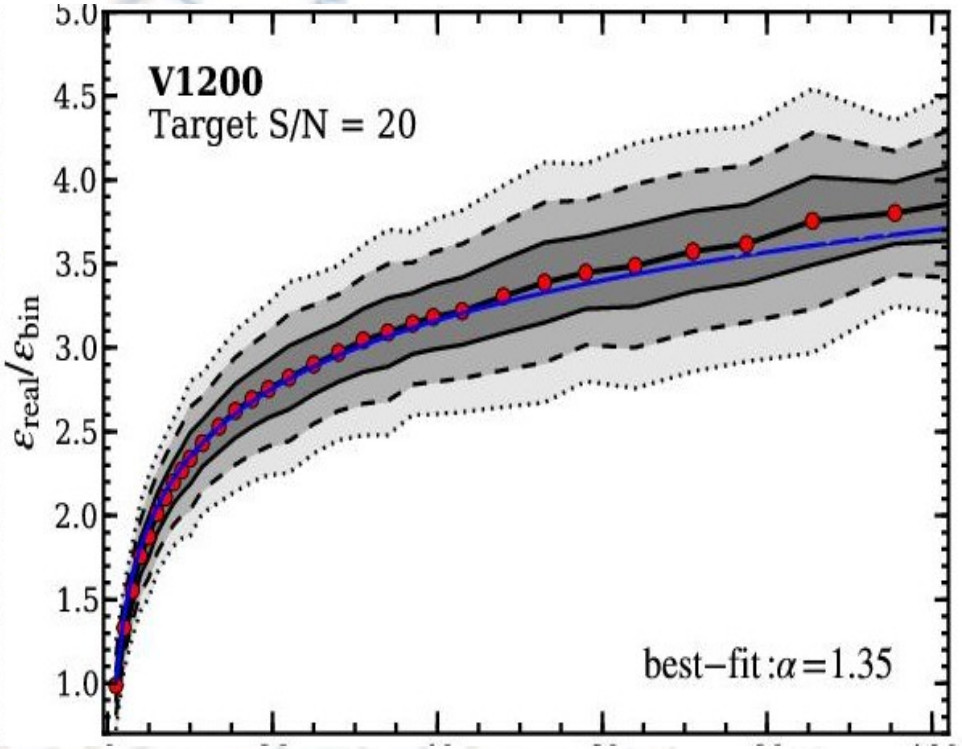


Dithering and co-variance

- Co-variance is everywhere: Spectra extraction, distorsion and dispersion correction, sky-subtraction...
- We can propagate to the final spaxel and spectral pixel.
- How to take into account when coadding adjacent spaxels? E.g., in Voronoi binning?

Dithering and co-variance





- How to take into account when coadding adjacent spaxels? E.g., in Voronoi binning?
- Empirical vs. Full propagation.

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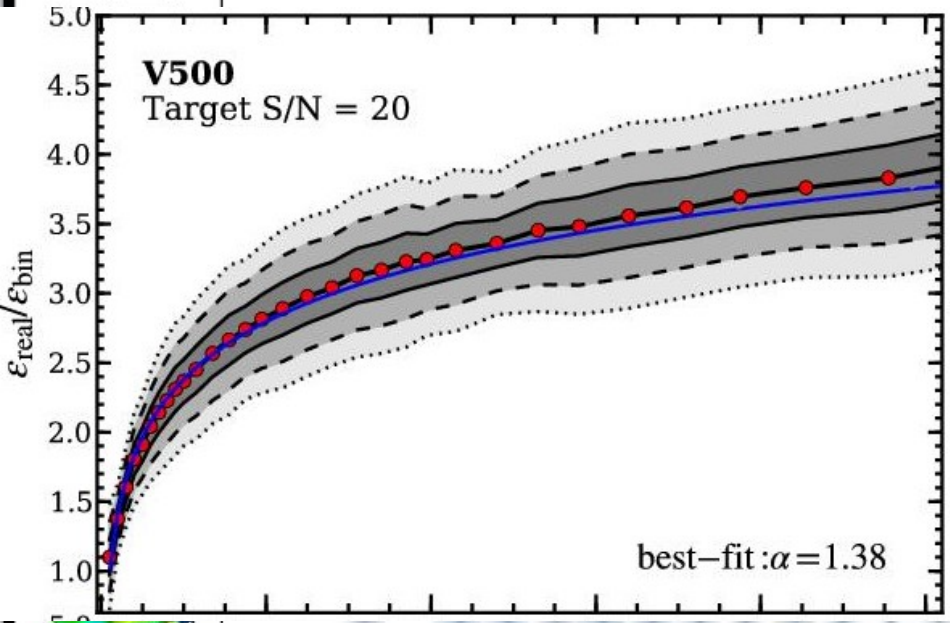
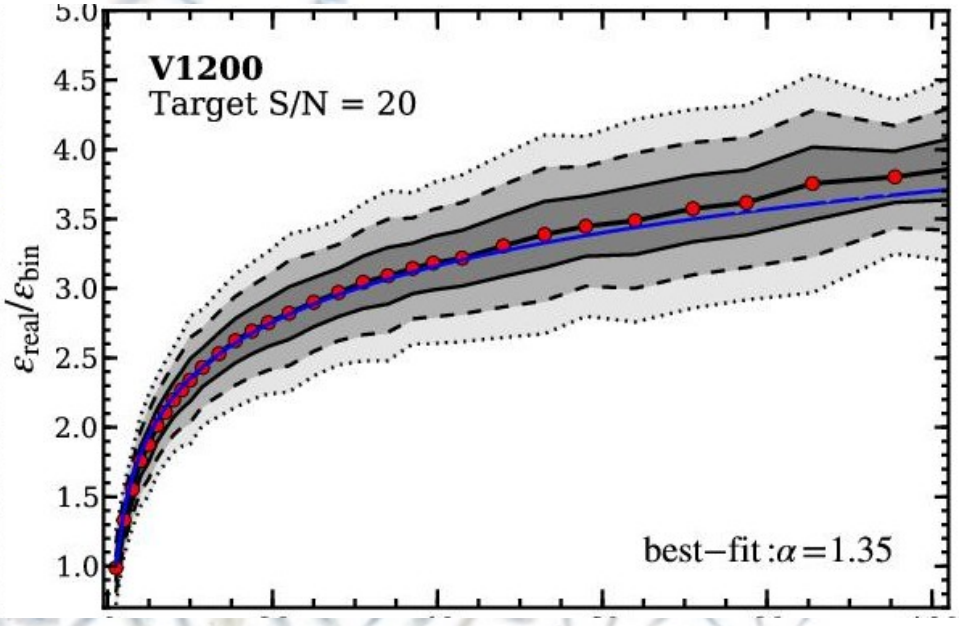
Dithering and co-variance





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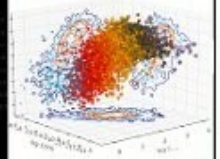

Spectrophotometric Calibration

- Incomplete sampling of the PSF.
- Single star pointing: ~8-10% of accuracy.
- Dithered star: ~ 5-8% of accuracy.
- Elliptical spectrophotometric stars (Husemann et al., in prep.): ~ 3-4%

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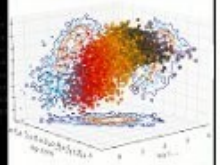
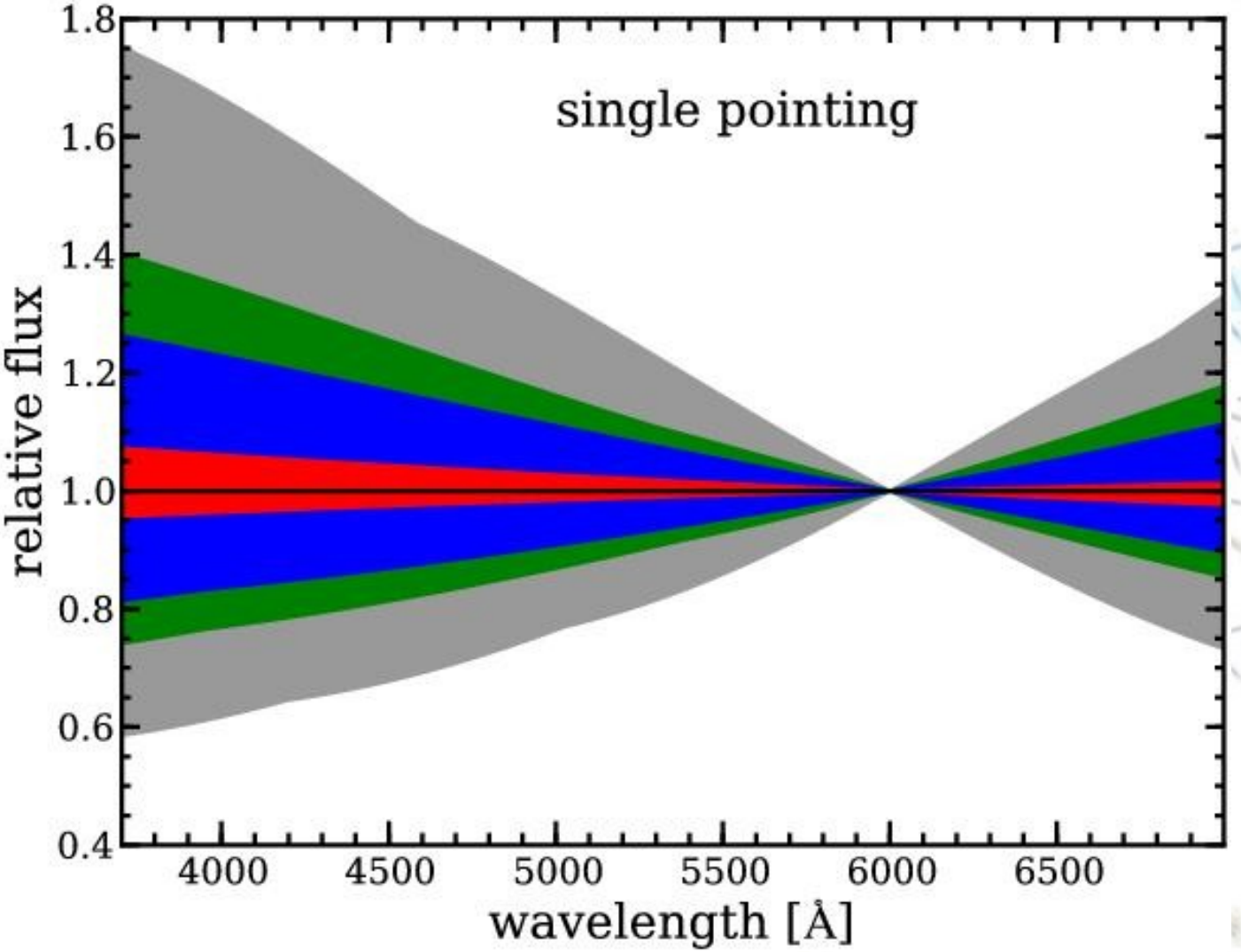


Spectrophotometric Calibration



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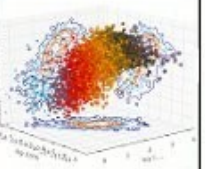
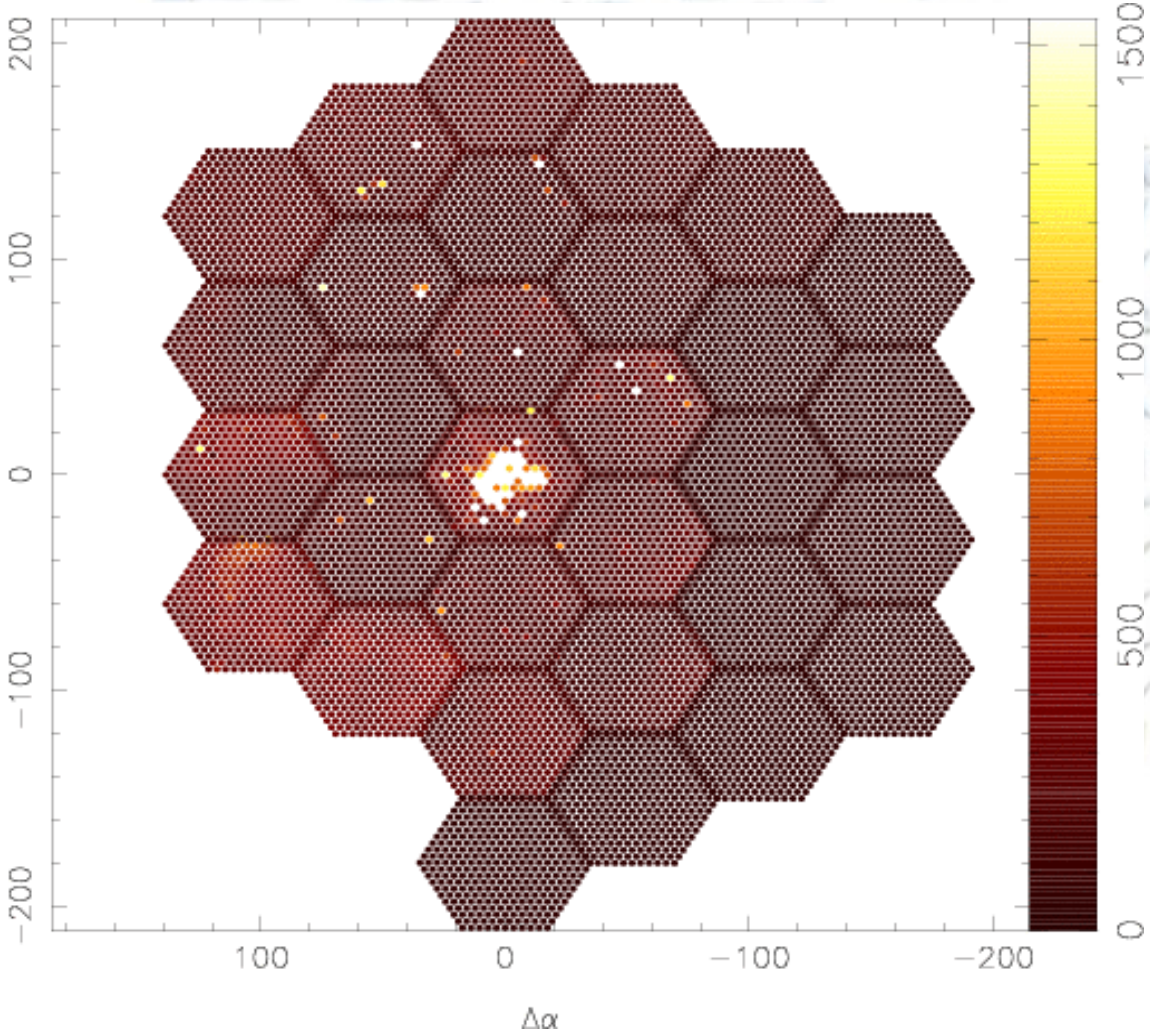
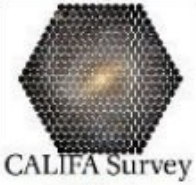
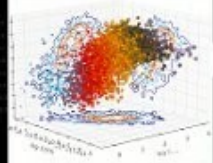
WF-IFS Mosaics, Problems to solve...



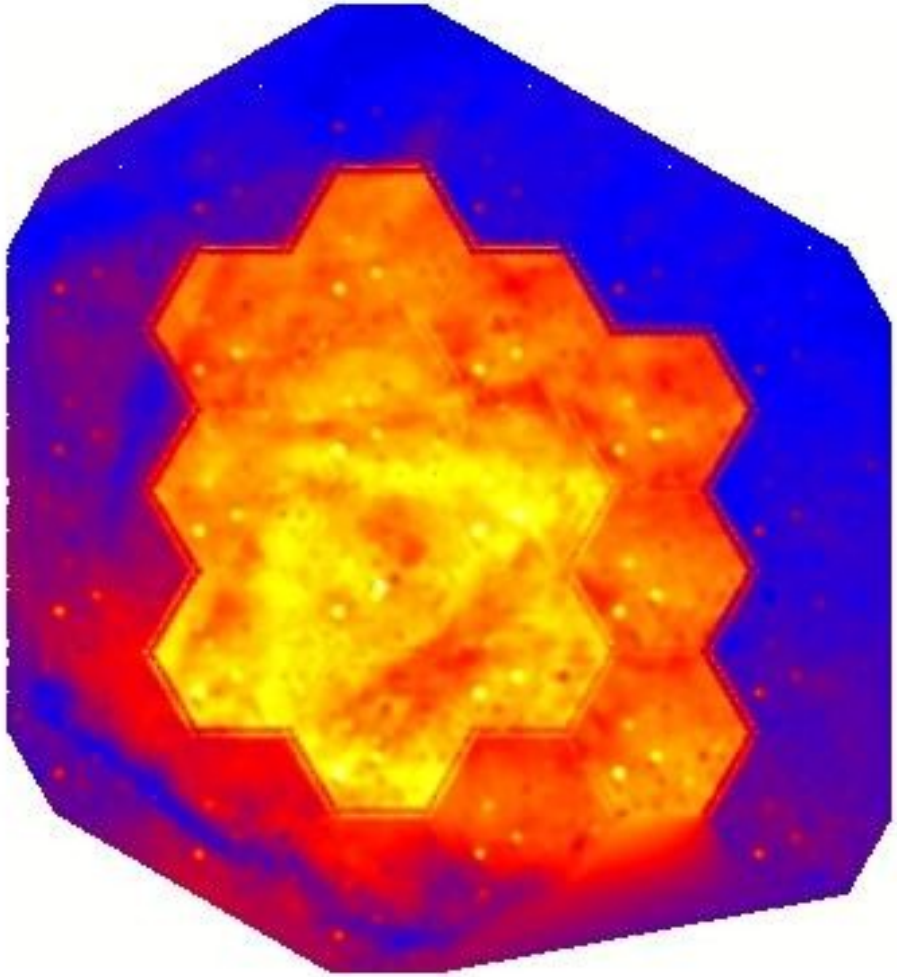






Matching the pointings.

- The pointings overlap, in at least 11 spectra.
- The change in transparency is critical
- Accuracy of the telescope offsets is also critical.
- Sky subtraction issues!!!



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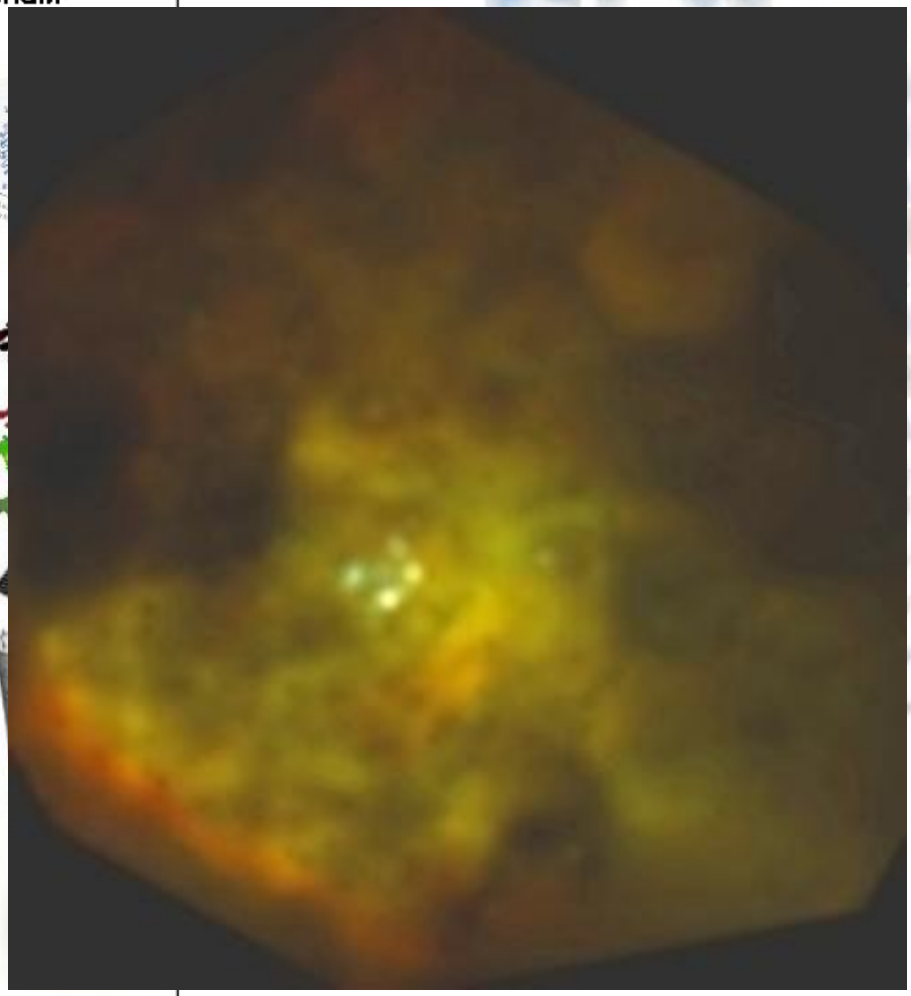
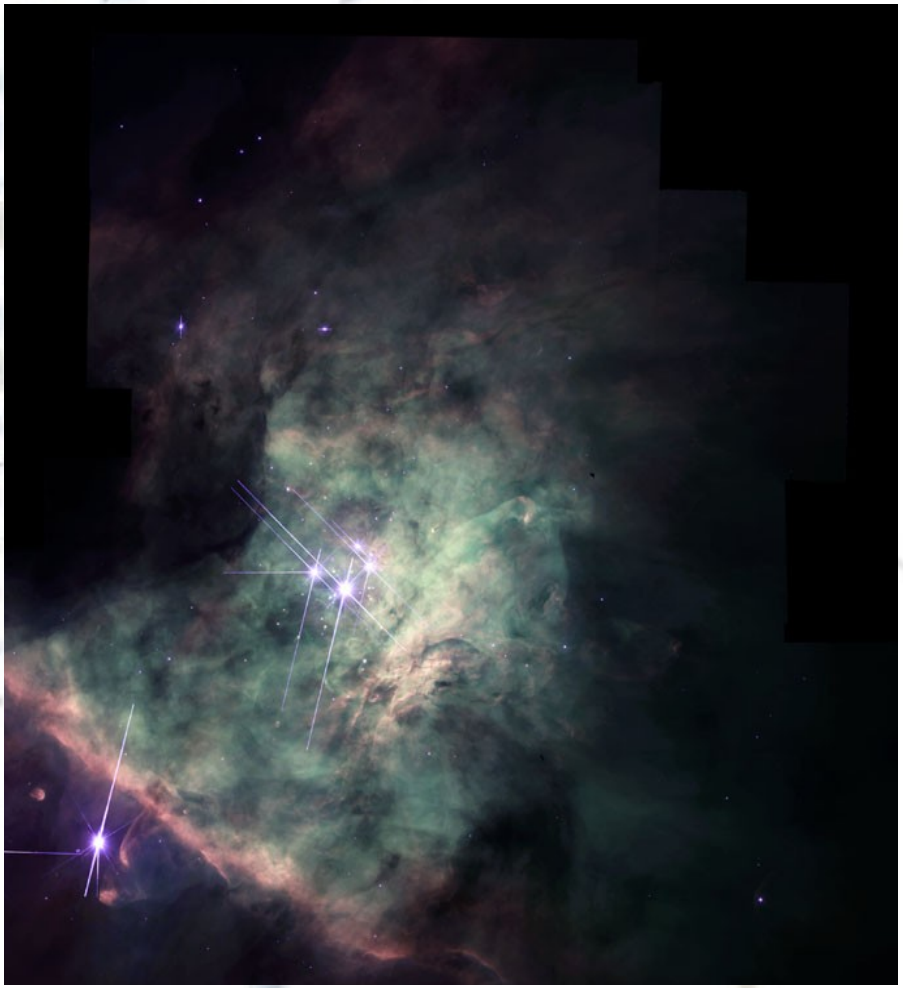
Results: Orion (Sánchez et al. 2006)





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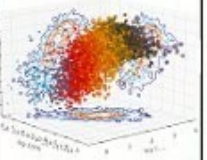

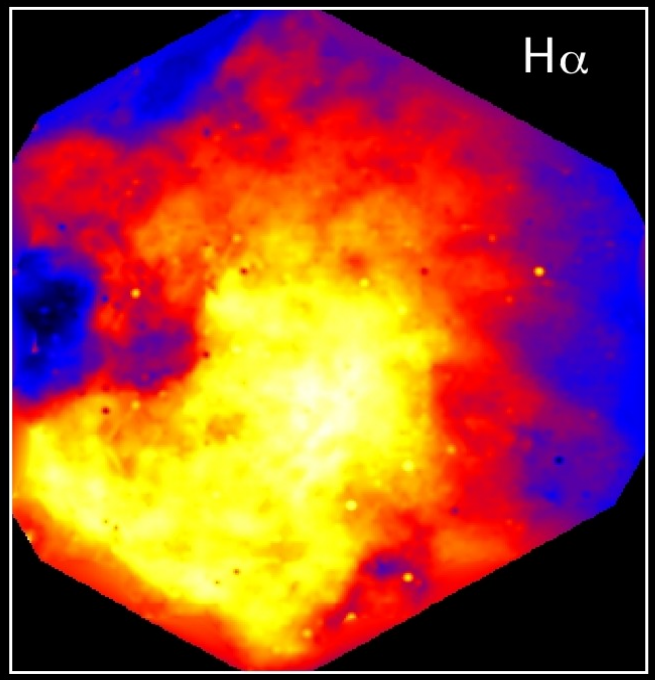

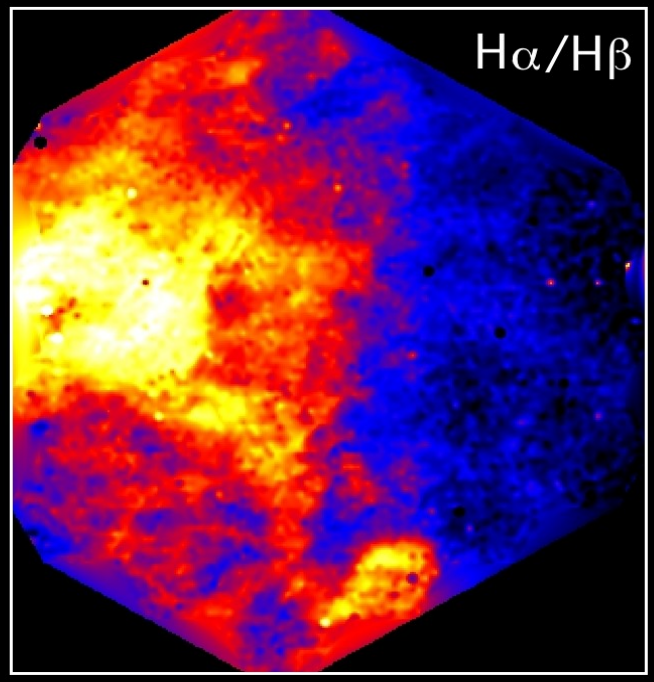

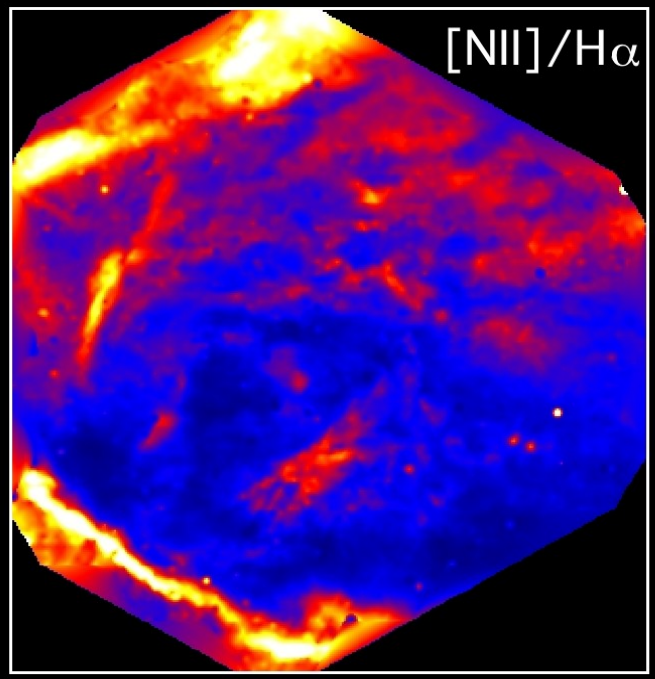

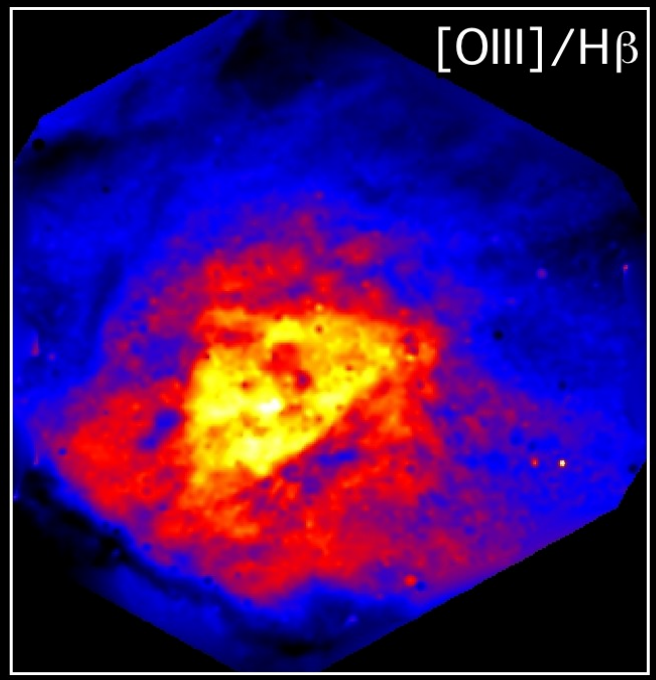

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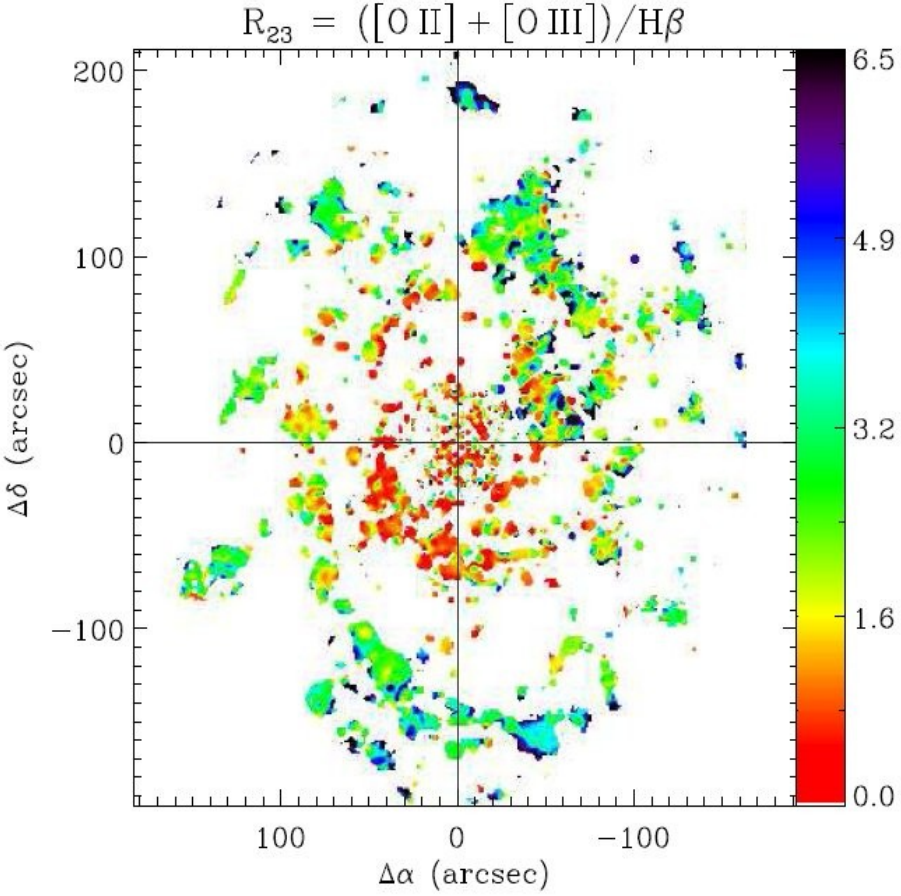
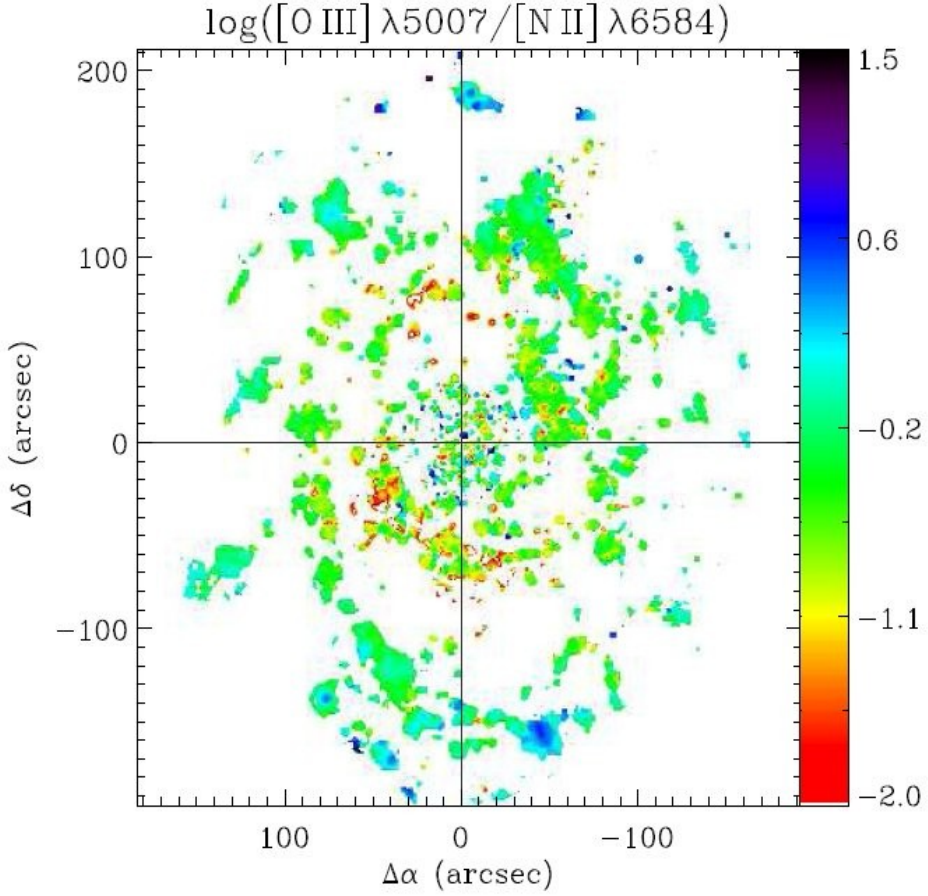
PINGS: Practical use of Mosaicing





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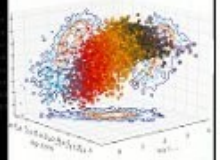

What you require to work with IFS?

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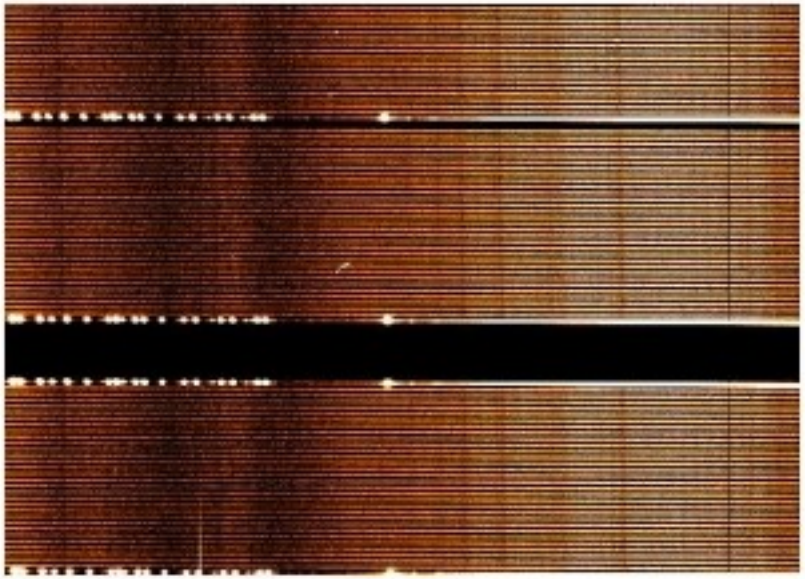
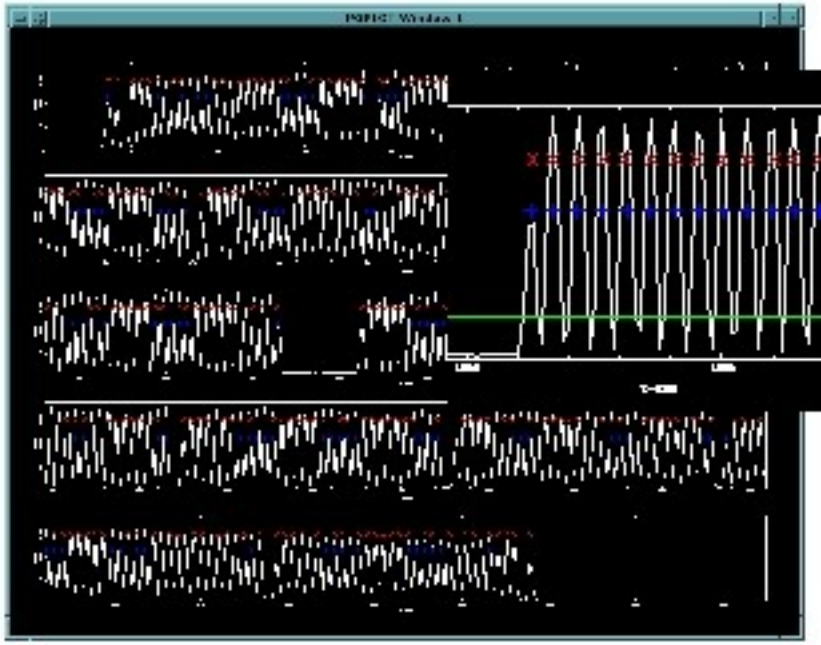
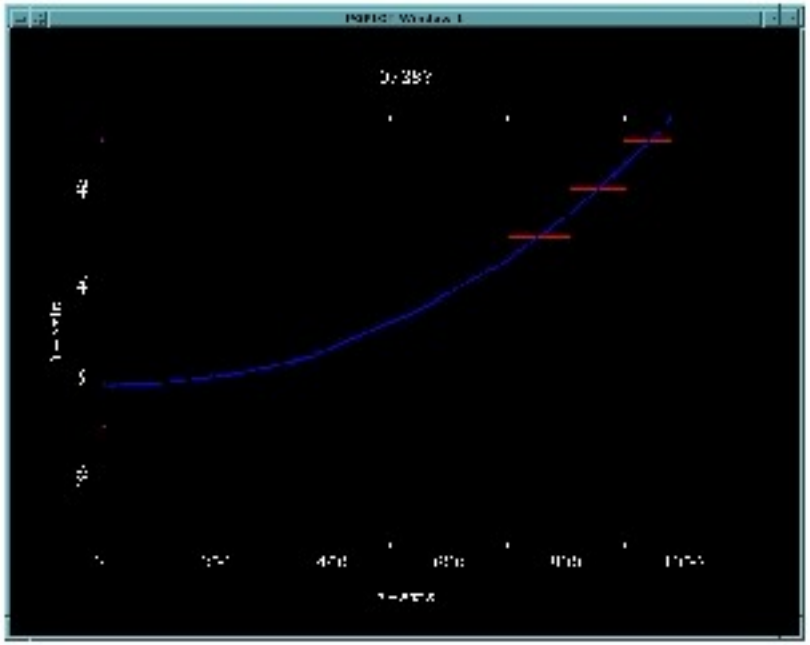
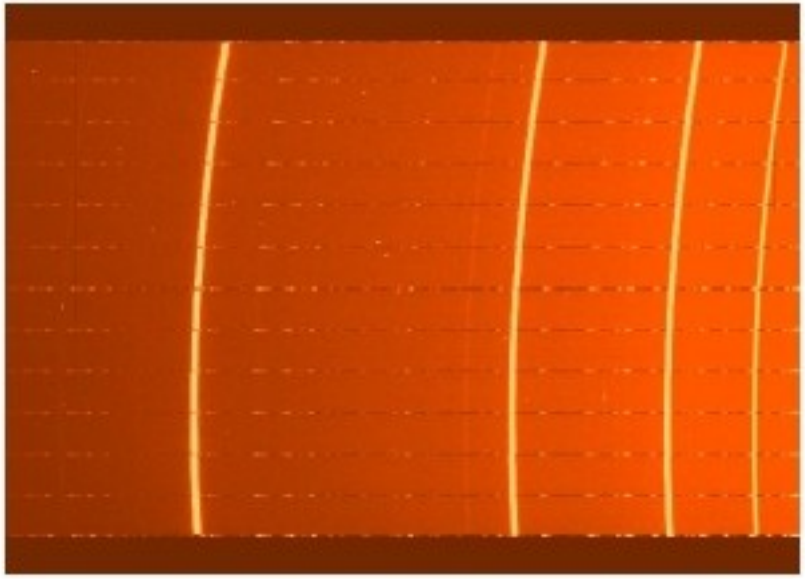
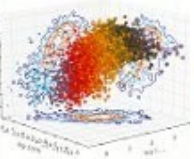
Dedicated Reduction Tools

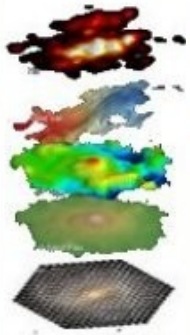












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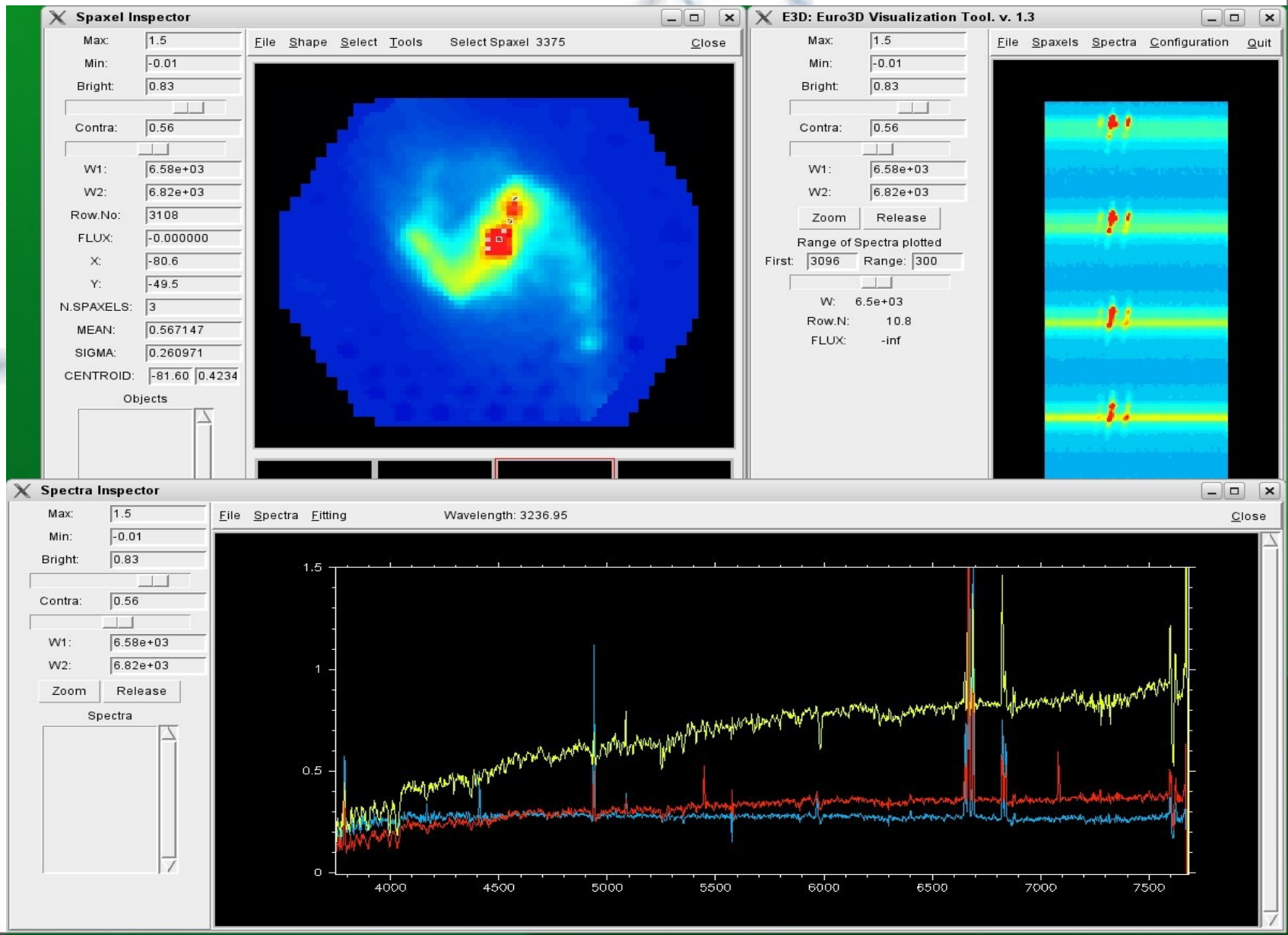
Dedicated Visualization Tools



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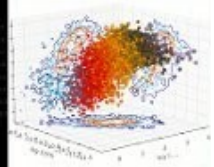
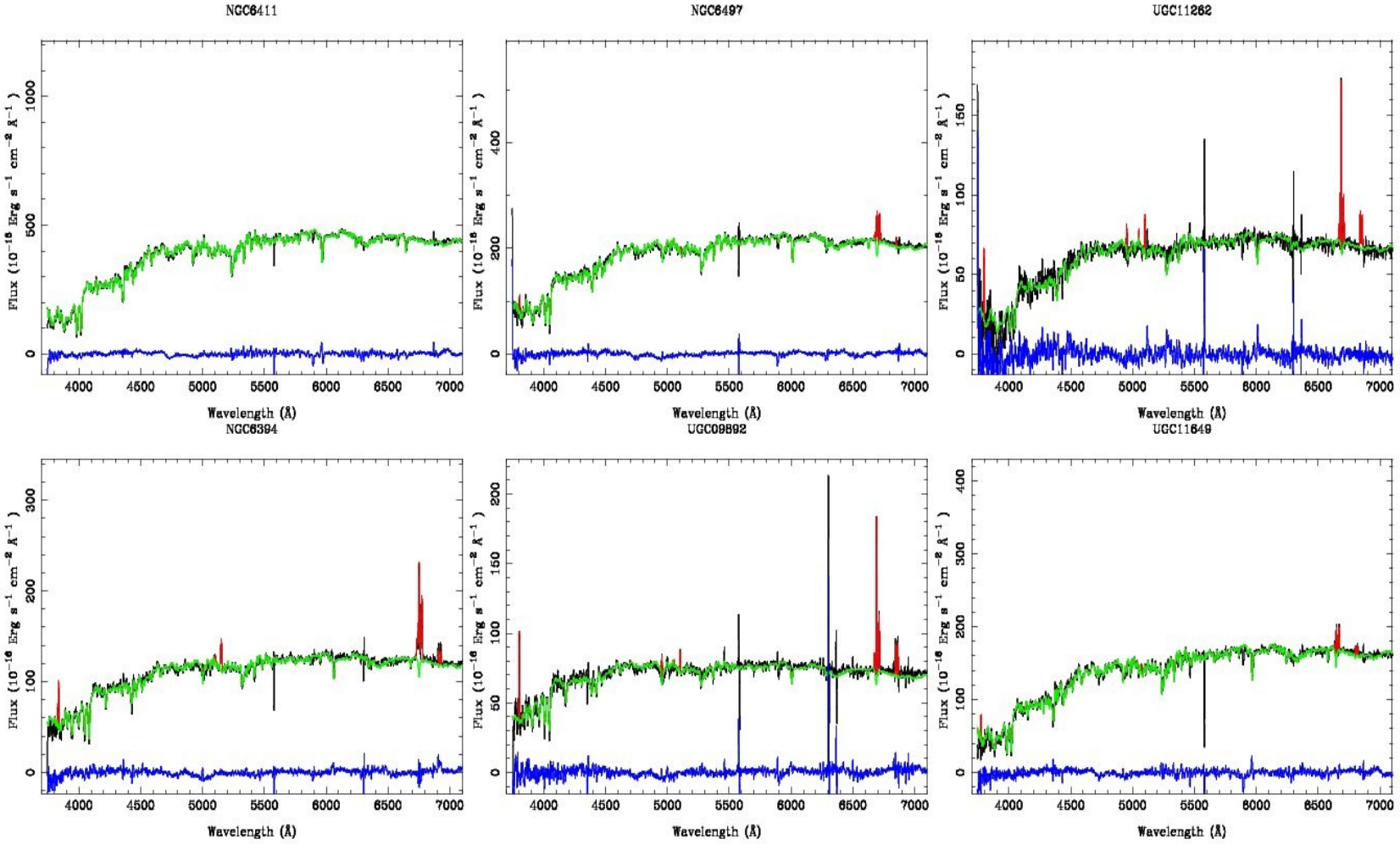
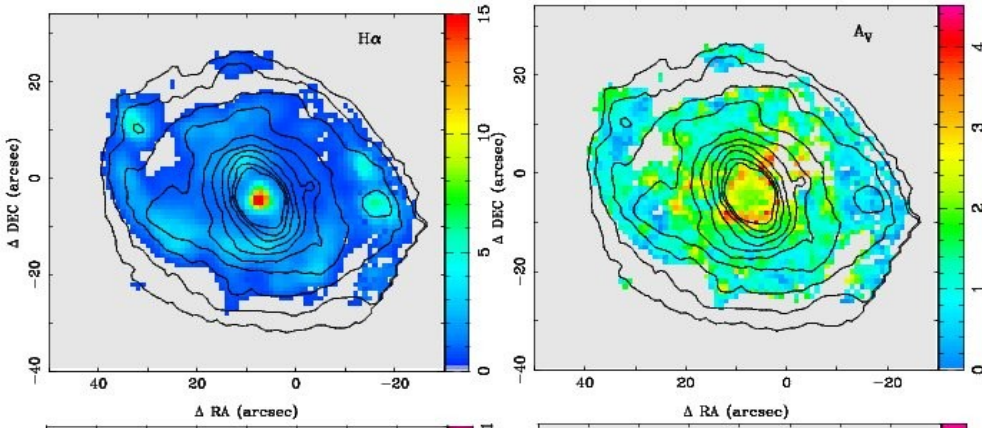


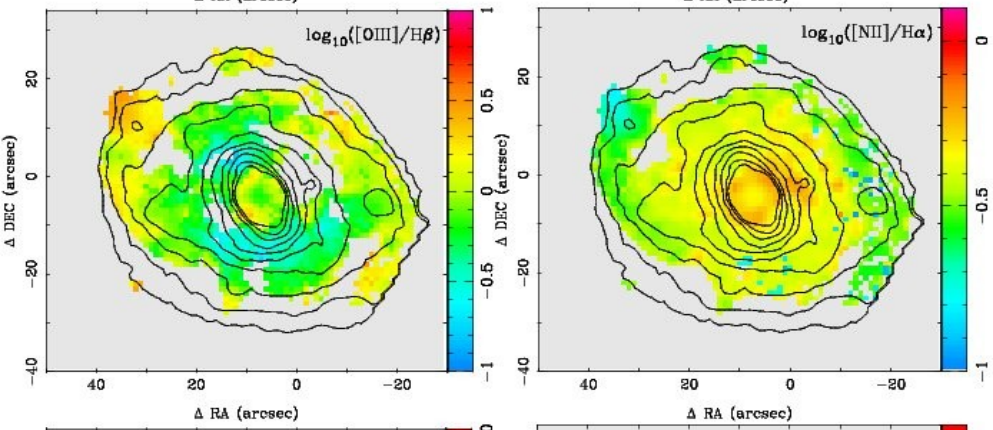
Dedicated Analysis Pipelines

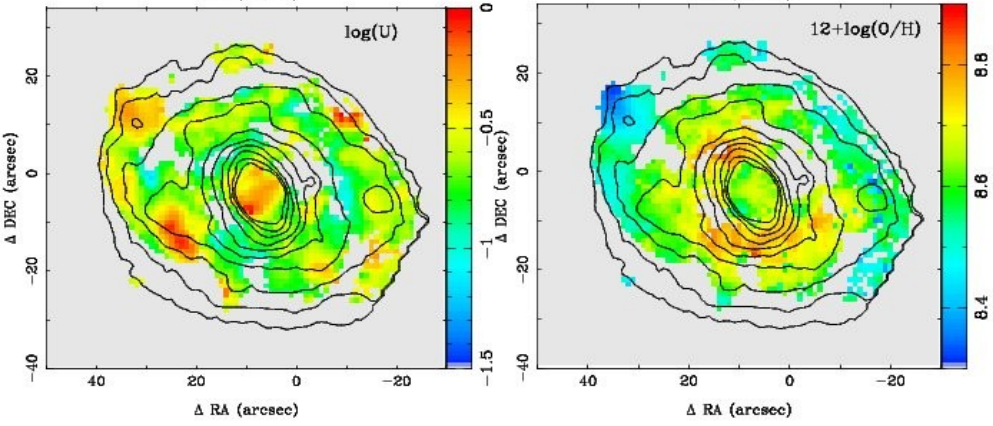


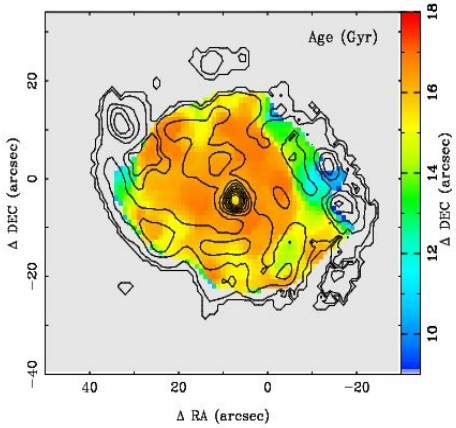
1 cube may comprise 2000 spectra!!!

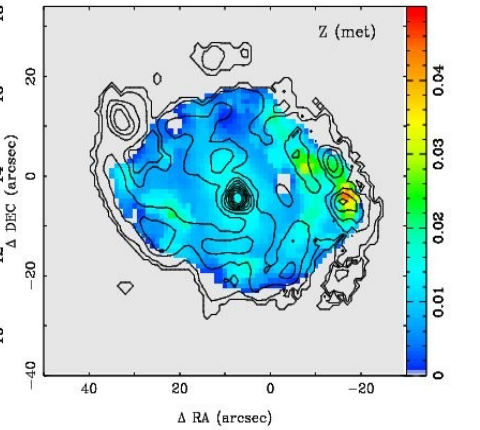
Large number of dataproducts

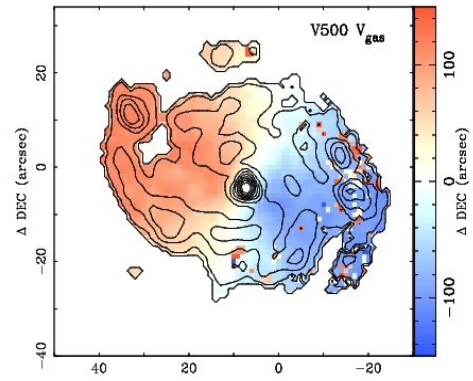


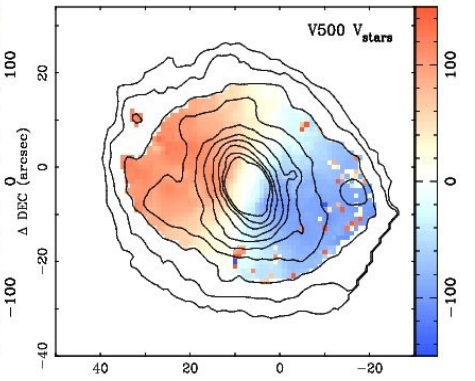


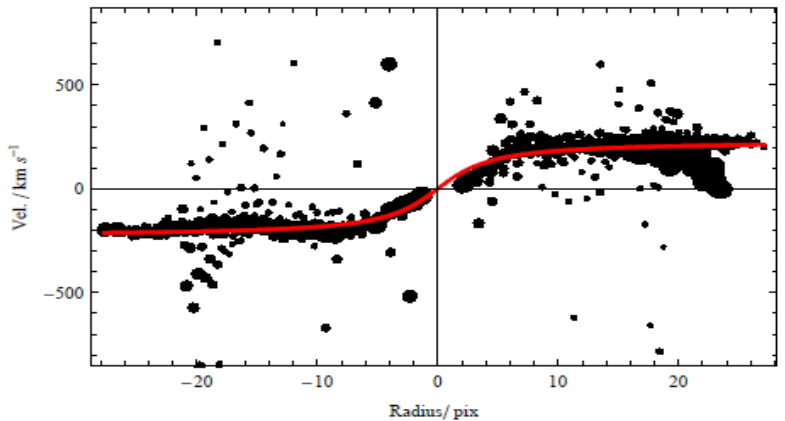












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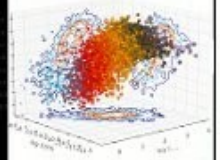

IFS Galaxy Surveys

- Use Integral Field Spectroscopy: Fiber-bundles, Image slicers, Lens-arrays.
- Large Sample of galaxies (100-10000).
- Statistically & well defined samples.
- Cover a substantial fraction of the extension of the galaxies: Integrated properties (~1 Reff or more).
- Enough spatial sampling:
  - Radial gradients.
  - 2D structure of the galaxies.
  - Resolve individual sub-structures (HII regions, spiral arms, bulges).
- Hundreds of thousand of spectra.
- Multiple Science Goals.

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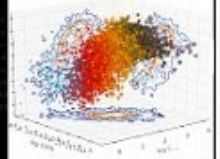
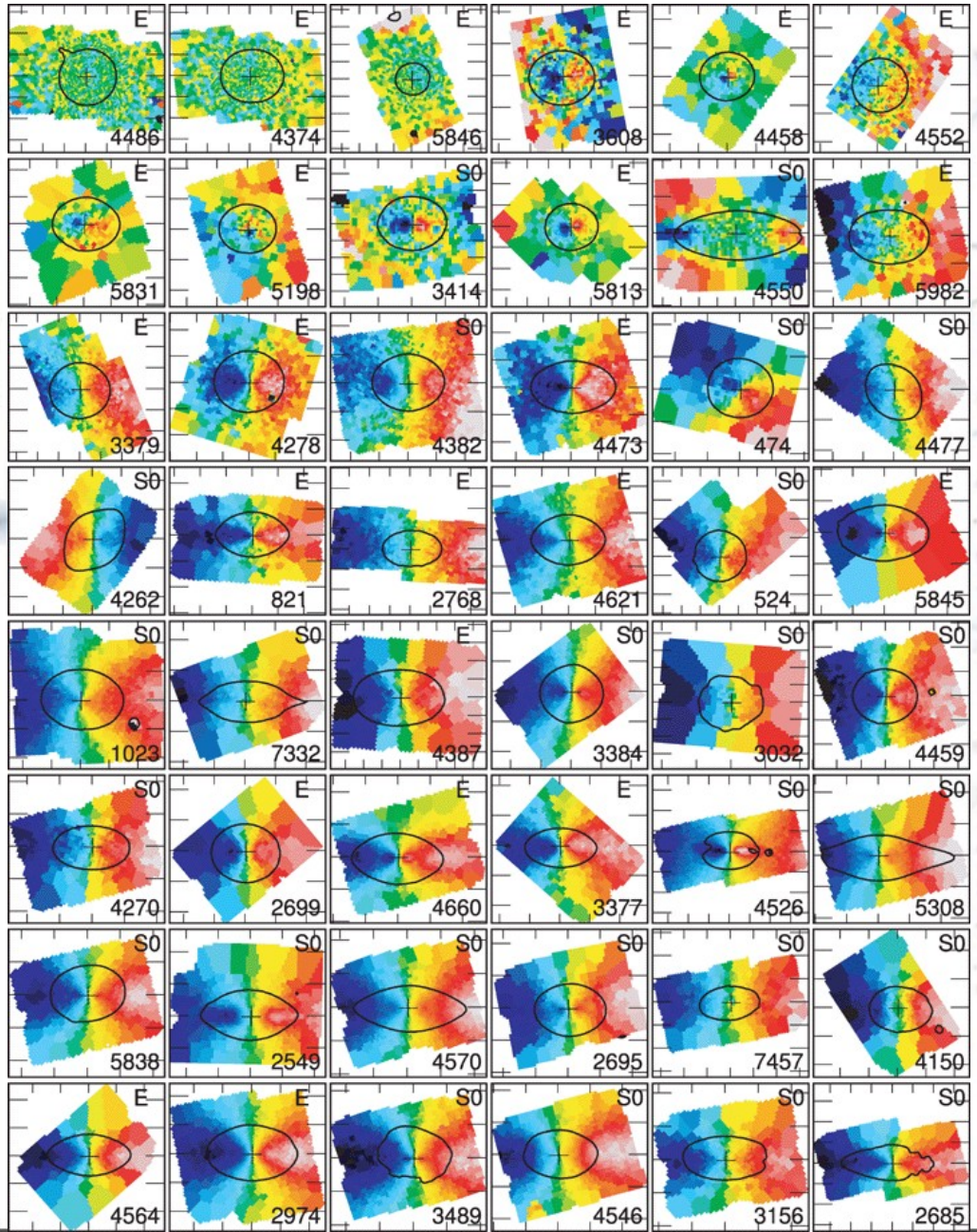


IFS GS: Precedents

- Disk Mass Survey: 46 face-on spirals (~2Reff). Super-high spectral resolution.
- SAURON: 72 (mostly) early-type galaxies (<1Reff).
- F-CALIFA: 48 (mostly) spiral galaxies (~2Reff).
- VENGA: 32 spiral galaxies (>2Reff).
- PINGS: 12 (mostly) spiral galaxies (~2Reff).
- Studies on individual galaxies.

The SAURON Survey



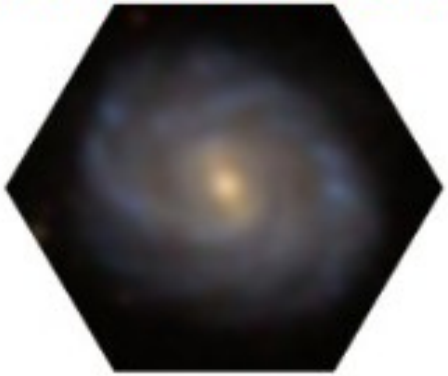
Bacon et al., MNRAS, 2001

SAURON

First evidence of the slow/fast rotators dichotomy.

SDSS 90”x90” image

CALIFA (V500/V1200)



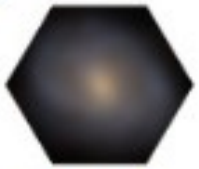
Atlas3D

Z~Z califa

Z~Z Atlas3D

MaNGA largest FoV

FoV~1.5Re

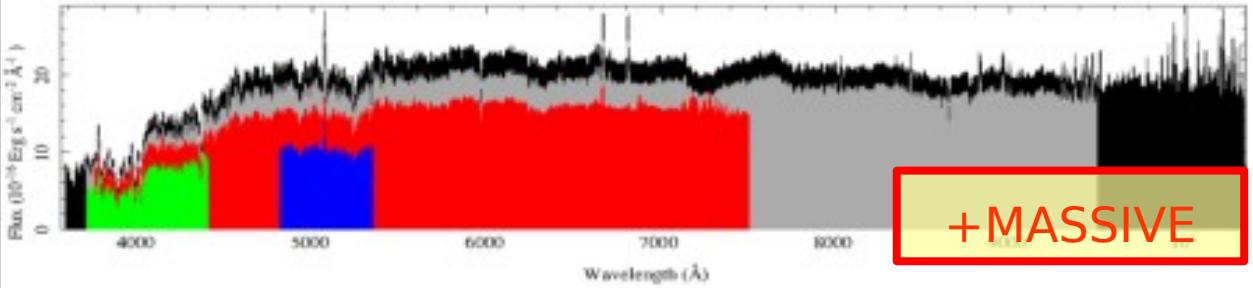


~2.5Re

SAMI

Z~Z califa

Z~Z SAMI



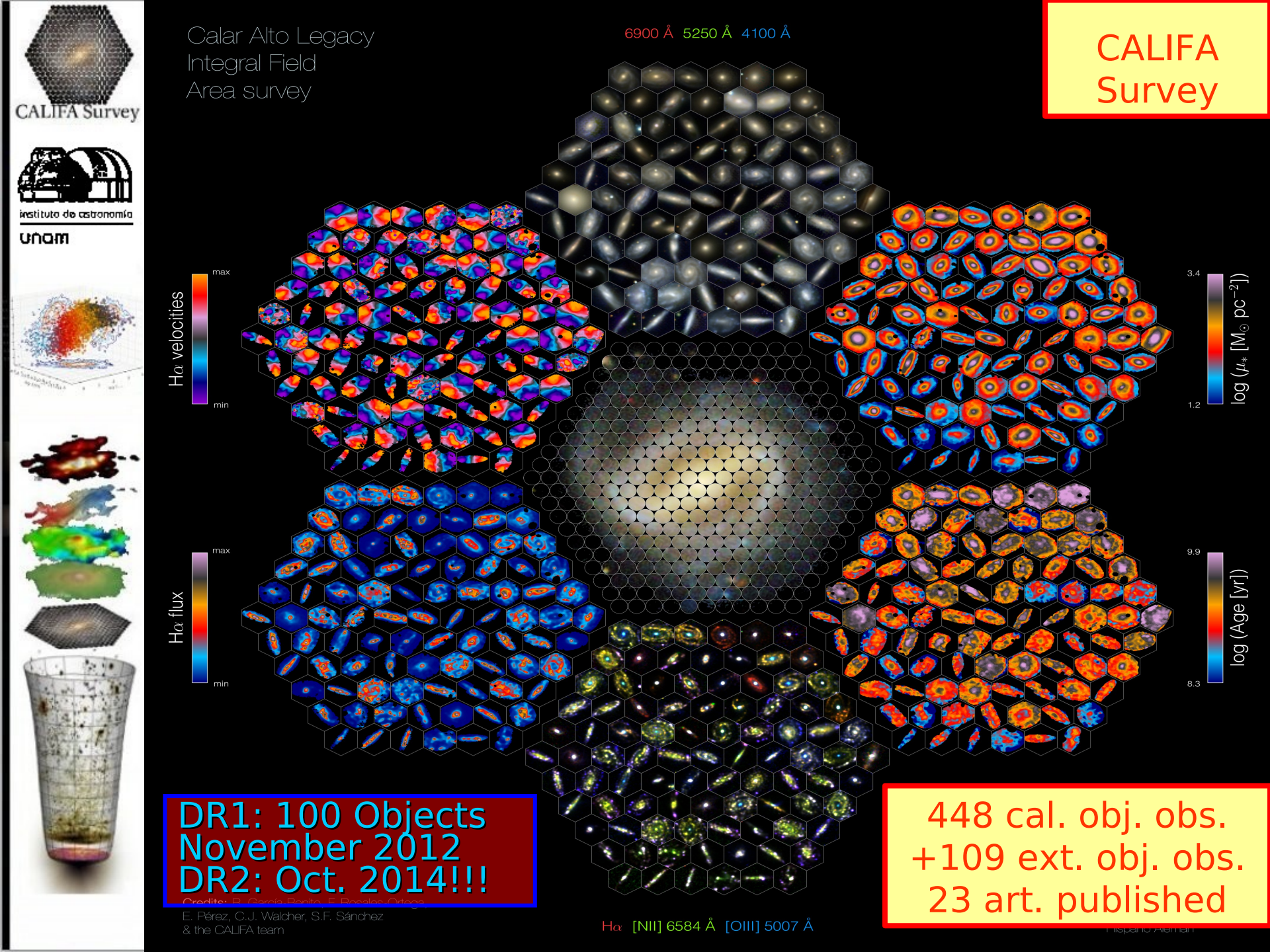
+MASSIVE

CALIFA
2x3x331 spaxels; 2.7”/spaxel
600 galaxies of any type
~1.200.000 spec.; 3700-7500 Å

Atlas3D
1577 spaxels; 0.94”/spaxel
260 ETGs
~400.000 spectra; 4810-5350 Å

MaNGA
3x(19-127) spaxels; 2”/spaxel
7000 gal. of any type (~1.5Re)
2000 gal. of any type (~2.5Re)
1000 gal. of any type (any Re)
~800.000 spec.; 3550-10000 Å

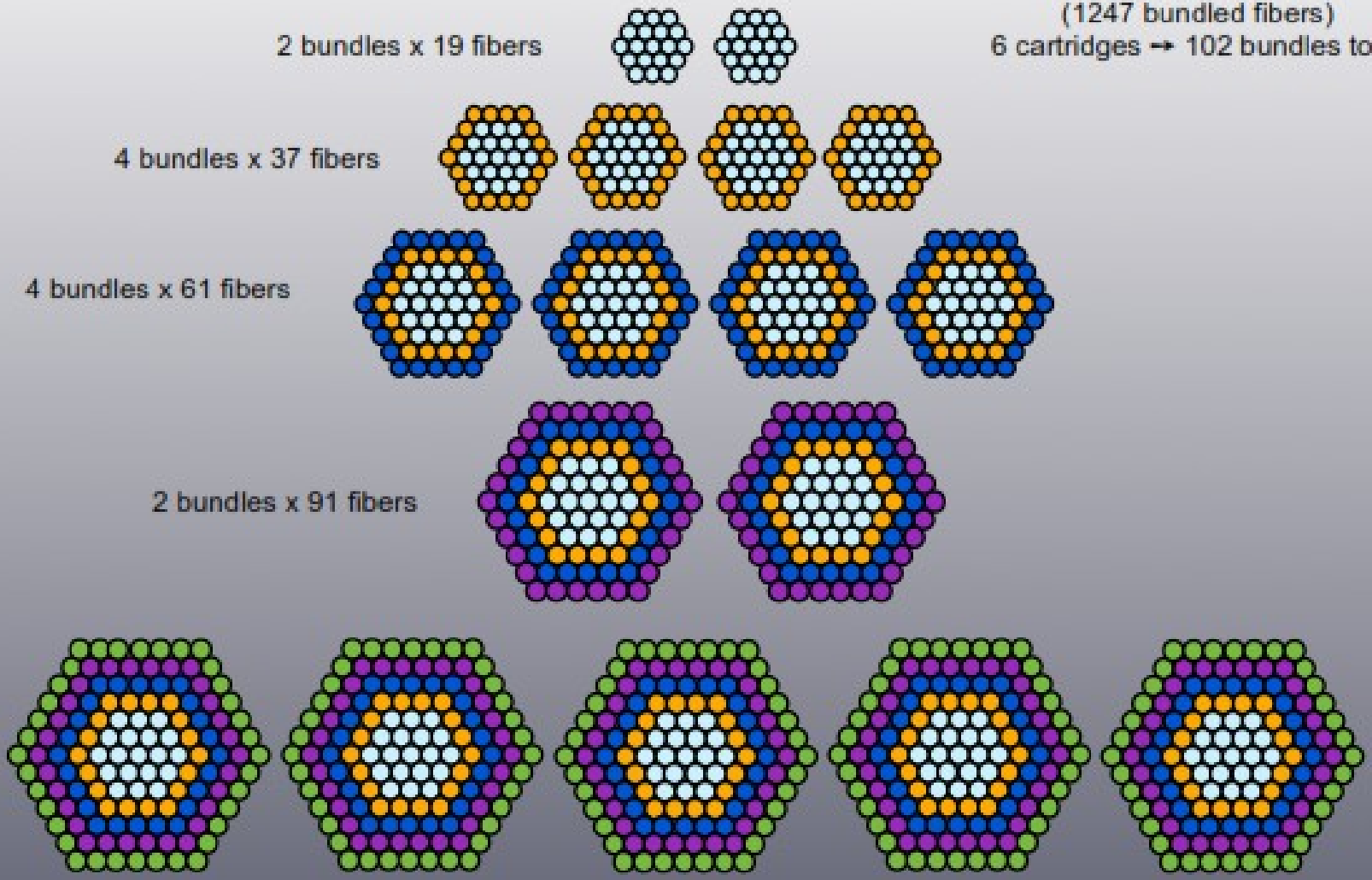
SAMI
9x61 spaxels; 1.6”/spaxel
3400 galaxies of any type
~1.900.000 spec.; 3700-9500 Å


CALIFA Survey
Instituto de Astronomía
UNAM
Calar Alto Legacy
Integral Field
Area survey
6900 Å 5250 Å 4100 Å
CALIFA
Survey
Hα velocities
max
min
Hα flux
max
min
3.4
1.2
log (μ* [M⊙ pc−2])
9.9
8.3
log (Age [yr])
DR1: 100 Objects
November 2012
DR2: Oct. 2014!!!
Credits: B. García-Benito, E. Rosales-Ortega,
E. Pérez, C.J. Walcher, S.F. Sánchez
& the CALIFA team
Hα [NII] 6584 Å [OIII] 5007 Å
448 cal. obj. obs.
+109 ext. obj. obs.
23 art. published

MaNGA Survey

Bundle size distribution

17 bundles per cartridge
(1247 bundled fibers)
6 cartridges → 102 bundles total



Bundy et al., in prep.

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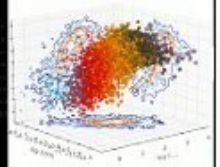
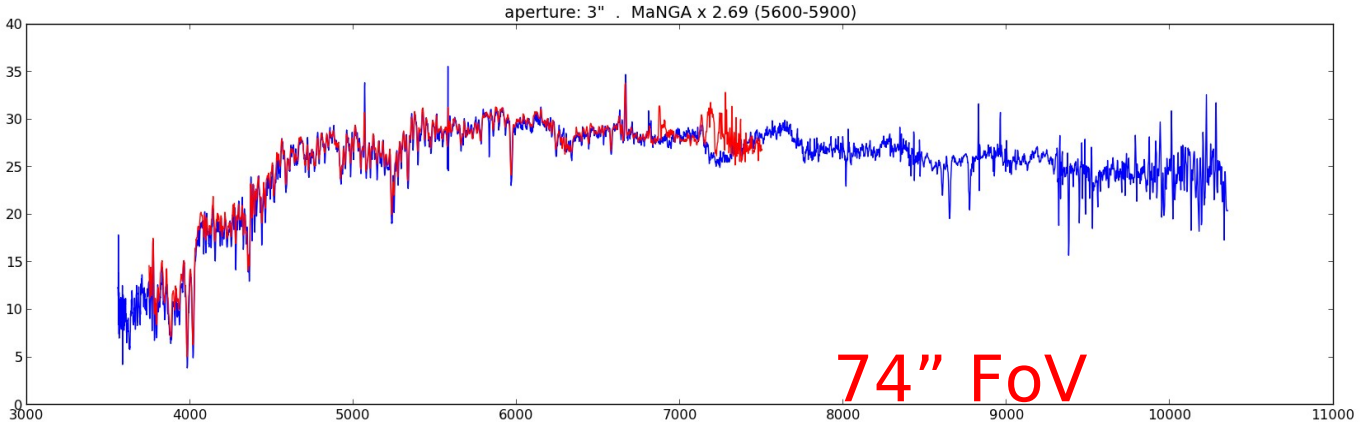
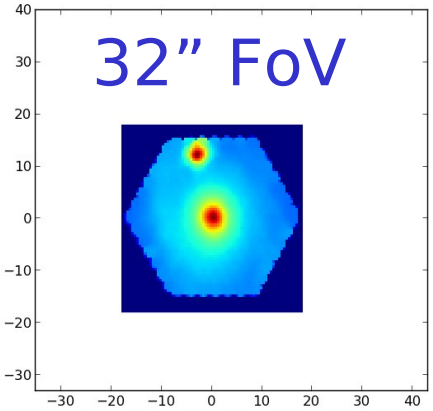
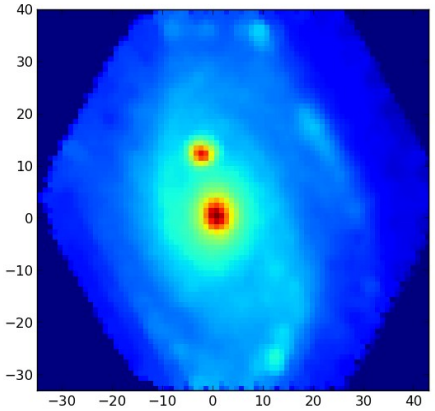


CALIFA compared with MaNGA







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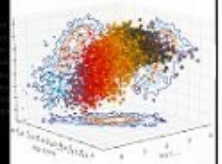
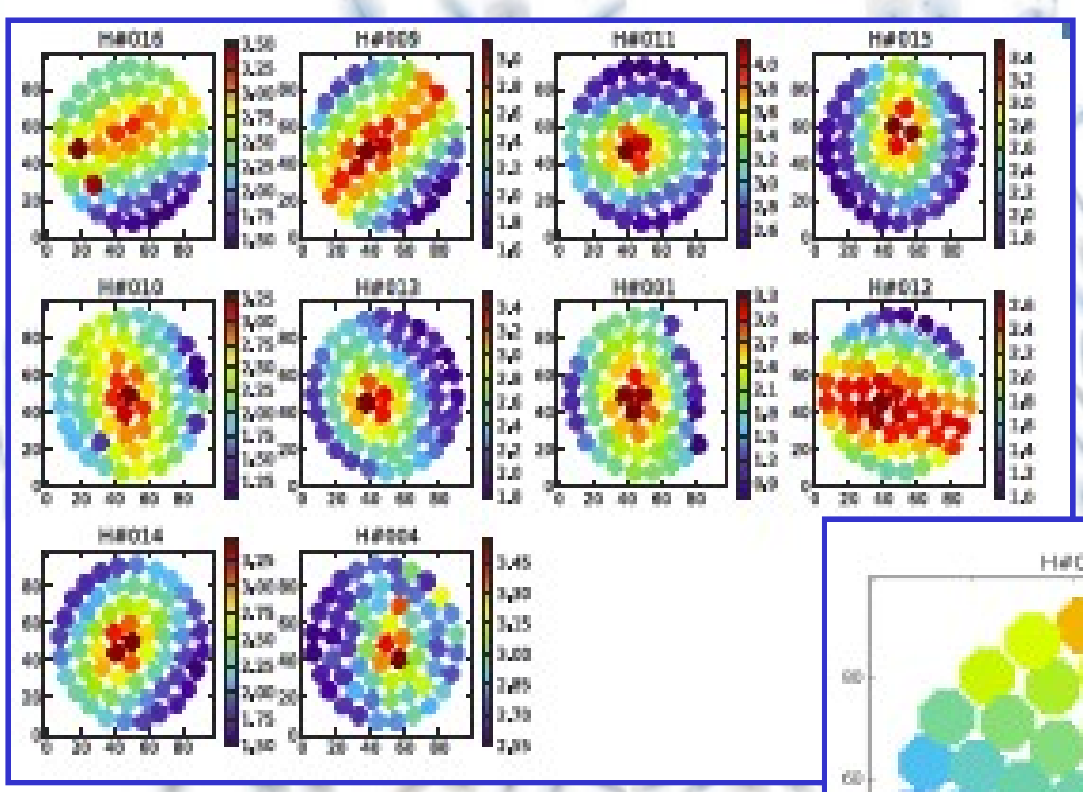
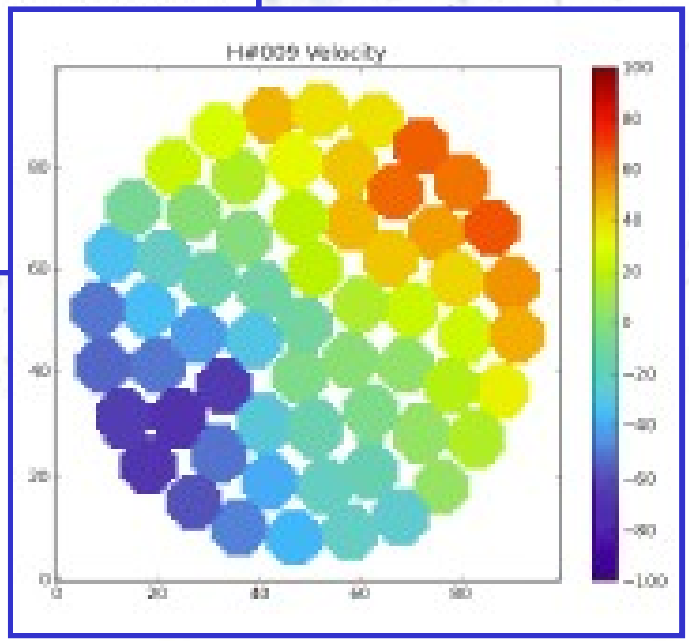
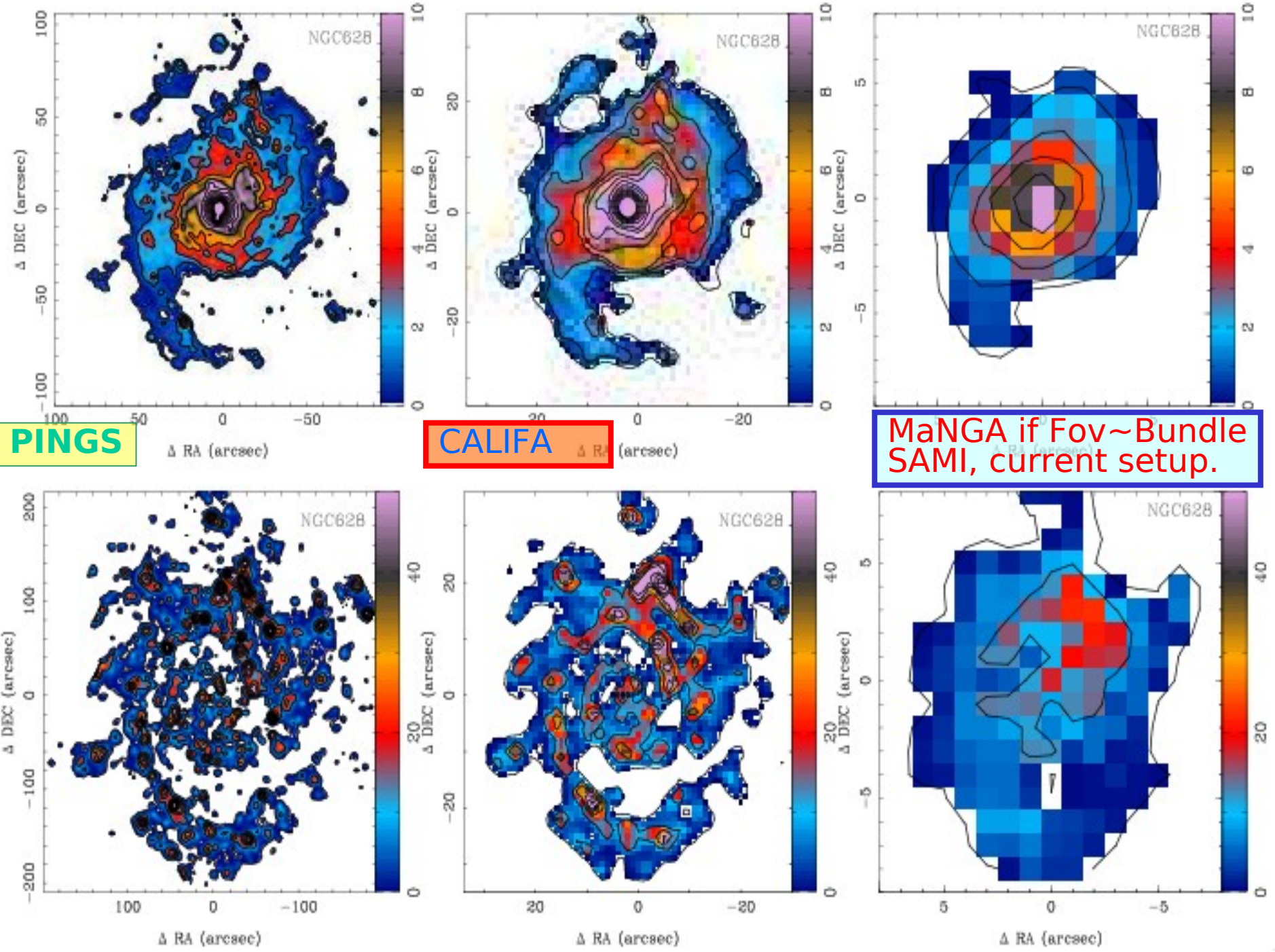


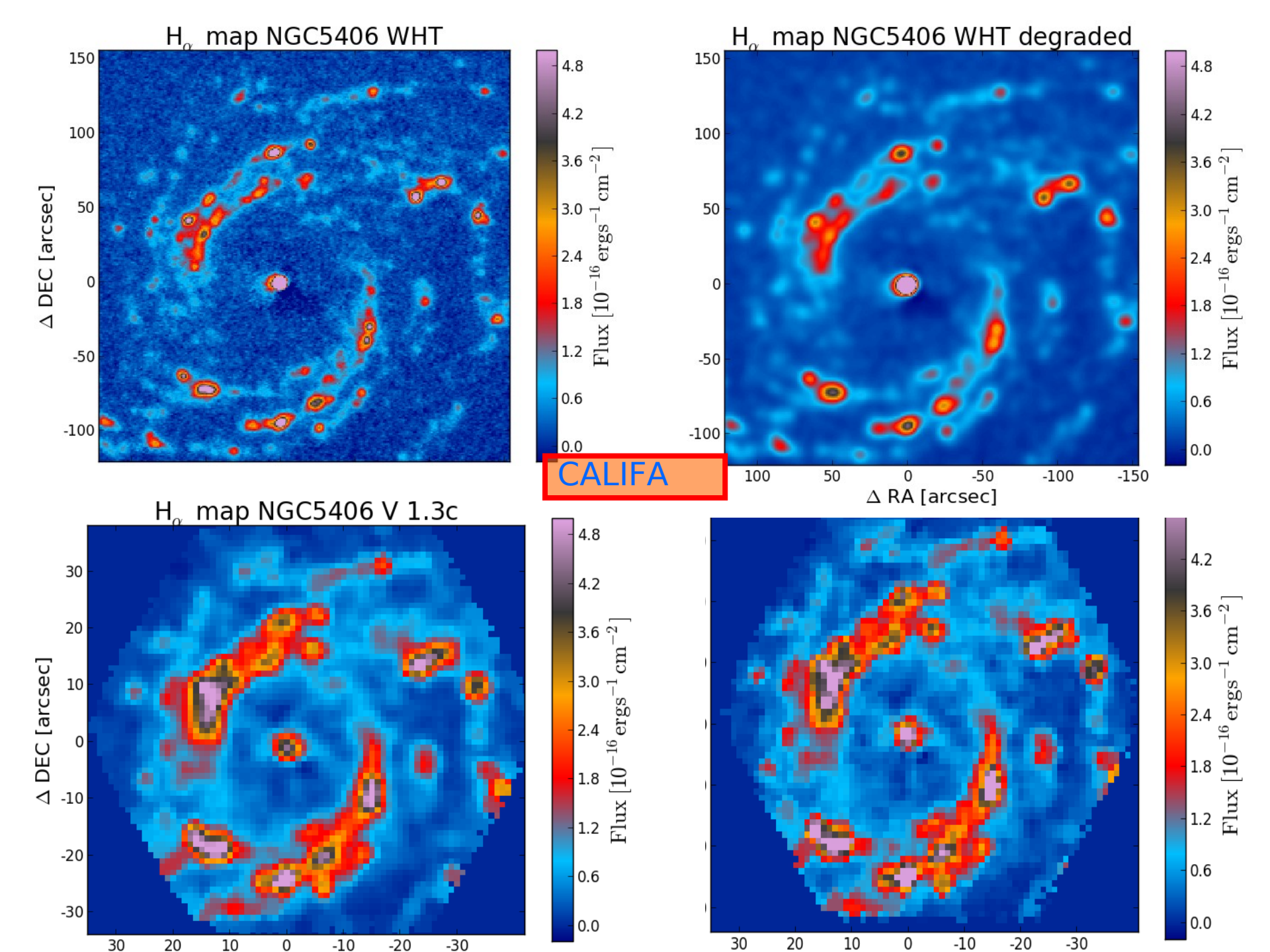
SAMI: The AAO Survey

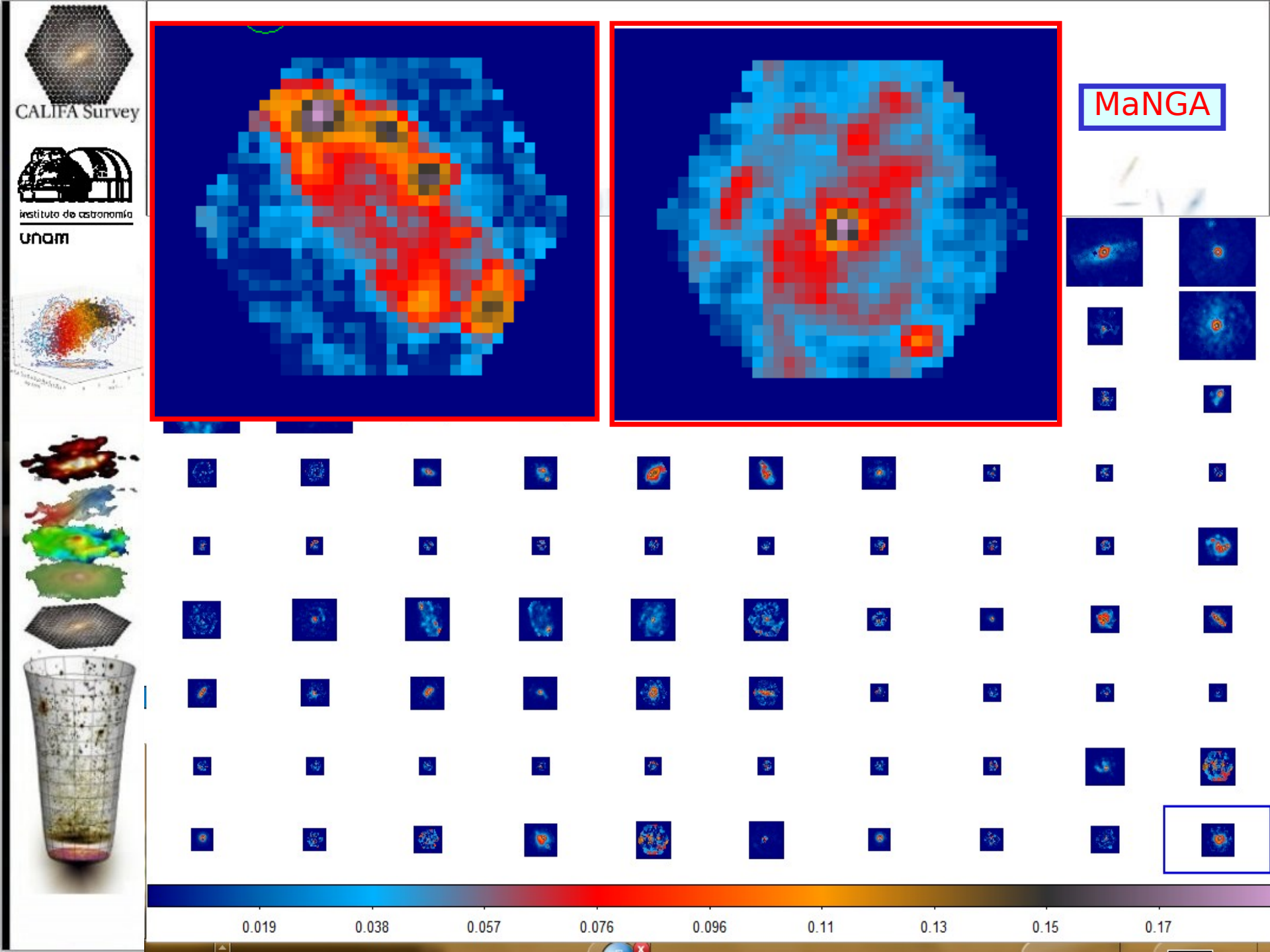


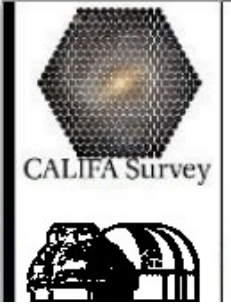


16” FoV

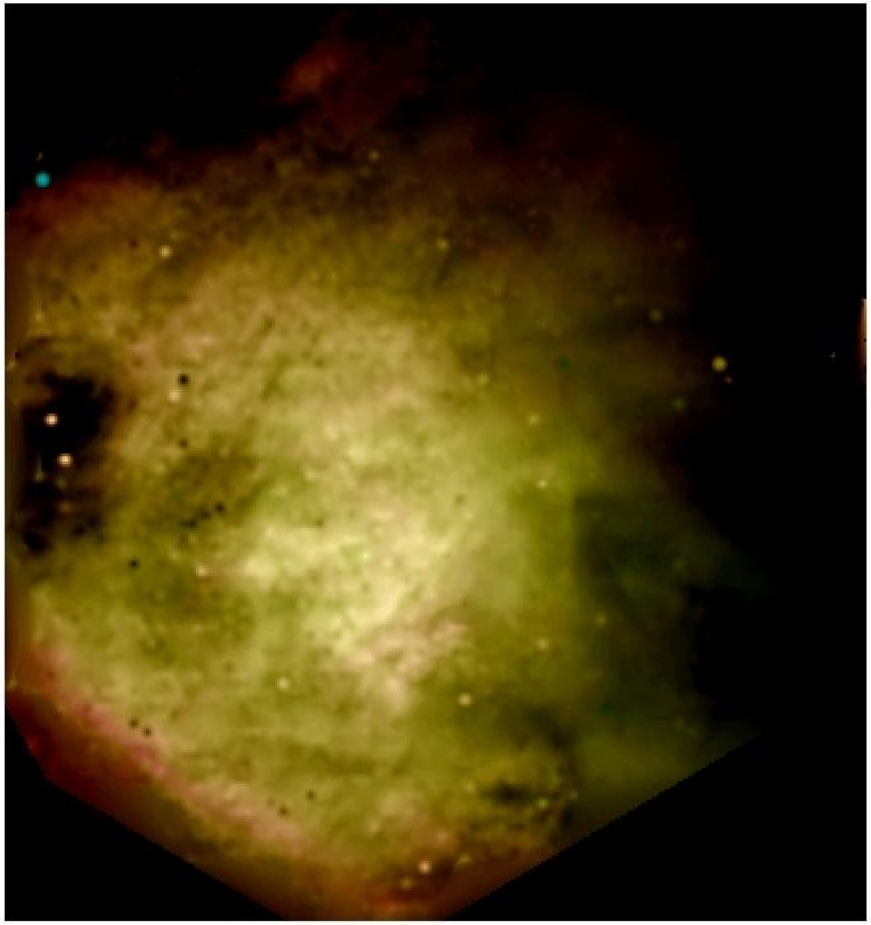

NGC628
Δ DEC (arcsec)
Δ RA (arcsec)
PINGS
CALIFA
MaNGA if Fov~Bundle
SAMI, current setup.


H$_\alpha$ map NGC5406 WHT
H$_\alpha$ map NGC5406 WHT degraded
H$_\alpha$ map NGC5406 V 1.3c
CALIFA
Δ DEC [arcsec]
Δ RA [arcsec]
Flux [10^{-16} ergs^{-1} cm^{-2}]

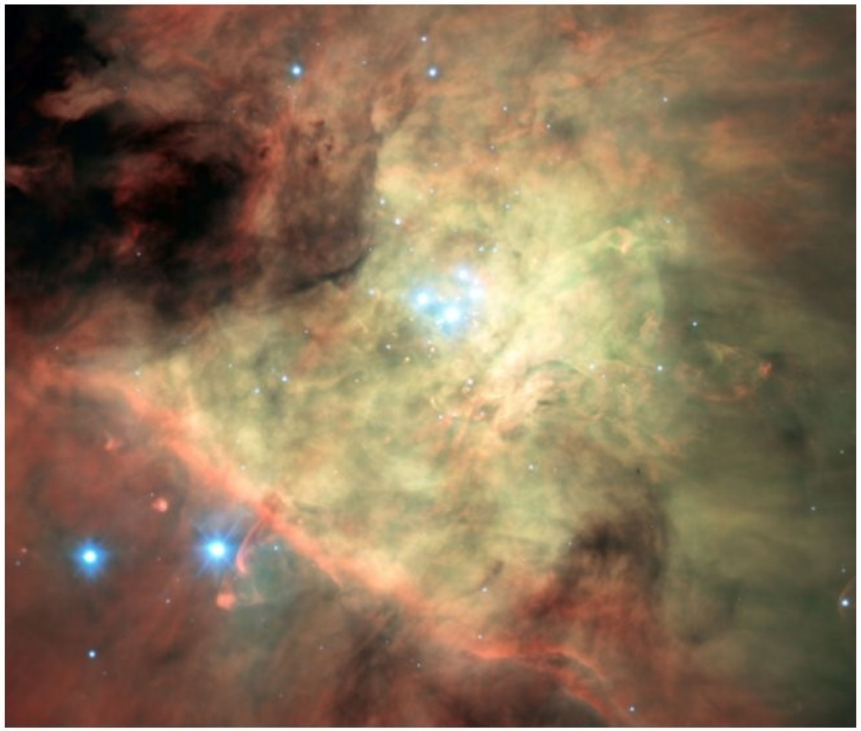

CALIFA Survey
instituto de astronomía
unam
MaNGA
0.019
0.038
0.057
0.076
0.096
0.11
0.13
0.15
0.17



PPAK

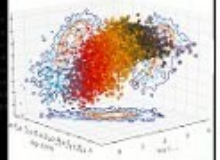


MUSE



CALIFA Survey

instituto de astronomía
unam



3D Spectroscopy Summary

- IFS is a common user technique (40% of the observations done with the 3.5m at CAHA, 80% of one of the UT/VLT).
- Many of proposed or new generations instruments are IFUs (MUSE, MEGARA).
- JWST will include an IFU.
- There is science that can only be done with IFUs.
- There are three major on-going IFU surveys: CALIFA, MaNGA, SAMI.
- You should be prepared for IFS!