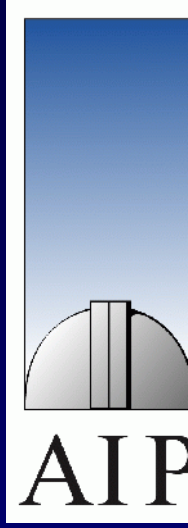
3D Spectroscopy: instrumentation and data reduction/analysis issues



Martin M. Roth (AIP)
Luz Marina Cairós Barreto (AIP)
Christer Sandin (AIP)
Peter Weilbacher (AIP)
Joris Gerssen (AIP)
Ana Monreal (ESO)

Astrophysikalisches Institut Potsdam

Estallidos Workshop: Integral Field Units
June 17-19, 2009, IAA Granada-Spain


Introduction
Instrumental Issues
Data Reduction / Data Analysis Issues
Conclusions

(1) Prelude

THE STAR-FORMING DWARF GALAXY POPULATION IN THE LOCAL UNIVERSE AND BEYOND:

"The first 3D Spectroscopic study of a sample of nearby Star-Forming Dwarfs"

Luz Marina Cairós Barreto

ASTROPHYSIKALISCHES INSTITUT POTSDAM

The Team

Astrophysikalisches Institut Potsdam :

L. Cairós, M. Roth, A. Kelz, P. Weilbacher

Instituto de Astrofísica de Canarias:

N. Caon, C. Zurita

Instituto de Astrofísica de Andalucía:

P. Papaderos, J.M. Vílchez,

Michigan University

C. Kehrig

THE FIRST 3D SPECTROPHOTOMETRIC MAPPING OF A LARGE SAMPLE OF STAR FORMING DWARFs

THE SAMPLE:

- 60 Galaxies
- Luminosity range: MB = -14.10 to **–20.50**
- Metallicity: 0.05 – **0.85 $Z_{\odot}$**
- All morphological subclasses (Cairós et al. 2001b)
- Additional deep imaging in at least two bands

IMMEDIATE AIMS

Build flux and equivalent width maps of emission lines: Hγ, Hβ, Hα, [OIII] or the shock-heated [SII], [OII]

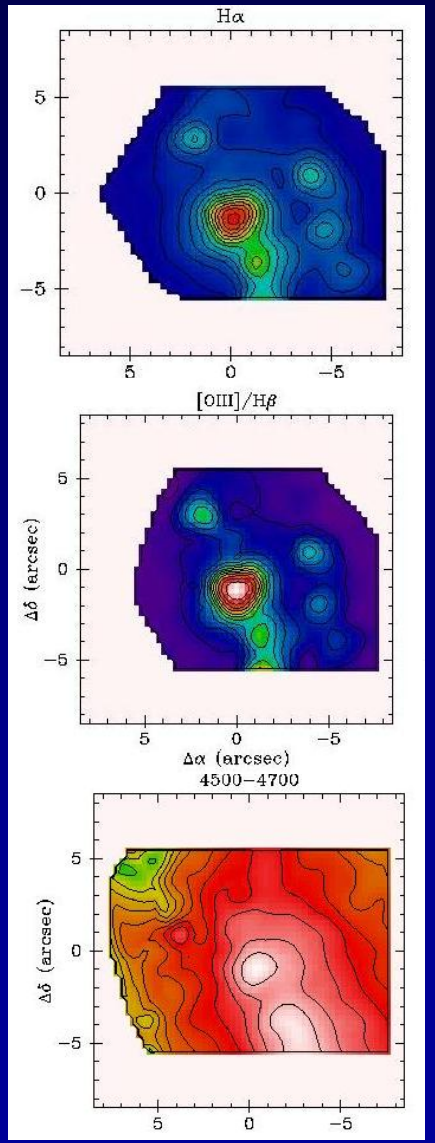
Age, SFR, trigger of SF

Build maps of the most interesting line ratios: [OIII]/ Hβ or [NII]/ Hα

Ionization mechanism

Build continuum maps : with and without emission lines

Morphology and stellar content



Mrk314

IMMEDIATE AIMS

Map the reddening

Dust content and distribution

Map WR features, 4650-4690 Å

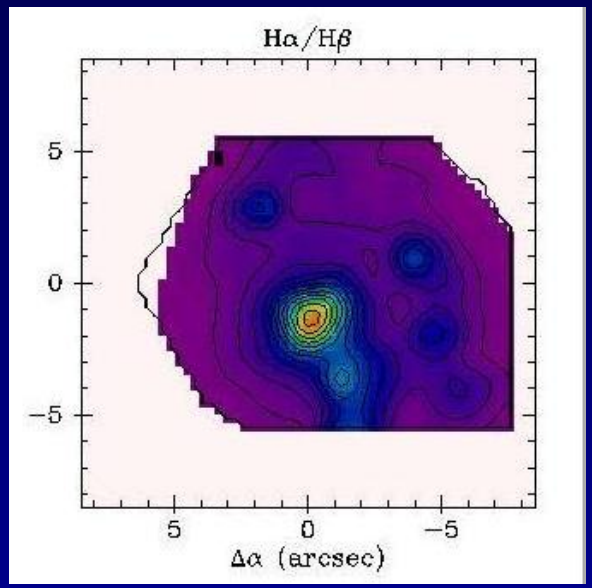
Ages and IMF parameters

Map the physical parameters of the gas (T_e,n_e)

Chemical abundances

Search for absorption features tracing the cooler stars: Mg 5167, 5184 Å, Fe 5270, 5335 Å , Na 5890, 5896 Å

Ages and metallicity of the old stars

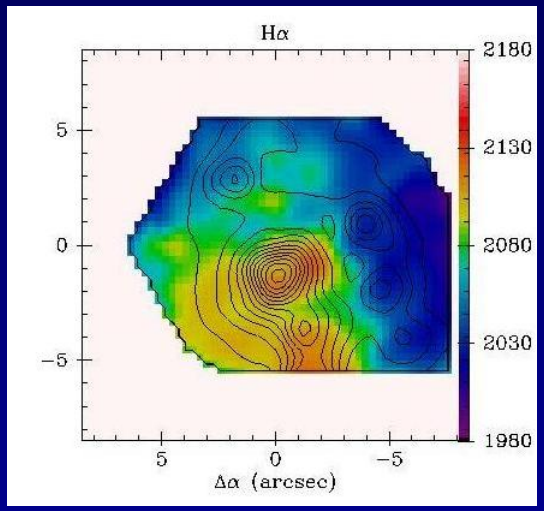


IMMEDIATE AIMS

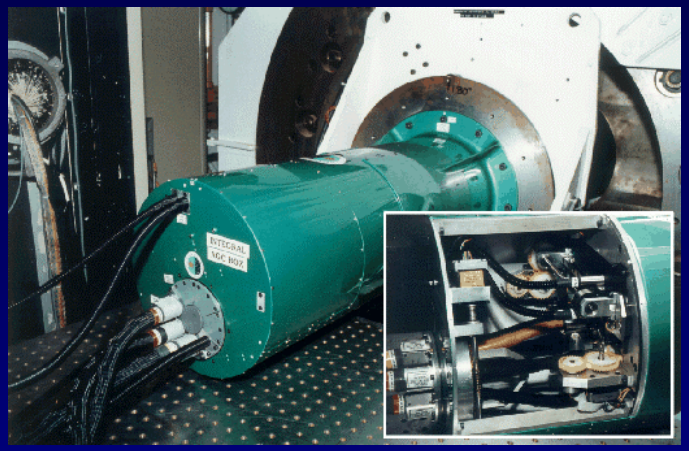
Gas velocity fields
+
Stars velocity fields

- mechamism that trigger the SF, interactions?

Starburst99 GALEV



OBSERVATIONS - INSTRUMENTATION



INTEGRAL, 4.2m WHT, ORM

FOV rectangular

STD/SB2 0.9'' FOV: 16.0 x 12.3

Number of fibers: 219 (189 + 30)

STD/SB3 2.7'' FOV: 33.6 x 29.4

Number of fibers: 135 (115 + 20)

Spectral range: 4300 – 7304; 3A/pix

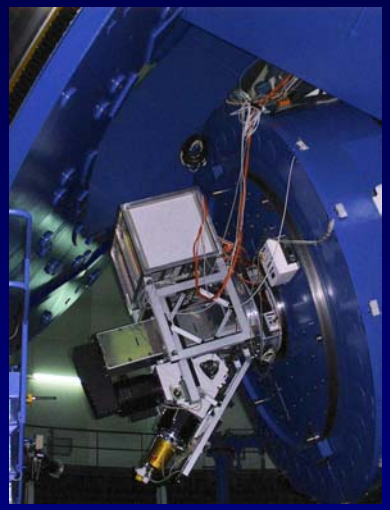
3700 –6900; 3 A/pix

Typical exposure times: 2 hours

- Mrk297, IIIZw102, Mrk314, Mrk370, Mrk35
- Mrk33, Mrk140, UM462, Mrk131, Mrk36, Mrk35

11 objects

OBSERVATIONS - INSTRUMENTATION



PMAS 3.5m CAHA

PMAS/Lens array	PPAK IFU
FOV rectangular	FOV hexagonal
1.0´´/lens FOV: 16.0 x 16.0	2.7´´ FOV: 74.0 x 65.0
Number of fibers: 256	Number of fibers: 331 + 36+15

Spectral range: 3600 – 7000 3A/pix

Typical exposure times: 2 hours

March 07 - 10 objects

April 08 – 4 objects

Mrk1418, Mrk407, Mrk409, Mrk32, Mrk750, Mrk206,Tololo 1434+032, Mrk475, Izw123, Izw159

Mrk1450, Mrk1481, SBS 1006+578, Mrk67

14 objects

OBSERVATIONS - INSTRUMENTATION

VIRUS-P, 2.7 Harlan J. Smith, McDonald Observatory, Texas

FOV hexagonal

4.10´´ FOV: 112 x 112

Spectral range ~ 3400-5650 1.2 A/pix

Number of fibers: 247

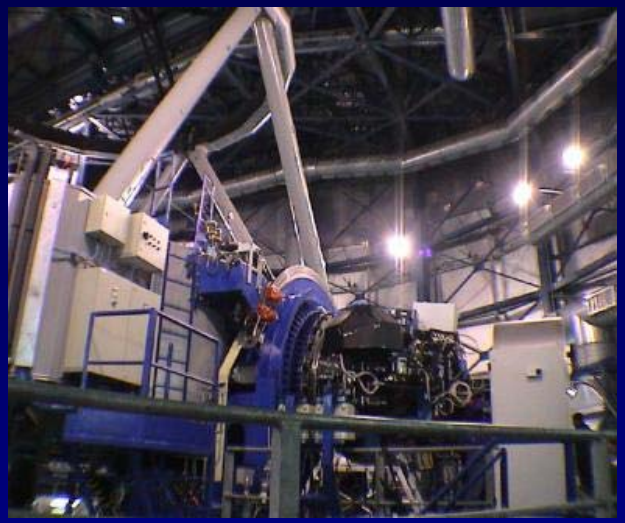
Typical exposure times: 3-4 hours

Oct-2007: IIIZw102, Mrk33, Mrk314, IIZw33

March-2008: Haro1, NGC4670

6 objects

OBSERVATIONS - INSTRUMENTATION



VIMOS, 8.2m VLT, ESO

FOV rectangular

0.67´´ FOV: 27.0 x 27.0

Spectral range ~ 4200 – 7400
3A/pix

Typical exposure times: 1-2.5 hours

3 nights in August 2007:

Tololo1937-423, Mrk900, Haro14, Haro11, Haro15,
Tololo1924-416, Mrk1131, Tololo 0127-397

8 objects

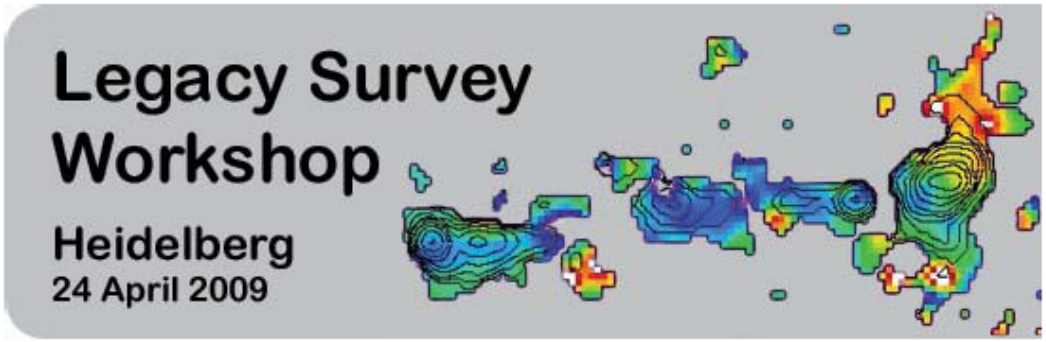
Proposed Large Program at Calar Alto (500 – 1000 Galaxies)

Calar Alto

suchen..

Home
About CAHA
Observing
Releases
Science
Staff
MPIA
IAA

Call for ideas for an IFU Legacy Survey at Calar Alto



Calar Alto observatory is looking for ideas for a legacy survey with the PMAS/PPAK Integral Unit, currently the widest field-of-view (74"x64") IFU in the world. The legacy survey will u substantial fraction of the open time at the 3.5m telescope over the next years and address a range of pertinent scientific topics. Observations and data reduction will be performed by C staff and the final data products (raw data, reduced and calibrated data, basic analysis, visualization tools) will be publicly available.

The proposed survey should be unique, clearly different from any other spectroscopic survey already performed, or to be performed, in a 4m-class telescopes and should explore the large field-of-view of PMAS. PMAS currently uses ~30% of the 3.5m telescope time, a fraction muc larger than any other similar instrument in the world, making 3D spectroscopy an expertise of Calar Alto.

EL UNIVERSO
ASTRONOMÍA
2009

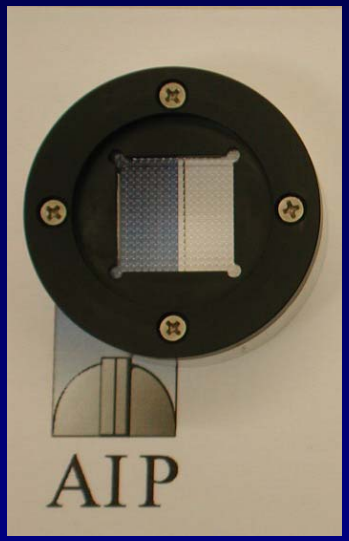
(2) Instrumental issues

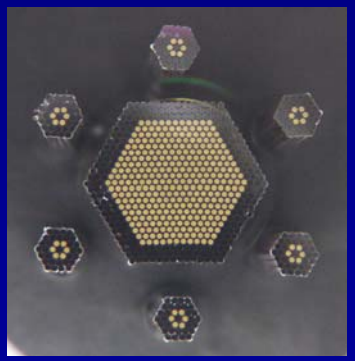
- Overall throughput
- Response variation
- Flexure
- IFU image quality
- Scattered light, ghosts

2.1 Overall Throughput

PMAS @ CAHA 3.5m

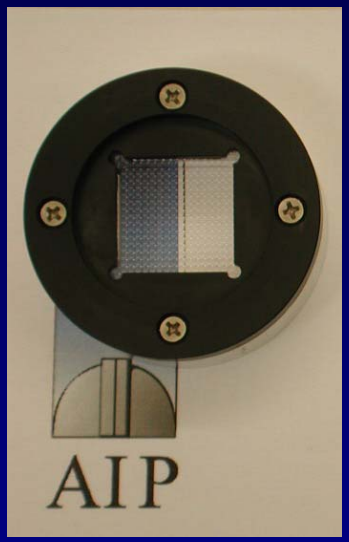
Fiber-slit	0.1 x 96 mm
Collimator	f = 450 mm, F/3
Camera	f = 270 mm, F/1.5
Gratings	300 / 600 / 1200 gr/mm (U,V,R)
Wavelength range	350 - 900 nm
Dispersion	1.7 – 0.8 – 0.35 A/pix
Coverage	3700 – 1600 – 720 A *)
Resolution ($\lambda/\Delta\lambda$)	730 – 1500 – 3600 (11000 in 2nd order)

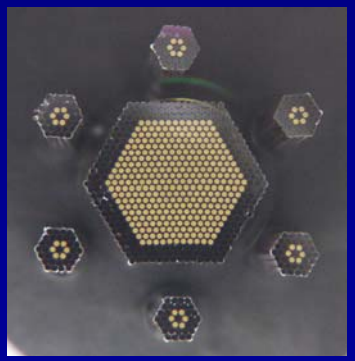


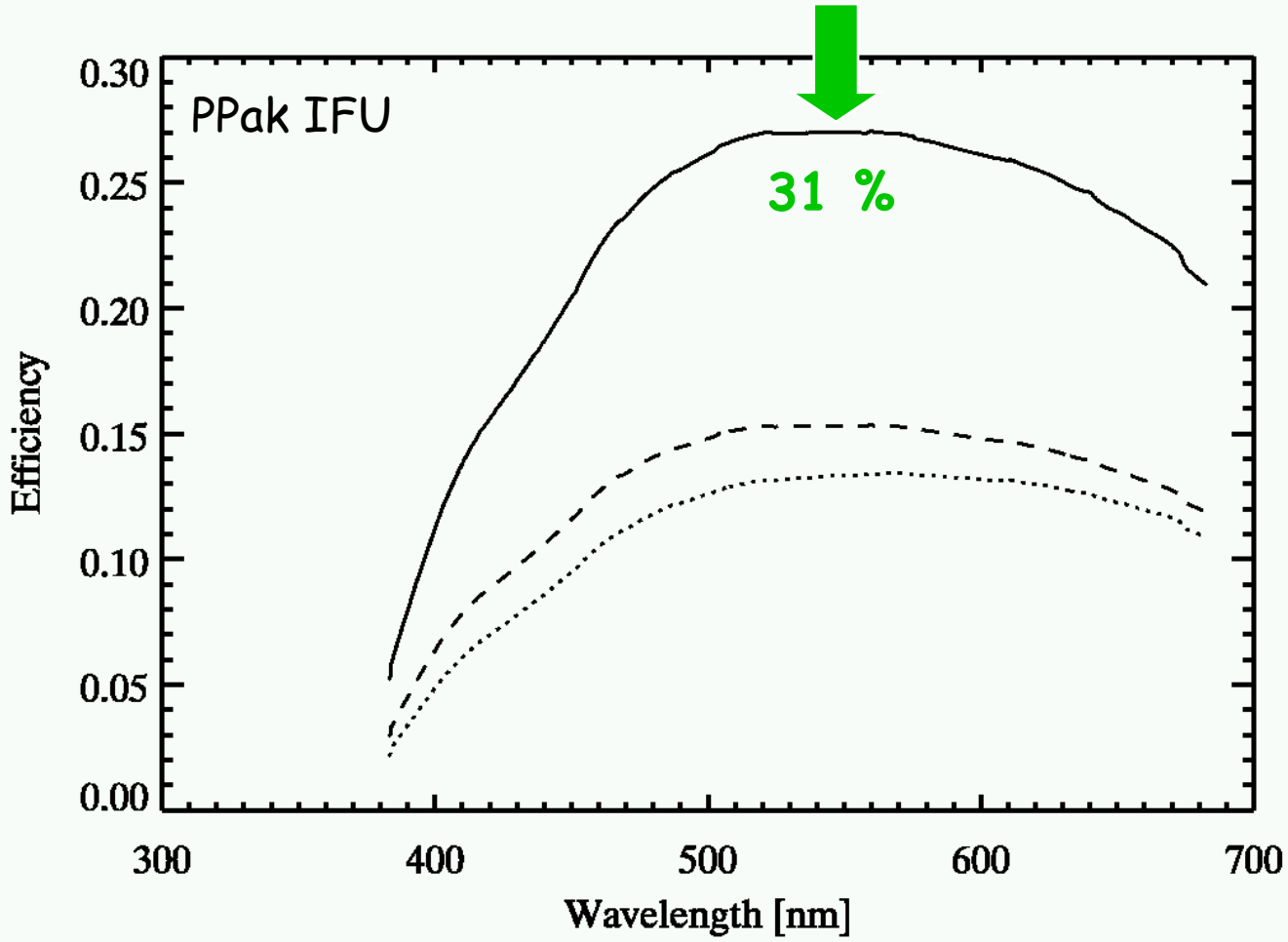


PMAS @ CAHA 3.5m

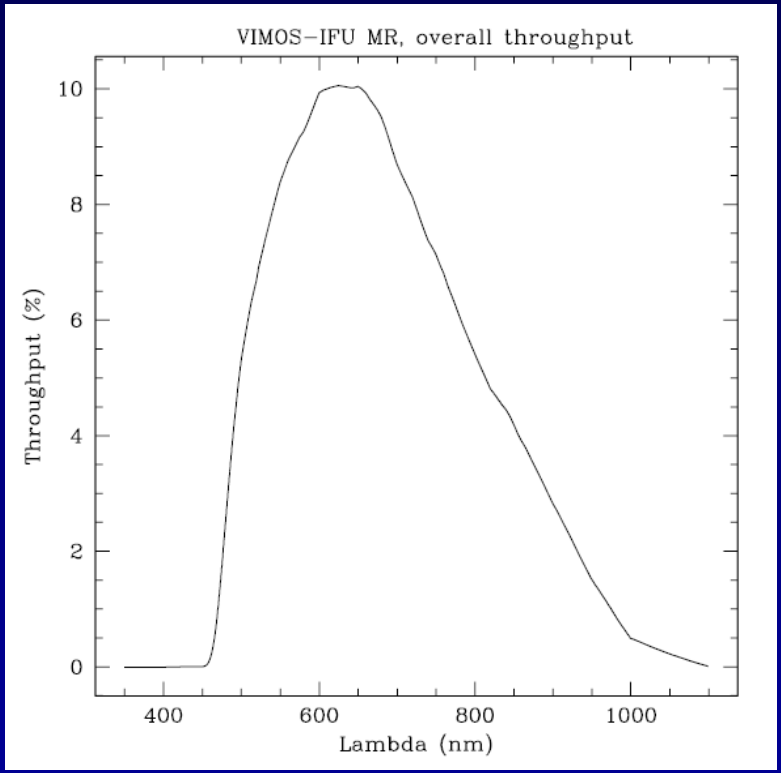
Fiber-slit	0.1 x 96 mm
Collimator	f = 450 mm, F/3
Camera	f = 270 mm, F/1.5
Gratings	300 / 600 / 1200 gr/mm (U,V,R)
Wavelength range	350 - 900 nm
Dispersion	1.7 – 0.8 – 0.35 Å/pix
Coverage	3700 – 1600 – 720 Å *)
Resolution ($\lambda/\Delta\lambda$)	730 – 1500 – 3600 (11000 in 2nd order)



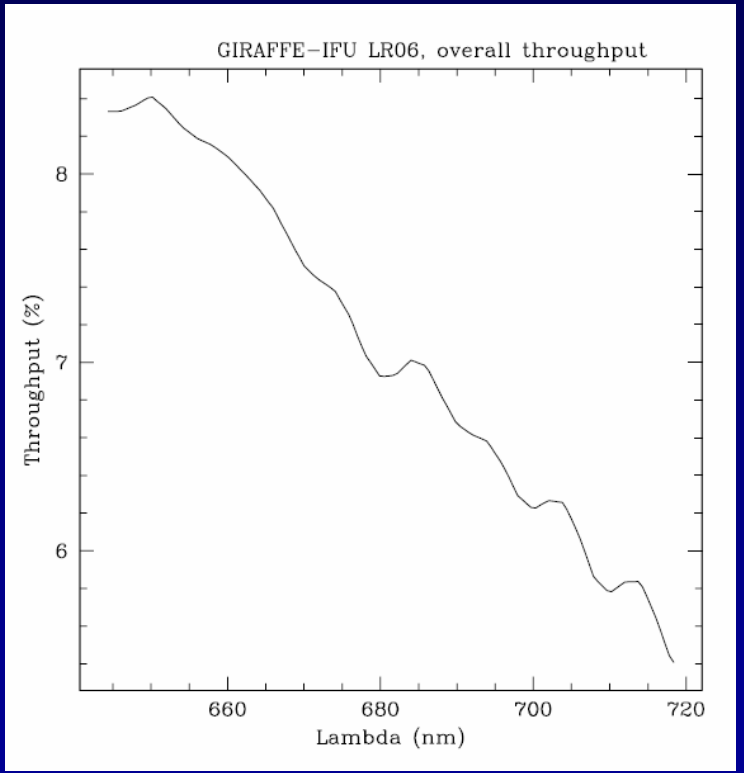


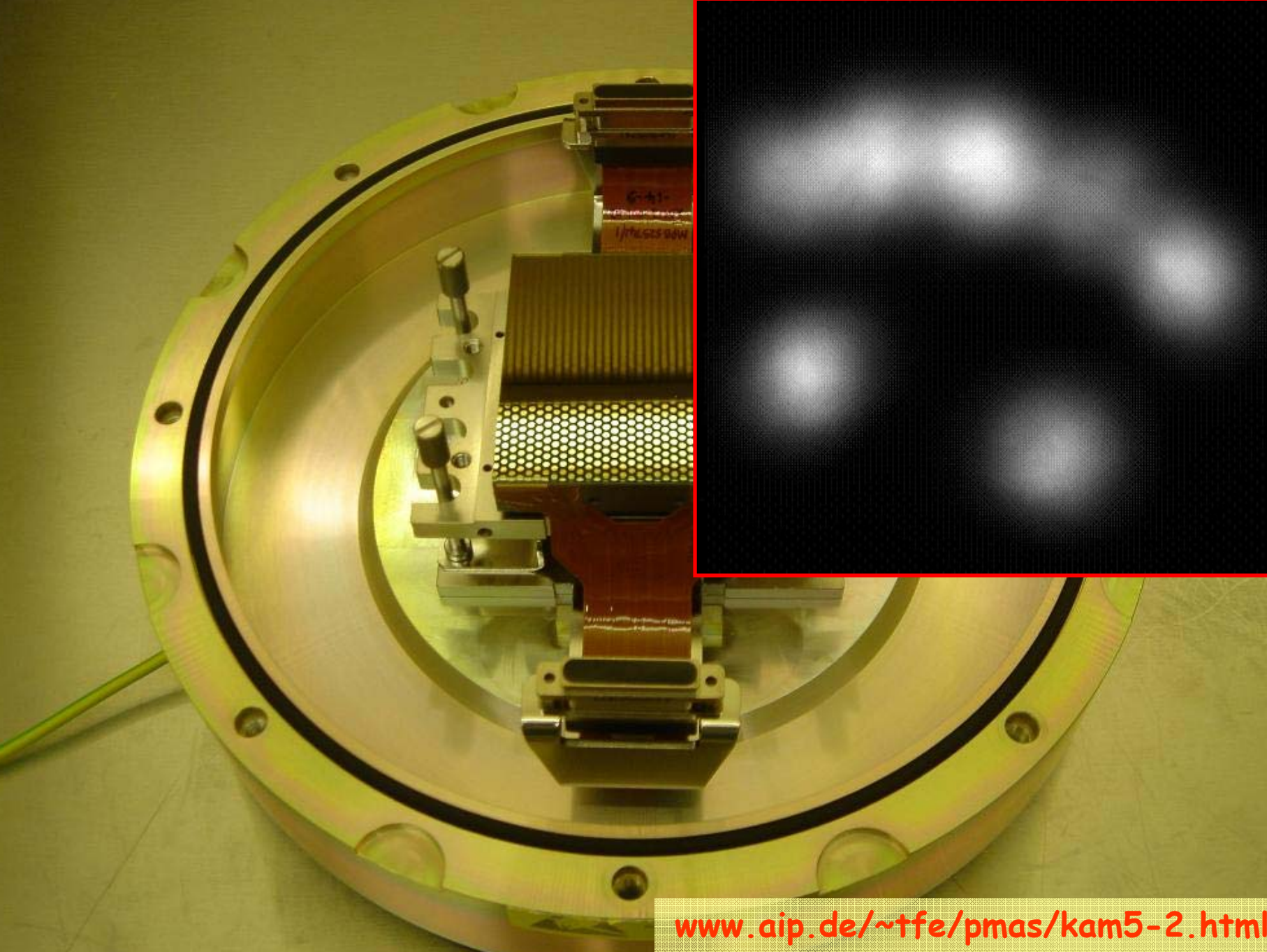

PPak IFU
31 %
Efficiency
0.30
0.25
0.20
0.15
0.10
0.05
0.00
300
400
500
600
700
Wavelength [nm]

VIMOS-IFU MR

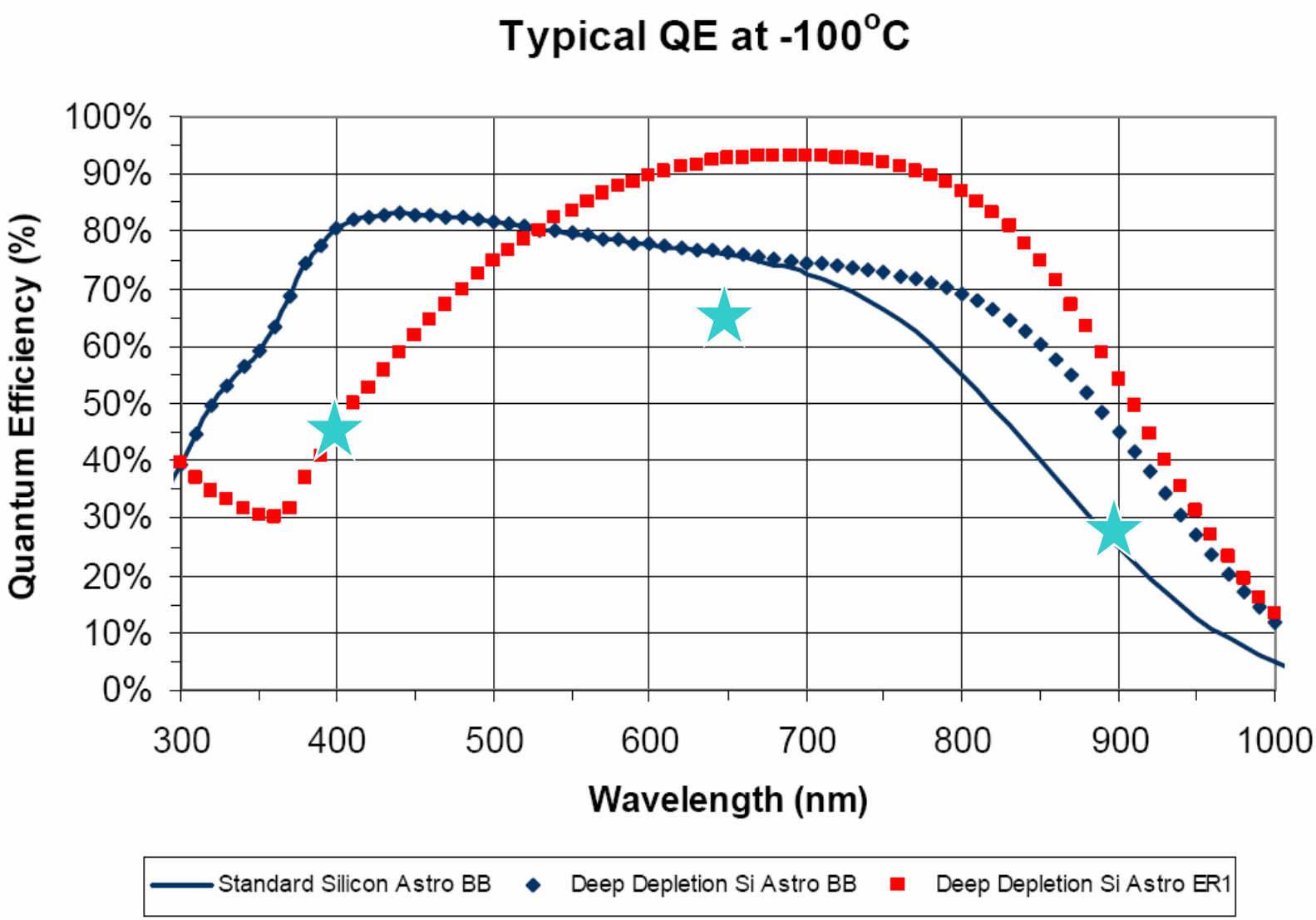


FLAMES ARGUS



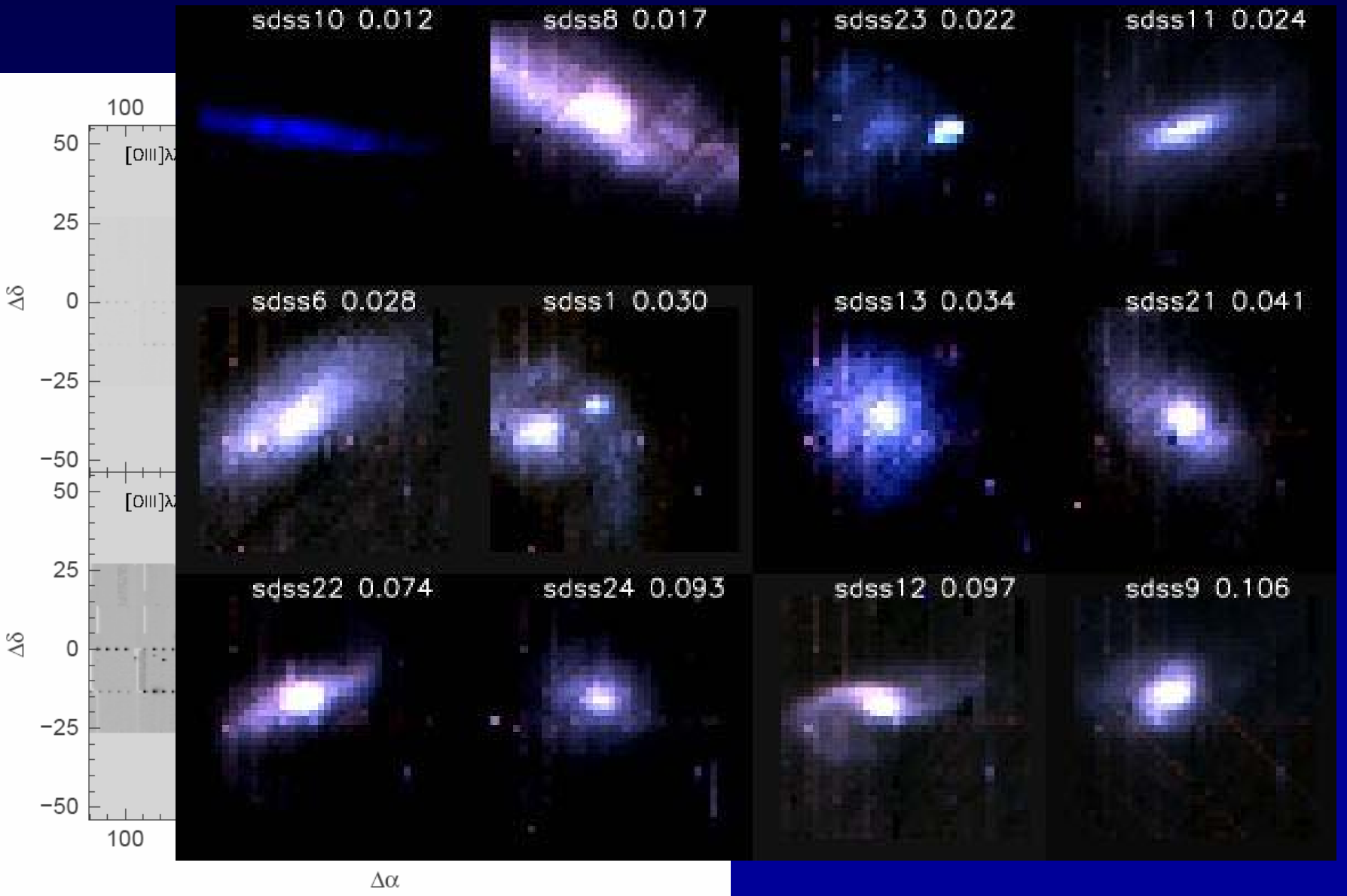


www.aip.de/~tfe/pmas/kam5-2.html

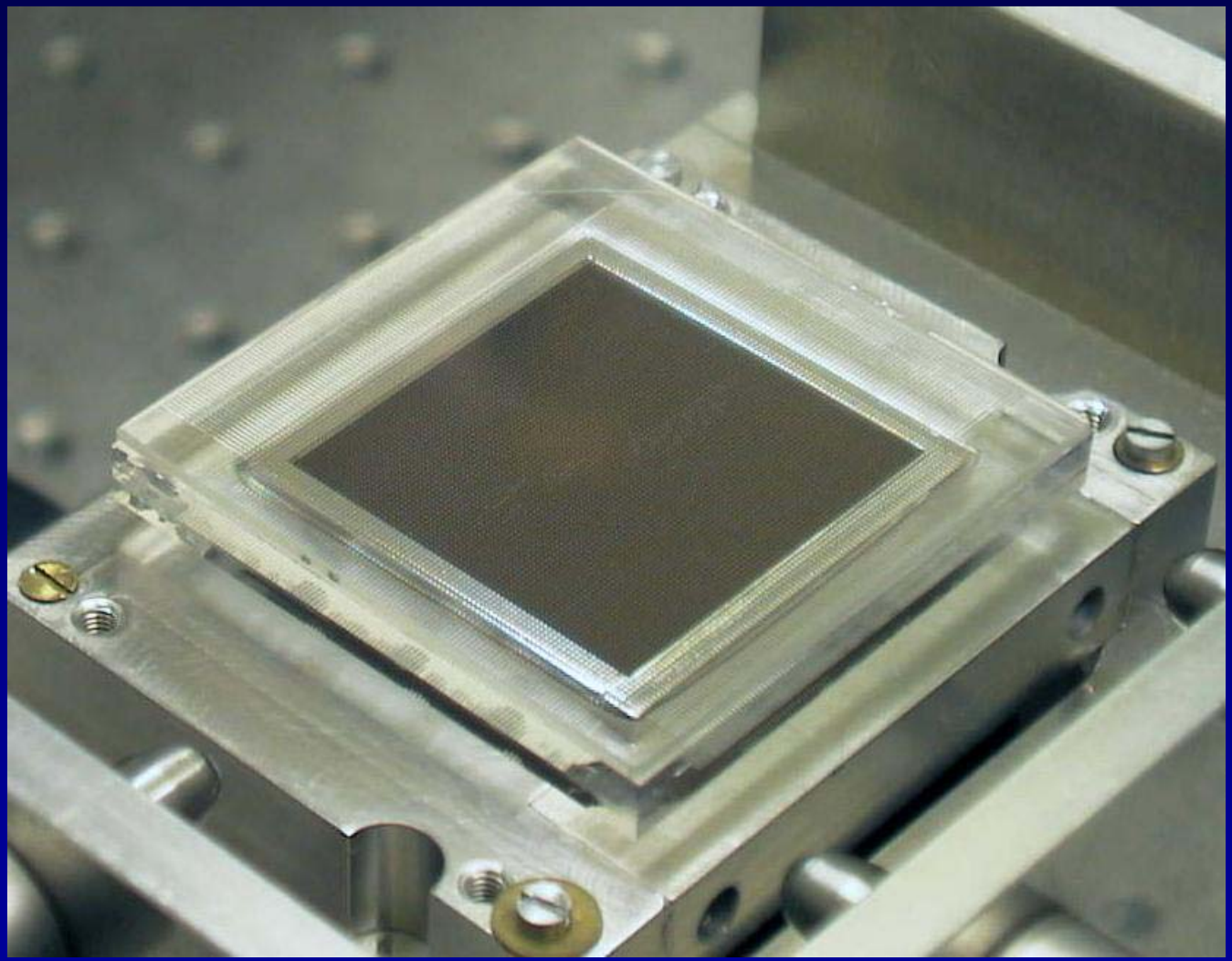

Typical QE at -100°C
Quantum Efficiency (%)
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
300
400
500
600
700
800
900
1000
Wavelength (nm)
Standard Silicon Astro BB
Deep Depletion Si Astro BB
Deep Depletion Si Astro ER1

2.2 Response variation

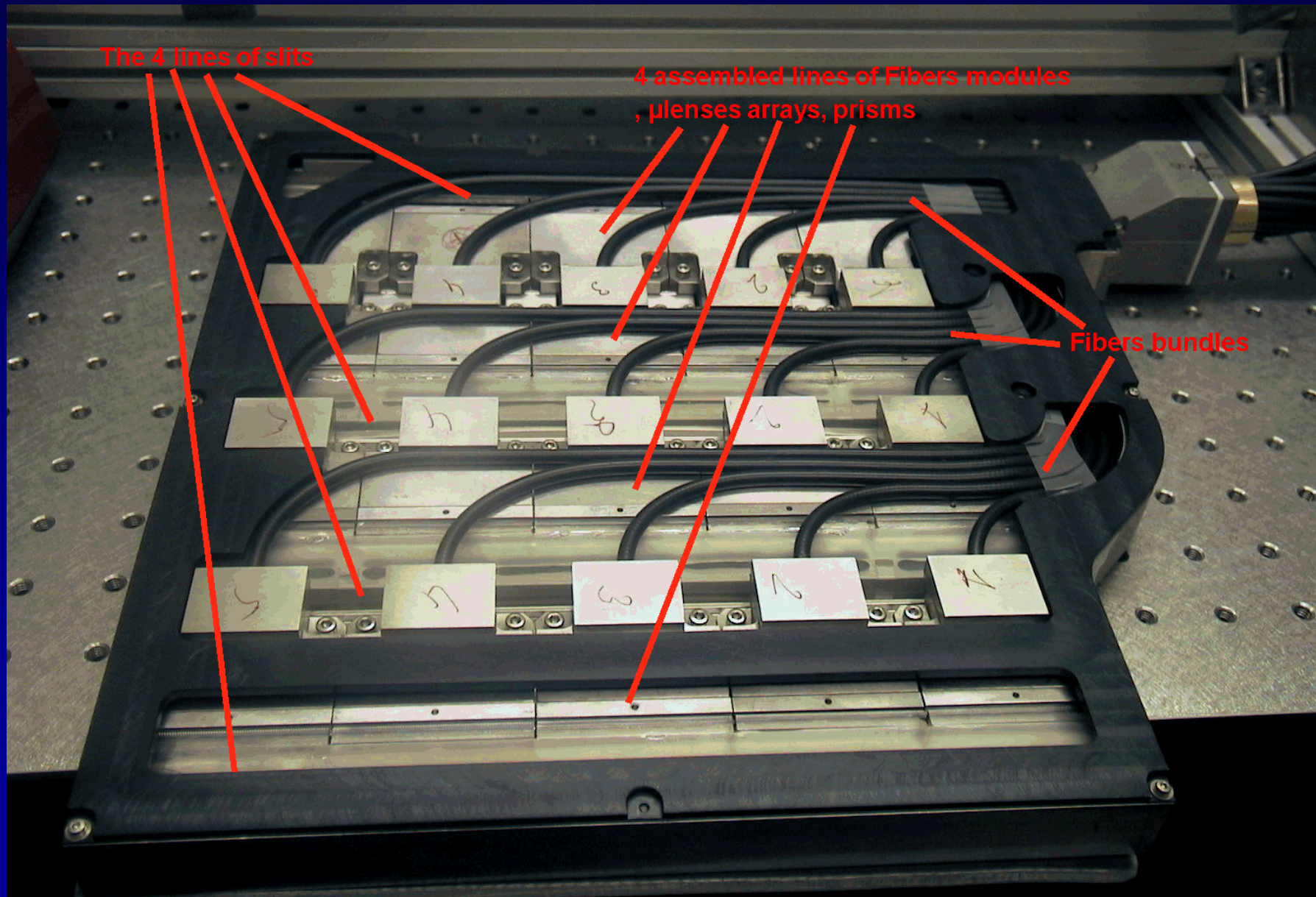
Response Variation



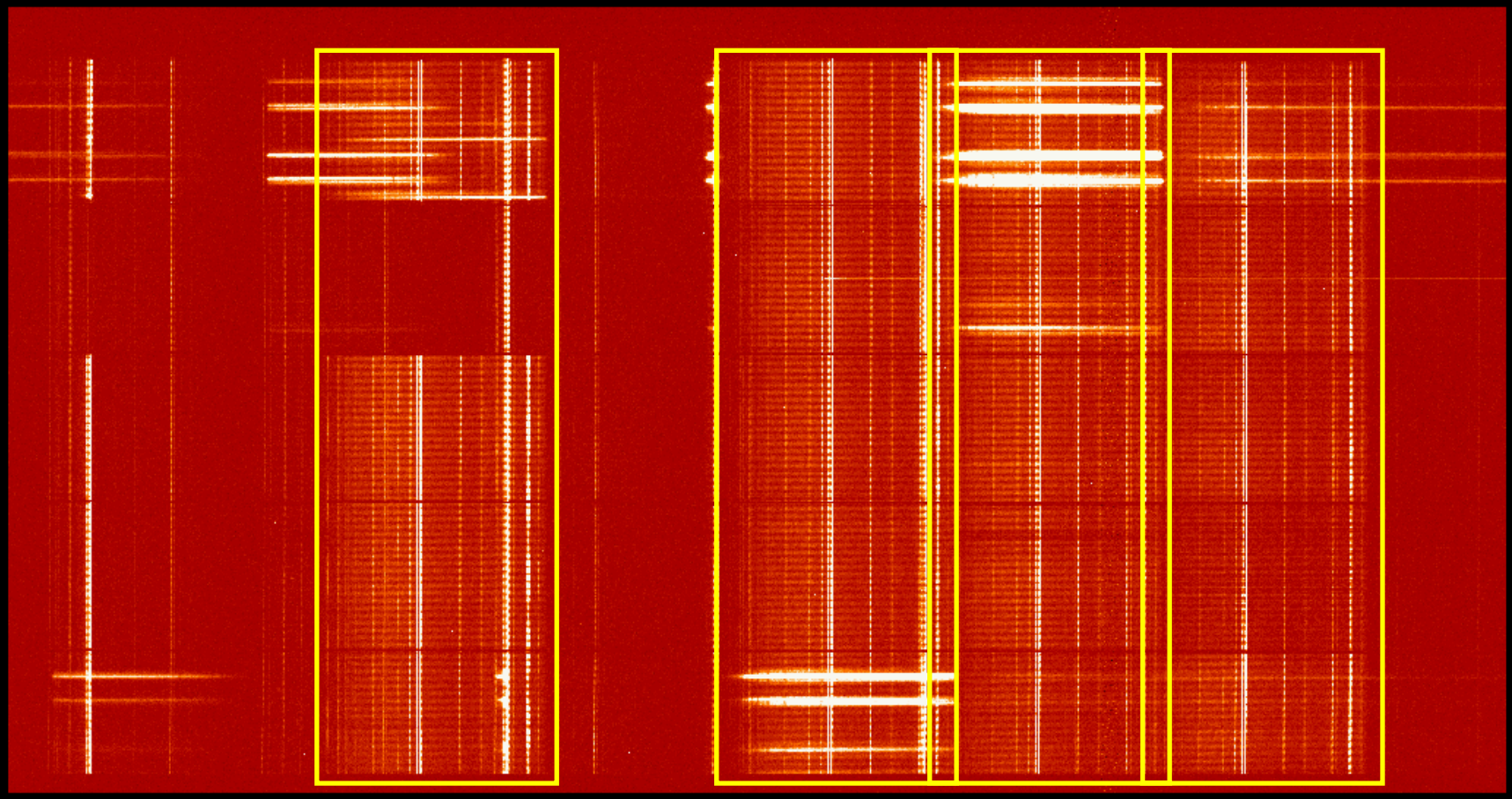
Response Variation



Response Variation

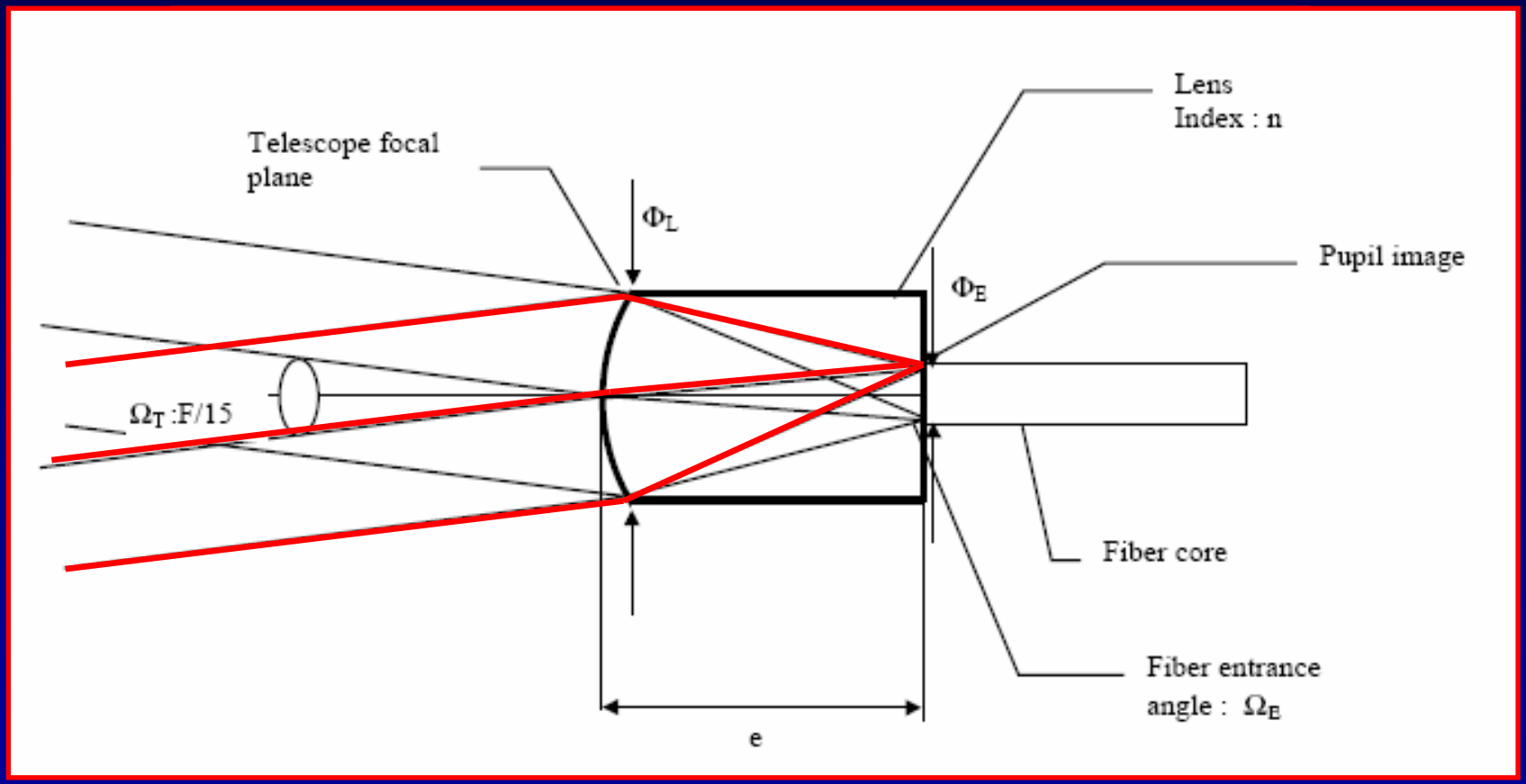


Response Variation



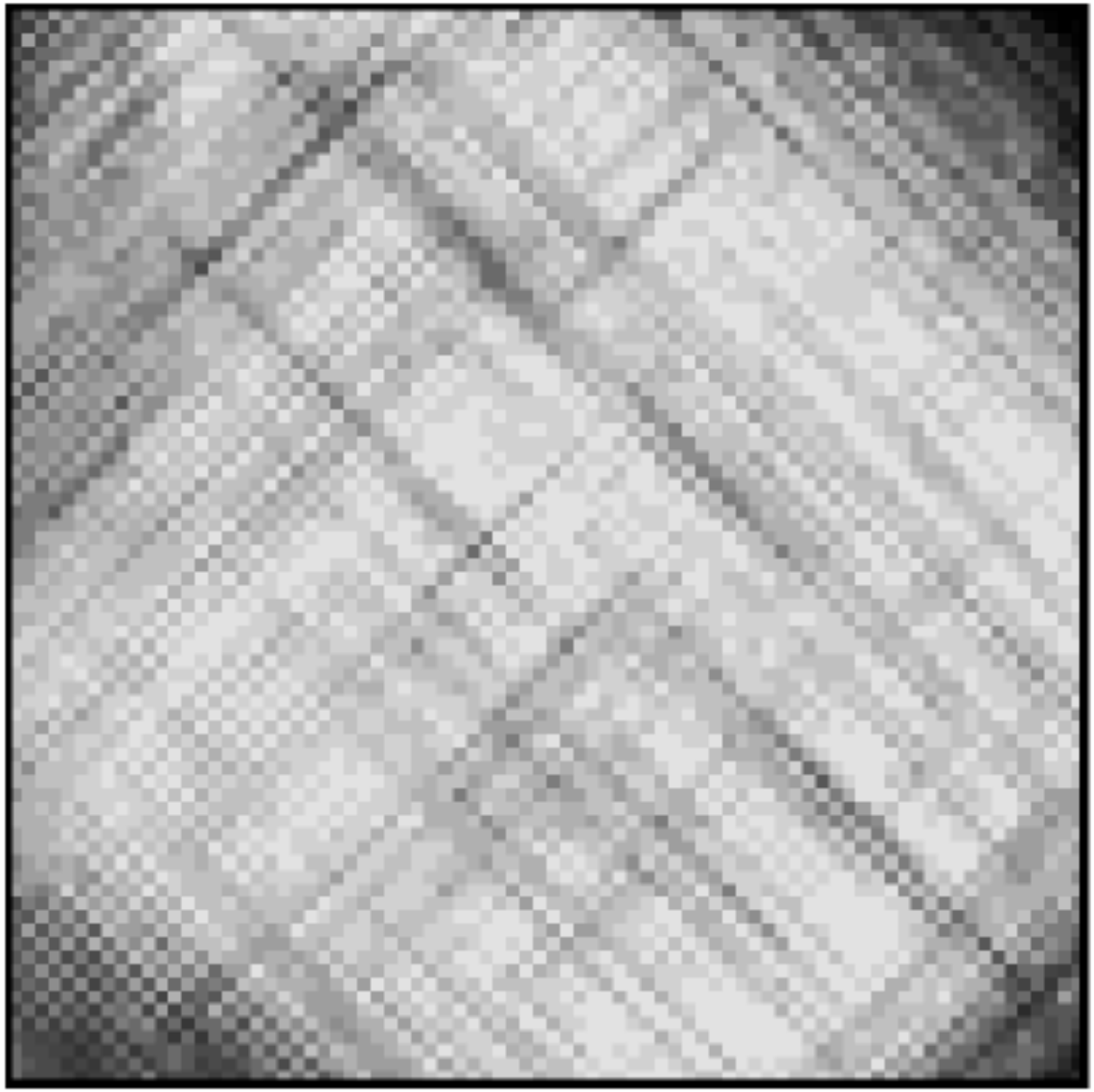
LR blue

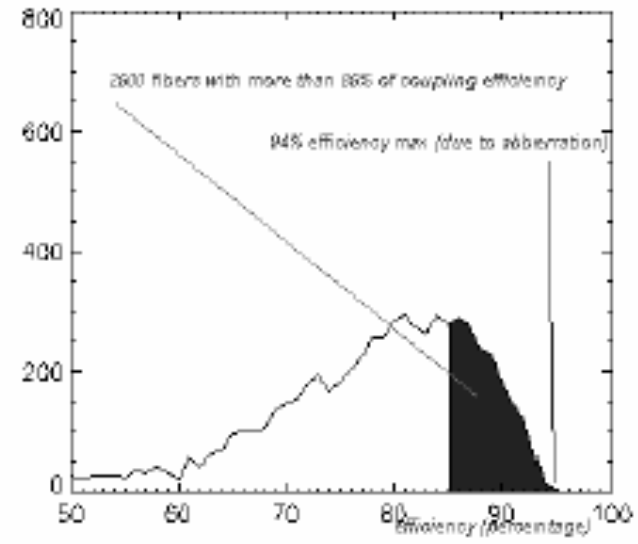
Response Variation

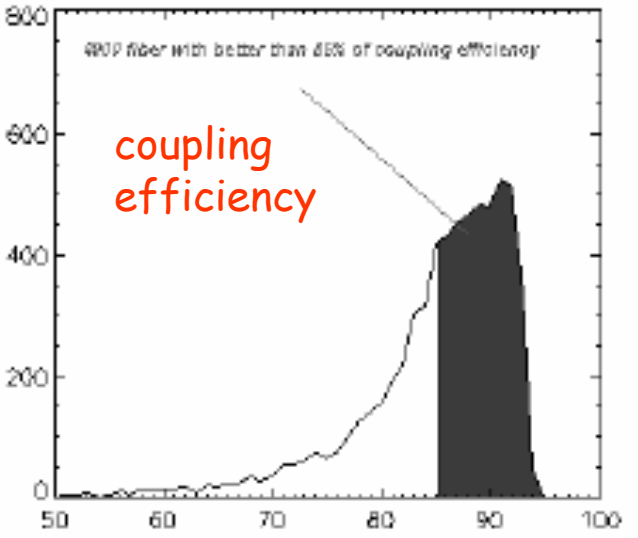


Prieto et al. 2000, SPIE 4008, 510

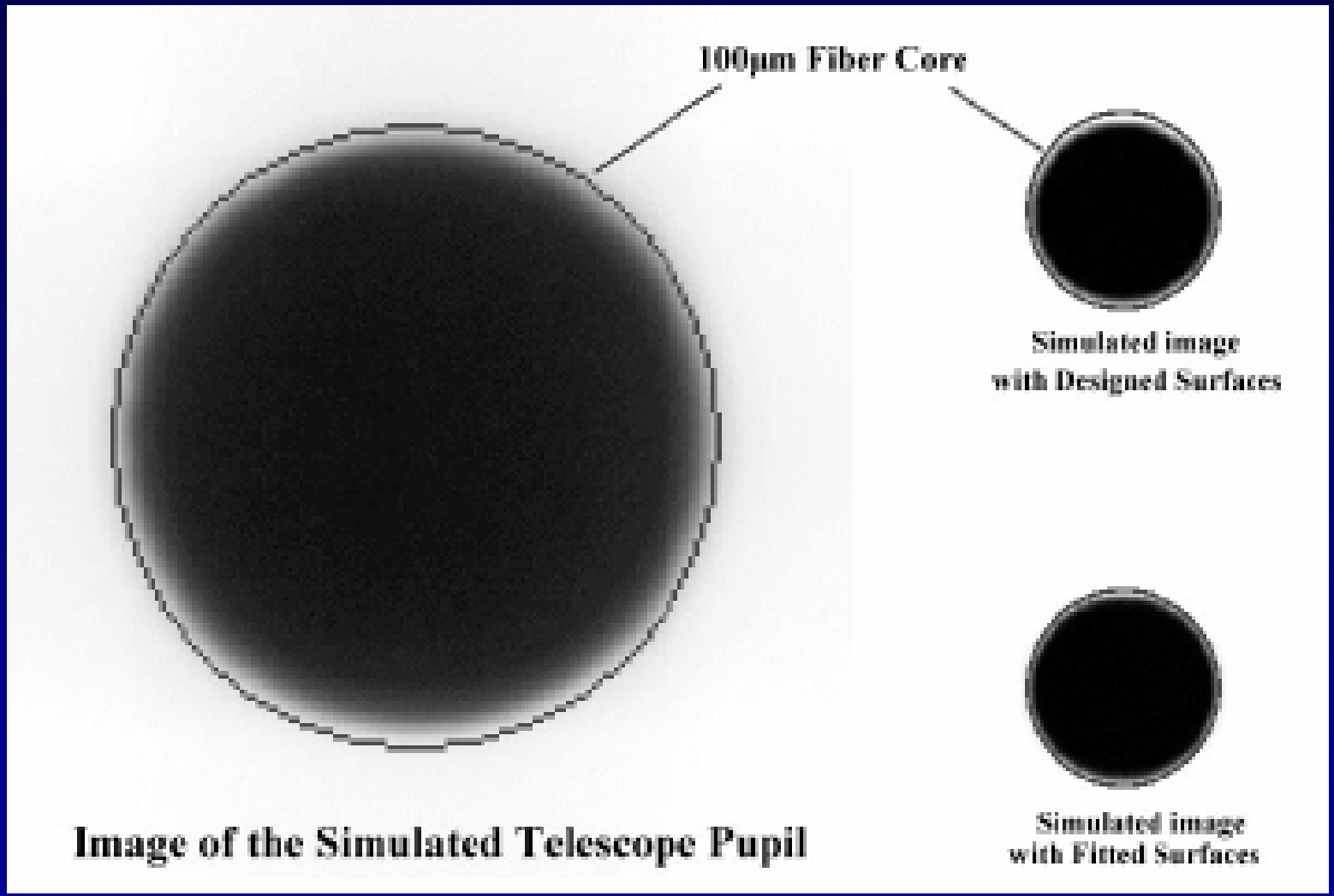
Response Variation



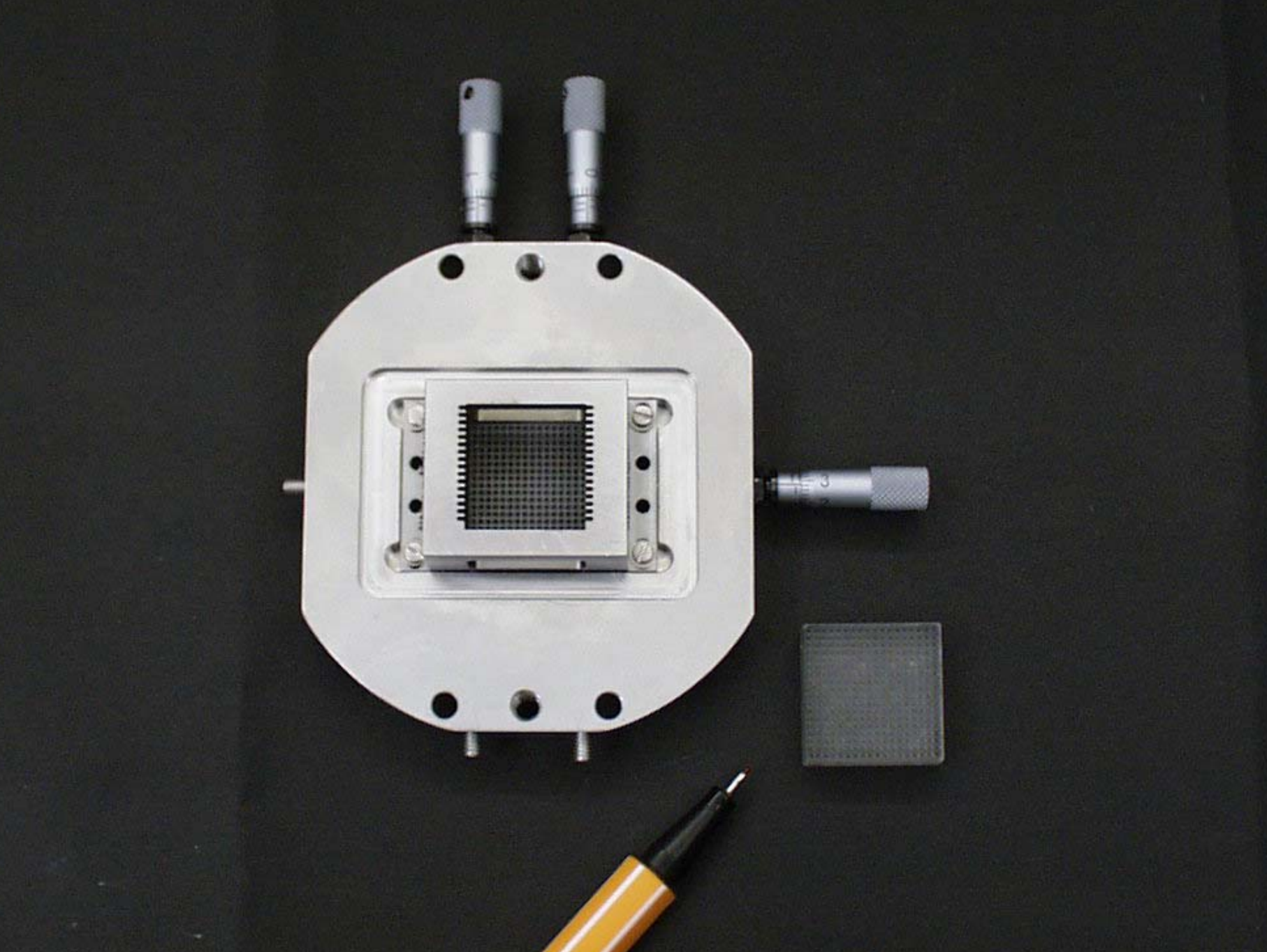




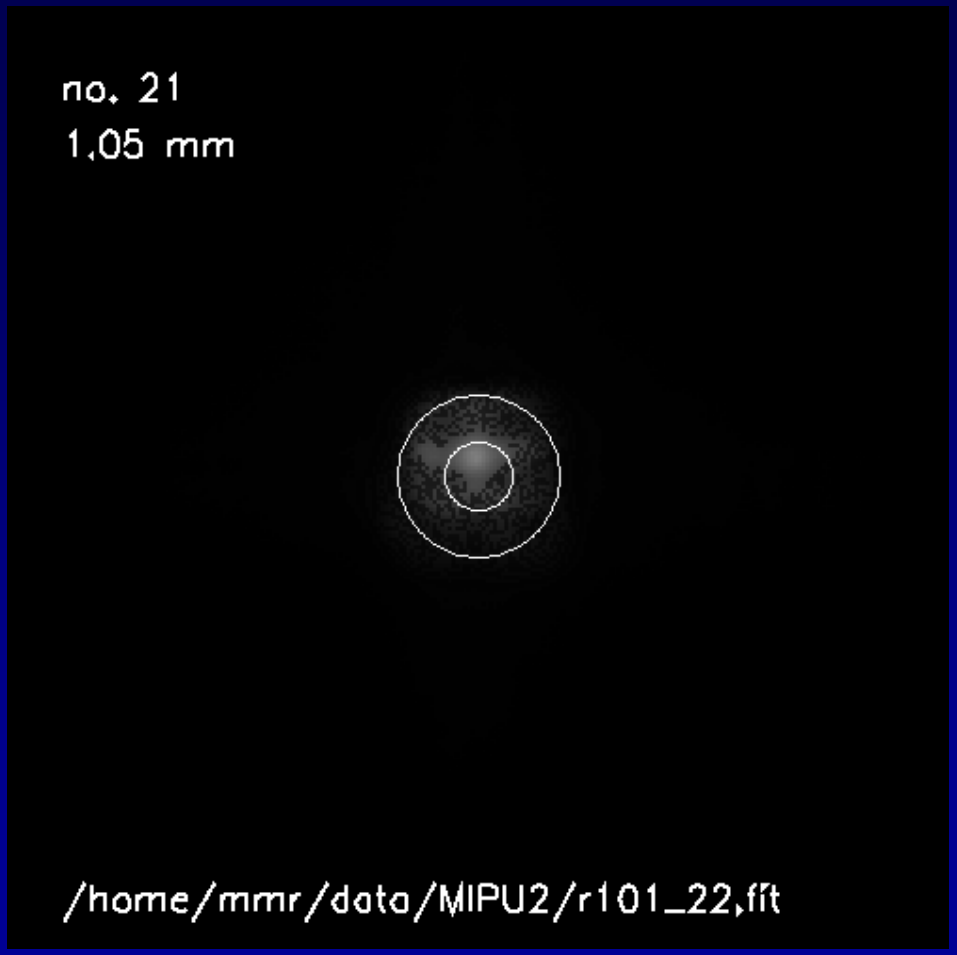
Response Variation



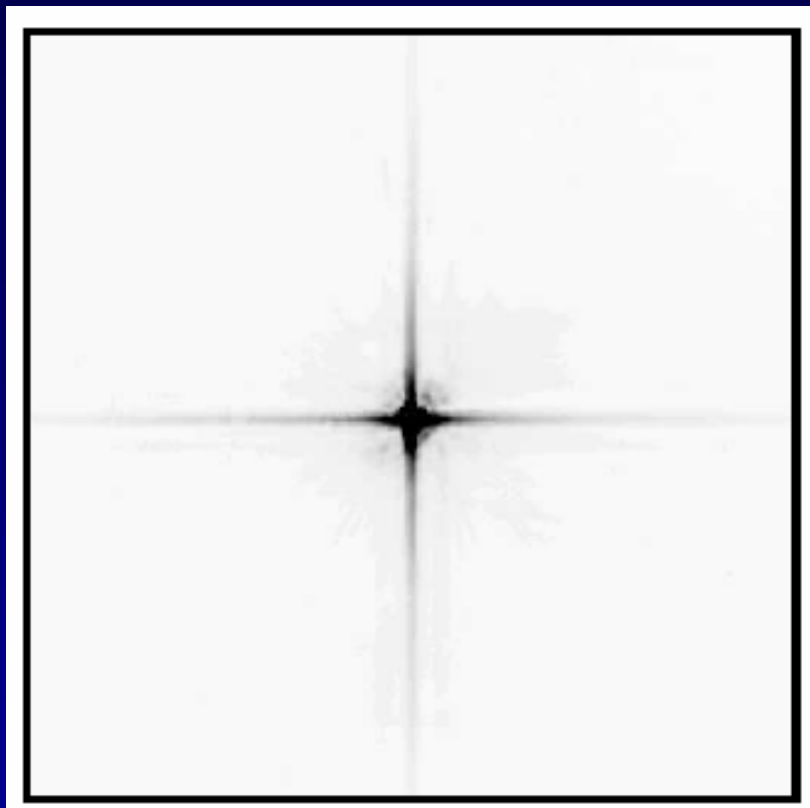
Prieto et al. 2000, SPIE 4008, 510



Response Variation

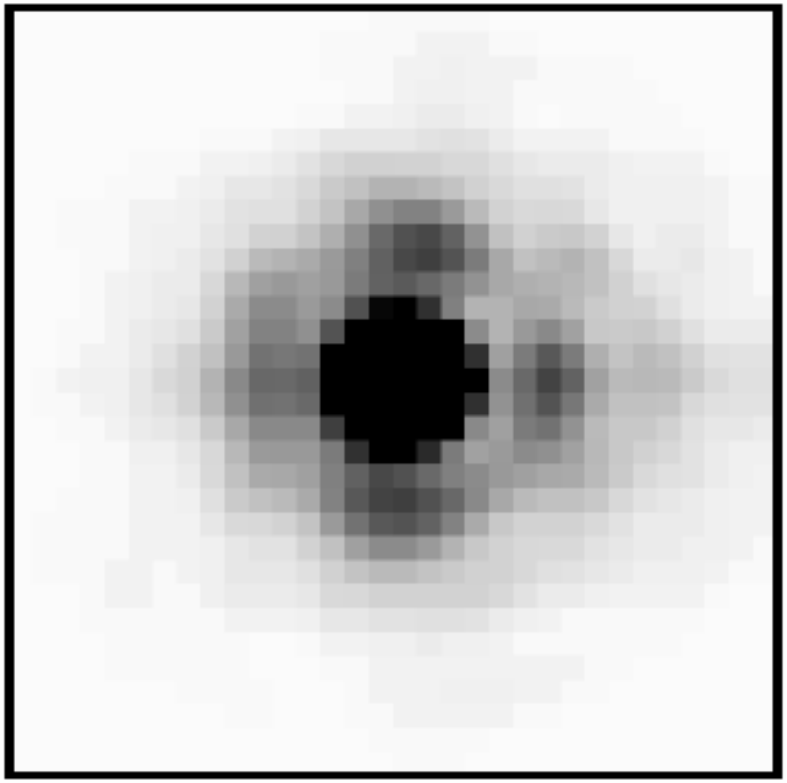


Response Variation



single lenslet PSF (100 frames)

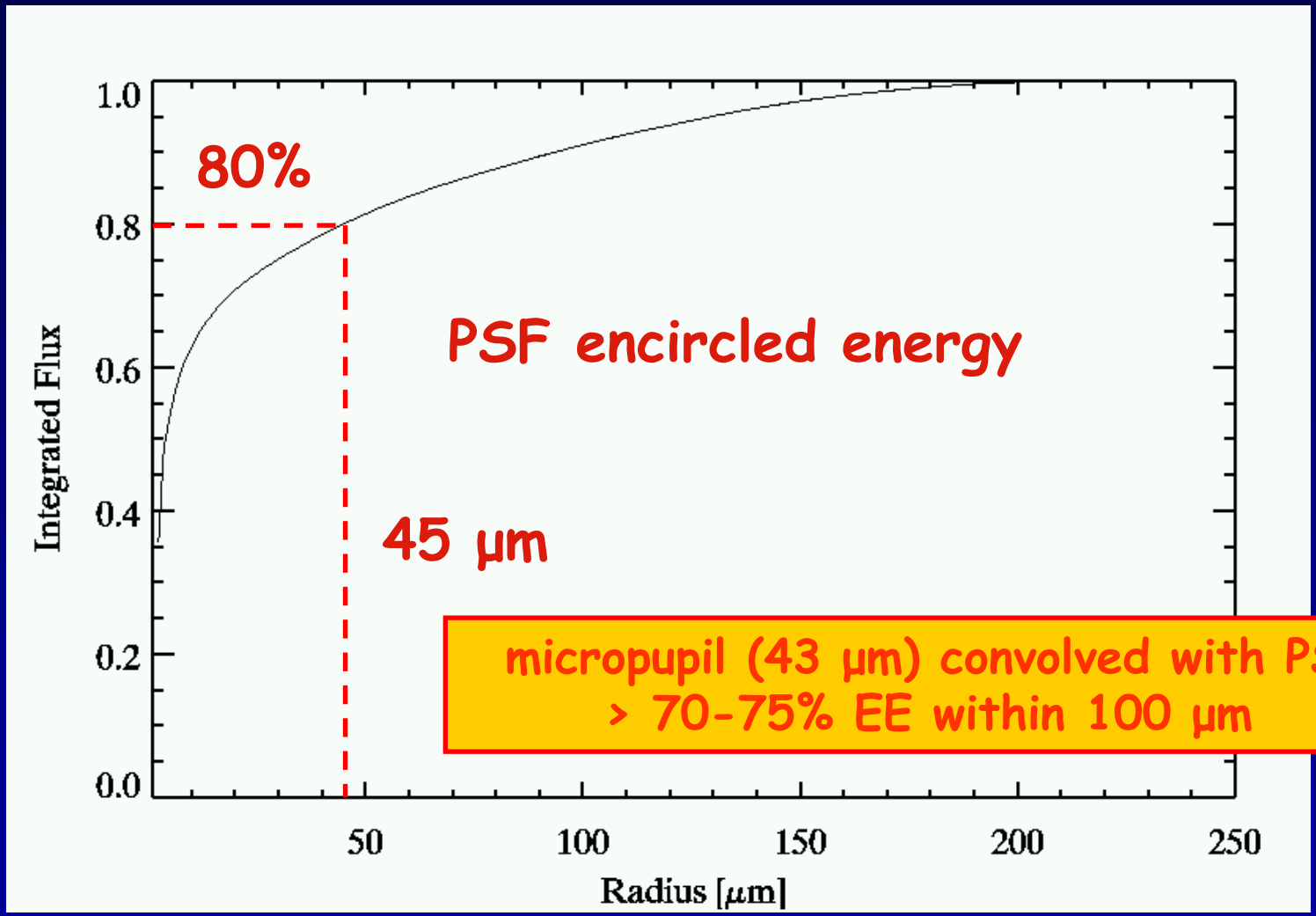
(1% peak scale)



zoom: Airy pattern

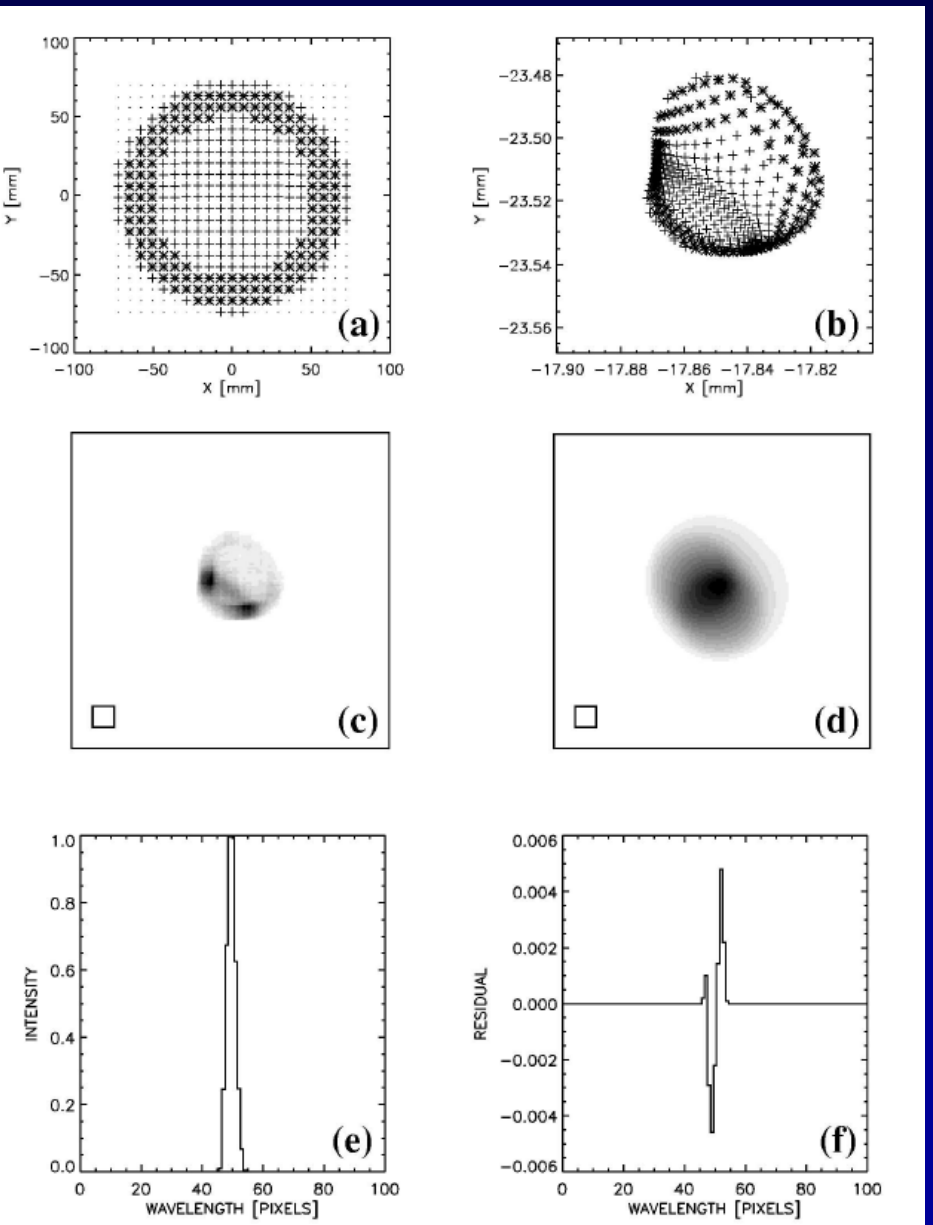
Roth et al. 2006, SPIE 6269, 15 (see also Lee et al. 2001, PASP 113, 140)

Response Variation



Response Variation

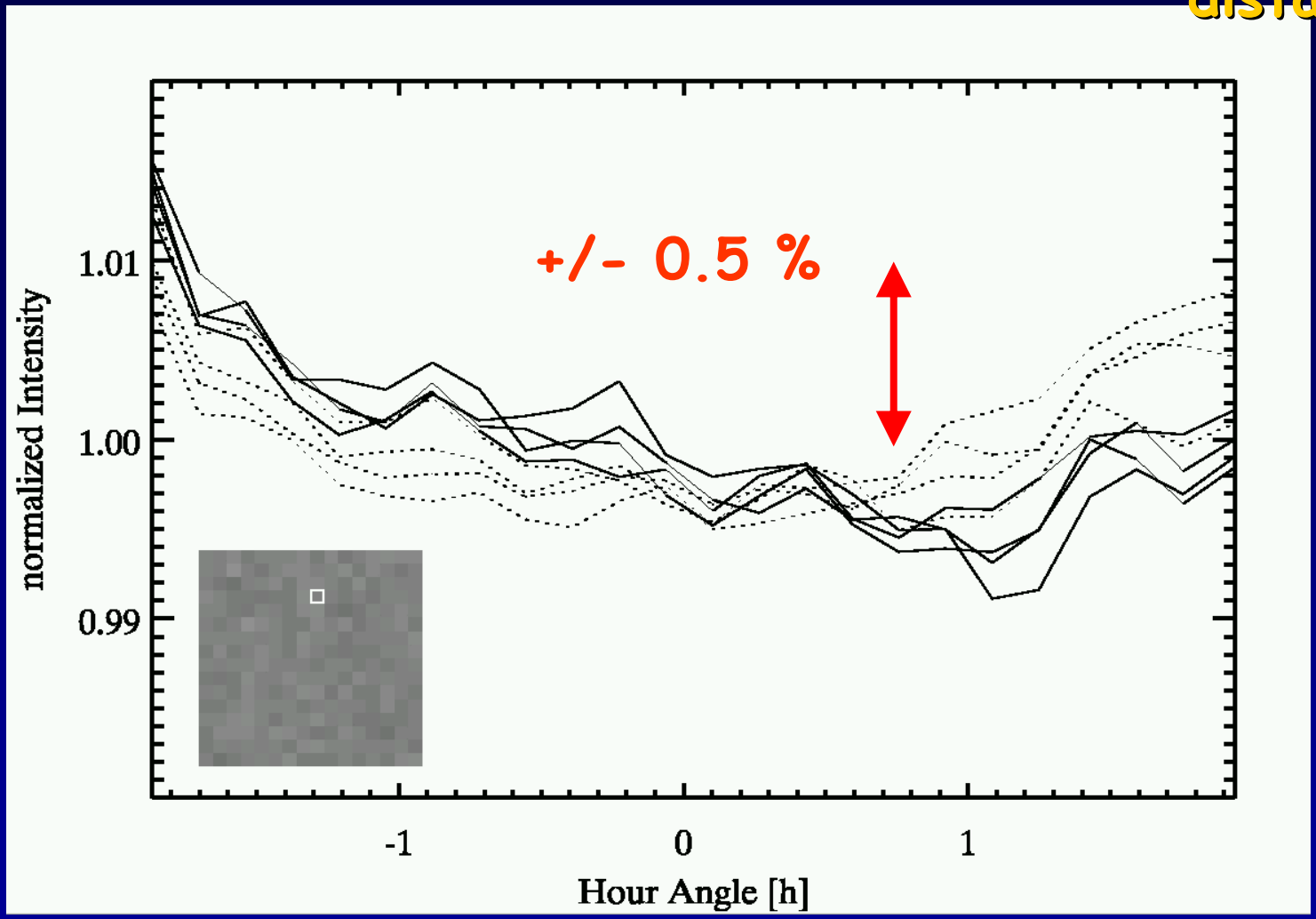
Response Variation



Influence of fiber illumination

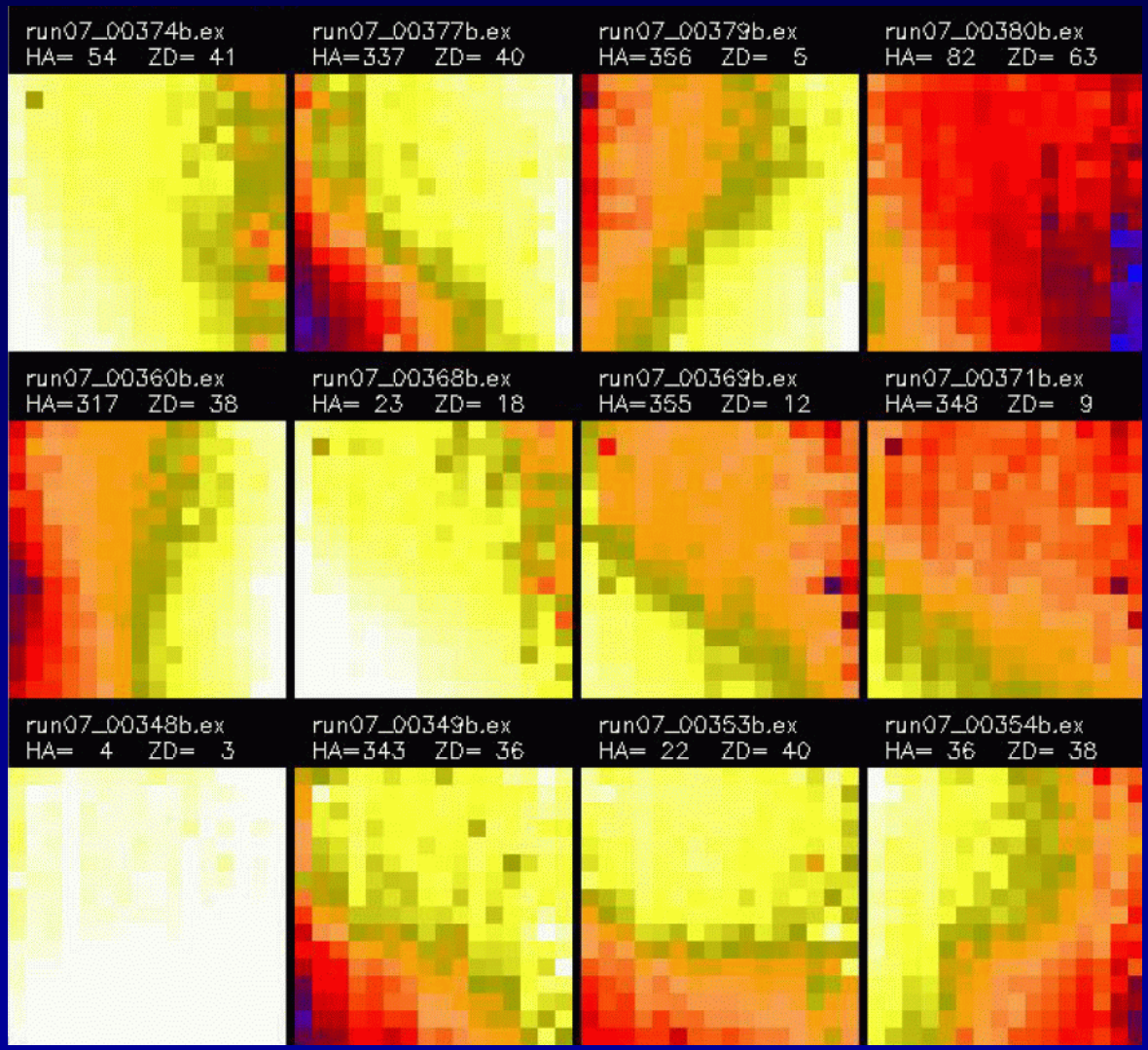
Schmoll et al. 2003, PASP 115, 854

Flat-field variation vs. telescope zenith distance



Single spaxel transmission variation over 4 hrs, tracking under real conditions

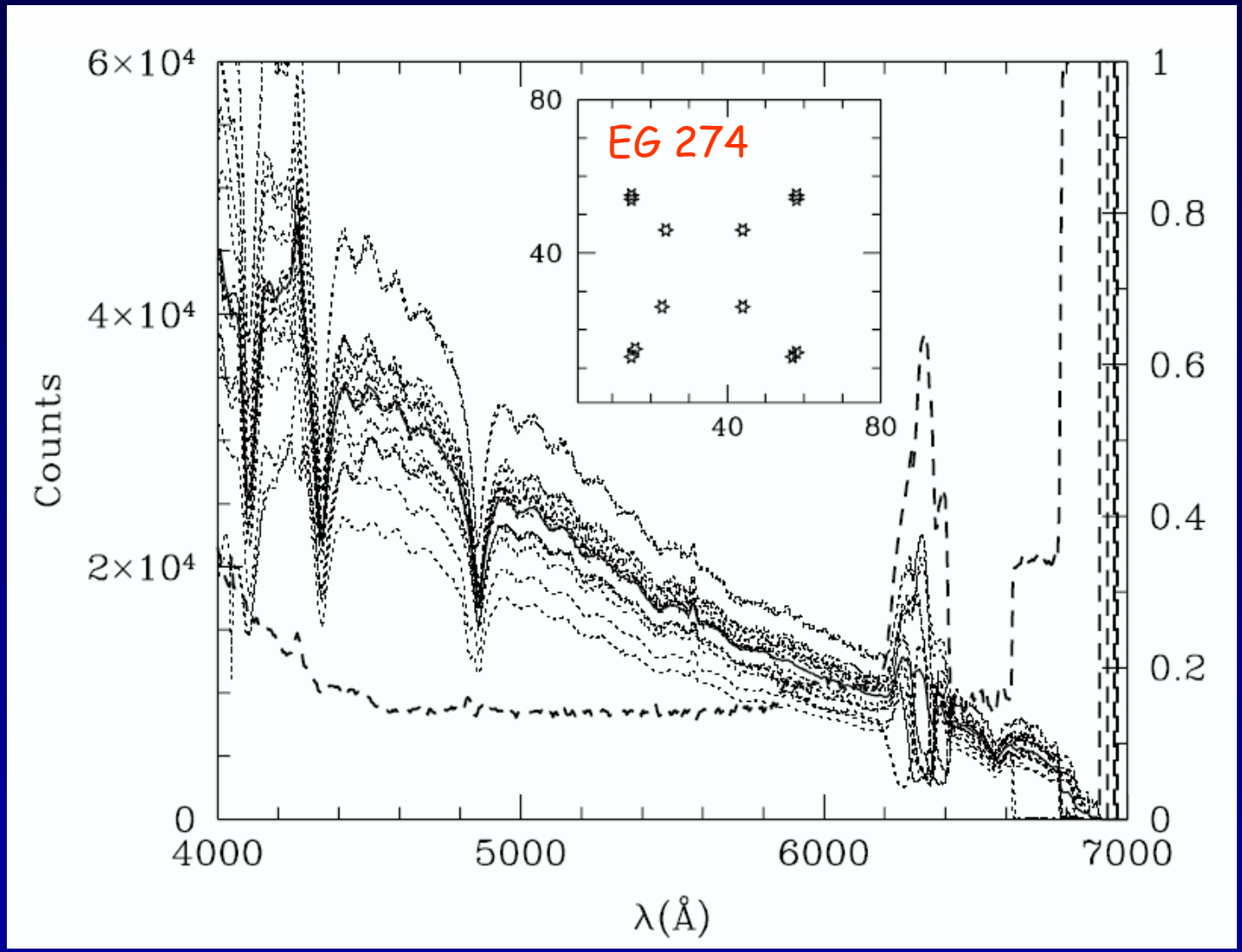
Flat-field variation vs. telescope zenith distance



colour scale
+/- 1 %

Response Variation

Flux Calibration

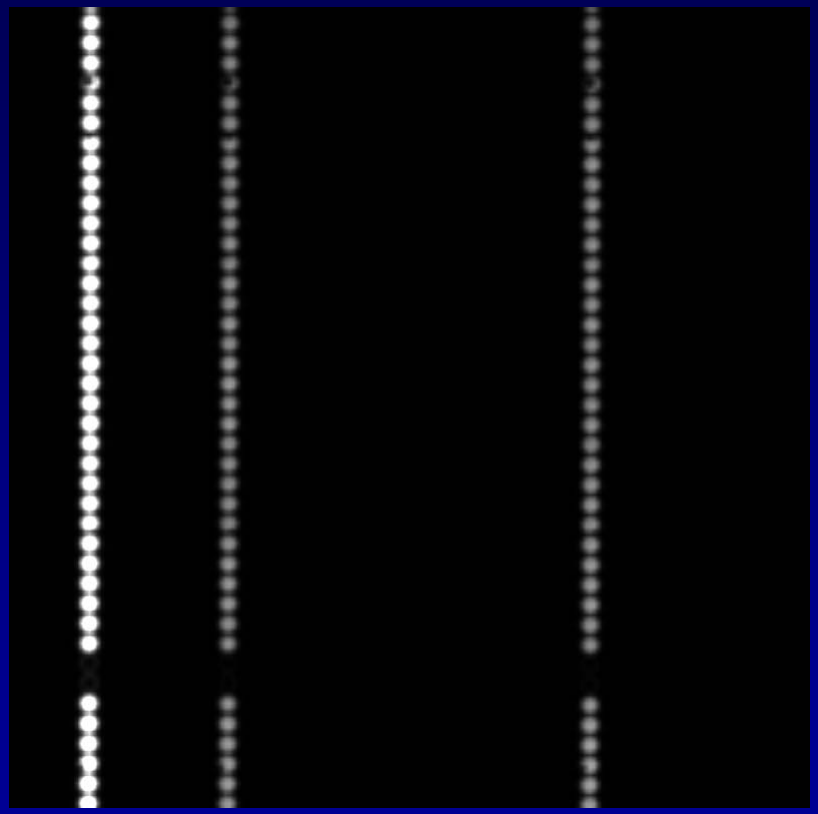


15 % rms
flux error
(12 pointings

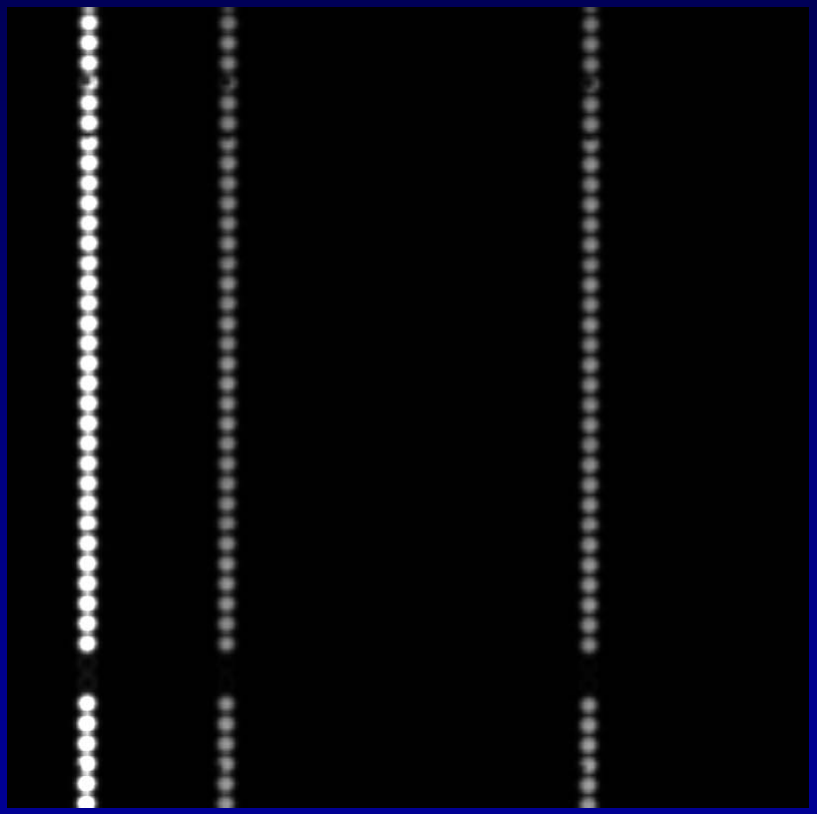
Monreal et al. 2006, New Astr. Reviews 50, 426

2.3 Flexure

Flexure

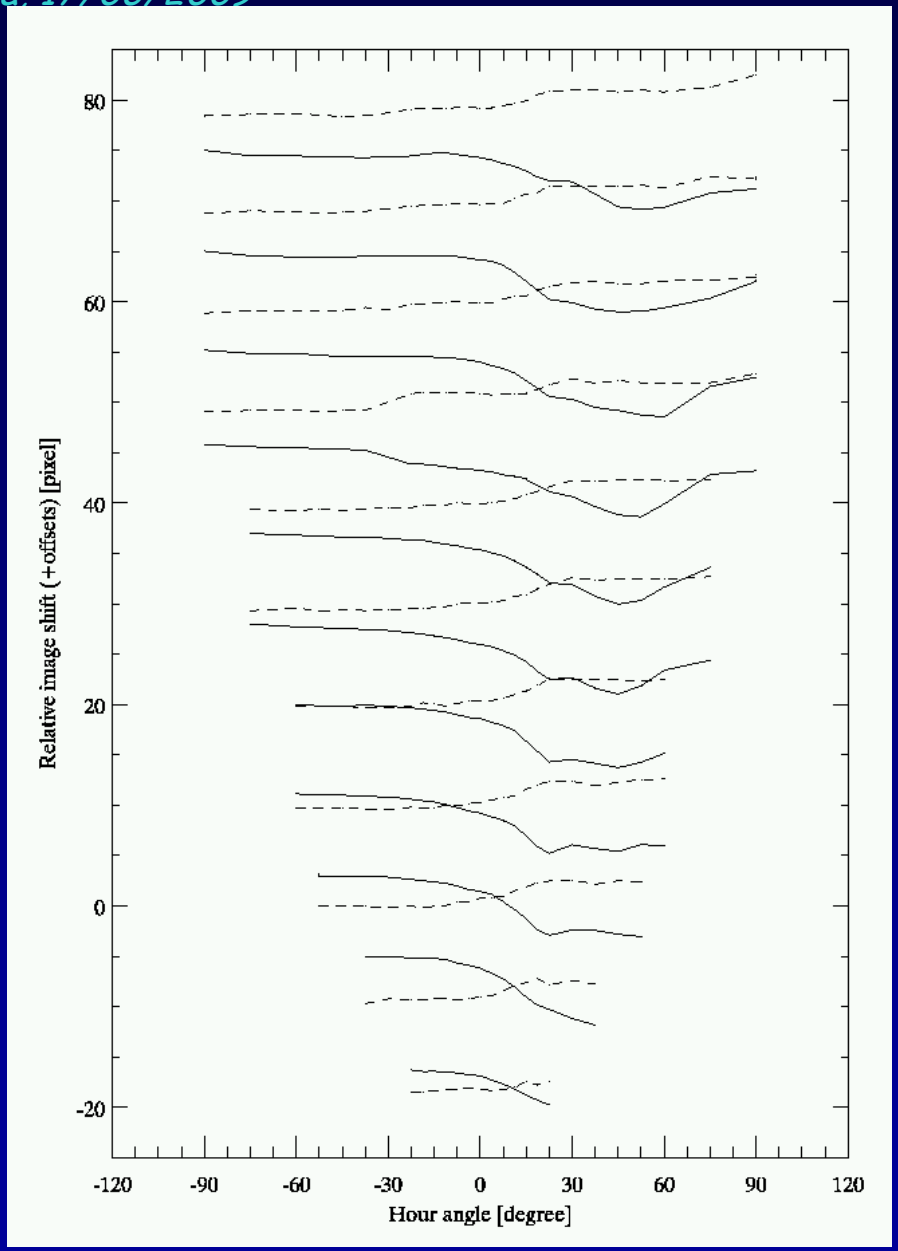


DATE-OBS= '2005-11-03T07:30:06.908'
ALT = 89.0 / AZ = 253.2

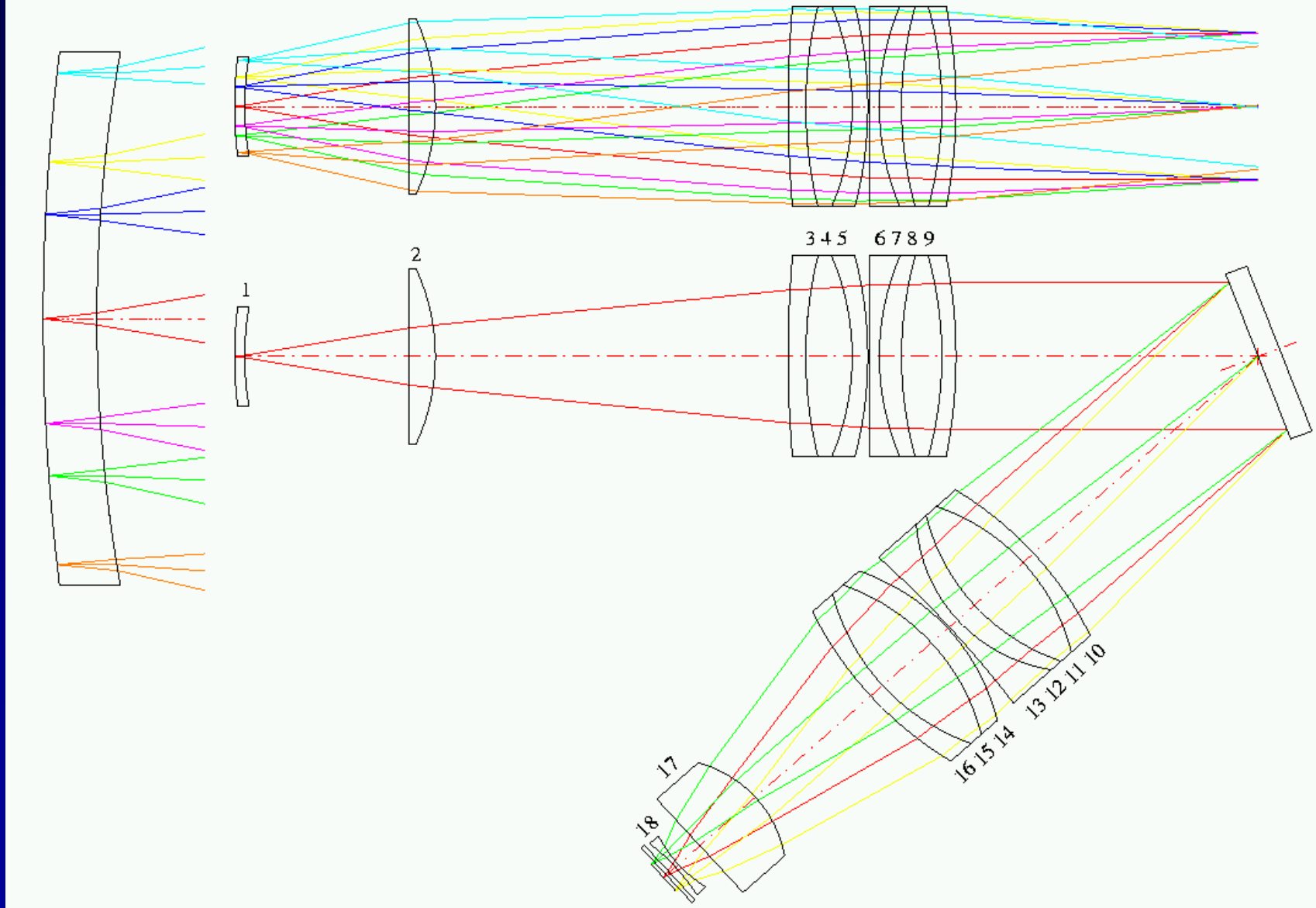


DATE-OBS= '2005-11-03T07:30:06.908,
ALT= 89.0 / AZ = 7.2

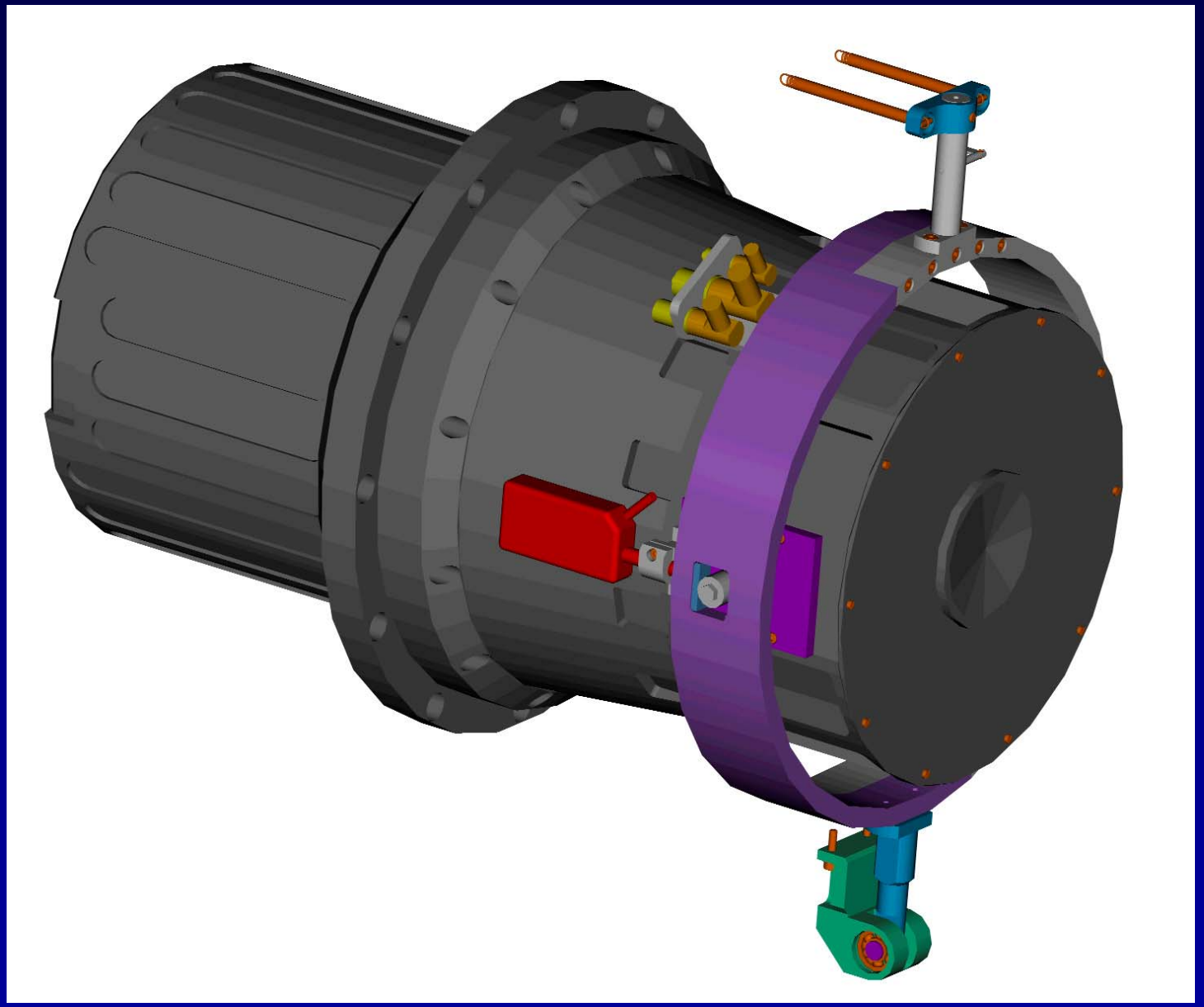
Flexure


Relative image shift (+offsets) [pixel]
80
60
40
20
0
-20
-120
-90
-60
-30
0
30
60
90
120
Hour angle [degree]

Flexure

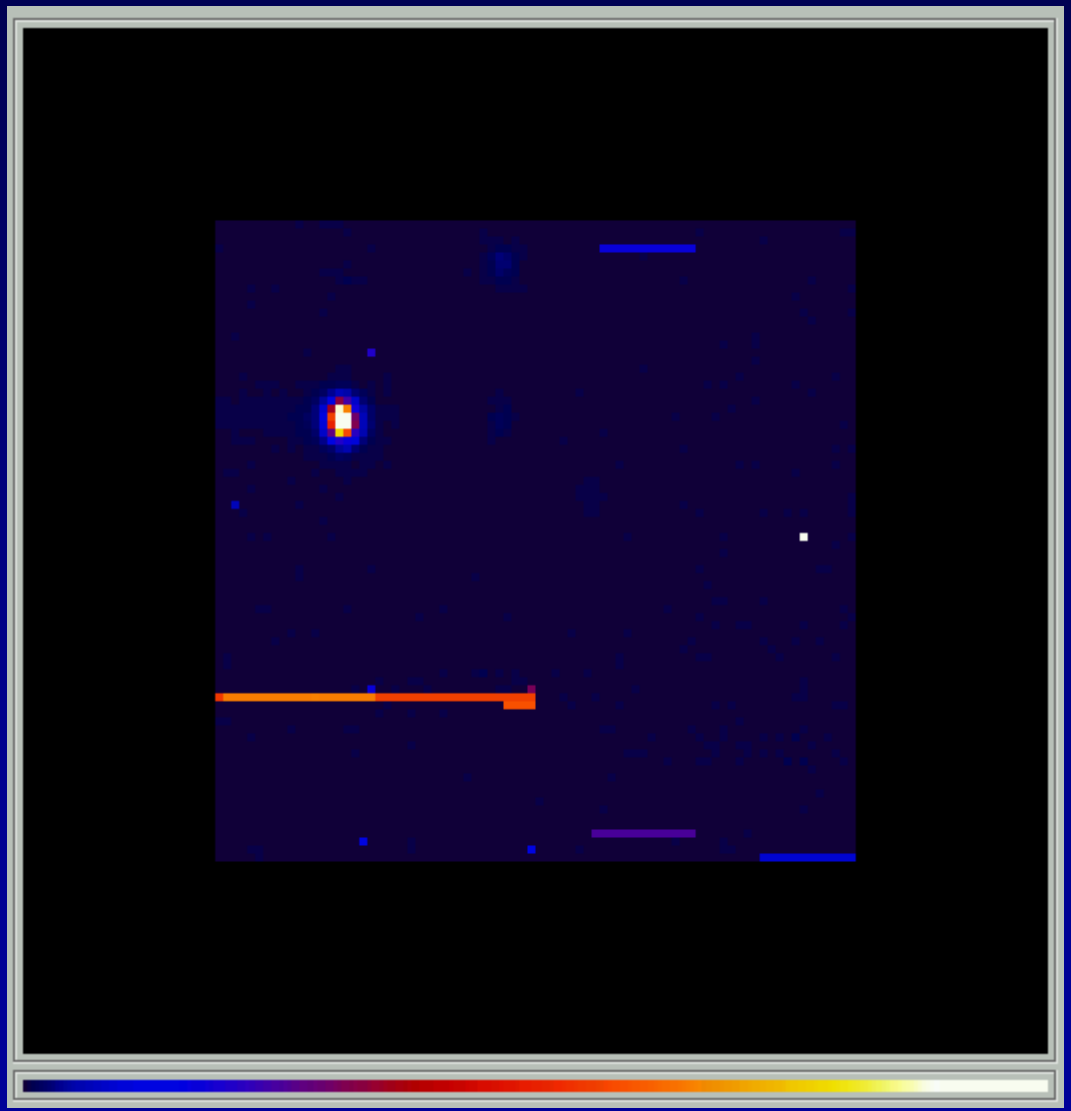


Flexure



2.4 IFU image quality

Image Quality



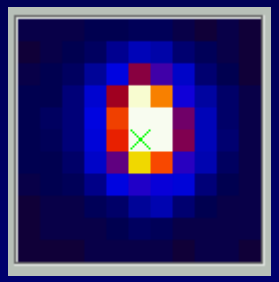


Image Quality

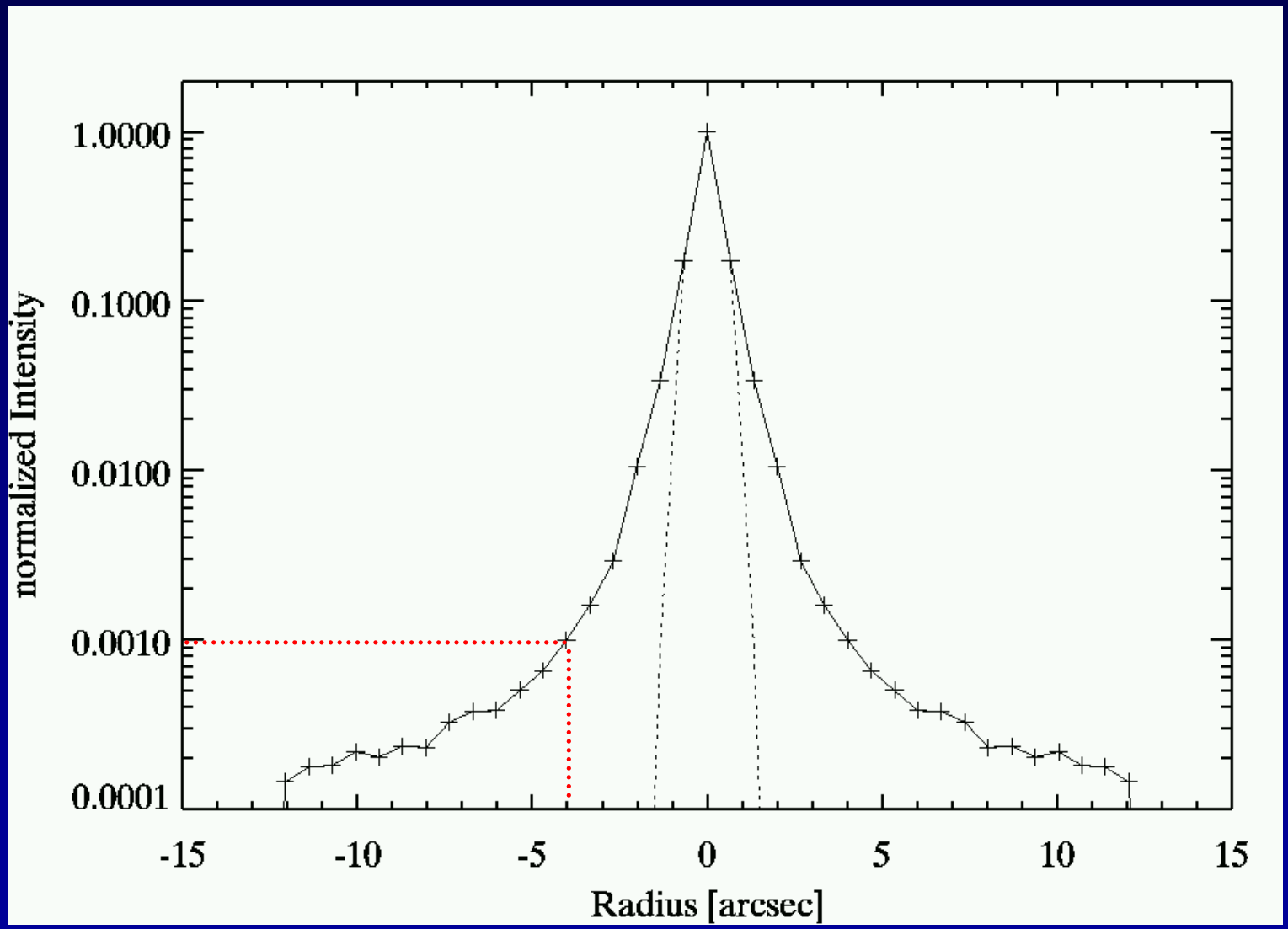
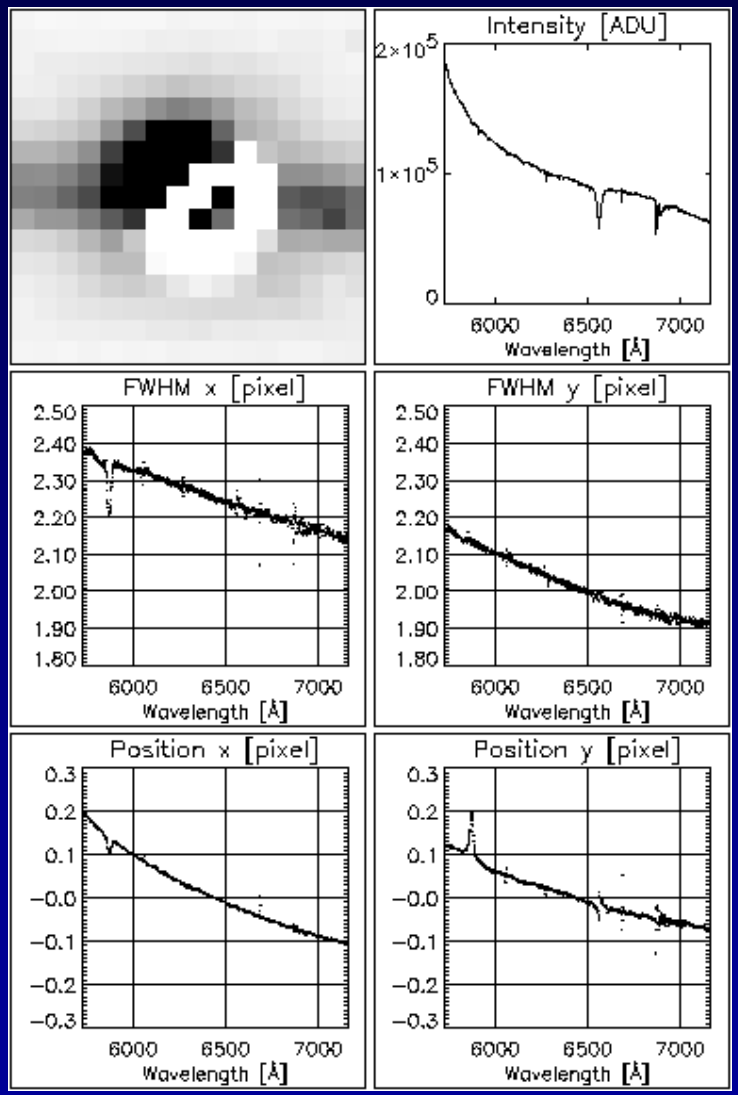
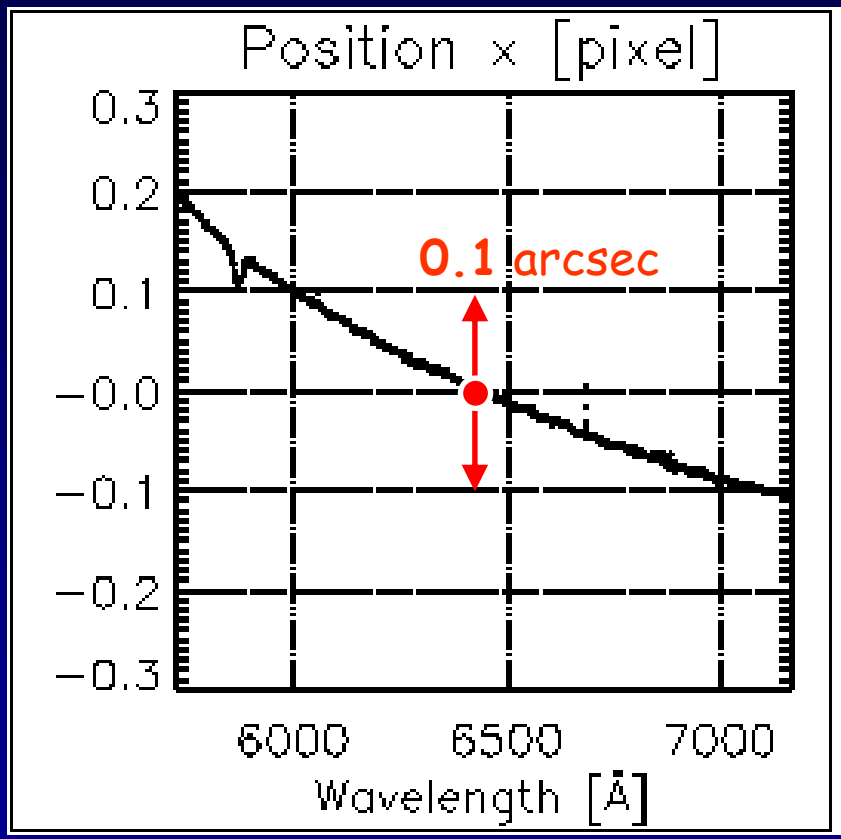


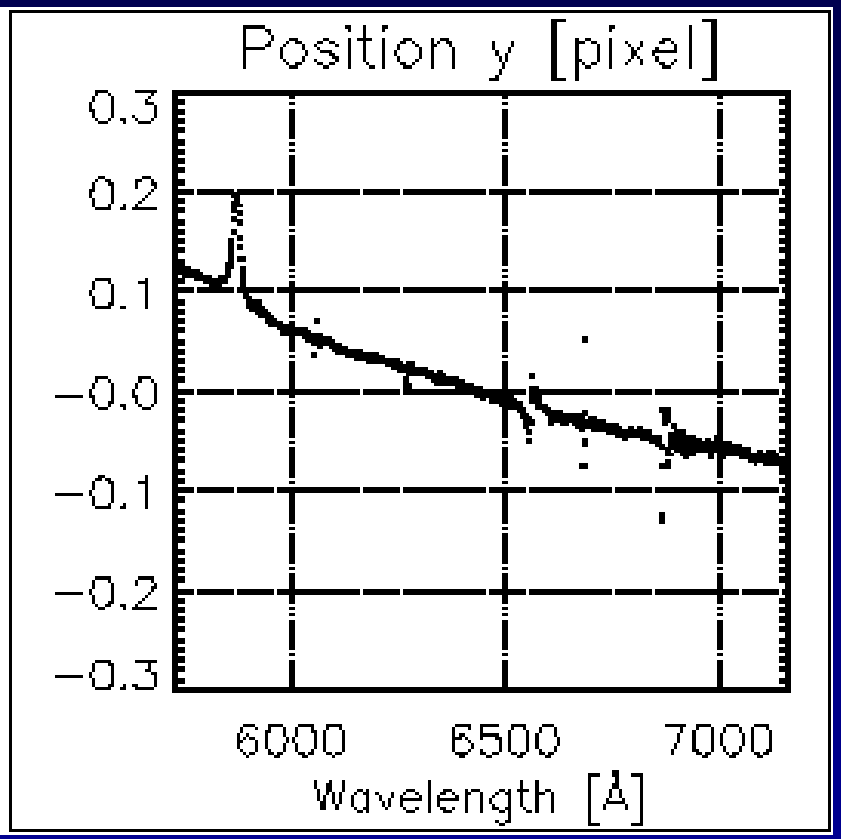
Image Quality



HR 1544

Image Quality





The new 'Southern Cross' HE 0435−1223

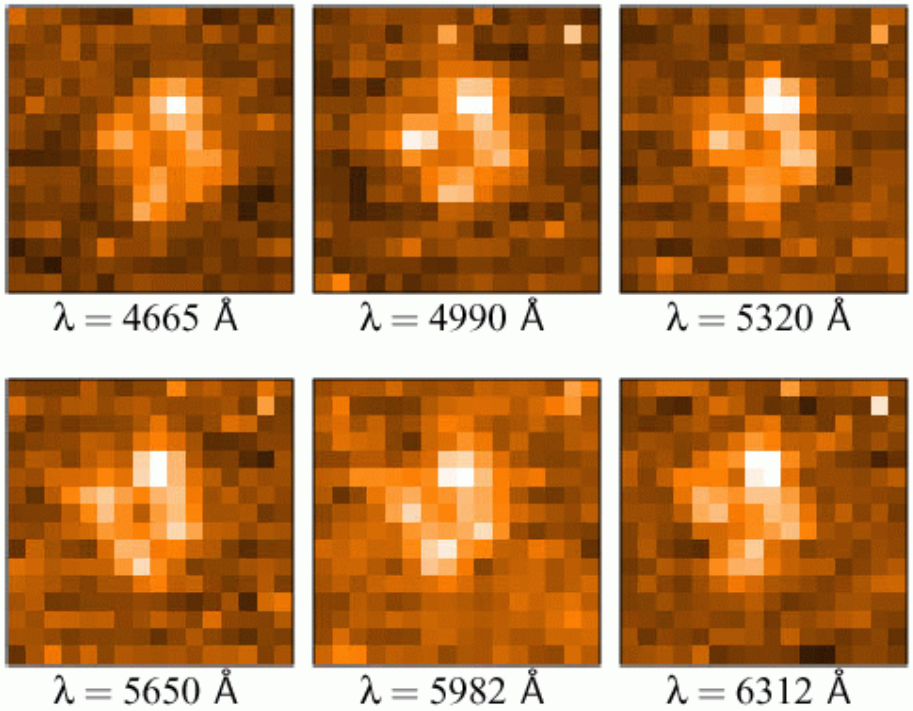
Spectrophotometry with PMAS

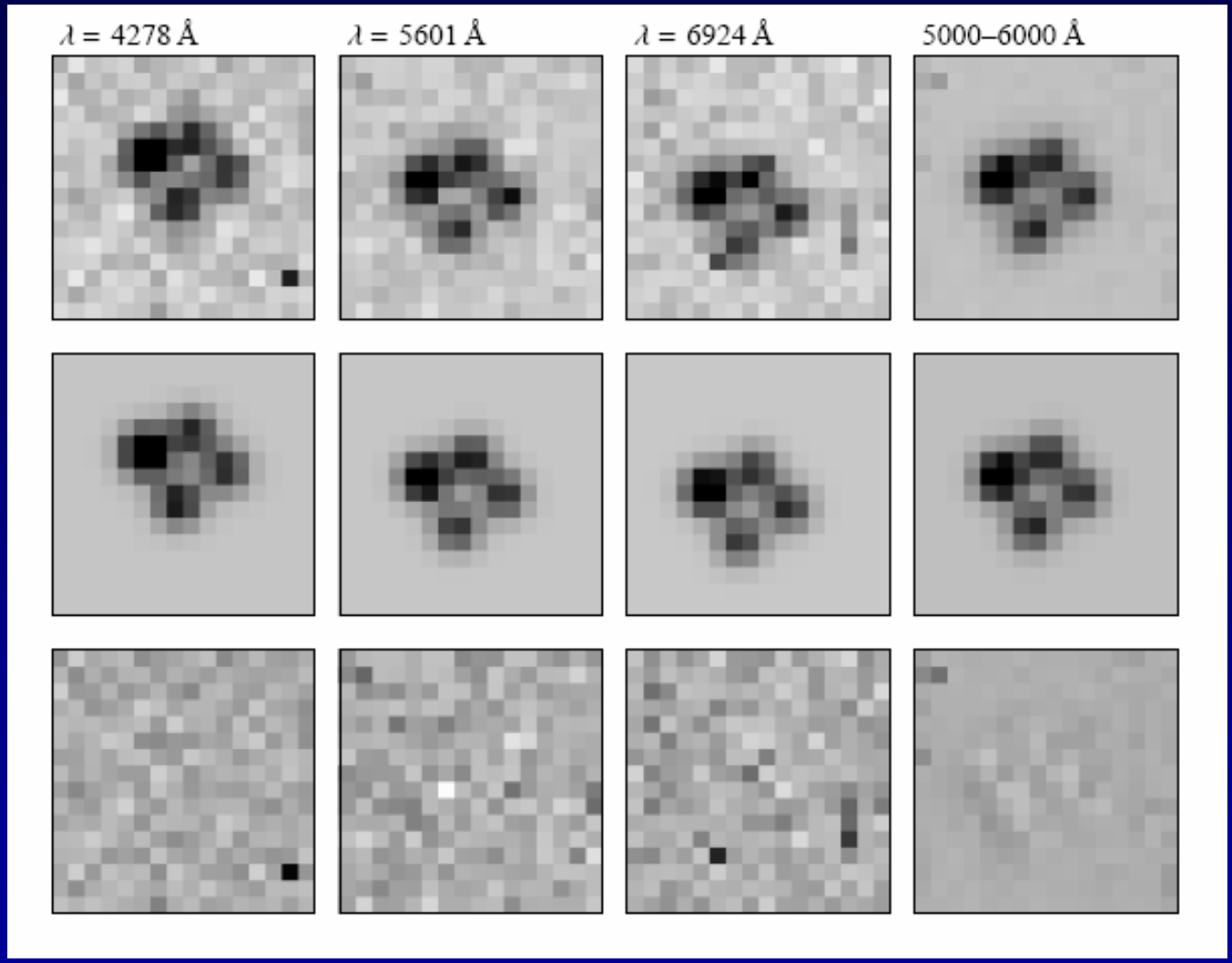
with T. Becker, L. Christensen, K. Jahnke, A. Kelz, M. Roth, S. Sanchez

1st visitor run with PMAS,
Calar Alto 3.5m, Sep 2002.

Total exposure time 5×30 min,
at seeing $1\farcs0$–$1\farcs5$.

Data reduced on the fly
with P3D.

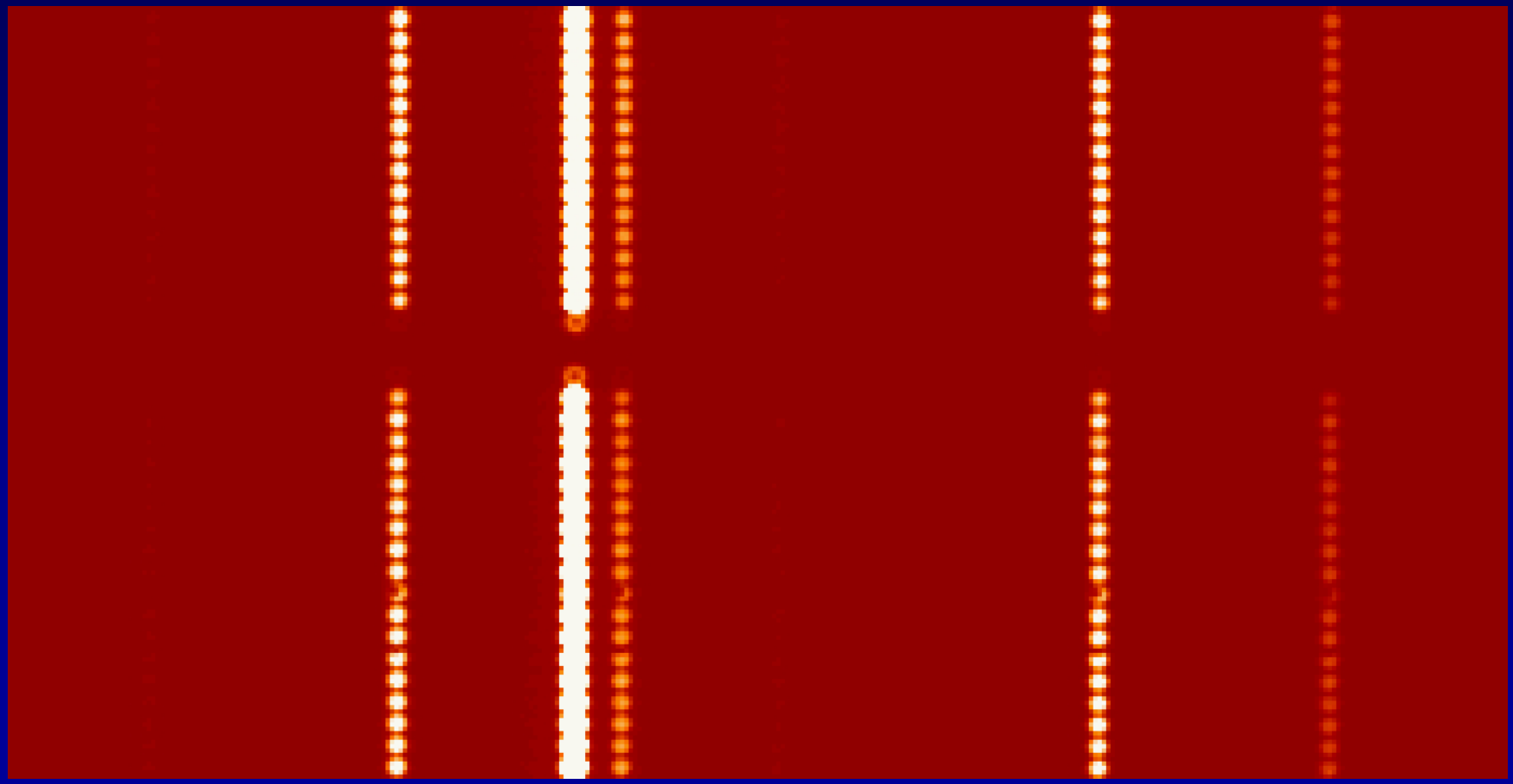



λ = 4278 Å
λ = 5601 Å
λ = 6924 Å
5000–6000 Å

2.5 Scattered light, ghosts

Scattered Light

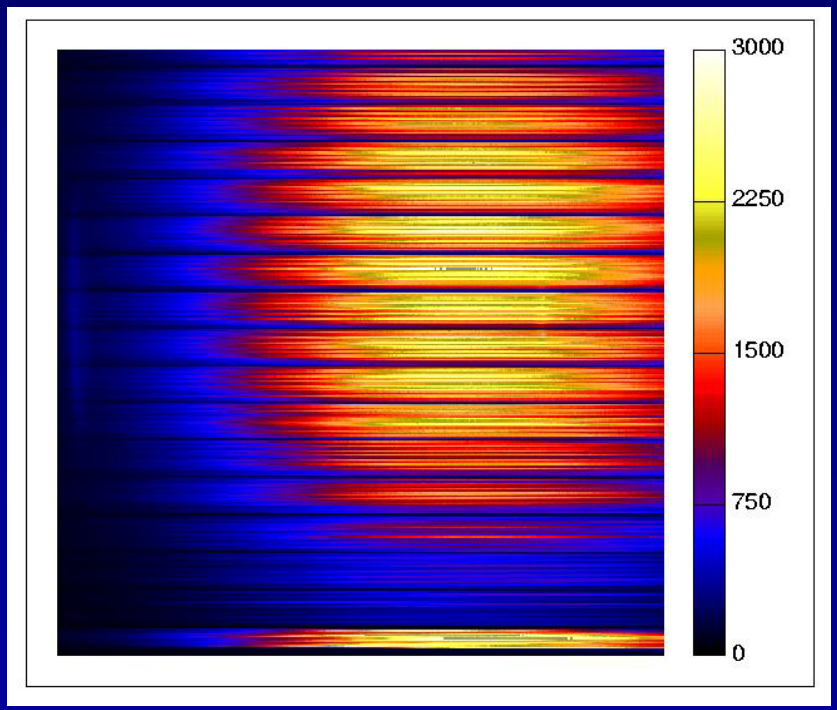
ghost images



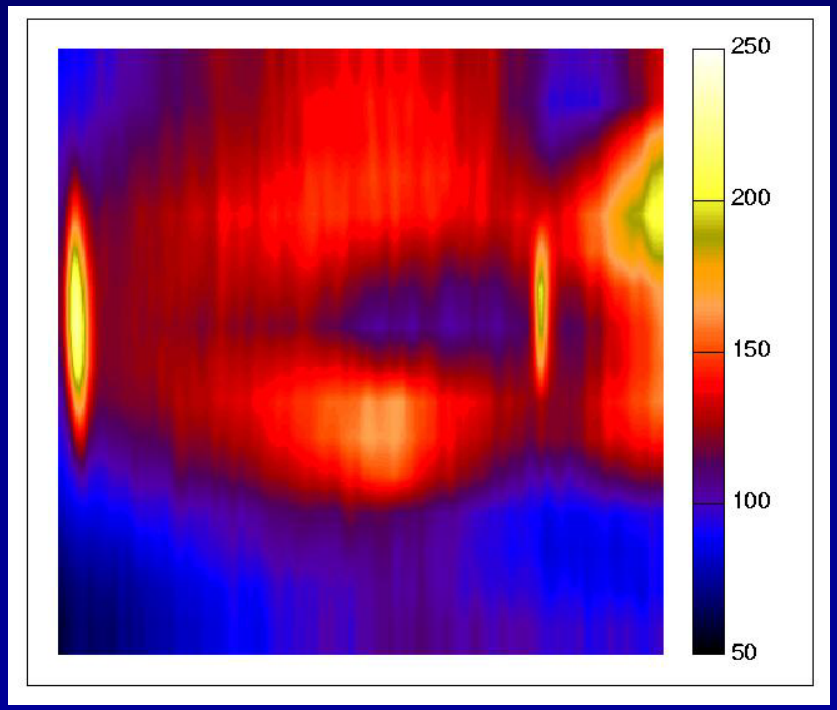
Scattered Light

Straylight Model

MPFS-Flatfield

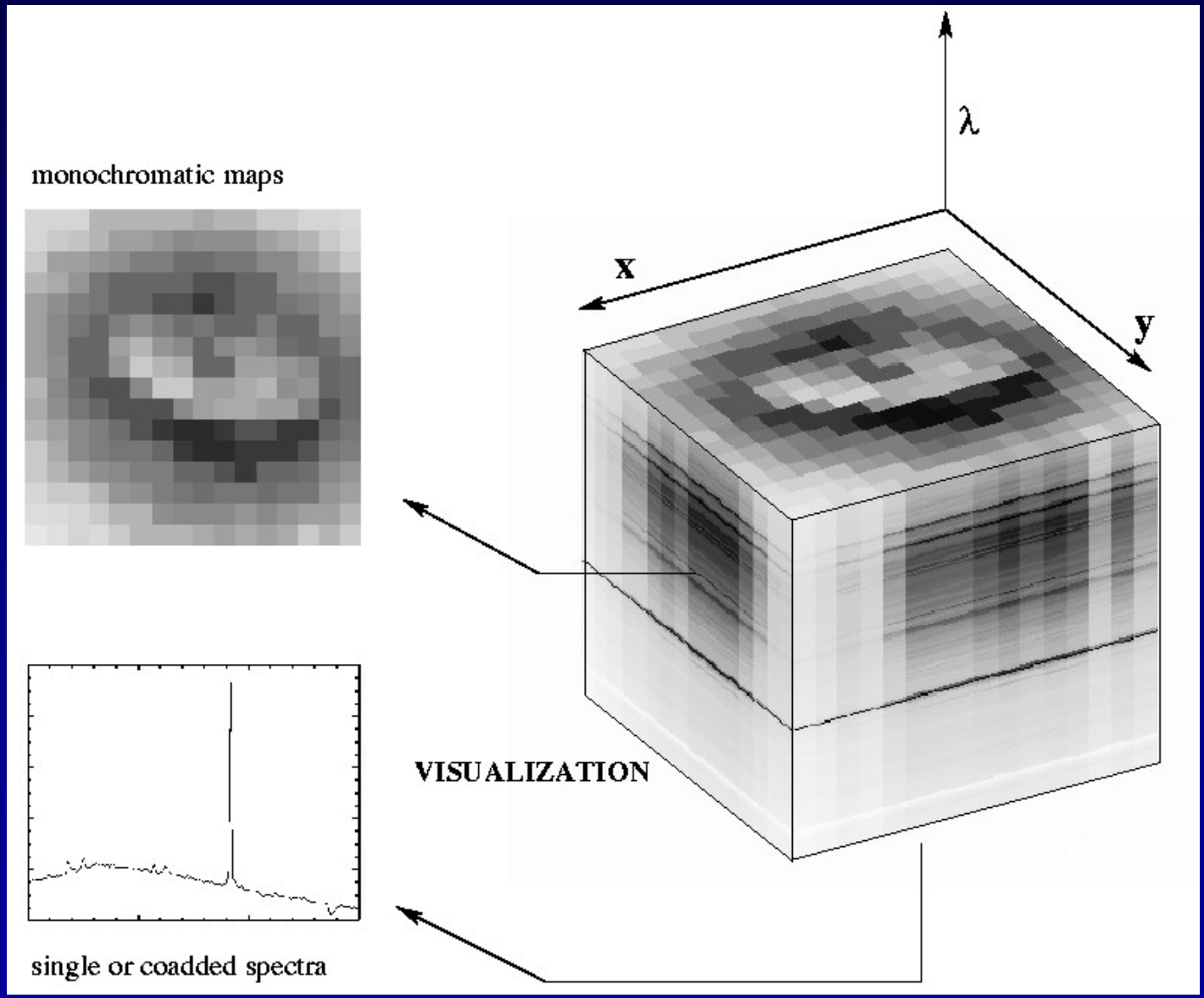


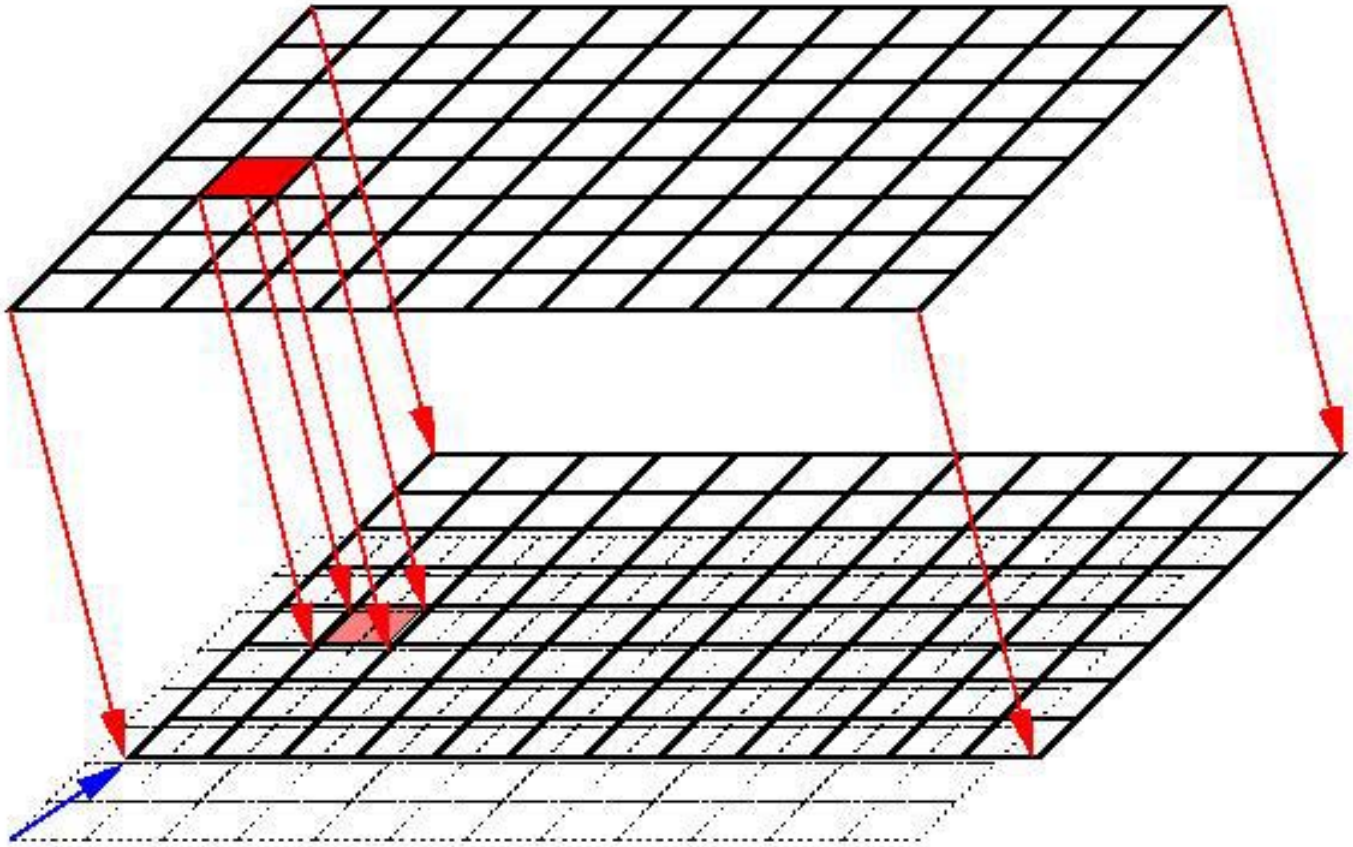
Straylight Map

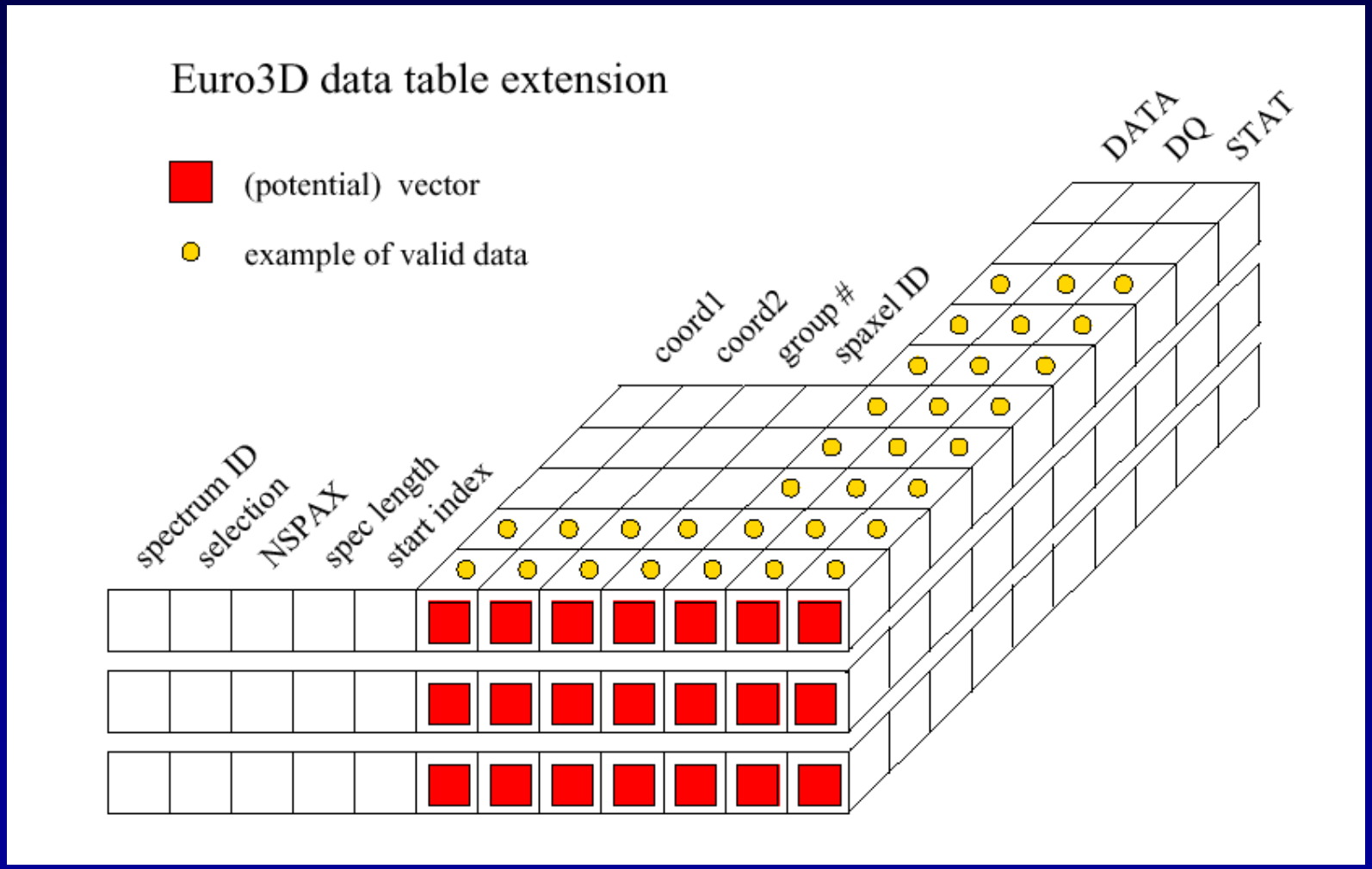


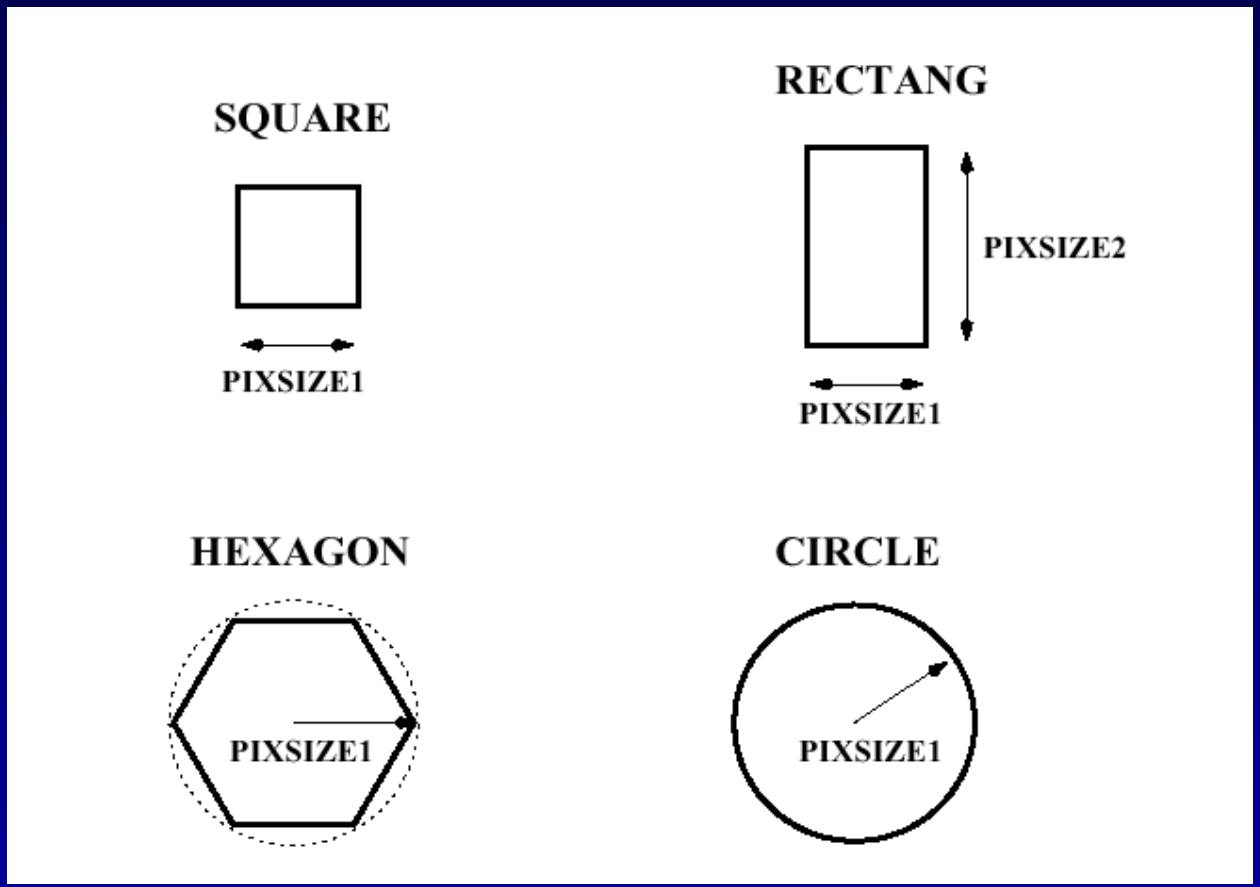
(3) Data reduction/analysis issues

- BIAS
- Tracing
- Extraction
- Deep 3D spectroscopy - stacking
- The new P3d tool

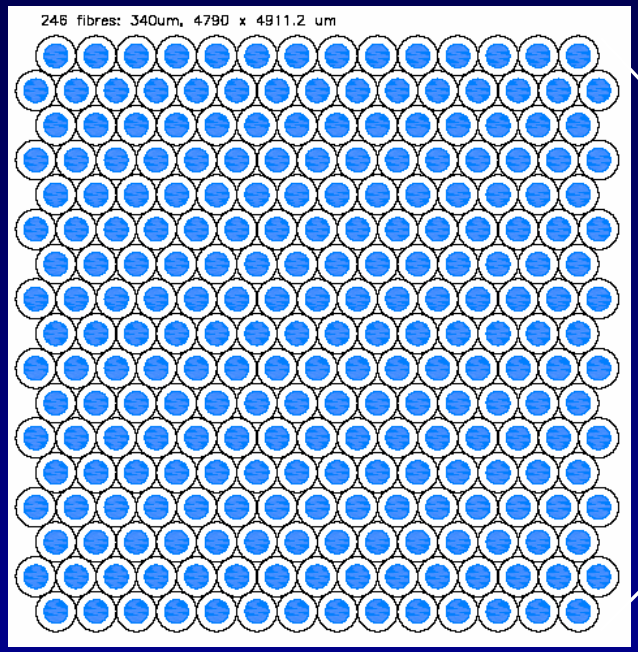

λ
x
y
monochromatic maps
VISUALIZATION
single or coadded spectra



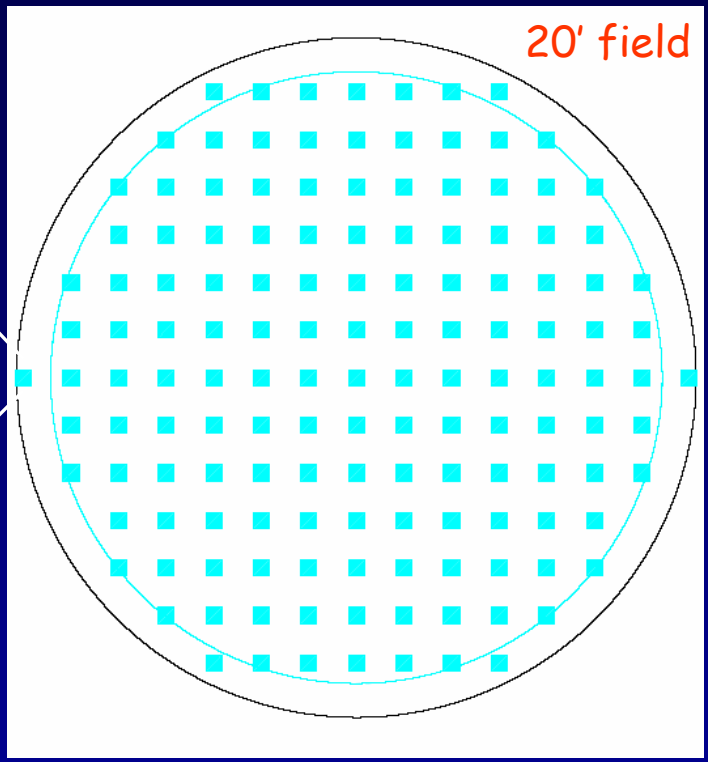

Euro3D data table extension
(potential) vector
example of valid data
DATA
DQ
STAT
coord1
coord2
group #
spaxel ID
spectrum ID
selection
NSPAX
spec length
start index


SQUARE
PIXSIZE1
RECTANG
PIXSIZE2
PIXSIZE1
HEXAGON
PIXSIZE1
CIRCLE
PIXSIZE1

VIRUS @ HET : 144 IFUs



0.22 sq. arcmin per raster of 3 exposures

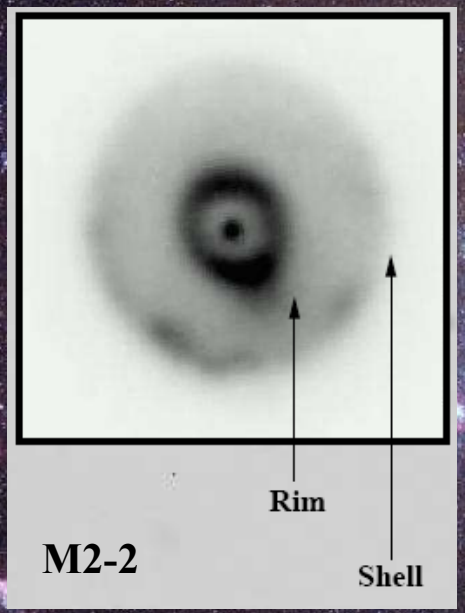


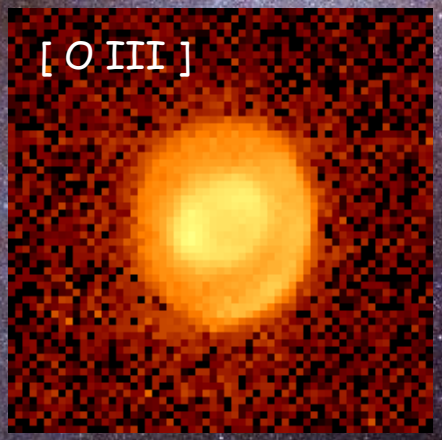
New HET wide field corrector FoV

- >35000 fibers
- >14 million resolution elements per exposure
- Layout with 1/9 fill factor, optimized for HETDEX

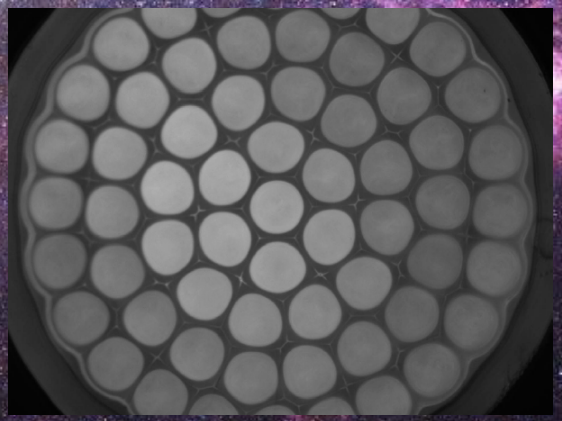
LMC/SMC FIREBALL Survey

3 arcsec





MG 40

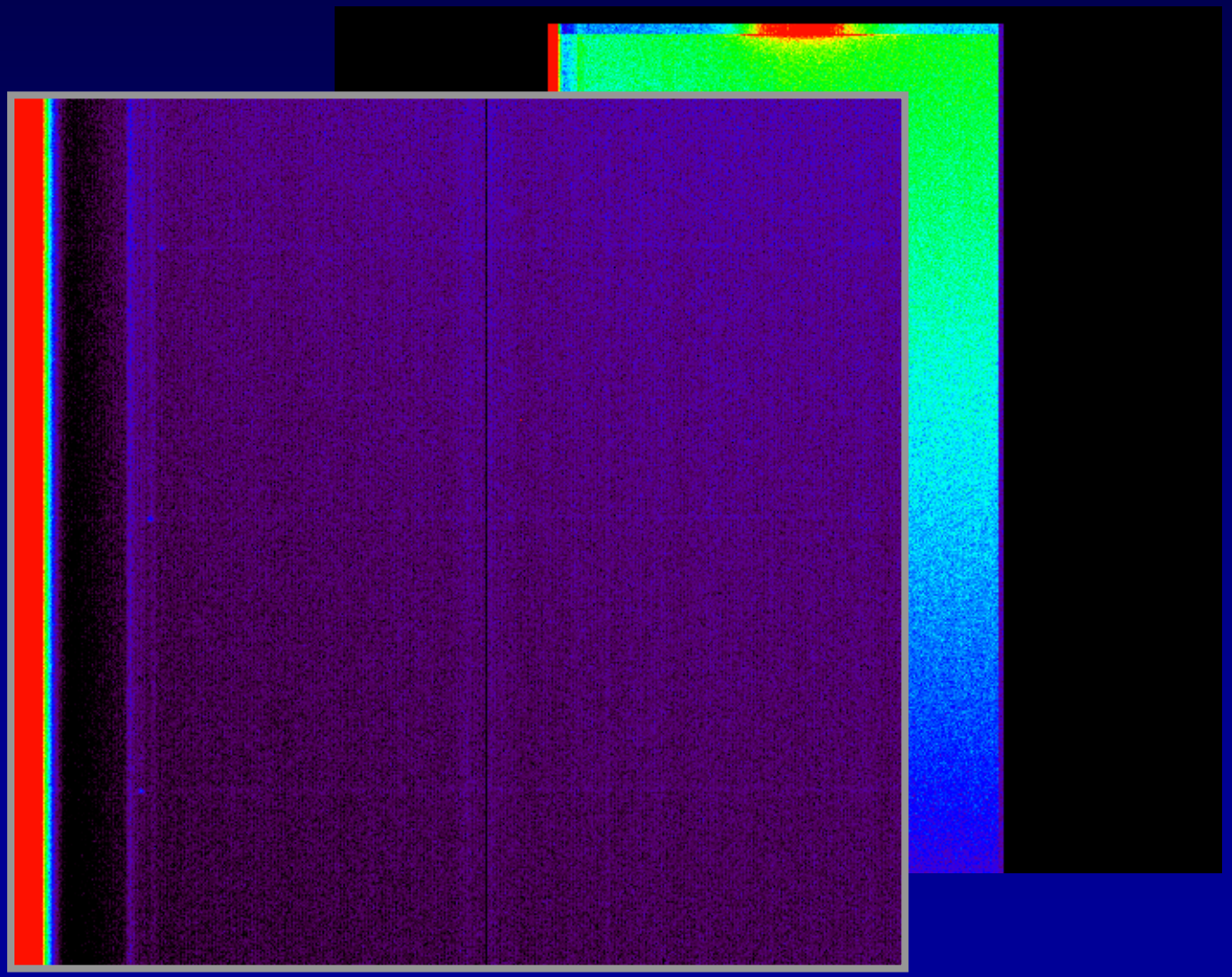


credit: MCPN Team STScI

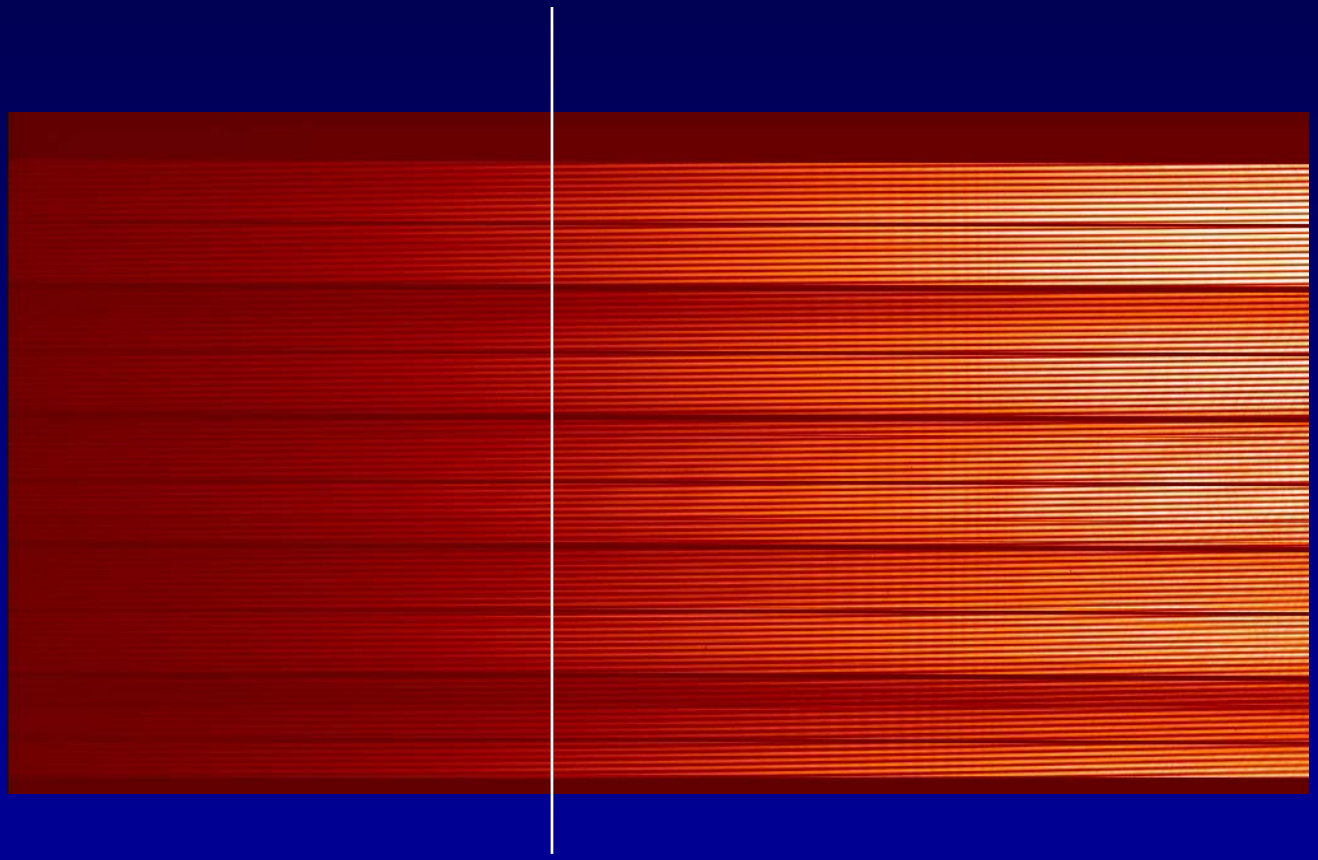
Data Reduction Pipeline

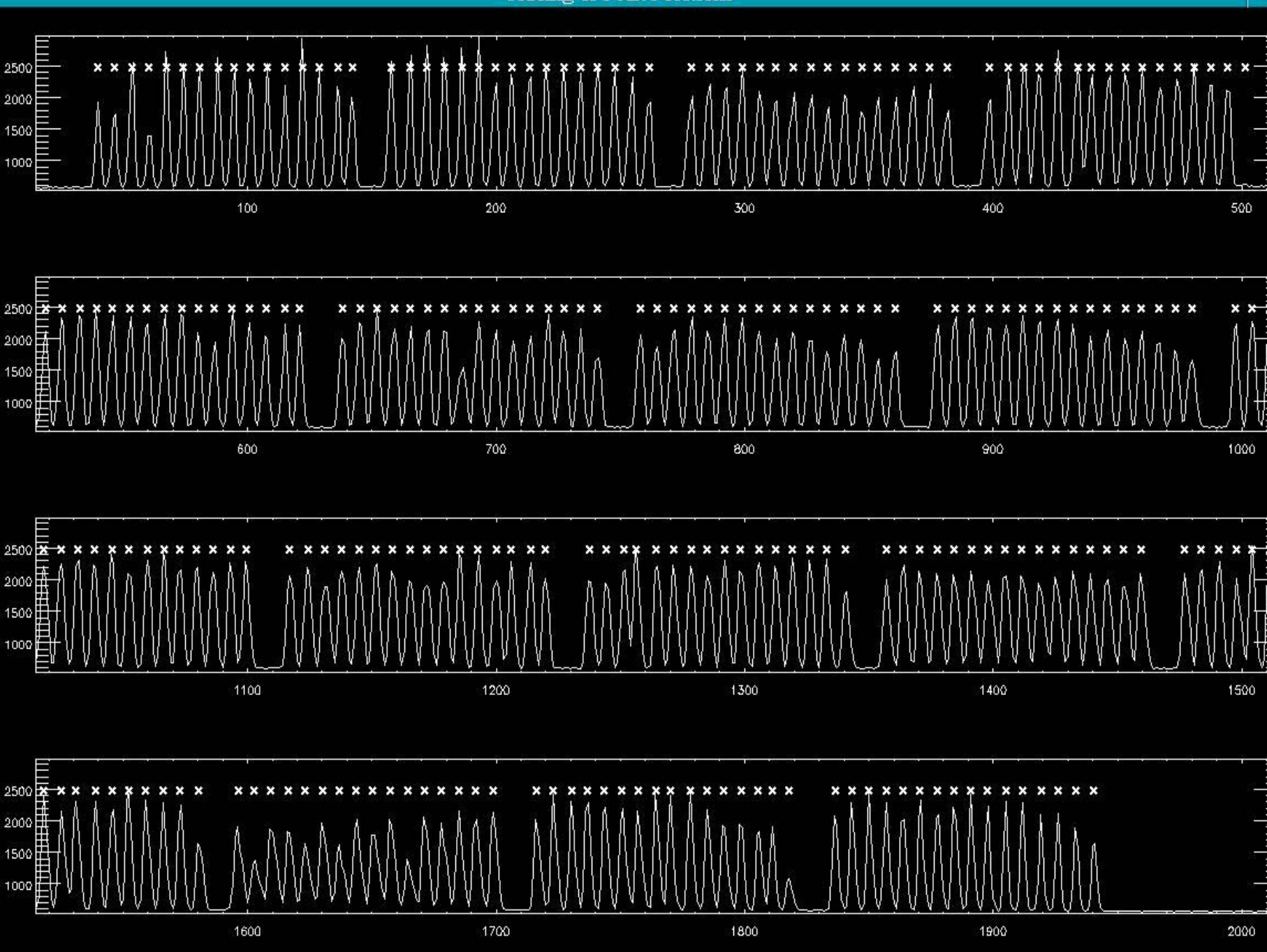
- Pre-reduction (bias,cosmics) → Propagation of Variance
- CCD Response Calibration → Propagation of Variance
- Tracing → Propagation of Variance
- Image Shift → Propagation of Variance
- Straylight Correction → Propagation of Variance
- Extraction → Propagation of Variance
- Wavelength Calibration → Propagation of Variance
- Fiber Response Calibration → Propagation of Variance

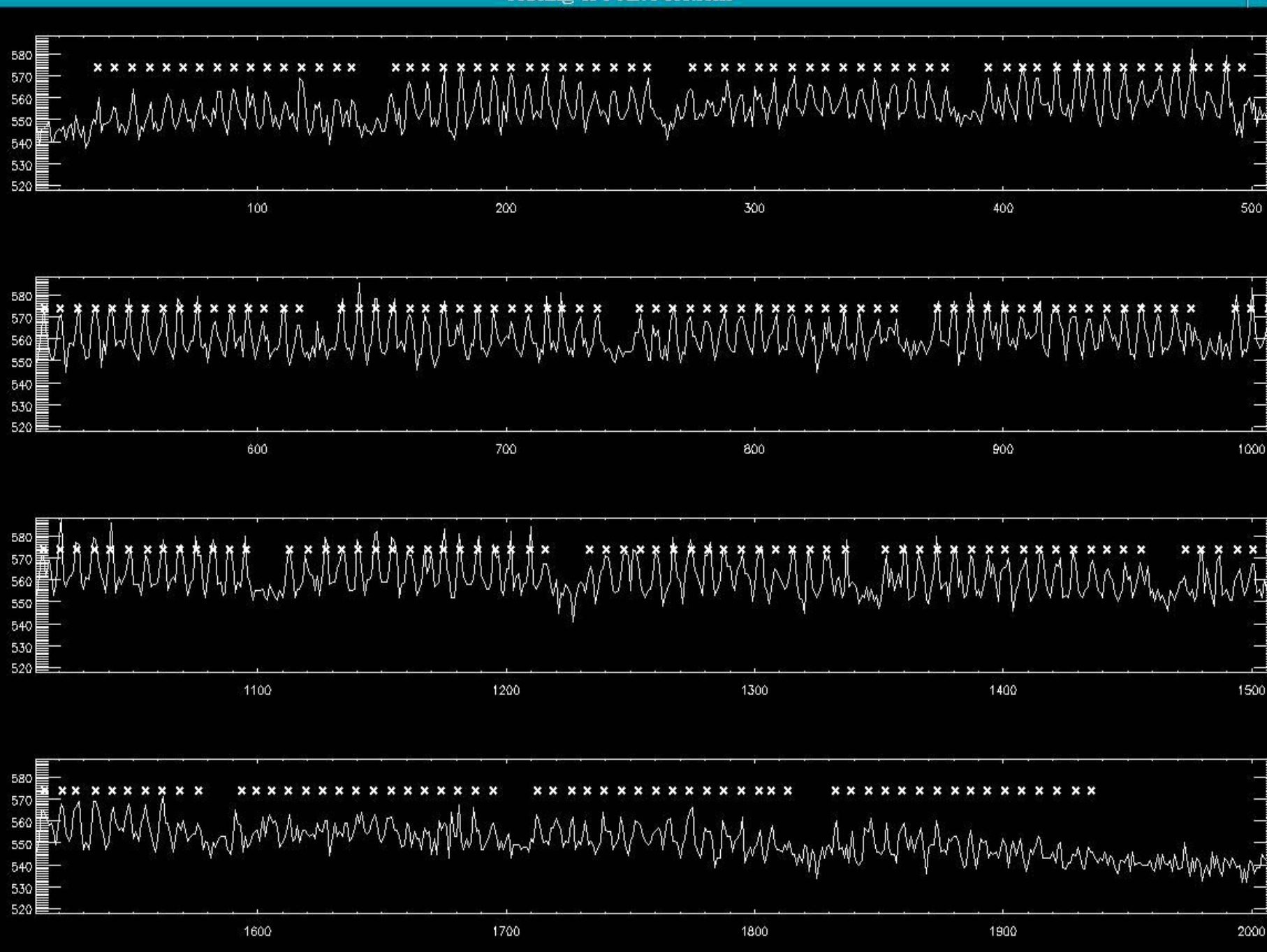
Data Reduction



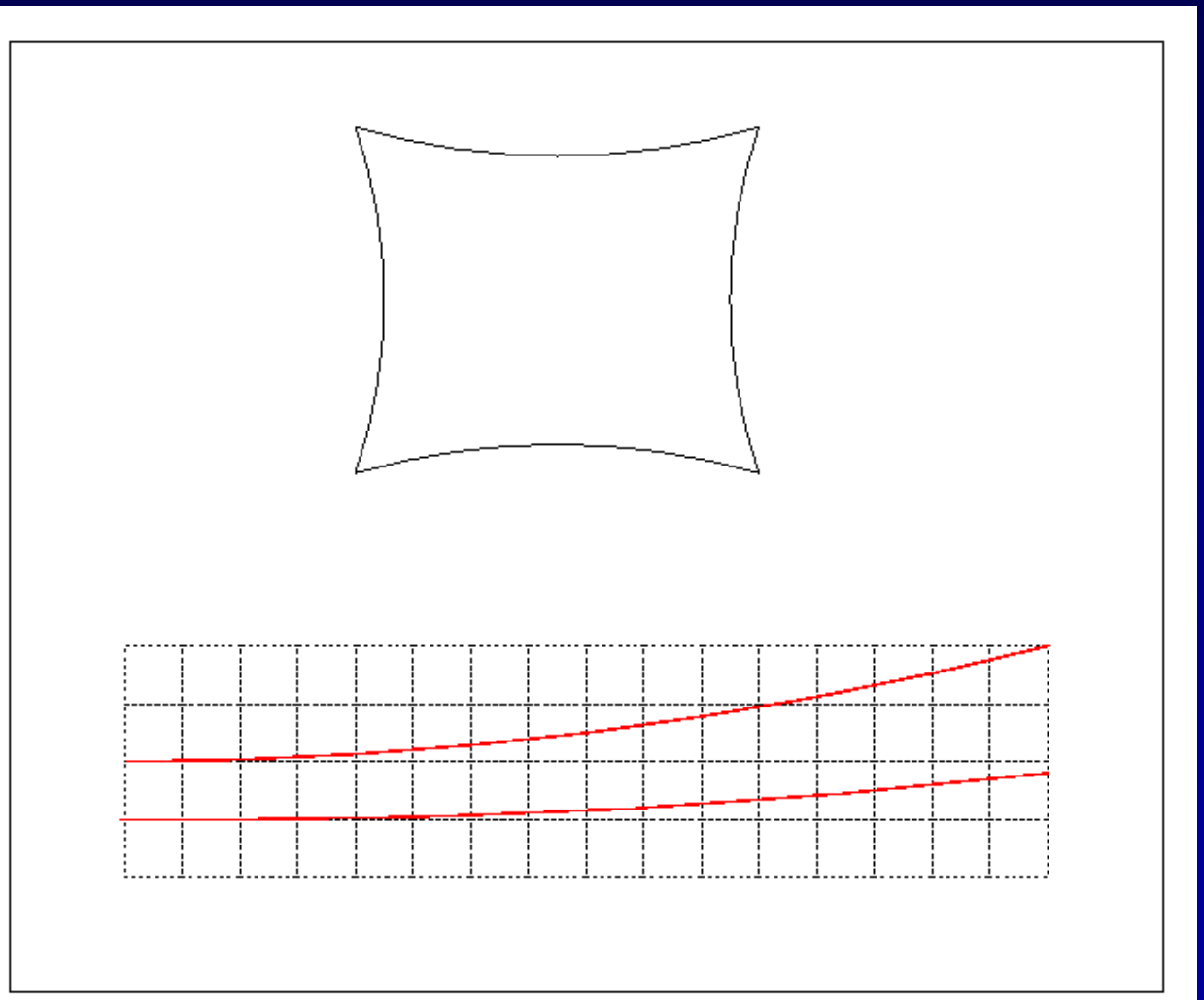
Data Reduction




2500
2000
1500
1000
100
200
300
400
500
2500
2000
1500
1000
600
700
800
900
1000
2500
2000
1500
1000
1100
1200
1300
1400
1500
2500
2000
1500
1000
1600
1700
1800
1900
2000

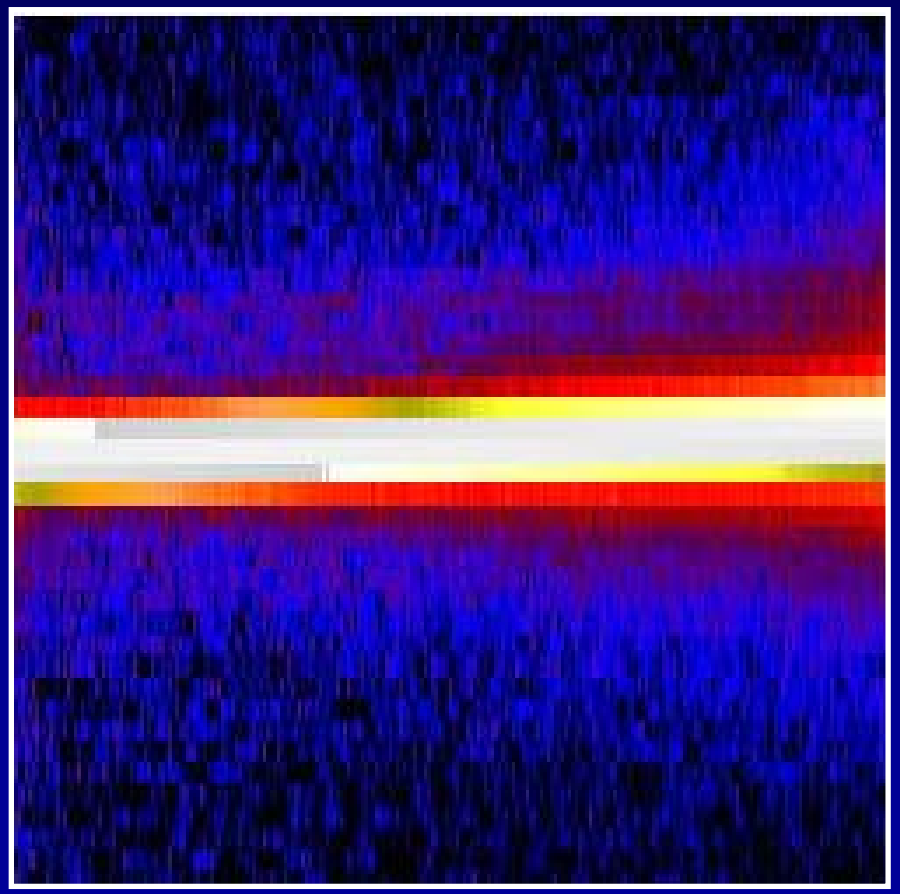

580
570
560
550
540
530
520
100
200
300
400
500
580
570
560
550
540
530
520
600
700
800
900
1000
580
570
560
550
540
530
520
1100
1200
1300
1400
1500
580
570
560
550
540
530
520
1600
1700
1800
1900
2000

Data Reduction



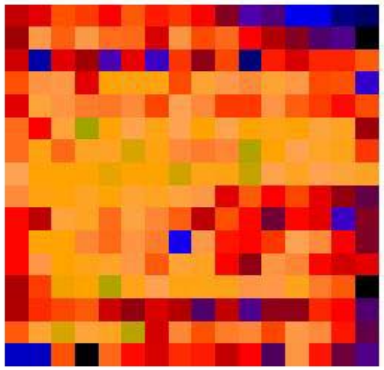
Data Reduction

varying profile (spatial direction) along a spectrum :



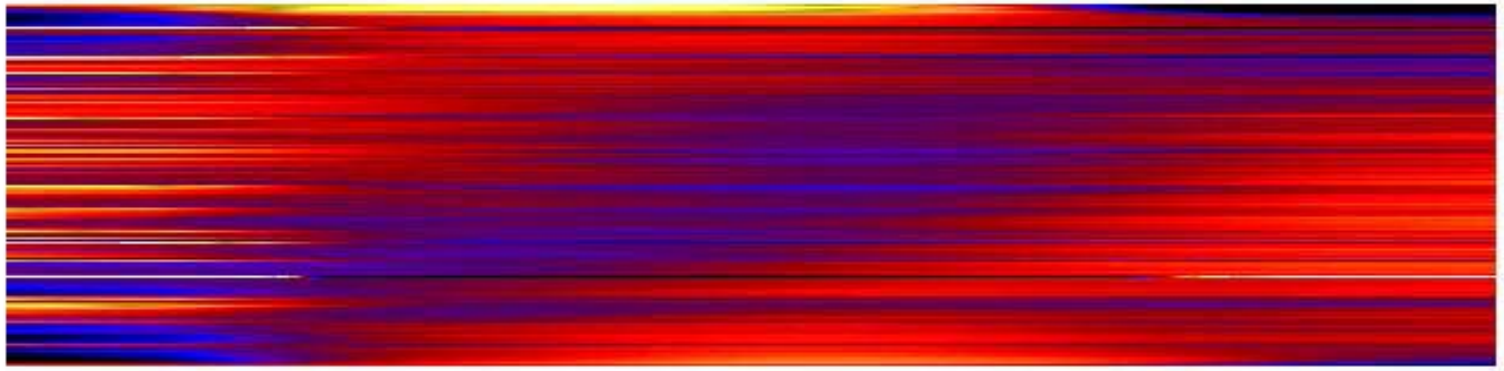
Data Reduction

Fiber Response Calibration („Fiber Flat")



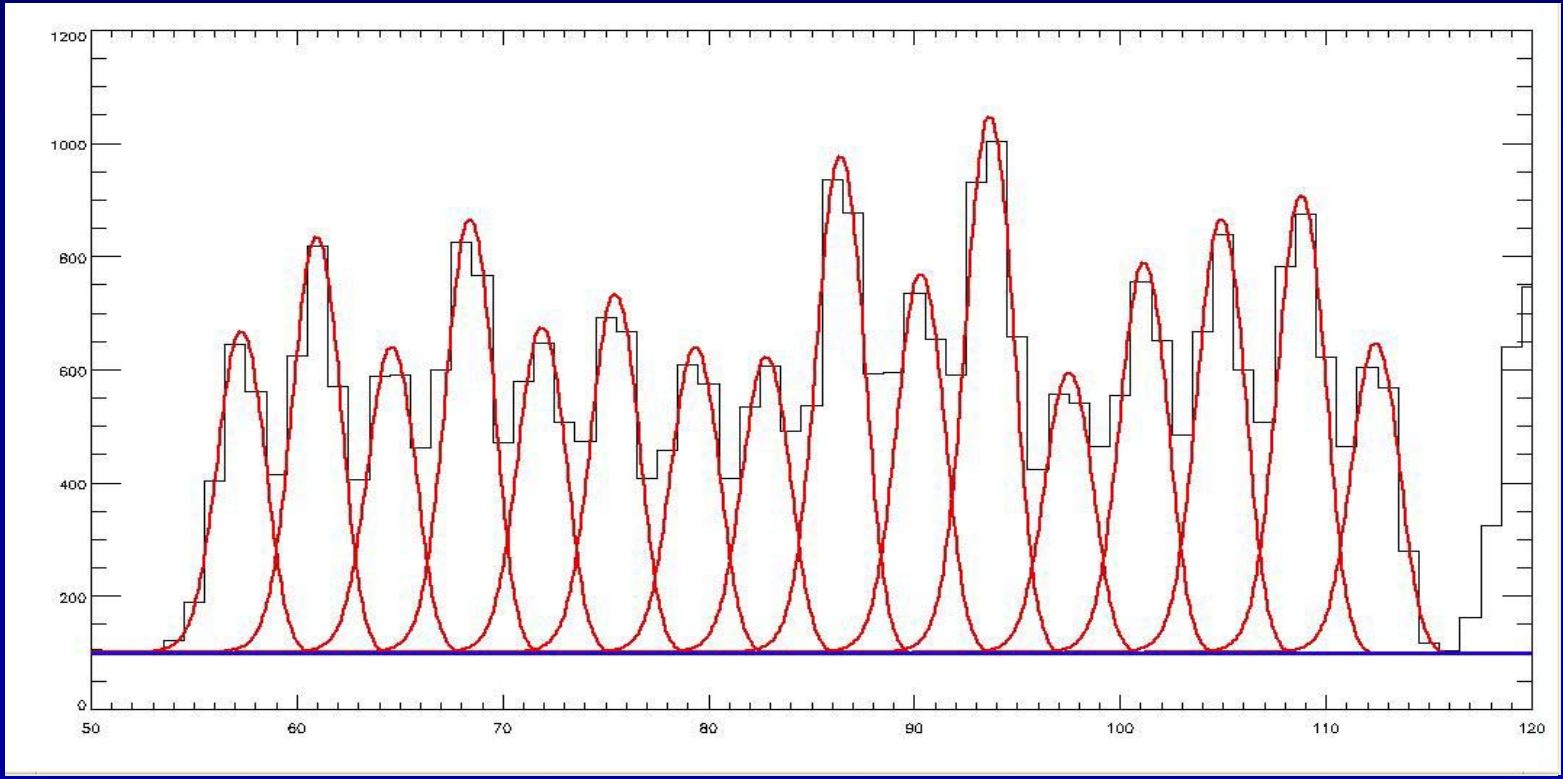
Total Spectra Sensitivity Variation: 8%

Wavelength-dependent Sensitivity Variation: 1-1.5%



Data Reduction

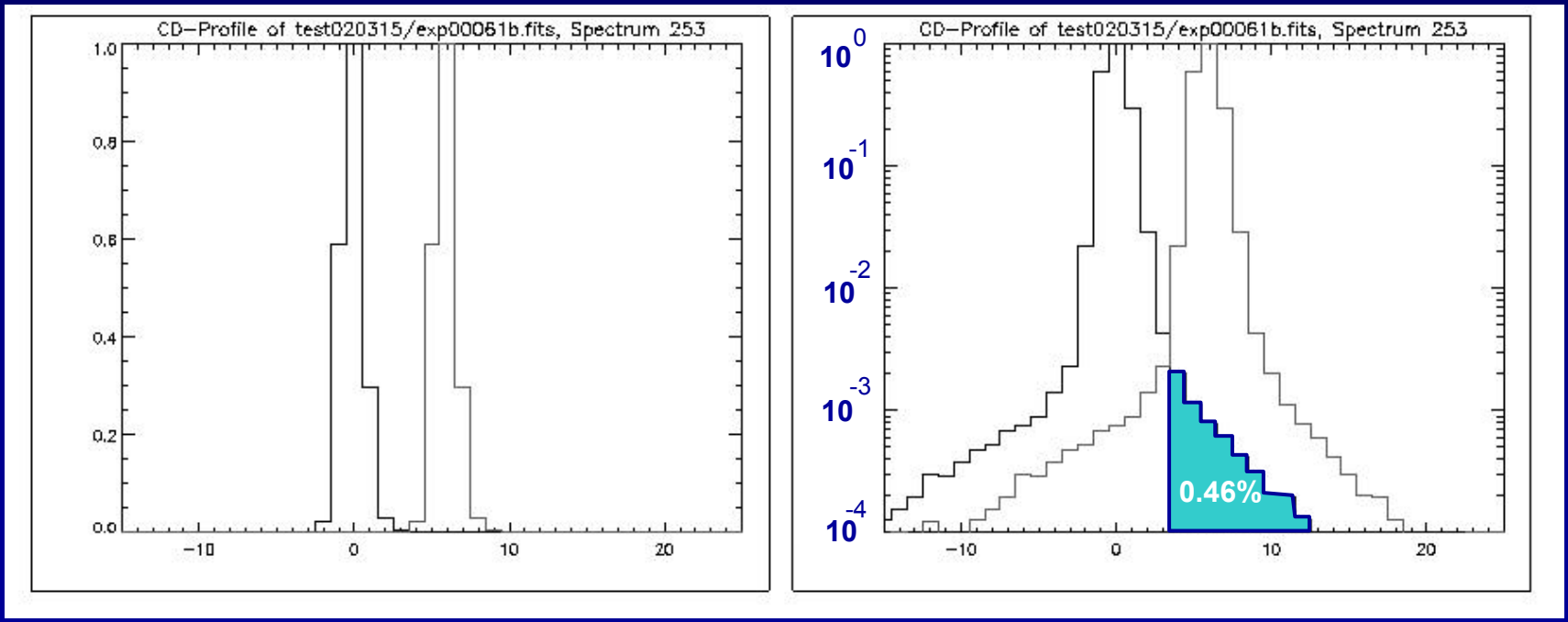
Cross-talk, extraction techniques



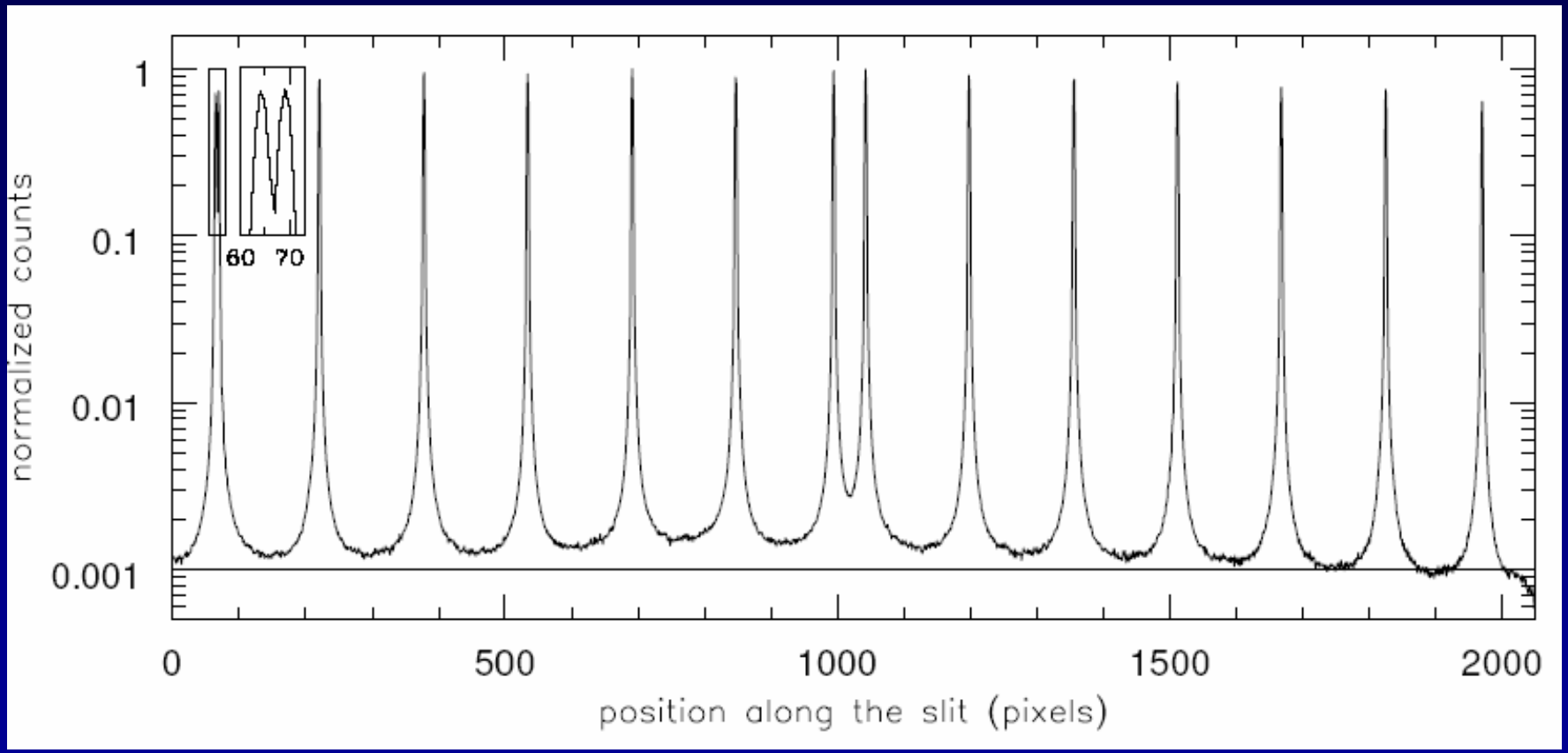
Data Reduction

separation of adjacent spectra: 7 pixels (2x2 binned)

FWHM: 2 pixels



Data Reduction

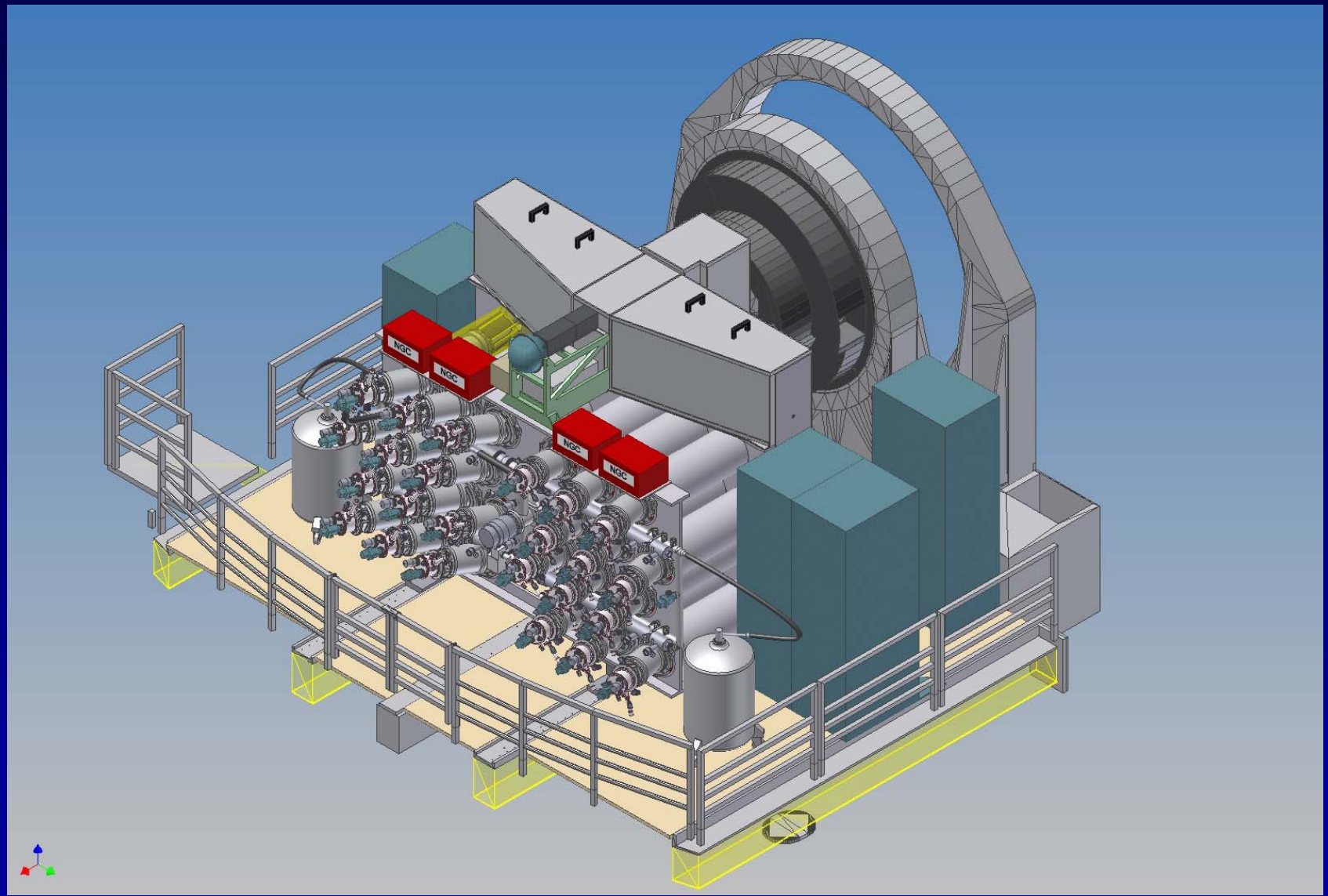


Data Reduction

Some existing codes :

- VIMOS Pipeline
  www.eso.org/projects/dfs/dfs-shared/web/vlt/vlt-instrument-pipelines.html
- P3d
  Becker 2002, Roth et al. 2005, PASP 117, 832
- VIPGI
  Scodeggio, M. et al. 2005, PASP 117, 1284
  Foucaud, S. et al. 2006, New Astr. Reviews, Vol. 50, p. 401
- R3D
  Sánchez, S.F. 2006, AN 327, 850
- XOASIS

MUSE



Spectral range (simultaneous)	0.465-0.93 μm
Resolving power	2000@0.46 μm
	4000@0.93 μm
Wide Field Mode (WFM)	
Field of view	1x1 arcmin^2
Spatial sampling	0.2x0.2 arcsec^2
Spatial resolution (FWHM)	0.3-0.4 arcsec
Gain in ensquared energy within one pixel with respect to seeing	2
Condition of operation with AO	70%-ile
Sky coverage with AO	70% at Galactic Pole
Limiting magnitude in 80h	I_{AB} = 25.0 (R=3500)
	I_{AB} = 26.7 (R=180)
Limiting Flux in 80h	3.9 10^{-19}erg.s^{-1}.cm^{-2}

4096 pixels

370 10^6 pixels

90,000 spaxels

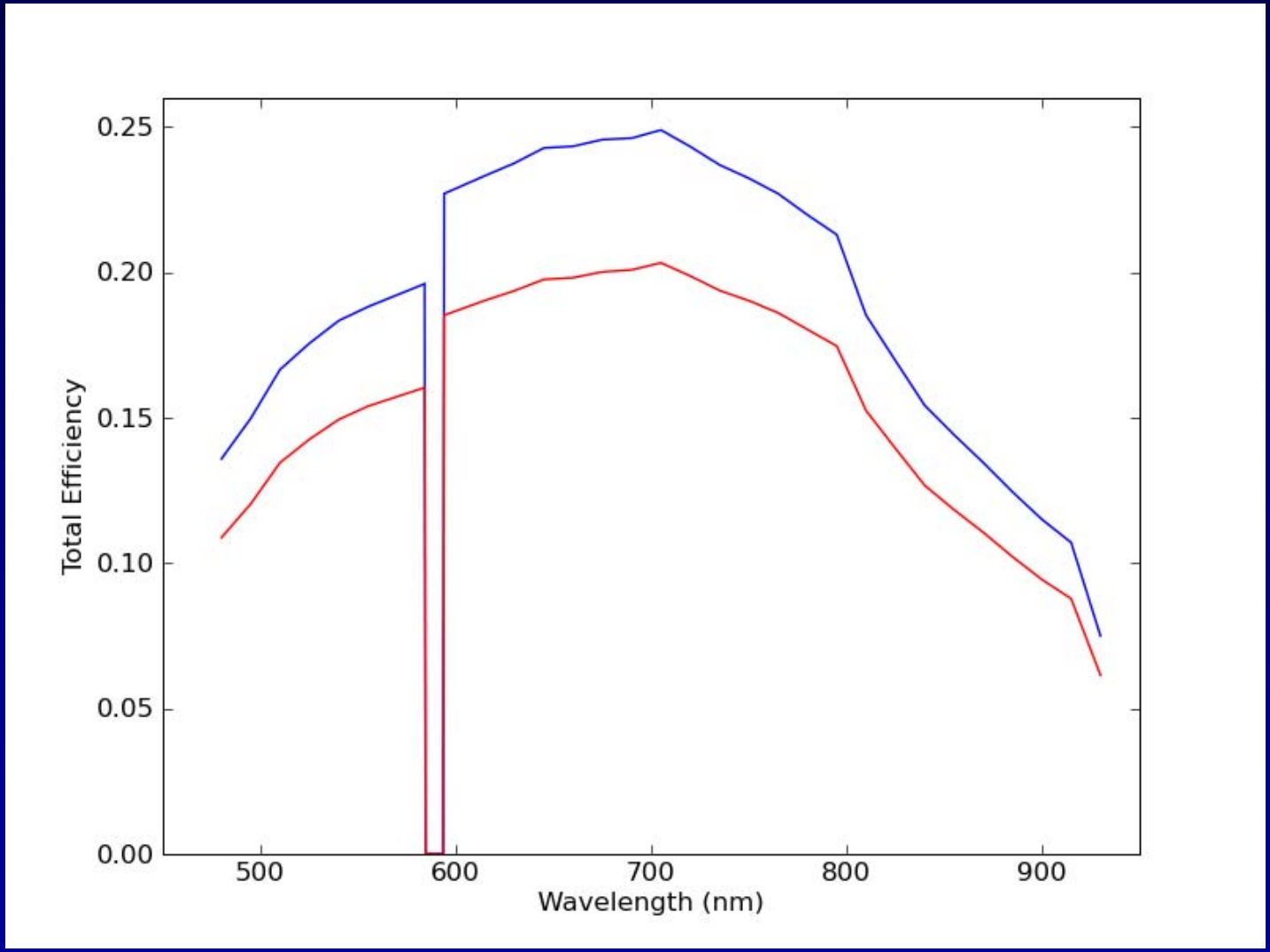
AO

Laser guide stars

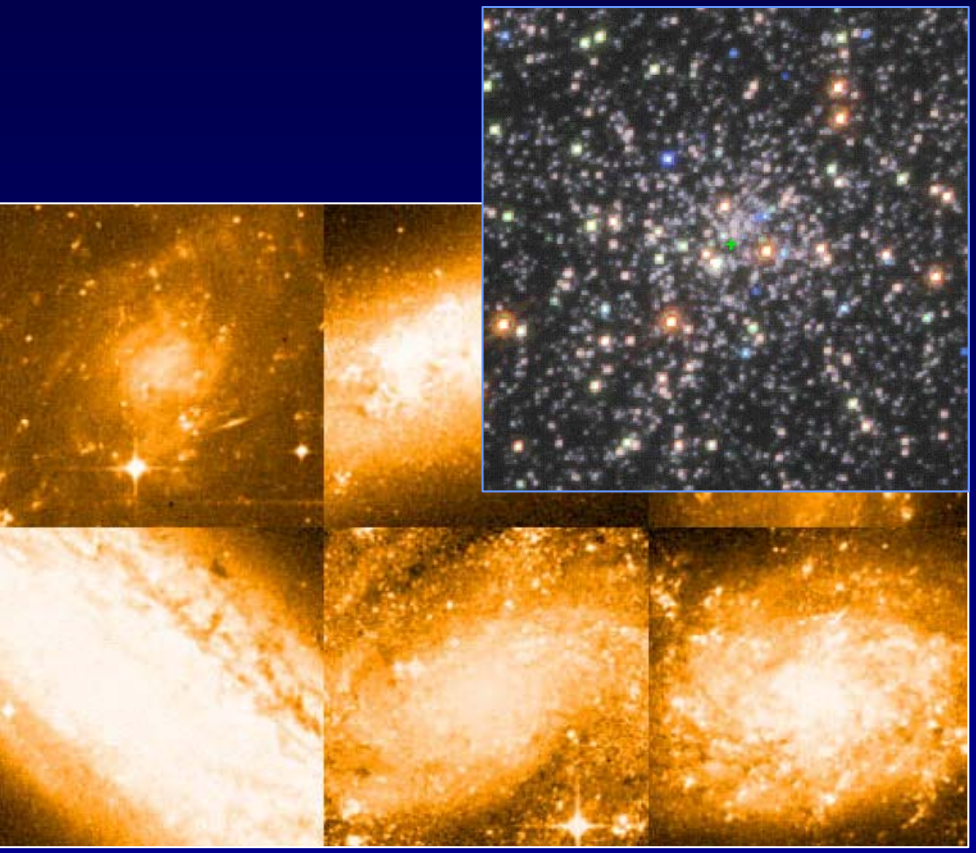
High throughput

Stability

MUSE total throughput



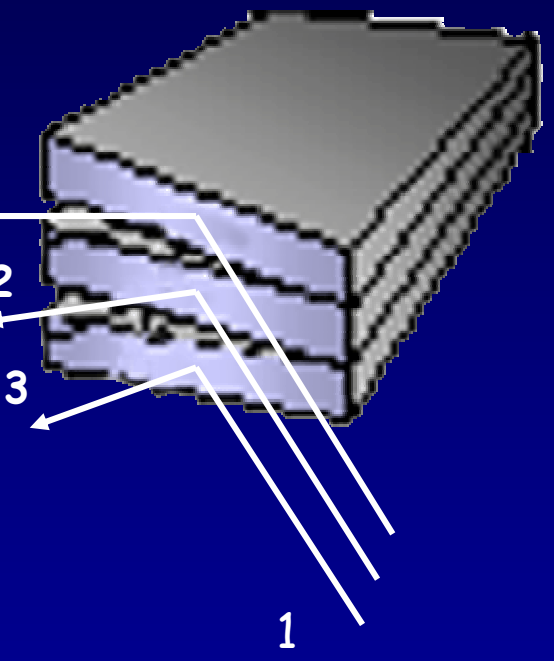
Stellar population: massive spectroscopy

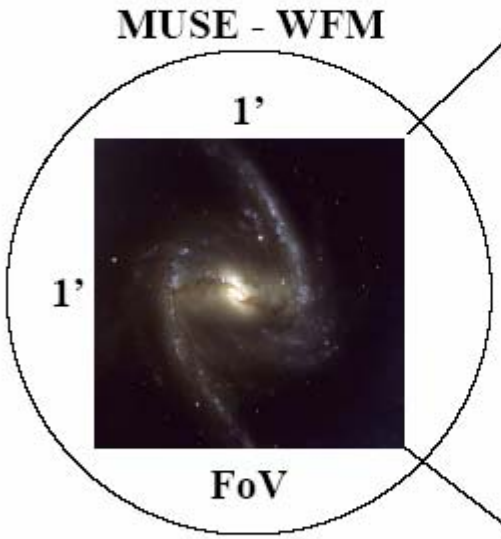


- Survey of nearby disk galaxies
  - 25 exposures of 4 hour: 5x5 arcmin^2
- Search for
  - Massive stars
    - 1000/galaxy
  - Planetary nebulae
    - > 100/galaxy
  - HII regions
  - Rare objects
    - LBV, WN/Ofpe, B[e], WN, WC
    - SNR, novae, ultra-luminous X-ray sources
  - Diffuse ISM

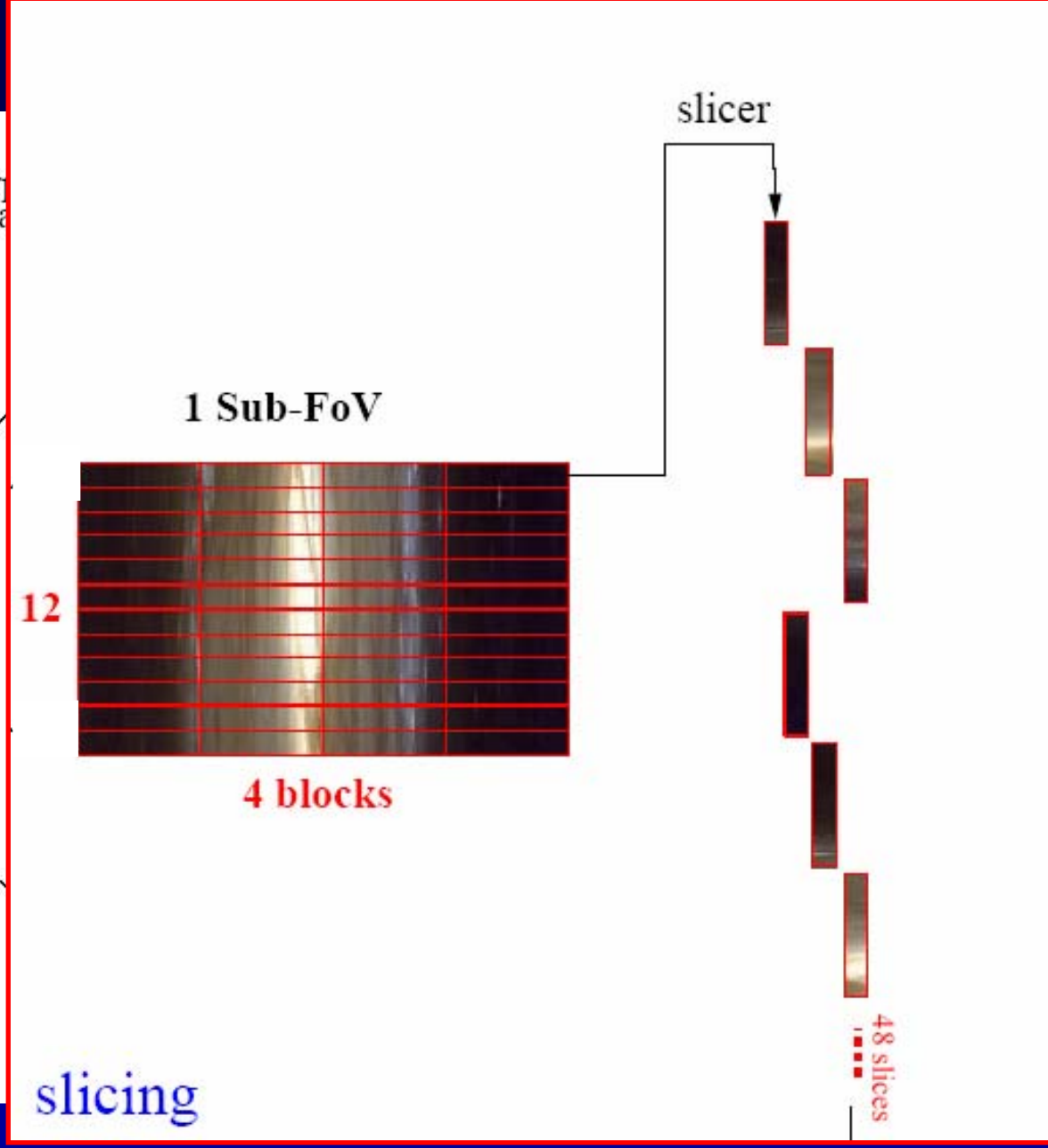
Pre-OWL science
GAIA complementarity

Slicer IFU :

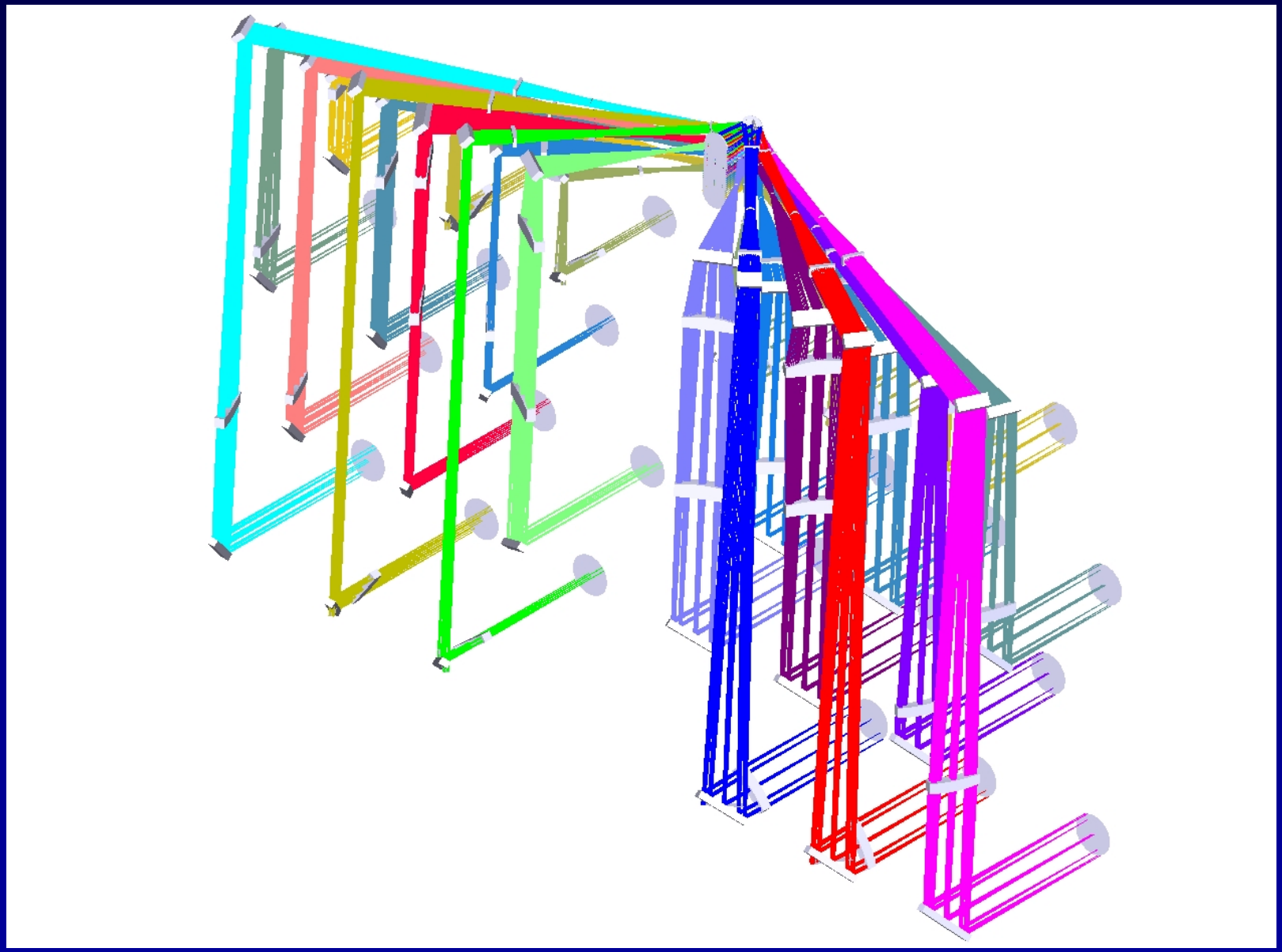


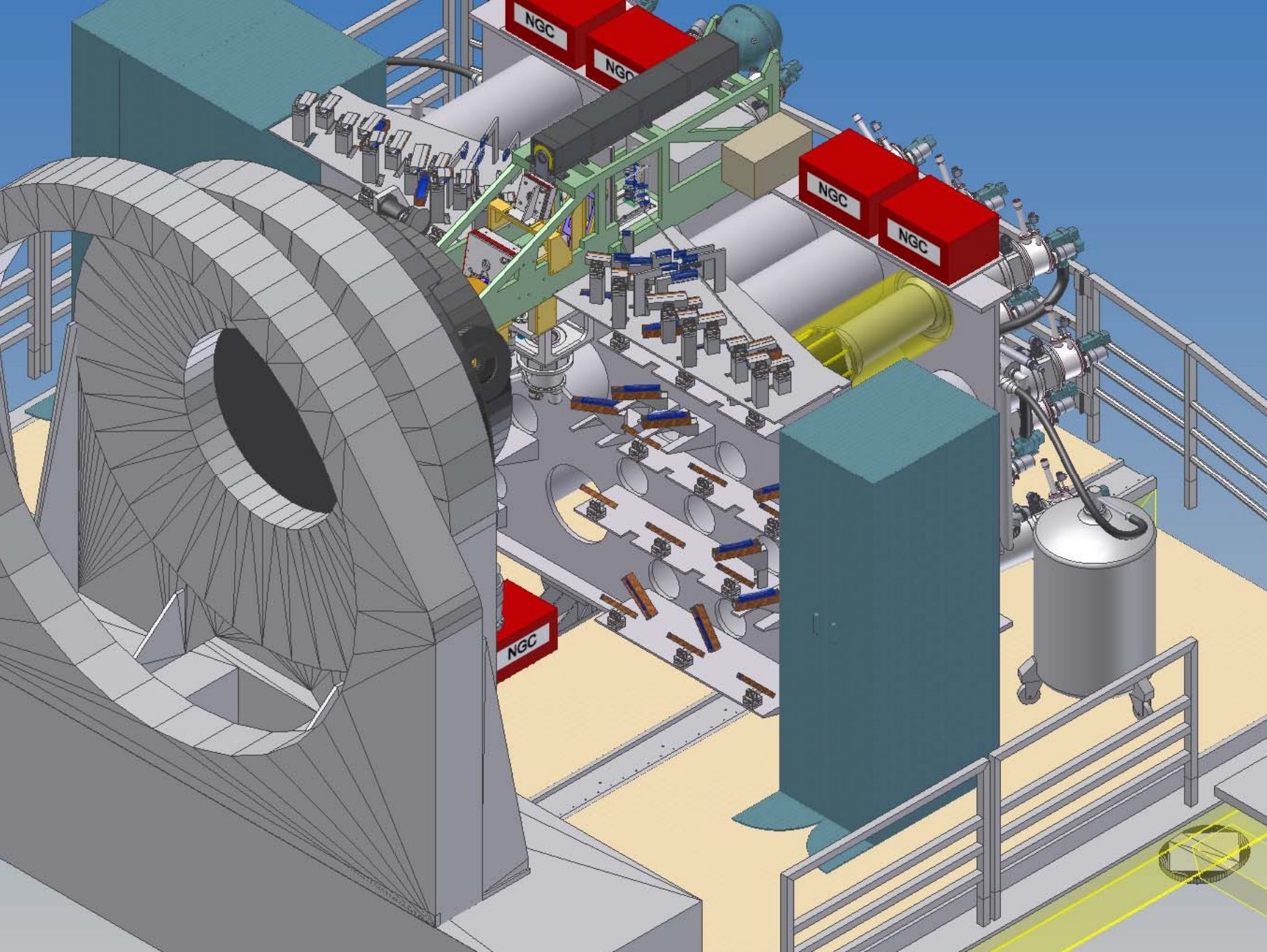


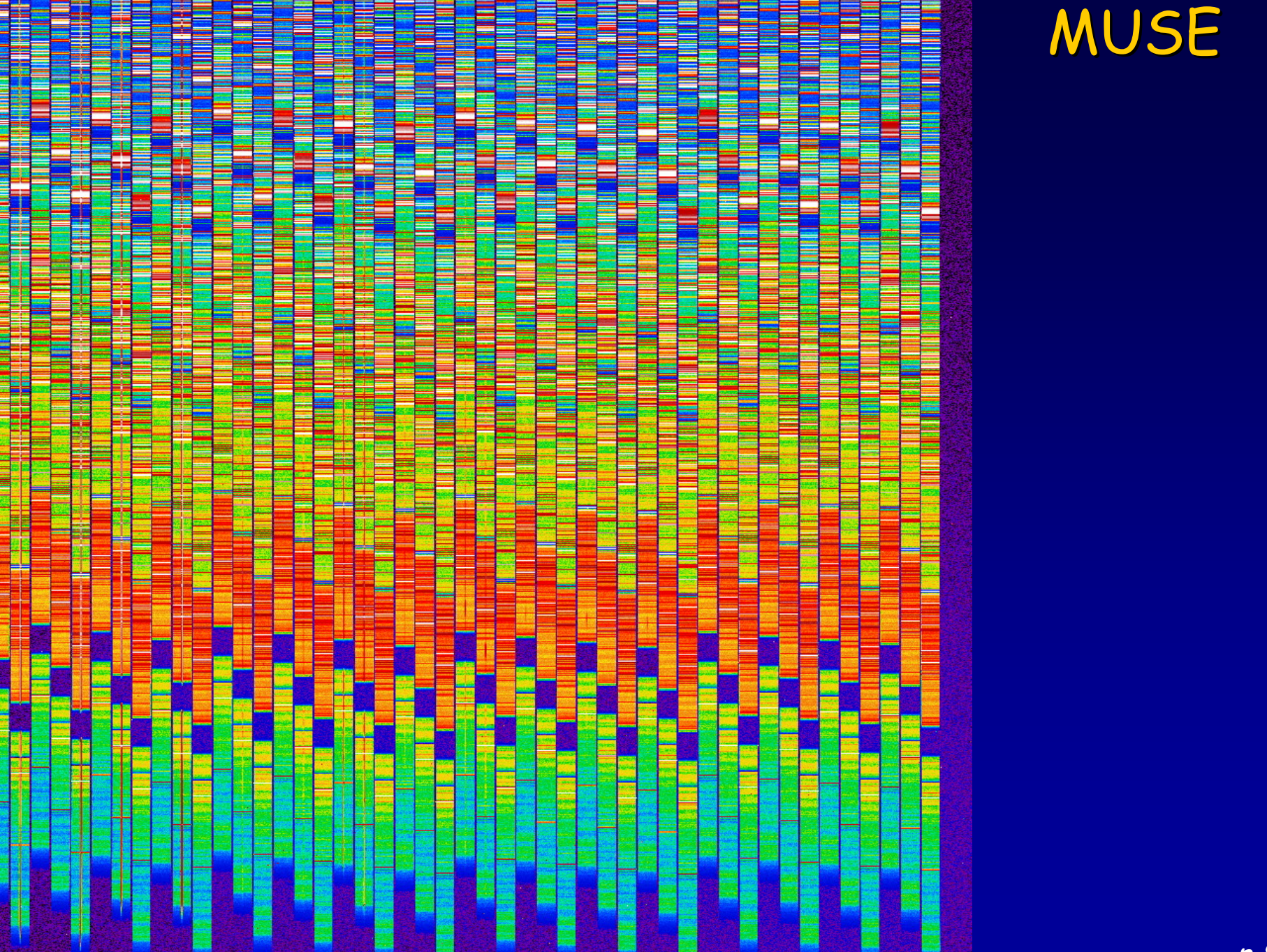
1.anamor
magnifica



Field Splitter and Separator

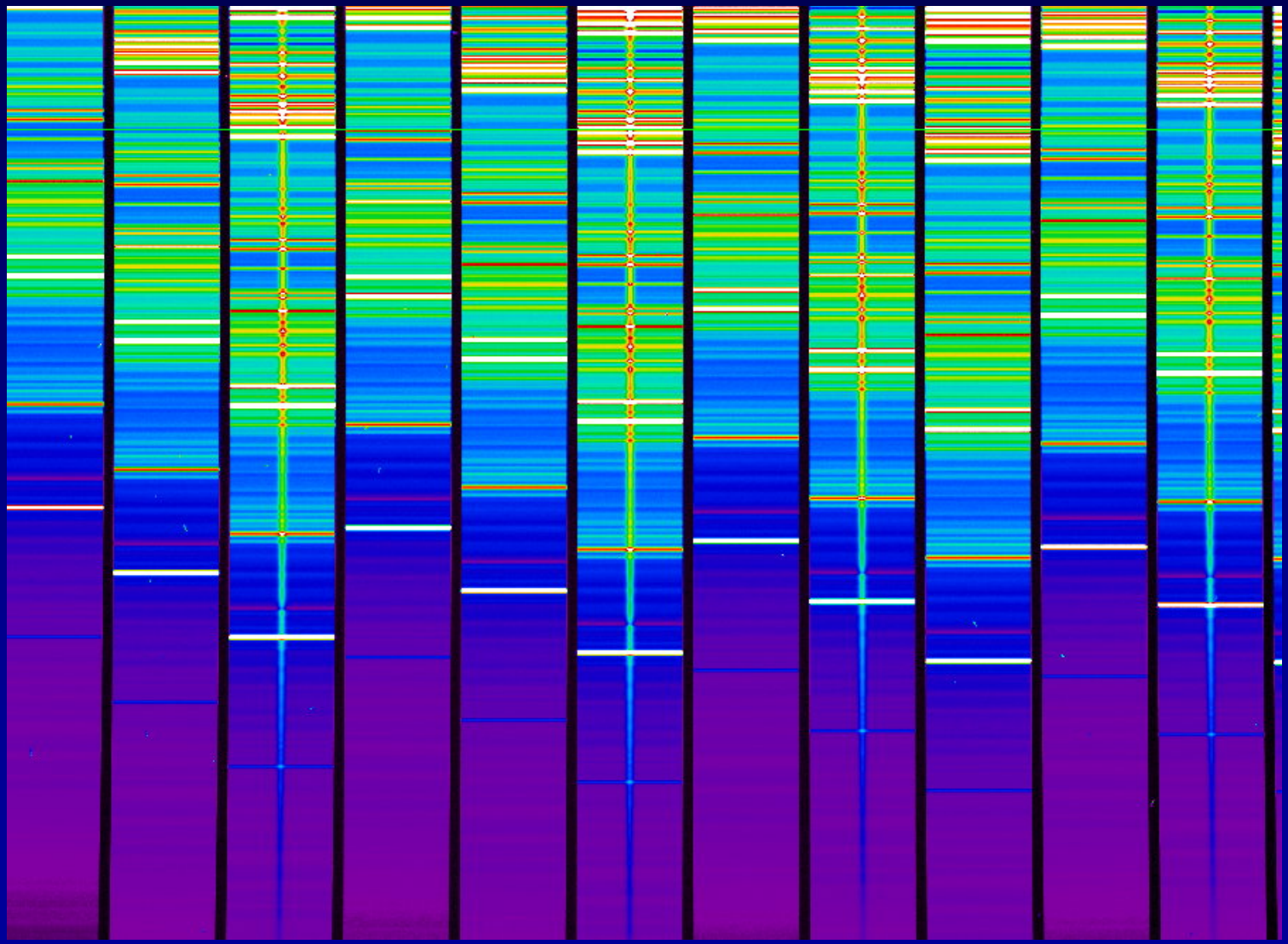


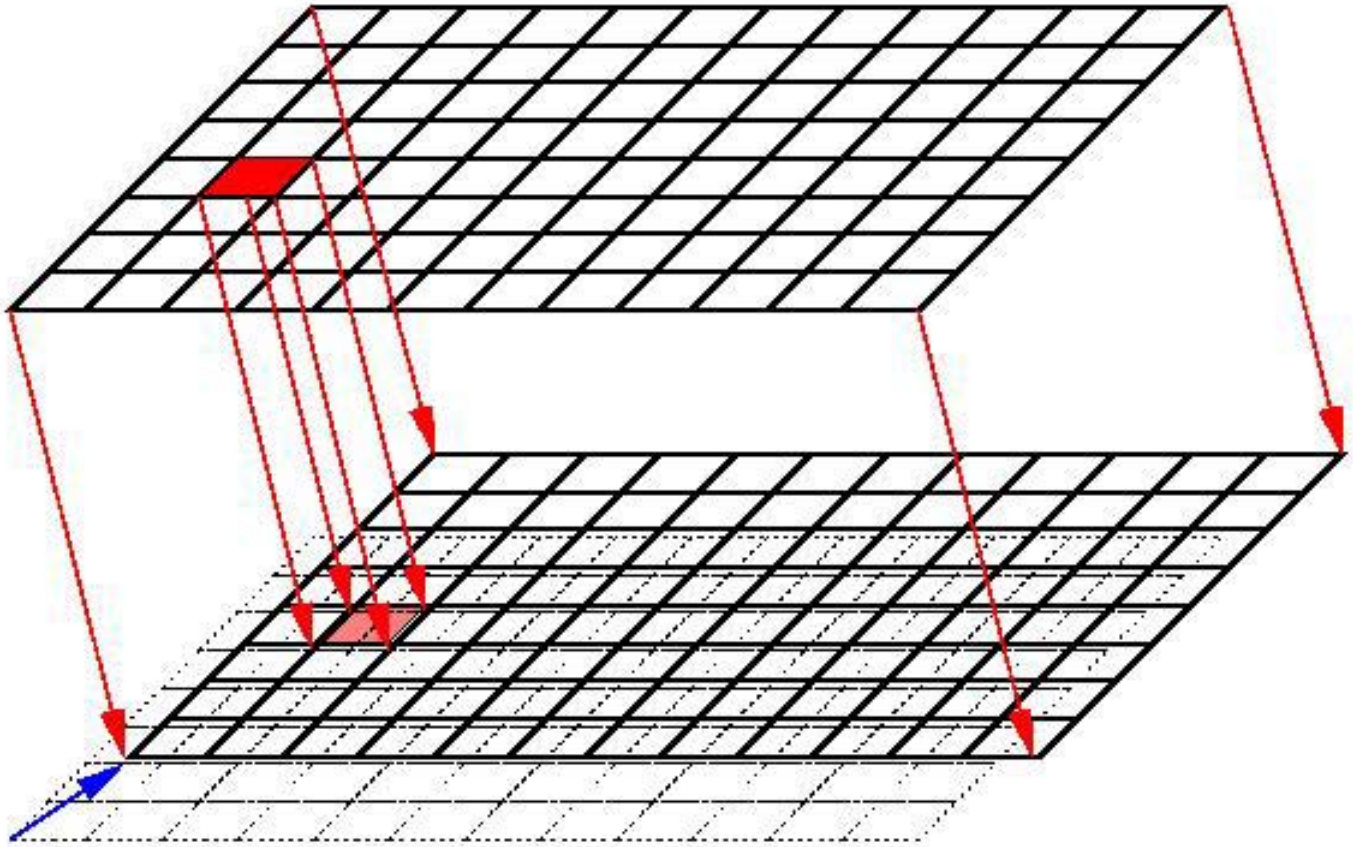

NGC
NGC
NGC
NGC
NGC

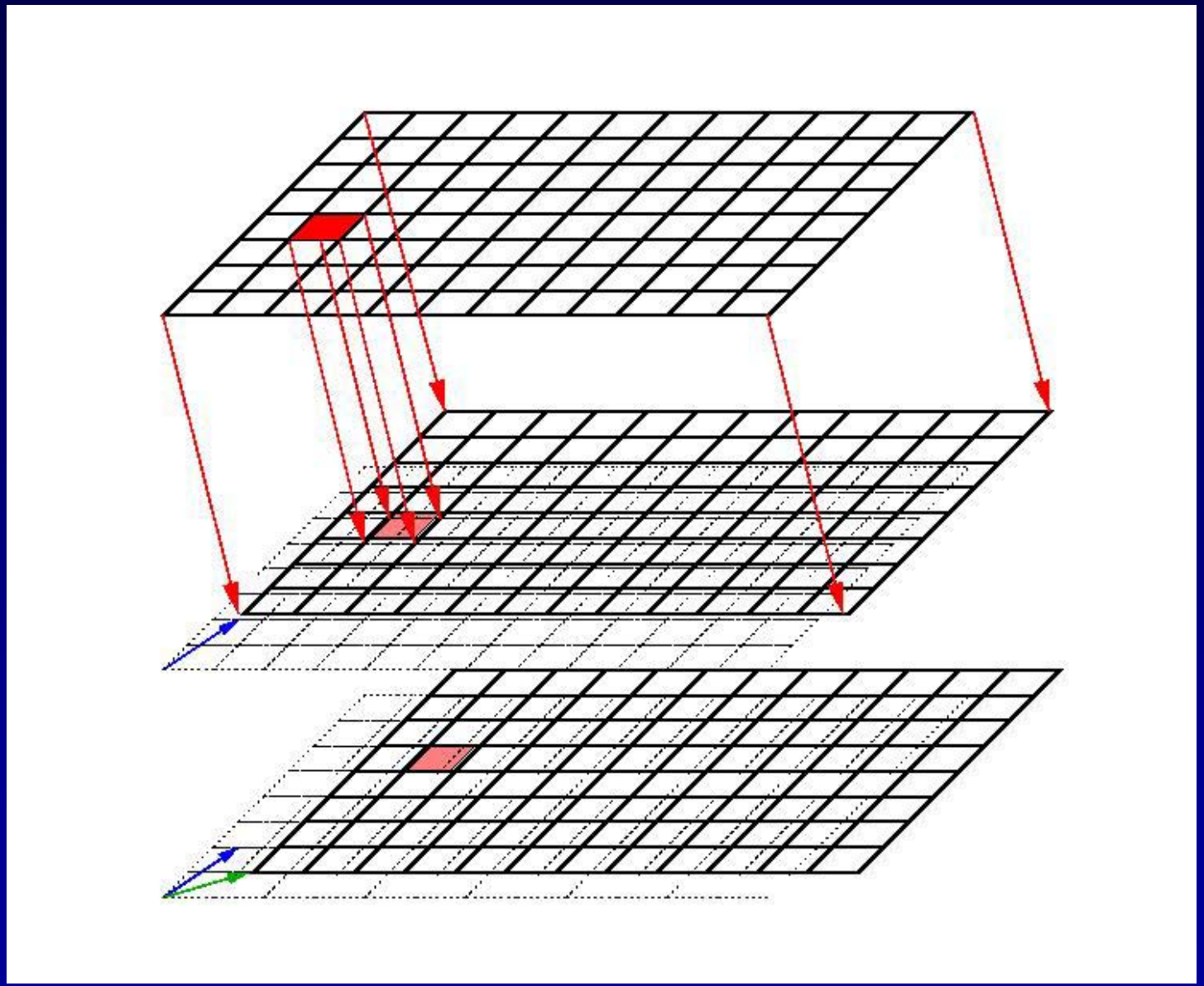

MUSE

raw science frame :

2400s, 158 cosmic ray hits



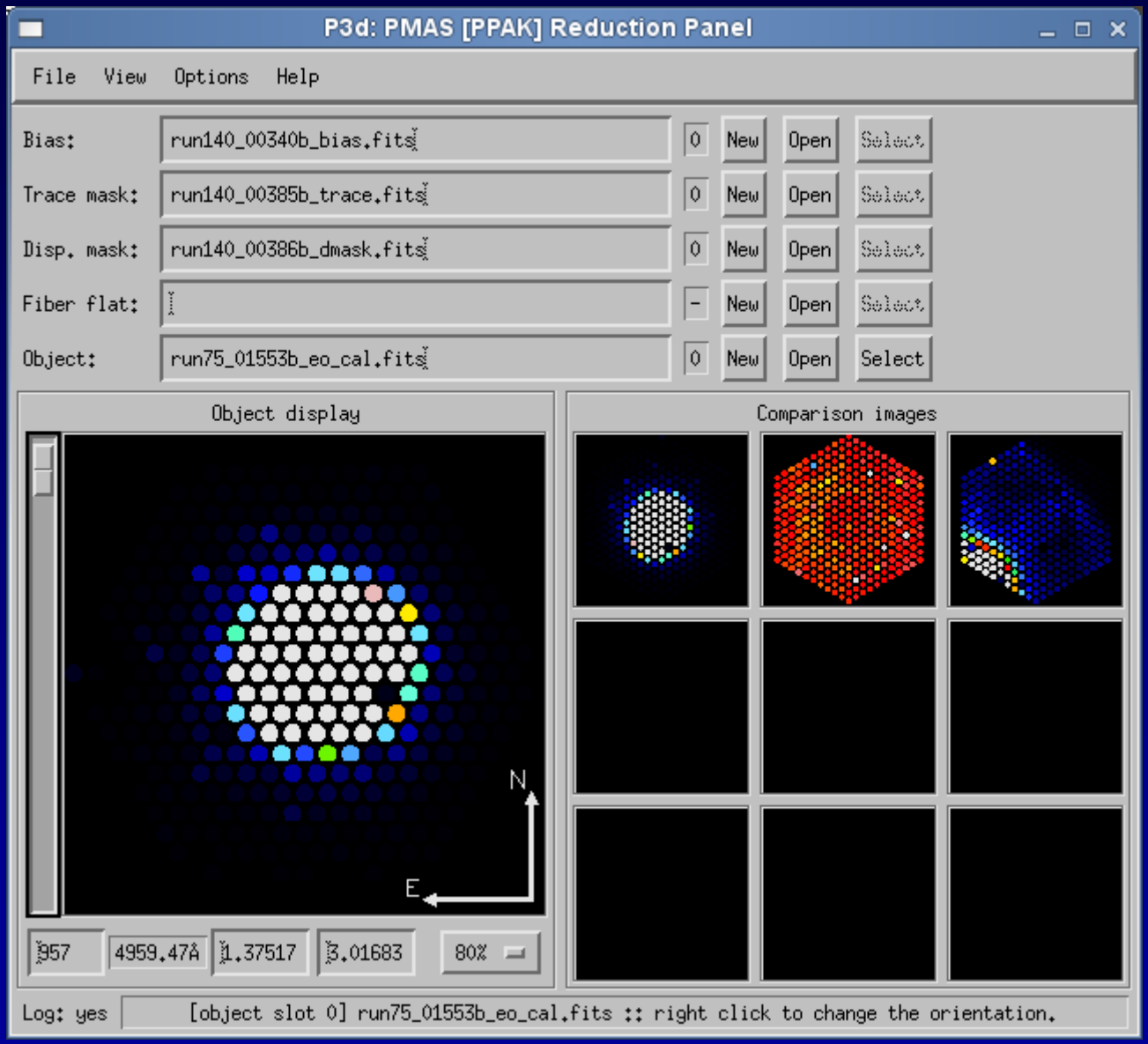




The Potsdam 3D Data Reduction and Analysis Tool

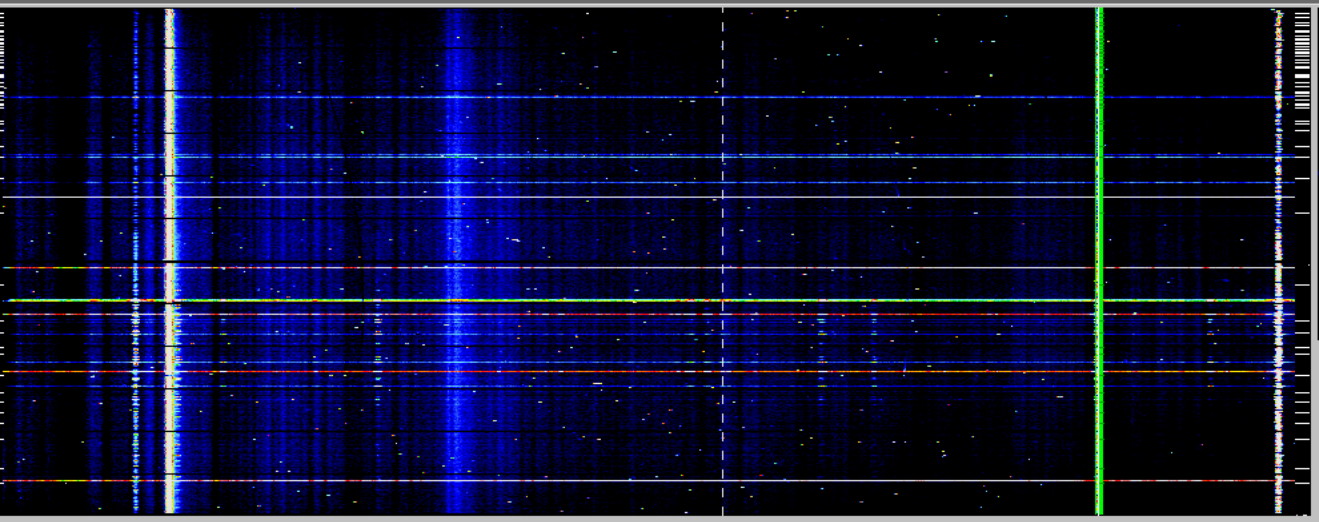
P3d

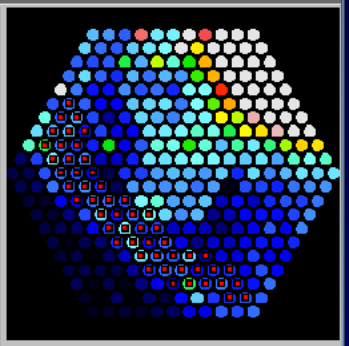
P3d



Sandin C., Gerssen J, Becker T., Cairós L., Weilbacher P., Böhm P., Monreal-Ibero A., Roth M.M. 2009, PASP, in prep.)

File Image view Monochromatic view Spectral view

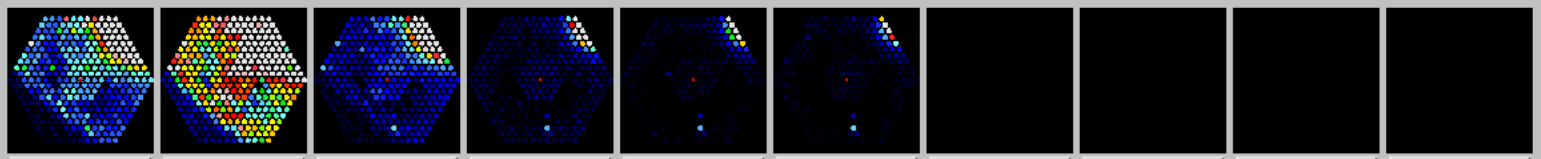




Sum all Subtract

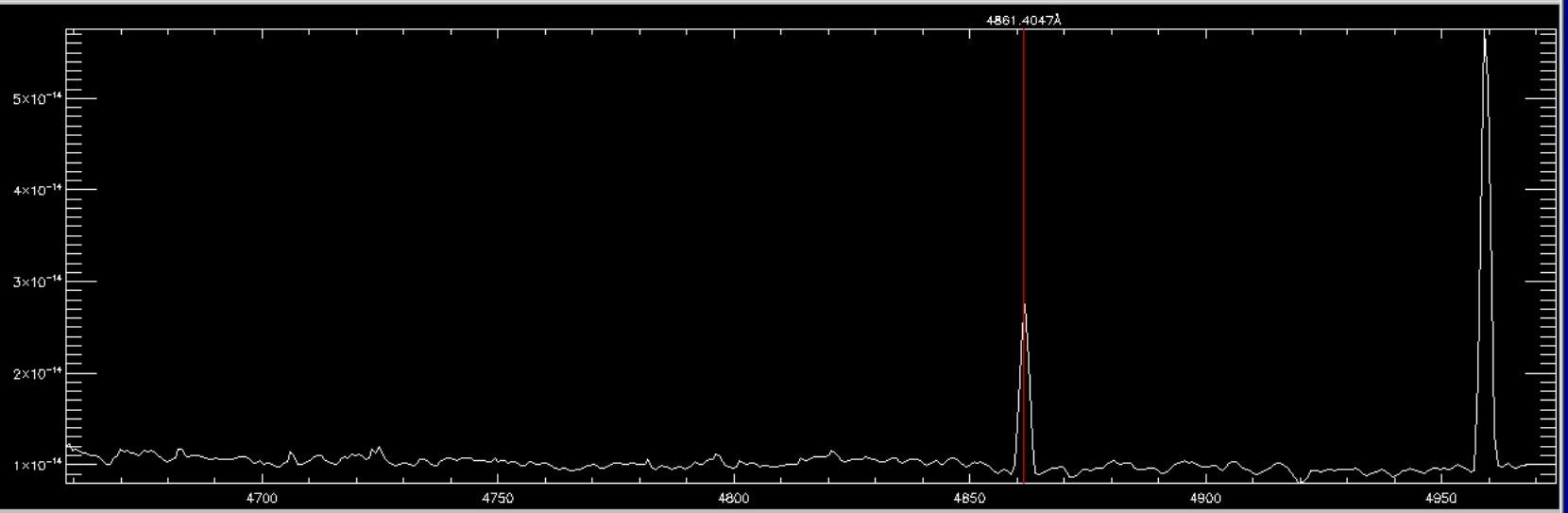
52

user 8.0e-16 823 Bandwidth: 3



4860-4865 4958-4963 4339-4344 4469-4474 4711-4716 4738-4743

This area shows the single, or summed, spectrum that is selected in the monochromatic image.



Conclusions

- 3D Spectroscopy is a very powerful technique
- 3D Spectroscopy is significantly more complex than direct imaging or conventional spectroscopy
- 3D Spectroscopy presents challenges for data reduction and analysis
- Spanish community has direct access to most IFUs
- Spanish community has made a good investment in human capital

▶ A bright future for 3D Spectroscopy…

Estallidos Workshop
Granada, 17/06/2009