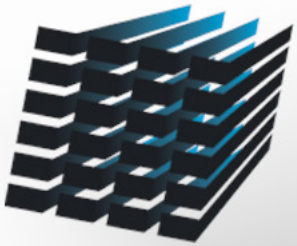


muse

multi unit spectroscopic explorer

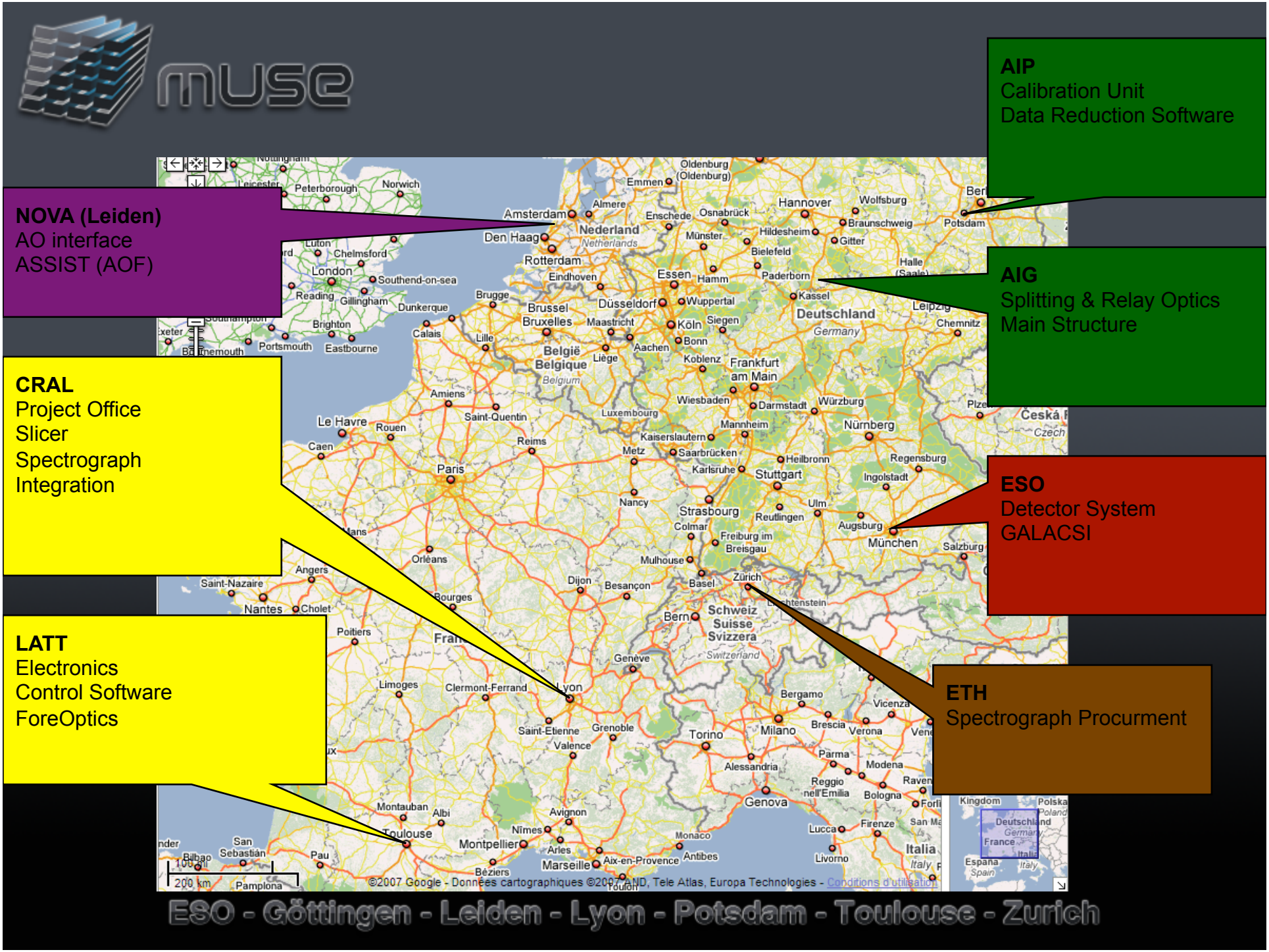
MUSE: The second generation instrument for the VLT

Realising the Astronomy of the Future

Oxford, 6-7 June 2012

What is MUSE ?

MUSE is a large field integral field spectrograph operating in the visible at high spatial resolution, optimized for long integration, with medium spectral resolution, large simultaneous spectral range and high throughput.


muse
AIP
Calibration Unit
Data Reduction Software
NOVA (Leiden)
AO interface
ASSIST (AOF)
AIG
Splitting & Relay Optics
Main Structure
CRAL
Project Office
Slicer
Spectrograph
Integration
ESO
Detector System
GALACSI
LATT
Electronics
Control Software
ForeOptics
ETH
Spectrograph Procurment
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Bacon R.[1], Accardo M.[4], Adjali L.[1], Anwand H.[5], Bauer S.[2], Biswas I.[2], Blaizot J.[1], Boudon D.[1], Brau-Nogué S.[6], Brinchmann J.[7], Caillier P.[1], Capoani L.[1], Carollo C.M.[3], Contini T.[6], Couderc P.[6], Daguisé E.[1], Deiries S.[4], Delabre B.[4], Dreizler S.[5], Dubois J.[1], Dupieux M.[6], Dupuy C.[4], Emsellem E.[1,4], Fechner T.[2], Fleischmann A.[5], François M.[1], Gallou G.[6], Gharsa T.[6], Glindemann A.[4], Gojak D.[4], Guiderdoni B.[1], Hansali G.[1], Hahn T.[2], Jarno A.[1], Kelz A.[2], Koehler C.[5], Kosmalski J.[1], Laurent F.[1], Le Floch M.[6], Lilly S.J.[3], Lizon J.-L.[4], Loupias M.[1], Manescau A.[4], Monstein C.[3], Nicklas H.[5], Olaya J-C[2], Parès L.[6], Pasquini L.[4], Pécontal-Rousset A.[1], Pello R.[6], Petit C.[1], Popow E.[2], Reiss R.[4], Remillieux A.[1], Renault E.[1], Roth M.[2], Rupprecht G.[4], Serre D.[7], Schaye J.[7], Soucail G.[6], Steinmetz M.[2], Streicher O.[2], Stuik R.[7], Valentin H.[6], Vernet J.[4], Weilbacher P.[2], Wisotzki L.[2], Yerle N.[6]

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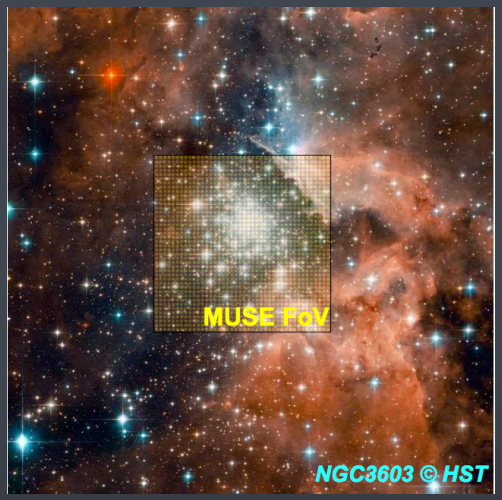
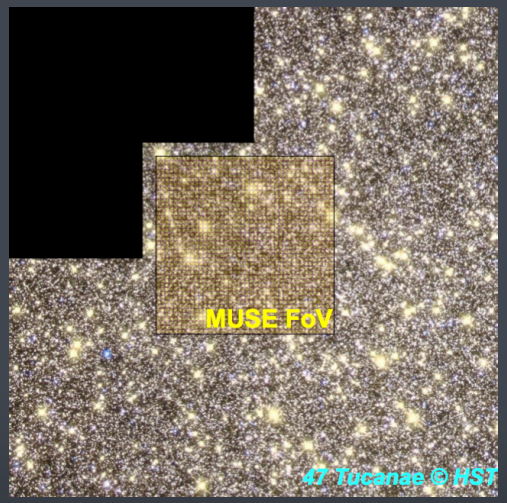
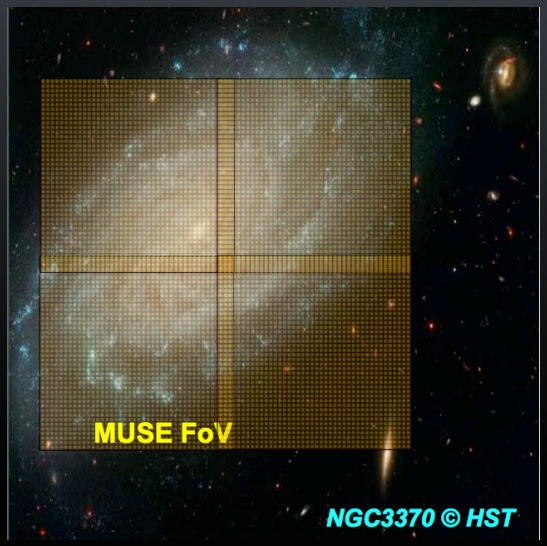
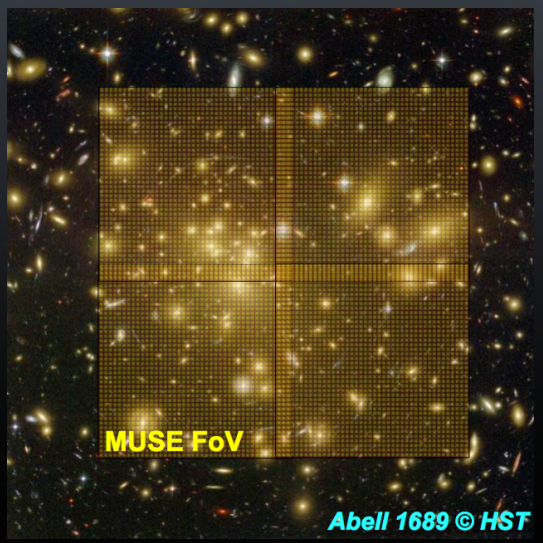
(6) Laboratoire d'Astrophysique de Toulouse-Tarbes (CNRS/University Paul Sabatier), Observatoire Midi Pyrénées, 14, avenue Edouard Belin, 31400 Toulouse, France
(7) NOVA Leiden Observatory, Leiden University, P.O. Box 9513, 2300 RA Leiden, The Netherlands

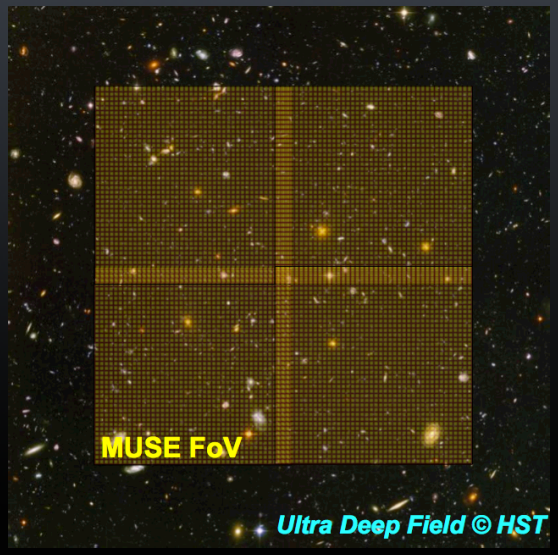
muse











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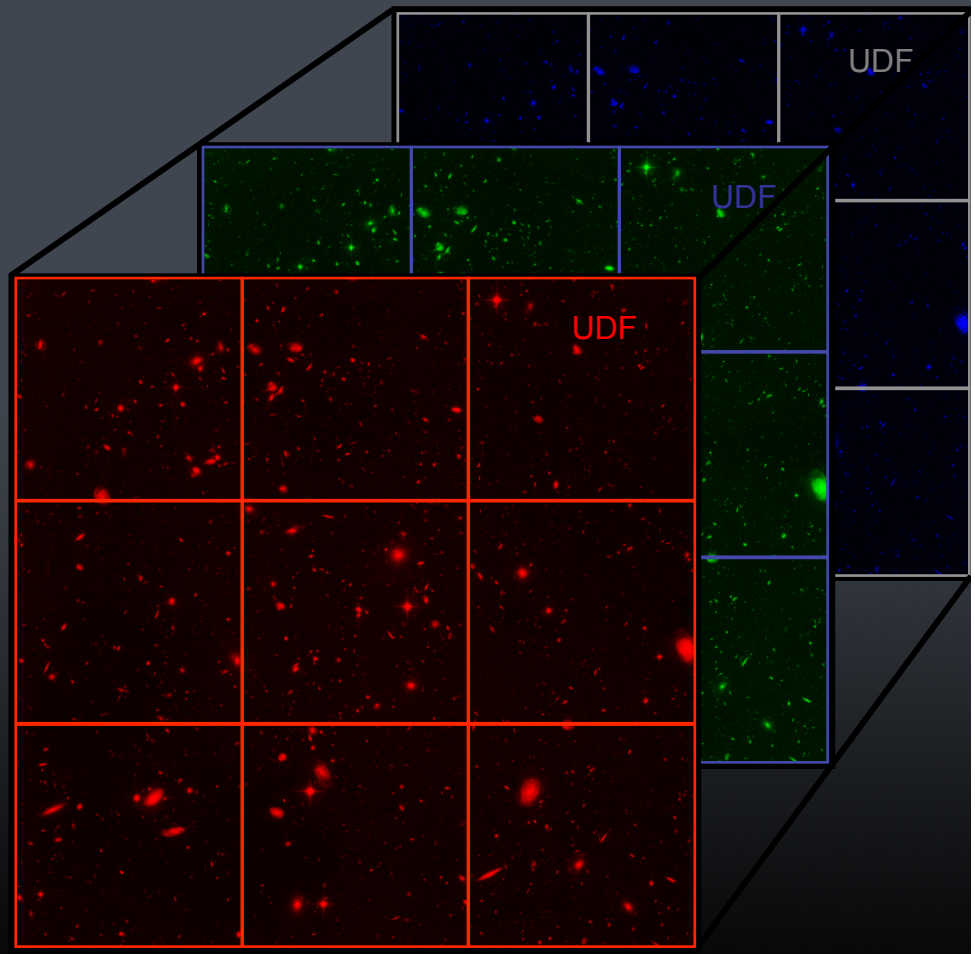
3D Deep Fields

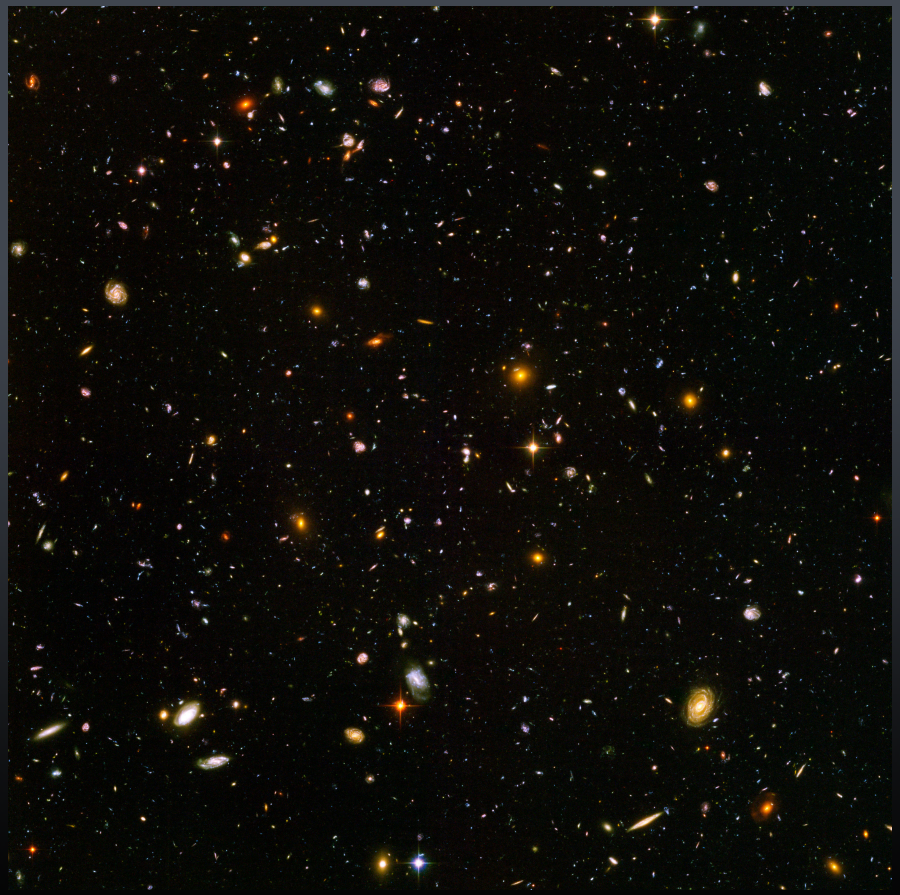
Get everything!

- Eliminates pre-imaging
- Eliminates pre-selection
- Observe only once
- Attack multiple science topics simultaneously
- Large discovery space for serendipitous sources



3D deep field: main science driver

- Detect
  - Large field of view
  - High throughput
  - Stable (long exposure)
- Measure
  - High spatial resolution
  - Medium spectral resolution
  - Wide simultaneous spectral range



Instrument Overview

- Integral Field Spectrograph
- Optimized for ESO AO Facility
  - but can run without AO
- Two modes only
  - WFM: Wide Field Mode
    - 0.2 arcsec, 1x1 arcmin^2
    - Spatial resolution
      - Non AO: seeing
      - AO: 0.3-0.4 arcsec
  - NFM: Narrow Field Mode
    - only with AO
    - 0.025 arcsec, 7x7 arcsec2
    - Spatial resolution
      - 10-20% Strehl ratio
- Spectral characteristics
  - 465-930 nm simultaneous
  - R~3000
- Data volume
  - 400 10^6 pixels
  - 90,000 spectra in one exposure

- Large field of view
- Large simultaneous spectral range
- High spatial resolution
- Medium spectral resolution

400 millions pixels

Single large optics + ccd mosaic
or
many smaller optics + ccd ?

One single instrument ?

or

many smaller units ?

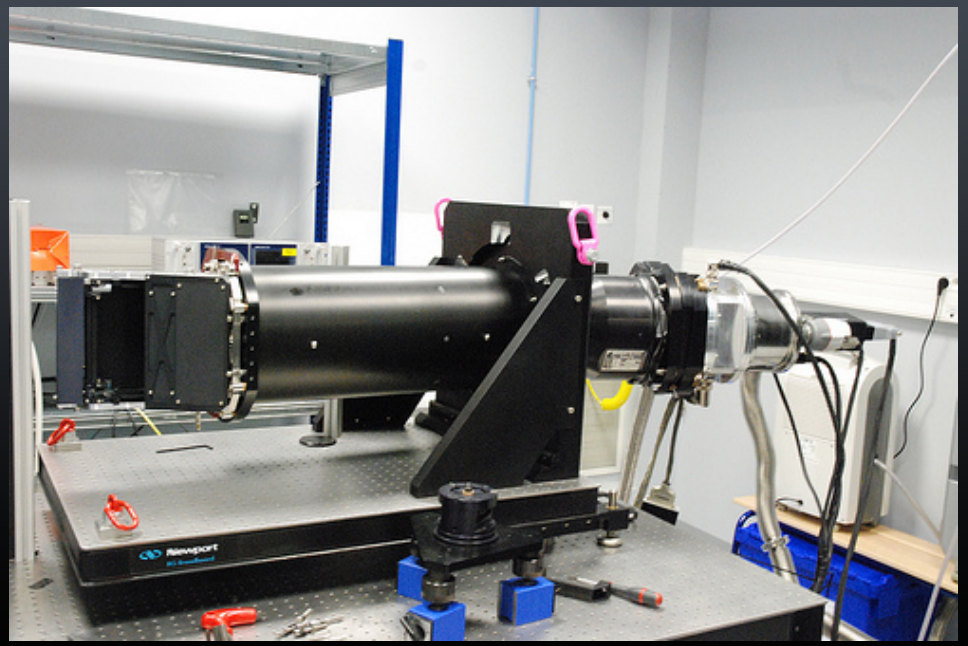
Optimized for long integrations

Stability

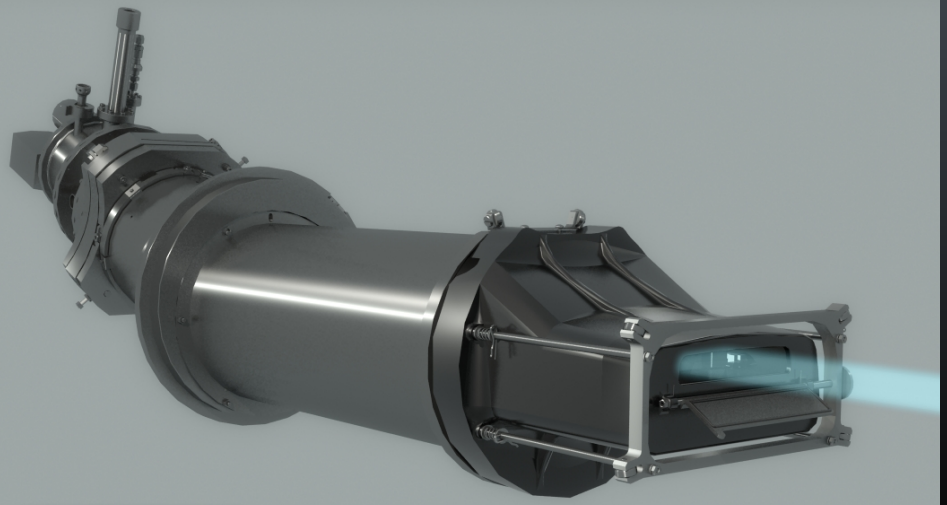
- Nasmyth gravity invariant focus
- Temperature invariant design
- No motion in modules
- Control of residual Nasmyth platform wobbling with a slow guiding system

IFU serial production

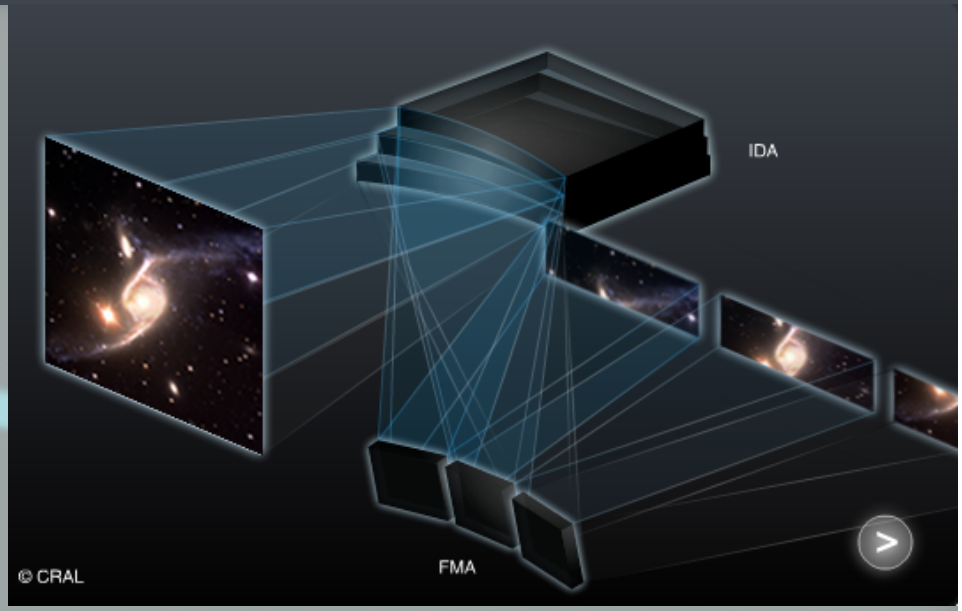
ISS / SPS / DV

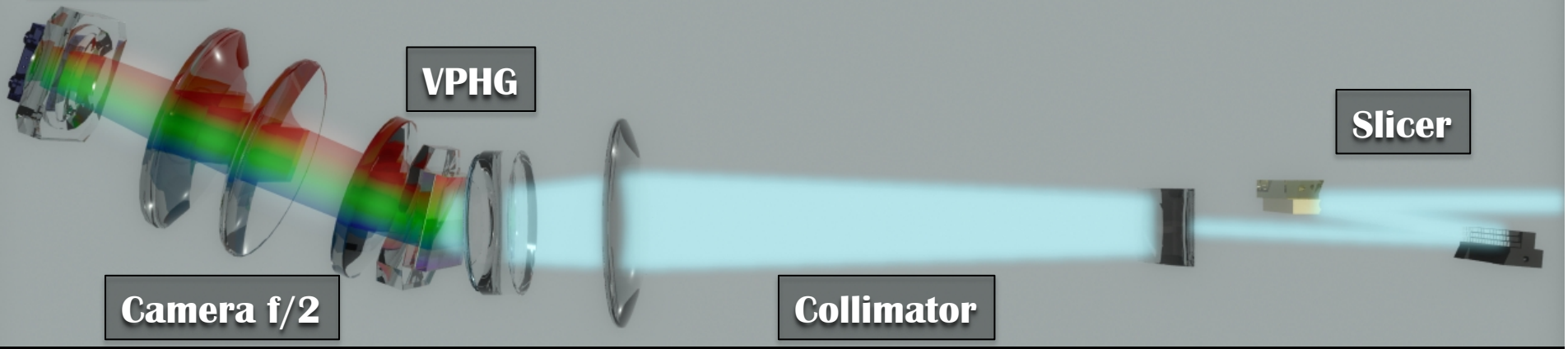


IFU x 24



CCD 4k²





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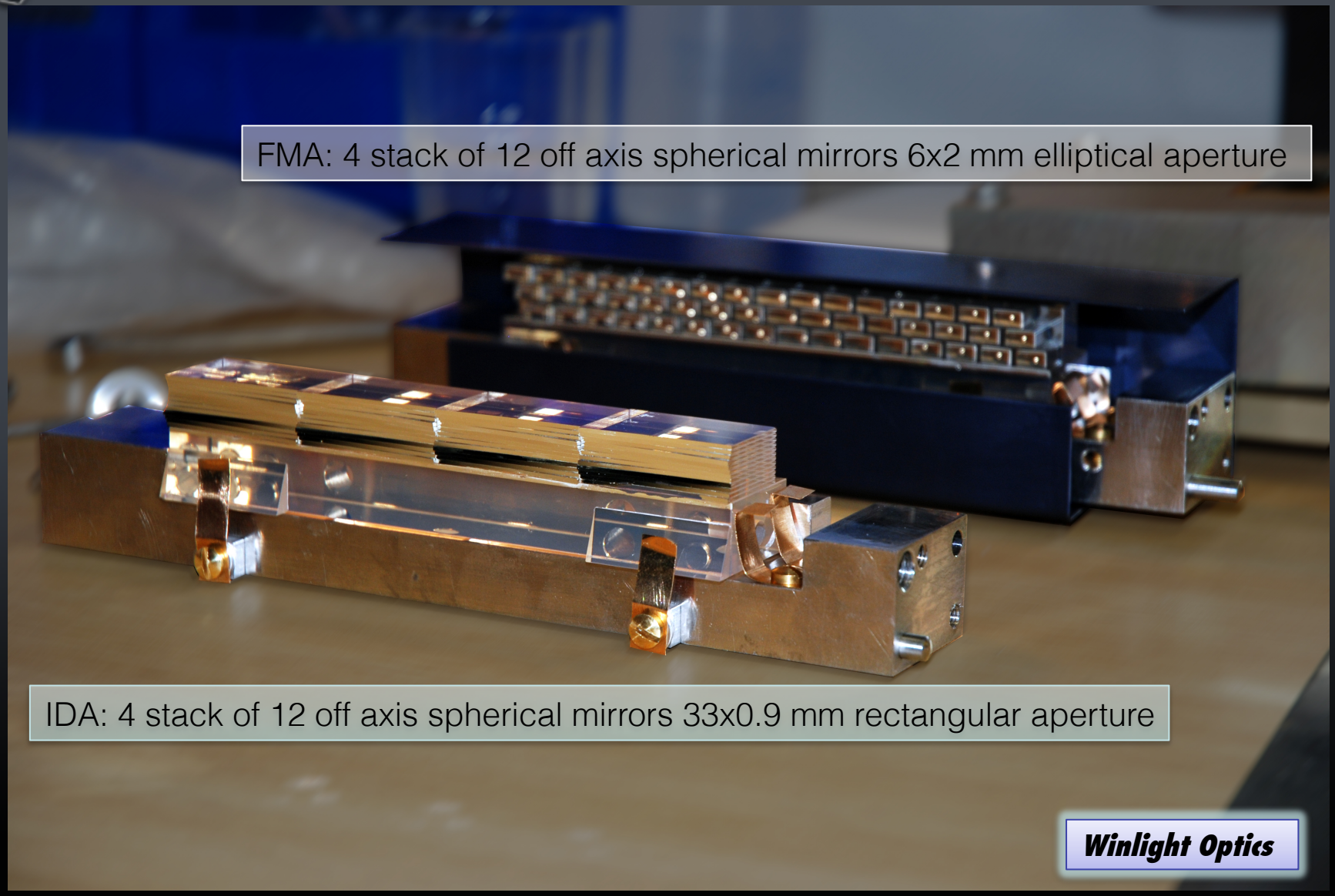
Slicer x 24



FMA: 4 stack of 12 off axis spherical mirrors 6x2 mm elliptical aperture

IDA: 4 stack of 12 off axis spherical mirrors 33x0.9 mm rectangular aperture

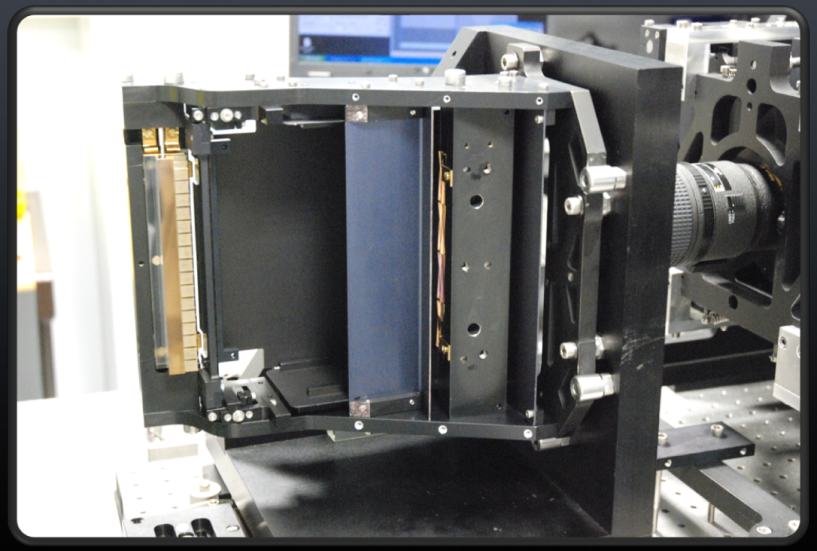
Winlight Optics

ISS support series: lateral parts (CRAL)

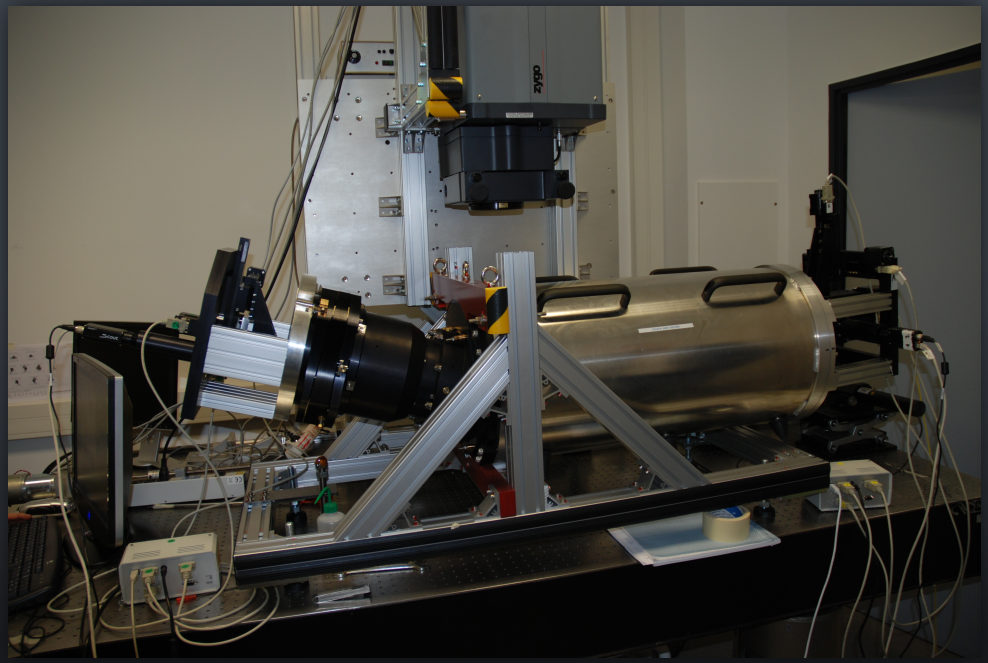
- 24/24 lateral parts manufactured
- ISS product number engraved
- anodized

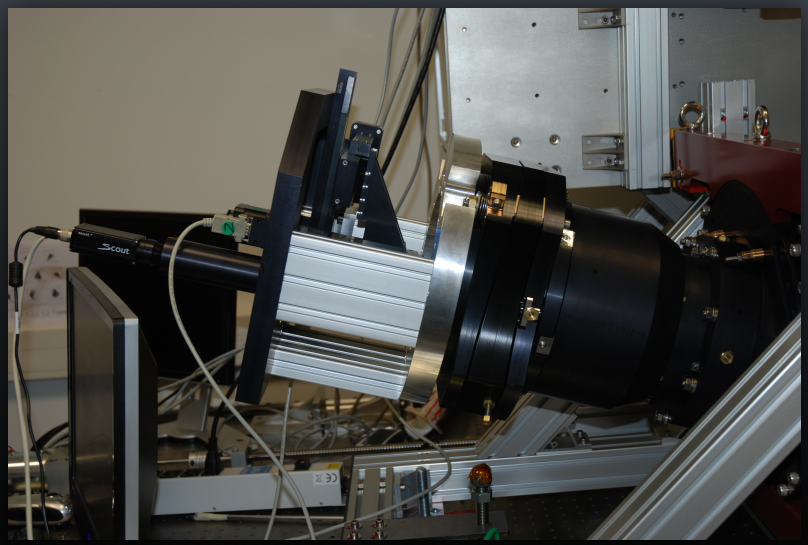
ISS series status

- 24 ISS supports assembled
- 23 IDA-FMA delivered (without any defect)
- 23 ISS assembled and tested
- 18 ISS integrated on an IFU

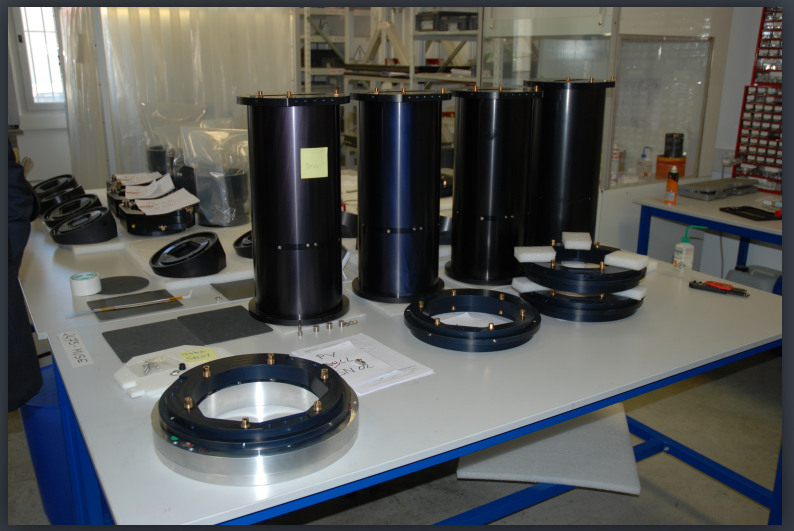


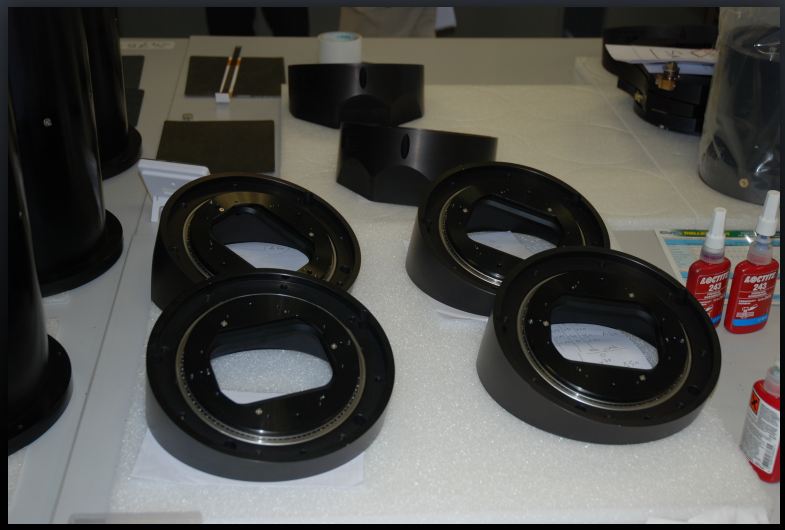
SPS #2 @ Winlight





SPS parts @ Winlight





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Spectrograph series status

- 24 Spectrographs delivered to CRAL
- 20 Spectrographs integrated on an IFU
- 1 Spectrograph at AIP for DV testing

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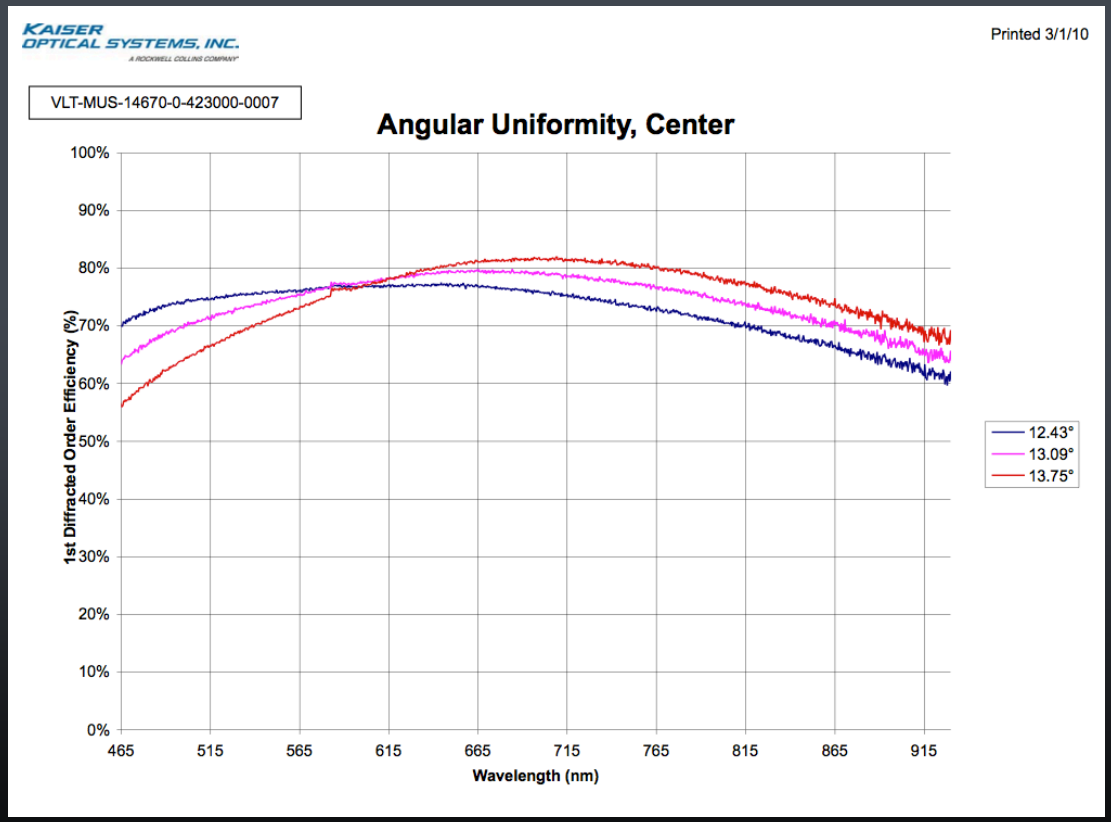
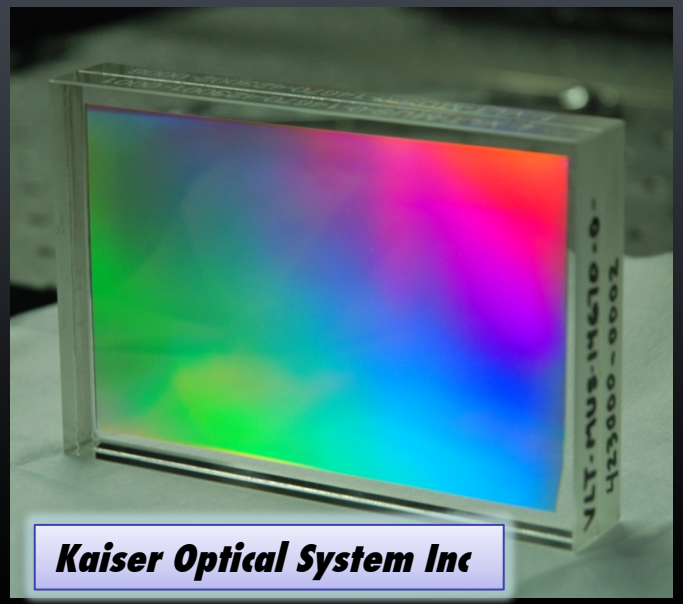
Volume Phase Holographic Grating





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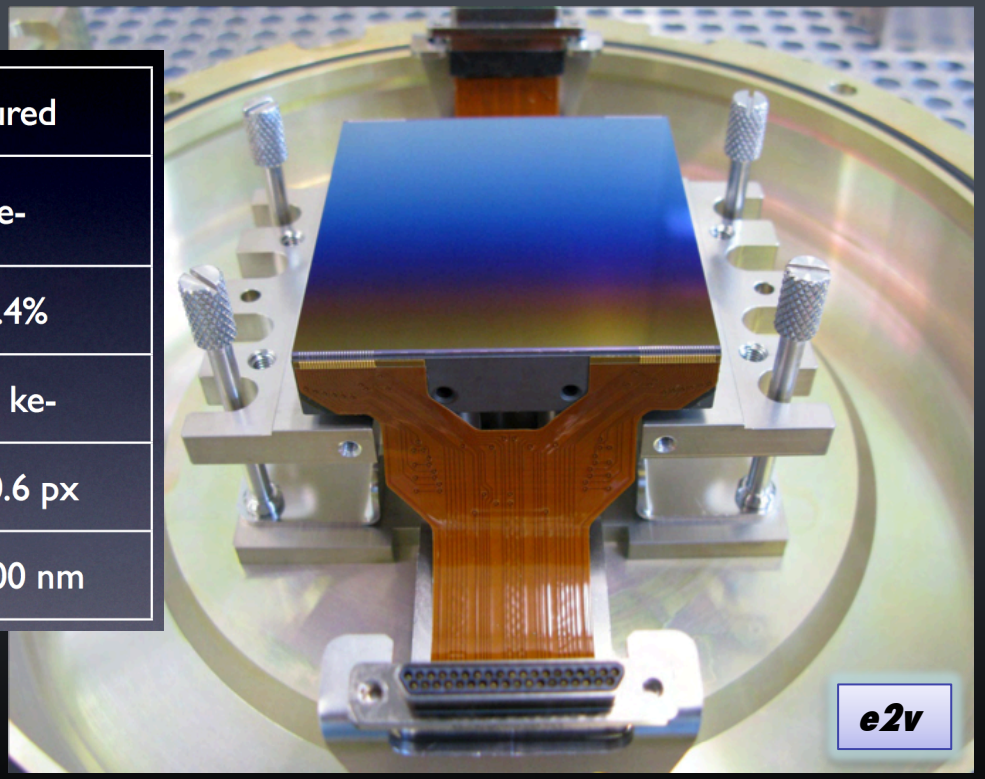
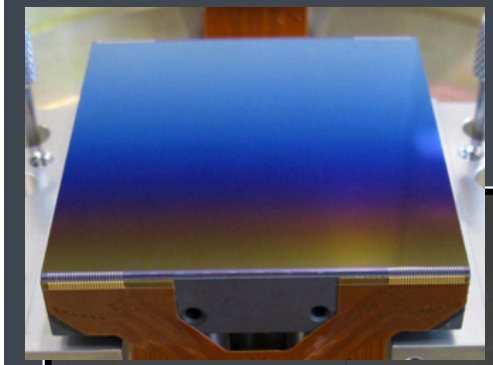
Detectors x24

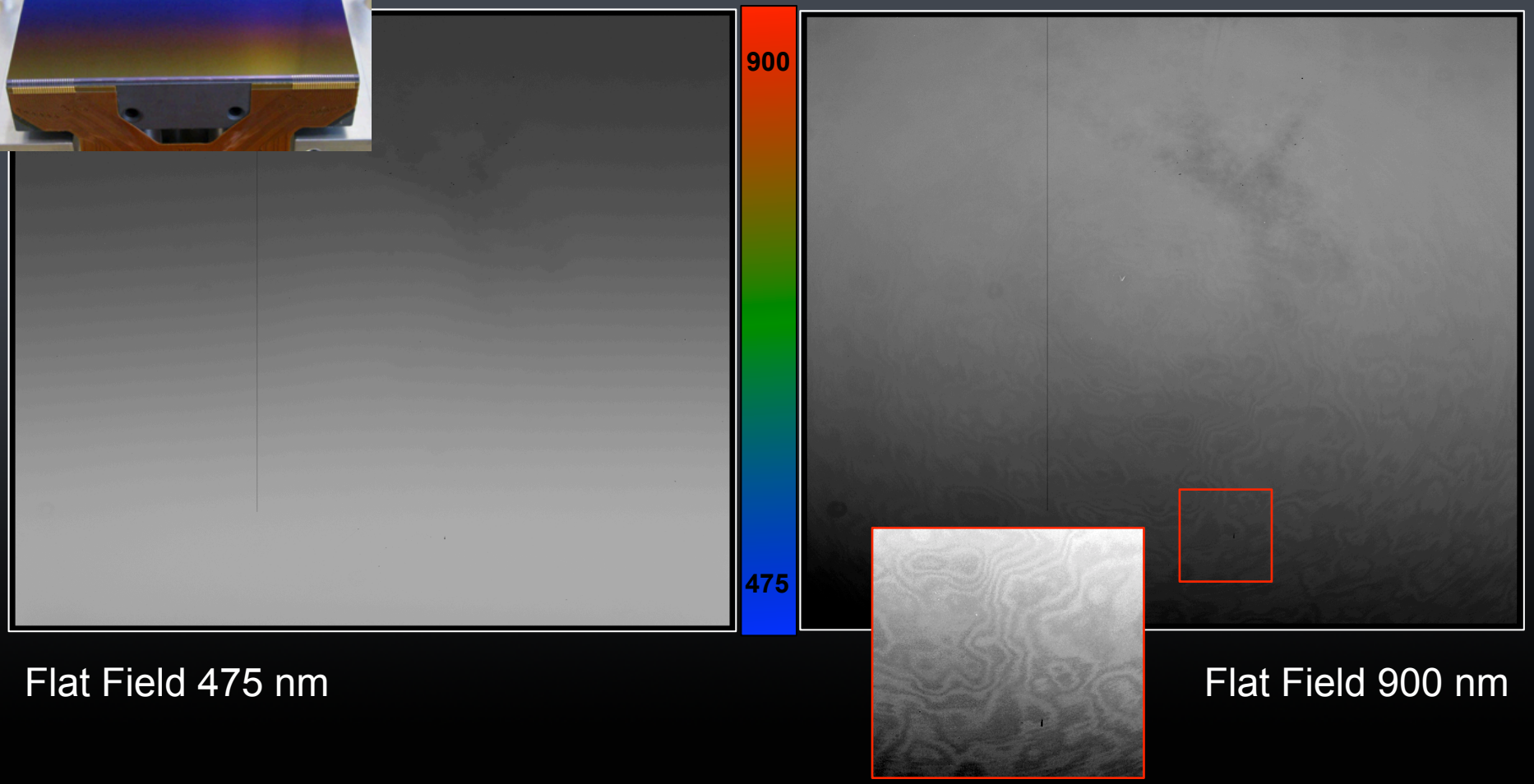
231-84 4kx4k

	spec	measured
read-out noise (1 min)	<= 2.5 e-	2.5 e-
linearity (1-100 ke-)	1%	0.2-0.4%
full well	>150 ke-	> 300 ke-
PSF @500/700nm	1 / 0.6 px	0.75 / 0.6 px
λλ	465-930 nm	300-1000 nm



Benefit of AR graded (1)

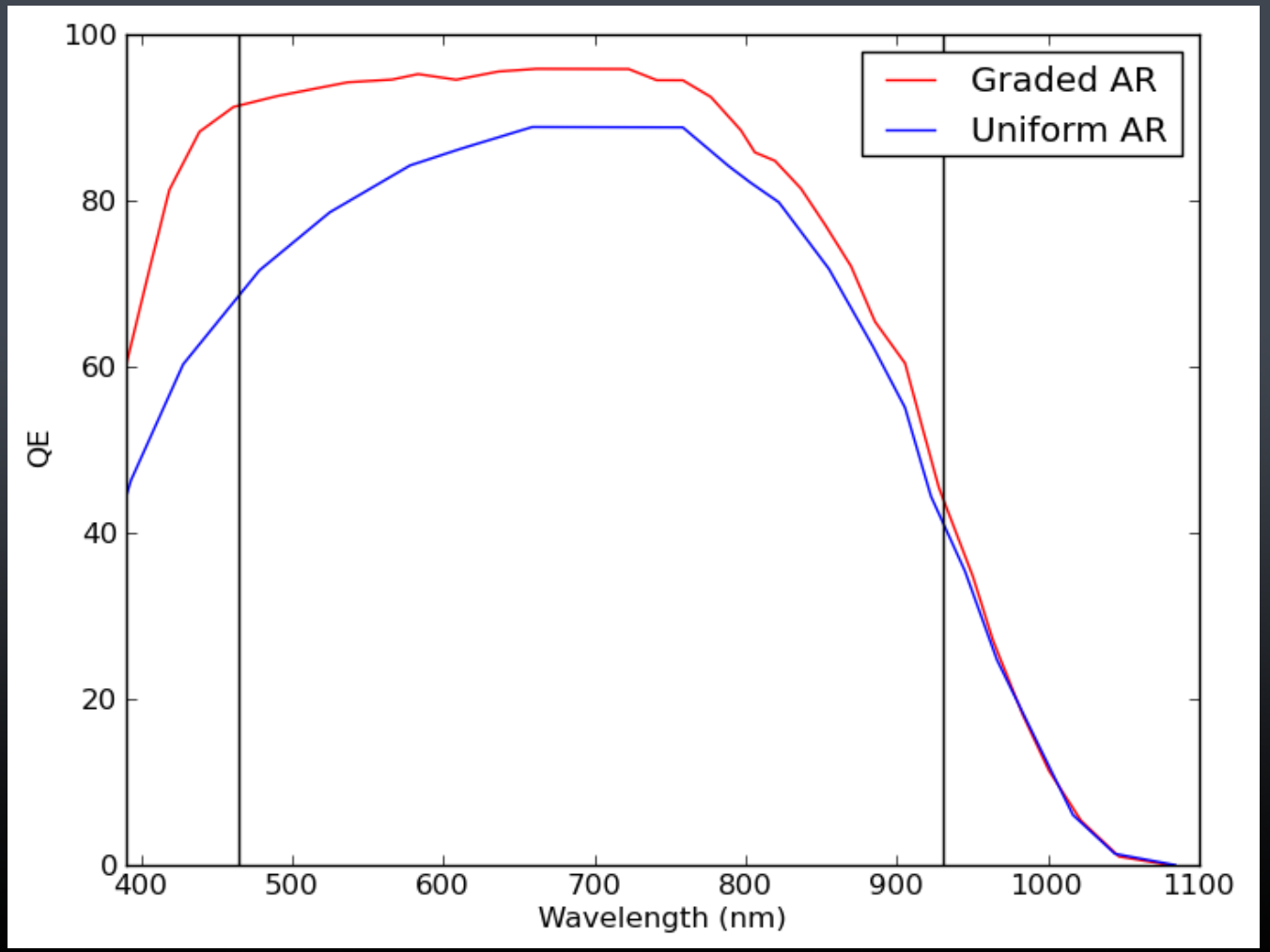




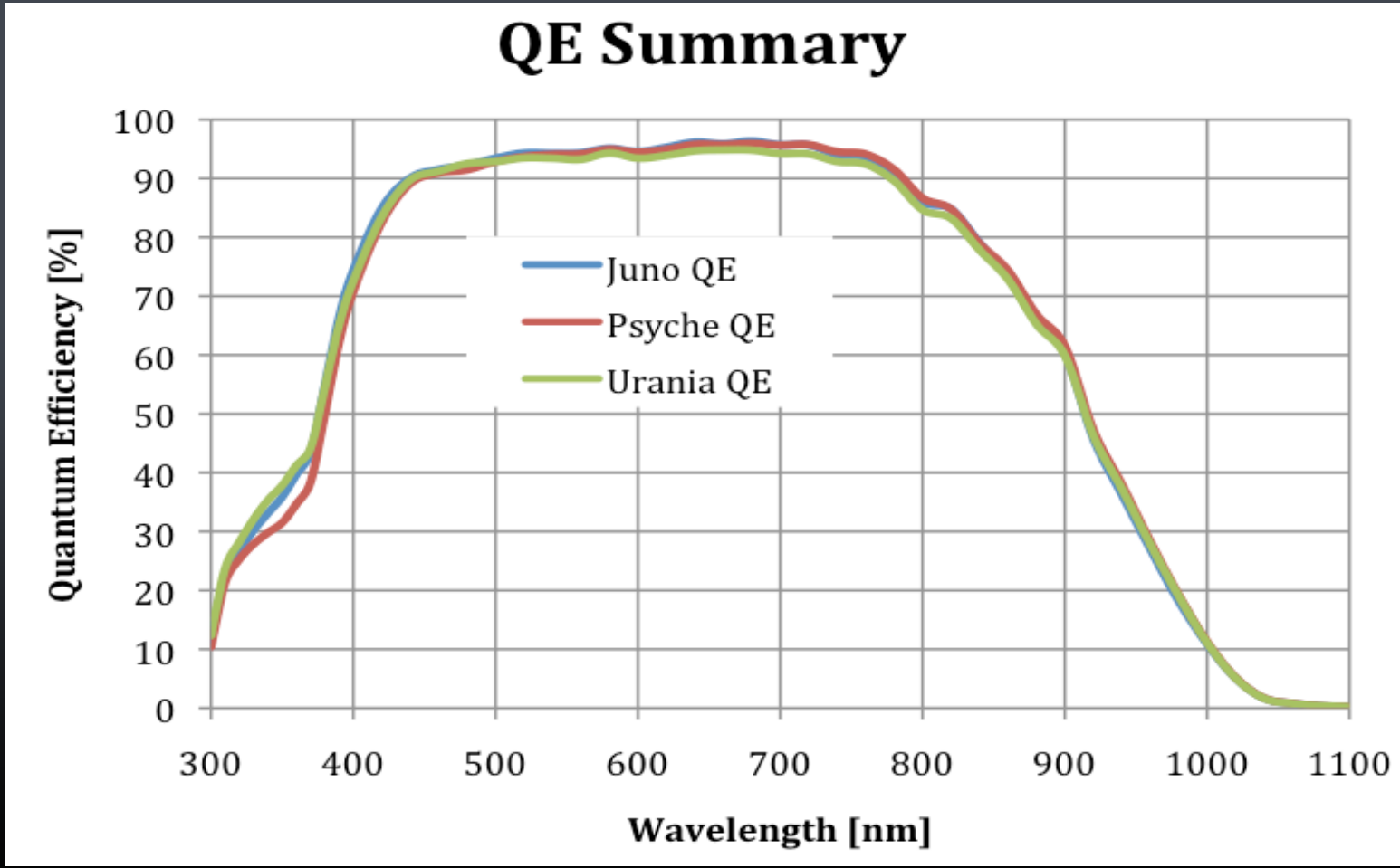
Flat Field 475 nm

Flat Field 900 nm

Benefit of AR graded (2)



High uniformity



CFC & 6 slots NGC @ ESO

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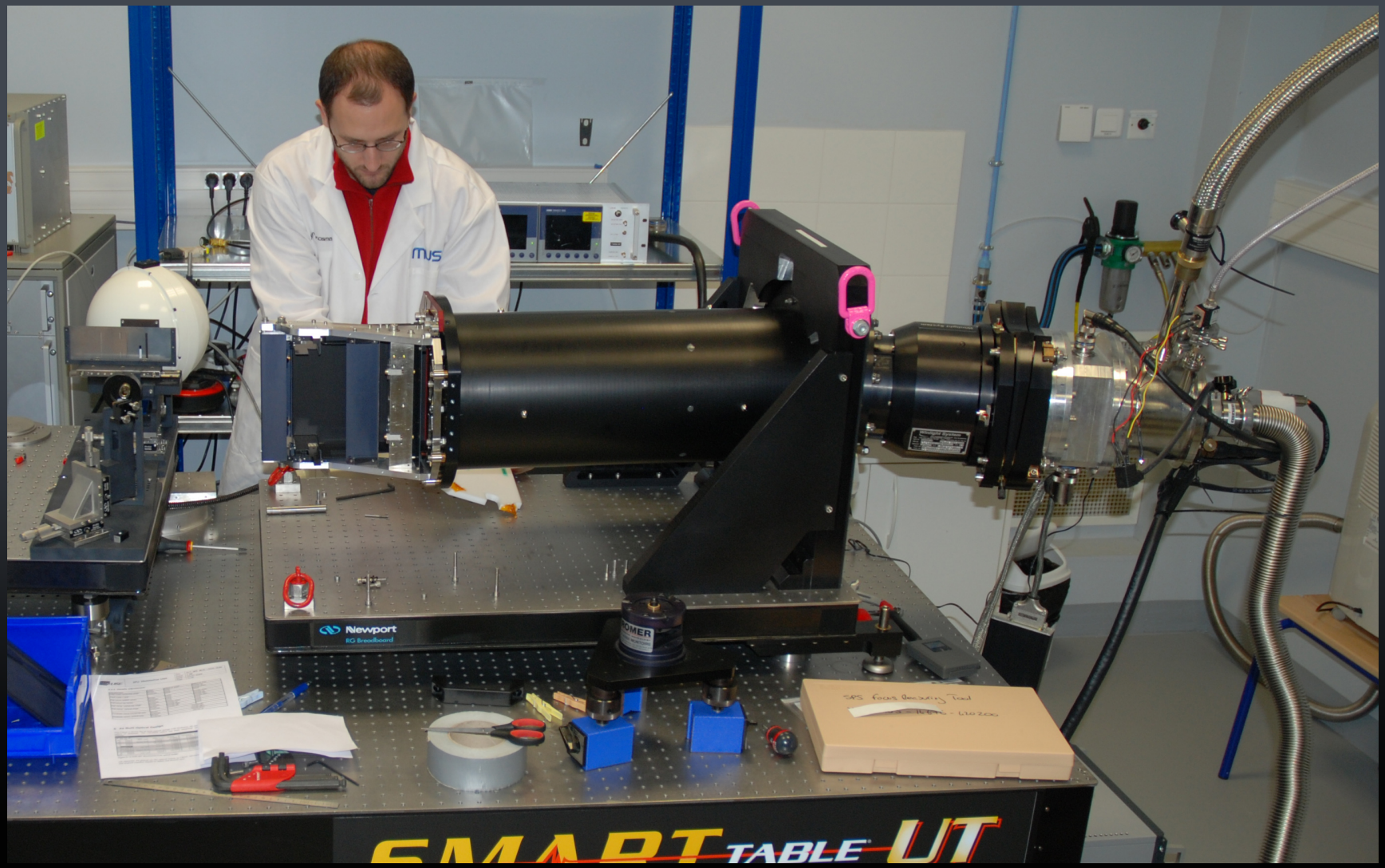
Detector Vessel series status

- 25 DV produced at ESO
- 25 DV to be validated at AIP
- 23 DV validated at AIP
- 23 DV delivered to CRAL
- 20 DV integrated on an IFU

Achieved performance I

Requirement Nr.	Parameter	Required value	Results	Comment
IDS-Rq 5	Read-out noise	< 3 e- RMS	2.11 avg. 2.32 max. 1.91 min.	Exposure mode 5
IDS-Rq 7	Read-out time (24 detectors)	< 1 min	45s	Exposure mode 5 For science exposures; MIA: with 6 detectors only
IDS-Rq 8	Read-out time (24 detectors)	< 10 sec	9.8s	Exposure mode 9 With reduced performance; initially with 6 detectors only

Integral Field Unit #1



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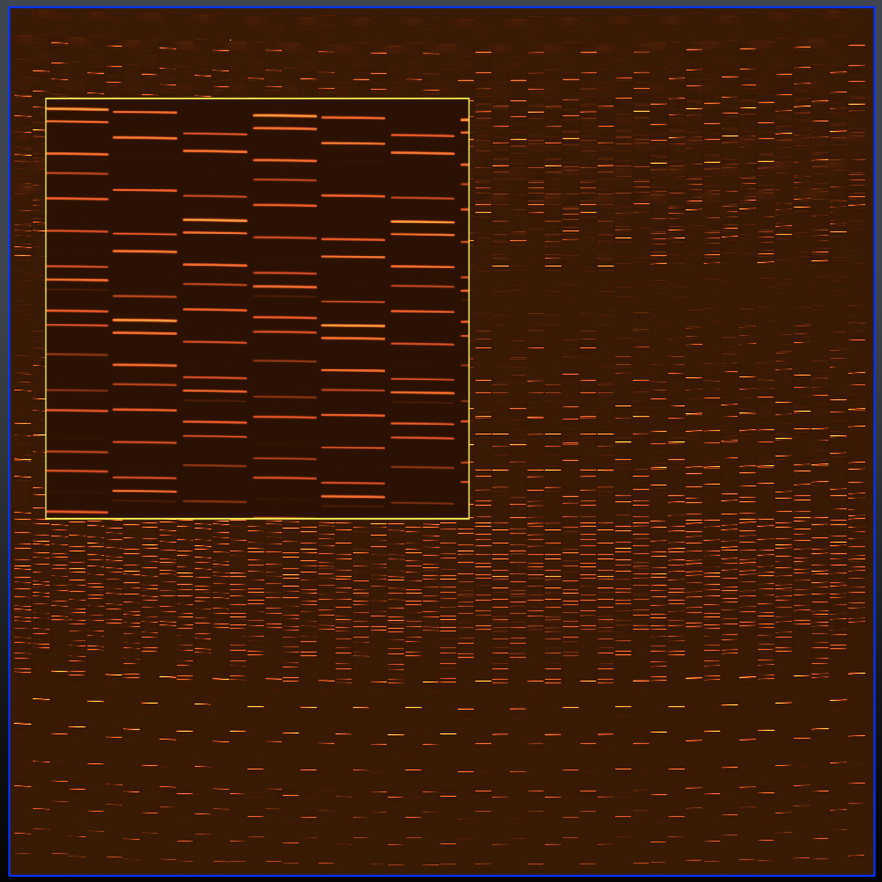
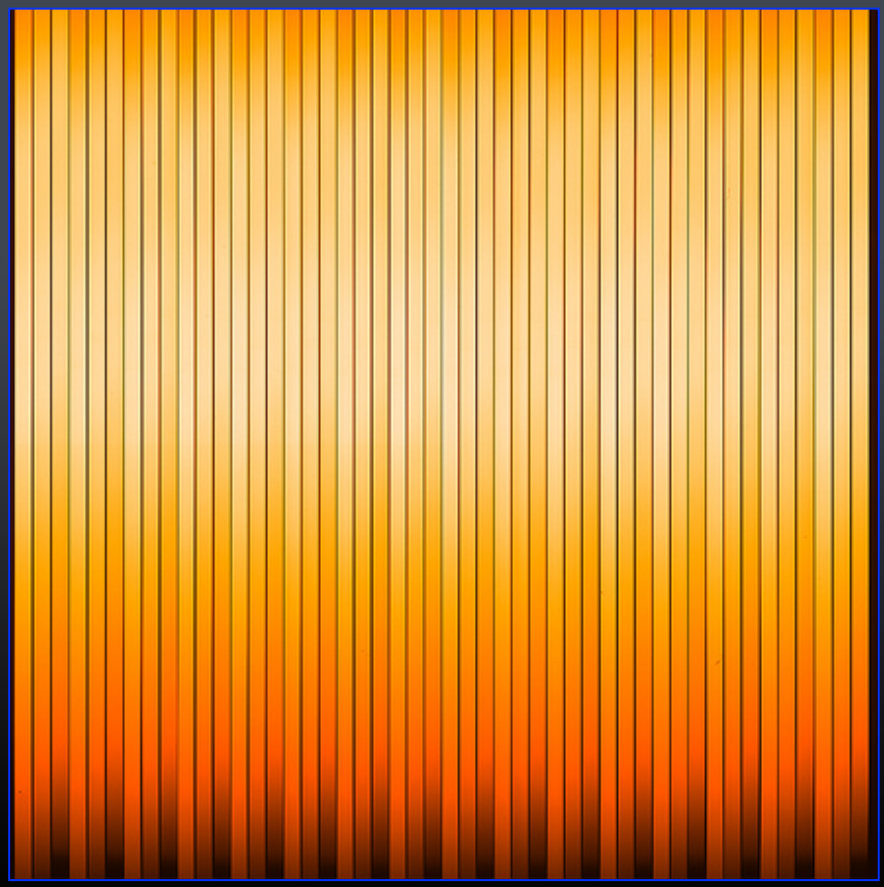
IFU technical first light

January 2010 at CRAL



HgCd + Ne + Xe arc

Continuum



3750 spectra, only 1/24 !

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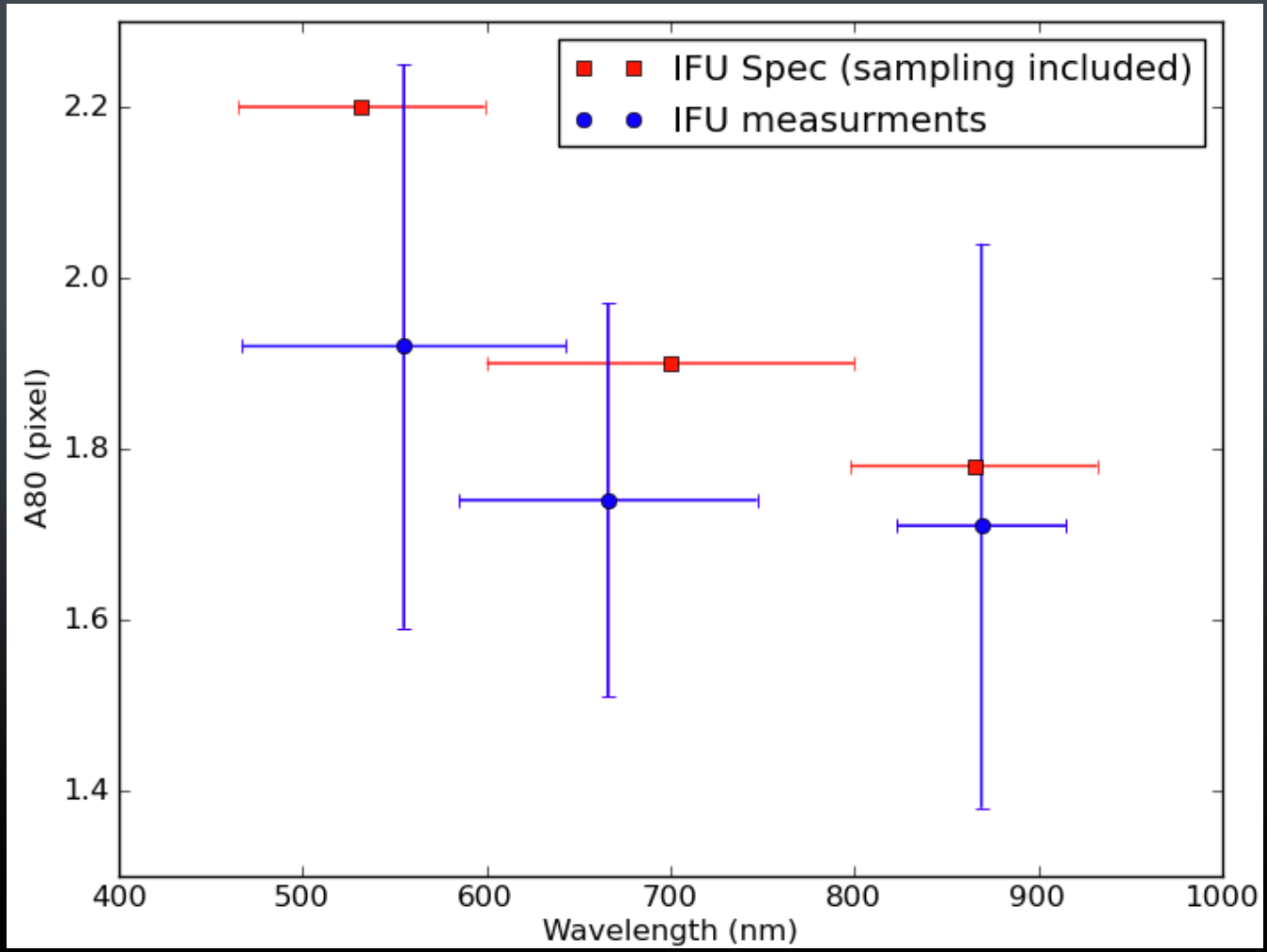
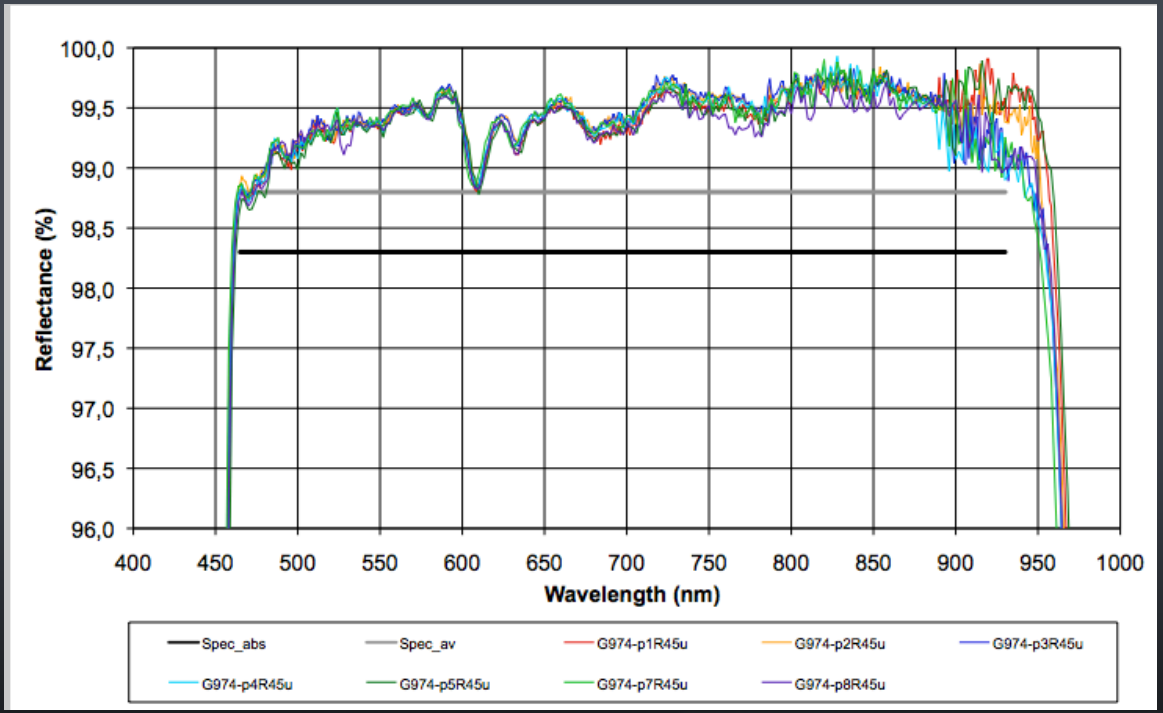
IFU #1 Image quality

FWHM = 1.5 (Blue) - 1.3 (Red) pixels

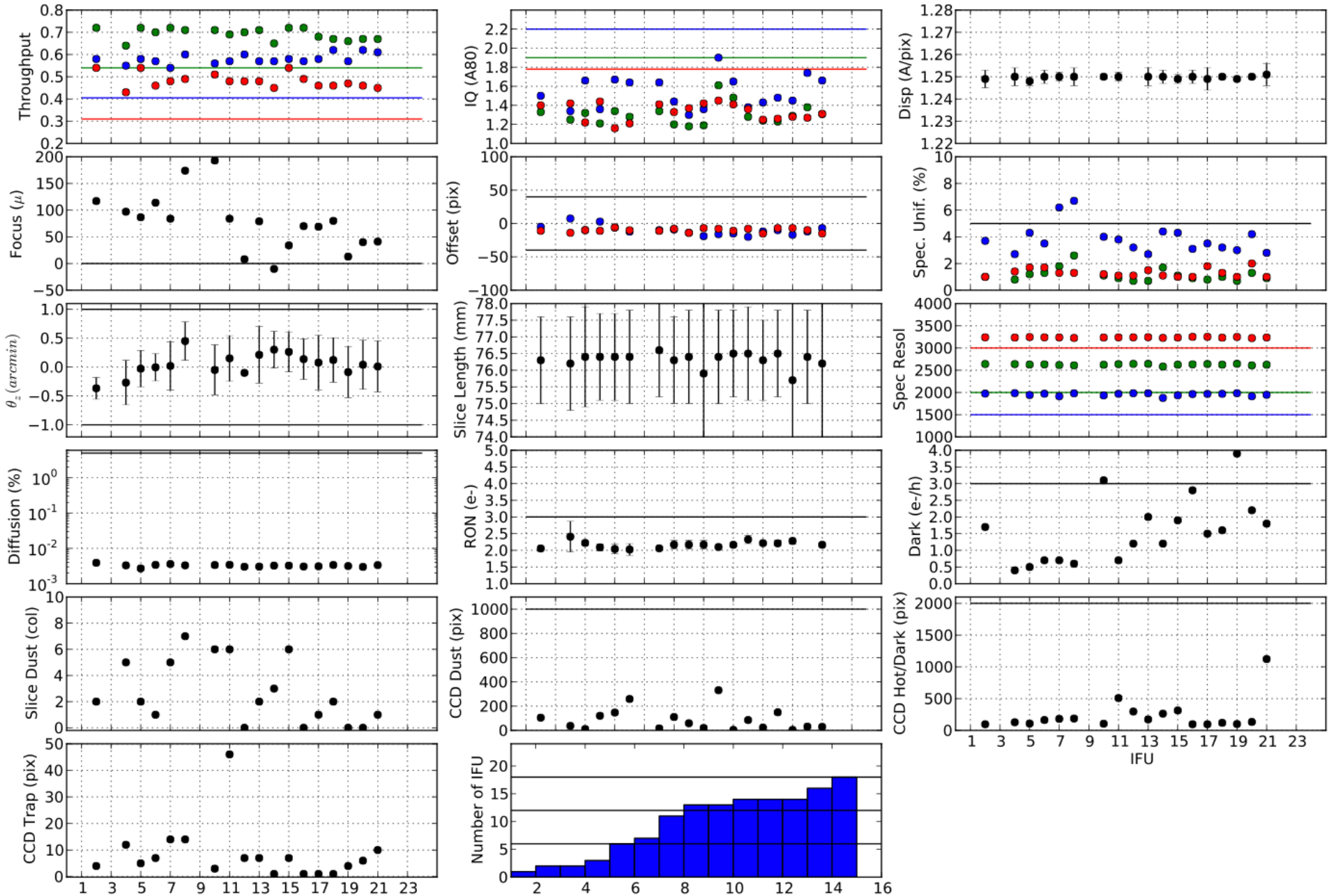


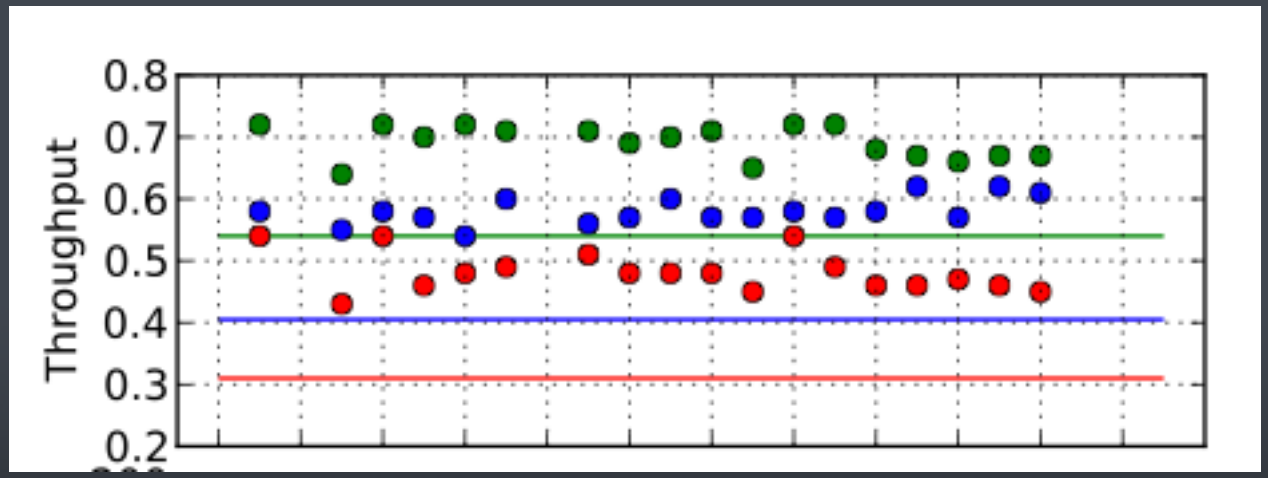
New coatings

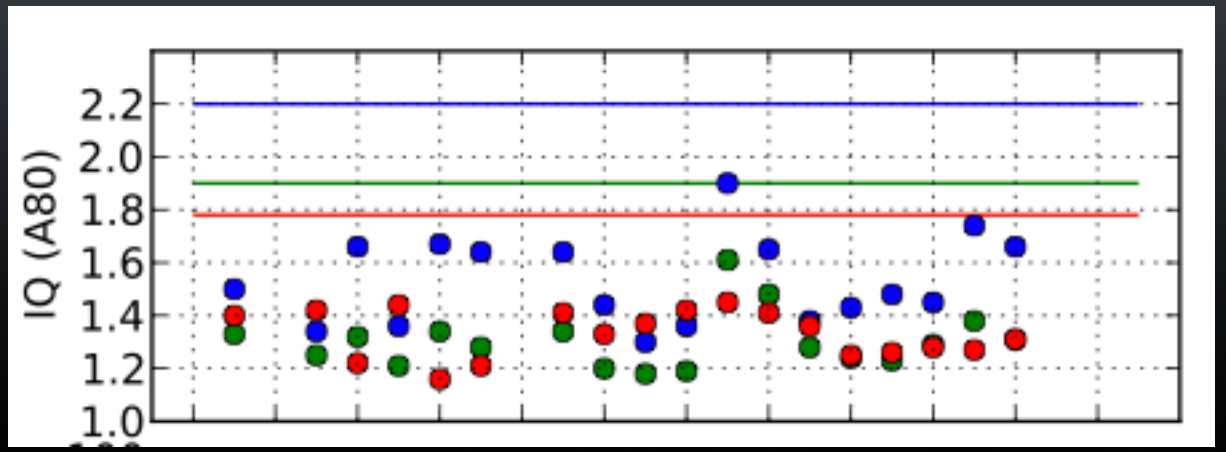
- Mirrors
  - Dielectric coating (80 layers)
  - Enhanced silver for the slicer
- New AR coating for the spectrograph



Optic Balzers (MSO Jena)


Throughput
IQ (A80)
Disp (A/pix)
Focus (μ)
Offset (pix)
Spec. Unif. (%)
$\theta_z (arcmin)$
Slice Length (mm)
Spec Resol
Diffusion (%)
RON (e-)
Dark (e-/h)
Slice Dust (col)
CCD Dust (pix)
CCD Hot/Dark (pix)
CCD Trap (pix)
Number of IFU
IFU


Throughput
0.8
0.7
0.6
0.5
0.4
0.3
0.2


IQ (A80)
2.2
2.0
1.8
1.6
1.4
1.2
1.0

IFUs Performance (18/24)

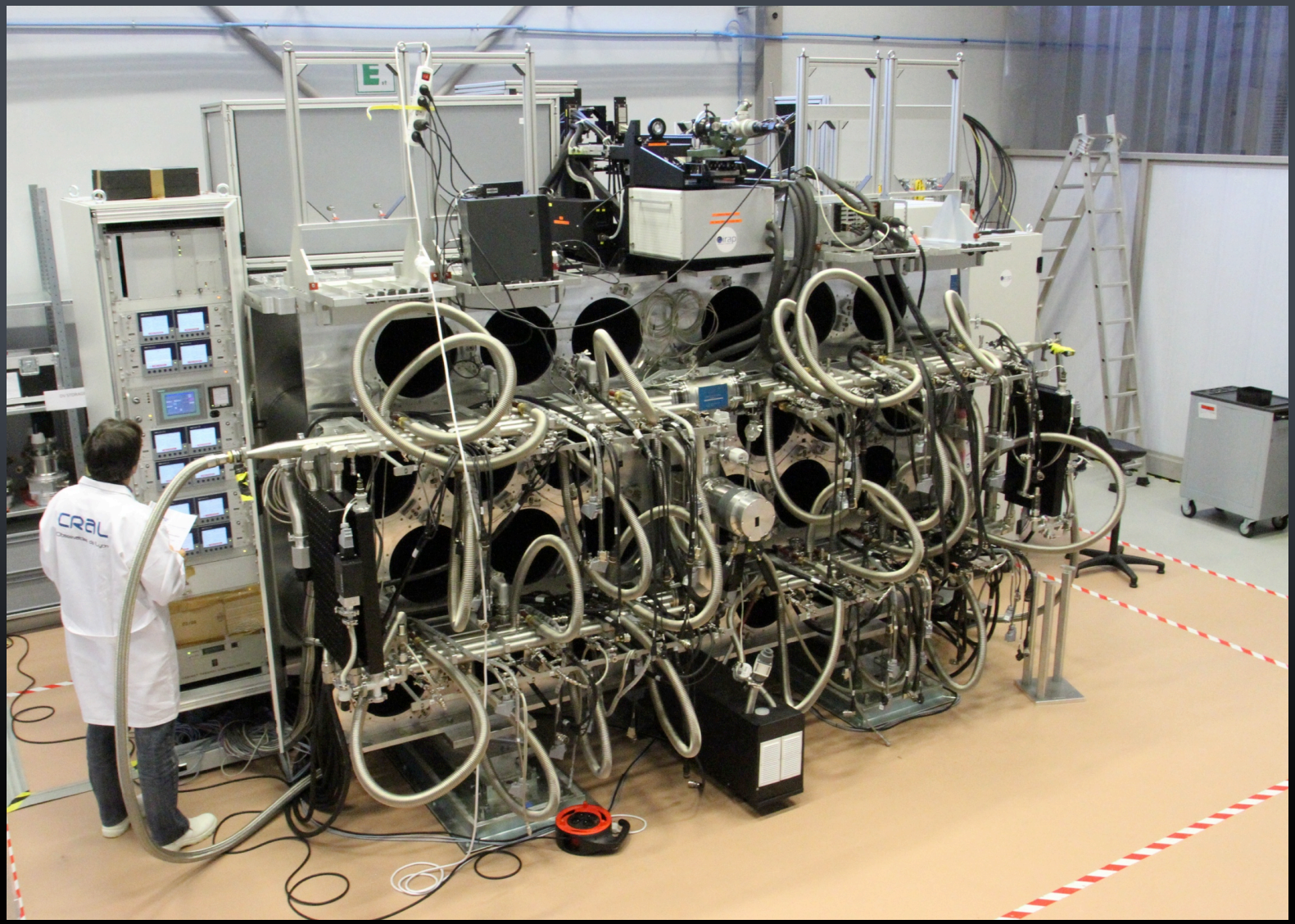
Throughput

Band (nm)	Spec	Measured	Gain
480-580	0.405	0.58±0.02	+43%
610-800	0.540	0.68±0.02	+26%
800-930	0.310	0.47±0.02	+51%

Image Quality (A80)

Band (nm)	Spec	Measured	Gain
480-580	2.20	1.53±0.16	+30%
610-800	1.90	1.30±0.10	+31%
800-930	1.74	1.33±0.09	+23%

December 2011



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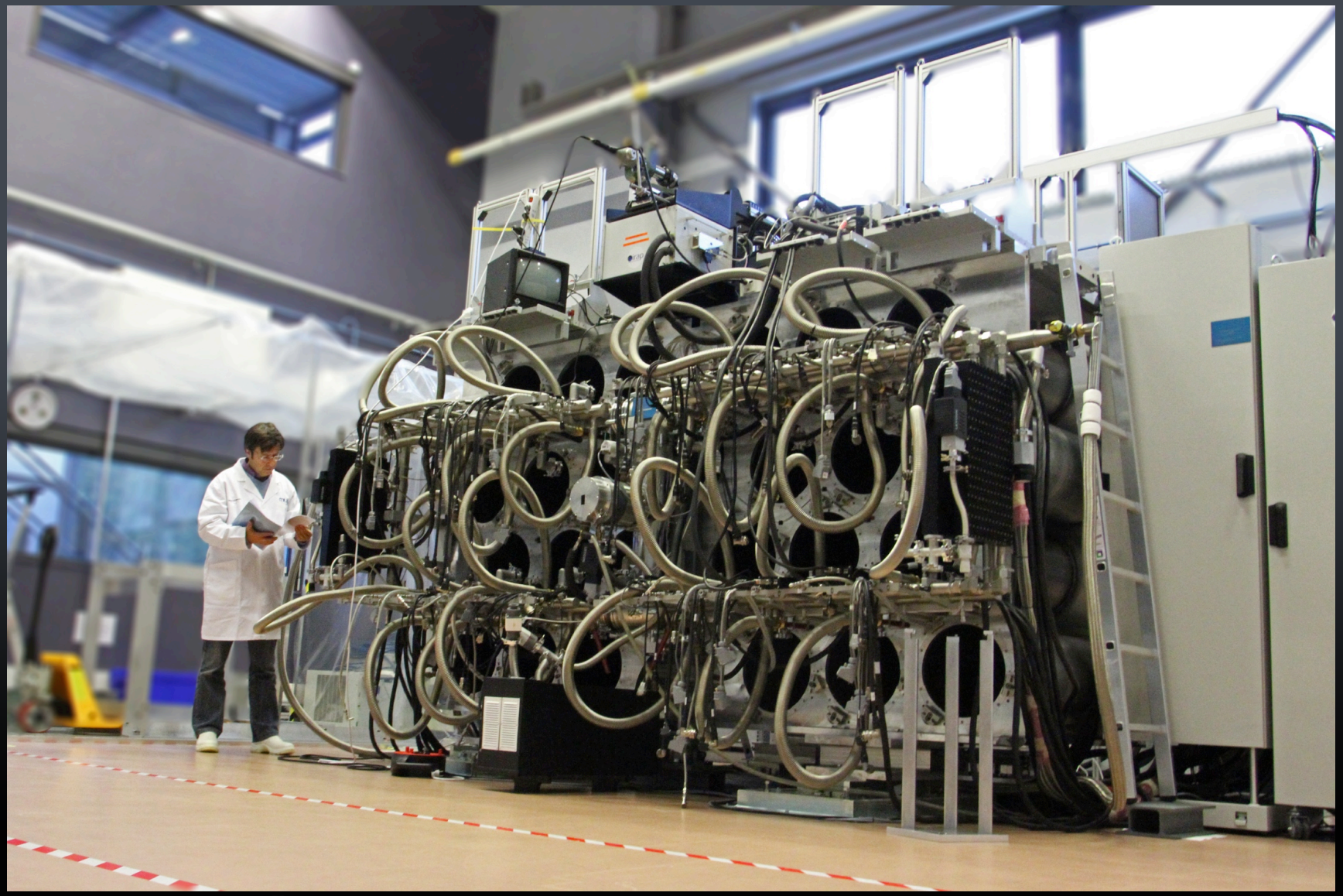
December 2011



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December 2011

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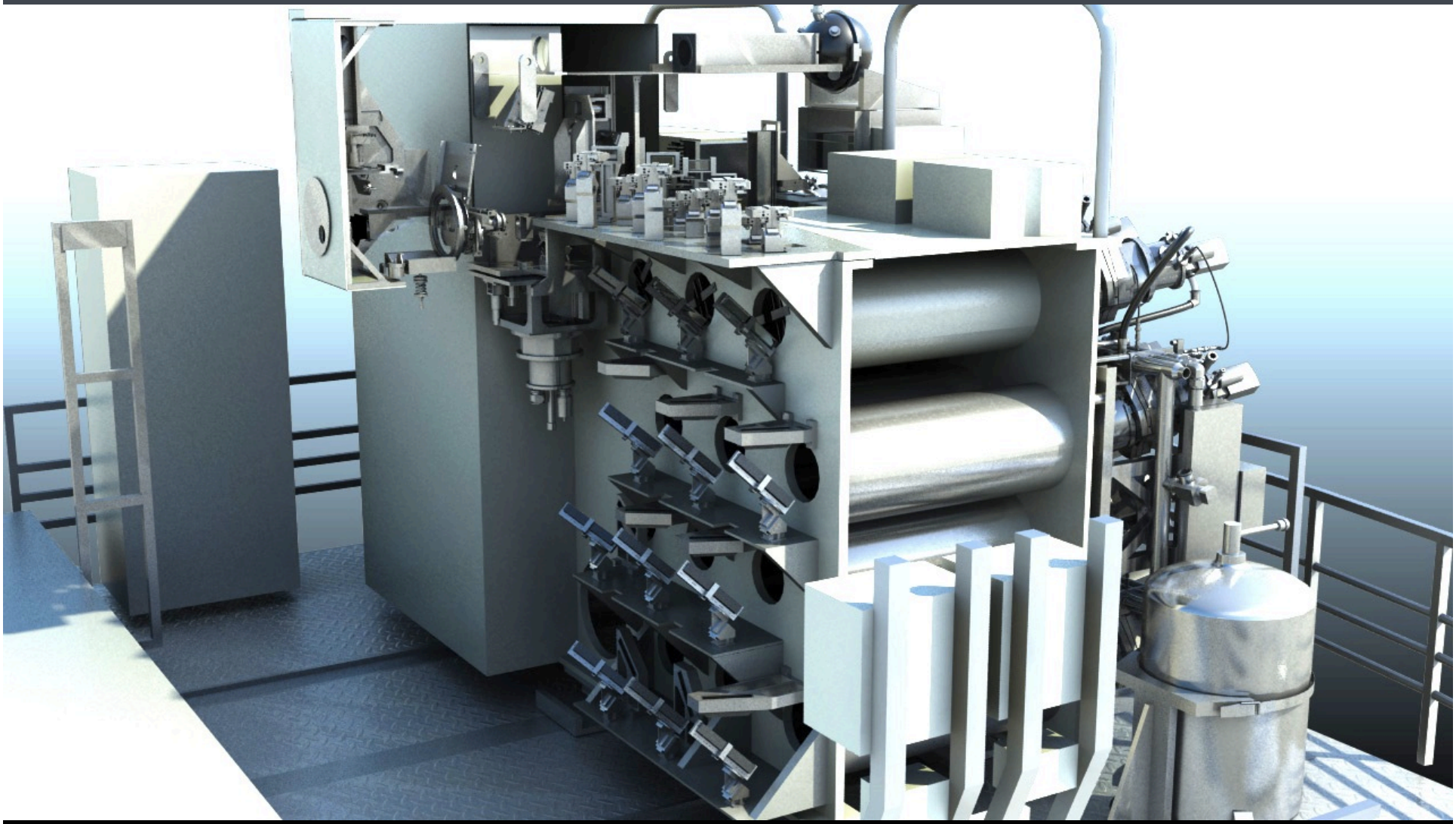
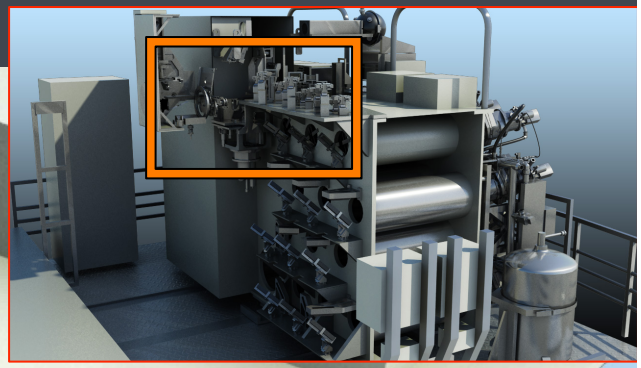
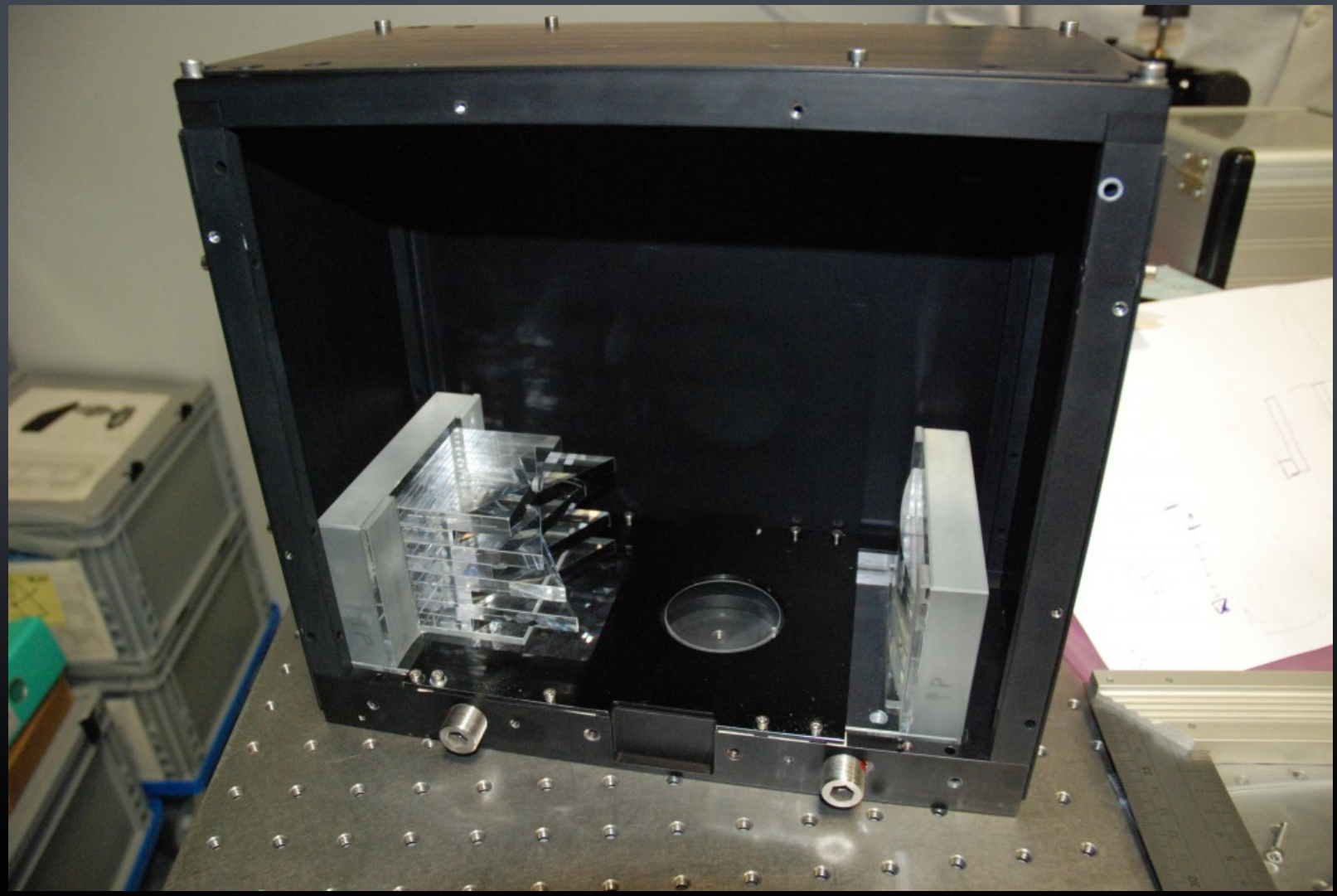
Front vue



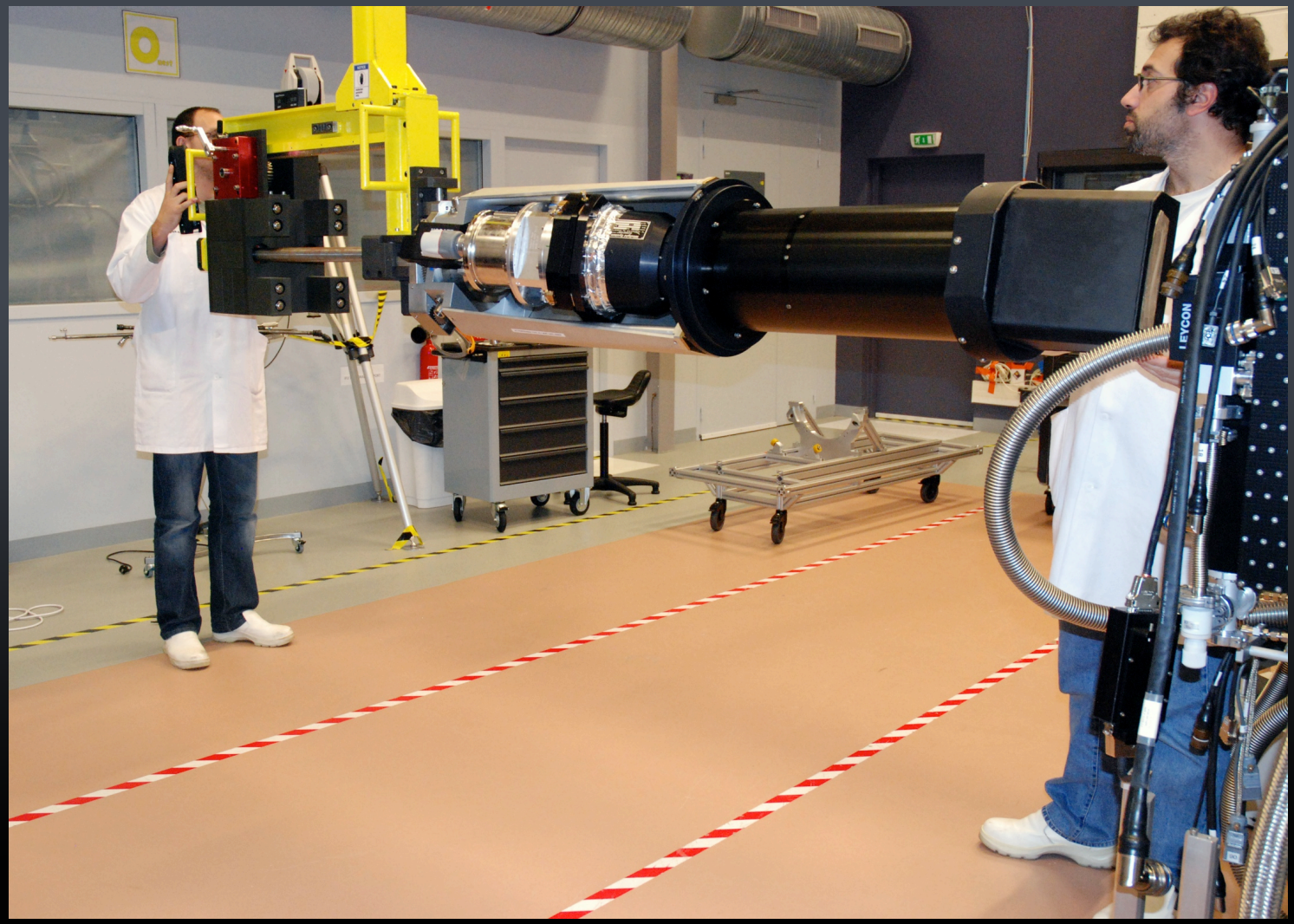
Relay optics



November 2011



December 2011



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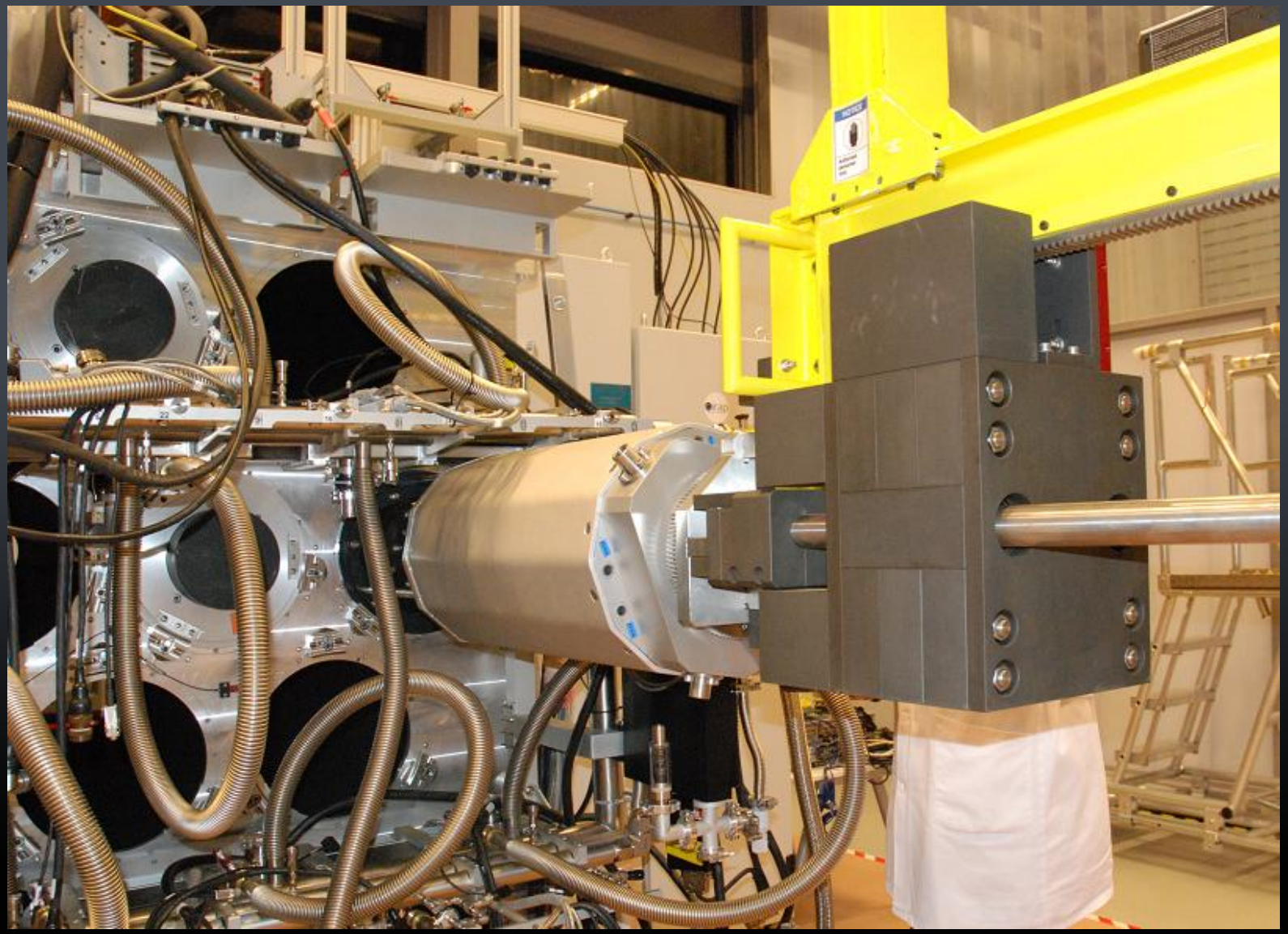
December 2011



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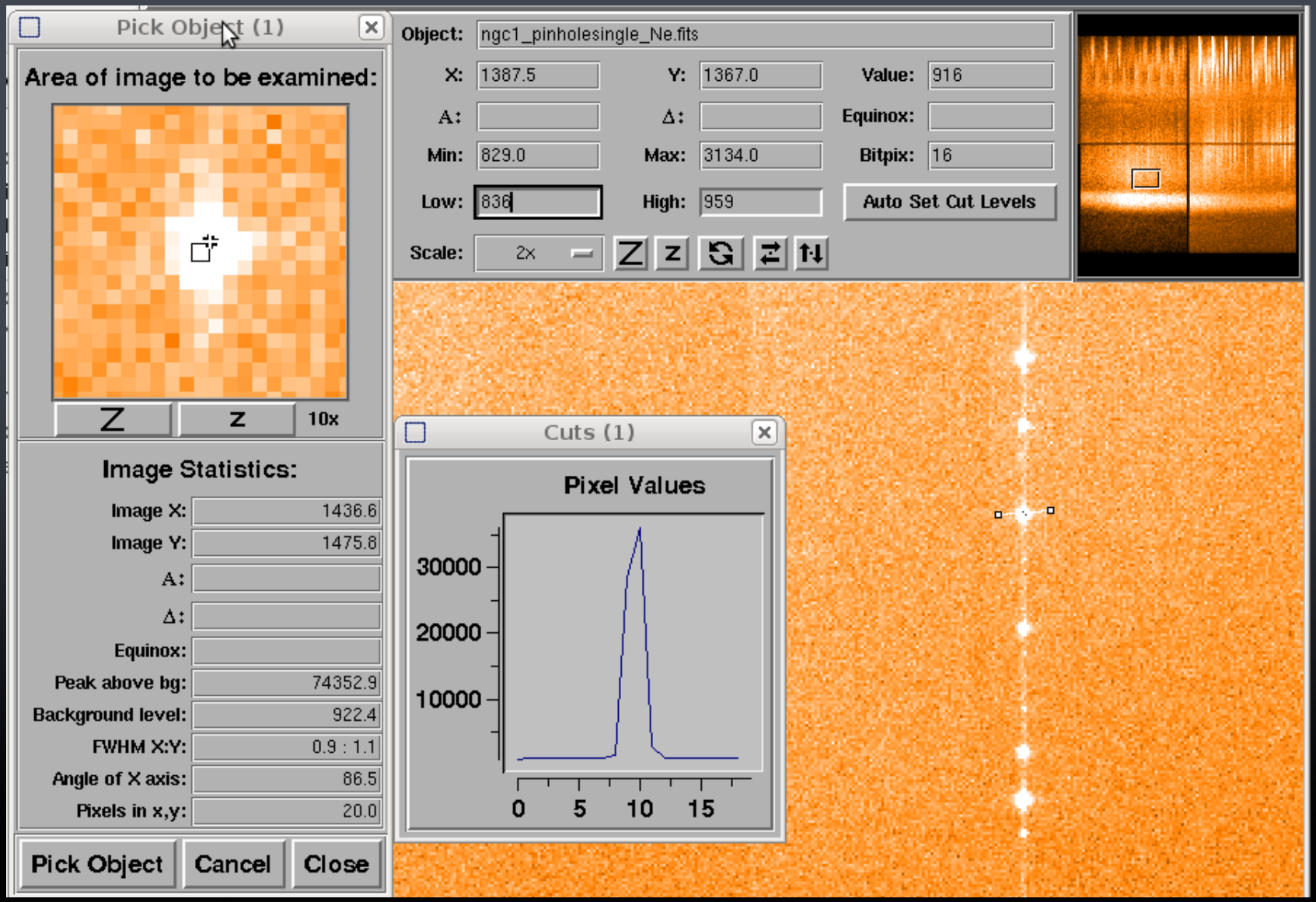
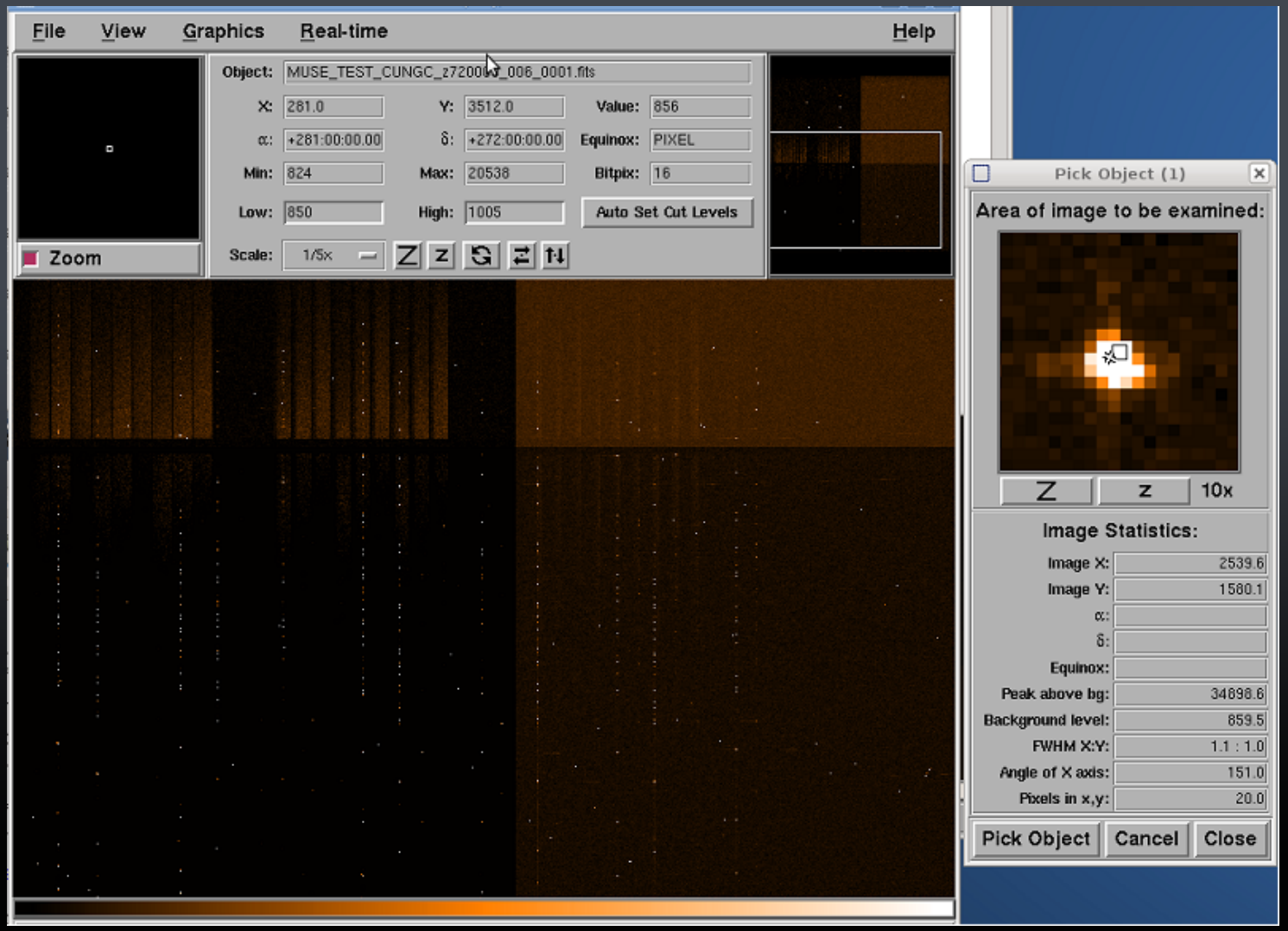
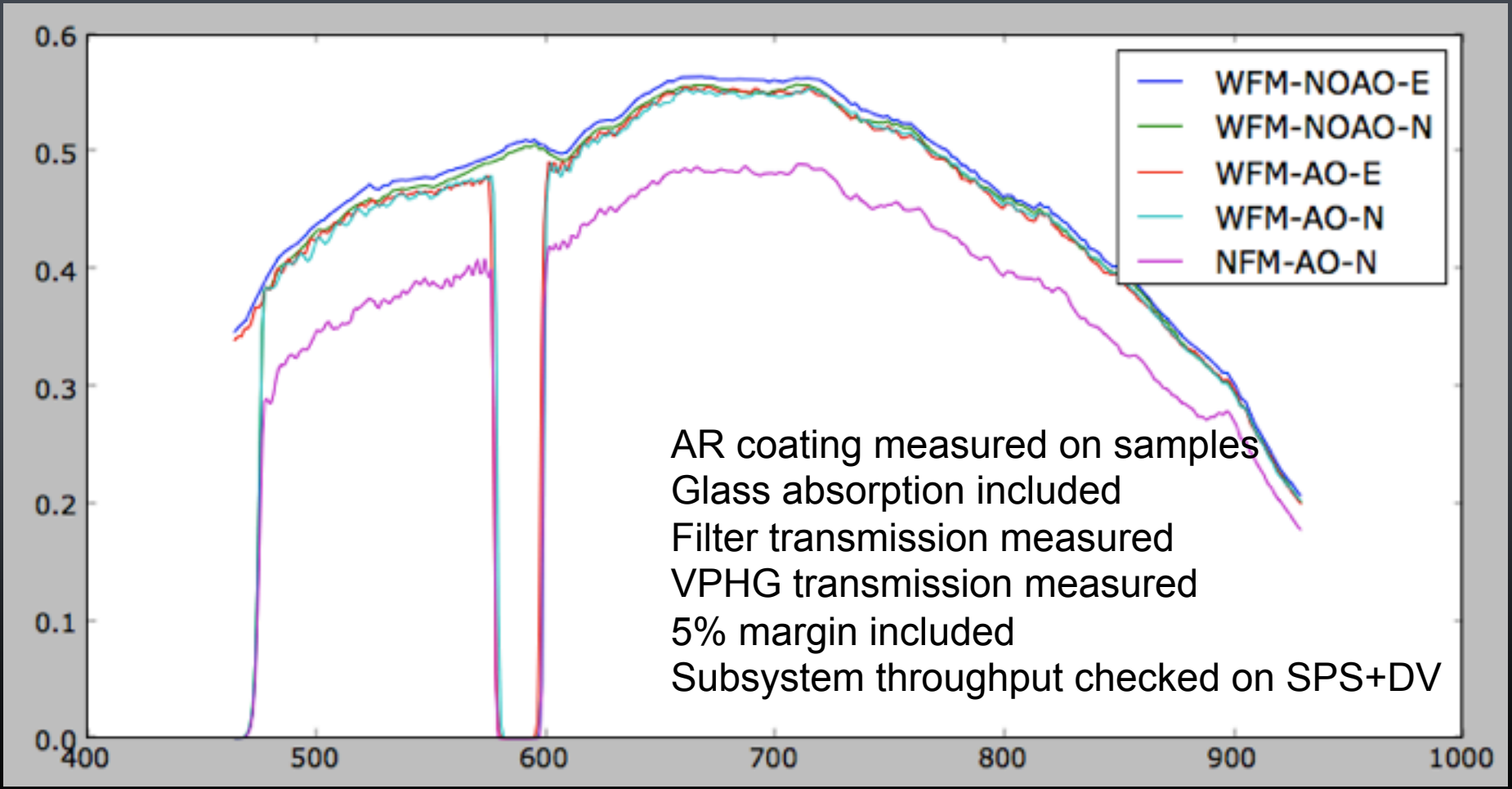
December 2011



January 2012

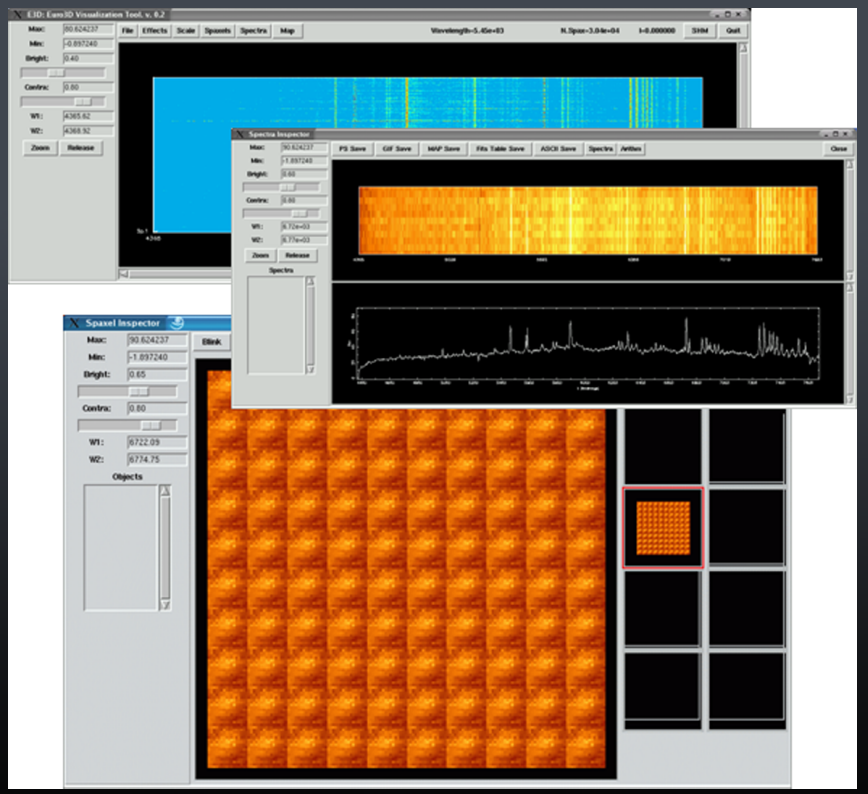


Instrument Throughput



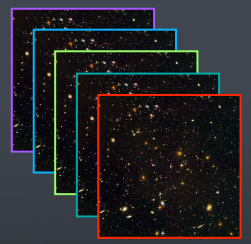
The challenge of data reduction and data analysis

- Volume
  - One exposure is 4.10^8 pixels
  - One deep-field is 80 exposures
- Complexity
  - Ex: Optimal summation of 80 exposures
  - Ex: PSF evolution with field, wavelength, time (a 4D problem)
  - Ex: Spectra extraction in dense stellar environment
  - Ex: Blind search of deep fields



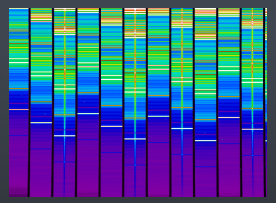
End to End Modelling

Astro. Scene Simulations

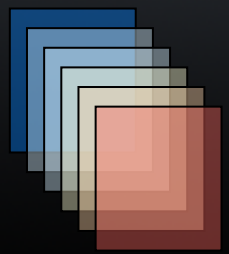


Atmos. & AO simulations

Instrument Numerical Model



Validation



Data Analysis Software Tools

Data Reduction System

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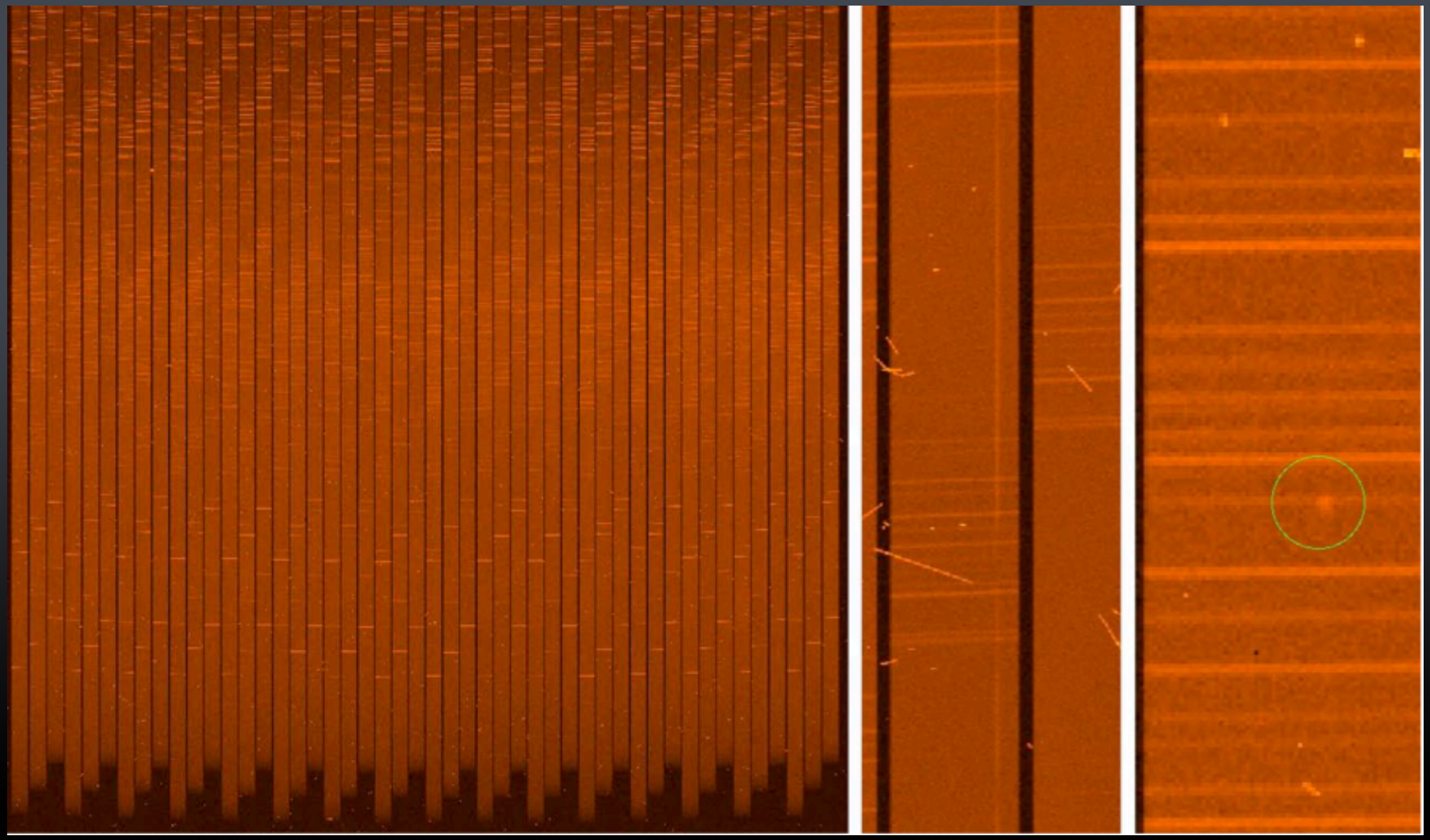
Example of INM exposure



Conclusion

Performance Type	Milestone	Indicators WFM Lim I Flux 80h WFM Spatial Resolution NFM Strehl Ratio @ 650 nm	Margins Throughput WFM IQ
Dreamed	Phase A	2.7-4.2 10^{-19} erg.s^{-1}.cm^{-2} 0.3-0.5 arcsec 5-10%	
Designed	PDR	2.6-4.2 10^{-19} erg.s^{-1}.cm^{-2} 0.33-0.52 arcsec 4-9%	14-17% 24-40%
	FDR	2.4-3.9 10^{-19} erg.s^{-1}.cm^{-2} 0.3-0.5 arcsec 11%	17-4-8% 41-24%
Build	PAE		43-26-51% [IFU] 30-31-23% [IFU]
Real	Comm.		