IFU Surveys –
the genesis of instrumentation

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Overview

The History of IFS:

- The Pioneers
- 2nd Generation IFS: Facility Instruments
- 3rd Generation IFS: high multiplex Instruments
- 4th Generation IFS: IFU-MOS
- The Future: IFS at ELTs

I. The Pioneers:

- Scanning Slit
- Imaging Fabry-Perot

- Fiber Bundle
- Lensarray / Micropupil (TIGER)
- Slicer

Fiber Bundle IFU

1980

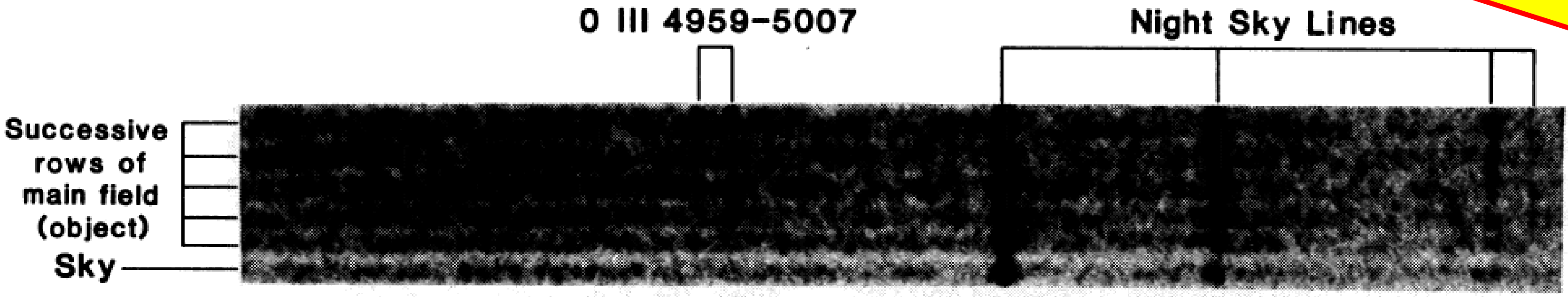
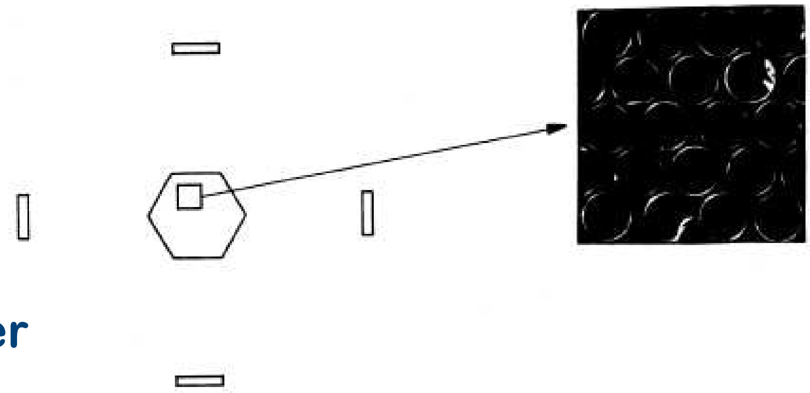


FIG. 2—Part of a spectrum of 3C 120 nebulosity (regions A and B of Fig. 3). Exposure: 20 mn.

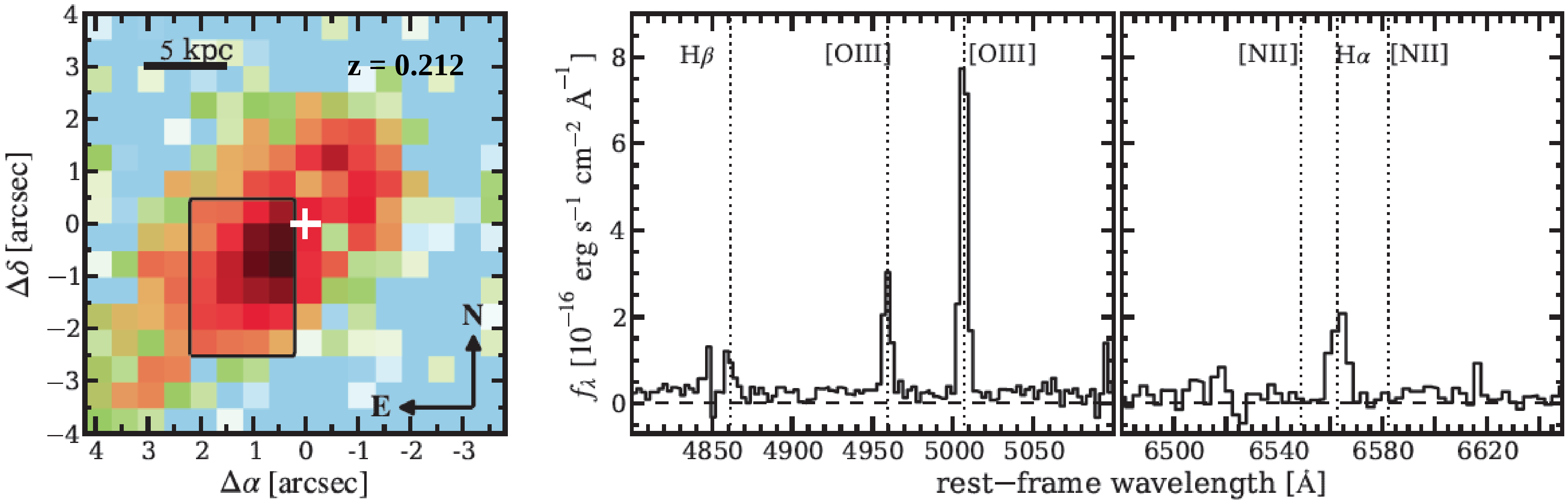
- Mauna Kea 2.2m Telescope
- hexagonal fiber bundle, 169 fibers
- 36 sky fibers (in 4 blocks)
- fill-factor ~ 75 %
- total of 205 fibers, 100 μm core diameter
- fiber diameter = 0.42 "on the sky
- photographic image-tube spectrograph (ill-adapted)



Vanderriest, C. (1980),
" Fiber-Optics Dissector for Spectroscopy of Nebulosities around Quasars and similar Objects"
PASP 92, 858

for comparison: PMAS LARR (2011)

Bernd Husemann et al.: The low-metallicity QSO HE 2158−0107



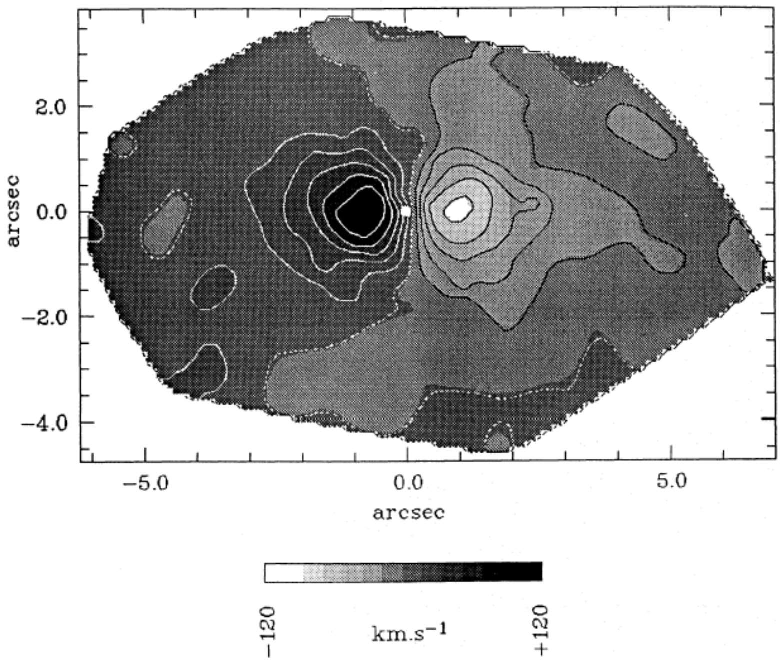
Husemann et al. 2011, A&A 535, 72

Lensarray / Micropupil "TIGER"

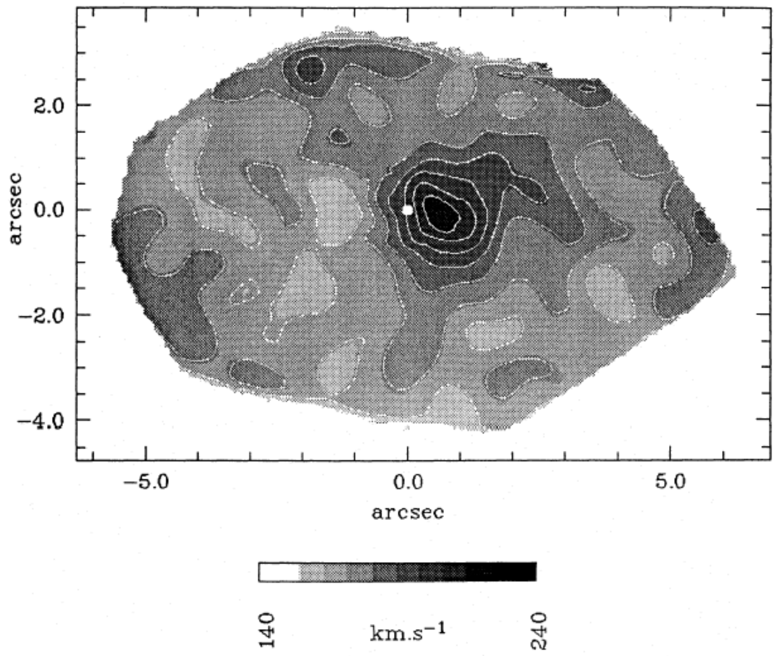
- CFHT 3.6m
- 572 element lensarray, hexagonal lenslets
- dedicated spectrograph f/8.2 collimator, f/5.8 camera
- CFHT SAIC CCD Detector 1024 x 1024 pixels
- scale / FOV: 0.39 "/ lens, 7 "x 7 "
  0.61 "/ lens, 10 "x 10 "
- spectral resolution: R = 1400, coverage 540 Å
  R = 370, coverage 2400 Å

Bacon, R. et al. (1995)," *3D spectrography at high spatial resolution. I. Concept and realisation of the integral field spectrograph TIGER "*
A&A Suppl. 113, 347

Lensarray / Micropupil "TIGER"



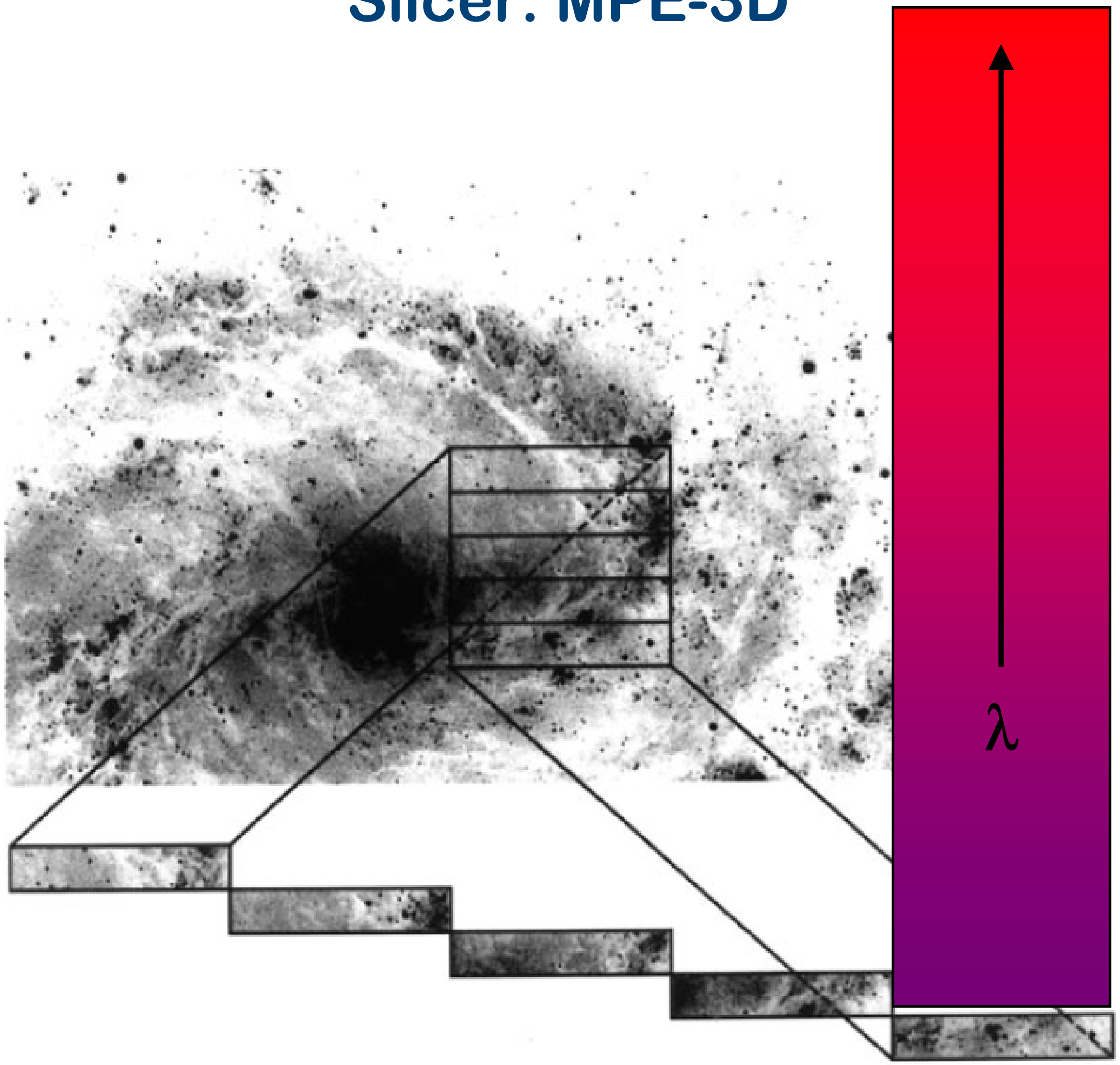
stellar velocity field



velocity dispersion

Bacon, R., Emsellem, E., Monnet, G., Nieto, J.L. (1994), " ***Sub-arcsecond 2D photometry and spectrography of the nucleus of M31: the supermassive black hole revisited."***
A&A 281, 691

Slicer: MPE-3D



Weitzel, L. et al. (1996), "*3D : the next generation near-infrared imaging spectrometer*" A&A Suppl. 119, 531

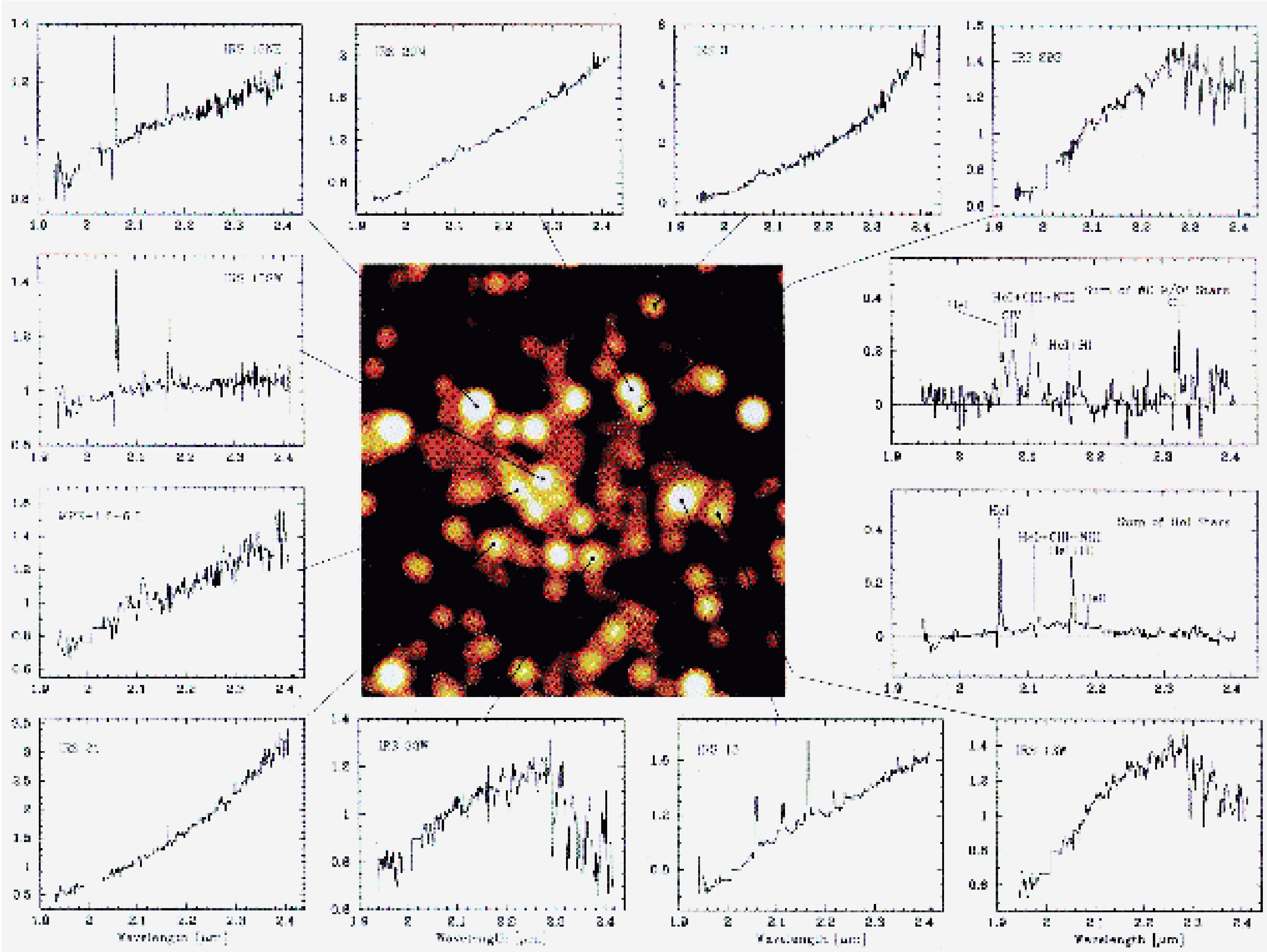
Slicer: MPE-3D

- travelling instrument, used at CAHA 3.5m, ESO-MPG 2.2m, AAT
- image slicer IFU (16 mirrors)
- Rockwell HgCdTe Detector 256 x 256 pixels
- NIR operation in H and K bands
- spatial sampling 0.3 "or 0.5 ", 16 x 16 spaxels

H :	1.48 ... 1.78 μ	R = 1250
K :	1.94 ... 2.41 μ	R = 1100
K_{short}:	1.95 ... 2.18 μ	R = 2100
K_{long}:	2.17 ... 2.43 μ	R = 2100

Weitzel, L. et al. (1996), " *3D : the next generation near-infrared imaging spectrometer",* A&A Suppl. 119, 531

Slicer: MPE-3D



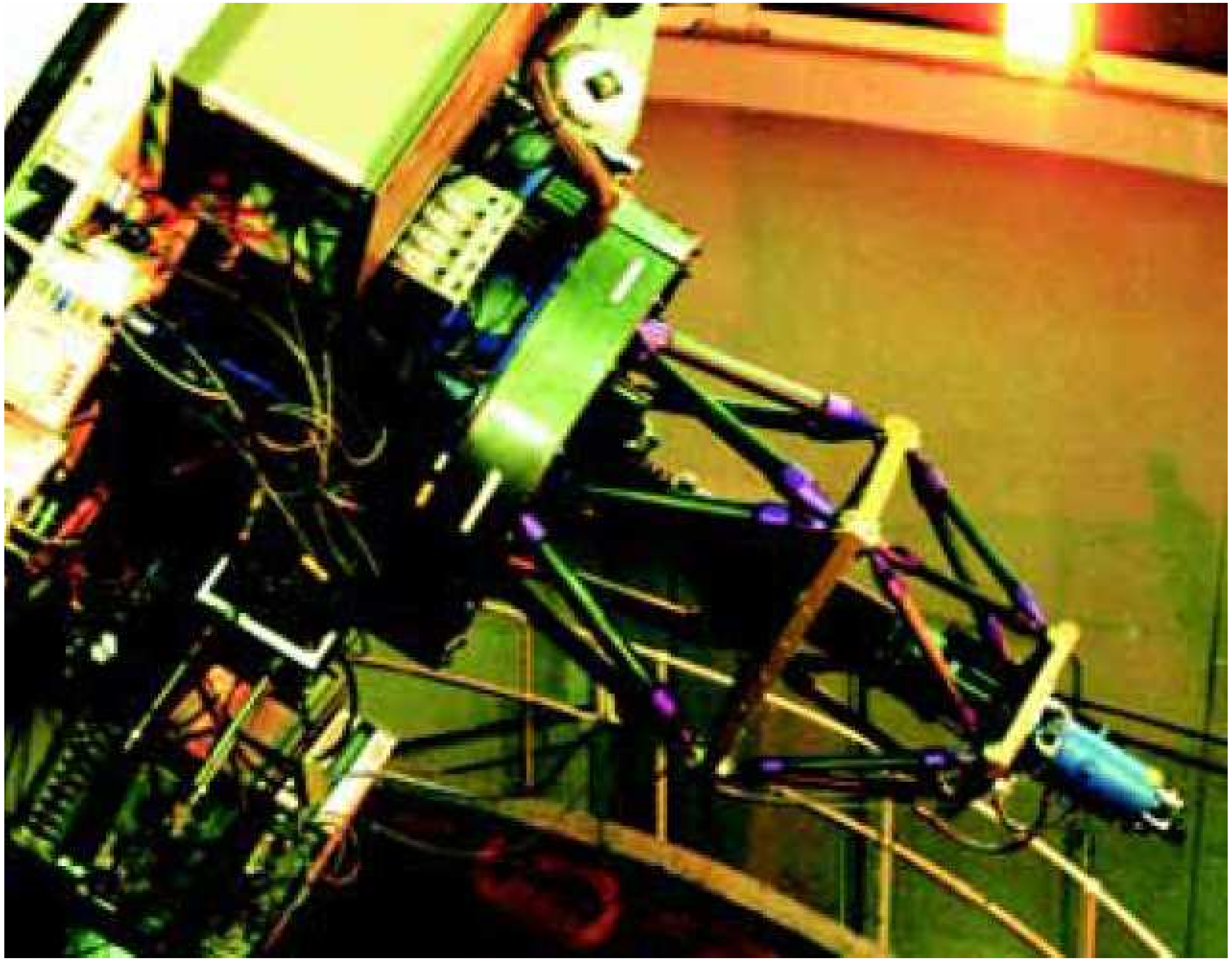
Krabbe, A. et al. (1995), "*The nuclear Cluster of the Milky Way: Star Formation and Velocity Dispersion in the central 0.5 parsec*", ApJ 447, L95

II. 2nd Generation IFS

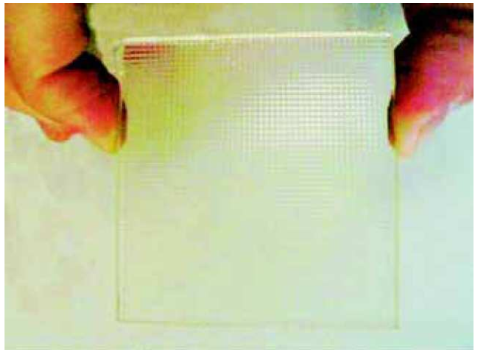
- **SAURON**
- **PMAS**

[SINFONI]

SAURON

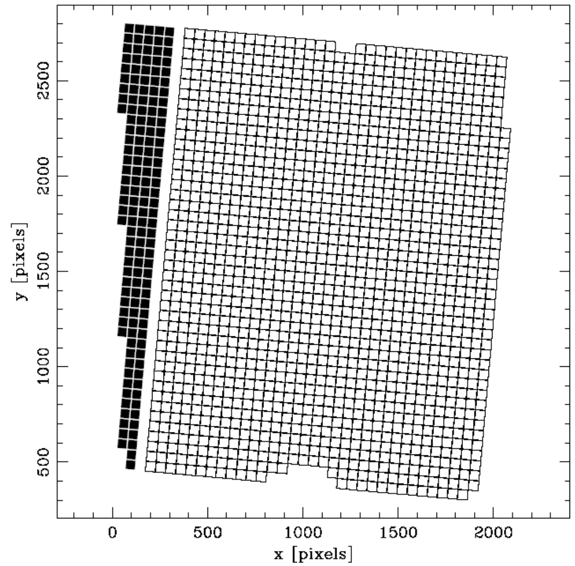


SAURON



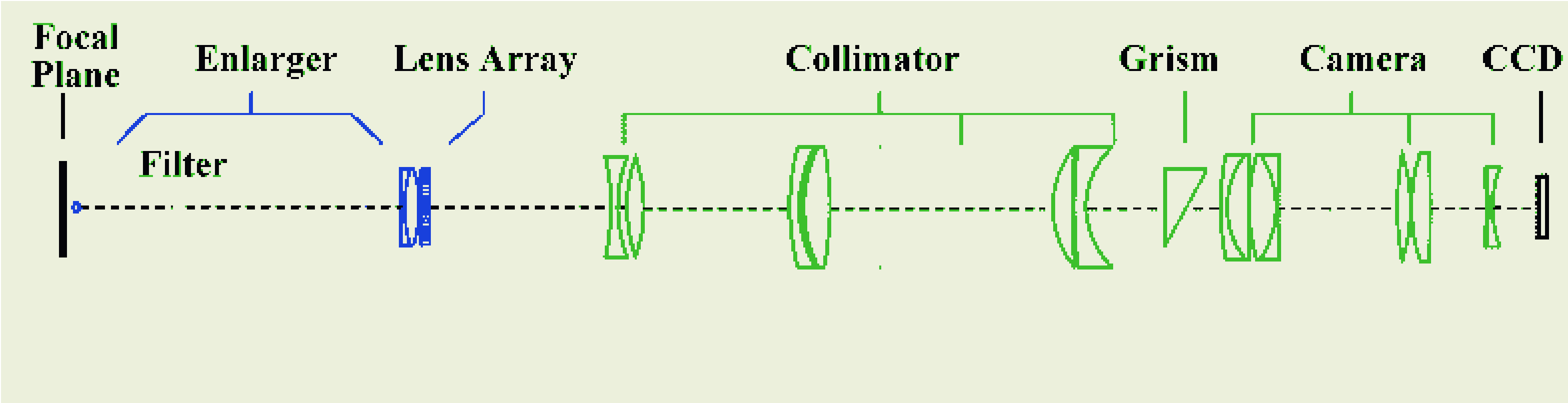
- WHT (4m), ORM La Palma (1999)
- focus station: Cassegrain
- IFU type: lensarray, square spaxels
- rectangular footprint
- fill factor ~ 100 %

	HR	LR
• spatial sampling	0.27 “	0.94 “
• FOV	9 “x11 “	33 “x41 “
• spectral Resolution	2.8 Å	3.6 Å



- dispersion 1.1 Å/pix
- coverage 4760 – 5400 Å (= 640 Å)

SAURON



Sauron Spectrograph Optical System

high efficiency: **35 % optics**
15 % total

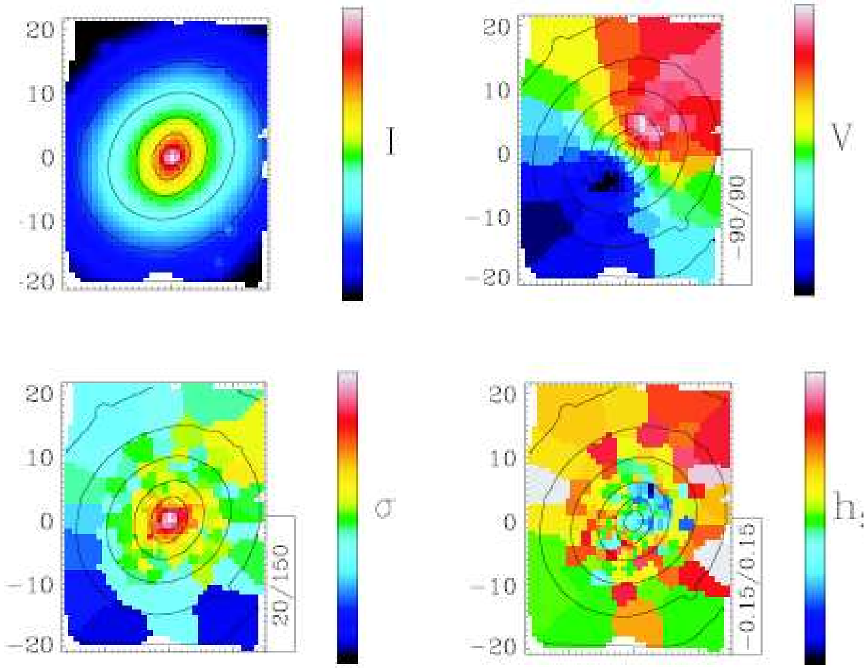
SAURON 2001 - 2006

Bacon et al. (2001)
The SAURON project - I. The panoramic integral-field spectrograph
MNRAS 326, 23

de Zeeuw et al. (2001)
The SAURON project - II. Sample and early results
MNRAS 329, 513

Emsellem et al. (2004)
The SAURON project - III. Integral-field absorption-line kinematics of 48 elliptical and lenticular galaxies
MNRAS 352, 721

Cappellari et al. (2006)
The SAURON project - IV. The mass-to-light ratio, the virial mass estimator and the Fundamental Plane of elliptical and lenticular galaxies
MNRAS 366, 1126

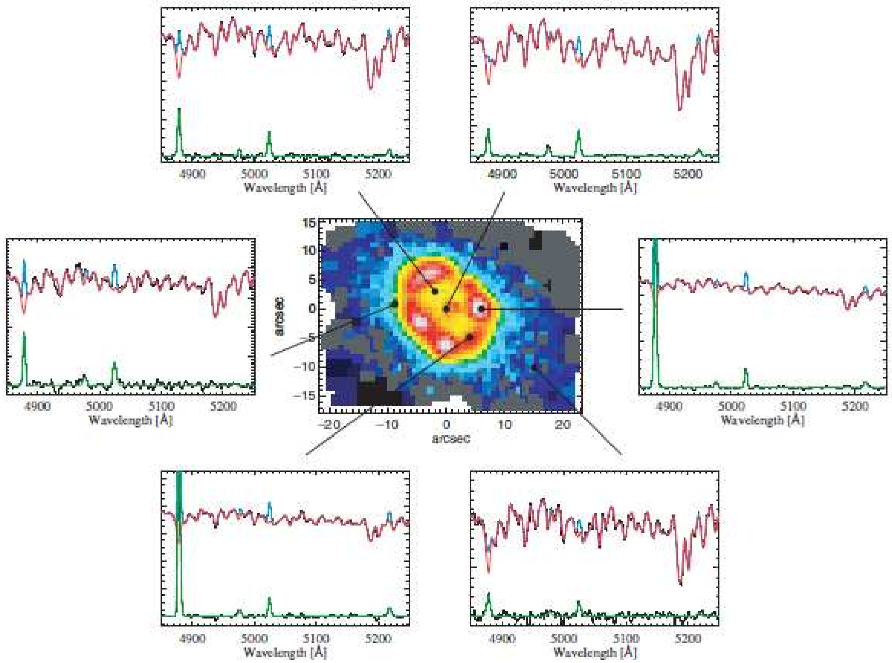


Sarzi et al. (2006)
The SAURON project - V. Integral-field emission-line kinematics of 48 elliptical and lenticular galaxies
MNRAS 366, 1151

Kuntschner et al. (2006)
The SAURON project - VI. Line strength maps of 48 elliptical and lenticular galaxies
MNRAS 369, 497

SAURON 2006 - 2008

NGC 4314



Falcon-Barroso et al. (2006)
The SAURON project - VII. Integral-field absorption and emission-line kinematics of 24 spiral galaxy bulges
MNRAS 369, 529

McDermid et al. (2006)
The SAURON project - VIII. OASIS/CFHT integral-field spectroscopy of elliptical and lenticular galaxy centres
MNRAS 373, 906

Emsellem et al. (2007)
The SAURON project - IX. A kinematic classification for early-type galaxies , MNRAS 379, 401

Cappellari et al. (2007)
The SAURON project - X. The orbital anisotropy of elliptical and lenticular galaxies: revisiting the (V/σ, ε) diagram with integral-field stellar kinematics
MNRAS 379, 418

Peletier et al. (2007)
The SAURON project - XI. Stellar populations from absorption-line strength maps of 24 early-type spirals
MNRAS 379, 445

Krajnovic et al. (2008)
The SAURON project - XII. Kinematic substructures in early-type galaxies: evidence for discs in fast rotators
MNRAS 390, 93

SAURON 2009 - 2011

Jeong et al. (2009)
The SAURON project - XIII. SAURON-GALEX study of early-type galaxies: the ultraviolet colour-magnitude relations and Fundamental Planes
MNRAS 398, 2028

Scott et al. (2009)
The SAURON Project - XIV. No escape from Vesc: a global and local parameter in early-type galaxy evolution
MNRAS 398, 1835

Shapiro et al. (2010)
The SAURON project - XV. Modes of star formation in early-type galaxies and the evolution of the red sequence
MNRAS 402, 2140

Sarzi et al. (2010)
The SAURON project - XVI. On the sources of ionization for the gas in elliptical and lenticular galaxies
MNRAS 402, 2187

Kuntschner et al. (2010)
The SAURON project - XVII. Stellar population analysis of the absorption line strength maps of 48 early-type Galaxies
MNRAS 408, 97

Bureau et al. (2011)
The SAURON project - XVIII. The integrated UV-line-strength relations of early-type galaxies
MNRAS 414, 1887

SAURON 2011 - 2013

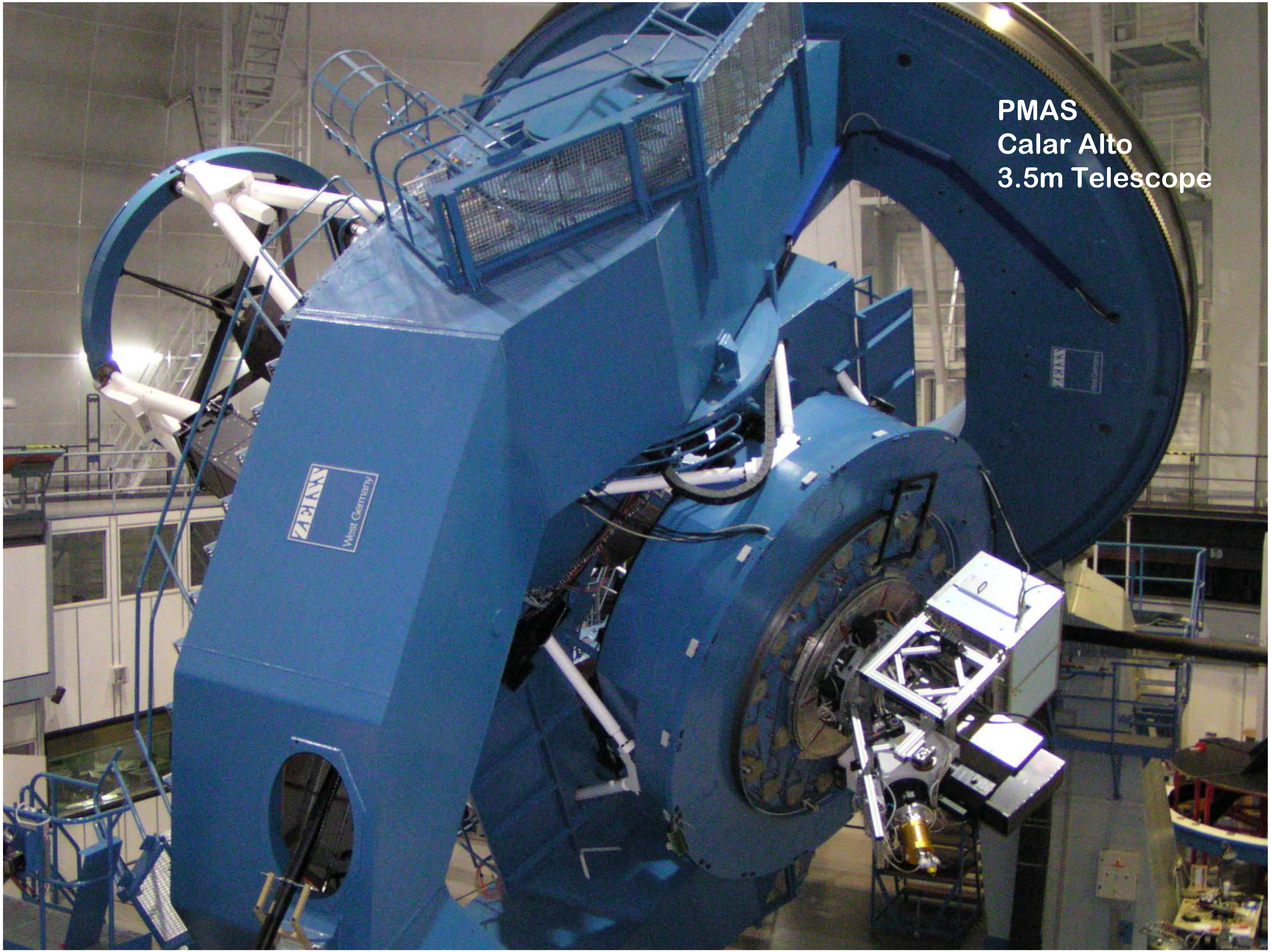
Falcon-Barroso et al. (2011)
The SAURON project - XIX. Optical and near-infrared scaling relations of nearby elliptical, lenticular and Sa galaxies
MNRAS 417, 1787

Peletier et al. (2012)
The SAURON project - XX. The Spitzer [3.6] - [4.5] colour in early-type galaxies: colours, colour gradients and inverted scaling relations
MNRAS 419, 2031

Jeong et al. (2012)
The SAURON project - XXI. The spatially resolved UV-line strength relations of early-type galaxies
MNRAS 423, 1921

...

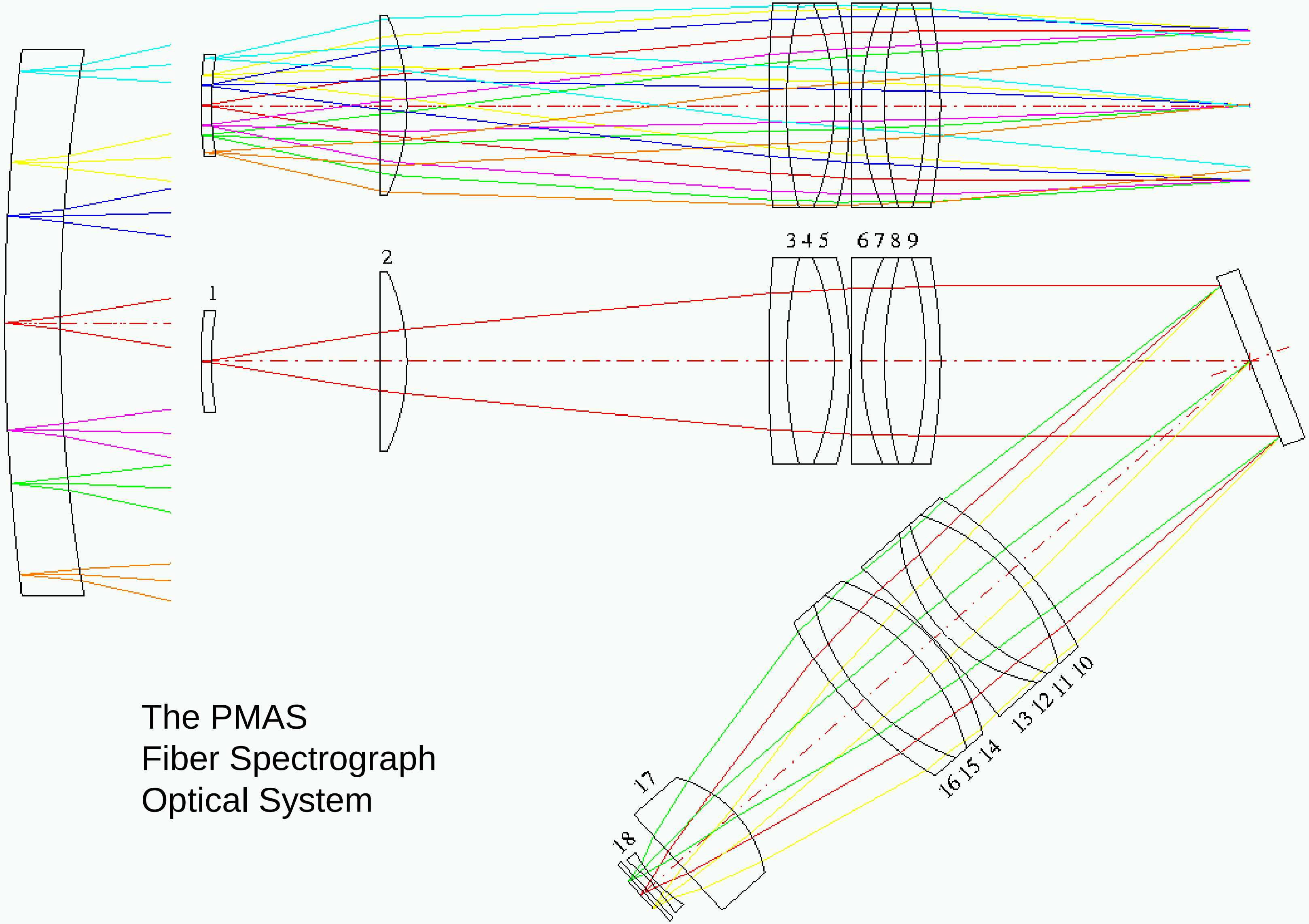
Bayet, Estelle; Bureau, Martin; Davis, Timothy A.; Young, Lisa M.; Crocker, Alison F.; Alatalo, Katherine; Blitz, Leo; Bois, Maxime; Bournaud, Frédéric; Cappellari, Michele; and 15 coauthors (2013),
The ATLAS3D project - XVI. Physical parameters and spectral line energy distributions of the molecular gas in gas-rich early-type galaxies
MNRAS 432, 1742


PMAS
Calar Alto
3.5m Telescope
ZEISS
West Germany

PMAS

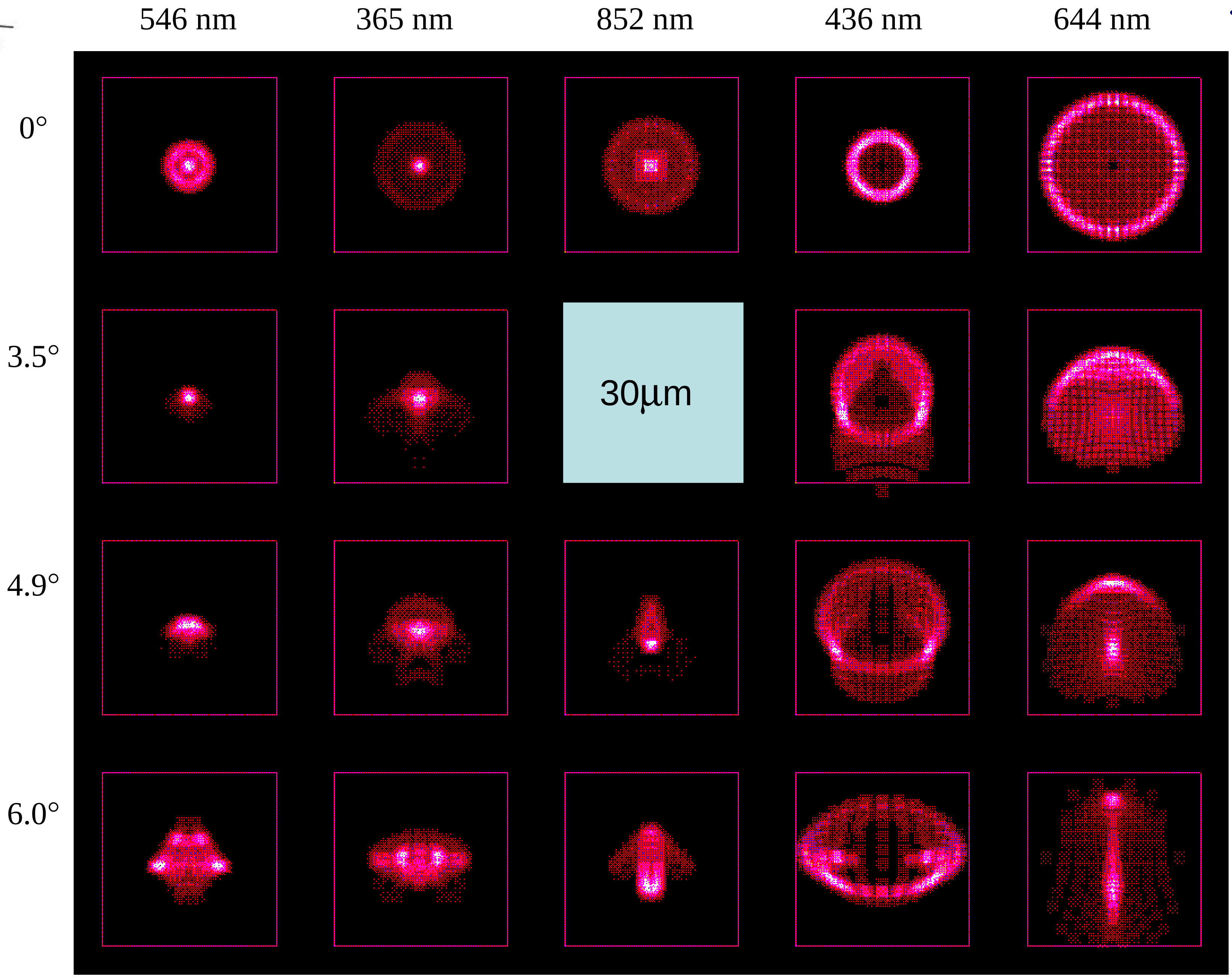
Fiber-slit	0.1 x 96 mm
Collimator	f = 450 mm, F/3
Camera	f = 270 mm, F/1.5
Gratings	300 / 500 / 600 / 1200 gr/mm (U,V,R)
Wavelength range	350 - 900 nm
Dispersion	1.7 – 0.8 – 0.35 A/pix
Coverage	3700 – 1600 – 720 A *)
Resolution ($\lambda/\Delta\lambda$)	730 – 1500 – 3600 (11000 in 2nd order)

PMAS

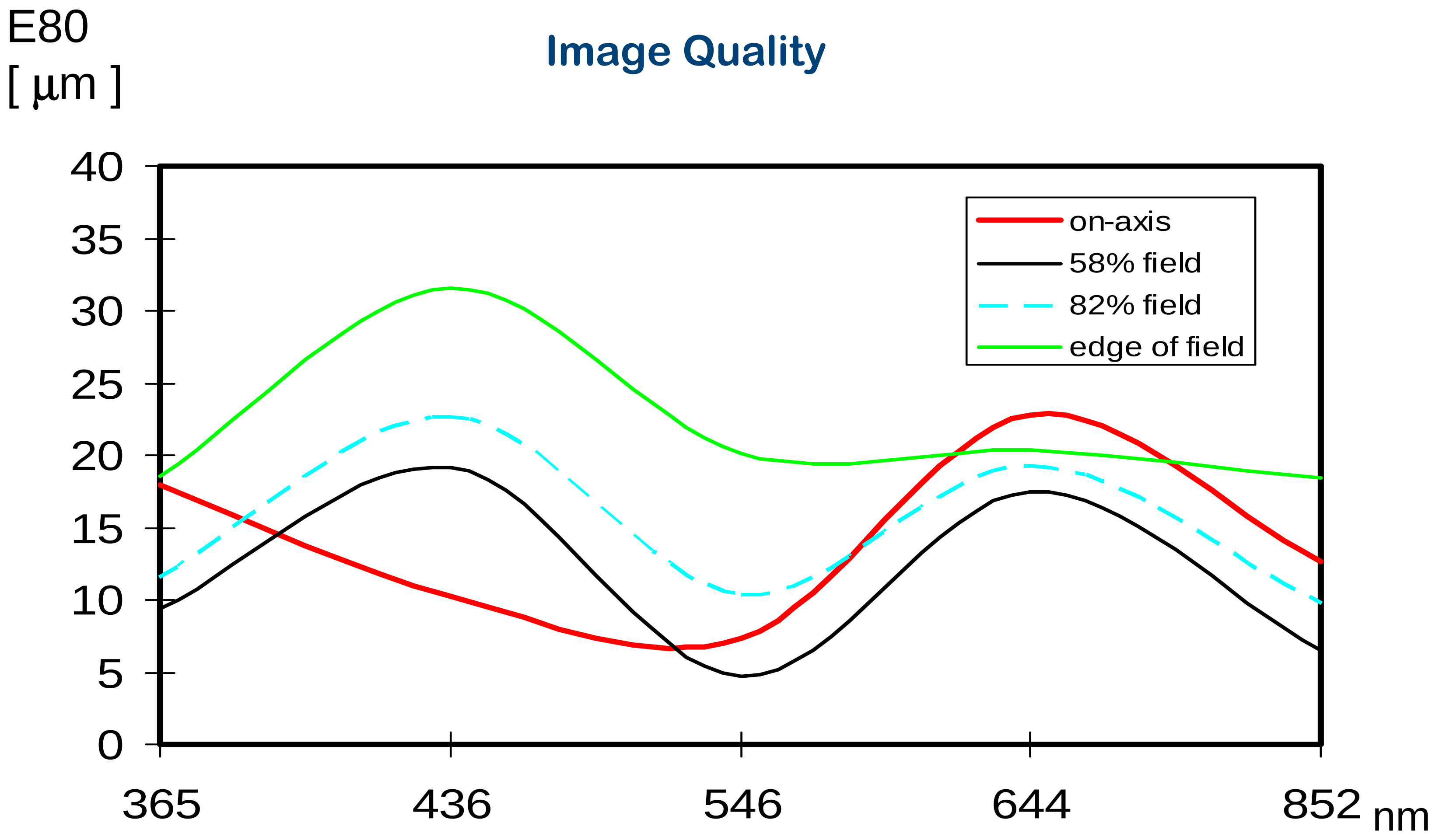


The PMAS
Fiber Spectrograph
Optical System

PMAS

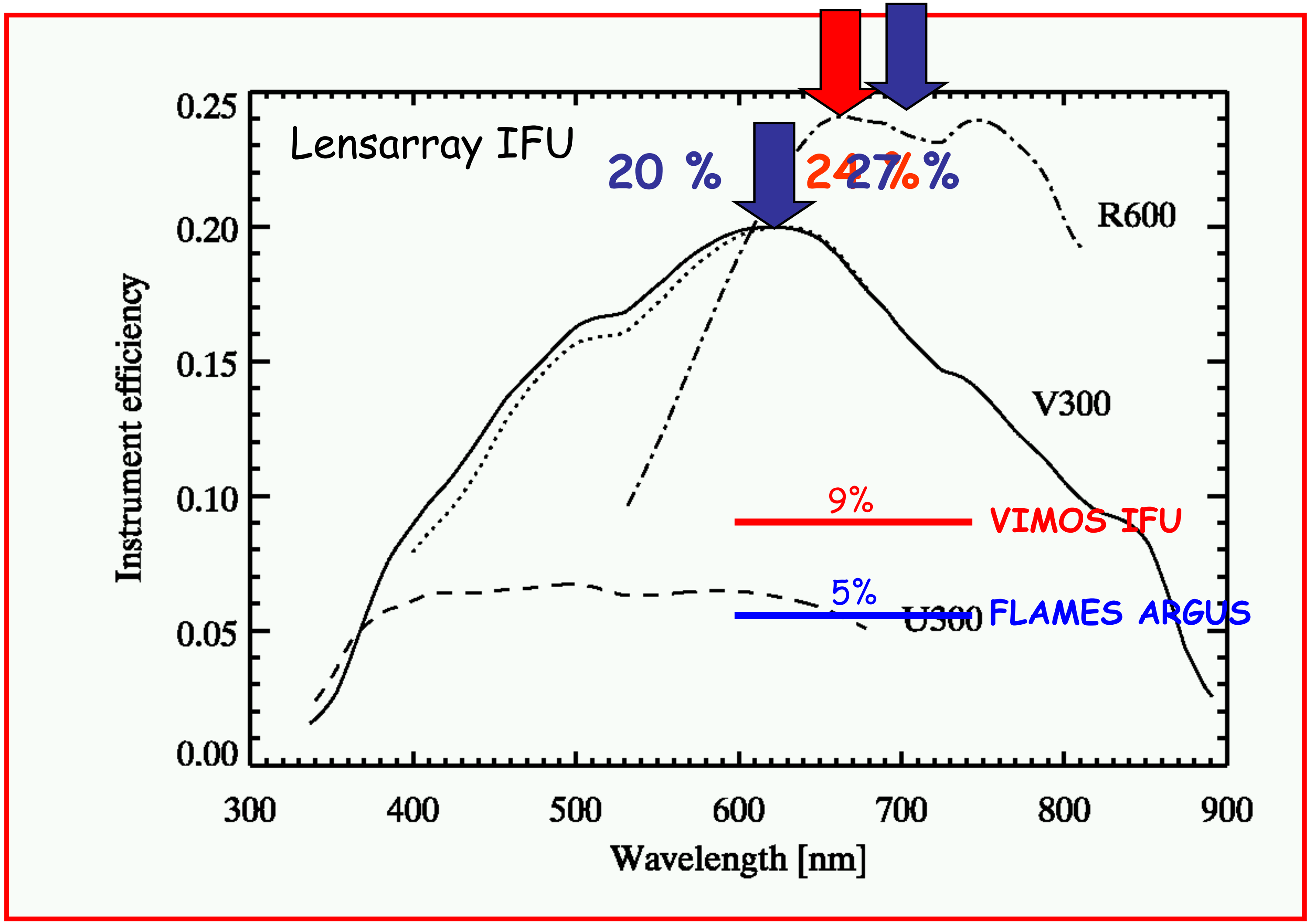


PMAS



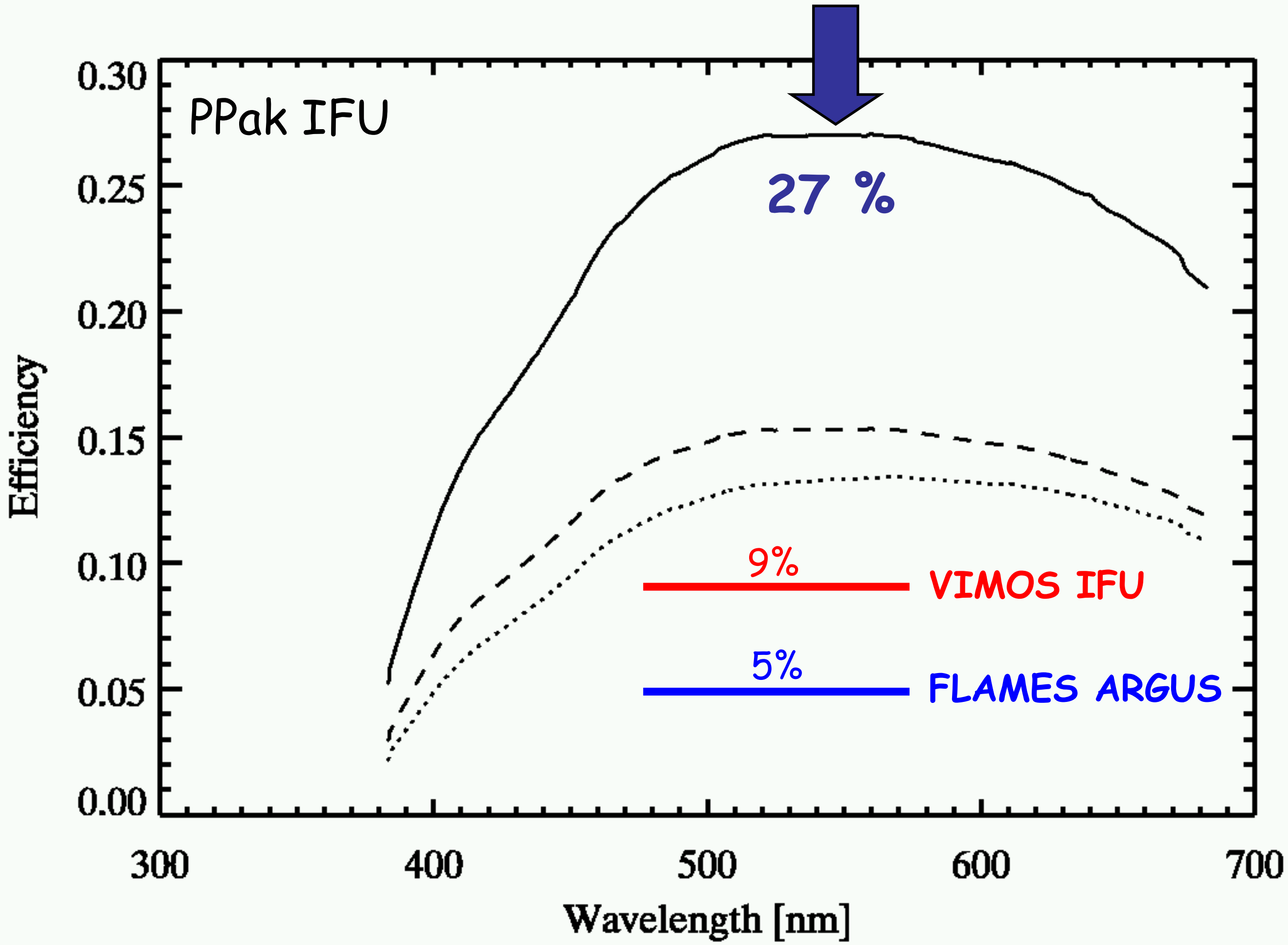
E80
[µm]
Image Quality
40
35
30
25
20
15
10
5
0
365
436
546
644
852
nm
on-axis
58% field
82% field
edge of field

PMAS

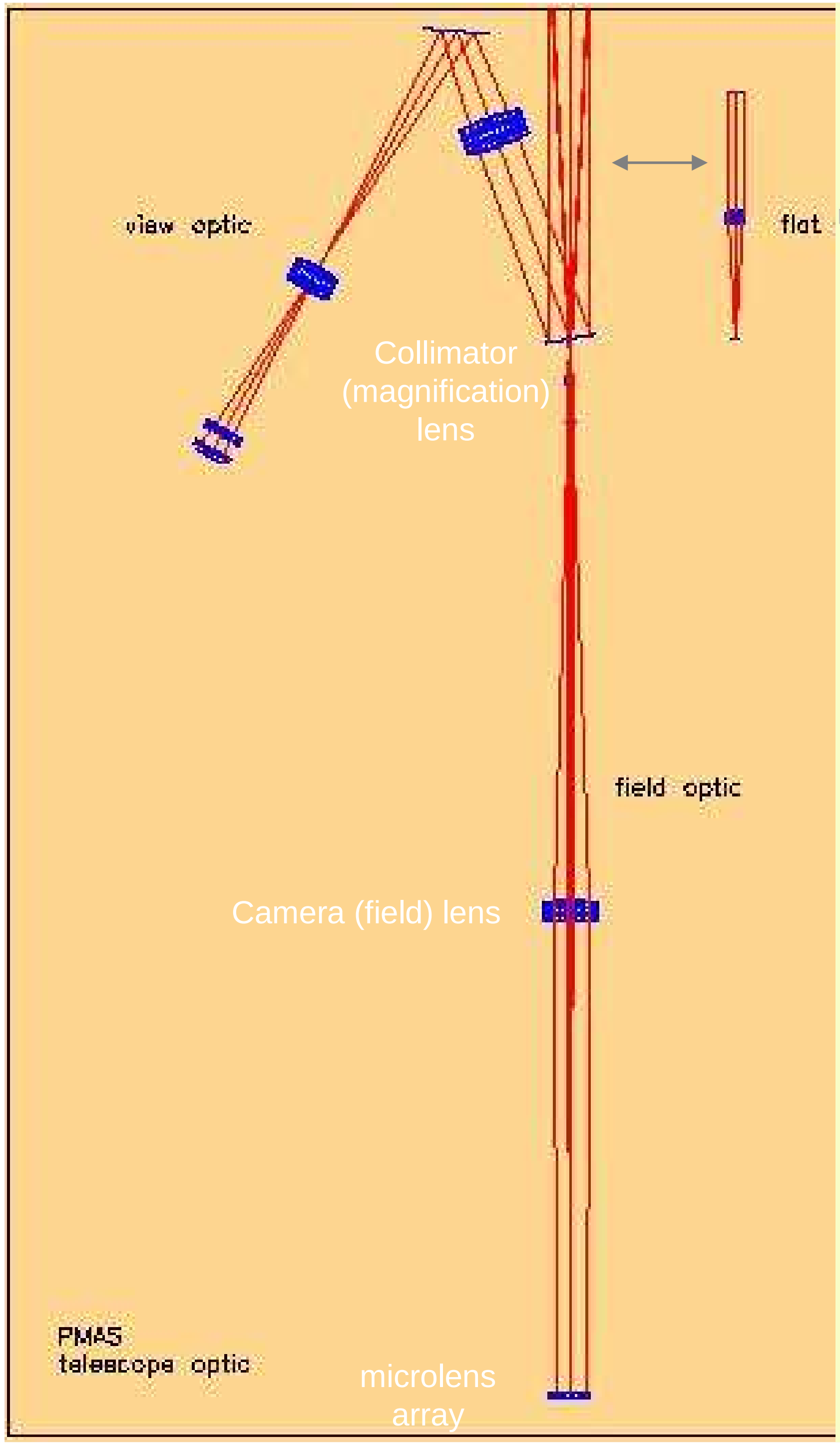


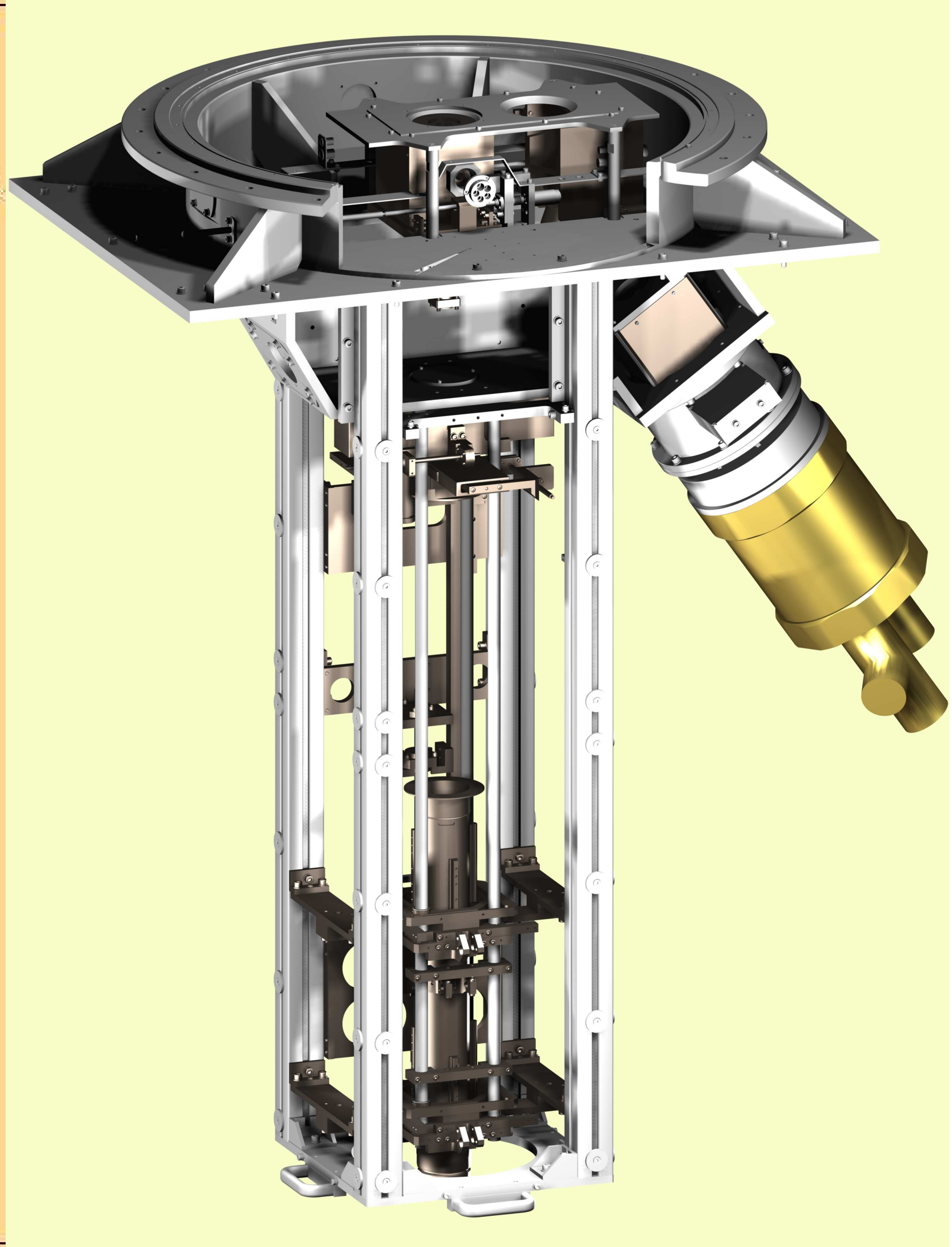
Lensarray IFU
20 %
24 %
27 %
R600
V300
9%
VIMOS IFU
5%
U300
FLAMES ARGUS
Instrument efficiency
0.25
0.20
0.15
0.10
0.05
0.00
300
400
500
600
700
800
900
Wavelength [nm]

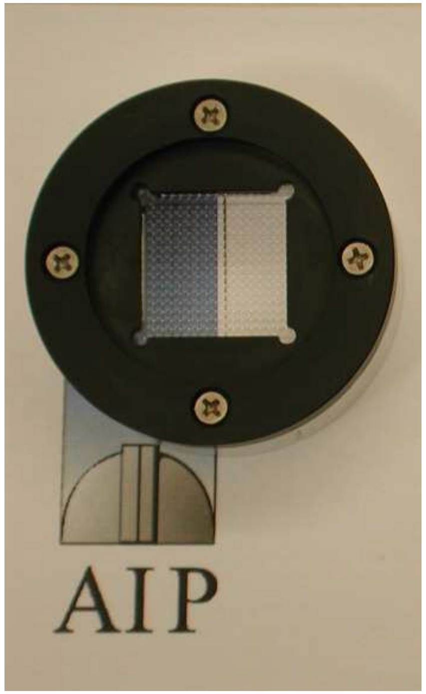
PMAS



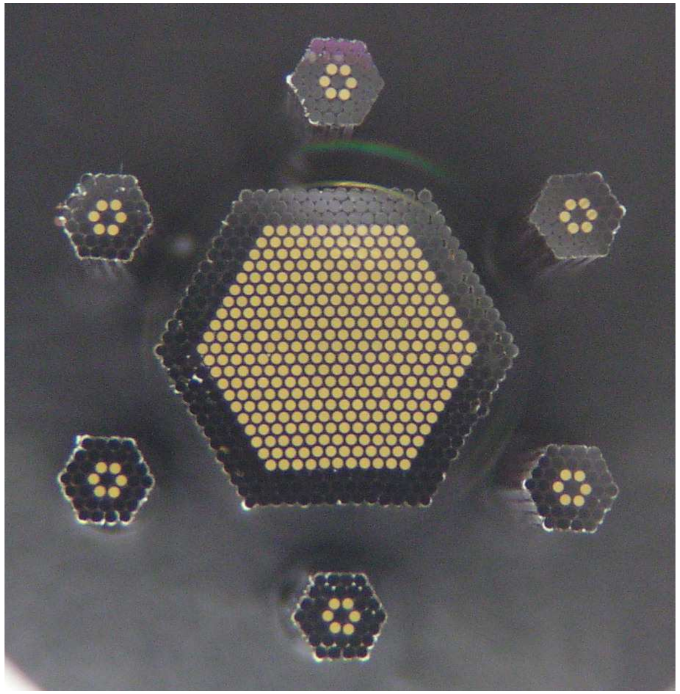
0.30
0.25
0.20
0.15
0.10
0.05
0.00
Efficiency
PPak IFU
27 %
9%
VIMOS IFU
5%
FLAMES ARGUS
300
400
500
600
700
Wavelength [nm]


view optic
flat
Collimator (magnification) lens
field optic
Camera (field) lens
PMAS telescope optic
microlens array





8 arcsec

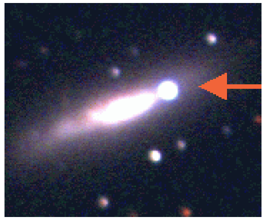


74 arcsec

Publications 2003

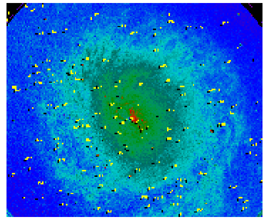
Wisotzki L., Becker T., Christensen L., Helms A., Jahnke K., Kelz A., Roth M. M., Sánchez S. F.
Integral-field spectroscopy of the quadruple QSO HE 0435-1223: Evidence for microlensing
A&A 408 (2003) 455

Christensen L., Becker T., Jahnke K., Kelz A., Roth M. M., Sánchez S. F., Wisotzki L.
Integral field spectroscopy of SN2002er with PMAS
A&A, 401 (2003) 479

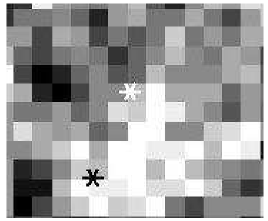


Publications 2004

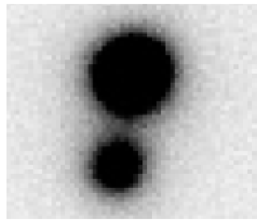
Roth, M.M., Becker, T., Kelz, A., Schmoll, J.
3D Spectrophotometry of Planetary Nebulae in the Bulge of M31
ApJ 603 (2004), 531



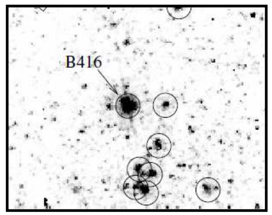
Christensen, L., Sánchez, S. F., Jahnke, K., Becker, T., Wisotzki, L., Kelz, A., Popovic, L. C., Roth, M. M.
"Integral field spectroscopy of extended Ly_alpha emission from the DLA galaxy in Q2233+131"
A&A 417 (2004), 487



Wisotzki, L., Schechter, P.L., Chen, H.-W., Richstone, D., Jahnke, K., Sánchez, S.F., Reimers, D.
"HE 0047-1756: A new gravitational Lensed double QSO"
A&A 419 (2004), 13

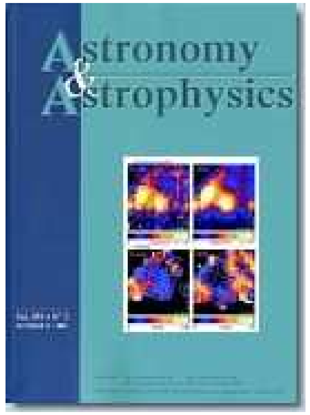


Becker, T., Fabrika, S. , Roth, M.M.
"Crowded Field 3D Spectroscopy"
AN 325 (2004) 2, 155



Roth, M.M., Becker, T., Böhm, P., Kelz, A.
"Science Verification Results from PMAS"
AN 325 (2004) 2, 147

Publications 2005



Lehmann, I. Becker, T., Fabrika, S., Roth,M.M., Miyaji, T., Afanasief, V., Sholukhova, O., Sánchez, S.F., Greiner, J., Hasinger, G., Constantini, E., Surkov, A., Burenkov, A.
"Integral field spectroscopy of the ultraluminous X-ray source Holberg II X-1"
A&A, 431 (2005) 847

Christensen, L., Schulte-Ladbeck, R.E., Sanchez, S.F., Becker, T., Jahnke, K., Kelz, A., Roth, M.M., Wisotzki, L. *„Abundances and kinematics of a candidate sub-damped Lyman-alpha galaxy toward PHL 1226"*
A&A (2005) 429 , 477

Sanchez, S.F., Becker, T., Garcia-Lorenzo, B., Benn, C.R., Christensen, L., Kelz, A., Jahnke, J., Roth, M.M.
„The merging/AGN connection II. Ionization of the circumnuclear regions"
A&A 429 (2005) L21

García-Lorenzo, B.; Sánchez, S. F.; Mediavilla, E.; González-Serrano, J. I.; Christensen, L.
„Integral Field Spectroscopy of the Central Regions of 3C 120: Evidence of a Past Merging Event"
ApJ, 621, 146

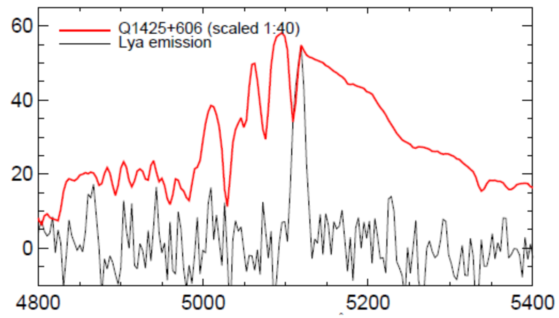
Publications 2006

G. Lamer, A. Schwope, L. Wisotzki, L. Christensen.
„Strange magnification pattern in the large separation lens SDSS J1004+4112 from optical to X-rays"
A&A 454 (2006), 493

L. Christensen, K. Jahnke, L. Wisotzki, S. F. Sanchez, K. Exter, M.M. Roth
„A jet-cloud interaction in the 3C 196 environment"
A&A 452 (2006), 869

L. Christensen, K. Jahnke, L. Wisotzki, S. F. Sanchez
„Extended Lyman-alpha emission around bright quasars"
A&A 459 (2006), 717

S. F. Sanchez, B. Garcia-Lorenzo, K. Jahnke, E. Mediavilla, J. I. Gonzalez-Serrano, L. Christensen, L. Wisotzki
„A new technique for decoupling the host and nuclear spectra of type I AGNs using integral field spectroscopy"
AN 327 (2006), 167



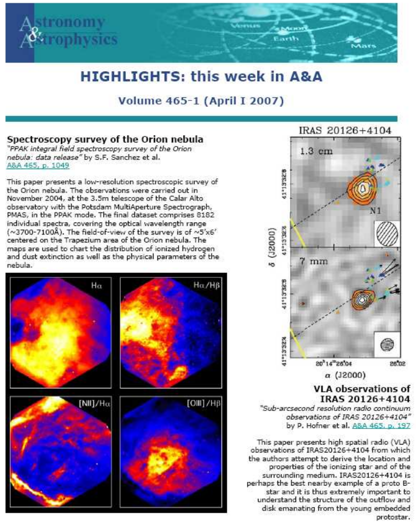
Publications 2007

S. F. Sanchez, N. Cardiel, M. A. W. Verheijen, D. Martin-Gordon, J. M. Vilchez, J. Alves
"PPAK integral field spectroscopy survey of the Orion nebula - Data release"
A&A 465,207

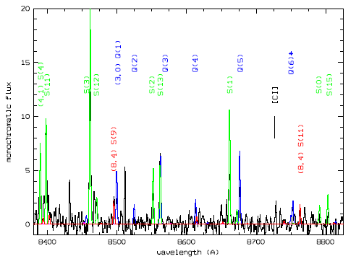
S. F. Sanchez, , N. Cardiel, , M. A. W. Verheijen, , S. Pedraz, G. Covone
"Morphologies and stellar populations of galaxies in the core of Abell 2218"
MNRAS 376 (2007),125

L. Christensen, L. Wisotzki, M.M. Roth, S.F. Snchez, A. Kelz, K. Jahnke
"An integral field spectroscopic survey for high redshift damped Lyman-alpha galaxies"
A&A 468 (2007),587

G. Garavini, S. Nobili, S. Taubenberger, A. Pastorello, N. Elias-Rosa, V. Stanishev, G. Blanc, S. Benetti,
A. Goobar, P. A. Mazzali, S. F. Sanchez, M. Salvo, B. P. Schmidt, W. Hillebrandt
"ESC observations of SN 2005cf II. Optical spectroscopy and the high-velocity features"



R. Gredel
"Quantitative optical and near-infrared spectroscopy of H2 towards HH91A"
A&A 474,941



Publications 2008

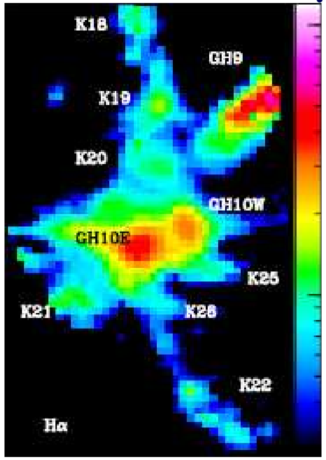
López R., Sánchez S.F., García-Lorenzo B., Gómez G., Estalella R., Riera A., Busquet G.
„The nature of HHL 73 from optical imaging and integral field spectroscopy"
MNRAS 384 (2008), 464

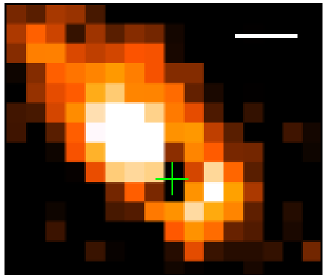
López R, García-Lorenzo B.,Sánchez S.F., Gómez G., Estalella R., Riera A.
„Integral field spectroscopy of HH 262: the spectral atlas"
MNRAS 391 (2008), 1107

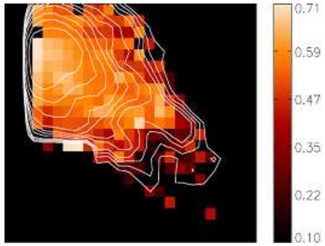
Husemann, B., Wisotzki, L., Sánchez, S.F., Jahnke, K.
„Extended emission-line regions in low-redshift quasars - Dependence on nuclear spectral properties"
A&A 488 (2008), 145

Kehrig C., Vílchez J.M., Sánchez S.F., Telles E., Pérez-Montero E., Martín-Gordón D.
„The interplay between ionized gas and massive stars in the HII galaxy IIZw70: integral field spectroscopy with PMAS"
A&A 477 (2008), 813

Sandin C.; Schönberner D.; Roth M.M.; Steffen M.; Böhm P.; Monreal-Ibero A.
„Spatially resolved spectroscopy of planetary nebulae and their halos. I. Five galactic disk objects"
A&A 486 (2008), 545





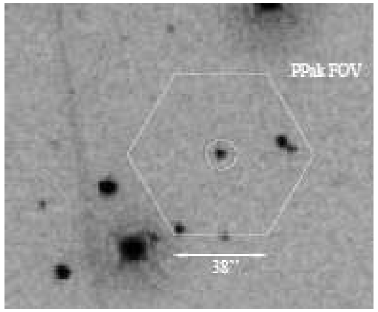


Publications 2009

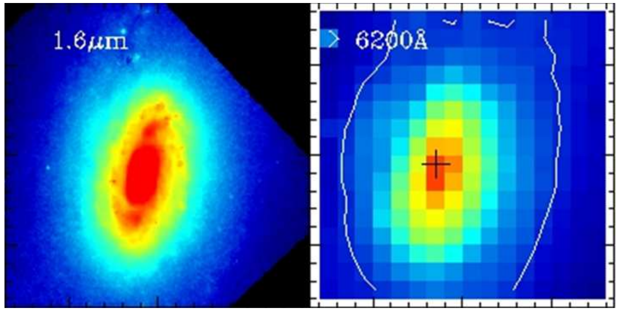
Sánchez S.F., Humphrey A.
"Integral field spectroscopy of two radio galaxies at z 2.3"
A&A 495,471

Belokurov V., Evans N.W., Hewett P.C., Moiseev A., McMahon R.G., Sanchez S.F.,King L.J.
"Two new large-separation gravitational lenses from SDSS"
MNRAS 392,104

P. Ferrero, S. Klose, D. A. Kann, S. Savaglio, S. Schulze, E. Palazzi, E. Maiorano, P. Böhm, D. Grupe, S. R. Oates, S.F. Sánchez, L. Amati, J. Greiner, J. Hjorth, D. Malesani, S.D. Barthelmy, J. Gorosabel, N. Masetti, M.M. Roth
"GRB 060605: multi-wavelength analysis of the first GRB observed using integral field spectroscopy"
A&A 497,729



A. Alonso-Herrero, M. García-Marín, A. Monreal-Ibero, L. Colina, S. Arribas, J. Alfonso-Garzón, A. Labiano
"PMAS optical integral field spectroscopy of luminous infrared galaxies. I. The atlas"
A&A 506,1541



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L. M. Cairós, N. Caon, C. Zurita, C. Kehrig, P. Weilbacher, M. Roth
"Mapping the starburst in blue compact dwarf galaxies - PMAS integral field spectroscopy of Mrk 1418"
A&A 507,1291

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ApJ 707,1676

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"Properties of the ionized gas in HH202 - I. Results from integral field spectroscopy with PMAS"
MNRAS 394,693

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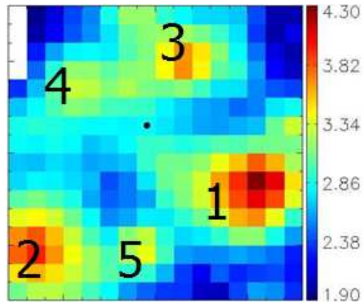
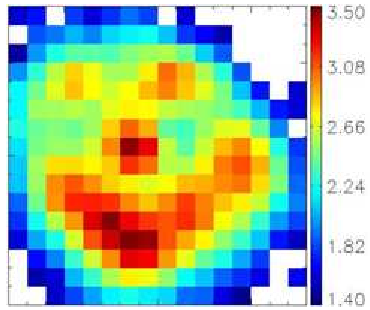
"On the Heating Efficiency Derived from Observations of Young Super Star Clusters in M82"
ApJ 700,931





Publications 2010

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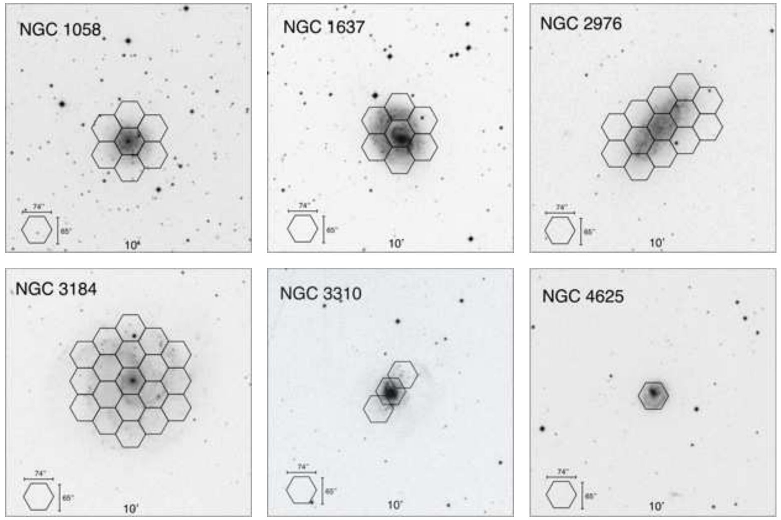
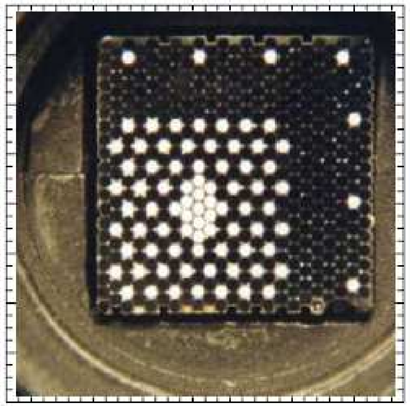
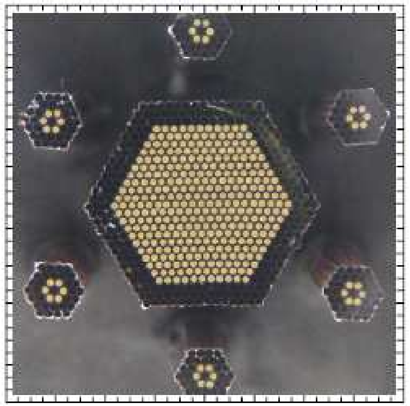
"PINGS: the PPAK IFS Nearby Galaxies Survey"
MNRAS 405,735



Bershady M.T., Verheijen M.A.W., Swaters R.A., Andersen D.R., Westfall K.B., Martinsson T.
"The DiskMass Survey. I. Overview"
ApJ 716,198





Bershady, M. A., Verheijen, M. A. W., Westfall, K. B., Andersen, David R.; Swaters, R.A., Martinsson, T.
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ApJ 716,234

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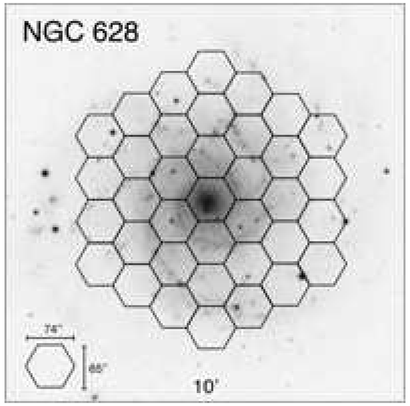
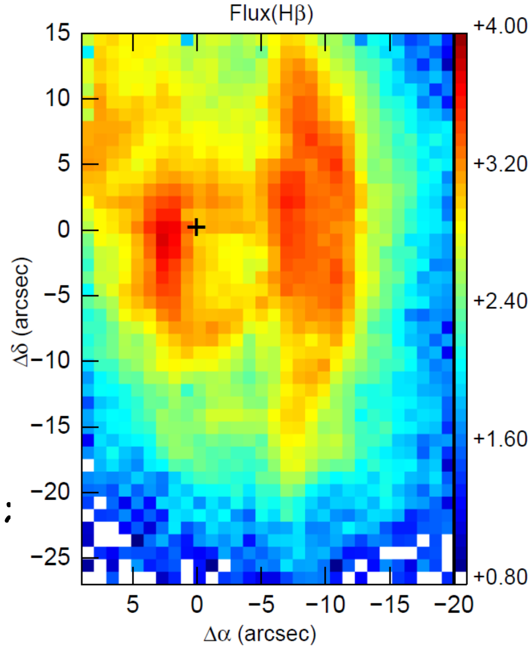
„PPAK Wide-field Integral Field Spectroscopy of NGC628 – I. The largest spectroscopic mosaic on a single galaxy"
MNRAS 410, 313



Neumayer, Nadine; Walcher, Carl Jakob; Andersen, David; Sánchez, Sebastian F.; Böker, Torsten; Rix, Hans-Walter
Two-dimensional Ha kinematics of bulgeless disc galaxies
MNRAS 413, 1875



Monreal-Ibero, A.; Relaño, M.; Kehrig, C.; Pérez-Montero, E.; Vílchez, J. M.; Kelz, A.; Roth, M. M.; Streicher, O.
A 2D multiwavelength study of the ionized gas and stellar population in the giant H II region NGC 588
MNRAS 413, 2242

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Galaxy Disks are Submaximal
ApJ 739, 47

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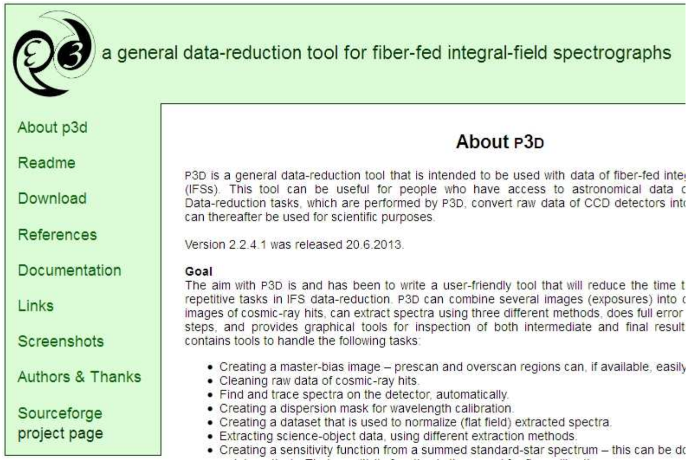
CALIFA, the Calar Alto Legacy Integral Field Area survey. I. Survey presentation
A&A 538, 8

Kehrig, C.; Monreal-Ibero, A.; Papaderos, P.; Vílchez, J. M.; Gomes, J. M.; Masegosa, J.; Sánchez, S. F.; Lehnert, M. D.; Cid Fernandes, R.; Bland-Hawthorn, J.; and 11 coauthors
The ionized gas in the CALIFA early-type galaxies. I. Mapping two representative cases: NGC 6762 and NGC 5966
A&A 540, 11

Westoby, P. B.; Mundell, C. G.; Nagar, N. M.; Maciejewski, W.; Emsellem, E.; Roth, M. M.; Gerssen, J.; Baldry, I. K.
A Magellan-IMACS-IFU Search for Dynamical Drivers of Nuclear Activity. I. Reduction Pipeline and Galaxy Catalog
ApJS 199, 1

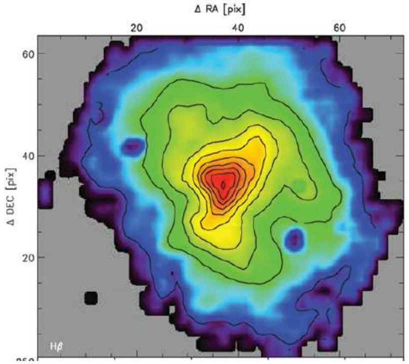
http://p3d.sourceforge.net/



Publications 2013

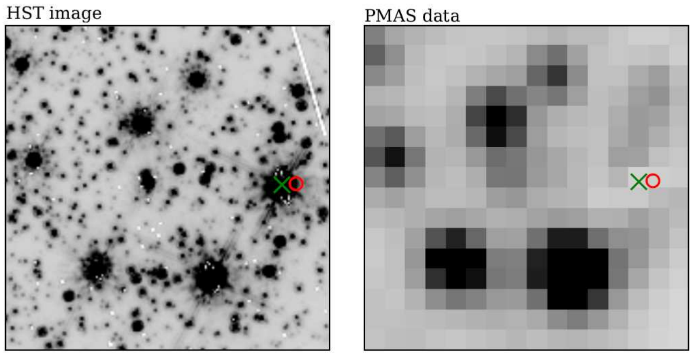
Husemann, B.; Jahnke, K.; Sánchez, S. F.; Barrado, D.; Bekeraitė, S.; Bomans, D. J.; Castillo-Morales, A.; Catalán-Torrecilla, C.; Cid Fernandes, R.; Falcón-Barroso, J.; and 66 coauthors
CALIFA, the Calar Alto Legacy Integral Field Area survey. II. First public data release
A&A 549, 87

Husemann, B.; Wisotzki, L.; Sánchez, S. F.; Jahnke, K
The properties of the extended warm ionised gas around low-redshift QSOs and the lack of extended high-velocity outflows
A&A 549, 43



López-Hernández, Jesús; Terlevich, Elena; Terlevich, Roberto; Rosa-González, Daniel; Díaz, Ángeles; García-Benito, Rubén; Vílchez, José; Hägele, Guillermo
Integral field spectroscopy of H II regions in M33
MNRAS 430, 472

Kamann, S.; Wisotzki, L.; Roth, M. M.
Resolving stellar populations with crowded field 3D spectroscopy
A&A 549, 71



Comparison

SAURON	PMAS
targeted survey design	experimental, general purpose
single mode of operation	many different modes testbed for experiments and retrofits (PPak, nod-shuffle, Phyteas, 3D spectropolarimetry)
simple	complex
stability	flexure
part of a larger team effort	single team development, eventually common user instrument
targeted science output early on	many different applications

III. 3rd Generation IFS
- high multiplex Instruments

- VIRUS
- MUSE

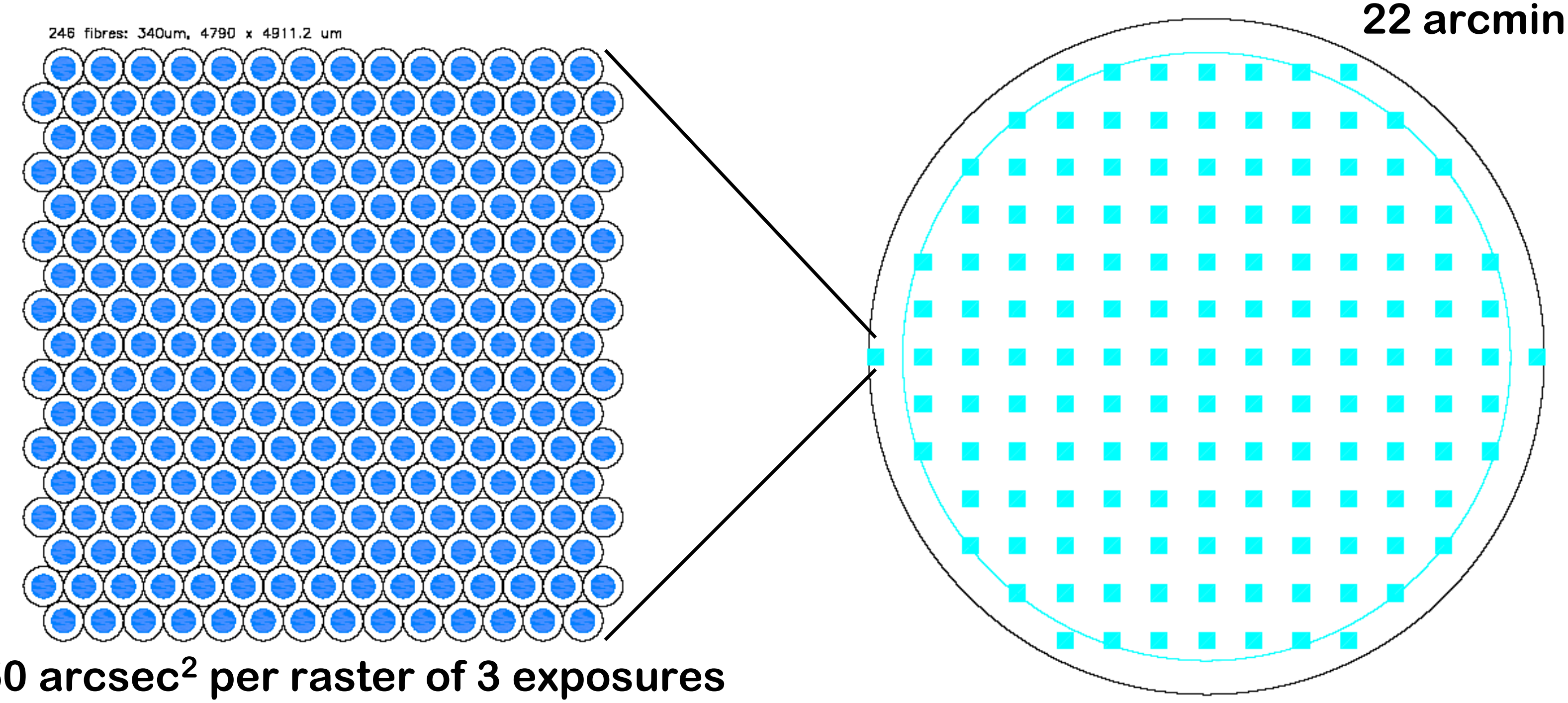

Hobby Eberly Telescope Dark Energy Experiment
http://hetdex.org
VIRUS

HETDEX Integral Field Unit

1 IFU with 448 fibers

max.150 IFUs with 33.600 fibers

22 arcmin FoV

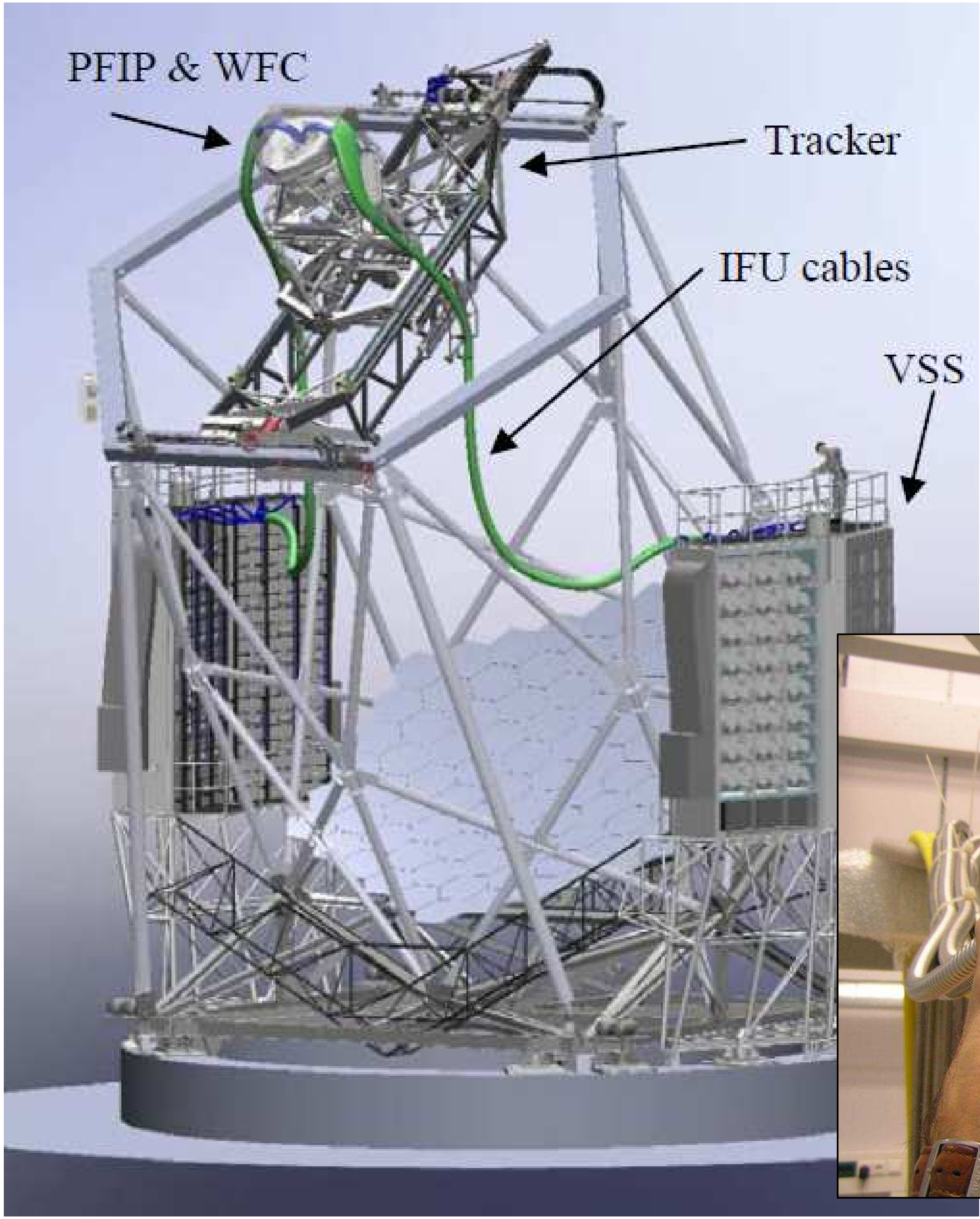


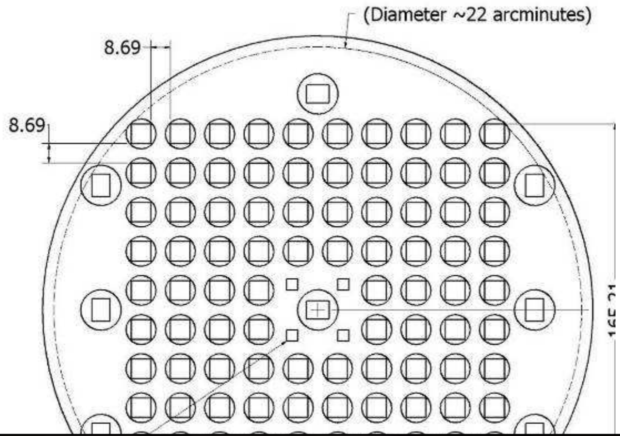
50 x 50 arcsec^2 per raster of 3 exposures

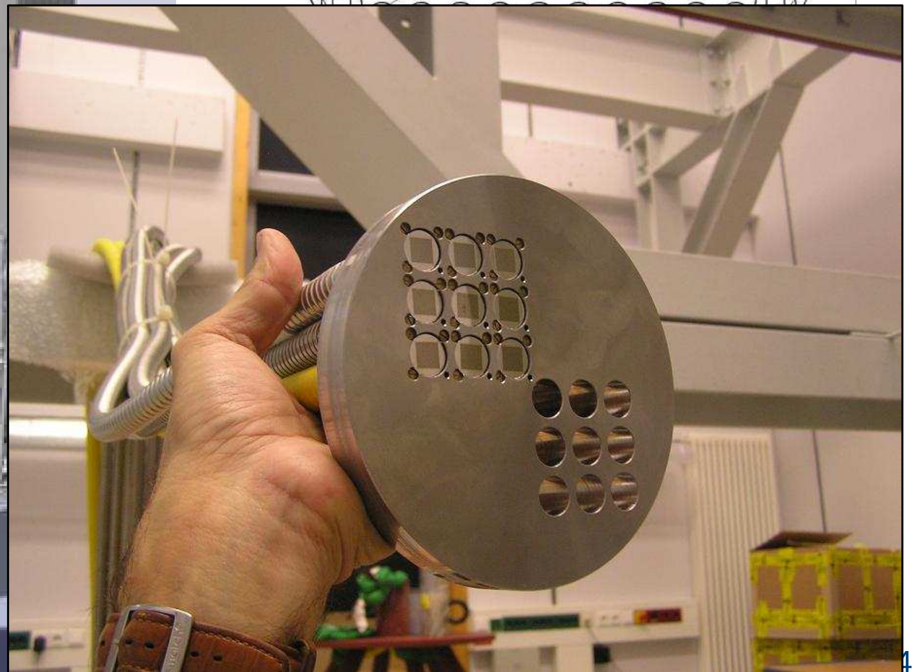
new HET wide field corrector

- 3-point dither operation

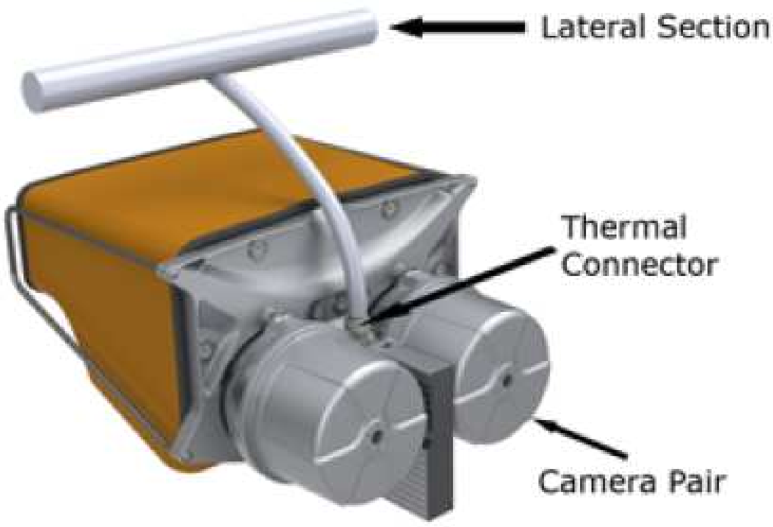
HETDEX

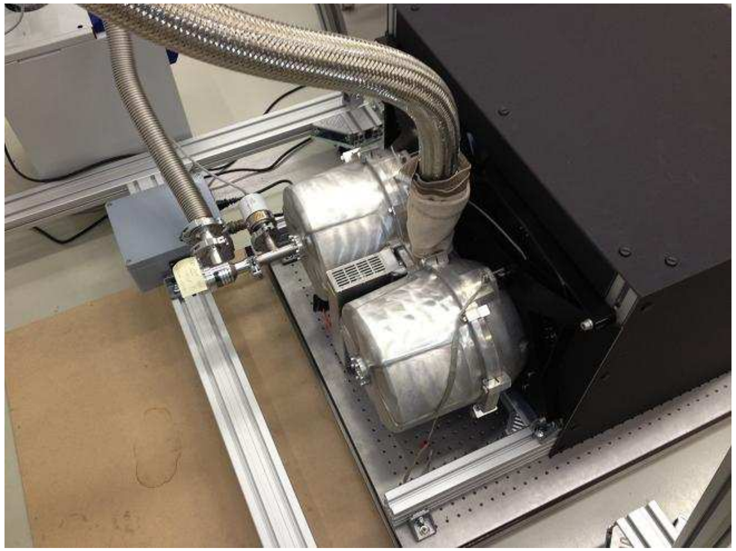

PFIP & WFC
Tracker
IFU cables
VSS


(Diameter ~22 arcminutes)
8.69
8.69

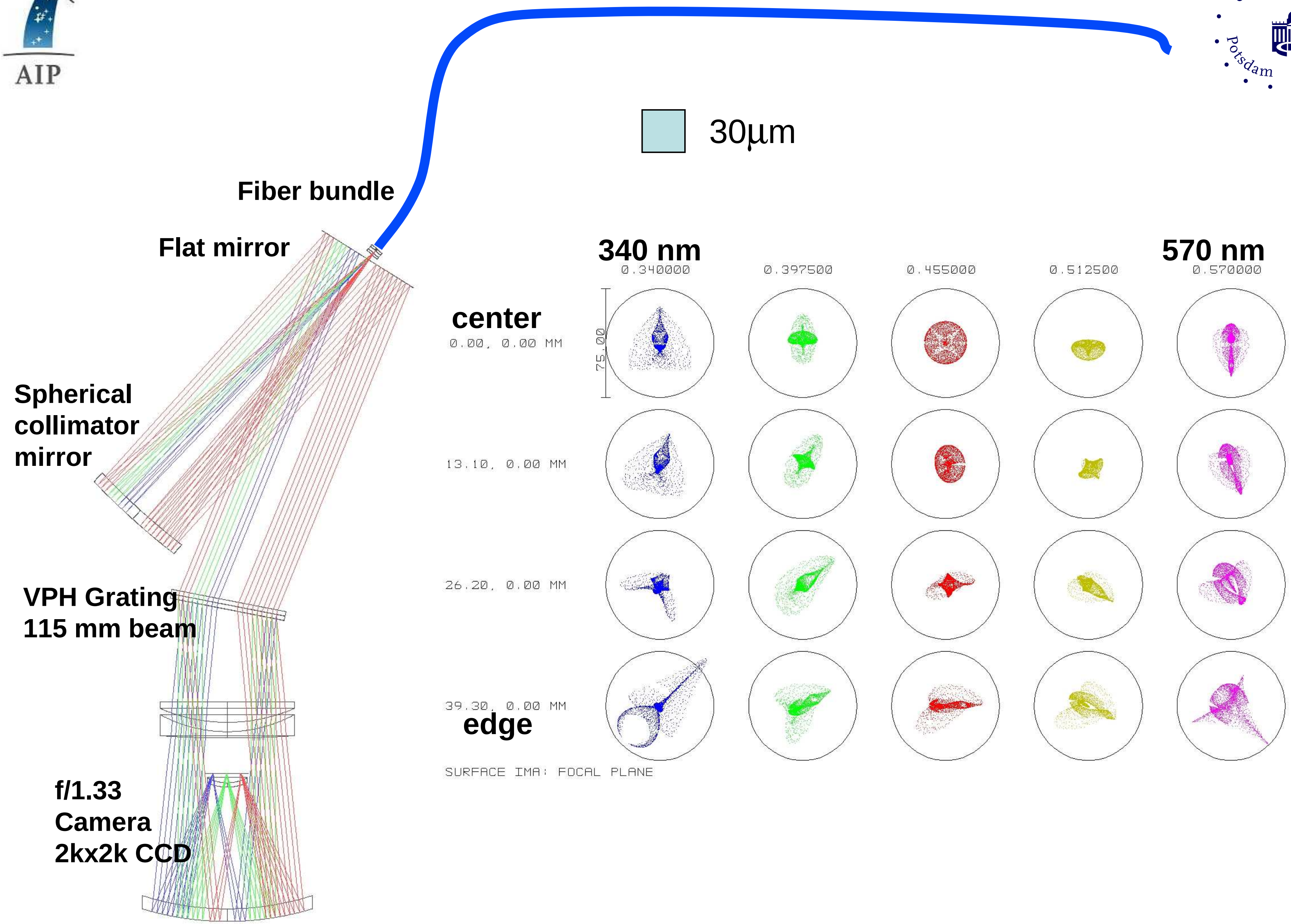


VIRUS: Visible Integral-field Replicable Unit Spectrograph



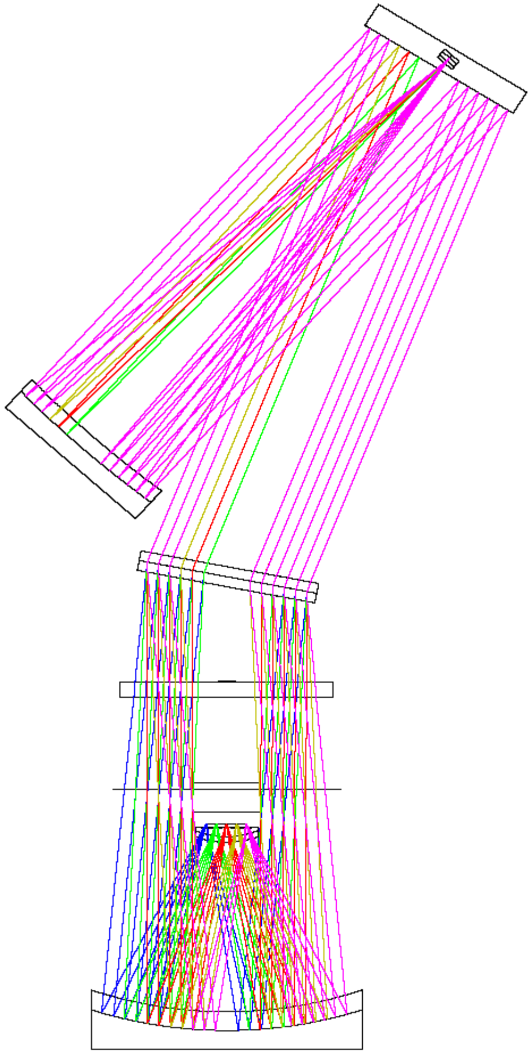


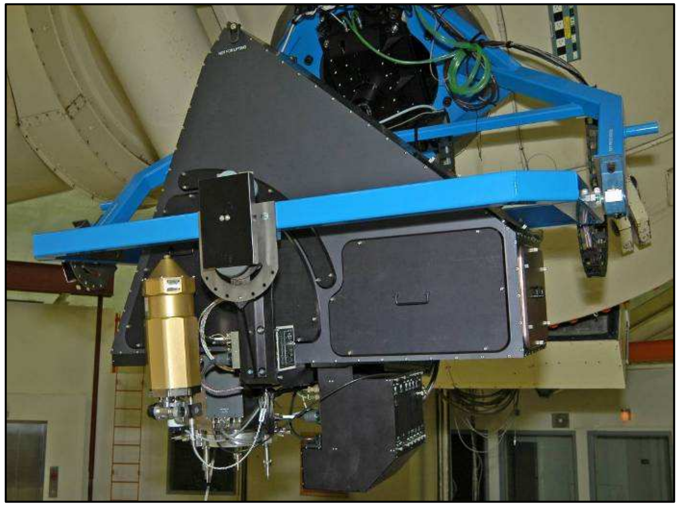
- unit spectrograph
  - 224 fibers, 1.5 arcsec on the sky
  - 350-550 nm wavelength range, R=700
- 2 unit spectrographs fed by one 50 arcsec x 50 arcsec IFU, 448 fibers
- 150 VIRUS cover
  - 33.600 spectra simultaneously
  - 12 million independent resolution elements per exposure
- Industrial replication concept
  - Massive replication of inexpensive unit spectrograph cuts costs and development time
  - Prototype development at AIP
  - R&D with local industry



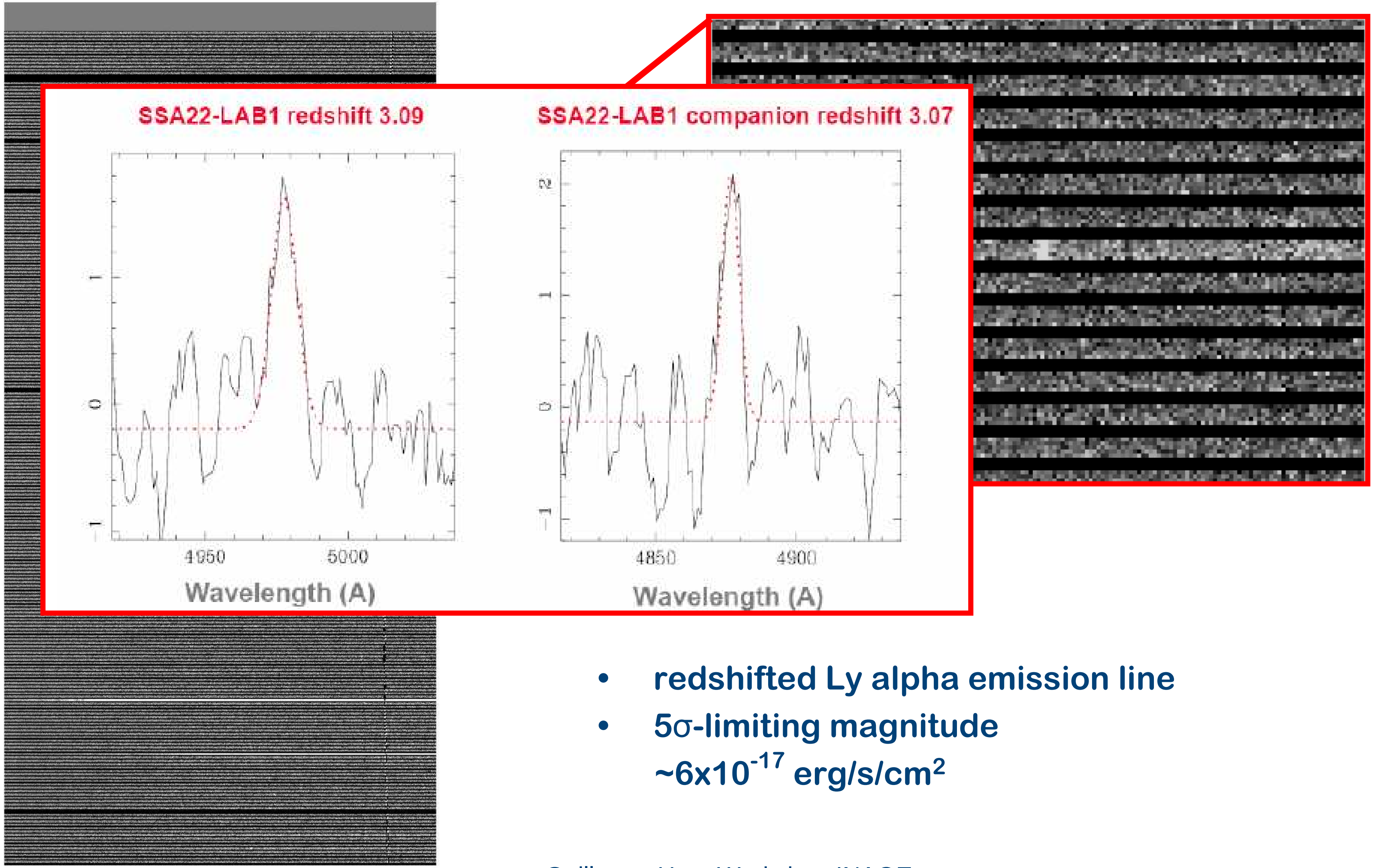
Fiber bundle
Flat mirror
Spherical collimator mirror
VPH Grating 115 mm beam
f/1.33 Camera 2kx2k CCD
30µm
340 nm
570 nm
0.340000
0.397500
0.455000
0.512500
0.570000
center
0.00, 0.00 MM
75.00
13.10, 0.00 MM
26.20, 0.00 MM
39.30, 0.00 MM
edge
SURFACE IMA: FOCAL PLANE

VIRUS-prototype on 2.7 m Smith Reflector





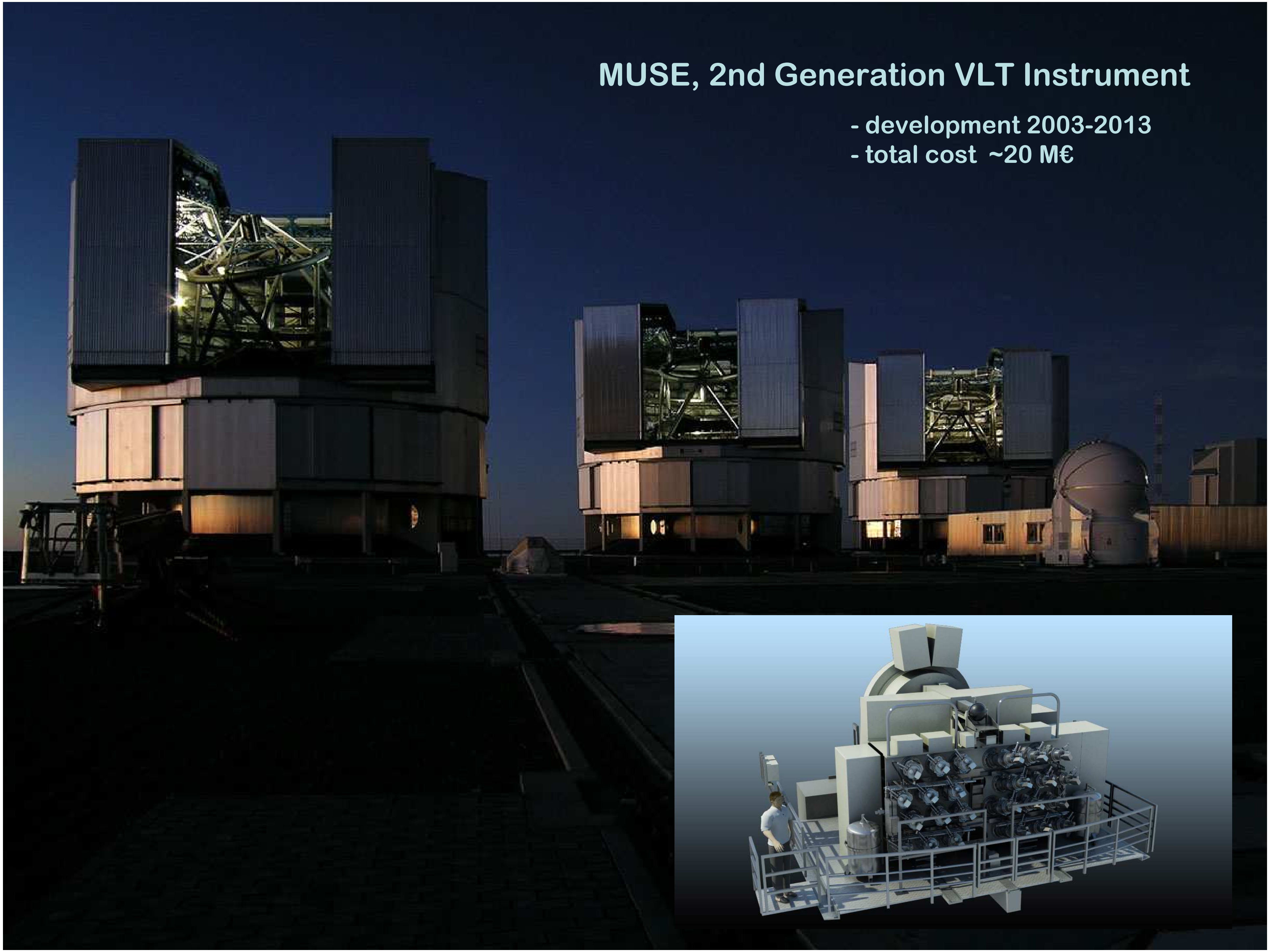
VIRUS-prototype on 2.7 m Smith Reflector



- **redshifted Ly alpha emission line**
- **5σ-limiting magnitude ~6x10^{-17} erg/s/cm^2**

MUSE, 2nd Generation VLT Instrument

- development 2003-2013
- total cost ~20 M€



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 x 10^6 pixels

90,000 spaxels

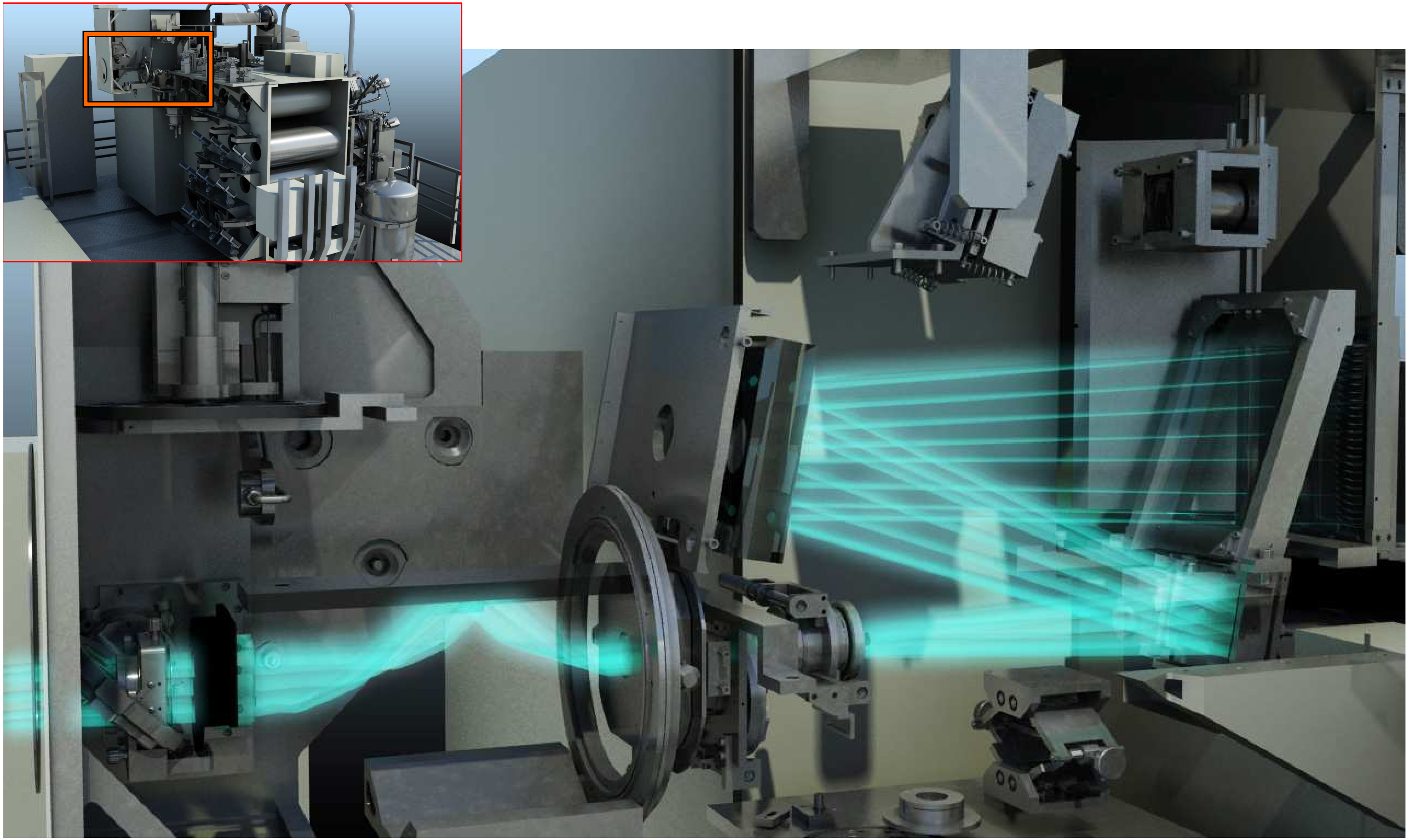
AO

Laser guide stars

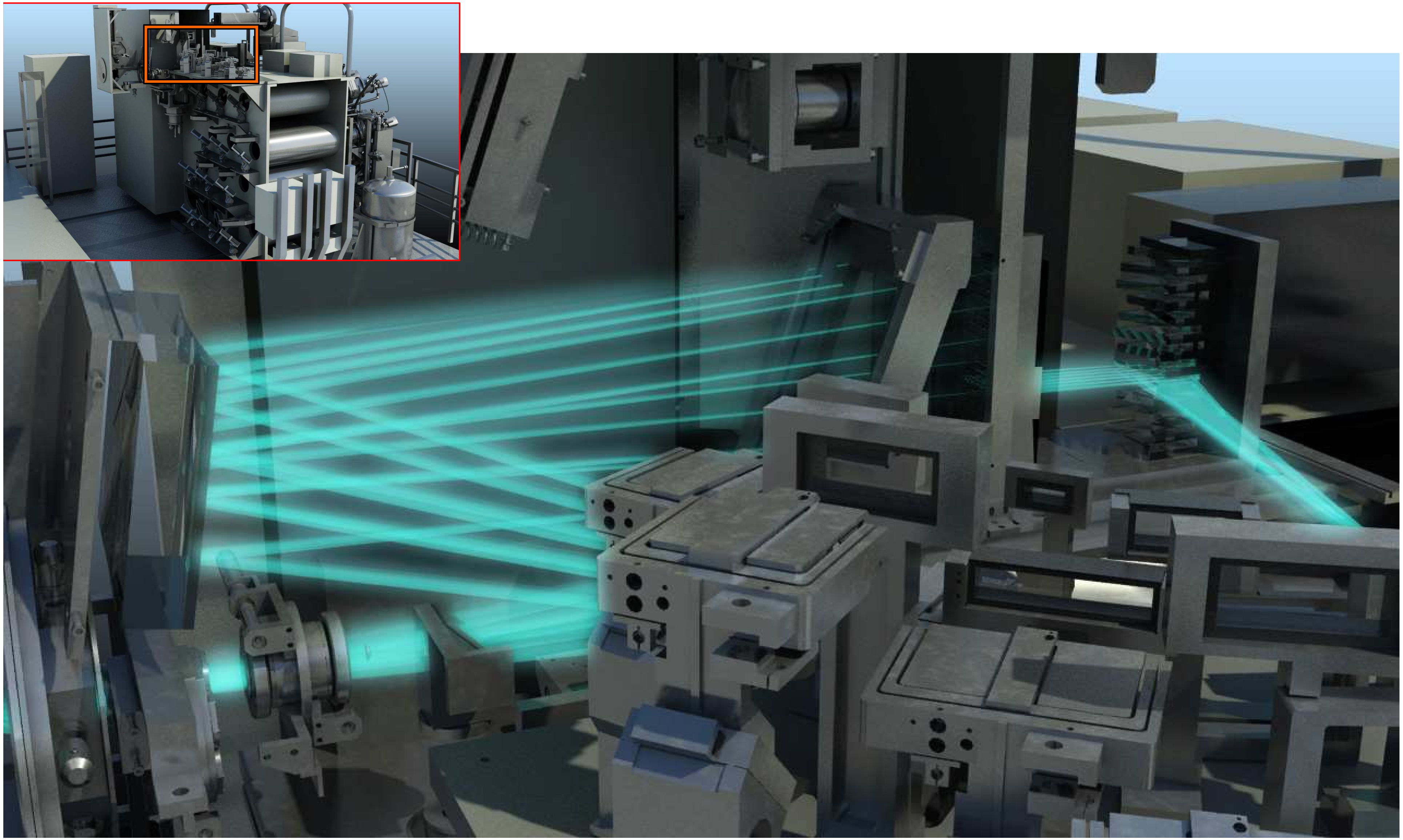
High throughput

Stability

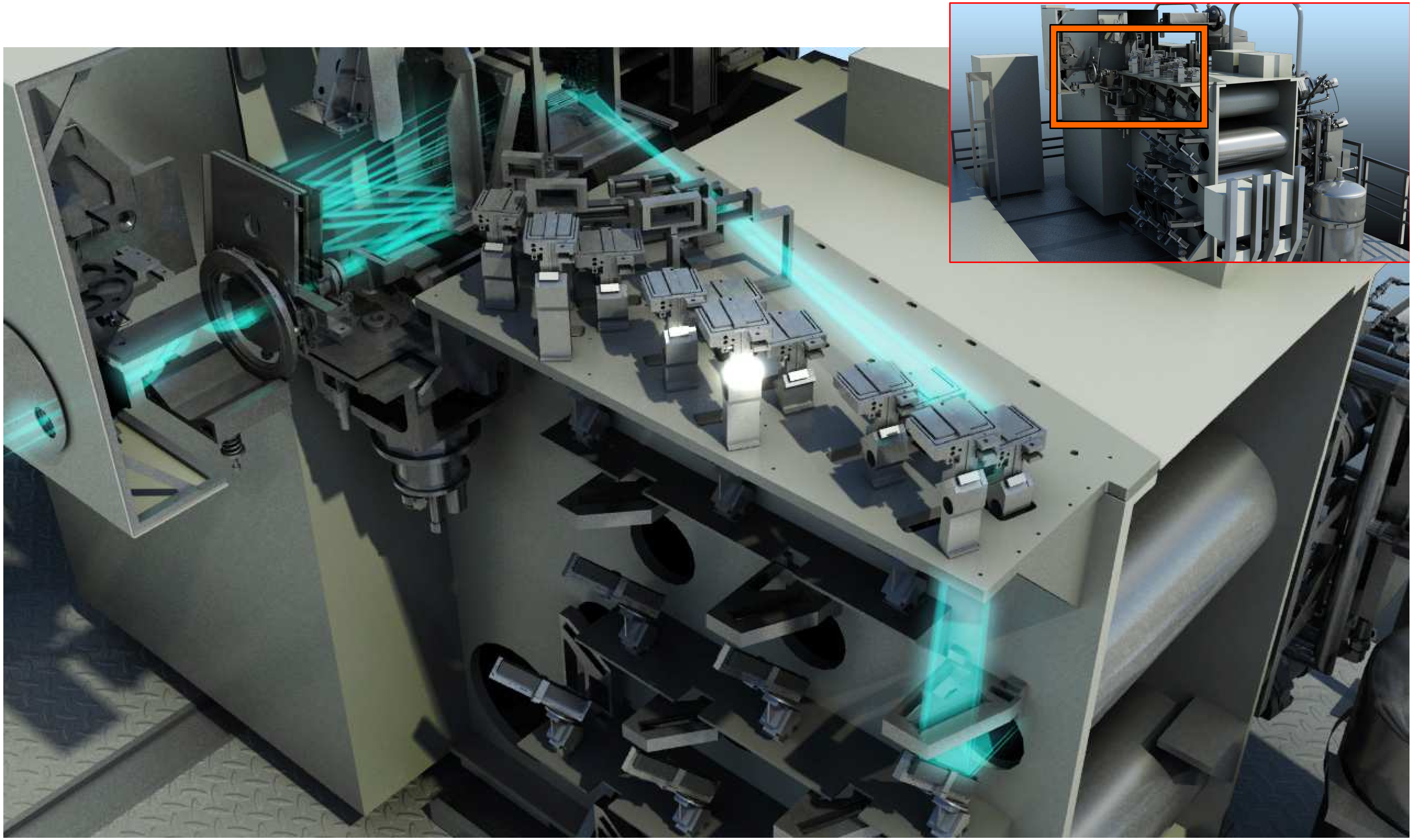
MUSE

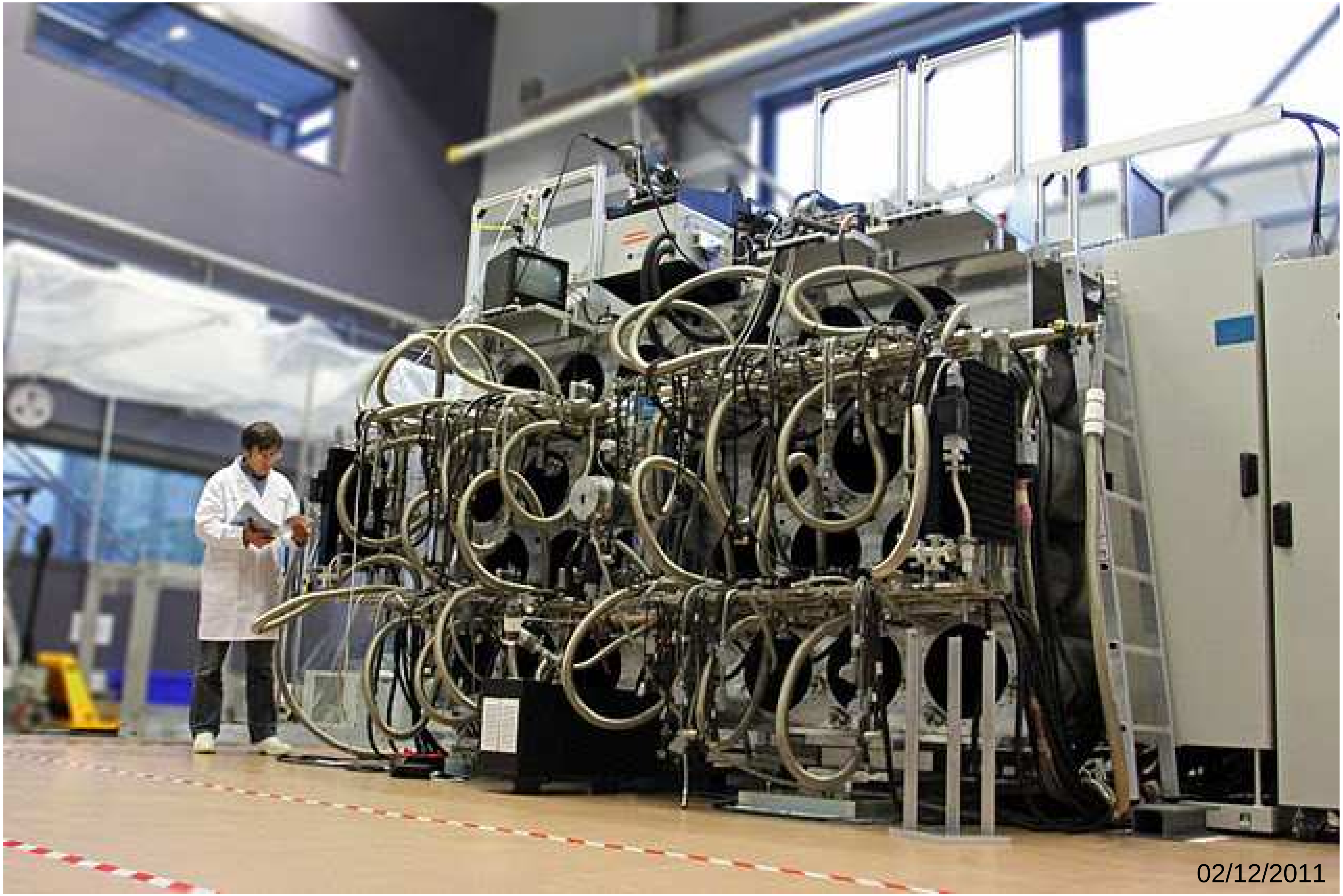


MUSE

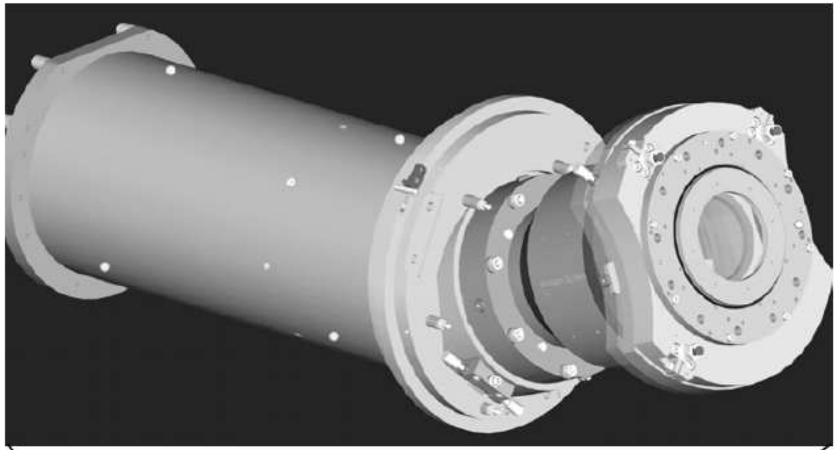


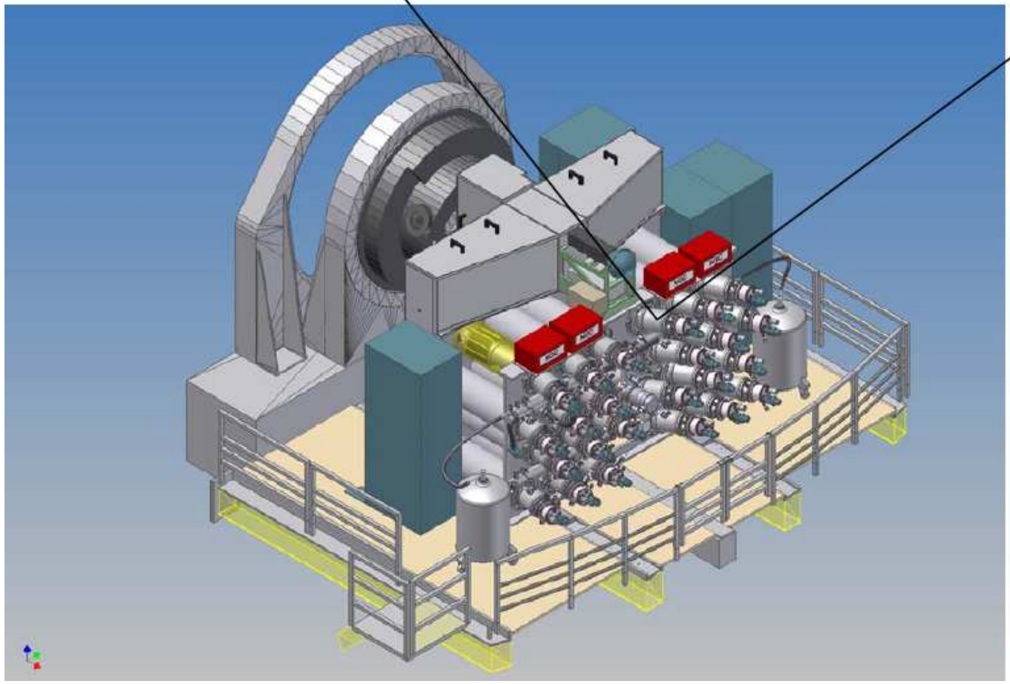
MUSE



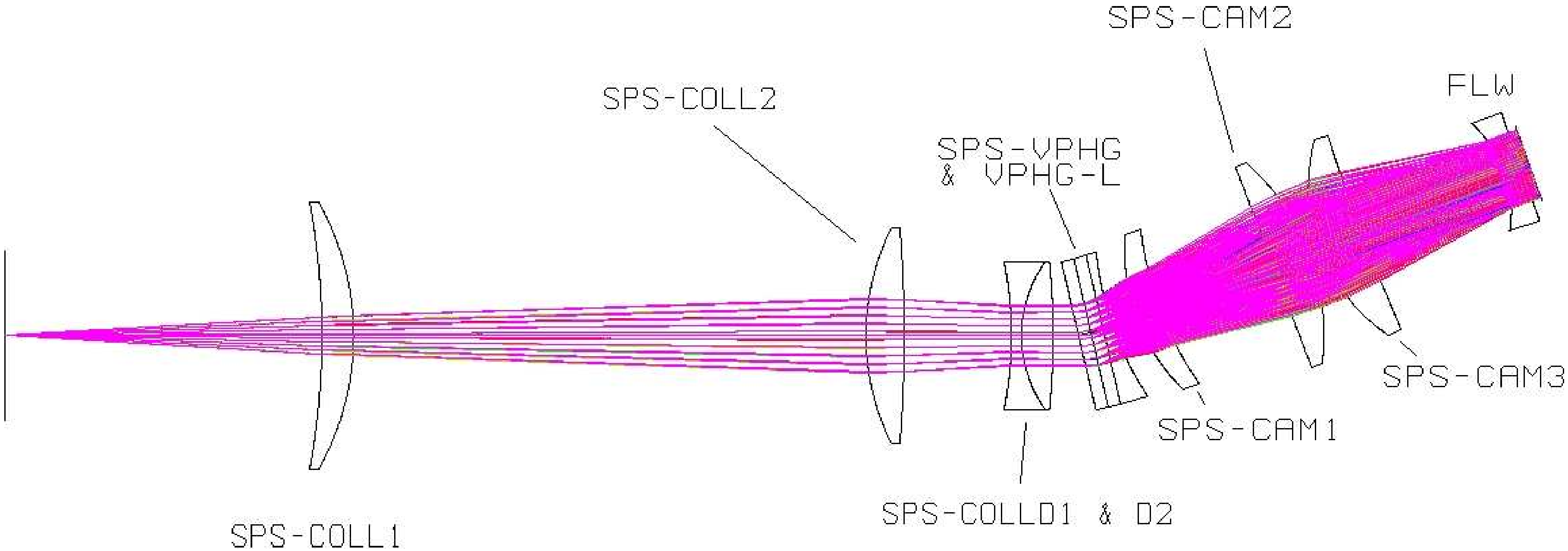

02/12/2011

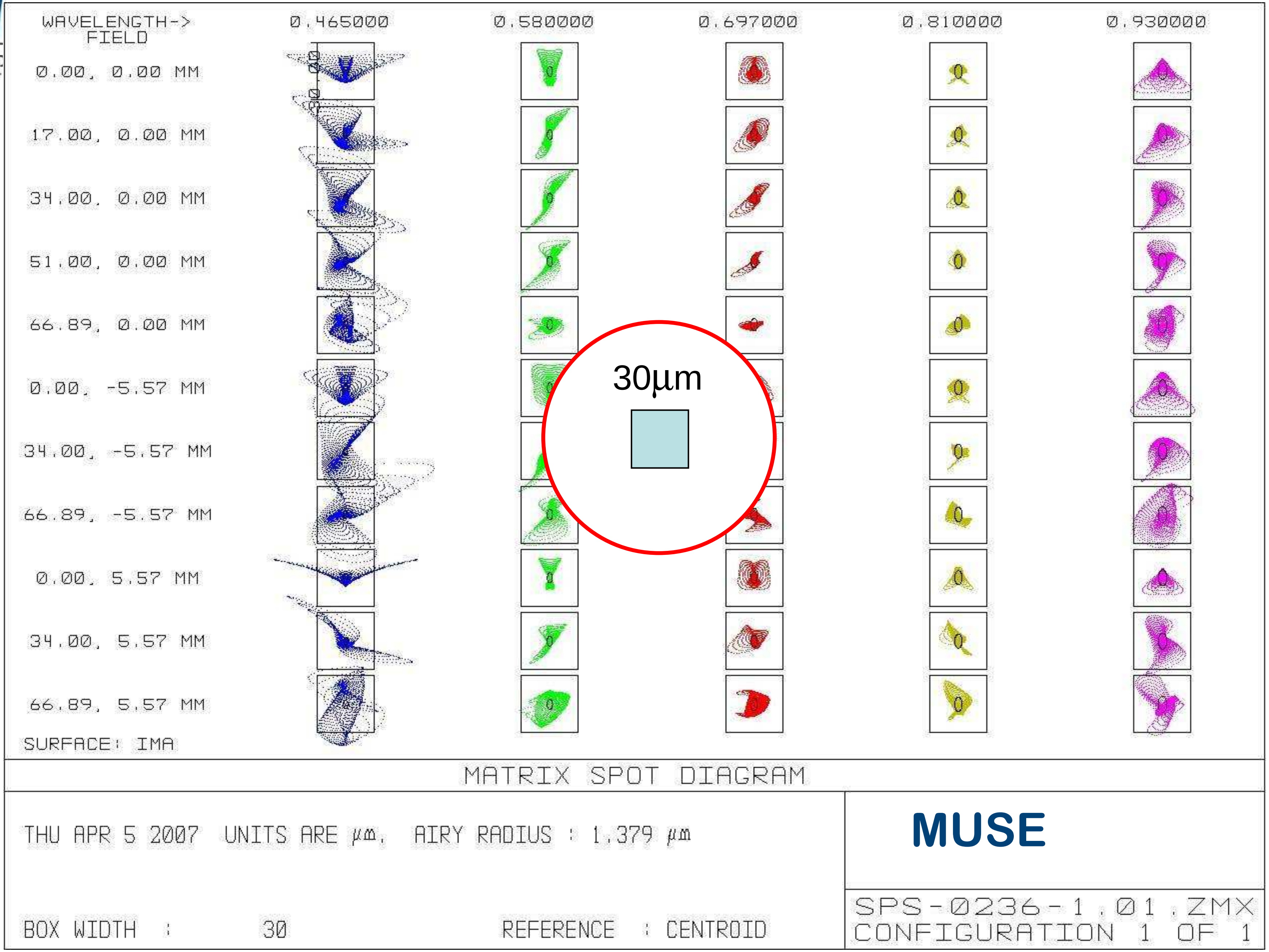
MUSE



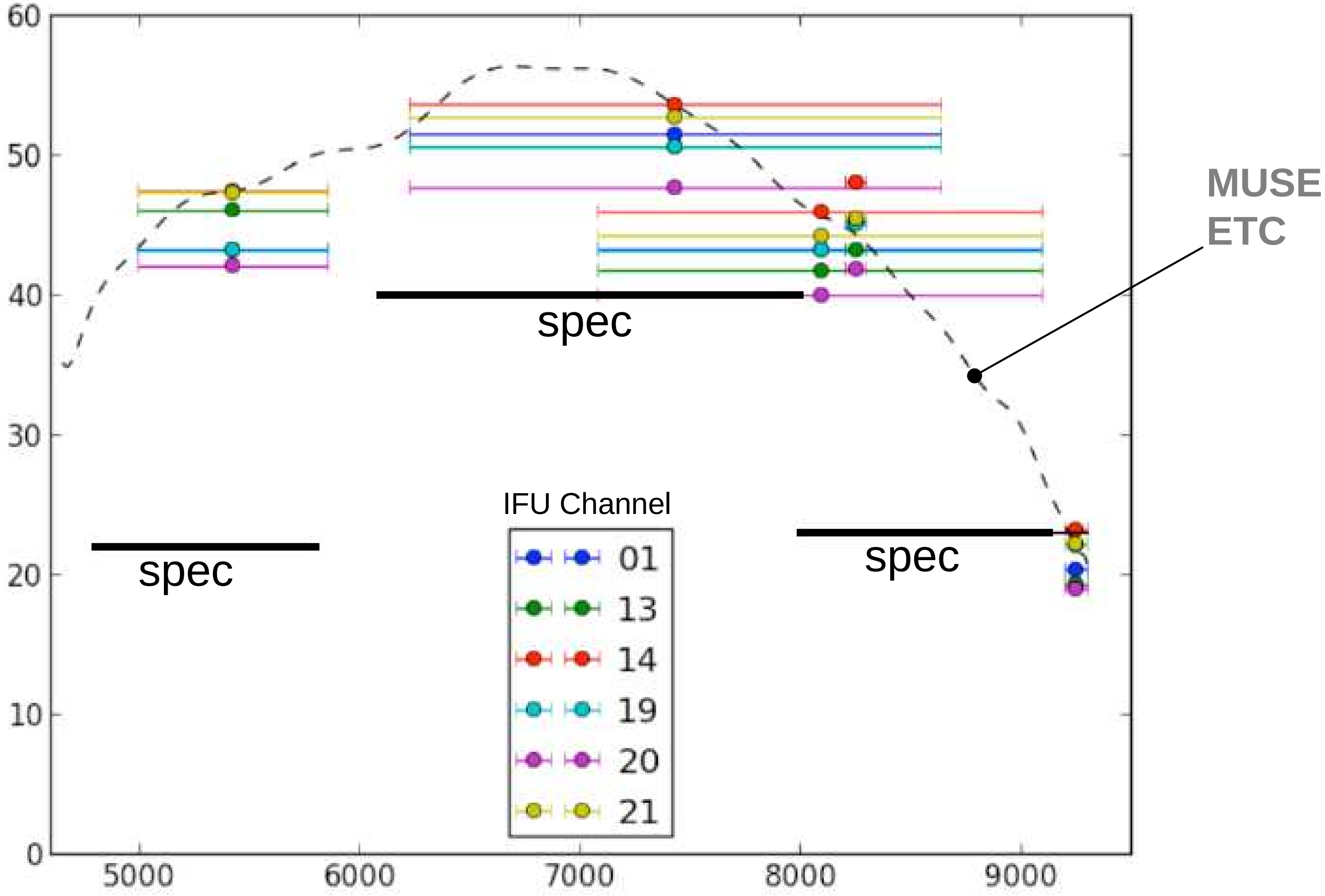


MUSE

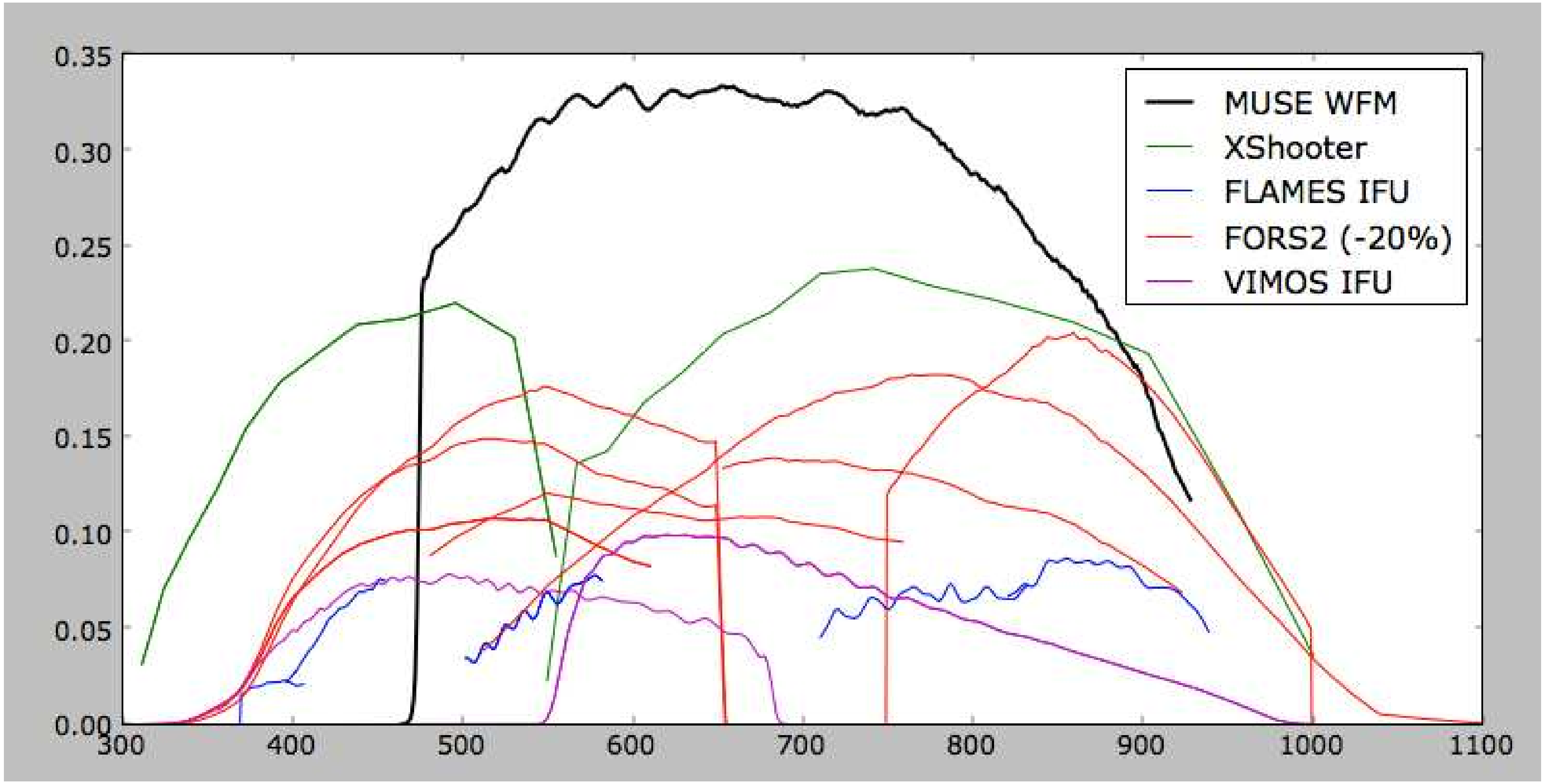

SPS-CAM2
FLW
SPS-COLL2
SPS-VPHG
& VPHG-L
SPS-CAM3
SPS-CAM1
SPS-COLLD1 & D2
SPS-COLL1


WAVELENGTH->
FIELD
0.465000
0.580000
0.697000
0.810000
0.930000
0.00, 0.00 MM
17.00, 0.00 MM
34.00, 0.00 MM
51.00, 0.00 MM
66.89, 0.00 MM
0.00, -5.57 MM
34.00, -5.57 MM
66.89, -5.57 MM
0.00, 5.57 MM
34.00, 5.57 MM
66.89, 5.57 MM
SURFACE: IMA
30µm
MATRIX SPOT DIAGRAM
THU APR 5 2007 UNITS ARE µm. AIRY RADIUS : 1.379 µm
BOX WIDTH : 30
REFERENCE : CENTROID
MUSE
SPS-0236-1.01.ZMX
CONFIGURATION 1 OF 1

Throughput Measurements, Test Report 15.4.2013

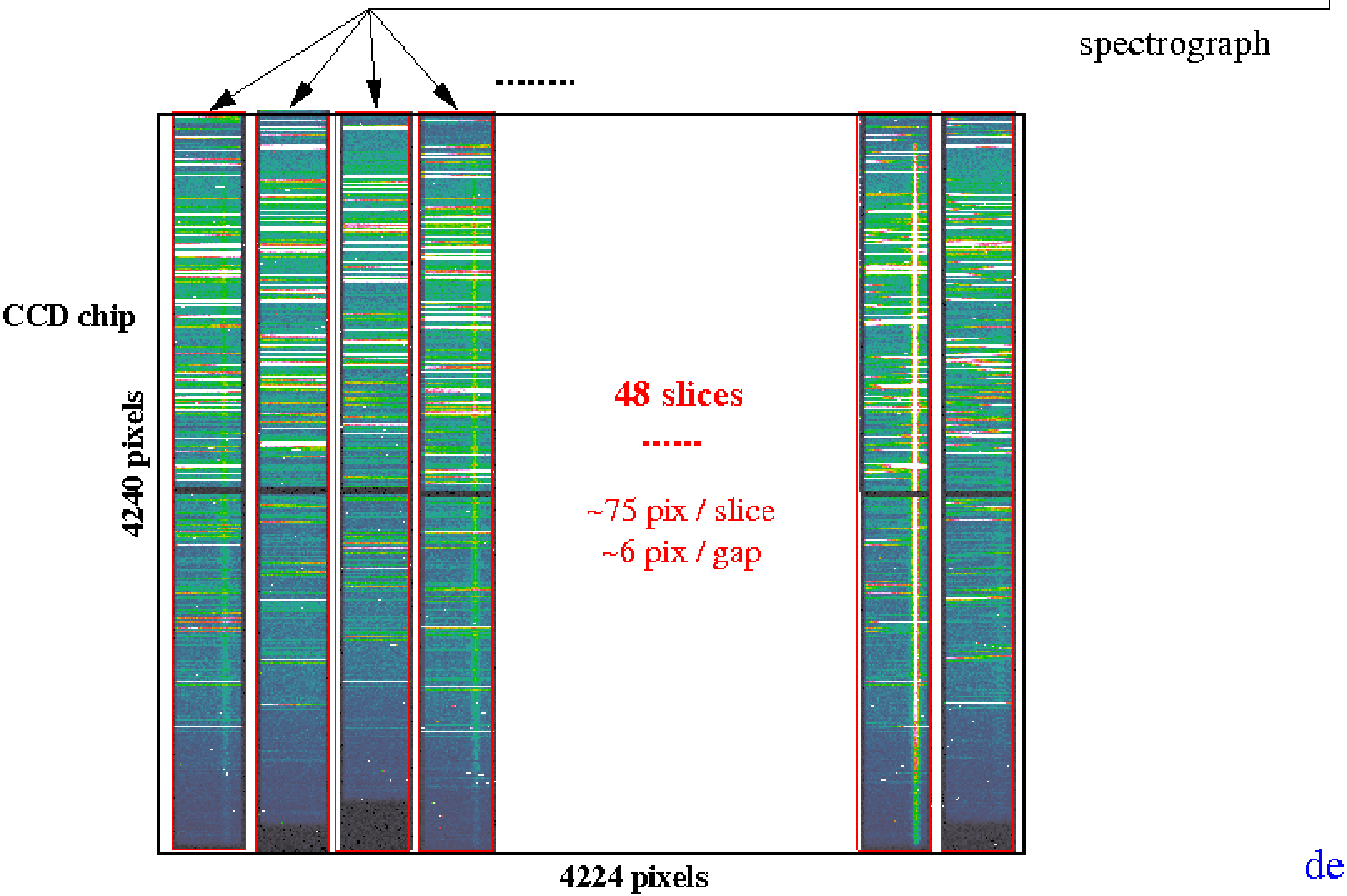


MUSE



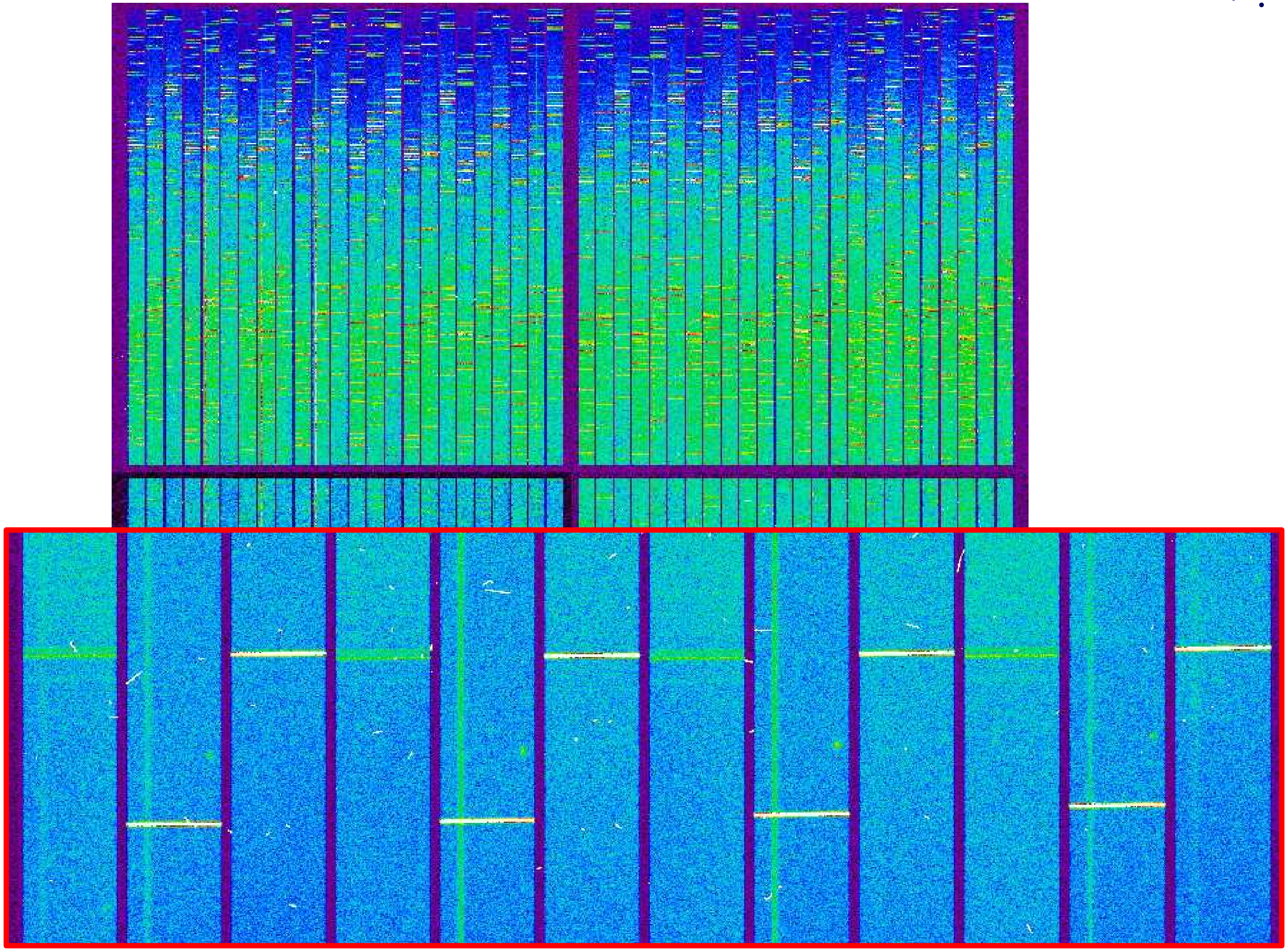
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
300
400
500
600
700
800
900
1000
1100
MUSE WFM
XShooter
FLAMES IFU
FORS2 (-20%)
VIMOS IFU

MUSE

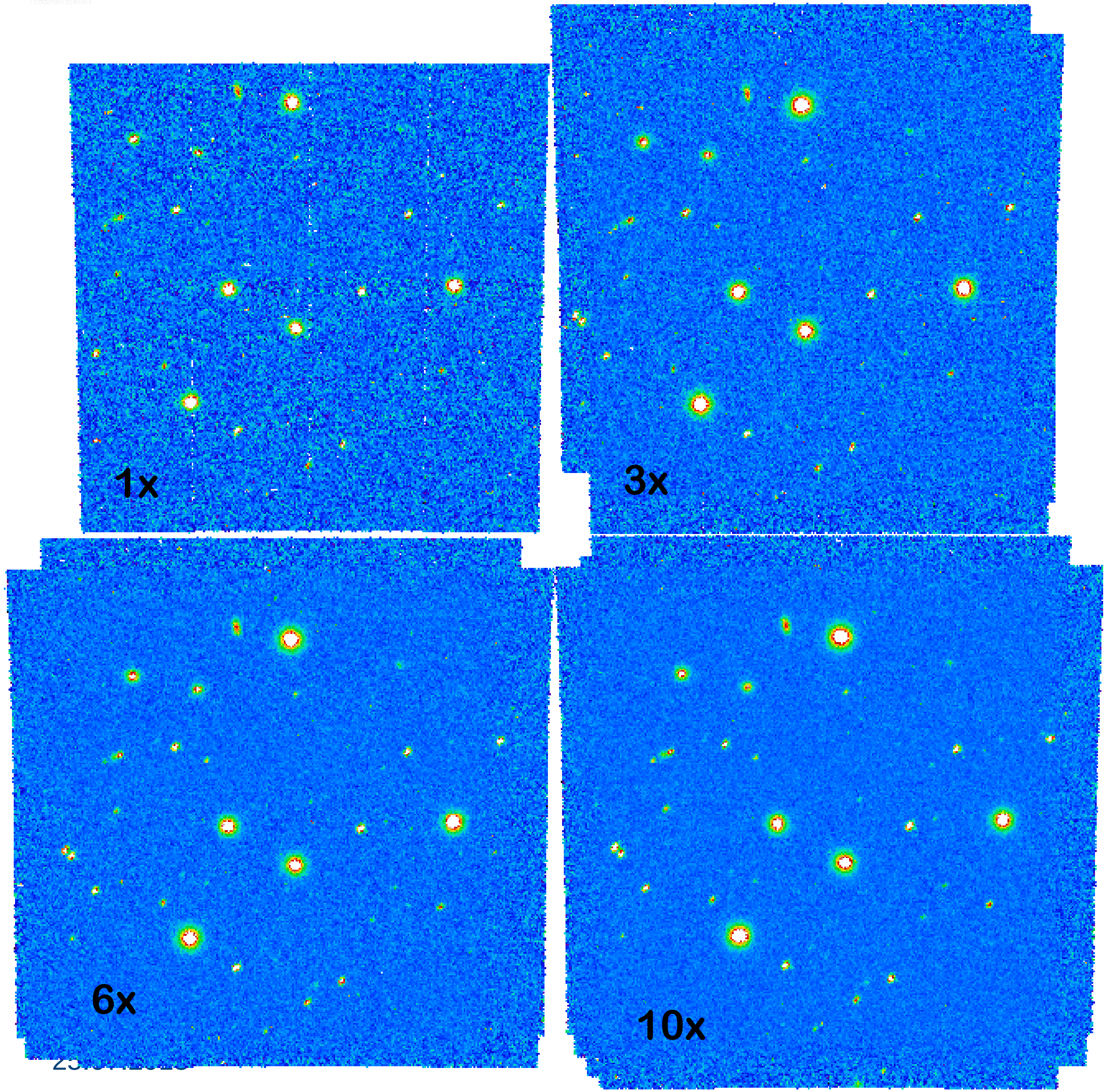


detection

MUSE



MUSE



Data Cube Simulations:

10 INM exposures:

- single frame
- 3 frames
- 6 frames
- 10 frames

Layer at 7001.2 Å

→ no artefacts

→ S/N as expected

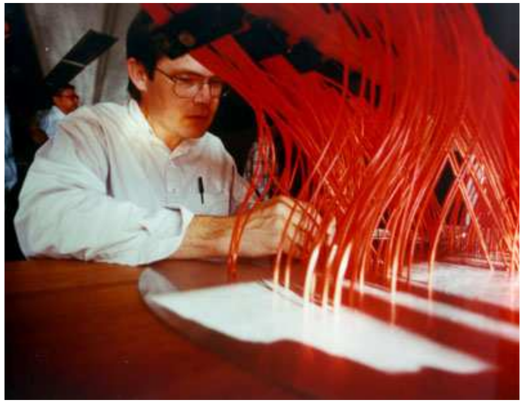
Comparison

VIRUS	MUSE
Fov: 75 x 50x50 arcsec^2	FoV: 1 arcmin^2
Sampling: 1.5 arcsec/fiber	0.2x0.2 arcsec^2
seeing-limited	ground-layer AO
350 – 570nm	(465) 480 – 930nm
Ly-α in $1.9 < z < 3.5$	Ly-α in $2.8 < z < 6.7$
R = 700	1750 - 3450

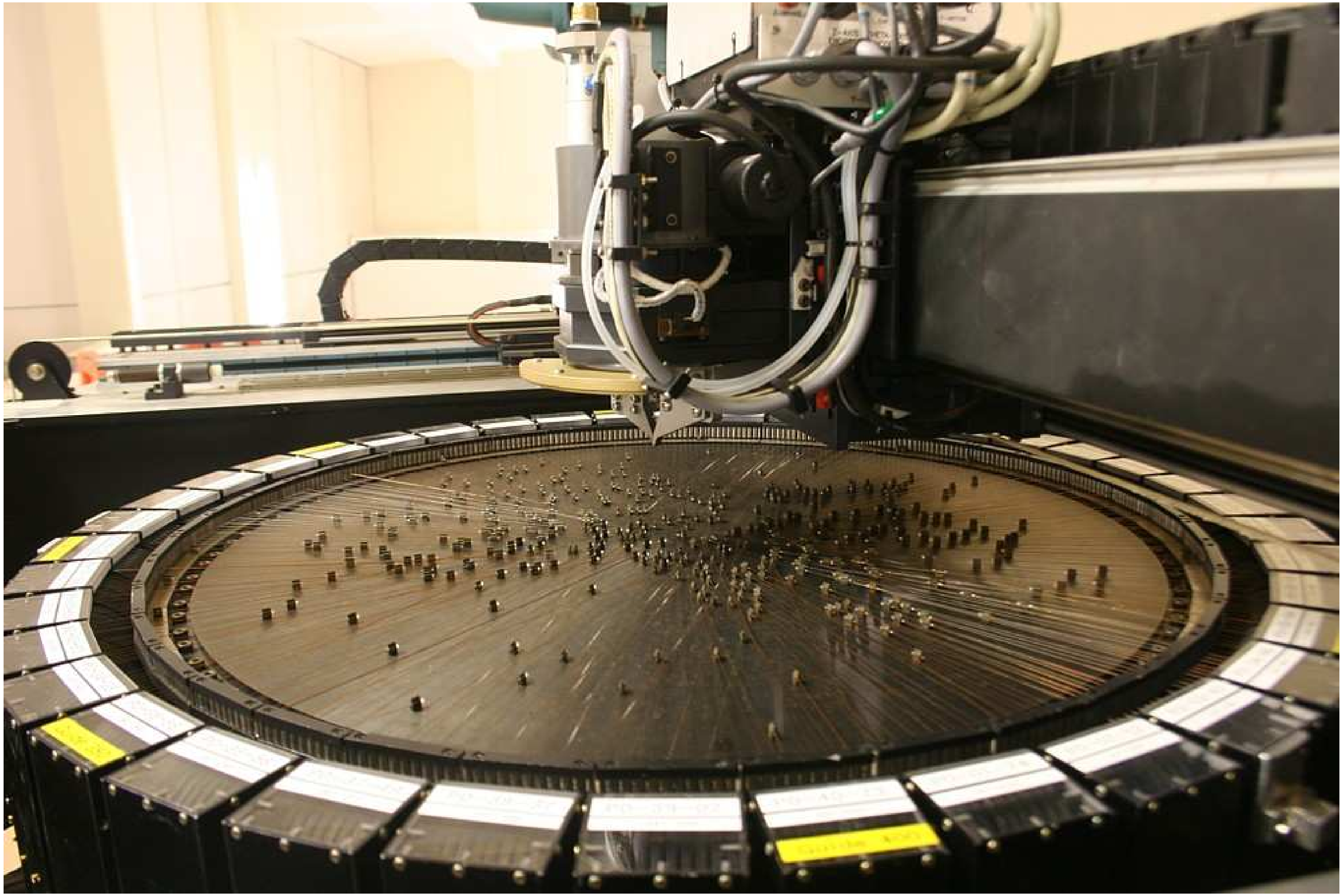
IV. 4th Generation IFS - IFU MOS

- SAMI
- MaNGA
- Fireball Concept

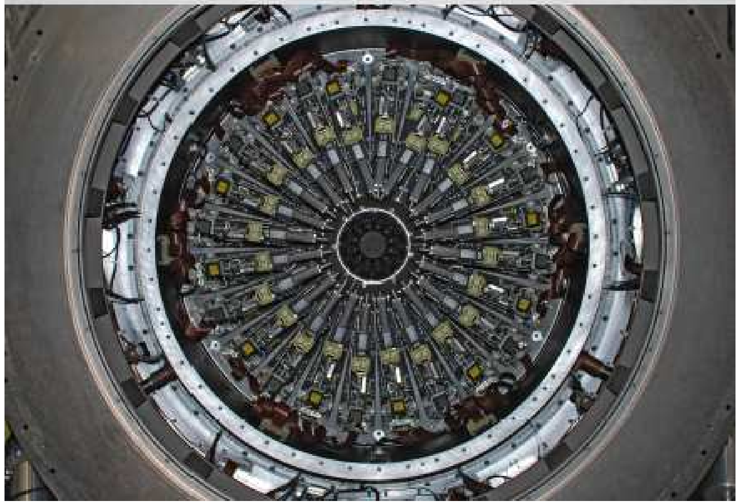
SLOAN Digital Sky Survey

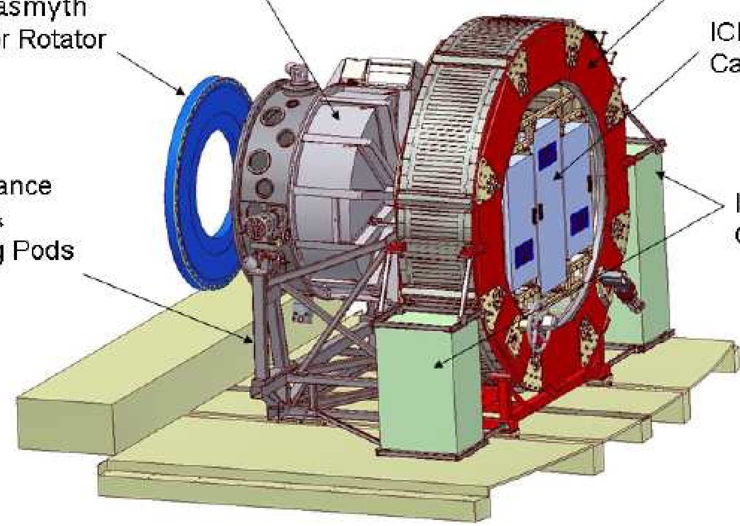


2dF



KMOS

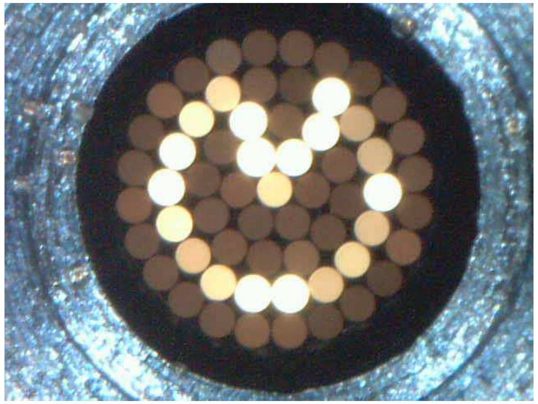




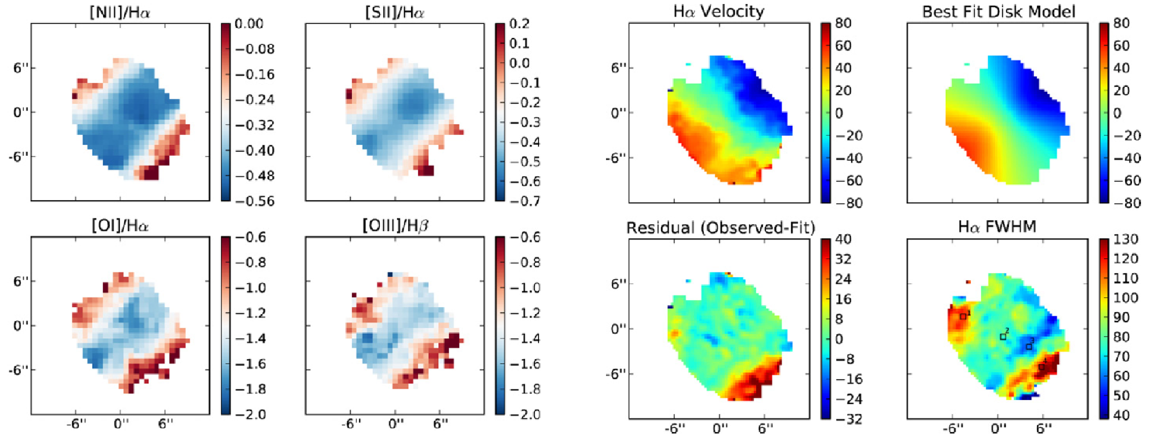
Wavelength coverage	**0.8µm to 2.5µm**
Spectral bands	**IZ, YJ, H, K, HK**
Spectral resolving power	**R = 3400, 3600, 4000, 4200, 2000 (IZ, YJ, H, K, HK)**
Number of IFUs	**24**
Extent of each IFU	**2.8” x 2.8”**
Spatial sampling	**0.2” x 0.2”**
Patrol field	**7.2 arcmin, circle**

Future/ongoing IFU-MOS surveys

SAMI (AAT)



Fogarty et al. 2012



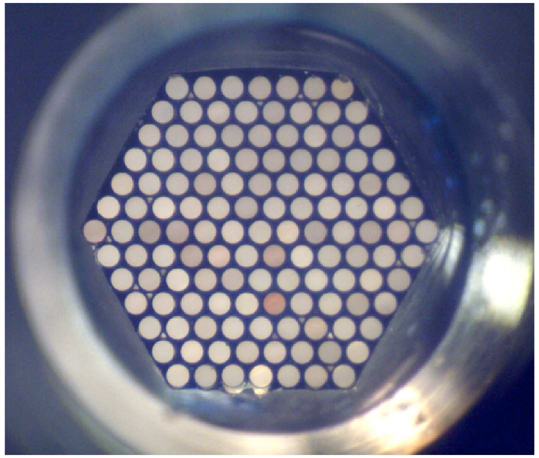
13 hexabundle IFUs
61 fibres per IFU

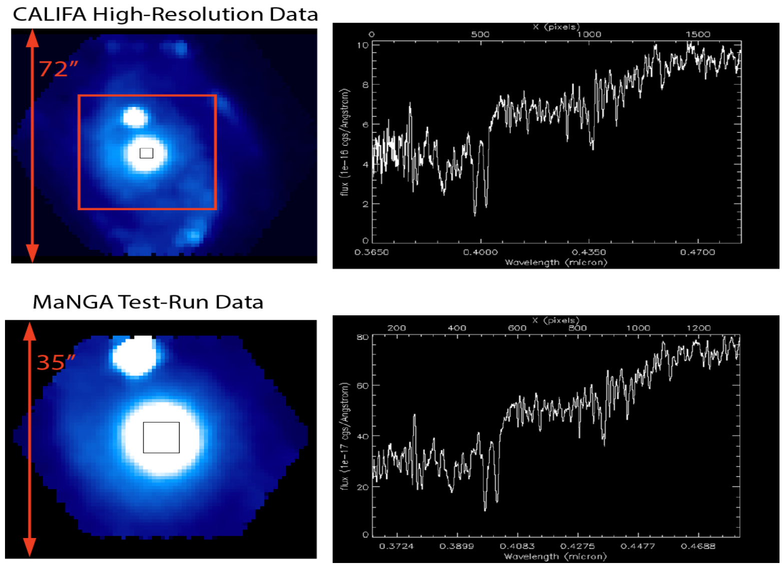
IFU FoV:	14.9 arcsec
sampling:	1.6 arcsec
patrol field:	1 degree
positioner:	plugg-plate

26 sky single fibres
AAO double-beam spectrograph
42m fibre cable

Future/ongoing IFU-MOS surveys

MaNGA (AS3)

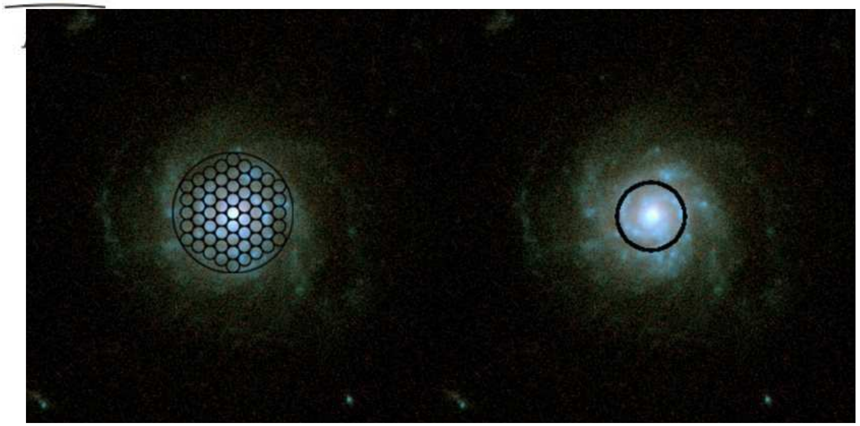


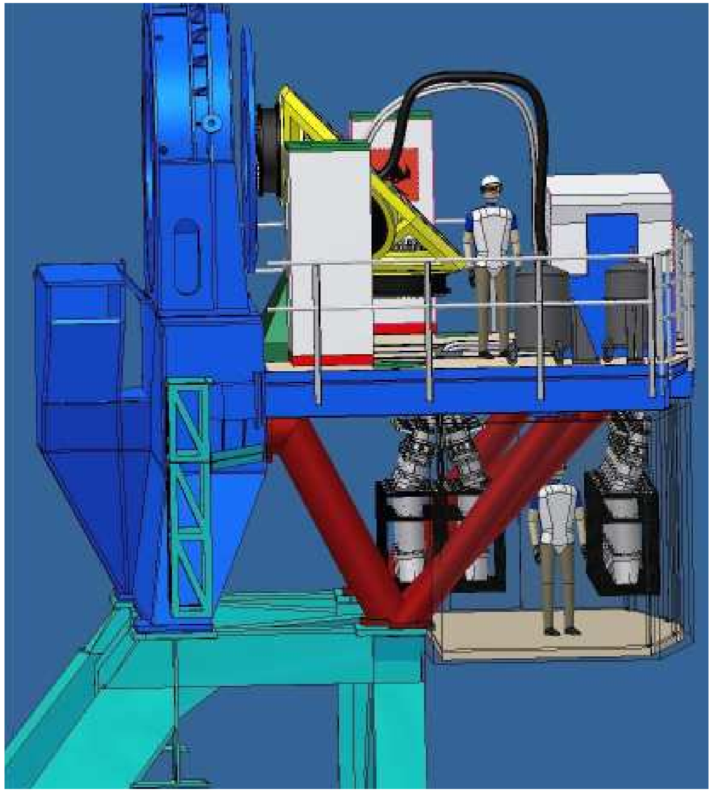


NGC 2916
(data from
recent test run)

1300 fibres in total,
19…125 fibres per IFU
IFU FoV: 14.9 arcsec
sampling: 2 arcsec
patrol field: 1.49 degree
238 sky single fibres
positioner: plugg-plate
BOSS spectrographs, 365 -1040nm, R=1500…2500
2.5m fibre bundle

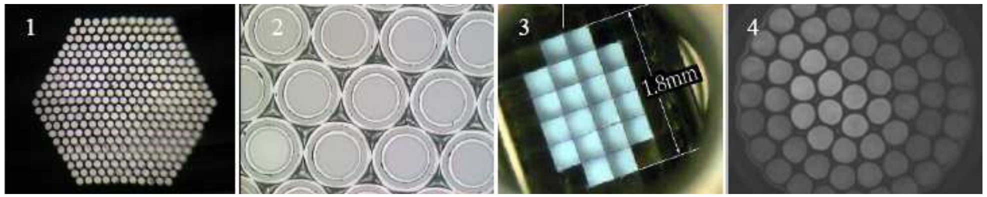
FIREBALL Concept





FIREBALL Baseline Parameters

- FLAMES OzPoz patrol field with 26’ diameter FoV
- 90 hexabundle IFUs, each with ~5” diameter FoV
- Hexabundles: 61 fibres, 0.6” projected fibre core diameter
- 6 spectrographs, adapted for fibre-feed, R~1200-2100
- free spectral range: 430-850nm (goal: blue extension)
- total throughput goal: 30%
- sensitivity: R ~19.8 survey limit, resulting in 100-160 galaxies per FLAMES field at median z ~ 0.2; typical half-light sizes for disk galaxies 2”-6” diameter
- detector head, NGC CCD controller, vacuum/cooling system adapted from MUSE
- individual spectrograph shutters
- no moving parts other than shutters + fibre positioner
- retain full existing facility and utilise as much FLAMES infrastructure as practical



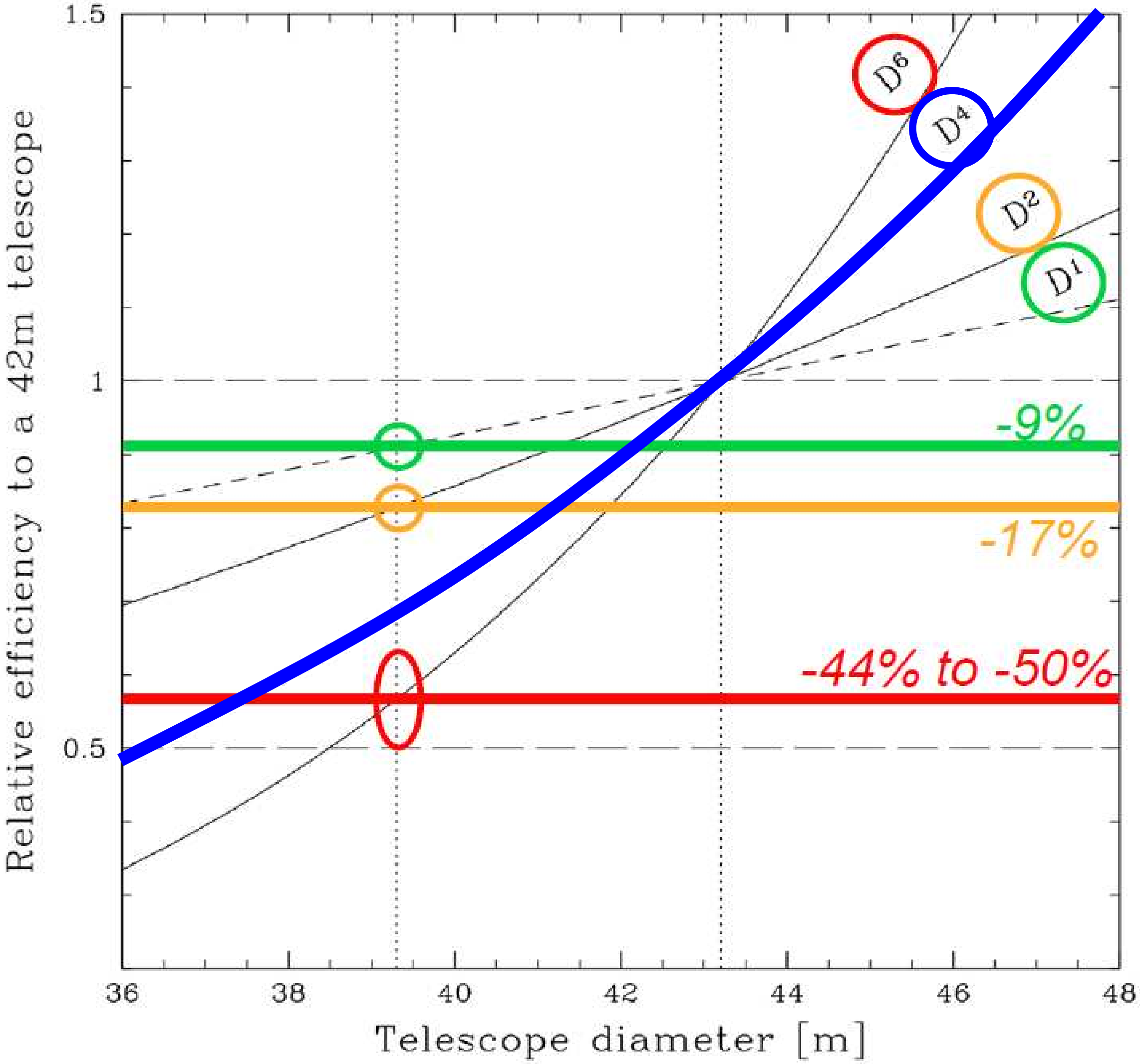

Newport

Conclusions

- choice of design:
  single purpose versus general user instrument
- targeted, single purpose design is a sufficient, however not necessary condition for sucess (e.g. SIMS, CALIFA)
- complex versus simple design:
  efficiency, stability, reliability, cost
- series production, modularity
- IFS is complex, IFU-MOS adds another complexity
- due to complexity, instrumentation must go in lock-step with community involvement

V. Epilogue
Future IFUs at ELT

E-ELT
Delta-Phase-B Trade-Off



~ **D^6**: *direct imaging of explanets*

~ **D^4**: *AO-limited observation, e.g. stellar spectroscopy in Virgo Cluster galaxies*

~ **D^2**: *photon-limited observations, e.g. cosmic expansion → CODEX*

~ **D^1**: *resolution limited obs., e.g. resolved stellar populations*

~ **D^0**: *RV research of exoplanets*

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DAOPHOT: A COMPUTER PROGRAM FOR CROWDED-FIELD STELLAR PHOTOMETRY

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ABSTRACT

The difficult art of stellar photometry in crowded fields is currently undergoing a surge of popularity, and a number of different computer programs for deriving photometric information from two-dimensional digital images are currently in use. This paper describes one such program, DAOPHOT, which was written and continues to be developed at the Dominion Astrophysical Observatory. Emphasis is placed on the various types of philosophical and technical complications which arise when accurate photometry is sought for blended stellar images, and on the mathematical algorithms with which DAOPHOT attempts to deal with these complications, rather than on details of the coding. Some ways in which DAOPHOT resembles or differs from other similar programs are mentioned, and a discussion is presented of known shortcomings of the current program as well as possibilities for future improvement.

Key words: data-handling techniques–photometry (general)

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Resolving stellar populations with crowded field 3D spectroscopy⋆,⋆⋆

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ABSTRACT

We describe a new method of extracting the spectra of stars from observations of crowded stellar fields with integral field spectroscopy (IFS). Our approach extends the well-established concept of crowded field photometry in images into the domain of 3-dimensional spectroscopic datacubes. The main features of our algorithm follow. (1) We assume that a high-fidelity input source catalogue already exists, e.g. from HST data, and that it is not needed to perform sophisticated source detection in the IFS data. (2) Source positions and properties of the point spread function (PSF) vary smoothly between spectral layers of the datacube, and these variations can be described by simple fitting functions. (3) The shape of the PSF can be adequately described by an analytical function. Even without isolated PSF calibrator stars we can therefore estimate the PSF by a model fit to the full ensemble of stars visible within the field of view. (4) By using sparse matrices to describe the sources, the problem of extracting the spectra of many stars simultaneously becomes computationally tractable. We present extensive performance and validation tests of our algorithm using realistic simulated datacubes that closely reproduce actual IFS observations of the central regions of Galactic globular clusters. We investigate the quality of the extracted spectra under the effects of crowding with respect to the resulting signal-to-noise ratios (S/N) and any possible changes in the continuum level, as well as with respect to absorption line spectral parameters, radial velocities, and equivalent widths. The main effect of blending between two nearby stars is a decrease in the S/N in their spectra. The effect increases with the crowding in the field in a way that the maximum number of stars with useful spectra is always ~0.2 per spatial resolution element. This balance breaks down when exceeding a total source density of one significantly detected star per resolution element. We also explore the effects of PSF mismatch and other systematics. We close with an outlook by applying our method to a simulated globular cluster observation with the upcoming MUSE instrument at the ESO-VLT.

Key words. methods: data analysis – techniques: imaging spectroscopy – globular clusters: general