BLUE muse

multi unit spectroscopic explorer

CRAL AAO AIM AIP ia Durham University ÉCOLE POLYTECHNIQUE FÉDÉRALE DE LAUSANNE UNIVERSITÉ DE GENÈVE LAM LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE Stockholm University

A Blue MUSE for the VLT

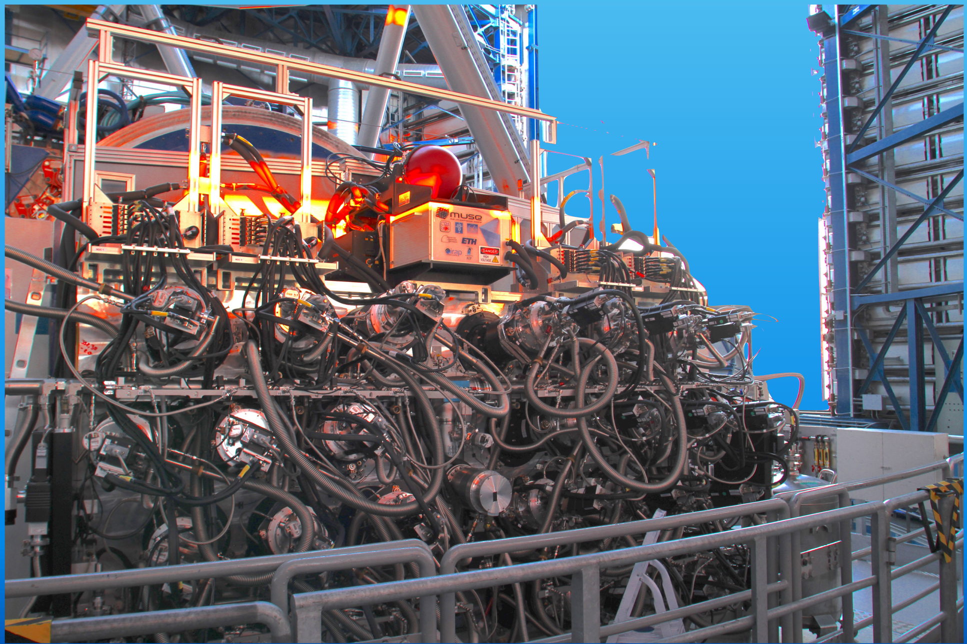
Johan Richard (CRAL)

Martin Roth (AIP)

Multi Unit Spectroscopic Explorer (MUSE)

- Large field IFU
- Visible 480-930 nm, R~3000
- Field 1'x1', 0.2" (WFM)
- Field 7"x7", 0.025" (NFM)

- Coupled to ESO AO Facility
  - 0"5 (WFM) & diffraction limited (NFM) resolution
- Throughput
  - 40% end-to-end

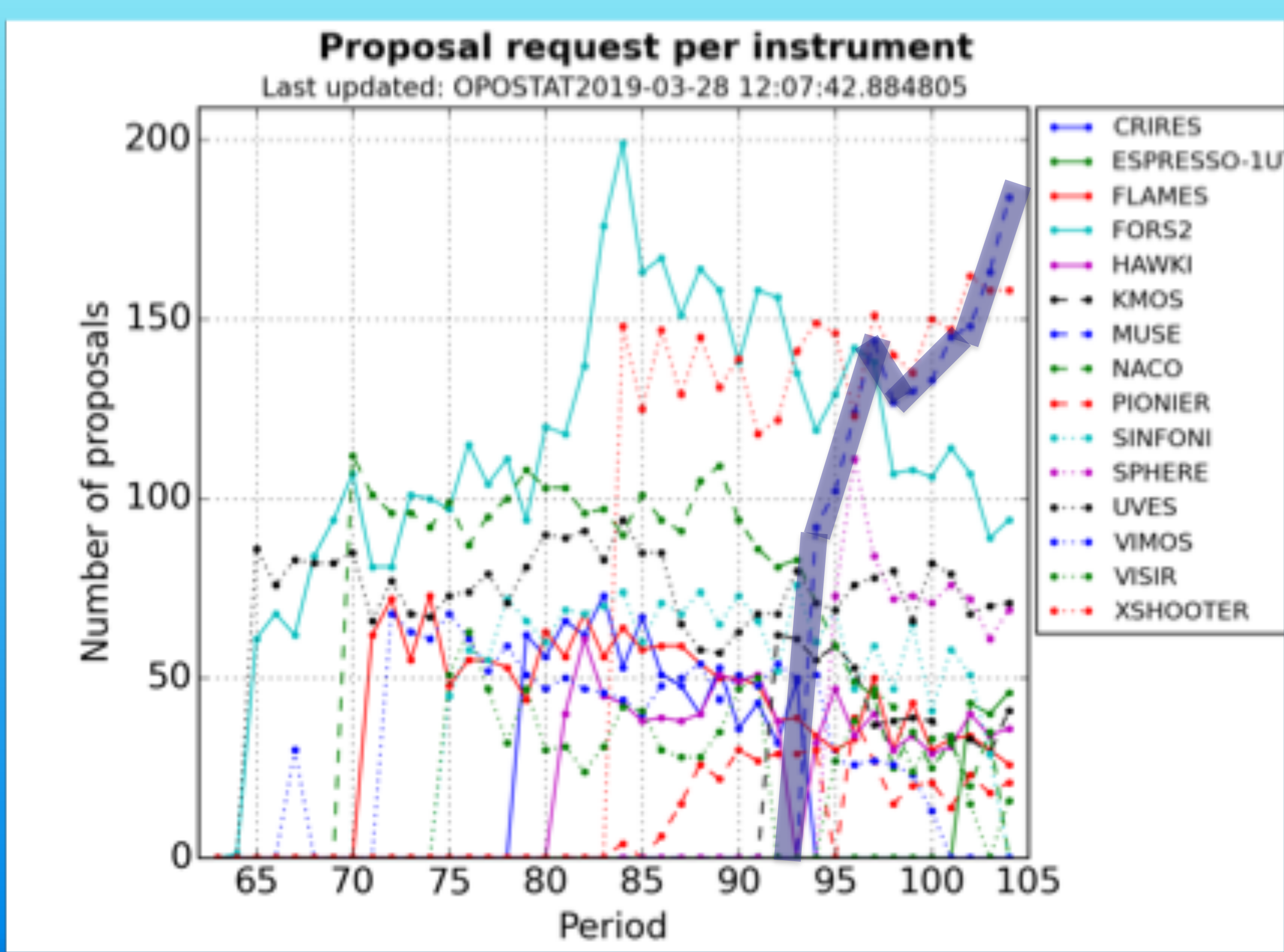


- An IFU with the image quality of an imager
- Very efficient in deep spectroscopy and crowded fields
- High multiplexing capabilities
- Simple to use and operate!

MUSE Statistics

Requested Nights

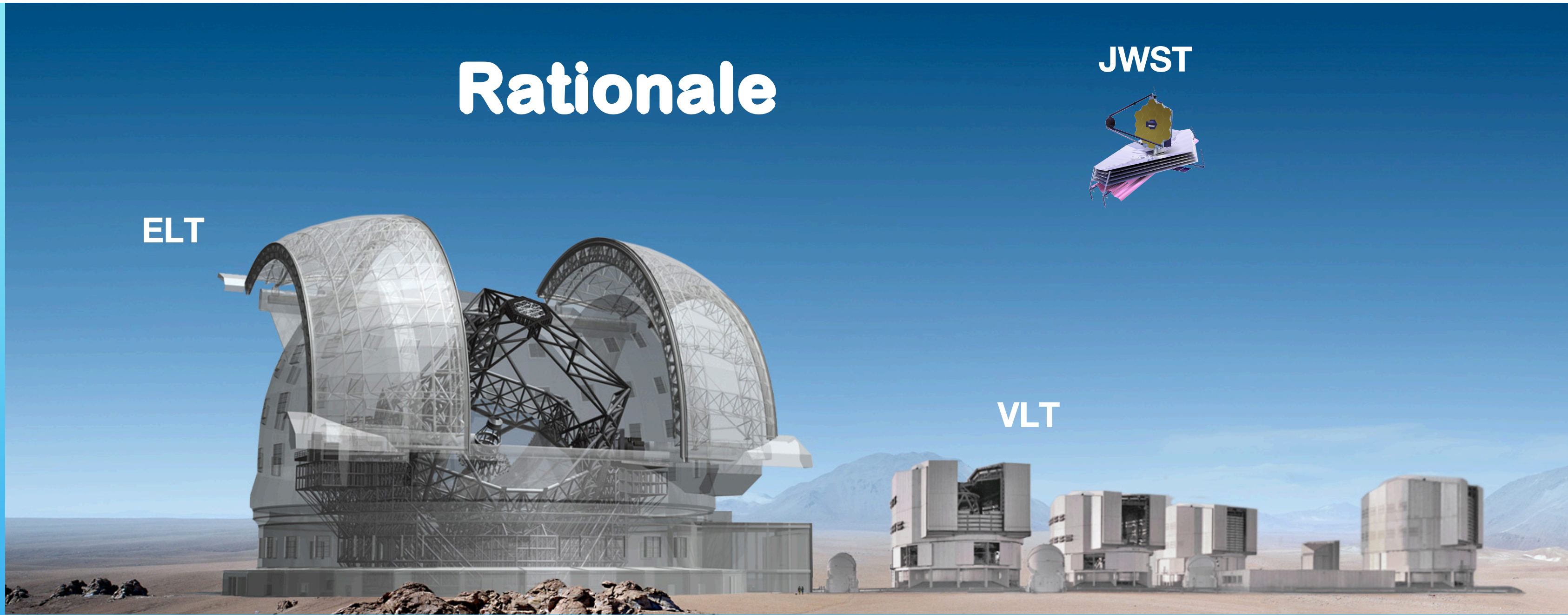
	XShooter	MUSE	FORS2
P97	221	220	215
P98	255	229	231
P99	188	203	198
P100	287	266	196
P101	201	186	177
P102	274	277	222
P103	280	250	140
P104	290	380	180



(B. Leibundgut's presentation)

BLUE MUSE — multi unit spectroscopic explorer

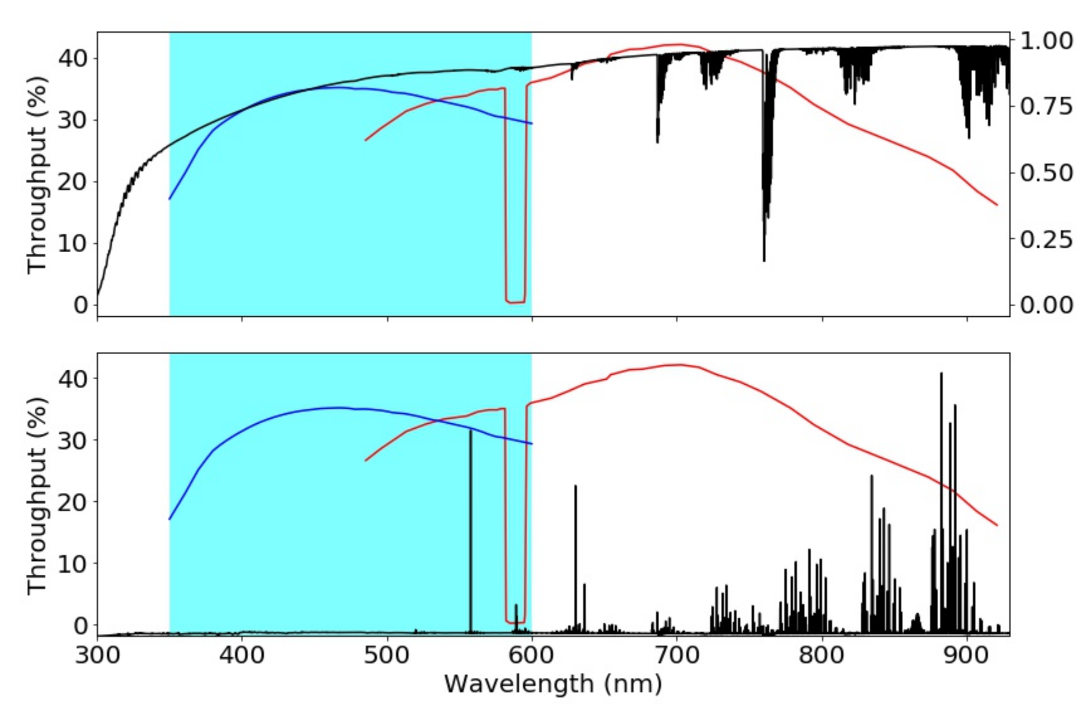
Rationale



- MUSE is a success: it is unique, largely over-subscribed, and has a high publication rate
- There is room for a 2nd MUSE type instrument
- By 2025-2030 the ELT and JWST instruments will focus on red and infrared wavelengths.
- The best mid-term solution is a complementary MUSE on another UT: BlueMUSE

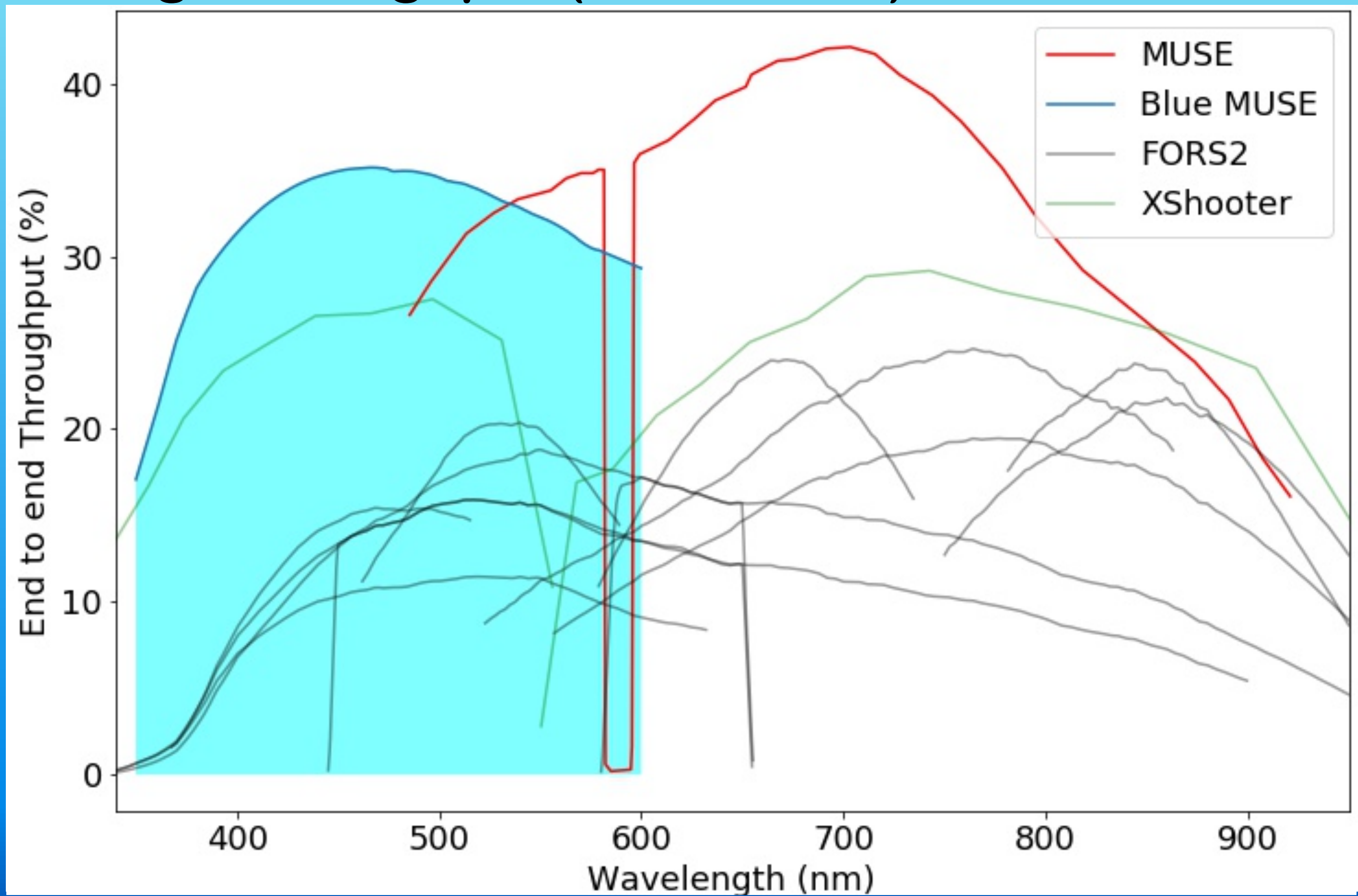
Top Level Parameters

- **Blue wavelength coverage: 350 - 600 nm**
  - **Complementarity with MUSE**
  - **Bluest limit adapted to atmosphere transmission (65% transmission)**
  - **Red limit might recover AO notch filter gap.**



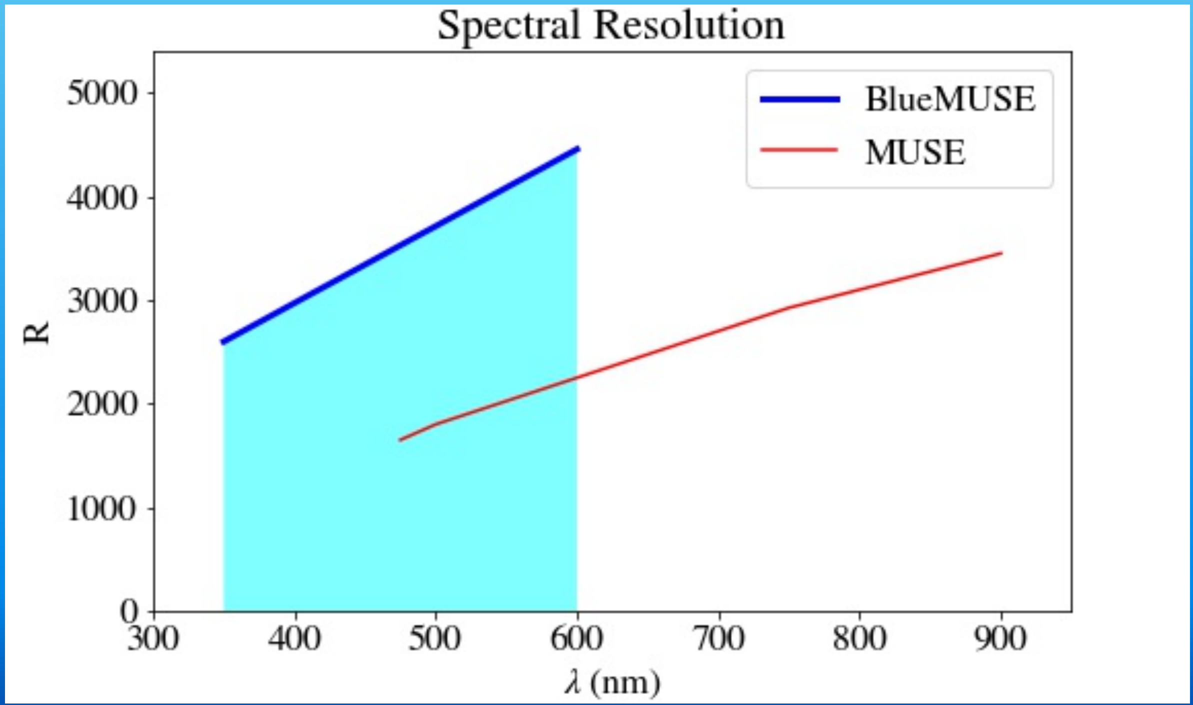
Top Level Parameters

- **High throughput (end-to-end)**



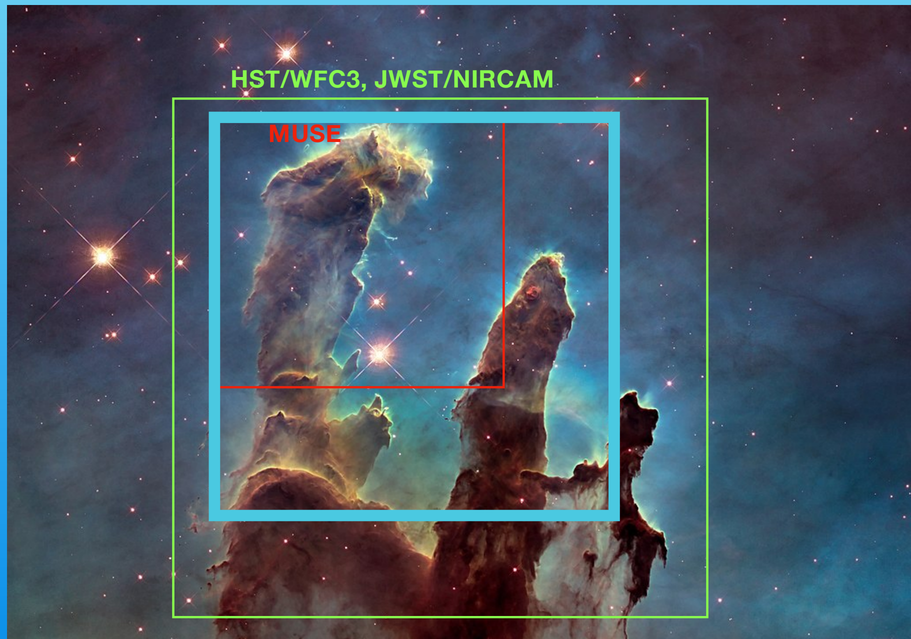
Top Level Parameters

- **Medium spectral resolution: R=3600 in average**
  - **Corresponds to 30 km/s at 480 nm**
  - **more than twice the MUSE spectral resolution at 465 nm < λ < 600 nm**
  - **Spectral sampling: 0.58 Å / pixel**

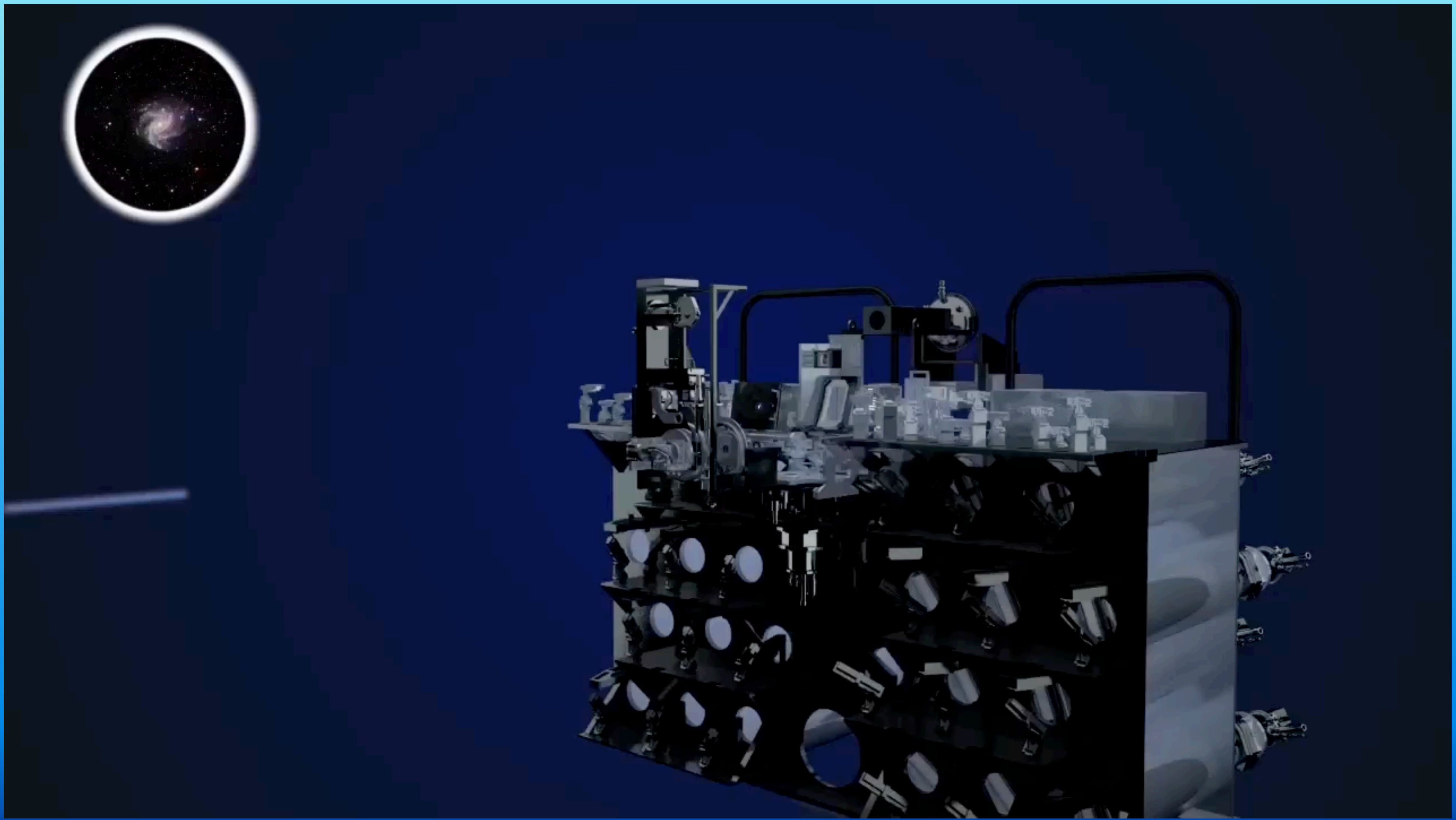


Top Level Parameters

- Larger field of view: 1.4 x 1.4 arcmin



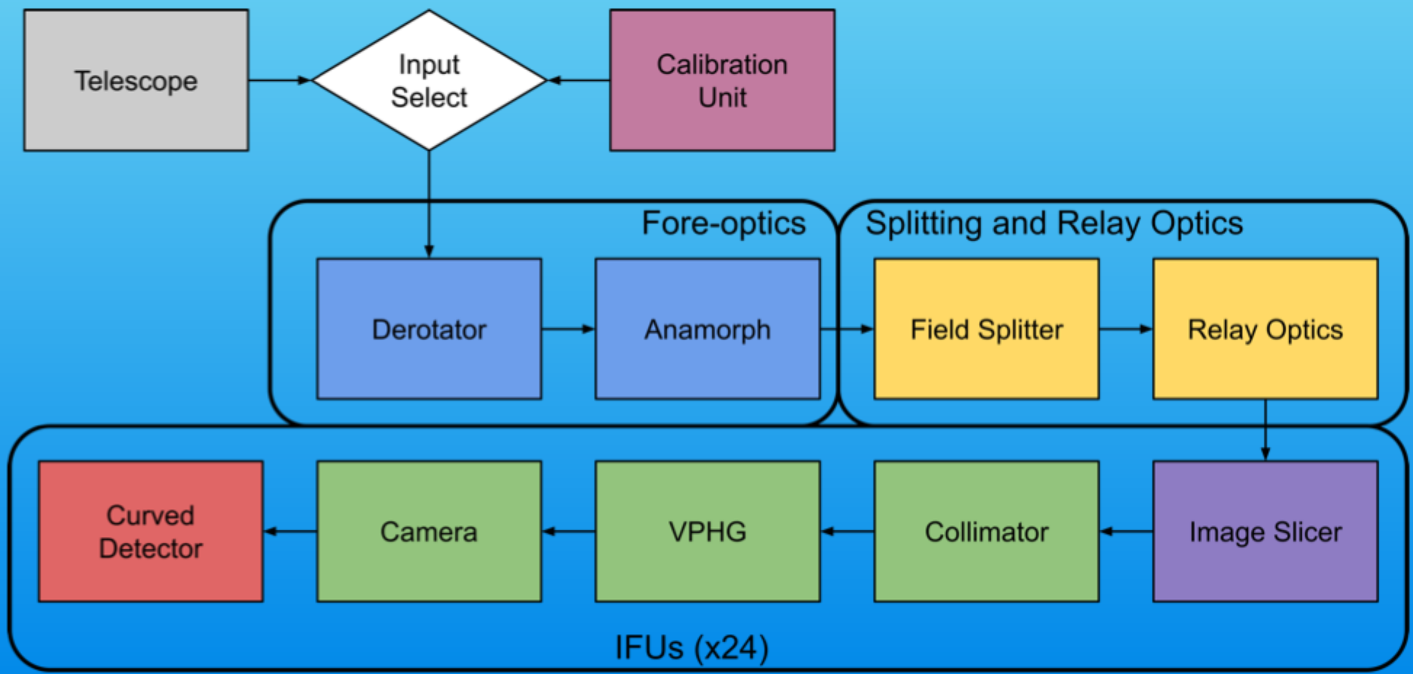
Sampling: 0.3” pixels (0.8” median seeing)



BlueMUSE Sub-Systems Design

Alexandre Jeanneau (CRAL), Eduard Muslimov (LAM), Emmanuel Hugo (LAM), Patrick Caillier (CRAL, ESO)

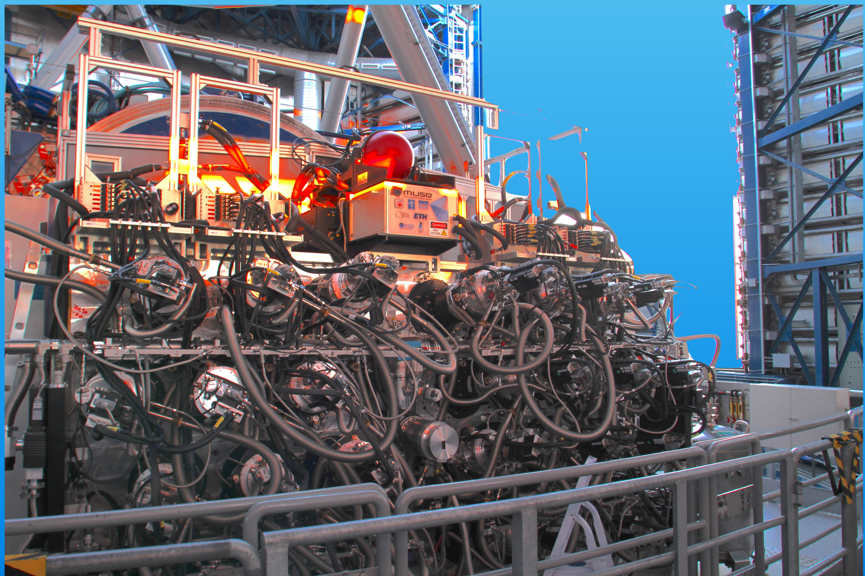
See the Poster!

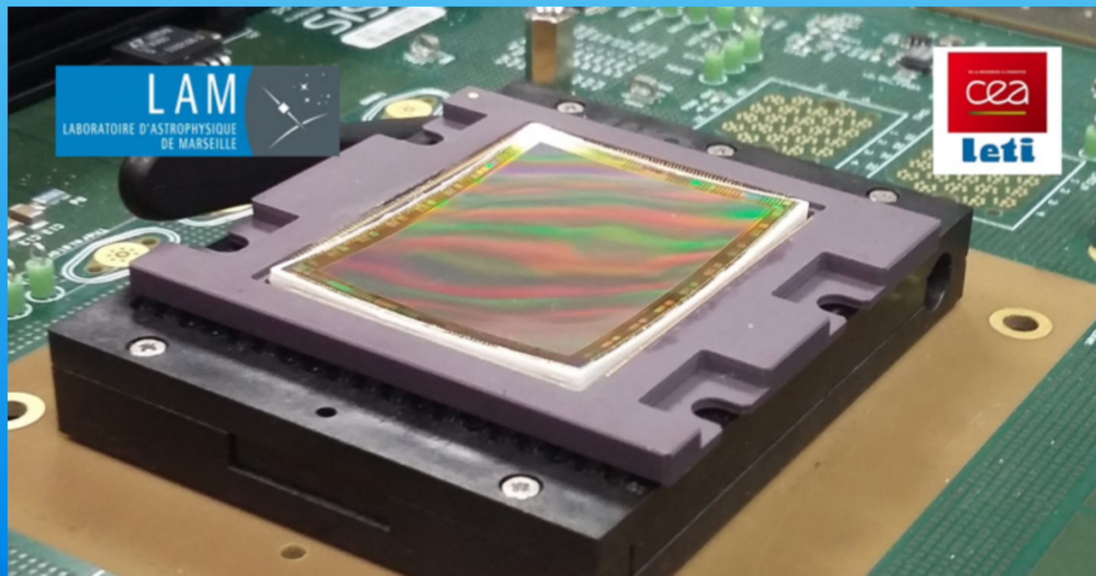


- Single mode: no plate scale change, no filter wheel
- Larger Fore-optics and longer relays
- Thermal control (enclosure)
- Curved detector

BlueMUSE Optical design

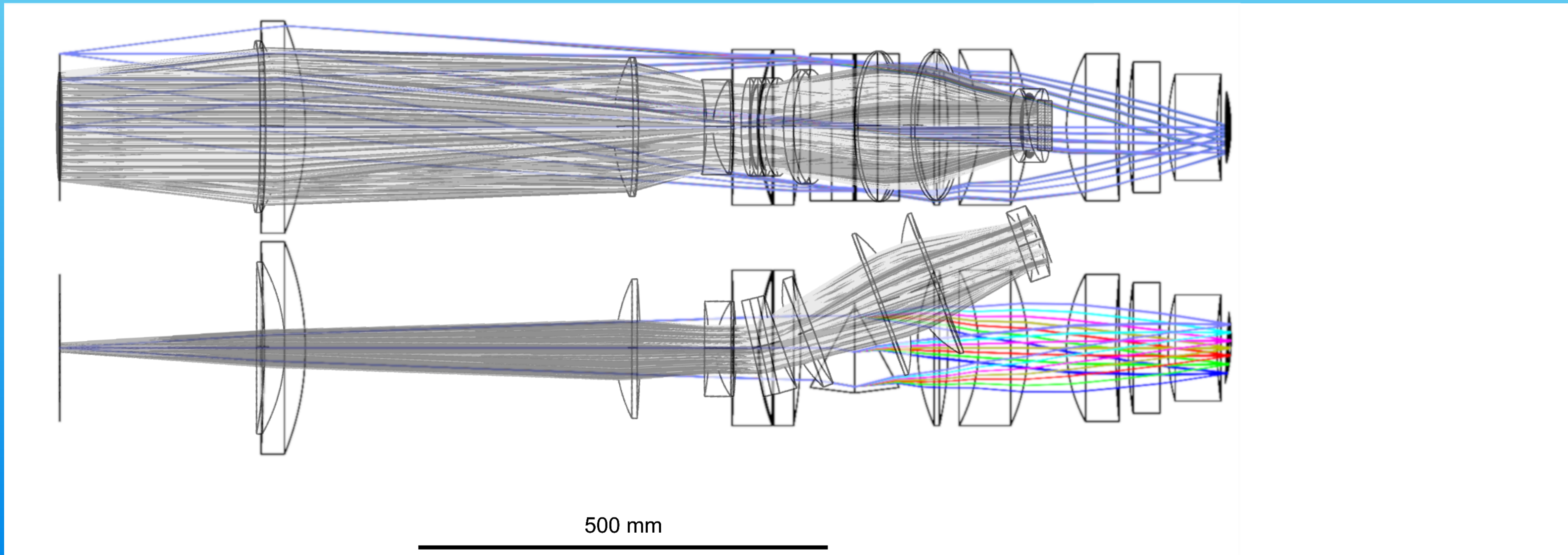
- A first optical design has been created for first feasibility
- MUSE already takes the entire space on the VLT Nasmyth platform: a larger FOV needs larger optics and seems difficult
- The solution currently studied is the use of curved detectors.





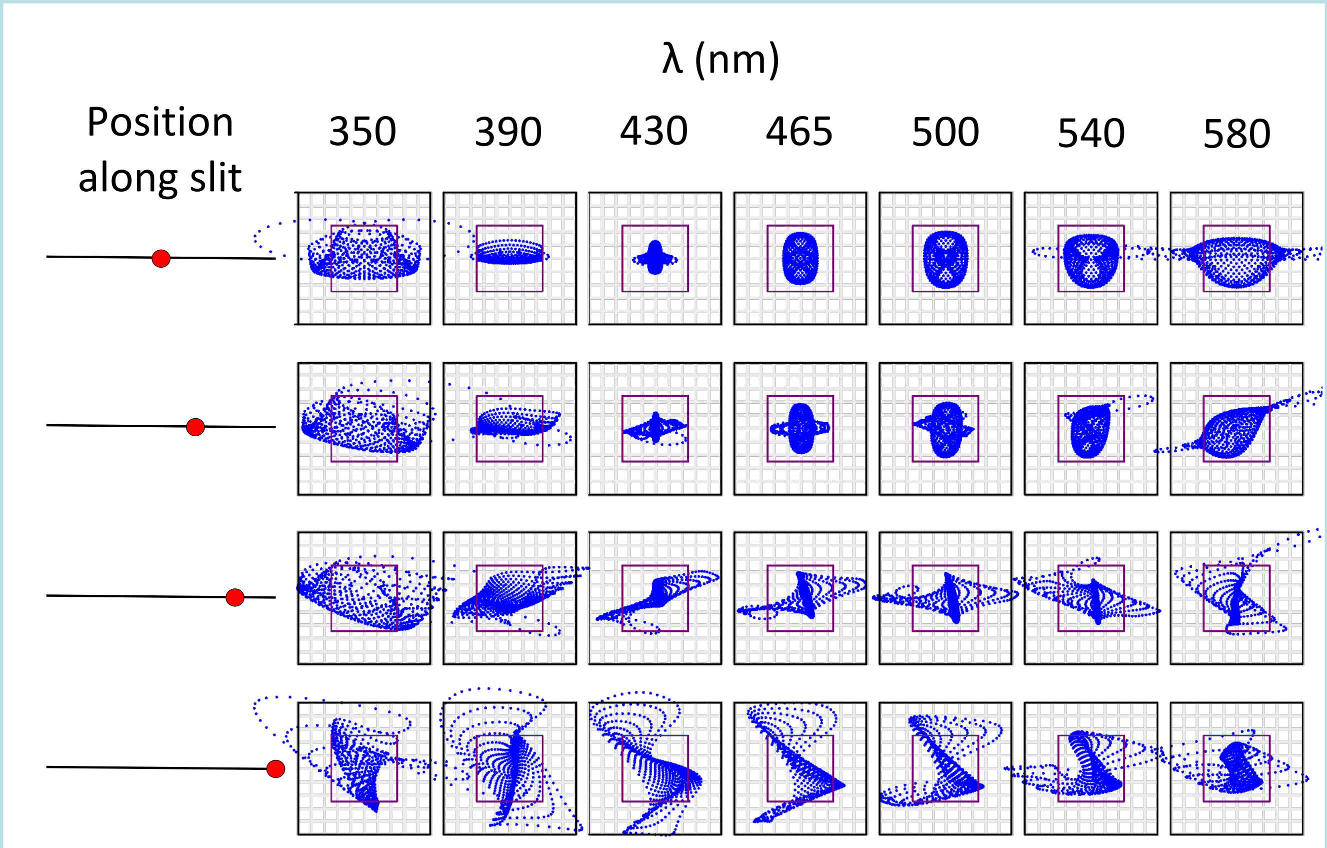
BlueMUSE Spectrograph

- F / 1.35 camera, zero deviation
- Curvature radius: ~ 200 mm

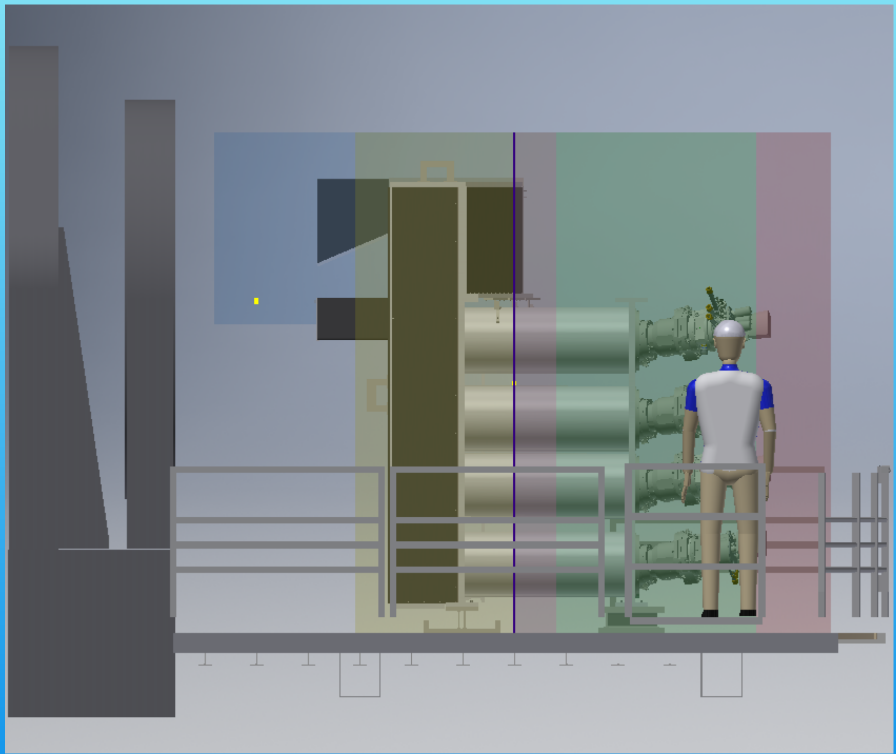


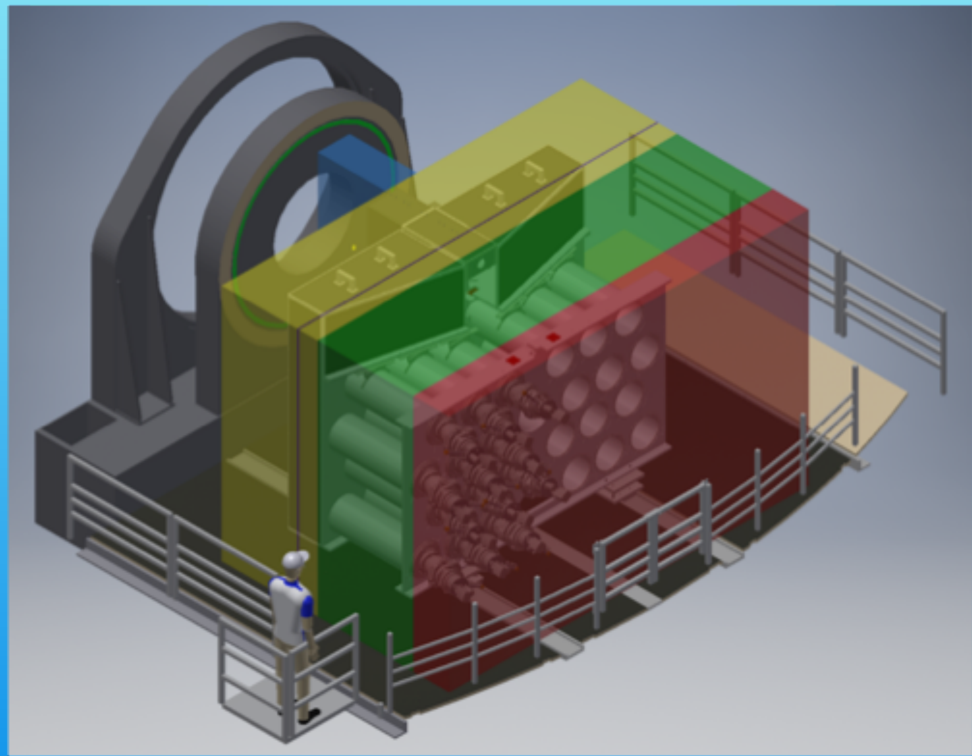
BlueMUSE Image Quality

Encircled Energy: > 95% within 2x2 pixels



Mechanical Footprint





Fore-optics

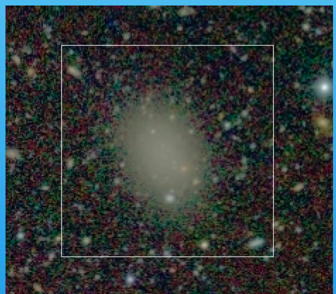
Splitting & Relay

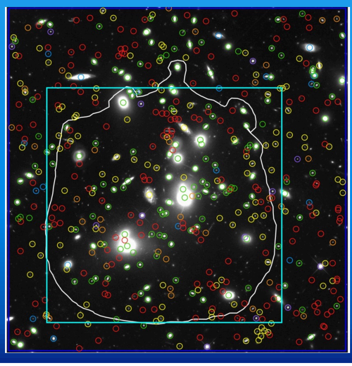
Spectrograph

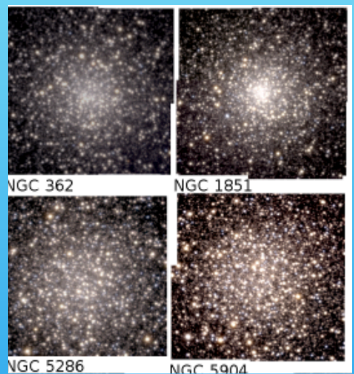
Curved Detector

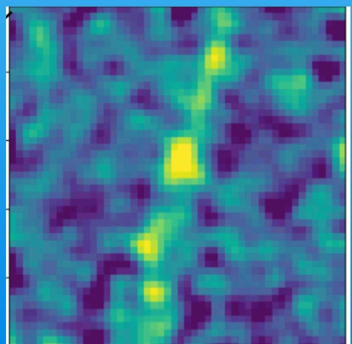
Science case: white paper

astro-ph: 1906.01657









BlueMUSE

Project Overview and
Science Cases

June 4th, 2019

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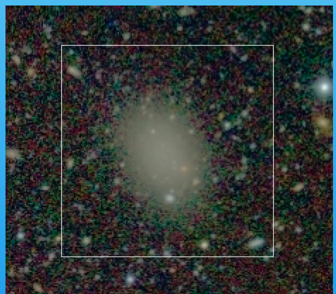
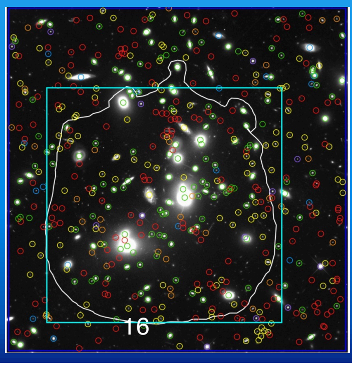
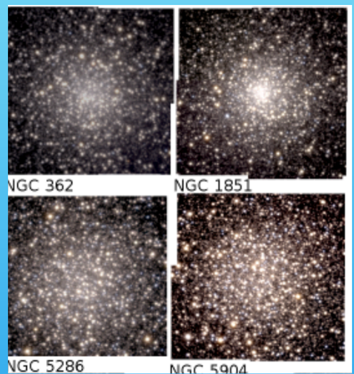
Abstract

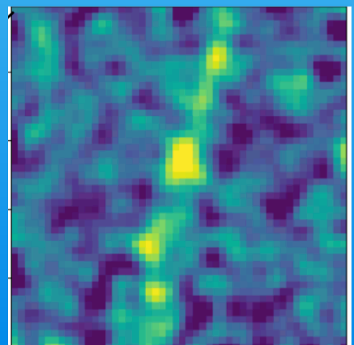
We present the concept of BlueMUSE, a blue-optimised, medium spectral resolution, panoramic integral field spectrograph based on the MUSE concept and proposed for the Very Large Telescope. With an optimised transmission down to 350 nm, a larger FoV (1.4 × 1.4 arcmin^2) and a higher

Science case: white paper









astro-ph: 1906.01657

Our galaxy and the local group

- Massive stars
- Globular Clusters
- Ultra Faint Dwarfs
- Ionized Nebulae
- Comets / asteroids

Martin Roth's presentation

See also: Norberto Castro and Martin Wendt's posters!

Nearby galaxies

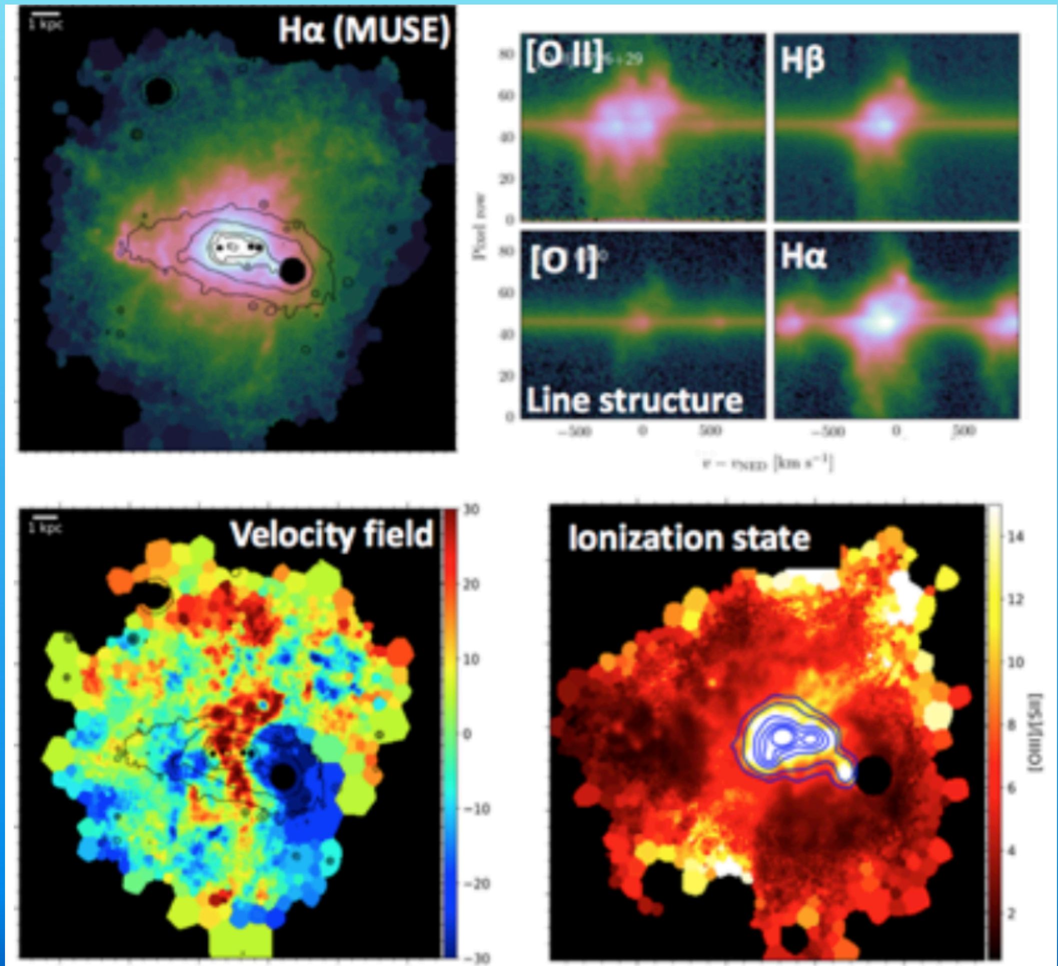
- ISM and HII regions, extreme starbursts
- Low surface brightness galaxies
- Environmental effects in local clusters

The distant Universe

- Deep fields
- Gas flows around and between galaxies
- Lyman-continuum emitters
- Gravitational Lensing in Clusters
- The emergence of the first galaxy clusters

BLUE MUSE
multi unit spectroscopic explorer

ISM and HII regions, Extreme starbursts



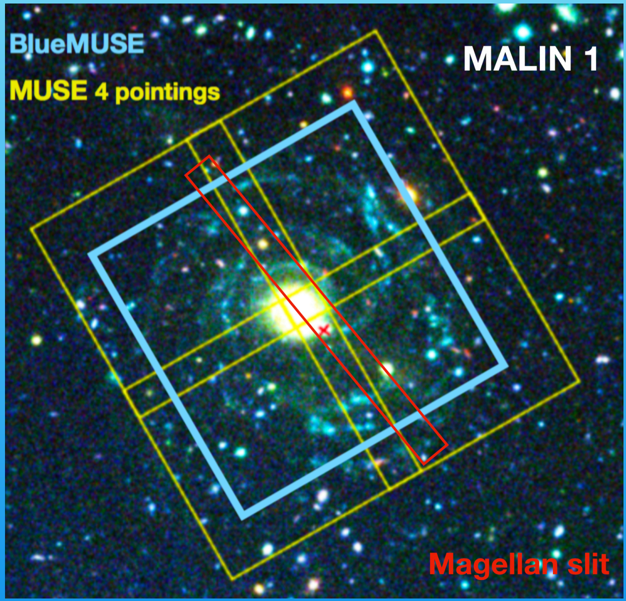
Bik et al. 2018

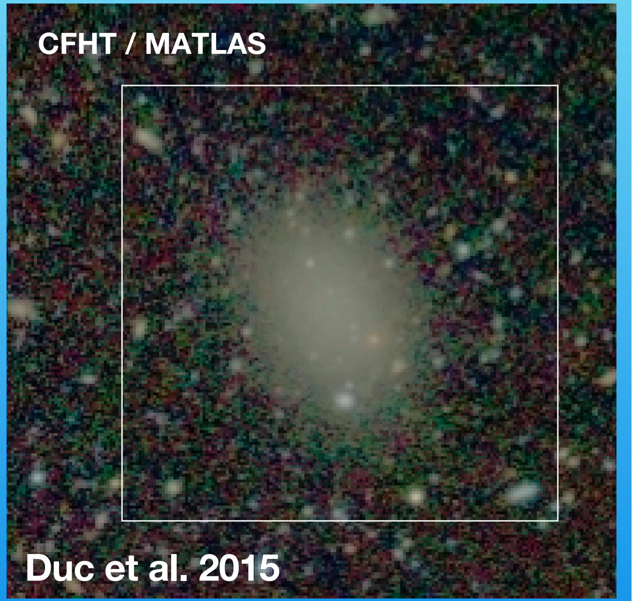
- Low mass, starburst galaxies at z ~ 0
- Physical conditions in the ISM and diffuse haloes of starburst galaxies from multiple emission lines
- Interplay between massive stars and their surroundings (winds, radiations)
- Analogues of high redshift galaxies / contributors to reionising the Universe

Access to key emission lines in the blue:
[OII]3727, [OIII]4363, HeII 4686, WR bump

Low Surface Brightness Galaxies

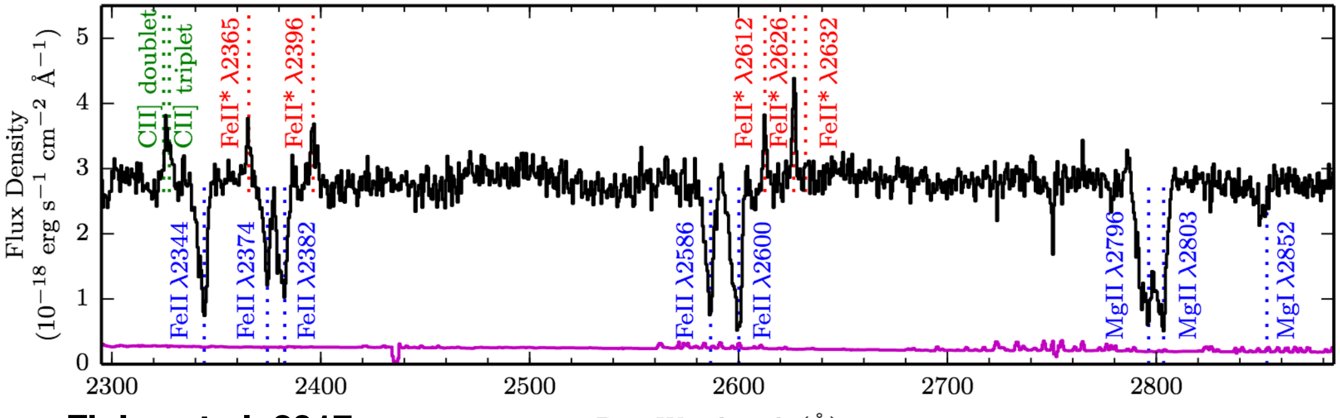
- Characterise star formation, dust properties and metals through emission line mapping.
- Measure distance and kinematics of Low Surface Brightness and Ultra Diffuse galaxies

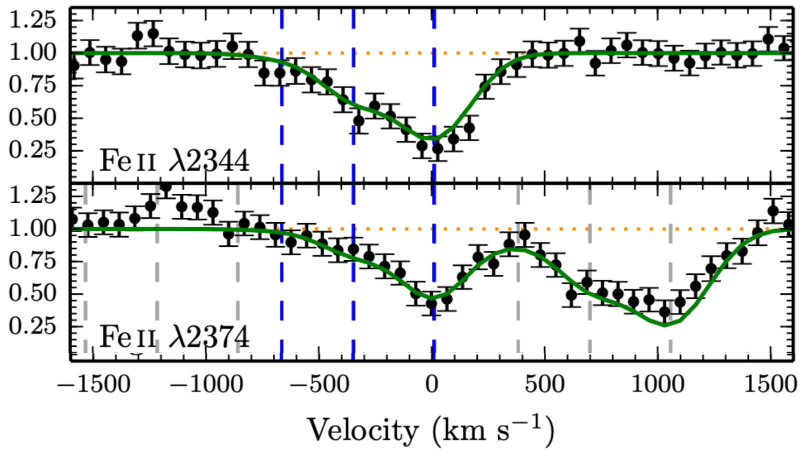




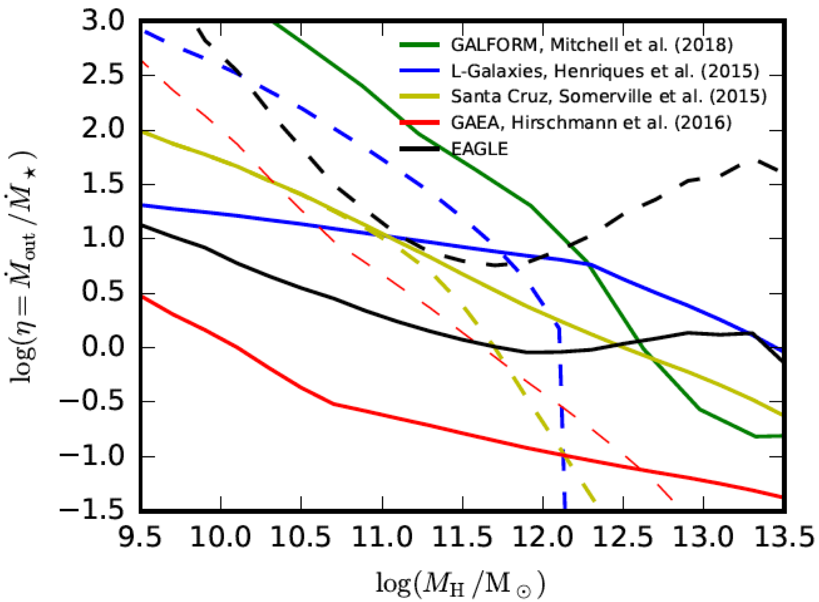
FoV well-suited for LSBs and their globular clusters
Access to age / metallicity indicators and Balmer lines for SFH
Higher spectral resolution with respect to MUSE

Gas flows from UV lines





Finley et al. 2017

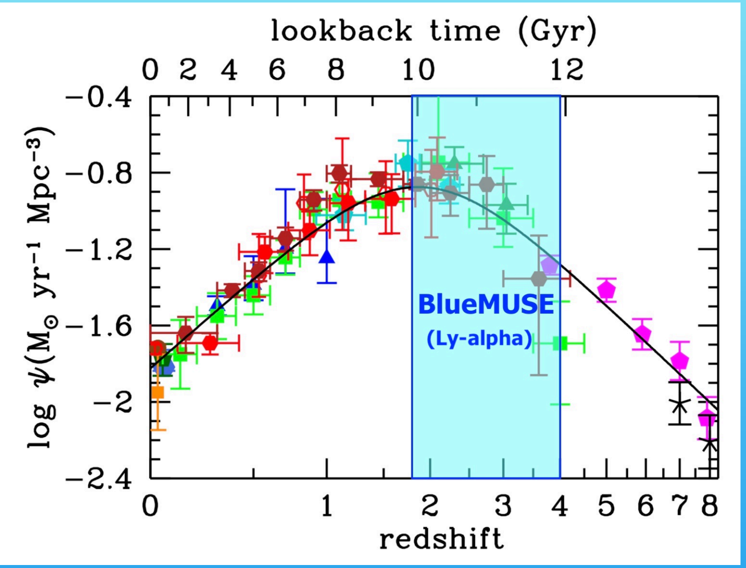


- **Model predictions for outflows give us a very degenerate picture!**
- **Metal absorption lines: tomography of the CGM**
- **Complemented with metal emission lines (FeII, MgII,…)**

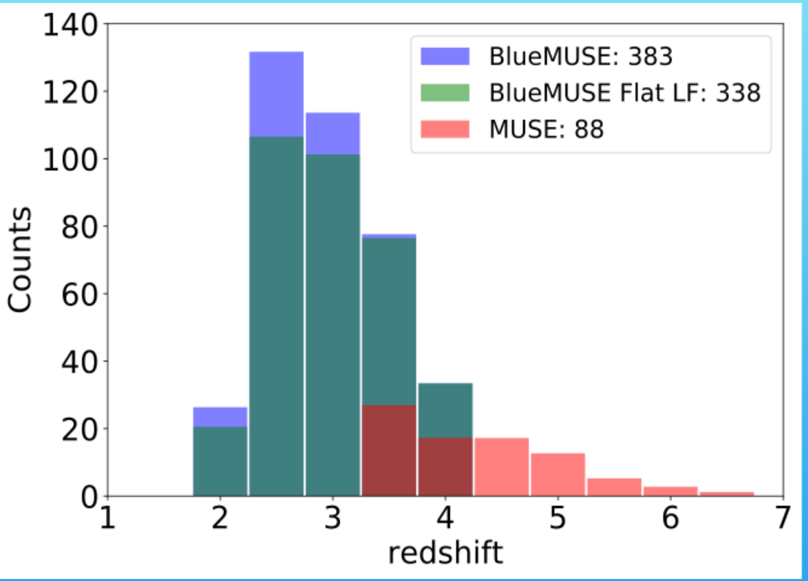
High density / multiple background sources z < 1

Higher spectral resolution to resolve outflows

Deep Fields



Madau & Dickinson (2010)



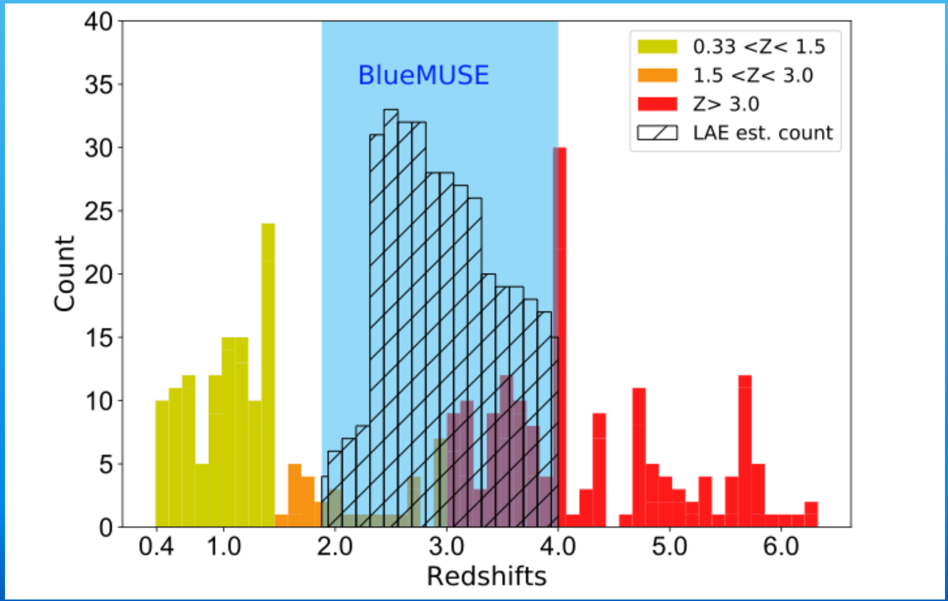
- **MUSE Deep fields (> 10 hrs per pointing) reveal faint emission line galaxies, and in majority Lyman-α emitters (LAEs)**
- **UV cosmic SFR peaks at z~2**

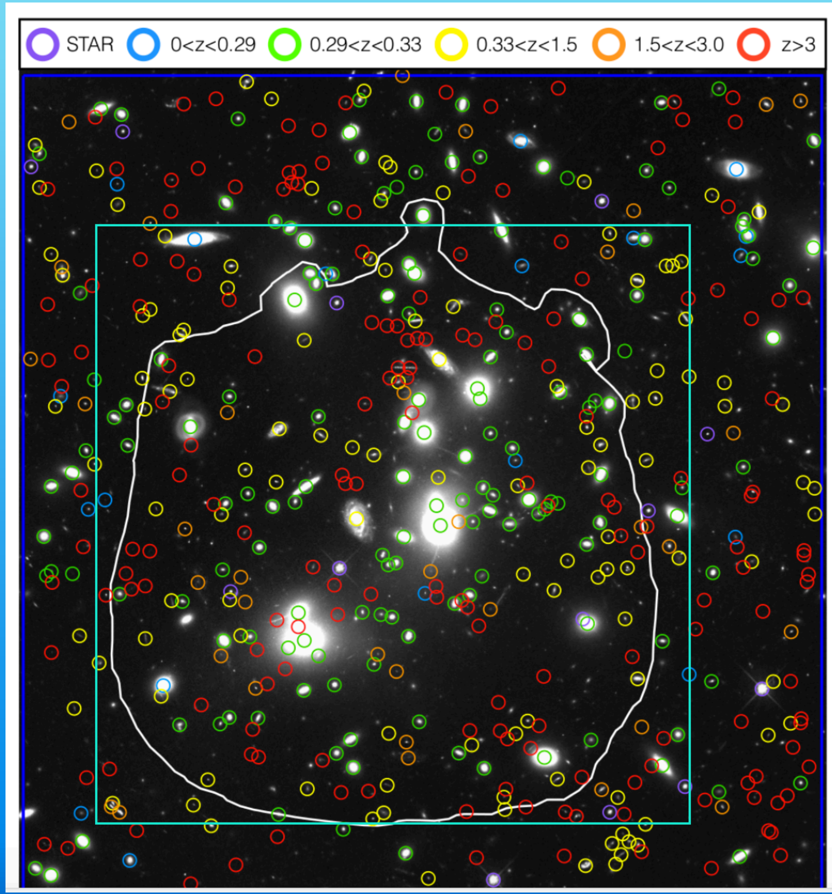
UDF + MUSE (10 hrs):
88 unique LAEs at 3<z<6.7 per pointing (Inami et al. 2017)

UDF+BlueMUSE **(10 hrs):**
383 unique LAEs at 1.9 <z<4

Lensed galaxies by massive clusters

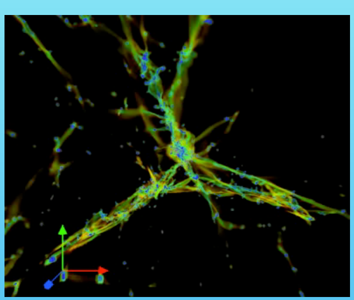
- Magnification allows to probe lower mass, lower luminosity galaxies
- Massive clusters have a magnification region extending to 1.5-2 arcmin.
- 1.9 < z < 4 is the peak of the redshift distribution for multiply-imaged galaxies





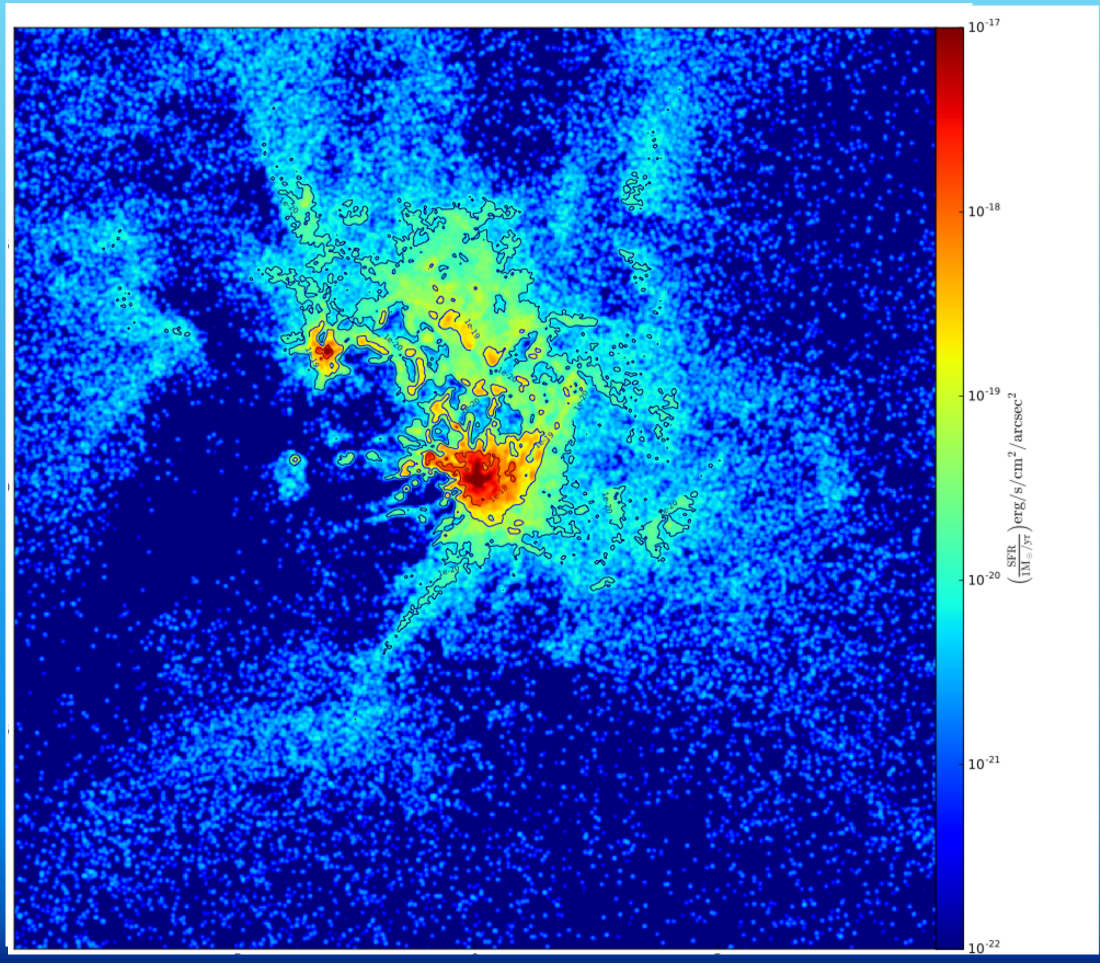
Mahler et al. 2018

High-redshift galaxies
Lyman-α at 1.9 < z < 4



- **Lyman-alpha emission probes the diffuse gas in the CGM.**

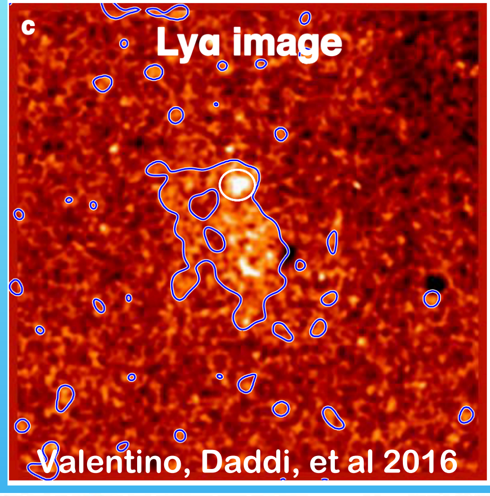
- BlueMUSE **can reach down to z=1.9 and benefit from surface brightness dimming (gain x3-4 between z=3 and z=1.9) ~10x gain in exposure time!**

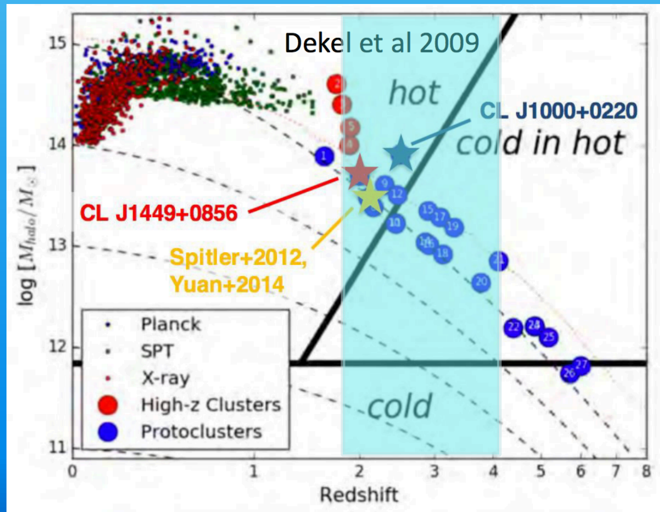


High redshift galaxy clusters

- Herschel and Planck have detected many high redshift cluster candidates, and Euclid shall discover 1000s of them!
- Cold (10^4 K) gas and hot (10^7 K) gas seem to coexist in some clusters, as seen with Lyman-α and X-ray
- Theory predicts that cold flows accretion is needed to maintain the steady state, still to be confirmed in observations.

Strong synergies between BlueMUSE **and Euclid, with follow-up using SKA (active clusters), ALMA (characterisation of cold gas) and Athena (interplay between hot and cold media).**

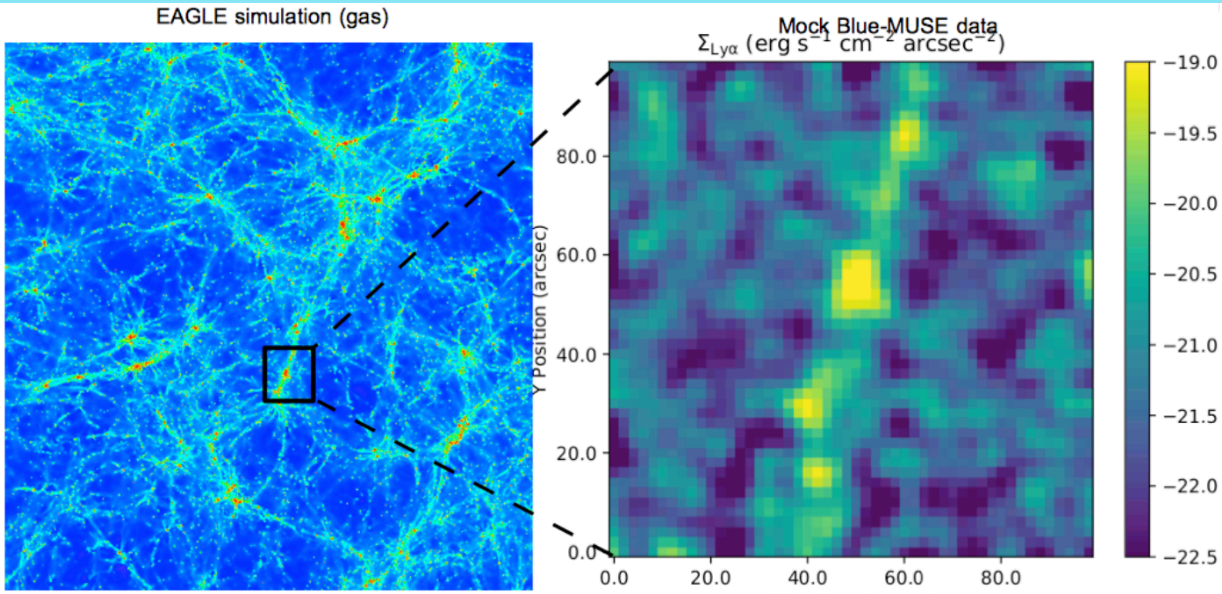


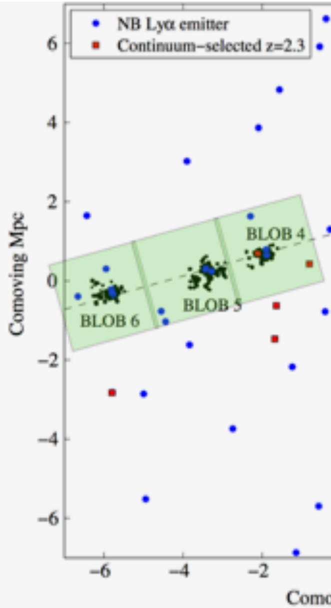


Valentino et al 2015; 2016; Overzier et al 2016

From CGM to IGM

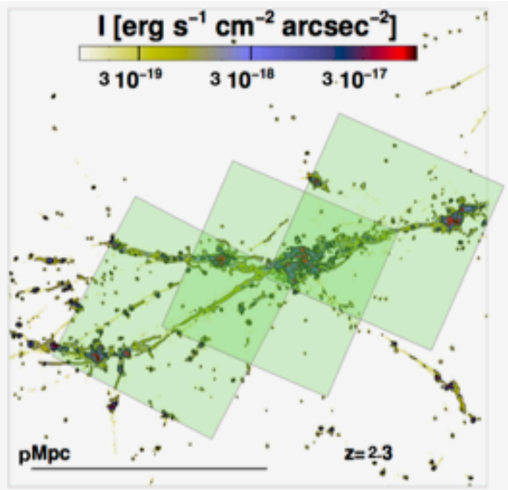
Blue wavelengths (surface brightness) and FoV give us access to gas emission in the Intergalactic Medium (IGM)



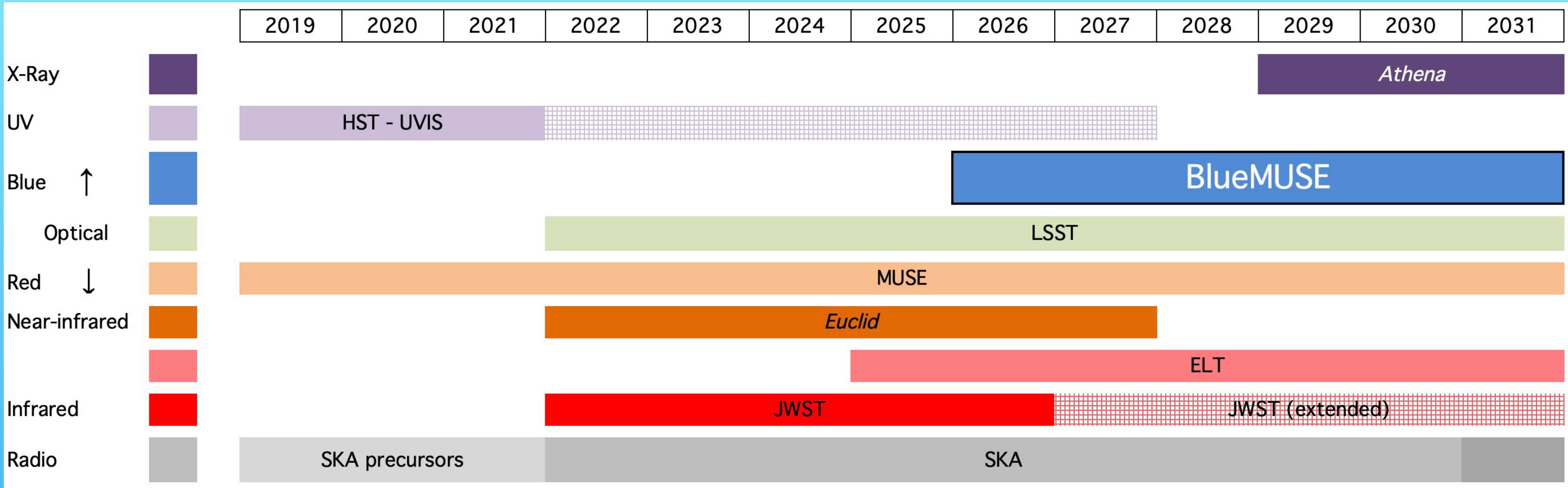


Erb et al. 2011

Rosdahl & Blaizot 2012



Synergies



- BlueMUSE **would be at the telescope when many facilities will focus on red/NIR**
- **Strong synergies with major facilities!**
- **JWST / Nirspec and ALMA deep fields: redshift overlap**
- **HARMONI follow-up of extended Lyman-α haloes at z=2**
- **…**

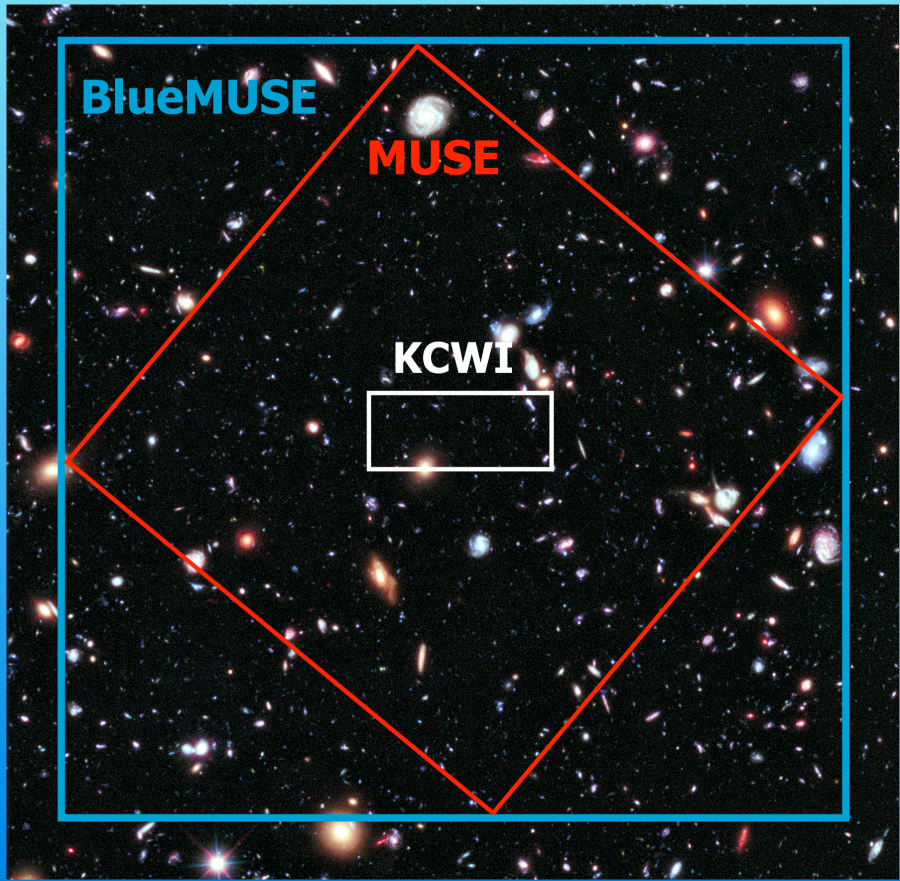
Complementarity with MUSE red

	MUSE	BlueMUSE **(curved)**	**Comment**
Field of view	1x1 $arcmin^2$	**1.4x1.4 $arcmin^2$**	**Factor 2 in area**
Sampling	0.2x0.2 $arcsec^2$	0.3x0.3 $arcsec^2$	
Median spatial resolution	0.4 arcsec with AOF	0.8 arcsec (seeing limited)	
Wavelength range	480-930 nm	350-600 nm	No 580 nm Na gap
Spectral Resolution	1800 @ 480 nm 3500 @ 930 nm	**~3000 @ 350 nm** **~5000 @ 600 nm**	**Factor 2 higher**
Spectral sampling	2 pixels	2 pixels	
Narrow Field Mode	7x7 $arcsec^2$ 0.025 arcsec	None	
OH sky lines	Many > 700 nm	None	
Throughput	0.35 @ 700 nm	Similar	No filter needed for 2^{nd} order

Uniqueness

- Unique combination of large FoV, resolution and wavelength

- Keck Cosmic Web Imager (KCWI): 8.24” x 20.4”

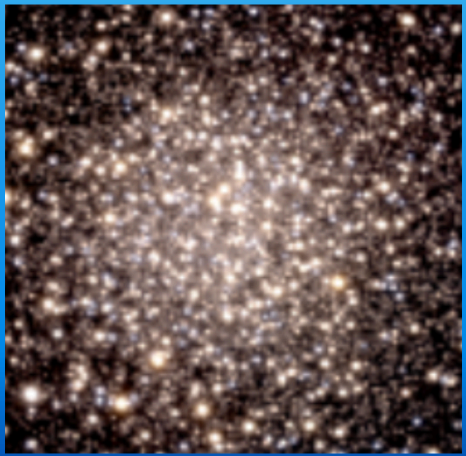


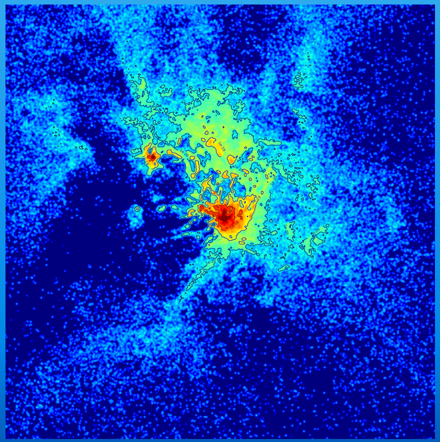
Feasibility & Risks

- Most technology exists: slicer, spectrograph, etc.
- New technology: use of 4k x 4k curved detector
- No narrow-field mode, no AO coupling, one single mode
- Larger optical derotator
- Lesson learned from MUSE (red)
  - Temperature control of the whole instrument
- Cost
  - slightly more expensive on hardware (larger fore-optics)
  - Less expensive in development
  - Current estimate: 10 Meuros hardware.
- Backup solution
  - 1x1 $arcmin^2$ field of view, smaller optics, 4k x 4k flat detector, but same spectral range

Conclusions

- BlueMUSE **is a unique opportunity to maintain our world leadership in the era of IFU science.**
- **Complementary to the current MUSE and to the ELT (no blue sensitive instrument for the ELT).**
- **Little risk, benefit from all existing developments and community know-how**
- BlueMUSE **will produce very good science at the first minute of observations**





BlueMUSE **Optical design**