AIP

Leibniz-Institut für Astrophysik Potsdam

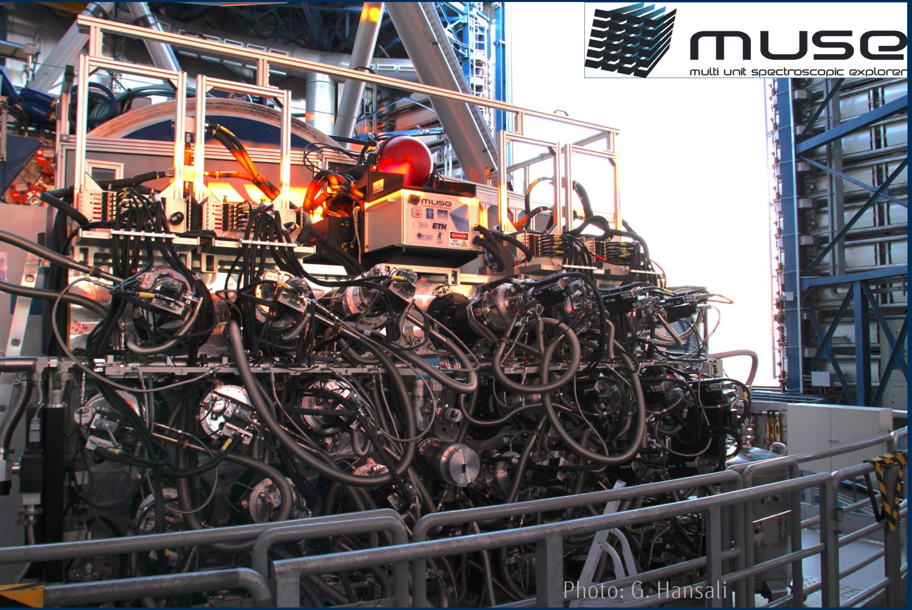
1700 - 2025
325 Jahre

and Lyman Radiation

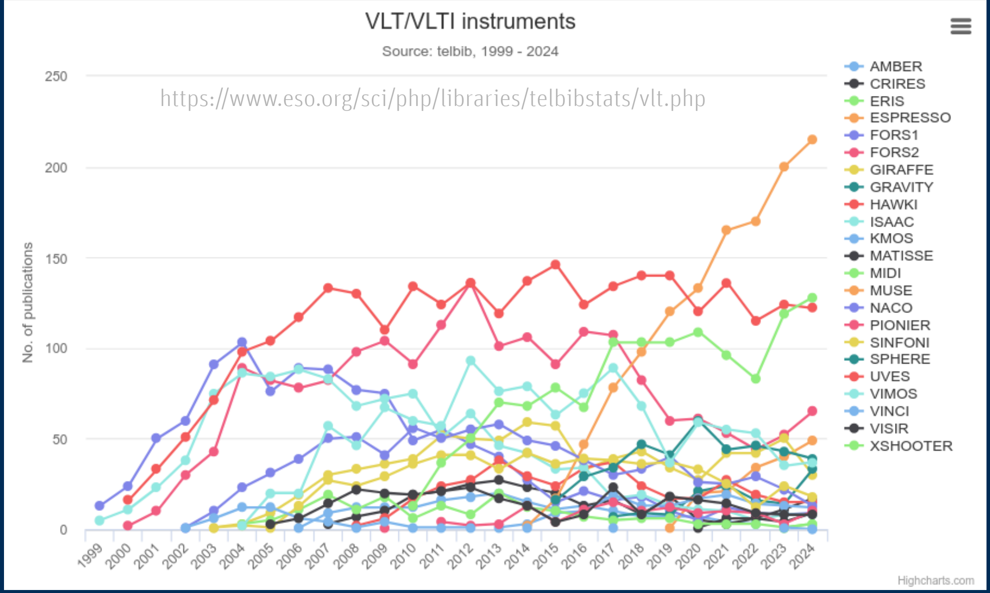
Peter Weilbacher (AIP) / OAC, Kolymbari / April 2025

and the BlueMUSE consortium

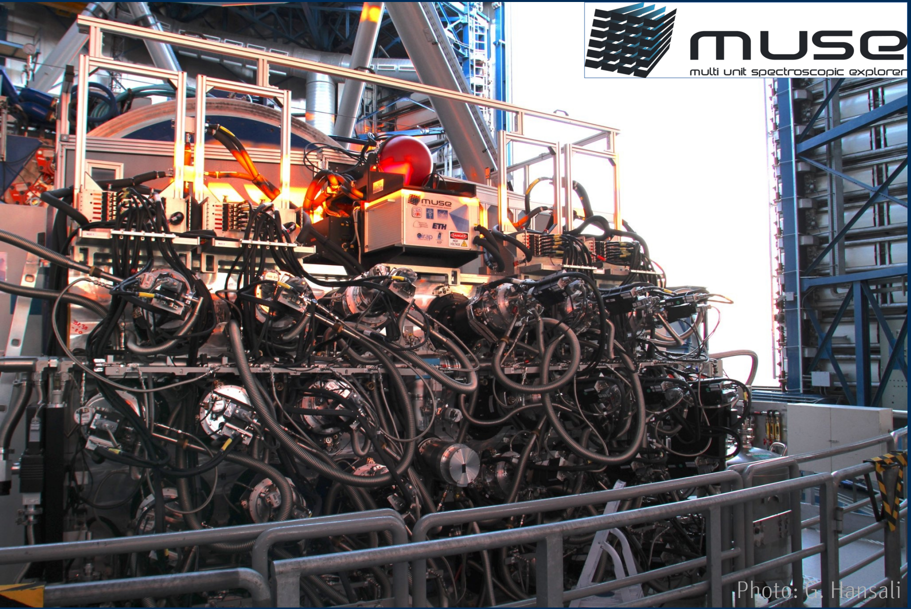
MUSE

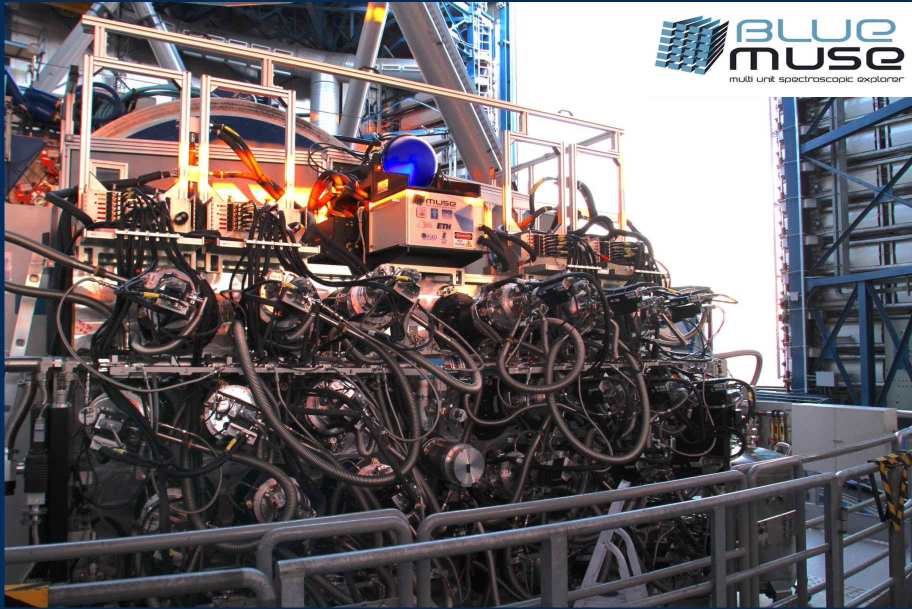


- MUSE: panoramic integral field spectrograph at VLT UT4
- operating since 2014
- the most successful ground-based astronomical instrument?

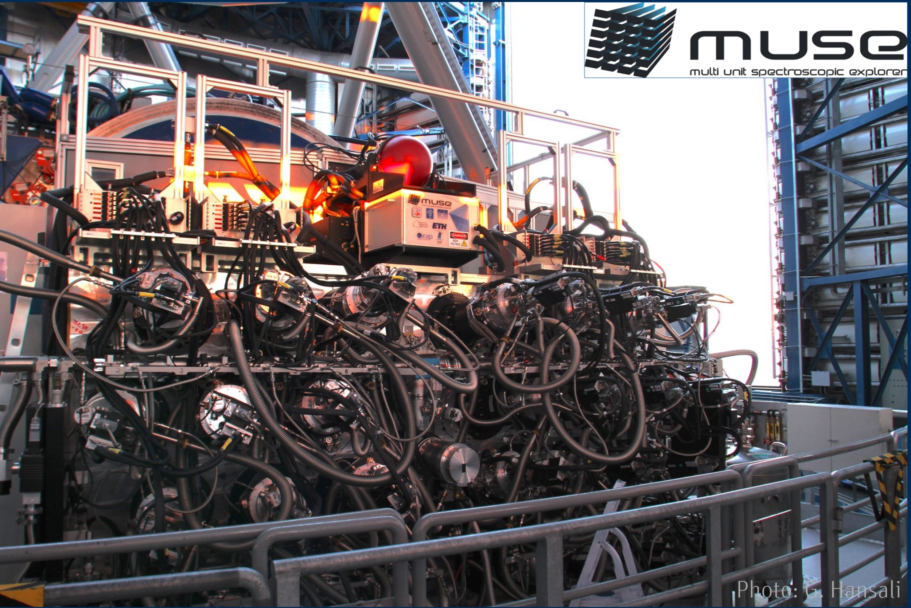


MUSE & BlueMUSE

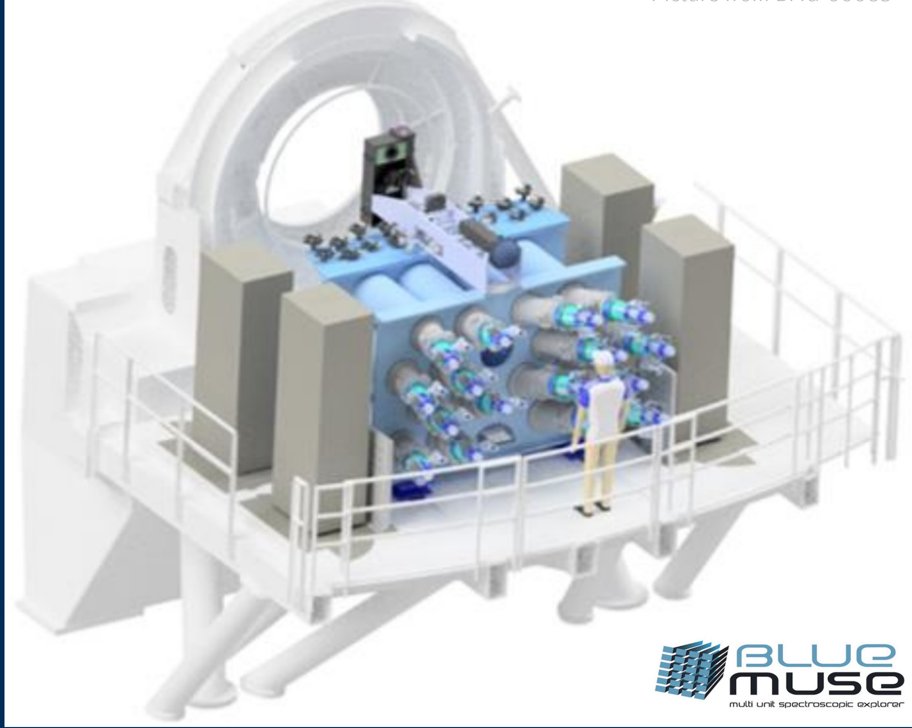




MUSE & BlueMUSE



Picture from BMU-00085



PI: Roland Bacon (CRAL)

CRAL · AIP · NOVA · Institut für Astrophysik Göttingen · ETH · irap astrophysique & planétologie · ESO

PI: Johan Richard (CRAL)

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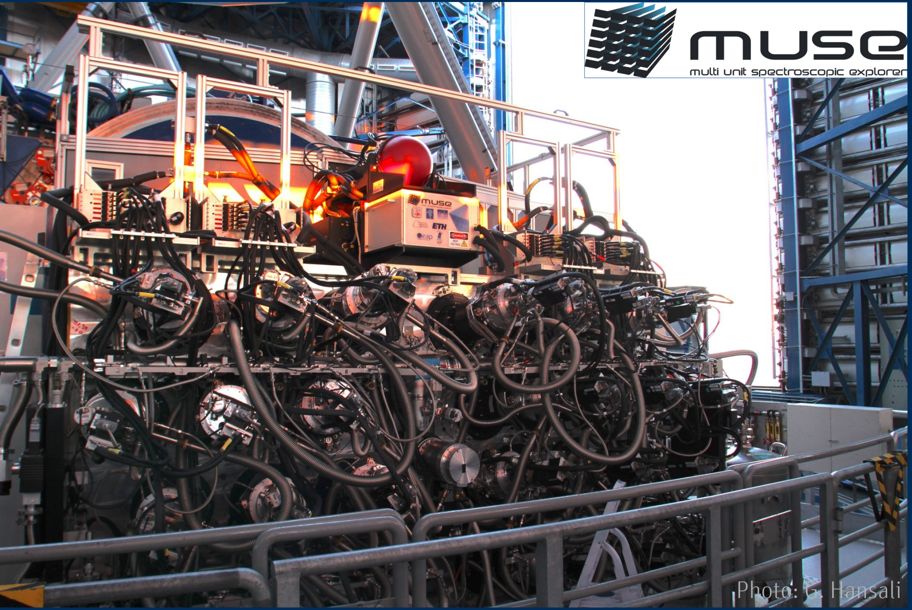
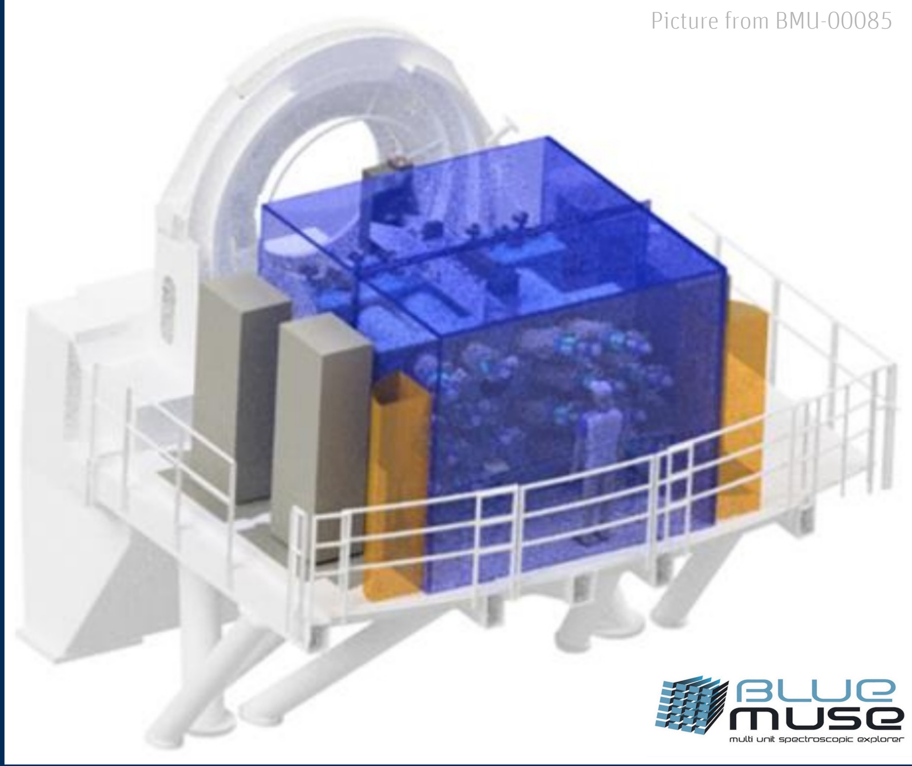
MUSE & BlueMUSE





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MUSE & BlueMUSE

Telescope	VLT UT4 Yepun
Instrument Type	Optical Integral Field Spectrograph
Wavelength range	(465)480 – 930 nm
Resolution	R ~ 1800 – 3600
Field of view	contiguous 1' x 1' (WFM)
Detectors	24 deep depl. CCDs (e2v), 4k x 4k
Sampling	0.2'' x 0.2'' x 0.125 nm
Throughput (incl. telesc. & atmosph.)	40% (16% at red end)
Commissioning	February – August 2014
AO support	
WFM (since 2017)	~2x EE improvement (GLAO)
NFM (since 2018)	high-order correction (7.5'' x 7.5'' field, sampled at 0.025'')

Telescope	another VLT UT
Instrument Type	Optical Integral Field Spectrograph
Wavelength range	at least 350 – 580 nm
Resolution	R > 2600, ‹R› > 3500
Field of view	contiguous 1' x 1'
Detectors	16 CCDs (4k x 4k)
Sampling	likely around 0.2'' x 0.3'' x 0.06 nm
Throughput (incl. telesc. & atmosph.)	>26% (>15% in the blue)
Commissioning	2032
AO support	None

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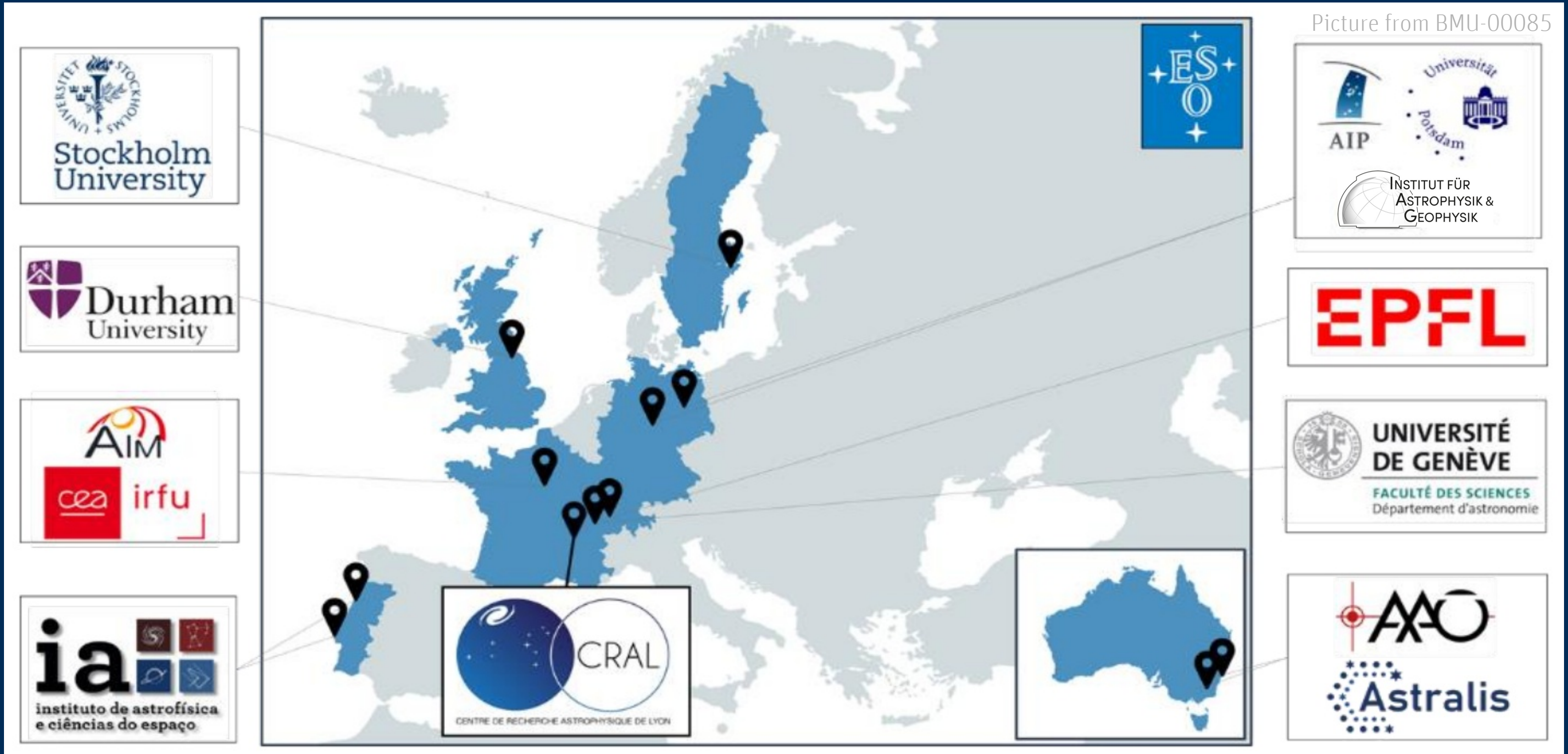
Commissioning	2032 Phase A just finished!
AO support	None

BlueMUSE Consortium



Project Office:

PI Johan Richard (CRAL)

PM Rémi Giroud (CRAL)

PS Davor Krajnović (AIP)

SE Florence Laurent (CRAL)

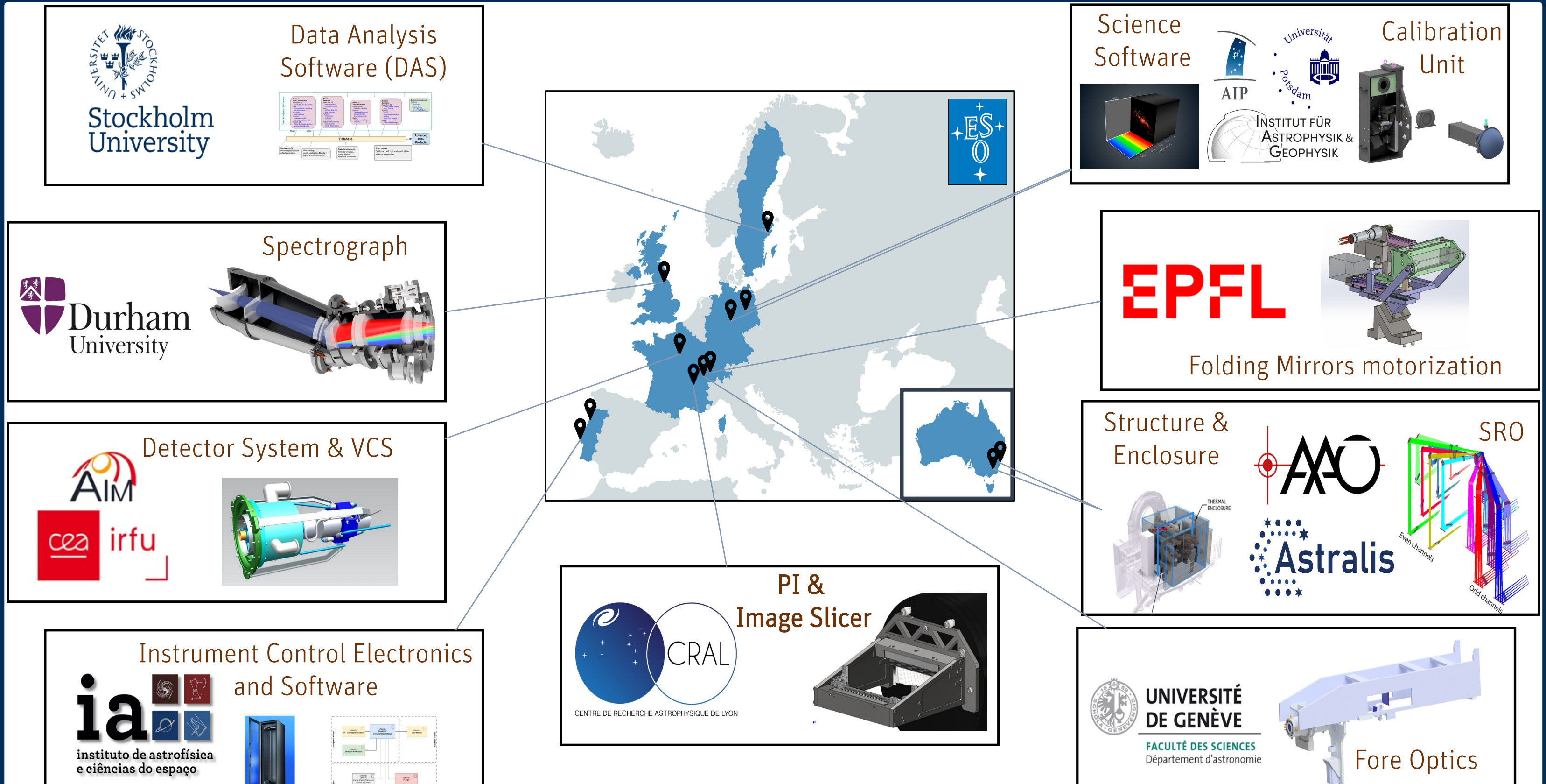
Institutional Board / Executive Board

Science Team

further technical teams

ESO follow-up Team

BlueMUSE Consortium

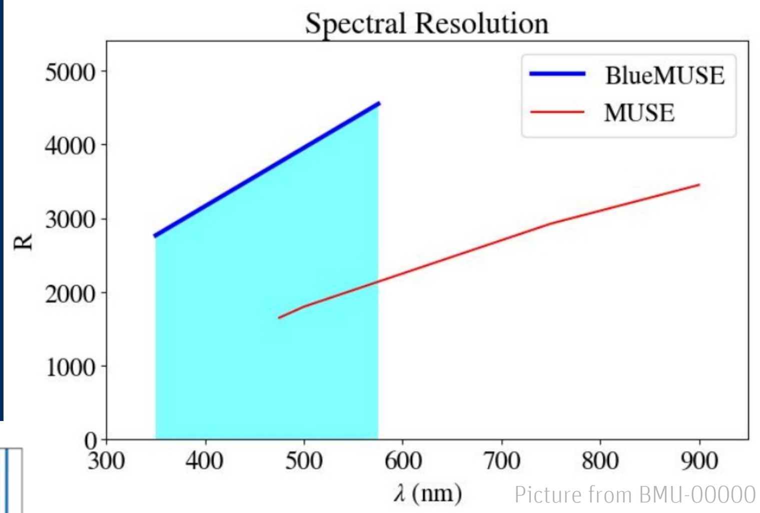


Graphics from PO

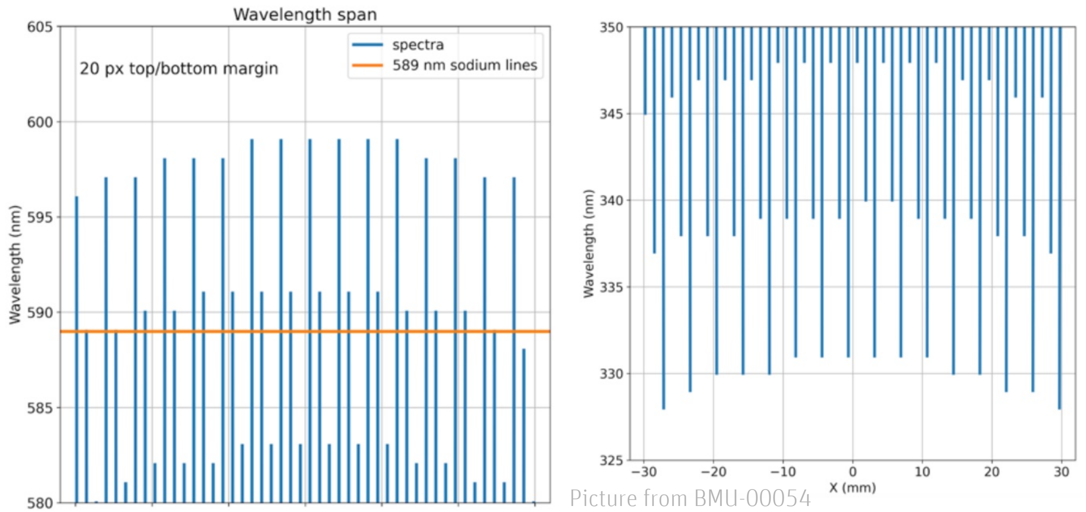
Spectral resolution & wavelength range

- Blue wavelength is limited by atmospheric cut-off
- Red cutoff related to spectral resolution and sensitivity

- 'extended' mode for a fraction of the FoV: ~330-600 nm



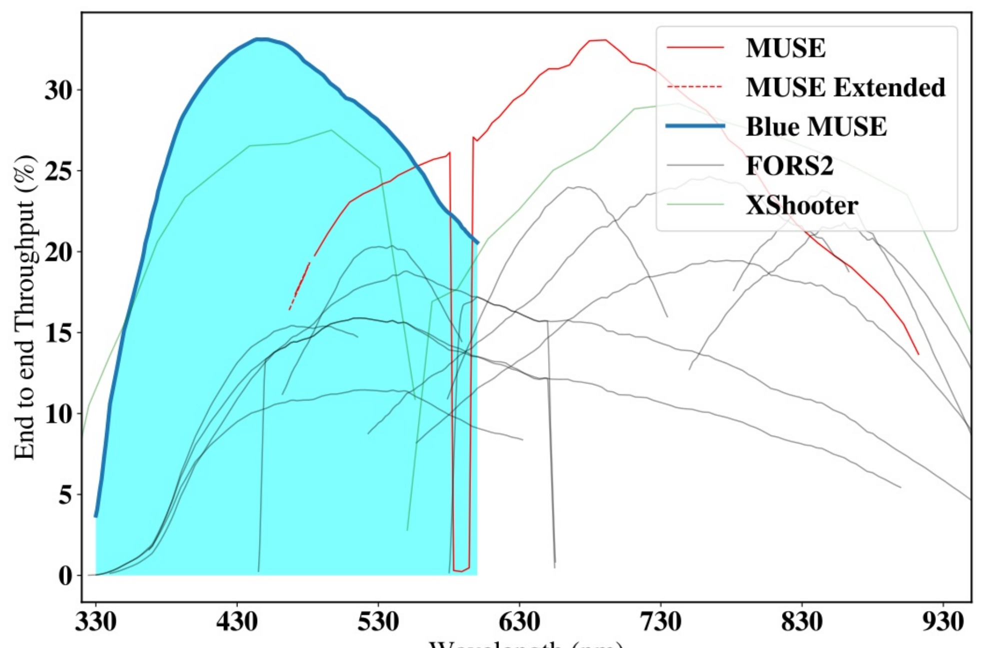
Picture from BMU-00000



Picture from BMU-00054

Efficiency and throughput

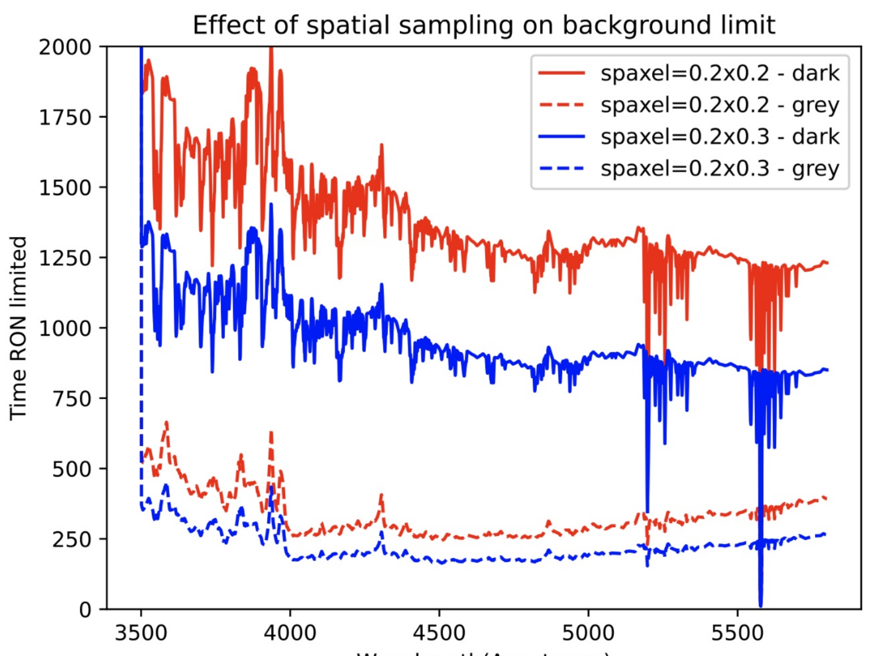
- Expected peak throughput similar to MUSE, up to 35%
- demonstrated by AIP lab spectrograph (MUSE-like but blue-sensitive)
- BlueMUSE + VLT more efficient in the blue than ELT
  - higher blue throughput
  - larger field of view
  - 11x more efficient than HARMONI at 500 nm



Picture from BMU-00000

Rectangular spaxels

- sampling 0.3'' sufficient in the blue
- 0.2'' in one dimension allows compact spectrograph
- MUSE-like sampling (0.2''x0.2''):
  read-out noise limited in dark time for $t_{exp} \approx 1500$ s
- 16 spectrographs instead of 24 can sample the 1'x1' field
- rectangular sampling (approx. 0.2''x0.3'') allows shorter exposures and does not degrade spatial resolution
- final cube will have square spaxels!



Picture from BMU-00000

Stability

- MUSE has various properties that change with temperature
  - slice illumination → flat-fielding / image artifacts
  - wavelength calibration → redshifts / velocities

- improve for BlueMUSE

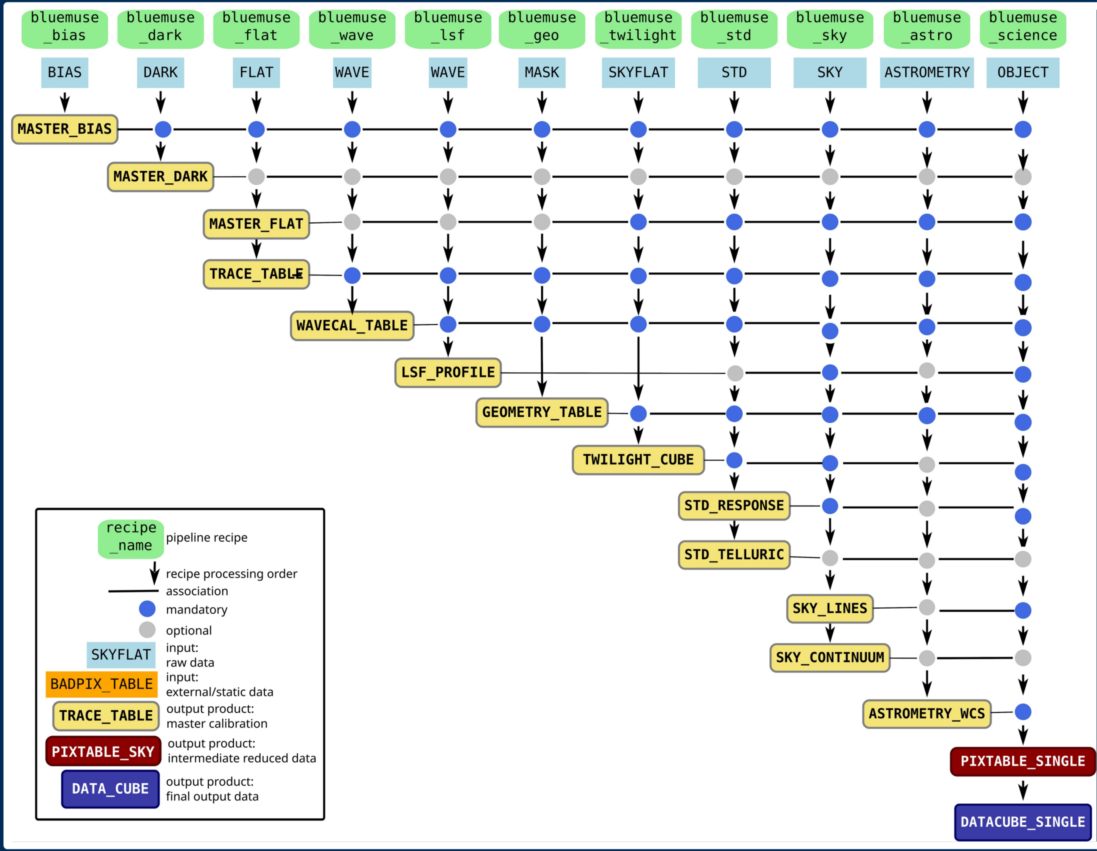
- fully leverage higher spectral resolution

- technical solutions studied:
  - thermal instrument cover
  - motorized folding mirrors

DRS

- Data Reduction Software → converts raw data into datacubes
- mostly like MUSE pipeline
- rough idea about the science processing steps
- improvements as far as issues are understood

(tell me now if there is something you always hated about the MUSE pipeline or the cubes!)



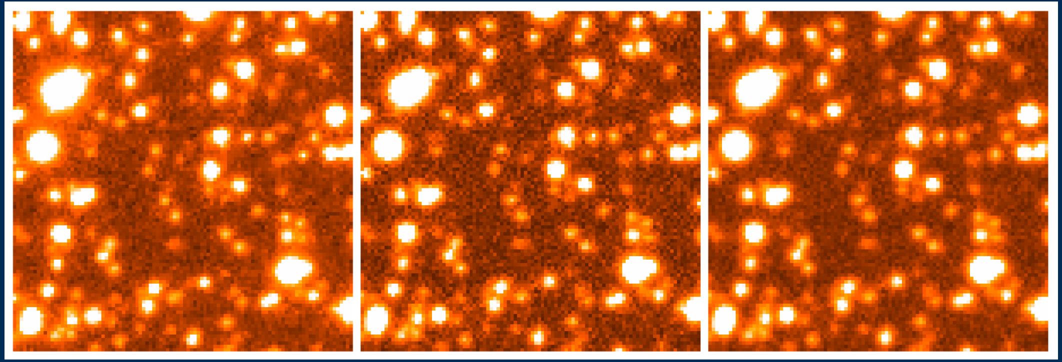
DAS

- Data Analysis Software → starts from reduced datacubes
- automated analysis for different science cases
- different modules:
  - detection
  - extraction
  - classification
  - cataloging
- example: automated creation of catalog of LAEs with spectral analysis

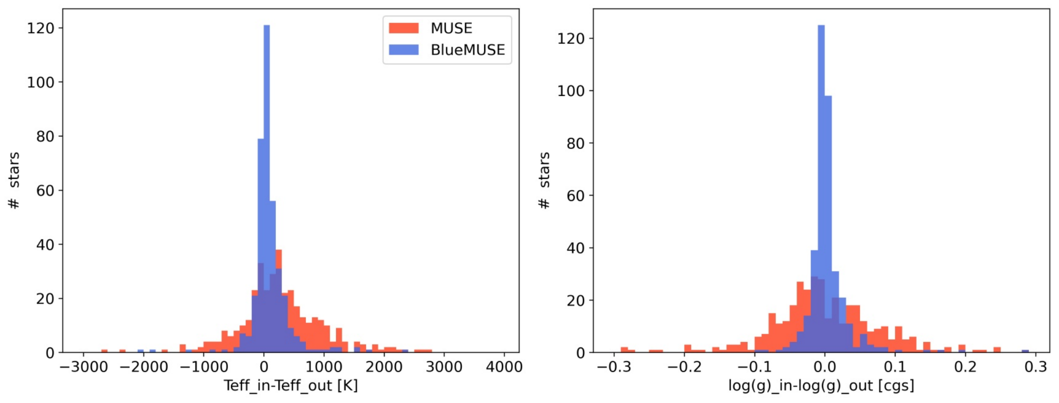
BlueSi

- simulating cubes for BlueMUSE
- test science cases and tools
- matched with up-to-date instrument parameters
- several scene types available
  - globular cluster
  - resolved young star cluster (gas content being implemented)
  - full galaxy (being worked on)
  - high-redshift objects (LAEs)
- SPIE paper: Wendt et al. arXiv:2406.13915

Wendt et al. (2024)



original MUSE BlueMUSE BlueMUSE with covariance approximation



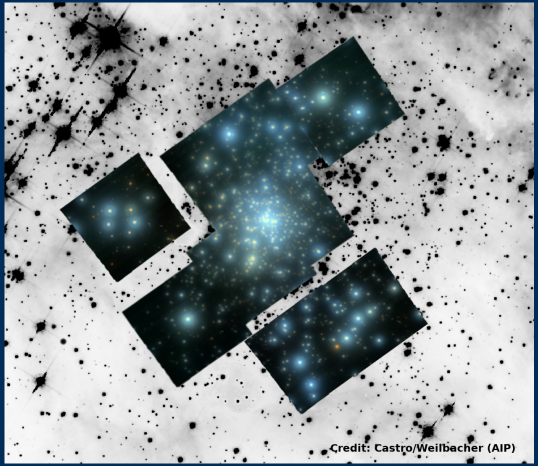
stellar parameter recovery (MUSE / BlueMUSE comparison)

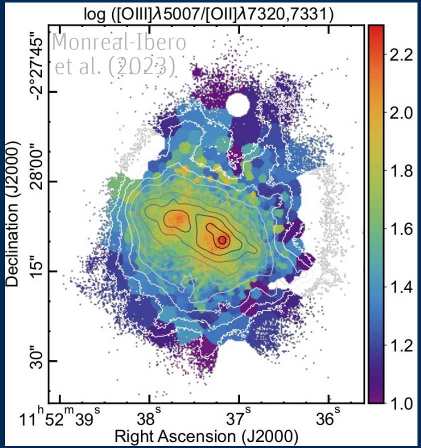
BlueMUSE science

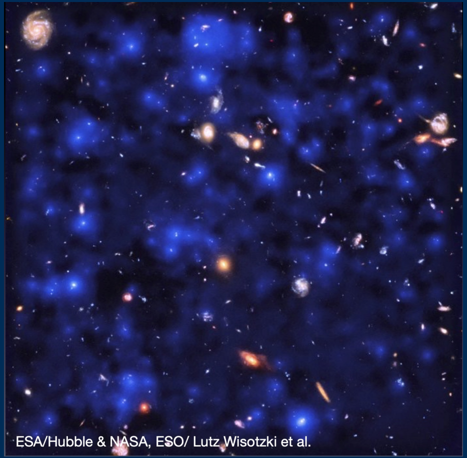
- Science: “Phase A **White Paper**”
  (current internal version: Krajnović et al. BMU-00000;
  old version Richard et al. arXiv:1906.01657)

- Different distances:
  - The Milky Way and the Local Group (organisers Angela Adamo, Norberto Castro)
  - Nearby galaxies (organisers Davor Krajnović, Angel Lopez-Sanchez)
  - The Distant Universe (organisers Tanya Urrutia, Mathilde Jauzac, Mark Swinbank)

- Key science cases
  - Massive stars
  - ISM and HII regions in extreme starbursts
  - Gas flows around and between galaxies



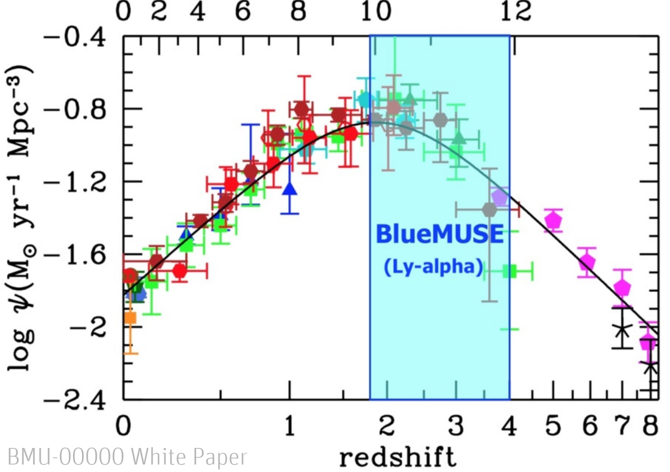




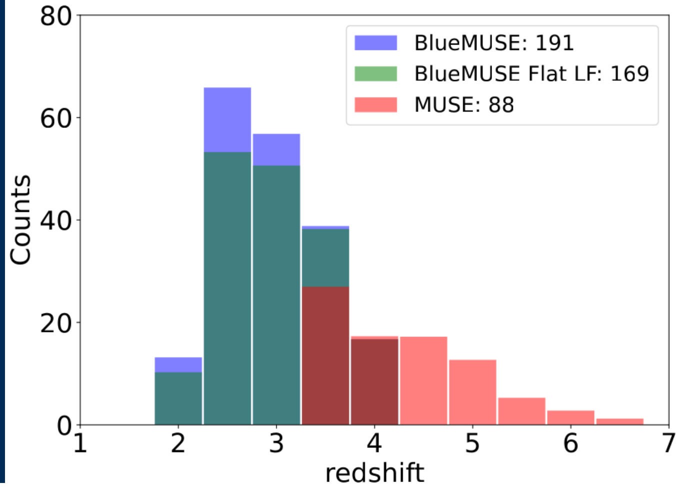
BlueMUSE and Lyman α

- Lyman α observable 1.9 < z < 3.8
- fills most of z-range currently not observable by MUSE
- cosmological surface brightness dimming
  - about 4x less at z=2-3 compared to z~4
  - 16x faster mapping of Lyα sources to same S/N
- Larger spaxels → easier to reach background noise
- estimate source counts
  - 10 h field (like MUSE UDF-10)
  - 5σ detection limit
  - extrapolated LF → 191 LAEs
  - flattened LF → 169 LAEs
  - ⇒ about 2x MUSE
- lensing fields: multiple images of fainter LAEs

adapted from Madau and Dickinson (2014)



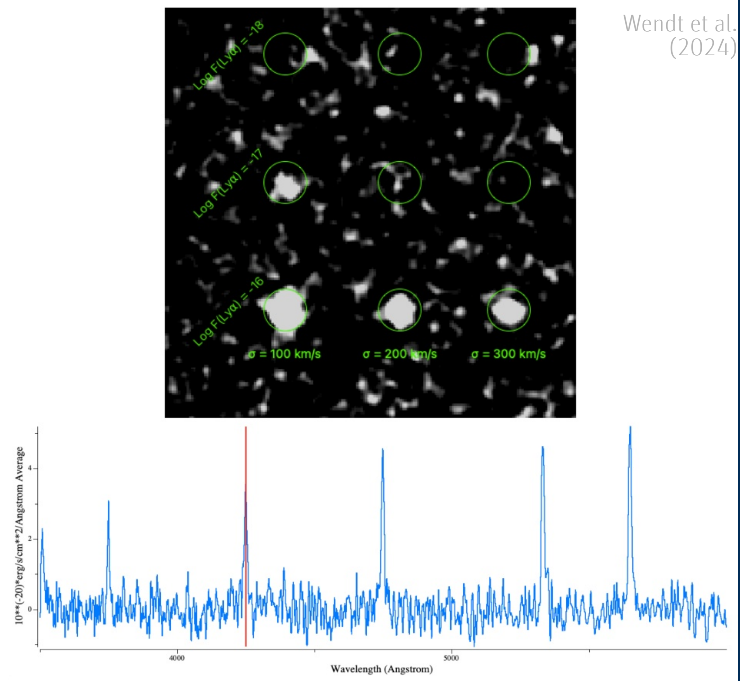
BMU-00000 White Paper



BlueMUSE and Lyman α: Simulation

- BlueSi: simulated cube
- Lyα emitters placed at regular intervals
- Depth simulated like MUSCATEL shallow fields
- Different Lyα fluxes and line widths
- Recovery testing using LSDCat matched filtering

→ John Pharo



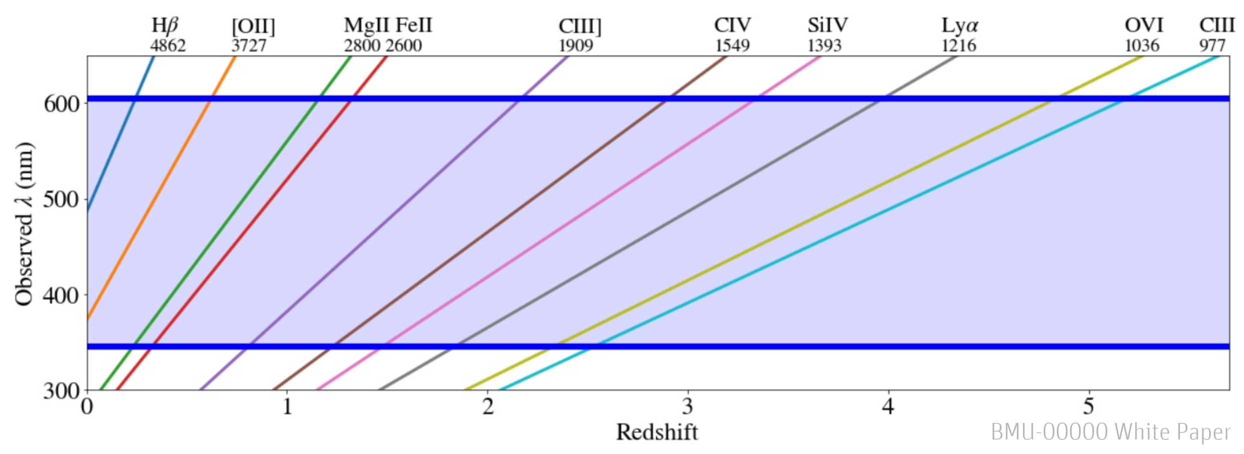
Wendt et al. (2024)

BlueMUSE and Lyman α halos

- halos (CGM) around LAEs at low surface brightness

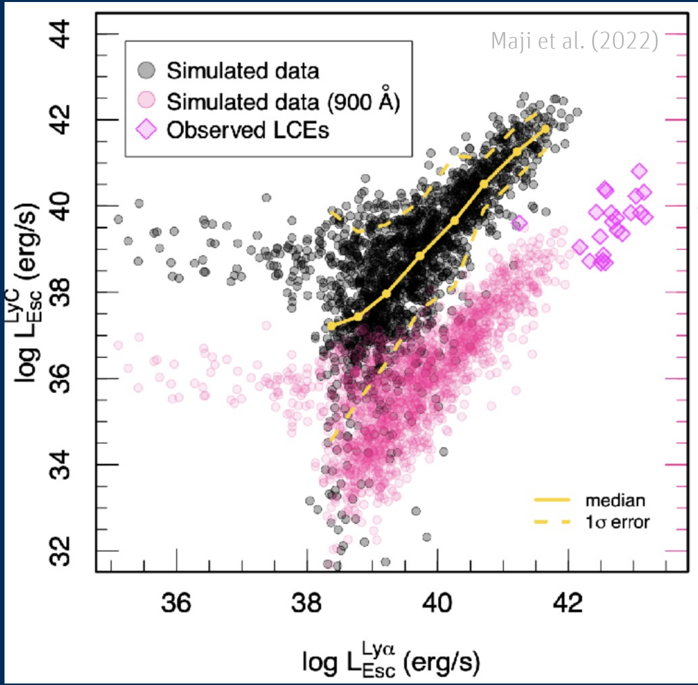
- few galaxies at z > 3
- evolution: brighter targets → observe gas flows around more galaxies individually
- CGM of SF galaxies in Lyα
- probing CGM in emission with metal lines
- CGM around AGNs

- also: absorption-line studies of CGM to sweet spot 0.6 < z < 0.7 with higher spectral resolution than MUSE



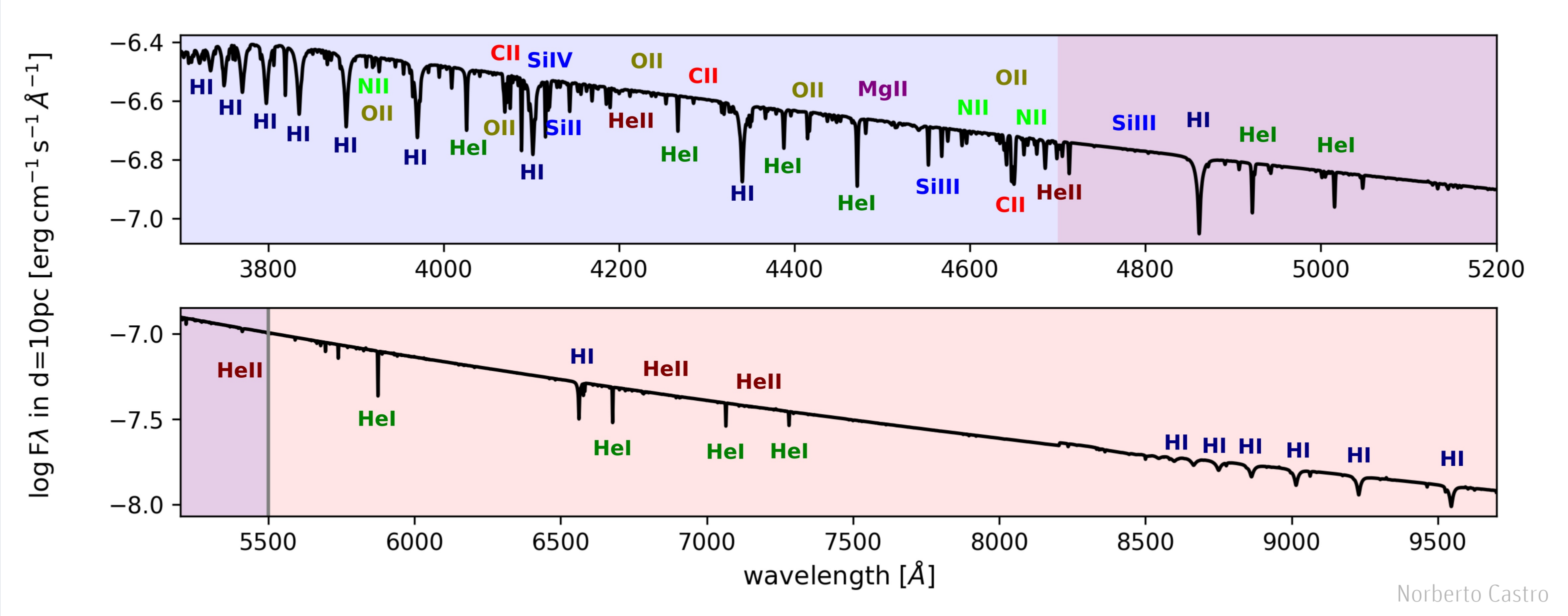
BlueMUSE and Lyman-continuum emitters

- direct LyC detections inefficient at z≳4 (increasing IGM opacity)
- BlueMUSE can probe LyC from sources at 3 < z < 5
- provide meaningful statistical samples of LyC emitters
- detection of ionizing emission down to ~780 Å for z~3.5 sources
  → constrain shape of LyC spectrum
- link to Lyα emission and Lyman-series absorption
  (HI density and covering fraction)



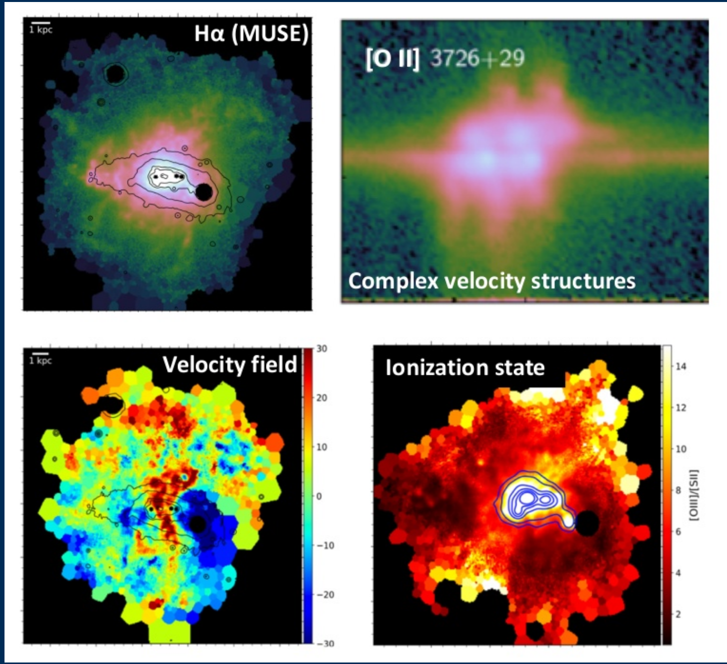
Key science case: Massive Stars

- O9.5V star spectrum from PoWR code
- Many metal lines between 3700 and 4700 Å!
- Much better chance to characterize the stars
- Improved determination of LyC injection → better estimate LyC escape



Key science case: ISM and HII regions in extreme starbursts

- Extreme starbursts → blue (dwarf) compact galaxies
  - Compact, irregular, low-luminosity, low metallicity
  - Short lived episode of SF
- Analogs of (low-mass) high-z SB systems
- Responsible for re-ionization
- Highly ionized ISM, compact, low [Z/H]
- What is their (massive) stellar content?
- What are the properties of the ionizing radiation?
- When/where do they leak LyC emission?
- How do the HII regions and the diffuse gas respond to the SF?
- BlueMUSE:
  - more precise kinematics
  - detection of critical lines [OII]3727,29 and [OIII]4363



Outlook & Conclusions

- BlueMUSE (multi unit spectroscopic explorer) will be a new panoramic IFS at the VLT
- Instrument design based on successful MUSE
  - various improvements
  - instrument parameters may still change
  - Phase A just passed, design phase starting now
- BlueMUSE will
  - contribute to Lyman α studies at $1.9 < z < 3.8$ → find more LAEe than MUSE!
  - study the CGM in emission with Lyα and metal lines in statistical samples
  - observe more and fainter LyC emitters
  - improve characterization of nearby massive stars
  - extend studies of nearby starbursts (and their LyC emission) to bluer wavelengths
- **BlueMUSE should be at the VLT in 2032!**

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The End