



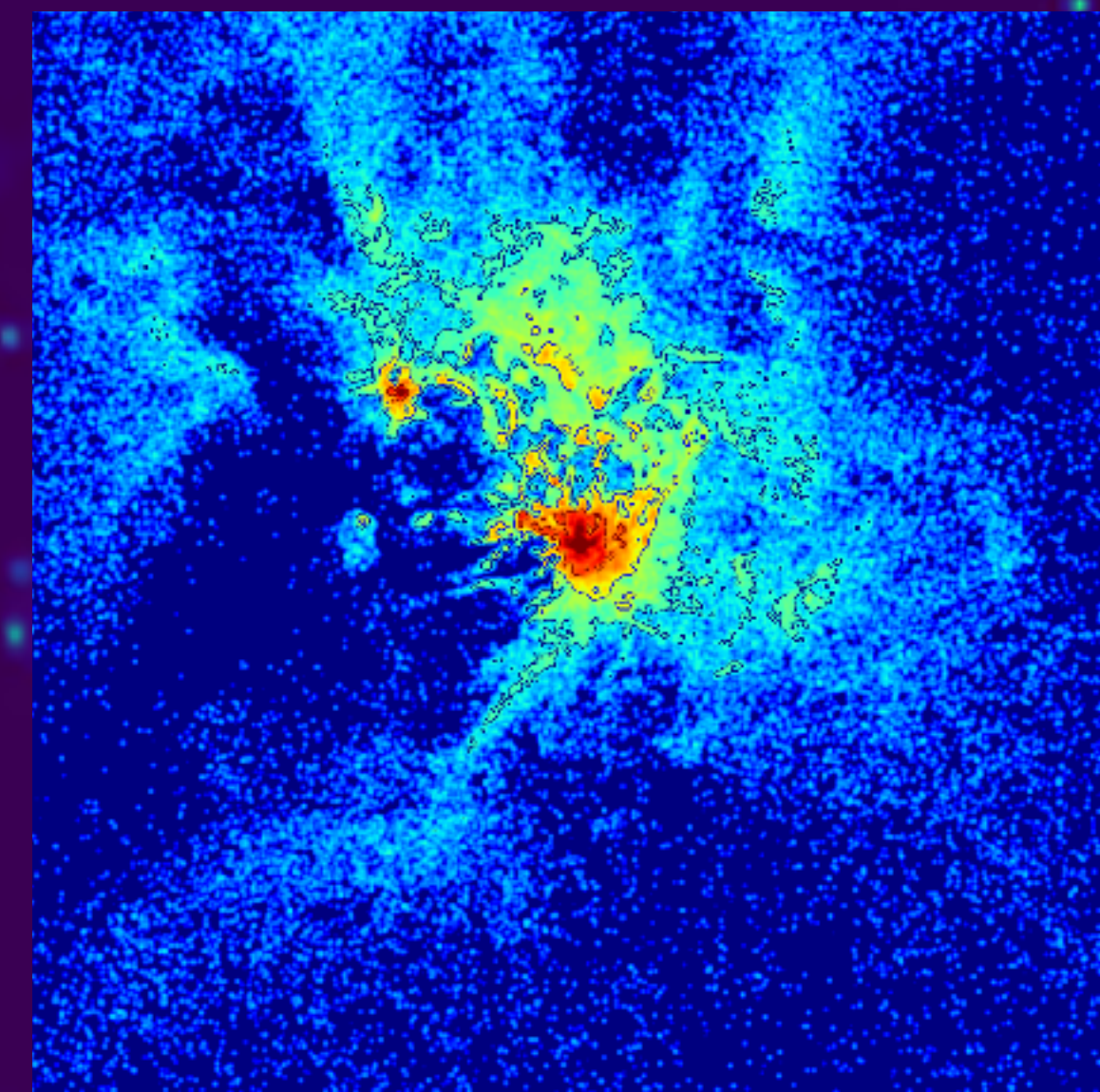
# a blue-optimised large field integral field spectrograph for the VLT

Johan Richard (CRAL)

on behalf of the BlueMUSE consortium

**A decade of discoveries  
with MUSE and beyond**

18–22 November 2024  
Garching b. Muenchen







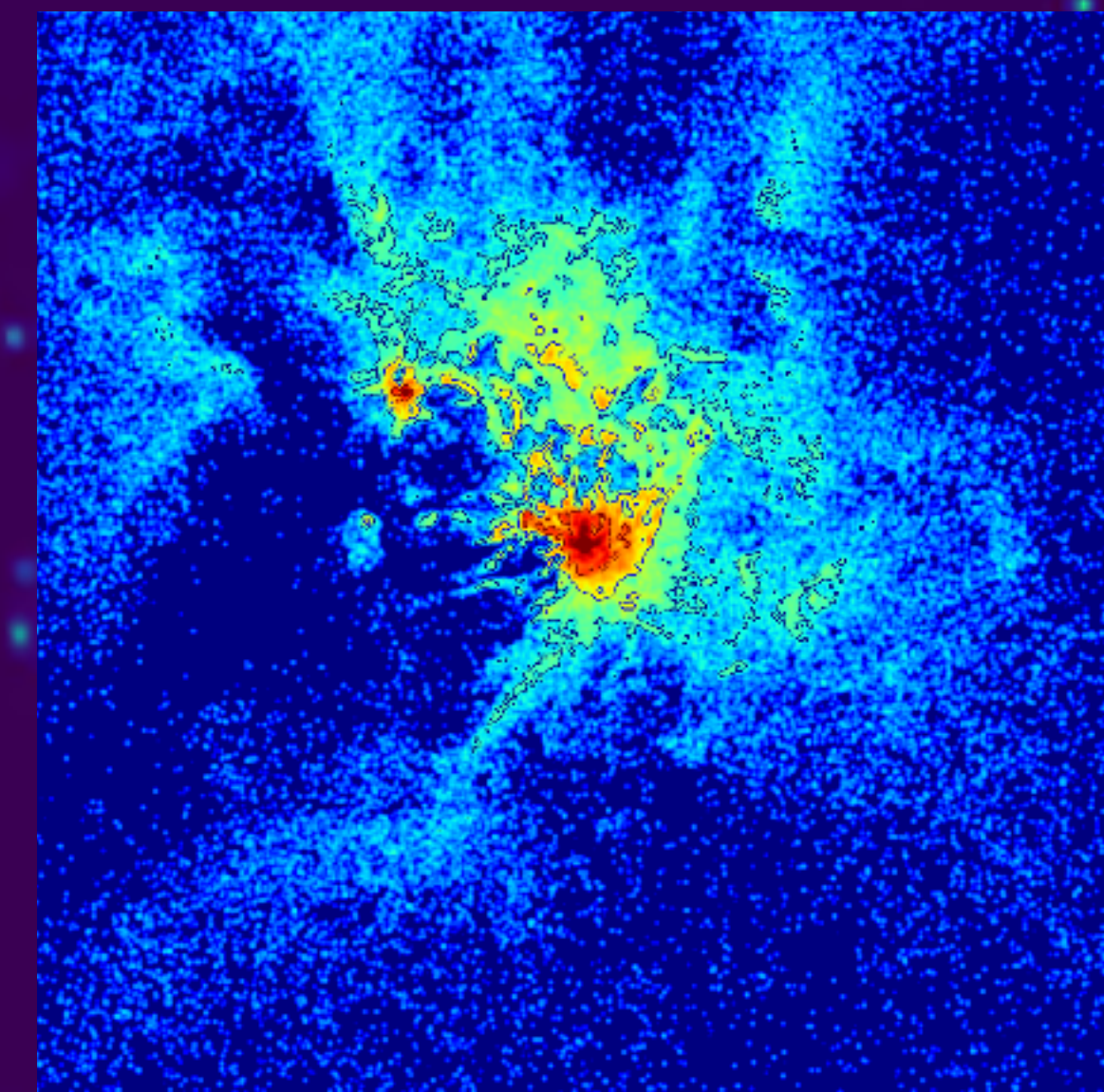
# “Bluer than the blue of MUSE”

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on behalf of the BlueMUSE consortium

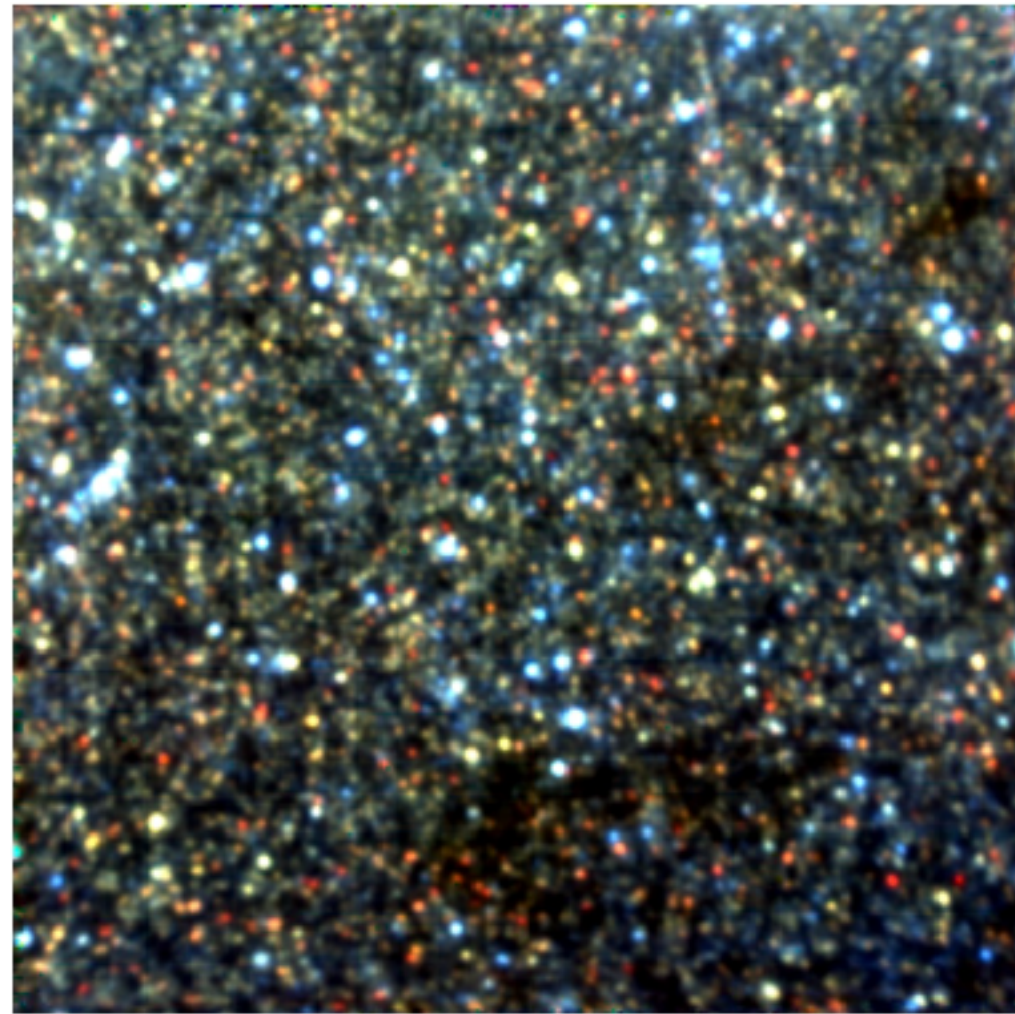
**A decade of discoveries  
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**18–22 November 2024**  
Garching b. Muenchen





# Why a new panoramic IFS?



Spectroscopy in crowded fields

- Spectroscopy of everything and not individual sources
- Knowledge of the environment: neighbours, gaseous media (e.g. circumgalactic / intergalactic medium), ...
- MUSE on the Very Large Telescope has set a new reference for massive spectroscopy in dense fields, extended sources and deep fields.

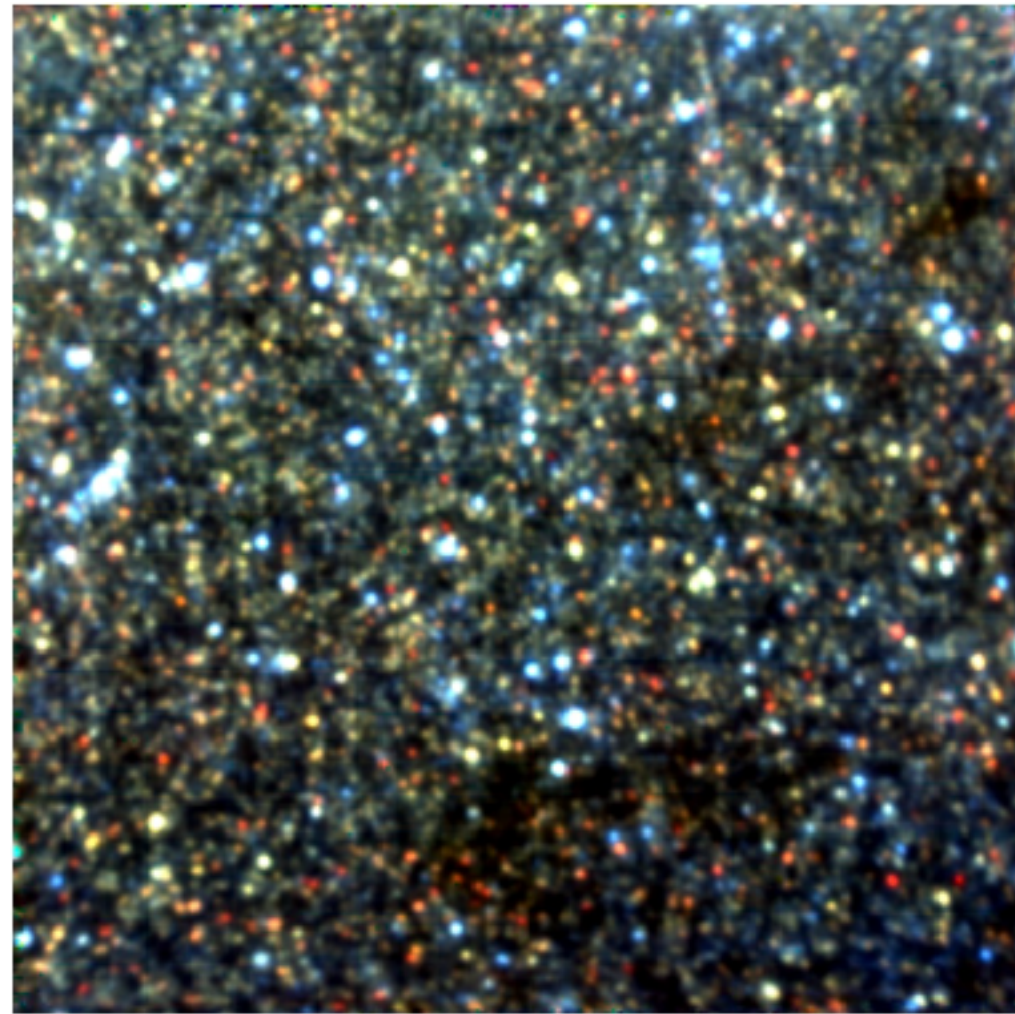
Next goal?



Galaxy environment



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## Next goal?

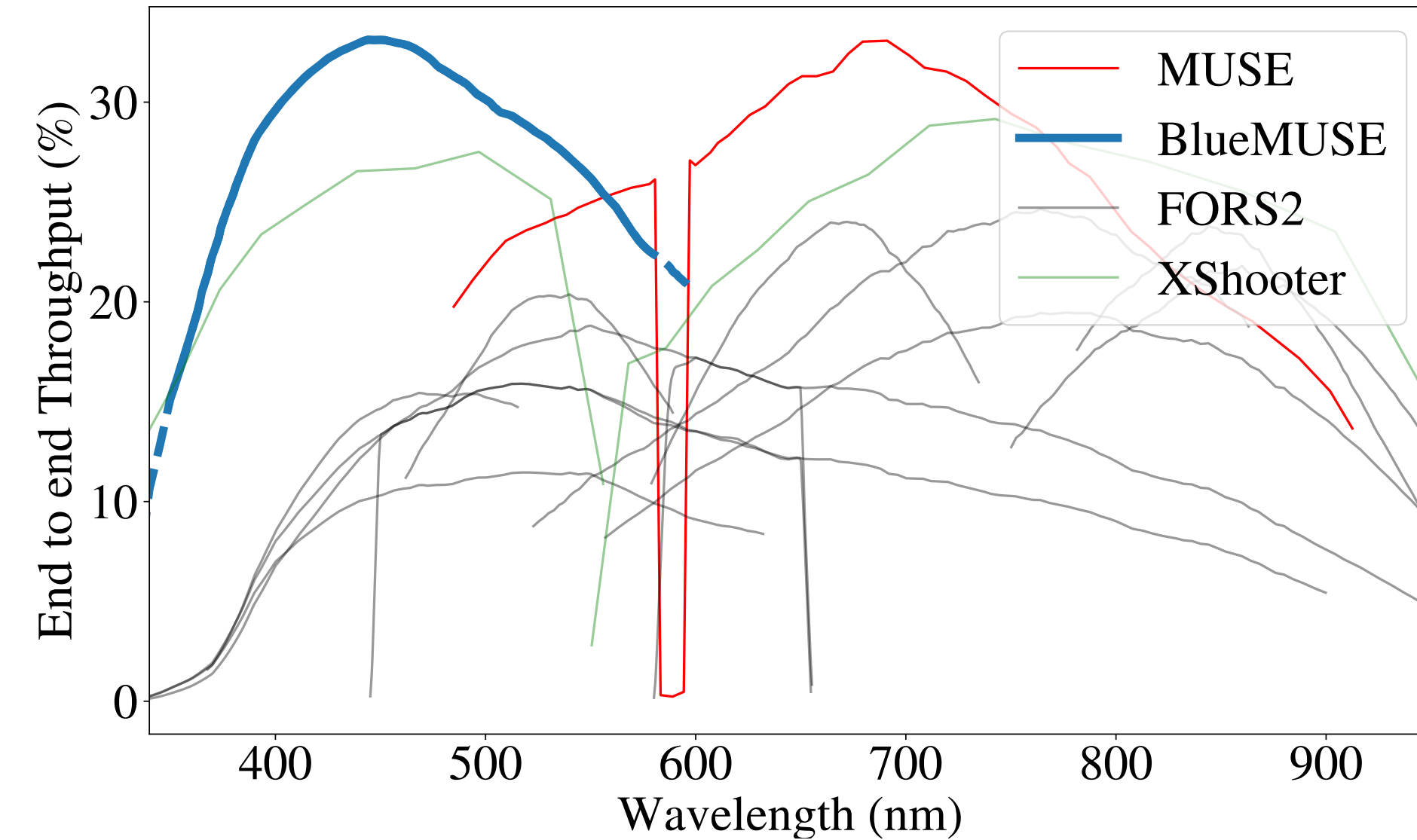
**Expand and complement the spectroscopic parameter space in the blue / UV**



Galaxy environment

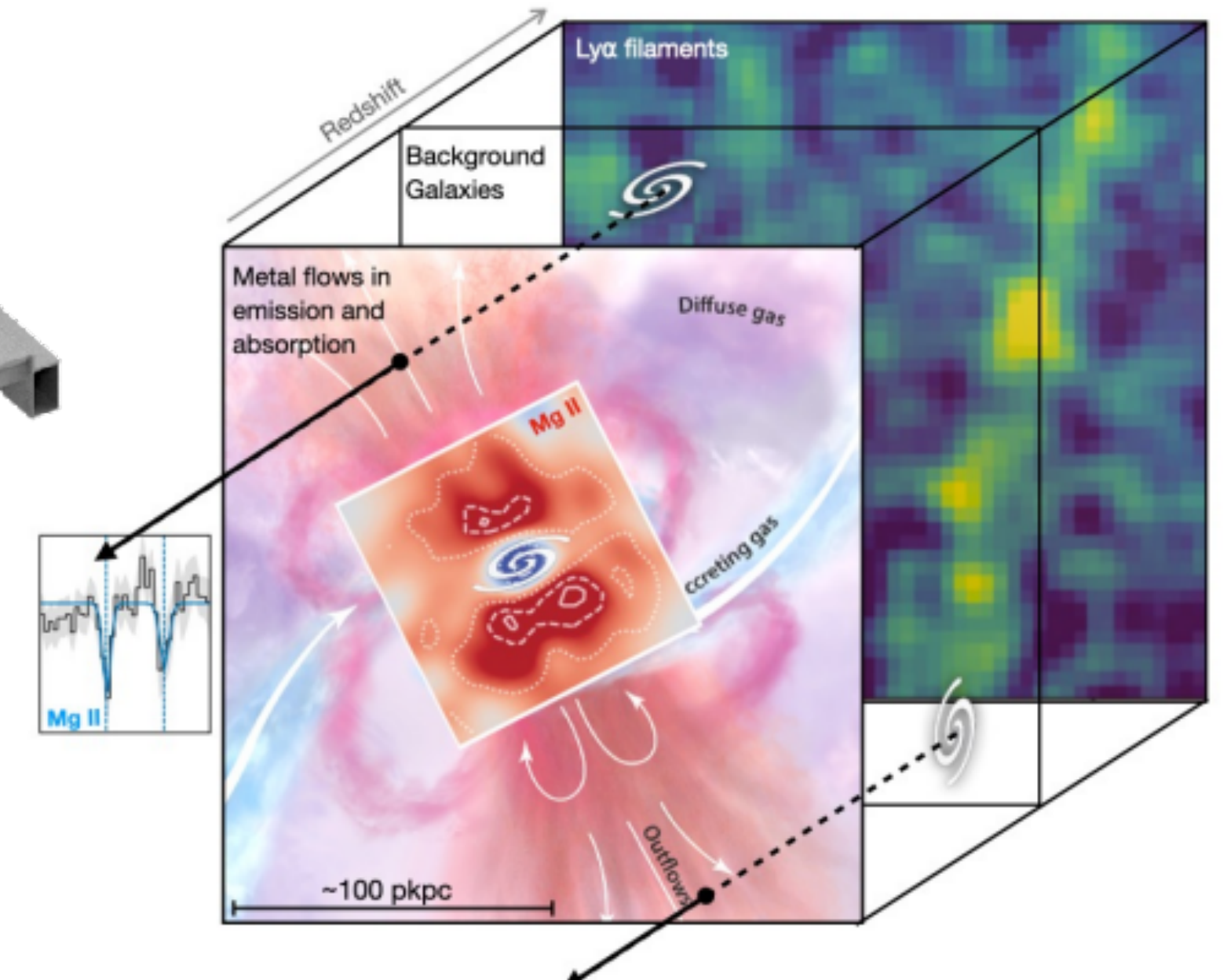
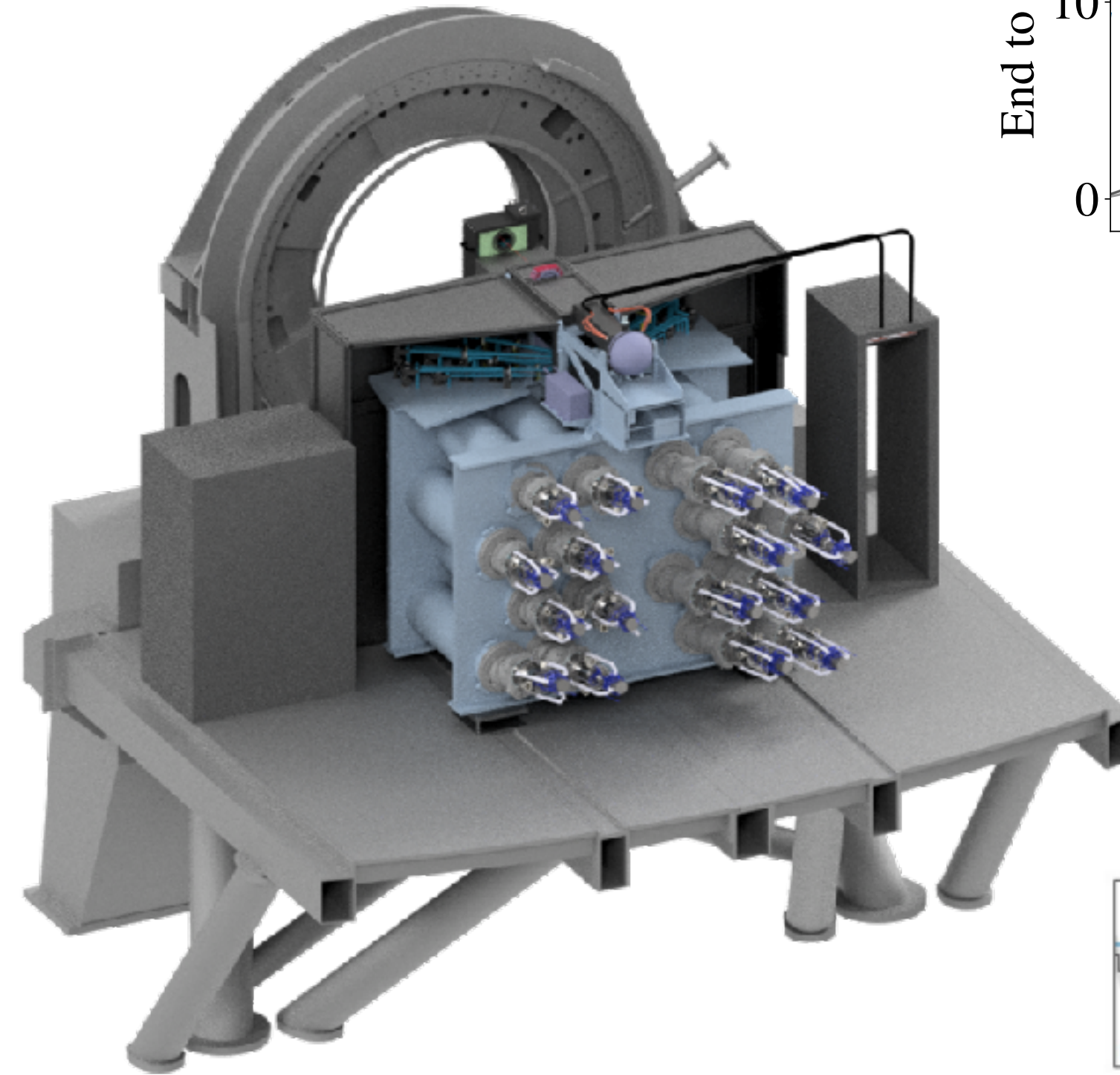


- A large field (**1 arcmin<sup>2</sup>**) Integral Field Spectrograph
- Optimised in the blue/UV **350-580 nm with  $R \sim 3500$**
- With a high end-to-end throughput
- Very efficient in deep spectroscopy and crowded fields, high multiplexing capabilities
- Simple to use and operate!



## Unique science cases ([Richard+2019](#))

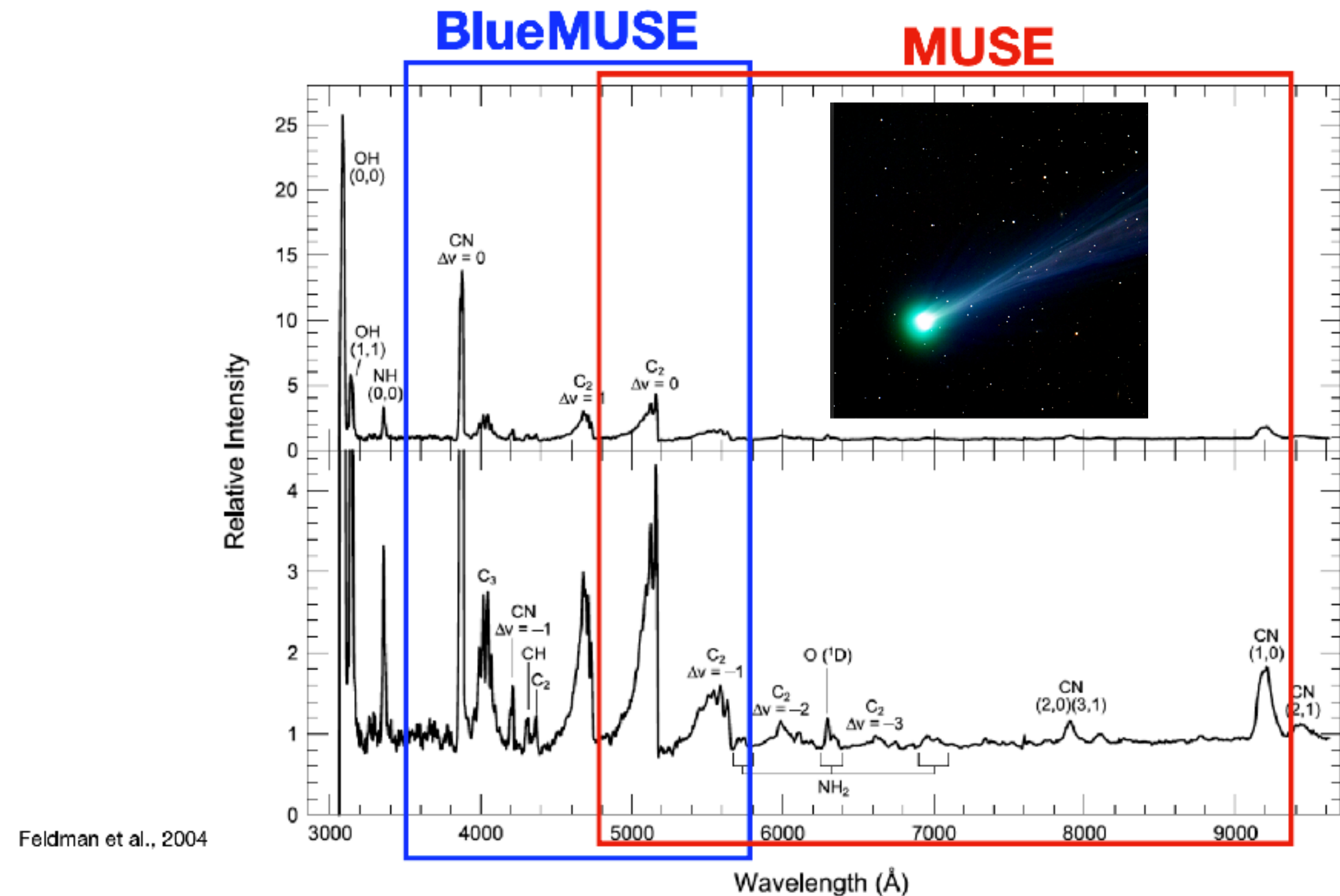
- Massive stars
- Low surface brightness galaxies
- Nearby starburst galaxies
- Gas flows in and around galaxies
- Distant protoclusters ...





## Co-leads: A. Adamo, N. Castro

- Comets
- Wolf-Rayet and OB stars evolution
- Resolved HII regions, ionised nebulae, SNRs
- Globular clusters
- Ultra Faint Dwarf (UFD) galaxies

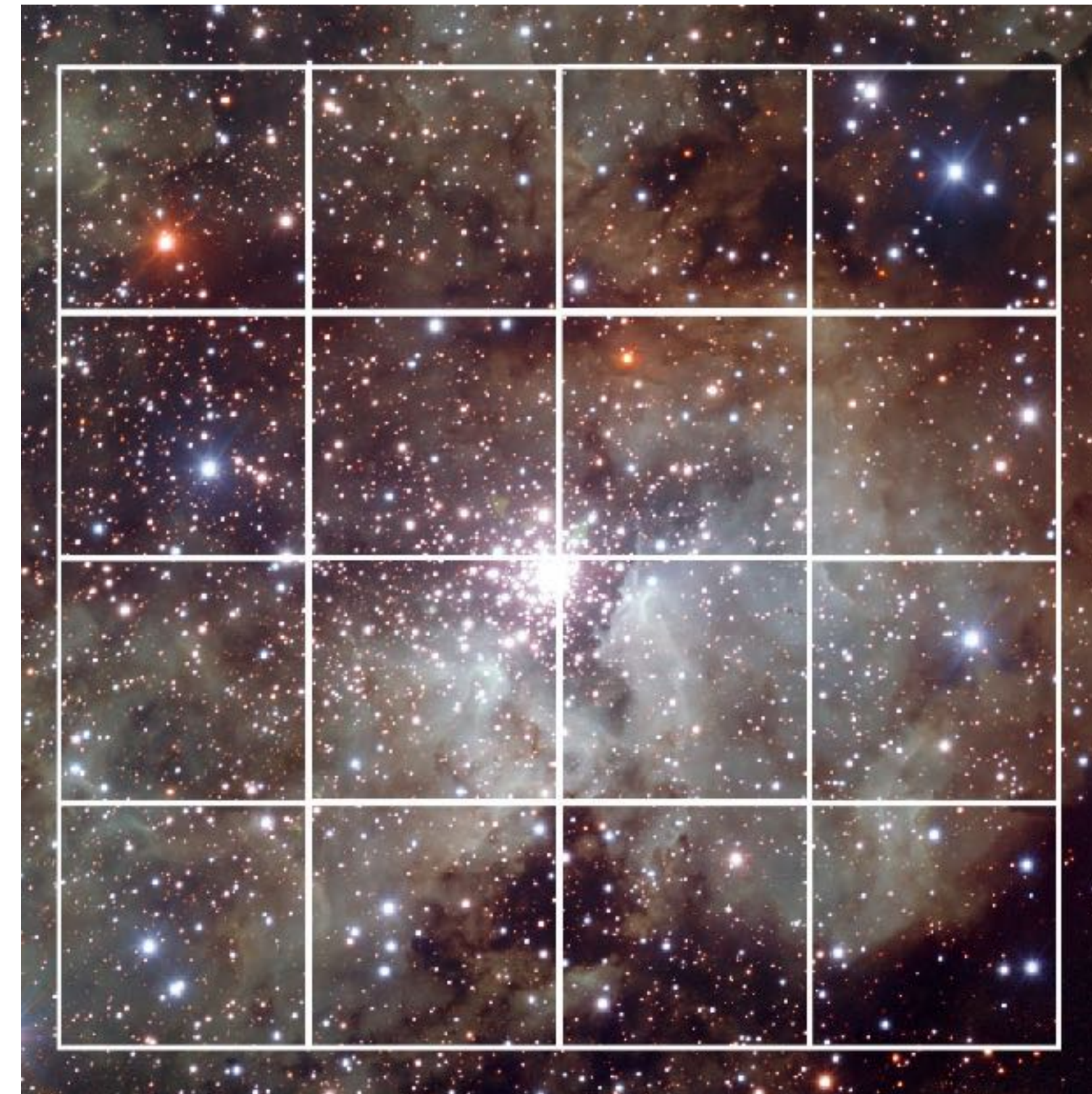


Opening of blue parameter space with bright  
cometary emission  
(CN, C3, CH)



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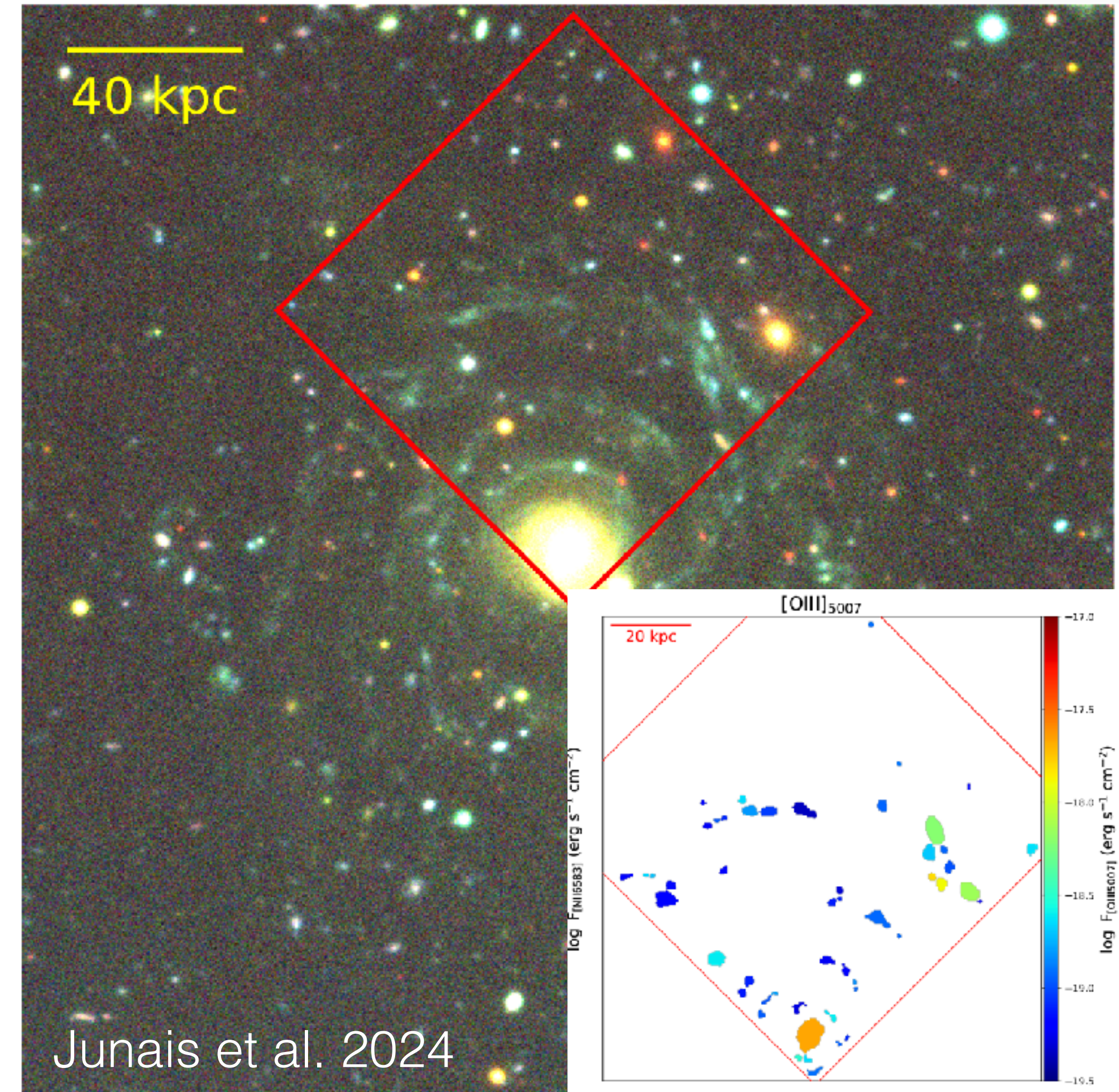
Characterisation of massive star clusters: evolution, ionising photons, WR signatures.



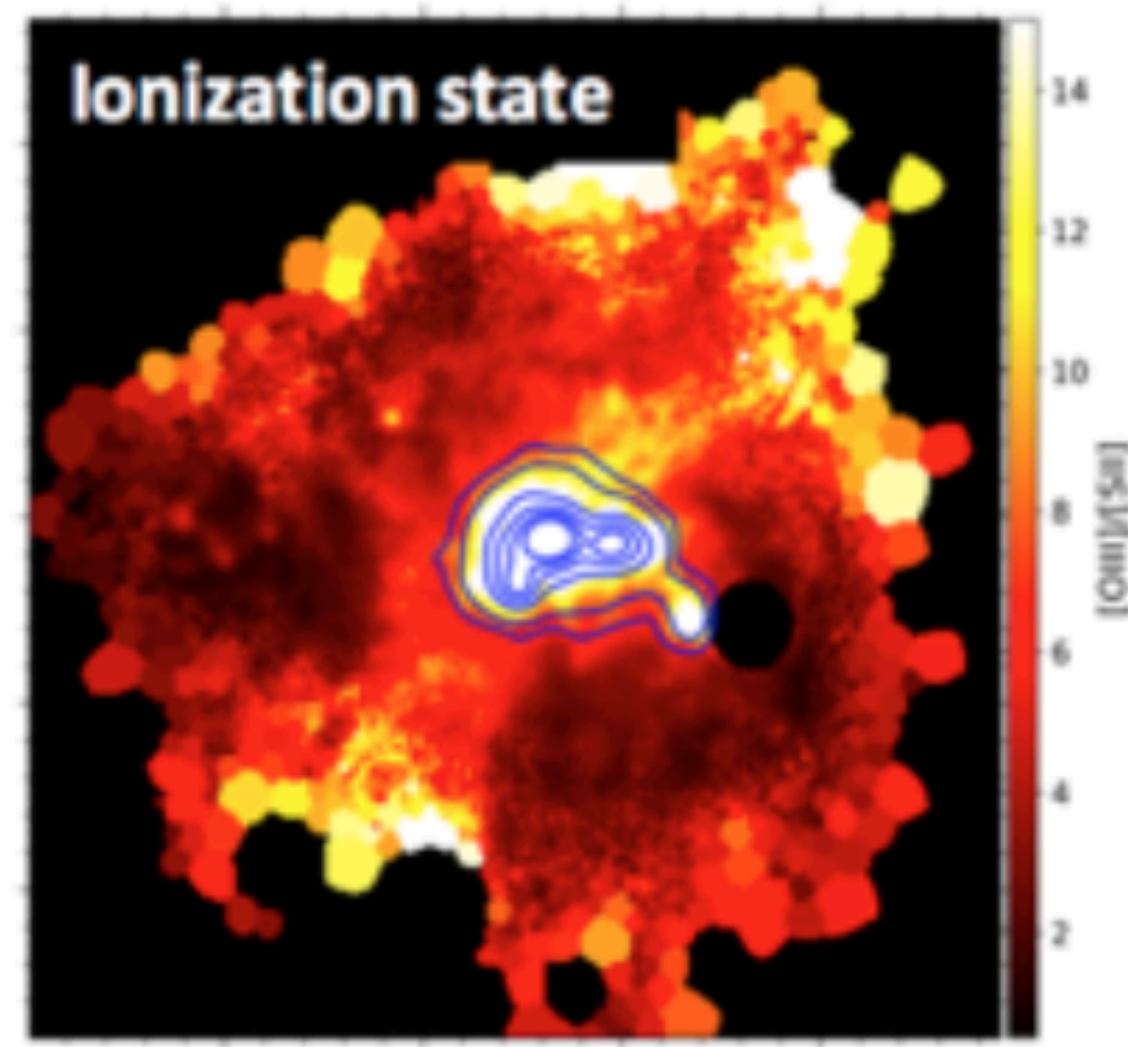
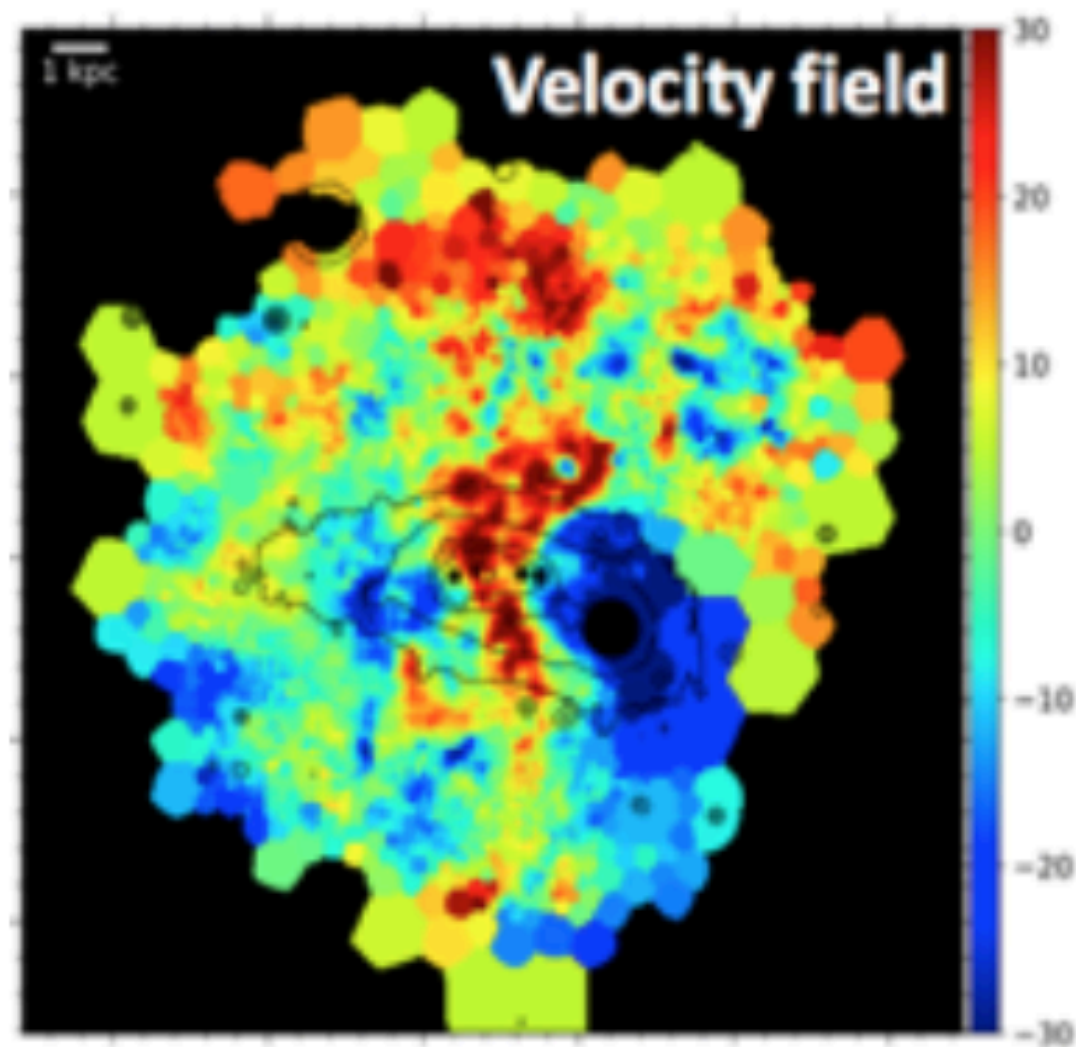
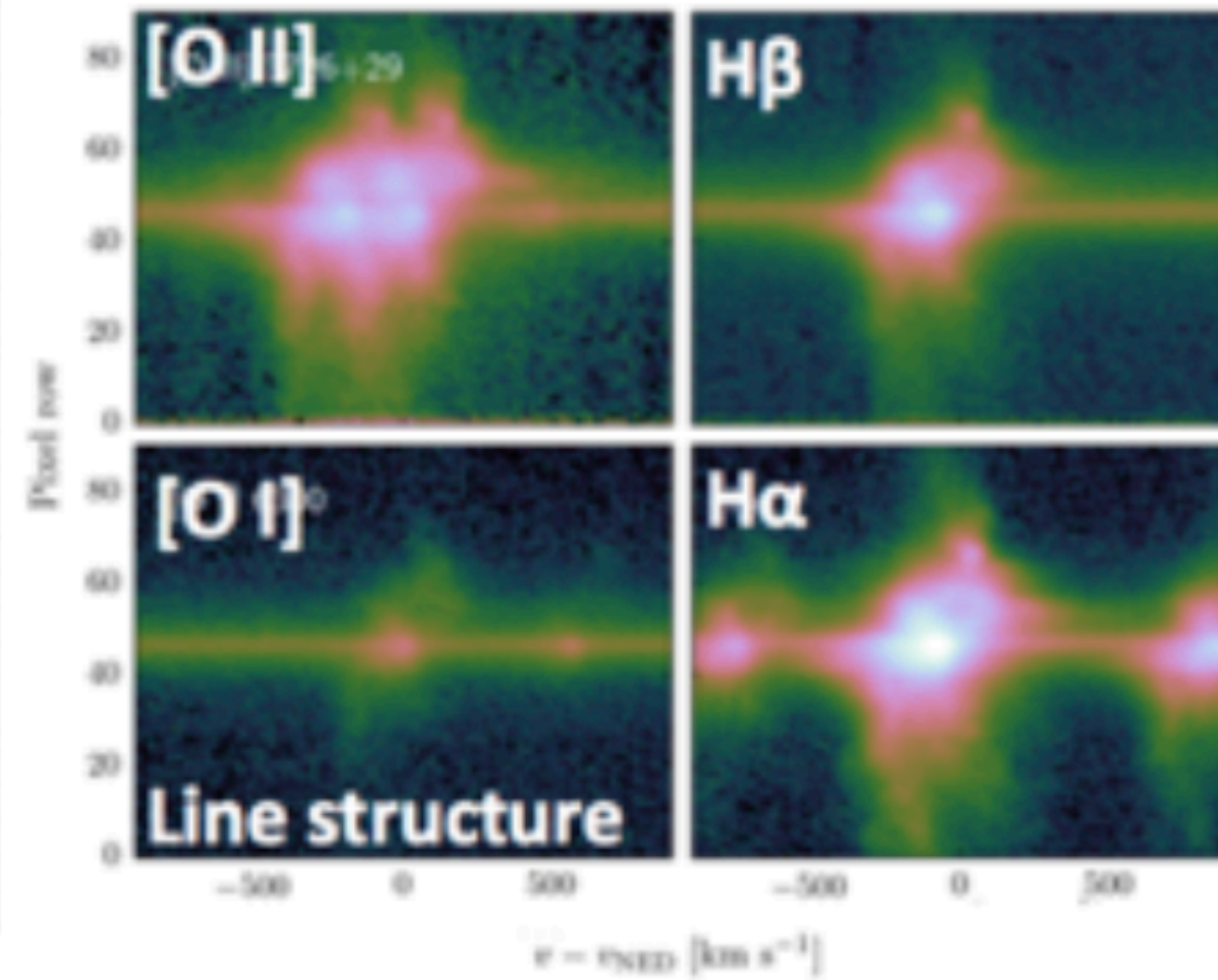
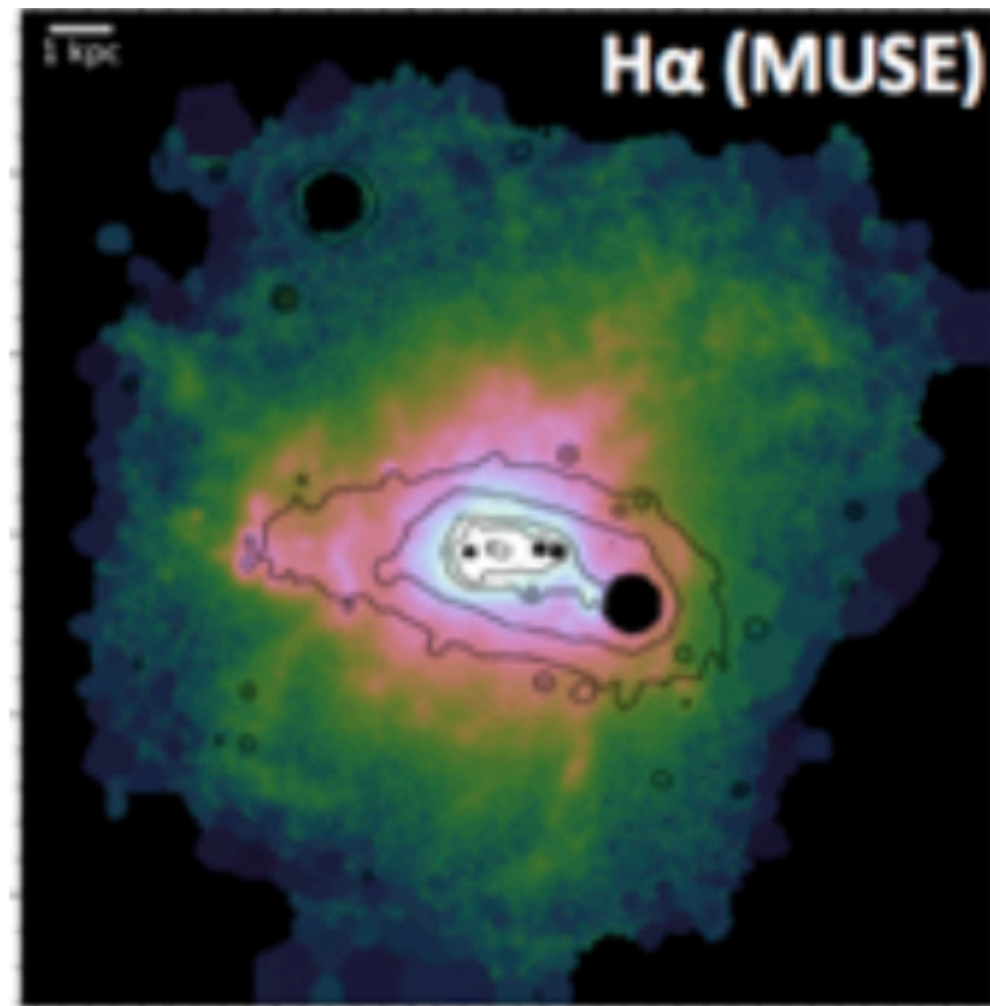
## Co-leads: D. Krajnović, Á. López-Sánchez

- ISM and HII regions in Extreme starburst galaxies
- Low surface brightness (LSB) galaxies
- Environmental effects in local galaxy clusters
- High order kinematics of cold stellar disks and dwarf galaxies
- PNs for stellar populations and kinematics of ell. galaxies + distances
- Soft X-ray sources and radiative shocks in metal-poor galaxies

e.g. LSB galaxies:  
Stellar populations and direct  
metallicity measurements,  
improved kinematics.







Low mass, starburst galaxies at  $z \sim 0$

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]<sub>3727</sub>, [OIII]<sub>4363</sub>, HeII<sub>4686</sub>, WR bump

*Bik et al. 2018*

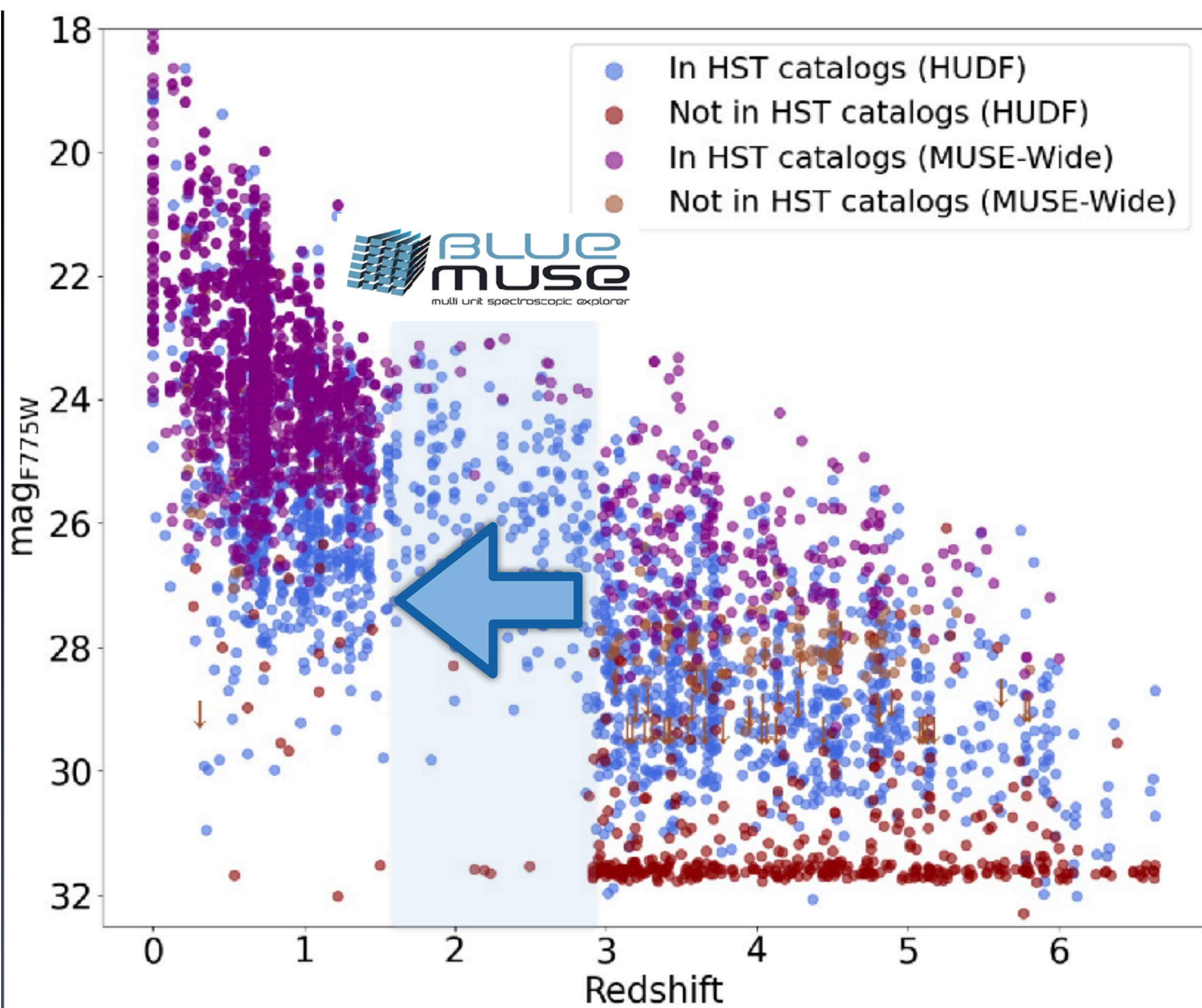
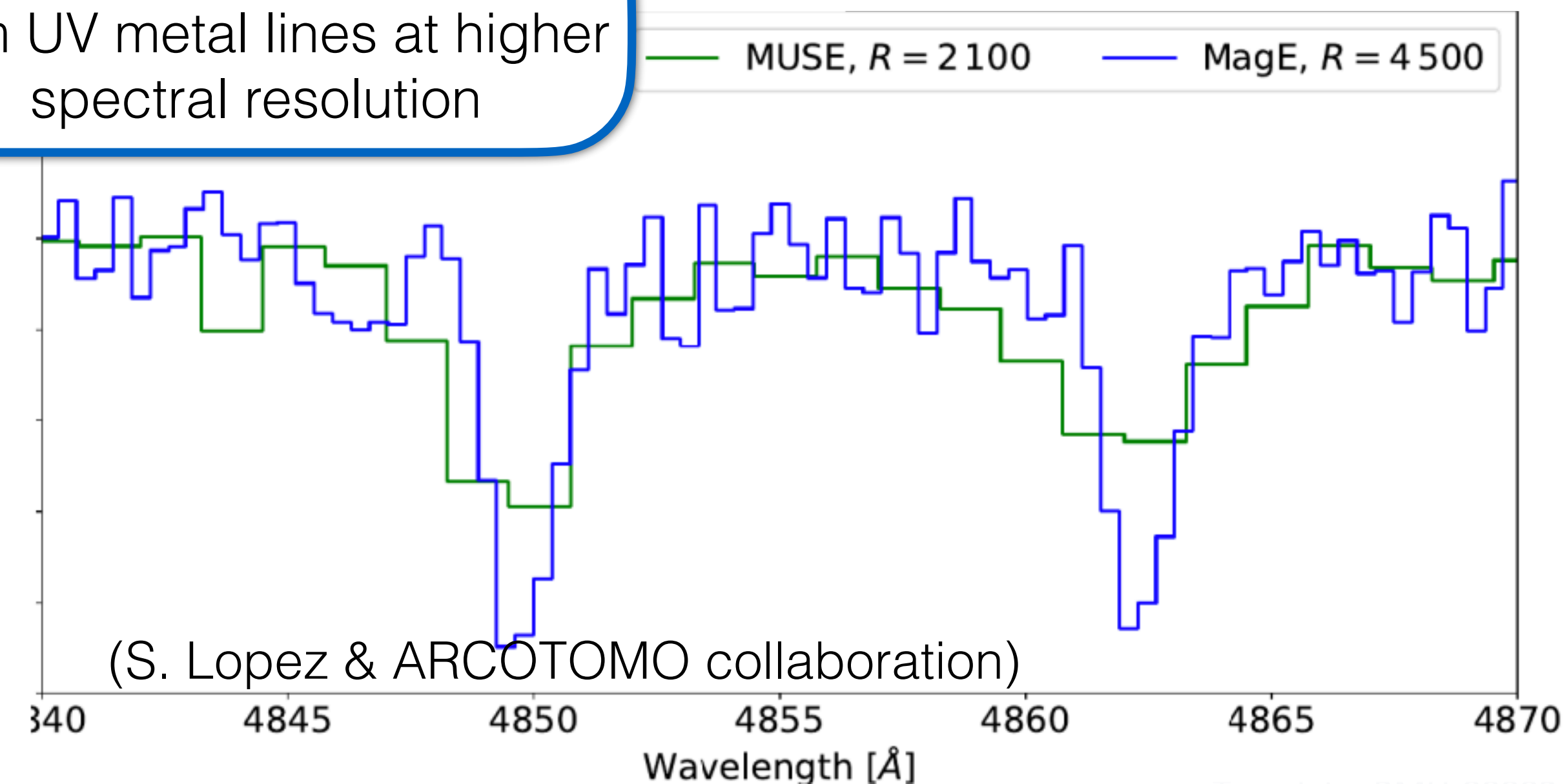


Co-leads: M. Jauzac, T. Urrutia, M. Swinbank

- Deep fields
- Gas flows around and between galaxies
- Gravitational lensing by massive clusters
- Forming groups and clusters
- Lyman continuum leakers



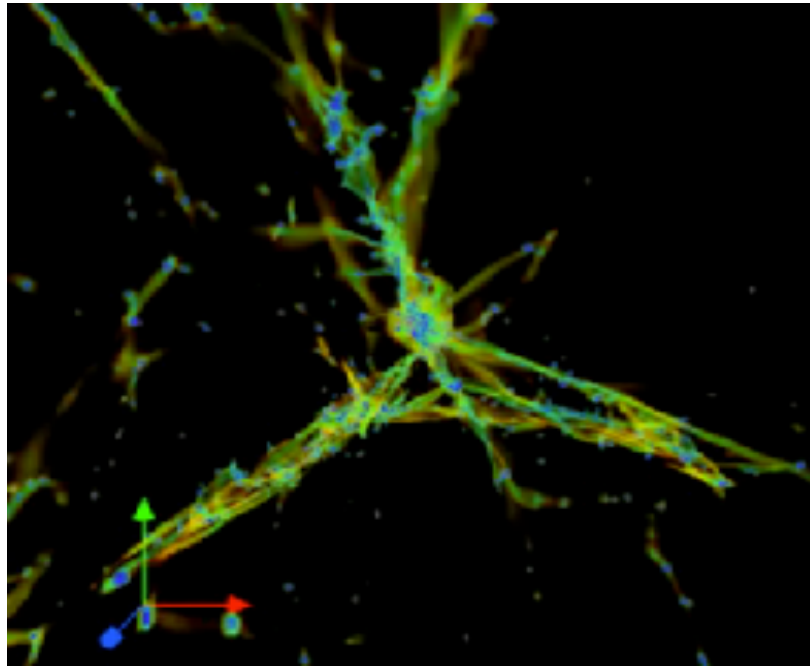
Characterising gas flows  
from UV metal lines at higher  
spectral resolution



Filling the redshift desert and the peak of the cosmic  
star formation history with Lyman-alpha emitters



# Diffuse gas



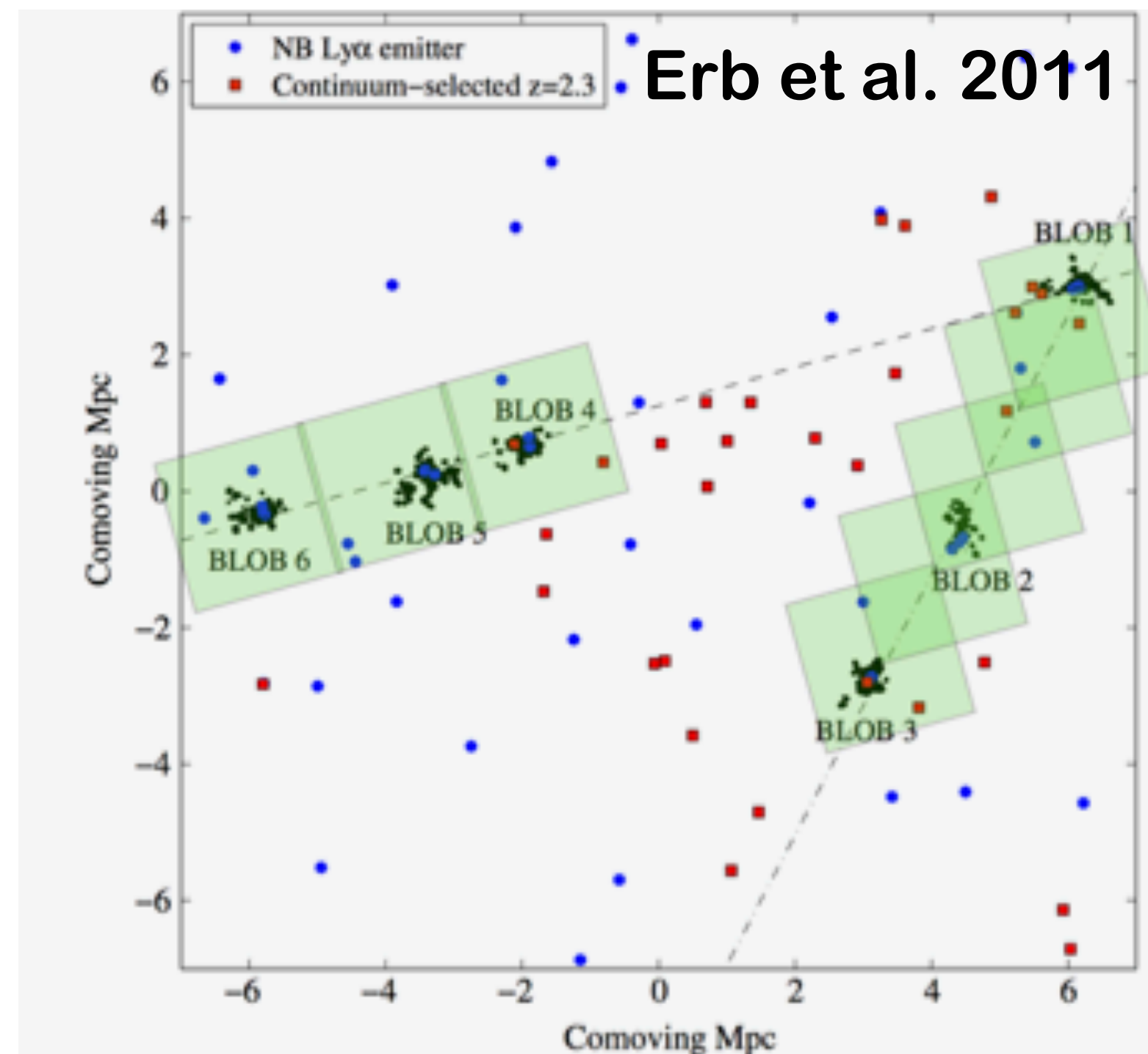
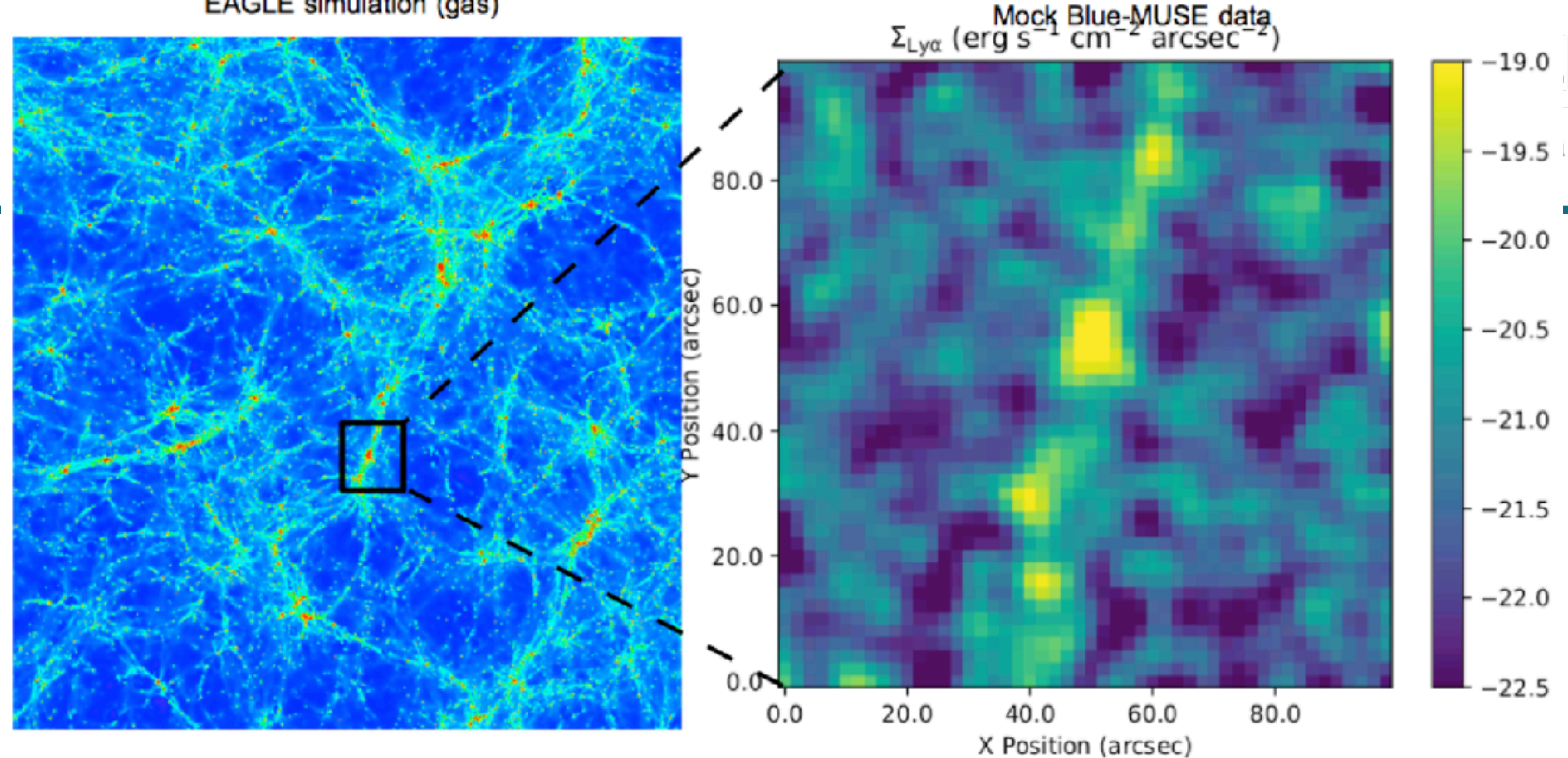
- Lyman-alpha emission probes the diffuse gas in the CGM and into the IGM

- First attempt with MUSE (>100-200 hrs):

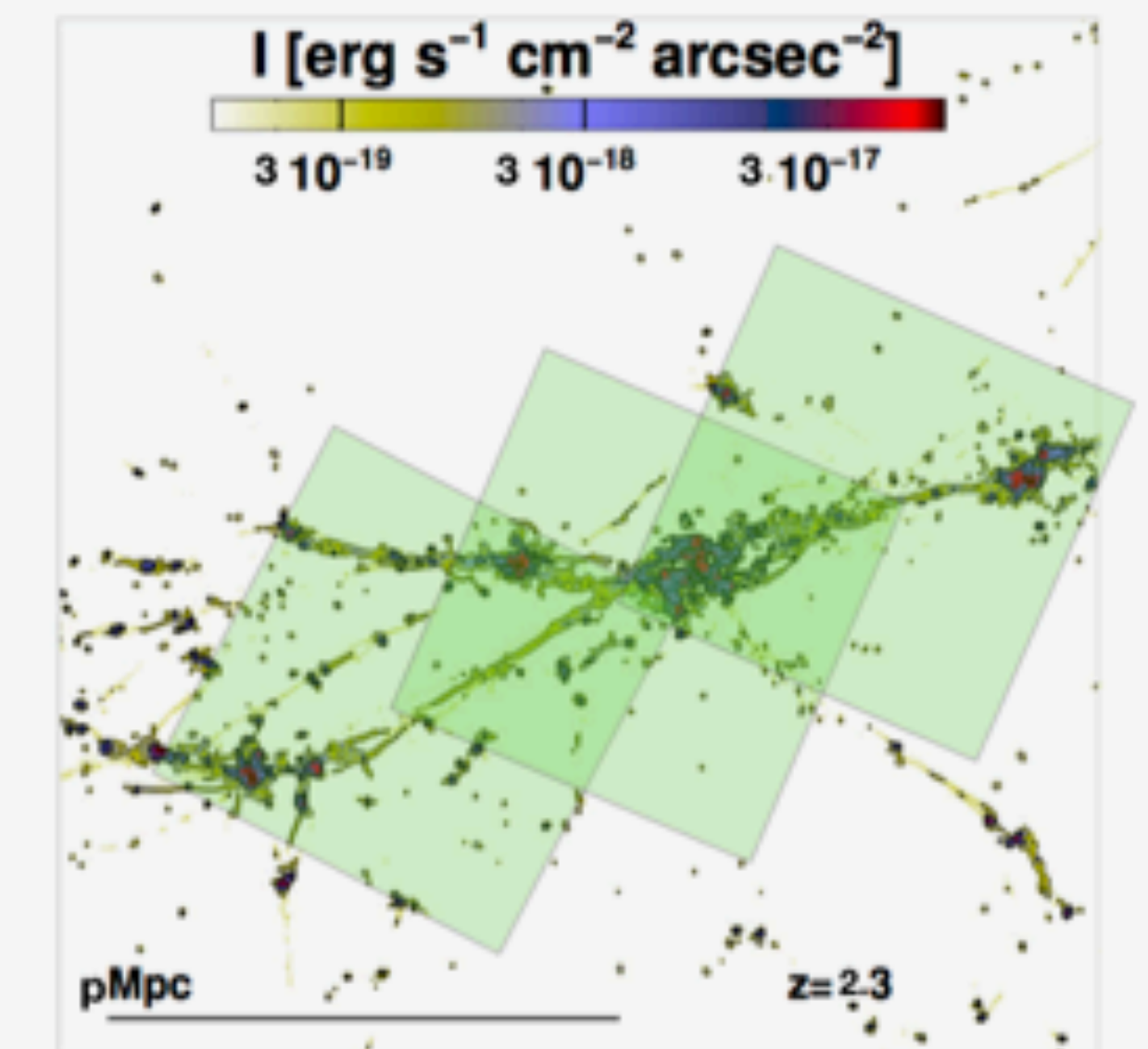
MUDF Lusso et al. 2019 (near quasars)

MXDF Bacon et al. 2021 (field overdensities)

- **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!

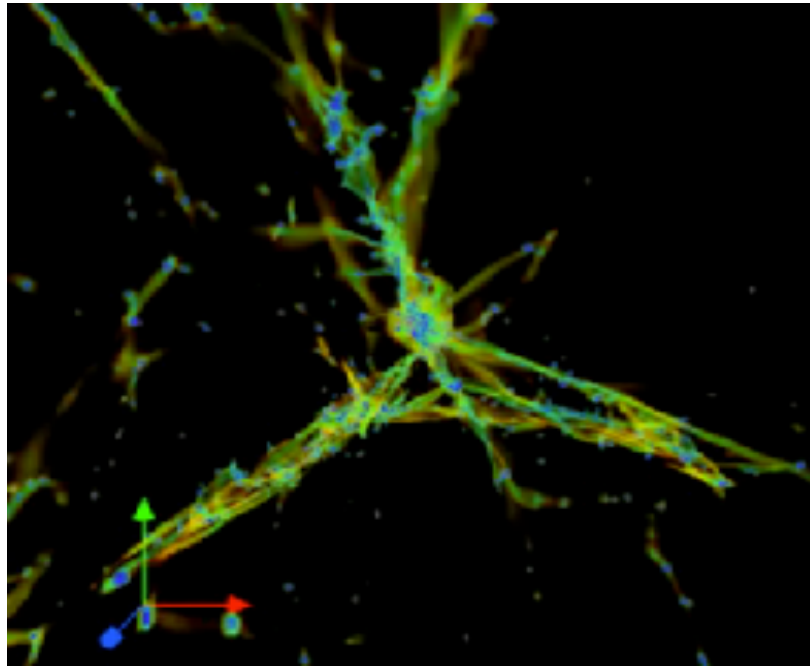


Rosdahl & Blaizot 2012





# Diffuse gas



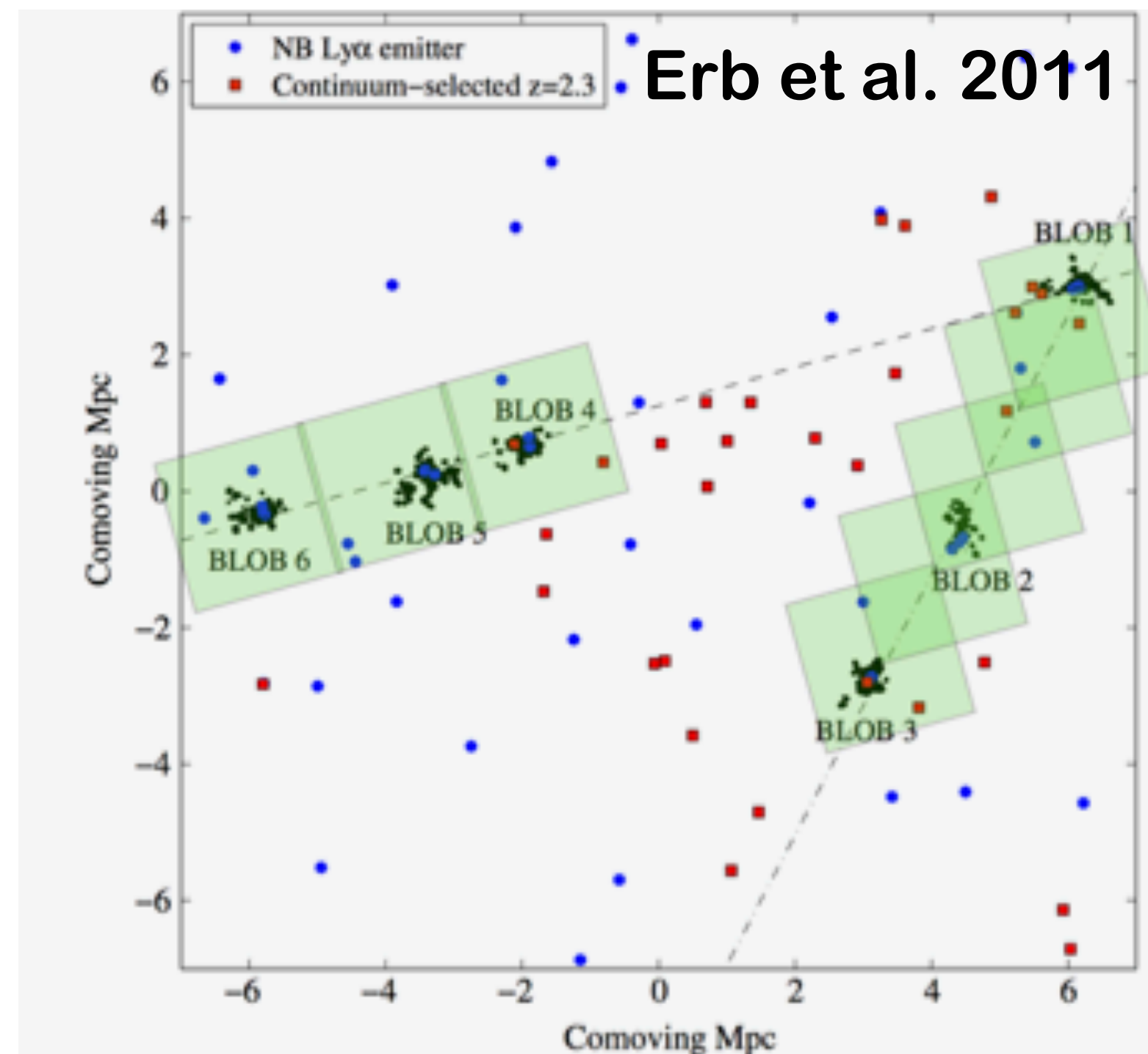
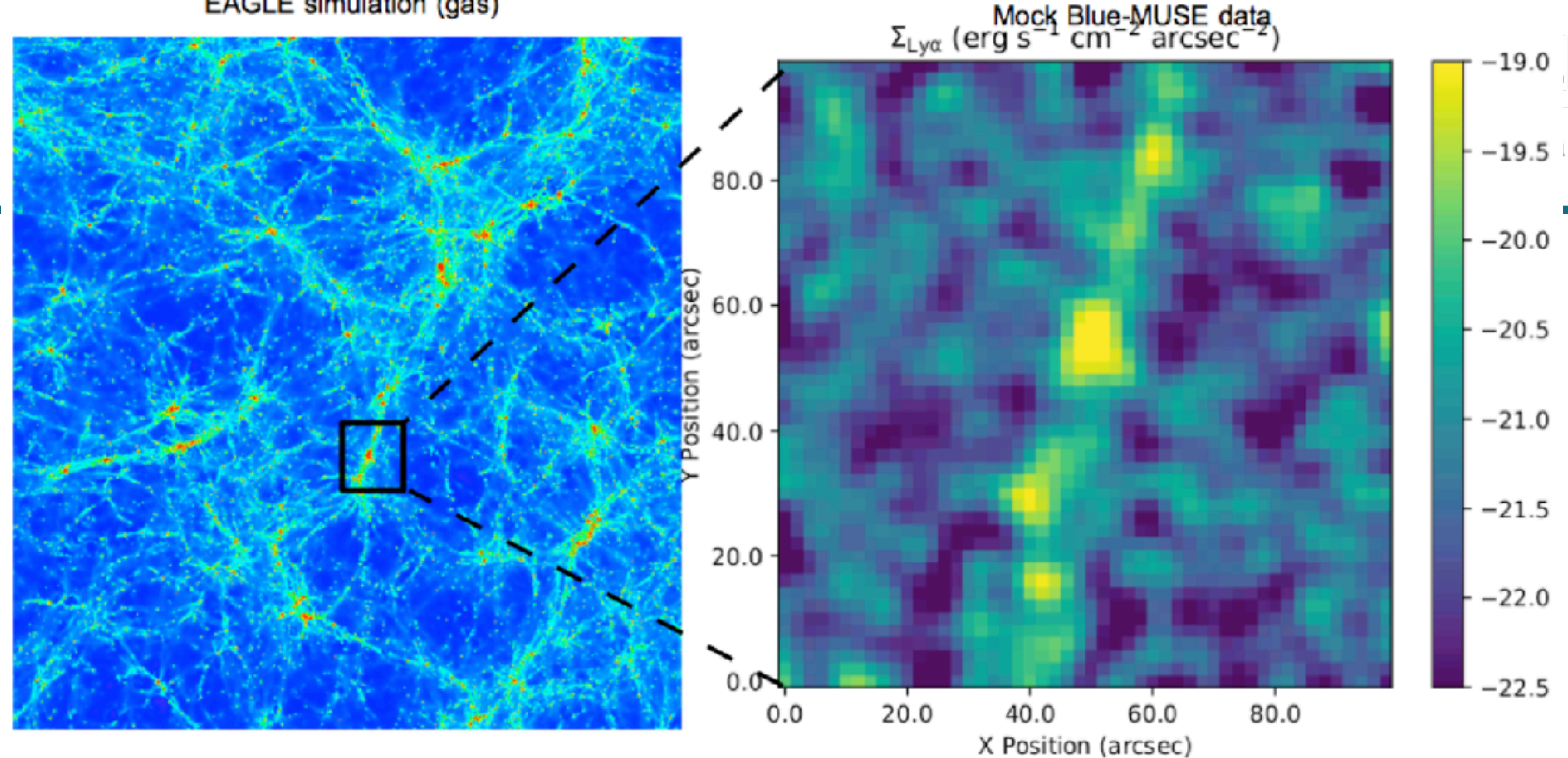
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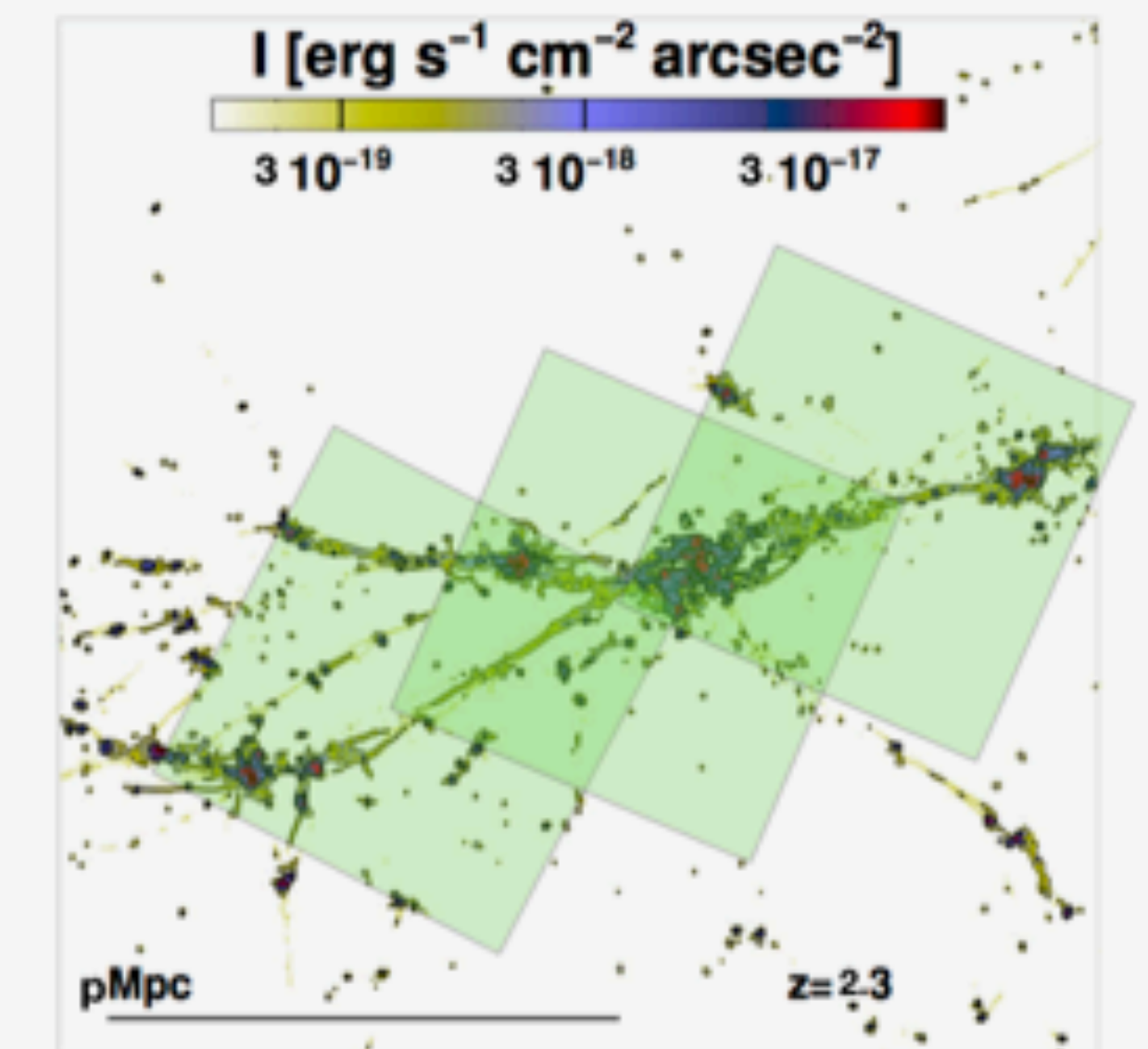
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Rosdahl & Blaizot 2012





Requirement	Parameter
Instrument concept	Panoramic IFU, one mode
<b>Operations efficiency</b>	<b>&gt; 70% open shutter time</b>
Nominal wavelength range	Min. 350 - 580 nm
Spectral resolution	Min. 3600, average > 3500
End-to-end throughput (incl. telescope and atmosphere)	Min. 15%, average > 26%
Limiting magnitude	23.4 AB in 1 hr at S/N = 5
Sky subtraction	5% (goal 2%)
Field of view	> 1 arcmin <sup>2</sup> , <u>no gaps</u>
Image quality	FWHM < 0.42"
Wavelength calibration	1/20th res. element (goal 1/30th)
<b>Stability during night</b>	<b>&lt; 0.1 pixel and &lt; 10% illumination</b>
Spatial sampling	0.2 < s < 0.3"
Spectral sampling	LSF over > 2 pixels (goal 2.5)

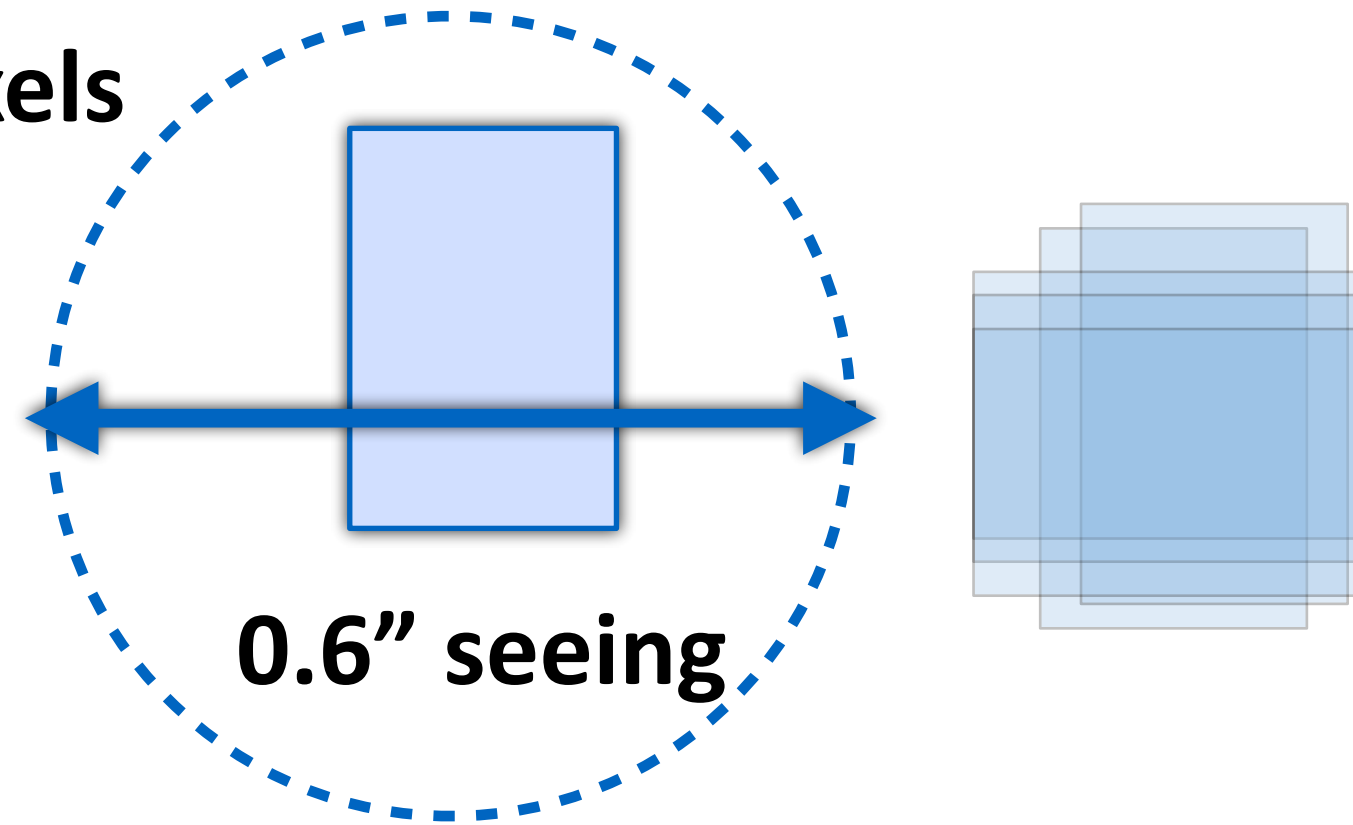


# Current design and performances



## 1 arcmin<sup>2</sup> FoV, 0.2 x 0.3" rectangular spaxels

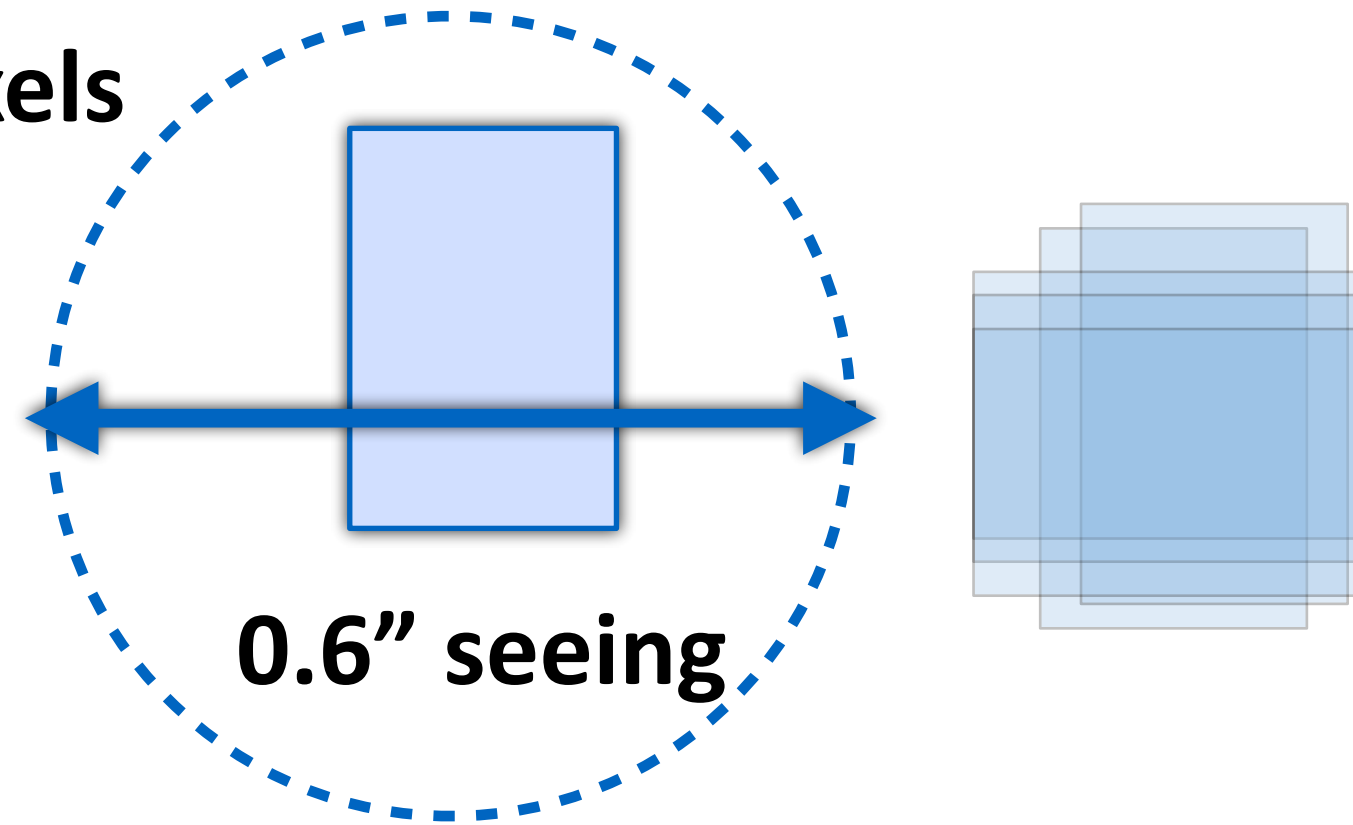
- larger spaxel helps background noise while properly sampling the PSF.
- dithering + 90 deg. rotations help with systematics.





## 1 arcmin<sup>2</sup> FoV, 0.2 x 0.3" rectangular spaxels

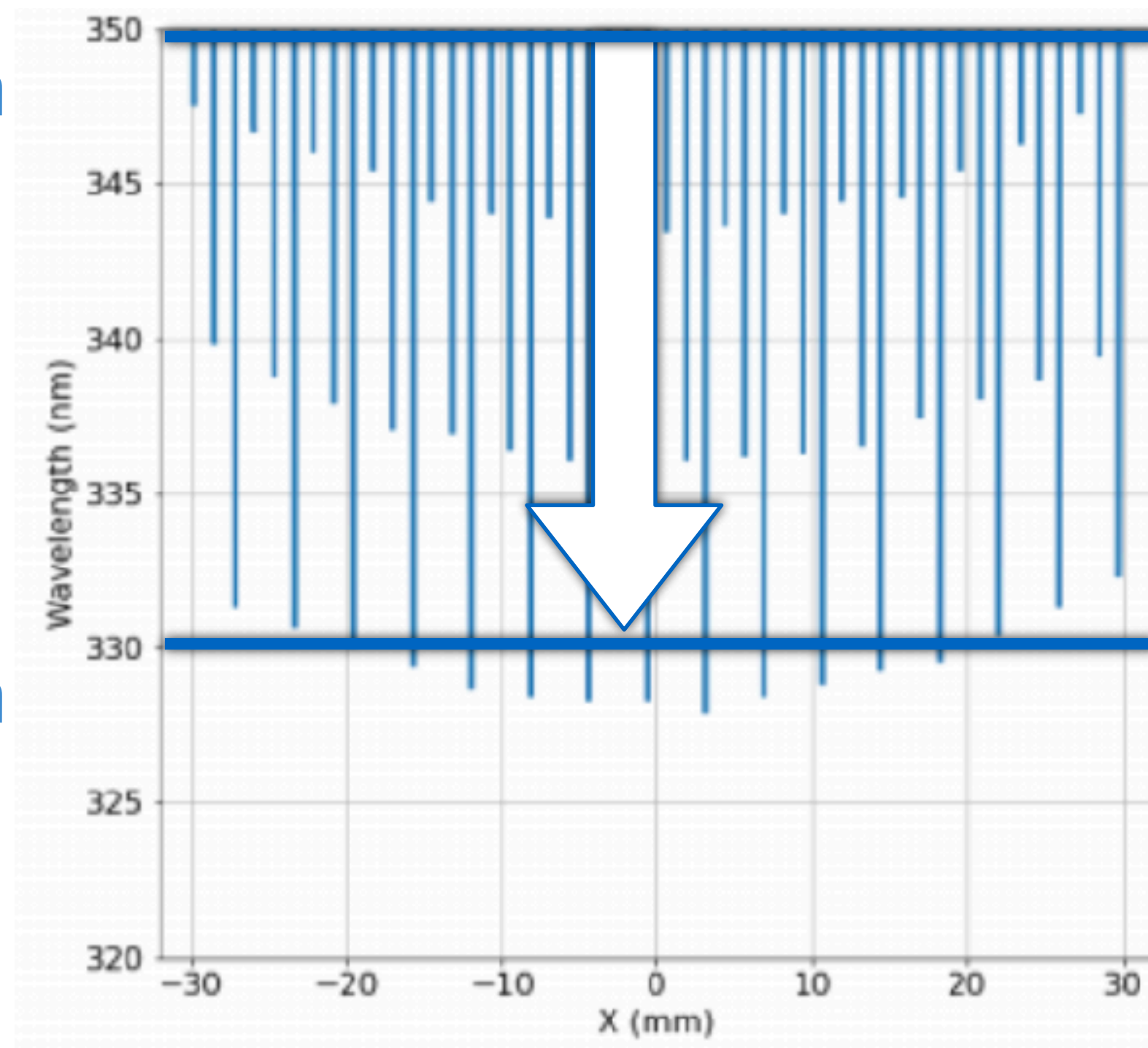
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Extended range: 330 - 600 nm

350 nm

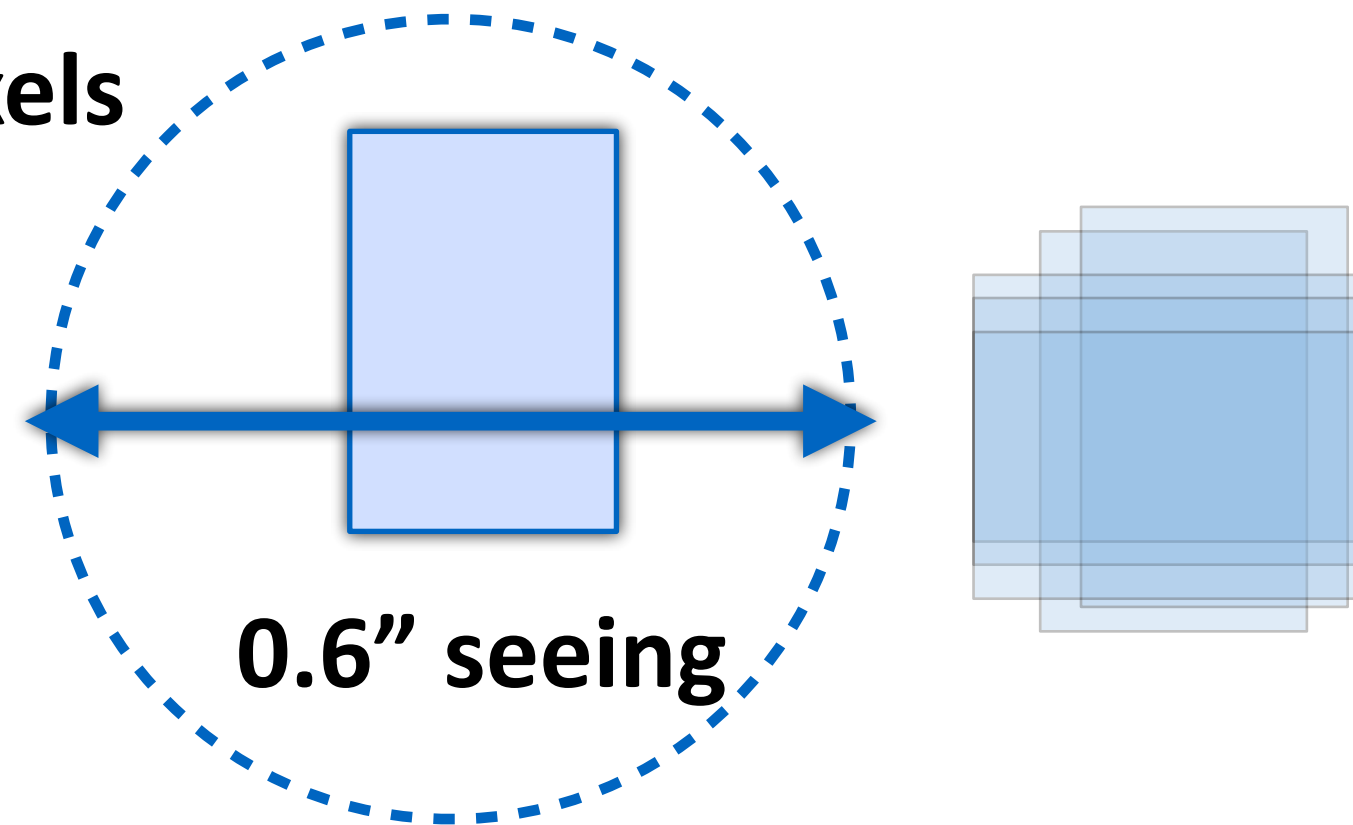
330 nm





## 1 arcmin<sup>2</sup> FoV, 0.2 x 0.3" rectangular spaxels

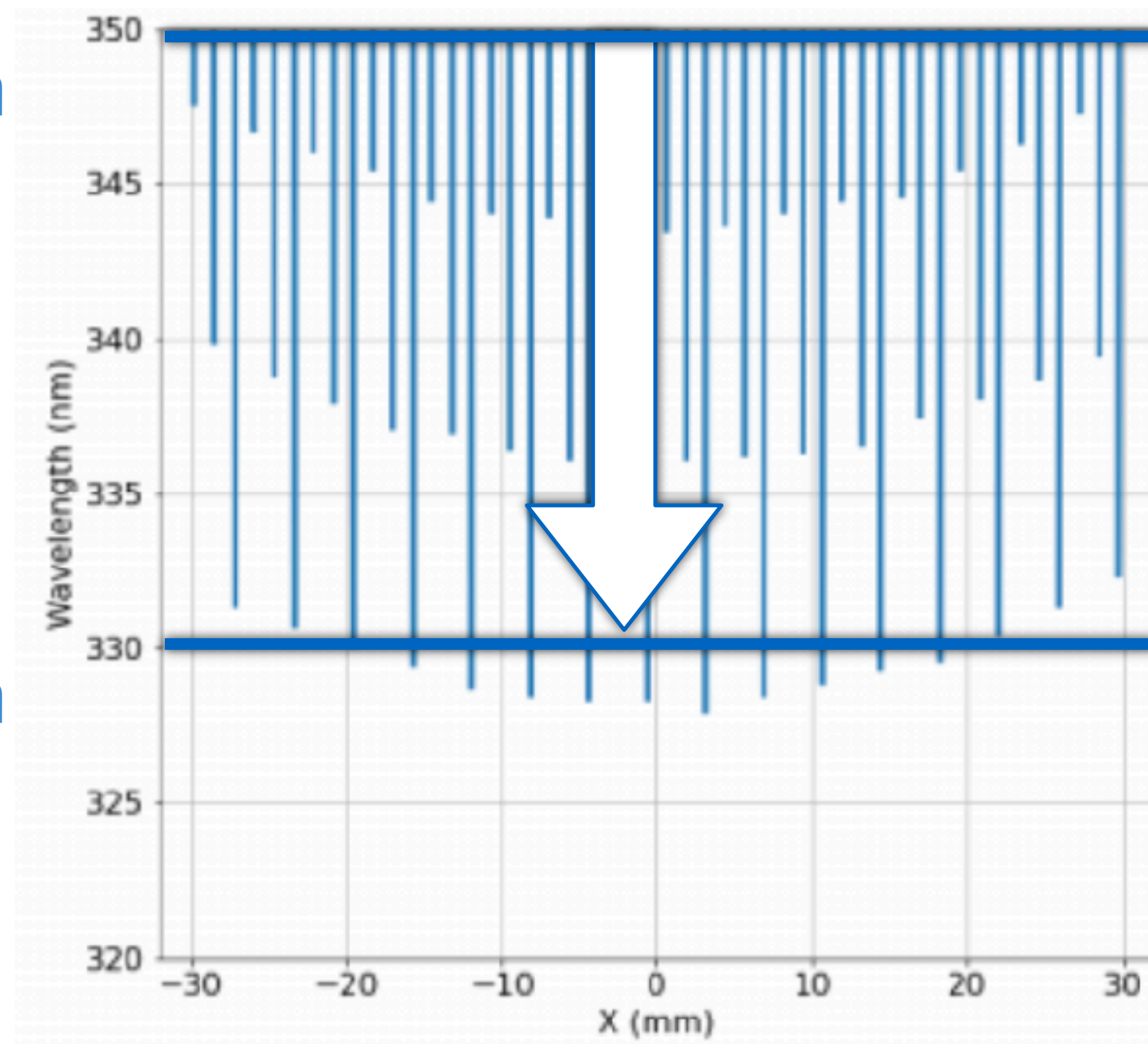
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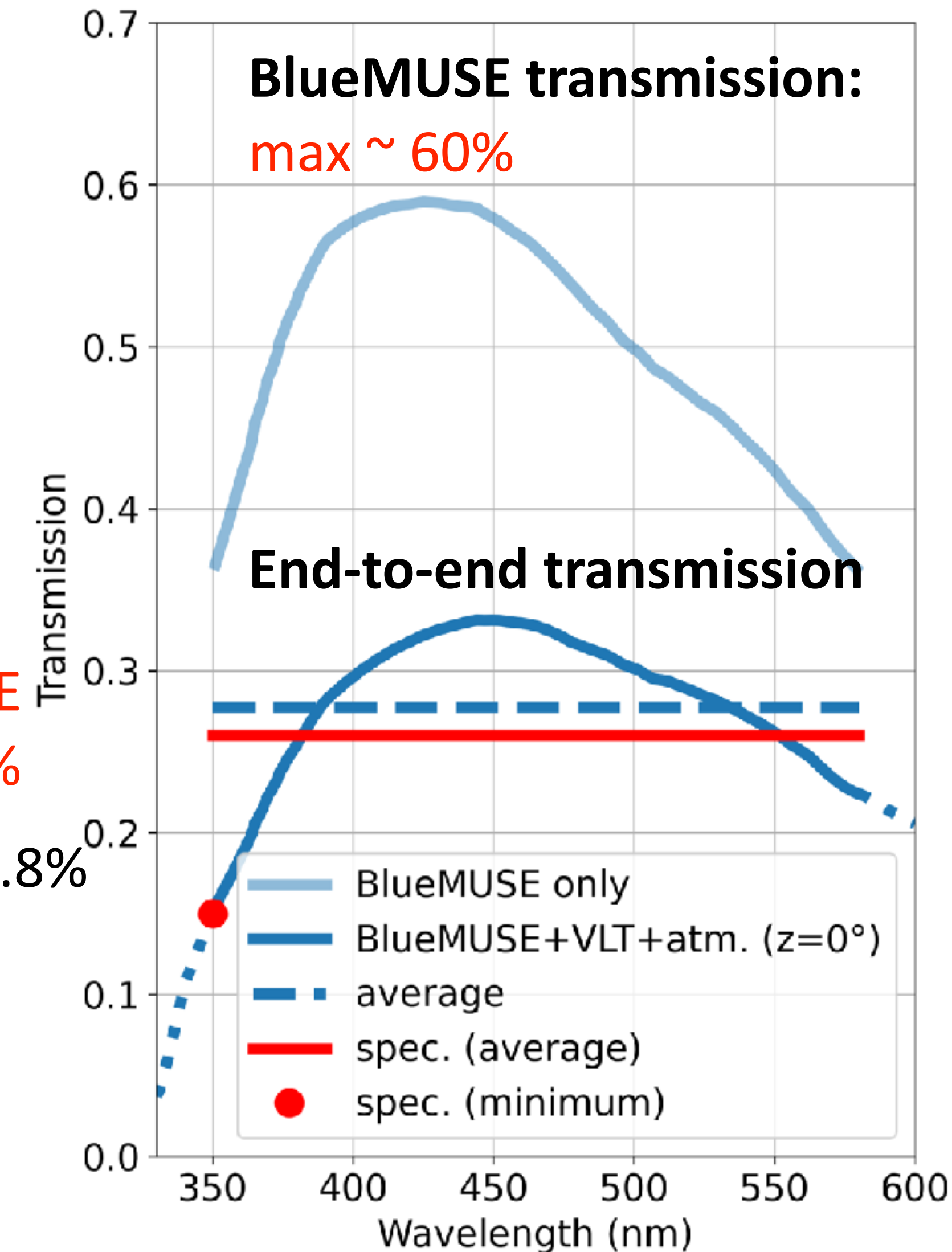
350 nm

330 nm



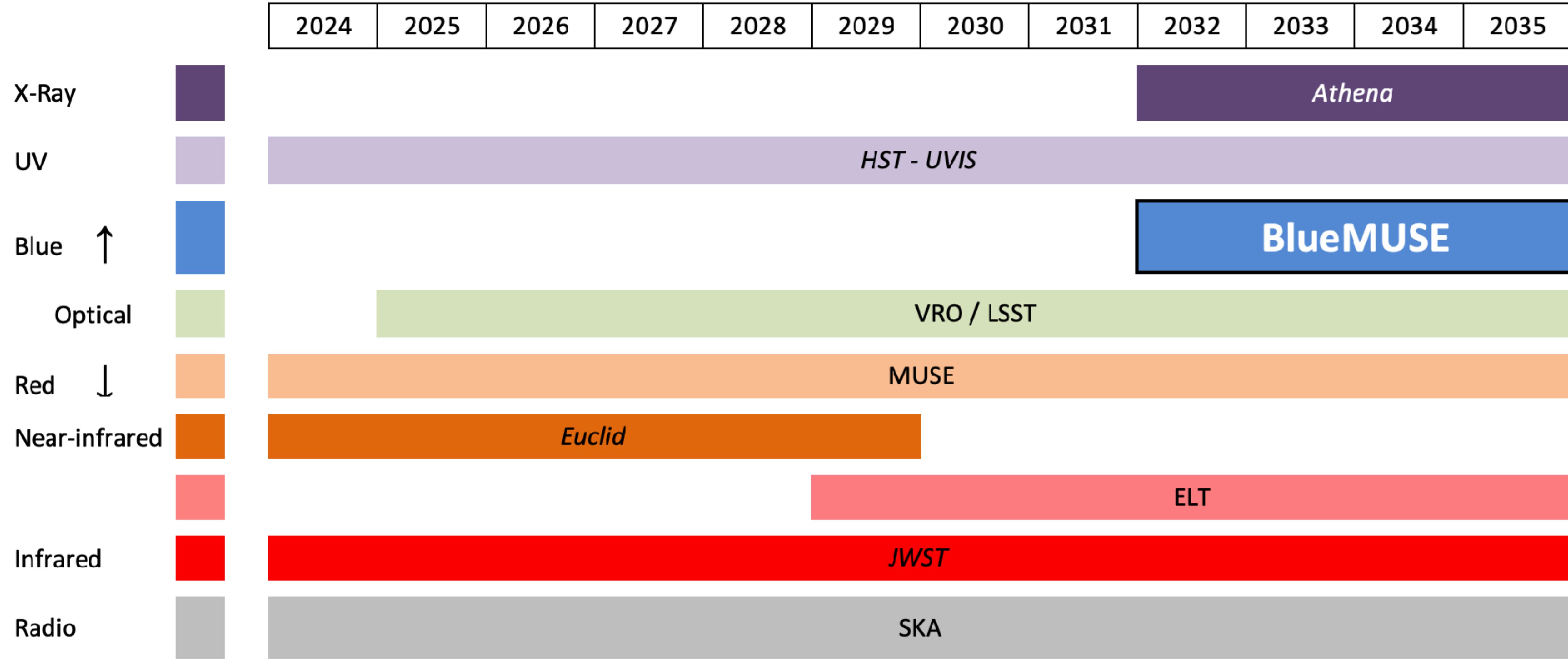
e2e BlueMUSE  
@350nm: 15%

XShooter ~ 13.8%  
UVES ~ 5%  
KCWI ~ 5%  
(eq. ~ 9%)

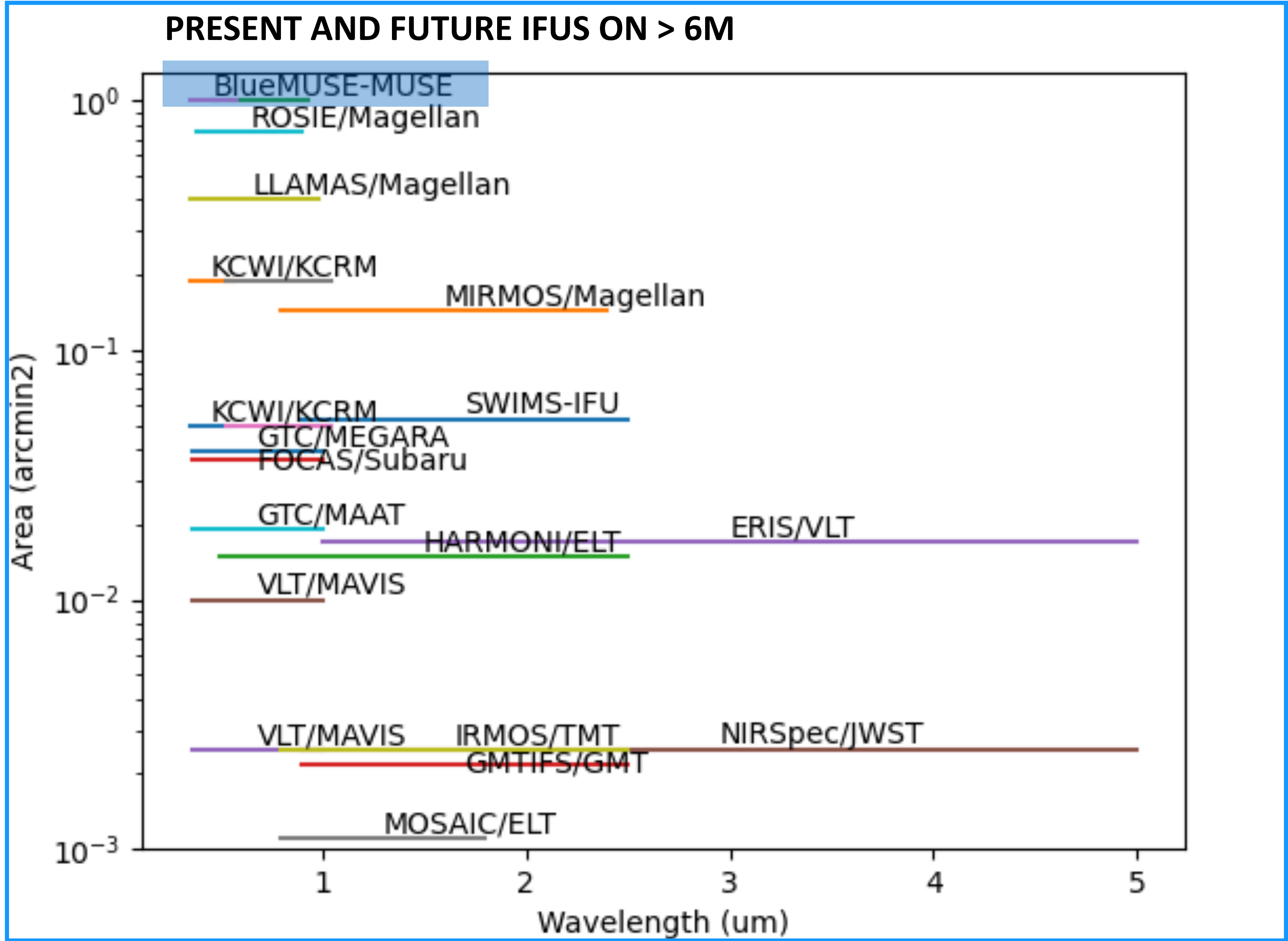


Public ETC <https://calc-bluemuse.univ-lyon1.fr/>













## MAVIS

- Higher spatial resolution
- Imaging sensitivity
- $\lambda$  coverage up to 1 micron
- Higher spectral resolution



## CUBES

- Higher spectral resolution  
(de-blending of absorption lines)
- $\lambda$  coverage down to 300 nm



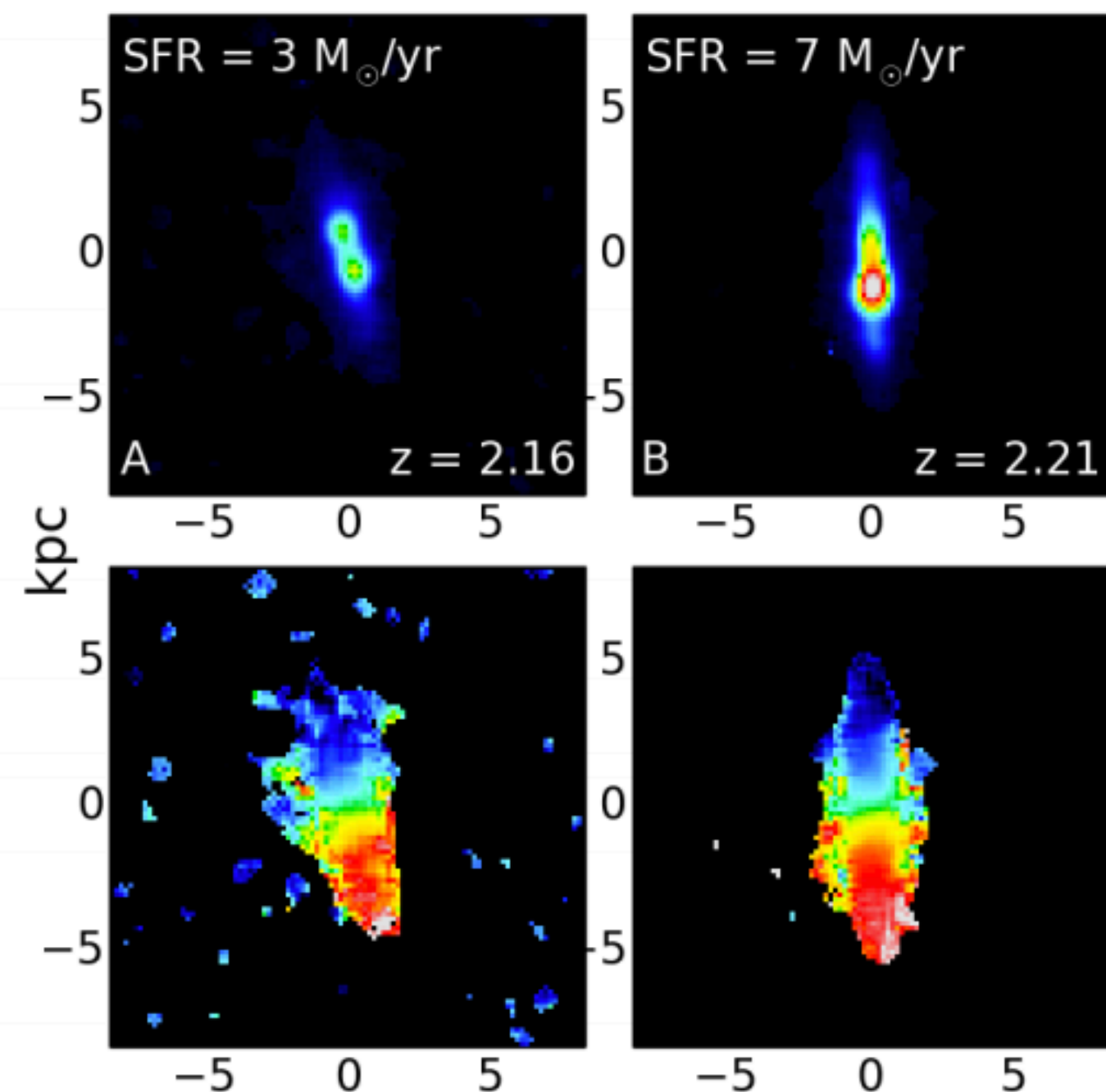
- Large field, IFU, multiplexing
- $\lambda$  coverage up to 580 nm / down to 350 nm
- High sensitivity to emission lines and low SB



## HARMONI

High spatial resolution

Follow-up of Lyman-alpha emitters for kinematics (dark matter content), extended haloes, resolved abundances etc.



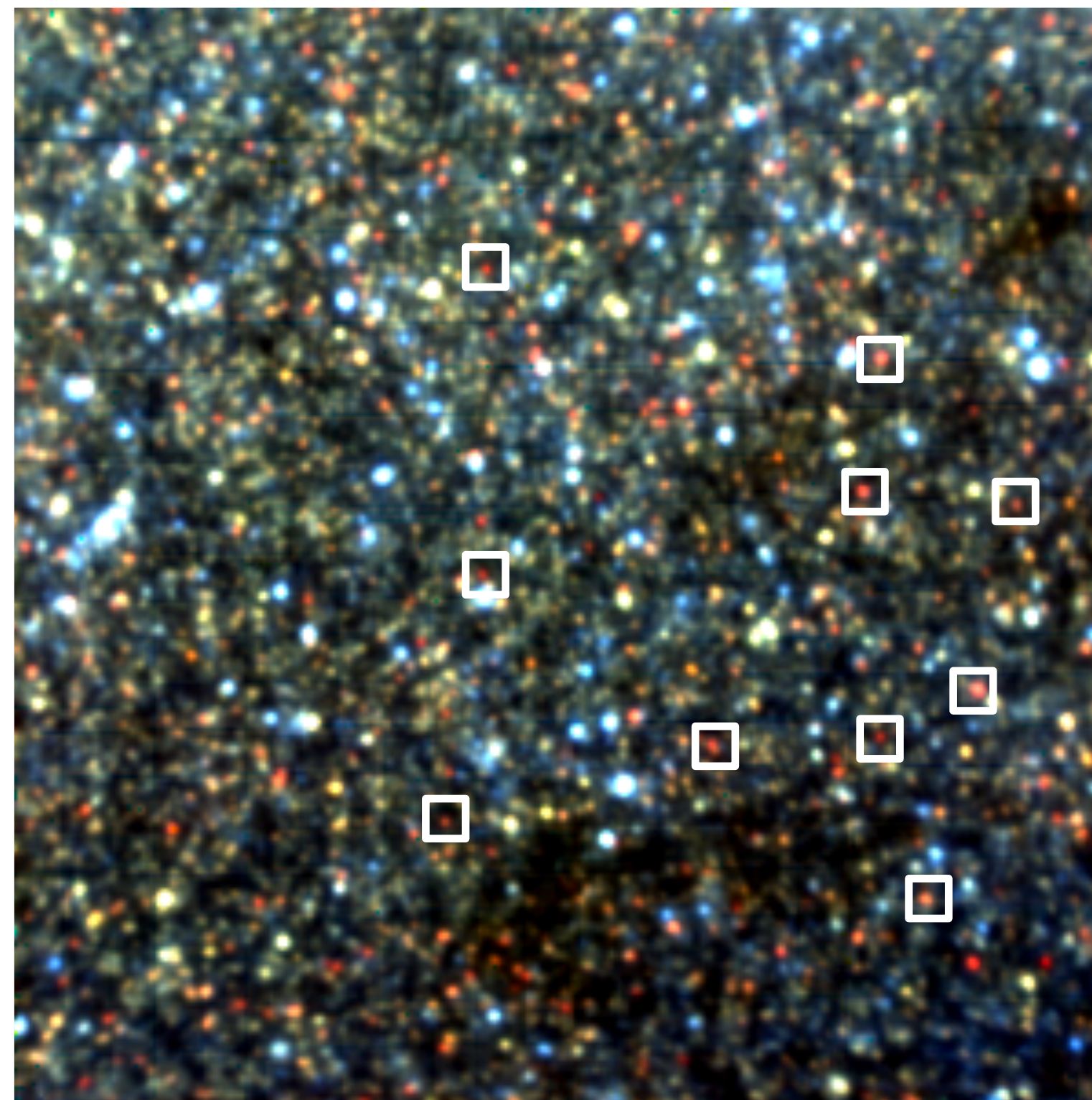
HARMONI H $\alpha$  simulations at  $z=2$

Zieleniewski et al. 2015



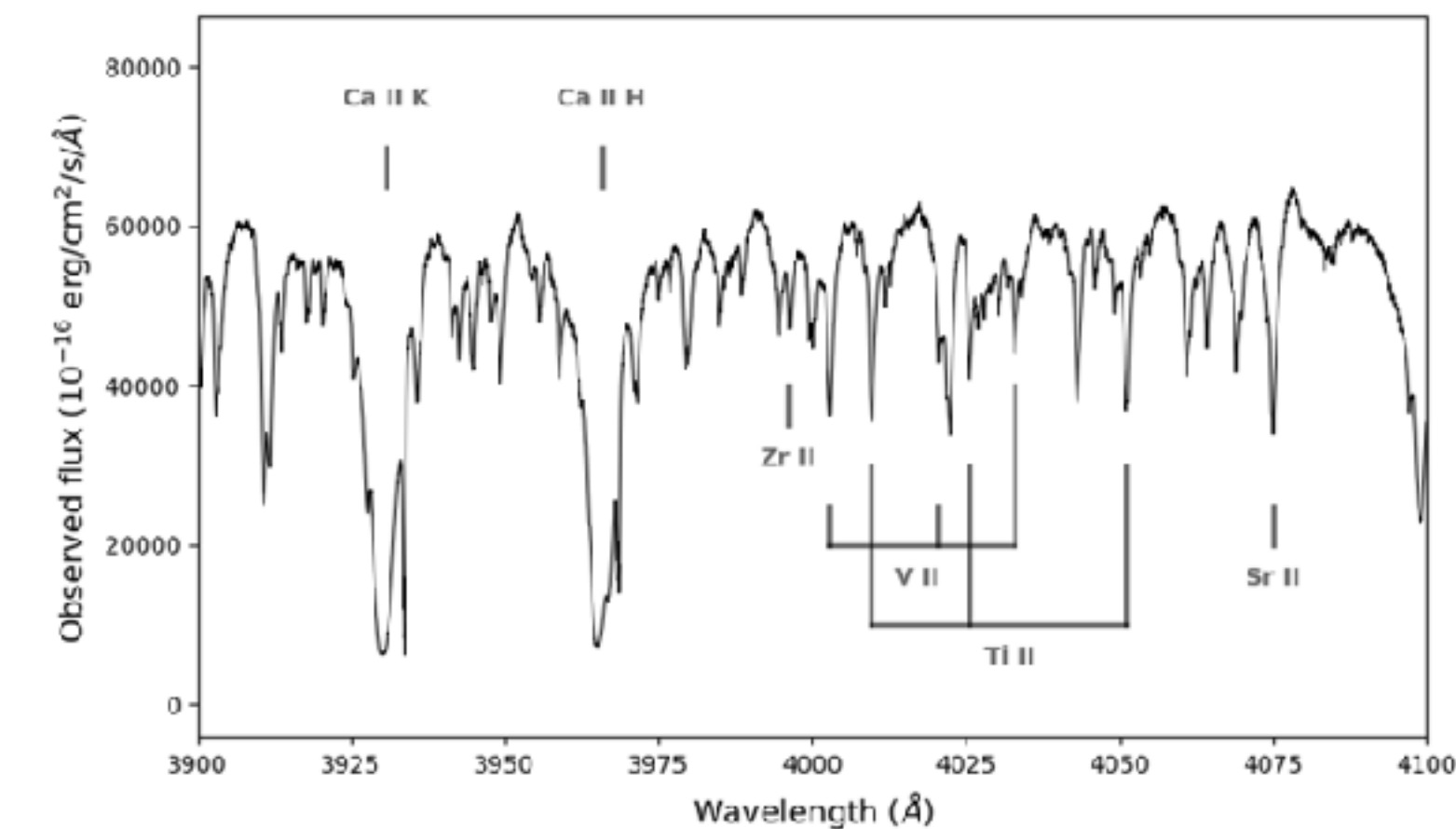
Multiplexing capability over a sky area comparable to BlueMUSE

e.g. Follow-up of massive stars at high resolution in HMM mode



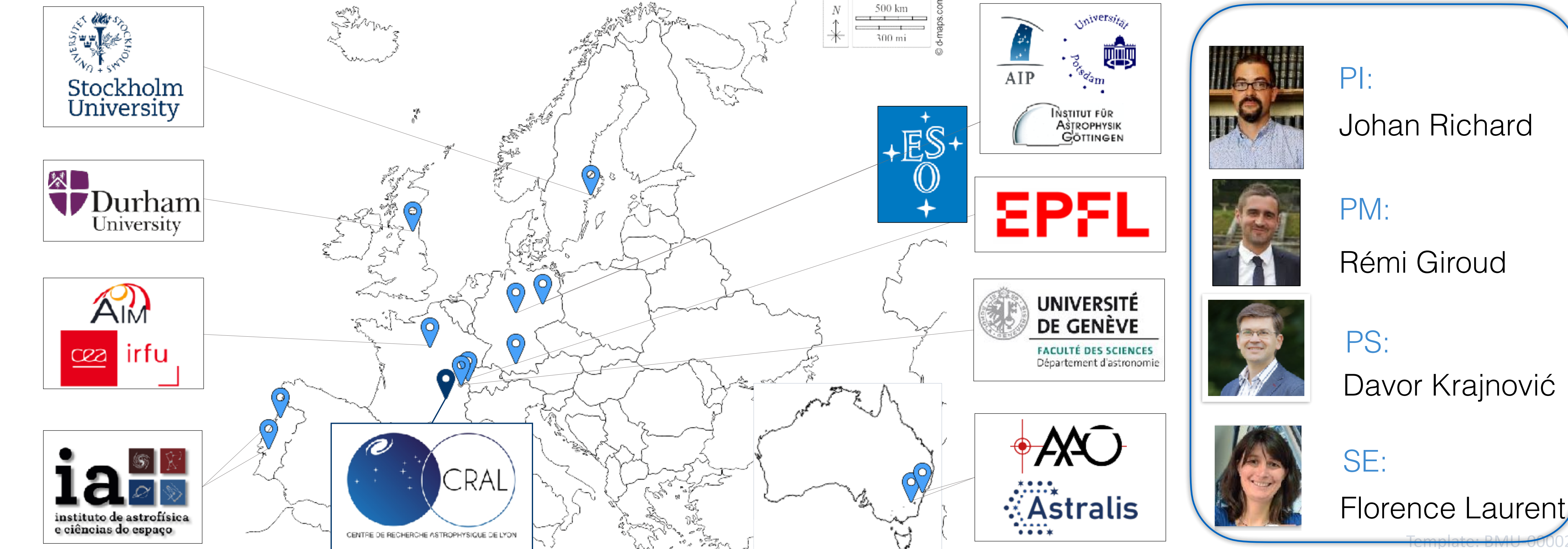
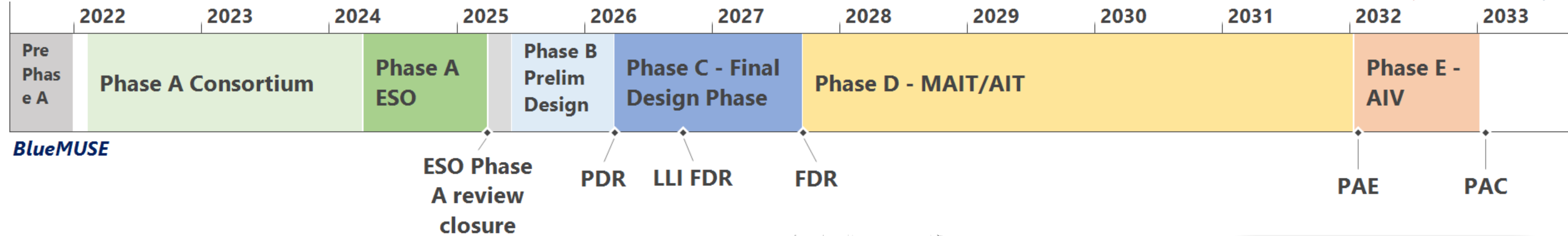
High spectral resolution

e.g. physics of stars and stellar populations at  $R \sim 100\,000$



D'Odorico et al. 2023





PI:  
Johan Richard



PM:  
Rémi Giroud

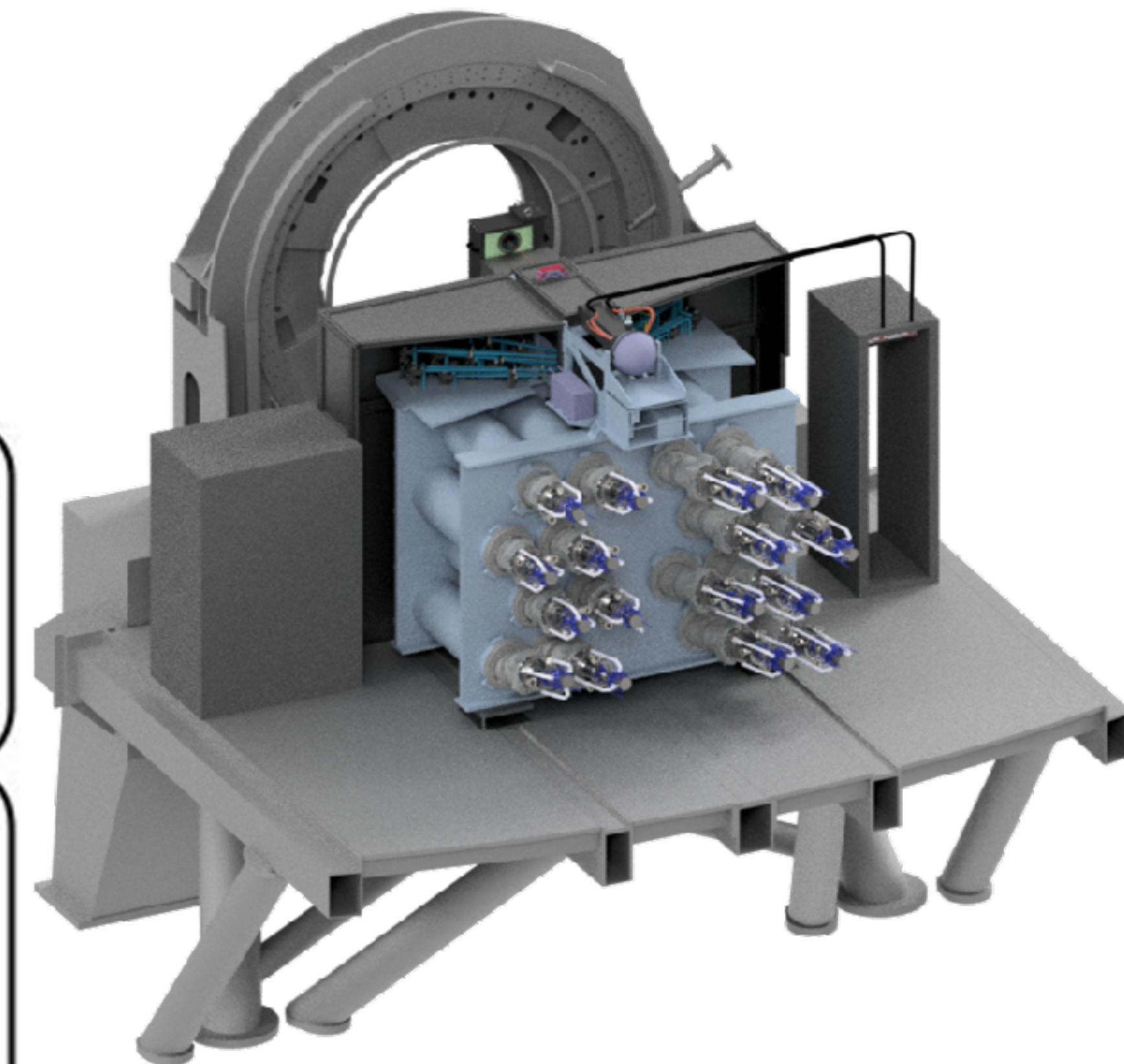
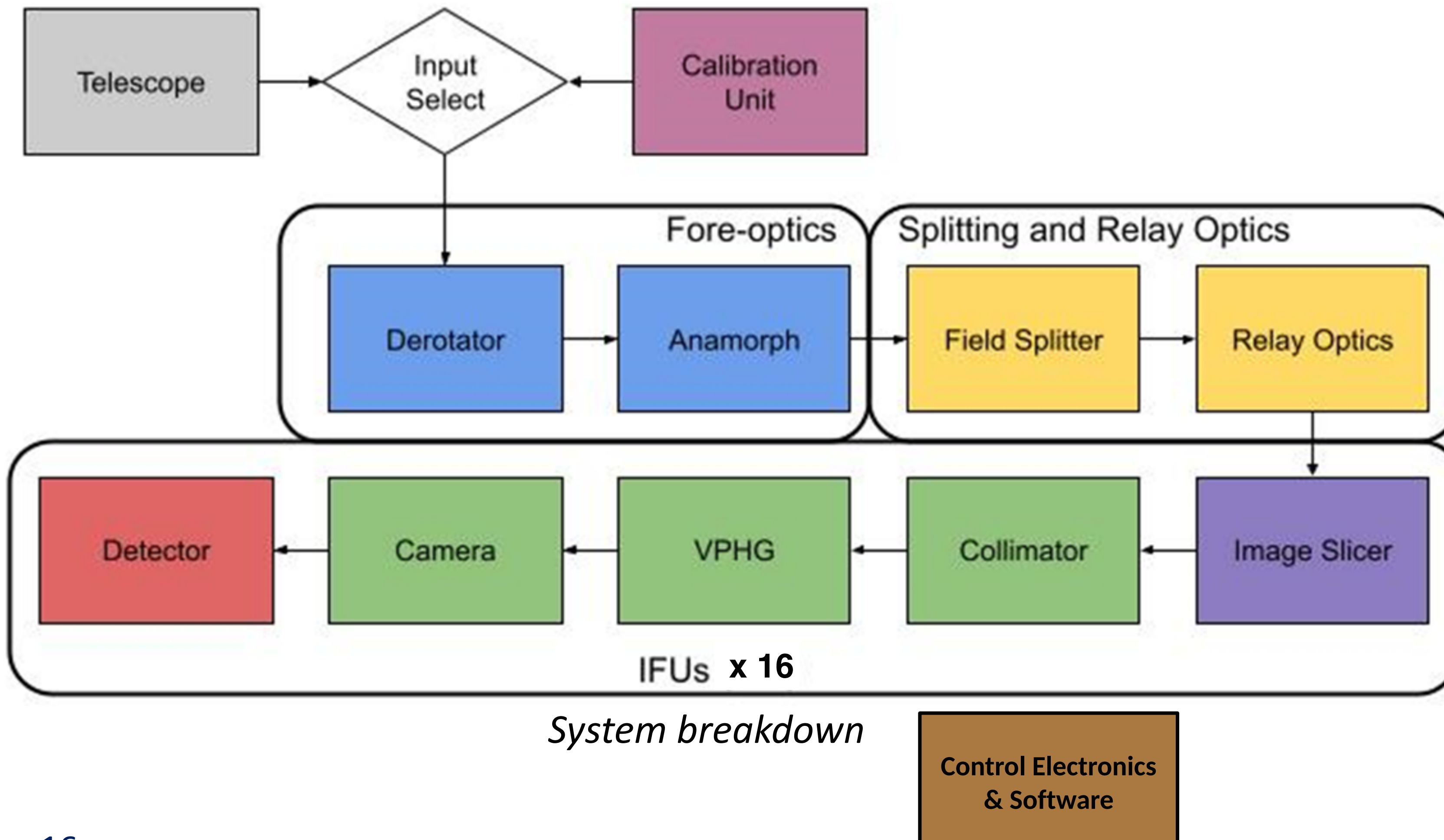


PS:  
Davor Krajnović



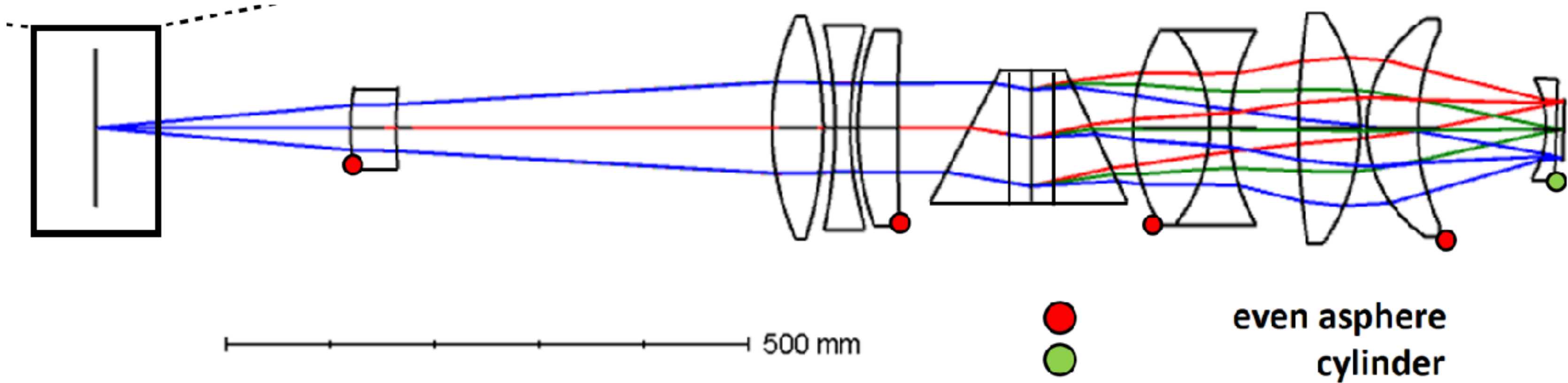
SE:  
Florence Laurent



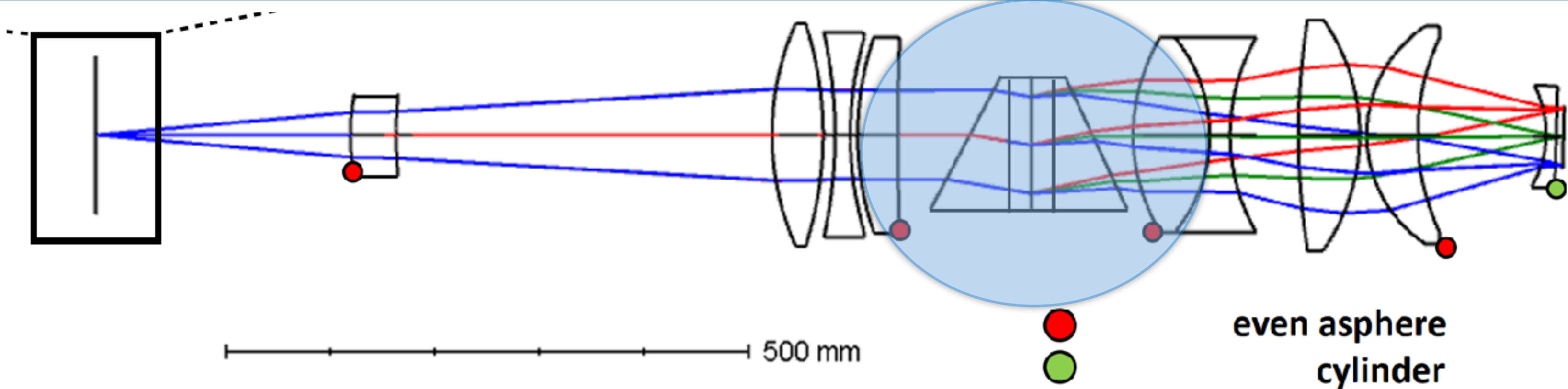


*BlueMUSE schematic aspect on the VLT Nasmyth platform*

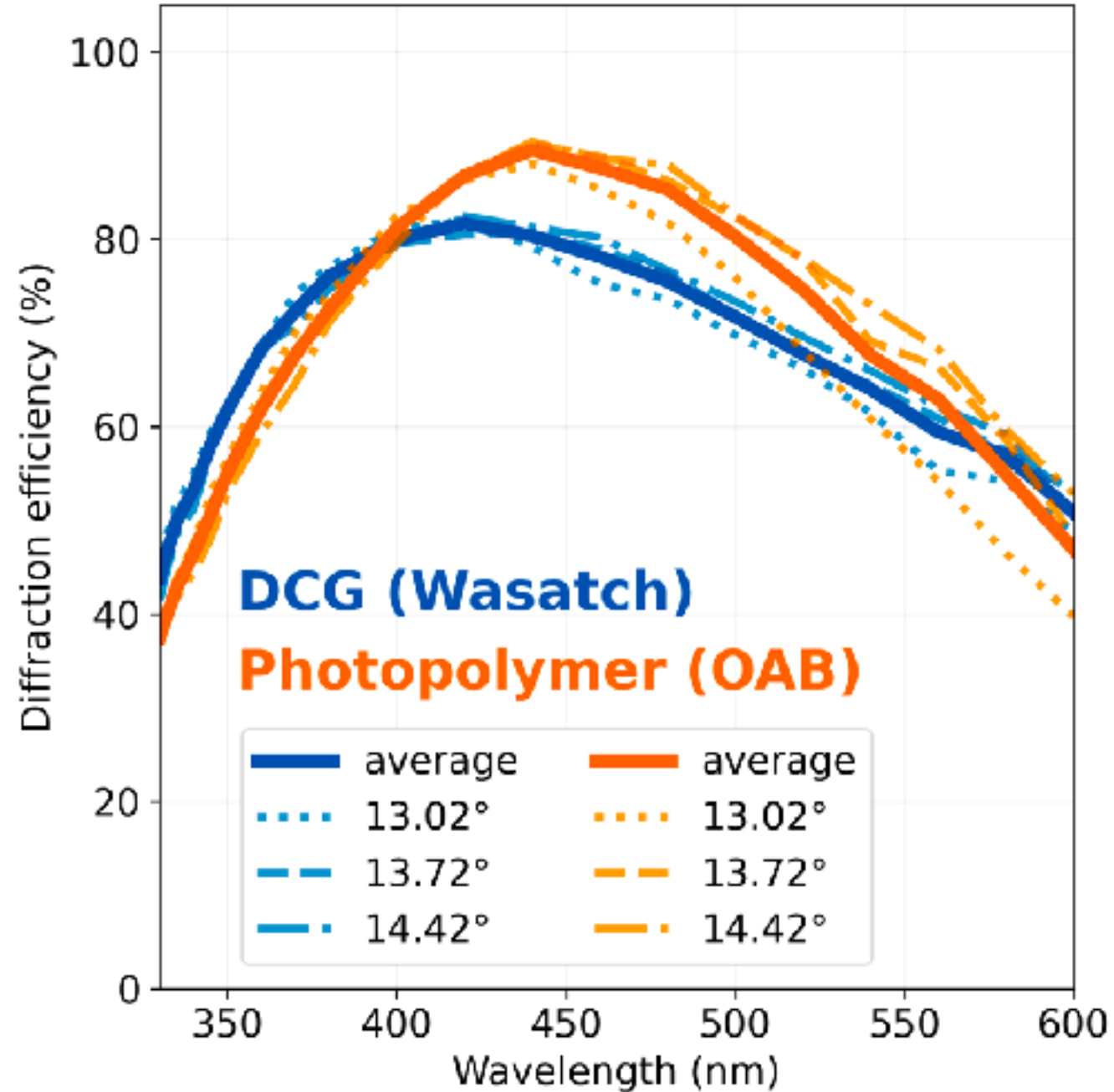
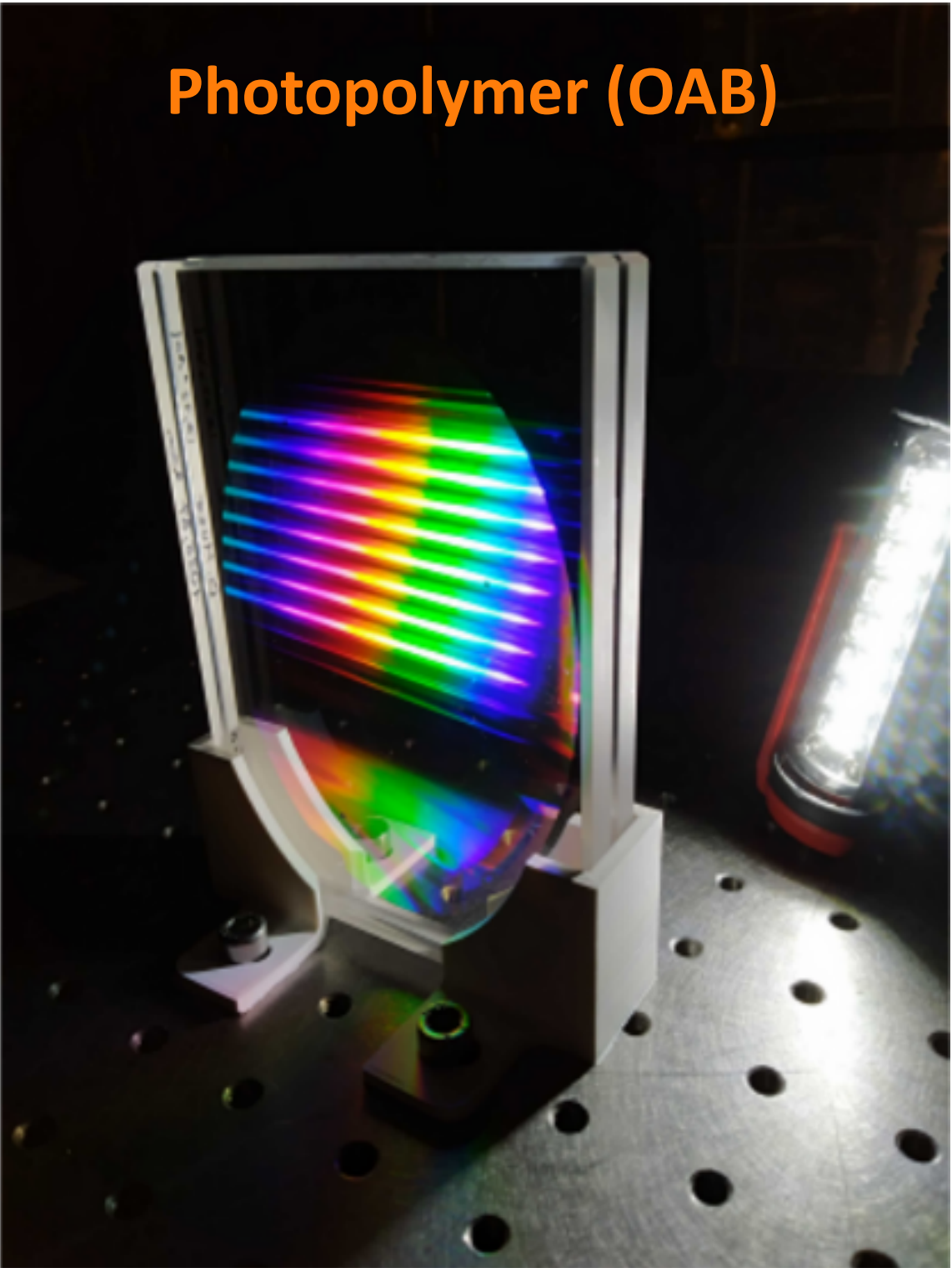
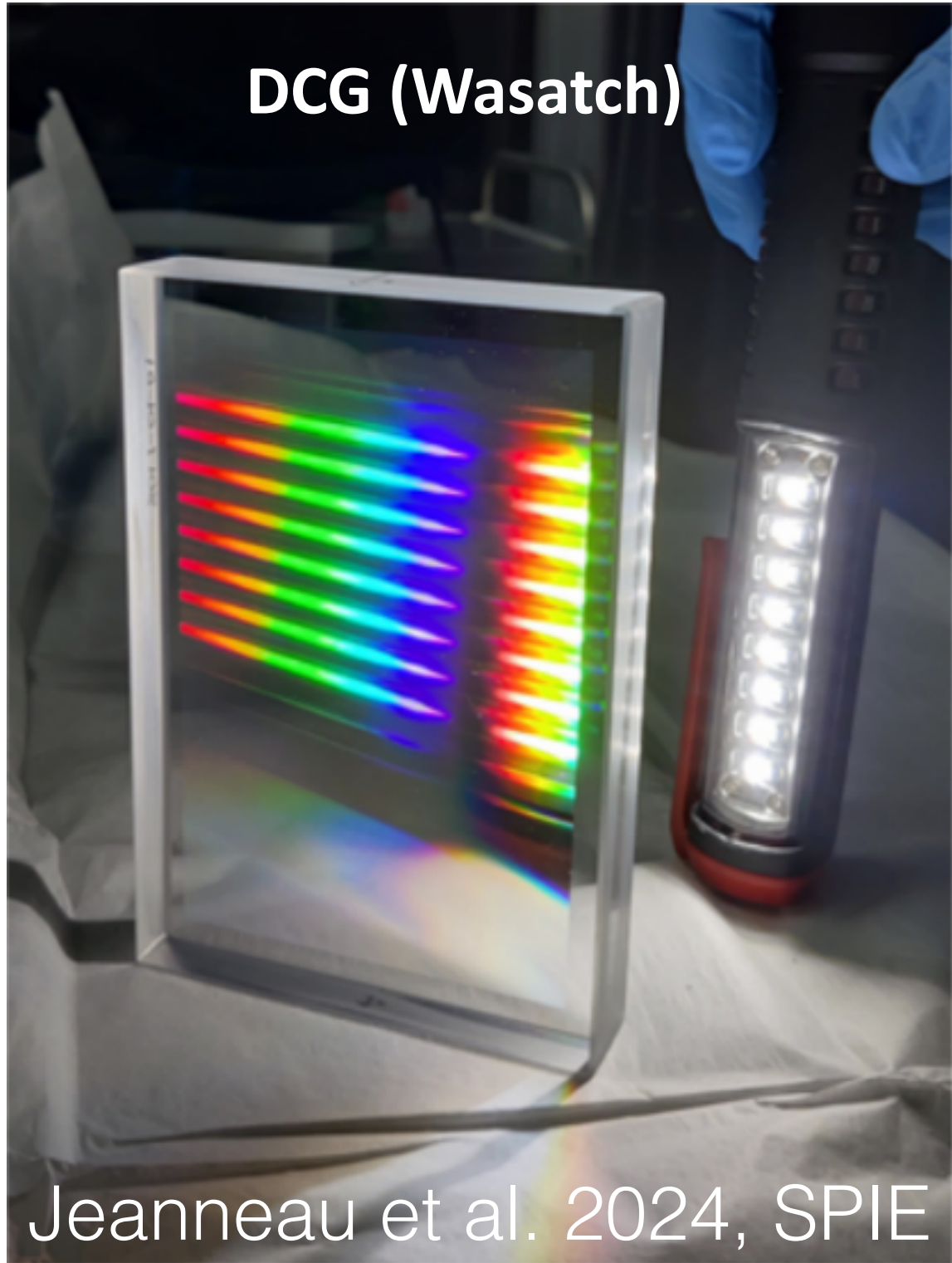






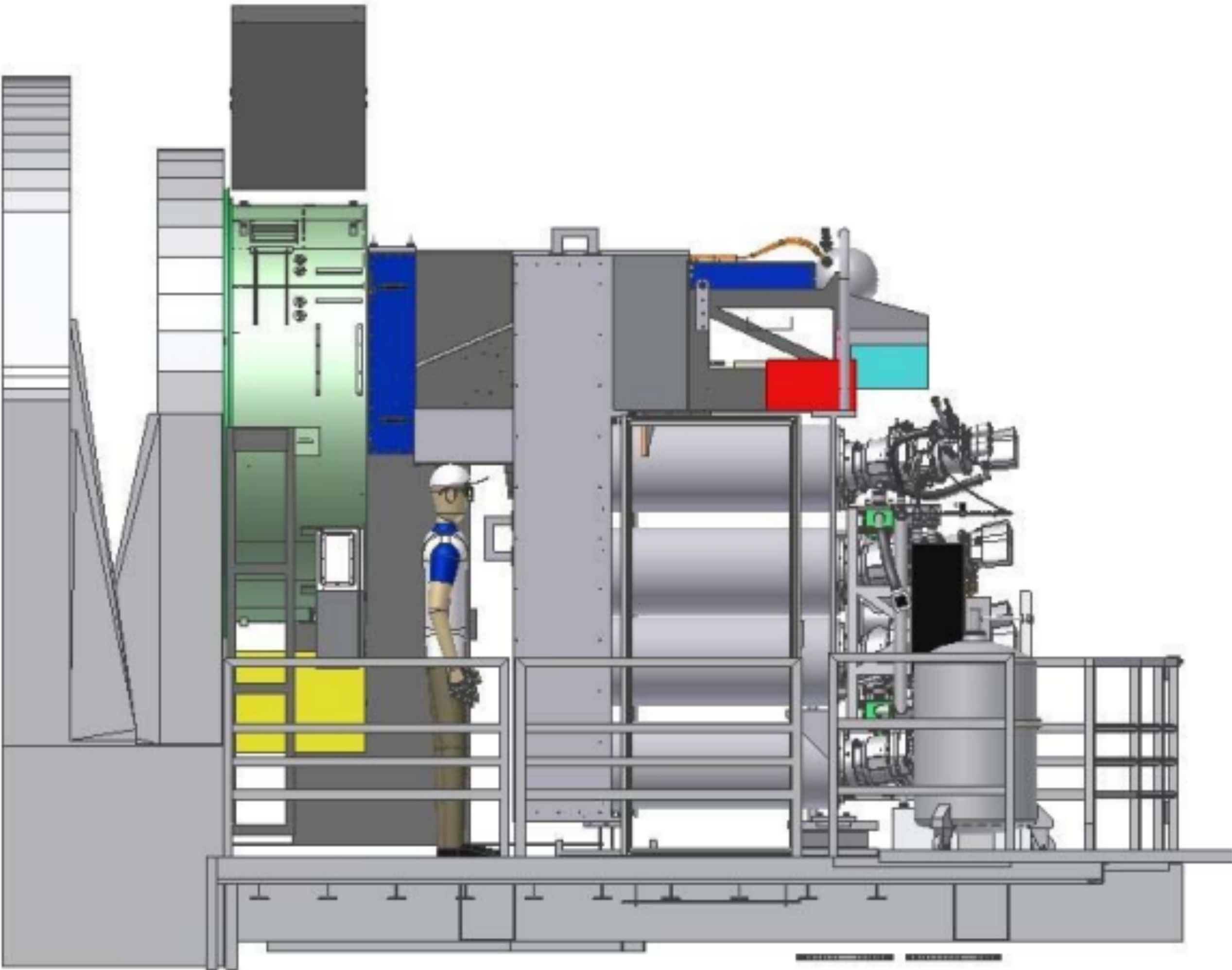


## VPH grating prototypes!





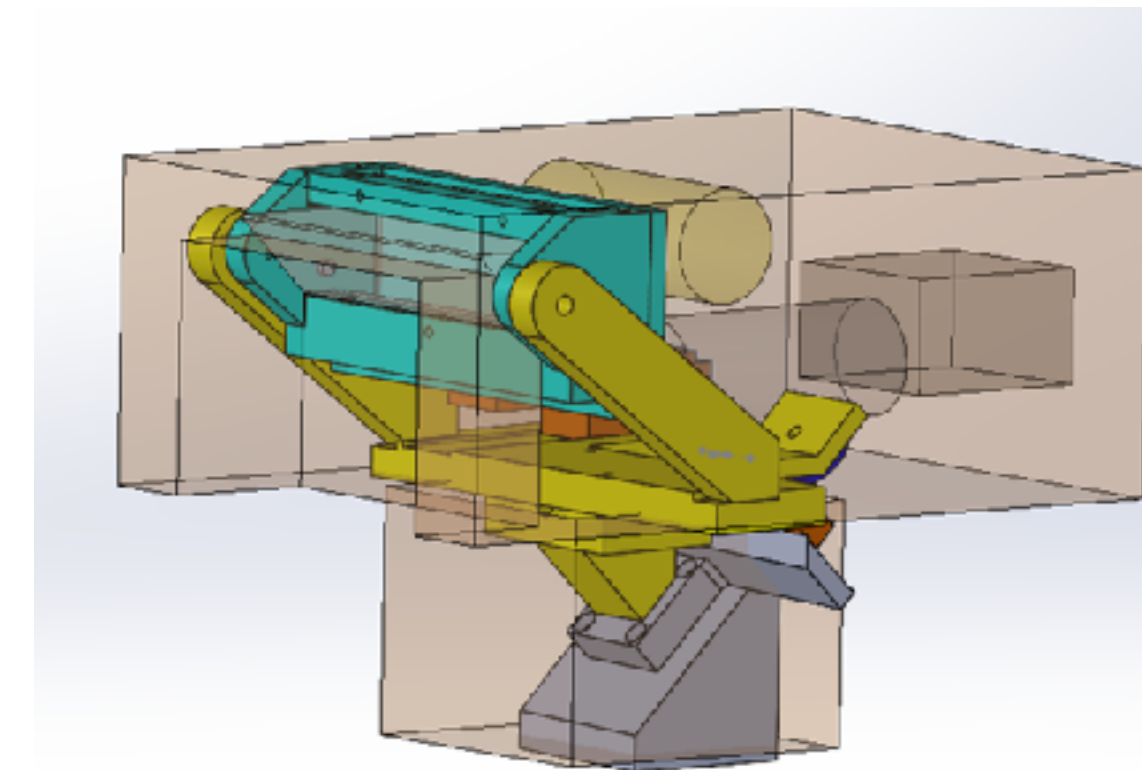
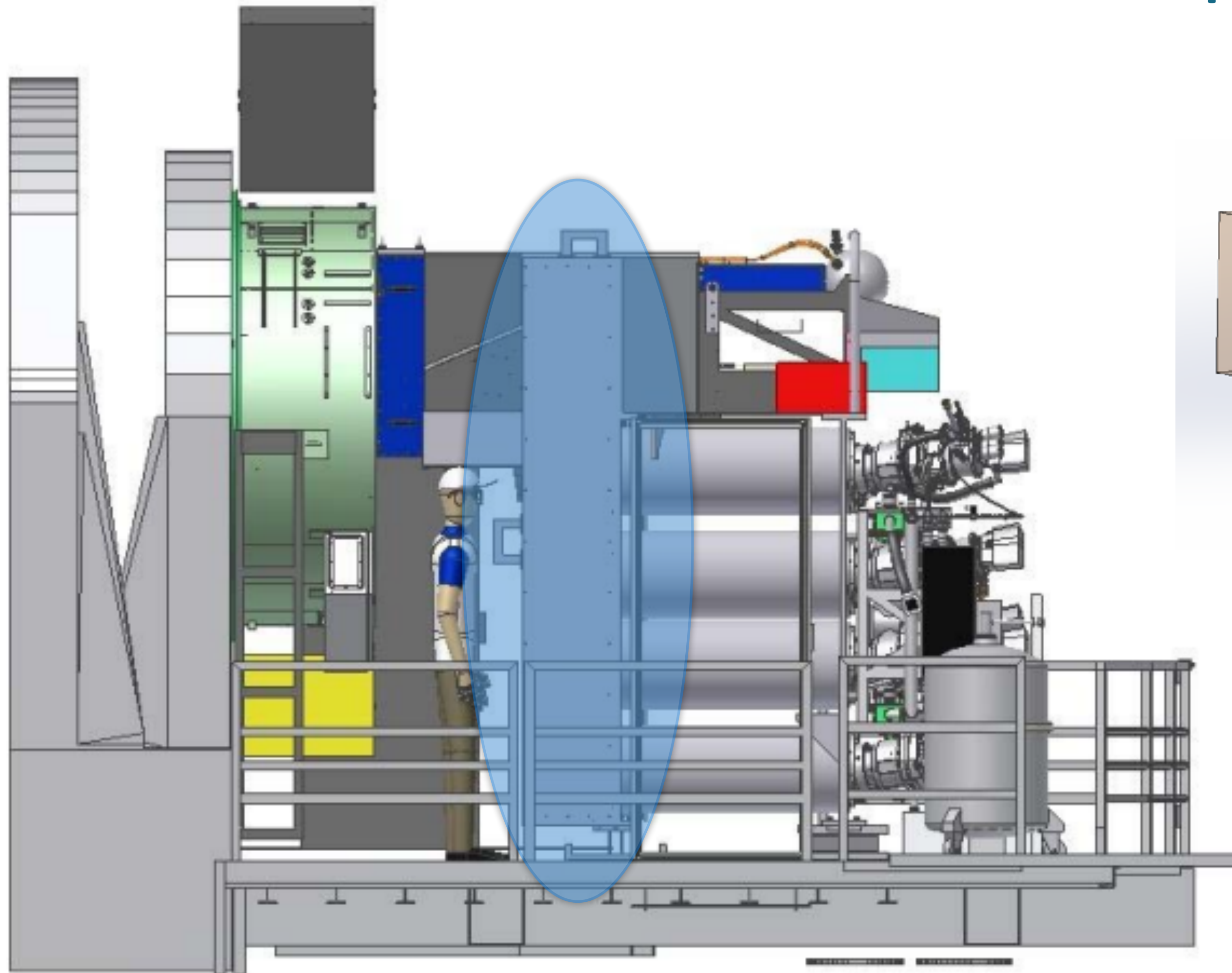
# Technological challenges





## Improved operations efficiency

**EPFL**



### Folding mirrors motorisation

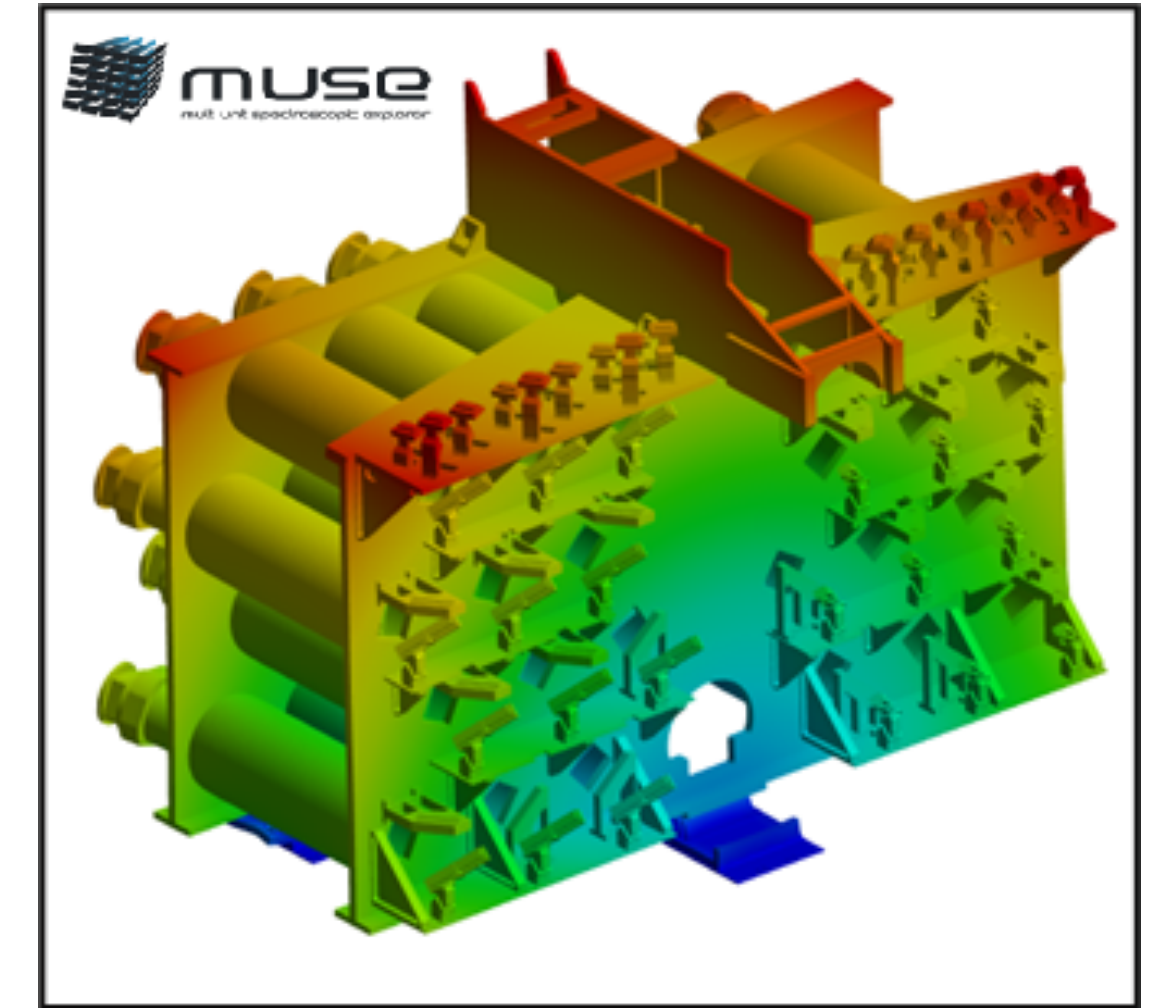
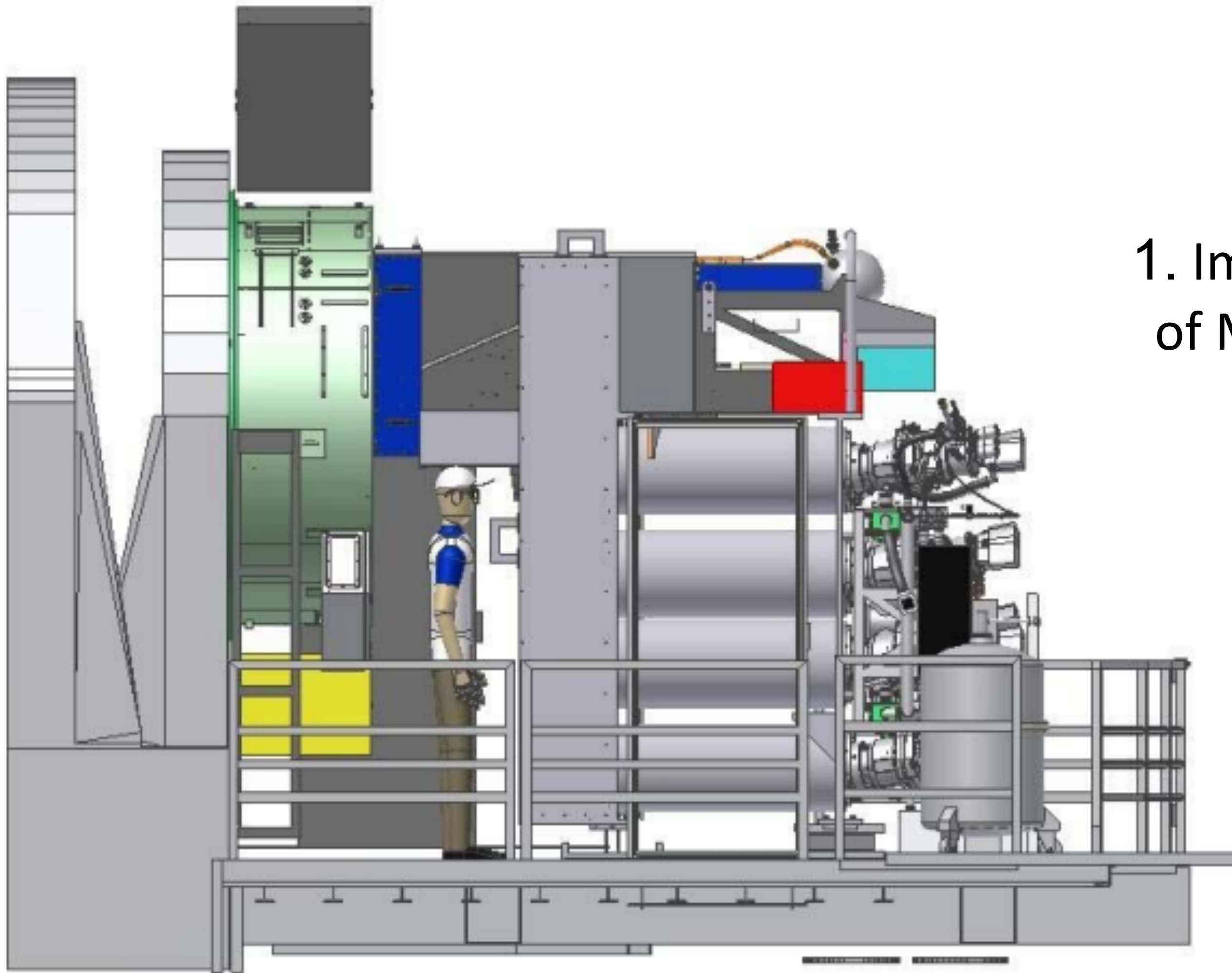
- Role is to help for AIT and compensate for seasonal thermal instabilities.



## Improved stability



### 1. Improved thermal model of MUSE + Platform



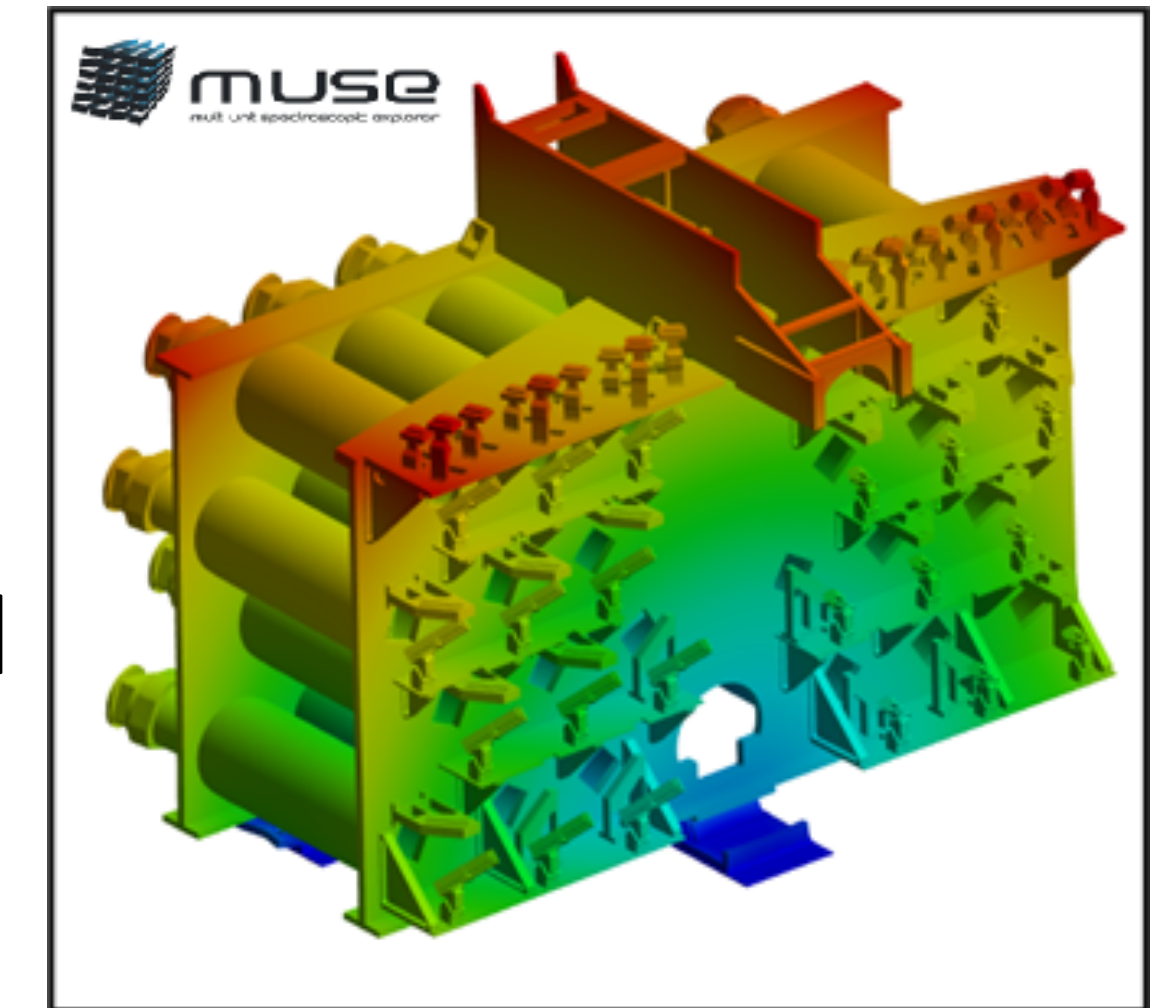
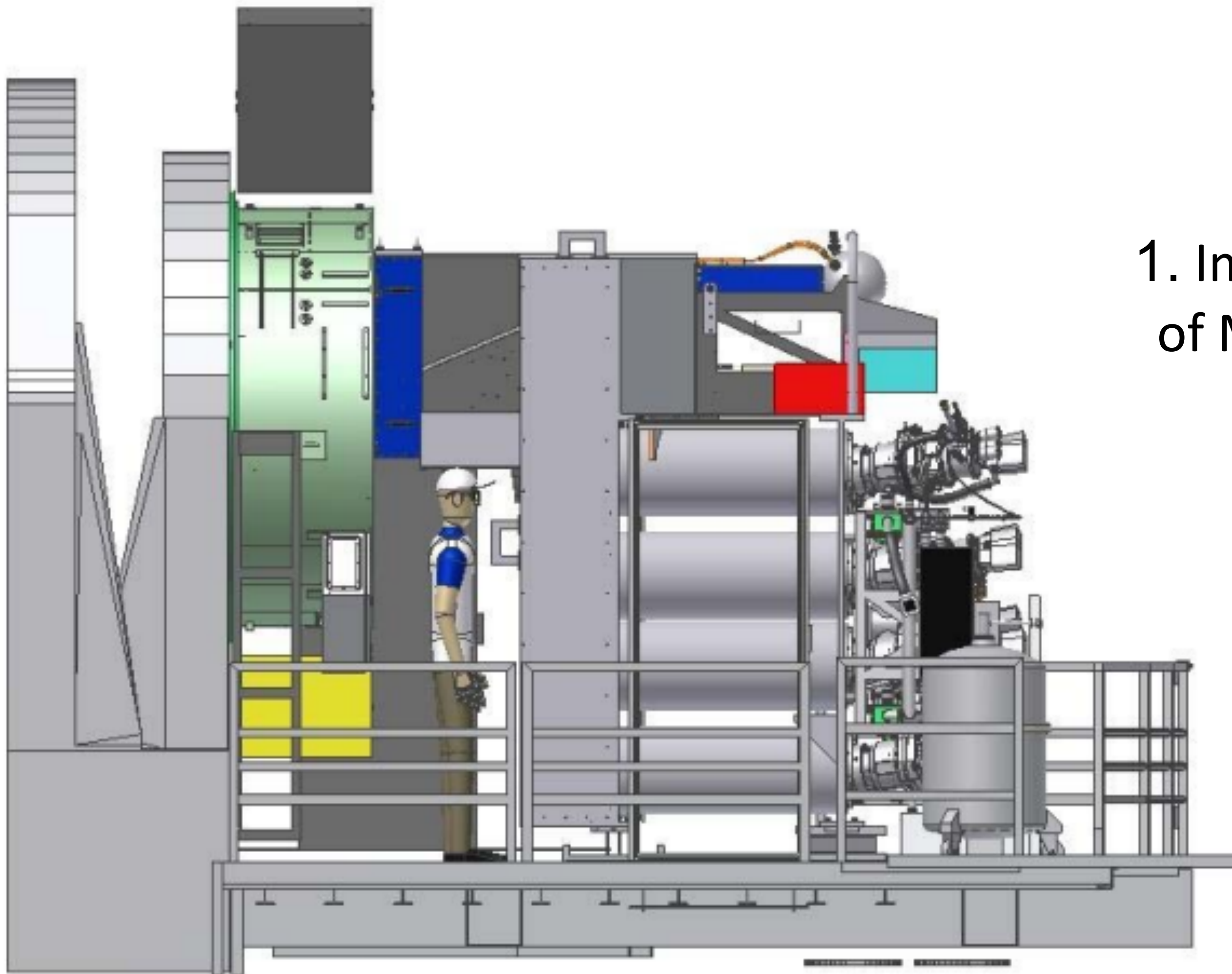
Cai et al. 2024, SPIE



## Improved stability



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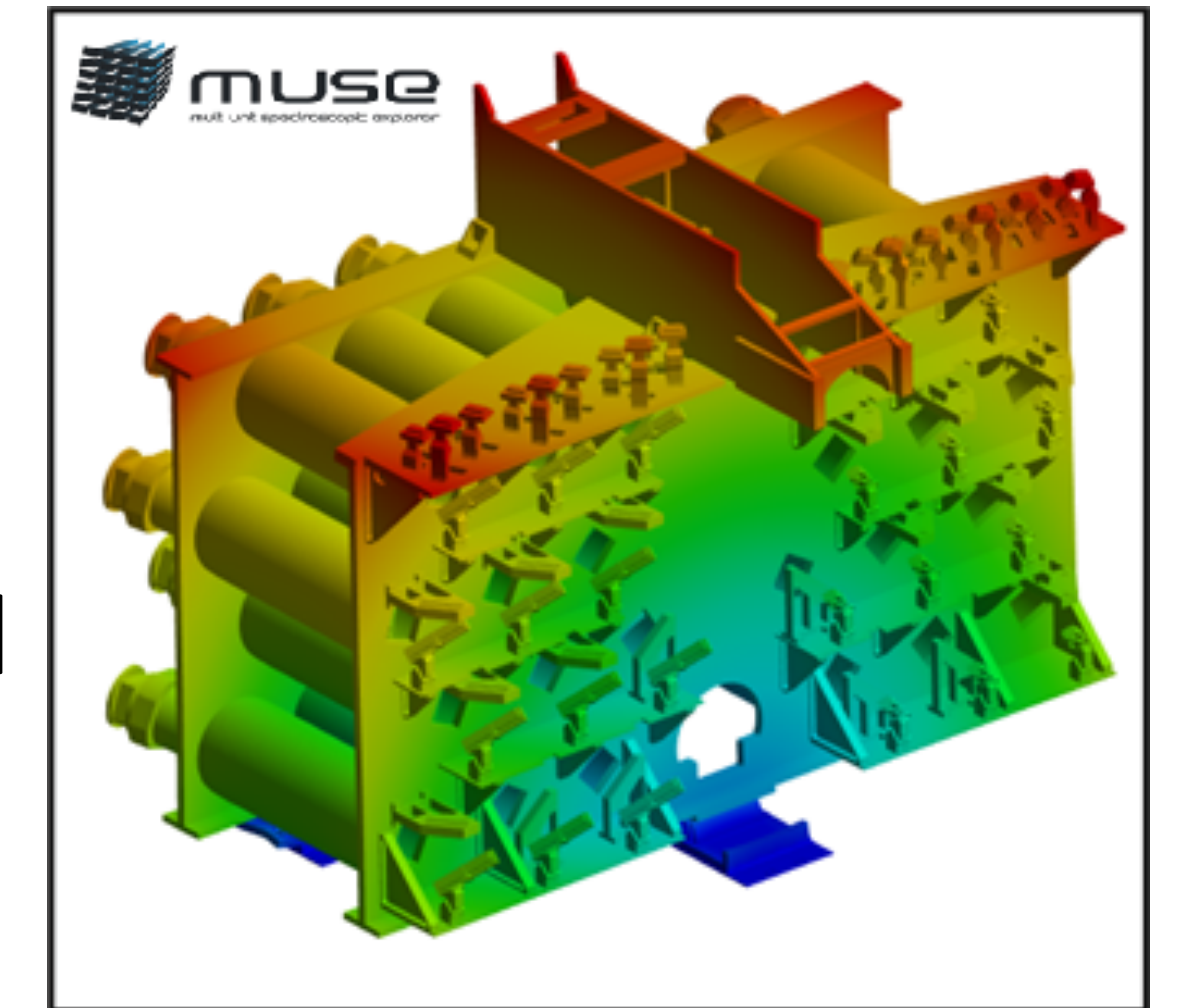
Cai et al. 2024, SPIE



## Improved stability

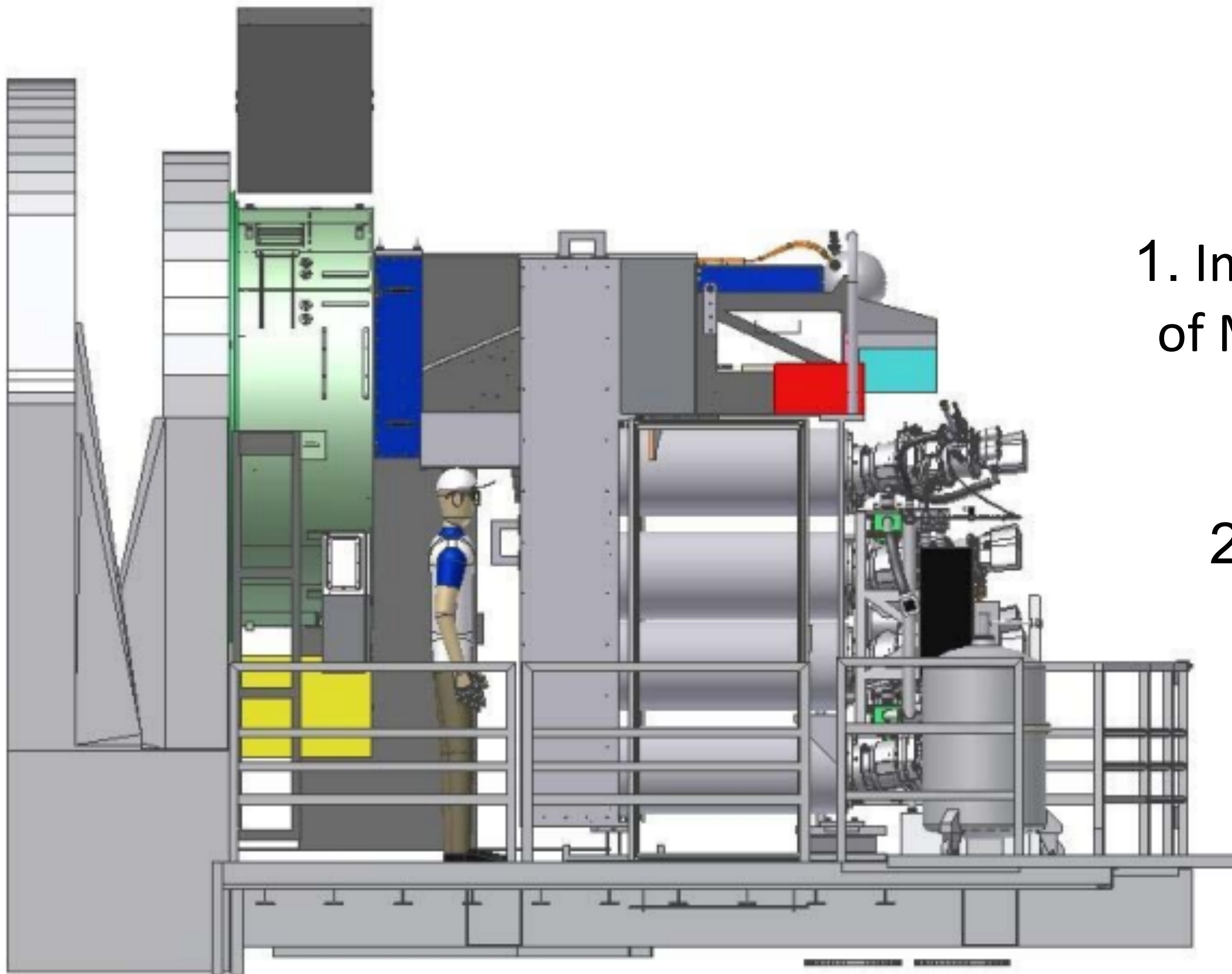
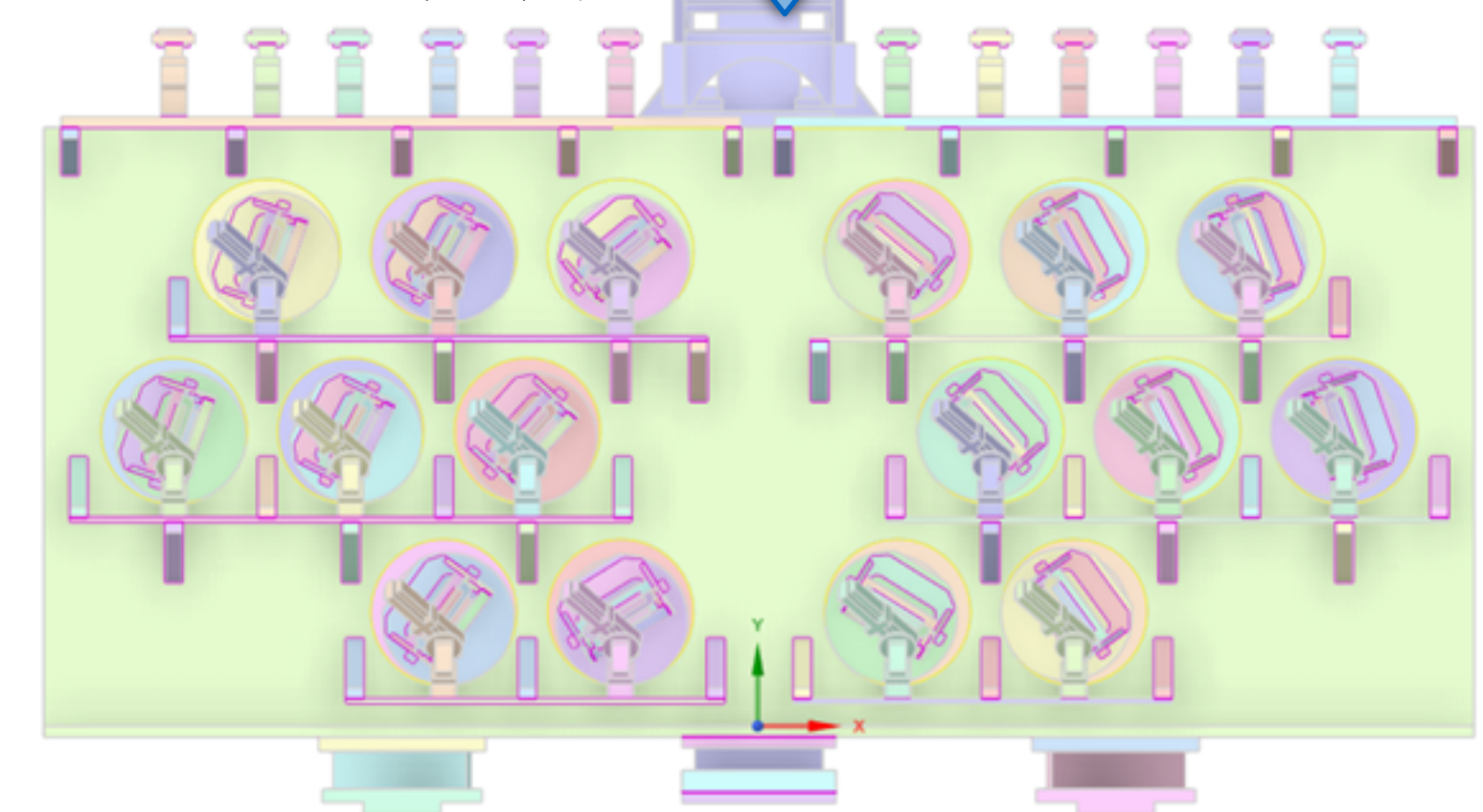
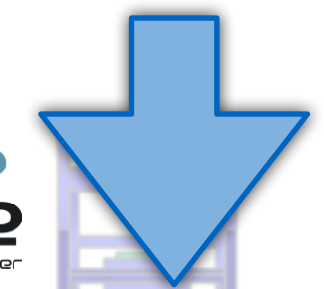


1. Improved thermal model of MUSE + Platform



Cai et al. 2024, SPIE

2. Optimisation of IFU locations

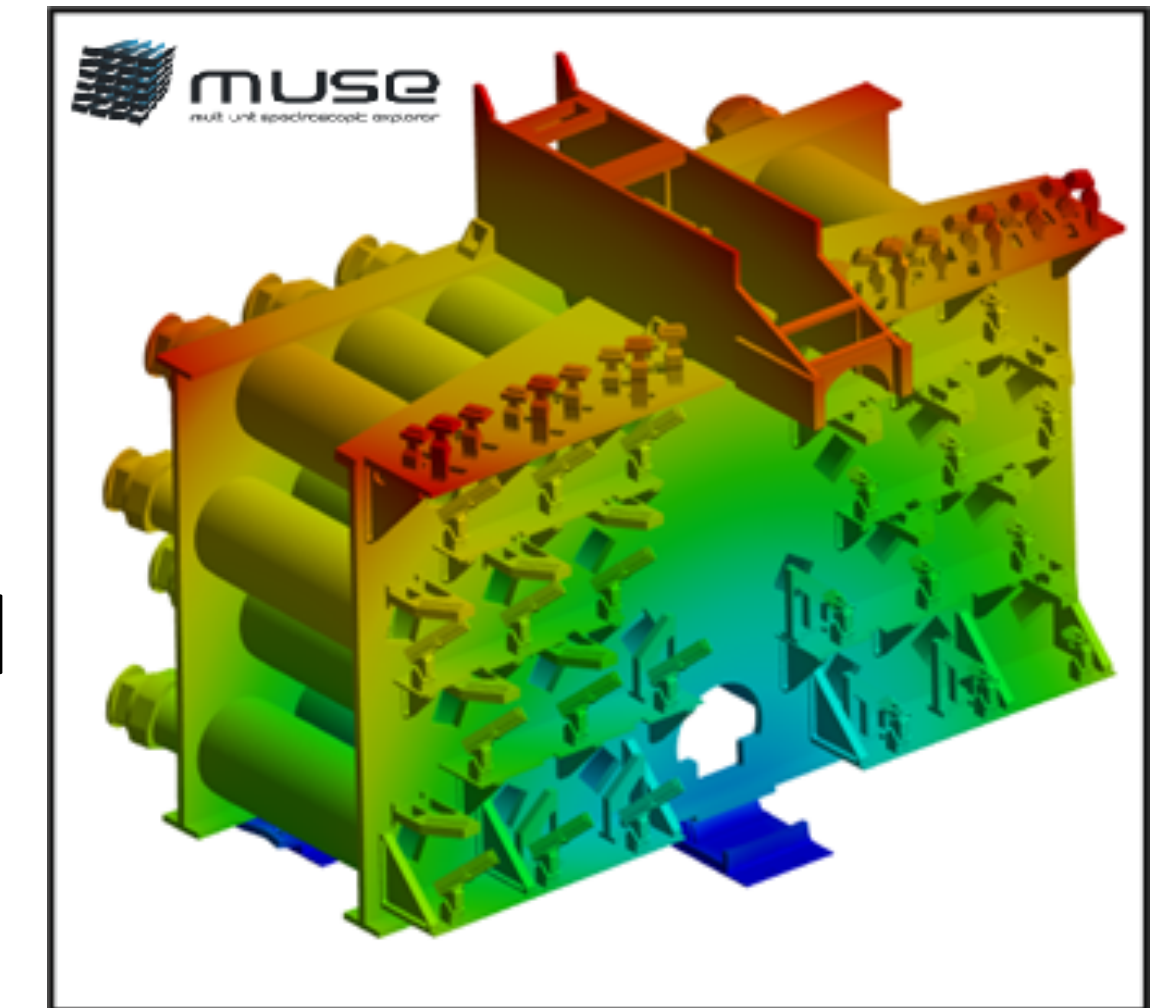




## Improved stability



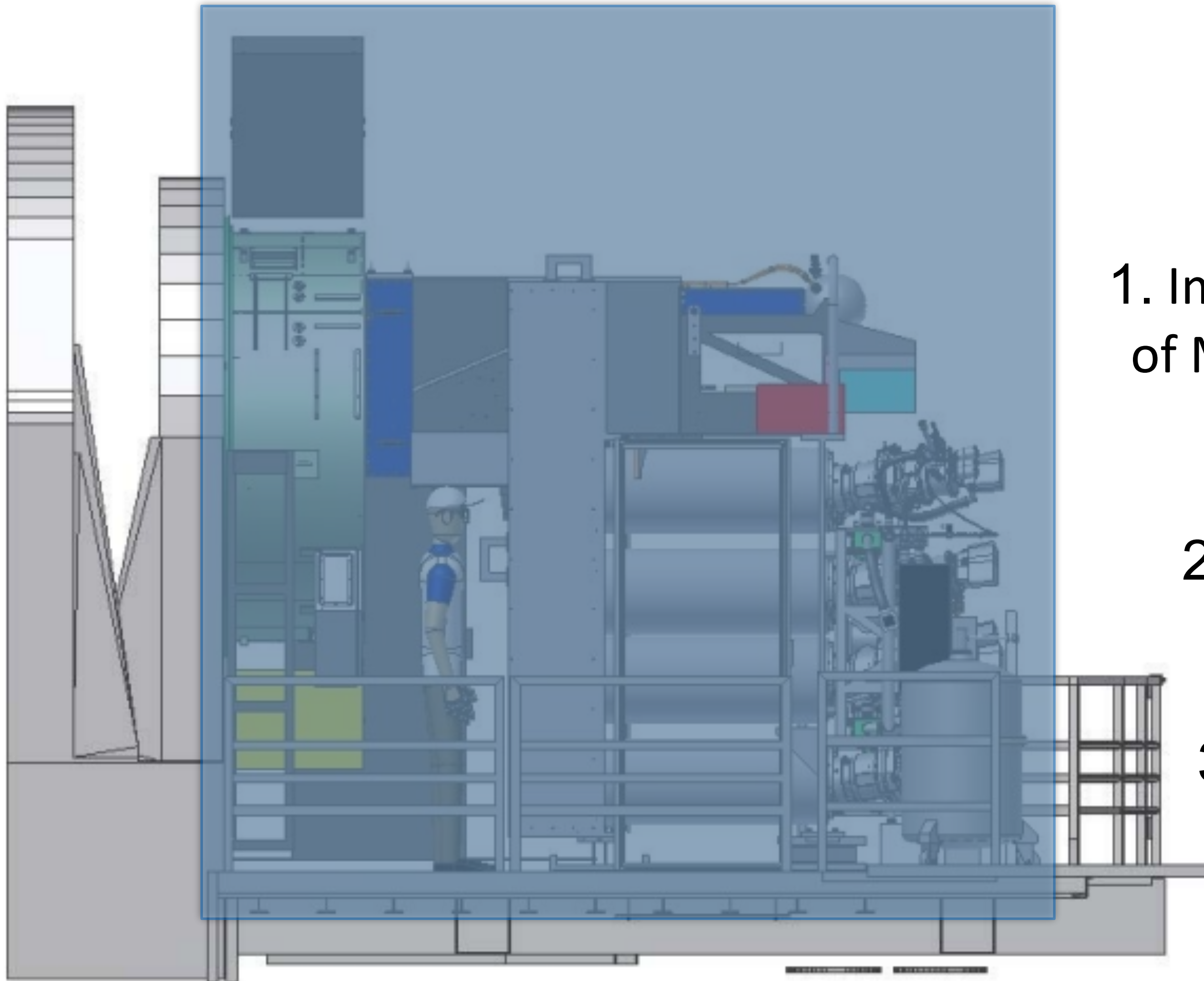
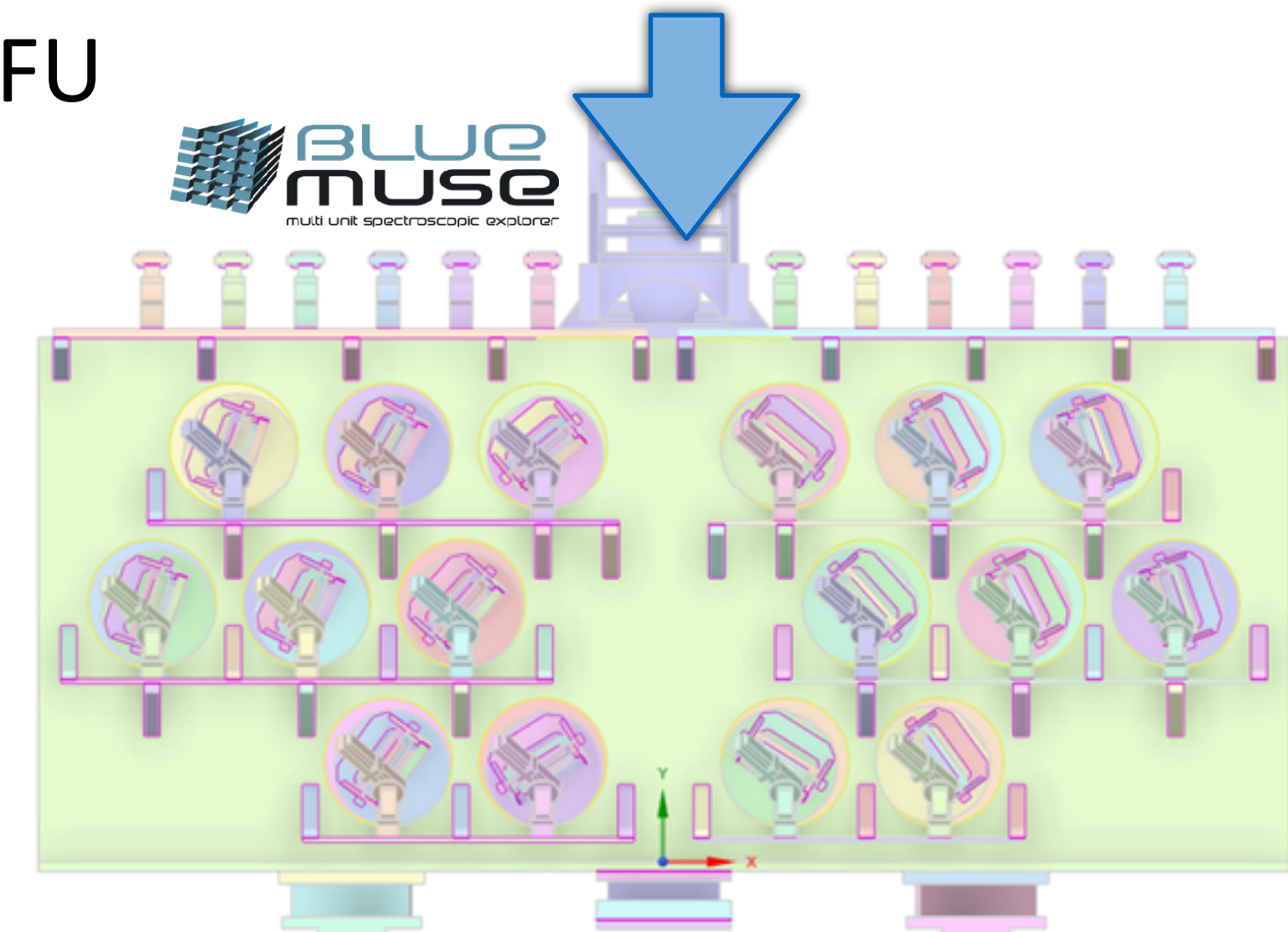
1. Improved thermal model of MUSE + Platform



Cai et al. 2024, SPIE

2. Optimisation of IFU locations

3. Enclosure study

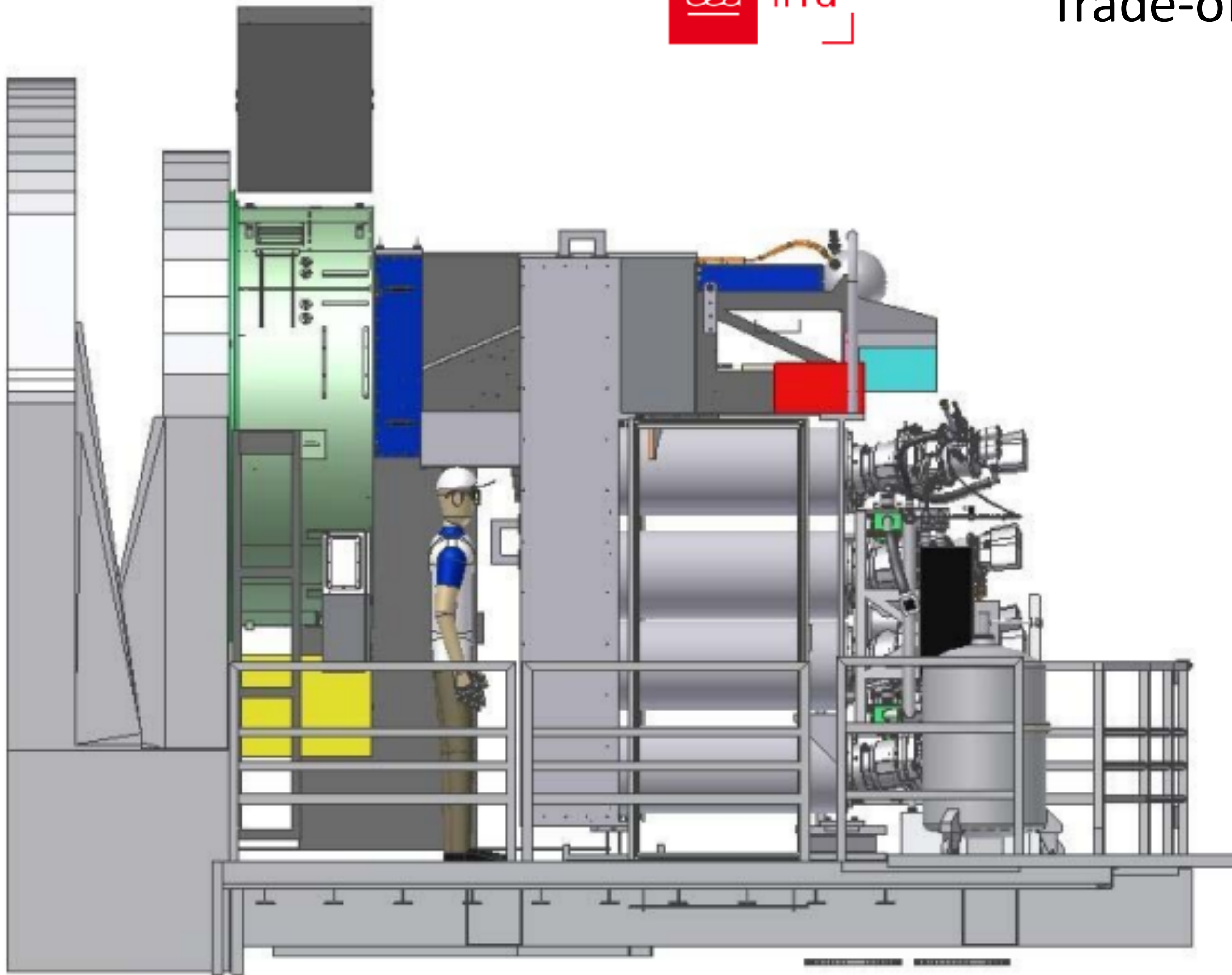






## Detectors and cryogenics

Trade-off over 2 choices of 4k x 4k 15  $\mu\text{m}$  detectors

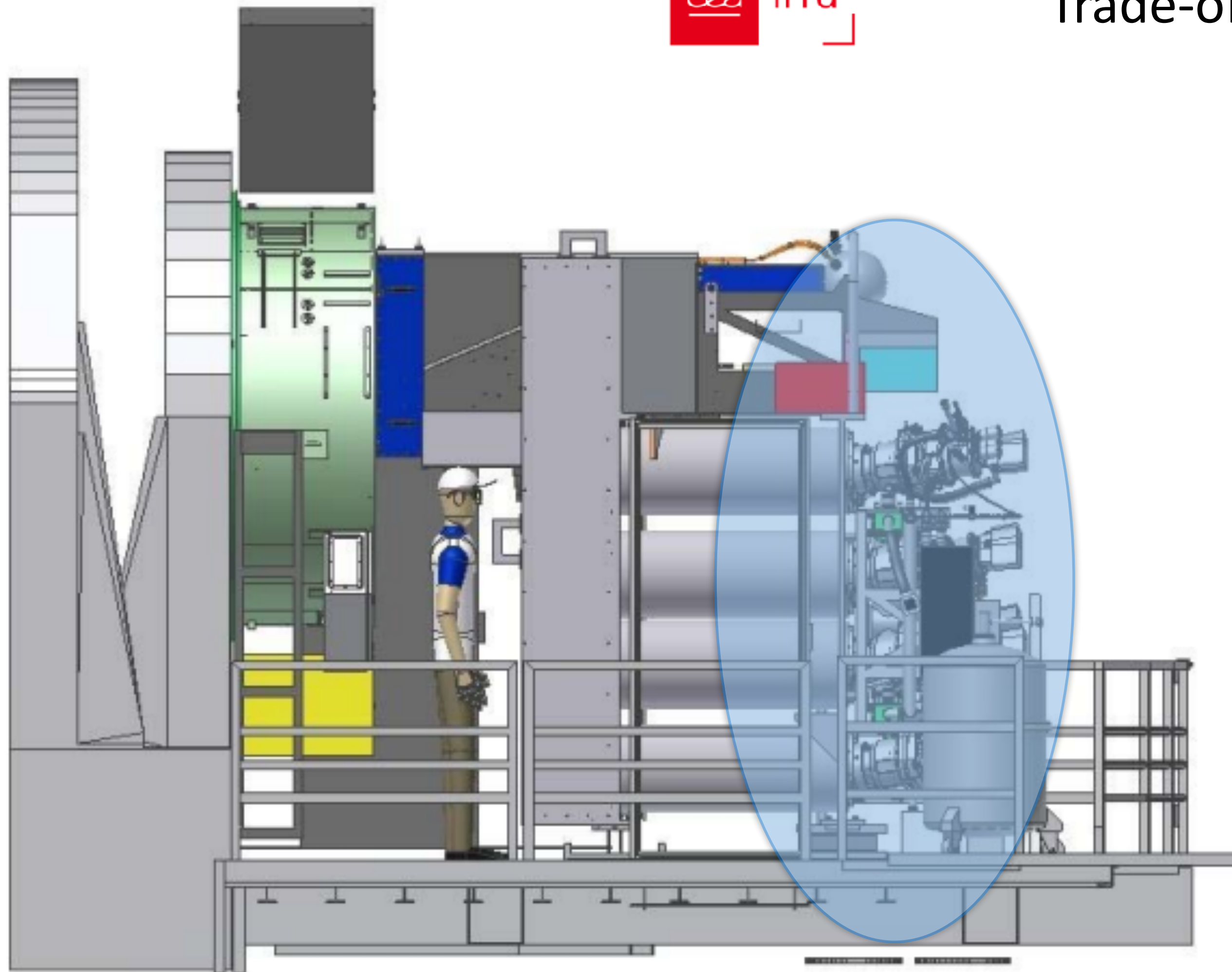






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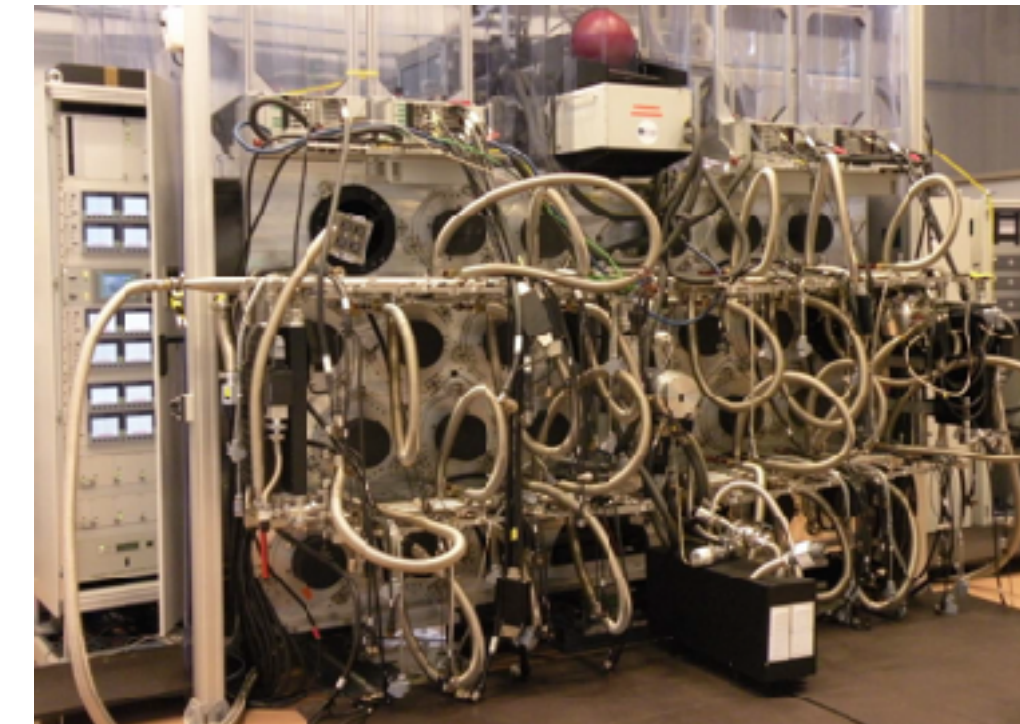
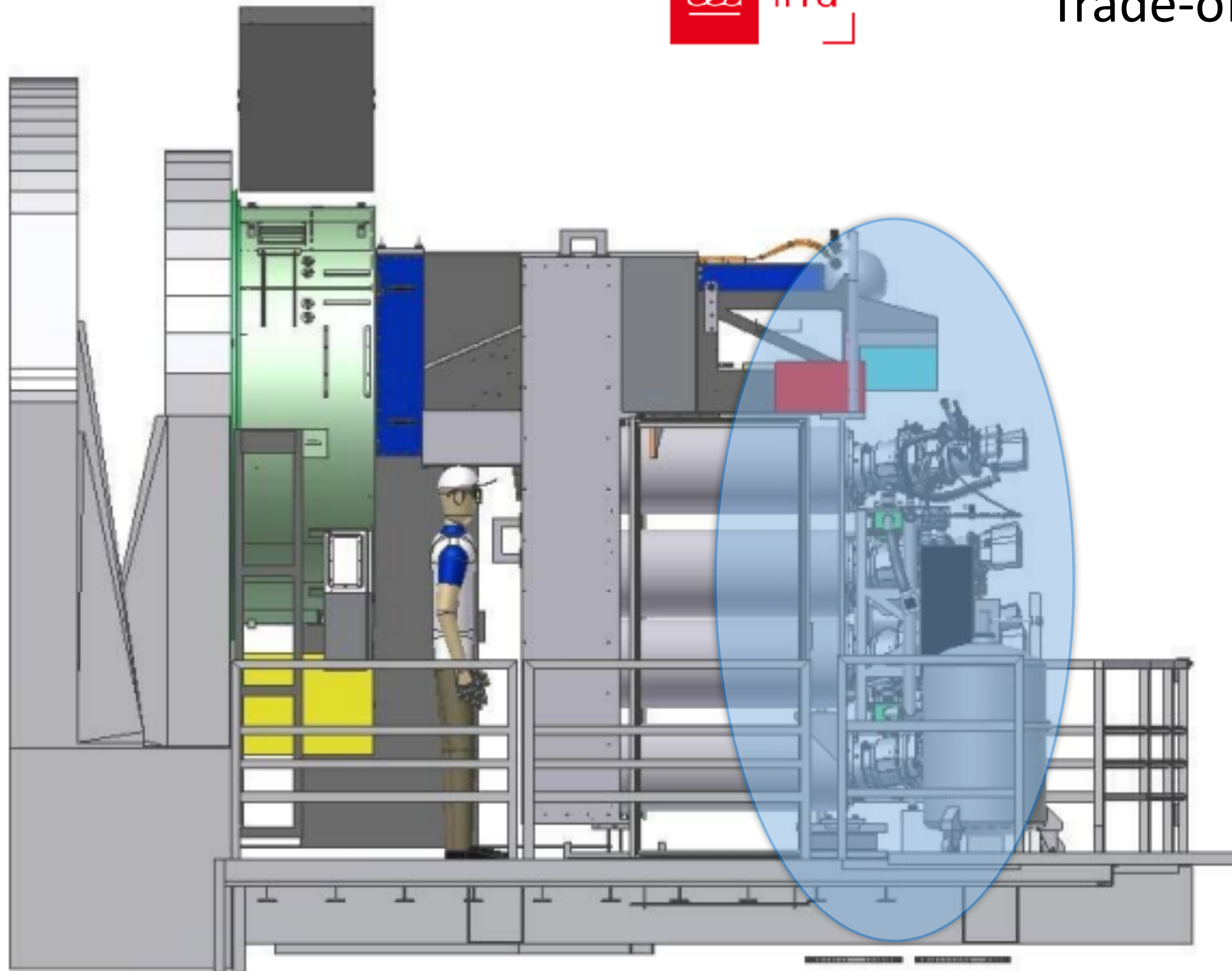






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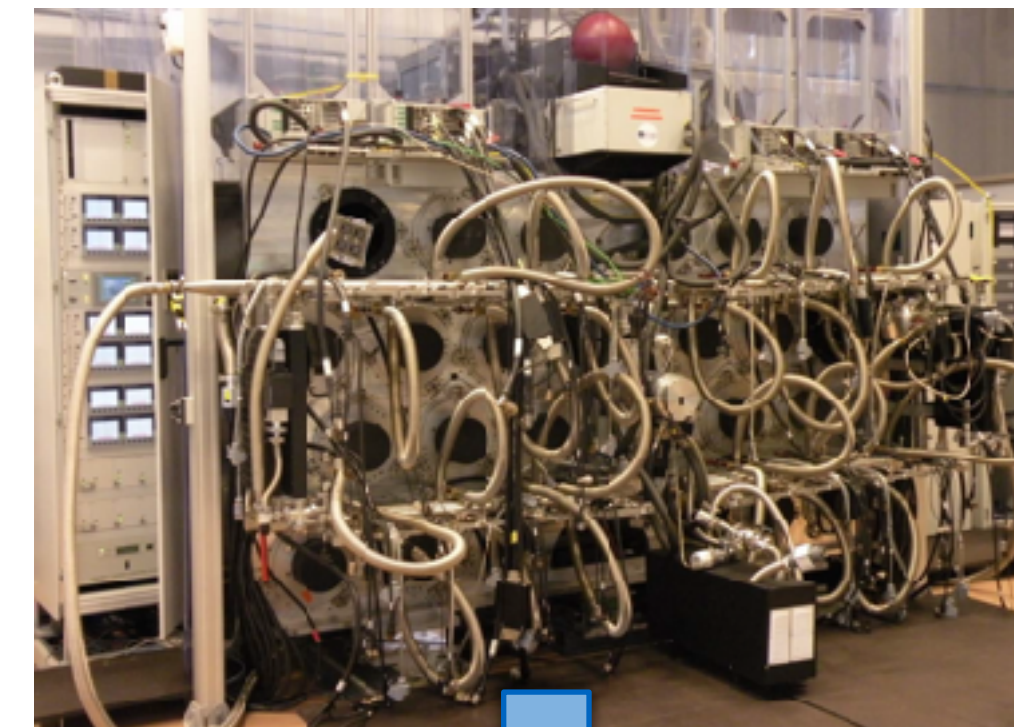
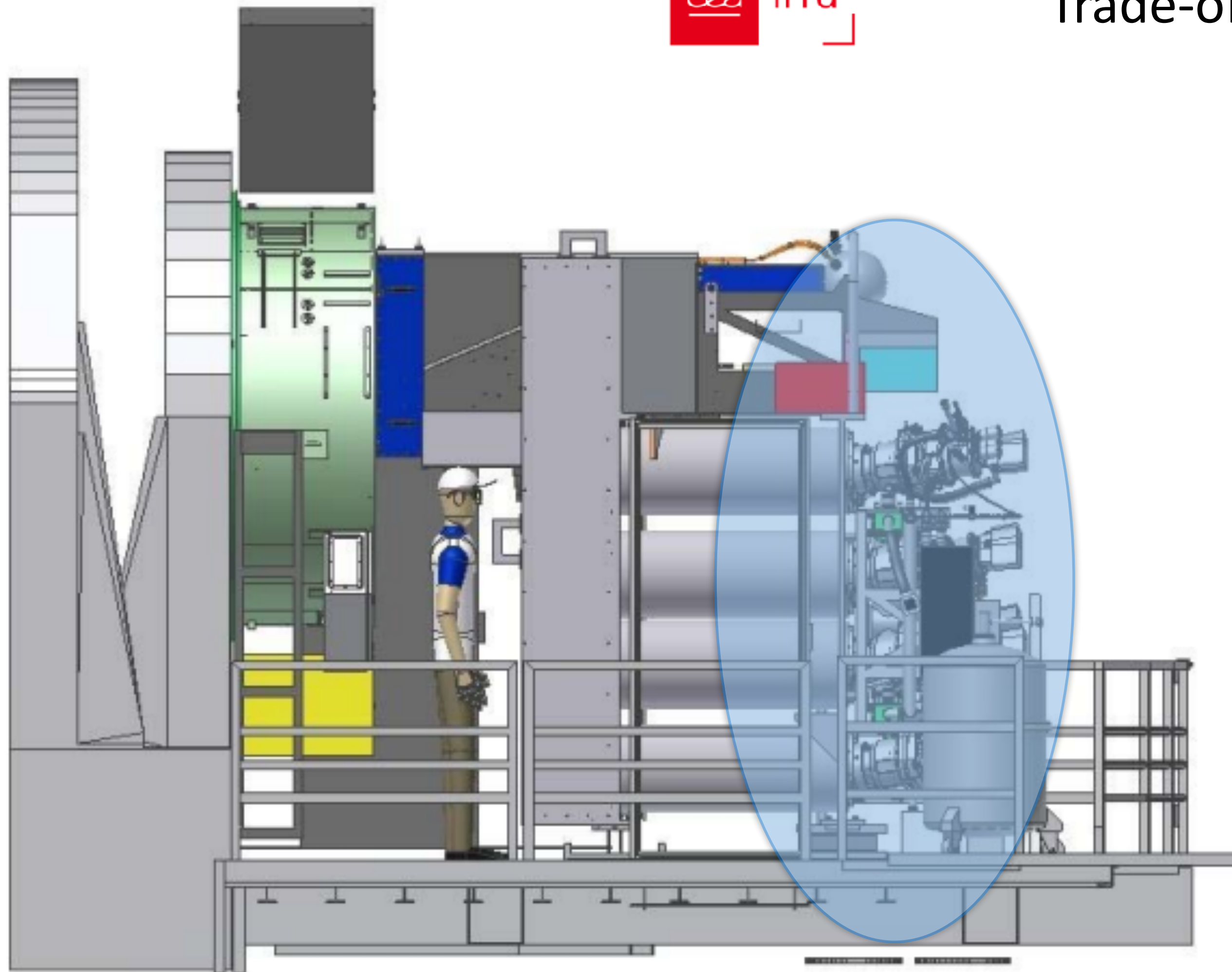
CFC  
technology  
with LN2



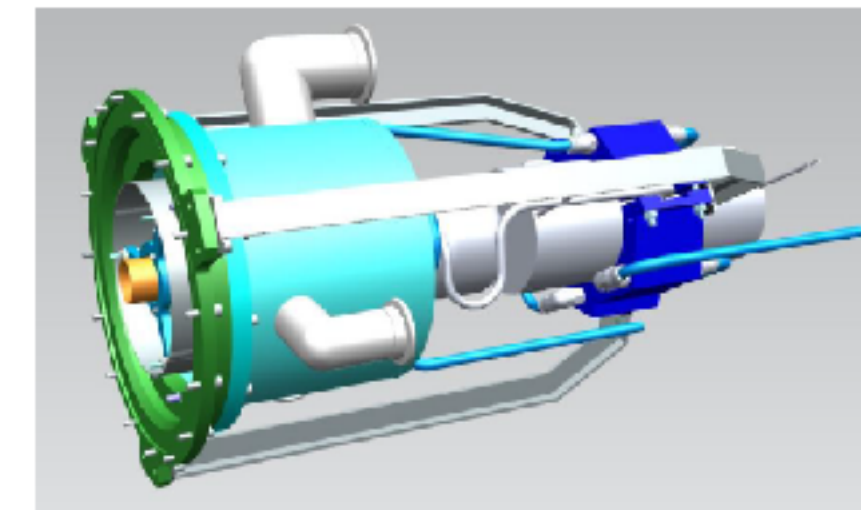


## Detectors and cryogenics

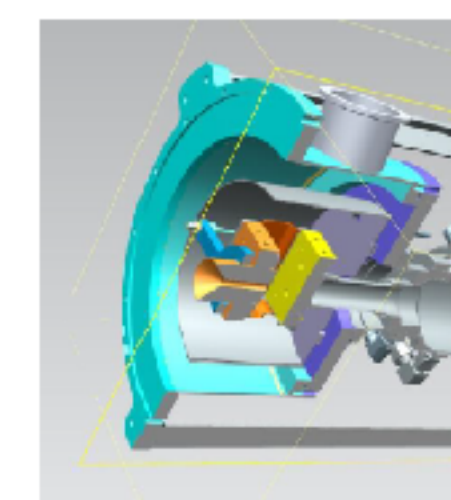
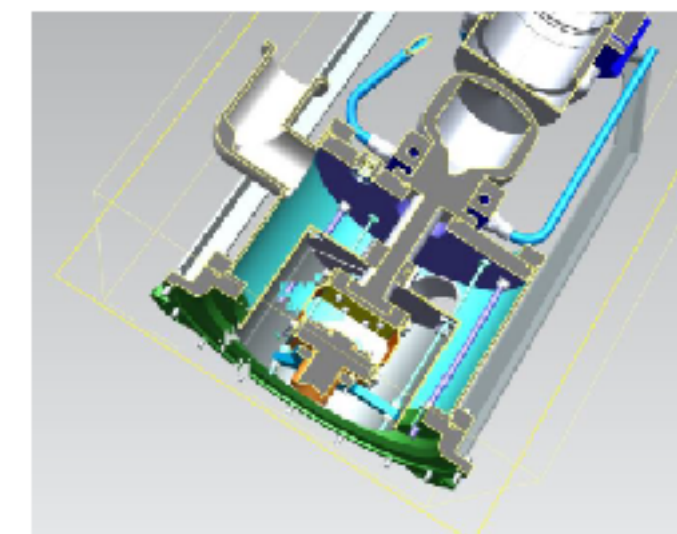
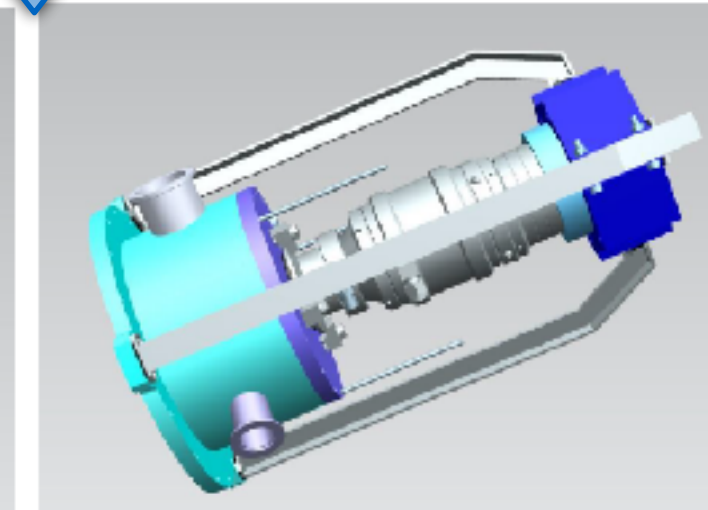
Trade-off over 2 choices of 4k x 4k 15  $\mu\text{m}$  detectors



Thales



Cryotel GT



CFC  
technology  
with LN2



Cryocoolers  
(2 prototypes,  
Pulse-tube or  
Stirling  
technology)

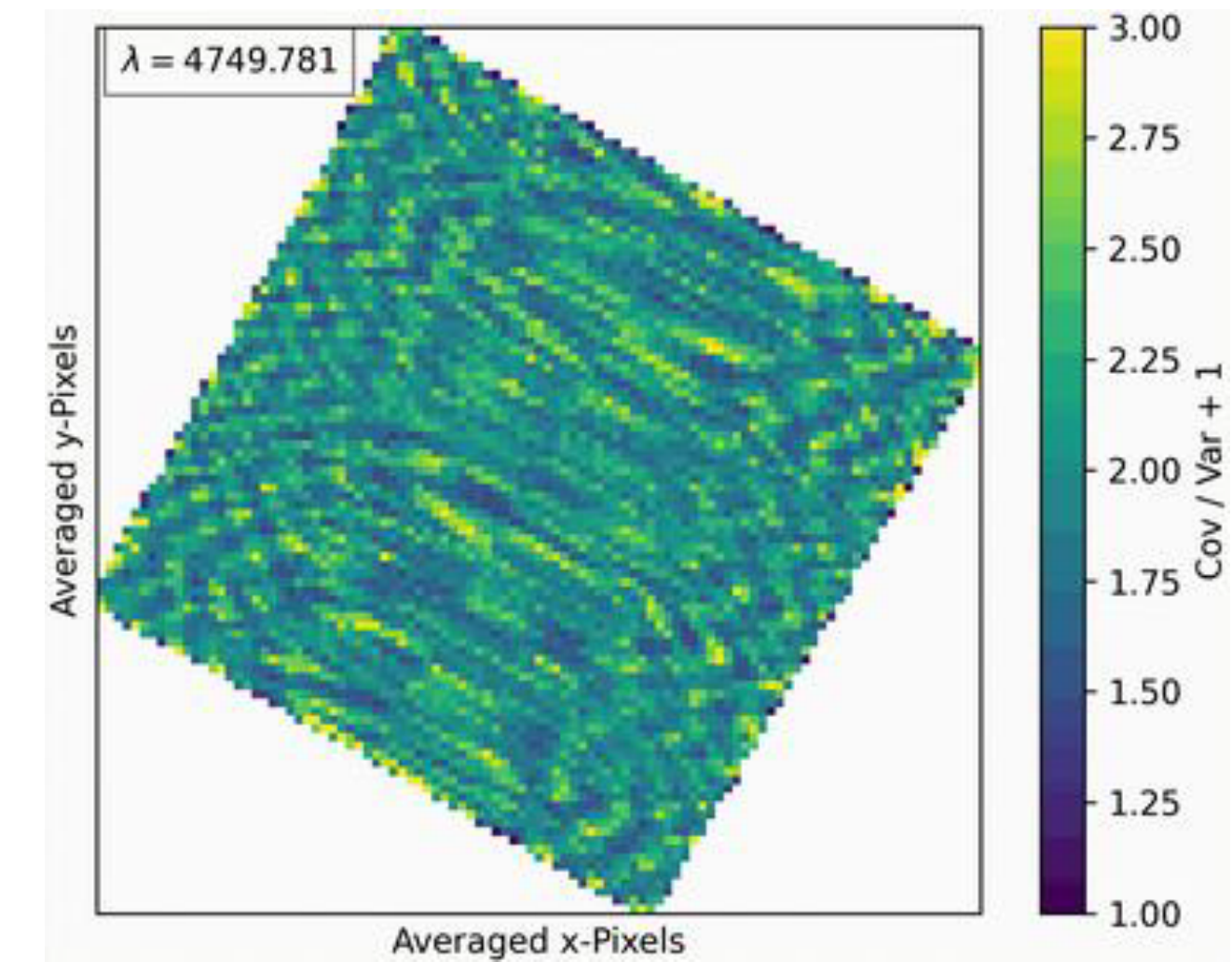




## Data Reduction Software (DRS):

- single step interpolation into a data cube.
- new developments: covariance and Line Spread Function (LSF) propagation, combination MUSE + BlueMUSE

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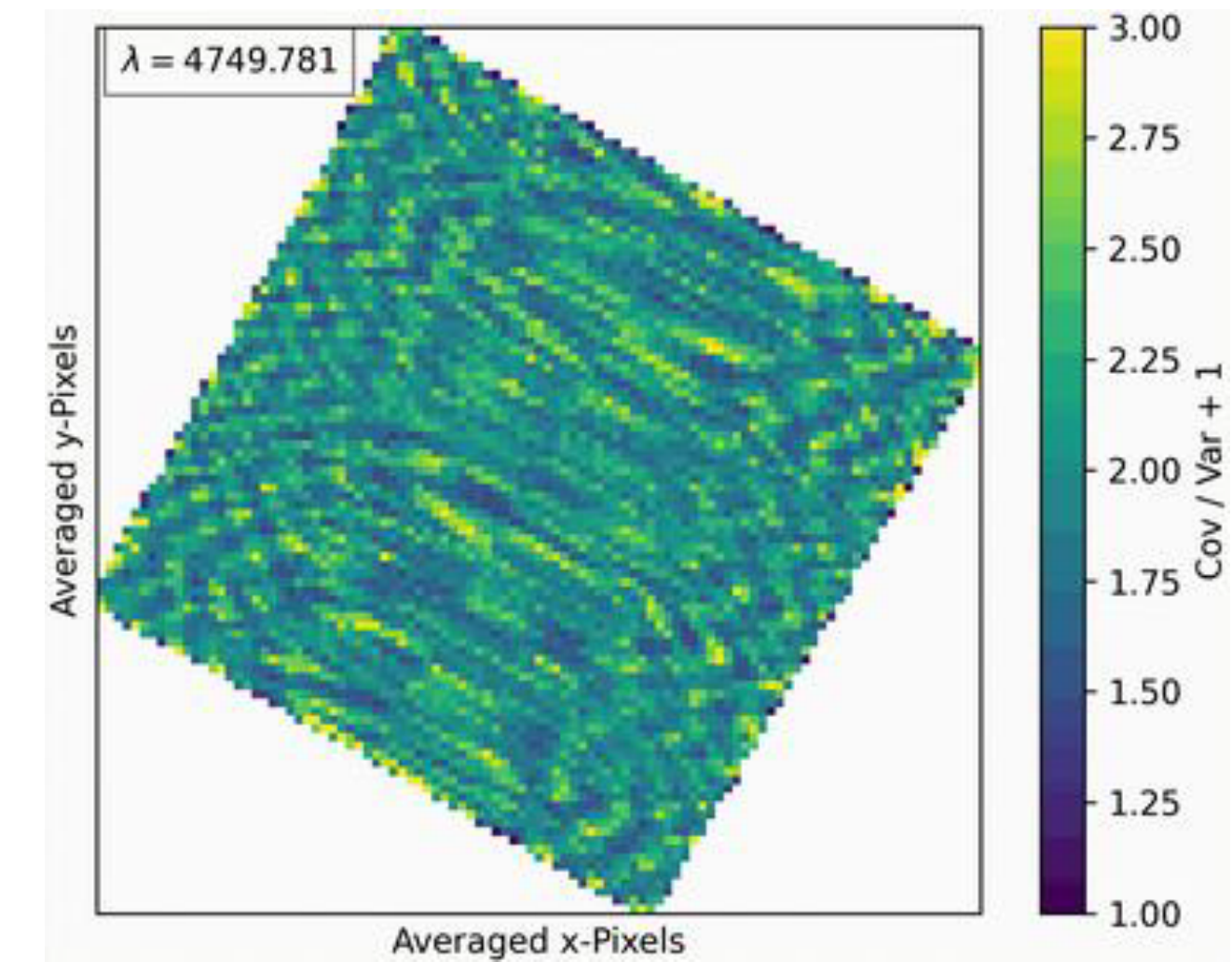




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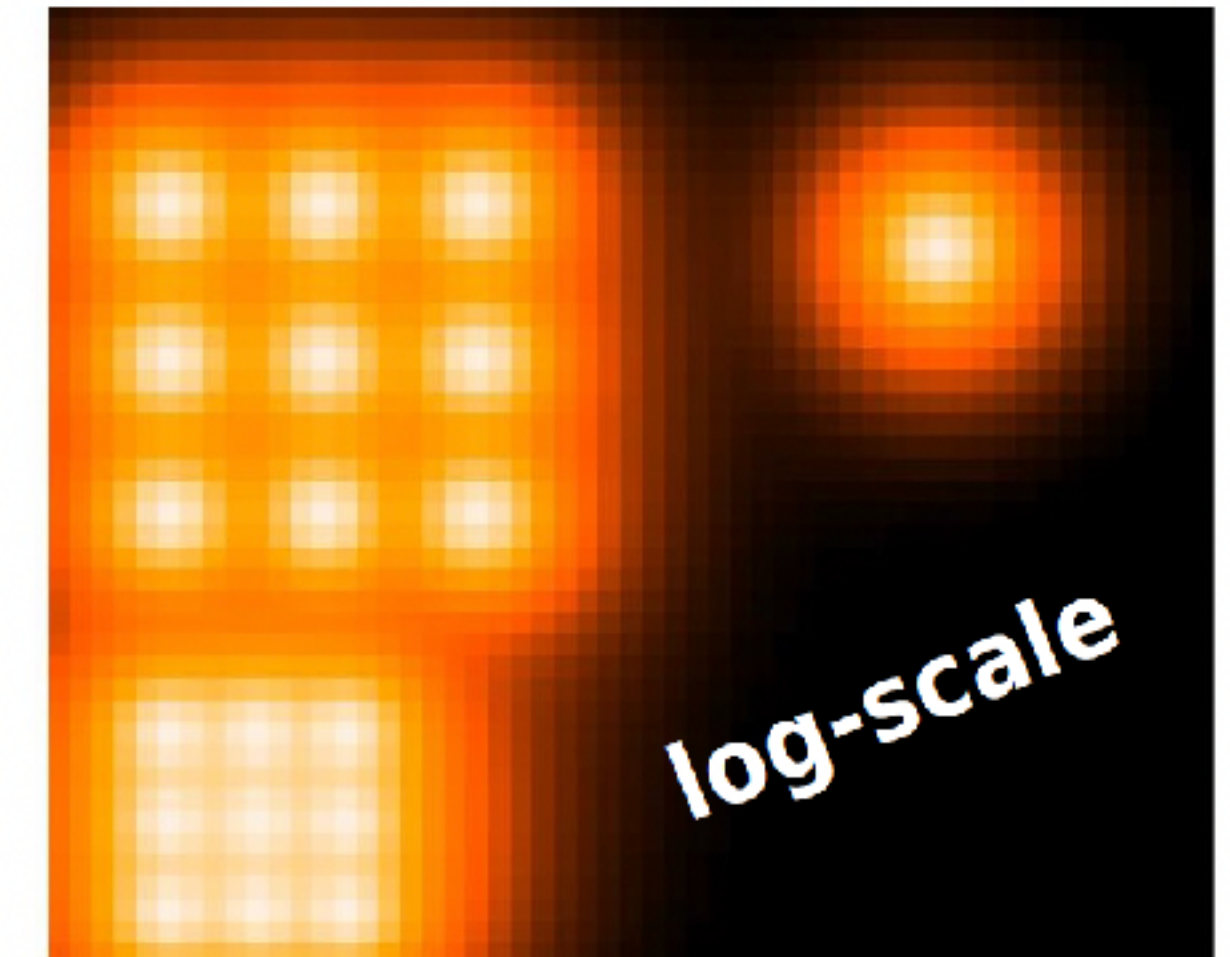
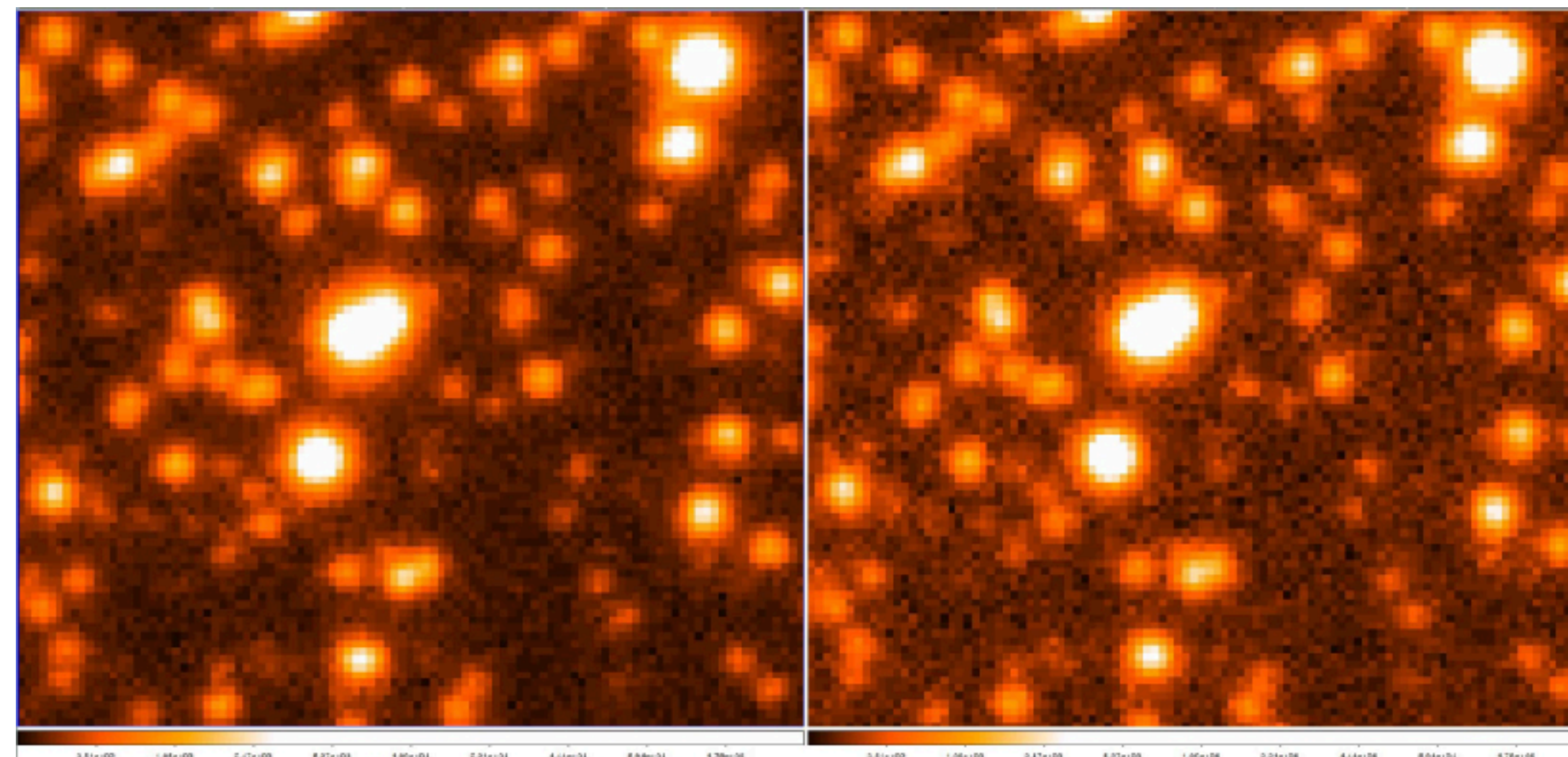


## Rectangular spaxels

**BlueSi:**  
end-to-end simulator



Wendt+2024





- BlueMUSE and MUSE share similar characteristics in data size / source content - perfect opportunity to develop strong data analysis tools and share them with the community!
- Large number of public tools already exist for MUSE
- The soil is fertile, the time is ripe.... how can we make it happen?

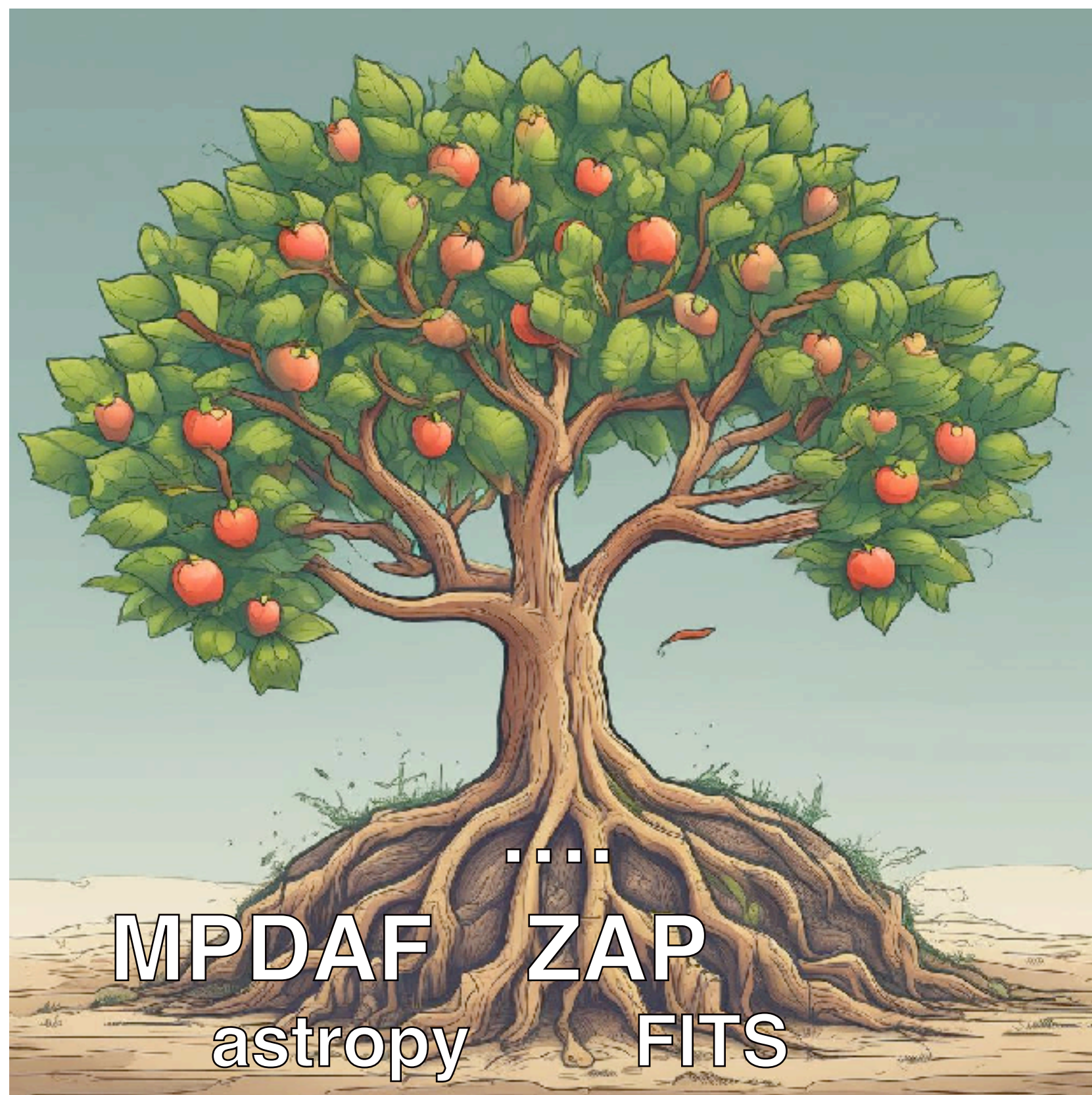


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MPDAF      ZAP  
astropy      FITS

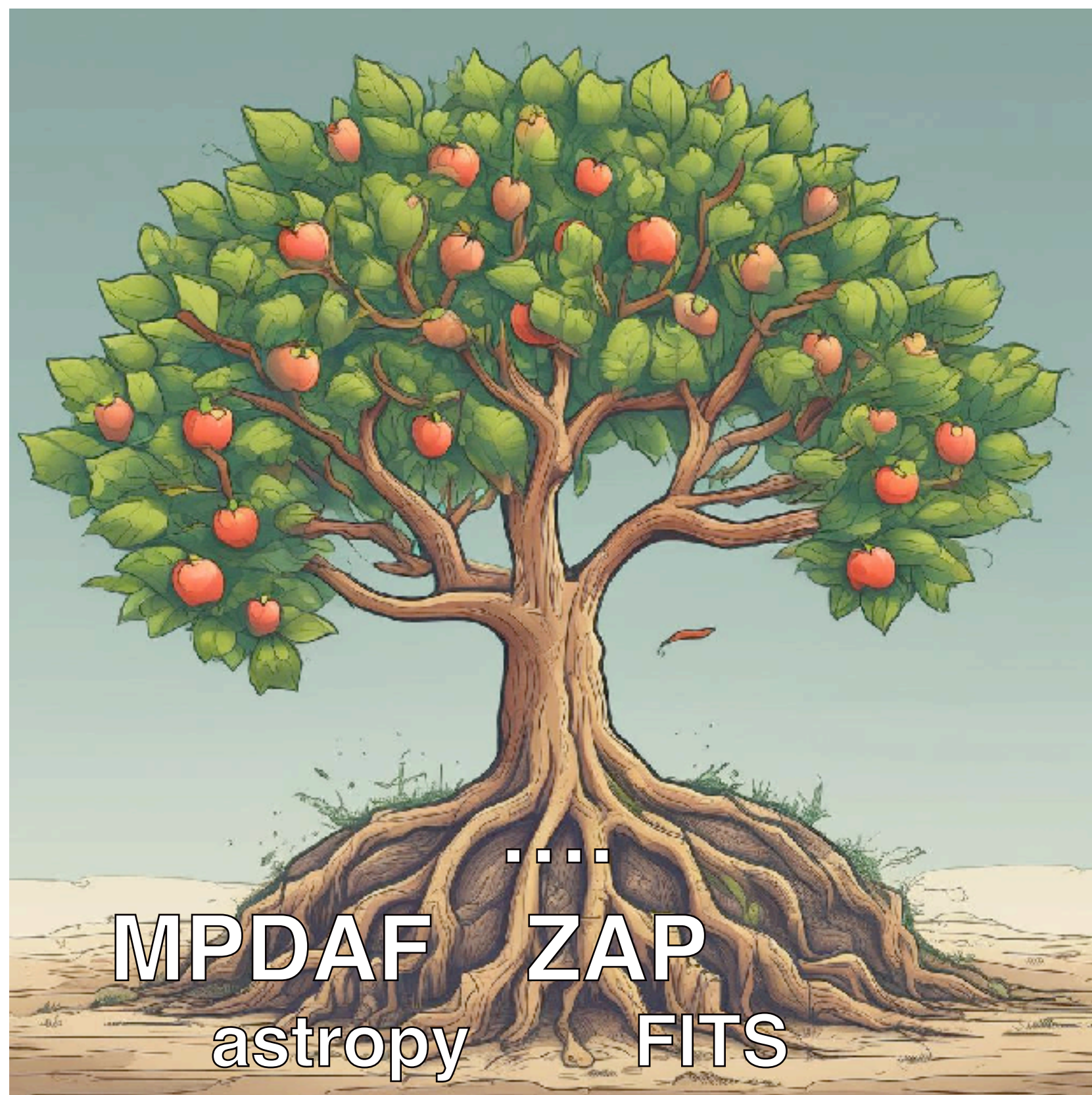


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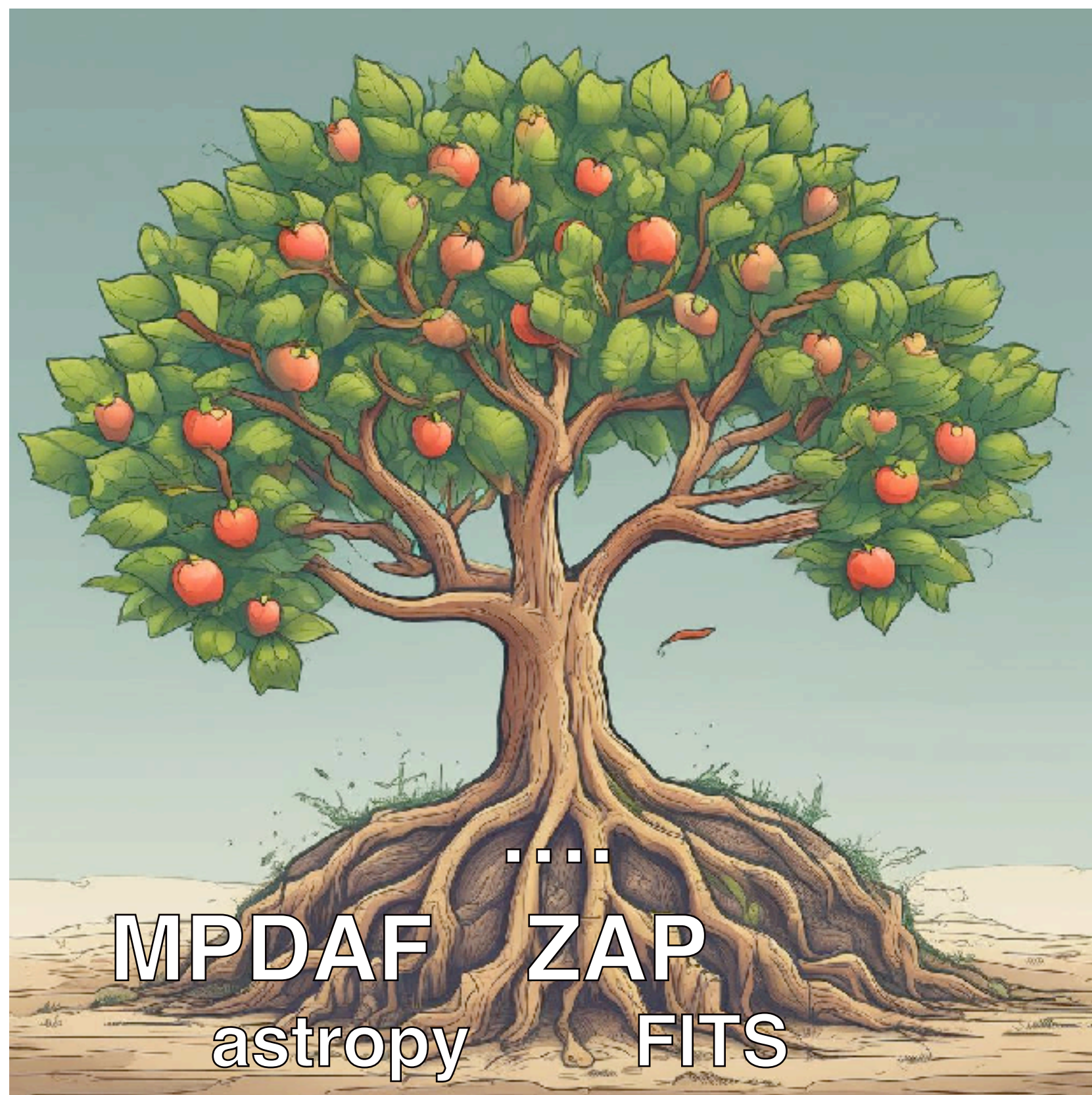
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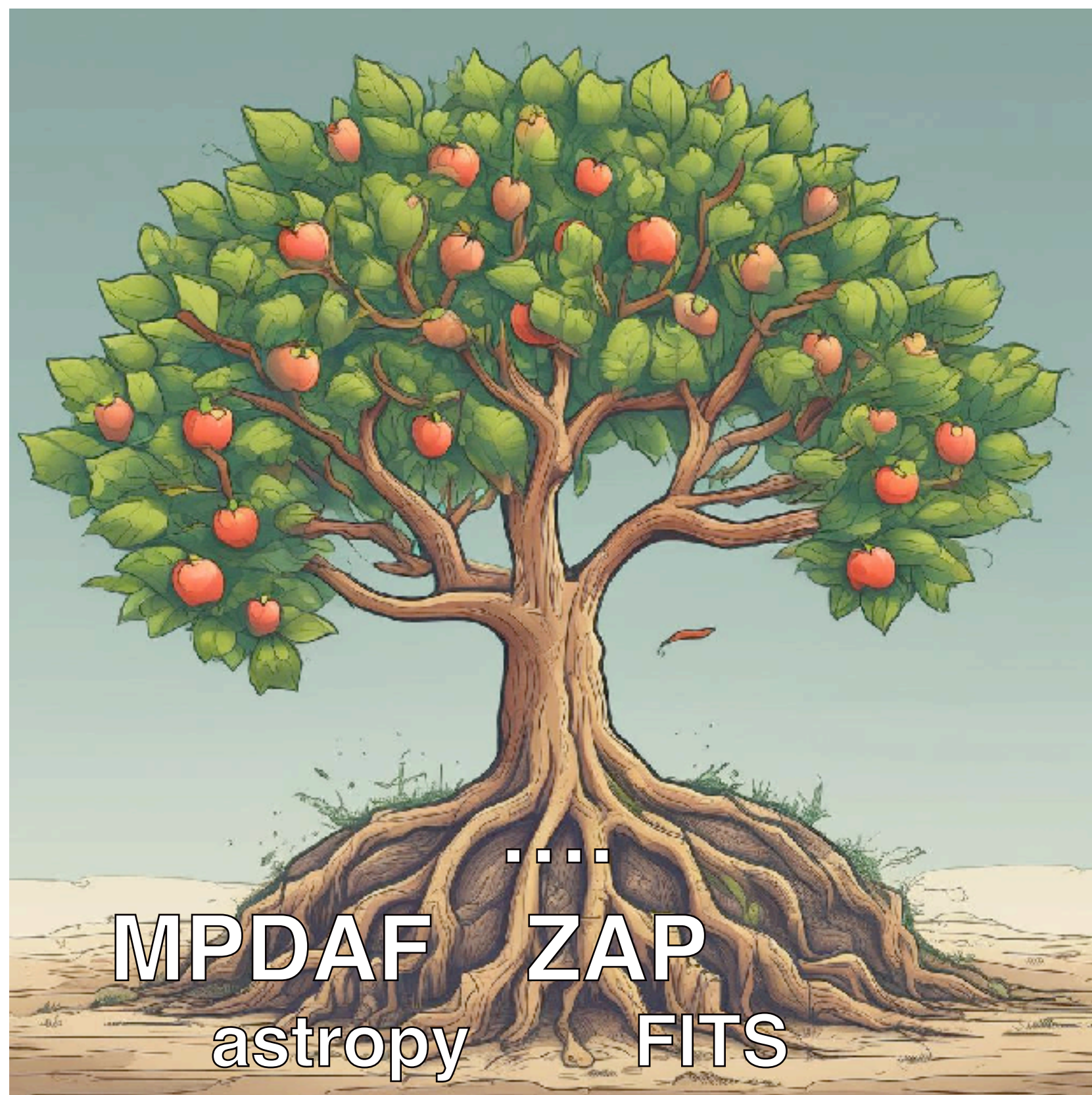
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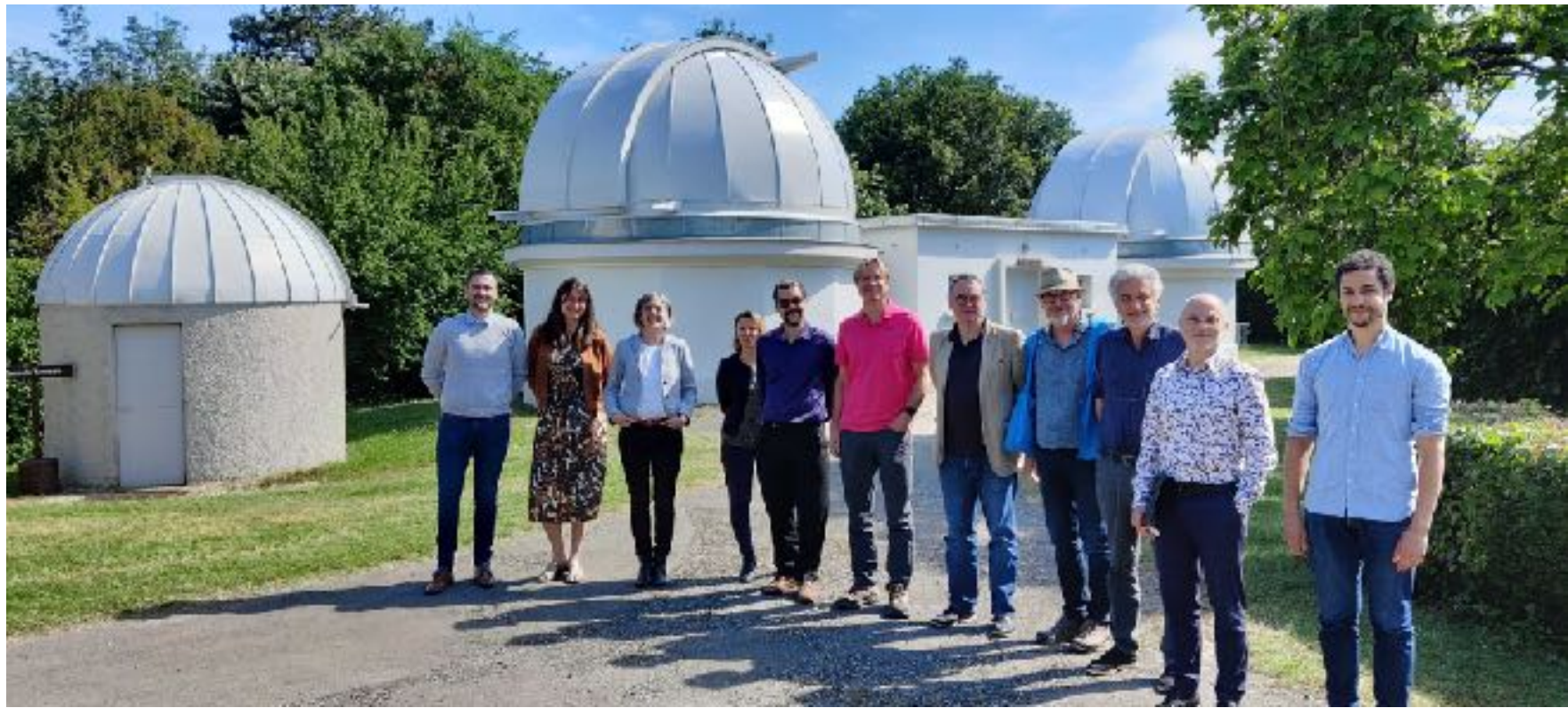
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- The BlueMUSE project has **started Phase A with ESO** for 10 months, with an expected first light in 2032 on the VLT.
- It will provide a **unique wide-field IFU capability in the Blue / UV**, and **strong synergies with MUSE, VLT2030 instruments and the ELT**.
- We benefit from all the MUSE expertise and past work since 2018, so that we can focus on **technical improvements** (integrated operations, stability, ...) and **prototyping activities** (VPHs, Cryogenics)
- Our chance to already prepare **Data Analysis tools** which would benefit MUSE, BlueMUSE and future IFUs (WST)





Thank you!