

# Multi Unit Spectroscopic Explorer

## MUSE: instrument and DRL overview

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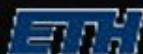
Lyon



Leiden



Zurich



Potsdam



ESO



Toulouse



Göttingen



# Instrument properties

Spectral range (simultaneous)	0.465-0.93 $\mu\text{m}$
Resolving power	2000@0.46 $\mu\text{m}$
	4000@0.93 $\mu\text{m}$
<b>Wide Field Mode (WFM)</b>	
Field of view	1x1 arcmin <sup>2</sup>
Spatial sampling	0.2x0.2 arcsec <sup>2</sup>
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	$3.9 \cdot 10^{-19} \text{ erg} \cdot \text{s}^{-1} \cdot \text{cm}^{-2}$

4096 pixels

370  $10^6$  pixels

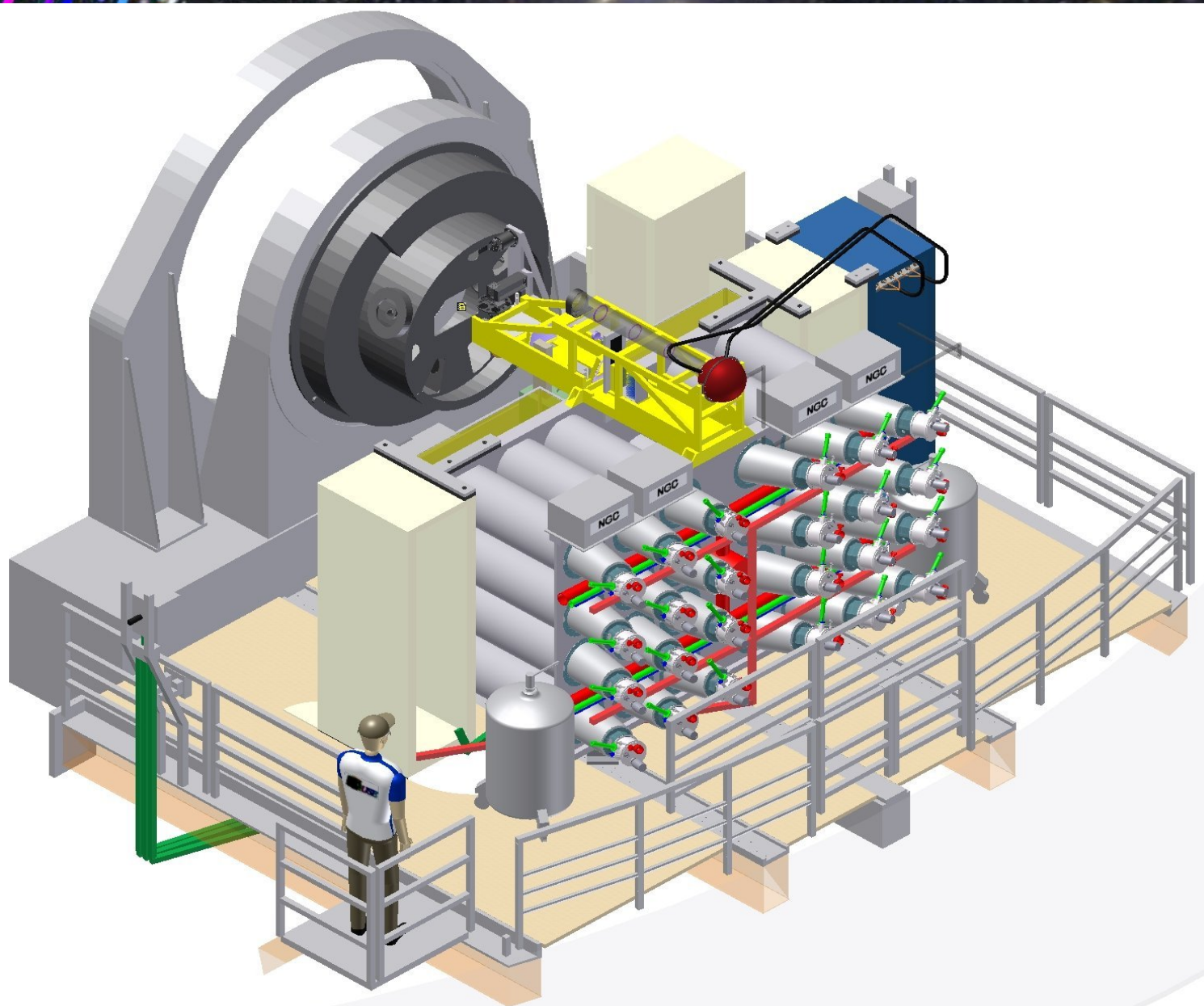
90,000 spaxels

AO

Laser guide stars

3 operating modes

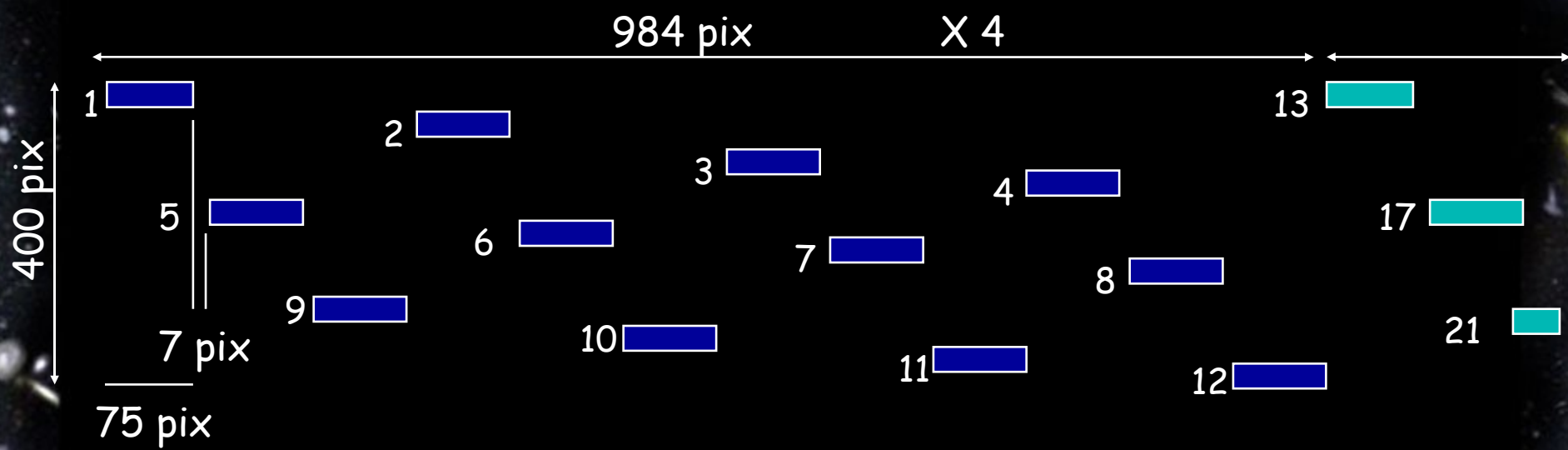
- No AO WFM
- AO WFM
- AO NFM



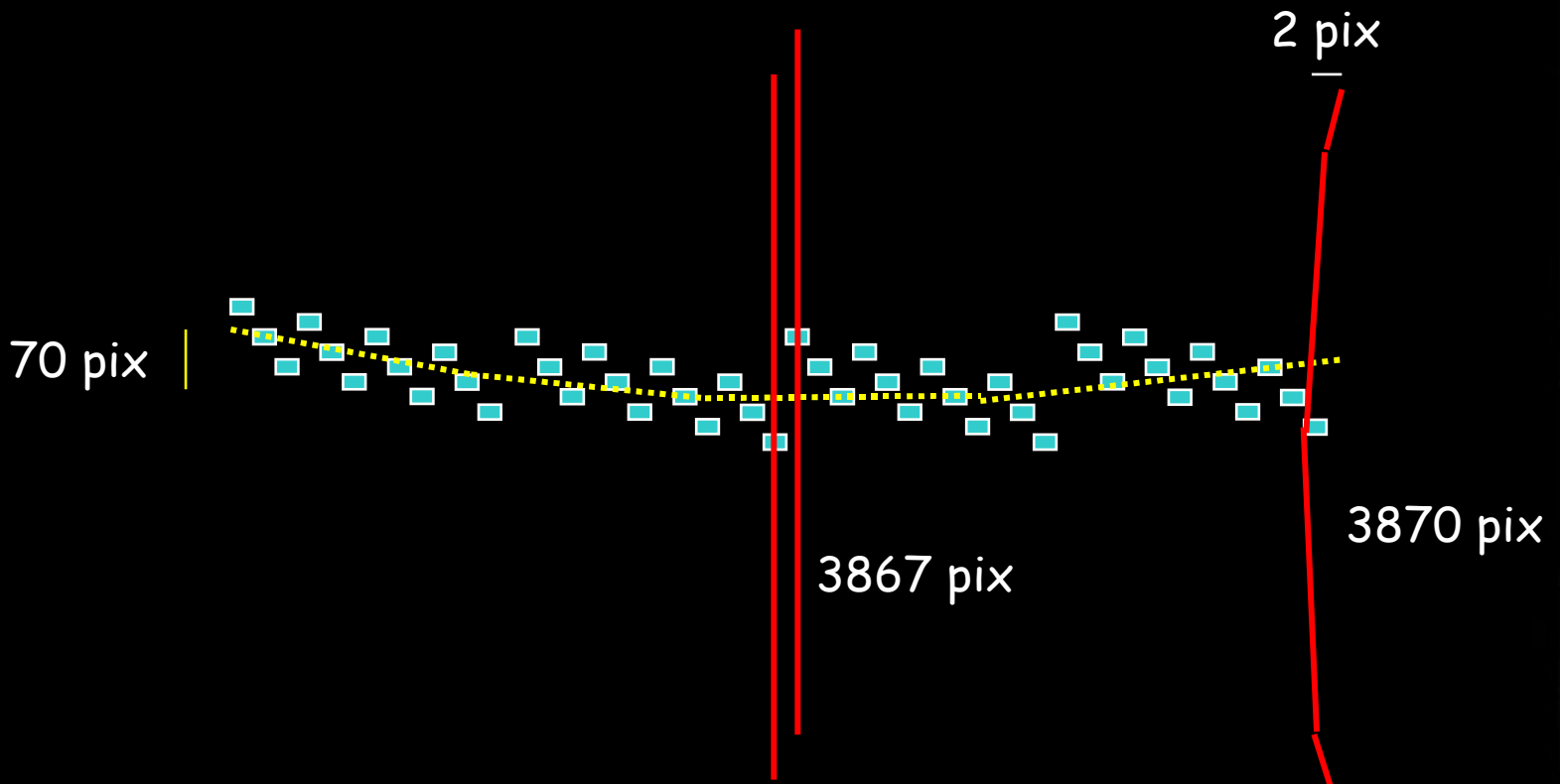
# Field splitting



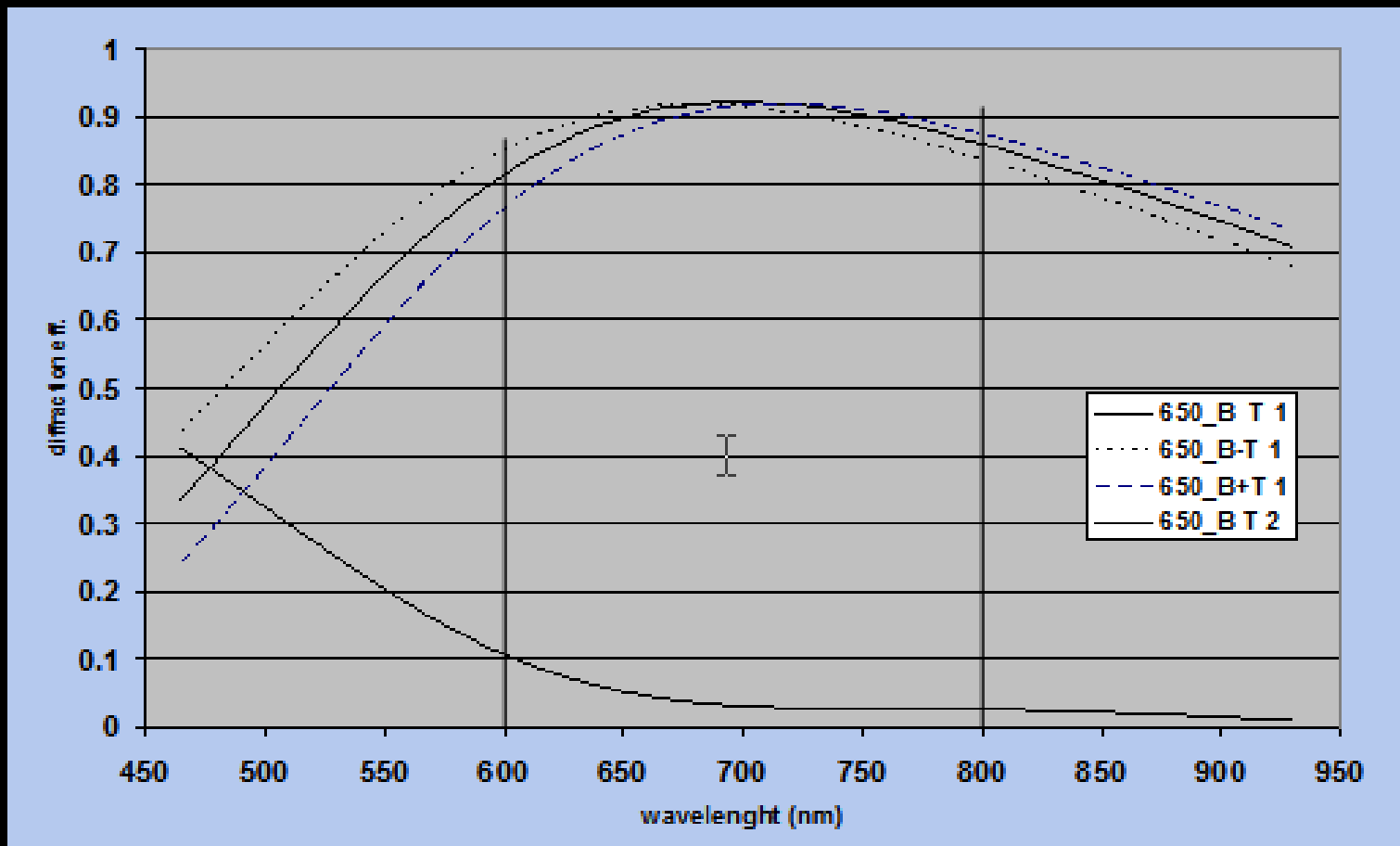
# Sub-field slicing



# Pattern on CCD

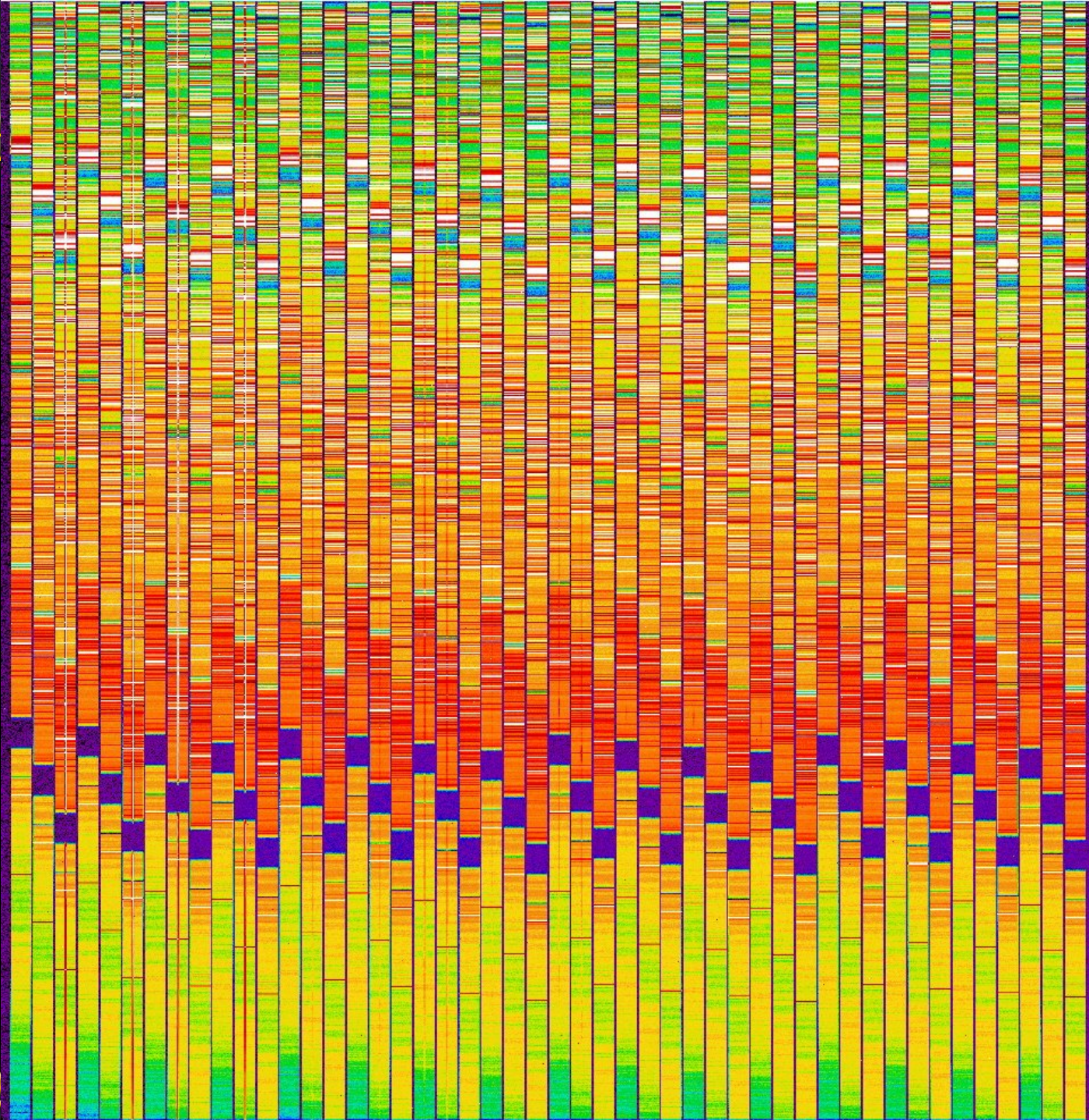


# Throughput



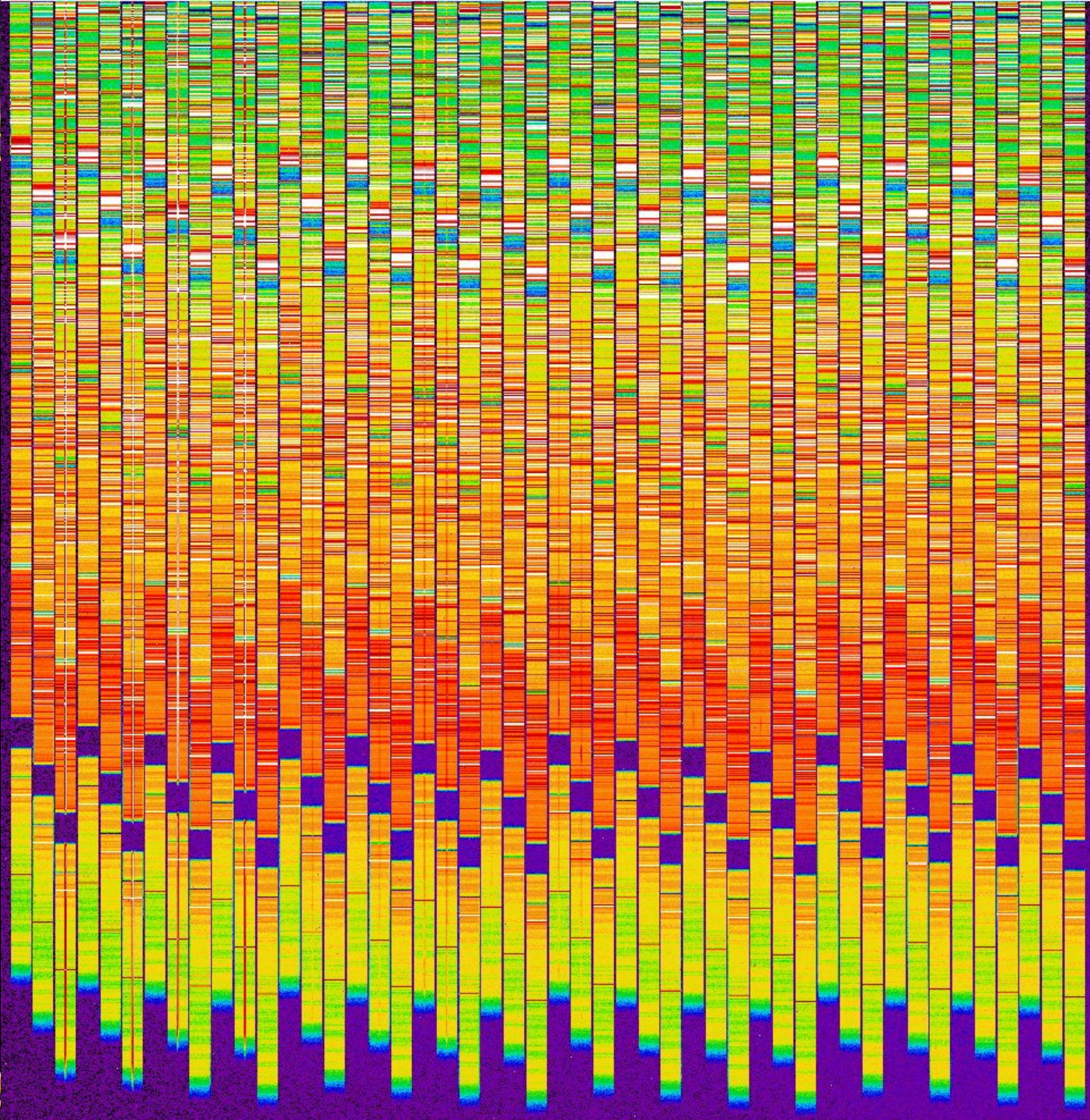
# Mock science data

1/24<sup>th</sup> of a full  
exposure!



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1/24<sup>th</sup> of a full  
exposure!



# Data volume

- One exposure (raw)  $4096^2$ px x 24 CCDs x 16bit  
→ 805 MB + headers
- One exposure (reduced) ~4.8 GB + headers!  
(Euro3D format with 3 extensions)
- Typical *raw* science data ~30 GB/night (min.  
~10 GB, max. 145 GB)
- Calibration raw data between 10 and 100 GB  
per night, typical ~25 GB

# Pipeline Design

- Two levels: CCD based and whole instrument
- All (?) calibrations and first part of science data reduction CCD based
- Second half of science data reduction depends on data from all IFUs
- Few recipes that combine most steps into one external call
- Parallelization perhaps trivial for first part, more difficult for second part (CPL + OpenMP?)

# Recipes

- (muse\_quick\_image)
- muse\_masterbias and -dark
- muse\_masterflat
- muse\_distortion
- muse\_arc
- muse\_scibasic
- muse\_scipost

# Science recipes

- muse\_scibasic: apply calibrations and transform input data into 3D lookup table (“apply” trace and wavelength calibration)
- muse\_scipost: most complex recipe:
  - Some common steps for all inputs, but output depends on type of input data (std vs. science)
  - Merge fields
  - Subtract sky / create sky spectrum
  - Apply flux calibration / compute response
  - Correct atmospheric refraction
  - Combine multiple exposures

# Reduction approach

- Output data Euro3D: data spectrum, bad pixel spectrum, and statistics (error) spectrum
- “Direct” measure of the S/N of an exposure
- Difficult to estimate correct errors through multiple resampling steps → only use one resampling?
- Create lookup tables (matrices?) in 3D, similar to wavelength maps in 2D
- Apply steps that need resampling to the “coordinates” in these lookup tables instead of data itself
- In the end one routine does the resampling using three dimensional interpolation in the lookup table

# Visualization tool

- E3D tool too slow, difficult to maintain, Tcl-based
- License problem with PGPLOT
- Create new visualization tool for 3D data
- Similar basic feature set of E3D but more user friendly
- Both command line and GUI (like IRAF/MIDAS/IDL)
- Able to access plots as variables from the shell
- Python + Gtk or Qt, C+CPL for fast routines?
- “Plugins” for extended functionality?

# Status

- PDR July 2007, FDR mid 2008, first light 2012
- Worked with CPL quite a bit so far
- CPL based coding: prototype code can (almost) determine and apply trace and wavelength calibration (still to do: write Euro3D output)
- Further prototype code in IDL, Python, c/IRAF e.g. for sky subtraction
- Experimented with OpenMP: works (only) using direct array access not when using CPL API
- Created first automated test scripts (IDL + shell scripts) for recipes