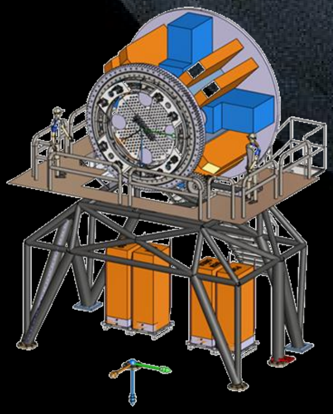
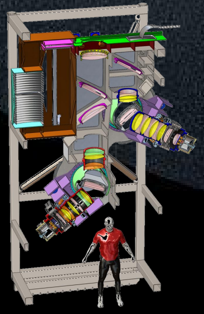
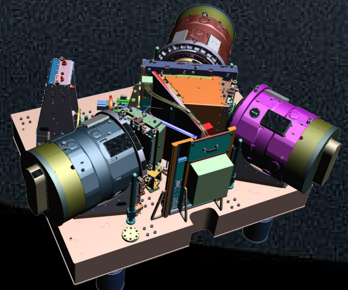
Future instrumentation for Galactic Archaeology







Bruno Castilho

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA

With thanks to:

MOSAIC: Roser Pello, Ruben Sanches

PFS: Nayouki Tamura

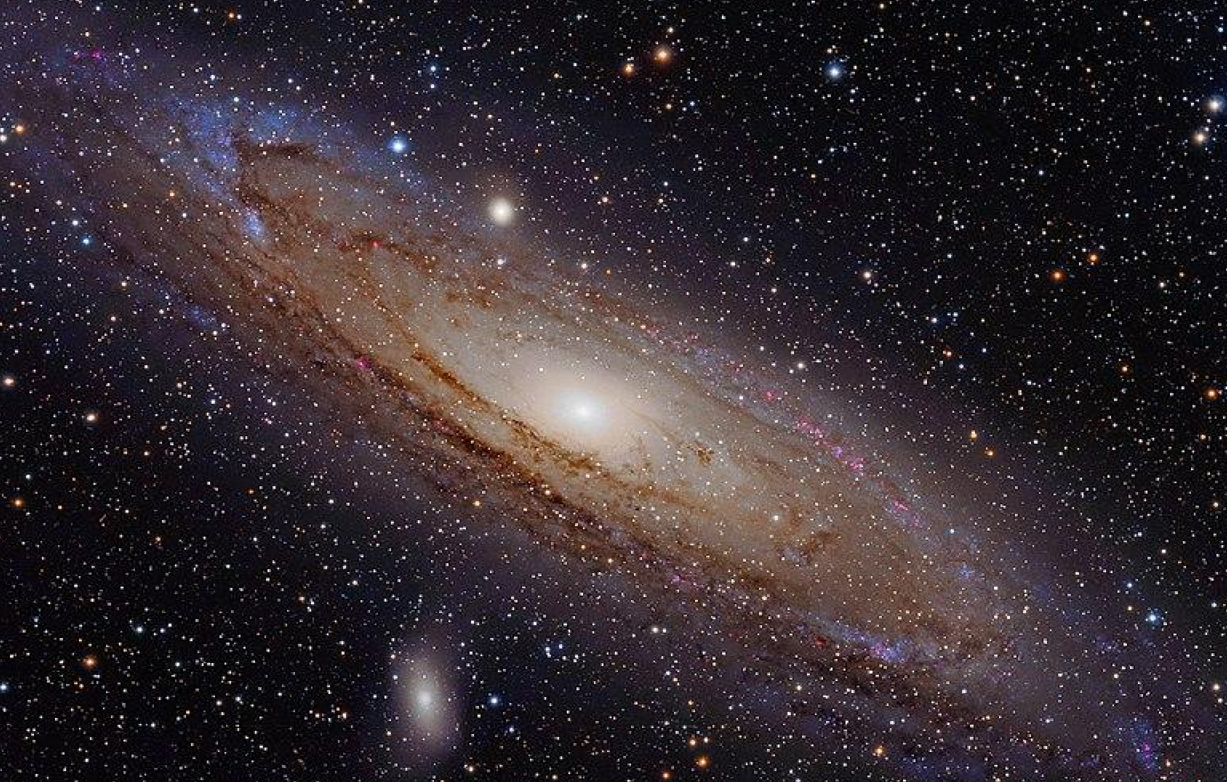
GMACS: Rafael Oliveira

PFS Brazilian team

MOSAIC Brazilian team

CUBES Brazilian team

GMACS Brazilian team



In the era of great surveys

- Much data were gattered by regular observations
- The big surveys are changing the game

LAMOST

- But ground based designed spectroscopy is still needed to solve several open questions

What we want

- High resolution
- Full VIS and IR coverage
- High multiplex - 1000s
- High efficiency
- Big telescope
- Lots fo time

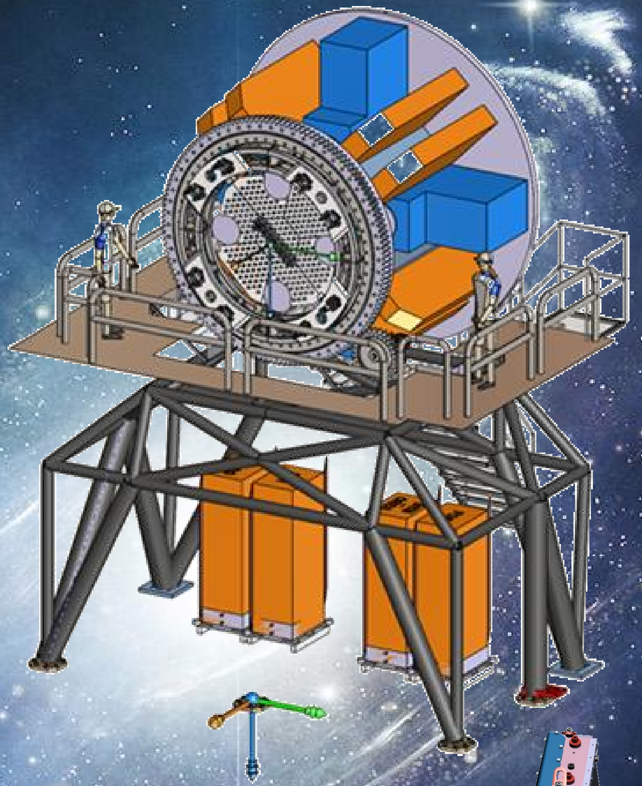
- Please fast and cheap.....

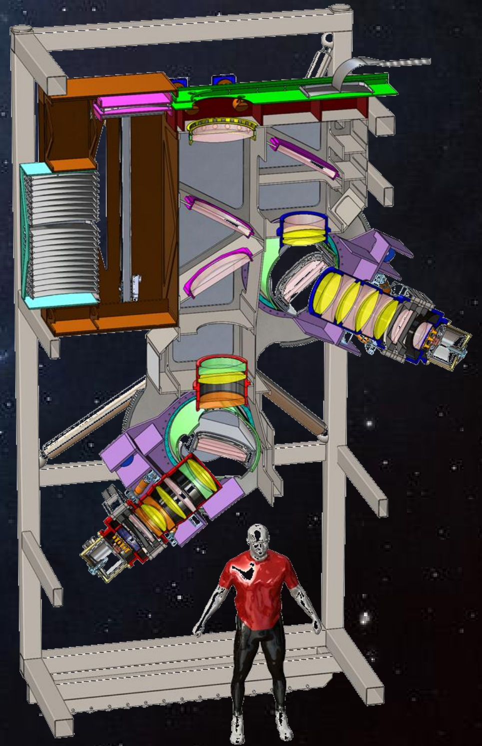
What we get

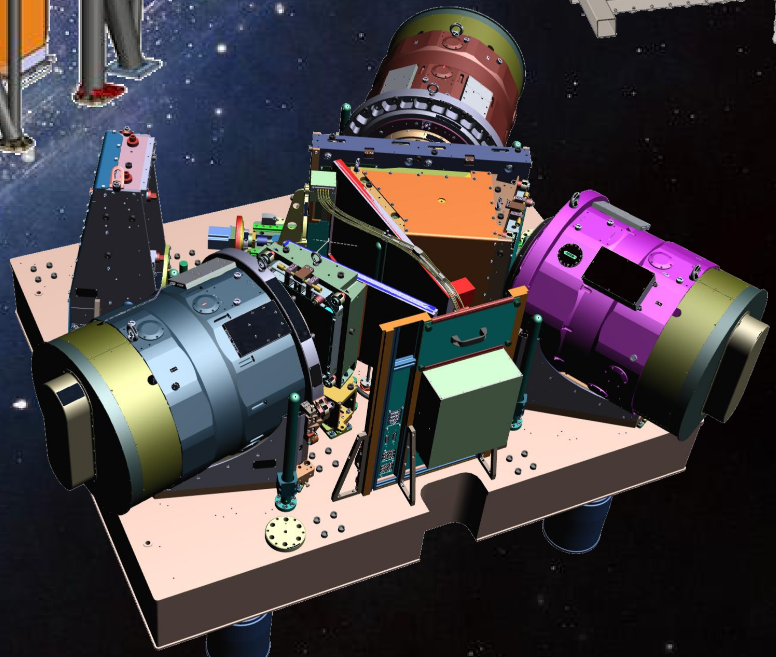
Feasibility

- 5k - 20k
- VIS + near IR
- 100s to few ks multiplex
- Medium efficiency

- 10 years or more
- expensive machines







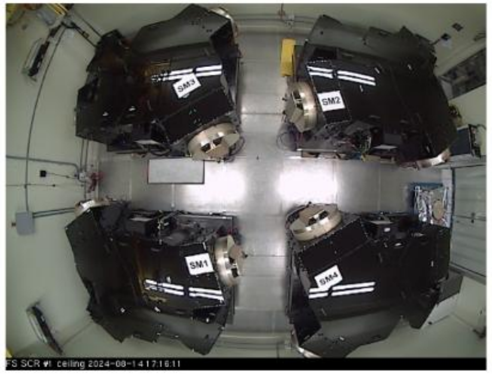
Previously in this show…

- The spec surveys - Vanessa Hill
- Gaia - Sofia Randich
- LAMOST - Haining Li
- Apogee - Ricardo Schiavon
- 4most - Marica Valentini
- SDSS-V - Jennifer Johnson
- GALAH - Sarah Martell
- MOONS, 4MOST - Luca Pasquini
- ….

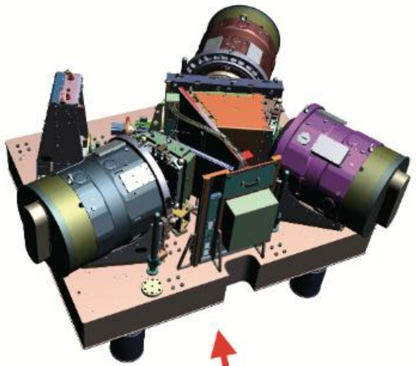
Some of the new tools

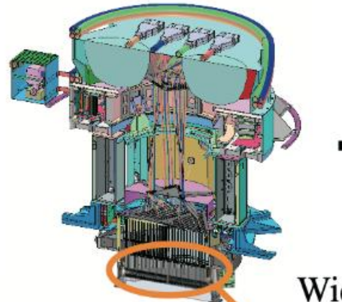
1. Subaru PFS
2. GMACS
3. MOSAIC
4. CUBES

Subaru Prime Focus Spectrograph (PFS)



Spectrograph System (SpS)

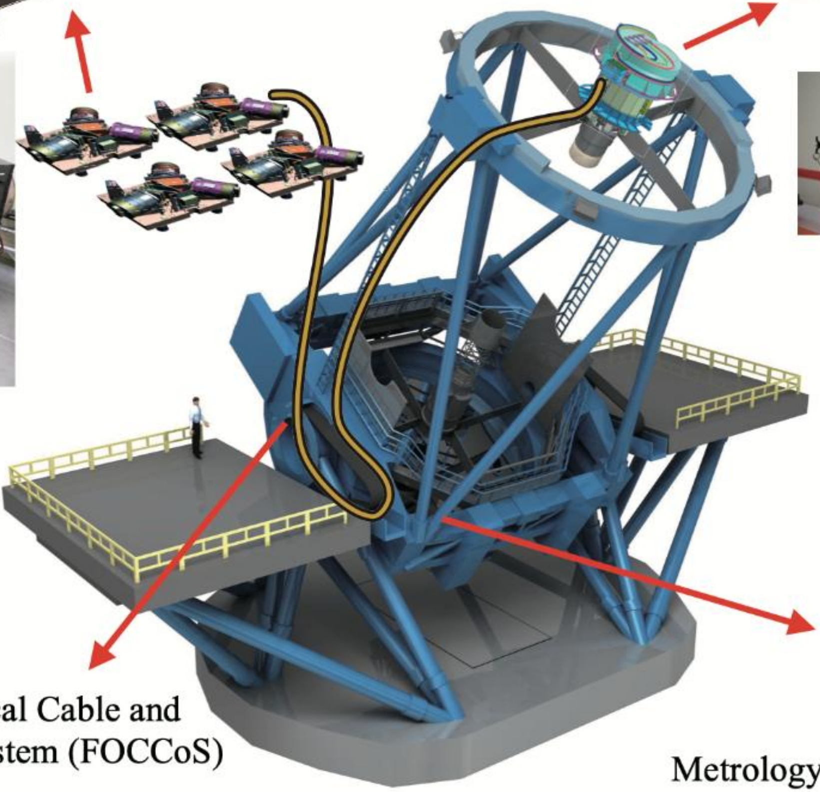




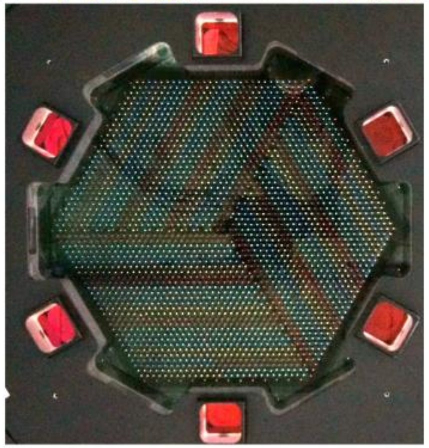
Prime Focus Instrument (PFI)

+

Wide Field Corrector (WFC)

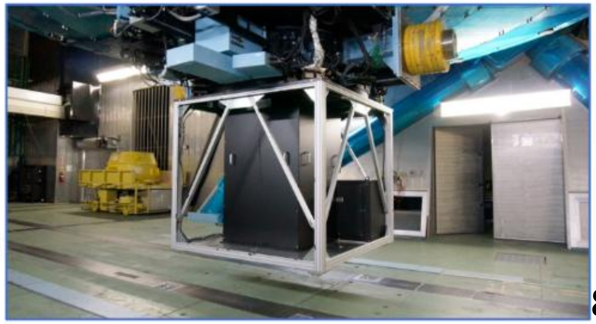


Fiber positioner "Cobra"



Fiber connectors:
SpS side

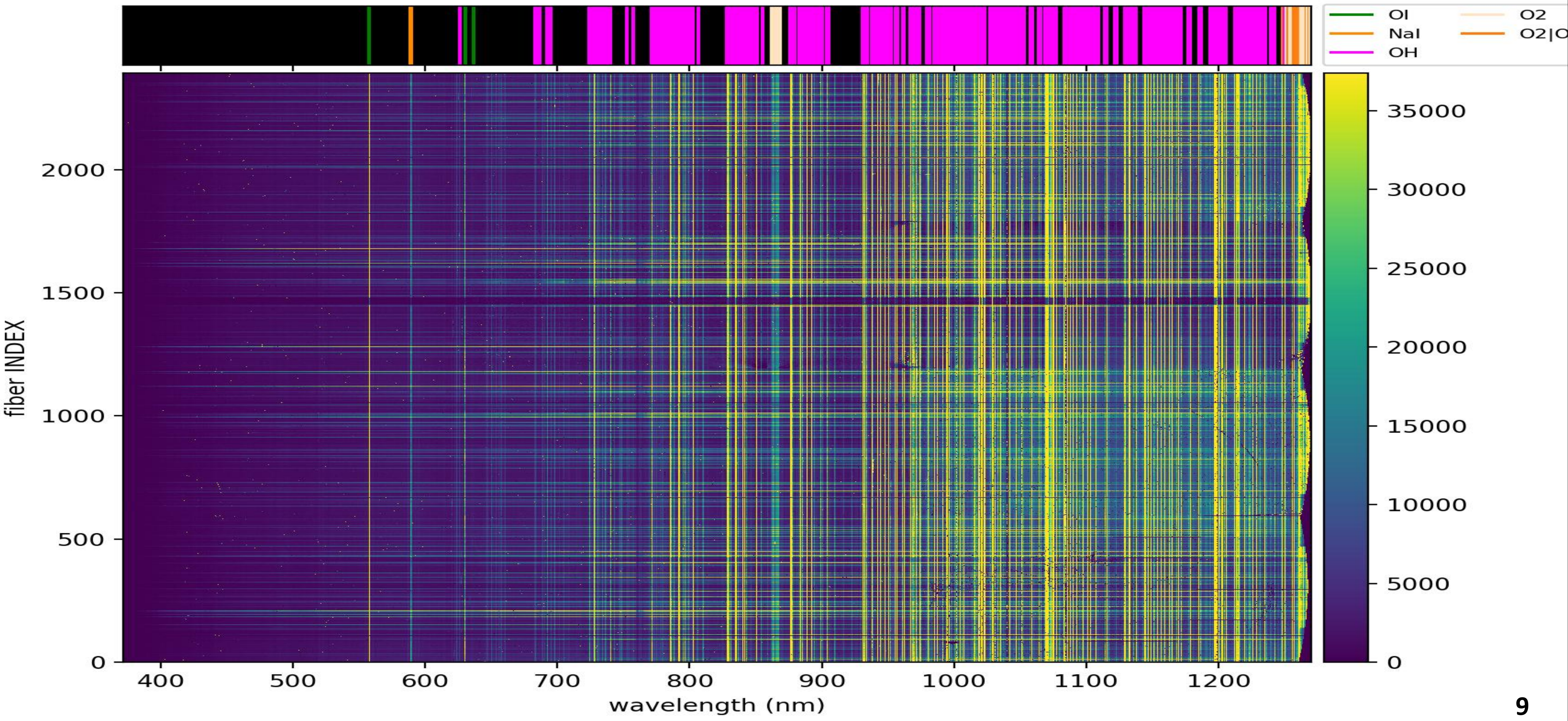
Fiber Optical Cable and
Connector System (FOCCoS)



Metrology Camera System (MCS)

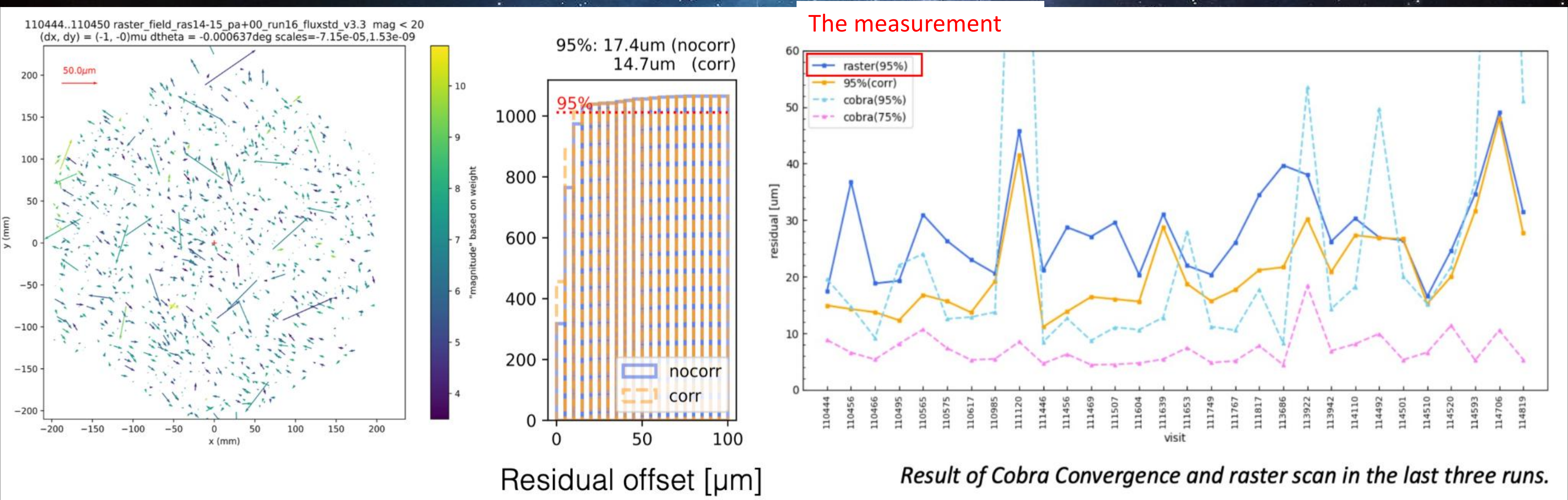
Fiber connectors:
PFI side

- ~2400 spectra from 380nm to 1260nm from every single exposure



Current statuses from engineering runs

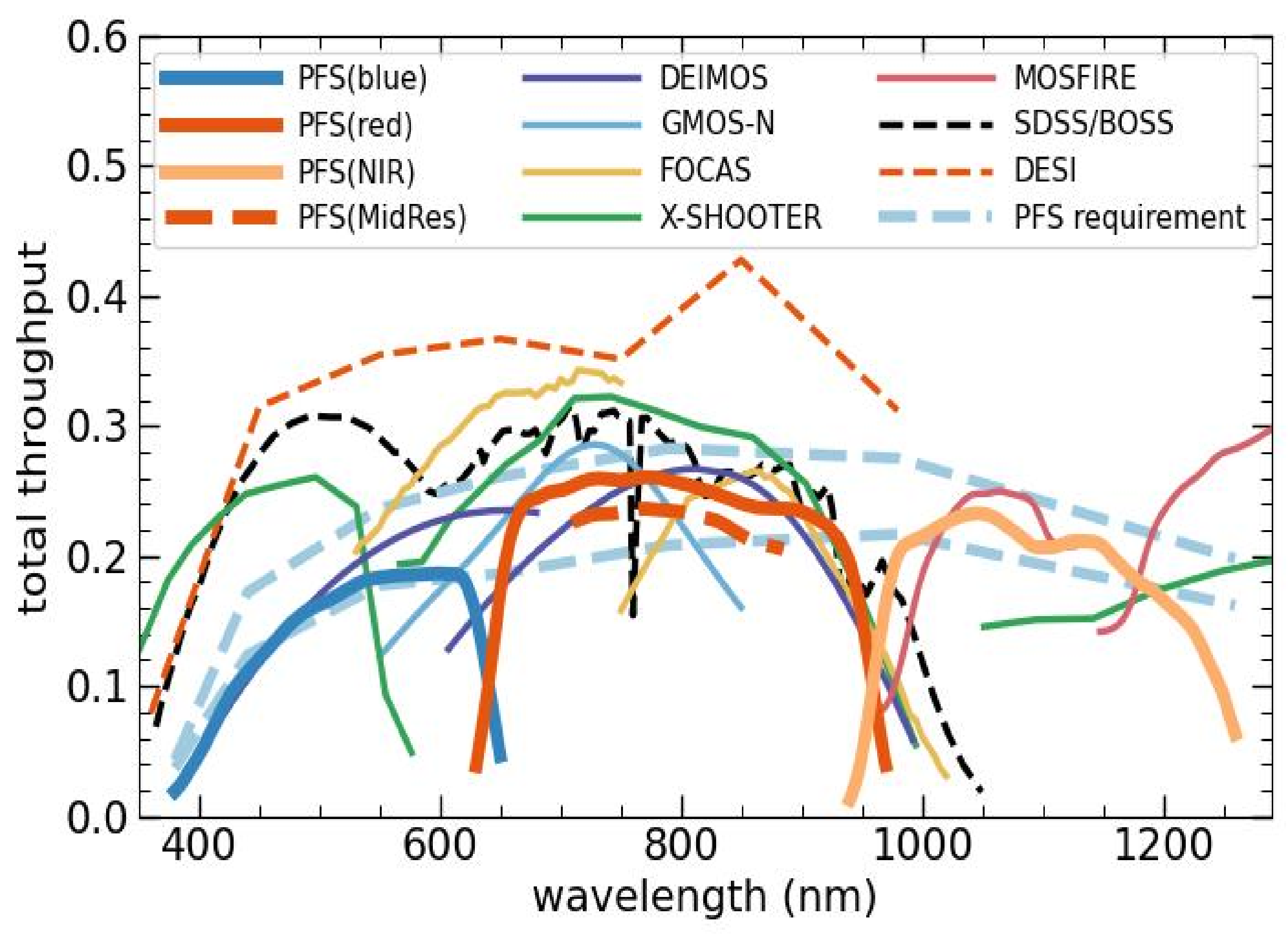
- Fiber reconfiguration accuracy and reconfiguration time



Result of Cobra Convergence and raster scan in the last three runs.

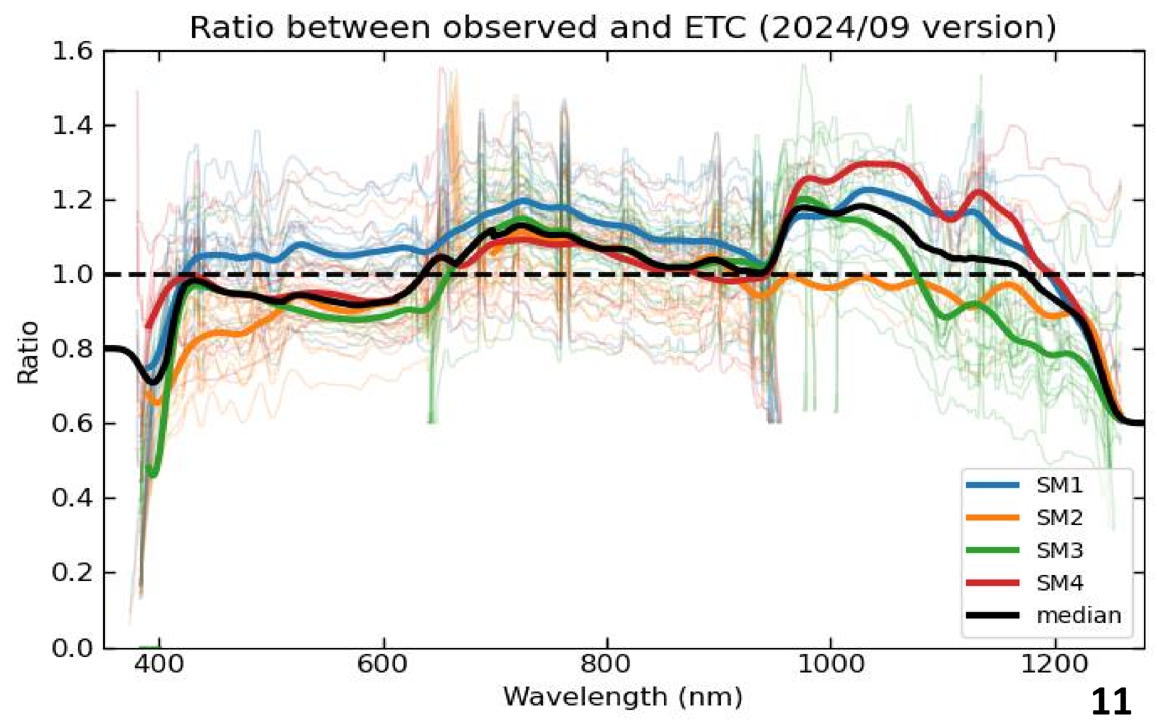
- Typically 95%-tile is ~20-30μm (20μm or even better when it's good: 20μm ≈ 0.2arcsec)
- The reconfiguration completes in ~130 sec (120 sec is the best record)
- Aiming at being "always the best".

Total throughput assessed by latest data sets and pipeline

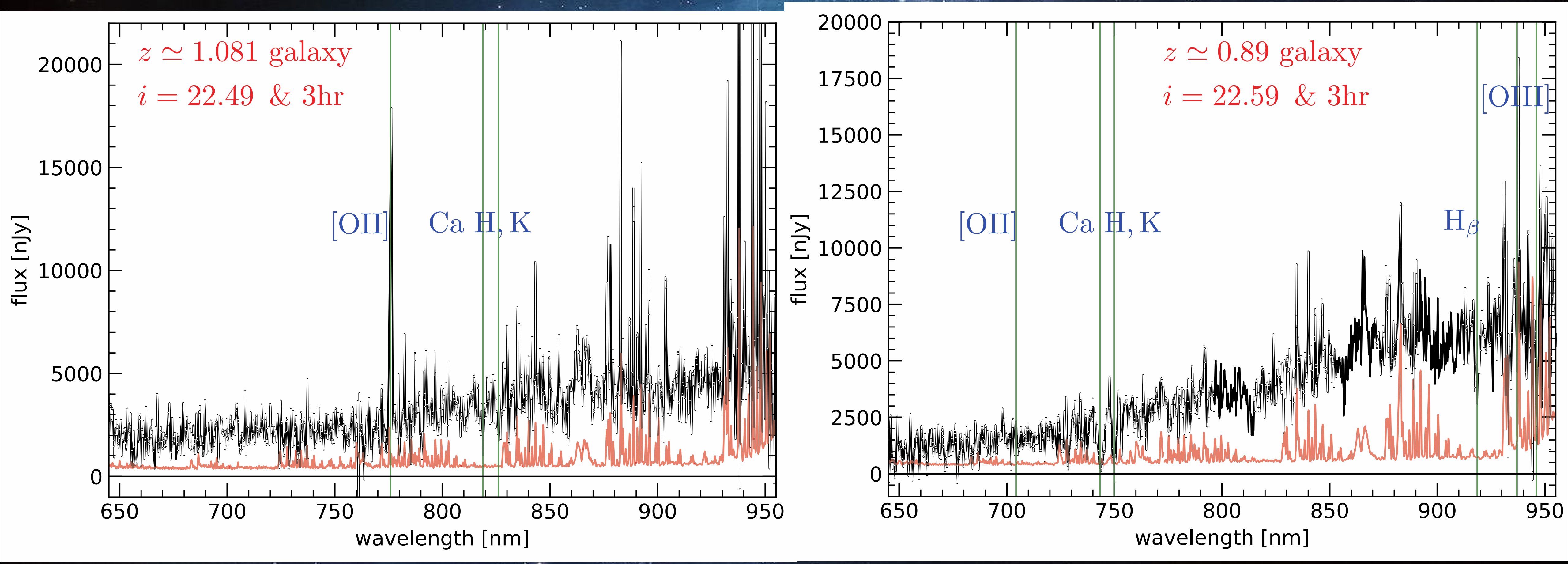


Thin line: Individual measurement

Thick line: Average on each SM



Examples of co-added faint galaxy spectra after 3-hour integration



(By courtesy of Lupton+)

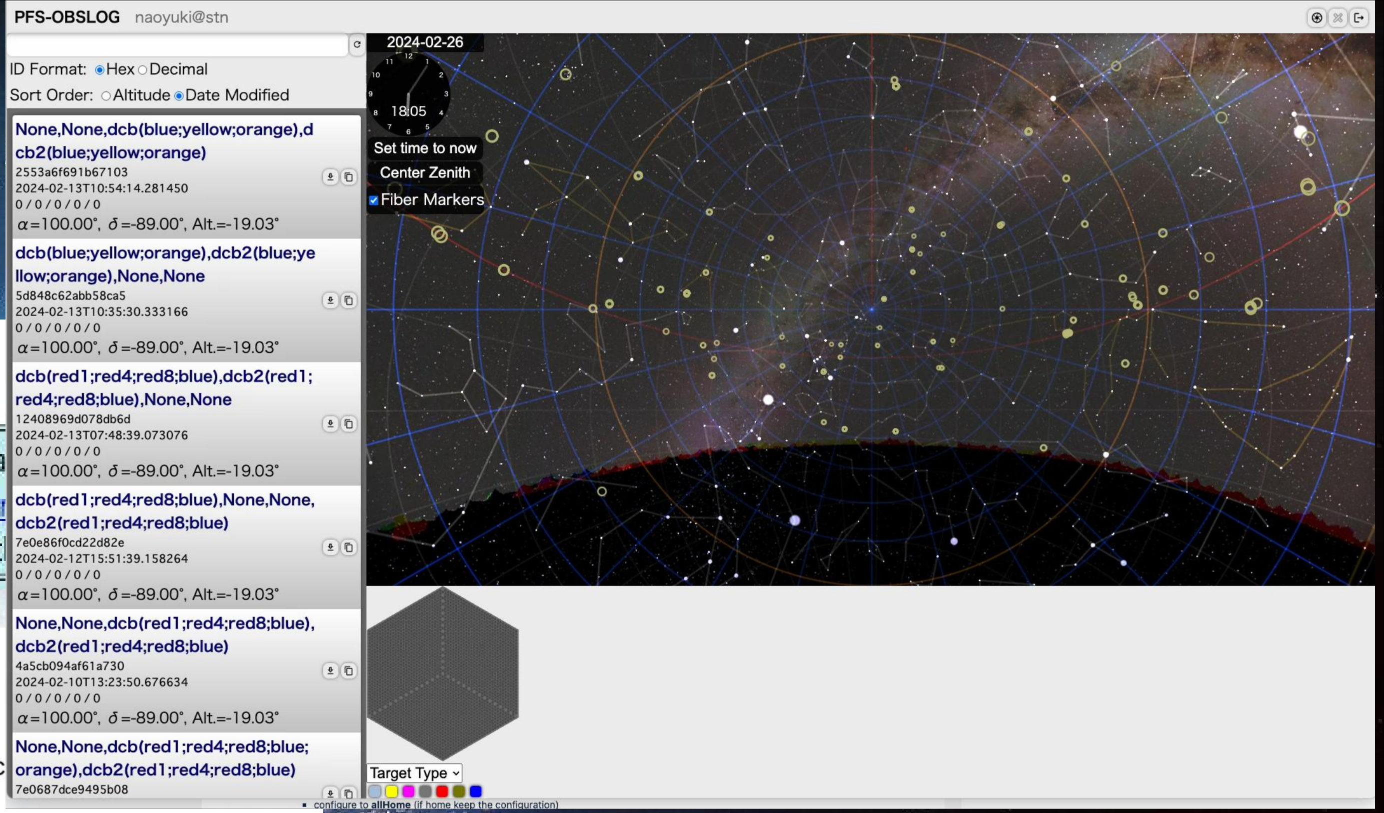
Call for Proposals

Semester S25A: February 1, 2025 -- July 31, 2025

Subaru Telescope, National Astronomical Observatory of Japan

Important Notice for S25A

Notice for PFS Observation	The Prime Focus Spectrogra We note that the PFS SSP pr applicants, please describe t



Instruments

Subaru Telescope has a suite of eight facility instruments providing imaging and spectroscopic c
from optical to mid-infrared.

- AO - Subaru Adaptive Optics system
  - AO188 - Subaru 188-elements Adaptive Optics system - delivers diffraction-limited images in the near-infrared comb curvature wavefront sensor (CWFS).
  - AO3K - Subaru 3,228-elements Adaptive Optics system - delivers diffraction-limited images combined with near infra sensor (NIR-WFS).
- FOCAS - Faint Object Camera And Spectrograph - provides optical imaging and longslit and multi-slit spectroscopy ove view.
- HDS - High Dispersion Spectrograph - provides extremely high-resolution optical spectroscopy.
- HSC - Hyper Suprime-Cam - provides optical imaging over a very large field of view (1.5 degree diameter) with a mosaic
- IRCS - Infrared Camera and Spectrograph - provides high-angular resolution imaging combined with AO188, low-resolut resolution echelle spectroscopies over 0.9-5.6 microns.
- MOIRCS - Multi-Object Infrared Camera and Spectrograph - provides imaging and low-resolution spectroscopy from 0.9 4 arcmin x 7 arcmin field of view.
- PFS - Prime Focus Spectrograph - allows simultaneous observations of approximately 2,400 targets using multiple fiber of about 1.25 square degrees and covers a broad wavelength range from 0.38 to 1.26 microns with a single exposure.

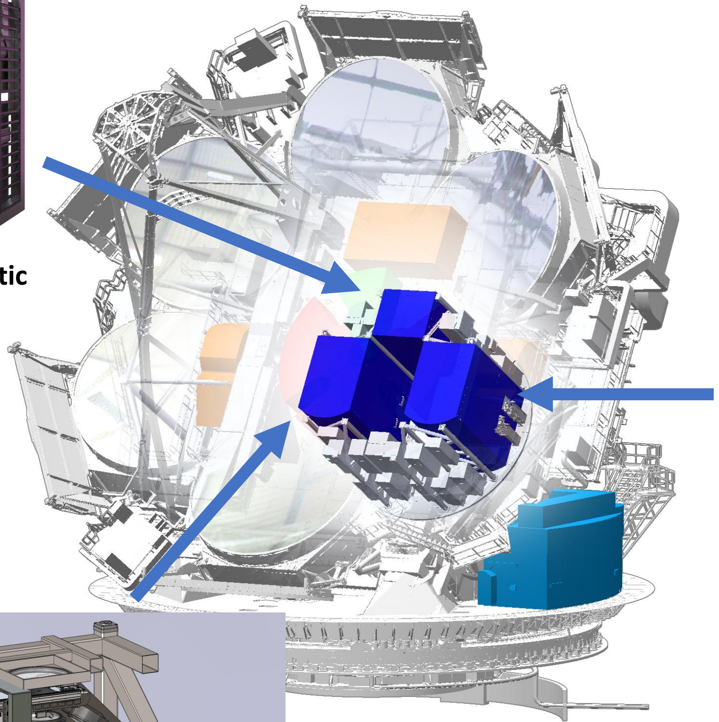
Queue mode operation by default where targets from multiple observing programs (including fillers) share a single focal plane to make the best use of the wide field and high multiplicity.

GMT First Generation

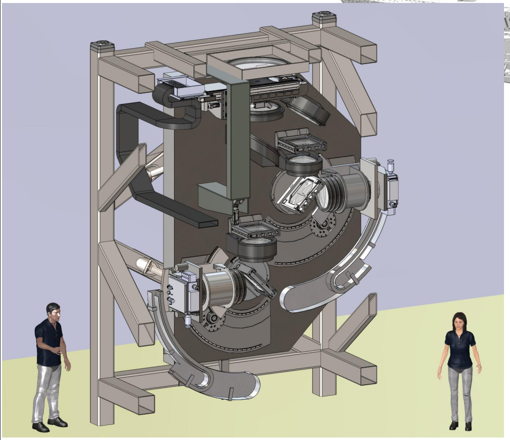
GIANT MAGELLAN TELESCOPE

Direct Gregorian

Wide-field Robotic Fiber Pos (MANIFEST)

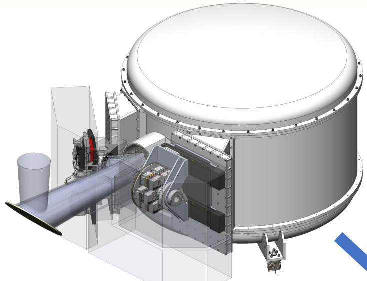


Large Imaging (ComCam)

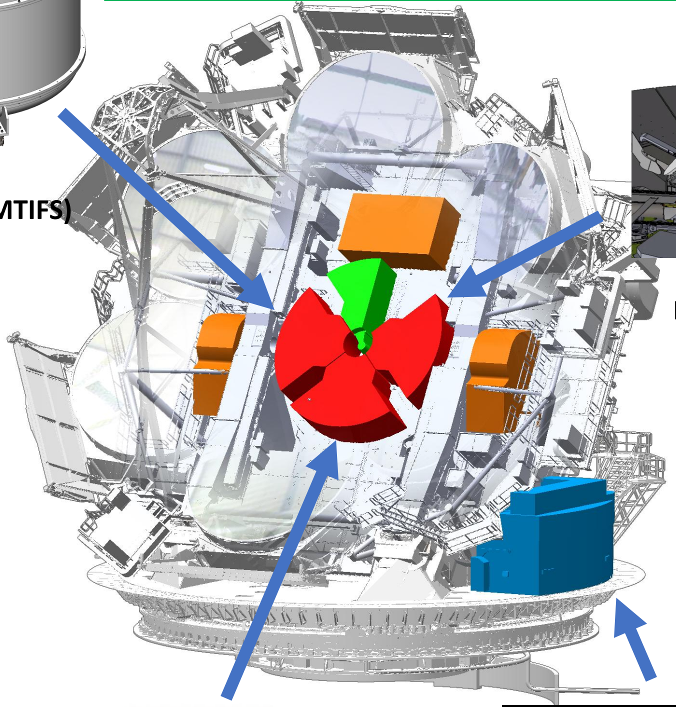


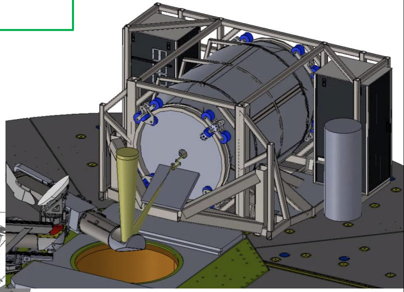
Wide-field Vis MOS (GMACS)

Folded Ports and Gravity Invariant

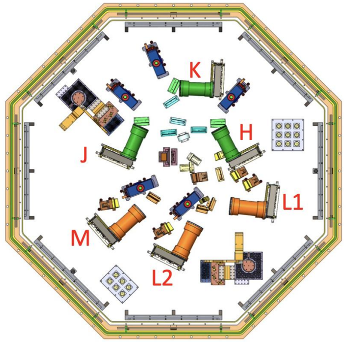


AO-fed NIR Spec/IFS (GMTIFS)

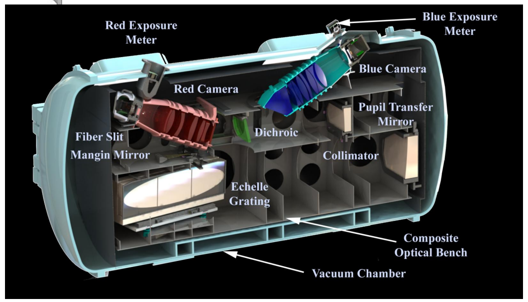




Ex-AO Vis/NIR (GMagAO-X)



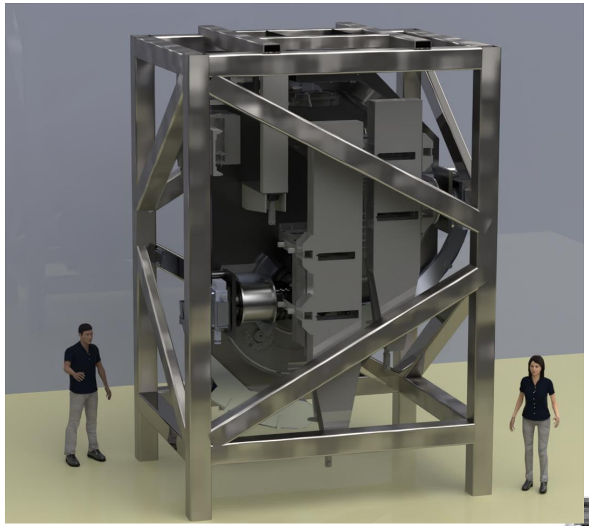
AO-fed High-Res NIR Spec (GMTNIRS)

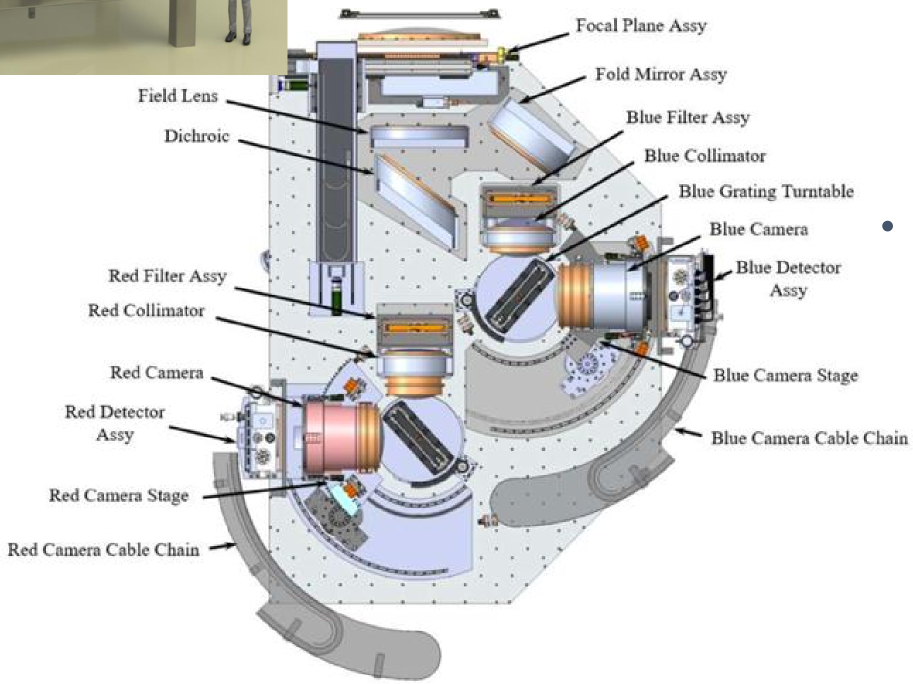


Hi-Res Vis Spec (G-CLEF)

GMACS (GMT Multi-object Astronomical and Cosmological Spectrograph)

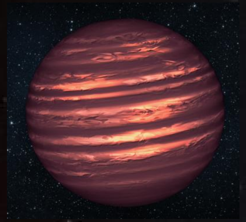
GIANT MAGELLAN TELESCOPE

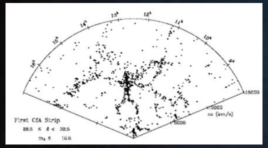
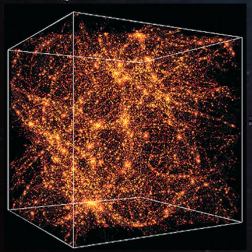




- Collaboration: SAO/CfA, Institute Steiner (Sao Paulo)
  - P.I.: Dan Fabricant, SAO.
- Phase: Final Design.
- Description:
  - Wide-field (7 (sp) x 6 (disp) arcmin), high throughput, medium spectral resolution (R 1,000 to 6,000), multi-object spectrograph operating from 330 nm to 1000 nm.
  - Natural Seeing + GLAO modes.
- Highlights:
  - PDR: February 2024.
  - Major changes since conceptual design:
    - Improved structure (to meet flexure reqs).
    - Higher throughput into the UV.
    - Cryocoolers instead of LN2.
    - ADC with excellent UV transmission to 330 nm.

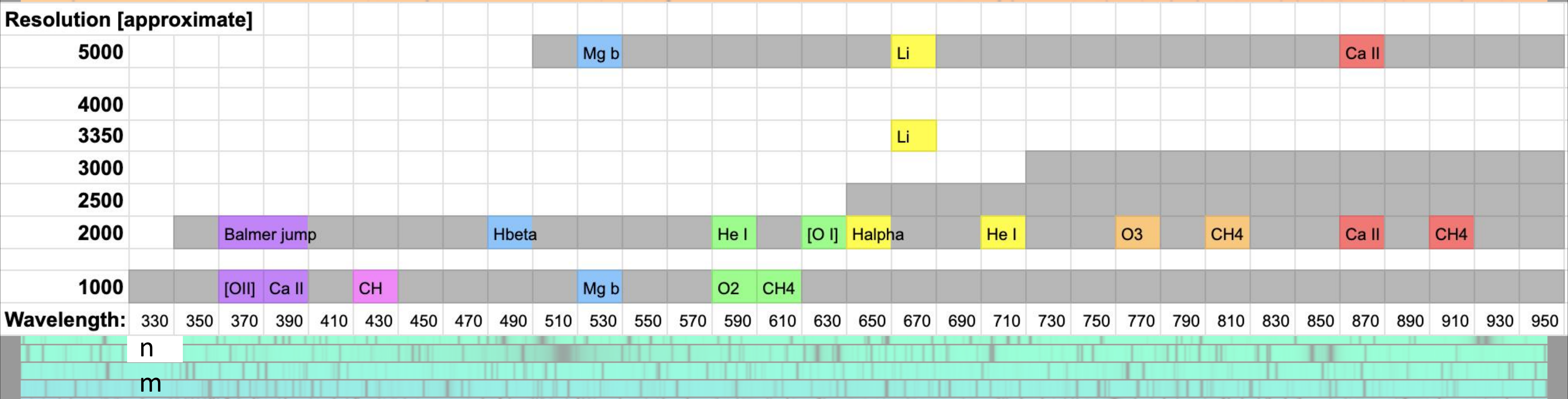
GMACS Science Drivers

Science Case	constraints
Time-domain science	High rel. precision/repeatability/efficiency; large simultaneous wavelength coverage
Brown dwarf/exoplanet atmospheres (weather)	5’ FOV, blueward of JWST wavelength coverage. High stability for transit spectroscopy.
Star/Star Cluster ages	<2 Å resolution at Li 6708Å for age measurements; blue coverage (Ca HK)
YSO accretion rates	simultaneous coverage of Balmer lines/break (365-656 nm)
Dwarf Galaxy dynamics	Coverage of CaT (850 nm, R~5000); ~1 km/s velocity precision, high stability. 20’ FOV preferable
Stellar Abundances	R~5000, blue/red wavelength coverage (370-540 nm; CaT 850 nm)
Redshift surveys (LSST follow-up)	High multiplexing, slitlength requirement: source density will be ~50-60 arcmin^{-2}. FOV as large as possible. Large simultaneous wavelength coverage to maximize efficiency.
Galaxy assembly, IGM/CGM studies	R~3000 and redder wavelength coverage for absorption line studies of z > 1 galaxies.
Properties of Galaxies during Reionization	Very red coverage (>900 nm for Ly-α at z > 6.5), higher resolution and high multiplexing/FOV helpful (~0.5-1 source/arcmin^2)

GMACS Gratings: Link to Science



GMACS

GMT's first-light multi-object optical spectrograph

Wavelength coverage 330 to 1000nm in two channels (330-630nm) and (630-1000nm)

Resolution R~1000 to R~5000 with 0.7" slit width

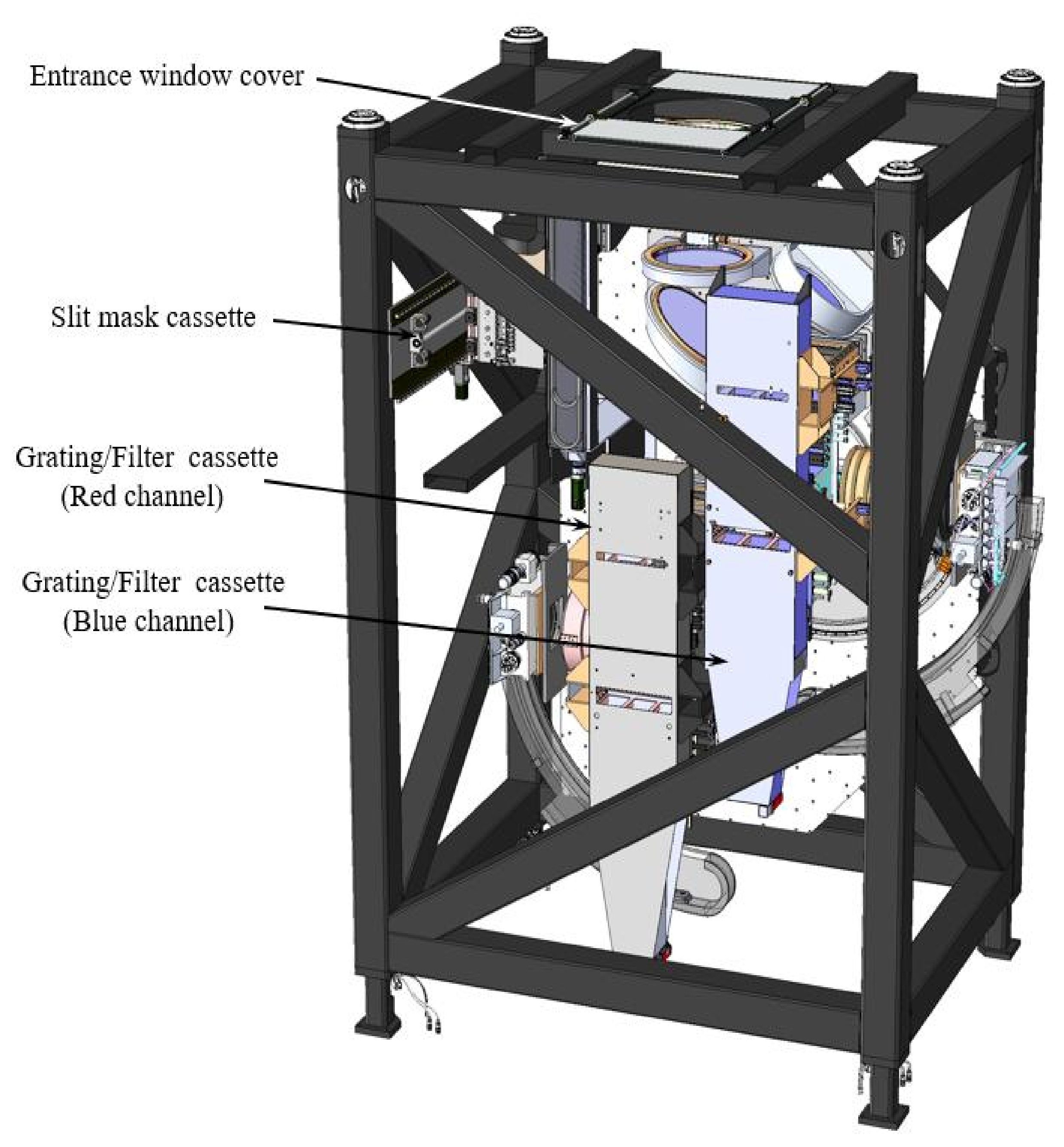
Field of view is 7´ in the spatial axis, up to 6´ in the dispersion axis

GMACS operates with a wide field corrector/ADC to minimize slit losses due to atmospheric dispersion and to allow long observations of a selected field.

GMACS accommodates 17 on-board laser-cut slit masks for object selection

GMACS also operates with MANIFEST, GMT's configurable fiber optic adapter. MANIFEST accesses a 14' field of view and offers up to R~10000 with mini IFUs.

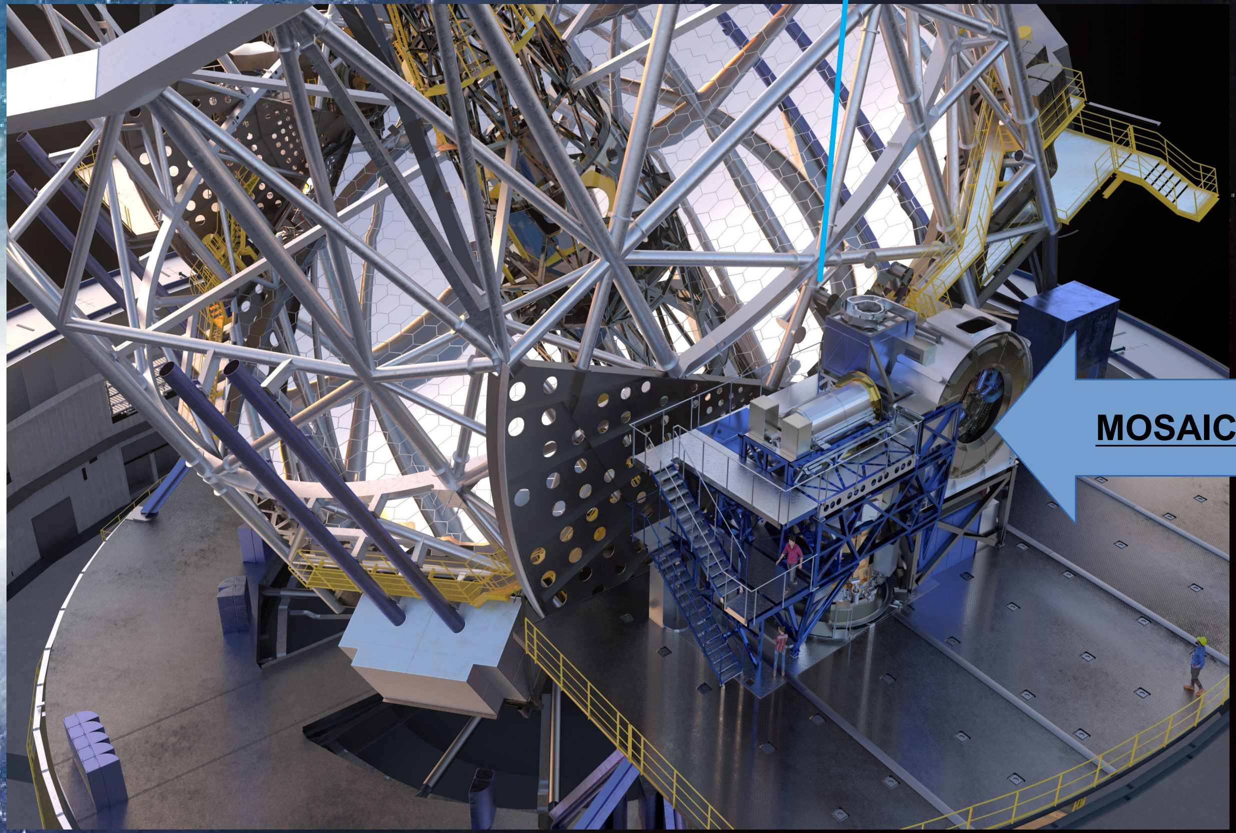
Plate scale is ~1mm/" at the slit mask and ~0.29mm/" at the detector



MOSAIC

- **MOSAIC** - the ELT Nasmyth **Multi-Object Spectrograph**

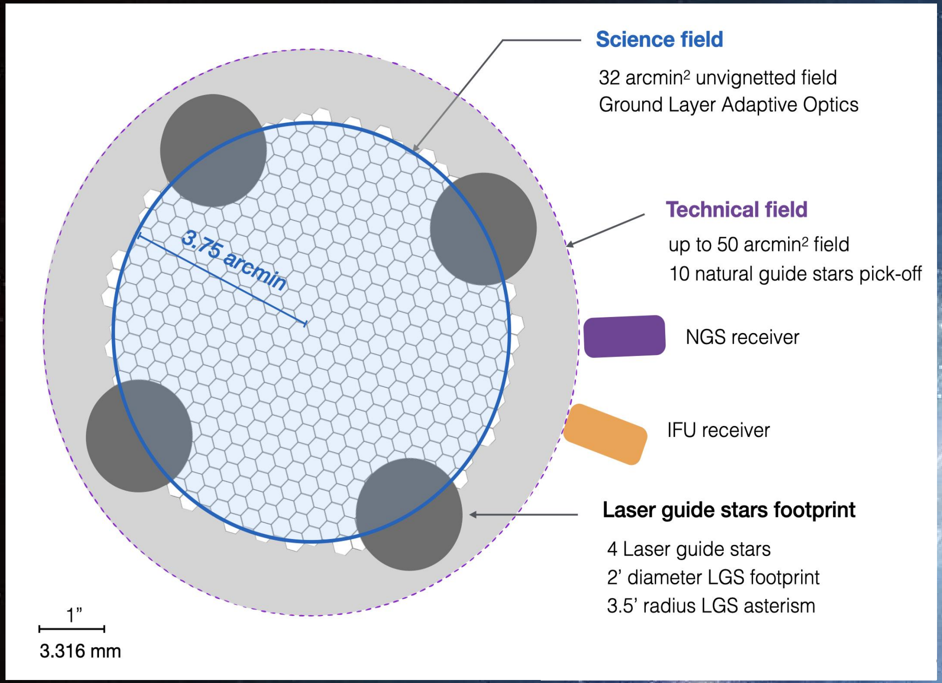
- *Wavelength coverage: 0.39 to 1.8 microns*
- *MOSAIC will use the* ***widest possible FoV provided by the ELT : ~40 arcmin²***
- *Two observing modes:* ***MOS & mIFU***
- ***Resolution - VIS 4k***
  - ***IR 4k 18k***



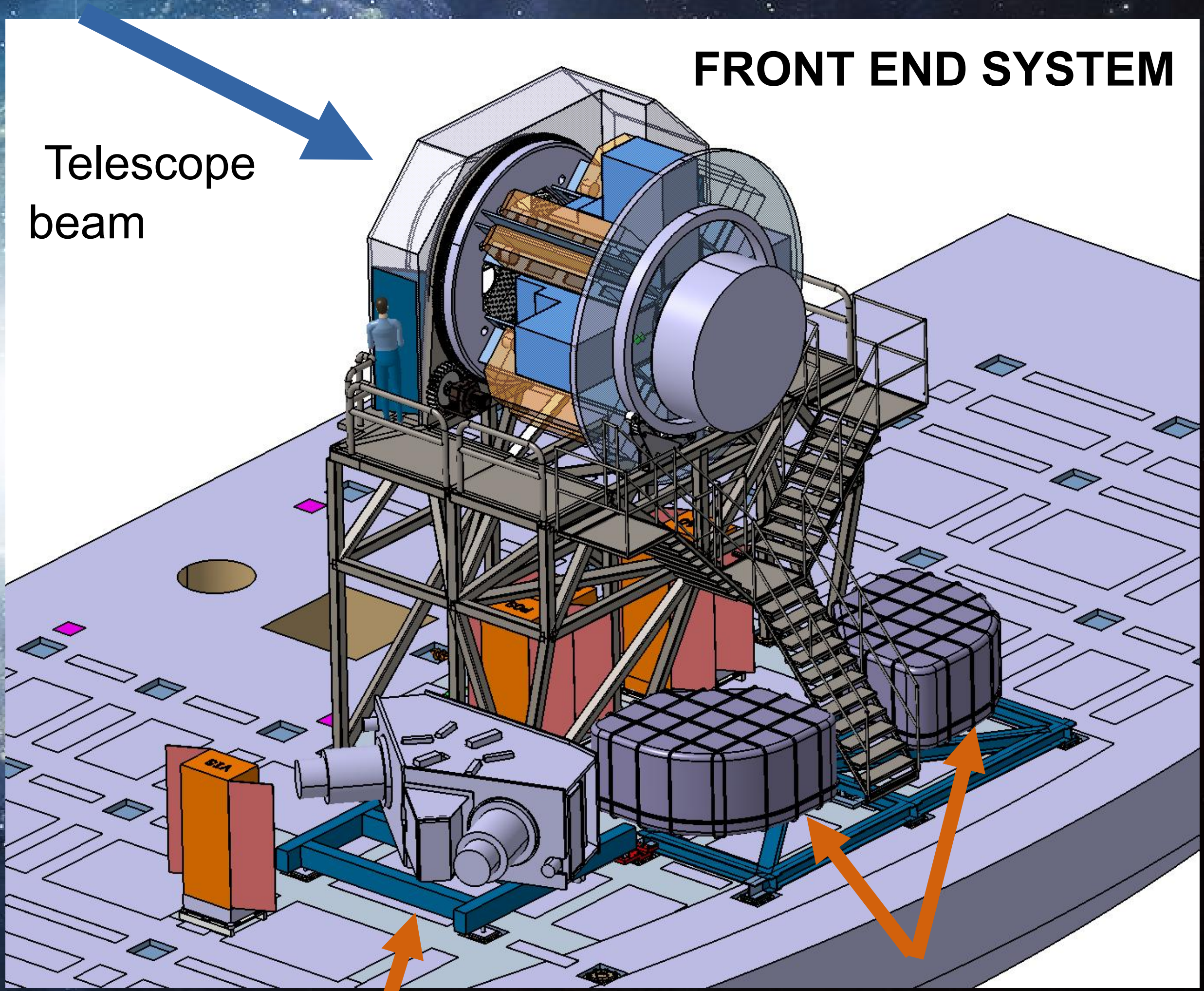
Nasmyth A

Nasmyth platforms (30mx15m). This is where the large instruments are located

MOSAIC concept



All MOSAIC modes will be assisted by **Ground-Layer Adaptive Optics** using both Natural and Laser Guide Stars.



TWO-ARMS VIS SPECTROGRAPH

TWO NIR SPECTROGRAPHS

Observing modes & Bandwidth coverage

- MOSAIC covers the full bandwidth from 0.39 to 1.8 microns
- VIS and NIR bandwidth are covered in a single exposure independently (not the same objects in VIS or NIR)
- 4 HR bands in VIS (can observe simultaneously two of them) and an HR in the H-band in NIR

MODE	N	λ(min) nm	λ(max) nm	R(mid)	R(min)	Sampling pixels	m_{AB}
MOS VIS-LR	140	390	950	5000	4000	>3.57	26.0
MOS NIR-LR	180	950	1800	R>4000 (goal 5000)	>4000	>2.5	26.0-25.4
mIFU-LR	8	950	1800	R>4000 (goal 5000)	>4000	>2.5	25.0
MOS VIS-HR B1		390	455				23.5
MOS VIS-HR B2	65	510	595	19000	<18000	2.61	24.7
MOS VIS-HR R1		610	712		in few SRE		24.2
MOS VIS-HR R2		800	934				24.4
MOS NIR-HR	180	1523	1620	R>18000 (goal 23000)	18000	>2.5	23.8
mIFU-HR	8	1523	1620	R>18000 (goal 23000)	18000	>2.5	23.4

MOSAIC SC4/5 – Stellar Populations & Galaxy Archaeology

Multi-IFUs

High multiplex visible

High multiplex Near-IR

Exploring the **star-formation and chemical-enrichment histories beyond the Local Group**.

Higher sensitivity (>8-10m class) - **probe further down in the color-magnitude diagram**, and to explore larger distances. In particular, MOSAIC will permit the measurement of physical parameters for dwarf stars where current observations are limited to giant stars.

Diagnostics based on several features: CaT, Mg Ib triplet, G band. Low R~5000 could be accepted, with high SNR>~20

The R~18000 of MOSAIC is enough to resolve the interesting species, in specific wavelength windows. Precision in **abundance measurements**.

MOSAIC Project Status

Phase B1 Kick-Off Meeting 14-15/03/23

Signature of B1 Phase Agreement (8/08/23)

Progress Meeting 7 Nov 2024

Specifications and Architecture Review (SAR) & B2 starts: JAN25

PDR: end 2025; **Preliminary acceptance in Europe (PAE): 2032**

First light: Depending on first-light instruments

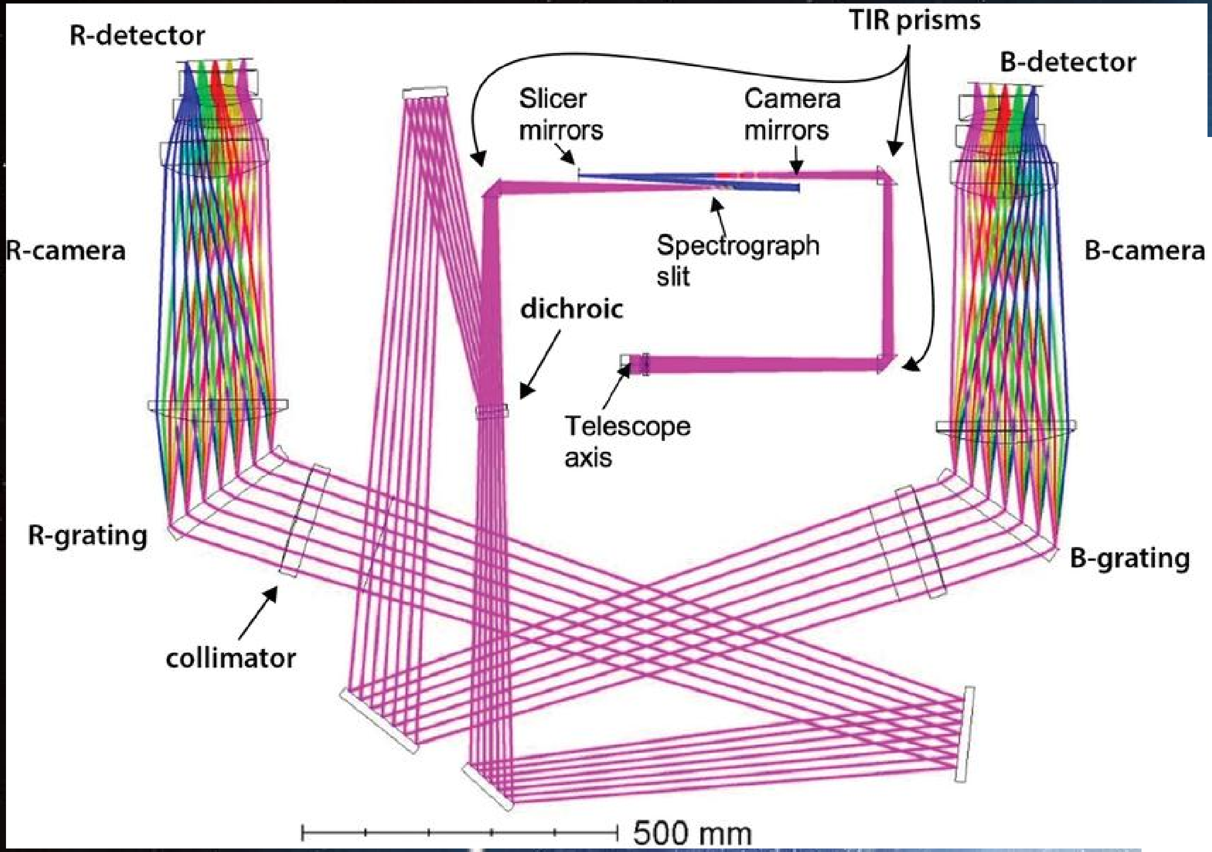
MOSAIC Consortium

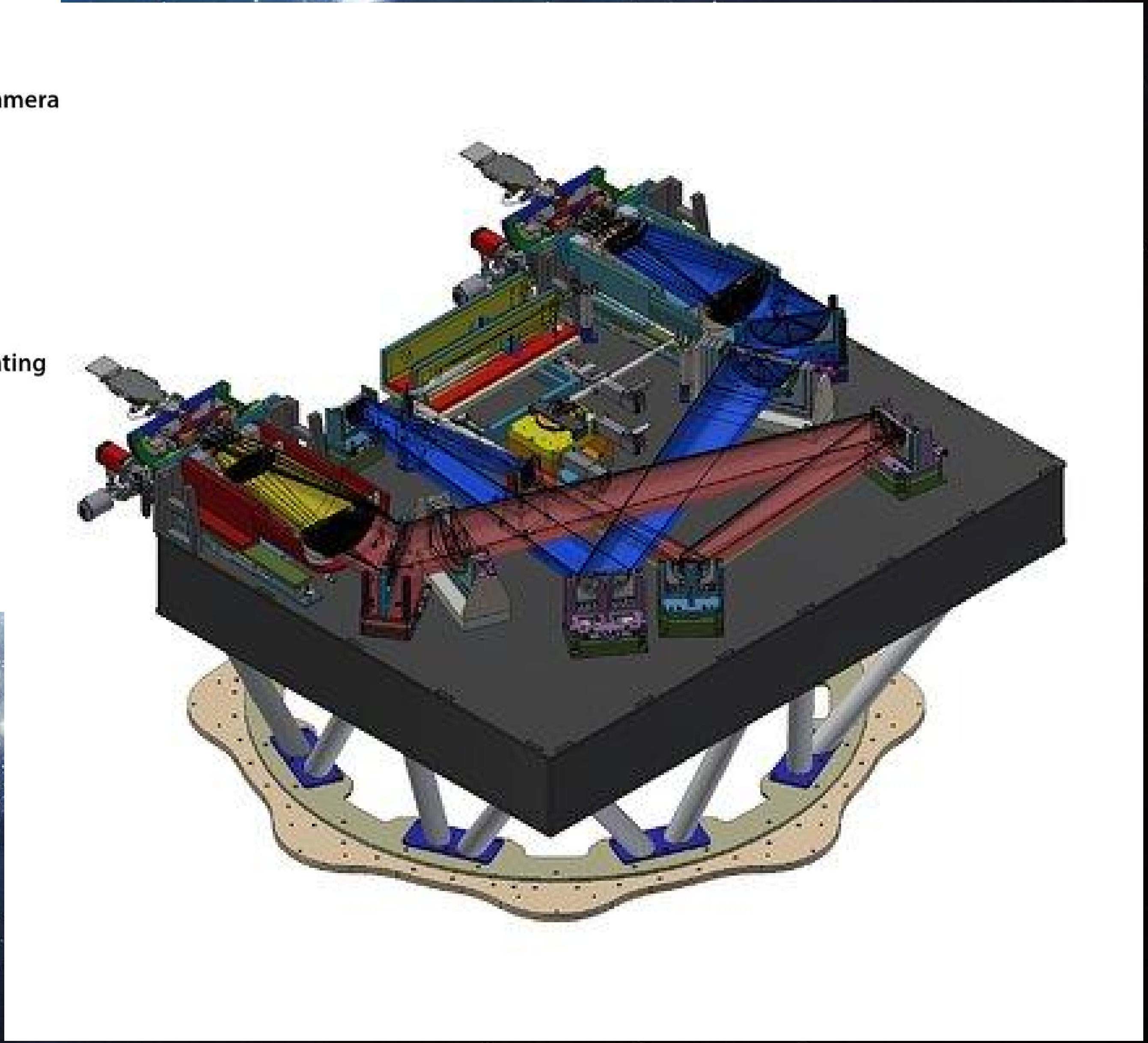
- 24 Institutional Partners
- 31 Laboratories
- 13 countries
- ~350 members

CUBES

- Cassegrain U-Band Efficient Spectrograph
- With a significant gain in sensitivity and spectral resolution in the ground UV will provide a unique capability for years to come.
- Stellar nucleosynthesis, in particular:
  - Beryllium
  - Iron-peak elements
  - Heavy elements
  - CNO abundances

300 - 400nm
single object
5k and 20k
slit fed
cassegrain


R-detector
TIR prisms
B-detector
Slicer mirrors
Camera mirrors
R-camera
Spectrograph slit
B-camera
dichroic
Telescope axis
R-grating
B-grating
collimator
500 mm



- The CUBES team:
  - Matteo Genoni, Hans Dekker, Stefano Covino, Roberto Cirami, Marcello A. Scalera, Lawrence Bissel, Walter Seifert, Ariadna Calcines, Gerardo Avila, Julian Stürmer, Christopher Ritz, David Lunney, Chris Miller, Stephen Watson, Chris Waring, Bruno V. Castilho, Marcio V. De Arruda, Orlando Verducci, Igor Coretti, Luca Oggioni, Giorgio Pariani, Edoardo A. M. Redaelli, Matteo D’ Ambrogio, Giorgio Calderone, Matteo Porru, Ingo Stilz, Rodolfo Smiljanic, Guido Cupani, Mariagrazia Franchini, Andrea Scaudo, Vincent Geers, Vincenzo De Caprio, Domenico D' Auria, Mina Sibalic, Cyrielle Opitom, Gabriele Cescutti, Valentina D’ Odorico, Ruben Sanchez-Janssen, Andreas Quirrenbach, Beatriz Barbuy, Stefano Cristiani, Paolo Di Marcantonio
- Congratulates Beatriz for her scientific achievemenst and is glad to have her as one of the CUBES leaders

- The CUBES team:
  - Matteo Genoni, Hans Dekker, Stefano Covino, Roberto Cirami, Marcello A. Scalera, Lawrence Bissel, Walter Seifert, Ariadna Calcines, Gerardo Avila, Julian Stürmer, Christopher Ritz, David Lunney, Chris Miller, Stephen Watson, Chris Waring, Bruno V. Castilho, Marcio V. De Arruda, Orlando Verducci, Igor Coretti, Luca Oggioni, Giorgio Pariani, Edoardo A. M. Redaelli, Matteo D' Ambrogio, Giorgio Calderone, Matteo Porru, Ingo Stilz, Rodolfo Smiljanic, Guido Cupani, Mariagrazia Franchini, Andrea Scaudo, Vincent Geers, Vincenzo De Caprio, Domenico D' Auria, Mina Sibalic, Cyrielle Opitom, Gabriele Cescutti, Valentina D' Odorico, Ruben Sanchez-Janssen, Andreas Quirrenbach, Beatriz Barbuy, Stefano Cristiani, Paolo Di Marcantonio
- Congratulates Beatriz f… st and is glad to…

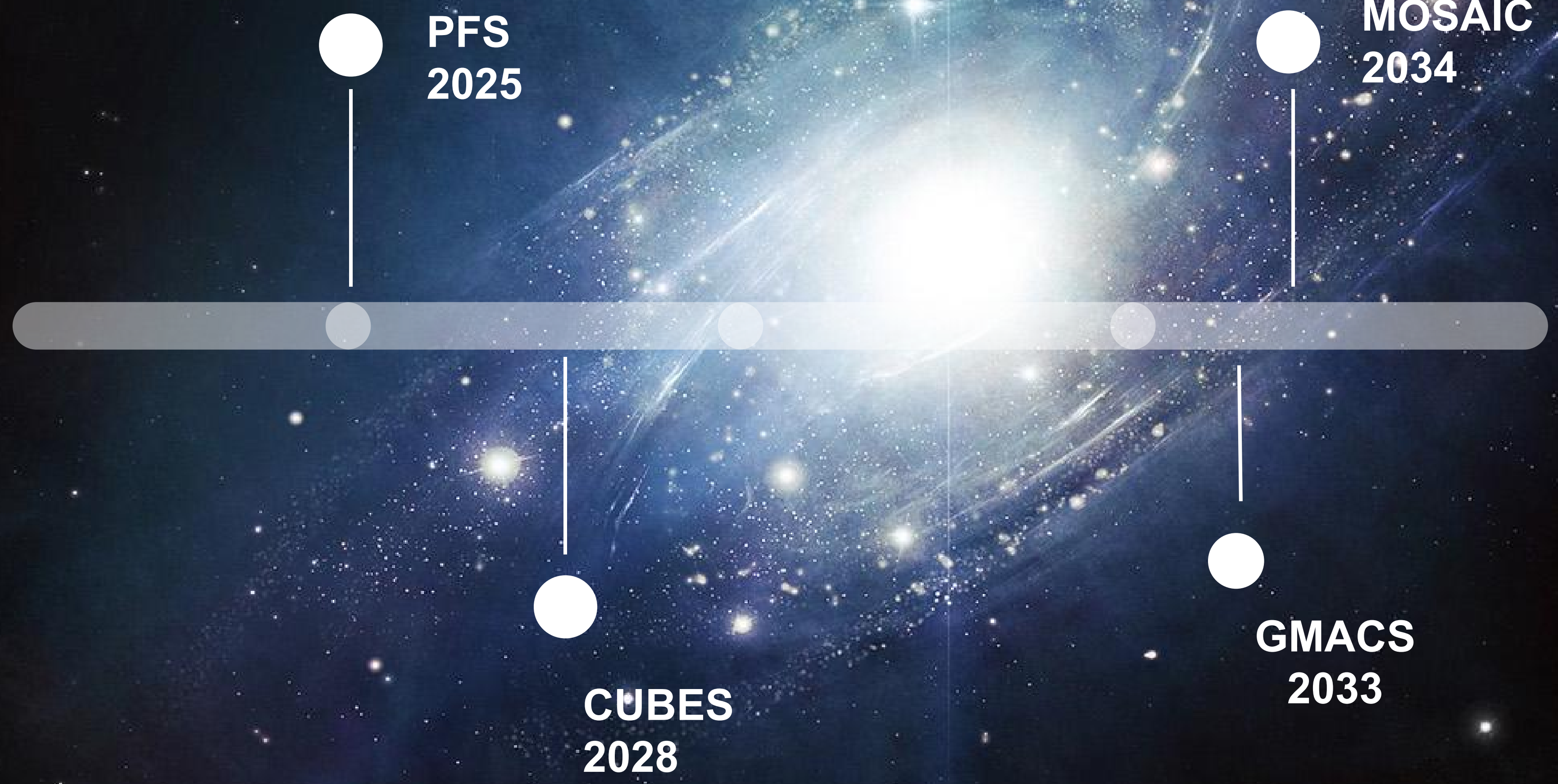
"It's remarkable that I'm writing this message for Beatriz from La Silla, the enchanted place where we first met - a memory that remains indelibly impressed in my mind. Beatriz had come for observations, and I was on the ESO staff of the mountain.
Since then, our paths have diverged and crossed several times over the decades, ultimately converging on the challenging CUBES project, which would not exist without Beatriz. I feel privileged to have had the opportunity in my life to meet and work with such an extraordinary person, not only a great scientist but also a wonderful individual."

Stefano Cristiani

Instruments Summary

Instrument	Description	Wavelenght Range (µm)	Spectral Resolving Power	Telescope / Modes	Comment	Current Phase
PFS	High multiplex 2400 fibers, prime focus, wide field,	0.31 to 1.26	2,300 - 4,300	SUBARU	Prime focus, campain mode	Comissioning
GMACS	Wide-field, medium spectral resolution, visible light multi-object spectrograph	0.33 to 1.0	1,000 to 6,000	GMT Seeing Limited / GLAO	Higher throughput into the UV, multi slit, vph gratings	Final Design
MOSAIC	Wide-field, medium resolution, VIS NIR multi-object spectrograph	0.39 to 1.6	4,000 (18,000 IR)	ELT GLAO	Multifiber + mini ifu	Design Phase - B1
CUBES	Single object UV mediun resolution	0.3 to 0.4	6,000 - 20,000	VLT Seeing Limited	UV only - single object electron etching grating	Passed Final Design Review

2024 Time line (can and will change)



Thanks !

LNA LABORATÓRIO NACIONAL DE ASTROFÍSICA