A Spectrograph Proposal for MORFEO@ELT

Paolo Saracco

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&

the SHARP Team

Layout

- Overview: ELT instruments
- What is SHARP (in brief)
- Why SHARP at ELT
- SHARP Properties, Optical Design, Capabilities
- Project Status

Overview: ELT instruments

		Instrument	Main specifications			Schedule				
			Field of view/slit length/ pixel scale	Spectral resolution	Wavelength coverage (μm)	Phase A	Project start	PDR	FDR	First light
1st Generation										
Not fiber fed	SCAO + MCAO	MICADO	Imager (with coronagraph) 50.5″ × 50.5″ at 4 mas/pix 19″ × 19″ at 1.5 mas/pix	*I, Z, Y, J, H, K* + narrowbands	0.8–2.45	2010	2015	2019		
			Single slit	*R* ~ 20 000						
	MCAO	MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015	2023		
	SCAO	HARMONI + LTAO	IFU 4 spaxel scales from: 0.8″ × 0.6″ at 4 mas/pix to 6.1″ × 9.1″ at 30 × 60 mas/pix (with coronagraph)	*R* ~ 3 200 *R* ~ 7 100 *R* ~ 17 000	0.47–2.45	2010	2015	2018		
	SCAO	METIS	Imager (with coronagraph) 10.5″ × 10.5″ at 5 mas/pix in *L*, *M* 13.5″ × 13.5″ at 7 mas/pix in *N*	*L, M, N* + narrowbands	3–13	2010	2015	2019		
			Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*						
			IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100 000						
2nd Generation										
Fiber fed	GLAO/SCAO	ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018				
			IFU (SCAO)							
			Multi object (TBC)	*R* ~ 10 000						
	GLAO	MOSAIC	~ 7-arcminute FoV ~ 200 objects (TBC)	*R* ~ 5 000–20 000	0.45–1.8 (TBC)	2018				
			~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)					
		PCS	Extreme AO camera and spectrograph	TBC	TBC					

Diff. limited PSF

$FWHM_{dl}$=1.22 λ/D

At λ=2.2 mu

$FWHM_{ELT}$ = 0.012”

$FWHM_{JWST}$ = 0.070”

SCAO: **0.012” on-axis**, Strehl ratio >0.8, **1 Natural Guide Star (NGS)<16** mag within 15”

MCAO: **0.012” uniformly over ~2’x2’**, Strehl ratio ~0.6, **1-3 NGS<21** mag within ~80” + **6 Laser GS**

GLAO: **~0.2” over the field**, (M4+M5 mirrors) seeing limited correction (enhanced seeing mode)

Courtesy of ESO-ELT

What is

(in brief)

SHARP in brief

Not fiber-fed

Near-IR Imager
Long-slit spectroscopy
along parallactic angle

MICADO

1st port

MORFEO
2nd port

Multi-Conjugate Adaptive Optics Module
Provides a **uniform** near-IR AO correction (**FWHM~0.012”**) over a FoV**~1.8’x1.8**’

2nd port

SHARP

NEXUS
MOS

VESPER
mIFU

NEXUS slitlets MOS.
Configurable Slit System

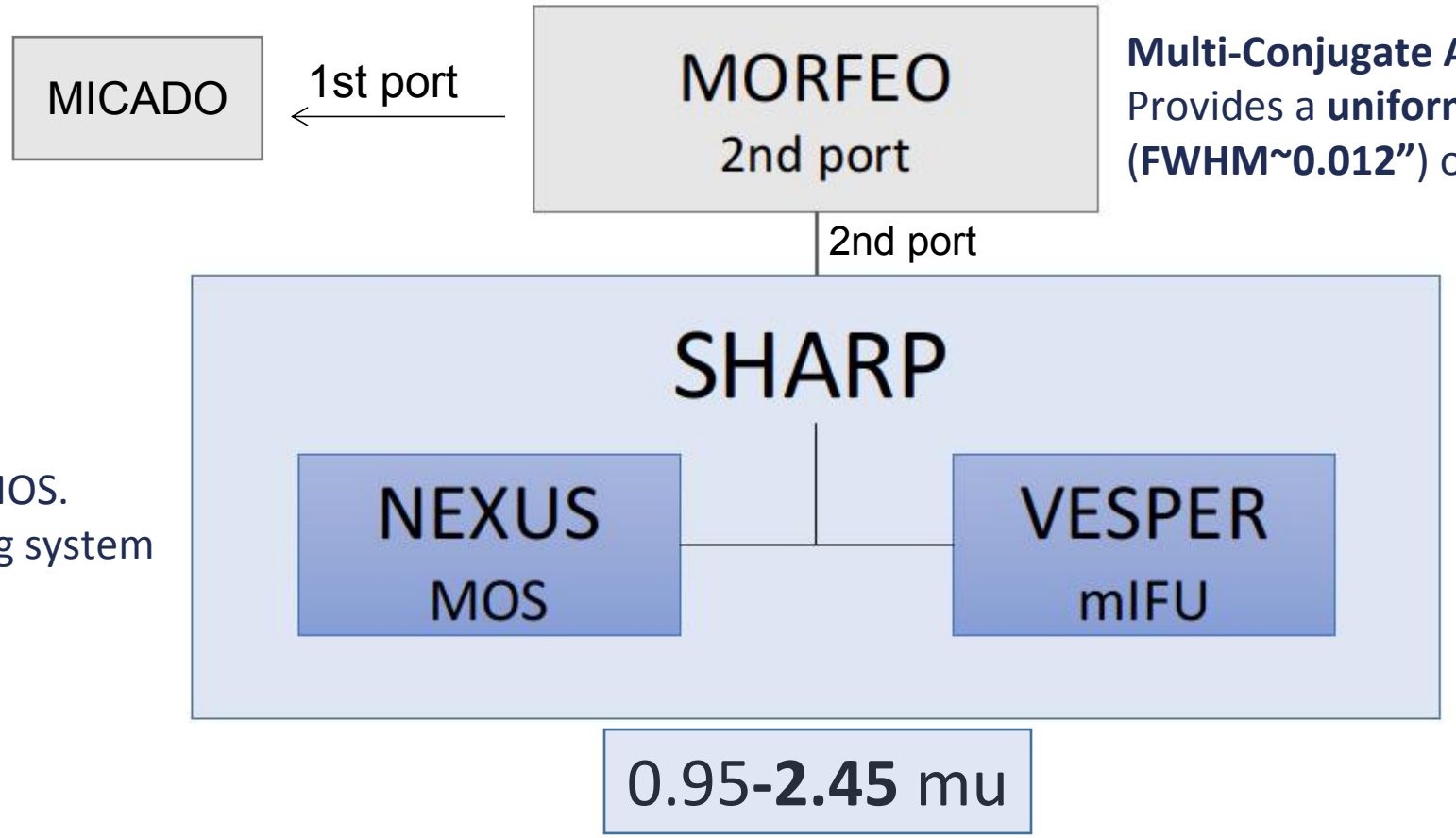
VESPER multi-IFU

0.95-**2.45** mu

SHARP is a Near-IR **multi-mode** spectrograph for a future ESO’s call of new instruments. SHARP is conceived to **fully exploit the ELT aperture,** to reach the **faintest reachable fluxes** at the **sharpest angular resolution** over the **widest AO corrected field**.

Not fiber-fed

Near-IR Imager
Long-slit spectroscopy
along parallactic angle



Multi-Conjugate Adaptive Optics Module
Provides a **uniform** near-IR AO correction (**FWHM~0.012”**) over a FoV**~1.8’x1.8**’

NEXUS slitlets MOS.
Robotic deploing system

VESPER multi-IFU

- **MORFEO** maximally concentrates the photons and corrects uniformly a large FoV;
- **NEXUS** maximally exploits the collecting area and AO reaching the faintest fluxes;
- **VESPER** maximally exploits the angular resolution of ELT over the corrected FoV;

Why

Scientific Rational and Main Requirements

THE DISTANT UNIVERSE

Understanding and reconstructing how baryonic matter assembled at early times to form the first stars, galaxies and structures, how these evolved over cosmic time.

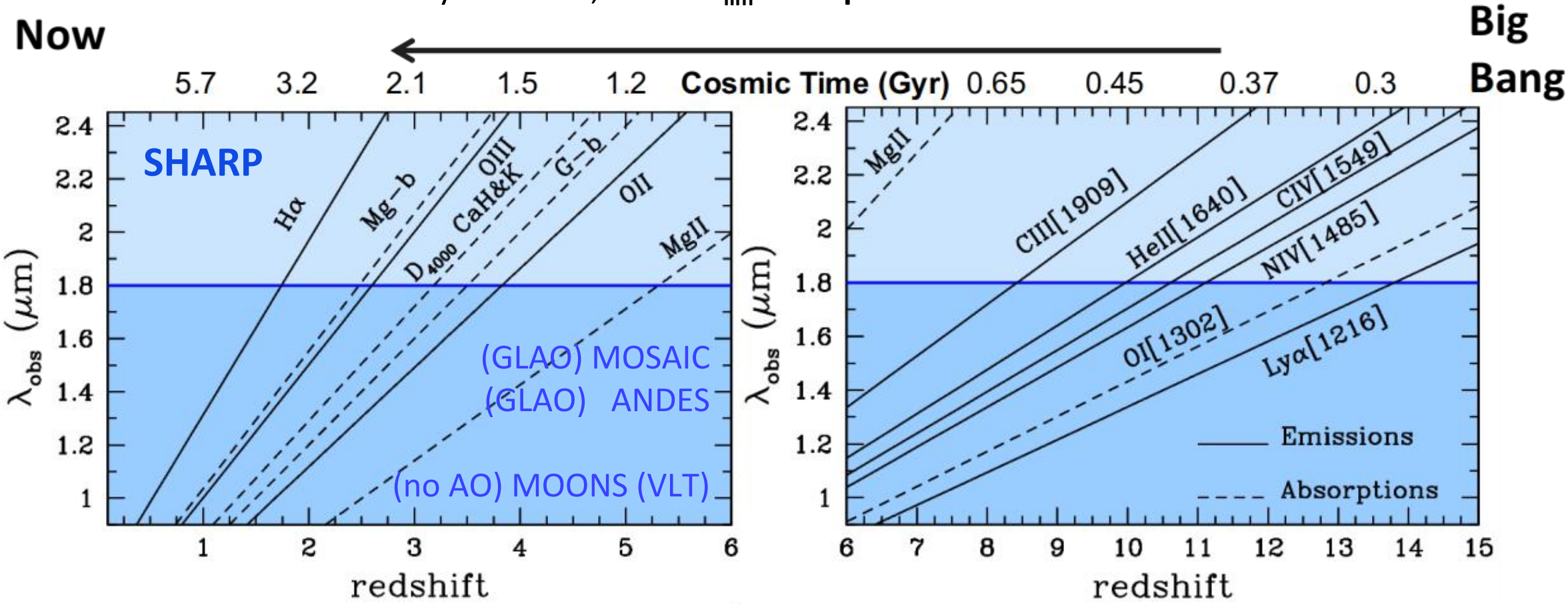
SOME KEY QUESTIONS

- *What are the extreme physical conditions governing star formation in the early Universe ?*
- *What regulates its quenching ?*
- *What is the dark matter content of high-z galaxies ?*
- *What is the physical interplay between black holes and galaxies ?*
- *"Where is" the elusive PopIII of primordial stars ?*
- *……*

MOST OF THE FUNDAMENTAL INFORMATION IS STORED IN THE SPECTRA

Why SHARP - The Distant Universe

1st Requirement - The study of **galaxies at z>2.5-3 and the early Universe requires deep observations in the near-IR** up to the limit where sky transmission is still high and sky emission can be still efficiently removed, i.e. to λ_{lim}**~2.45 µm**.



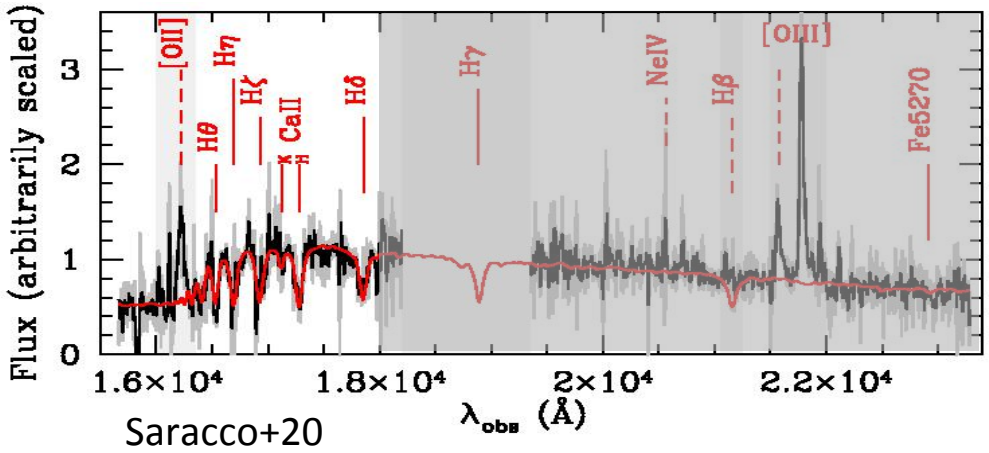
$\lambda_{obs}=\lambda_{rest}(1+z)$

Why SHARP - Why λ_{lim} = 2.45 μm

A CONCRETE EXAMPLE

High-mass galaxies at z>3: an issue for galaxy formation models

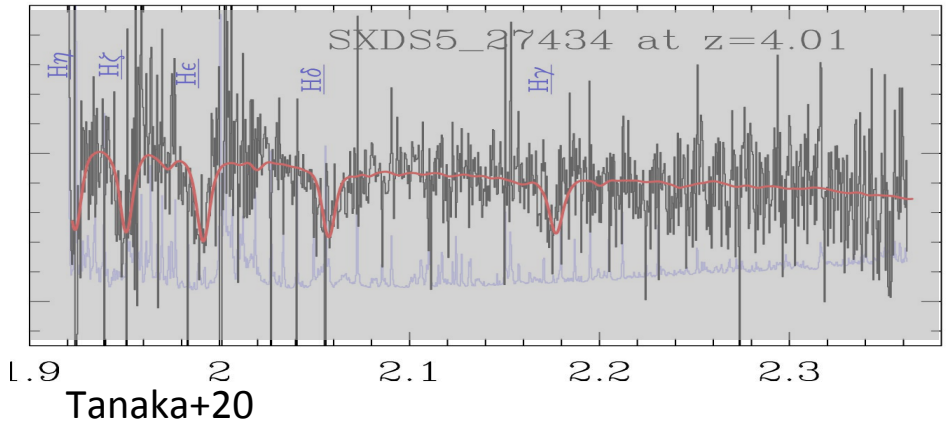
LBT-LUCI



Saracco+20

z=3.35

Keck-MOSFIRE



Tanaka+20

z=4.01

1ST REQUIREMENT

Wavelength range extending to 2.45 µm, the near-IR limit still efficiently reachable from the ground.

Why SHARP - Why λ_{lim} = 2.45 μm

A CONCRETE EXAMPLE

High-mass galaxies at z>3: an issue for galaxy formation models

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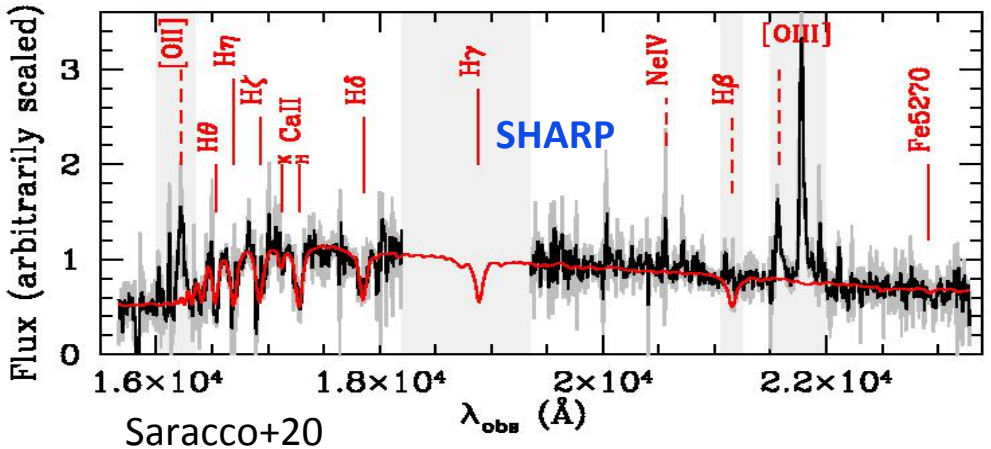

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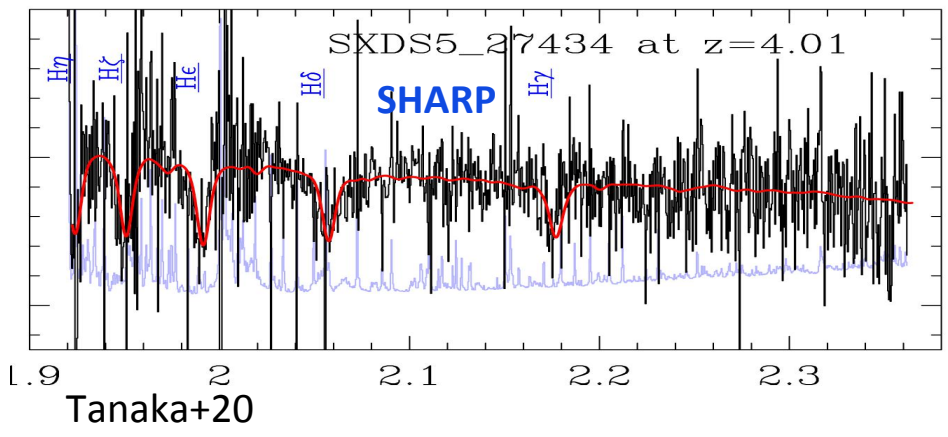


Tanaka+20

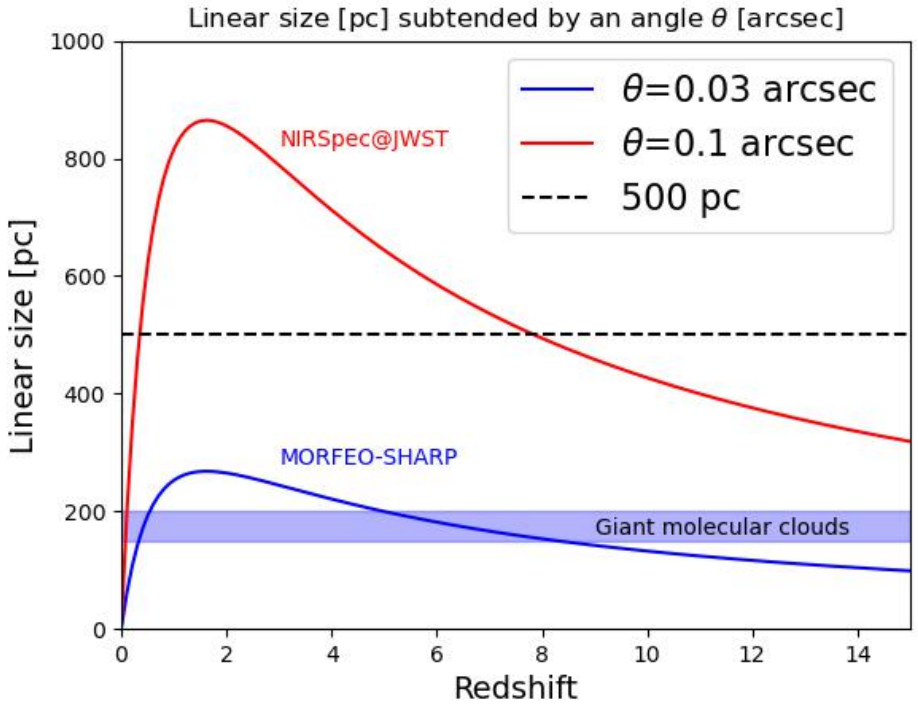
z=4.01

1ST REQUIREMENT

Wavelength range extending to 2.45 µm, the near-IR limit still efficiently reachable from the ground.

Giant molecular gas clouds ~150-200 pc: up to 10^6 $M_\odot$ of molecular gas

- The largest fuel reservoir ==> the place where massive star formation occurs;
- Tracers of metal enrichment within galaxies and galaxy rotation ==> Dark matter



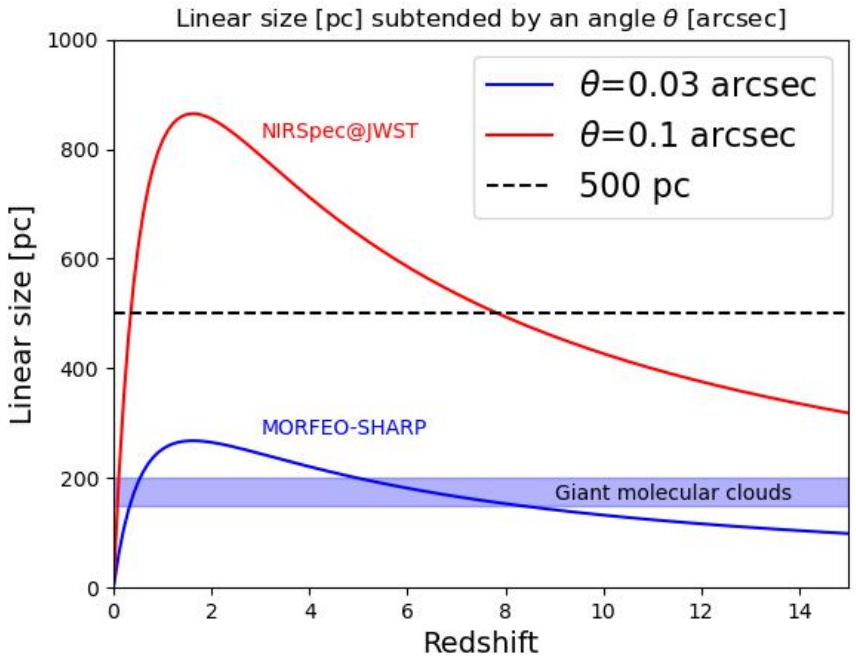
2ND REQUIREMENT

Angular resolution ~0.03” (30 mas): sizes comparable to those of giant molecular clouds are resolved over the entire cosmic time.

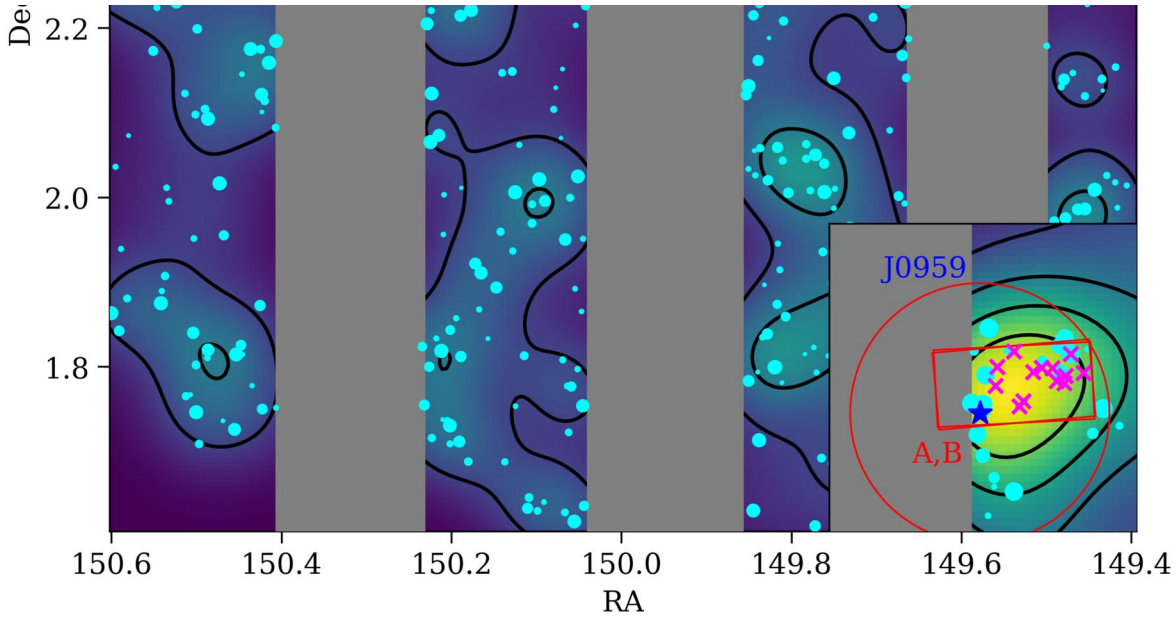
Why SHARP - Why Multiplexing ==> Multi-conjugate AO

Clusters, Protoclusters, Overdensities, Clumps at Early Epochs

- Spatially resolved measurements for several galaxies at once (1/2 Abell Radius ~0.5 Mpc ~ 65” at z~3.5)
- This maximizes also the efficiency of the ELT.



Protocluster z=3.37 *(McConachie et al., 2022)*



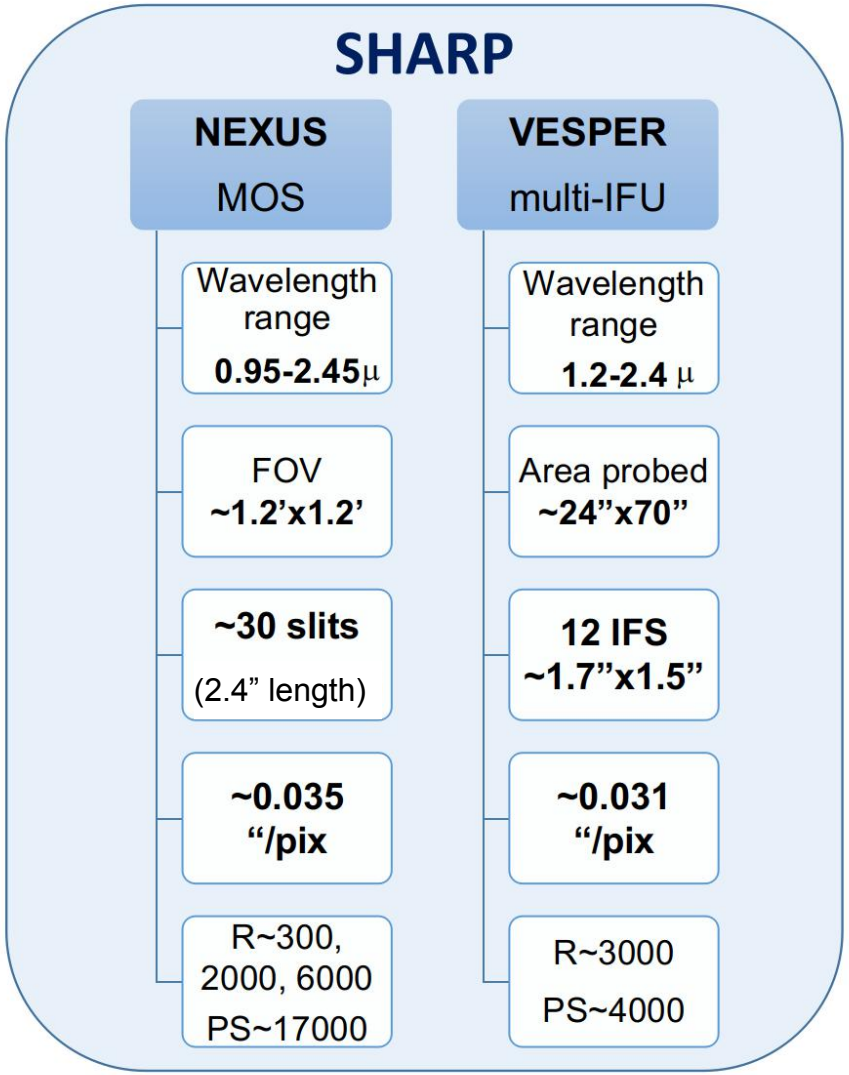
3RD REQUIREMENT

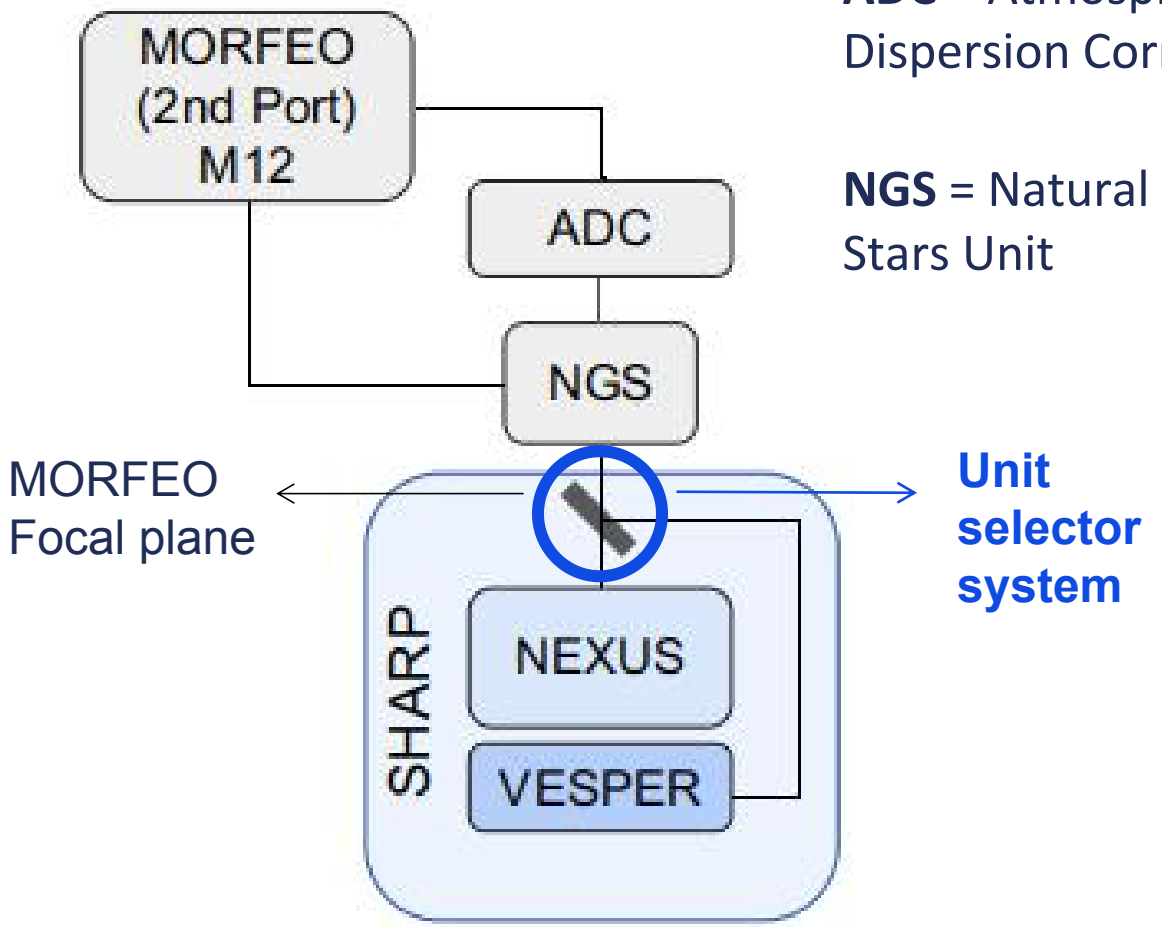
Multiplexing capabilities coupled with a large area uniformly corrected for atmospheric turbulence ==> **Multi-Conjugate AO** ==> **MORFEO**

What is

(in detail)

SHARP in a Nutshell

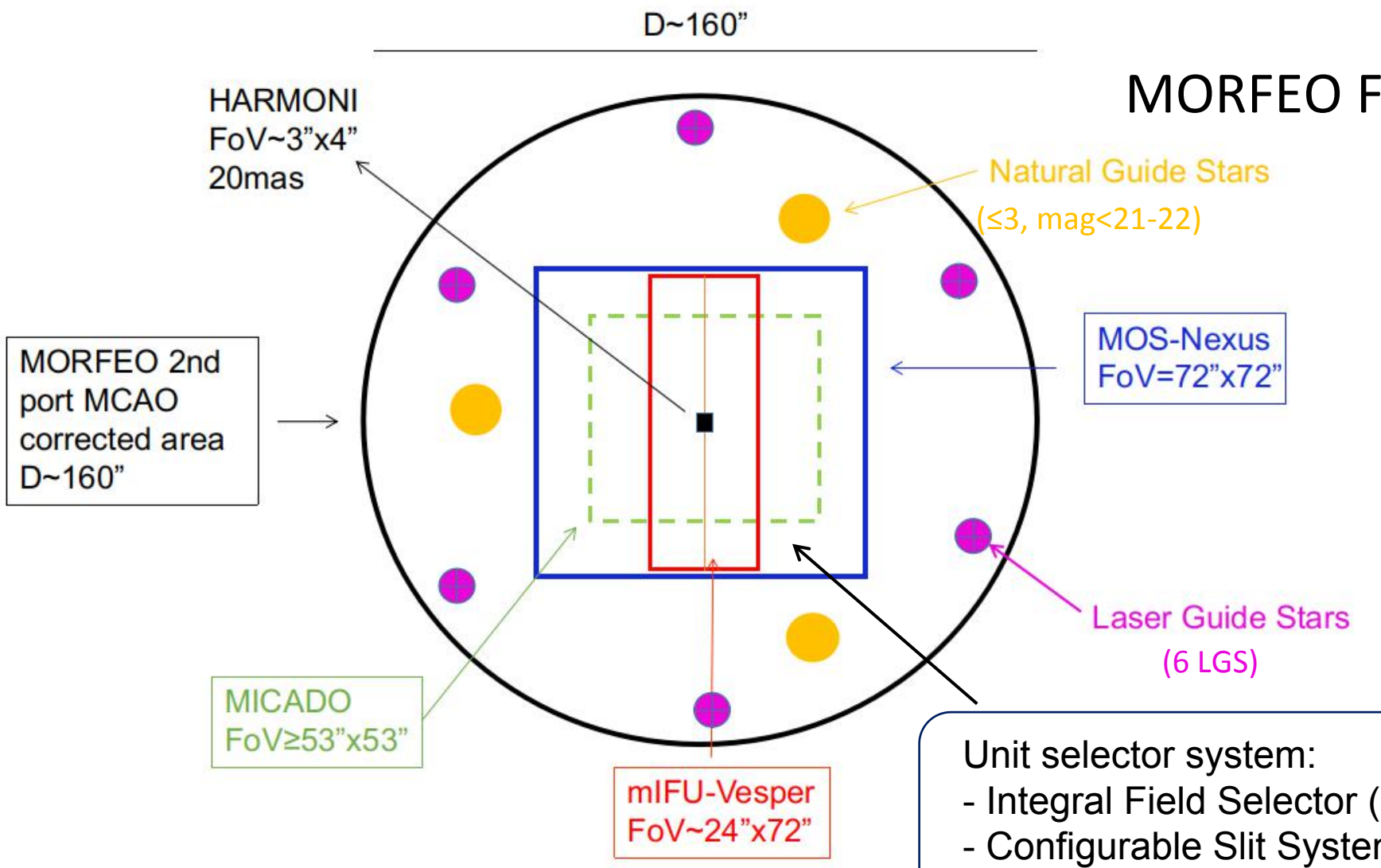




ADC = Atmospheric Dispersion Corrector

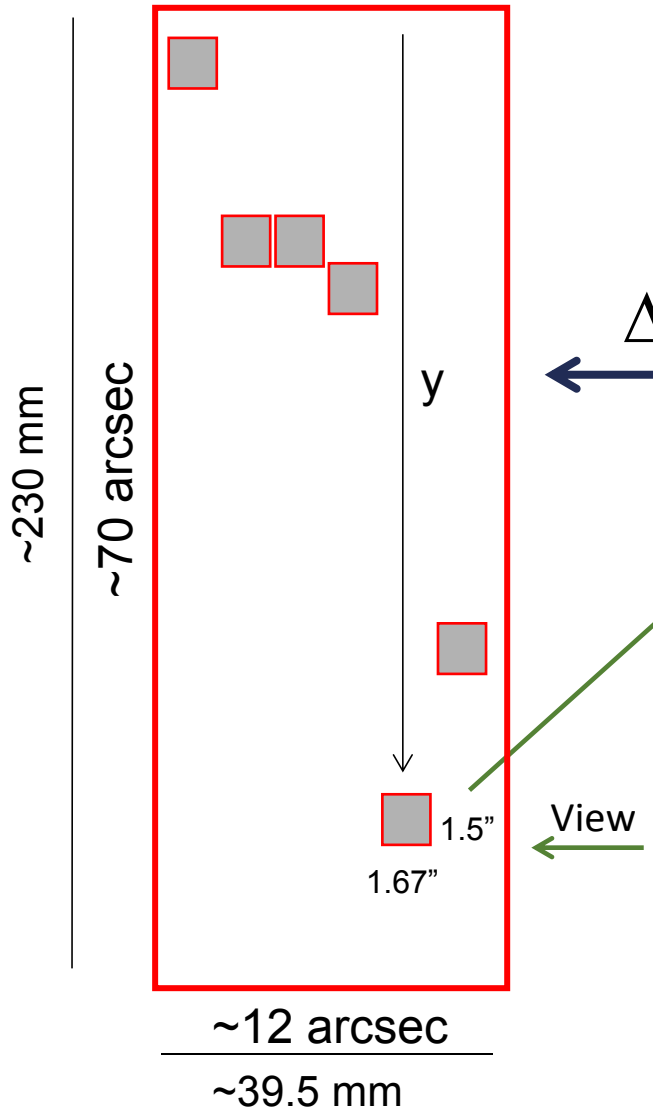
NGS = Natural Guide Stars Unit

MORFEO Focal Plane



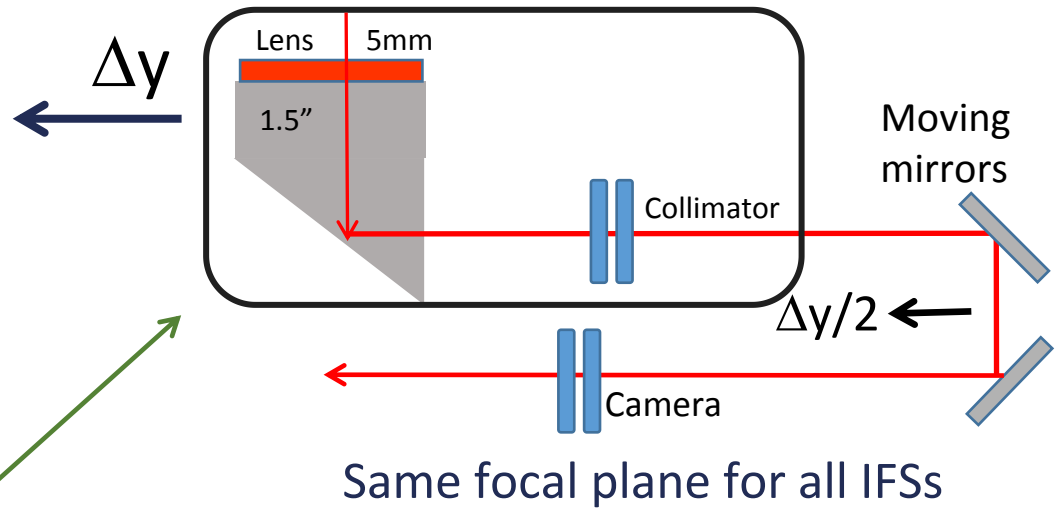
VESPER - The multi-IFU

One channel of VESPER comprises 6 probes called Integral Field Selector deployable over ~12”x70”



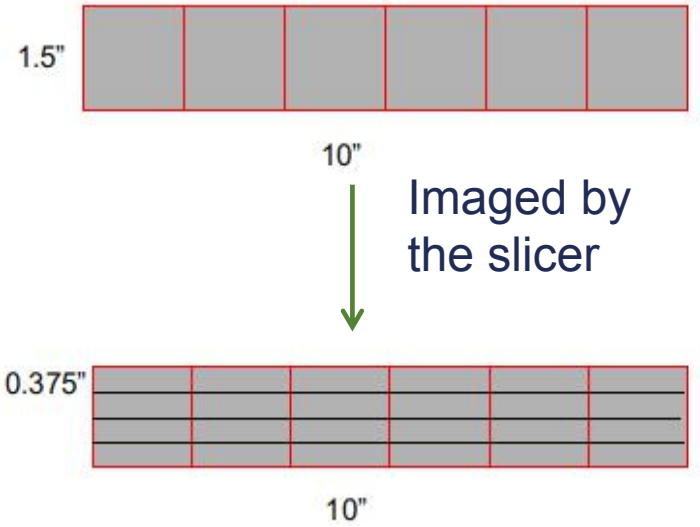
Integral Field Selector (IFS)

The “Swiss Clock” of VESPER



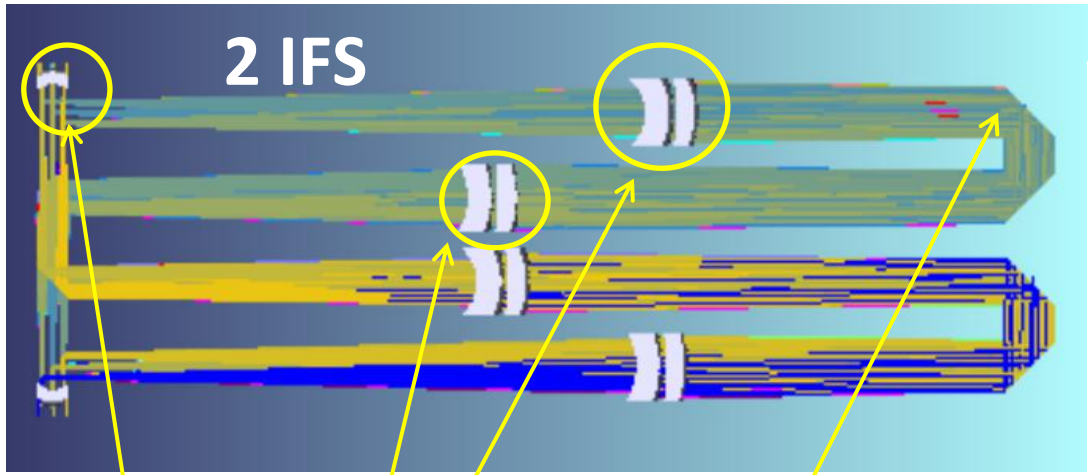
Same focal plane for all IFSs

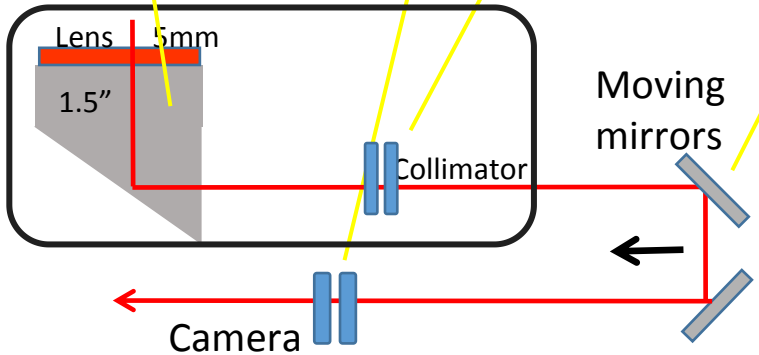
Sky strip resulting from 6 IFSs

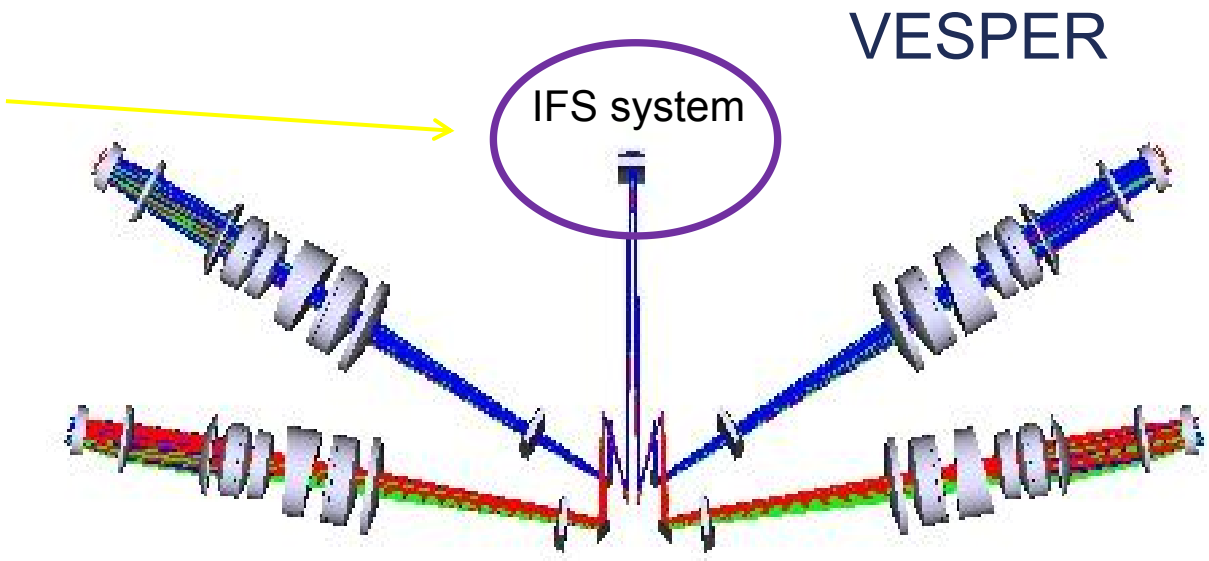


Slicing along the wide direction.
Insensitive to the number of IFSs.

VESPER - The multi-IFU





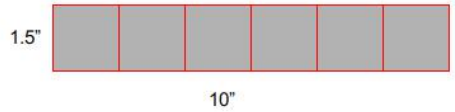


No aspheric components in VESPER

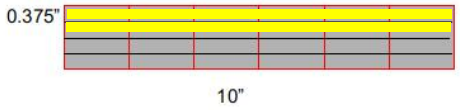
Optical design by Paolo Conconi

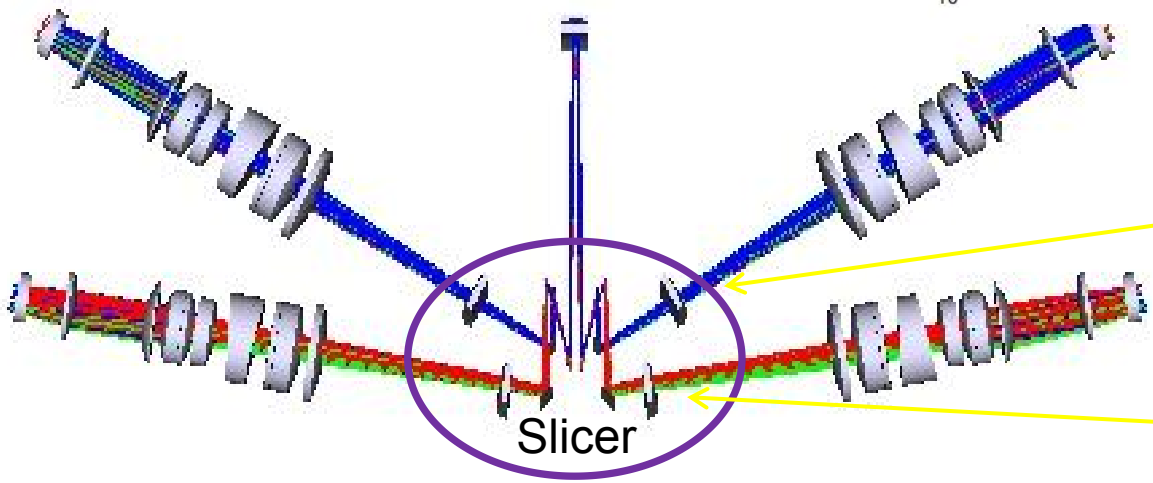
VESPER - The multi-IFU

Slicer on the focal plane (conceptually similar to MUSE)
288 mirrors, devided into 4 groups;

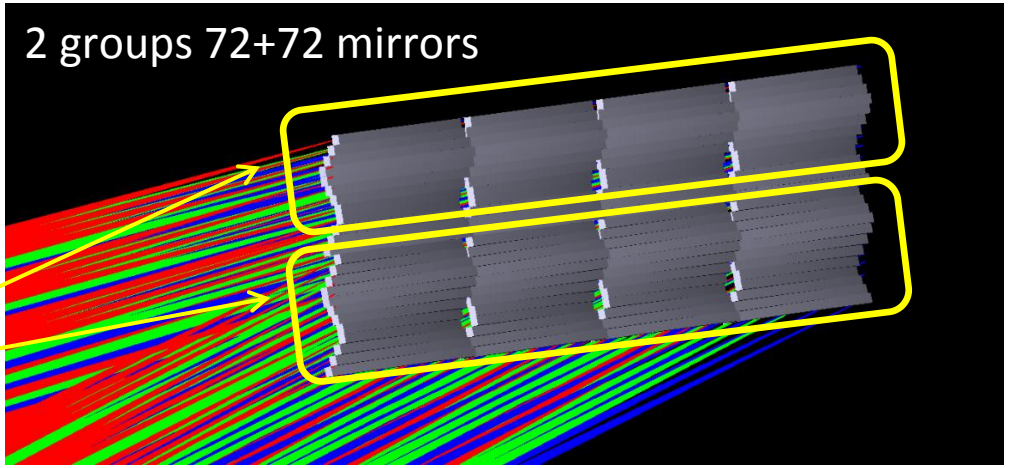


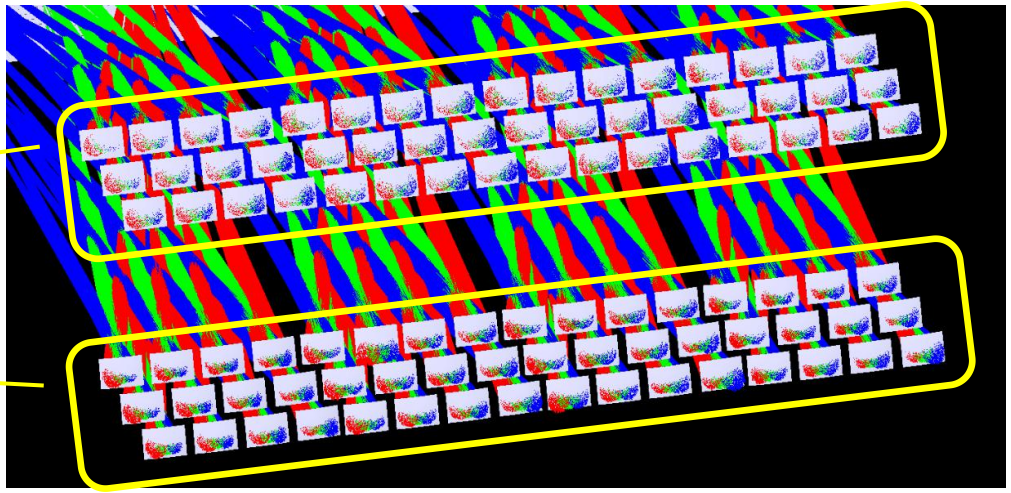
Each group samples a slice of the image
4 groups --> 4 slices --> 4 cameras





Optical design by Paolo Conconi

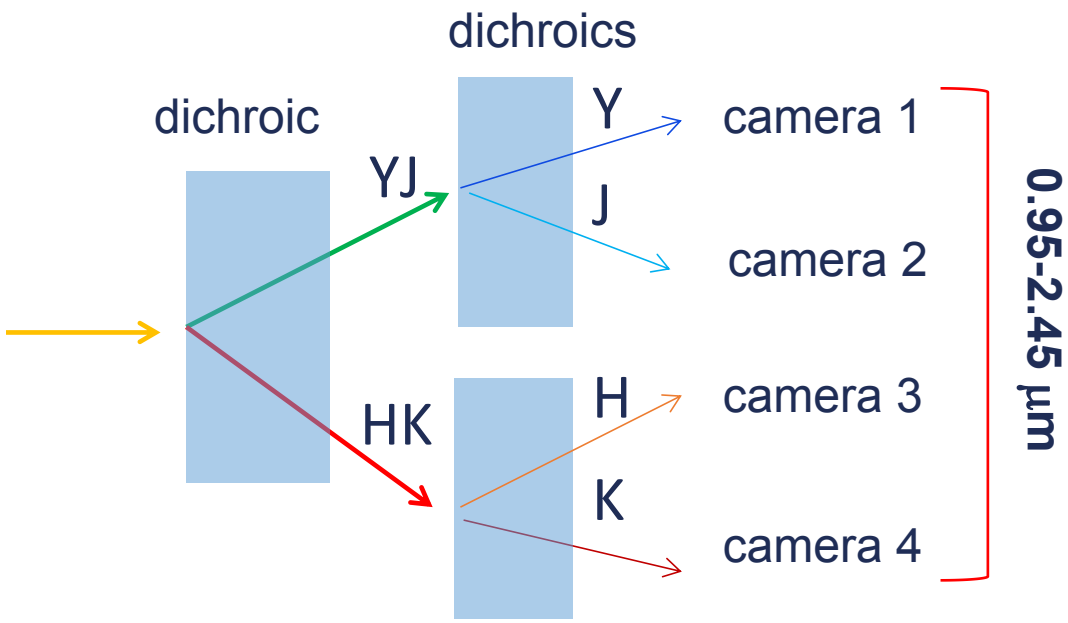


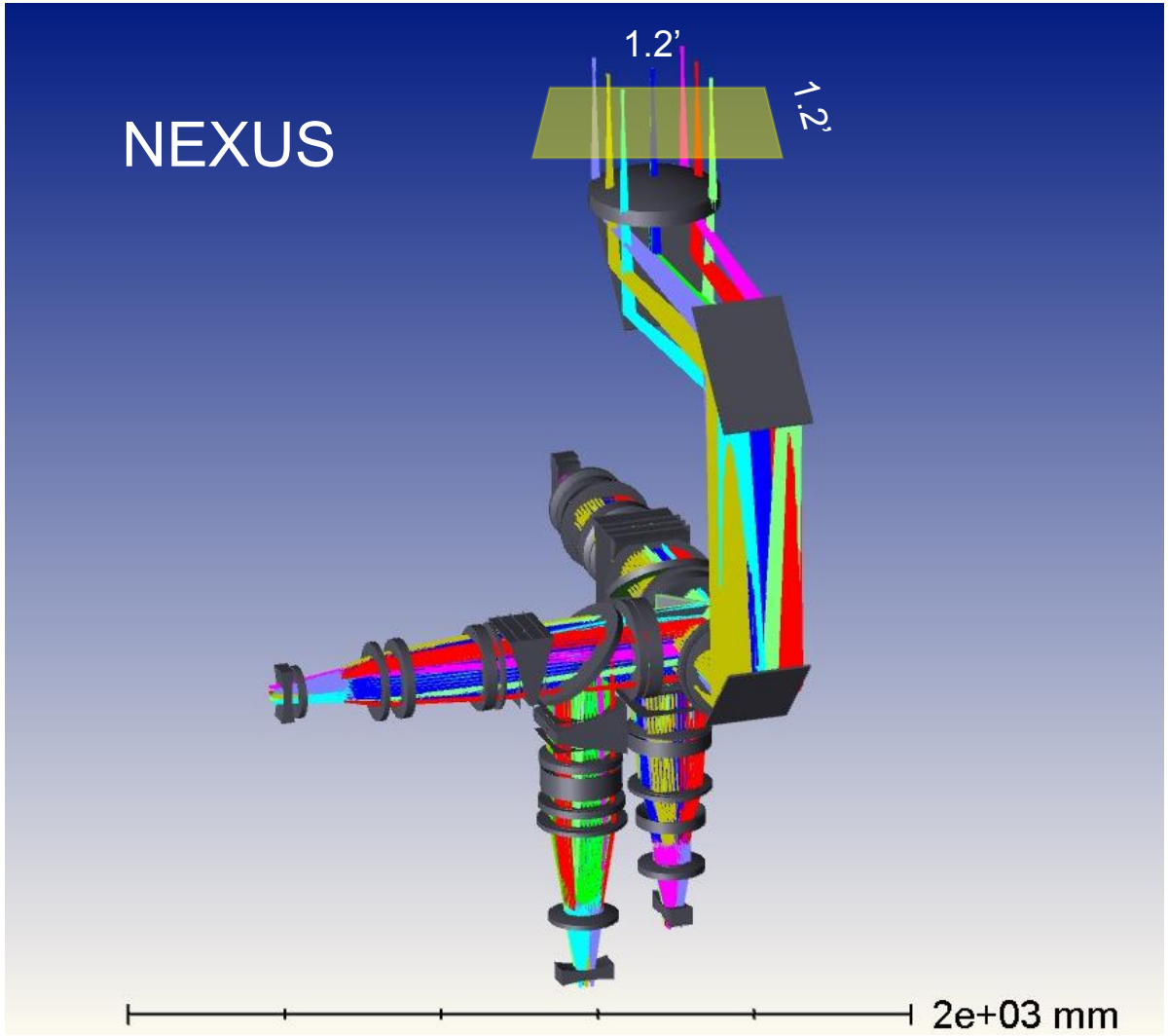


Corresponding 72+72 pupil mirrors.

No aspheric components in NEXUS

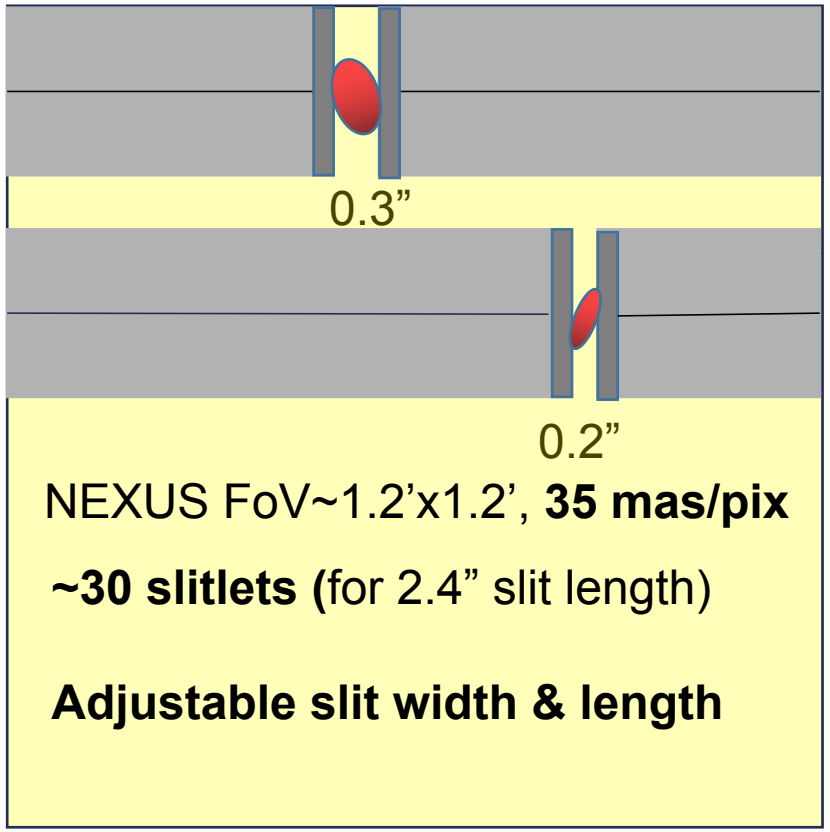
3 folding mirrors + 3 dichroics
4 cameras: Y, J, H, K





Optical design by Paolo Conconi

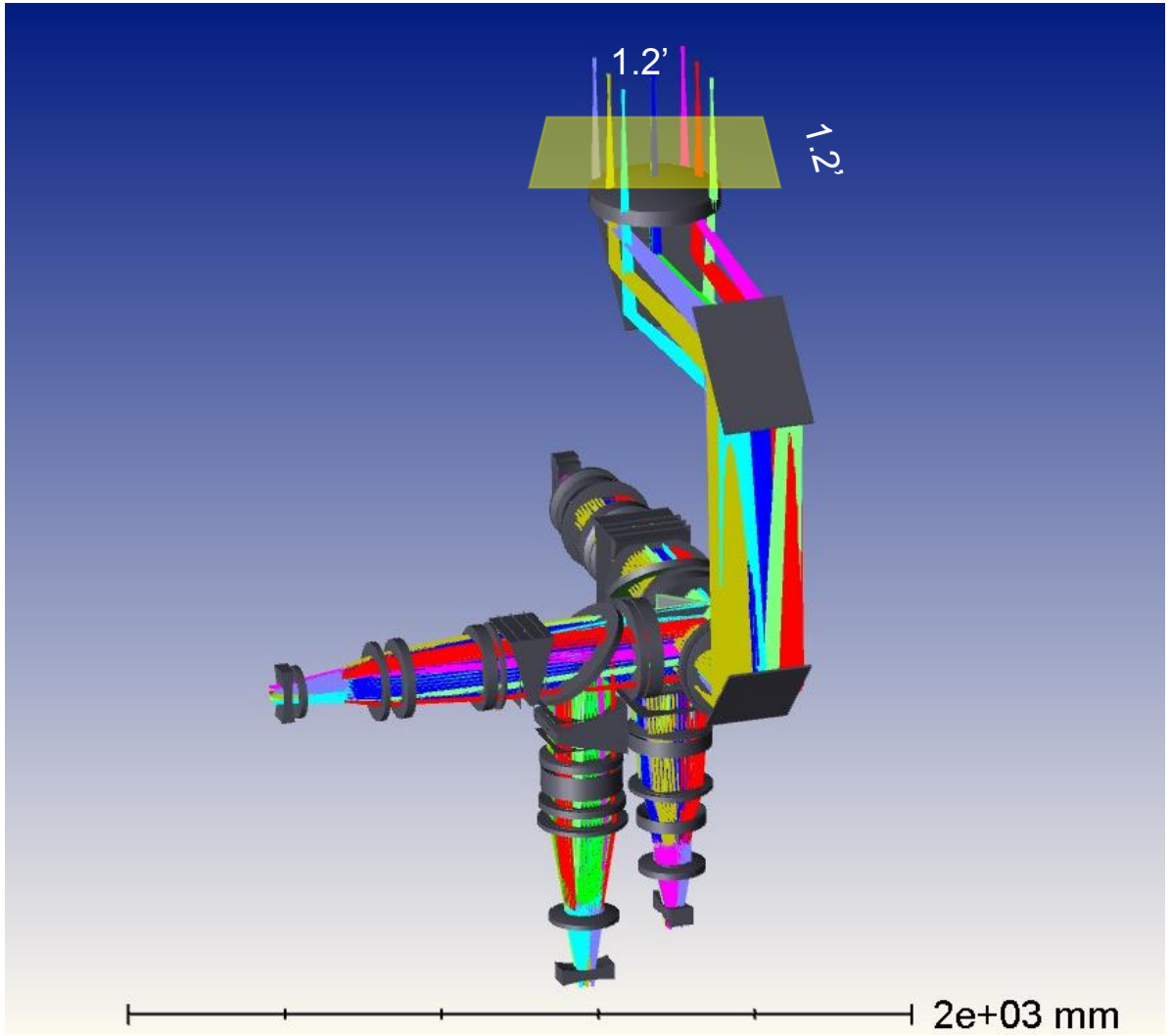
Configurable Slit System (CSS) of NEXUS
(e.g. MOSFIRE at Keck)



NEXUS FoV~1.2’x1.2’, **35 mas/pix**

~30 slitlets (for 2.4” slit length)

Adjustable slit width & length



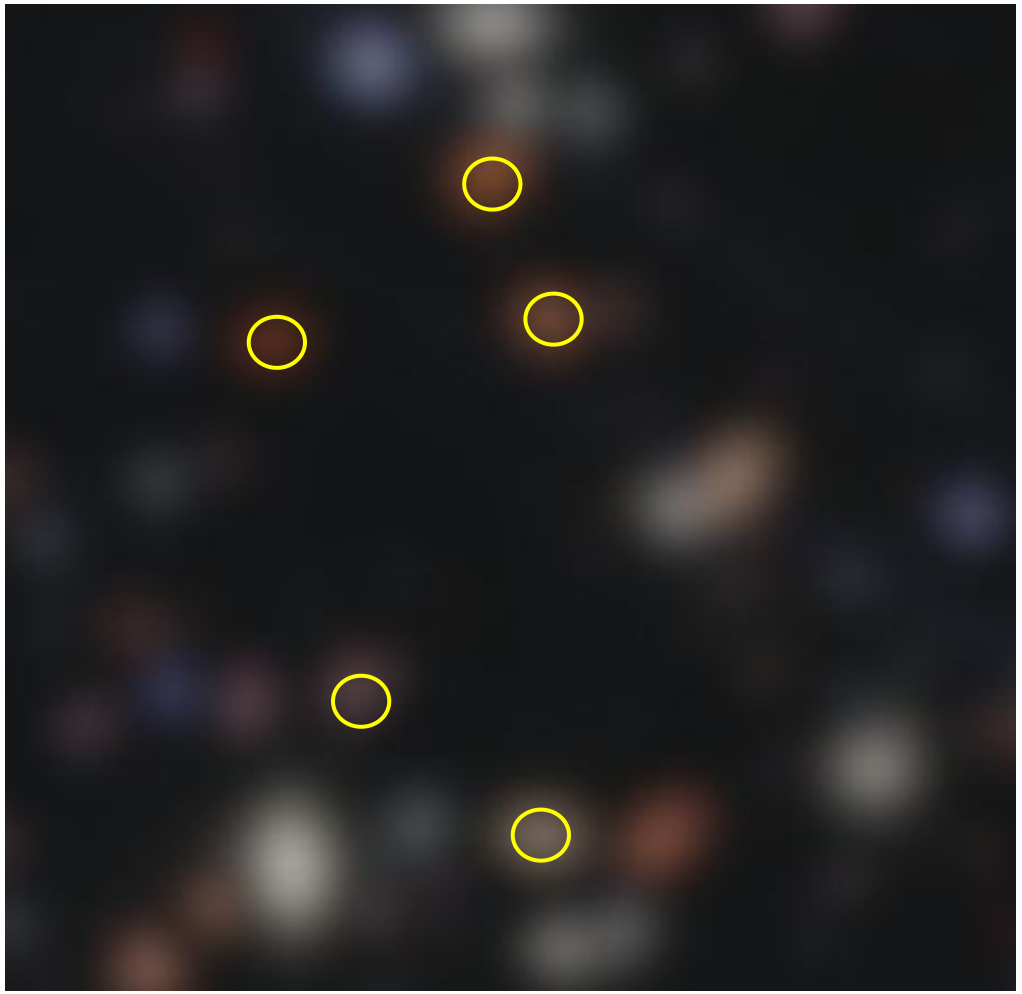
Optical design by Paolo Conconi

JWST NIRCam ~0.07”

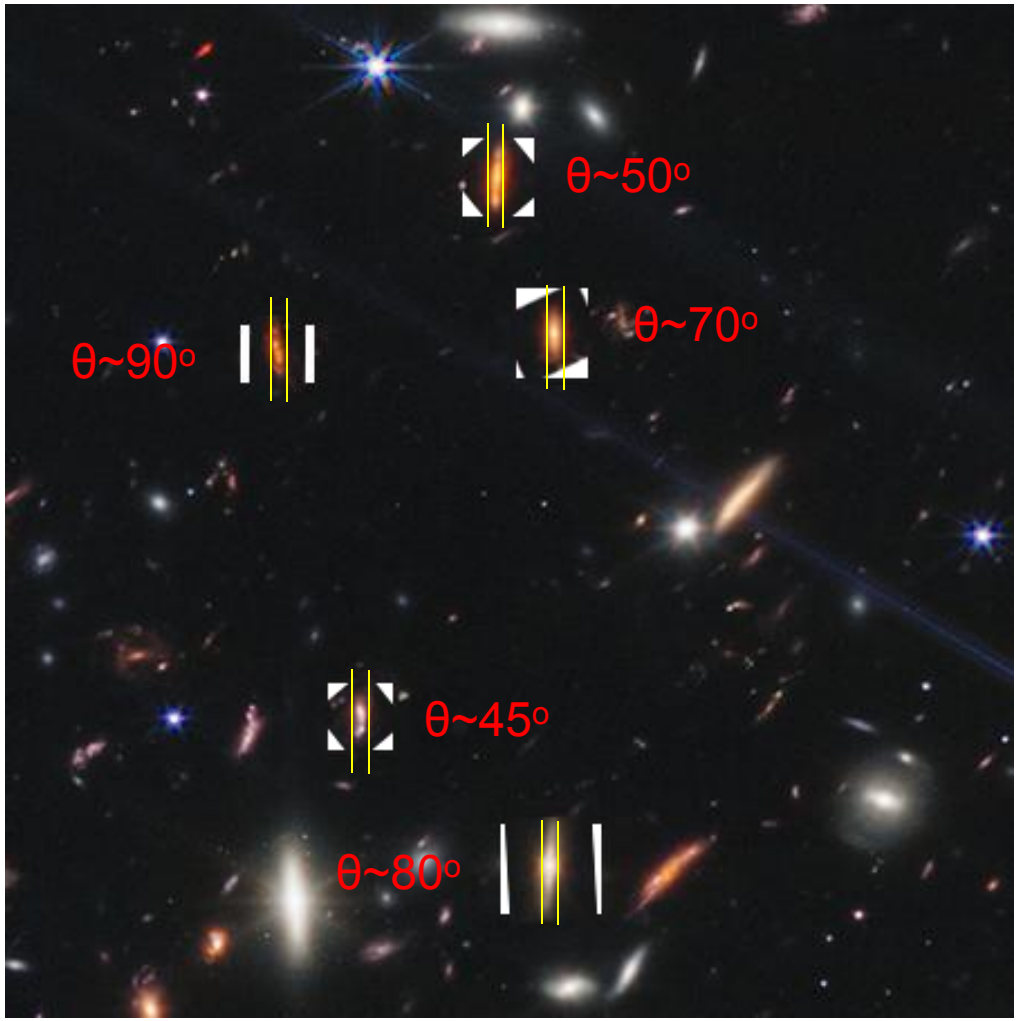
GLAO ~0.2”

JWST NIRCam ~0.07”

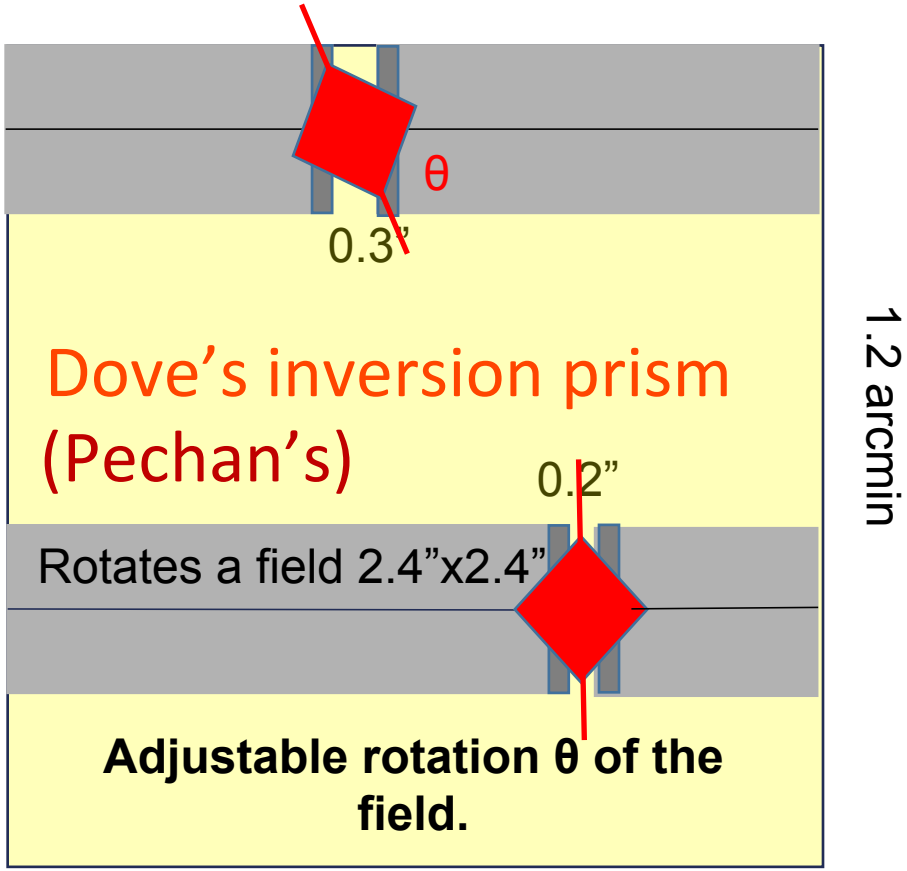
GLAO ~0.2” (e.g. MOSAIC)



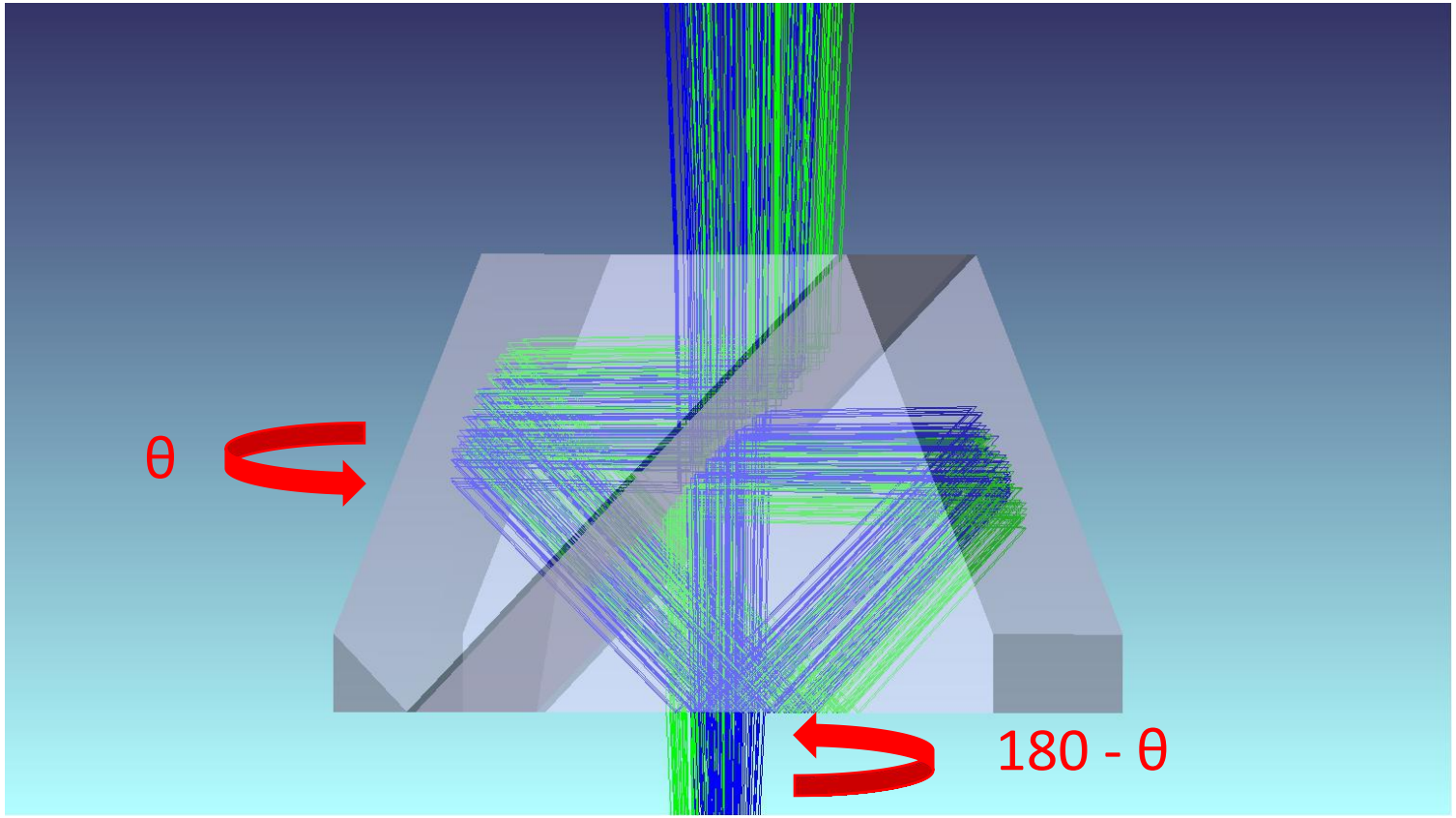
Turn the galaxies to see them better!



The "Swiss Clock" of NEXUS

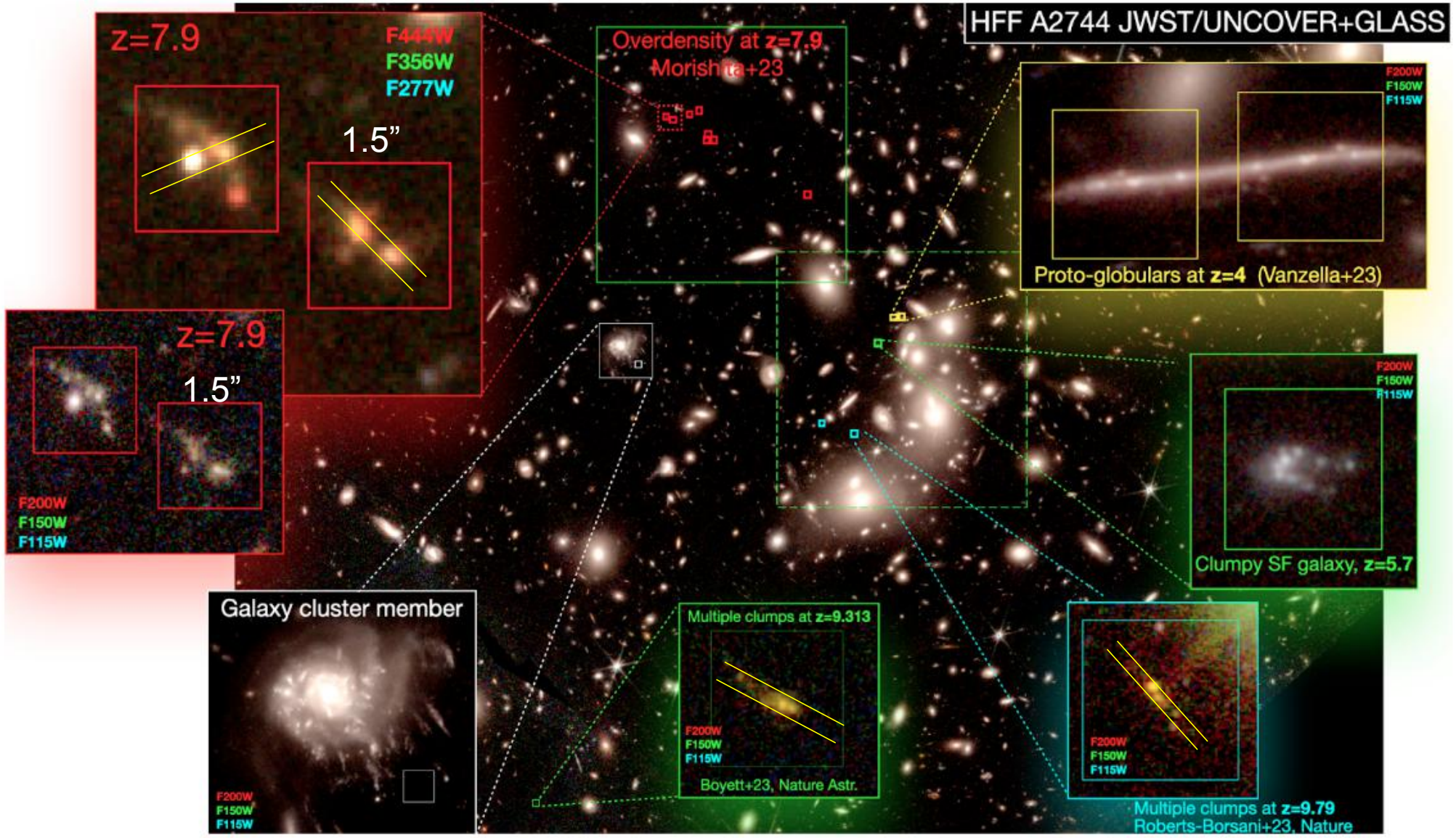


Inversion Prism



Science with

SHARP Potentialities - The distant Universe



VESPER

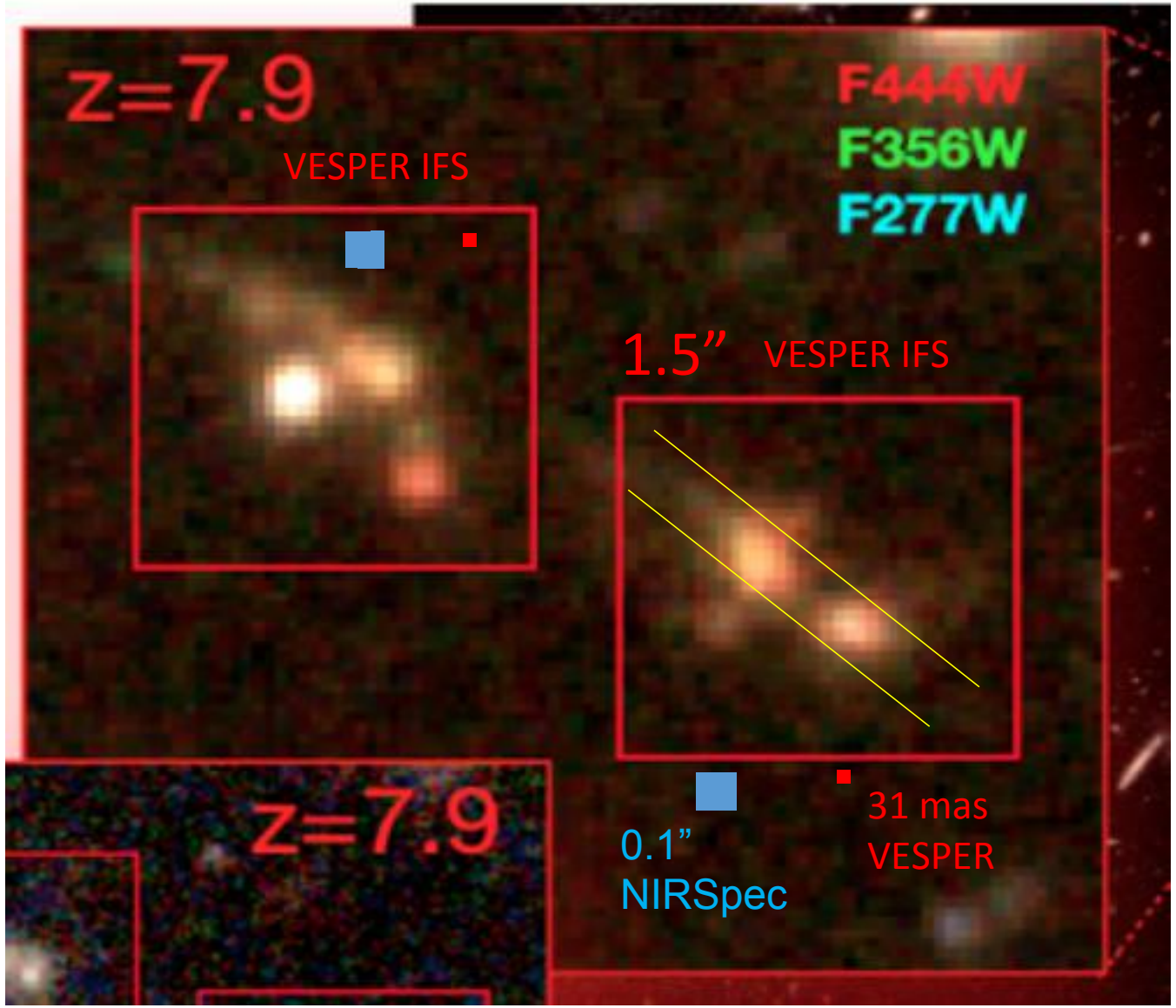
12 IFSs
1.7”x1.5”
31 mas/pix

NEXUS

30 slits
Rotating FoV
35 mas/pix

Thanks to E. Vanzella, A. Gargiulo, WG1&WG2

SHARP Potentialities - The distant Universe



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Rotating FoV
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Project Status

SHARP Current Team *(10 INAF Institutes, 3 Universities)*

INAF - OA Brera Milano
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Marcella Longhetti
Hossein Mahmoodzadeh
Emilio Molinari (PM)
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Juan Manuel Alcala'
Alessandro Grazian
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Vincenzo De Cicco
Luca Izzo
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Vincenzo Ripepi

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Ivan Di Antonio

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Andrea Longobardo

INAF - OA Roma
Giuliana Fiorentino

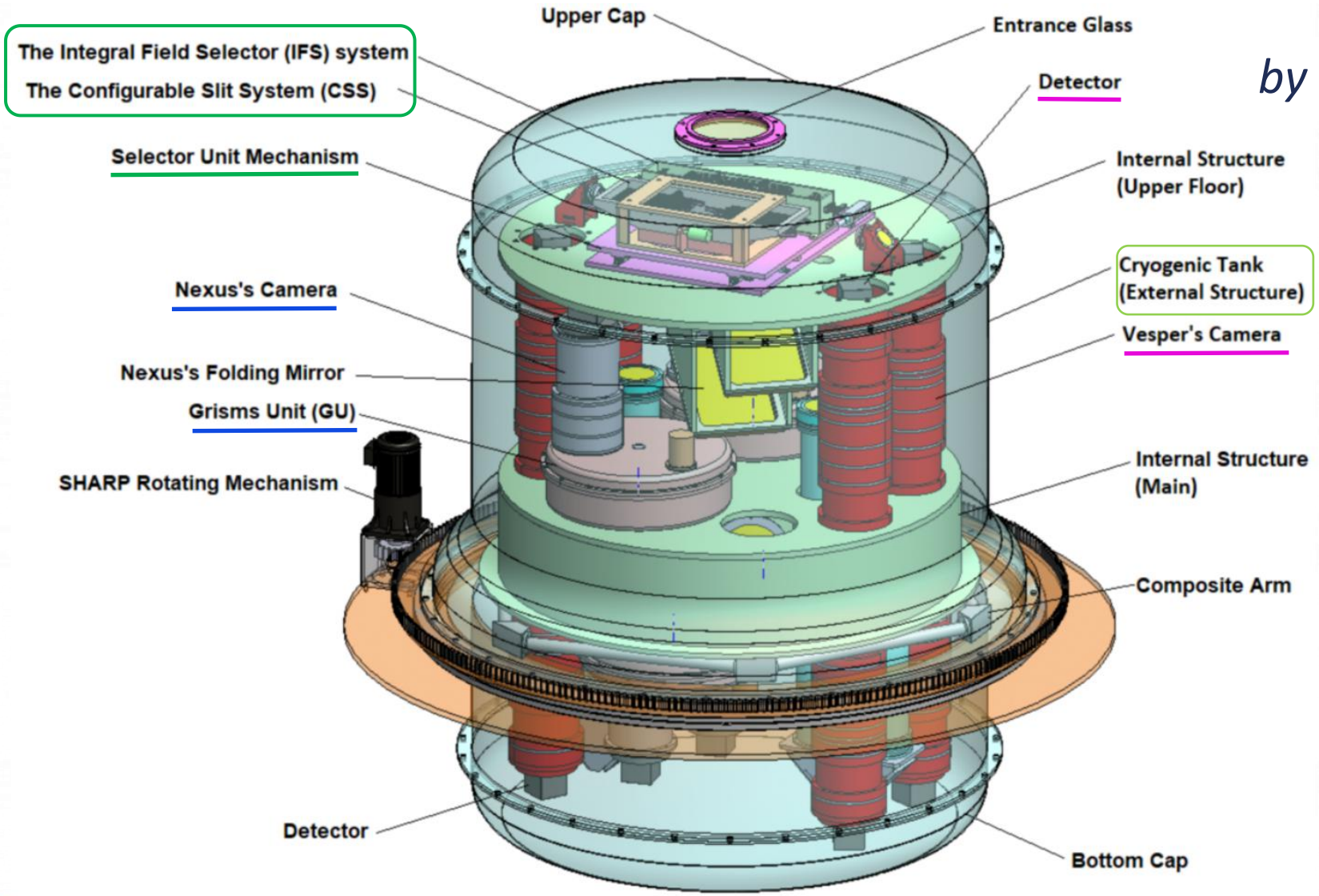
Univ. Roma Tor Vergata
Valentina D'Orazi (WG4)

Univ. Roma 3
Federica Ricci

SHARP needs an International Consortium to grow

We are open to collaboration with potentially interested foreign institutes

SHARP - Opto-mechanical Conceptual Design



by Hossein Mahmoodzadeh

Follow the “pills” on
30th Sept afternoon
and
1st Oct morning

Objectives and Ambitions

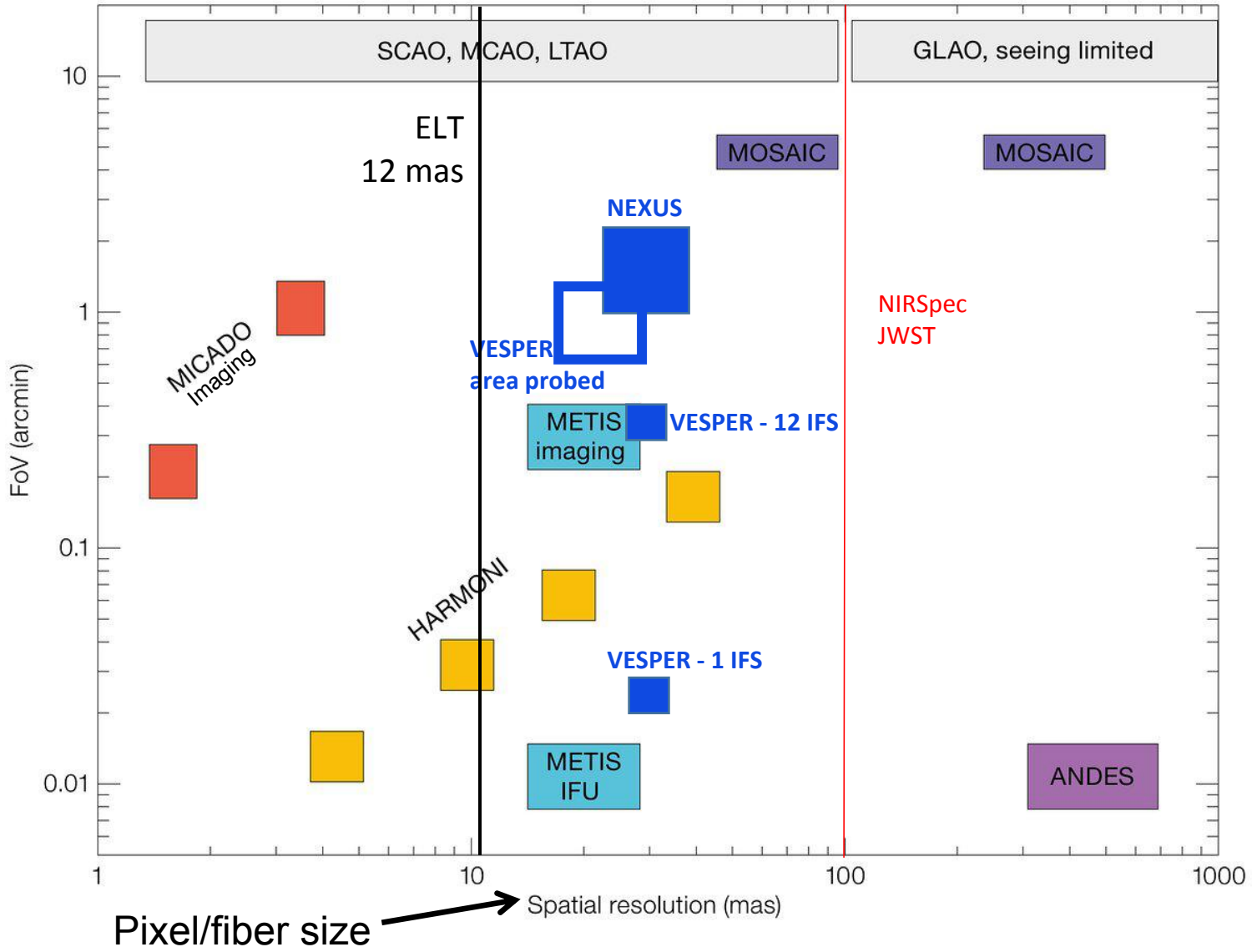
MORFEO-SHARP exceeds the observational limits fixed by NIRSpec@JWST
allowing us to explore the new paths that JWST is opening.

MORFEO-SHARP can take up the baton left by JWST when its mission ends.

This is SHARP

Thank you!

SHARP vs Other ELT Instruments



Courtesy of ESO-ELT