A Near-IR Multi-mode Spectrograph Conceived for the Multi-conjugate Adaptive Optics Module MORFEO@ELT

Paolo Saracco

INAF - Osservatorio Astronomico di Brera

&

the SHARP Team

Logo Design by Laura Barbalini

Layout

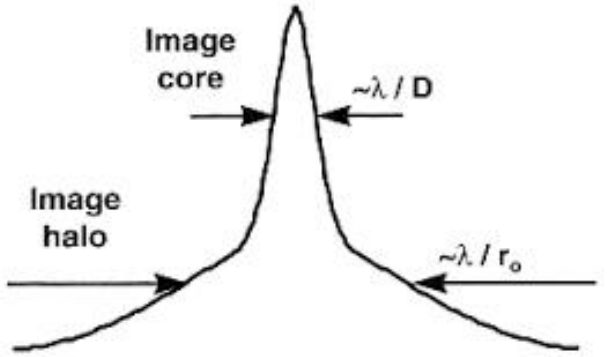
- Overview: ELT Instruments
- What is SHARP (in brief)
- Why SHARP at ELT
- SHARP Properties, Optical Design, Capabilities
- The SHARP Team
- Project Status

Overview: Some Useful Definitions

SCAO: Single Conjugate AO, **on-axis correction**, **1 Natural Guide Star (NGS)<16** mag within 15”
MCAO: Multi Conjugate AO, **~2’x2’ corrected**, **1-3 NGS<21** mag within ~80” + **6 Laser GS**
GLAO: Ground Layer AO (M4+M5), **seeing limited correction** (enhanced seeing)

AO PSF is made up of two components:

1. Diffraction limited core
2. Seeing-limited halo



$FWHM_{dl}=1.22\ \lambda/D$

At λ=2.2 mu (K band)

$FWHM_{ELT}$ = 0.012 arcsec
$FWHM_{JWST}$ = 0.070 arcsec

Strehl Ratio SR = $I_{actual\_PSF}/I_{dl\_PSF}$ = intensity peak **actual PSF / diff-lim PSF**

AO system	FWHM (arcsec)	SR
SCAO	0.012	~0.8 on-axis
MCAO	0.012	~0.6 F.o.V.
GLAO	~0.2	.....

AO System (ELT-ETC)	Texp (s) H_{AB}=25	Texp (s) K_{AB}=25	Radius of SN area (mas)
MCAO	**30**	**90**	20
GLAO	**630**	**5280**	150
Gain (Texp)	**~20**	**~58**	(point source)

MCAO ~20(>50) times more efficient than GLAO in H(K)-band

Overview: ELT - Timescale and Instruments

2028 - First Light & Science Verification (Planned, ESO page)

		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			2028
			Single slit	*R* ~ 20 000							
	AO Module	MORFEO	AO Module SCAO – MCAO		0.8–2.45	2010	2015	2023			~2029
	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			~2029
	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			~2030
			Single slit	*R* ~ 1400 in *L* *R* ~ 1900 in *M* *R* ~ 400 in *N*							
	2nd Generation		IFU 0.6″ × 0.9″ at 8 mas/pix (with coronagraph)	*L, M* bands *R* ~ 100 000							
Fiber fed	GLAO/SCAO	ANDES	Single object	*R* ~ 100 000	0.4–1.8 simultaneously	2018					> 2032
			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					> 2033
			~ 8 IFUs (TBC)	*R* ~ 5 000–20 000	0.8–1.8 (TBC)						
		PCS	Extreme AO camera and spectrograph	TBC	TBC						TBD

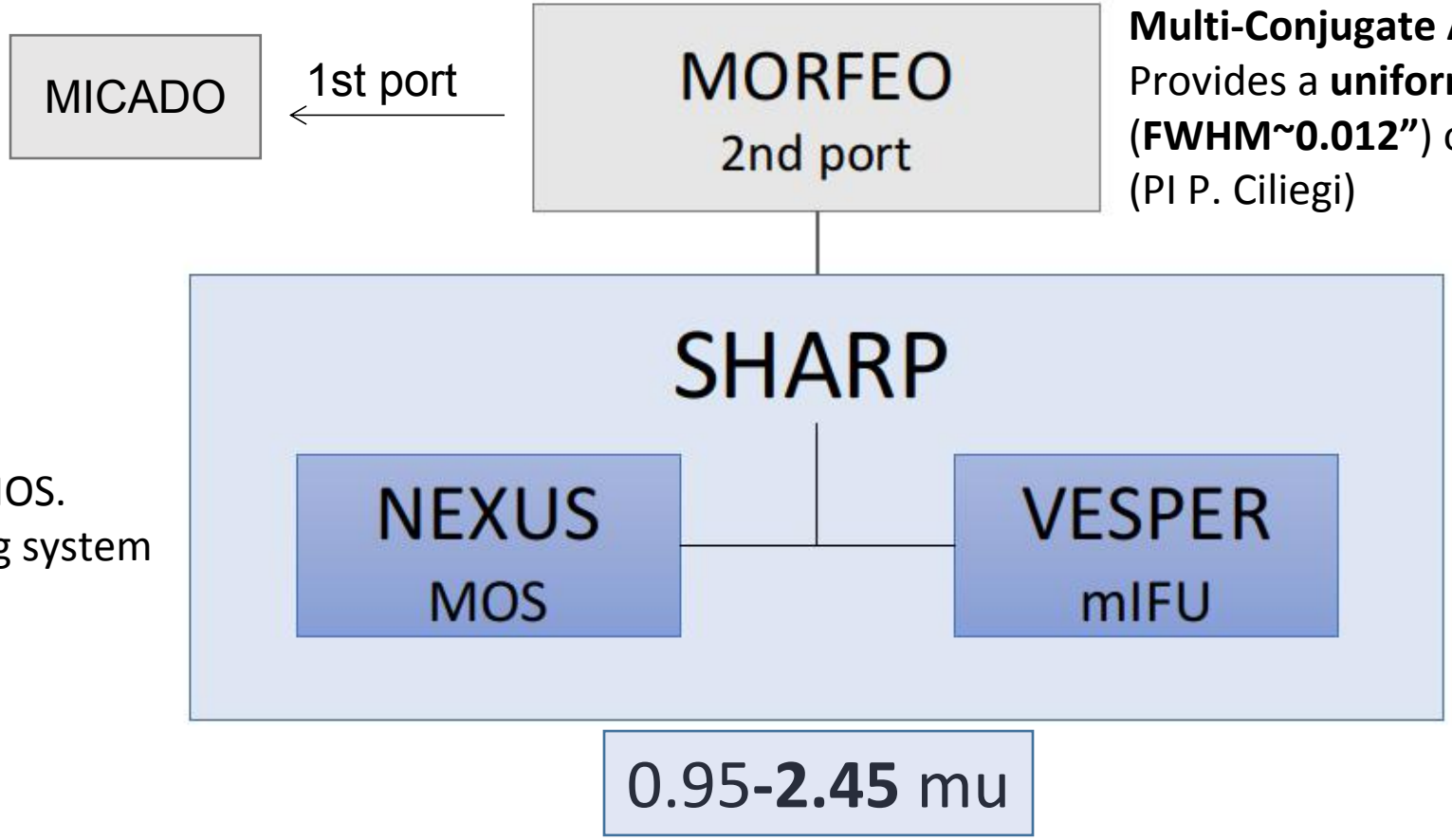
Courtesy of ESO-ELT

What is

(in brief)

SHARP in brief

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**’
(PI P. Ciliegi)

NEXUS slitlets MOS.
Robotic deploing system

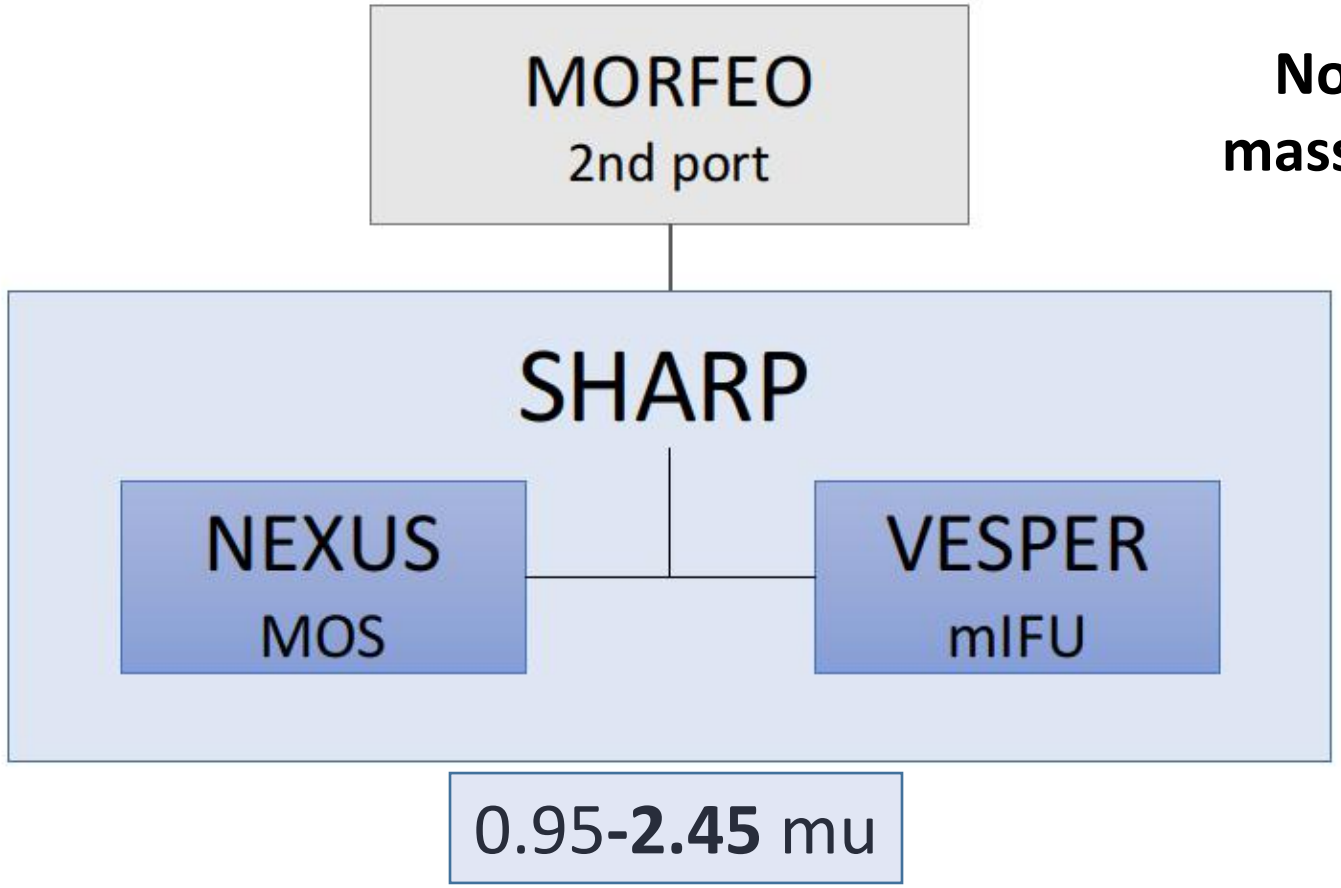
VESPER multi-IFU

SHARP is a Near-IR **multi-mode** spectrograph conceived to **fully exploit the ELT aperture** providing spectra of astronomical sources at the **faintest reachable fluxes**, at the **sharpest angular resolution** over the **widest AO corrected field**.

SHARP in brief

Not fiber-fed

Not conceived for massive spectroscopy



NEXUS slitlets MOS.
Robotic deploing system

VESPER multi-IFU

- **MORFEO** to maximally concentrate the photons and to correct a large FoV;
- **NEXUS** to maximally exploit the collecting area and AO reaching the faintest fluxes;
- **VESPER** to maximally exploit the angular resolution of ELT over the corrected FoV;

Why

Scientific Rationale 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.

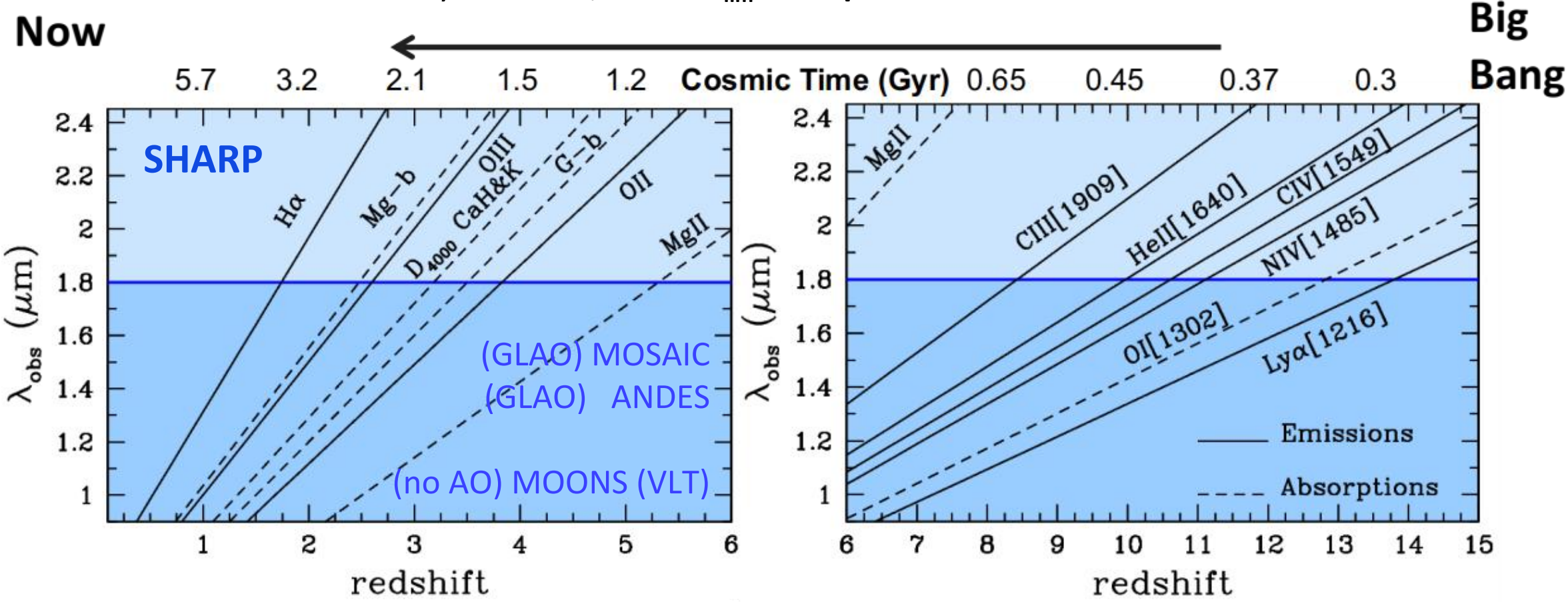
SOME KEY QUESTIONS

- *What are the extreme physical conditions governing star formation in the early Universe ?*
- *What drives the formation of massive galaxies ? What regulates their 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**.



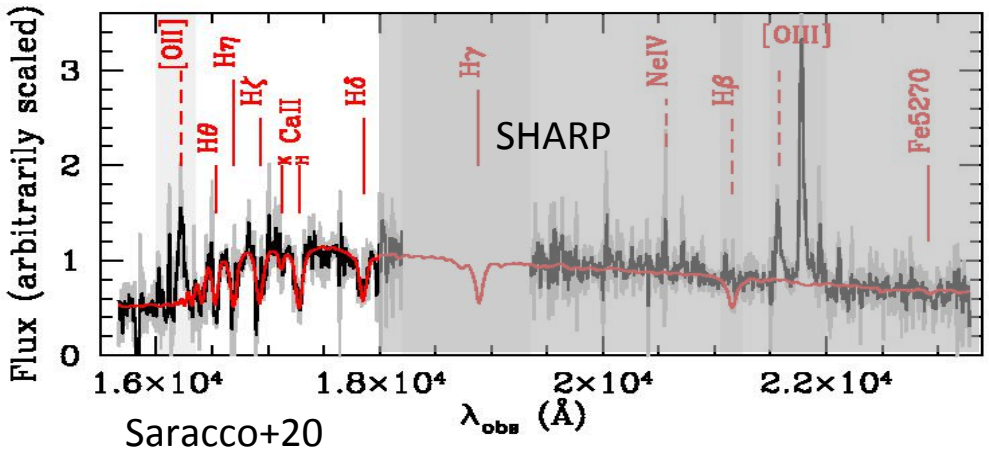
$\lambda_{obs}=\lambda_{rest}(1+z)$

Why SHARP - Why λ_{lim} = 2.45 μm

A CONCRETE EXAMPLE

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

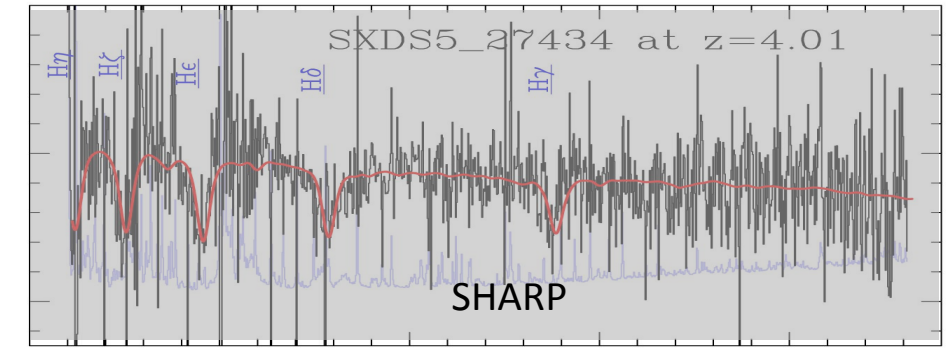
LBT-LUCI



Saracco+20

z=3.35

Keck-MOSFIRE



Tanaka+20

z=4.01

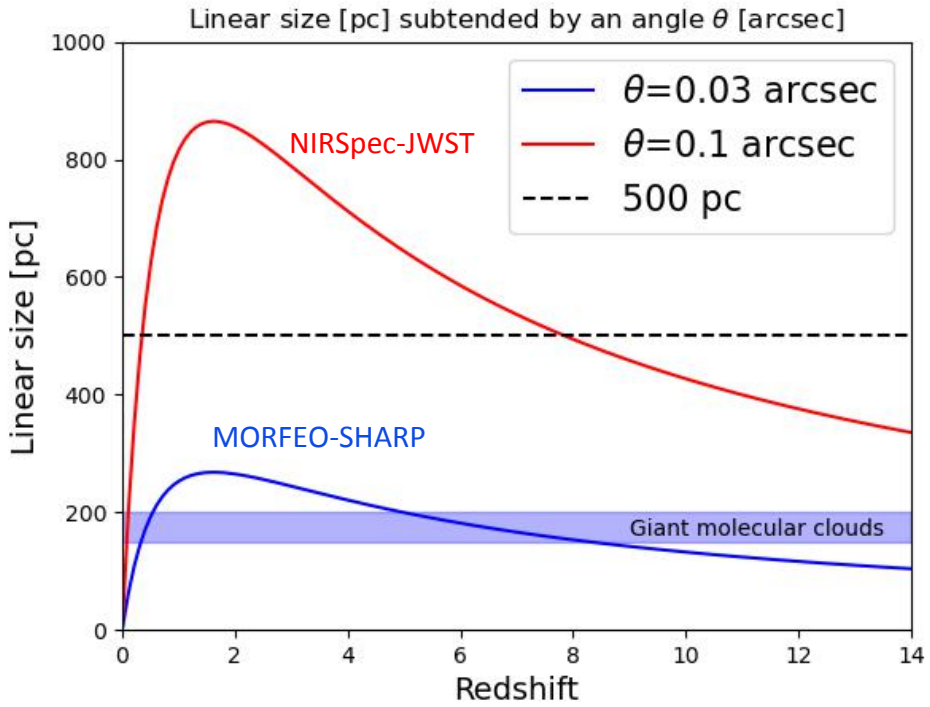
1ST REQUIREMENT

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

Why SHARP - Why AO, which angular resolution

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



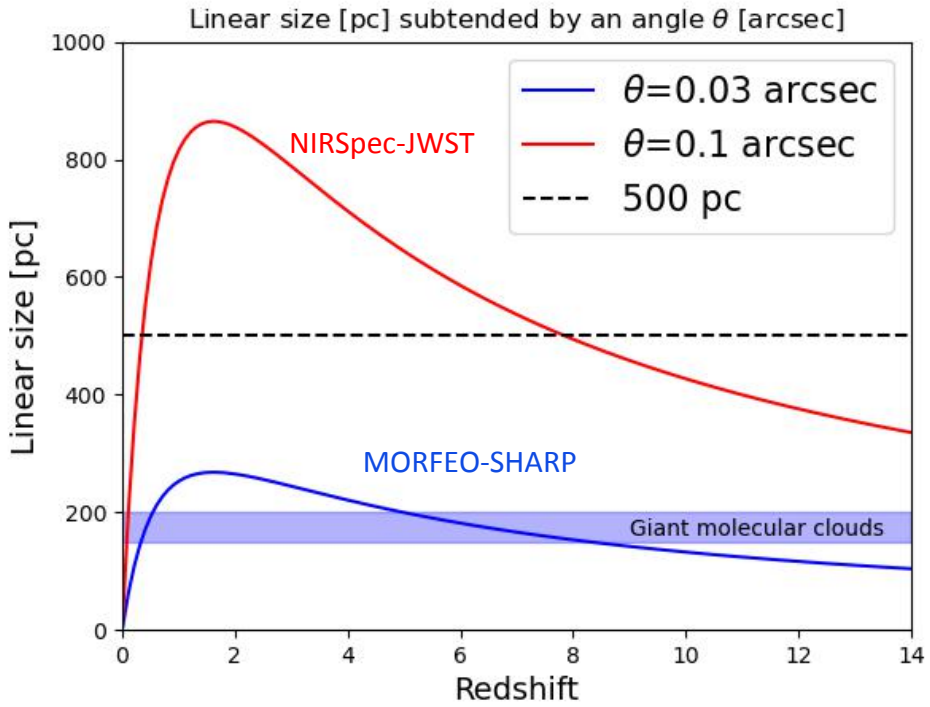
2ND REQUIREMENT

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.
- This maximizes also the efficiency of the ELT.



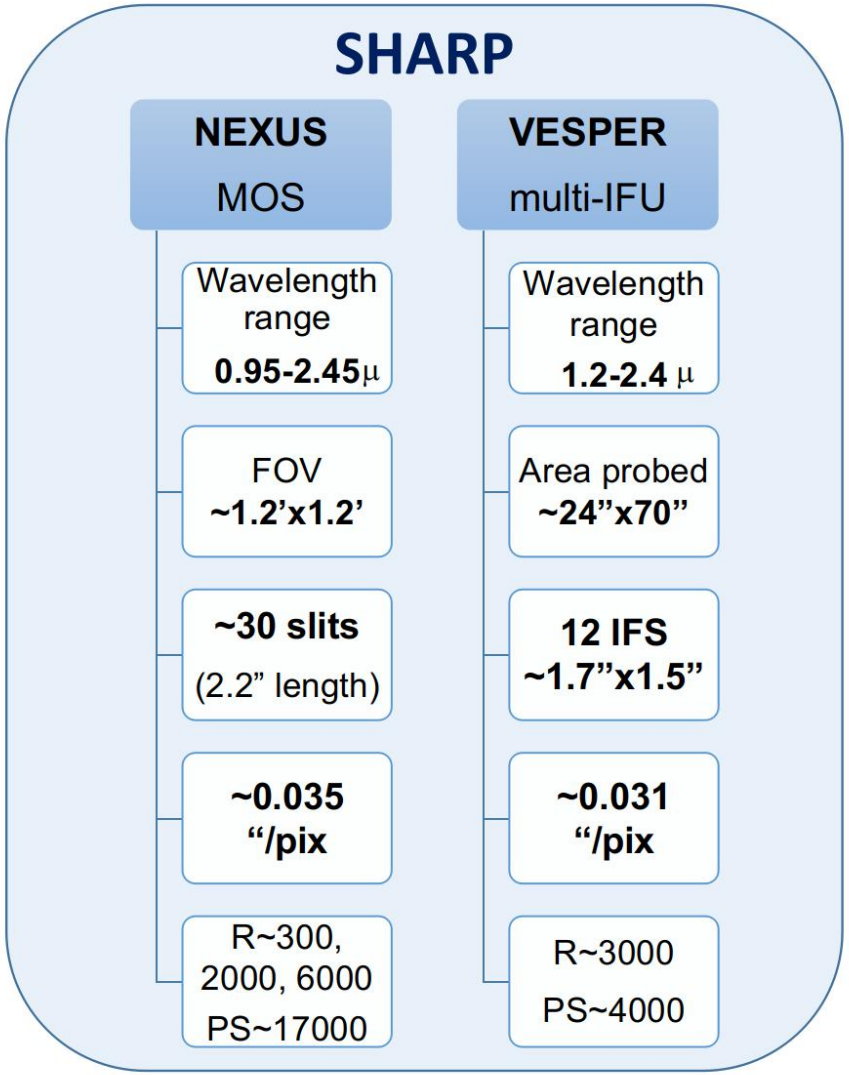
3RD REQUIREMENT

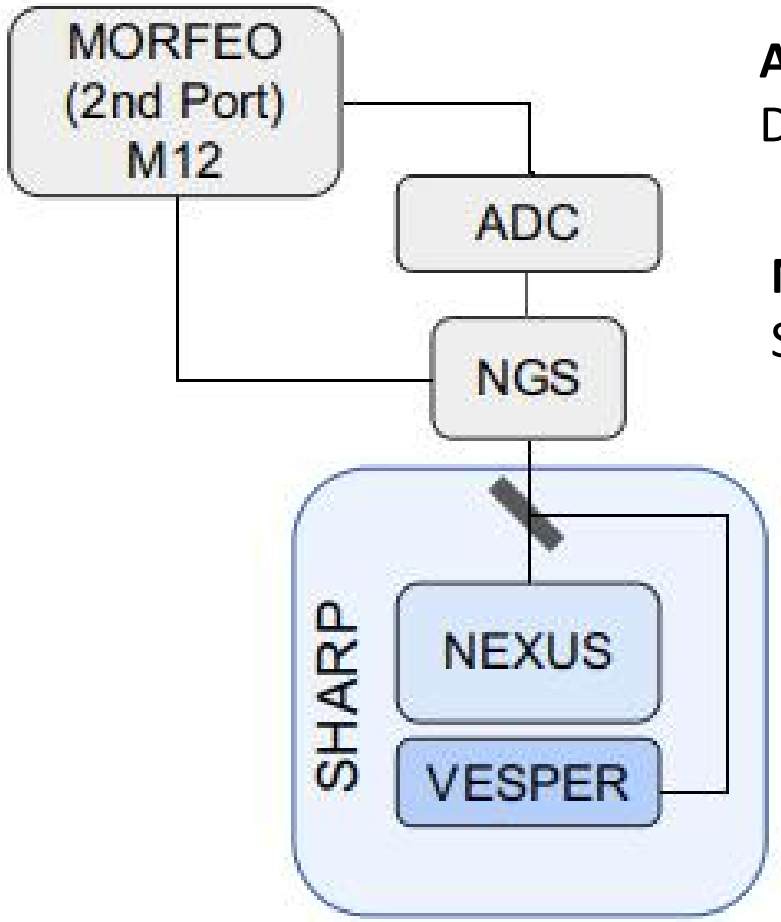
Multiplexing capabilities coupled with a large area uniformly corrected for atmospheric turbulence ==> **Multi-Conjugate AO** ==> **MORFEO**

What is

(in detail)

SHARP in a Nutshell

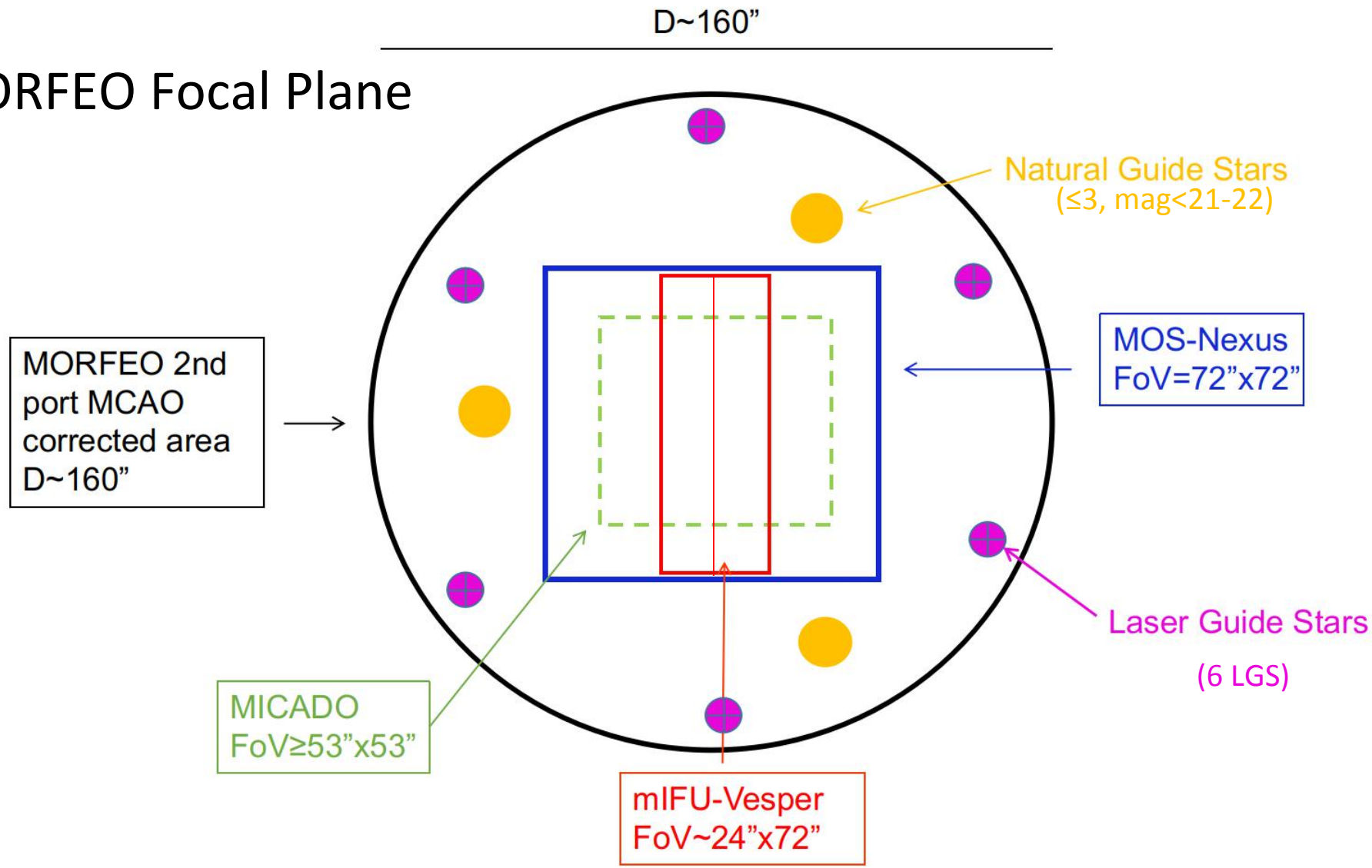




ADC = Atmospheric Dispersion Corrector

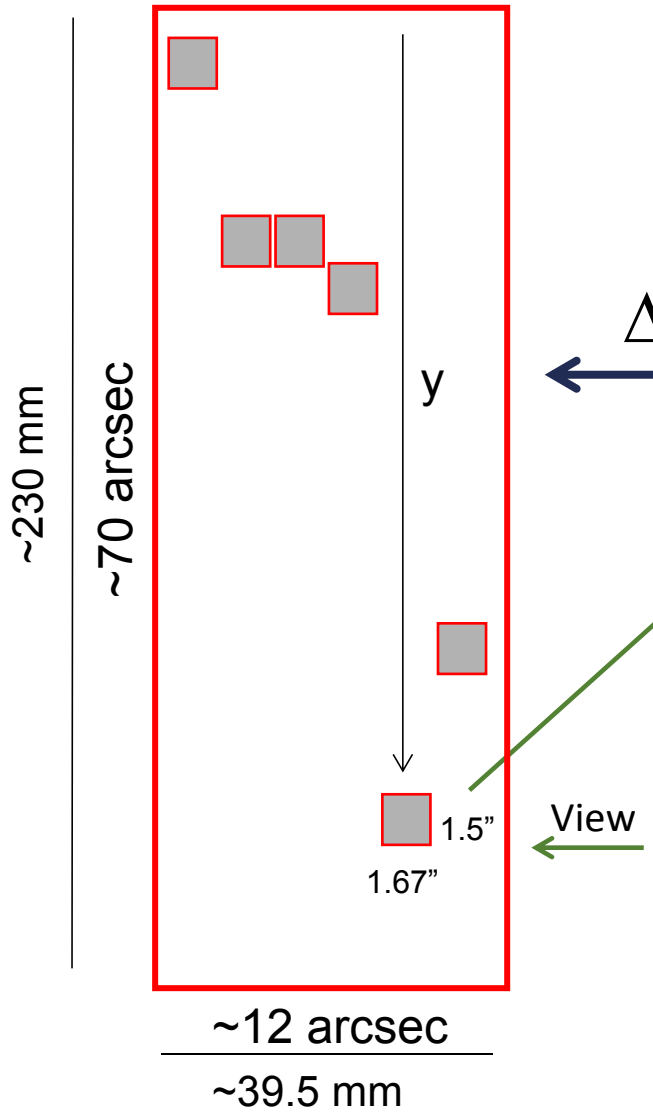
NGS = Natural Guide Stars Unit

MORFEO Focal Plane



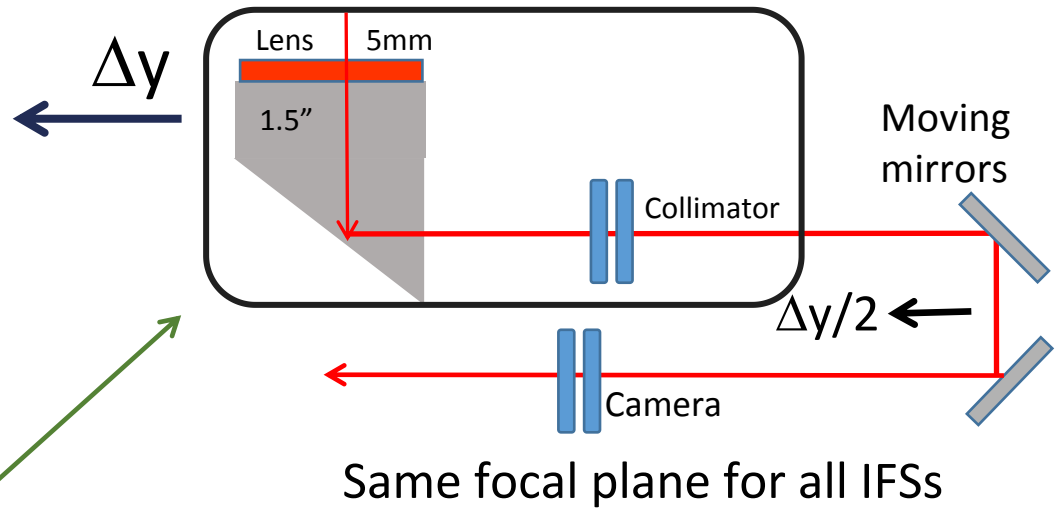
VESPER - The multi-IFU

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



Integral Field Selector (IFS)

The “Swiss Clock” of VESPER

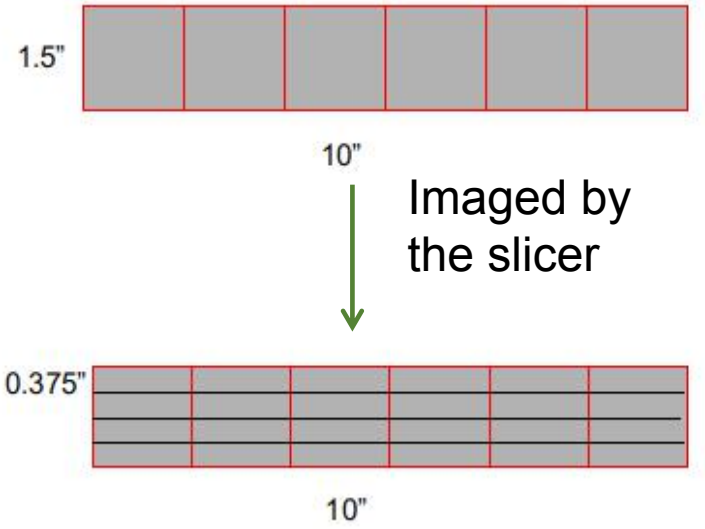


Same focal plane for all IFSs

The number of IFSs can be changed without modifying the slicer

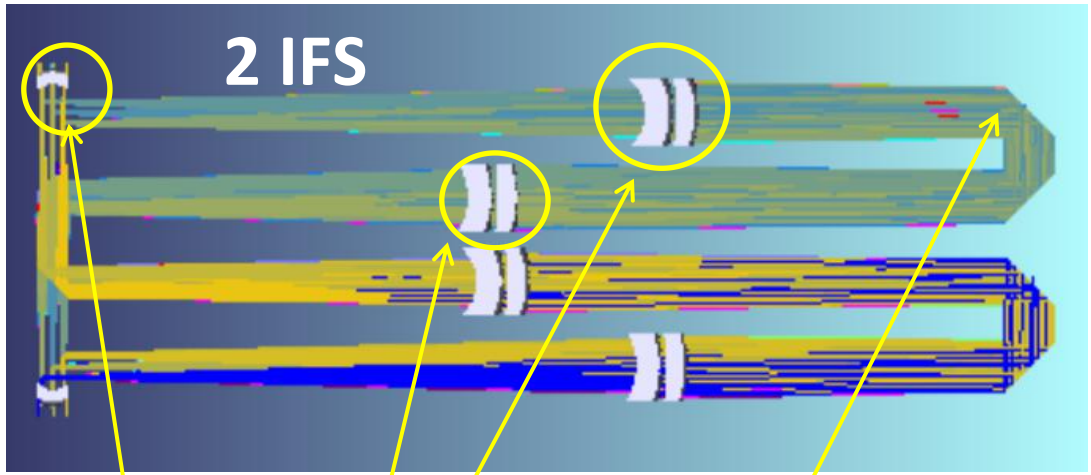
10.2” ~ 1.7”x 6 IFS = 1.3” x 8 IFS = ...

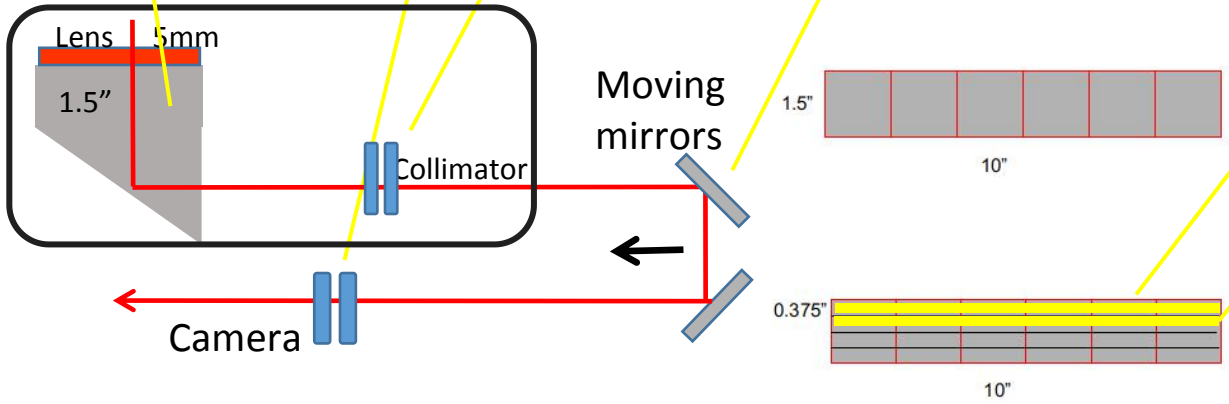
Sky strip resulting from 6 IFSs



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

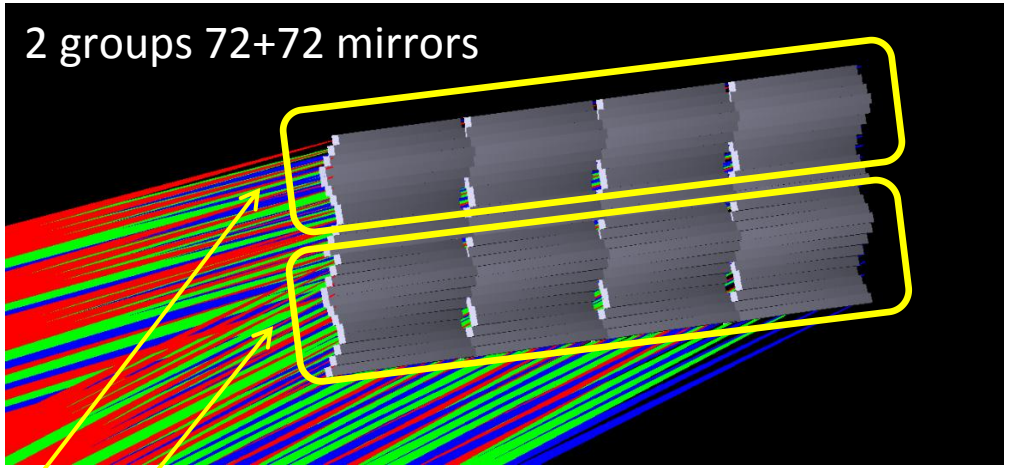
VESPER - The multi-IFU

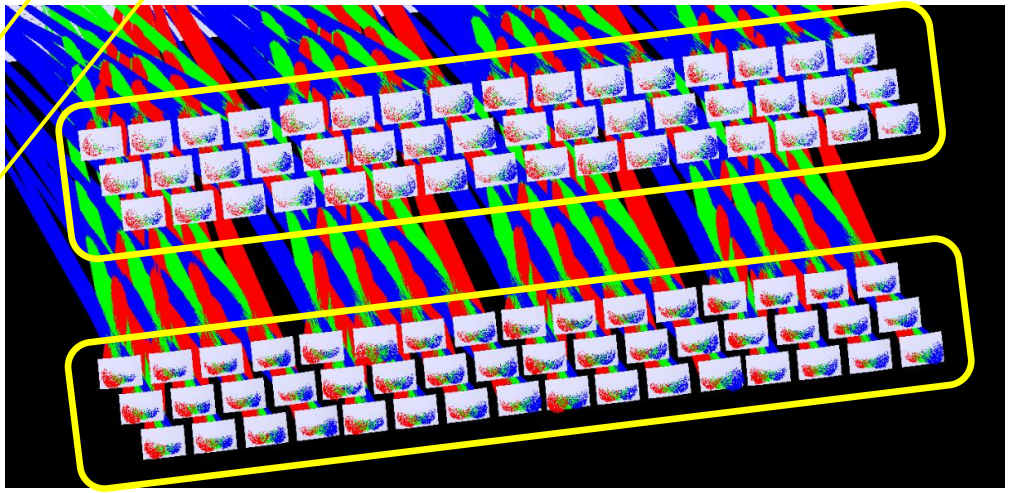




Optical design by Paolo Conconi

Slicer on the focal plane, 288 mirrors, 4 groups



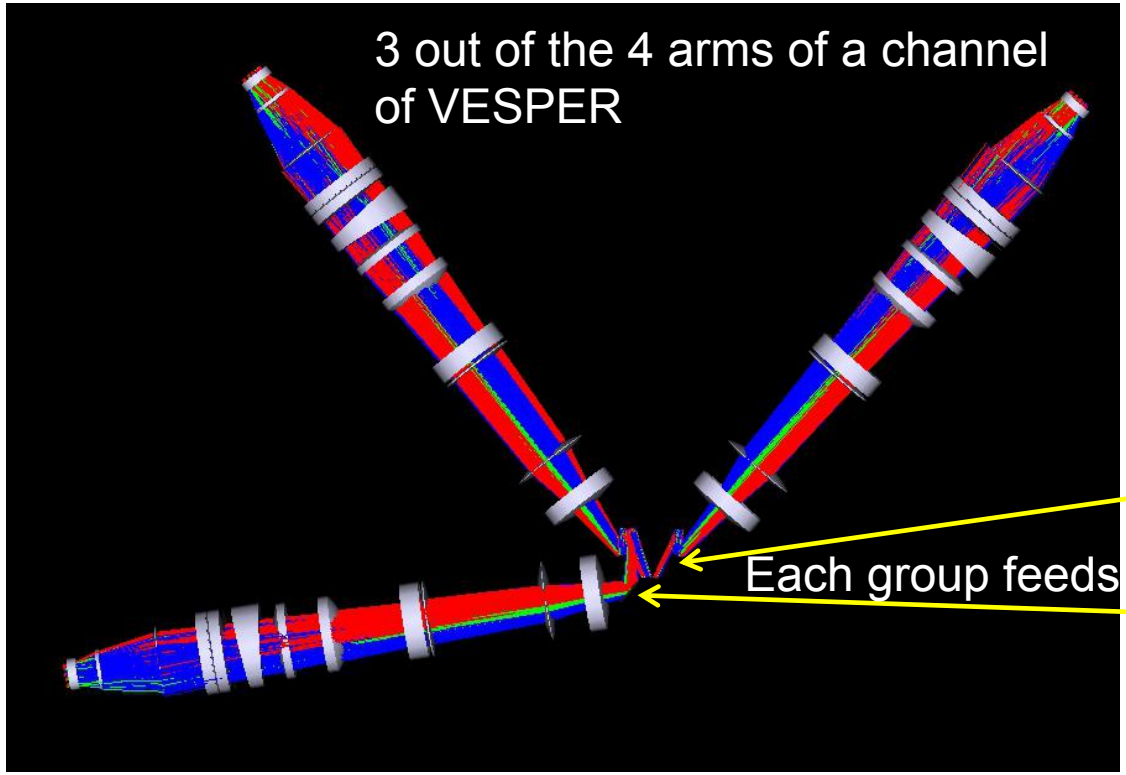


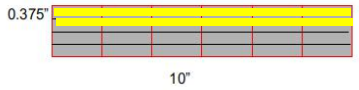
Corresponding 72+72 pupil mirrors.

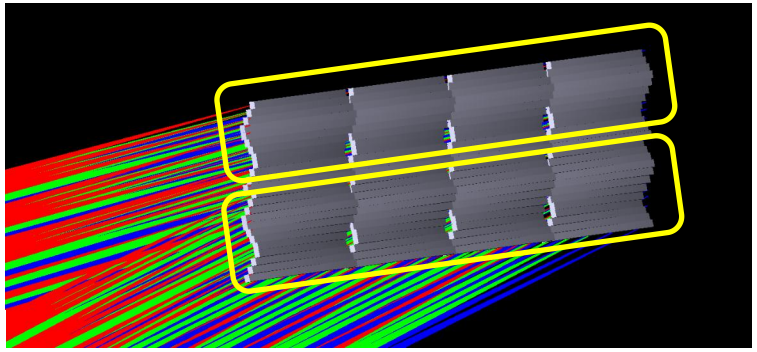
VESPER - The multi-IFU

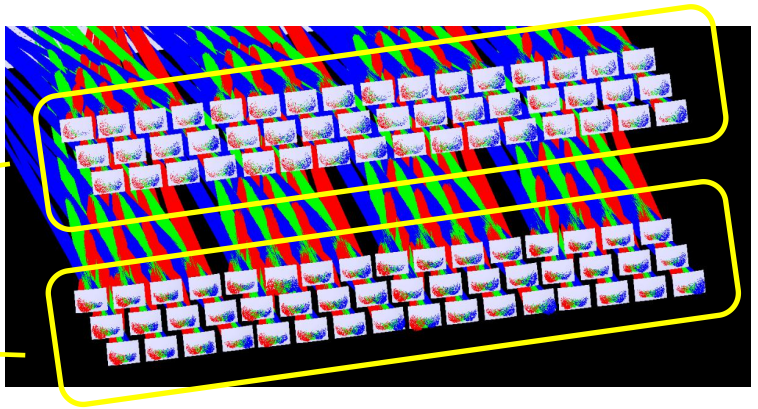
No aspheric components in VESPER

One channel of VESPER is fed by four arms



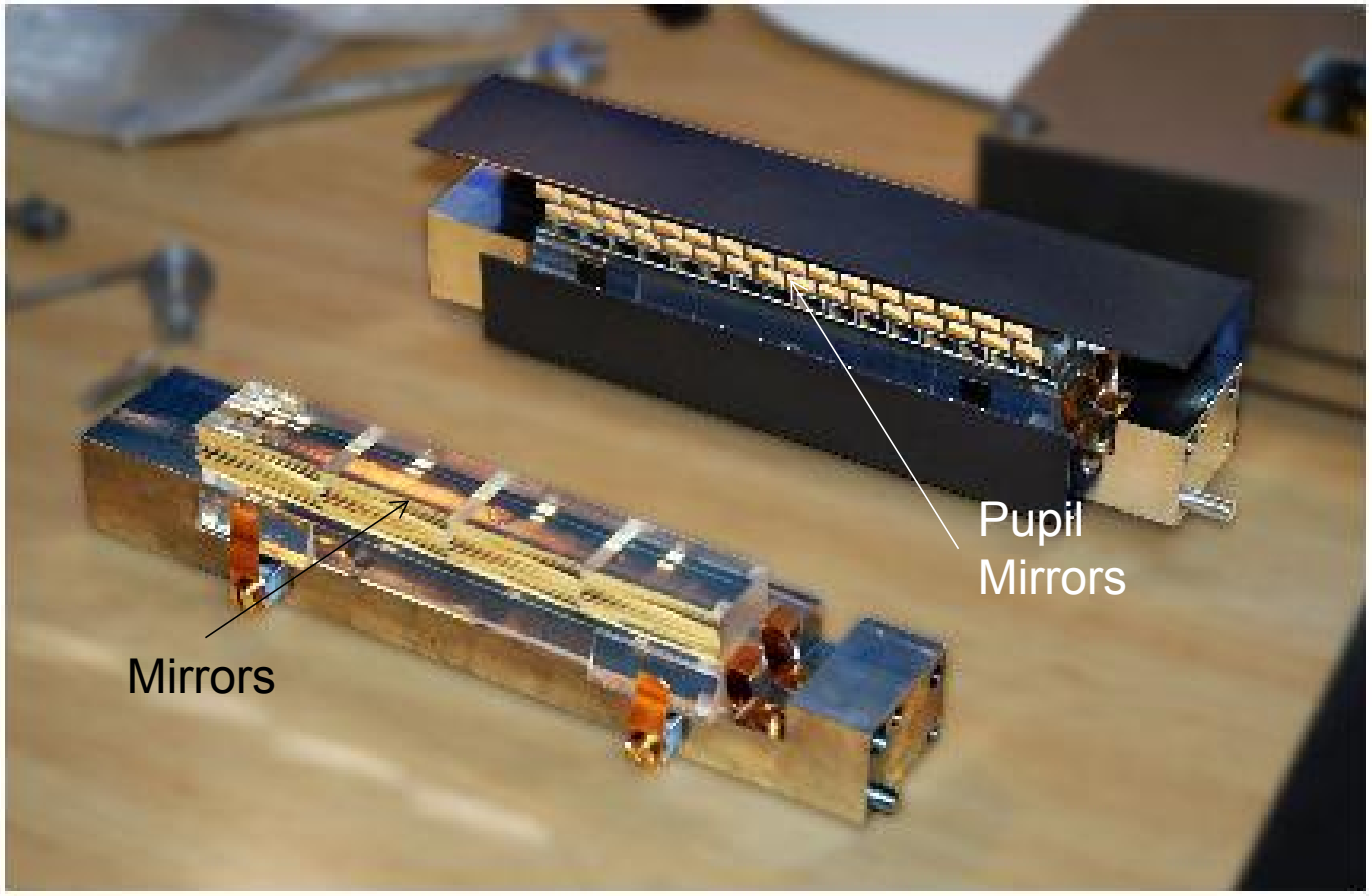






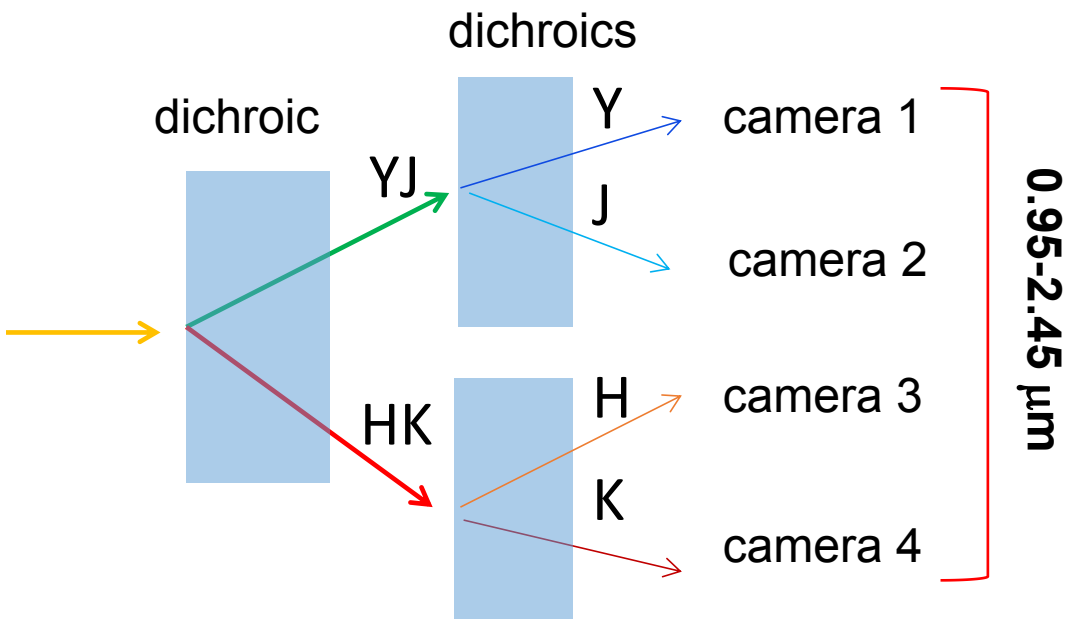
Optical design by Paolo Conconi

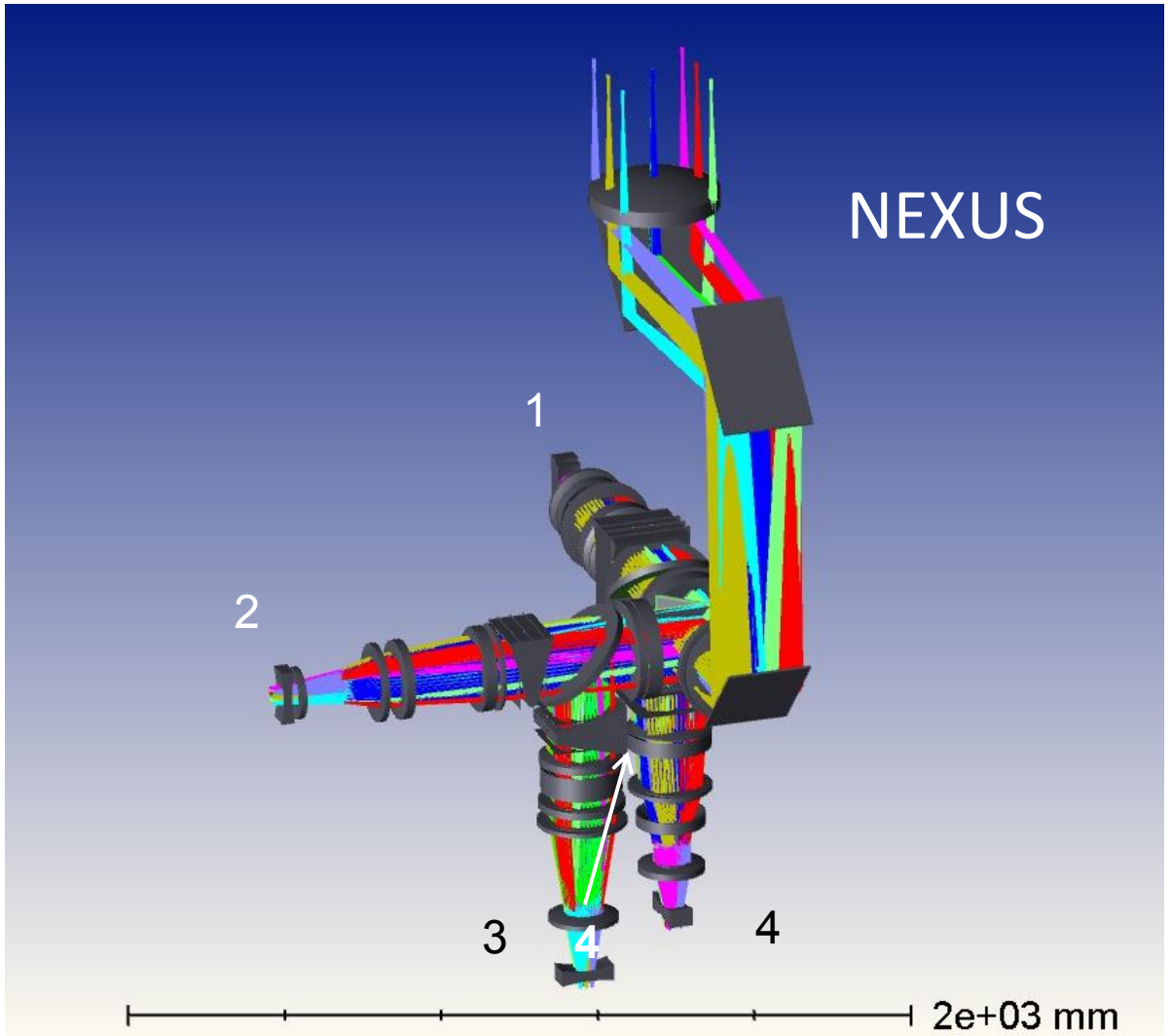
MUSE mirrors (0.8mm) and pupil mirrors



No aspheric components in NEXUS

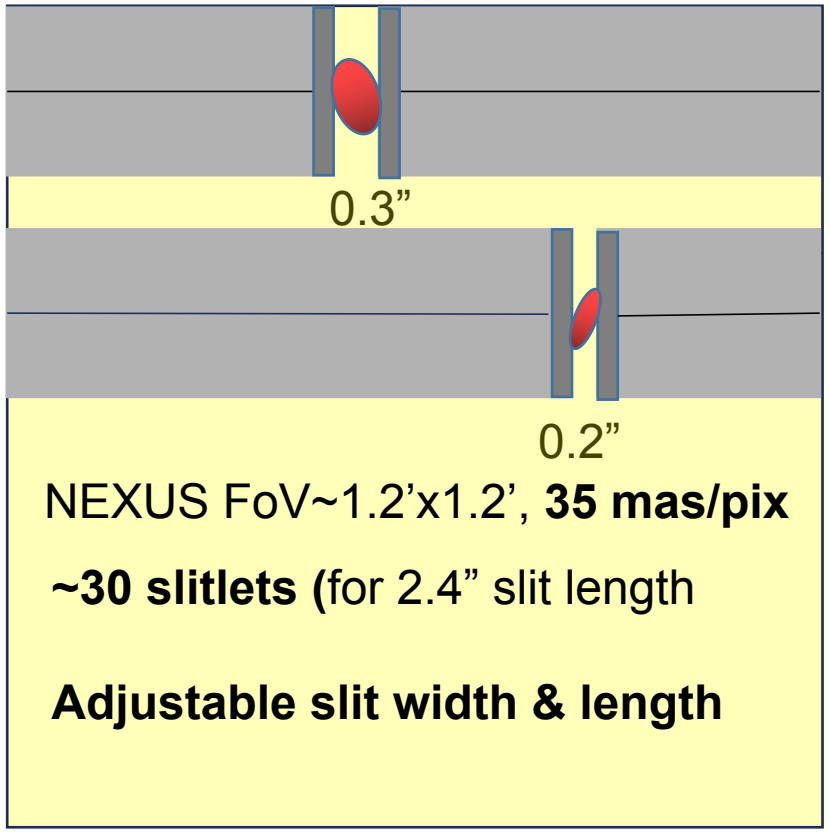
Folding mirrors + 3 dichroics
Four arms (cameras): Y, J, H, K

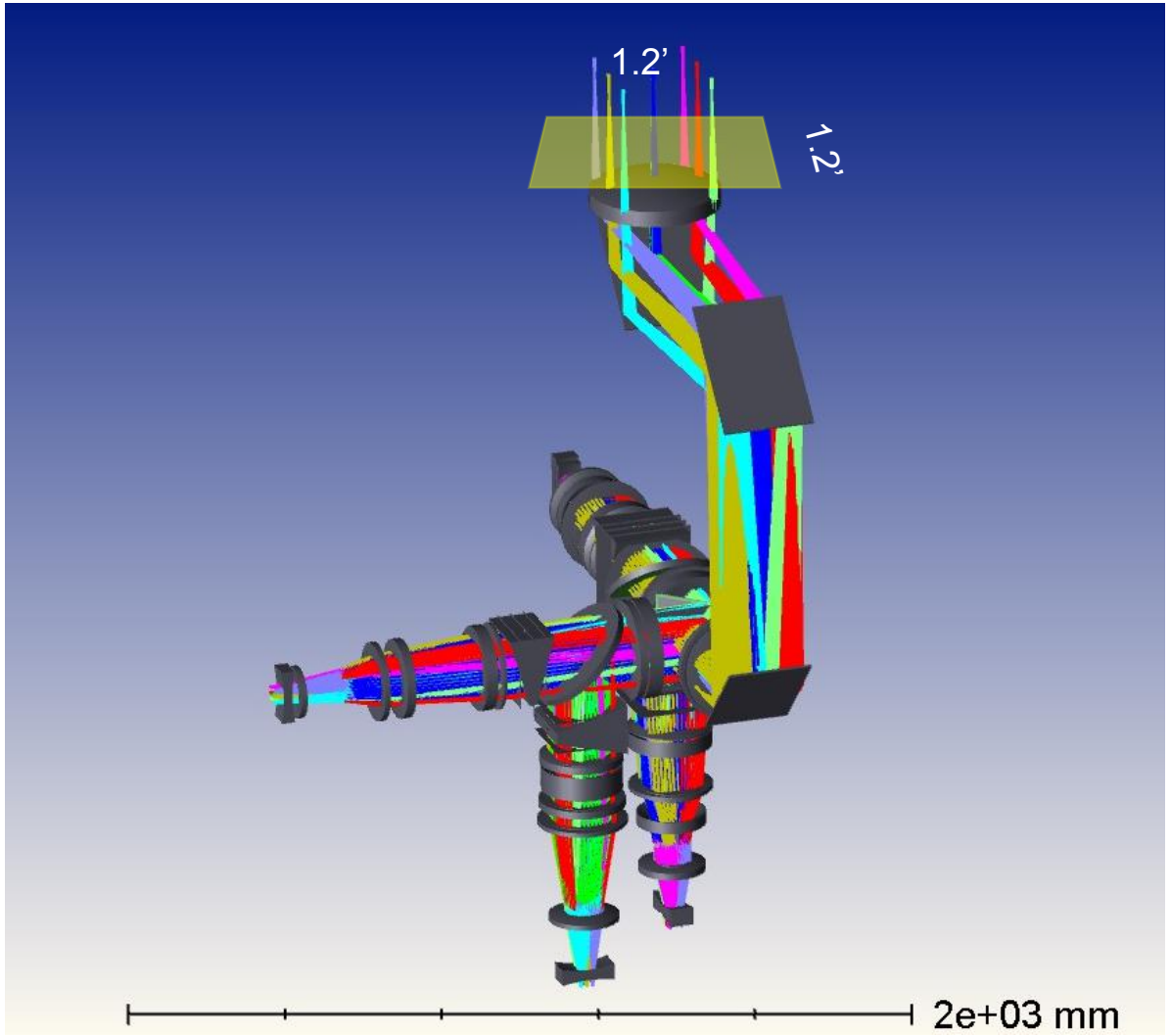




Optical design by Paolo Conconi

Robotic slit deployment system of NEXUS
(e.g. MOSFIRE at Keck)





Optical design by Paolo Conconi

NEXUS - The Multi-Object Spectrograph

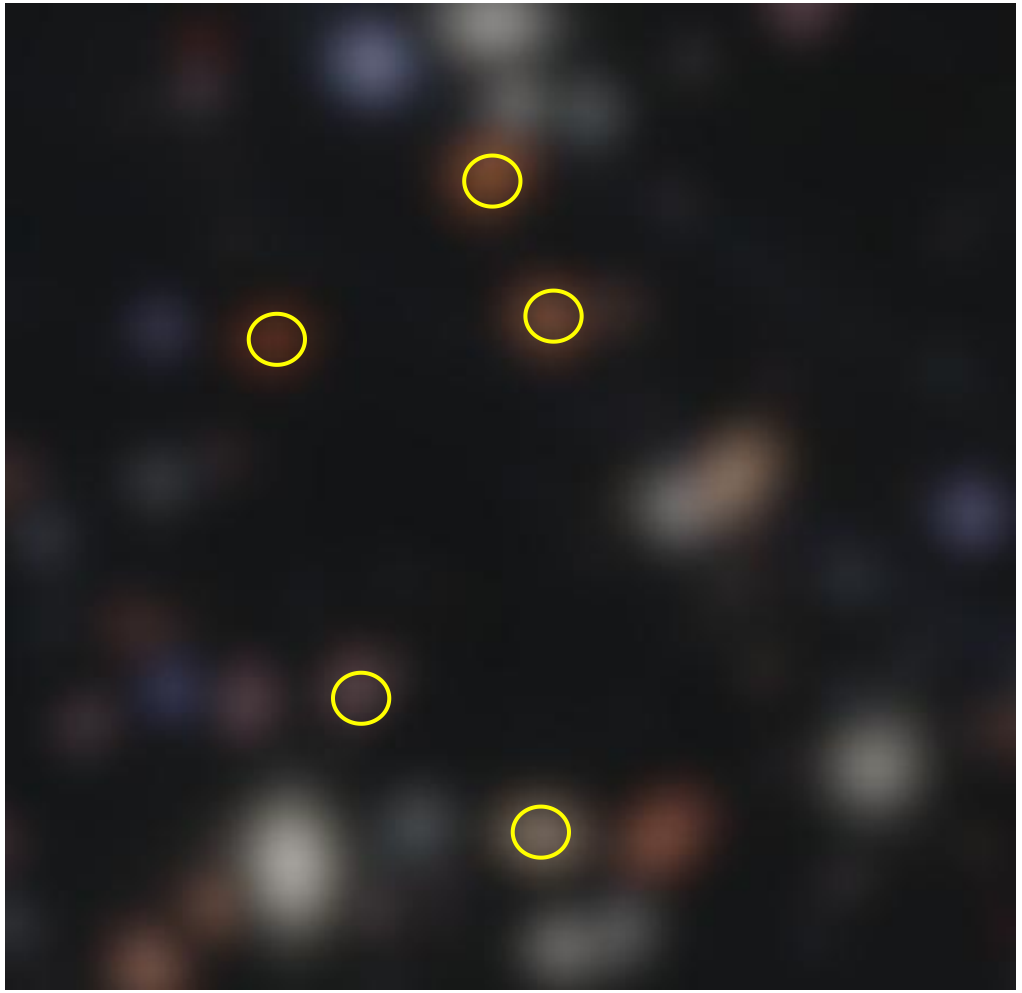
JWST NIRCam ~0.07”

GLAO ~0.2”

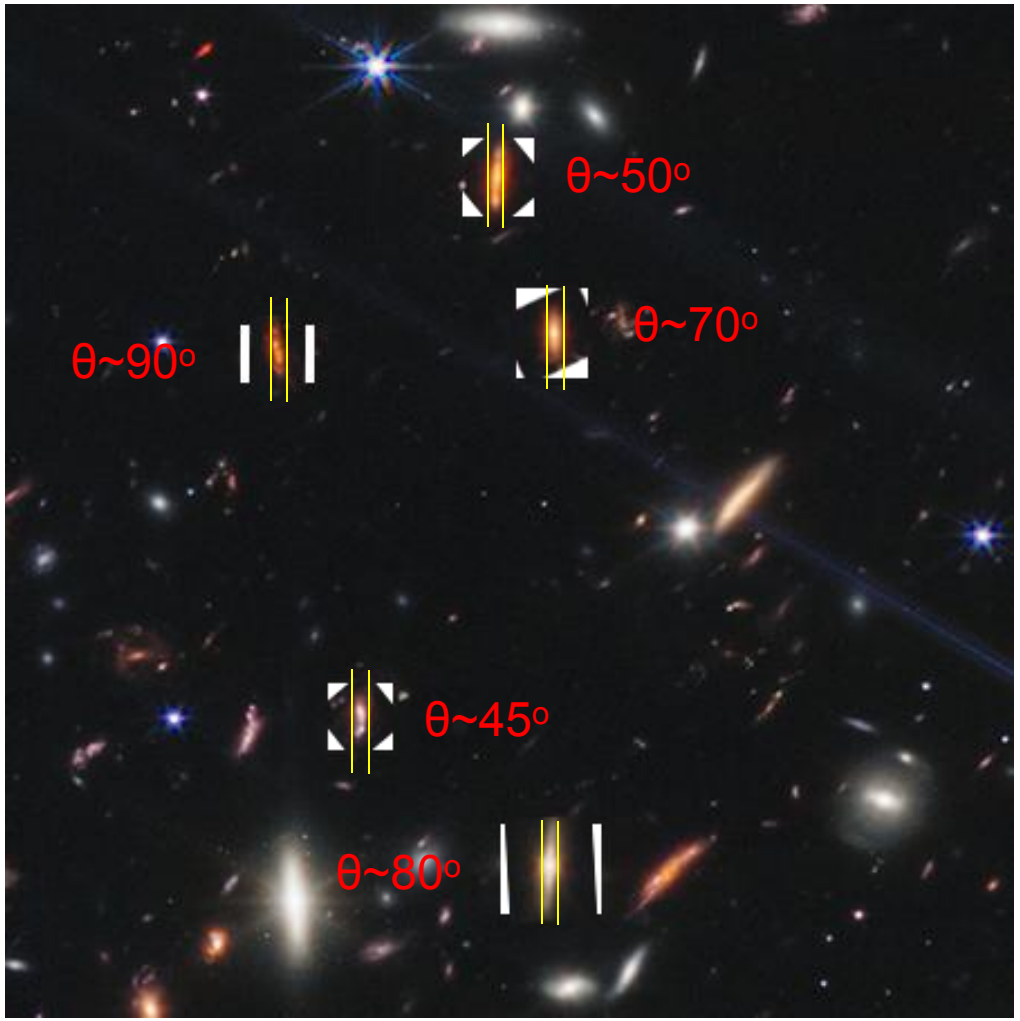
NEXUS - The Multi-Object Spectrograph

JWST NIRCam ~0.07”

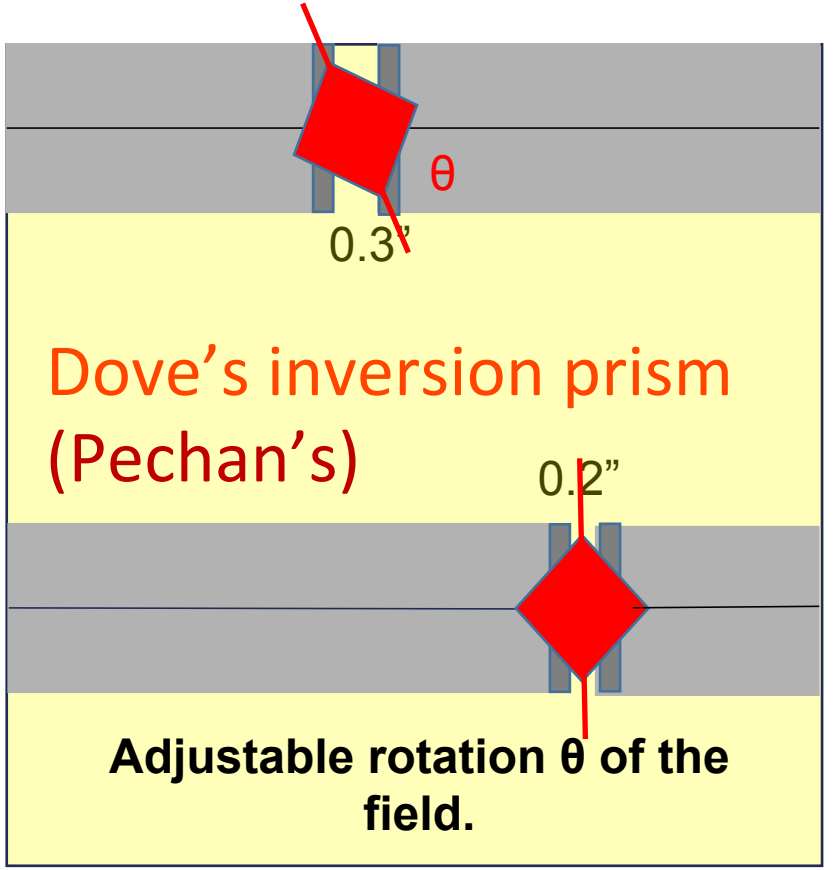
GLAO ~0.2” (e.g. MOSAIC)



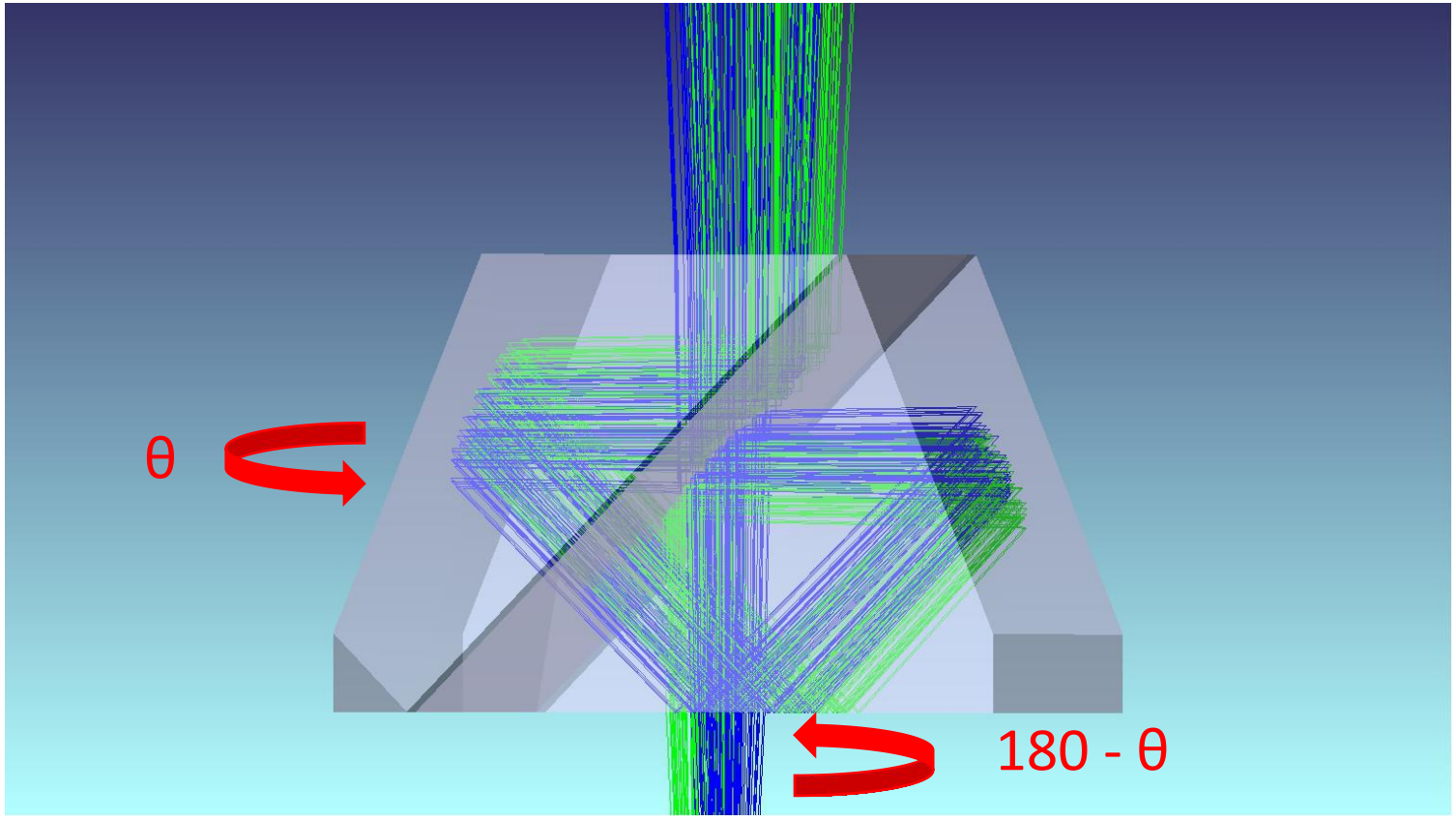
Turn the galaxies to see them better!



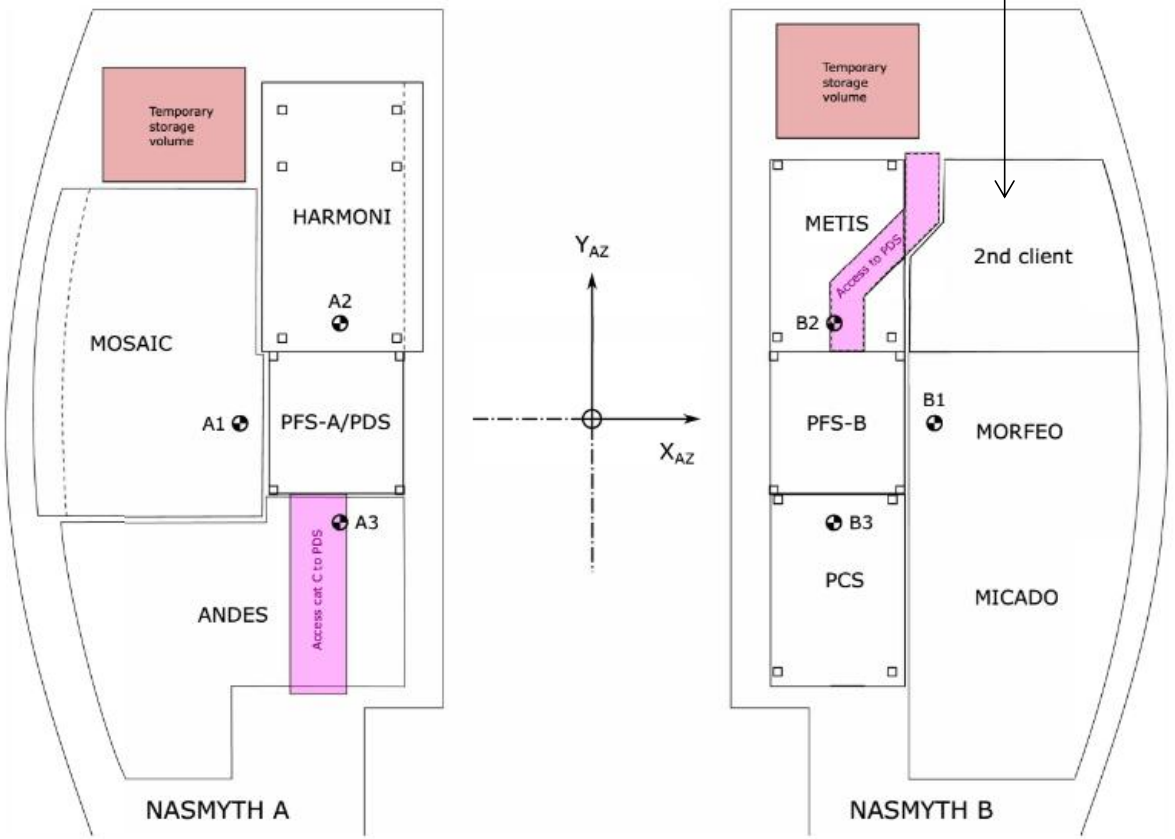
The “Swiss Clock” of NEXUS

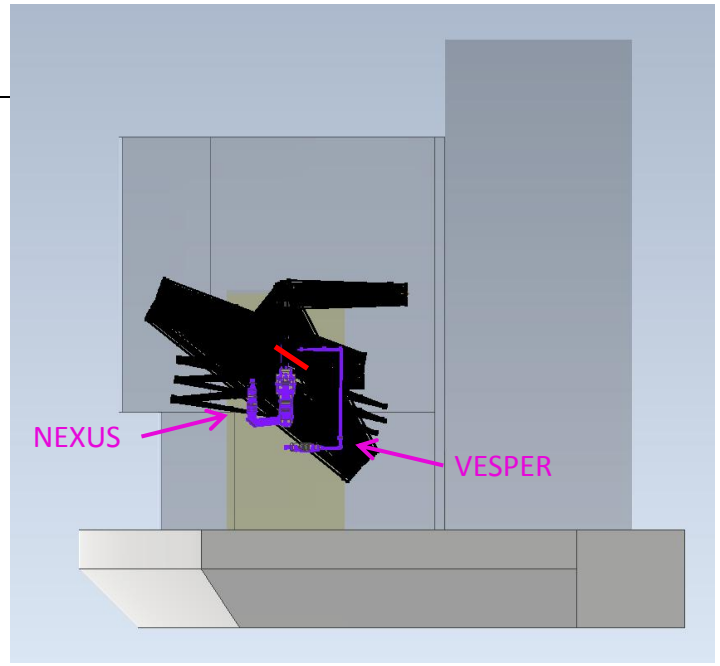


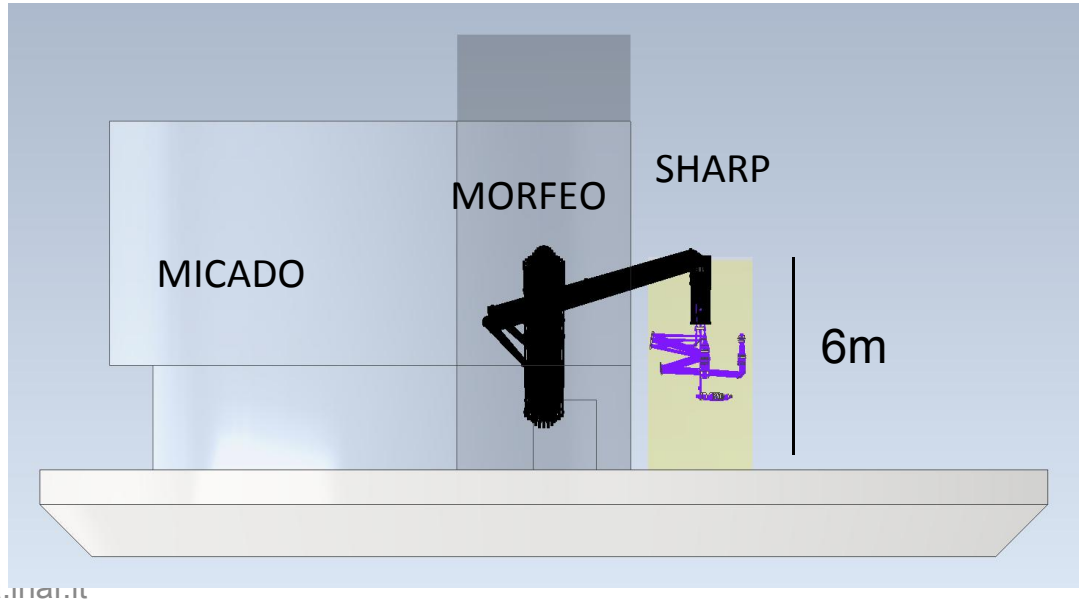
Inversion Prism



SHARP at ELT

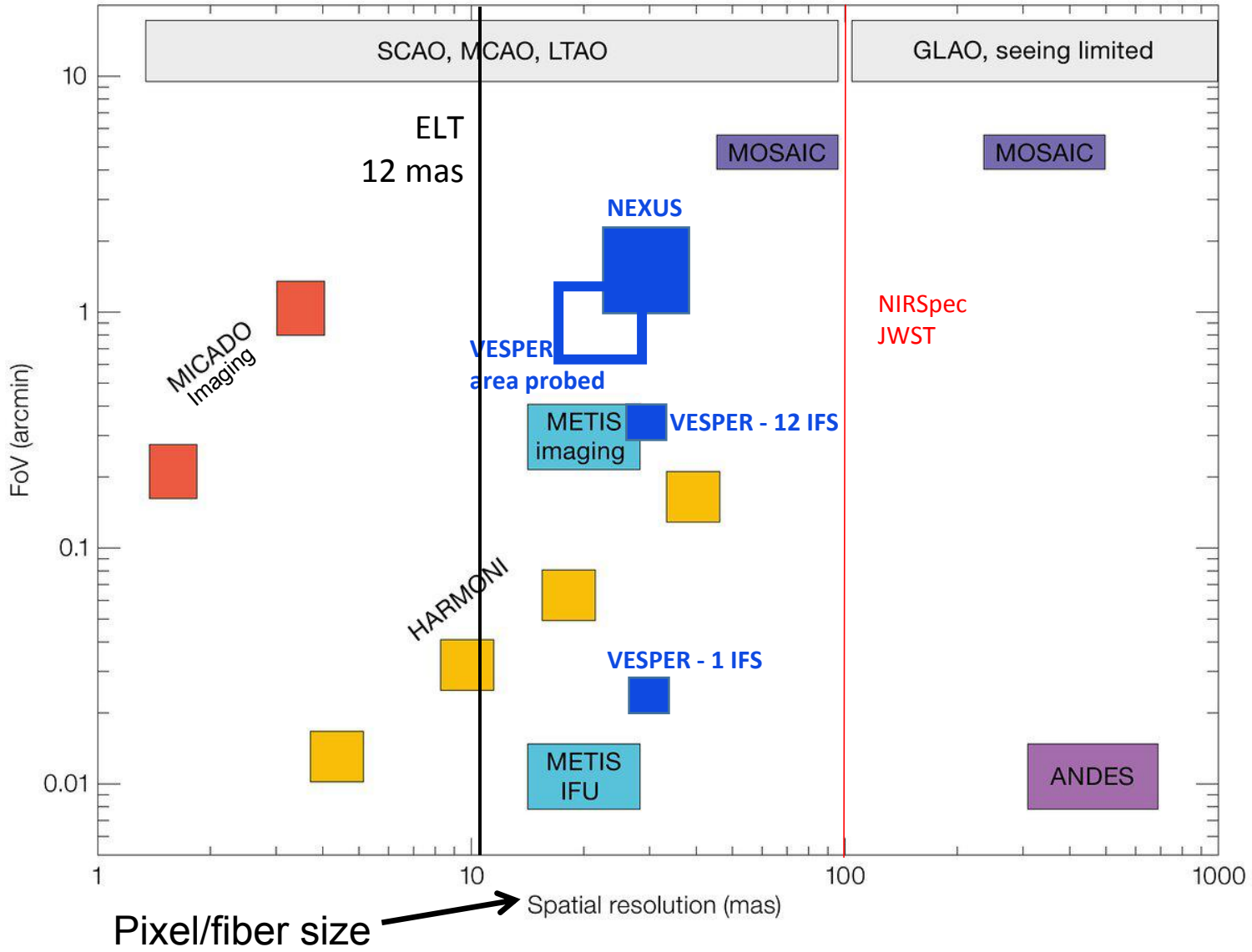






CAD by Ivan Di Antonio

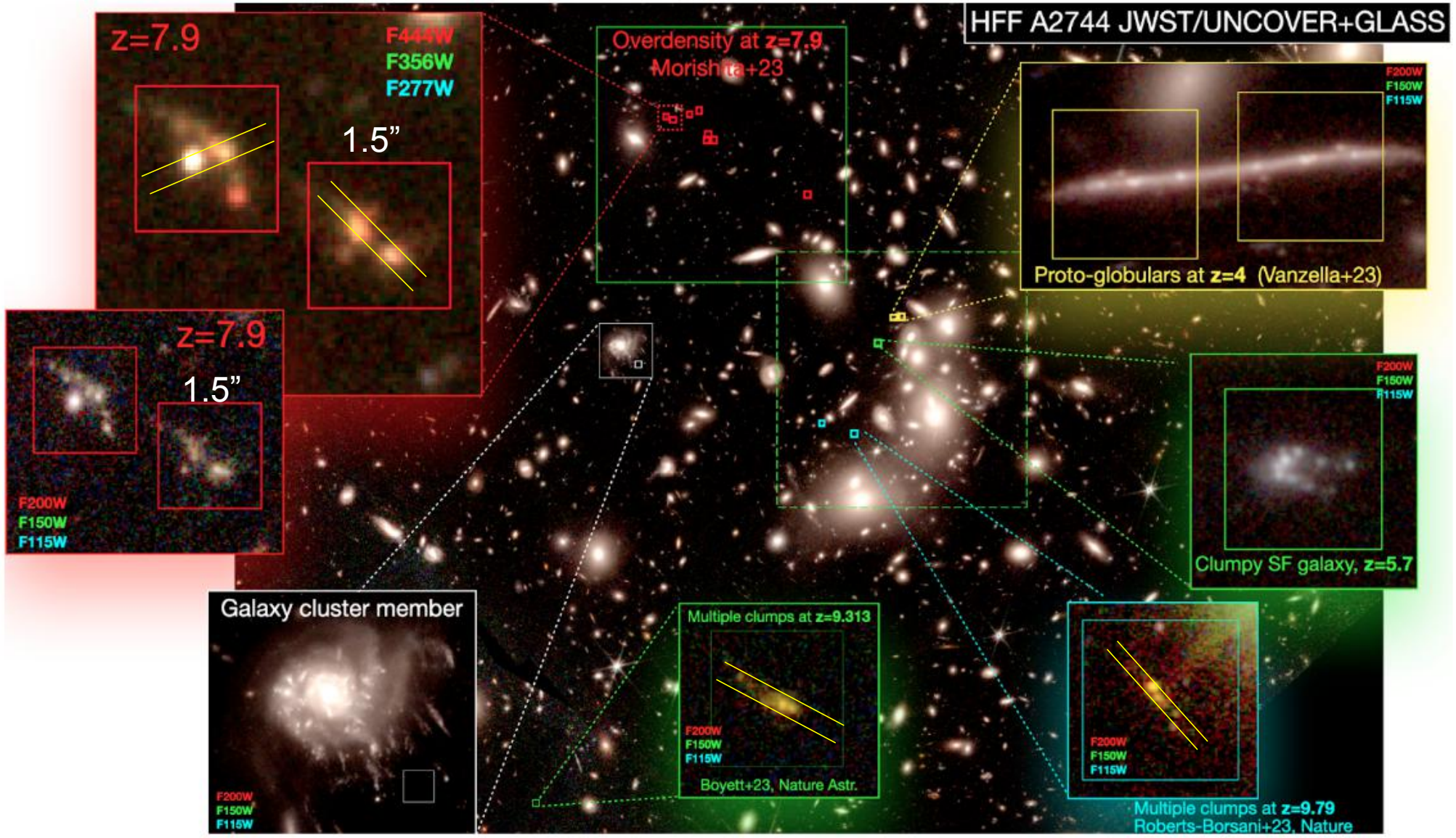
SHARP vs Other ELT Instruments



Courtesy of ESO-ELT

Science with

SHARP Potentialities - The distant Universe



VESPER

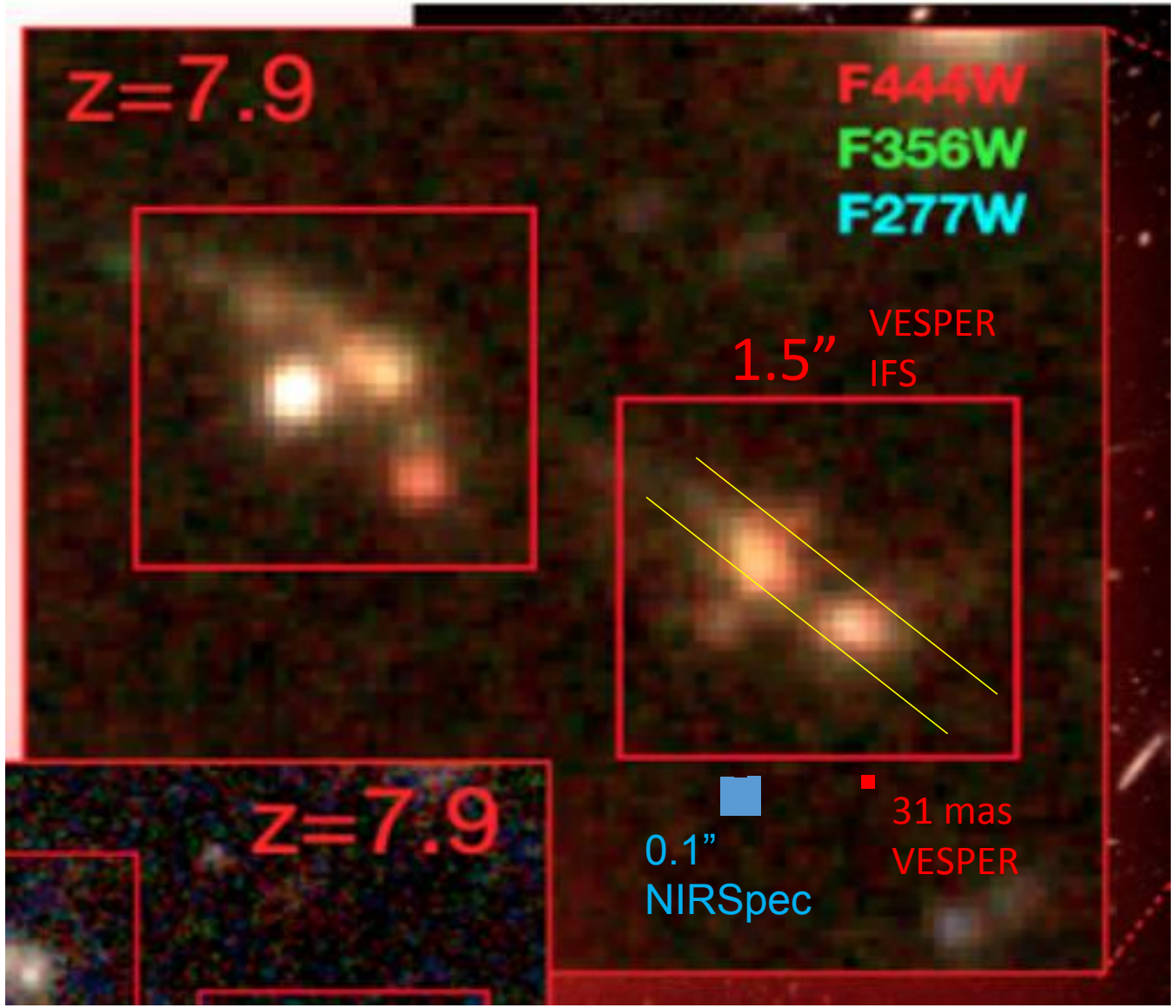
12 IFSs
1.7”x1.5”
31 mas/pix

NEXUS

30 slits
Rotating FoV
35 mas/pix

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

SHARP Potentialities - The distant Universe



VESPER

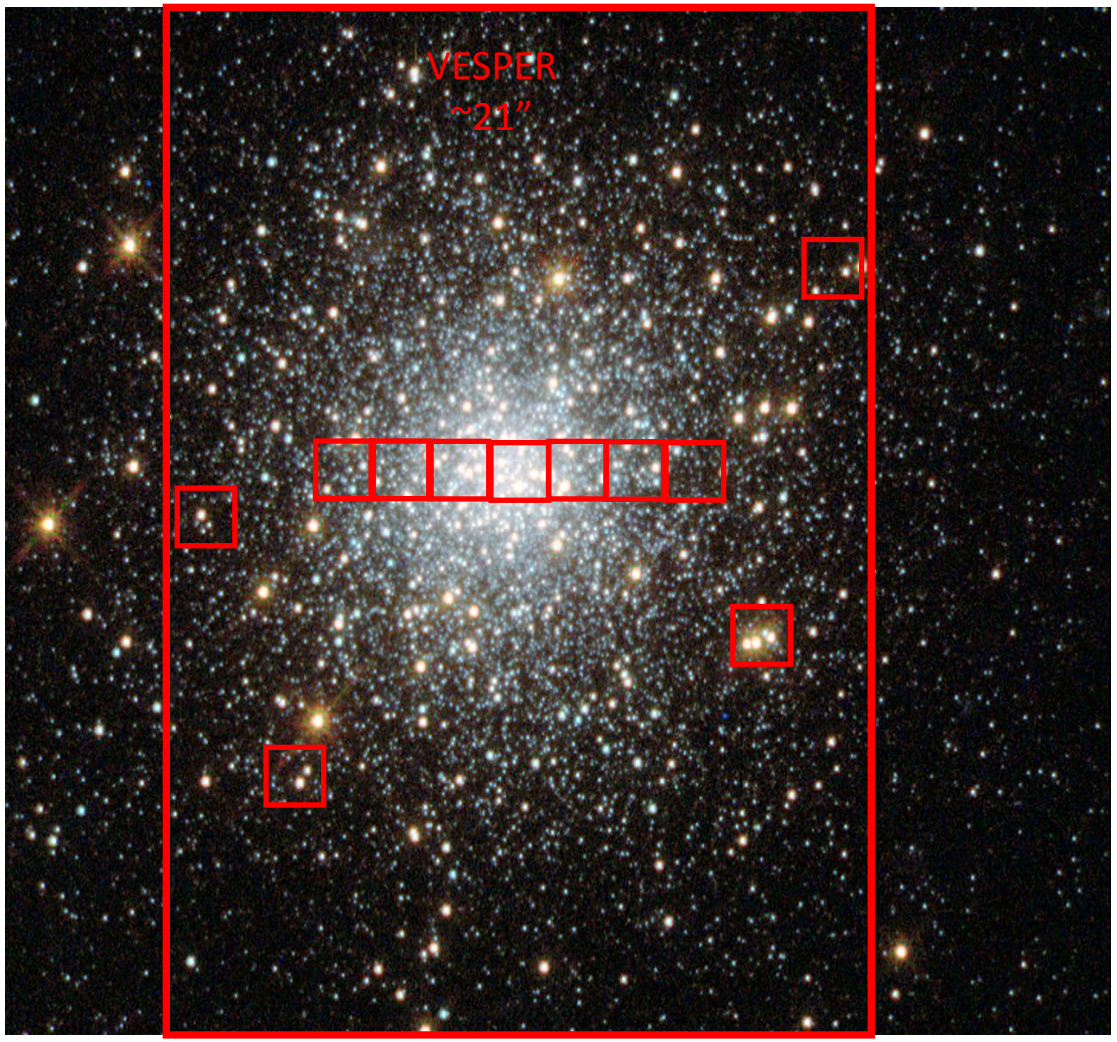
12 IFSs
1.7”x1.5”
31 mas/pix

NEXUS

30 slits
Rotating FoV
35 mas/pix

SHARP - Globular clusters within and outside the Local Group

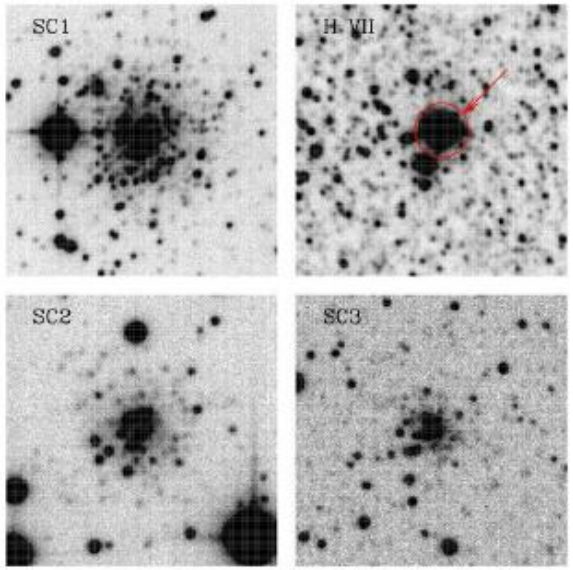
Globular cluster n.5 in the dwarf galaxy Fornax



~30 arcsec

Individual stellar properties (kinematics, chemistry) within the Local Group:
Fornax at ~150 kpc; NGC6822 at ~500 kpc

Star clusters in the halo of NGC6822



Does intermediate MBHs exist?

Accurate kinematics of hundreds stars along the major axis of GCs (within and outside LG).

Thanks to V. D’Orazi, D. Fedele, WG3&WG4

Team & Structure

SHARP Current Team (10 INAF Institutes, 3 Universities)

INAF - OA Brera Milano
Paolo Saracco (PI)
Paolo Conconi (Opt. des)
Ilaria Arosio (Com. Off.)
Laura Barbalini
Marcella Longhetti
Hossein Mahmoodzadeh
Emilio Molinari (PM)
Marco Riva (advisor)
Marcello Scalera (PhD)
GOLEM

INAF - IASF Milano
Susanna Bisogni
Paolo Franzetti
Marco Fumana
Adriana Gargiulo (WG2)
Chiara Mancini
Maria Polletta
Marco Scodeggio
Giustina Vietri

INAF - OAS Bologna
Roberto Decarli
Gabriele Rodeghiero
Eros Vanzella (WG1)

Univ. di Bologna
Carmela Lardo
Michele Moresco

INAF - OA Padova
Carmelo Arcidiacono (IS)
Davide Greggio

INAF - OA Palermo
Sara Bonito
Loredana Prisinzano

INAF - OAstr. Arcetri
Davide Fedele (WG3)
Anna Rita Gallazzi
Laura Magrini
Linda Podio
Veronica Roccatagliata
Lorenzo Spina

INAF - OA Capodimonte
Juan Manuel Alcala'
Alessio Caratti O Garatti
Enrico Cascone
Massimo Dall'Ora
Vincenzo De Caprio
Luca Izzo
Francesco La Barbera
Vincenzo Ripepi

INAF - OA d'Abruzzo
Gianluca Di Rico
Elisa Portaluri
Benedetta Di Francesco (PhD)
Ivan Di Antonio

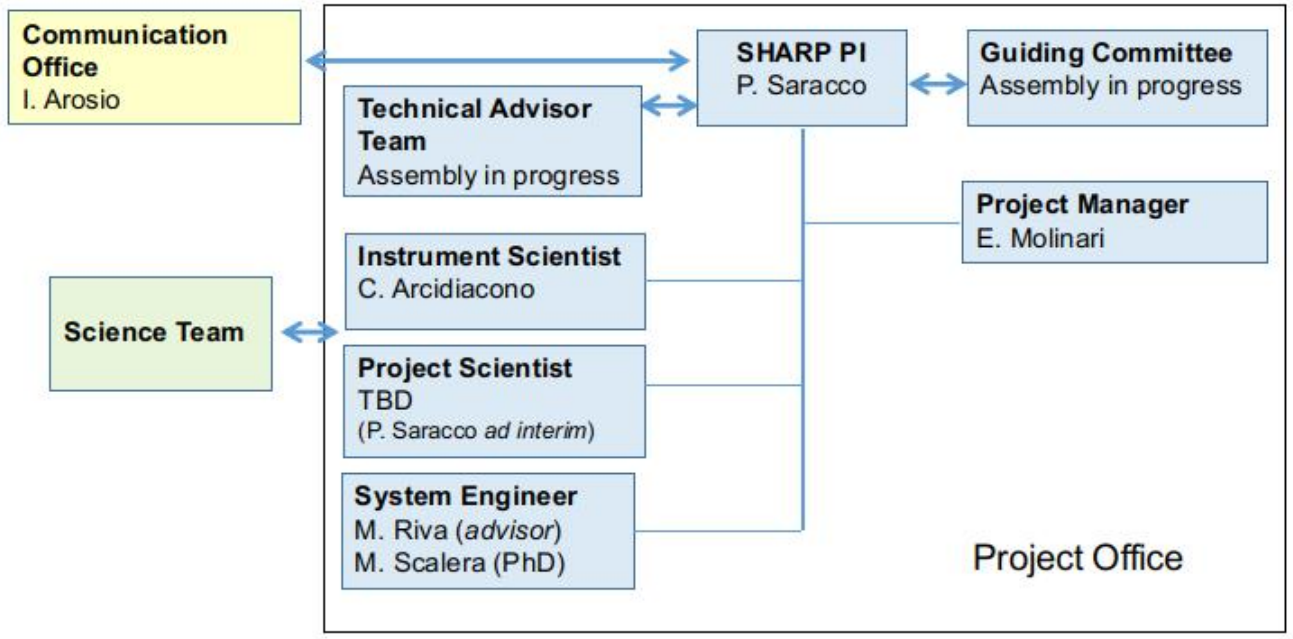
INAF - IAPS Roma
Andrea Longobardo

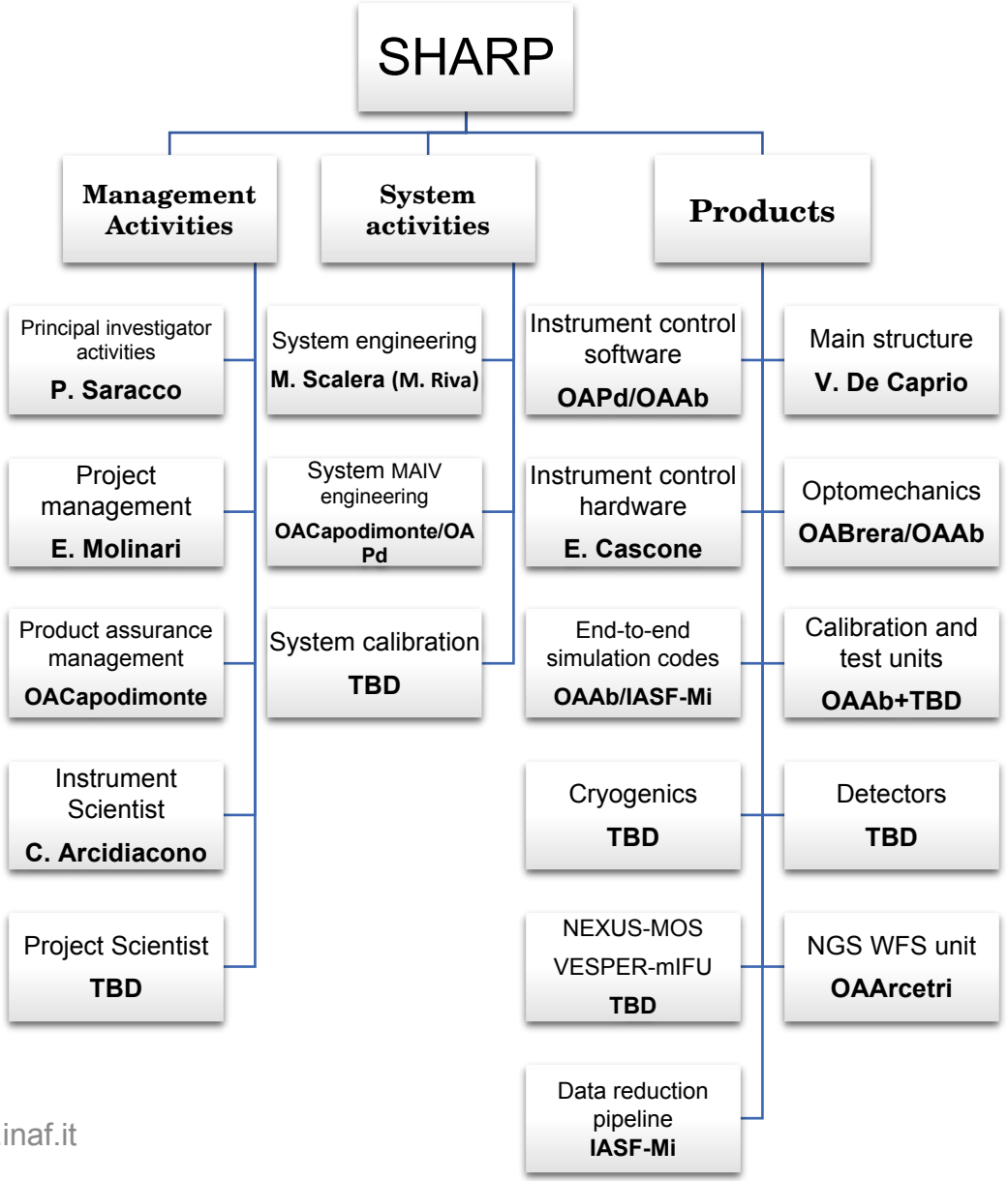
INAF - OA Roma
Giuliana Fiorentino

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

Univ. Roma 3
Federica Ricci

SHARP - Project Office & Work Breakdown Structure





Guiding Committee - Composed of experienced/seniors. Provides the projects with guidance and assures the reliability of the project. It will become the Steering Committee when the International Consortium will be assembled.

SHARP - Science Team

SHARP Science Team: 4 Working Groups

WG1 - Early Universe and Cosmology

Themes: Early Universe, primordial galaxies, reionization, intergalactic/circumgalactic medium, absorption systems, gravitational lensing, dark matter, cosmological parameters

WG2 - Galaxies and AGNs

Themes: galaxies in their environment; structure, dynamics and kinematics; interactions; unresolved stellar populations; assembly of galaxies; chemical evolution of galaxies; coevolution; physics of AGNs, supermassive BHs.

WG3 - Interstellar medium, young stellar objects, planetary systems

Themes: gas and dust, molecular clouds, HII regions, massive stars, (pre) MS stars, star formation, chemical processes in interstellar medium, extrasolar planet search.

WG4 - Resolved stellar populations

Themes: local Group, local volume, Milky way, Supernovae, pulsars, planetary nebulae, AGB/postAGB stars, star clusters

WG#1

Eros Vanzella
Giuliana Fiorentino
Luca Izzo
Michele Moresco
Vincenzo Ripepi

WG#2

Adriana Gargiulo
Susanna Bisogni
Roberto Decarli
Anna Gallazzi
Luca Izzo
Francesco La Barbera
Marcella Longhetto
Chiara Mancini
Mari Polletta
Elisa Portaluri
Federica Ricci
Marco Scodeggio
Giustina Vietri

WG#3

Davide Fedele
Juan Manuel Alcala'
Rosaria (Sara) Bonito
Andrea Longobardo
Linda Podio
Loredana Prisinzano
Veronica Roccatagliata
Alessio Caratti

WG#4

Valentina D'Orazi
Massimo Dall'Ora
Vincenzo Ripepi
Giuliana Fiorentino
Giuseppe Bono
Laura Magrini
Carmela Lardo
Lorenzo Spina

Open to those interested in SHARP

Project Status

Short Term Goal (2025-2026)

Proposing SHARP for the 2nd port of MORFEO at the ESO call for new instrumentation (probably in 2026).

Tasks to be completed by 2025-early 2026

- ✓ Optical design
- Engineering assessment
- International consortium

Engineering Assessment

- **Techno Grant 2022** - 98 kE ==> Recruitment of an optomechanical engineer

84 kE (85%) used to fund **Dottorato di Ricerca Dept. Ingegneria Meccanica - Politecnico di Milano**

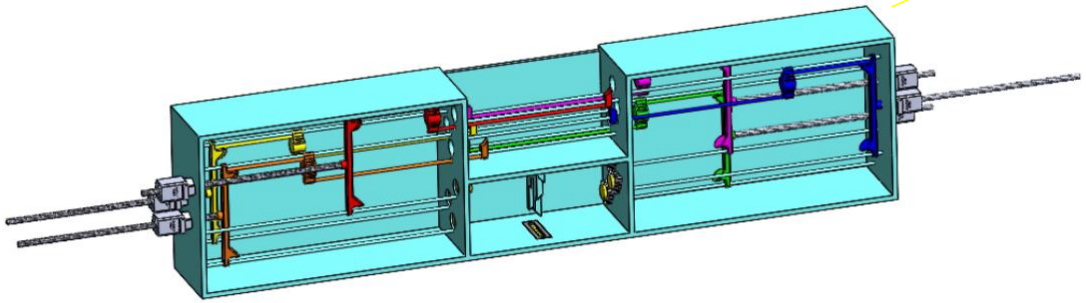
Ing. Hossein Mahmoodzadeh (PhD PoliMi)

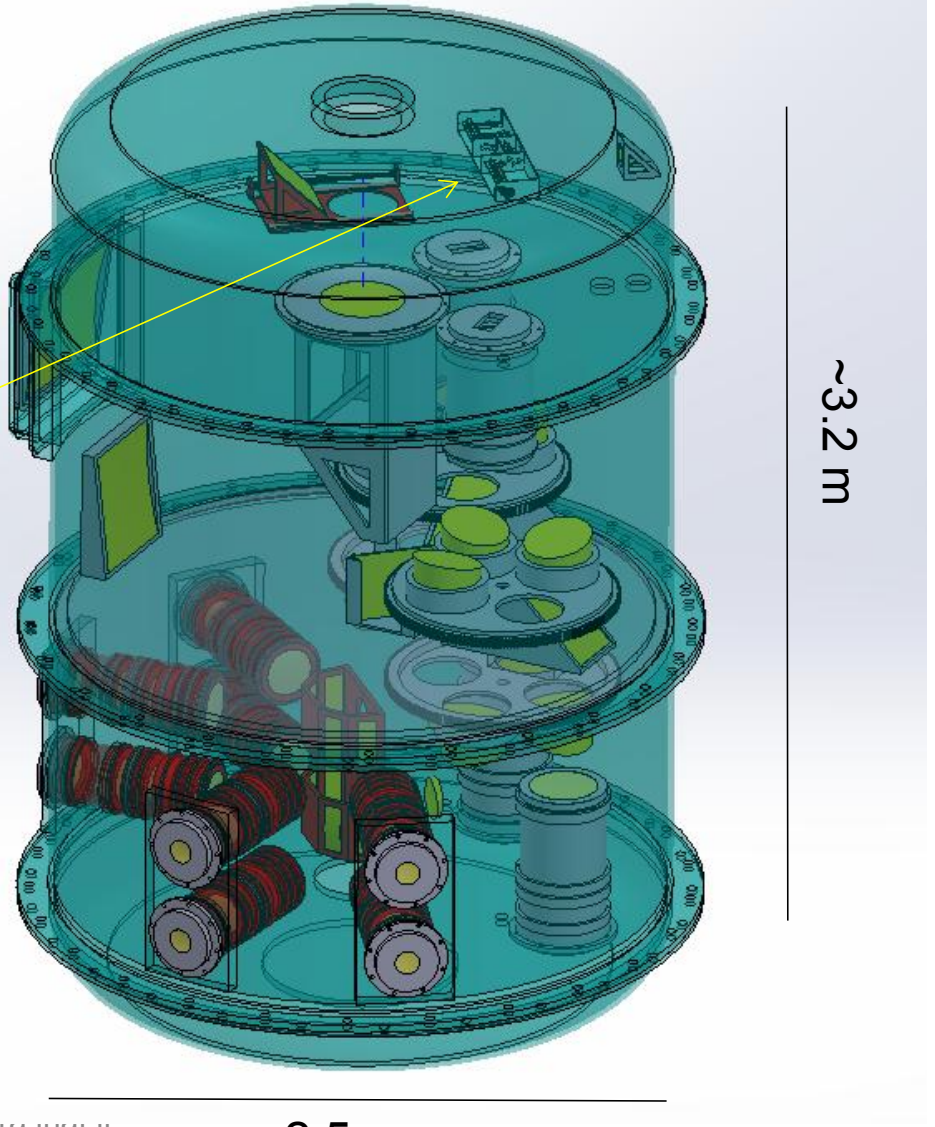
- We plan to adopt the **Concurrent Design Facility**

Conceptual Engineering Design Ongoing

by Ing. Hossein Mahmoodzadeh
(PhD PoliMi)

VESPER
Integral Field Selector System





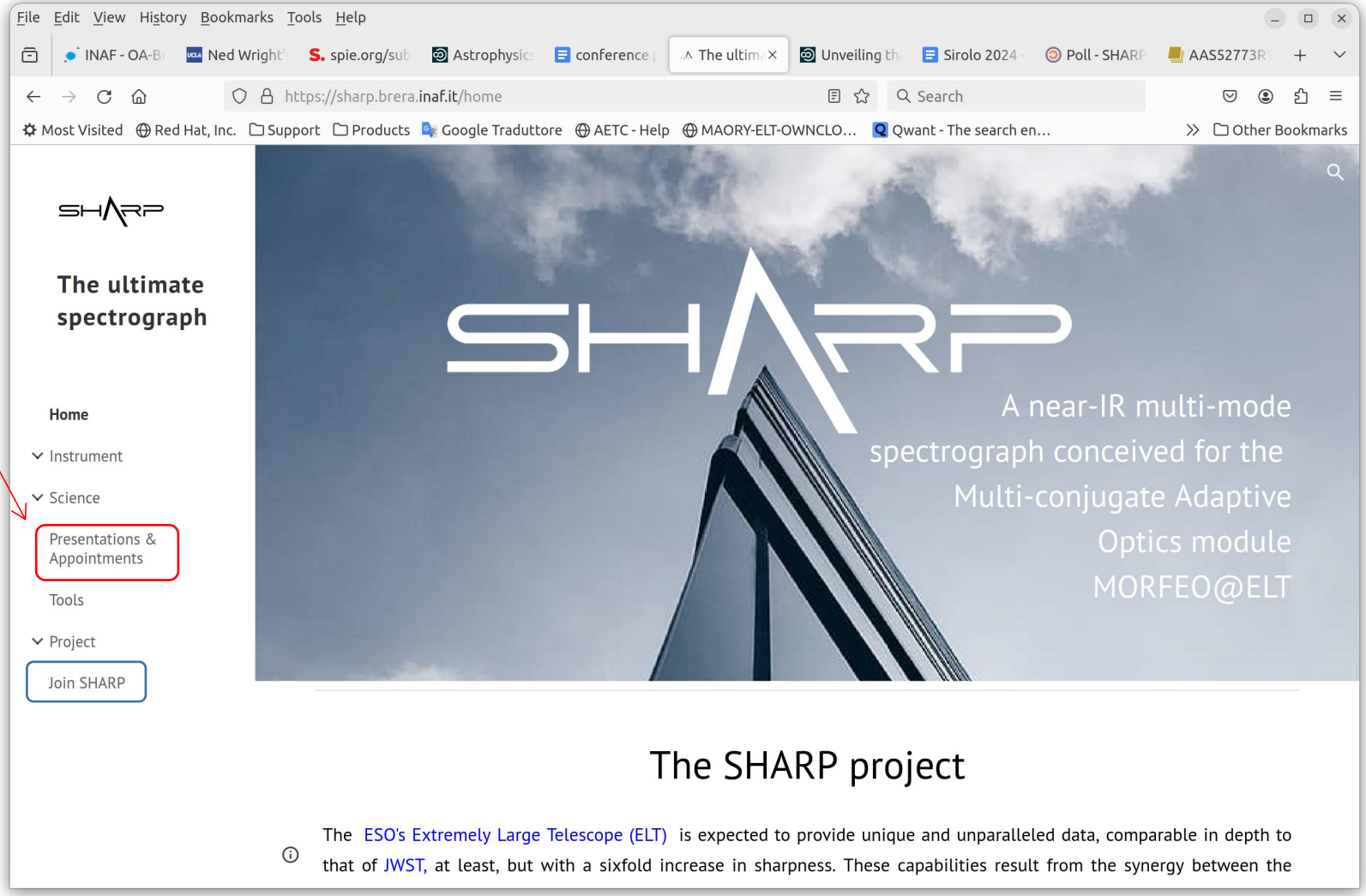
SHARP - Project Status

http://sharp.brera.inaf.it

2024 - SHARP meeting
Unveiling the Universe with SHARP
30 September-02 October 2024, Milan
To involve the community in the **White Books**
(to be published, e.g., MemSait)

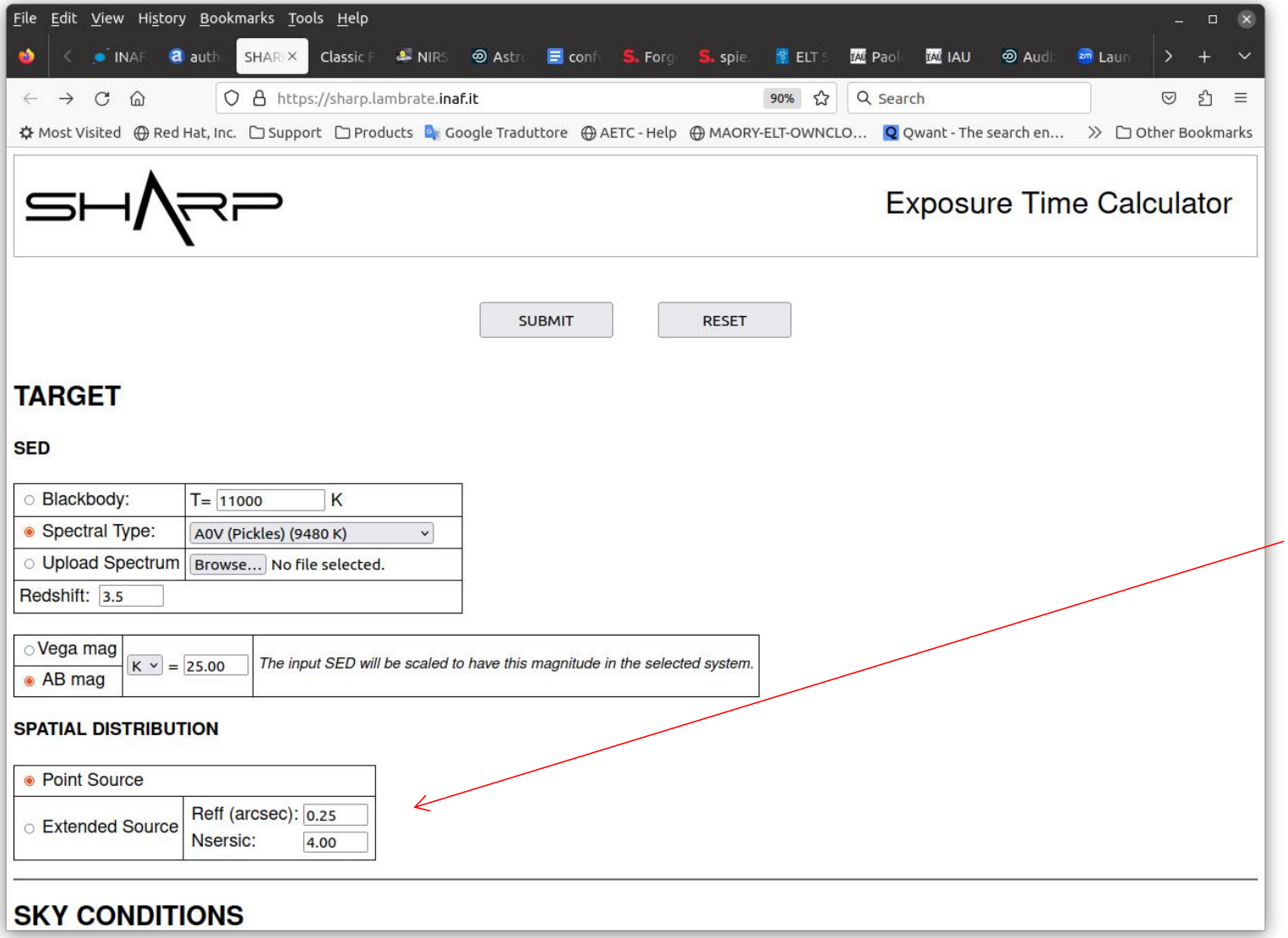
To join the SHARP project
sharp_join.oabr@inaf.it

or email to
paolo.saracco@inaf.it
carmelo.arcidiacono@inaf.it



SHARP - Project Status

http://sharp.brera.inaf.it



SHARP - ETC
(SHARP website, under *Tools*)

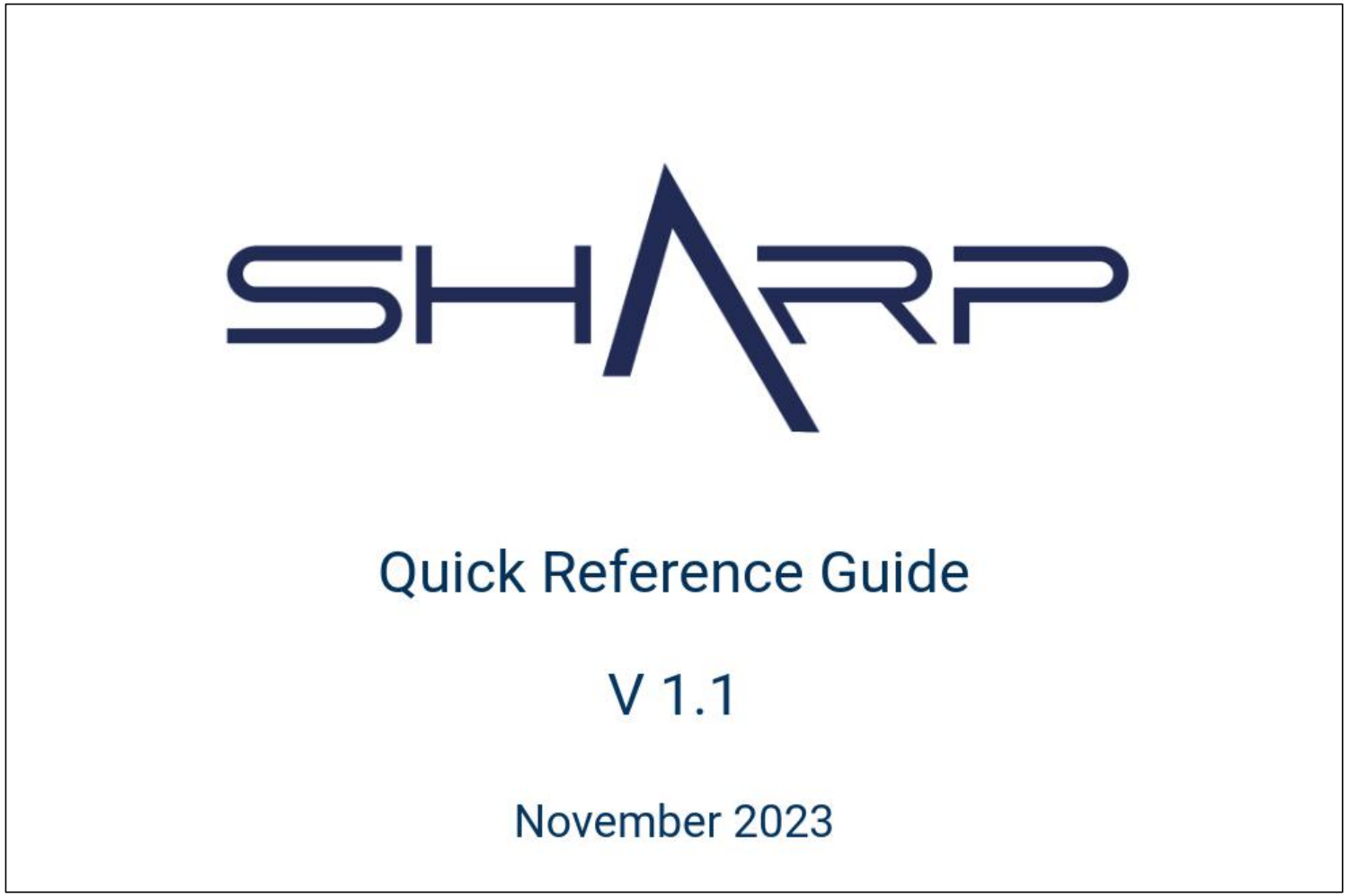
ETC - Fundamental tool for developing your own science cases

SHARP ETC takes into account

- the light profile and
- the angular size of the source

fundamental parameters for AO observations

ETC by Paolo Franzetti & Marco Fumana



2024 - National focus meeting
Unveiling the Universe with SHARP
30 September-02 October 2024, Milan

To involve the community in the **White Books**

Tools:
SHARP-ETC
SHARP Quick Reference Guide

To join the SHARP project
sharp_join.oabr@inaf.it

Objectives and Ambitions

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

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

This is SHARP

Thank you!