MOSAIC

http://www.mosaic-elt.eu

MOSAIC:
a Multi Object Spectrograph for the ELT

A gigantic step into the Deep Universe

L. Pentericci

on behalf of the MOSAIC team

OAR

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

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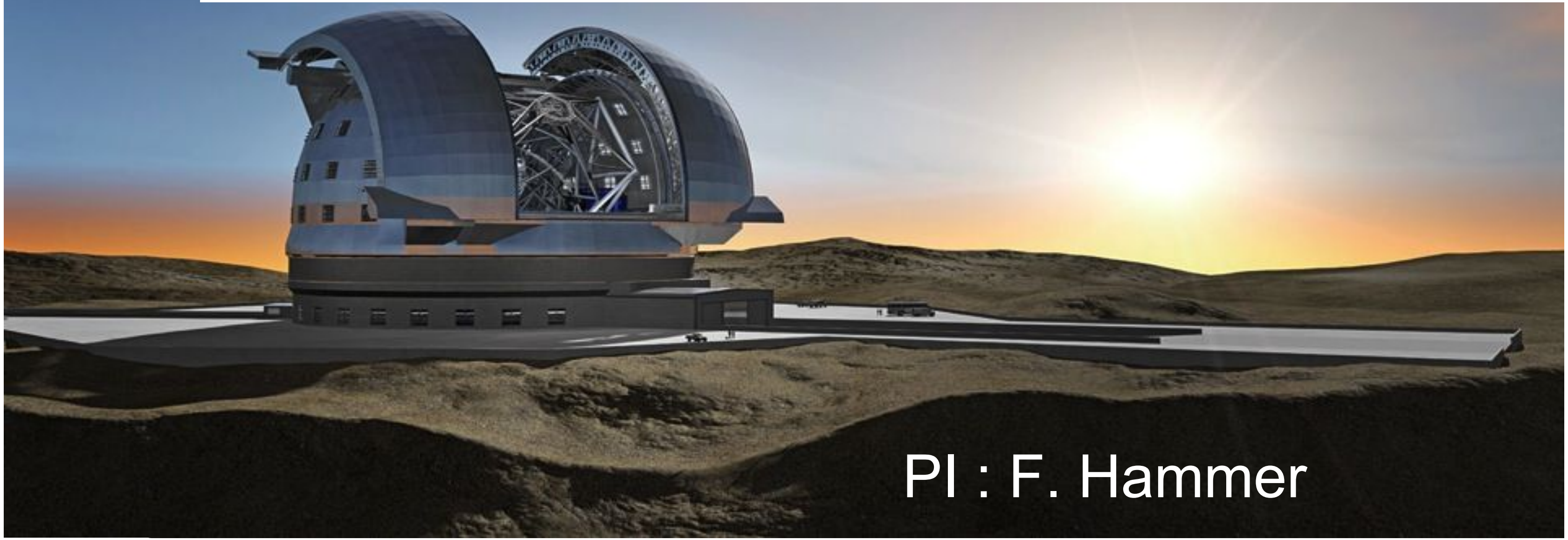
Also: Heidelberg/Göttingen, Stockholm/Lund, Helsinki/Turku, Madrid Complutense/IAA, INAF Roma/Arcetri, Vienna, Lisboa/Porto Last newcomers: Geneva and Univ. of Michigan



PI : F. Hammer

l'Observatoire de Paris

Science & Technology Facilities Council UK Astronomy Technology Centre

LAM

Universiteit van Amsterdam

Durham University

NOVA

University of Oxford

irap astrophysique & planétologie

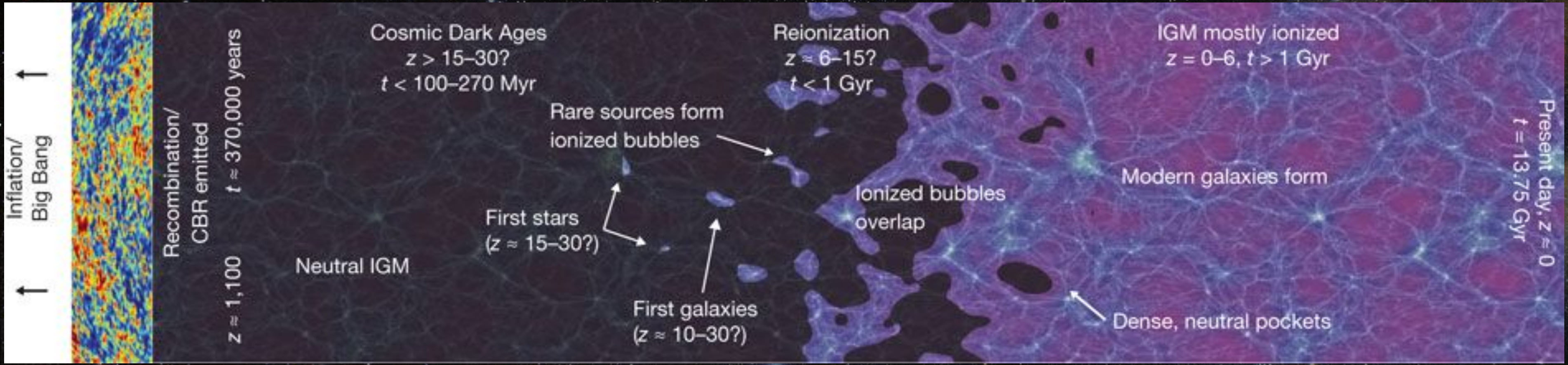
Key science cases

There are eight key science cases (SC) for an ELT-MOS, which form the core cases for MOSAIC (White Paper Evans et al. 2015):

SC1: ‘First light’ – Spectroscopy of the most distant galaxies;
SC2: Evolution of large-scale structures/IGM tomography/high-z clusters
SC3: Mass assembly of galaxies through cosmic time/the role of dwarf galaxies
SC4: Active Galactic Nuclei-Galaxy co-evolution & AGN feedback;
SC5: Resolved stellar populations beyond the Local Group;
SC6: Galaxy archaeology;
SC7: Galactic Centre science;
SC8: Planet formation in different environments.

SC1: First galaxies and reionization

E-ELT & JWST VLT & HST

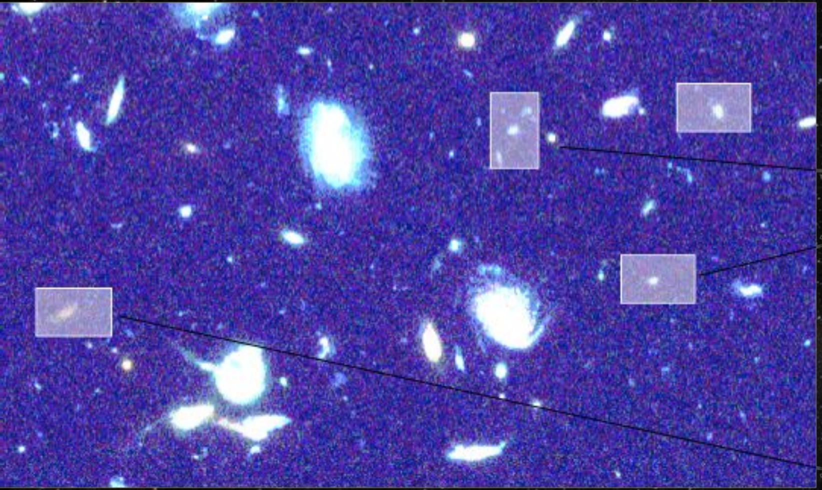


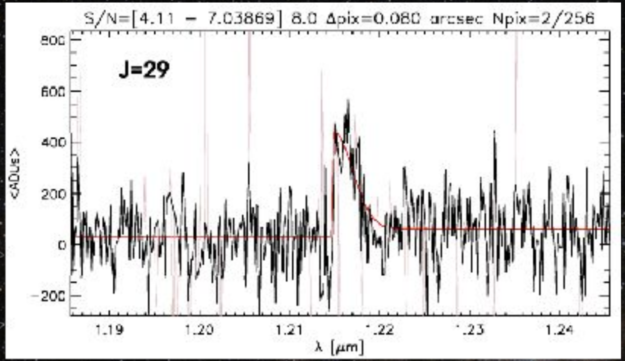
Dark ages → First galaxies popIII-dominated objects → Ionized bubbles overlap → Reionization completed

VLT & HST

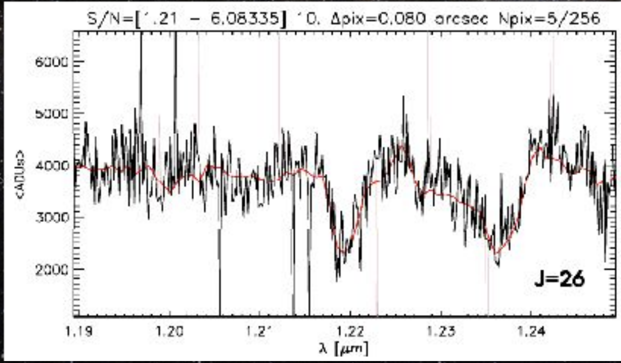
SC1: First galaxies and reionization

Most distant galaxies: MOSAIC will follow up JWST sources





Simulations of a Lyα emitter with EW=20A and J_{AB} =29 @z=9 with t_{int}=10 hours



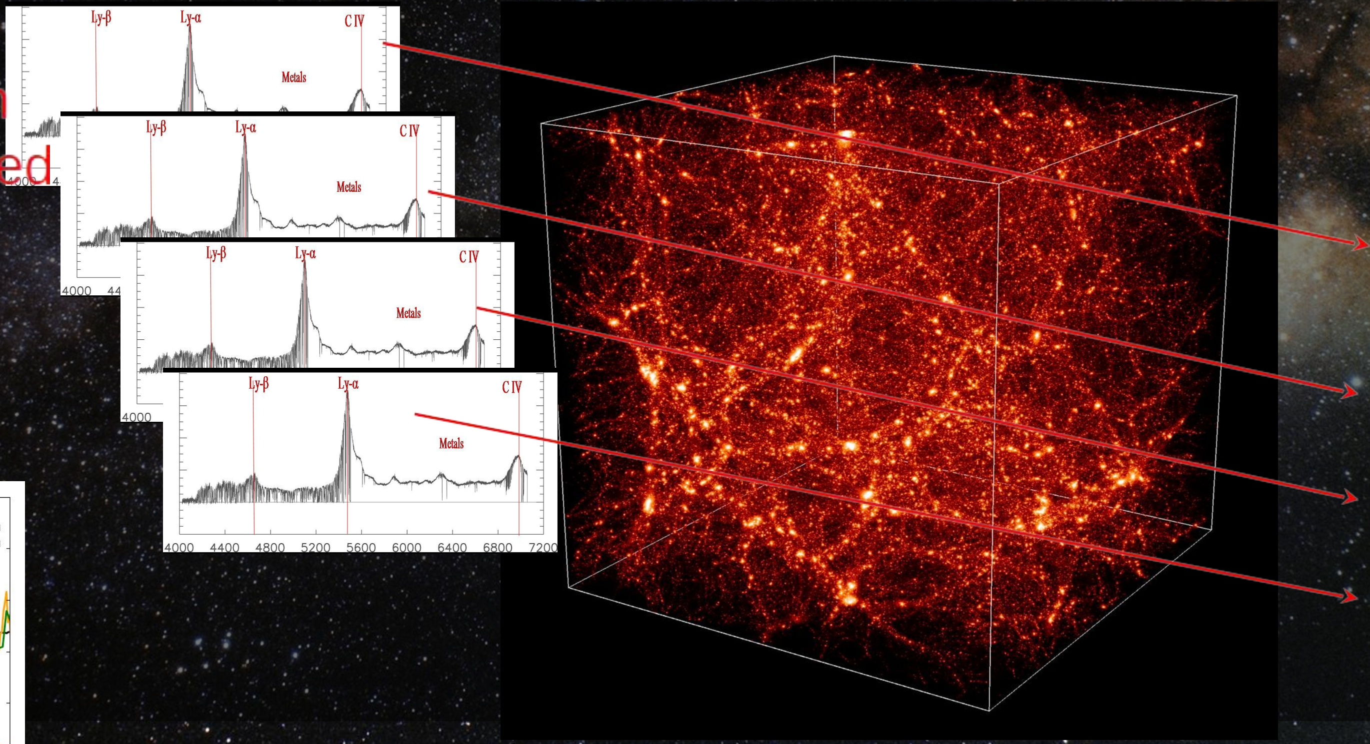
Simulation of UV interstellar absorption lines for a J_{AB}=26 LBG @z=7

WEBSIM-COMPASS :public web-based simulation tool dedicated to the ELT
websim-compass.obspm.fr (Puech et al. 2016 SPIE)

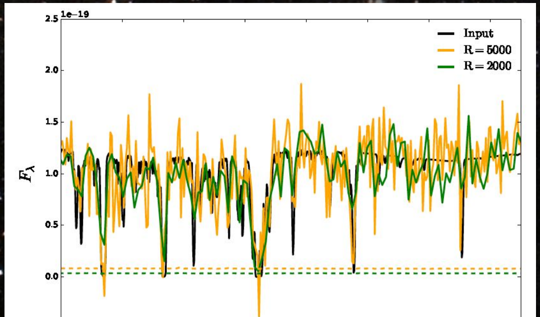
SC2: IGM tomography

Direct 3D reconstruction of the IGM (courtesy of Petitjean)

No QSOs but Lyman break galaxies observed with R≥ 5000

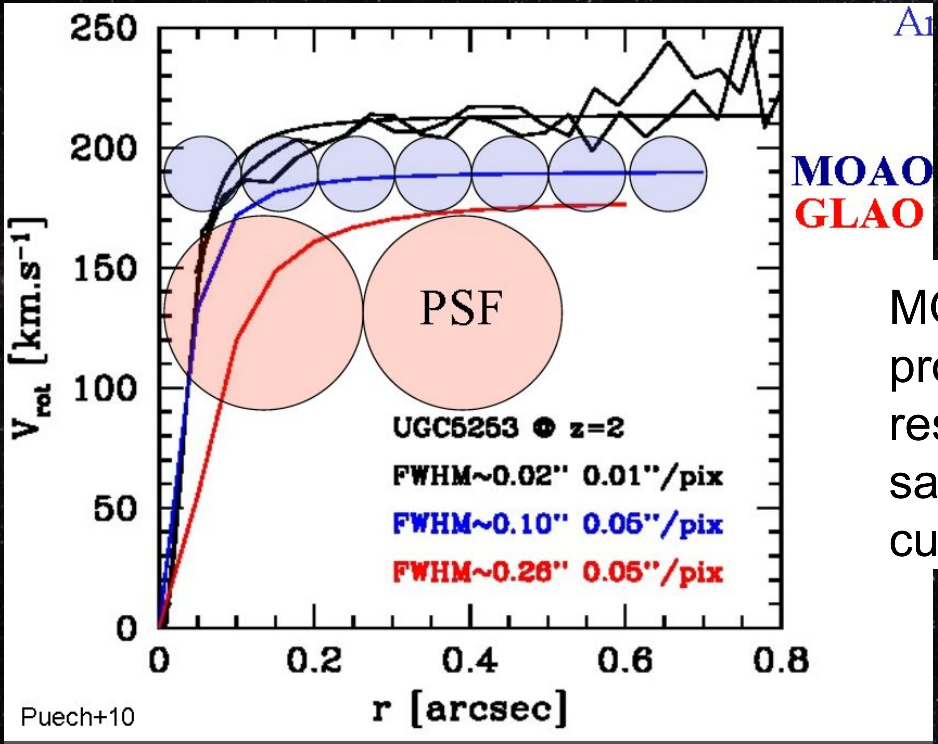


Lyman forest targets at z=3.5
AB=24.5-25.5 (2-10 hours



SC3: Mass assembly of galaxies

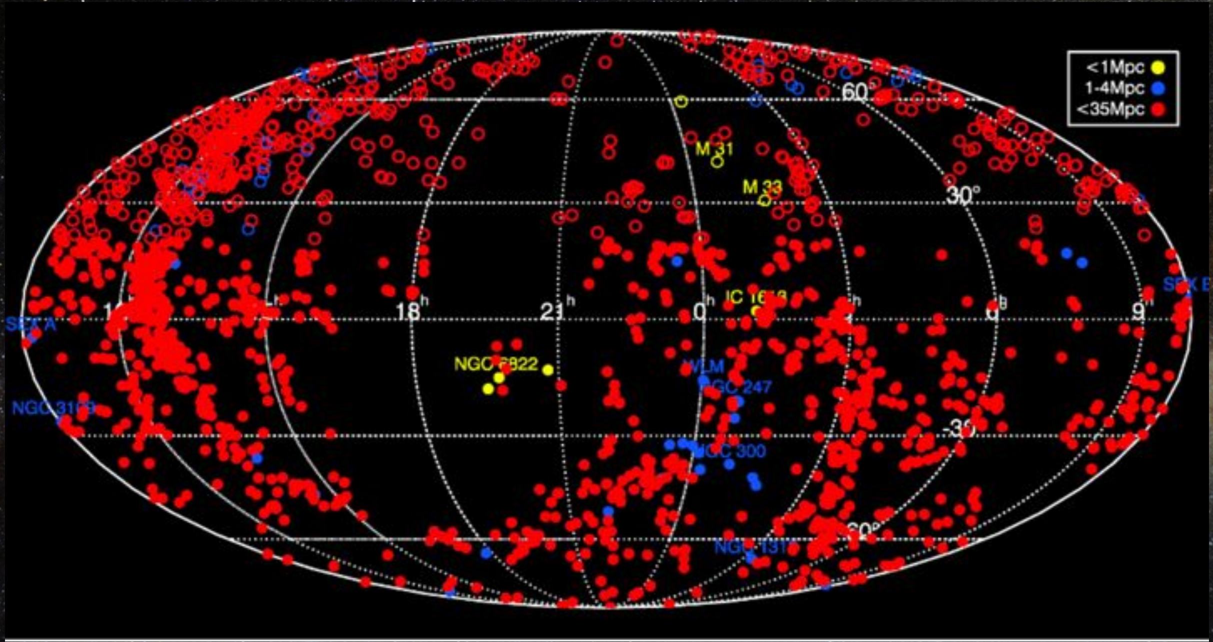
High definition mode: dark matter evolution from well-sampled rotation curves up to z=4



MOAO is required to provide at least 5 to 7 resolution elements to sample the rotation curve

VLT & HST

SC5: Resolved stellar population in external galaxies



MOSAIC spectroscopy of RedSuperGiants with the ELT will open-up a huge range of external galaxies for abundance studies. Galaxies with δ ≤ 20°, i.e. observable from Cerro Armazones at reasonable altitudes (≥45°), are indicated by the closed symbols. MOAO + J band will reach RSGs to 30-35 Mpc.

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Table 7: Summary of top-level requirements from each Science Case (with desirable reqs. in italics).

Case	Multiplex	FoV/target	Spatial sampling	λ-coverage (μm)	*R*
SC1 First light	20-40	2"x2" *	40-90 mas	1.0-1.8 *1.0-2.45*	5,000
	≥150	-	(GLAO: 0.6''Ø)	1.0-1.8 *1.0-2.45*	>3,000
SC2 Large-scale structures	≥10-15	2"x2"	(GLAO: IFU)	0.4-0.6 *0.37-0.6*	>3,000
	50-100	-	(GLAO)	0.6-1.8 *0.6-2.45*	>3,000
	>400	-	(GLAO)	0.4-1.4 *0.37-1.4*	>3,000
SC3 Gal. evolution	≥10	2"x2"	50-80 mas	1.0-1.8 *1.0-2.45*	5,000
	≥100	-	(GLAO: 0.6''Ø)	1.0-1.7 *0.8-2.45*	≥5,000 *~10,000*
	≥10	2"x2"	(GLAO: IFU)	0.385-0.7 *0.37-0.7*	5,000
SC4 AGN	~10	-	< 100 mas	1.0-1.8	>3,000
SC5 Extragal. stellar pops.	Dense	1"x1" *1.5"x1.5"*	< 75 mas *20-40 mas*	1.0-1.8 *0.8-1.8*	5,000
	10s arcmin^{-2}	-	(GLAO)	0.4-1.0	≥5,000 *≥10,000*
SC6 Gal. archaeol.	10s arcmin^{-2}	-	(GLAO)	0.41-0.46 & 0.60-0.68 *0.38-0.46 & 0.60-0.68*	≥15,000 *≥20,000*
SC7 GC science	Dense	> 2"x2"	~100 mas	1.5-2.45	≥5,000 *≥10,000*
SC 8 Planet form.	10s	-	(GLAO)	0.5-0.6	≥20,000

From each science case the specific instrument requirements were collected (multiplex, FoV, spatial sampling, wav. coverage and resolutions

(see summary of science cases in the White paper Evans et al. 2015 and in Evans et al. 2016 SPIE)

VLT & HST

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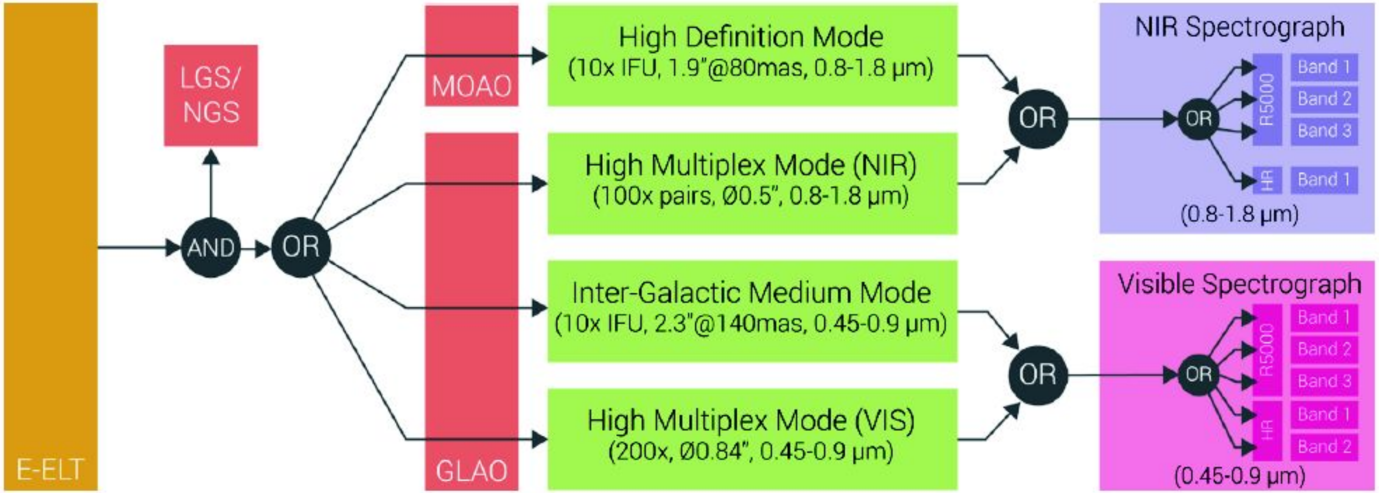
Instrument operation concept

- Fibre-fed instrument
- Spectrographs are shared between modes



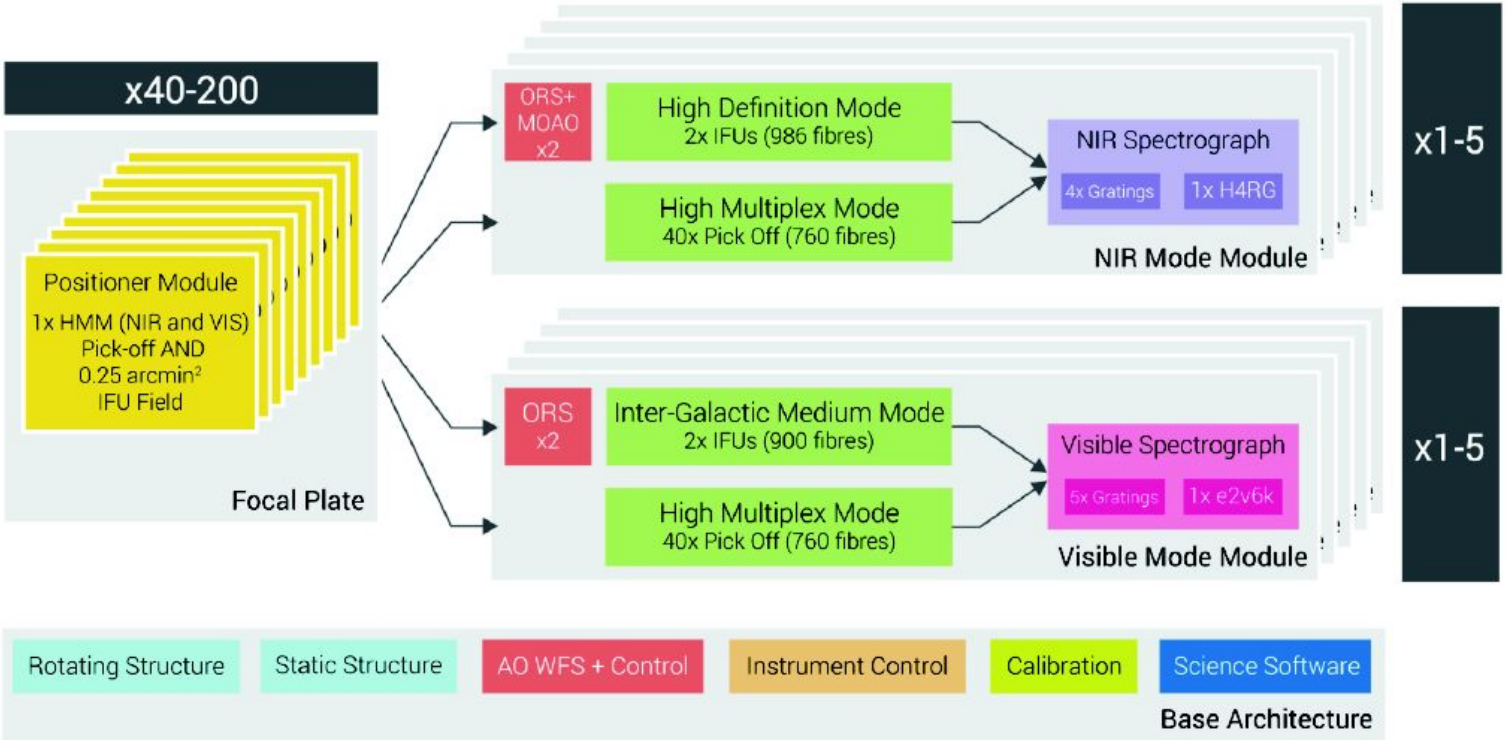
2 IFS modes

VIS-IFU HDM

2 high multiplex modes

HMM-VIS HMM-NIR

Modular concept



MOSAIC has been designed since the beginning to be highly modular, allowing for both potential descopes and phased deployment (from Morris et al. 2018 SPIE)

Spectral bands

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VIS bands

	λ_{min} (nm)	λ_{max} (nm)	R
Band 1 (BV)	450	600	5000
Band 2 (R)	557	743	5000
Band 3 (I)	686	914	5000
Band Ha HR	627	688	15,000
Band CaT HR	840	885	15,000

Spectral sampling: 4.2 pixels per resolution element

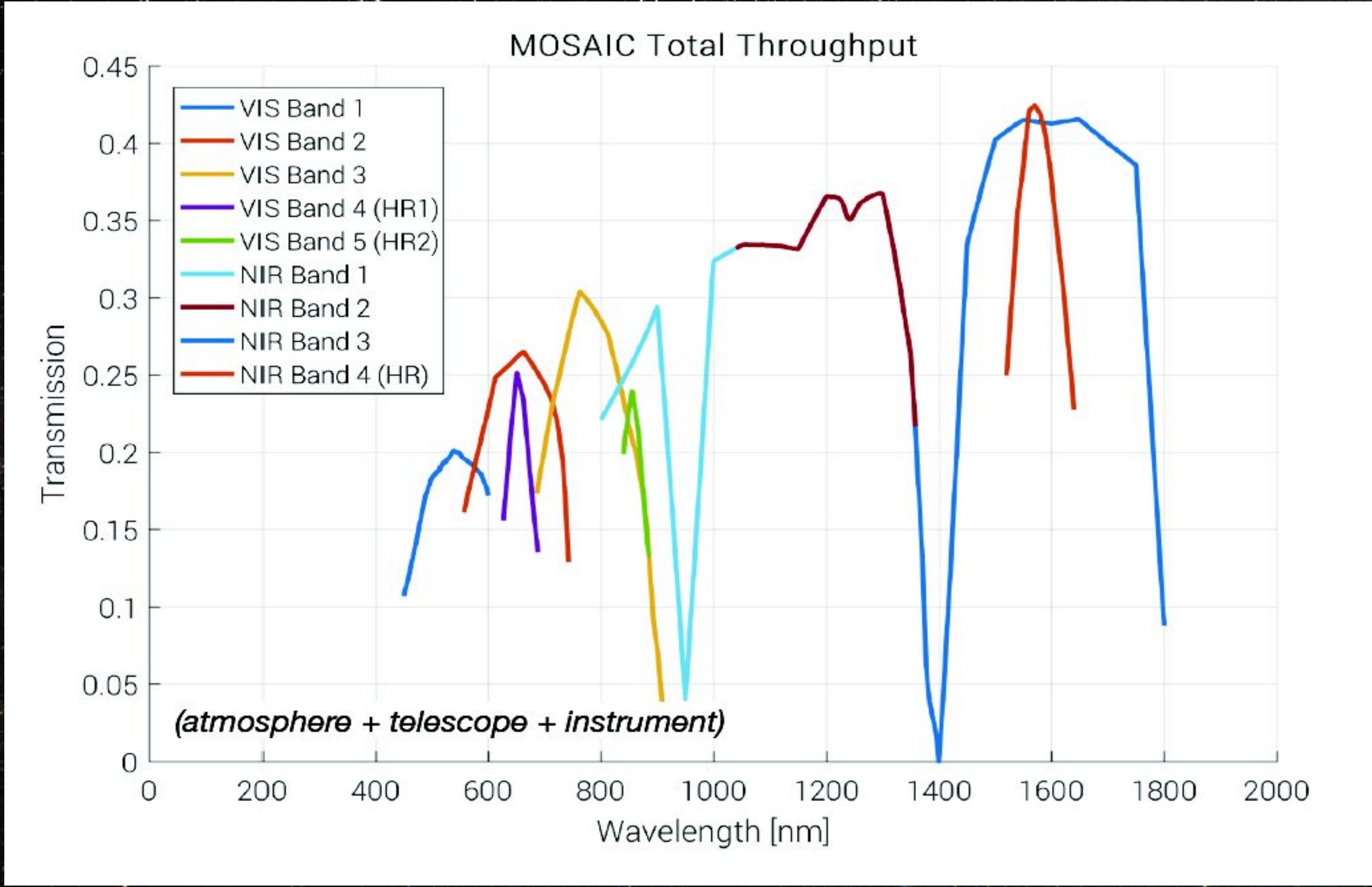
NIR bands

	λ_{min} (nm)	λ_{max} (nm)	R
Band 1 (zY)	800	1060	5000
Band 2 (YJ)	1040	1378	5000
Band 3 (H)	1358	1800	5000
Band 1 HR (H)	1520	1644	20,000

Spectral sampling: 3.1 pixels per resolution element

Lower cut in λ =450 nm due to mirror coating. No K band

Total throughput



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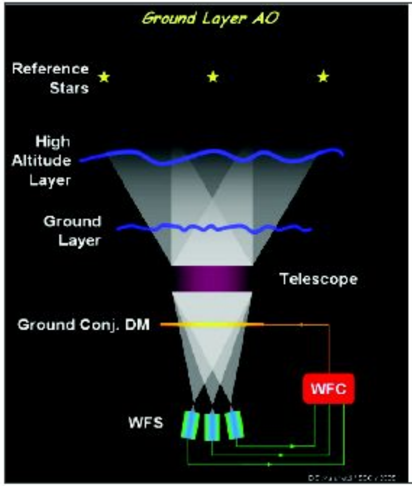
Adaptive optics

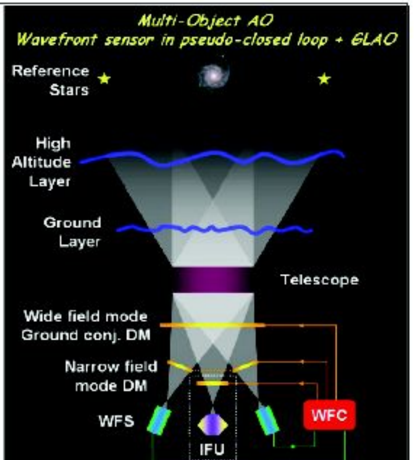


Ground Layer Adaptive Optics (GLAO)

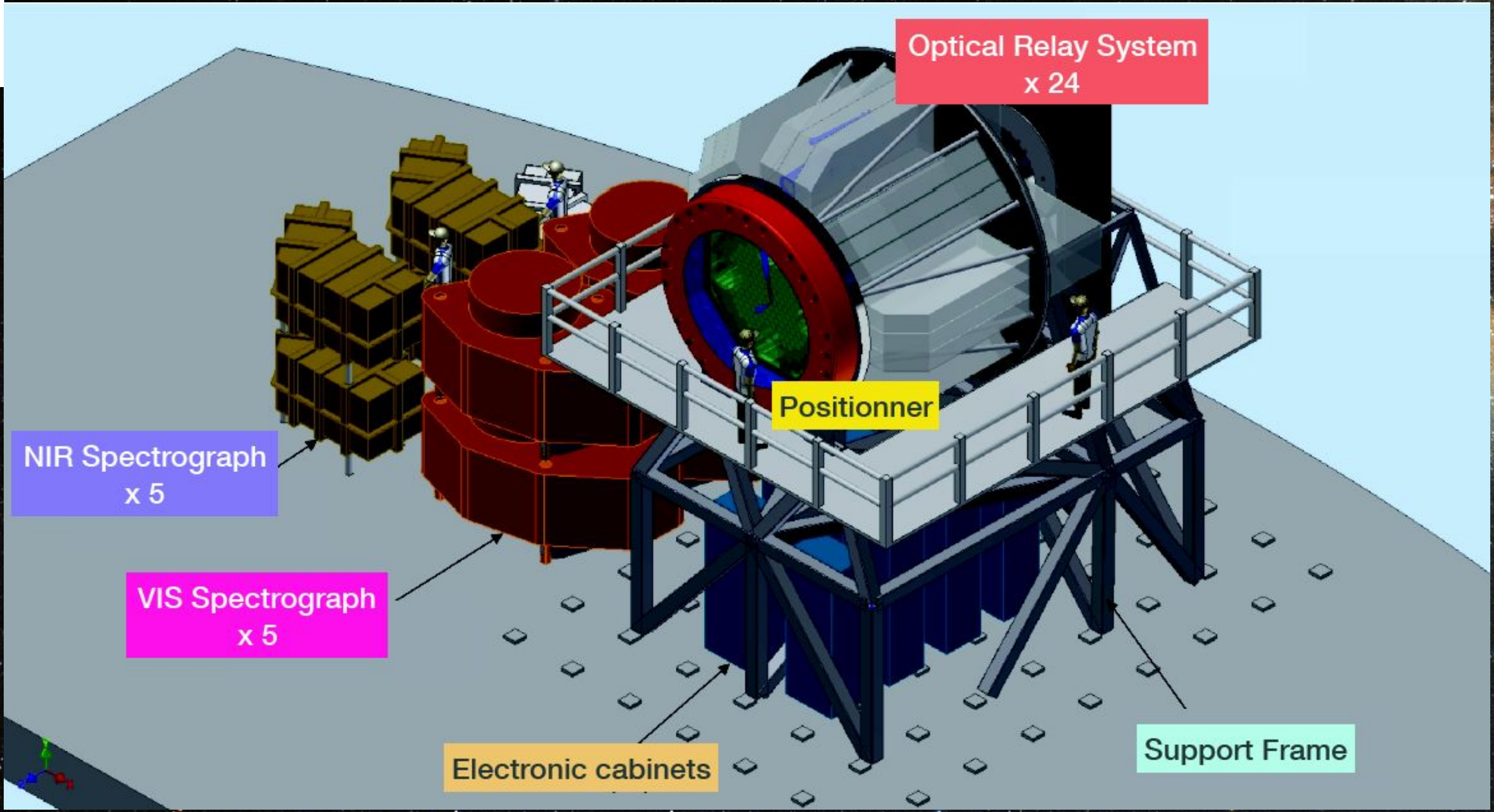
- Correction across the full wavelength range of the instrument
- Expected performance at the blue-end (<6000Å) ~ seeing-limited observations
- In NIR and over excellent seeing conditions, GLAO can potentially reach MOAO performance.

Multi Object Adaptive Optics (MOAO)

- NIR (0.80 - 1.8μm)
- High Definition mode only
- Provide a 25% EE correction within 150 mas in the H-band



Design



Optical Relay System
x 24
Positionner
NIR Spectrograph
x 5
VIS Spectrograph
x 5
Electronic cabinets
Support Frame

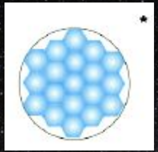
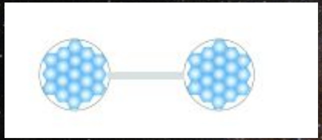
MOSAIC at the end of Phase A

MOSAIC

- HMM-NIR: 160 fibre units (80 objects + 80 on sky)
- HMM-VIS : 80 fibre units (no sky fiber)
- HDM-NIR: 8 IFUS (1.9’’ across 80 mas spaxels)
- VIFU: 4(8) IFUs (2.3’’ across, GLAO)

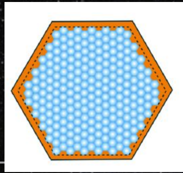
Estimated HW cost: 23 M€ (excluding 15% contingency and Pre-Focal station)
Mass 29.5 Tons (at the limit of ESO allocation =30 tons)
Overall goal has been to maximise parameter space

High Multiplex Modes (HMM)

	Visible(HMM-VIS)	Near-IR (HMM-NIR)
Subfield		
Number of apertures	80	80+80 on sky
Patrol Area	52.1 $arcmin^2$	47.3 $arcmin^2$
Operating bandwidth	0.45- 0.9 μm	0.8-1.8 μm
Diameter of aperture on sky	840 mas	500 mas
Spectral resolution	5000 e 15000	5000 e 20000
AO performance	GLAO (seeing limited)	GLAO

*Sub-fields are fragmented into 19 fibres, but should not be considered as being small integral field units.

HDM and VIFU modes

	VIFU Visible IFU	HDM
		
Number of apertures	80+8	8
Patrol Area	44.2 arcmin^2	44.2 arcmin^2
Operating bandwidth	0.45- 0.9 µm	0.8-1.8 µm
Outer diameter on sky	2.31 arcsec (inner circle 2.0)	1.9 arcsec (inner circle 1.72)
Spectral resolution	5000 e 15000	5000 e 25000
Sampling	138 mas	80 mas
AO performance	GLAO (seeing limited)	MOAO

MOSAIC at the end of Phase A

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Following Phase A there was an external panel of 11 experts who gave further assessment

- VIFU provides least added value ✓
- Suggested push towards large multiplexing (min 200 ideally 500)
  Note that early decision in Phase A was to prioritize a wide field IFU (many science cases) vs higher multiplex (few cases)
- More resolving power in the visible is desirable ✓
- More simultaneous wavelength coverage is desirable in many cases
- For the High Definition Model survey speed of HARMONI vs HDM-NIR needs to be re- assessed

➡ **ESO Pushes for a HMM-only instrument with higher multiplex**

MOSAIC at the end of Phase A

MOSAIC

- HMM-NIR: 160 fibre units (80 objects + 80 on sky)
- HMM-VIS : 80 fibre units
- HDM-NIR: 8 IFUS (1.9'' across 80 mas spaxels)
- ~~VIFU: 8 IFUs (2,3 " across, GLAO)~~ **ELIMINATED**

Estimated HW cost: 21.5 M (excluding 15% contingency and pre-Focal station)

Overall goal has been to maximise parameter space

Ongoing re-assessment of HDM mode to be completed soon

MOSAIC at the end of Phase A

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1. Finalize trade offs- multiplex depends on mass/volume/budget but keeping discovery space as large as possible

   MOS capabilities have already been limited (no mirror coating at <450nm, no K-band, no overlap with Harmoni pixel size)

2. Interfaces with the telescope still not clear: for Pre-Focal station ESO proposed half cost to be paid by each MOSAIC/HIRES consortia (answer no). Also weight is at the limit

3. Principle of contract with ESO: GTO against FTE (65 nights =430 FTEs) and Hardware (60 nights =25 M €).

   Possibility of Public surveys to be awarded instead of part of GTO with an incentive factor (e.g. for i=1.5 GTO 99 nights +PS 52 nights =151 nights)
   → risk, no guarantee of success for consortium in public call

Italian participation (open list!) interests and and possible contribution

OATorino:
Daniele Gardiol, Davide Loreggia, Leonardo Corcione, Alessandro Sozzetti, Sebastiano Ligori -- IR detectors / Instrument control SW / data reduction

IASF Milano
Bianca Garilli,Marco Scodeggio,Paolo Franzetti,Marco Fumana,Dario Bottini,Mari Polletta -- s/w pipelines

OAArcetri
Anna Gallazzi, Stefano Zibetti, Sofia Randich,Laura Magrini,Germano Sacco,Lorenzo Morbidelli,Elena Pancino,Elena Franciosini -- science codes for spectral analysis for stellar parameters

OARoma
Laura Pentericci, Emanuele Giallong, Enzo Brocato , Fabrizio Fiore

Others
Marcella Longhetti, Angela Iovino Enrico Held Amata Mercurio Eros Vanzella

Ad-hoc Committee

The goal of the exercise was to get advices from the committee on few specific points, as detailed in the questions below. The methodology was first to collect written feedback from all the members of the panel, and then discuss them in a FTF meeting with the Steering Commette
The 5 questions were:

1. how does MOSAIC compare to other 2020s facilities?
2. which one of the 4 additional architectures is preferred?
3. what are the missing MOS capabilities?,
4. is having a smaller pixel for the HDM desirable?
5. is the simultaneous spectral coverage adequate?

HDM vs HARMONI on extended sources z=4

Table 4: Survey speed comparison between MOSAIC and HARMONI at 1.65 μm*.

	MOSAIC HDM	**HARMONI *R*=3500**	**HARMONI *R*=7500**
Spaxel scale [mas x mas]	80x80	30x60	30x60
R	5000	3500	7500
Multiplex	8 (10)	1	1
Dark current [e/s/pix]	0.0041	0.0041	0.0041
Read-out noise [e/pix]	3	3	3
Spectral sampling [pix]	5	3	3
Spatial sampling along X axis [pix]	2	4	4
Spatial sampling along Y axis [pix]	2	2	2
Ensquared Energy per spaxel [%]	35 %	45 %	45 %
***S/N* ratio (HARMONI / MOSAIC)**		0.6	0.4
Survey speed HARMONI vs. MOSAIC		**0.04 (0.03)**	**0.02 (0.01)**
Survey speed H vs. M *per IFU*		0.3	0.1

*All ratios refer to HARMONI/MOSAIC. The resulting noise (sky background + read-out noise + dark current) and object flux ratios are estimated within one spaxel and for an element of spectral resolution, for an integration time DIT=600s (see Evans et al. 2016 for details and assumptions). We applied a linear correction in Ensquared Energy (EE) to the object flux ratio before estimating the resulting *S/N* ratio between MOSAIC and HARMONI to account for the better EE delivered by LTAO (HARMONI) compared to MOAO (MOSAIC). EE=45% per spaxel for the HARMONI LTAO (H band) was assumed (Dr B. Neichel., priv. comm.). The last line gives the survey speed ratio per IFU (i.e., assuming multiplex=1 for MOSAIC). Note that the same comparison in the *J*-band gives approx.. the same results (assuming EE=30% for LTAO vs. EE=24% for MOAO).

Cost of a GTO night according to ESO

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ESO proposal:
Against FTEs: 65 GTO nights, cost (430 FTEs) 660k€/night (100k€/FTE)
Against Hardware (incl. PFS): 60 GTO nights, 25M€ 420k€/night

Official value of one GTO night (ESO proposal to the Council):

- 300 k€ (2015) for an ESO member
- 600 k€ (2015) for a non-member

Accounting for possible Public Surveys that are not part of the GTO
Call for Public Surveys are expected to be issued by a specific ESO Committee
No guarantee for the Consortium to be successful
Could we pay hardware cash knowing such a risk?
If yes, which incentive factor could be applied to a Public Survey night (below 1.5?)

With factor i=1.5, cost of a Public Survey night is 280 k€, however taking the risk, additional FTEs & management
Example: with i=1.5 the Consortium could get 99 GTO nights + 52 nights for Surveys
Note: ESO used i=1.25 that would have led to only 141 nights, instead

Preparation of MoU principles

Requires an accurate knowledge of survey/GTO ratios

For surveys that include GTO + ESO survey time, one would account similar reward rule for each partner (ESO or not)

Exchange between contributions (FTEs & budget) and participation to (1) a Survey Board; (2) different Surveys; (3) Publications.

Survey Board to be nominated by the Steering Committee

Chair of the Survey Board proposed by the PI (interactions)

Agreement on contributions per country