Ultra-Deep galaxy surveys with the EELT: why and how ?

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Why surveys ?
(obvious but good to remember)

- A basic tool in Astrophysics: assemble a representative sample from a population to infer the global population properties
- Quantitative measurements with controlled errors
- Large surveys provide well defined sub-populations
- Surveys are more than ever the backbone of exploration

Understanding galaxy formation and evolution requires multi-layer surveys

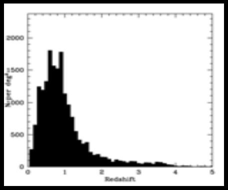
A several step process

1. Search for objects: need to find objects before doing physics !
2. Estimate the mean properties: N(z), luminosity, gas/stellar masses, SFRD, morphology, clustering, ...
   → assemble representative samples
3. Isolate well defined sub-populations for detailed studies, e.g. kinematics
4. Infer a scenario & compare to models / simulations

Deep multi-band imaging

↓

Large multiplex MOS



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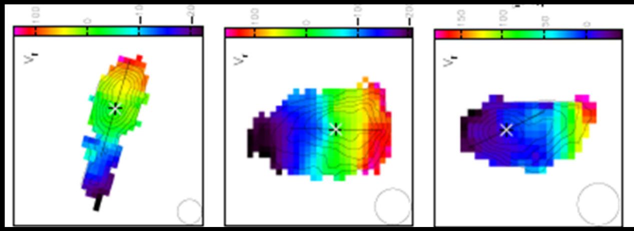
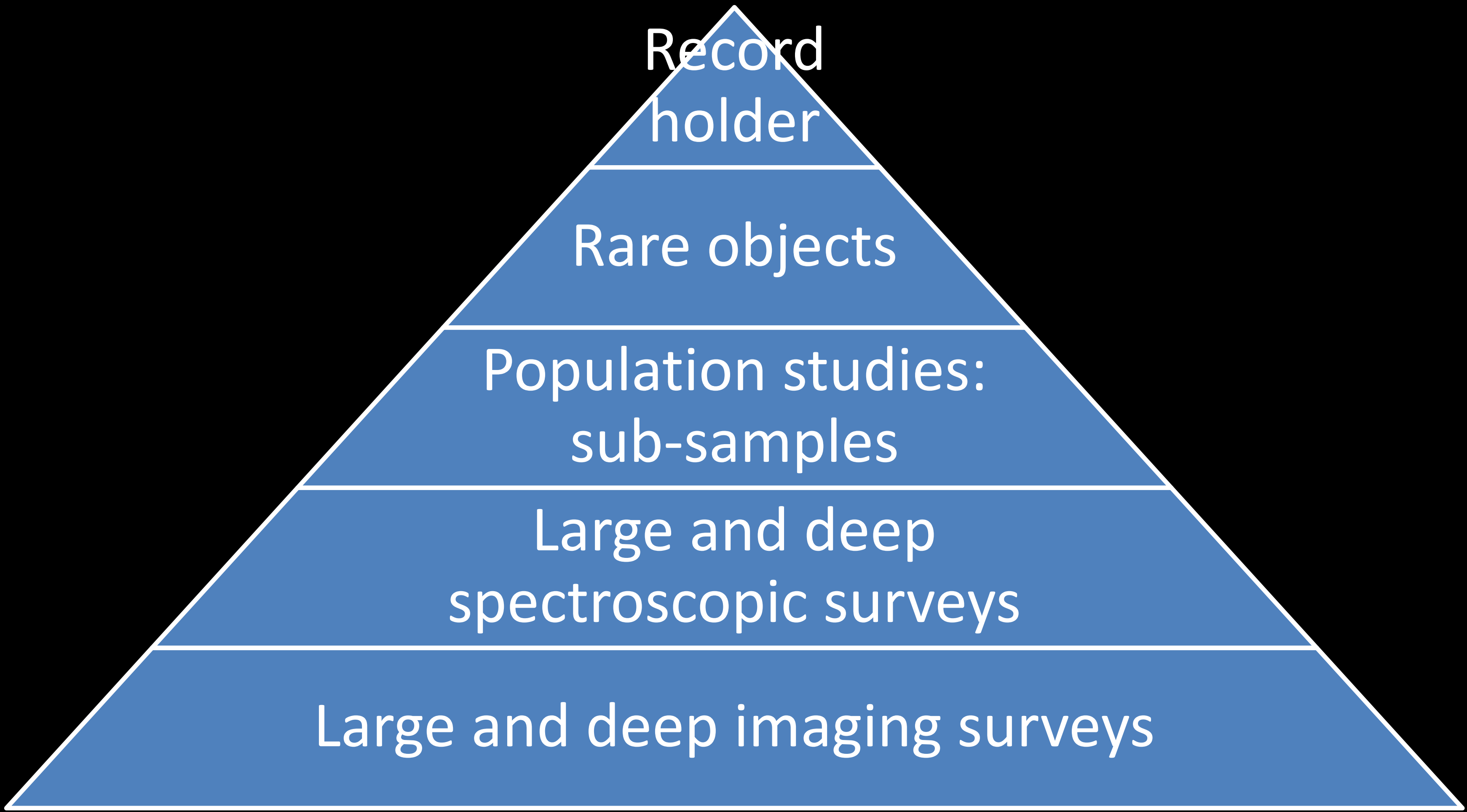
IFU, AO-imaging, high-res spectra…

c.f. CFRS, DEEP2, VVDS/MASSIV, LBG/SINS, zCOSMOS…

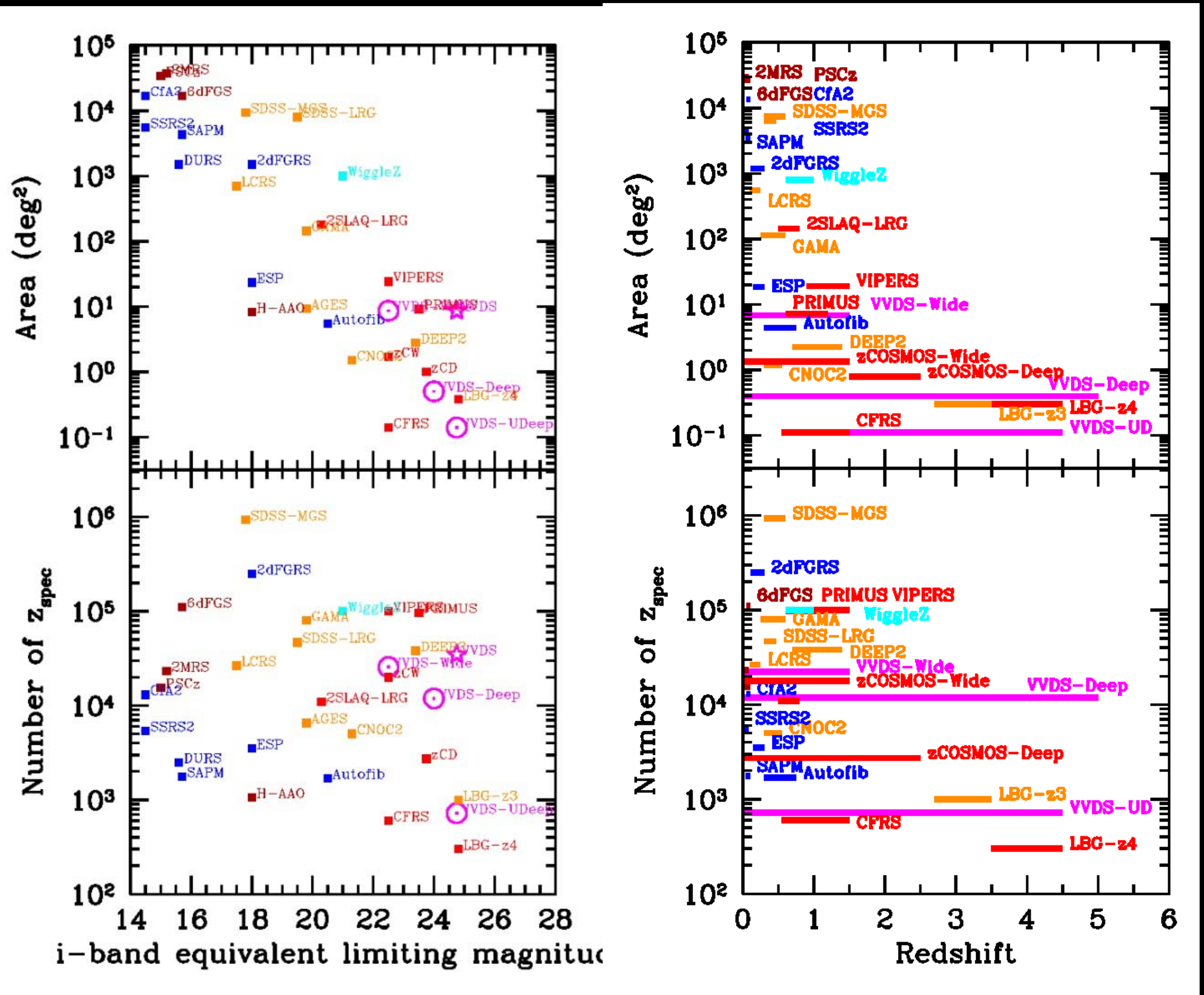


A bottom-up pyramid of exploration

the base is needed before going to the top



Galaxy redshift surveys f(area, depth, redshift)



When EELT is ready: z<2 “all sky” coverage on-going (EUCLID)

z>2 will still be under-explored: a few sq.deg

First galaxies ?
Mass assembly ?
Build-up of large scale structures ?

Finding first light objects z>6.5

What are we looking for ?

- Very faint objects AB>26.5
- The IGM will cut their observed flux below Lyα
  - Main signatures: Lyα-dropout and Lyα emission
- Need to sample the very rare bright objects and the more numerous small building bricks (still rare on the plane of the sky)
- At z>6.5 all the information is in the NIR

Careful:

- Take predictions on number density with caution (see historical perspective)

Expect the unexpected...

⇒ Keep a large parameter space for instruments

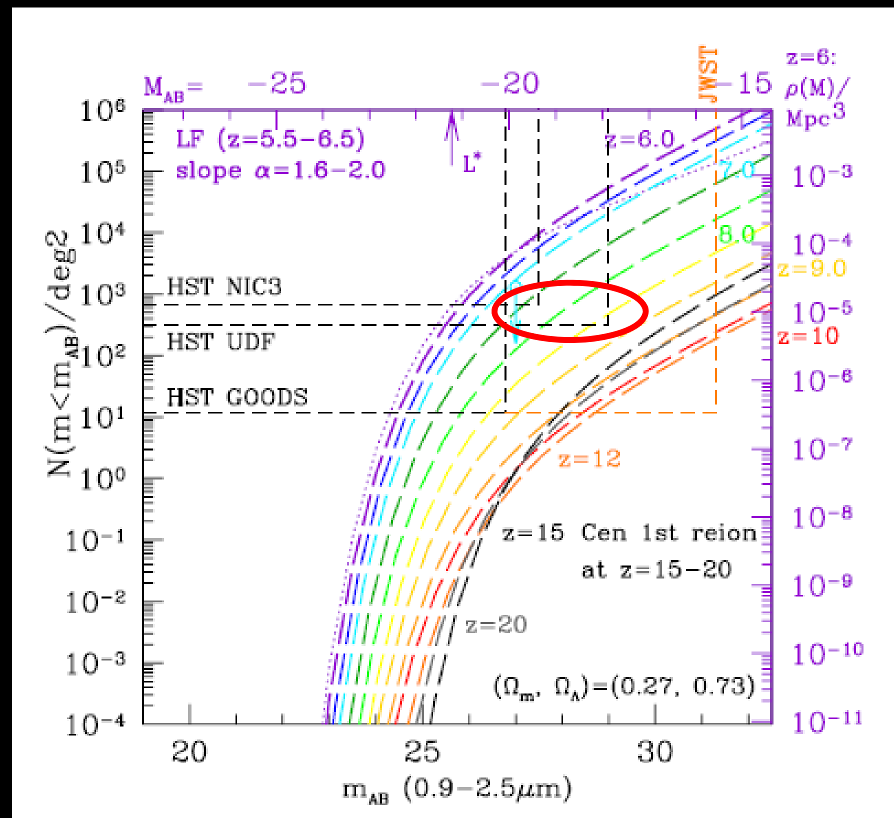
Some properties of real objects at z~6-7

Object type	Flux	Projected density	Size	UV morphology
LBG	AB~27-28	~1-10 LBG/arcmin²/dz	1-2 kpc	Compact / blobby
LAE	10^{-18} ergs/cm²/s	~1 LAE/arcmin²/dz	<5 kpc	Compact
	10^{-17} ergs/cm²/s	<0.2 LAE/arcmin²/dz	<10 kpc	Large blobs

- Small <0.5 arcsec with a few (rare) bigger

- A few per arcmin²
Need area
Depth is not enough

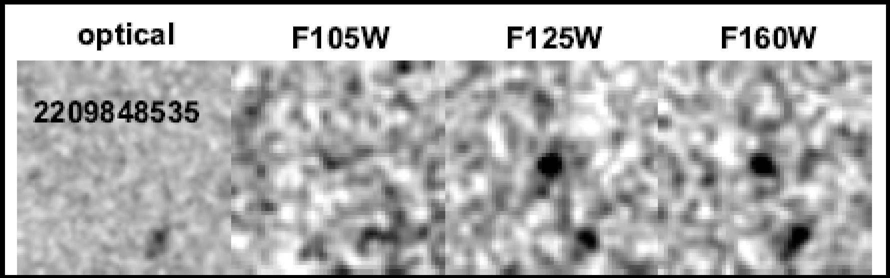
Windhorst et al., 2005



Current state of the art in looking for z>6.5 candidates: CANDELS example

- Largest HST program in history: 902 orbits
- 668 arcmin² wide survey (J_{AB}~26.4), 120 arcmin² on deep survey (J_{AB}~27.4)
- 16 candidates z~8 on deep survey (0.15/arcmin²), TBC
- 150 z-band candidates z~7

→ A few hundred candidates that will be heavily targetted until EELT arrives !



z~8 candidate

Where would the photometric targets for EELT z>6.5 spectroscopy come from ?

- Need a well defined target list from deep multi-band photometry before spending a lot of EELT spectroscopy time
- Need IR photometry as flux=0 in visible bands for z>6.5

Target source	Magnitude	FOV	Numbers	Comments
4m infrared (VISTA)	H_{AB}=26	0.6 deg^2	100 ? Total over lifetime	7 years survey
8m visible	-	-	-	No target z>6.5
8m IR ?	-	-	-	Not even planned
HST	H_{AB}=27	5 $arcmin^2$	~1000 over lifetime	
JWST	K_{AB}=30	8 $arcmin^2$	>100 per field	Small FOV, 5y lifetime, US
EUCLID	H_{AB}=26	40 deg^2	~5000 total	Bright end of Lum.Func.
EELT	H_{AB}=30	50 $arcmin^2$	>400 per field	Only facility at ESO capable of deep enough imaging

Need a 20m wide field imaging telescope ! (to do what 4m have been doing to 8m)
If not: need wide field imaging on the EELT !

Where would the targets for EELT high spatial/spectral spectroscopy come from ?

- Need a well defined target list with spectroscopic redshifts, on targets with main features outside the OH sky-lines
  ⟹ Need Wide Field high multiple MOS before spending a lot of high spatial / spectral spectroscopy time
- Need IR spectroscopy as flux=0 in visible bands for z>6.5

Target source	Magnitude	FOV	Numbers	Comments
4m infrared spectroscopy	H_{AB}=23.5	1 deg^2	None z>6.5 A few×10^2 at 4<z<6.5	Too shallow
8m IR spectroscopy (PFS, MOONS,…)	H_{AB}=24.25	1.5 deg^2	A few×10^3 at 4<z<6.5 A few tens at z>6.5 ?	Too shallow
JWST-NIRSPEC	K_{AB}=26.8	9 $arcmin^2$	Several tens at z>6.5 per FOV	Small FOV, 5y lifetime, US
EELT	J_{AB}=26.5	50 $arcmin^2$	Several×10^2 z>6.5 per FOV	10-25× JWST

MOS(s) on the VLT

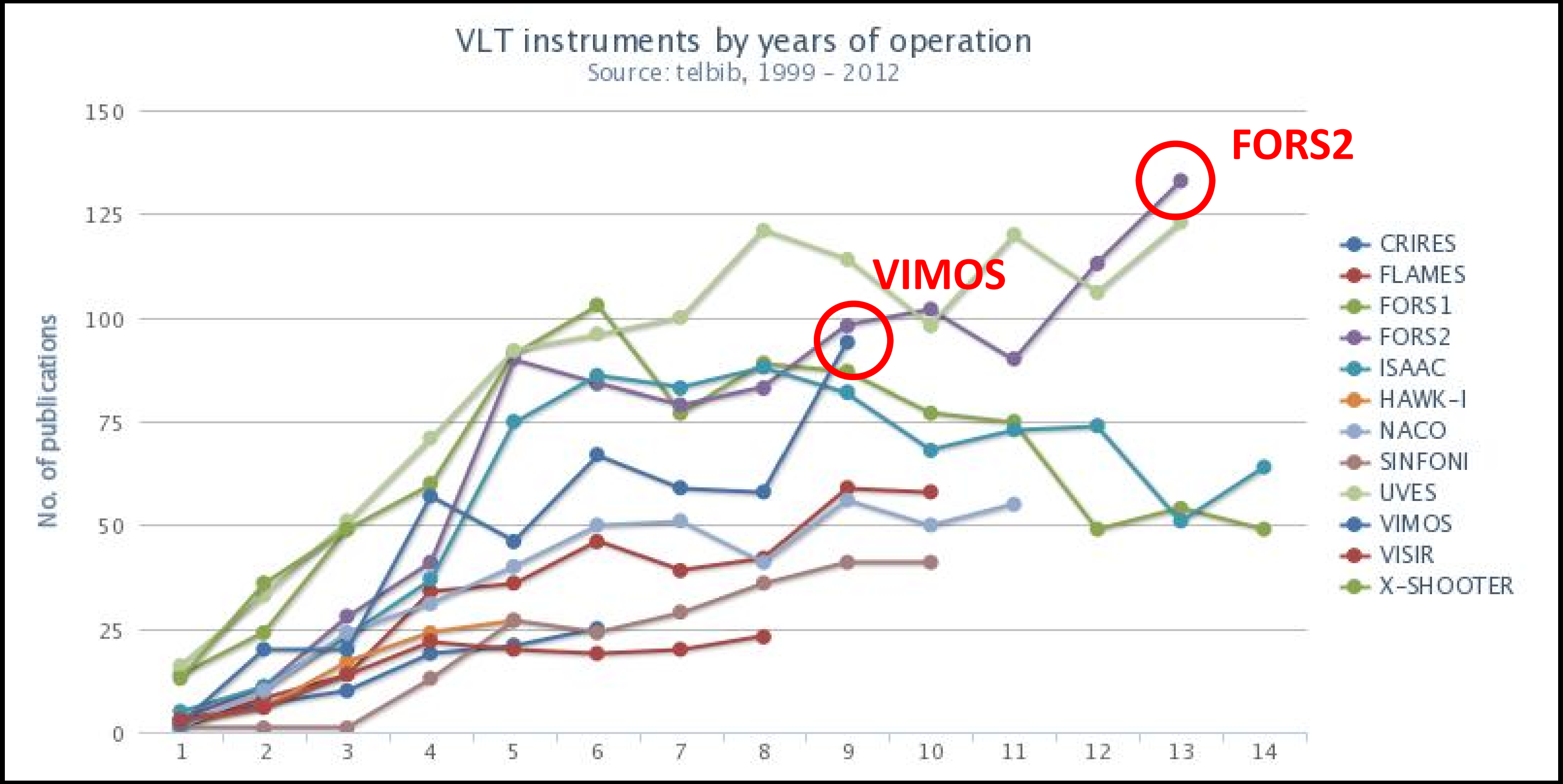
5-6 MOS flavors

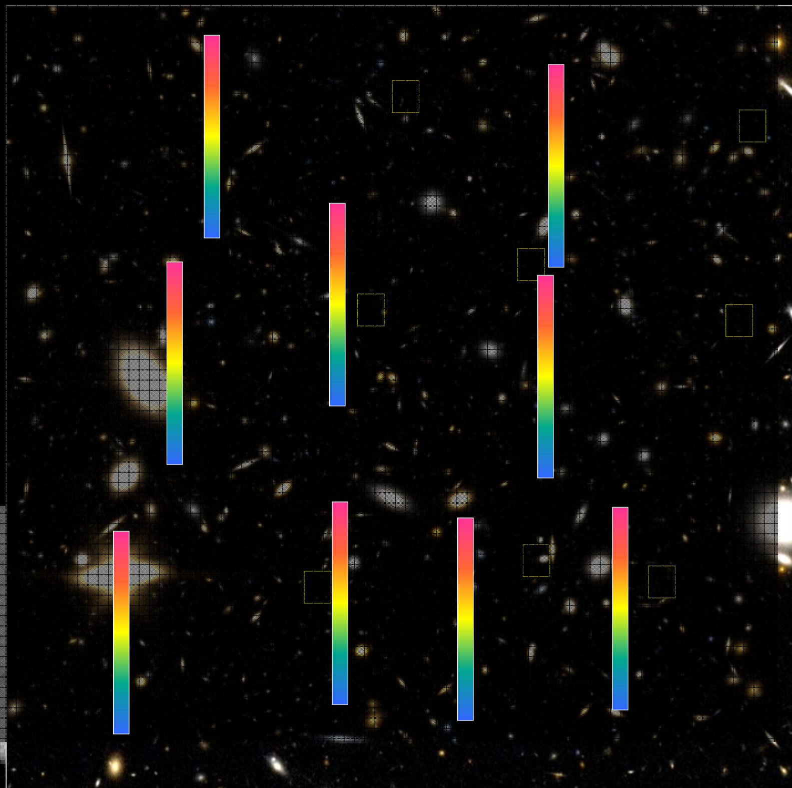
MOS	Field	λ	R	Multiplex
FORS	50 arcmin^2	3300Å-1μm	<3000	100
FLAMES/GIRAFFE	450 arcmin^2	3600Å-1μm	7000-25000	<130
VIMOS	225 arcmin^2	3600Å-1μ	250-2500	~800
KMOS	45 arcmin^2	0.6-2.5μm	1800-4200	24
UVES/FLAMES	450 arcmin^2	3000-1μm	~100000	8
(MUSE)	1 arcmin^2	0.48-0.93μm	1500-3000	IFU

To cover a consistent parameter (discovery) space we need at least 2 of these, ideally combining modes, on the EELT

2 imaging-multi-slit MOS in the top 3 @VLT

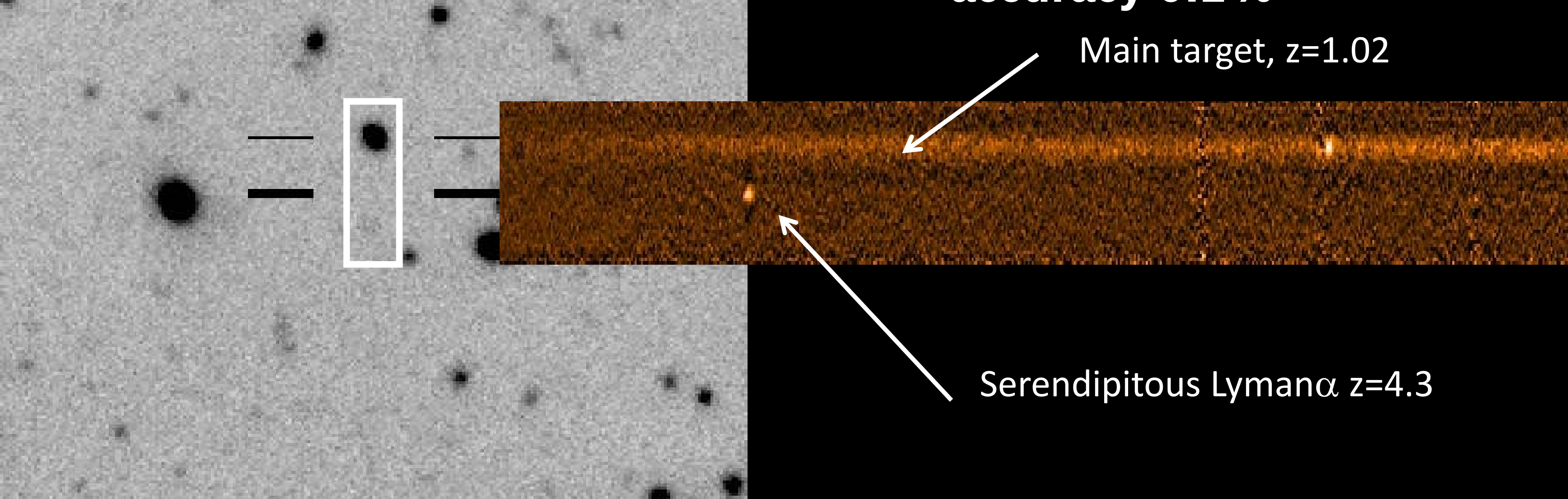
- Demonstrates « work-horse » versatile use





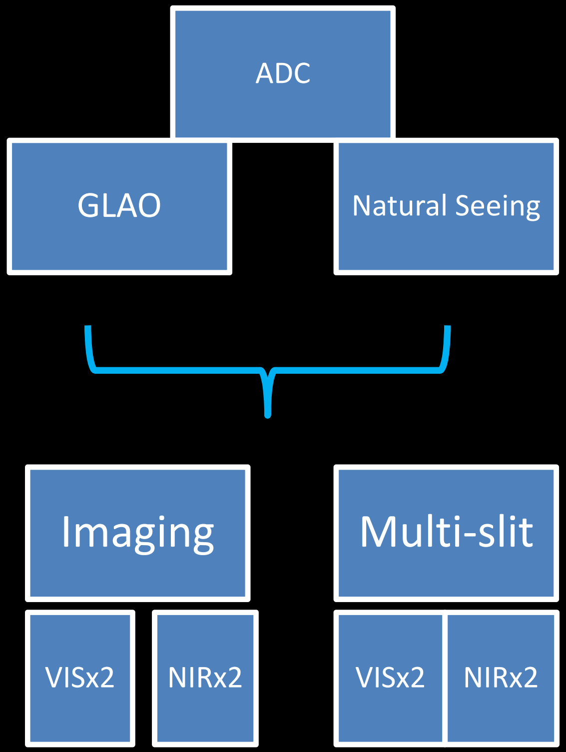
Power of imaging-MOS

- Multi-band imaging
  - Positions, magnitudes, shapes
- Select the sample
  - Magnitudes, colors, NB…
- Multi-slit Spectroscopy
  - Spectral features
  - Redshift
  - **High sky subtraction accuracy 0.1%**

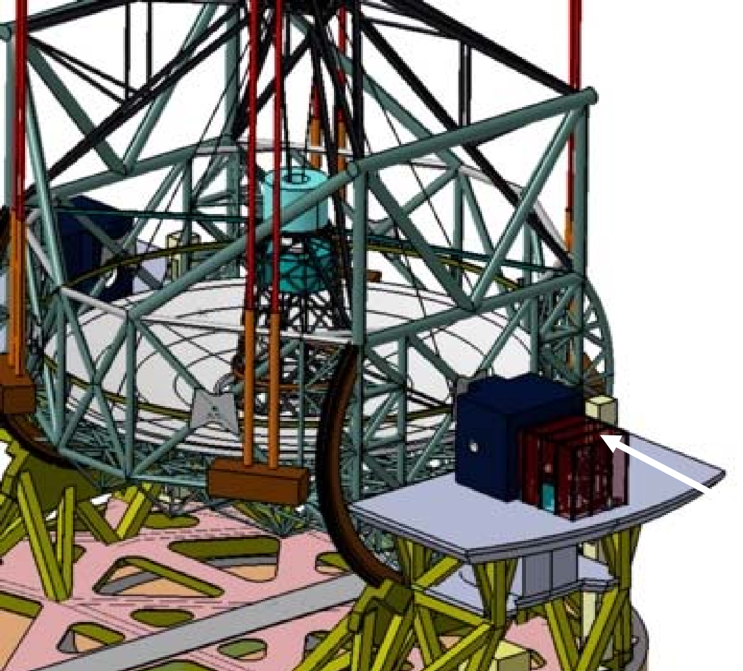


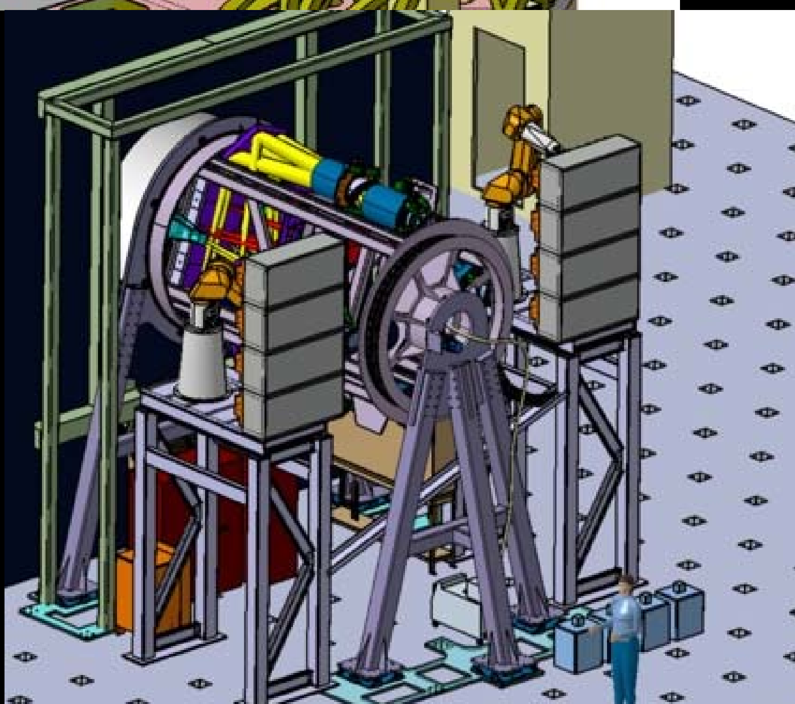
led to DIORAMAS instrument concept – phase A study

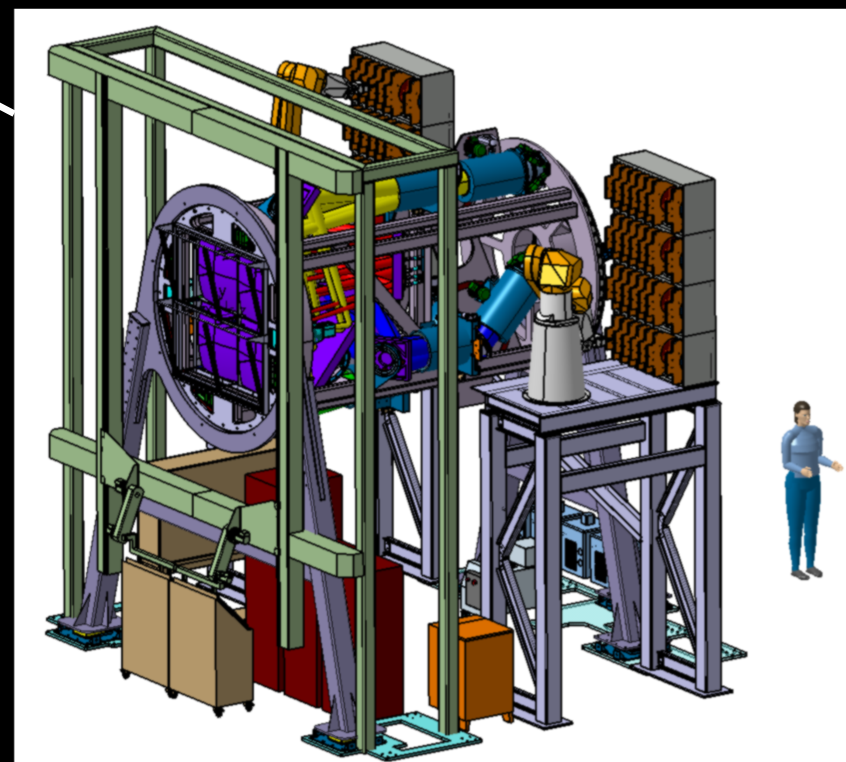
- High multiplex MOS with slits
- Imaging mode
- Use EELT natural seeing or GLAO-corrected beam
  - Instrument concept accomodates both
- Wide field: 6.8x6.8 arcmin^2
- 0.37-1.6 microns



DIORAMAS Opto-mechanical layout







DIORAMAS design parameters

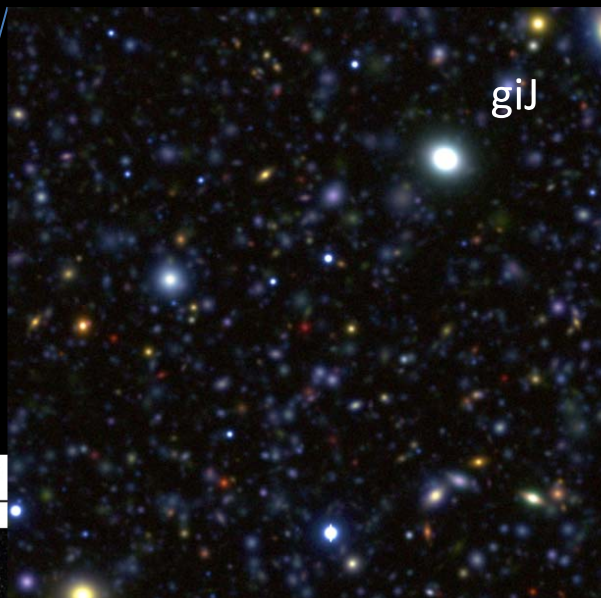
Item	**Design value**
Spectral range	[0.37 μm, 1.6 μm]
Field of view	6.78 x 6.78 $arcmin^2$
Slit size	Any width: mean 0.5 arcsec, min.: 0.1 arcsec
Pixel scale and sampling	0.05 arcsec per pixel
MOS multiplex	480 slits of 5 arcsec length at R~300 160 slits of 5 arcsec length at R~2000-3000
Spectral resolution	R~300 to 2700 for visible; R~400 to 3000 for NIR

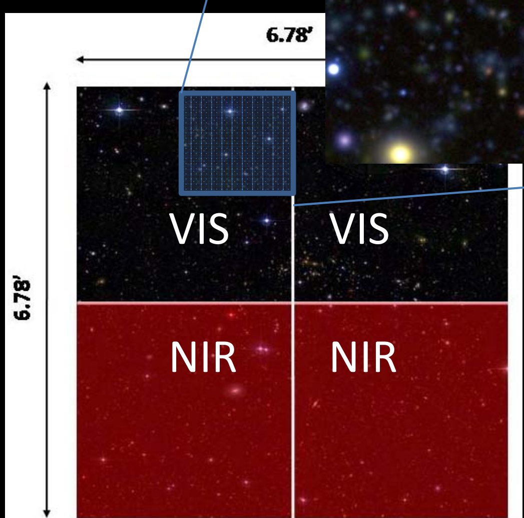
High throughput: 30% VIS, 45% NIR (with detector)

Excellent image quality: 150 mas 80% encircled energy

Wide field, multi-mode

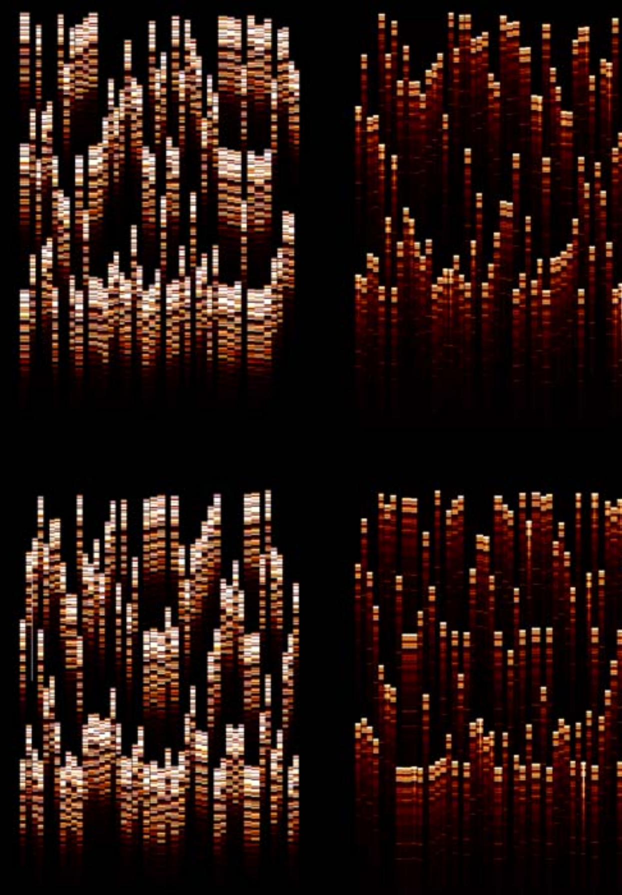
Imaging





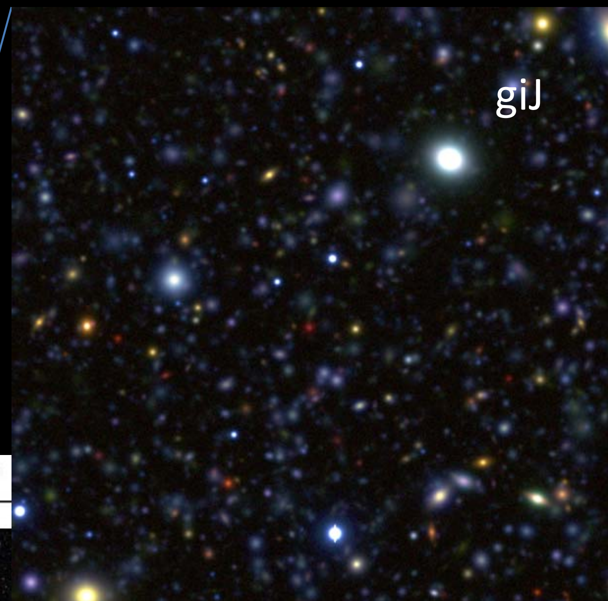
>30,000 sources in 7'x7' to r_{AB}=29.8

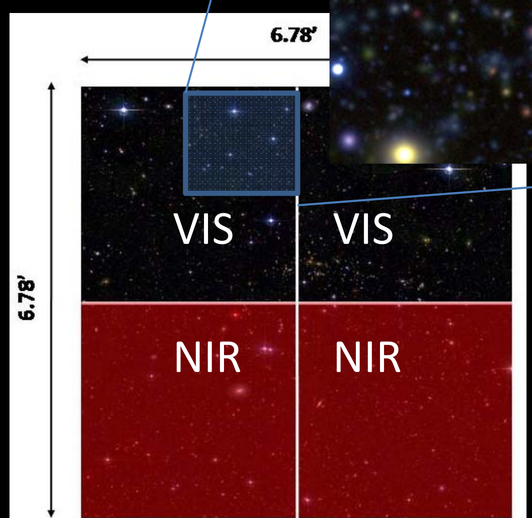
Multi-slit R~300
High multiplex 480 slits



Wide field, multi-mode

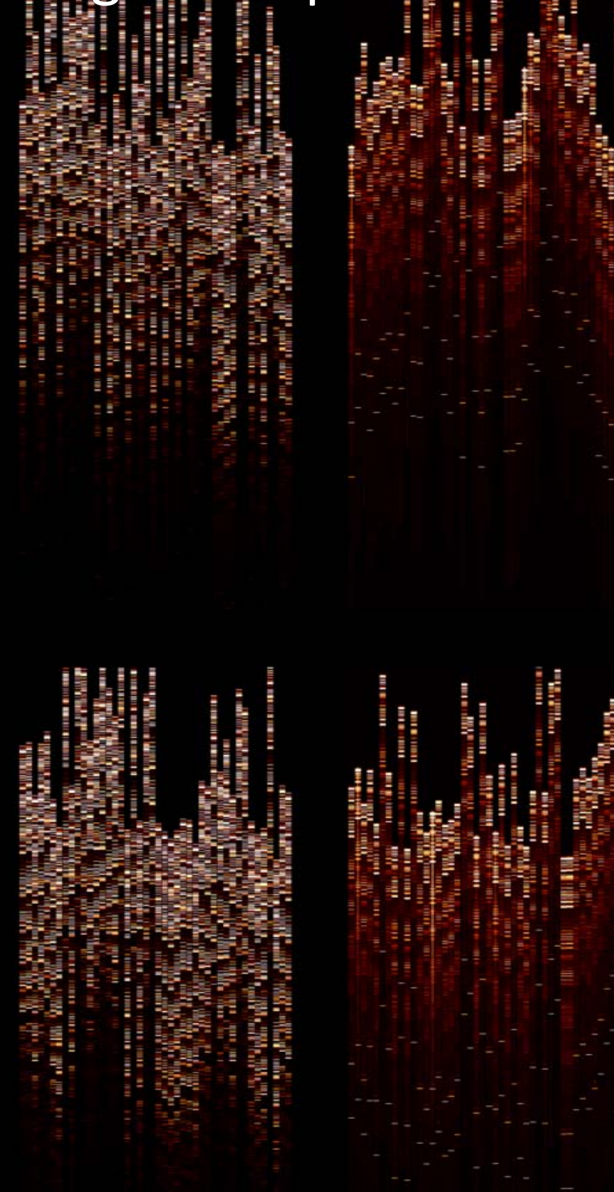
Imaging





>30,000 sources in 7'x7' to r_{AB}=29.8

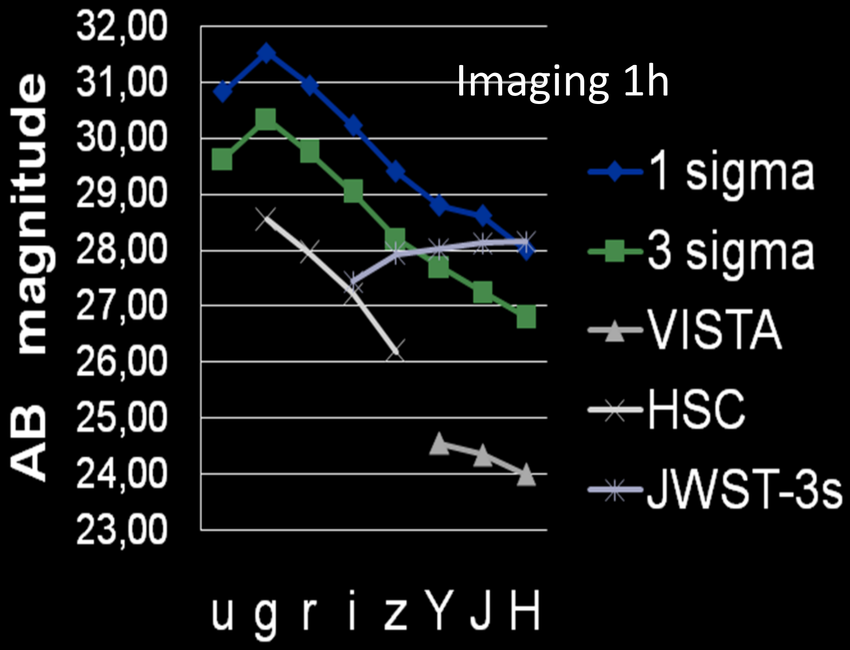
Multi-slit R~3000
High multiplex: 160 slits

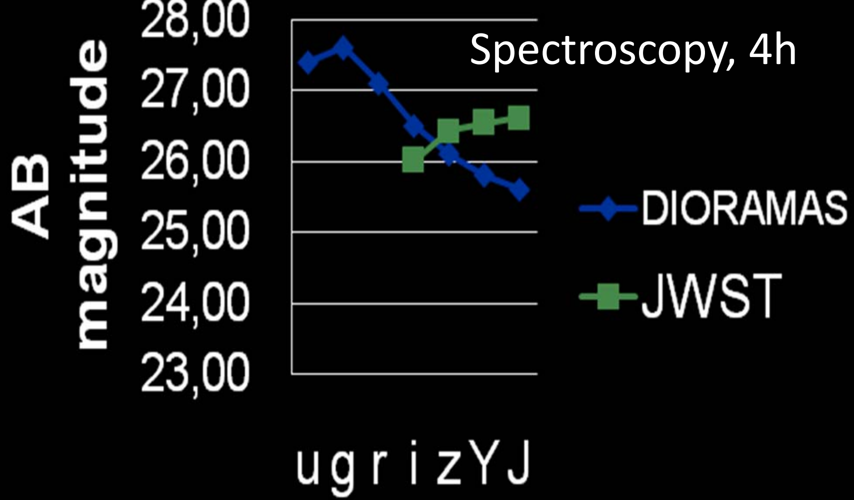


High level of performances

- High multiplex: 160-480 slits
- Extremely deep imaging from u’ to H
- Excellent image quality and high throughput: ultimate depth on EELT
  - MOS: 0.25mag deeper than fibers
  - Sky subtraction 0.1% in slits vs. 0.5% in fibers
- Limiting magnitude (4h): AB~29 in imaging, AB~26.5 in MOS
- GLAO: ~0.4 arcsec over FOV

<u>Gain @1µm 10-25× compared to JWST-NIRSPEC</u>: x5 multiplex, x2.5-5 FOV, at equivalent depth/unit time





MOS spectroscopy at the EELT: summary
"extragalactic"

Need at least 2 MOS flavors

A powerful combination for high-z: DIORAMAS + EAGLE