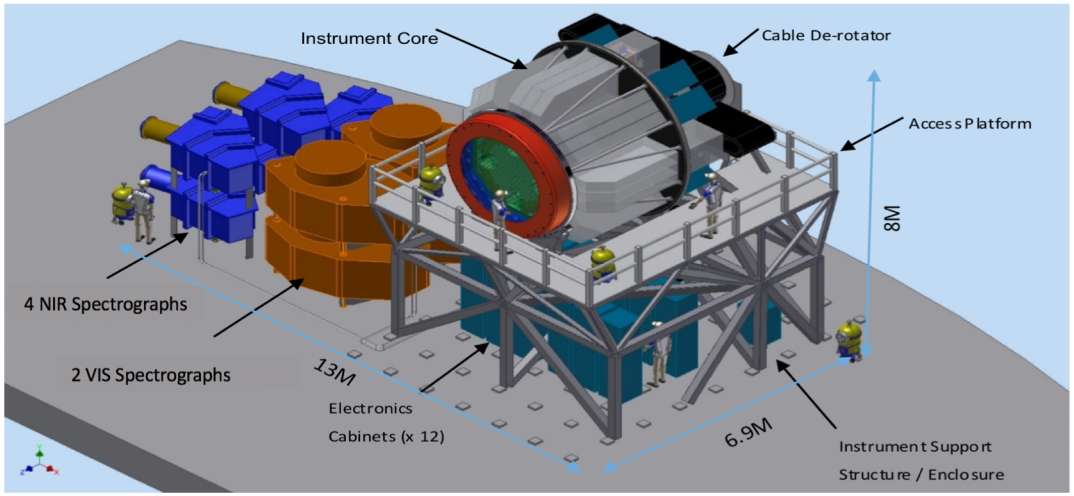
MOSAIC for the ESO-ELT

François Hammer
On behalf of the MOSAIC team

(see http://www.mosaic-elt.eu)



MOSAIC

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

Soon to come (October 2nd): STSci, ANU (Australia)

l'Observatoire de Paris

LAM Laboratoire d'Astrophysique de Marseille

Science & Technology Facilities Council
UK Astronomy Technology Centre

Universiteit van Amsterdam

irap astrophysique & planétologie

Durham University

University of Oxford

AIP

NOVA

MOSAIC

MOS ‘Principle’

1. exploits the telescope collecting surface

1. a moderately good image quality

➔ To perform exceptional & unique science advances in 2020s

MOSAIC

4 Science Cases used for trade-off

First-light galaxies

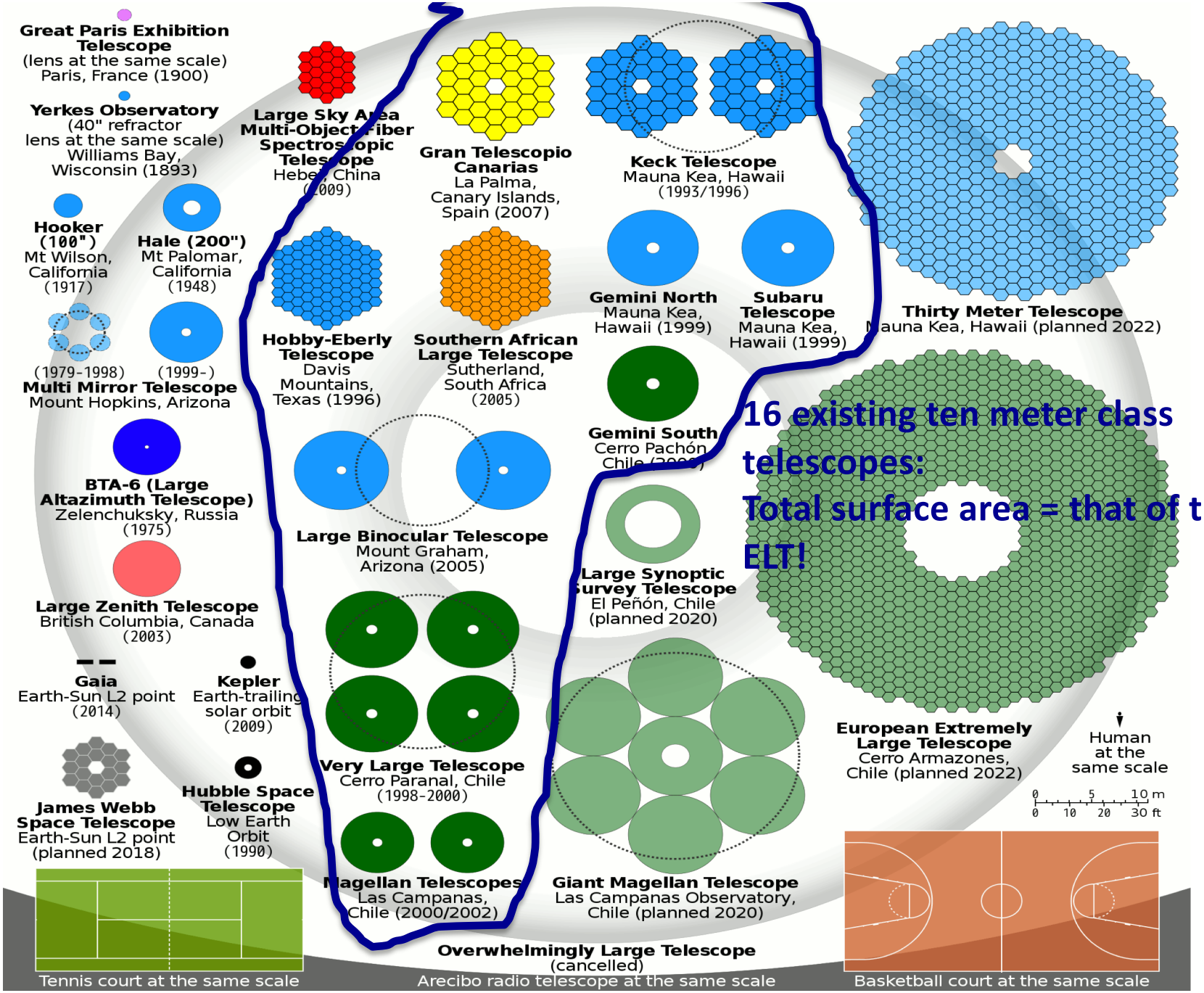
Dwarf galaxies

Inventory of matter at high z (halo gas & dark matter)

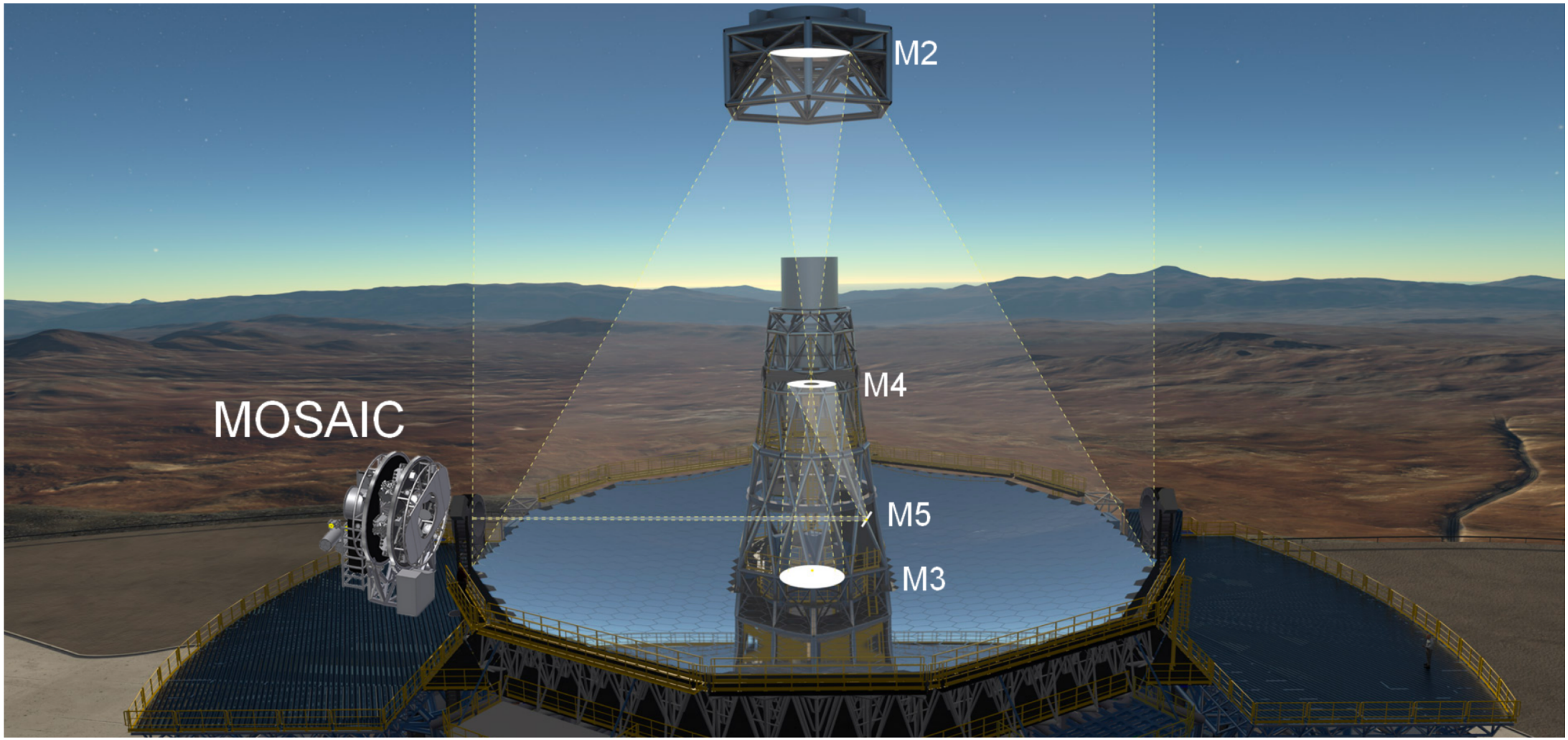
Extragalactic stellar populations

Cf Phase A Science Description

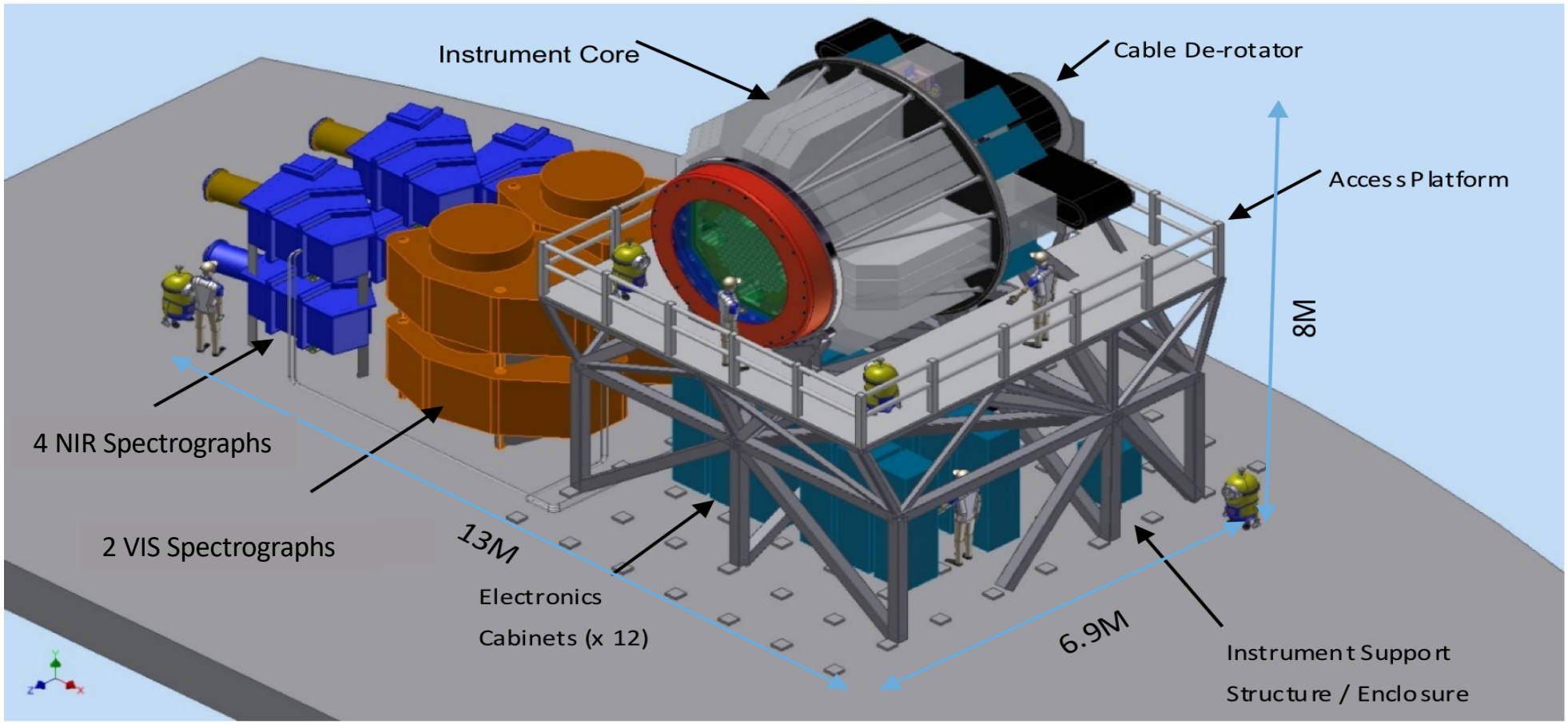
MOSAIC


Great Paris Exhibition Telescope
(lens at the same scale)
Paris, France (1900)
Yerkes Observatory
(40" refractor lens at the same scale)
Williams Bay, Wisconsin (1893)
Hooker (100")
Mt Wilson, California (1917)
Hale (200")
Mt Palomar, California (1948)
(1979-1998)
(1999-)
Multi Mirror Telescope
Mount Hopkins, Arizona
BTA-6 (Large Altazimuth Telescope)
Zelenchuksky, Russia (1975)
Large Zenith Telescope
British Columbia, Canada (2003)
Gaia
Earth-Sun L2 point (2014)
Kepler
Earth-trailing solar orbit (2009)
James Webb Space Telescope
Earth-Sun L2 point (planned 2018)
Hubble Space Telescope
Low Earth Orbit (1990)
Large Sky Area Multi-Object Fiber Spectroscopic Telescope
Hebei, China (2009)
Hobby-Eberly Telescope
Davis Mountains, Texas (1996)
Large Binocular Telescope
Mount Graham, Arizona (2005)
Very Large Telescope
Cerro Paranal, Chile (1998-2000)
Magellan Telescopes
Las Campanas, Chile (2000/2002)
Gran Telescopio Canarias
La Palma, Canary Islands, Spain (2007)
Southern African Large Telescope
Sutherland, South Africa (2005)
Keck Telescope
Mauna Kea, Hawaii (1993/1996)
Gemini North
Mauna Kea, Hawaii (1999)
Subaru Telescope
Mauna Kea, Hawaii (1999)
Gemini South
Cerro Pachón, Chile (2000)
Large Synoptic Survey Telescope
El Peñón, Chile (planned 2020)
Giant Magellan Telescope
Las Campanas Observatory, Chile (planned 2020)
Overwhelmingly Large Telescope
(cancelled)
Thirty Meter Telescope
Mauna Kea, Hawaii (planned 2022)
European Extremely Large Telescope
Cerro Armazones, Chile (planned 2022)
Human at the same scale
0 5 10 m
0 10 20 30 ft
16 existing ten meter class telescopes:
Total surface area = that of the E-ELT!
Tennis court at the same scale
Arecibo radio telescope at the same scale
Basketball court at the same scale

MOSAIC on ELT

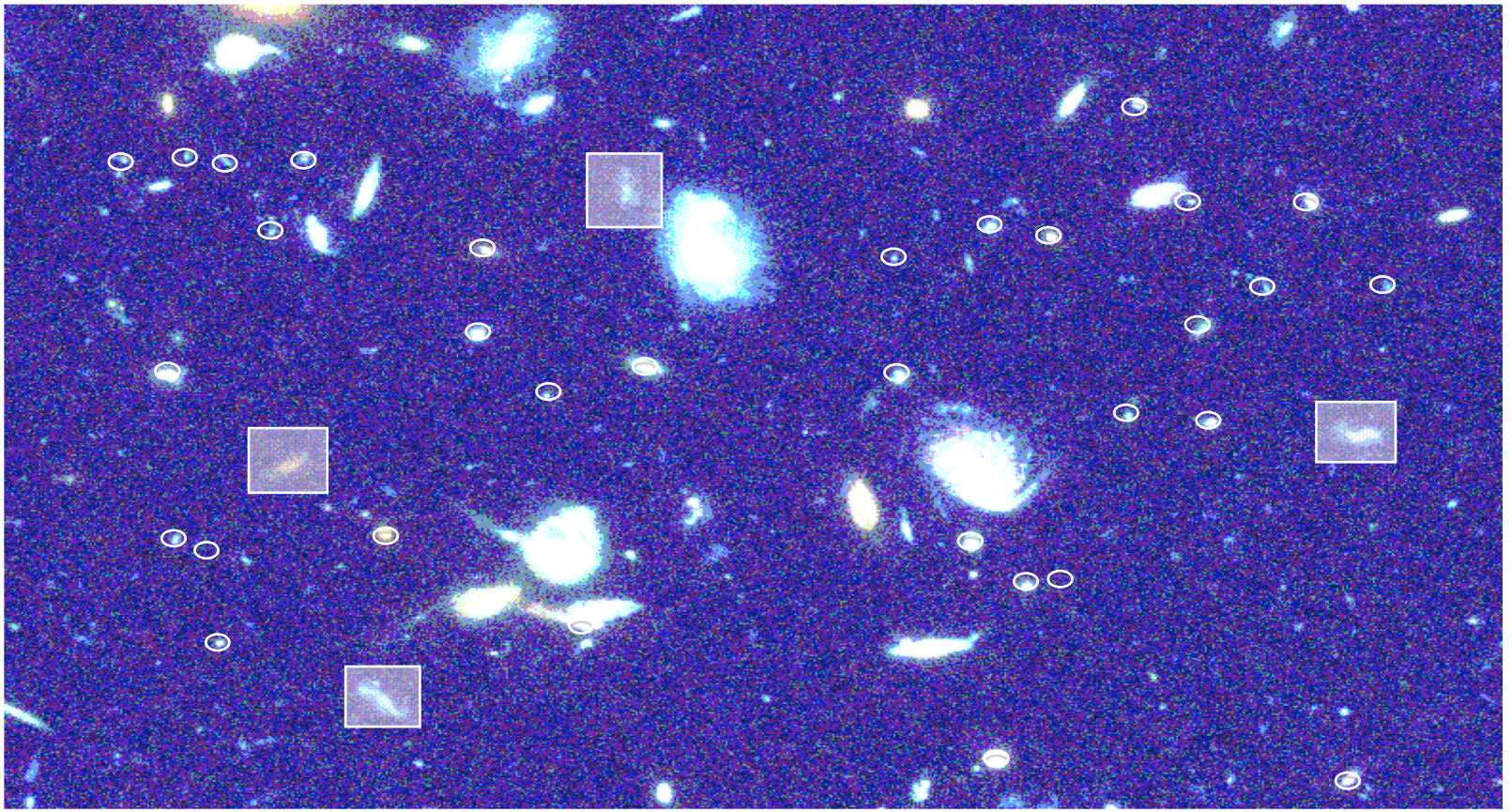


MOSAIC on ELT platform



IFUs & high multiplex modes over FoV= 50 arcmin^2

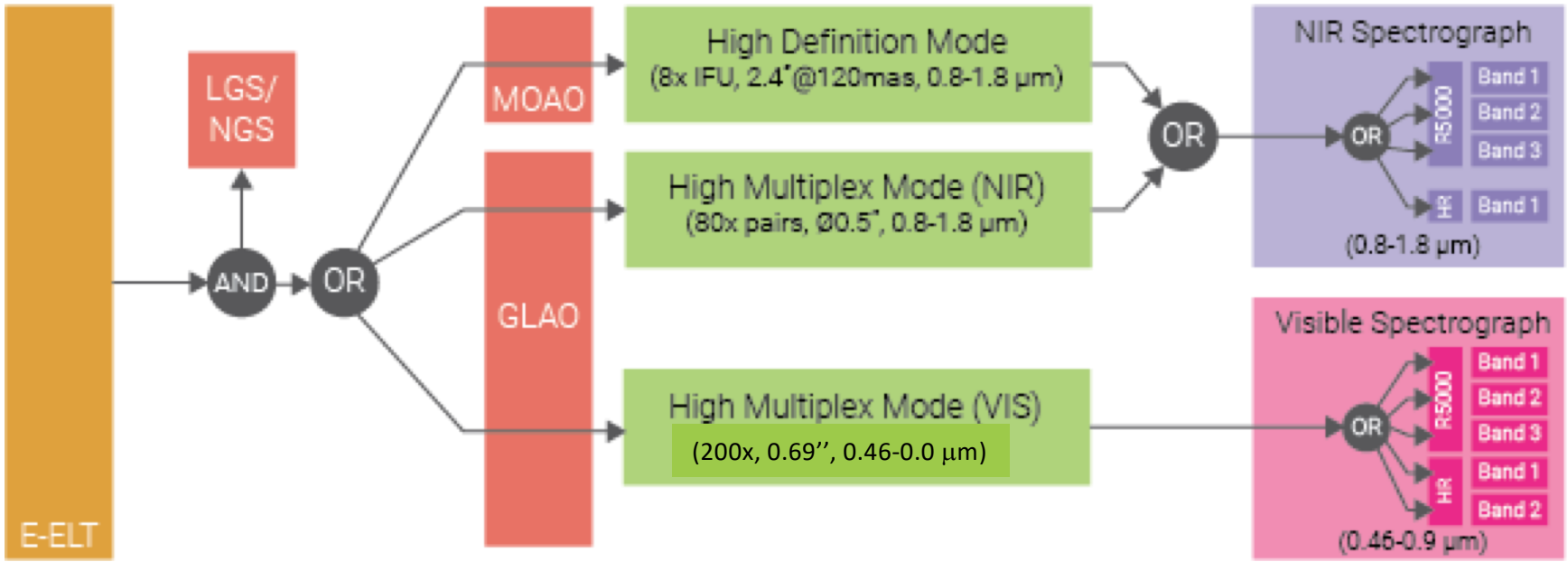
MOSAIC



- 200 point like objects in VIS, ≥ 200 in NIR (though sky subtraction may limit)
- 8-10 IFUs with MOAO in NIR (High Definition Mode, ~ 80-100 mas)
- VIS could be observed simultaneously with NIR
- R=5000 + windows at R~ 10,000

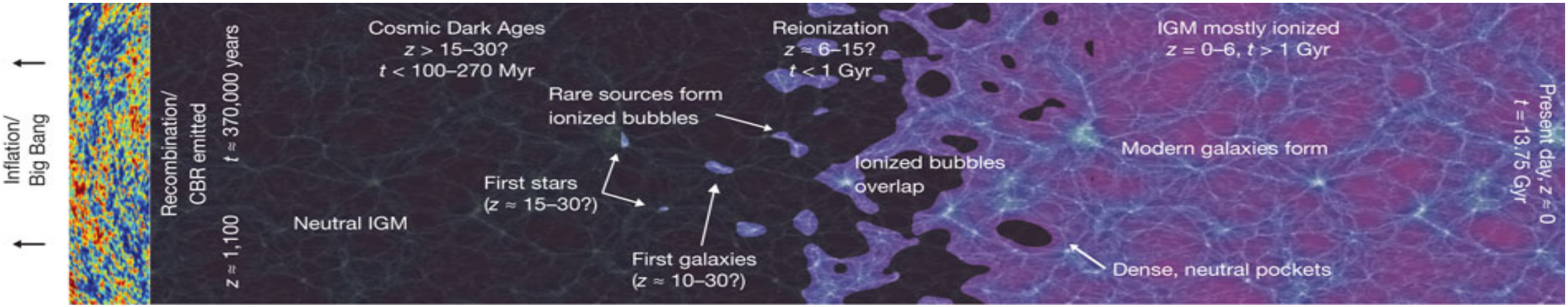
MOSAIC

Distribution & Operation of observing modes



THE REIONISATION OF THE UNIVERSE: FIRST OBJECTS

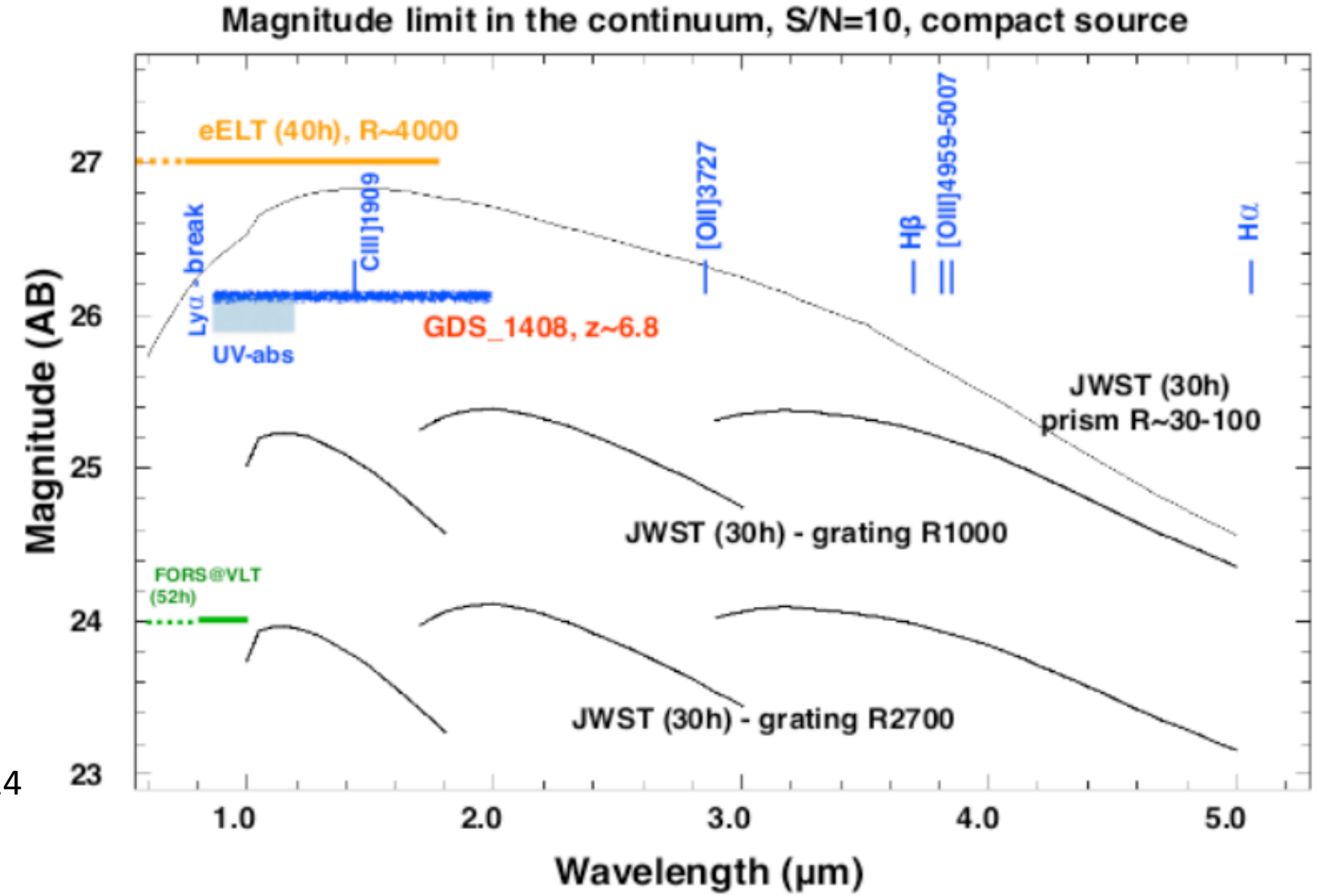
ELT & JWST VLT & HST



Given the overwhelming number of foreground objects in the FoV, only a MOS can provide significant discoveries & progresses in the field!

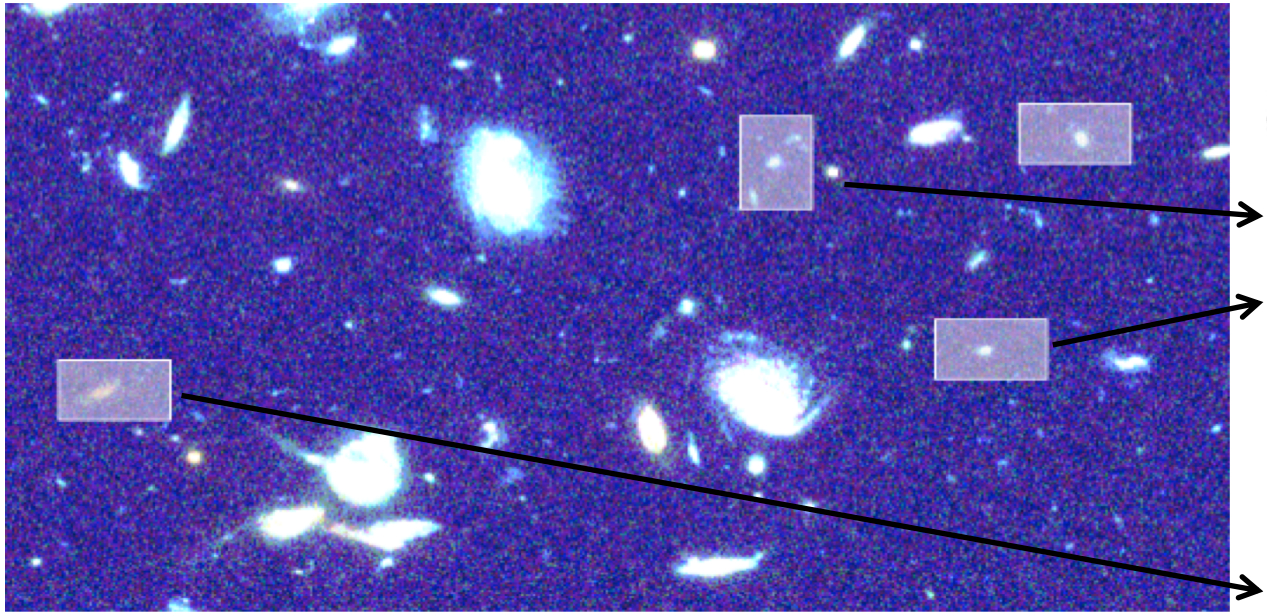
MOSAIC

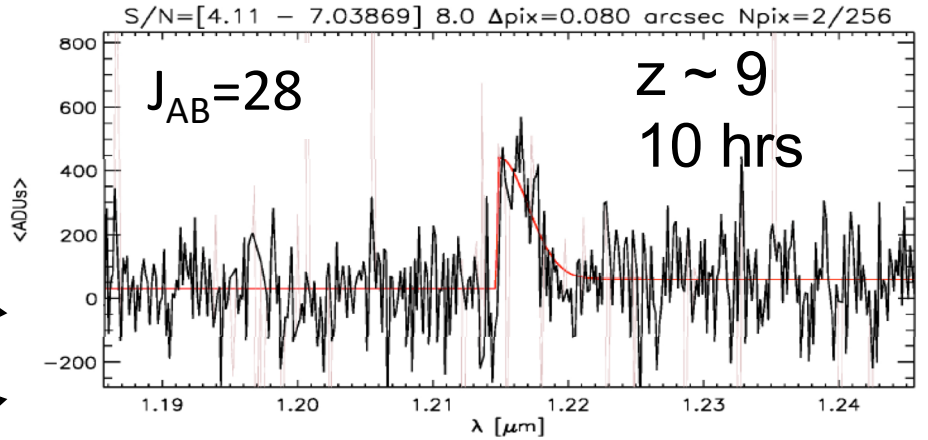
Collecting surface ensures MOSAIC without competitors for faintest sources in NIR

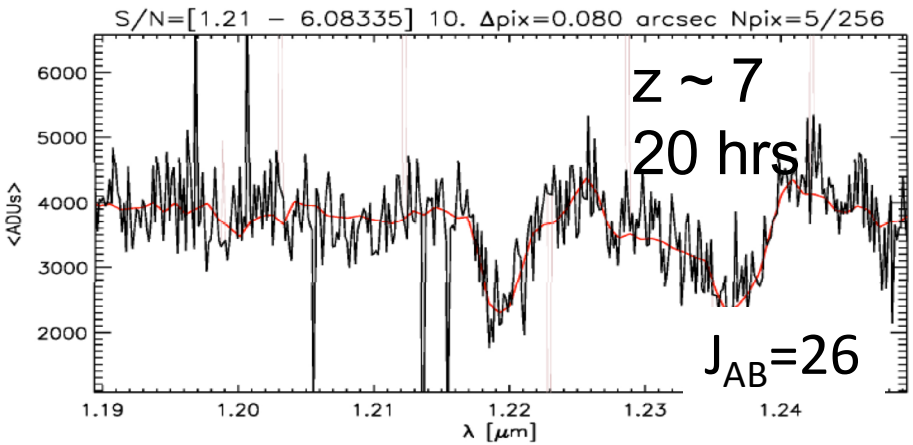


From Vanzella et al. 2014

Most distant galaxies: MOSAIC, follow-up of JWST imagery: Higher spectral resolution, search for popIII?



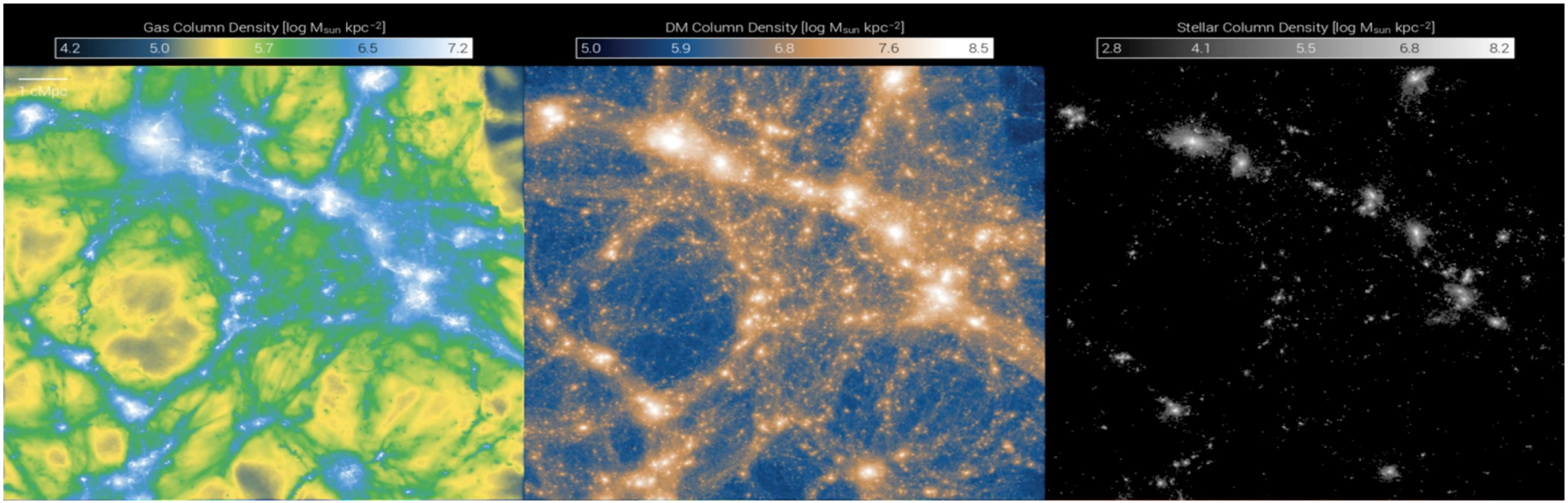




Simulations: Disseau et al., 2014

IFUs: unbeatable for the best sky subtraction

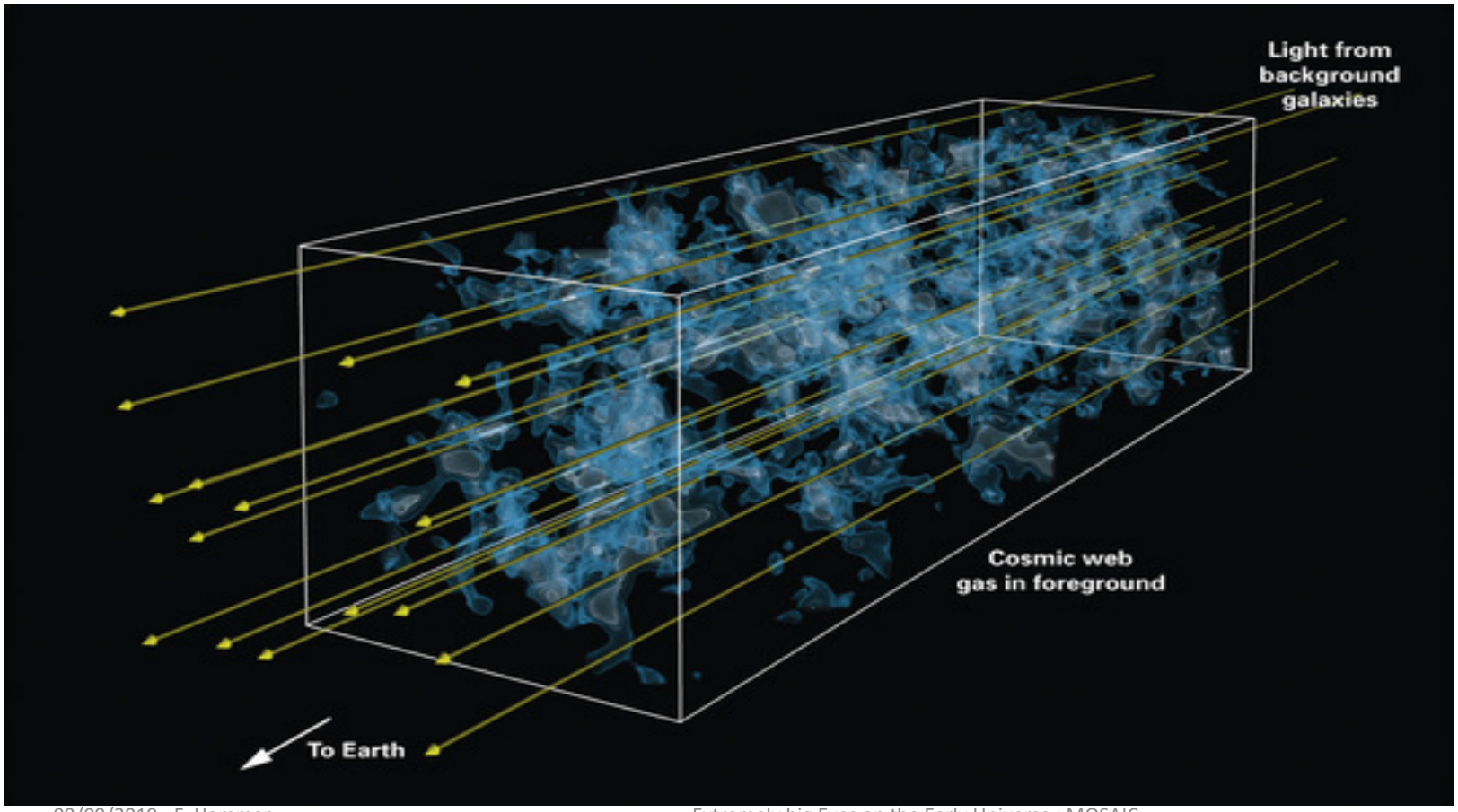
INVENTORY OF MATTER IN THE DISTANT UNIVERSE



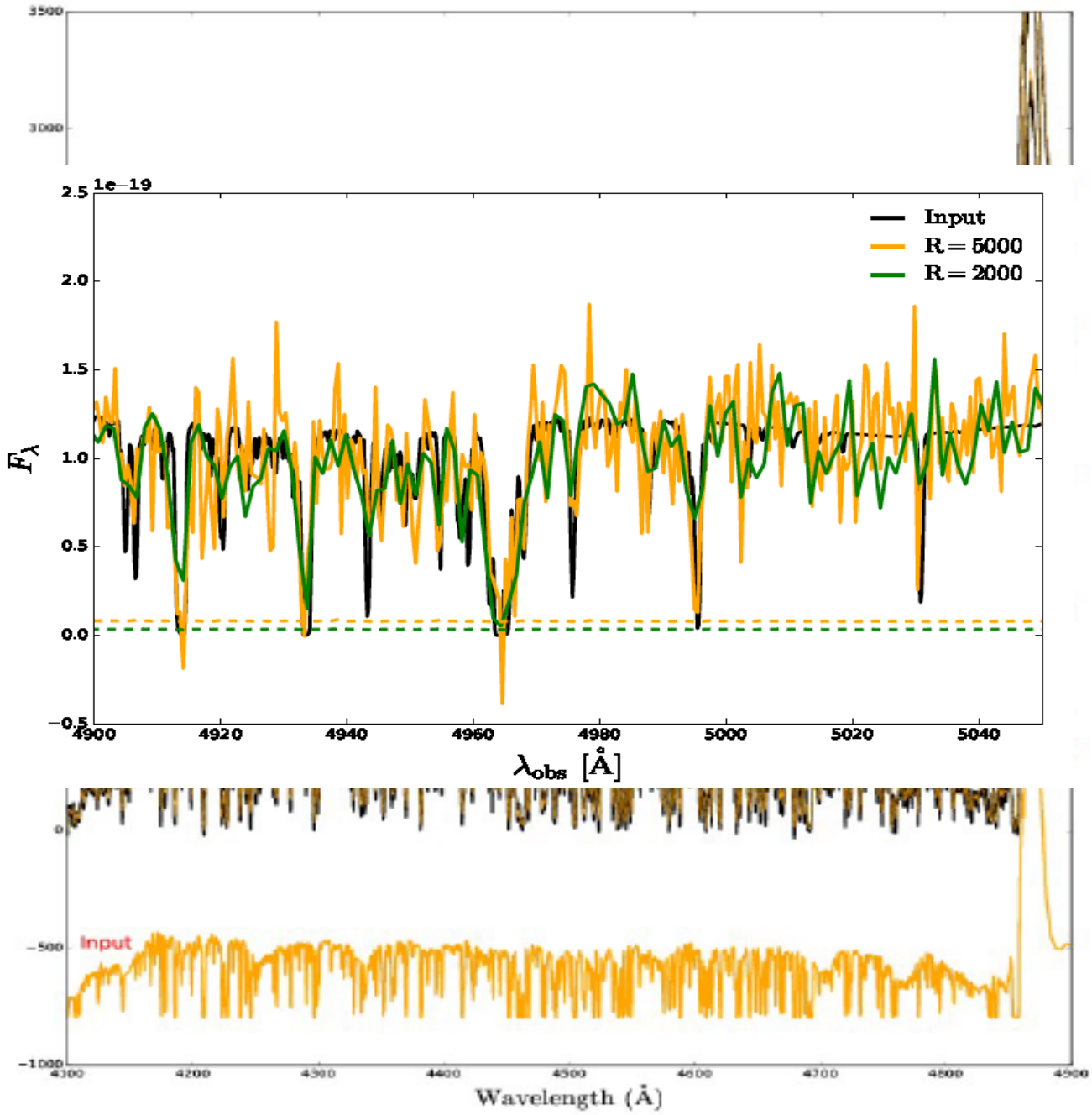
GAS DARK MATTER STARS ILLUSTRIS-TNG

INVENTORY OF MATTER IN THE DISTANT UNIVERSE

INTERGALACTIC MEDIUM TOMOGRAPHY



Simulations done in Japelj et al. 2019, submitted



Lyman forest:

LBG targets at z=3.5, AB=24.5-25.5 (2-10 hrs)

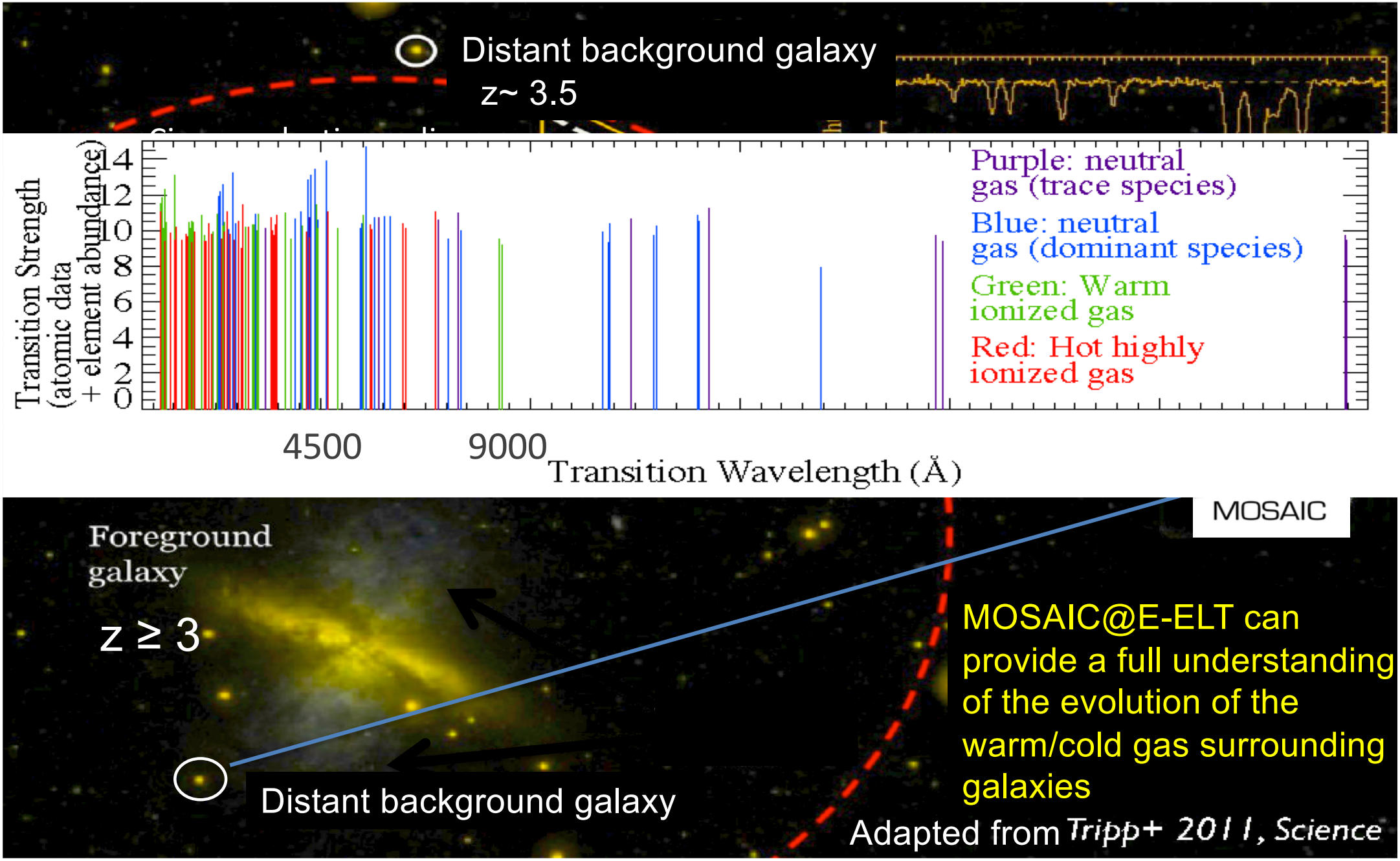
Simulations: Japelj et al. 2019

AND

Metallic lines (missing baryons):

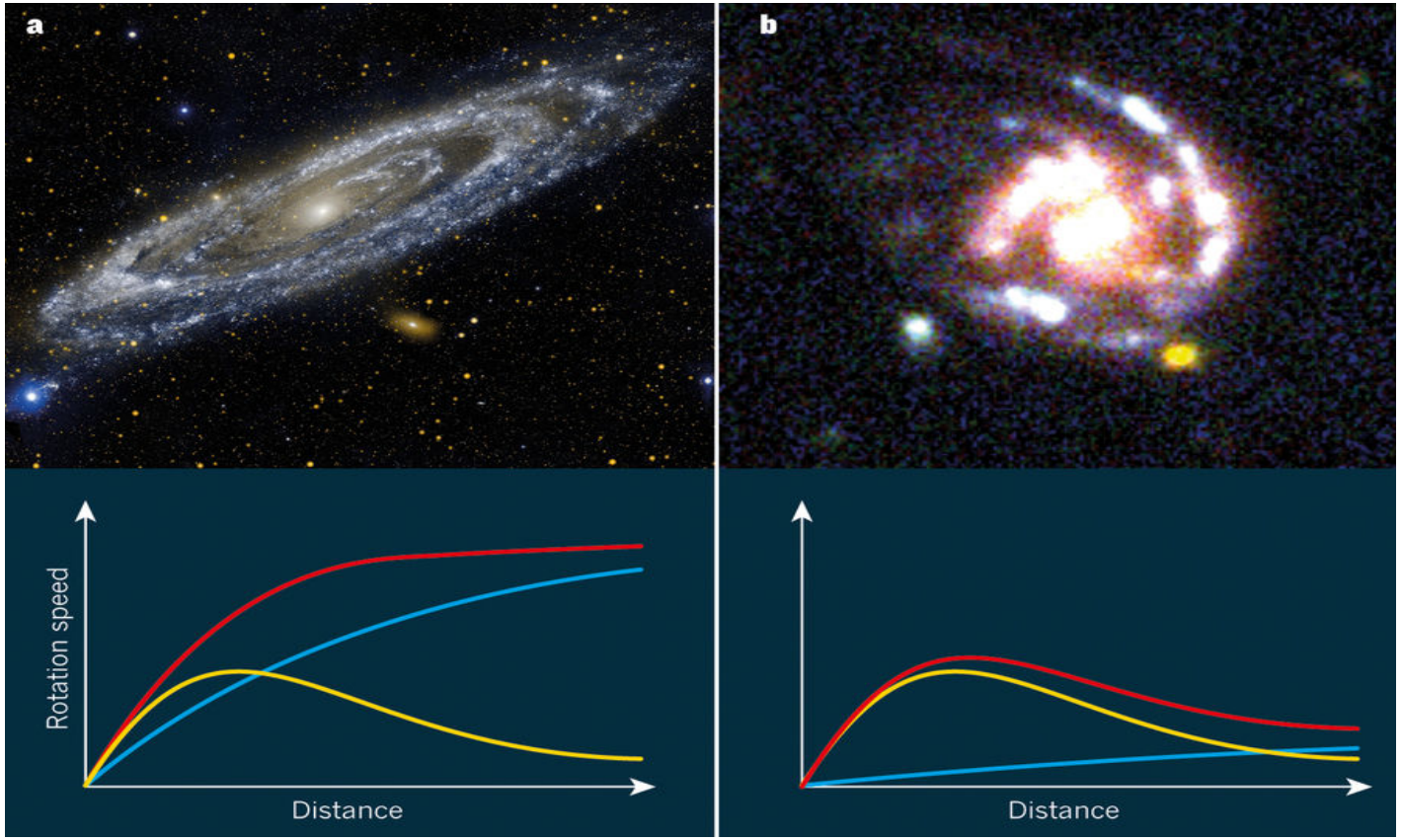
targets at z= 3.5, AB=24.5-25.5

Simulations: Rahmani et al. (in prep.)


Distant background galaxy
z~ 3.5
Transition Strength
(atomic data
+ element abundance)
0 2 4 6 8 10 12 14
Purple: neutral
gas (trace species)
Blue: neutral
gas (dominant species)
Green: Warm
ionized gas
Red: Hot highly
ionized gas
4500
9000
Transition Wavelength (Å)
MOSAIC
Foreground
galaxy
z ≥ 3
Distant background galaxy
MOSAIC@E-ELT can
provide a full understanding
of the evolution of the
warm/cold gas surrounding
galaxies
Adapted from Tripp+ 2011, Science

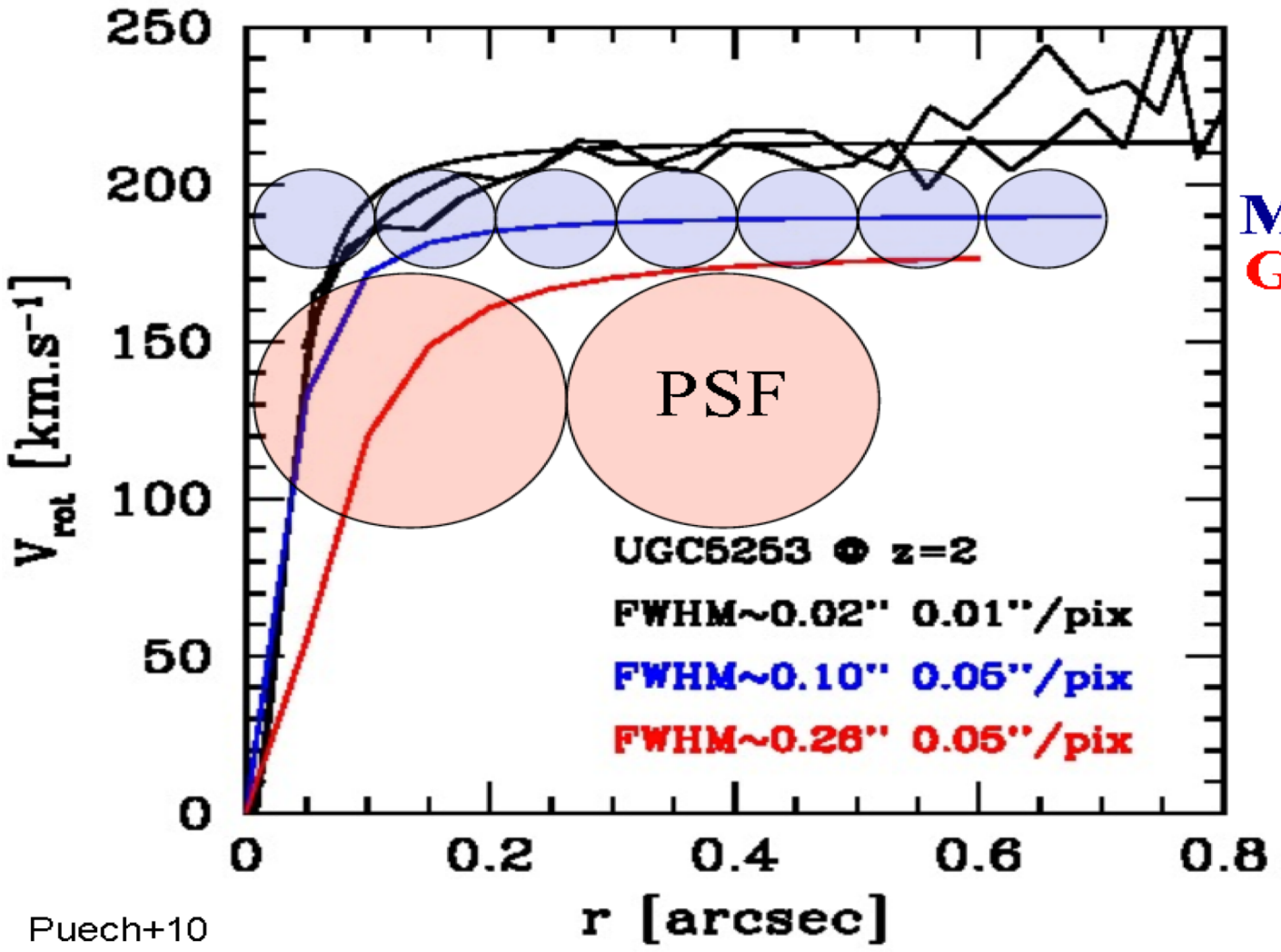
INVENTORY OF MATTER IN THE DISTANT UNIVERSE

DARK MATTER FROM ROTATION CURVES



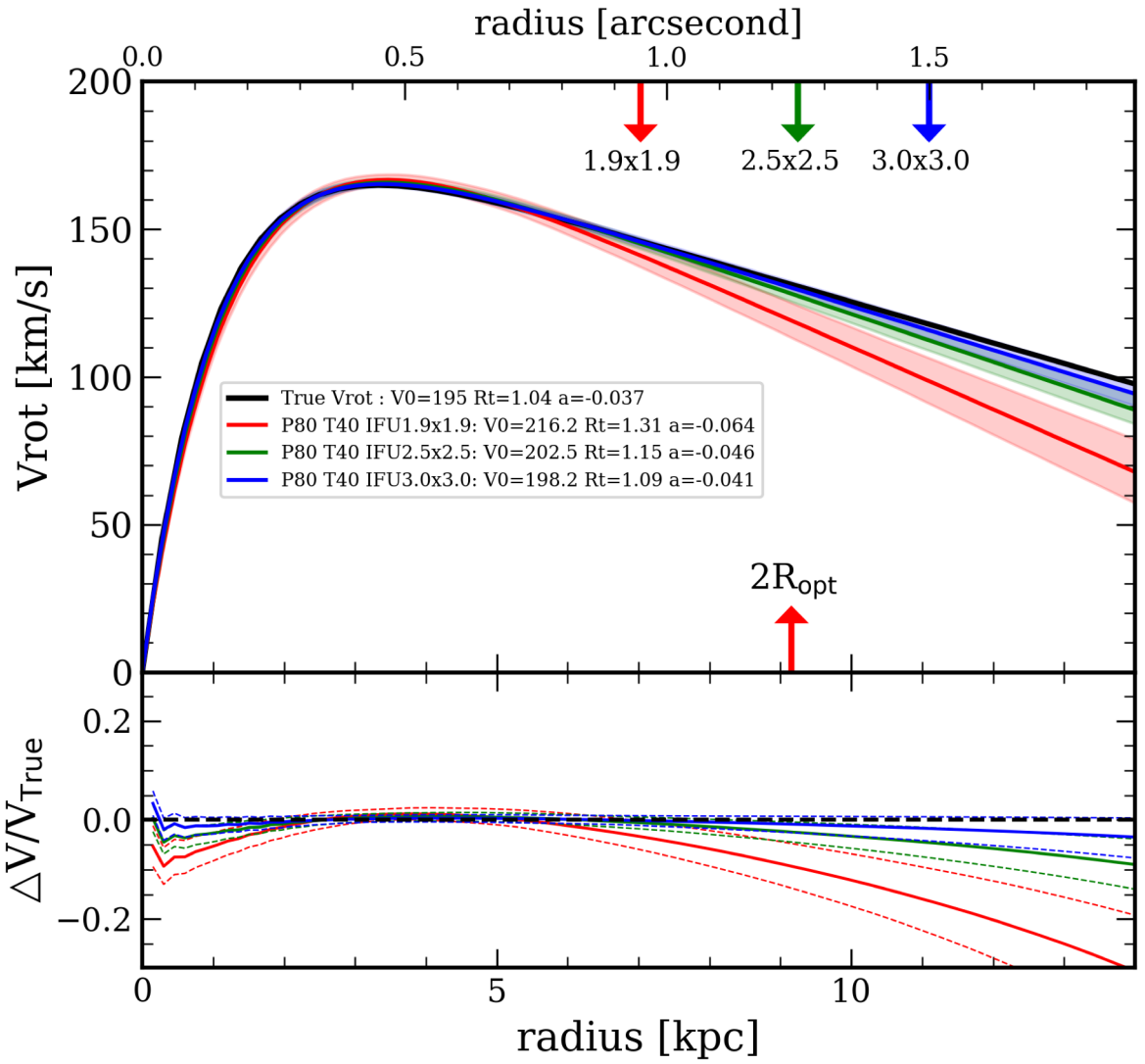
GENZEL+17

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



Puech+10

MOAO is required to provide at least 5 to 7 resolution elements per rotation curve side



Simulations of a z=3.6 L* galaxy,

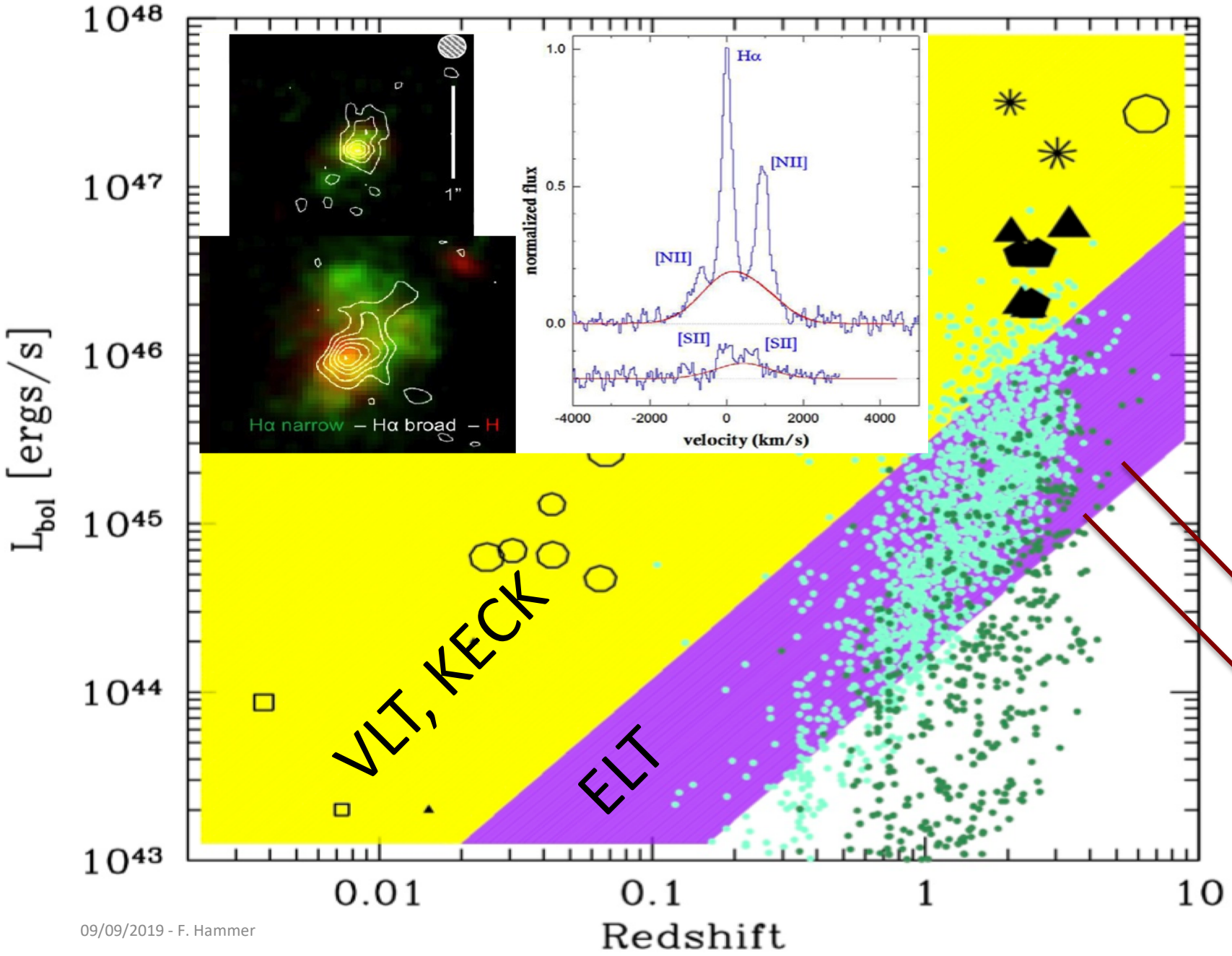
pixel scale =80 microns ➔ fine tuning of the size of the IFU/pixel

Simulations: Wang, Puech et al.

MOSAIC

1- Survey speed: MOSAIC will be ~ 8 times faster than HARMONI in doing rotation curves

2- Since not all distant galaxies are rotating disks, multi-IFUs are mandatory to pre-select the targets



At z > 6:
witnessing the elaboration of the first super massive black holes

Science and final TLRs for MOSAIC

Finalize Trade-offs after comparison with other facilities in the 2020s:

- Pre-Phase B: Mass/budget imposes us to limit to:
  4 NIR Spectrographs + 2 VIS Spectrographs
  no VIS IFU for limiting # of modes
  limited high spectral resolution mode in VIS (~ 10,000)

- Goals: multiplex ≥ 200 in both VIS and NIR, however:

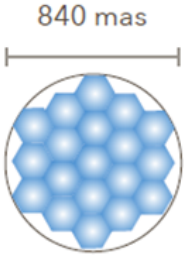
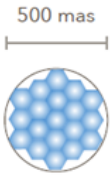
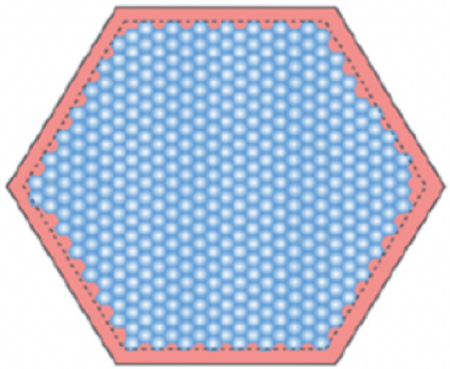
- In NIR sky subtraction could be a limitation in the high-multiplex mode

- only HDM still competitive for reaching ~ 2 mag deeper than JWST & for doing galaxy kinematics (larger IFU including for sky subtraction)

- Final-final trade-offs (science then technique) in pre-Phase B expected very soon in agreement between MOSAIC, ESO & STC

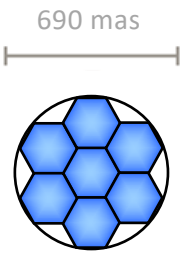
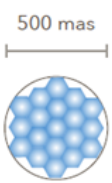
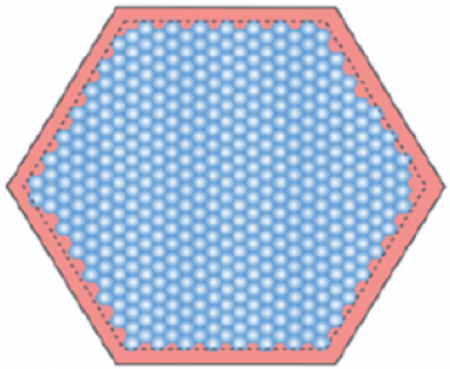
MOSAIC

Apertures and sampling sizes for the various MOSAIC modes

Mode	HMM-VIS	HMM-NIR	HDM IFUs
Aperture (shown to scale)			
Diameter	840 mas	500 mas	1.9 arcsec
Microlens sampling	168 mas	100 mas	80 mas
Actual spatial resolution	840 mas	500 mas	160 mas
Fibres/ Object	19	19	493

MOSAIC

Apertures and sampling sizes for the three MOSAIC modes

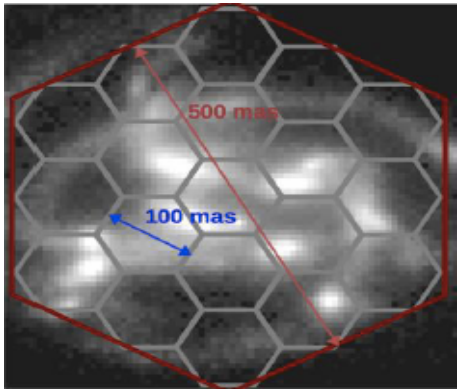
Mode	HMM-VIS	HMM-NIR	HDM IFUs
Aperture (shown to scale)			
Diameter	690 mas	500 mas	2.5 arcsec
Microlens sampling	230 mas	100 mas	80 mas
Actual spatial resolution	690 mas	500 mas	160 mas
Fibres/ Object	7	19	493

Increasing the multiplex to 200 by reducing # of fibers in the VIS bundles: lost of R=20,000 in VIS

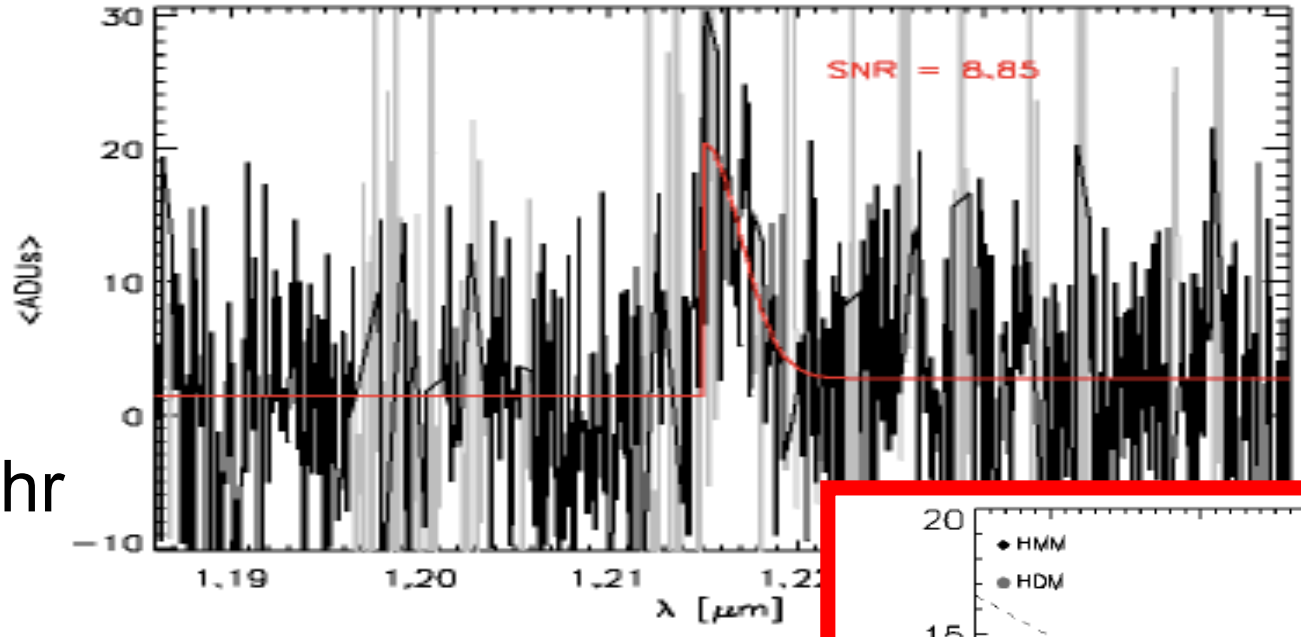
In NIR:

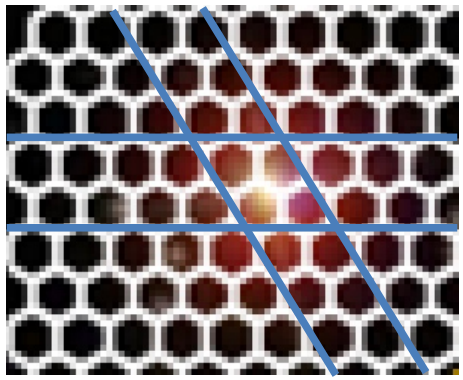
- Multiplex up to 160, to be increased to ~ 200 or more
- HDM-IFUs also require 2.5 arcsec aperture for, e.g., sky subtraction and also source sizes (kinematics, high-z emission lines)
- A possible increase of HDM-IFU spaxel size (last debate before soon coming TLR release)

Example: z~9 LAEs/LBGs

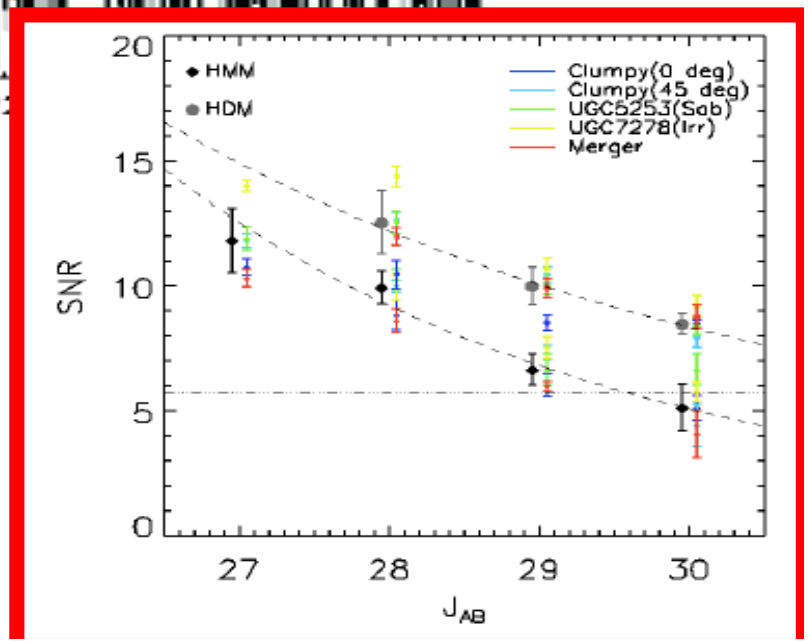


z=9, mJ=28,10 hr





Possible sky-subtraction scheme with IFUs

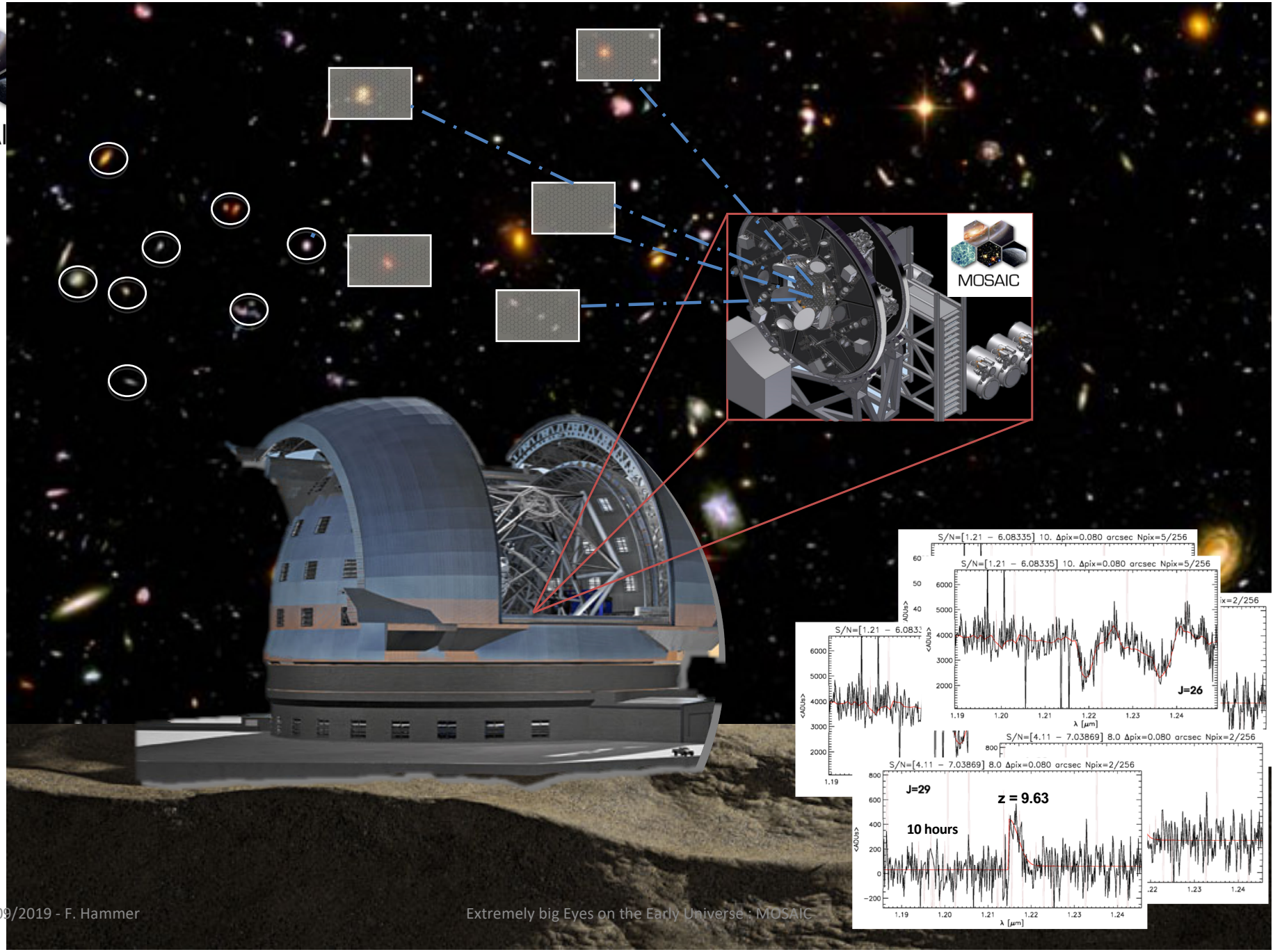


Conclusions

- MOS is essential for scientific programs requiring statistics, or source ID & their environments
- The ELT-MOS is unique for ALL targets not reachable by 10 meter telescopes,
- It will increase by ~ 5 the distance to which massive young stars can be analysed,
- Spectroscopy of first galaxies (AB >27) requires multiplex: 8000 H_{AB} = 27 galaxies in one FoV! But to reach this depth requires an efficient sky subtraction (HDM-IFUs)!

- 2019: starting preparation of GTO (125 to 140 GTO nights), mostly surveys to be defined
- Requires scientists willing to simulate science of the 2020-30 & to prepare surveys
- Websim-compass simulator http://websim-compass.obspm.fr/

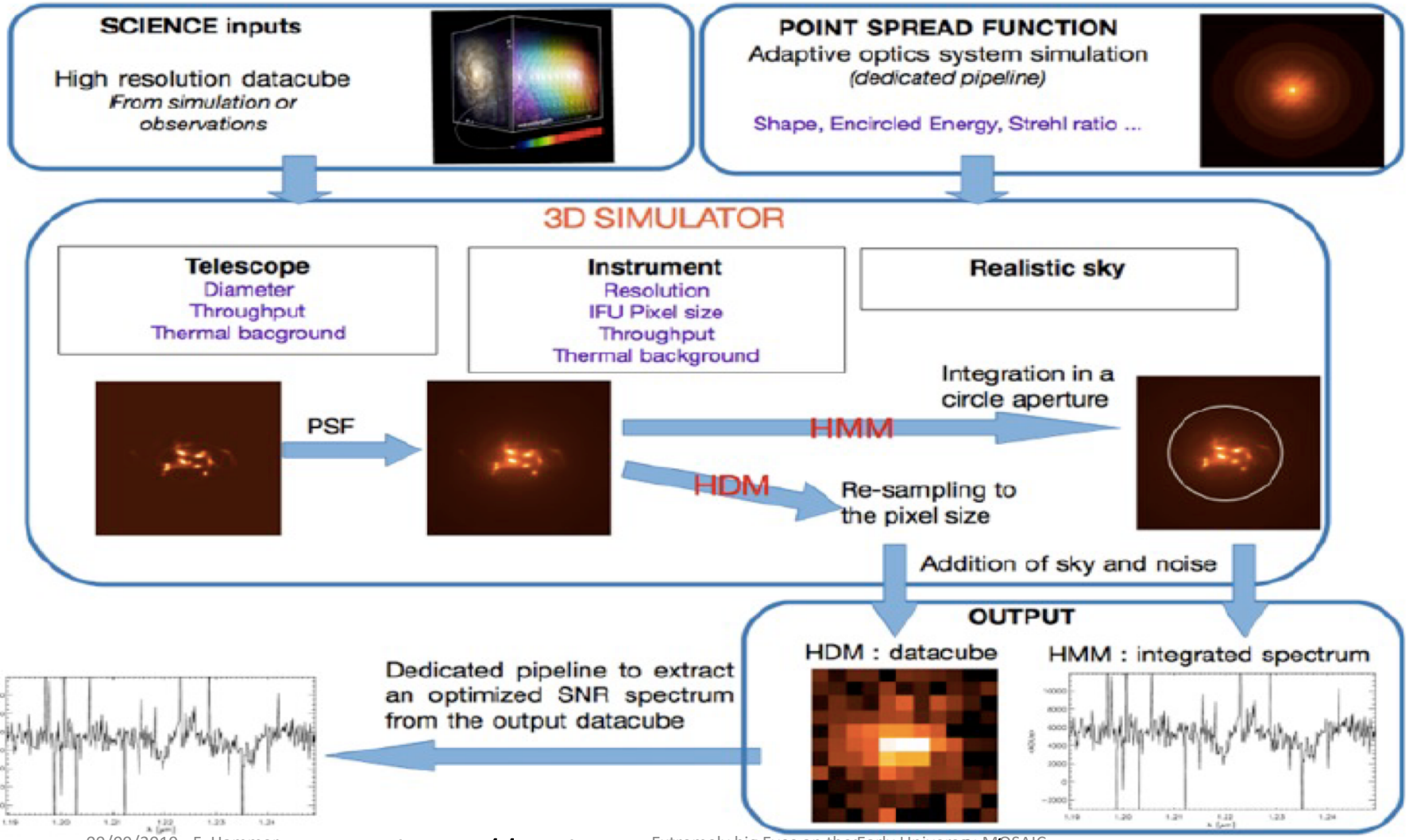
- ESO is involved to the MOS despite difficulties on the telescope and on some first-light facilities.
- This year 2019: finalize last TLR detailss and prepare the Phase B contract
- Prepare the Consortium (80 M€ including 30 M€ for hardware), up to 15 countries, 40 Institutes
- Preparation of Contract, SoW & MoU in course with ESO and partners
- Budget for hardware almost closed, still few new partners in contact


MOSAIC
S/N=[1.21 – 6.08335] 10. Δpix=0.080 arcsec Npix=5/256
J=26
S/N=[4.11 – 7.03869] 8.0 Δpix=0.080 arcsec Npix=2/256
J=29
z = 9.63
10 hours
<ADUs>
λ [μm]

Timeline (draft)

	2020		2021		2022		2023		2024		2025		2026		2027		2028		2029	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Prephase B	MoU/Cons.Agree./TLR/ICD																			
			t0 = Dec. 2020 (unlikely before)																	
Phase B	B1		B1		Nov. 2021: System Req Review															
B2					B2		June 2023 : PDR													
Phase C							CDR		Nov 2024: Critical Design Review											
OFDR									OFDR		June 2025: Optical Final Design Review									
FDR									FDR --> MRR		Nov. 2025: Final Design Review (All)									
Phase D: MAIT											Manufacture and Procure									
sub-systems													AIT Units and SS							
AIT System															AIT System --> Instrument					
Armazones AIT																				
Hall																				
Telescope																				

WEBSIM-COMPASS simulator

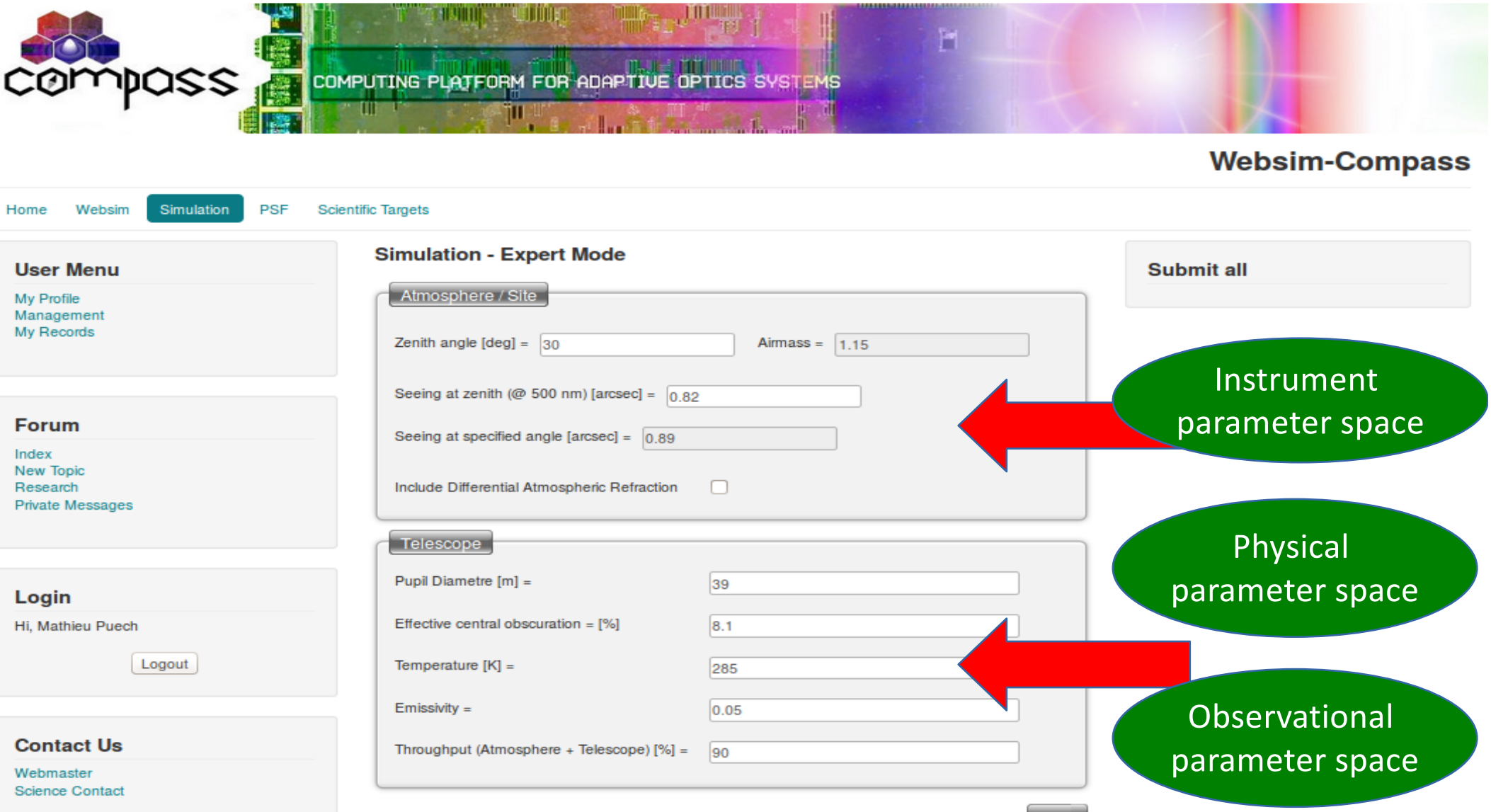


HMM=High Multiplex Mode (mono-aperture fibers)

HDM=High Definition Mode (IFUs)

http://websim-compass.obspm.fr/

Puech, SPIE, 2016



Exploring all the parameter space(s) (N>>10 parameters) for all SCs would be prohibitive in (calculation & human) time