
MAVIS: MCAO-ASSISTED VISIBLE IMAGER AND SPECTROGRAPH FOR THE VLT
SHARPER THAN JWST, DEEPER THAN HST
THE 3RD PIETRO BARACCHI CONFERENCE
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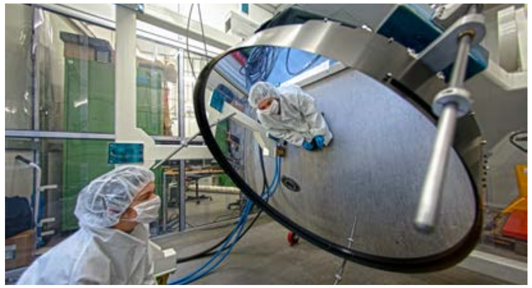
MACQUARIE UNIVERSITY, SYDNEY
ON BEHALF OF THE MAVIS CONSORTIUM
AAO
INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS
LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE
ESO

ESO STRATEGIC PARTNERSHIP – AN IMPORTANT OPPORTUNITY

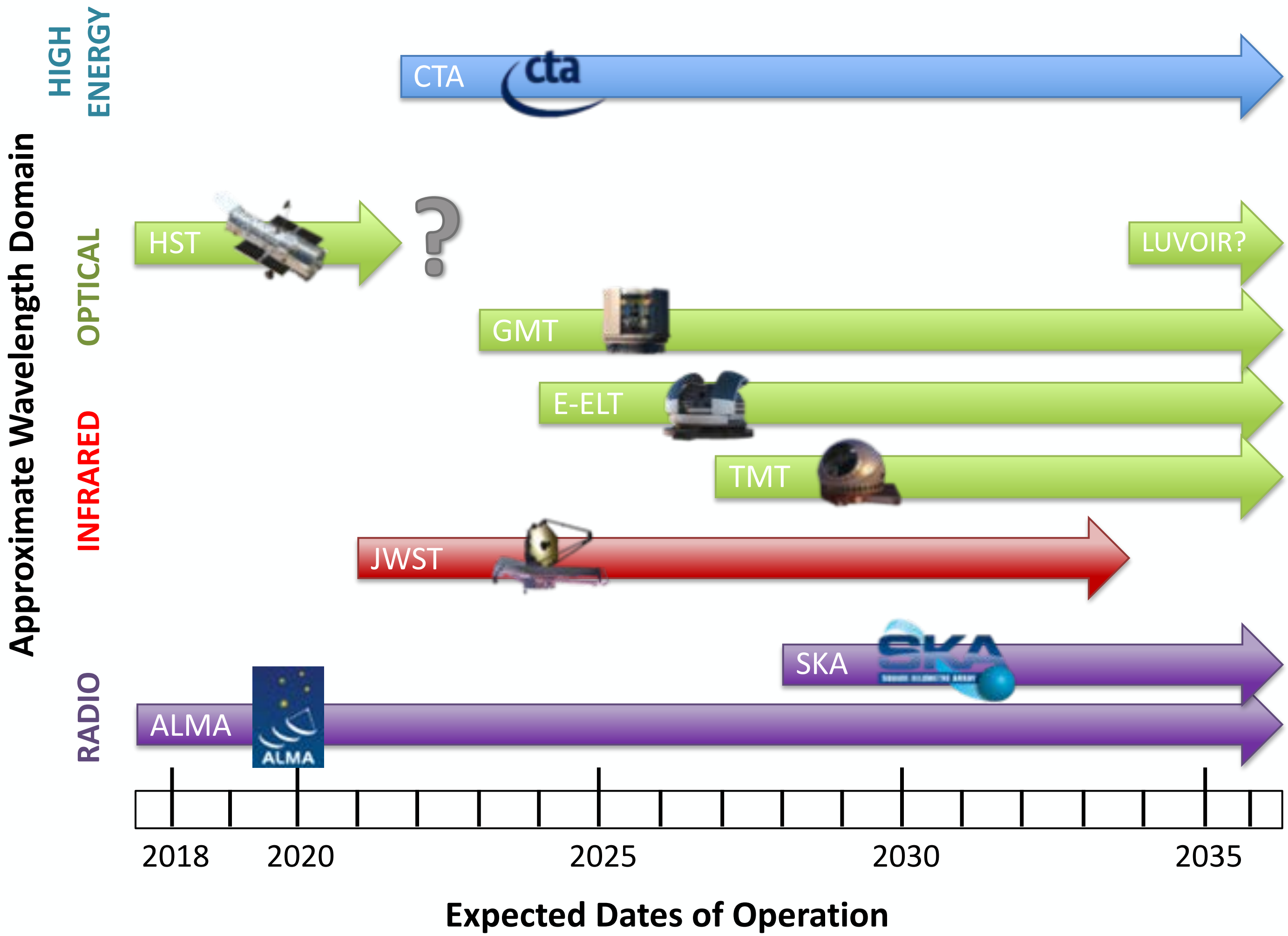
- Australia joined ESO as **strategic partner, July 2017**
- Opened opportunities for leading instrumentation projects
- Instrumentation opportunities for Australia limited to La Silla and Paranal, but **Adaptive Optics Facility (AOF)** newly commissioned
- Key technical components of AOF:
  - **Four laser guide stars**, 20W each, operating above specifications
  - **Deformable secondary mirror** with high actuator density
- Currently mainly ground-layer AO (wide field, low Strehl)
- MUSE Narrow Field Mode approaches diffraction limit, but only for bright on-axis guide stars (IRLOS upgrade helps, but still small off-axis distance)
- **Full AOF science potential not being realized**
- **In 2018, MAVIS Consortium selected for Phase A study of MCAO-fed optical imager/spectrograph**

Australia Enters Strategic Partnership with ESO

11 July 2017

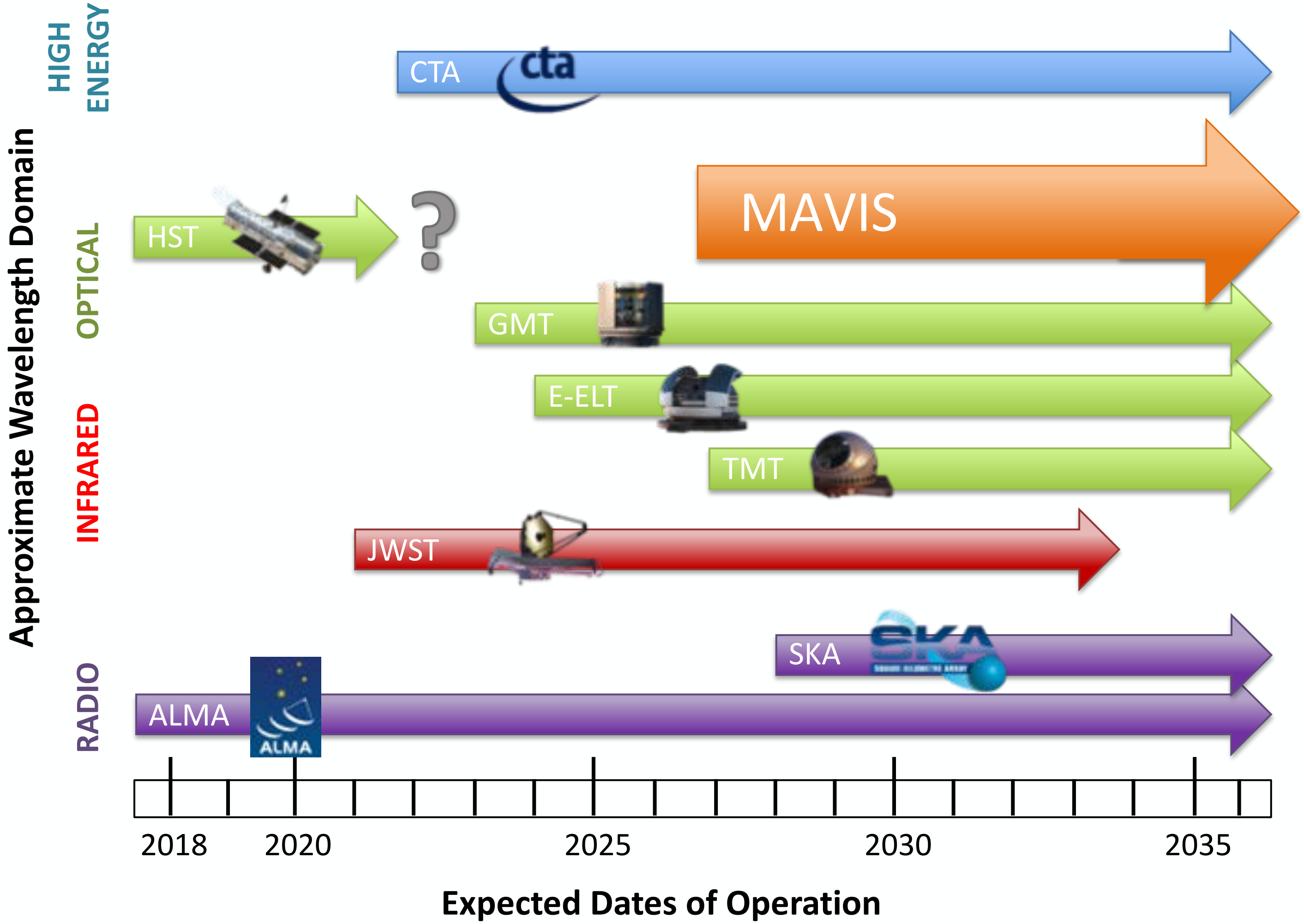


FUTURE FACILITIES

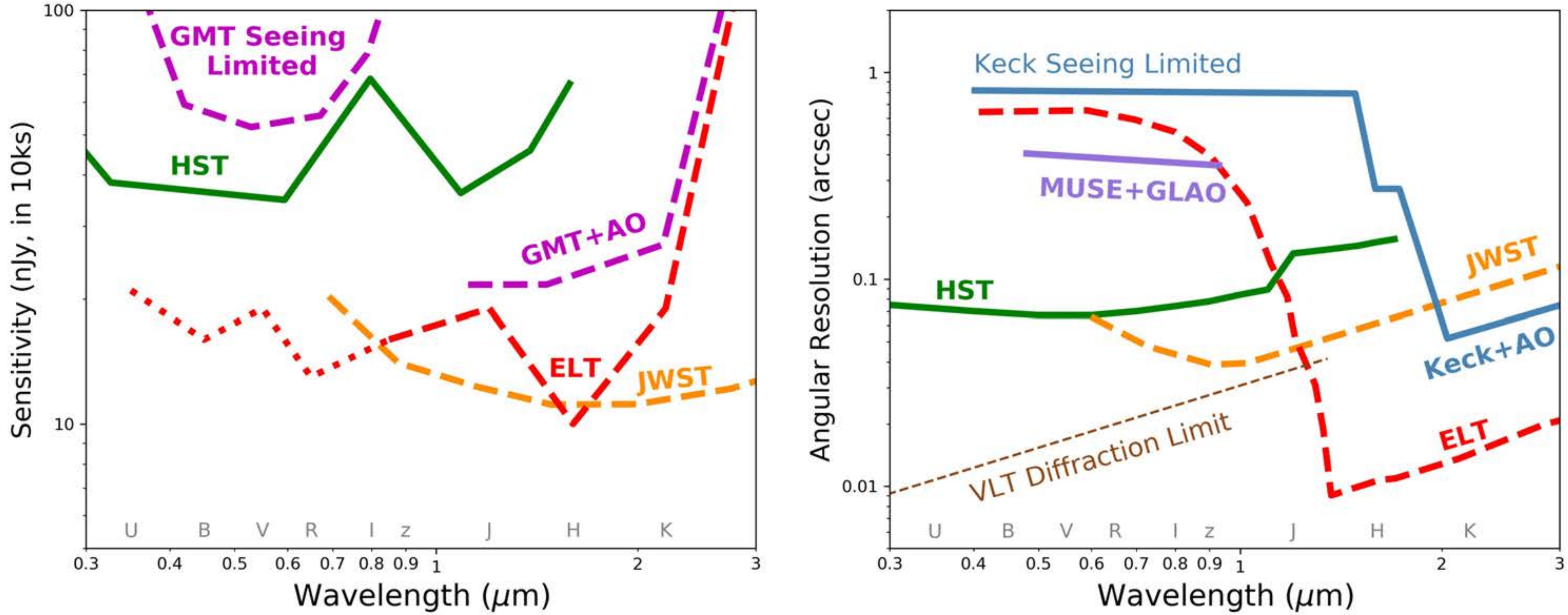


FUTURE FACILITIES

- MAVIS operations overlaps well with ELT era
- Overlaps with JWST core (5yr) and goal (10yr) mission
- Will fill the gap left at optical wavelengths in the post-HST era



FUTURE FACILITIES: EXPECTED PERFORMANCE



- MAVIS will provide comparable sensitivity to JWST and ELTs, but with higher angular resolution

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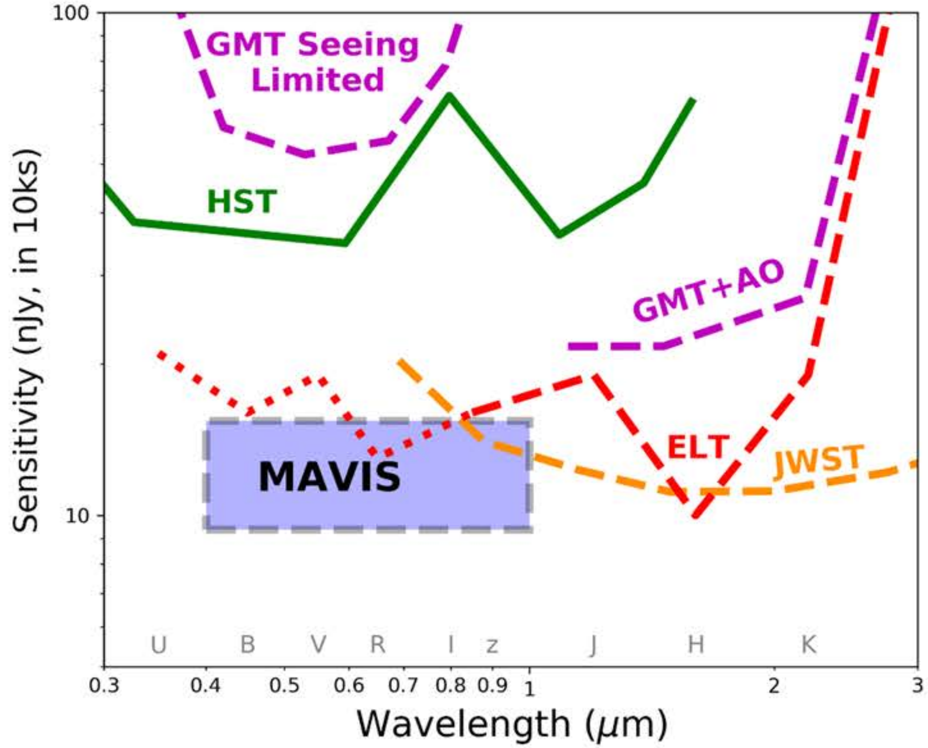

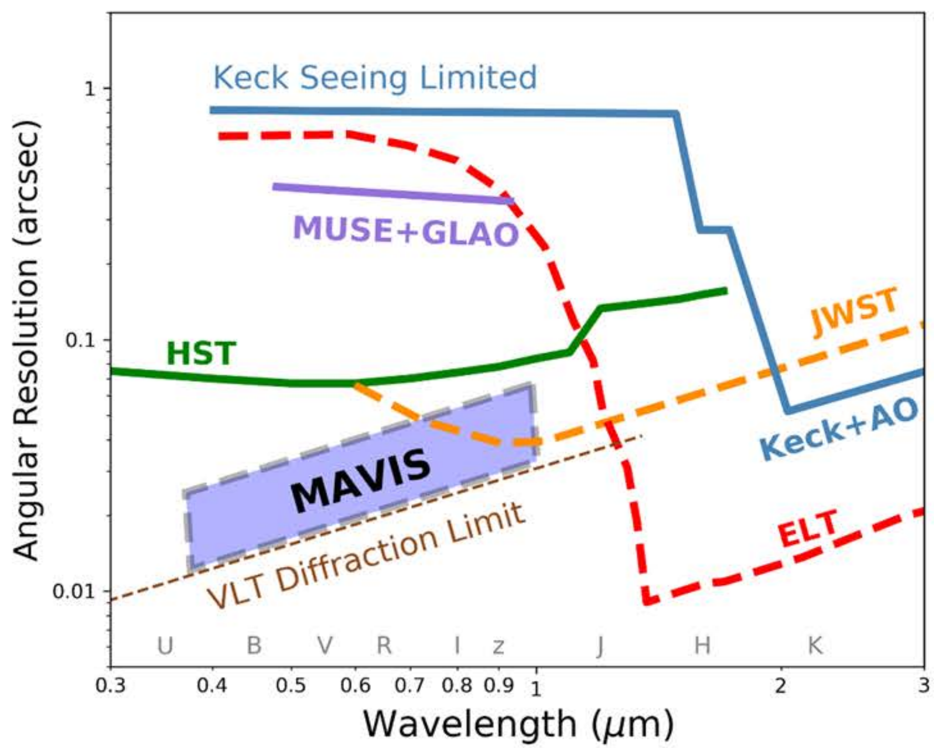

- MAVIS will provide comparable sensitivity to JWST and ELTs, but with higher angular resolution

SOME REASONS TO UNLOCK THE VISIBLE WITH AO

- Optical wavelengths are **information-rich**, with many well-understood astrophysical diagnostics
- **Sky background** is x1,000-10,000 times fainter than IR - possible to **compete with space** facilities
- **Detectors** are larger, lower noise, faster frame rates, and cheaper
- **500nm on an 8m gives same angular resolution as 2μm on an ELT**

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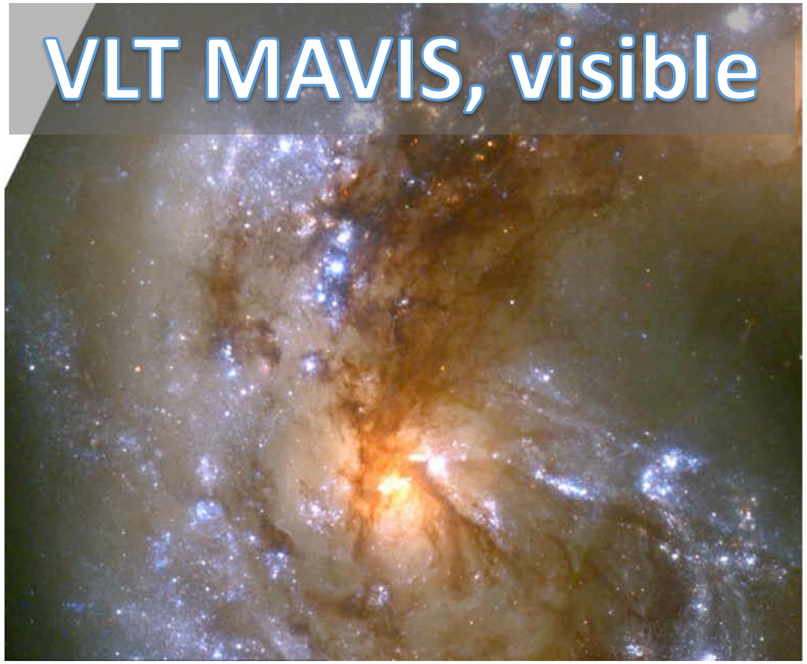
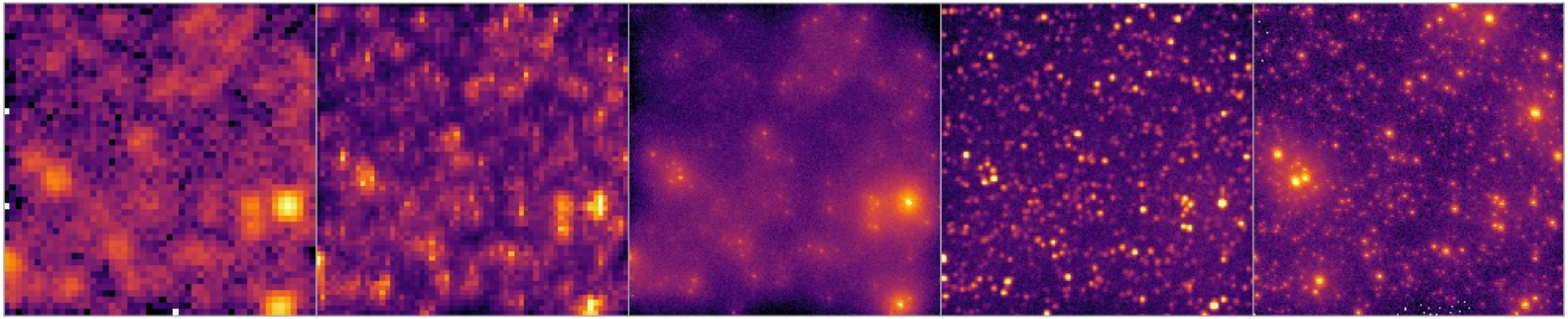


RESOLVED STELLAR POPULATIONS IN EARLY-TYPE GALAXIES



Old population, sb=22 mag/sq arcsec @4 Mpc

- Key future facilities JWST and ELT are not well-optimized for <1µm
- MAVIS is crucial to provide optical coverage at matched angular resolution to ELT in the IR

Generated using the Advanced Exposure Time Calculator (AETC) http://geode.oapd.inaf.it (Falomo et al. 2011)

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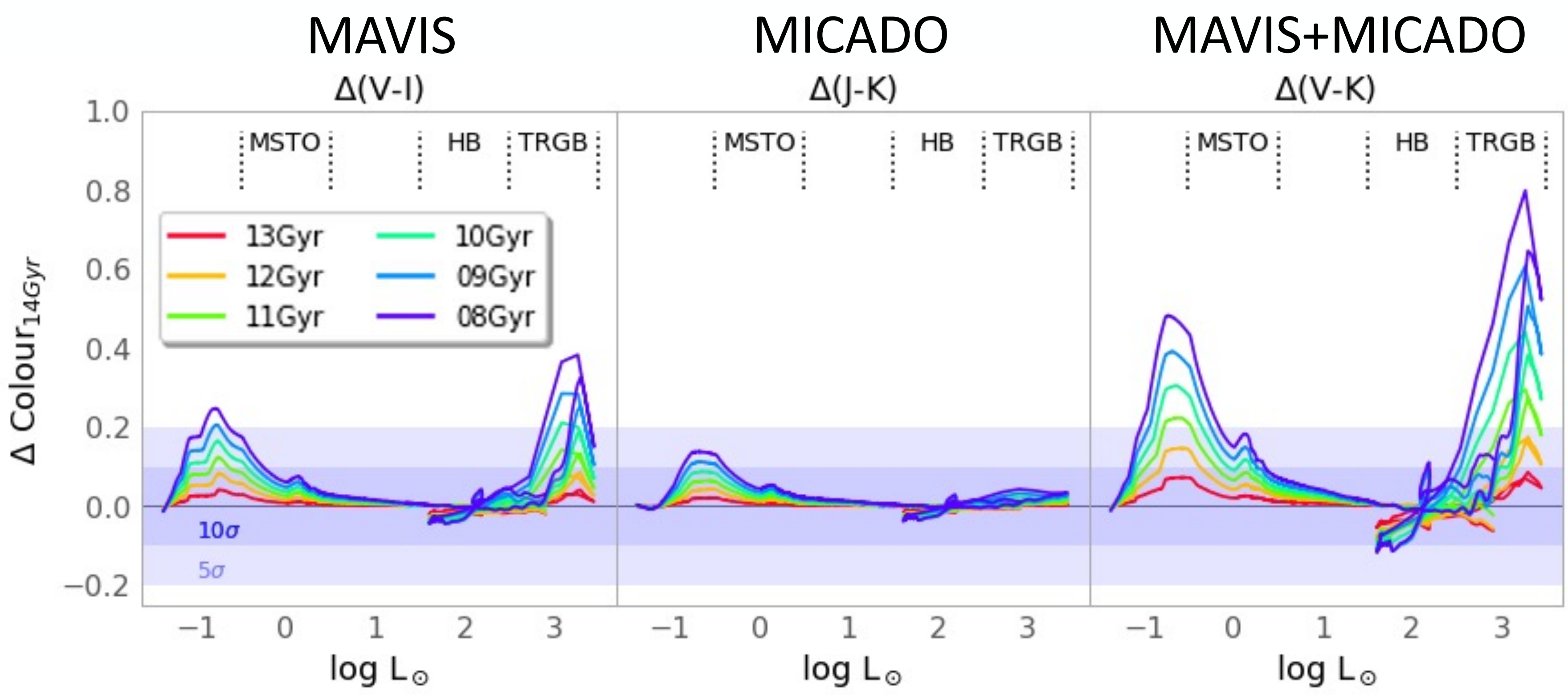

- MAVIS adds significant value to ELT science (e.g. distinguishing old stellar populations)

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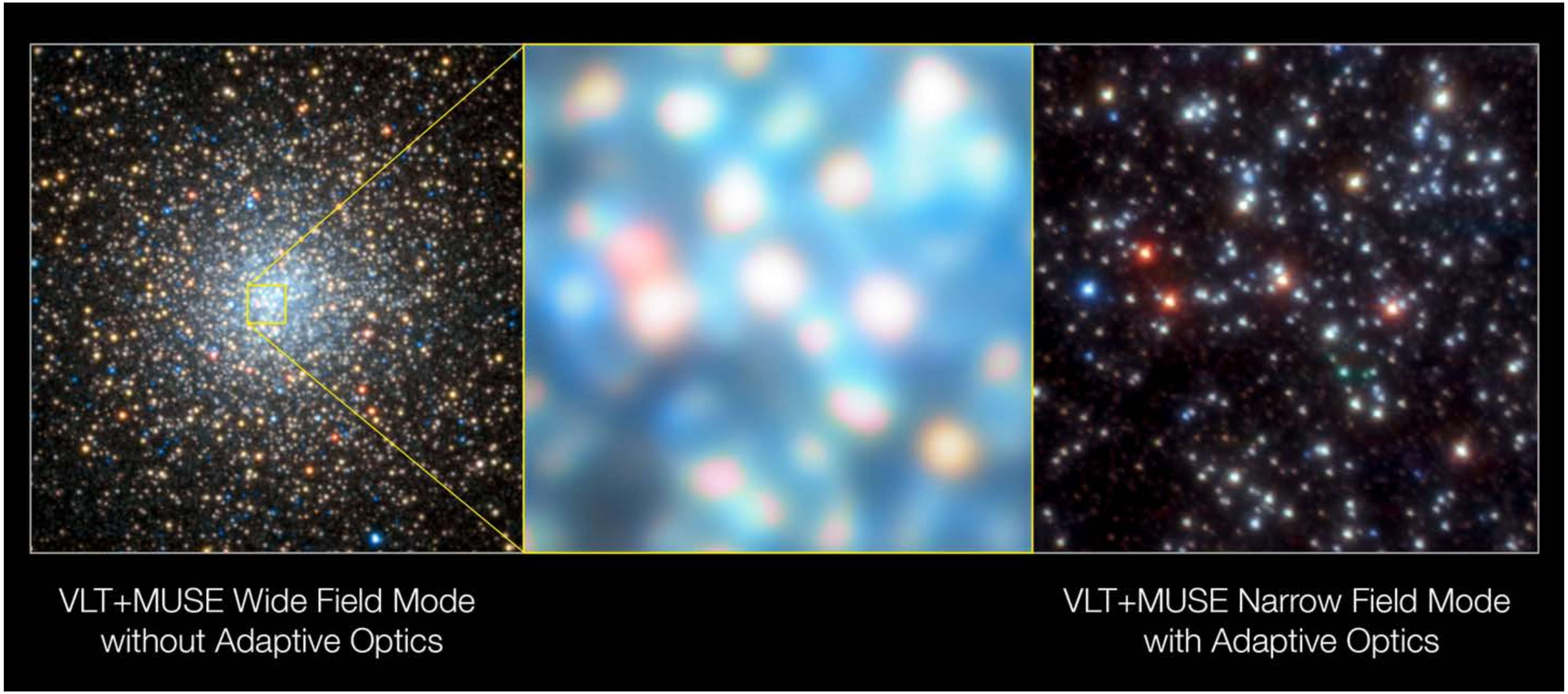
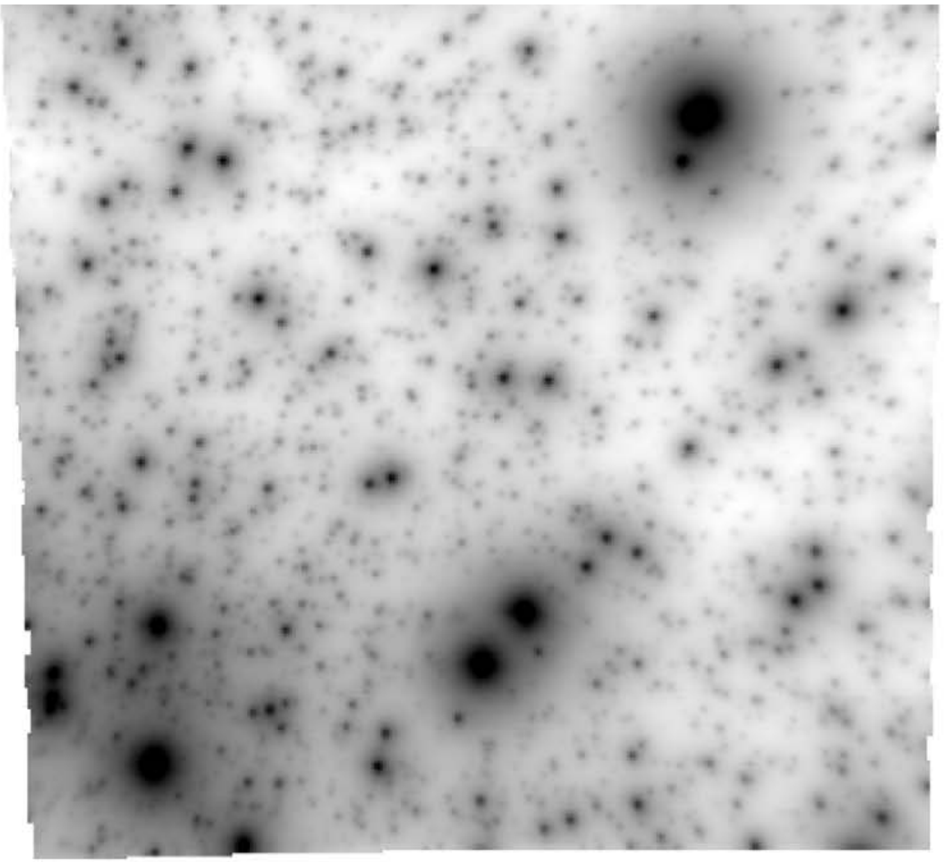


The visible is do-able!

ESO Press Release, July 2018
Credit: S. Kammann (LJMU)

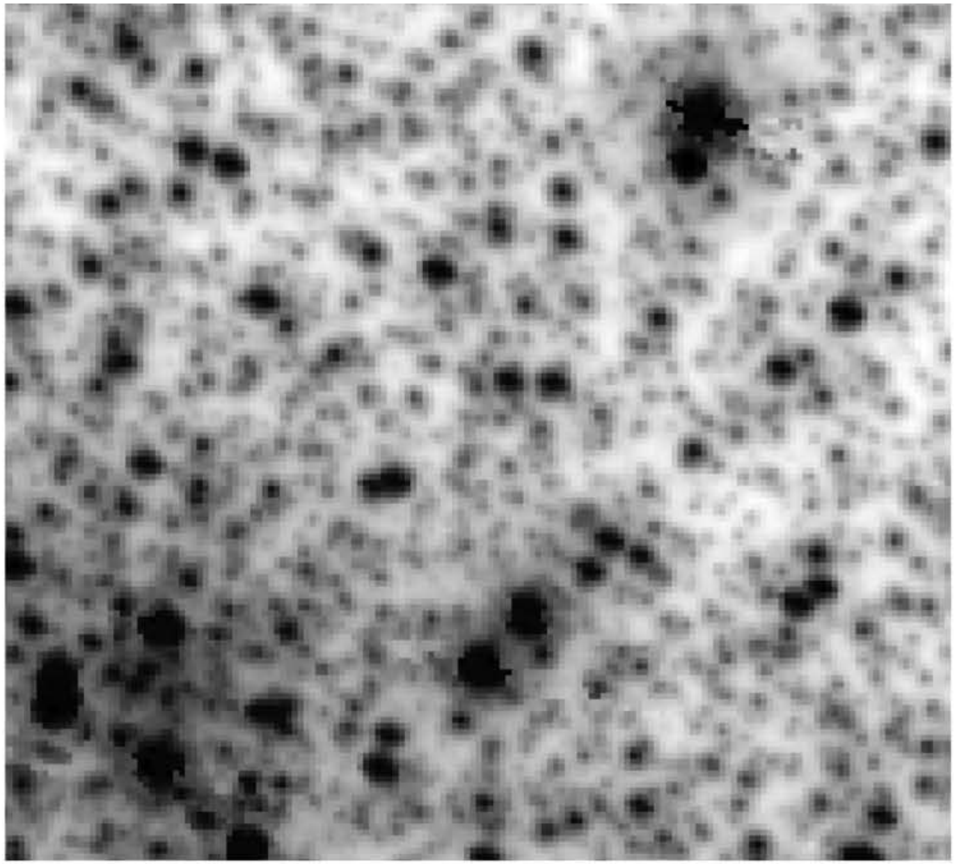
SOME REASONS TO UNLOCK THE VISIBLE WITH AO

MUSE NFM



HST ACS

Usher e al. 2021



MAVIS CONSORTIUM

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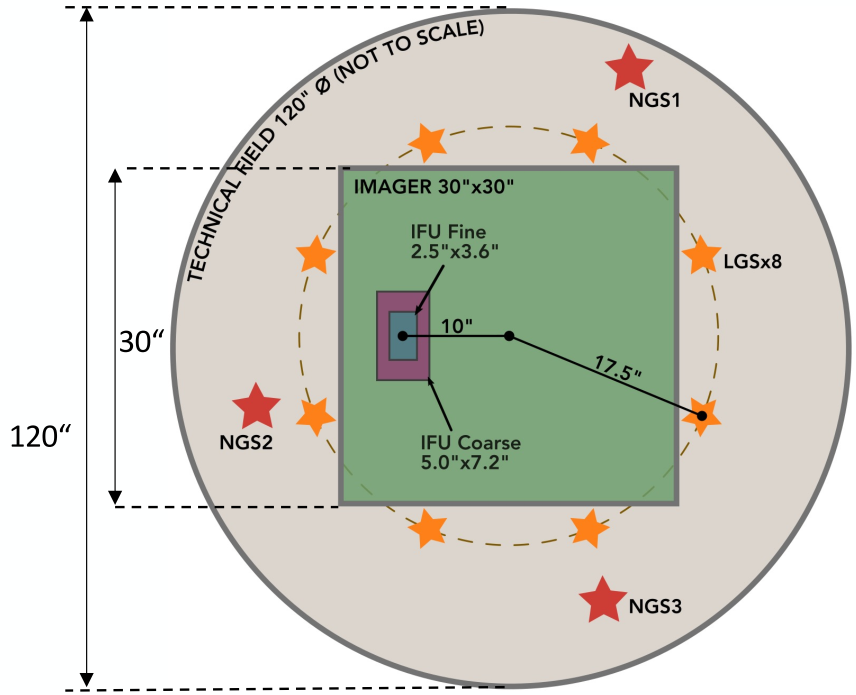
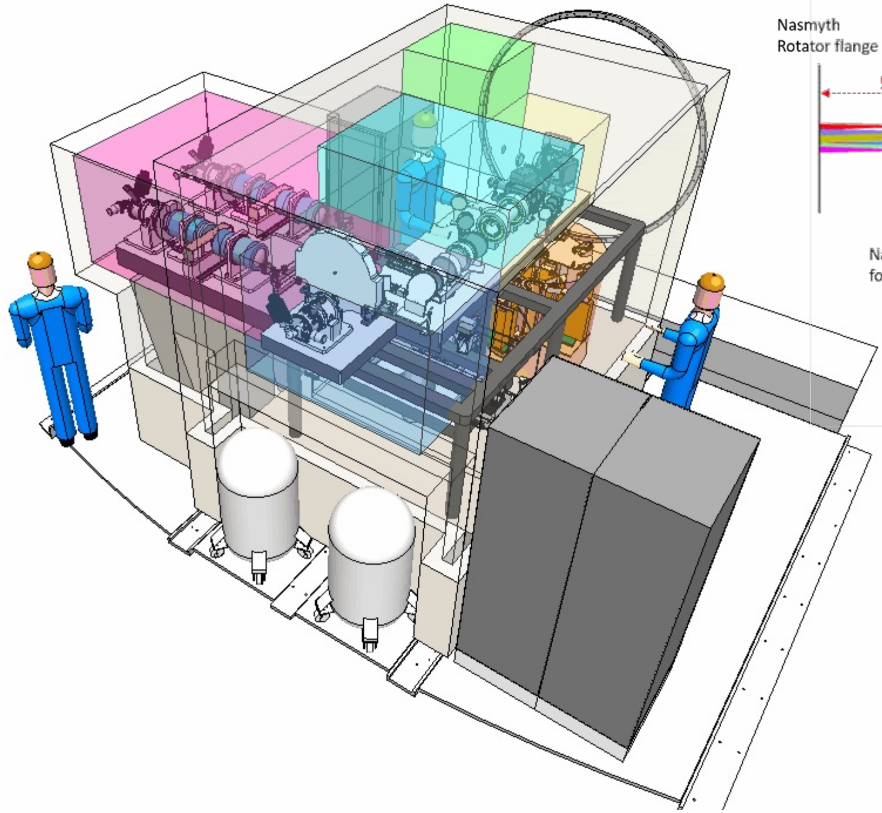
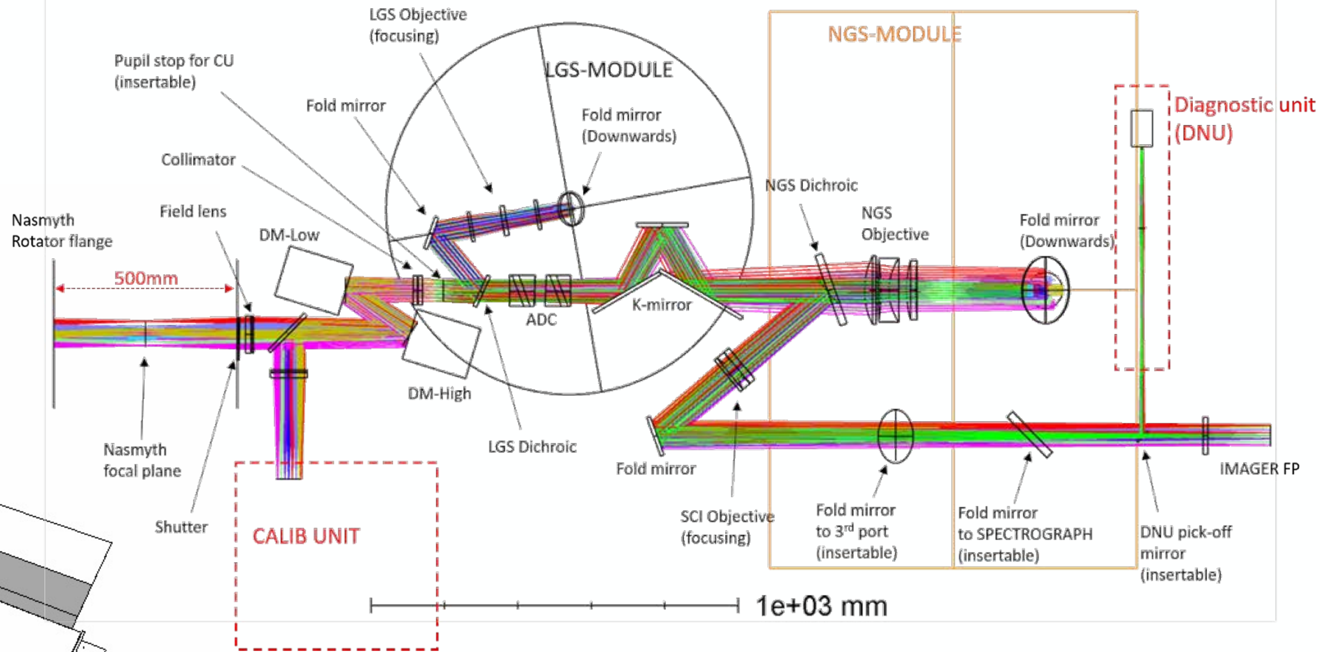
MAVIS TOP-LEVEL SPECIFICATIONS

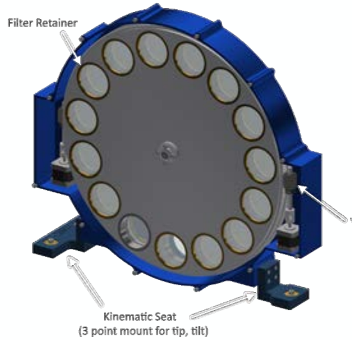
Science Field	30” x 30”
Number of Guide Stars	3 NGS / 6-8 LGS (via LGS splitting)
Angular Resolution	FWHM ~20mas at V band
Strehl Ratio	15% at V under median conditions
Sky Coverage	> 50% at the Galactic Pole
Wavelength Coverage	VRI (optimized); B-z (extended)
Imager	~7mas pixel scale. 7 broad- and 15 narrow-band filters. 1hr 10σ limiting mag ~29.5 in V
Spectrograph	Image slicer. Two spatial modes: 3”x3” @ 25mas and 6”x6” @ 50mas. Four Spectral modes: 370-1000nm, R=5,000-15,000
Visitor Port	Potential for third instrument port for visitor instruments

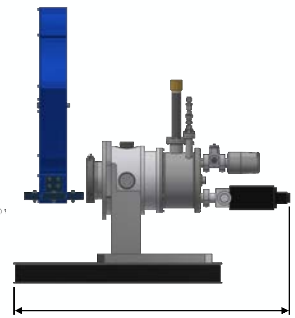


MAVIS AO MODULE AND IMAGER

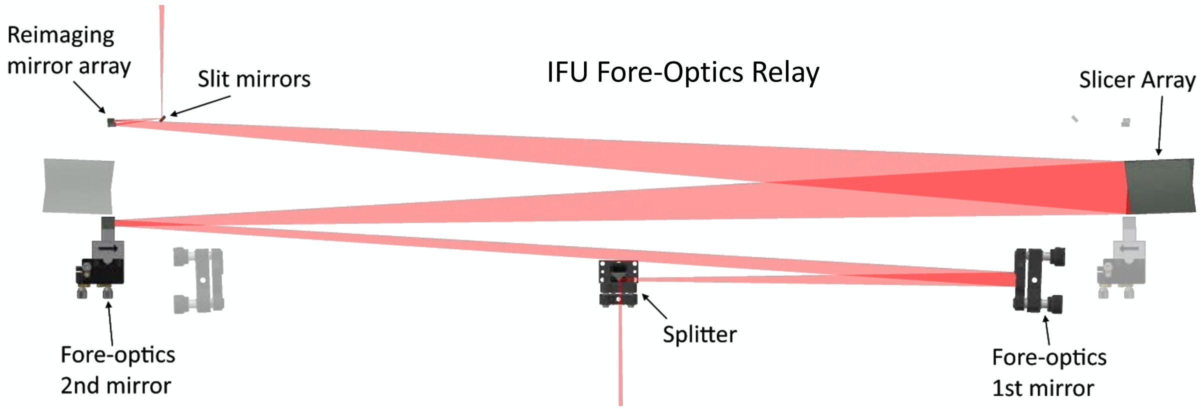


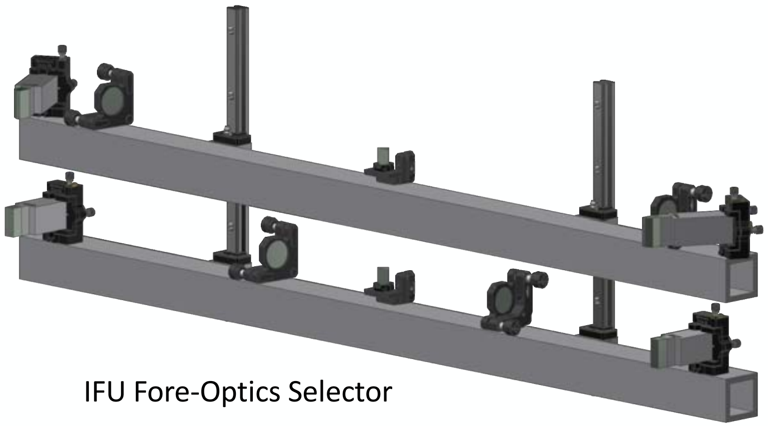


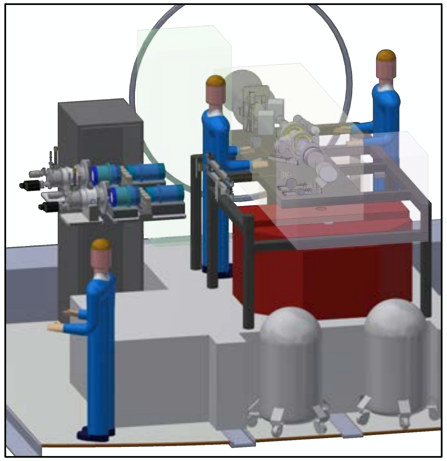


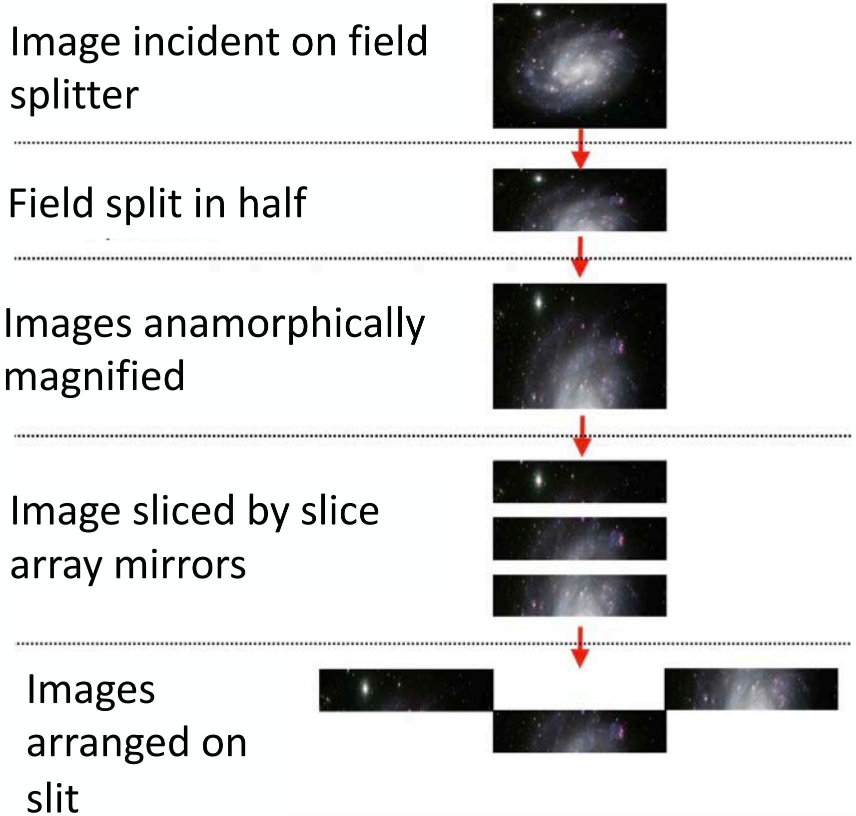


MAVIS INTEGRAL FIELD SPECTROGRAPH





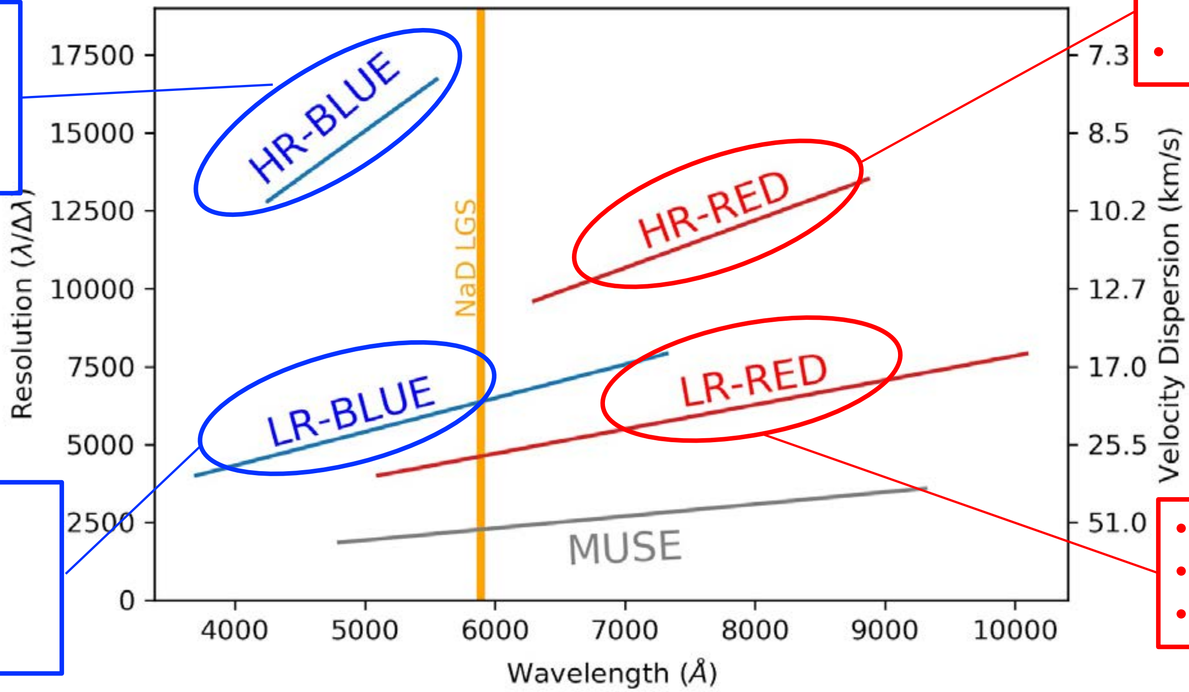




MAVIS INTEGRAL FIELD SPECTROGRAPH

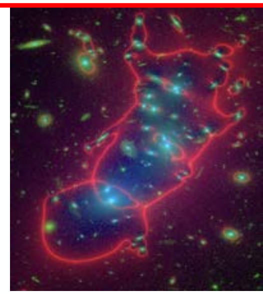
- **Stellar abundances in crowded fields**
- **Radial velocities of stars and gas < 1km/s**

- **Ionised gas properties**
- **Hot/Massive stars, young stellar populations**
- **Extreme Metal Poor stars**



- **Evolution of ISM turbulence in galaxy disks**
- **IMBHs**

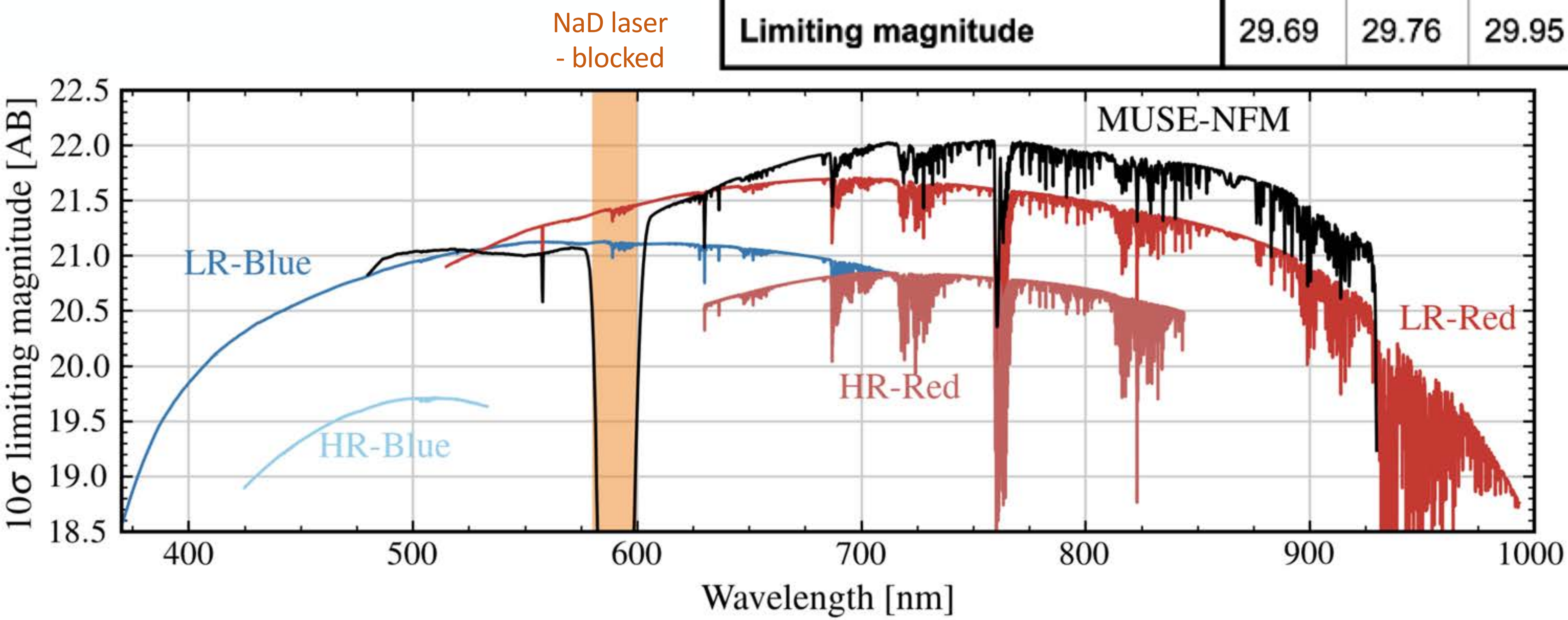
- **Evolution of ISM chemistry**
- **Stellar dynamics z<1**
- **Lyα sources at z>6.6**



- Expands and complements current spectral capabilities of VLT AOF
- Higher resolution well suited to stars and small dynamical scales

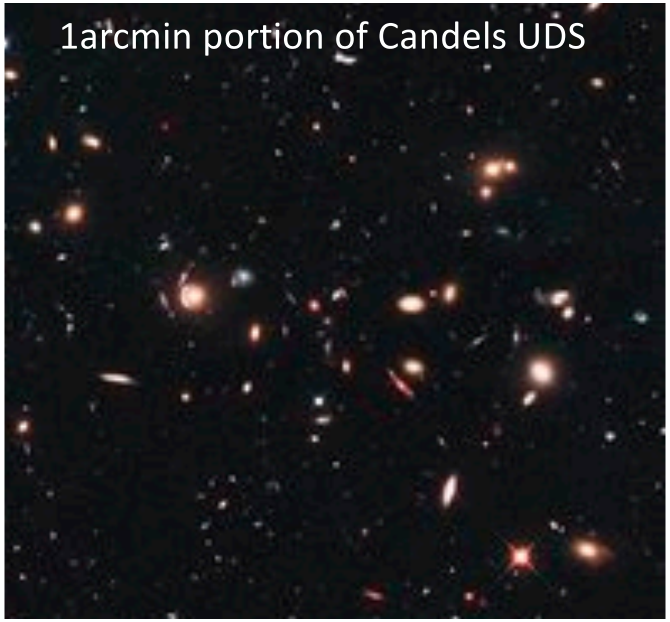
MAVIS SENSITIVITY

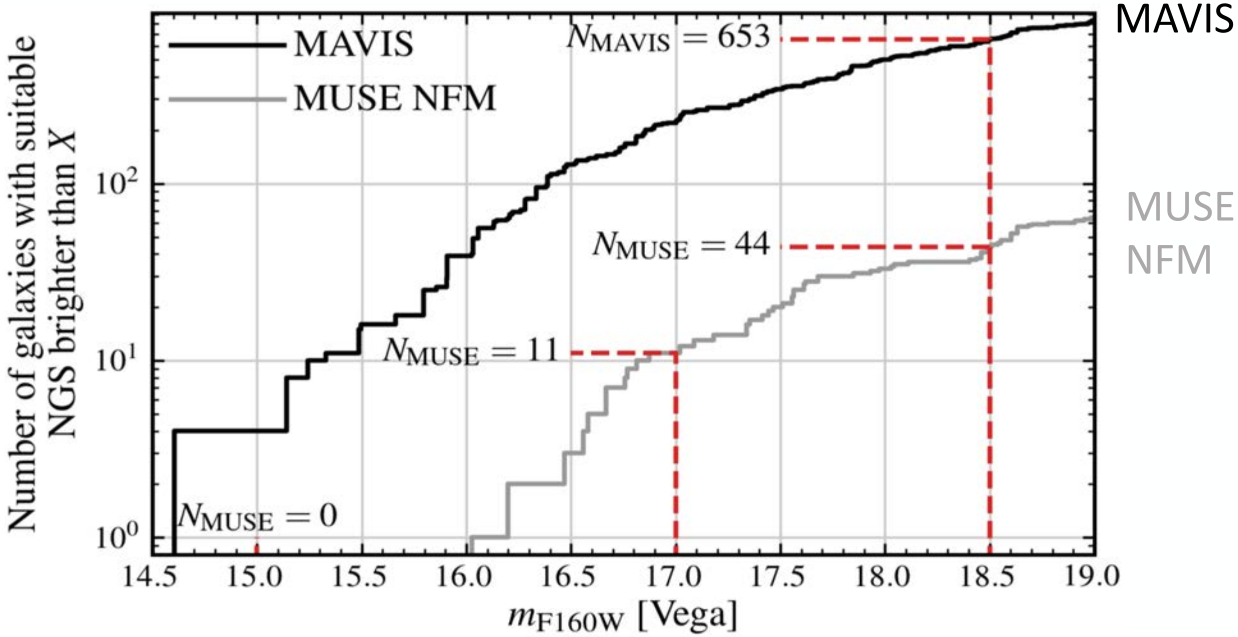
MAVIS Imaging (5σ, 1hr)	*B*	*V*	R_c	I_c
Limiting magnitude	29.69	29.76	29.95	29.37



- Point source sensitivity estimates for MAVIS spectrograph and imager modes
- Includes chromatic PSF effects, assumes good conditions

MAVIS SKY COVERAGE IS A GAME CHANGER





- **Use Case:** No. of observable intermediate-z galaxies in GOODS-S, COSMOS and UDS with MAVIS and upgraded MUSE-NFM vs faintest NGS magnitude
- MAVIS sky coverage gives > 1 order of magnitude more targets

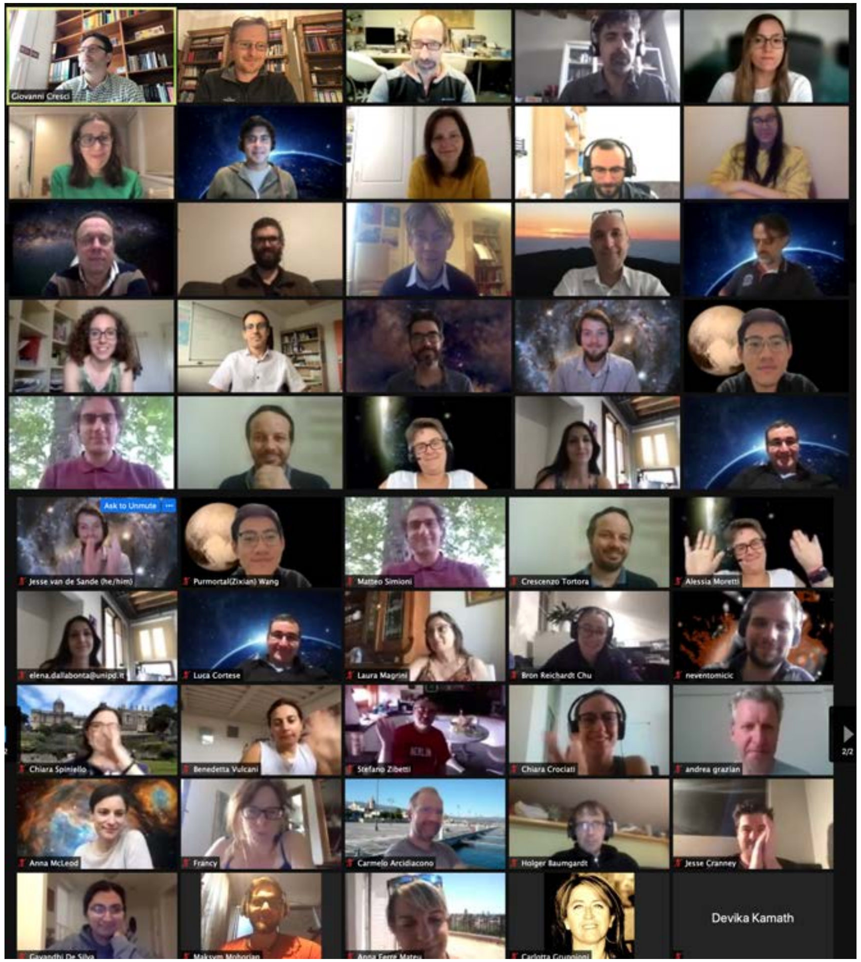
⇒ MAVIS makes statistical samples and general follow-up possible

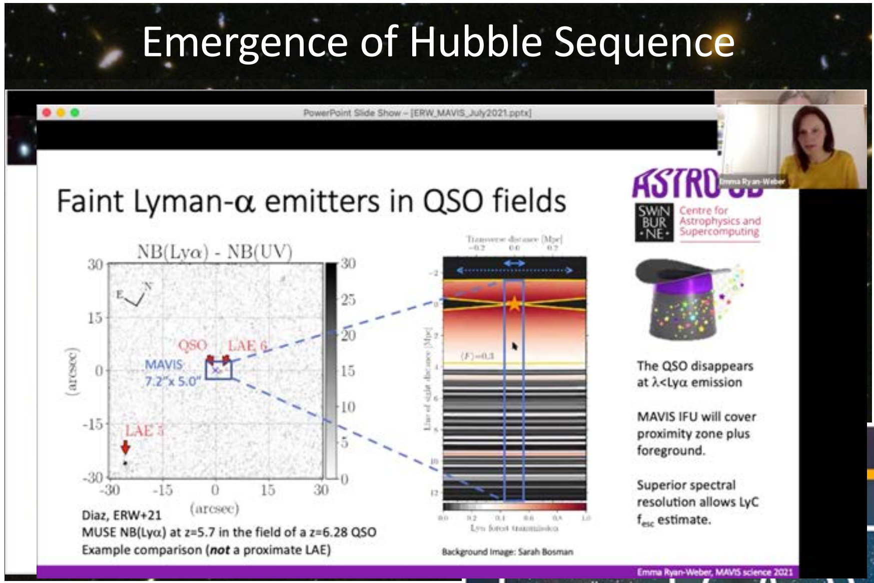
ONLINE WORKSHOP: 5-8 JULY 2021

- 4 days, >140 registrations
- Mix of recorded & live talks during 3hr overlap each day with Europe
- Lively discussion sessions!
- All talks and sessions available online:

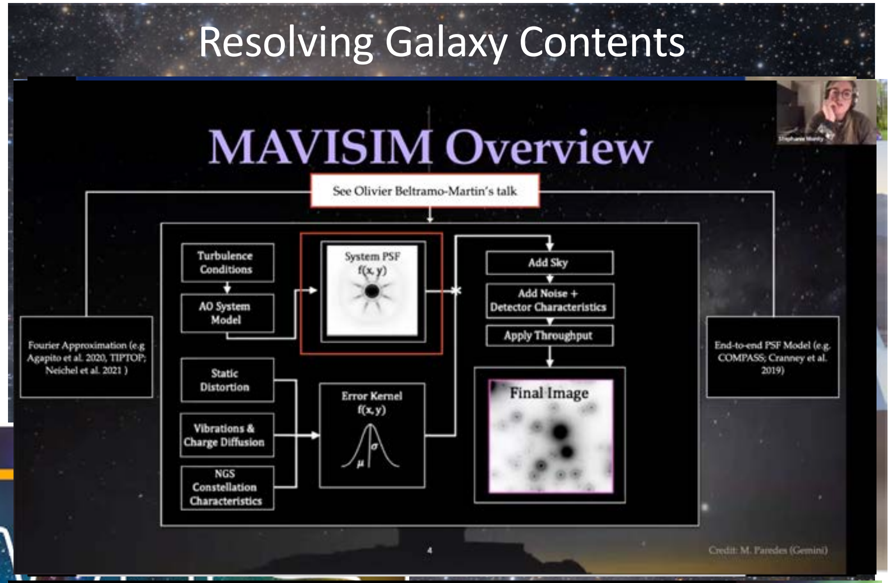
https://indico.ict.inaf.it/event/1420

Conference Photo

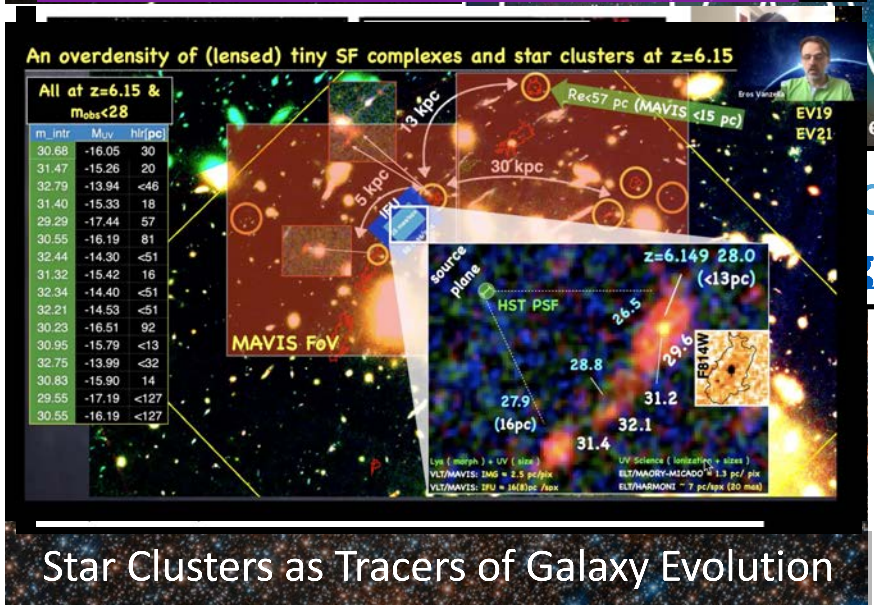




Emergence of Hubble Sequence
Faint Lyman-α emitters in QSO fields
NB(Lyα) - NB(UV)
QSO
LAE 6
LAE 3
MAVIS
7.2"x 5.0"
(arcsec)
Diaz, ERW+21
MUSE NB(Lyα) at z=5.7 in the field of a z=6.28 QSO
Example comparison (not a proximate LAE)
Background Image: Sarah Bosman
ASTRO 3D
SWIN BUR NE
Centre for Astrophysics and Supercomputing
The QSO disappears at λ<Lyα emission
MAVIS IFU will cover proximity zone plus foreground.
Superior spectral resolution allows LyC f_{esc} estimate.
Emma Ryan-Weber, MAVIS science 2021



Resolving Galaxy Contents
MAVISIM Overview
See Olivier Beltramo-Martin's talk
Turbulence Conditions
AO System Model
Static Distortion
Vibrations & Charge Diffusion
NGS Constellation Characteristics
System PSF f(x, y)
Error Kernel f(x, y)
Add Sky
Add Noise + Detector Characteristics
Apply Throughput
Final Image
Fourier Approximation (e.g. Agapito et al. 2020, TIPTOP; Neichel et al. 2021)
End-to-end PSF Model (e.g. COMPASS; Cranney et al. 2019)
Credit: M. Paredes (Gemini)



An overdensity of (lensed) tiny SF complexes and star clusters at z=6.15
All at z=6.15 & m_{obs}<28
m_intr | M_{UV} | hlr[pc]
30.68 | -16.05 | 30
31.47 | -15.26 | 20
32.79 | -13.94 | <46
31.40 | -15.33 | 18
29.29 | -17.44 | 57
30.55 | -16.19 | 81
32.44 | -14.30 | <51
31.32 | -15.42 | 16
32.34 | -14.40 | <51
32.21 | -14.53 | <51
30.23 | -16.51 | 92
30.95 | -15.79 | <13
32.75 | -13.99 | <32
30.83 | -15.90 | 14
29.55 | -17.19 | <127
30.55 | -16.19 | <127
Re<57 pc (MAVIS <15 pc)
EV19
EV21
13 kpc
30 kpc
5 kpc
MAVIS FoV
source plane
HST PSF
z=6.149 28.0 (<13pc)
26.5
29.6
28.8
27.9 (16pc)
31.2
32.1
31.4
F814W
Star Clusters as Tracers of Galaxy Evolution

Observing planet formation in action
PDS 70 with SPHERE, Credit: ESO/A. Müller et al.
Birth, Life, Death of Stars and Planets

SUMMARY

- MAVIS will be a facility instrument, and so must be:
  - ***Versatile*** *– Maximise sky coverage, rich discovery space, multiple use-cases*
  - ***Sensitive*** *– Maximise throughput and sensitivity*
  - ***Stable*** *– Allow deep-exposures, high repeatability, high-quality astrometry*
  - ***Robust*** *– Push-button operations, high up-time, minimal modes*
- *Phase A was successfully passed in 2020*
- *Phase B agreement signed on June 1st – MAVIS IS GO!*
- *To be finalized during Phase B:*
  - *Detailed IFU sampling, field shape*
  - *Detailed astrometry error budget*
  - *Real Time Control (RTC) design/architecture (baseline is new GPU-based system)*
  - *Planning for GTO programmes*

MAVIS

Deeper than HST, sharper than JWST

Special Thanks to the MAVIS Science Team: **Giovanni Cresci (co-Project Scientist),** Simone Antoniucci, Giuseppe Bono, Jean-Claude Bouret, Gayandhi De Silva, Marco Gullieuszik, Devika Kamath, **Laura Magrini**, Davide Massari, **Trevor Mendel**, Stephanie Monty

Blog: www.mavis-ao.org

Email List Signup: bitly.com/join_mavis_list

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