MAVIS: MCAO-ASSISTED VISIBLE IMAGER AND SPECTROGRAPH FOR THE VLT

SHARPER THAN JWST, DEEPER THAN HST

Firenze 22/10/2019

THE 2ND PIETRO BARACCHI CONFERENCE

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INAF- Osservatorio di Arcetri

on behalf of the MAVIS team

A BRIEF HISTORY

- **"ESO Community Days"** annual workshop to discuss future instrumentation and upgrades:
  - 2015+2016, a **visible MCAO capability** gathered most interest
  - Concept initially presented by Simone Esposito (INAF Arcetri)
- July 2017: Australia joined ESO as strategic partner
- October 2017: **consortium formed** to address ESO phase A call, with INAF (Arcetri, Padova & Roma), Laboratoire d'Astrophysique de Marseille (LAM), and Australian Astronomical Optics (AAO, including ANU, MQ & UniSyd)
- Initial science workshop November 2017 in Sidney
- October 2018: Phase A proposal submitted to ESO
- November 2018: **MAVIS awarded agreement for phase A** conceptual design study by ESO

Australian National University

INAF
ISTITUTO NAZIONALE DI ASTROFISICA
NATIONAL INSTITUTE FOR ASTROPHYSICS

AAO

LAM
LABORATOIRE D'ASTROPHYSIQUE DE MARSEILLE

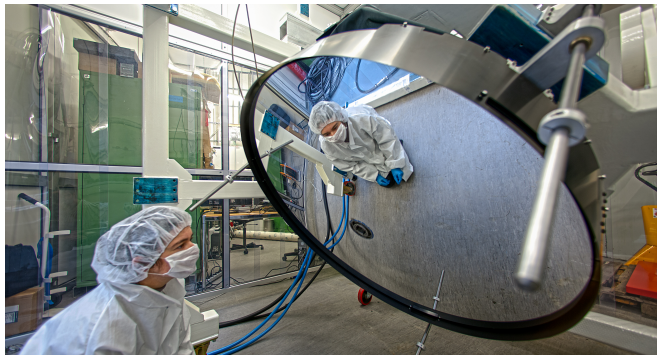
SWINBURNE UNIVERSITY OF TECHNOLOGY

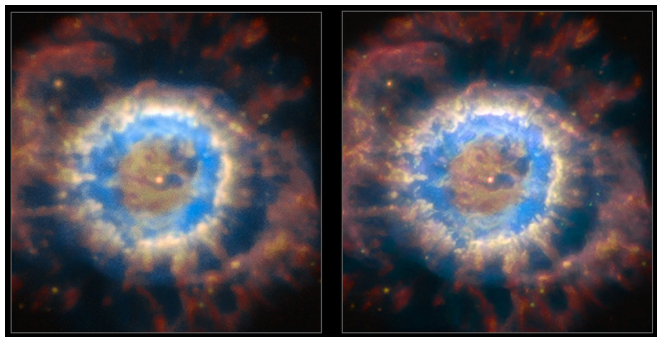
ONERA
THE FRENCH AEROSPACE LAB

MACQUARIE University
SYDNEY·AUSTRALIA

ADAPTIVE OPTICS FACILITY (AOF)

- Upgrade of VLT UT4 with AO fully integrated into the telescope
- Key technical components:
  - Deformable secondary mirror with high actuator density
  - Four laser guide stars, 20W each, operating above specifications
  - Both key for high performance in the optical
- Current instrumentation:
  - MUSE: Optical IFU
  - HAWK-I: Wide-field IR imager
  - ERIS (from 2020): 1-5μm imager/IFU
- Mainly ground-layer AO (wide field, low Strehl)
- MUSE narrow field mode gives diffraction limit in optical, but only bright guide stars (<14 J-H mag, within 3.75″) and limited performances (Strehl~5%, FWHM~50 mas)

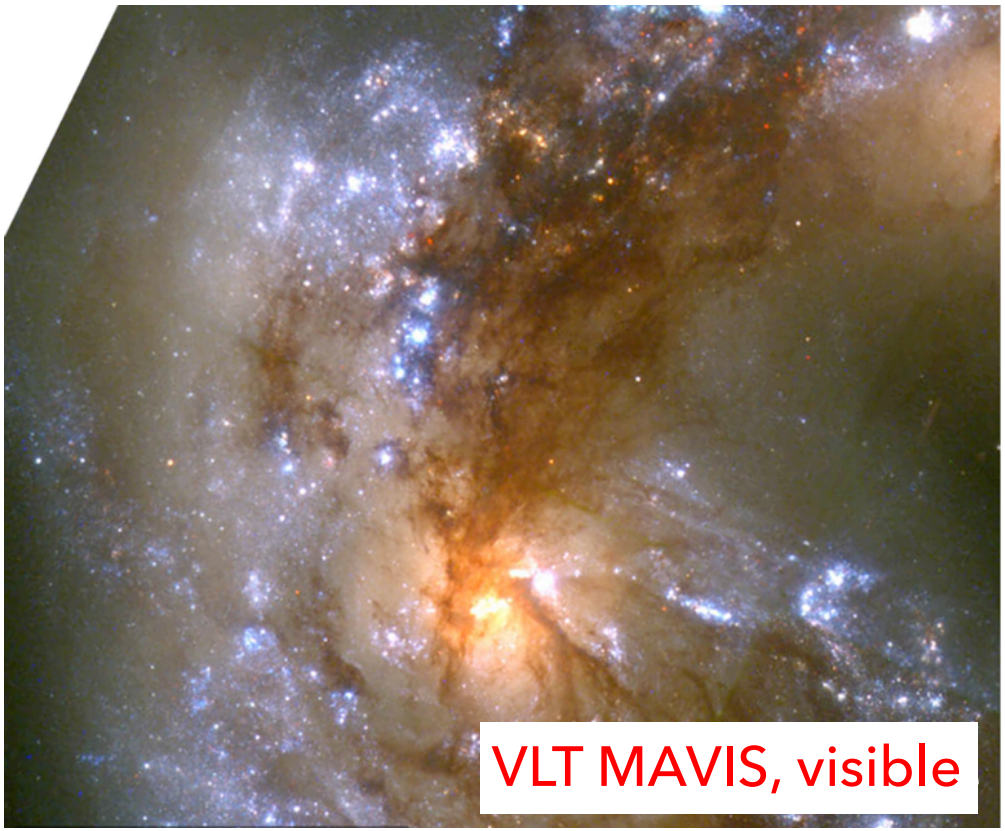




Full AOF science potential not being realized

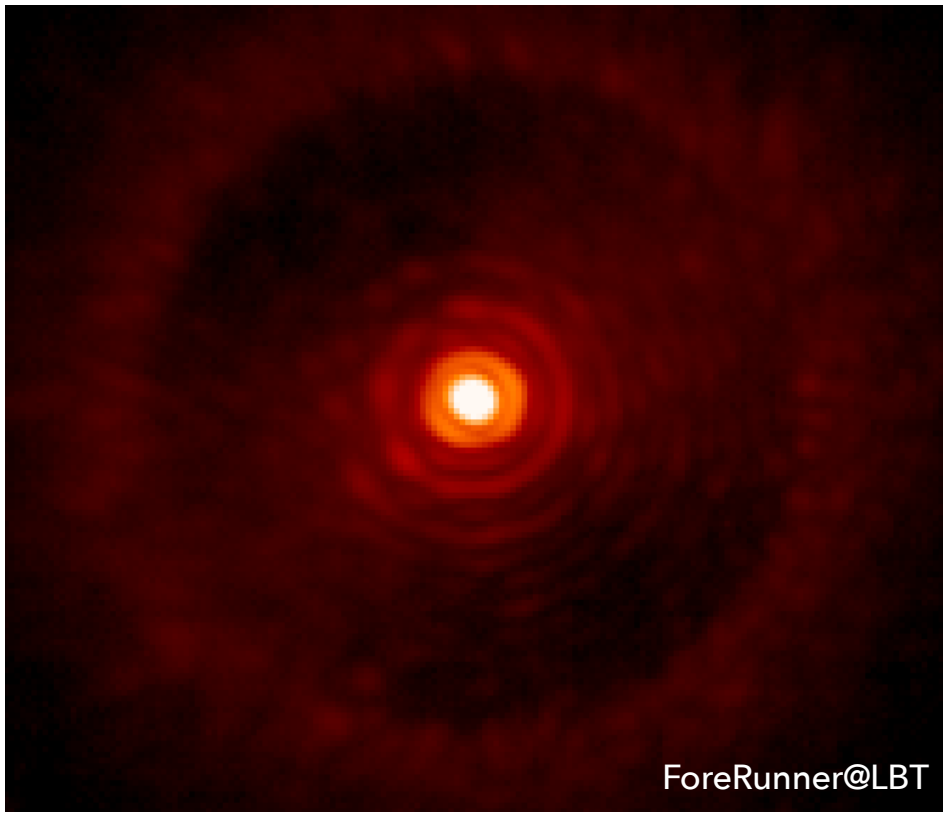
IN THE VISIBLE WITH AO

- Optical wavelengths are information-rich, with many well-understood astrophysical diagnostics
- Sky background is x1,000-10,000 times lower than infrared, 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 2mm on an ELT



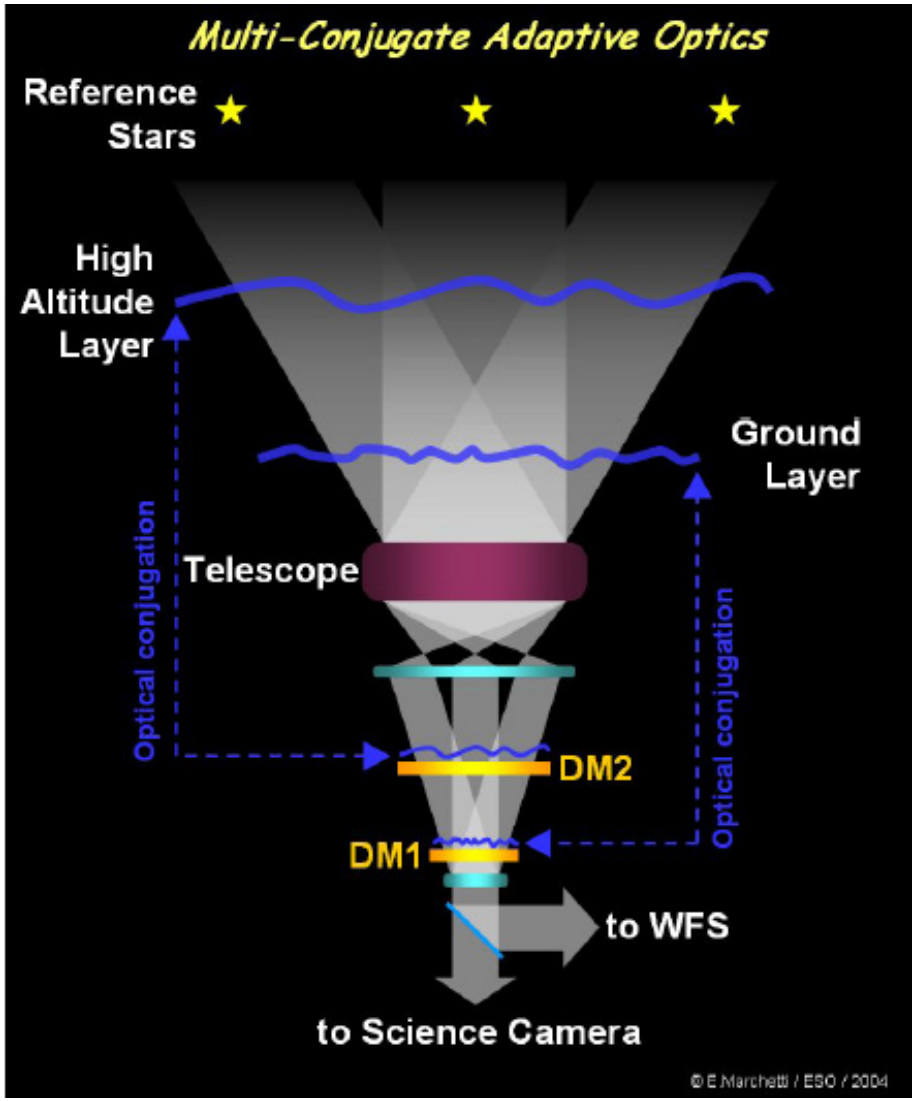
SINGLE CONJUGATE AO IN THE VISIBLE

- 650nm images from SHARK-VIS ForeRunner@LBT
  - Adaptive secondary
  - 0.8" seeing
  - 50% Strehl ratio!
  - 18 milliarcsec FWHM
- Similar examples from:
  - SPHERE @VLT
  - MAG-AO @Magellan
- **Visible AO is feasible!**



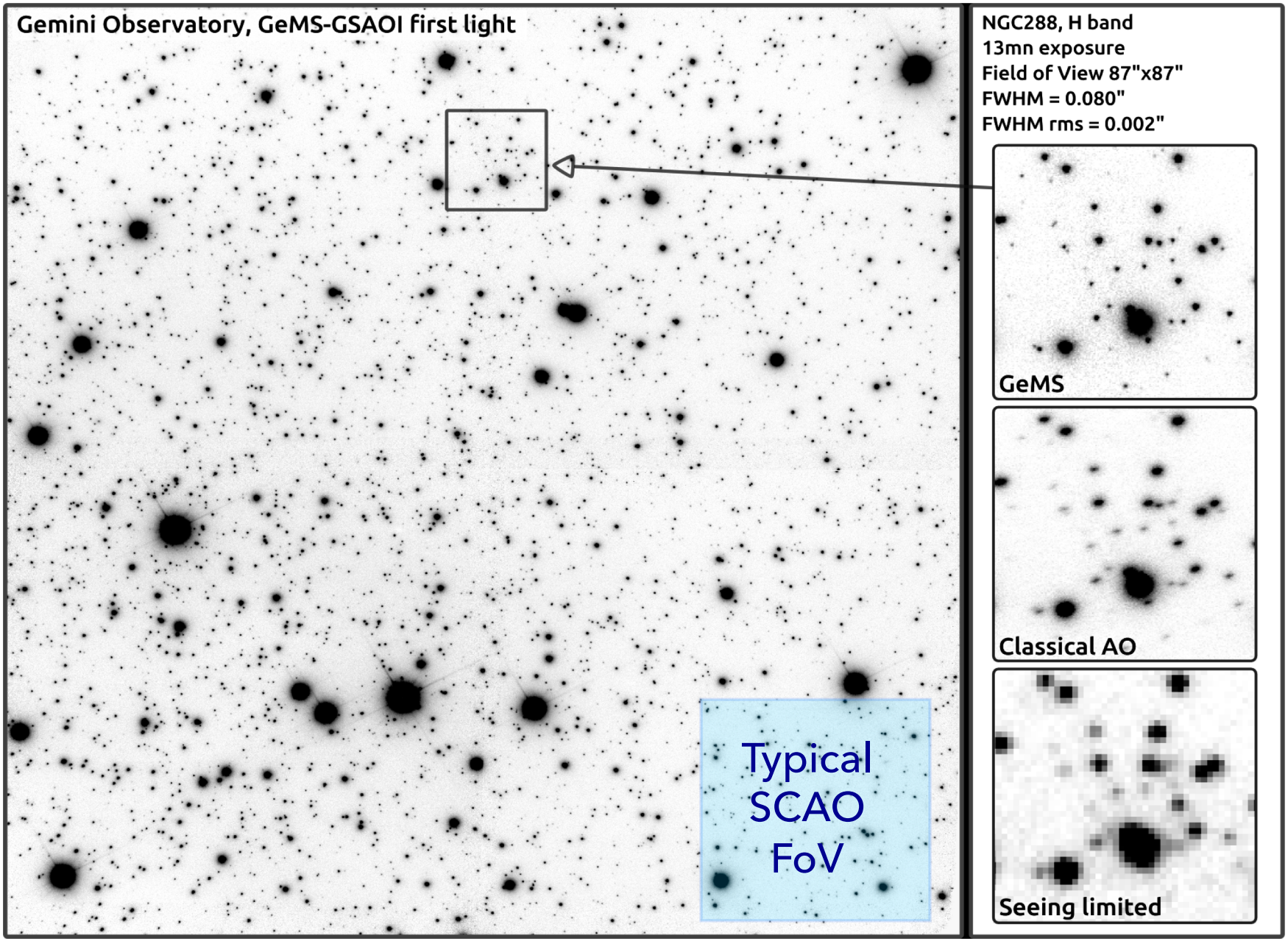
MULTI CONJUGATE AO

- Classical SCAO has limited corrected field of view and heavy PSF variations
- MCAO uses multi deformable mirrors, optically conjugated to different distances from the telescope, to correct aberrations produced by different layers
- Each mirror is driven by several wavefront sensors using different stars or LGS in the field, to reconstruct the 3D structure of the atmosphere



MCAO IN THE NIR

see also MAD@VLT



WHAT IS MAVIS?

MAVIS (***MCAO-Assisted Visible Imager & Spectrograph***) is a proposed instrument for the VLT AOF (Adaptive Optics Facility) currently in phase A.

It will provide near-diffraction limit image quality over a large (~30''x30'') fov using Multi-Conjugate AO

IFU spectroscopic mode for spatially resolved spectroscopy

High sky coverage

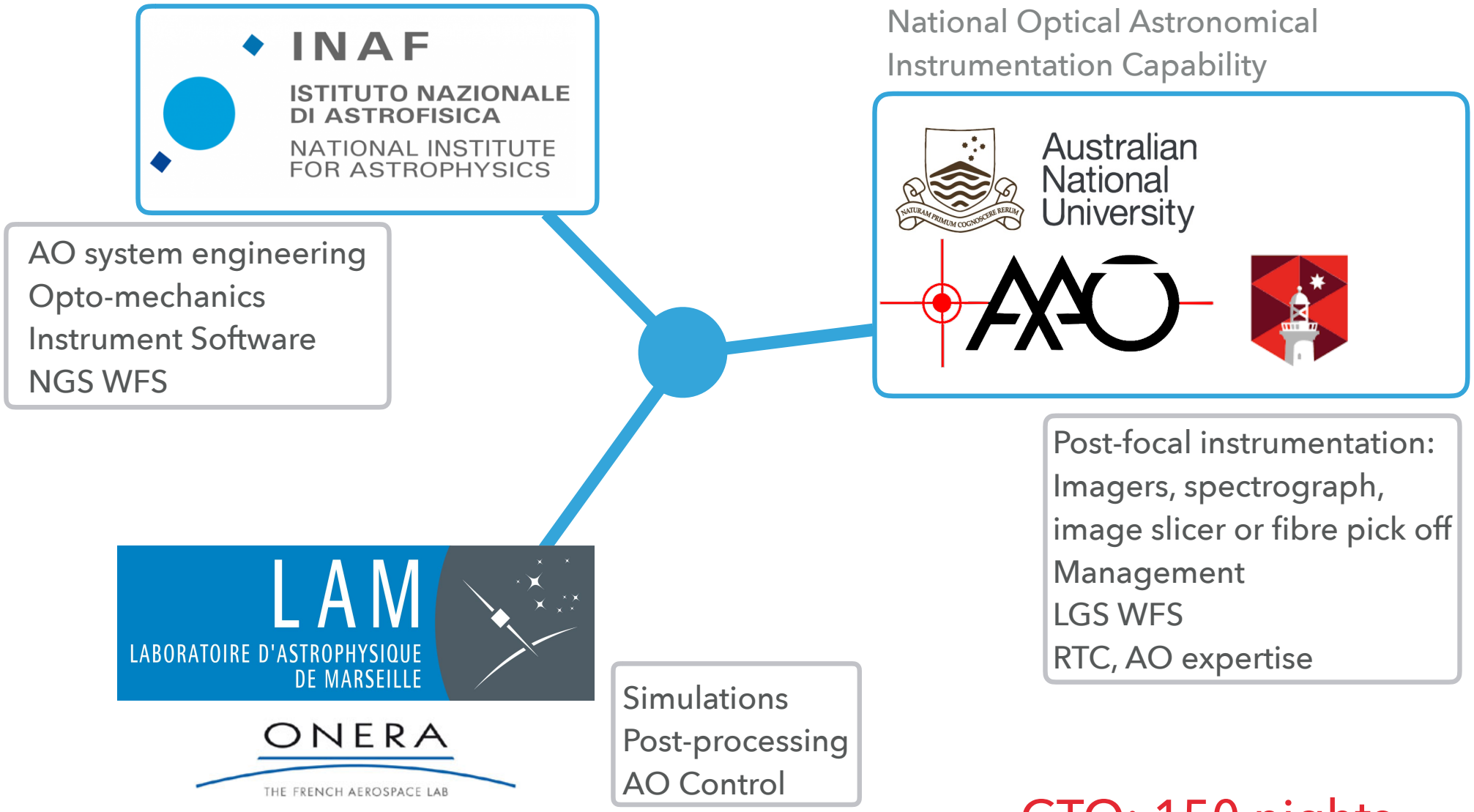
Current MAVIS baseline

Field of view	30"x30"
Angular resolution	FWHM ~ 20mas at V band
Wavelength coverage	VRI, extended to UBz
Strehl ratio	15% at V under median seeing conditions
Sky coverage	> 50% at Galactic Poles
Imager	~ 7mas pixel size. Broad and narrow band filters. Tuneable filters - to be explored
Spectrograph	image slicer Integral Field Unit Field of view / sampling: 3.6"x2.5" (@25mas spaxels) and up to 7.2"x5" (@50mas) Wavelength coverage / resolution: 370-950nm simultaneously at R=5,000, and in 2 settings at R=10,000

- *Blog: www.mavis-ao.org*

MAVIS CONSORTIUM

PI: F. Rigaut (AAO-STROMLO)

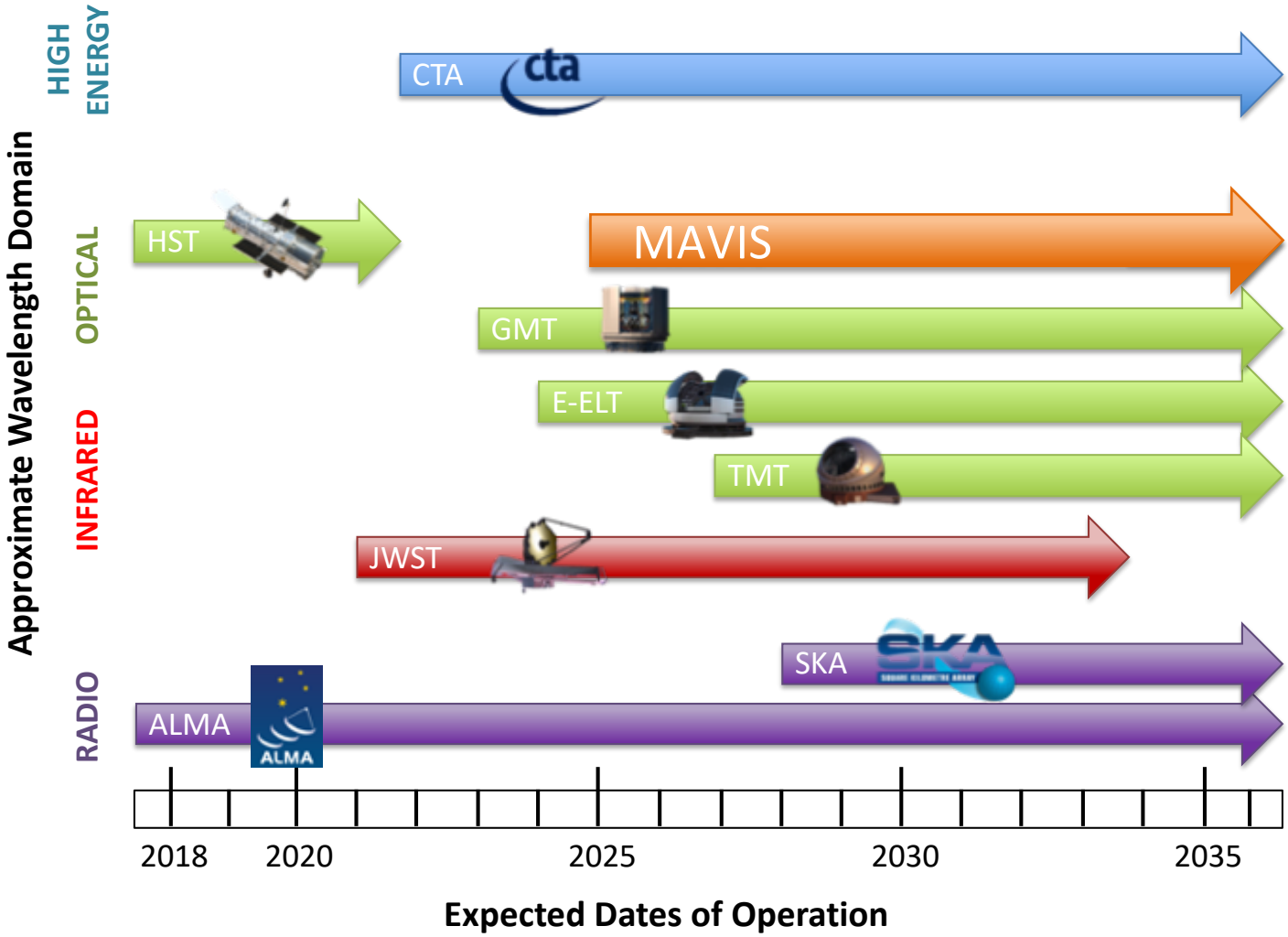


GTO: 150 nights

MAVIS IN CONTEXT

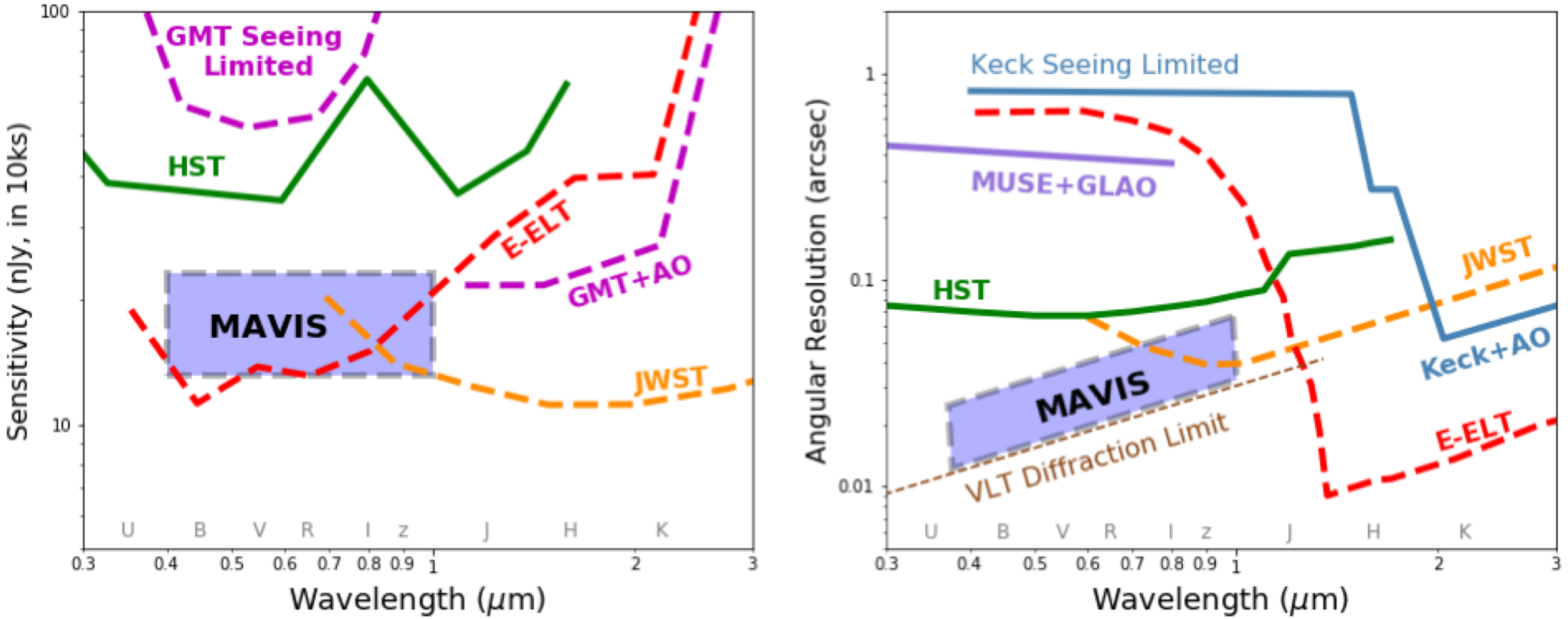
MAVIS operations overlap with forthcoming era of high sensitivity, high resolution astronomy with large telescopes

MAVIS will fill the gap at optical wavelengths in the post-HST era



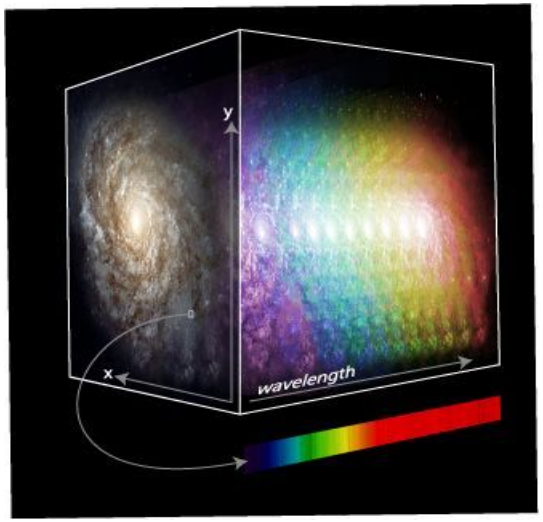
MAVIS IN CONTEXT

Improvement in resolution from future facilities limited to $\lambda > 1\ \mu m$



MAVIS in the optical will provide comparable sensitivity to JWST and ELTs, but with higher angular resolution

A SPECTROGRAPH FOR MAVIS



Two main options being explored

Monolitic image slicer IFU

- R band diffraction limit = 19 mas
- spaxel ~25 mas: fov ~3.6″x2.5″
- spaxel ~50 mas: fov ~7.2″x5″
- R~4000-15000
- λ~$370 - 950\ nm$
- ✓ Image slicer provides higher throughput and higher spaxel number

Multiple fiber fed IFU

- ~ 2000 fibers
- multiplicity ~10
- fov ~0.5″x0.5″
- fov ~3″x3″
- patrol field ~30″x30″
- ✓ best use of the large AO corrected field

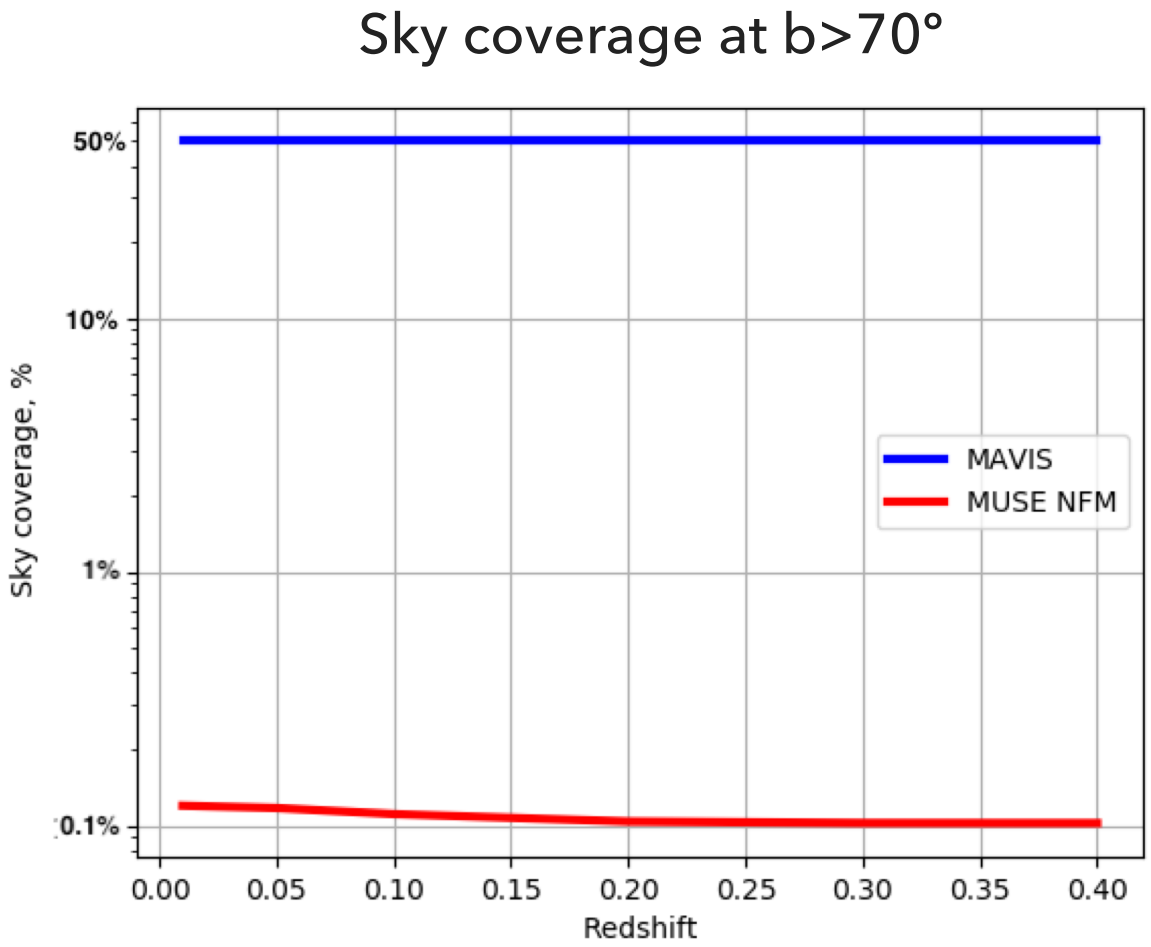
Current baseline

MAVIS VS Narrow field mode muse multi unit spectroscopic explorer

- **Field of view:** ~3.6″x2.5 or 7.2″x5″
- **Spectral resolution:** R~5000/15000
- **Strehl ratio and spatial resolution:** SR~50% and 20mas
- **Blue coverage:** ~370 nm ?
- **Sky coverage :** ~50% sky coverage at galactic pole

- **Field of view:** 7.4″x7.4″
- **Spectral resolution:** R~2000
- **Strehl ratio and spatial resolution:** SR~15% and 50mas
- **Blue coverage:** 460 nm
- **Sky coverage :** NGS with H<14 mag within 3.25″

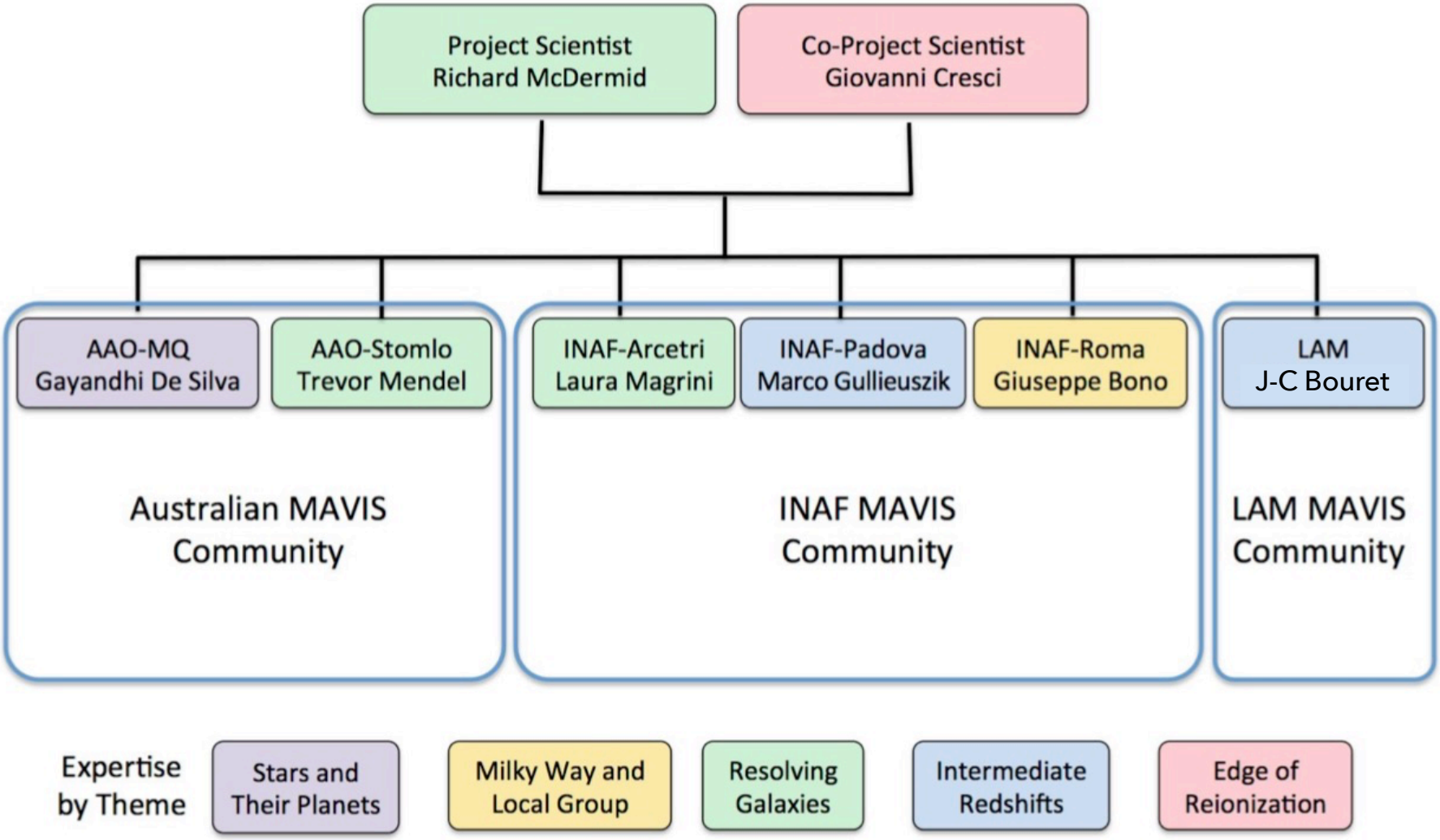
MAVIS VS MUSE NFM



MUSE NFM only targets the 0.1% brightest objects at intermediate redshift

MAVIS opens to optical AO spectroscopy to extragalactic targets

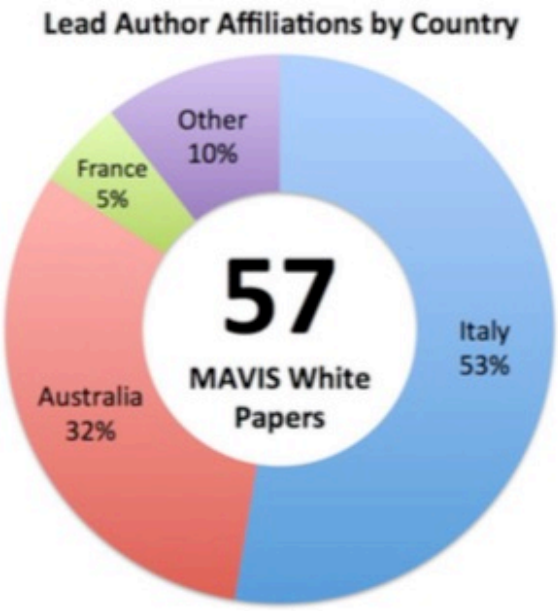
MAVIS SCIENCE TEAM

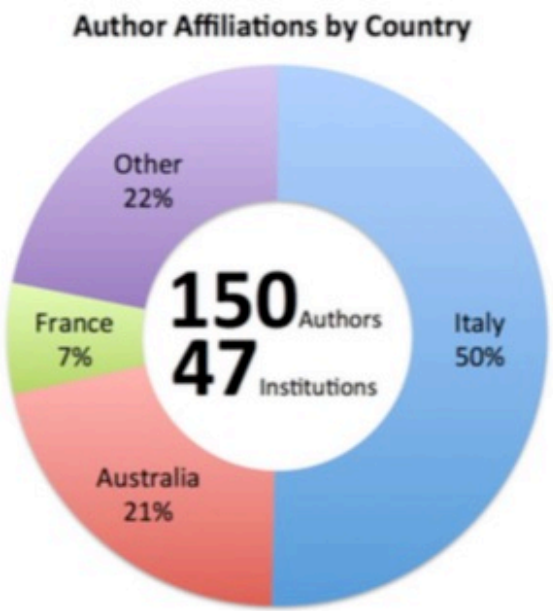


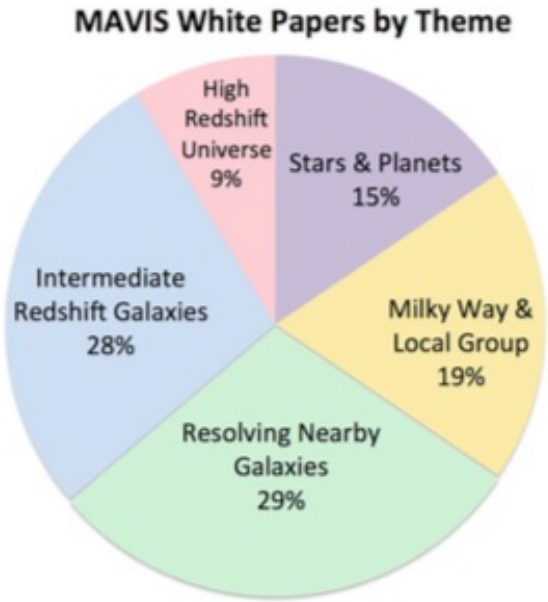
From geographical to scientific structure after Science Meeting in Florence in 15 days (4-8 November – Villa il Gioiello)

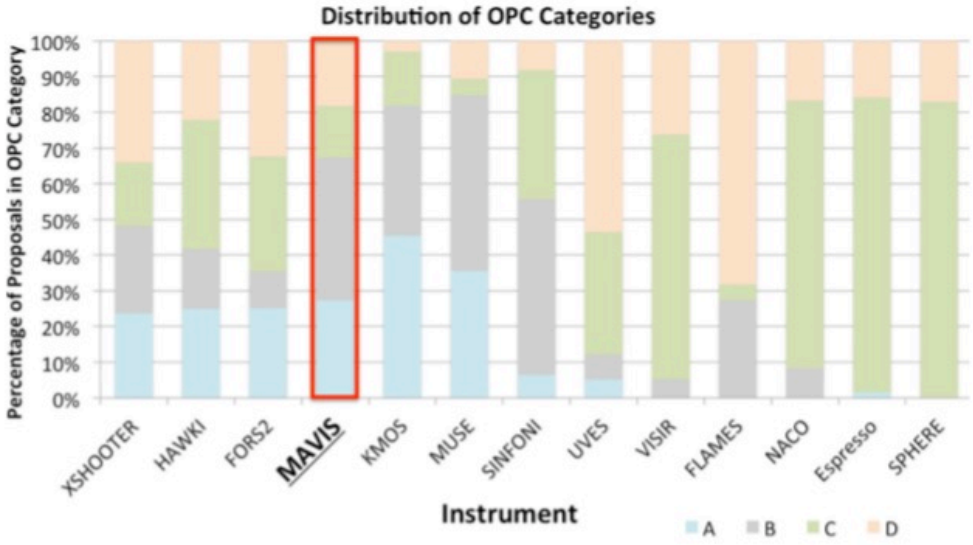
SCIENCE WITH MAVIS: WHITE PAPERS

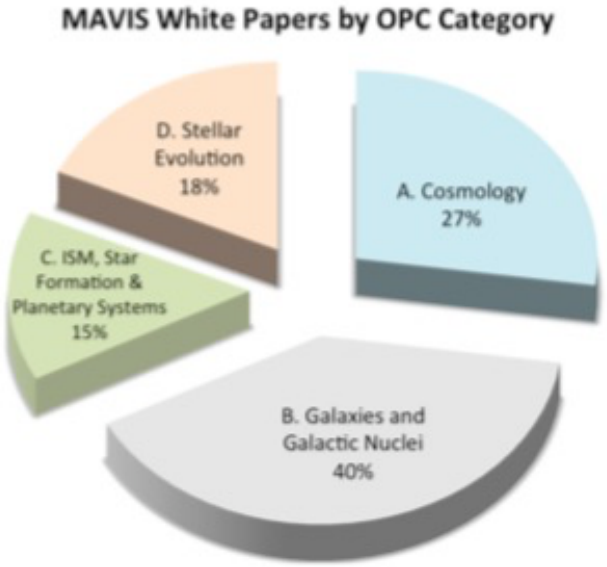
Call in July 2018







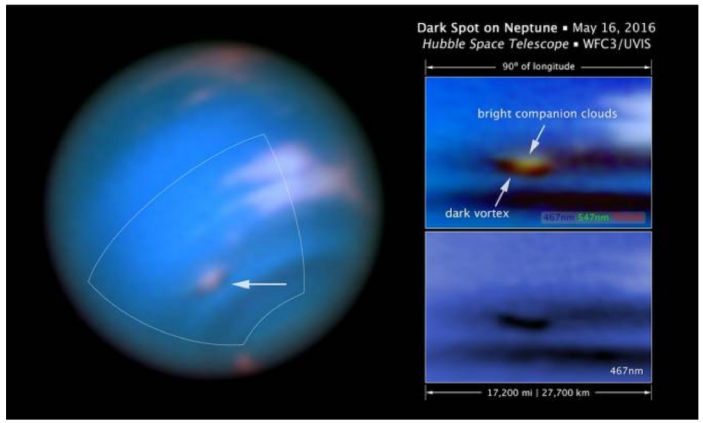


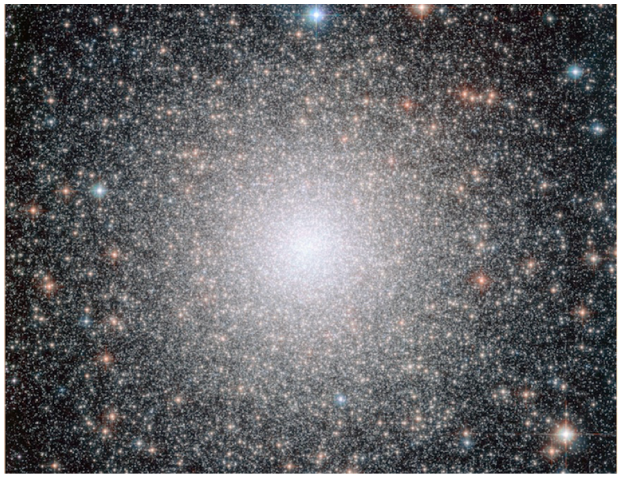


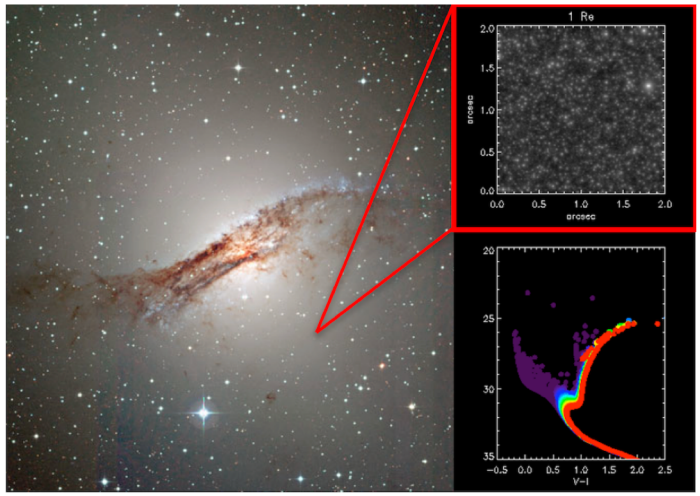
A general purpose instrument!

SCIENCE WITH MAVIS:

- Crowded Field Photometry & Spectroscopy
- Precision Astrometry and Proper Motions
- Solar System Science
- ExoPlanets
- Initial Mass Function
- Proto-planetary disks
- Stellar jets
- Binary stars and WD
- Galaxy structure and morphology
- Resolved Stellar Populations beyond the Local Group
- Outflows and Feedback
- Morphology of Young Galaxies
- Probing the Edge of Reionization
- Transient follow-ups
- Synergy with future facilities
- …

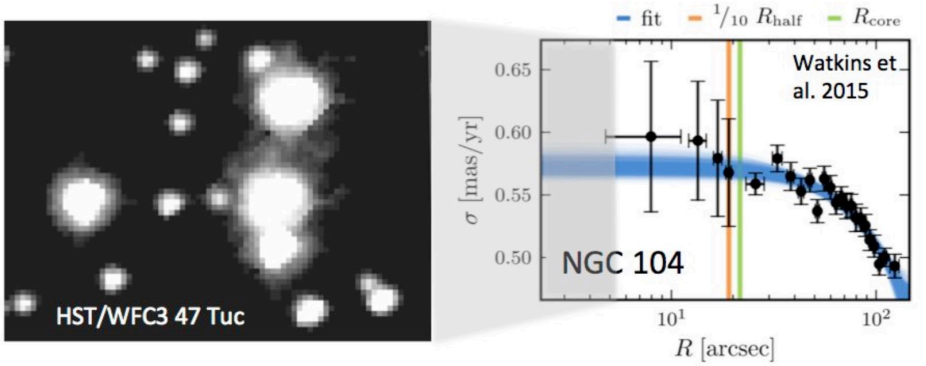


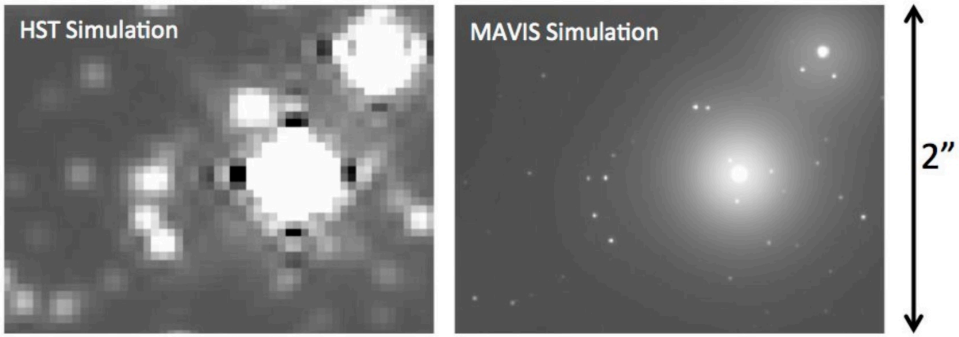


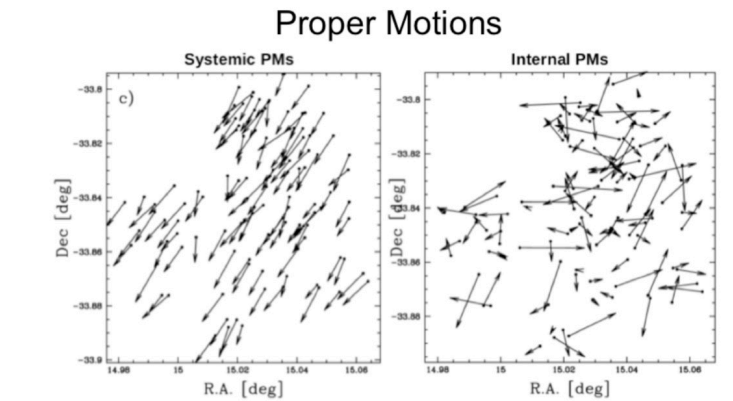


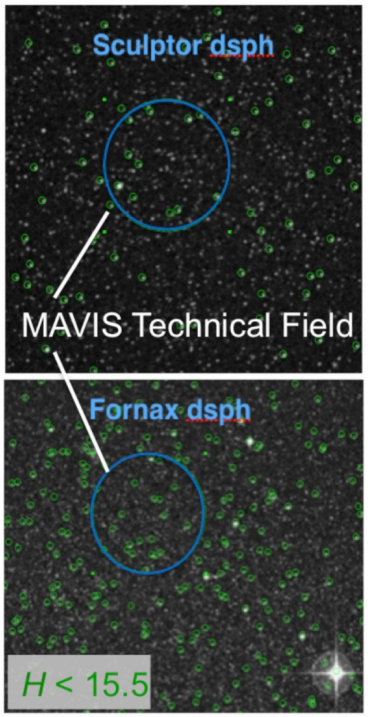
SCIENCE WITH MAVIS: IMBH

Search for **intermediate mass BH** in nearby dwarf galaxies and globular clusters





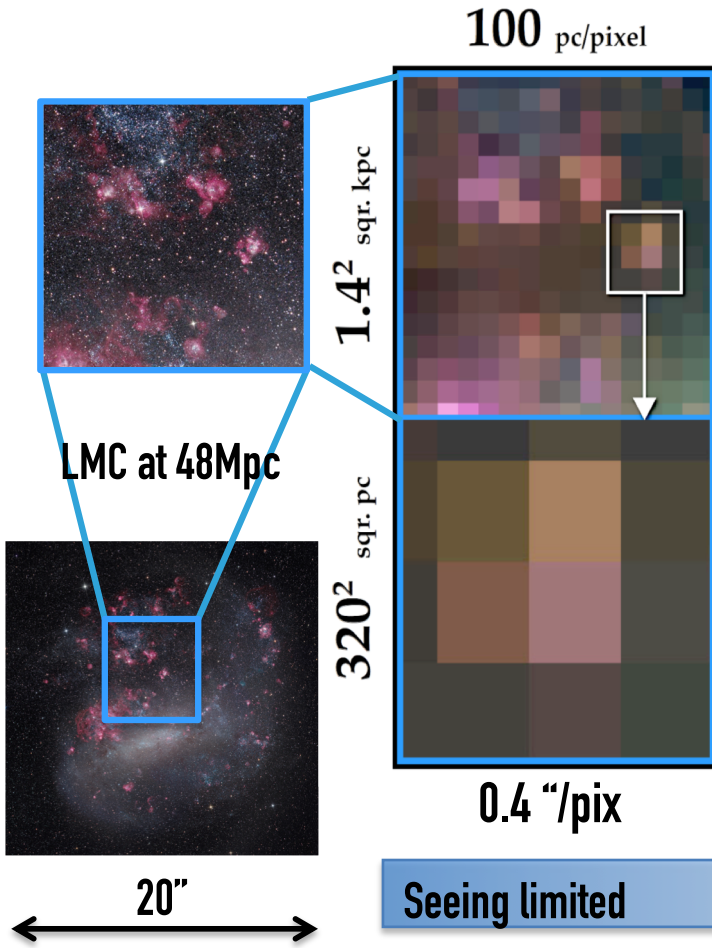




Sculptor dsph

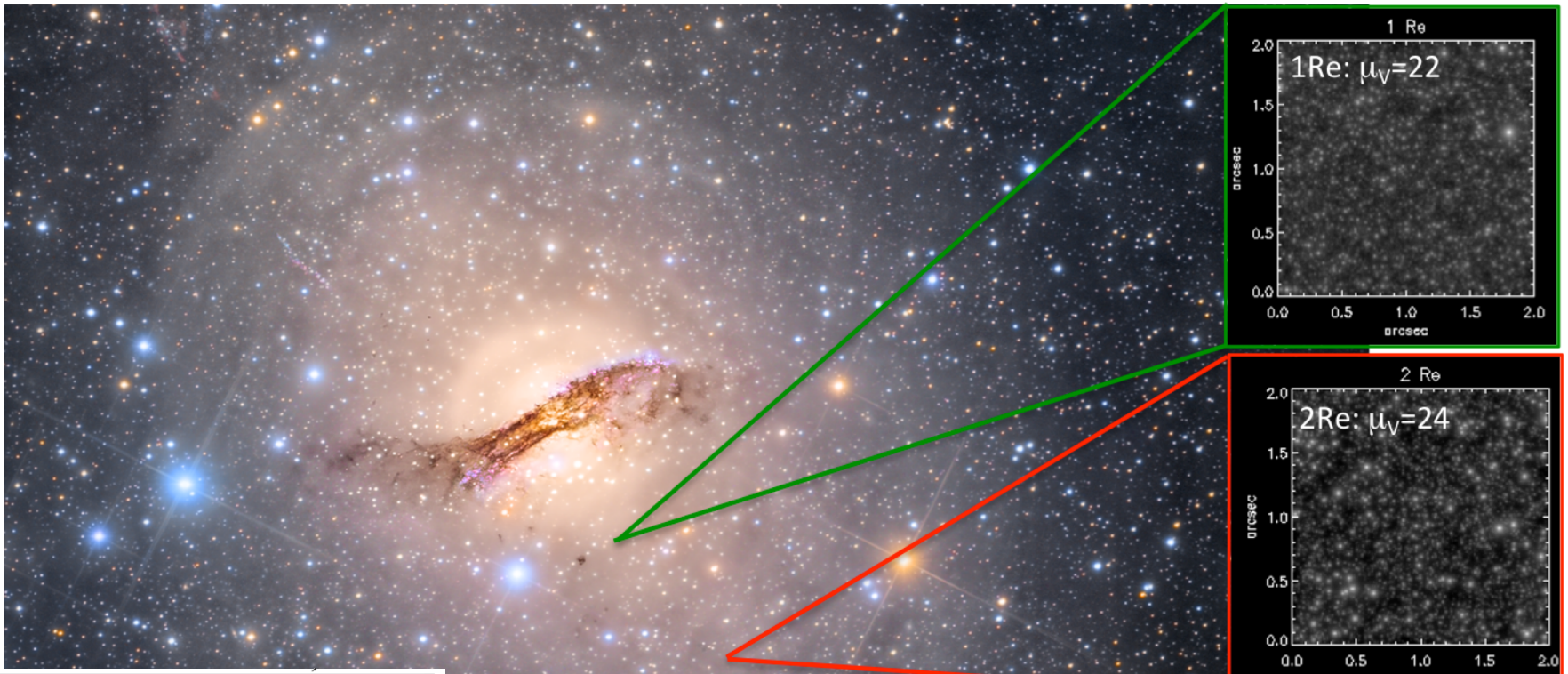
Combining precision astrometry and MOS spectroscopy in crowded fields with unprecedented resolution

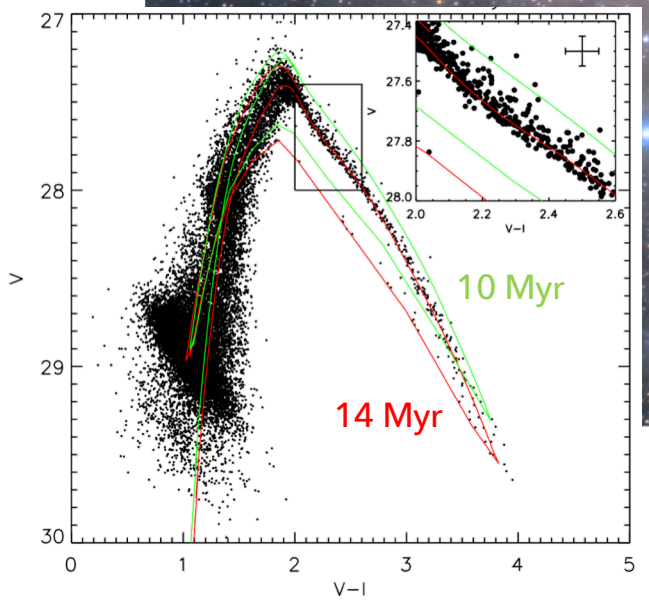
SCIENCE WITH MAVIS: RESOLVED COMPLEXITY



Resolving complexity in galaxies beyond the local group

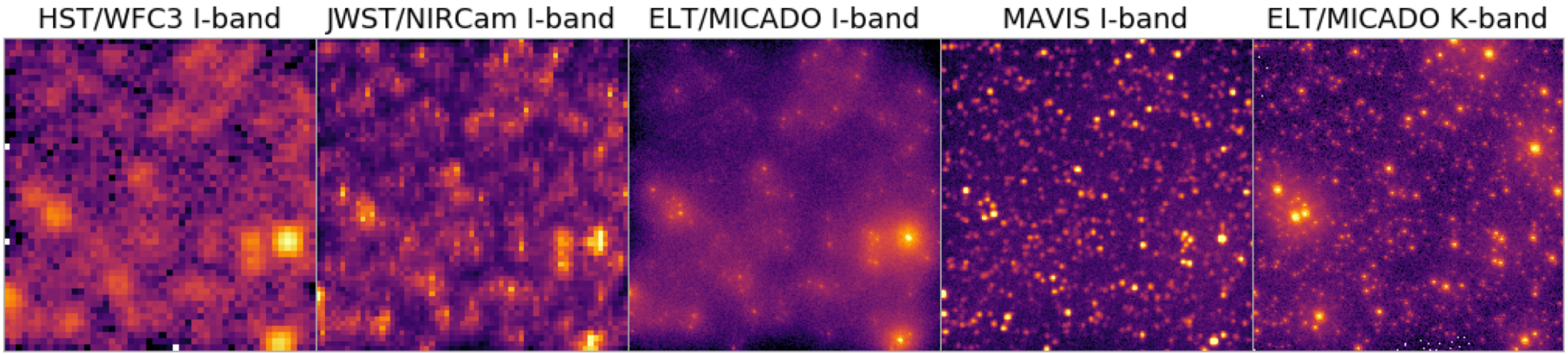
SCIENCE WITH MAVIS: RESOLVED STELLAR POP BEYOND LOCAL GROUP



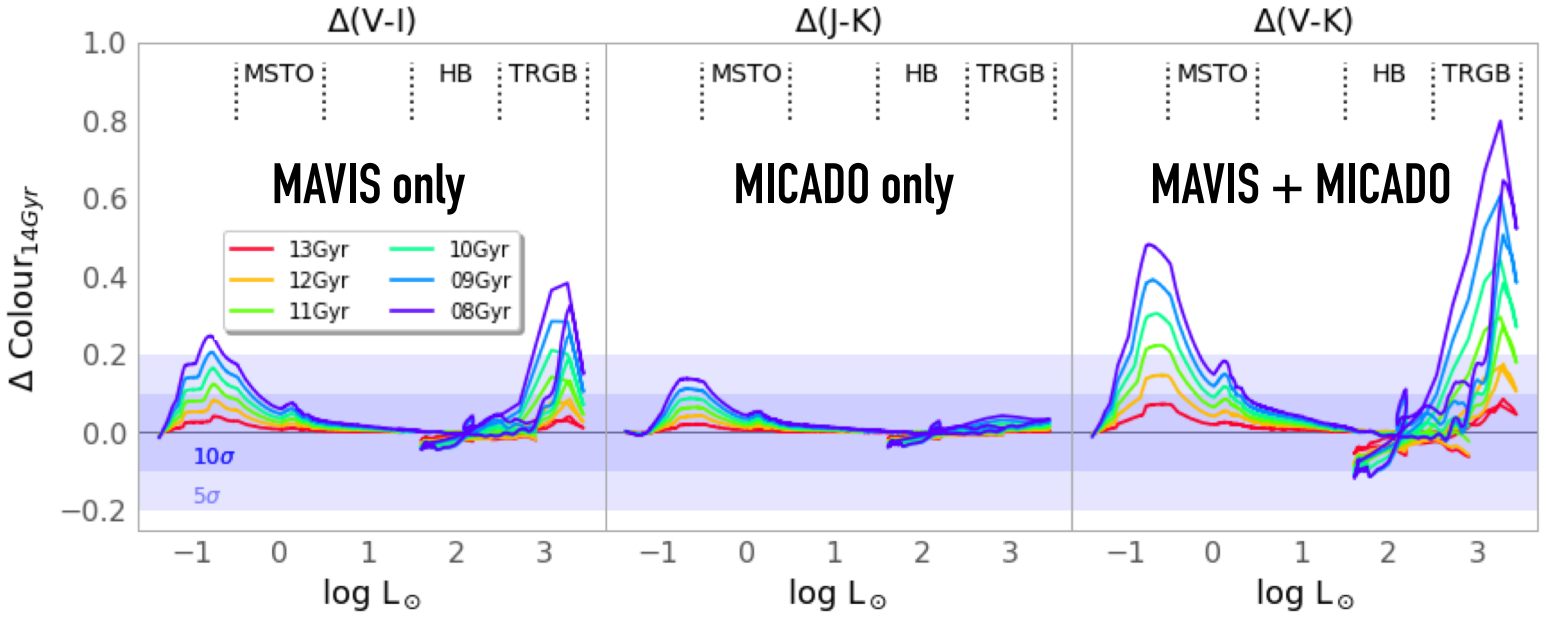


CEN A simulated MAVIS frames

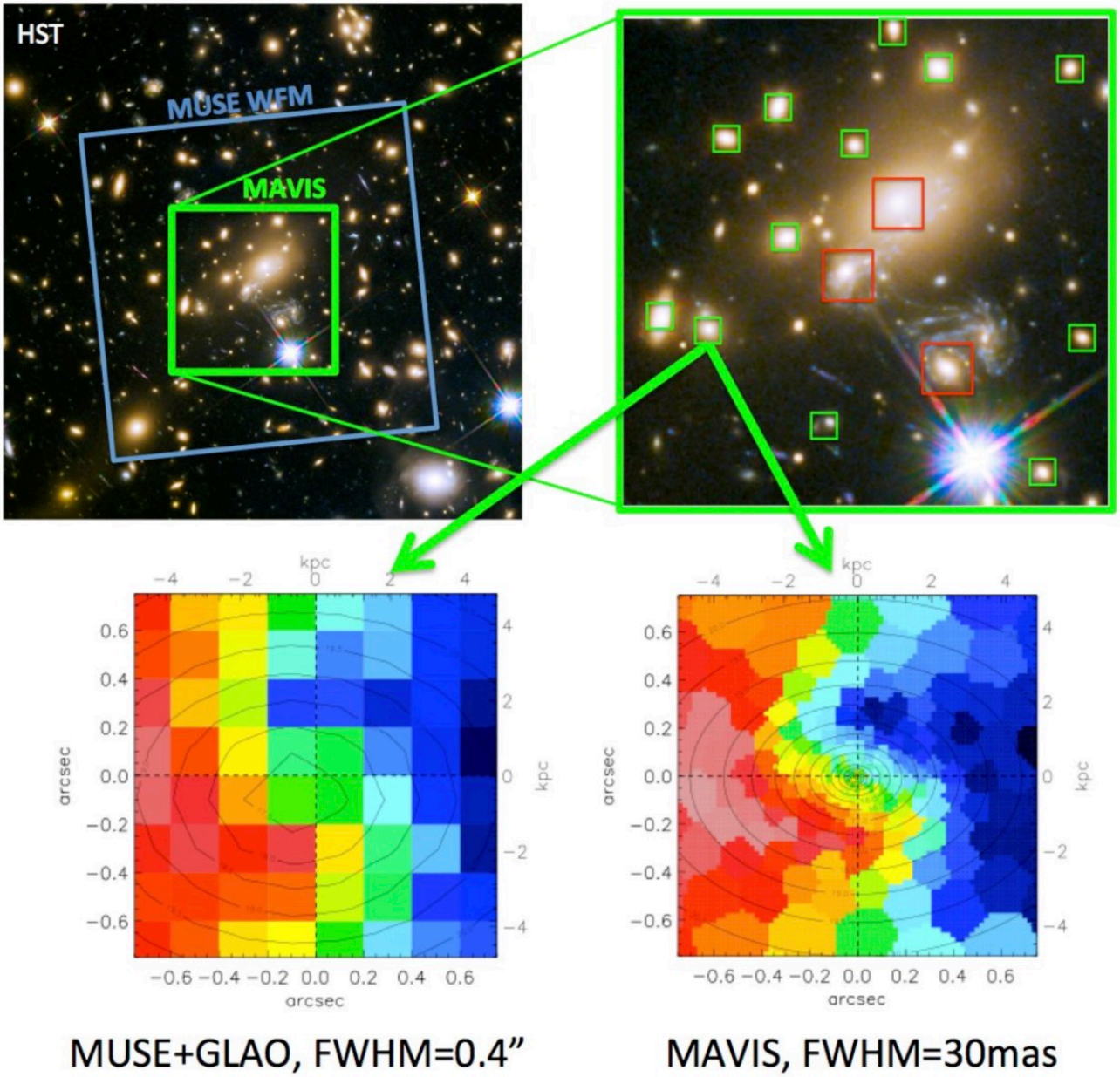
SCIENCE WITH MAVIS: RESOLVED STELLAR POP BEYOND LOCAL GROUP



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



SCIENCE WITH MAVIS: RESOLVED KINEMATICS



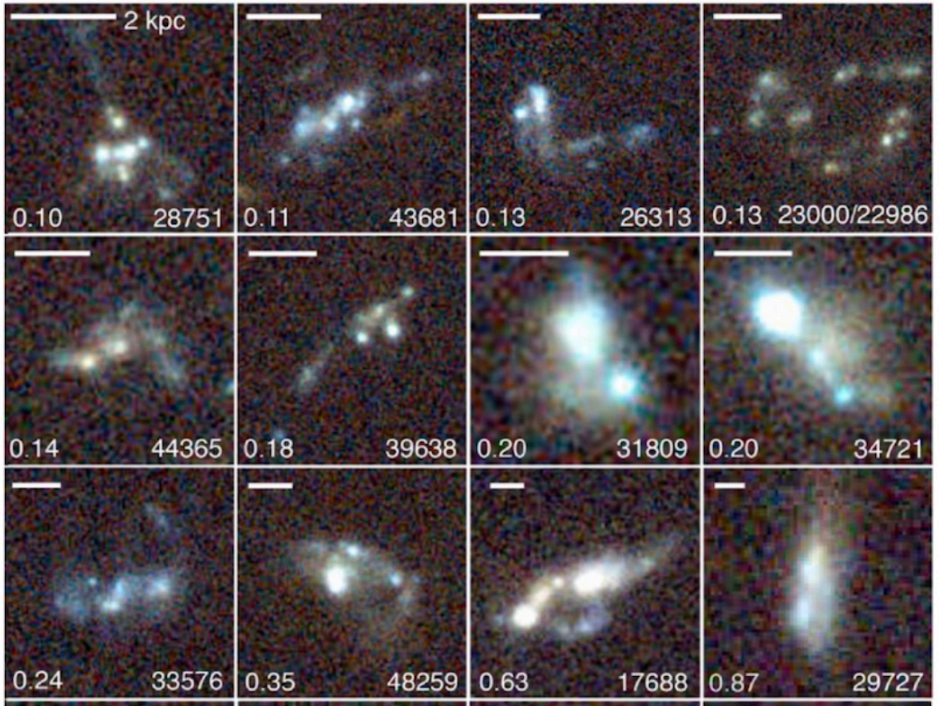
Kinematics on Sub-Kiloparsec Scales at z~0.5:

high spatial resolution <0.1” required for precise kinematic classification

SCIENCE WITH MAVIS

The majority of galaxies at z>1 – 2 are dominated by bright star-forming "clumps":

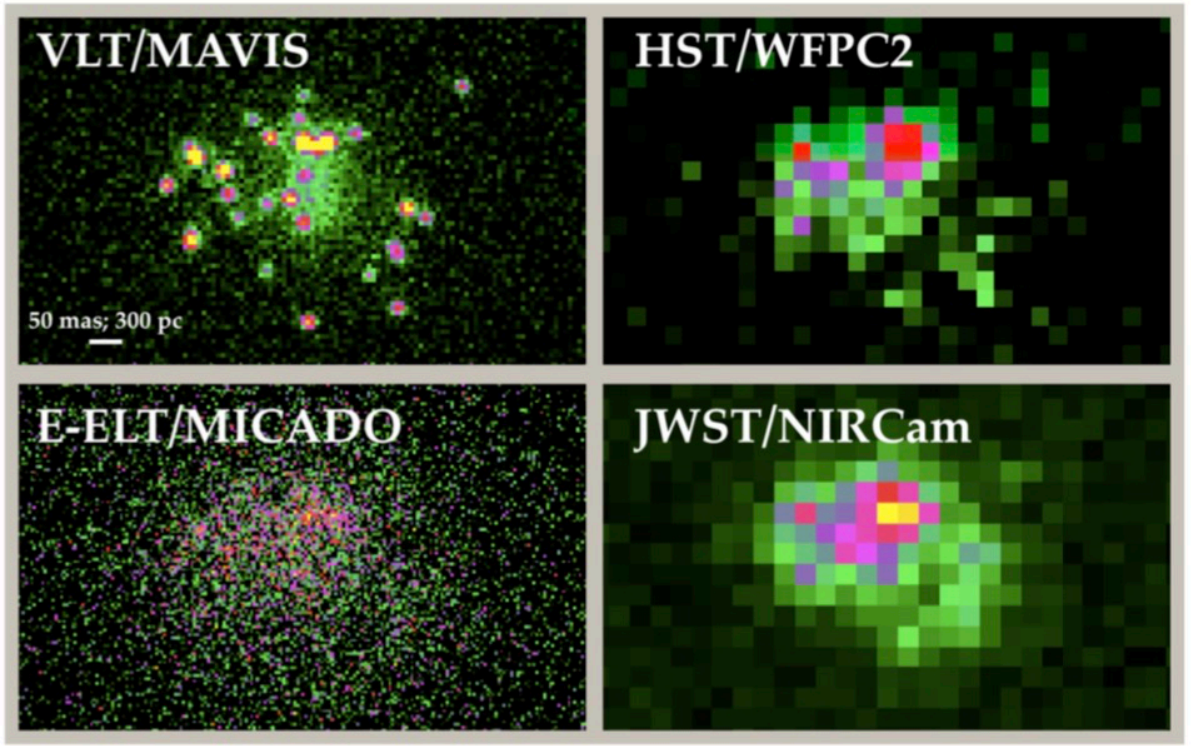
- stellar masses ~10^9 M_{sun}
- typical sizes ≤1 kpc (≤0.1" at z ~2) but unresolved

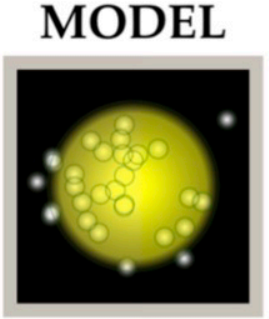


UV spectroscopy:

Lyα, CIII]λ1909, HeIIλ1640, Mg IIλ2798 …

- dynamics
- outflows
- IMF
- escape fraction
- …

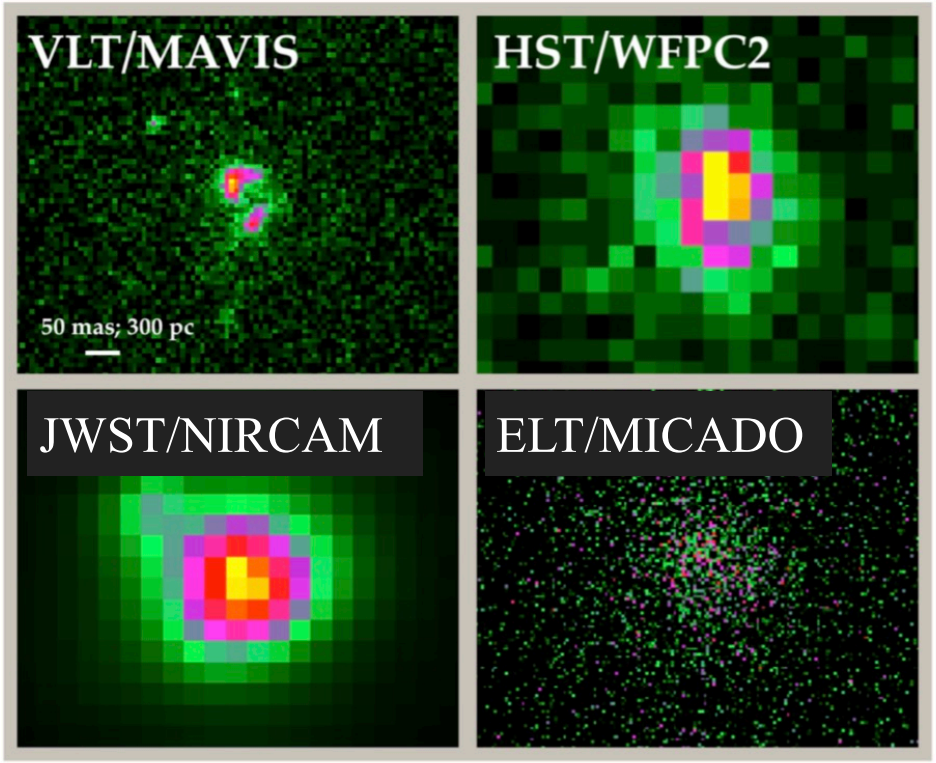




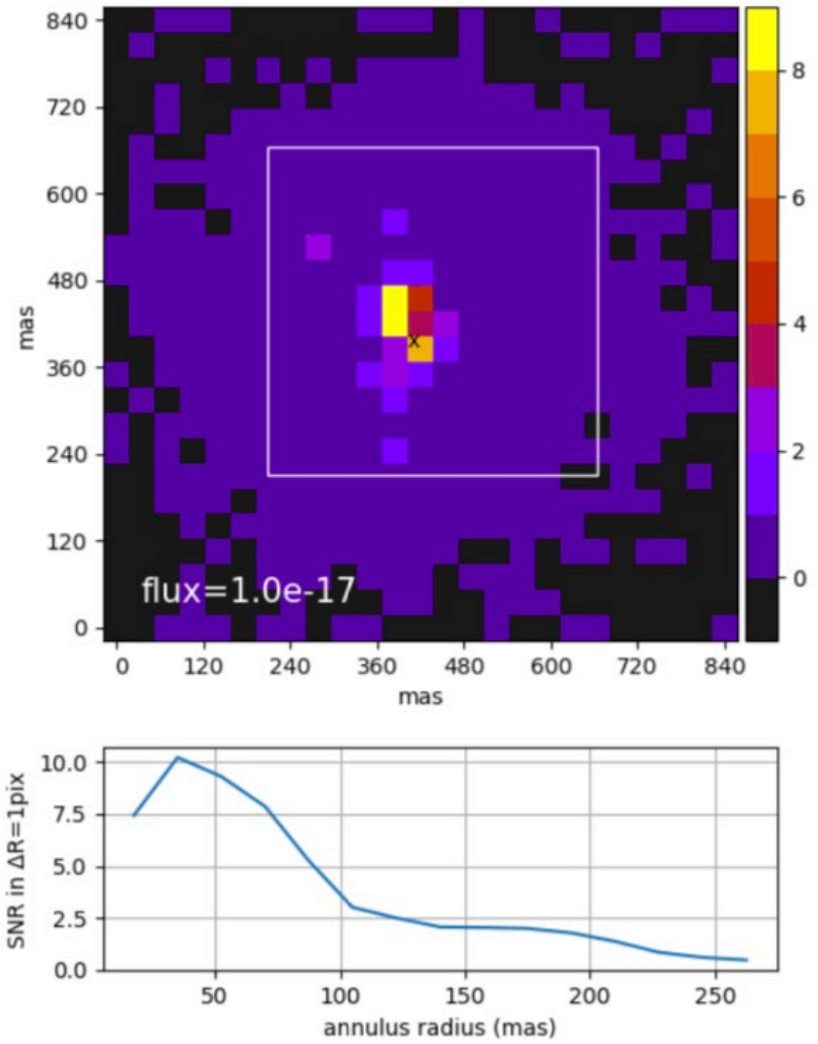
I band simulations ($\sigma = 0.1''$ 0.6 kpc at z=5)

SCIENCE WITH MAVIS: HIGH-Z GALAXIES

Spatially resolved rest frame UV spectroscopy of z~5-6 galaxies (Re~500 pc ~ 80mas) possible for the first time!



I band 1 hr exposure simulations: imaging



10 hrs Lyα exposure simulations: spectroscopy

CONCLUSIONS

MAVIS

- Diffraction limit optical imaging and spectroscopy
- Phase A started in January 2019
- A joined Australian, Italian and French effort in technology and science
- A new discovery window: *sharper than JWST, deeper than HST*
- An unique, multipurpose instrument complementary with existing and forthcoming facilities
- Expected first light ~2025

Interested? Want more info?
Follow the blog: www.mavis-ao.org
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