MAVIS

GALSPEC2021
16/4/21

MAVIS: Sharper than JWST, deeper than HST

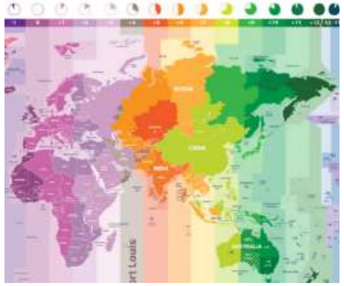
Giovanni Cresci (INAF – Arcetri)
on behalf of the MAVIS team

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, LAM and Australian Astronomical Optics (AAO, including ANU, MQ & UniSyd)
- November 2018: MAVIS awarded agreement for phase A conceptual design study by ESO
- May 2020: Phase A review passed
- April 2021: construction agreement with ESO and Phase B kickoff

MAVIS CONSORTIUM

PI: F. Rigaut
(AAO-STROMLO)



10h time difference!

AO system engineering
& numerical simulations
Opto-mechanics
Instrument Software
NGS WFS

Project Office (Stromlo)
LGS WFS, AO expertise
RTC & AO control
Post-focal instrumentation:
Imager, spectrograph,
IFU front-end

Post-processing
AO expertise

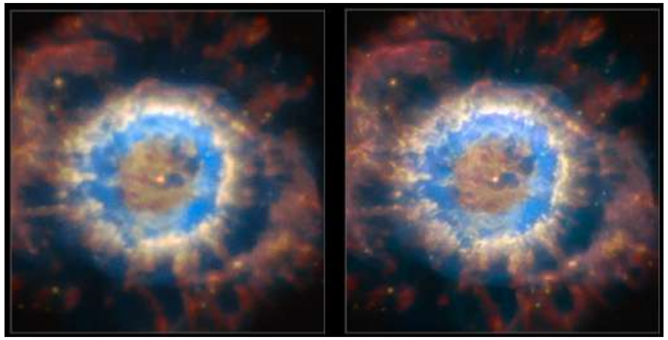
Observatory
interfaces, LGSF,
Deformable Mirrors

VLT Adaptive Optics Facility

- Upgrade of VLT UT4 since 2016 with AO fully integrated into the telescope

- Key technical components:
  - **Deformable secondary mirror** with high actuator density (1170 actuators)
  - **Four laser guide stars**, 20W each, operating above specifications with high photon return
  - Both key for high performance in the **optical**

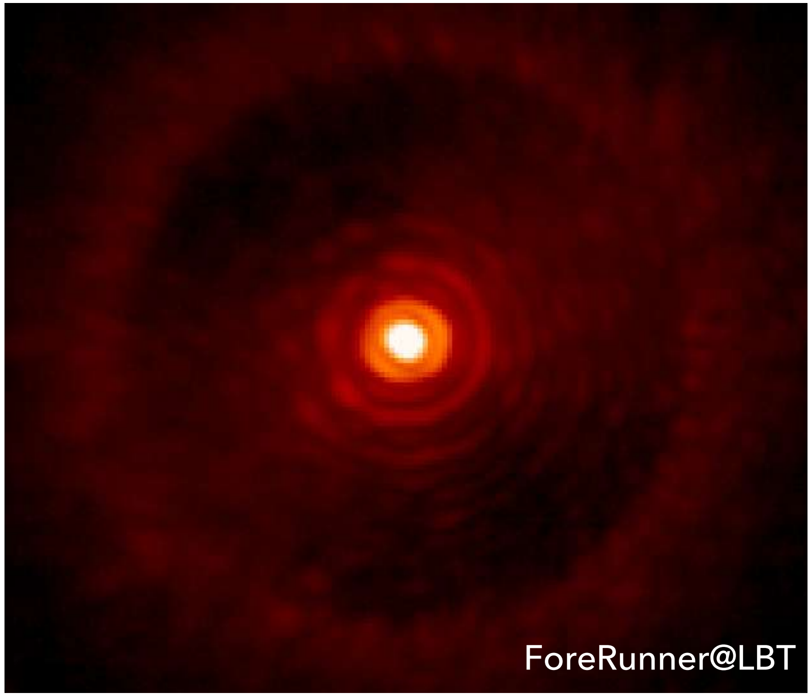
Full AOF science potential not being realized yet

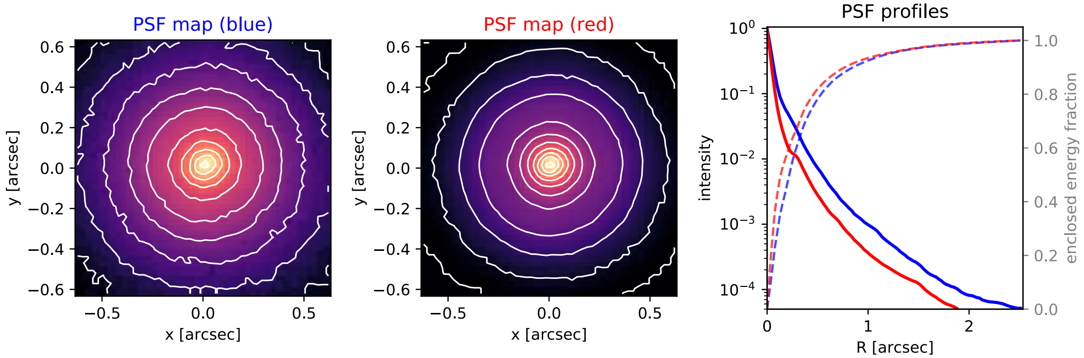


MAVIS

Single conjugate AO in the visible

- **Optical AO much harder** ($r_0 \sim \lambda^{6/5}$)
- 650nm images from SHARK-VIS ForeRunner@LBT+FLAO
    - Adaptive secondary
    - 0.8” seeing
    - 50% Strehl ratio!
    - 18 milliarcsec FWHM
- Similar examples from:
    - SPHERE @VLT
    - MAG-AO @Magellan
    - MUSE Narrow Field Mode
- **Visible AO is feasible!**

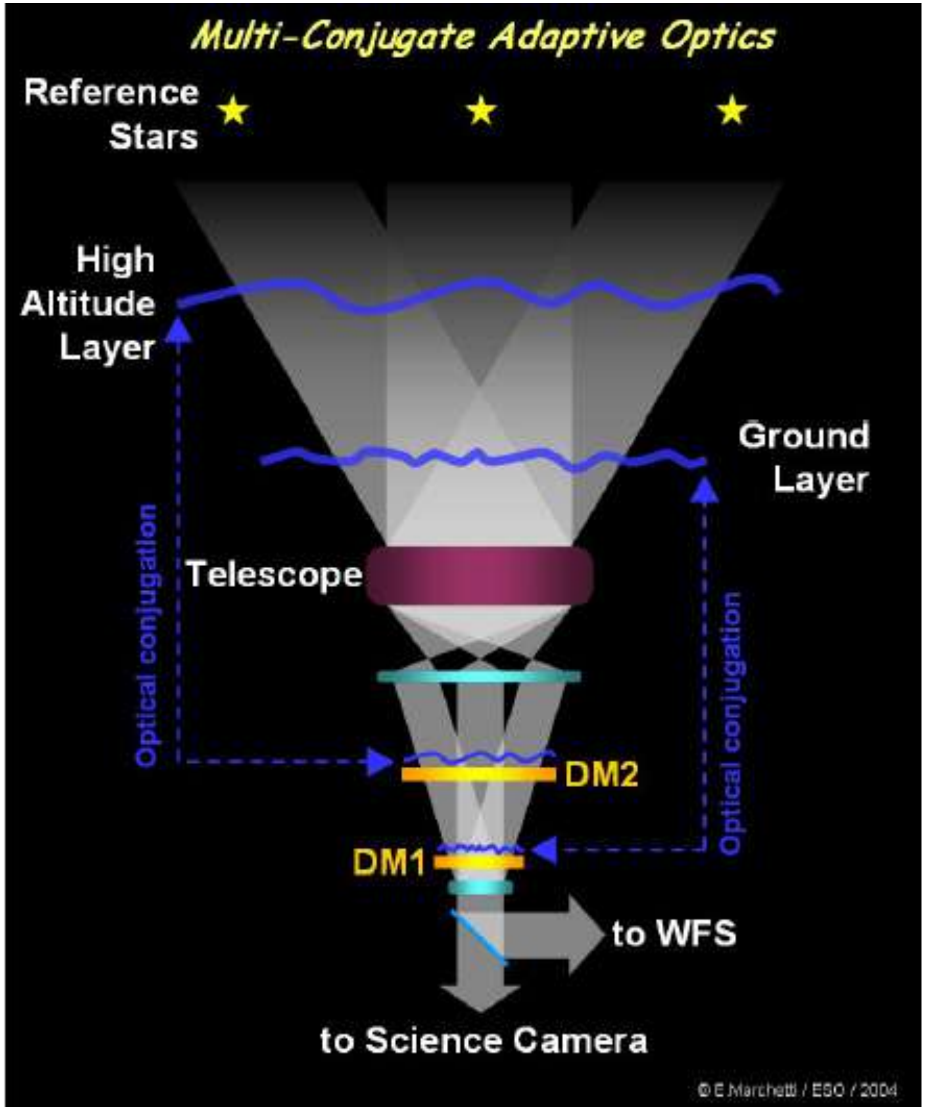




MUSE NFM, Marasco, GC et al. 2020

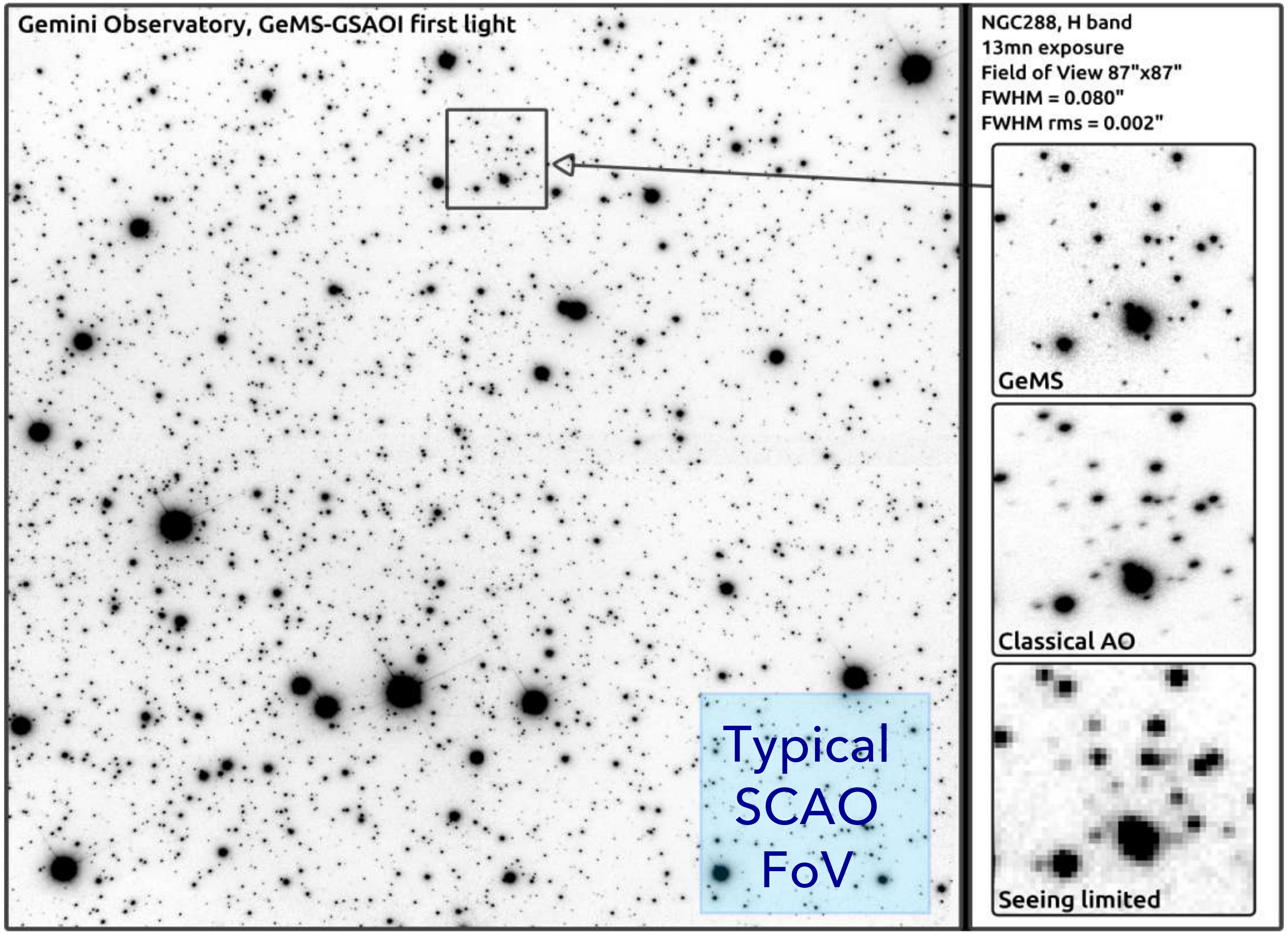
MULTI conjugate ao (MCAO)

- 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 with NGS



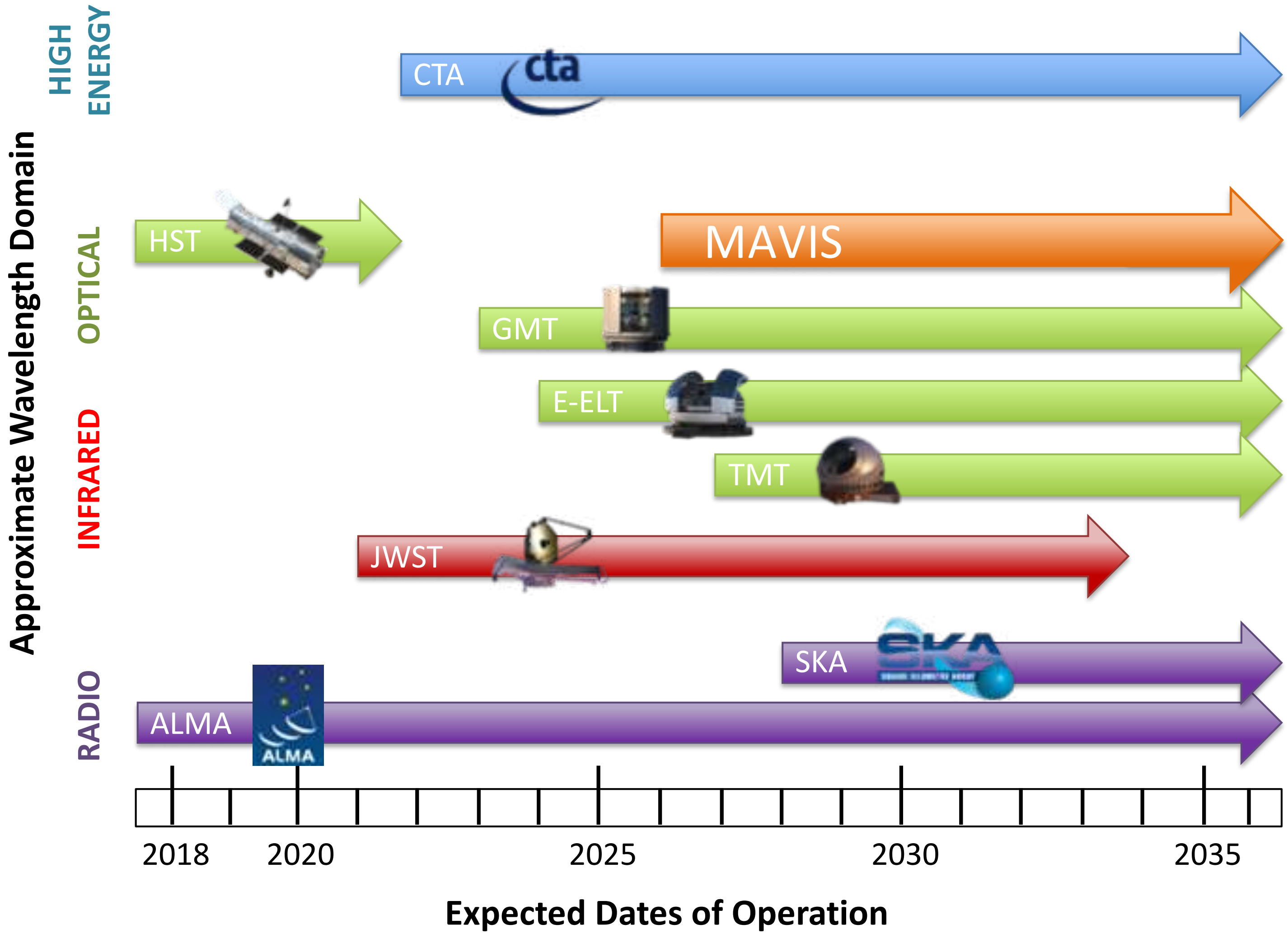
… MCAO in optical has never been done before!

The need for MAVIS

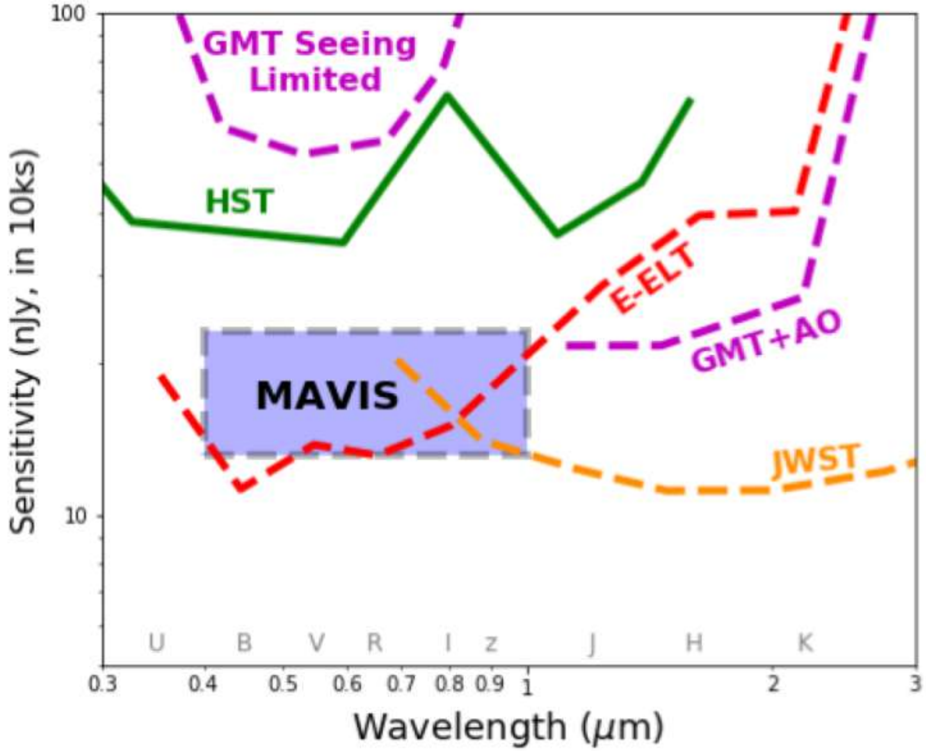
MAVIS operations overlap with forthcoming era of high sensitivity, high resolution astronomy with large telescopes

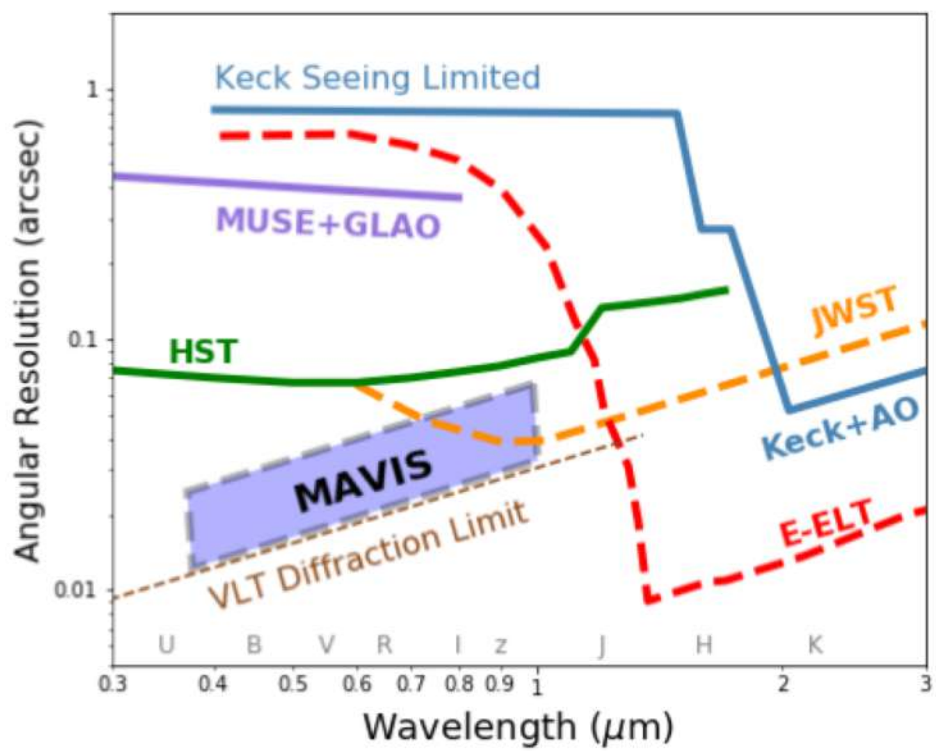
Expected First Light ~2027

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



deeper than HST, Sharper than JWST





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

What is MAVIS

Uses VTL UT4 AO Facility

- Existing deformable secondary
- Existing laser guide star facility (4x2)

AO Module

- **Visible** (VRI, UB goal)
- **30"x30"** field of view corrected
- FWHM ≈ **20mas** (V band)
- Strehl ratio ≈ **15%** (V band)
- Sky coverage ≈ **50%** @ Gal. pole

Imager

- 30"x30" FoV, 7.3 mas pixel
- U-z bands (Diffraction limited V-z)
- 4Kx4K pixels
- Wide + narrow band filters
- V=29.5 in 1 hr (5 σ)

MAVIS - *MCAO-Assisted Visible Imager & Spectrograph*

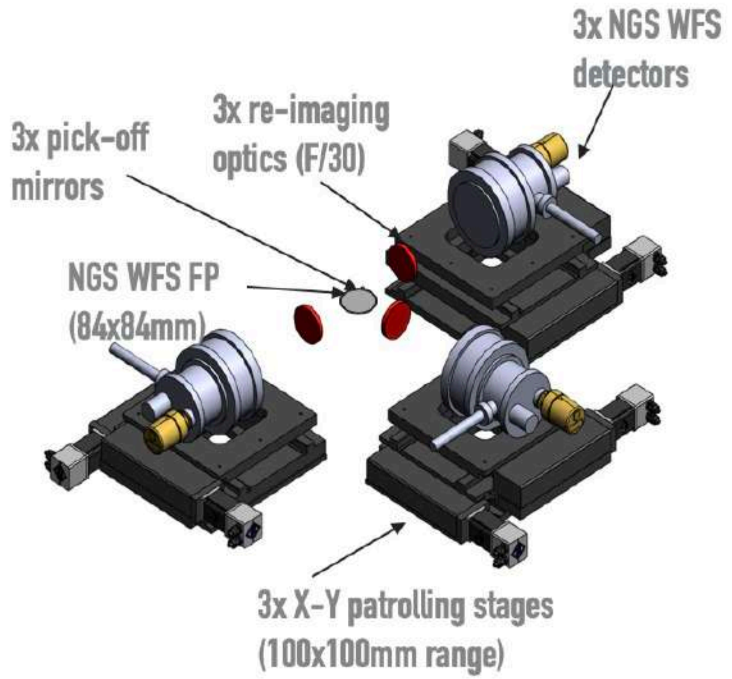
IFU Spectrograph

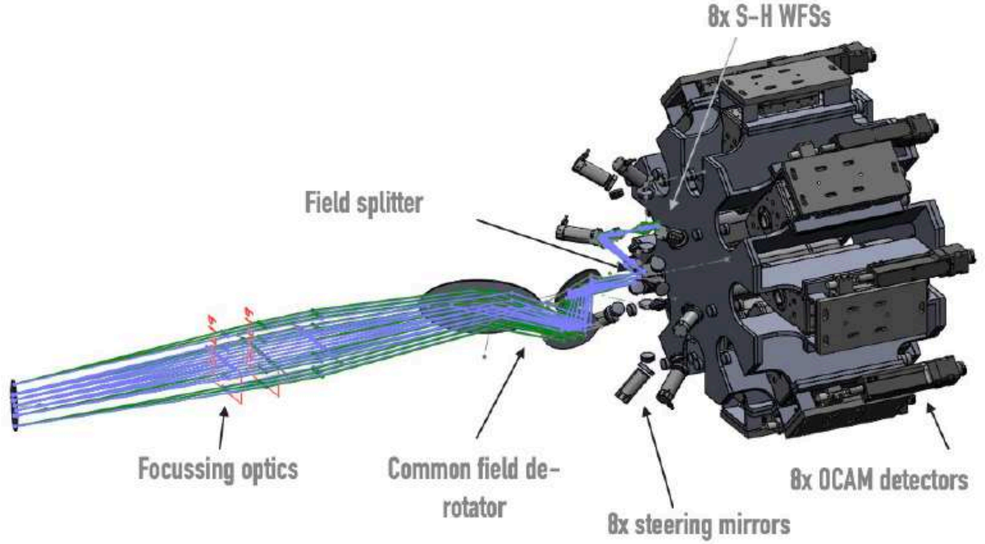
- image slicer IFU
- 25 mas and 50 mas spaxels
  - 2.5"x3.6" and 5"x7.2" FoV
- R~5000 and ~12000
- λ = 370-1000 nm
- 4 interchangeable VPH gratings
- 15% encircled energy in 50 mas spaxels

AO module

NGS Wavefront Sensors

- Up to 3 NGS sensed in J+H band
- H≲20 in 2 arcmin patrol field
- Tomographic truth sensing





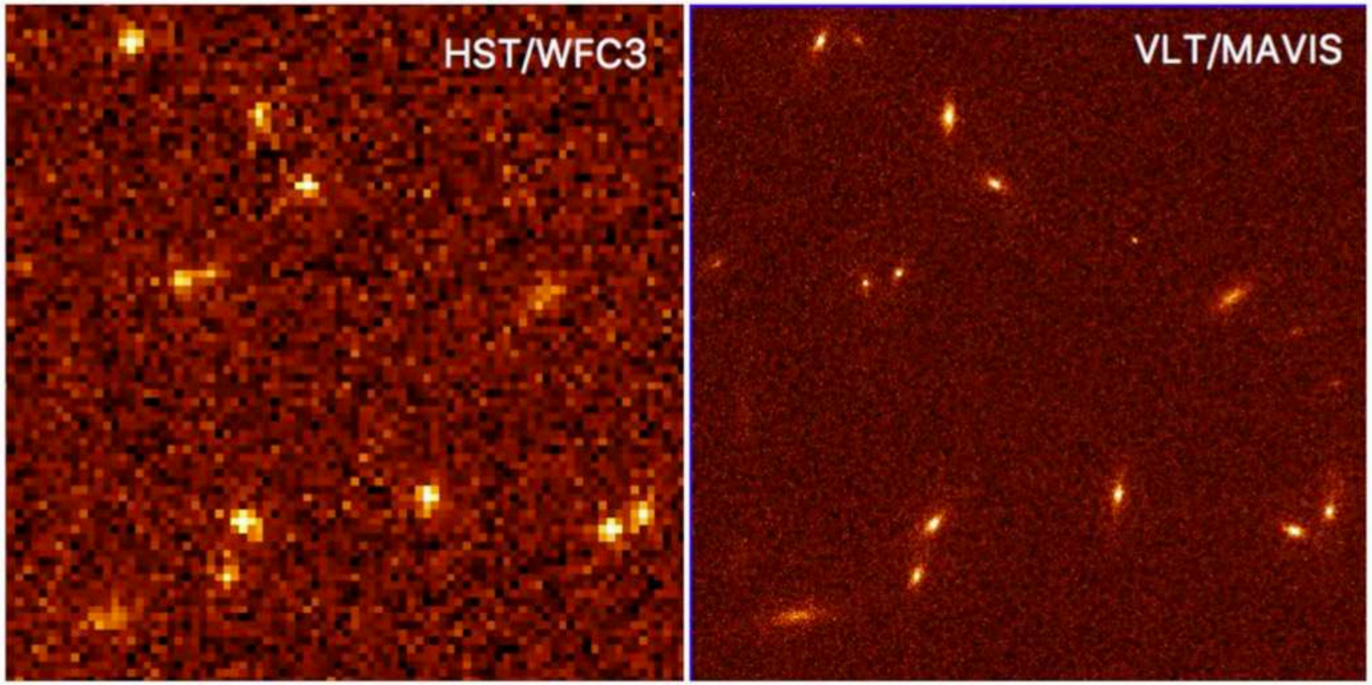
LGS Wavefront Sensors

- 8 LGS S-H WFS
- 17.5" radius circular asterism
- including FP steering mirrors and FoV derotation

Imager

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

- 30″x30″ FoV
- 7mas pixel
- U-z coverage (Diffraction limited imaging V-z)
- 4Kx4K detector pixels
- Wide + narrow band filters



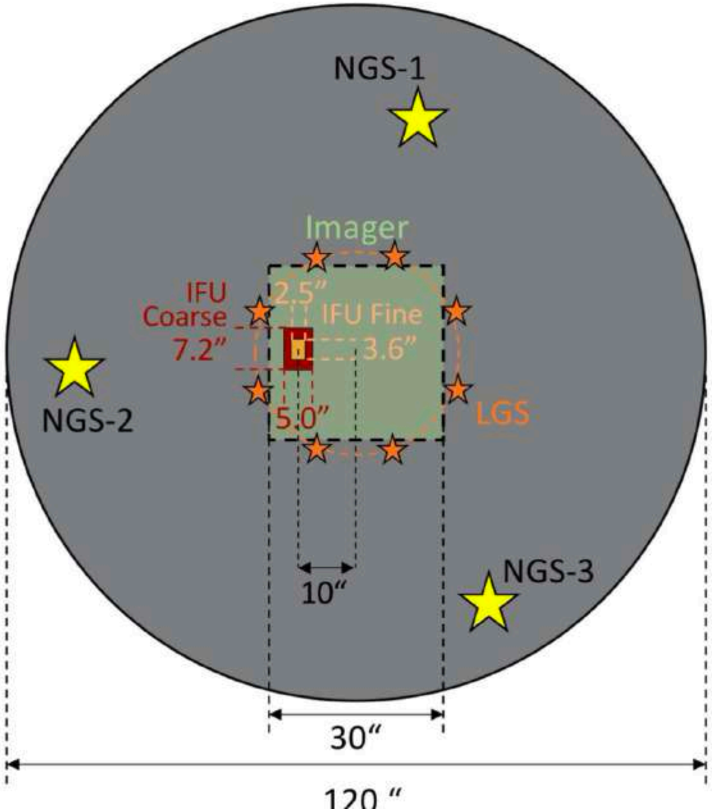
A MAVIS Deep Field

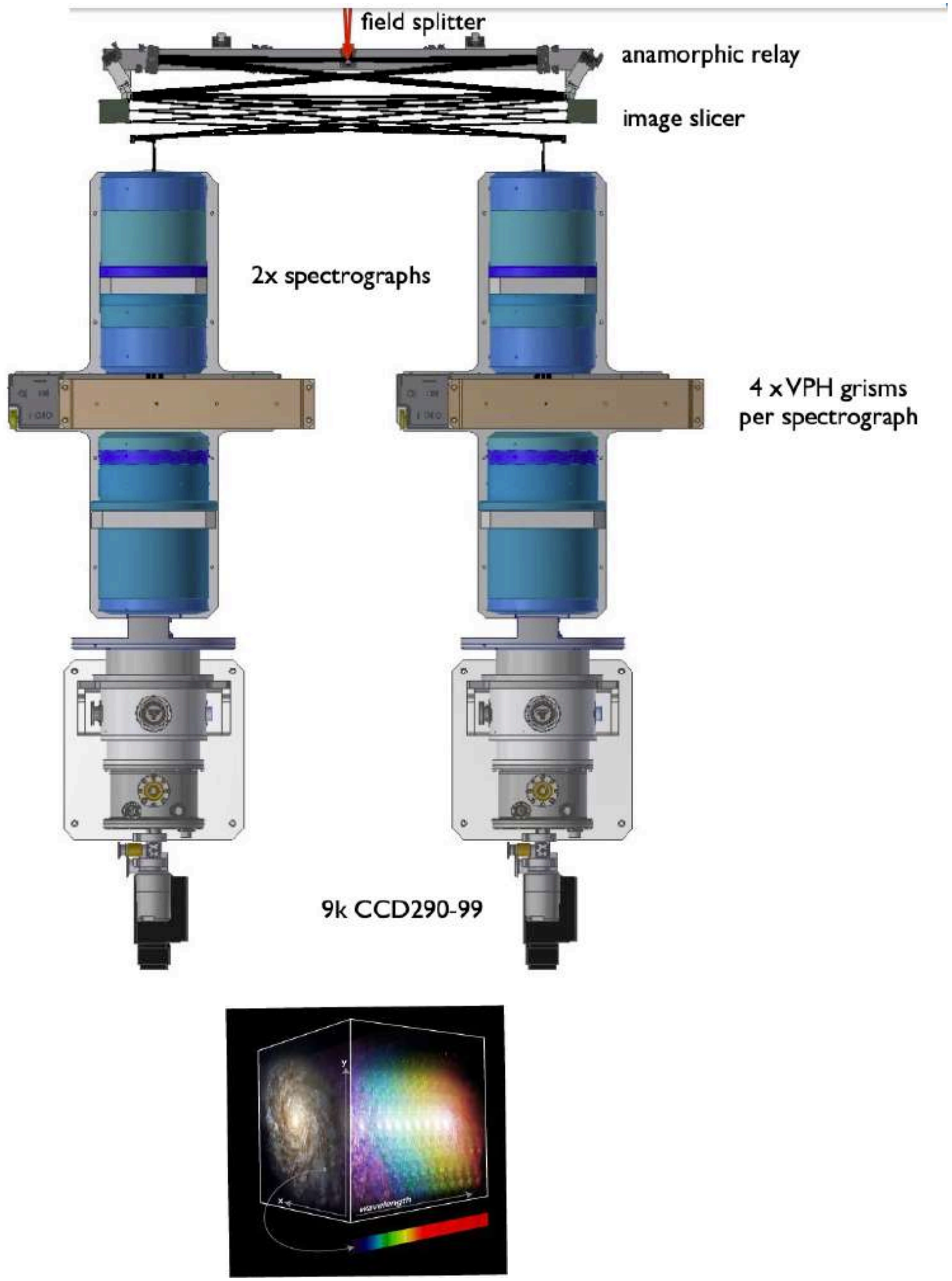
In 10 hours, MAVIS can reach a 5σ limiting mag of 30.4 AB in the I band.

This is about 1 mag deeper than the HST UDF in i775 (96h)

IFU Spectrograph

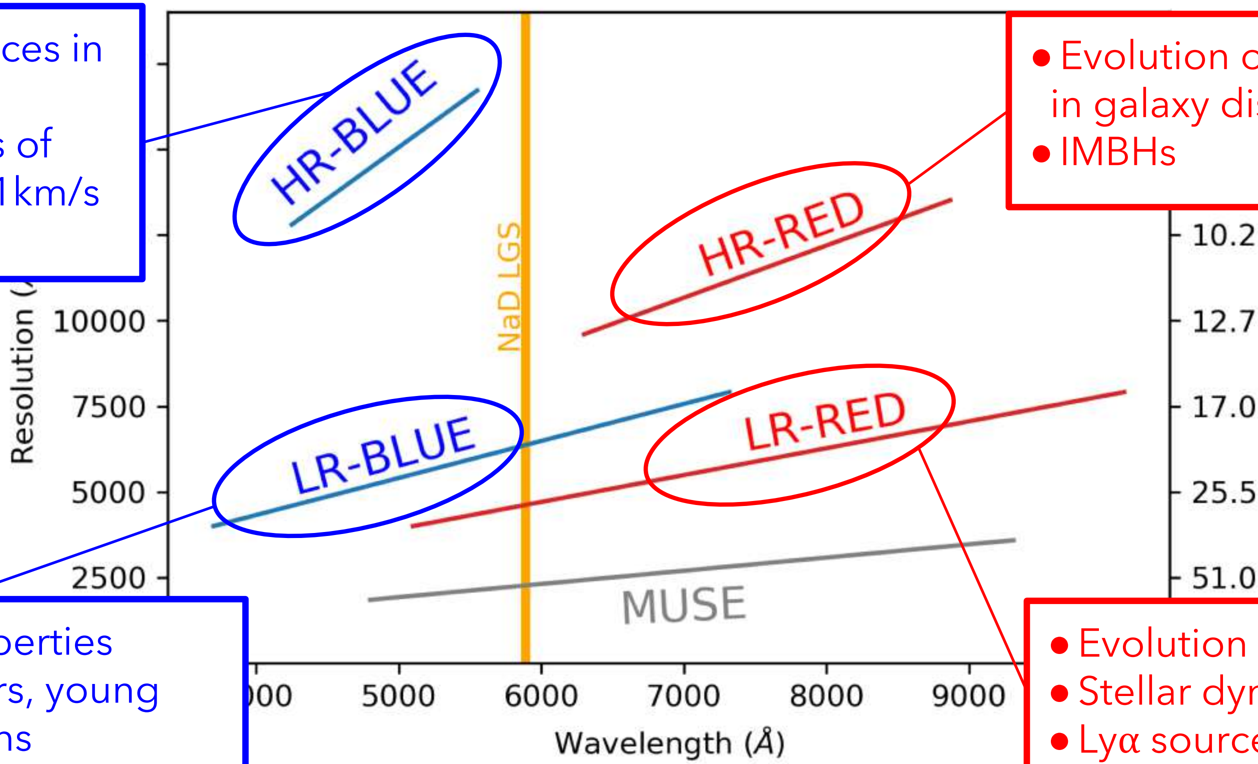
- Two spectrographs 9k x 9k detectors
- image Slicer IFU
- R band diffraction limit = 19 mas
- spaxel ~25 mas: fov ~3.6″x2.5″
- spaxel ~50 mas: fov ~7.2″x5″
- R~4000-15000
- $\lambda\sim370-1000$ nm





IFU Spectrograph

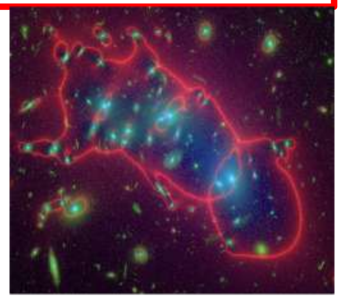
- Stellar abundances in crowded fields
- Radial velocities of stars and gas < 1km/s



- Evolution of ISM turbulence in galaxy disks
- IMBHs

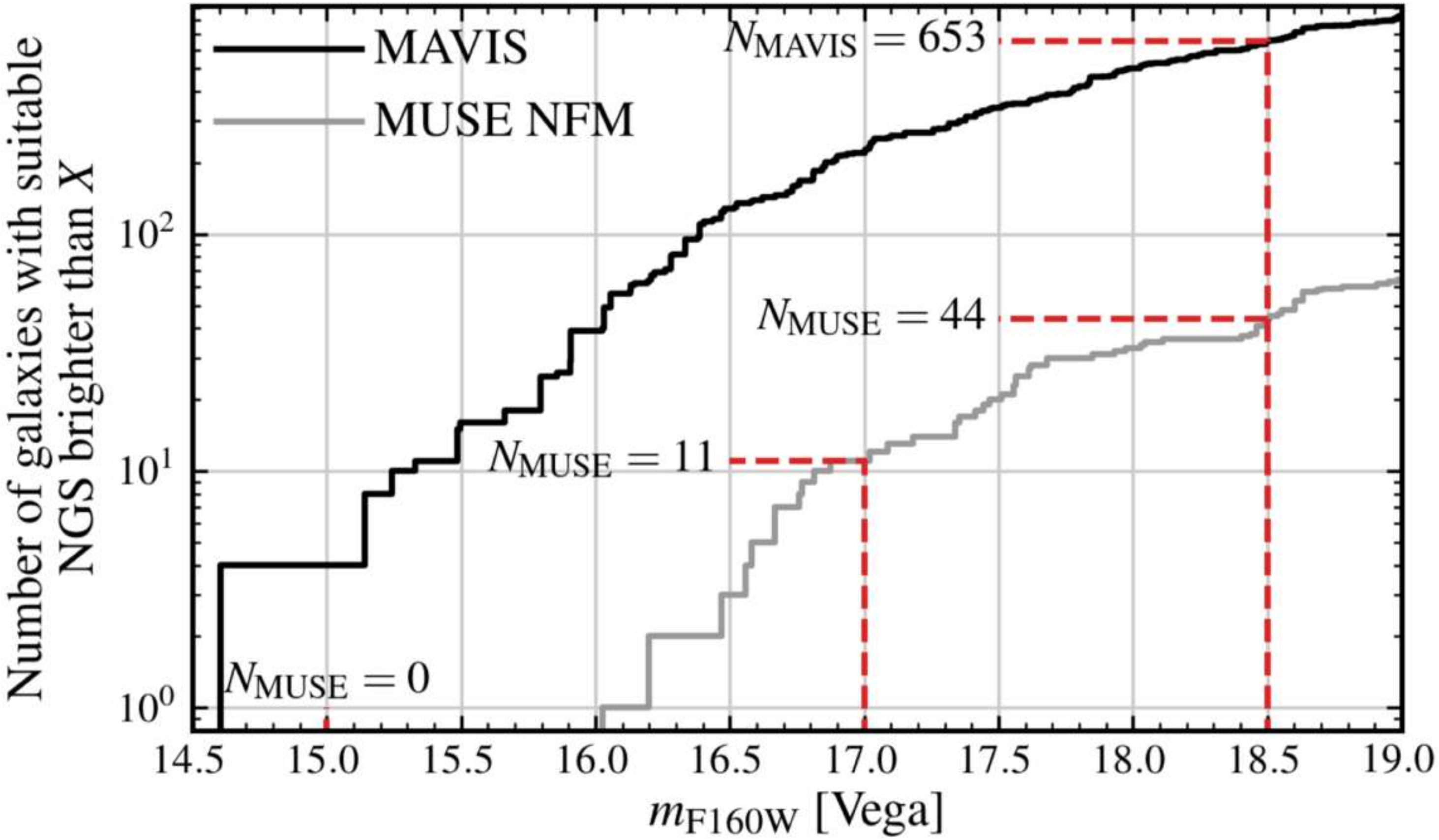
- Ionised gas properties
- Hot/Massive stars, young stellar populations
- Extreme Metal Poor stars

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



4 different gratings to cover the whole
3700-10000 Å band
optimized for different science requirements

Sky Coverage

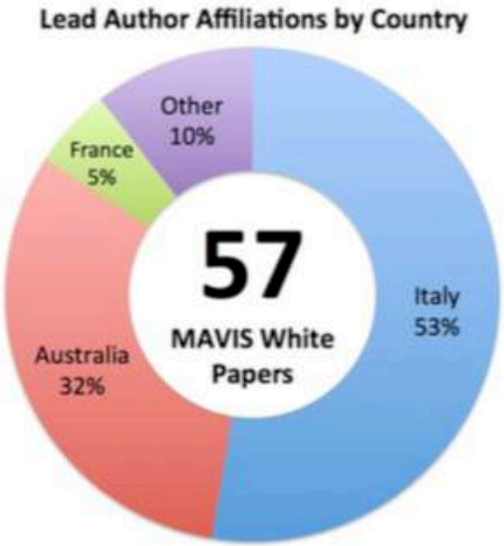


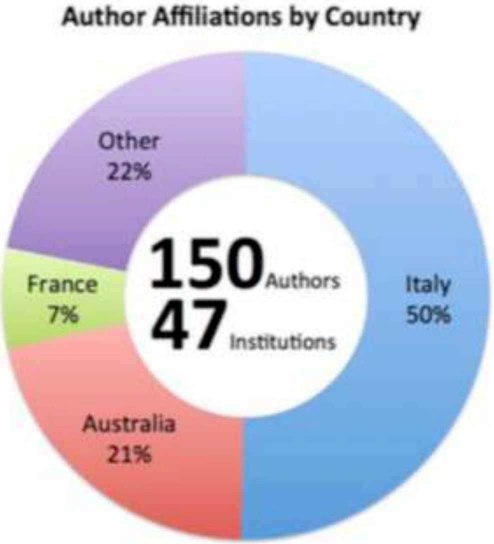
- **Use Case:** No. of observable intermediate-z galaxies in GOODS-S, COSMOS and UDS with MAVIS and MUSE-NFM as a function of (faintest) NGS magnitude
- MAVIS sky coverage gives > 1 order of magnitude more targets

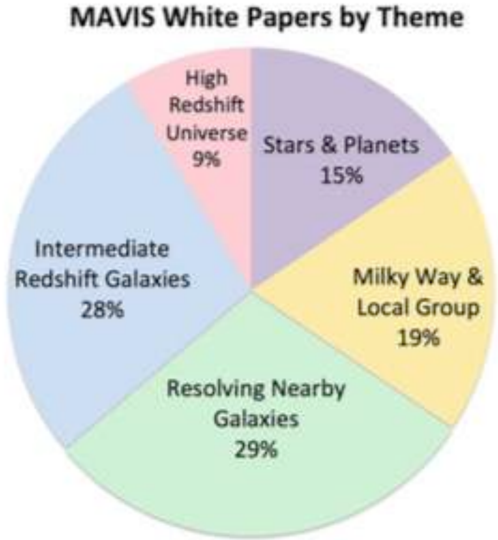
⇒ MAVIS makes statistical samples possible

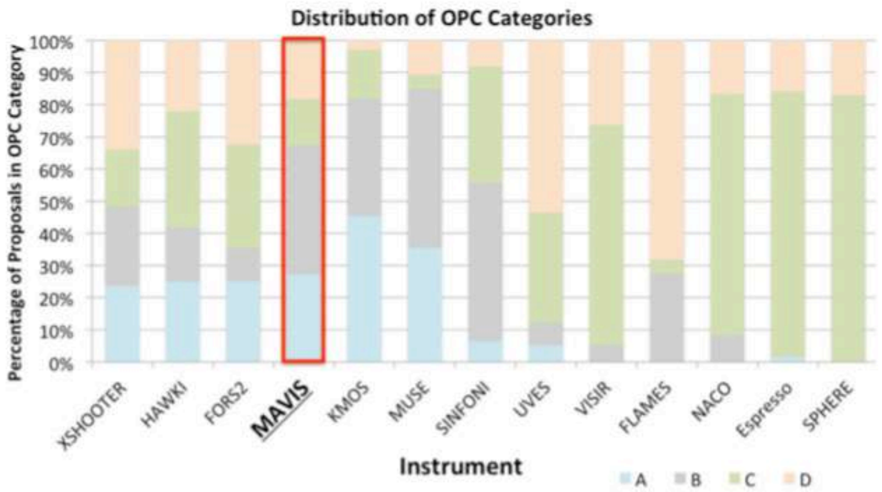
SCIENCE with MAVIS: White papers

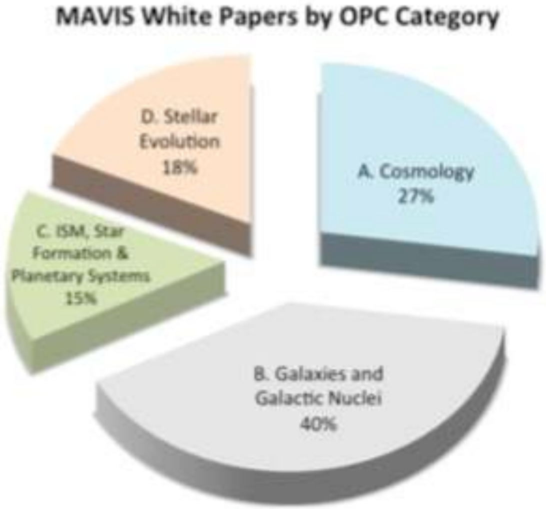
Call in July 2018





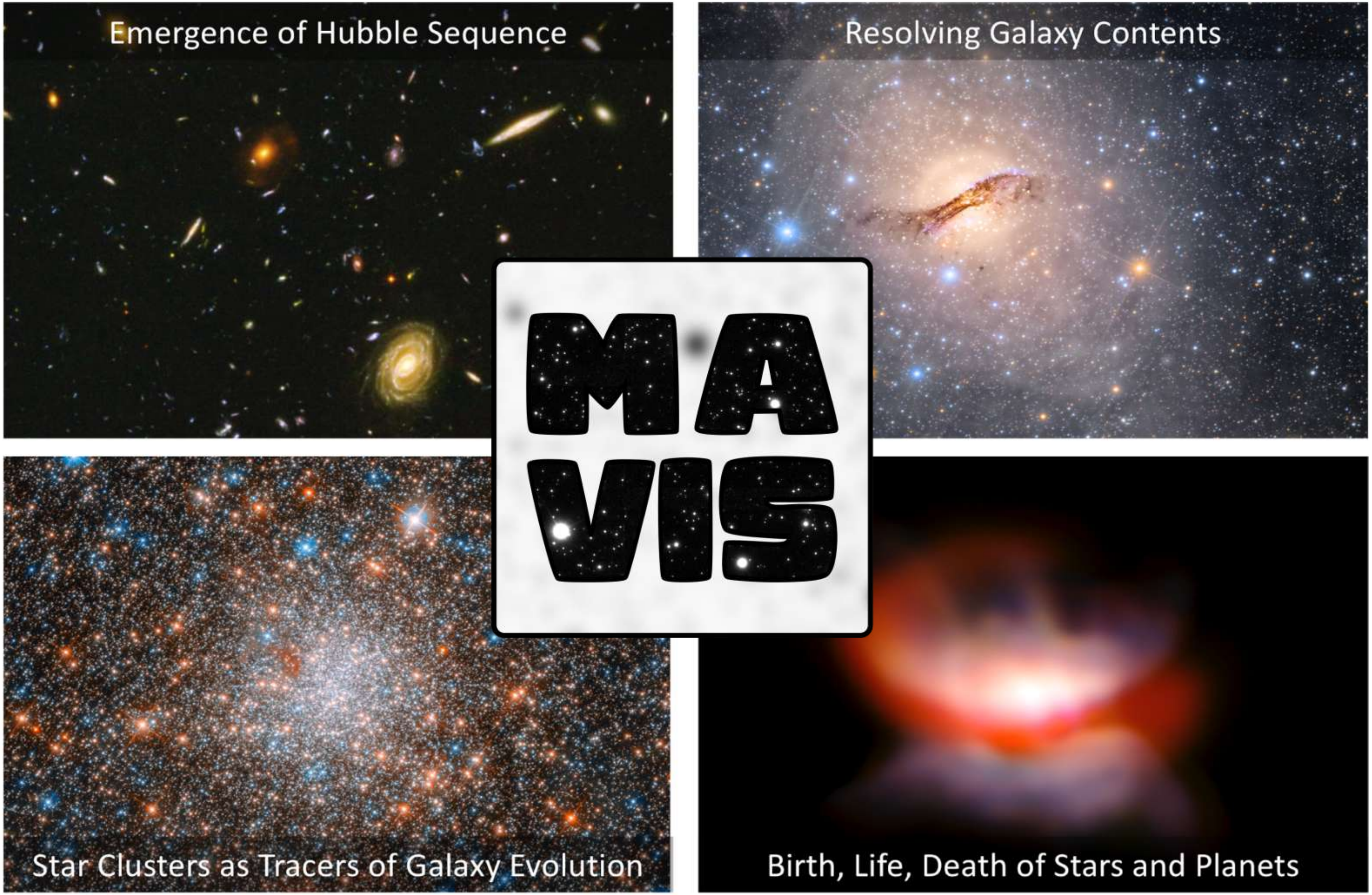






A general purpose instrument!

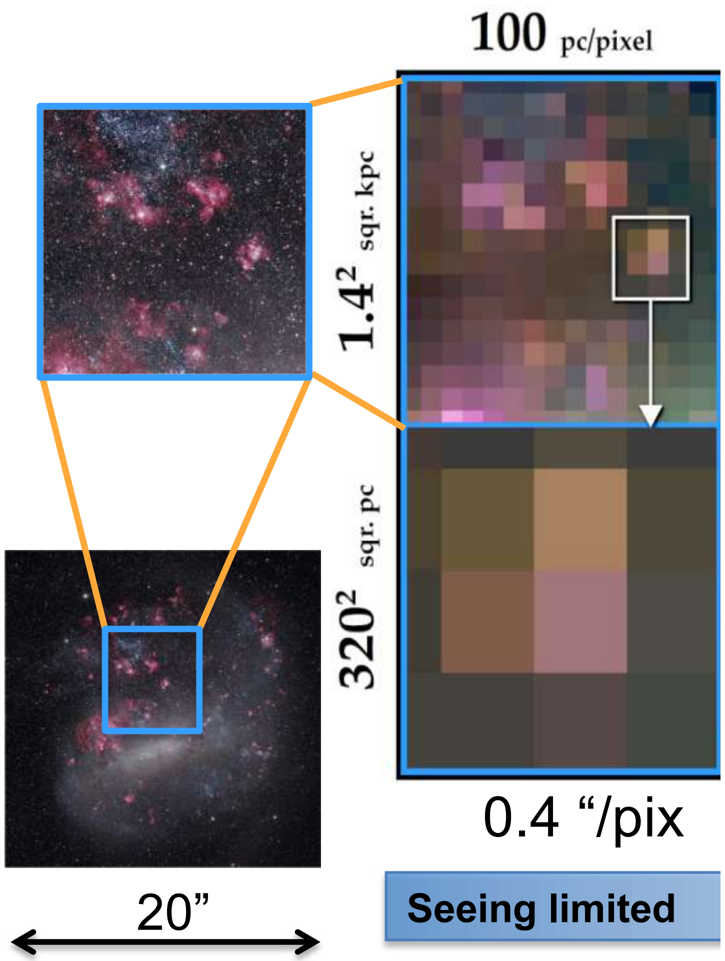
Complete science case: https://arxiv.org/abs/2009.09242



Resolving Galaxy Contents

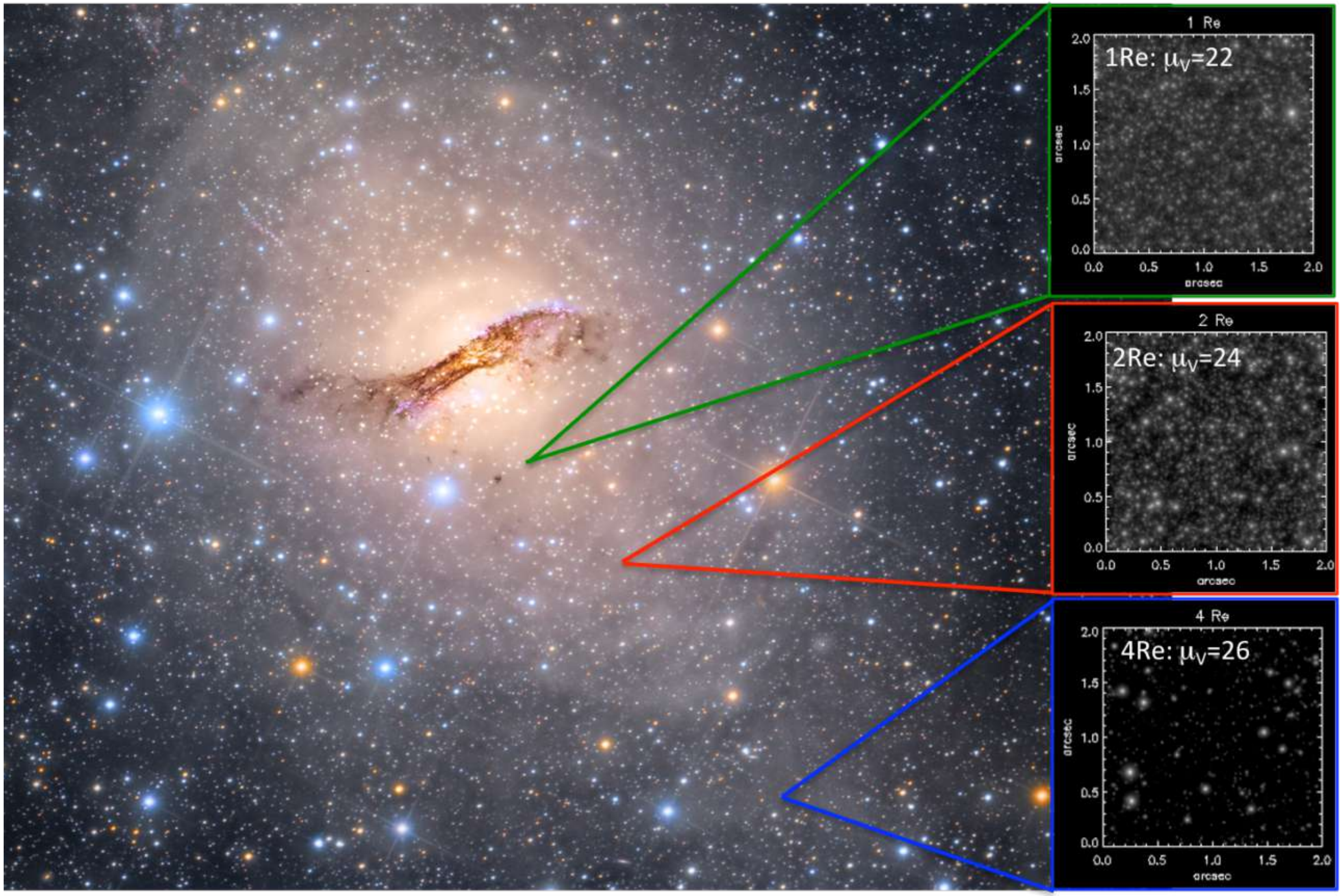
Image Credits: M. Seibert

LMC at 48Mpc



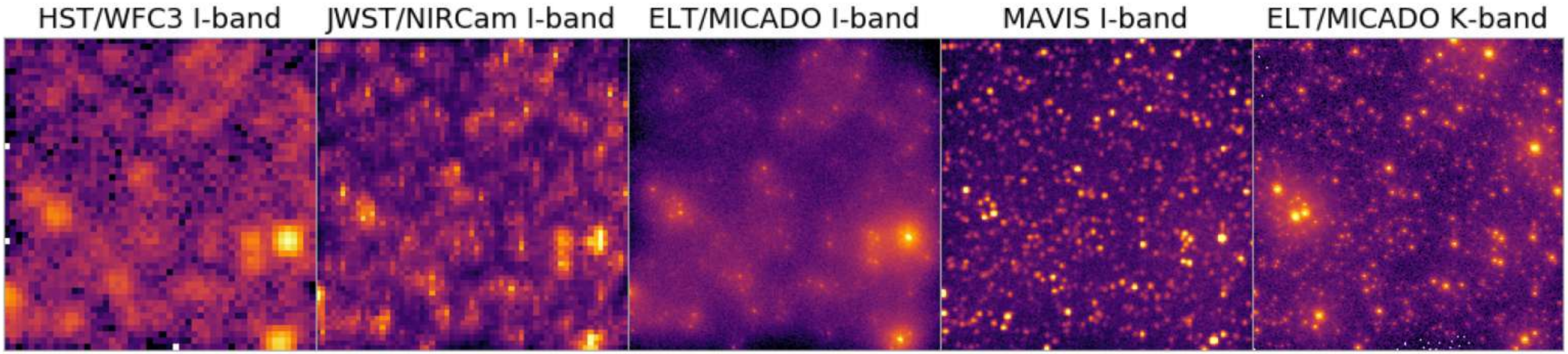
Resolving complexity in galaxies beyond the local group

Resolving galaxy contents: Beyond local group

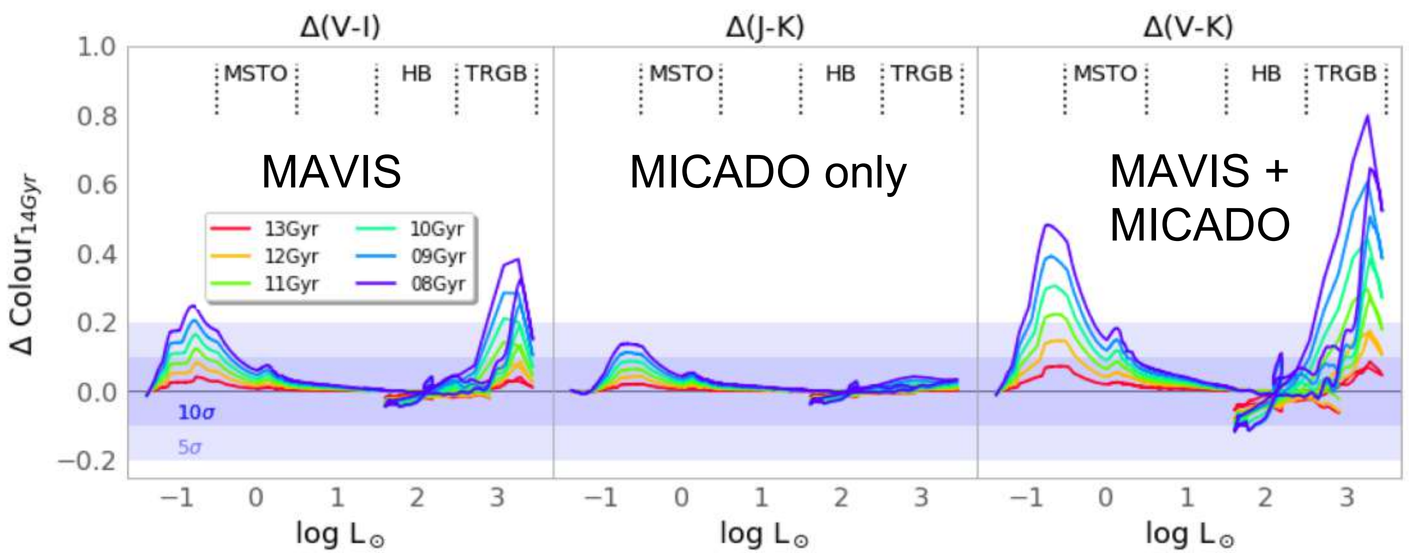


CEN A simulated MAVIS frames

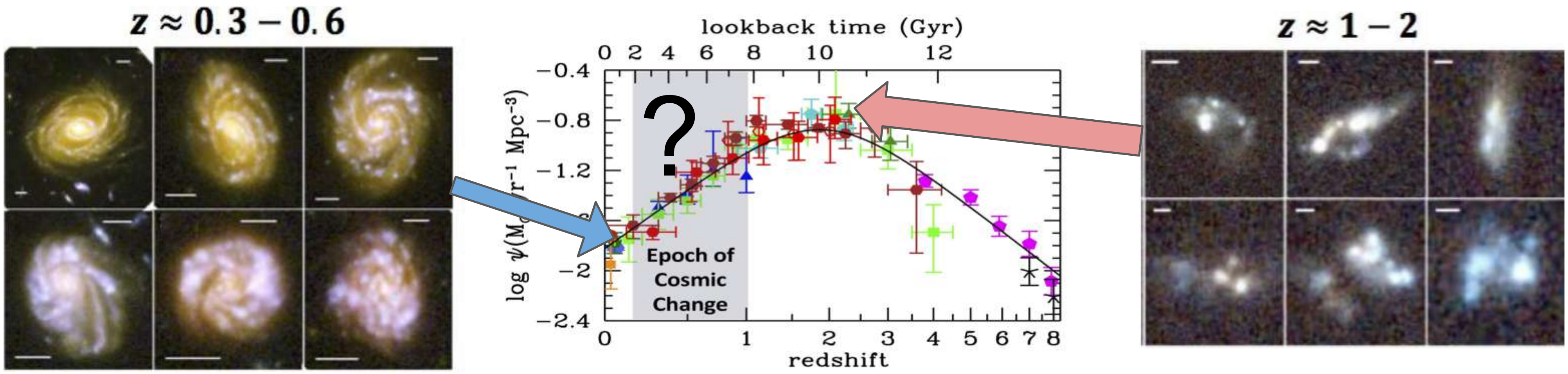
Resolving galaxy contents: Beyond local group



- 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

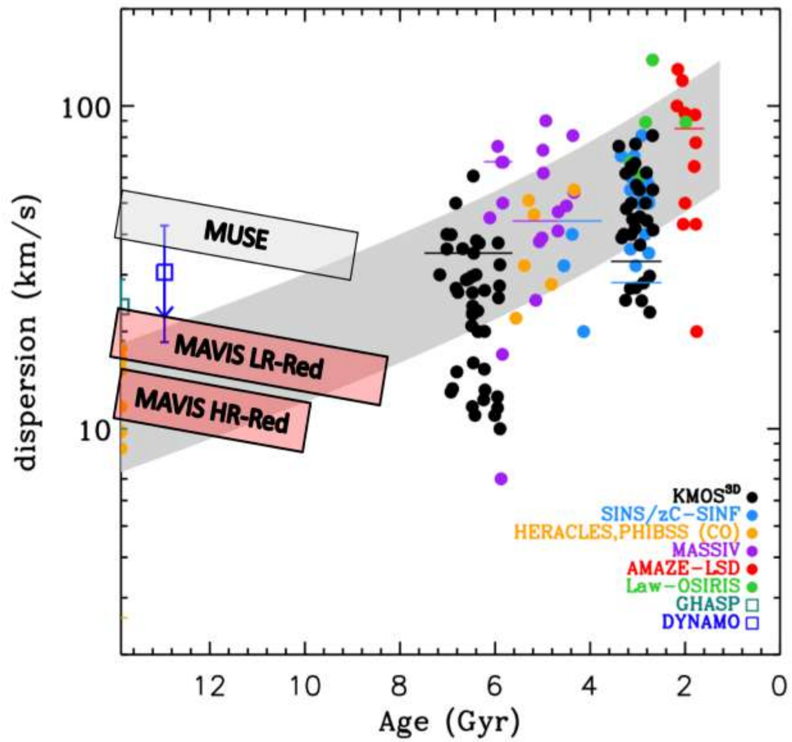


Emergence of the Hubble Sequence

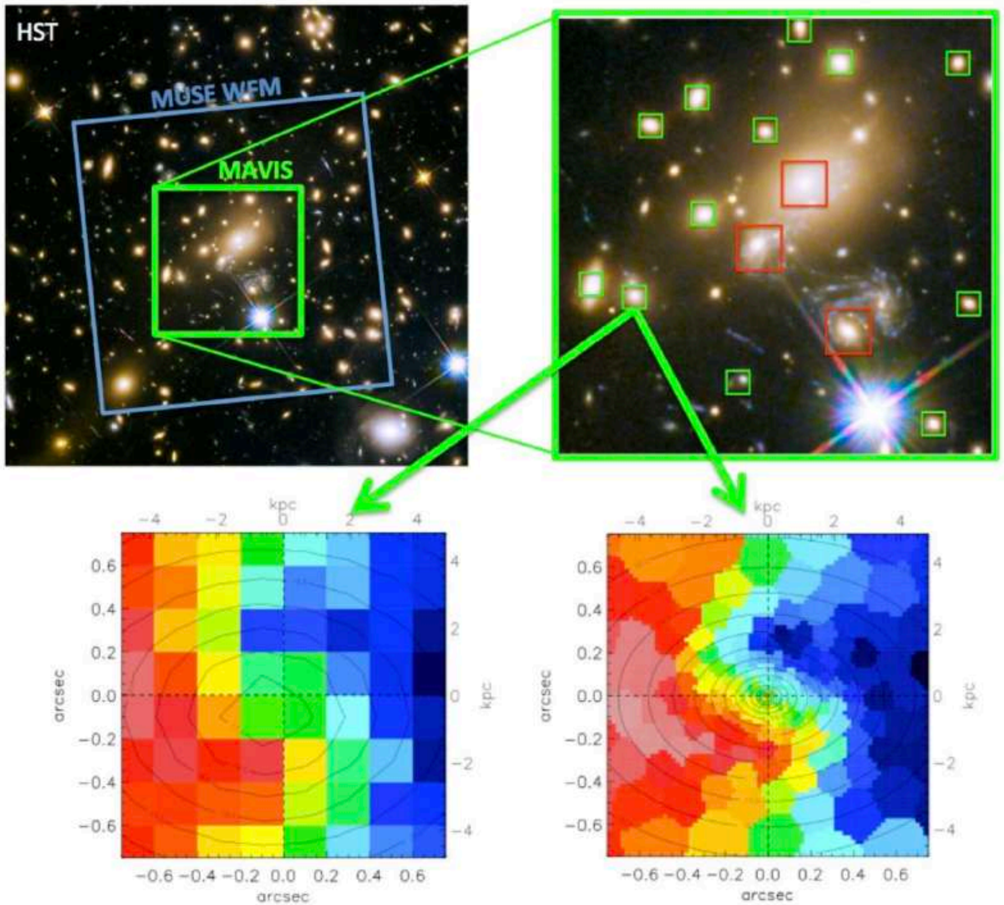


- The Hubble Sequence becomes established between z=1 and today
- Galaxies change from turbulent and clumpy to regular and dynamically cold
- Change in feedback processes? Bulge formation and disk growth?

  ⇒ Only MAVIS has sufficient spectral and spatial resolution to disentangle gravitational and non-gravitational processes



Emergence of the Hubble Sequence

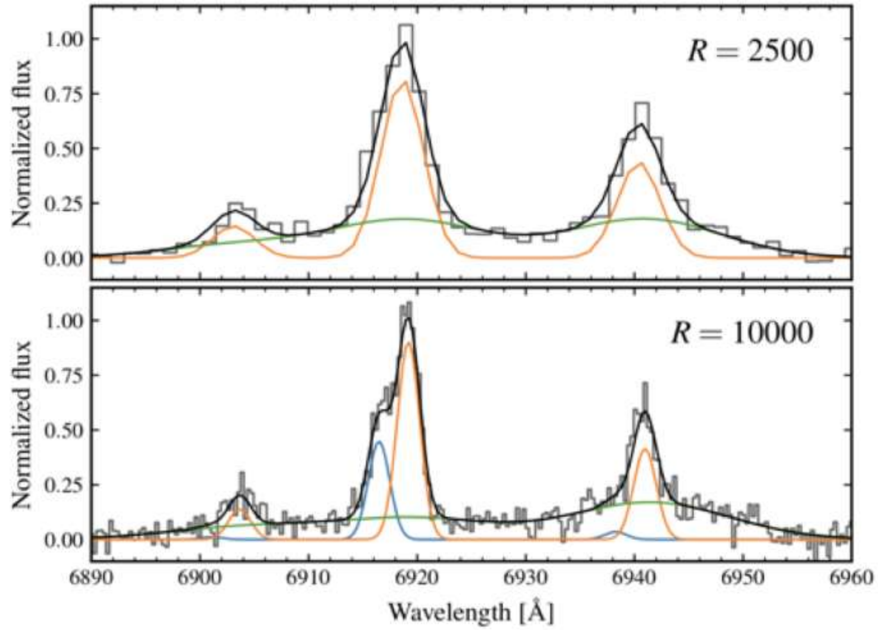


MUSE+GLAO, FWHM=0.4”

MAVIS, FWHM=30mas

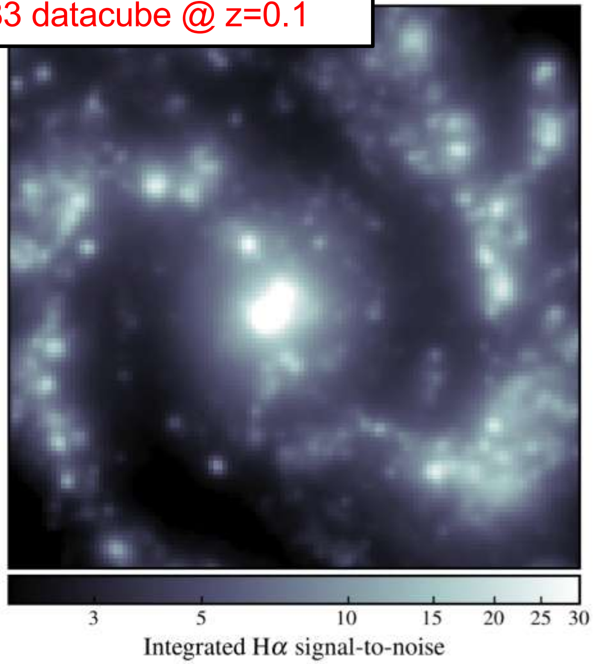
Kinematics on Sub-Kiloparsec Scales at z~0.5:

- High spatial resolution <0.1″ required for precise kinematic classification
- High spectral resolution needed to pin down cold disk dispersion and identify additional components



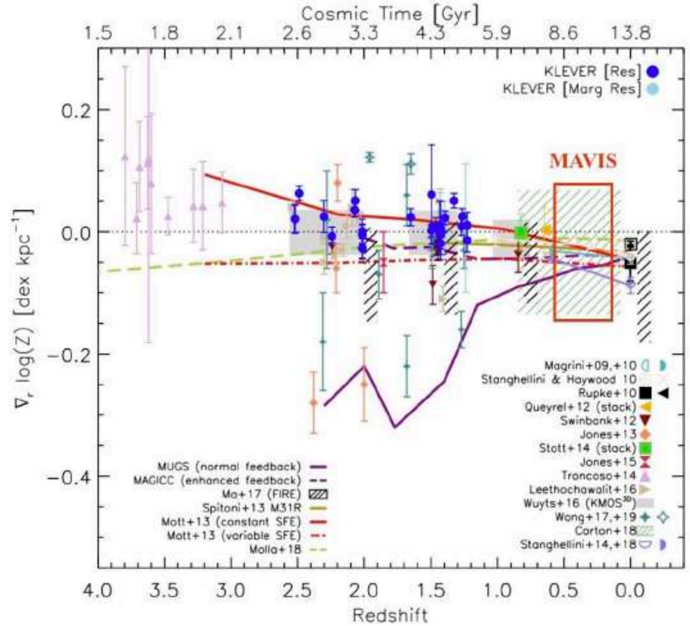
Emergence of the Hubble Sequence

M83 datacube @ z=0.1



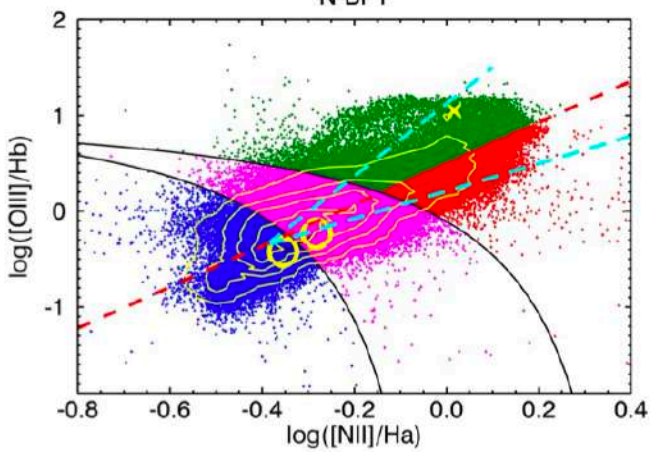
Resolved chemical and physical properties of the ISM (e.g. metallicity, ionisation, densities etc)

on scales <100 pc up to z~0.15!

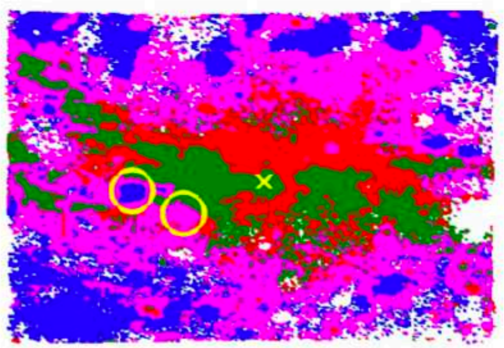


Curti et al. 2019

N-BPT



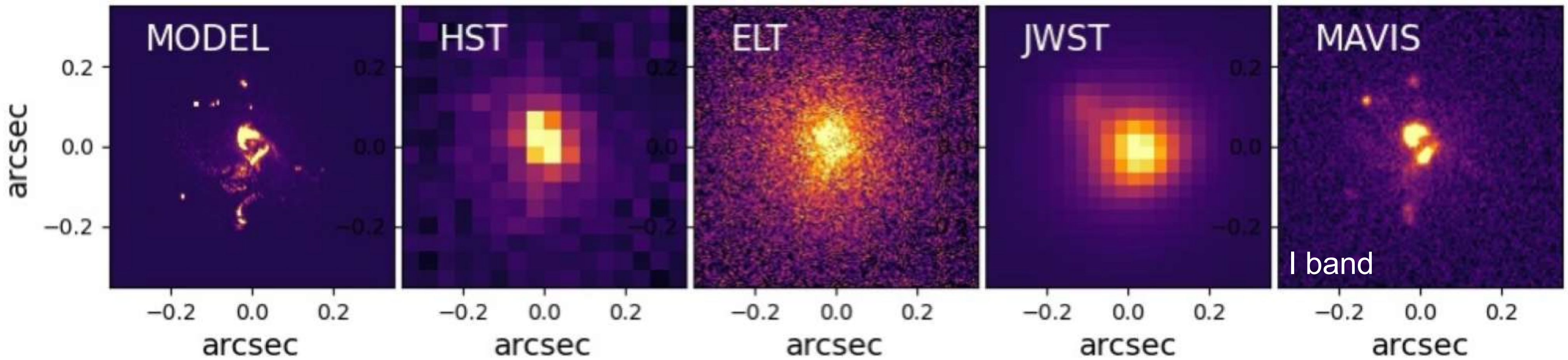
N-BPT map



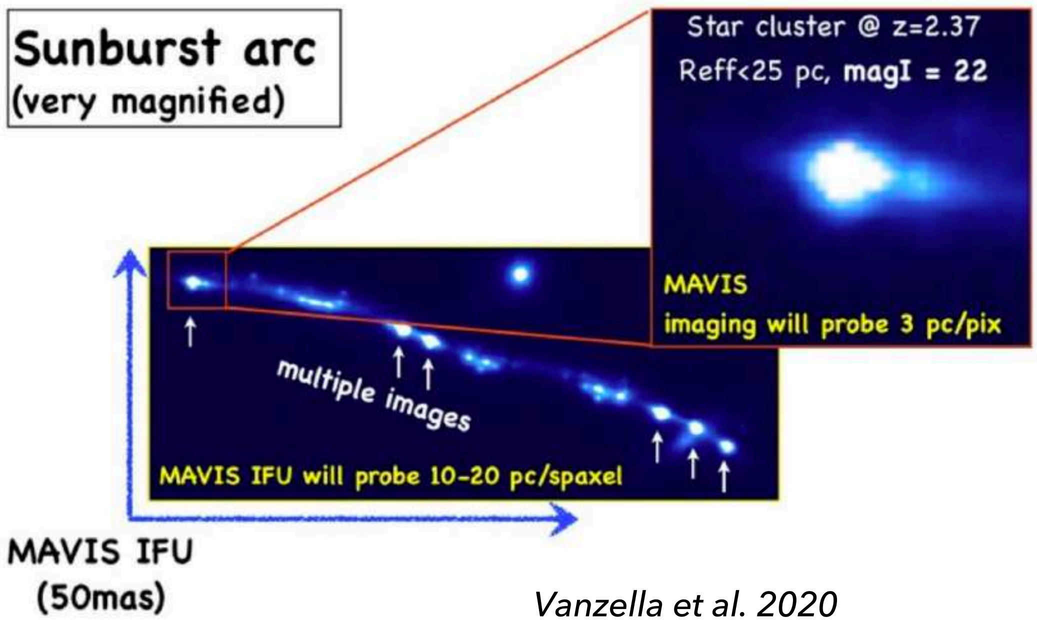
Cresci et al. 2015

High-z Galaxies

Simulated galaxy at z~5 from Pallottini et al. 2017



MAVIS will **resolve** the internal rest frame UV structure of high-z galaxies, identify **globular cluster precursors** up to the reionization epoch and quantify their ionizing photon production efficiency



Vanzella et al. 2020

Schedule and Risks

Phase Name	Start	Finish	Dur.	2019	2020	2021	2022	2023	2024	2025	2026	2027
Phase A - Concept study	02/2019	06/2020	1.3yr									
Phase B - Preliminary design	08/2020	02/2022	1.4yr									
Phase C - Final design	03/2022	03/2023	1.1yr									
Long lead item procurement	07/2022	11/2023	1.4yr									
Phase D - MAIV	04/2023	12/2026	3.7yr									
Phase E - Installation & Commissioning	01/2027	08/2027	8mo									

- Agreement signature in few days (April 2021)
- Consortium has already started the phase B work
- Schedule brings us **in line with ELT commissioning** & MICADO SCAO
- Risks include:
  - Funding (missing €2-4M) may be challenging in time of COVID
  - International travel impossible because of COVID

Science Meeting

- First MAVIS Science Workshop November 2018 in Sydney
- Second Science Meeting November 2019 in Galileo Galilei’s villa in Arcetri

- Given the current pandemic restrictions the second upcoming MAVIS Science Meeting will be fully online:

MAVIS online Science Meeting
July 5-9, 2021
https://indico.ict.inaf.it/event/1420/

Registration open!

- Diffraction limit optical imaging and spectroscopy is coming
- 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 ~**2027**
- Upcoming Science Meeting – July 5-9, 2021 (https://indico.ict.inaf.it/event/1420/)

Interested? Want more info?

Science case: https://arxiv.org/abs/2009.09242

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