MAVIS

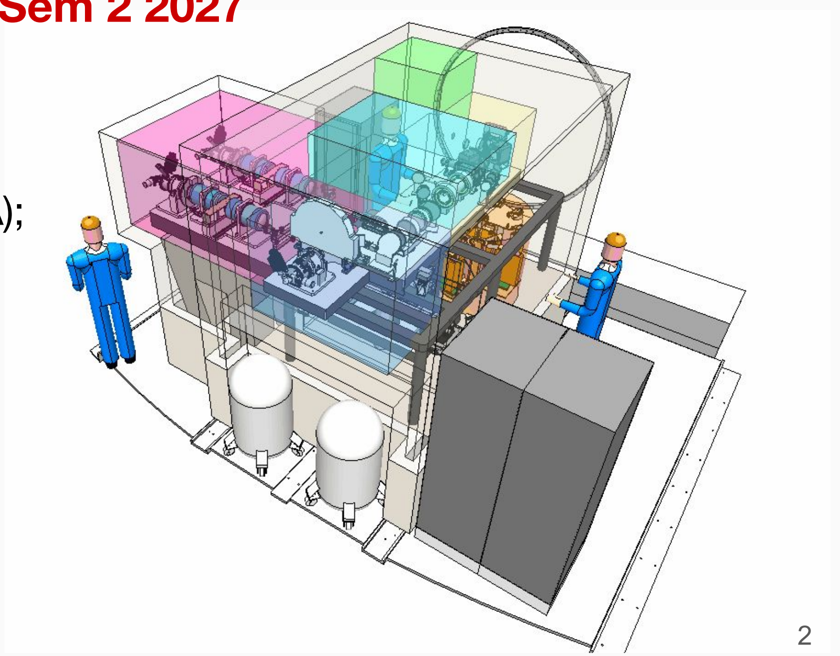
Deeper than HST, Sharper than JWST

Status - May 2021

Prof Francois Rigaut (ANU, Principal Investigator)
A/Prof Richard McDermid (MQ, Project Scientist)
Dr Giovanni Cresci (INAF, Deputy Project Scientist)

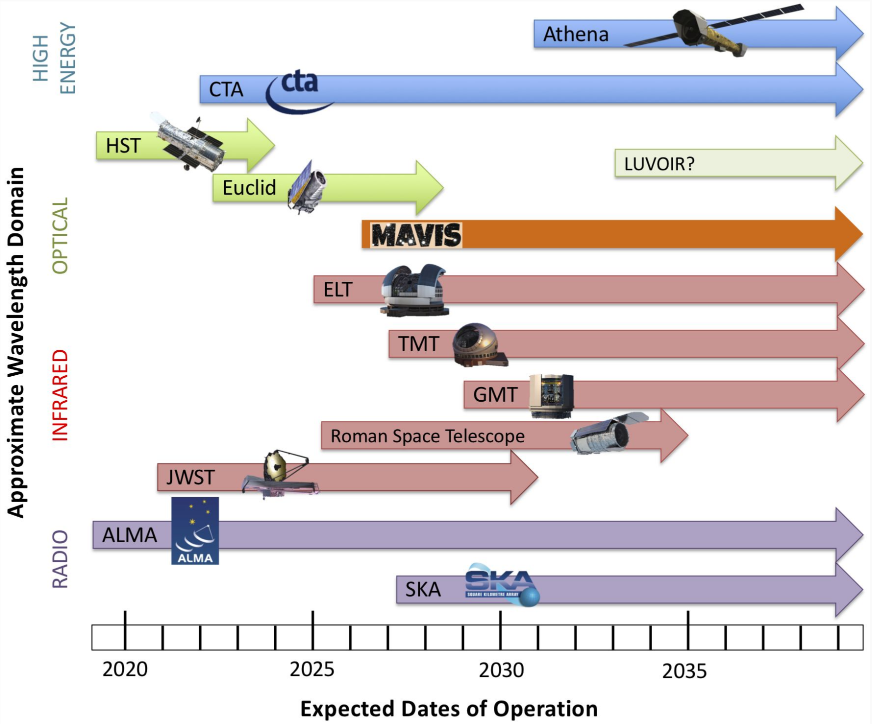
MAVIS: Deeper than HST, Sharper than JWST

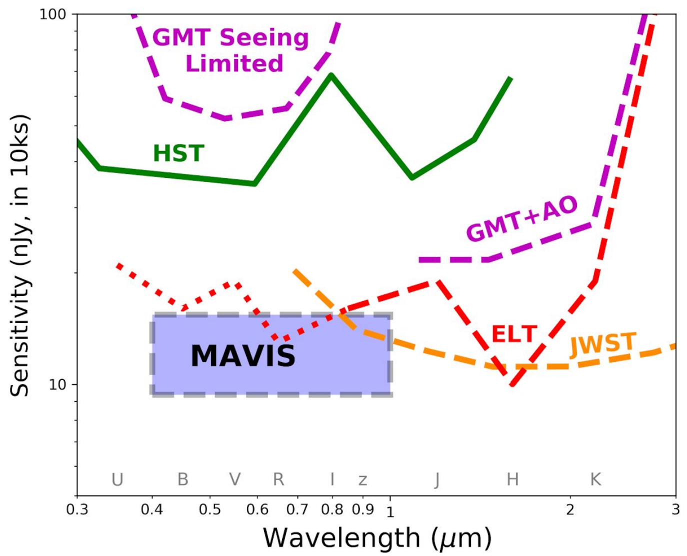
- **Multi-conjugate Adaptive Optics** system for correction in the **visible**
  - complete with an **4k×4k imager** @ 7.3mas pixels
  - and an **IFU w/ 4 spectral resolution modes** (4-12k), ¼ number of MUSE spaxels
- Expecting > **10% Strehl** (goal 15%) **at V band** over **30"x30"**
- **50% sky coverage** @ South GP for 15% encircled energy in 50 mas spaxel
- Imager 5 sigma limiting mag in 1 hour **V = 29.5** (SNR = HST x 2 on . source)
- Consortium Australia (**AAO Consortium**, lead) / **INAF / LAM / ESO**
- Passed phase A 06/2020, **first light expected Sem 2 2027**
- For the ESO VLT AOF (UT4)
  - 4x2 Laser Guide Stars;
  - 3 Near-IR NGS Wavefront Sensors (using SAPHIRA);
  - 3 Deformable mirrors (DSM + 2 post focal DMs);
- A **brilliant science case** (publicly available on arXiv)

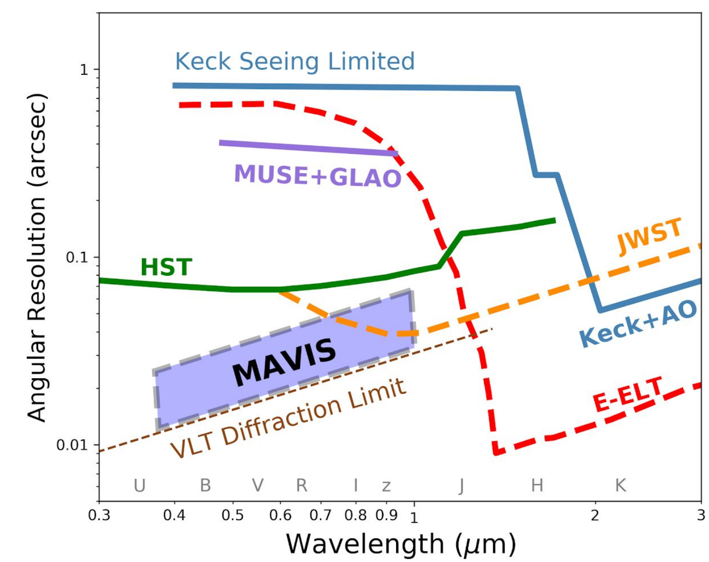


MAVIS Context & Science

BY MID-2020'S THE NEED FOR MAVIS WILL BE URGENT

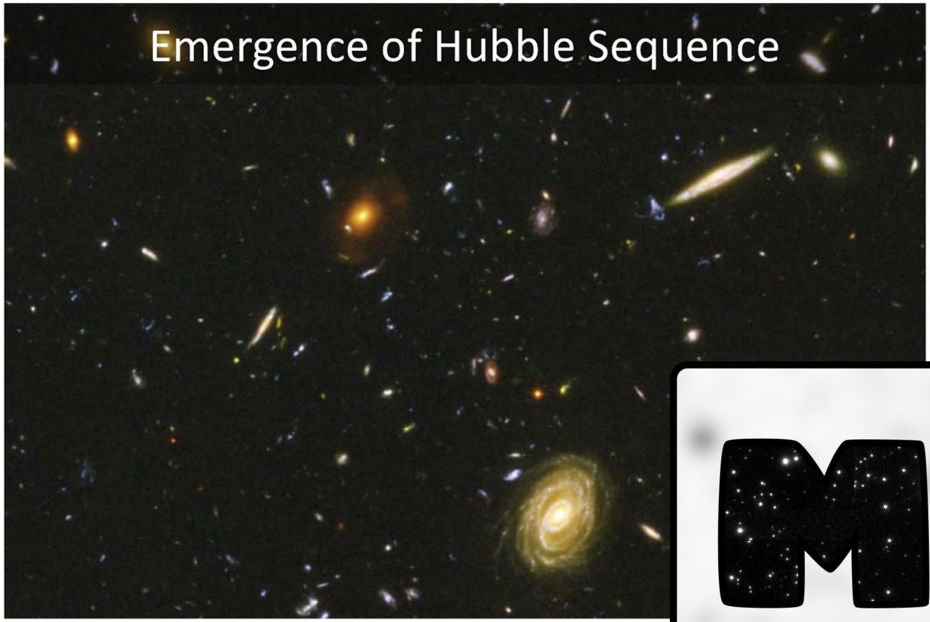






- Future facilities will look deeper and sharper than ever before
- Among general purpose facility instruments, only MAVIS combines high sensitivity with high angular resolution at optical wavelengths

(General Purpose = Imaging+Spectroscopy over most of sky)

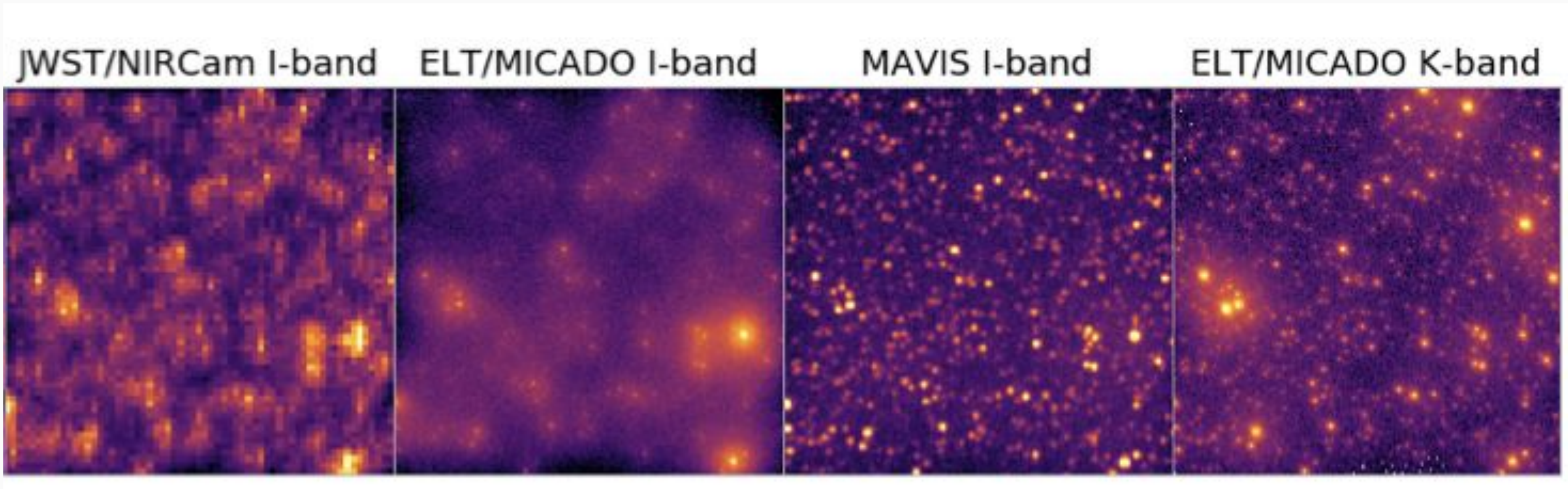


MAVIS

Phase A Science Case

https://arxiv.org/abs/2009.09242

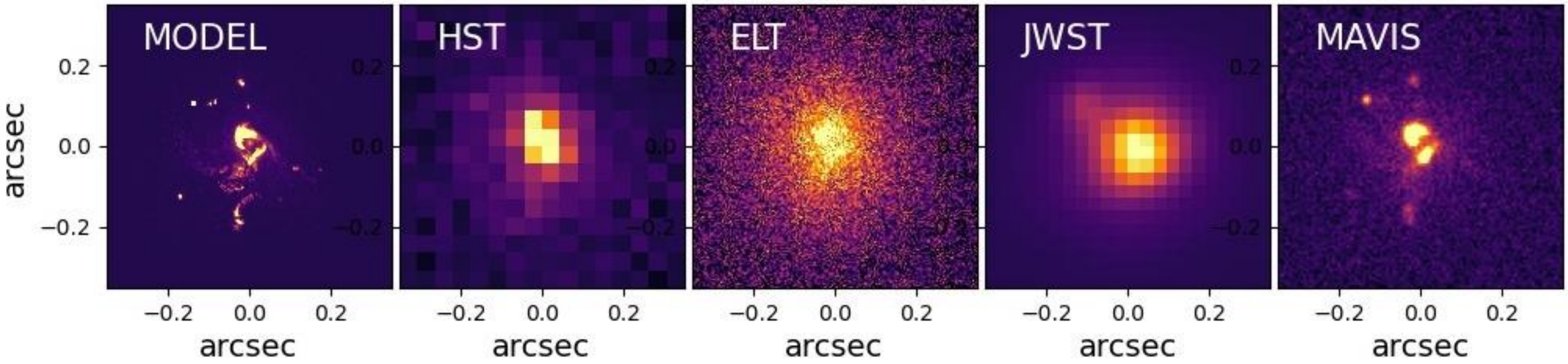
By mid-2020's the need for MAVIS will be urgent



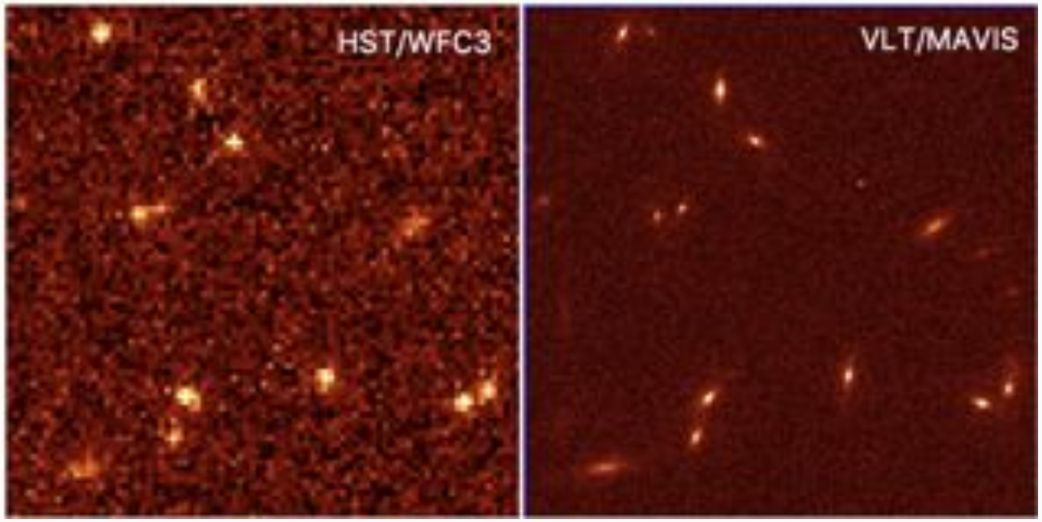
- Key future facilities (e.g. JWST and ELT) are not well-optimized for <1um
- MAVIS is crucial to provide optical coverage at matched angular resolution to ELT in the IR

Complementarity MAVIS visible ↔ ELT Near Infrared

Snapshot Science: Galaxy Rest-frame UV Morphologies

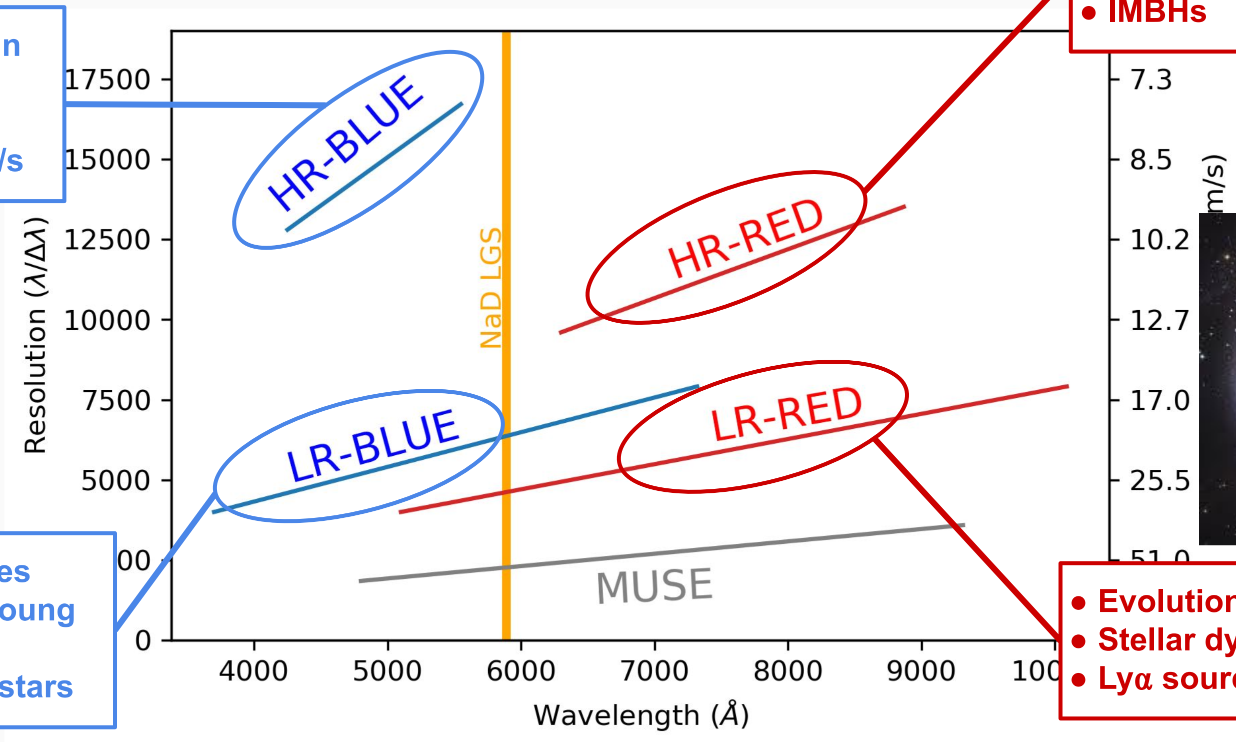


- MAVIS will allow the deepest optical images ever taken
- Crucial for understanding the UV morphology of the faintest galaxies at high redshift

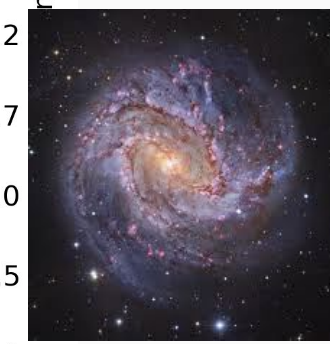


MAVIS Spectral Capabilities

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



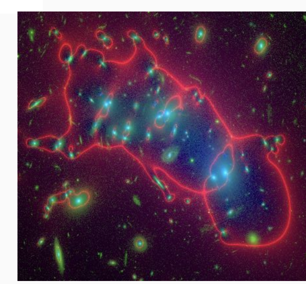
- Evolution of ISM
- Turbulence in galaxy disks
- IMBHs



- 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

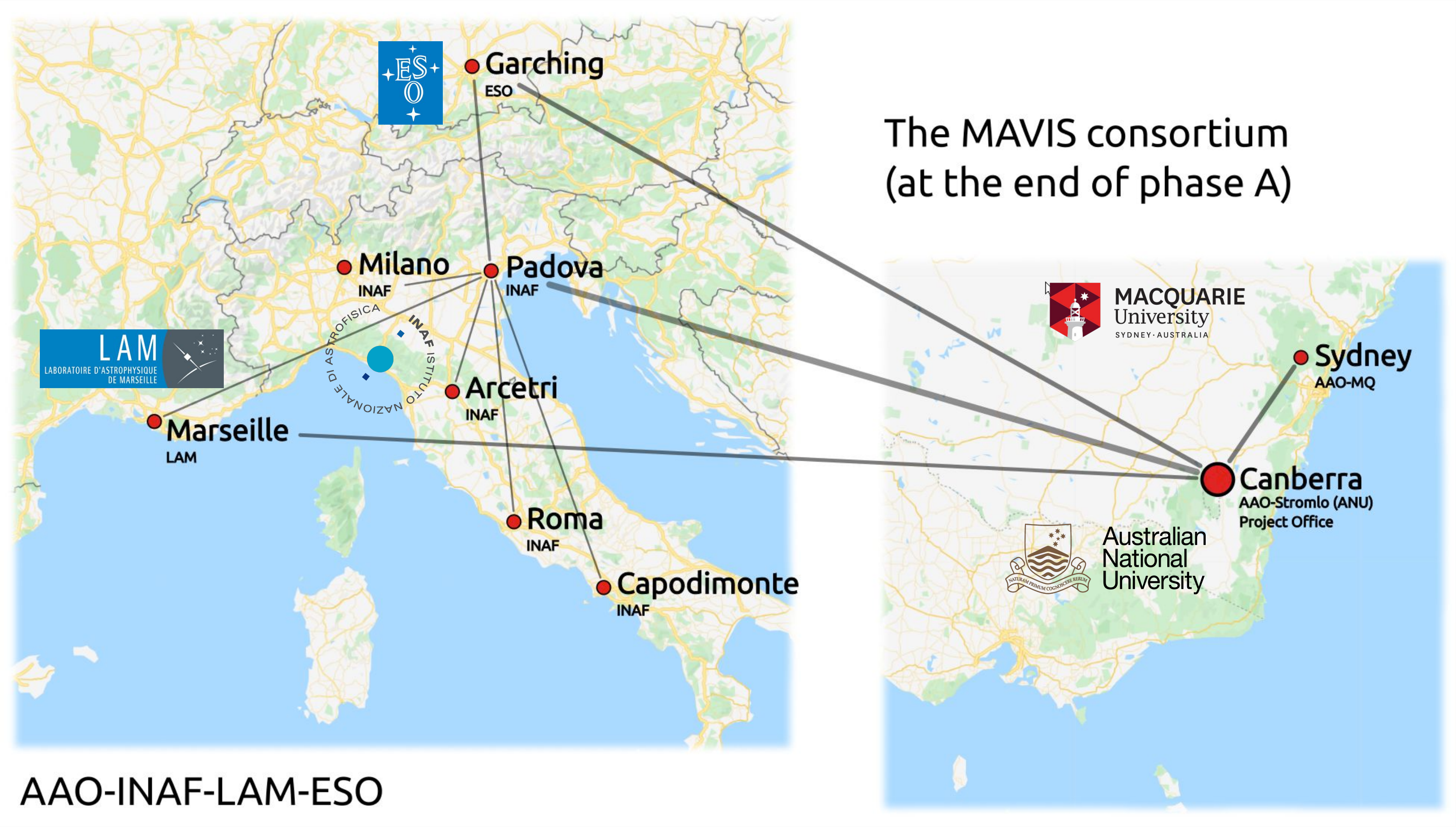
- This is science that CANNOT be done with MUSE-NFM spectral resolution, wavelength coverage, and lack of high-res imaging
- Significantly higher sky coverage of MAVIS amplifies this contrast by also allowing statistical samples and rare objects to be readily observed



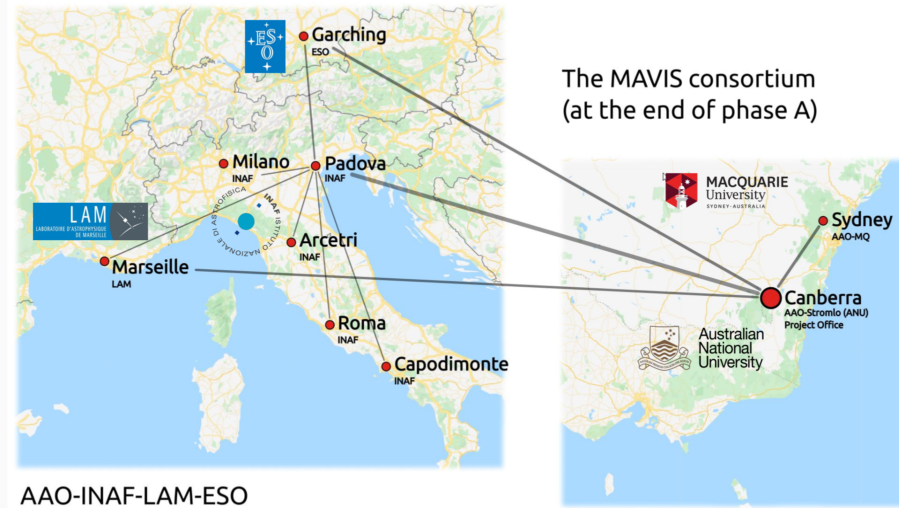
MAVIS Background and Project

AUSTRALIA STEPS IN AS A STRATEGIC PARTNER

- Australia-ESO strategic partnership 2018-2027
- First ESO instrument led by Australia
- Workload split about 50-50 Australian/European partners



Funding and FTEs



- ESO funds €8M non-labour
- Consortium h/w cost estimate is **€12M** (includes €2M contingency)
- Strategy to bridge gap includes **grants** (e.g. LIEF in Australia) and **looking for new partners**.. Preparing call for expression of interest.
- Labour estimate **200 FTEs**
  - Note Australia had to work out long term plan for funding of its FTEs through the project, funded and managed by AAL (AUD22.5M 2019-2026)
- MAVIS is clearly **an opportunity for Australia** to capitalise on its strategic partnership and to step in as a possible future full partner. It is strongly supported in Australia (AAL funding $22.5M / wide LIEF support)

Schedule and Risks

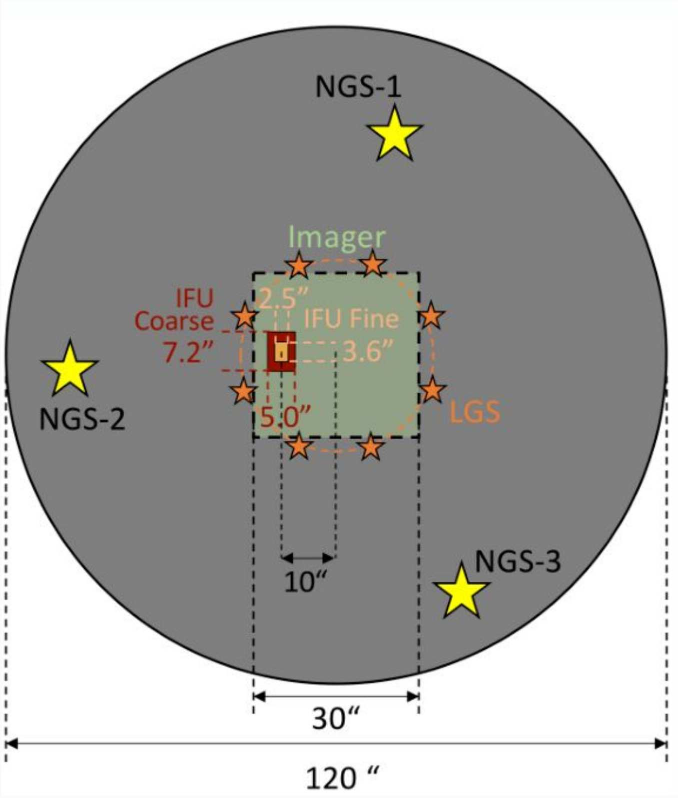
Phase Name	Start	Finish	Dur.	2019	2020	2021	2022	2023	2024	2025	2026	2027
Phase A - Concept study	02/2019	06/2020	1.3yr									
Phase B - Preliminary design	08/2020	06/2022	1.4yr									
Phase C - Final design	07/2022	07/2023	1.1yr									
Long lead item procurement	12/2022	03/2024	1.4yr									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

- Schedule brings us **in line with ELT commissioning** & MICADO SCAO
- MAVIS approved by STC in Oct and Council in Dec, agreement signature planned for May 2021.
- Consortium has already started the phase B work (albeit at a slow pace)
- Risks include:
  - Funding (missing €2-4M) may be challenging in time of COVID
  - Timeliness of some h/w (NGCII, ALICE) and s/w (RTCtoolkit) deliveries from ESO
  - International travel impossible because of COVID

MAVIS Instrument Design

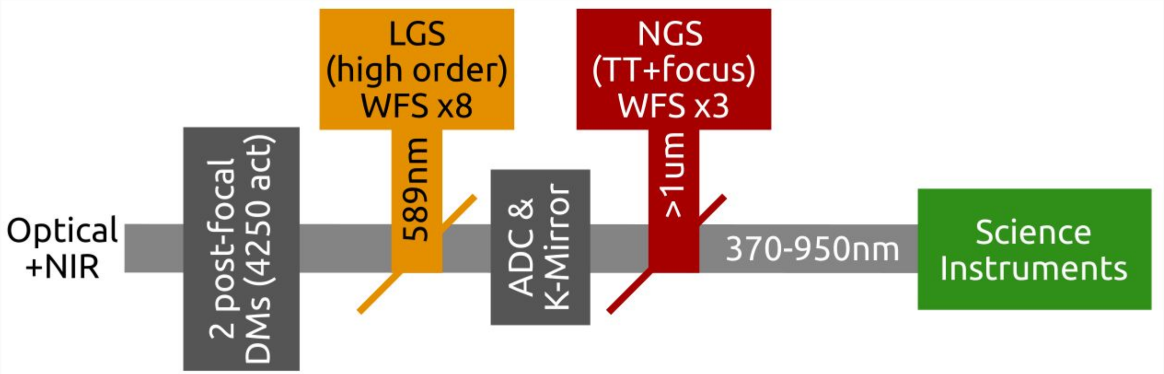
MAVIS TOP-LEVEL SPECIFICATIONS (BASELINE)

Science Field	30”x30”
Angular Resolution	FWHM ~ 20mas at V band
Strehl Ratio	>10% (15% goal) at V under median conditions
Sky Coverage	> 50% at the Galactic pole
Wavelength Coverage	VRI (optimised); B-z (extended)
Imager	~ 7mas pixels. 7 broad and 15 narrow band filters, 1h 10σ for V ~ 29.5
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



Design Parameters (needed to achieve the specs)

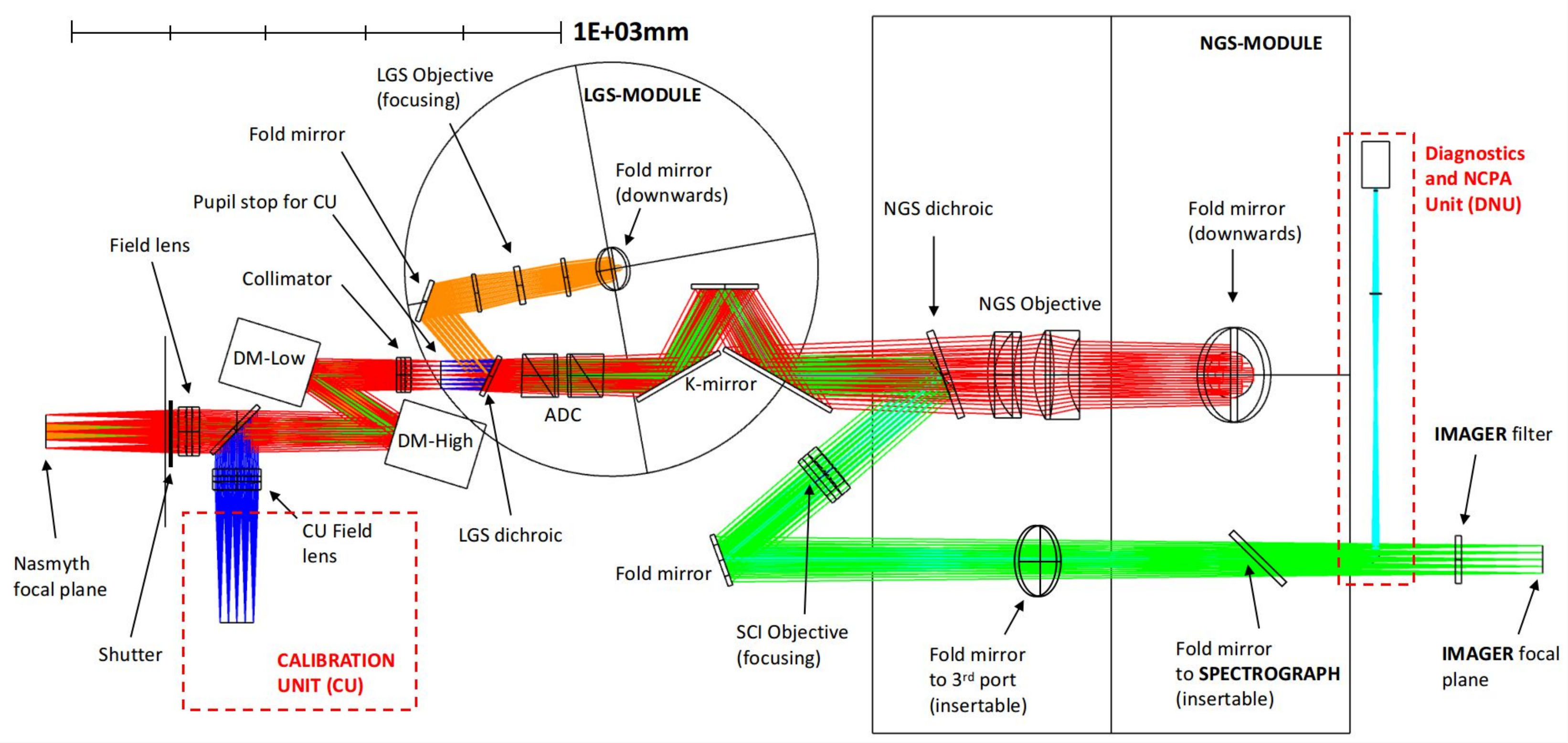
- Wavelength splitting:
  - Science: 370-950nm (goal 1000nm)
  - High order Wavefront Sensors (**WFS**): 589nm (Sodium LGS)
  - Low order (Tip-Tilt + Focus & truth): NIR (1-1.8μm)



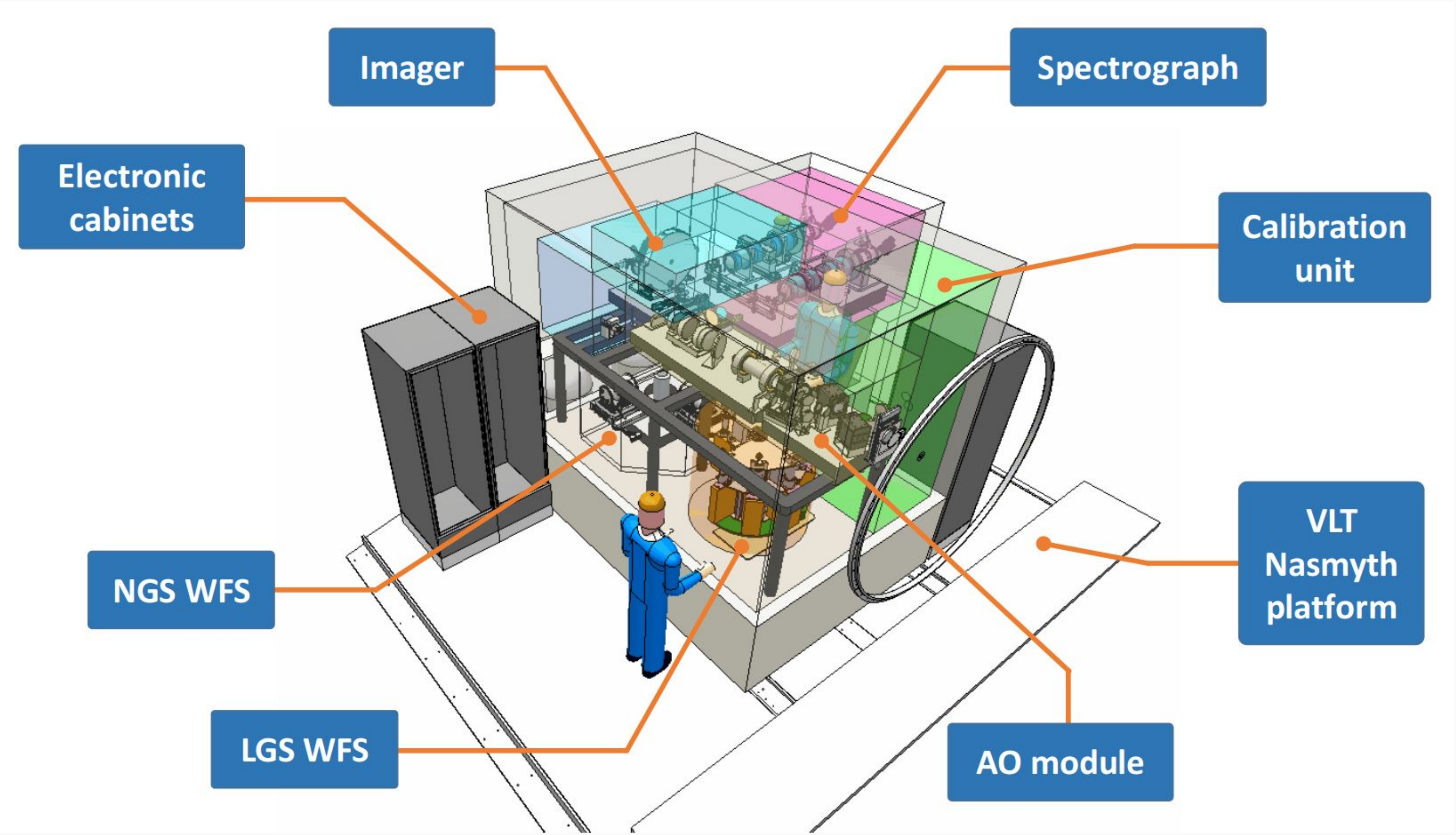
- AOF Deformable Secondary, plus **two post focal DMs** conjugated to 6 and 13.5 km (5420 actuators total)
- **Eight LGS** (4 lasers split x2), feeding **eight 40x40 LGS WFS**. Using ALICE ESO EMCCD CCD220 with NGCII controllers. Sampling 1-1.5kHz.
- **Three NIR NGS Wavefront Sensors**, also providing low order (2x2) truth sensing and focus. Using 3x SAPHIRA detectors with NGCII controllers.

An Innovative Optical Design

- > 5 iterations on optical design (below design as of 10/2020)
- Innovative: (a) uses refractive elements and (b) does not collimate the beams
- Everything gravity invariant (except K mirror and ADC)
- Very "healthy" design, all zero-order principles of AO design are there.



MAVIS on the AOF Nasmyth platform

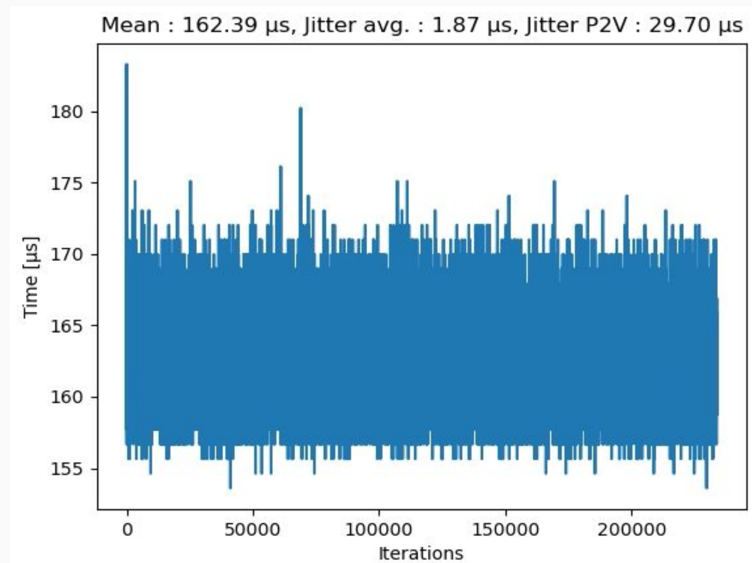


Real-Time Controller (RTC) & Control

- Top expertise in **tomographic wavefront control**
  - MMSE / Learn & Apply / Pseudo-Open Loop Control
  - Using experience from GeMS, ERIS, LBT, GALACSI
  - New results in predictive controls provide performance margin
- Agreed with ESO on a **RTC architecture that satisfies ESO ELT standards** while retaining all the developments done within the Green Flash project.

Two components RTC (COSMIC platform, synergy with MICADO):

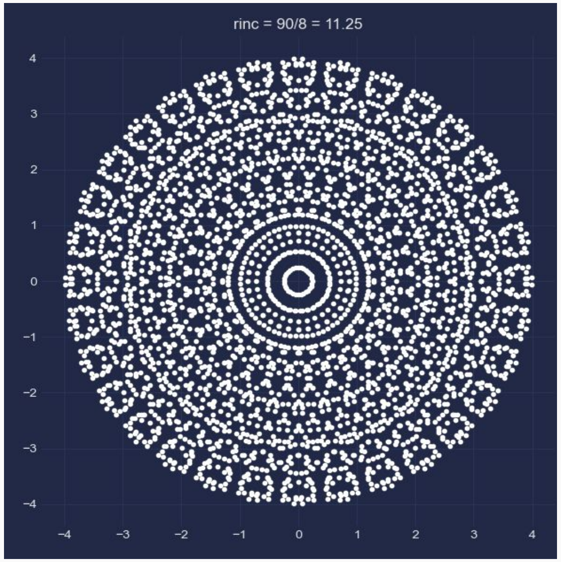
- **Hard RTC** (HRTC):
  - Extremely fast: **160us latency, 2us jitter**
  - Interfaces to h/w (WFS, DMs)
  - Multi-GPU server, **prototype exist**, COTS
- **Soft RTC** (SRTC):
  - Telemetry
  - CPU server w/ GPU accelerators
- **COSMIC** now **demonstrated on sky** (Keck, 04/2021) with ~110 μs latency.



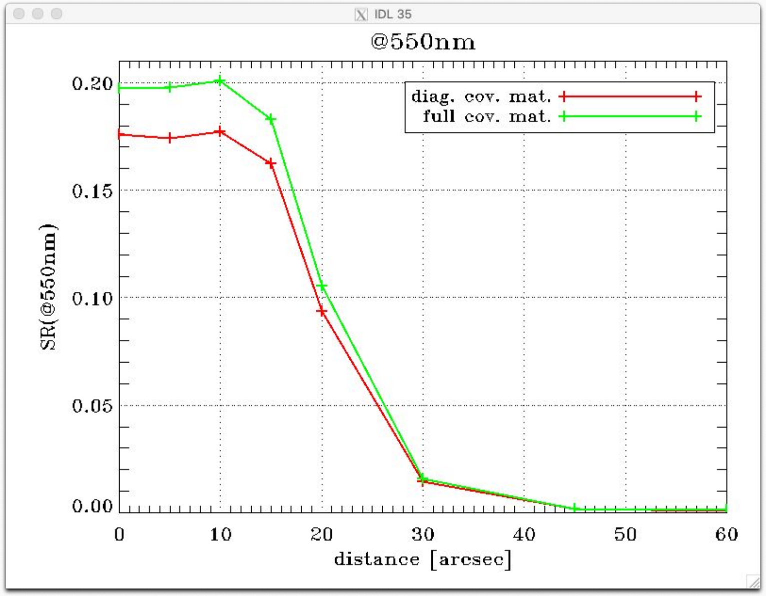
COSMIC demonstrated MICADO size (ObsPM)

AO PERFORMANCE

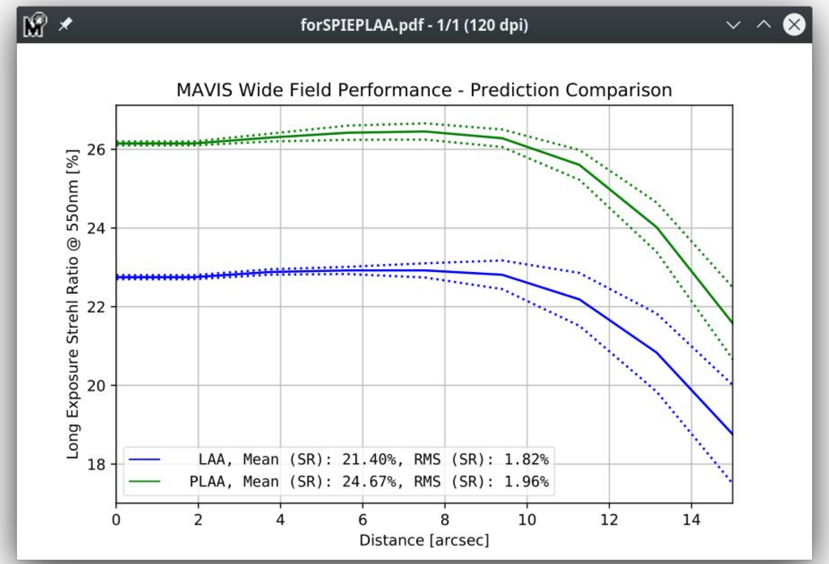
- Simulation team: **Arcetri** (Synergy w/ **MAORY**), seconded by **AAO-Stromlo**
- **4+ simulations tools** from Arcetri (PASSATA, Fourier code), LAM (Fourier code) and AAO-Stromlo (yao, COMPASS). Good redundancy.
- Comprehensive AO simulation driving the design



New super-resolutions methods (Jesse Cranney & Guido Agapito)



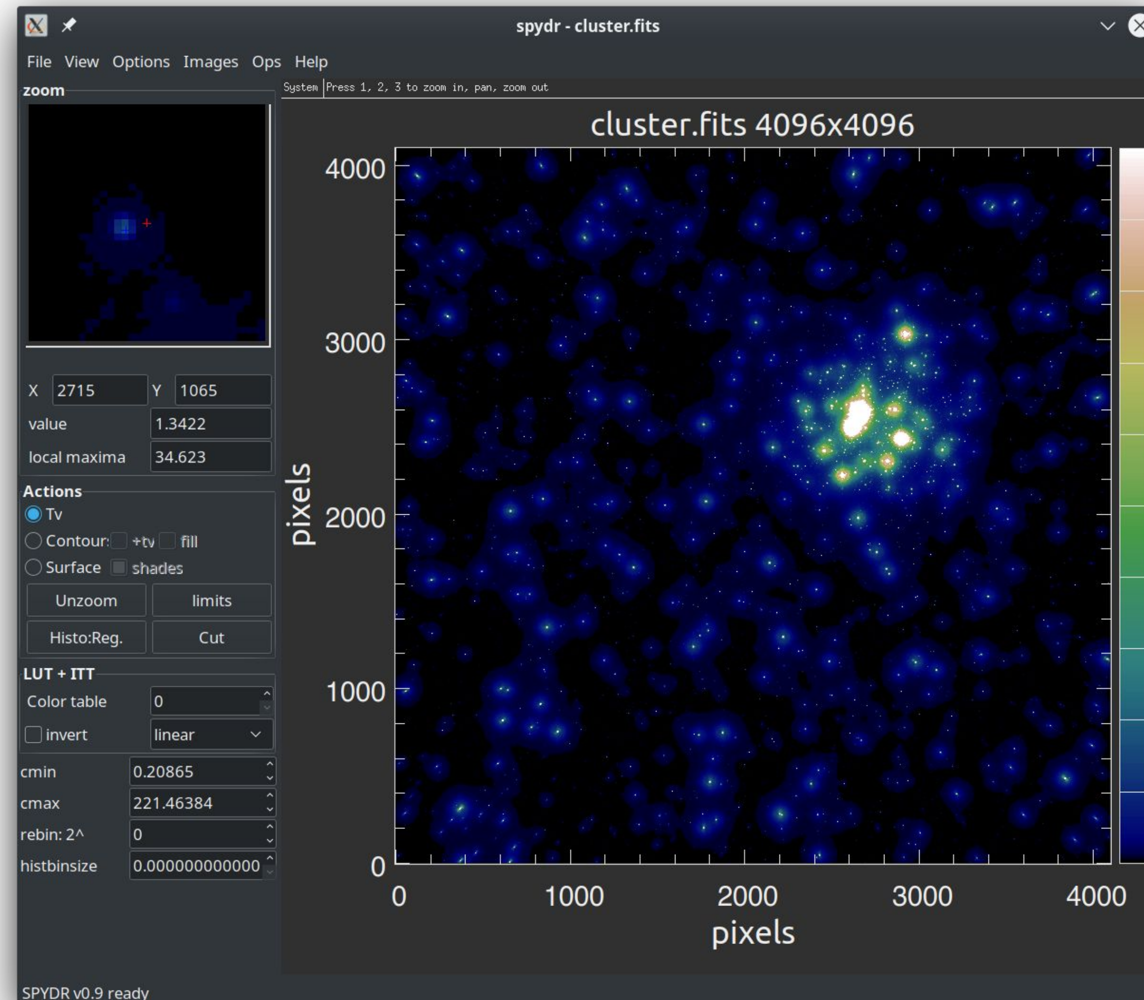
Example of performance under median conditions (Guido Agapito)



Performance with predictive methods (Jesse Cranney)

Science image Simulator & PSF reconstruction

- In progress @ AAO (S.Monty); use both simple Fourier and end-to-end PSFs.
- **Object** models, combined w/ **AO** and **instrument** performance models to generate image
- Used to investigate **astrometric** performance
- **PSF reconstruction** WP also in the work, led by LAM. Folded in from the start.



Challenges

- Very **tight errors budget**; targeting 135 nm rms (goal 120)
  - Non-Common Path Aberrations
  - Any drift due to temperature and gravity changes
  - Can't tolerate significant "unknown" error budget term
  - New live monitoring, **active supervisor approach** of error budget
- **Sky coverage**
  - We are adopting a no-compromise approach to reach the specifications
  - NIR, diffraction limited PSFs for TT sensing
  - Use of **SAPHIRA APD-arrays**
- **Astrometry**
  - Multi-conjugate fixes aberrations over the FoV, but can also **mess up distortions**
  - Targeting similar requirements than MICADO
  - Developing calibration/observation/reduction strategy
  - Folding into design to reduce impact on astrometry
- **LGS flux marginal** in low season
  - Looking at possibility to increase laser power and/or use predictive control

A Happy MAVIS Consortium