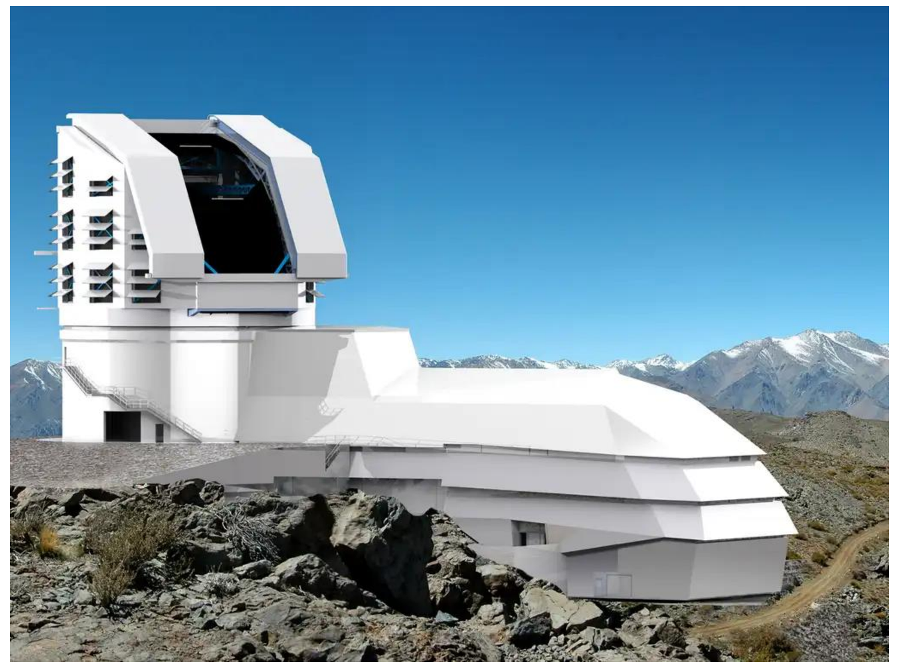
The Wide-field Spectroscopic Telescope

Pietro Schipani
and the WST collaboration

Why WST? Landscape in the 2020-2030

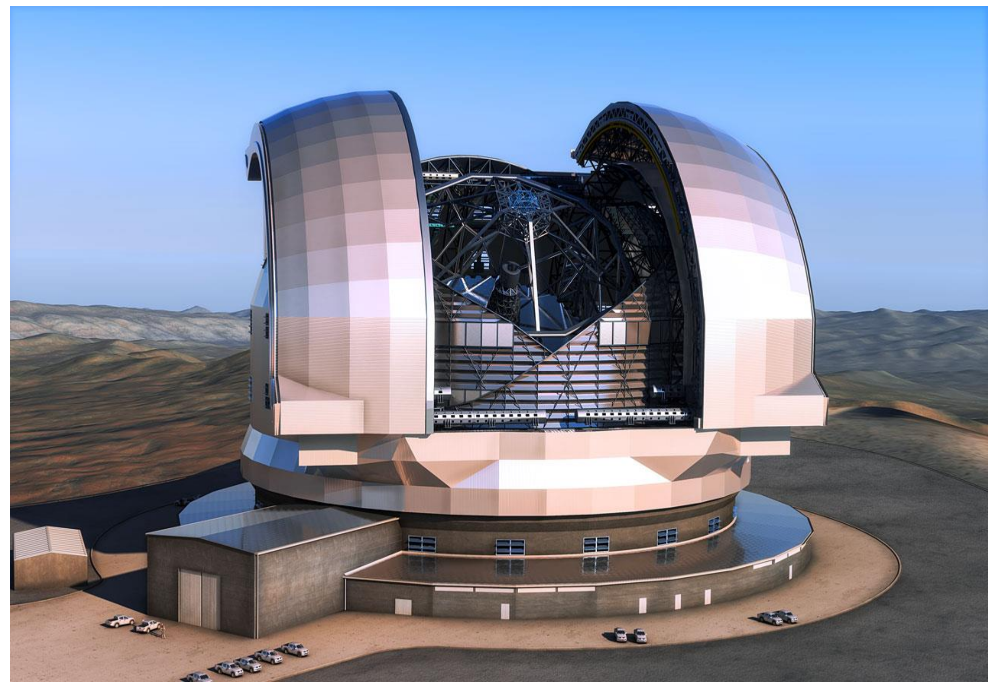
- Upcoming ground-based telescopes: LSST/VRO (Vis), SKAO (Radio), CTA (High Energy)
- Upcoming space telescopes: Euclid (Vis/NIR), Roman Space Telescope (Vis/NIR), Athena (X-rays)
- Their imaging capabilities will detect and classify a huge number of objects.

- To go from astronomy to astrophysics, spectroscopic follow-up on the main cases at adequate spectral resolution and cadence is required.
- Given the expected number of sources (e.g., 20 billion galaxies and 17 billion stars down to R~27.5 for the Vera C. Rubin alone), only a dedicated spectroscopic facility will be able to fully realize the scientific potential of these wide-field imaging surveys for cosmology, extra-galactic and galactic science

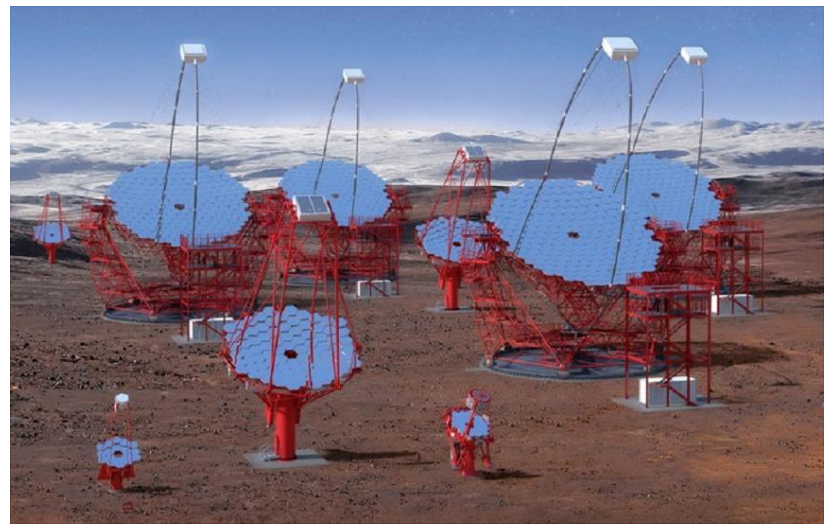


Vera Rubin Observatory

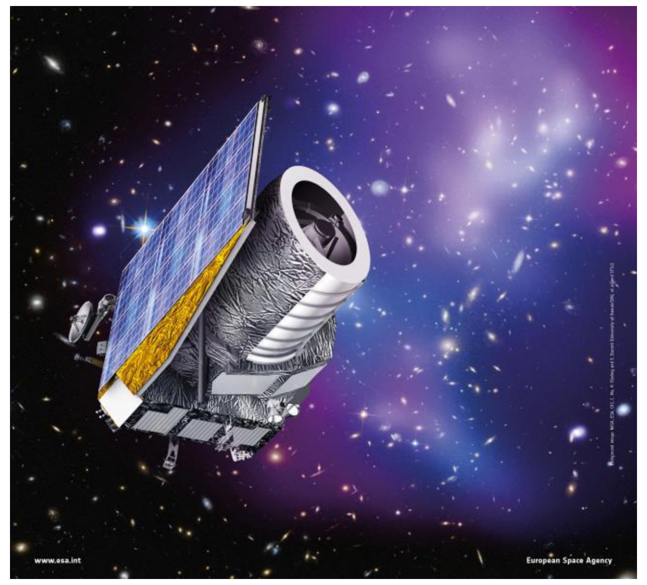
SKA



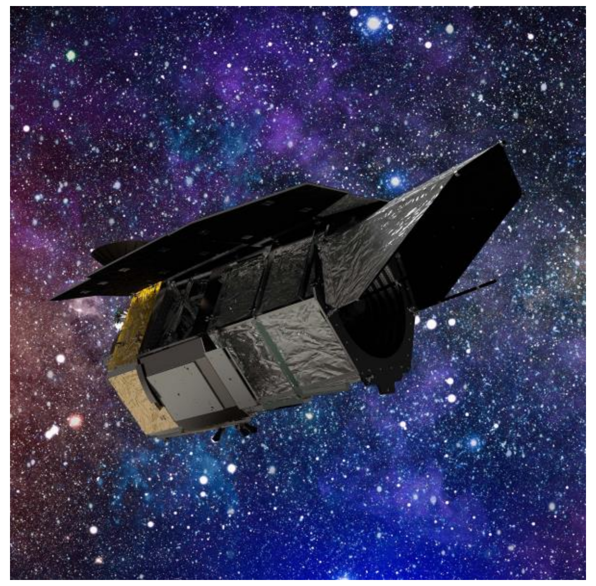
ELT



CTA



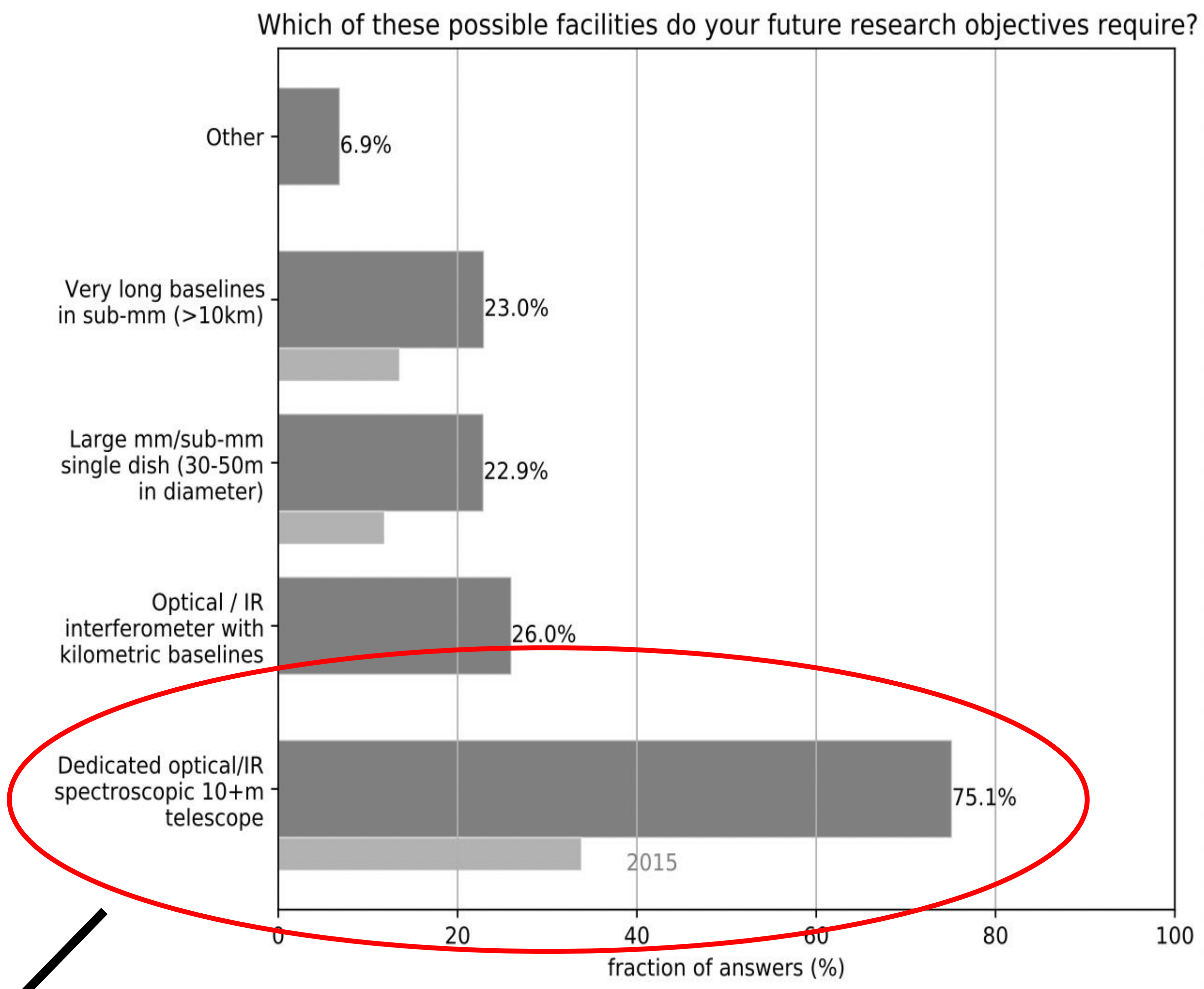
Euclid (ESA)



Roman ST

The future of MOS?

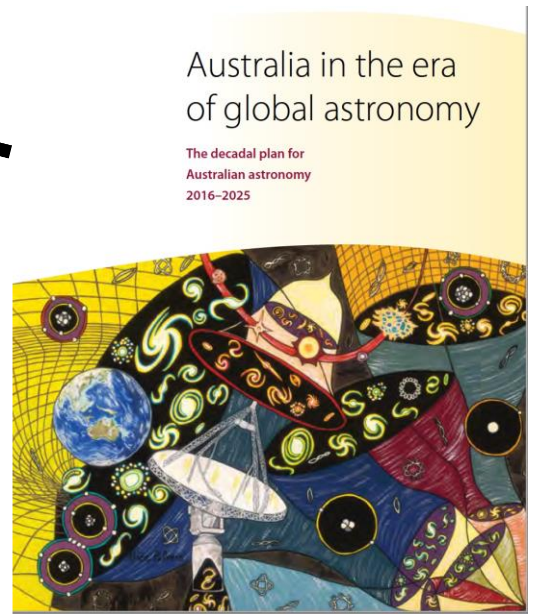
- New MOS facilities using **dedicated 4m-class** telescopes : DESI, 4MOST, WEAVE
- New MOS instruments will be installed on existing 10m class **multi-purpose** telescopes : PFS at Subaru, MOONS at VLT
- The upcoming giant telescopes (ELT, TMT, GMT) are limited to a **small field-of-view** and a correspondingly small multiplex capability
- The 2nd generation IFS (MUSE) with large field and exquisite sensitivity has open new opportunities in the field of spectroscopic surveys which are complimentary to MOS surveys



Scientific Prioritisation Community poll following the "VLT in the 2030" ESO workshop (Merand+21, The Messenger, 184, 8)

A new spectroscopic survey facility on a dedicated wide field-of-view 10m-class telescope equipped with a very high-multiplex MOS and a panoramic IFS

A wide field spectroscopy facility is one of the three new ground based facilities (with CTA and EST) proposed in Astronet 2022



https://www.wstelescope.com/

Proposal for a dedicated facility with an advanced MOS and a giant panoramic IFS working in synergy

Aims to be the next big project of European Astronomy after ELT

Project office

R. Bacon
Coordinator

S. Randich
Deputy Coordinator

V. Mainieri
Project Scientist

I. Bryson
System Architect

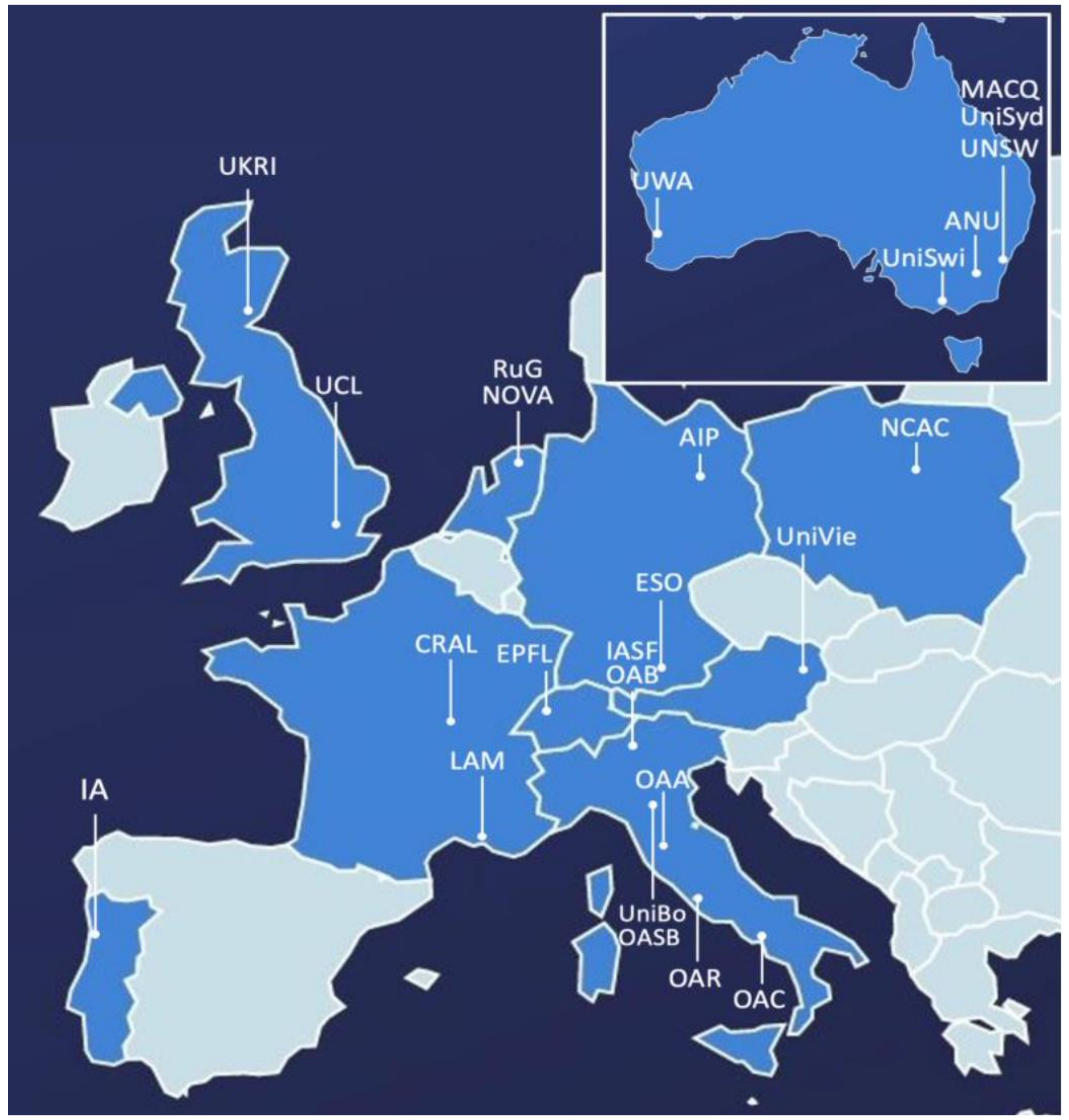
P. Schipani
Project Manager

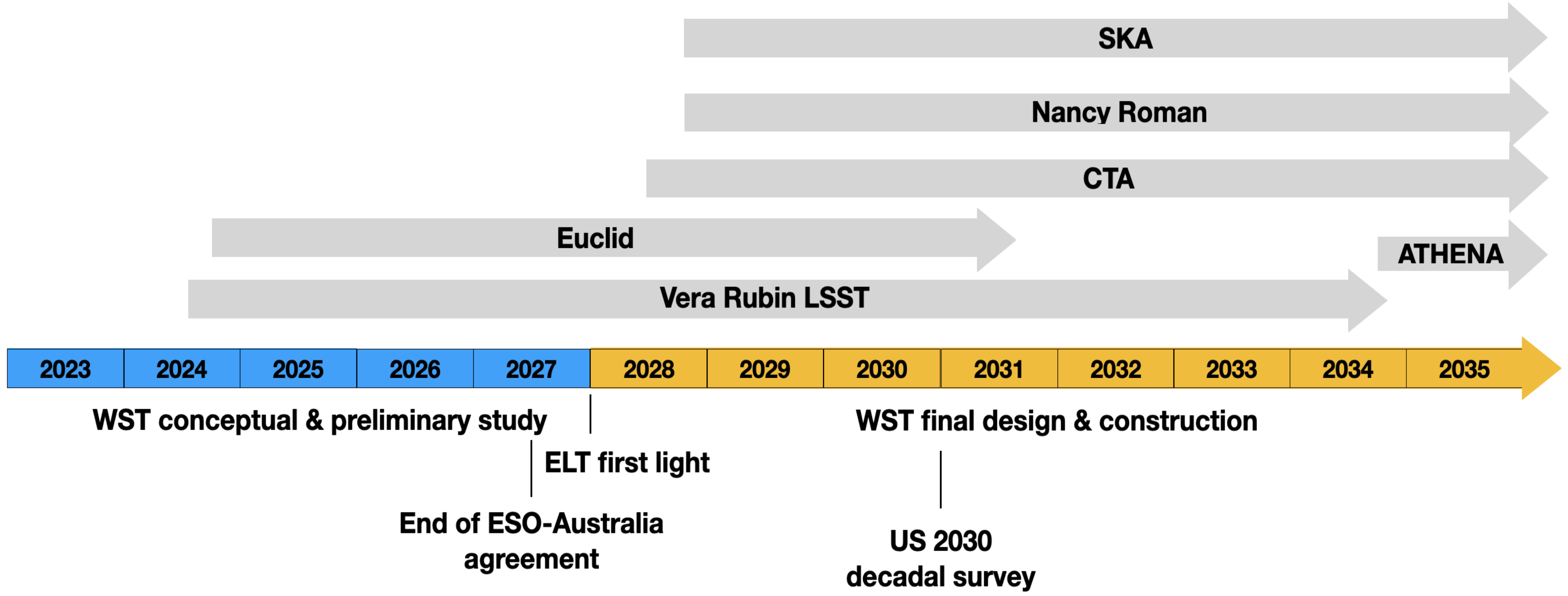
P. Dierickx
System Engineer

J. Vernet
Instrument Coordinator

B. Garilli
Operation Coordinator

10 Countries (9 Europe + Australia)

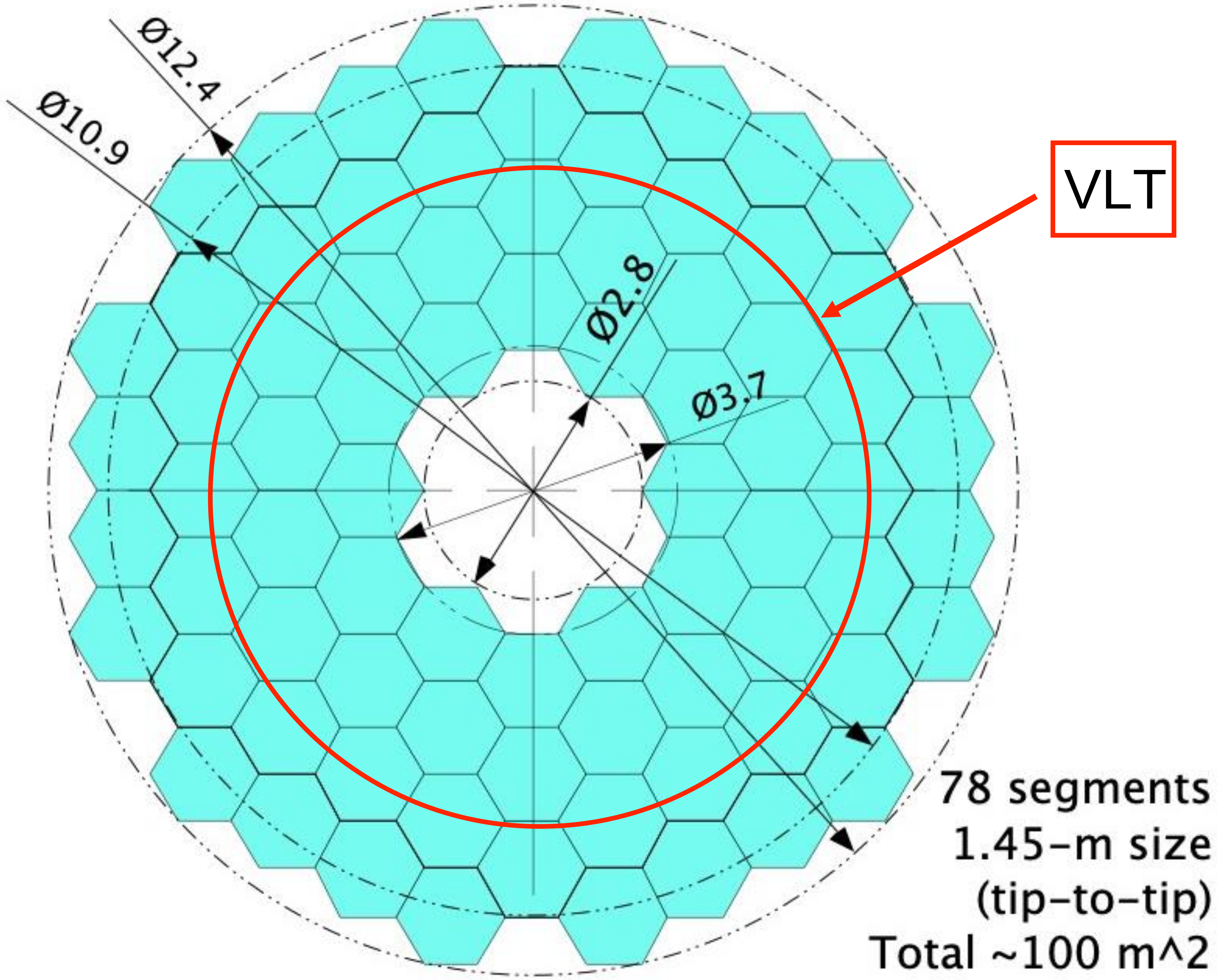




Science teams
Cosmology, Galaxy evolution, Galactic, Time domain
White Paper 2023

UPCOMING WST CONFERENCE!
Science with the Wide-field Spectroscopic Telescope
May 23-26, Wien
https://www.wstelescope.com/meetings/symposium

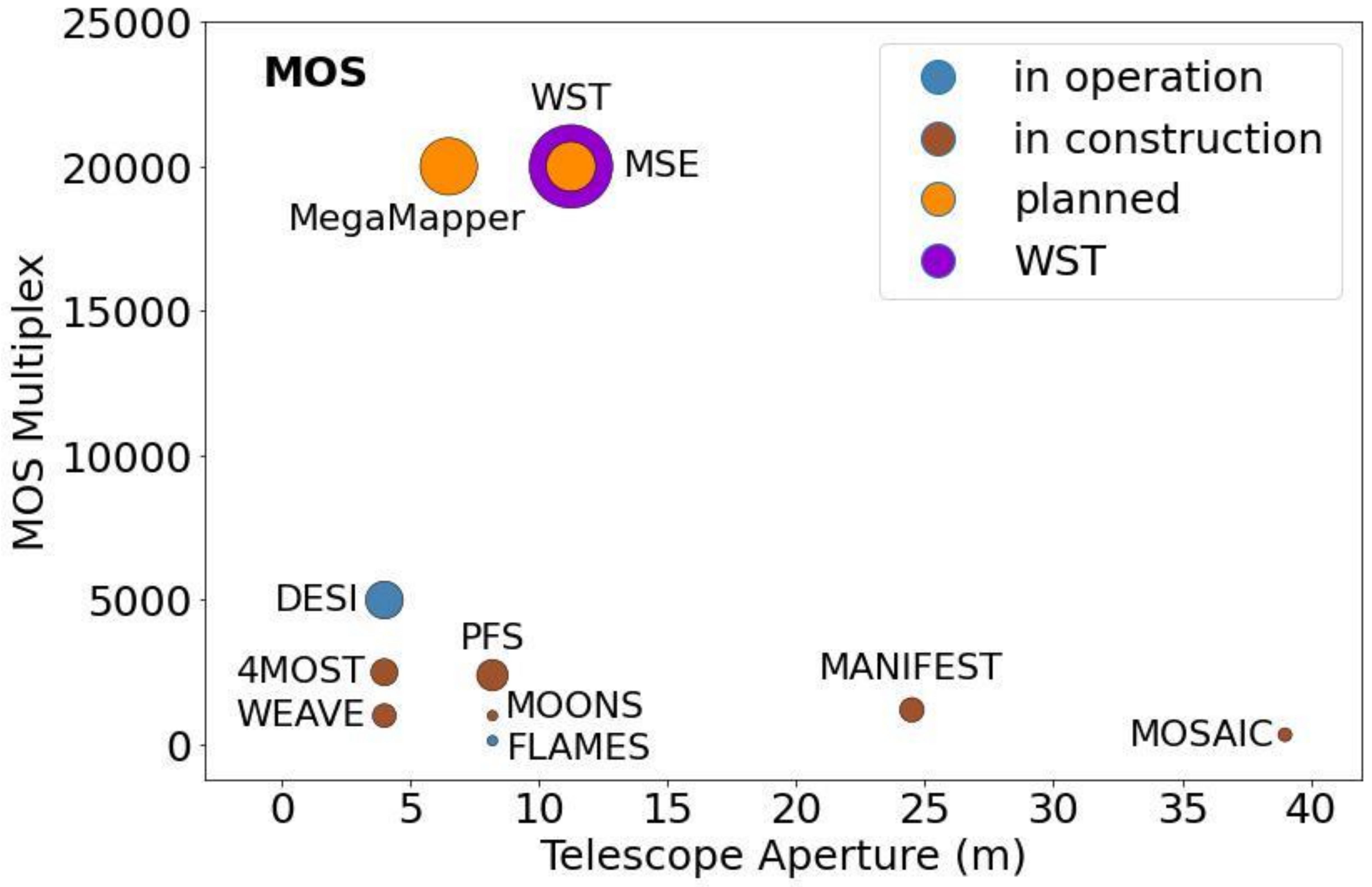
Preliminary TLR

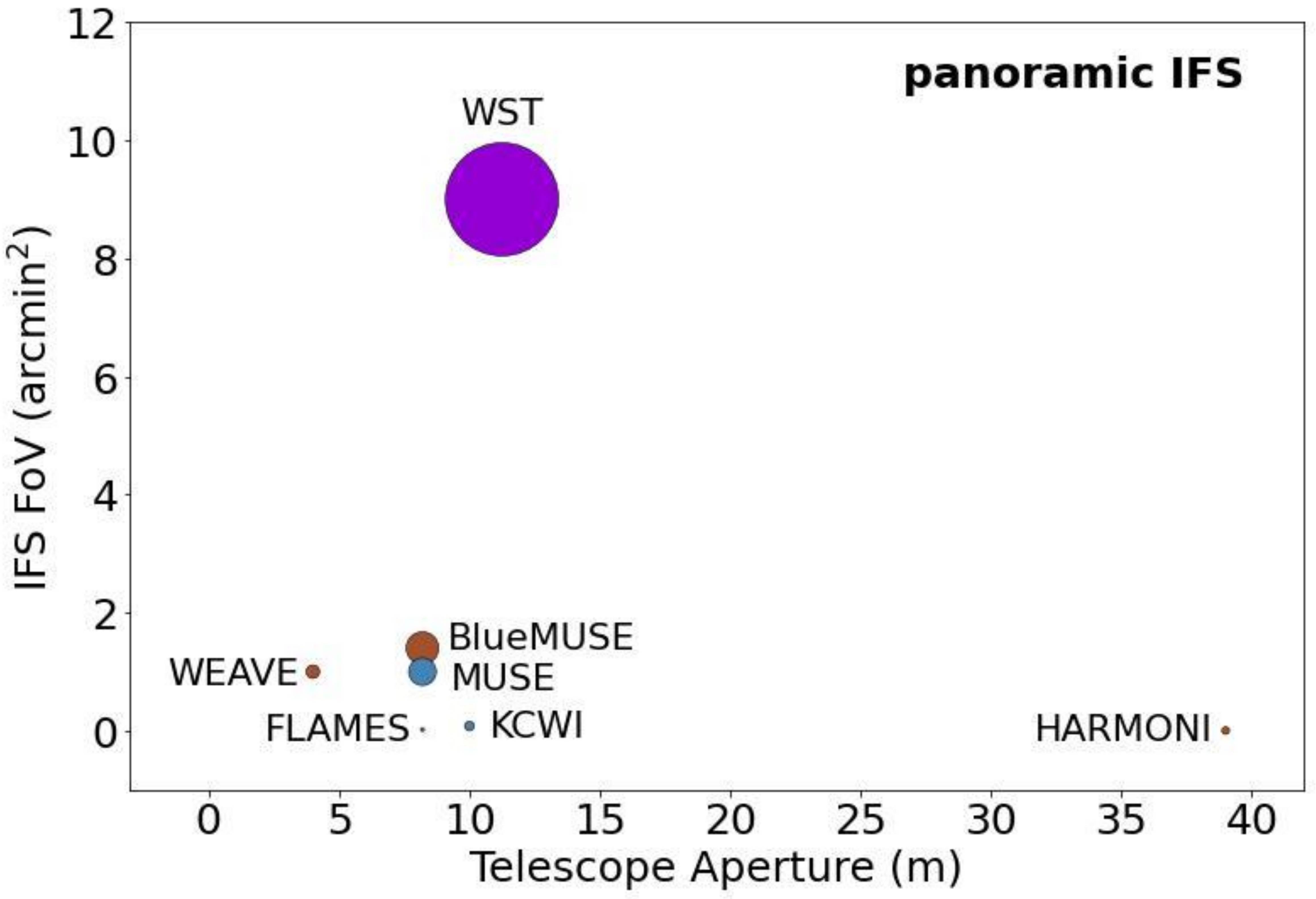


Re-use ELT segments

Telescope Aperture	12 m, seeing limited
Telescope FoV	2.5 - 5 deg^2
MOS LR Multiplex	20,000
MOS LR Resolution	2,000-7,000
MOS LR Spec Range	370 (350) - 970 nm
MOS HR Multiplex	2,000
MOS HR Resolution	20,000-40,000
MOS HR Spec Range	3-4 regions in 350-970 nm
IFS FoV	3x3 arcmin^2
IFS Resolution	3,000-5,000
IFS Spec Range	370-970 nm
IFS Mosaic	9x9 arcmin^2
MOS & IFS simultaneous operation	

Comparison with other facilities





Comparison of MOS (left panel) and IFS (right panel) capabilities with existing and proposed ground-based spectroscopic facilities. **Circle areas are proportional to the etendue (i.e., aperture times field of view area)**.

INAF ISTITUTO NAZIONALE DI ASTROFISICA in WST

- Scheda INAF 2023 (100 people)
- INAF has the following roles in the Project Office:

  Deputy Coordinator (S. Randich), Project Manager (P. Schipani), Operations Coordinator (B. Garilli)
- Steering Committee Members: A. Fontana, L. Magrini
- INAF leader of several work-packages in the proposed study (e.g. Operations, HR Spectrographs, Cosmology, VPHG, etc.)
- **Looking forward to next Horizon call: 2024**

MSE

The Maunakea Spectroscopic Explorer

Olga Cucciati, Micol Bolzonella, Angela Bragaglia
(INAF-OAS)

[Not yet really involved in MSE (AB is part of general Science Team), nor been contacted by someone in MSE… just interested in a project we think could be useful for the future INAF generations.

This is why the survey for interest was proposed to INAF researchers (see later slide)]

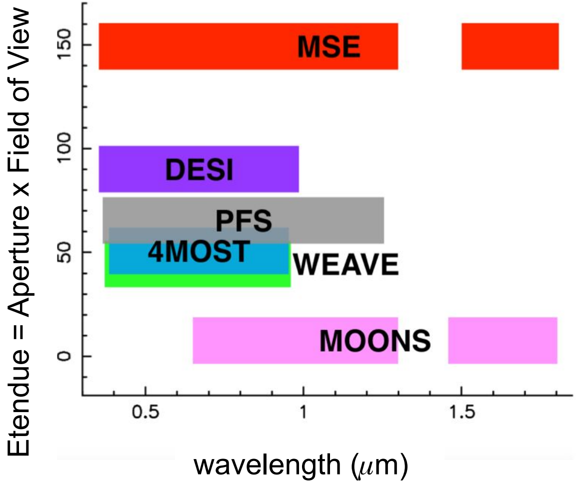
Giornate INAF 2023

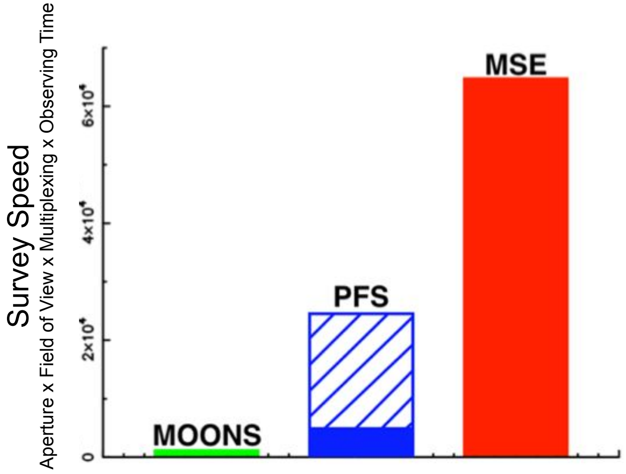
Interest from the astronomical community

- **Worldwide interest:** 10m-class telescope dedicated to spectroscopic surveys
  - see eg many national strategic science plans (e.g., US 2020 decadal survey, 2016-2025 decadal plan for Australian astronomy, Canadian astronomy long range plan 2020-2030).
- **In Europe:** 75% of ESO users identified such a facility as the most crucial one for the future (see Messenger 161 and arxiv 1701.01976)
- **Response to this need:** two **complementary** large spectroscopic survey telescopes
  - the Mauna Kea Spectroscopic Explorer **(MSE)** in the northern hemisphere
  - the Wide-Field Spectroscopic Telescope **(WST)** in the southern hemisphere.
- **What is collectively going on in the community** (for example)**:**
  - **WST Symposium** (May 2023):
    - talk "Update on the Maunakea Spectroscopic Explorer and the MSE Pathfinder" by Andrew Sheinis
    - talk "Refining the science cases for 10-m class, wide-area, massively multiplexed spectroscopic surveys like MSE and WST" by Peter Frinchaboy
  - **EAS 2023** (July 2023): lunch session "Science case and overview of the North (MSE) and South (WST) Spectroscopic Survey Telescopes projects"

Maunakea Spectroscopic Explorer

- Consortium: Canada, France, U. Hawaii, Australia, China, and India
- Site: will replace the 4m Canada-France-Hawaii Telescope (CFHT) on the summit of Maunakea (CFHT internal building renovation and structural upgrades)
- Expected timeline:
  - construction in early 2030s
  - science operations to begin in early 2040s
  - preceded by a pathfinder (science operations expected around 2030)
- Website: https://mse.cfht.hawaii.edu/
- Cheat Sheet: https://mse.cfht.hawaii.edu/wp-content/uploads/2019/03/MSE_CheatSheet_20190306_with_coverpage1.pdf





MSE: overview

- Primary mirror: 11.25m aperture *(with a possible upgrade to 12.5m)*
- Field of view : hexagonal, 1.5 deg^2 area
- Fiber-fed: Two fibers can approach with 7 arcsecs of each other (three fibers can be placed within 9.9 arcsec diameter circle, i.e. good also for clustered targets)
- High-resolution (HR) spectrograph: **1,084** spectra
    - wavelength range from **360 to 900 nm**:
        - **R~40,000** for λ < 520 nm (**blue** & **green** channels)
        - **R~20,000** for λ > 500 nm (**red** channel)
    - Note: actual resolution to be finalised
- Low and moderate resolution (LMR) spectrograph: **3,249** spectra.
    - Moderate resolution: wavelength range **390 - 900 nm + 1500-1800 nm**, **R~4400-6200**
    - Low resolution : wavelength range **360 - 1300 nm , R~2500-3600**

This is the baseline design. However, a new design is under study, which will permit to host about 20,000 fibers within the same FoV, i.e. a 5x increase

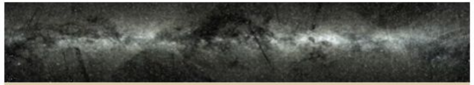
MSE: enabled science

- **Exoplanets and stellar astrophysics**
  MSE will provide spectroscopic characterization at high spectral resolution and high signal to noise ratio of the faint end (g ~16) of the PLATO target distribution, to allow for statistical analysis of the properties of planet-hosting stars as a function of stellar and chemical parameters.
- **Chemical tagging in the outer Galaxy: the definitive Gaia follow-up**
  MSE will focus on the halo, thick disk and outer disk of the Galaxy - inaccessible to 4 metre class telescopes - through the use of its unique capability for chemical tagging experiments. Chemistry can to be used in addition to, or instead of, phase space to reveal the stellar associations that represent the remnants of the building blocks of the Galaxy.
- **The Dark Matter Observatory**
  For Milky Way dwarfs, MSE will obtain complete samples of tens of thousands of member stars to very large radius and with multiple epochs to remove binary stars. Such analyses will allow the internal dark matter profile to be derived with high accuracy and will probe the outskirts of the dark matter halos accounting for external tidal perturbations as the dwarfs orbit the Galaxy
- **The connection between galaxies and the large scale structure of the Universe**
  Mapping the distribution of stellar populations and supermassive black holes to the dark matter haloes and filamentary structures is needed to understand how galaxies evolve and grow relative to the DM structure in which they are embedded.
- **Cosmology**
  MSE will probe a large volume of the Universe with a galaxy density sufficient to measure the extremely-large-scale density fluctuations required to explore primordial non-Gaussianity and inflation. Will provide confirmation of the neutrino mass hierarchy from astronomical observations.
- **The growth of supermassive black holes**
  MSE will allow an unprecedented, extragalactic time domain program to measure directly the accretion rates and masses of a large sample of supermassive black holes through reverberation mapping.
- **Following time-variable events**
  With its large multiplex advantage and good sky overlap with other surveys, MSE can provide large-aperture followup of faint transient events using a few fibres while simultaneously continuing uninterrupted observation of main survey programs with the remainder of the installed fibre set.

current working groups:

Exoplanets and stellar astrophysics

Maria Bergemann, MPIA Heidelberg
Daniel Huber, University of Hawaii



Milky Way and resolved stellar populations

Xiaoting Fu, Kavli Institute for Astronomy and Astrophysics at Peking University
Sarah Martell, University of New South Wales, Australia

Chemical nucleosynthesis

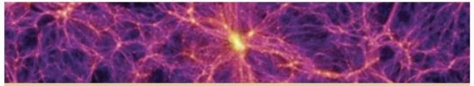
Ricardo Schiavon, Liverpool John Moores University
Charli Sakari, San Francisco State University

Galaxy formation and evolution

Aaron Robotham, University of Western Australia
Sean McGee, University of Birmingham

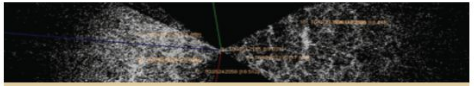
AGN and supermassive black holes

Andreea Petric, Space Telescope Science Institute
Manda Banerji, University of Southampton, UK



Astrophysical tests of dark matter

Ting Li, University of Toronto
Manoj Kapinghat, University of Waterloo, Canada



Cosmology

Will Percival, University of Waterloo, Canada
Christophe Yeche, CEA-Saclay, France

Time domain astronomy and transients

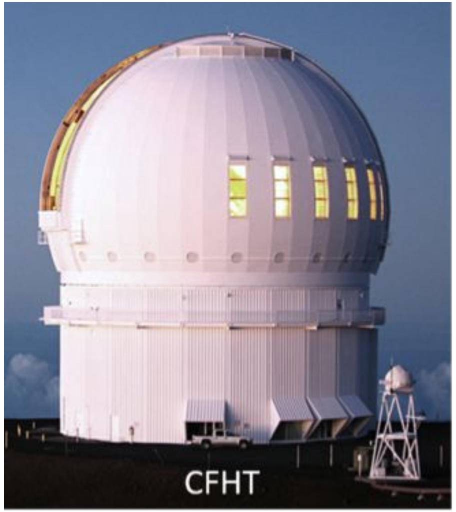
Suvi Gezari, Space Telescope Science Institute
Chien-Hsiu Lee, NOAO/NOIRLab

MSE: pathfinder overview

- deployed on the current 4m-class CFHT
- IFU 33” x 28.5” field of view
- MOS 1.3 degree diameter FOV
- ~1000 fibers , R ~ 3000-5000, optical wavelength regime (360-980 nm)
- 5-7 years to completion
- envisaged ~80% of time for large surveys and ~20% for PI programs
- complement large area space missions such as Gaia, Euclid, eROSITA, Roman, and JWST.
- follow-up to augment data from several current and future ground-based facilities e.g. LSST, KIDS, DES, and SKA

The multiobject spectroscopic (MOS) and integral field unit (IFU) instrument capability of the MSE-Pathfinder will enable the exploration of a wide range of science cases from cosmology to stellar astrophysics. **Five potential science areas** of focus for the MSE-Pathfinder include:

- Time Domain and Transients
- Milky Way and Local Volume Science
- Cosmology
- High-Energy
- Extragalactic Census (Galaxy Evolution)



MSE: miscellaneous

- Recent **call for interest for design** of MSE and its pathfinder: see email forwarded by Adriano Fontana on 24/03/2023

- **Poll for identify scientific interest** for MSE and its pathfinder in INAF: see email by Olga Cucciati on 13/04/2023
→ https://forms.gle/ZfdEmMU3sWND1KTJ9
→ decided not to close the poll yet, waiting for what this talk could trigger in the INAF community
→ poll intended to understand whether there is a scientific interest in INAF, and in case start a discussion in the Italian community about what to do next

- **Tuesday 9th of May,** at 14:00 at INAF-OAS (+remote link to be distributed):

  Special Talk on MSE by **Laurence Tresse**, member of the MSE Management Group

MSE and WST planned characteristics (as of May 2nd 2023, changes possible)

	MSE		WST
Primary mirror diameter	11.25m	*[with the possibility of 12.5m]*	12m
MOS			
FOV	1.5 deg^2		2.5 – 5 deg^2
Low Resolution	3000		2000 – 7000
Medium Resolution	4400 – 6200		–
High resolution	20000 (red) – 40000 (blue, green)		20000 – 40000
Wavelength (LR / MR / HR)	360 – 1320 / 390 – 900 + 1457 – 1780 / 360 – 900 nm		350 – 970 / – / 350 – 970 nm
Multiplex LR	3249 (LR & MR)	*[with the possibility of a 5x*	20000
Multiplex HR	1083	*increase, up to 20000 in total]*	2000
IFU	[second generation instrument]		
FOV			3 × 3 $arcmin^2$
Resolution			3000 – 5000
Wavelength			370 – 970 nm
Site	Maunakea		Chile (Paranal/La Silla) TBC
Operation start	~ 2040		?
Funding consortium	CFHT+		?