Future telescopes and instruments for the study of heavy elements

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s, i, & r element nucleosynthes (sirEN) conference –Giulianova, June 10, 2025

A synergic approach, integrating ***experiments, observations, and theoretical frameworks****, is pivotal for understanding the complex mechanisms underlying the nucleosynthesis of heavy elements*

This talk:

- Highlights the **observational pillar** of this synergy
- Focuses on one **facility –WST- and one instrument –HRMOS-** both poised to revolutionize how we trace **s-, i-, and r-process** signatures in stars and galaxies

WST and HRMOS capabilities in brief

[Very] high spectral resolution → precise abundances [and isotopes]

[Extremely] large numbers of stars down to faint magnitudes

→ sampling all Galactic and Local Group environments and populations up to large distances

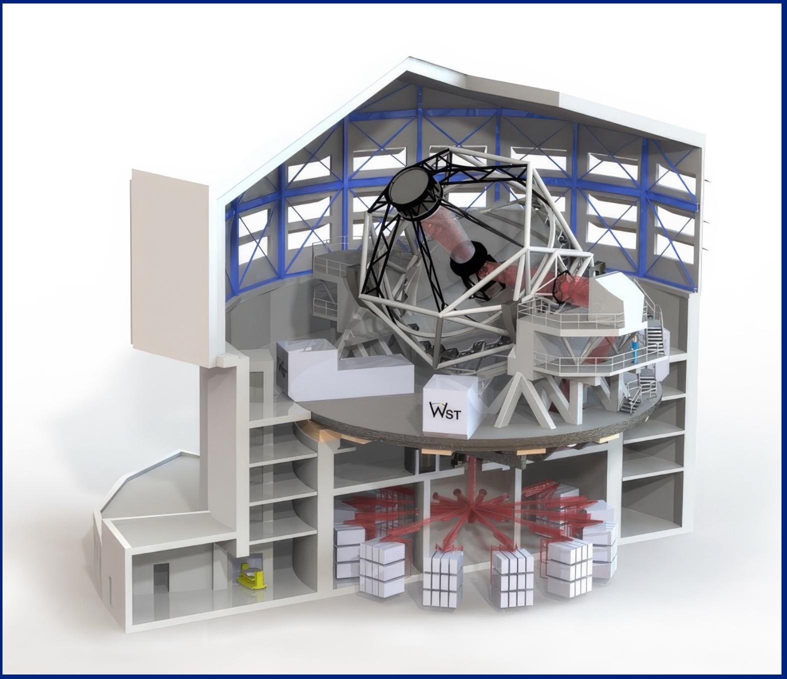
Blue spectral coverage → optimizing observations of heavy elements features

Funded by the European Union

Pushing the Boundaries of Spectroscopic Surveys

The Wide-field Spectroscopic Telescope

An innovative facility dedicated to spectroscopic surveys



The Facility - baseline

telescope

12.1 m, seeing limited

3.1 deg^2

Spectral range: 0.35 – 1.6 μm

three instruments/modes working in parallel

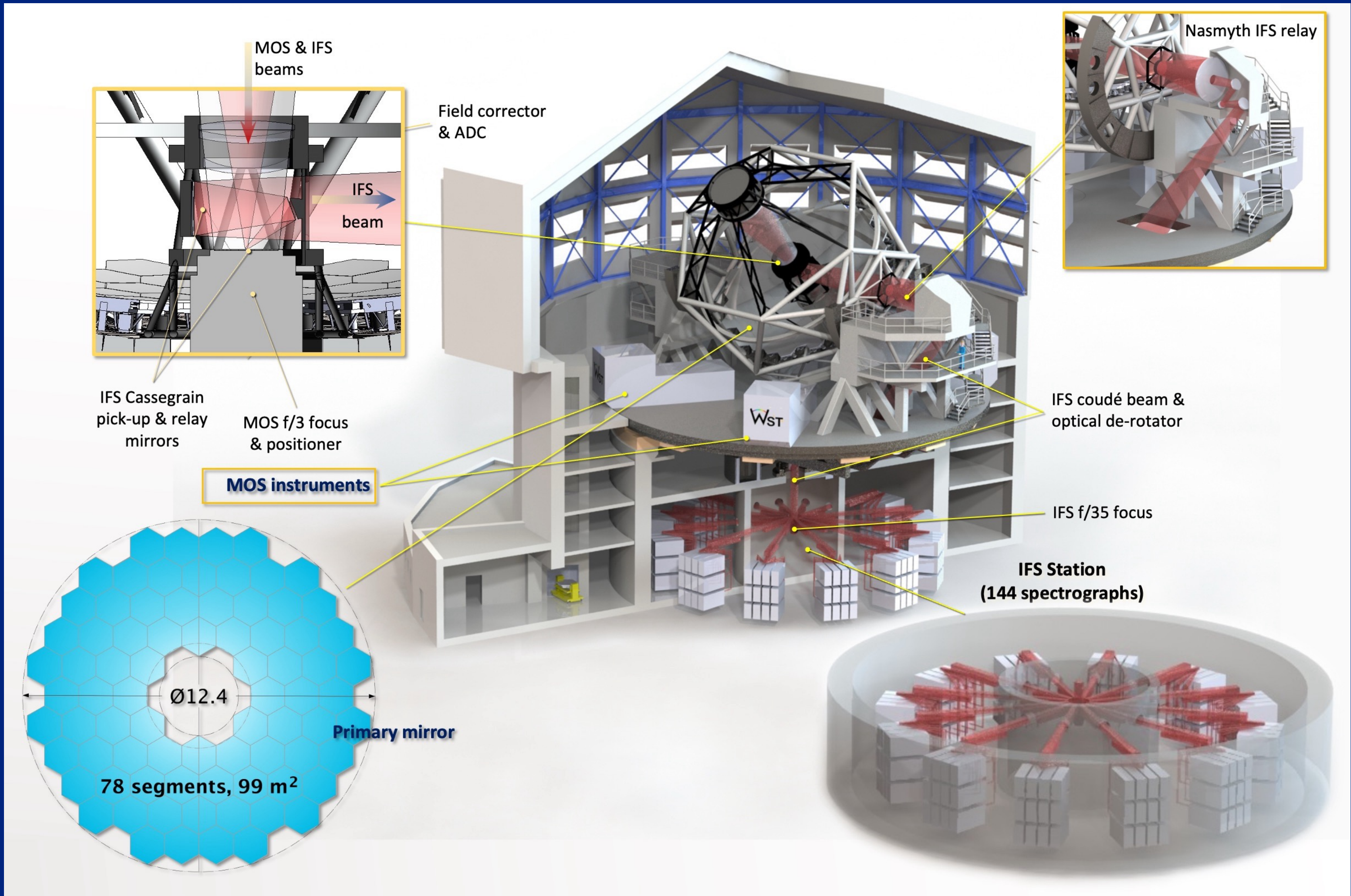
-low resolution MOS

-high resolution MOS

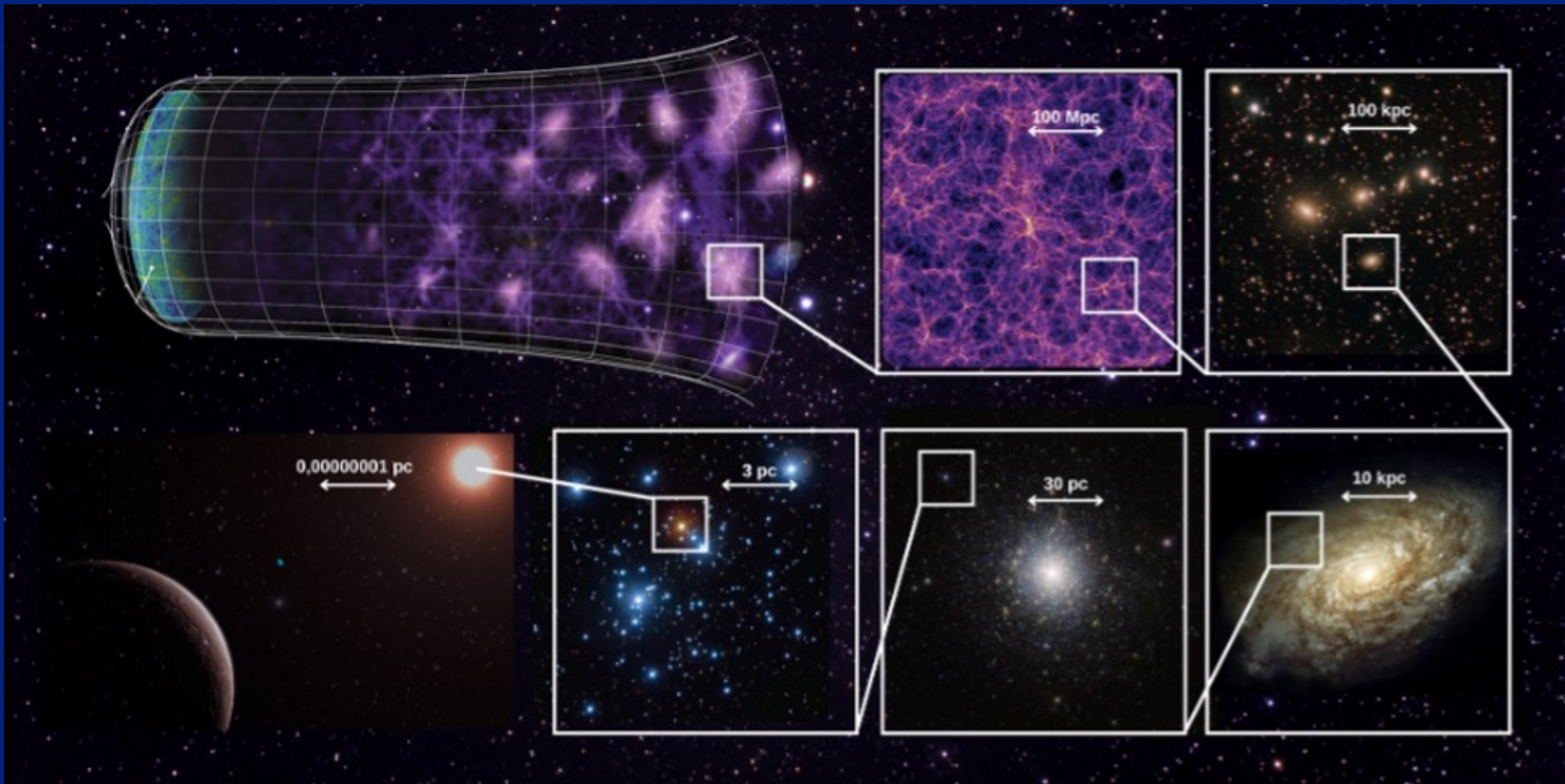
-central IFS

baseline + "upgrade"

MOS LR Multiplex	30,000
MOS LR Resolution	3,000-4,000
MOS LR Spec Range	370–970 nm (simultaneous)
MOS HR Multiplex	2,000
MOS HR Resolution	40,000
MOS HR Spec Range	350–970 nm (3–4 regions)
IFS FoV	3×3 $arcmin^2$
IFS Resolution	3,500
IFS Spec Range	370–970 nm (simultaneous)
IFS Patrol Field	13 arcmin diameter
MOS & IFS parallel operations	
ToO implemented at telescope and fibre level	


MOS & IFS beams
IFS beam
Field corrector & ADC
Nasmyth IFS relay
IFS Cassegrain pick-up & relay mirrors
MOS f/3 focus & positioner
MOS instruments
IFS coudé beam & optical de-rotator
IFS f/35 focus
IFS Station (144 spectrographs)
Ø12.4
Primary mirror
78 segments, 99 m2
WST

Science with WST

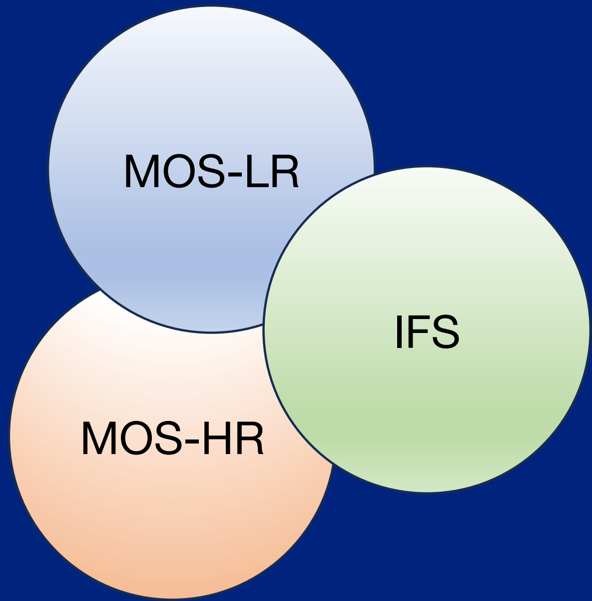


Credit to Rossella Spiga (INAF)

WST: a facility to answer a wide range of cutting-edge scientific questions that cannot be addressed with current or planned facilities

Science Case

- Cosmology
- Extragalactic
- **Resolved Stellar Pop.**
- **Galactic**
- Time Domain



ELT
Gaia
Rubin/LSST
Euclid, Roman
SKAO
Einstein Telescope

White paper (v1),
Mainieri et al, 2024

Register to become a science team member at *www.wstelescope.com*

Galactic Science Cases

WST

Three science themes:

- **Origins of elements**
- Origin of the Milky Way system
- Origin of stars and planets

Science in the 2040s: Building upon Gaia+4MOST+WEAVE

HR will allow tracing diverse nucleosynthetic channels

Not only reaching fainter targets, but adding new key and precise information

MOS-HR

In a five years survey

A few millions stars (to AB 17.0), over most of the Galaxy

3.2.1 The sources of neutron-capture elements

The heavy elements produced by various neutron capture rates (rapid, slow, and intermediate) provide fundamental insights into the energetic physical processes that create neutron fluxes and into their importance throughout the history of star formation in the Universe. Most elements can be formed by more than one of these processes, but some key elements trace only one formation channel. In the following, we list some open questions and mention examples of elements that can be used to trace the neutron capture processes in stars of different ages. Some of these elements are outside the wavelength range covered by current or planned surveys or cannot be measured because of the low resolution. Other listed elements are being or will be measured in these surveys, but *WST* in MOS-HR mode will be able to measure them more precisely and/or for more stellar types and metallicity regimes. This will allow for a more accurate understanding of these physical processes.

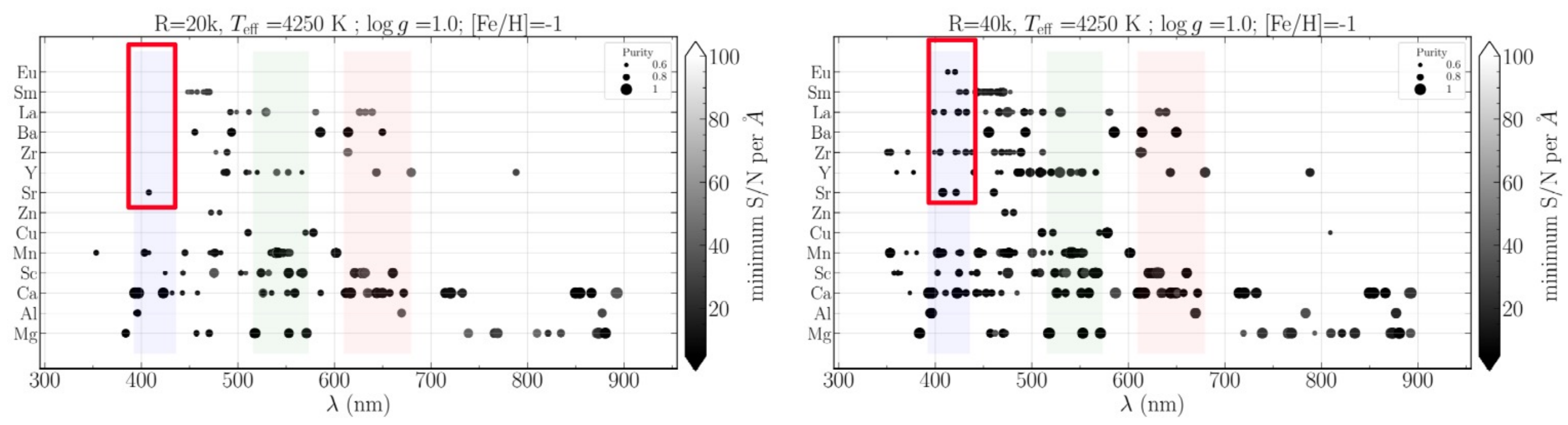
r-process elements Quantifying the relative importance of the various sources of r-process elements is still missing. We know that neutron-star mergers (NSMs) produce r-process elements(Watson et al. 2019), but are they the dominant source (Cowan et al. 2021)? Can NSMs alone explain the abundance of *r*-process elements in the first, second, and third peaks (Côté et al. 2019)? Are there other sites for the r-process, such as magneto-rotational supernovae (MRSNe) (Nishimura et al. 2006) and collapsars? Are there stars that do not have any r-process elements (Cescutti et al. 2015), which one may expect if all r-process elements are produced by rare (early?) events?
Key elements: Sr, Y, Zr, Eu, Gd, Dy, Sm, Os, Th

s-process elements Low- and intermediate-mass AGB stars ($\sim 1-8\,M_\odot$) are the main production sites of *s*-process elements. Do we know enough about the evolution of such
... s and mixing mechanisms (Karakas & Lattanzio
... ($\gtrsim 8\,M_\odot$) also produce neutron-capture elements
... efficiency of this nucleosynthesis channel depends
... llicity (e.g., Limongi & Chieffi 2018). Can we
... massive stars through the abundances of *s*-process
... process vary with mass, mixing mechanisms, and
... b

... culiar abundance patterns in stars (mostly metal
... d r-process elements (r/s-stars) is still an open
... asseron et al. 2010; Gull et al. 2018). Several scenarios have been explored to explain the hybrid abundance properties, and one is the so-called intermediate neutron capture process (e.g. Choplin et al. 2021), where the neutron

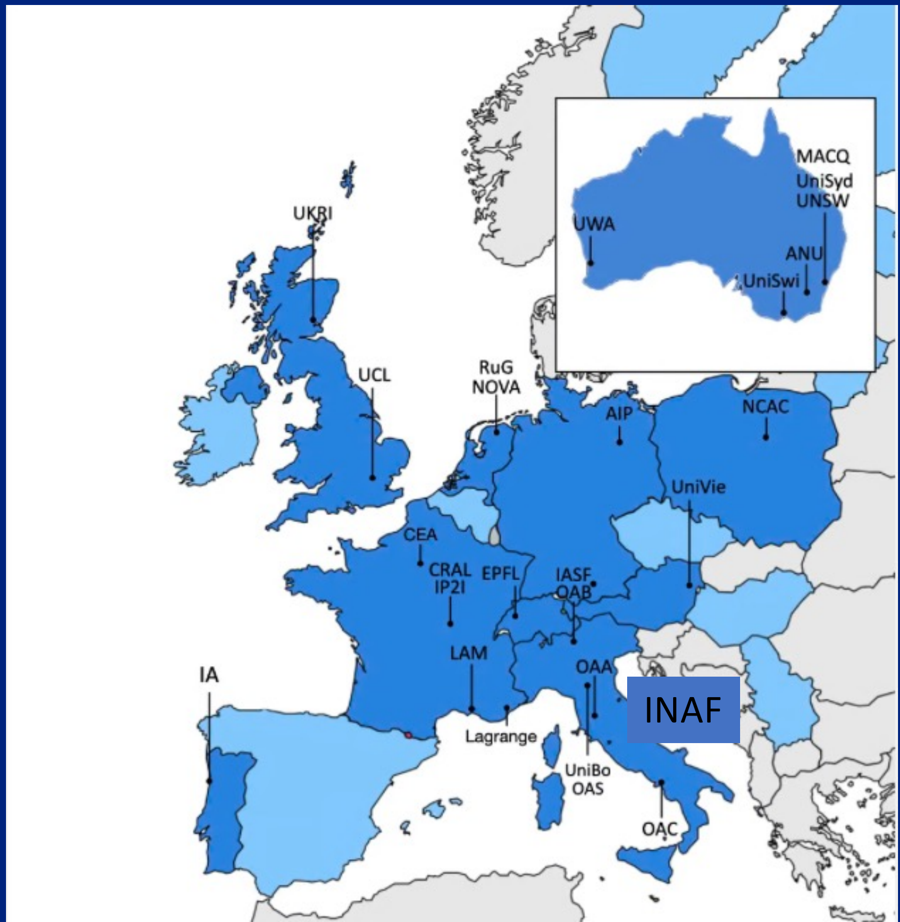
The gain at R=40,000

4MOST



Mainieri et al. 2024

A world-wide consortium



- **Coordinator:** R. Bacon (CRAL-Lyon);
  Deputy: S. Randich
- **23** research **institutes** or universities spread over 10 different countries

- ~700 science team members from 34 countries

Status and plans

- WST complete **concept study** funded within the Horizon Europe programme (*HORIZON-INFRA-2024-DEV-01)*
- Feb. 1 2025 – Jan. 31 2028
- Science (including a 5 years survey plan), telescope & instruments, operations (including plans for data management), sustainability, site selection

- Make WST the **next ESO project** after ELT completion
- If approved, operational in 2040++

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- *Feb. 1 2025 – Jan. 31 2028*
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instruments, operations (
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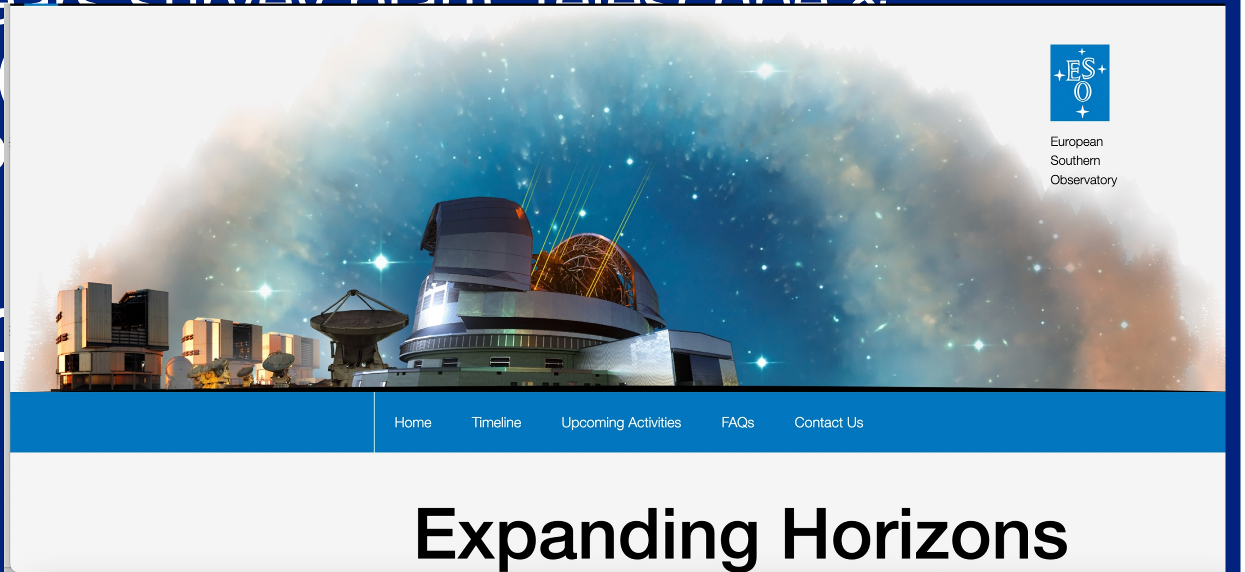
- *ESO Call in Q3 2026*
- LoIs
- *Full proposal July 1° 2027*
- ESO selection Q3 2028



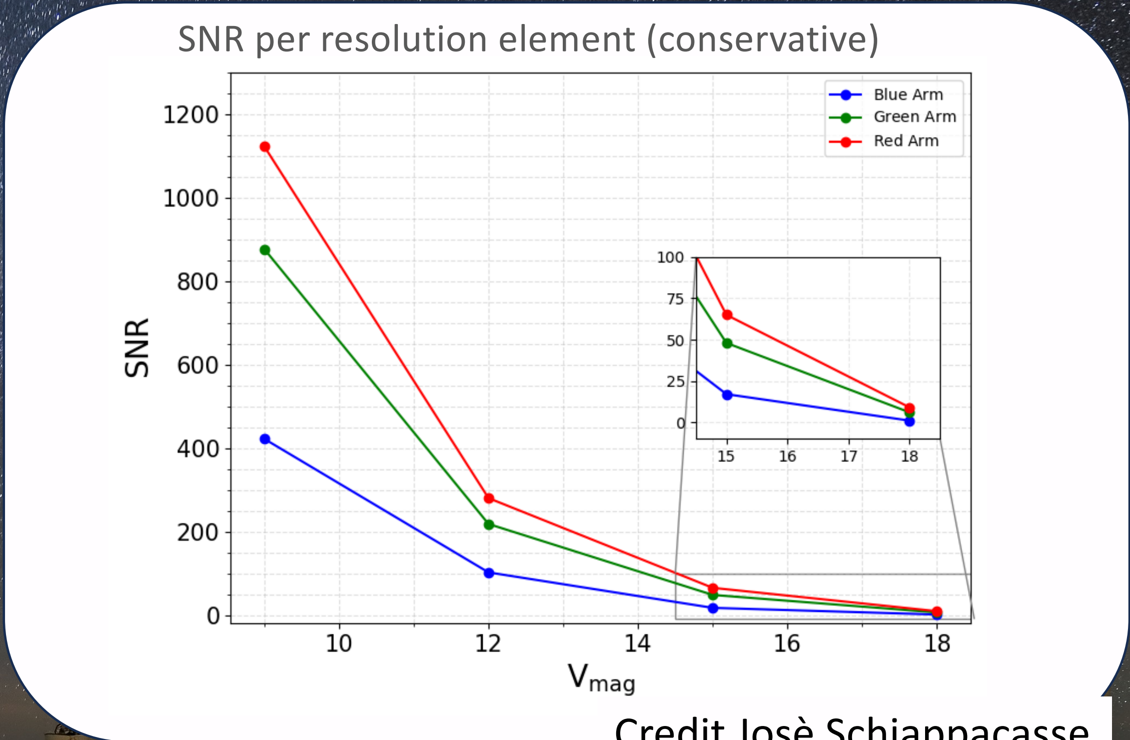
HRMOS

a **high resolution multi-object** spectrograph for the **ESO VLT**

HRMOS main characteristics

	Requirement (goal)
Resolution	R=80,000
Multiplex	N=50 (80)
Spectral range	385 – 420 nm 480 – 525 nm 613 – 675 nm (total 142 nm)
RV precision	10 m/s (5m/s)

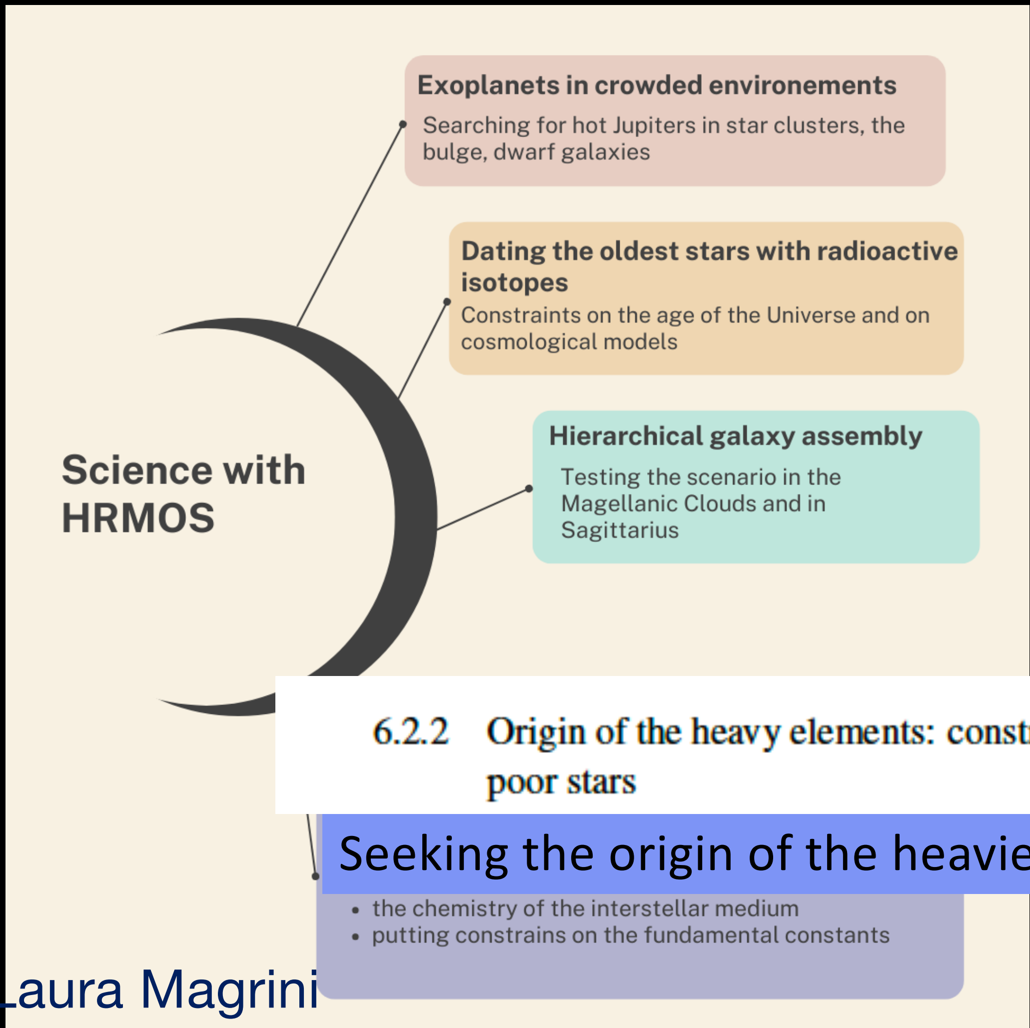
1 h exposure, solar-type star



Credit Josè Schiappacasse

To be proposed at the next call for VLT instrumentation – operational in mid 2030?

Science Drivers



HRMOS White Paper: Science Motivation

Show affiliations | Hide authors

Magrini, Laura ; Bensby, Thomas ; Brucalassi, Anna ; Randich, Sofia ; Jeffries, Robin ; de Silva, Gayandhi ; Skuladottir, Asa ; Smiljanic, Rodolfo ; Gonzalez, Oscar ; Hill, Vanessa ; Lagarde, Nadege ; Tolstoy, Eline ; Arroyo-Polonio, Jose' Maria ; Baratella, Martina ; Barnes, John R. ; Battaglia, Giuseppina ; Baumgardt, Holger ; Bellazzini, Michele ; Biazzo, Katia ; Bragaglia, Angela ; Carter, Bradley ; Casali, Giada ; Cescutti, Gabriele ; Danielski, Camilla ; Delgado Mena, Elisa ; Drazdauskas, Arnas ; Gieles, Mark ; Giribaldi, Riano ; Hawkins, Keith ; Hoeijmakers, H. Jens ; Jablonka, Pascale ; Kamath, Devika ; Louth, Tom ; Fabiola Marino, Anna ; Martell, Sarah ; Merle, Thibault ; Montet, Benjamin ; Murphy, Michael T. ; Nisini, Brunella ; Nordlander, Thomas ; D'Orazi, Valentina ; Pino, Lorenzo ; Romano, Donatella ; Sacco, Germano ; Sandford, Nathan R. ; Sollima, Antonio ; Spina, Lorenzo ; Tautvaisiene, Grazina ; Ting, Yuan-Sen ; Tozzi, Andrea ; Van der Swaelmen, Mathieu ; Van Eck, Sophie ; Watson, Stephen ; Worley, C. Clare ; Zocchi, Alice

The High-Resolution Multi-Object Spectrograph (HRMOS) is a facility instrument that we plan to propose for the Very Large Telescope (VLT) of the European Southern Observatory (ESO), following the initial presentation at the VLT 2030 workshop held at ESO in June 2019. HRMOS provides a combination of capabilities that are essential to carry out break

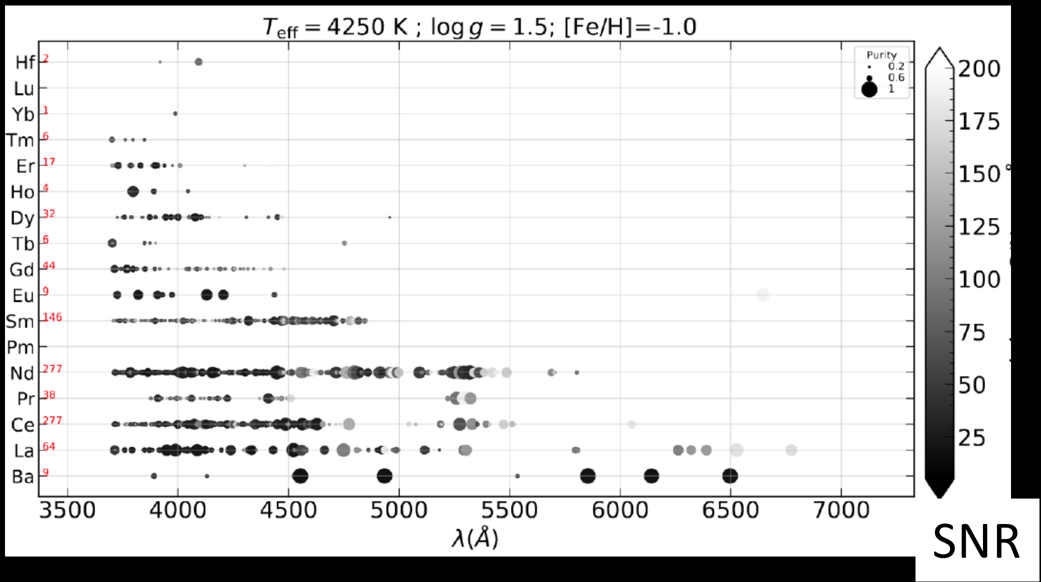
stellar astrophy

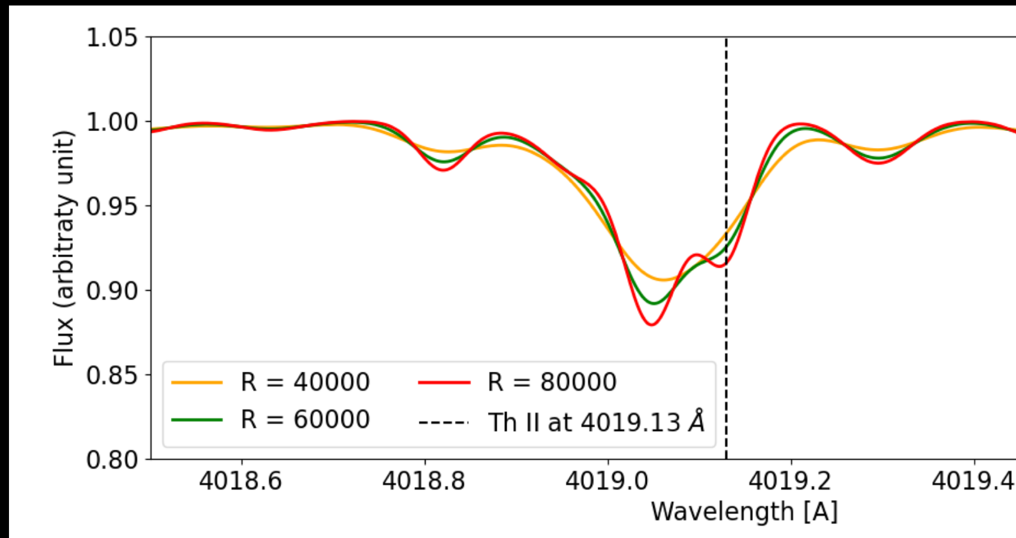
Magrini et al (2023), White Paper v1

6.2.2 Origin of the heavy elements: constraints from elemental and isotopic abundances in metal poor stars

Seeking the origin of the heaviest elements

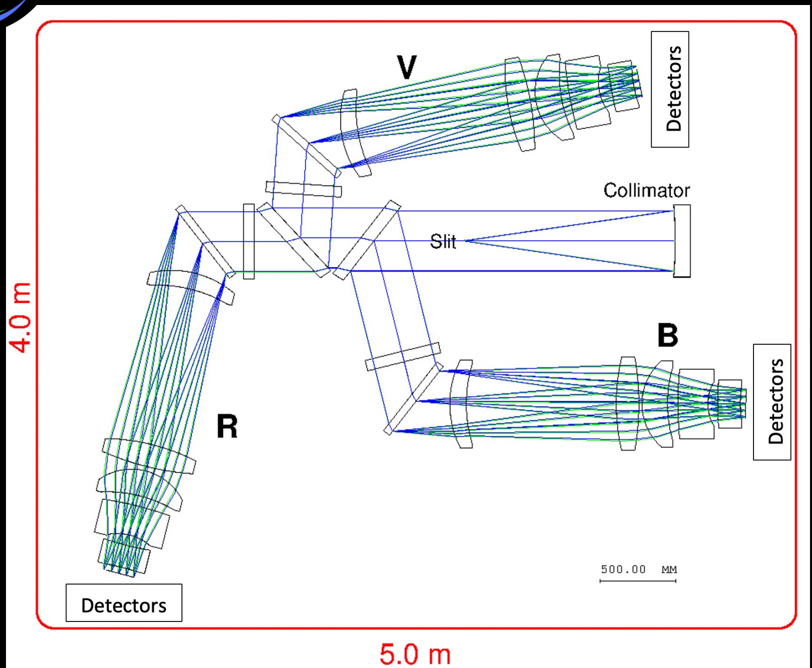
Credit: Laura Magrini





High resolution (R~80,000) and
SNR (>200/pix) is needed for precise A(Th)

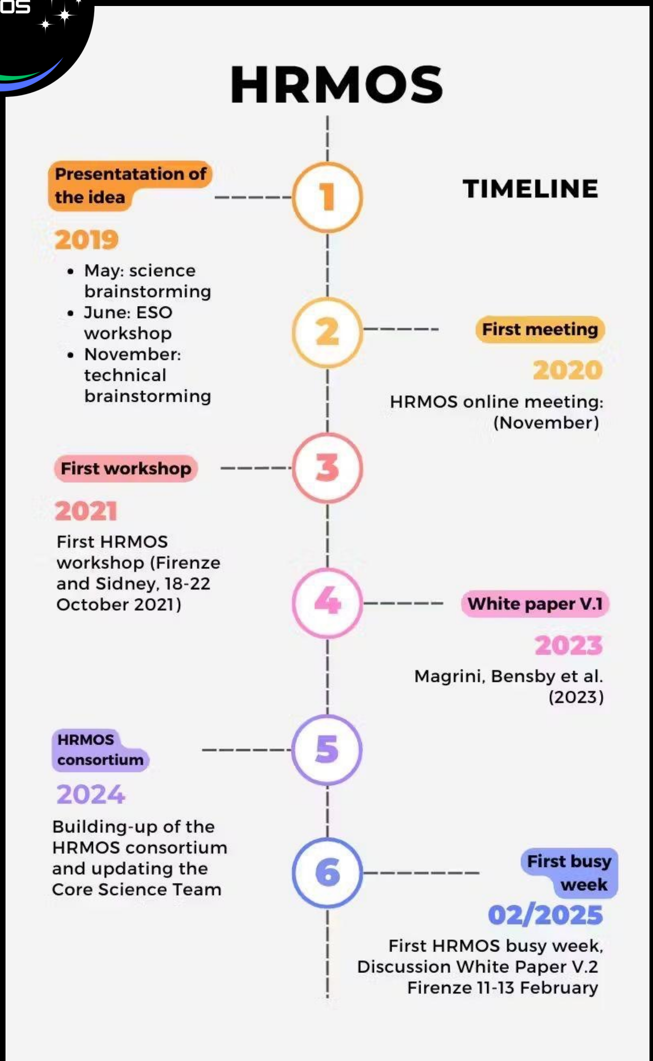
The instrument



- Layout and rays tracing of a three-channel solution for HRMOS
- Fiber slicing
- ADC solution being studied
- Calibration system being studied

- New concept
- Heritage of MOONS and KMOS
- Optimised for HRMOS

Timeline



Next milestone

propose HRMOS at the upcoming ESO call for **VLT instrumentation**

- INAF
- UK ATC
- Durham University (UK)
- IAC (Spain)
- IA (Portugal)

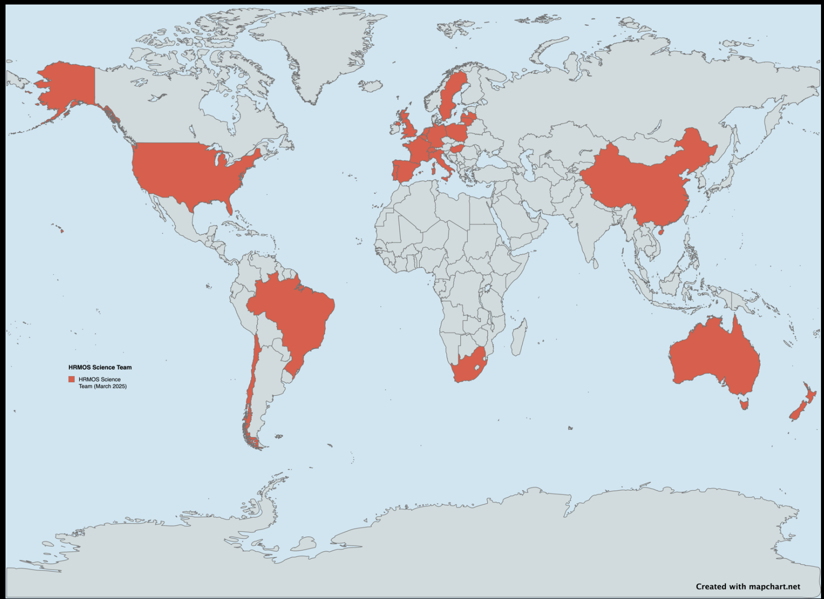
Consortium and team

Broader Science Team:

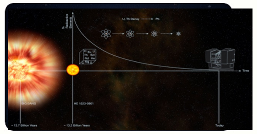
- >100 researchers
- > 20 institutes

PI Board

PI: Sofia Randich
deputy: Andrea Bianco (INAF)
UKATC PI: **Oscar Gonzalez**
IAC PI: **Emma Fernandez**
IA Porto PI: **Sergio Sousa**



Nucleocosmochronology
Vanessa Hill, Georges Kordopatis

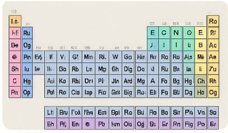


Exoplanets, Young Stars and Magnetic Fields
Robin Jeffries & Sergio Sousa

Stellar Physics, Star Cluster and Asteroseismology
Germano Sacco, Nadege Lagarde
Andrea Miglio

The Chemistry of the Interstellar Medium
TBD

Origin of Elements and Nucleosynthesis
Rodolfo Smiljanic &
Emma Fernandez Alvar



Hierarchical Galaxy Formation in the Local Group
Asa Skuladottir

Summary

High resolution multi-object spectrograph for the VLT - HRMOS

- ESO VLT, 8 m
- **"small" FoV**
- **R=80,000**
- three windows: 390, 520, 690 nm
- 50-80 fibers
- high stability → RV precision 10 m/s
- **if approved, operational in 2030+**

Wide-field spectroscopic telescope - WST

- 12 m, seeing limited
- **3.1 deg²**
  - 2 MOS: **R=40,000**; R=3-4,000
  - 2000 and 30,000 fibers
  - Three windows; 370-970 nm
- parallel gigantic IFS
  - 3x3 arcmin²
  - R=3,500
- **If approved, operational in 2040+**

WST Special Session (SS7) at the EAS meeting in Cork (Ireland) June 23rd, 2025

HRMOS Special Session (SS44) at the EAS meeting in Cork (Ireland) June 24th, 2025

Get involved in WST and HRMOS and join the teams

www.wstelescope.com

www.hrmos.eu

Thank you!