The next generation of high-resolution spectrographs: What they can do for us, and what we can do for them

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Ministero dell'Università e della Ricerca
Finanziato dall'Unione europea
NextGenerationEU
Italiadomani

COSMIC POT

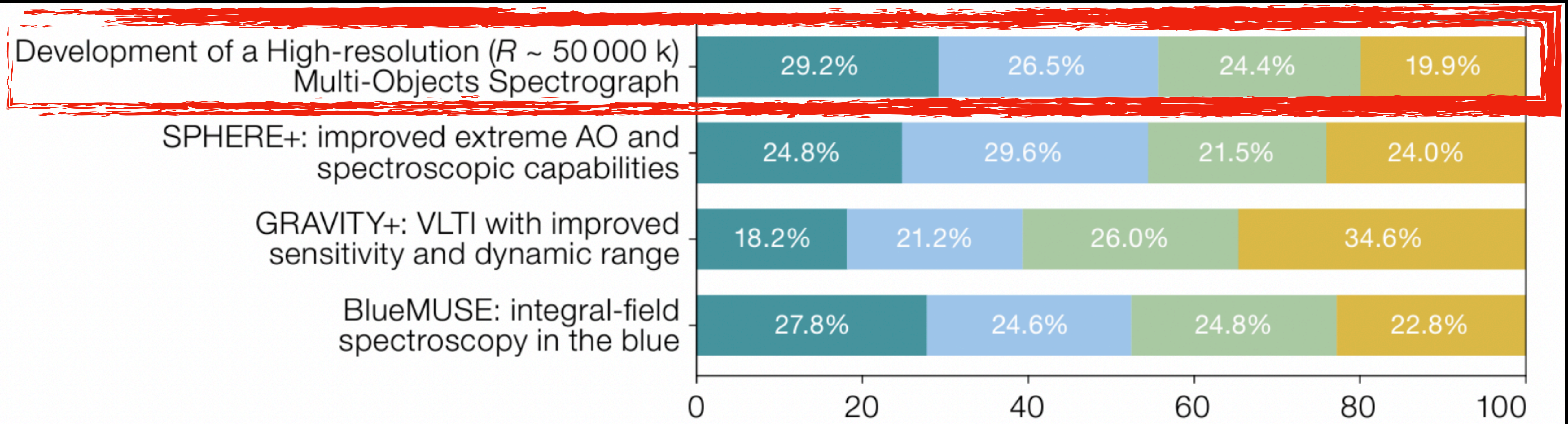
EPOCH
Beyond metallicity: Exploiting the full POtential of CHemical elements
LARGE Grant INAF 2023

CHECS
Mini Grant INAF 2022

WST
HRMOS
GaiaESO

Bologna, SPA meeting 26/03/2024

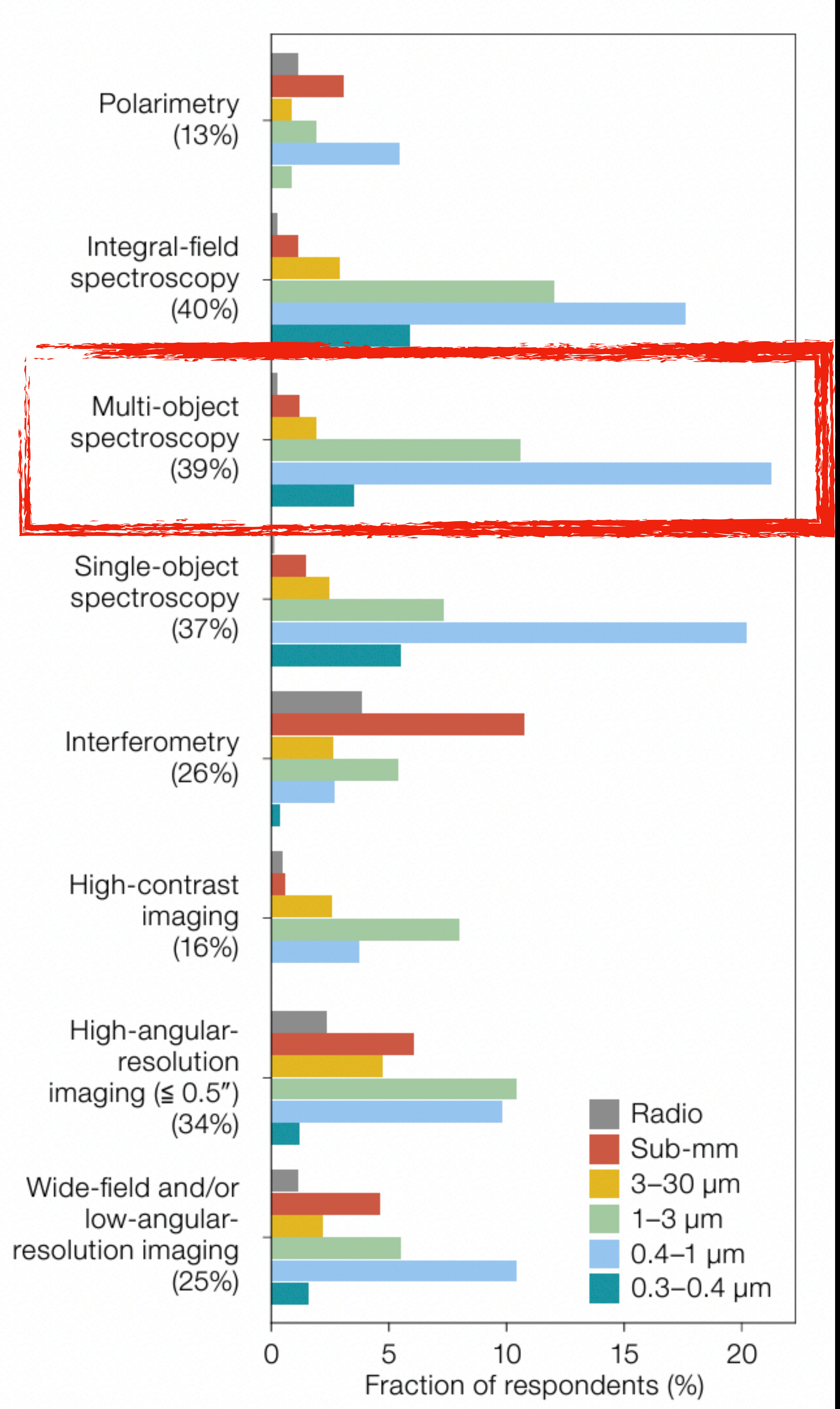
The 2020 ESO community pool



Mérand et al. (2021)

High-resolution (multi-object) optical spectroscopy is still one of the most requested ground-based capabilities in the 2030+ timeframe

"In broad terms, the missing capabilities for the VLT are in the areas of multi-object spectrographs and integral-field units (99 answers), in the near- infrared, or concern adaptive optics at bluer wavelengths. " from 2020 ESO community poll



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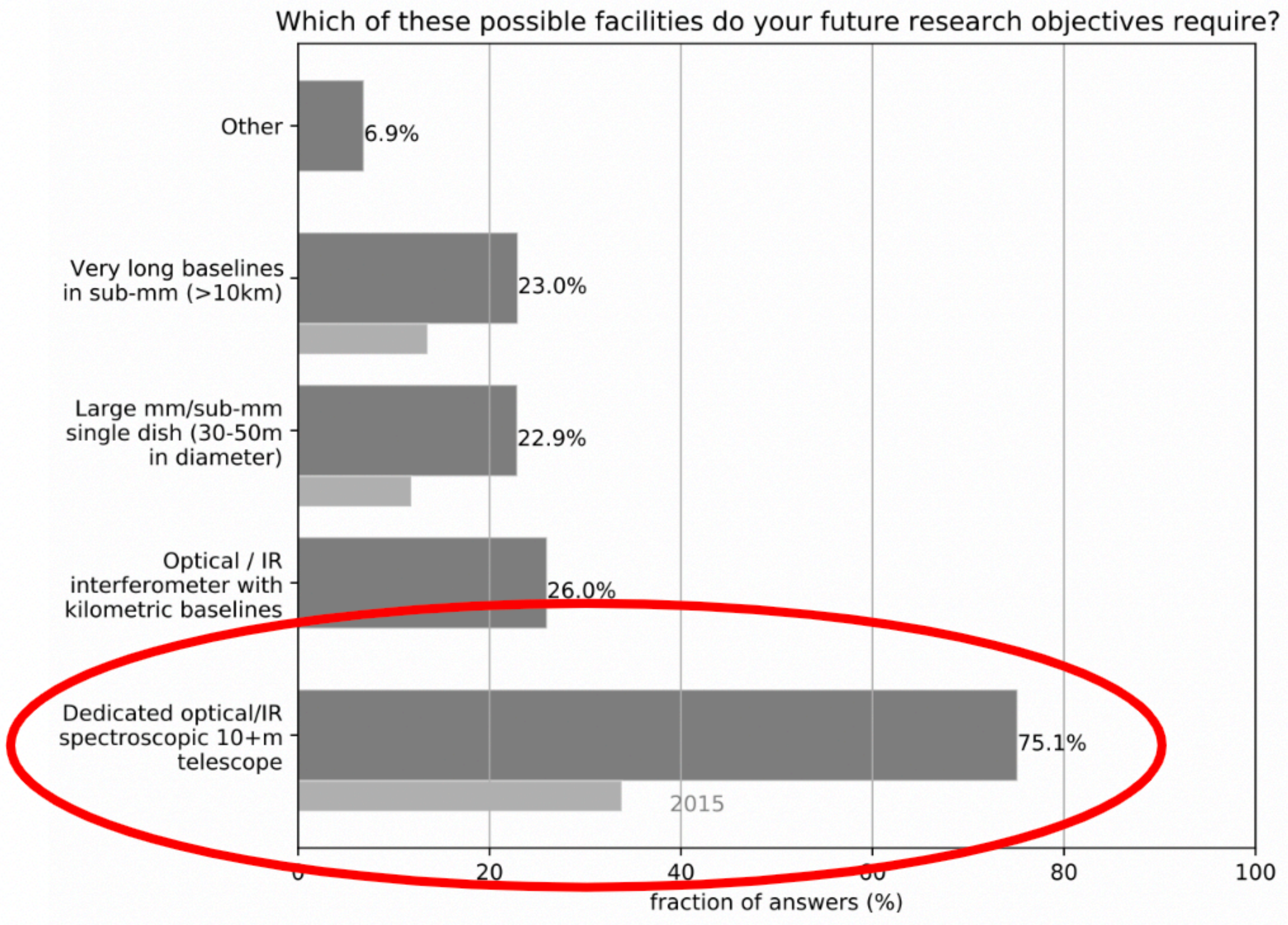
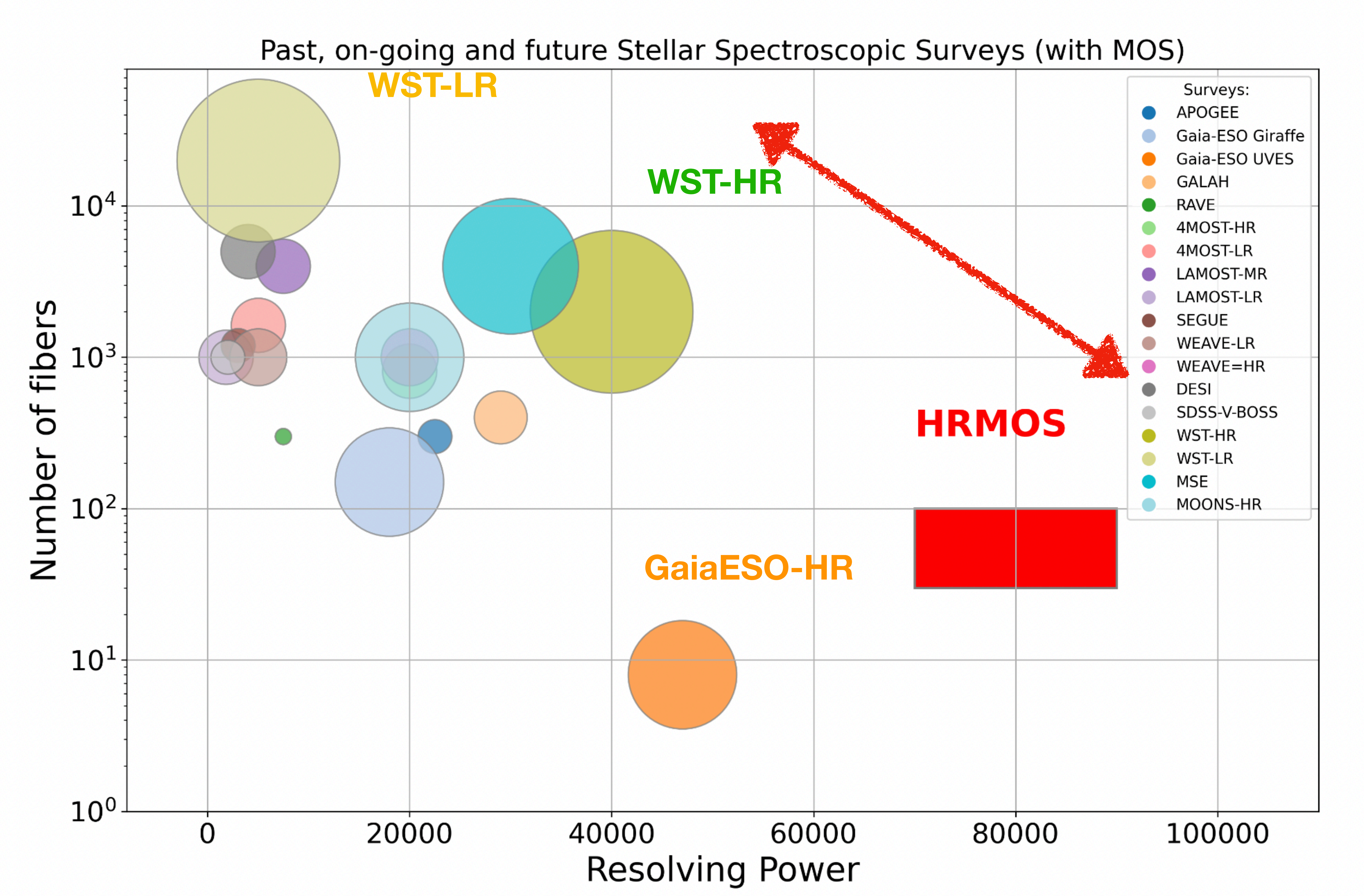
The 2020 ESO community pool



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

The present and future spectroscopic survey panorama



Two new proposals:

The Wide-field spectroscopic telescope

High resolution multi-object spectrograph @VLT

Two different kinds of instruments:

WST

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

-> Follow-up for facilities such as JWST, VRO, Gaia, Euclid.....

R =40000 for the HR MOS

HRMOS

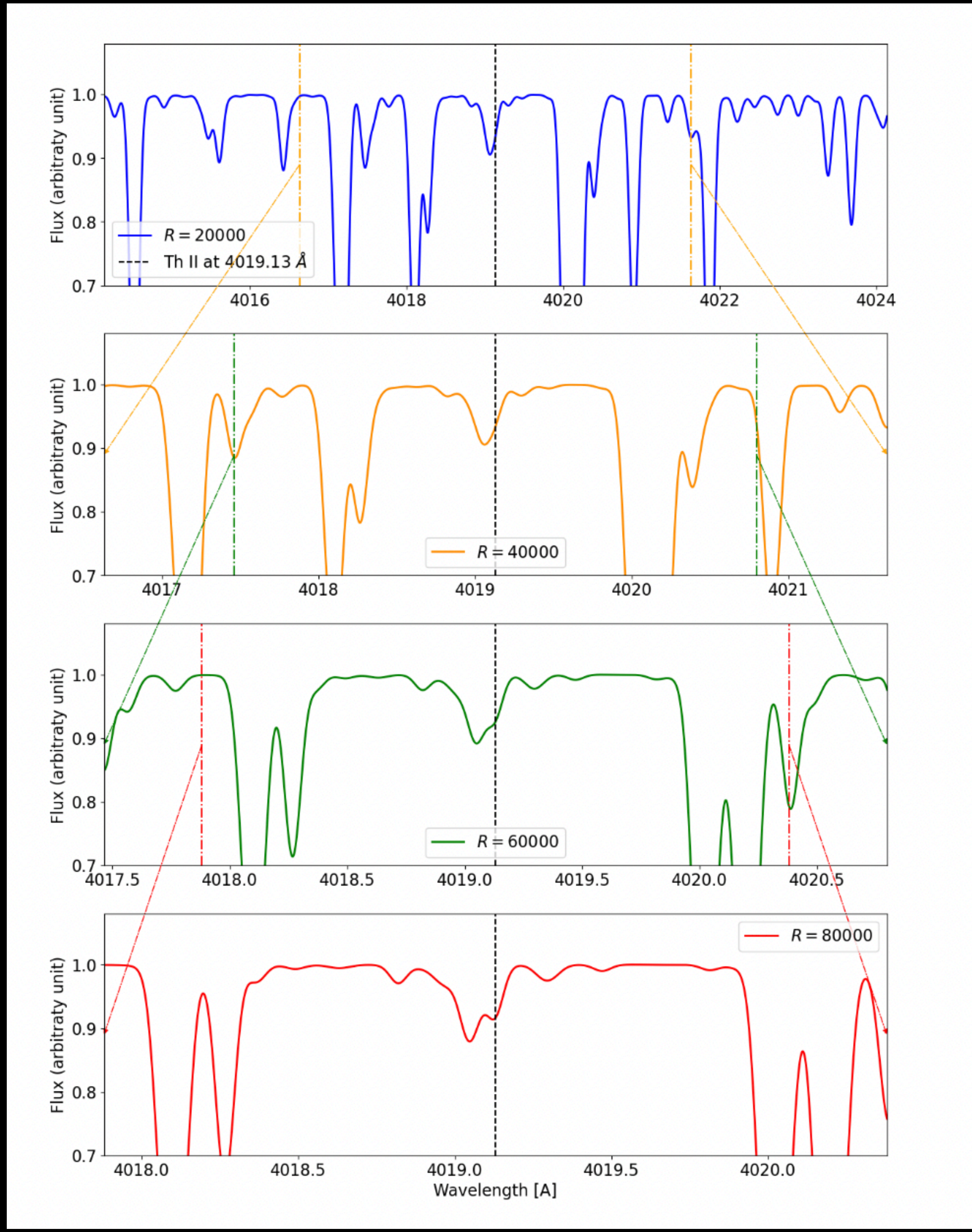
A very high-resolution spectrograph for the new generation instruments @VLT

-> A unique capability for stellar and Galactic science, follow-up of the large spectroscopic surveys at low/medium resolution

R=80000 for the HR MOS

Both replying to the need of high-res spectroscopy

Two different kinds of instruments:



Example:

Independent stellar age estimate with radioactive isotopes (nucleocosmochronology)

The requirements:

Th II isotopic weak line, blended and in the blue part of the spectrum

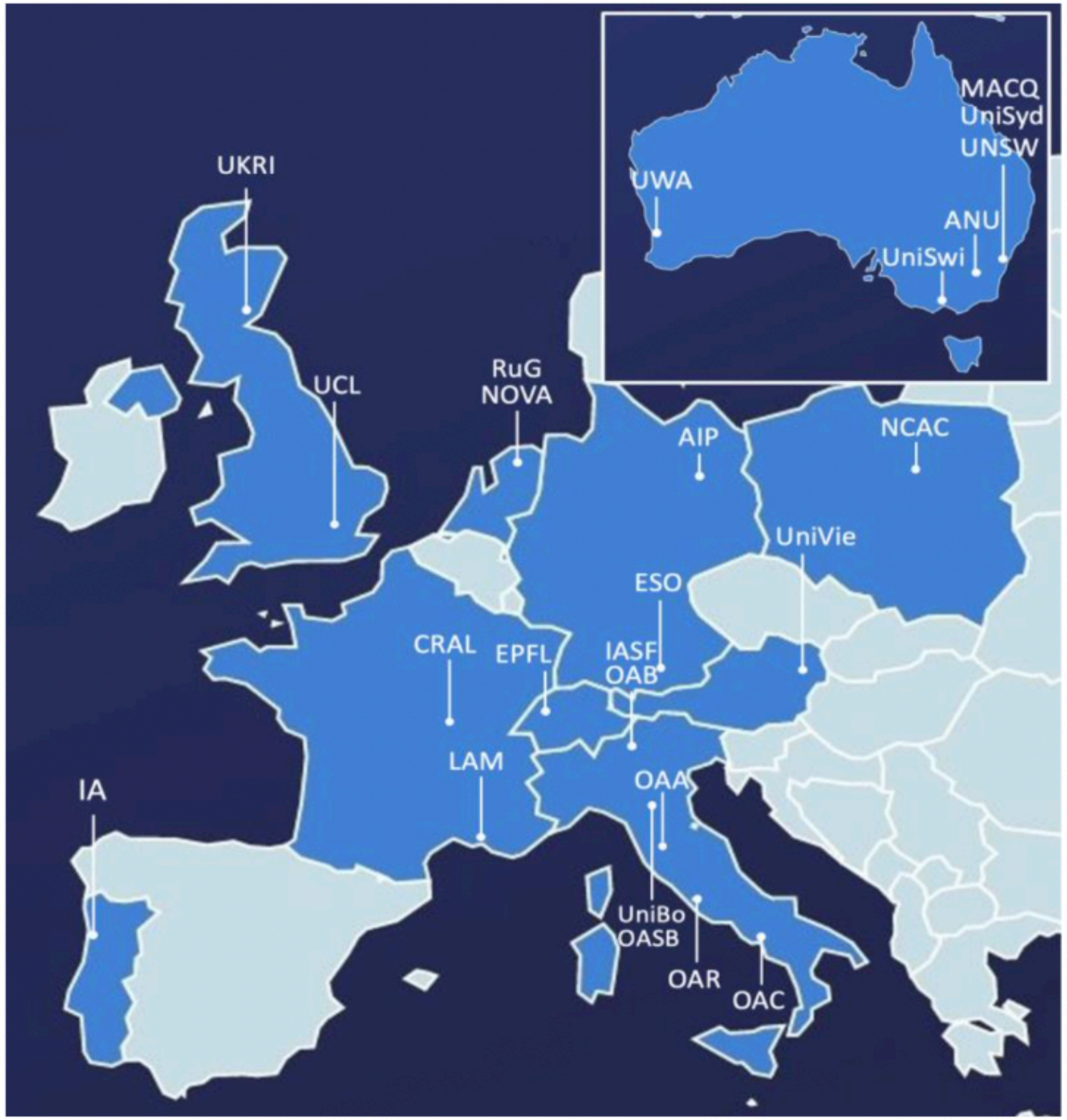
R=80000 and high SNR are needed

Similar but different…from R=40000 to R=80000 things change a lot!

Short history of the project and the consortium

- WST
  - 2021 A consortium is formed in the context of the EU Horizon infrastructure concept call
  - Revised top level requirements: MOS-HR, simultaneous operation of the MOS & IFS
  - 3-year concept study not founded by Horizon 2022
  - Interim-study, to be re[illegible]itted to Horizon in 2024

Submitted on March 11th



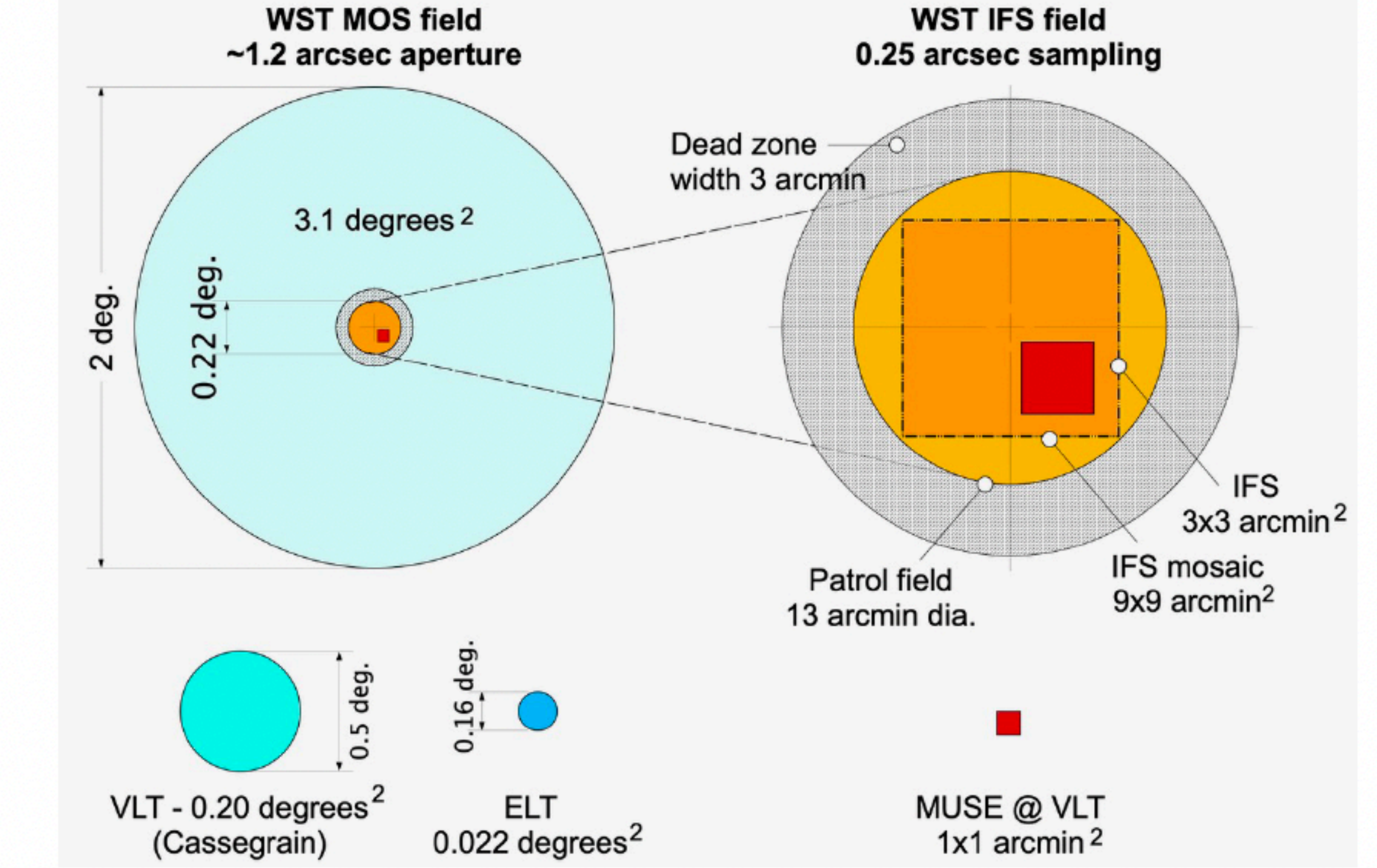
Top level requirements:

Telescope aperture (M1)	12 m seeing limited		
Telescope FoV	3.1 deg^2		
Telescope Spec. range	0.35-1.6 μm		
Operations	MOS and IFS simultaneous operations ToO implemented at telescope and fibre level		
Modes	MOS-LR	MOS-HR	IFS
FoV	3.1 deg^2	3.1 deg^2	3x3 arcmin^2 (mosaic on 9x9 arcmin^2)
Spectral range (simultaneous)	0.37-0.97 μm	0.37-0.97 μm 3-4 windows	0.37-0.97 μm
Spectral resolution	4000	40000	3500
Multiplexing	20000	2000	

Table 1: The baseline top-level requirements for *WST*.

Mainieri et al. (2024), WST white paper

WST FoV: combining the three instruments



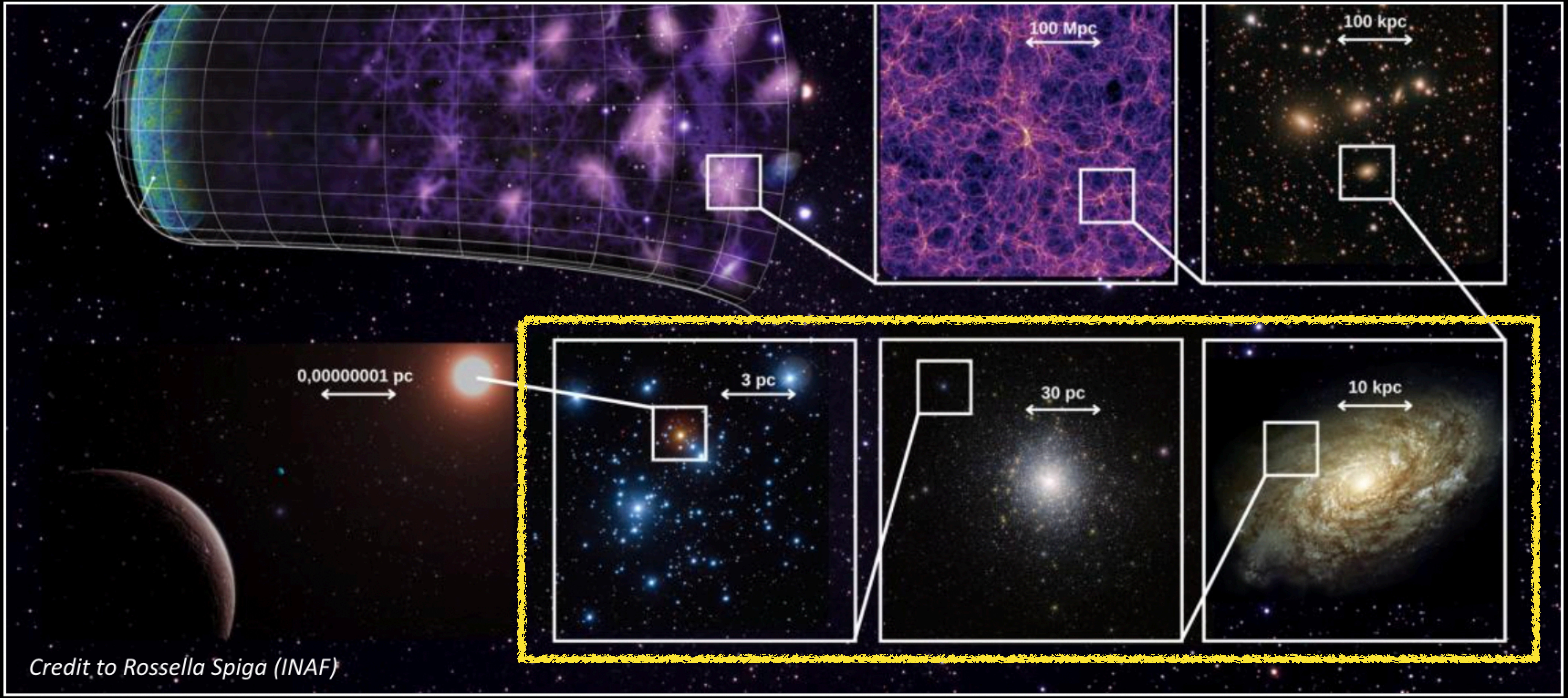
Limiting magnitudes:

- 24.5 (MOS LR)
- 25.2 (IFS)
- In 1 hr, SNR=3

- 19.4 (MOS HR)
- In 1 hr, SNR=30 (per A)

Mainieri et al. (2024), WST white paper

A wide variety of science cases:



A multi-purpose facility covering a wide range of cutting-edge scientific topics

An overview of (some of) the Galactic science cases

3 Exoplanet, Stellar and Galactic Science Case

Authors Rodolfo Smiljanic,[11] Eline Tolstoy[12], Vanessa Hill[6], Tadafumi Matsuno[12], Georges Kordopatis[6], Laura Magrini[14], Richard I. Anderson[2], Francesca Annibali[16], Amelia Bayo[1], Michele Bellazzini[16], Maria Teresa Beltran[14], Leda Berni[24], Simone Bianchi[14], Katia Biazzo[25], Joss Bland-Hawthorn[28], Henri M. J. Boffin[1], Rosaria Bonito[30], Giuseppe Bono[31], Dominic Bowman[32], Vittorio F. Braga[25], Angela Bragaglia[16], Anna Brucalassi[14], Innocenza Busà[35], Giada Casali[19], Viviana Casasola[40], Norberto Castro[41,10], Lorenzo Cavallo[45], Cristina Chiappini[10], Laura Colzi[46], Francesco Damiani[30], Camilla Danielski[14], Ronaldo da Silva[25,51], Roelof S. de Jong[10], Valentina D'Orazi[31,50], Ana Escorza[21,22], Michele Fabrizio[25], Giuliana Fiorentino[25], Francesco Fontani[25], Patrick François[26], Francisco J. Galindo-Guil[57], Daniele Galli[14], Jorge Garcia-Rojas[21,22], Mario Giuseppe Guarcello[30], Amina Helmi[12], Daniela Iglesias[59], Valentin Ivanov[1], Pascale Jablonka[2], Sergei Koposov[9], Sara Lucatello[50], Nicolas Martin[66], Davide Massari[16], Jaroslav Merc[81], Thibault Merle[82,83], Andrea Miglio[84], Ivan Minchev[10], Dante Minniti[86,87,88], Núria Miret Roig[71], Ana Monreal Ibero[89], Ben Montet[90,91], Andres Moya[93], Thomas Nordlander[19], Marco Padovani[14], Anna F. Pala[96], Loredana Prisinzano[30], Roberto Raddi[103], Monica Rainer[104], Sofia Randich[14], Alberto Rebassa-Mansergas[103], Donatella Romano[16], Germano Sacco[14], Jason Sanders[5], Lorenzo Spina[14], Matthias Steinmetz[10], Grazina Tautvaišienė[108], Yuan-Sen Ting[19], Maria Tsantaki[14], Elena Valenti[1], Mathieu van der Swaelmen[14], Chistopher Theissen[109], Guillaume Thomas[21], Sophie Van Eck[82], Carlos Viscasillas Vázquez[108], Haifeng Wang[45], Martin Wendt[121], Nicholas J. Wright[116]

Great participation, covering a large variety of science themes

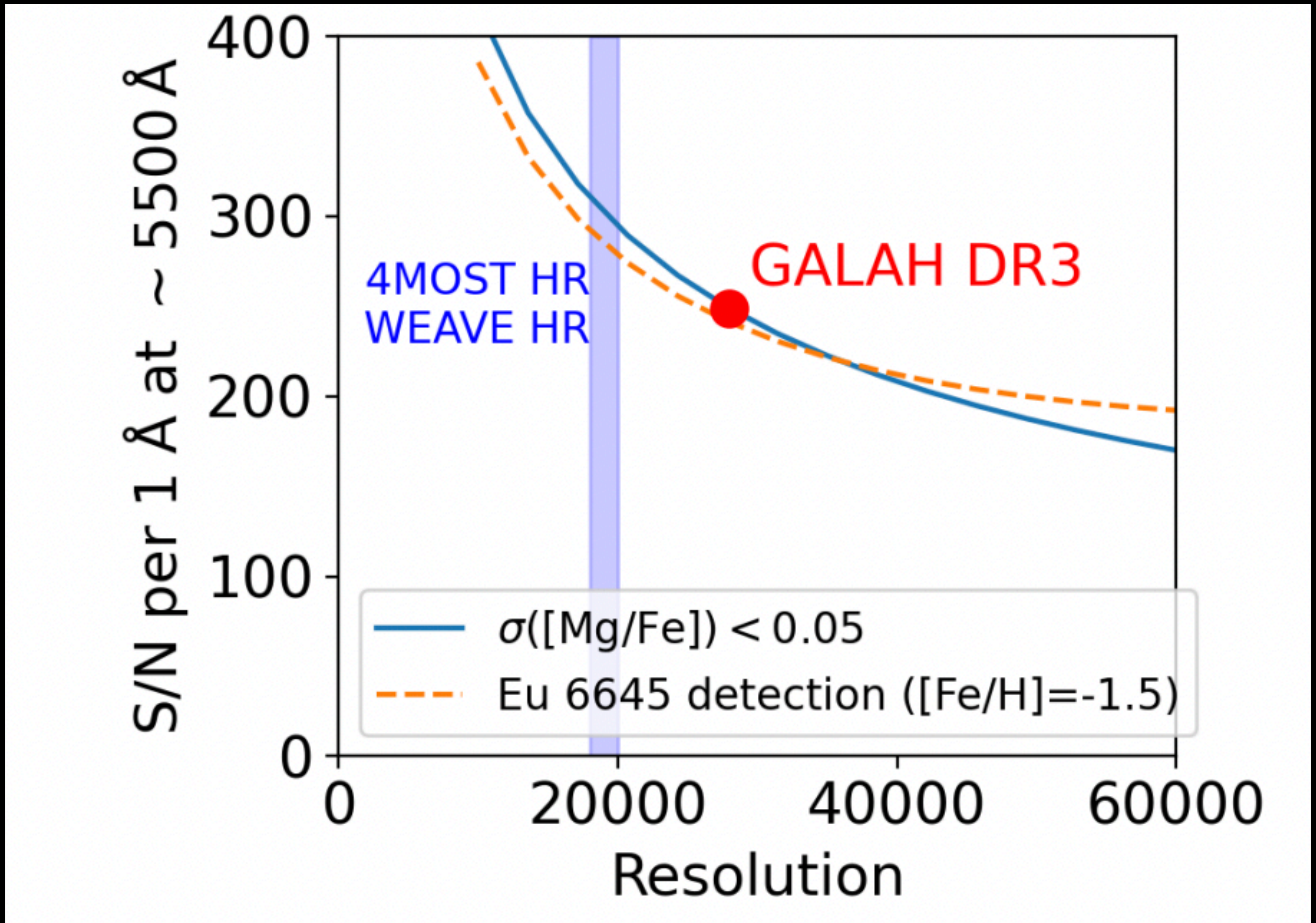
Main requirements:

Precision and detection of weak lines

Powerful combination of high multiplex (1000-2000 objects) over a ~3.1 deg^2 field of view with the large telescope collecting area, and R=40000

In 5−10 years

- ~3.3×10^7 high-quality stellar spectra
- Abundance precision ~0.05 dex
- Elements in all nucleosynthesis channels



In blue: precision in the measurement of [Mg/Fe] as a function R

In orange: detection of typically weak line of a key-element, Eu

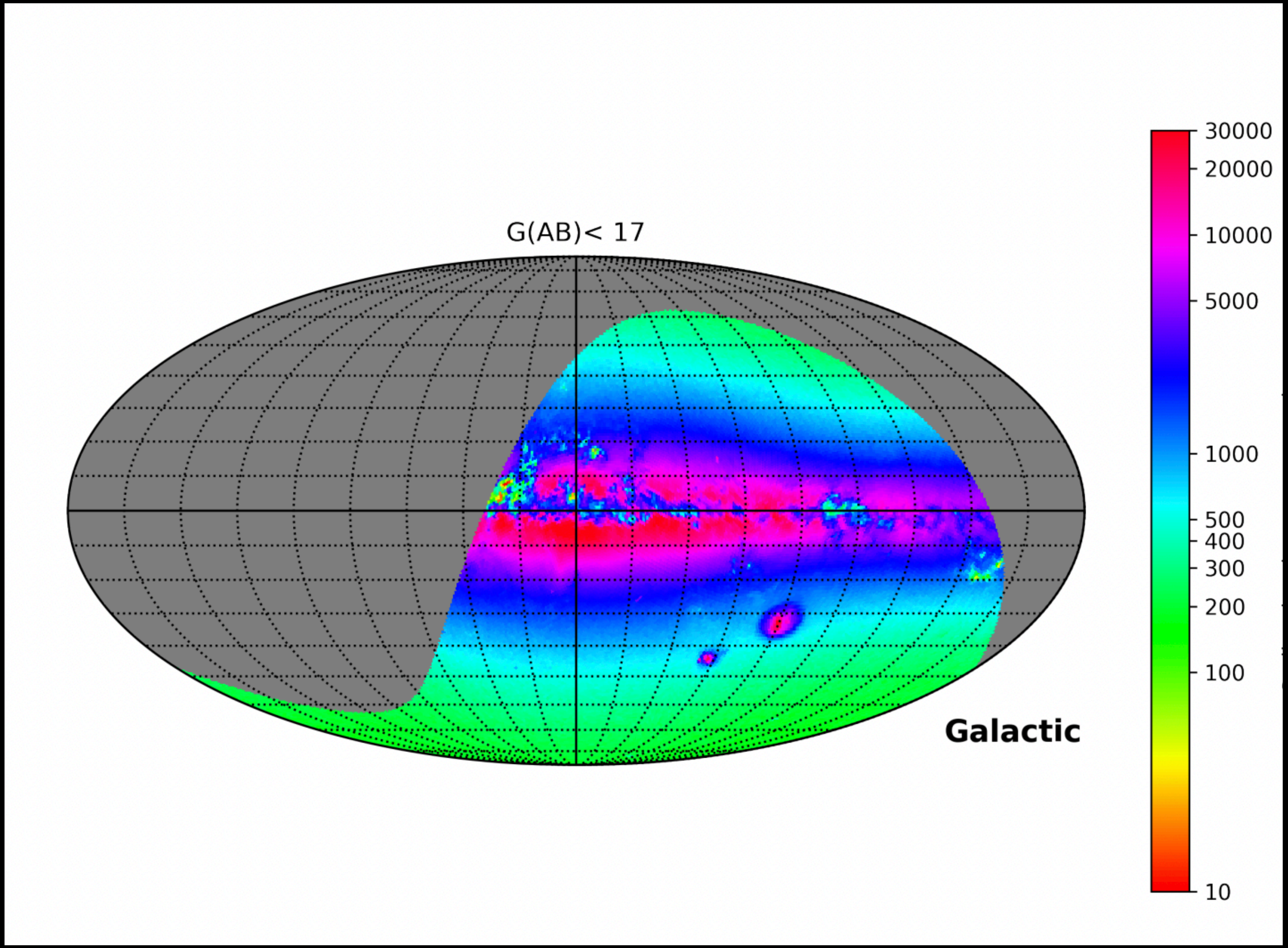
Mainieri et al. (2024), WST white paper

Main requirements:

High-multiplex

1000-2000 fibres over a ~3.1 deg^2 field of view:

- High-coverage in the thin and the thick disc
- Shared strategy in the halo, where the density is lower



Mollweide map of stellar density from Gaia DR3 in Galactic coordinates selected with Dec < 20○ on the sky, showing the stars accessible from the southern hemisphere. The map is colour-coded with stellar density per square degree, G<17 with extinction A0< 2.

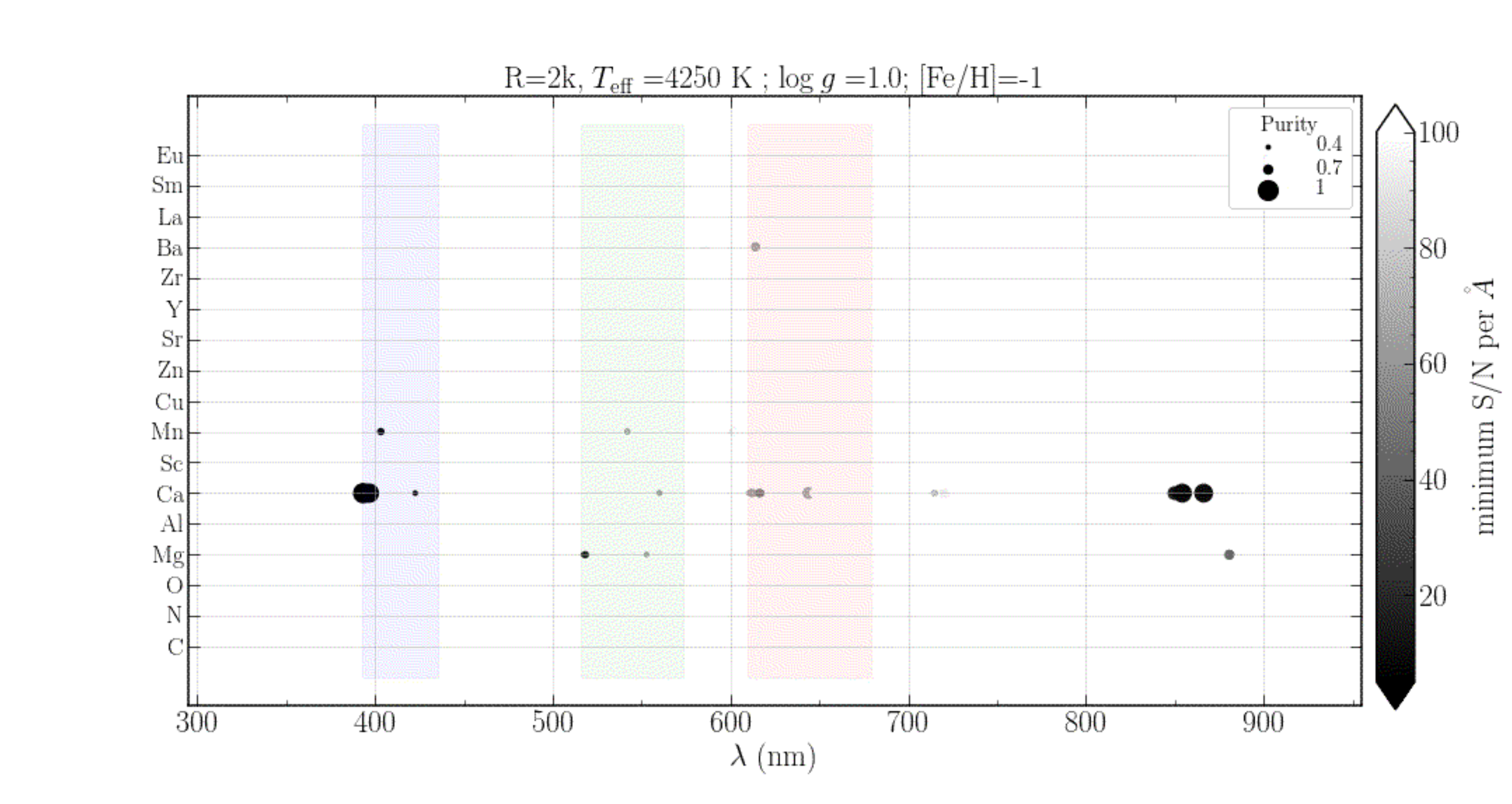
Mainieri et al. (2024), WST white paper

Line detectability as a function of R

Large number of chemical elements

- Abundance precision ~0.05 dex
- Elements in all nucleosynthesis channels

- Chemical tagging
- Characterisation of halo streams and mergers
- Detection and characterisation of tidal tails of open clusters
- Chemical clocks



Courtesy of V. Mainieri from Kordopatis, Hill, Lind 2023

The three main Galactic science cases:

Origin of elements

Origin of Milky Way system

Origin of stars and planets

The three main Galactic science cases:

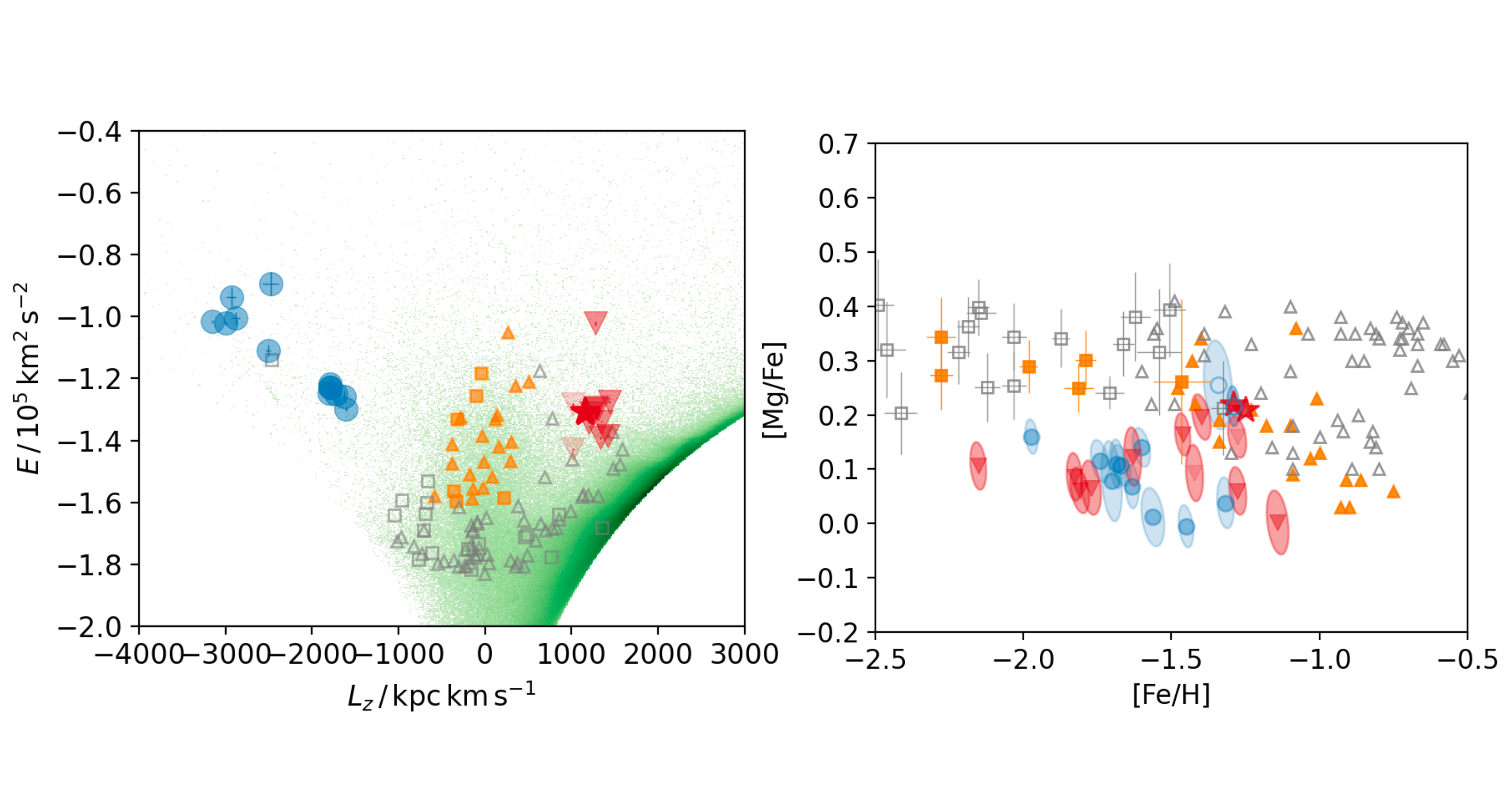
Origin of elements

- Quantifying the relative importance of the various sources of r-process elements (neutron merger stars, magneto-rotational supernovae?)
- The origin of s-process elements in AGB (stellar rotation dependence on metallicity, mixing mechanisms)
- The i-process elements: intermediate processes which need to be investigated
- Insights on supernovae type I nucleosynthesis (their types, and their products, the link with Pop III stars?)

- Key elements: Sr, Y, Zr, Ba, La, Ce, Eu, Gd, Dy, Sm, Os, Th, Pb, Nd, Mg, C, N, O, Na, Mg, Si, Ca, Sc, Mn, Co, Cu, Zn

The three main Galactic science cases:

Origin of Milky Way system

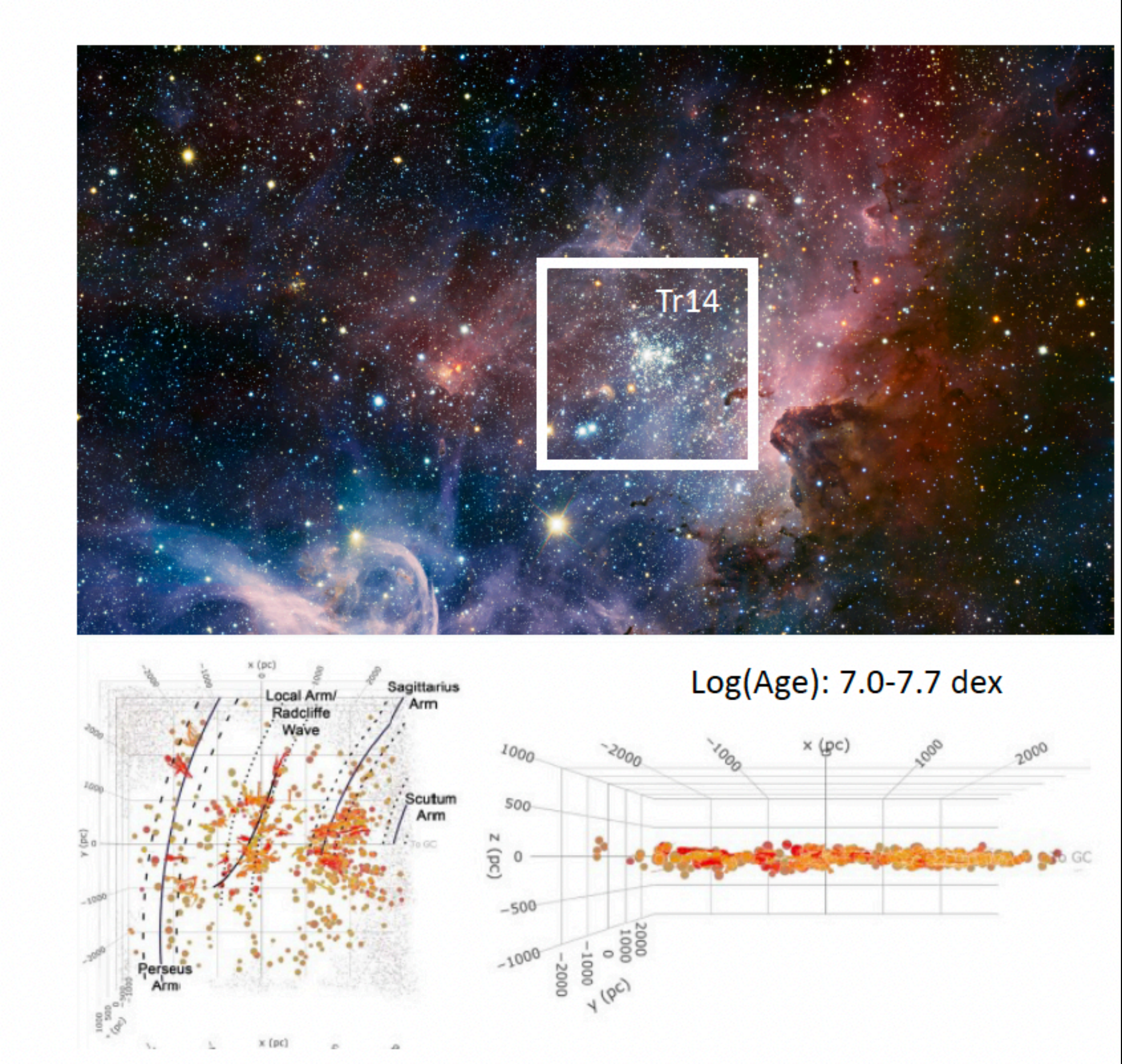


Mainieri et al. (2024), WST white paper

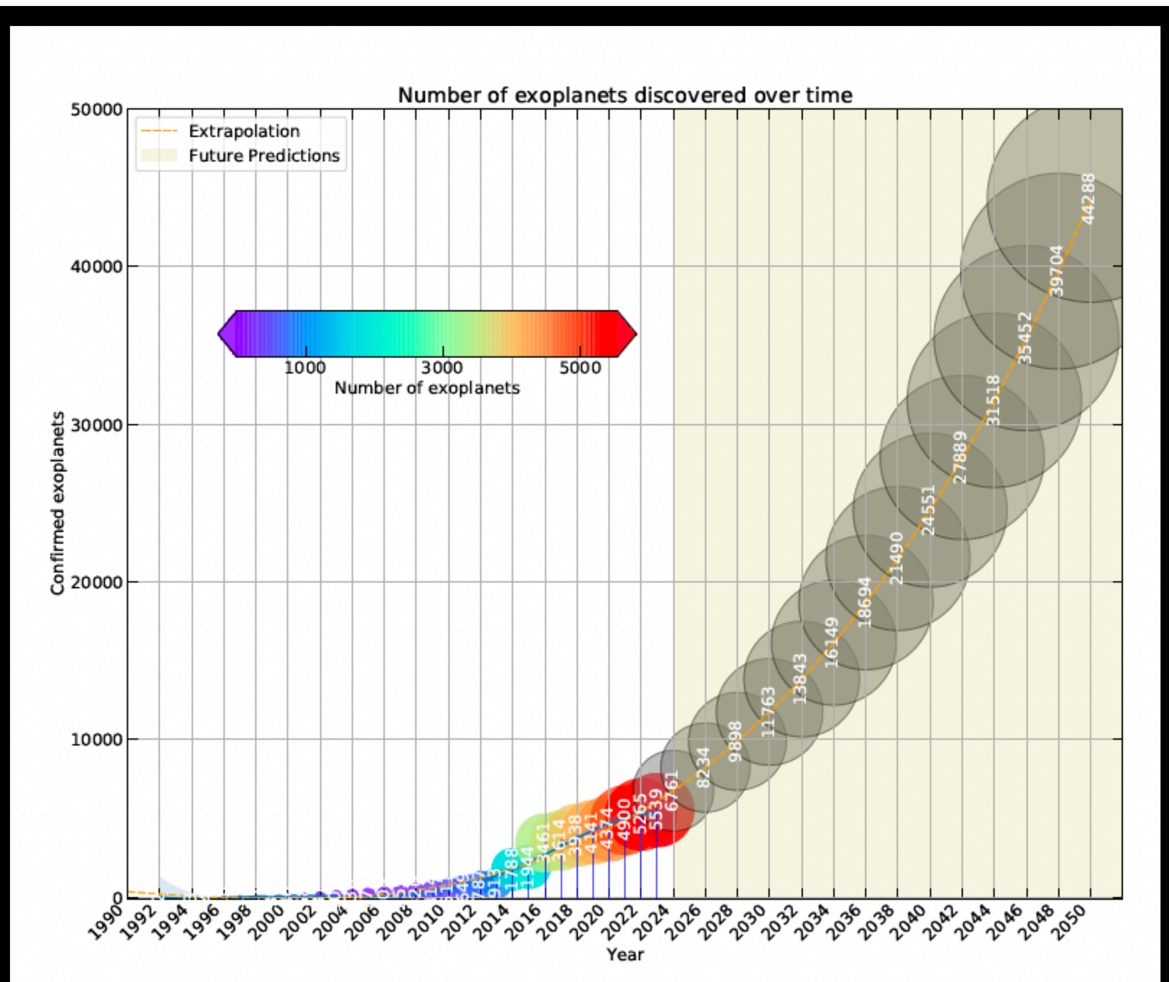
- **Dissecting the Milky Way disc with chemical tagging**: HR spectroscopy to identify related group of stars and reconstruct the star formation history of the disc
- **Characterising the assembly and accretion history of the Milky Way:** high-quality abundances to be used as chemical fingerprint identification of past accretions (combining precise abundances with kinematic properties)
- **Open clusters with their tidal tails and stellar streams:** to trace the Galactic potential, including non Newtonian effects
- **Chemical clocks to measure stellar ages:** s-process/alpha elements and C/N to infer stellar ages

The three main Galactic science cases:

Origin of stars and planets

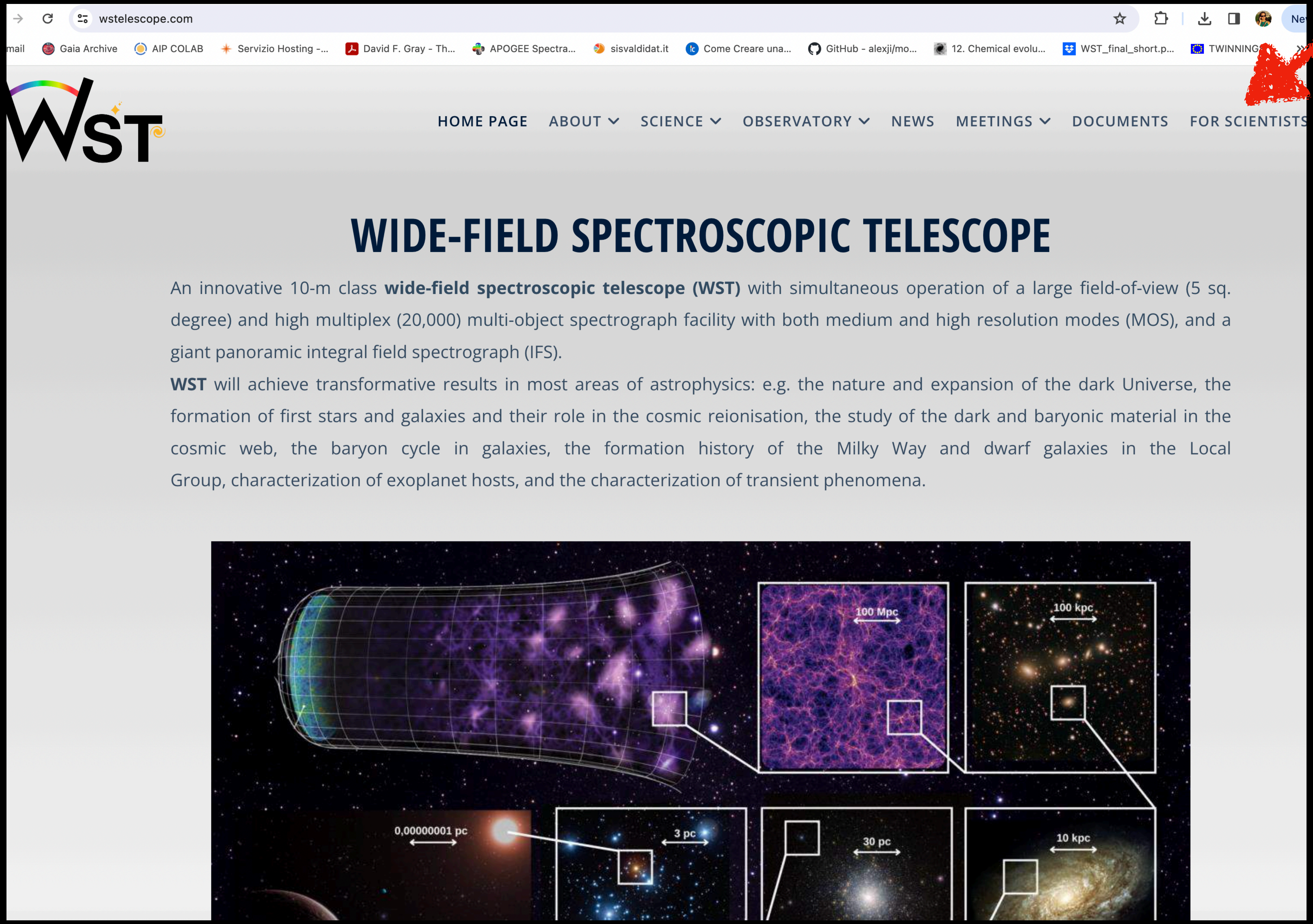


- Investigation the nature of Galactic Strings: HR spectroscopy to measure their composition of the verify their coherence and homogeneity
- Effects of the star formation environment on the properties of stars and planetary system: test on the universality of the IMF, accretion and outflow
- Link host-star chemical composition and planetary systems: full chemical characterisation of planet host stars, link to the definition of Galactic habitable zone (GHZ)



Expected number of exoplanets in the next decades

How to get involved



- **White paper:**
  - *on ArXiv in March 2024*
  - *Proposal for the EU Horizon funding (deadline 12 March 2024, submitted 11 March)*
  - *If you are interested in participating to the Science Team www.wstelescope.com (for scientist)*

White paper: https://arxiv.org/abs/2403.05398

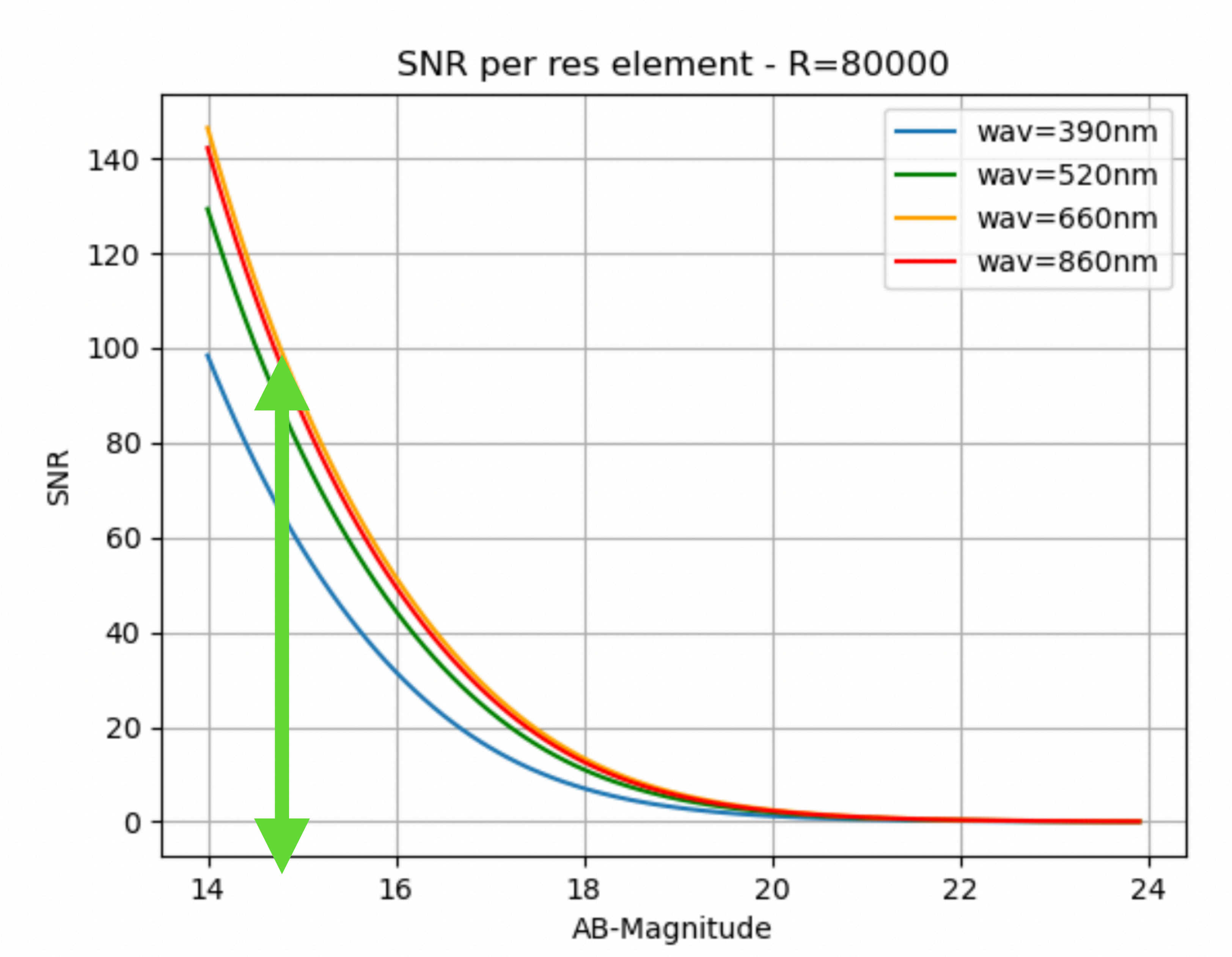
HRMOS

On a different scale...a new MOS spectrograph for VLT:

Key characteristics:

- High spectral resolution (R = 60000 - 80000)
- Multi-object capabilities (20-100 fibers)
- Long term stability with excellent radial velocity precision and accuracy (10 m s^{-1}).
- SNR=100 in about one hour for a star with mag(AB) = 15
- Field of View of about 25 arcmin in diameter

Preliminary ETC



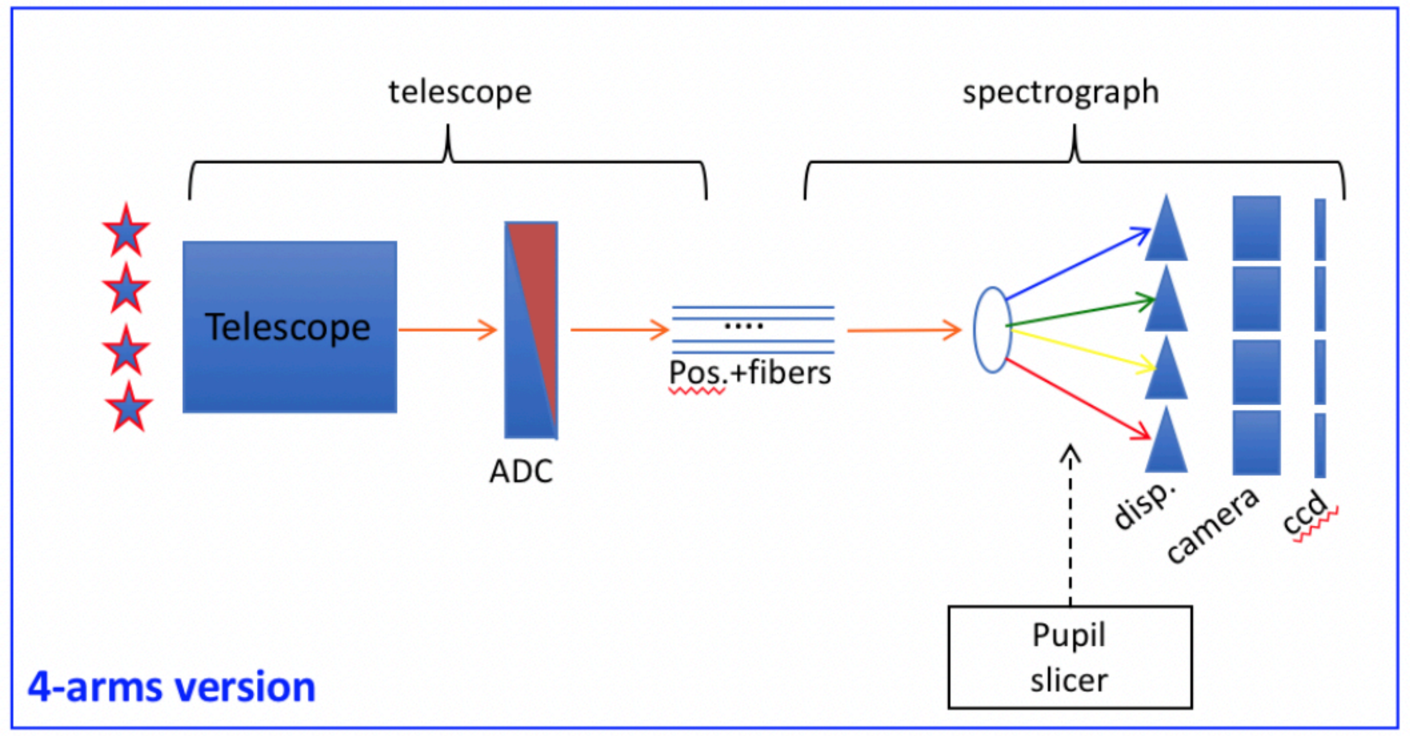
LM et al. (2024), HRMOS white paper

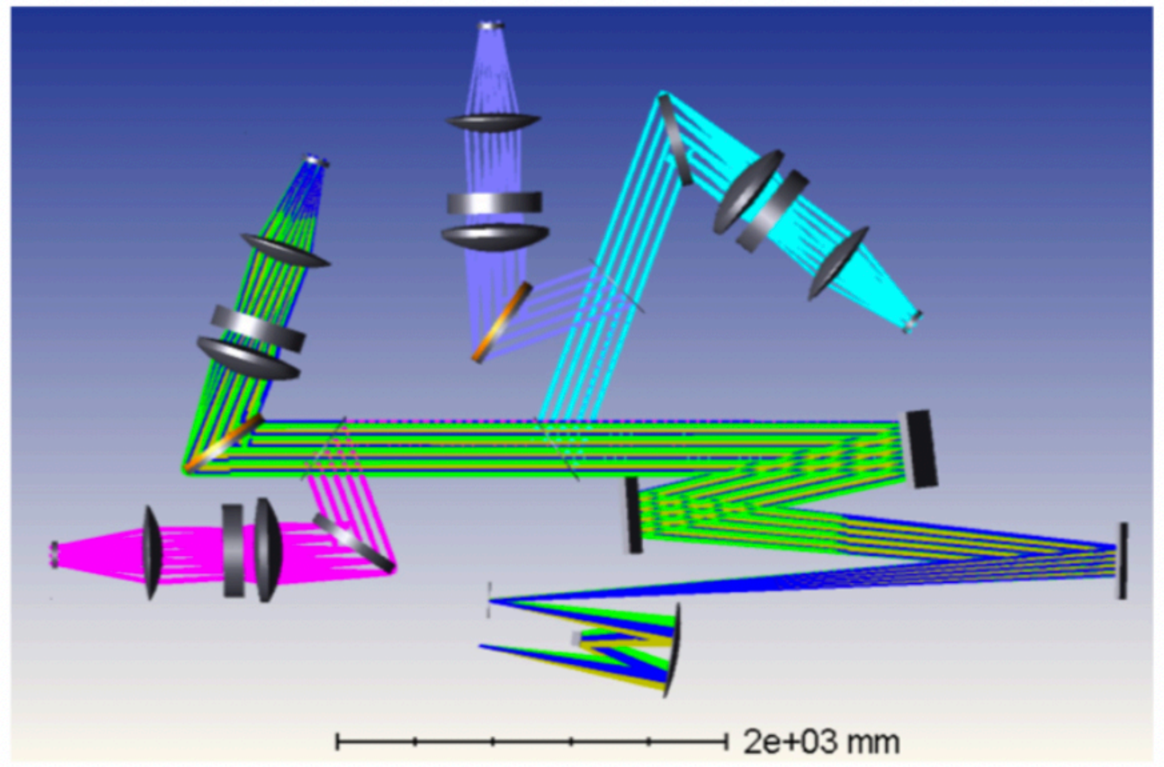
A new MOS spectrograph for VLT:

The four arm design

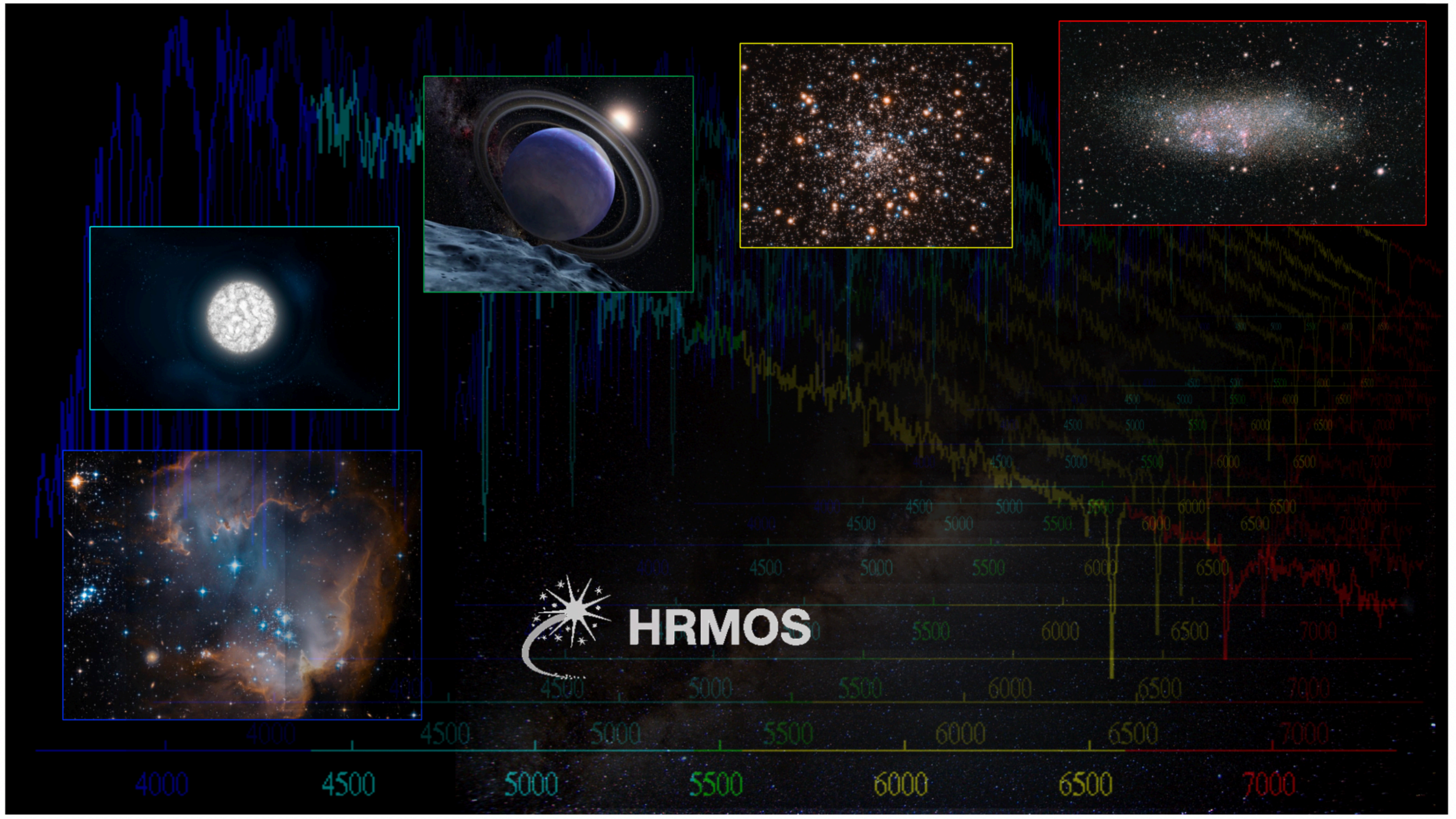
- A wide spectral range in four windows:
  - 770-800 nm: OI triplet, $^{12}C/^{13}C$ isotopic ratio
  - 630-670 nm: Halpha, [OI], CN molecular bands
  - 510-570 nm: C_2 band heads at 516.5 and 563.5 nm
  - 380-420 nm: neutron-capture elements, including Pb and Th
  - very large simultaneous wavelength coverage (110 nm) and thus, for the same field, shorter observing times to cover the full wavelength range.

The 4 arms configuration





HRMOS



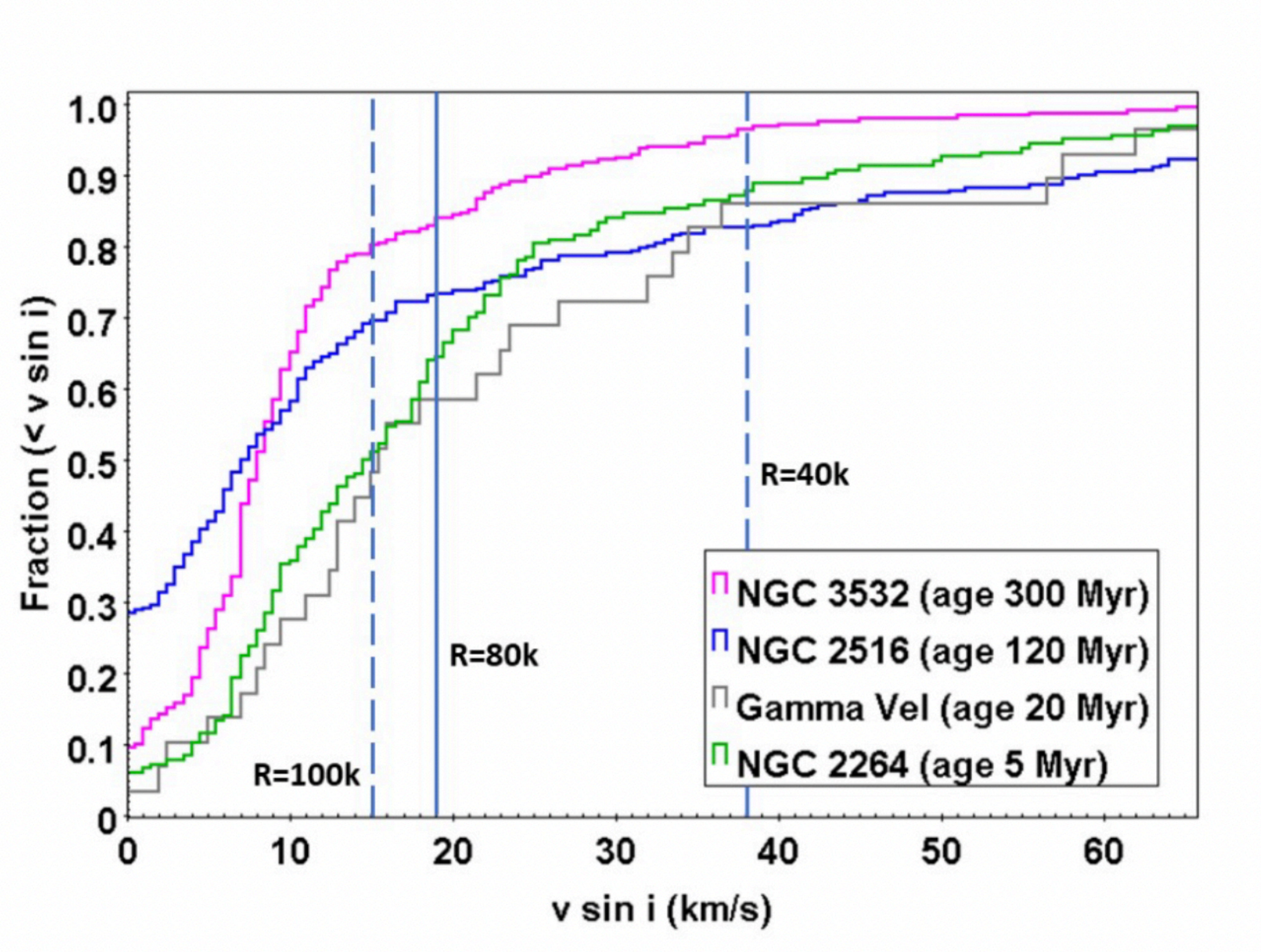
- High precision abundances
- with expected errors < 0.05 dex, going down to 0.01 dex

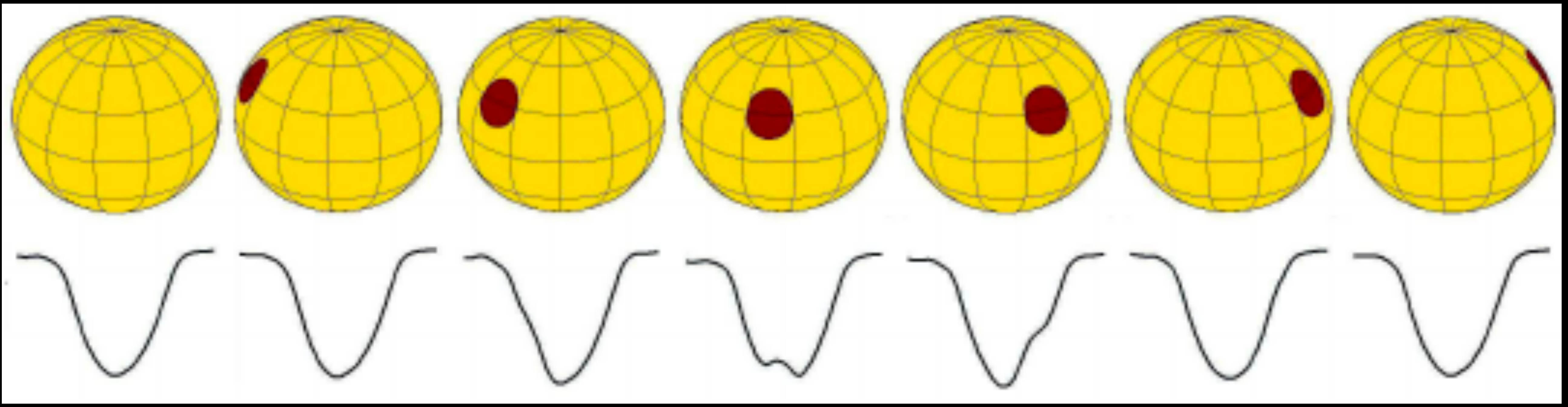
- High precision radial velocities, down to 10 m s-1
- High stability (long term for planet detection)

HRMOS

(A selection of) main Science cases (proposed so far)

- **Young stellar populations:**
  - Resolving magnetic structures with Doppler tomography and map the dynamos, starspots, prominences, magnetospheres, jets and winds of young star
  - Testing the magnetospheric accretion and the star-disc interaction resolving the emission line profiles (Balmer lines and collisional excited lines)

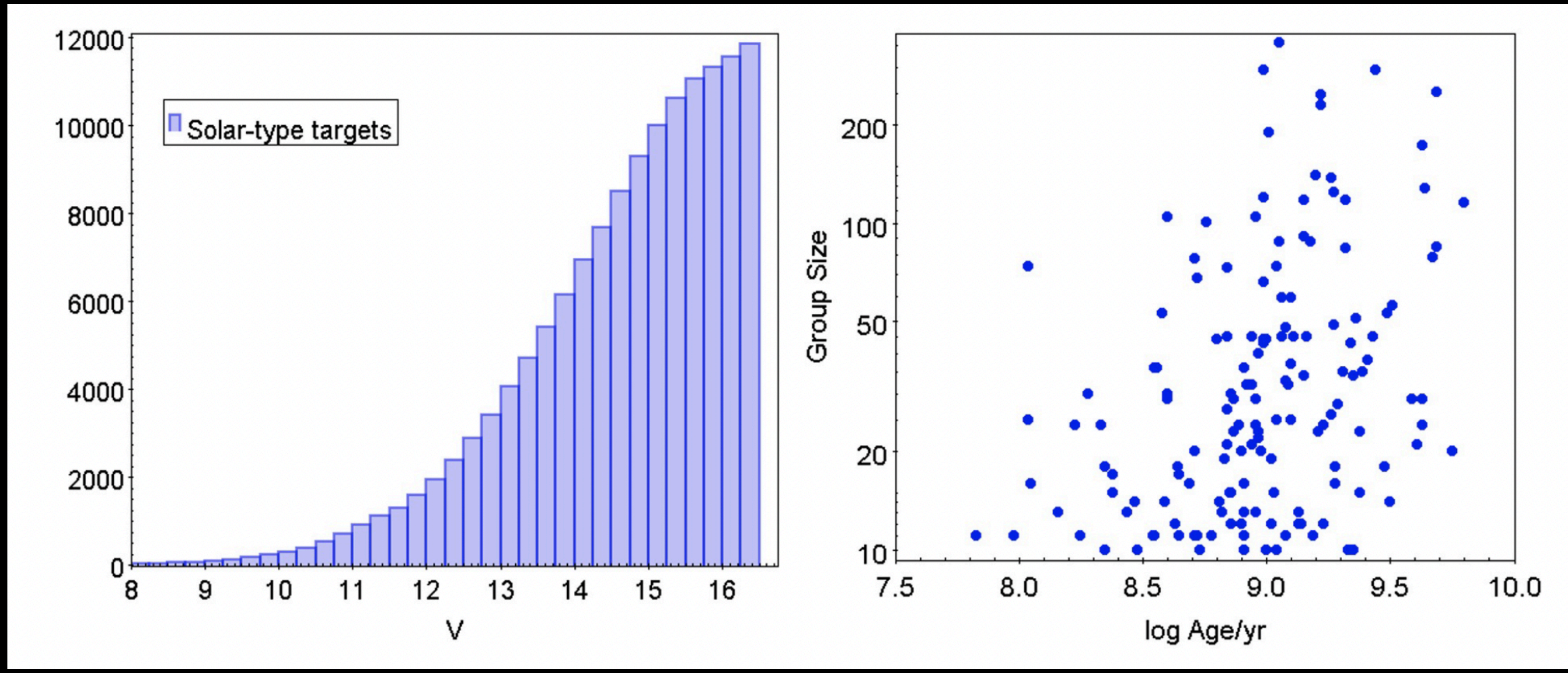




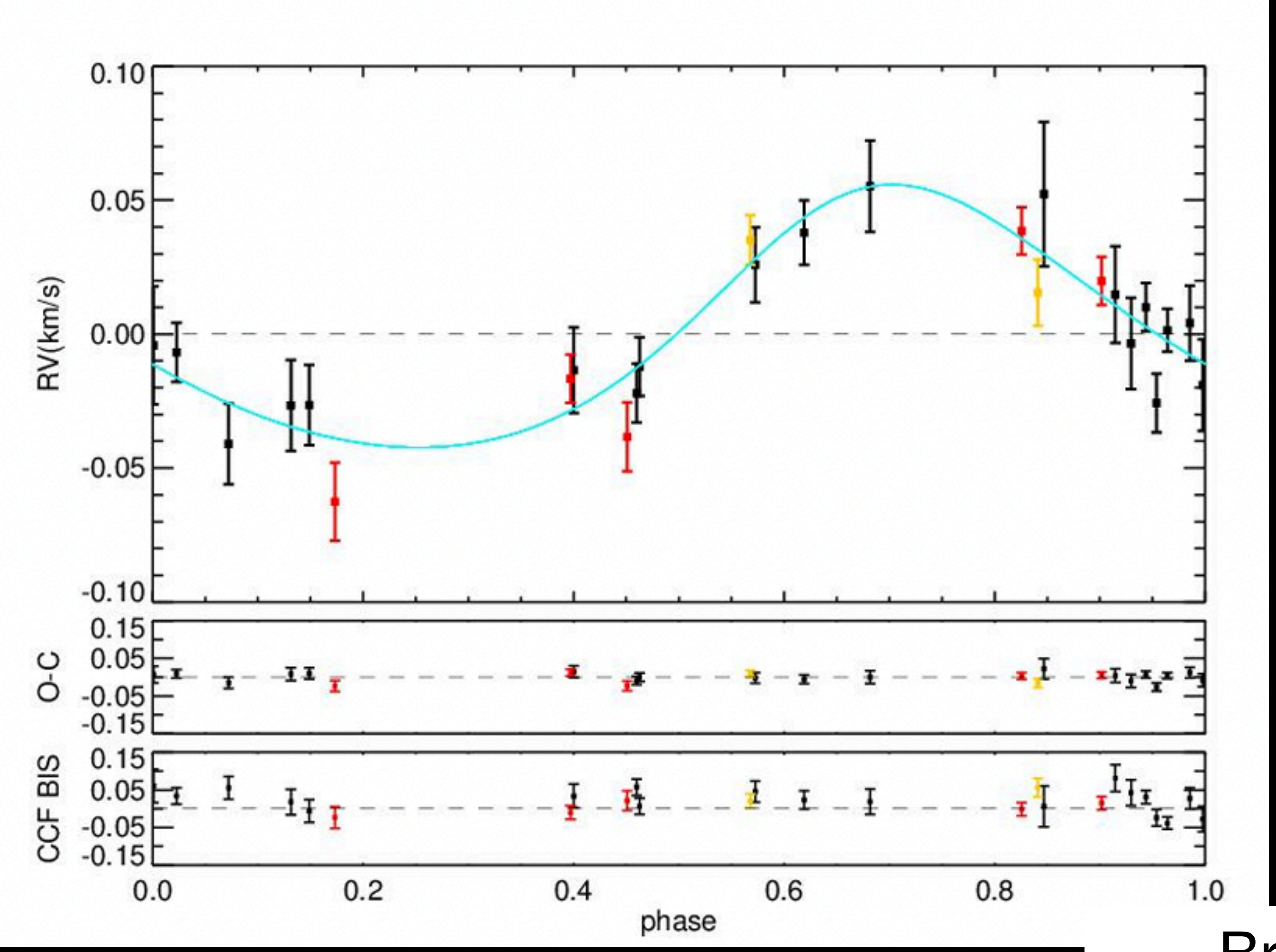
- **Systematic investigation in nearby star clusters**
- **Relations with age, mass and environment**

(A selection of) main Science cases (proposed so far)

- **Exoplanet populations in our Galaxy (and in other galaxies)**
  - Searching for exoplanet in star clusters to discriminate the importance of various mechanisms and empirically calibrate the timescales of planet formation/evolution/migration
  - Seeking connection between stellar properties and planetary system properties (chemistry, mass, age, environment, magnetic activity)



The cumulative frequency of apparent magnitude for suitable solar-type cluster targets for HRMOS in the southern hemisphere.
Right: The number of targets within a single VLT FoV plotted versus the age of the cluster



Brucalassi et al. 2016

- **High mass exoplanets with orbital periods less than ~100 days**
- **> 140 clusters can be reached (ages from 0.1 to 6.5 Gyr) [at least 10 targets in HRMOS FoV]**

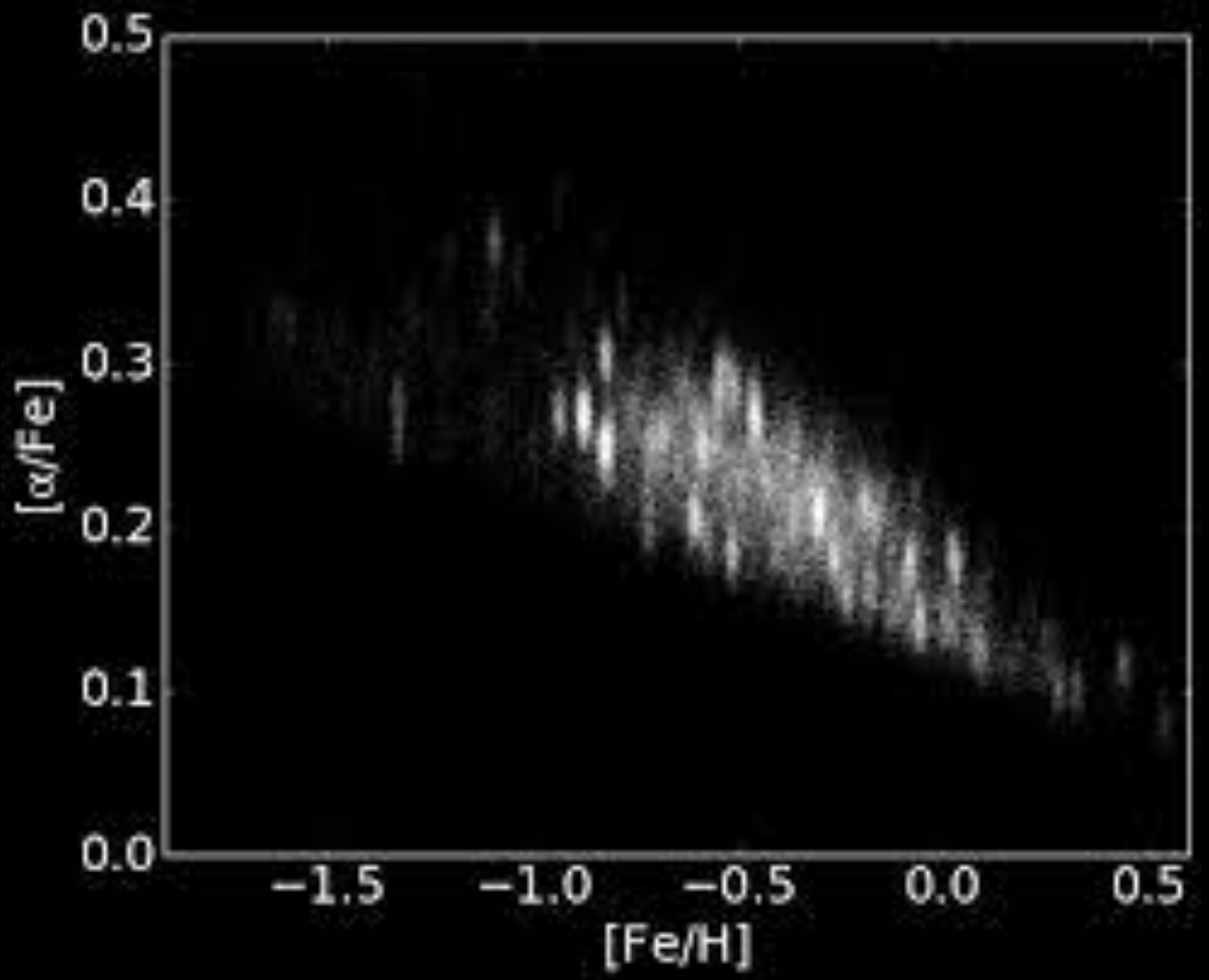
(A selection of) main Science cases (proposed so far)

- **Deep investigation of the properties of star clusters**

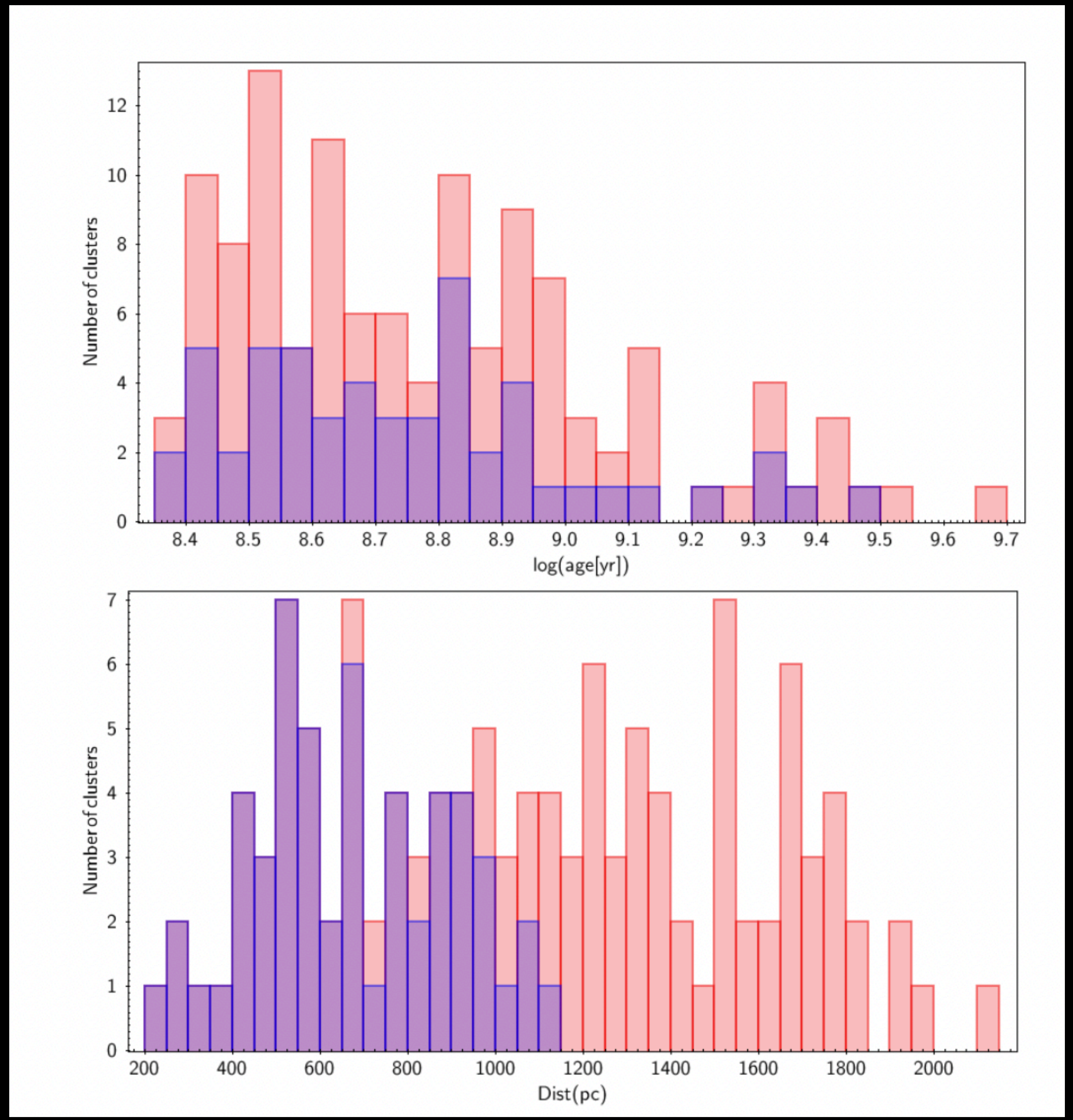
Chemical tagging:

- Internal homogeneity
- Chemical abundances to trace back the formation sites
- open clusters to design the best strategies for chemical tagging

Internal processes (Mixing and atomic diffusion)

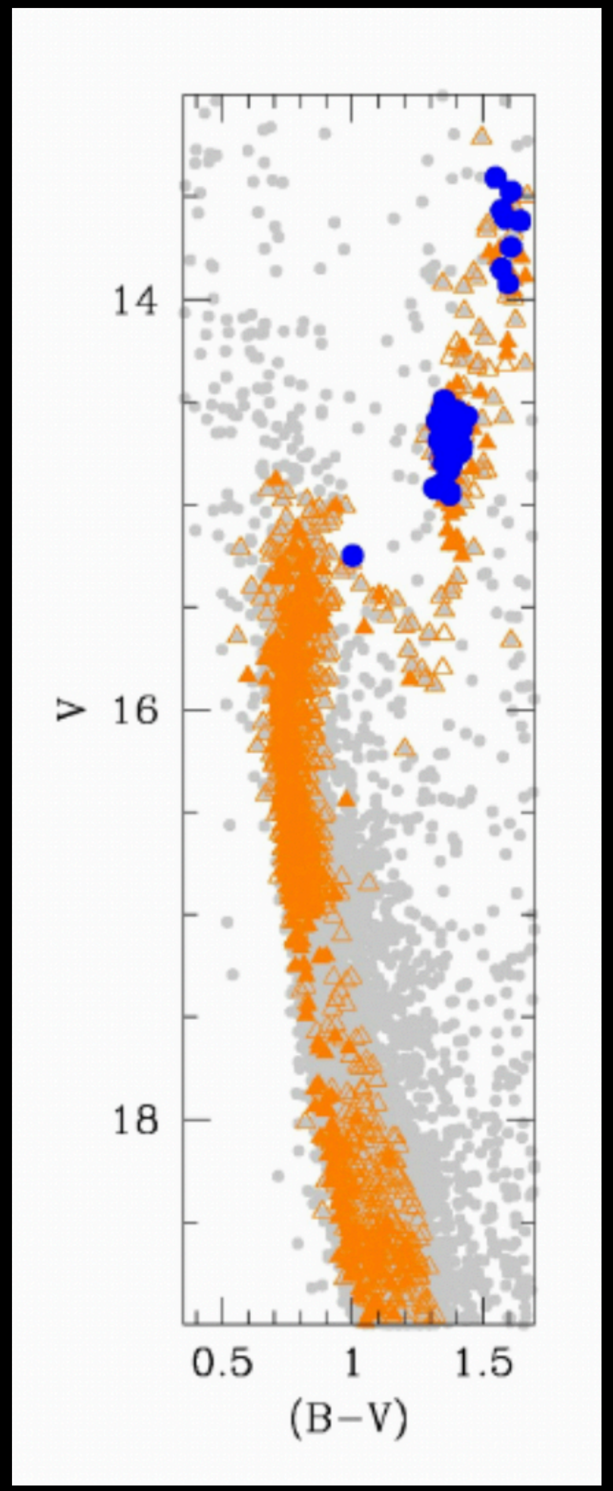


Courtesy Y-S. Ting



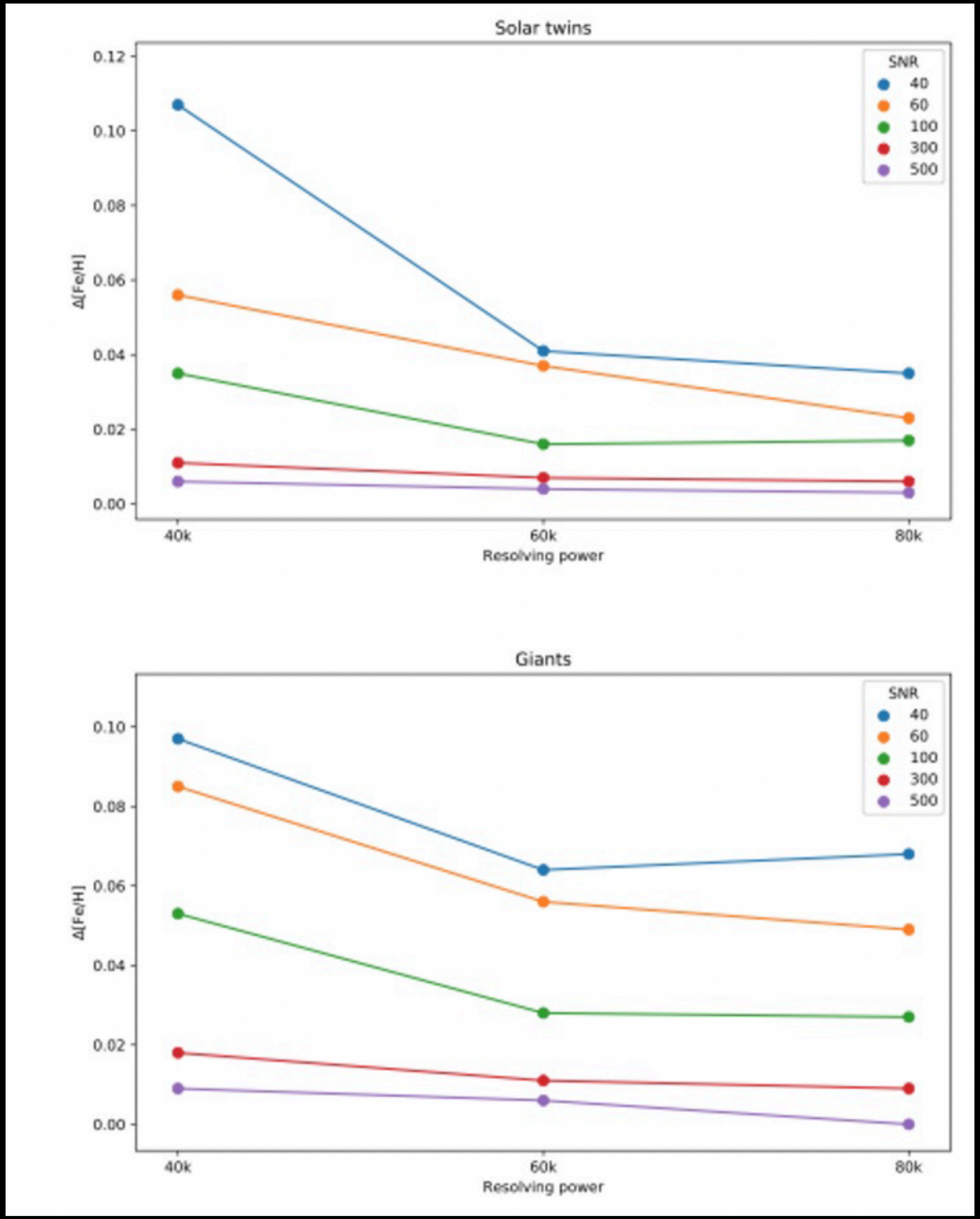
Age distributions (upper panel) and distance distributions (lower panel) for the proposed samples of open clusters (in red the sample of 120 clusters, considering a limiting magnitude of mag(AB)=17, and in blue mag(AB)=15)

Trumpler 20 (in Gaia-ESO)



(A selection of) main Science cases (proposed so far)

- **Deep investigation of the properties of star clusters**
  - *Need of precise abundances to investigate the degree of intra and inter-homogeneity*
  - *Design of method based on differential analysis (line-by-line analysis on similar stars)*
  - *To reach precision in abundances better than 0.05 dex with SNR=100, we need R > 60000-80000*



- **New strategy to investigate the abundances variation in young stars**
  - *Testing the effects of triggered star formation in extended clusters/regions*
  - *Differential analysis considering the stellar activity*

How to get involved

Project Coordinator
Sofia Randich (INAF)

- **Science Team Coordinators**
  Thomas Bensby (SE)
  Laura Magrini (INAF)
  - **Star clusters and stellar physics**
    Laura Magrini (IT), Nadège Lagarde (FR)
  - **Dwarf Galaxies and LG**
    Asa Sküladottir (IT), Vanessa Hill (FR)
  - **Young stars and exoplanets**
    Rob Jeffries (UK), Sergio Sousa (PT)
  - **Galactic Science**
    Thomas Bensby (SE),
    Gayandhi Da Silva (AU)
  - Simulation group
    Rodolfo Smiljanic (PL), Oscar Gonzales (UK)
- **Technical Team Coordinator**
  Andrea Tozzi (INAF)
  - Spectrograph: INAF
  - Front-end: STFC-ROE
  - ETC:
    INAF

- **White paper:**
  - *on ArXiv in December 2023*
  - *Proposal for the next ESO call for new instruments (end of 2024?)*
  - *If you are interested in participating to the Science Team send an email:*
  - *sofia.randich@inaf.it*
  - *laura.magrini@inaf.it*
  - *thomas.bensby@fysik.lu.se*

White paper: https://arxiv.org/abs/2312.08270


Thank you!