Stellar Clusters in 4MOST

Angela Bragaglia
INAF-OAS Bologna
(on behalf of the survey)

Astrophysics Talk - Bologna, 1 March 2022

INAF
ISTITUTO NAZIONALE
DI ASTROFISICA


Galactic Archeology
Gaia complement

4MOST


Galactic Archeology
Gaia complement


High-energy sky
eROSITA complement


Cosmology and galaxy evolution
Euclid complement
LSST/SKA/Etc.

4MOST: 4-metre Multi-Object Spectroscopic Telescope

Name	Function	Affiliation
Roelof de Jong	4MOST Principal Investigator	AIP
Joar Brynnel	4MOST Project Manager	AIP
Karin Lind	4MOST Galactic Project Scientist	SU
Jon Loveday	4MOST Extragalactic Project Scientist	US
Jakob Walcher	Operations Manager	AIP

4MOST

Instrument parameter	Design value
Field of view (hexagon)	~4.2 square degrees (Ø = 2.6 degrees)
Accessible sky (zenith angle < 55 degrees)	> 30 000 square degrees
Expected on-target fibre-hours per year	LRS: > 3 200 000 h yr^{-1}, HRS > 1 600 000 h yr^{-1}
Multiplex fibre positioner	2436 (1624 LR + 812 HR)
Low-Resolution Spectrographs LRS (× 2)	
Resolution	<*R*> = 6500
Number of fibres	812 fibres (x2: 1624)
Passband	3700–9500 Å
Velocity accuracy	< 1 km s^{-1}
Mean sensitivity 6 × 20 min, mean seeing, new moon, S/N = 10 $Å^{-1}$ (AB-magnitude)	4000 Å: 20.2, 5000 Å: 20.4, 6000 Å: 20.4, 7000 Å: 20.2, 8000 Å: 20.2, 9000 Å: 19.8
High-Resolution Spectrograph HRS (× 1)	
Resolution	<*R*> = 20000
Number of fibres	812 fibres
Passband	3926–4355, 5160–5730, 6100–6790 Å
Velocity accuracy	< 1 km s^{-1}
Mean sensitivity 6 × 20 min, mean seeing, 80% moon, S/N = 100 $Å^{-1}$ (AB-magnitude)	4200 Å: 15.7, 5400 Å: 15.8, 6500 Å: 15.8
Smallest target separation	15 arcseconds on any side
# of fibres in random Ø = 2 arcminute circle	≥ 3
Fibre diameter	Ø = 1.45 arcseconds

The **4MOST** instrument will be on 4m VISTA

4MOST will operate in **public survey mode**

The **4MOST Consortium** has **70%** of time in first 5 years of operation

30% is open to surveys:

15 just approved (8 as full survey, 7 as sub-survey)

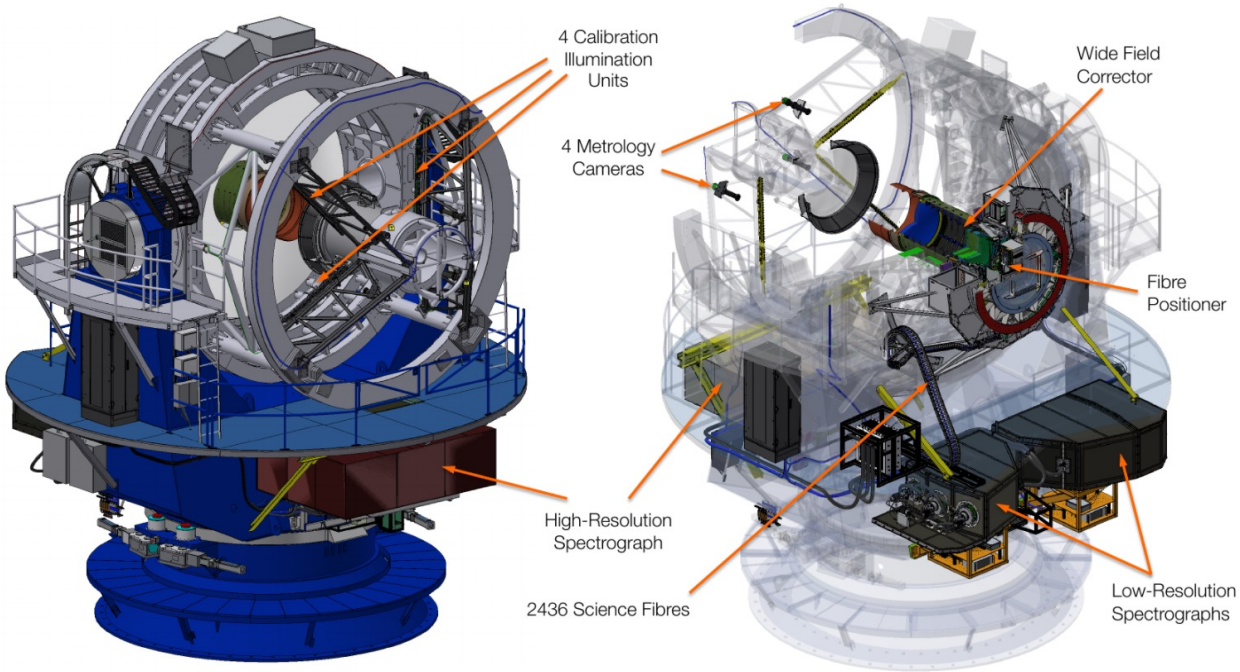
https://www.4most.eu/cms/

4most.eu/cms/

4MOST - 4-metre Multi-Object Spectroscopic Telescope

Home | News | Science | Facility | Operations | Publications | Collaboration | Team | Help | Internal | Mgmt | Angela Bragaglia

Overview



The 4MOST consortium has been selected by the European Southern Observatory (ESO) to provide the ESO community with a fibre-fed spectroscopic survey facility on the VISTA telescope with a large enough field-of-view to survey a large fraction of the southern sky in a few years. The facility will be able to simultaneously obtain spectra of ~2400 objects distributed over an hexagonal field-of-view of 4.2 square degrees. This high multiplex of 4MOST, combined with its high spectral resolution, will enable detection of chemical and kinematic substructure in the stellar halo, bulge and thin and thick discs of the Milky Way, thus help unravel the origin of our home galaxy. The instrument will also have enough wavelength coverage to secure velocities of extra-galactic objects over a large range in redshift, thus enabling measurements of the evolution of galaxies, black holes, and the structure of the cosmos.

Search

Search for

Register Account

Please visit the registration page to obtain a 4MOST account.

Project Culture

4MOST has a Code of Conduct and Ombudspersons.

Important Dates

23–25 May 2022: Science Team Meeting in Hamburg

19–23 Sep 2022: All-Hands Meeting in Potsdam

News

Community Surveys selected 2022-02-04

SPIE 2022 2022-02-03

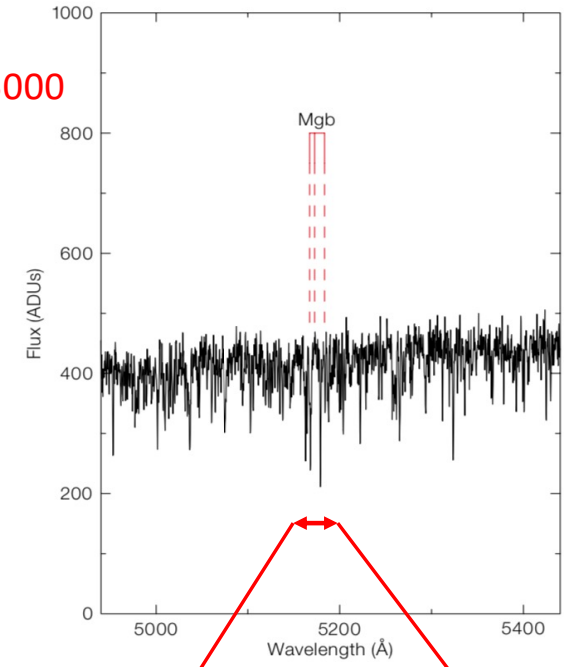
LRS-A Local Acceptance Review 2021-12-20

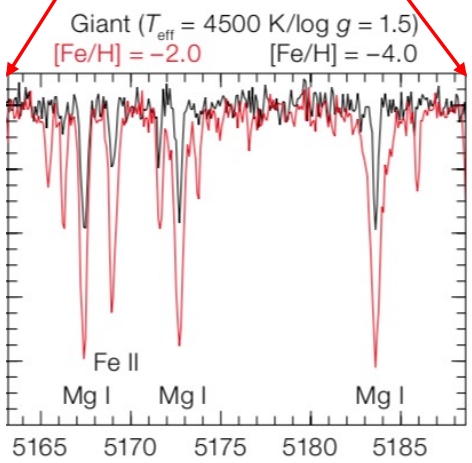
4MOST Code of Conduct released 2021-11-30

Introducing the new Project Scientists 2021-11-23

https://www.4most.eu/cms/

R=5000



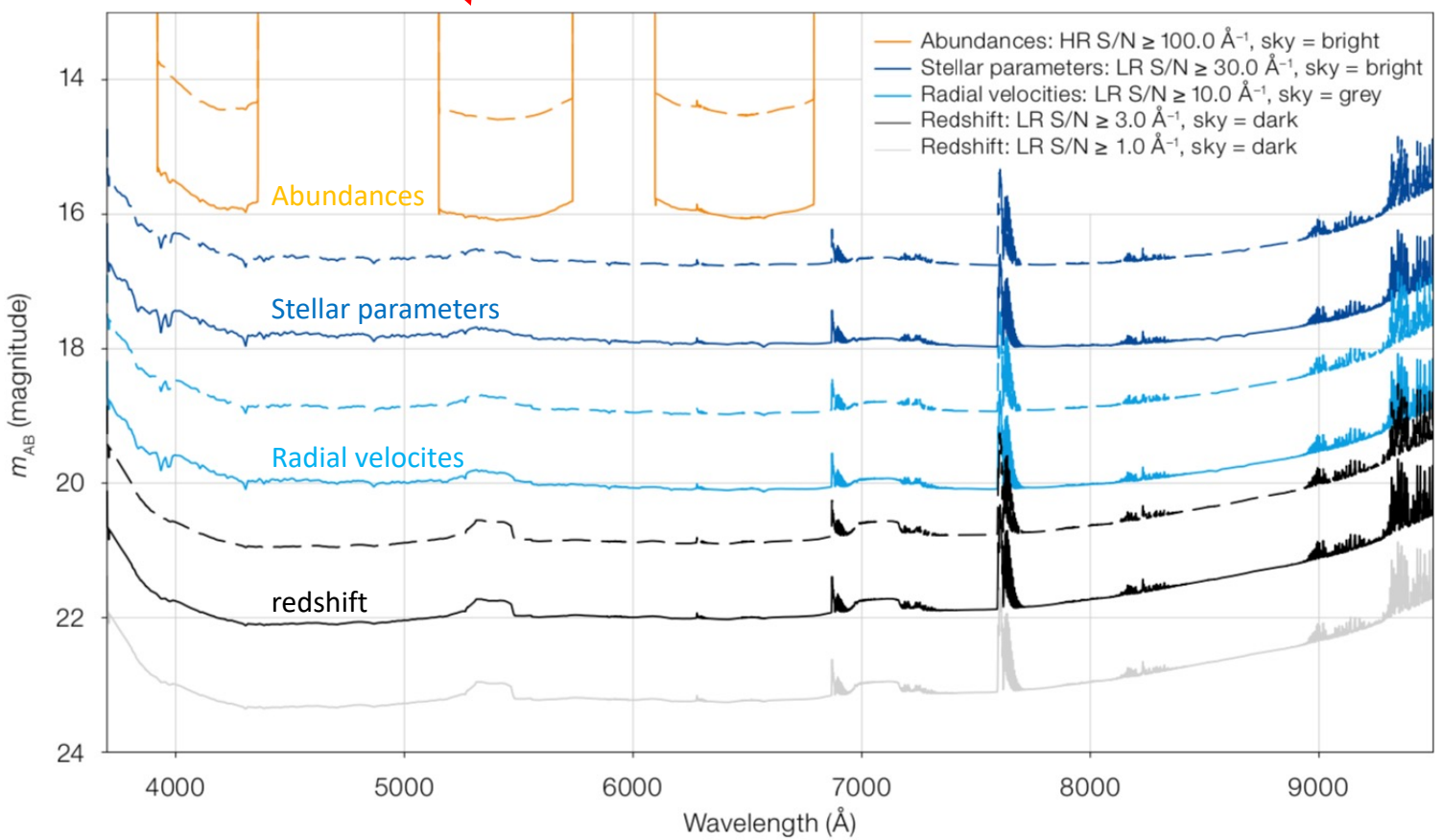


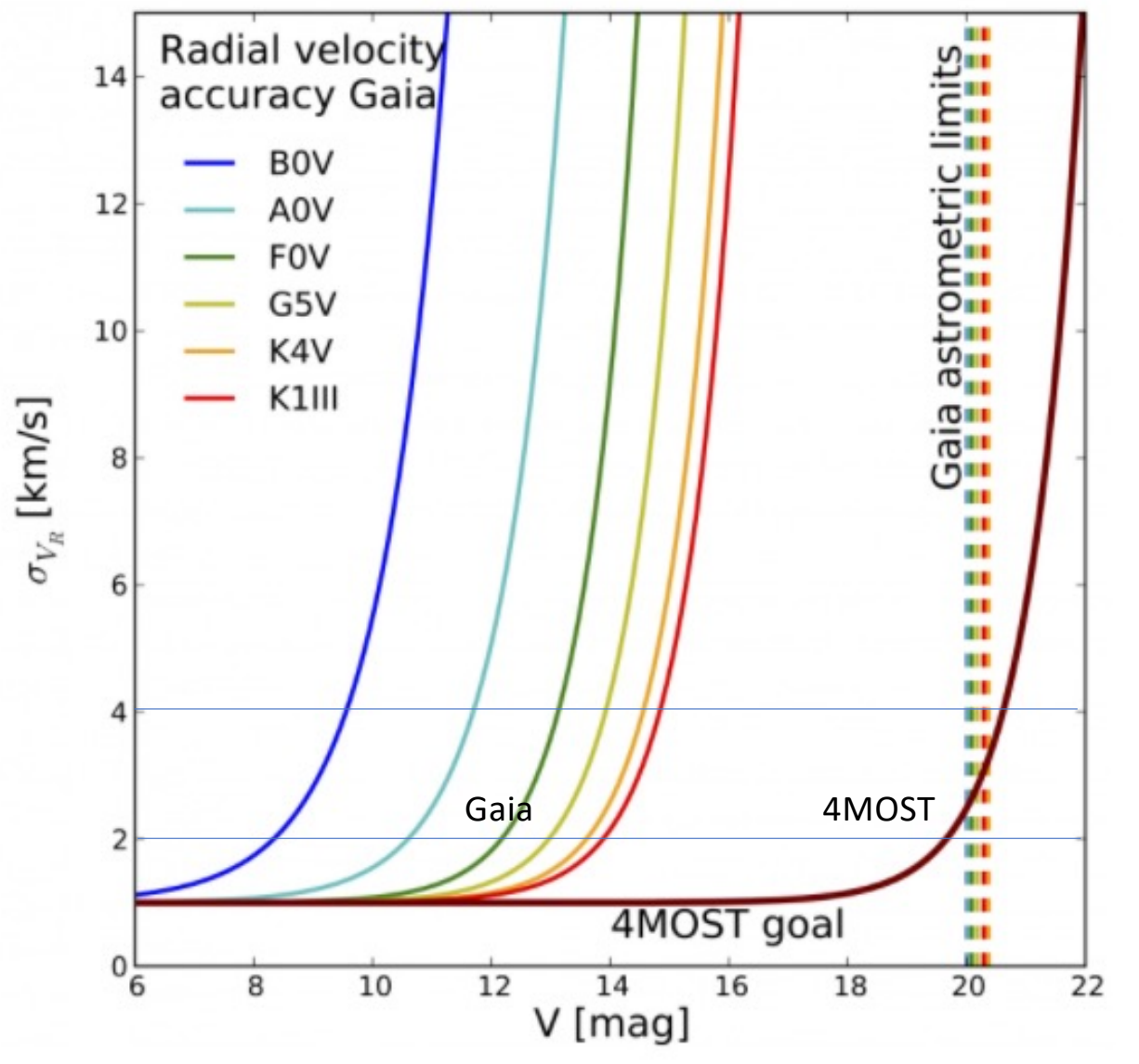
R=20000

3 WL regions for HRS

120 min

20 min




Radial velocity accuracy Gaia
B0V
A0V
F0V
G5V
K4V
K1III
Gaia astrometric limits
Gaia
4MOST
4MOST goal
σ_{V_R} [km/s]
V [mag]
0
2
4
6
8
10
12
14
6
8
10
12
14
16
18
20
22

Consortium Surveys (10 CS, will use 70% of time for the 5 years of the public survey)

Survey	PI
S1 - Milky Way Halo Low Resolution Survey	Else Starkenburg
	Mike Irwin
S2 - Milky Way Halo High Resolution Survey	Norbert Christlieb
S3 - Milky Way Bulge and Disk Low Resolution Survey (4MIDABLE-LR)	Cristina Chiappini
	Ivan Minchev
S4 - Milky Way Bulge and Disk High Resolution Survey (4MIDABLE-HR)	Thomas Bensby
	Maria Bergemann
S5 - Galaxy Clusters Survey	Johan Comparat
S6 - AGN Survey	Andrea Merloni
S7 - Galaxy Evolution Survey (WAVES)	Joe Liske
	Simon Driver
S8 - Cosmology Redshift Survey (CRS)	Jean-Paul Kneib
	Johan Richard
S9 - Magellanic Clouds Survey (1001MC)	Maria-Rosa Cioni
S10 - Time-Domain Extragalactic Survey (TiDES)	Mark Sullivan

5 Stellar (MW & MCs)

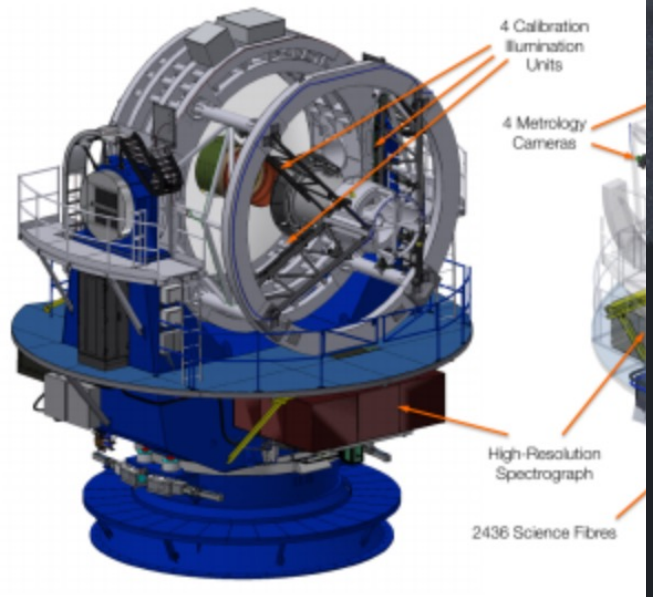
5 Extragalactic

15 Community Surveys selected (6 Galactic, 9 extragalactic
8 as full survey, 7 as sub-survey)

4MOST Community Surveys Selected

Published: 08 Feb 2022

LoI : 2019
Proposal : Dec 2020
Approval : end 2021 (informal)



The 4MOST instrument will conduct surveys in a five-year programme. The selection of the surveys fo
Operations Policies and involved calls for Letters of Intent and invitations to submit a proposal followin
recommended 15 community surveys to be selected for 4MOST observations. The selection was endo
2021. The selected surveys will become part of the 4MOST project in preparation for the observing pla

Selezionate le prime 15 survey di 4MOST

Tre programmi osservativi hanno la guida scientifica di ricercatrici e ricercatori INAF

Seguendo le raccomandazioni del Public Survey Panel (PS) e dell'Observing Programmes Committee (OPC), l'European Southern Observatory (ESO) ha selezionato 15 survey che verranno condotte con lo strumento 4MOST durante i suoi primi cinque anni di attività.

Tra le survey selezionate quelle che vedono il coordinamento e la guida scientifica dell'INAF sono:

Stellar Clusters in 4MOST con PI **Sara Lucatello, Angela Bragaglia, Antonella Vallenari** (survey galattica)

The 4MOST Survey of Young Stars (4SYS) con PI **Giuseppe Germano Sacco** (survey galattica)

4MOST-StePS: a Stellar Population Survey using 4MOST con PI **Angela Iovino** (survey extragalattica)

Inoltre, la survey galattica "4MOST survey of dwarf galaxies and their stellar streams (4DWARFS): small but fundamental" ha come PI Asa Skuladottir, dell'Università degli Studi di Firenze e associata INAF.

4MOST è una nuova ed avanzata *facility fibre-fed* per survey spettroscopiche che verrà installata al telescopio VISTA dell'ESO. 4MOST sarà in grado di ottenere contemporaneamente gli spettri di circa 2400 oggetti su un campo di vista esagonale di 4,2 gradi quadrati.

Per maggiori informazioni:

- Il sito web dello strumento 4MOST
- la pagina web delle 15 survey di 4MOST selezionate da ESO

Also INAF News

https://www.eso.org/sci/publications/announcements/sciann17466.html

Galactic Surveys selected

Stellar Clusters in 4MOST. as full survey
PIs Sara Lucatello, Angela Bragaglia, Antonella Vallenari (INAF)

4MOST Gaia RRLyrae Survey (4GRoundS)
PI Rodrigo Ibata (Observatoire Astronomique de Strasbourg)

(Michele Bellazzini, Gisella Clementini, Alessia Garofalo, Alessio Mucciarelli, Antonio Sollima)

4MOST survey of dwarf galaxies and their stellar streams (4DWARFS): small but fundamental. as full survey
PI Asa Skuladottir (University of Florence)

(Davide Massari)

Spectroscopic Discovery of Binaries with Dormant Black Holes
PI Michal Pawlak (Jagiellonian University), Tsevi Mazeh (Tel Aviv University)

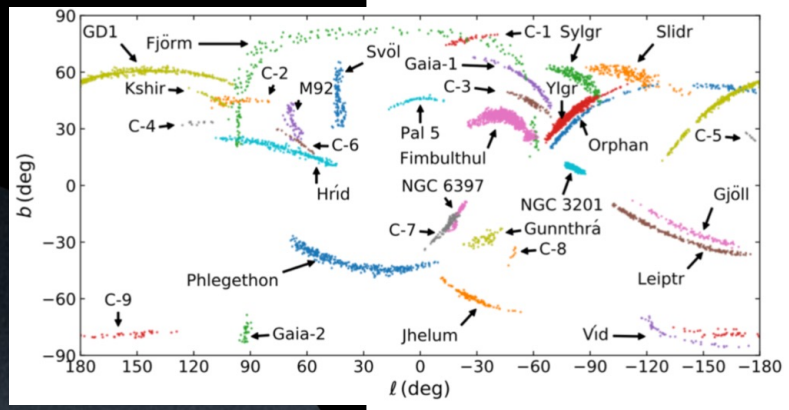
The 4MOST Survey of Young Stars (4SYS)
PI Giuseppe Germano Sacco (INAF)

(strong Italian involvement, 1/3 of proponents; ~200k stars, D<500pc, age<100Myr; LR+HR)

The White Dwarf Binary (WDB) survey.
PIs Odette Toloza Castillo (University of Warwick), Alberto Rebassa-Mansergas (Univeritat Politecnica de Catalunya)

Some of our scientific aims with 4GRoundS

- Dynamical mass modelling of the outer Galaxy
- Old stellar streams in the outer Galaxy
- Search for low-mass satellites
- Global halo asymmetry due to the arrival of the LMC
- Distant disk
- Bulge/halo decomposition
- Spatial variations in kinematic coherence through the halo



10^5 RR Lyr stars, LR

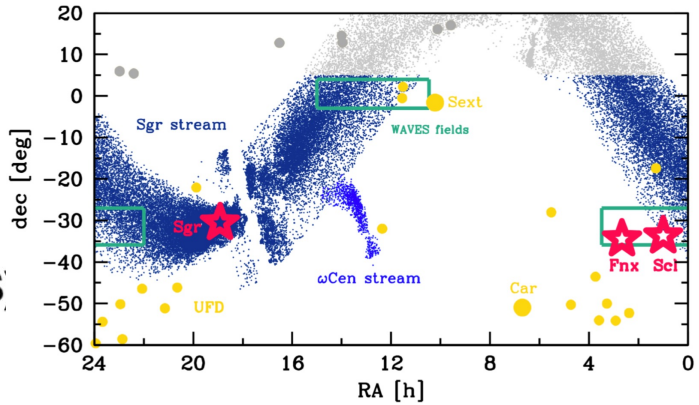
Derive 6-d structure of outer MW using a powerful tracer (RRLyr, which provide distances and are old)

Study DM distribution and kinematic response of streams and stellar halo to clumpiness of DM sub-halos

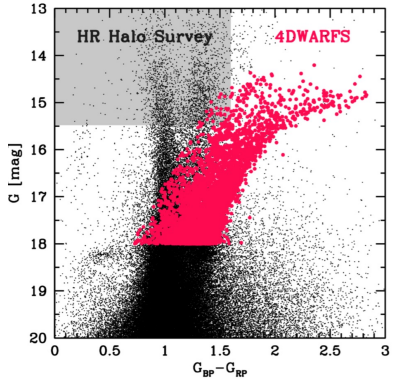
Sub-survey of S1

Locally: Michele Bellazzini, Gisella Clementini, Alessia Garofalo, Alessio Mucciarelli, Antonio Sollima

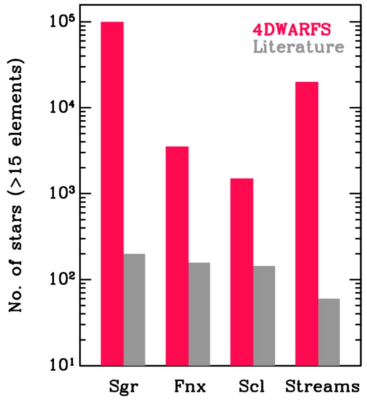
- **4DWARFS is a ~~proposed~~ accepted 4MOST community survey**
  - All dwarf galaxies in the Southern Hemisphere
  - The Sagittarius stream + the Omega Cen stream
  - Targets: 130,000 stars
  - Total observational time: 512k fibre hours (~1/3 HRS and ~2/3 LRS)



- **Science goals:**
  - (I) ORIGIN: First stars
  - (II) EVOLUTION: Nucleosynthetic channels (SNIa, AGB stars, NSM)
  - (III) GLOBAL PICTURE: Hierarchical galaxy formation
  - Other: IMF variations, globular clusters, lithium-rich giants etc.



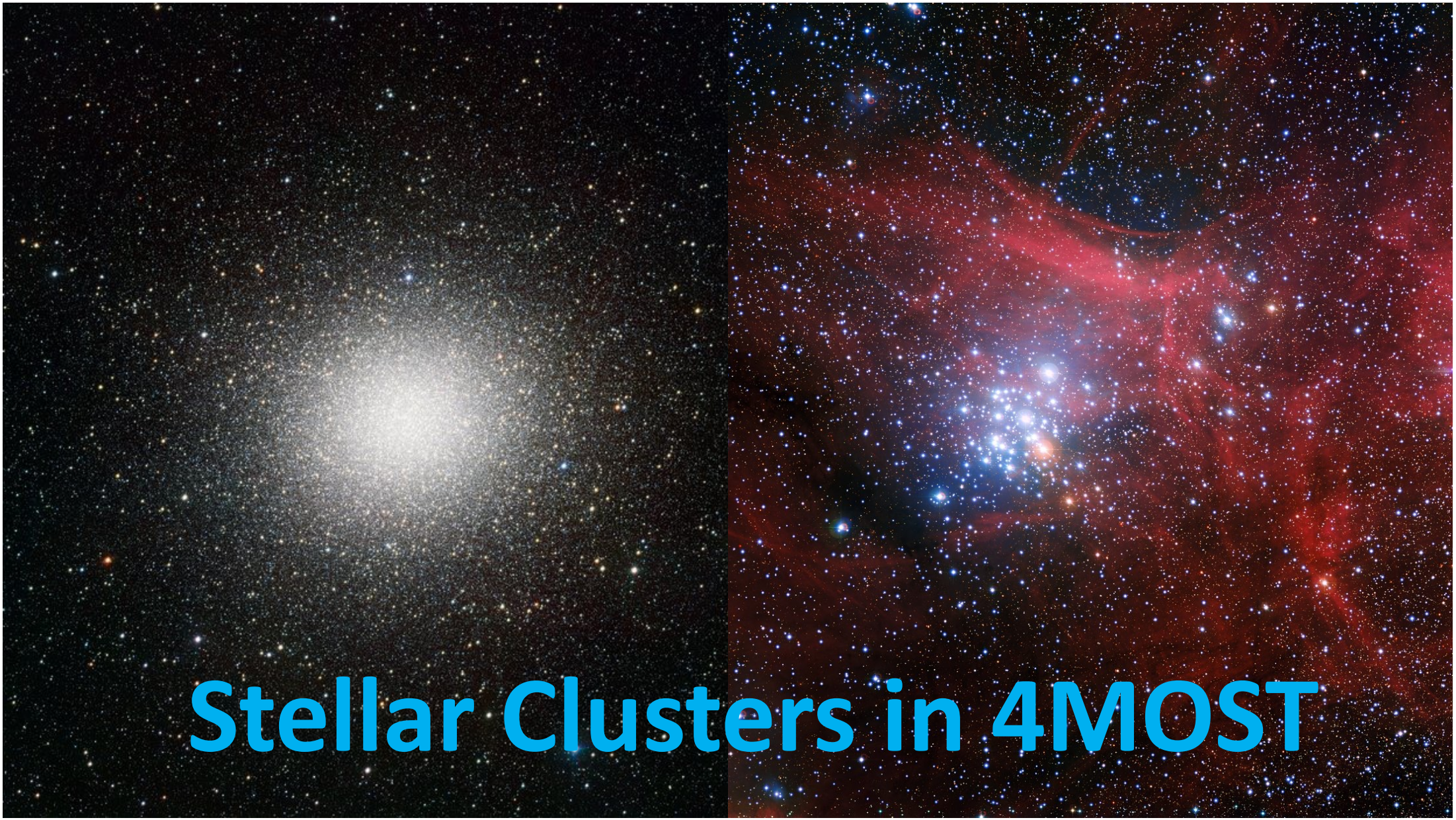
- **Will provide radial velocities, chemical abundances and ages for all the target stars**
- **4DWARFS will increase the number of stars in dwarf galaxies and streams with detailed abundance information (>15 elements) by several orders of magnitude, ensuring the far-reaching impact of this survey.**



- **Highly complementary to existing Galactic surveys, as well as S10 TiDES**

4DWARFS: 4MOST survey of dwarf galaxies and their stellar streams

Full Survey
Locally: Davide Massari


Stellar Clusters in 4MOST

Stellar Clusters in 4MOST

PIs : **Angela Bragaglia** (INAF-OAS Bologna)
Sara Lucatello (INAF-OA Padova)
Antonella Vallenari (INAF-OA Padova)

E.J. Alfaro, L. Balaguer-Nunez, E. Balbinot, D. Barrado, H. Baumgardt, **M. Bellazzini**, **R. Bonito**, D. Bossini, H. Bouy, T. Cantat-Gaudin, **G. Carraro**, **R. Carrera**, **E. Carretta**, L. Casamiquela, **S. Cassisi**, **G. Catanzaro**, **V. D'Orazi**, **E. Dalessandro**, **F. Damiani**, G.M. De Silva, A. Ferguson, **F.R. Ferraro**, **E. Flaccomio**, **A. Frasca**, P. Galli, M. Gieles, F. Gran, **R. Gratton**, **M.G. Guarcello**, M. Hilker, R. Jeffries, C. Jordi, A.J. Korn, P. Kuzma, **B. Lanzoni**, S. Larsen, J. Lattanzio, M. Lugaro, **M. Mapelli**, **D. Massari**, **G. Micela**, **A. Miglio**, S. Mikolaitis, N. Miret Roig, A. Moitinho, **Y. Momany**, **A. Mucciarelli**, J. Olivares, **C. Pallanca**, **M. Pasquato**, **L. Prisinzano**, **V. Roccatagliata**, M. Salaris, R. Schiavon, R. Smiljanic, **A. Sollima**, **R. Sordo**, C. Soubiran, **L. Spina**, G. Tautvaisiene, E. Valenti, A.L. Varri, M. Zoccali *[60+ researchers, 10+ countries]*

[INAF-OAS Bologna, DIFA Bologna, Italy]

Stellar Clusters in 4MOST → Scheda INAF ...

Dettagli - Scheda SC-4MOST

Ritorna alla Scheda

TO BE UPDATED

Informazioni Pubbliche

12. Keywords ERC (opzionali)

PE9_6; PE9_7

13. Linee di ricerca / Campi di azione

Star cluster; Globular star clusters; Open star clusters; Young star clusters; Galactic Archeology; Milky Way stellar halo; Galactic bulge; Milky Way disk, Milky Way formation; Galactic abundances

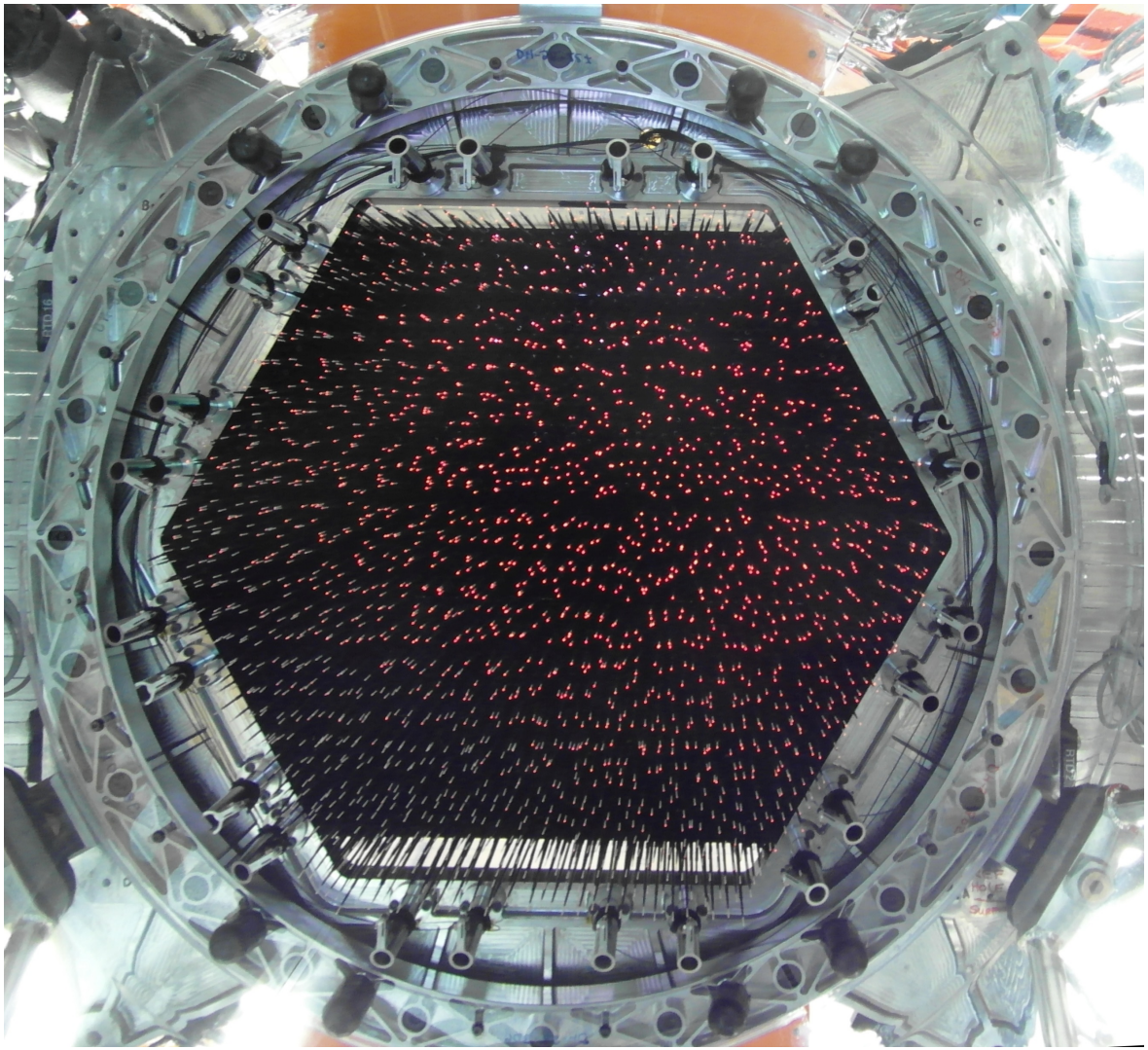
17. Ruolo di Leadership INAF (se applicabile)

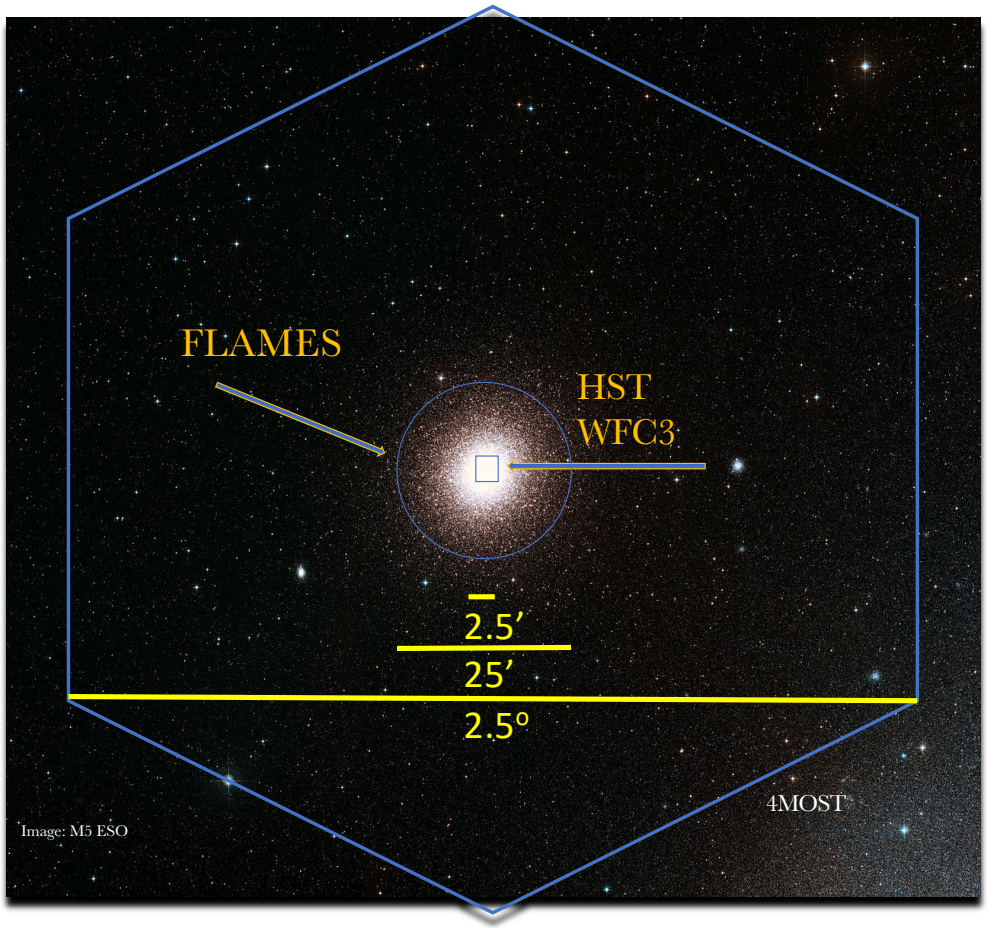
The top level coordination of the program will be done by the PI's (INAF employees), who will be overseeing the survey design and provide the top level input for the scientific requirements and the target selection function. Several other key positions within the survey are filled by INAF employees (steering committee, pipeline development, catalog coordinator, calibration).
There is no doubt that even in the program is intrinsically very international, INAF is the main player.

20. Infrastrutture coinvolte

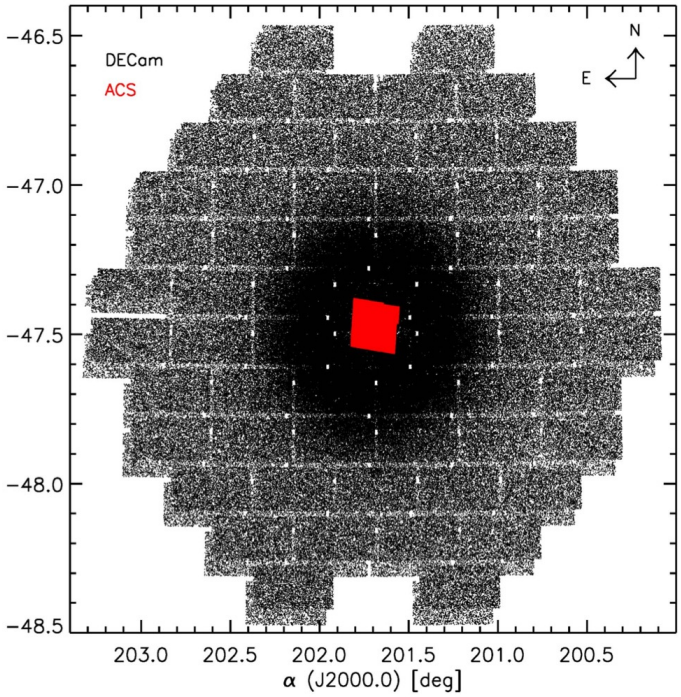
4MOST; ESO

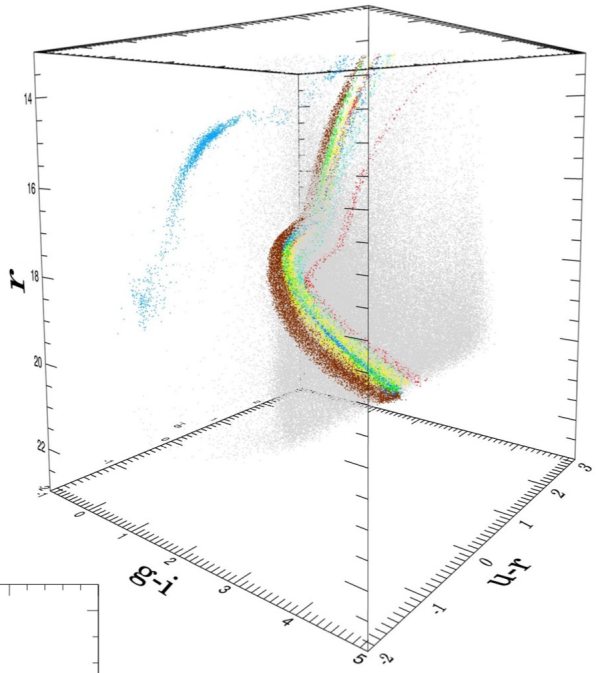
4MOST: 4-metre Multi-Object Spectroscopic Telescope

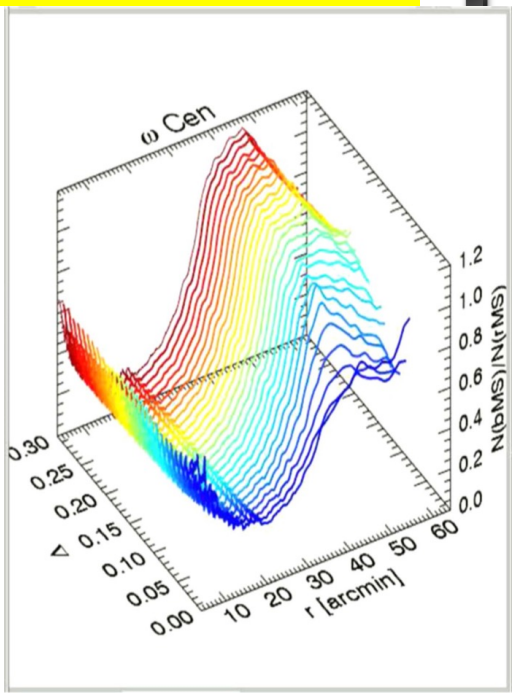




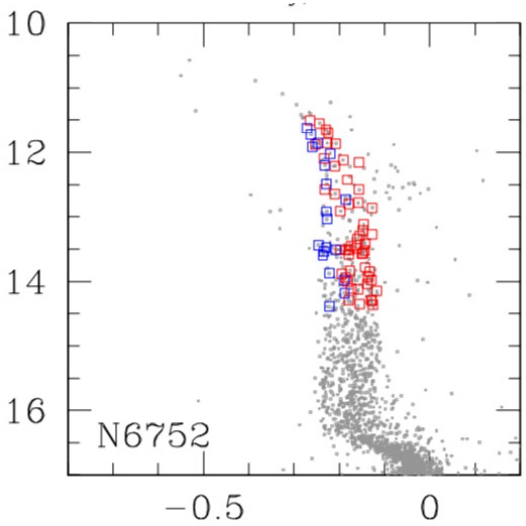
Globular Clusters require a large FoV

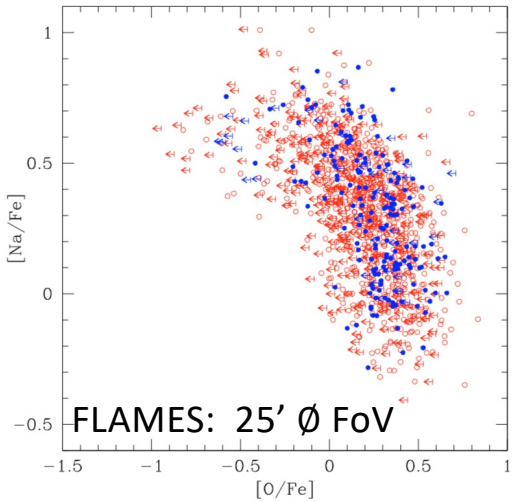






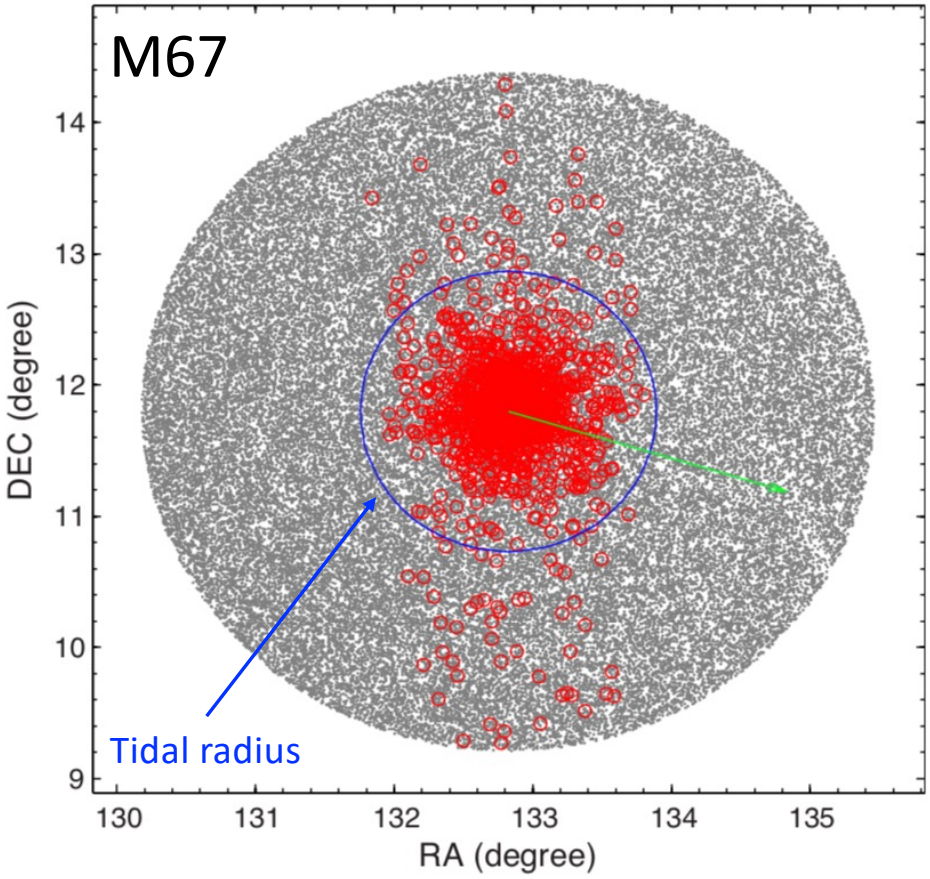
Calamida+2017
Carretta+2009, 2011



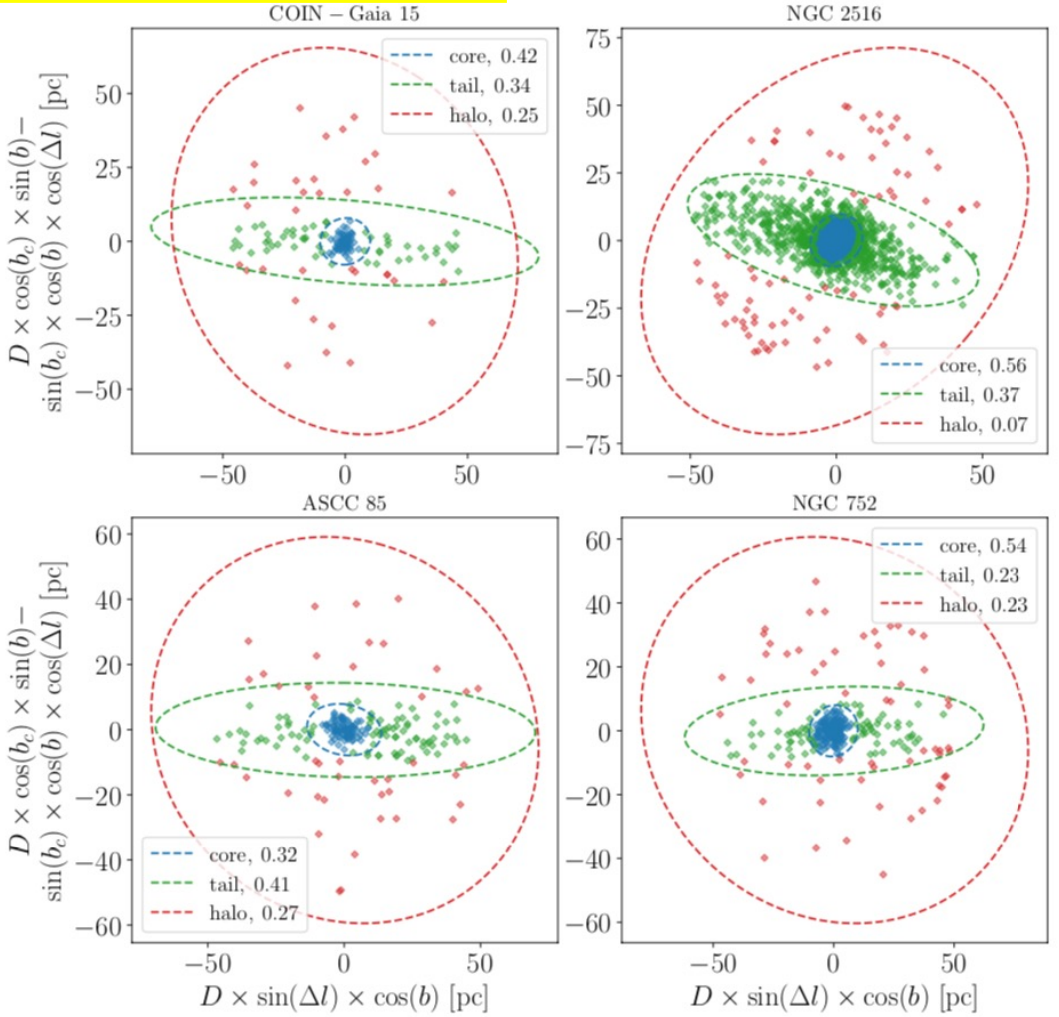


c_y *vs* y Stromgren CMD [where c_y= (u-v)-(v-y)] (left)
Na-O anticorrelation (right)

And the same is valid for Open Clusters



Gao 2020



Tarricq+ 2021

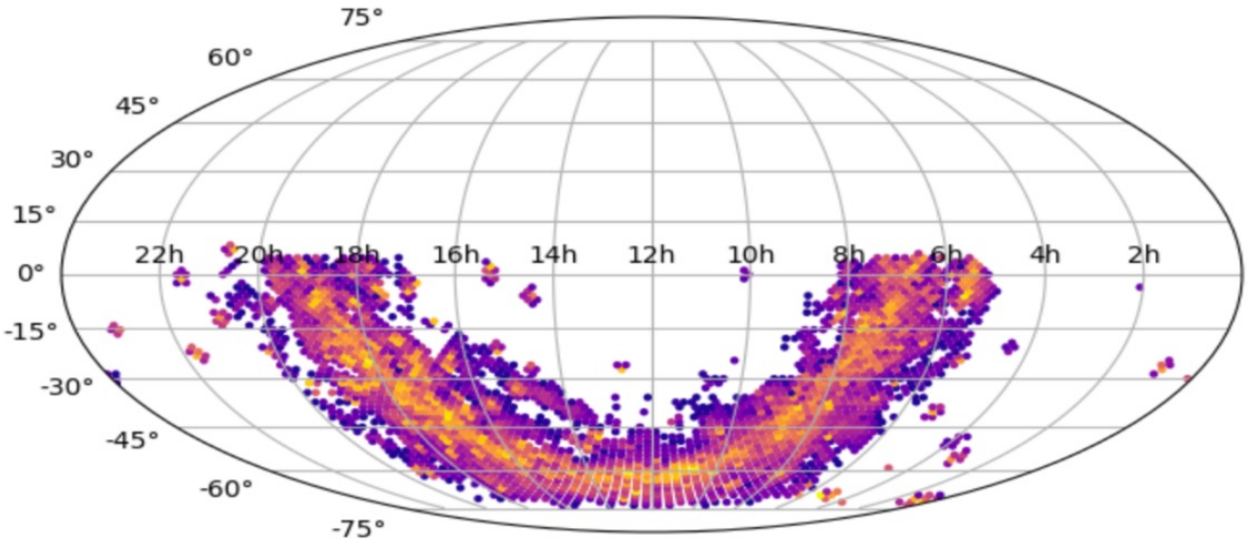
The axes are simply the projection of the star's position in the plane of the sky

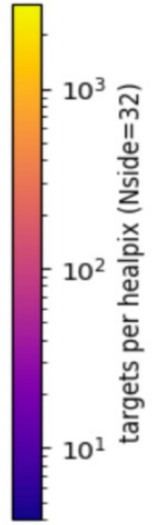
Abstract

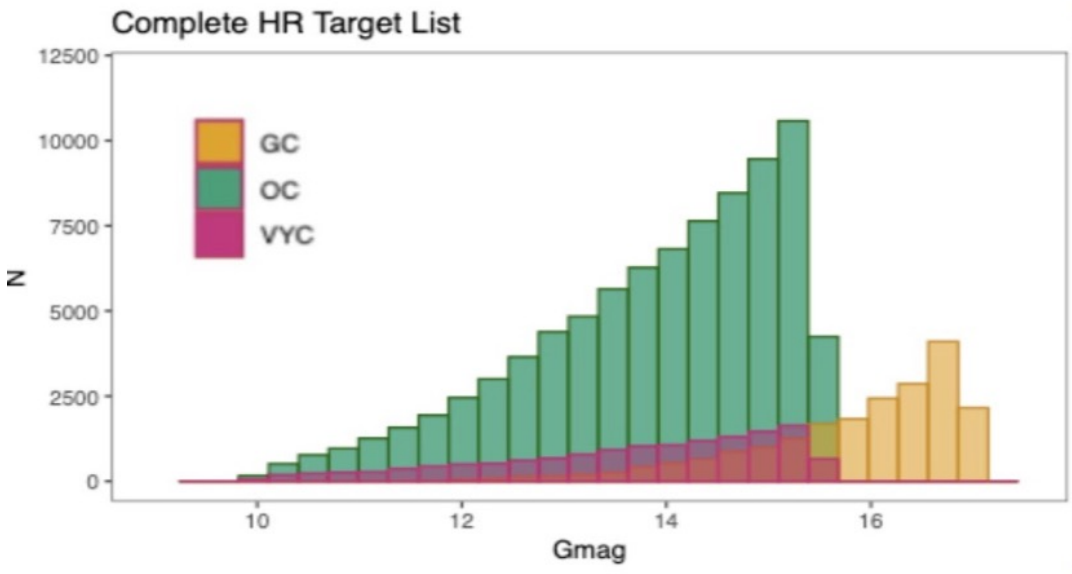
- high legacy value, sample of unprecedented accuracy and size
- resolved Stellar Clusters in the Milky Way and Magellanic Clouds :
  - 150 Globular Clusters in the Milky Way and the Magellanic Clouds
  - essentially all visible MW Open Clusters and Star Forming Region (2000+)
- fill metallicity/age distribution: [Fe/H] = −2.5 of GCs to super-solar OCs, a few Myr to 13.5 Gyr
- clusters studied both with LR and HR (~120K stars in LR and ~90K in HR)
- coordinate with the planned CSs

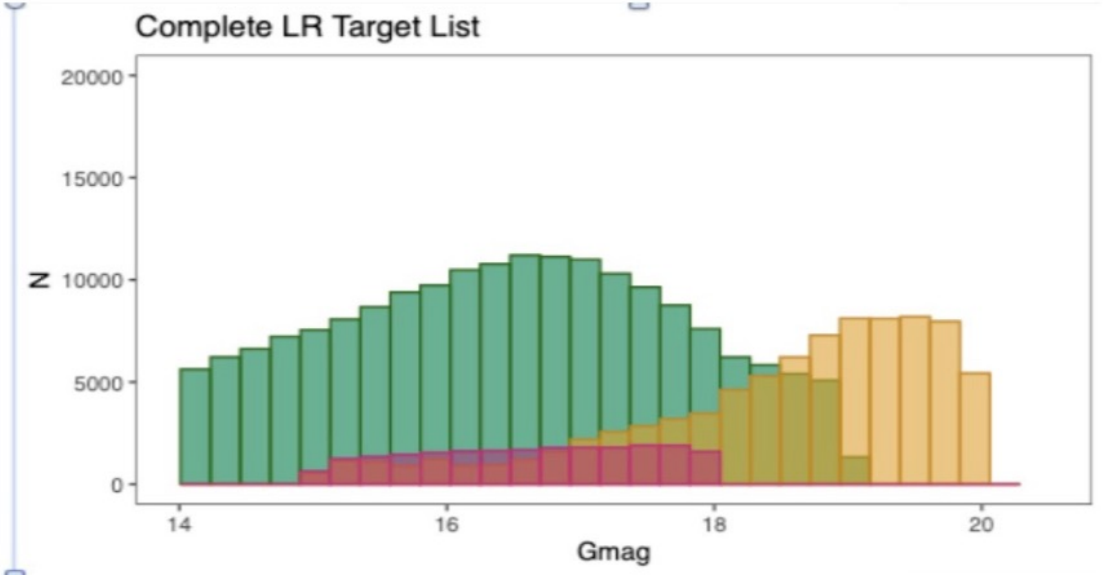
- understand how clusters form, evolve, dissolve, and populate the MW
- calibrate complex physics that affect stellar evolution (on which our ability to measure ages ultimately stands)
- measure the contribution of star clusters to the formation and evolution of the individual Galactic components
- derive a thorough and homogeneous chemo-dynamical picture (constraints on models of Galaxy formation)

Targets

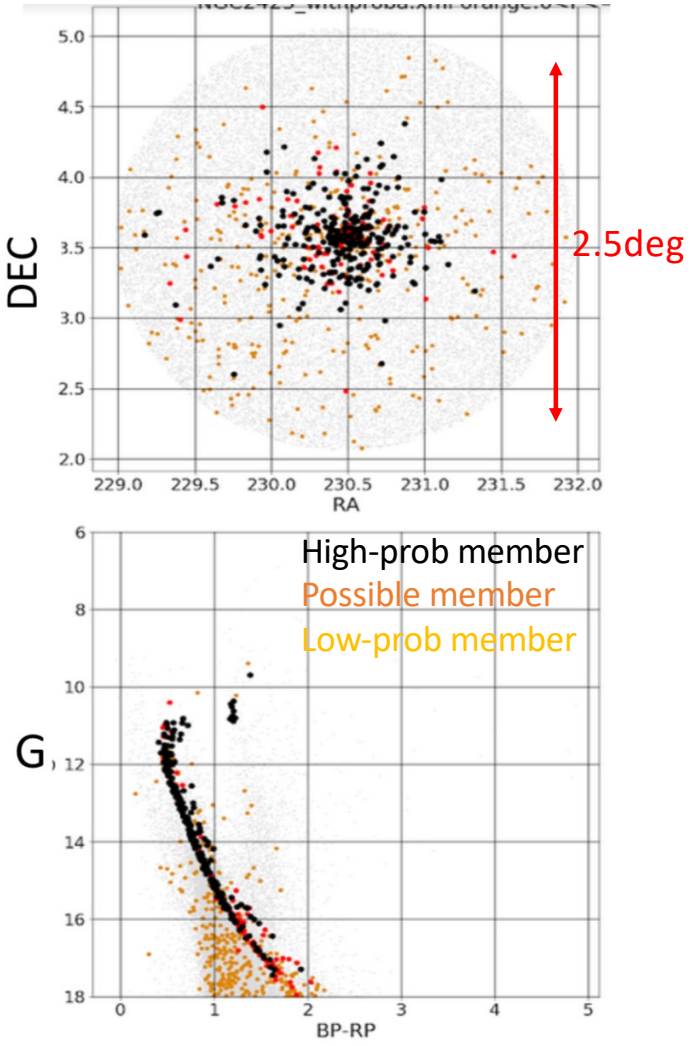

75°
60°
45°
30°
15°
0°
-15°
-30°
-45°
-60°
-75°
22h
20h
18h
16h
14h
12h
10h
8h
6h
4h
2h

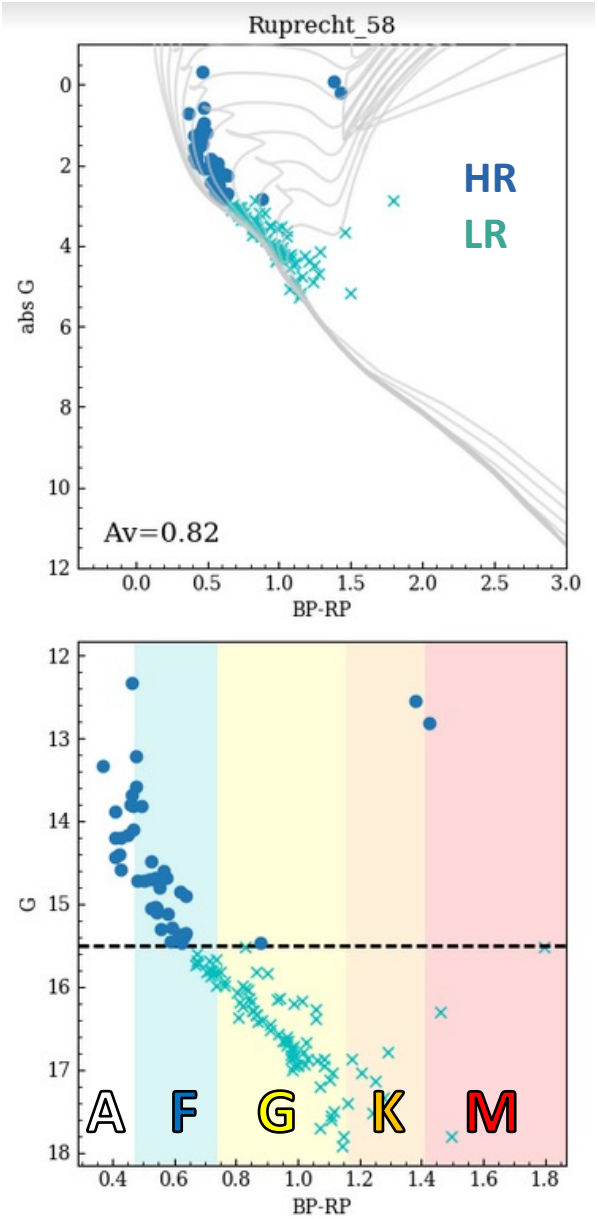

10^3
10^2
10^1
targets per healpix (Nside=32)


Complete HR Target List
12500
10000
7500
5000
2500
0
N
GC
OC
VYC
10
12
14
16
Gmag


Complete LR Target List
20000
15000
10000
5000
0
N
14
16
18
20
Gmag

Targets (Open Clusters)





Targets

Survey Regions	RA (deg)	Dec (deg)	Area (Deg2)	Spectrograph (Lrs/Hrs)	Range of Targets Density (Targets/Deg2)	Range and Average Texp (Hours)	Magnitude Range	Execution Priority	Spectral Success Criteria S/N/A ~@6300
OCs	0-360	-72-+5	7070	HRS	2-180	0.3-2 avg=0.8	10-15.5	1	70-350
OCs	0-360	-72-+5	6770	LRS	2-650	0.3-2 avg=0.5	14-19	1	20-170
GCs	0-360	-72-+7	569	HRS	1-220	0.3-2 avg=1.5	11-17	1	70-350
GCs	0-360	-72-+7	1477	LRS	1-800	0.3-2 avg=0.75	15.5-20	1	20-170
VYC	80-280	-65-+5	580	HRS	1-200	0.3-2 avg=0.4	10-15.5	1	150
VYC	80-280	-65+5	590	LRS	1-400	0.3-2 avg=0.6	15-18	1	40-80

GC: HR 20700, LR 85200 targets

OC: HR 84600, LR 184200 targets → grand total ~120 000 HR, ~290 000 LR → 289 000 fibre/hr

YC: HR 14200, LR 22000 targets

Products

- Spectral classification
- Radial velocities
- Stellar parameters (Teff, log, metallicity)
- Elemental abundances from all nucleosynthetic chains
- Cluster membership (confirming Gaia membership of faint stars with radial velocities and with Li in VYCs)
- Stellar ages and masses for the sample clusters/stars

- For FGK stars in OCs and GCs these will be produced through the 4MOST pipelines
- For VYC the data products will be provided through an ad-hoc pipeline developed by our team (with additional characterisation of properties of accretion/ejection processes and nebular contribution through Hα, [SII], and [NII] emissions)

Expected Scientific Outcome

- homogeneous metallicity scale from [Fe/H]=-2.5 to twice solar eliminating systematics and providing the basic calibrators to allow the possibility of combining datasets from different sources.
- provide calibration of multiple empirical age indicators (chromospheric activity, Li, [Y/Mg] etc.), to be calibrated as a function of mass and [Fe/H], to determine the age of field stars, difficult to ascertain otherwise
- ultimate sample to be used for cross-calibrating (including other Large Surveys (e.g. WEAVE, MOONS, SDSS-V) and make them candidate Standard Fields
- information for detecting binaries in Stellar Clusters (radial velocity measurements at two epochs for an unprecedented number of cluster stars
- complementarity to photometric data, e.g., provide LSST with precise calibration of a photometry-based metallicity scale, thus allowing to extend the metallicity estimates to much fainter objects
- calibration of stellar models, with impact e.g. on the initial mass function slope and its universality; the timescale of star formation and star formation histories, improving field star age determination; the stellar fiducials for population synthesis models to interpret the properties of unresolved stellar populations in distant galaxies
- homogeneous set of RVs, abundances, rotational velocities, activity indicators and stellar characteristics for clusters/cluster members.

4MOST: times & data

- Now : all Community Surveys being integrated in 4MOST
- May 2022 : simulation of whole survey with all catalogues merged
- May 2023 : “final” catalogues frozen & Survey Management Plan ready
- March 2024 : all systems installed at telescope & Preliminar Acceptance Chili
- **May 2024 : science survey starts** (ends April 2029)

- Level 0 data (raw data, calibration data, environmental data) : *public immediately*
- Level 1 data (1D, calibrated, science-ready) : public *(schedule TBD)*
- Level 2 data (products of science analyses of the 1D spectra, e.g. physical properties of 4MOST targets, element abundances for stars or redshifts and stellar ages for galaxies, spectra stacked over several OBs) : delivered back to ESO in Phase 3, go to ESO’s Science Archive Facility) *(schedule TBD)*

4MOST Galactic Pipeline

4MOST Galactic Pipeline (4GP, developed by IWG7)

4GP will analyse the HR & LR spectra of stellar sources, from O to M spectral types, including variable stars and white dwarfs. For all of the sources, 4GP will measure:

- heliocentric line-of-sight velocities
- stellar parameters

[Teff, log, metallicity etc and also age - considering also astrometric, photometric, and asteroseismic information when available]

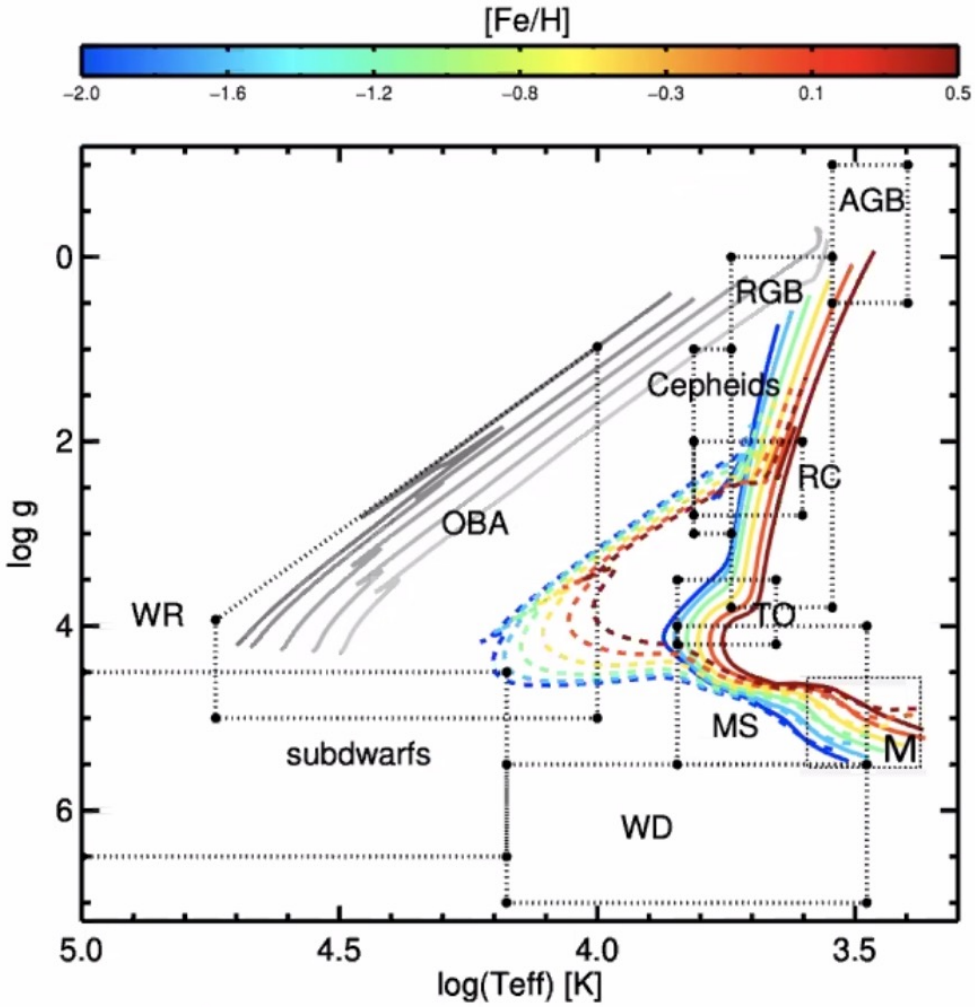
- chemical abundances

[for FGK-type stars, up to 20 individual chemical abundances. Whenever possible, non-LTE and 3D hydrodynamic models will be used]

➔ for whole survey (Consortium & Community surveys)

4MOST Galactic Pipeline

- All evolutionary phases from pre-MS to stellar remnants.
- IWG7 prototype pipeline currently has three main submodules:
  - WD
  - FGK(M)
  - OBA
- Dedicated multiplicity working group
- Homogenous analysis of all stars of a given spectral type is crucial for the science goals of all surveys.



Taken from a presentation by K. Lind & J. Loveday

Can I join 4MOST now?

Yes

And No

PhD students of a 4MOST member join freely

Researchers

can join a single project (external participation) if their expertise is missing
(approval needed)

can join a Survey if approved
(however, only a limited number of additions is permitted)

Note : about 330 4MOST Consortium Surveys participants
about doubled with the Community Surveys