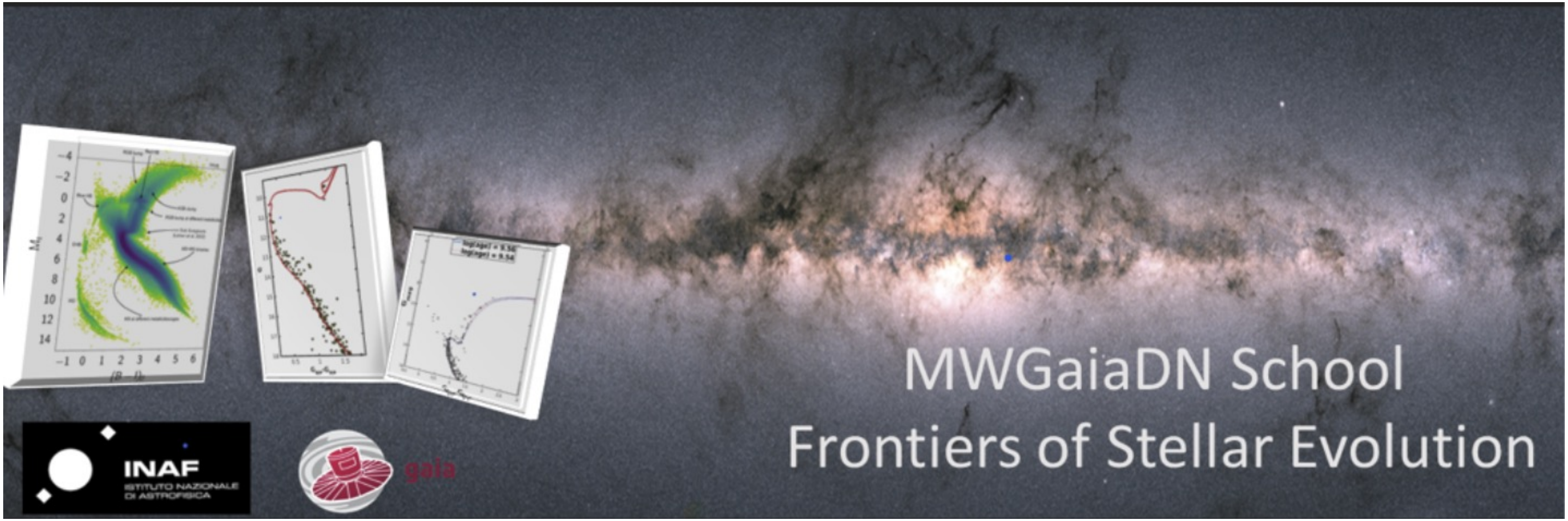
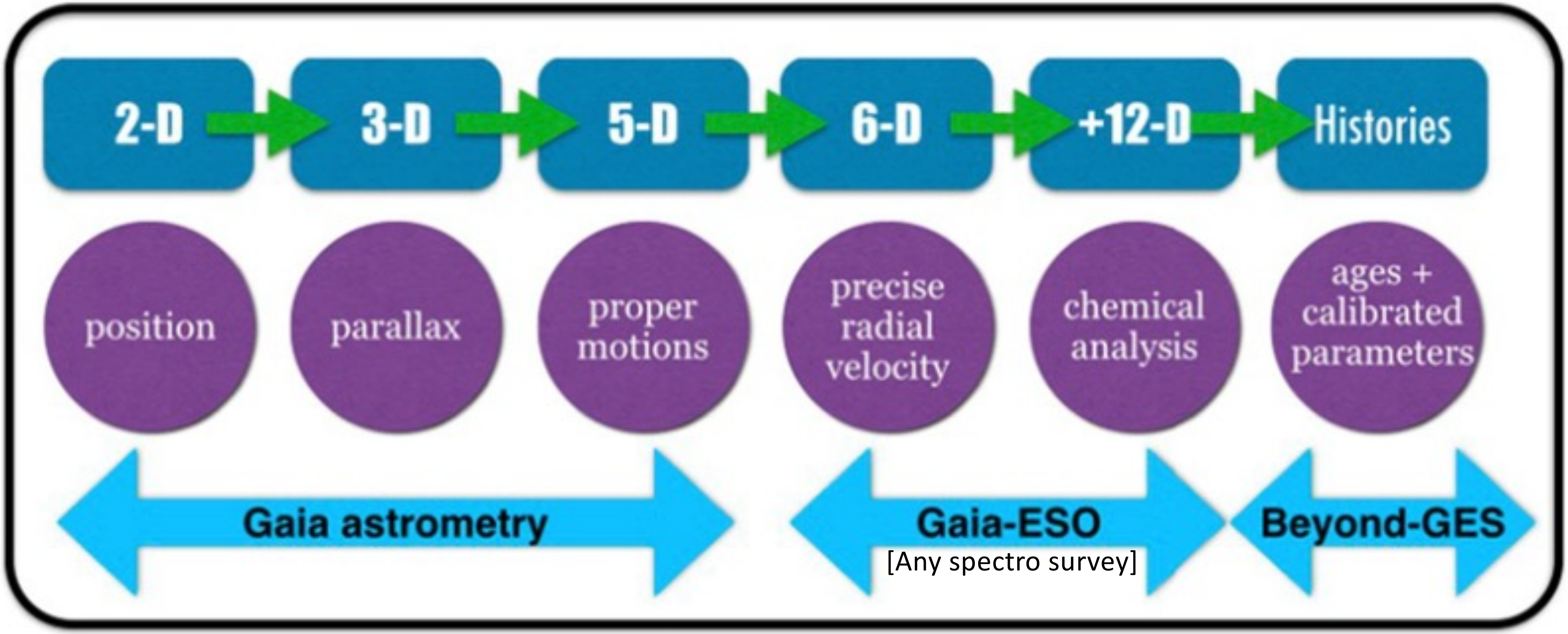
# The importance of spectroscopic surveys

**Angela Bragaglia (INAF-OAS Bologna)**

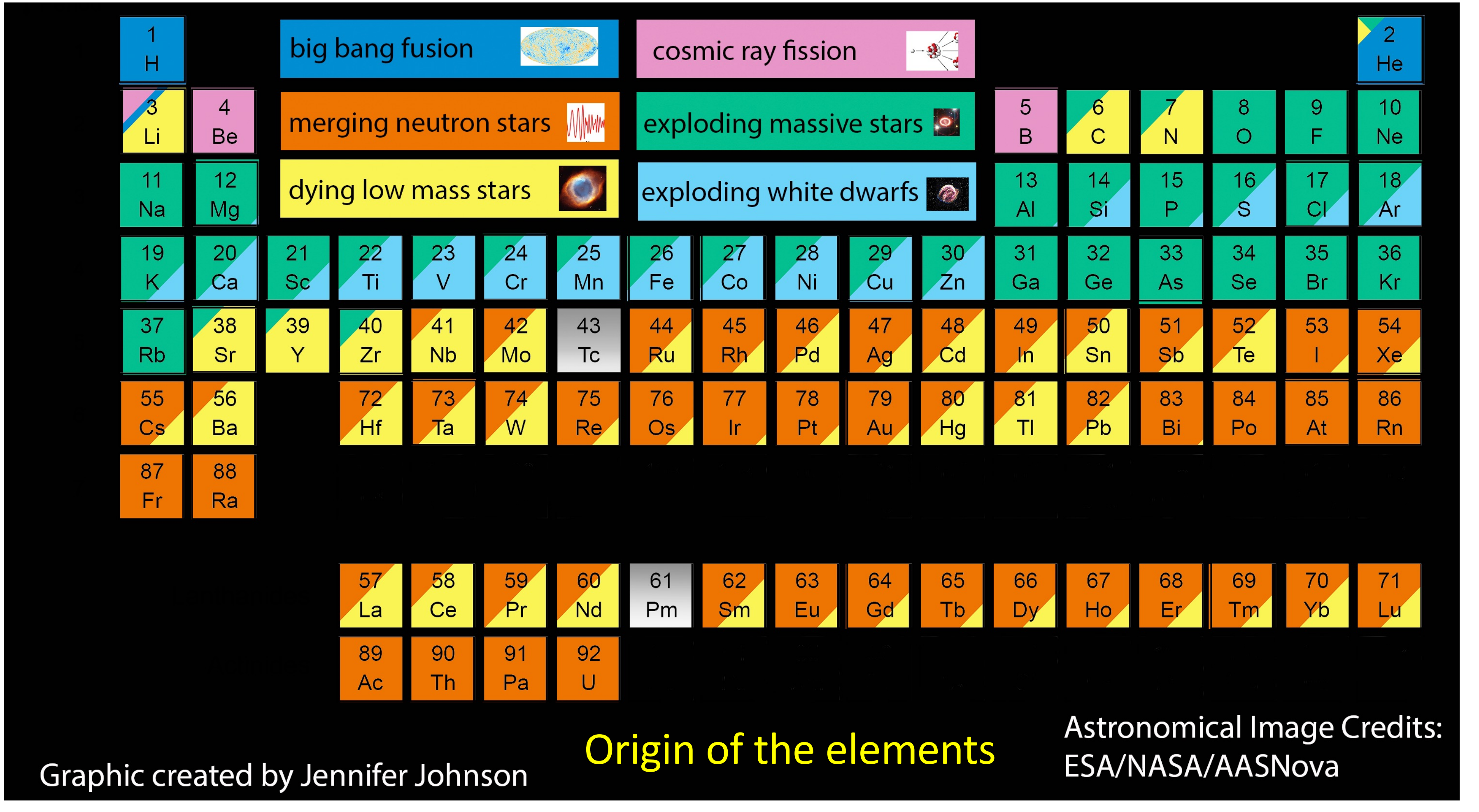


# Spectroscopic surveys : why



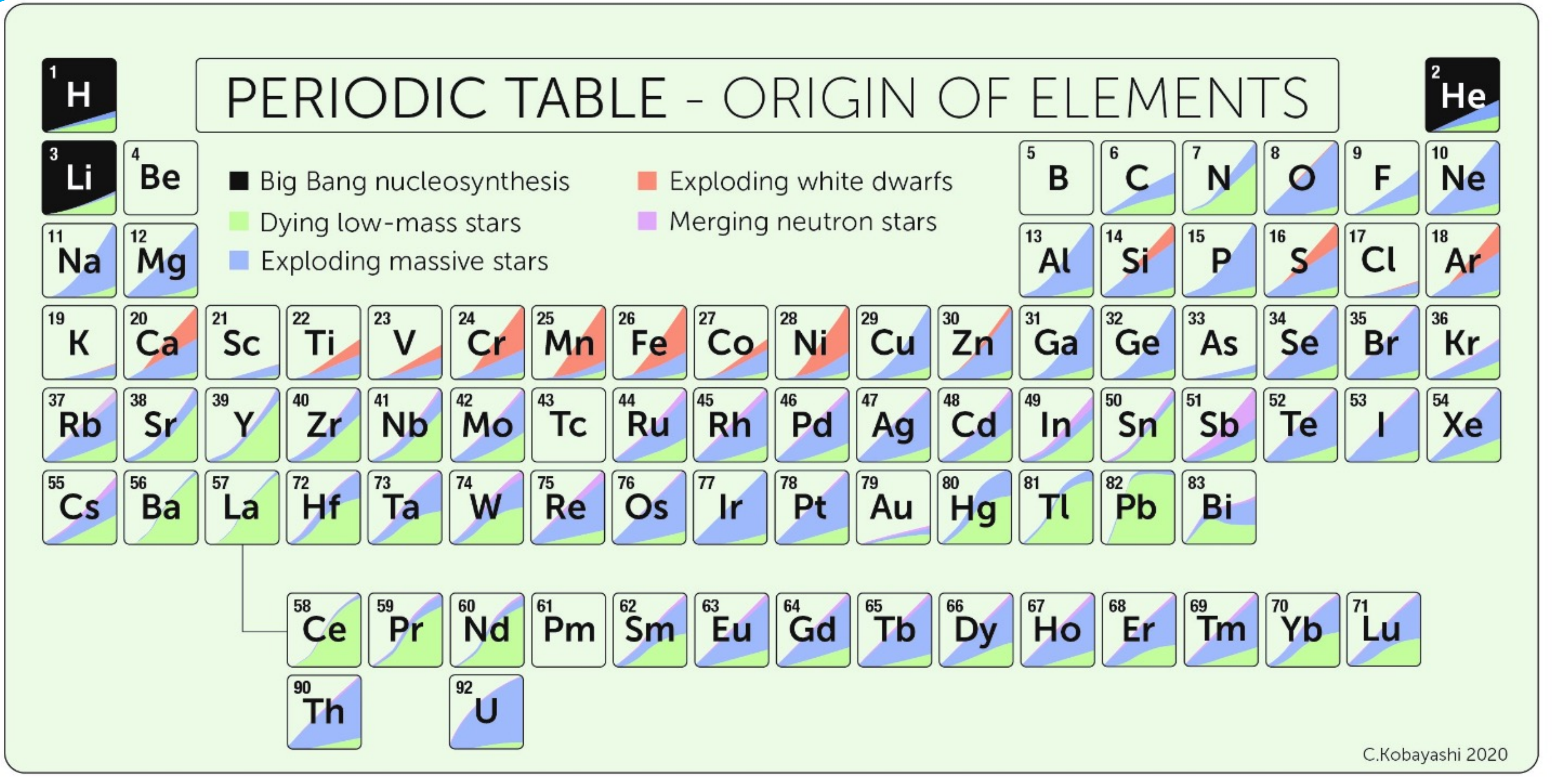

*Gilmore+2022*

# Origin of the elements



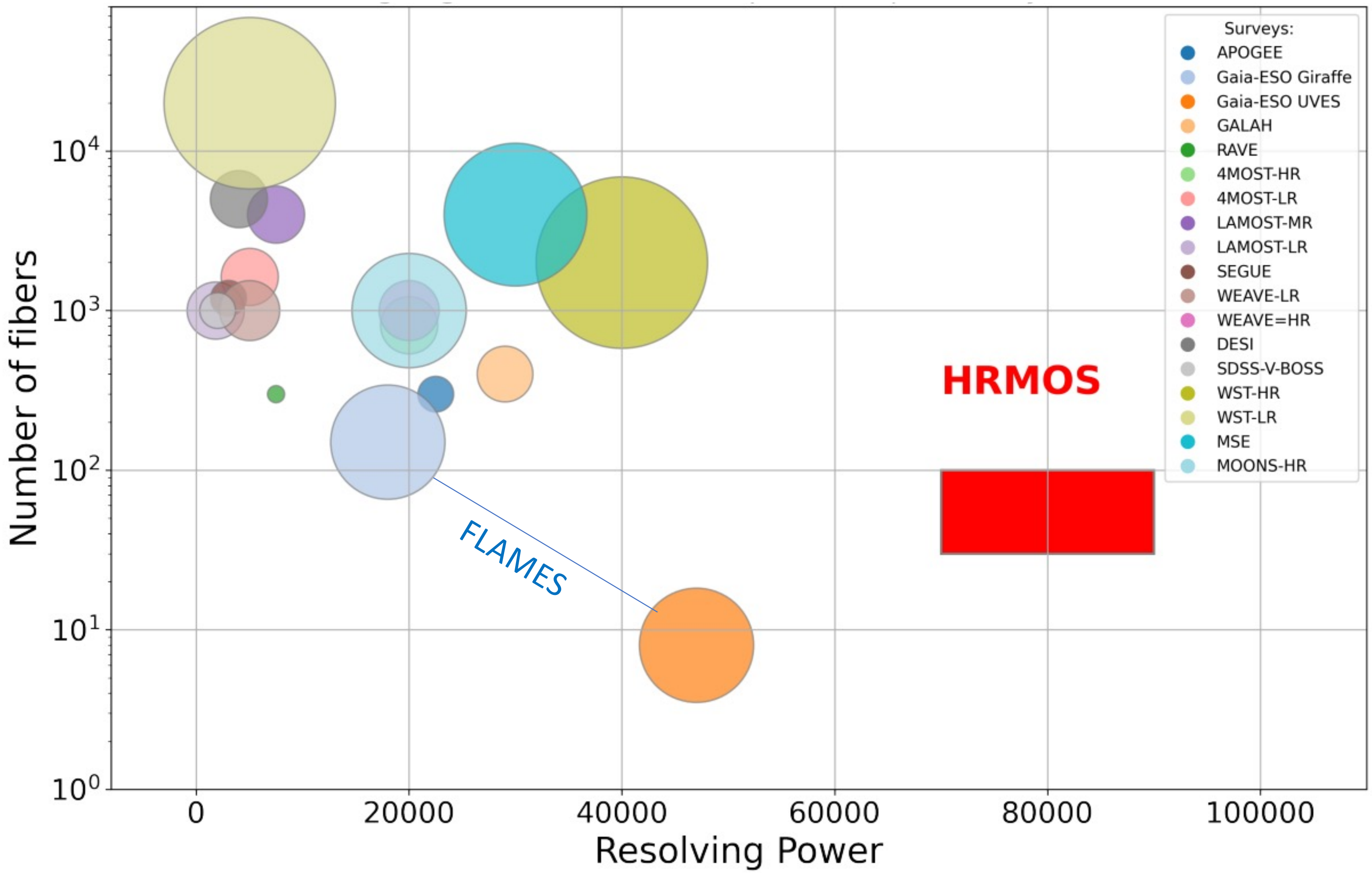

*An original version of this was made by Inese Ivans and J. Johnson in 2008 and refined and improved by Anna Frebel*

# Origin of the elements




*The Periodic Table, showing naturally occurring elements up to uranium. Shading indicates stellar origin. (Content: Chiaki Kobayashi et al.; Artwork: Sahm Keily)*

# Past & future (stellar) MOS spectroscopic surveys




RAVE, **Gaia-ESO**, **APOGEE** terminated

**GALAH**, LAMOST, DESI, SDSS V (APOGEE) on-going

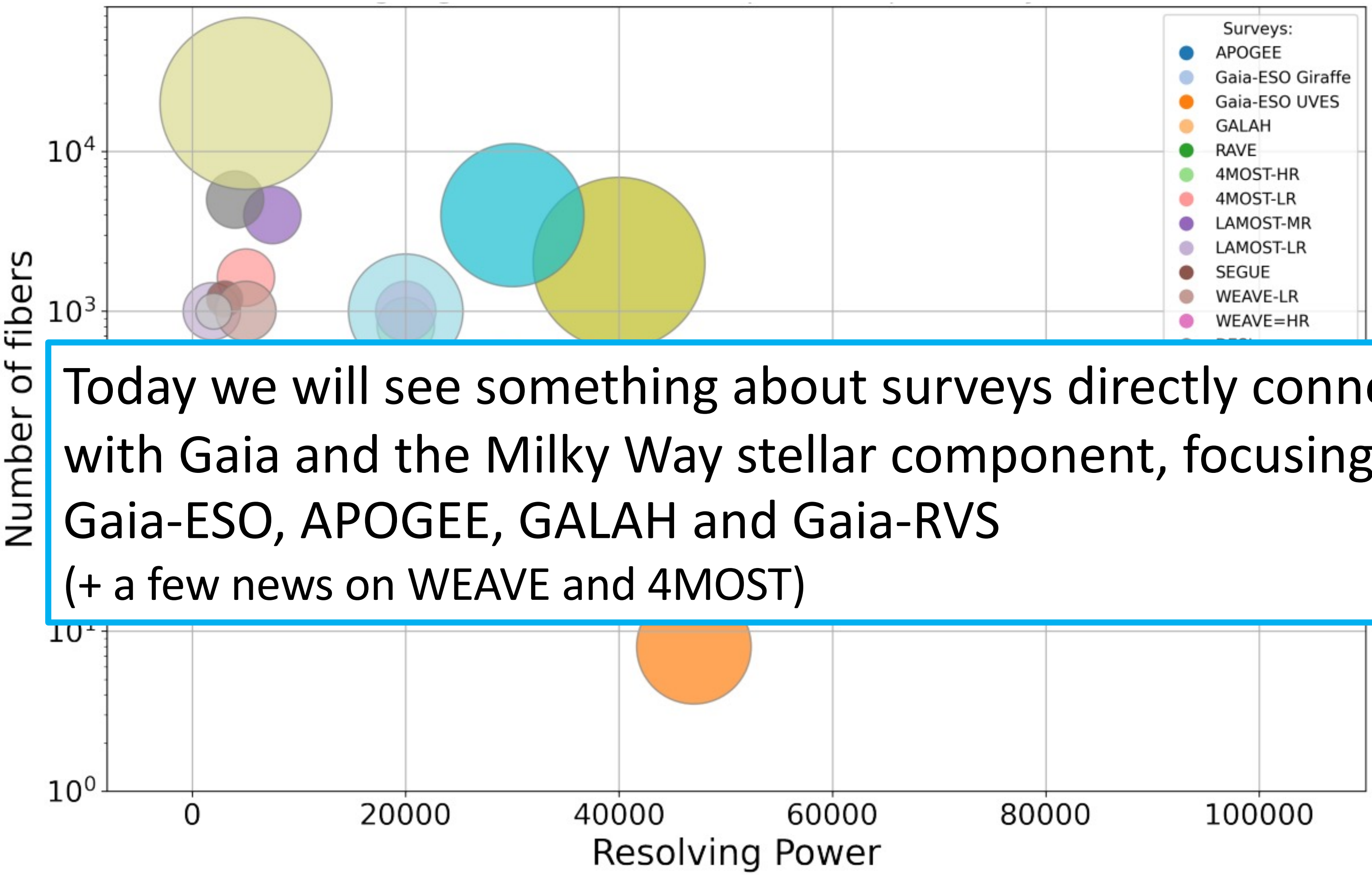
WEAVE, 4MOST, MOONS starting/spectrographs almost at telescope

WST, HRMOS, MSE proposed

Note: **Gaia-RVS** missing here [it's not MOS] R=11000 and >100 M stars

*Magrini+2023 [https://arxiv.org/pdf/2312.08270](https://arxiv.org/pdf/2312.08270) [HRMOS White Paper]*

# Past & future (stellar) MOS spectroscopic surveys




Today we will see something about surveys directly connected with Gaia and the Milky Way stellar component, focusing on Gaia-ESO, APOGEE, GALAH and Gaia-RVS

(+ a few news on WEAVE and 4MOST)

RAVE, **Gaia-ESO**, **APOGEE** terminated

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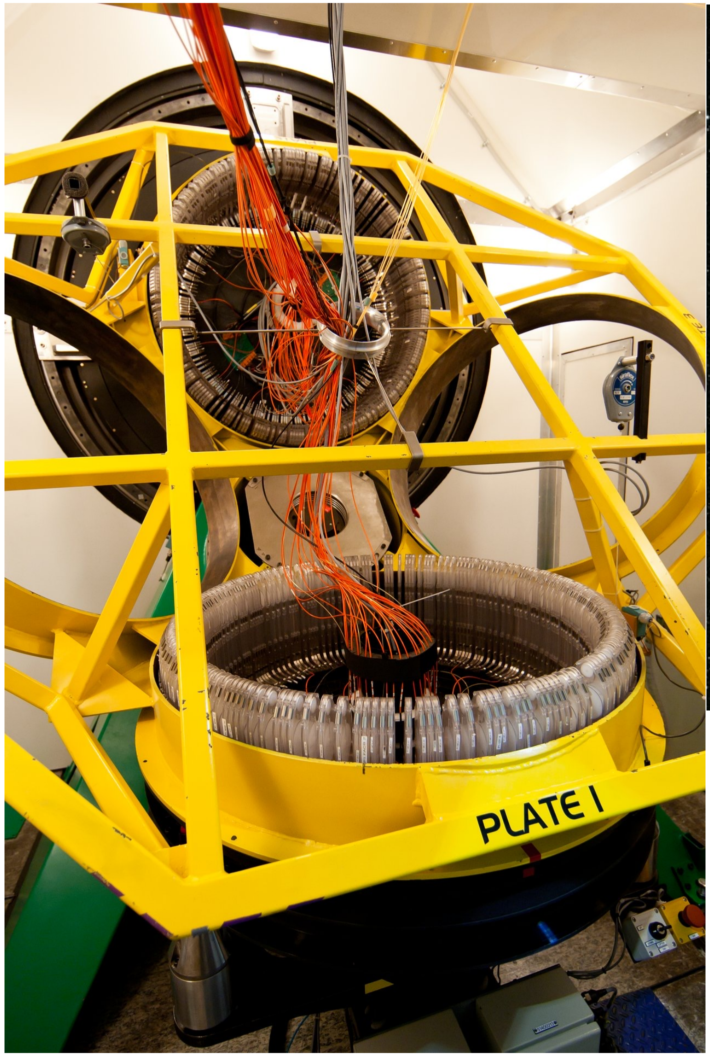
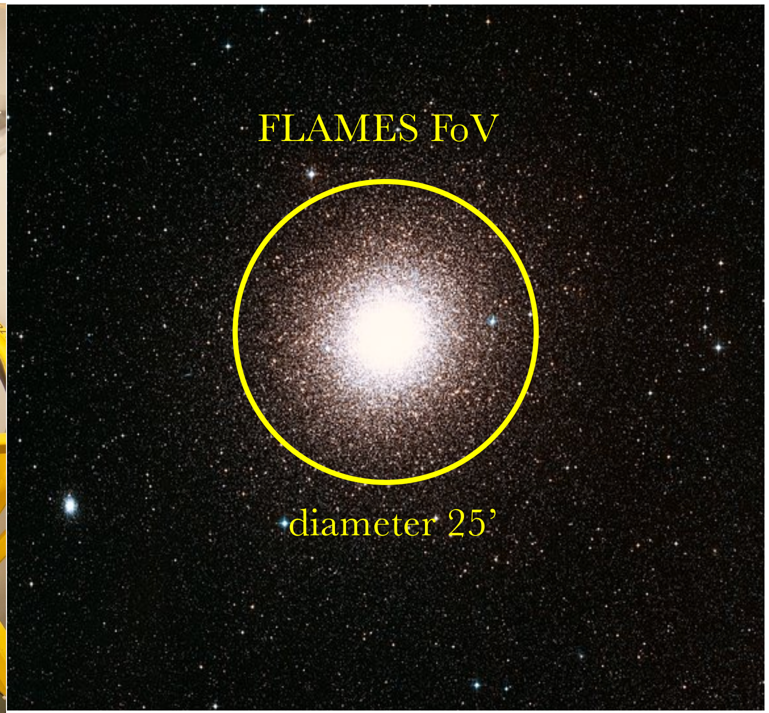
# Gaia-ESO public spectroscopic survey

# Gaia-ESO public survey (with FLAMES@VLT)



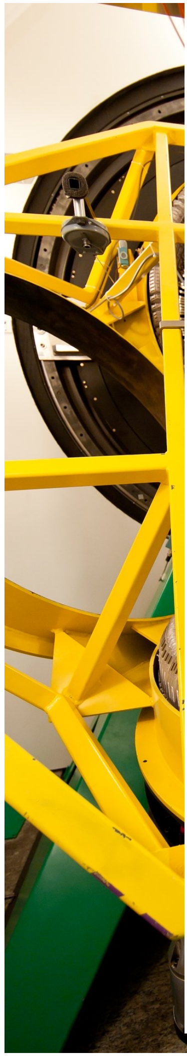

ESO VLT UT2 (8m)
-FLAMES
-FoV = 25 arcmin Ø
-R=47000 (UVES, 8 fibres)
-R=20000 (GIRAFFE, 130 fibres)

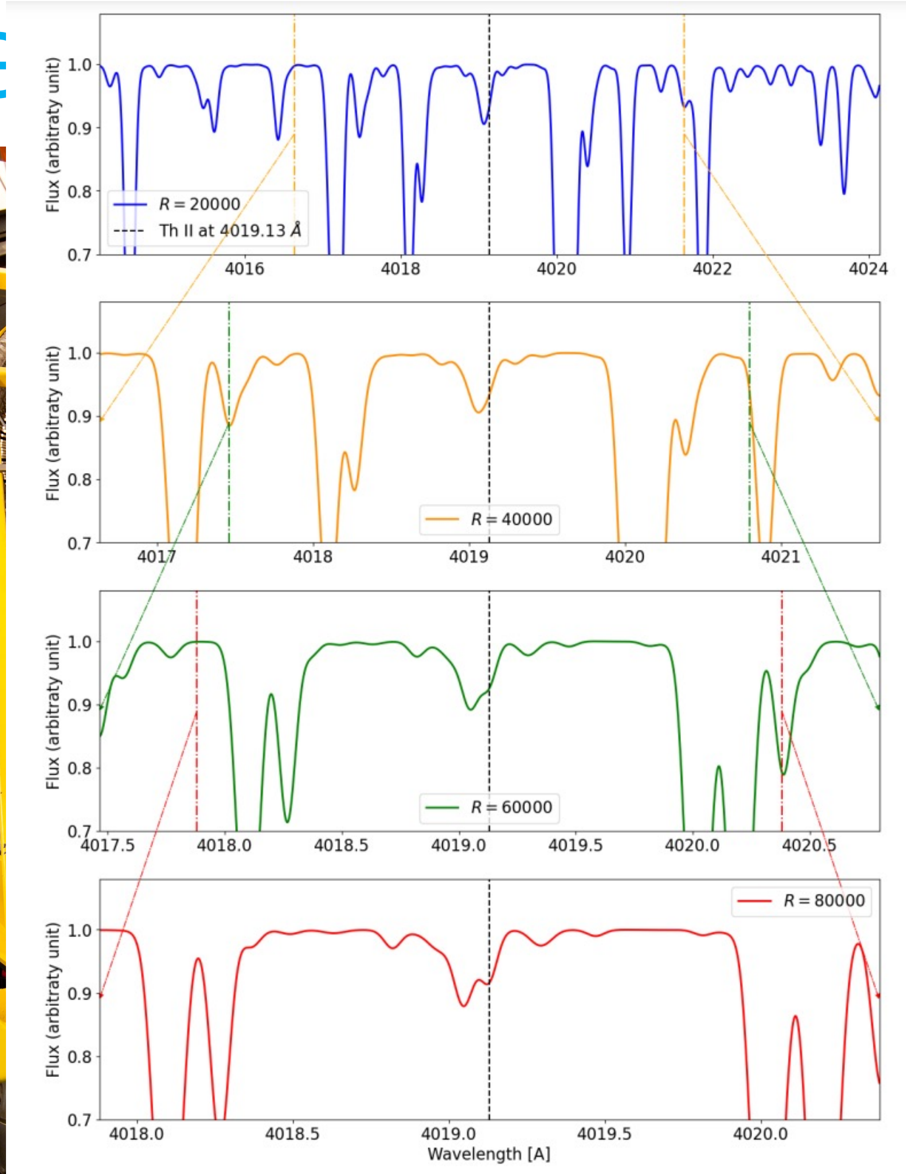
-analysis done with “classical” methods (EW, synthetic spectra) and automatic pipelines
→ many analyses, combined
→ systematics studied

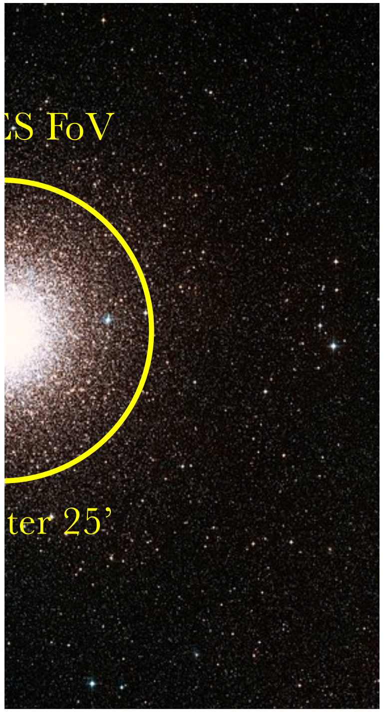
PIs : G. Gilmore (IoA Cambridge)
S. Randich (INAF-Arcetri)

*Gilmore+2022, Randich+2022*

# G (with FLAMES@VLT)






Effect of increasing reaolution *(from HRMOS White paper)*

ESO VLT UT2 (8m)

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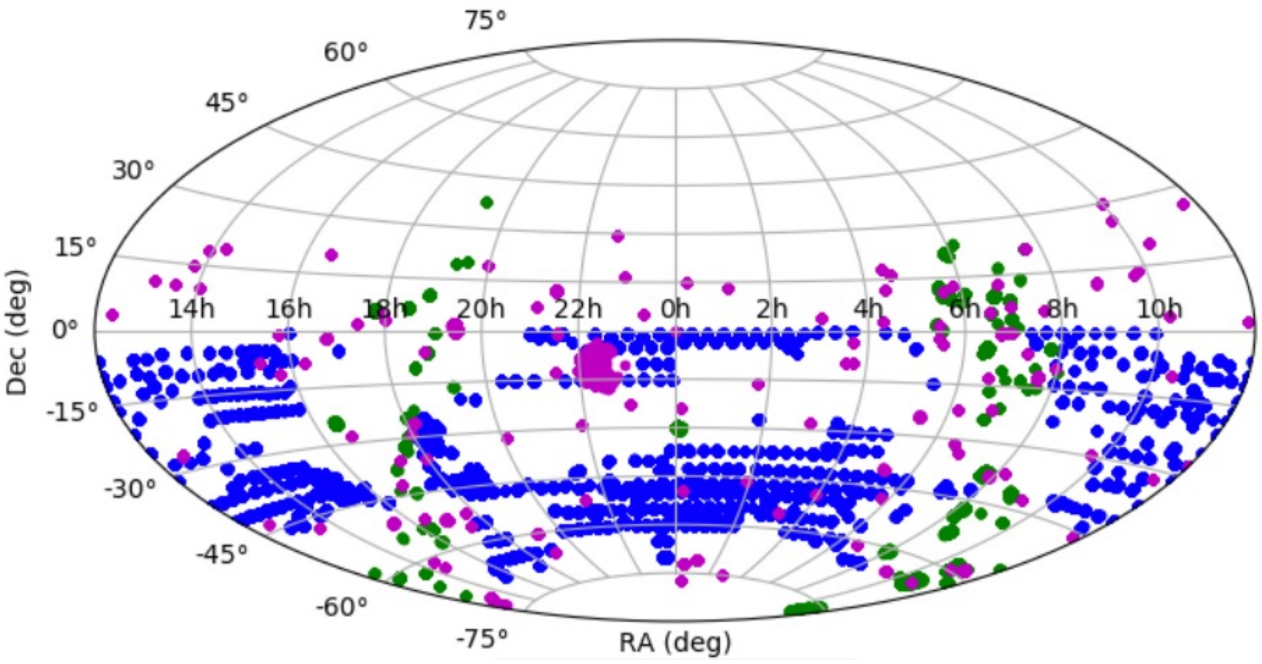
*Gilmore+2022, Randich+2022*

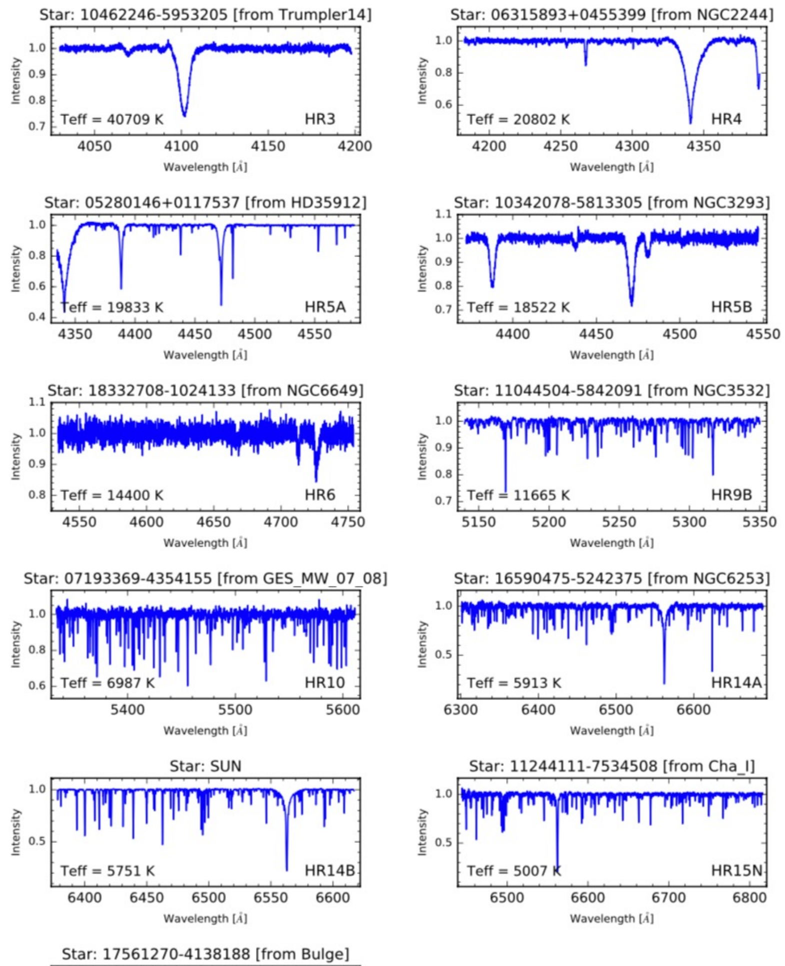
# Gaia-ESO Survey

# Gaia-ESO Survey (GES)

**Public Survey** Gaia-ESO Jan 2012-Jan 2018 (340 nights)
see *Gilmore+2022, Randich+2022*
115k stars, GIRAFFE + UVES : MW field stars & stellar clusters
open clusters (60+, archive), globulars (15, as calibrators, new+archive)




Milky Way Clusters Std & calib

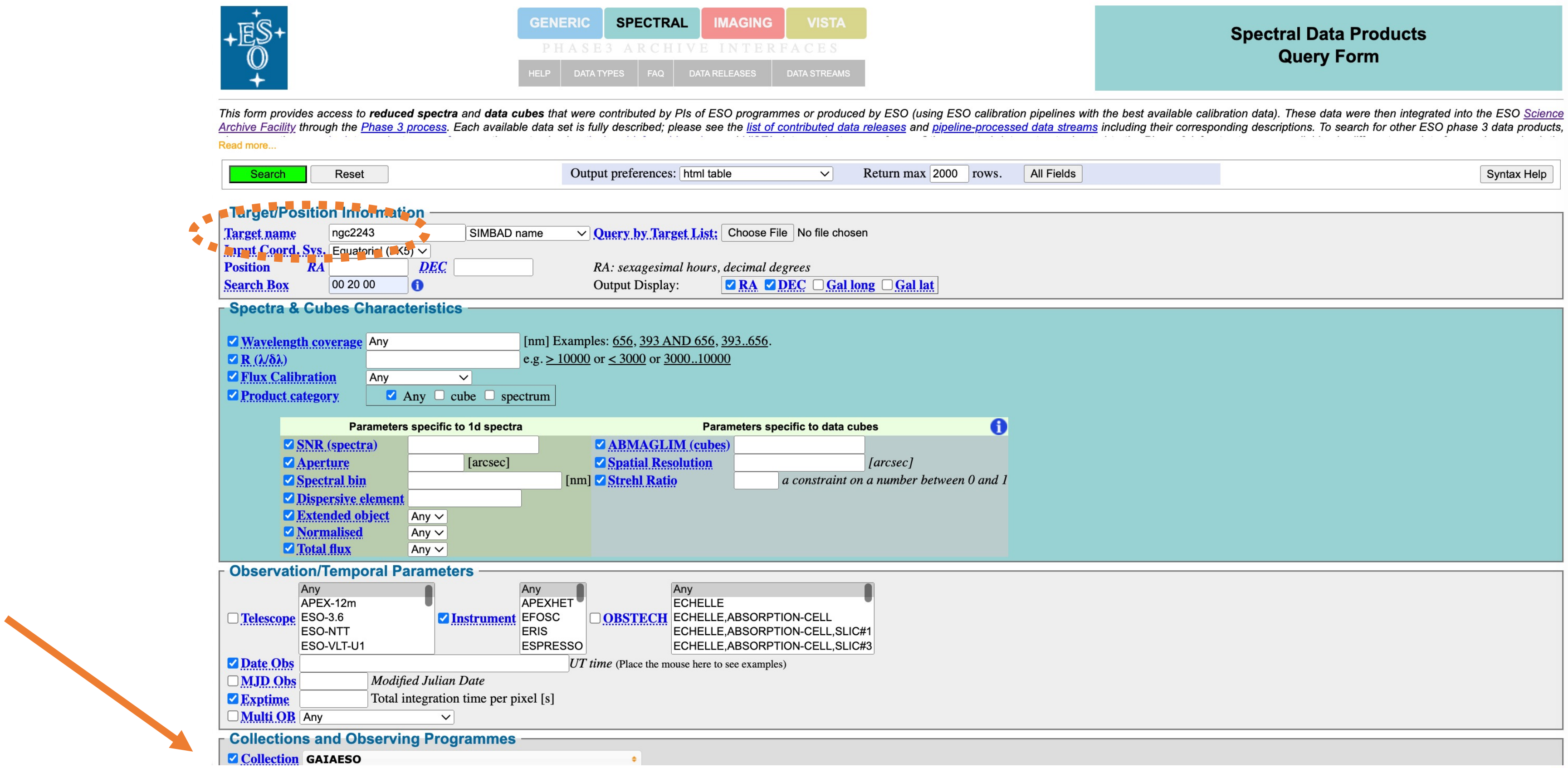



Examples of GIRAFFE setups
main MW: HR10,21
main OC: HR15n,9
main UVES: 480-680nm

# Gaia-ESO Survey : where to find the data

What is available :

- All raw spectra (UVES & GIRAFFE) : ESO raw data archive [ https://archive.eso.org/eso/eso_archive_main.html ]
- All 1-d science ready spectra, produced by GES consortium : ESO Advanced Data Product science portal [https://archive.eso.org/wdb/wdb/adp/phase3_spectral/form ]



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PHASE3 ARCHIVE INTERFACES

**Spectral Data Products**
**Query Results**

- To request data please mark the checkbox in the left-most column (or click anywhere in the row), then press the **Request marked datasets** (or Request this dataset) button
- Datasets which are under proprietary period have the mark button highlighted in **red**;
- Datasets which are publicly available have the mark button highlighted in **green**;
- Datasets which are obsolete have the record highlighted in **orange**;
- Datasets which have been deprecated have the record highlighted in **sunset orange**;
- The version value links to the version history information including submission and processing information;
- The run/program ID value links to the scheduling information and from there to related publications;
- The object name value links to other data products with the same object name and within the same data collection;
- To sort the result table by a given column, click on the empty part of its header cell; click again to toggle between ascending (blue) and descending(red) order;
- The timestamp in a Phase 3 ARCFILE identifier (ADP.timestamp) is related to the time of the data archival, it does not denote the time of observation as it is instead the case for raw data;
- The 1d spectra help page provides a quick guide on the spectral format adopted by Phase 3.

SIMBAD coordinates for ngc2243 : 06 29 34.8, -31 16 55.2.

View Sky | View Previews | Coordinates: sexagesimal | Hide empty columns

Dynamic filter: (# 1120/1120) MarkFiltered | UnmarkFiltered | View only marked records

Request marked datasets | Request marked datasets (old way) | Reset | MarkAll | MarkPublic | MarkProprietary | New query | Programmatic | Your Requests

| Mark | More | ARCFILE | HDR | provenance | Object | RA | DEC | Wavelength coverage | R (λ/δλ) | SNR (spectra) | Instrument | Date Obs | Exptime | Collection | Product version | Release Description | Run/Program ID | ORIGFILE | R |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | ADP.2020-12-07T15:35:01.789 | Header | Display provenance | 06285287-3115375 | 97.220291 | -31.260416 | 644.400..681.600 | 19200 | 71.1 | GIRAFFE | 2013-11-06T07:12:07.973 | 6000.00 | GAIAESO | 4 | [doc id:152] | 188.B-3002(V) | gir3_06285287-3115375_H665.0_iDR6.fits | |
| | | ADP.2020-12-07T15:35:01.793 | Header | Display provenance | 06285343-3117326 | 97.222624 | -31.292388 | 644.400..681.600 | 19200 | 17.9 | GIRAFFE | 2013-11-09T04:34:51.180 | 6000.00 | GAIAESO | 2 | [doc id:152] | 188.B-3002(V) | gir3_06285343-3117326_H665.0_iDR6.fits | |
| | | ADP.2020-12-07T15:35:01.794 | Header | Display provenance | 06285390-3115213 | 97.224583 | -31.255916 | 644.400..681.600 | 19200 | 14.7 | GIRAFFE | 2013-11-09T04:34:51.180 | 6000.00 | GAIAESO | 2 | [doc id:152] | 188.B-3002(V) | gir3_06285390-3115213_H665.0_iDR6.fits | |
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| | | ADP.2020-12-07T15:35:01.799 | Header | Display provenance | 06285471-3119505 | 97.227958 | -31.330694 | 847.500..898.200 | 18000 | 92.7 | GIRAFFE | 2013-11-09T06:34:25.480 | 5400.00 | GAIAESO | 4 | [doc id:152] | 188.B-3002(V) | gir3_06285471-3119505_H875.7_iDR6.fits | |
| | | ADP.2020-12-07T15:35:01.798 | Header | Display provenance | 06285471-3119505 | 97.227958 | -31.330694 | 644.400..681.600 | 19200 | 24.3 | GIRAFFE | 2013-11-08T05:18:47.356 | 3000.00 | GAIAESO | 4 | [doc id:152] | 188.B-3002(V) | gir3_06285471-3119505_H665.0_iDR6.fits | |
| | | ADP.2020-12-07T15:35:01.797 | Header | Display provenance | 06285471-3119505 | 97.227958 | -31.330694 | 533.400..561.100 | 21500 | 64.2 | GIRAFFE | 2013-11-08T06:23:43.463 | 8100.00 | GAIAESO | 4 | [doc id:152] | 188.B-3002(V) | gir3_06285471-3119505_H548.8_iDR6.fits | |
| | | ADP.2020-12-07T15:35:59.778 | Header | Display provenance | 06285487-3119368 | 97.228624 | -31.326888 | 644.400..681.600 | 19200 | 11.9 | GIRAFFE | 2013-11-08T03:19:29.443 | 9000.00 | GAIAESO | 2 | [doc id:152] | 188.B-3002(V) | gir3_06285487-3119368_H665.0_iDR6.fits | |

You can download the selected files
[ you need to have an account at the ESO portal, it's easy to set up ]

# Gaia-ESO Survey : where to find the data

What is available :

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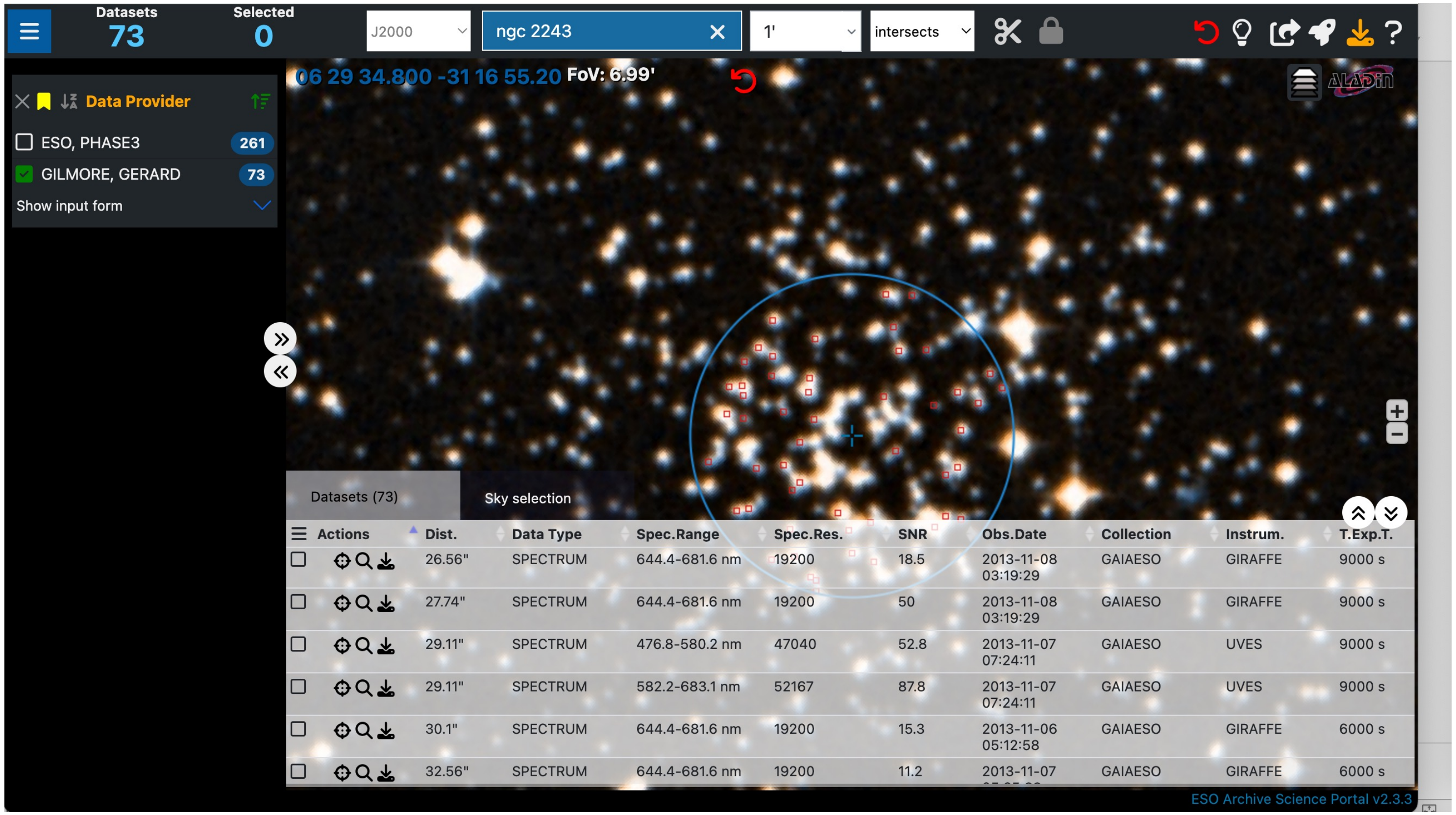
- All 1-d science ready spectra, produced by GES consortium : ESO science portal [ https://archive.eso.org/scienceportal/home ]

**Alternative webpage, with the "modern form" access**

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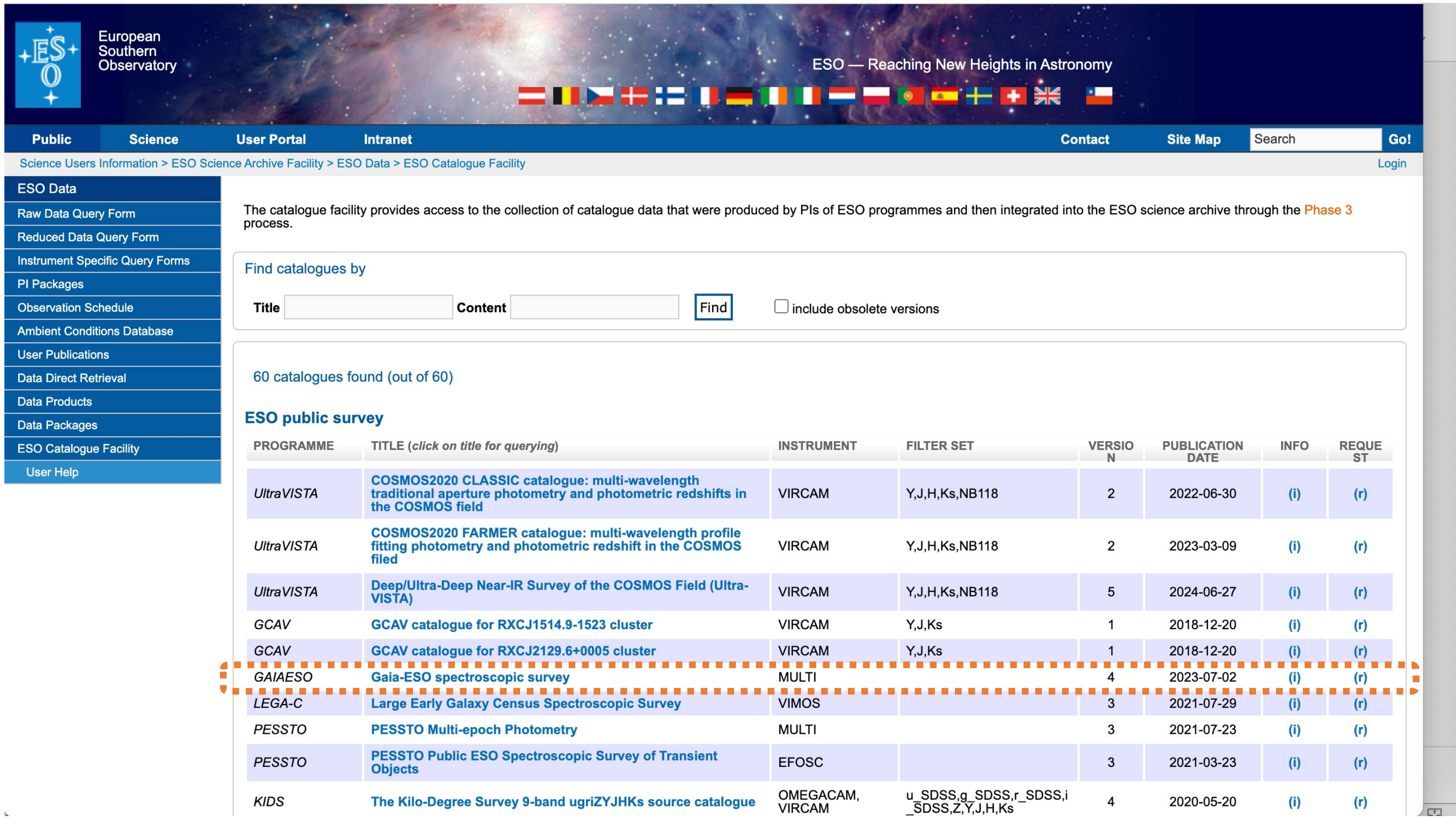
- A catalogue with RV, stellar parameters, elemental abundances : ESO catalogue facility [ https://www.eso.org/qi/ ]



European Southern Observatory

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ESO Data
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- PI Packages
- Observation Schedule
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- User Publications
- Data Direct Retrieval
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- Data Packages
- ESO Catalogue Facility
- User Help

The catalogue facility provides access to the collection of catalogue data that were produced by PIs of ESO programmes and then integrated into the ESO science archive through the Phase 3 process.

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Title | Content | Find | include obsolete versions

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**ESO public survey**

| PROGRAMME | TITLE (*click on title for querying*) | INSTRUMENT | FILTER SET | VERSION | PUBLICATION DATE | INFO | REQUEST |
|---|---|---|---|---|---|---|---|
| *UltraVISTA* | COSMOS2020 CLASSIC catalogue: multi-wavelength traditional aperture photometry and photometric redshifts in the COSMOS field | VIRCAM | Y,J,H,Ks,NB118 | 2 | 2022-06-30 | (i) | (r) |
| *UltraVISTA* | COSMOS2020 FARMER catalogue: multi-wavelength profile fitting photometry and photometric redshift in the COSMOS filed | VIRCAM | Y,J,H,Ks,NB118 | 2 | 2023-03-09 | (i) | (r) |
| *UltraVISTA* | Deep/Ultra-Deep Near-IR Survey of the COSMOS Field (Ultra-VISTA) | VIRCAM | Y,J,H,Ks,NB118 | 5 | 2024-06-27 | (i) | (r) |
| *GCAV* | GCAV catalogue for RXCJ1514.9-1523 cluster | VIRCAM | Y,J,Ks | 1 | 2018-12-20 | (i) | (r) |
| *GCAV* | GCAV catalogue for RXCJ2129.6+0005 cluster | VIRCAM | Y,J,Ks | 1 | 2018-12-20 | (i) | (r) |
| *GAIAESO* | Gaia-ESO spectroscopic survey | MULTI | | 4 | 2023-07-02 | (i) | (r) |
| *LEGA-C* | Large Early Galaxy Census Spectroscopic Survey | VIMOS | | 3 | 2021-07-29 | (i) | (r) |
| *PESSTO* | PESSTO Multi-epoch Photometry | MULTI | | 3 | 2021-07-23 | (i) | (r) |
| *PESSTO* | PESSTO Public ESO Spectroscopic Survey of Transient Objects | EFOSC | | 3 | 2021-03-23 | (i) | (r) |
| *KIDS* | The Kilo-Degree Survey 9-band ugriZYJHKs source catalogue | OMEGACAM, VIRCAM | u_SDSS,g_SDSS,r_SDSS,i_SDSS,Z,Y,J,H,Ks | 4 | 2020-05-20 | (i) | (r) |

# Gaia-ESO Survey : where to find the data

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| *GCAV* | **GCAV catalogue for RXCJ2129.6+0005 cluster** | VIRCAM | Y,J,Ks | 1 | 2018-12-20 | (i) | (r) |
| *GAIAESO* | **Gaia-ESO spectroscopic survey** | MULTI | | 4 | 2023-07-02 | (i) | (r) |
| *LEGA-C* | **Large Early Galaxy Census Spectroscopic Survey** | VIMOS | | 3 | 2021-07-29 | (i) | (r) |

**Details - Gaia-ESO spectroscopic survey**

You get details

**Catalogue** | Columns

| | |
|---|---|
| **Title** | Gaia-ESO spectroscopic survey |
| **Version** | 4 |
| **Data Provider/P.I.** | Gerard Gilmore |
| **Data Collection** | GAIAESO |
| **Data Release** | DR5.1 |
| **Submission Date** | 2023-06-01 |
| **Publication Date** | 2023-07-02 |
| **Description** | Gaia-ESO is a large public spectroscopic survey carried out with FLAMES, targeting 114916 stars, systematically covering all major components of the Milky Way from halo to star-forming regions providing an homogeneous overview of the distributions of radial velocities and elemental abundances. *Please refer to the full data release description for further information.* |
| **Telescope** | ESO-VLT-U2 |
| **Instrument** | MULTI |
| **Technique of Observation** | MOS |
| **Start of Observations** | 52,670.093 (2003-01-31T15:14:40) |
| **End of Observations** | 58,144.165 (2018-01-26T16:58:21) |
| **Filter Set/bands** | |
| **Sky Solid Angle** | |
| **Number of Records** | 114916 |
| **Number of Columns** | 350 |
| **Reference** | |
| **Acknowledgment Policy** | Please include the following acknowledgment in any published material that makes use of this data product: Based on data obtained from the ESO Science Archive Facility with DOI: https://doi.org/10.18727/archive/25 |

You can download the catalogue as a whole [ you need to have an account at the ESO portal, it's easy to set up ]

# Gaia-ESO Survey : where to fi

| | | | |
|---|---|---|---|
| *GCAV* | **GCAV catalogue for RXCJ2129.6+0005 cluster** | VIRCAM | Y,J,Ks |
| *GAIAESO* | **Gaia-ESO spectroscopic survey** | MULTI | |
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**Details - Gaia-ESO spectroscopic survey**

**Catalogue** Columns

| | |
|---|---|
| **Title** | Gaia-ESO spectroscopic survey |
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ESO Science Archive Facility - Phase 3 Data Release Description

ESO public survey programme Gaia-ESO spectroscopic survey, Data Release DR5.1

provided by Gerard Gilmore, submitted on 2023-06-01, published on 2023-07-02

## ESO Phase 3 Data Release Description

### Gaia-ESO Survey Release 5.1


### Abstract

Gaia-ESO is a large public spectroscopic survey carried out with FLAMES, targeting 114916 stars, systematically covering all major components of the Milky Way, from halo to star-forming regions, providing the first homogeneous overview of the distributions of kinematics and elemental abundances. This alone is revolutionising our knowledge of Galactic and stellar evolution: when combined with *Gaia* astrometry the survey quantifies the formation history and evolution of young, mature and ancient Galactic populations. With well-defined samples, we have observed the bulge, thick and thin discs and halo components, and open star clusters of all ages and masses. The UVES and GIRAFFE spectra have: quantified individual elemental abundances in each star; yielded precise radial velocities for a 4-D kinematic phase-space; mapped kinematic gradients and abundance; followed the formation, evolution and dissolution of open clusters as they populate the disc and provided a legacy dataset that adds enormous value to the Gaia mission and on-going ESO surveys.


### Overview of the observations

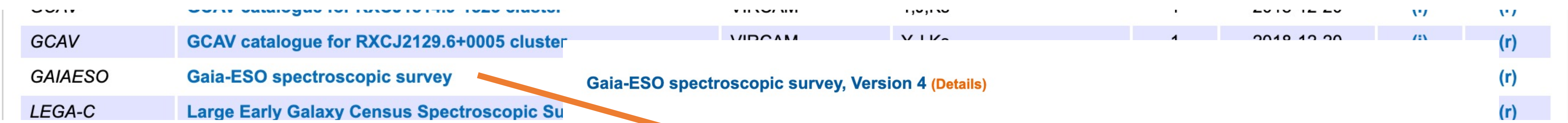
This is the last release of the Gaia-ESO Survey (GES) and include all the astrophysical parameters derived from the observations carried out between December 2011 and January 2018. These include Milky Way field observations, Open Cluster observations, and calibration observations of different targets, such as radial velocity standard stars, benchmark stars, globular clusters, COROT and Kepler 2 red giants and more (see Pancino et al. 2017, A&A, 589, A5). There are also included astrophysical parameters derived from complementary observations extracted from the ESO archive and processed with the GES pipelines. These encompass mostly cluster observations retrieved to benefit both science and calibrations as well as some bulge observations and are denoted by use of the prefix 'AR' rather than 'GE' in the GES_TYPE header keyword of the spectra. See Table 1 for a list of GES_TYPEs and the corresponding field types. Figure 1 shows the location of the fields on the sky.

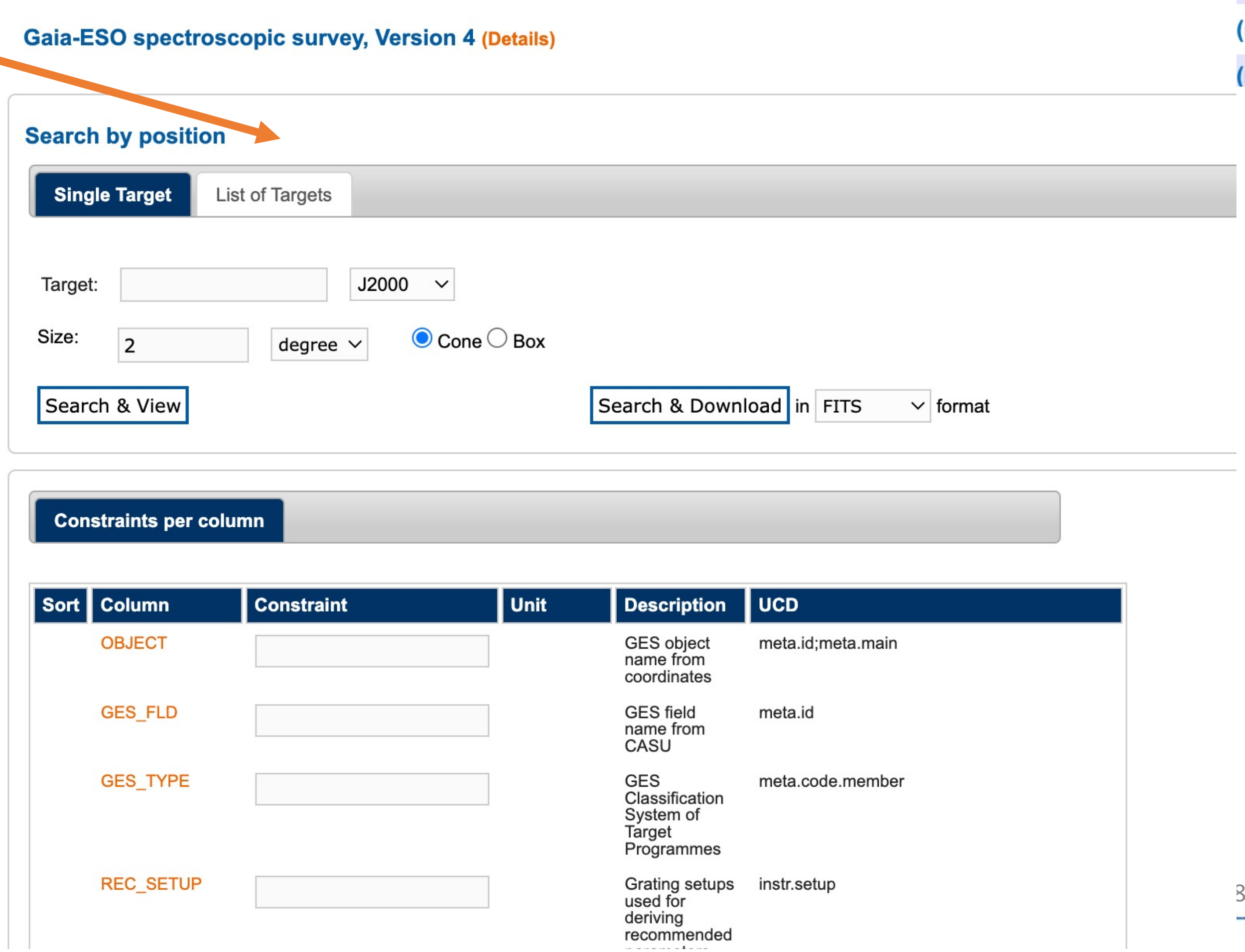
*Table 1: The list of GES_TYPE header keywords used within the Survey to denote the observation and field types, and their definition.*

| GES TYPE prefix | Observation type |
|---|---|
| GE | Observed by GES |
| AR | ESO Archive Observation |
| | |
| **GES_TYPE**[1] | **Field type** |
| * _MW | Milky Way programme |
| * _MW_BL | Milky Way programme: bulge field |
| * _CL | Open Cluster programme field |

[1] In the following list "*" denotes either the string 'GE' or 'AR', which complete the GES_TYPE keyword.

# Gaia-ESO Survey : where to find the data




If you do not want the whole catalogue you can select in a cone or box region (with the possibility of limiting the columns you want and putting constraints on columns)

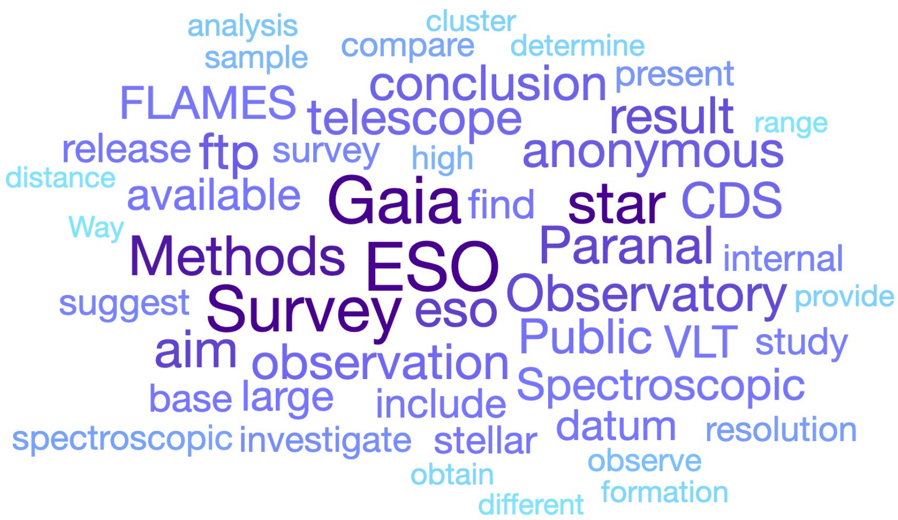
# Gaia-ESO Survey : the science

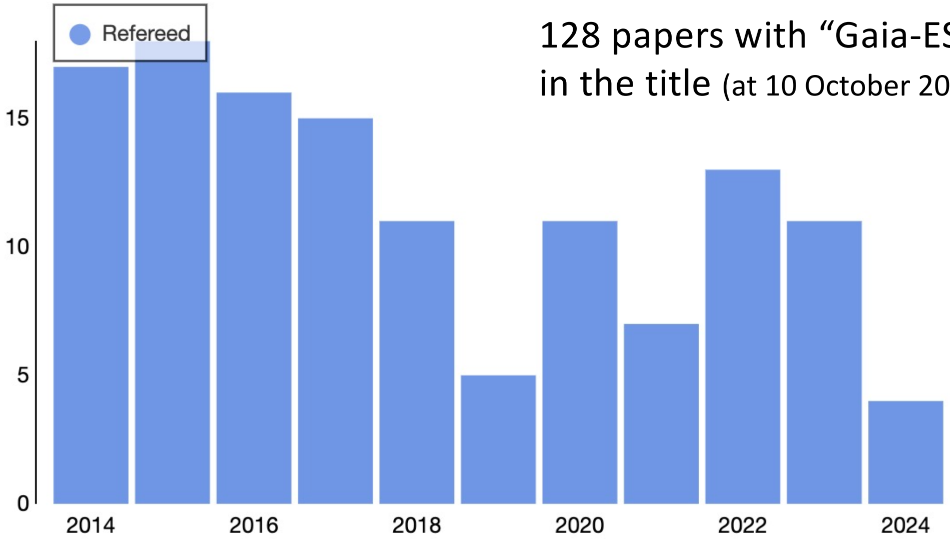
**Milky Way:** radial metallicity gradient, Galactic evolution, age-metallicity relation, bulge metallicity and kinematics, bulge evolution, thin/thick disk transition, DIBs and reddening, lithium-rich and Li Galactic evolution, chemical clocks such as [C/N] and [Y/Mg], binaries

**Open clusters:** individual objects (membership, RV, metallicity, abundances, accretion, kinematic structure, N-body modelling, etc), disk metallicity and evolution, test of mixing/dilution in atmospheres, Li-rich giants, cluster parameters with Gaia-ESO & Gaia

**Globulars:** kinematics, rotation and models, field interaction, abundances, Li-rich

[plus papers leveraging on homogeneous analysis of field and cluster stars]

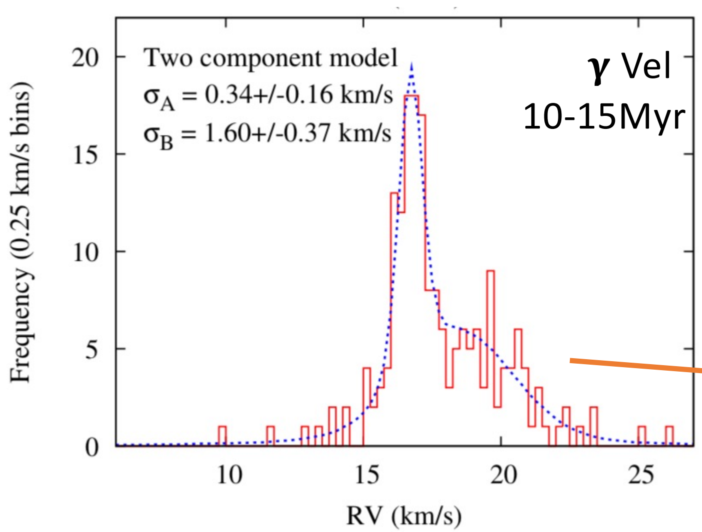


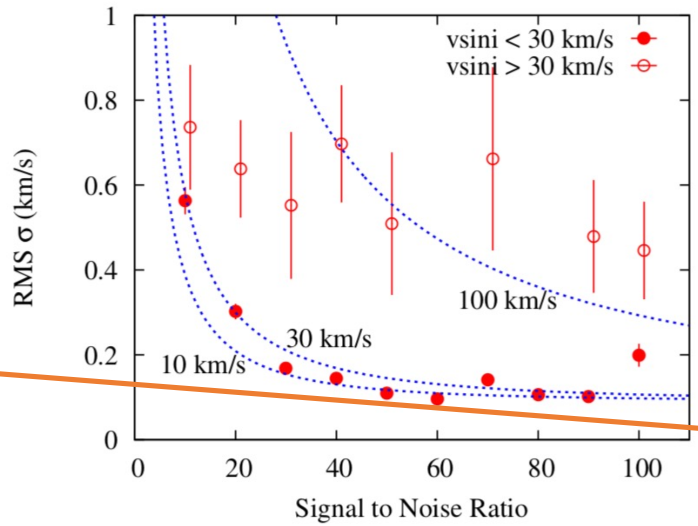



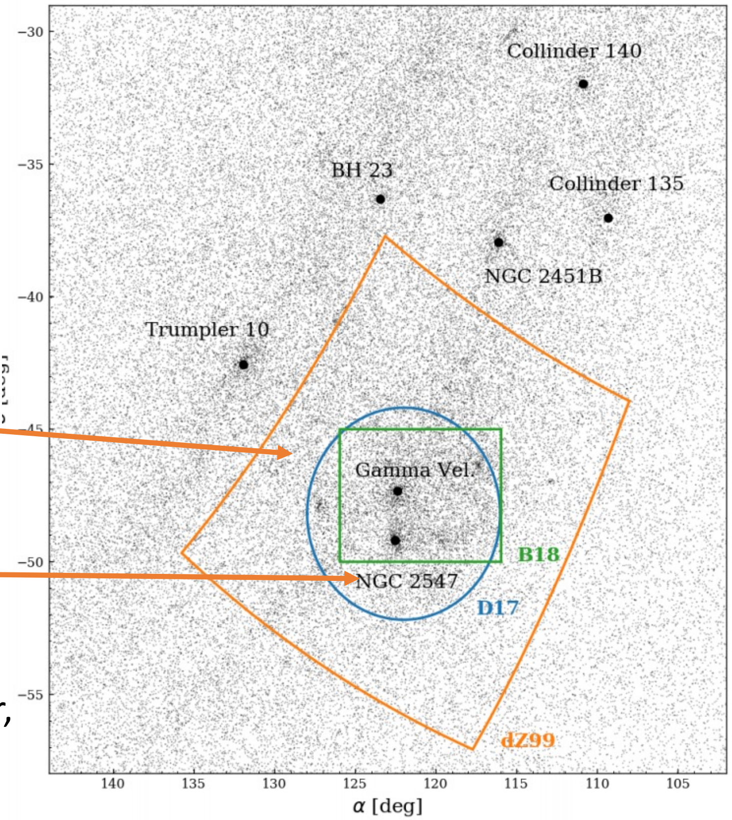

128 papers with "Gaia-ESO" in the title (at 10 October 2024)

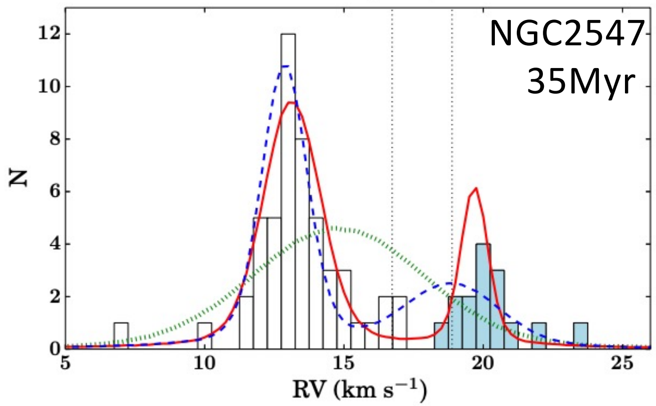
# Gaia-ESO Survey : science results (examples)

**High-recision RV measurements for large samples of cluster stars : kinematical substructures in young clusters**
(later confirmed by Gaia)



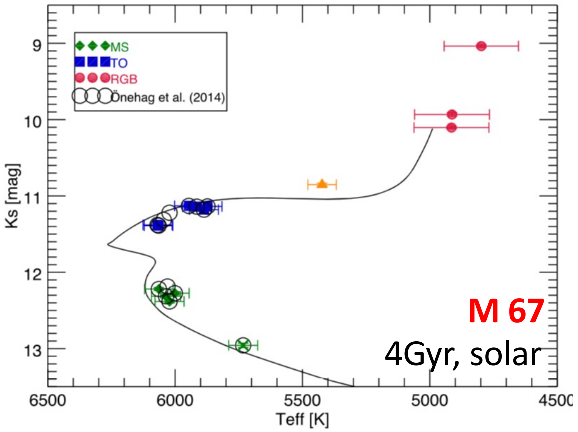



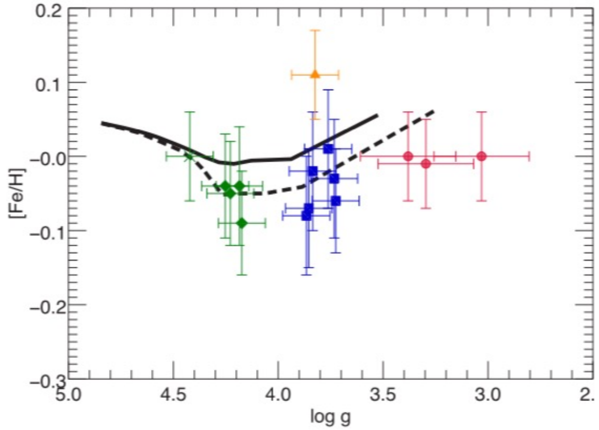

-**γ** Vel has 2 components
-NGC2547 has second component, younger, kinematically similar to **γ** Vel B
-young stellar pop spread over degrees

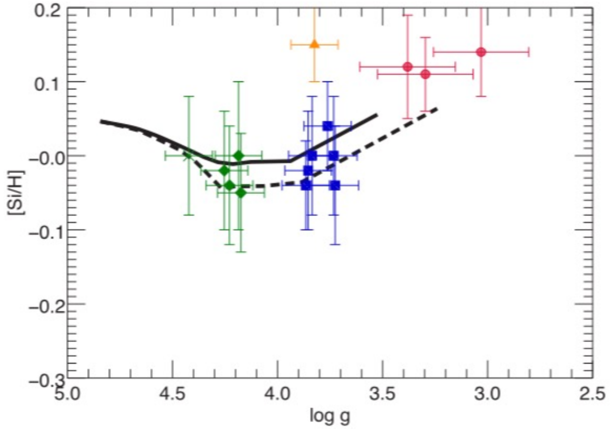
*Jeffries+2014; Sacco+2015; Cantat-Gaudin+201*

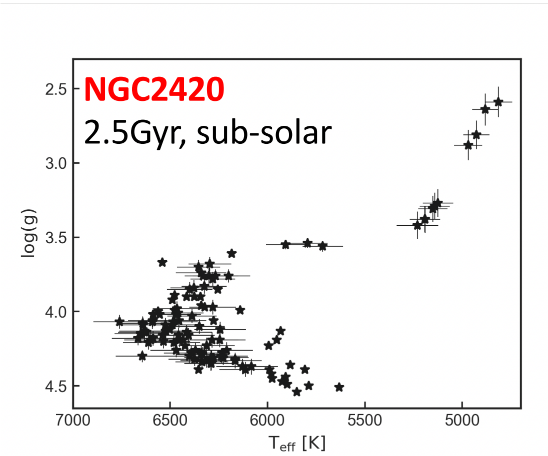
# Gaia-ESO Survey : science results (examples)

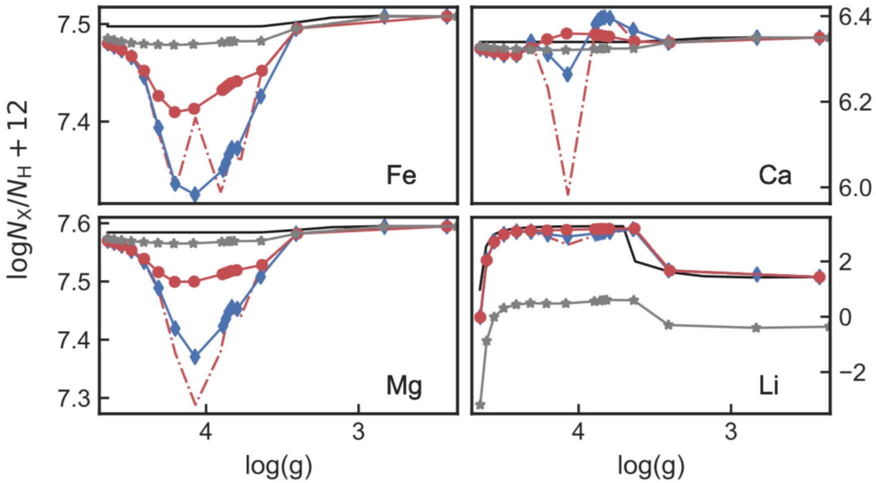
**Diffusion of elements : a challenge for chemical tagging** (check done using old open clusters observed from MS to giants)



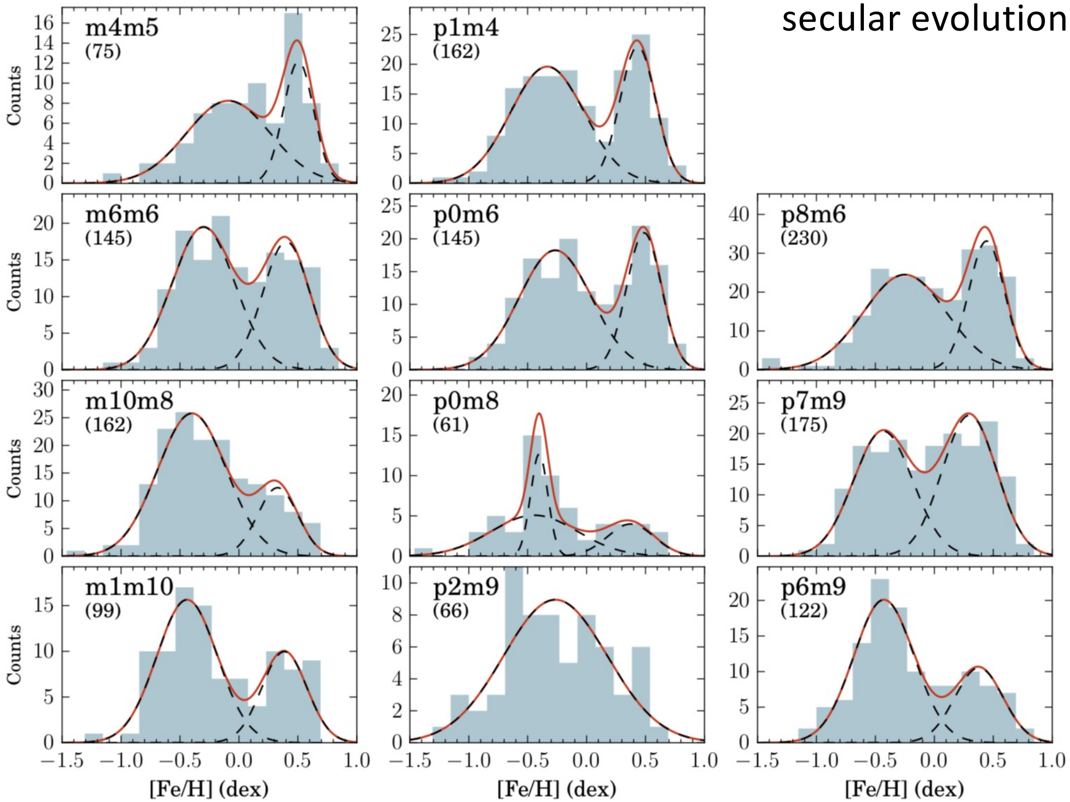

- Models predict variations in surface abundance due to diffusion
- Larger at MSTO
- Original values restored after 1DU

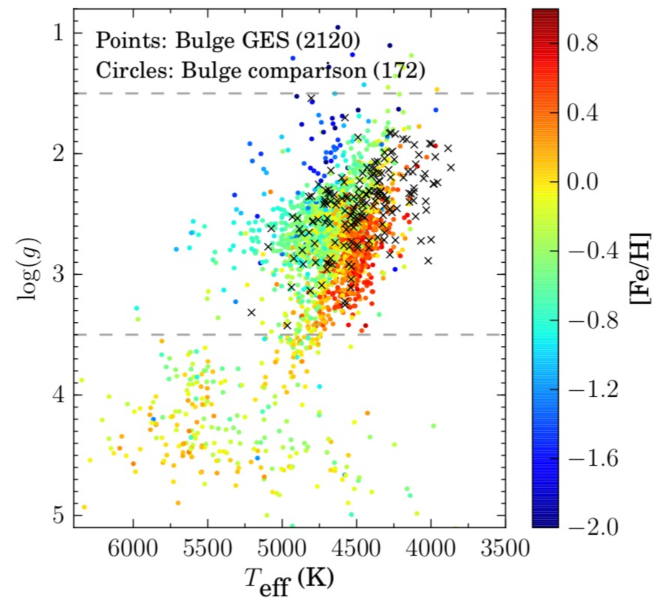
*Bertelli Motta+2018; Semenova+2020*

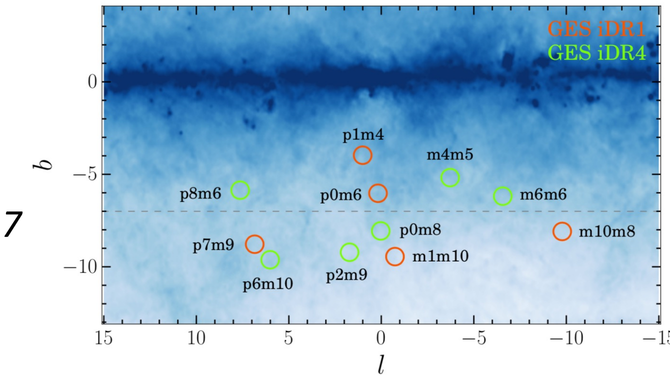
# Gaia-ESO Survey : science results (examples)

**Metallicity distribution in the MW bulge :** first analysis of bulge MDF and α-abundances in a large area, with homogeneous, fully spectroscopic analysis of HRS, high S/N data.

- 2500 bulge RC stars + 6300 disk stars for comparison
- MDF, Mg, space distribution, kinematics (MR: bar kinematics)
- Metallicity bimodality, f(l,b) : MR associated with the boxy/peanut bulge, formed by secular evolution of the inner disk

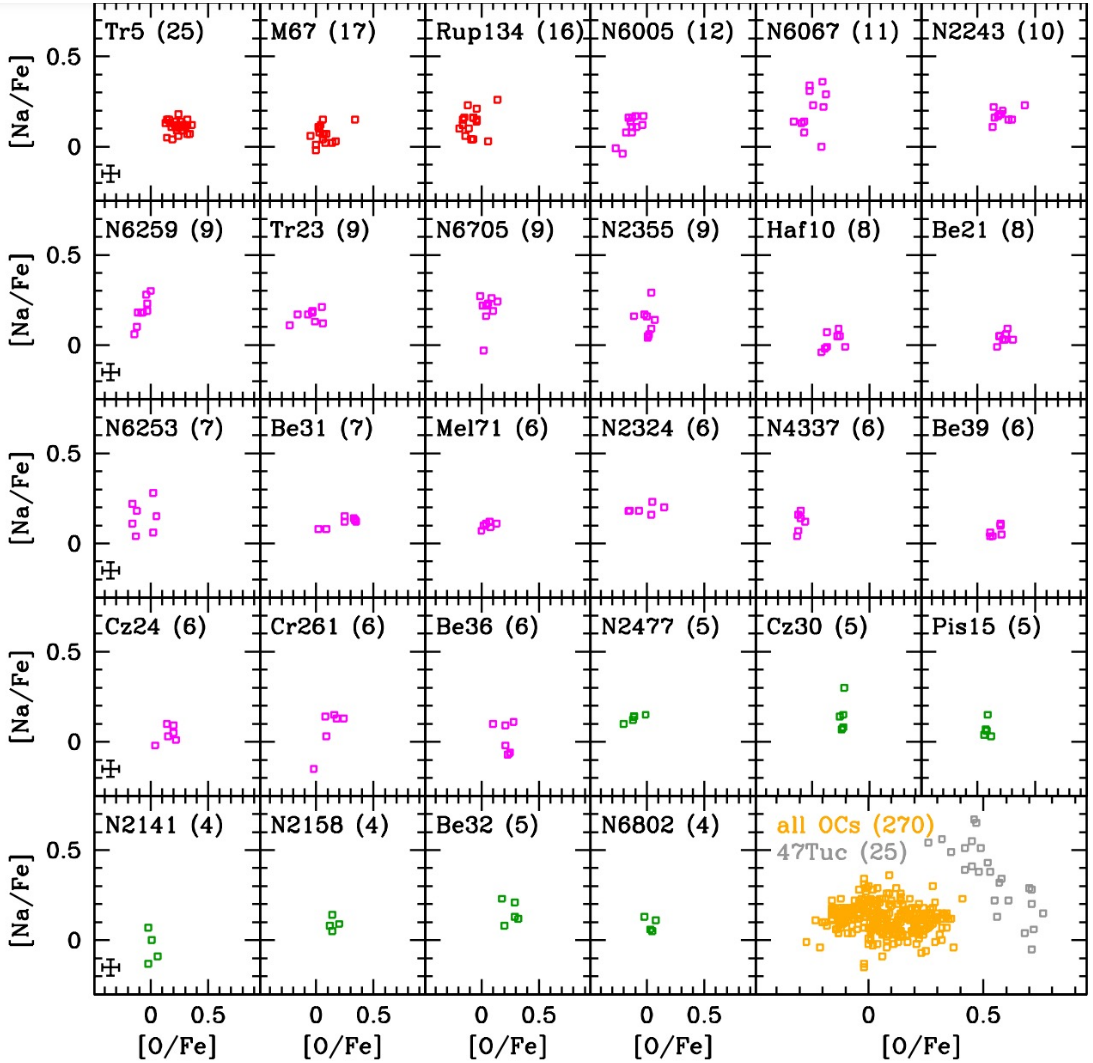


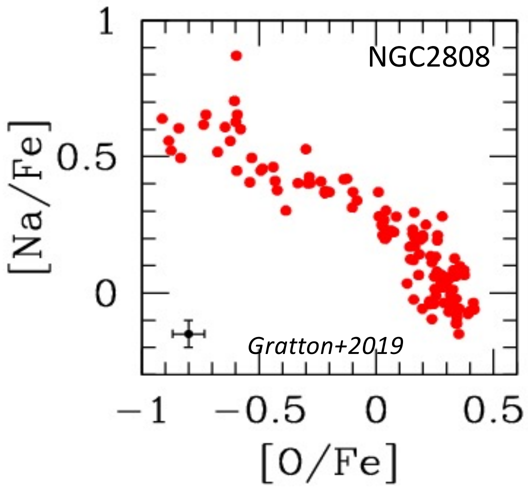

*Rojas Arriagada+2017 (similar work using APOGEE, RA+2019. Chemical models in Matteucci+2019)*

# Gaia-ESO Survey : science results (examples)




No sign of multiple stellar population in open clusters from their sodium and oxygen abundances

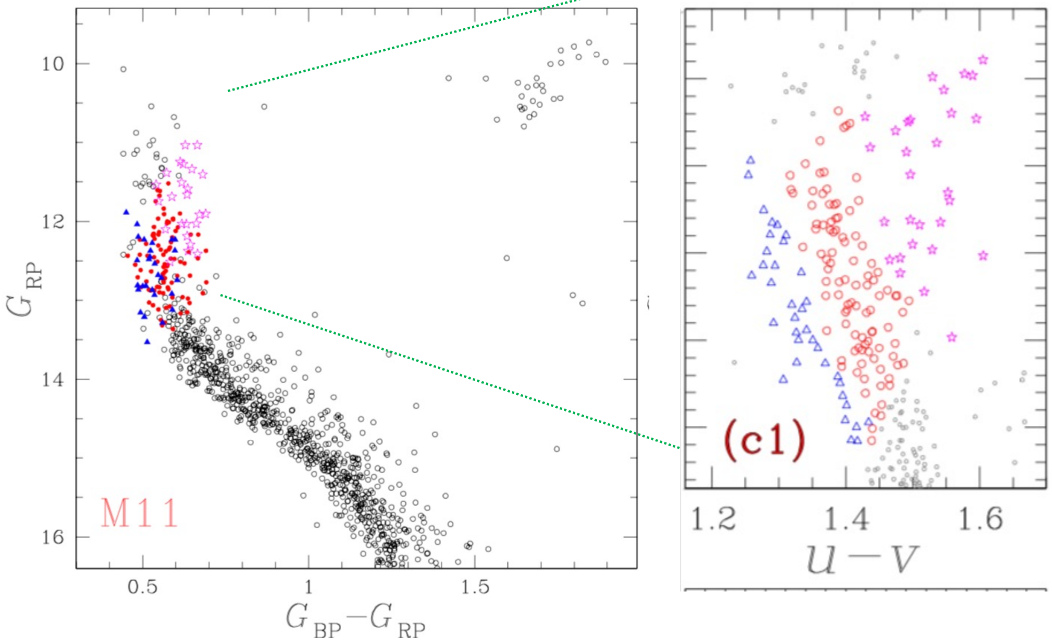
Compare the O-Na distributions in OCs with that in GCs

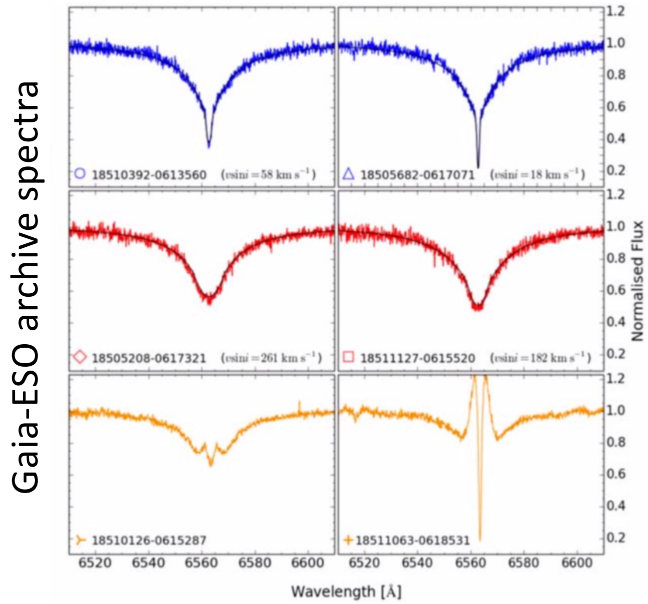



*Bragaglia+2022*

# Gaia-ESO Survey : use of archive spectra

Gaia CMD Strömgren *v,u-v* CMD




**Extended MSTO common in MC clusters : multiple populations?**

**- M11 (MW open cluster) :** photometry + Gaia-ESO spectra

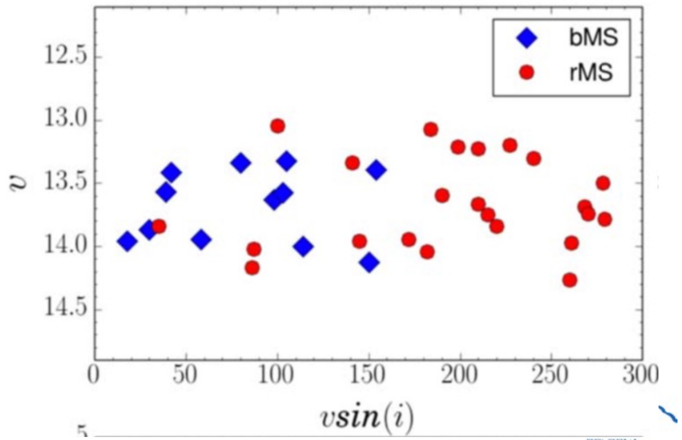
**bMS** stars slow rotators, **rMS** stars fast rotator

eMSTO → effect of rotation

no need for extended SF

simple SP, not multiple

*Marino+2018*



# APOGEE (part of Sloan Digital Sky Surveys)

# Sloan Digital Sky Surveys

- **SDSS** (2000-2008)
  - Legacy
  - Supernova
  - SEGUE-1 (Sloan Extension for Galactic Understanding and Exploration, stars, optical, MOS, R~2000)
- **SDSS-III** (2008-2014)
  - APOGEE (Apache Point Observatory Galactic Evolution Experiment: near IR, MOS, R=22500)
  - BOSS (Baryon Oscillation Spectroscopic Survey: map of the Universe )
  - MARVELS (Multi-Object APO Radial Velocity Exoplanet Large-area Survey: local search for exo-planets)
  - SEGUE-2
- **SDSS-IV** (2014-2020)
  - APOGEE-2 (APO-N + APO-S)
  - eBOSS
  - MaNGA (Mapping Nearby Galaxies at APO; 7 science IFUs per 7 $deg^2$ plate, optical, R=2000)
- **SDSS-V** (2020- )
  - Milky Way Mapper (optical/NIR spectra of >4M of MW & Local Group stars) – first release in DR19
  - Local Volume Mapper (optical, IFU, MW, MCs & other local volume galaxies)
  - Black Hole Mapper (optical, MOS, multi-epoch for QSOs)

https://www.sdss.org/

# Sloan Digital Sky Surveys

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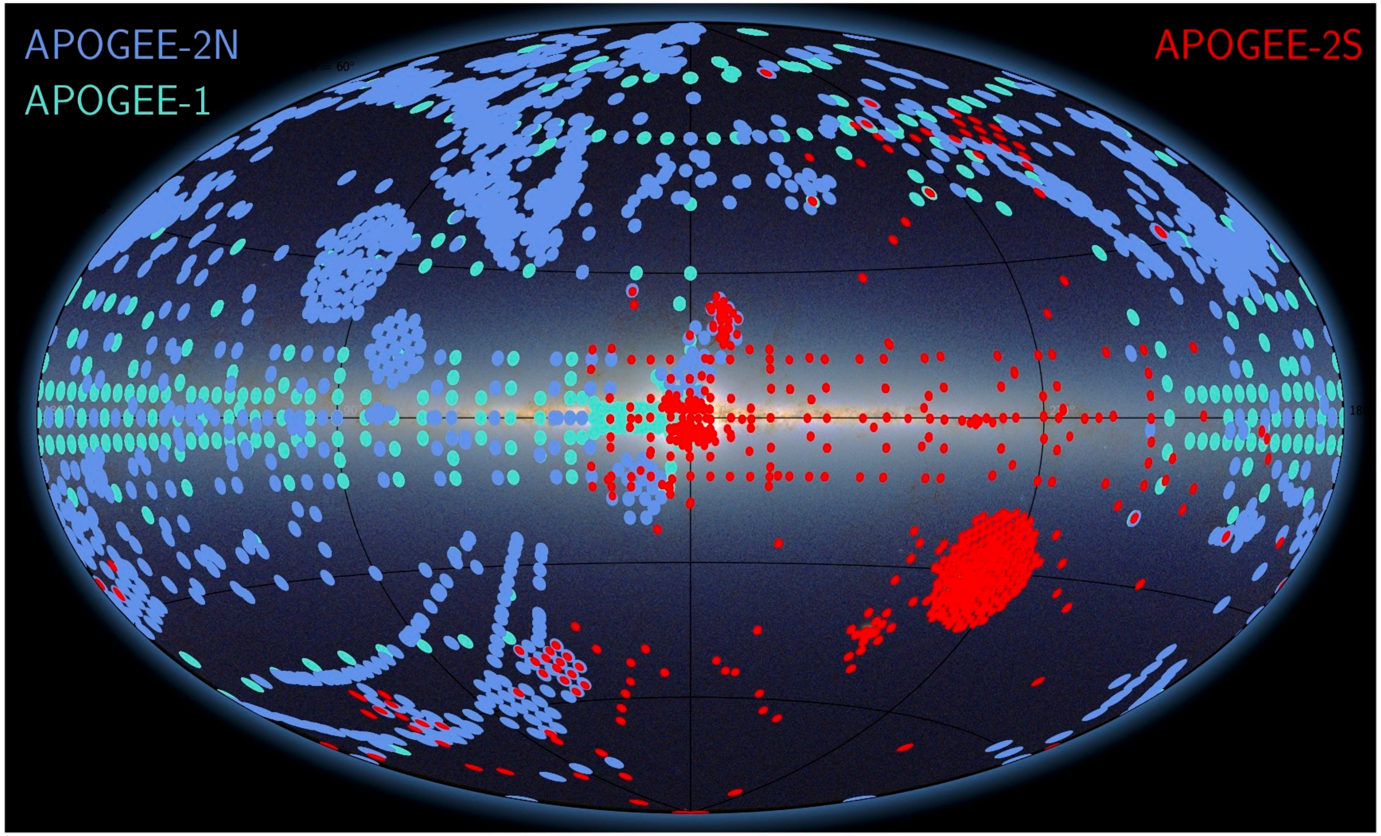
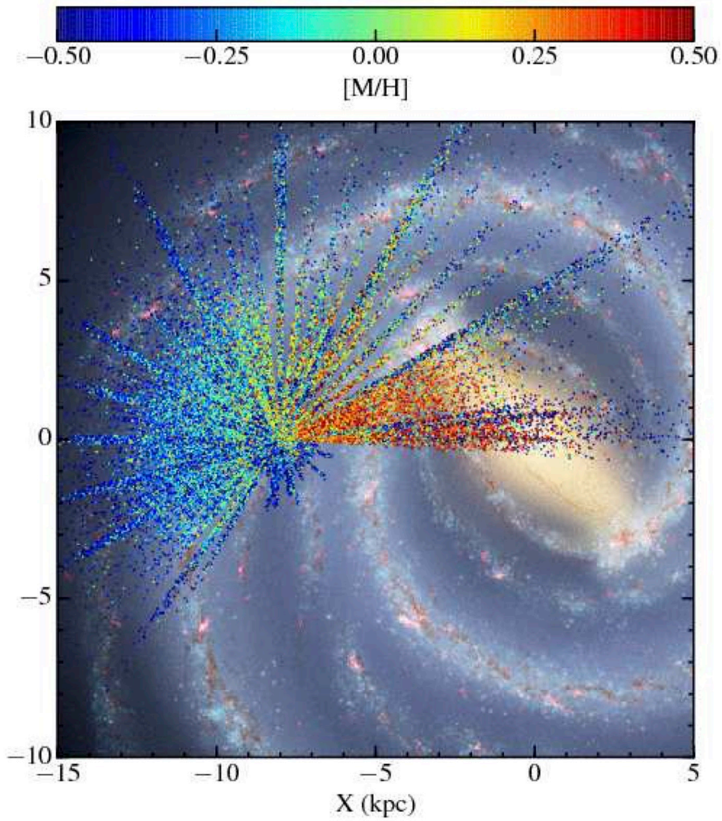
[https://www.sdss.org/](https://www.sdss.org/)

# APOGEE

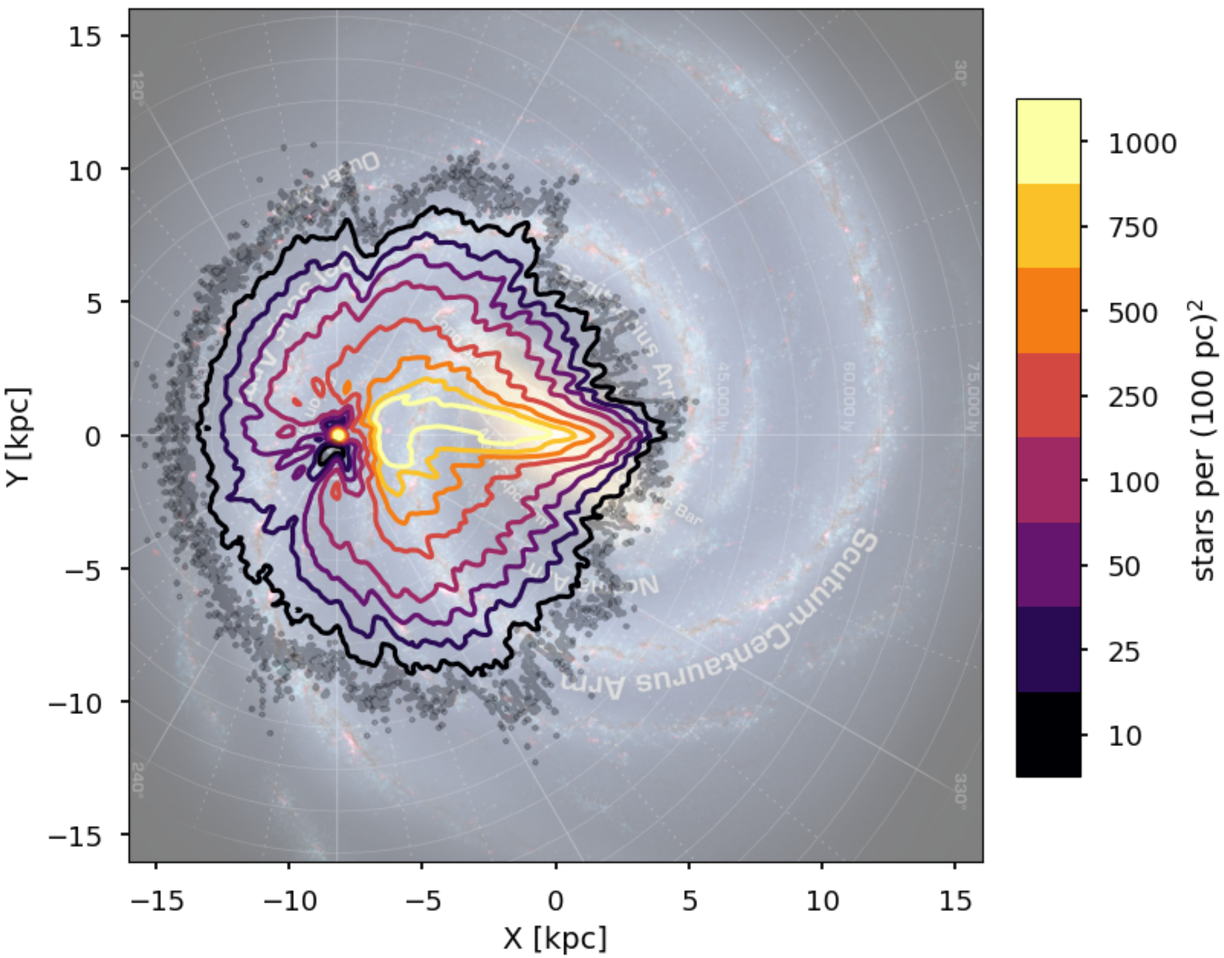


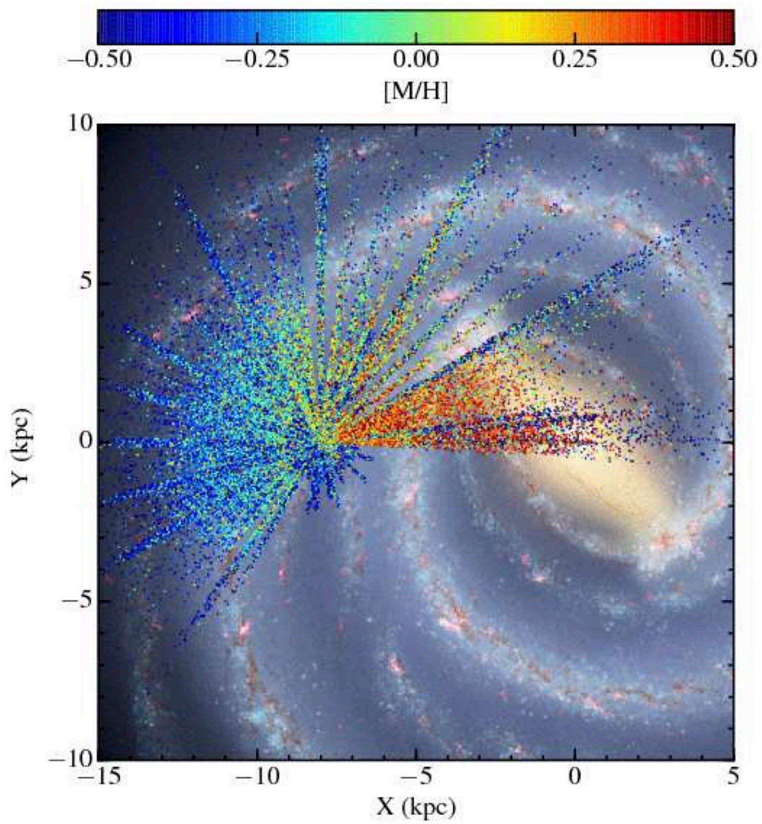




Galactic distribution for APOGEE-1

Last data release of APOGEE-1 + APOGEE-2 (DR17) containts 657000 stars

# APOGEE



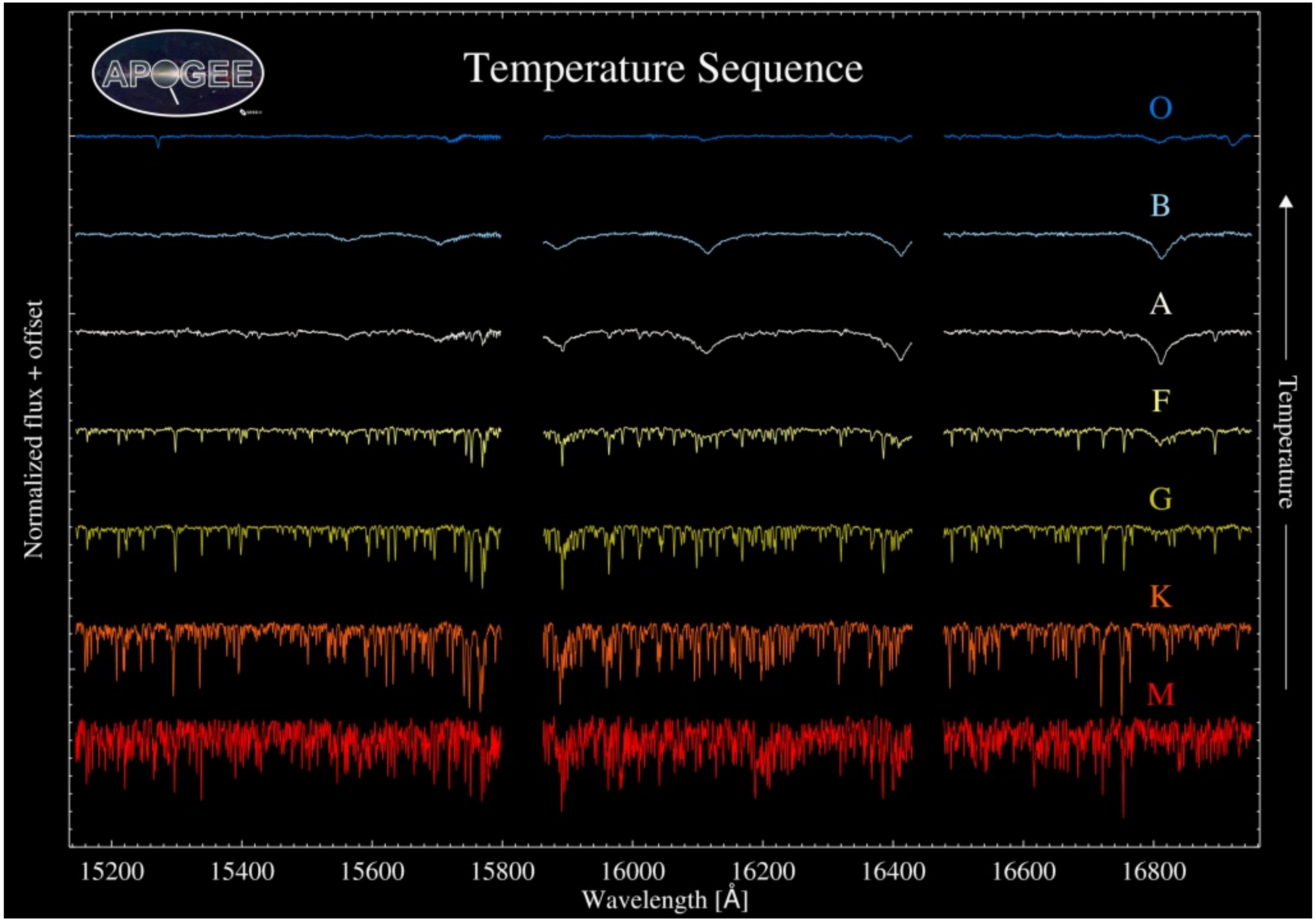




Galactic distribution for APOGEE-1

Galactic distribution for MWM-Galactic Genesis program (±500 pc from MW midplane)

# APOGEE

300 fibers
2.5m Apache Point (North, NM)
2.5m LCO (South, Chile)
Near IR (H band)
R=22500




Exemplar APOGEE spectra for stars of O, B, A, F, G, K, and M spectral types.
(Figure by S. Chojnowski)

# APOGEE DR17

**DR17 provides:**

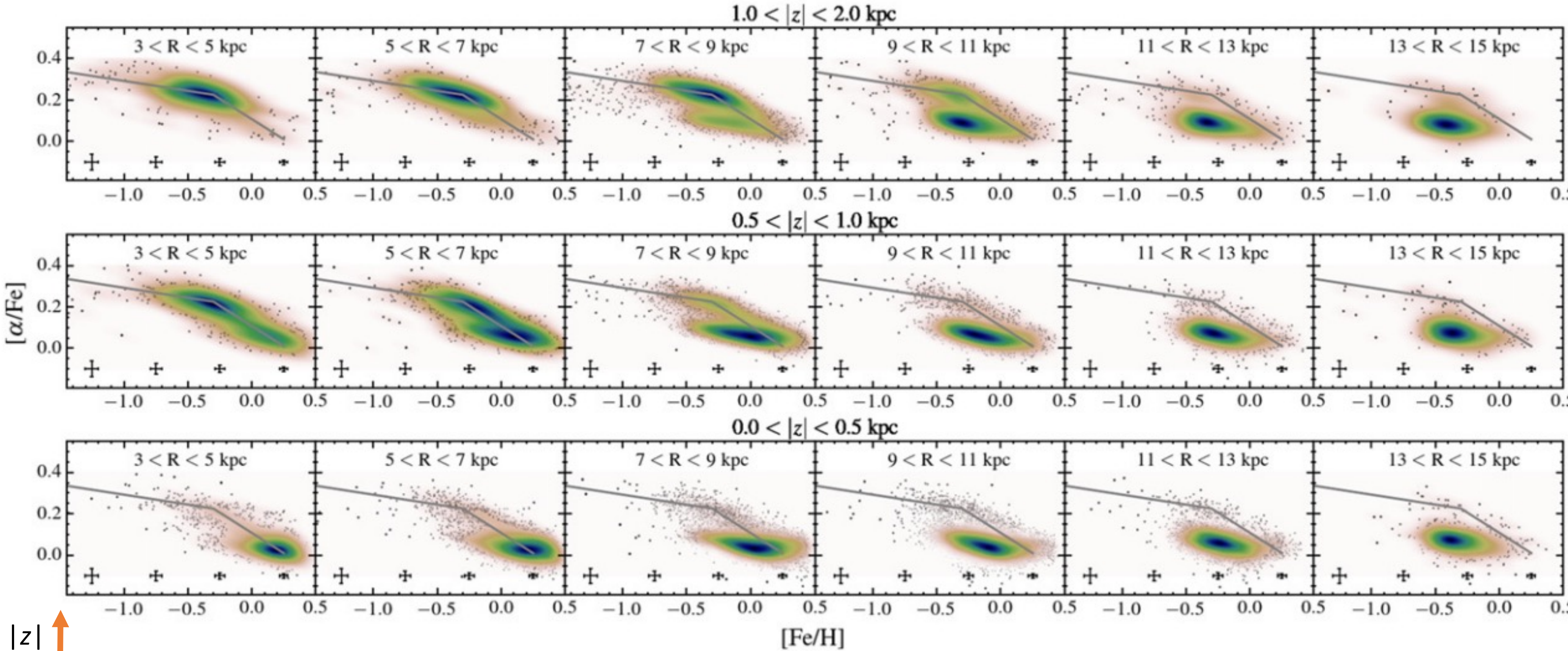
- visit spectra, combined spectra (also pseudo-continuum normalized)

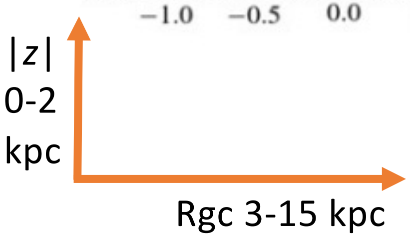
- heliocentric radial velocities
- stellar atmospheric parameters ($T_{eff}$, log $g$, $v_{micro}$, [M/H], [C/M], [N/M], [α/M], $v$sin$i$ or $v_{macro}$) + abundance for up to 20 species (C, C I, N, O, Na, Mg, Al, Si, S, K, Ca, Ti, Ti II, V, Cr, Mn, Fe, Co, Ni, Ce) derived using ASPCAP (APOGEE Stellar Parameters and Chemical Abundance Pipeline) (use allStar-dr17-synspec_rev1.fits )

- Value added catalogs, e.g. *OCCAM* (Open Cluster Chemical Abundance and Mapping); *The Joker* (posterior samplings in Keplerian orbital parameters); *APOGEE Net* (predicted stellar parameters derived with a convolutional neural network); *astroNN* (stellar and orbital parameters derived with astroNN deep-learning code); *StarHorse* (distances, extinctions, and stellar parameters, combined with Gaia EDR3, derived with the Bayesian isochrone-fitting code StarHorse); etc

Information on which is what, how to download, how to access, caveats (e.g. instruction on how to use the abundances, see https://www.sdss4.org/dr17/irspec/abundances/ ) can be found here https://www.sdss4.org/dr17/irspec/spectro_data/

# APOGEE : example (DR12)



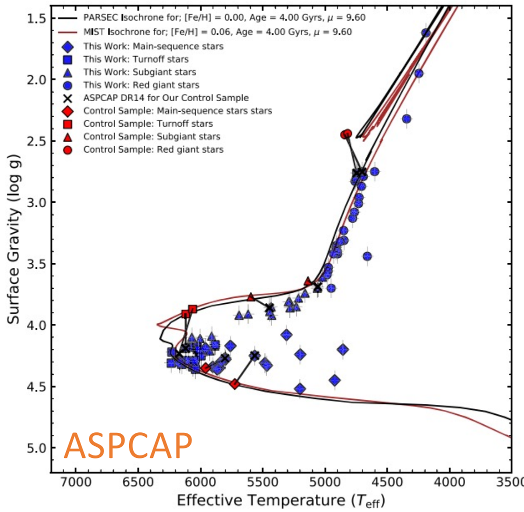

Variation in distribution of α-rich (thick disk) and α-poor (thin disk) stars along the disk and in height

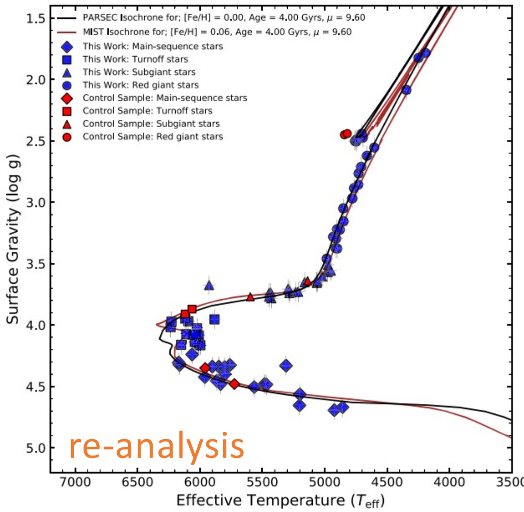
Variation of MDF (metal-poorer at larger Rgc)

[ Based on ~70k red giants ]

*Hayden+2015*

# APOGEE : example (DR14)



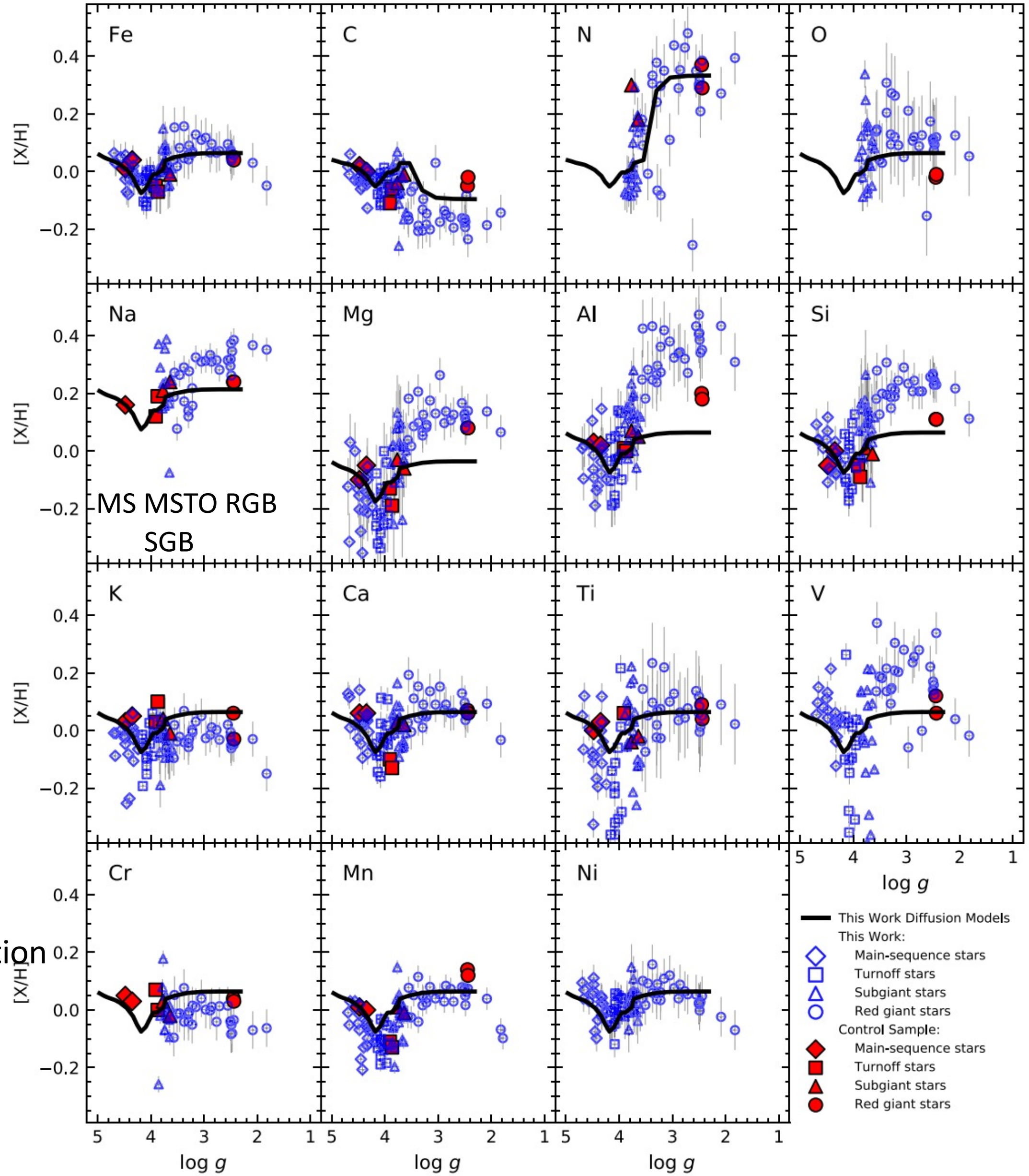




The surface abundandes depend on the evolutionary phase (here indicated by logg, but could use Teff or mass)

First dredge-up* important for C, N, Na, etc)

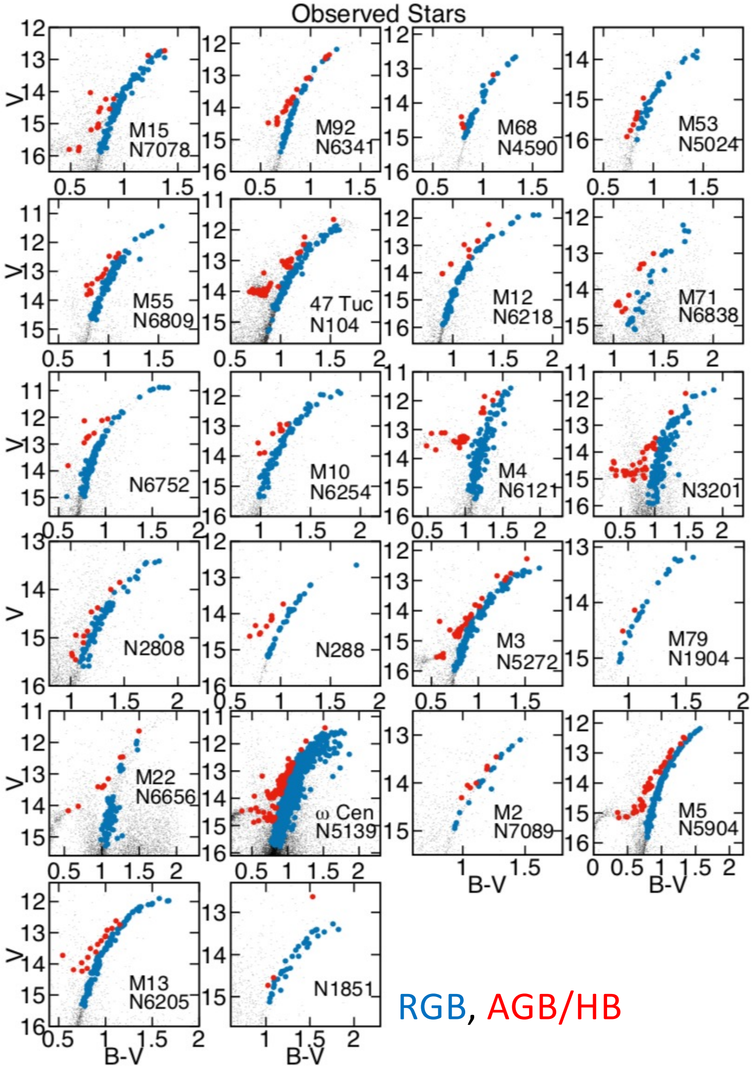
Diffusion is required to explain the variation MS→ MSTO → SGB → RGB (note: MS abu == RGB abu)

*Maximum depth of convective envelope, touching nuclear-reaction modified central region




*Souto+2019*

# APOGEE : example (DR16)




RGB, AGB/HB

For abundances: BACCHUS (Brussels Automatic Code for Characterizing High accUracy Spectra, Masseron+ 2016)

Originally: 44 GCs and 3380 stars

Keep GC & star if :

-E(B-V)<0.4

-Teff<5500 K

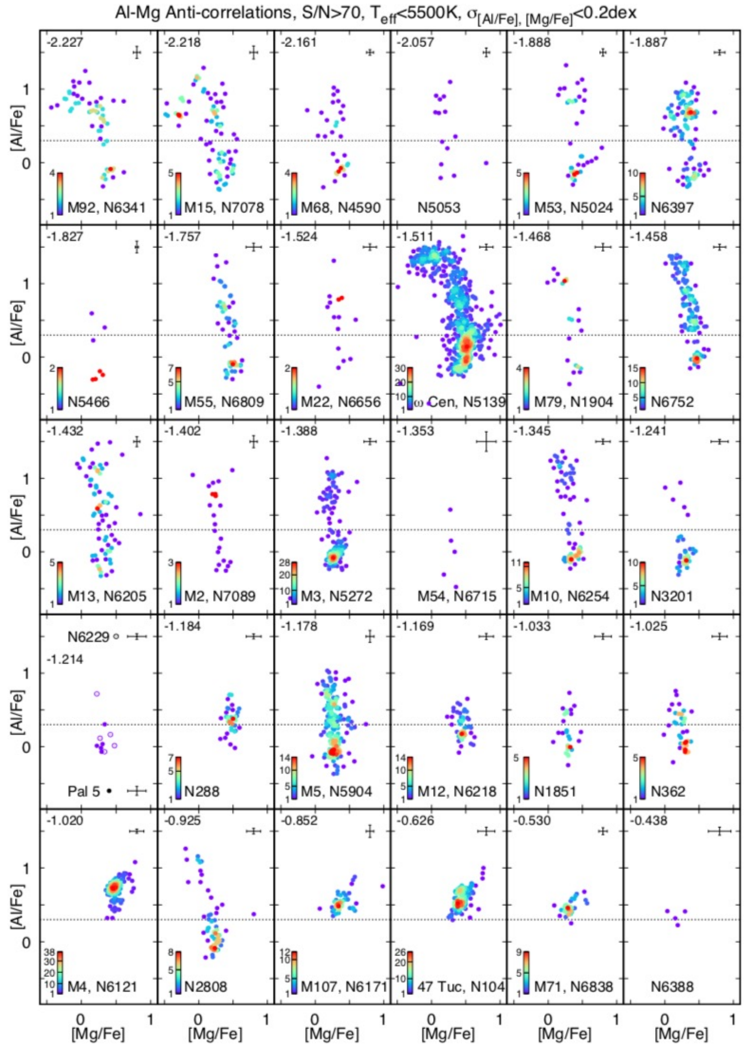
-S/N>70

*(and small errors on studied abundance)*

➔ **2280 stars in 31 GCs**

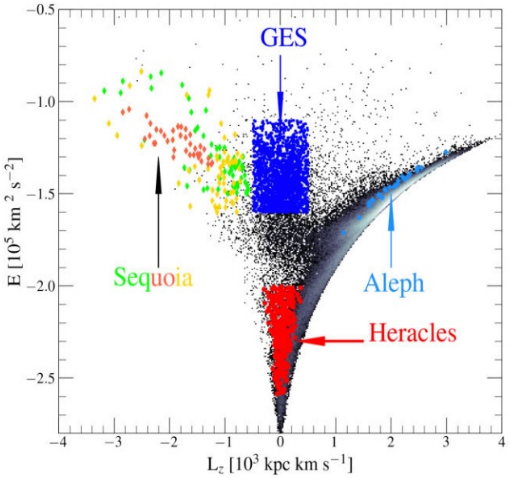
Investigate:

- (possible) Fe spread
- shape & statistics of Al-Mg & N-C anti-correlations as *f*(GC mass, age, metallicity)




*Meszaros+2020*

# APOGEE : example (DR17) + Gaia DR3

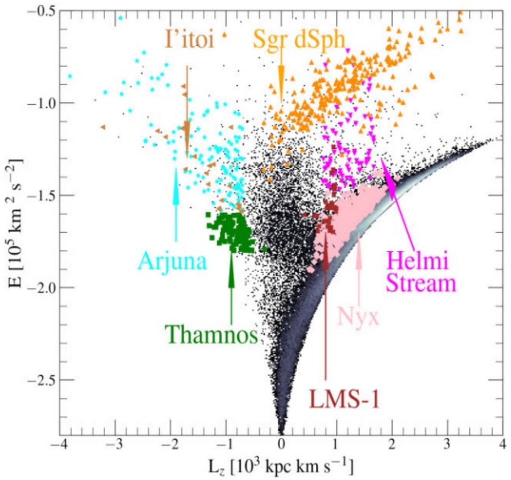



How did the MW halo assemble

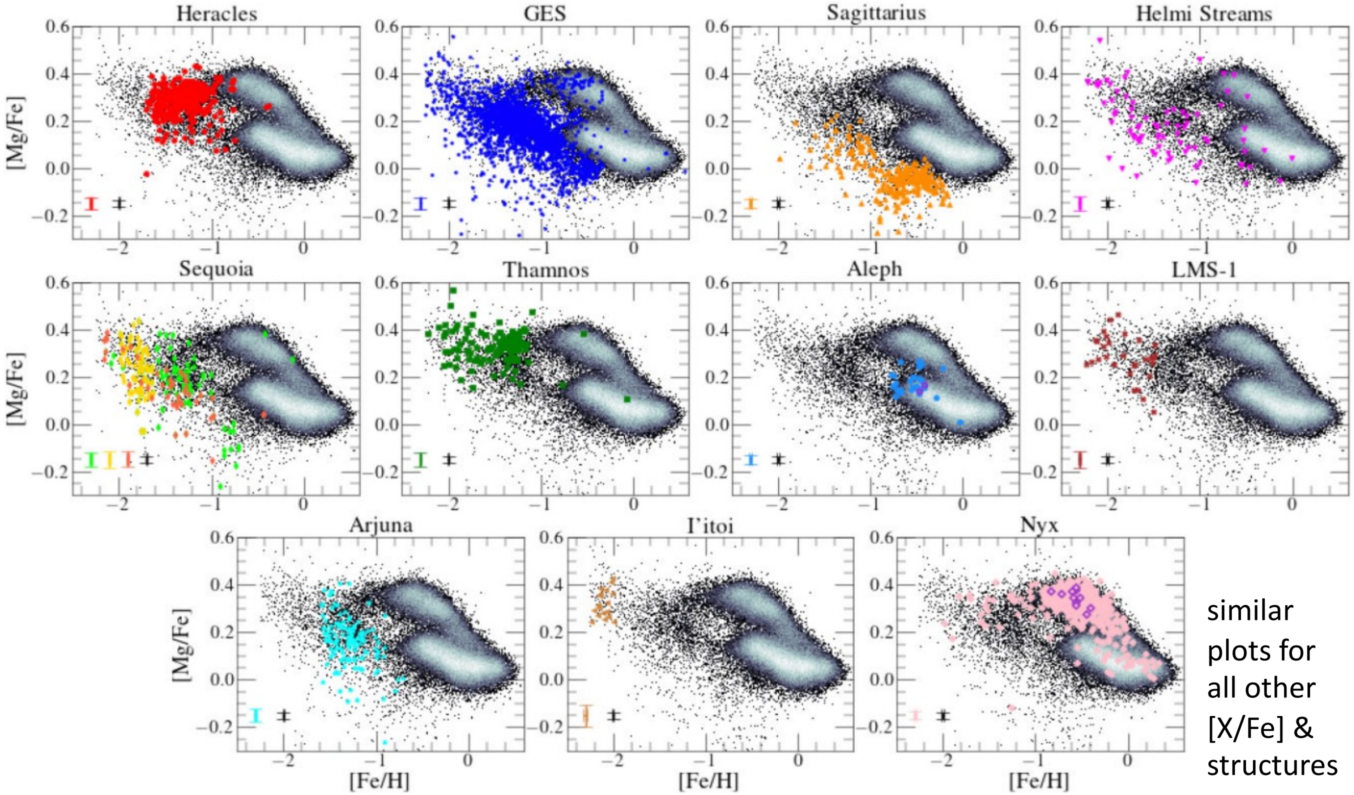
How different are the substructures in chemistry

Not all are merger events (e.g. Aleph, Nix are in situ)

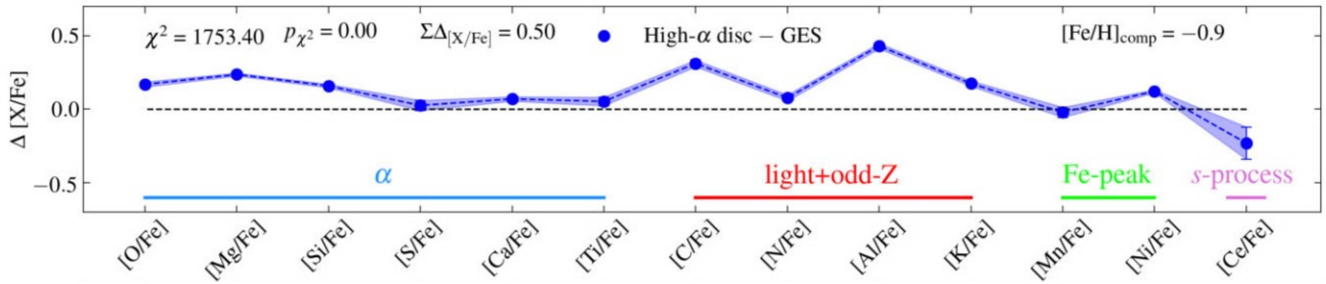
Some have common origin




*Horta+2023*



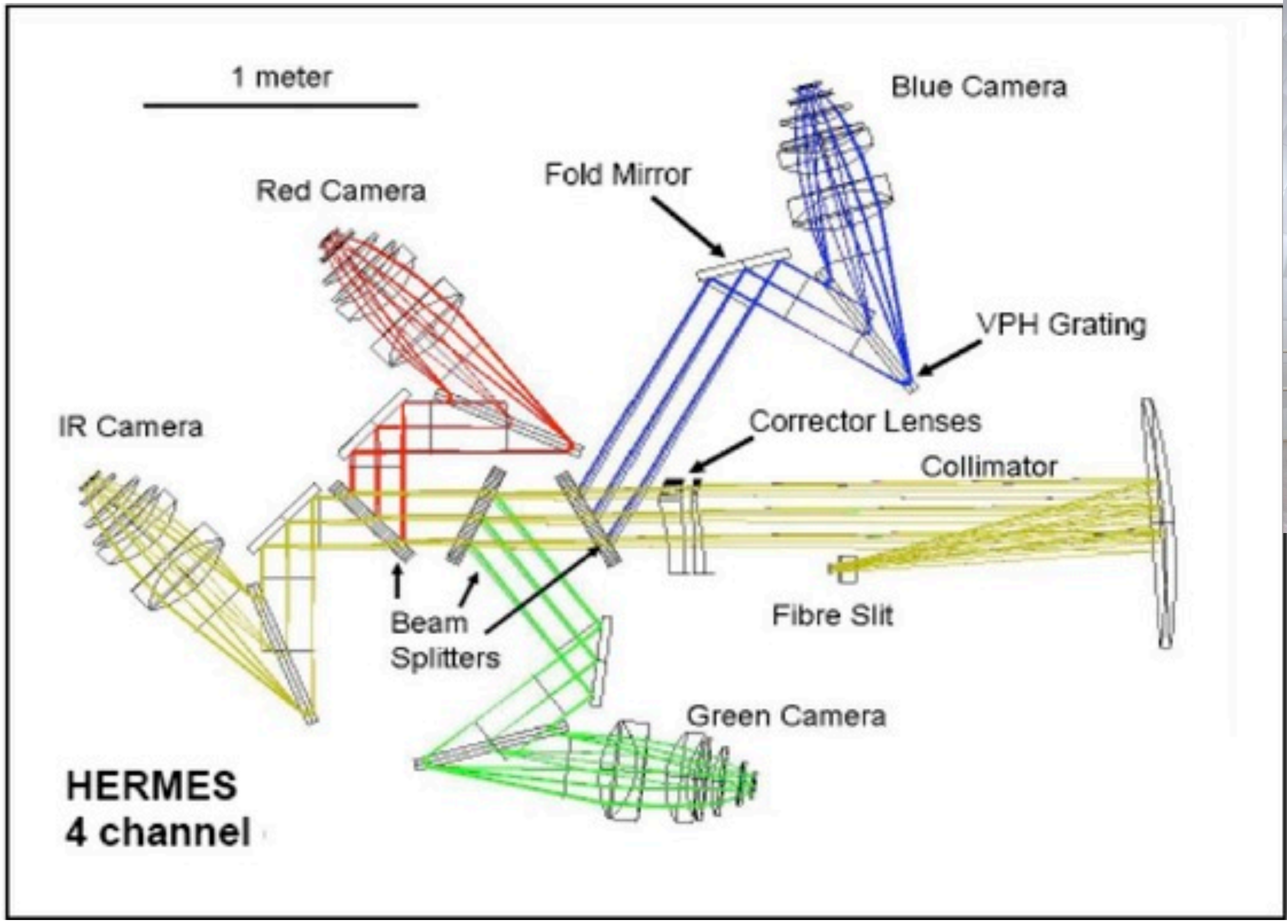

similar plots for all other [X/Fe] & structures

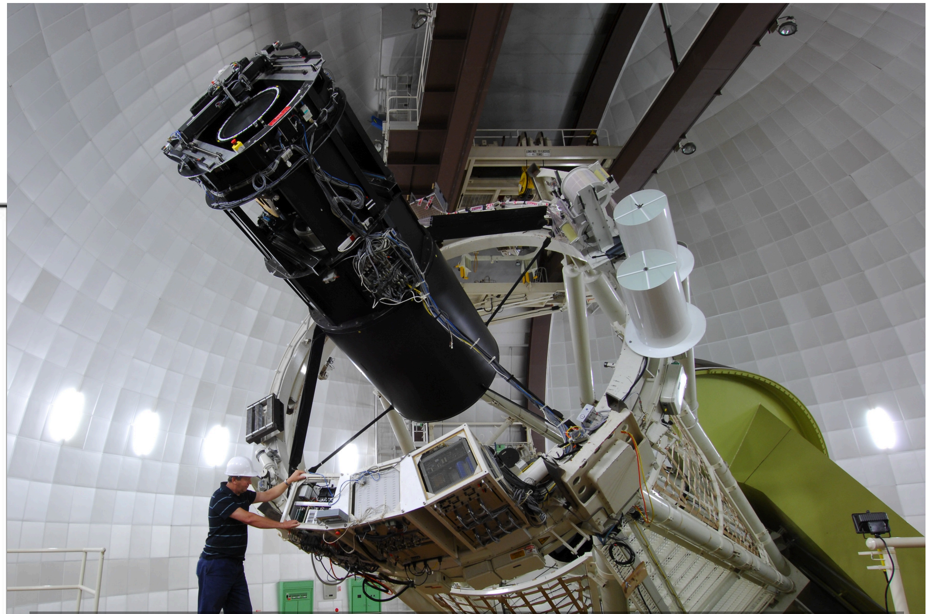


# GALAH

## GALactic Archaeology with HERMES

# GALAH : HERMES@AAT



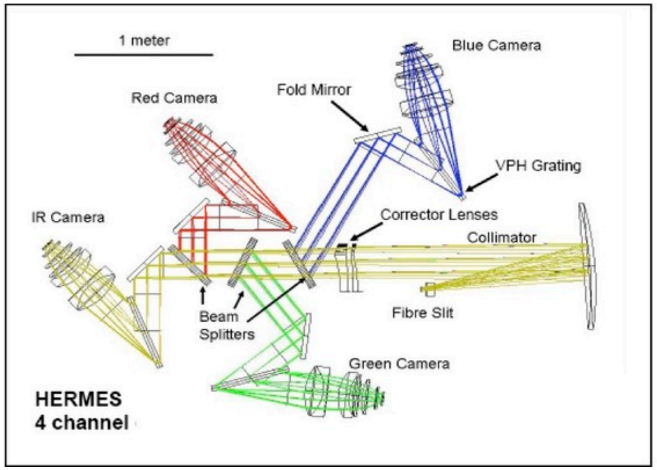
4m AAT + Two-Degree Field (2dF) fibre positioner with the HERMES spectrograph

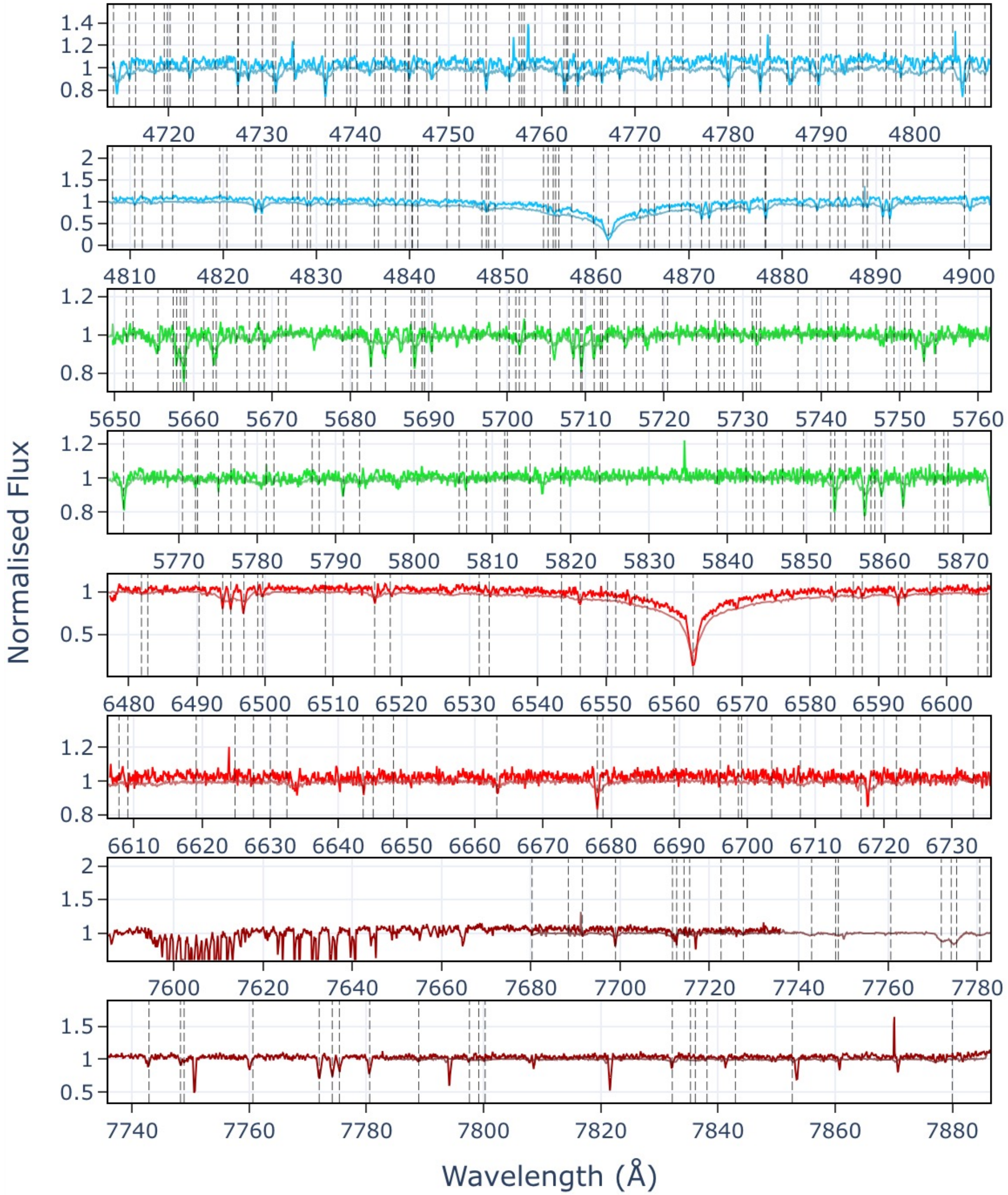
| Band | $\lambda_{min}$ (nm) | $\lambda_{max}$ (nm) |
|---|---|---|
| Blue | 471.8 | 490.3 |
| Green | 564.9 | 587.3 |
| Red | 648.1 | 673.9 |
| IR | 759.0 | 789.0 |

Field: 2deg diam
Fibres: 392
R=28000 (or 50000)
~100 nm (470-790nm)

# GALAH

https://apps.datacentral.org.au/galah/spectra



# GALAH DR4

Observations between
December 2013 and August 2023.

Two main catalogues for
stellar parameters and abundances
for up to 32 elements per star
(Li, C, N, O, Na, Mg, Al, Si, K, Ca, Sc, Ti,
V, Cr, Mn, Fe, Co, Ni, Cu, Zn, Rb, Sr, Y,
Zr, Mo, Ru, Ba, La, Ce, Nd, Sm, Eu)

SME + neural networks (*The Payne*)

14 elements in NLTE

https://arxiv.org/pdf/2409.19858

*Publications of the Astronomical Society of Australia* (2024), 1–43

CAMBRIDGE UNIVERSITY PRESS

RESEARCH PAPER

## The GALAH Survey: Data Release 4

S. Buder,[1,2,3] J. Kos,[4] E. X. Wang,[1,2] M. McKenzie,[1,2] M. Howell,[5,2] S. L. Martell,[6,2,7] M. R. Hayden,[8,6,9,2] D. B. Zucker,[10,11,2] T. Nordlander,[1,2] B. T. Montet,[6,2,7] G. Traven,[4] J. Bland-Hawthorn,[9,2] G. M. De Silva,[11] K. C. Freeman,[1,2] G. F. Lewis,[9] K. Lind,[12] S. Sharma,[13] J. D. Simpson,[6,2] D. Stello,[6,9,2,14] T. Zwitter,[4] A. M. Amarsi,[15] J. J. Armstrong,[16] K. Banks,[6,2] M. A. Beavis,[17] K. Beeson,[4] B. Chen,[1,2] I. Ciucă,[1,2] G. S. Da Costa,[1,2] R. de Grijs,[10,18,19] B. Martin,[1] D. M. Nataf,[20] M. K. Ness,[1,2] A. D. Rains,[15] T. Scarr,[1] R. Vogrinčič,[4] Z. Wang,[9,2,21] R. A. Wittenmyer,[17] Y. Xie,[1,2] and The GALAH Collaboration[22]

[1]Research School of Astronomy and Astrophysics, Australian National University, Canberra, ACT 2611, Australia
[2]ARC Centre of Excellence for All Sky Astrophysics in 3 Dimensions (ASTRO 3D), Australia
[3]ACCESS-NRI, Australian National University, Canberra, ACT2601, Australia
[4]Faculty of Mathematics & Physics, University of Ljubljana, Jadranska 19, 1000 Ljubljana, Slovenia
[5]School of Physics and Astronomy, Monash University, Clayton, VIC 3800, Australia
[6]School of Physics, UNSW, Sydney, NSW 2052, Australia
[7]UNSW Data Science Hub, University of New South Wales, Sydney, NSW 2052, Australia
[8]Homer L. Dodge Department of Physics & Astronomy, University of Oklahoma, 440 W. Brooks St., Norman, OK 73019, USA
[9]Sydney Institute for Astronomy, School of Physics, A28, The University of Sydney, NSW 2006, Australia
[10]School of Mathematical and Physical Sciences, Macquarie University, Balaclava Road, Sydney, NSW 2109, Australia
[11]Macquarie University Research Centre for Astronomy, Astrophysics and Astrophotonics, Sydney, NSW 2109, Australia
[12]Department of Astronomy, Stockholm University, AlbaNova University Centre, SE-106 91 Stockholm, Sweden
[13]Space Telescope Science Institute, 3700 San Martin Drive, Baltimore, MD, 21218, USA
[14]Stellar Astrophysics Centre, Aarhus University, Ny Munkegade 120, DK-8000 Aarhus C, Denmark
[15]Department of Physics and Astronomy, Uppsala University, Box 516, 751 20 Uppsala, Sweden
[16]Department of Space, Earth & Environment, Chalmers University of Technology, SE-412 96 Gothenburg, Sweden
[17]Centre for Astrophysics, University of Southern Queensland, West Street, Toowoomba, QLD 4350, Australia
[18]Astrophysics and Space Technologies Research Centre, Macquarie University, Balaclava Road, Sydney, NSW 2109, Australia
[19]International Space Science Institute Beijing, 1 Nanertiao, Zhongguancun, Beijing 100190, China
[20]Department of Physics & Astronomy, University of Iowa, Iowa City, IA 52242, USA
[21]Department of Physics and Astronomy, University of Utah, Salt Lake City, UT 84112, USA
[22]https://www.galah-survey.org
**Author for correspondence:** S. Buder, Email: sven.buder@anu.edu.au.



**Abstract**

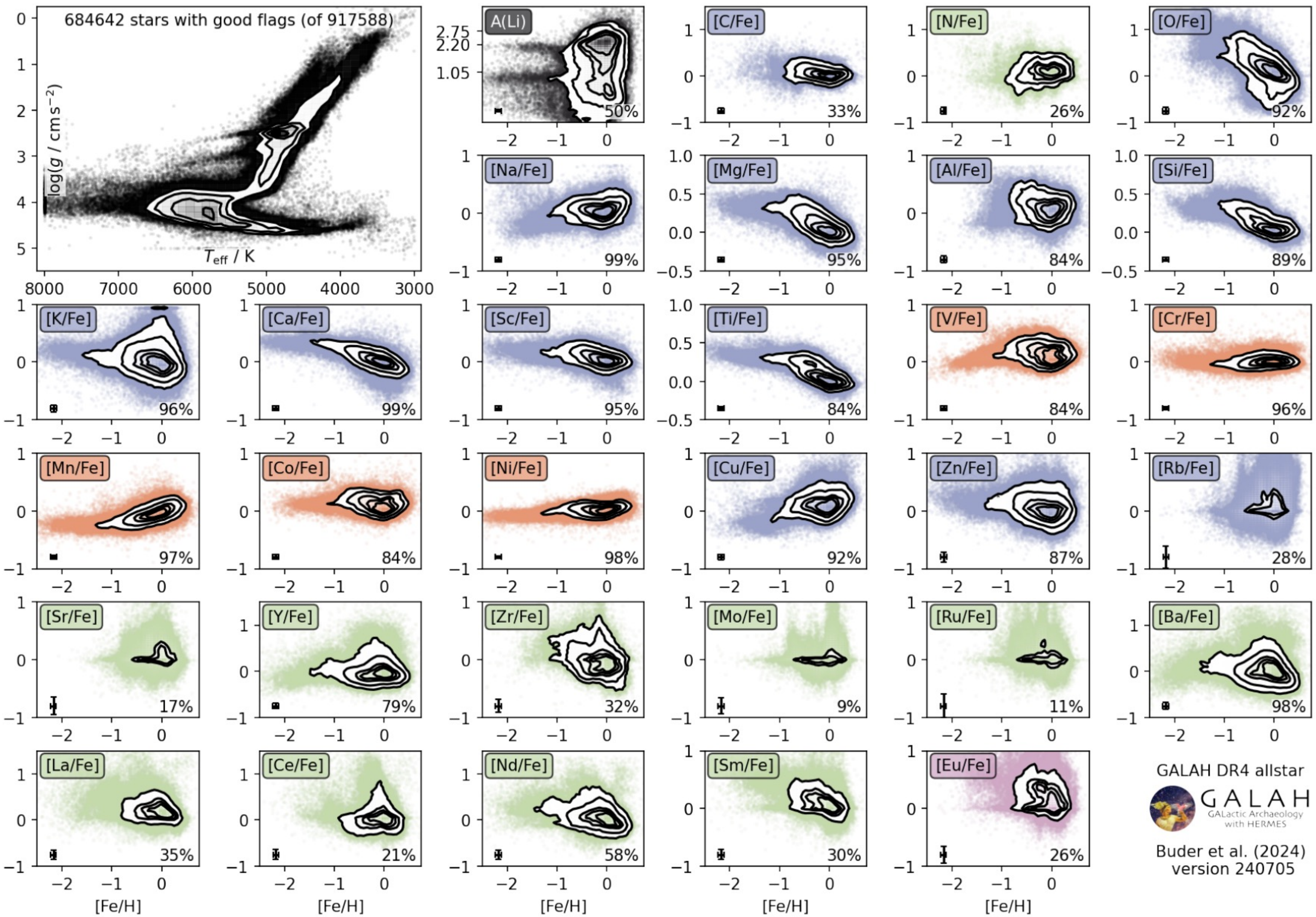
The stars of the Milky Way carry the chemical history of our Galaxy in their atmospheres as they journey through its vast expanse. Like barcodes, we can extract the chemical fingerprints of stars from high-resolution spectroscopy. The fourth data release (DR4) of the Galactic Archaeology with HERMES (GALAH) Survey, based on a decade of observations, provides the chemical abundances of up to 32 elements for 917 588 stars that also have exquisite astrometric data from the *Gaia* satellite. For the first time, these elements include life-essential nitrogen to complement carbon, and oxygen as well as more measurements of rare-earth elements critical to modern-life electronics, offering unparalleled insights into the chemical composition of the Milky Way.

For this release, we use neural networks to simultaneously fit stellar parameters and abundances across the full spectrum, leveraging synthetic grids computed with Spectroscopy Made Easy. These grids account for atomic line formation in non-local thermodynamic equilibrium for 14

# GALAH DR4

Li, C, N, O, Na, Mg, Al,
Si, K, Ca, Sc, Ti, V, Cr,
Mn, Fe, Co, Ni, Cu, Zn,
Rb, Sr, Y, Zr, Mo, Ru, Ba,
La, Ce, Nd, Sm, Eu

Not all measured
Not in all stars



# GALAH DR4

https://www.galah-survey.org/dr4/overview/

# GALAH DR4

Fourth Data Release

The Fourth Data Release of the Galactic Archaeology with HERMES (GALAH) survey provides one-dimensional spectra, stellar atmospheric parameters and individual elemental abundances for 1,085,520 spectra of 917,588 stars in the Milky Way. They were observed with the HERMES spectrograph at the Anglo-Australian Telescope between December 2013 and August 2023. The release will be fully described in ~~the forthcoming~~ Buder *et al.* (2024)
https://arxiv.org/pdf/2409.19858

**Want to start working right now with GALAH DR4?**

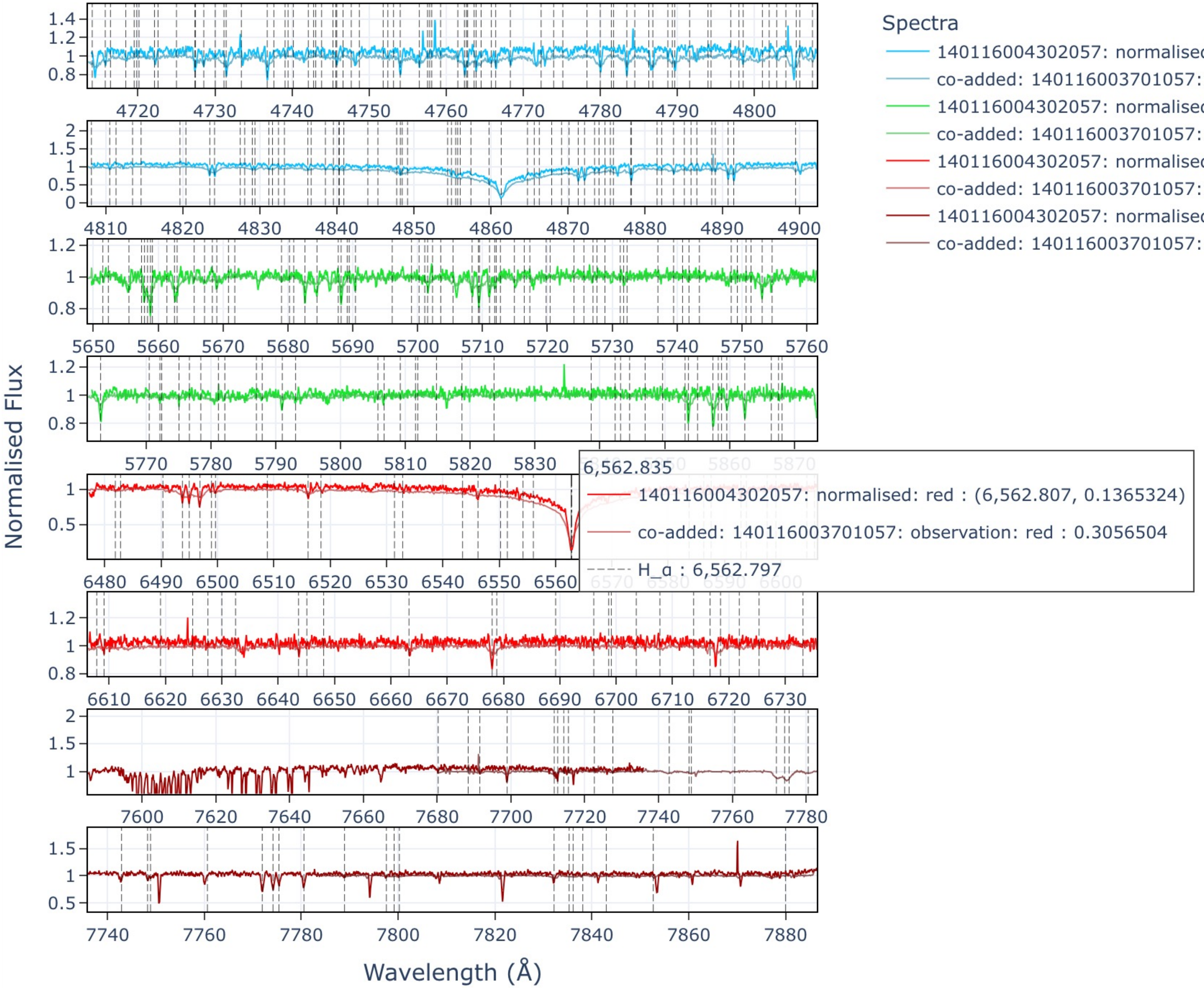
We recommend the `galah_dr4_allstar_240705.fits` catalogue if you want our best effort stellar parameters and elemental abundances. This catalogue can be directly downloaded.
https://cloud.datacentral.org.au/teamdata/GALAH/public/GALAH_DR4/catalogs/

Please read our best practices for using GALAH DR4.

INAF OAS

# GALAH DR4

https://apps.datacentral.org.au/galah/spectra

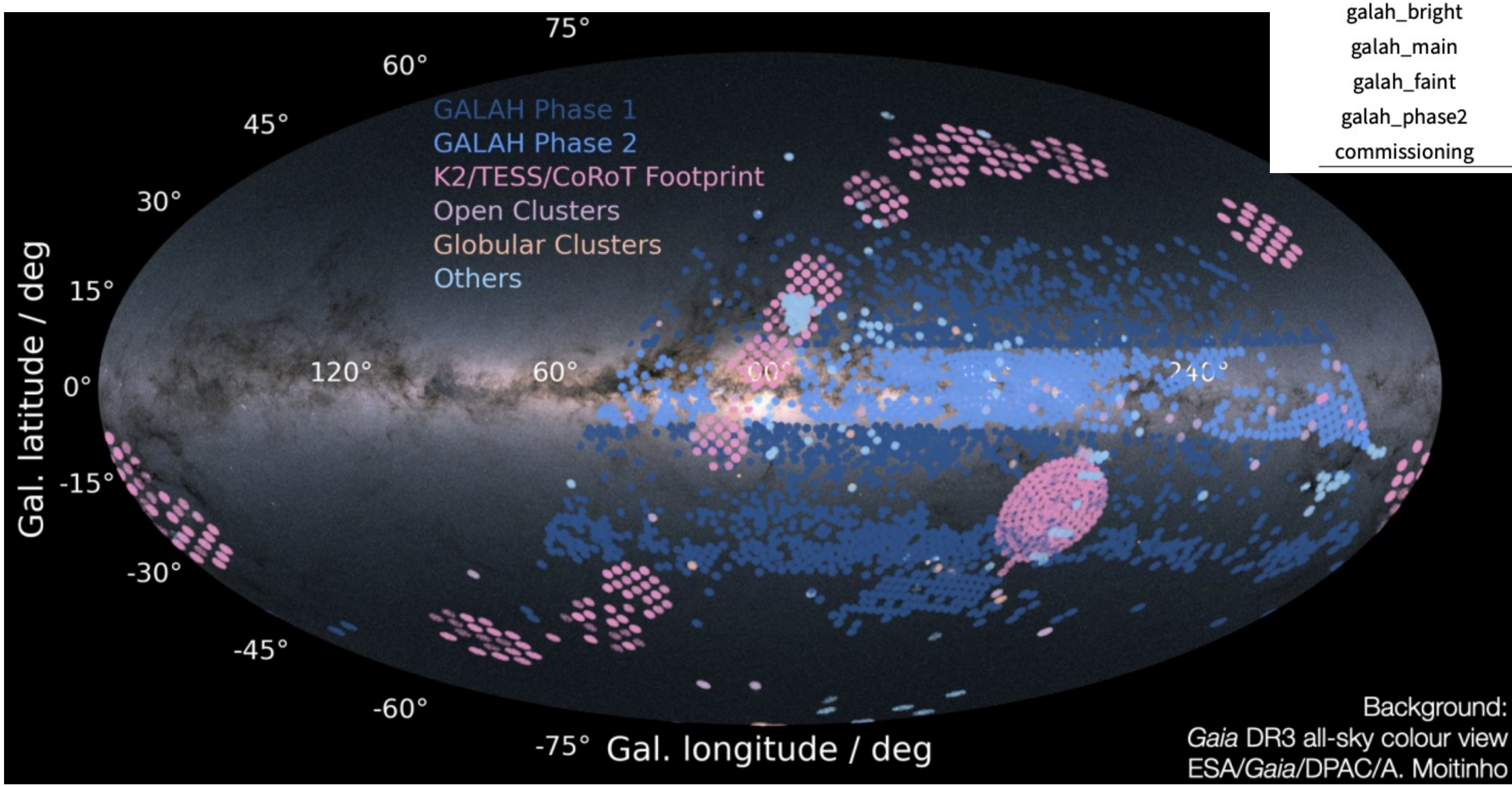



Howerig over the image you get Information on WL, name of star, lines

# GALAH DR4: coverage

**Table 1. Overview of stars observed for the programs included in GALAH DR4.** Numbers of open and globular cluster observations were estimated after observations as described in Sec. 2.3.3. We have observed 30 globular clusters (23 with $\geq 5$ stars) and 361 open clusters (109 with $\geq 5$ stars).

| Program | No. Stars | Program | No. Stars |
|---|---|---|---|
| galah_bright | 67 680 | k2_hermes | 117 736 |
| galah_main | 434 901 | tess_hermes | 37 129 |
| galah_faint | 33 907 | globular clusters | 2 509 |
| galah_phase2 | 172 494 | open clusters | 3 706 |
| commissioning | 2 625 | other | 44 901 |




30 GCs (23 >5 stars)

361 OCs (109 >5 stars)

# GALAH DR4: coverage

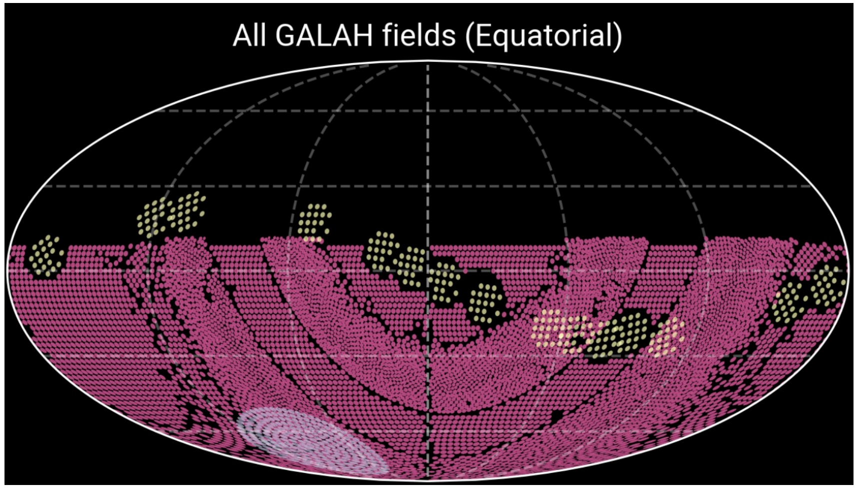
**Main/faint:** 12 < V < 14 (faint to 14.3),
$\delta < +10°$ and $|b| > 10°$

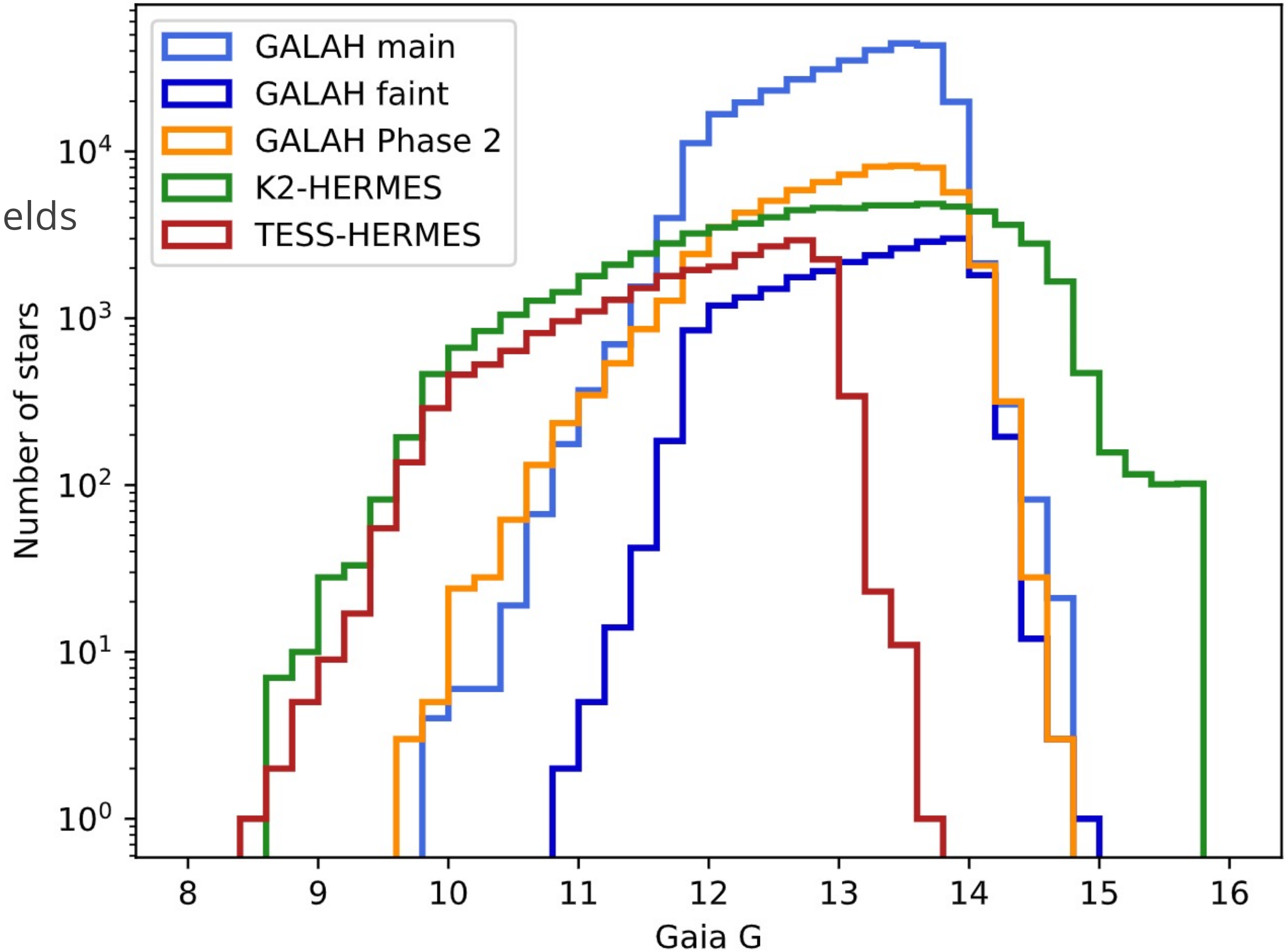
Phase 2: selected MSTO stars, after GDR2
increase coverage $0° < |b| < 10°$

K2-HERMES: 11<V<15 in K2 asteroseismic fields

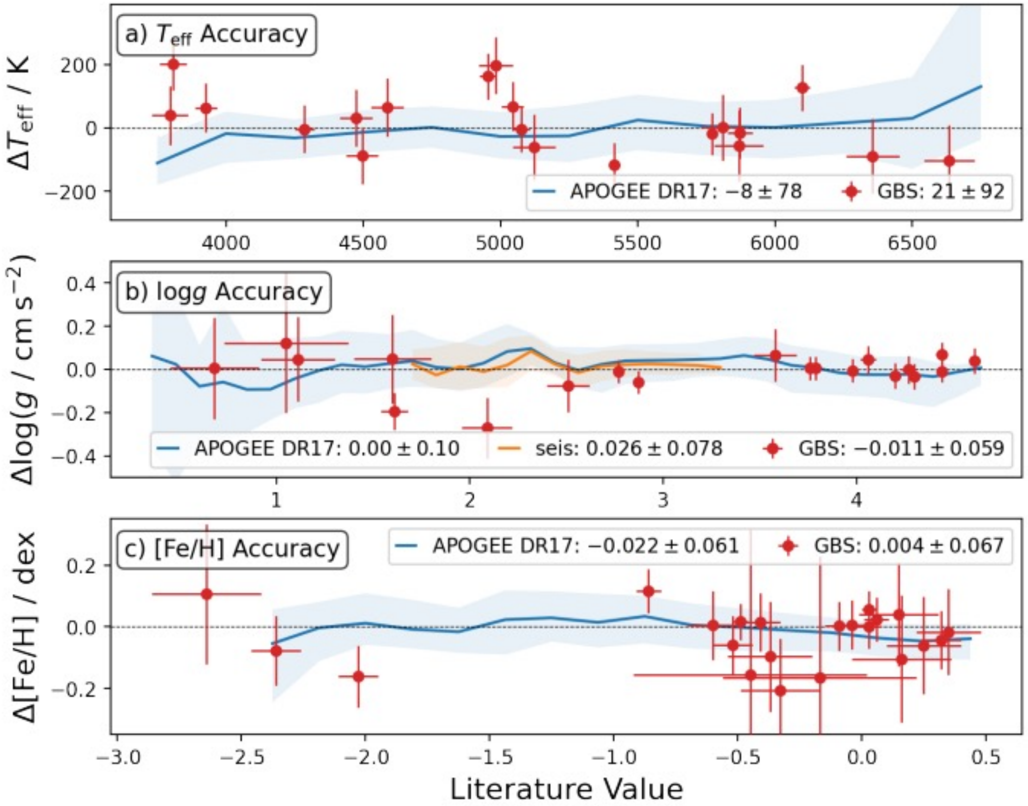
TESS-HERMES: 11<v<13.1 in CVZ

Other: pointed fields (eg GCs, OCs)



# GALAH DR4




Gaia Benchmark stars

APOGEE DR17

logg from asteroseismology

**Table 4.** List of accuracy and representative precision uncertainties for stellar parameters in GALAH DR4. Accuracy values are estimated from comparisons with literature references (see Sec. 6.2.1), whereas precision estimates are estimated from covariance uncertainties and repeat observations (Secs. 6.2.2). Here, we list the median precision uncertainties for stars with $SNR = 50 \pm 10$ in CCD2 (see Fig. 20).

| Parameter / Unit | Accuracy | Precision ($SNR$ = 50) |
|---|---|---|
| $T_{eff}$ / K | 66 | $23 \pm 5$ |
| $\log(g$ / cm s$^{-2})$ | 0.042 | – |
| [Fe/H] / dex | 0.051 | $0.025 \pm 0.004$ |
| $v_{mic}$ / km s$^{-1}$ | 0.28 | $0.05 \pm 0.03$ |
| $v \sin i$ / km s$^{-1}$ | 1.4 | $0.5 \pm 0.2$ |
| $v_{rad}$ / km s$^{-1}$ | 0.15 | $0.17 \pm 0.02$ |

*Buder+2024*

# GALAH DR4 – best practices & caveats

- There are two main catalogues: **galah_dr4_allstar_240705.fits** (one entry per star, with parameters and abundances – to be preferred for general use) and **galah_dr4_allspec_240705.fits** (one entry per spectrum, only for expert use)

- To download a catalogue: wget https://cloud.datacentral.org.au/teamdata/GALAH/public/GALAH_DR4/catalogs/galah_dr4_allstar_240705.fits

- Use flags to select best quality parameters. Main recommendations: snr_px_ccd3 > 30, only stellar parameters for stars with flag_sp == 0, only elemental abundances with flag_X_fe == 0 *[NOTE flag_fe_h is incorrect, should not be used]*

- For stellar luminosity, mass , age, and reddening the recommended values are: lbol, mass, age, ebv (from Schlegel+1998), all in galah_dr4_allstar_240705 catalogue

- For heliocentric distance, use r_med in galah_dr4_allspec_240705 catalogue (matches Gaia DR3, except in clusters)

- For entries where there are multiple values for the same star across the various catalogues, preferred choices are indicated (e.g. rv_galah versus rv_gaia_dr2, rv_guess, etc)

- Binarity flags are not a complete guarantee, especially for fast rotators (method to be developped)

- For GCs, although use of mean distance has improved parameters trends, there are still issues woth zeropoints ans scatter

[ https://www.galah-survey.org/dr4/using_the_data/ https://www.galah-survey.org/dr4/caveats/ https://www.galah-survey.org/dr4/flags/ ]

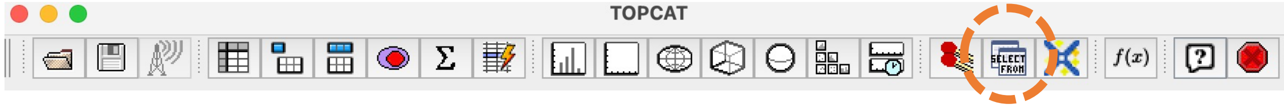
# GALAH DR4 catalogues

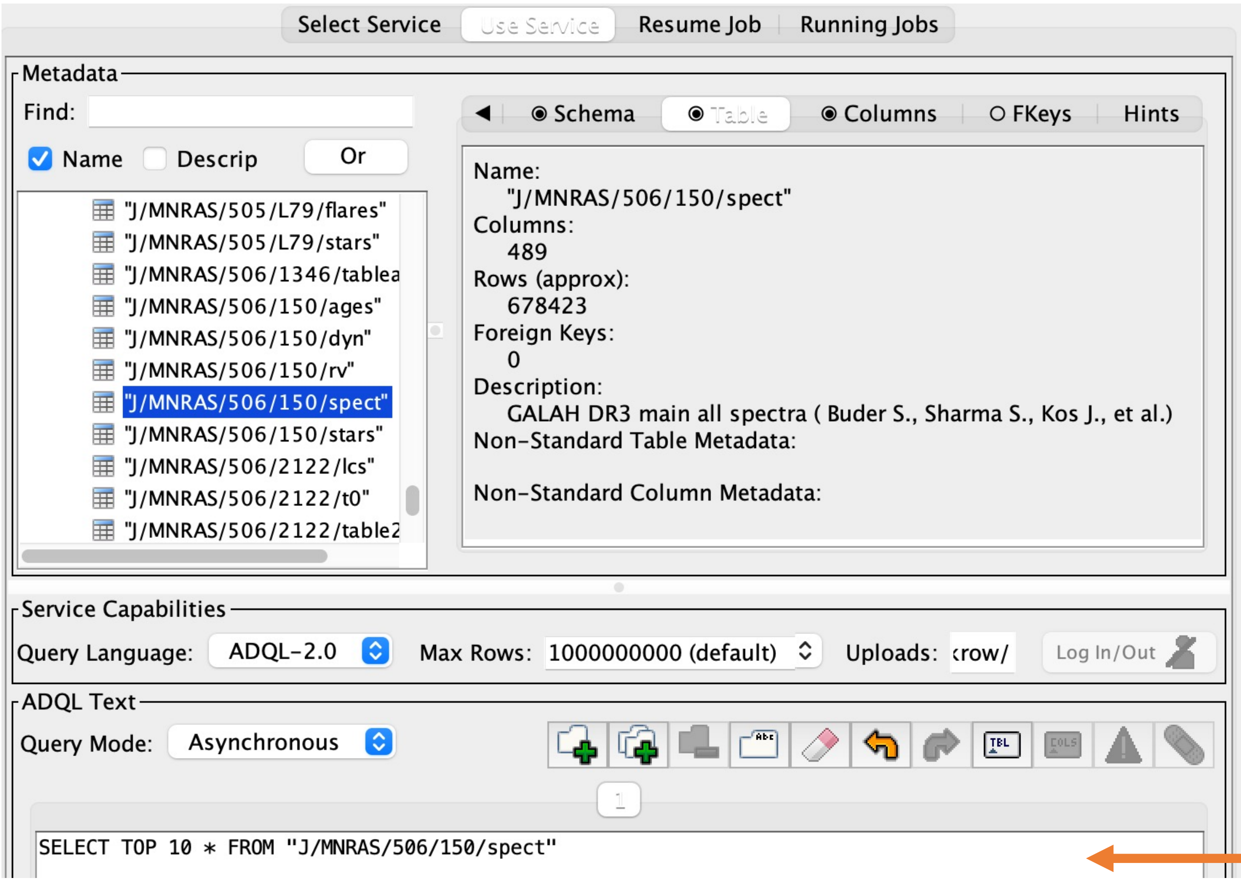
Main catalogues (recommended parameters and abundances for all stars/all spectra):
galah_dr4_allstar_240705.fits plus galah_dr4_allspec_240705.fits
Value added catalogues (VAC):
galah_dr4_vac_wise_tmass_gaiadr3_240705.fits : x-match to WISE, 2MASS, Gaia DR3
→ photometry (Gaia, 2MASS, WISE), Gaia astrometry, Gaia distance (Bayesian geometric & photogeometric from Bailer-Jones+2021), Gaia spectroscopic info (Teff, log g, [Fe/H] from GSPphot on Bp, Rp low-res spectra; RV, Vbroad from RVS)
galah_dr4_vac_dynamics_240705.fits : Galactic kinematics and dynamic information
→ heliocentric cartesian (XYZ, UVW), Galactocentric cylindrical (R, z, ϕ; RVr, RVz, RVt), orbital angles & phases, actions (Jr, Lz, Jz), eccentricity, Zmax, Rperi, Rapo, Energy
galah_dr4_vac_3dnlte_a_li_240705.fits : 3D NLTE Li abundances
→ Li EW, FWHM, abundance, quality flag

Primary repository of GALAH DR4 is provided by Data Central (https://docs.datacentral.org.au/ ).
From them you can download catalogues as FITS files, or use wget, or query via TAP or ADQL
wget https://cloud.datacentral.org.au/teamdata/GALAH/public/GALAH_DR4/catalogs/galah_dr4_allstar_240705.fits

# GALAH "DR4" catalogues

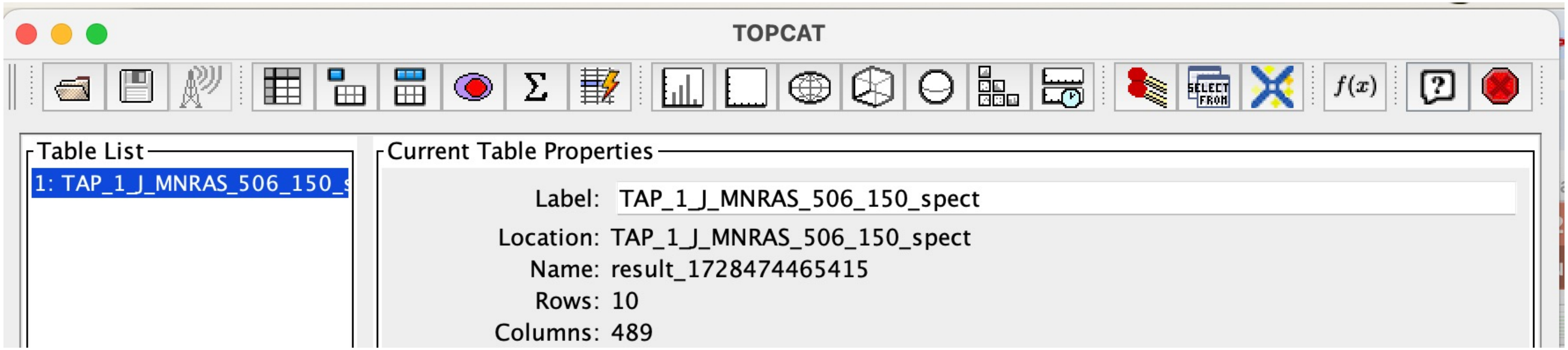
Example using **TOPCAT** (I found up to GALAH DR3)
Use Table Access Protocol (TAP), select GALAH




ADQL query

# GALAH "DR4" catalogues



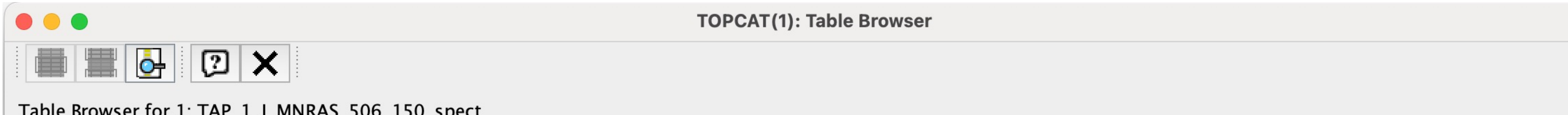




Table Browser for 1: TAP_1_J_MNRAS_506_150_spect

| | recno | 2MASS | GALAH | GaiaDR2 | GaiaEDR3 | Survey | Field | flagRepeat | WG4Field | WG4Pipeline | Flagsp |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 67884 | 03021680+0405226 | 140710006601104 | | | other | -1 | 0 | 10k_1 | lbol | 256 |
| 2 | 243286 | 03532090+1132153 | 160109002001142 | 3673451598259980 8 | 3673451598259980 8 | k2_hermes | 6595 | 0 | 10k_35 | lbol | 0 |
| 3 | 243282 | 03533856+1131543 | 160109002001138 | 36735031378673152 | 36735031378673152 | k2_hermes | 6595 | 0 | 10k_32 | lbol | 0 |
| 4 | 221038 | 03535366+1133062 | 151110003701135 | 36735306256577280 | 36735306256577280 | k2_hermes | 6595 | 0 | 10k_17 | lbol | 0 |
| 5 | 221040 | 03533827+1133360 | 151110003701139 | 36735886075071616 | 36735890372376192 | k2_hermes | 6595 | 0 | 10k_22 | lbol | 0 |
| 6 | 221039 | 03535368+1136155 | 151110003701137 | 36736504550361984 | 36736504550361984 | k2_hermes | 6595 | 0 | 10k_46 | lbol | 0 |
| 7 | 221042 | 03531337+1134098 | 151110003701145 | 36737741501383808 | 36737741501383808 | k2_hermes | 6595 | 0 | 10k_53 | lbol | 0 |
| 8 | 243290 | 03533185+1141166 | 160109002001146 | 36740975613404032 | 36740975613404032 | k2_hermes | 6595 | 0 | 10k_31 | lbol | 0 |
| 9 | 243274 | 03542046+1137110 | 160109002001130 | 36741868966597760 | 36741868966597760 | k2_hermes | 6595 | 0 | 10k_27 | lbol | 0 |
| 10 | 243276 | 03543215+1142513 | 160109002001132 | 36744372930447616 | 36744377227750016 | k2_hermes | 6595 | 0 | 10k_36 | lbol | 0 |

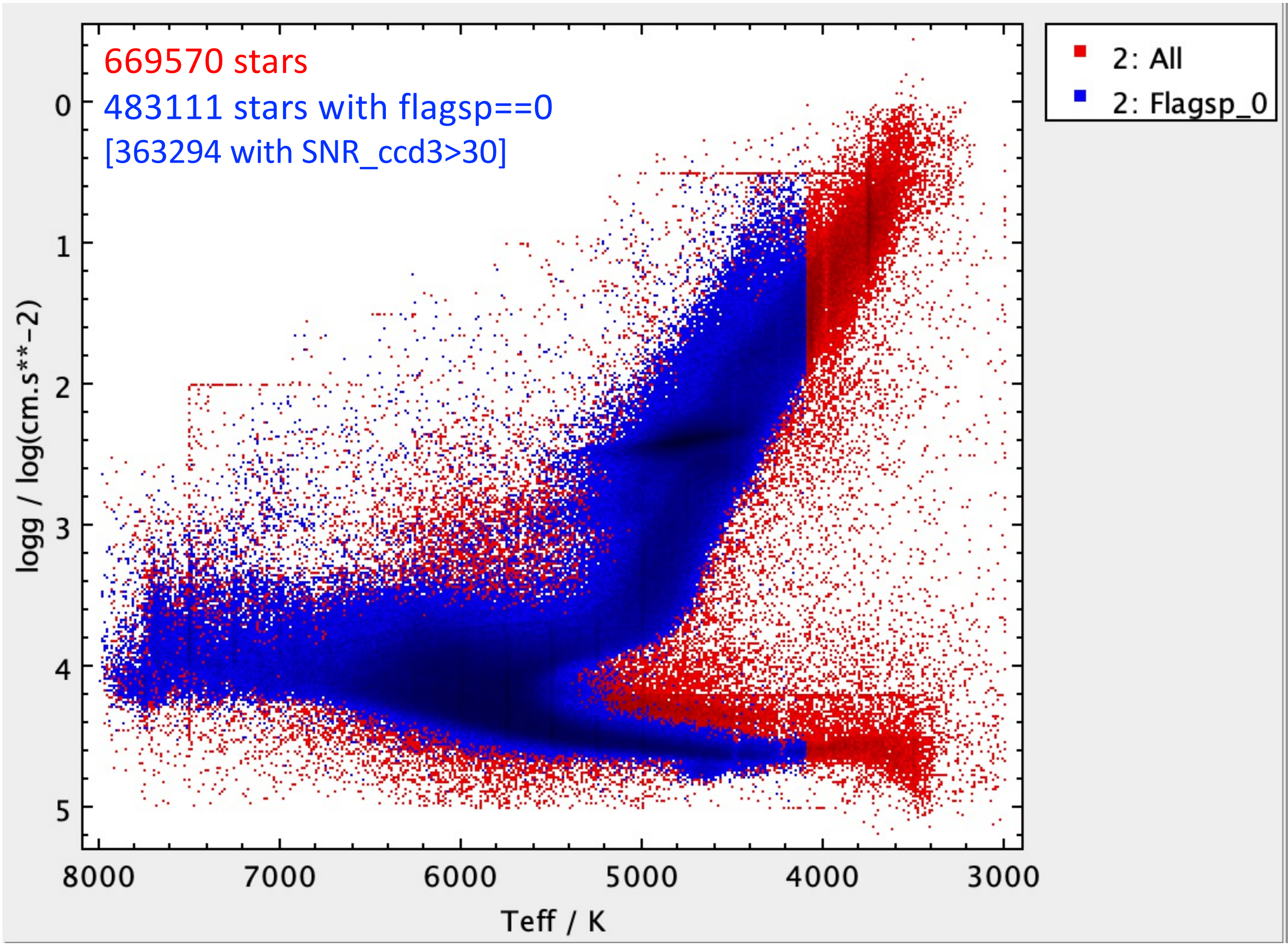
# GALAH "DR4" catalogues

SELECT * FROM "J/MNRAS/506/150/spect"

Takes (much) longer to get the whole table, 678423 lines x 489 columns

Hint: download the whole tables from GALAH webpages and use them offline

However: TOPCAT is useful to join your tables with repositories (e.g Gaia, 2MASS, Gaia-ESO, etc)

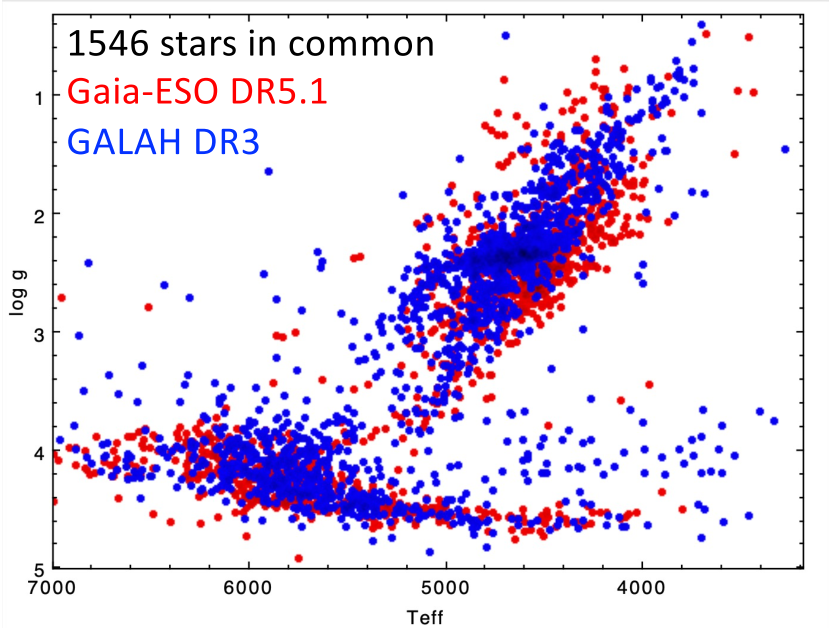


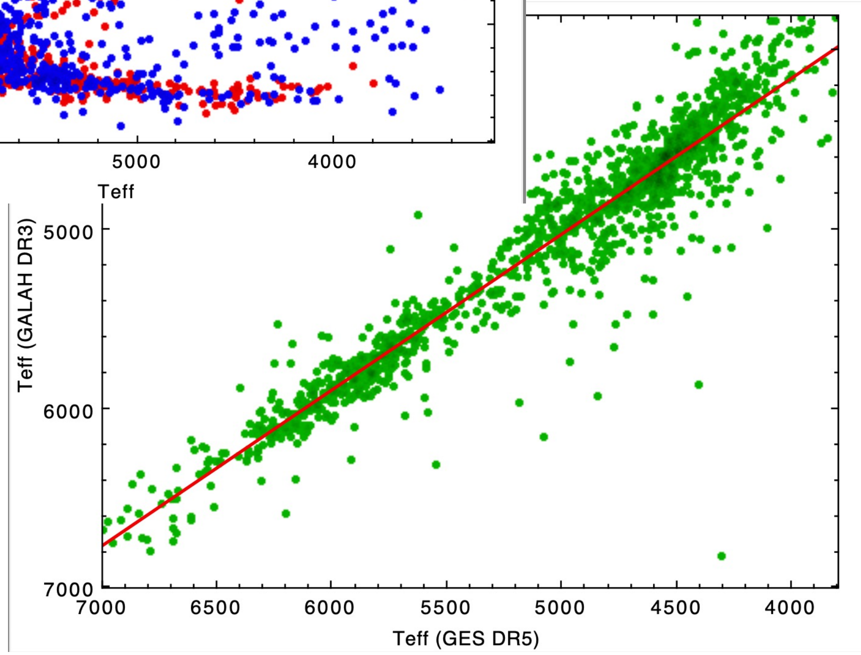
# GALAH *vs* Gaia-ESO

However: TOPCAT is useful to join your tables
with repositories
(e.g Gaia, 2MASS, Gaia-ESO, etc)

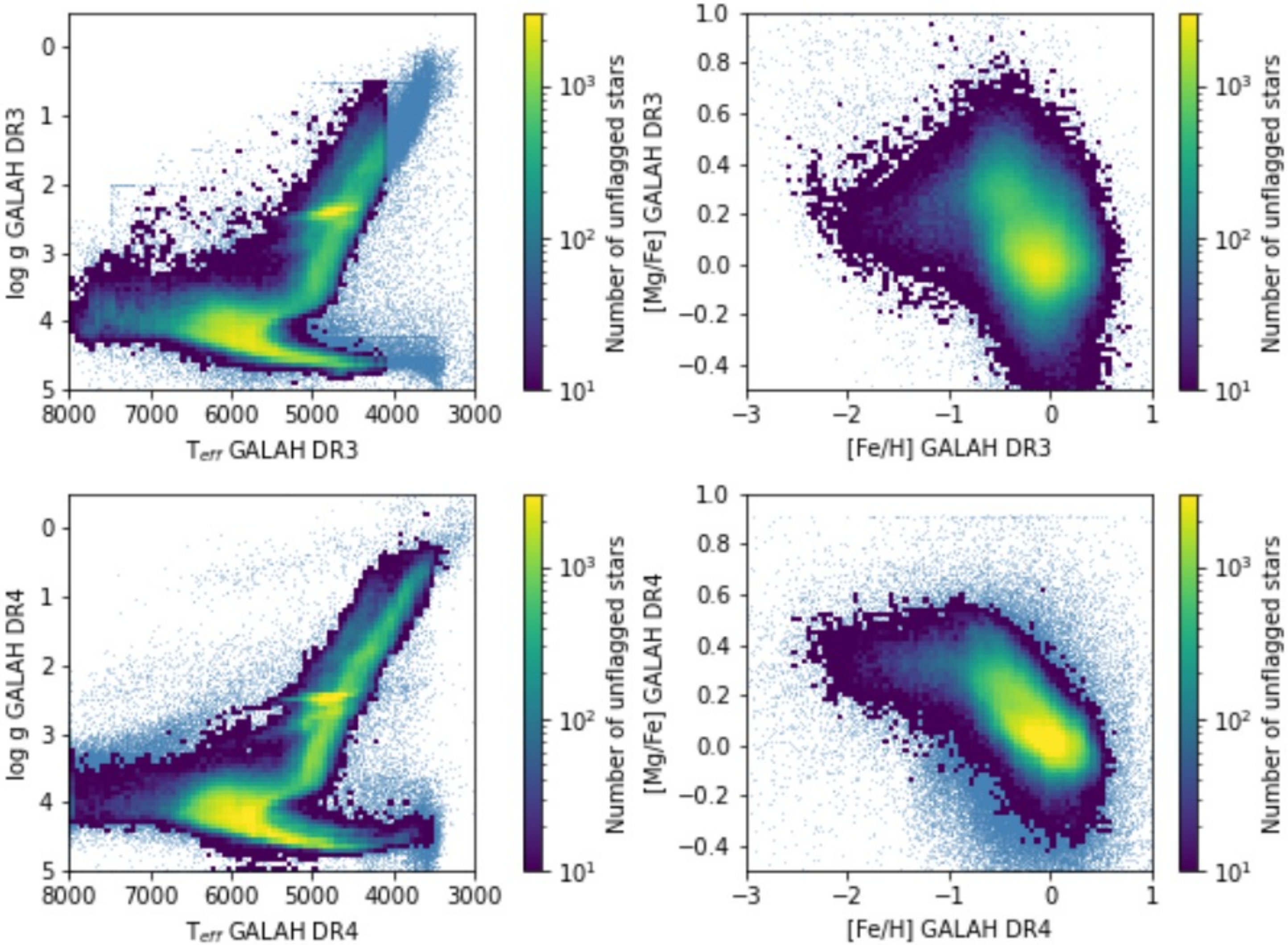
```
SELECT *
FROM GES_DR5_1_V1 AS db
JOIN TAP_UPLOAD.t2 AS tc
ON 1=CONTAINS(POINT('ICRS', DB.RA, DB.DECLINATION),
           CIRCLE('ICRS', tc.RA_ICRS, tc.DE_ICRS, 2./3600.))
```

[ or something similar…
  or use downloaded tables to x-match on ra,dec ]



# GALAH DR4 *vs* DR3




DR3 (upper panels) *vs* DR4 (lower panels)

Note:
DR1 & DR2: The Cannon
DR3: SME (Spectroscopy Made Easy)
DR4: SME + neural networks

# GALAH DR4 - spectra

In case you want to perform your analysis, spectra are available for dowloand, for a few/many/all stars
[ instructions at this webpage https://www.galah-survey.org/dr4/the_spectra/ ]

**Table 2.** Data product 1: FITS files of reduced spectra.

| FITS Ext. | Description |
|---|---|
| Ext. 0 | Un-normalised signal / counts |
| Ext. 1 | Normalised signal (by reduction pipeline) |
| Ext. 2 | Relative uncertainty of signal |
| Ext. 3 | Subtracted sky signal / counts |
| Ext. 4 | Applied telluric correction |
| Ext. 5 | Scattered light / counts |
| Ext. 6 | Cross-talk / counts |
| Ext. 7 | Resolution profile / FWHM |

It is possible to get the entire spectral catalogue with the bulk download option described above, but the query takes about 20 hours to complete.

On decompression, you will require about 385 GB of free space. The decompressed files are located in a single directory, so please be aware of any file management limitations you might have dealing with millions of files in a single directory.

# GALAH : examples of results (DR2)

**Chemically tagging the stream Fimbulthul to the GC $\omega$ Cen**

Fimbulthul : stream discovered in GDR2, possibly connected to $\omega$ Cen (for orbital energy, angular momentum and metallicity, Ibata et al 2019)

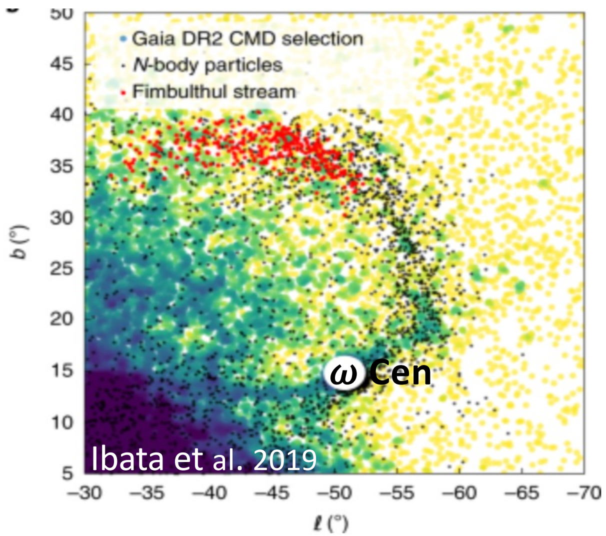
New candidate members identified in GALAH DR2

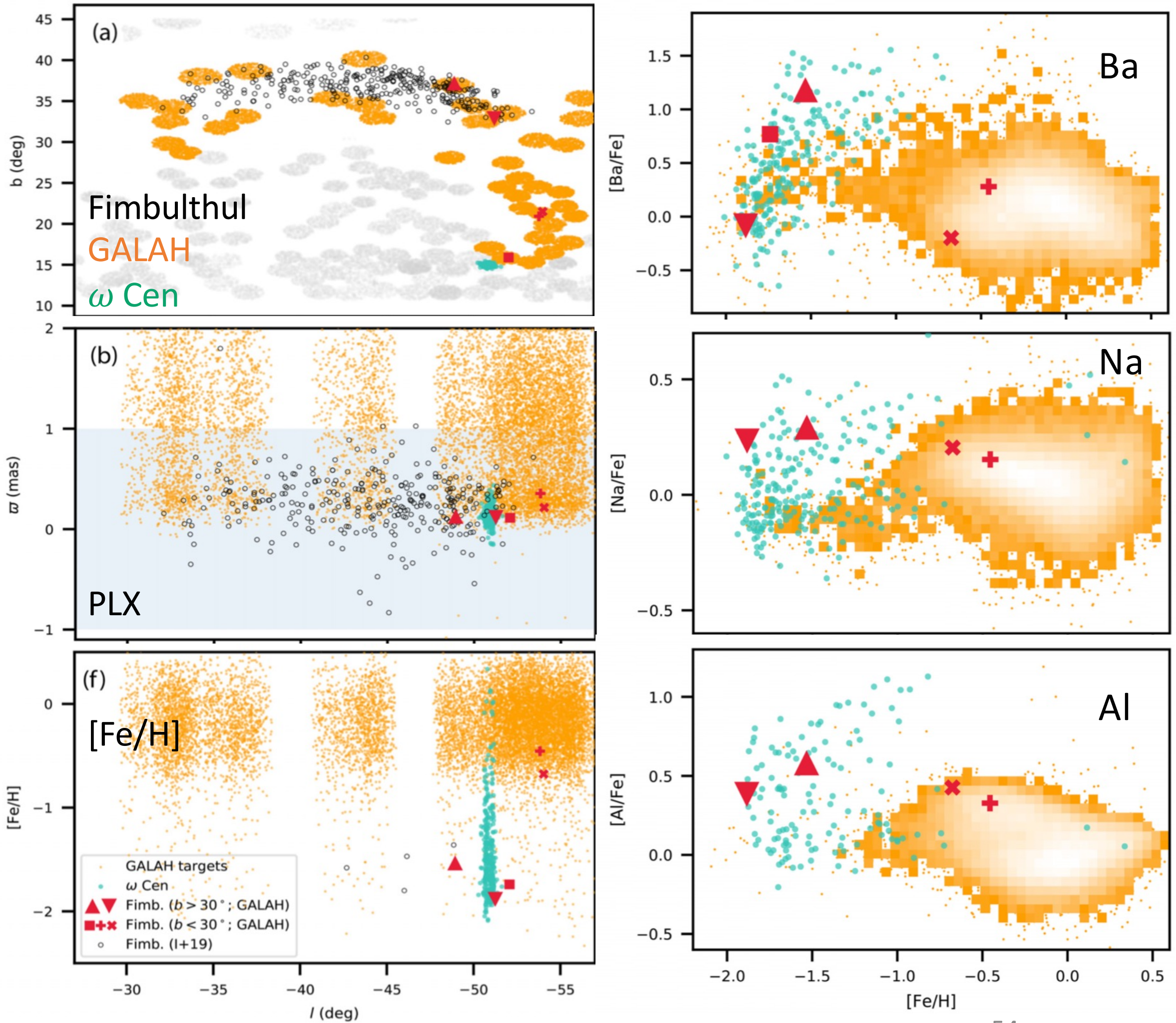
Two of them

-share $\omega$ Cen properties

-show high Na, Al (as stars in GCs)

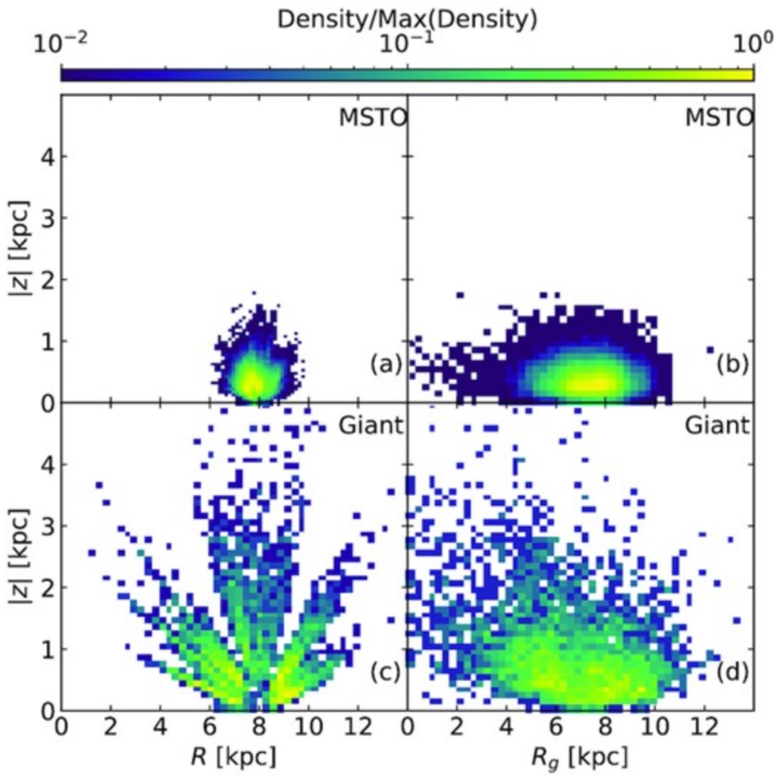
-show $\omega$ Cen-like n-process el.




Simpson+2020

# GALAH : examples of results (

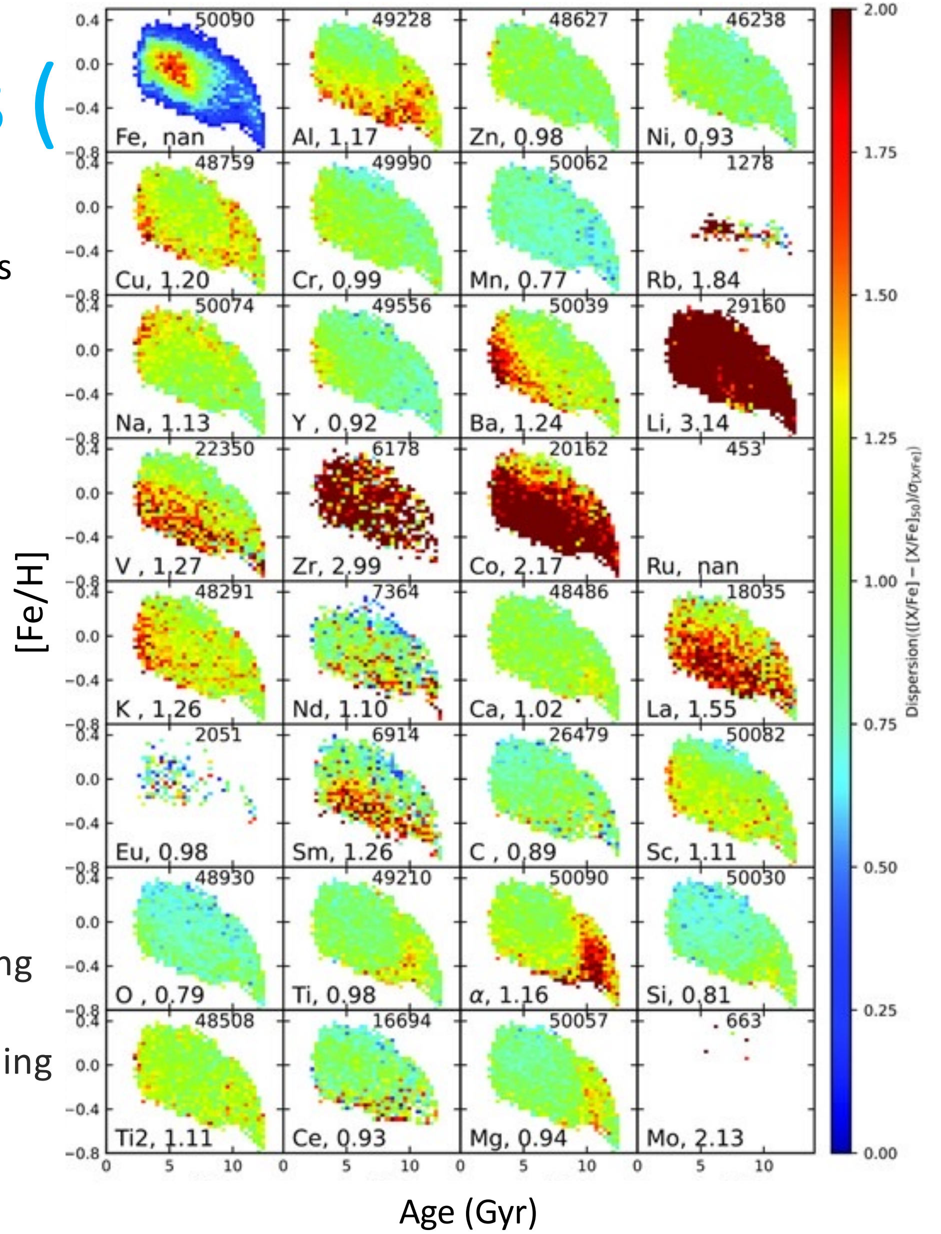



Selection of stars with accurate ages: MSTO or giants with asterosesimic data

**Aim:** explore the dependence of abundances on age and metallicity (MW disk stars)

Dispersion of abundances in the (age,[Fe/H]) plane, generally small

Intrinsic scatter about the Age-met relations is small
→ implications for Galactic Archaeology
→ possible to estimate age and birth radius of stars using abundances
→ simplify chemical modelling

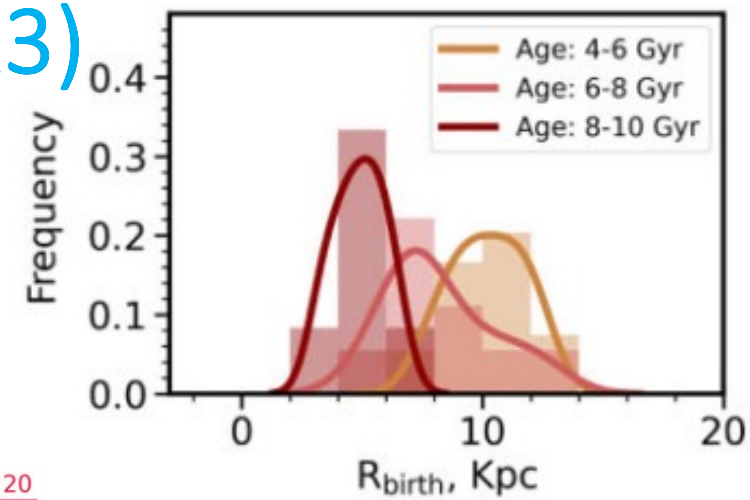



*Sharma+2022*

# GALAH : examples of results (DR3)

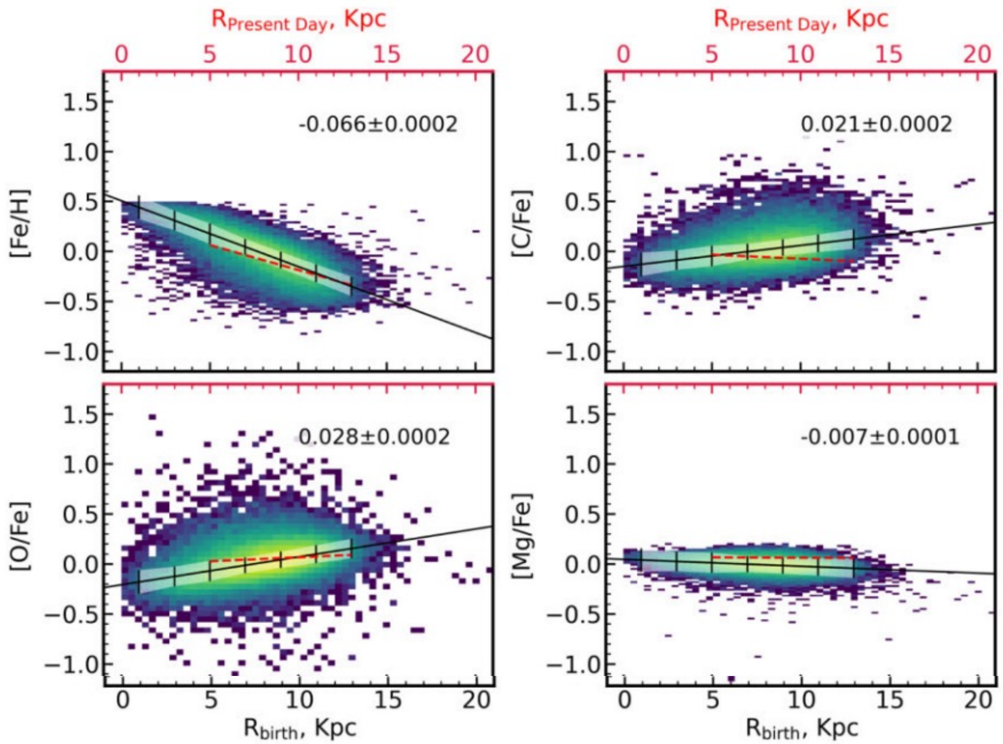
**Aim:** to determine, given [α/Fe] and [Fe/H] abundances, the distribution of [X/Fe] across different birth radii (Rbirth), under an assumed relation between [Fe/H]–[α/Fe] and Rbirth (*cf models, e.g. NIHAO-UHD, Buck 2020*)

The location of the peaks shows that older stars have a smaller mean Rbirth than younger stars → inside–out formation of the Milky Way.

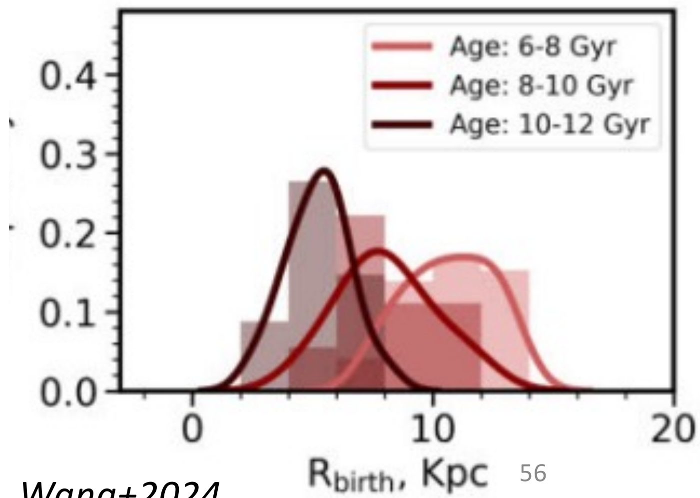



[Fe/H]=-0.25 to 0

Rbirth distribution for disc stars :
Fe, Mg, Si, Ca, Mn, and Al decrease with Increasing Rbirth
C, O, Y, and Ba increase with increasing Rbirth.

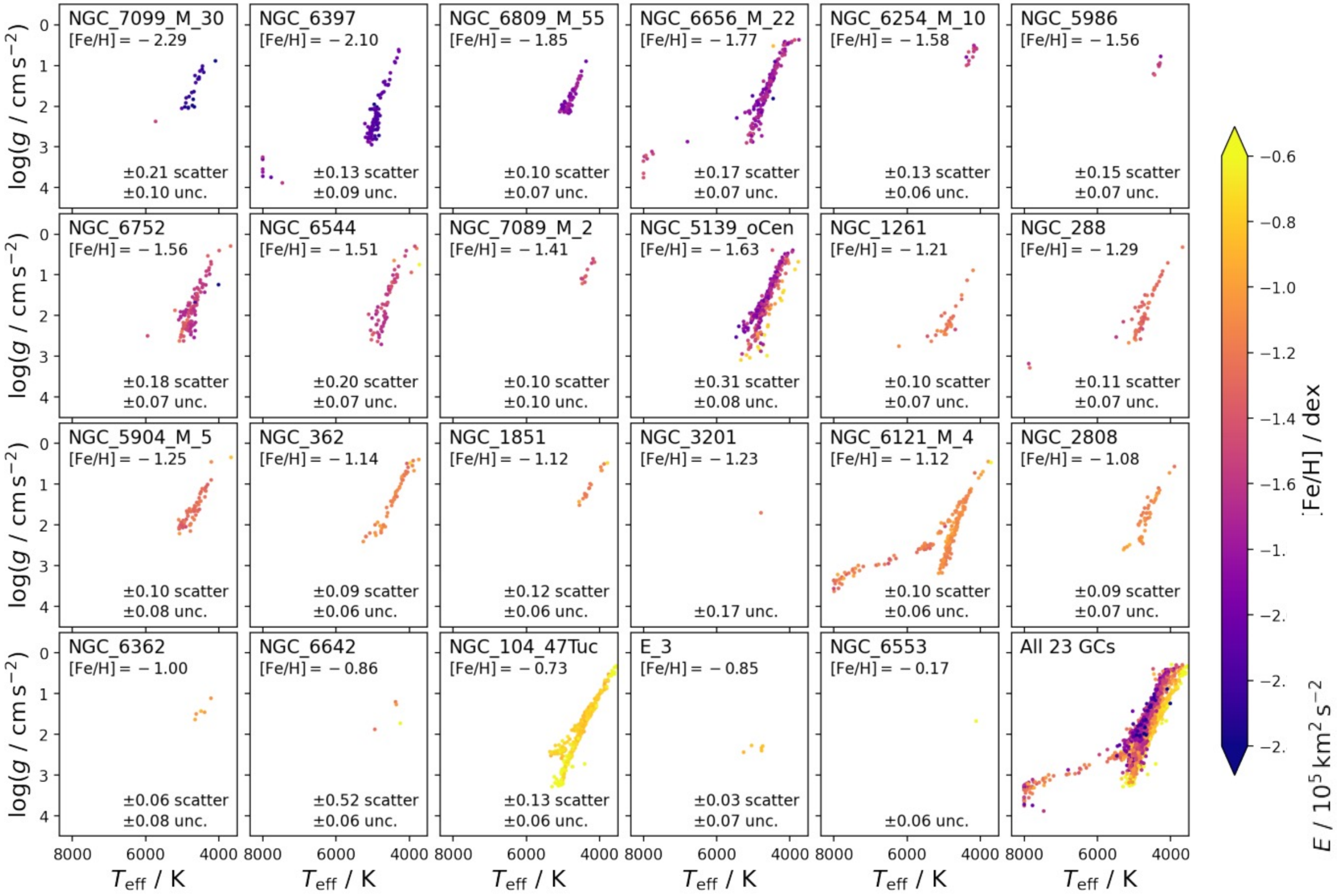


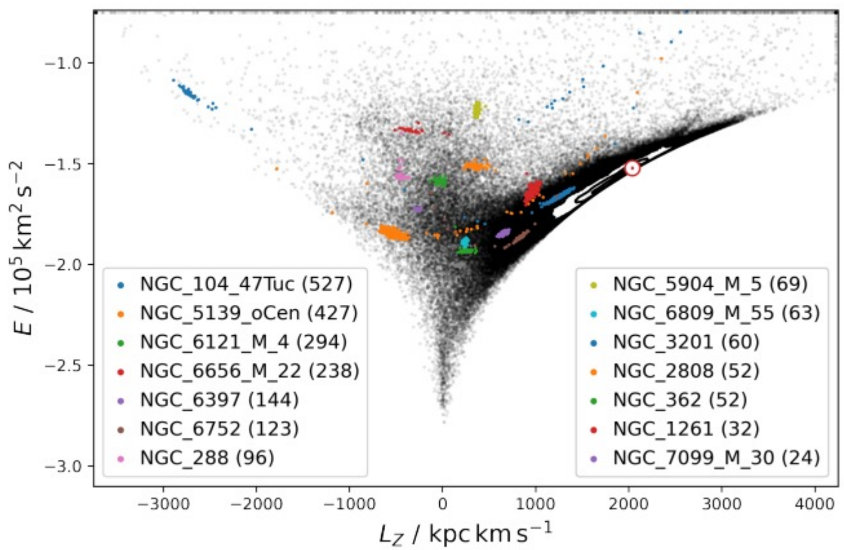

[Fe/H]=-0.5 to -0.25




*Wang+2024*

# GALAH DR4



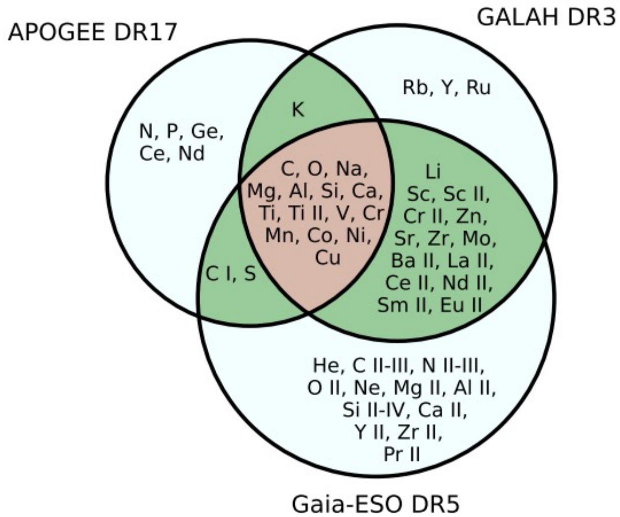




*Buder+2024*

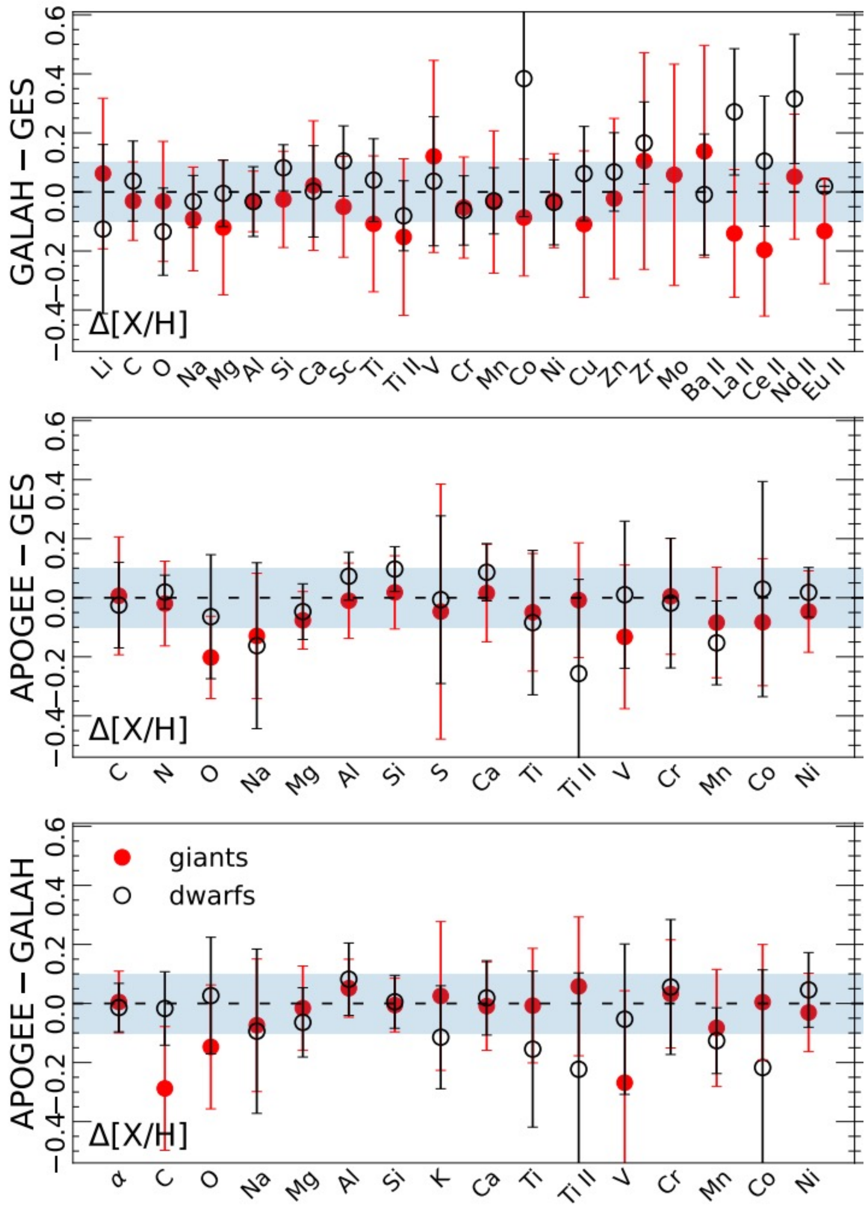
# GALAH, APOGEE, Gaia-ESO

Comparative analysis of atmospheric parameters and abundances

| | APOGEE-GALAH | APOGEE-GES | GALAH-GES |
|---|---|---|---|
| No. common stars [(a)] | 37 770 (15 537) | 2502 (804) | 1510 (441) |
| Common parameters | $T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], [α/Fe], $v_{\rm micro}$ | $T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], $v_{\rm micro}$ | $T_{\rm eff}$, $\log g$, $v_{\rm rad}$, [Fe/H], $v_{\rm micro}$ |
| Common elements | C, O, Na, Mg, Al, Si, K, Ca, Ti, Ti II, V, Cr, Mn, Co, Ni, Cu | C, C I, O, Na, Mg, Al, Si, S, Ca, Ti, Ti II, V, Cr, Mn, Co, Ni, Cu | Li, C, O, Na, Mg, Al, Si, Ca, Sc, Sc II, Ti, Ti II, V, Cr, Cr II, Mn, Co, Ni, Cu, Zn, Sr, Zr, Mo, Ba II, La II, Ce II, Nd II, Sm II, Eu II |




Conclusions: "In general we find good agreement between the three surveys within their respective uncertainties. However, there are certain regimes in which strong variants exist, which we discuss. There are still offsets larger than 0.1 dex in the absolute abundance scales."




*Hegedus+2023*

# Gaia Radial Velocity Spectrograph (GaiaRVS)

gaia

# Gaia RVS = Radial Velocity Spectrometer

esa

## *Gaia* Data Release 3: Analysis of RVS spectra using the *General Stellar Parametriser from spectroscopy*

Alejandra Recio-Blanco[1]*, P. de Laverny[1], P. A. Palicio[1], G. Kordopatis[1], M. A. Álvarez[2],

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## *Gaia* Data Release 3

### Properties and validation of the radial velocities

D. Katz[1], P. Sartoretti[1], A. Guerrier[2], P. Panuzzo[1], G. M. Seabroke[3], F. Thévenin[4], M. Cropper[3], K. Benson[3],

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## *Gaia* Data Release 3: Chemical cartography of the Milky Way

[PVP]

*Gaia* Collaboration, A. Recio-Blanco[1], G. Kordopatis[1], P. de Laverny[1], P.A. Palicio[1], A. Spagna[2], L. Spina[3], D. Katz[4], P. Re Fiorentin[2], E. Poggio[1,2], P.J. McMillan[5], A. Vallenari[3], M.G. Lattanzi[2,6], G.M. Seabroke[7], L. Casamiquela[8,4], A. Bragaglia[9], T. Antoja[10], C.A.L. Bailer-Jones[11], M. Schultheis[1], R. Andrae[11],

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## Gaia Data Release 3: Exploring and mapping the diffuse interstellar band at 862 nm

[PVP]

*Gaia* Collaboration, M. Schultheis[1], H. Zhao[1], T. Zwitter[2], D.J. Marshall[3], R. Drimmel[4], Y. Frémat[5],

and references therein

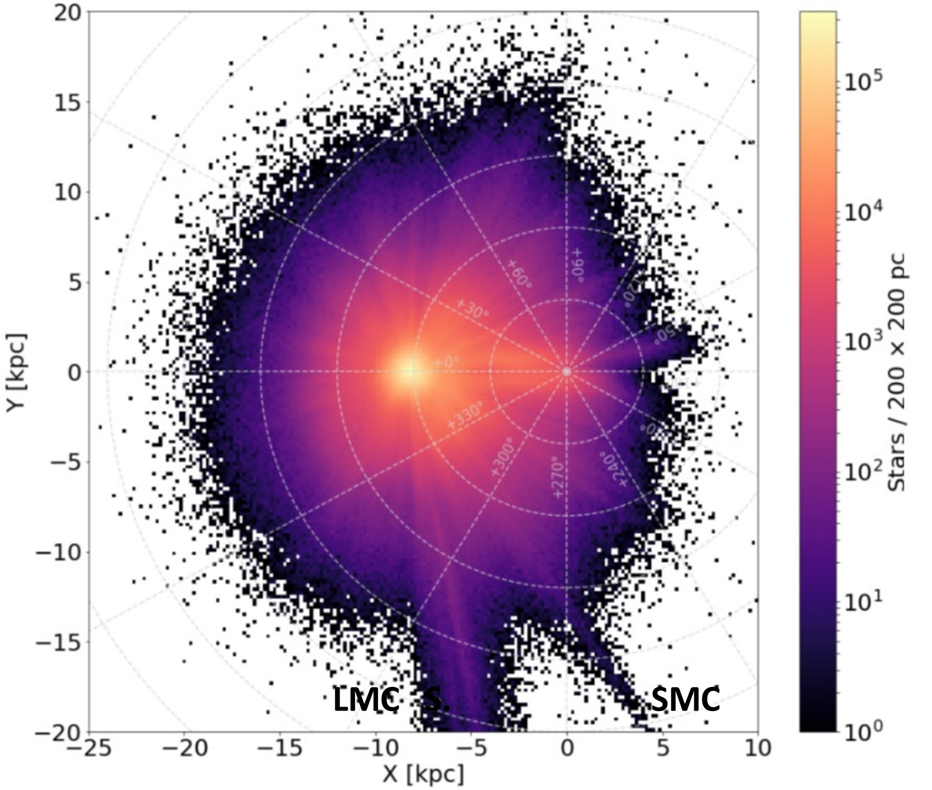
# Gaia RVS

| Field | Units | DB column name |
|---|---|---|
| Combined radial velocity | km $s^{-1}$ | radial_velocity |
| Combined radial velocity formal uncertainty | km $s^{-1}$ | radial_velocity_error |
| Combined radial velocity method | | rv_method_used |
| Number of transits 2-227 (median 18) | transits | rv_nb_transits |
| Number of de-blended transits | transits | rv_nb_deblended_transits |
| Number of visibility periods | | rv_visibility_periods_used |
| Duration of the radial velocity time series | days | rv_time_duration |
| Expected signal-to-noise ratio | | rv_expected_sig_to_noise |
| Renormalised goodness of fit | | rv_renormalised_gof |
| Chi-square P-value | | rv_chisq_pvalue |
| Amplitude of the radial velocity time series | km $s^{-1}$ | rv_amplitude_robust |
| Template effective temperature | K | rv_template_teff |
| Template surface gravity | dex | rv_template_logg |
| Template metallicity | dex | rv_template_fe_h |
| Origin of the atmospheric parameters | | rv_atm_param_origin |
| Availability of radial velocity time series | | has_epoch_rv |
| Median broadening velocity | km $s^{-1}$ | vbroad |
| Broadening velocity uncertainty | km $s^{-1}$ | vbroad_error |
| Number of vbroad transits | transits | vbroad_nb_transits |
| Median $G_{RVS}$ | mag | grvs_mag |
| $G_{RVS}$ uncertainty | mag | grvs_mag_error |
| Number of $G_{RVS}$ transits | transits | grvs_mag_nb_transit |
| Availability of the mean spectrum | | has_rvs |
| Signal-to-noise ratio per pixel of the mean spectrum | | rv_spec_sig_to_nois |
| Mean spectrum * | | rvs_mean_spectrum |

Look here: gaiadr3.gaia_source_table [* DataLink product]

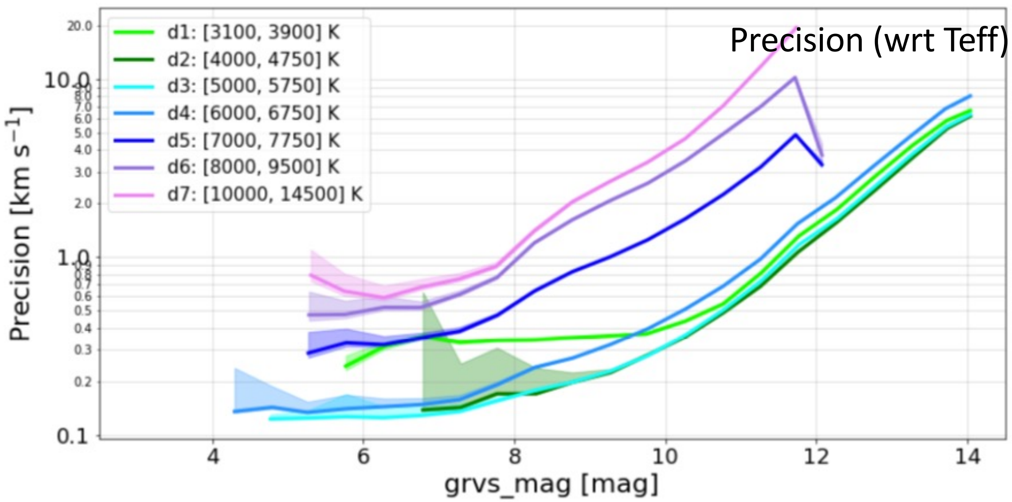
*Gaia Collaboration, Katz+2022*

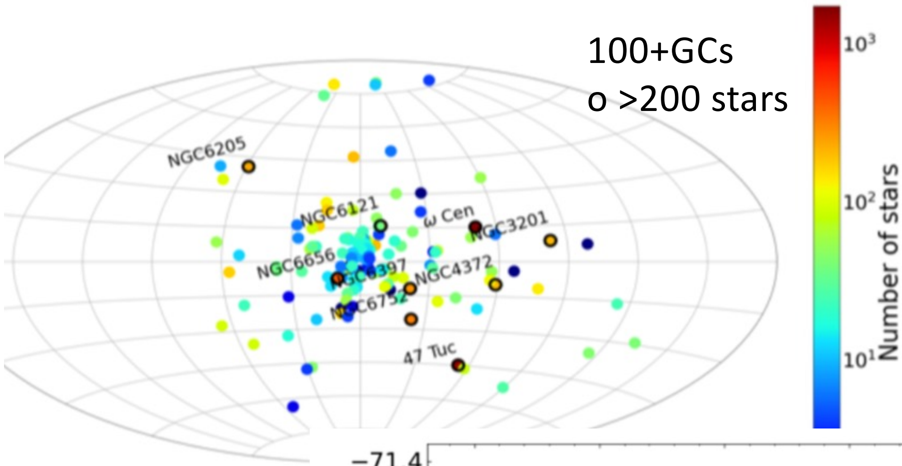
*Gaia* DR3 contains the **combined radial velocities of 33.8M** stars to $G_{RVS}$ ~ 14 [i.e. G ~15-16]
[*in* GDR2: ~7M]

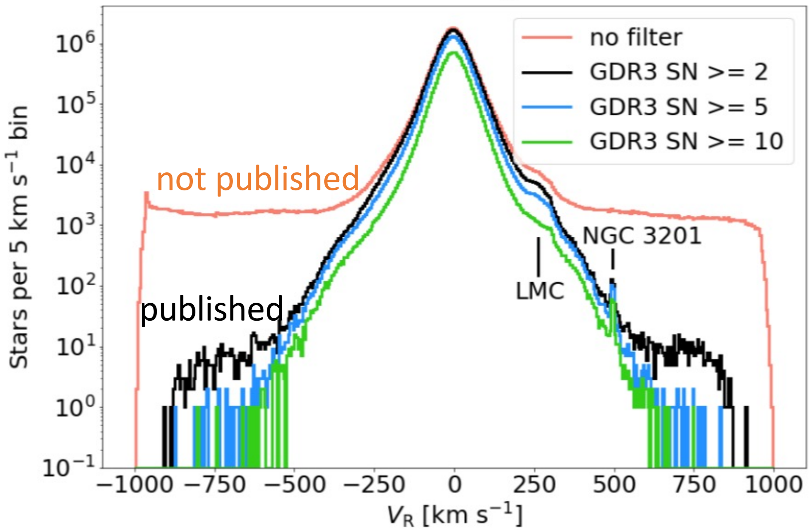


# Gaia RVS

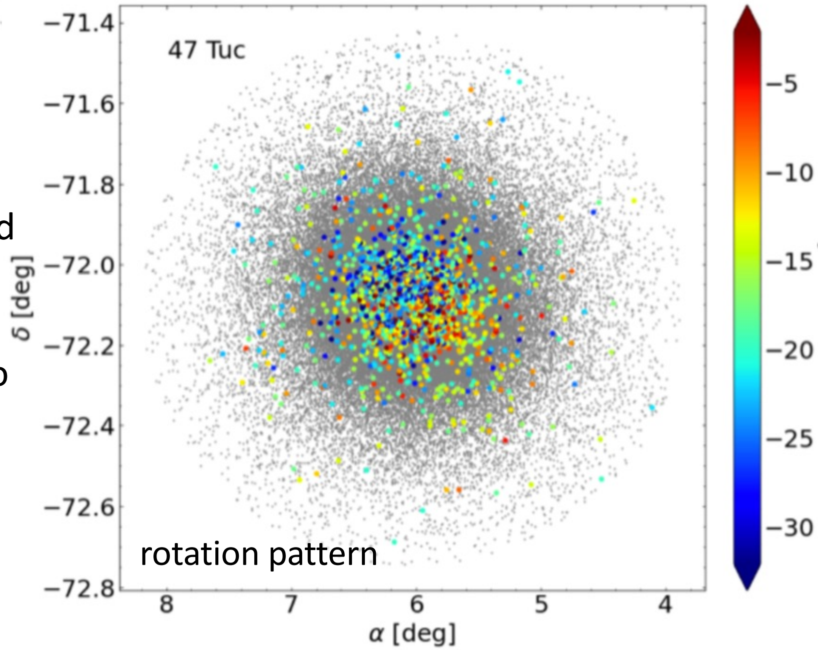
*GC, Katz+2022*



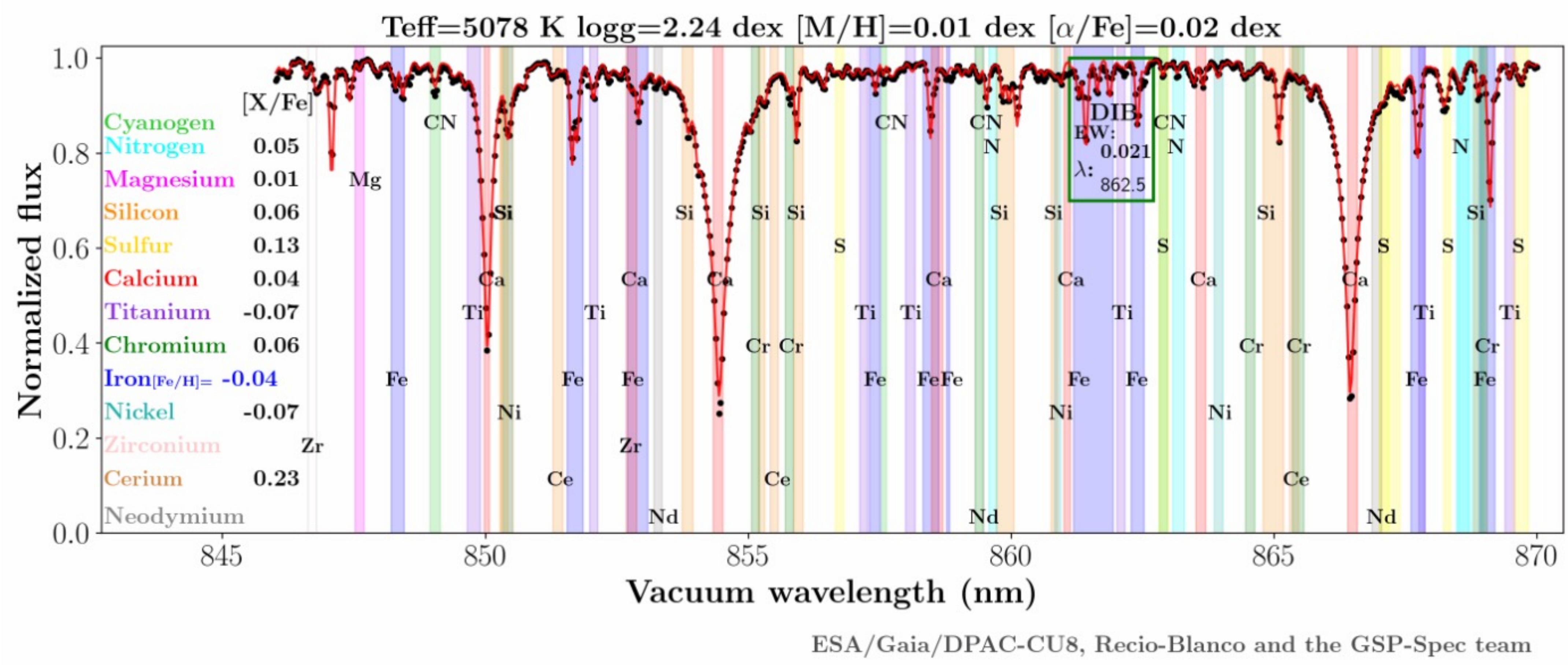




- Validation wrt ground-based surveys
- Comprise large part of disk (also beyond GC), inner halo (to distance ~15 kpc)
- 1000+ open clusters
- 100+ globular clusters
- Magellanic Clouds




Look here: gaiadr3.gaia_source_table

# Gaia RVS : not only radial velocities



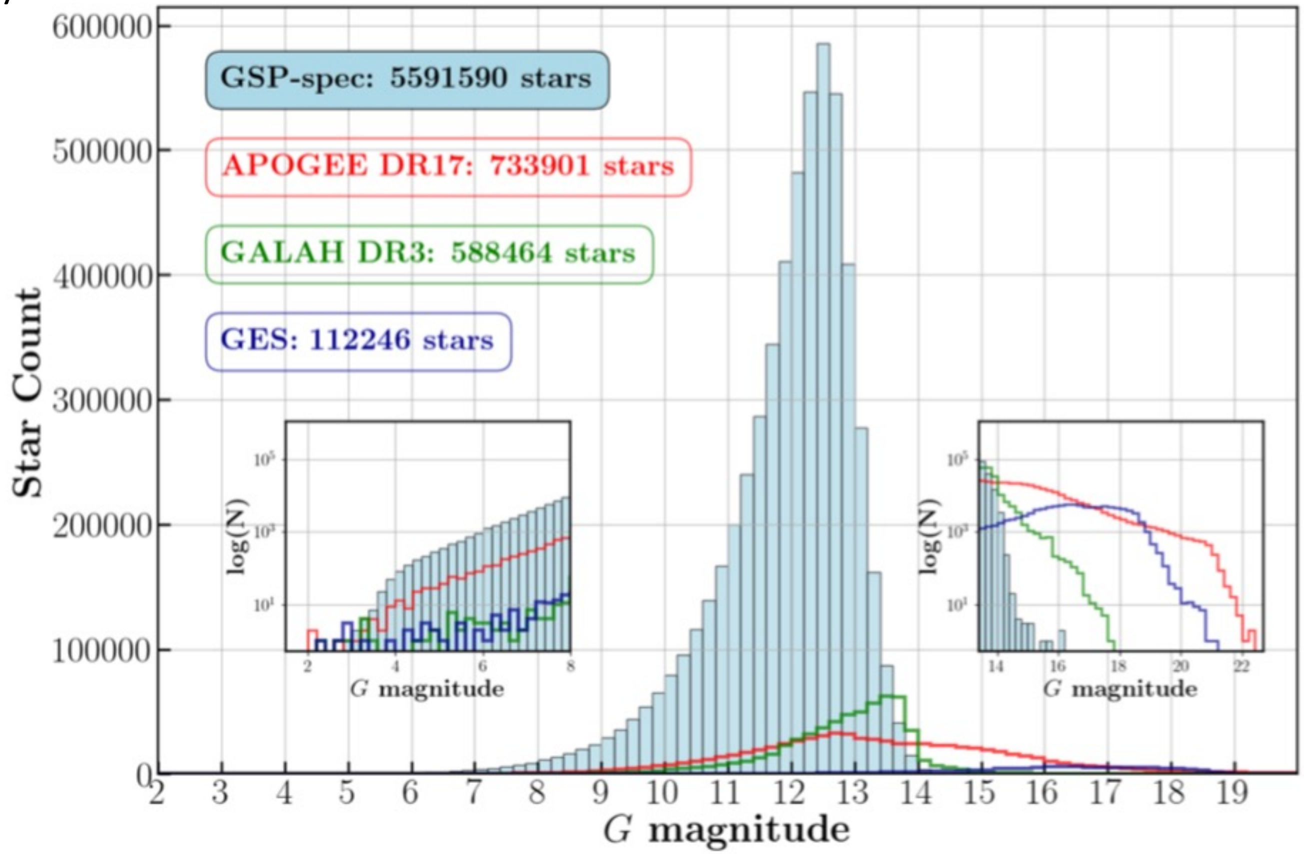

https://www.cosmos.esa.int/web/gaia/iow_20210709

# Gaia RVS : not only radial velocities

*GC, Recio-Blanco+2022a*

Of the 33.8M stars, 5.6M have *GSP-spec* results [ 7.5 x APOGEE DR17, 9.5 x GALAH DR3, 48.5 x Gaia-ESO ]
*GSP-Spec*=General Stellar Parametriser-spectroscopy

*GSP-Spec* estimates the chemo-physical parameters from combined RVS spectra of single stars, without additional inputs from astrometric, photometric, or spectrophotometric BP/RP data




Two workflows:
MatisseGauguin (projection & optimisation)
➔ Teff, log g, [M/H], [X/M], CN, DIB
ANN (artificial neural network)
➔ Stellar parameters for classification

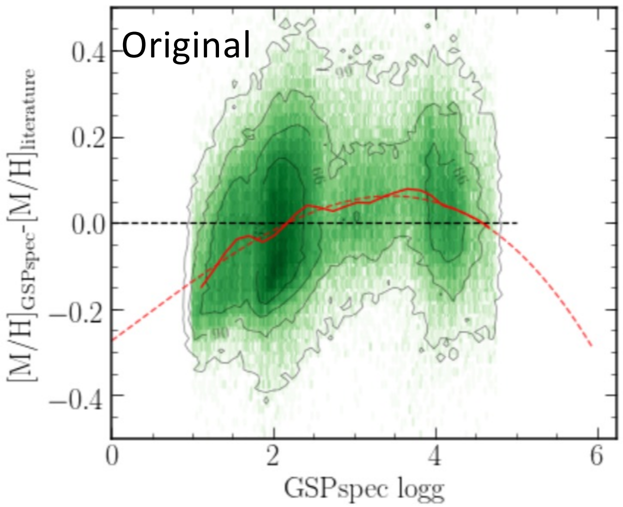
Internal and external biases studied, a system of flags is defined

Low-degree polynomial calibrations suggested

Look here: `gaiadr3.astrophysical_parameters [MatisseGauguin] &`
`gaiadr3.astrophysical_parameters_supp [ANN]`

# Gaia RVS results [GSP-spec]

*GC, Recio-Blanco+2022a*



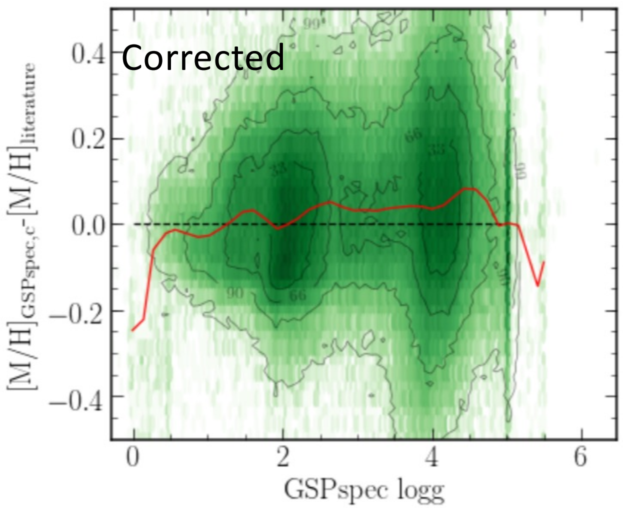



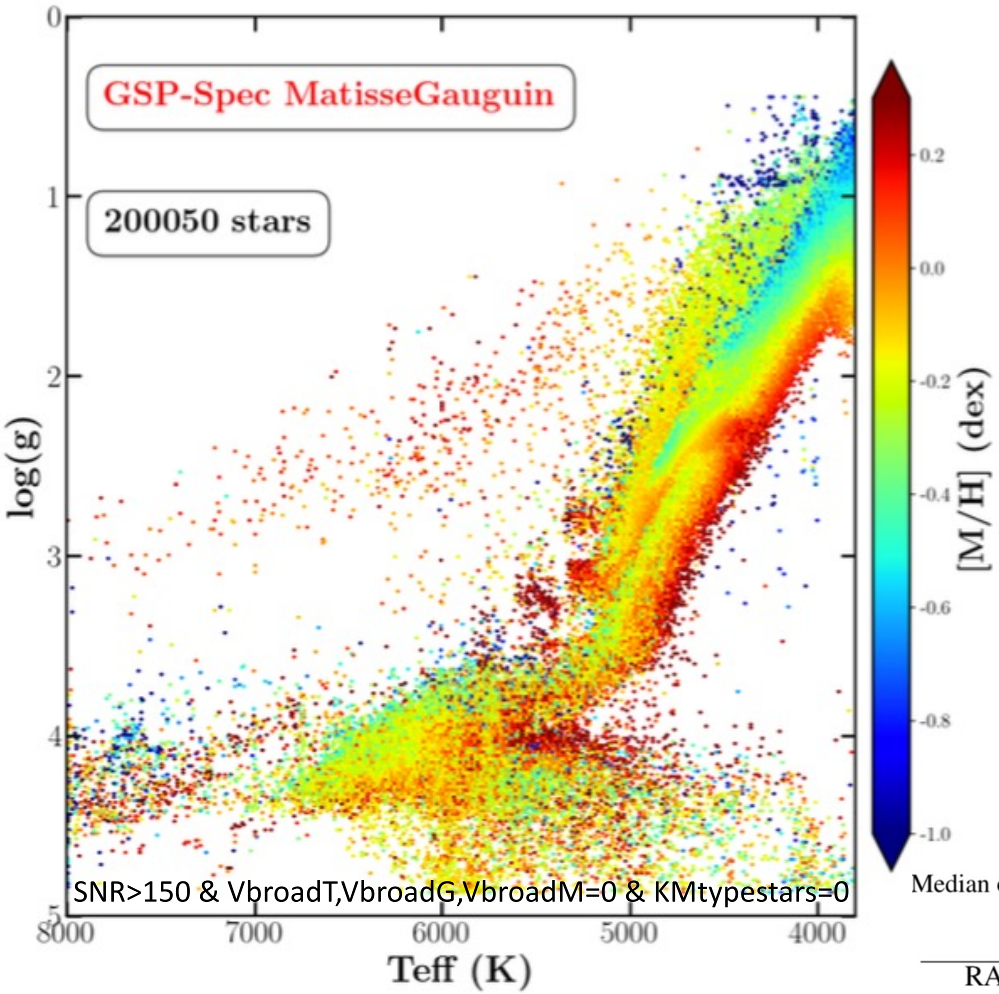

**Table 2.** Definition of each character in the *GSP-Spec* quality flag string chain (*flags_gspspec*), including the possible values (col.3) and the related subsection and tables providing further information (col.4). Flag names are split into three categories: Parameter flags (green), individual abundance flags (blue), and EW flags (orange). All flags concern the MatisseGauguin parameters, while only the parameter flags except KMgiantPar are applied to ANN results.

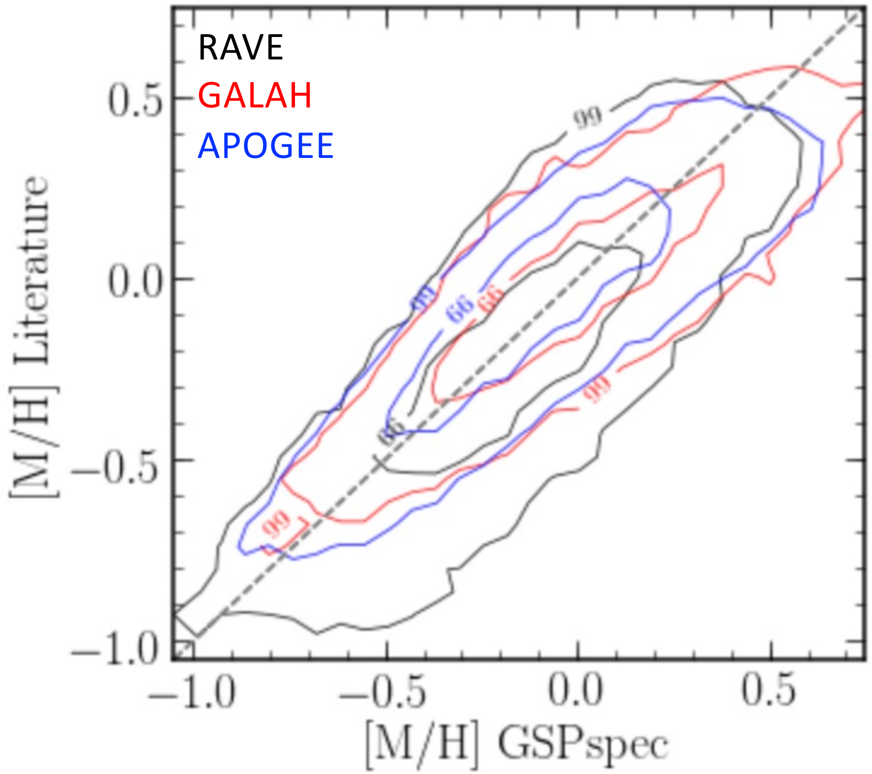
*flags_gspspec*

| Chain character number - name | Considered quality aspect | Possible adopted values | Related subsection and table |
|---|---|---|---|
| 1 **vbroadT** | *vbroad* induced bias in $T_{eff}$ | 0,1,2,9 | 8.1 & C.1 |
| 2 **vbroadG** | *vbroad* induced bias in log($g$) | 0,1,2,9 | 8.1 & C.1 |
| 3 **vbroadM** | *vbroad* induced bias in [M/H] | 0,1,2,9 | 8.1 & C.1 |
| 4 **vradT** | $V_{Rad}$ induced bias in $T_{eff}$ | 0,1,2,9 | 8.2 & C.2 |
| 5 **vradG** | $V_{Rad}$ induced bias in log($g$) | 0,1,2,9 | 8.2 & C.2 |
| 6 **vradM** | $V_{Rad}$ induced bias in [M/H] | 0,1,2,9 | 8.2 & C.2 |
| 7 **fluxNoise** | Flux noise induced uncertainties | 0,1,2,3,4,5,9 | 8.3 & C.3, C.4 |
| 8 **extrapol** | Extrapolation level of the parametrisation | 0,1,2,3,4,9 | 8.4 & C.5, C.6 |
| 9 **negFlux** | Negative flux *wlp* | 0,1,9 | 8.5 & C.7 |
| 10 **nanFlux** | NaN flux *wlp* | 0,9 | 8.5 & C.7 |
| 11 **emission** | Emission line detected by CU6 | 0,9 | 8.5 & C.7 |
| 12 **nullFluxErr** | Null uncertainties *wlp* | 0,9 | 8.5 & C.7 |
| 13 **KMgiantPar** | KM-type giant stars | 0,1,2 | 8.6 & C.8 |
| 14 **NUpLim** | Nitrogen abundance upper limit | 0,1,2,9 | 8.7 & C.9 |
| 15 **NUncer** | Nitrogen abundance uncertainty quality | 0,1,2,9 | 8.7 & C.10 |
| 16 **MgUpLim** | Magnesium abundance upper limit | 0,1,2,9 | 8.7 & C.9 |
| 17 **MgUncer** | Magnesium abundance uncertainty quality | 0,1,2,9 | 8.7 & C.10 |
| ... | | | |
| 38 **NdUpLim** | Neodymium abundance upper limit | 0,1,2,9 | 8.7 & C.9 |
| 39 **NdUncer** | Neodymium abundance uncertainty quality | 0,1,2,9 | 8.7 & C.10 |
| 40 **DeltaCNq** | Cyanogen differential equivalent width quality | 0,9 | 8.8 & C.12 |
| 41 **DIBq** | DIB quality flag | 0,1,2,3,4,5,9 | 8.9 & C.13 |

# Gaia RVS: quality checks

*GC, Recio-Blanco+2022a*



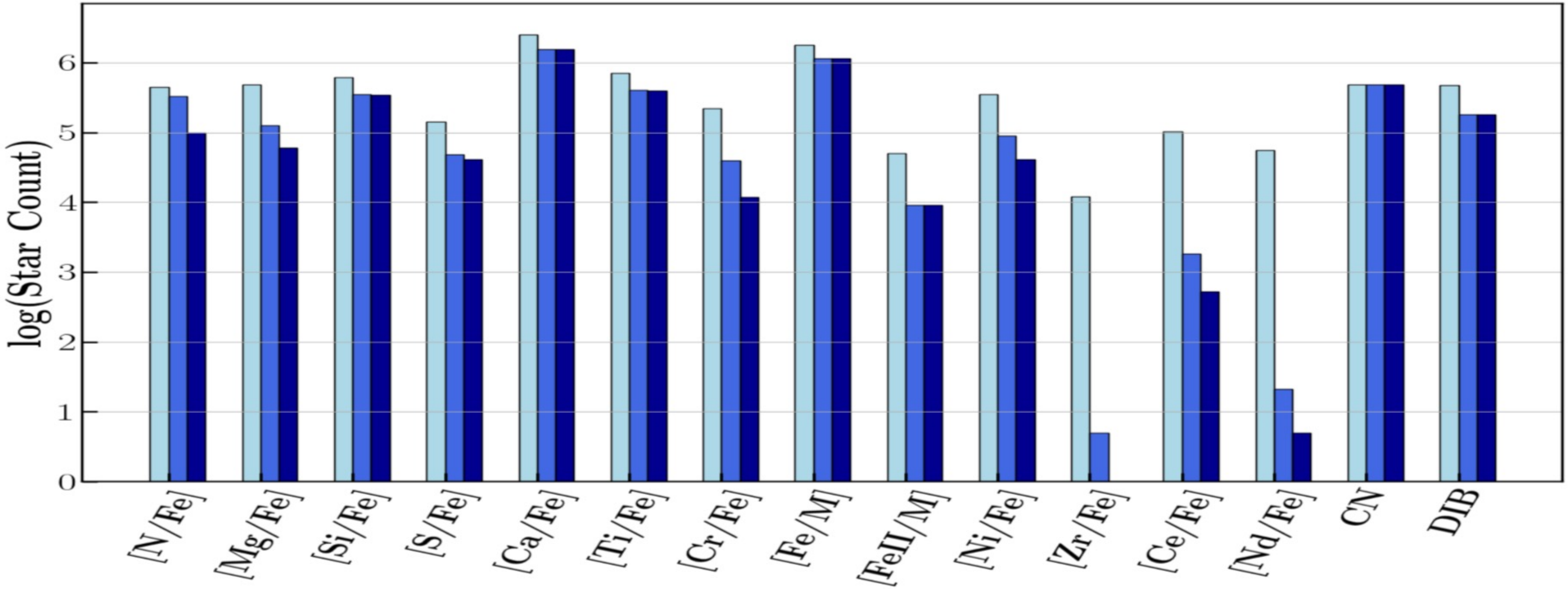




Median offsets and robust sigma between *GSP-Spec* and individual surveys

| | $T_{\rm eff}$ | log($g$) | [M/H] | log($g$)$_{\rm calibrated}$ | [M/H]$_{\rm calibrated}$ | RVS S/N |
|---|---|---|---|---|---|---|
| RAVE-DR6 | (-12; 93) | (-0.28; 0.19) | (-0.05; 0.11) | (-0.003; 0.18) | (-0.05; 0.09) | (94; 64) |
| GALAH-DR3 | (20;87) | (-0.26; 0.21) | (0.01; 0.10) | (0.003; 0.18) | (-0.001; 0.10) | (68; 53) |
| APOGEE-DR17 | (-32; 86) | (-0.32; 0.17) | (0.04; 0.12) | (-0.005; 0.15) | (0.06; 0.12) | (65; 80) |

# Gaia RVS : not only metallicity

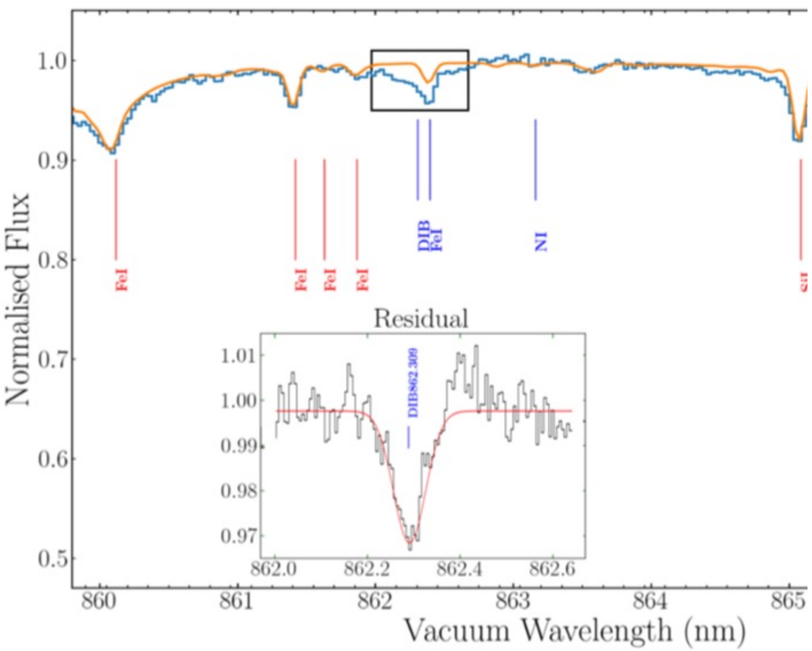
*GC, Recio-Blanco+2022a*

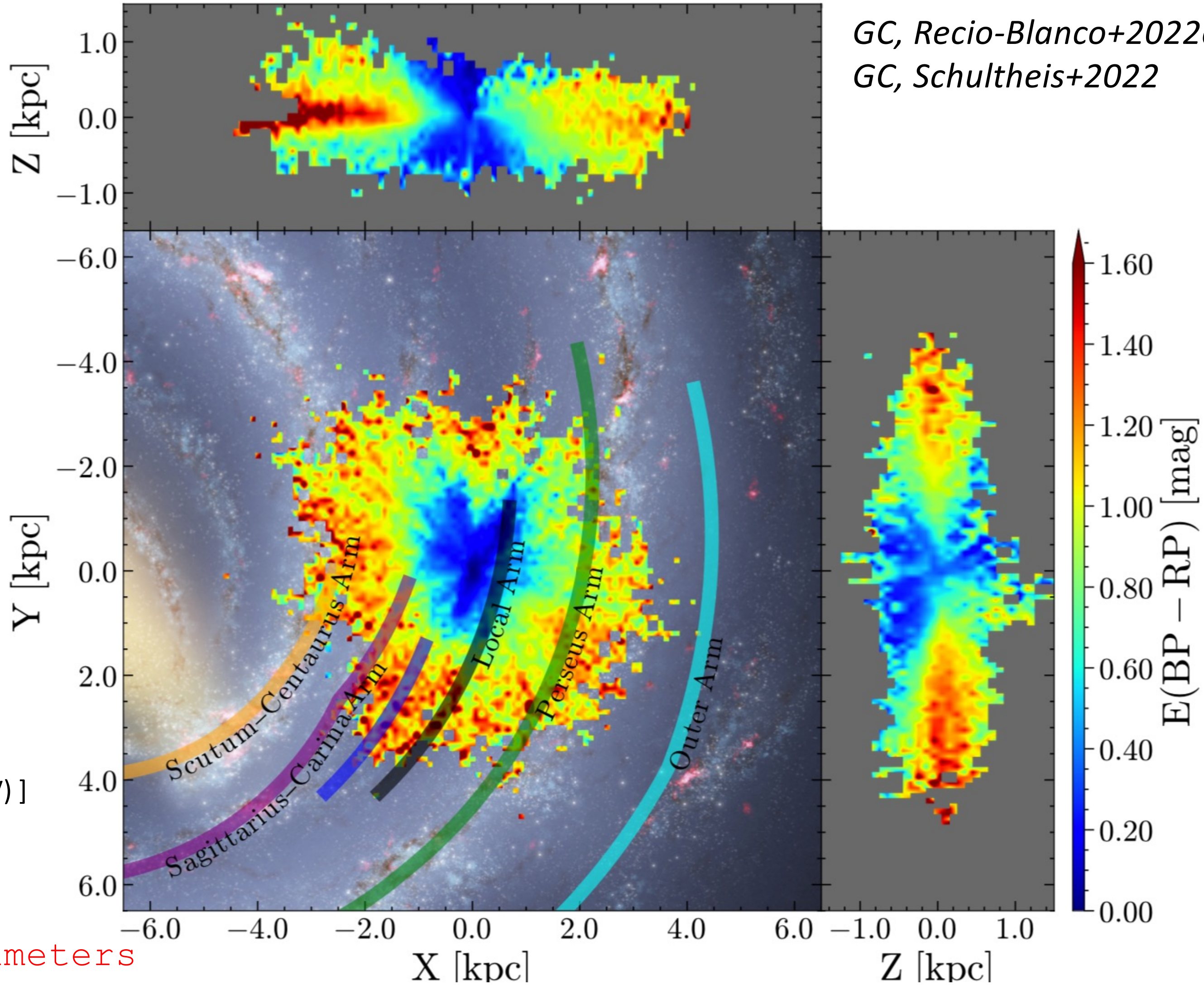



Whole sample *UpLimits ≤ 1 *UpLimits ≤ 0

Look here: `gaiadr3.astrophysical_parameters`

# Gaia RVS results: DIBs & reddening




*GC, Recio-Blanco+2022a*
*GC, Schultheis+2022*

- DIBs=Diffuse Interstellar Bands
- Origin: molecules [ CO for the 862nm ? ]
- Trace ISM
- Correlate with absorption [ linear relation EW/E(B-V) ]
- About 480k measurements [ within ~ 4kpc ]
- About 140k in high-quality sample

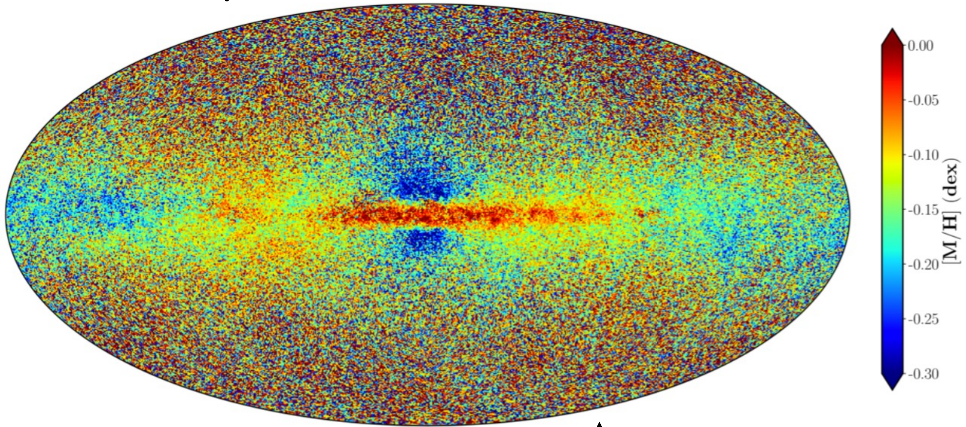
Look here: `gaiadr3.astrophysical_parameters`

# Gaia RVS results: chemical cartography

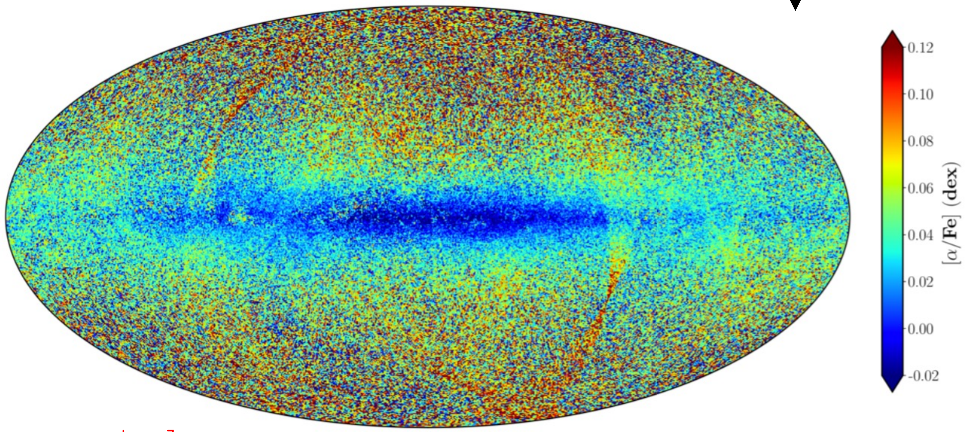
*GC, Recio-Blanco+2022b*

Cartography = combine *GSP-spec* + astrometry + RV (all in Gaia DR3) to study relations between chemistry and Milky Way structure, stellar kinematics, and orbital parameters

- Unprecedented spatial resolution, largest dataset [complete: 5.6M ; medium-quality: 4.1M; high-quality: 2.2M; per element: a few $10^4$ to 2M]
- Symmetric vertical distribution
- Flared disk
- Observed kinematic disturbances and kinematic/orbital substructures associated with chemistry
- **α**, metallicity and iron peak, heavy elements distribution define thin/thick disk
- Younger stars in solar neighborhood are metal-poorer
- Accretion structures identified (dynamics+chemistry)
- Globular clusters recovered
- Nearly 600 open clusters have metallicity, chemical abundances
- Metallicity and **α** element gradients based (also) on OCs



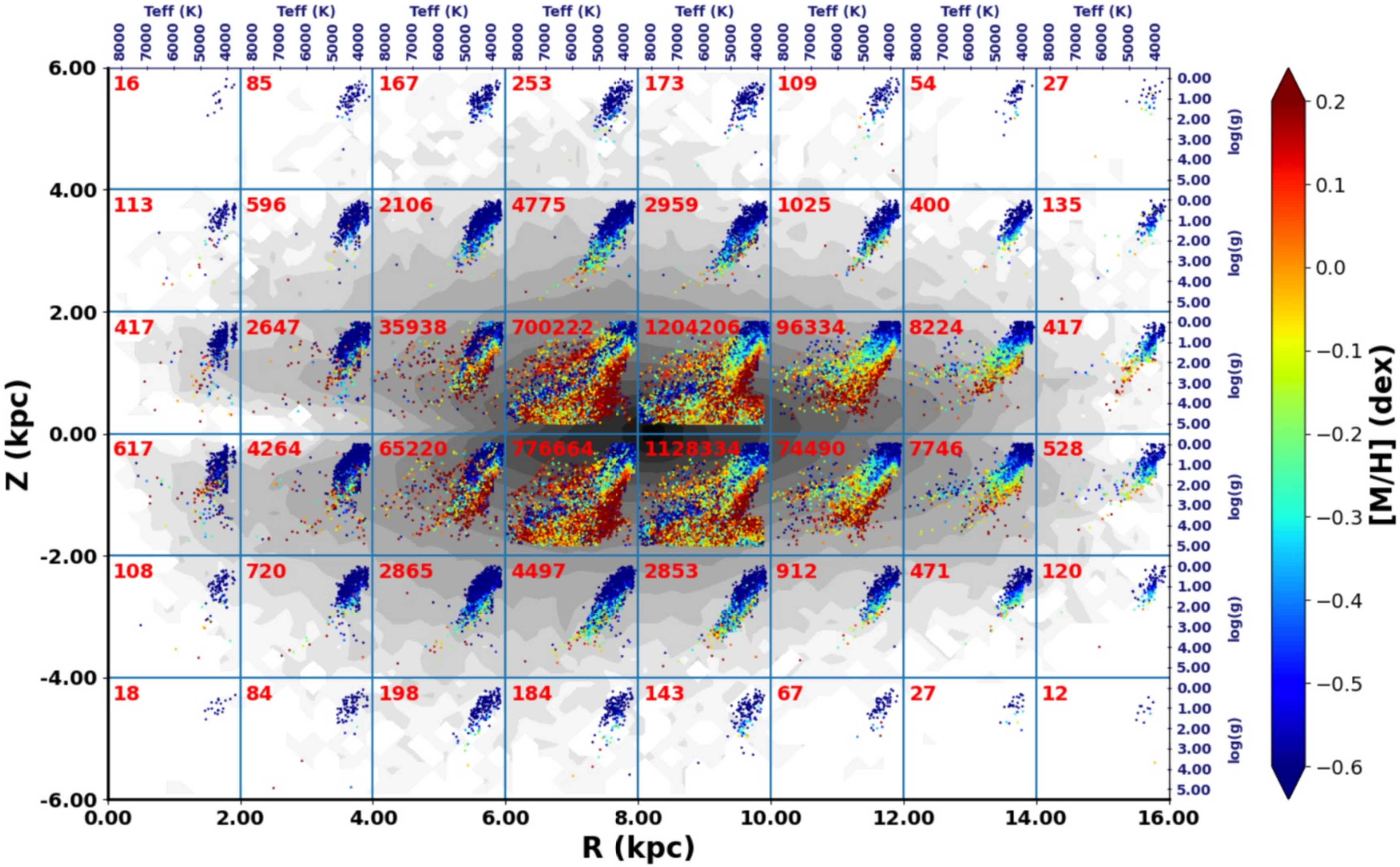

*GSP-spec* coloured with metallicity ↑ and [α/Fe] ↓




*In DR3, 99% of the GSP-Spec catalogue has Gmag<13.6 but future releases will reach much fainter magnitudes thanks to on-going Gaia observations*

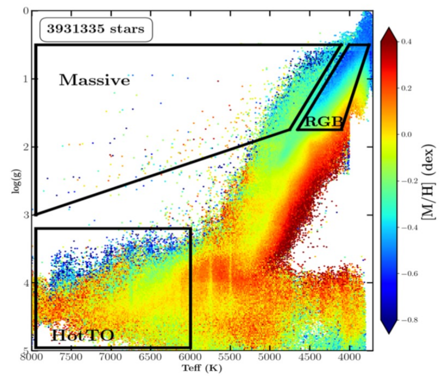
Look here: `gaiadr3.astrophysical_parameters [ *_gspspec_* ]`

# Gaia RVS results: disk tomography




*GC, Recio-Blanco+2022b*

Kiel diagram (Teff, logg)




Giants: also far
Dwarfs: close-by

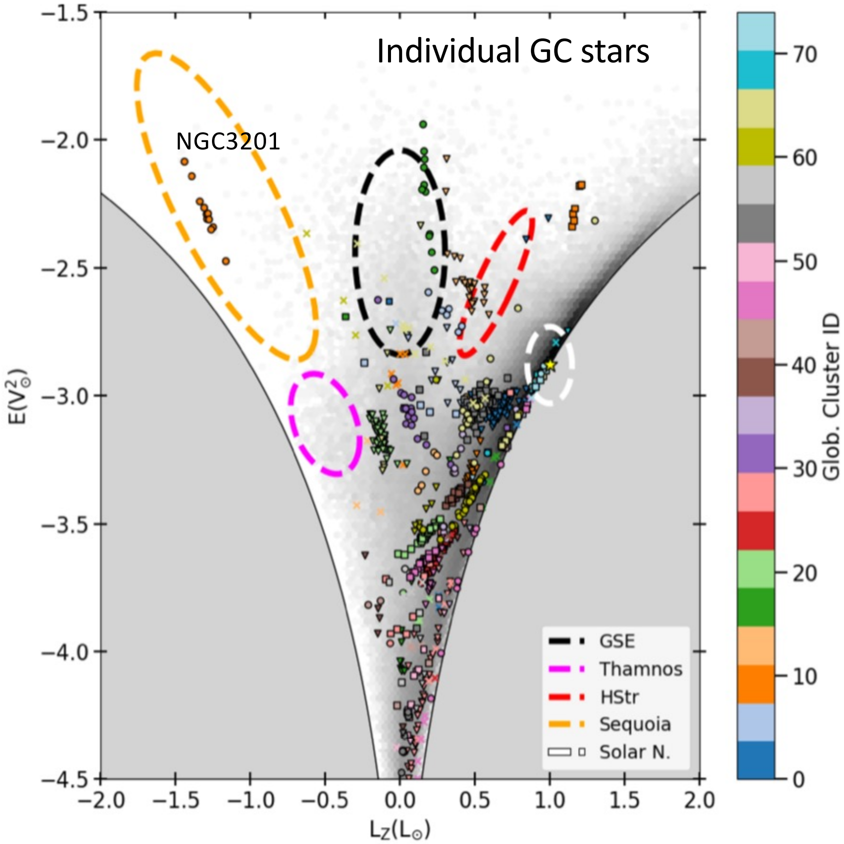
2<Rgc<16 kpc
-3<Z<+3 kpc

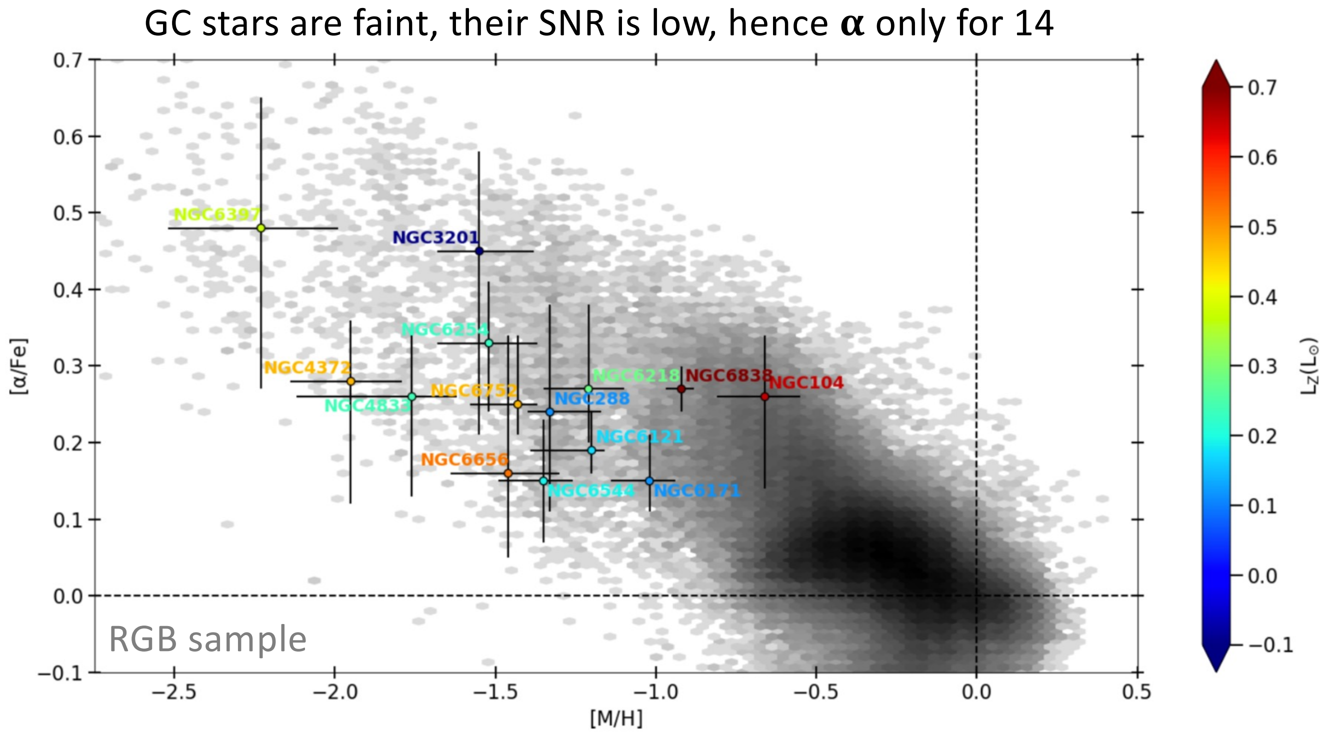
medium-quality sample (4.2M)

# Gaia RVS results: structures & GCs

*GC, Recio-Blanco+2022b*

GCs will require more data (future DRs) but are already present and give reasonable results



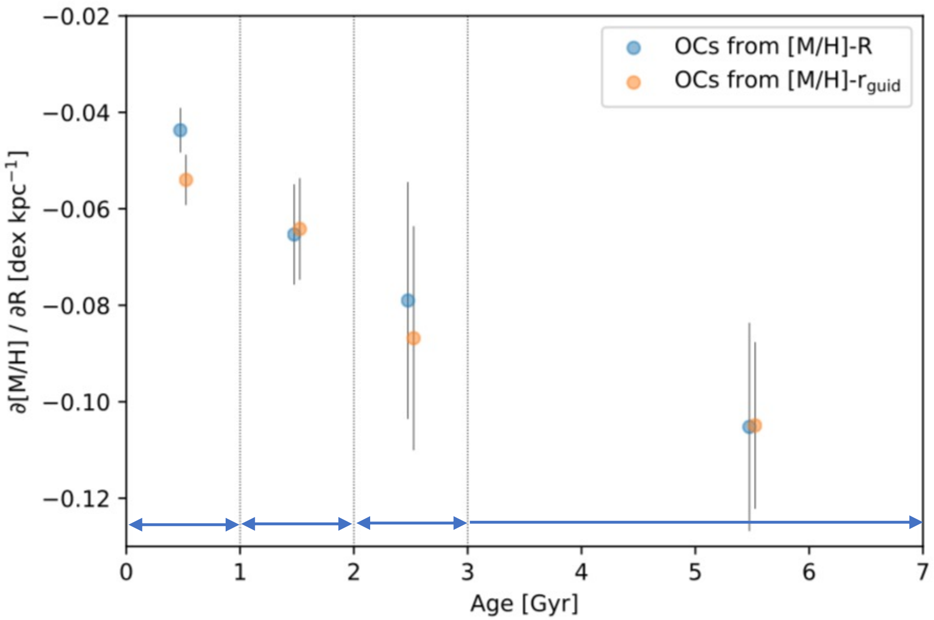



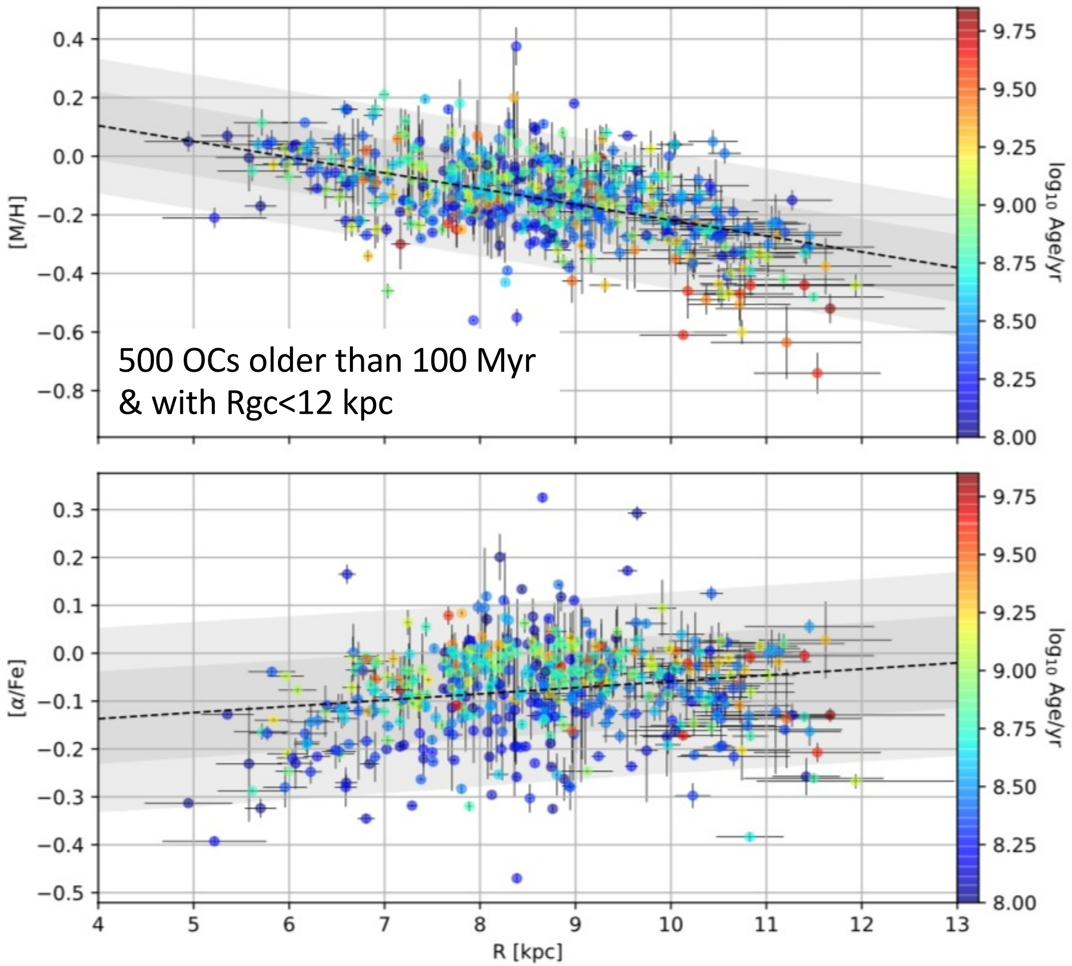
# Gaia RVS results: open clusters

*GC, Recio-Blanco+2022b*

About 6800 member stars have [M/H]
After quality cuts : 1600 stars in 600 open clusters
[number of stars: 1-55, median 18]

- Derive metallicity and [α/Fe] gradients (compare well with literature)
- Divide in 4 age ranges : older OCs have steeper gradient (confirm literature)

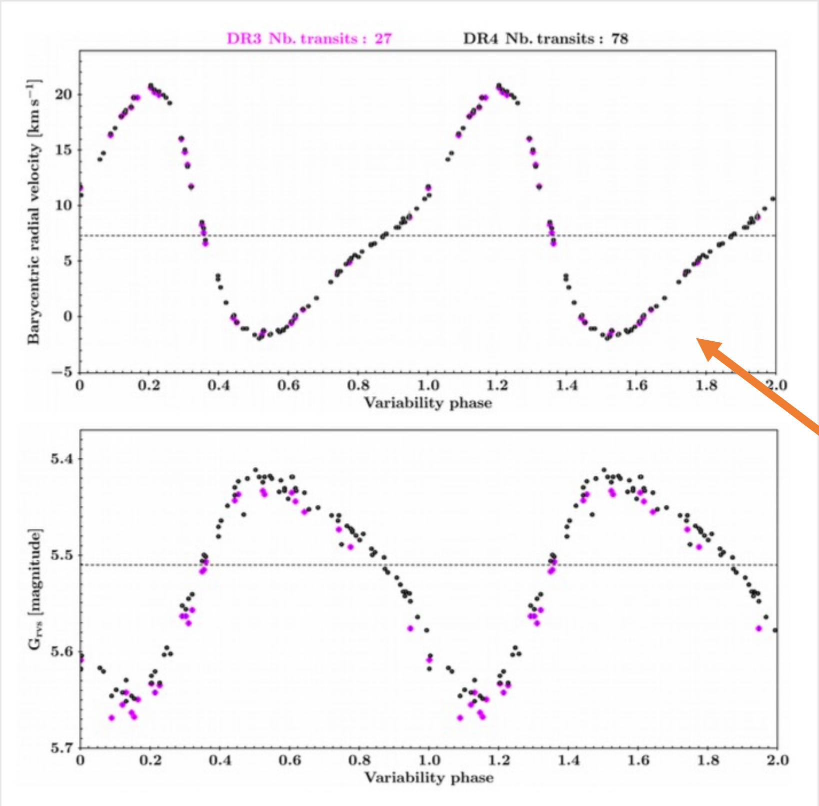


# Gaia RVS : what to expect in DR4 ?

Gaia DR4 (based on 66 months of data) not before mid 2026

## Gaia DR4 radial velocities




DPAC/ CU6/ DPCC team

- Gaia DR4 includes time series for all bright sources ($G_{RVS} < 14$)
- Figure shows example of pulsational RV variations for a Cepheid variable
  - Radial velocity time series
  - XP spectra time series
  - RVS spectra time series

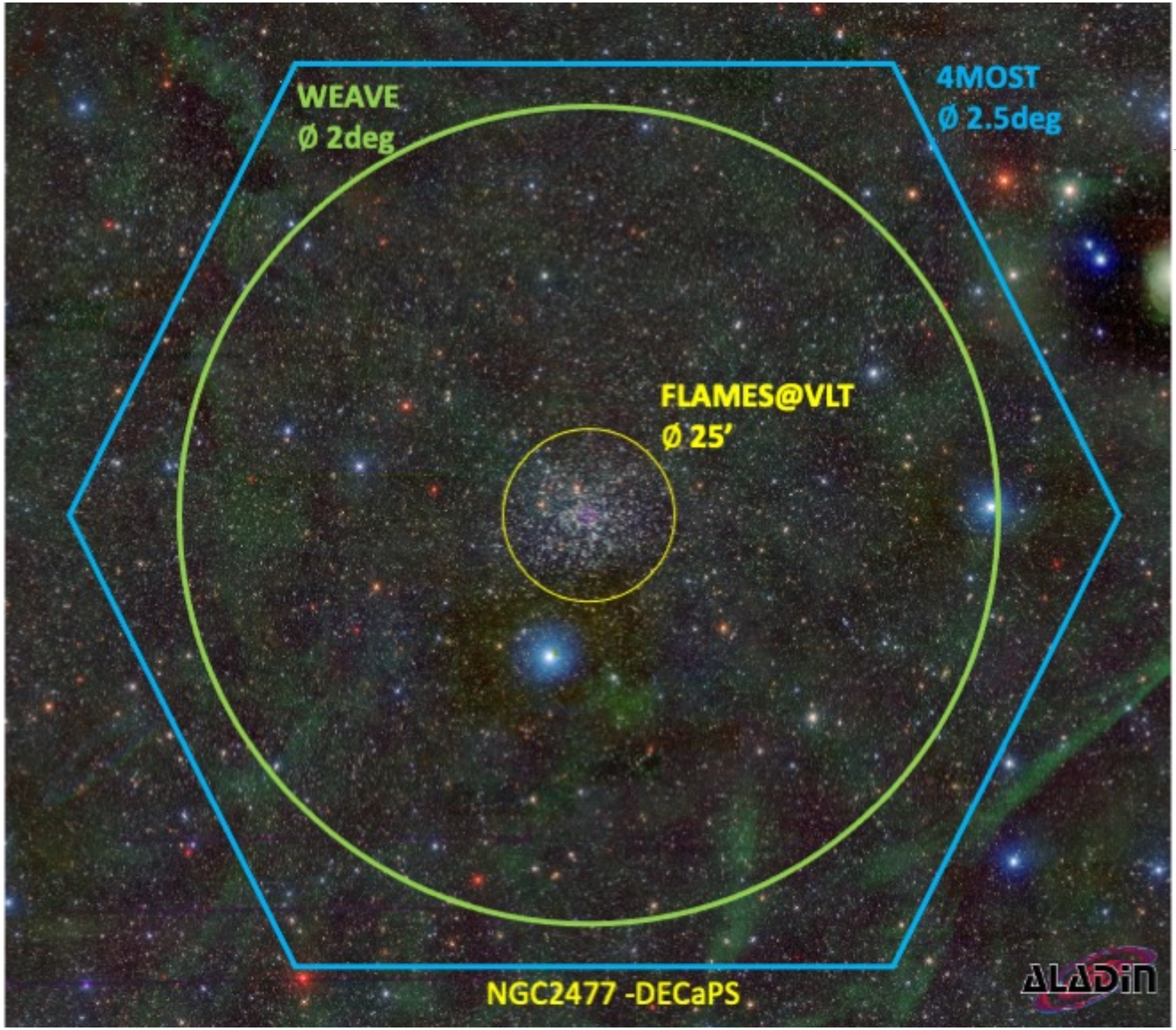
[slide borrowed from Anthony Brown's presentation at EAS 2024]

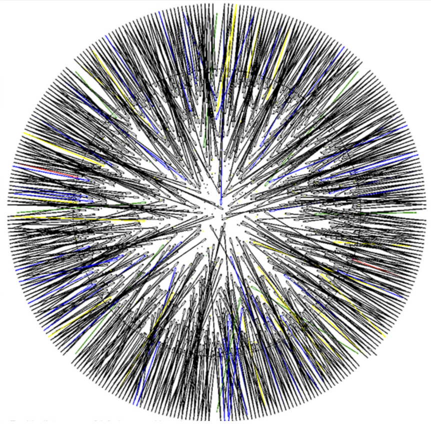
# A couple of near future European spectroscopic surveys: WEAVE & 4MOST

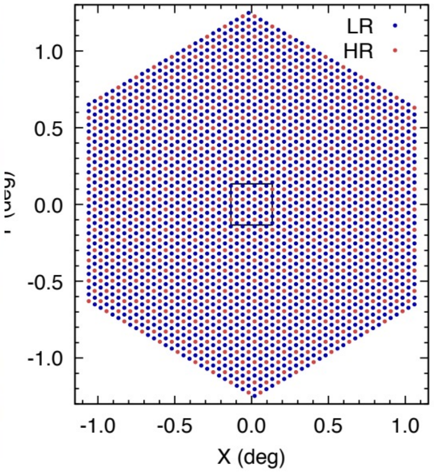
# A couple of future surveys

To study large star samples in the MW, MOS coupled with a large field of view (FoV) is needed.

This is also valid for stellar clusters, if we want to cover the whole extent, from the center to the outskirt, halo, and tails





## WEAVE *(Jin, Trager, Dalton+2024)*

- 4m WHT telescope
- 2 deg diameter
- HR (R=20000) or LR (R=5000)
- HR: Blue/Green + Red
- MOS 960 fibers x field (Plate A & B)
- Multiplex per pointing 960
- Cannot observe HR and LR at once
- fibre minimum distance: 60 arcsec
- Fiber size 1.3 arcsec
- Mini-IFUs + LIFU
- 70% of WHT time for 5 years

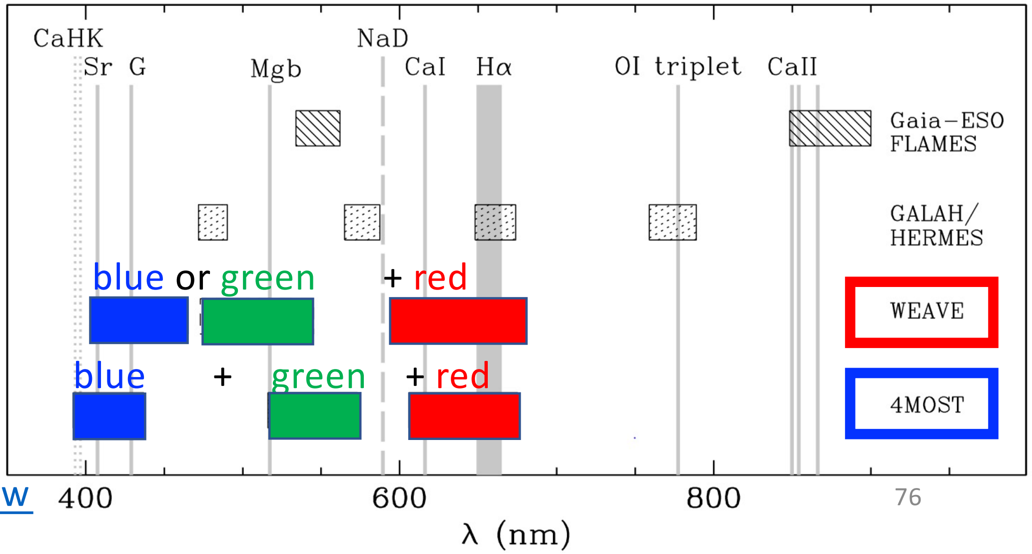
## 4MOST *(de Jong+2019)*

- 4m VISTA telescope
- 2.5deg diameter FoV
- HR (R=20000) & LR (R=5000)
- HR: Blue + Green + Red
- 812 high-res (HR) fibres & 1624 low-res (LR) fibres –working at same time
- Fibre multiplex per pointing ~2400
- HR & LR at same time
- Fibre minimum distance 15 arcsec
- Fibre size 1.3 arcsec
- No IFUs
- 5 years

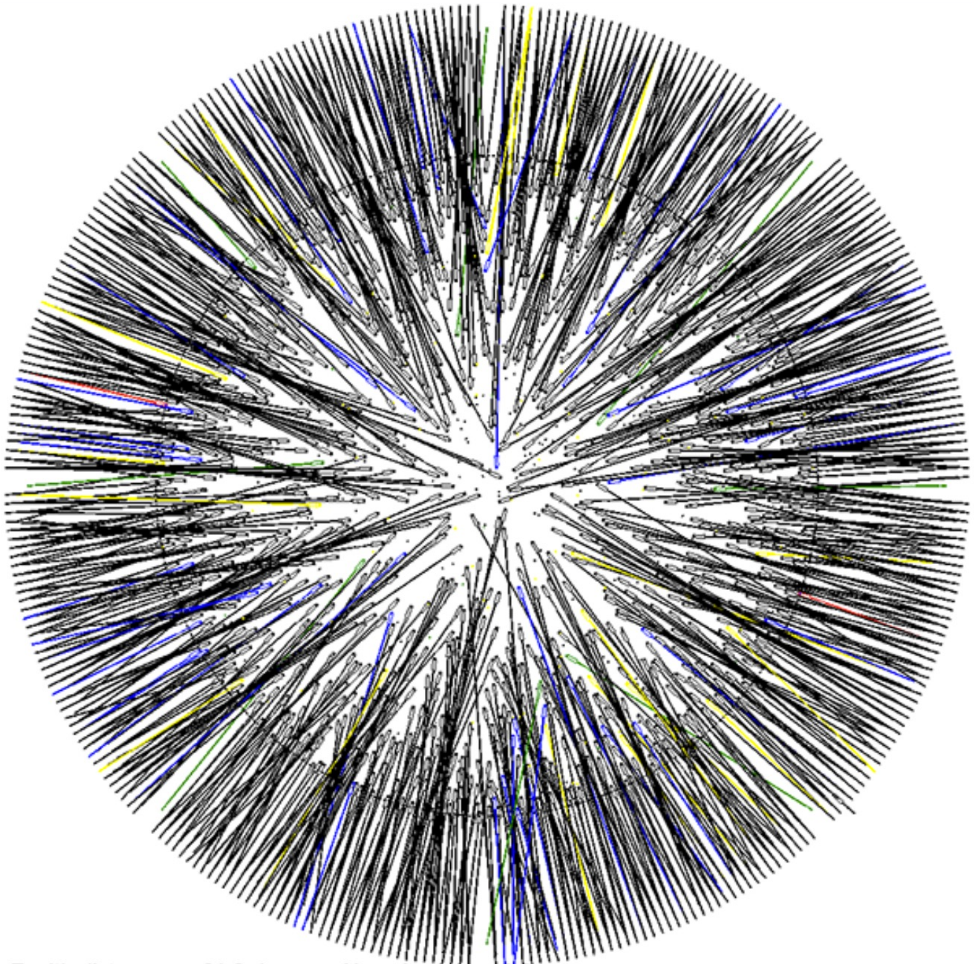
WEAVE: commissioning & SV phase on-going, LIFU survey started in Fall 2023, MOS survey due to start in 2025 (TBC)

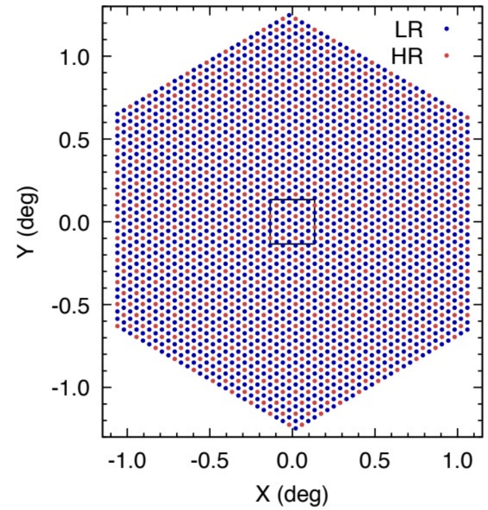
4MOST: instrument assembly on-going, SV in 2025, survey starts 2026 (TBC)

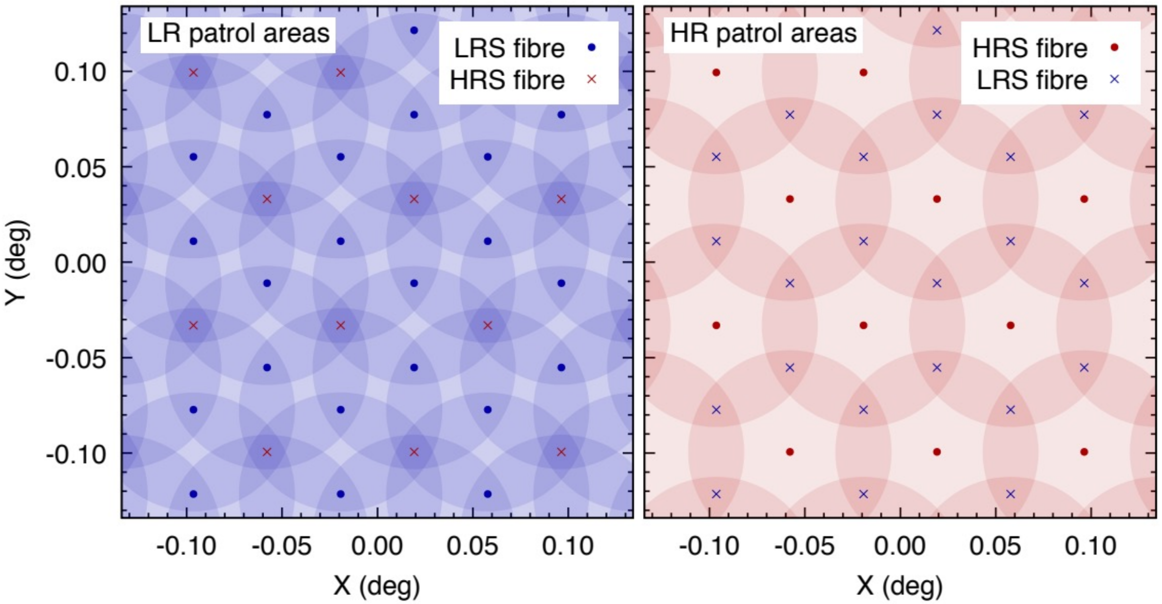
https://www.4most.eu/cms/home/
https://weave-project.atlassian.net/wiki/spaces/WEAVE/overview



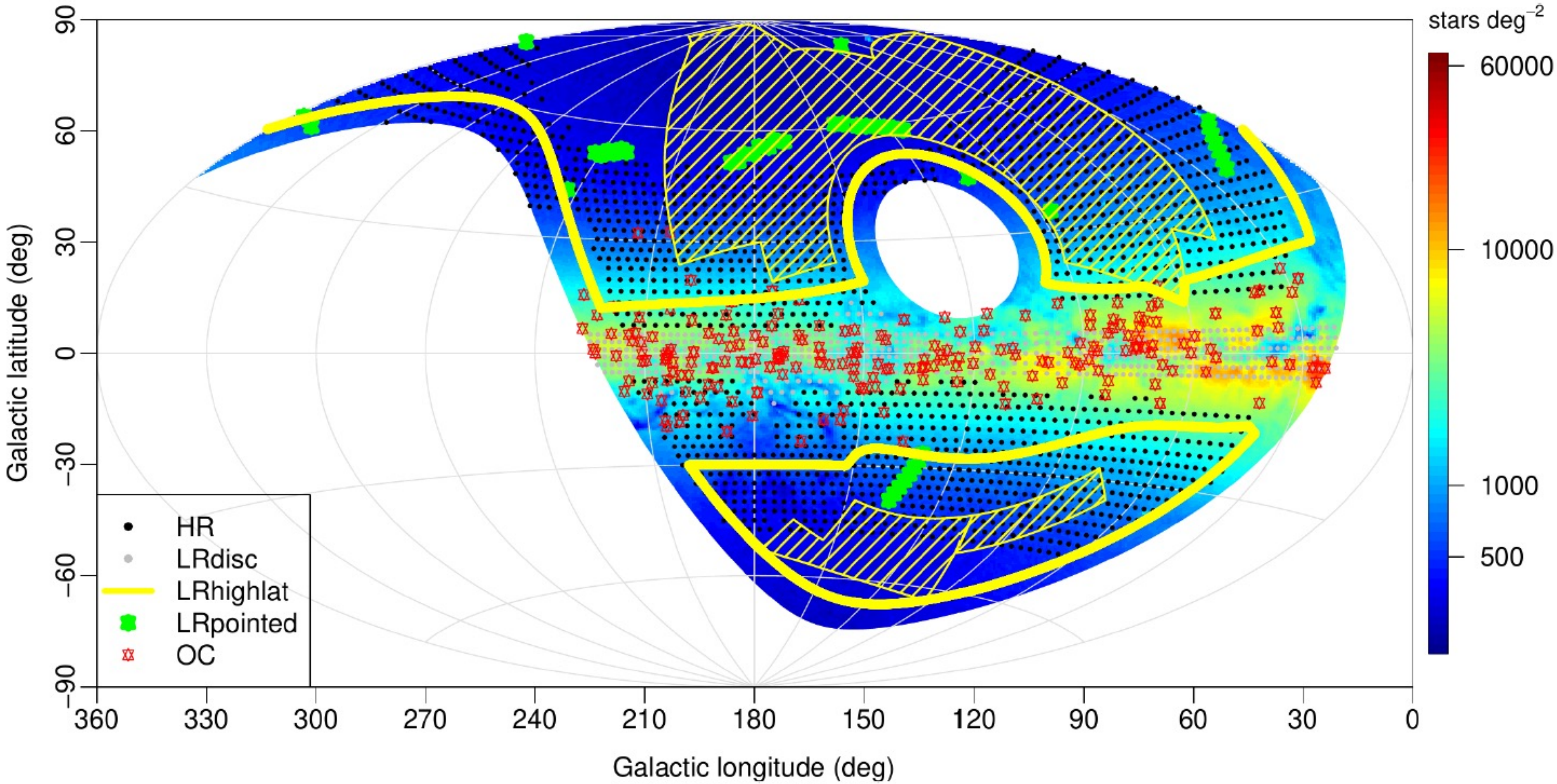
# WEAVE *vs* 4MOST





# WEAVE footprint for Galactic surveys




*Jin, Trager, Dalton et al. 2024*

# Any question? Ask me…