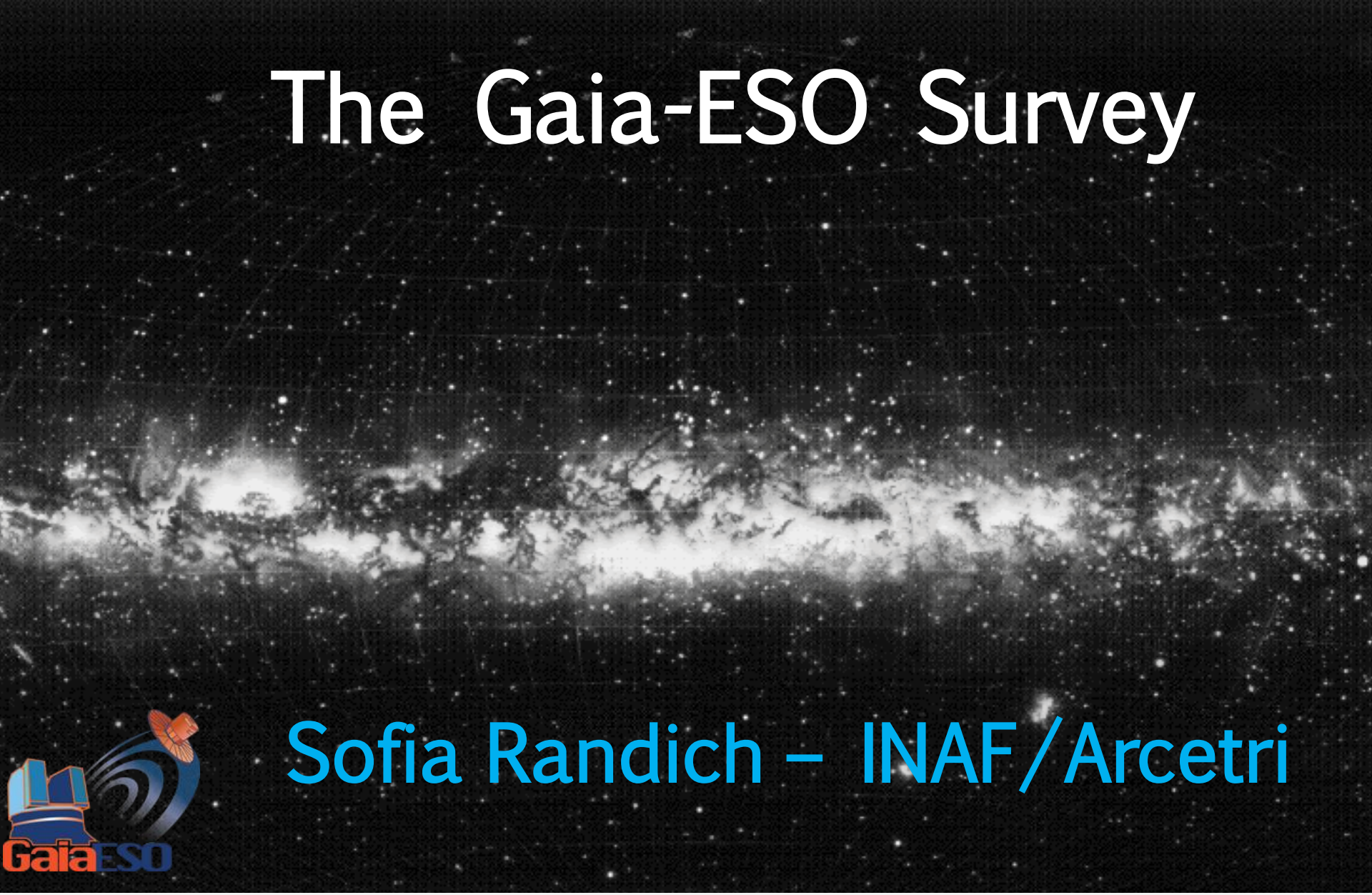
The Gaia-ESO Survey



Sofia Randich – INAF/Arcetri

Galactic Surveys: New Results on Formation, Evolution, Structure and Chemical Evolution of the Milky Way, Sesto Pusteria Jan. 25-29 2016

The Consortium

- **Co-PIs:** Gerry Gilmore & Sofia Randich
- **Steering group:** 12 members+ CoPIs
- **450++ Co-Is, 95+ institutes**
- 20 WGs

1 Co-PIs: Gerry Gilmore[1], Sofia Randich[2]

Cols: M. Asplund[1490], J. Binney[1611], P. Bonifacio[1588], J. Drew[1668], S. Feltzing[1472], A. Ferguson[1649], R. Jeffries[1132], G. Micela[1344], I. Negueruela[7639], T. Prusti[1278], H-W. Rix[1469], A. Vallenari[1343], U. Abbas[1346], D. Aden[1473], V. Adibekyan[1200], C. Aerts[1399], L. Affer[1344], J-M. Alcala[1340], E. Alfaro[1392], C. Allende Prieto[1393], G. Altavilla[7530], J. Alves[1893], T. Antoja[1422], A. Aparicio[1393], F. Arenou[1588], C. Argiroffi[1683], A. Asensio Ramos[1393], C. Babusiaux[1588], C. Bailer-Jones[1489], L. Balaguer-Nunez[1821], G. Barentsen[1668], A.Bayo[1261], B. Barbuy[1828], G. Barisevicius[1376], D. Barrado y Navascues[1068], C. Battistini[1473], I. Bellas-Velidis[1555], M. Bellazzini[1329], V. Belokurov[1370], T. Bensby[1473], M. Bergemann[1490], G. Bertelli[1343], K. Biazzo[1340], O. Bienayme[1582], S. Blanco Cuaresma[1592], J. Bland-Hawthorn[2044], R. Blomme[1650], C. Boeche[2112], S. Bonito[1344], S. Boudreault[1393], J. Bouvier[1449], A. Bragaglia[1337], I. Brandao[1200], A. Brown[1716], E. Brugaletta[1874], J. de Bruijne[1278], M. Burleigh[1244], J. Caballero[6545], E. Caffau[2112], F. Calura[1337], T. Cantat[1343],R. Capuzzo-Dolcetta[1657], M. Caramazza[1344], G. Carraro[1261], L. Casagrande[1490], S. Casewell[1244], S. Chapman[1370], C. Chiappini[1135], Y. Chorniy[1376], N. Christlieb[1982], M. Cignoni[7530], G. Coccoza[7530], M. Colless[1017], R. Collet[1490], M. Collins[1489], M. Correnti[1329], M. Cottaar[1371], E. Covino[1340], D. Crnojevic[1649], M. Cropper[1242], P. Cruz Gamba[1088], M. Cunha[1200], F. Damiani[1344], M. David[1213], A. Delgado[1392], E.Delgado-Mena[1200], R. Dorda Laforet[7639], S. Duffau[2112], S. Van Eck[1358], B. Edvardsson[6181], J. Eldridge[1370], H. Enke[1135], K. Eriksson[6181], N.W. Evans[1370], L. Eyer[1377], B. Famaey[1582], M. Fellhauer[1824], I. Ferreras[1242], F. Figueras[1821], G. Fiorentino[1422], E. Flaccomio[1344], C. Flynn[2044], D. Folha[1200], E. Franciosini[1335], P. Francois[1588], A. Frasca[1341], K. Freeman[1129], Y. Fremat[1650], E. Friel[1355], B. Gaensicke[1241], P. Galindo[1088], J. Gameiro[1200], F. Garzon[1393], M. Gebran[5741], S. Geier[5677], D. Geisler[1824], O. Gerhard[1496], B. Gibson[1197], M. Gieles[1370], A. Gomboc[1995], A. Gomez[1588], C. Gonzalez-Fernandez[7639], J.I. Gonzalez Hernandez[1393], E. Gosset[1359], E. Grebel[2112], R. Greimel[1423], M. Groenewegen[1650], J Groh[1484], F. Grundahl[1368], P. Gruyters[6181], M. Guarcello[1312], B. Gustafsson[6181], P. Hadrava[1116], T. Hansen[1982], D. Hatzidimitriou[1559], N. Hambly[1649], P. Hammersley[1258], C. Hansen[2112], M. Haywood[1588], U. Heber[5677], U. Heiter[6181], E. Held[1343], A. Helmi[1422], G. Hensler[1893], A. Herrero[1393], V. Hill[1591], S. Hodgkin[1370], N. Huelamo[8545], A. Huxor[2112], R. Ibata[1582], M. Irwin[1370], H. Jacobson[1481], R. Jackson[1132], P. Jofre[1592], R. de Jong[1135], P. Jonker[1660], S. Jordan[2112], C. Jordi[1821], A. Jorissen[1358], N. Kacharov[1244], D. Katz[1588], D. Kawata[1242], S.

http://gaia-eso.eu (public survey pages) http://great.ast.cam.ac.uk/GESwiki/GESHome

http://casu.ast.cam.ac.uk/gaiaeso/ http://ges.roe.ac.uk (public archive)

Outline

- Why Gaia-ESO - main science drivers
- Gaia-ESO in a nutshell
- Data flow and strategy
- Calibration concept
- Survey progress
- Science (focus on MW science)
- Summary

We have Gaia!

We have Gaia!

Revolution in MW science

We have Gaia! We want more…

- Gaia has somewhat limited spectroscopic capabilities (limiting mag., precision)
- Many ambitious ground-based projects planned to complement Gaia astrometry
- Weave, 4MOST, GALAH, .., LAMOST, MOONS
- One precursor is the

Gaia-ESO Large Public Spectroscopic Survey

Scientific drivers

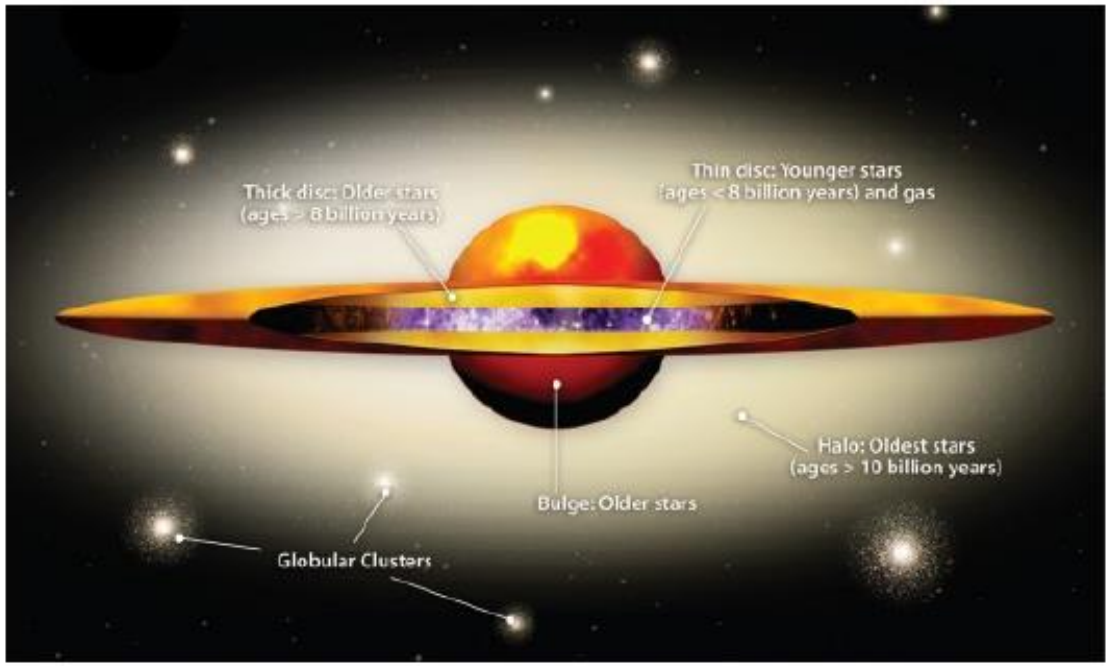
Key open issues in the formation and evolution of the MW and its component stars and stellar populations, e.g:

- linking stellar populations from birth to the old field
- age, mass, and environment dependences of abundances, kinematics, stellar properties
- radial, vertical and azimuthal abundance gradients and their age evolution: from the inner Galaxy to the outer parts

With Gaia-ESO and Gaia basic questions are evolving into more detailed issues

Gaia-ESO Survey in a Nutshell - general

- FLAMES: Giraffe & UVES parallel
- 300 (240+60) nights over 5 (4+1) years
- Started in 12/2011 (P88)



$>10^5$ stars
All populations of the MW:

- Halo
- Bulge
- Thick & Thin discs
- Open Clusters

+ calibrators

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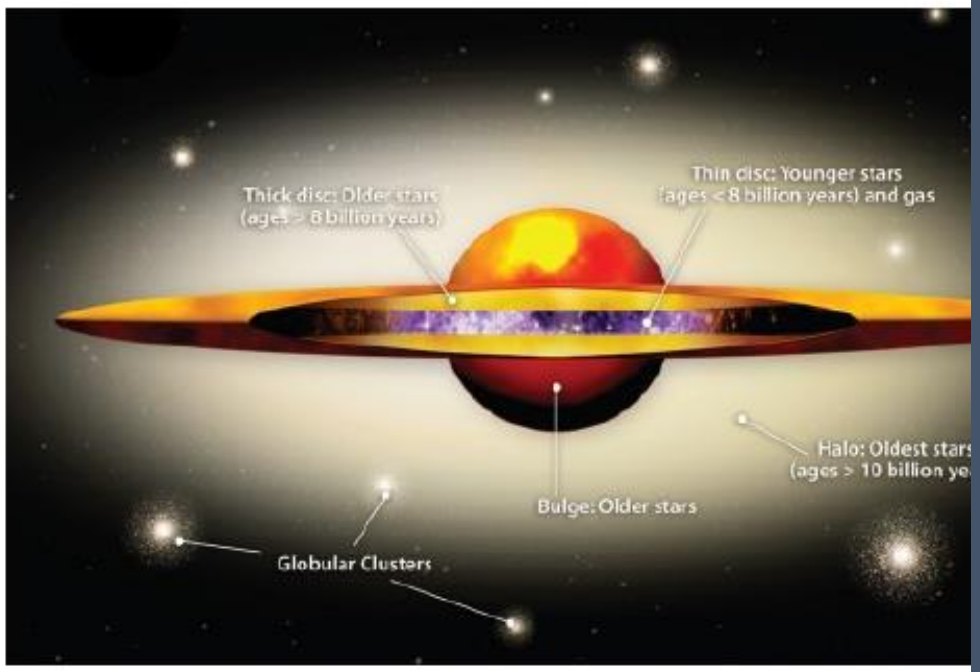


All stellar types:

- O-type → M dwarfs
- PMS → MS → giant stars
- metal-poor → metal rich

+ calibrators

Gaia-ESO Survey in a nutshell - Targets

MW field Giraffe: **Bulge:** mostly giant stars; **halo /thick disc** FG TO stars (17 < r < 18); giants in known streams; thin disc –only RVs for dynamics; I<19
UVES parallels: Solar neighborhood: 5000- star sample. Look at Mv~5.5 → unbiased survey to 1kpc at V=15.

60-70 OCs in all phases of evolution (~1 Myr → several Gyr), sampling the age-distance-R_{GC}-density-mass-[Fe/H]) parameter space.
UVES: Mostly known members (PMS, MS, evolved – V<16.5) – from 10 to 50 stars per cluster
Giraffe: unbiased samples, photometric candidates (V < 19) – several x 100 stars/cluster

Gaia-ESO Survey in a Nutshell - products

Giraffe, 132 fibers
R=16000-25000, H3…H21
403-476…848-900

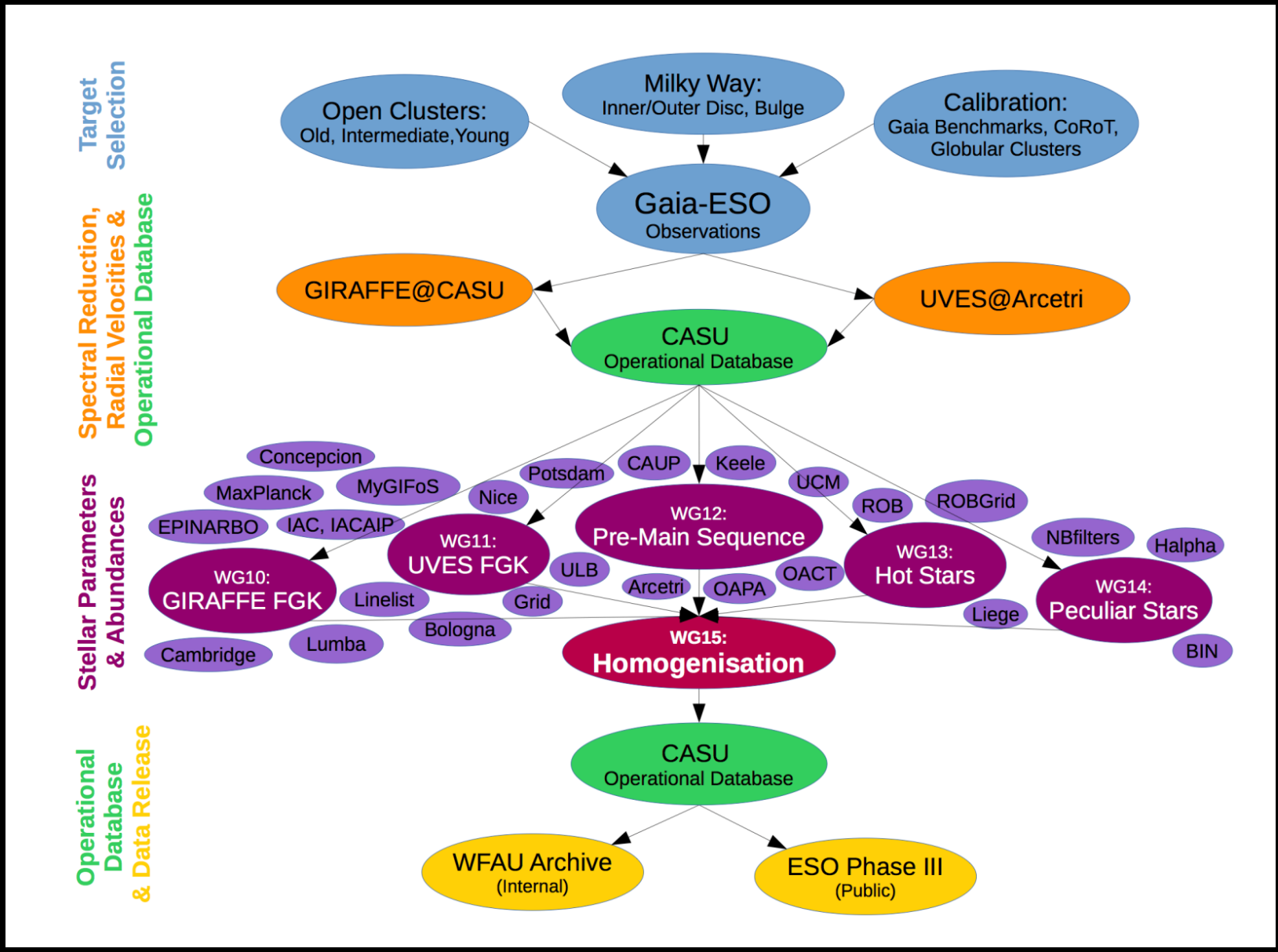
Parallel UVES, 6/8 fibers
R=42,000, 520/580 nm
416-617/475-678

Plus ESO archive re-analysis

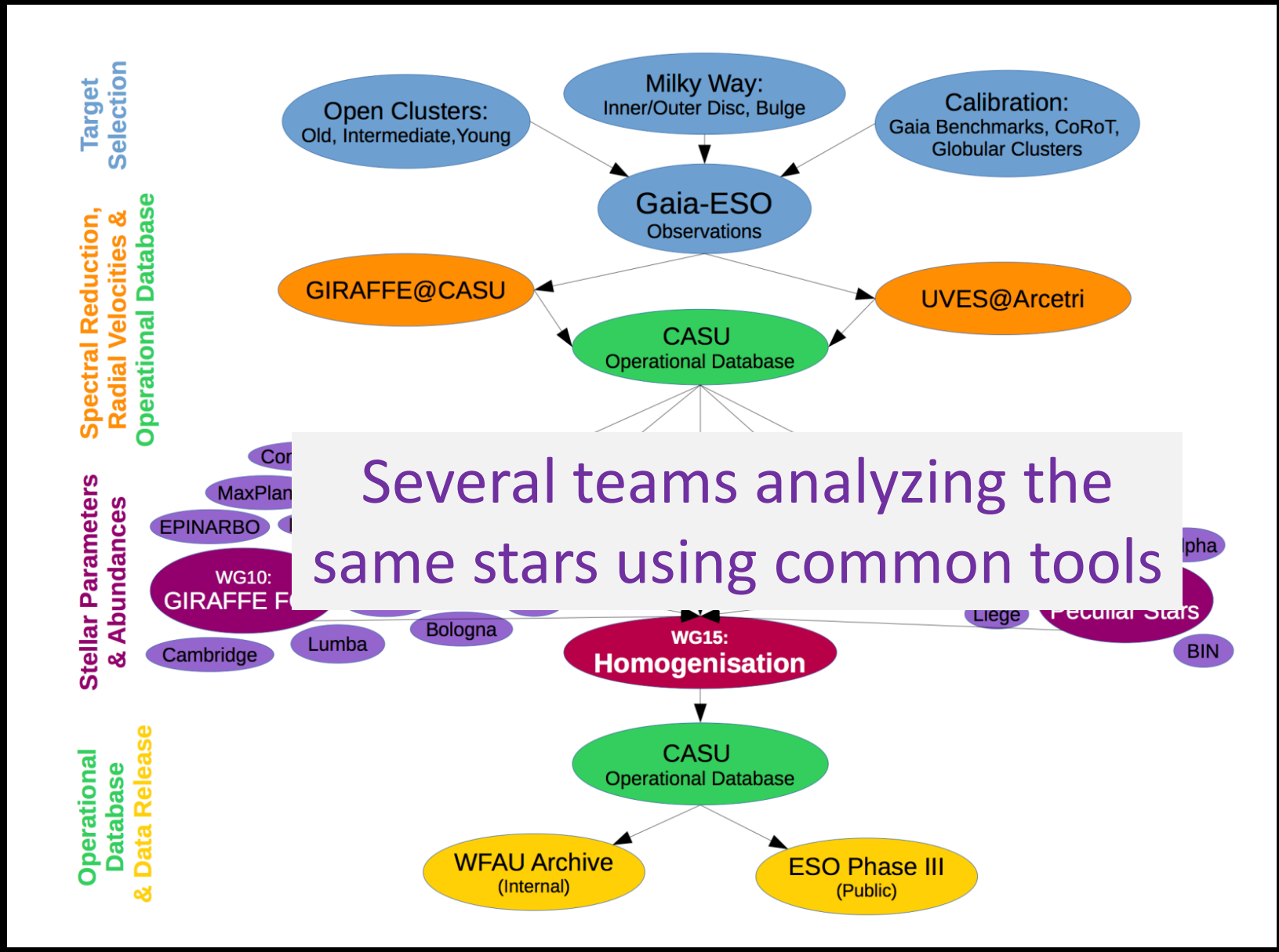
→ ADVANCED PRODUCTS

- RVs (+variability), vsini
- T_{eff}, log g, [Fe/H], [X/Fe] (Li, α, Fe-, s-,..)
- stellar properties: (activity, M_{acc}, $\dot{M}$, etc.)

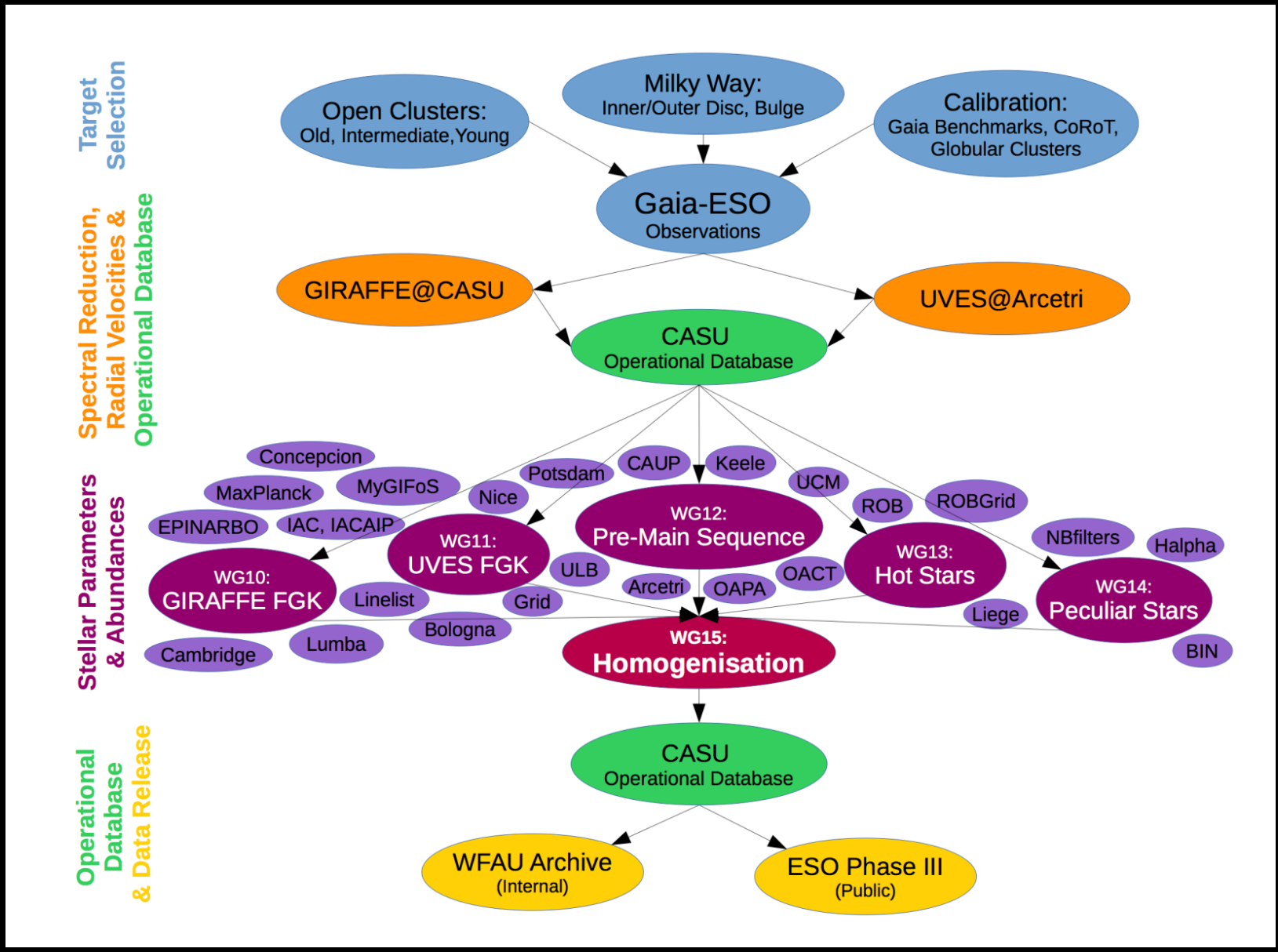
Gaia-ESO Survey in a Nutshell - dataflow



Gaia-ESO Survey in a Nutshell - dataflow



Gaia-ESO Survey in a Nutshell - dataflow



Calibration Concept (1/2)

internal calibrations: different stellar types and settings, several nodes analyzing the same stars

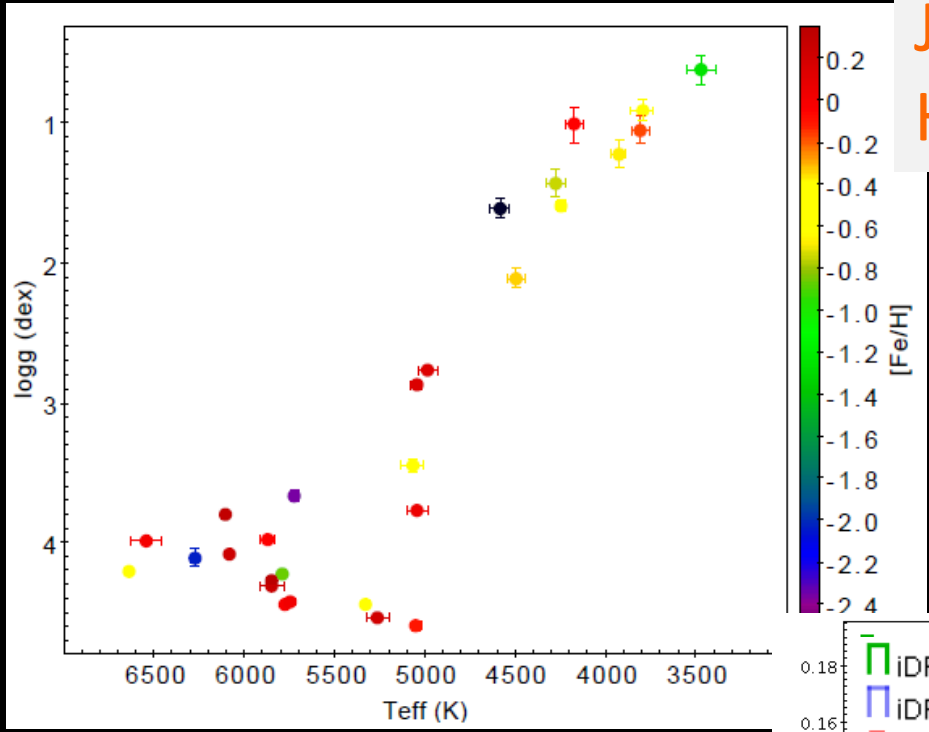
external calibrations: w.r.t other surveys and Gaia

maximize legacy value and provide a rich dataset for future inter-survey calibration

- RV standards
- Gaia benchmark stars: method/node performances, internal homogeneization
- Clusters: hot vs. cool; PMS vs. MS vs. evolved; test metallicity
- CoRoT Red Giants and Kepler II targets: asteroseismic gravities and ages

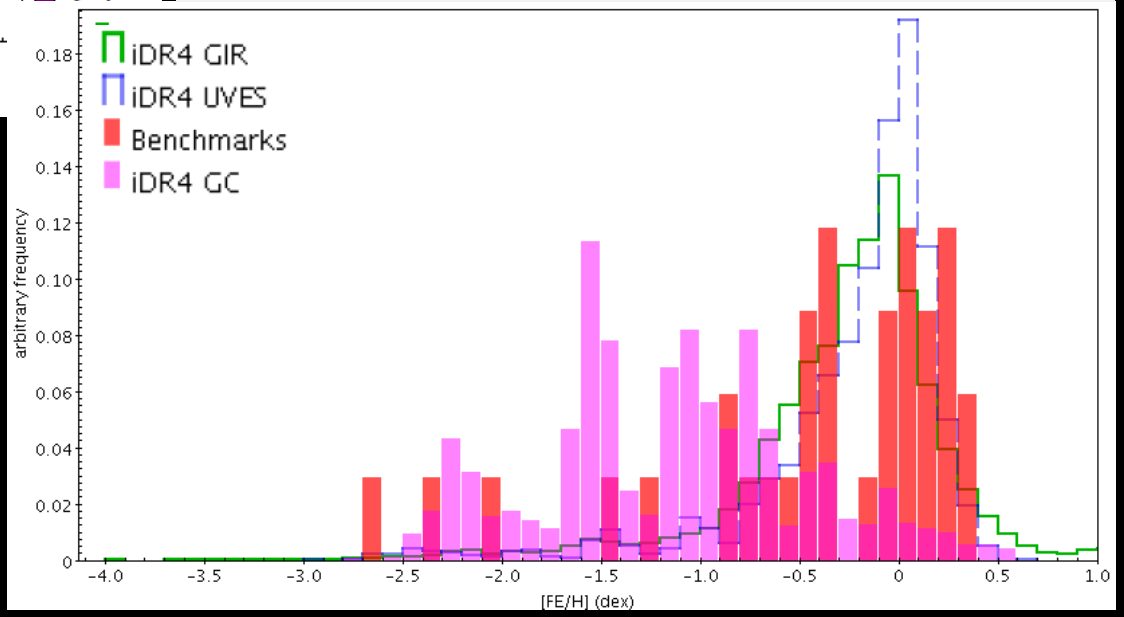
Calibration Concept (2/2)

Jofre+, 2014;
Heiter+, 2015



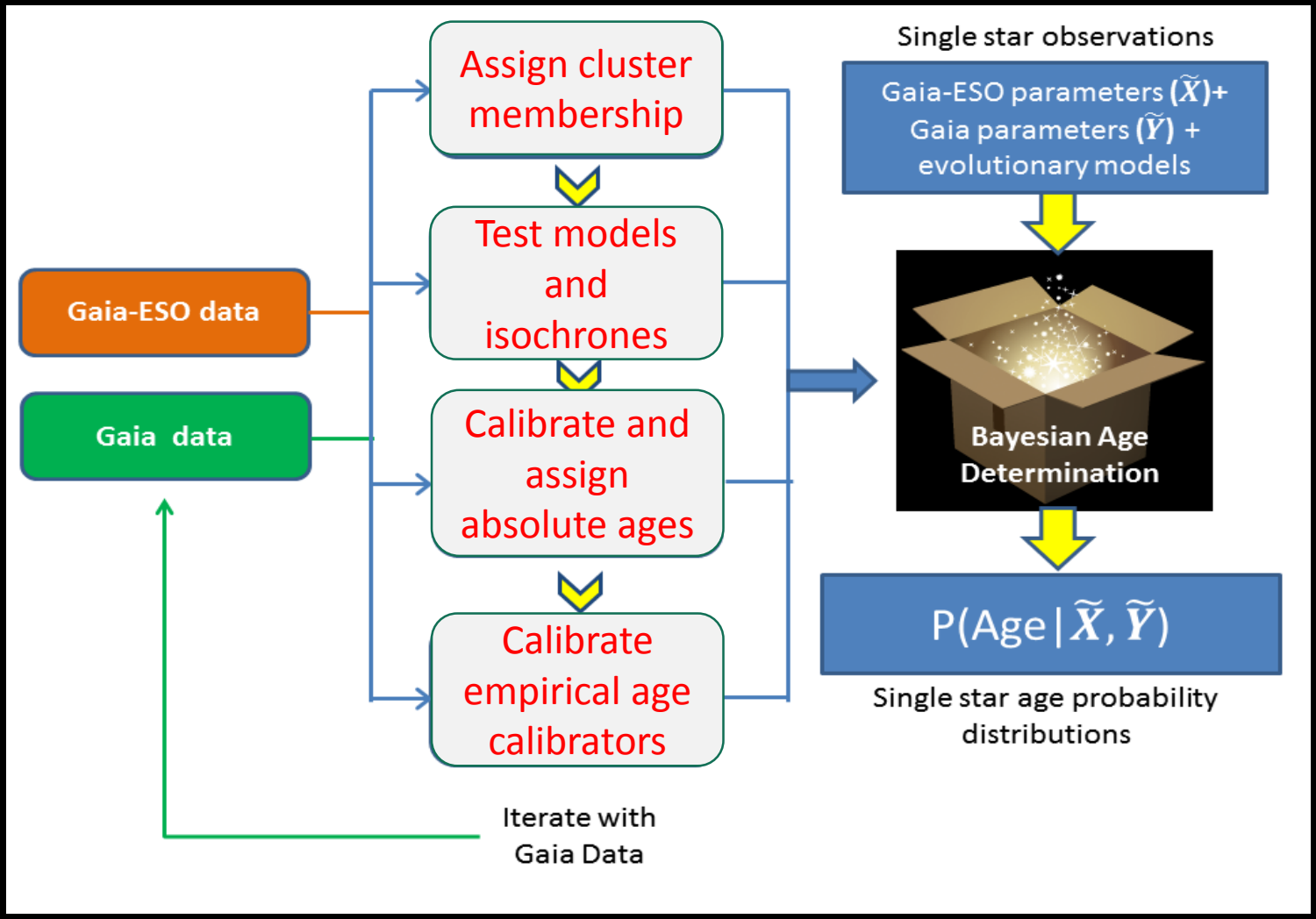
HR diagram of benchmark stars

[Fe/H] distribution of calibrators vs. [F/H] distribution of Gaia-ESO targes

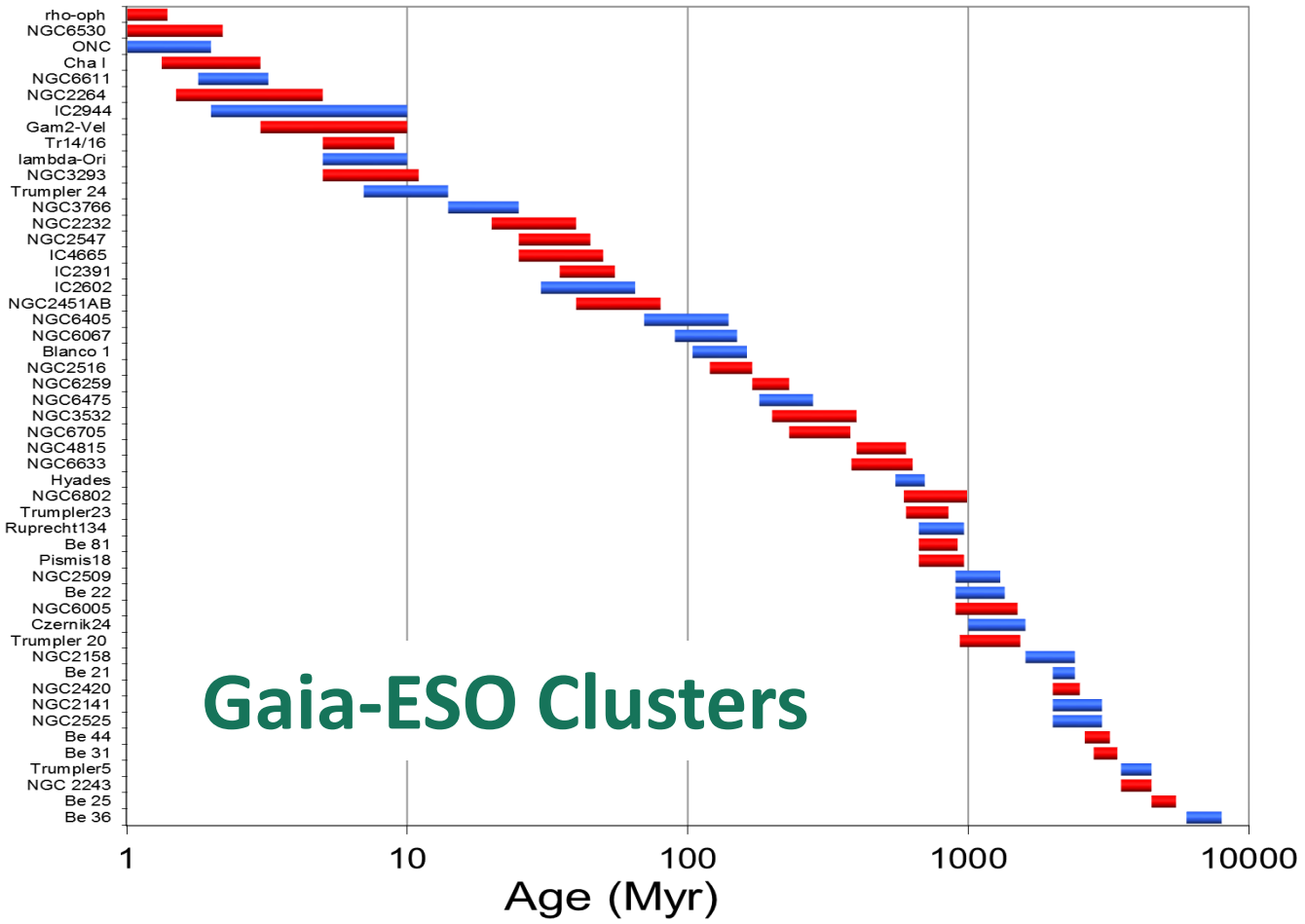


Calibration of ages

One of the legacies of the cluster dataset



Calibration of ages



Gaia-ESO survey progress

- 4 years observations completed, 242 nights
- large **variety of MW fields; 39 science OCs**; >8000 **calibators**
- > 120,000 spectra collected
- 4 analysis cycles and internal releases completed (54690 individual objects) ; next analysis cycle to start in March
- Two phase 3 releases to ESO (reduced spectra & advanced products)
- 4th year review: Fall 2015. Positive feedback –**fifth year allocated plus 47 nights compensation → Gaia-ESO will continue through mid-2017**

Gaia-ESO survey progress

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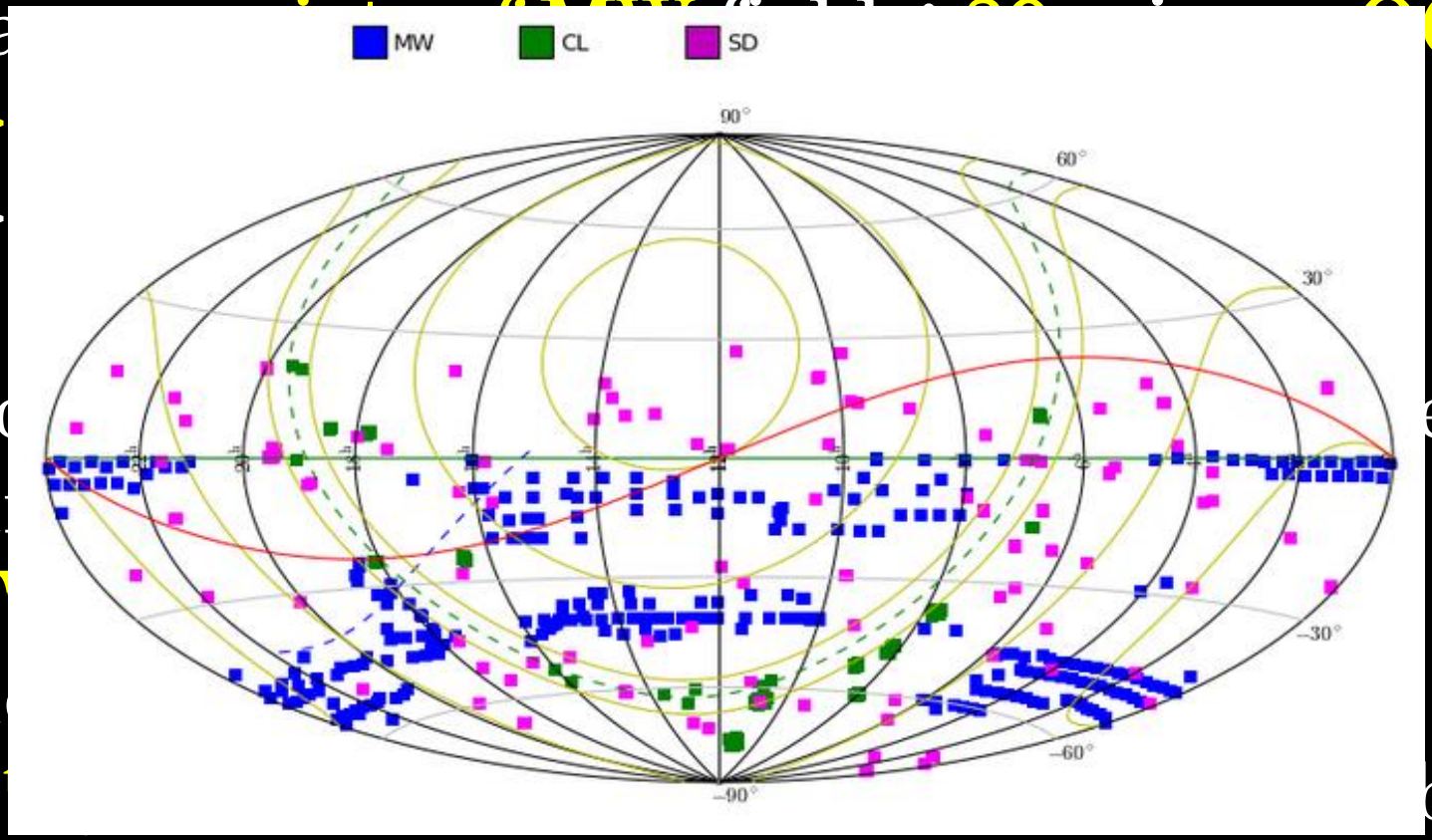

Cs;

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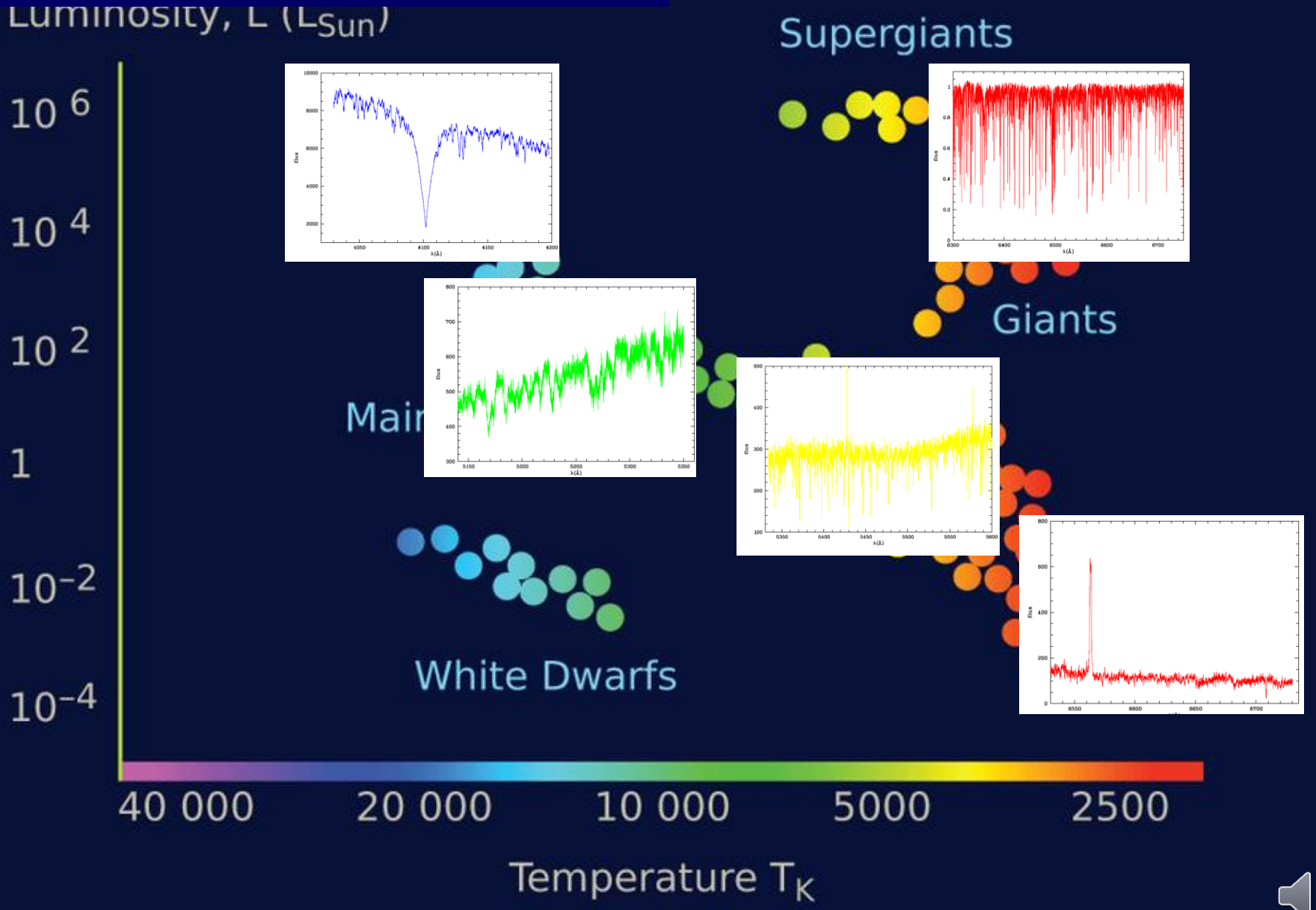
back –

fifth year allocated plus 40 nights compensation

Some spectra



Gaia-ESO Science

Gaia-ESO Science – overview

- Bottom-up approach
- Three all-hands meetings; a few focused meetings
- ADS lists 70 papers with Gaia-ESO in the title (about 35 refereed ones) + another few submitted
- 4 A&A highlights + 3 A&A cover pages; 2 Messenger overview articles
- All original science topics addressed, plus unexpected results

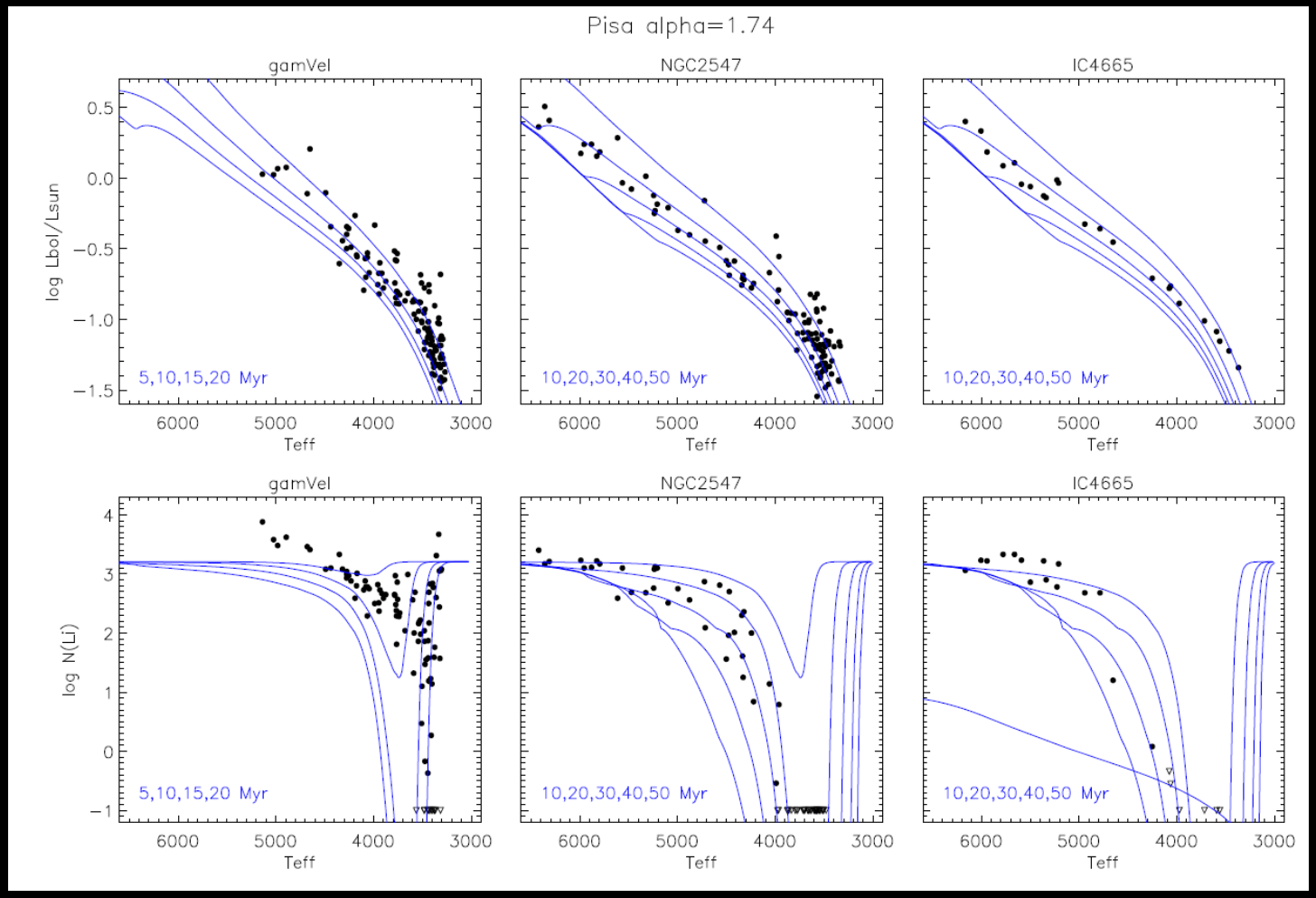
Gaia-ESO Science – focus on:

- Constraints on stellar physics/models: some examples
- The radial metallicity distribution
- Velocity dispersions and their chemical dependences

See also the talks by:
Bensby, Bragaglia, Lind, Magrini, Rojas, Romano

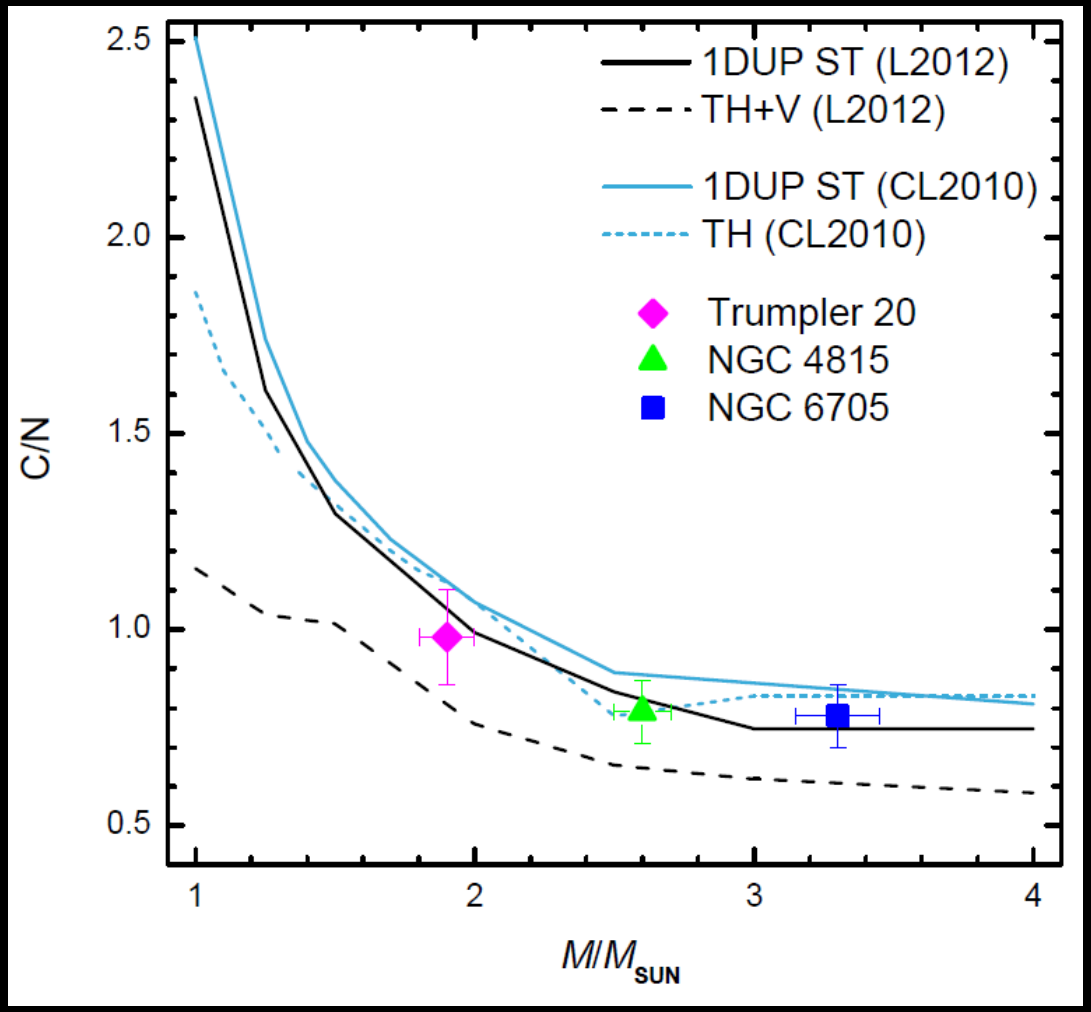
Constraints on stellar physics/models (1)

Li depletion in young clusters – Franciosini +(2016)



Constraints on stellar physics/models (2)

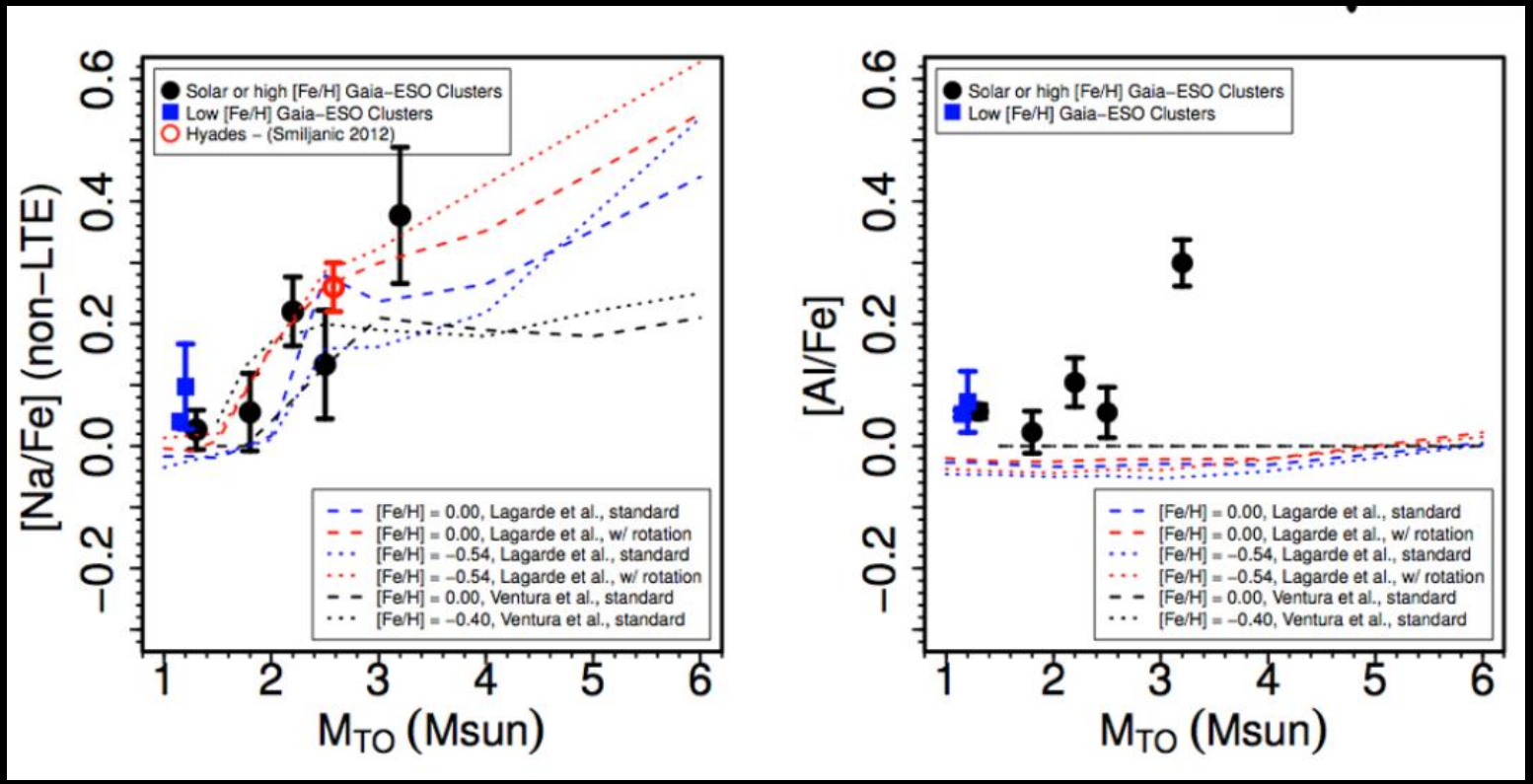
Extra-mixing during post-MS –Tautvaisiene+ (2015)



From the first internal data release. Many more clusters available now

Constraints on stellar physics/models (3)

Extra-mixing during post-MS Smiljanic+(2016)

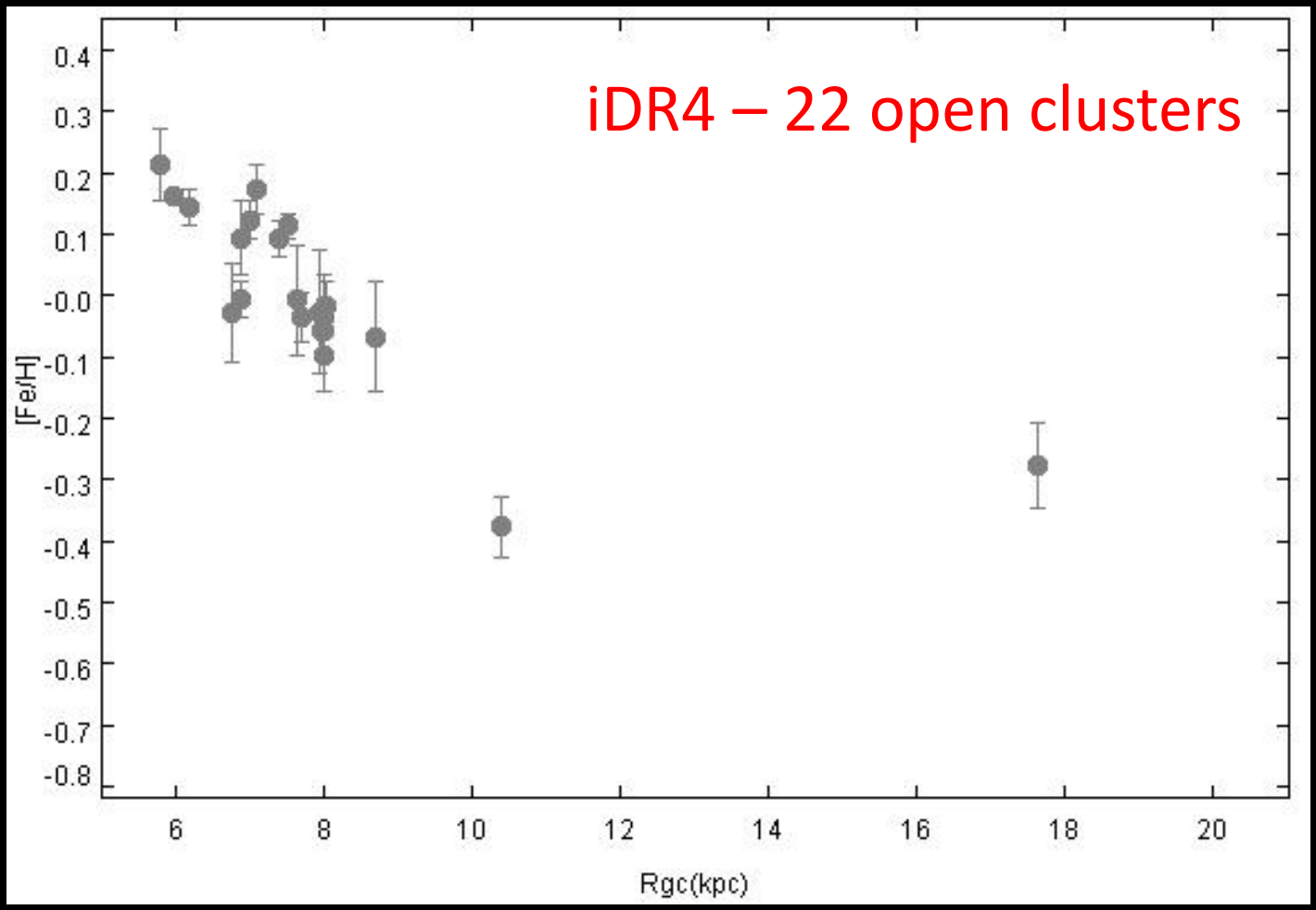


Radial metallicity distribution: open questions

Presence of gradient well established since almost 35 years now (….). But

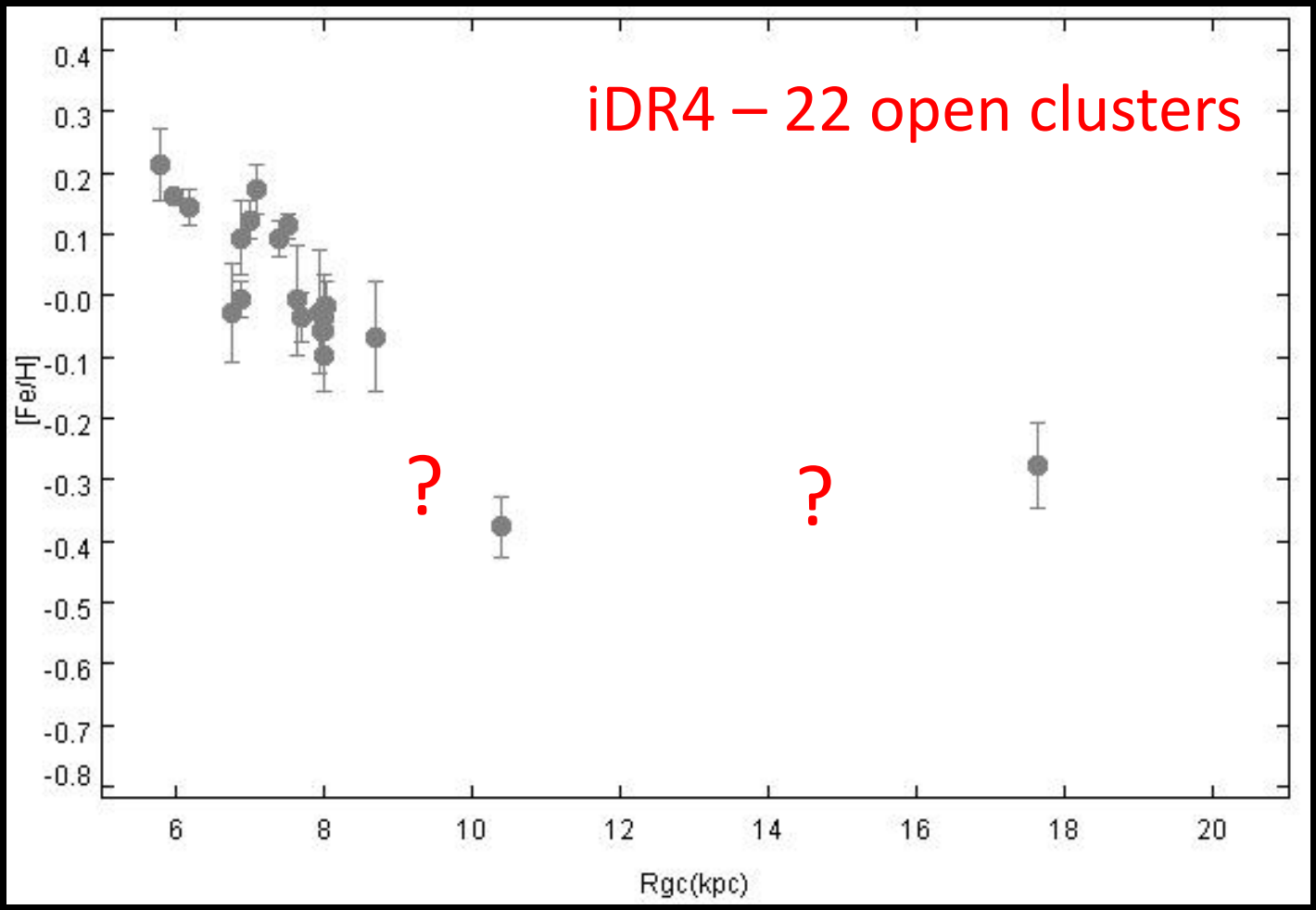
- One slope? Step function? Flattening?
- Dispersion at a given RGC?
- Evolution with age?
- azimuth z dependence?

Radial metallicity gradient – GES OCs



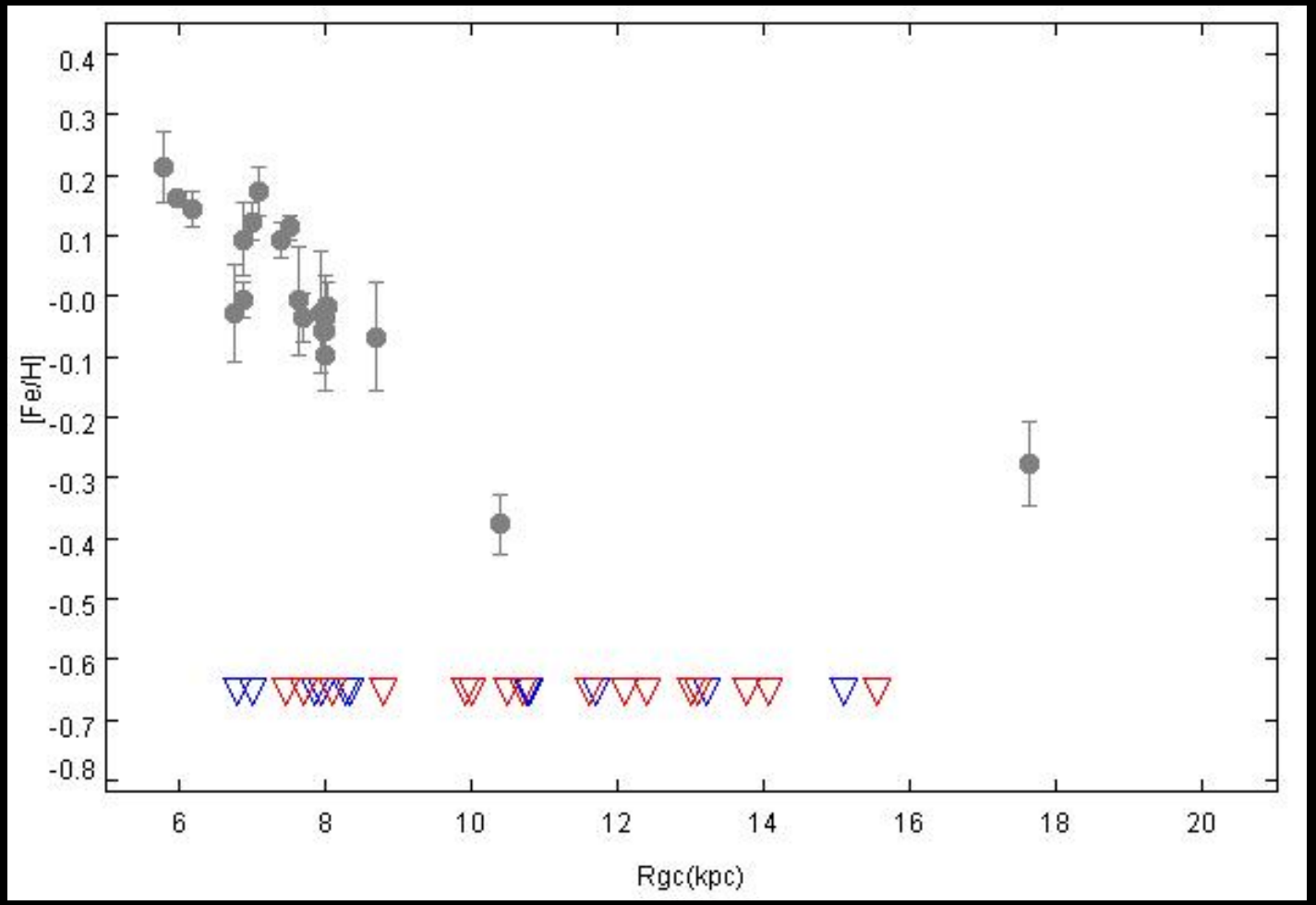
Randich+, in preparation

Radial metallicity gradient – GES OCs



Randich+, in preparation

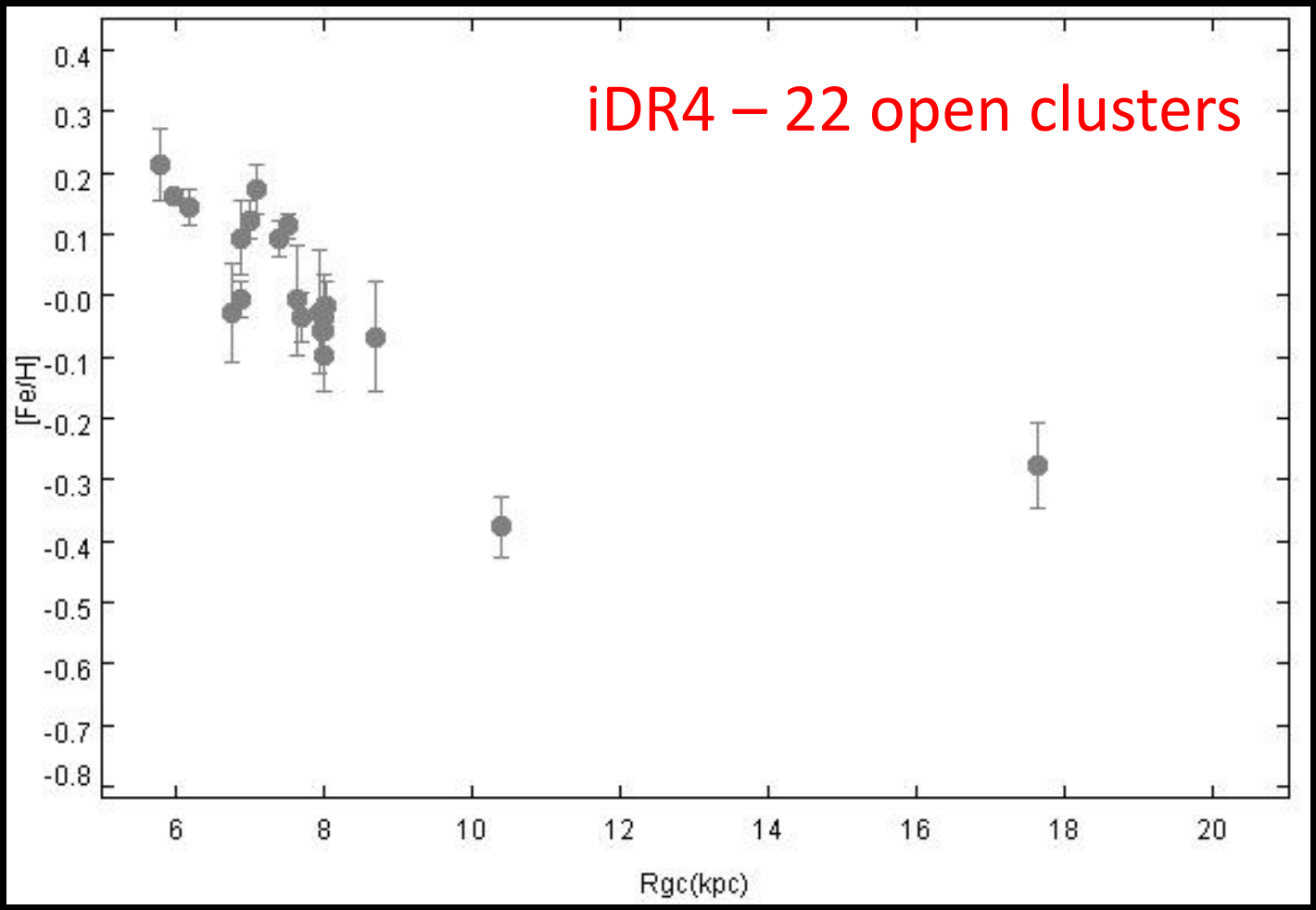
Radial metallicity gradient – GES OCs



▽ Next analysis cycle

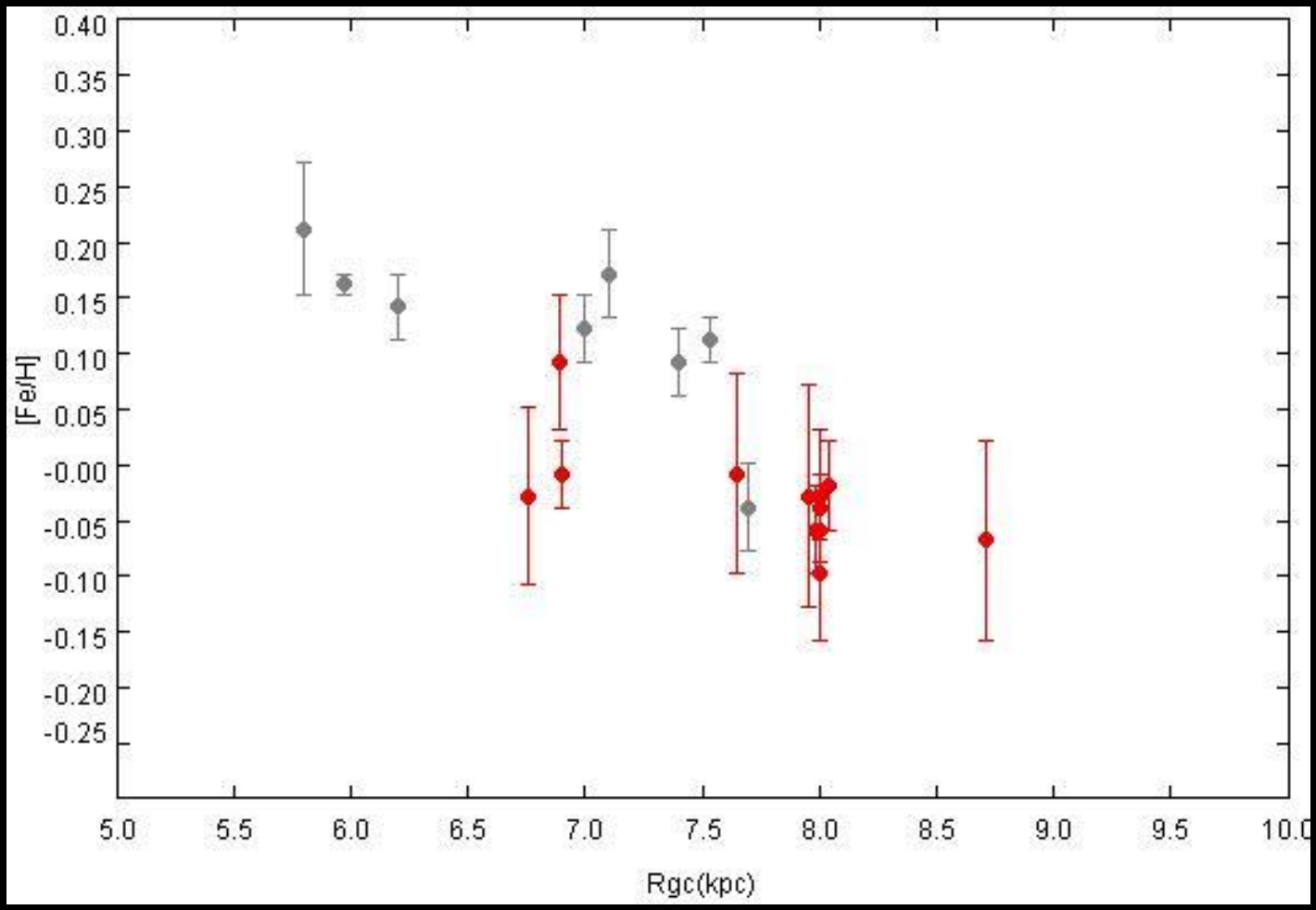
▽ To be observed

Radial metallicity gradient – GES OCs



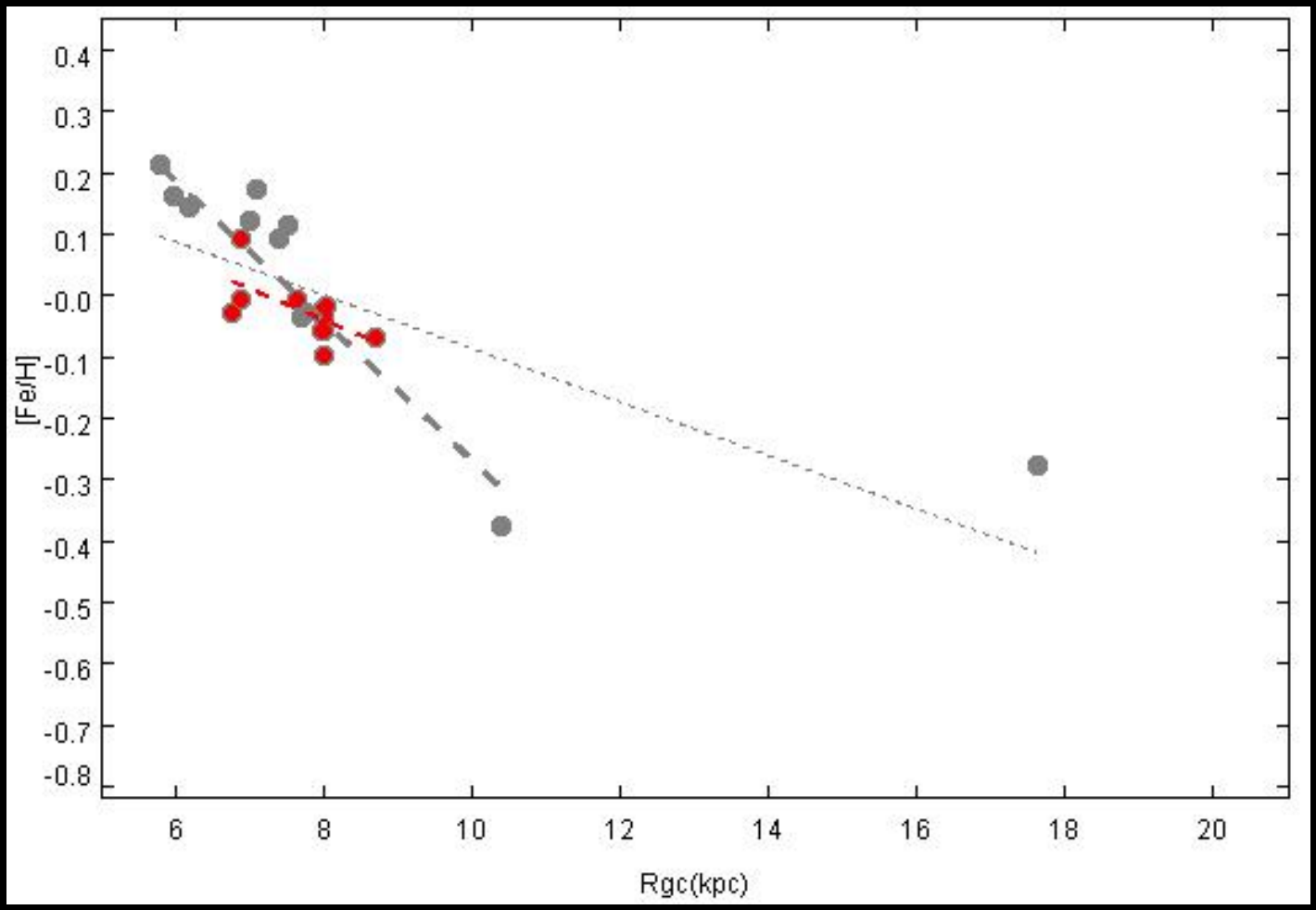
Randich+, in preparation

Radial metallicity gradient – GES OCs

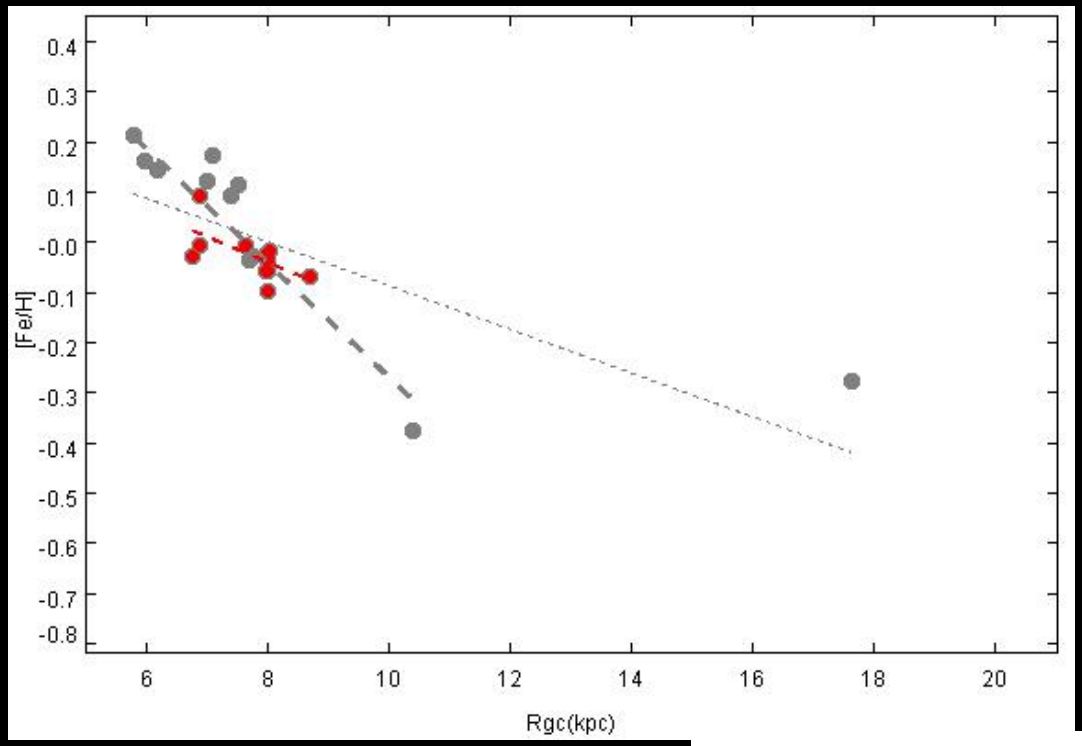


RED: age < 0.5 Gyr

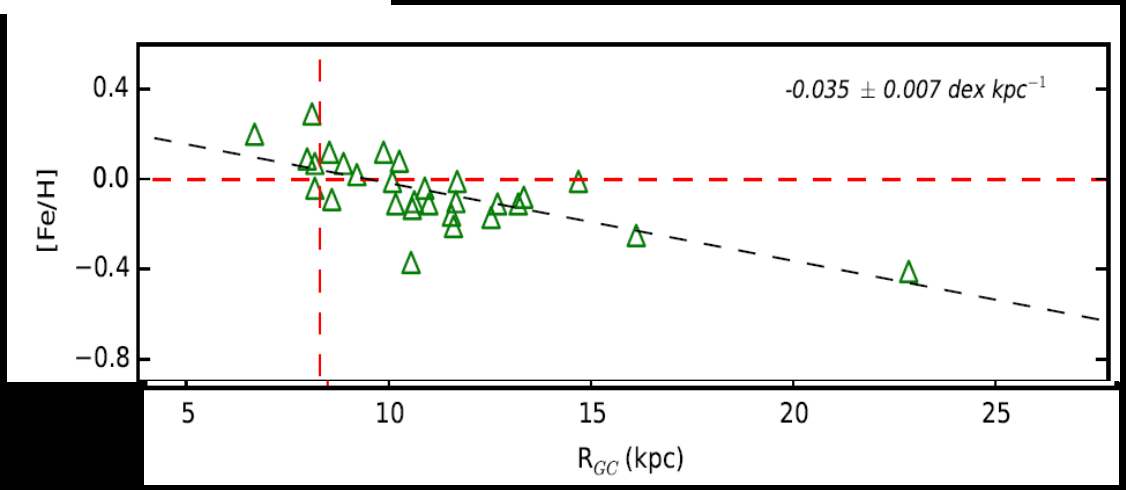
Radial metallicity gradient – GES OCs



Radial metallicity gradient – GES OCs

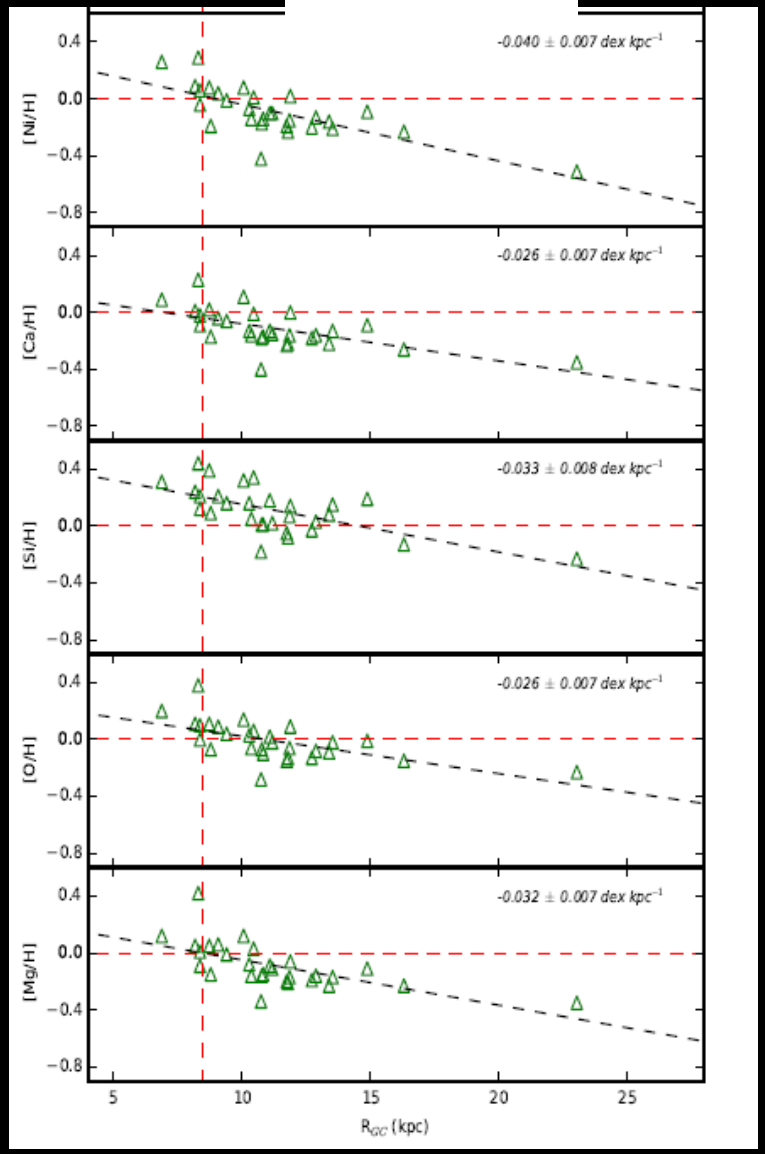


APOGEE
Kunha+,2016

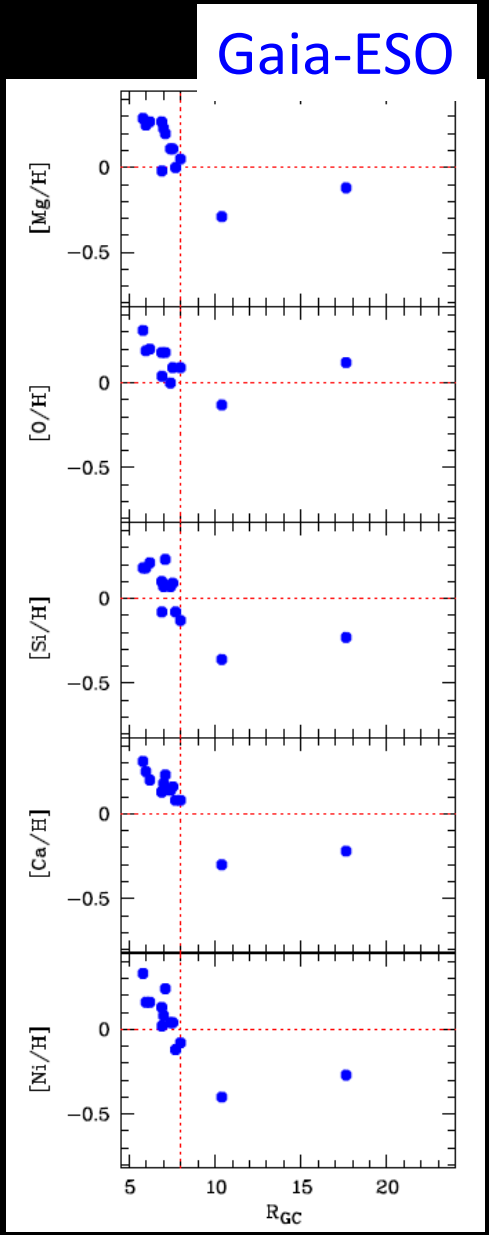


Radial anundace distribution

APOGEE

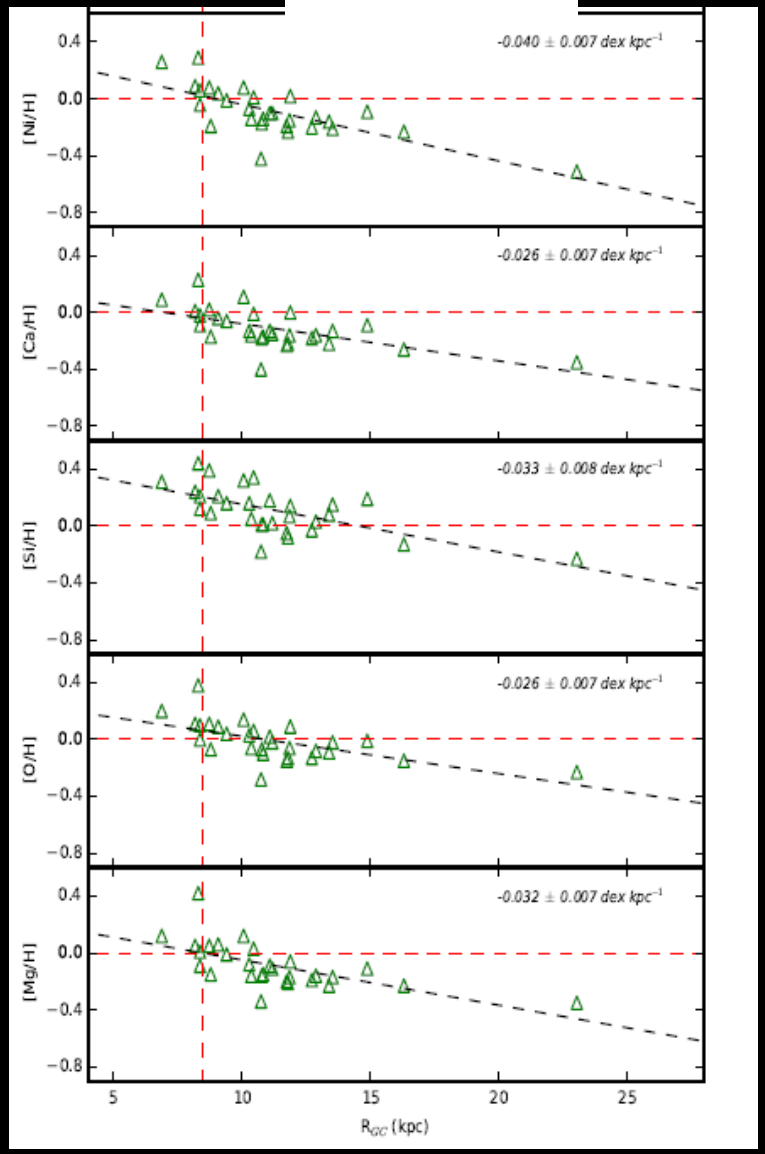


Gaia-ESO

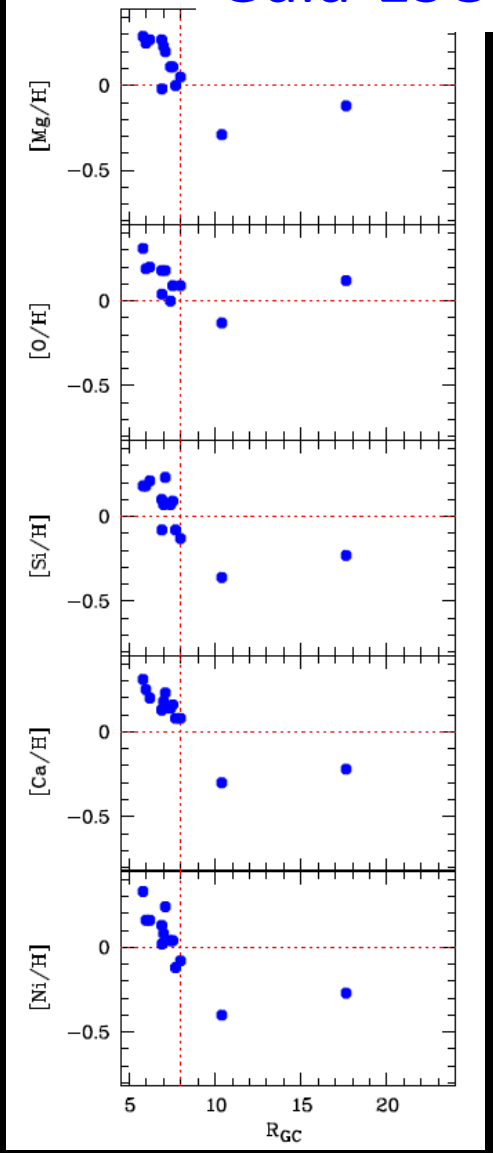


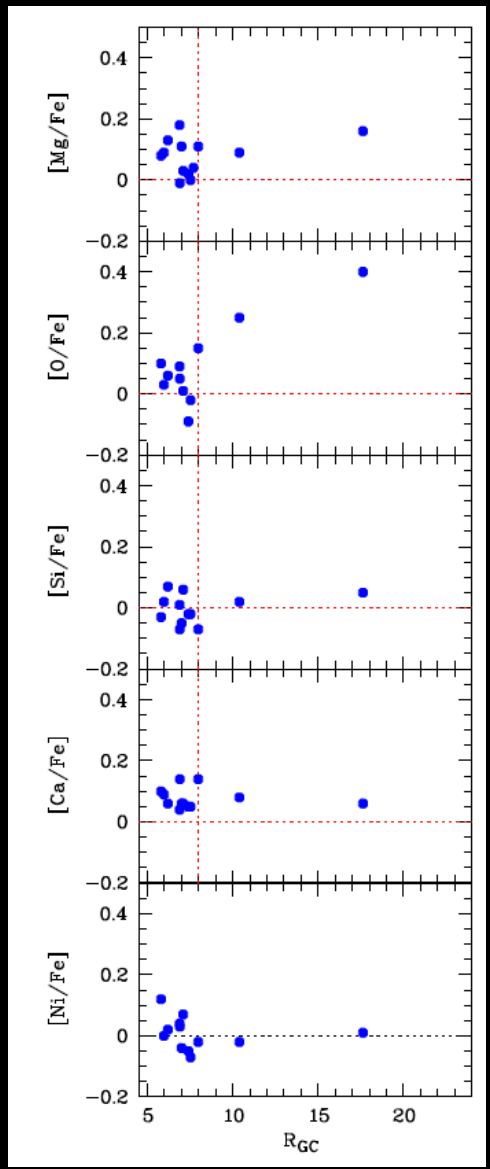
Radial abundace distribution

APOGEE

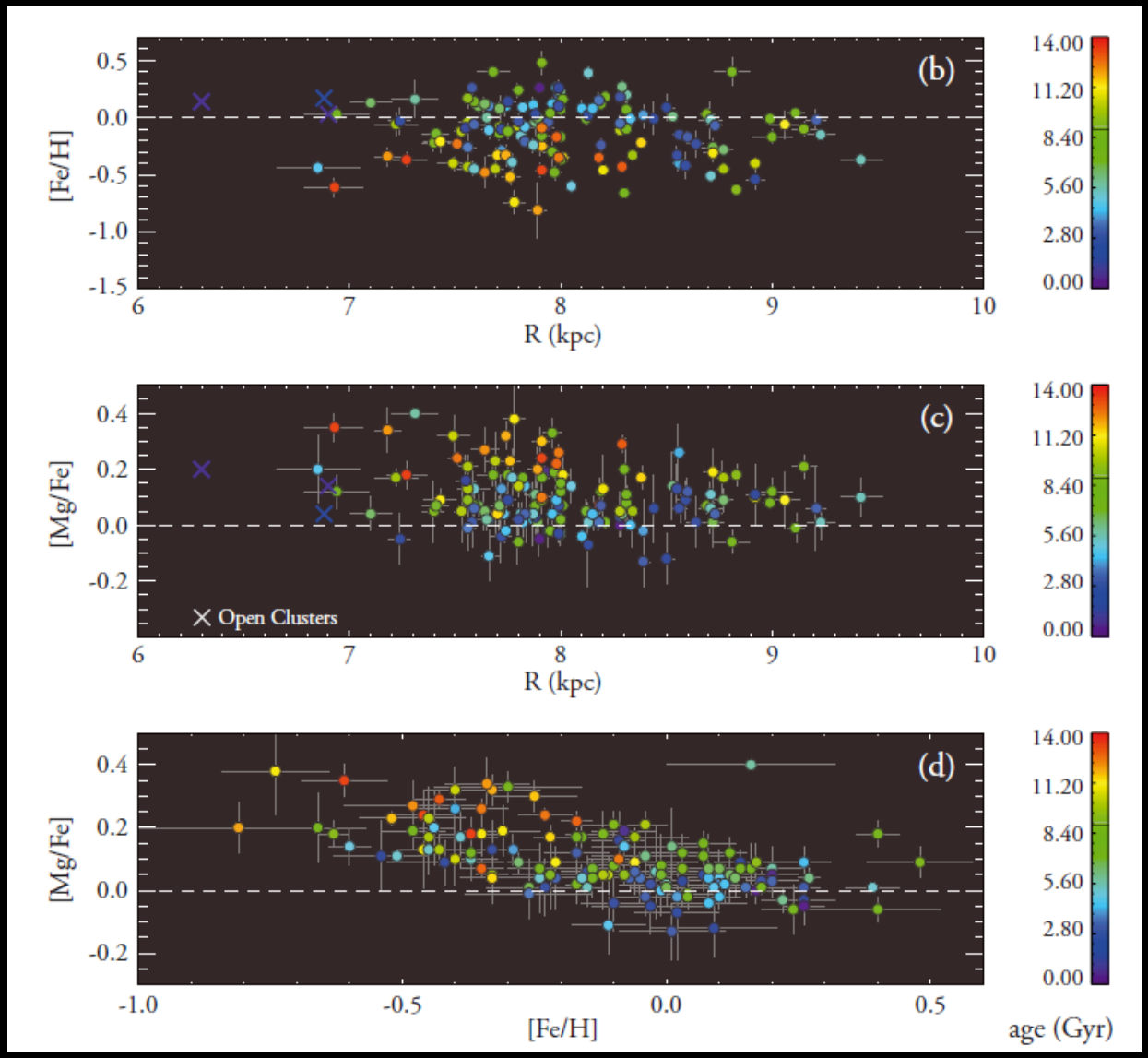


Gaia-ESO





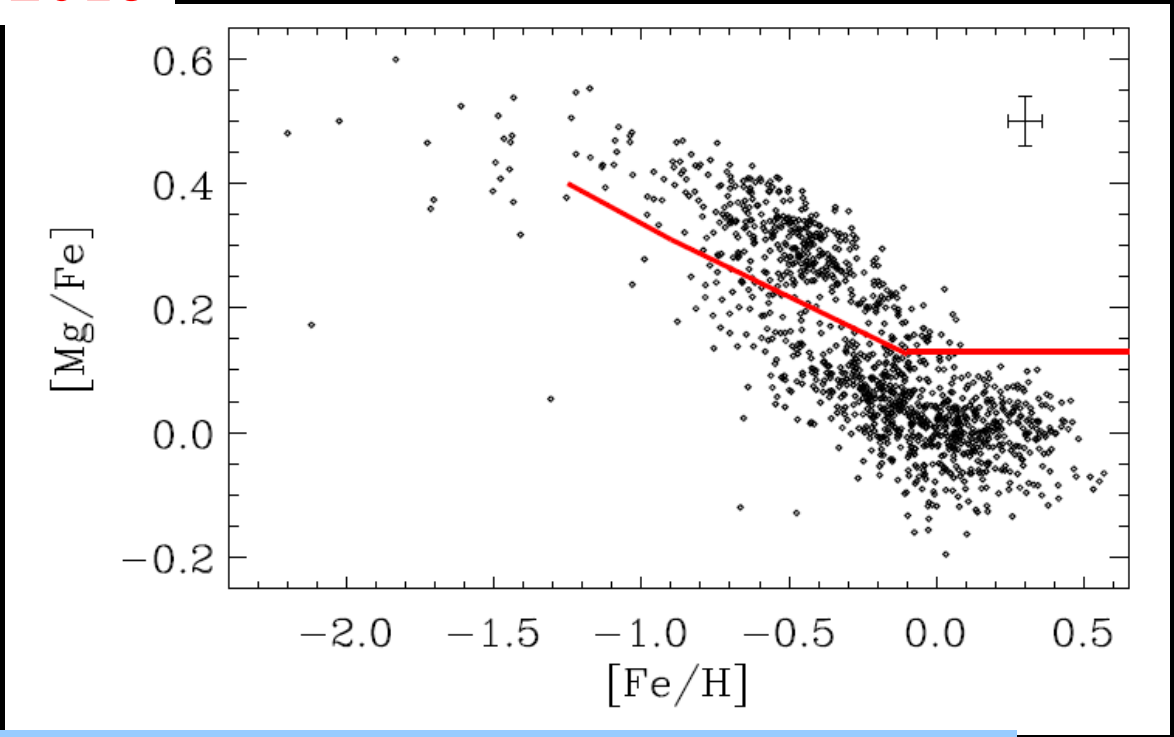
Radial abundance distribution – MW field



Bergmann, + 2014 (based on UVES data)

Galactic velocity dispersion and its chemical dependencies

Guiglion+, 2015



Separation between thin and thick disc (beyond the solar neighborhood)

see also Recio Blanco+, 2014; Mikolaitis+, 2014; Rojas+, 2015

Galactic velocity dispersion and its chemical dependencies

Guiglion+, 2015

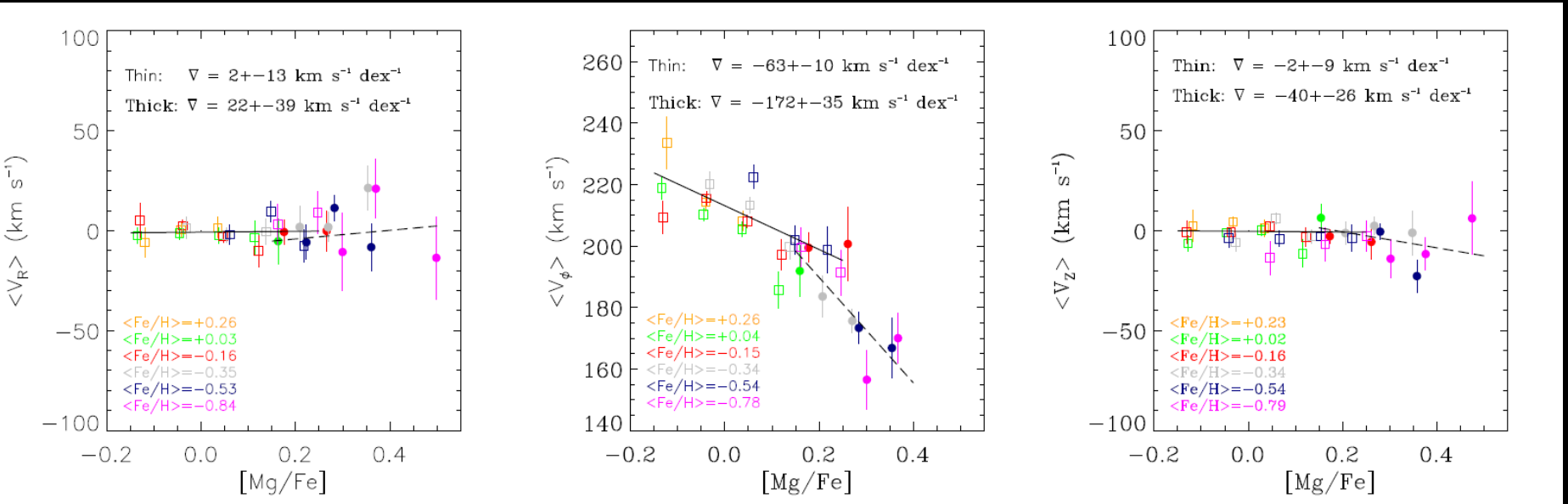


Fig. 6. Average radial, azimuthal and vertical velocity ($< V_R >$, $< V_\phi >$ and $< V_Z >$) as a function of the [Mg/Fe] ratio. The [Fe/H] curves are colour coded and the average values of each one are written in the legend. The symbols, errors bars and linear fit are the same as in Fig. 5.

Summary

- **Gaia-ESO is working:** an operational survey from target selection, to ESO releases of calibrated results
- **Excellent science,** with clear potential for a substantial impact
- Includes **all major spectroscopic analysis methods** → resolves the major systematics underlying spectrum analysis
- **Calibration effort** ensures consistency between Gaia-ESO and Gaia, and the major spectroscopic surveys
- **Calibration** of stellar **isochrones** and stellar **ages** indicators from a few Myr to several Gyr