The Gaia-ESO Survey

Sofia Randich and Gerry Gilmore

INAF/Arcetri, IoA-Cambridge

Rainbows on the Southern sky – ESO HQ Garching, Oct. 7, 2015

The Consortium

- **Survey Co-PIs:** Gerry Gilmore & Sofia Randich
- **Steering group:** 12 members+ CoPIs
- **450++ Co-Is, 95+ institutes** (mostly, from Europe)
- 20 WGs

Altavilla[7530], J. Alves[1893], T. Antoja[1422], A. Aparicio[1393], F. Arenou[1585], C. Argiroffi[1685], A. Asensio Ramos[1393], C. Babusiaux[1585], 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[1592], 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[1317], I. Brandao[1200], A. Brown[1716], E. Brugaletta[1874], J. de Bruijne[1278], M. Burleigh[1244], J. Caballero[8545], E. Caffau[2112], F. Calura[1337], T. Cantat[1343],R. Capuzzo-Dolcetta[1857], M. Caramazza[1344], G. Carraro[1261], L. Casagrande[1490], S. Caswell[1244], S. Chapman[1370], C. Chiappini[1135], Y. Chorniy[1376], N. Christlieb[1982], M. Cignoni[7530], G. Cocozza[7510], M. Colless[1017], R. Collet[1490], M. Collins[1489], M. Correnti[1229], M. Cottaar[1371], E. Covino[1340], D. Crnojevic[1649], M. Cropper[1242], P. Cruz Gamba[1088], M. Cunha[1200], F. Damiani[1344], M. David[1233], A. Delgado[1392], E.Delgado-Mena[1200], R. Dorda Laforet[7629], 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[1159], Y. Fremat[1650], E. Friel[1355], B. Gaensicke[1241], P. Galindo[1088], J. Gameiro[1200], F. Garzon[1392], M. Gebran [5741], S. Geier[5677], D. Geisler[1824], O. Gerhard[1496], B. Gibson[1197], M. Gieles[1370], A. Gomboc[1895], A. Gomez[1588], C. Gonzalez-Fernandez[7659], J.I. Gonzalez Hernandez[1593], E. Gosset[1359], E. Grebel[2112], R. Greimel[1423], M. Groenewegen[1650], J Groh[1494], 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[1592], 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. Keller[1139], N. Kharchenko[1135], R. Klement[1489], A. Klutsch[1803], J. Knude[1966], A. Koch[1244], O. Kochukhov[6181], M. Kontizas[1560], S. Koposov[1370], G. Kordopatis[1370], A. Korn[6181], A. deKoter[1614], P. Koubsky[1116], A. Lanzafame[1874], R. Lallement[1588], C. Lardo[1537], P. de Laverny[1591], F. van Leeuwen[1370], B. Lemasle[1422], G. Lewis[2044], K. Lind[1490], H.P.E. Lindstrom[1966], A. Lobel[1359], J. Lopez Santiago[1803], P. Lucas[1668], H. Ludwig[2112], T. Lueftinger[1893], L. Magrini[1335], L. Mahy[1359], J. Maiz Apellaniz[1392], J. Maldonado[1801], M. Mapelli[1343], G. Marconi[1261], A. Marino[1490], S. Marinoni[1337], C. Martayan[1261], S. Martell[1017], I. Martinez-Valpuesta[1496], T. Masseron[1358], G. Matijevic[1995], R. McMahon[1370], S. Messina[1341], M. Meyer[1377], A. Miglio[1359], S. Mikolaitis[1376], I. Minchev[1135], D. Minniti[1801], A. Moitinho[8848], Y. Momany[1261], L. Monaco[1261], M. Montalto[1200], M.J. Monteiro[1200], R. Monier[5691], D. Montes[1803], A. Mora[1350], E. Moraux[1449], T. Morel[1359], J. Muijos[5688], N. Mowlavi[1583], A. Mucciarelli[7530], U. Munari[1343], R. Napiwotzki[1668], N. Nardetto[1591], T. Naylor[1130], Y. Naze[1359], G. Nelemans[1638], S. Okamoto[1616], S. Ortolani[6211], G. Pace[1200], F. Palla[1335], J. Palous[1116], E. Pancino[1337], R. Parker[1377], E. Paunzen[1893], J. Penarrubia[1828], I. Pillitteri[1312], G. Piotto[1343], H. Posbic[1588], L. Prisinzano[1344], N. Przybilla[1251], L.Puspitarini[1588], E. Puzeras[1376], A. Quirrenbach[2112], S. Ragaini[7530], P. Re Fiorentin[1346], J. Read[1377], M. Read[1649], A. Recio-Blanco[1591], C. Reyle[1592], J. De Ridder[1399], N. Robichon[1588], A. Robin[1592], S. Roeser[2112], D. Romano[1337], F. Royer[1588], G. Ruchti[1490], C. Ruhland[1668], A. Ruzicka[1116], S. Ryan[1668], N. Ryde[1473], G. Sacco[1645], H. Sana N. Santos[1200], J. Sanz Forcada[8545], L.M. Sarro Baro[5688], L. Sbordone[1982], E. Schilbach[2112], S. Schuneja[2112], O. Schnurr[1135], R. Schoenrich[1490], R-D. Scholz[1135], G. Seabroke[1242], P. Sestito[1803], S. Sharma[2044], G. De Silva[1017], R. Smiljanic[1258], M. Smith[1616], J. Sobeck[1591], E. Solano[8545], R. Sordo[1343], C. Soubiran[1444], S. Sousa[1200], A. Spagna[1346], L. Spina[1335], M. Steffen[1135], M. Steinmetz[1135], B. Stelzer[1344], E. Stempels[6181], H. Tabernero[1803], G. Tautvaisiene[1376], F. Thevenin[1591], J. Torra[1821], M. Tosi[1337], E. Tolstoy[1422], M. Tsantaki[1200],

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)

- **Survey Co-PIs:** Gerry Gilmore & Sofia Randich
- **Steering group:** 12 members+ CoPIs
- **450++ Co-Is, 95+ institutes** (m… from E…
- 20…

The Consortium

Altavilla[7530], J. Alves[1893], T. Antoja[1422], A. Aparic… Argiroffi[1685], A. Asensio Ramos[1393], C. Babusiaux[1588], C. Bailer-Jones[1489], L. Bal… [1668], A.Bayo[1261], B. Barbuy[1828], G. Barisevicius[1376], D. Barrado y Nava… elidis[1555], M. Bellazzini[1329], V. Belokurov[1370], T. Bensby[1473], M. B… O. Bienayme[1592], S. Blanco Cuaresma[1592], J. Bland-Hawth… [1344], S. Boudreault[1393], J. Bouvier[1449], A. Bragaglia[137… Bruijne[1278], M. Burleigh[1244], J. Caballero[8545], E. C… [1657], M. Caramazza[1344], G. Carraro[1261], J… [135], Y. Chorniy[1376], N. Christlieb[1982]… [1489], M. Correnti[1229], M. Cott… M. Cunha[1200], F. Da… S. Duffau[2112], S. Van Evans[1370], L. Eyer[1377], B. … E. Flaccomio[1344], C. Flynn[2044], … [1159], Y. Fremat[1650], E. Friel[1355], B. …ebran [5741], S. Geier[5677], D. Geisler[1824], … A. Gomez[1588], C. Gonzalez-Fernandez[7659], … R. Greimel[1423], M. Groenewegen[1650], J Groh[1494], … B. Gustafsson[6181], P. Hadrava[1116], T. Hansen[1982], D. …ey[1258], C. Hansen[2112], M. Haywood[1588], U. Heber[5677], U. …er[1893], A. Herrero[1393], V. Hill[1591], S. Hodgkin[1370], N. Huelamo[8545], …, H. Jacobson[1481], R. Jackson[1132], P. Jofre[1592], R. de Jong[1135], …rdi[1821], A. Jorissen[1358], N. Kacharov[1244] D. Katz[1588], D. Kawata[1242], S. … R. Klement[1489], A. Klutsch[1803], J. Knude[1966], A. Koch[1244], O. Kochukhov[6181], …[1370], G. Kordopatis[1370], A. Korn[6181], A. deKoter[1614], P. Koubsky[1116], A. Lanzafame[1874], …Lardo[1537], P. de Laverny[1591], F. van Leeuwen[1370], B. Lemasle[1422], G. Lewis[2044], K. …Lindstrom[1966], A. Lobel[1359], J. Lopez Santiago[1803], P. Lucas[1668], H. Ludwig[2112], T. Lueftinger[1893], …, L. Mahy[1359], J. Maiz Apellaniz[1392], J. Maldonado[1803], M. Mapelli[1343], G. Marconi[1261], A. …, S. Marinoni[1357], C. Martayan[1261], S. Martell[1017], I. Martinez-Valpuesta[1496], T. Masseron[1358], G. …atijevic[1995], R. McMahon[1370], S. Messina[1341], M. Meyer[1377], A. Miglio[1359], S. Mikolaitis[1376], I. Minchev[1135], D. Minniti[1801], A. Moitinho[8848], Y. Momany[1261], L. Monaco[1261], M. Montalto[1200], M.J. Monteiro[1200], R. Monier[5691], D. Montes[1803], A. Mora[1350], E. Moraux[1449], T. Morel[1359], J. Muijos[5688], N. Mowlavi[1583], A. Mucciarelli[7530], U. Munari[1343], R. Napiwotzki[1668], N. Nardetto[1591], T. Naylor[1130], Y. Naze[1359], G. Nelemans[1638], S. Okamoto[1616], S. Ortolani[6211], G. Pace[1200], F. Palla[1325], J. Palous[1116], E. Pancino[1337], R. Parker[1377], E. Paunzen[1893], J. Penarrubia[1828], I. Pillitteri[1312], G. Piotto[1343], H. Posbic[1588], L. Prisinzano[1344], N. Przybilla[1251], L.Puspitarini[1588], E. Puzeras[1376], A. Quirrenbach[2112], S. Ragaini[7530], P. Re Fiorentin[1346], J. Read[1377], M. Read[1649], A. Recio-Blanco[1591], C. Reyle[1592], J. De Ridder[1399], N. Robichon[1588], A. Robin[1592], S. Roeser[2112], D. Romano[1337], F. Royer[1588], G. Ruchti[1490], C. Ruhland[1668], A. Ruzicka[1116], S. Ryan[1668], N. Ryde[1473], G. Sacco[1645], H. Sana N. Santos[1200], J. Sanz Forcada[8545], L.M. Sarro Baro[5688], L. Sbordone[1982], E. Schilbach[2112], S. Schuneja[2112], O. Schnurr[1135], R. Schoenrich[1490], R-D. Scholz[1135], G. Seabroke[1242], P. Sestito[1803], S. Sharma[2044], G. De Silva[1017], R. Smiljanic[1258], M. Smith[1616], J. Sobeck[1591], E. Solano[8545], R. Sordo[1343], C. Soubiran[1444], S. Sousa[1200], A. Spagna[1346], L. Spina[1135], M. Steffen[1135], M. Steinmetz[1135], B. Stelzer[1344], E. Stempels[6181], H. Tabernero[1803], G. Tautvaisiene[1376], F. Thevenin[1591], J. Torra[1821], M. Tosi[1337], E. Tolstoy[1422], M. Tsantaki[1200], …

Thanks to all

GaiaESO

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

We have GAIA!

We have GAIA!

Revolution in MW science

We have GAIA! We want more…
(see also H.-W Rix review)

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

Gaia-ESO Large Public Spectroscopic **Survey**

We have GAIA! We want more…

ESO Workshop on wide field spectroscopic surveys

*large public spectroscopic surveys, using current ESO VLT instrumentation, "could place the European community in a favourable situation … generating the data required to complement Gaia if the surveys begin **soon**".*

Scientific Drivers

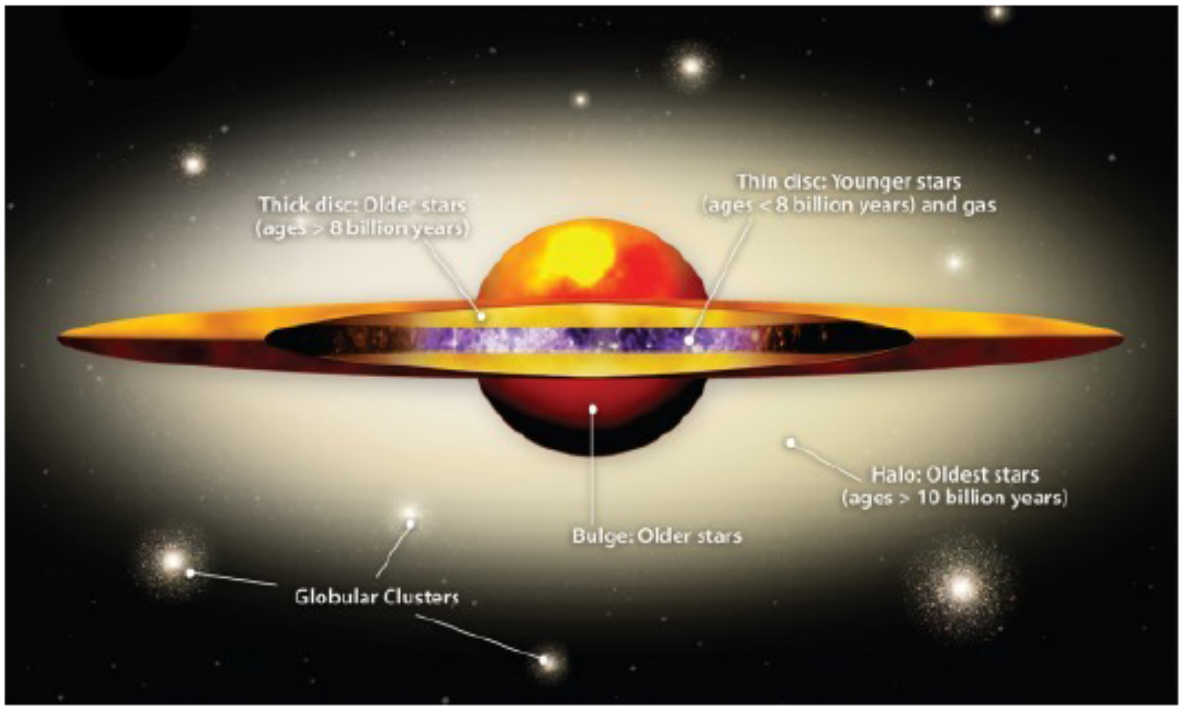
Key open issues in the formation and evolution of the MW and its component stars and stellar populations

- Cluster formation and evolution
- Stellar physics/evolution + ages
- Formation and evolution of the thin and thick discs, and bulge
- Halo substructure,…

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

GAIA-ESO Survey in a Nutshell (1/2)

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



$>10^5$ stars

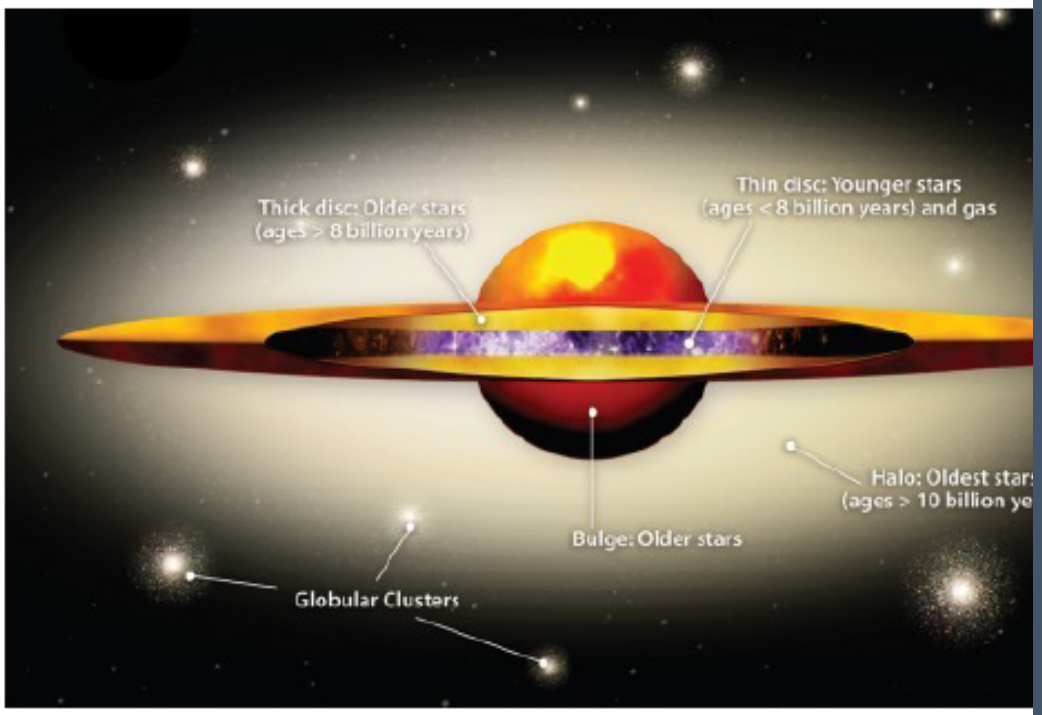
All populations of the MW:

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

+ calibrators

GAIA-ESO Survey in a Nutshell (1/2)

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



All stellar types:

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

+ calibrators

GAIA-ESO Survey in a Nutshell (1/2)

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

Well defined and rigorously implemented target selection criteria

All stellar types:

O-type → M dwarfs
PMS → MS → giant stars

- metal-poor → metal rich

+ calibrators

GAIA-ESO Survey in a Nutshell (2/2)

Giraffe, 132 fibers

R=16000-25000, H3…H21

403-476…848-900

V<19

Parallel UVES, 6/8 fibers

R=42,000, 520/580 nm

416-617/475-678

V<16.5

Plus ESO archive re-analysis

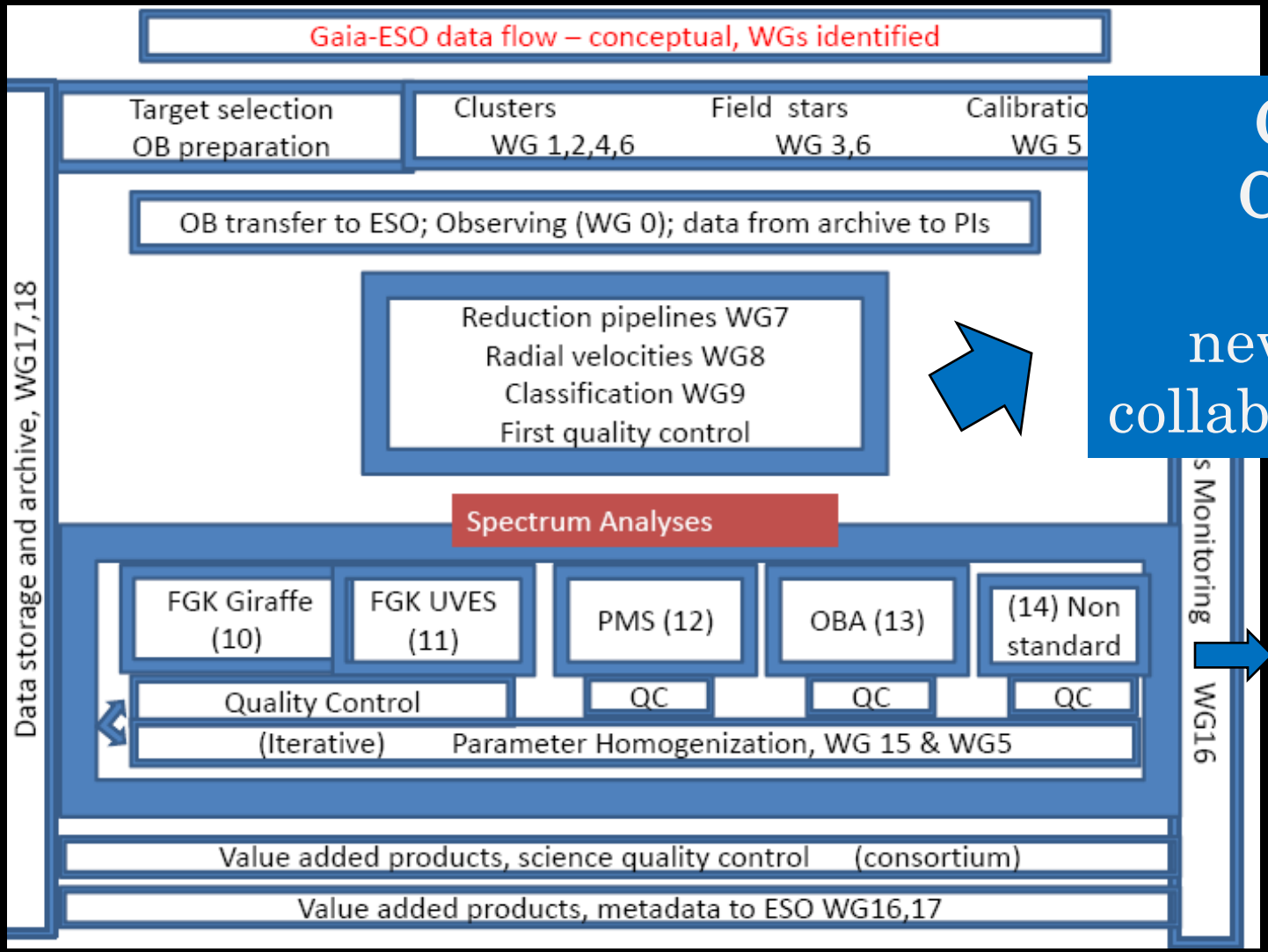
→ PRODUCTS

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

Uniform analysis

homogeneous overview of kinematics and abundances

Data flow



Centralized: Cambridge & Arcetri
new pipeline and collaboration with ESO

Multiple analyses; **common tools:** line list, model atm., grid of spectra

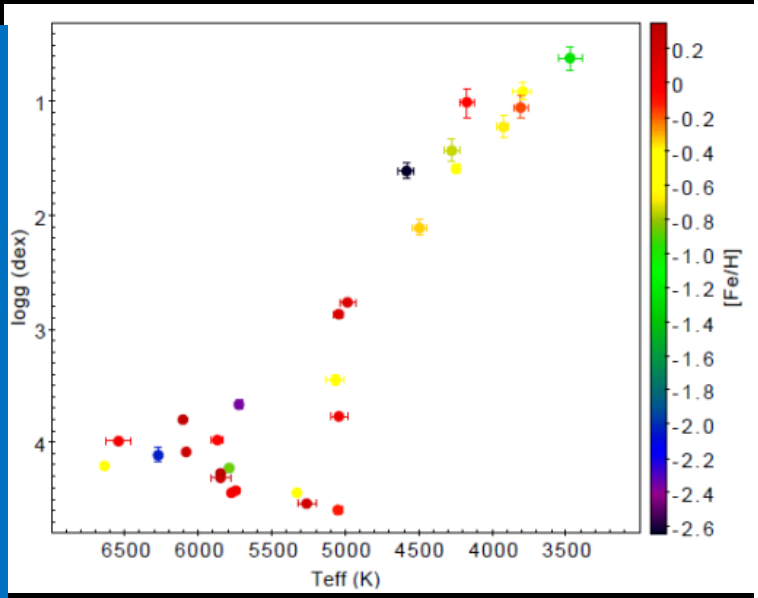
Edinburgh Archive

Calibration Concept

- **internal calibrations:** different stellar types; different settings
- **external calibrations:** w.r.t other surveys and Gaia

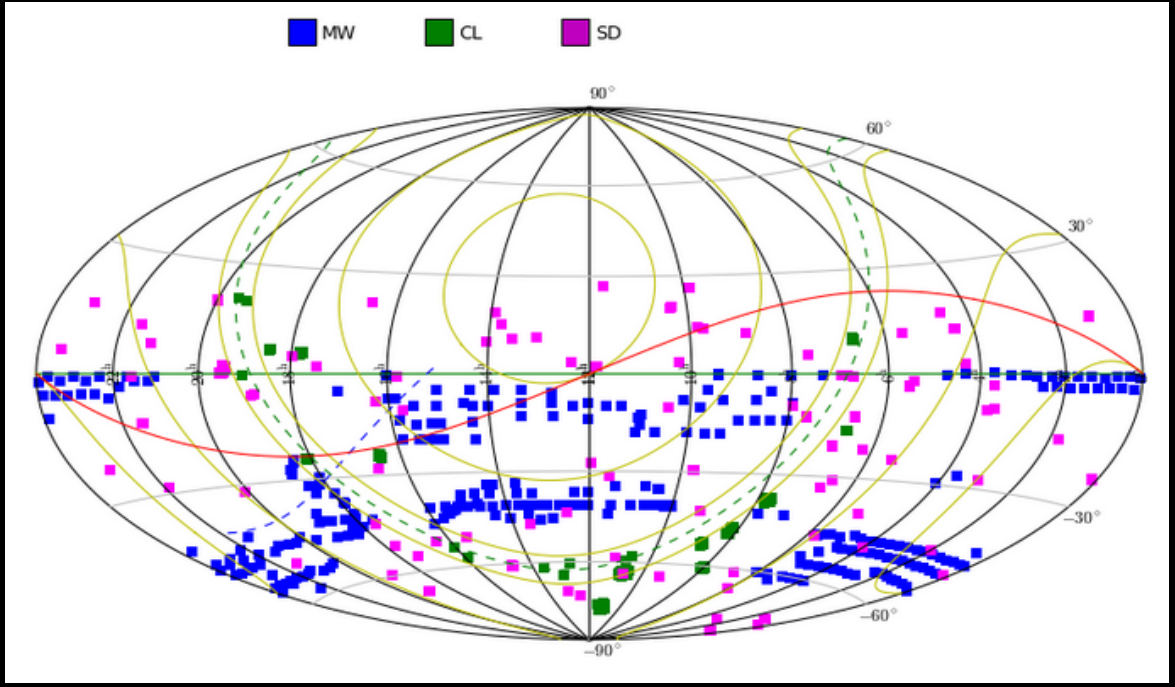
maximize legacy value and provide a rich dataset for future inter-survey calibration

- RV standards
- Gaia benchmark stars: method/node performances, internal homog.
- Open Clusters: hot vs. cool; PMS vs. MS vs. evolved; metallicity (high [Fe/H])
- Globular Clusters: test metallicity (low [Fe/H])
- CoRoT Red Giants: asteroseismic gravities and ages



Jofre+, 2014;
Heiter+, in prep

Survey progress

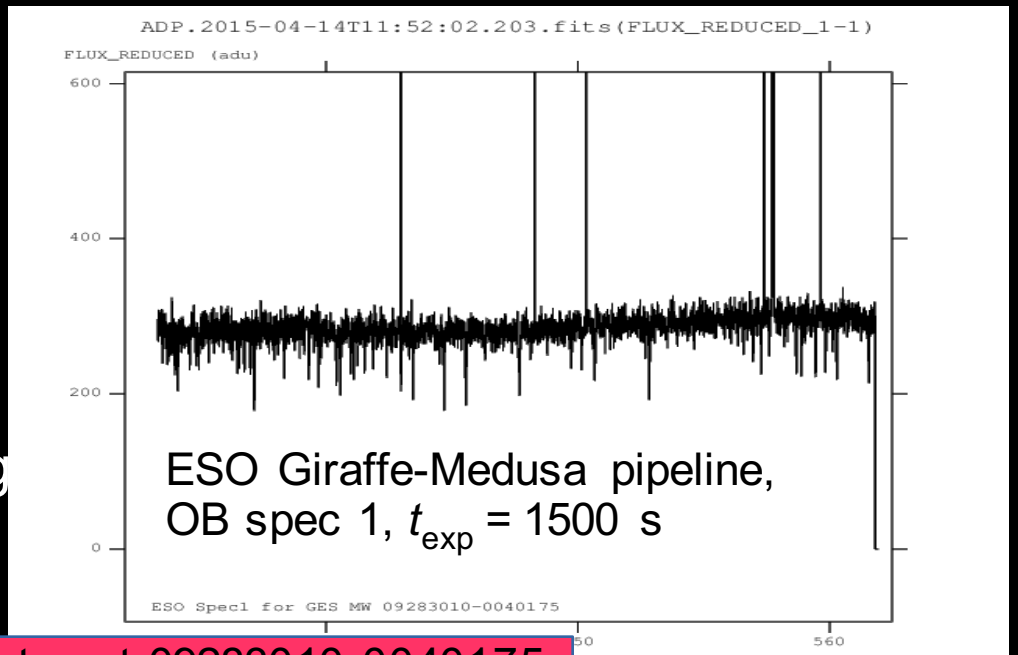


- 40 runs, **225/300** nights (~20 % lost) → **180 nights**
- large **variety of MW fields; 34 science OCs**; >8000 **calibrators**
- 100,000 spectra
- 4 analysis cycles and internal releases completed
- Two phase 3 releases to ESO (spectra & products)

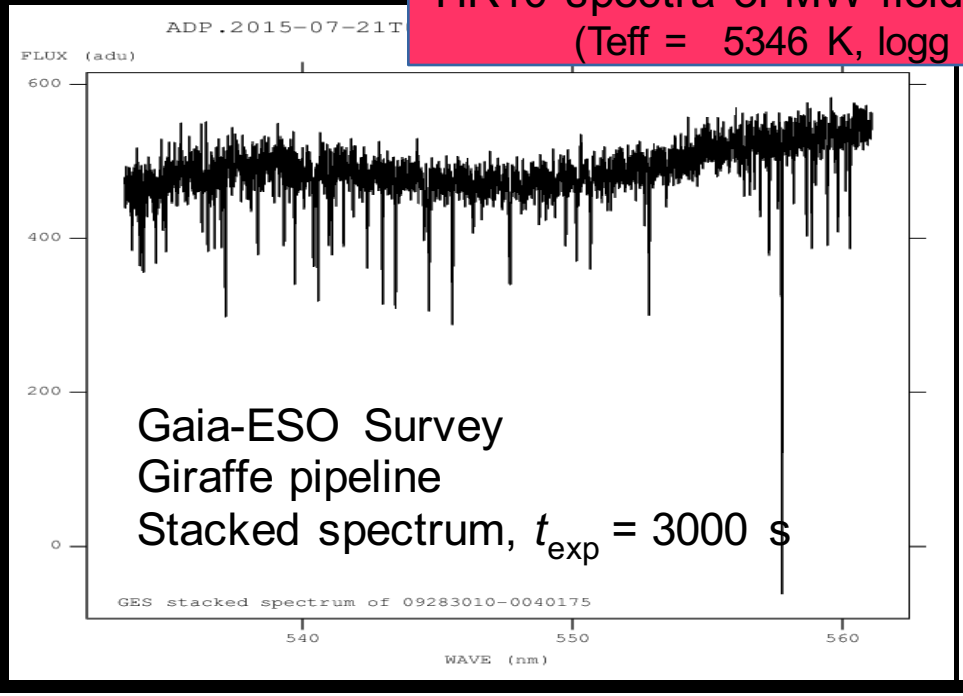
Comparison of Gaia-ESO Survey spectra with ESO FLAMES/GIRAFFE pipeline spectra

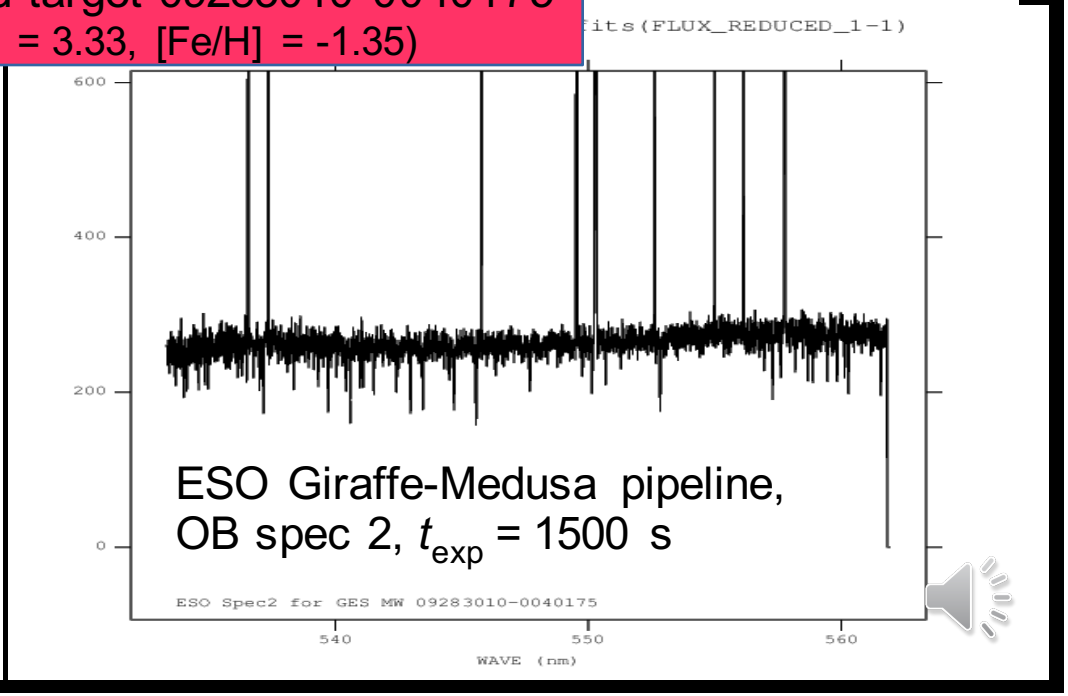
Gaia-ESO: wavelength-calibrated, heliocentrically-corrected and sky-subtracted stacked spectra with cosmic ray removal

ESO: wavelength-calibrated, heliocentrically-corrected. No stacking sky-subtraction or CR removal (but sky spectra are delivered)



HR10 spectra of MW field target 09283010-0040175
(Teff = 5346 K, logg = 3.33, [Fe/H] = -1.35)

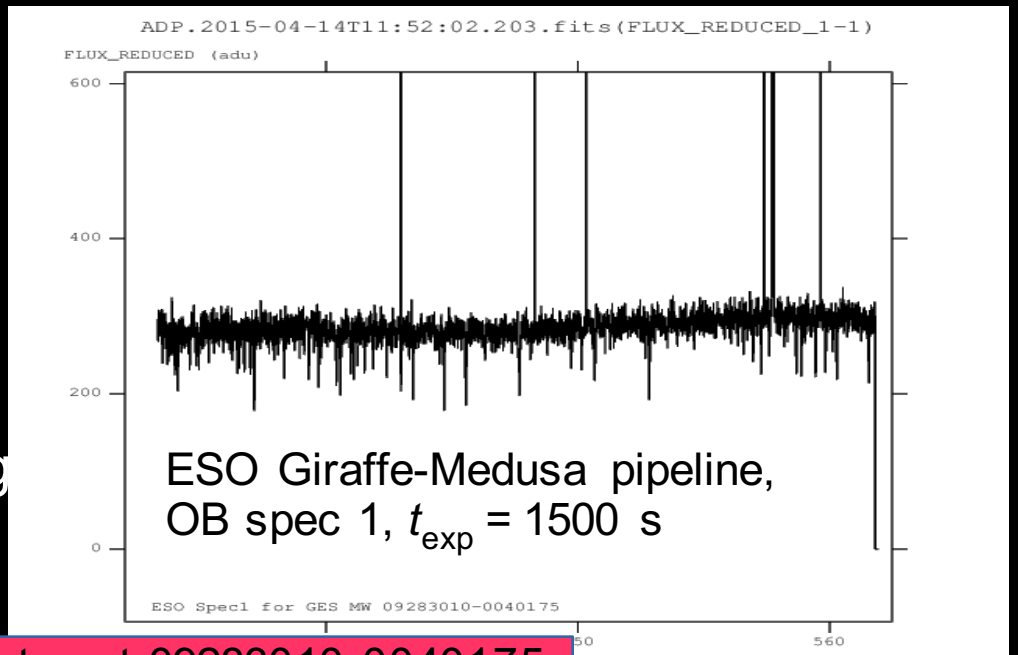




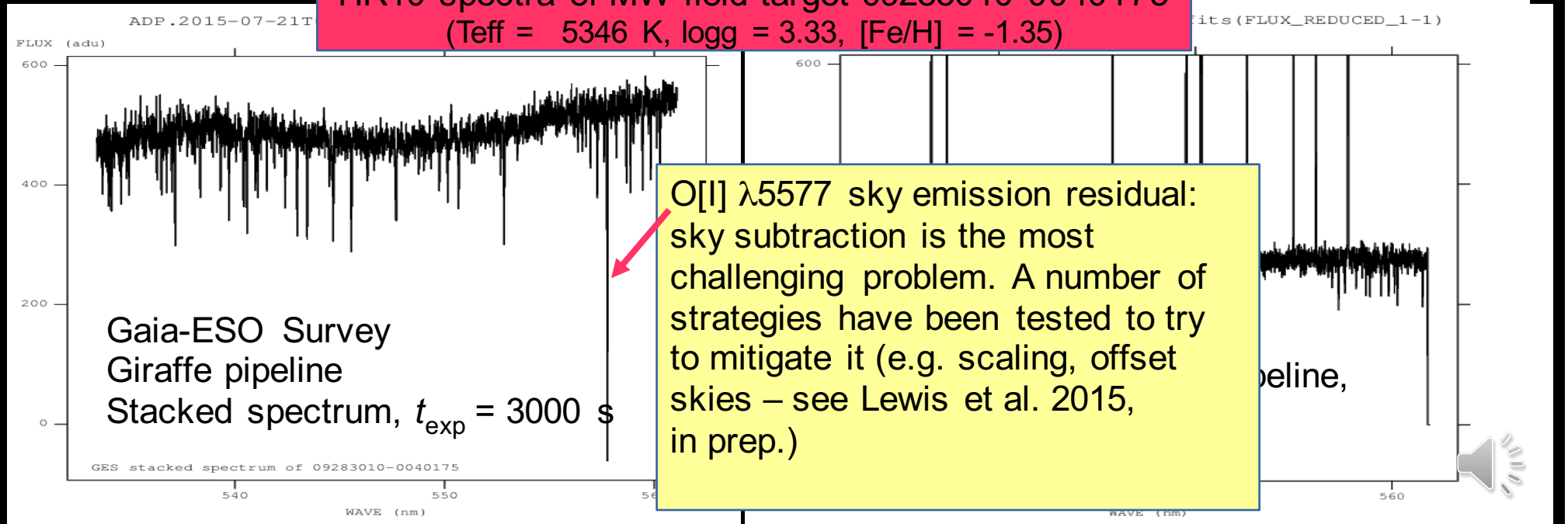
Comparison of Gaia-ESO Survey spectra with ESO FLAMES/GIRAFFE pipeline spectra

Gaia-ESO: wavelength-calibrated, heliocentrically-corrected and sky-subtracted stacked spectra with cosmic ray removal

ESO: wavelength-calibrated, heliocentrically-corrected. No stacking sky-subtraction or CR removal (but sky spectra are delivered)

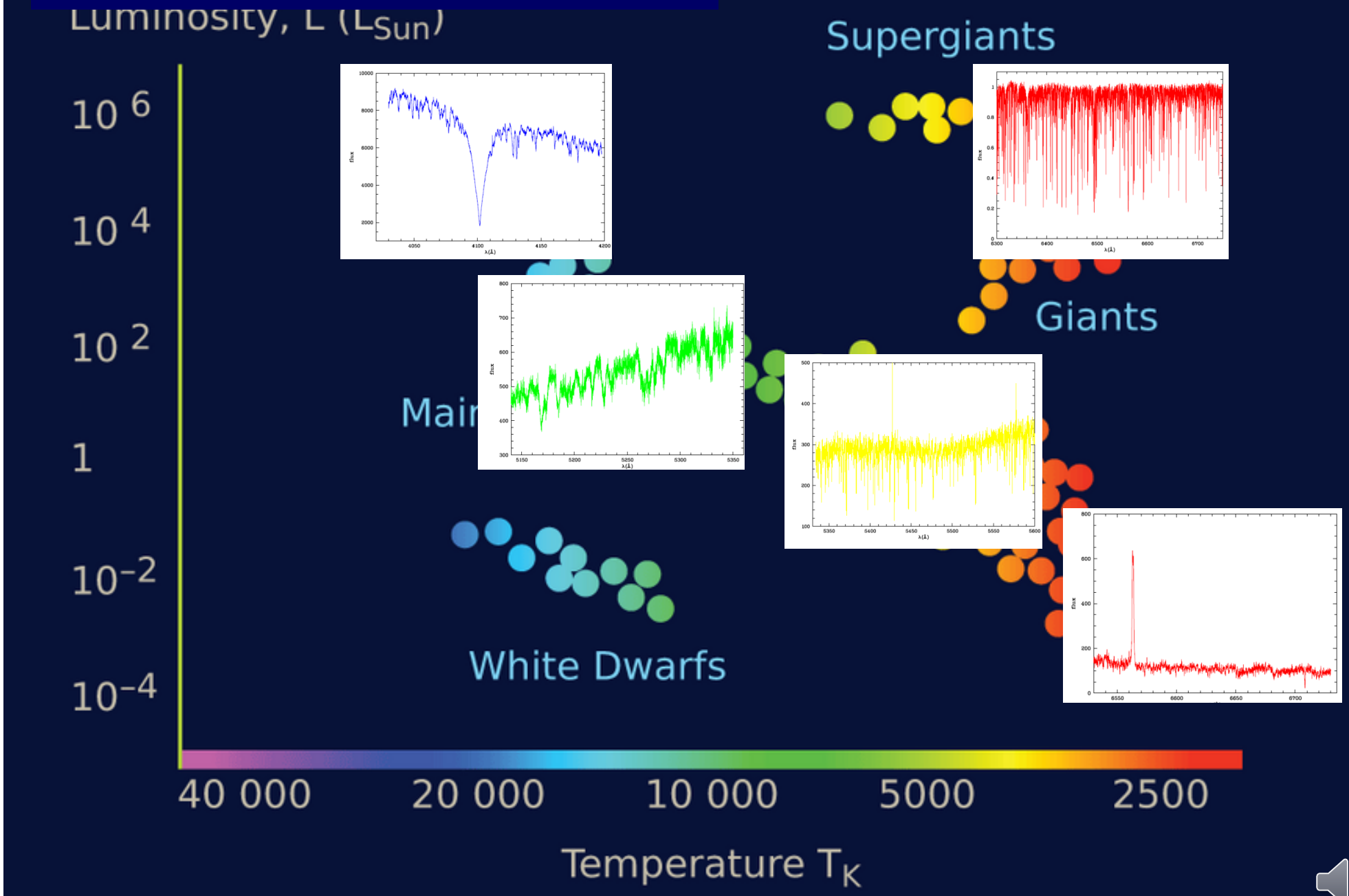


HR10 spectra of MW field target 09283010-0040175
(Teff = 5346 K, logg = 3.33, [Fe/H] = -1.35)

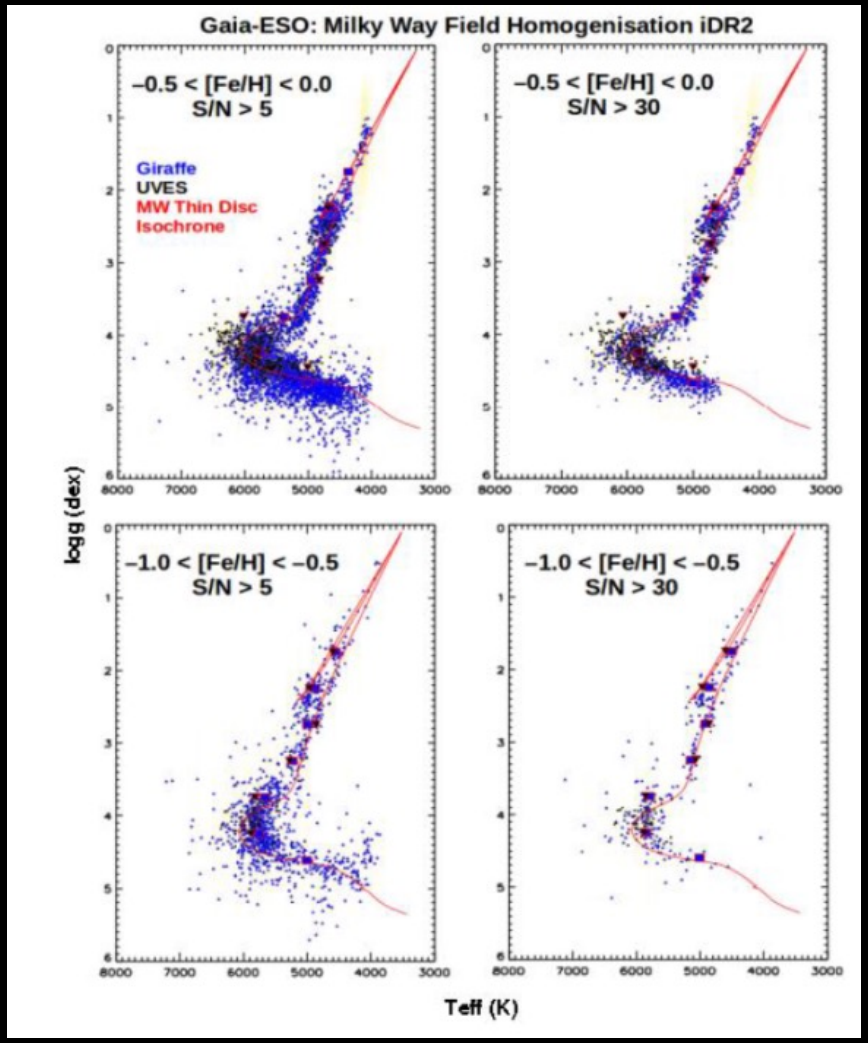


O[I] λ5577 sky emission residual: sky subtraction is the most challenging problem. A number of strategies have been tested to try to mitigate it (e.g. scaling, offset skies – see Lewis et al. 2015, in prep.)

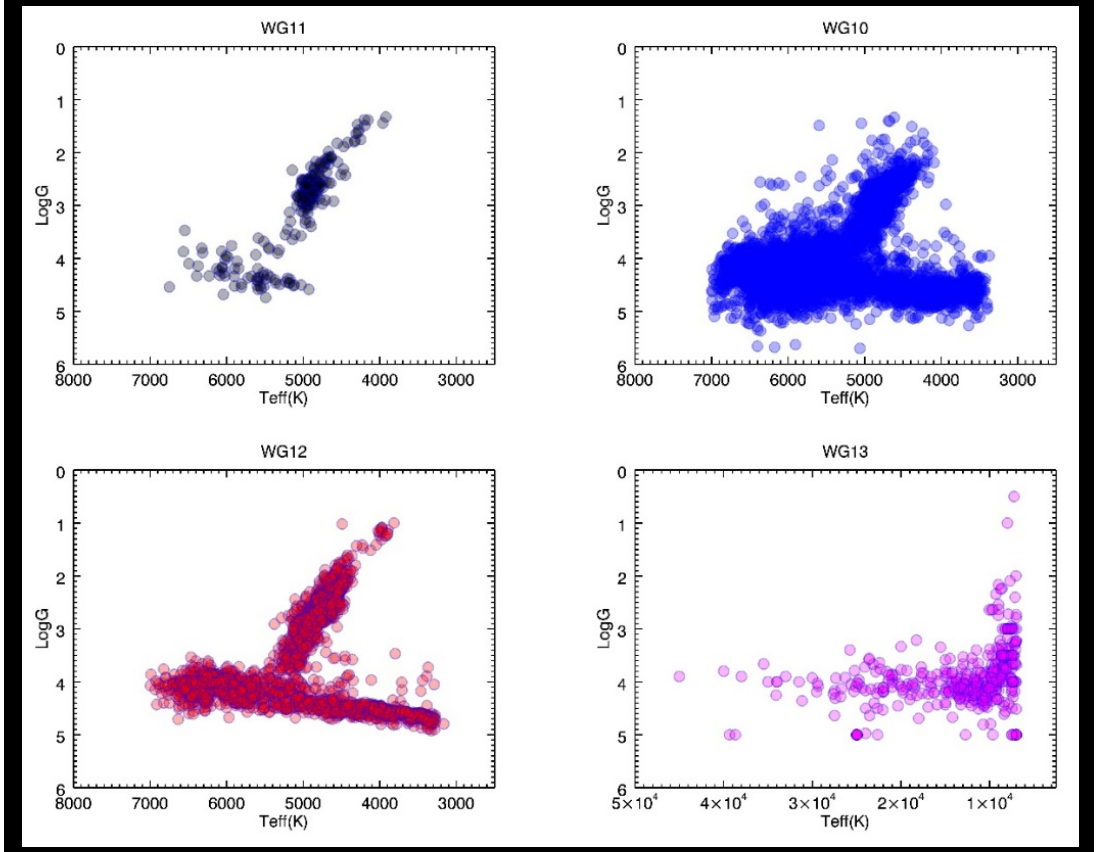
More spectra



Stellar parameters



MW field



Open Clusters

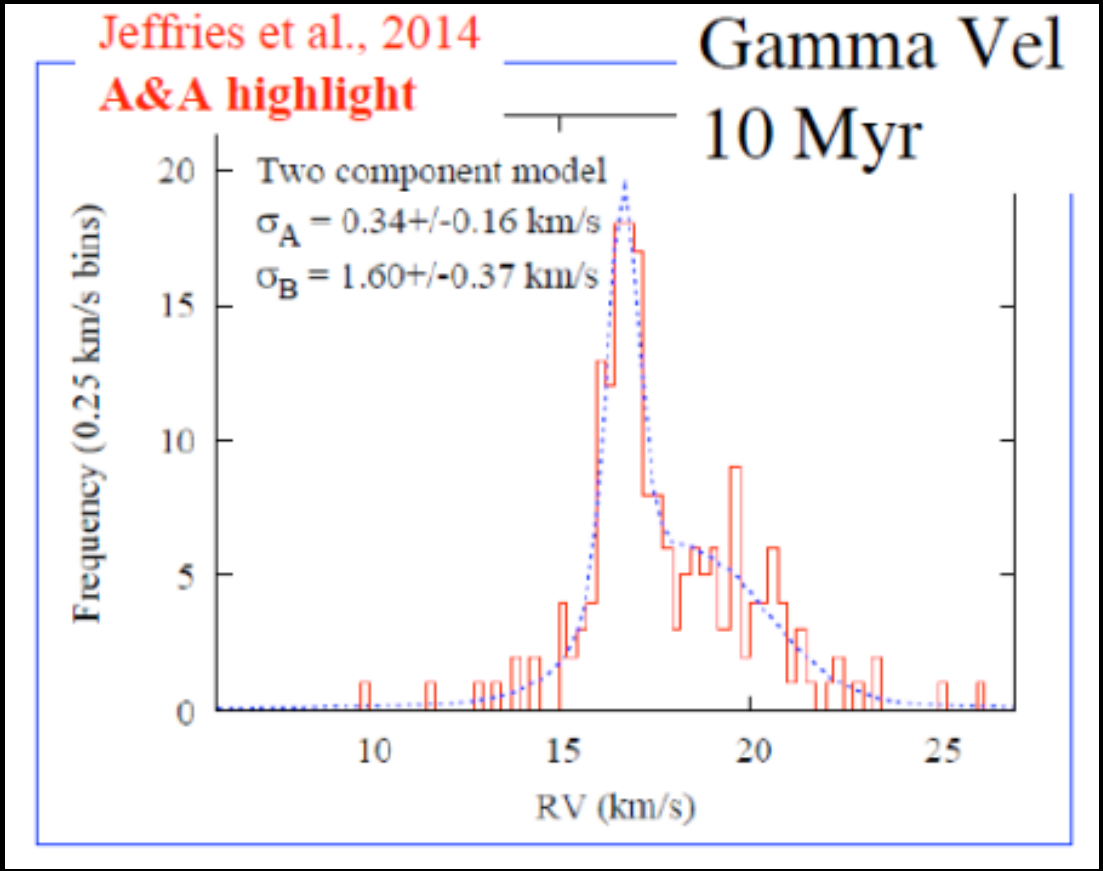
Gaia-ESO Science

Gaia-ESO Science - overview

- Bottom-up approach
- Two + one (TBD) all-hands meetings; a few focused meetings
- 36 science papers since iDR1 (August 2013); 6 technical papers; 2 Messenger articles
- 4 A&A highlights + 3 A&A cover pages
- All original science topics addressed, plus unexpected results
- A significant fraction of papers led by students and post-docs

New science from precise RVs

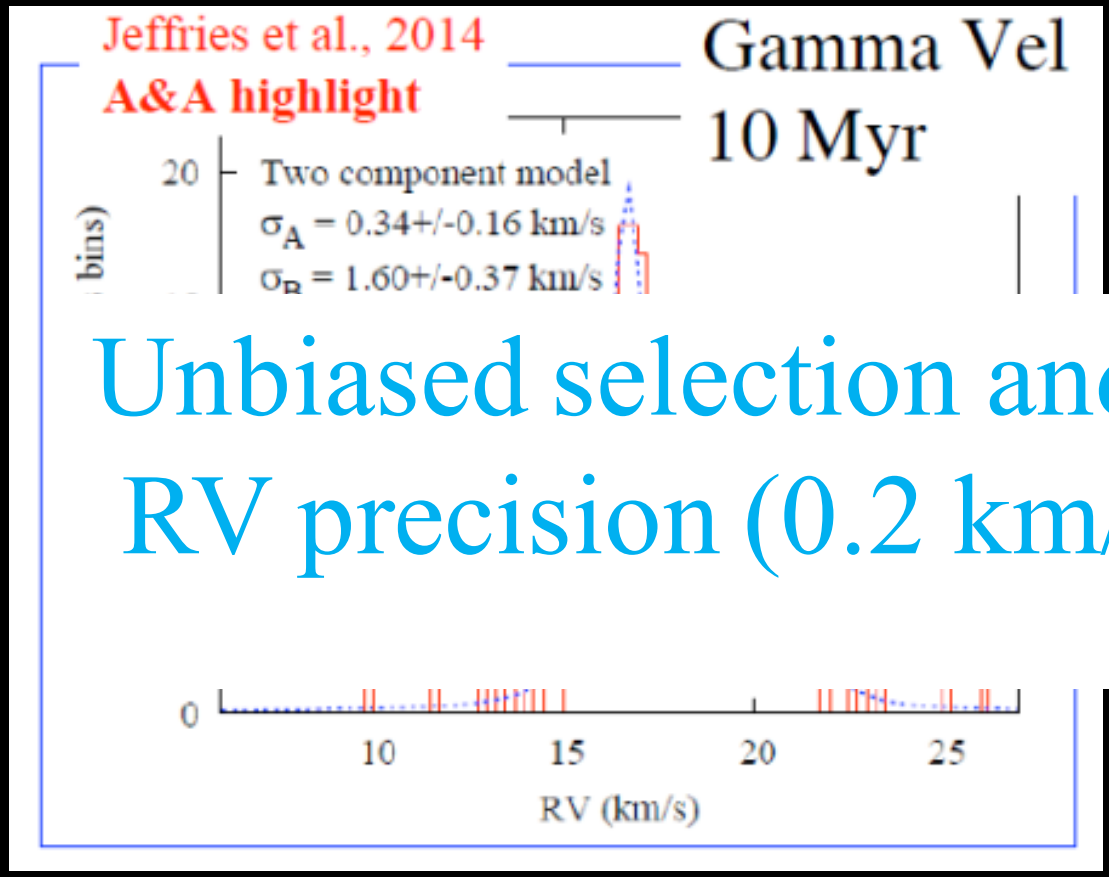
A key science goal of Gaia-ESO is to use the kinematics of low-mass stars in young clusters to probe their dynamical histories and how they populate the field as they become unbound



Two kinematic populations in gamma Vel (10 Myr) -> insights on the cluster formation scenarios (see also Mapelli et al. 2015; Sacco et al. 2015; Rigliaco et al., 2015)

New science from precise RVs

A key science goal of Gaia-ESO is to use the kinematics of low-mass stars in young clusters to probe their dynamical histories and how they populate the field as they become unbound



Unbiased selection and RV precision (0.2 km/s)

Two kinematic populations in gamma Vel (10 Myr)

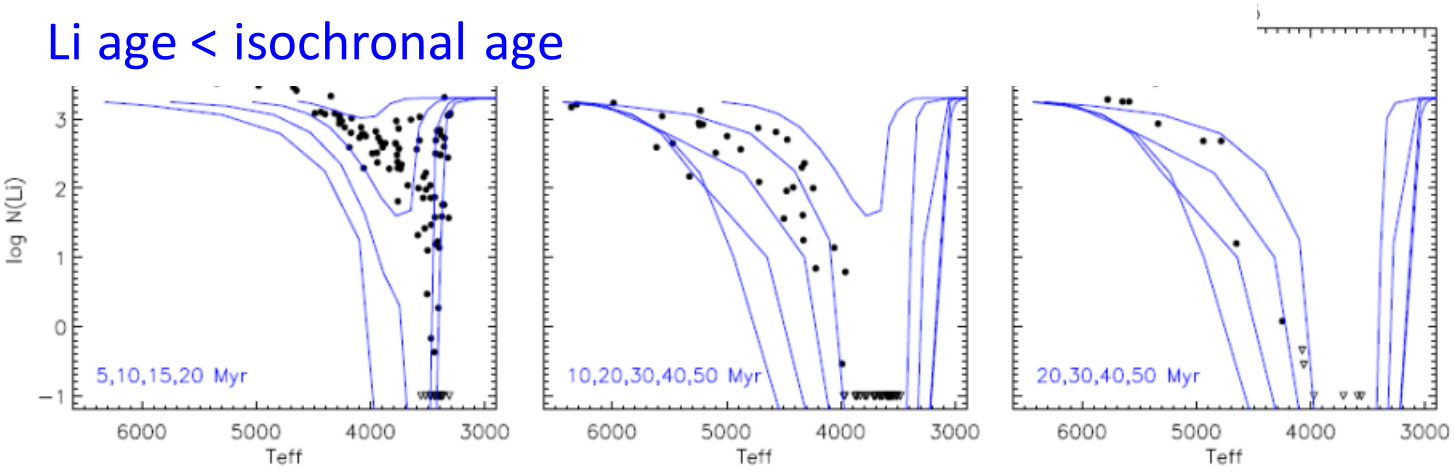
insights on the
uster formation
enarios
ee also Mapelli et al.
2015; Sacco et al.
2015; Rigliaco et al.,
2015)

waiting for Gaia proper motions!

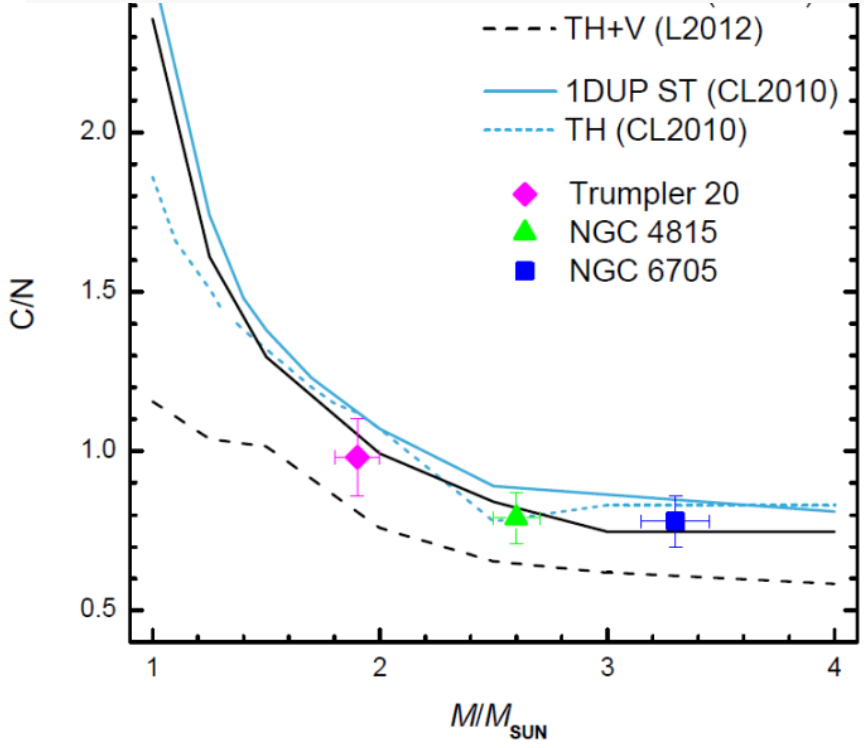
Constraints on stellar models

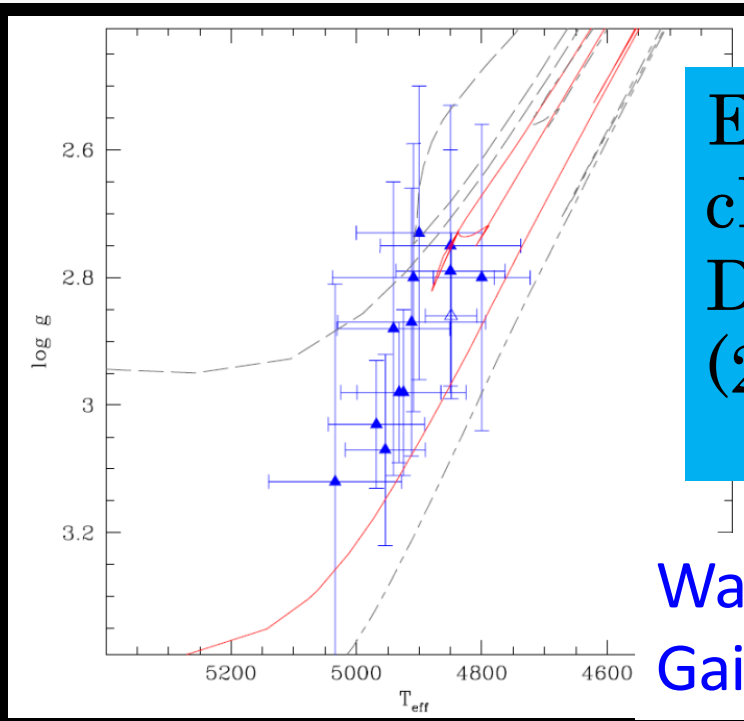
Li depletion in young clusters – Franciosini, +(2015)

Li age < isochronal age



Extra-mixing during post-MS –Tautvaisiene, + –see also talk by Smiljanic

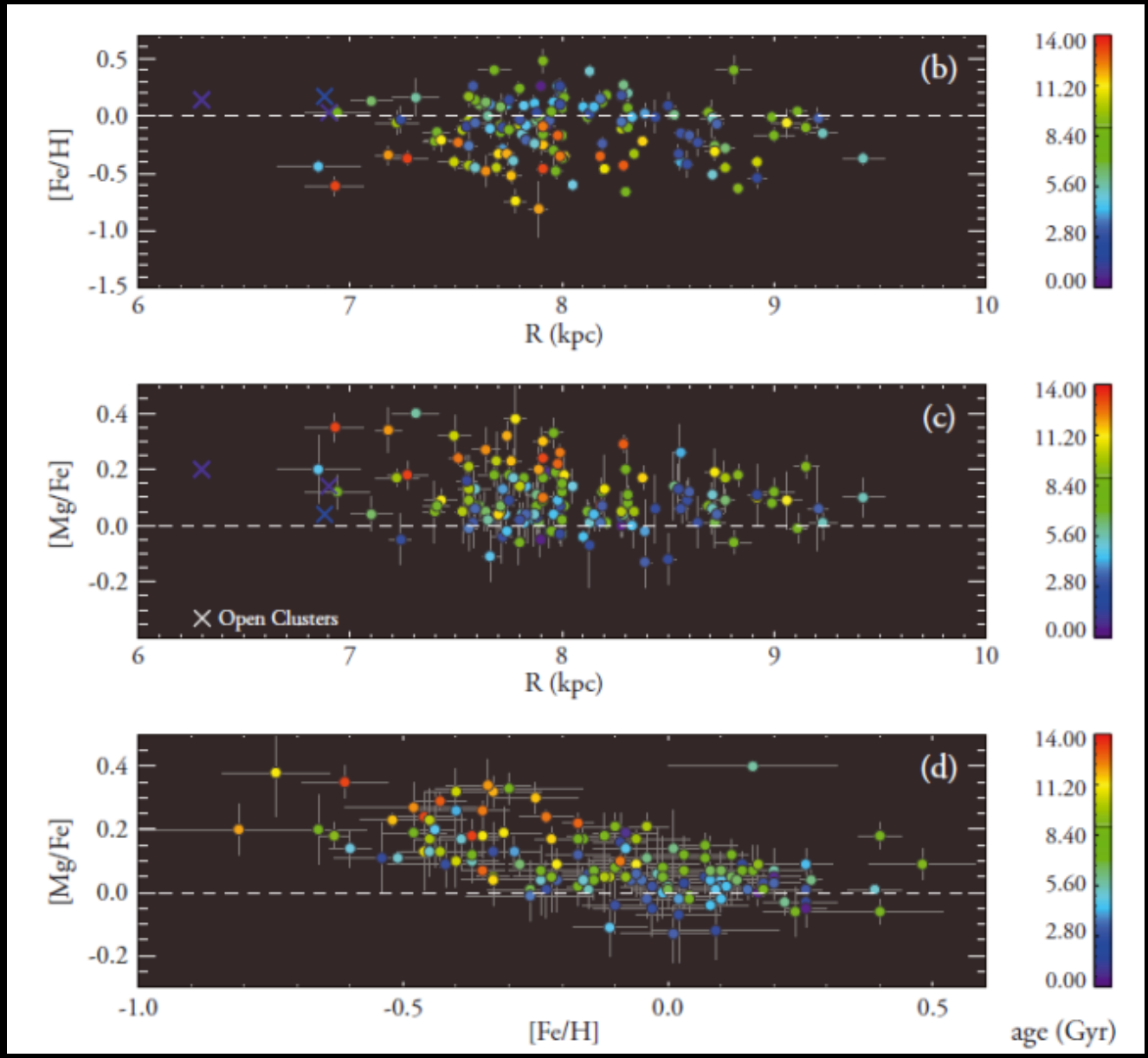




Estended clumps Donati+, (2014)

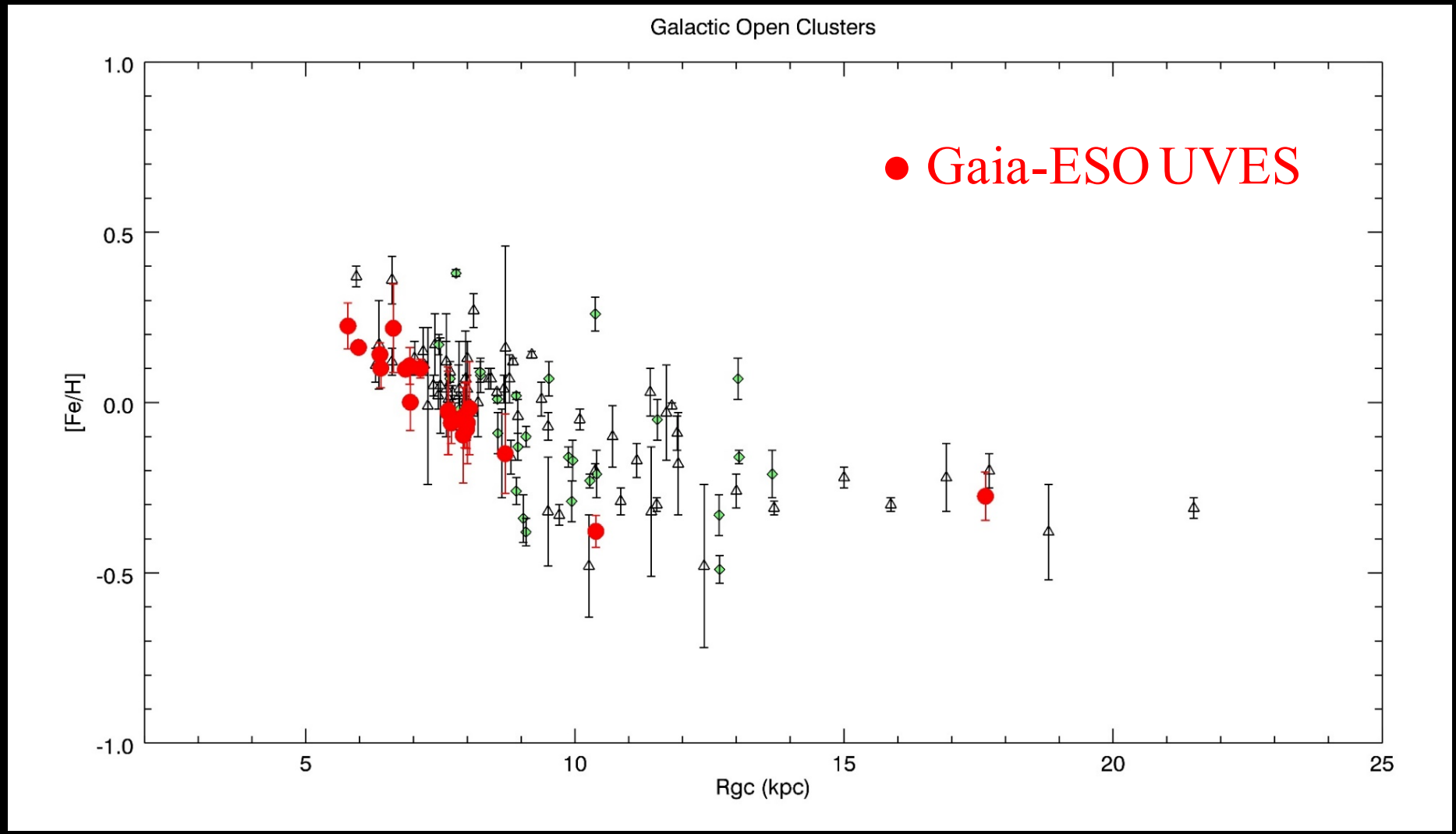
Waiting for Gaia parallaxes!

Radial metallicity gradient – MW field



Bergmann, + 2014 (based on UVES data)

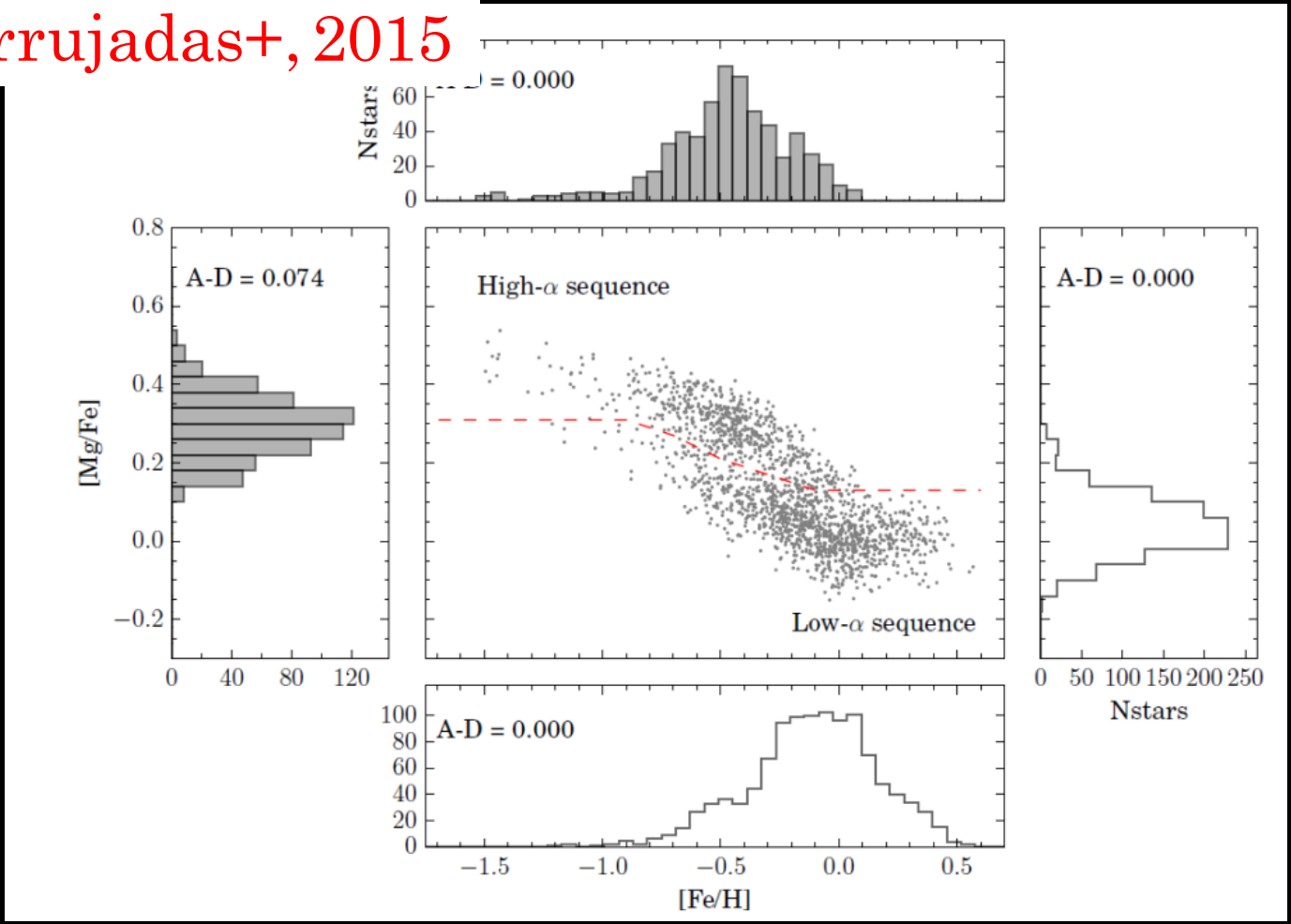
Radial metallicity gradient – OCs
(well known ages and distances; located throughout the disc)



Randich+, in prep.; Jacobson+, (2015)

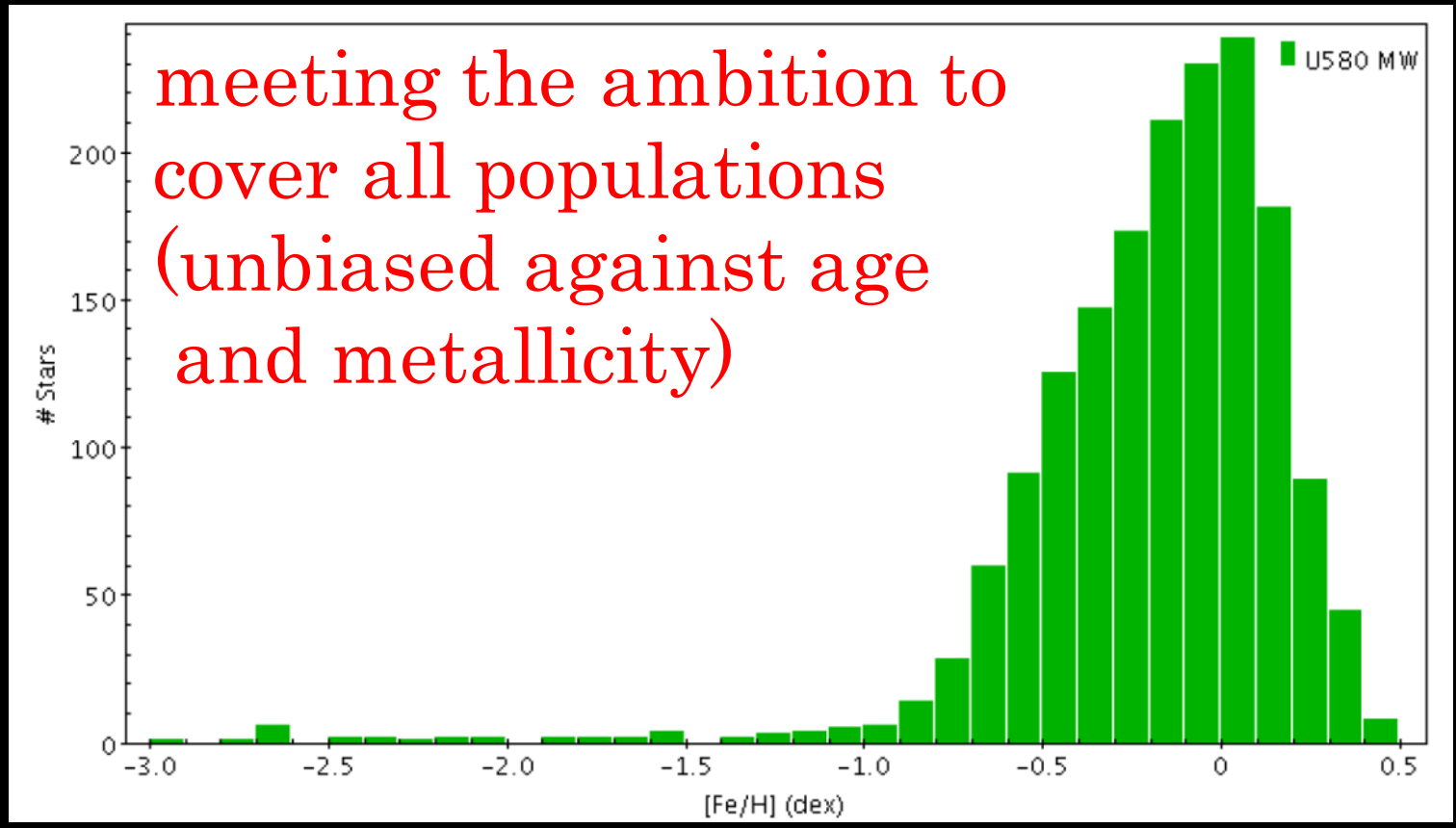
Disentangling disc chemical substructure

Rojas Arrujadas+, 2015



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

The [Fe/H] distribution of the MW UVES parallel sample



Excellent range for Gaia: 6-D phase space data to be complemented by the 6-8 dimensions of APs and abundances

Conclusions: stressing the legacy value

- **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
- **New**/improved data reduction **pipelines**
- 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