EAS 2021 Leiden Virtual

The Gaia promise of Astrophysical Parameters in GDR3

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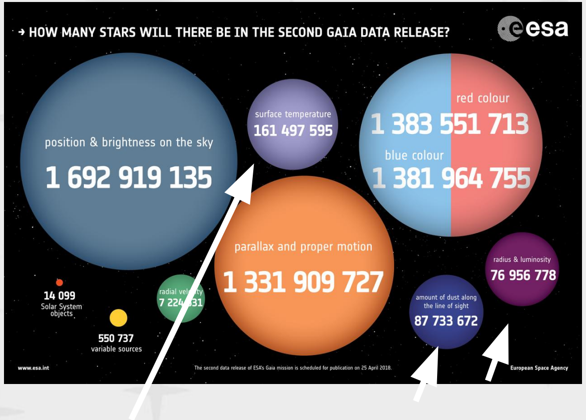
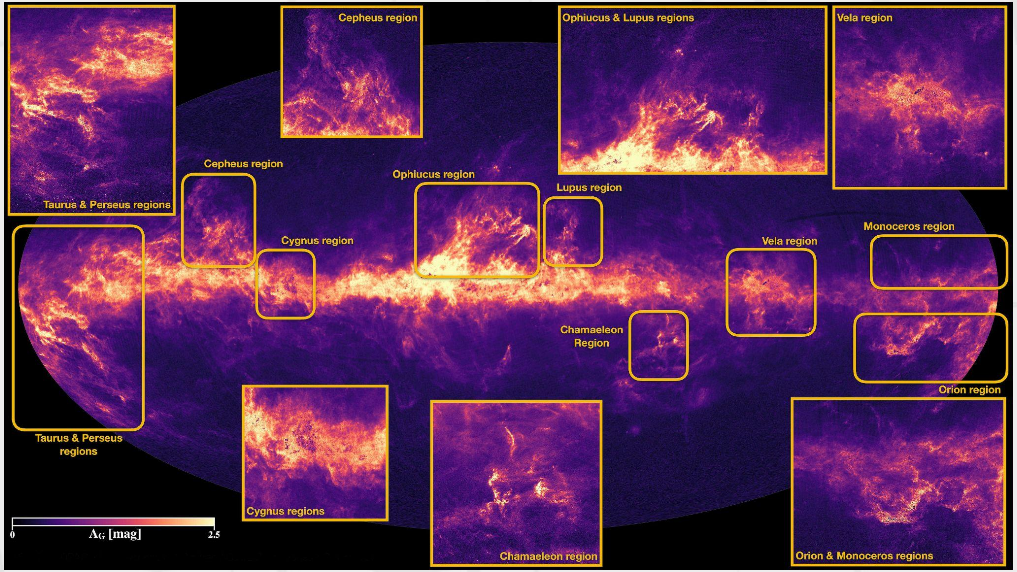
In the last episode (DR2), …





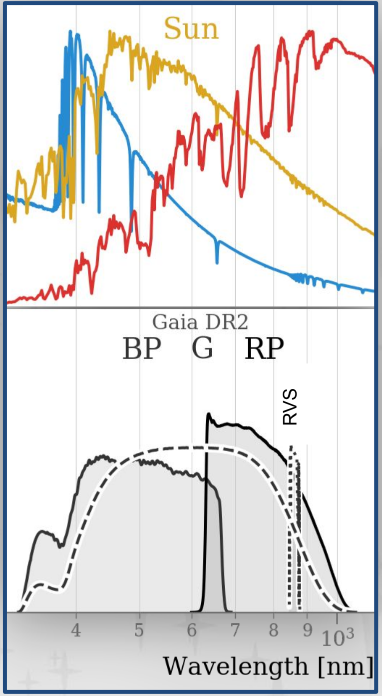
(G, Bp, Rp, varpi) →

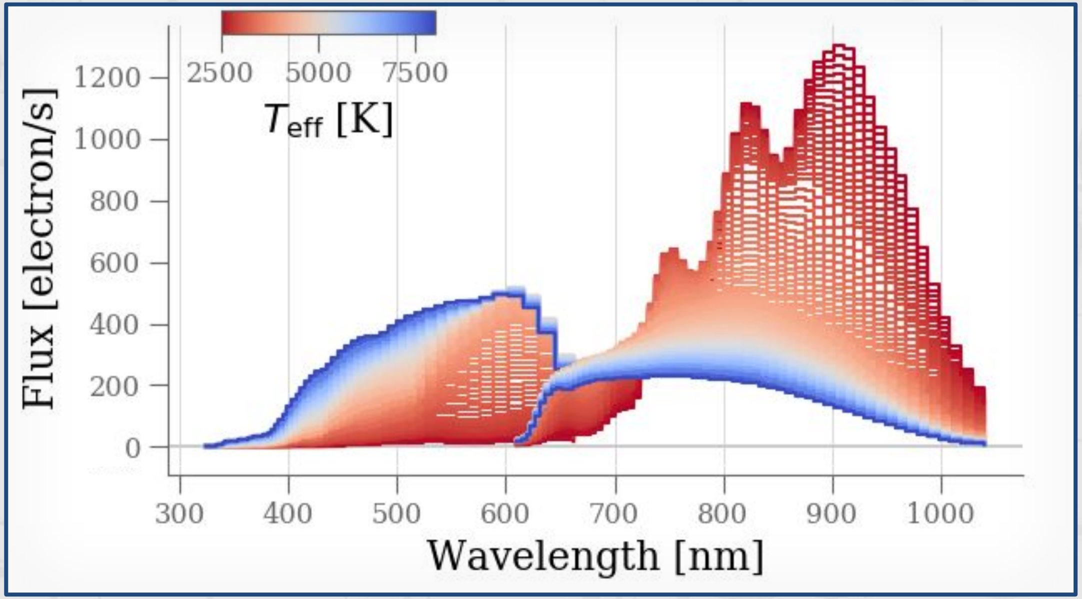
T_{eff}, A_G, E(Bp-Rp), *R*, *L*

Gaia-DPAC-CU8- GSP-Phot / FLAME (Andrae+ 2018)

In the next episode (DR3), ...

Use of mean Bp and Rp Spectra

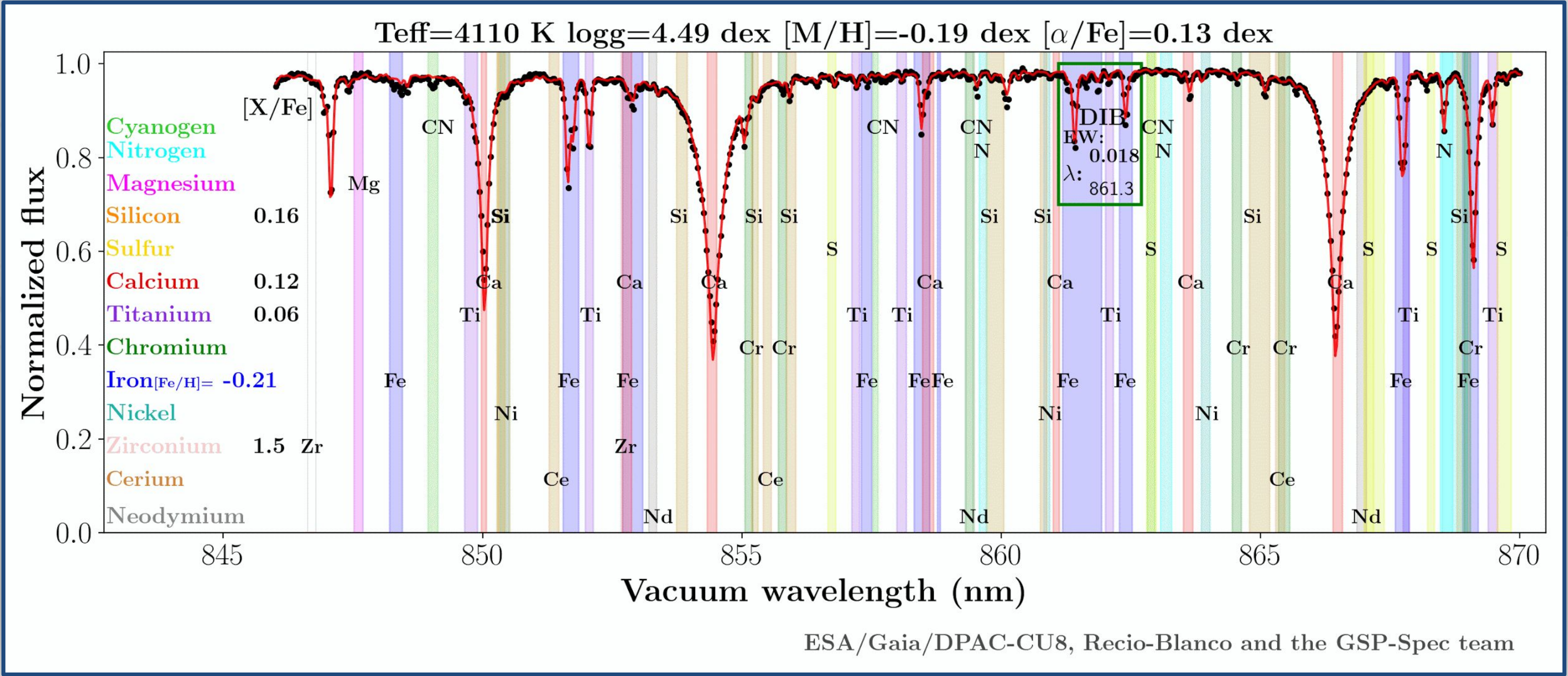




Bp and Rp spectra produced by Gaia-DPAC-CU5/DPCI

Astrophysical Parameters (APs) produced by Gaia-DPAC-CU8/DPCC

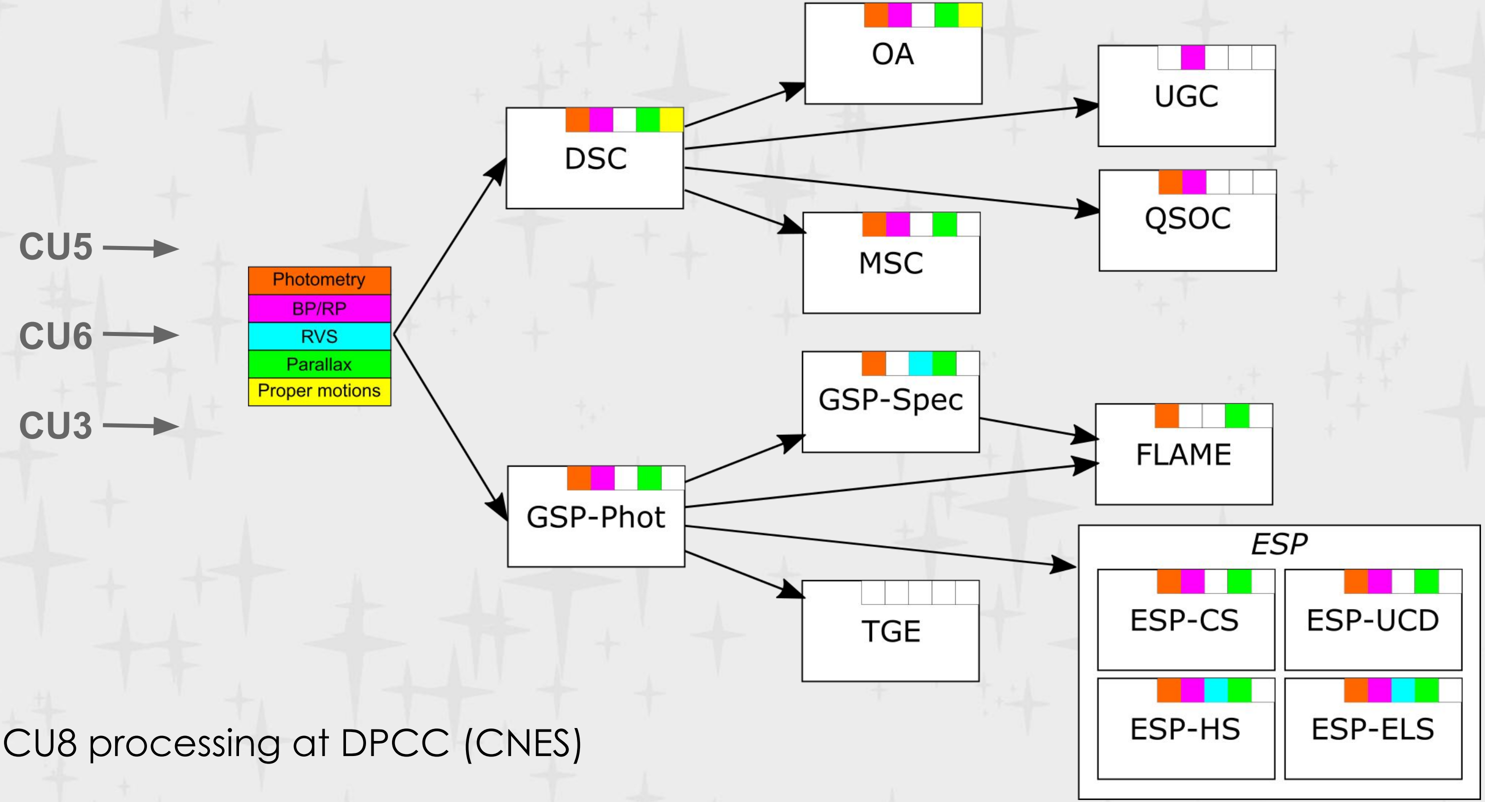
Use of mean RVS spectra



RVS spectra produced by Gaia-DPAC-CU6/DPCC; APs, Abundances, DIB produced by CU8/DPCC

Behind CU8 Astrophysical Parameters

Astrophysical Parameters from CU8



CU8 processing at DPCC (CNES)

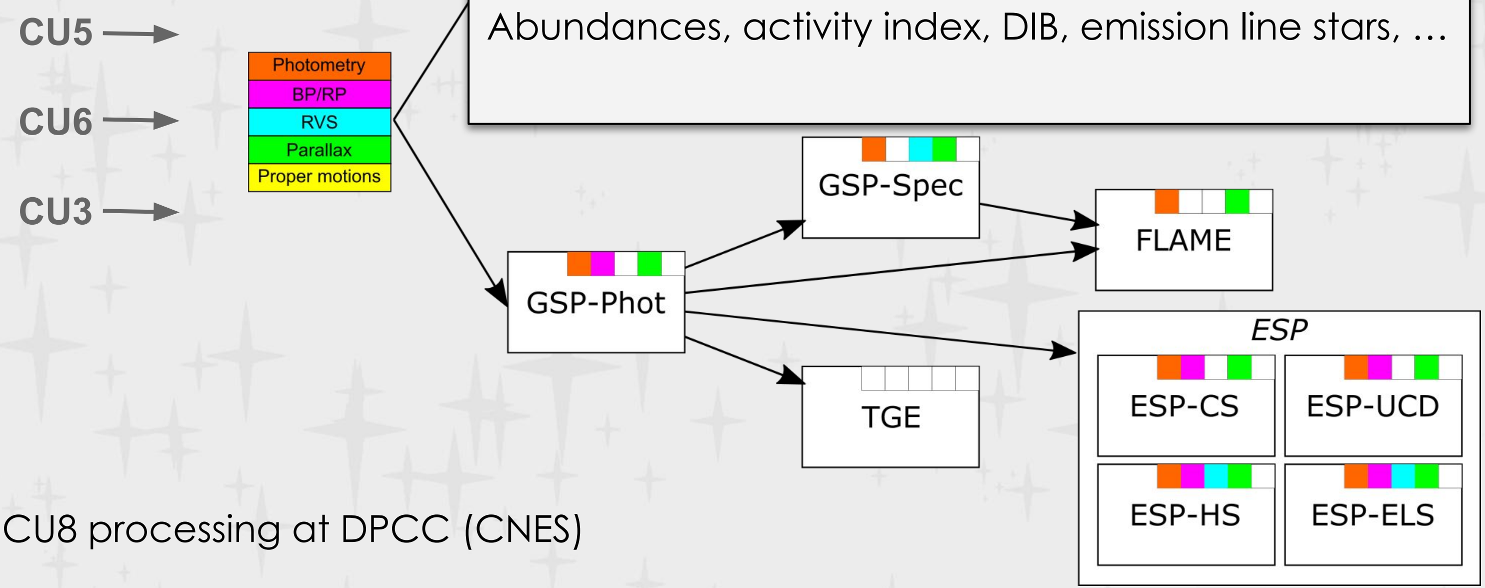
Astrophysical Parameters from CU8

Stellar Parameters

T_{eff}, A_G, E(Bp-Rp), logg, [M/H], ...

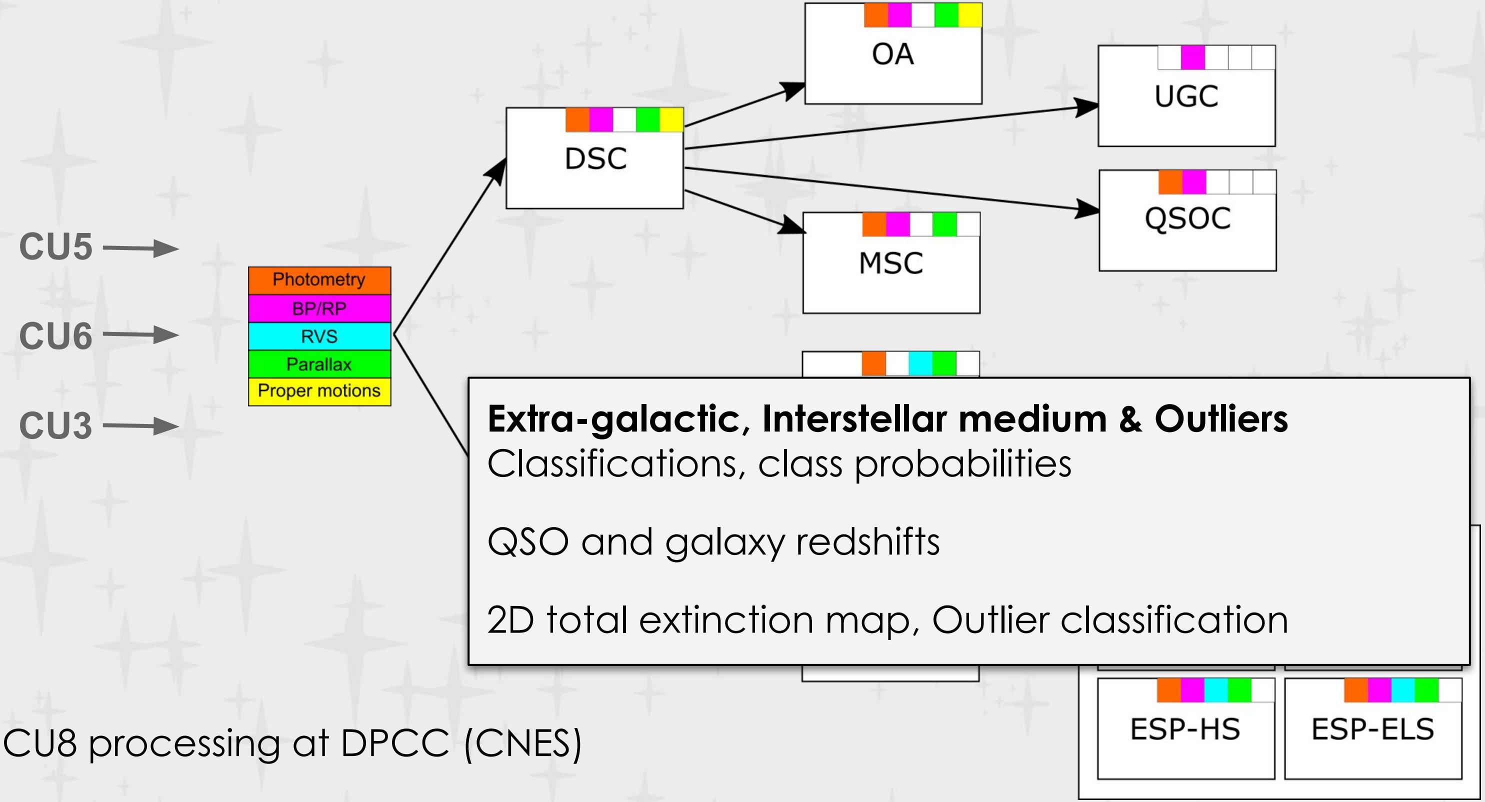
R, L, distance, mass, age, binarity, ..

Abundances, activity index, DIB, emission line stars, …



CU8 processing at DPCC (CNES)

Astrophysical Parameters from CU8



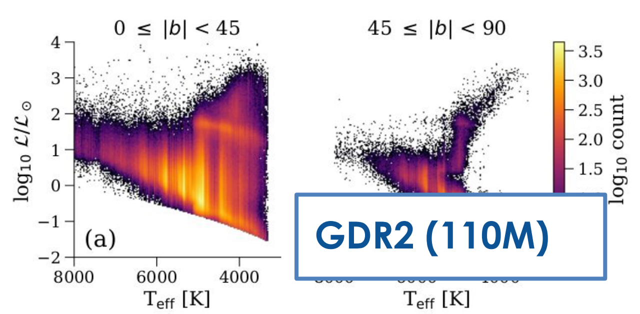
Extra-galactic, Interstellar medium & Outliers
Classifications, class probabilities

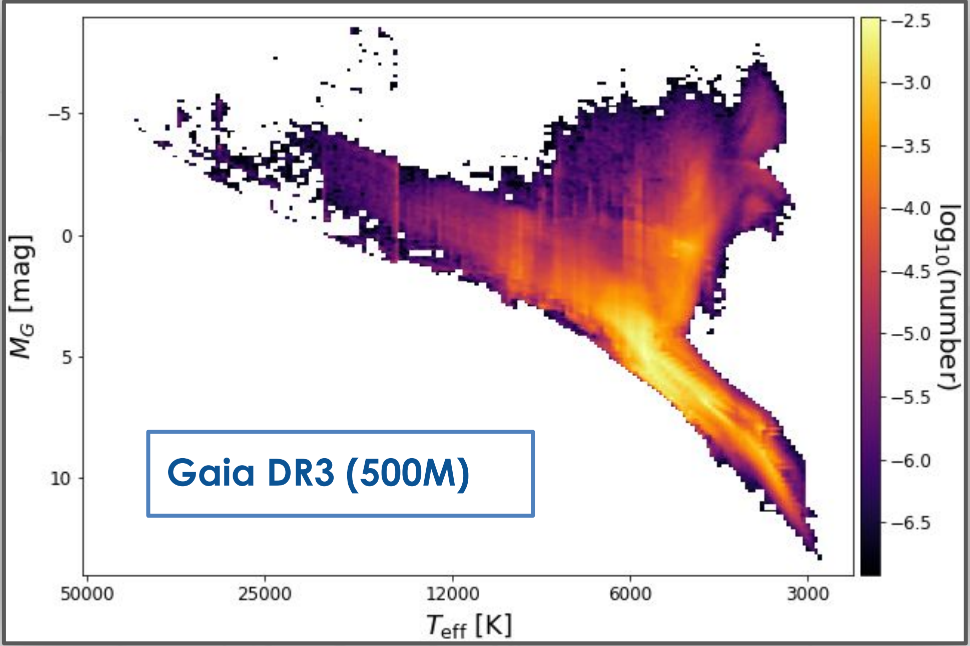
QSO and galaxy redshifts

2D total extinction map, Outlier classification

CU8 processing at DPCC (CNES)

The HR diagram for 500M stars

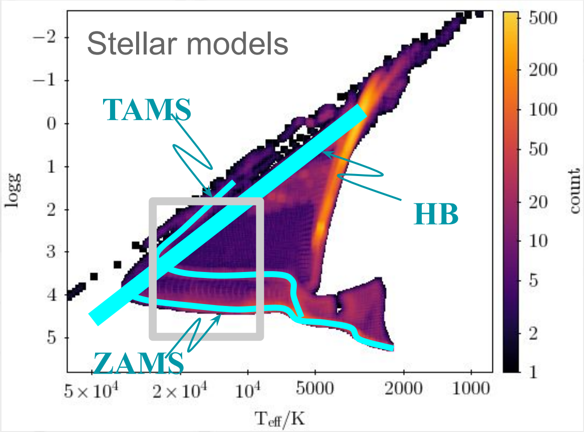




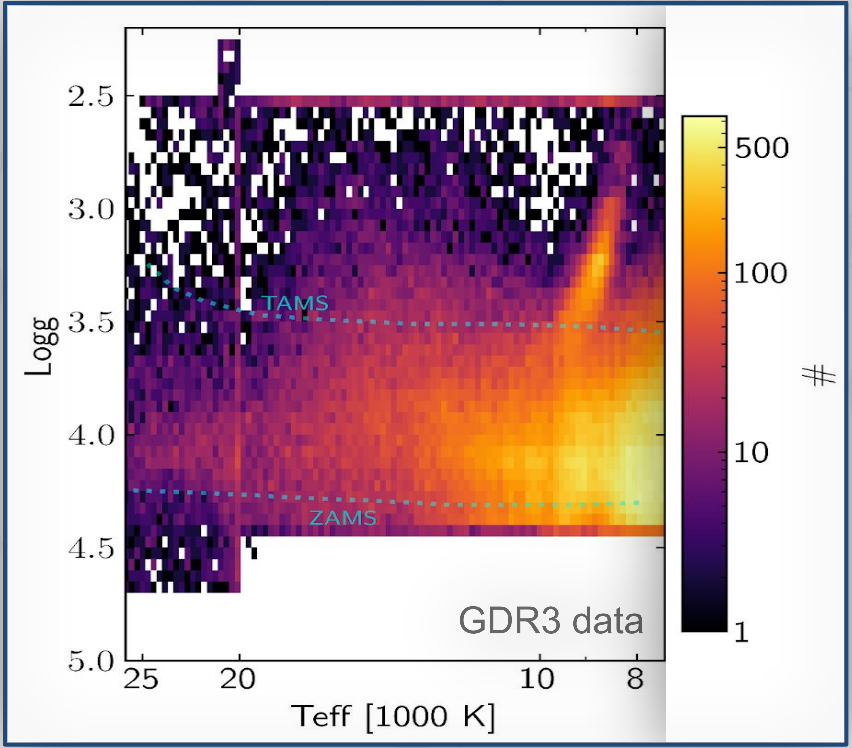
GSP-Phot derives T_{eff}, logg, [M/H], A_G from XP spectra for stars

- 2,500 < T_{eff} < 55,000 K
- 0< A_G < 10
- G < 19
- Use of isochrones for distance

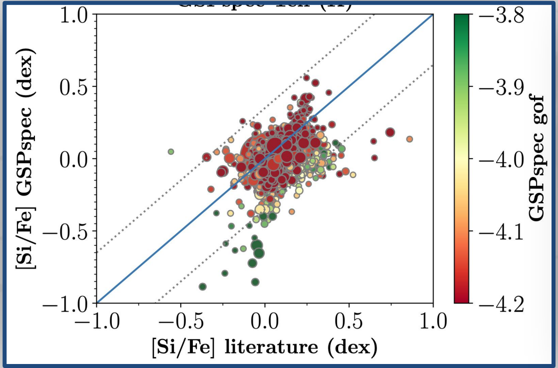
Insight into Hot-Star physics

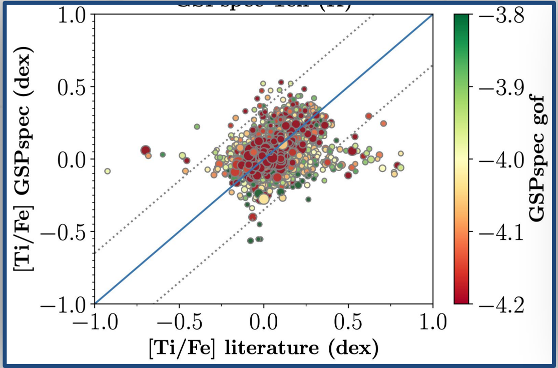


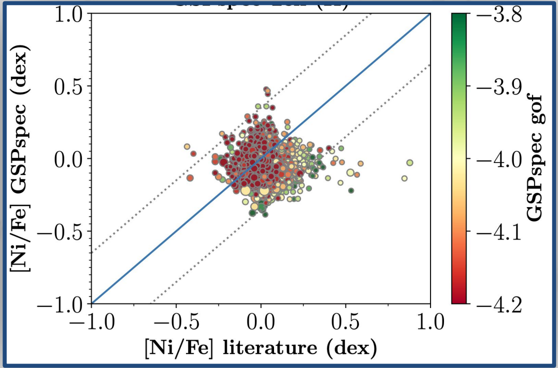
Hot stars dominating the region between the ZAMS and TAMS. The more advanced stages (horizontal branch) can be clearly seen by the overdensity in the top right (ESP-HS).



Chemical abundances in stellar atmospheres







Chemical abundances of FGK stars from RVS spectra by GSP-Spec
(Recio-Blanco+ 2016)

N, Mg, Si, S, Ca, Ti, Cr, Fe, FeII, Ni, Zr, Ce, Nd

Diffuse interstellar bands

The DIBs are absorption features seen in high resolution stellar spectra.

In the RVS spectra the 862nm DIB is observed and its EW is measured by GSP-Spec for about 500,000 spectra, (He+ 2020).

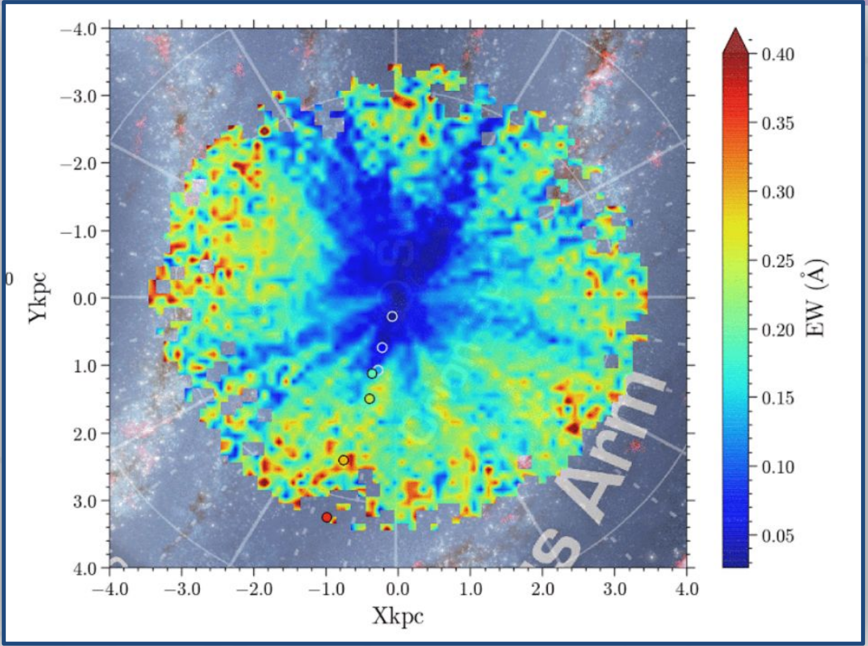
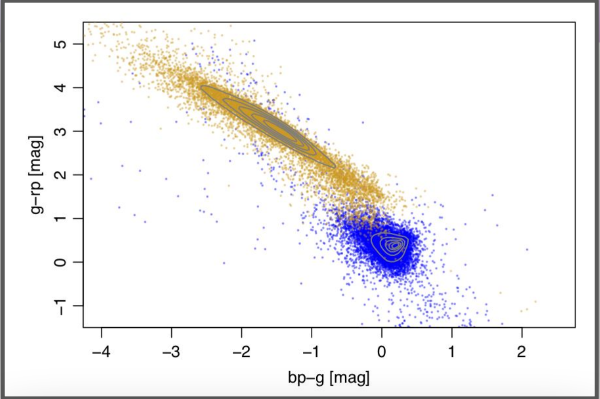


Figure: Top-down view of the Milky Way in the solar neighbourhood showing the strength of the DIB features which increases with distance.

Class Probabilities and classification

DSC (Bailer-Jones+ 2019) provides class probabilities of sources using XP spectra, photometry and astrometry

- Star
- Galaxy
- Quasar
- White dwarf
- Binary



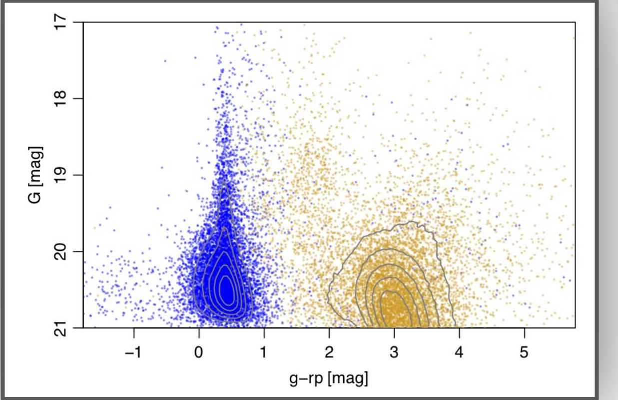
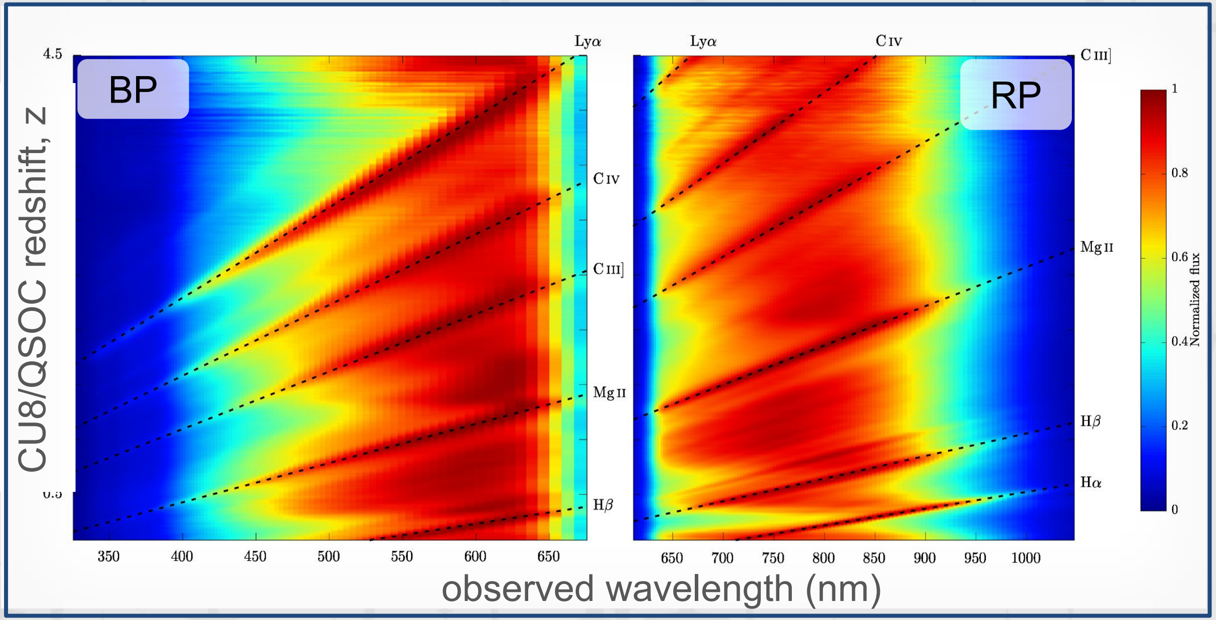


Figure: photometric indices of the sources classified as **galaxies** and **quasars** for a high completeness sample

QSO emission lines BP/RP spectra 17 ≤ G ≤ 20 mag

QSOC (Delchambre+2018) measures ~1.8M qso candidates with 0 ≤ z ≤ 6 from Bp and Rp spectra



Bp and Rp spectra ordered by QSOC redshift (z). The colour-code indicates the normalised flux (more intense red lines are the redshifted emission lines)

CU8 harvest in Gaia DR3

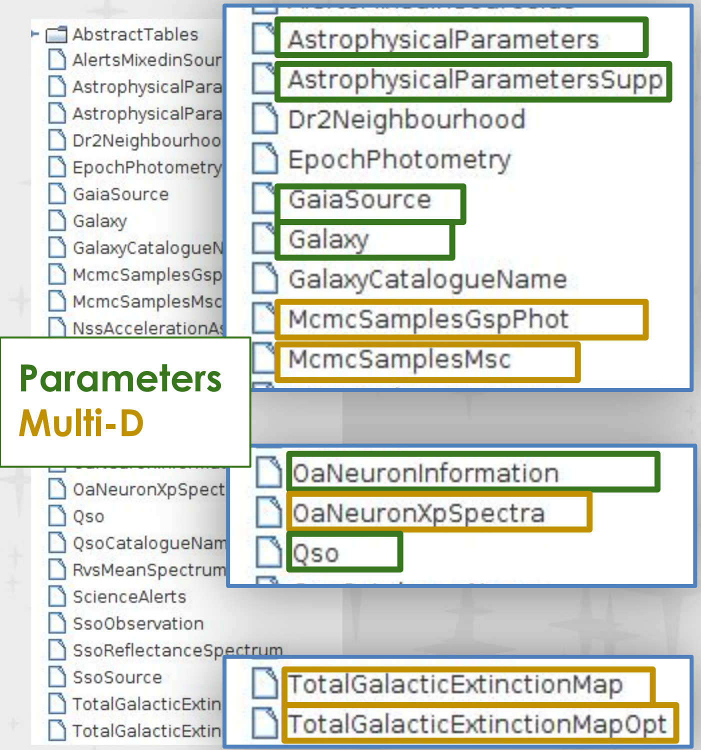
- Classification probability → ~1.8G sources
- APs from XP spectra → ~500M stars
- Evolutionary parameters → ~330M stars
- APs from RVS spectra → ~4.8M stars
- Chemistry from RVS spectra → ~50K - 4.3M stars
- Redshifts → ~1.3M unresolved galaxies + ~1.8M QSOs
- Activity index, Ha EW, emission line stars classes, hot star classes, binary
- 2D map of total Galactic extinction
- Outlier analysis (self-organised map and statistics)

Quite rich and complex dataset, stored in 11 different archive tables

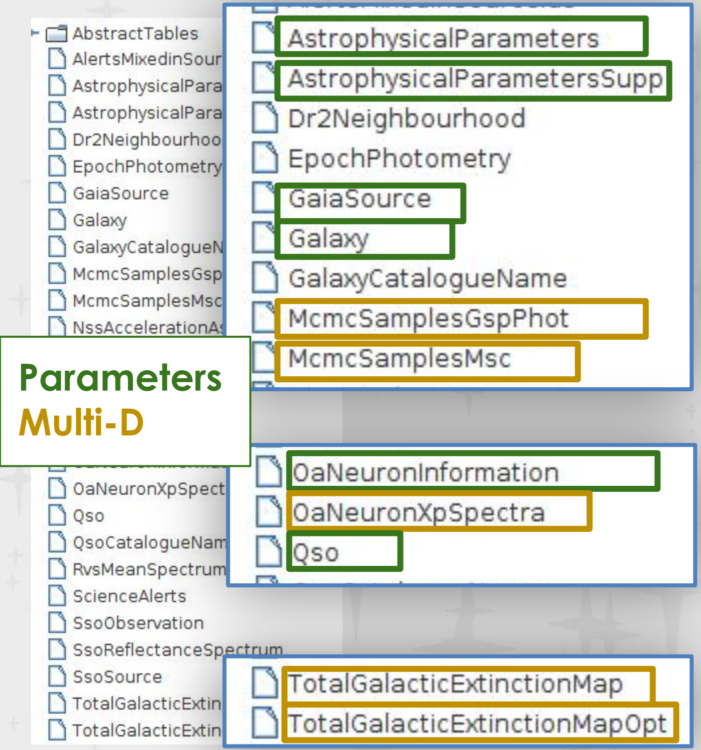
Where are all of these parameters?

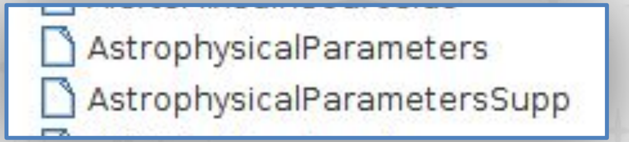
- AbstractTables
  - AlertsMixedinSourceids
  - AstrophysicalParameters
  - AstrophysicalParametersSupp
  - Dr2Neighbourhood
  - EpochPhotometry
  - GaiaSource
  - Galaxy
  - GalaxyCatalogueName
  - McmcSamplesGspPhot
  - McmcSamplesMsc
  - NssAccelerationAstro
  - NssMultipleAstroOrbits
  - NssNonLinearSpectro
  - NssTwoBodyOrbit
  - NssVimFl
  - OaNeuronInformation
  - OaNeuronXpSpectra
  - Qso
  - QsoCatalogueName
  - RvsMeanSpectrum
  - ScienceAlerts
  - SsoObservation
  - SsoReflectanceSpectrum
  - SsoSource
  - TotalGalacticExtinctionMap
  - TotalGalacticExtinctionMapOpt

Where are all of these parameters?



Where are all of these parameters?





teff

Gspphot	teff_gspphot, teff_gspphot_marcs
Gspspec	teff_gspspec, teff_gspspec_ann
Espucd	teff_espucd, teff_espucd_uncertainty
Esphs	teff_esphs, teff_esphs_uncertainty
Msc	teff_msc1, teff_msc2, teff_msc1_upper

Conclusions

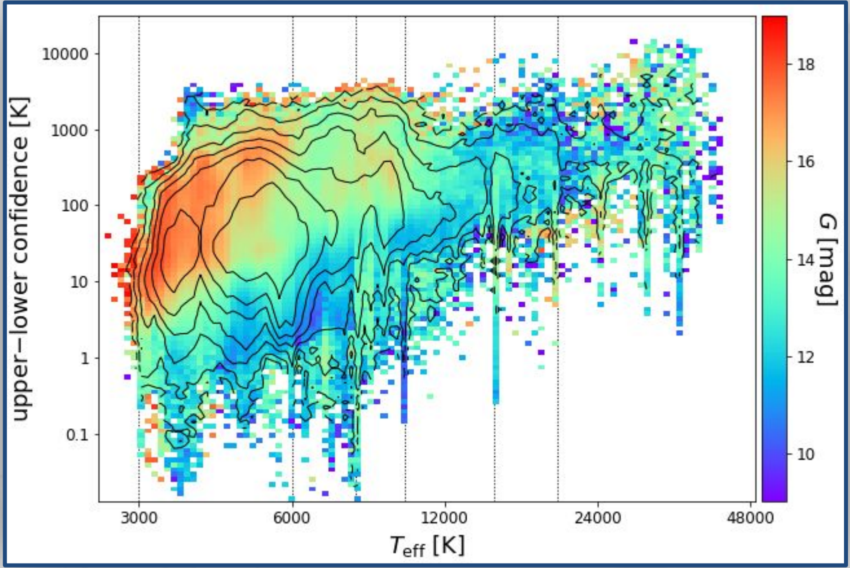
- Gaia DR3 is the first data release for most of CU8
- Process Bp and Rp (mean) spectra, RVS spectra, astrometry, photometry
- Stellar parameterization
  - XP ($10^{8/9}$s): T_{eff}, A_G, logg, [M/H], mass, age, distances, classprob.
  - RVS (10^6s): T_{eff}, logg, [M/H], [X/M], DIB, activity index
  - Multiple values of some APs: tailor to your specific need (hot, cool,...)
- Extra-galactic parameterization:
  - (10^6s) Unresolved galaxy and quasar redshifts, classlabels
- Multi-dimensional tables:
  - MCMCs, self-organised maps, 2D extinction map
- Supplementary material on the following slides

Supplementary material

General Stellar Parametrizer (GSP-Phot)

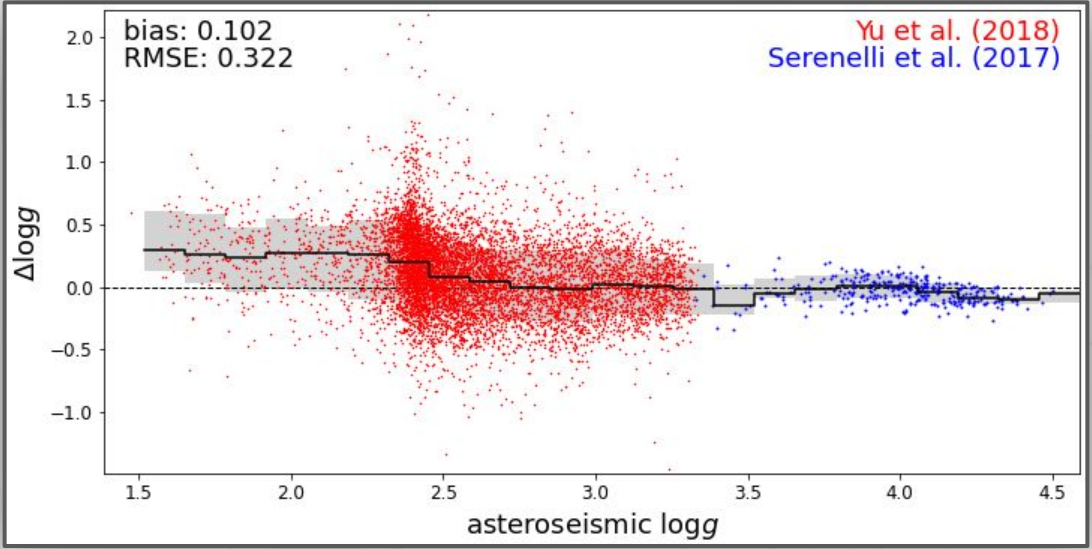
GSP-Phot provides T_{eff}, A_G logg, [M/H], E(Bp-Rp), A0 from XP spectra and, using isochrones, distance, absolute magnitude and radius

500M stars (G<19) 2500 < Teff < 55000



<u>Figure:</u> `teff_gspphot_upper – teff_gspphot_lower` (uncertainties) as a function of `teff_gspphot` and colour-coded by observed G magnitude. The contours denote density of sources.

General Stellar Parametrizer (GSP-Phot)



Comparison of `logg_gspphot` with logg derived from asteroseismology for **dwarfs** and **giants**

Extended Stellar Parametrizer: Emission Line Stars (ESP-ELS)

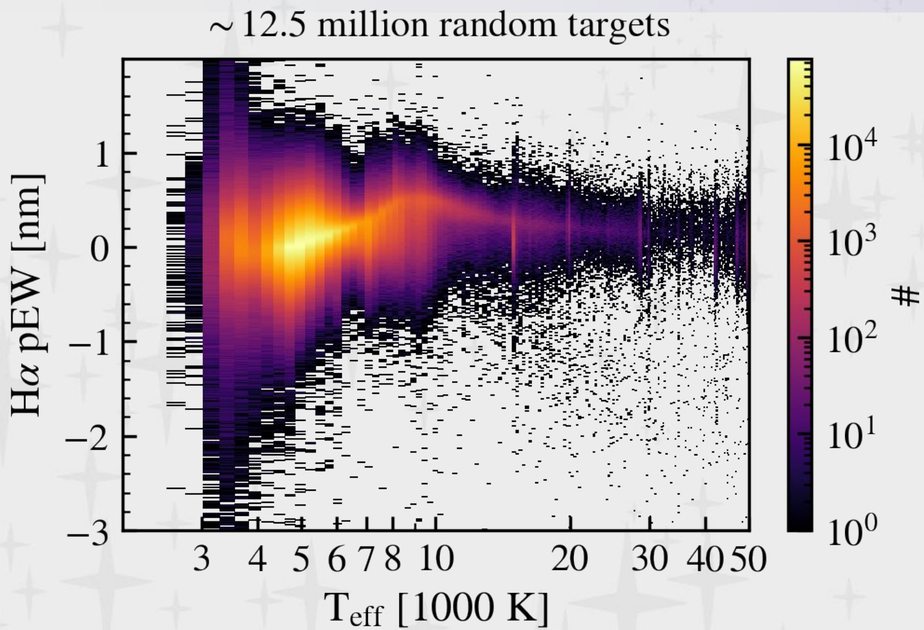


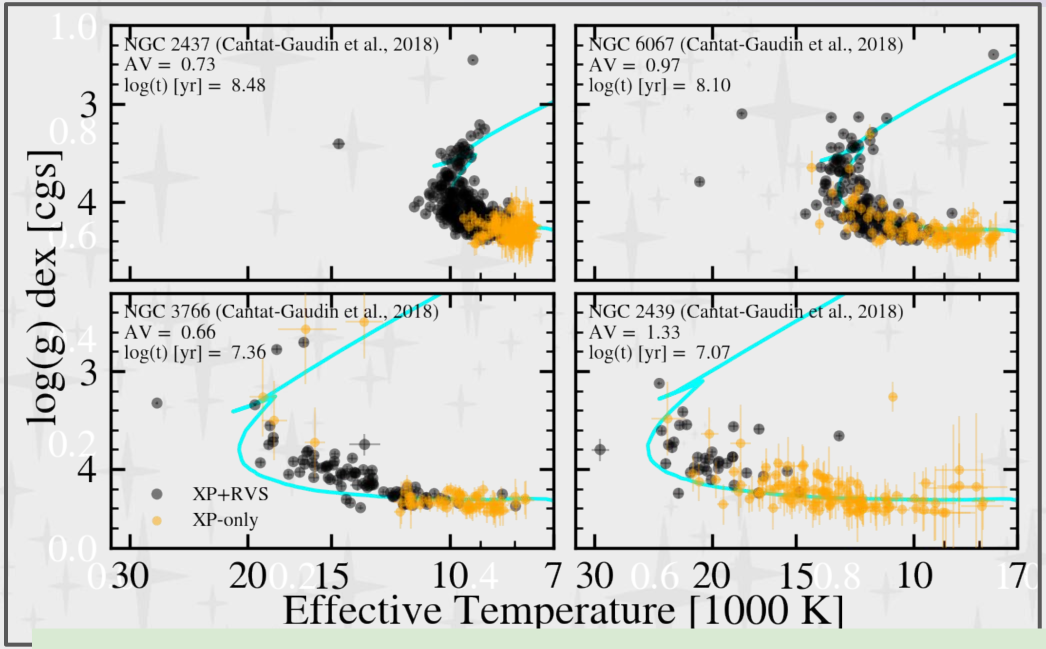
Figure: Effective temperature variation of the Hα pseudo equivalent width (pEW) of targets with and without emission. Below Teff 5000 K, the value measured on the closest synthetic spectrum was subtracted from the observed value to take into account blends with other spectral lines and molecular bands (eg. TiO).

Goals: measurement of Hα pseudo-equivalent width, spectral type tagging (carbon star, M, K, G, F, A, B, O), classification of emission-line stars in terms of 7 (candidate) classes: Wolf Rayet (WC, WN), Be star, Herbig Ae/Be, T Tauri, dwarf Me, planetary nebula

Method: random forest algorithms trained on synthetic spectra and observations

GDR3 parameters: Hα pEW on observed spectrum, Hα pEW theo. on closest synthetic spectrum (GSP-Phot APs), class label (WC,WN, …) and corresponding probabilities, spectral type tag (carbon star, M, K …)

Extended Stellar Parametrizer: Hot Stars (ESP-HS)



*Kiel diagram of open clusters. Surface gravities and effective temperatures were derived by using **RVS and XP spectra**, or by using **XP spectra only**. Cluster membership and age are taken from Cantat-Gaudin et al, 2018. The closest isochrone (Bertelli et al. 1994) is shown in cyan.*

Method: Fitting of synthetic spectra to **XP+RVS** or **XP-only** data.

GDR3 parameters: Teff, log(g), A0, AG, E(BP-RP), [v.sin(i)], assuming [M/H] = 0

Validity range: > 7500 K, log (g): 2.5/3 - 4.75, A0 < 10

Expected number of sources: ~ 3 million A, B, and O targets. Completeness ~ 70%. G < 17.6

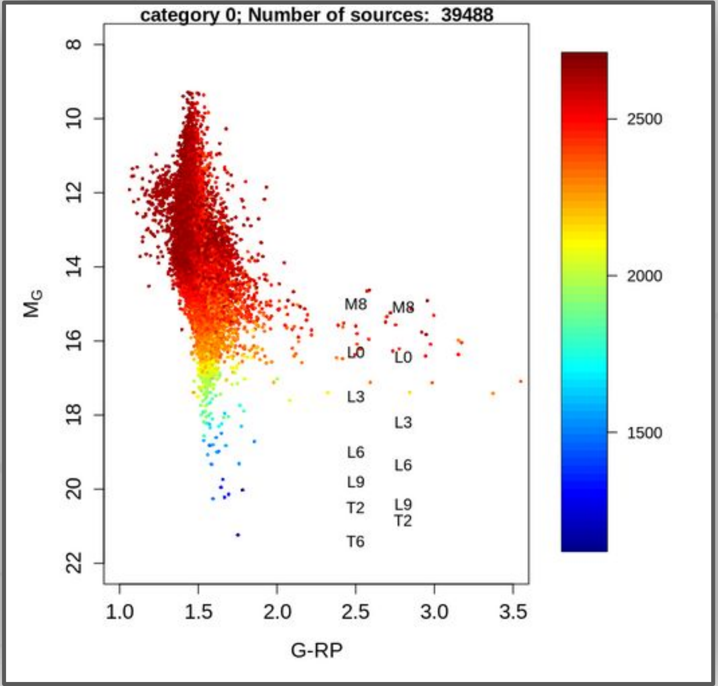
	Uncertainty Teff [K]	Uncertainty log(g) [dex, c.g.s]
A	~300 to 500	~0.2 to 0.3
B	~1000 to 2000	~0.2 to 0.4
O	~4000 to 7000	~0.4 to 0.7

Extended Stellar Parametrizer - ultra-cool dwarfs (ESP-UCD)

The ESP-UCD module derives effective temperatures (with uncertainties and flags) for ultra-cool dwarfs

Expected Number of sources: ~ 10^5 (many of these sources are on the hotter side of UCDs)

Validity range: 500 - 2700 K



Caption: CMD of category 0 sources (best). The colour code reflects the `teff_espucd` inferred by the module. The spectral types shown correspond to a calibration based on the Gaia UltraCool Dwarf Sample (GUCDS; left) and Stephens+ (2009, right)

Final Luminosity Mass Age Estimator (FLAME)

FLAME derives the radius, luminosity, mass, age, evolution stage, and gravitational redshift for stars processed by GSP-Phot and GSP-Spec down to G<18.25

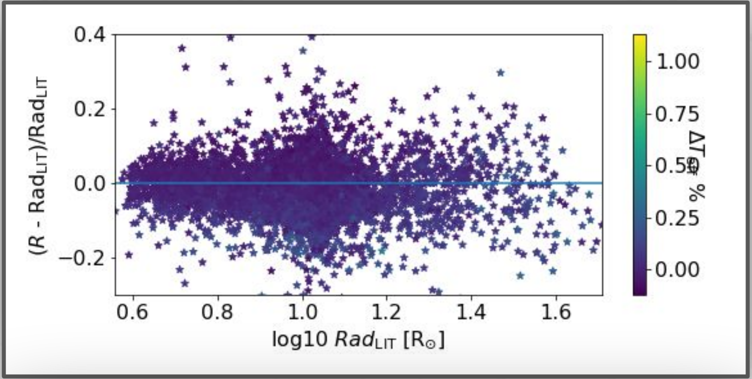
Validity ranges and Numbers:

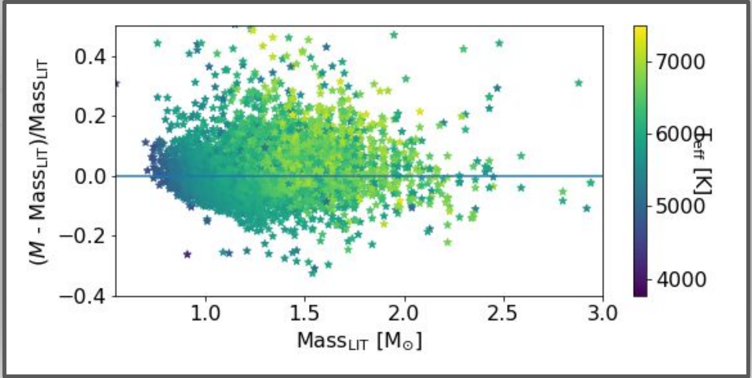
300M sources based on GSP-Phot APs

Validity range: $2500 < T_{eff} < 20000$

5M sources based on GSP-Spec APs

Validity range: $4000 < T_{eff} < 7500$





<u>Figure:</u> Comparison of `radius_flame` (upper) and `mass_flame` (lower) with Pinsonneault et al 2018 and Casagrande et al. 2011, resp.

Extended Stellar Parametrizer: Cool Stars (ESP-CS)

ESP-CS provides the chromospheric activity index from the Ca IRT for 2.5 million late-type stars

Validity range:
3000 < teff < 8000, 3.0 < logg < 5.0, -1< [M/H] < +0.5

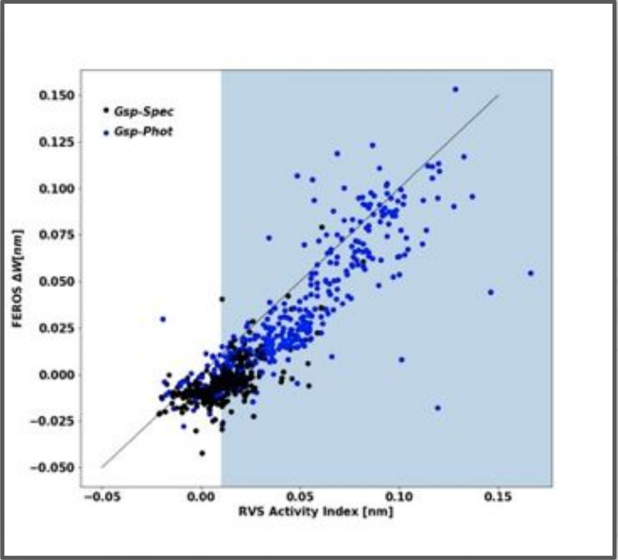


Figure: Comparison of `activityindex_espcs` derived from RVS spectra and FEROS spectra. A small bias on the order of 0.014 nm is seen, with a scatter of 0.015 nm. The different colours indicate whether the spectroscopic parameters were constrained by **GSP-Phot** or **GSP-Spec**

Multiple Star Classifier (MSC)

MSC provides stellar parameters of sources (teff, logg, lumratio, [M/H], A0, AG, distance) assuming a non-resolved binary in Bp and Rp spectra. Two parameters are derived for T_{eff} and logg, e.g. `teff_msc1`, `teff_msc2`

In GDR3 there are results on ~300M sources, with only ~10% being binary. The MCMC quality indicators are useful for finding reliable parameter estimates.

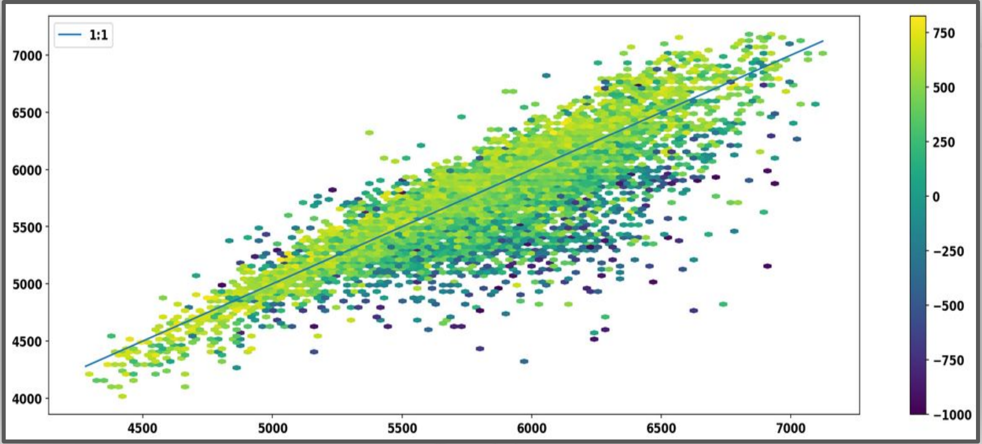


Figure: Comparison of T_{eff} of primary component from MSC `teff_msc1` (y-axis) with the T_{eff} from Traven+2020 (~10k GALAH sources, x-axis). Colour-code indicates quality of fit

DSC: probabilistic classification

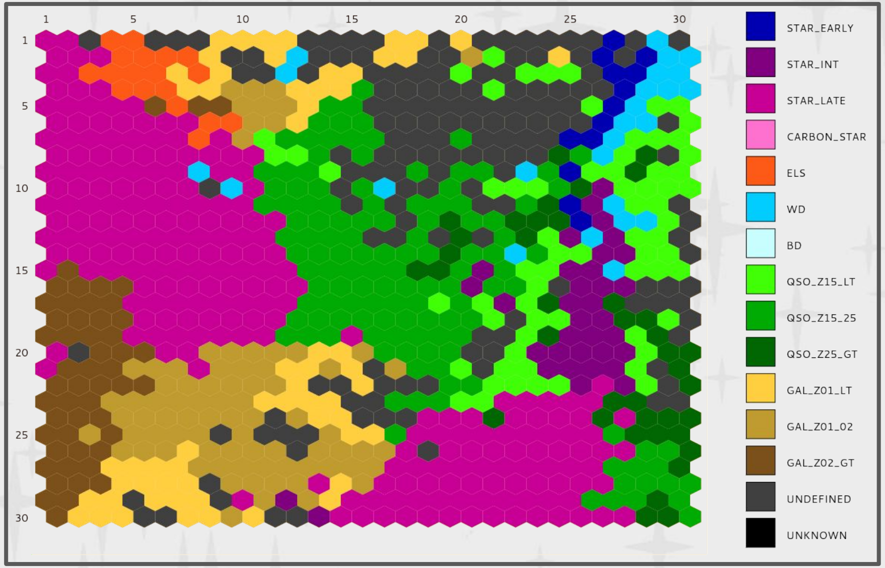
Probabilistic classification using XP spectra, colours, astrometry, and G-band variability of 1.8 billion sources into 5 classes: galaxy, quasar, star, binary, white dwarf, in the archive as `classprob_dsc_xxxxx`.

From this we extract a high completeness, low purity, sample of nearly 10 million quasars and galaxies, together with a class label (`classlabel_dsc_joint`) indicating a purer subset of 550k quasars and 250k galaxies.

	`classprob_dsc_combmod > 0.5`			
	classlabelDsc		**& classlabelDscJoint**	
	completeness	**purity**	**completeness**	**purity**
Quasar	0.916	0.240	0.385	0.621
Galaxy	0.935	0.219	0.826	0.638

Outlier Analysis (OA)

The OA module performs unsupervised classification using Self-Organized Maps and a statistical description/quality assessment/class labeling for the neurons (group of similar objects). It analyses objects that have no class probability > 0.5 for DSC classes (galaxy, quasar, star, binary, white dwarf)



36% of high quality neurons represent 54% of the sources, and were labeled using reference templates for different astronomical types of objects.

47% of intermediate quality neurons represent 35% of the sources, present heterogeneous spectra, typically quasars.

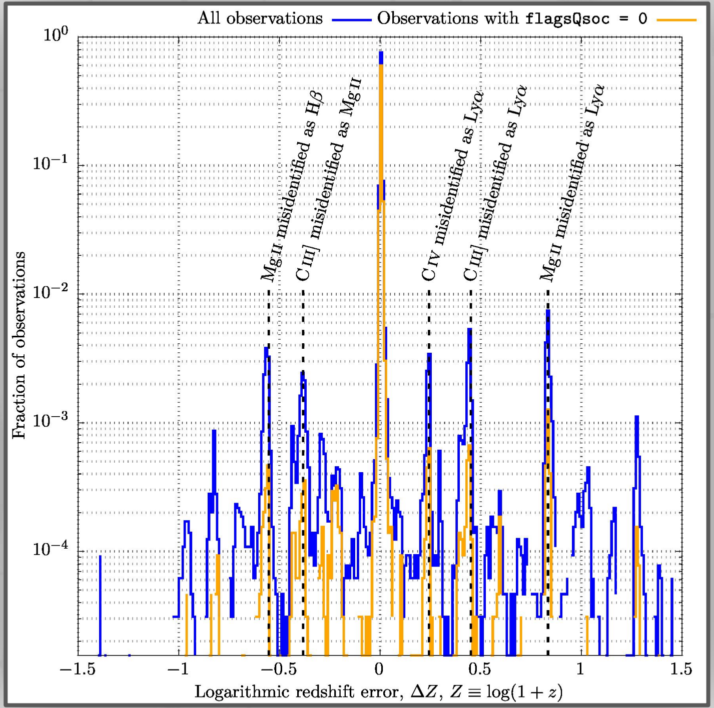
17% of the neurons were assigned a low-quality index and they represent 11% of the sources, which have a few number of transits and very heterogeneous spectra, such as artifacts.

QSOC: qso redshift prediction

QSOC predicts the redshift (z) for ~1.8M qsos
Validity range: $0 \leq z \leq 6$

81% of the G < 20 mag quasars have $|\Delta z| < 0.1$
Resp. 96.5% if flagQsoc = 0

<u>Figure:</u> Comparison of the redshift as predicted by QSOC against values from the literature for $17 \leq G \leq 19$ mag quasars. The logarithmic redshift scale highlights the common degeneracies existing in the prediction of the redshift that are mostly due to mismatches between emission lines. The presence of a quality flag, flagQsoc, allows to mitigate the effect of these degeneracies without affecting too much the central peak.



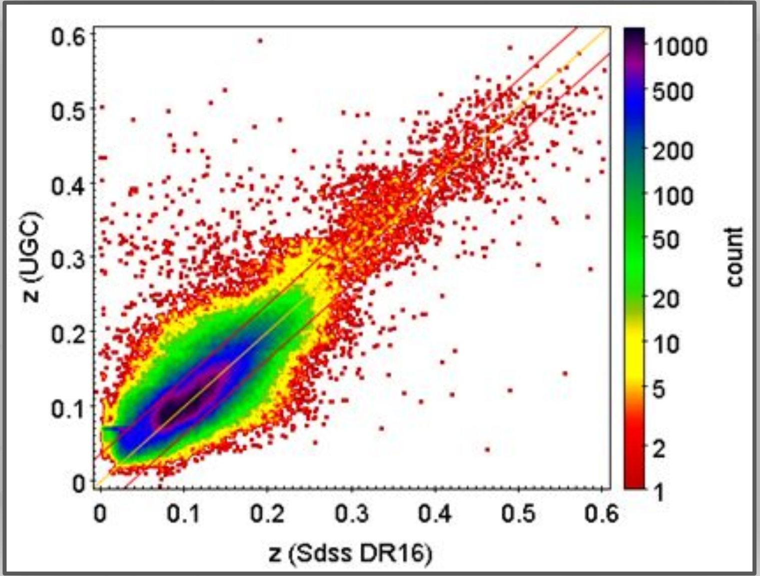
UGC: galaxy redshift from Unresolved Galaxy Classifier

The UGC module derives the galaxy redshift of non-resolved galaxies for ~ 1.1M

Validity range: $0.0 \leq z \leq 0.6$

UGC Implements Support Vector Machine (SVM) models using Gaia BP/RP spectra. Trained with ~6K Gaia observed "reference" galaxies with known redshifts (SDSS DR16).

UGC results validated against ~300K SDSS DR16 galaxies cross-matching Gaia observed sources. The standard error of the redshift prediction is ±0.037



Comparison of the predicted z (UGC) with the redshift z (SDSS) of reference galaxies. The error range is indicated by the red lines.

Thank you for your attention

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