ESP-ELS and ESP-HS modules

Focused processing of hot (OBA) & emission-line stars for Gaia DR3

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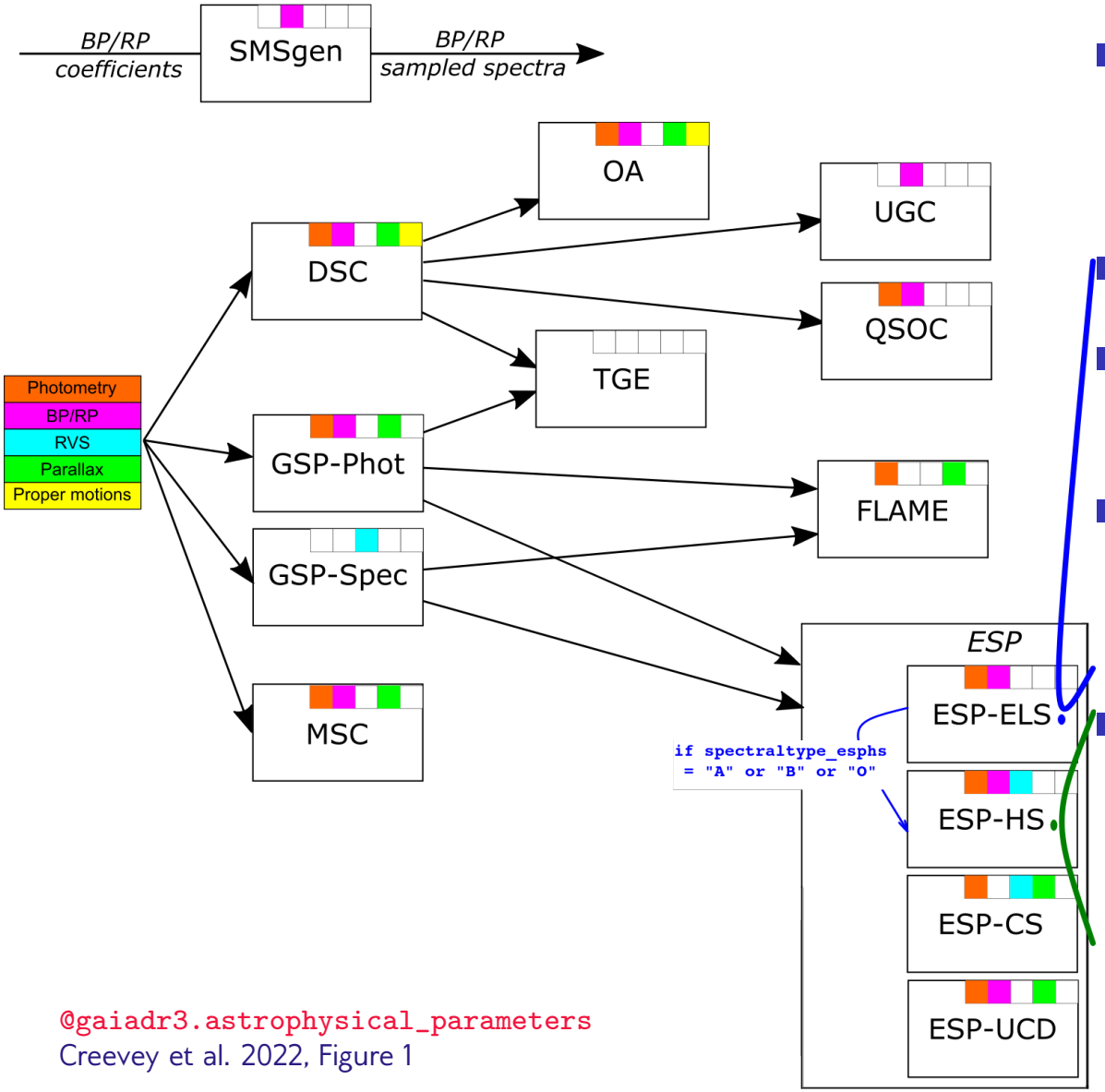
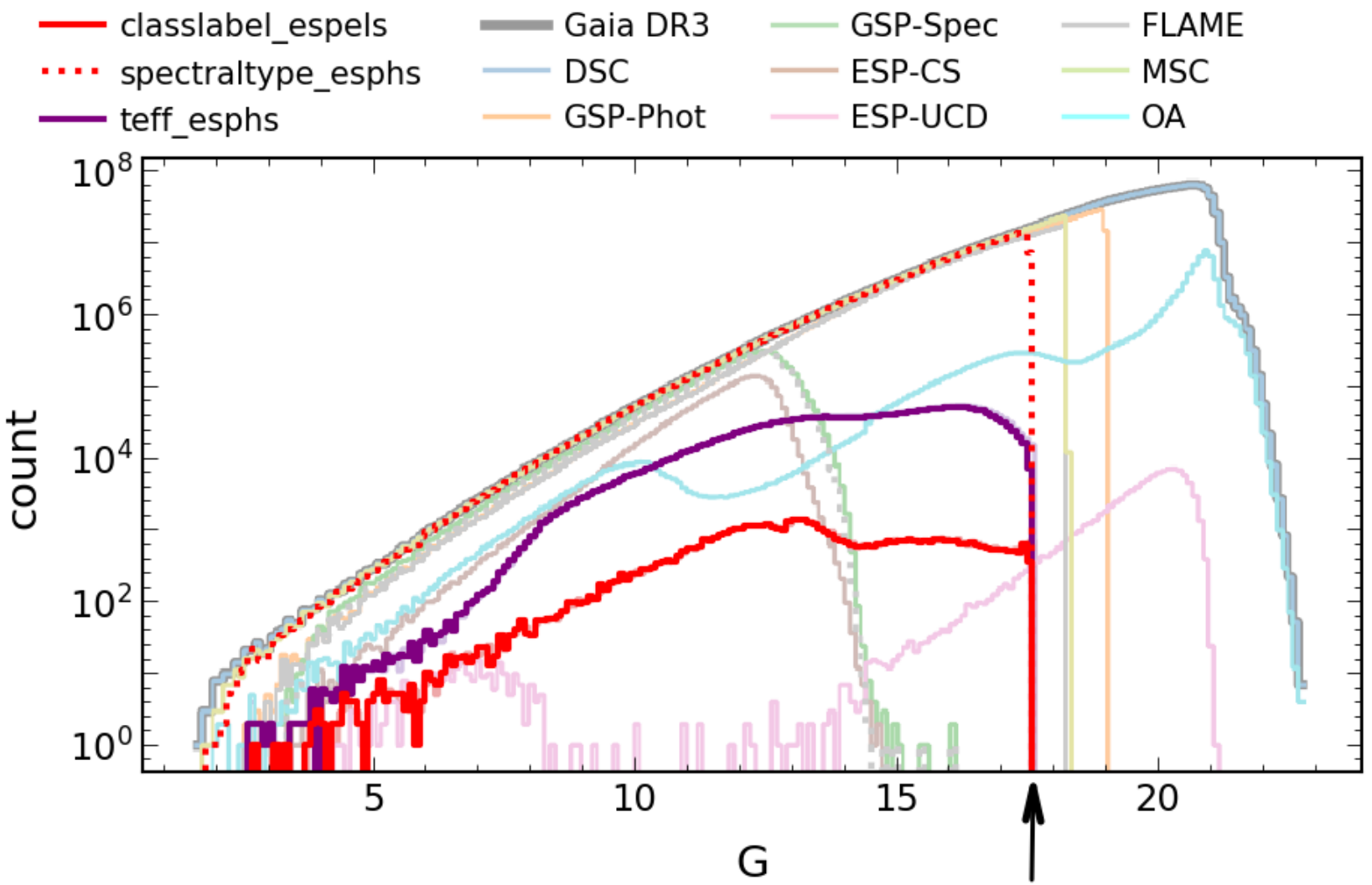
Apsis & ESP Workflows



@gaiadr3.astrophysical_parameters
Creevey et al. 2022, Figure 1

- Extended Stellar Parametrizer: ELS (Emission-Line Stars) and HS (Hot Stars)
- `spectraltype_esphs`
- `classlabel_espels`, `classprob_espels_...`
- `ew_espels_halpha`, `ew_espels_halpha_model`, `ew_espels_halpha_flag`
- `teff_esphs`, `logg_esphs`, `azero_esphs`, `ag_esphs`, `ebpminrp_esphs`, `(vsini_esphs)`

Output: Magnitude Distribution



Adapted from Creevey et al. 2022, Figure 2

ESP-ELS/HS magnitude cut at G=17.65

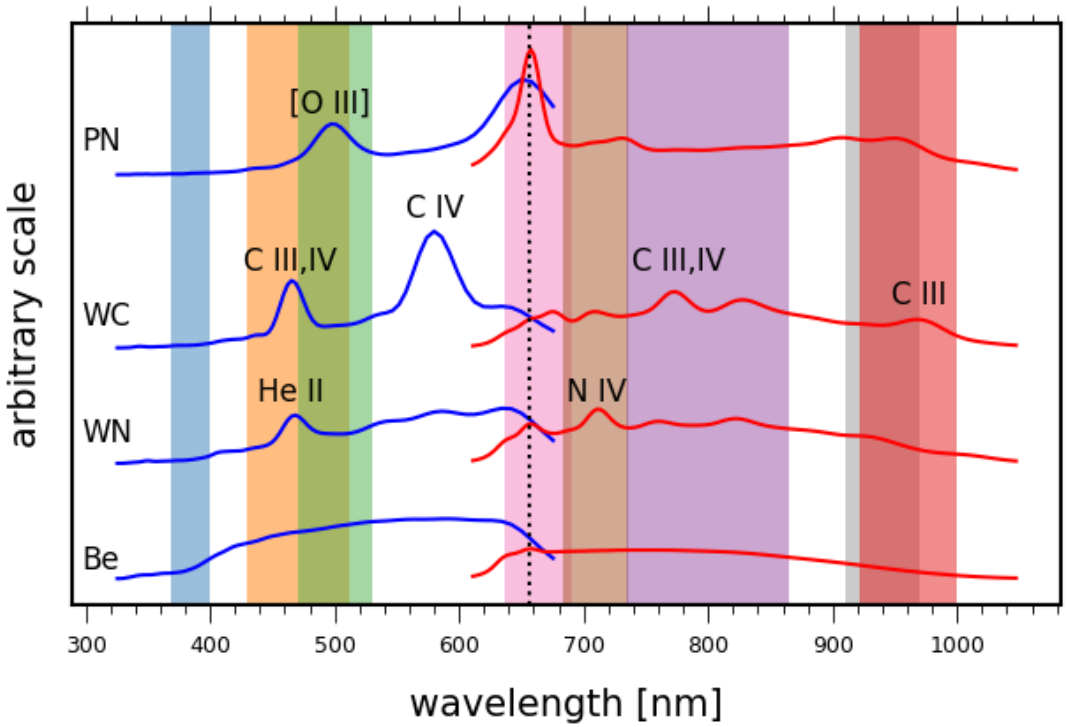
Presentation Outline

- ESP-ELS
  - Methods
  - Results
- ESP-HS
  - Methods
  - Results
- Overview & DR3 to DR4

Classification of Emission-Line Stars (ELS): Methodology

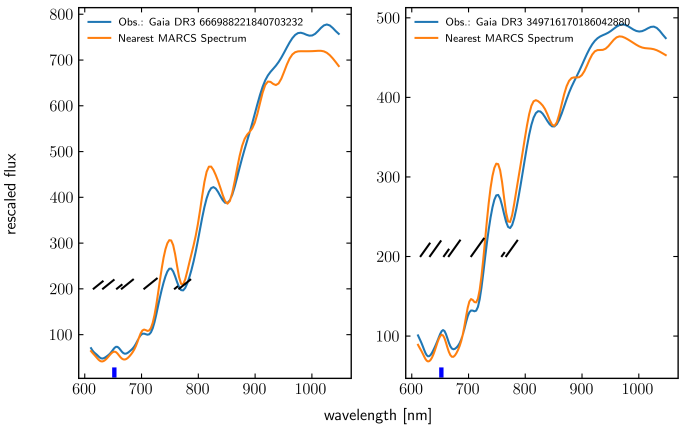
- Apsis only processes co-added spectra, not externally calibrated
- Division by a mean 'response' curve
- Extraction main emission features in the BP and RP
- Locally normalize these
- Combine with GSP-Phot APs (before post-processing) for ELS classlabel

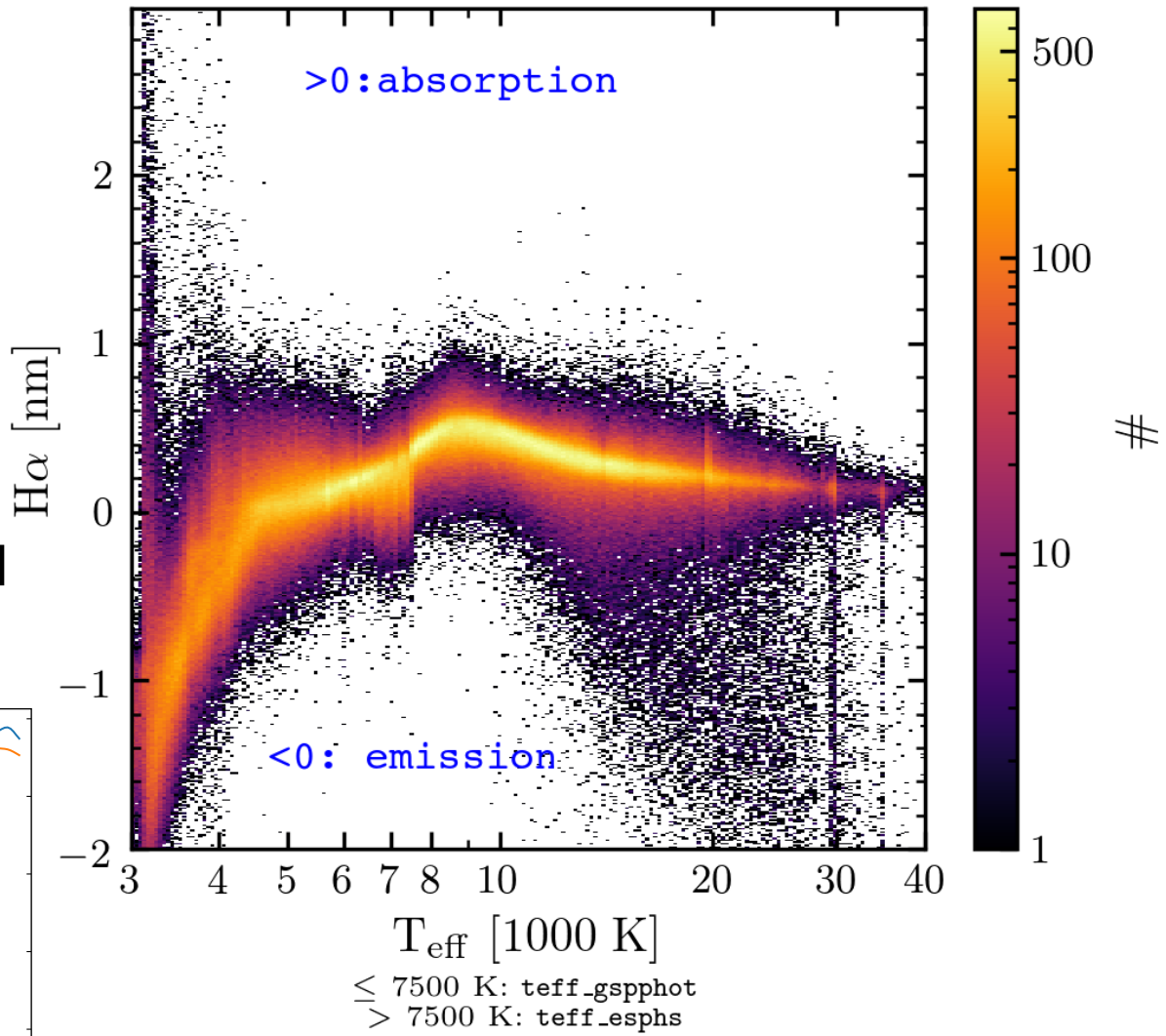
Creevey et al. 2022, Figure 8



Measurement of Hα pseudo-Equivalent Width (pEW)

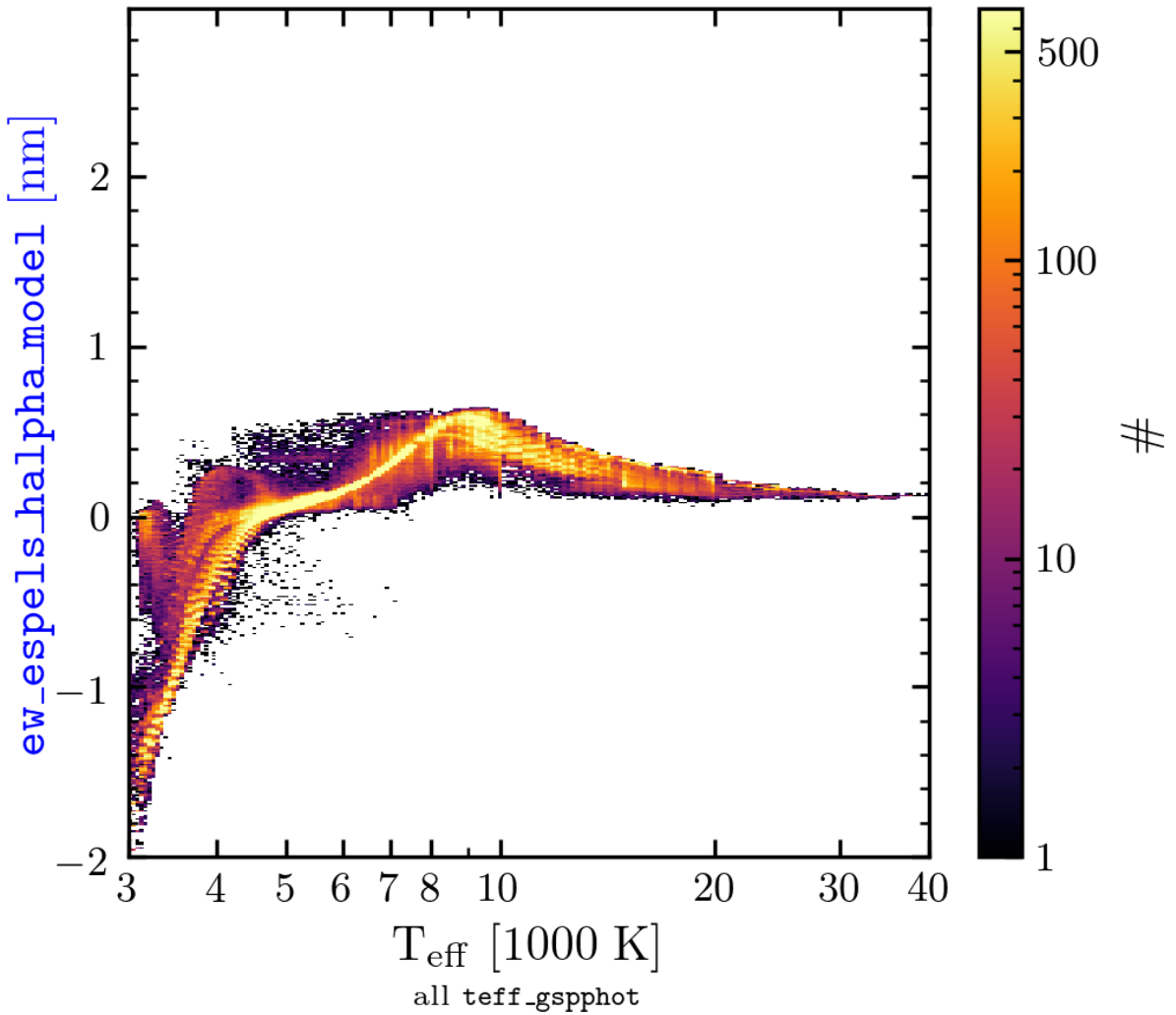
- Facts: at (RP) Hα resolution 8 nm and 2.5 nm samples
- Measurement band: 646 - 670 nm.
- No Hα absorption in M and K stars, but molecule blends bend the continuum.





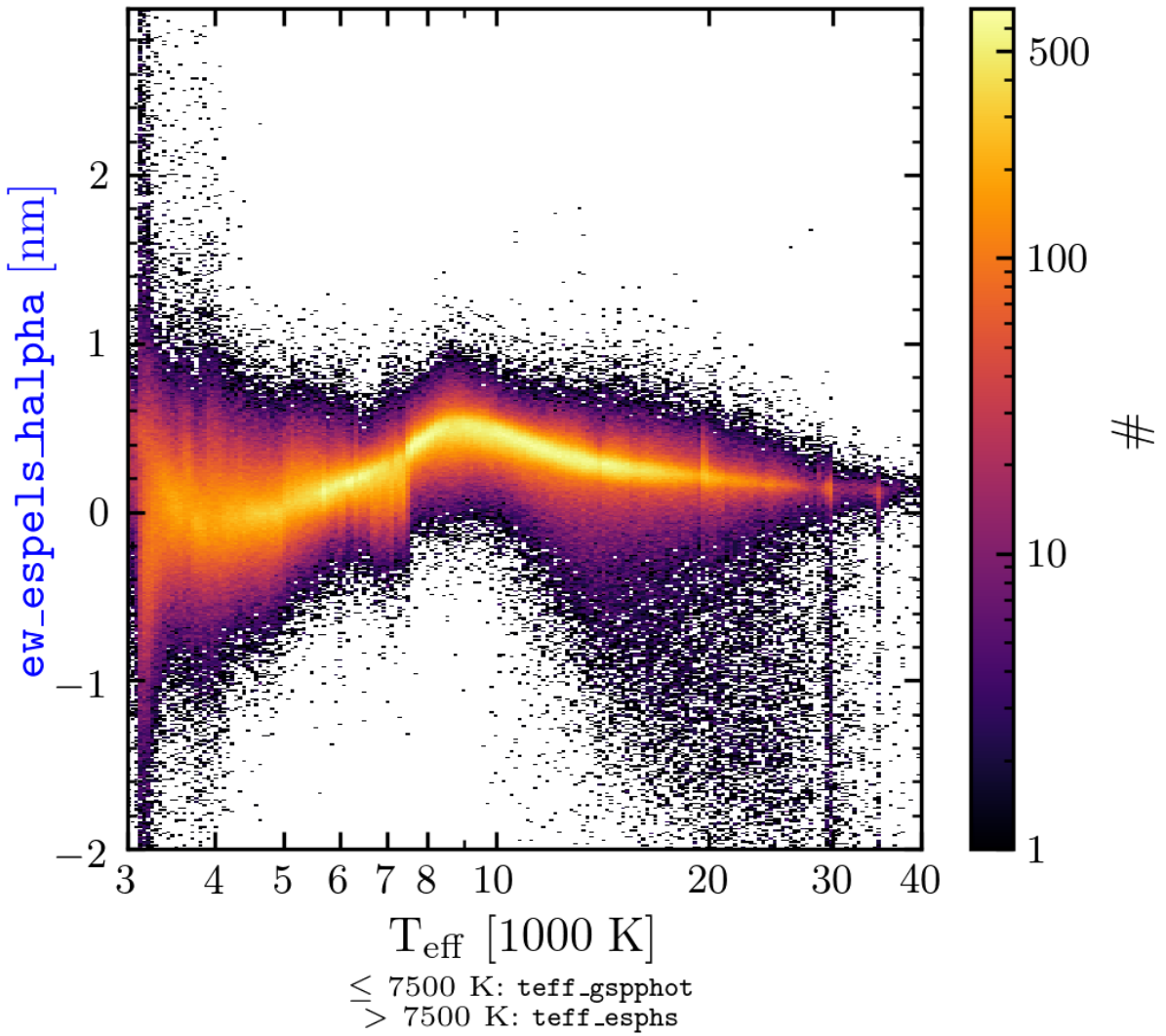
Hα pEW (model ෆ GSP-Phot APs)

- $\sim$2 M. random targets uniformally distributed over $T_{\rm eff}$
- Variations seen in synthetic spectra.
- GSP-Phot APs available (i.e. before post-processing) when Hα is measured
- Model value used to 'correct' at $T_{\rm eff} \leq 5000$K.



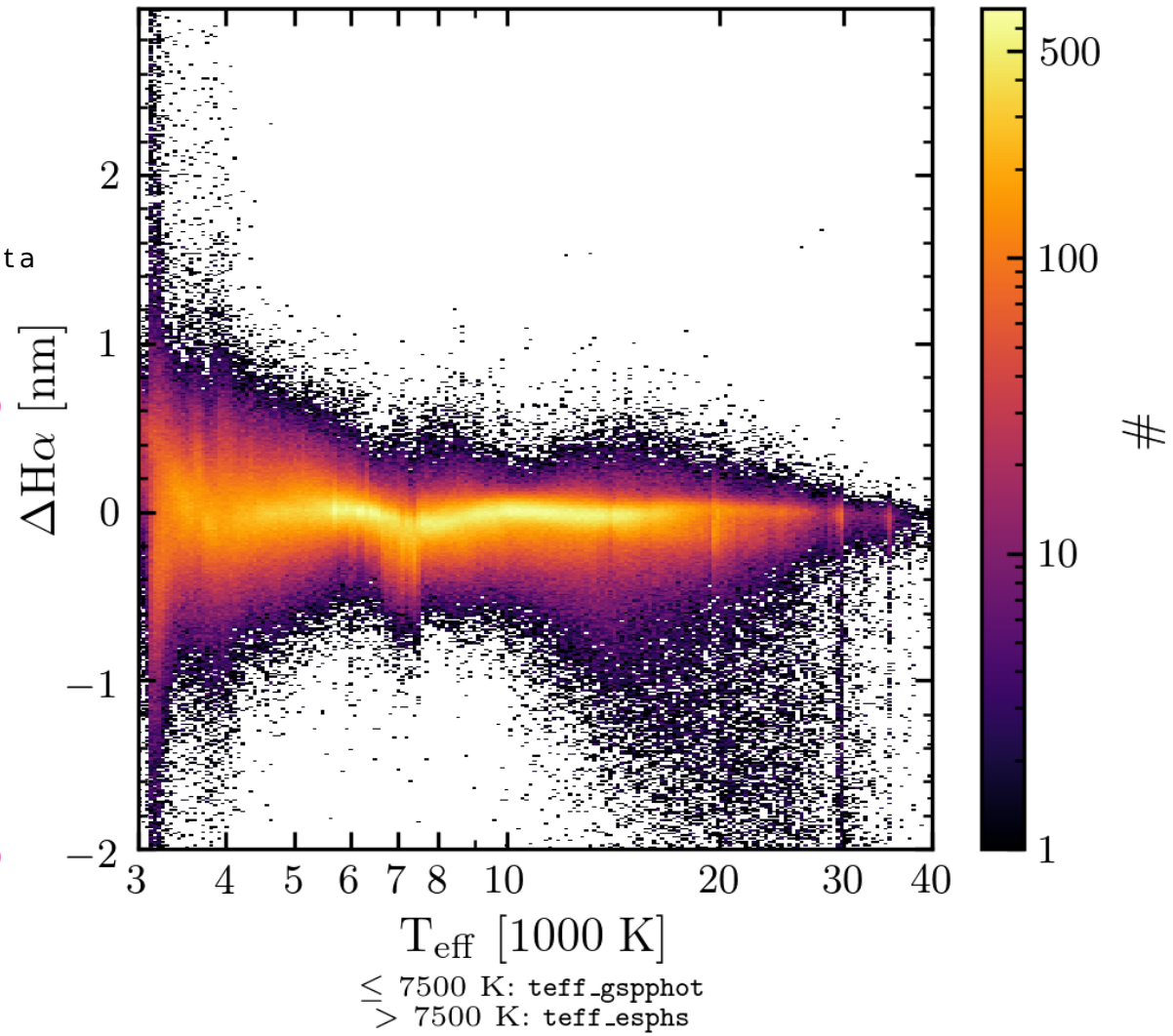
Hα pEW ('corrected' ෆ GSP-Phot APs)

- ew_espels_halpha_flag: 0 (model not subtracted), 1 (model subtracted)
- stored in ew_espels_halpha
- ew_espels_halpha_model allways present
- pEW used to trigger/identify ELS



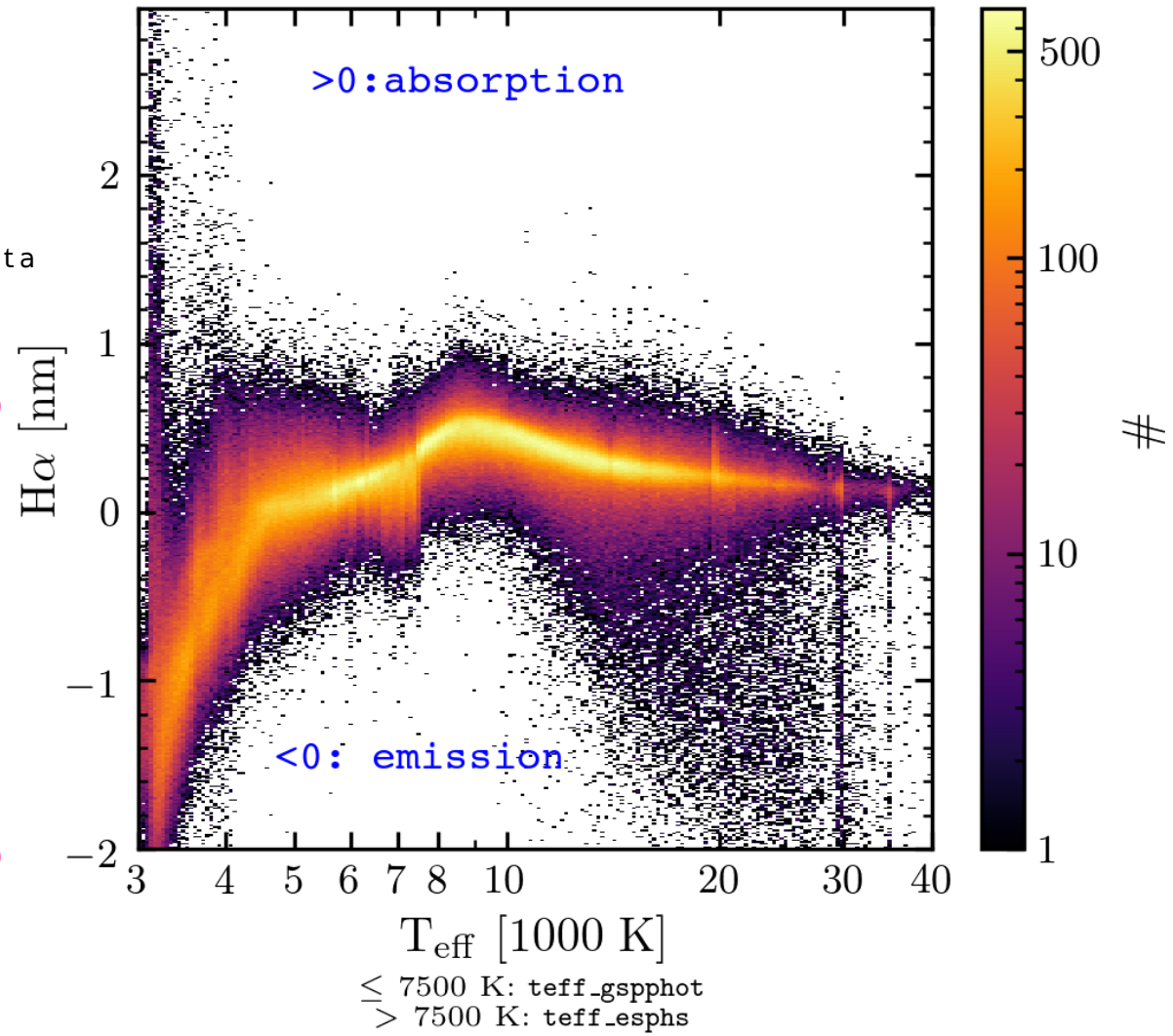
Hα pEW (all 'corrected' ෆ GSP-Phot APs)

```
SELECT
 TOP 50
 source_id,
 teff_gspphot,
 teff_esphs,
 (ew_espels_halpha
  -ew_espels_halpha_model) AS delta
FROM
 gaiadr3.astrophysical_parameters
WHERE
 ew_espels_halpha IS NOT NULL AND
 ew_espels_halpha_flag = '0'
UNION
SELECT
 TOP 50
 source_id,
 teff_gspphot,
 teff_esphs,
 ew_espels_halpha AS delta
FROM
 gaiadr3.astrophysical_parameters
WHERE
 ew_espels_halpha IS NOT NULL AND
 ew_espels_halpha_flag = '1'
```



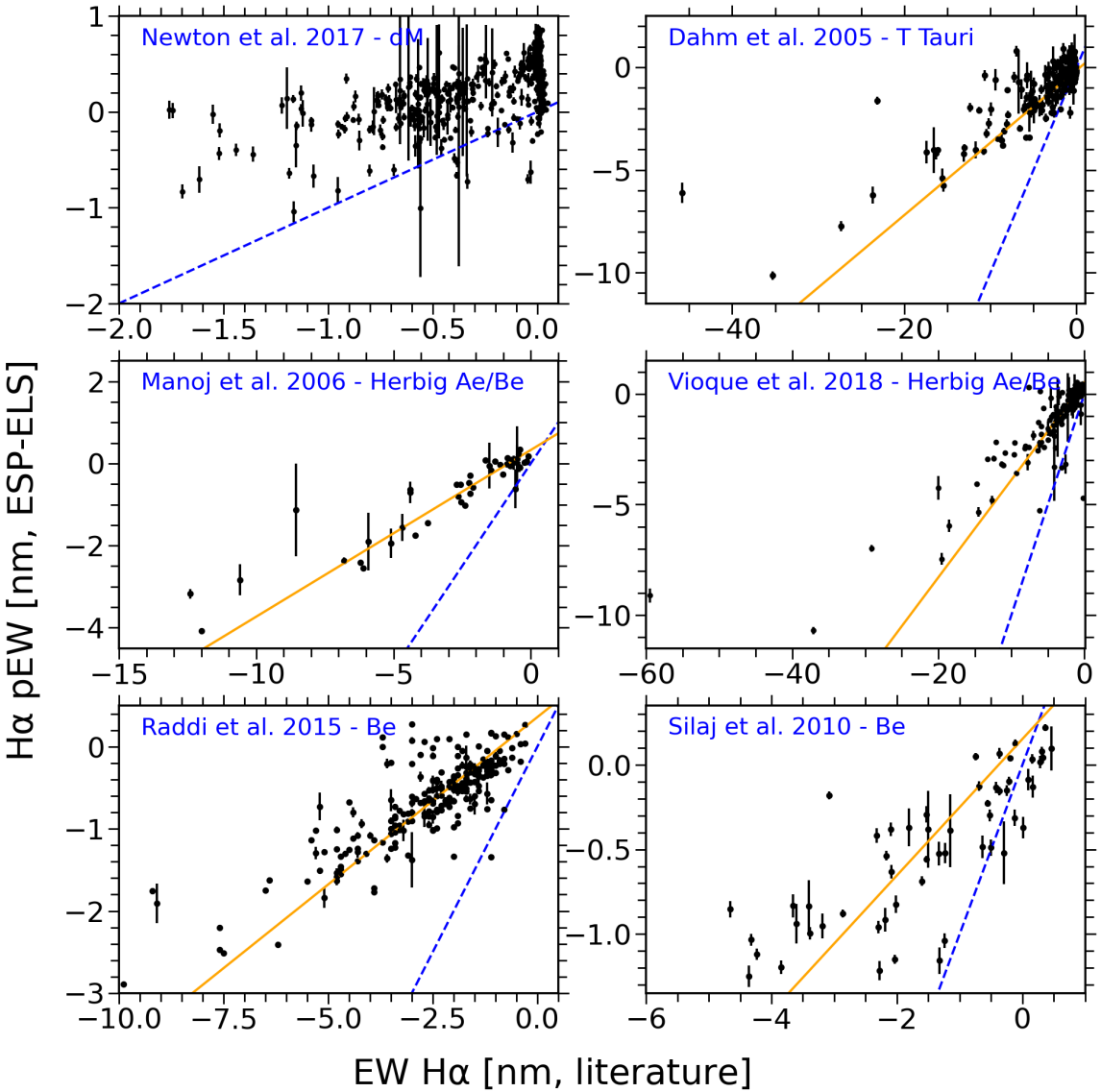
Hα pEW (return to measurement)

```
SELECT
 TOP 50
 source_id,
 teff_gspphot,
 teff_esphs,
 (ew_espels_halpha
  +ew_espels_halpha_model) AS delta
FROM
 gaiadr3.astrophysical_parameters
WHERE
 ew_espels_halpha IS NOT NULL AND
 ew_espels_halpha_flag = '1'
UNION
SELECT
 TOP 50
 source_id,
 teff_gspphot,
 teff_esphs,
 ew_espels_halpha AS delta
FROM
 gaiadr3.astrophysical_parameters
WHERE
 ew_espels_halpha IS NOT NULL AND
 ew_espels_halpha_flag = '0'
```



Gaia DR3 Hα pseudo-Equivalent Width vs Hα

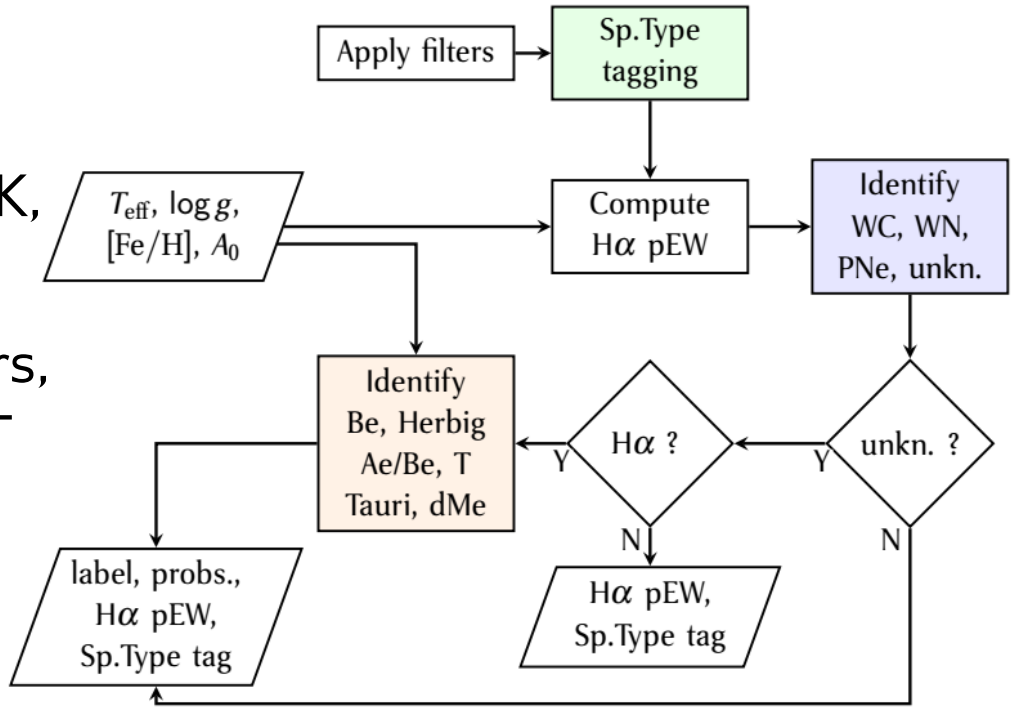
- blue: 1-1 relation
- value 2 to 3 times smaller than expected, worse for M and K stars.
- comparisons with LAMOST: see Shridharan et al. 2022, AA, 668, A156



Fouesneau et al. 2022, Figure 21

ESP-ELS: Labelling Workflow

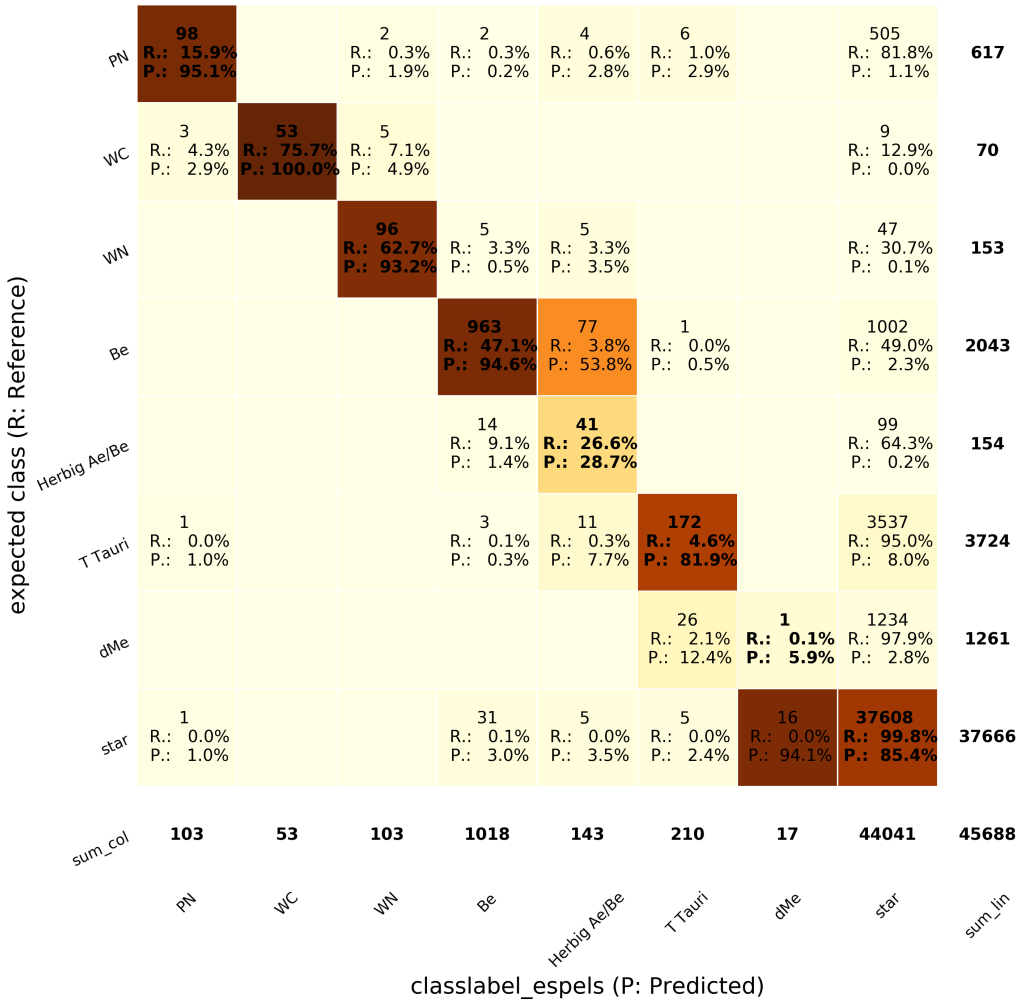
- Three RF classifiers all trained on synthetic and observed data.
- Spectral type tag (`spectraltype_esphs`): M, K, ... B, O, CSTAR
- Identification of WC/WN stars, PN, then Be, Herbig Ae/Be, T Tauri, and active M dwarf stars.
- `classlabel_espels` and `classlabel_espels_flag`
- `classprob_*`



Online Doc. Sect. 11.3.7, Figure 11.37

ESP-ELS: `classlabel` Confusion Matrix

- R/P: horizontally/vertically sums up. Color shades vary with P.
- Most PNs, TTauris and dMes lost, half of Be and Ae/Be stars identified
- Classifier most reliable for Be, WC.
- No filtering during the post-processing.
- `classlabel_espels _flag`: 1 - 4 (50 % probability if ≤ 2).
  - +10 if APs not consistent with `spectraltype_esphs`
  - +20 if APs removed from Gaia DR3 after post-processing.



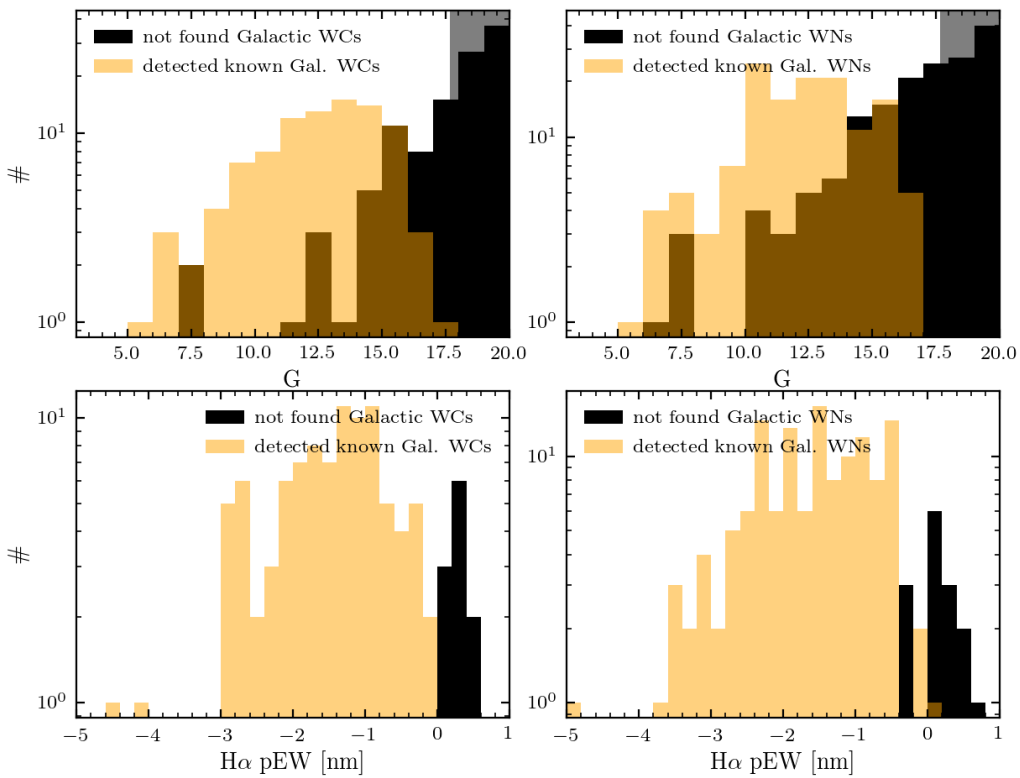
ESP-ELS: classlabel

Fouesneau et al. 2022

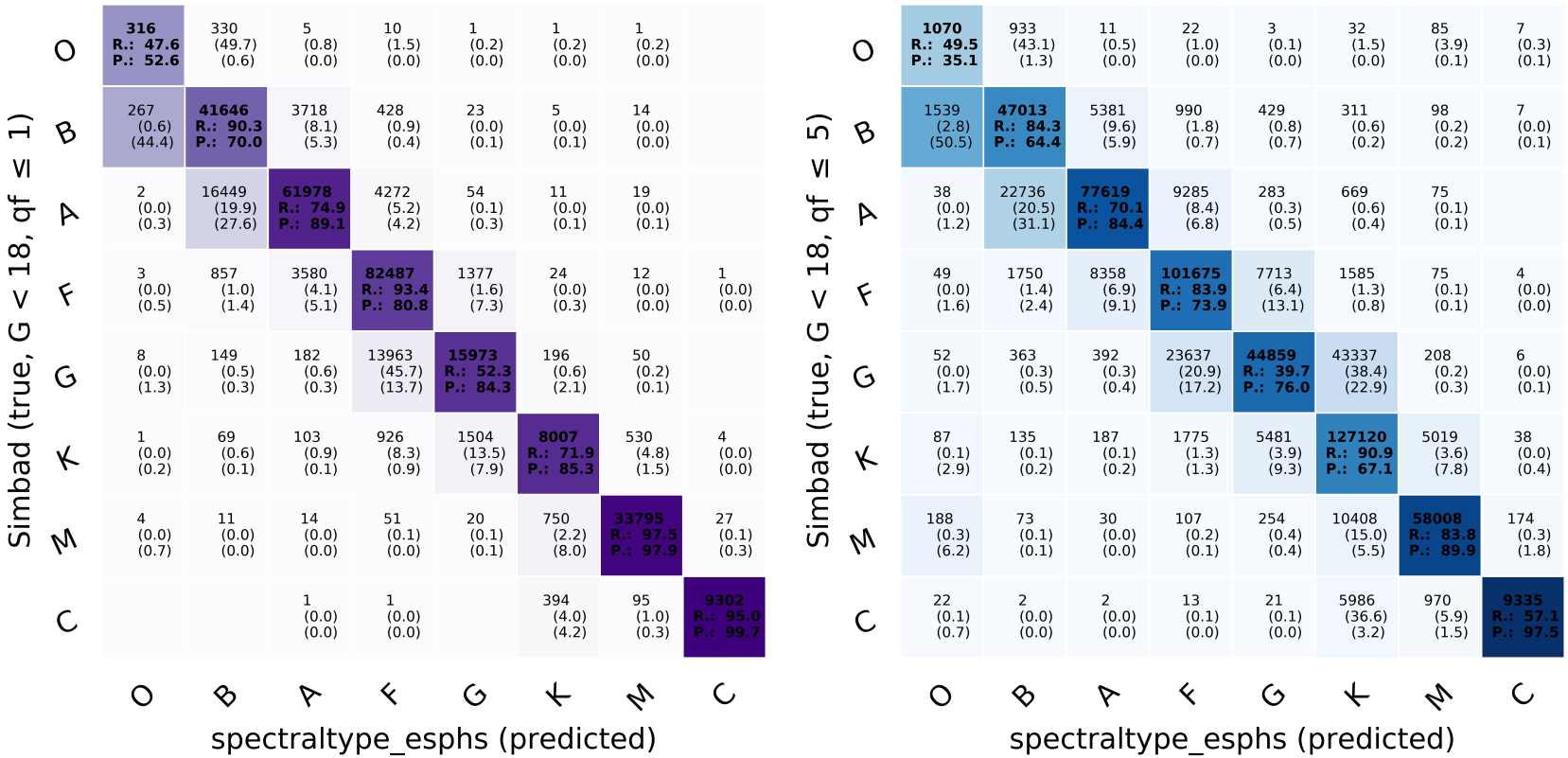
Table 2. Number of identified candidates per ELS class and per quality flag (QF) value. QF ≤ 2 implies a probability larger than 50%.

Class	classlabel_espels_flag (QF)						
	0	1	2	3	4	10-14	20-24
Be	3 210	3 118	2 815	2 332	1 475	122	3 879
Ae/Be	35	94	231	519	972	299	1 754
T Tauri	914	2 052	1 594	1 083	740	1 180	27 594
dMe	0	1	5	54	178	43	380
PN	37	52	83	85	16	0	0
WC	106	13	8	7	2	0	0
WN	173	38	29	142	47	0	0

- 57939 not null classlabel_espels
- classlabel_espels_flag ≤ 2
- See Online Doc. Sect. 11.3.7 (Results), e.g. Figure 11.41



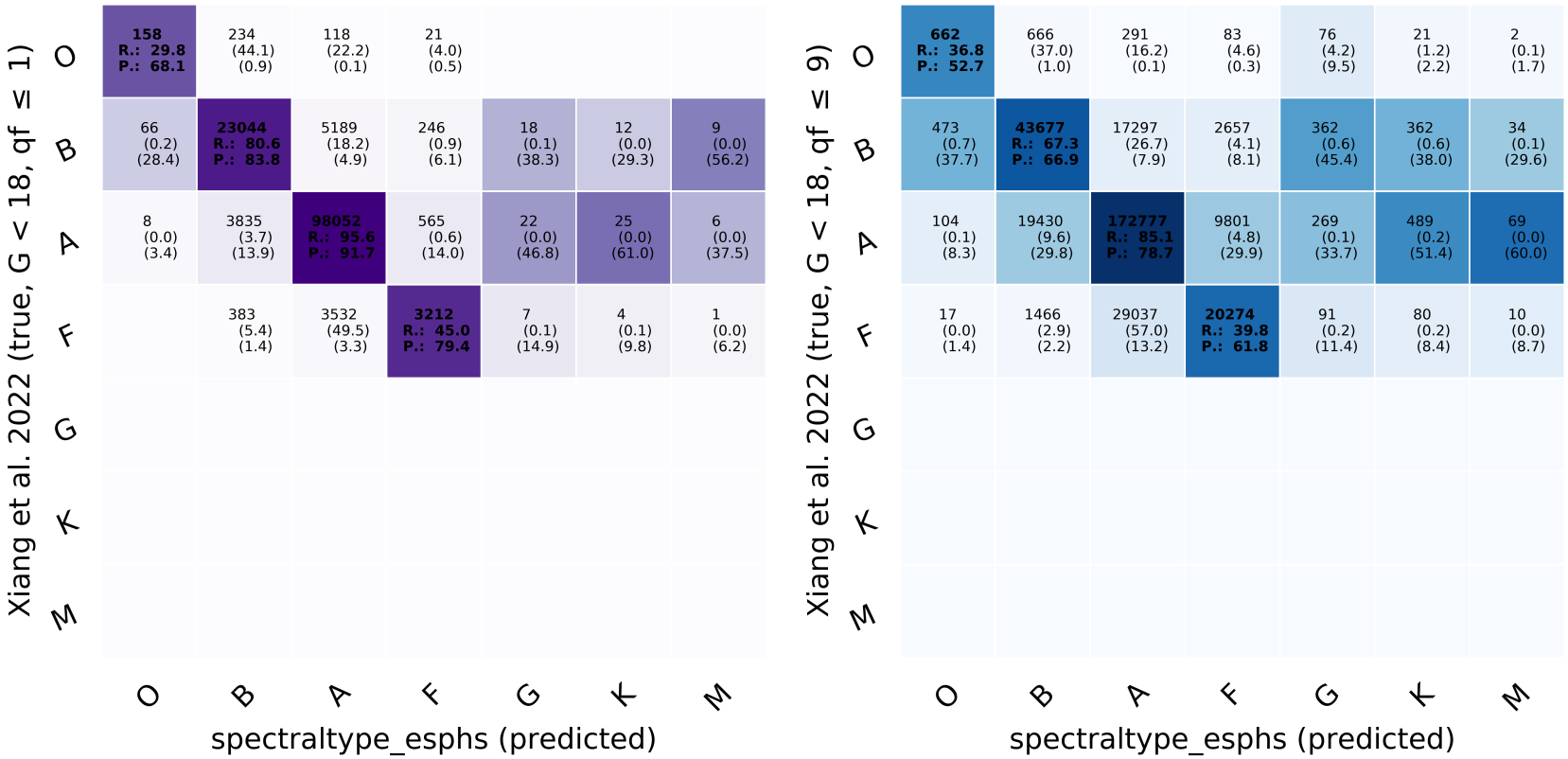
spectraltype_esphs vs Simbad



- qf=flags_esphs[1:2]
- color shades vary vertically, with lower (P) percentage in the cell
- contamination from neighbour types expected, but much stronger between O and B types

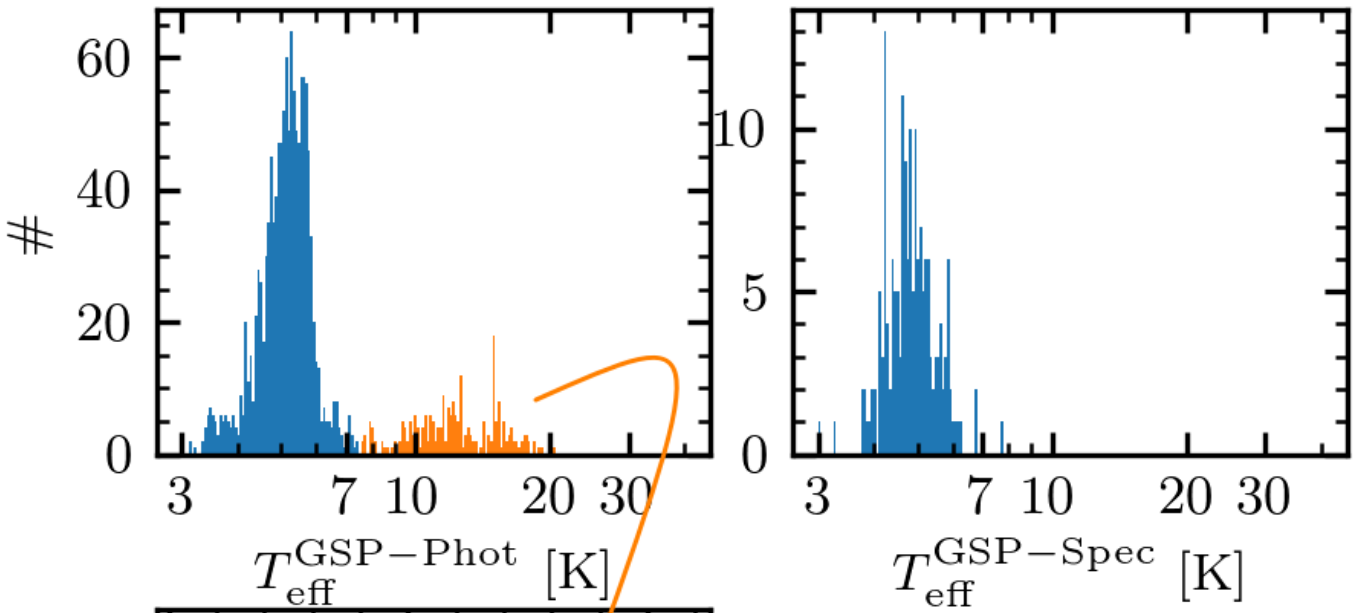
spectraltype_esphs vs LAMOST DR6

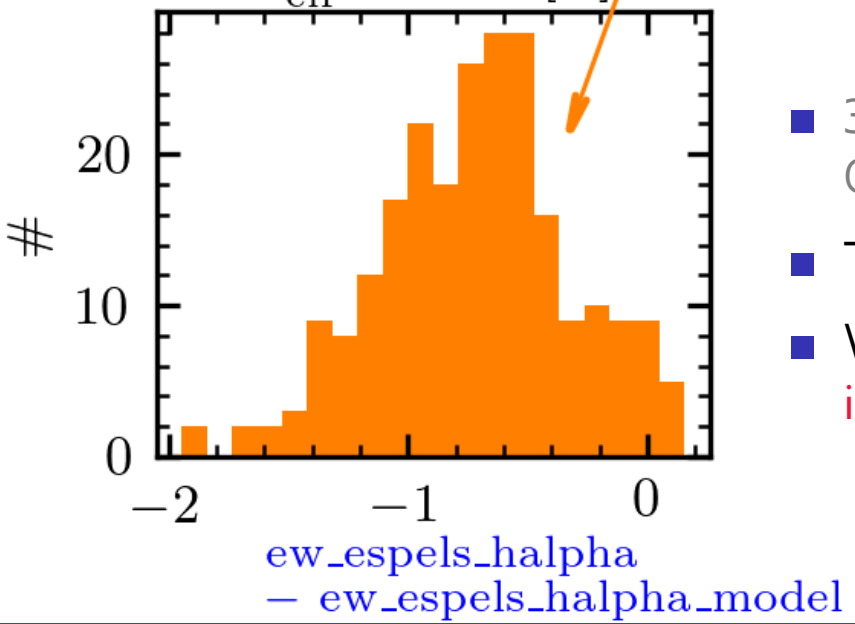
Xiang et al. 2022



- Xiang et al's $T_{\rm eff}$ converted into spectral type tag. See Table A.1 in Creevey et al. 2022.
- 320 578 with ESP tag. 1865 received a G,K or M tag ...

spectraltype_esphs vs LAMOST DR6

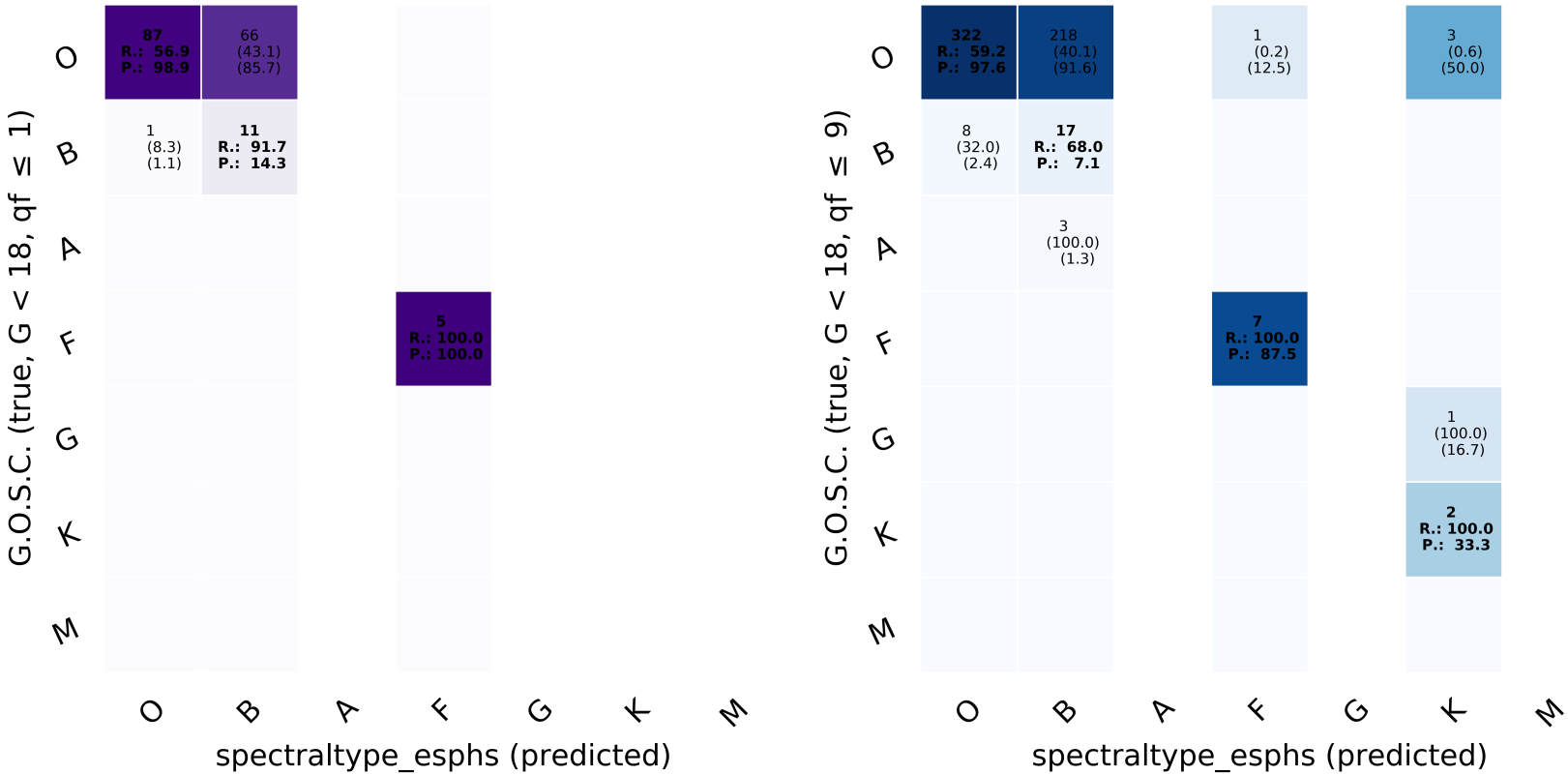




- 320 578 with ESP tag. 1865 received a G,K or M tag ...
- Tag more consistent with GDR3 results
- Wrong tag: probably due to x-match issues or due to emission.

spectraltype_esphs vs Galactic O Star Catalogue

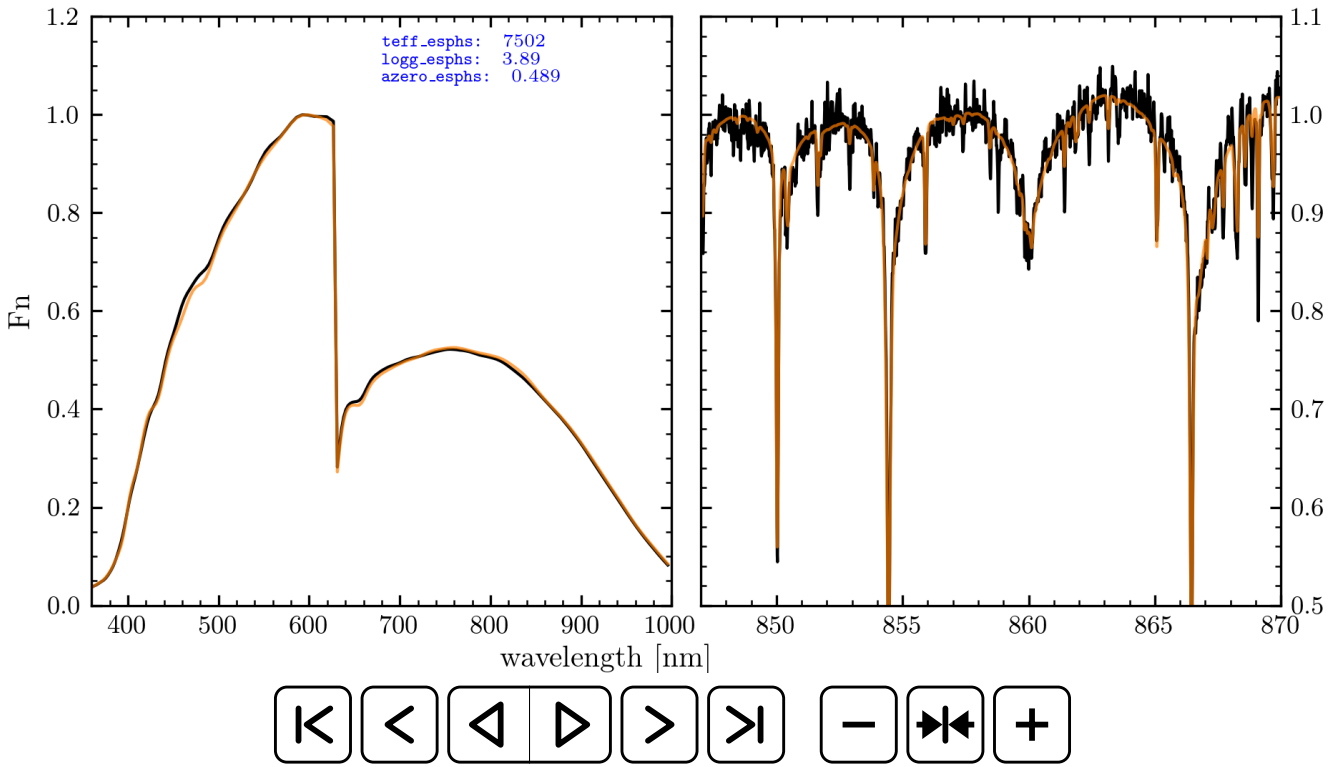
GOSC: Maíz Apellániz, J. et al. (2013)



- input list of 620 targets (main & supps). 582 found (21 too faint, 7 XP poor quality, 9 ?)
- filtering on qf=flags_esphs[1:2]: no significant impact on classification quality.
- strong O/B contamination (not depending on R_V nor A_V)

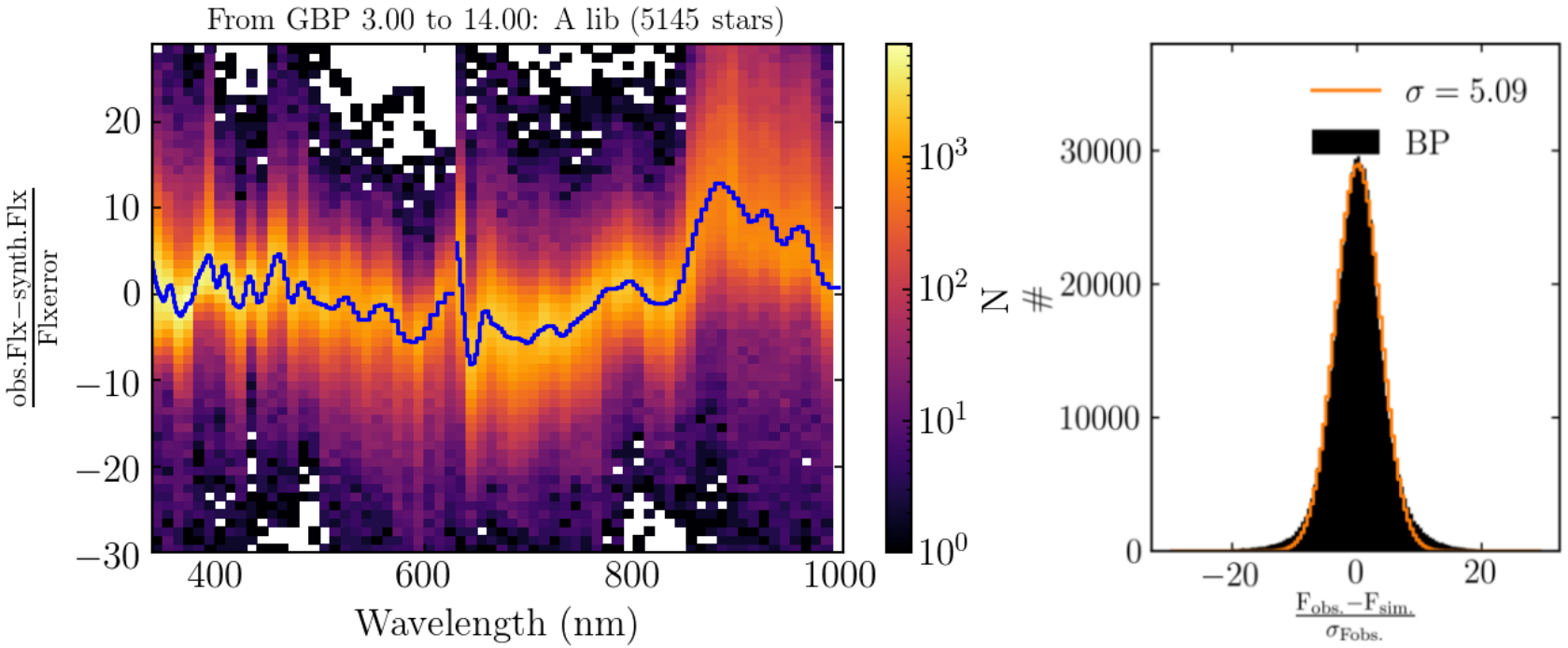
AP Determination with ESP-HS

- Synthetic spectrum fit to XP and RVS data (when available).
- rebinned to 3 samples
- Libs.: O. Kochukhov & D. Shulyak, OB star models (Lanz & Hubeny), Synspec
- Assumption: Solar chemical composition

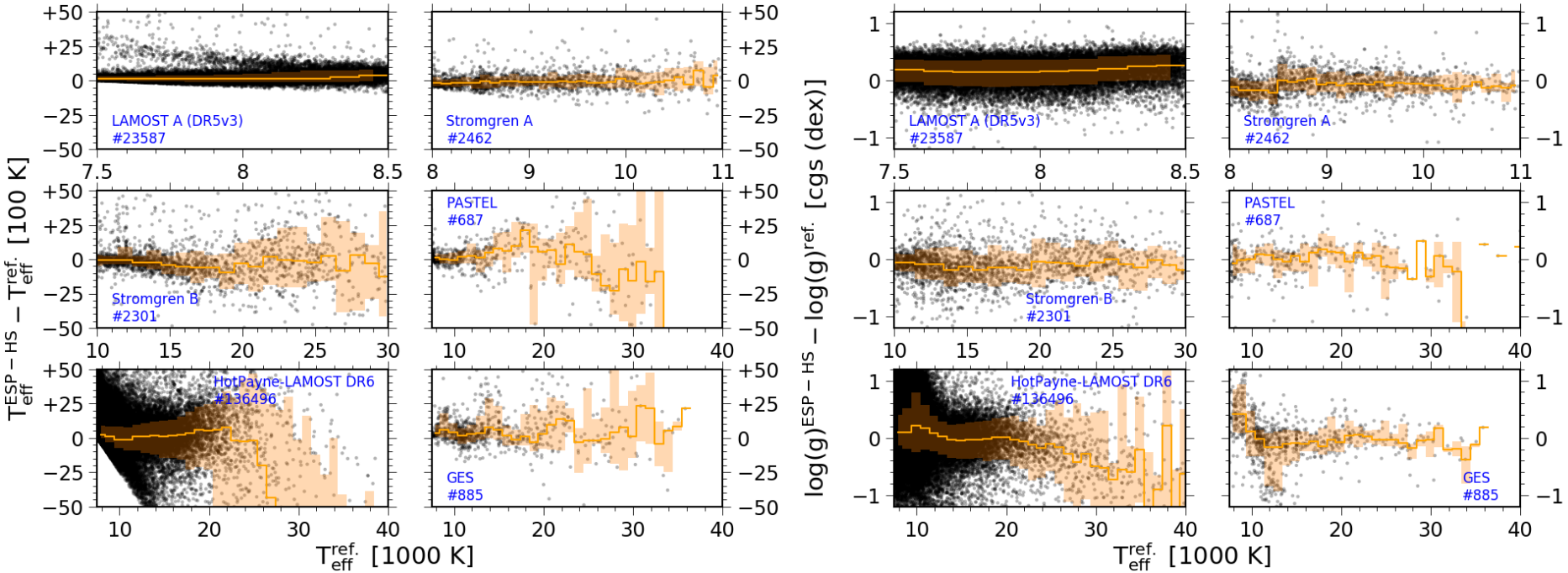


AP Determination with ESP-HS

- Extinction: Fitzpatrick (1999), $R_V = 3.1$
- Synthetic/Simulations spectra of reference of A and B stars (w. stromgren photometry) compared to Gaia XP data
- comparisons used to empirically improve the simulations, exclude domains
- no correlations taken into account

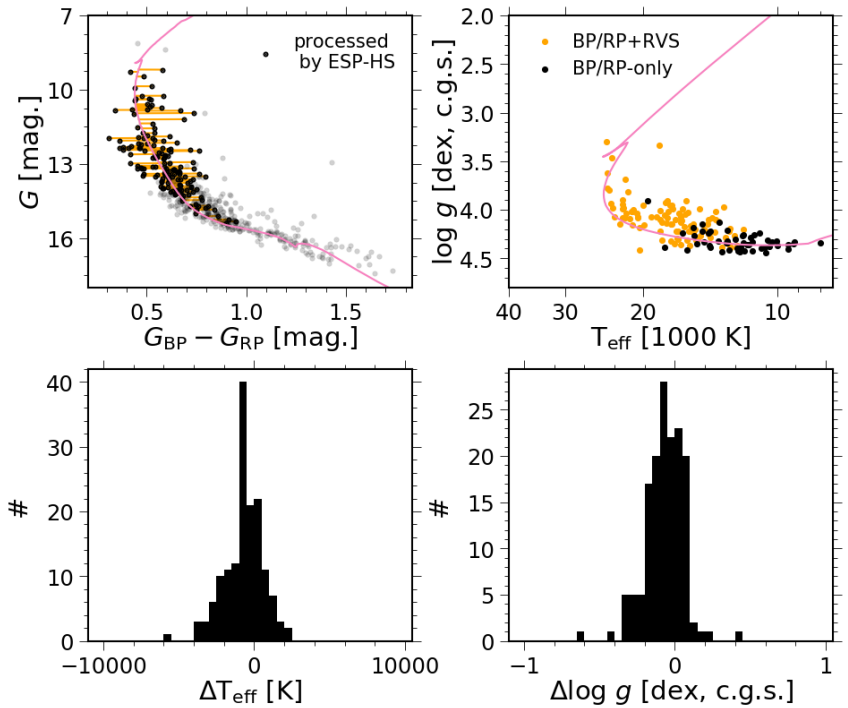


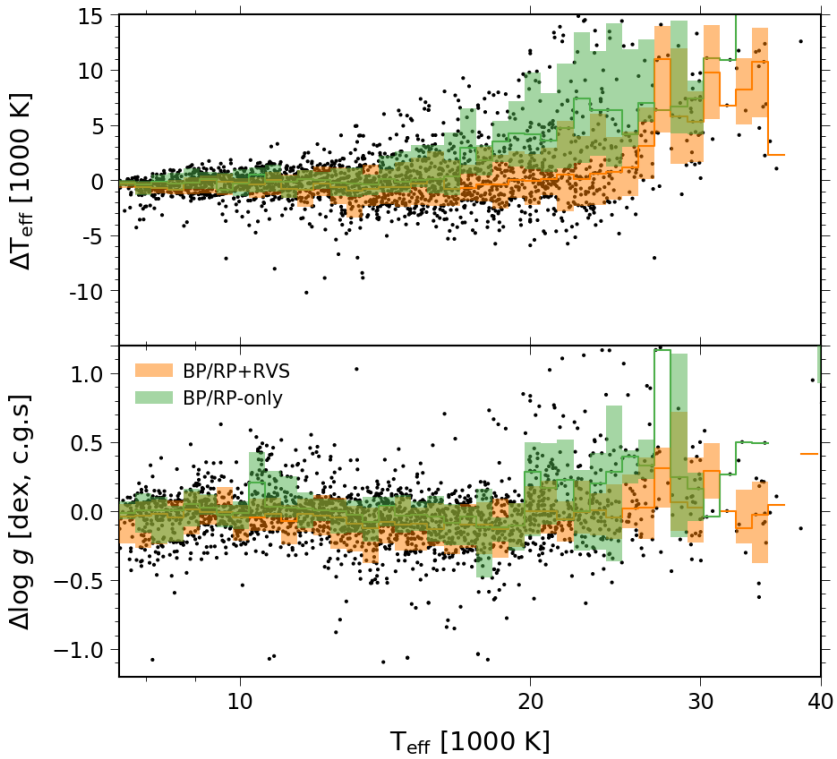
AP Determination vs GroundBased Surveys



- in orange: median (line), interquantile dispersion (shades)
- $T_{\rm eff}$: trend to underestimate the temperature, especially above 25 000 K. Scatter increases with $T_{\rm eff}$ from 200-600 K (A-type), to 3000-10000 K (O-type).
- $\log g$: dispersion 0.3-0.5, double for O-type stars.

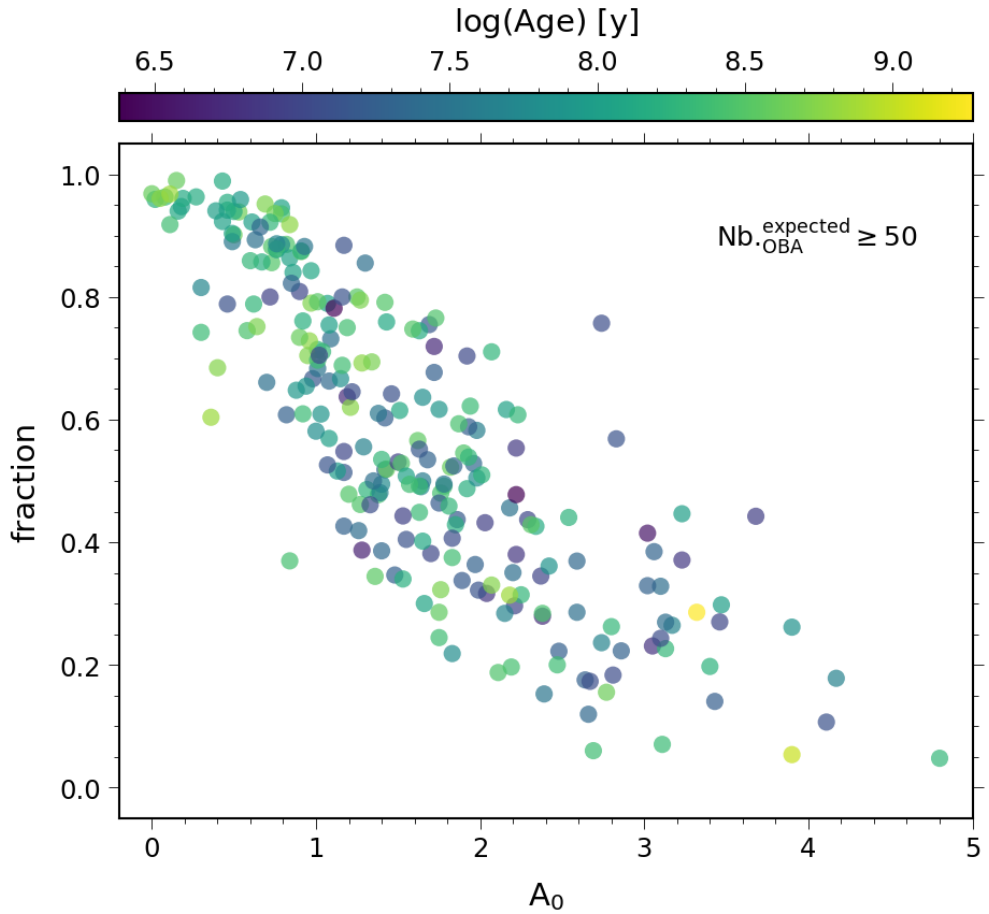
AP Determination vs Clusters





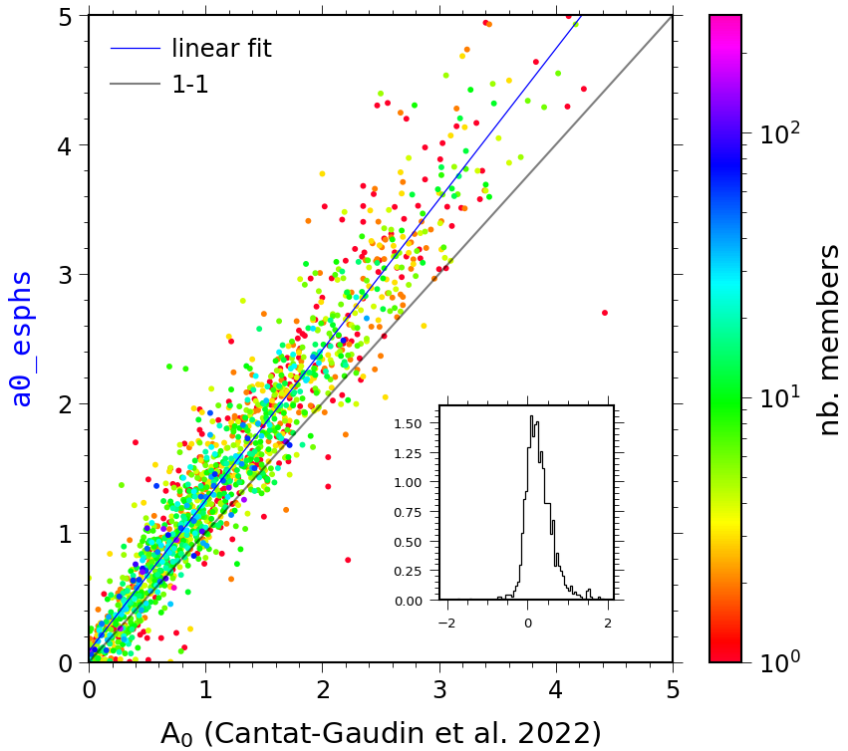
- Left: Case of NGC869, Right: 1524 members of 42 open clusters
- CD used to identify the closest isochrone point
- $T_{\rm eff}$: disp 800-6000 K; $\log g$: disp 0.15-0.30 dex

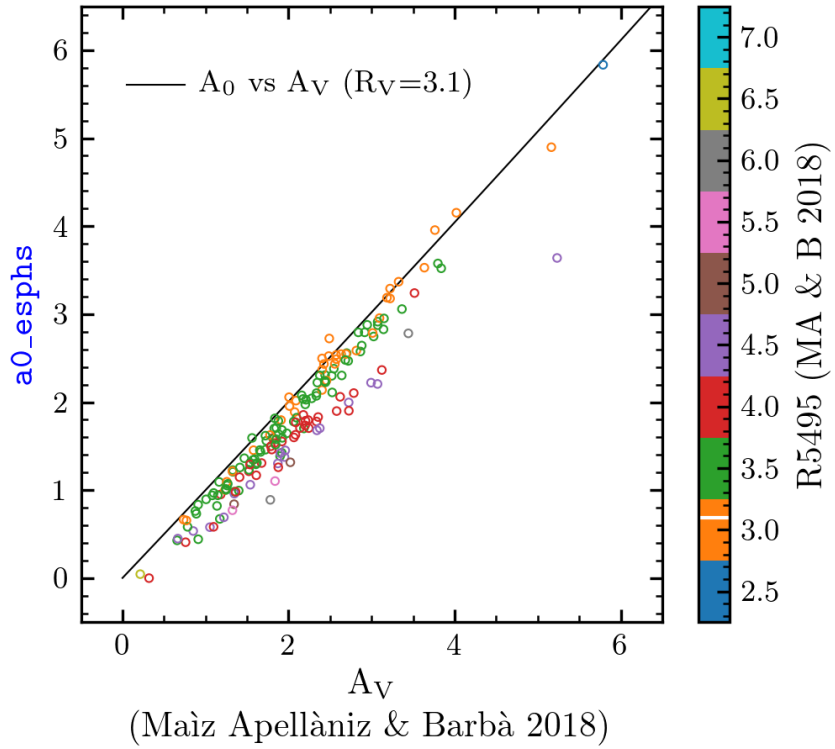
Completeness of the OBA Sample from OCs



- Post-processing based on gof in XP and RVS (e.g 1/3rd of GOSC stars remaining).
- lack of stars trends with extinction

Interstellar Reddening



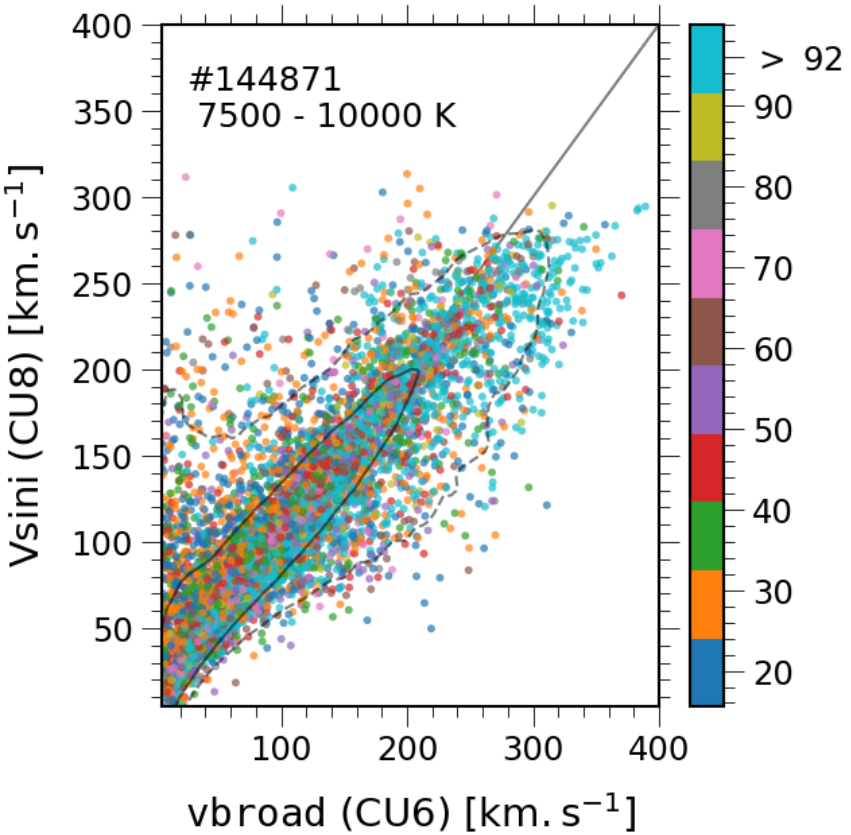


- Fair agreement with other surveys and cluster data.
- left: comparison with OCs; right: comparison for O-type stars with different R_V. Different trends, expected trend with R5495, as assumption is R_V=3.1 .

V sin *i* Determination vs. epoch vbroad

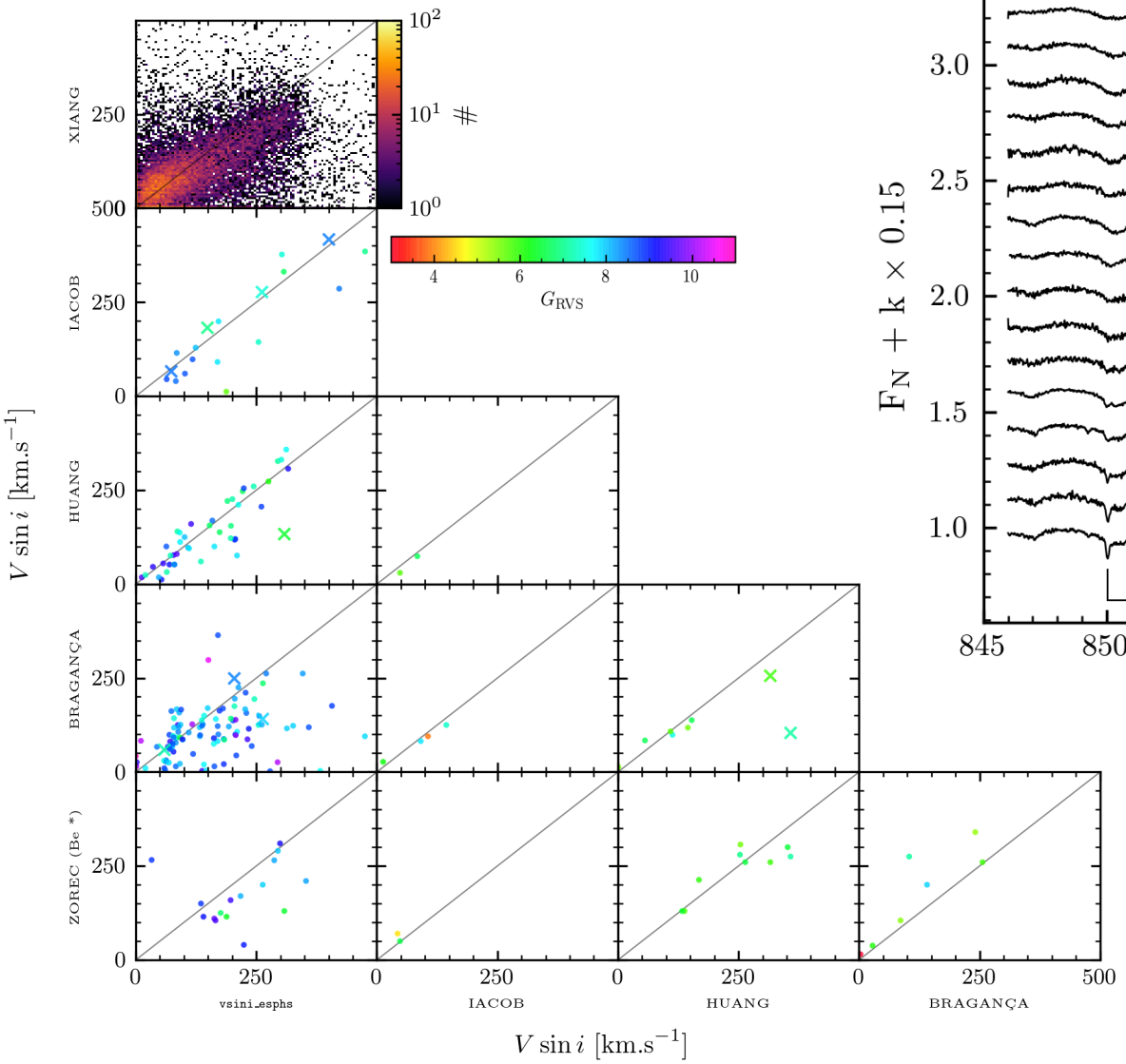
- Performed on co-added spectra, assuming Gaussian LSF, in the AP determination.
- vsini_esphs larger than CU6/'epoch' vbroad at small values
- behaviour similar to vbroad (Frémat et al. 2022):

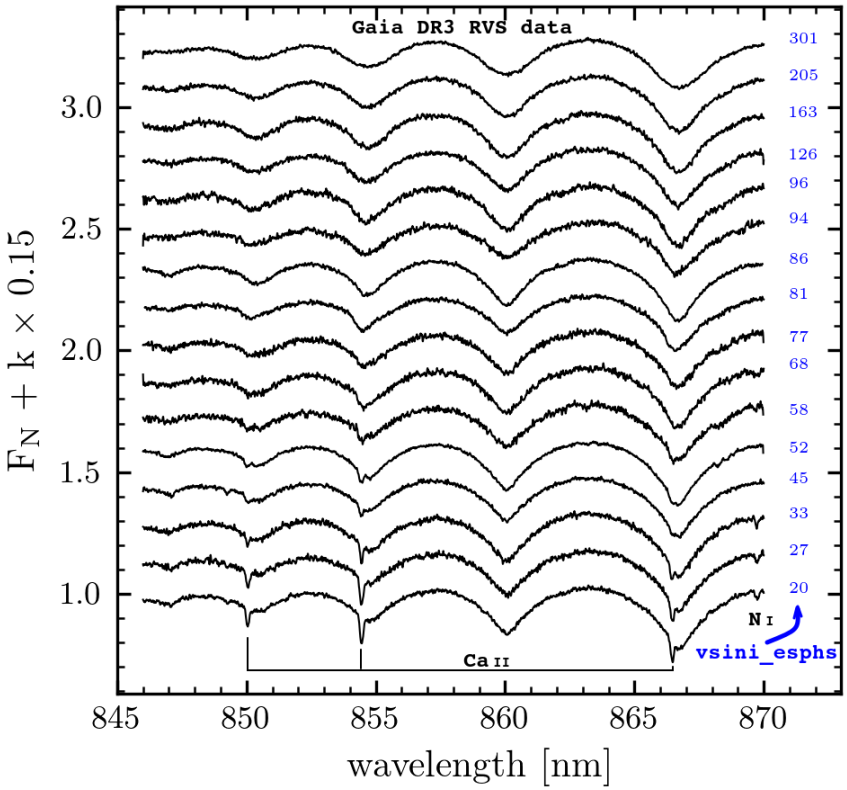
  The quality degrades rapidly with magnitude and $T_{\rm eff}$, above G=10 and $T_{\rm eff}$>10 000K.
- see also Figure 20 in Fouesneau et al. 2022



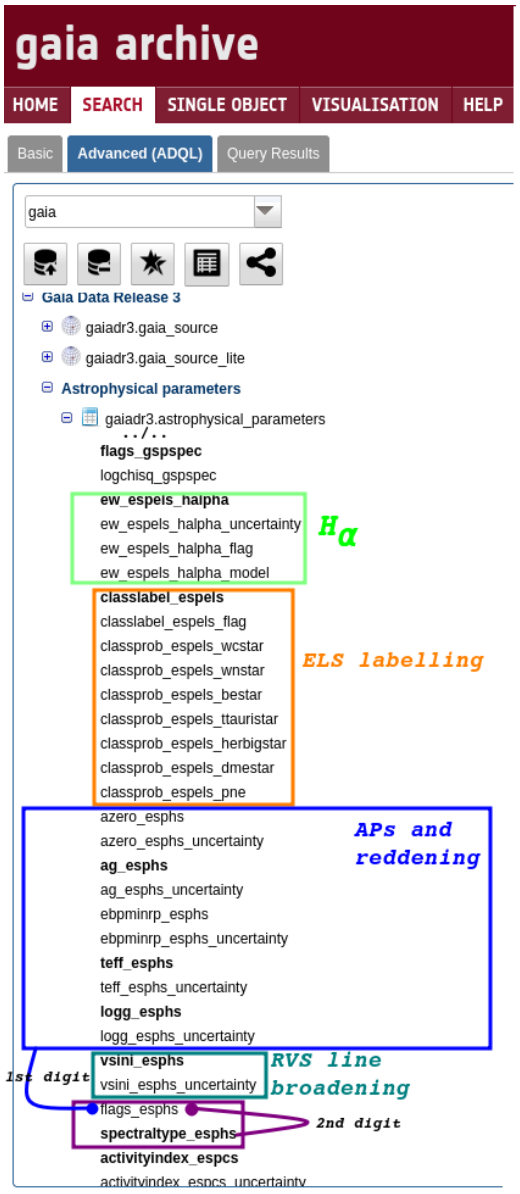
$V \sin i$ Determination from co-added RVS

Figures to appear in Zorec 2023





Overview & from DR3 to DR4



- ESP-ELS:

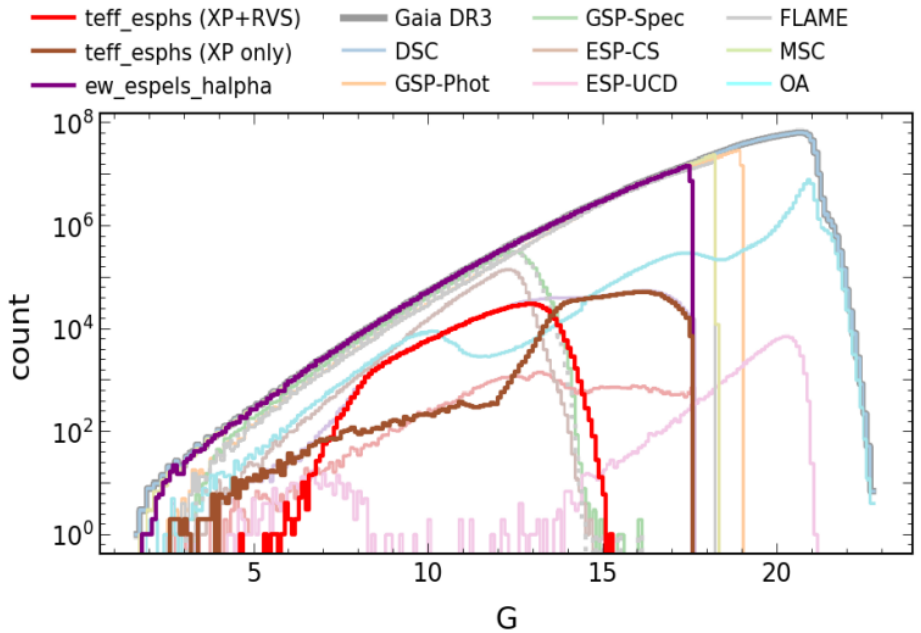
DR4> probability of Hα being in emission

DR4> RVS included in the classification

- ESP-HS:

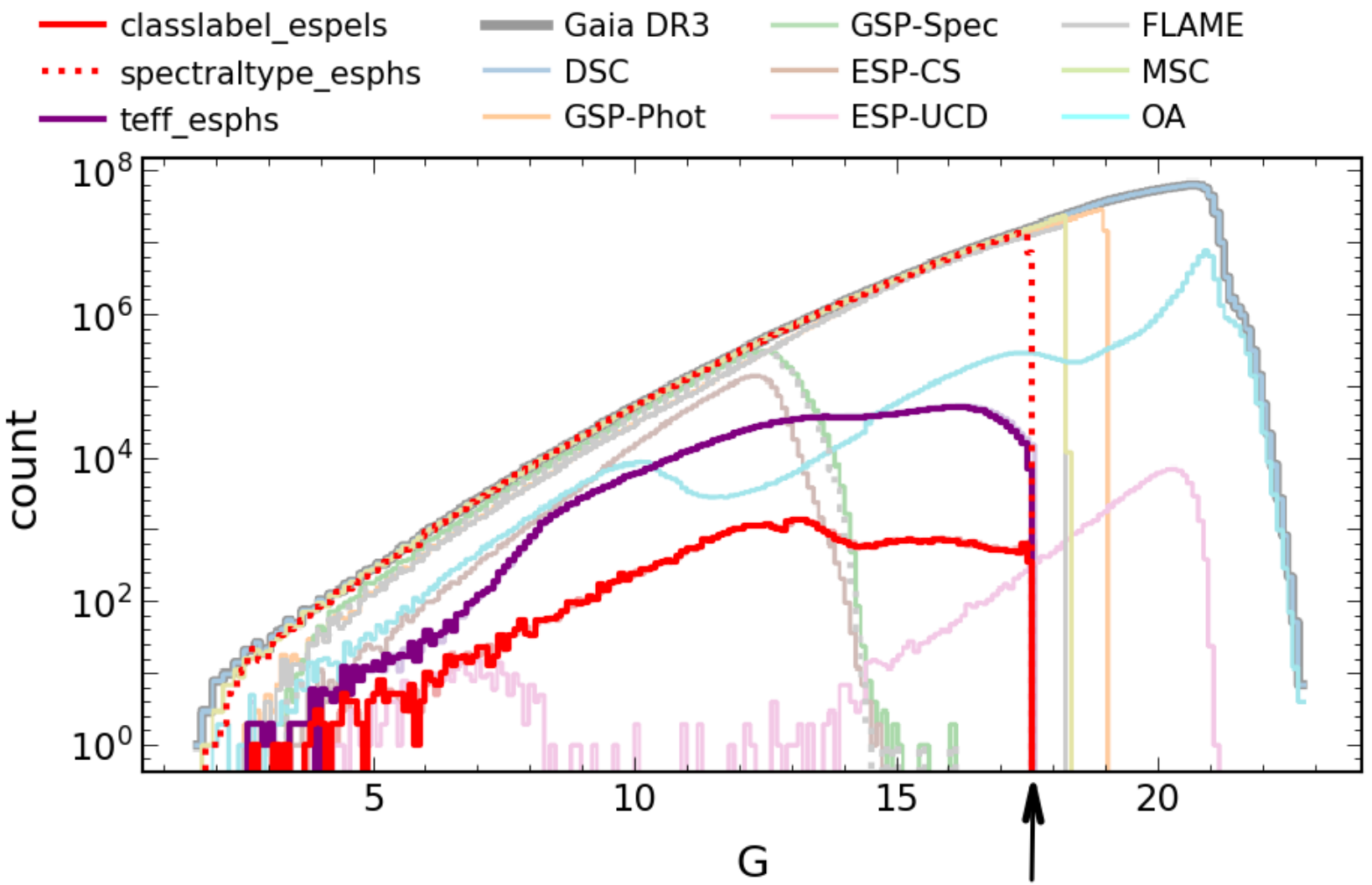
DR4> Metallicity determination from RVS for A and late-B stars.

DR4> Post-processing less restrictive.



Thank you for your attention

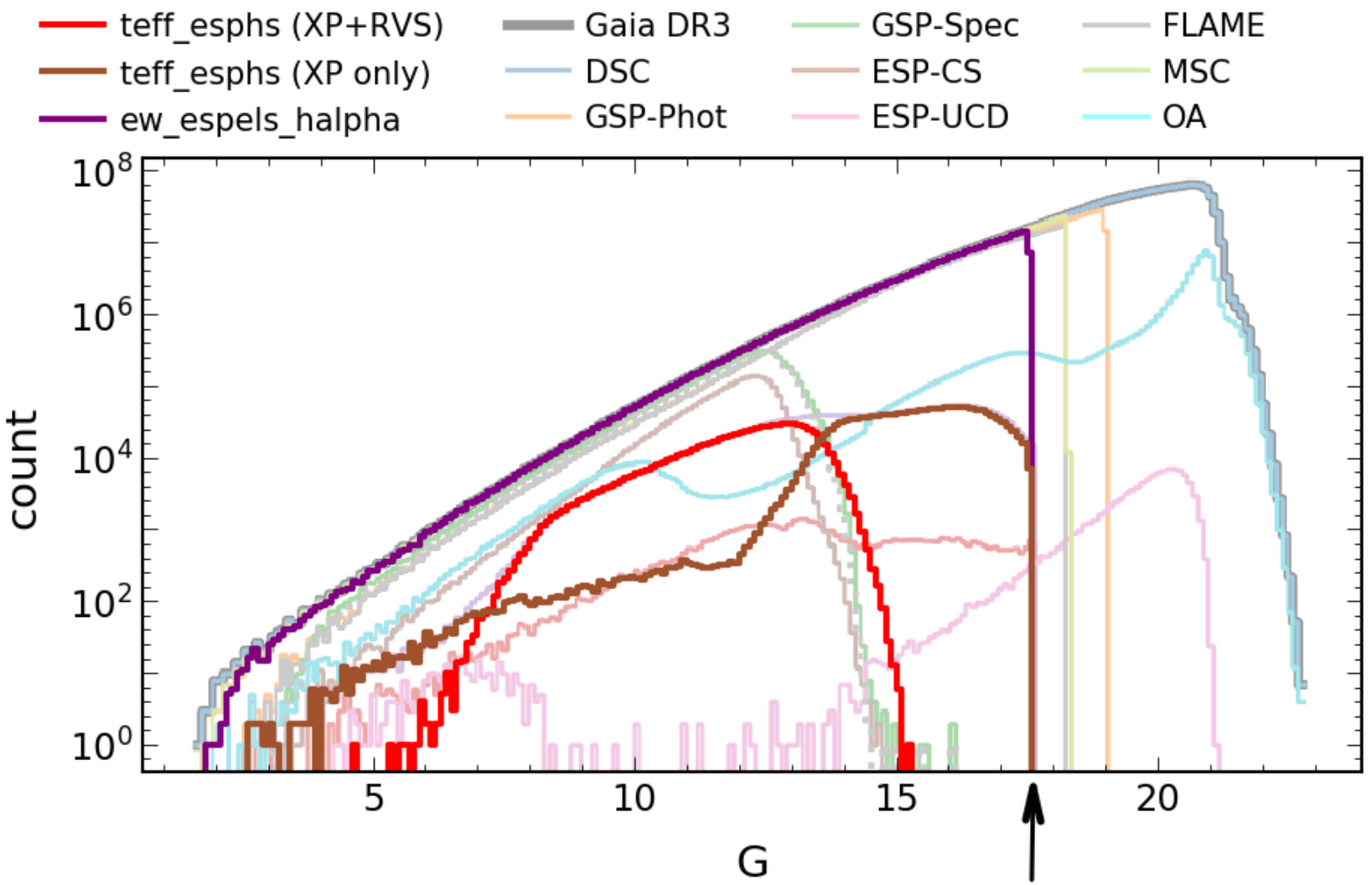
Output: Magnitude Distribution



Adapted from Creevey et al. 2022, Figure 2

ESP-ELS/HS magnitude cut at G=17.65

Output: Magnitude Distribution



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ESP-ELS/HS magnitude cut at G=17.65