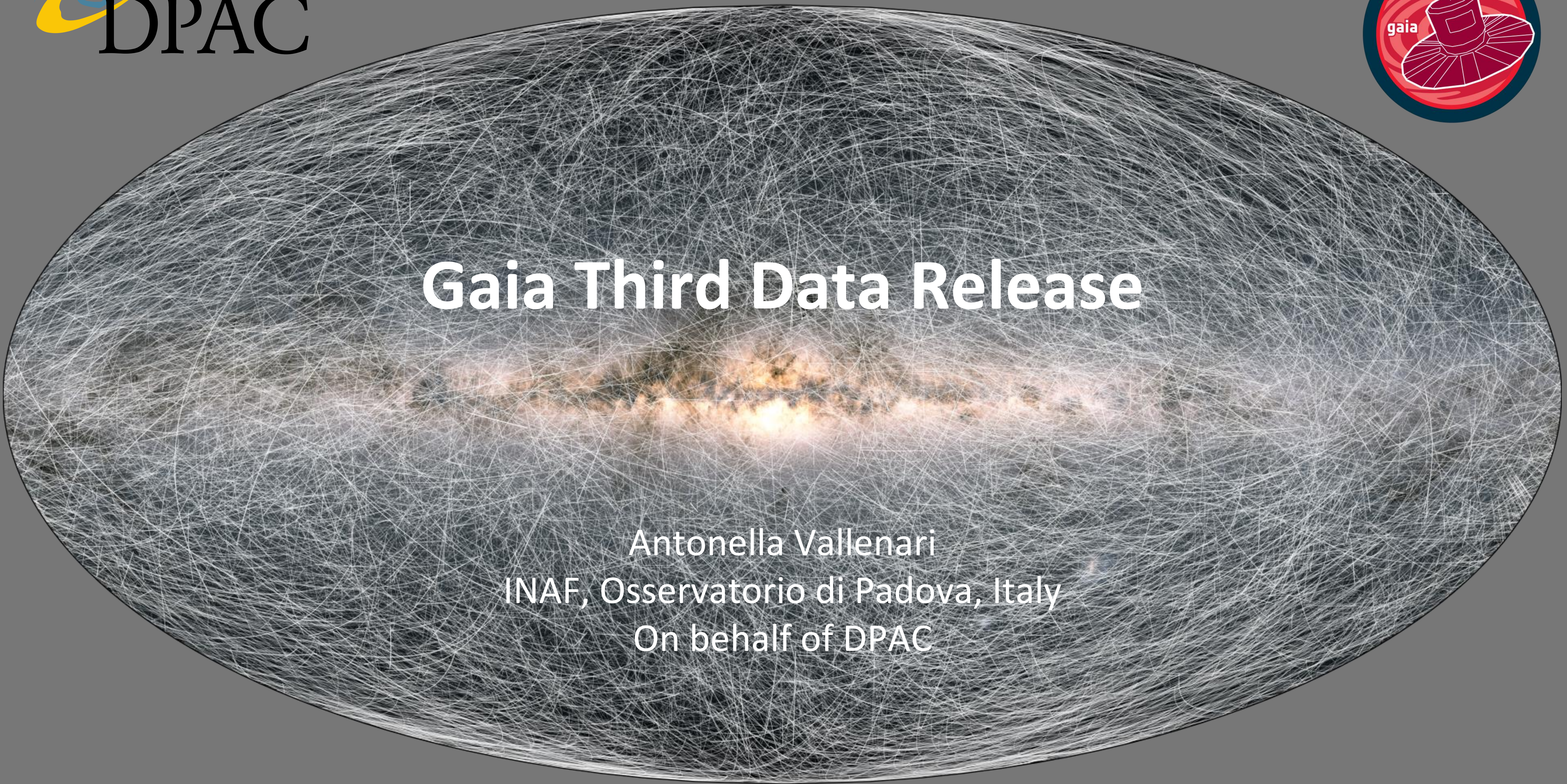
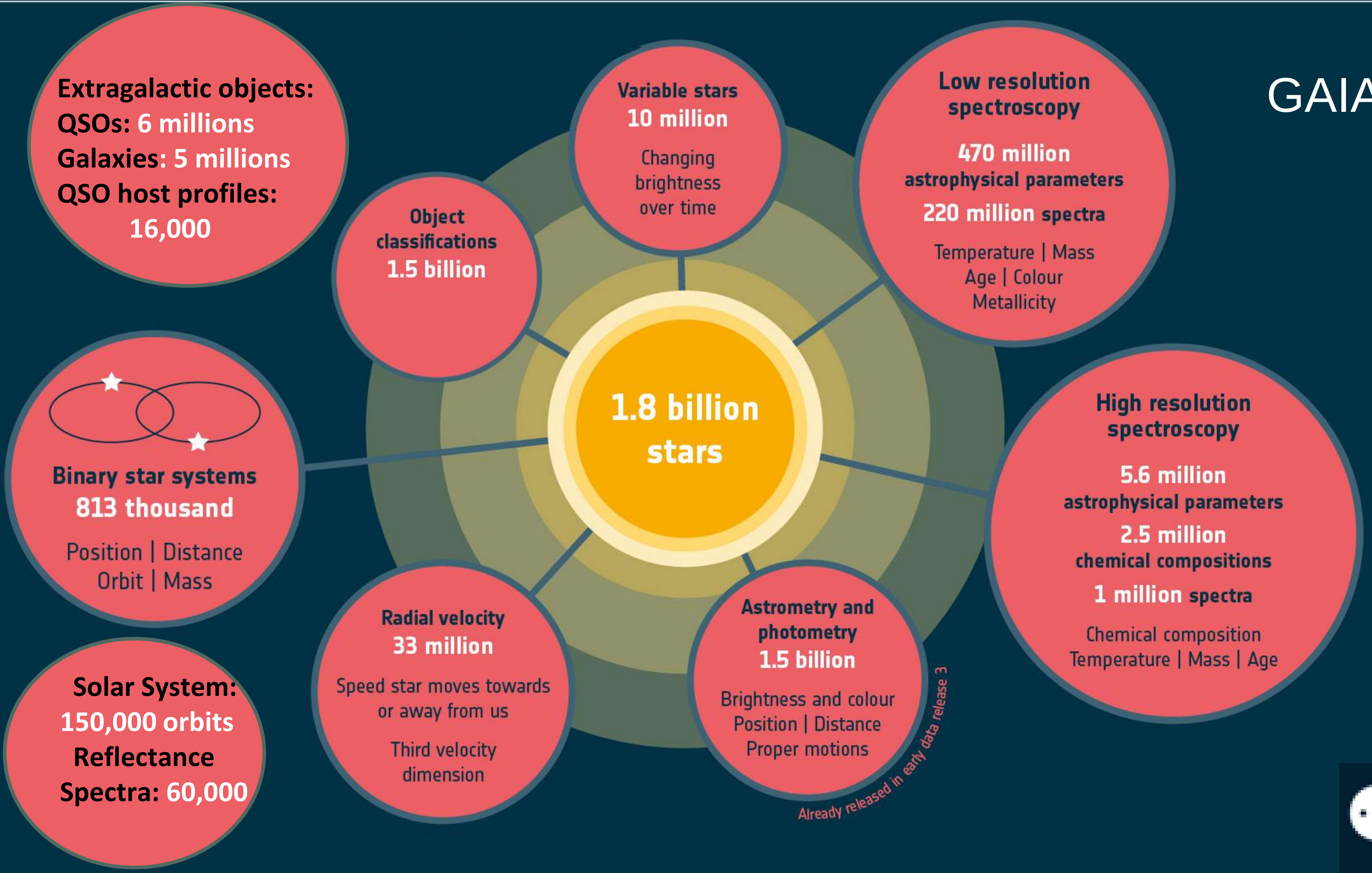
Gaia Third Data Release



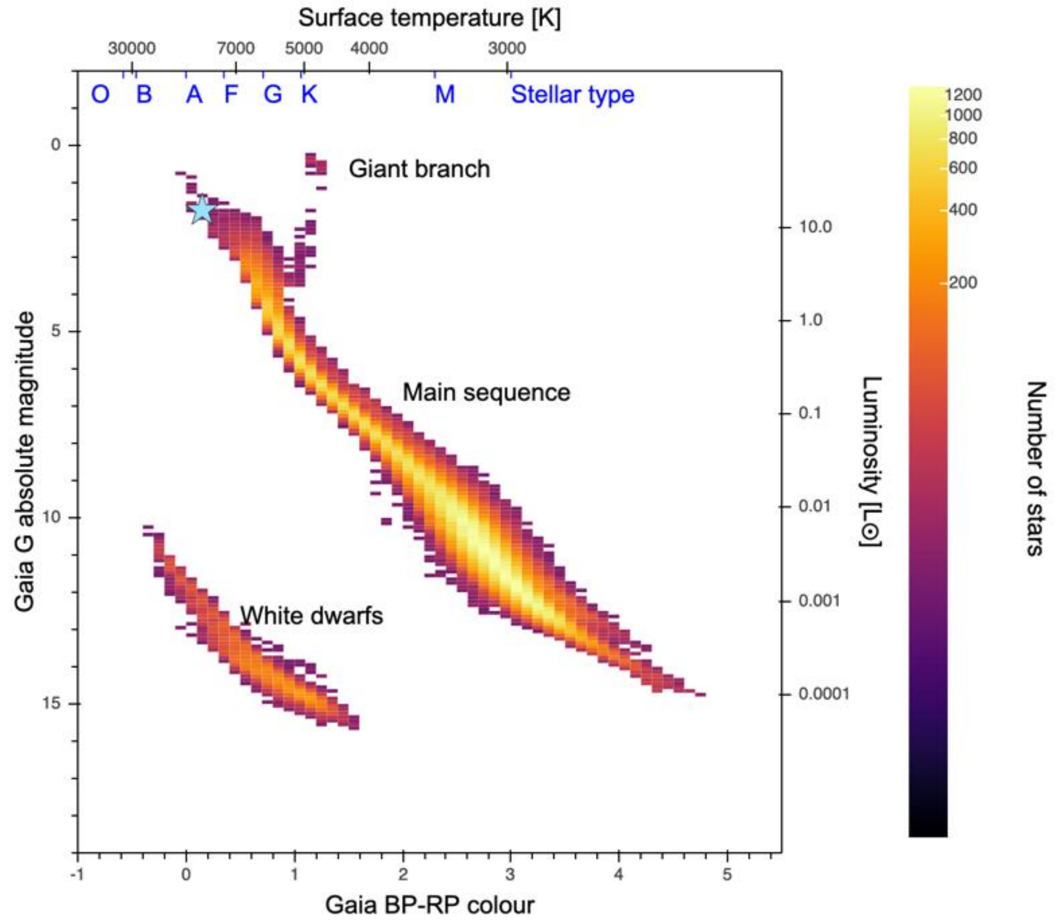
Antonella Vallenari
INAF, Osservatorio di Padova, Italy
On behalf of DPAC

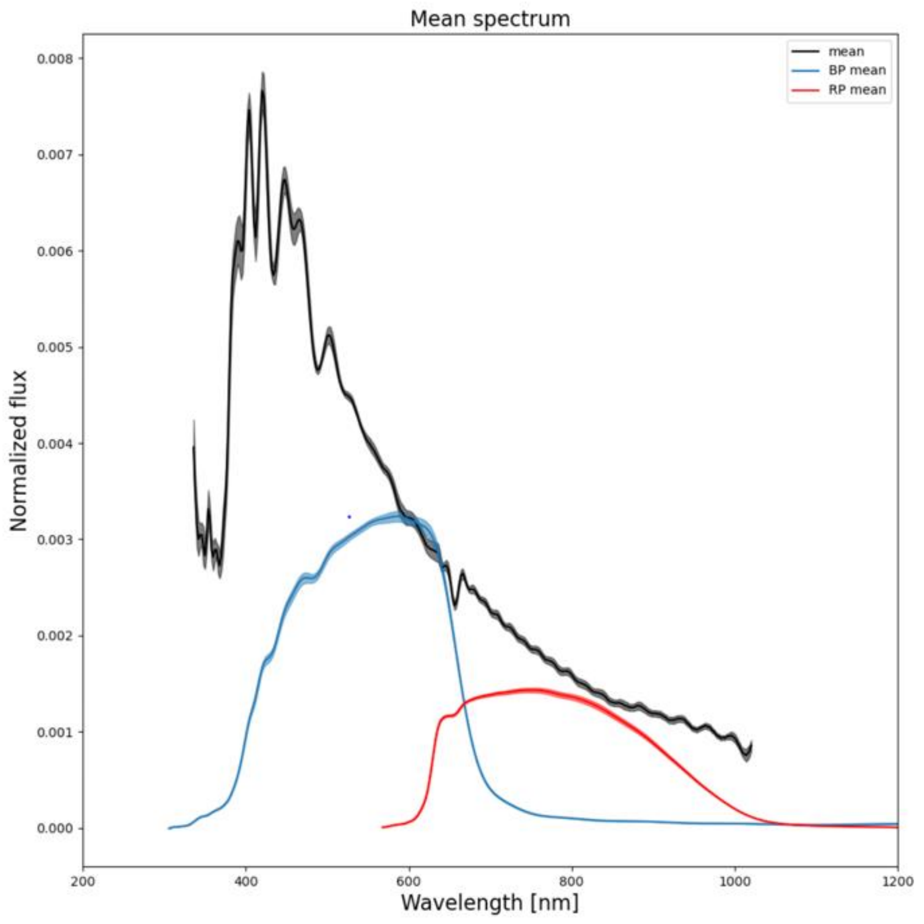
GAIA DR3

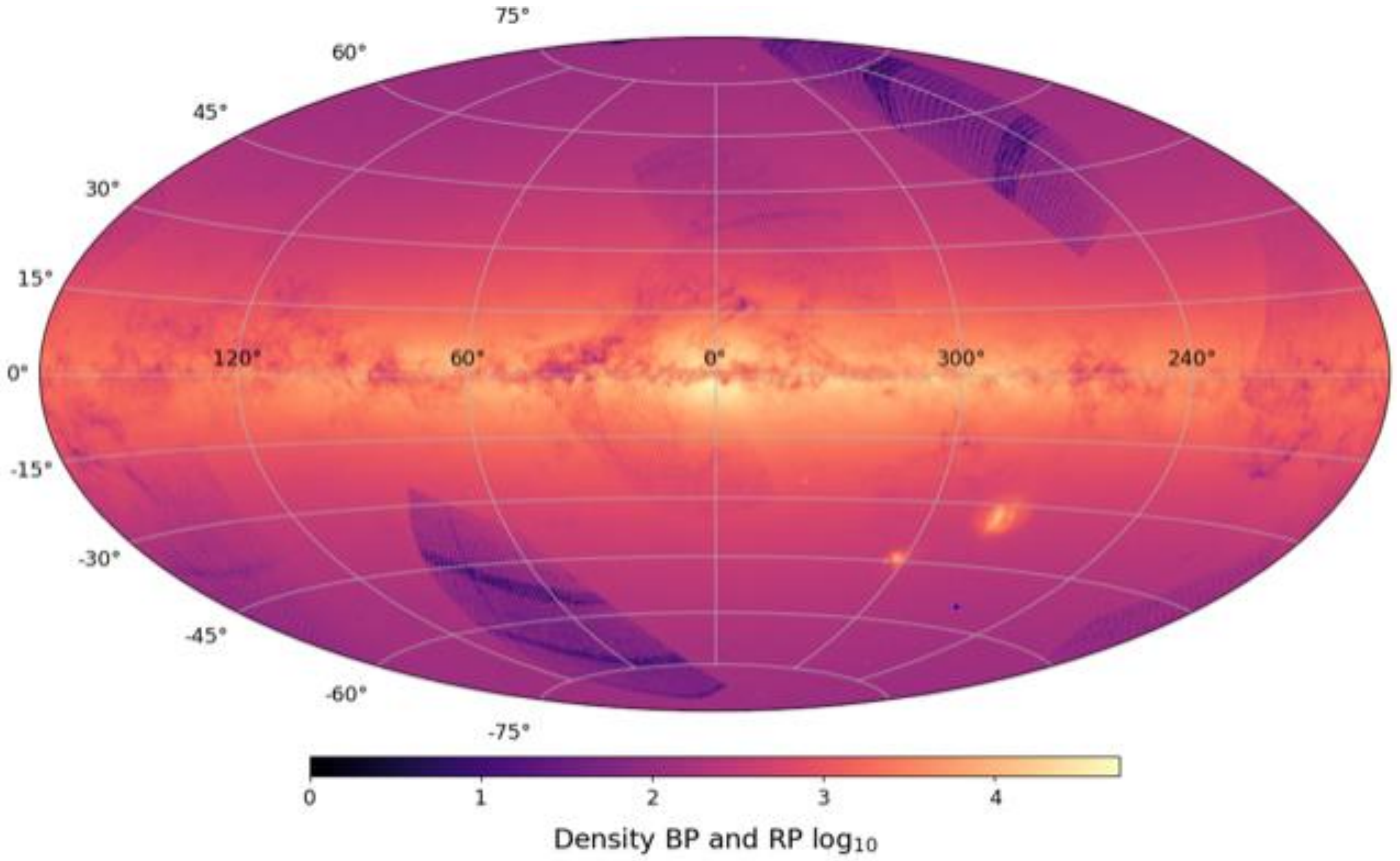


Gaia Collaboration, Vallenari, Brown et al (2022)

BP/RP spectra



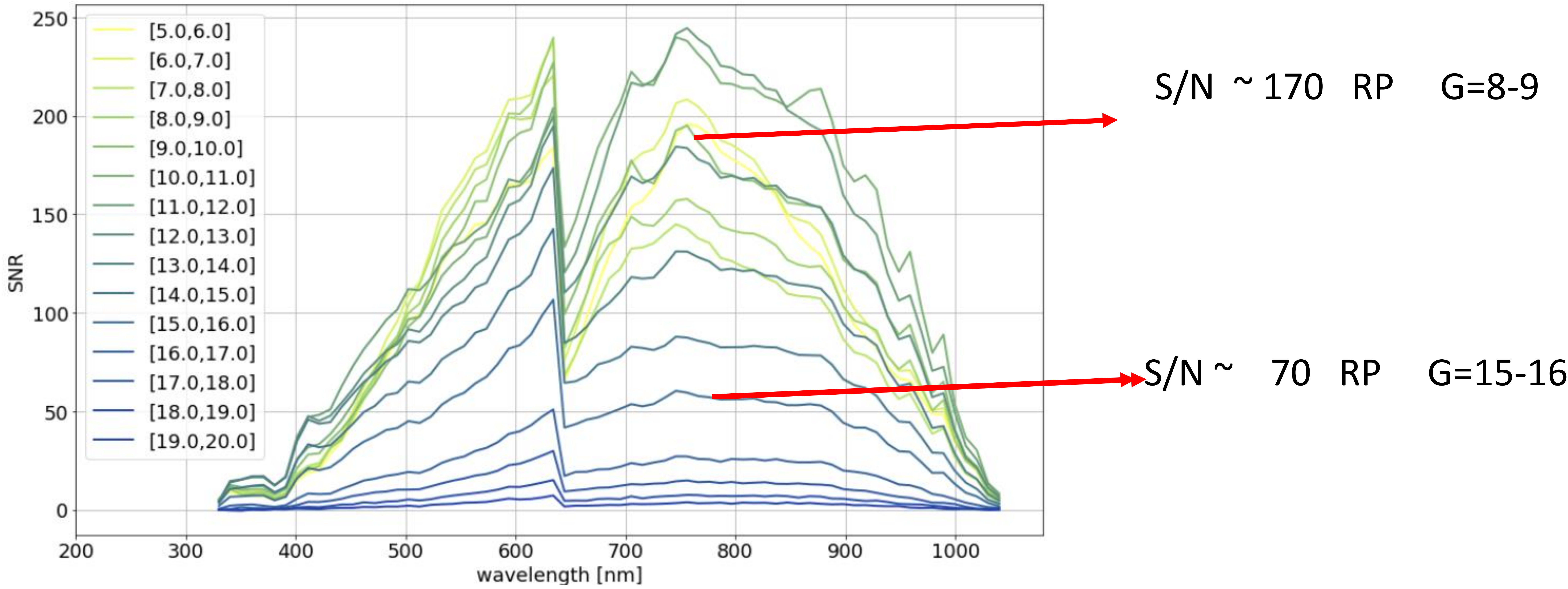




De Angeli et al (2022)

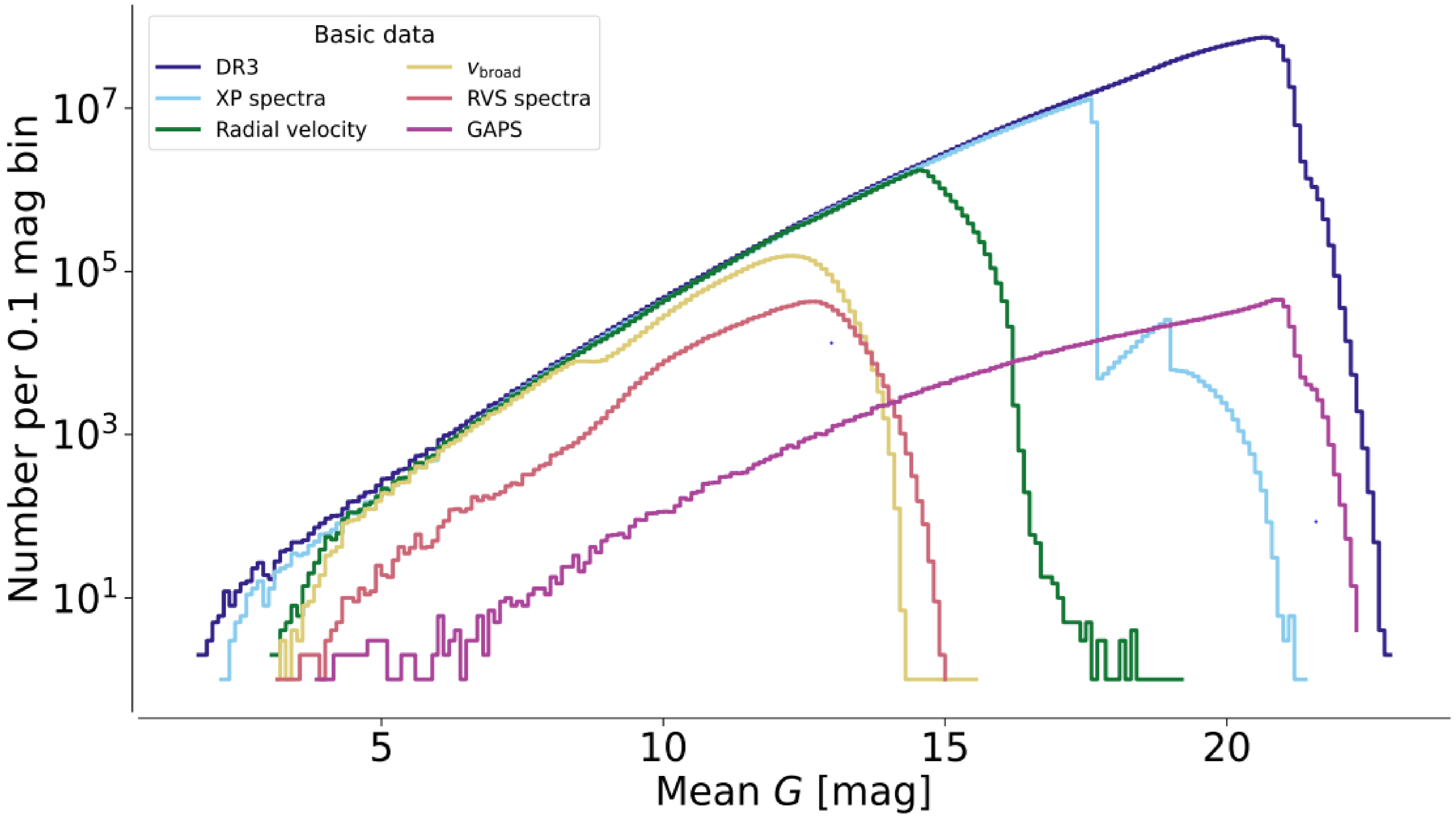
Data Product	No. of sources	Comments
Gaia Andromeda Photometric survey	1.3 million	Photometric time series for all sources in 5.5 degree radius around M31
Mean XP spectra	220 million	$G < 17.65$ + small sample fainter sources

De Angeli et al (2022)
Montegriffo et al (2022)
Carrasco et al (2021)
Pancino et al (2021)
Evans et al (2022)
Babusiaux et al (2022)



The Signal-to-Noise ratio as a function of absolute wavelength averaged over sources within magnitude bins (DeAngeli et al)

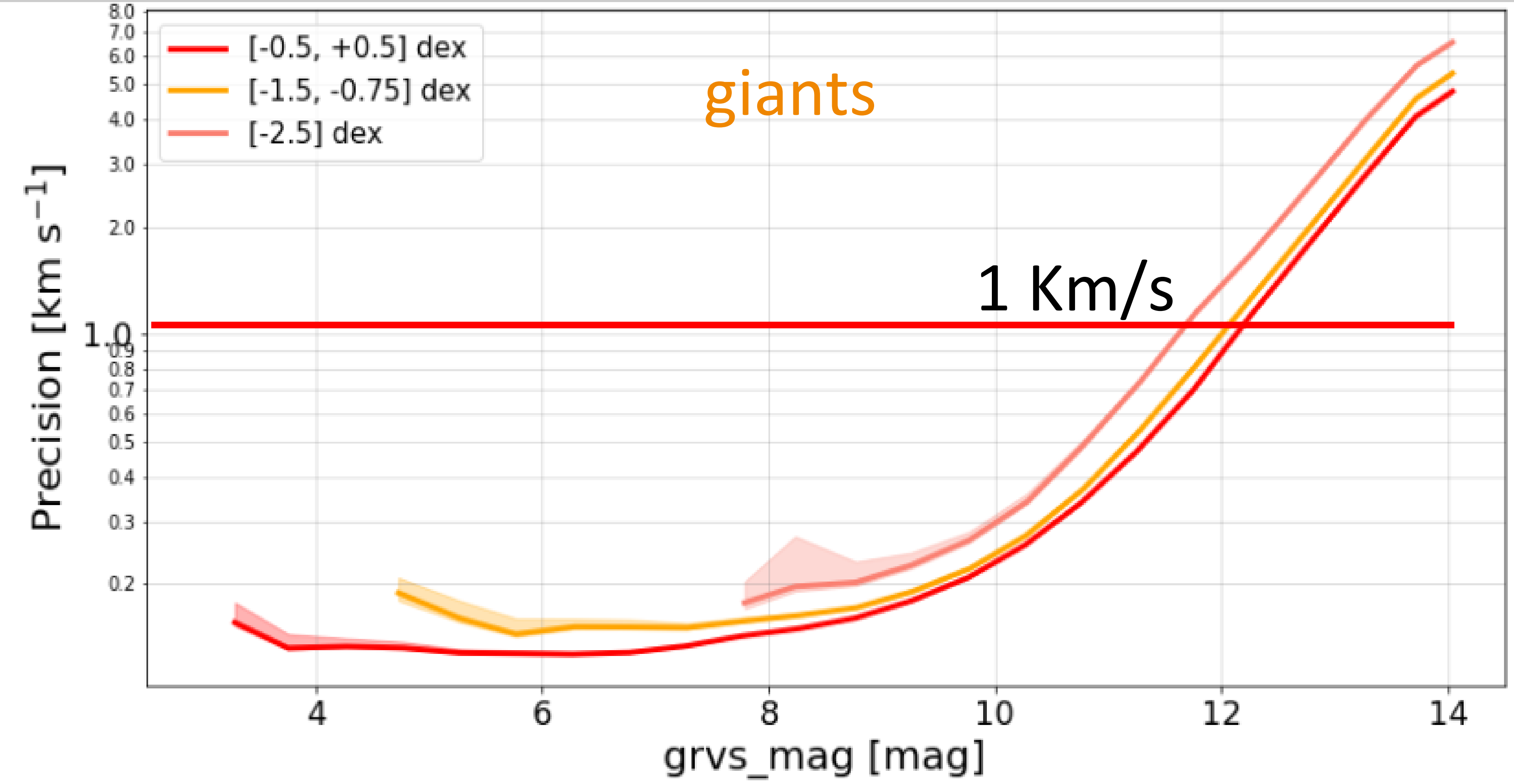
RVS data products

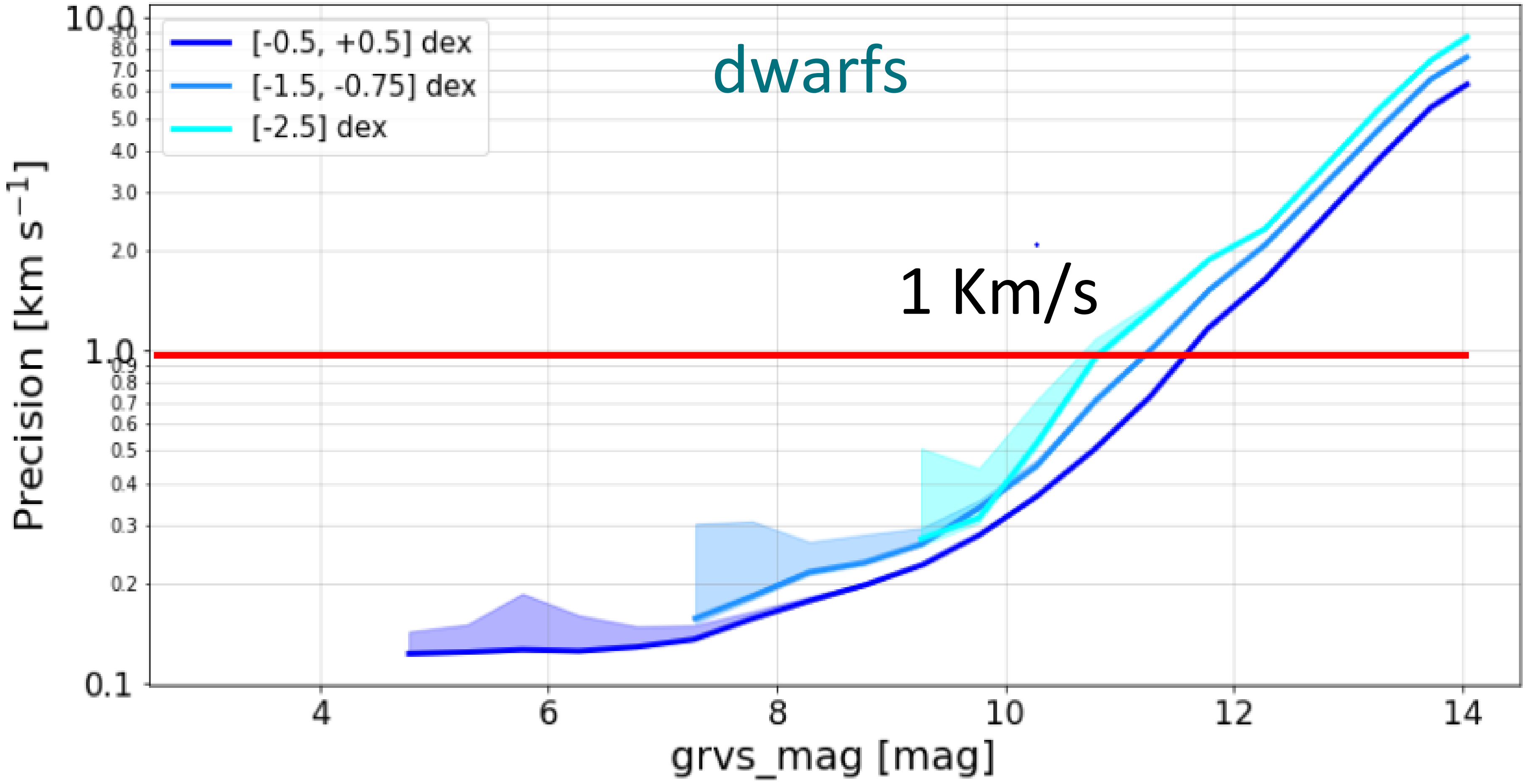


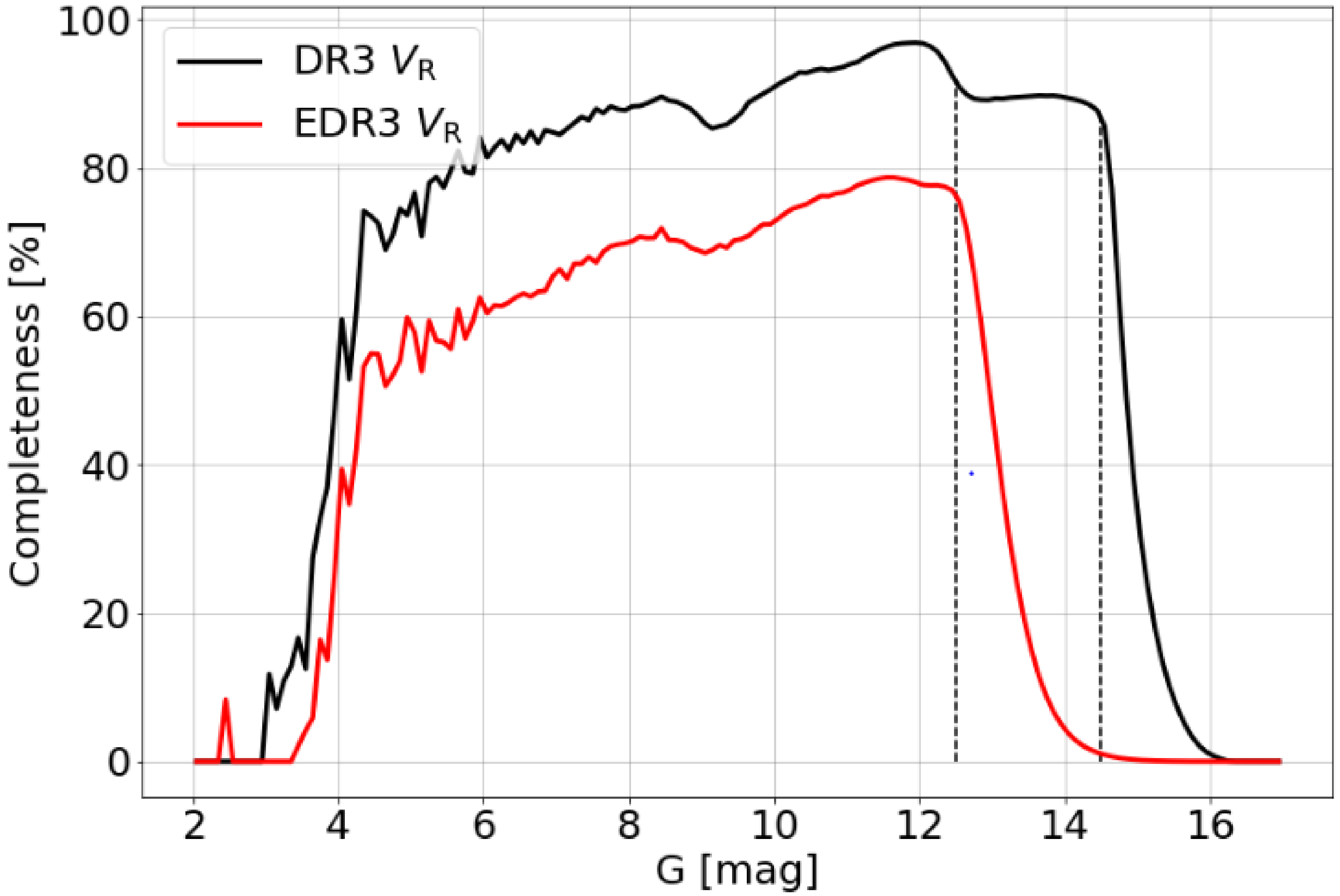
Katz et al (2022)
Sartoretti et al (2022)
Blomme et al (2022)
Fremat et al (2022)

Radial velocity	33 812 183	$G_{RVS} < 14$, $3100 < T_{eff} < 14\,500$ K
G_{RVS}-band	32 232 187	
v_{broad}	3 524 677	
RVS mean spectra	999 645	AFGK spectral type with SNR $>$ 20, and sample of lower SNR spectra

Radial velocity precision

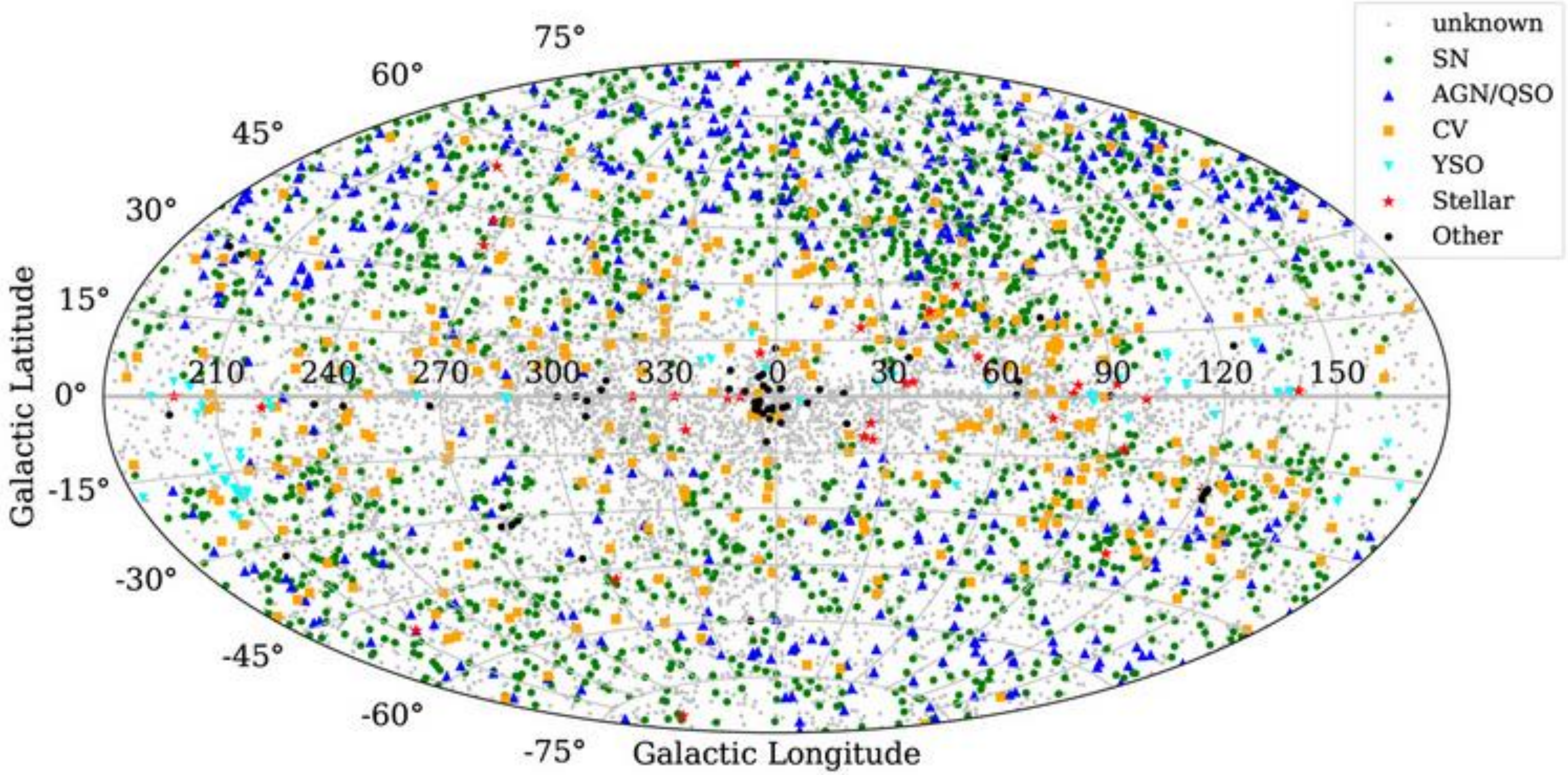






Katz et al (2022)

Science Alert

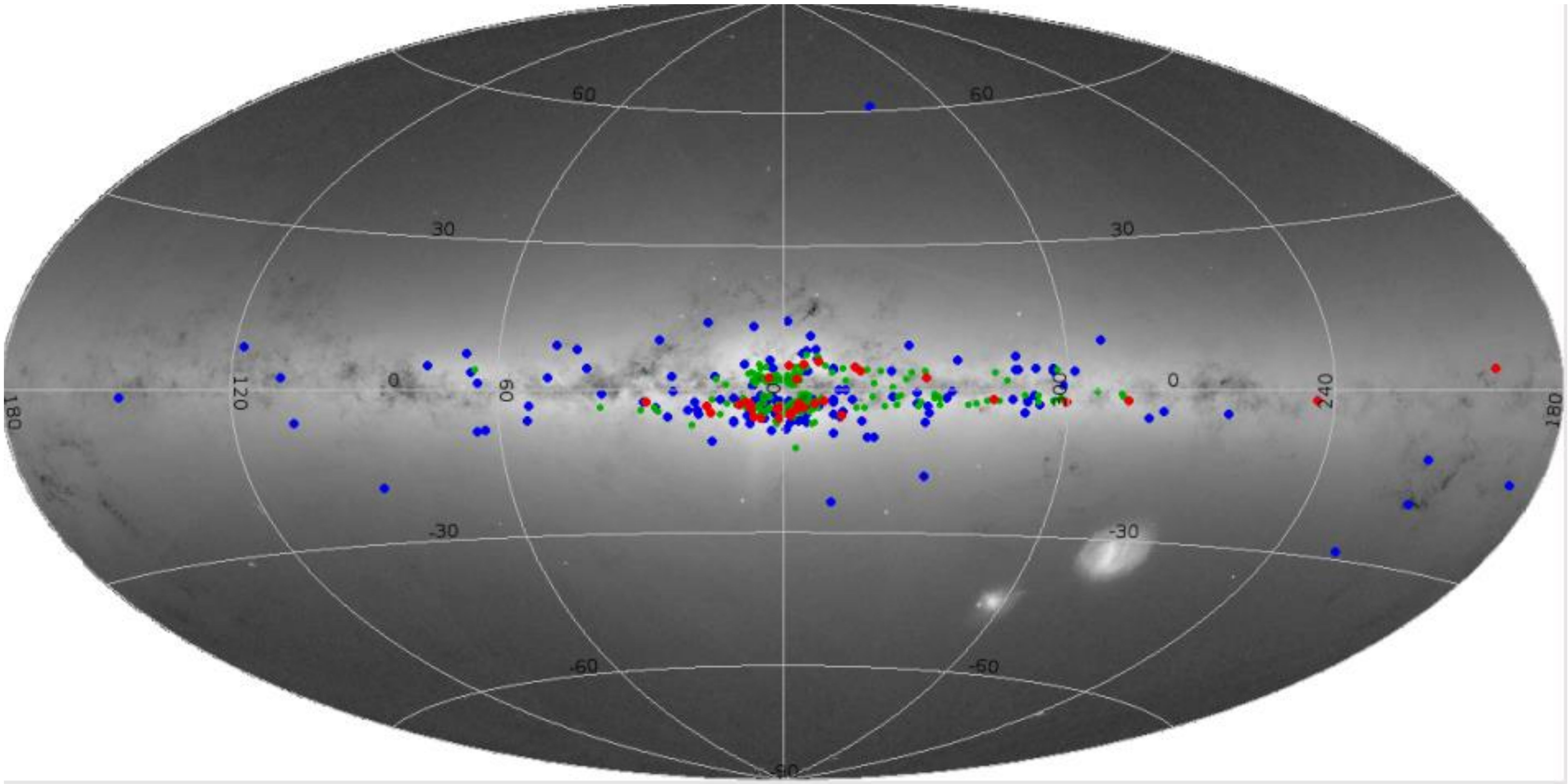


2612 Events triggered between 25-07-2014 to 28-05-2017

Per-transit photometry precision: 1% (G=13); 3%(G=19)

Per-transit astrometry precision : 55mas

(Hodgkin et al 2021)



363 micro-lensing events, of which 152 new!

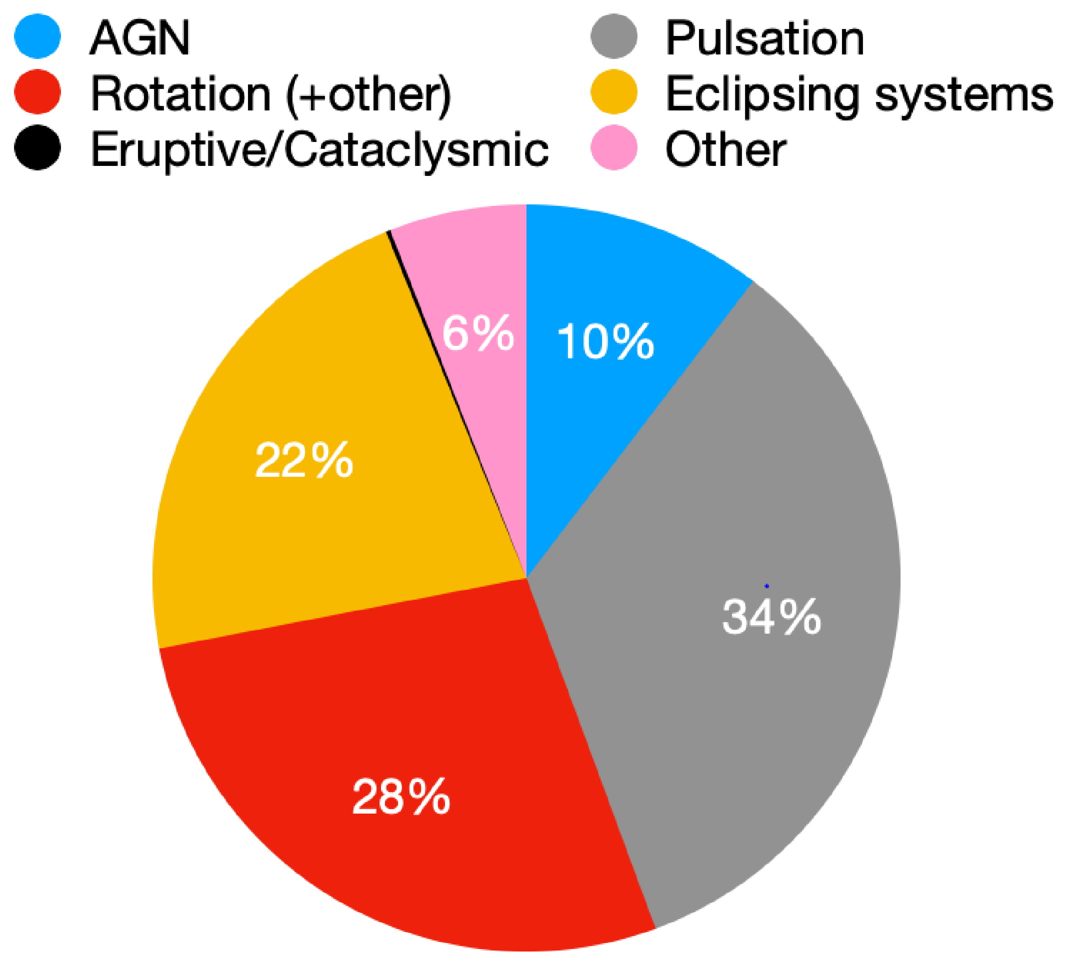
Green: literature only

Red: pipeline + literature

Blue: new (pipeline only)

Variables

	Classified as variable	
Total	10 509 536	
Cepheids	15 021	
Compact companions	6 306	
Eclipsing binaries	2 184 477	
Long-period variables	1 720 588	
Microlensing events	363	152 new
Planetary transits	214	
RR Lyrae stars	271 779	
Short-timescale variables	471 679	
Solar-like rotational modulation variables	474 026	
Upper-main-sequence oscillators	54 476	
Active galactic nuclei	872 228	
Radial velocity time series	1898	Sample of Cepheids and RR Lyrae



In DR2 500,000 stars in 6 variability type

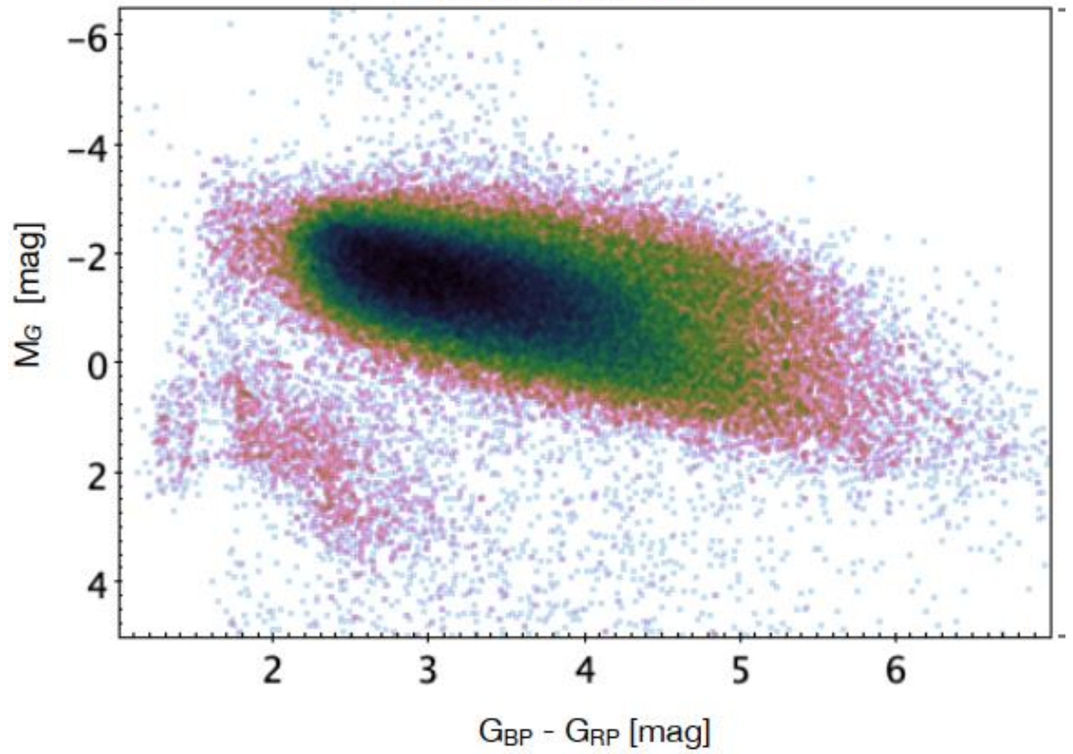
Overview:

Eyer et al (2022) and references therein

6000 ellipsoidal variables with possibly massive secondary and 262 with high probability compact secondary (Gomel 2022)

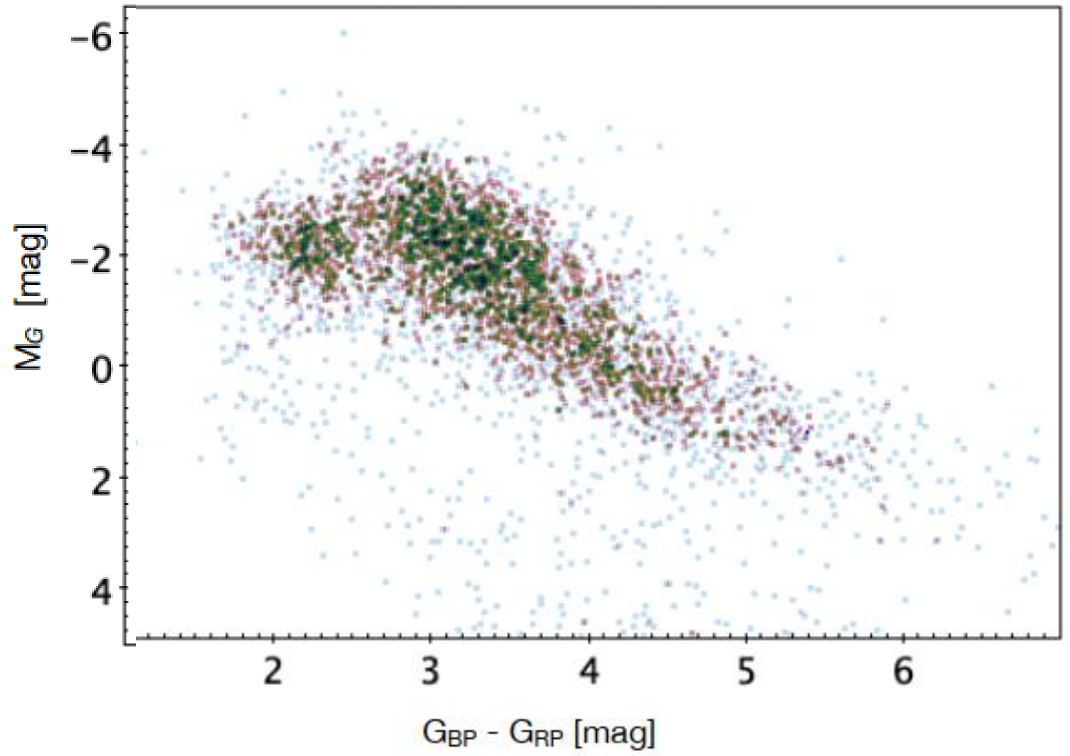
O-rich

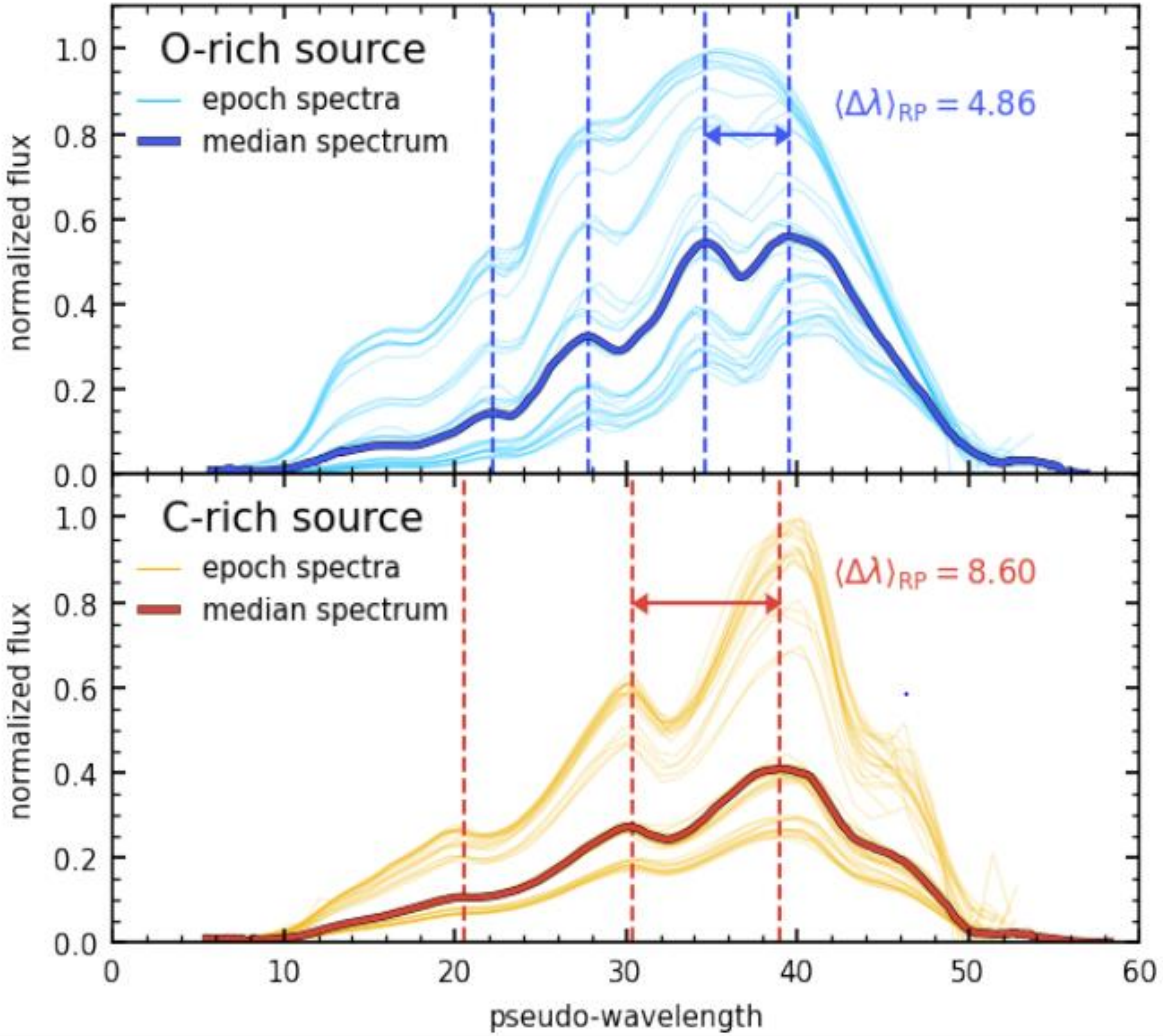
(91'936 candidates)



C-rich

(4'954 candidates)





TiO band near 900 nm

CN band near 800 nm

- LPV in DR3: 1.7 million

Non-radial pulsator dwarfs

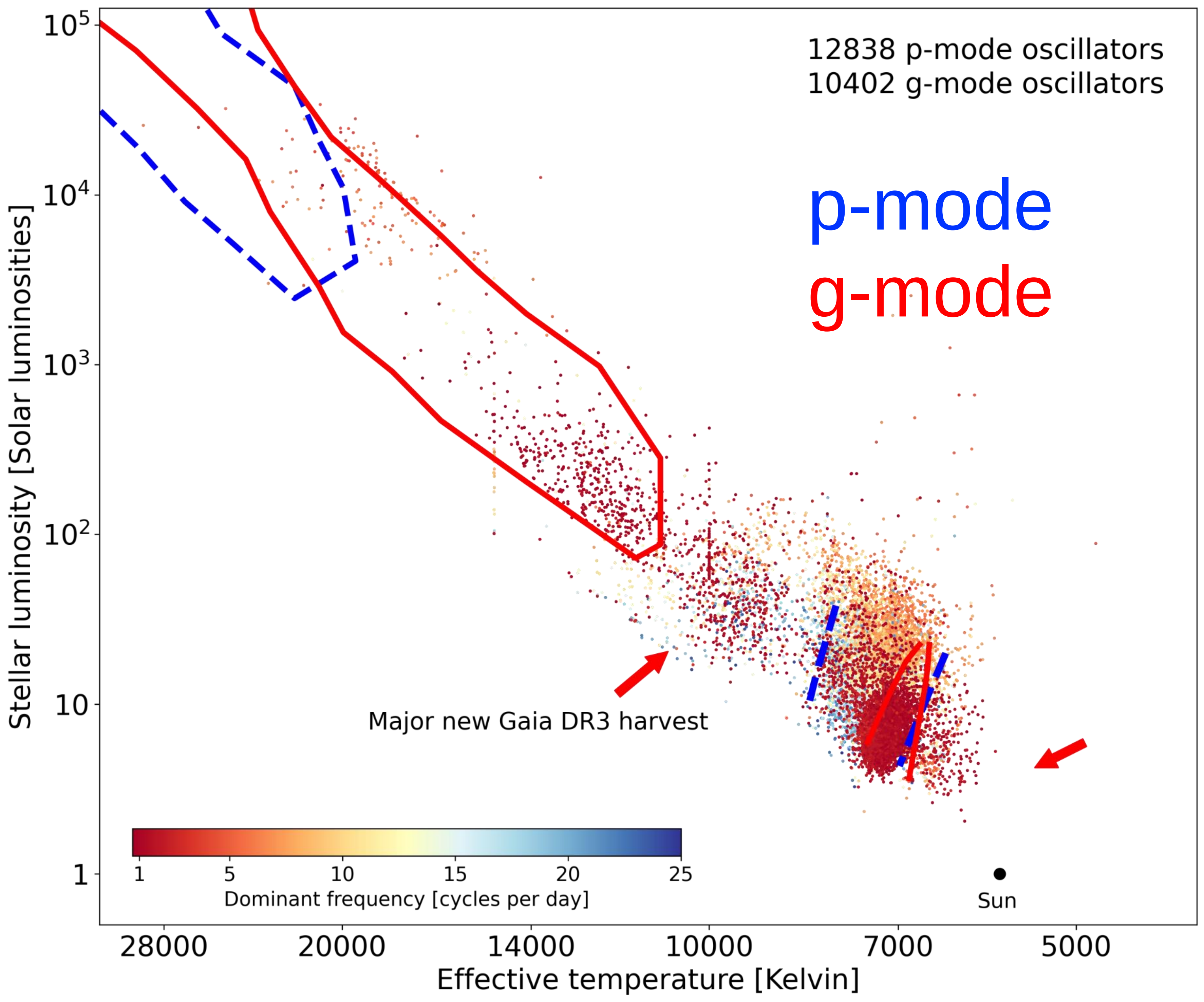
- Two types of oscillations:
  - Pressure modes: probe envelope
  - Gravity modes: probe deep interior

- Predicted to occur in “instability strips”

- Interpretation: gravito-inertial modes in rapid rotators or in close binaries

- Dominant mode frequencies cross-verified from Kepler & TESS data

(Gaia Collaboration, De Ridder et al. 2022)



Binaries

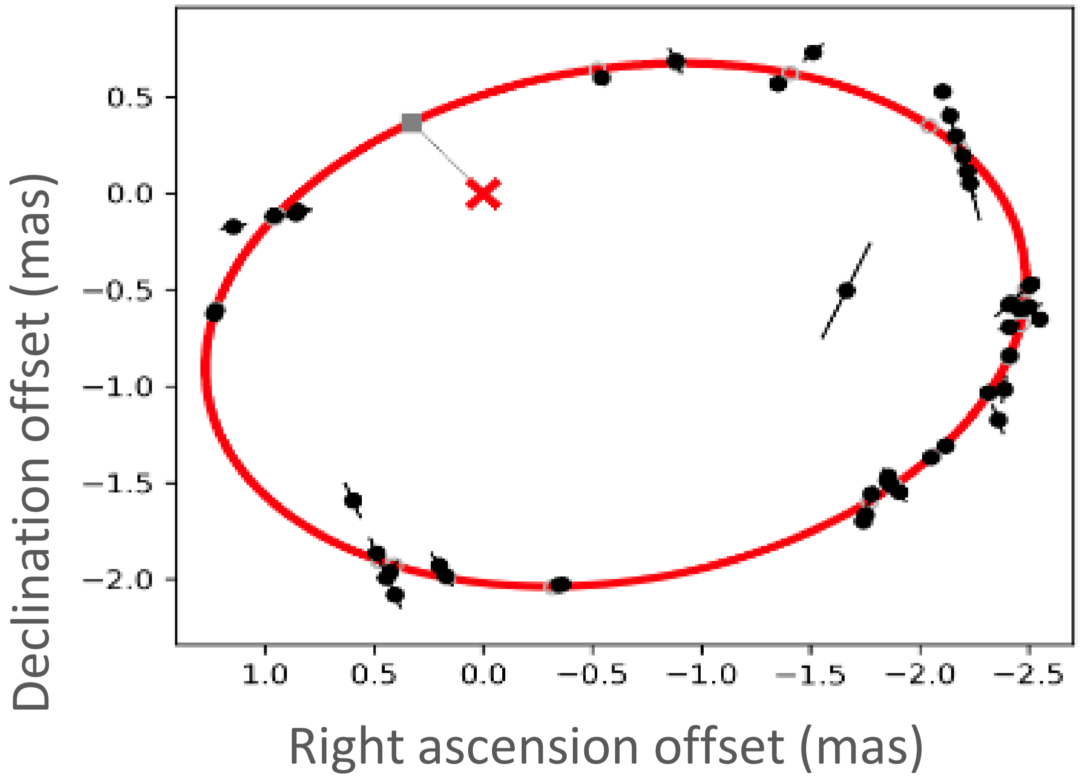
Non-single stars		
Total	813 687	
Acceleration solutions	338 215	
Orbital astrometric solutions	169 227	including astroSpectroSB1 combined solutions
Orbital spectroscopic solutions (SB1/SB2)	220 372	including astroSpectroSB1 combined solutions
Trend spectroscopic solutions	56 808	
Eclipsing binaries	87 073	including eclipsingSpectro combined solutions

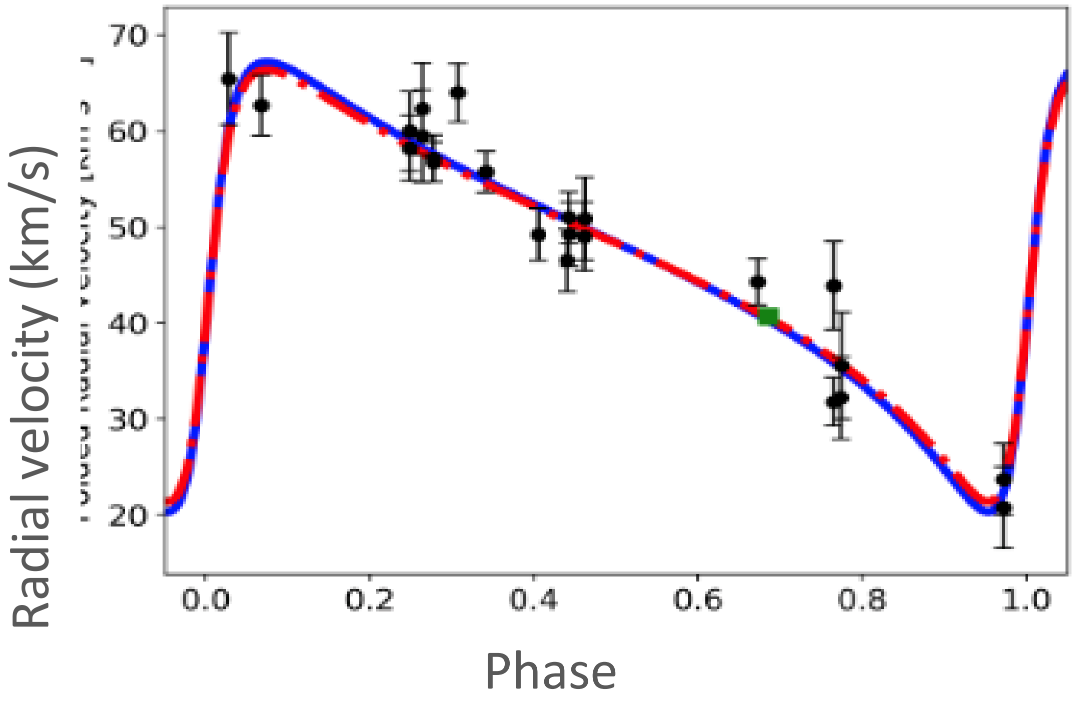
40 x orbits in Orb6

45 x orbits in SB9

Gaia Collab, Arenou et al (2022) and refer. therein

Gaia may detect large mass companions



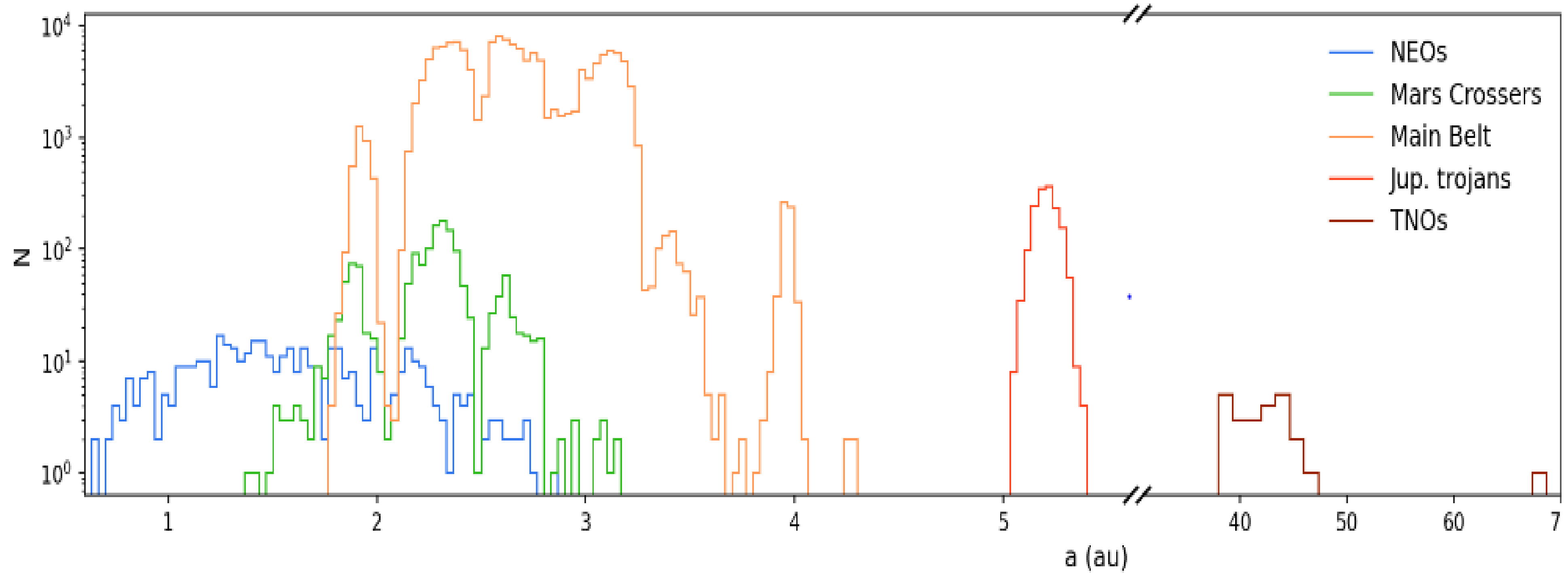


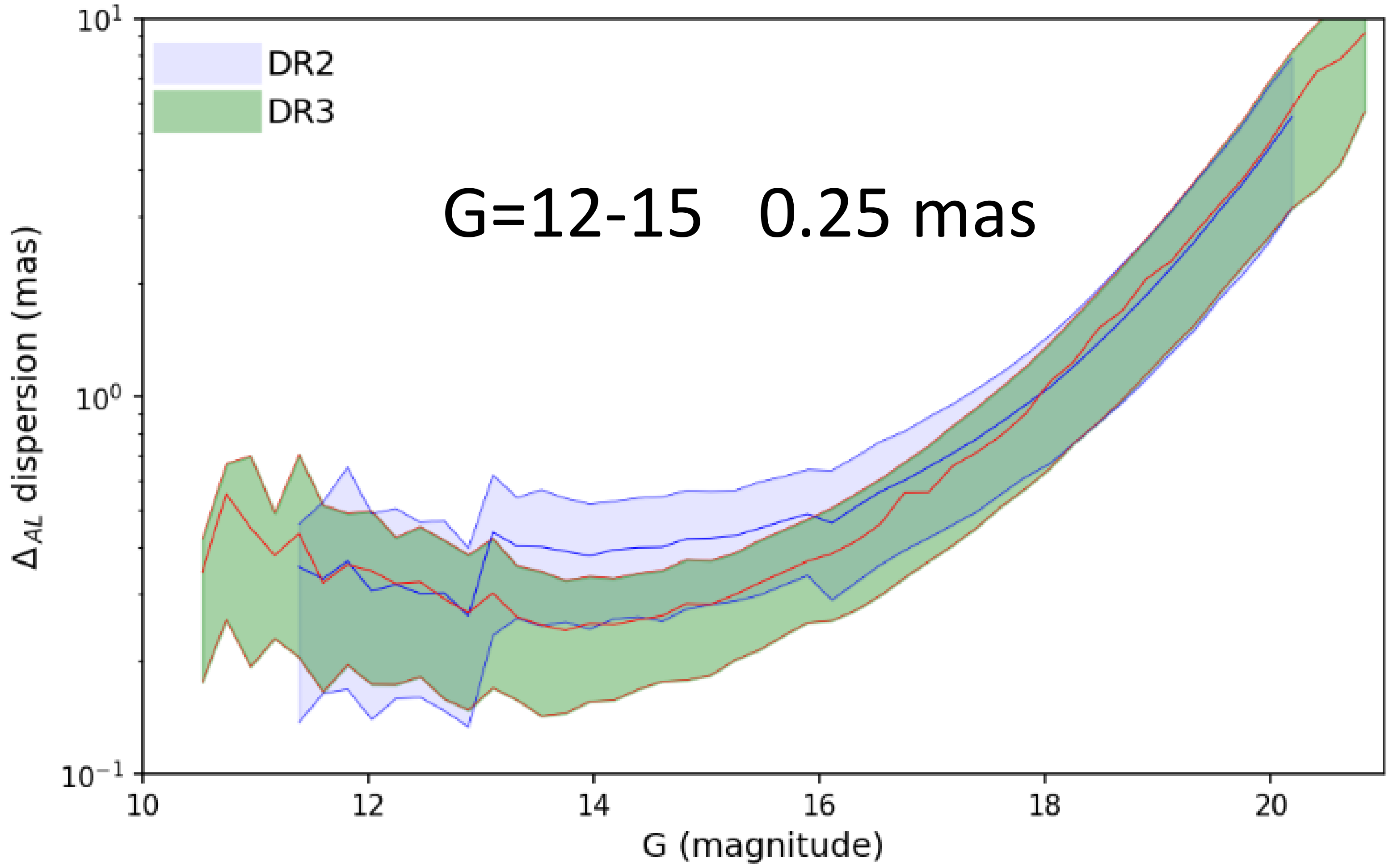
- Several spectroscopic binaries involve non (or less?) luminous companions, more massive than the visible star
- Dormant neutron stars or even black holes?
- Confirmation is needed because of alternative possibilities
- Several dozen of exoplanets candidates

Gaia DR3 5136025521527939072
Both Astrom. + spectro., period 546d
1.2 $\mathfrak{M}_{\odot}$ +1.5 $\mathfrak{M}_{\odot}$ (neutron star?)

Credits: ESA/Gaia/DPAC/CU4/NSS, Pasquale Panuzzo & Johannes Sahlmann

Solar System Objects

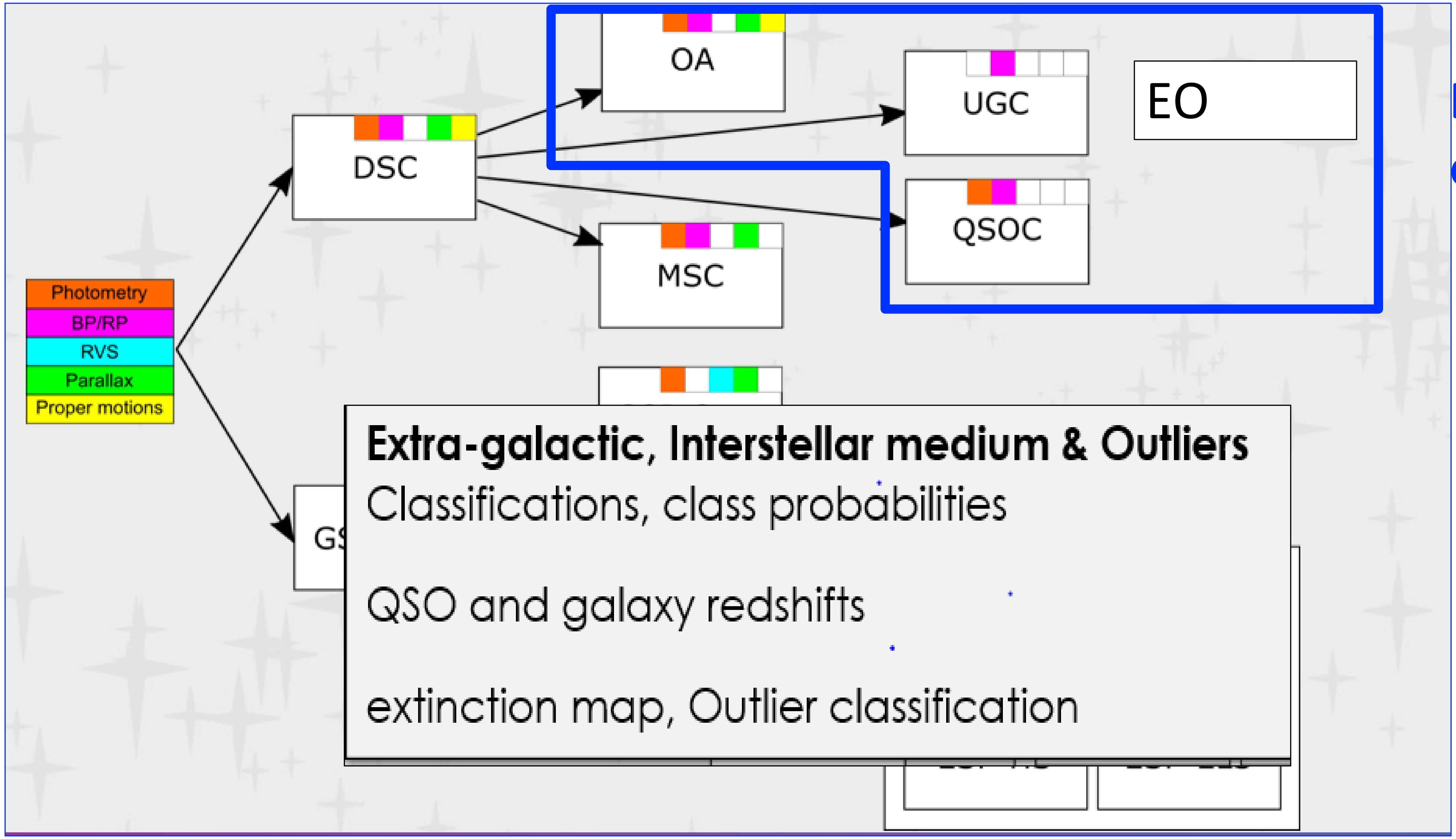




Solar System objects photometry	158,000 epoch astrometry and
SSO reflectance spectra	60,000
Planet moons	31
NEOs	447
Binary asteroids	

Tanga et al (2022)
Gaia Collab,Galluccio et al (2022)

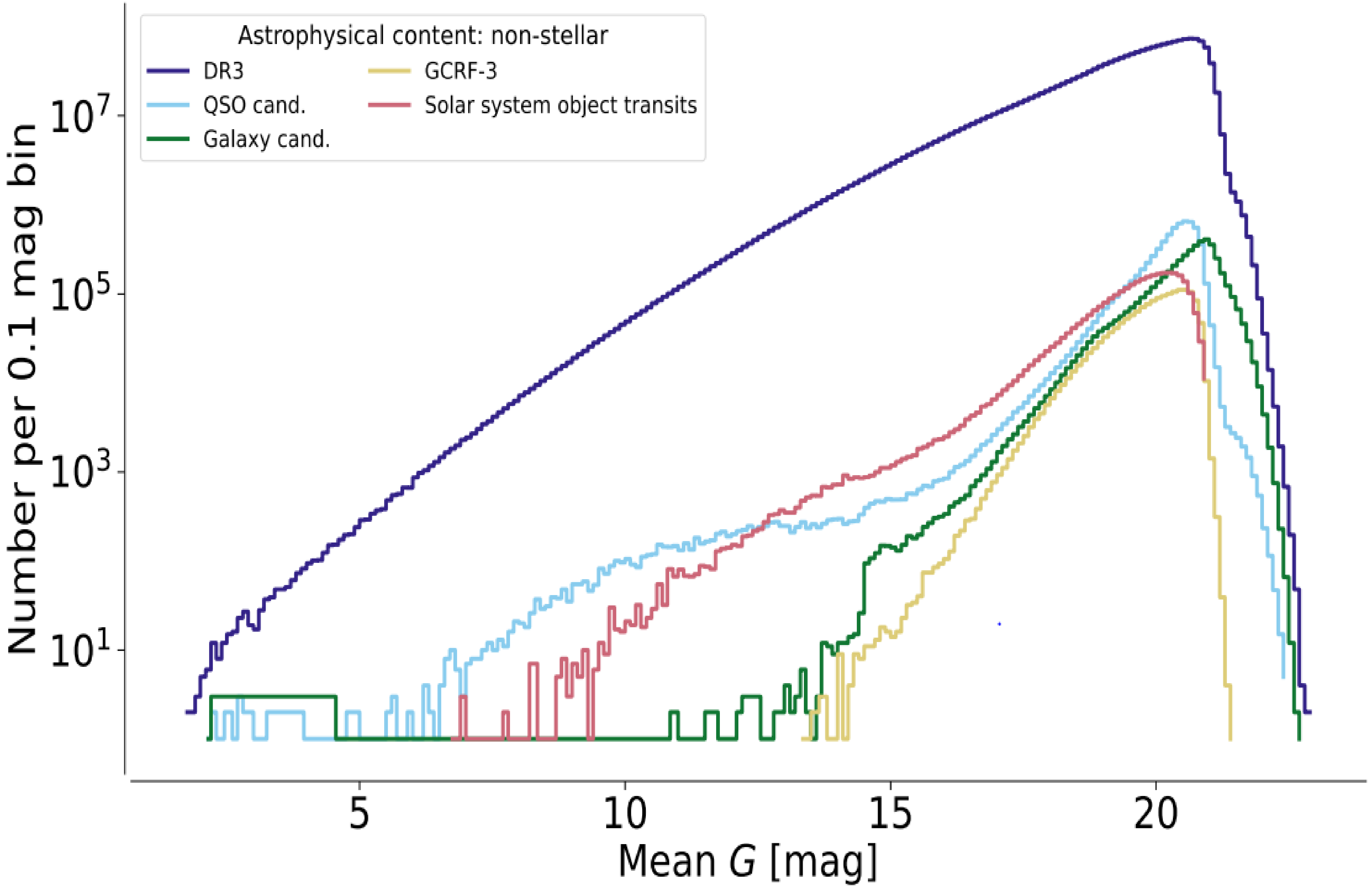
Astrophysical parameters: Extragalactic objects



Extragalactic objects

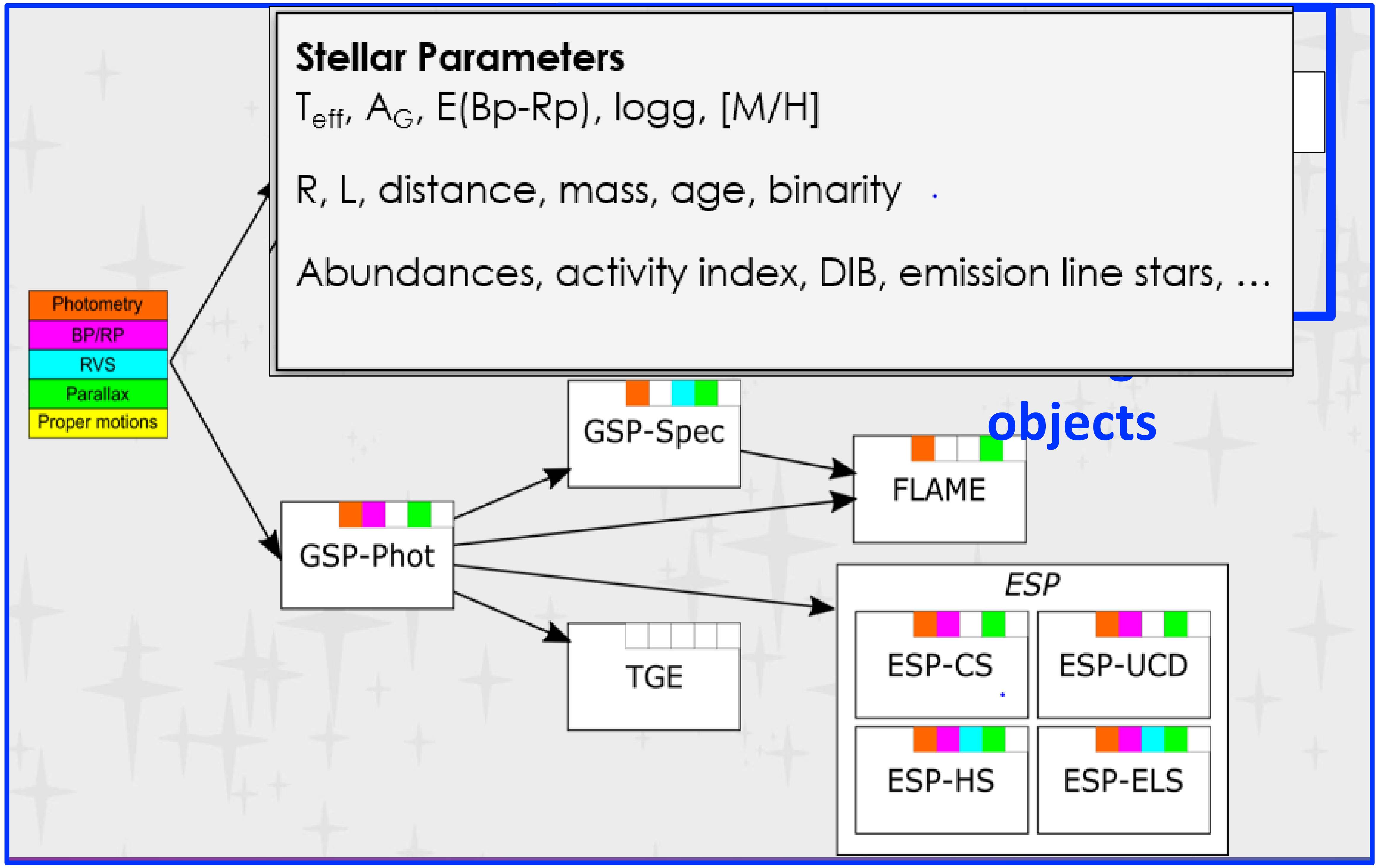
Delchambre et al (2022)
Gaia Collab, Bailer-Jones et al (2022)
Ducourant et al (2022)

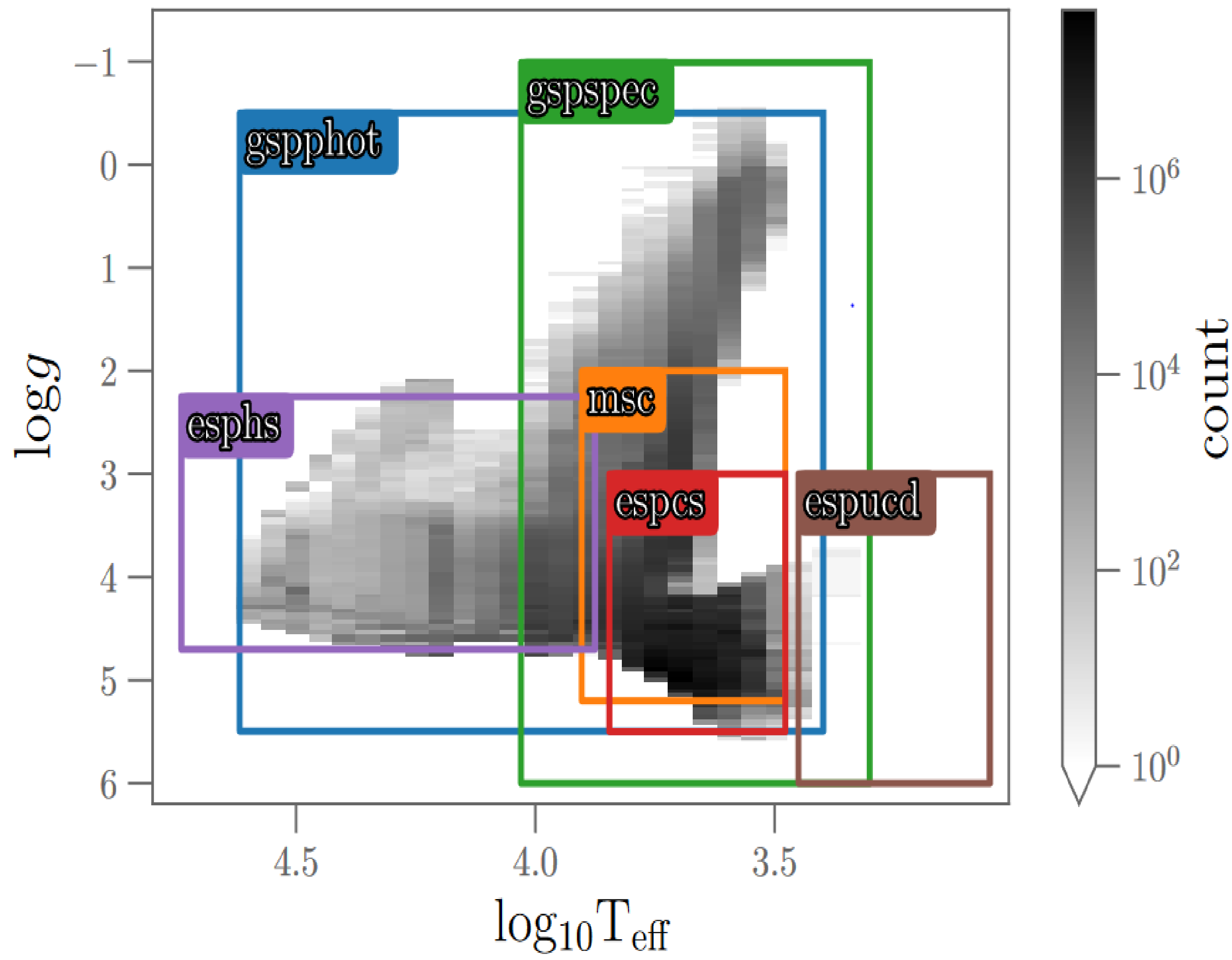
See talks by
Coryn, Christine, Francois



QSO candidates	6 649 162	High completeness, low purity
QSO redshifts	6 375 063	
QSO host galaxy detected	64 498	
QSO host galaxy profile	15 867	
Galaxy candidates	4 842 342	High completeness, low purity
Galaxy redshifts	1 367 153	
Galaxy profiles	914 837	

Astrophysical parameters

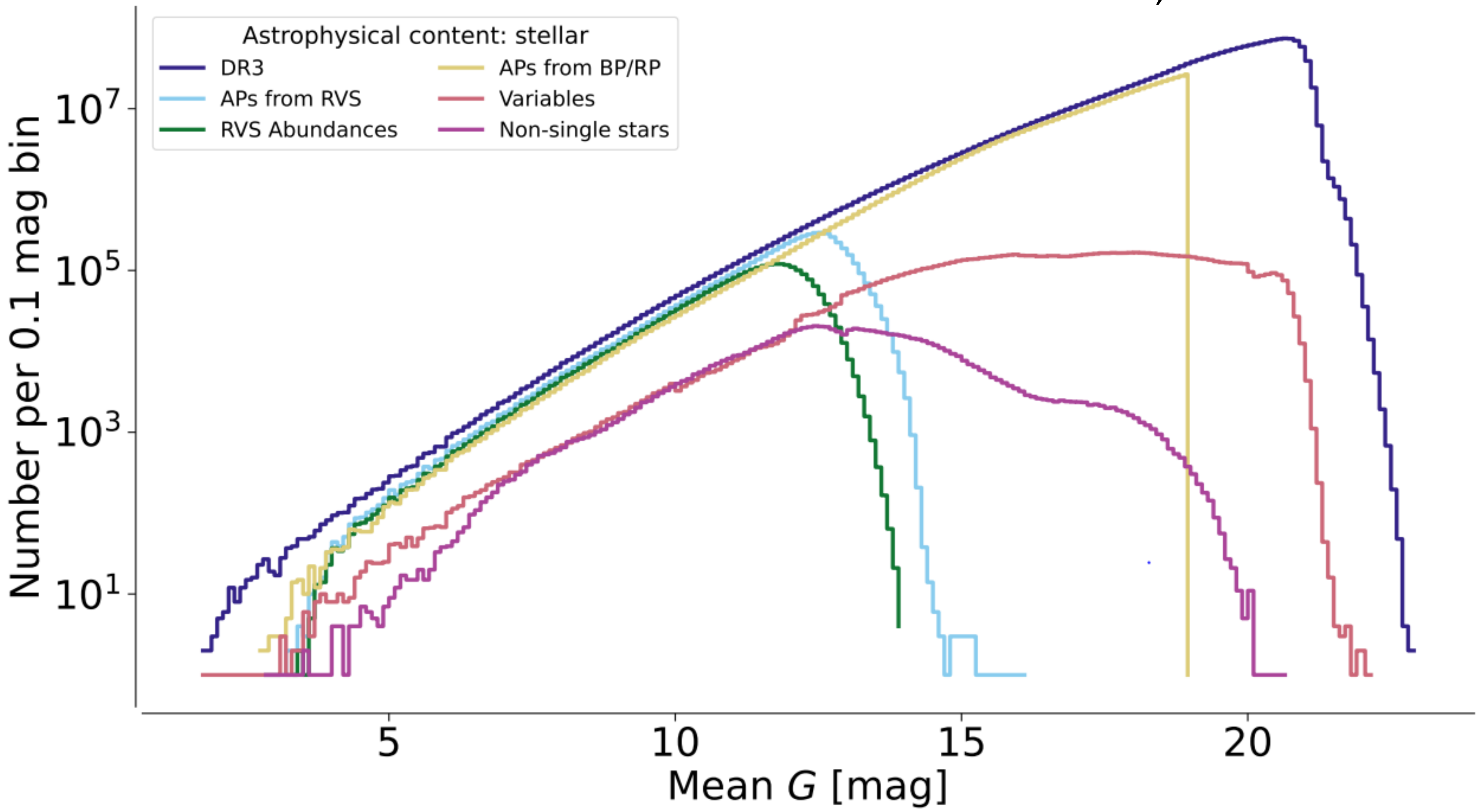


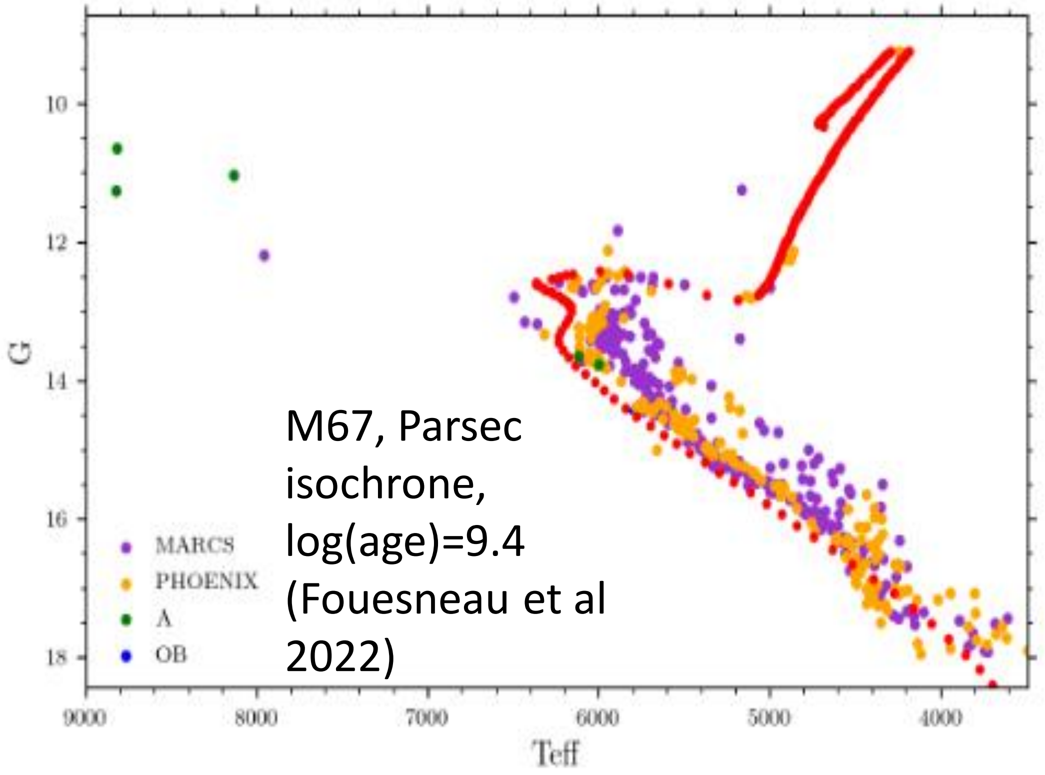


Creveey et al (2022)
Andrae et al (2022)
Fremat et al (2022)
Fouesneau et al (2022)

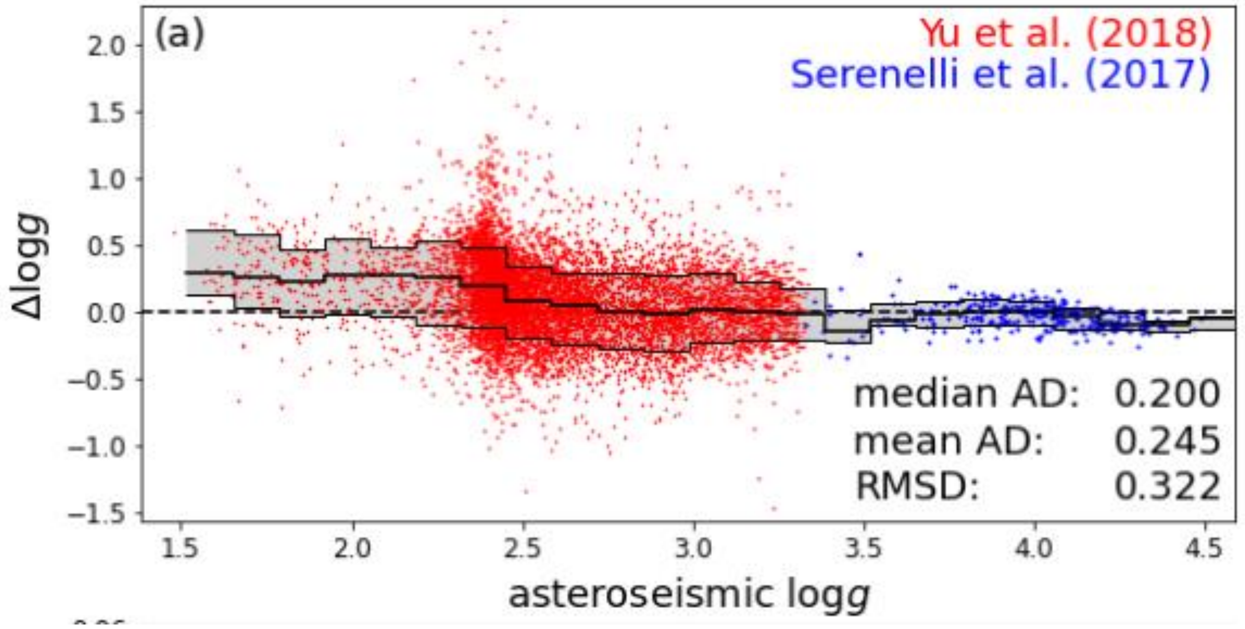
Parameters from BPRP data

Gaia Collaboration, Vallenari et al 2022





M67, Parsec isochrone, log(age)=9.4 (Fouesneau et al 2022)



Median Teff error =120 K /mean 180 K

[M/H] dispersion in OC 0.5

Systematics

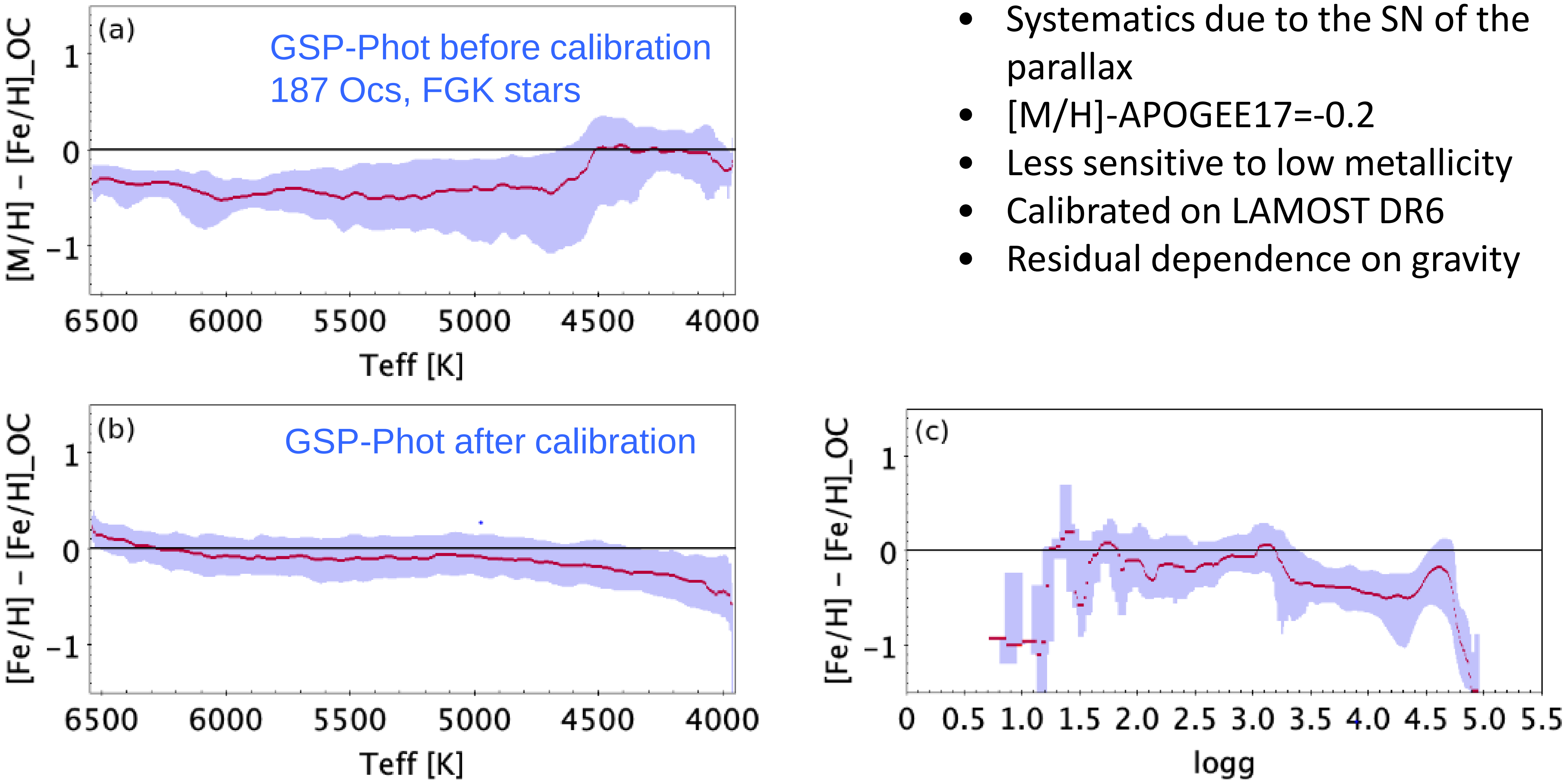
- Variability not taken into account
- Teff-AG degeneracy
- Parallax SN dependence
- Affected by crowding

(Gaia Collaboration, Vallenari et al 2022, Fouesneau et al 2022, Babusiaux et al 2022)

Grey: 68% interval
GSP-Phot
(Andrae et al 2022)

Comparison with literature:GSP-Phot

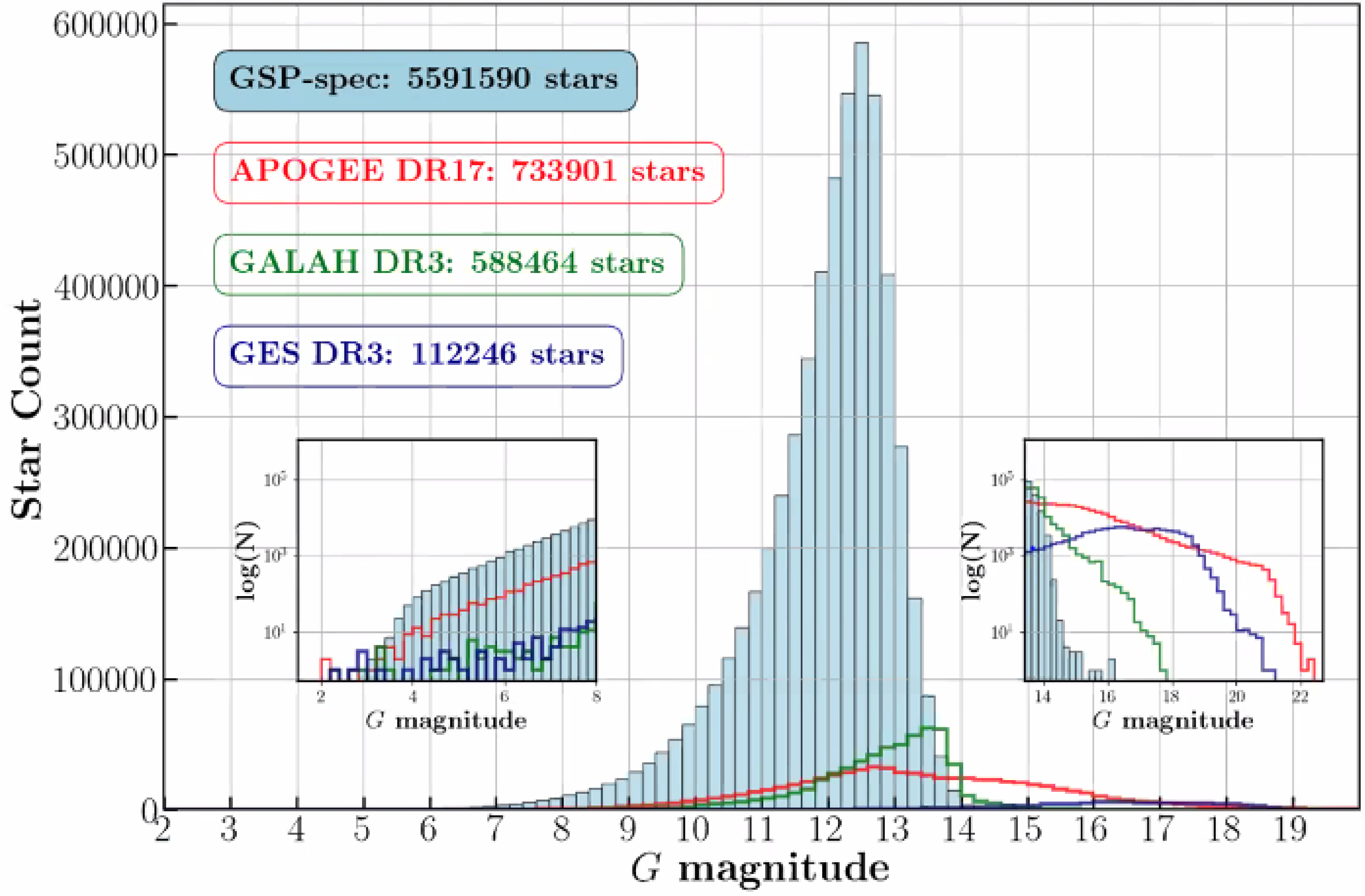
- Sample of 200,000 stars in 1000 OCs
- Systematics due to the SN of the parallax
- [M/H]-APOGEE17=-0.2
- Less sensitive to low metallicity
- Calibrated on LAMOST DR6
- Residual dependence on gravity



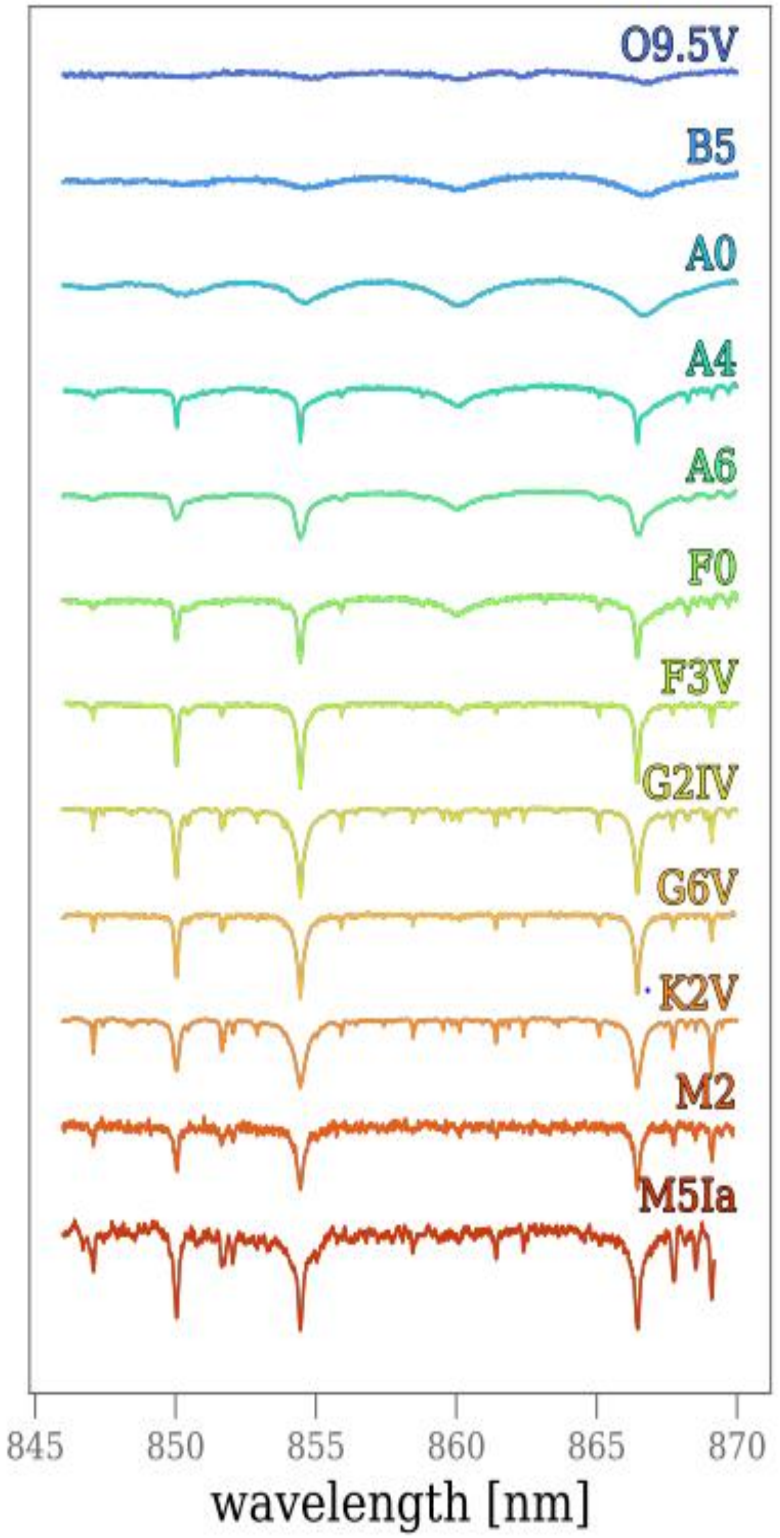
Andrae et al (2022)

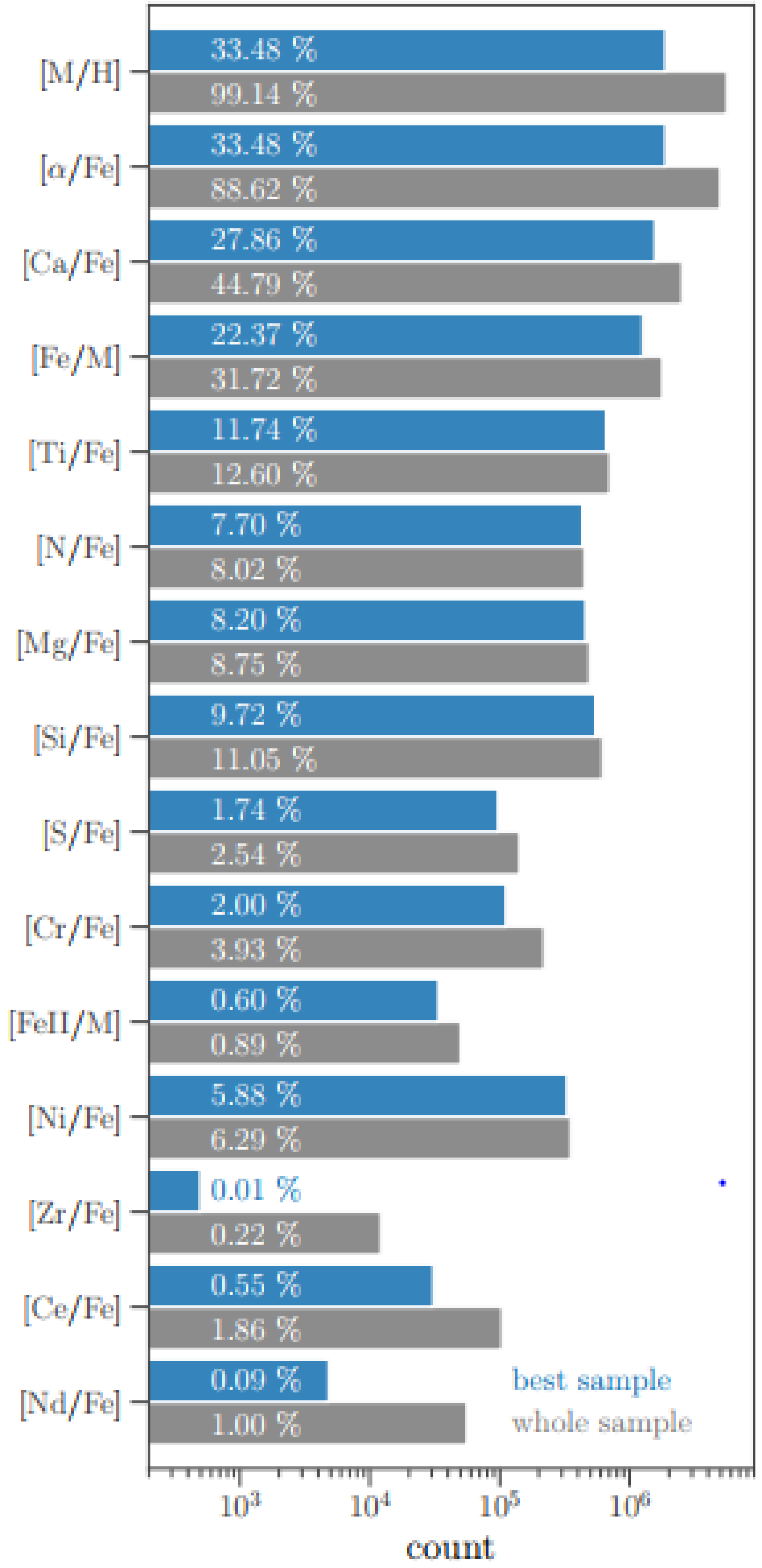
https://www.cosmos.esa.int/web/gaia/dr3-software-tools

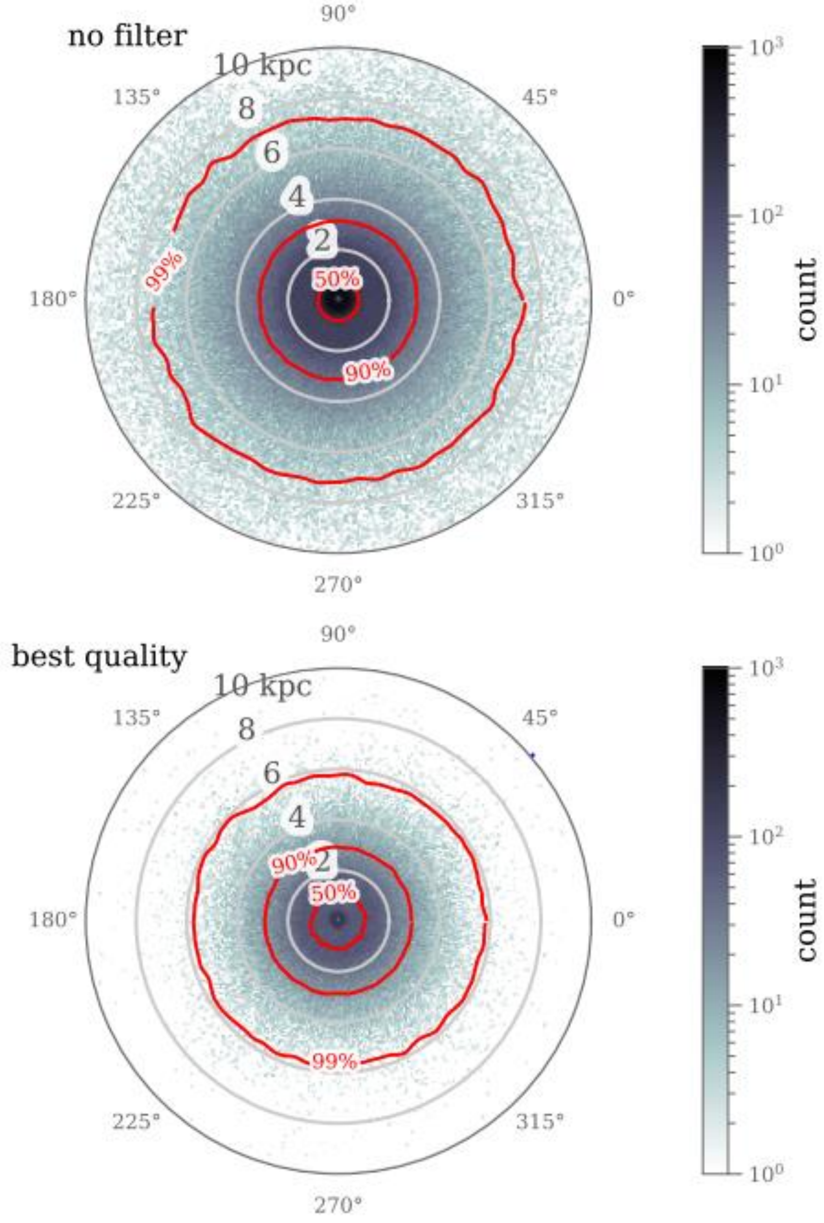
GSP-Spec Survey



Detailed chemical abundances







Fouesneau et al 2022

Over 2.5 million data

FGK stars
Best measured stars
[M/H](GSP-Phot(cal)-GSP-Spec)=0.1

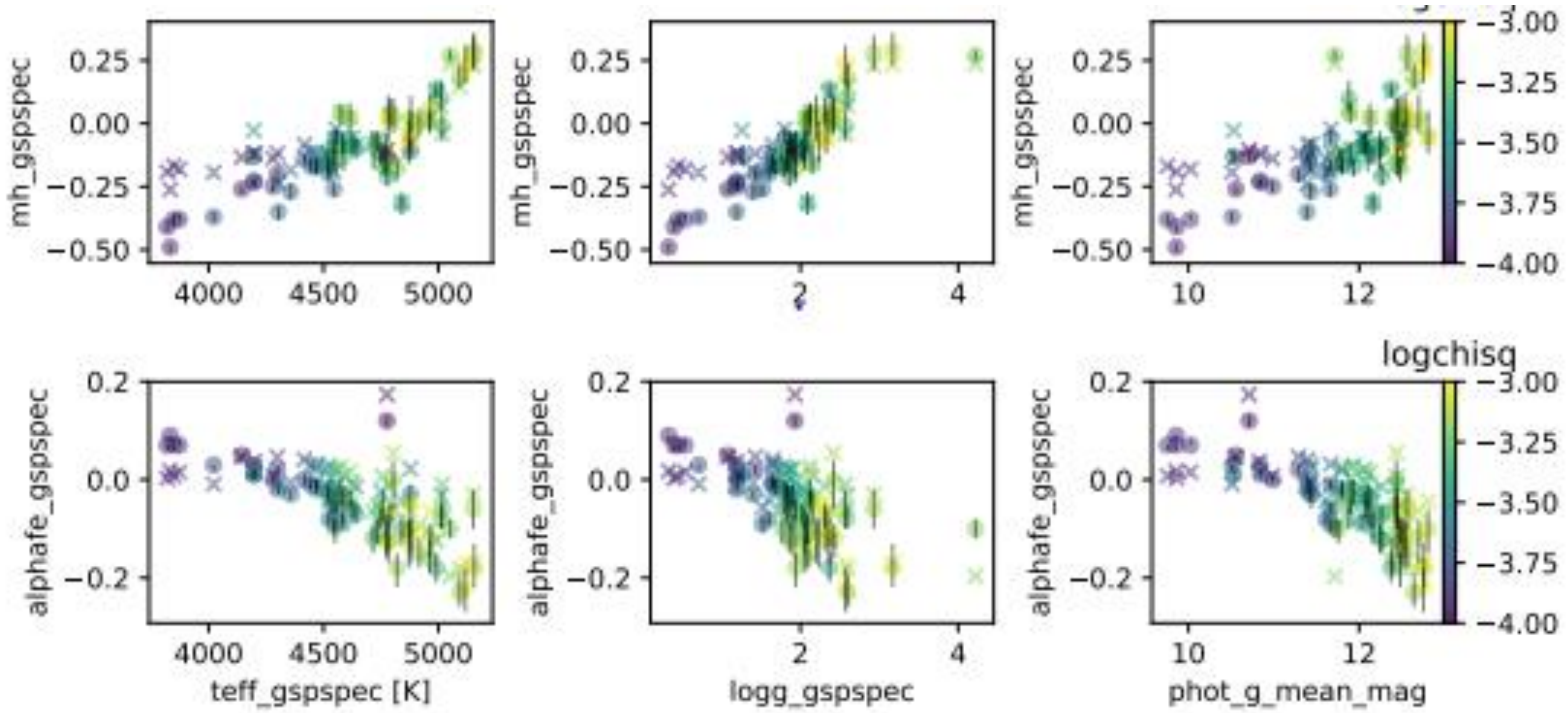
12 chemical abundances from RVS for 2,5 million stars and stellar parameters for 5,5 million stars (Gaia Collab, Recio-Blanco et al 2022)

Comparison with literature:GSP-Spec

- SN>20, (G< 16)
- No use of parallax
- [M/H]-APOGEE17=+0.04 (σ=0.08) before calibration

- Log(g) dependent correction for [Fe/H] and [alpha/Fe] vs (APOGEE17, GALAH3, RAVE6) (Recio-Blanco et al 2022)
- After calibration: [M/H]-APOGEE17=-0.005 (σ =0.15)
- Residual trends with gravity and Teff

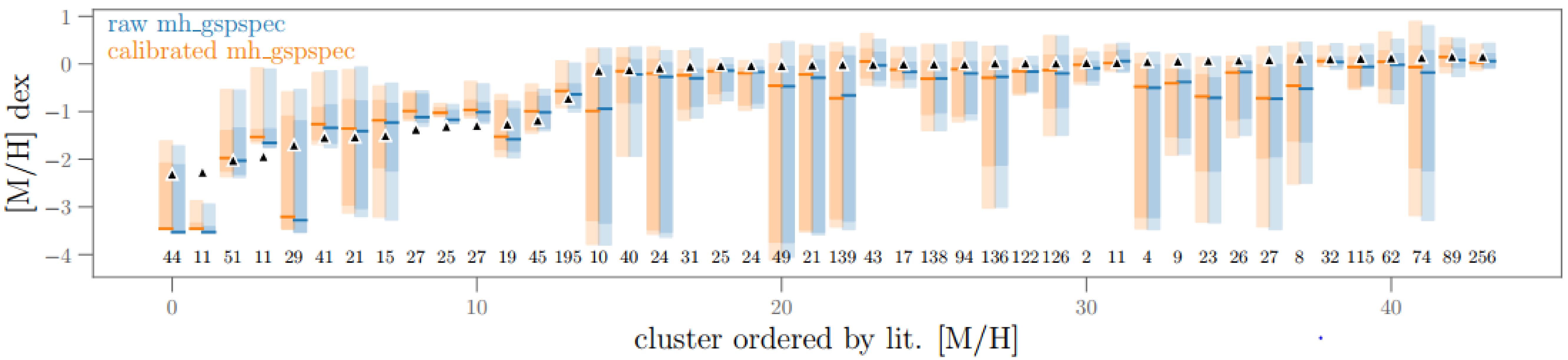
X calibration



Babusiaux et al (2022)

GSP-Spec Matisse-Gauguin

Fouesneau et al (2022)

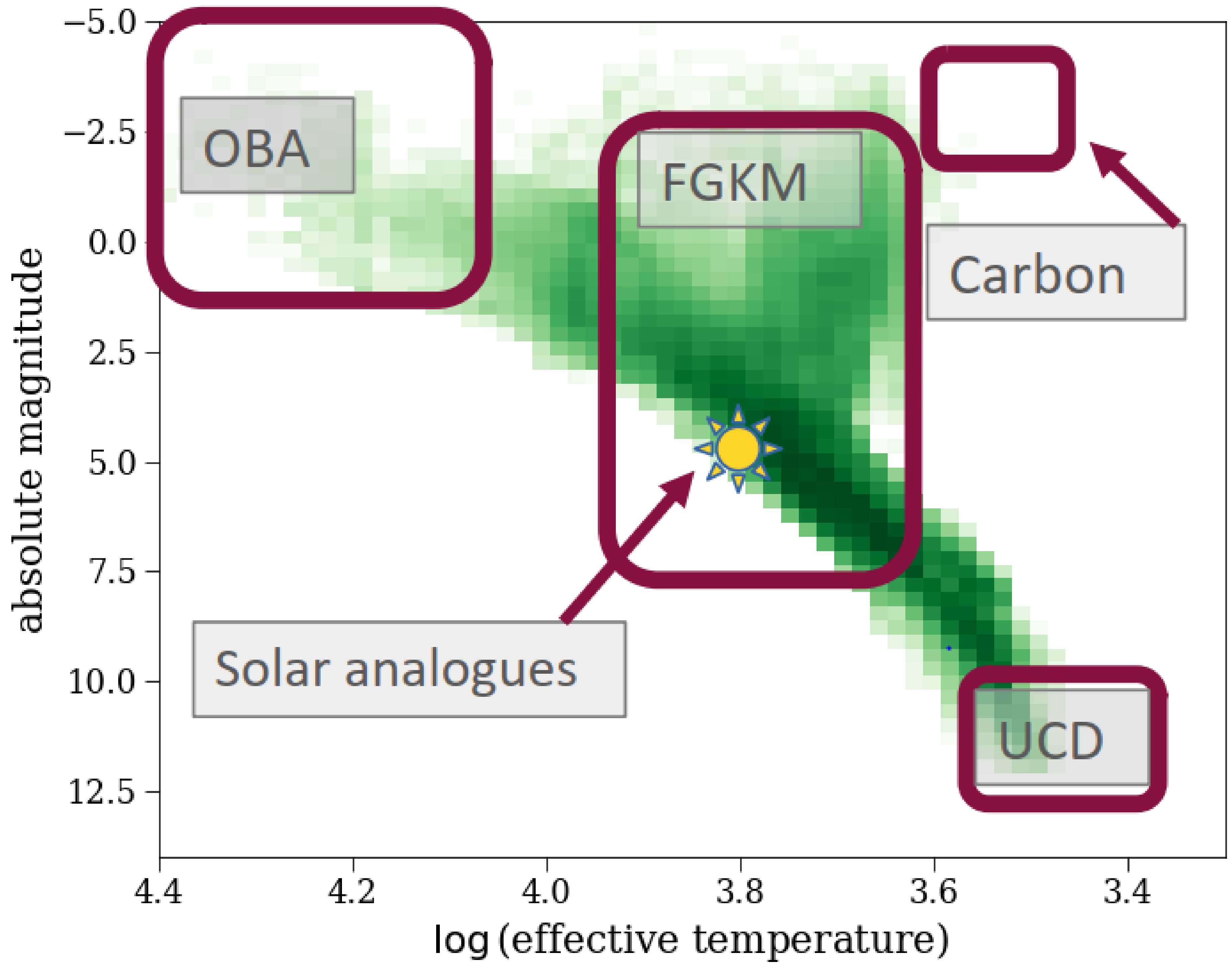


Golden samples

6 DR3 Catalogs of Objects

- Young OBA stars: 3 million
- FGKM stars: 3 million
- Solar analogues:5600
- Carbon stars:400,000
- UCDs:20,000
- SSP standards

- In the archive:
- gaiadr3.gold_sample_xxx



Gaia Coll. Creevey et al 2022

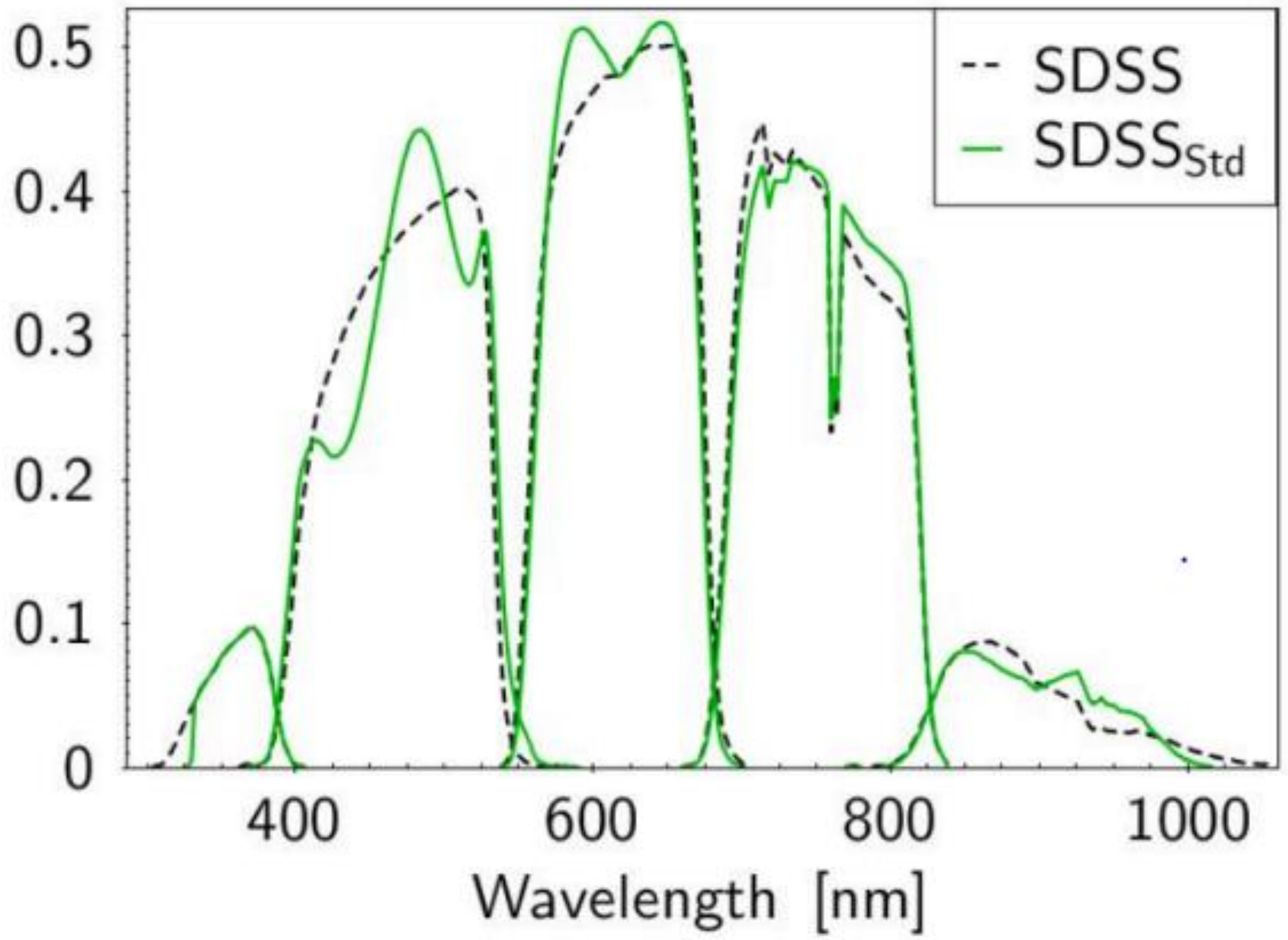
Synthetic photometry

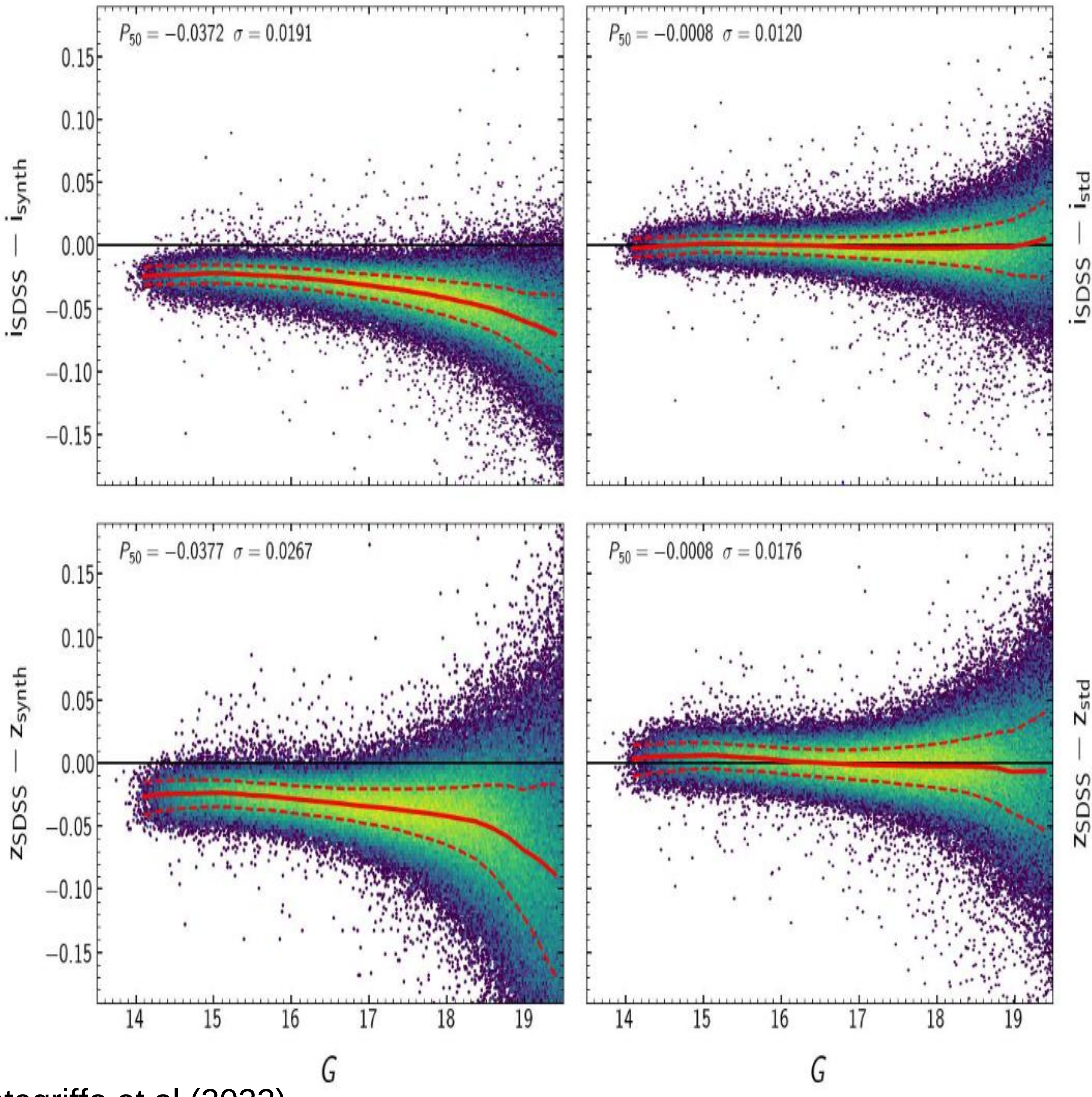
- Any photometric passband enclosed in the range 330-1050 nm with characteristic width larger than the BP/RP LSF at the relevant wavelength

- Unbiased data set for G< 17.65

Standardisation against a top-quality reference catalogue minimises residual systematics in the BP/RP spectra and allows to reach accuracies from a few millimag to sub-millimag for wide passbands in the range λ > 400 nm

Standardised

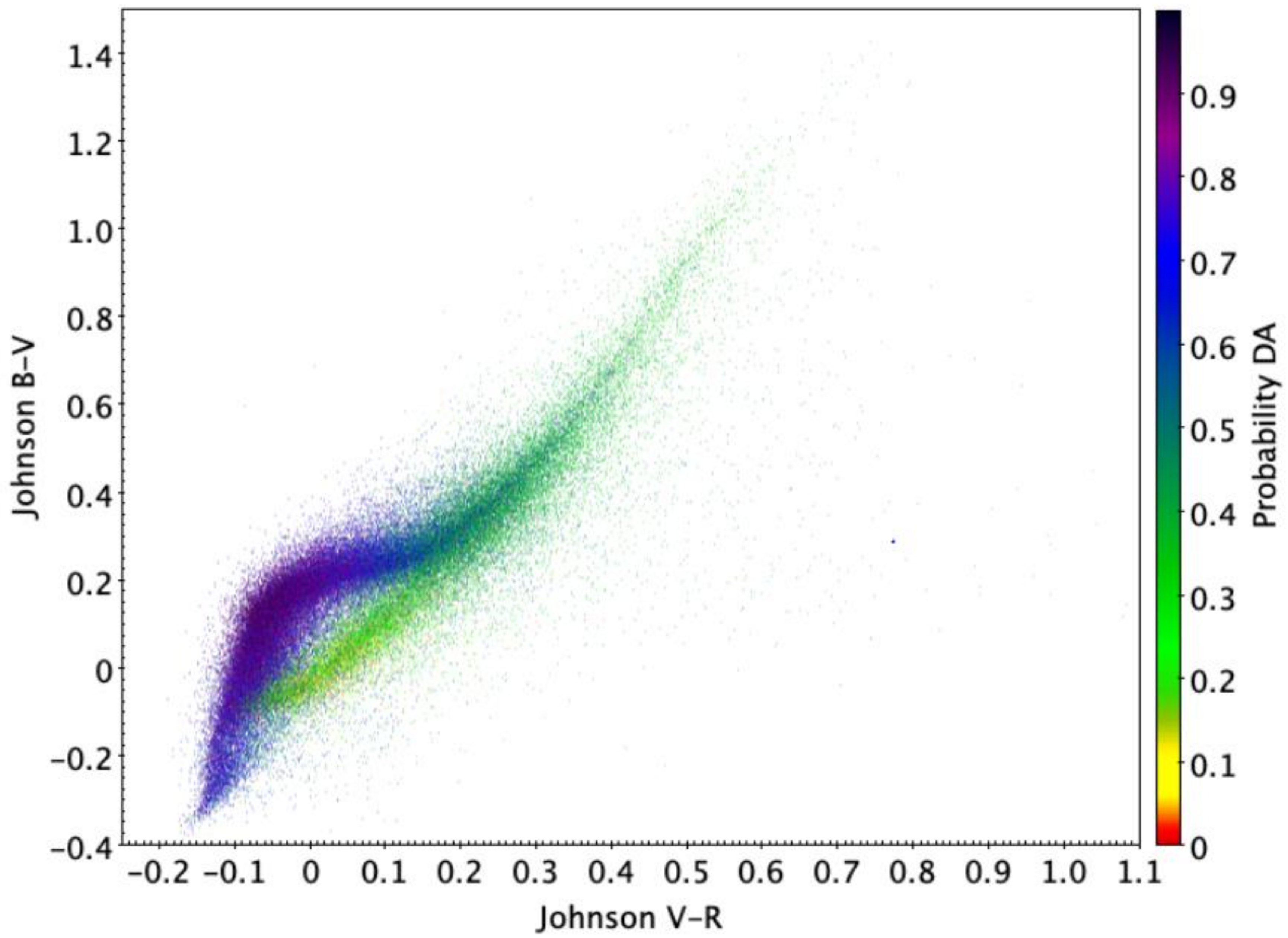




Gaia Collab, Montegriffo et al (2022)

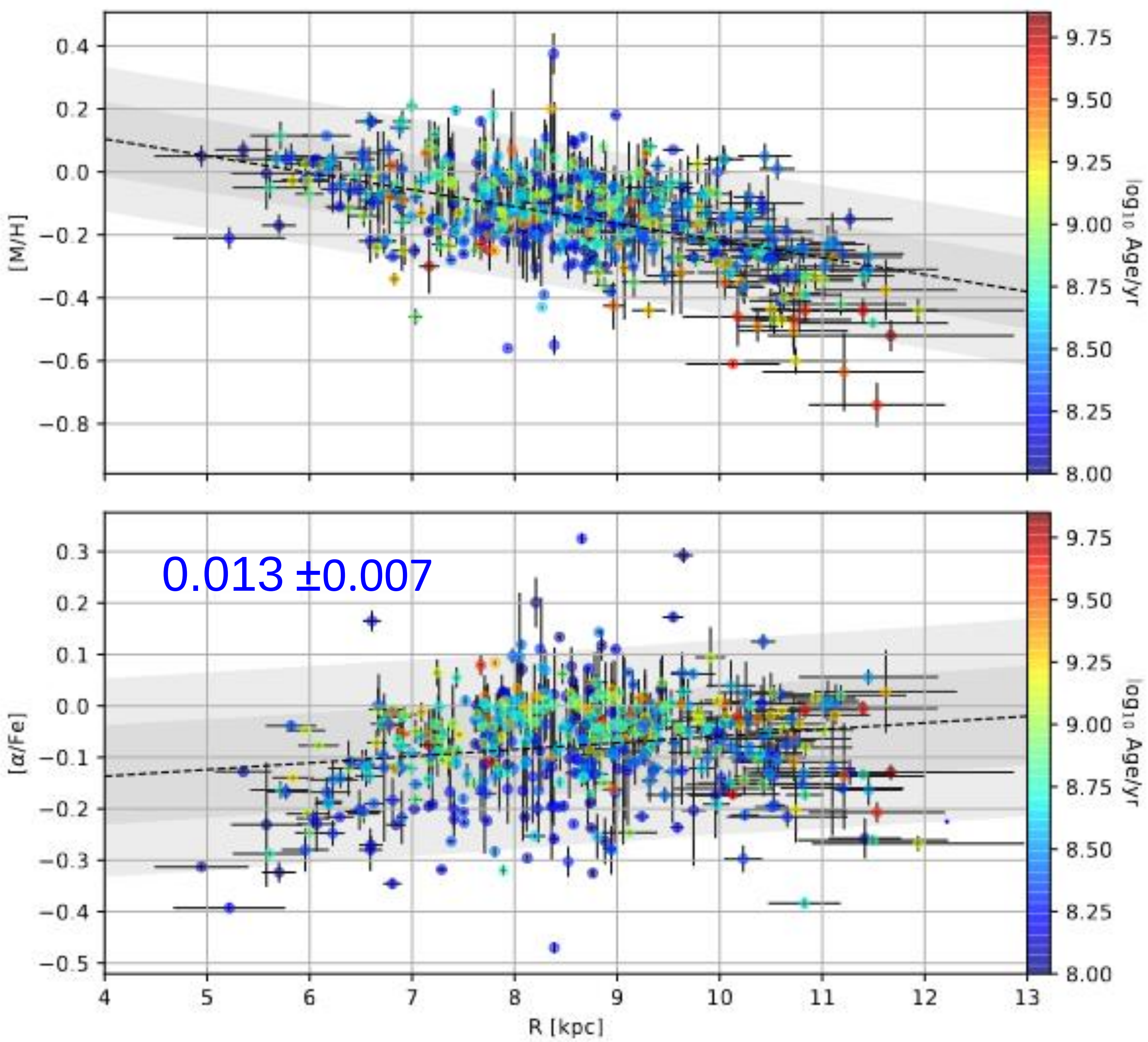
Available in DR3

- GSPC Gaia Synthetic Photometry catalogue
  - query-able from the DR3 archive
  Standardised Johnson-Kron-Cousins (U,B,V,R,I), SDSS (u,g,r,i,z), PanSTARRS1 (y), ACS/WFC (F606W, F814W) photometry
- GSPC-WD ~ 100K WDs with G<20
  Standardised Johnson-Kron-Cousins (U,B,V,R,I), SDSS (u,g,r,i,z), J-Plus photometry with DA (H-rich) / non-DA classification from random forest
- GaiaXPy : to derive synthetic photometry in your favorite bands



GaiaXPy @ https://gaia-dpci.github.io/GaiaXPy-website/

Radial metallicity gradient



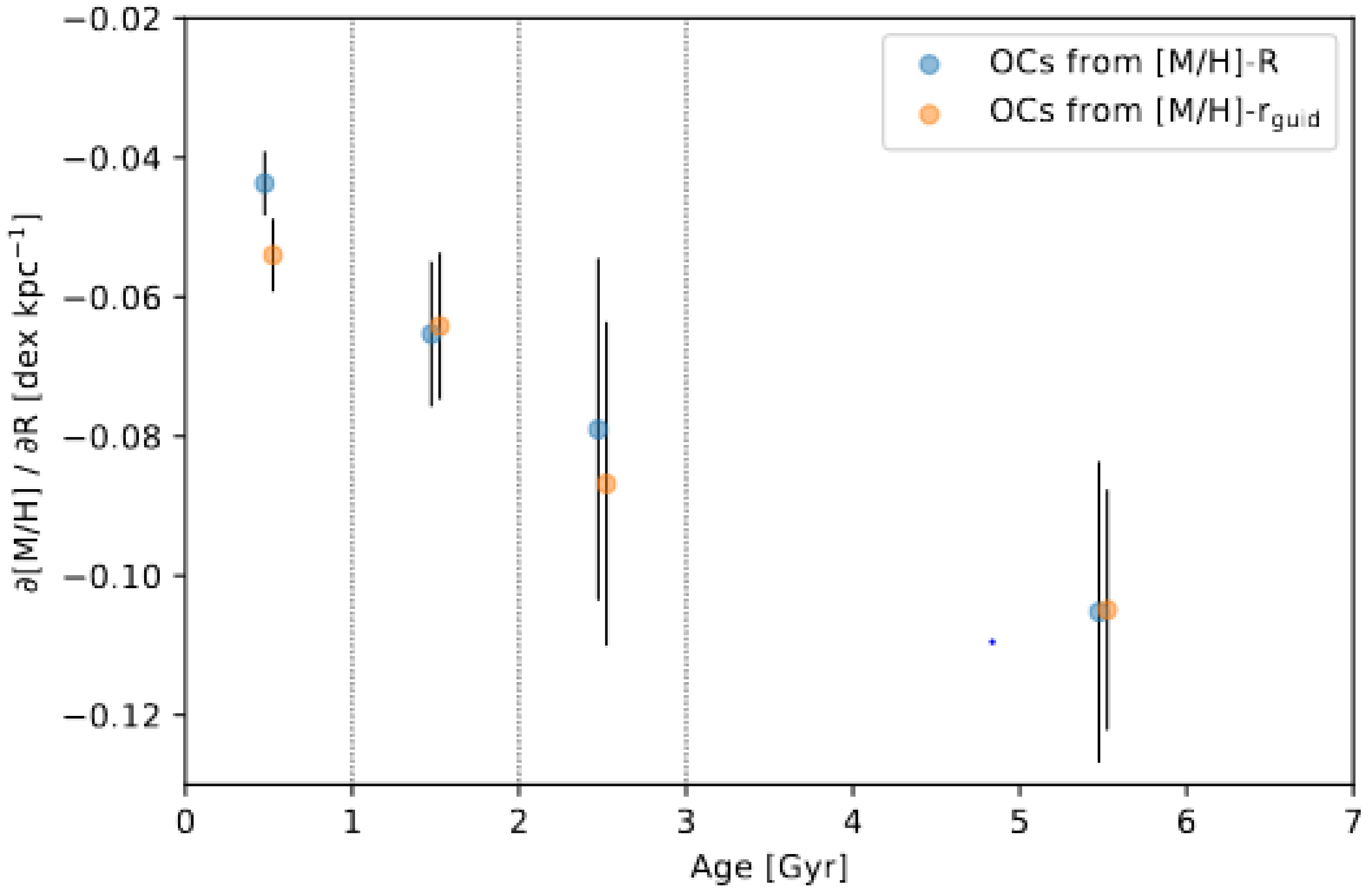
Gaia Collaboration Recio-Blanco et al (2022)

- Selection criteria:
- teff_gspspec<8000 K, and rv_expected_sig_to_noise≥40.
- 1613 stars in 597 OCs with 1-55 stars
- Age>100 Myr→ 503 OCs

- Radial gradient:
  0.054±0.008 dex /kpc
- Consistent with Casamiquela et al. (2019-18 Ocs), Spina et al.(2022, 175 OCs)
- higher than Jacobson et al. (2016), Netopil et al. (2016), Carrera+(2019),
  Donor+ (2020), Zang+(2021-157Ocs)
  from -0.10 ± 0.02 to -0.066±0.005

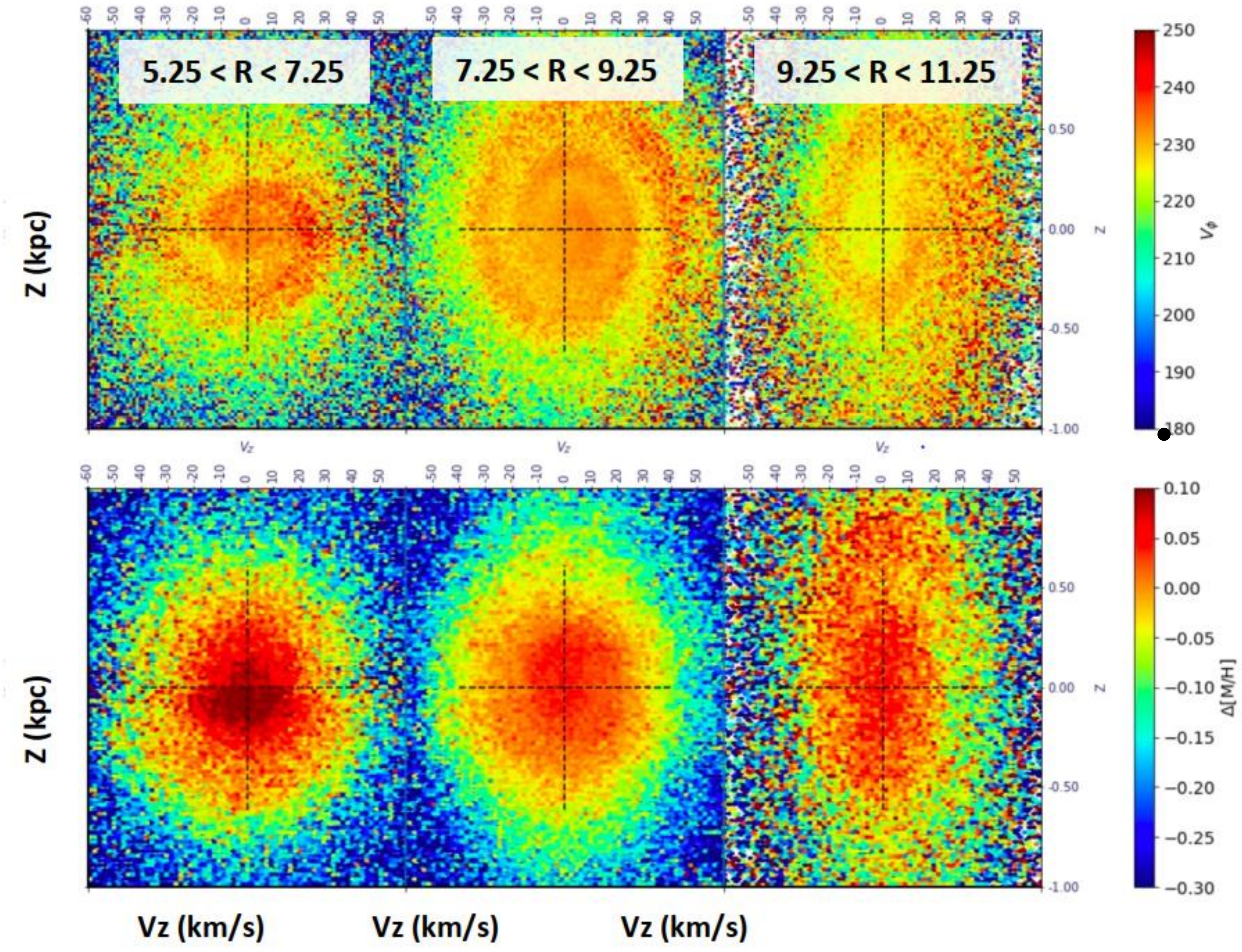
-

Age dependent gradient



- Young OC gradient flatter
- Field stars have an opposite behavior (Anders et al 2017, Minchev et al 2018…)
- Consistent with young field population from pure Gaia data
  - Full sample -0.055 ±0.007
  - Young Massive -0.036± 0.002 dx/kpc

Chemical markers of disk perturbations



Phase spiral correlation with metallicity excess within thin disc populations, detected for the first time

Gaia Coll. Recio Blanco et al 2022

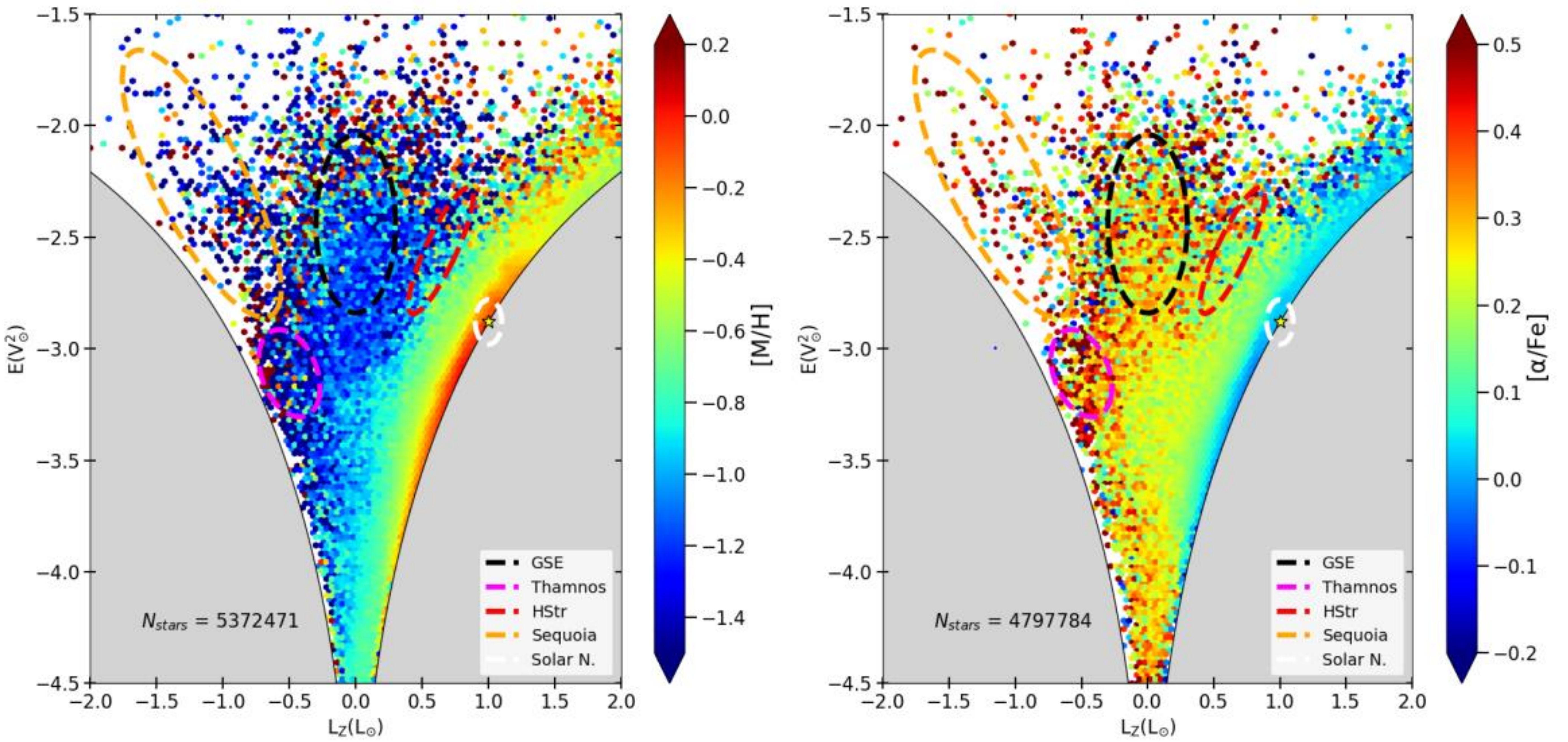
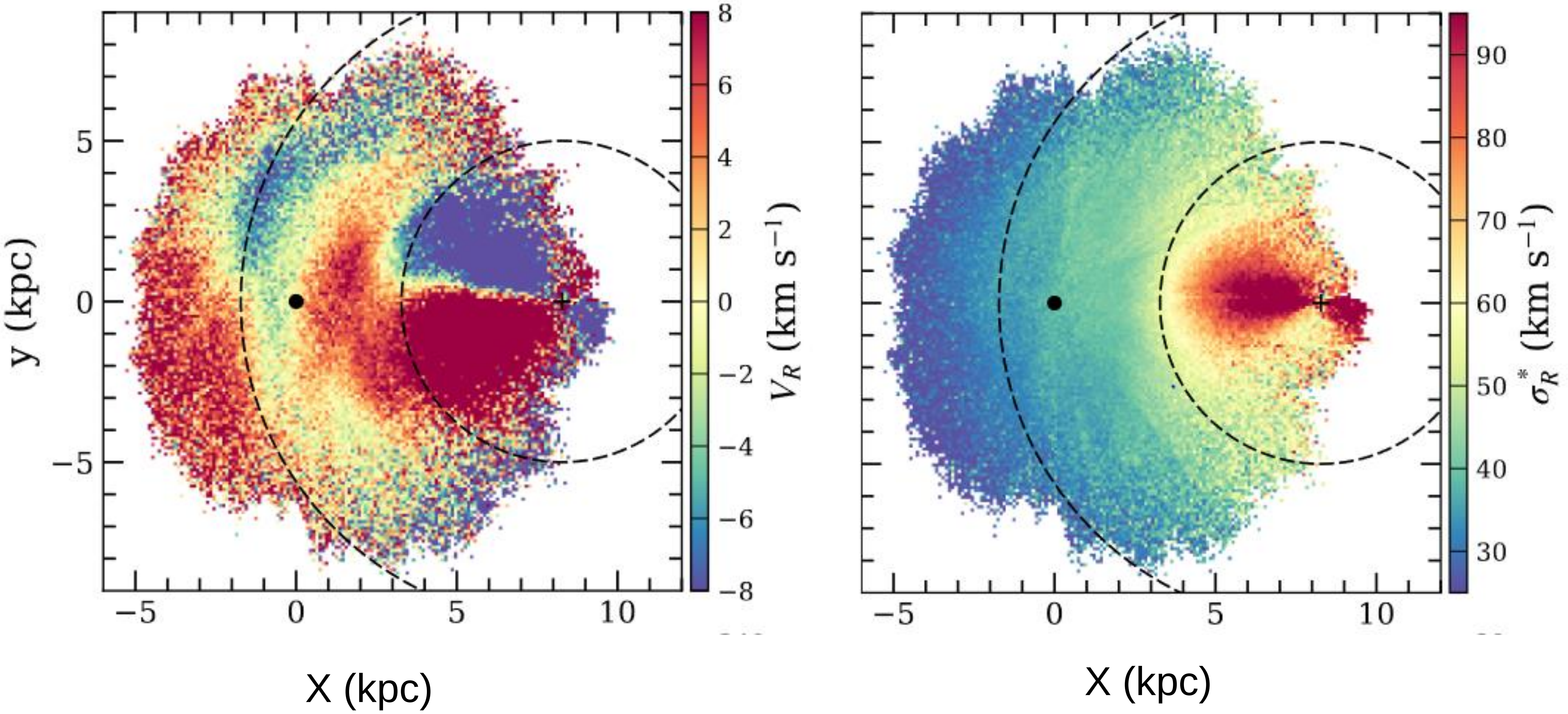


Fig. 27. Distribution of median metallicities (left panel) and α−elements enrichment with respect to iron (right panel) in the energy-angular momentum (E, L_Z) plane for the *General Sample* stars without those sources with log(g)<0.5. The coloured ellipses illustrate the selected areas associated with Gaia-Sausage-Enceladus (black), Thamnos (magenta), the Helmi stream (red), Sequoia (orange) and the Solar neighbourhood sample (white).

Sequoia candidates have a metallicity distribution peaking around [M/H]∼ -1.4 dex for [α/Fe]∼0
Gaia-Enceladus-Sausage peaks at [M/H]∼ -1.2 dex at the same [alpha/Fe]

Kinematic detection of the Galactic Bar

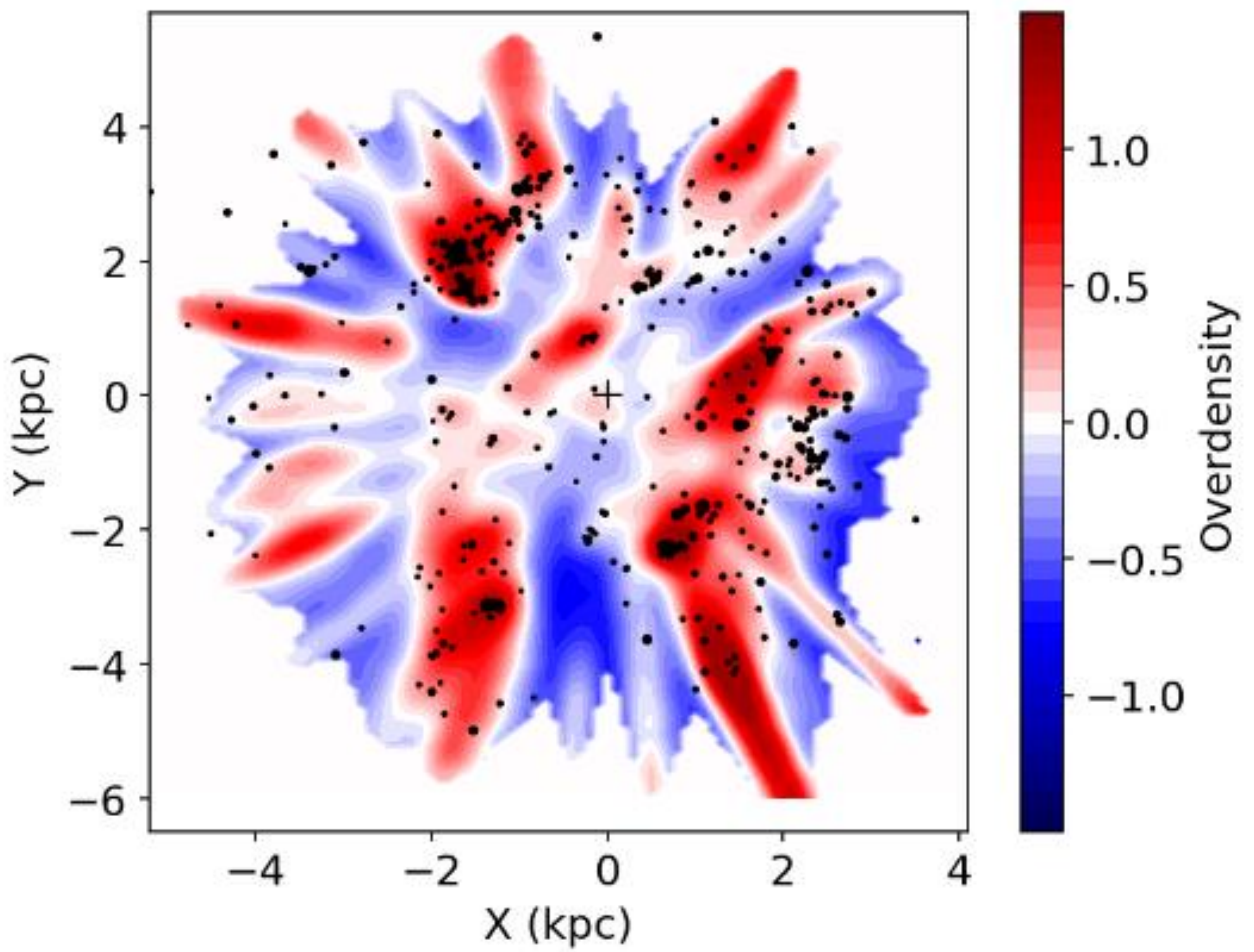


Vr radial velocities dominated by the bar out to 10 Kpc
Bar angle: 19 deg
Corotation at 5.4 Kpc; OLR at 9.7 Kpc

Gaia Coll. Drimmel et al 2022

Spiral arms

OBs +OCs



1000 OCs and 77,000 OBs with RVS data

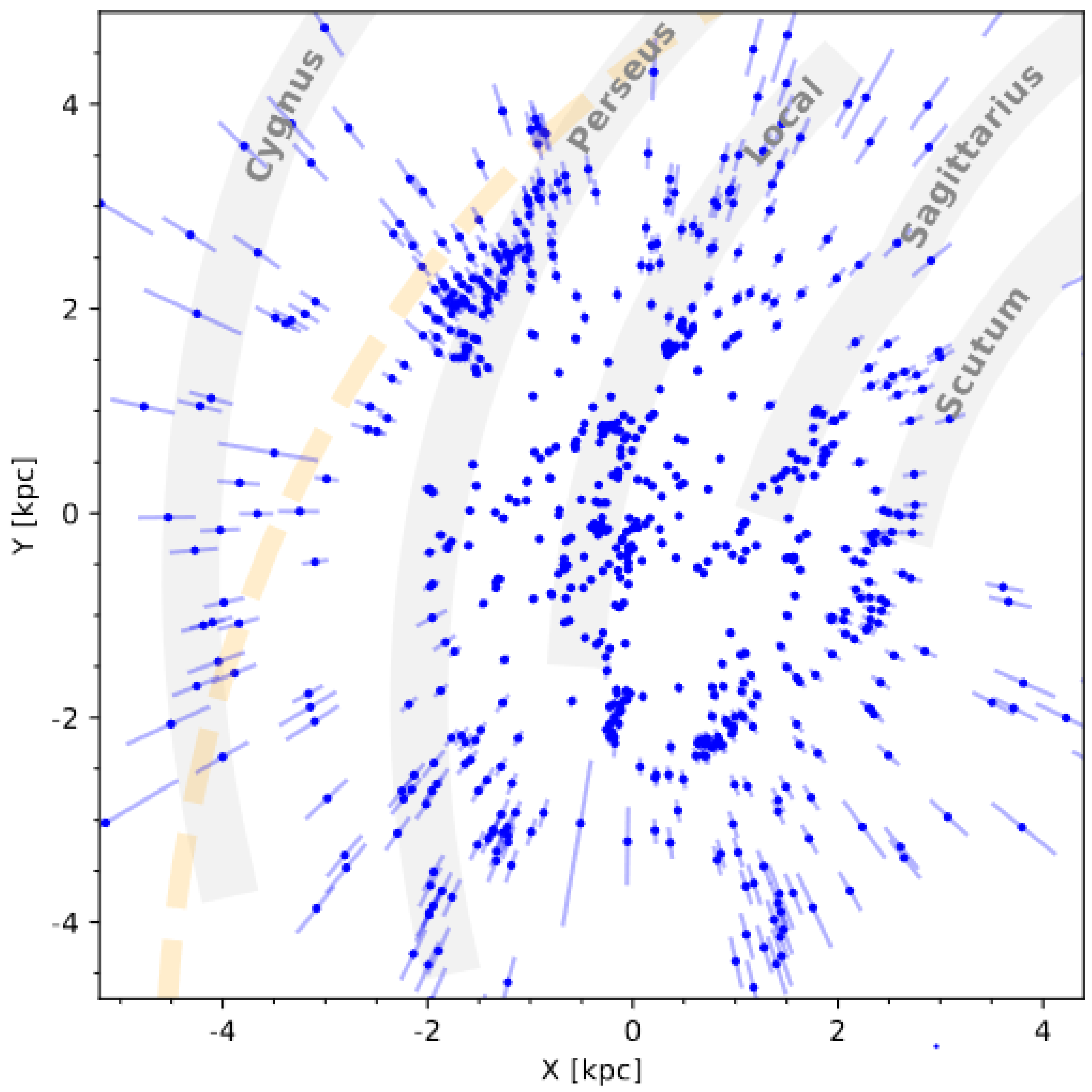
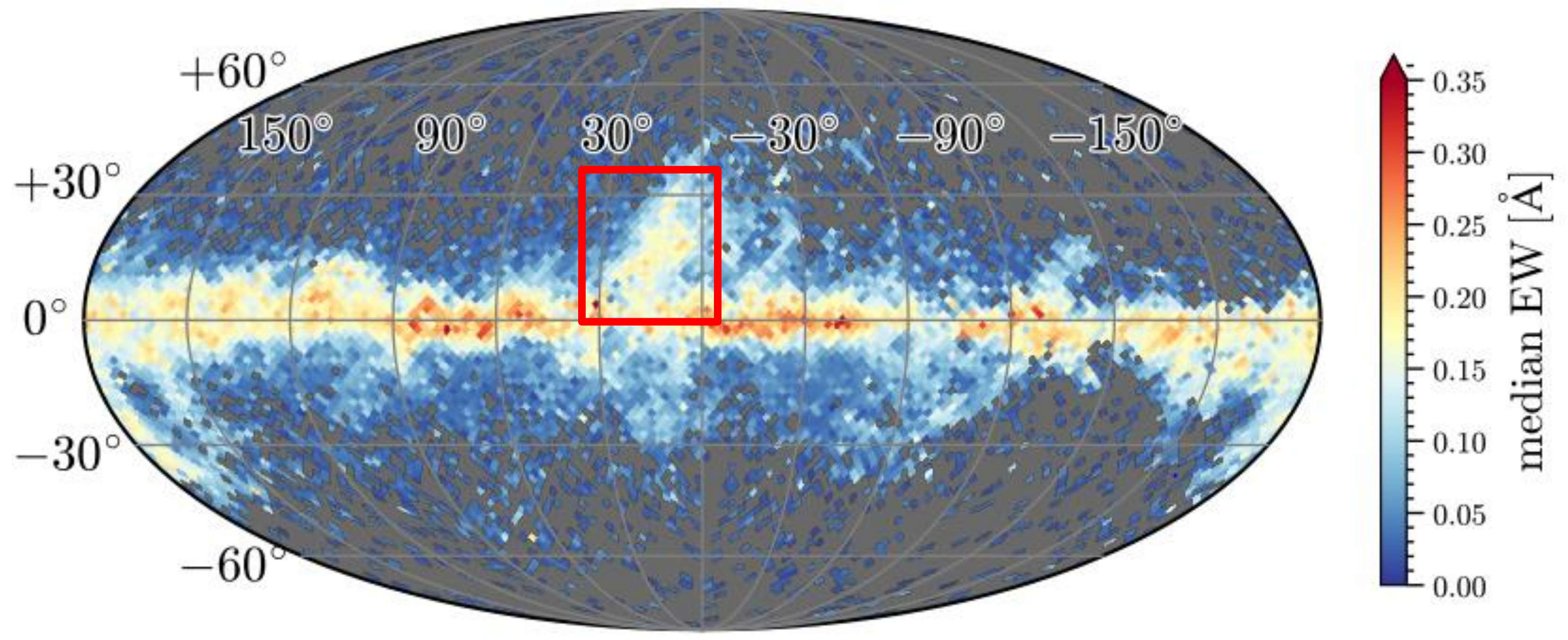


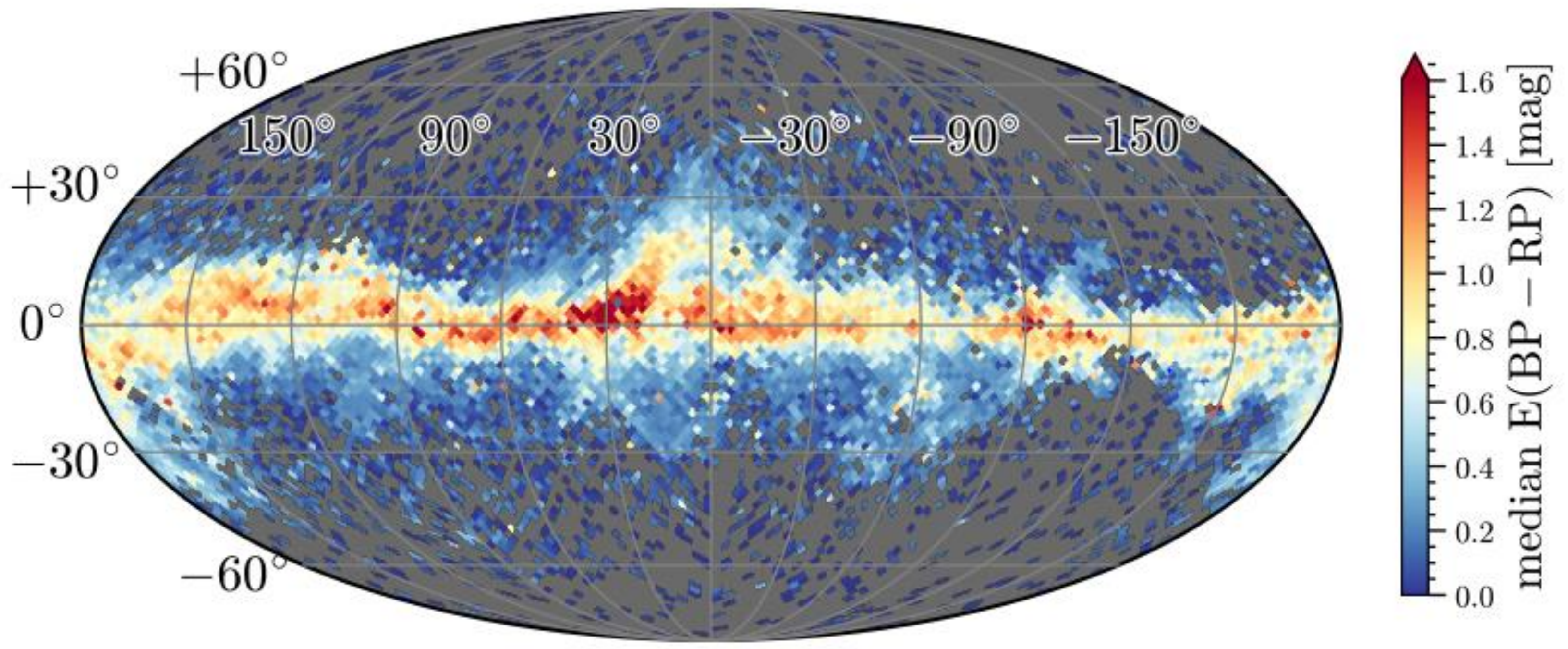
Fig. 14. Heliocentric coordinates of the clusters younger than log t=7.6 (63 Myr). The solid lines are the spiral arm model of Reid et al. (2019), and the dashed line is the trace of the Perseus arm modelled by Levine et al. (2006). The bars represent the 1-σ uncertainty on the distance, taking into account statistical and systematic parallax errors.

Diffuse interstellar bands

DIB



Dust



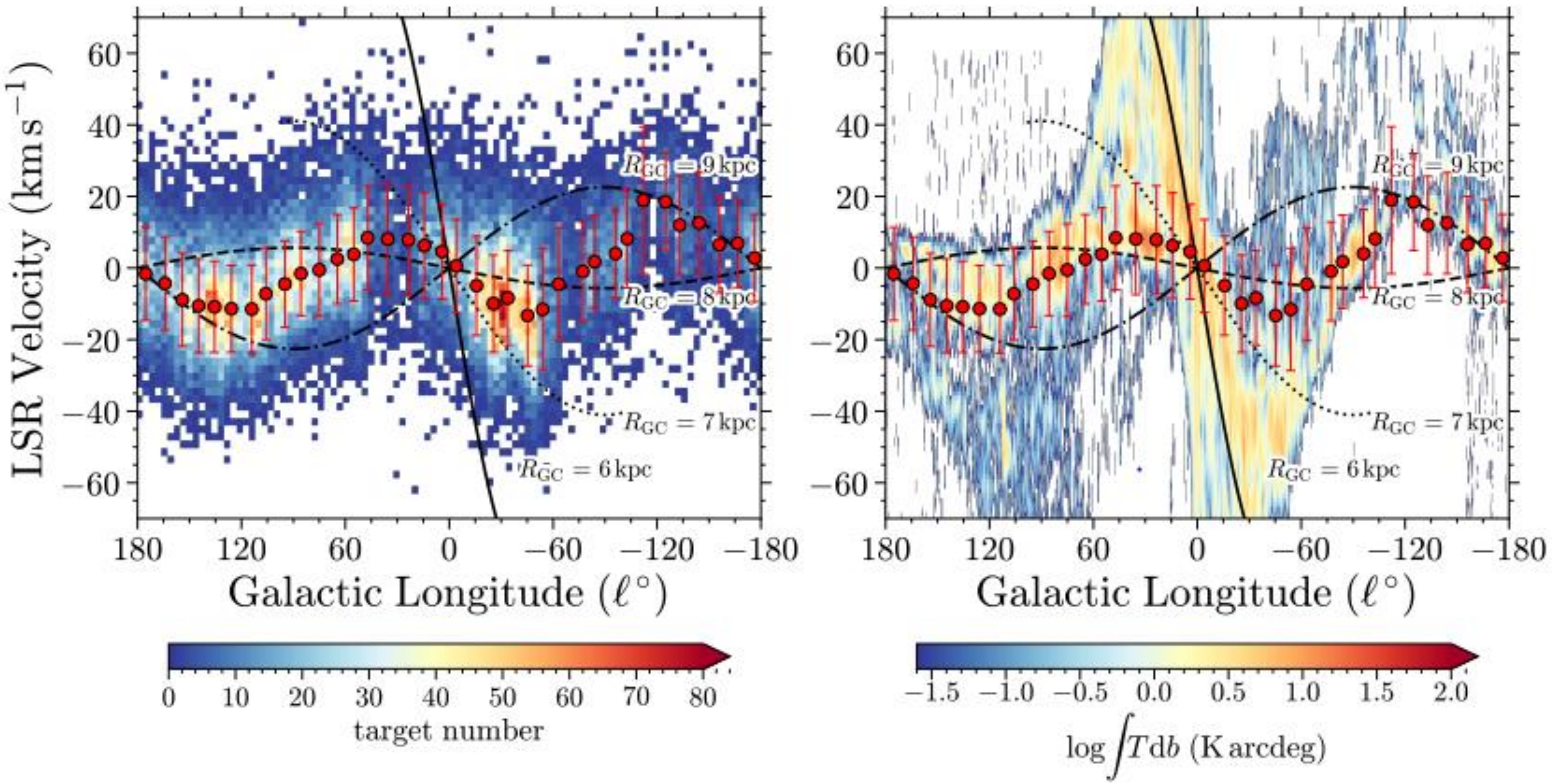
476 117 DIBs (862 nm) up to 4Kpc

Good correlation between DIB and dust but also differences:

- scale height `- generally DIB more concentrated to the plane,but on Galactic center
- At l~ 30 deg massive star forming regions show a large amount of dust but relatively weak DIBs.

Gaia Collab, Schultheis et al 2022

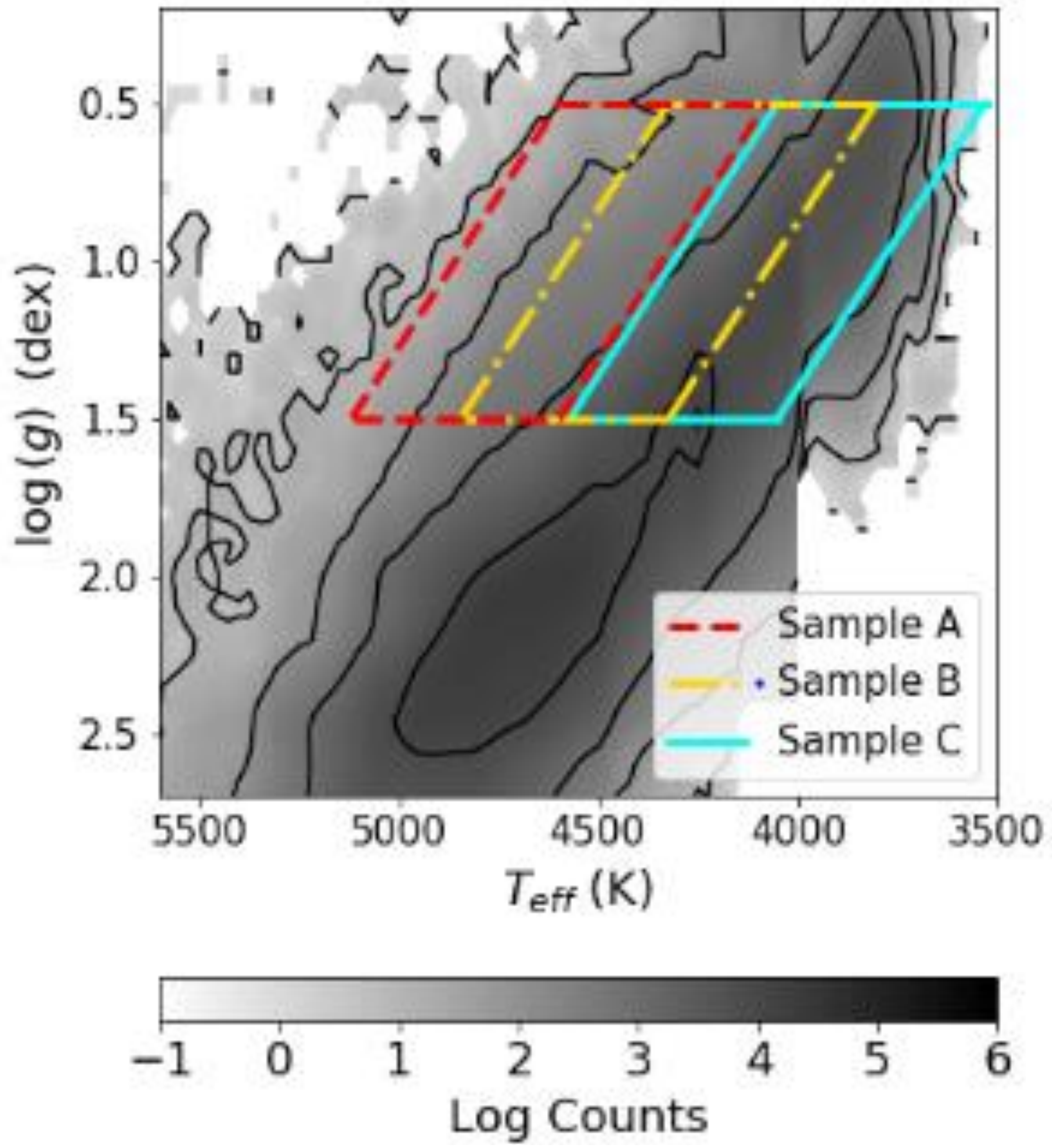
DIB

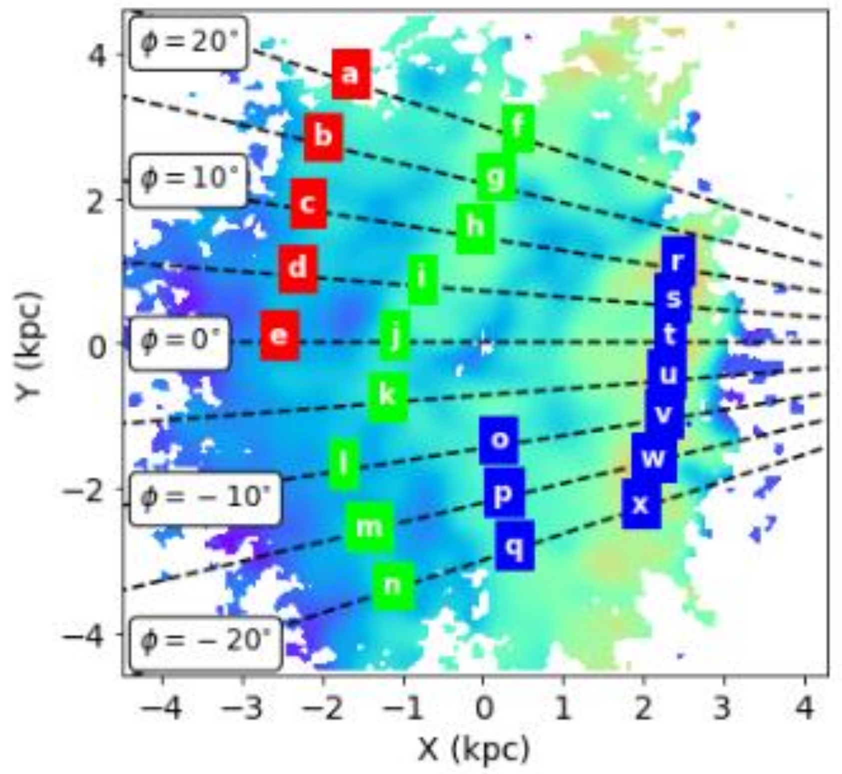


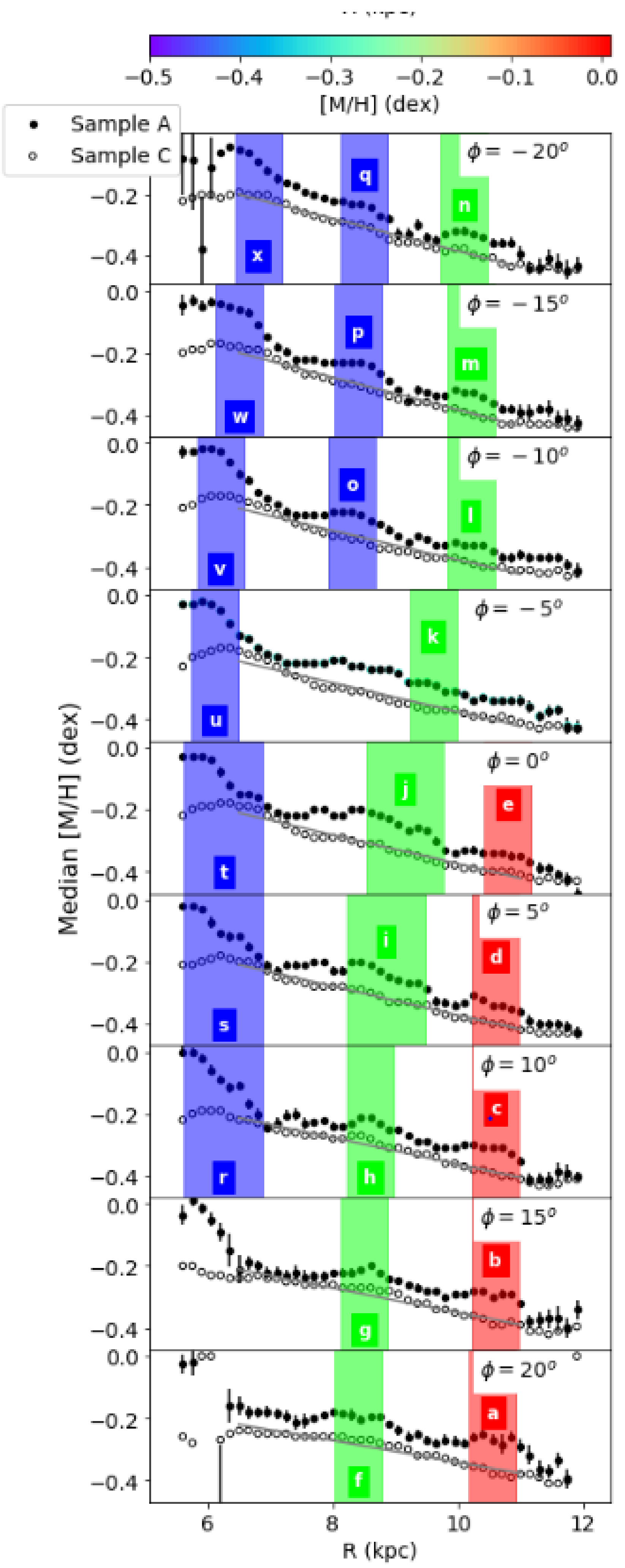
CO

Fig. 16. (Left panel): Longitude–velocity diagram for the Gaia HQ DIBs sample. The circles indicate the median V_{LSR} and standard uncertainty of the mean for each field. Velocity curves calculated by Model A5 in Reid et al. (2019) for different galactocentric distances (R_{GC}) are overplotted. (Right panel): The same but superimposed on the ^{12}CO data from Dame et al. (2001)

- **The first global kinematic study of DIBs.**
  It reveals the Galactic rotation of carrier molecules at $7 < R_{GC} < 9$ kpc
- **DIB carrier shares the kinematics of CO-related gaseous molecules**







Metallicity gradient

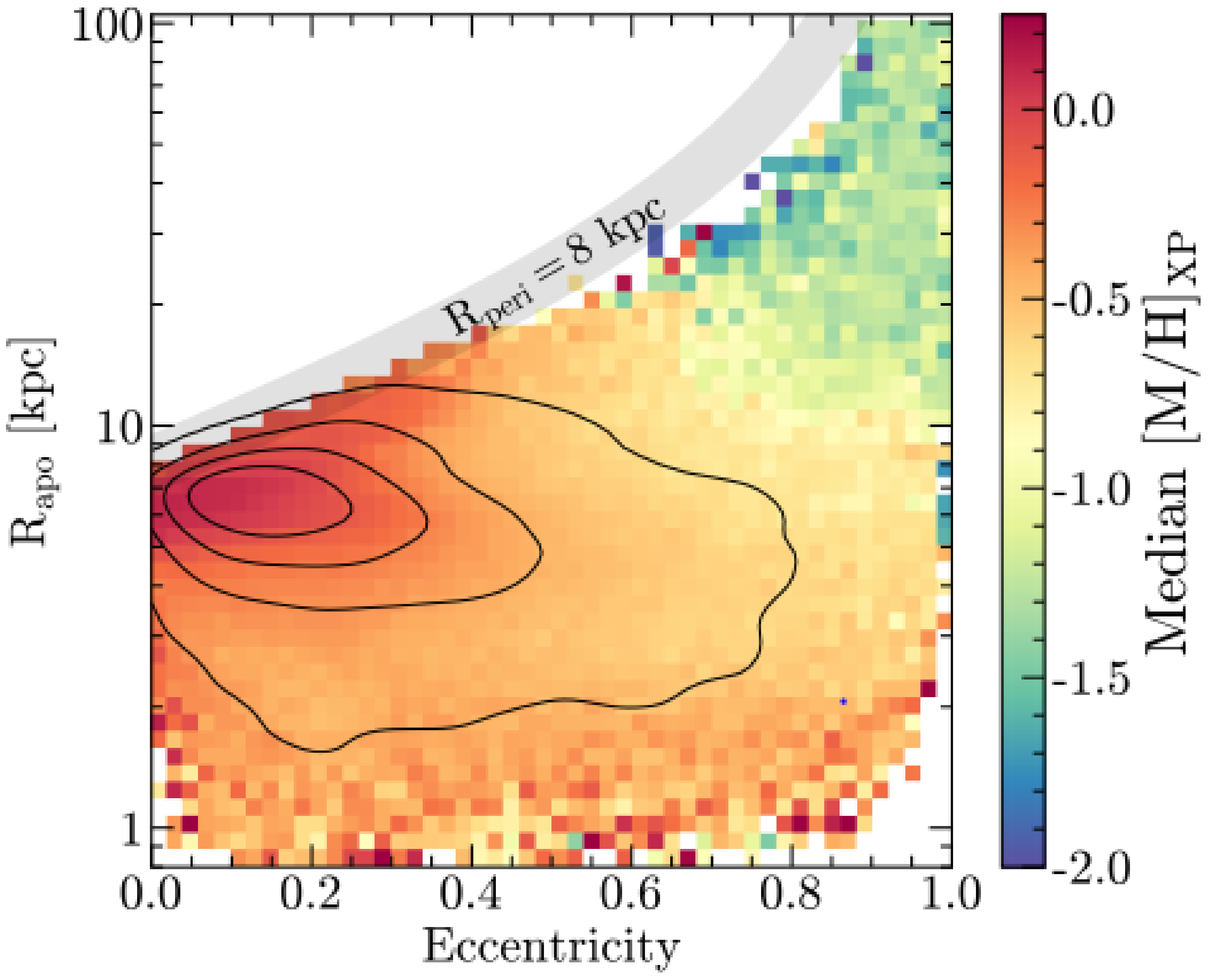
- Effect of the spiral arms on the azimuthal metallicity gradient (Poggio et al 2022)

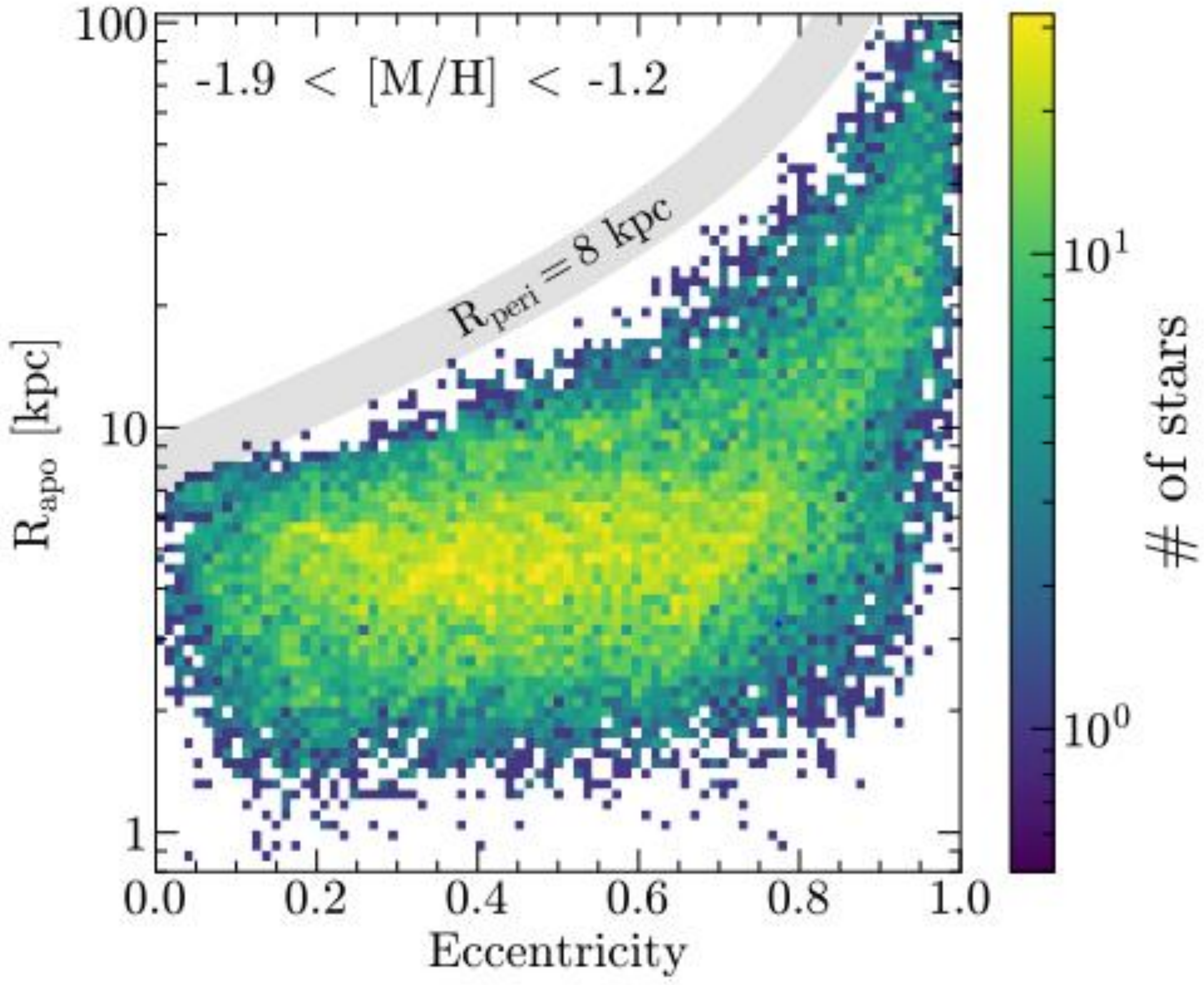
- Sample of different ages
- A:100-300 Myr
- C: > 1 Gyr
- B intermediate age

- Khoperskov et al. (2018): kinematically cold and hot populations react differently to perturbations

- Perseus
- Local
- Sag/Scutum

Metal poor stars in the inner Galaxy





Two million inner halo stars with low metallicity ([M/H]<-2) from XP spectra
Their [alpha/Fe] suggests they are probably due to in situ formation

Rix et al 2022

Binaries with dark companion &Rare objects

- Ellipsoidal binaries analysis Fu et al 2022, Andrew et al 2022, Tanikawa + 2022
- discussion El Badry & Rix 2022 (BH impostors, i.e. mass transfer binaries)
- El Badry et al 2022: a Sun-like G =13.8 mag, d=480 p, P=186 days orbiting a dark object (about 9.8 Mo) possibly a BH
- PNs in binary systems (Chornay &Walton 2022)

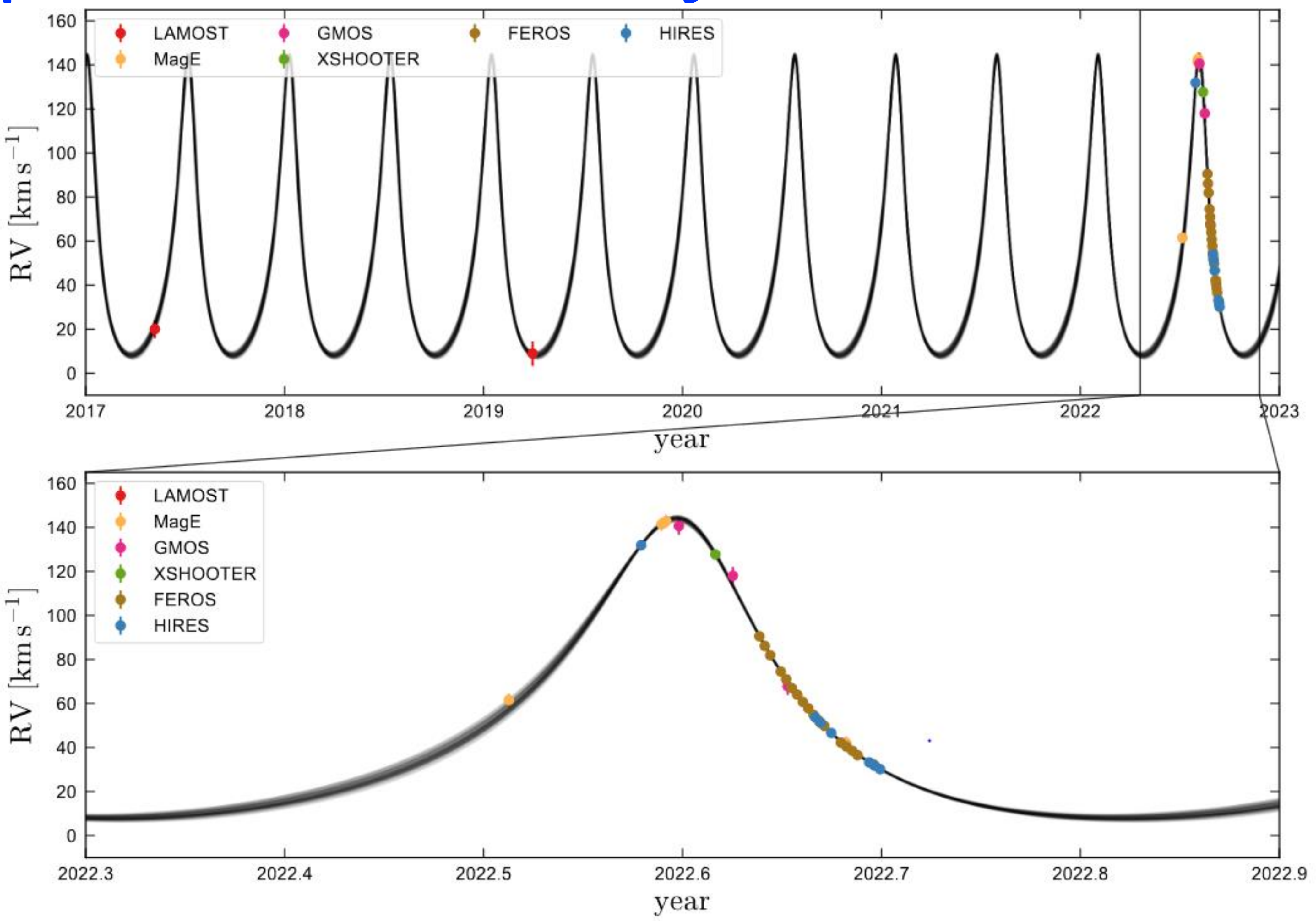
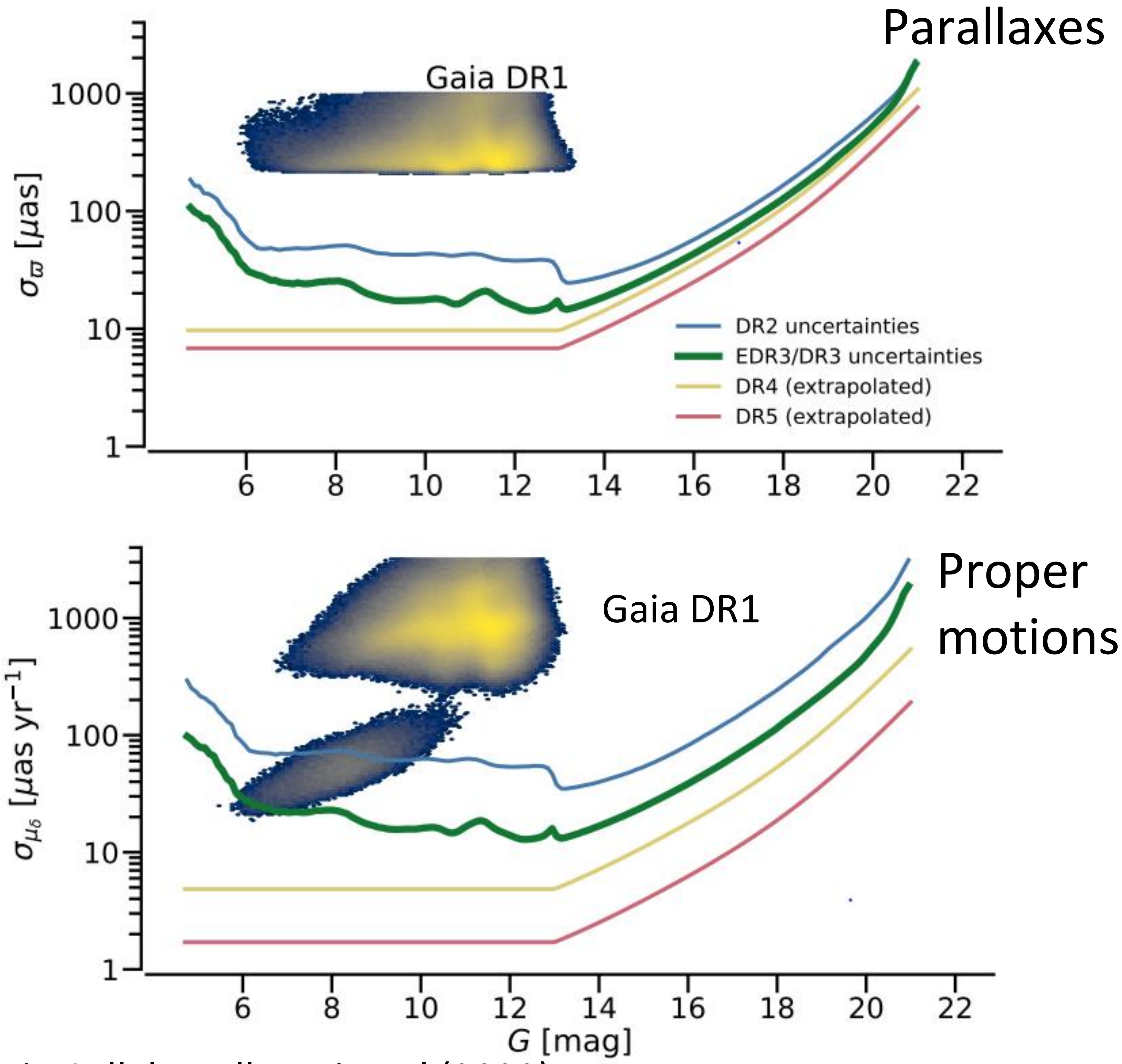


Figure 2. Radial velocities. Points with error bars are measurements; gray lines are draws from the posterior when jointly fitting these RVs and the *Gaia* astrometric constraints. Top panel shows all available RVs, including observations by the LAMOST survey in 2017 and 2019; bottom panel highlights our follow-up in 2022. The best-fit solution has a period of 186 days, eccentricity 0.45, and RV semi-amplitude of 68 km s^{-1}. Together with the inclination constraint from astrometry, this implies a companion mass of $9.8 \pm 0.2\ M_{\odot}$.

El Badry et al 2022

Long term plans-I

- Gaia end-of-life 2025
- Nominal mission ended on 2019; Formally extended until end of 2022
- Indicative approval until 2025
- Gaia DR4 : not before end 2025
  - Final release for the nominal mission, 66 months of data
  - Including a 6 months period of reverse direction of the satellite precession
  - To mitigate degeneracy between AC stellar motion and parallax
  - Full Epoch data: epoch astrometry, broad band photometry, radial velocity, BPRP, RVS,
  - Full astrometric, photometric, and radial-velocity catalogues, variable-stars and non-single-star solutions, classification, exoplanet list, RB/RP and RVS spectra
- Gaia DR5   targeted not before the end of 2030
  - Final release of the mission
  - 10 years of data.



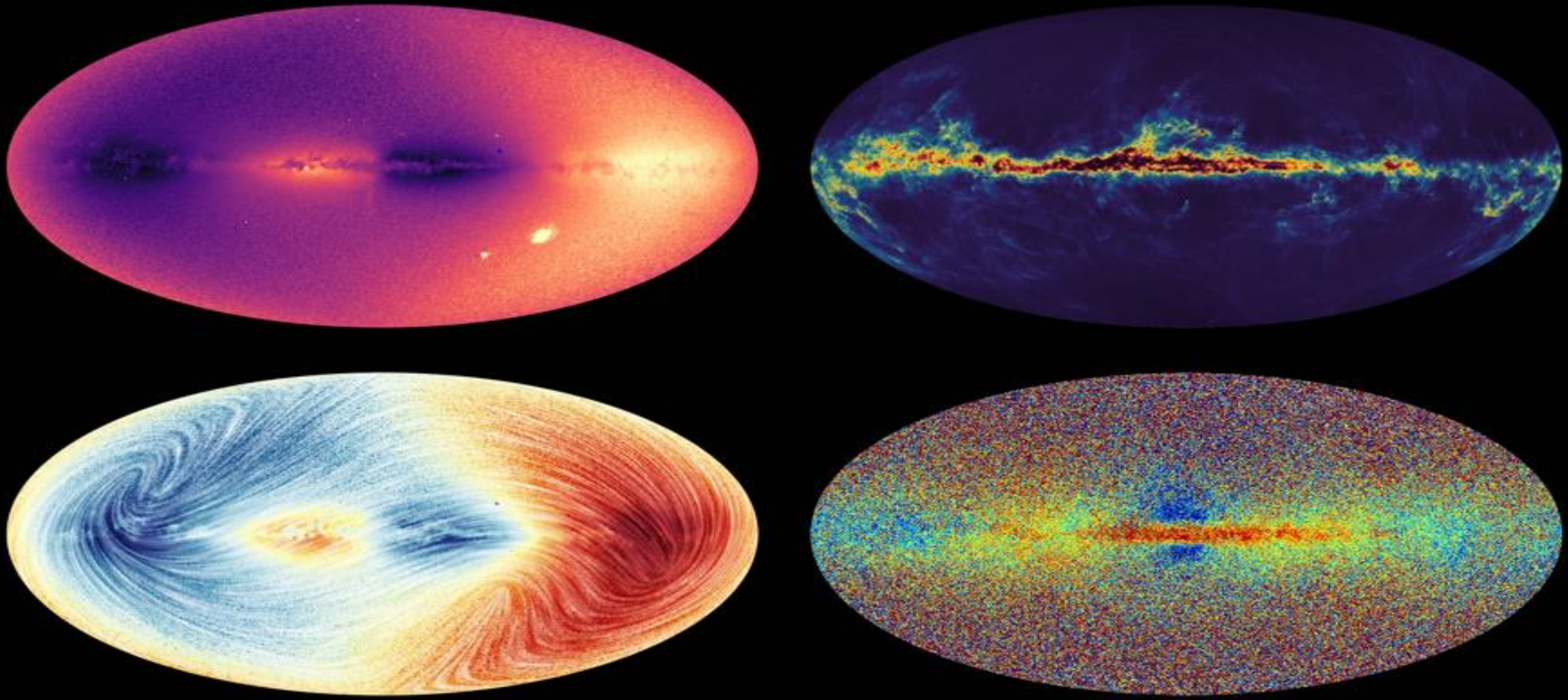
Gaia Collab, Vallenari et al (2022)

- Basic mission results improve with $t^{-0.5}$

  (Positions, parallaxes, photometry and radial velocities)→ factor 1.4 (DR4), 1.9(DR5)

- Proper motion improvement scales as $t^{-1.5}$
- Rapidly increasing gain in kinematics and dynamics→ factor 2.7 (DR4), 6.6 (DR5)
- More complex systems scale faster, e.g. improvement in unambiguous determination of orbital period, mass and distance of a perturbing body scales as $t^{-4.5}$

GAIA: EXPLORING THE MULTI-DIMENSIONAL MILKY WAY



Thank you for your attention

www.esa.int

Long term plans-II

- Gaia DR5   targeted not before the end of 2030
  - Final release of the mission
  - 10 years of data
  - Full astrometric, photometric, and radial-velocity catalogues, variable-star and non-single-star solutions, classification, exoplanet list, epoch and transit data,RB/RP and RVS spectra, epoch data
  - Legacy Archive

- Gaia DR3 is:
- The most accurate astrometric and photometric survey to date (Gaia EDR3):
- Largest ever spectrophotometric survey
- Largest ever radial velocity survey
- First space-based all-sky survey of QSO galaxy hosts and of the surface brightness profiles of galaxies in the local universe
- Highest accuracy spectrophotometric-dynamical survey of asteroids
- For many classes of variable stars: largest survey ever
- Largest ever collection of astrophysical data for stars in the Milky Way
- Non-single star survey that surpasses all the work on non-single stars from the past two centuries
- Data processing is in more than 30 papers on A&A special issue:
- https:/https://www.aanda.org/component/toc/?task=topic&id=1641
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