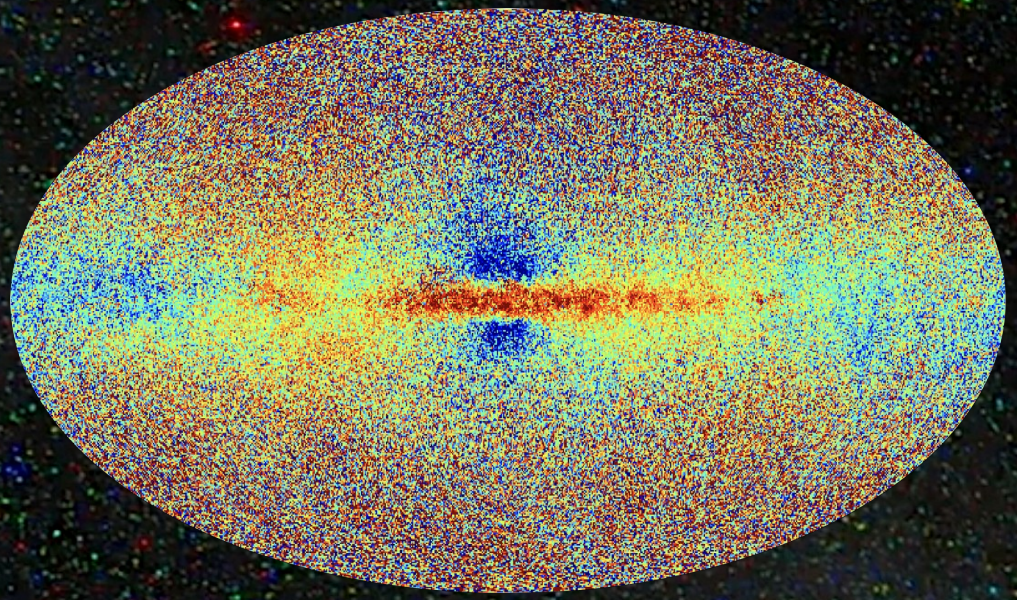
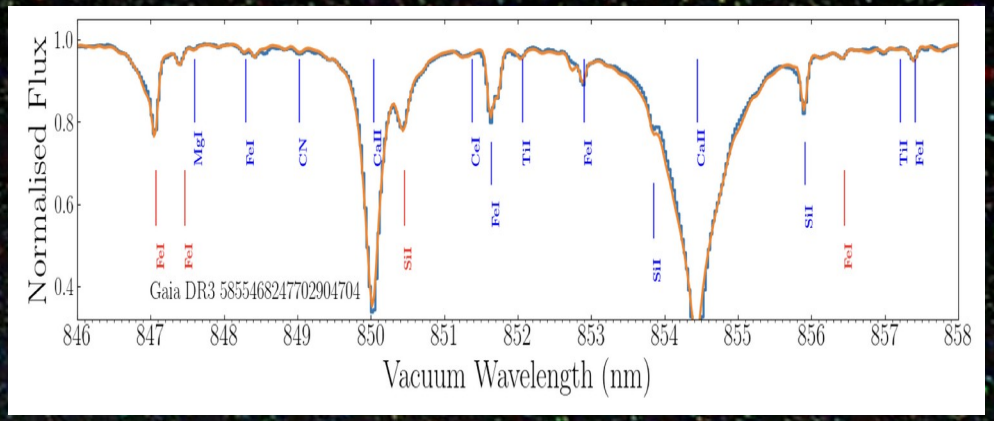
Le Relevé Spectroscopique Gaia/GSP-spec

Apports à la Physique Stellaire





RVS = Radial Velocity Spectrograph

Alejandra Recio-Blanco & Patrick de Laverny
Lab. Lagrange, Observatoire de la Côte d'Azur

GSP-spec = General Stellar Parametrizer - spectroscopy

Gaia/GSP-spec: the first space spectroscopic survey

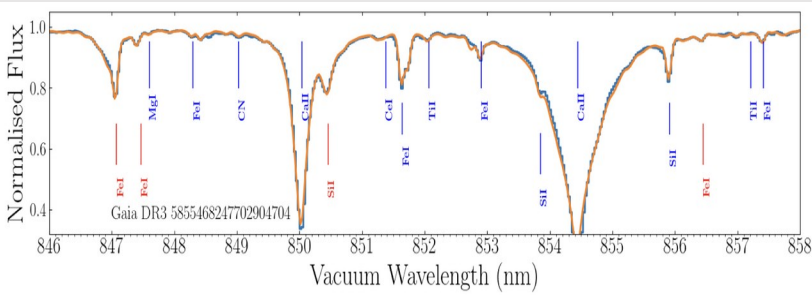
RVS/GSPspec: 5.6 million stars parametrized in Gaia DR3

Related Gaia DR3 Papers (June 2022)

- Recio-Blanco, de Laverny, Palicio et al. 2023 (GSP-spec)

***Gaia* Data Release 3**

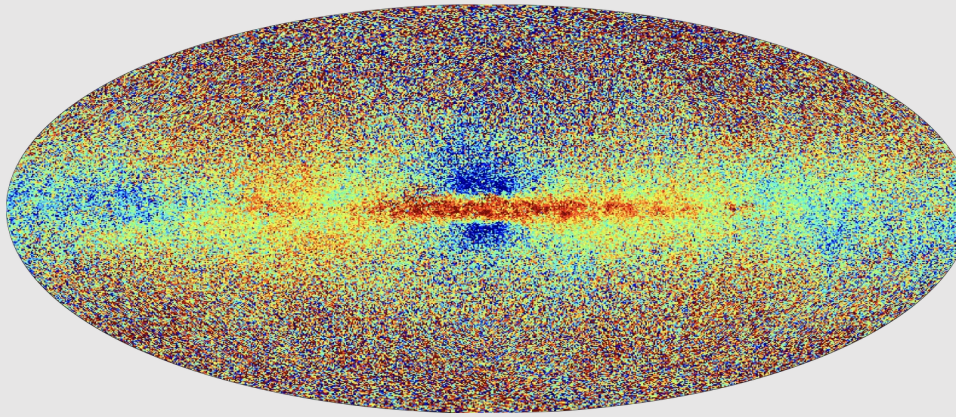
Analysis of RVS spectra using the General Stellar Parametriser from spectroscopy



- Gaia Collaboration, Recio-Blanco et al. 2023 (PVP)

***Gaia* Data Release 3**

Chemical cartography of the Milky Way



- Associated papers published after DR3 :

P.A. Palicio+23a&b, Poggio+22, Spitoni+23, Contursi+23a&b, Prantzos+23, Recio-Blanco+24, Babillon+24, de Laverny+24, Denis+24, ...

Thèse/Post-doc

Gaia/GSP-spec: the first space spectroscopic survey

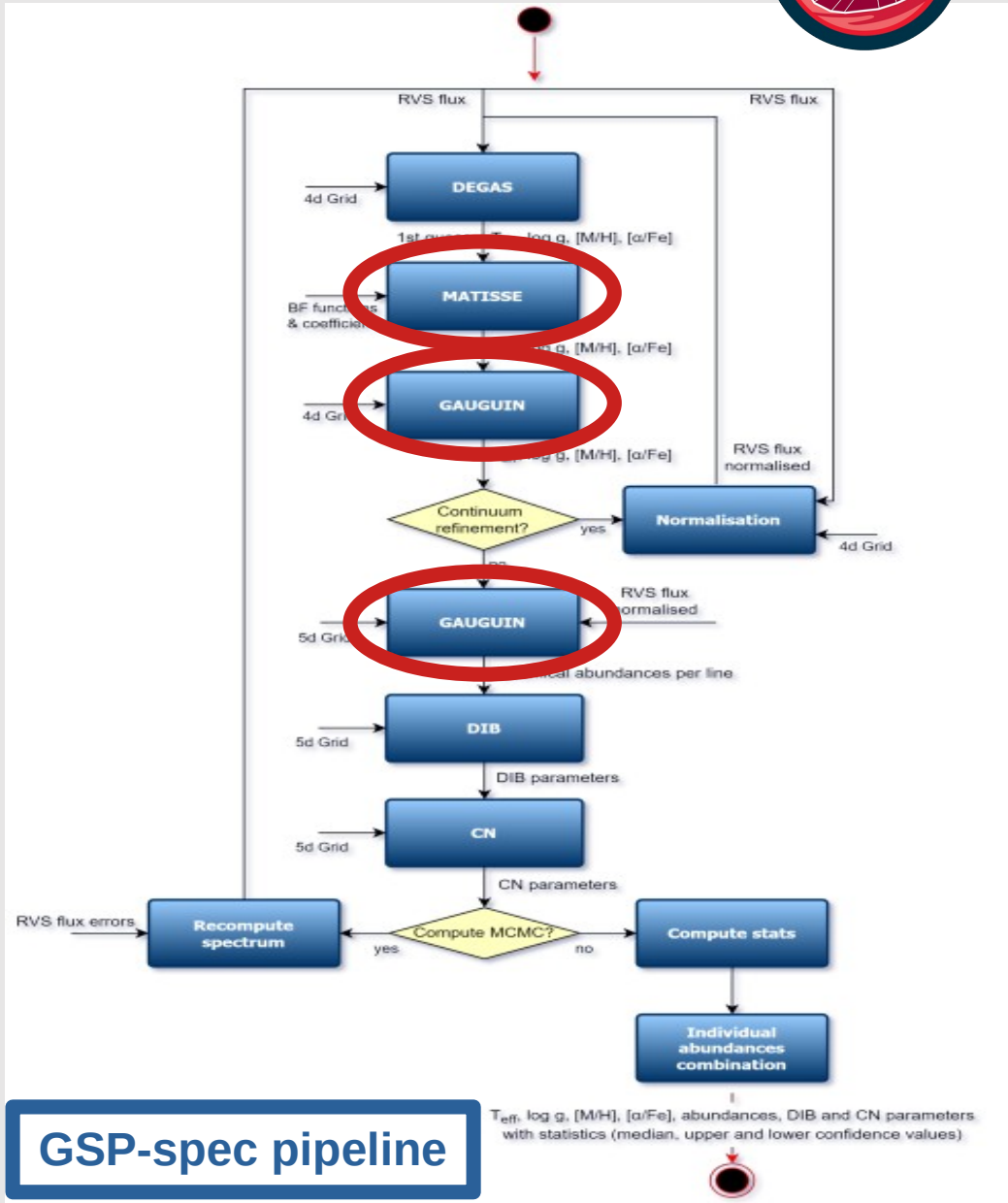
CU8/GSP-spec: Automatic (and fast) analysis of millions of stellar spectra

==> Model-driven methods

Specific Analysis tools

– **MATISSE** : Projection method
→ atmospheric parameters
(Recio-Blanco+06)

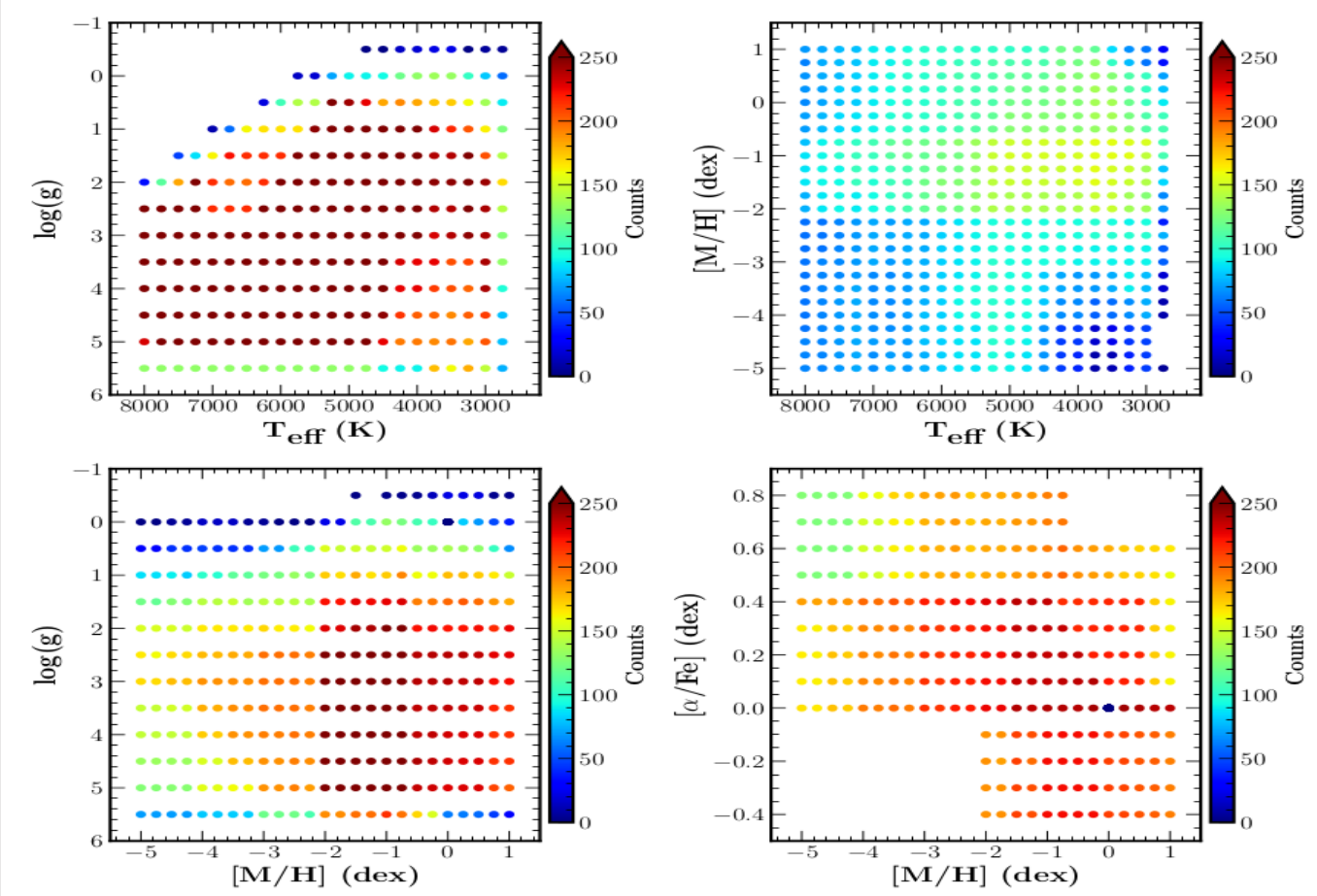
– **GAUGUIN** : Optimisation method
→ atmospheric parameters
→ chemical abundances
(Bijaoui+11)



Gaia/GSP-spec: the first space spectroscopic survey

CU8/GSP-spec: Automatic (and fast!) analysis of millions of stellar spectra

==> Model-driven methods



Reference grids of FGKM-type spectra

– MARCS models (Gustafsson+08)

– Optimized line list (Contursi+21)

– Turbospectrum (Plez+12)

– 1D, LTE, V_{mic}, Hydrostatic, .../...

→ >50,000 spectra in Teff, logg, [M/H], [a/Fe]

>>500,000 spectra in 5D (with [X/Fe])

Gaia/GSP-spec: the first space spectroscopic survey

CU8/GSP-spec: Automatic (and fast) analysis of millions of stellar spectra

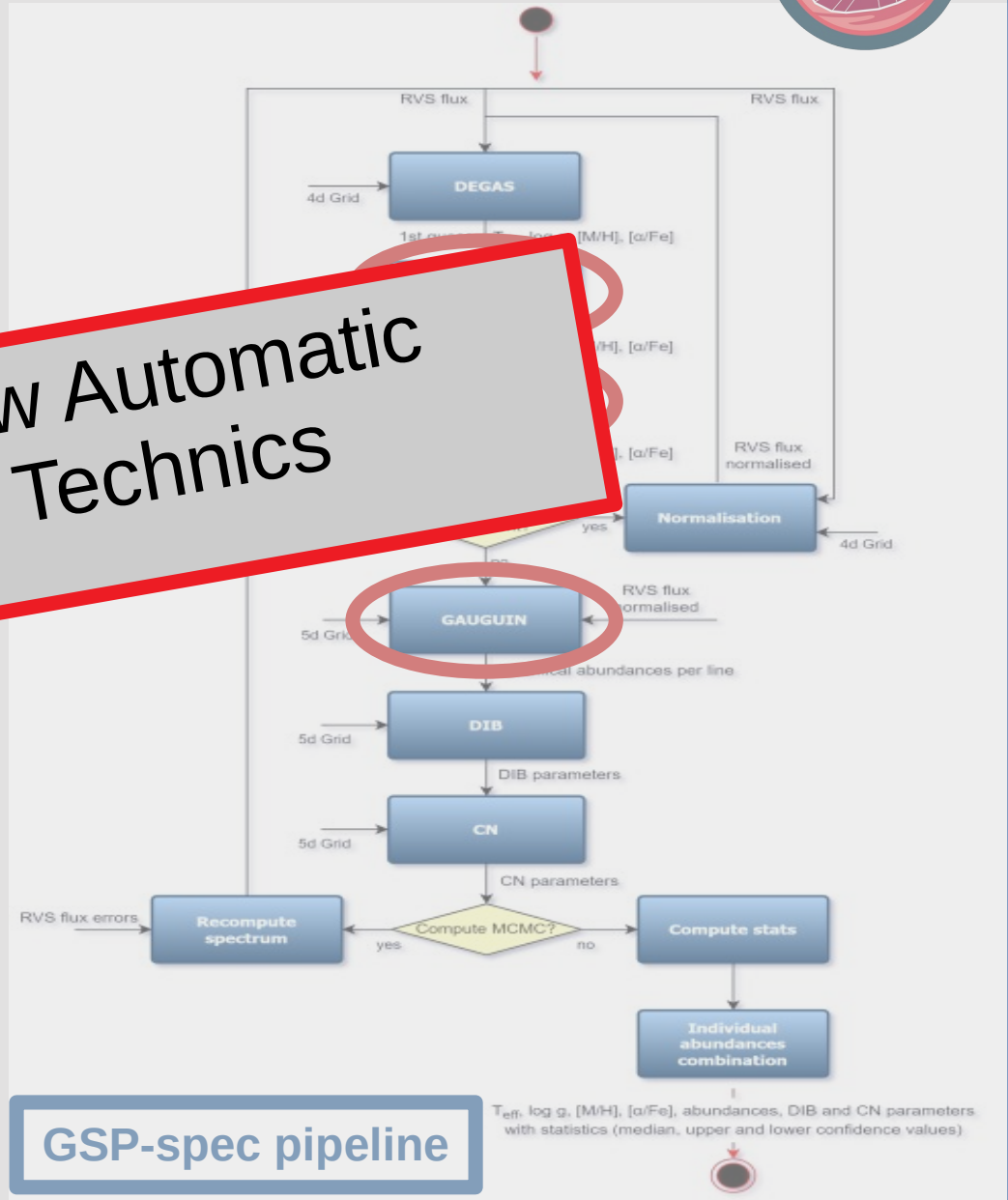
==> Model-driven methods

FUTURE: Development of New Automatic Spectral Analysis Technics

Specific Analysis t

– M

– **GAUGUIN** : Optimisation method
  → atmospheric parameters
  → chemical abundances
  (Bijaoui+11)



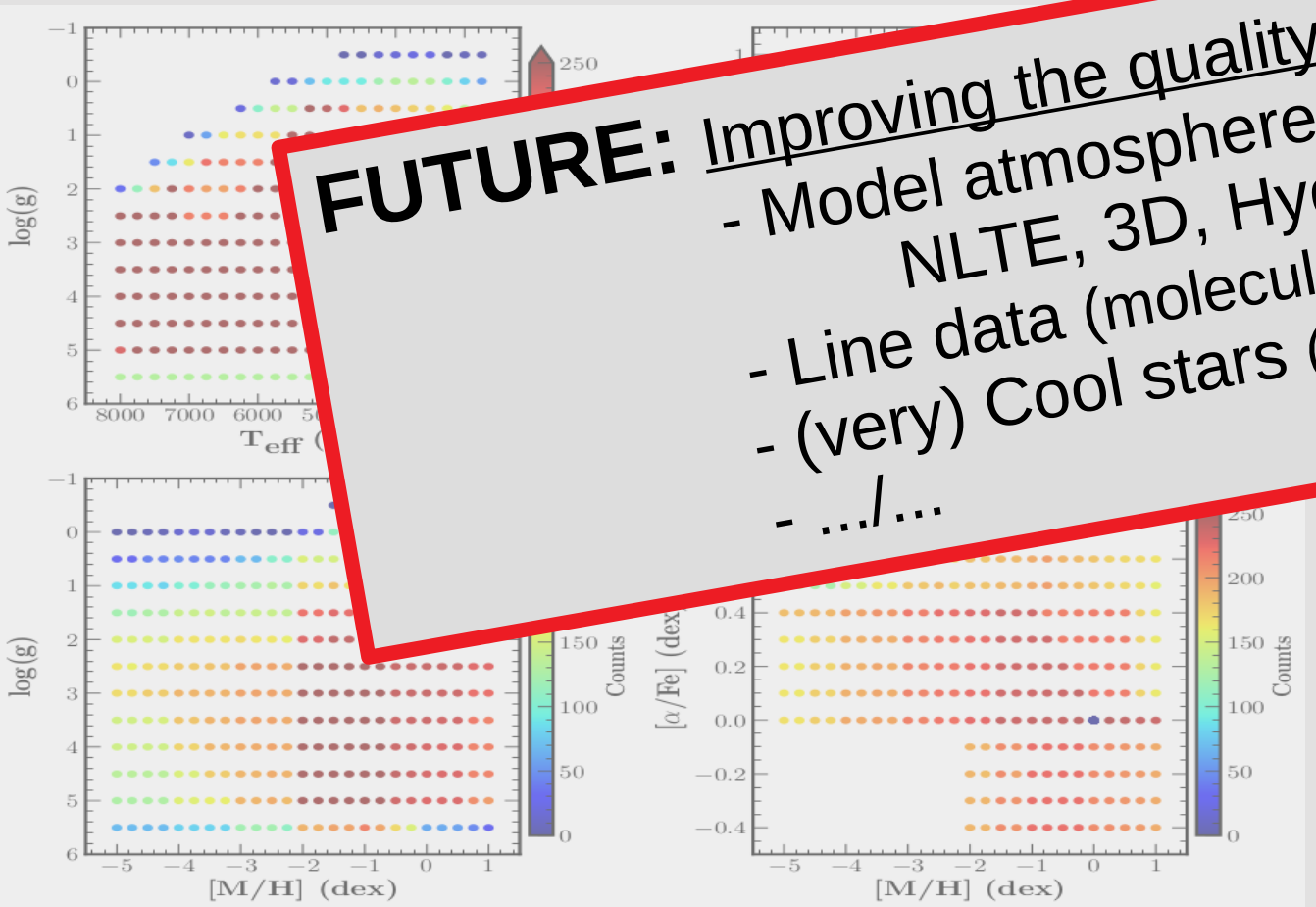
GSP-spec pipeline

Gaia/GSP-spec: the first space spectroscopic survey

CU8/GSP-spec: Automatic (and fast!) analysis of millions of stellar spectra

==> Model-driven methods

FUTURE: Improving the quality of reference models
- Model atmospheres + RT codes with NLTE, 3D, Hydrodynamics, …
- Line data (molecules!)
- (very) Cool stars (M- and C-types)
- .../...



…netic spectra

– …+08)

– …3+21)

– Turbospectrum (Plez+12)

– 1D, LTE, V_{mic}, .../...

→ >50,000 spectra in Teff, logg, [M/H], [a/Fe]

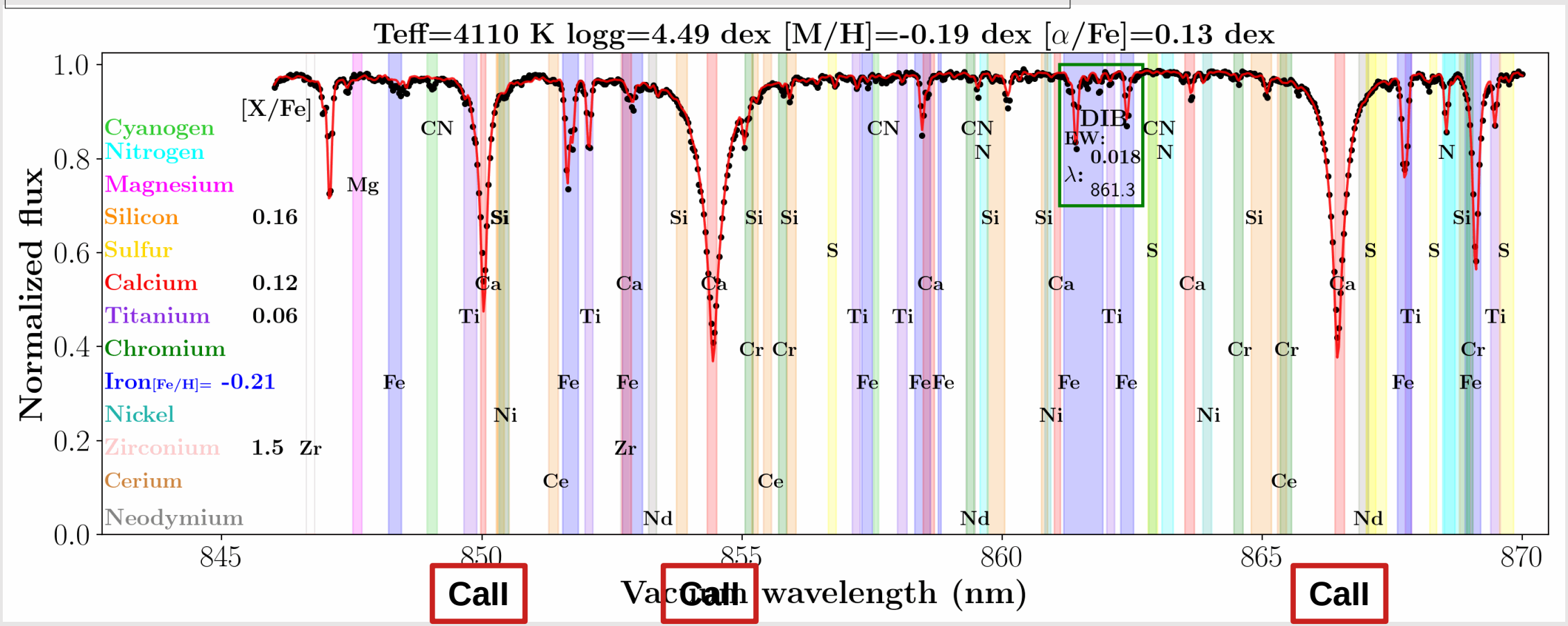
>>500,000 spectra in 5D (with [X/Fe])

Gaia/GSP-spec: the first space spectroscopic survey

Do not forget the Gaia **astrometric** & **spectro-photometric** catalogues

Radial Velocity Spec. : Resolving power= 11 500 Wavelength domain= 846 - 870 nm

RVS/GSPspec: **5.6 million stars parametrized in Gaia DR3**



Gaia/GSP-spec: the first space spectroscopic survey

Gaia/RVS is **SPACE spectroscopy** ≠ ground-based spectroscopy

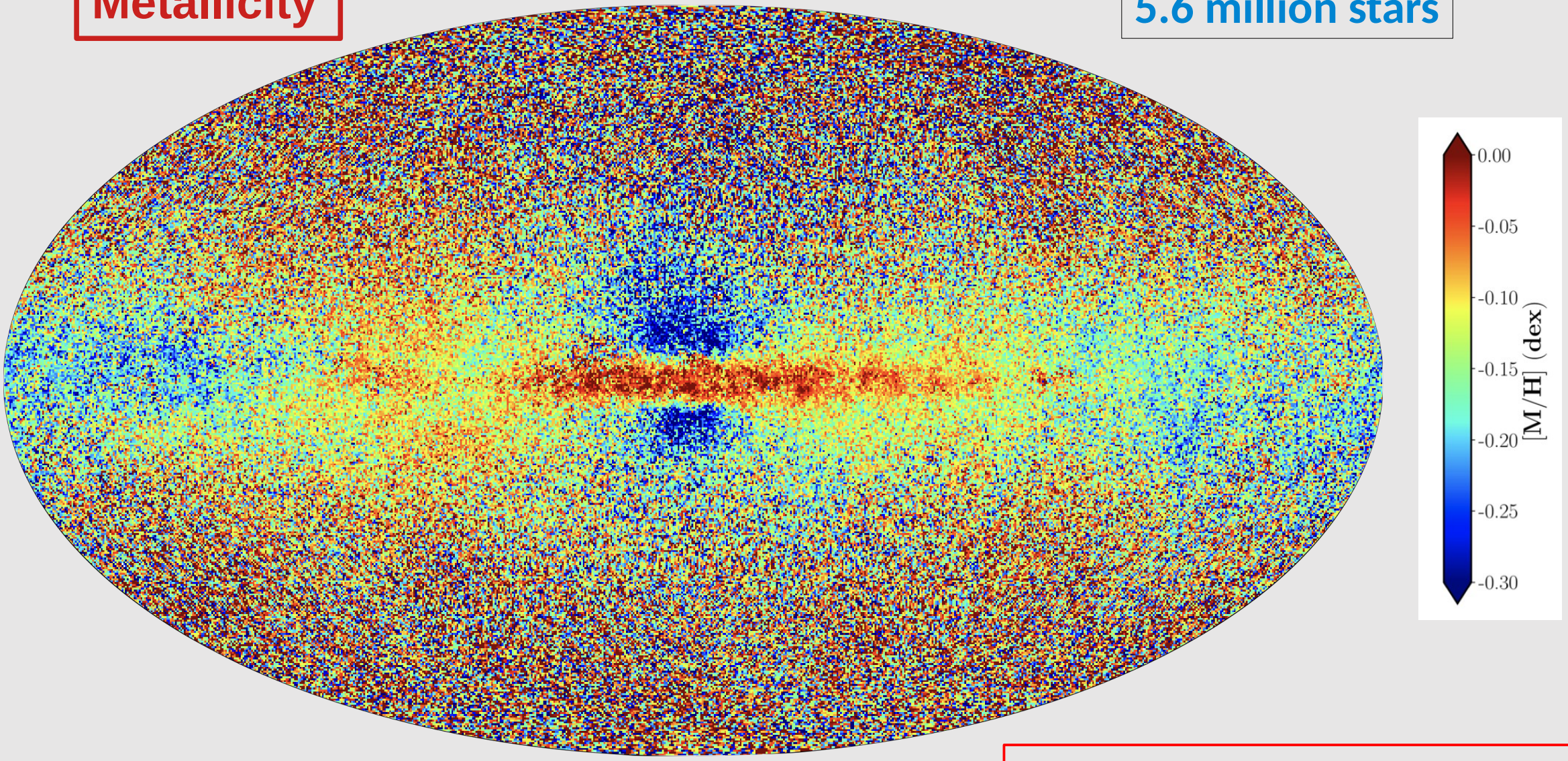
- Continuous observations for years:
  34 months for DR3 (~25 000 h of continuous observations), 60 months for DR4
- High number statistics providing **hundreds of thousands** of high **SNR** (**>150**) spectra
- Stable conditions (no atmosphere)
- Very good control and modeling of systematics
- **Extremely homogeneous treatment**

Parametrization quality comparable to ground-based surveys of higher spectral resolution and wavelength coverage

Gaia/GSP-spec: Chemical cartography of the Milky Way

Metallicity

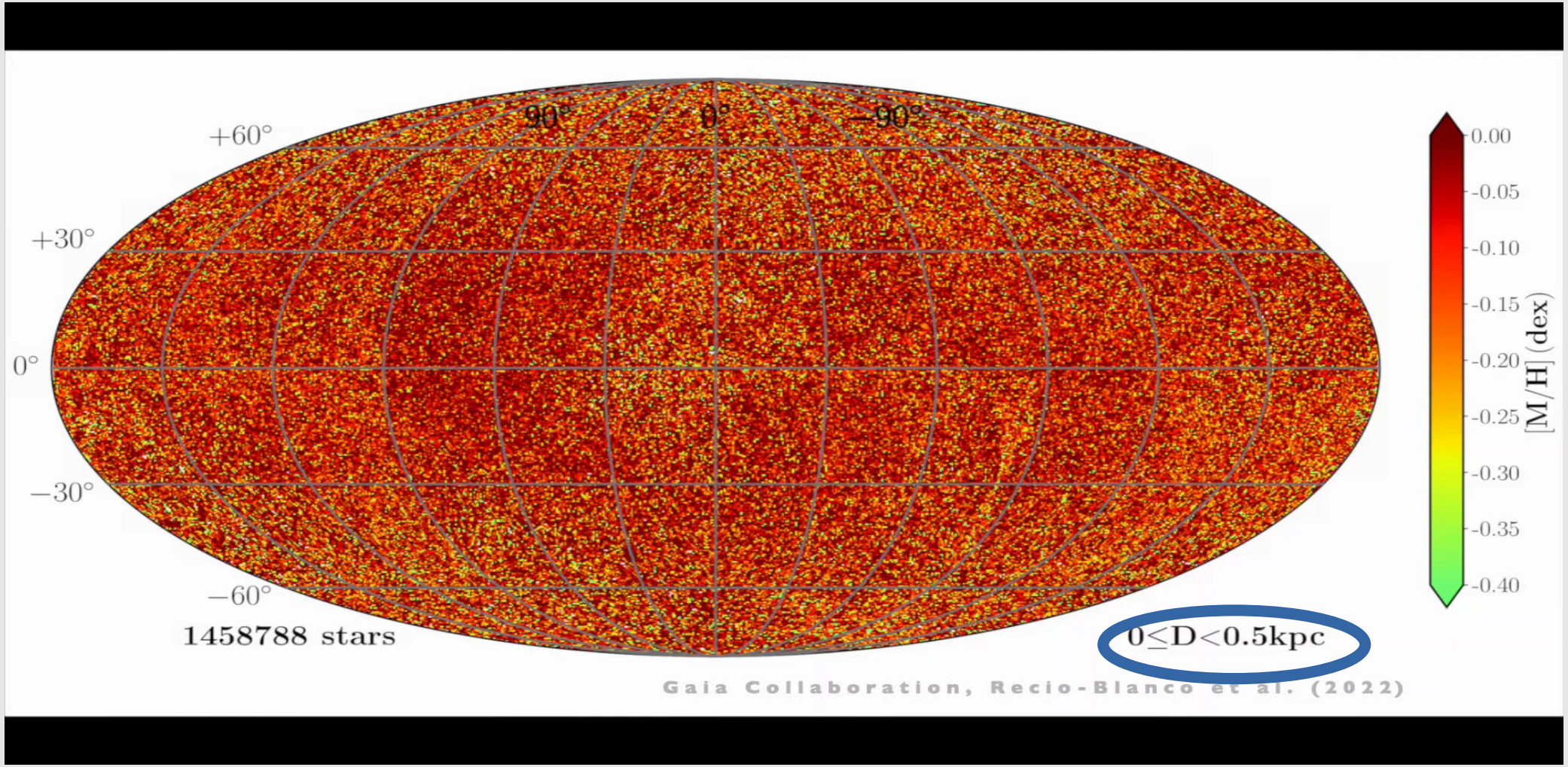
5.6 million stars



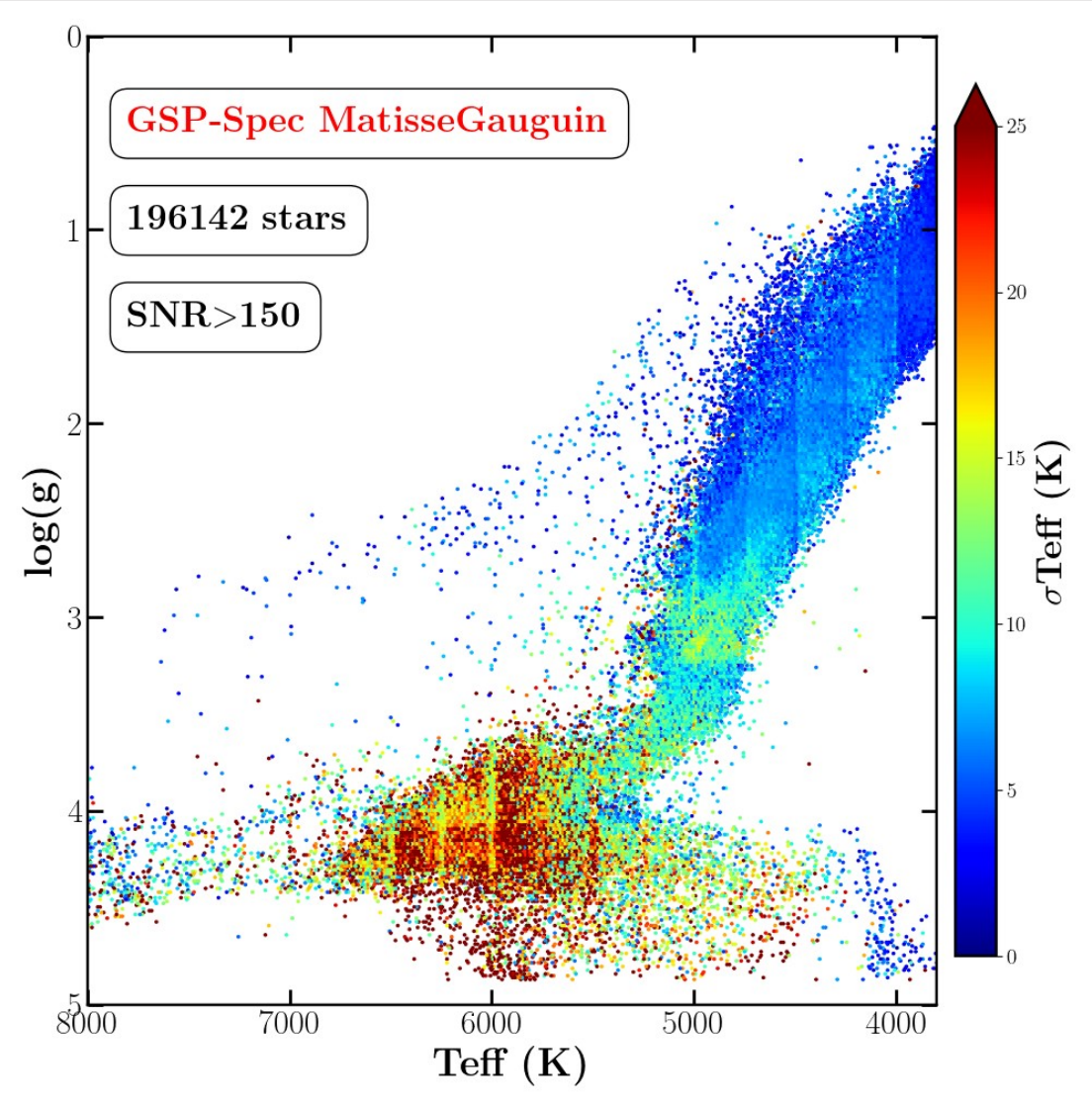
Gaia Collaboration, Recio-Blanco et al. 2023

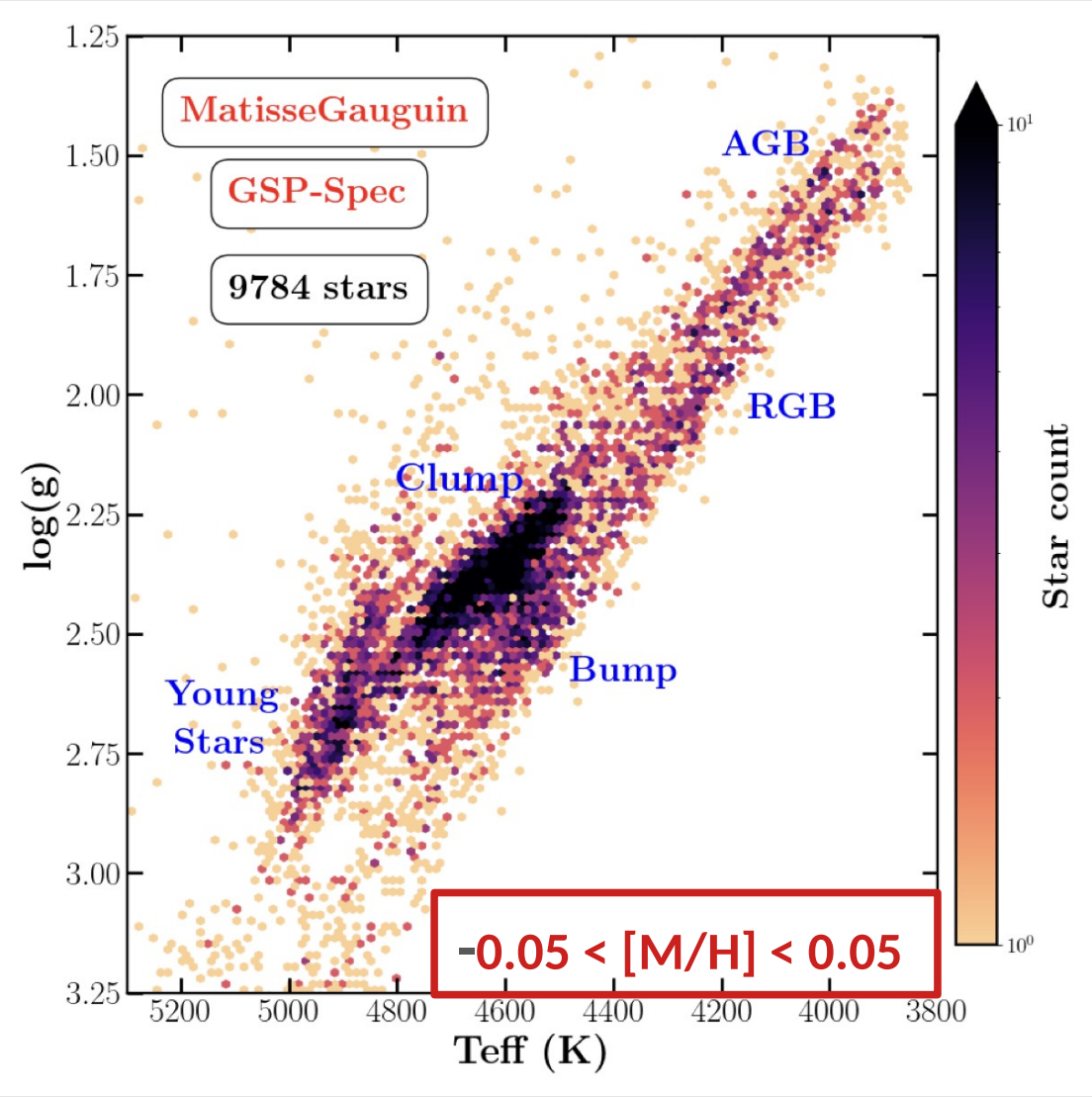
Gaia/GSP-spec: Chemical cartography of the Milky Way

Metallicity



Gaia/GSP-spec parameters: High-precision

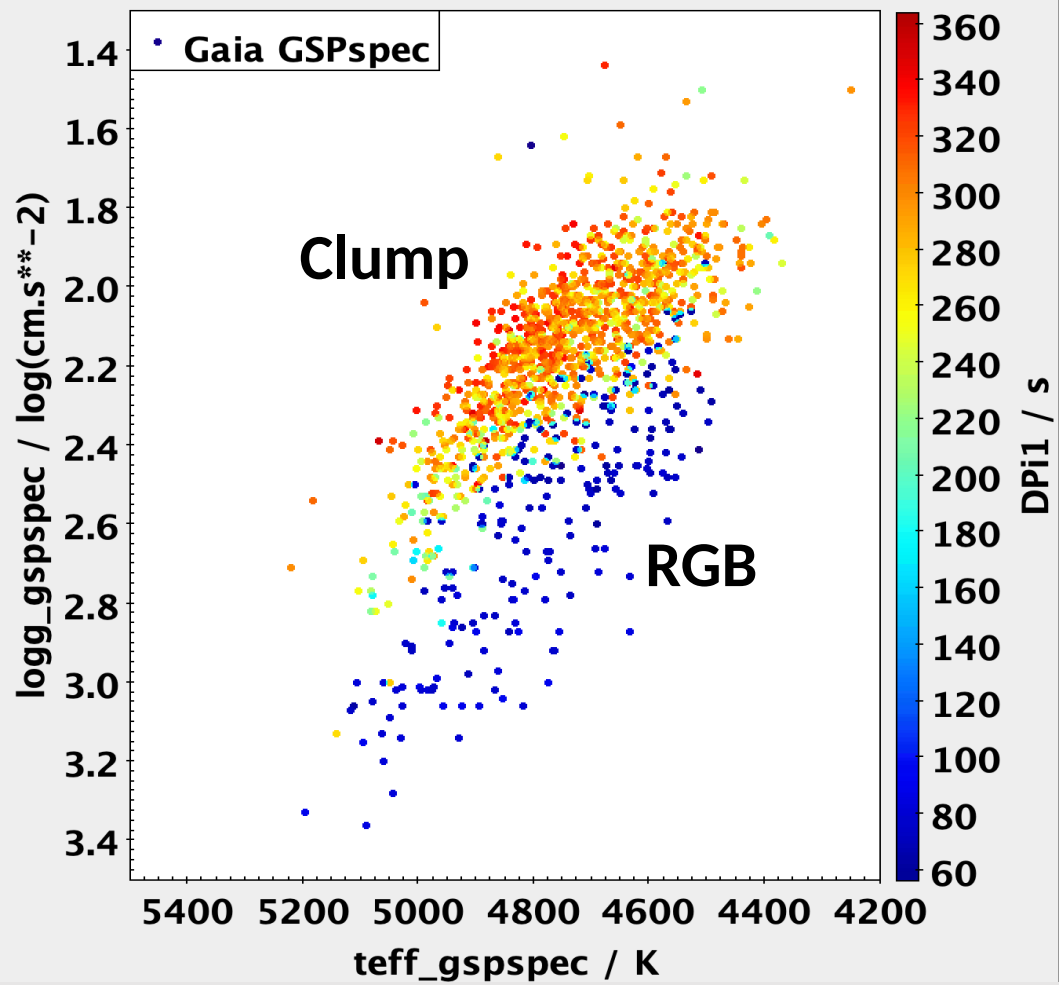




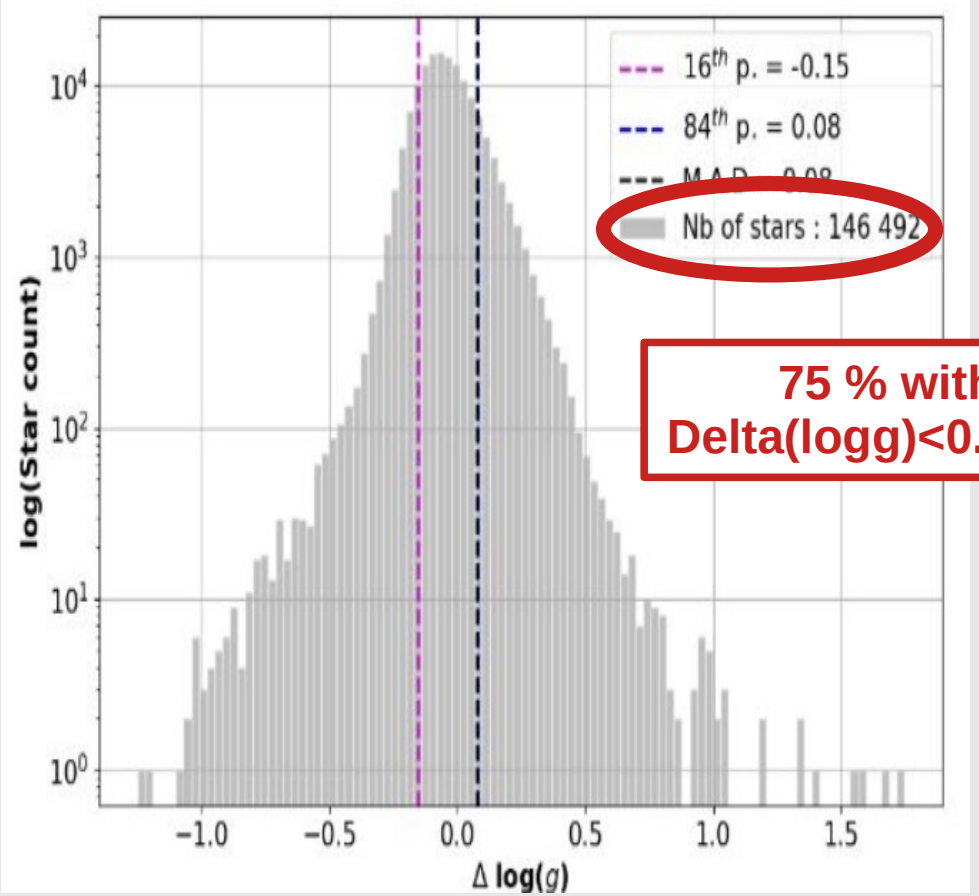
Gaia/GSP-spec parameters: High-precision

Comparison with asteroseismology : Kepler & TESS

Kepler Delta π

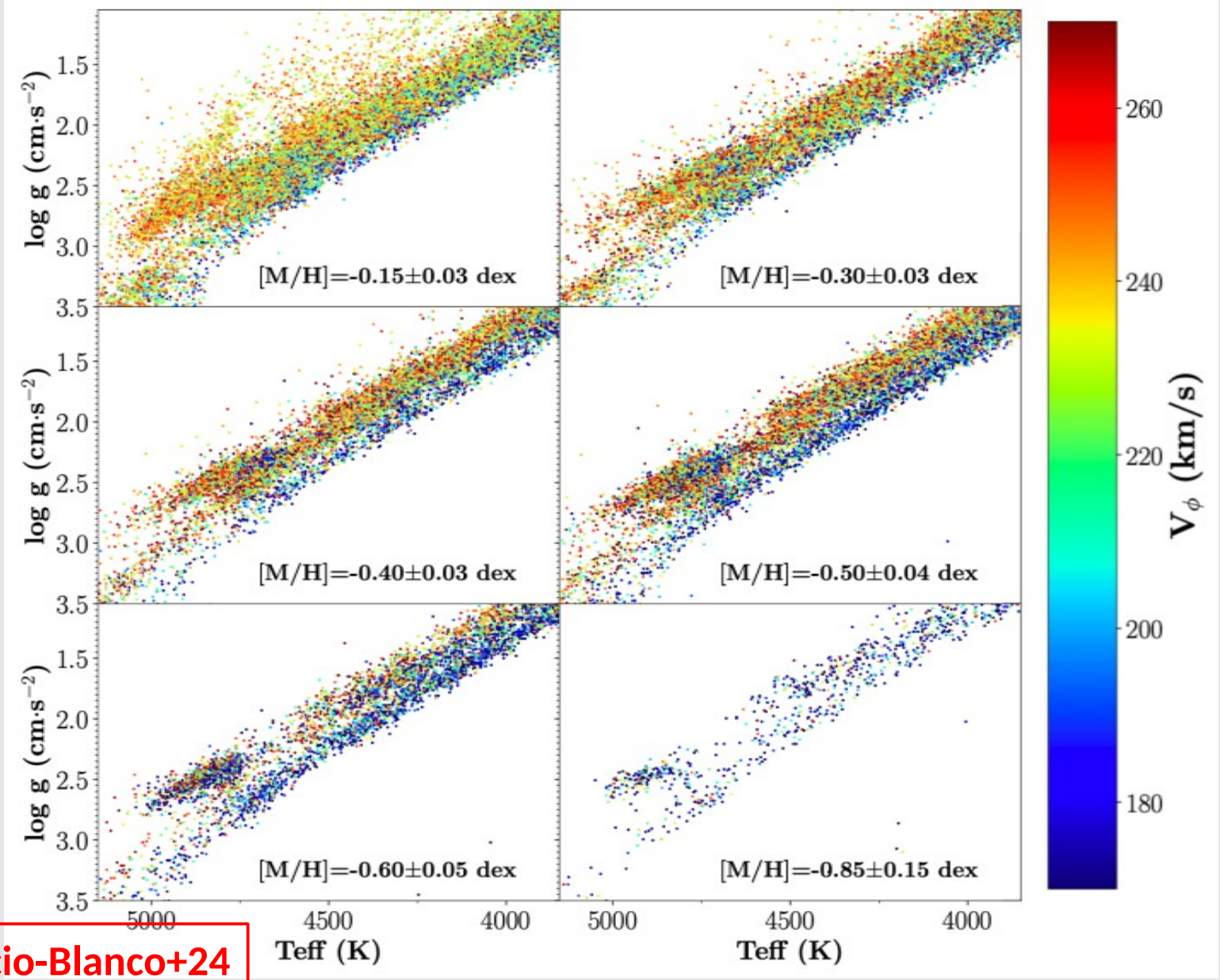


TESS Bump/Clump stars



75 % with Delta(logg)<0.15dex

Gaia/GSP-spec parameters: High-precision



Recio-Blanco+24

MW populations & Stellar evolution

Thin disc "hotter" sequence:
- dominates at high metallicity
- progressively fades as metallicity decreases

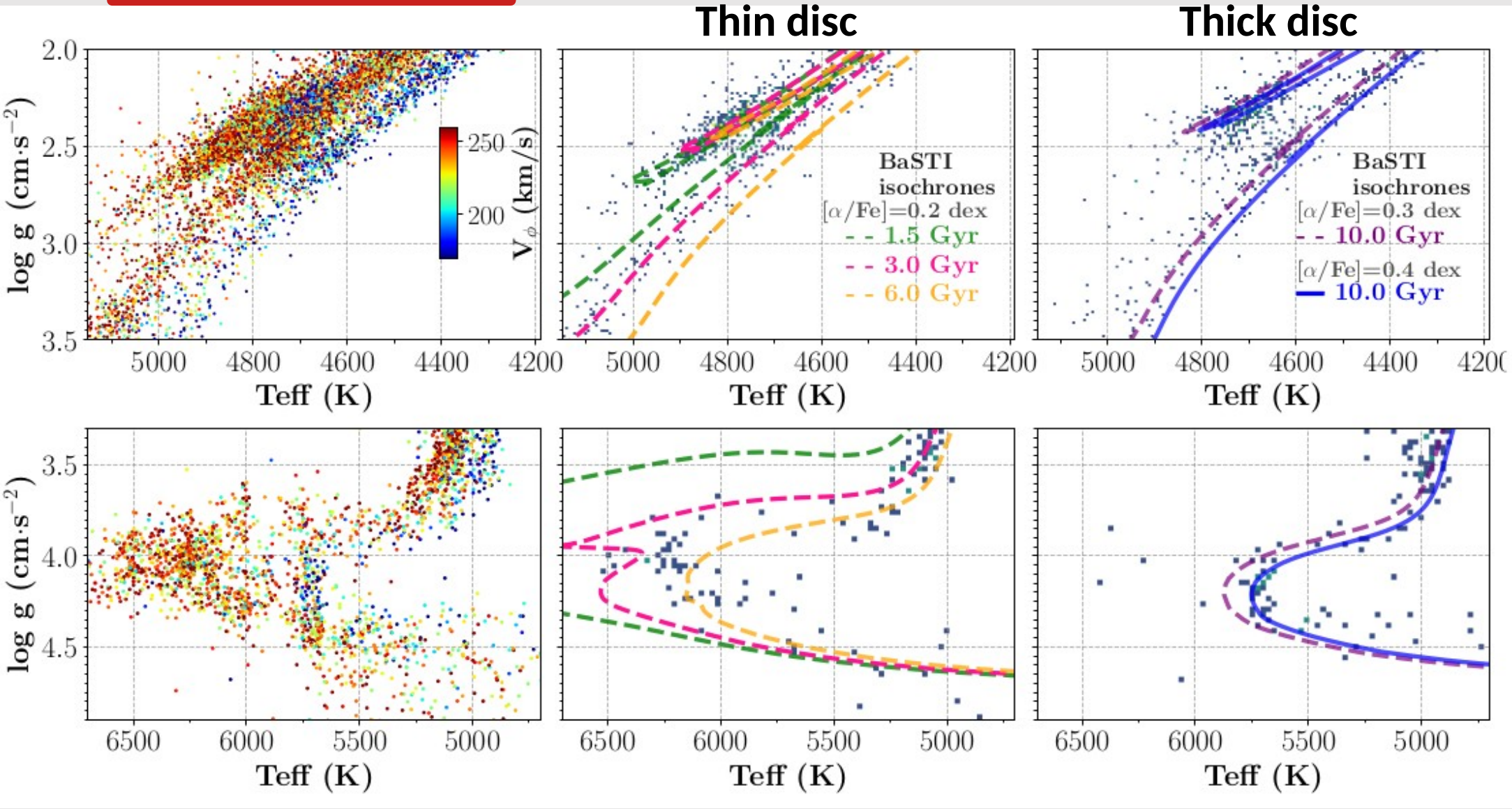
Thick disc "cooler" sequence:
- more and more visible as metallicity decreases

Red Clump and RGB bump visible in both sequences

Gaia/GSP-spec parameters: High-precision

Stellar evolution

-0.4<[M/H]<-0.3 dex

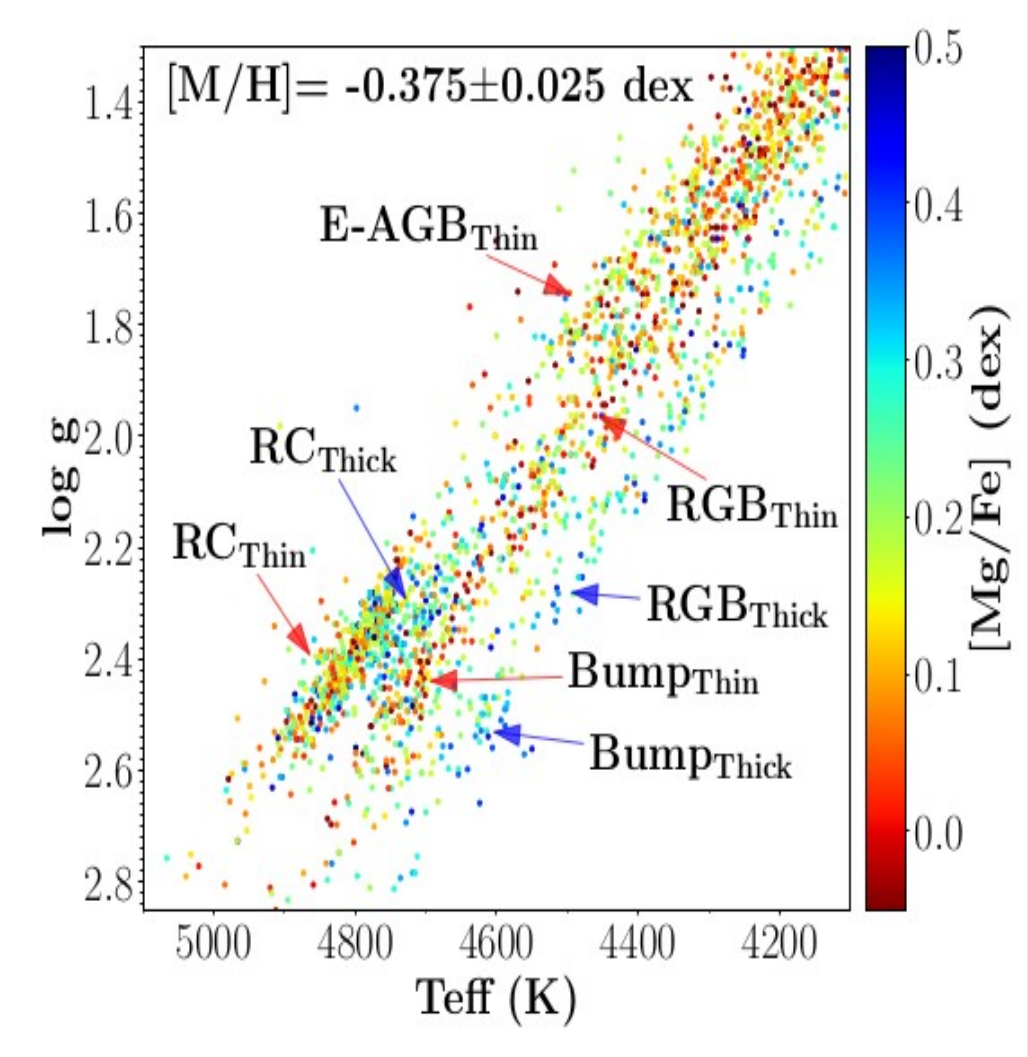


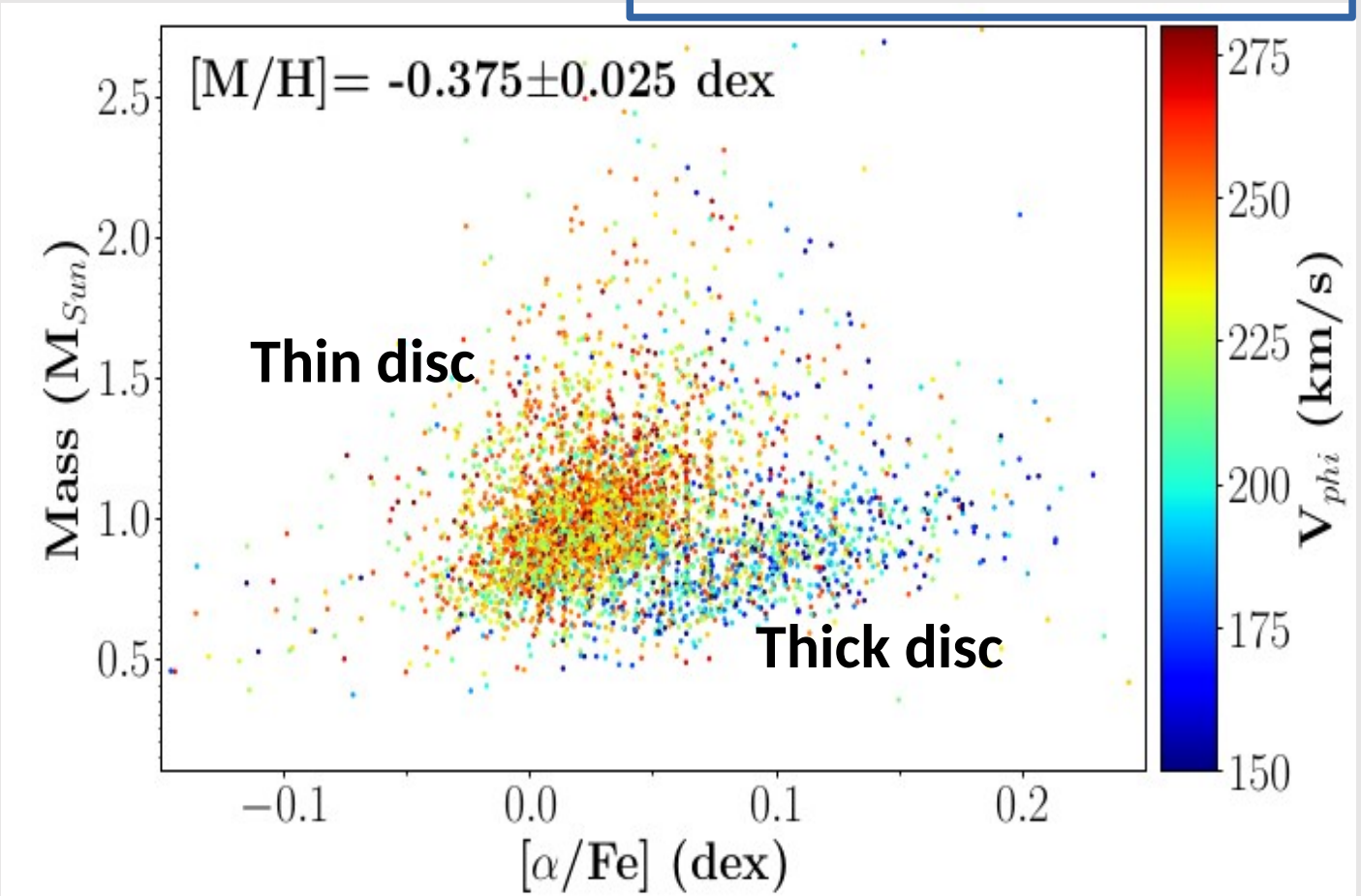
RGB & HB

Turn-Off

Gaia/GSP-spec parameters: High-precision

Stellar evolution





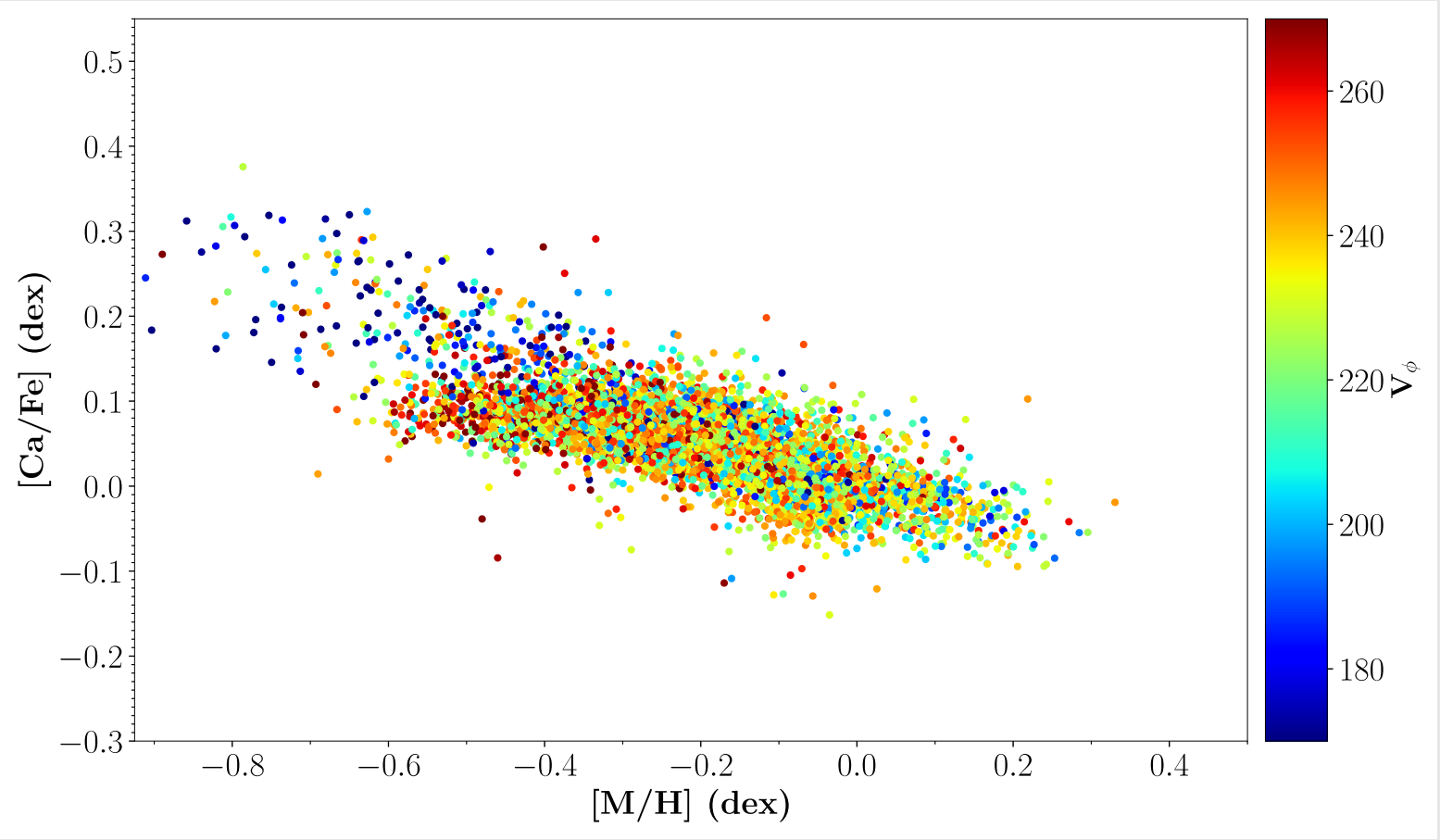
'Spectroscopically' estimated masses

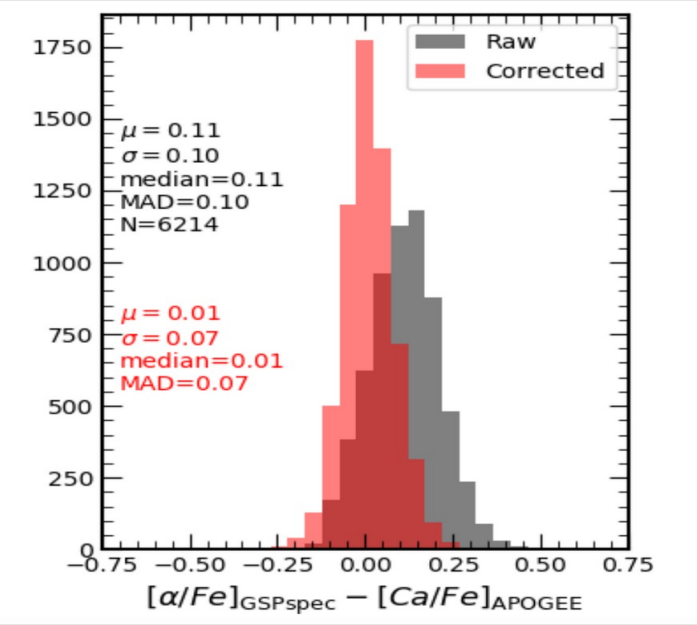
- Mass-alpha relations → Different ages
- Thick disc: lower mass & higher alpha

Gaia/GSP-spec chemical abundances

MW populations

Gaia spectra dominated by CaT lines : [α /Fe] ~ [Ca/Fe]





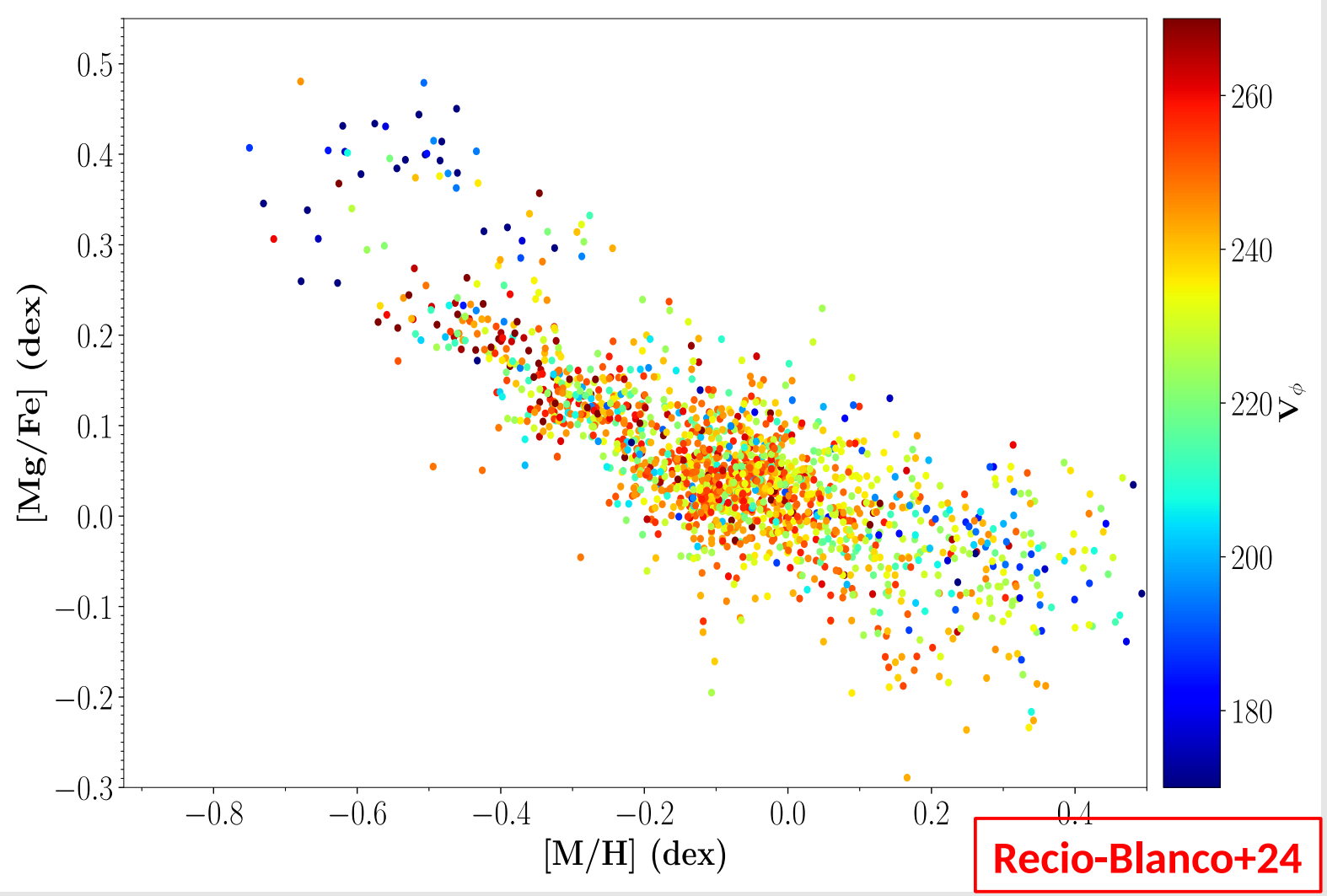
Ca is **not** produced by short-lived sources

Small thin/thick disc separation even with low uncertainties

Gaia/GSP-spec chemical abundances

MW populations

... but if considering [Mg/Fe] low-uncertainties abundances



Recio-Blanco+24

Mg is produced by short-lived sources

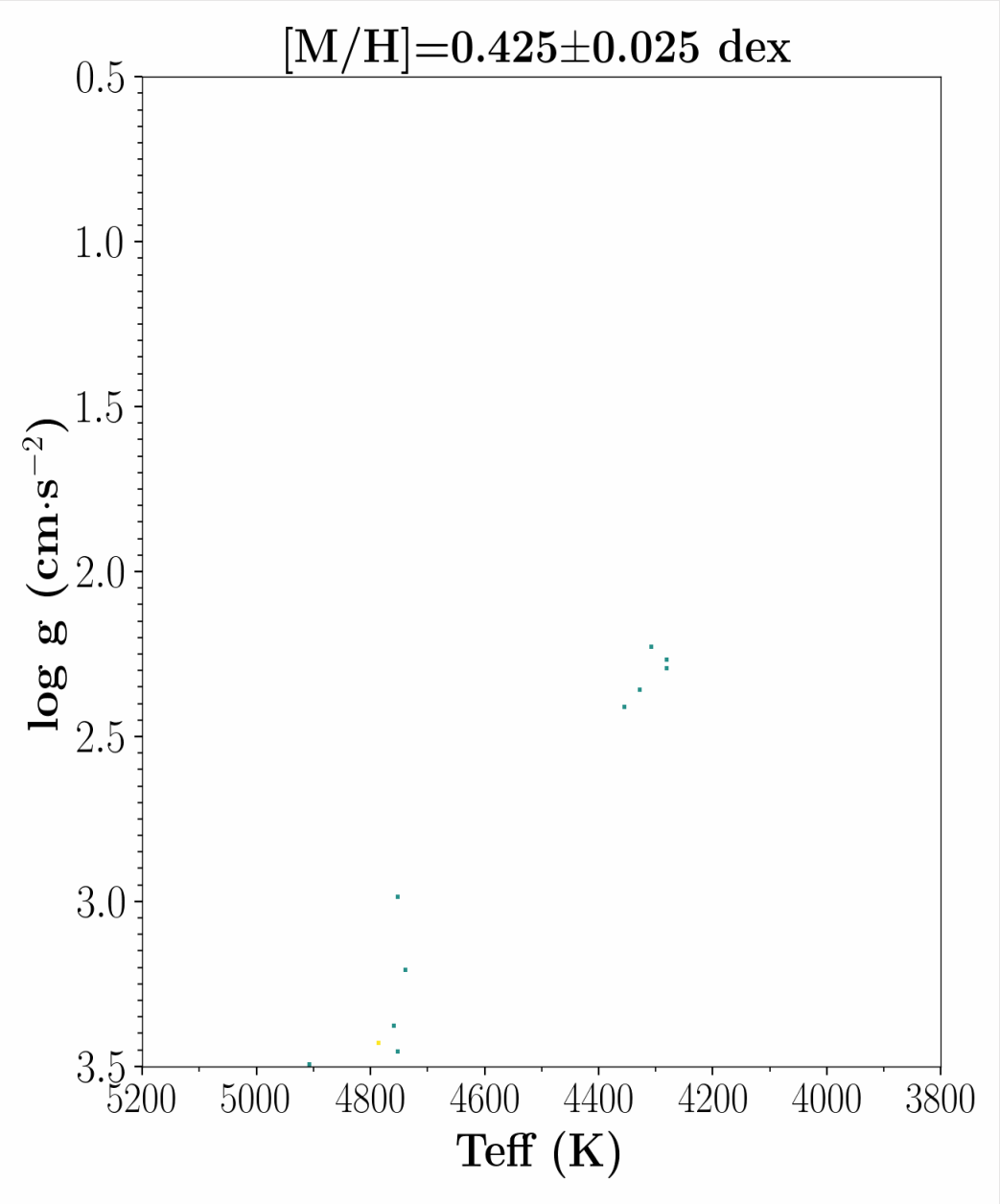
Larger thin/thick separation, as expected...

and with only R=11 500 at 846 - 870 nm

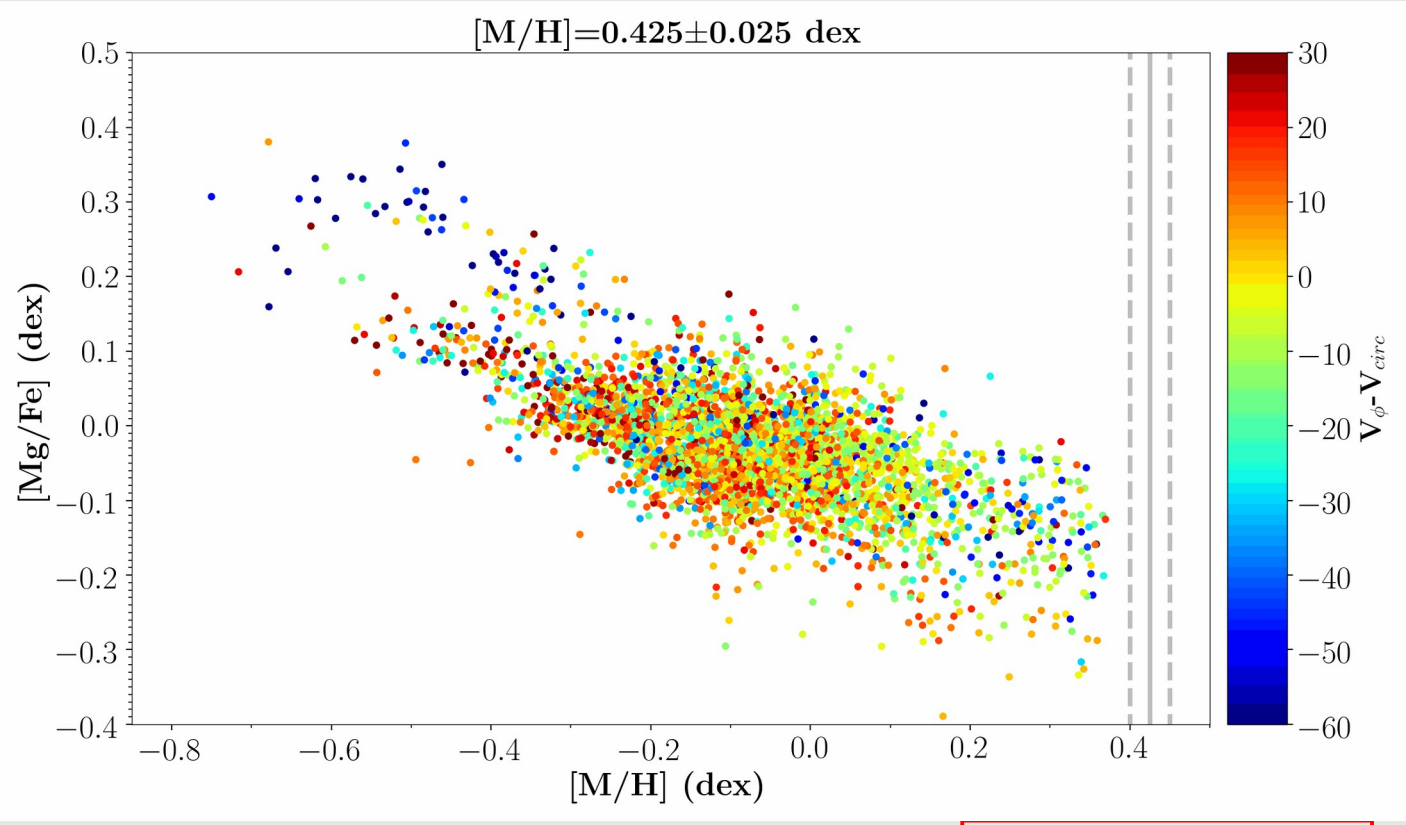
Gaia/GSP-spec chemical abundances

MW populations

⇒ RGB & RC with high-precision



Gaia GSPspec : mono-abundance disc populations



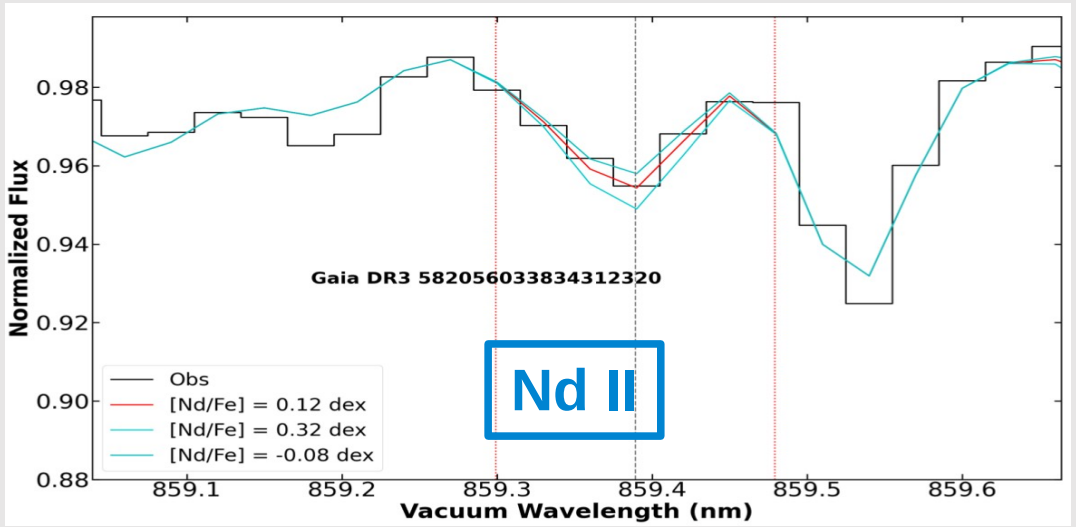
Recio-Blanco+24

Gaia/GSP-spec chemical abundances

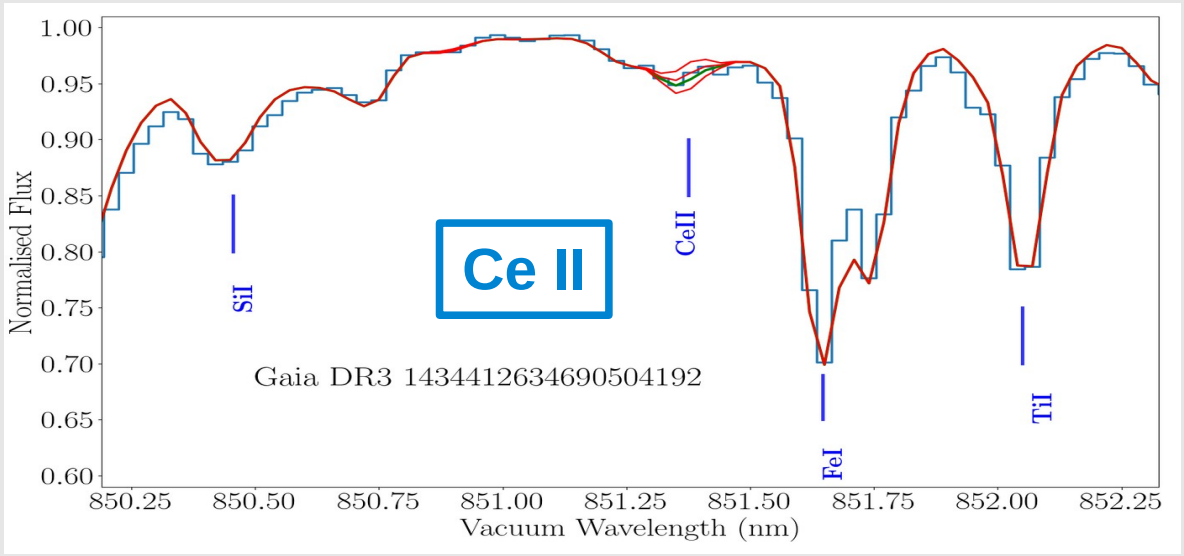
AGB: s-process elts

- **About 175,000 AGB with GSP-spec parameters**

- **Abundances of three n-captured (s-process) elements**
  - Cerium : ~46,000 stars (~18,000 with very high-quality abundances)
  - Neodynium : ~35,000 stars (~4,000 with very high-quality abundances)
  - Zirconium : ~10,000 stars



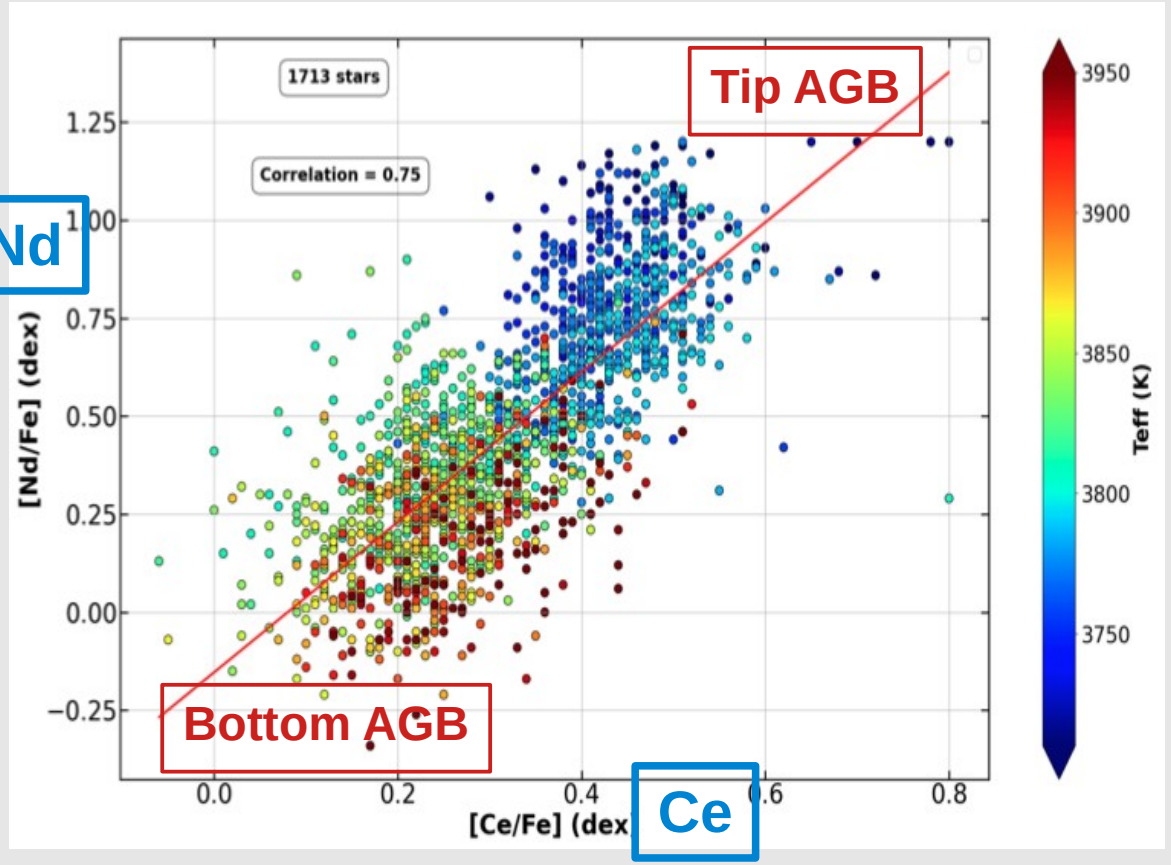
$T_{\rm eff}$ = 3825 K, log(g) = 0.37, [Fe/H] = -0.74 dex, [α/Fe] = 0.12 dex, [Nd/Fe] = 0.12 dex and [Ce/Fe] = 0.14 dex.

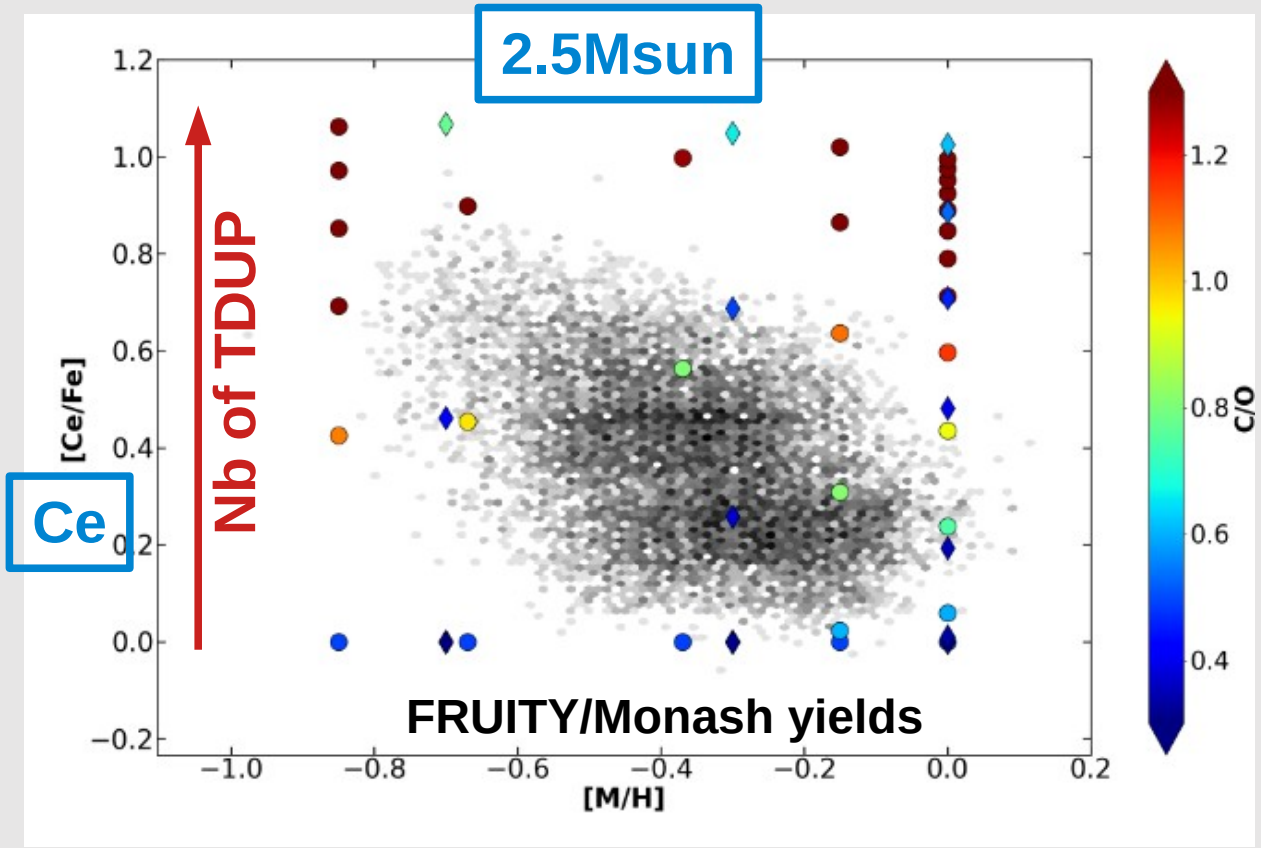


[Ce/Fe]=0.26dex [M/H]=-0.4dex

Gaia/GSP-spec chemical abundances

AGB: s-process elts





AGB production of s-process elements:

- Higher Ce & Nd for more evolved AGB stars of similar metallicity
- AGB with M~1-3 Msun are the main producers

Contursi et al. 2022 & 23 + PhD thesis

Gaia/GSP-spec Frequently Asked (and not-Asked) Questions

- **When I query the Gaia catalogue, I do not see the GSPspec parameters.**
  - Please check that you query the right table: **AstophysicalParameters**

- **When I plot GSPspec parameters, there is a cloud of points…**
  - Please **always** check the **quality flag chain**
  - **Filter out** results with quality lower than desired
  - Check also the **published uncertainties** and the SNR (rv_expected_sig_to_noise)

- **GSPspec parameters have to be calibrated**
  - See recommendations in Recio-Blanco et al. 2023

Gaia/GSP-spec: the first space spectroscopic survey

SUMMARY

- **Gaia/GSP-spec offers high-precision parametrization**
  Quality comparable to ground-based data of higher spectral resolution/coverage

- Unprecedented **higher number statistics**

- Catalogue of atmospheric parameters & chemical abundances
  - Any stages of stellar evolution
  - Any masses
  - Contraints to stellar models, chemical evolution,...
  - .../...

Gaia/GSP-spec: FUTURE space spectroscopic surveys

- **The Gaia future is bright !**

- **Spectroscopy : much larger chemo-dynamical catalogues to come:**
  - DR4 (2026) : – ~40 million stars + ~450,000 Epoch spectra of ~11,000 Cepheids/RR Lyr
    – Higher SNR ⇒ Even better accuracy
    – Abundance of new chemical species (r-process?)
    – Purely 'spectroscopic' Extinction, Luminosity, Radius, Masses,…
  - DR5 (>2030) : ~100 million stars + ~10^{10} Epoch spectra

- **New developments to be planned:**
  - Grids of theoretical spectra : Linedata & Atm. models + RT (NLTE, 3D, Hydrodynamics,…)
  - Machine learning tools for spectral analysis
  - Interpretation with Stellar evolution codes, Stellar yields predictions, ….

- The **Gaia Revolution** impacts any branches of astrophysics including **Stellar Physics !**

Gaia/GSP-spec: the first space spectroscopic survey