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Italiadomani

PIANO NAZIONALE  
DI RIPRESA E RESILIENZA



Centro Nazionale di Ricerca in HPC,  
Big Data and Quantum Computing

*Progress report on the use of old stellar tracers to  
constrain the early formation of the Galactic spheroid*

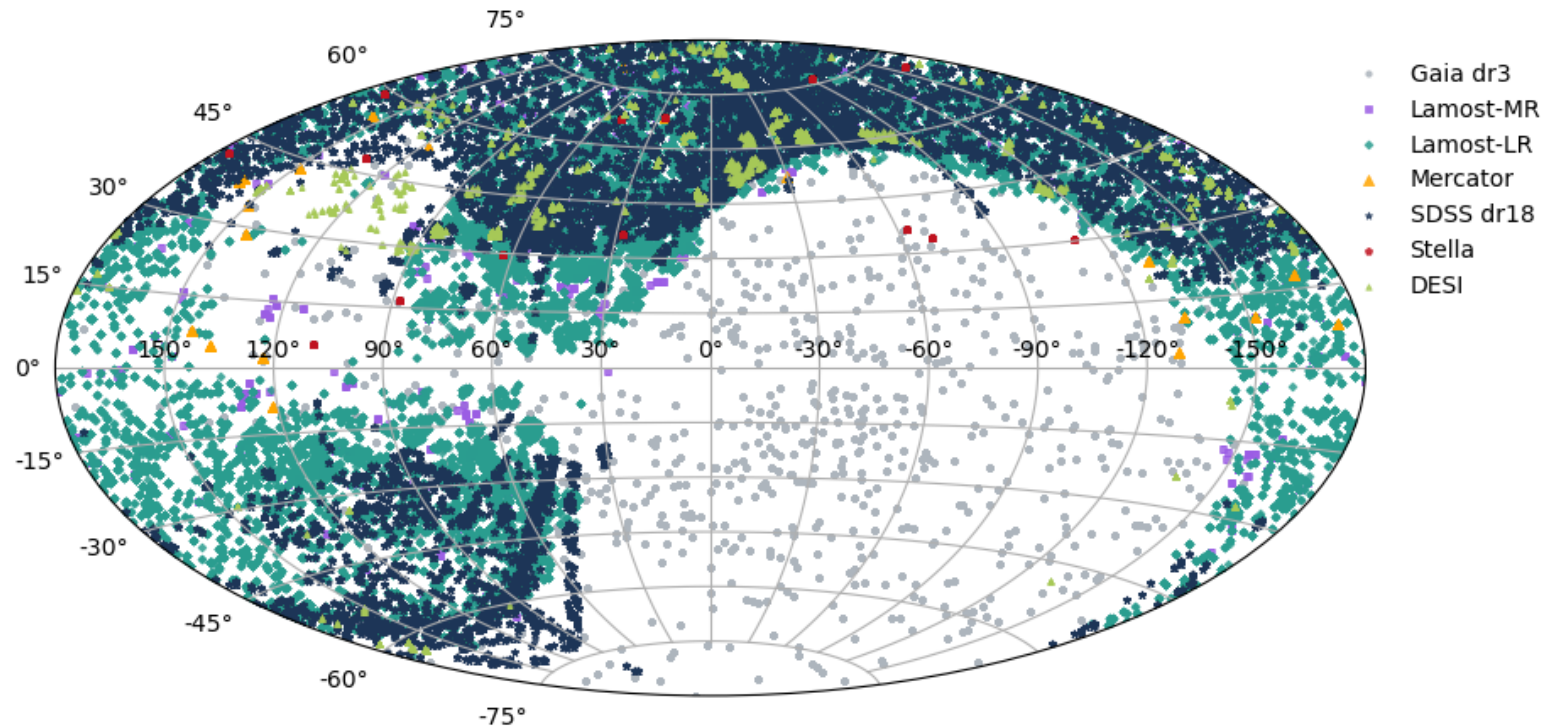
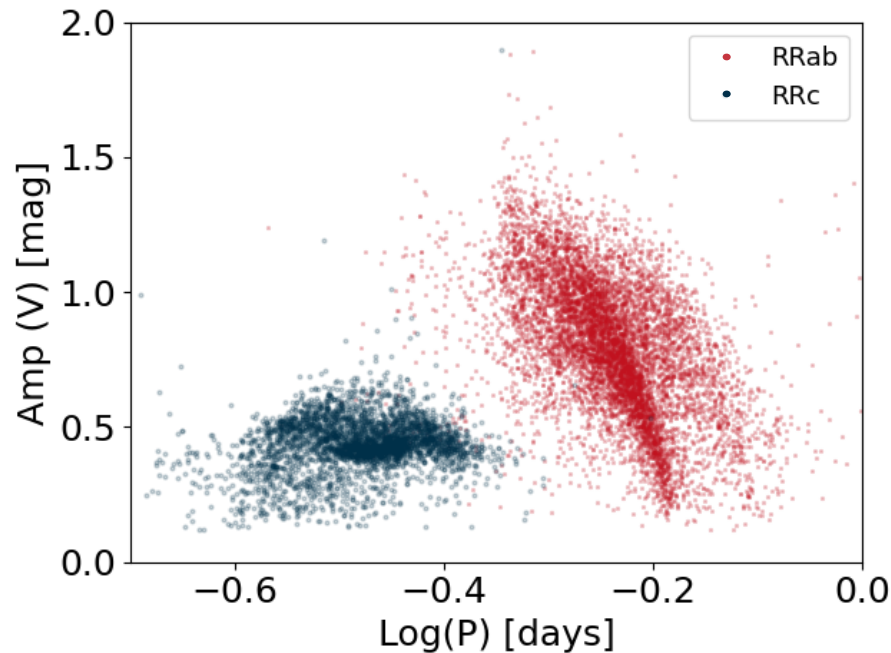
*K. Baeza-Villagra, G. Bono*

**Spoke 3 II Technical Workshop, Bologna Dec 17 -19, 2024**

# Scientific Rationale

**Project Main Goal:** Provide the largest spectroscopic catalog of RR Lyrae stars (RRLs). These stars are solid tracers to investigate the early formation history of the Galactic spheroid and for performing chemical tagging analyses.

**Our current work includes ~ 15.000 RRLs**



# Technical Objectives, Methodologies and Solutions

→ Estimation of Gamma-velocity using radial velocity curve templates for Balmer lines, Fe and Mg.

- **STELLA Robotic Observatory**
- **Mercator Telescope - HERMES spectrograph**
- The Dark Energy Spectroscopic Instrument (DESI)
- LAMOST dr8 v2 - MR
- GAIA dr3
- Sloan Digital Sky Survey (SDSS dr18)
- LAMOST dr8 v2 - LR

→ Application of the Delta-S method to obtain metallicity estimates for RR Lyrae stars from low-resolution spectra.

# Technical Objectives, Methodologies and Solutions

→ On the basis of individual distances, gamma-velocities, proper motions & coordinates (Gaia) we can constrain the dynamical properties of these stars and their orbits (MW potential).

The chemo-dynamical properties of old stellar tracers allow us to trace in space and in time the assembling history of the Milky Way in its early stages.

# Technical Objectives, Methodologies and Solutions

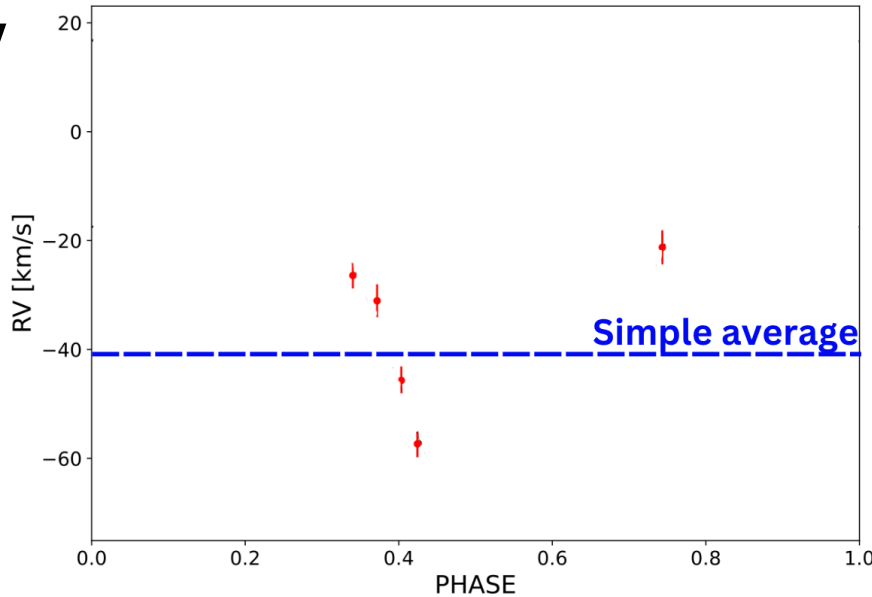
RV templates



Gamma-Velocity ( $V_\gamma$ )

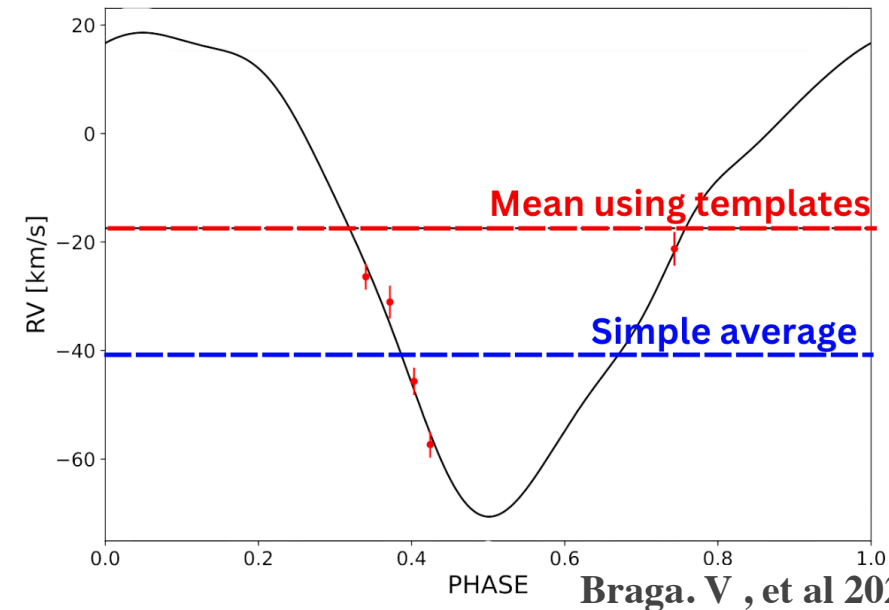
Classical approach

Simple average



This work

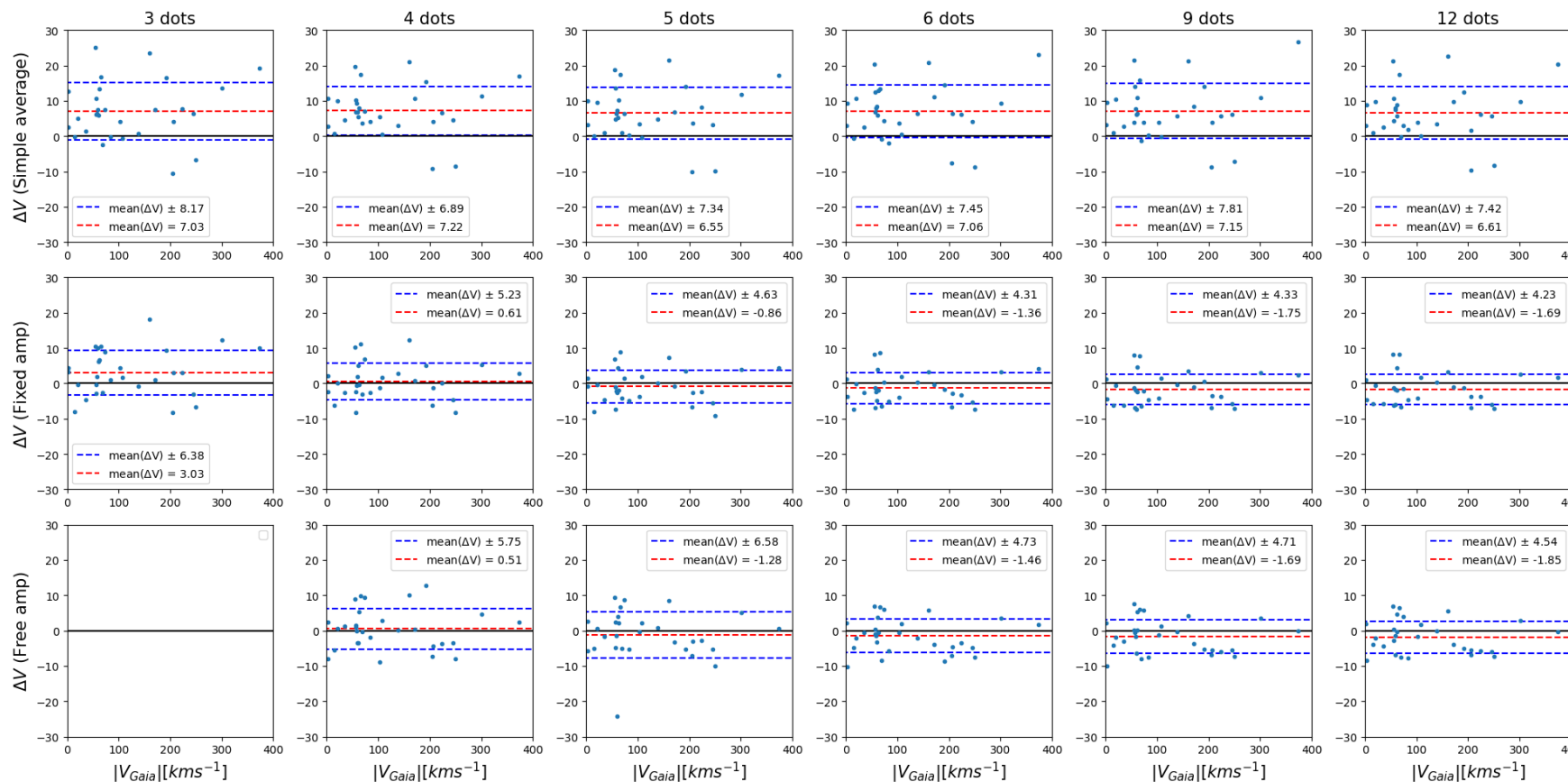
RV templates (more than 3 spectra)



Braga. V , et al 2021

# Technical Objectives, Methodologies and Solutions

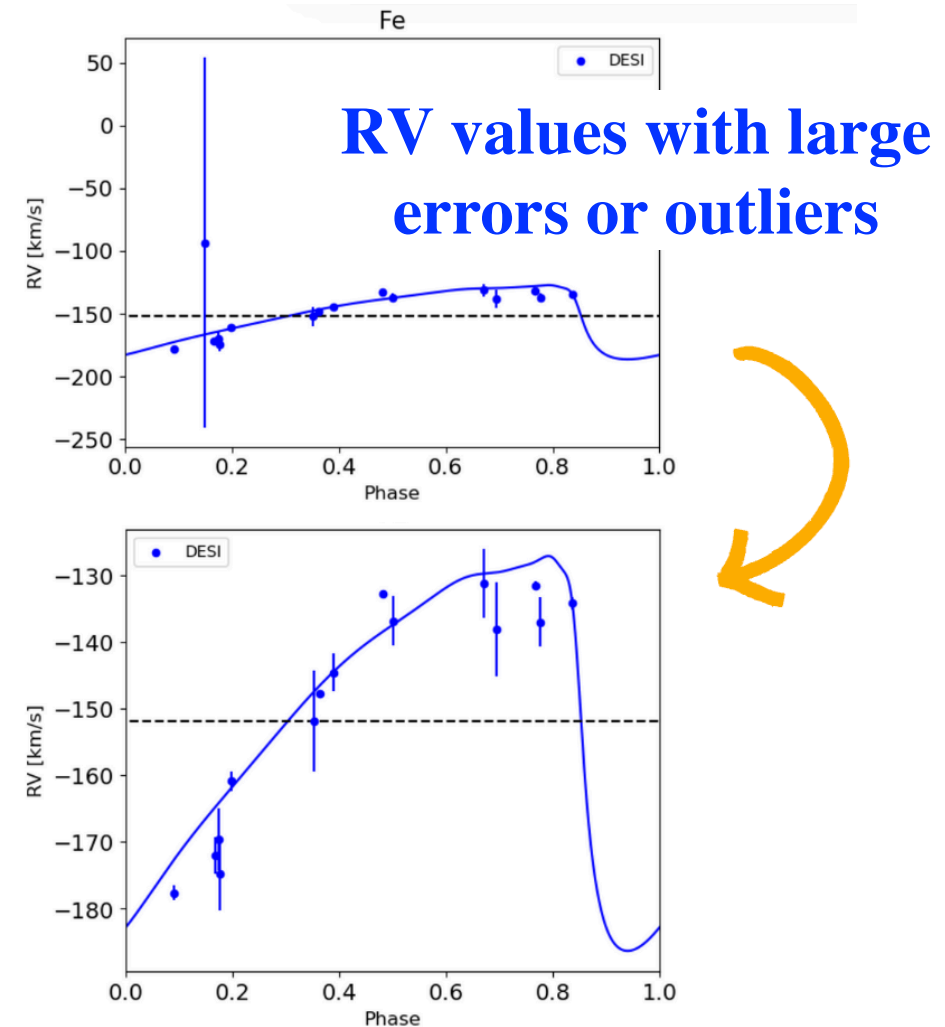
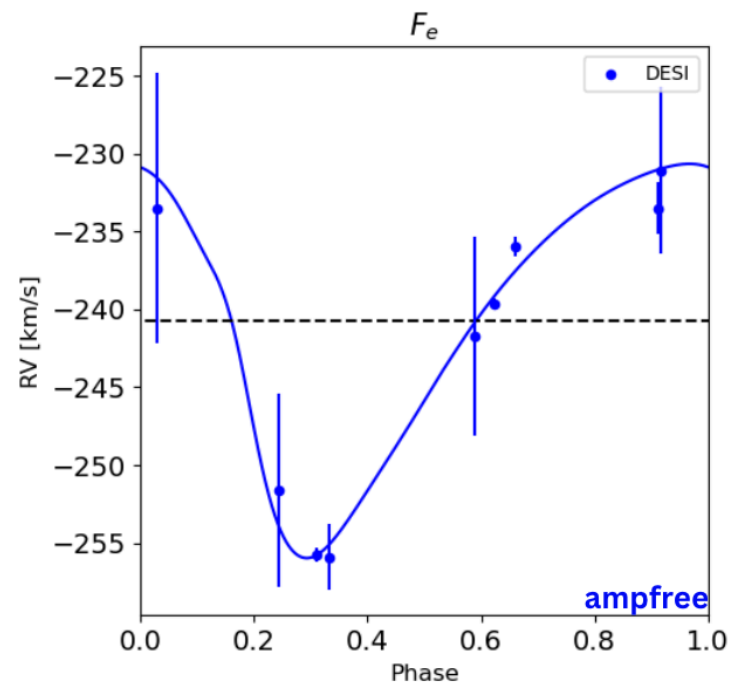
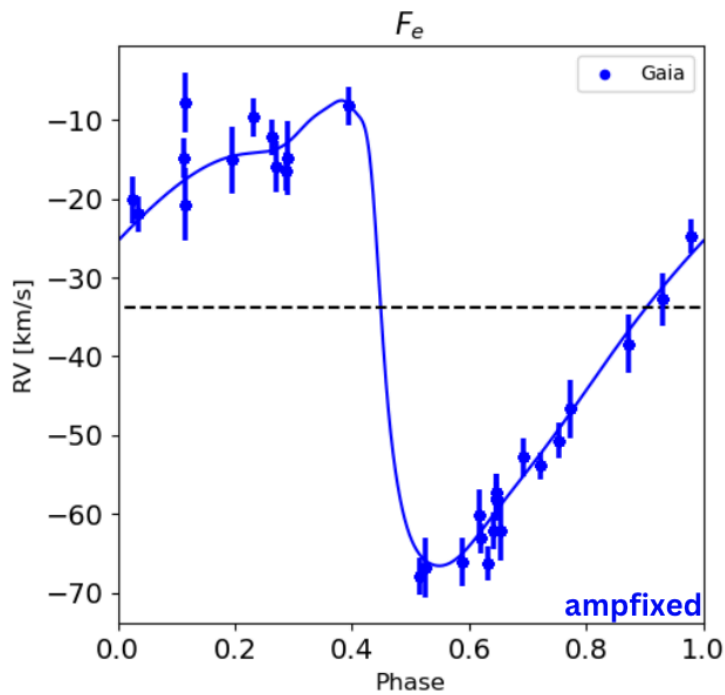
Calibration Sample:  
36 stars  
Line:  $H\alpha$



The offset with respect to the best estimate of the  $V_\gamma$  decreases from  $> \sim 7$  [km/s] to less than  $\sim 2$  [km/s] when we use the templates.

# Technical Objectives, Methodologies and Solutions

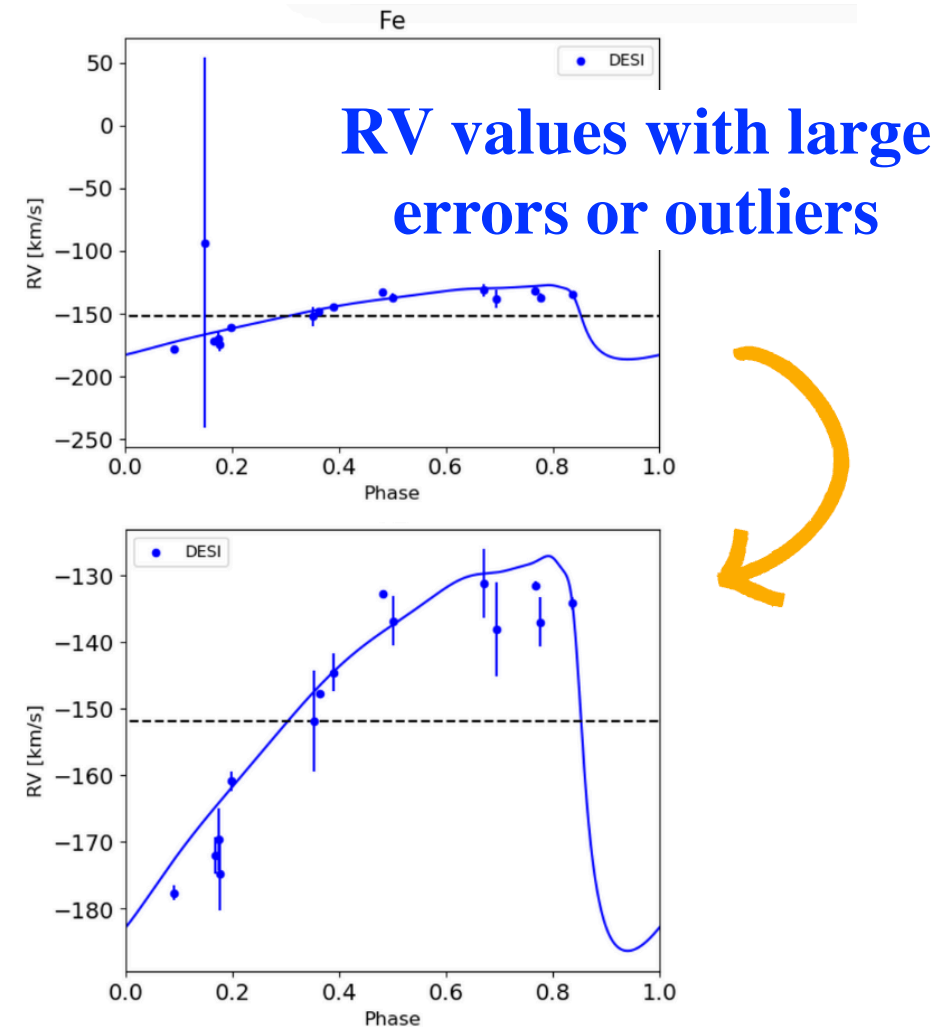
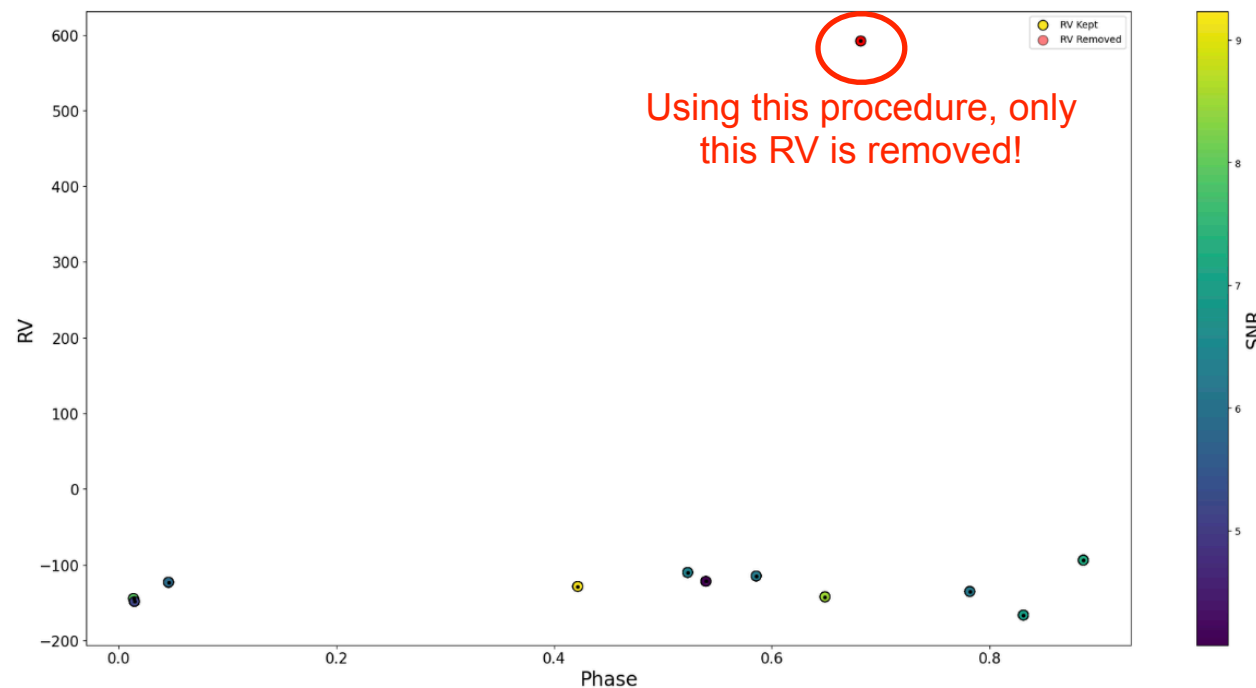
## Ideal case: without outlayers



# Technical Objectives, Methodologies and Solutions

**Sigma clipping** → Only if  $SNR \leq 15$   
This process includes two steps:

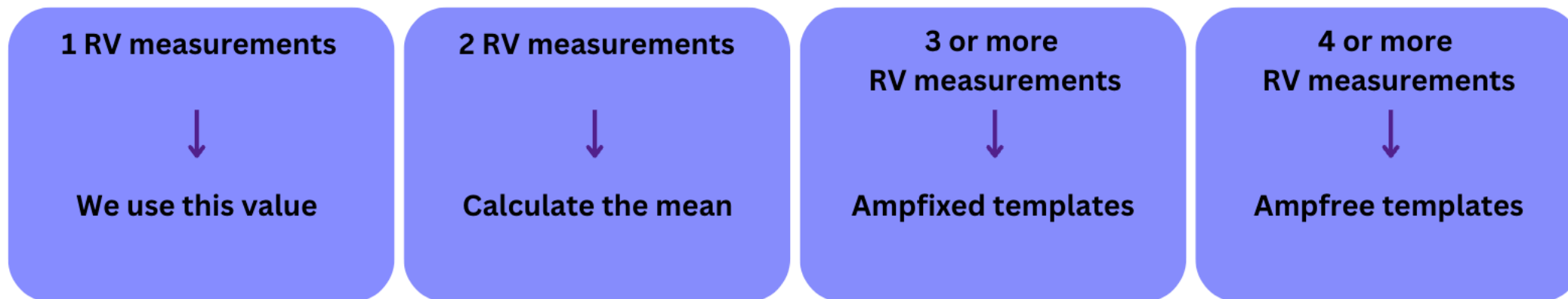
- RV error filtering ( $2\sigma$ )
- RV measurements filtering ( $2\sigma$ )





# Technical Objectives, Methodologies and Solutions

Thus, finally:



# Technical Objectives, Methodologies and Solutions

$\Delta S$  method



Metallicities

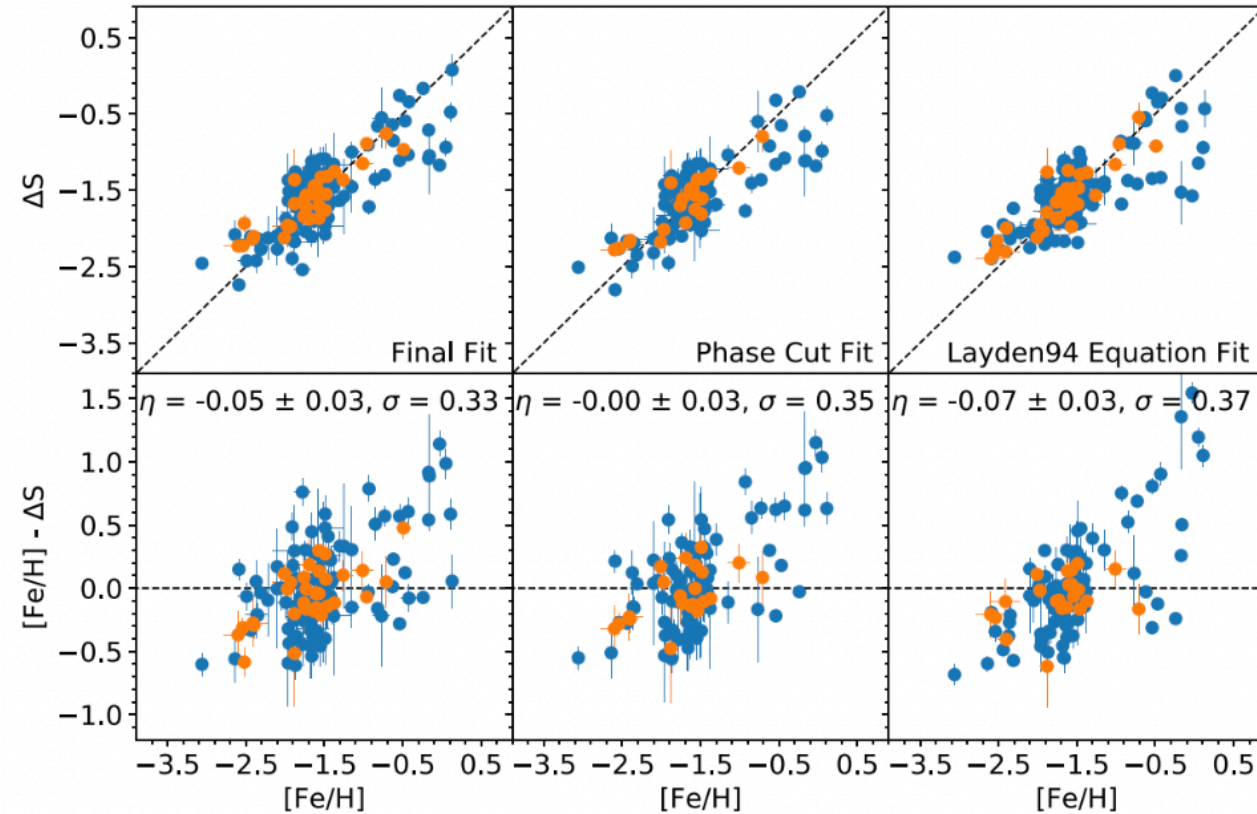
The equivalent widths of the Ca II K and three of the Balmer series features can also be associated with the metallicity of RRLs



The low-resolution measurements are sufficient to provide metallicity estimates !



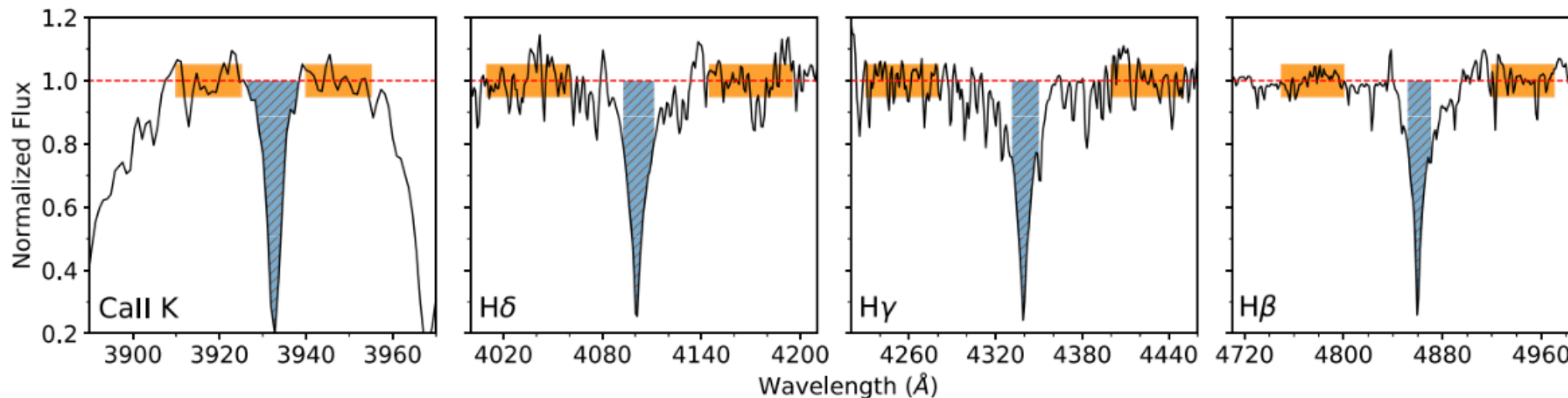
$$[F_e/H]_{\Delta S} = c_0 + c_1 K + c_2 H_{\delta} + c_3 H_{\gamma} + c_4 H_{\beta}$$



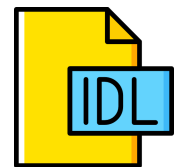
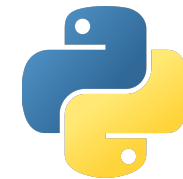
Crestani et al, 2021

# Technical Objectives, Methodologies and Solutions

- Correct each spectra by RV and center the line
- Spectrum normalization and spectrum cleaning: we calculated the mean flux in the continuum bands on either side of the line and replaced normalized flux values above 1.25 with the average of their neighboring points.
- Continuum evaluation using the Crestani et al. 2021 limits
- Calculate the EW and  $[Fe/H]_{\Delta S}$  using eq. 1 of Crestani et al. 2021
- Calculate the mean in case we have more than 1 spectra per star

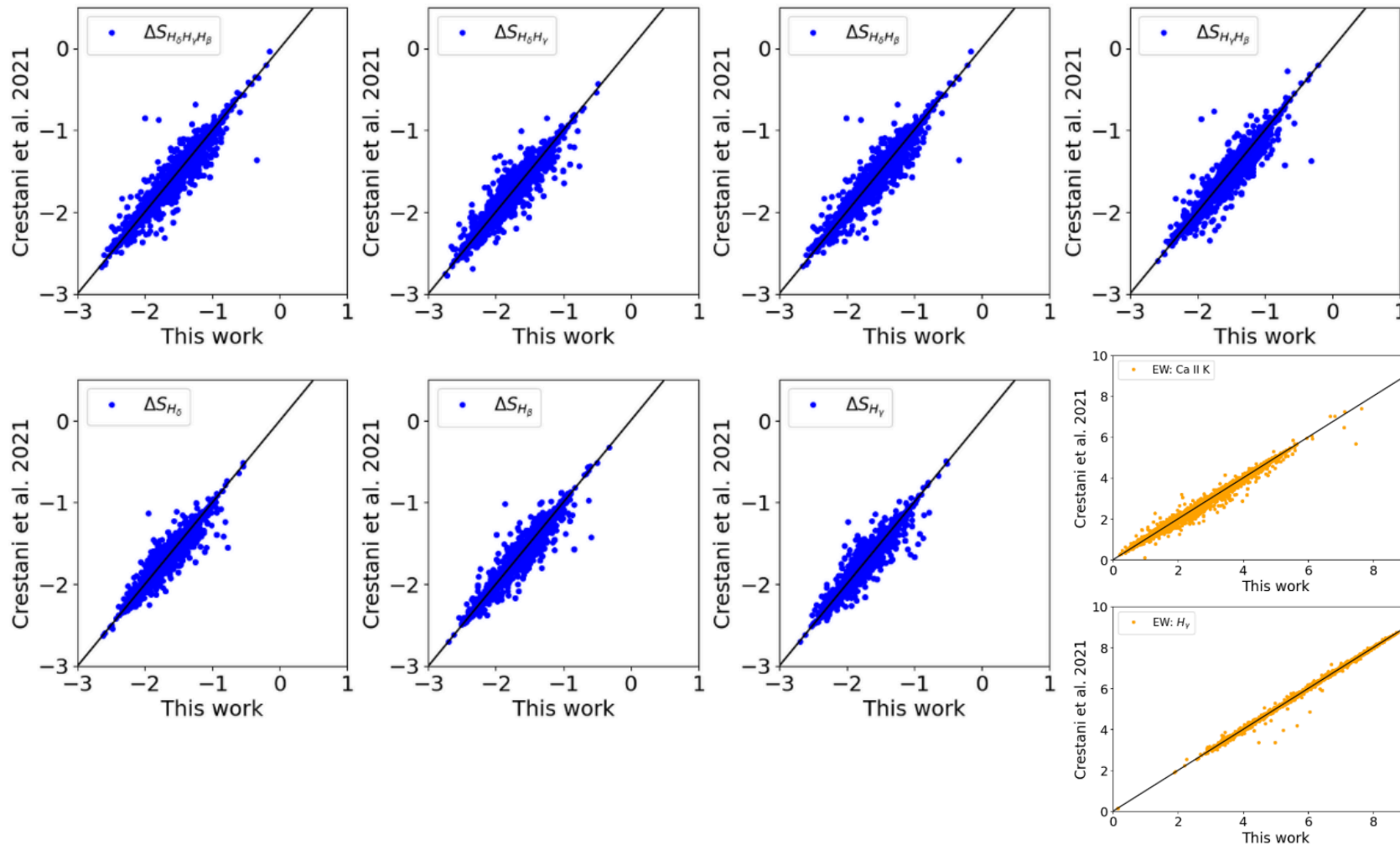


Code available in :



Crestani et al, 2021

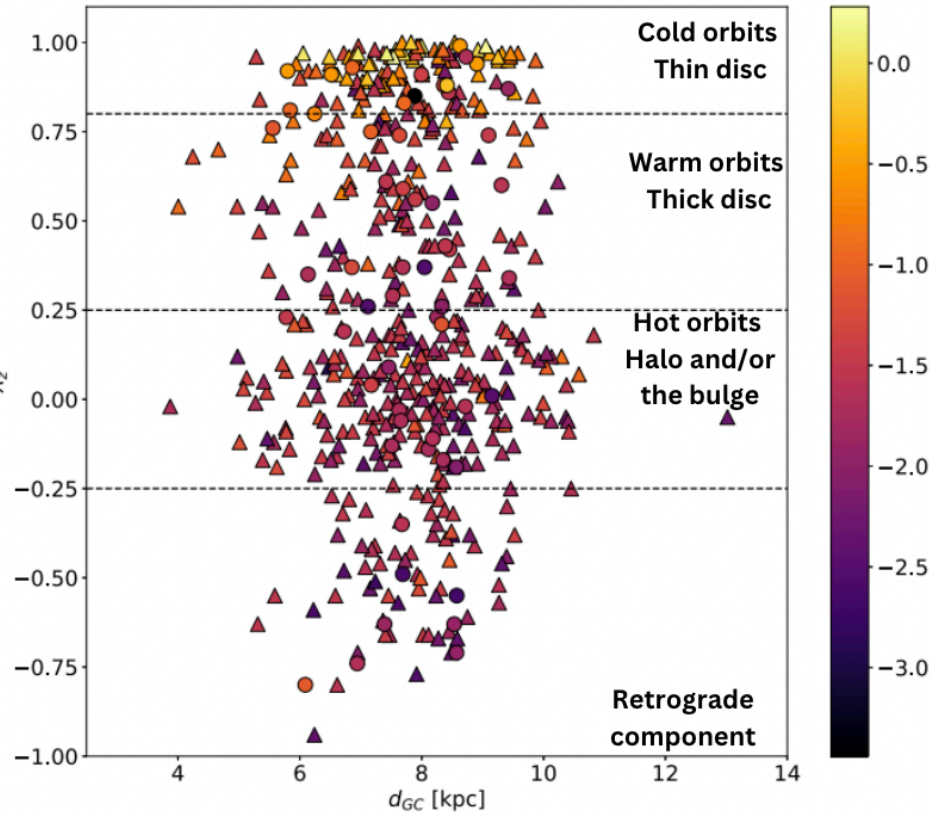
# Technical Objectives, Methodologies and Solutions



**Good agreement  
using the coadded  
spectra from SDSS!**

# Technical Objectives, Methodologies and Solutions

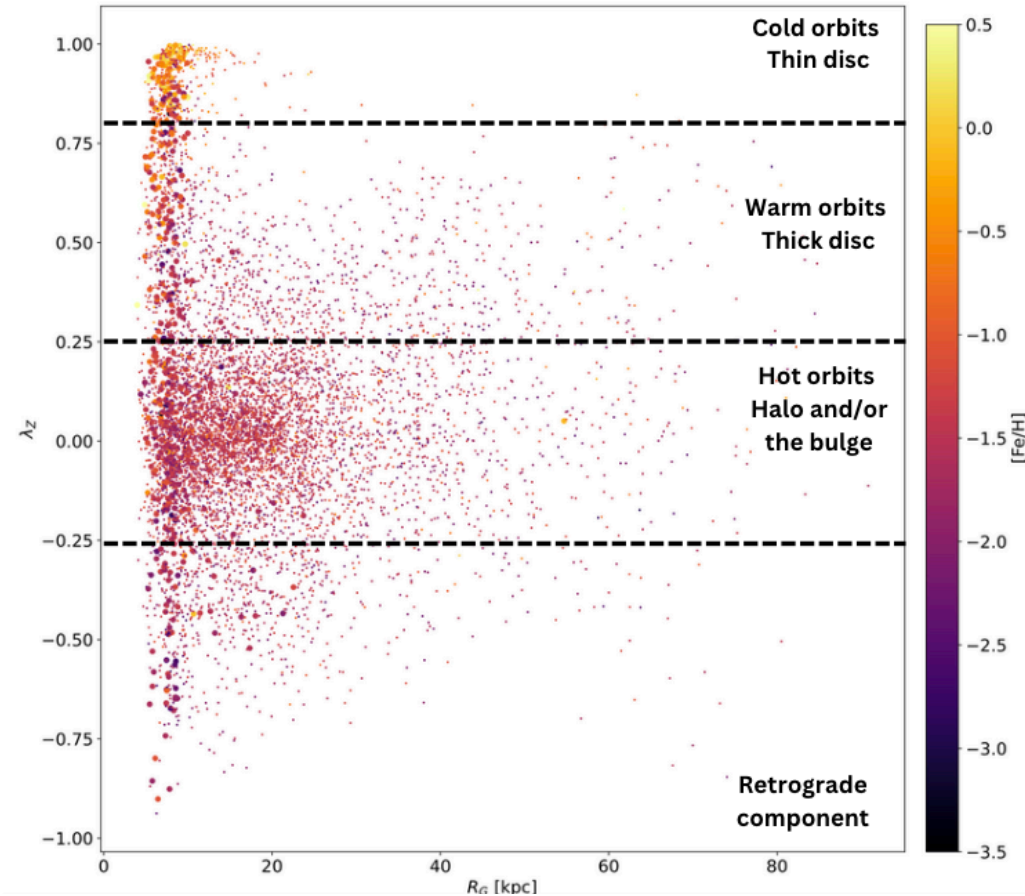
Full sample of 535 RRLs



V. D'Orazi et al 2024

Galactocentric distance

Previous sample ~ 8000 RRLs



Bono, Braga, V et al. (in prep)

6D parameters

Circularity of the orbit

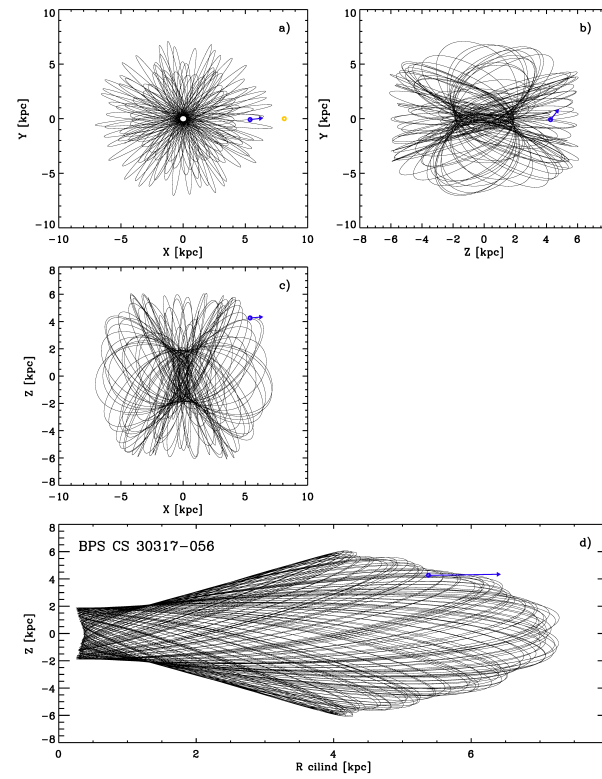
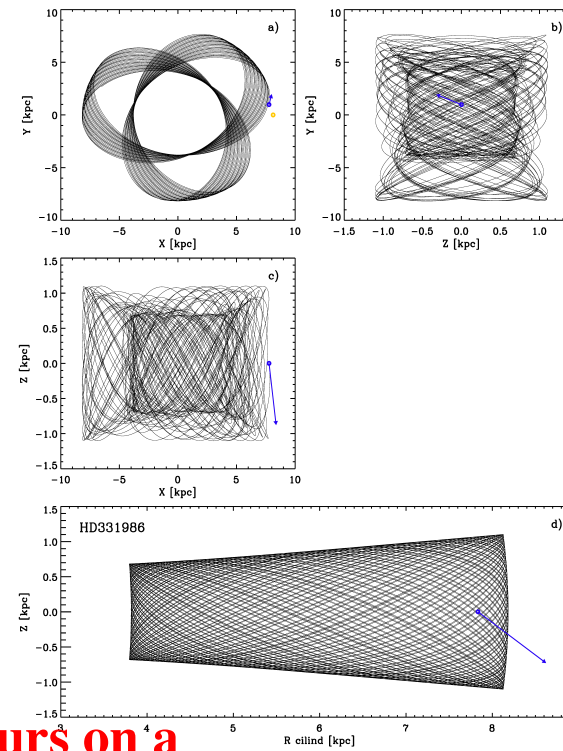
Dynamical properties

# Technical Objectives, Methodologies and Solutions

→ RRL kinematics based on MW-potential (Bovy 2015)

→ To estimate the errors the six input parameters ( $V_r$ ,  $d$ ,  $PM[ra,dec]$ ,  $position[ra,dec]$ ) are randomly changed assuming Gaussian distributions.

→ 10,000 points randomly distributed to trace orbital variations (Price-Whelan 2018)



**To run these simulations are required several tens of hours on a**

AS-2015CS-TNR Supermicro CloudDCA

AMD EPYC 9754 Processor (128-cores/256-threads), 512 GB ram

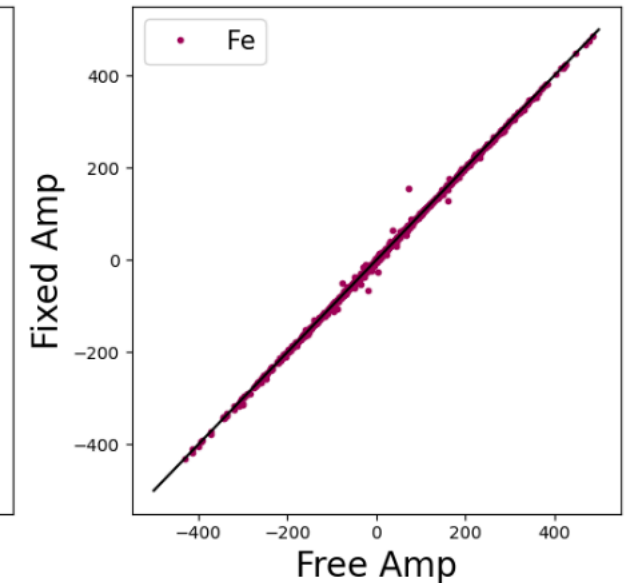
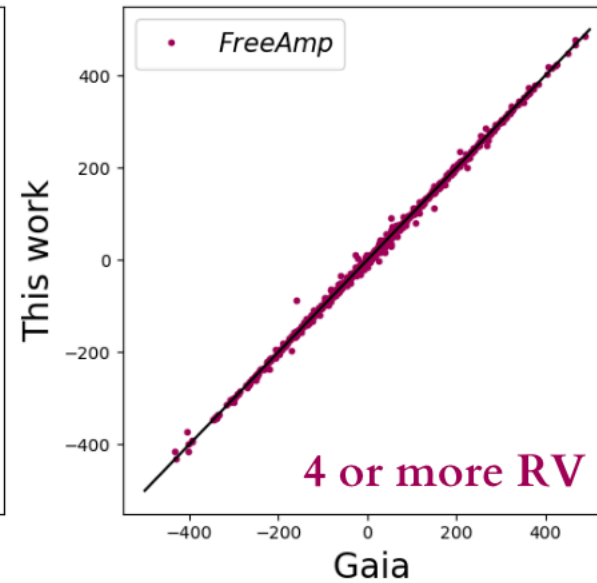
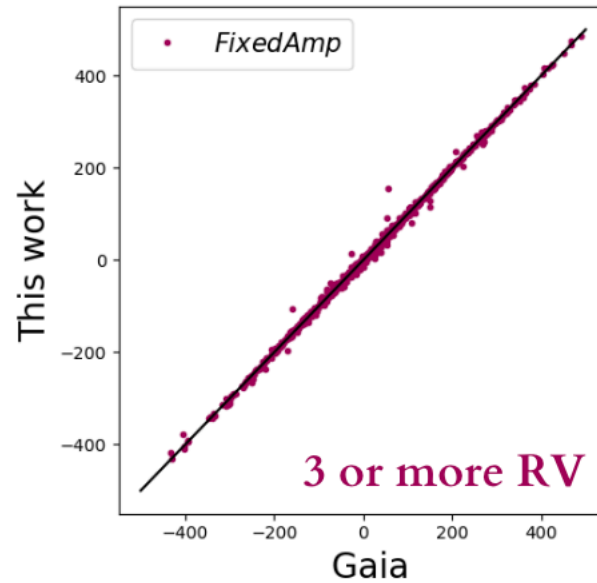
**Work in progress ...**

V. D'Orazi et al 2024

# Main Results

## Example for Gaia Data Release 3: Vy

- STELLA
- DESI
- LAMOST - MR
- GAIA dr3
- SDSS dr18
- LAMOST - LR
- Mercator (work in progress)



**Very good agreement !**

# Main Results

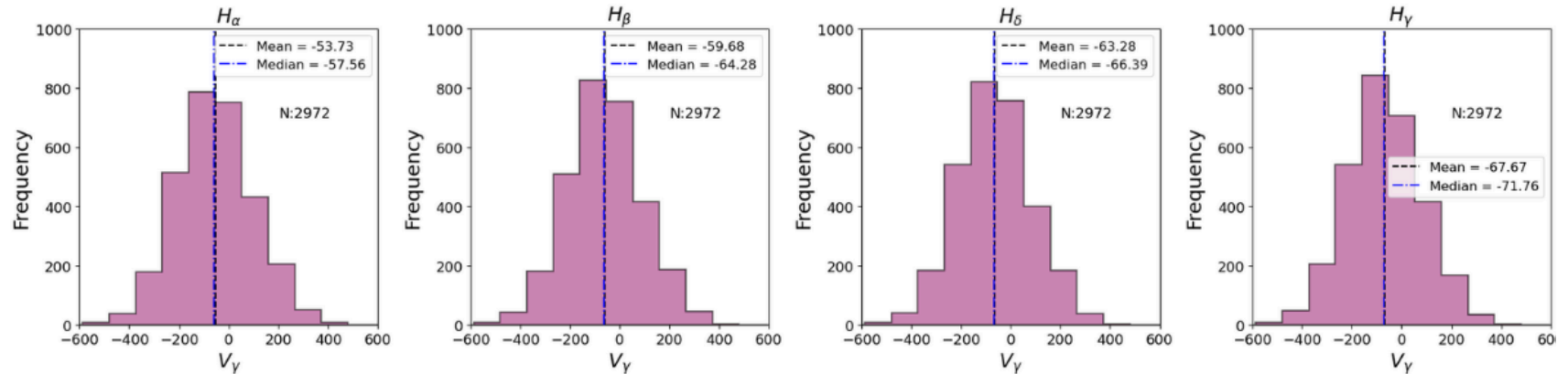
We identified stars with high  $V_Y$ , which will be analyzed separately!

18 stars with high  $V_Y$

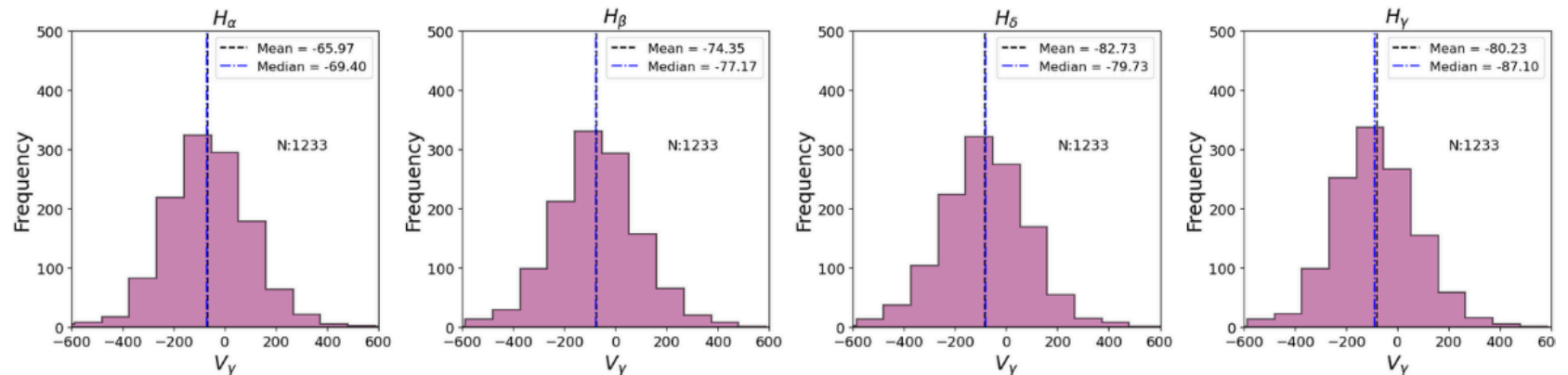


$500 \text{ [km/s]} < |V_Y|$

Template: Fixed amplitud



Template: Free amplitud

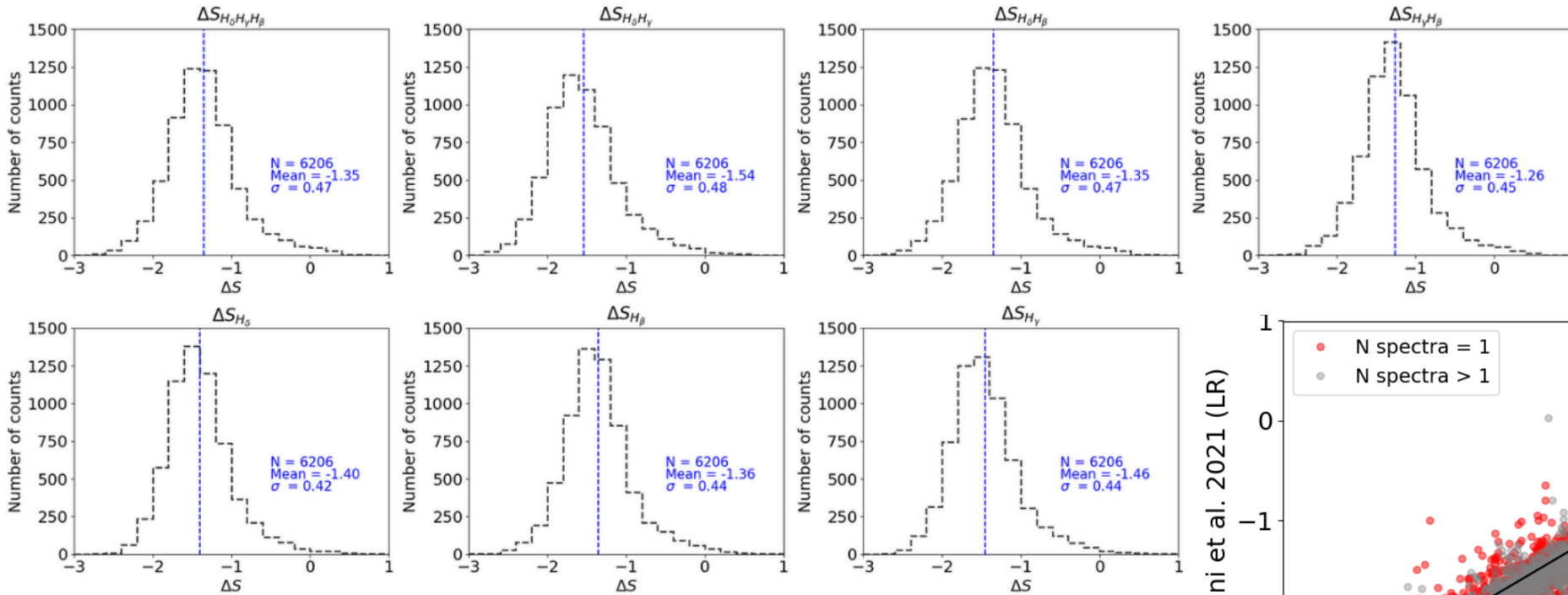


Example for SDSS:  $V_Y$



# Main Results

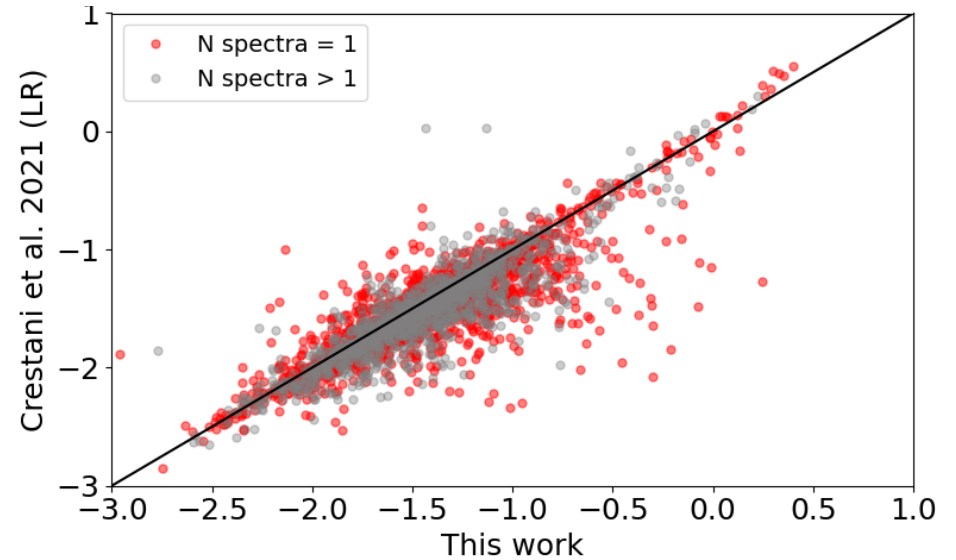
## Example for Lamost-LR: $\Delta S$ method



★ Mean( $\Delta S$ )

★ SNR  $\geq 10$

Mean( $\Delta S$ ) = -1.35 with a dispersion of 0.47 dex



# Final Steps

## Next steps:

- Obtain radial velocities for the Mercator catalog and begin working with the GALAH catalog to complement the dataset (optional).
- **Calculate stellar orbits to study their dynamical properties.**
- Initiate the following analyses:

**In-situ/Accreted Classification:** Identify stars formed in situ versus those accreted during mergers.

**Identification of metal-poor stars with disc-like orbits**

**Oosterhoff Typing**

**High-Velocity Stars:** Investigate stars with unusually high velocities to explore their origins and dynamics.

# Final Steps

## Expected results (and KPI):

- A scientific paper with high-velocity RR Lyrae stars by K. Baeza-Villagra et al.
- A scientific paper with the largest spectroscopic catalog of RR Lyrae stars by K. Baeza-Villagra et al.
- Create a GitHub repository to host the Python code for implementing the Delta-S method.

# Thank for your attention!

Contact:

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