Metallicity spread among the primordial population of Galactic GCs

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S. Kamann, T.-O. Husser, S. Dreizler
& MUSE GC Team

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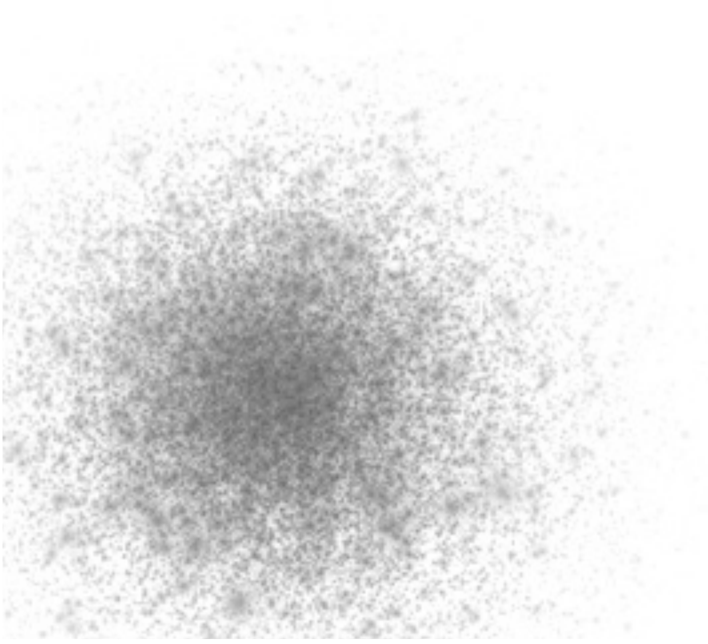
August 20th , 2024

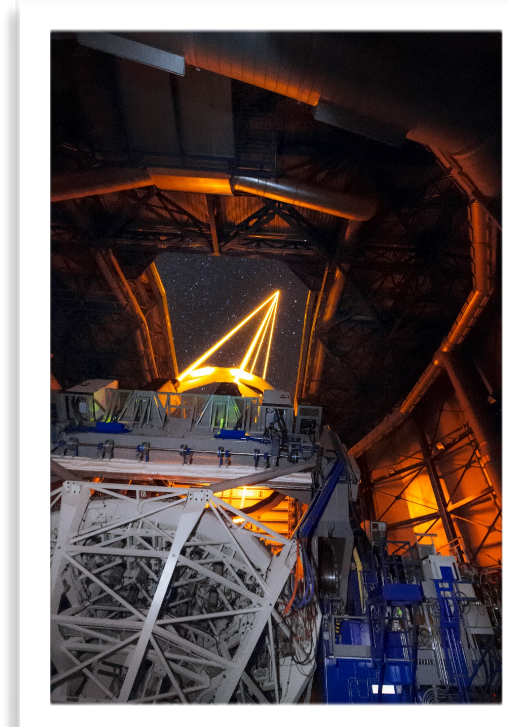


The MUSE Globular Cluster Survey

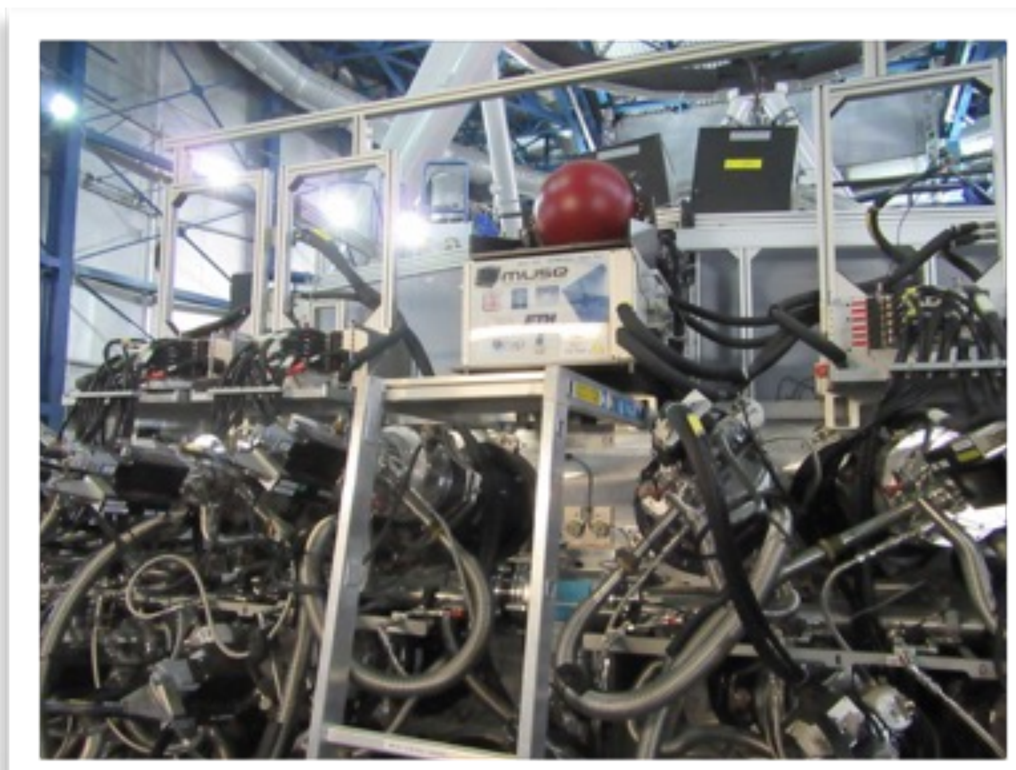
muse
multi unit spectroscopic explorer

MUSE

- Integral field spectrograph at the UT4 of the VLT
- Wide Field Mode –> 1′x1′ field of view (0.2" sampling)
  Narrow Field Mode –> 7.5"x7.5" field of view (0.025" sampling)
- 4650-9300 Å, R~3000 (Δλ~2.5 Å)



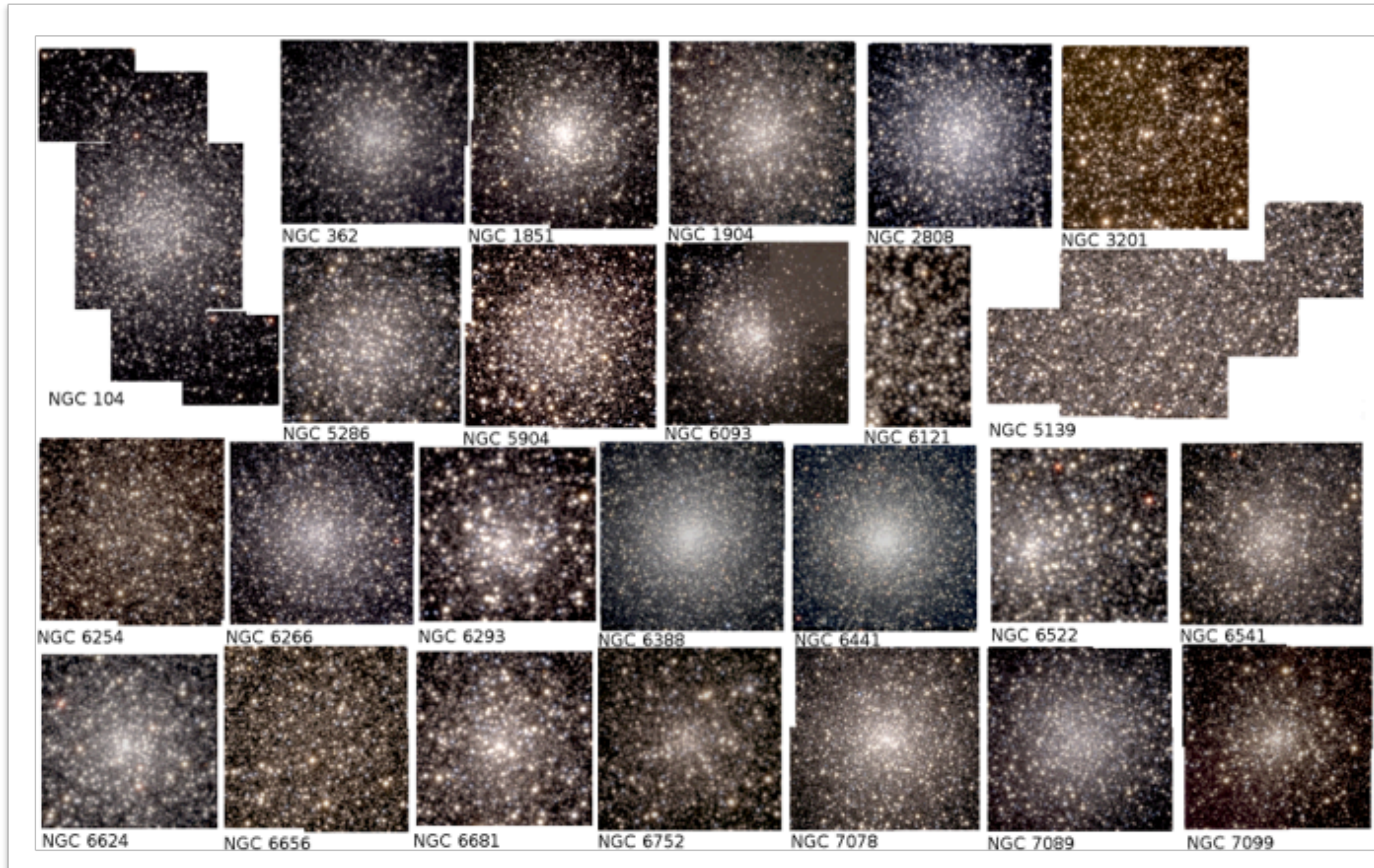
credit: ESO



The MUSE Globular Cluster Survey

The Survey

- GTO time (2014-2022)
- 26 Galactic GCs
  8 Magellanic Cloud GCs
- 1-10 WFM pointings / GC
  1-3 NFM pointings / GC
- 3+ epochs / pointings
- 10+ epochs in 4 GCs (47Tuc, ωCen, NGC3201, NGC1851)
- Spectra for 10 000+ stars / GC

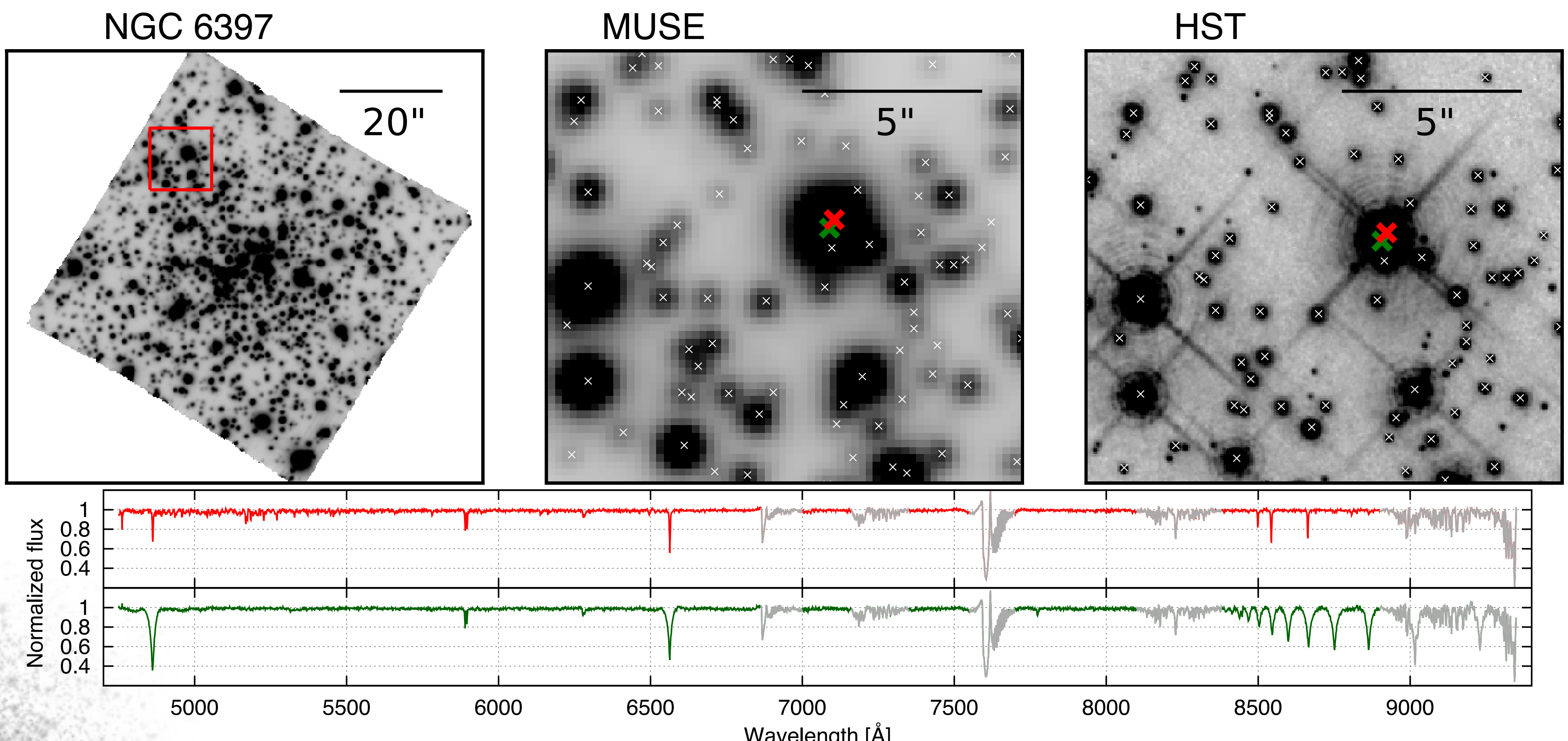


Kamann et al. 2018

The MUSE Globular Cluster Survey

Data Analysis

Spectral extraction (Pampelmuse, Kamann et al. 2013)



Husser et al. 2016

The MUSE Globular Cluster Survey

muse
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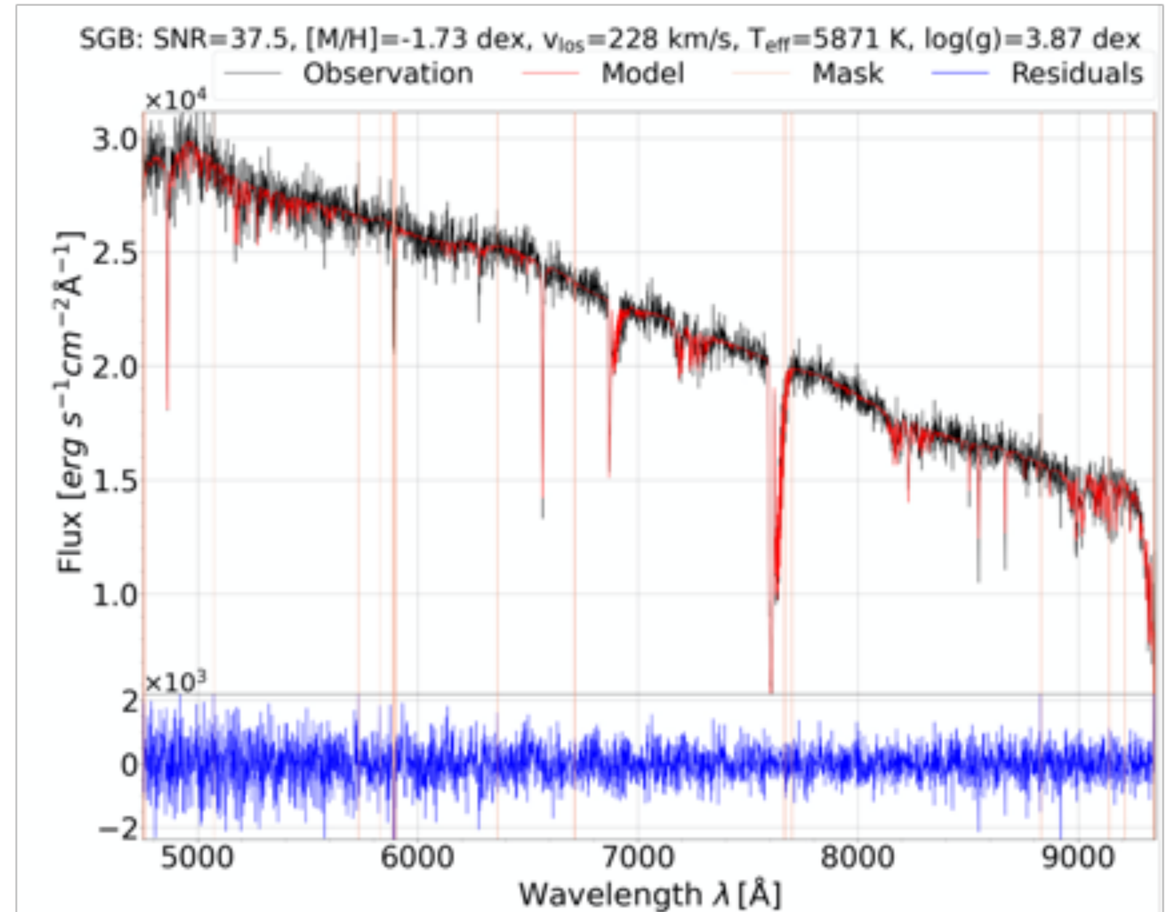
<u>Data Analysis</u>

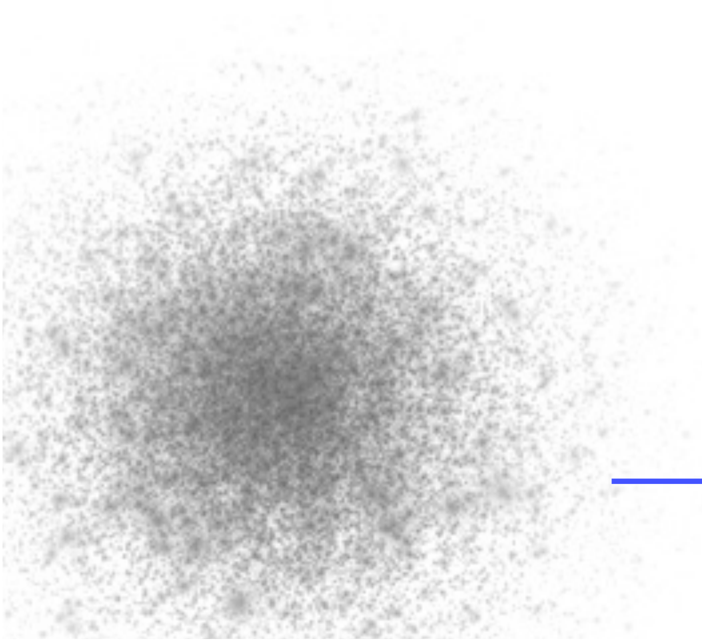
Spectral fitting

- Göttingen Spectral Library of Phoenix model atmospheres (Husser et al. 2013)
- Full spectrum fit with SPEXXY (Husser et al. 2016)
- T_{eff}, metallicity [M/H], V_{rad}, telluric components



(d) Subgiant branch star

Nitschai et al. 2023

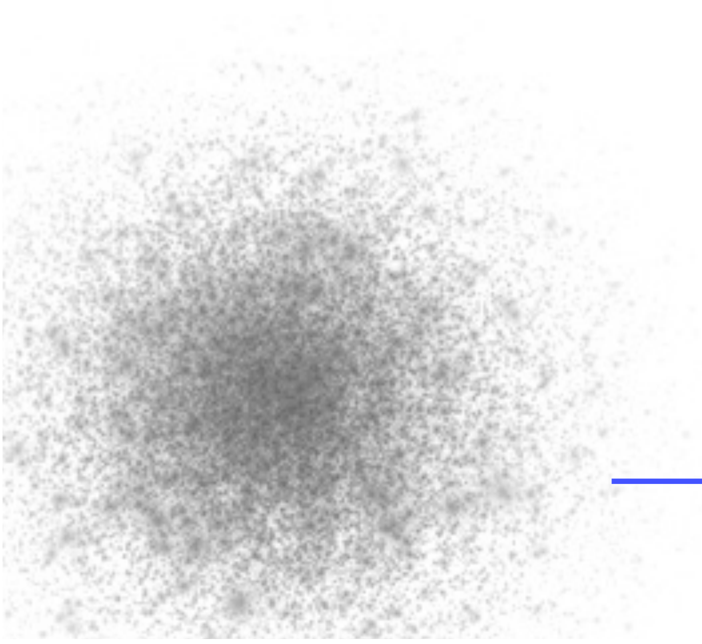


The MUSE Globular Cluster Survey

SCIENCE CASES

1. Radial velocities
   - **Kinematics** (talk by R. Pechetti and poster by E. Balakina)
   - **Binaries** (talks by S. Saracino, S. Dreizler)

2. Chemistry / Stellar parameters
   - **CaT - metallicity** (Husser et al. 2020)
   - **Metallicities in ω Cen** (Latour et al. 2021, Nitschai et al. 2023)
   - **Horizontal Branch Stars** (Latour et al. 2023)
   - **Multiple populations** (Latour et al. 2019, Latour et al. in prep.)



Metallicity spread in P1 stars

The MUSE Globular Cluster Survey

Science Cases

1. Radial velocities
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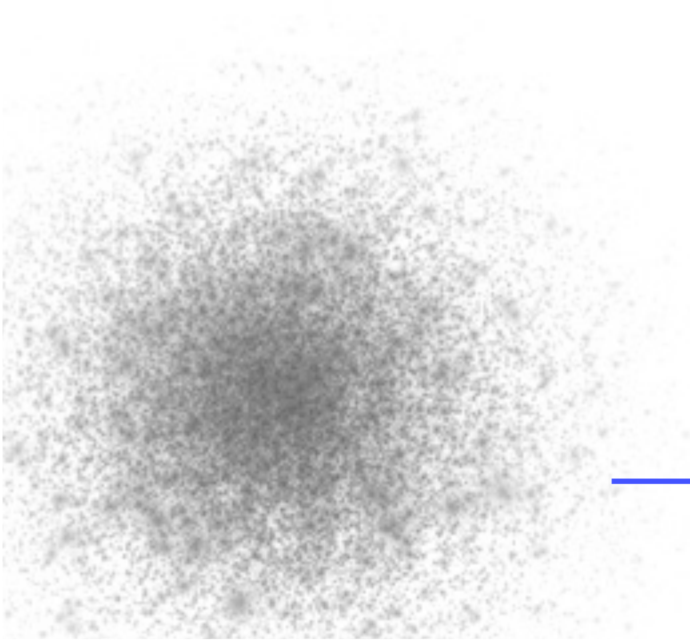
Metallicity spread / dispersion among the P1 stars



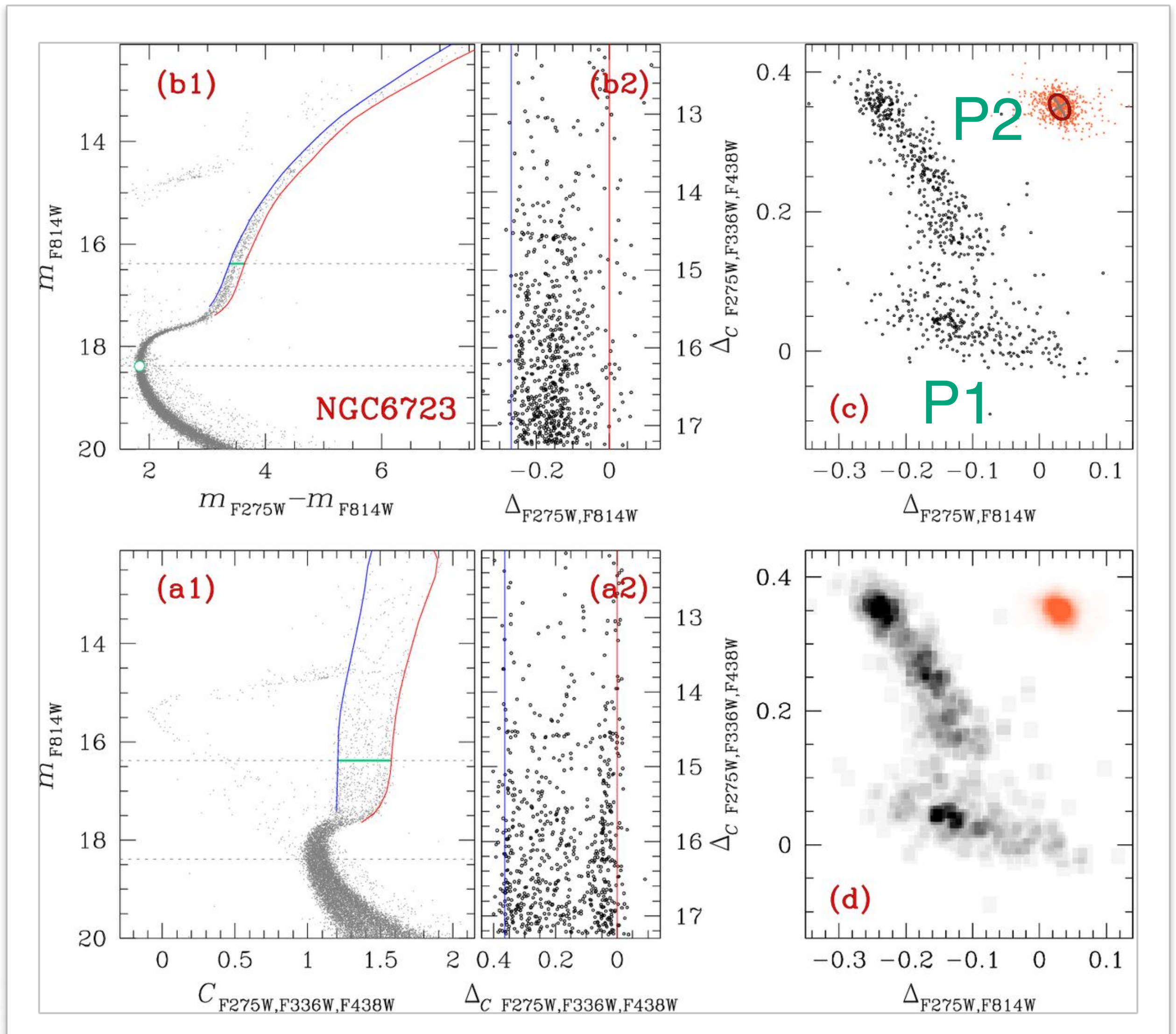
Metallicity spread among the P1 stars

<u>**Main Goals**</u>

1) For the primordial population stars (P1): quantify the metallicity spread in connection with the pseudo-color F275W - F4814W (x-axis of the chromosome map).

2) Determine intrinsic metallicity dispersions for the P1 and P2 stars.

The chromosome maps



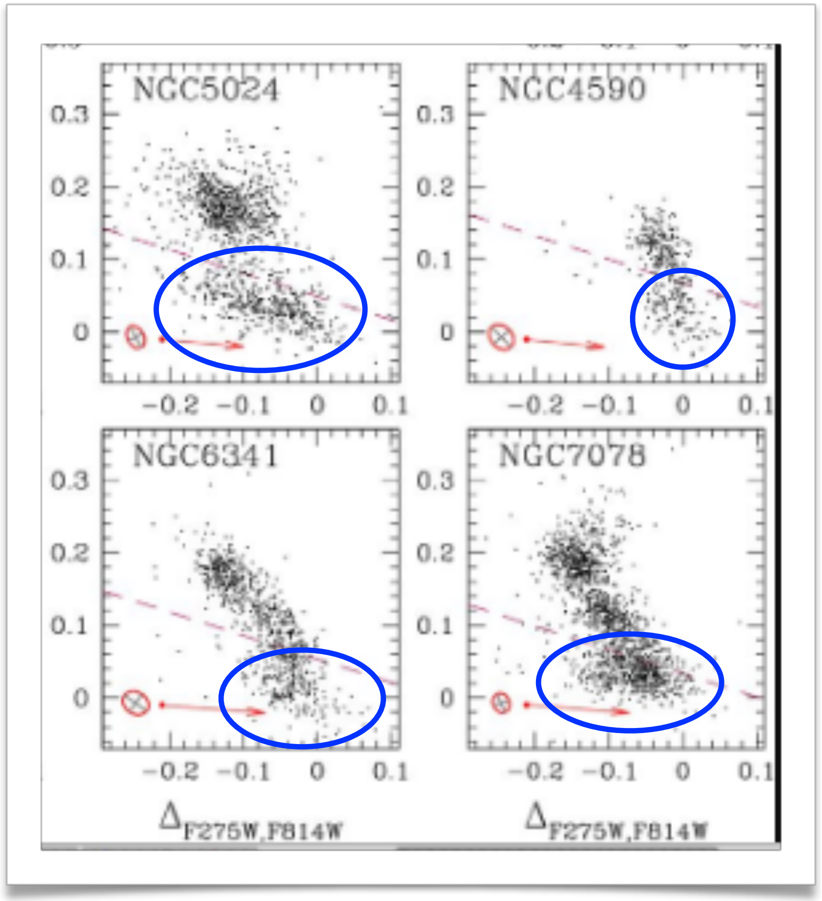
Milone et al. 2017

Metallicity spread in P1 stars

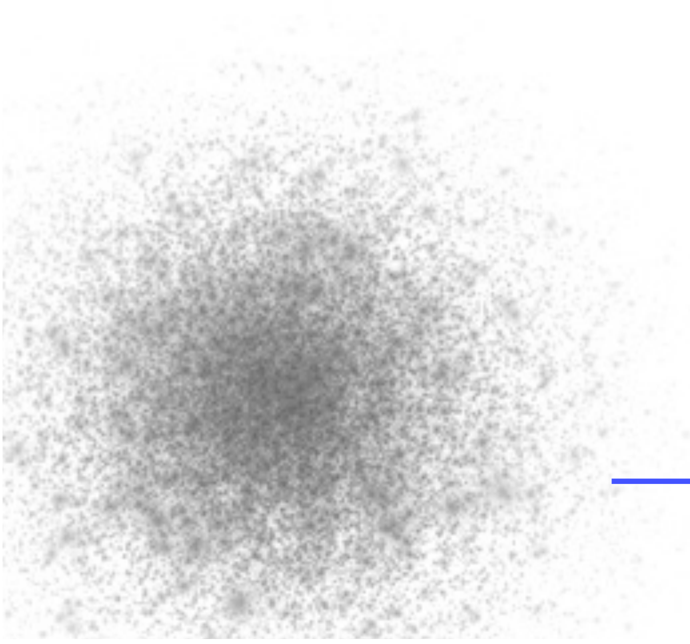
What causes the color spread among the P1 stars?

The P1 stars should be a very homogeneous population.

Iron (metallicity) variations (Lardo et al. 2022)



Milone et al. 2017



Metallicity spread in P1 stars

What causes the color spread among the P1 stars?

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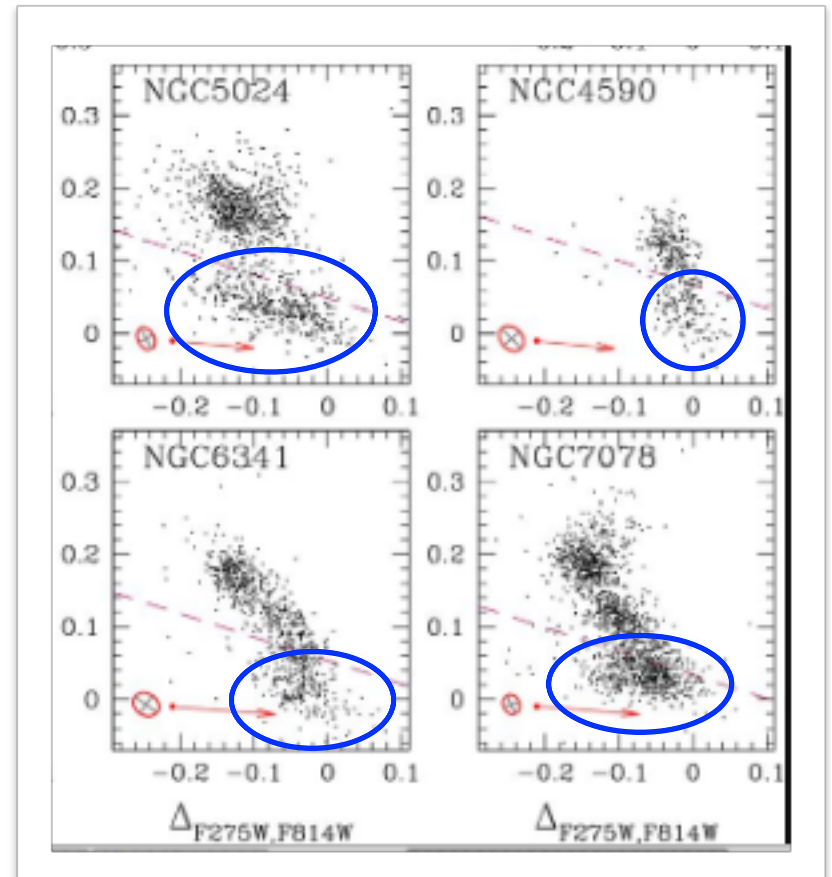
Iron (metallicity) variations (Lardo et al. 2022)

In the literature so far :

- Spectroscopic iron variations in 3 GCs:
  –> NGC 2808, ~0.15 dex, 5 stars (Lardo et al. 2023)
  –> NGC 3201, ~0.10 dex, 12 stars (Marino et al. 2019)
  –> NGC 104 (47 Tuc), 0.14 dex, 21 stars (Marino et al. 2023)
- Photometric metallicity variations:
  –> Sample of 50 GCs, 0.05-0.30 dex (Legnardi et al. 2022)



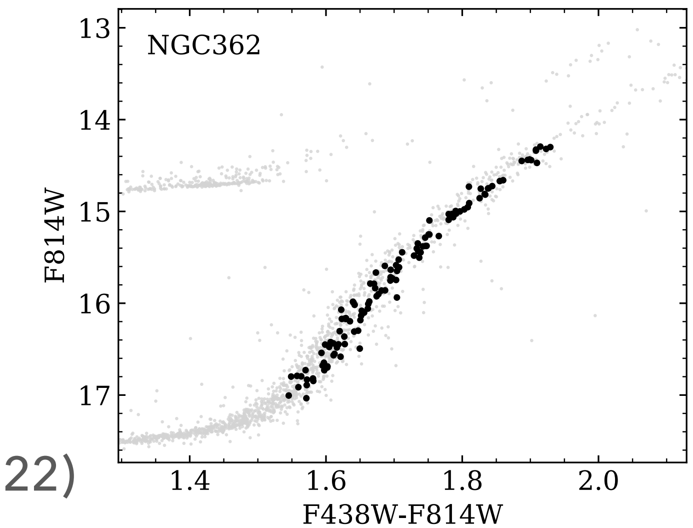
Milone et al. 2017

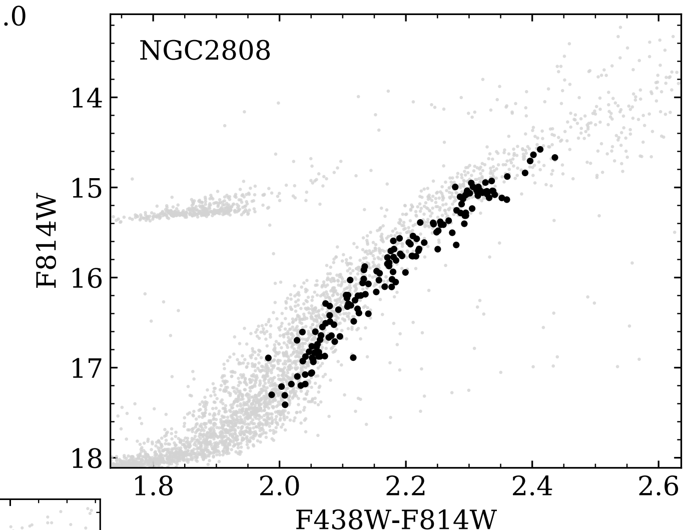
The metallicities of the P1 stars

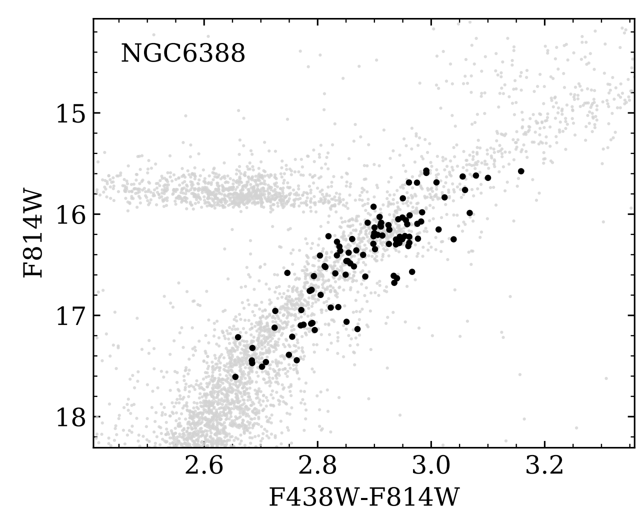
Stars selection

- Average metallicity per star (N>= 3)
  From individual spectra with SNR > 20
- Membership from proper motions (Libralato et al. 2022)
- Exclude the brightest RGBs (3-4 mag)
- Exclude stars with Vrad variability (binaries)
- Consistency between T_{eff} spec and T_{eff} isochrone

Between 30 and 250 P1 stars in 21 GCs.





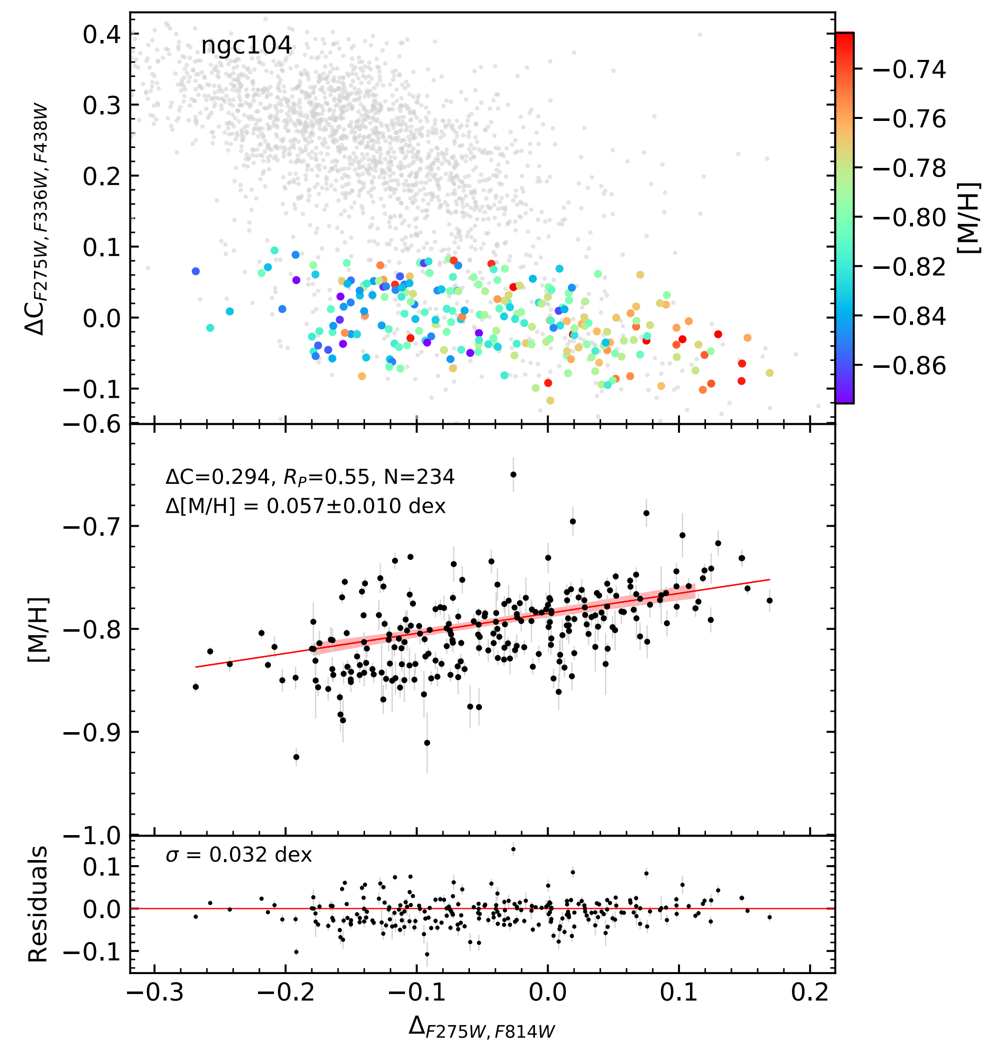


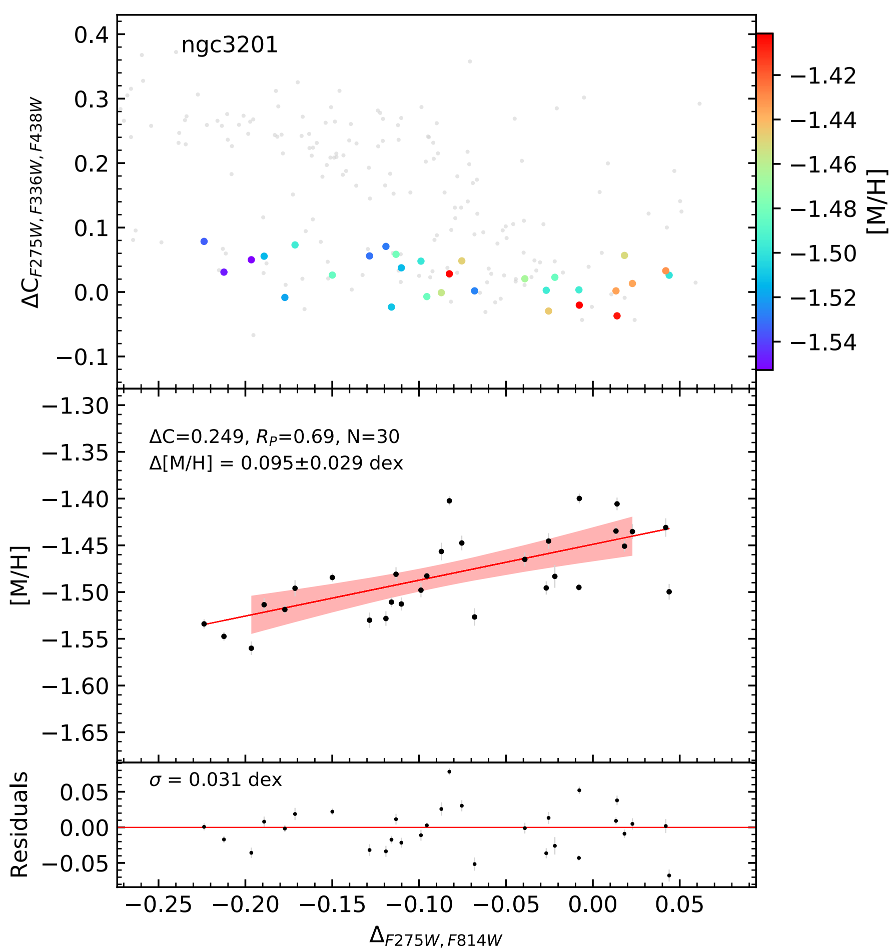
Metallicity spread in P1 stars

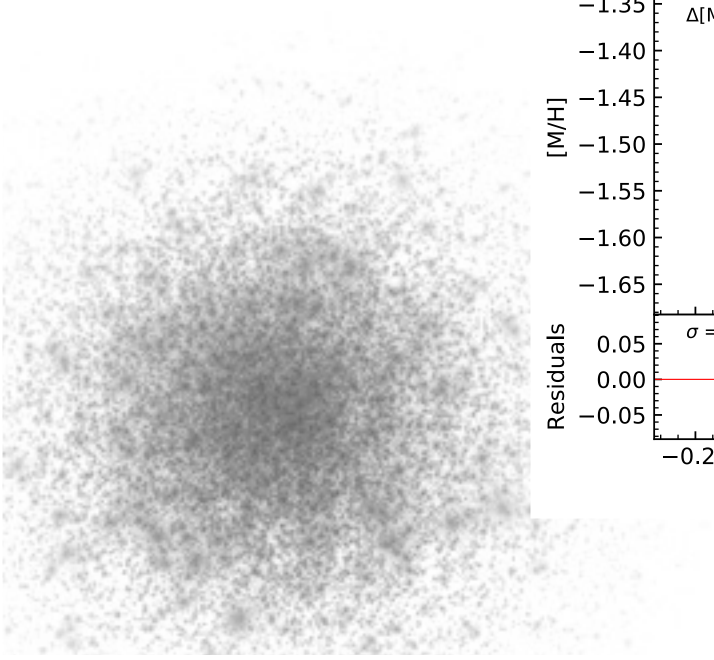
The metallicities of the P1 stars

<u>Metallicity spread of the P1 stars</u>

- Weighted least-square fit
- ΔC from 5th - 95th percentile –> Δ [M/H]
- Intrinsic metallicity dispersion –> σ [M/H]

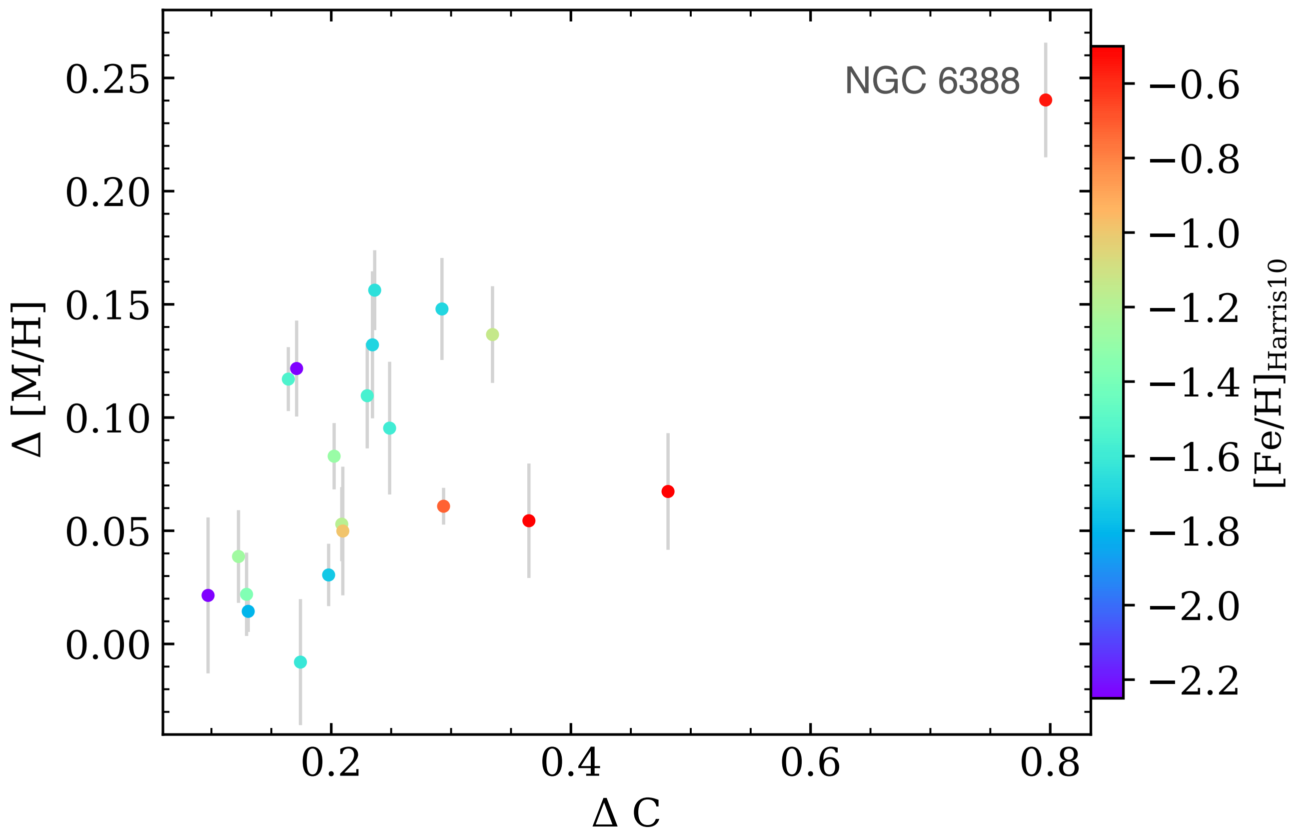






Metallicity spread in P1 stars

The metallicities of the P1 stars



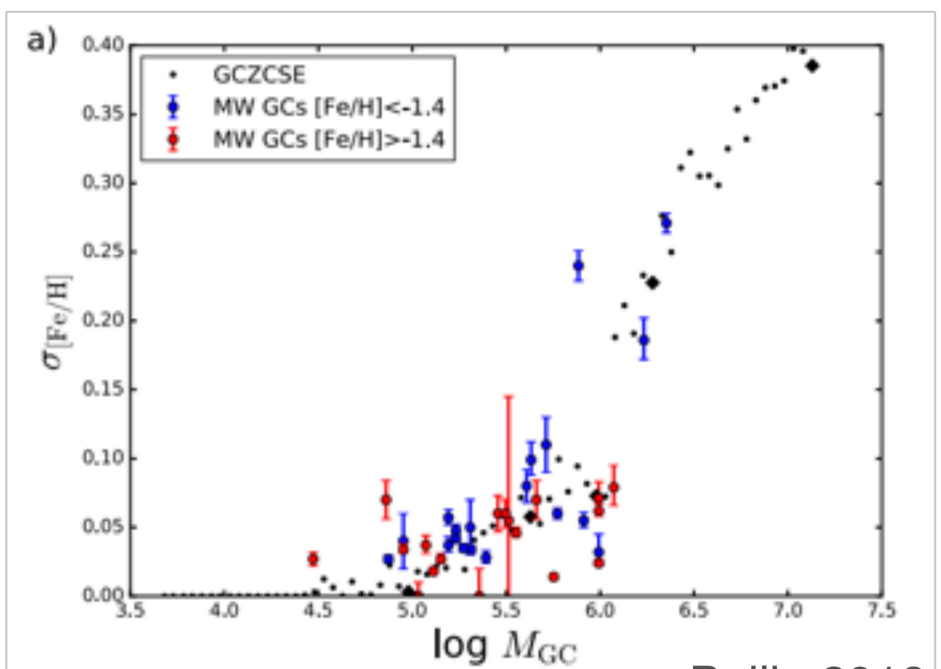
Results

- Significant metallicity spreads in 18 out of 21 GCs.
- Spread between 0.02 - 0.2 dex

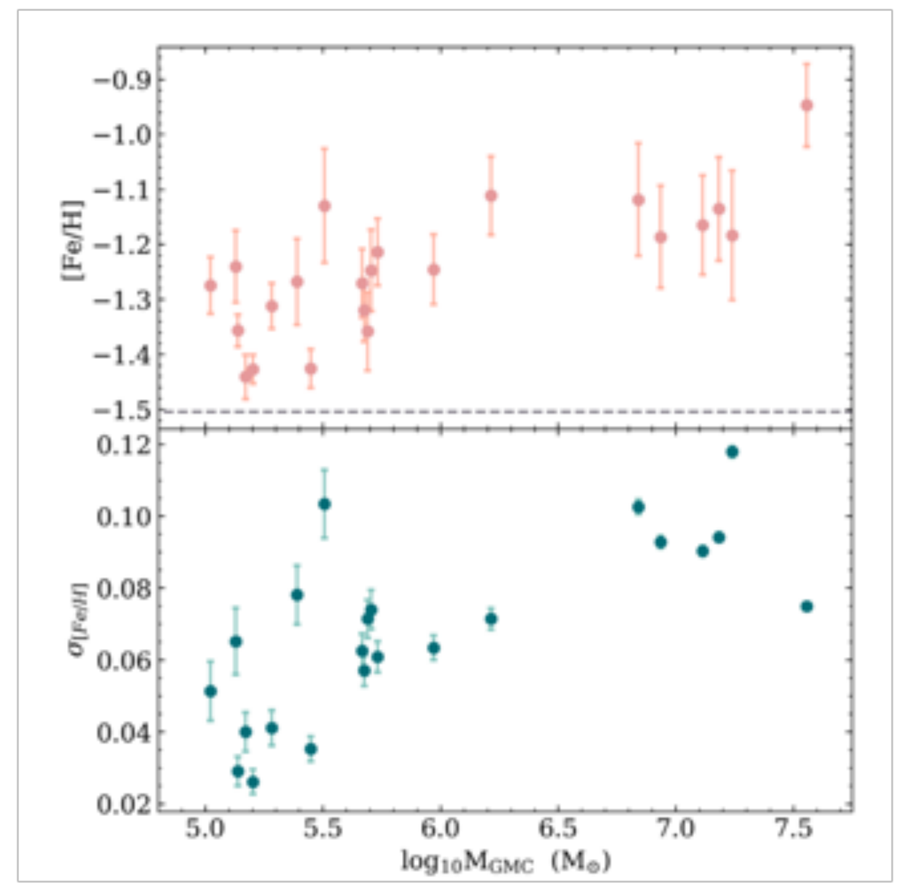
Metallicity spread versus clusters mass

Some theoretical predictions

- Increase in metallicity dispersion with the Globular cluster's mass due to self-enrichment. (Bailin 2018, 2021, McKenzie & Bekki 2022)



Bailin 2018



McKenzie & Bekki 2022

Metallicity spread versus clusters mass

Some theoretical predictions

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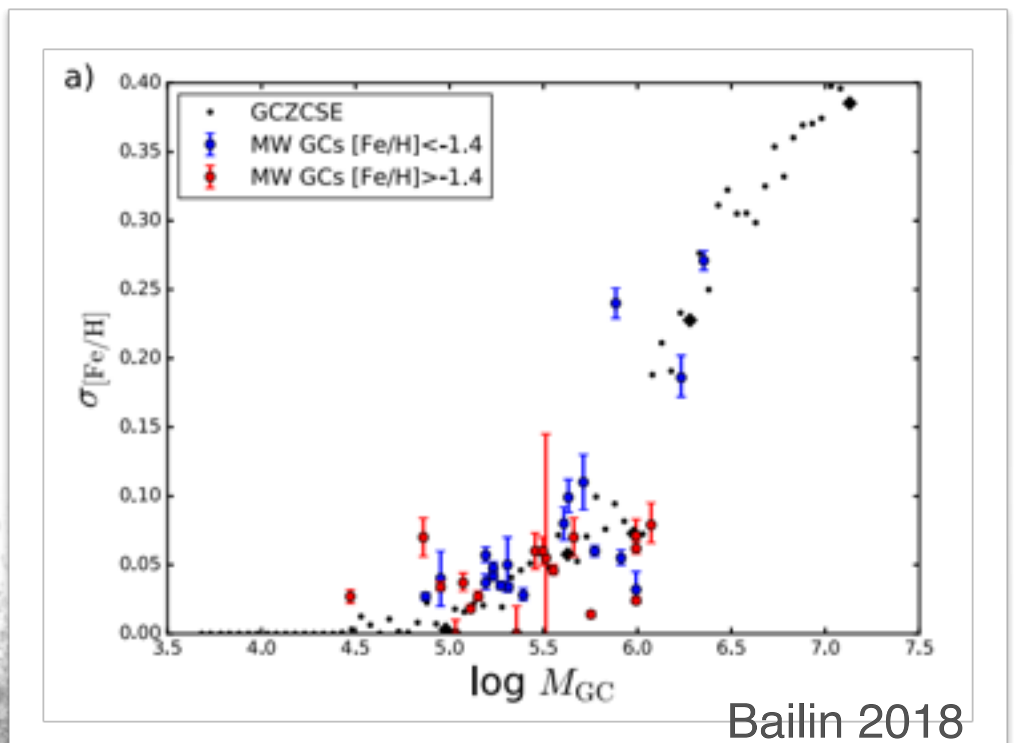
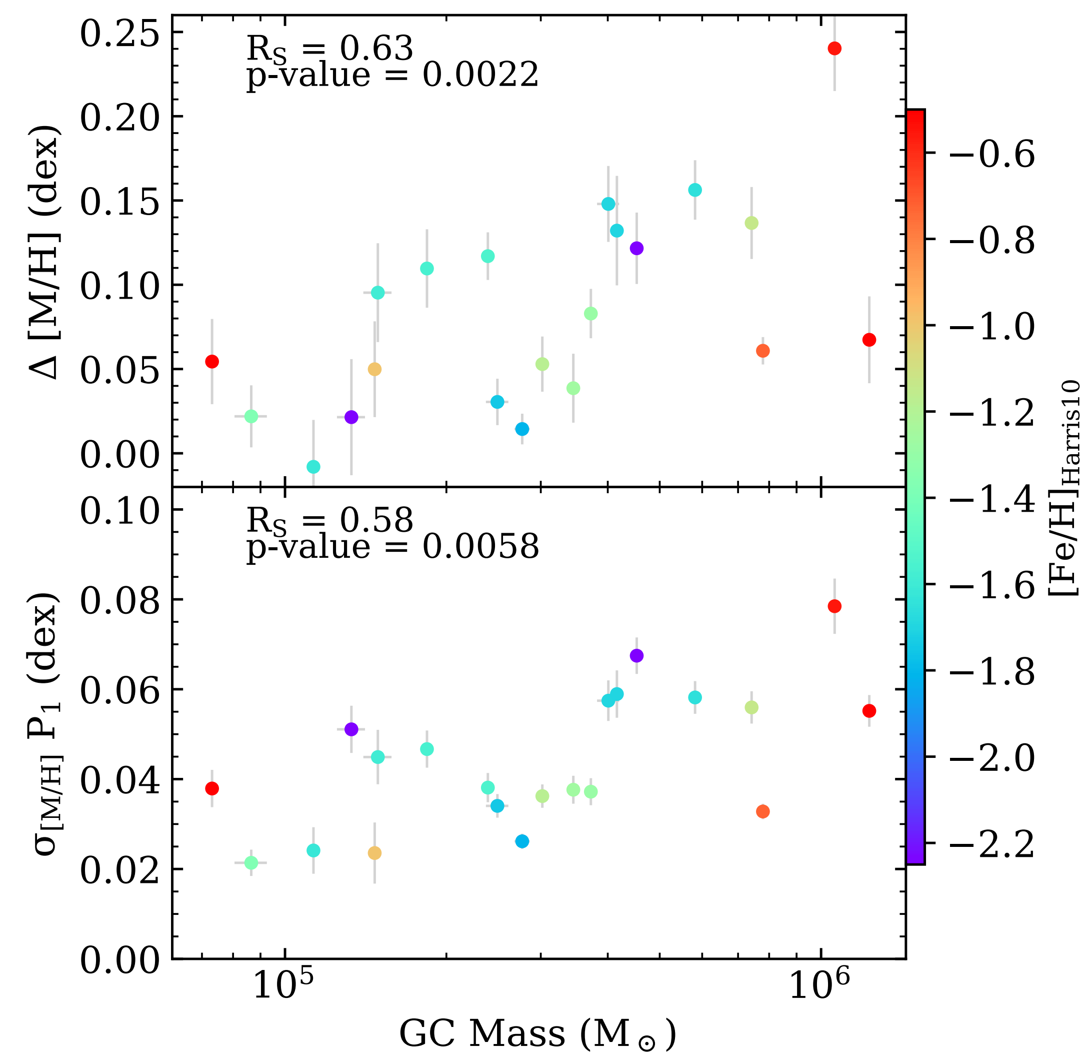


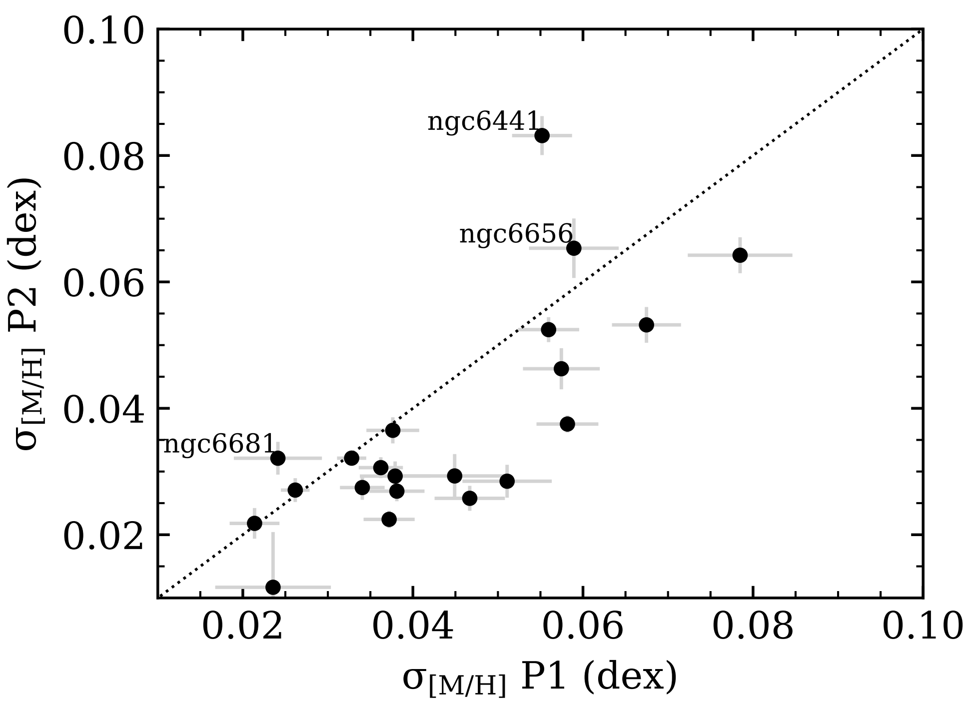


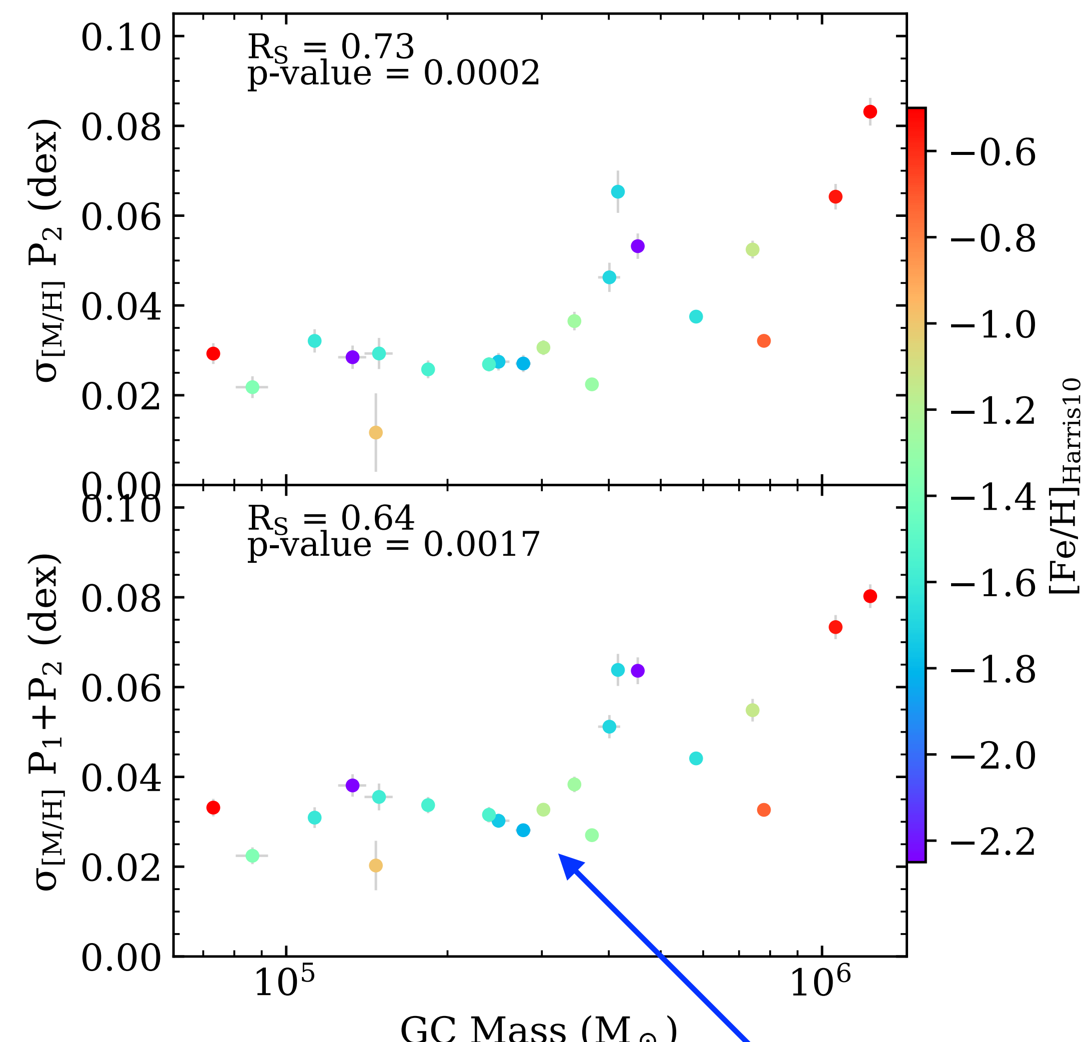
Metallicity spread in P1 stars

Metallicity dispersion P1 vs P2

Results

- The P2 stars have equal or smaller σ than the P1 stars (shown for NGC 6362, NGC 6838, Legnardi et al. 2022)
- σ correlates well with GC mass





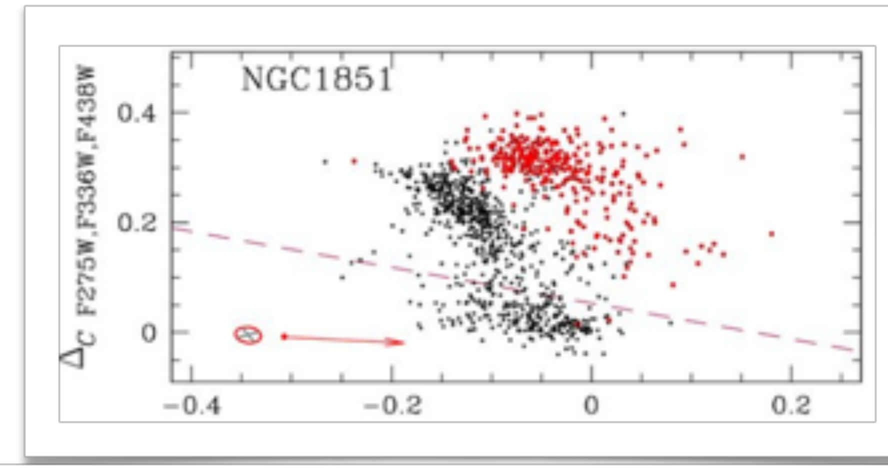
$3x10^5$ Msun

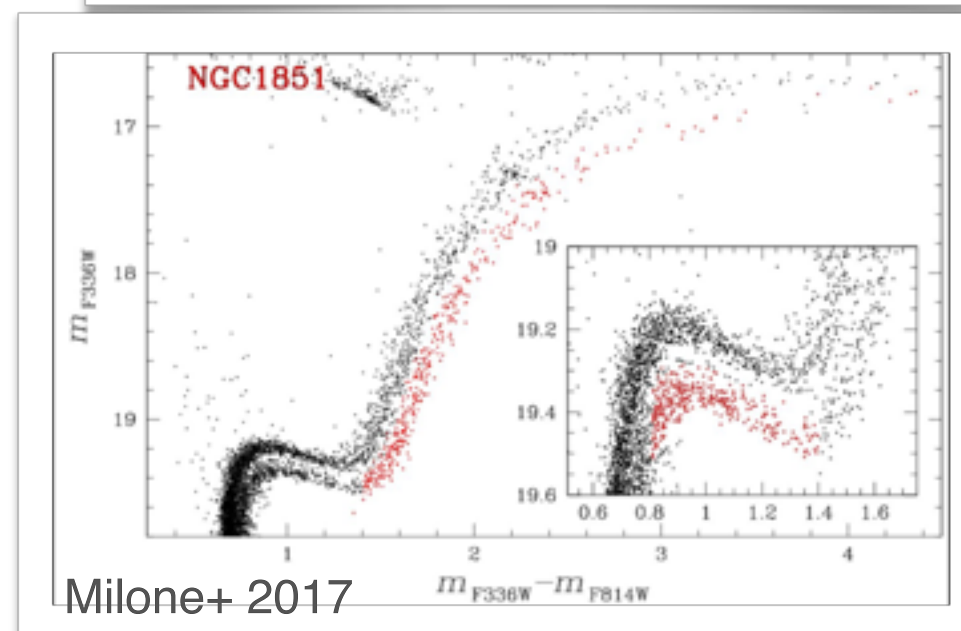
Metallicity spread in P1 stars

Type II GCs

<u>What about the Type II GCs and their "P3" ?</u>

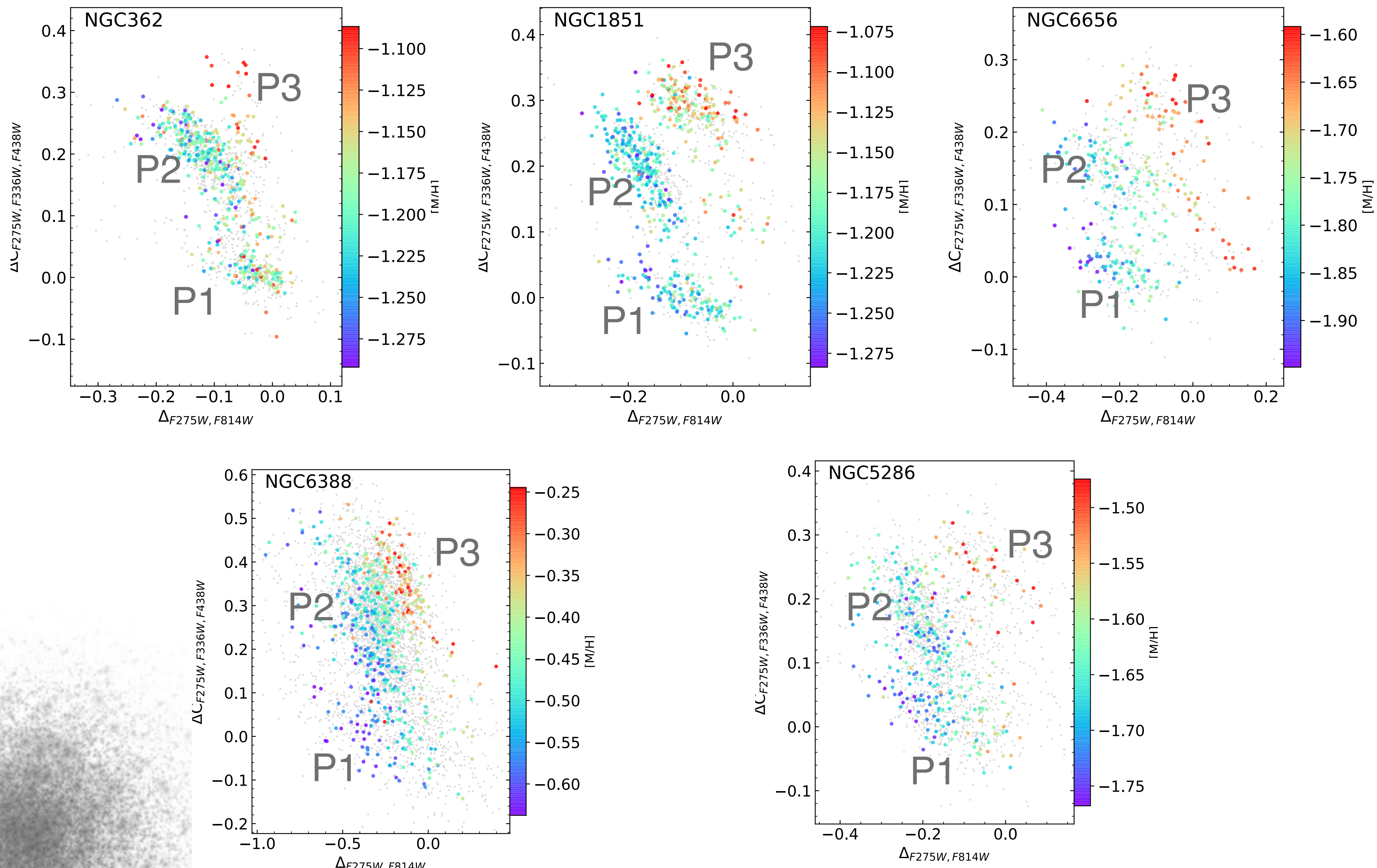
- Type II GCs have an "extra" population (red-RGB, Milone et al. 2017)
- NGC 1851, NGC 6656 (M22), NGC 5286, NGC 362, NGC 7089 (M2), NGC 6388
- P3 stars (in some GCs) have variations in s-elements (Ba), C+N+O, iron.
- The status of some Type II GCs (NGC 6388) and the presence of iron-spread is still debated (Carretta & Bragaglia 2022, 2023, Vargas et al. 2022)





Milone+ 2017

Type II GCs



Metallicity spread in P1 stars

Conclusion

- We measured the correlation between the metallicity of the P1 stars and their F275W-F814W pseudo-color in 21 GCs.
- We measured metallicity spreads Δ [M/H] between 0.02 - 0.20 dex in 18 GCs.
- We find the P2 stars to have a metallicity dispersion smaller or equal to that of the P1 stars.
- We see a correlation between metallicity spread, dispersion and the GC mass, similar to the theoretical expectations.

What next ?

- Investigate the metallicity/abundance differences in the Type II GCs.

Extra Slides

e 1. Parameters of the $\Delta_{F275W,F814W}$ pseudo-color–metallicity relationship and metallicity spread derived among the P1 stars.

Cluster	*N*star	[M/H]err	ΔC	R_P	*p*-value	*a*	*b*	Δ[M/H]
NGC 104	226	0.008	0.29	0.58	7.96e-22	0.21 ± 0.03	-0.787 ± 0.003	0.061 ± 0.008
NGC 1851	127	0.011	0.21	0.40	4.29e-06	0.25 ± 0.10	-1.169 ± 0.011	0.053 ± 0.016
NGC 2808	152	0.018	0.33	0.57	3.35e-14	0.41 ± 0.08	-1.072 ± 0.008	0.137 ± 0.021
NGC 3201	30	0.007	0.25	0.69	2.29e-05	0.38 ± 0.15	-1.449 ± 0.018	0.095 ± 0.029
NGC 362	113	0.017	0.12	0.21	2.54e-02	0.32 ± 0.20	-1.159 ± 0.009	0.039 ± 0.020
NGC 5286	115	0.023	0.29	0.67	3.27e-16	0.51 ± 0.10	-1.585 ± 0.016	0.148 ± 0.023
NGC 5904	113	0.015	0.20	0.63	7.36e-14	0.41 ± 0.09	-1.296 ± 0.006	0.083 ± 0.015
NGC 6093	234	0.025	0.20	0.24	2.02e-04	0.15 ± 0.09	-1.647 ± 0.008	0.030 ± 0.014
NGC 6218	64	0.015	0.13	0.22	7.55e-02	0.17 ± 0.18	-1.319 ± 0.011	0.022 ± 0.018
NGC 6254	83	0.016	0.23	0.68	1.51e-12	0.48 ± 0.13	-1.497 ± 0.009	0.110 ± 0.023
NGC 6362	33	0.025	0.21	0.38	2.76e-02	0.24 ± 0.17	-1.090 ± 0.013	0.050 ± 0.028
NGC 6388	97	0.018	0.80	0.81	1.45e-23	0.30 ± 0.04	-0.471 ± 0.012	0.240 ± 0.025
NGC 6441	148	0.018	0.48	0.35	1.34e-05	0.14 ± 0.07	-0.406 ± 0.010	0.067 ± 0.026
NGC 6541	255	0.017	0.13	0.16	1.12e-02	0.11 ± 0.08	-1.727 ± 0.006	0.014 ± 0.009
NGC 6624	68	0.017	0.36	0.48	3.33e-05	0.15 ± 0.09	-0.761 ± 0.013	0.054 ± 0.025
NGC 6656	72	0.014	0.23	0.55	5.14e-07	0.56 ± 0.17	-1.715 ± 0.035	0.132 ± 0.032
NGC 6681	38	0.024	0.17	0.02	8.99e-01	-0.05 ± 0.22	-1.546 ± 0.014	-0.008 ± 0.028
NGC 6752	92	0.012	0.16	0.72	5.50e-16	0.71 ± 0.11	-1.499 ± 0.006	0.117 ± 0.014
NGC 7078	220	0.033	0.17	0.47	2.86e-13	0.71 ± 0.15	-2.195 ± 0.010	0.122 ± 0.021
NGC 7089	171	0.019	0.24	0.70	1.23e-26	0.66 ± 0.09	-1.484 ± 0.008	0.156 ± 0.018
NGC 7099	67	0.021	0.10	0.05	6.63e-01	0.22 ± 0.45	-2.172 ± 0.020	0.021 ± 0.034

Metallicity spread in P1 stars

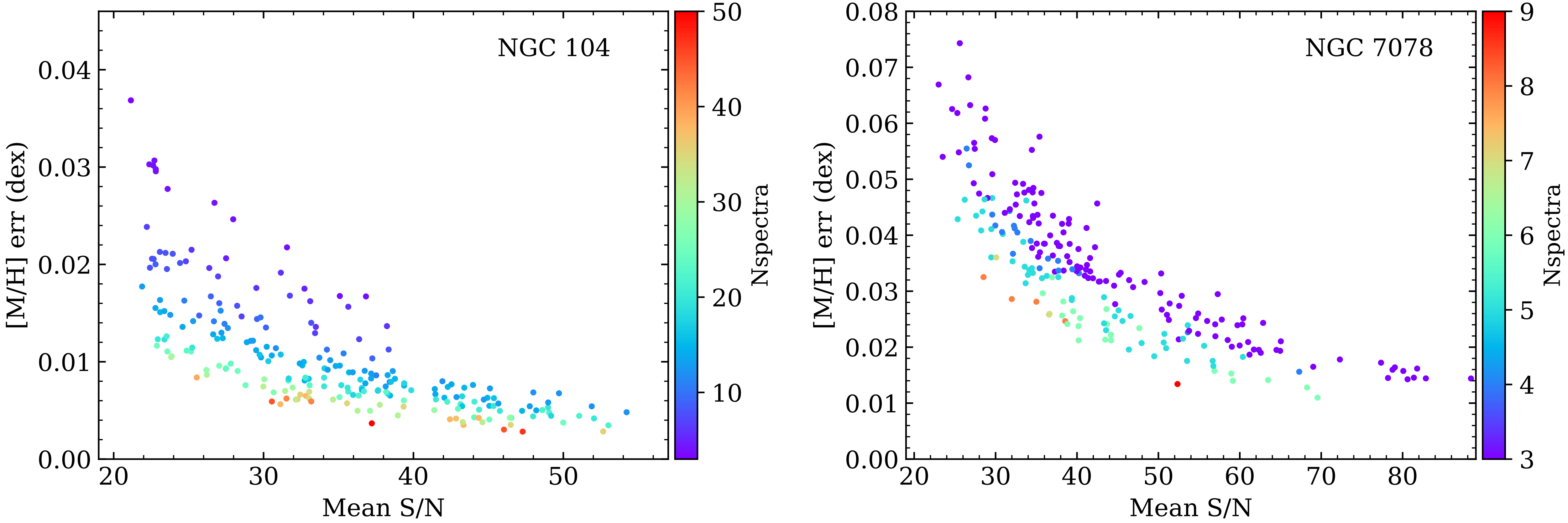
Extra Slides

Table 2. Mean metallicity and dispersion measured in the P1 and P2 stars with their 1σ uncertainties.

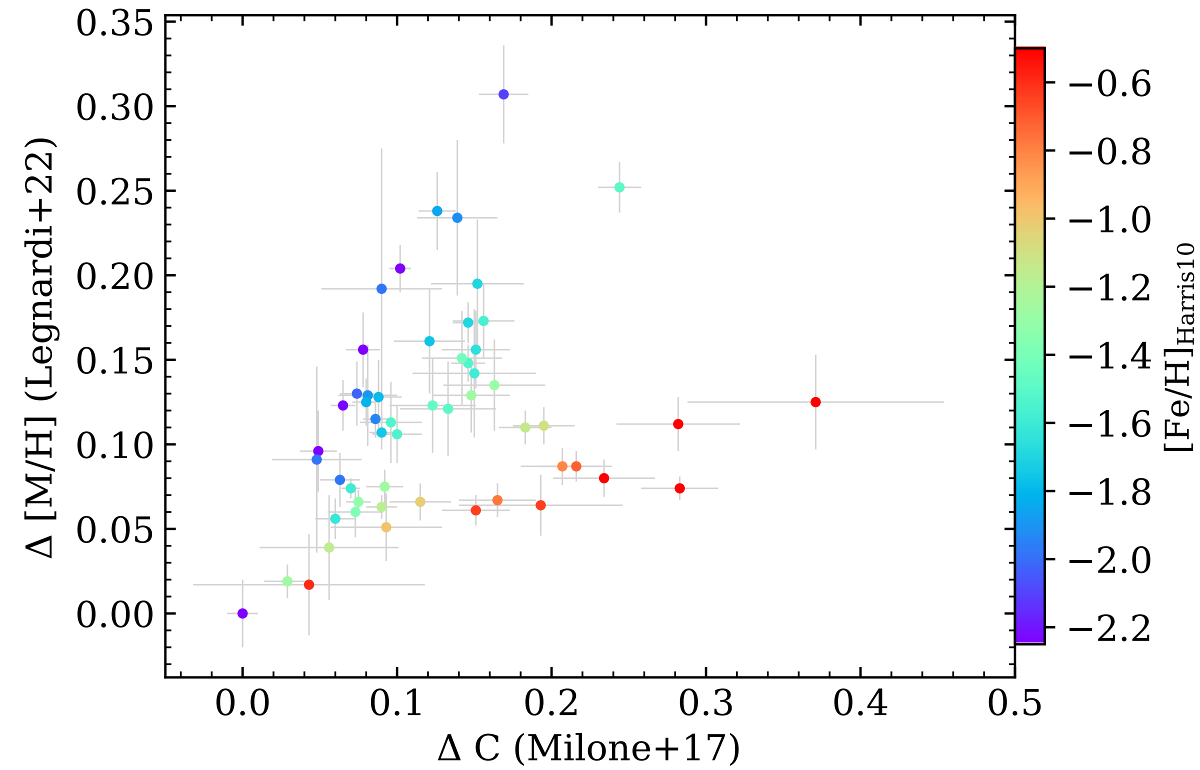
Cluster	*N*stars	Mean [M/H] P1	σ [M/H]	*N*stars	Mean [M/H] P2	σ [M/H]	Mean [M/H] P1+P2	σ [M/H]
NGC 104	226	-0.802 ± 0.002	0.033 ± 0.002	916	-0.802 ± 0.001	0.032 ± 0.001	-0.802 ± 0.001	0.033 ± 0.001
NGC 1851	127	-1.207 ± 0.003	0.036 ± 0.003	239	-1.210 ± 0.002	0.031 ± 0.002	-1.209 ± 0.002	0.033 ± 0.001
NGC 2808	152	-1.108 ± 0.005	0.056 ± 0.004	483	-1.096 ± 0.002	0.052 ± 0.002	-1.105 ± 0.003	0.055 ± 0.003
NGC 3201	30	-1.482 ± 0.008	0.045 ± 0.006	47	-1.474 ± 0.004	0.029 ± 0.003	-1.477 ± 0.004	0.036 ± 0.003
NGC 362	113	-1.178 ± 0.004	0.038 ± 0.003	281	-1.195 ± 0.002	0.037 ± 0.002	-1.191 ± 0.002	0.038 ± 0.002
NGC 5286	115	-1.663 ± 0.006	0.057 ± 0.005	174	-1.654 ± 0.004	0.046 ± 0.003	-1.658 ± 0.003	0.051 ± 0.003
NGC 5904	113	-1.307 ± 0.004	0.037 ± 0.003	355	-1.315 ± 0.001	0.022 ± 0.001	-1.313 ± 0.001	0.027 ± 0.001
NGC 6093	234	-1.661 ± 0.003	0.034 ± 0.003	324	-1.662 ± 0.002	0.027 ± 0.002	-1.662 ± 0.002	0.030 ± 0.002
NGC 6218	64	-1.330 ± 0.003	0.021 ± 0.003	97	-1.345 ± 0.003	0.022 ± 0.002	-1.339 ± 0.002	0.022 ± 0.002
NGC 6254	83	-1.519 ± 0.005	0.047 ± 0.004	171	-1.524 ± 0.002	0.026 ± 0.002	-1.523 ± 0.002	0.034 ± 0.002
NGC 6362	33	-1.101 ± 0.006	0.024 ± 0.007	18	-1.119 ± 0.007	0.012 ± 0.009	-1.108 ± 0.005	0.020 ± 0.006
NGC 6388	97	-0.541 ± 0.008	0.078 ± 0.006	312	-0.498 ± 0.004	0.064 ± 0.003	-0.507 ± 0.004	0.073 ± 0.003
NGC 6441	148	-0.433 ± 0.005	0.055 ± 0.004	374	-0.378 ± 0.004	0.083 ± 0.003	-0.394 ± 0.004	0.080 ± 0.003
NGC 6541	255	-1.736 ± 0.002	0.026 ± 0.002	242	-1.743 ± 0.002	0.027 ± 0.002	-1.740 ± 0.001	0.028 ± 0.001
NGC 6624	68	-0.786 ± 0.005	0.038 ± 0.004	175	-0.804 ± 0.003	0.029 ± 0.002	-0.799 ± 0.002	0.033 ± 0.002
NGC 6656	72	-1.831 ± 0.007	0.059 ± 0.005	107	-1.806 ± 0.006	0.065 ± 0.005	-1.816 ± 0.005	0.064 ± 0.004
NGC 6681	38	-1.547 ± 0.005	0.024 ± 0.005	180	-1.558 ± 0.003	0.032 ± 0.003	-1.556 ± 0.003	0.031 ± 0.002
NGC 6752	92	-1.518 ± 0.004	0.038 ± 0.003	220	-1.514 ± 0.002	0.027 ± 0.002	-1.517 ± 0.002	0.032 ± 0.002
NGC 7078	220	-2.242 ± 0.005	0.067 ± 0.004	329	-2.200 ± 0.003	0.053 ± 0.003	-2.237 ± 0.004	0.064 ± 0.003
NGC 7089	171	-1.515 ± 0.005	0.058 ± 0.004	670	-1.526 ± 0.002	0.038 ± 0.001	-1.524 ± 0.002	0.044 ± 0.001
NGC 7099	67	-2.184 ± 0.007	0.051 ± 0.005	150	-2.167 ± 0.003	0.028 ± 0.003	-2.172 ± 0.003	0.038 ± 0.002

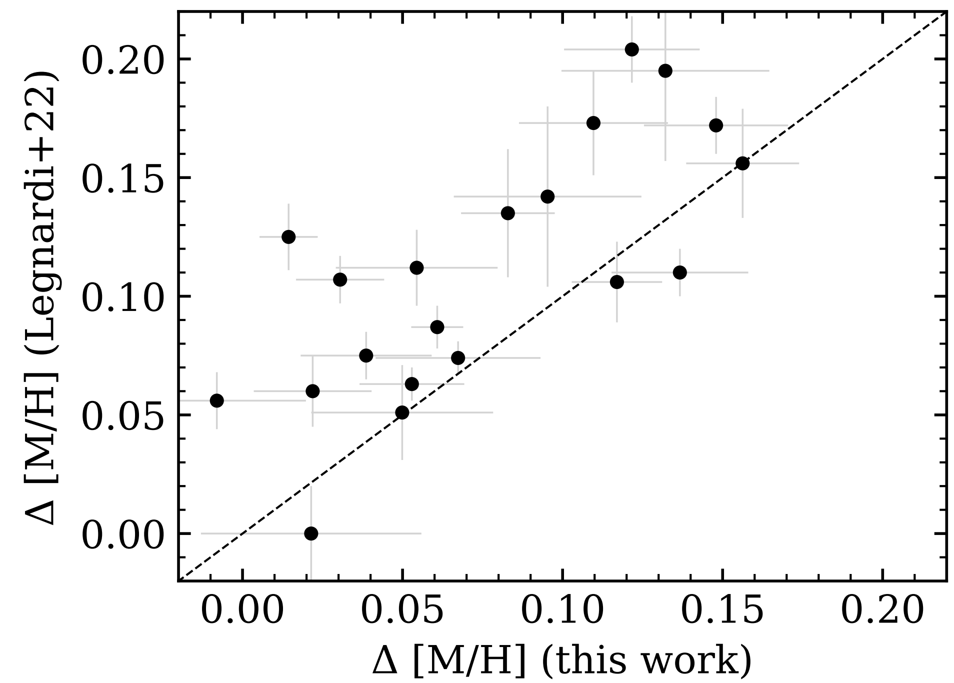
Metallicity spread in P1 stars

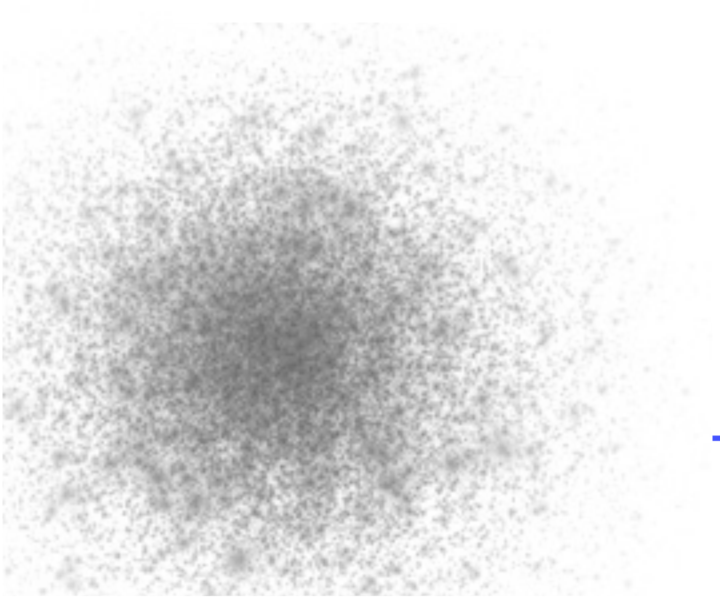
Extra Slides



Extra Slides

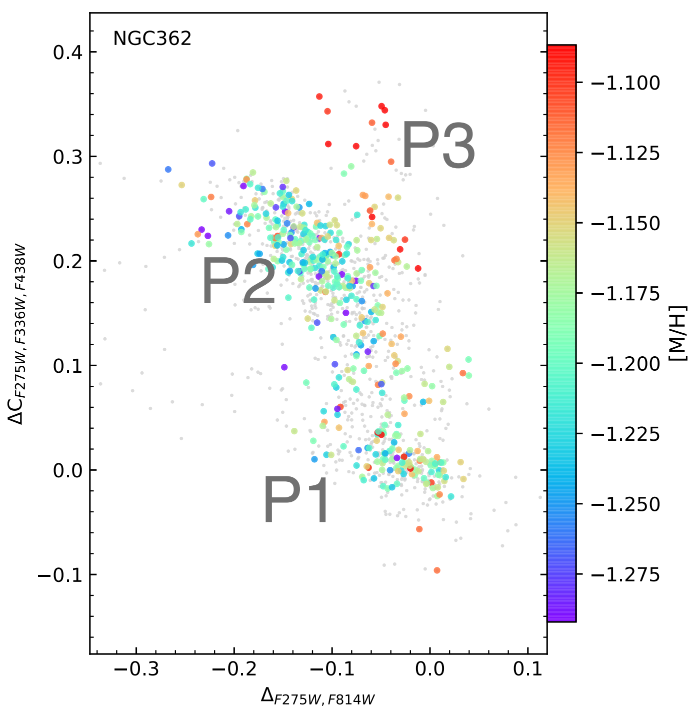


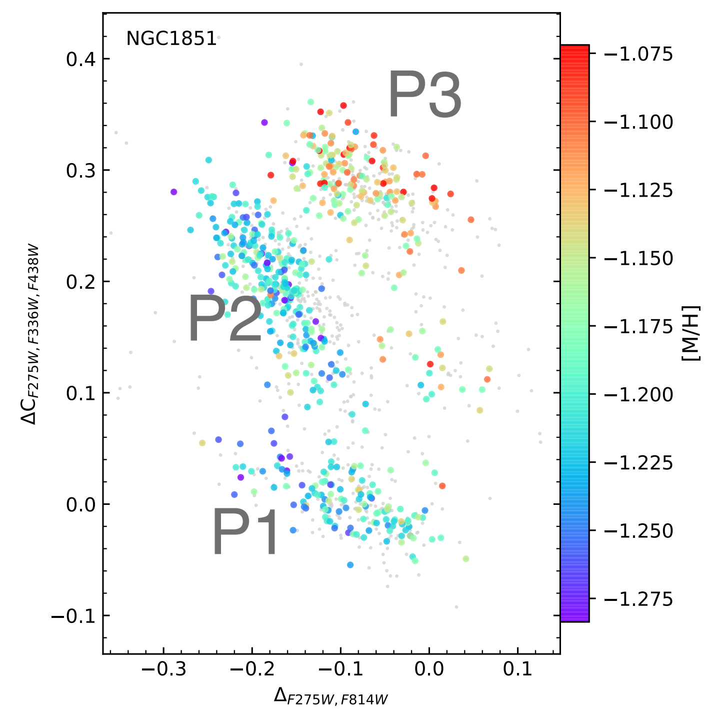


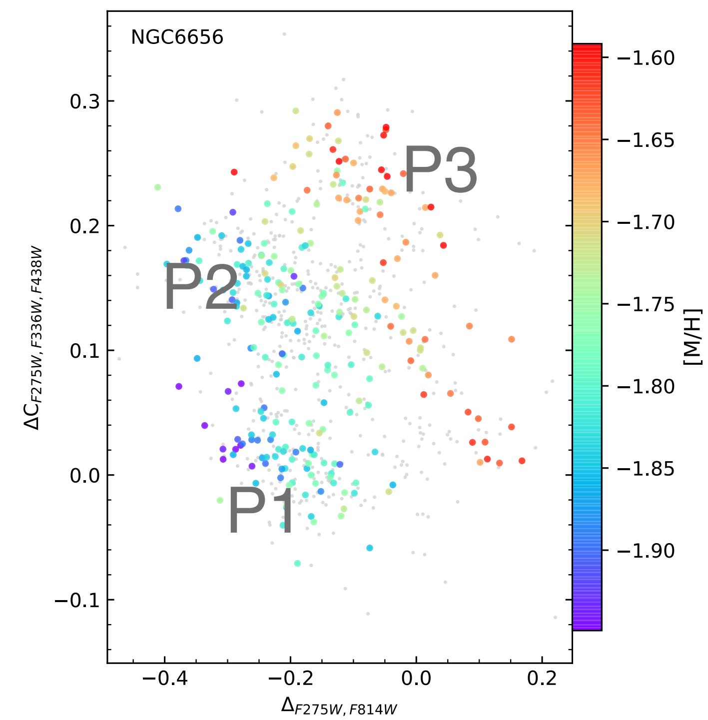


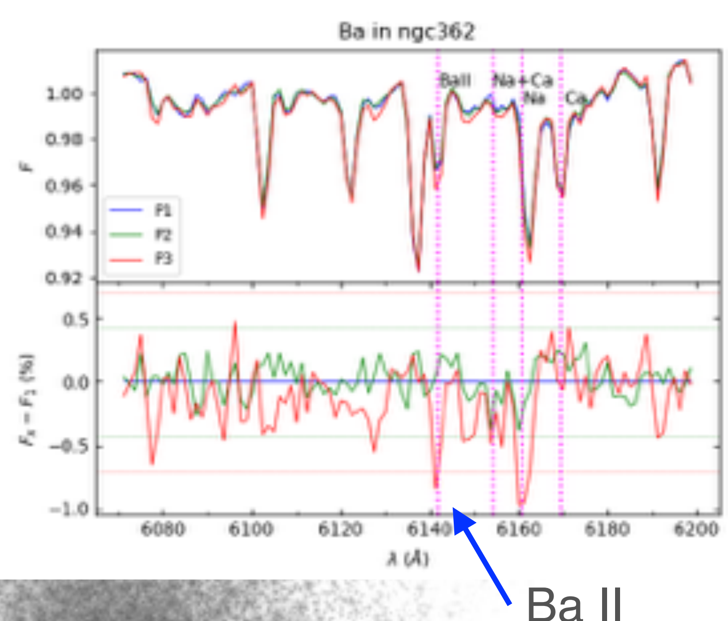
Metallicity spread in P1 stars

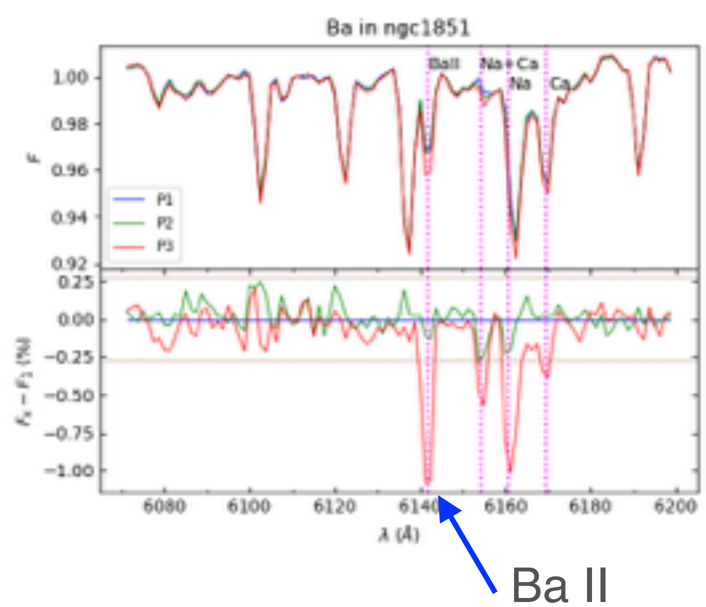
Type II GCs

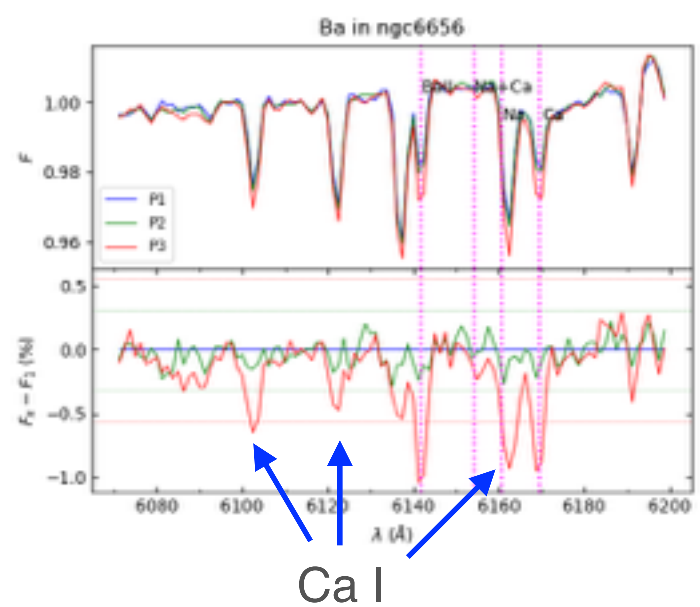












Metallicity spread in P1 stars