Chemical Enrichment History of Galaxies

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American University of Sharjah

Some geography first .. ☺

Sharjah - UAE

Outline

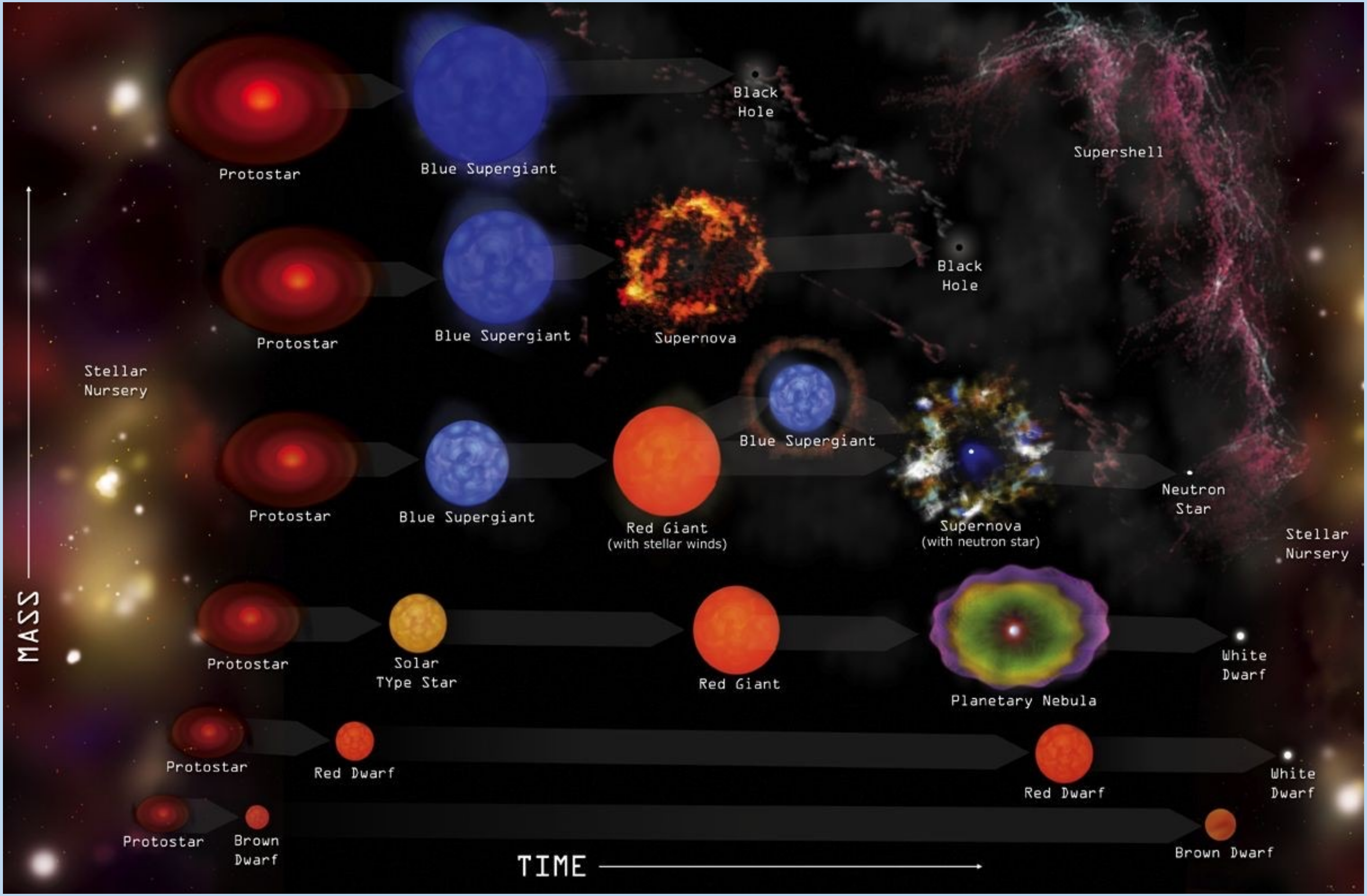
- Introduction and motivation

- Star Clusters

- Results from resolved data (examples from MW)
  a. VDBH222
  b. Alicante-8 (not a cluster anymore!)

- Results from unresolved data (examples from LMC)
  a. Discussion about the precision of the method
  b. First study to obtain CEH using integrated spectra
  c. Detailed abundances
  d. ongoing work

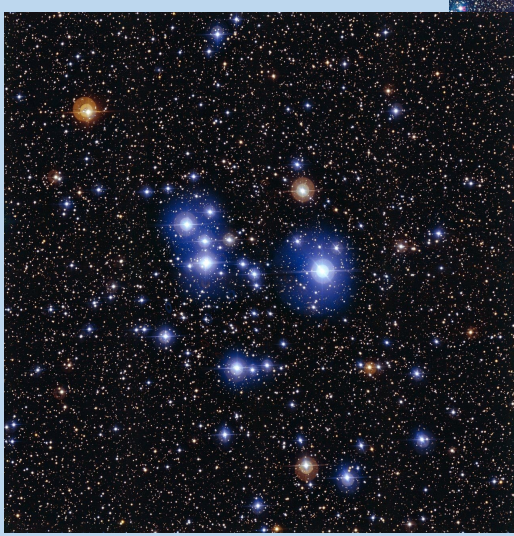
What do we know about the chemical composition of the universe?



Chemical enrichment history requires knowing:

Chemical Composition + Age

This is done by studying Star Cluster



There are two ways to study star clusters:

A. Using resolved data
B. Using integrated spectra (or photometry)

Part 1:

A. Using resolved data
B. Using integrated spectra (or photometry)

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Analysis of Red Supergiants in VDBH 222

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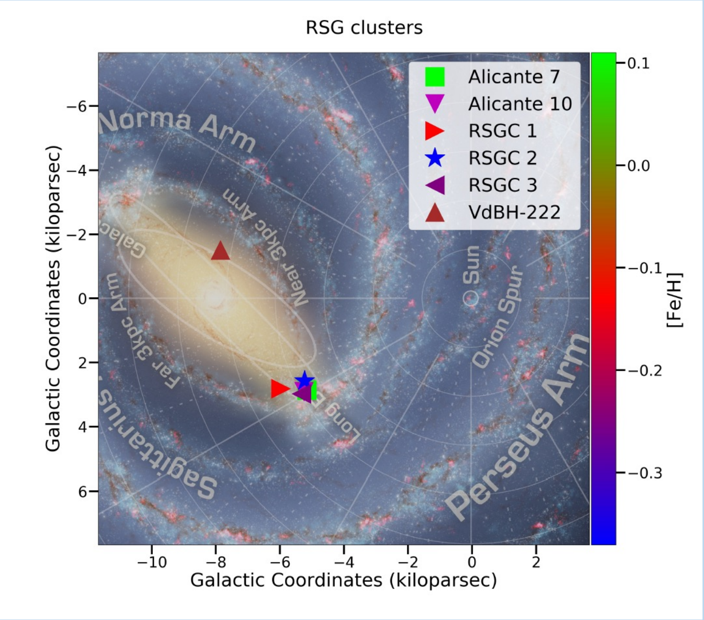
We observed RSGs in the newly discovered Young Massive Clusters that host dozens of RSGs in the inner Milky Way.

These clusters are ideal for studying the most recent and violent star formation events in the inner Galaxy.



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Analysis of Red Supergiants in VDBH 222

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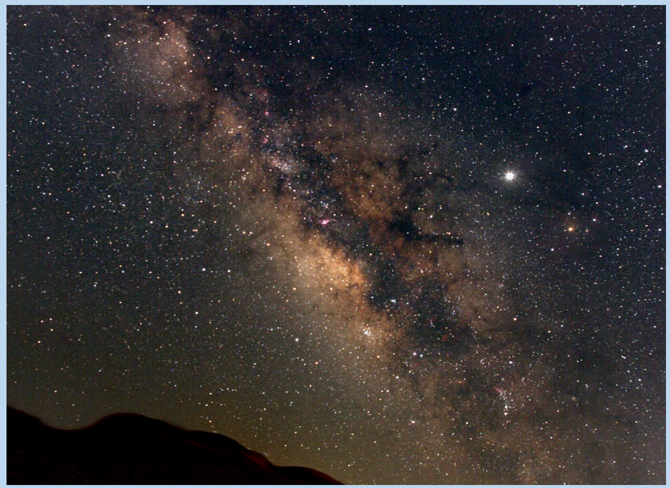


Due to large distance, clusters near the center of the galaxy can only be identified by the presence of very bright red supergiants.

- We obtained IR spectra for six RSGs in VDBH222 with VLT-Xshooter.

ESO programme number 0103.D-0881(A) (PI R. Asad)

The kinematic parameters and chemical abundances were derived by comparing the observed spectra with synthetic spectra generated by the Payne spectral model through a $\chi 2$ minimization.

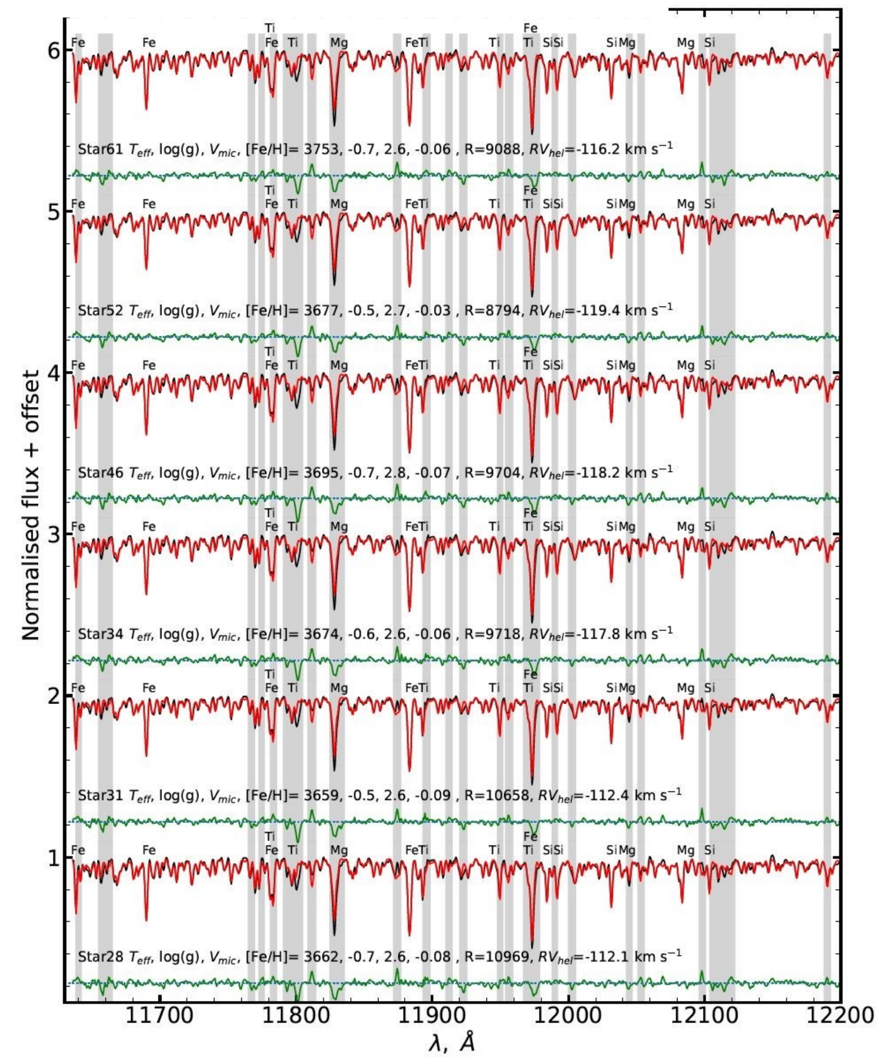
The NLTE spectral grids were computed by Bergemann et al. (2015), using NLTE departures for Si, Ti, and Fe lines from Bergemann et al. (2012a, 2012b, 2013). This model is similar to the model used in Davies et al. (2015).

Table 1
Parameters and Abundances of the RSG Sample

ID	Res.	RV (km s^{-1})	R.A.	Decl.	T_{eff} (K)	log(g)	[Fe/H]	ξ	S/N
Star28	10969	−112.1	259.70310	−38.29149	3662 ± 21	−0.7 ± 0.1	−0.08 ± 0.04	2.6 ± 0.1	291
Star31	10658	−112.4	259.70198	−38.28356	3659 ± 27	−0.5 ± 0.1	−0.09 ± 0.06	2.6 ± 0.1	261
Star34	9718	−117.8	259.68680	−38.29786	3674 ± 21	−0.6 ± 0.1	−0.06 ± 0.04	2.6 ± 0.1	118
Star46	9704	−118.2	259.69237	−38.27003	3695 ± 21	−0.7 ± 0.1	−0.07 ± 0.05	2.8 ± 0.1	244
Star52	8794	−119.4	259.70270	−38.30095	3677 ± 21	−0.5 ± 0.1	−0.03 ± 0.04	2.7 ± 0.1	251
Star61	9088	−116.2	259.69552	−38.28856	3753 ± 22	−0.7 ± 0.1	−0.06 ± 0.04	2.6 ± 0.1	234
Mean Value	⋯	−116.5 ± 3	⋯	⋯	3686 ± 35	−0.6 ± 0.1	−0.07 ± 0.02	2.7 ± 0.1	233

We obtained the first [Fe/H] measurement for VdBH 222

[Fe/H] = -0.07+/-0.02
Age = 16 Myr



Asa'd et al. (2020)

We aimed to apply the same method on Alicante-8 but…

TO BE OR NOT TO BE: ALICANTE-8, A CLUSTER OR NOT?

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ABSTRACT

Recent surveys have uncovered new Young Massive Clusters that host dozens of red supergiants (RSGs) near the inner Galaxy. However, many of them are still not fully studied. Using Very Large Telescope VLT/X-shooter near infrared (NIR) spectra, we present the first radial velocity analysis for the putative members of the candidate RSG cluster Alicante-8. Our results show a large dispersion of radial velocities among the candidate member stars, indicating that Alicante-8 does not seem to be a real cluster, unlike Alicante-7 and Alicante-10, which are confirmed by the distribution of the radial velocities of their RSG members. Measuring the spectral indices reveals that the assumption that the candidate stars are RSGs was incorrect, leading to the misclassification of Alicante-8 as a candidate RSG cluster. Our results imply that spectral classification based on the widely used CO band at 2.3 micron alone is not a sufficient criterion, because both red giants and RSGs can attain similar CO equivalent widths,and that spectroscopic radial velocities are needed in order to confirm unambiguously the cluster membership.

Asa'd et al. 2023 (accepted in AJ)

Analysis

Table 1. Positions and radial velocities in km/s of the target star
The signal-to-noise ratios (S/Ns)of the spectra are also listed.

Cluster/star	RA (J2000)	DEC (J2000)	RV[1]	RV[2]	S/N
Alicante-7					
S14	18:44:27.00	-03:29:42.00	85±0.6	84	216
S43	18:44:29.57	-03:30:04.68	75±0.5	79	178
S55	18:44:39.64	-03:29:59.60	108±0.6	107	163
S64	18:44:46.96	-03:31:09.70	63±0.5	63	189
S76	18:44:20.68	-03:28:45.52	74±0.5	75	171
S96	18:44:30.40	-03:28:49.22	71±0.6	73	160
Alicante-10					
S67	18:45:11.25	-03:39:36.14	71±0.6	74	191
S90	18:45:36.53	-03:39:21.92	16±0.5	17	173
S91	18:45:17.13	-03:41:25.91	75±0.5	75	178
Alicante-8					
S1	18:34:58.40	-07:14:27.46	–33±0.5		174
S2	18:34:55.28	-07:15:11.59	71±0.6		92
S3	18:34:50.23	-07:14:28.07	37±0.5		146
S4	18:34:51.15	-07:14:02.11	88±0.7		43
S5	18:34:51.65	-07:13:17.65	–9±0.5		102
S6	18:34:41.72	-07:11:40.34	111±0.6		112
S7	18:34:43.72	-07:13:30.61	–4±0.6		110

1 Radial velocities obtained in this work using equation 1.
2 Radial velocities from the literature.

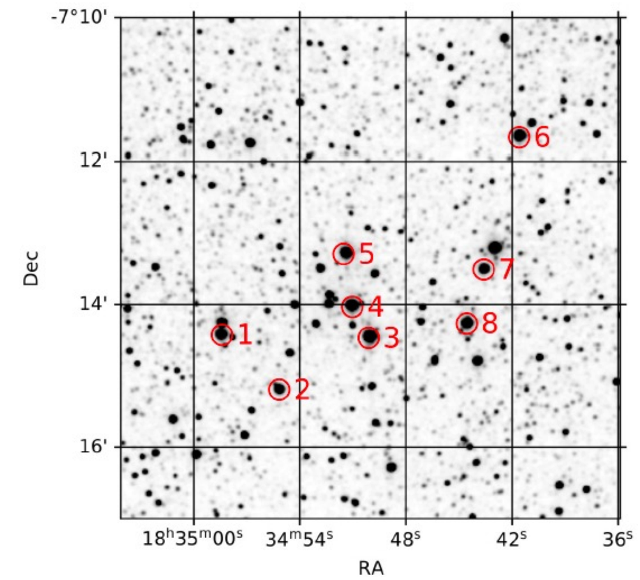

Figure 1. 2MASS K_S band finding chart for the Alicante-8 candidate member stars **from** Negueruela et al. (2010). It is a linearly scaled 2MASS K_S band image, with a field of view of $\sim 7' \times 7'$, centered at (RA,DEC)∼(18:34:50,–07:13:30). North is up and East is left.

Asa'd et al. 2023 (accepted in AJ)

More Analysis

- We estimated the luminosity class of the stars based on spectral indices sensitive to the surface gravity in Messineo et al. (2021) to evaluate the assumption that the bright potential members of Alicante-8 are RSGs.

- Most objects fall in between the RGB and AGB loci, rather than in the RSG locus, suggesting that these stars are not RSGs.

Asa’d et al. 2023 (accepted in AJ)

Conclusion (Part 1):

- Spectra with sufficiently high resolving power to measure radial velocities are necessary to confirm cluster membership.

- Using the K-band part of the NIR spectra alone does not provide reliable means to classify stars, due to the degeneracy between 2.3 micron CO EWs with different spectral types – both giants and RSGs can attain similar values of the EWs. This is an important caveat to keep in mind for studies of stars in Young Massive Clusters as well as field stars near the inner Galaxy.

Part 2:

A. Using resolved data
B. Using integrated spectra (or photometry)

On the precision of full-spectrum fitting technique

Acknowledgement: STScI

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MNRAS **00,** 1 (2020) doi:10.1093/mnras/staa2515
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On the precision of full-spectrum fitting of simple stellar populations – I. Well-sampled populations

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On the precision of full-spectrum fitting of simple stellar populations – II. The dependence on star cluster mass in the wavelength range 0.3–5.0 μm

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On the precision of full-spectrum fitting of stellar populations – III. Identifying age spreads

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On the precision of full-spectrum fitting of simple stellar populations – IV. A systematic comparison with results from colour–magnitude diagrams

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← The most exciting one!

Applications – Obtaining the CEH

- Can we use integrated spectra of star clusters to trace the chemical enrichment history of distant galaxies?

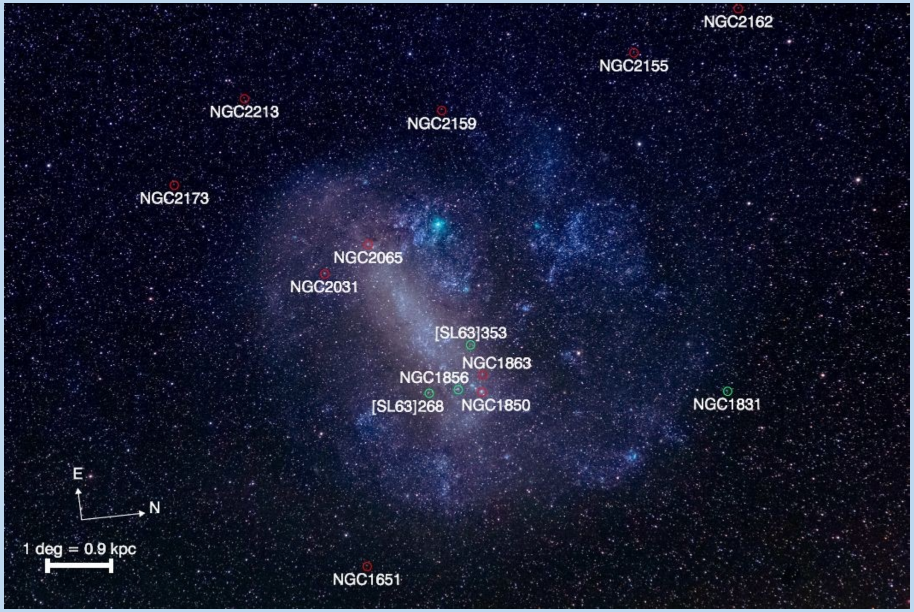
To answer this question we will compare results from our observed data with theoretical models of the Chemical Enrichment History.

A: Results from Chilingarian & Asa'd (2018)
B: Results from Asa'd et al. (2022)
C: Work in progress

The Large Magellanic Cloud (LMC) galaxy

- It is a good laboratory to get resolved clusters as well as integrated spectra and photometry.

- Has about 1200 clusters – with a well-mixed stellar populations.



The Model for the Chemical Enrichment (Spitoni et al. 2017)

We start with the instantaneous recycle approximation in which the stellar lifetime is negligible:

$$Z(t) = Z(0) + \frac{y_Z(1-R)}{1-R+\lambda} \ln \frac{M_{\rm gas}(0)}{M_{\rm gas}(0) - (1-R+\lambda)\int_0^t \psi(T)dT}$$

y_Z: The mass fraction of heavy elements formed in stars and returned into the ISM.

R: The returned mass fraction of gas that goes back to ISM.

λ: The outflow coefficient.

$M_{gas}(0)$: Initial mass of the gas.

$\psi(t)$: Star formation rate.

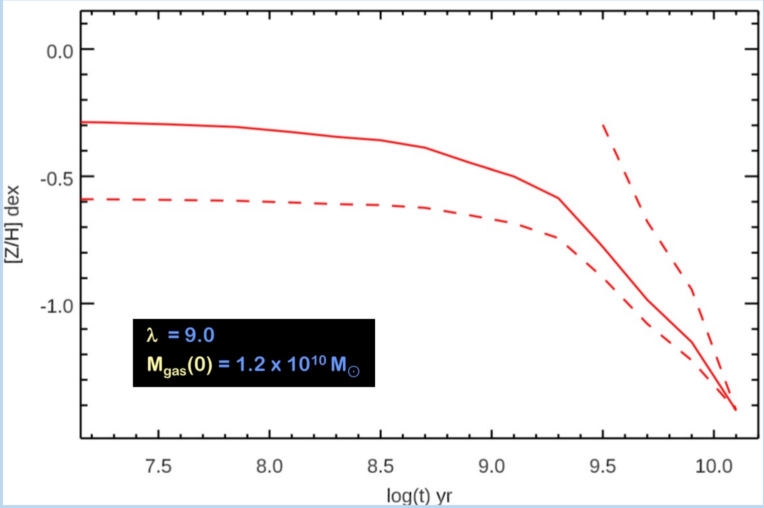
Applying it to the LMC galaxy

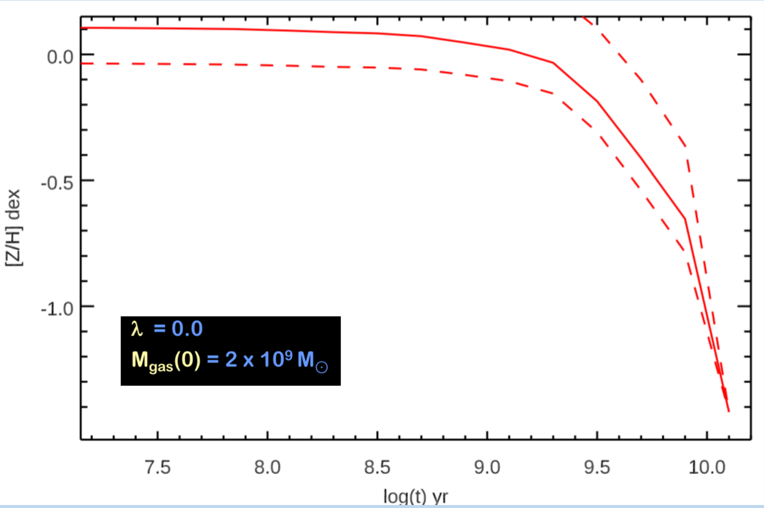
$$Z(t) = Z(0) + \frac{y_Z(1-R)}{1-R+\lambda} \ln \frac{M_{\rm gas}(0)}{M_{\rm gas}(0) - (1-R+\lambda)\int_0^t \psi(T)dT}$$

- Spitoni et al (2017) computed R and y_z.
- Z(0) corresponds to the metallicity the of oldest LMC clusters. [Z/H] = -1.42
- $M_{gas}(0)$ and λ are free parameters.
- If we know $\psi(t)$, we can obtain the the chemical enrichment Z(t).
- We use the global star formation history of the LMC derived from resolved data by Harris & Zaritsky (2009).

Applying it to the LMC galaxy

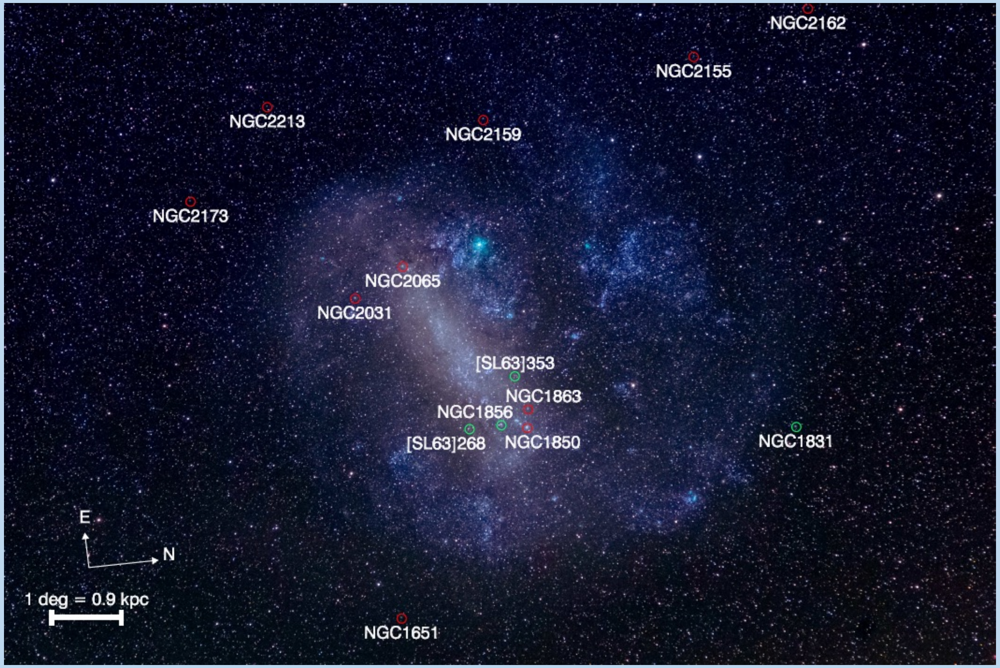
$$Z(t) = Z(0) + \frac{y_Z(1-R)}{1-R+\lambda} \ln \frac{M_{\rm gas}(0)}{M_{\rm gas}(0) - (1-R+\lambda)\int_0^t \psi(T)dT}$$





Data: Our Observed Sample (initial sample)

- 11 clusters observed with the 4 m SOAR telescope (Goodman Spectrograph).
- 4 clusters observed with the 6.5 m Magellan Baade telescope (MagE spectrograph)



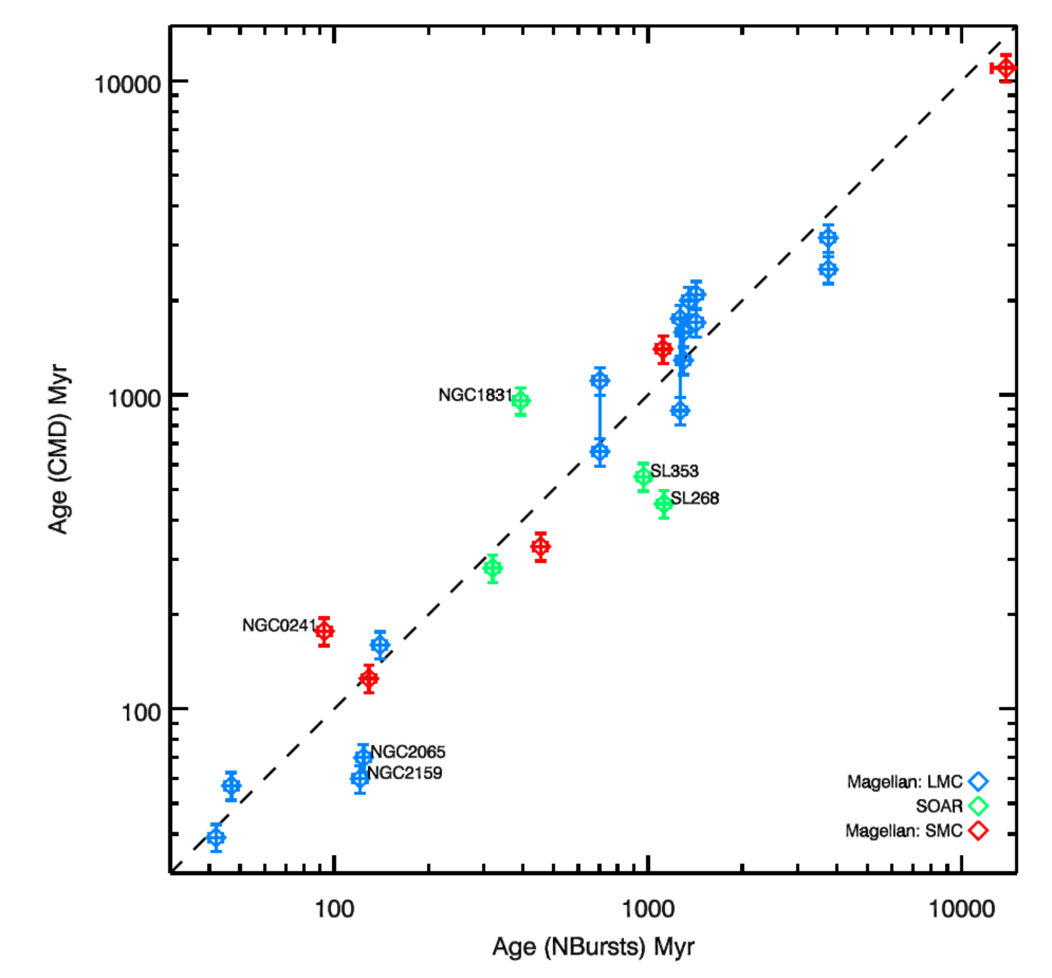
Using Nburst to obtain the age and metallicity:

Table 1
Ages and Metallicities of the LMC Cluster Obtained with the NBURSTS Full Spectrum Fitting

Object	t, Myr	[Fe/H], dex	Data Set
NGC1651	1353 ± 70	-0.25 ± 0.03	SOAR
NGC1831	393 ± 20	-0.14 ± 0.02	*Magellan*
NGC1850	42 ± 2	-0.12 ± 0.01	SOAR
NGC1856	320 ± 16	-0.13 ± 0.01	*Magellan*
NGC1863	47 ± 3	-0.18 ± 0.01	SOAR
NGC2031	140 ± 7	-0.14 ± 0.02	SOAR
NGC2065	124 ± 6	-0.16 ± 0.02	SOAR
NGC2155	3757 ± 190	-0.64 ± 0.03	SOAR
NGC2159	121 ± 6	-0.13 ± 0.03	SOAR
NGC2162	1298 ± 60	-0.32 ± 0.04	SOAR
NGC2173	1423 ± 70	-0.37 ± 0.02	SOAR
NGC2213	1267 ± 60	-0.51 ± 0.02	SOAR
NGC2249	703 ± 35	-0.39 ± 0.02	SOAR
[SL63]268	1125 ± 60	-0.32 ± 0.01	*Magellan*
[SL63]353	969 ± 50	-0.31 ± 0.02	*Magellan*

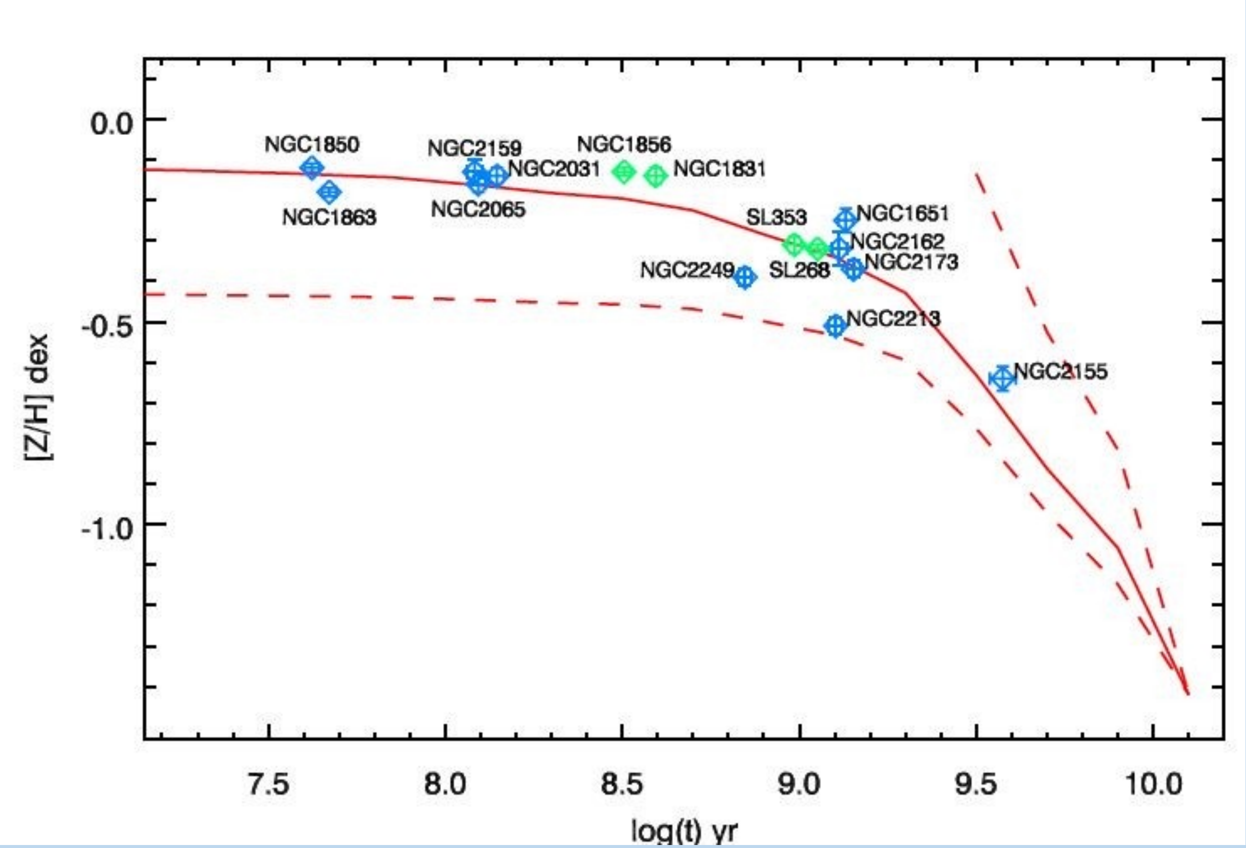
Chilingarian & Asa'd (2018)

Comparing with ages obtained from CMDs



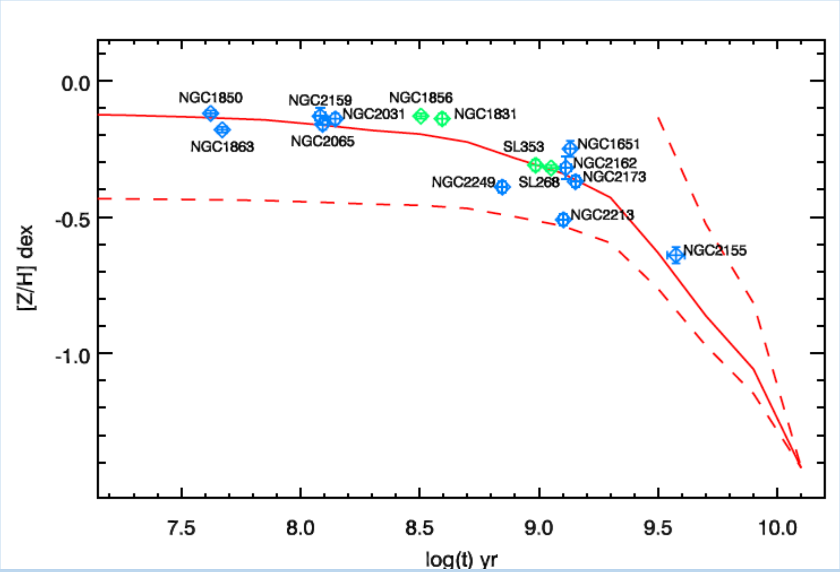
Chilingarian & Asa'd (2018)

Results:



Chilingarian & Asa'd (2018)

For Chabrier IMF:



- λ = 5.7

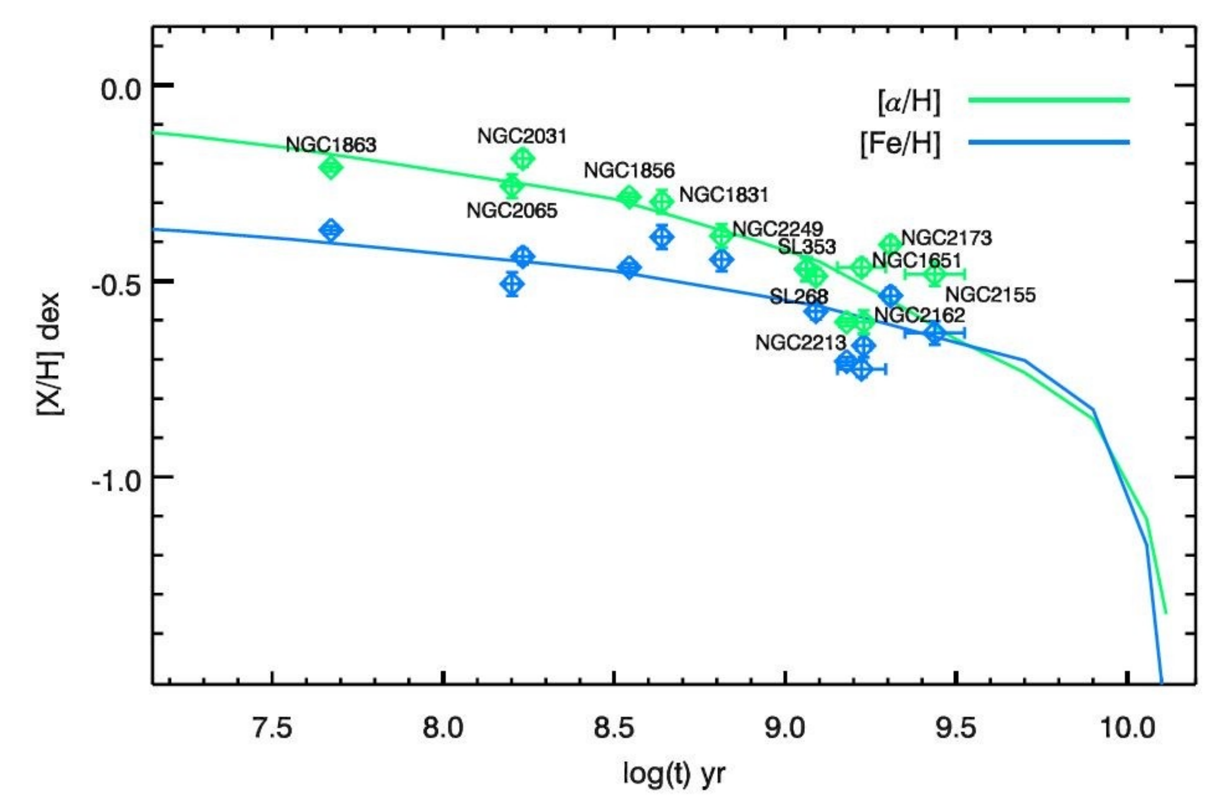
This is a typical value (0.6 – 10.2) for this IMF

- $M_{gas}(0) = 7.9 \times 10^9 M_\odot$
- $M_{gas}(now) = 6.2 \times 10^8 M_\odot$

This agrees with the observed total gas mass in the LMC within uncertainties.

α- enhancement

The chemical enrichment with α- elements (O, Ne, Mg, Si, S, Ar, Ca, and Ti) is not at the same time as Fe-peak elements (Sc, V, Cr, Mn,Fe, Co and Ni)



Chilingarian & Asa'd (2018)

One Step Further: Detailed Abundances

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Detailed Chemical Abundances of Star Clusters in the Large Magellanic Cloud

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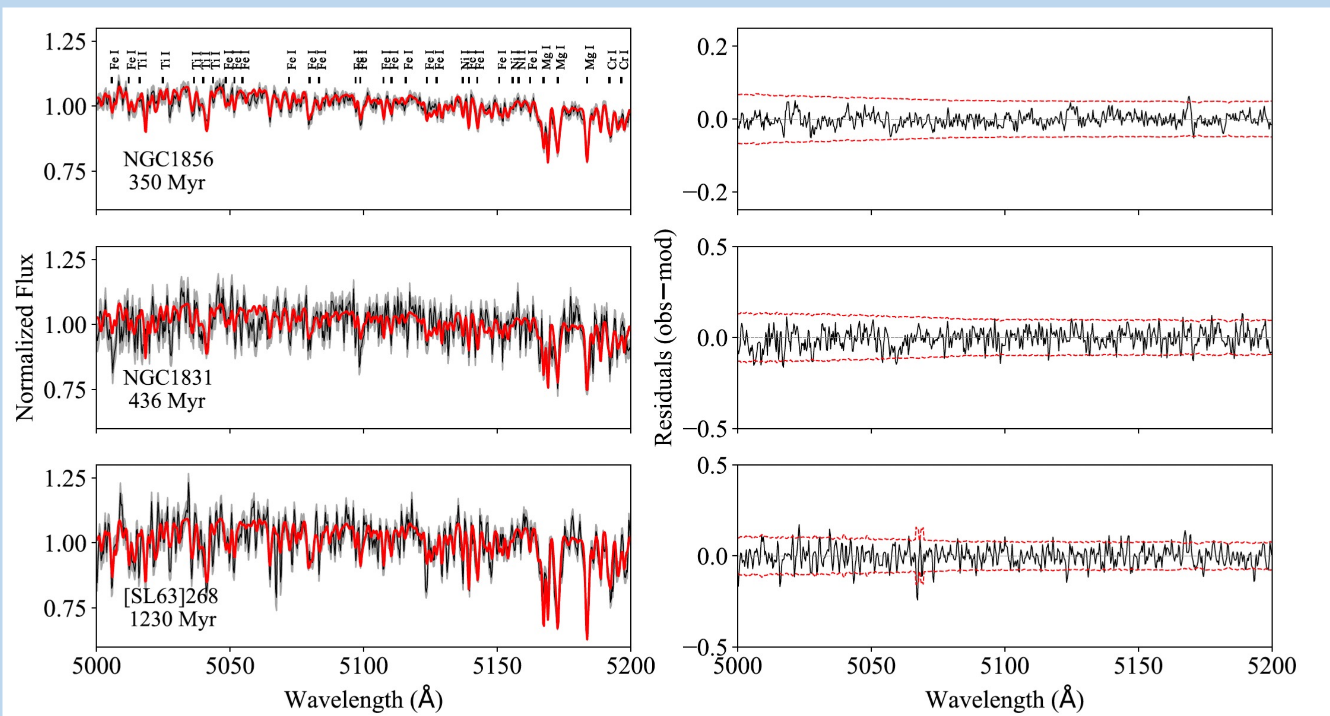

One Step Further: Detailed Abundances

Using the software developed for GCs by Larsen et al. (2012), and later applied to YMCs by Hernandez et al. (2017)

Table 1
Our Results

	NGC 1831	NGC 1856	[SL63]268
RV (km s^{-1})	290 ± 7	279 ± 4	278 ± 4
σ_{sm} (km s^{-1})	23.9	26.9	24.6
[Z]	-0.418 ± 0.07	-0.574 ± 0.06	-0.51 ± 0.04
[Fe/H]	-0.375 ± 0.12	-0.455 ± 0.11	-0.506 ± 0.1
[Ca/Fe]	0.814 ± 0.41	0.375 ± 0.2	-0.277 ± 0.39
[Na/Fe]	0.023 ± 0.77	0.093 ± 0.38	0.357 ± 0.08
[Mg/Fe]	0.082 ± 0.16	-0.074 ± 0.13	0.07 ± 0.11
[Ti/Fe]	0.547 ± 0.42	0.262 ± 0.2	0.233 ± 0.19
[Cr/Fe]	0.002 ± 0.5	0.132 ± 0.16	0.111 ± 0.0
[Mn/Fe]	0.323 ± 0.38	-0.263 ± 0.32	-0.199 ± 0.21
[Ni/Fe]	0.318 ± 0.5	-0.194 ± 0.08	-0.224 ± 0.41

Asa'd et al. (2022)

Ongoing work:

1. Larger Sample of integrated Spectra in LMC.

2. Extending to the Small Magellanic Cloud (SMC)

3. Compare our results with results extracted from the simulations of dwarf galaxies in the NIHAO sample

Spyropoulos et al. (in prep)

Conclusion (Part 2):

- Integrated spectra of star clusters can be used to trace the chemical enrichment history (CEH) of the host galaxy.
- This is significant because our approach can be used to study CEH of distant galaxies for which the star clusters can't be resolved.

Thank you!