Fluorine abundances in Open Clusters

Shilpa Bijavara Seshashayana
Malmö University
Supervisor: Henrik Jönsson

Why Fluorine (F)?

- It is easily destroyed in stellar interiors.
- It has one stable isotope (^{19}F).
- F is the 24th most abundant element in the Milky Way, it makes up less than 1% of the solar abundance of its periodic table neighbours.
- All of these conditions place constraints on chemical and stellar evolution models.

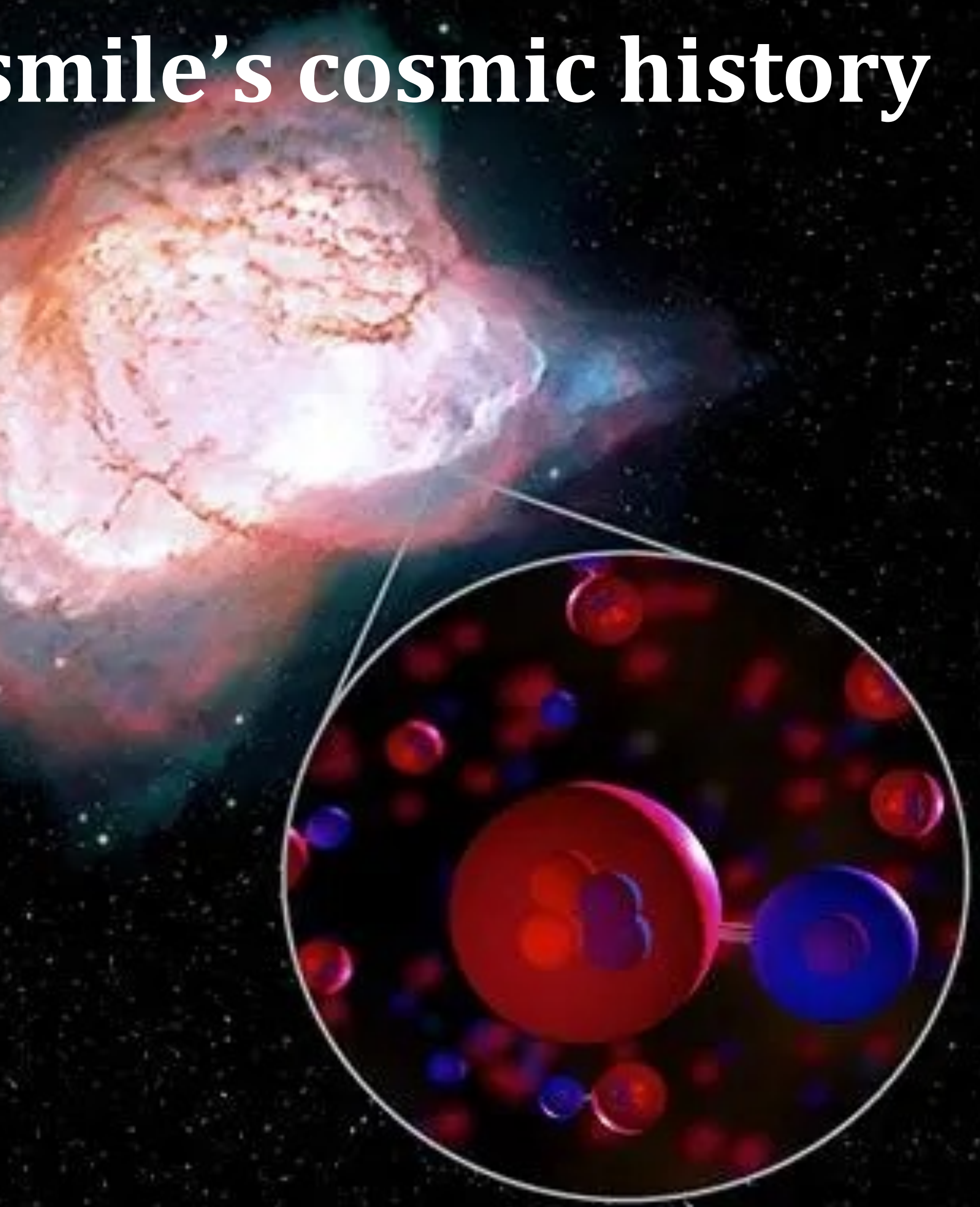
Your smile's cosmic history

High Mass stars:

- Rapidly rotating massive stars
- Massive stars that evolve as the rare W-R stars
- Type II SuperNovae (SNe II)

Low and Intermediate mass stars (LIMS):

- AGB stars
- Novae



Observations

The Galileo National Telescope (Italian: Telescopio Nazionale Galileo, TNG, a 3.58-meter Italian telescope, located at the Roque de los Muchachos Observatory, La Palma, Canary Islands, Spain).

Instruments used:

HARPS-N (High Accuracy Radial velocity Planet Searcher).

GIANO-B, high-resolution echelle spectrograph for observations in the near infrared.

Analysis (PySME)

- The observed spectra have been analyzed with PySME, which fits synthetic spectra by radiative transfer calculations (Wehrhahn 2021).
- PySME uses 1D MARCS grids (Gustafsson et al. 2008, Kurucz 2013). The grids cover temperatures (Teff) from 2500K to 8000K, surface gravities (log g) from -0.5 to 5.5, and [Fe/H] from -5 to 1 dex.
- VALD linelists are used for lineslists (Kupka et al. 1999, Kupka et al. 2000, Piskunov et al.1995).
- PySME has support for the use of non-LTE departure coefficient grids, which greatly improves the accuracy of the lines (Amarsi et al. 2016, Amarsi et al. 2018).

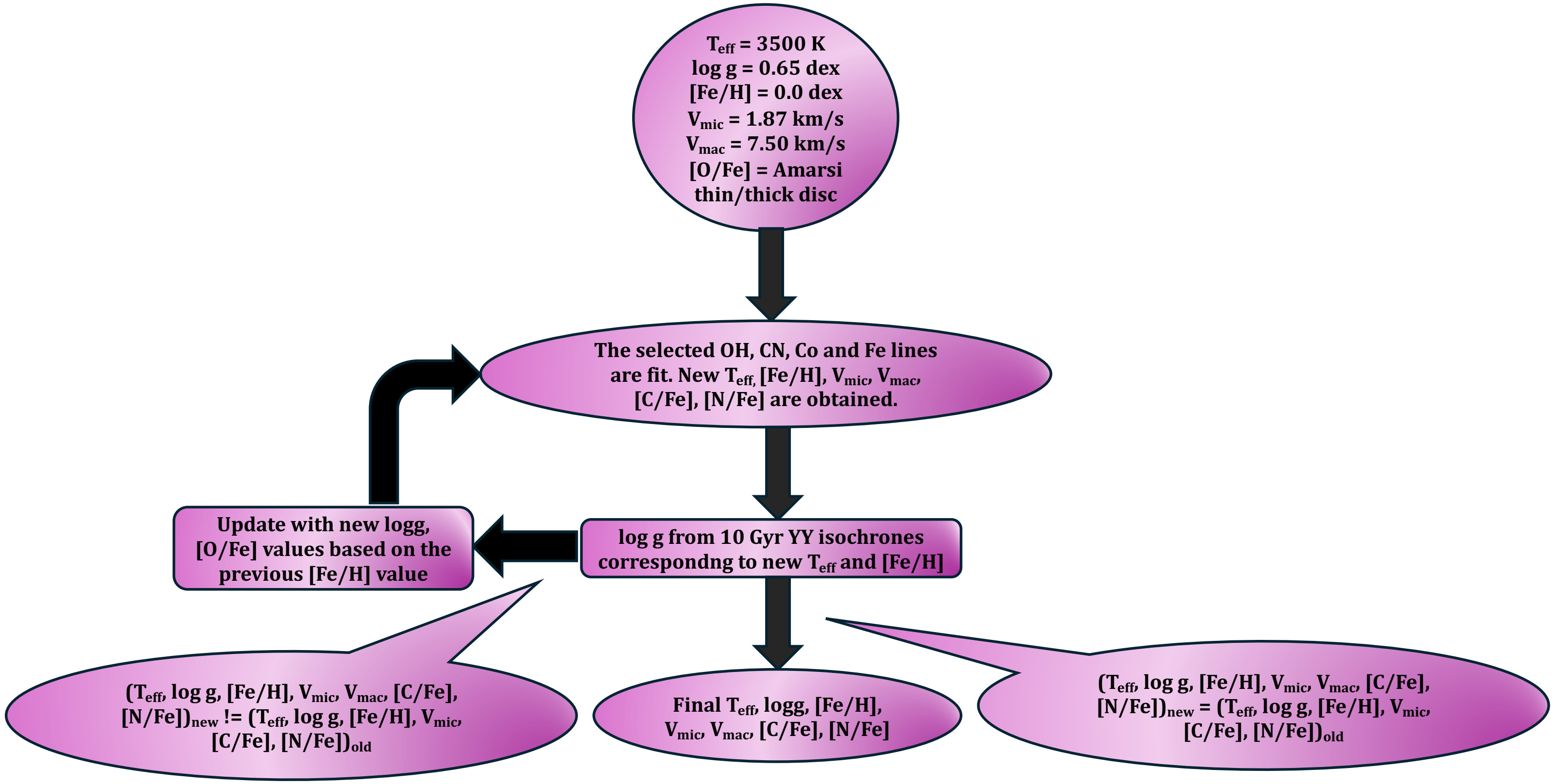
Sample Objects

Stellar cluster	Star	Gaia DR3 ID
NGC 7789	N7789_1	1995061928762465536
age=1.55Gyr	N7789_2	1995014409242207872
R_{GC} = 9.43 kpc	N7789_4	1995059592301326848
NGC 7044	N7044_1	1969807040026523008
age=1.66Gyr	N7044_2	1969807276235623552
R_{GC} = 8.73 kpc	N7044_3	1969806073644788992
	N7044_4	1969800576086654592
NGC 6819	N6819_a	2076394728016615680
age=2.24Gyr	N6819_b	2076582950658667264
R_{GC} = 8.03 kpc		
Ruprecht 171	Rup171_1	4103073693495483904
age=2.75Gyr	Rup171_2	4102882309792631552
R_{GC} = 6.90 kpc		
Trumpler 5	Trumpler5_1	3326783231129992704
age=4.27Gyr		
R_{GC} = 11.21 kpc		
King 11	King11_1	2211216117949545216
age = 4.47Gyr	King11_2	2211121972266402304
R_{GC} = 10.21 kpc	King11_3	2211220211058075776
NGC 6791	N6791_2	2051105616974709504
age = 8.31Gyr	N6791_3	2051287002031070208
R_{GC} = 7.94 kpc		

Cantat-Gaudin et al. 2020; Brogaard et al. 2021

Stellar Parameters

Stellar parameters, namely the effective temperature (T_{eff}), surface gravity (log g), metallicity ([Fe/H]), macroturbulence (v_{mac}), and microturbulence velocity (v_{mic}), are derived using a set of molecular OH lines along with Fe atomic lines, CN, and CO molecular band heads in the H-band wavelength range (Nandakumar et al. 2023).



Reproduced from Nandakumar et al. (2023)

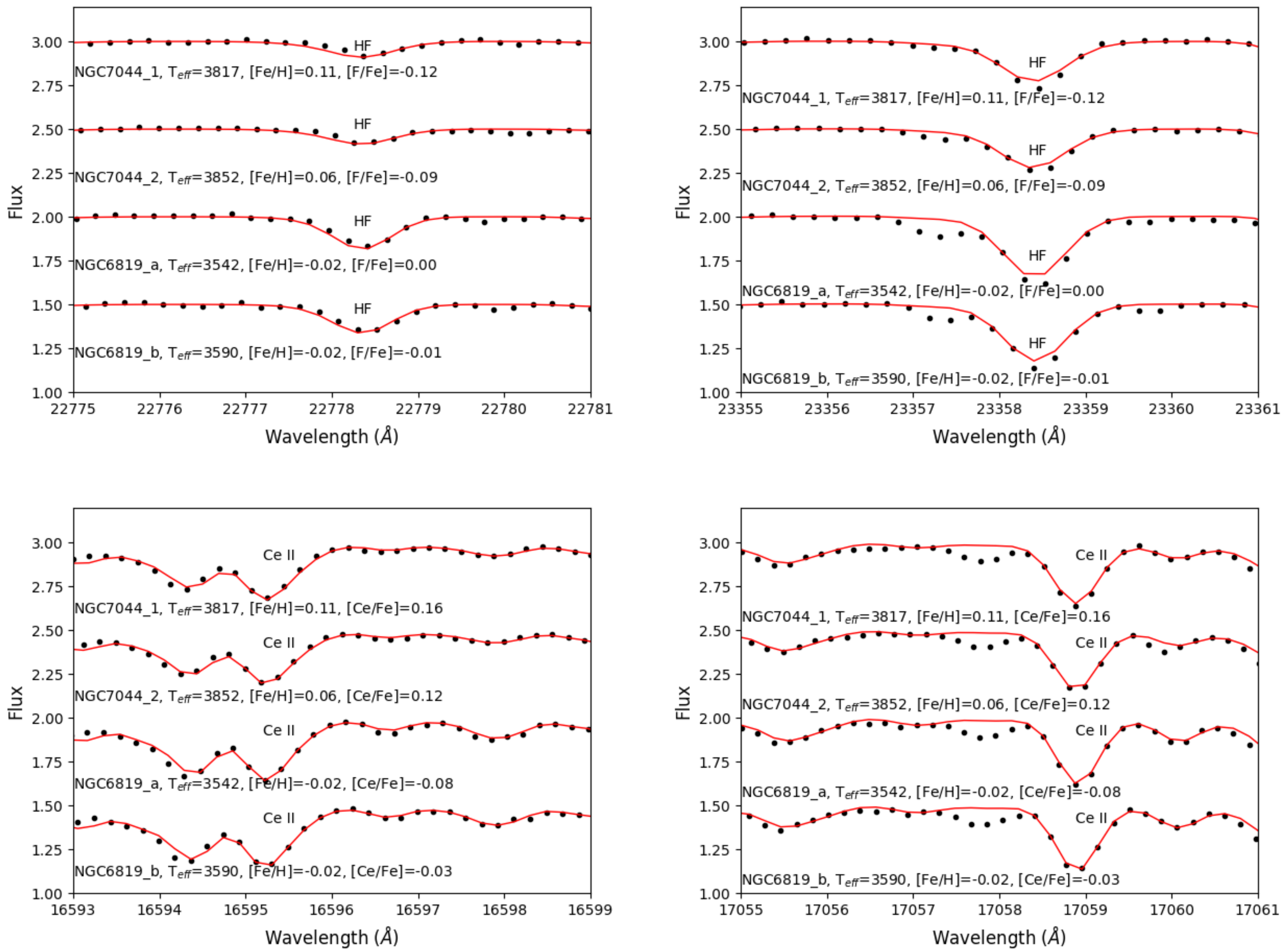
S-process elements

- The interplay between s-process elements and F is of great significance.
- Since both production chains include neutrons from He-nuclear reactions with ^{13}C, fluorine is expected to correlate with the s-process elements (Abia et al. 2019).
- In particular, AGB stars and massive stars can produce both s-process elements and F.

Line Data

Species	Λ_{air} (Å)	log(gf)	E_{low} (ev)
HF	22778.249	-3.969	0.674
HF	23358.329	-3.962	0.227
Ce II	16595.180	-2.114	0.122
Ce II	17058.880	-1.425	0.318

Jönsson et al. (2014); Montelius et al. (2022)



HF
NGC7044_1, T_{eff}=3817, [Fe/H]=0.11, [F/Fe]=-0.12
NGC7044_2, T_{eff}=3852, [Fe/H]=0.06, [F/Fe]=-0.09
NGC6819_a, T_{eff}=3542, [Fe/H]=-0.02, [F/Fe]=0.00
NGC6819_b, T_{eff}=3590, [Fe/H]=-0.02, [F/Fe]=-0.01
Ce II
NGC7044_1, T_{eff}=3817, [Fe/H]=0.11, [Ce/Fe]=0.16
NGC7044_2, T_{eff}=3852, [Fe/H]=0.06, [Ce/Fe]=0.12
NGC6819_a, T_{eff}=3542, [Fe/H]=-0.02, [Ce/Fe]=-0.08
NGC6819_b, T_{eff}=3590, [Fe/H]=-0.02, [Ce/Fe]=-0.03
Flux
Wavelength ($\AA$)

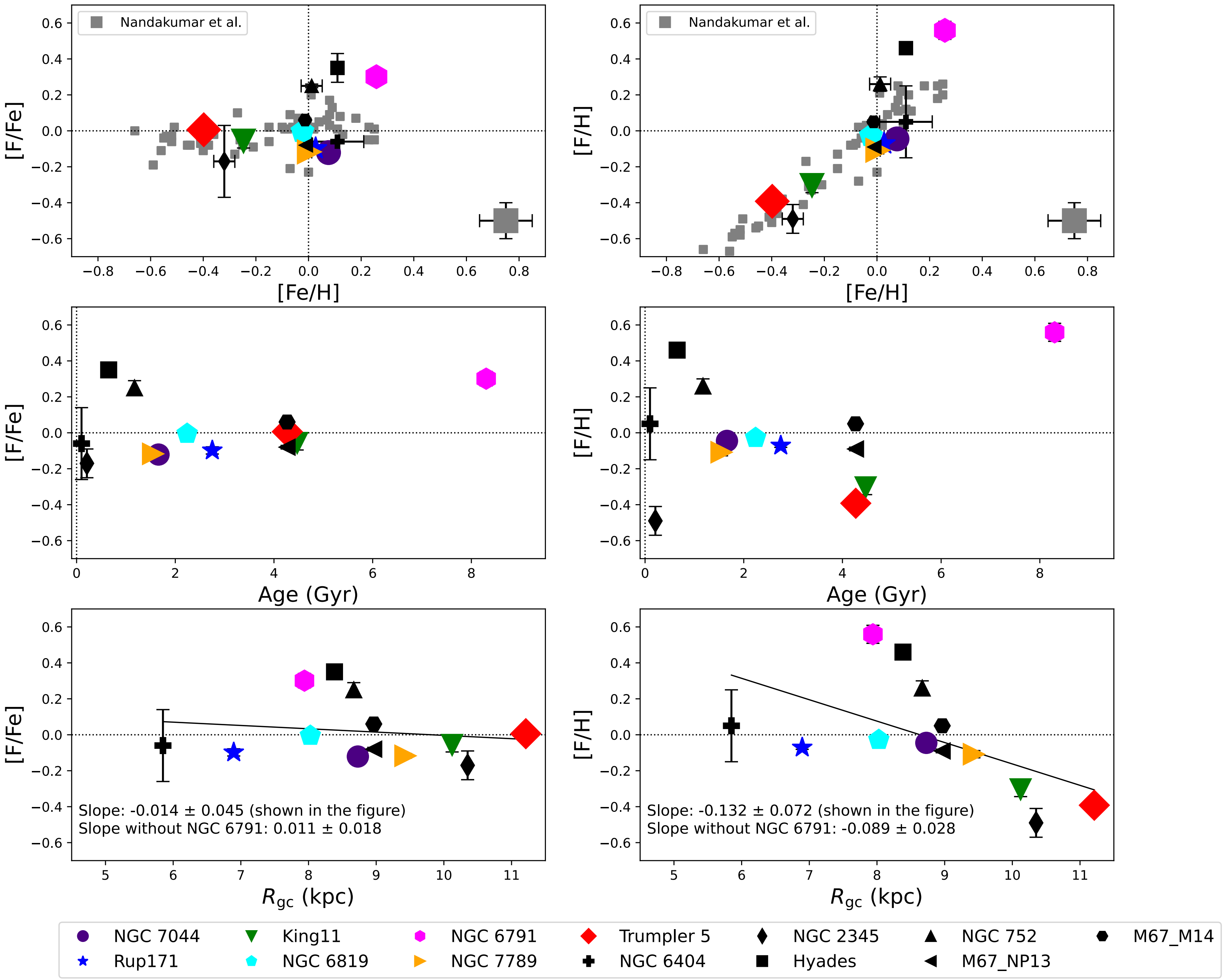
Star	T_{eff} (K)	log$g$ (dex)	[Fe/H] (dex)	v_{mic} (km s^{-1})	v_{mac} (km s^{-1})	[C/Fe] (dex)	[N/Fe] (dex)	[O/Fe] (dex)	[F/Fe] (dex)	[F/H] (dex)	[Ce/Fe] (dex)	[Ce/H] (dex)
N7789_1	3811	1.20	0.00	1.76	6.30	-0.18	0.26	-0.04	-0.13±0.11	-0.13±0.15	0.09±0.11	0.09±0.15
N7789_2	3802	1.20	0.02	1.68	5.96	-0.18	0.21	-0.05	-0.10±0.11	-0.09±0.15	0.05±0.07	0.07±0.12
N7789_4	3930	1.43	0.00	1.55	6.28	-0.18	0.25	-0.04	-0.12±0.14	-0.13±0.17	0.13±0.09	0.13±0.16
N7044_1	3817	1.30	0.11	1.75	6.78	-0.19	0.26	-0.08	-0.12±0.08	-0.02±0.13	0.04±0.08	0.15±0.13
N7044_2	3852	1.32	0.06	1.72	6.93	-0.17	0.27	-0.06	-0.09±0.11	-0.03±0.15	0.00±0.07	0.06±0.12
N7044_3	3890	1.39	0.06	1.66	7.02	-0.20	0.26	-0.06	-0.12±0.13	-0.05±0.16	0.02±0.10	0.08±0.14
N7044_4	3877	1.39	0.08	1.67	6.61	-0.19	0.24	-0.07	-0.16±0.13	-0.08±0.16	0.03±0.07	0.11±0.12
N6819_a	3542	0.71	-0.02	1.83	5.85	-0.14	0.15	-0.03	0.00±0.10	-0.03±0.14	-0.20±0.08	-0.22±0.13
N6819_b	3590	0.79	-0.02	1.82	6.16	-0.14	0.11	-0.03	-0.01±0.08	-0.03±0.13	-0.15±0.08	-0.17±0.13
Rup171_1	3881	1.36	0.02	1.60	6.77	-0.16	0.23	-0.05	-0.08±0.12	-0.06±0.16	-0.04±0.10	-0.02±0.14
Rup171_2	4012	1.62	0.03	1.51	6.72	-0.17	0.19	-0.06	-0.12±0.12	-0.08±0.16	0.01±0.08	0.03±0.13
Trumpler5_1	3582	0.58	-0.40	1.99	6.98	-0.11	0.19	0.10	0.01±0.09	-0.39±0.13	0.09±0.08	-0.31±0.13
King11_1	3356	0.28	-0.25	1.90	10.25	-0.17	0.21	0.05	-0.04±0.07	-0.29±0.12	-0.18±0.09	-0.43±0.13
King11_2	3711	0.86	-0.25	1.85	6.39	-0.11	0.13	0.05	-0.11±0.10	-0.36±0.14	-0.01±0.07	-0.26±0.12
King11_3	4083	1.56	-0.24	1.57	6.78	-0.13	0.21	0.05	-0.02±0.14	-0.26±0.17	0.11±0.08	-0.13±0.13
N6791_2	3493	0.83	0.25	1.81	6.50	0.05	0.10	0.06	0.26±0.10	0.51±0.14	-0.24±0.08	0.01±0.13
N6791_3	3490	0.87	0.27	1.76	6.39	0.02	0.14	0.06	0.34±0.11	0.61±0.15	-0.21±0.08	0.06±0.13

Abundance ratios are scaled to the solar values of A(C) = 8.46, A(N) = 7.83, A(O) = 8.69, A(F) = 4.40, A(Fe) = 7.46, and A(Ce) = 1.58 (Asplund et al. 2021) . Typical uncertainties of the derived stellar parameters are ±100 K in Tef f , ±0.2 dex in log g , ±0.1 dex in [Fe/H], ±0.1 km s−1 in vmic, ±0.1 dex in [C/Fe], and ±0.1 dex in [N/Fe]

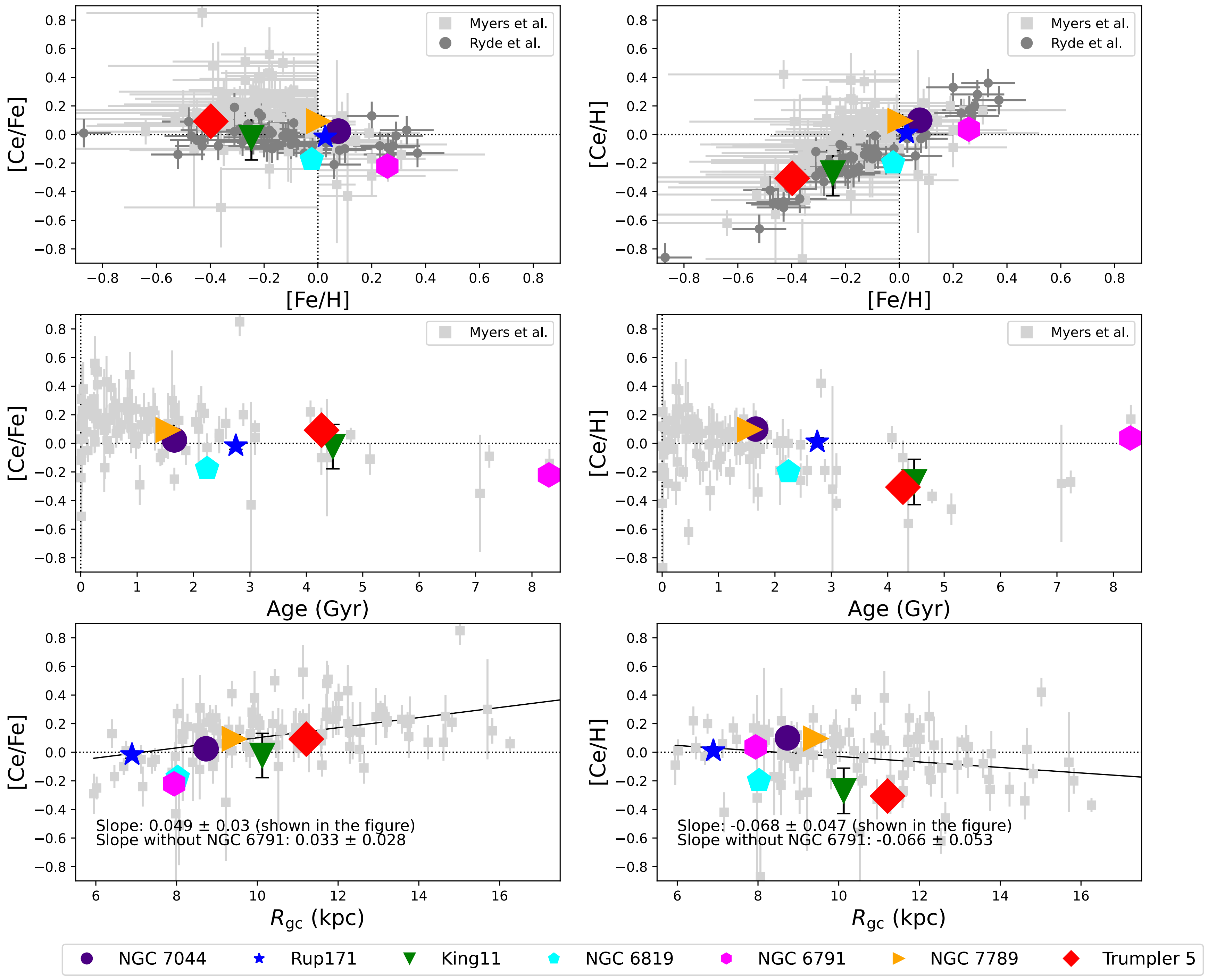
Stellar cluster	Age (Gyr)	R_{GC} (kpc)	[Fe/H] (dex)	[F/Fe] (dex)	[F/H] (dex)	[Ce/Fe] (dex)	[Ce/H] (dex)
NGC 7789	1.55	9.43	0.00±0.01	-0.11±0.01	-0.11±0.02	0.10±0.03	0.10±0.03
NGC 7044	1.66	8.73	0.08±0.02	-0.12±0.02	-0.04±0.02	0.02±0.03	0.10±0.03
NGC 6819	2.24	8.03	-0.02±0.01	0.00±0.01	-0.03±0.01	-0.18±0.02	-0.20±0.02
Ruprecht 171	2.75	6.90	0.03±0.01	-0.10±0.02	-0.07±0.01	-0.02±0.02	0.01±0.03
Trumpler 5	4.27	11.21	-0.40±0.01	0.01±0.01	-0.39±0.01	0.09±0.01	-0.31±0.01
King 11	4.47	10.12	-0.25±0.01	-0.06±0.04	-0.30±0.04	-0.02±0.12	-0.27±0.12
NGC 6791	8.31	7.94	0.26±0.01	0.30±0.04	0.56±0.05	-0.22±0.02	0.04±0.03

Averaged abundance values for the seven stellar clusters.

Results…

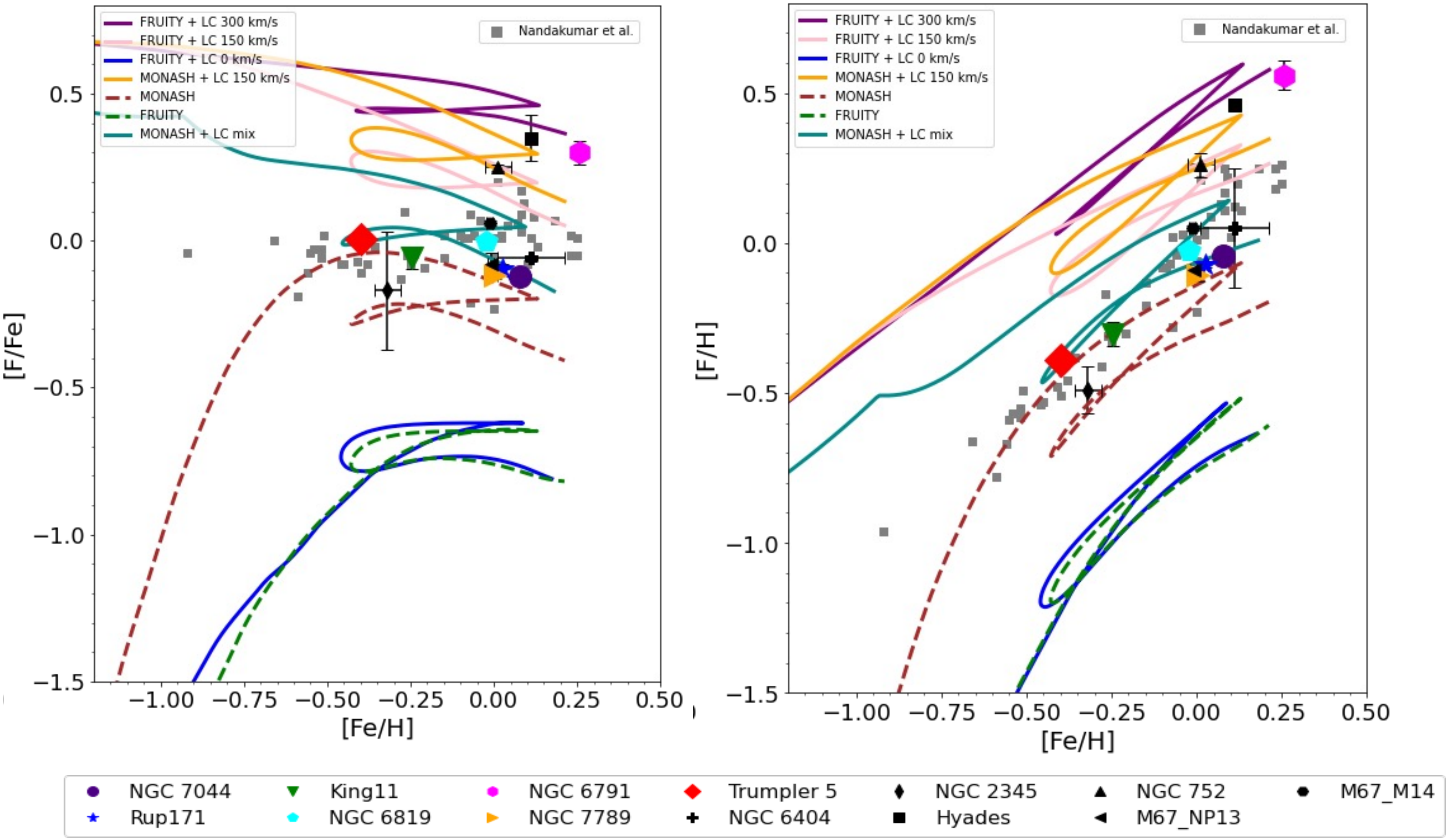


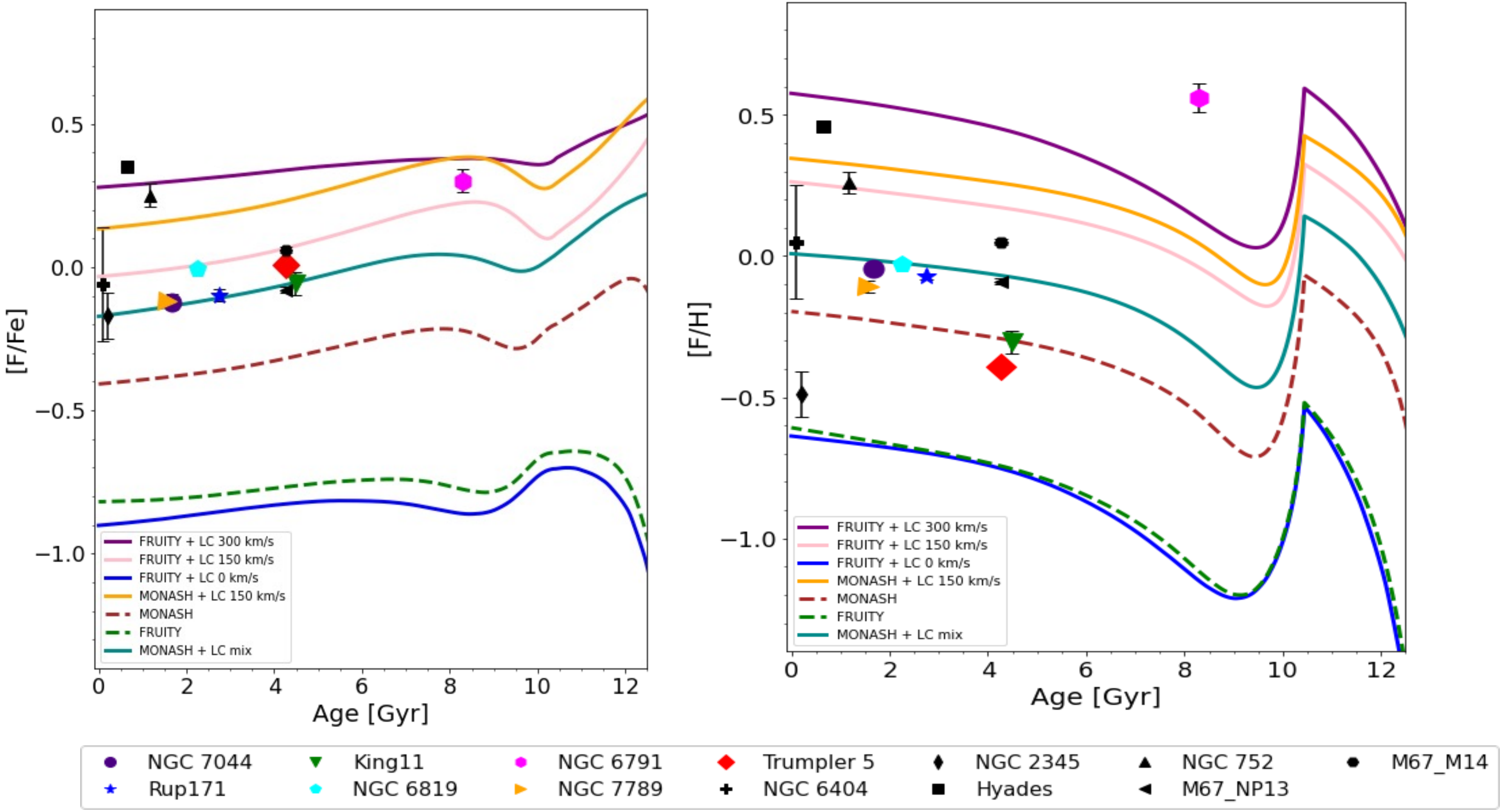
Nandakumar et al.
[F/Fe]
[F/H]
[Fe/H]
Age (Gyr)
R_{gc} (kpc)
Slope: -0.014 ± 0.045 (shown in the figure)
Slope without NGC 6791: 0.011 ± 0.018
Slope: -0.132 ± 0.072 (shown in the figure)
Slope without NGC 6791: -0.089 ± 0.028
NGC 7044
Rup171
King11
NGC 6819
NGC 6791
NGC 7789
Trumpler 5
NGC 6404
NGC 2345
Hyades
NGC 752
M67_NP13
M67_M14



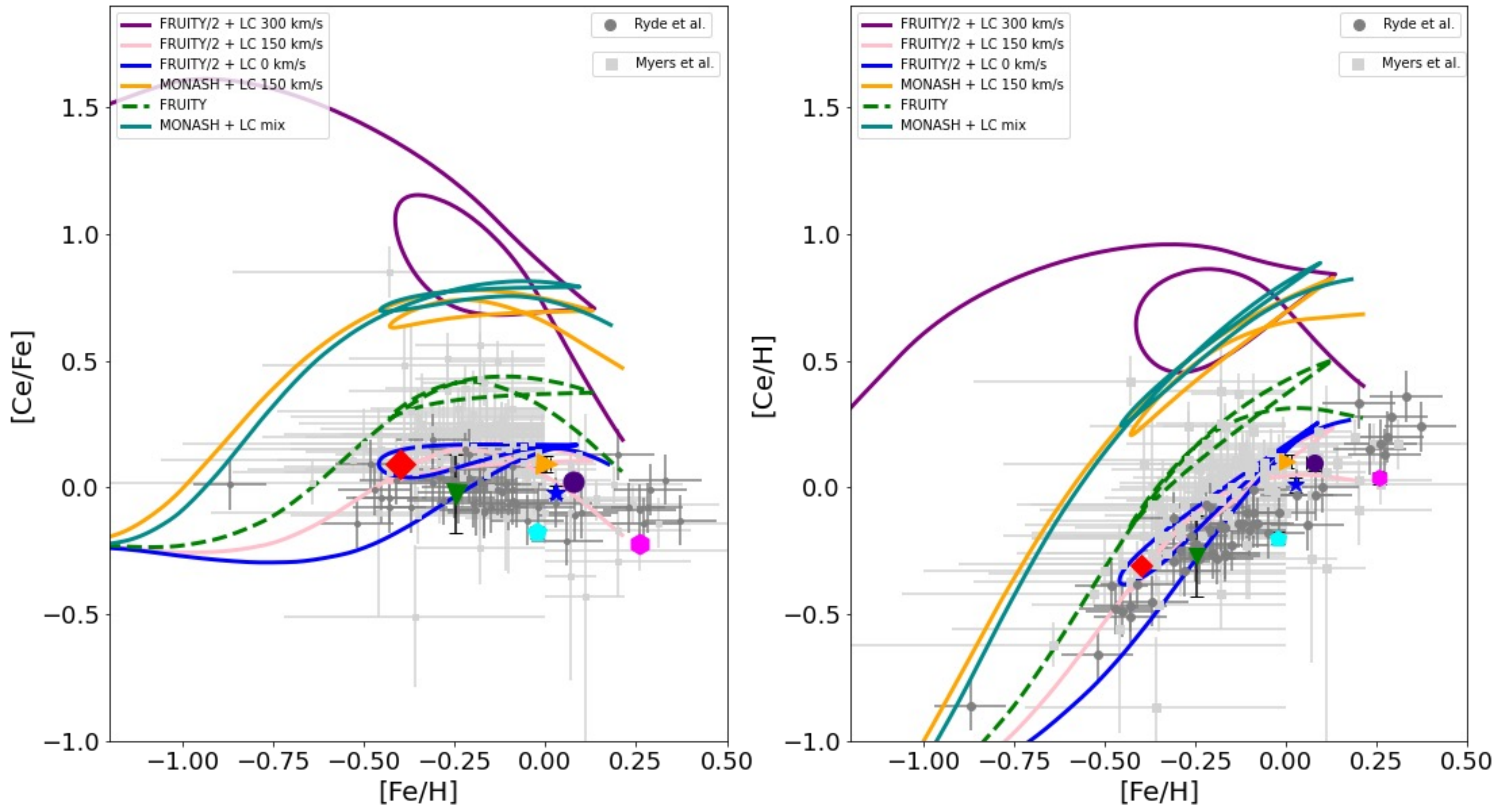
Myers et al.
Ryde et al.
[Ce/Fe]
[Ce/H]
[Fe/H]
Age (Gyr)
R_{gc} (kpc)
Slope: 0.049 ± 0.03 (shown in the figure)
Slope without NGC 6791: 0.033 ± 0.028
Slope: -0.068 ± 0.047 (shown in the figure)
Slope without NGC 6791: -0.066 ± 0.053
NGC 7044
Rup171
King11
NGC 6819
NGC 6791
NGC 7789
Trumpler 5

Comparison with models...





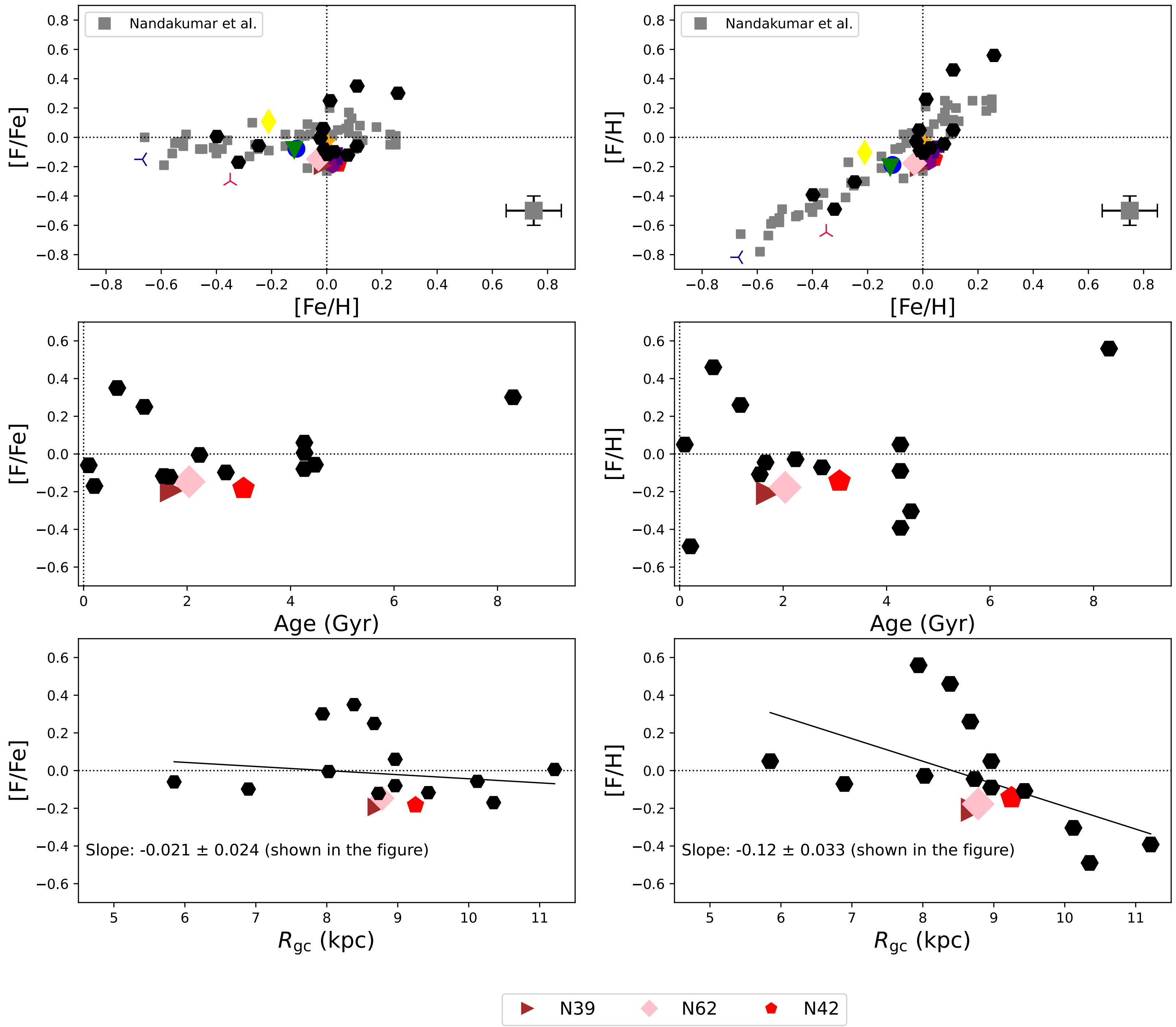
[F/Fe]
Age [Gyr]
[F/H]
Age [Gyr]
FRUITY + LC 300 km/s
FRUITY + LC 150 km/s
FRUITY + LC 0 km/s
MONASH + LC 150 km/s
MONASH
FRUITY
MONASH + LC mix
NGC 7044
King11
NGC 6791
Trumpler 5
NGC 2345
NGC 752
M67_M14
Rup171
NGC 6819
NGC 7789
NGC 6404
Hyades
M67_NP13



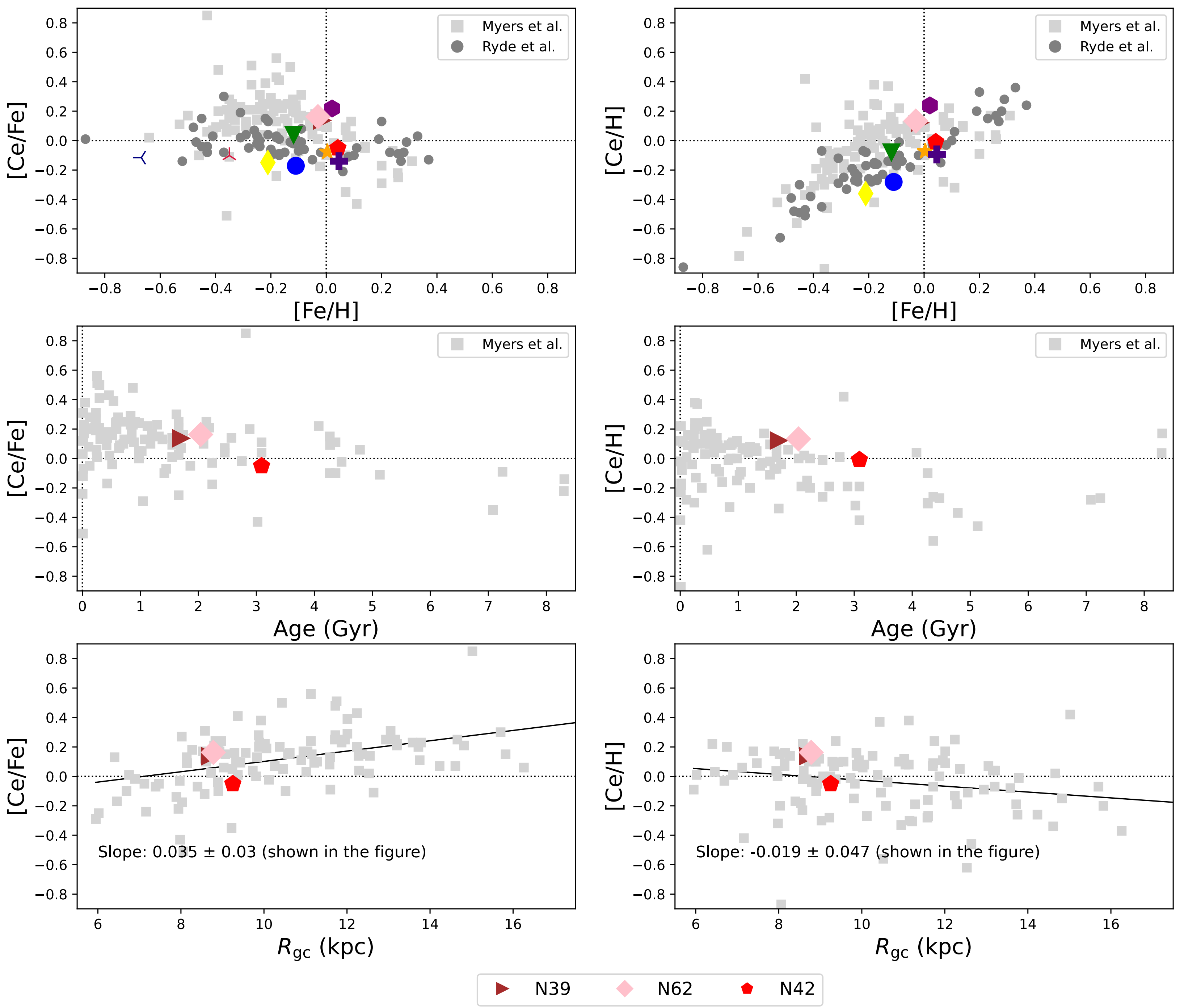
FRUITY/2 + LC 300 km/s
FRUITY/2 + LC 150 km/s
FRUITY/2 + LC 0 km/s
MONASH + LC 150 km/s
FRUITY
MONASH + LC mix
Ryde et al.
Myers et al.
[Ce/Fe]
[Ce/H]
[Fe/H]
1.5
1.0
0.5
0.0
−0.5
−1.0
−1.00
−0.75
−0.50
−0.25
0.00
0.25
0.50

Conclusion

- The abundance of F over the different ages of the clusters is essential, with a special emphasis on the younger and older clusters.
- The observed anomalies suggest the possible involvement of more than one source.



Nandakumar et al.
[F/Fe]
[F/H]
[Fe/H]
Age (Gyr)
R_{gc} (kpc)
Slope: -0.021 ± 0.024 (shown in the figure)
Slope: -0.12 ± 0.033 (shown in the figure)
N39
N62
N42



Myers et al.
Ryde et al.
[Ce/Fe]
[Ce/H]
[Fe/H]
Age (Gyr)
[Ce/Fe]
[Ce/H]
Slope: 0.035 ± 0.03 (shown in the figure)
Slope: -0.019 ± 0.047 (shown in the figure)
R_{gc} (kpc)
N39
N62
N42

She is an enigma.

Even she finds it difficult to understand herself

E.M Poetry

Thank You!

Our article: Stellar Population Astrophysics (SPA) with TNG, Fluorine Abundances in Seven Open Clusters.

S. Bijavara Seshashayana, H. Jönsson, V. D'Orazi, G. Nandakumar, E. Oliva, A. Bragaglia, N. Sanna, D. Romano, E. Spitoni, A. Karakas, M. Lugaro, L. Origlia

Tune in: A **second article** with 24 more stars will follow soon to study the chemical evolution and provide even better constraints (field stars included).