GCE MODELS: FLUORINE AND OTHER STRANGE ELEMENTS

3 6.941
Li
Lithium
[He] $2s^1$
Alkali metel

15 30.974
P
Phosphorus
[Ne] $3s^2 3p^3$
Nonmetal

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DI ASTROFISICA

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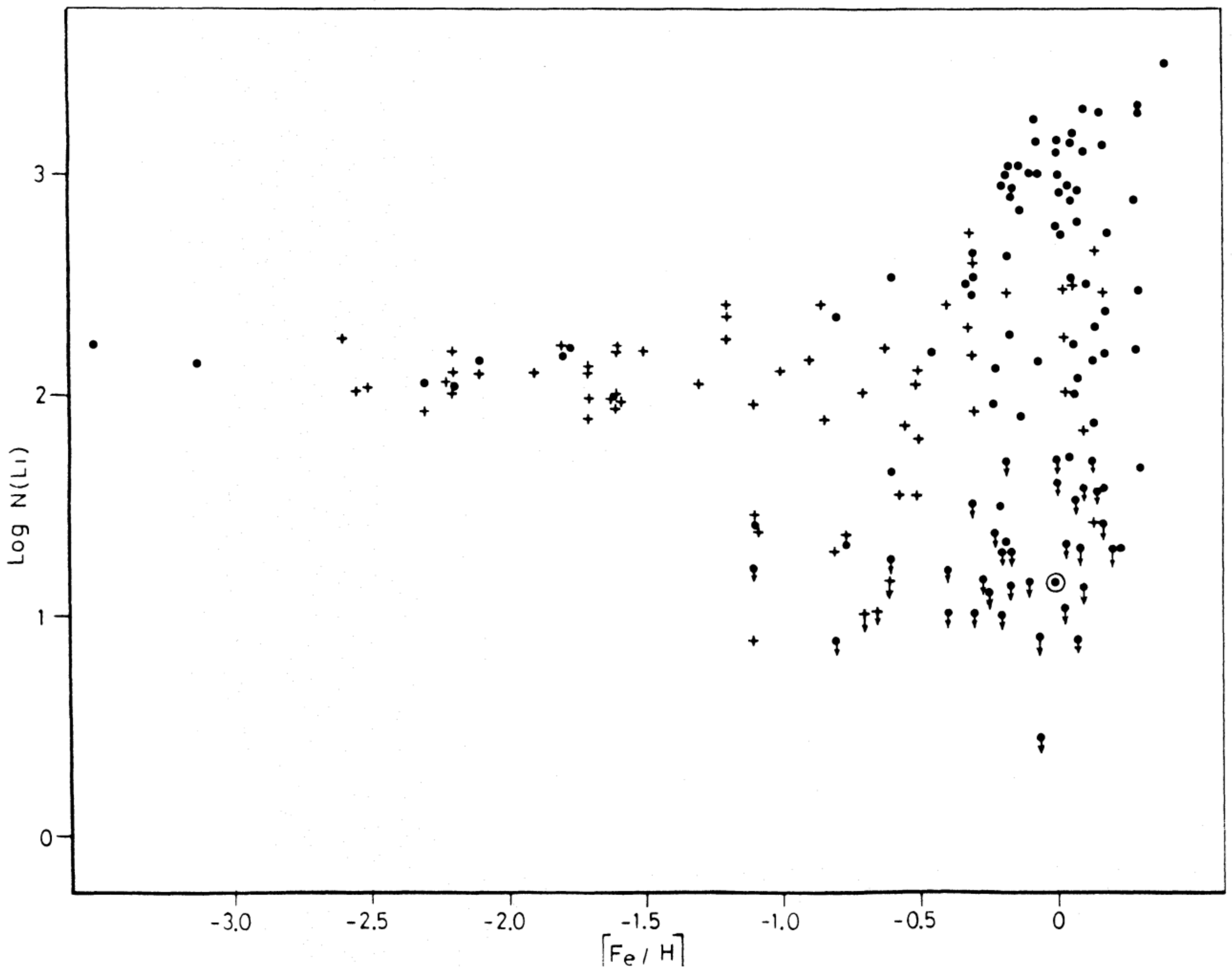
9 18.998
F
Fluorine
[He] $2s^2 2p^5$
Halogens

55 132.905
Cs
Cesium
[Xe] $6s^1$
Alkali metel

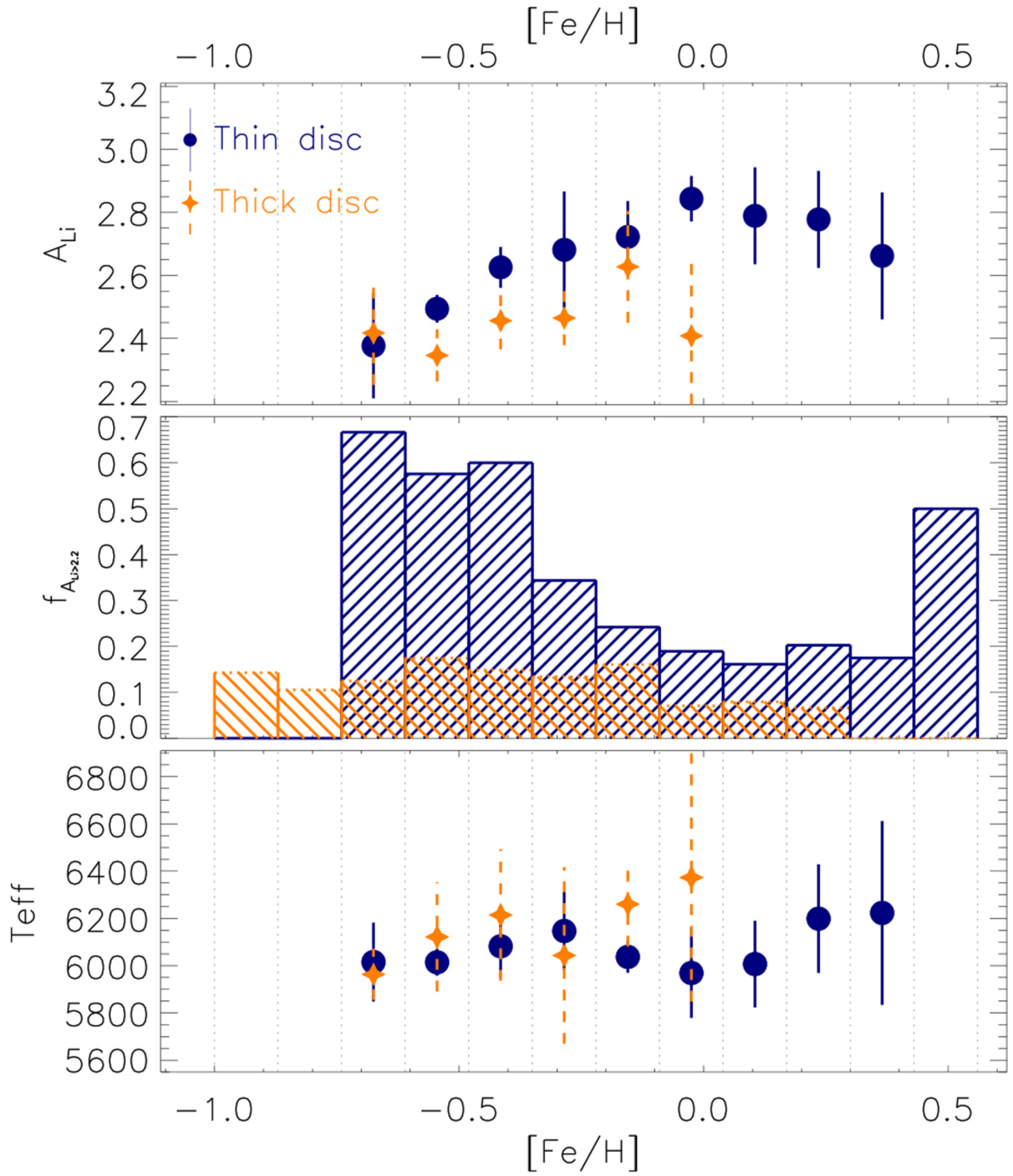
THE LITHIUM PUZZLE

- Cosmological ^{7}Li problem: A(^{7}Li)$_{P, obs}$ ~ 2.2 dex (Spite & Spite 1982; Bonifacio & Molaro 1997; Sbordone+ 2010) vs A(^{7}Li)$_{P, th}$ ~ 2.7 dex (Pitrou+ 2018)
- Galactic ^{7}Li problem: A(^{7}Li)$_{meteorites}$ ~ 3.3 dex (e.g., Lodders+ 2009). Several possible ^{7}Li sources suggested in the literature and included in Galactic chemical evolution (GCE) models, with changing fortunes (D'Antona & Matteucci 1991; Matteucci+ 1995; Romano+ 1999, 2001, 2021; Travaglio+ 2001; Grisoni+ 2019)
- Other pieces of the puzzle have to do with stellar evolution (opening Pandora's box…)

THE EVOLVING PICTURE OF LITHIUM EVOLUTION



Rebolo, Molaro, Beckman (1988)



Fu, DR+ (2018)
(see also Delgado Mena+ 2015; Guiglion+ 2016)

NEW FIELD AND OC STAR DATASETS FROM GES

- Based on the last internal data release (iDR6) of the *Gaia*-ESO Survey (GES; Gilmore+ 2022, Randich+ 2022)

- Stellar parameters, [α/Fe] and ^{7}Li abundances (1D, LTE) 'homogeneously' derived for ~1/3 of the targets (~10^5 stars) observed with FLAMES-UVES ($R \simeq 47{,}000$; see Smiljanic+ 2014, Lanzafame+ 2015) and FLAMES-GIRAFFE ($R \simeq 19{,}000$; see Gilmore+ 2022) in open clusters (OCs) and in the field

- Cross-match with *Gaia* EDR3 catalogue (Prusti+ 2016; Brown+2020):
  - Ages computed using aussieq2 (Casali+ 2020)
  - Orbital parameters computed using galpy (Bovy 2015)

https://github.com/spinastro/aussieq2 https://github.com/jobovy/galpy

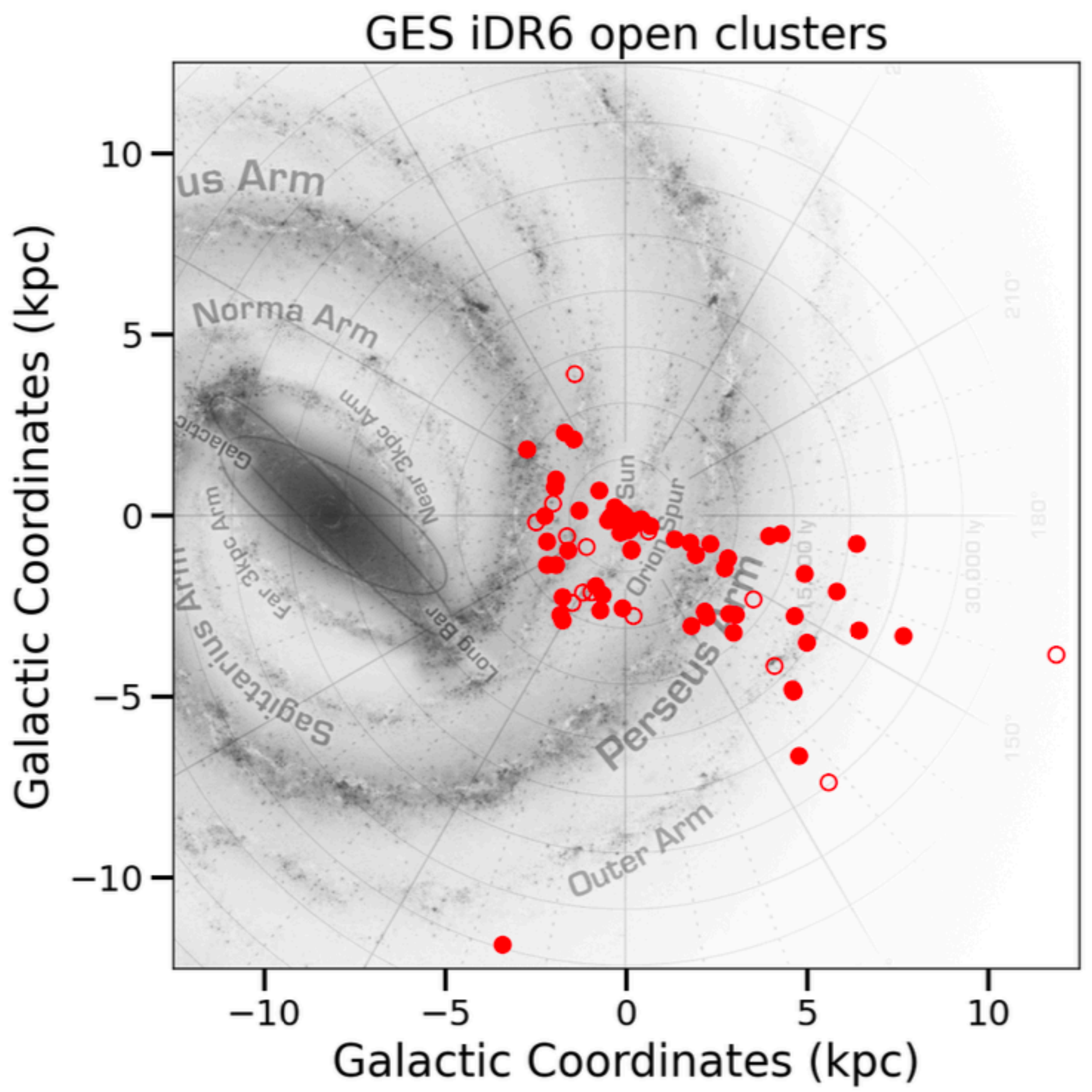
GaiaESO

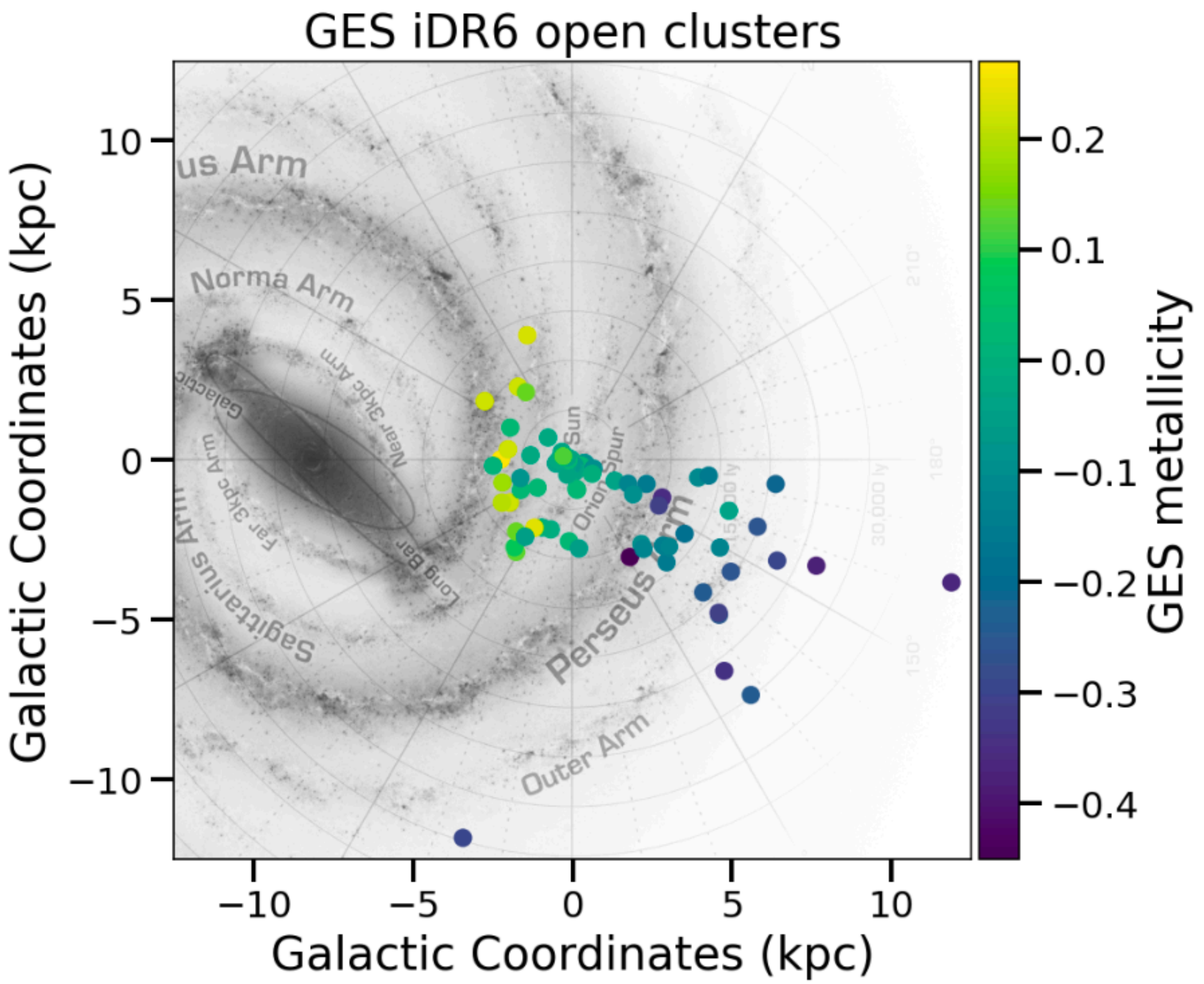
NEW FIELD AND OC STAR DATASETS FROM GES

- Field star sample:
  - (I) stars observed in GES fields (keywords GES_MW, GES_MW_BL, GES_K2, GES_CR in field GES_FLD)
  - (II) non-members observed in OC fields
- Selection on stellar parameters: $\delta T_{\rm eff}$ < 100 K, δlog(g) < 0.2 dex, δ[Fe/H] < 0.15 dex, δA(Li) < 0.25 dex
- After removing giants: 6207 stars with 5300 < $T_{\rm eff}$/K < 7000, 3.5 < log(g) < 4.6, −1.5 < [Fe/H]/dex < +0.5
- Quality cut (SNR ≥ 50): 3210 stars left

NEW FIELD AND OC STAR DATASETS FROM GES

- OC sample:
  - 26 OCs (out of 87) for which we could safely compute average maximum ^{7}Li abundances $A(Li)_{max}$.





Figures from Randich+ (2022)

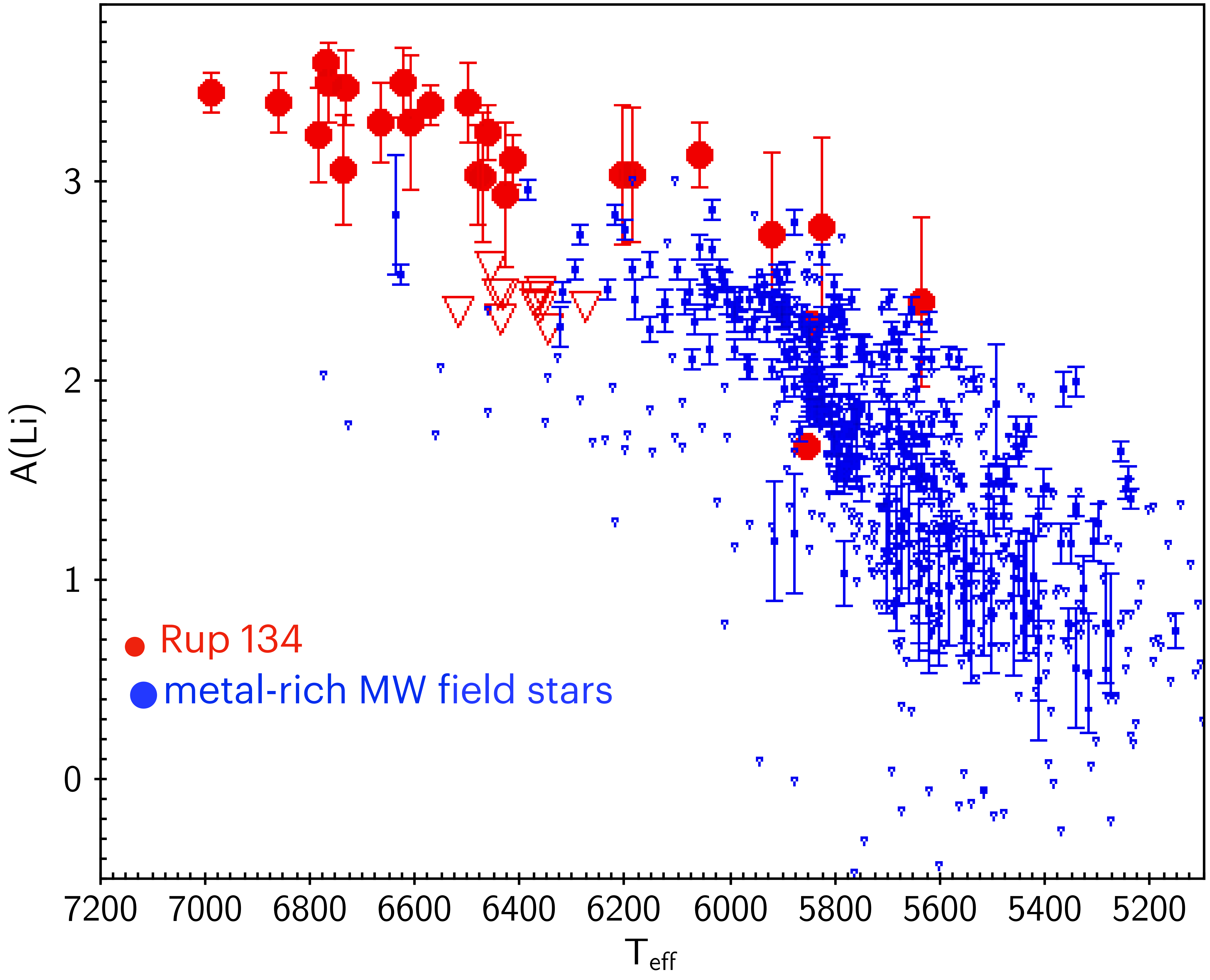
OPEN CLUSTER SAMPLE

Cluster	Age [Gyr]	R_{GC} [kpc]	[Fe/H] [dex]	$A(Li)_{max}$ [dex]	# of stars	T_{eff} range [K]
ρ Oph[a]	0.003	7.88	(−0.265)	3.28 ± 0.13	25	3006–4536 (pre-main sequence)
Alessi 43	0.011	8.18	+0.02 ± 0.06	3.27 ± 0.22	46	3513–5135 (pre-main sequence)
25 Ori[b]	0.013	8.31	(0.02)	3.18 ± 0.14	7	3119–3386 (pre-main sequence)
Collinder 197	0.014	8.20	(0.02)	3.21 ± 0.15	64	3515–4441 (pre-main sequence)
NGC 2232	0.018	8.27	(0.005)	3.22 ± 0.11	14	5031–6891 (young)
NGC 2547	0.032	8.05	(−0.055)	3.35 ± 0.10	8	5748–6286 (young)
IC 4665	0.033	7.71	(0.00)	3.44 ± 0.10	5	5674–6133 (young)
NGC 6405	0.035	7.54	(−0.01)	3.31 ± 0.08	7	5848–6419
IC 2602	0.036	7.95	(−0.01)	3.31 ± 0.13	4	5766–6438 (young)
Blanco 1	0.105	7.96	−0.12 ± 0.07	3.15 ± 0.04	7	5923–6476 (young)
NGC 6067	0.126	6.16	+0.03 ± 0.05	3.38 ± 0.09	15	6518–8000
NGC 6709	0.190	7.22	−0.03 ± 0.06	3.31 ± 0.01	2	6628–7410
NGC 2516	0.240	7.98	−0.04 ± 0.05	3.33 ± 0.07	3	6531–6839
Berkeley 30	0.295	13.59	−0.15 ± 0.05	3.11 ± 0.17	14	6630–6980
NGC 6705	0.309	6.02	+0.02 ± 0.01	3.34 ± 0.02	7	6673–6984
NGC 3532	0.398	7.85	−0.01 ± 0.05	3.25 ± 0.07	4	6825–6865
NGC 6802	0.660	6.71	+0.14 ± 0.04	3.32 ± 0.02	2	6677–6919
NGC 2355	1.000	9.84	−0.07 ± 0.05	3.17 ± 0.09	6	6716–6975
Berkeley 81	1.148	5.21	+0.22 ± 0.05	3.39 ± 0.11	1	6836
Berkeley 73	1.413	14.97	−0.26 ± 0.05	3.16 ± 0.11	8	6721–6885
Berkeley 44	1.445	6.58	+0.22 ± 0.05	3.21 ± 0.10	9	6564–6761
NGC 2158	1.549	13.18	−0.16 ± 0.05	3.19 ± 0.09	5	6585–6889
Ruprecht 134	1.660	5.44	+0.27 ± 0.05	3.47 ± 0.04	8	6697–6879
NGC 2420	1.738	10.49	−0.16 ± 0.05	3.19 ± 0.07	22	6378–6769 (turn-off)
Trumpler 20	1.862	6.82	+0.13 ± 0.04	3.29 ± 0.12	7	6700–6928
NGC 2243	4.365	11.00	−0.44 ± 0.05	2.94 ± 0.10	7	6064–6314 (post turn-off)

- Ages from young to relatively old
- Large galactocentric distance baseline
- For each cluster, only members that suffered minimal lithium depletion are selected to compute $A(Li)_{max}$

Romano+ (2021)

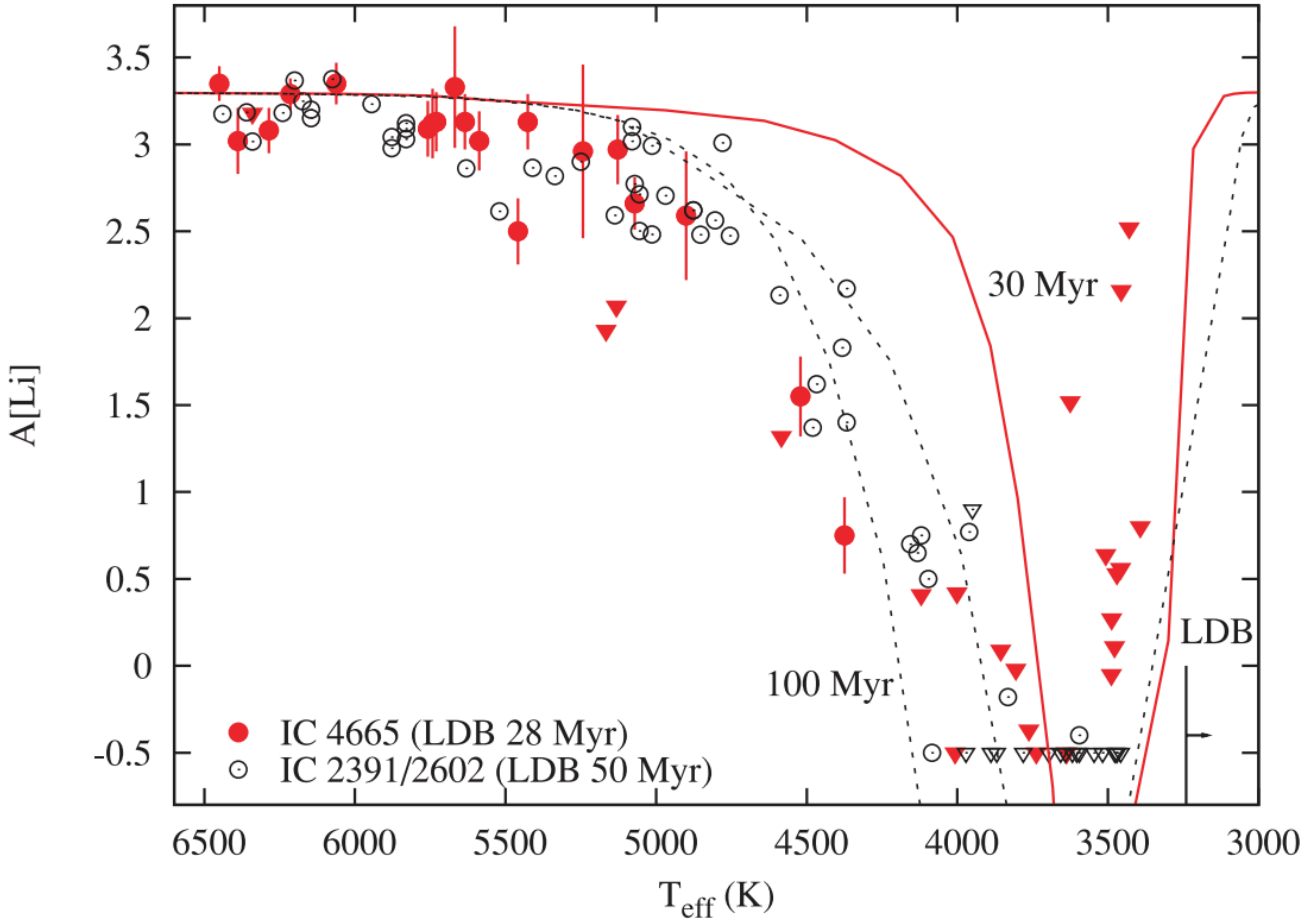
OPEN CLUSTER SAMPLE



Randich+ (2020)

- For clusters older than 100 Myr we use stars on the blue (warm) side of the Li dip (Boesgaard & Tripicco 1986)
- Exception: NGC 2243 (age = 4.4 Gyr)

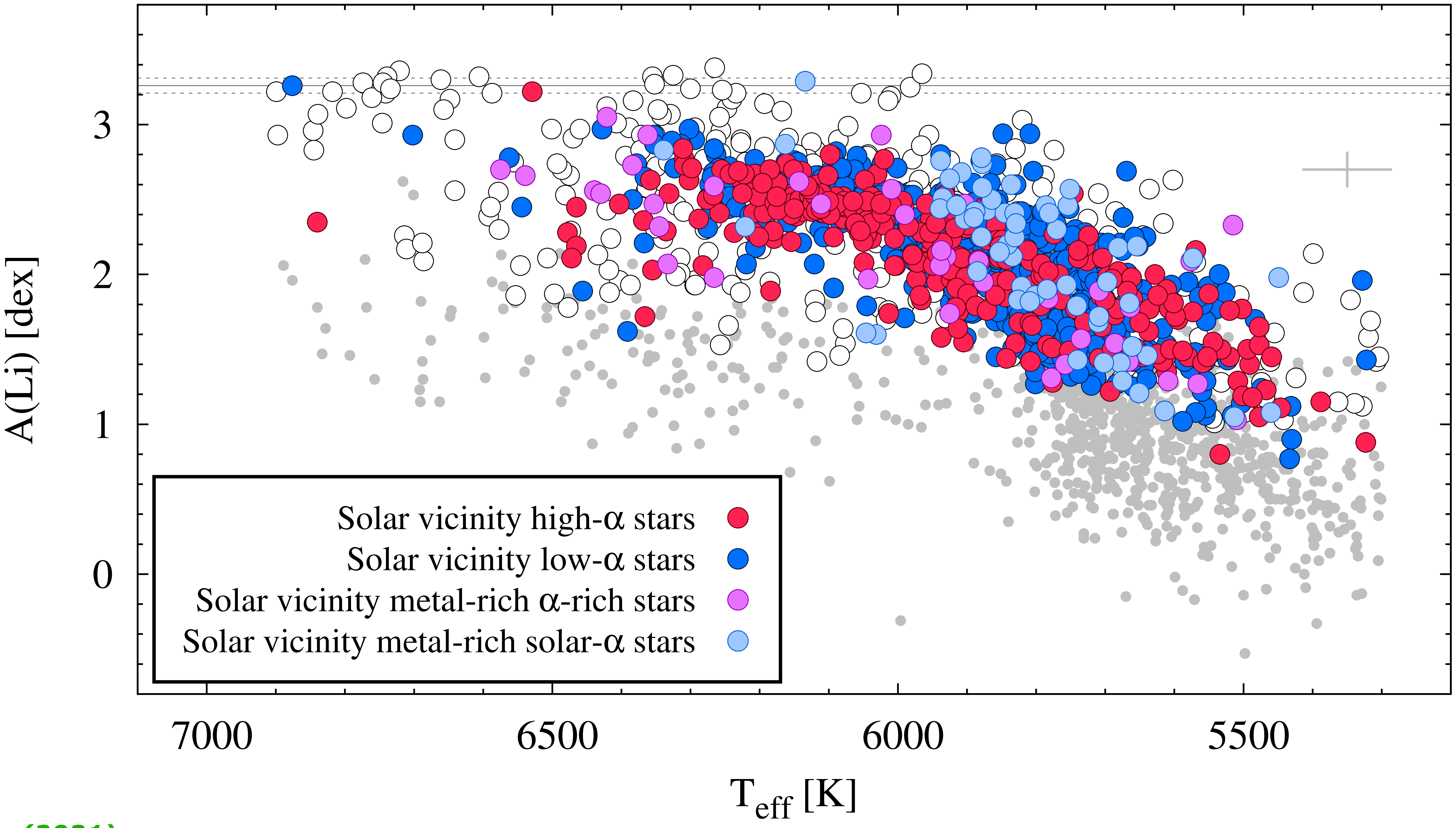
OPEN CLUSTER SAMPLE



Jeffries+ (2009)

- Cluster younger than 100 Myr host pre-main sequence or zero age main-sequence stars. ^{7}Li depletion may show up in cool members of clusters as young as 5 Myr (Bouvier+ 2016; Jeffries+ 2021) → use only stars that trace the upper envelope of the A(Li)—T_{eff} distribution in clusters sampled well enough
- Metallicity and rotation effects!

FIELD STAR SAMPLE



Chemical selection criteria (Recio-Blanco+ 2014; Guiglion+ 2016, 2019)

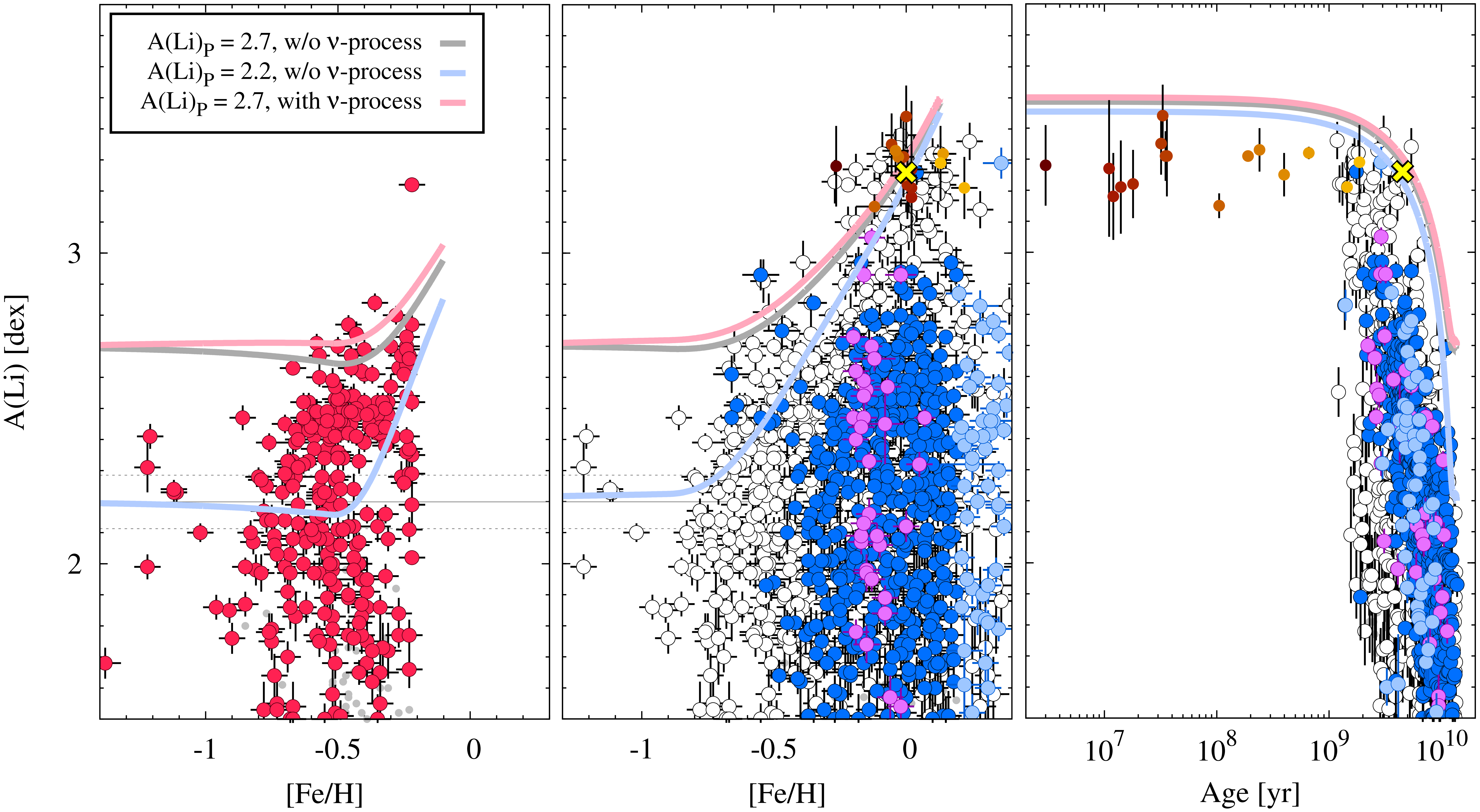
Romano+ (2021)

GaiaESO

Galactic Chemical Evolution of ^{7}Li

- Nucleosynthesis prescriptions (Romano+ 2019b, 2021):
  - For low- and intermediate-mass stars (1–9 $M_\odot$, including super-AGBs): yields from Ventura+ (2013, 2014, 2018, 2020)
  - For CCSNe (13–100 $M_\odot$): yields from Limongi & Chieffi (2018) + (halved) ν-process ^{7}Li yields from Woosley & Weaver (1995)
  - For SNeIa: yields from Iwamoto+ (1999)
  - Empirical ^{7}Li production from novae after Izzo+ (2015)
  - ^{7}Li production from GCR spallation after Lemoine+ (1998)

SOLAR NEIGHBOURHOOD



DATA:

- High-alpha stars
- Low-alpha stars
- Metal-rich alpha-rich
- Metal-rich solar-alpha
- No [alpha/Fe]
- OC / A(Li)max

NO ^{7}LI DECREASE AT HIGH [Fe/H] (also Guiglion+ 2019; Randich+ 2020; Charbonnel+ 2021)

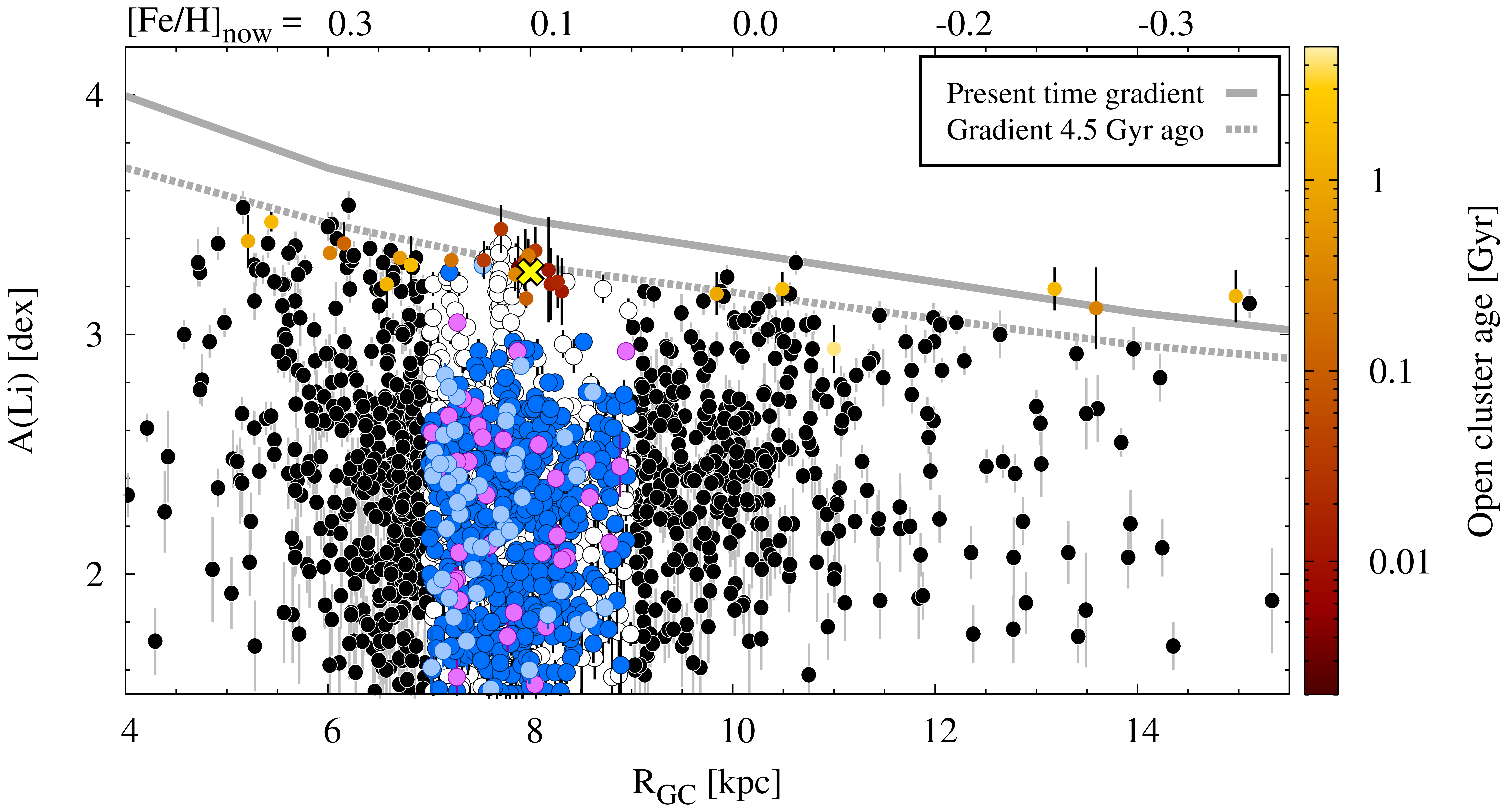
MODELS:

Left: thick disc

Middle and right: thin disc

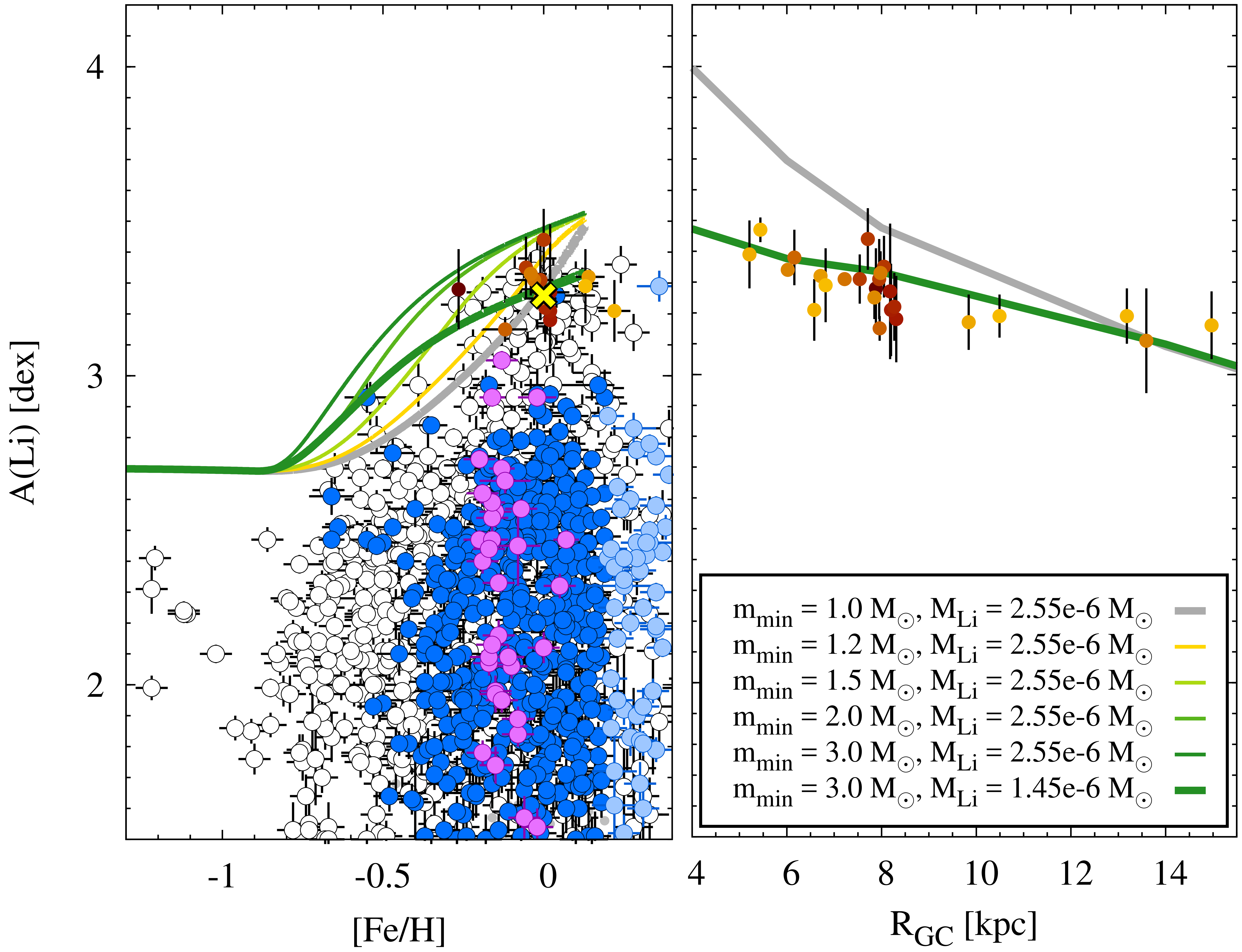
Romano+ (2021)

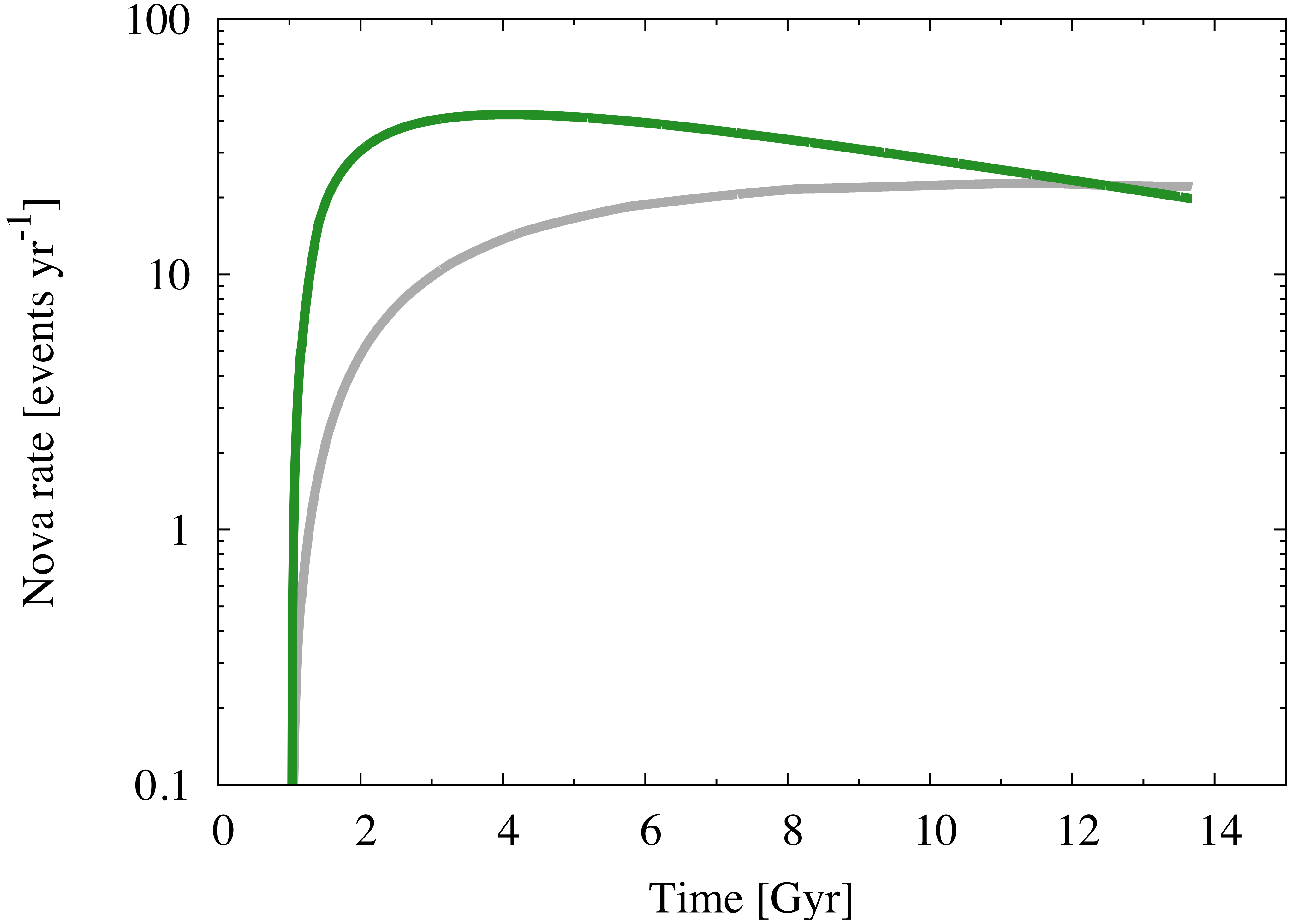
DISC GRADIENT



Romano+ (2021)

IMPLICATION: HIGHER MASSES OF NOVA PROGENITORS?

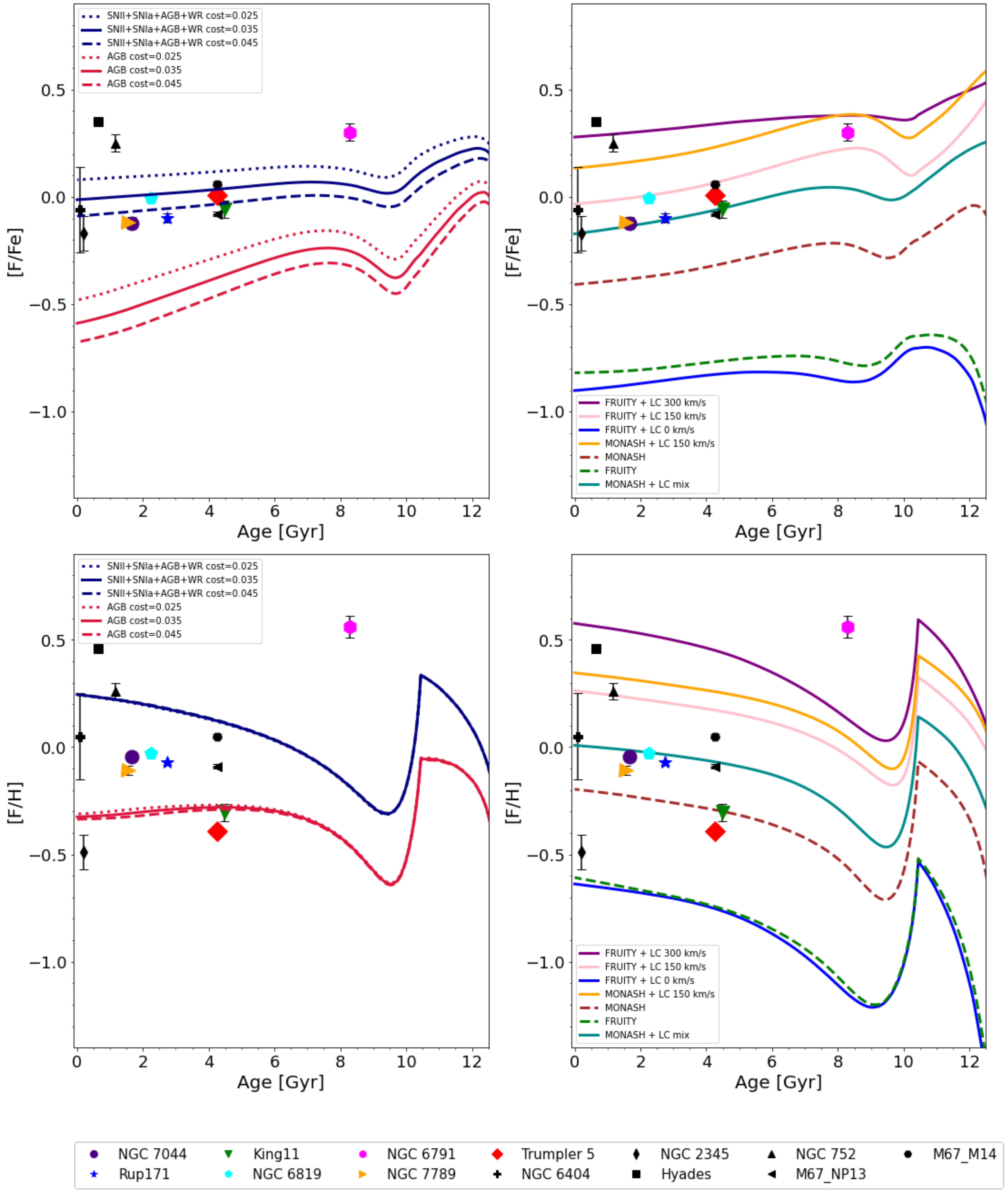




Lower nova rate at higher metallicities

(Gao+ 2014, 2017; Fu+ 2018; Grisoni+ 2019)

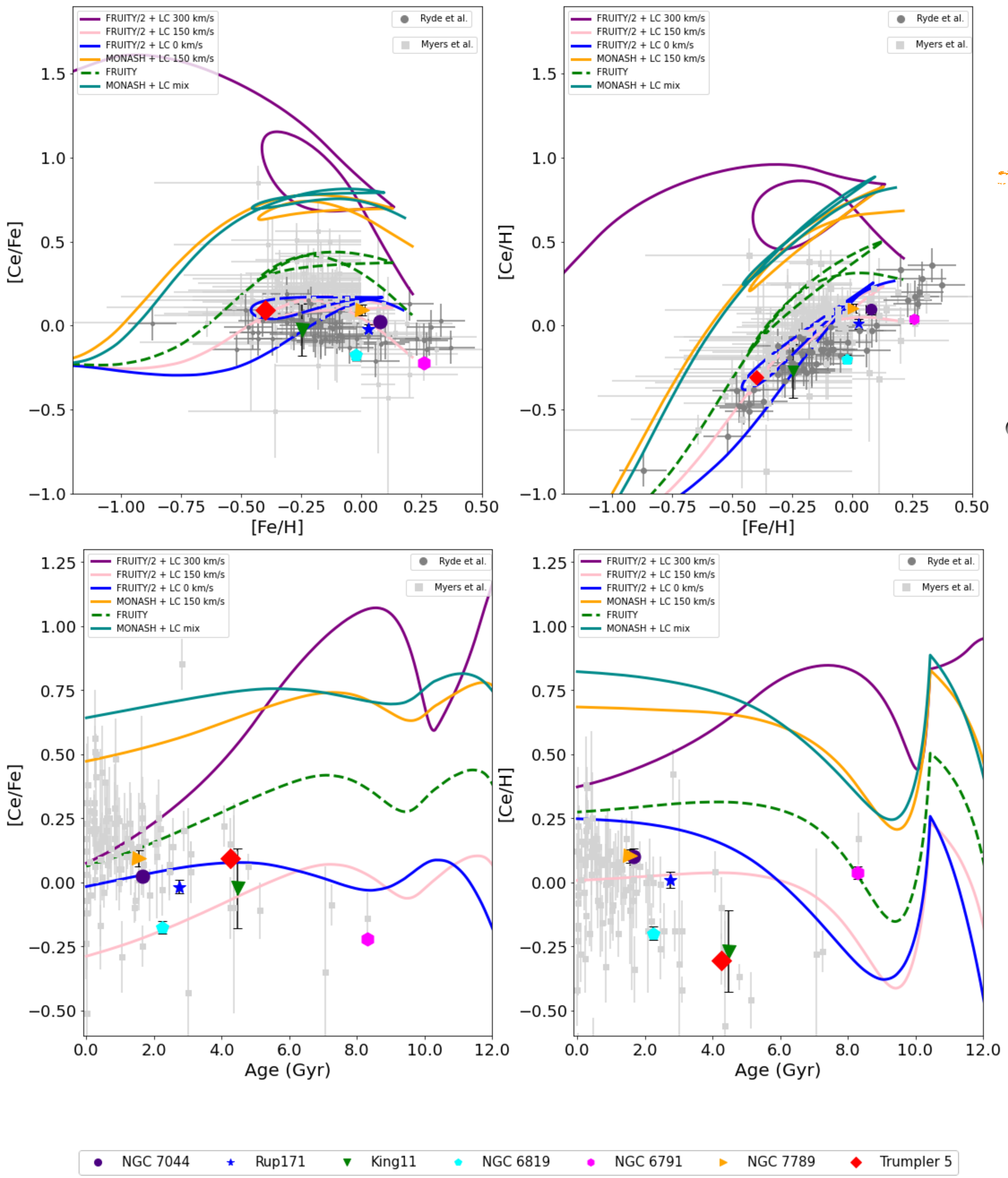
Romano+ (2021)



FLUORINE

- Nucleosynthesis prescriptions:
  - Left panels: yields from Karakas (2010); Kobayashi+ (2006); Meynet & Maeder (2002)
  - Right panels: yields from FRUITY (Cristallo+ 2009, 2011, 2015); Monash (Lugaro+ 2012; Fishlock+ 2014; Karakas & Lugaro 2016; Karakas+ 2018); Limongi & Chieffi (2018)

Bijavara Seshashayana+ (2024)

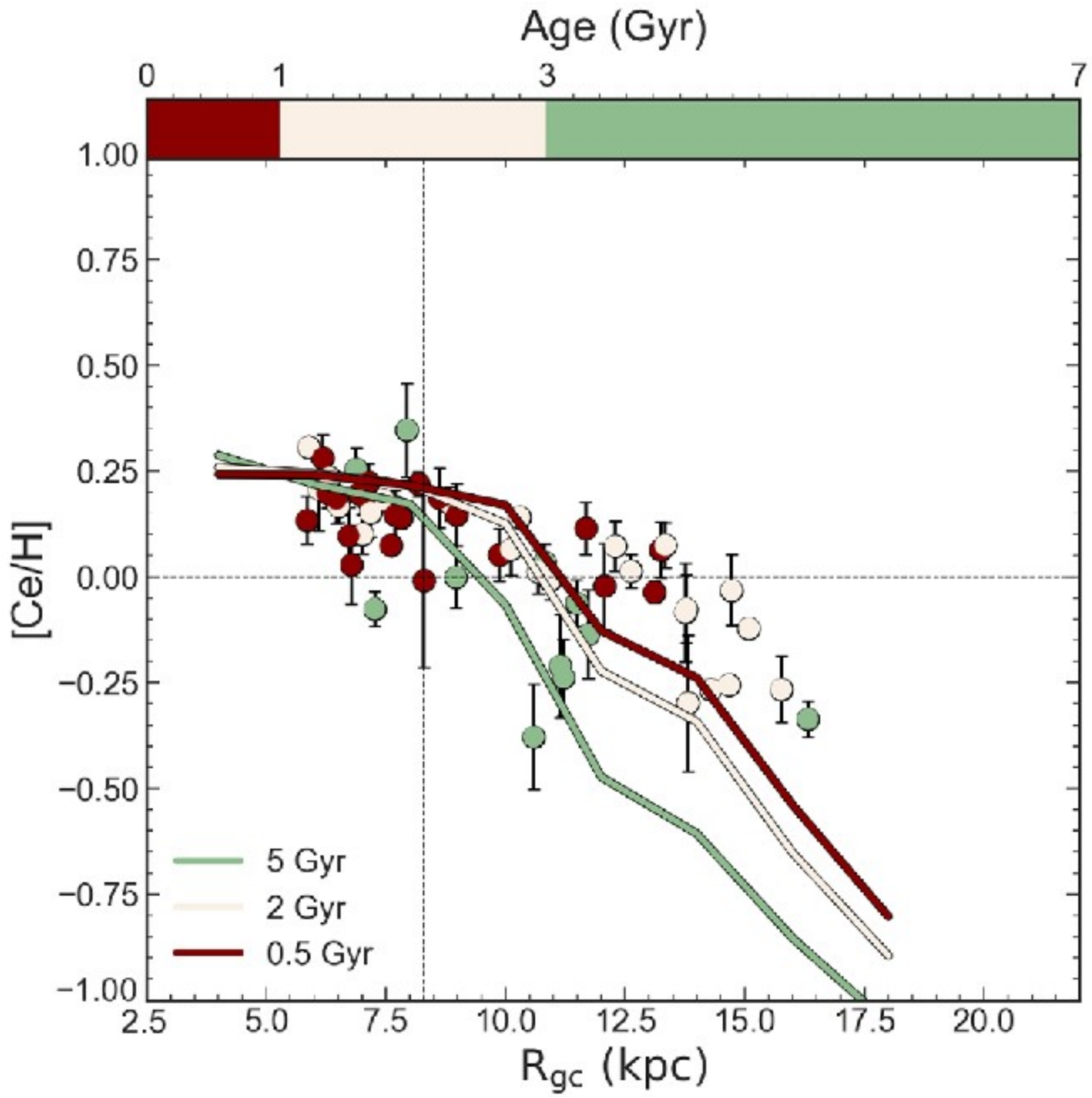


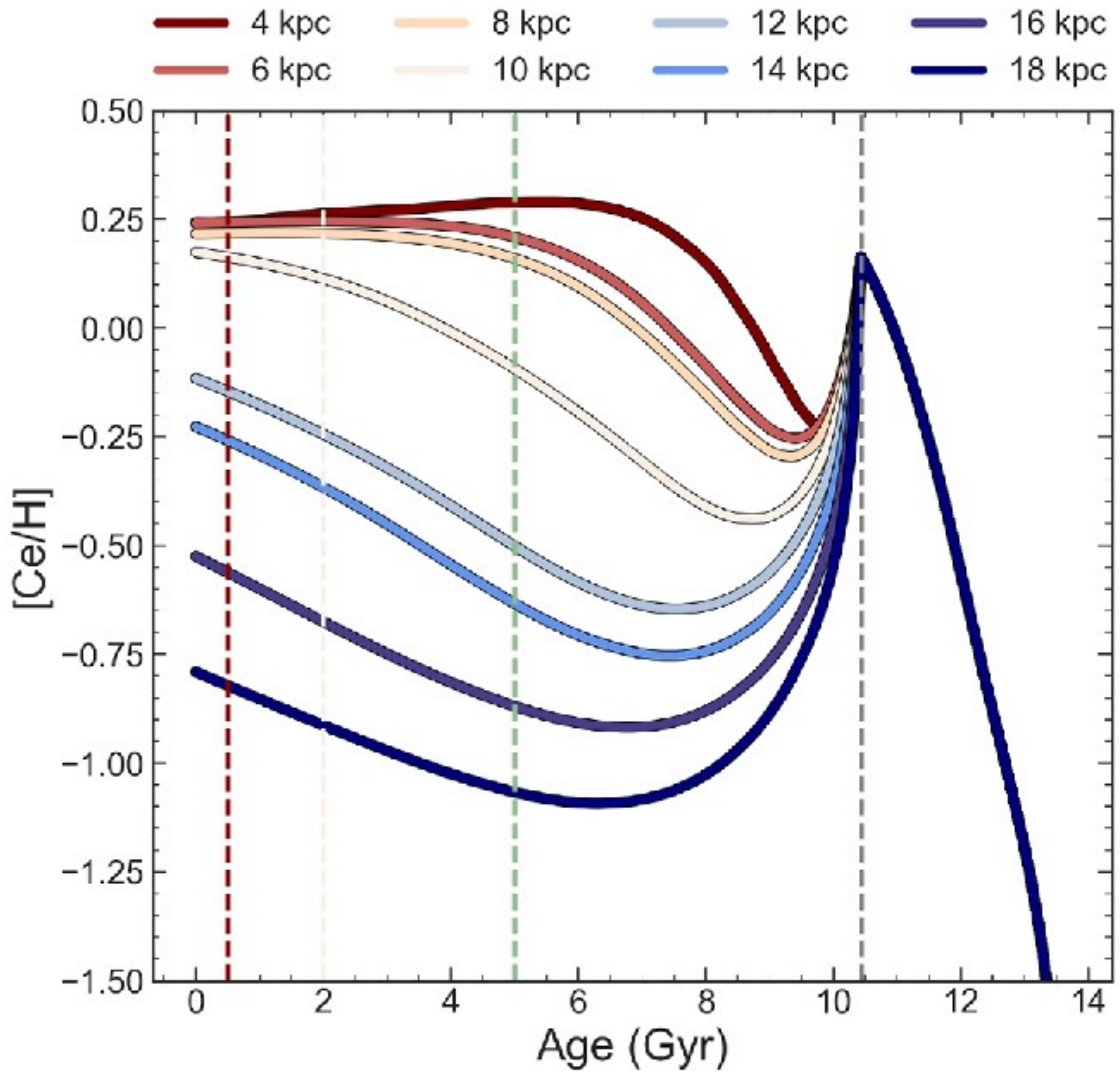
CERIUM

- Nucleosynthesis prescriptions:
  - ☆ Yields from FRUITY (Cristallo+ 2009, 2011, 2015); Monash (Lugaro+ 2012; Fishlock+ 2014; Karakas & Lugaro 2016; Karakas+ 2018); Limongi & Chieffi (2018)

Bijavara Seshashayana+ (2024)

CERIUM

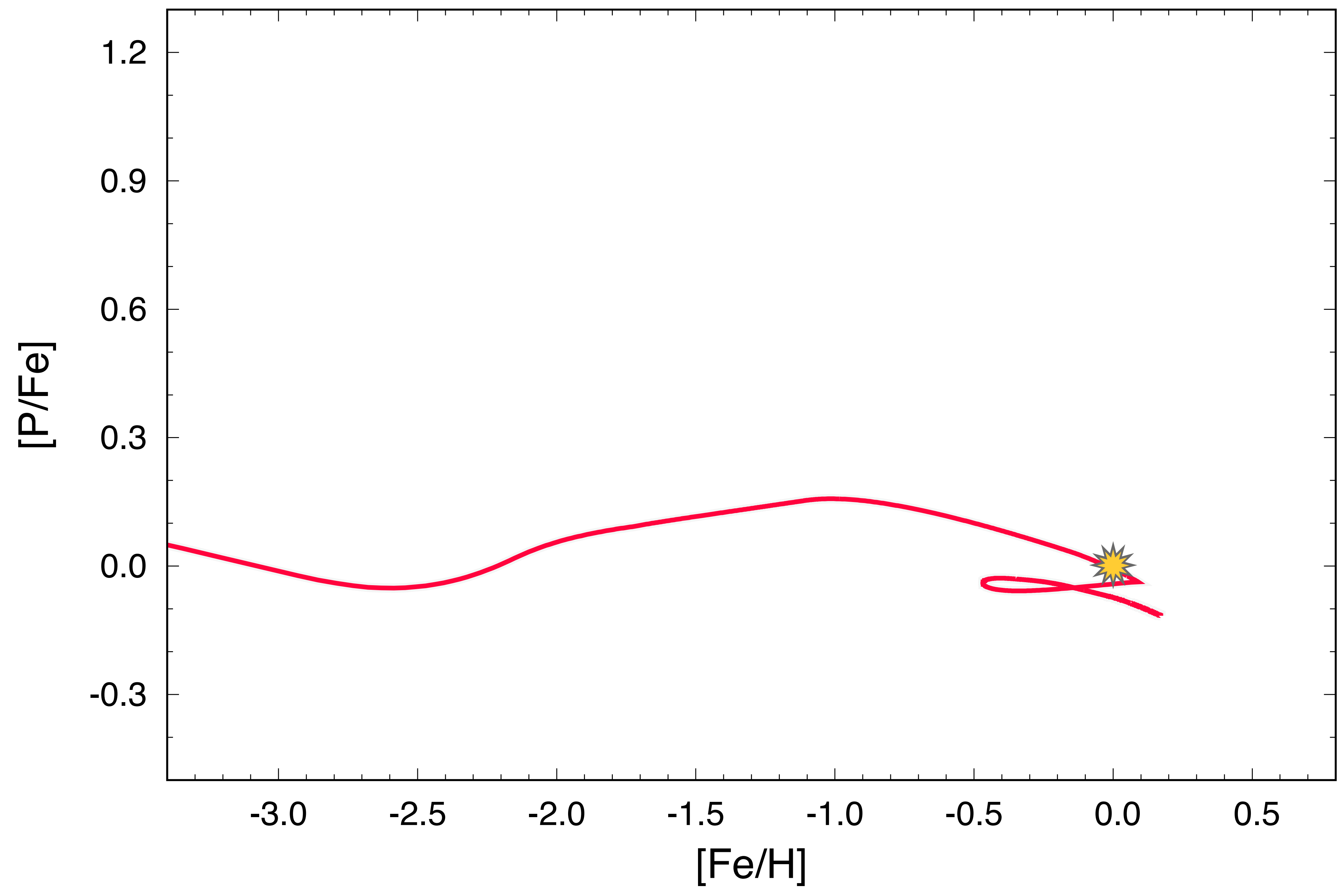




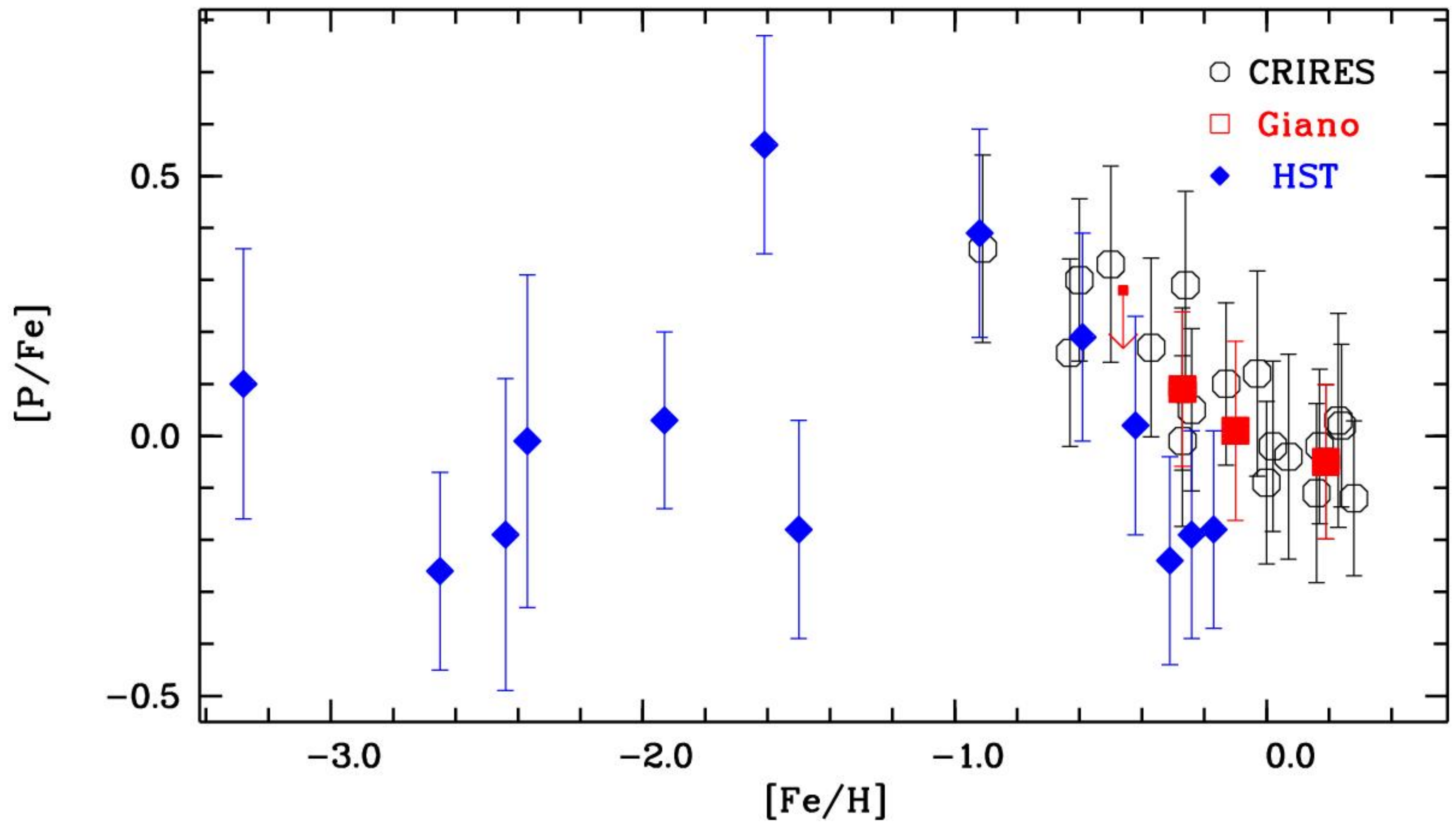
Molero+ (2023)

PHOSPHORUS

- Observe P-bearing molecules across the Galactic disc, 0-22 kpc (with L. Colzi & V. Rivilla)
- Stellar abundances (SPA-OC?). P I NIR lines @ ~1050 nm or UV lines @ ~213 nm (from space)
- GCE models exploring different grids of stellar yields



Romano+ (in prep.)



Caffau+ (2016)

NOTES