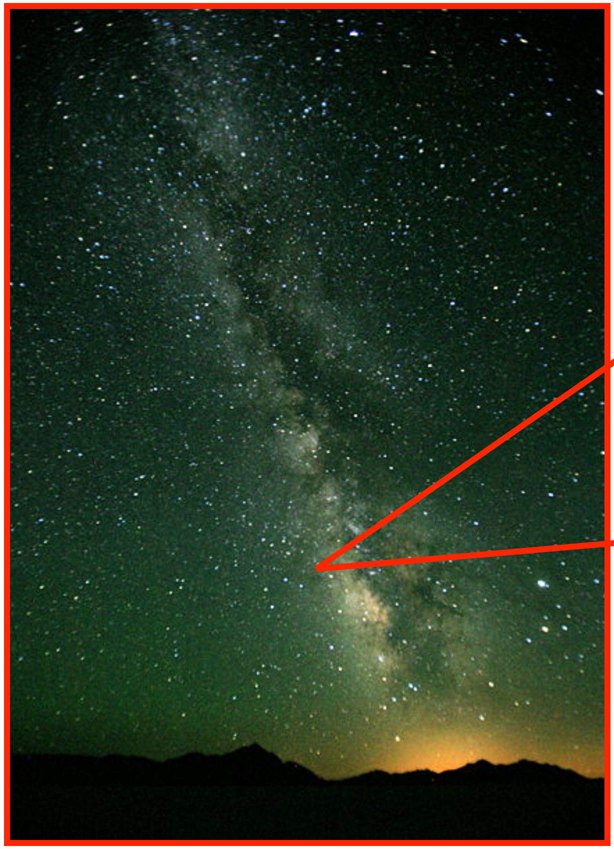
Chemical Abundance Anomalies as Tracers of Multiple Stellar Populations in the Globular Cluster M22



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Collaborators

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Outline

- The Galactic Globular Cluster (GC) System and M22
- Observational Data and Main Goal
- Results and Comparisons
- Conclusions and Perspectives

Alves-Brito et al. A&A, 2012

and see also D'orazi et al. ApJ, 2013

Why we care about globular clusters (GCs)?

Gravitationally-bound systems of $\sim 10^5$Msun

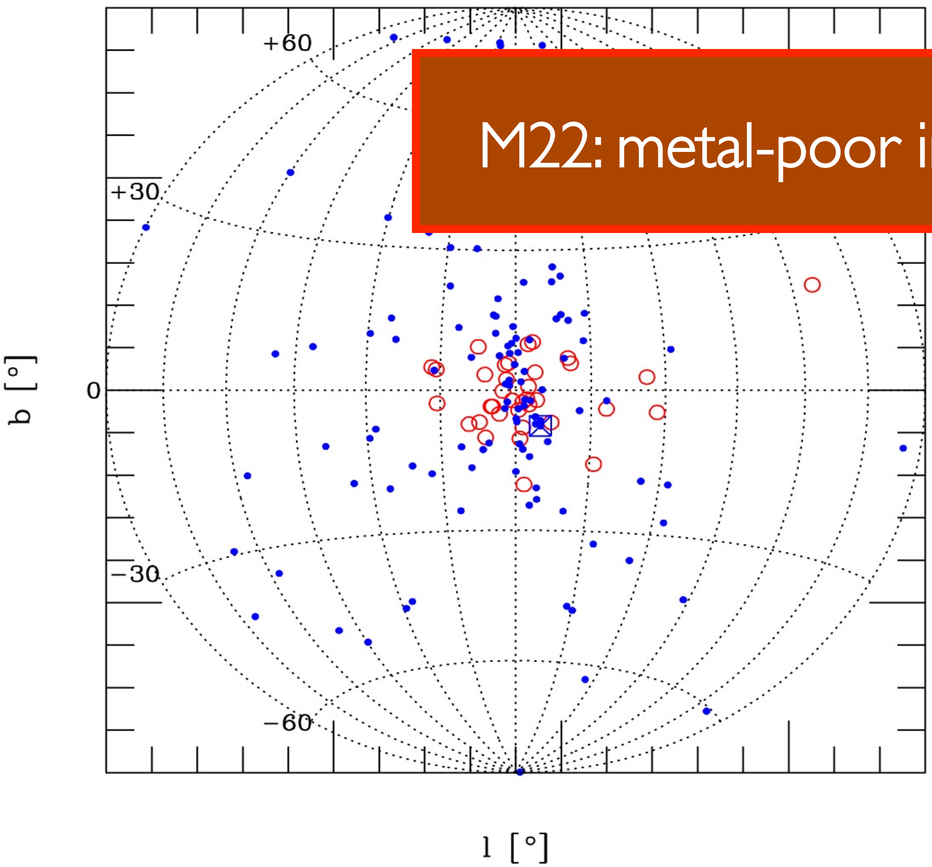
- Among the oldest objects in the Universe
- Very bri[illegible]s
- Present in all Hubble morphological types

The deaths of stars and the lives of galaxies

Harris 1991; Gratton et al. 2004; Brodie & Strader 2006

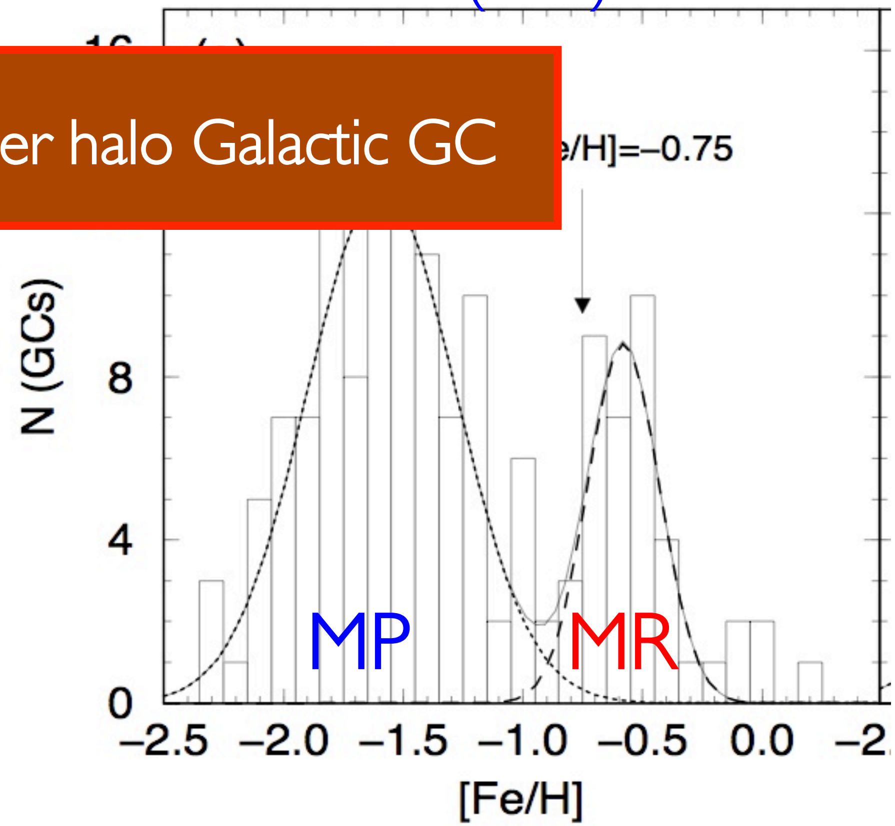
The Galactic GC system: ~ 150 GCs

M22: metal-poor inner halo Galactic GC



Catalogue used: Harris 1996, 2010

Bica et al. (2006)



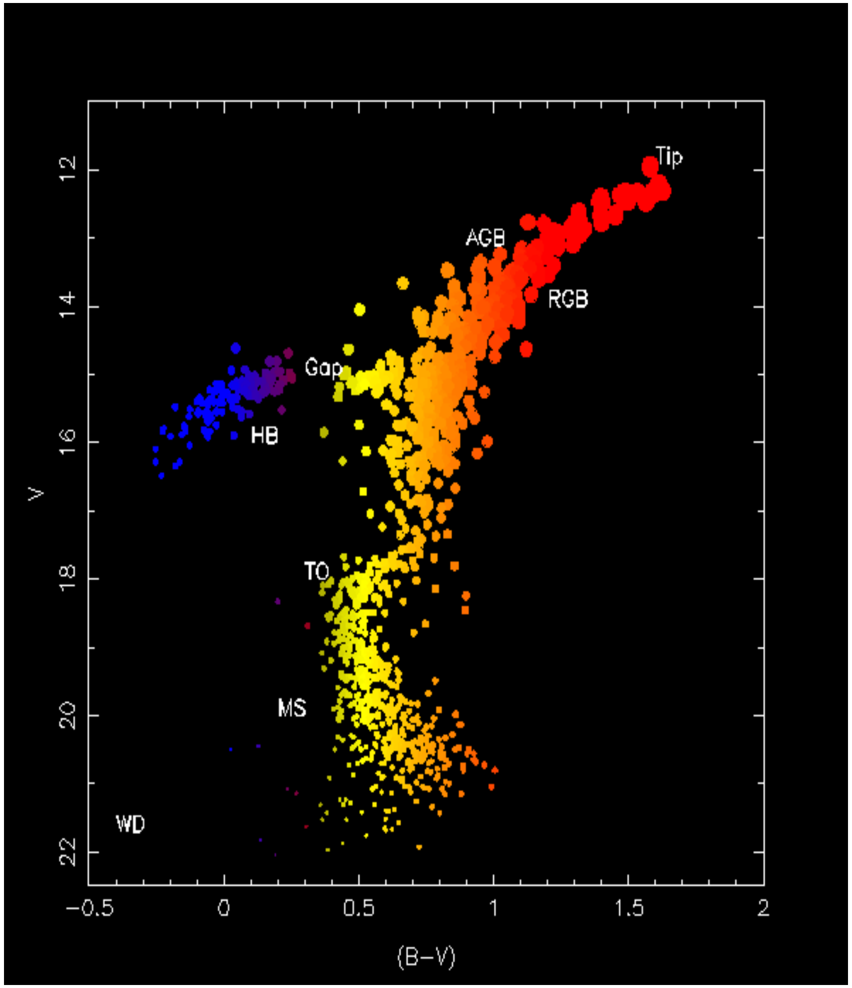
[Fe/H] = log(Fe/H)_star - log(Fe/H)_sun

GCs: Simple Stellar Populations (SSPs)?

Characterizing a SSP:

(Renzini & Buzzoni 1986)

- Age
- Composition (Y and Z)
- IMF



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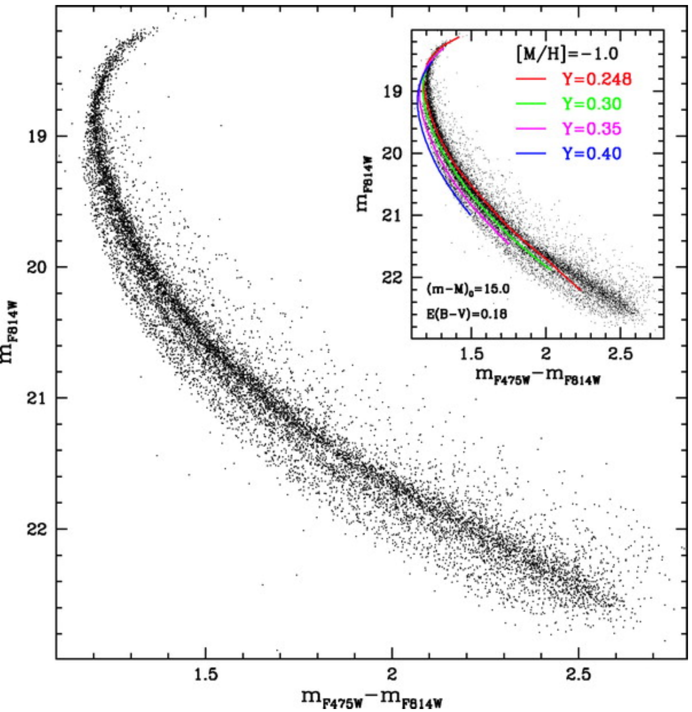
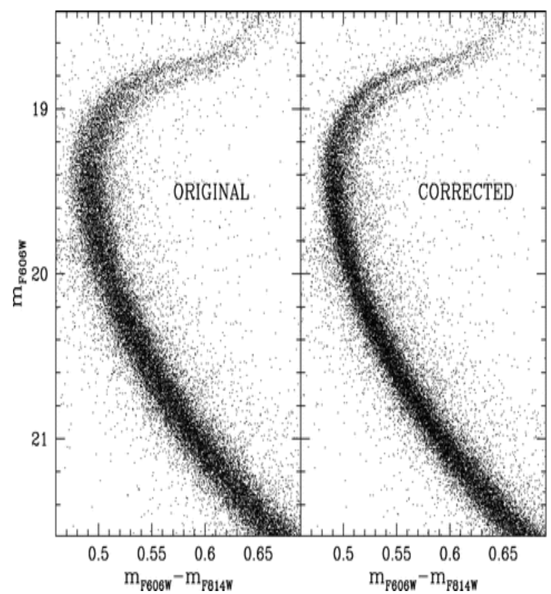
Photometry: GCs ARE NOT SSPs

Galactic

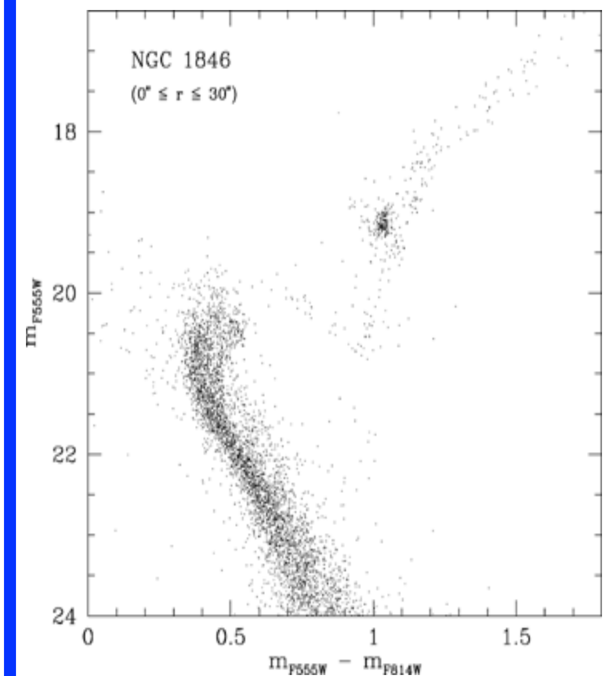


NGC2808: Piotto et al. 2007

NGC1851: Milone et al. 2008



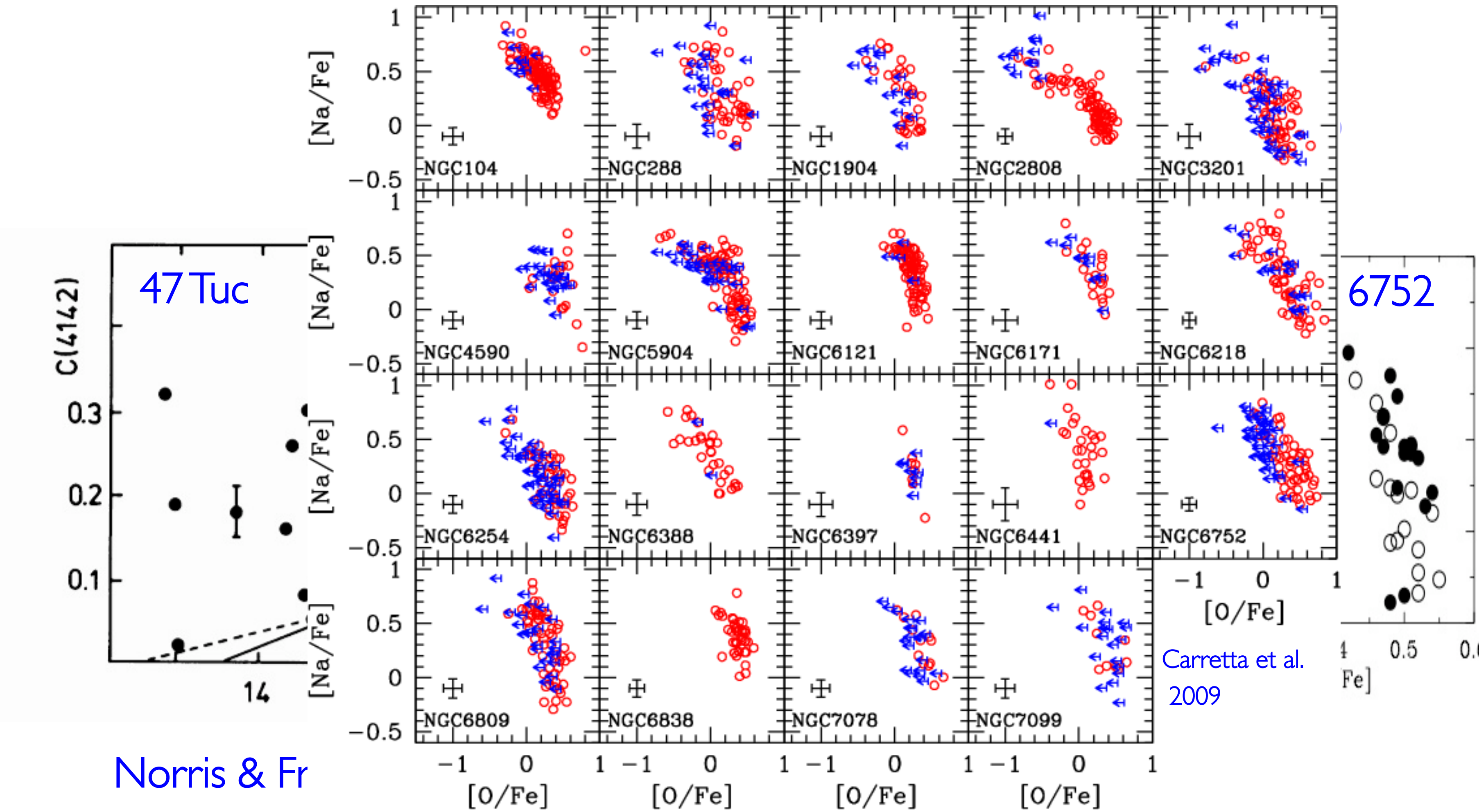
Extragalactic



LMC NGC1846:

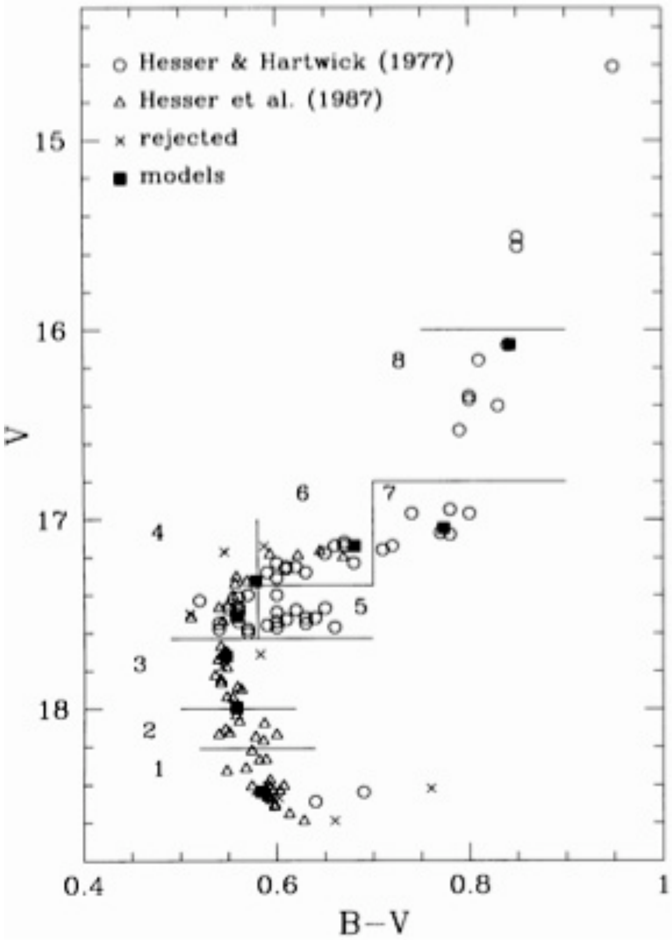
Mackey et al. 2007

Spectroscopy: GCs ARE NOT SSPs



How to understand this puzzle?

e.g. Cannon et al. 1998; Gratton et al. 2001



Anticorrelations comes from HOT hydrogen burning: C(NO), Ne-Na, Mg-Al

1. IM-AGB stars (4 – 8 Msun) experiencing Hot Bottom Burning (e.g. Cottrell & Da Costa 1981; Ventura & D'Antona 2009)

2. (Winds of) Fast Rotating Massive Stars (20-120Msun, e.g. Norris 2004; Maeder & Meynet 2006)

see also Valcarce & Catelan 2011

Why should we study M22?

- CO, CH, A(Ca) and CN variatior

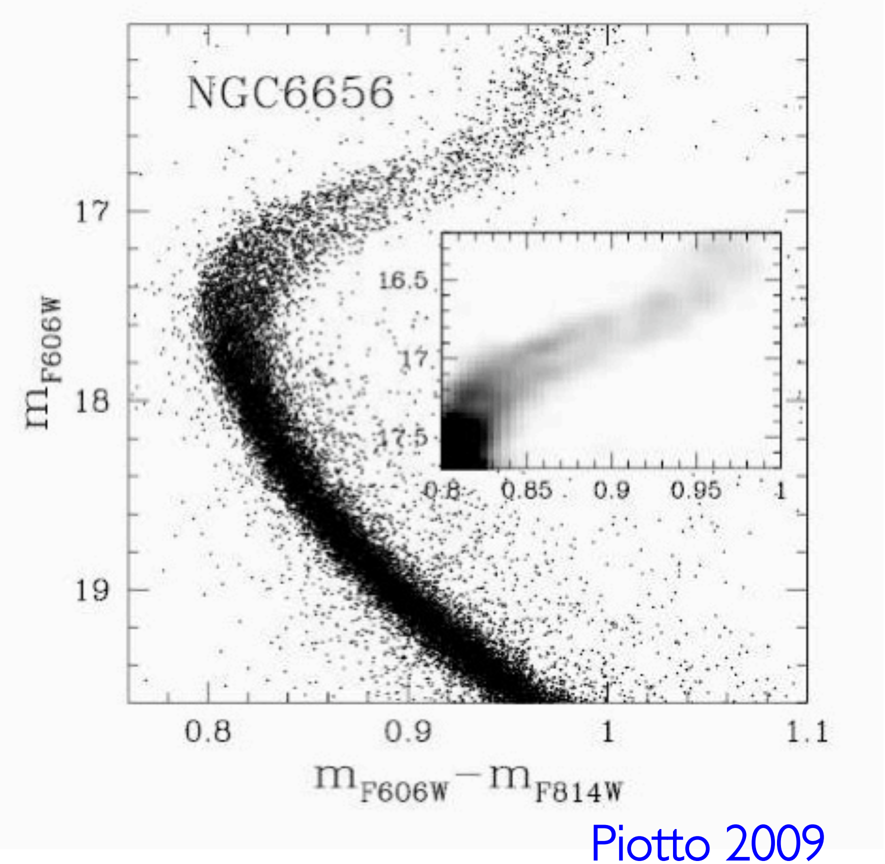
  1990; Kayser et al. 2008)

- Is there a [Fe/H] abundance sprea

  - R limited to 20,000:

  Pilachowski et al. 1982; Brown et. Al 199(

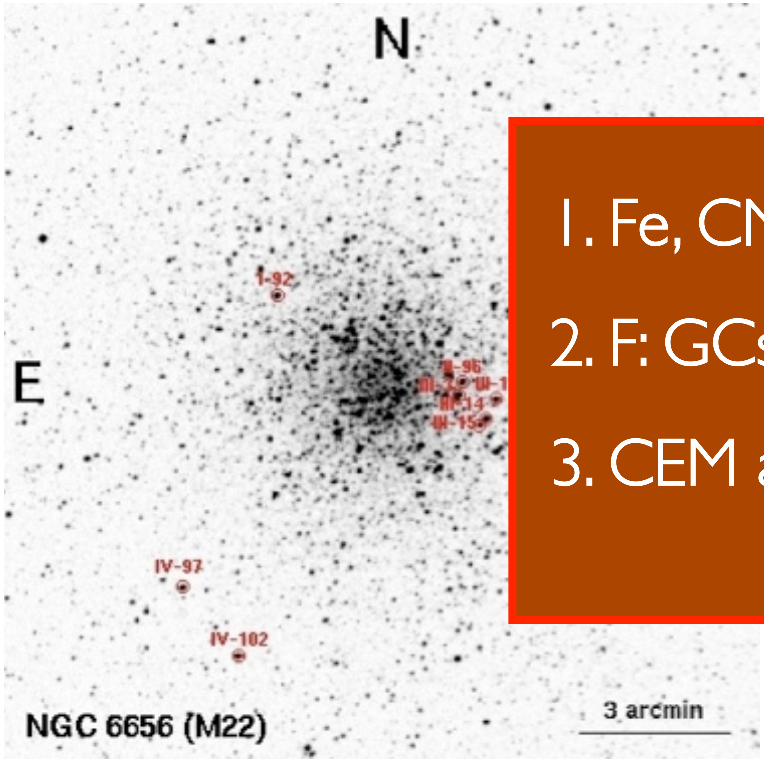
  Cohen 1981; Gratton 1982; Ivans et al. 2(

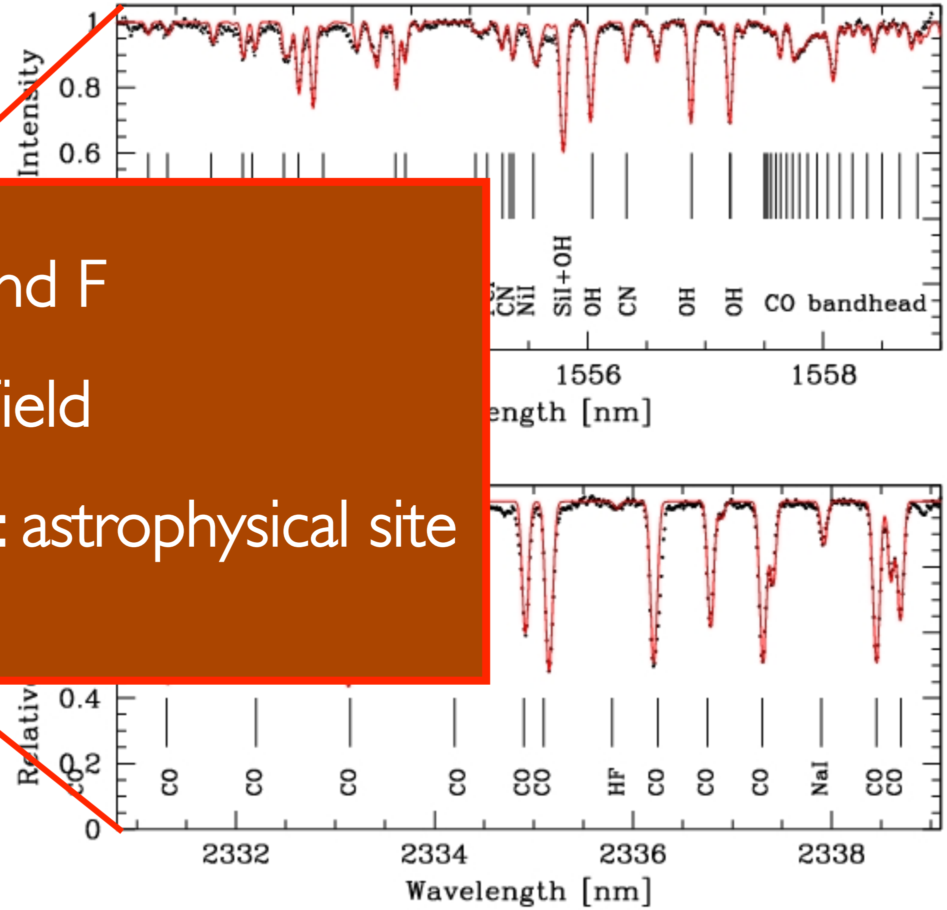


Piotto 2009

controversial results

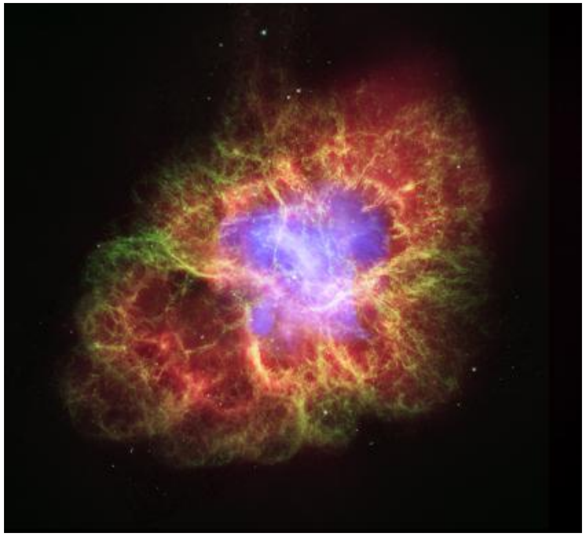
Observations and Main Goal





1. Fe, CNO and F
2. F: GCs vs. Field
3. CEM and F: astrophysical site

CNO and Fe: Astrophysical Sites



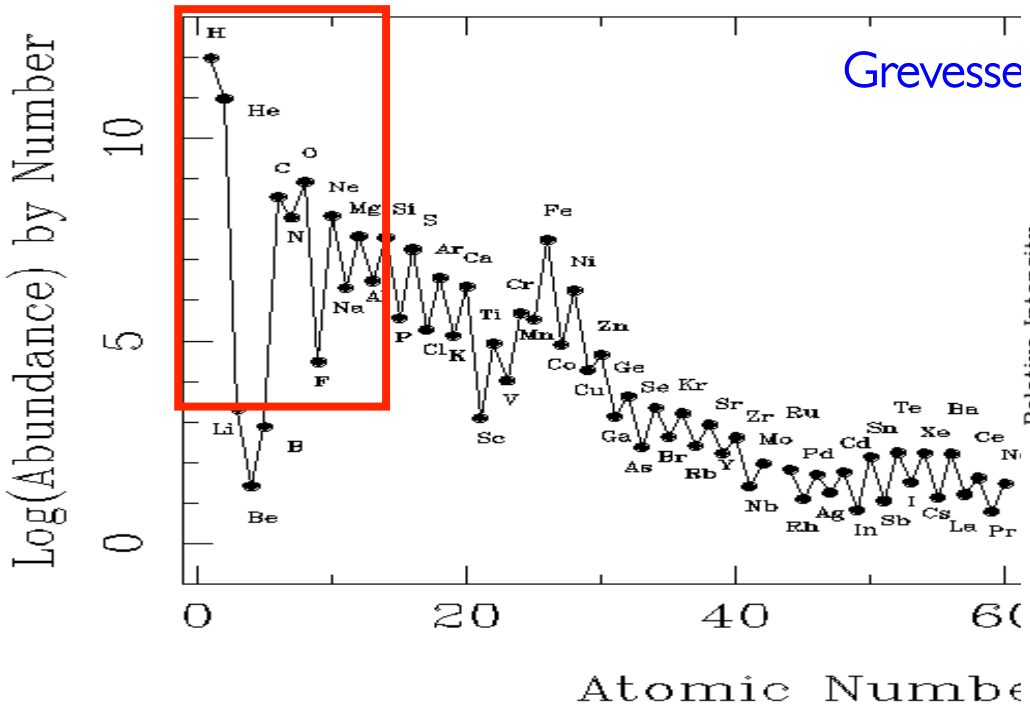
SN II: O, Mg, … (Myrs)

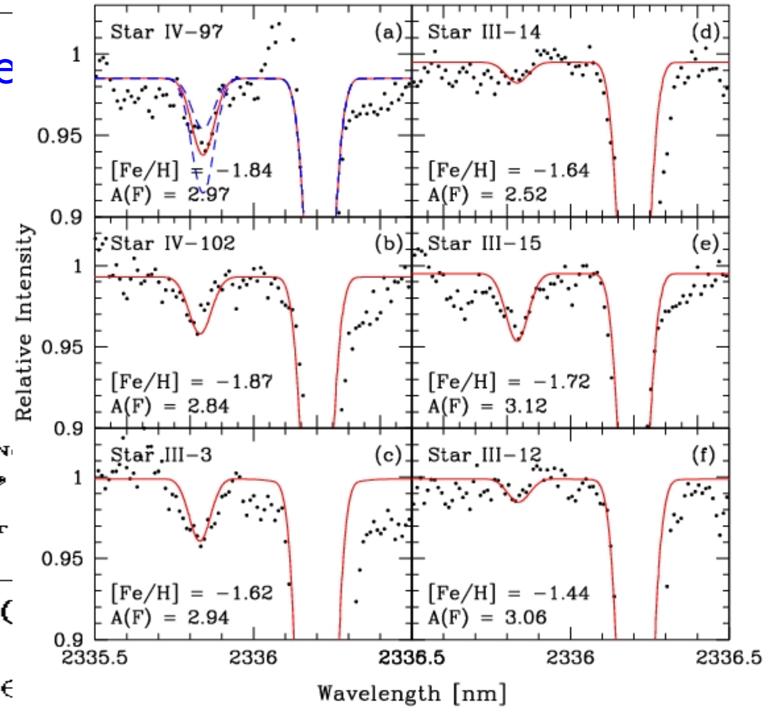
SN Ia: Fe, … (Gyrs)

PNe: C, N (Gyrs)

The deaths of stars and the lives of galaxies

What about F?





- Neutrino spallation: SNeII (Woosley & Haxton 1988)
- He-rich intershell of TP-AGB stars (Jorissen et al. 1992; Cristallo et al. 2009; Karakas & Lattanzio 2007)
- He-burning core of Wolf-Rayet stars (Meynet & Arnould 2000)

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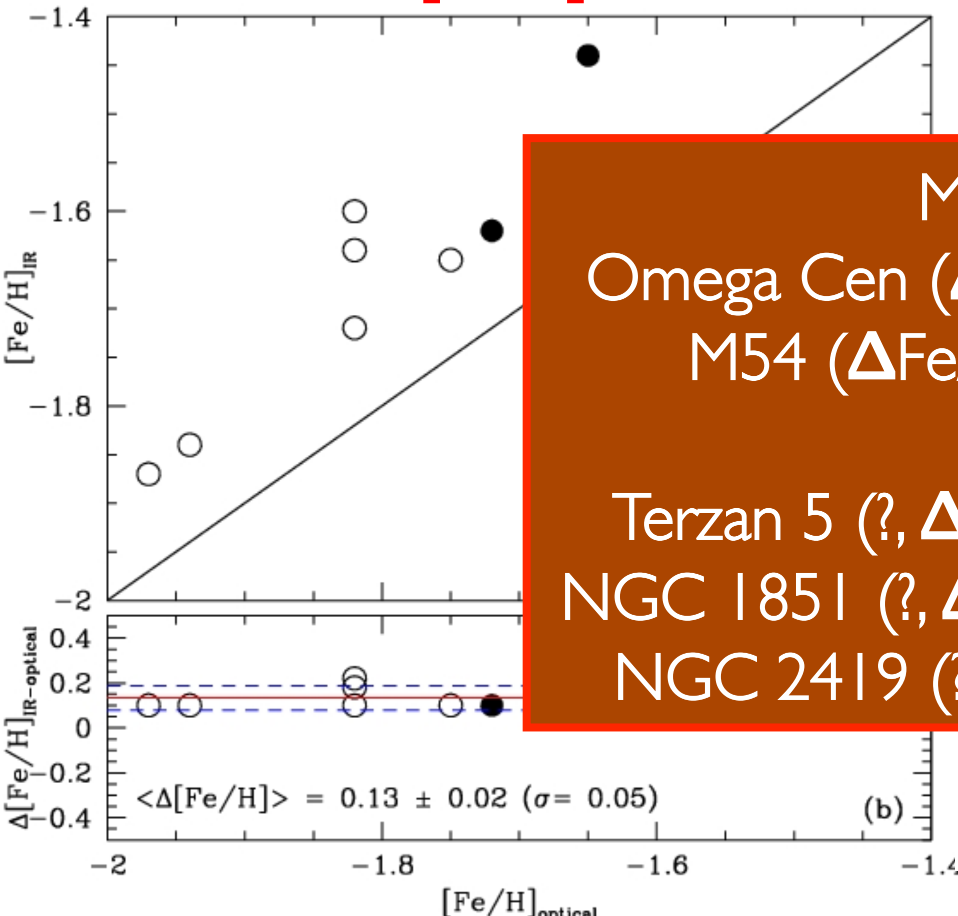
[Fe/H]

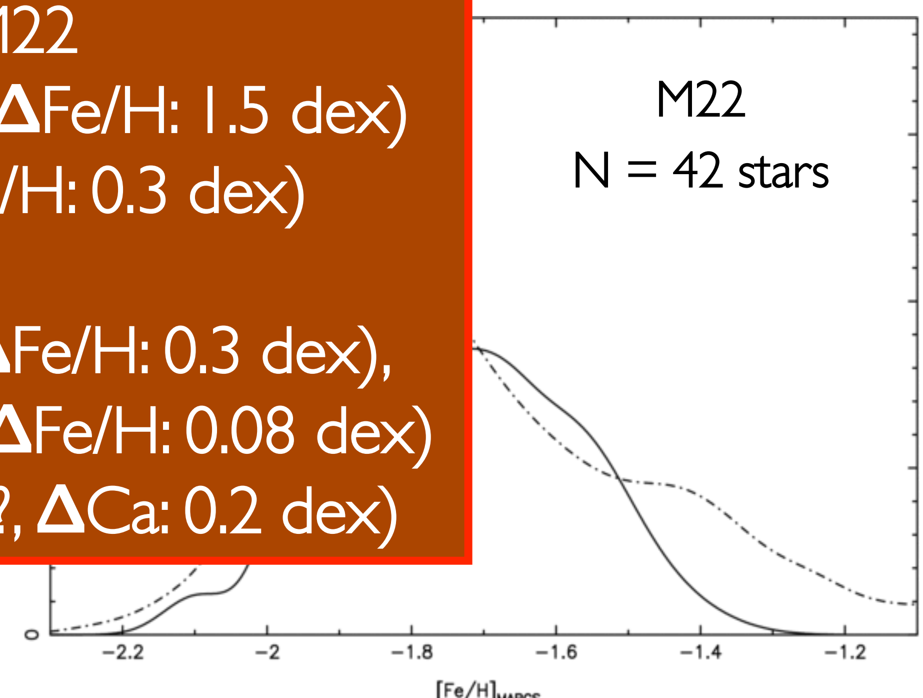
-1.9 < [Fe/H] < -1.4



s-poor ● s-rich

M22
Omega Cen (ΔFe/H: 1.5 dex)
M54 (ΔFe/H: 0.3 dex)

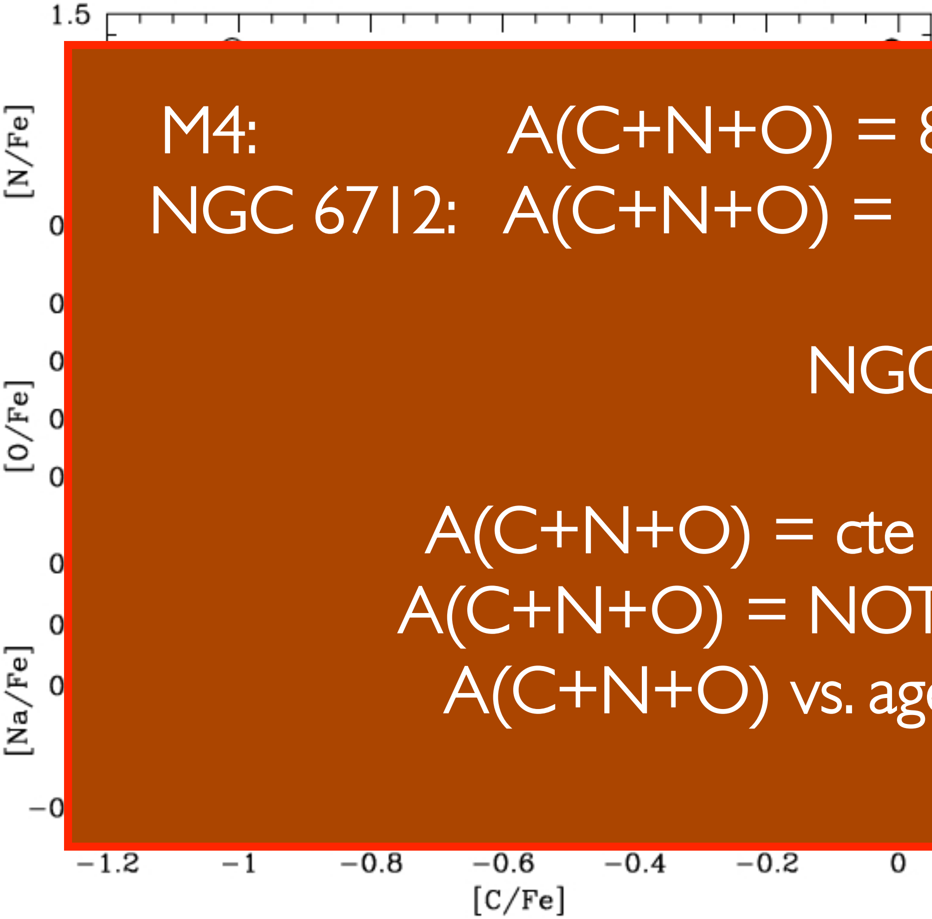
Terzan 5 (?, ΔFe/H: 0.3 dex),
NGC 1851 (?, ΔFe/H: 0.08 dex)
NGC 2419 (?, ΔCa: 0.2 dex)



Da Costa et al. 2009,
but see also Marino et al. 2009

[(C,N,O, Na)/Fe]

See also Marino et al. 2009; 2011



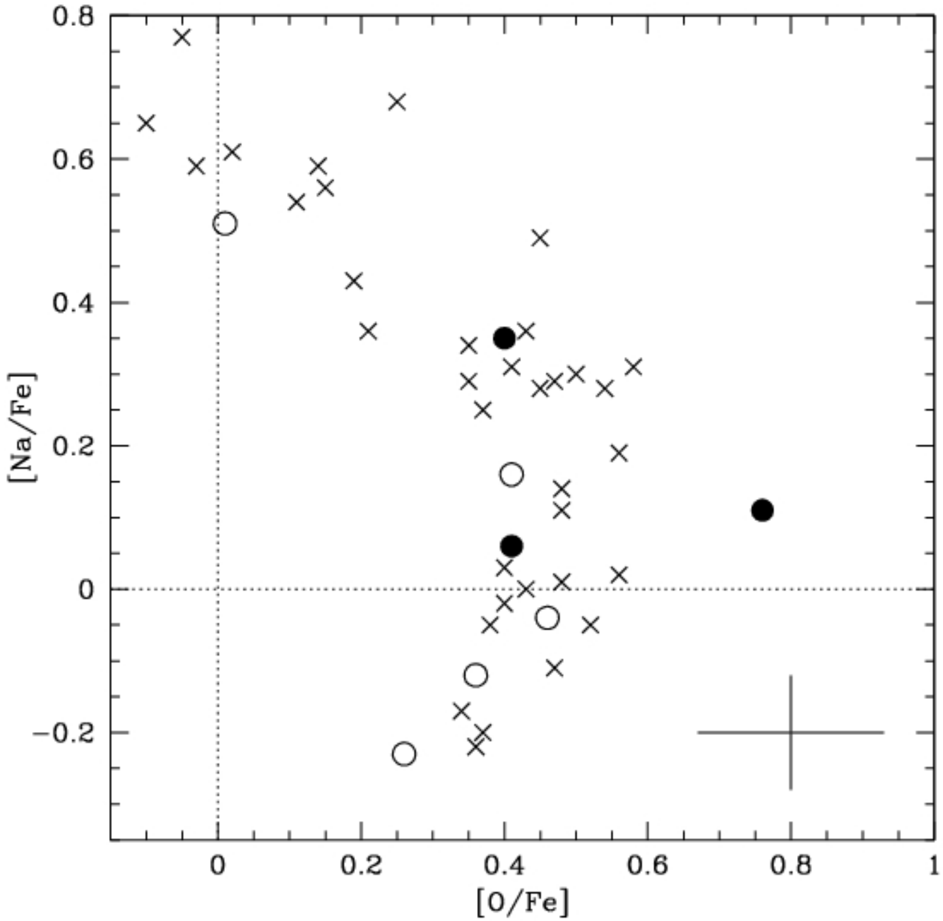
M4: A(C+N+O) = 8.16 +/- 0.08 (Smith et al. 2005)
NGC 6712: A(C+N+O) = 8.39 +/- 0.14 (Yong et al. 2008)

NGC 1851:

A(C+N+O) = cte (Villanova et al. 2010)
A(C+N+O) = NOT cte (Yong et al. 2009)
A(C+N+O) vs. age (Cassisi et al. 2008)

[(Na, O)/Fe]: IR vs. Optical

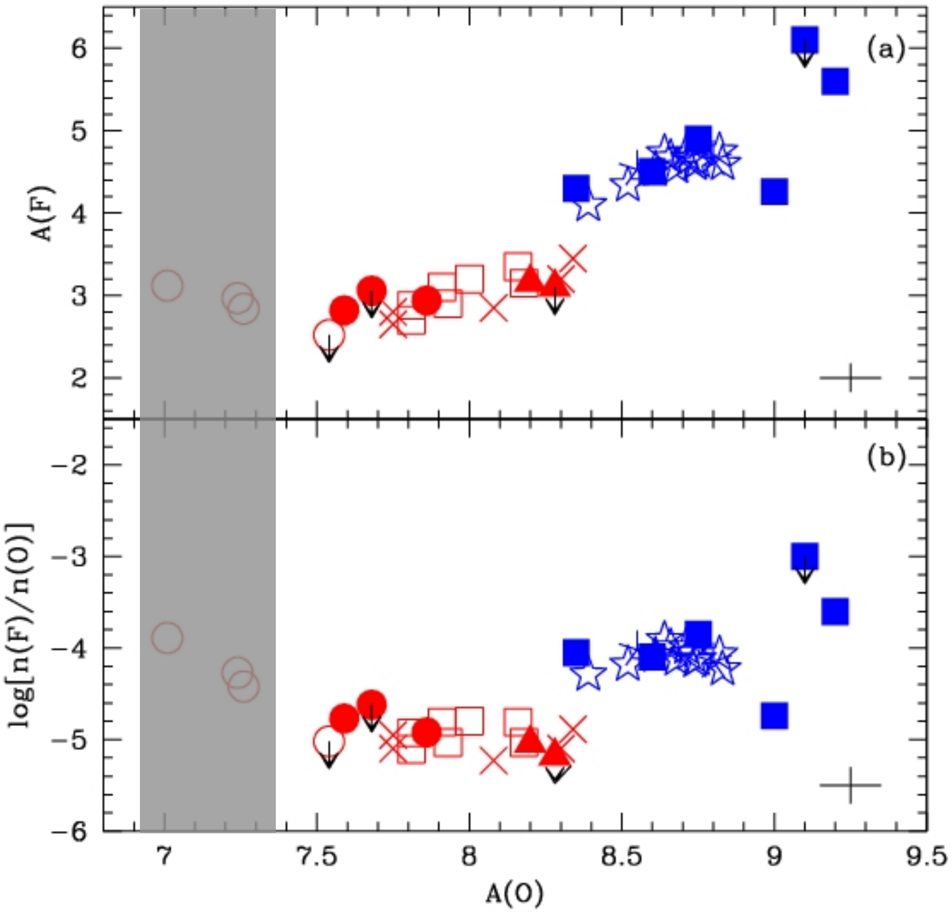
See also Marino et al. 2009; 2011



○ s-poor ● s-rich

Field vs. GCs: A(F) vs. A(O)

A(F) ~ 0.6 dex : -0.86 < [F/O] < +0.27: see also D'orazi et al. 2013



○ s-poor ● s-rich

Field stars: Cunha et al. 2003,2008; Cunha & Smith 2005

GC stars: M4 (❏, Smith et al. 2005); NGC6712 (X, Yong et al. 2008); and Omega Cen (▲, Cunha et al. 2003)

Conclusions and Perspectives

Our study confirms and expands upon the chemical diversity seen in this complex stellar system, where both massive and low mass stars have contributed

- Th
- La
- A(C+N+O) ~ 0.7 dex; but cte in the M22 s-process groups

A(C, N, O, F, Na, Fe) vs. A(**α**-, s- and r-process elements): what are they telling us about the death of the stars?

- N
- F abundance spread of 0.6 dex is found
- [F/O] v

A(F):
further investigation is necessary, GCs vs. field

Australian National University

ESO

¡muchas gracias!

BESO

Uncertainties

$\Delta T = \pm 100K : \Delta \log g = \pm 0.30$ dex : $\Delta v = \pm 0.20$ Km/s

C: 0.10 dex

N: 0.13 dex

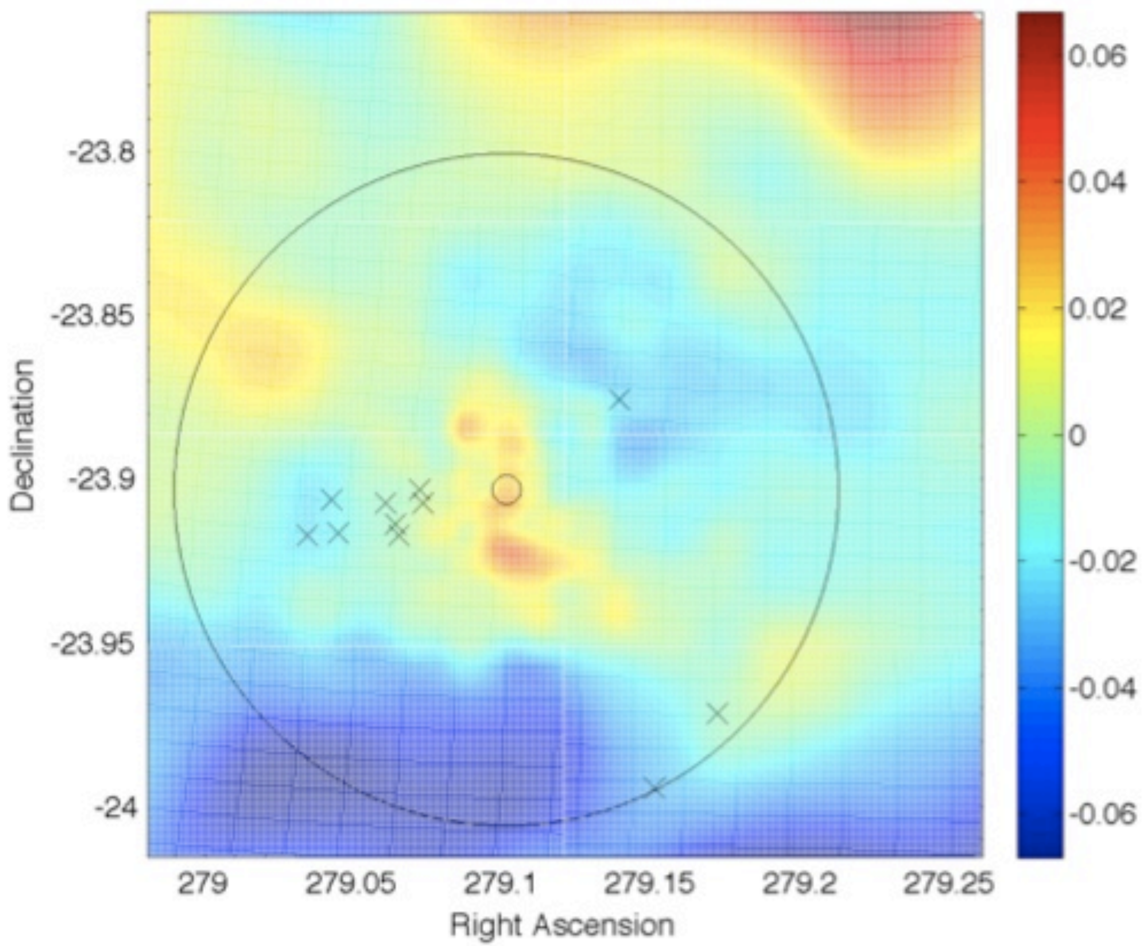
O: 0.10 dex

F: 0.17 dex

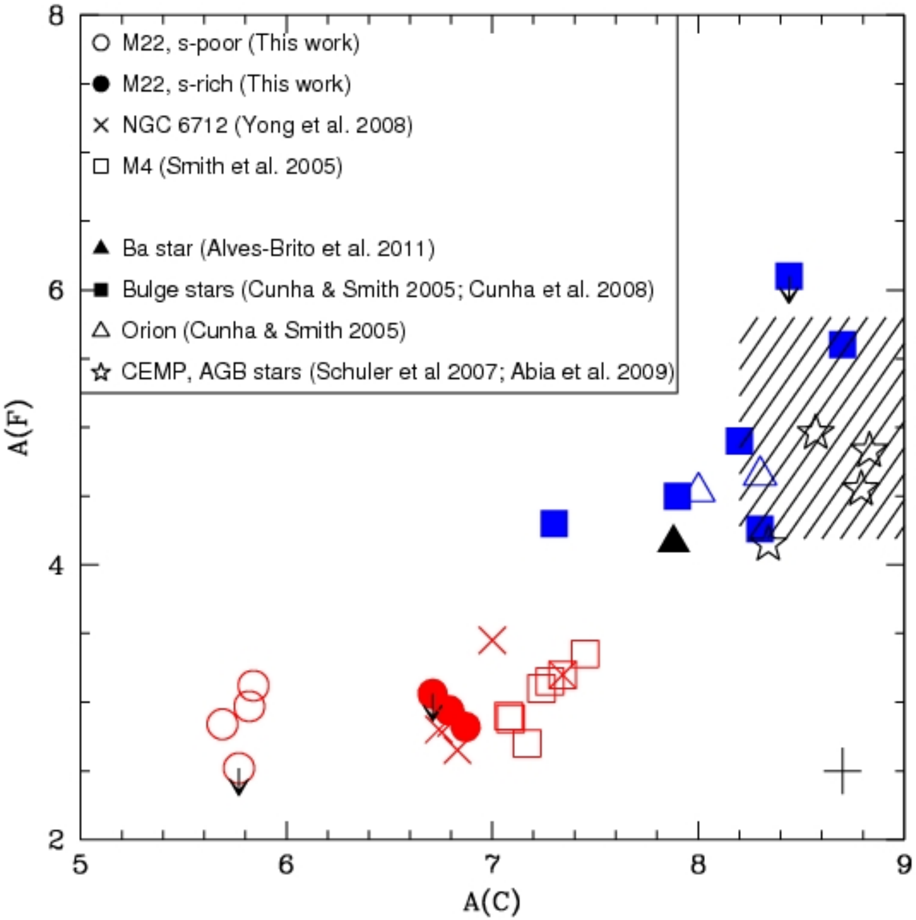
Na: 0.08 dex

Fe: 0.04 dex

E(B-V) in our M22 sample

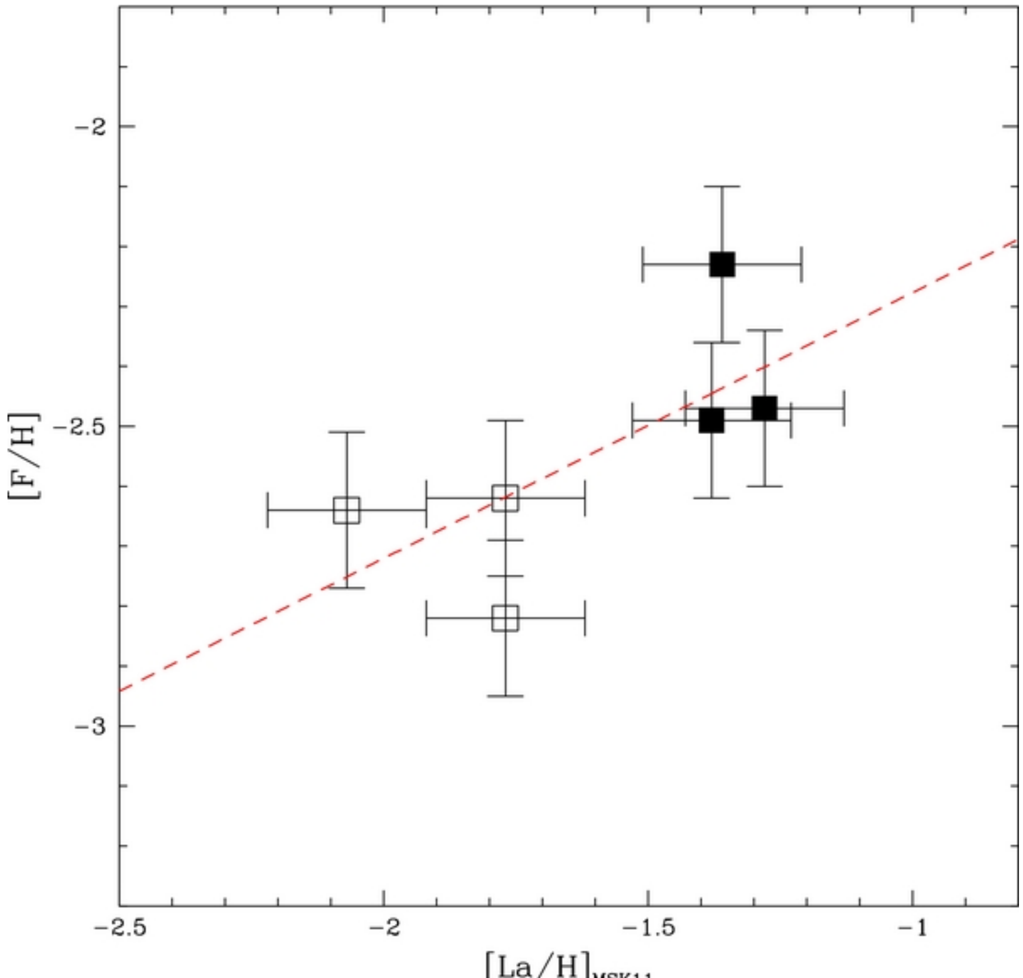


Field vs. GCs: A(F) vs. A(C)



- s-poor
- s-rich

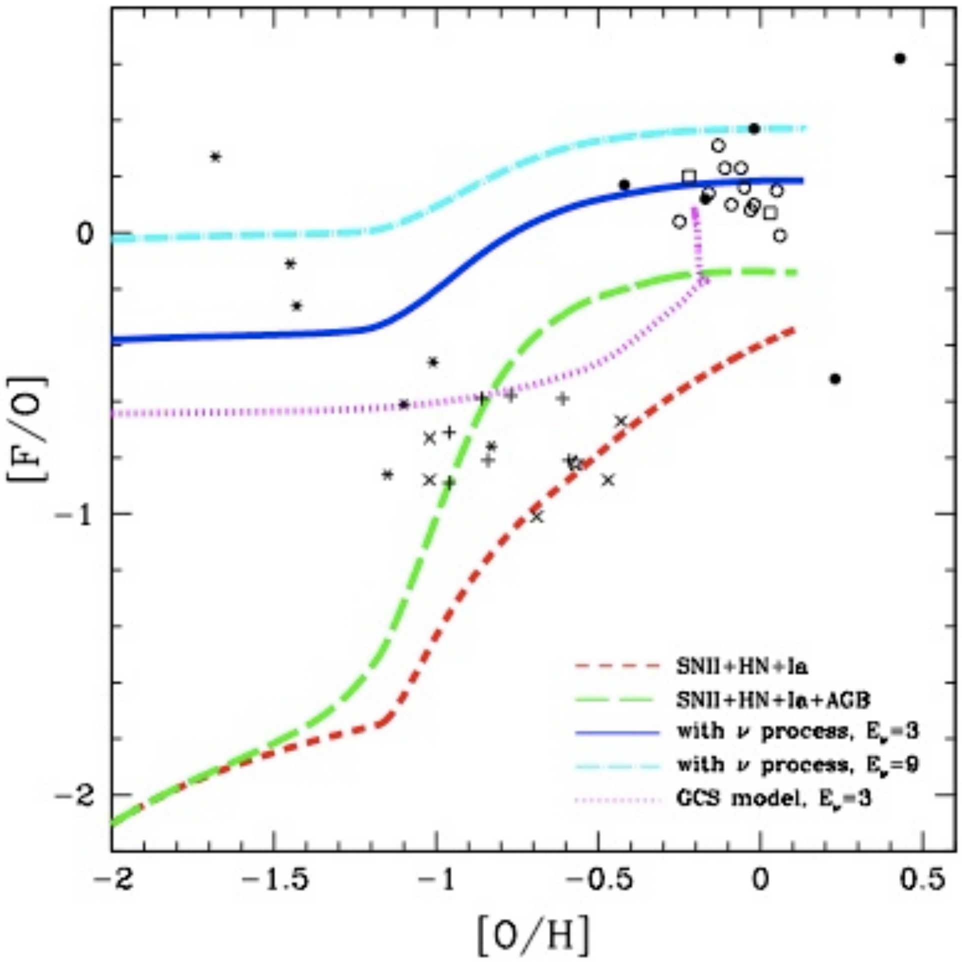
[F/H] vs. s-process



D'orazi et al. 2013

- ❍ s-poor
- ● s-rich

Field vs. GCs: [F/O] vs. [O/H]



Kobayashi et al. 2011

- Neutrino spallation: SNeII (Woosley & Haxton 1988)
- He-rich intershell of TP-AGB stars (Jorissen et al. 1992; Cristallo et al. 2009; Karakas & Lattanzio 2007)

M22 Basic Properties

Quantity	Value
E(B-V)	0.34 mag
Prograde Orbit	178 +/- 20 km/s
Vr	-146 +/- 0.20 km/s
Apocentric Distance	9.5 kpc
Pericentric Distance	2.9 kpc
Period	~200 Myr
Mass	0.6 x 10^6 Msun
Destruction Rate (bulge/disk)	> 3 X the Hubble Time
Half-Mass Two Body Relaxation Time	1.4 Gyr (no significant mass was lost)

Making F in a giant star

$^{13}C + {}^{4}He \rightarrow {}^{16}O$ + neutron (dominant reaction)

^{14}N + neutron $\rightarrow {}^{14}C$ + proton

^{26}Al + neutron $\rightarrow {}^{26}Mg$ + proton

$^{14}N + {}^{4}He \rightarrow {}^{18}F$

$^{18}F \rightarrow {}^{18}O$ + positron

^{18}O + proton $\rightarrow {}^{15}N + {}^{4}He$

$^{15}N + {}^{4}He \rightarrow {}^{19}F$

^{19}F + proton $\rightarrow {}^{16}O + {}^{4}He$

Making F in a massive star

1. In a massive star, F is mainly produced in a convective He shell as a secondary product:

$$^{15}N + {}^{4}He \rightarrow {}^{19}F + \text{gamma}$$

2. With the ν-process, F is produced in the O- and Ne-enriched region:

$$^{20}Ne + \nu \rightarrow {}^{19}F + \nu'\text{proton}$$