

STELLAR ABUNDANCES in CLUSTERS

High-resolution, multi-object spectroscopy of
globular & open clusters in the Milky Way

Angela Bragaglia

INAF-Oss. Astronomico Bologna



There are more surveys in heaven and earth, Horatio...

- **large scale**

Gaia-ESO public spectroscopic survey

P. Donati, D. Romano, M. Tosi, L. Magrini, S. Randich,
T. Cantat Gaudin, R. Sordo, A. Vallenari, E. Friel, H. Jacobson
& *GES Consortium (400+)*

- **“private”**

FLAMES GC program

E. Carretta, V. D’Orazi, R. Gratton, S. Lucatello,
A. Sollima, C. Sneden

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PRIN-MIUR 2010-11 :

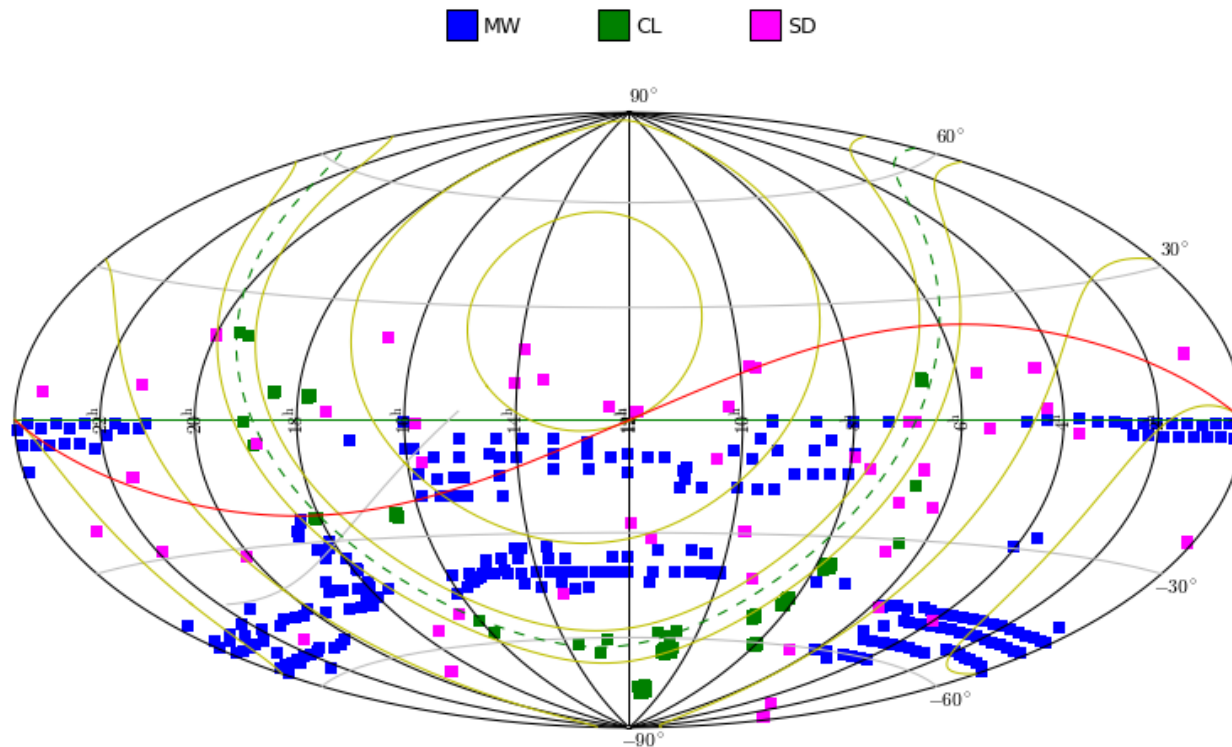
“The chemical and Dynamical Evolution of the Milky
Way and Local Group Galaxies” (PI F. Matteucci)

- “private”

FLAMES GC program

E. Carretta, V. D’Orazi, R. Gratton, S. Lucatello,
A. Sollima, C. Sneden

The Gaia-ESO Survey in a nutshell



- PI Randich/Gilmore
- 400+ researchers
- 300 VLT nights/5 years
(3 yrs / 32 obs runs)
- FLAMES
- 10^5 MW stars
- 70+ open clusters
(~30 observed)
- STD / GCs
- distributed analysis

For information : <http://www.gaia-eso.eu>



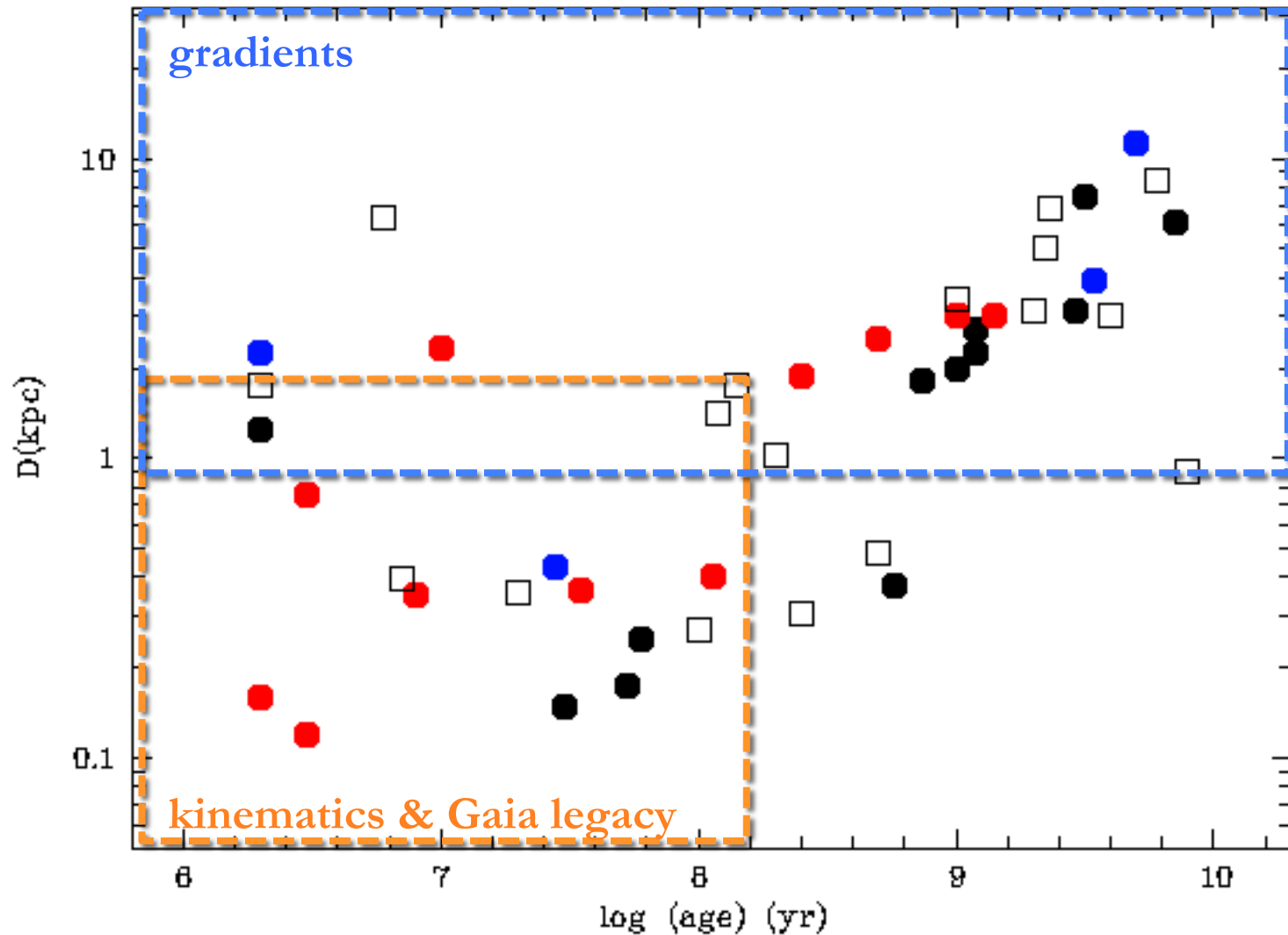
The Gaia-ESO Survey – open clusters

core science

- Open cluster formation & dynamics
- Properties & evolution of MW disk
- Stellar evolution

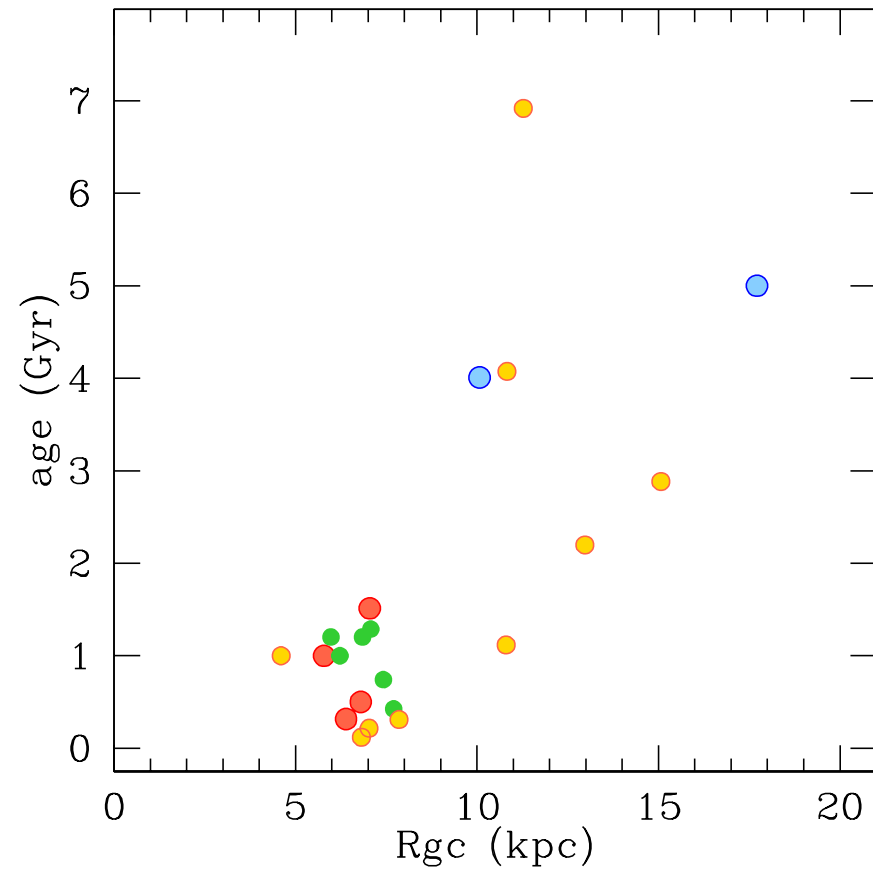
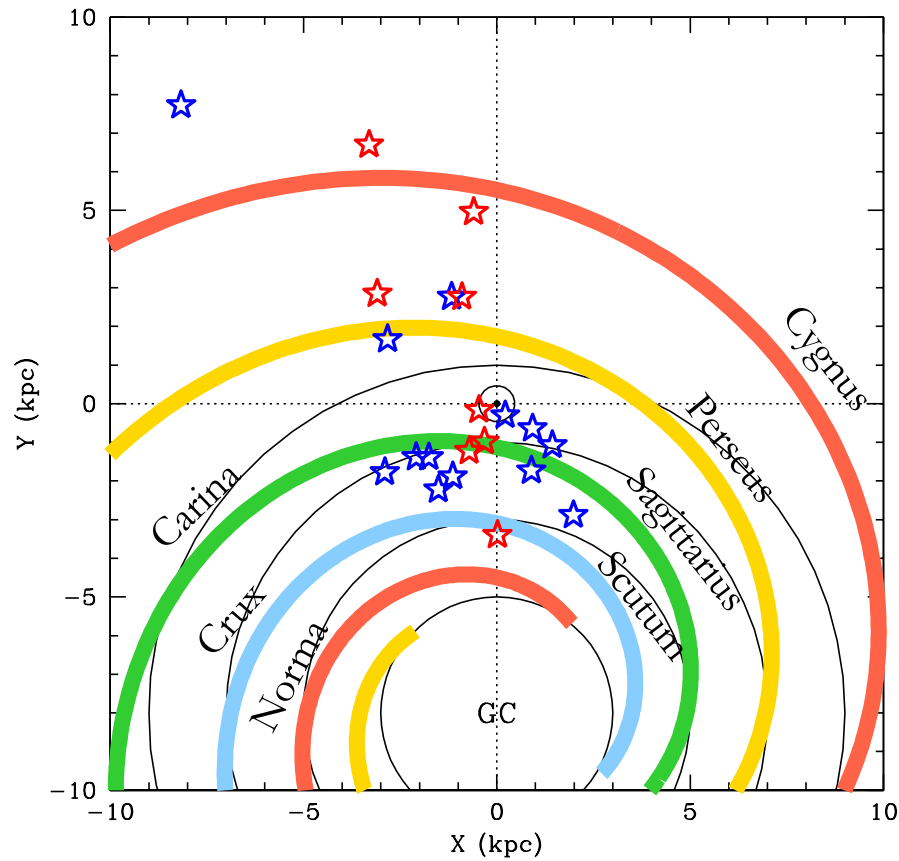
The Gaia-ESO Survey – all OCs

- 18 months
- 24 months
- 31 months
- protected

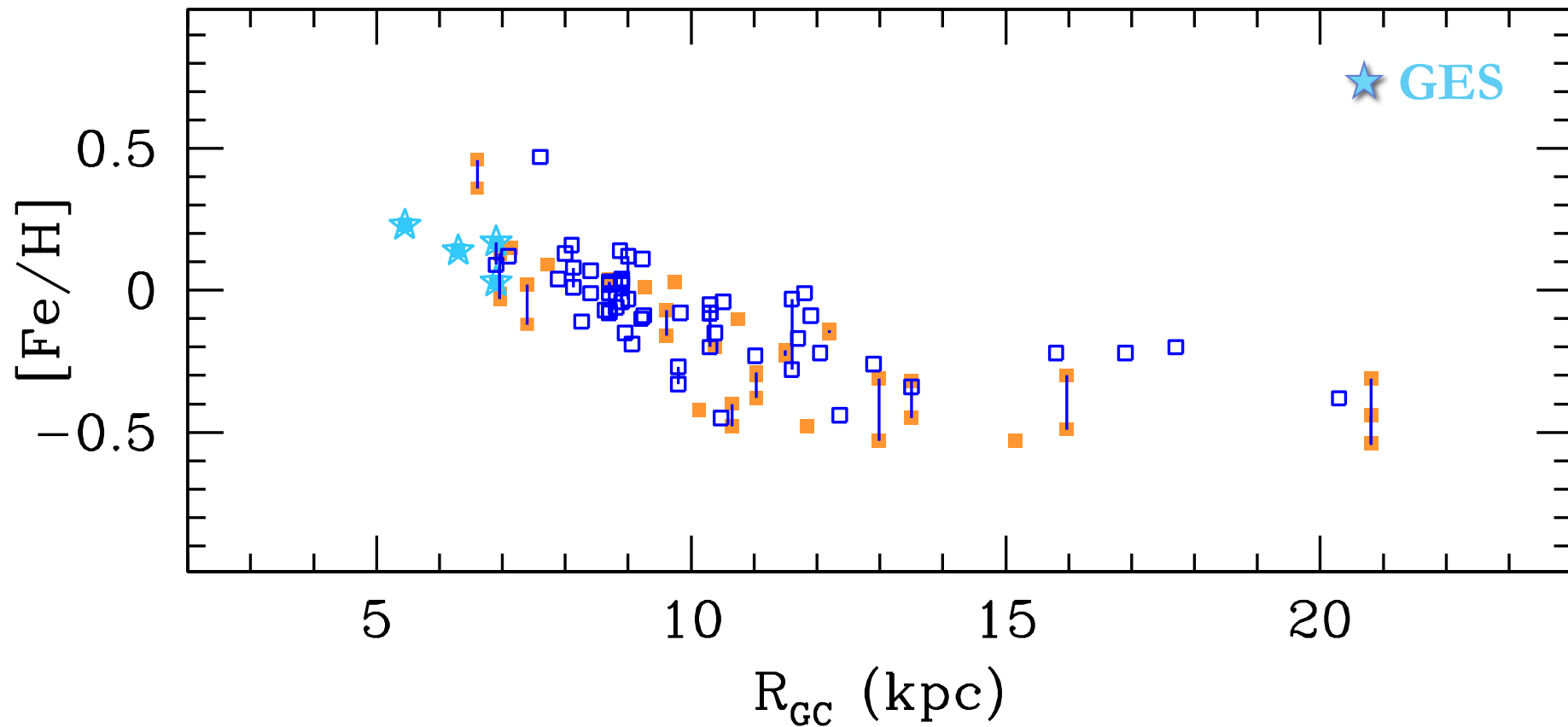


courtesy
S. Randich

The Gaia-ESO Survey – old OCs

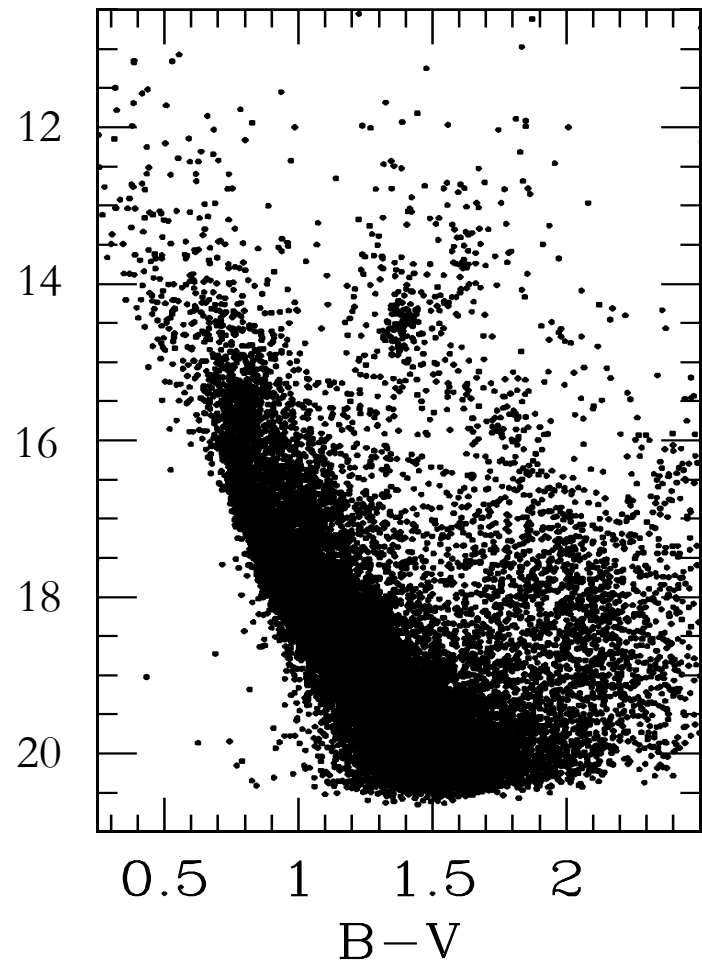


The Gaia-ESO Survey – old OCs

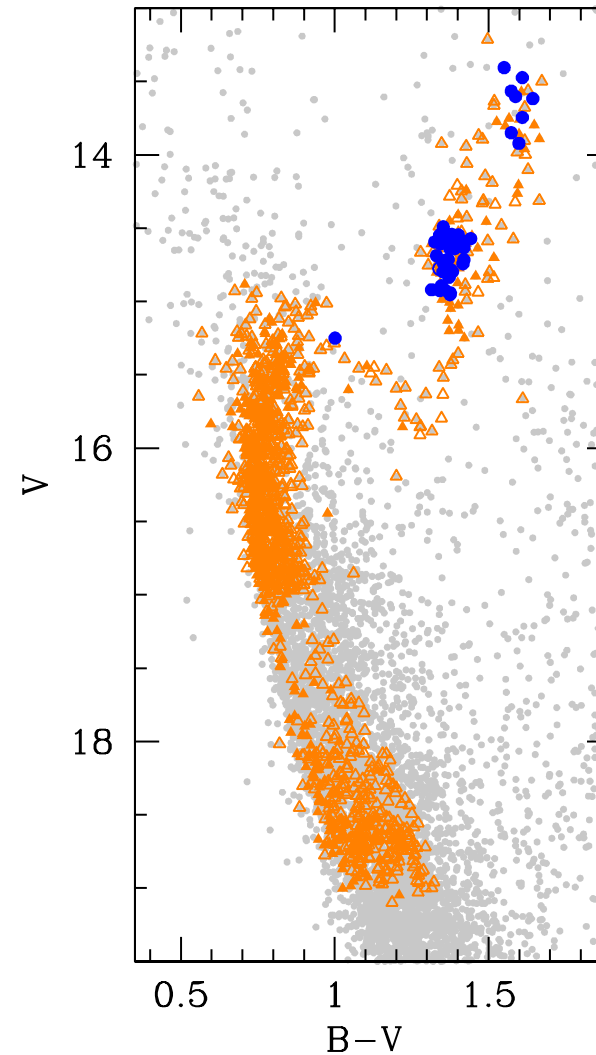


Yong+2012 & literature $[Fe/H]$ after 2012 ; BOCCE age, R_{gc} if available

The Gaia-ESO Survey – Trumpler 20

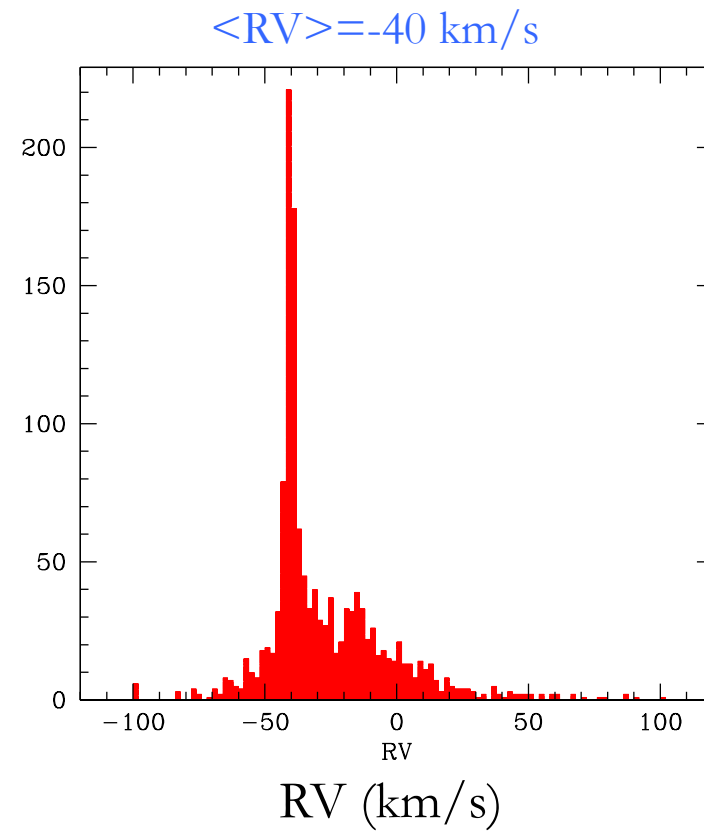
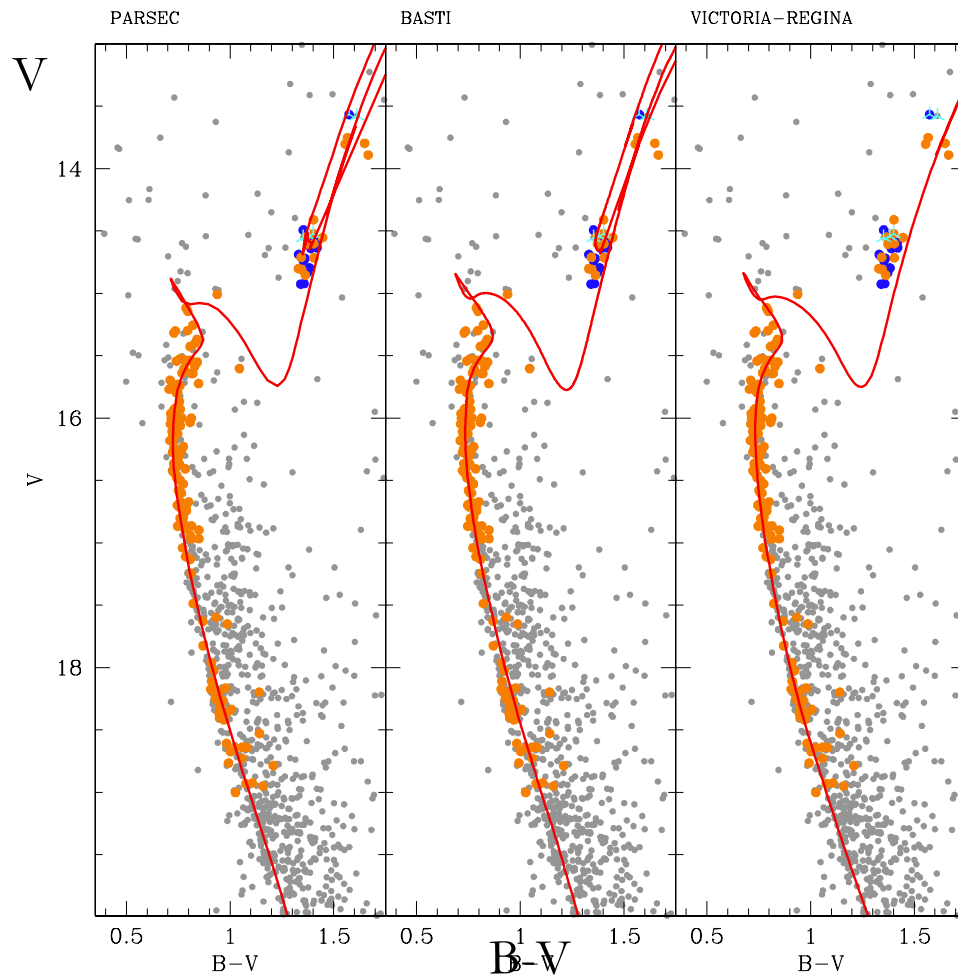


Carraro+2010



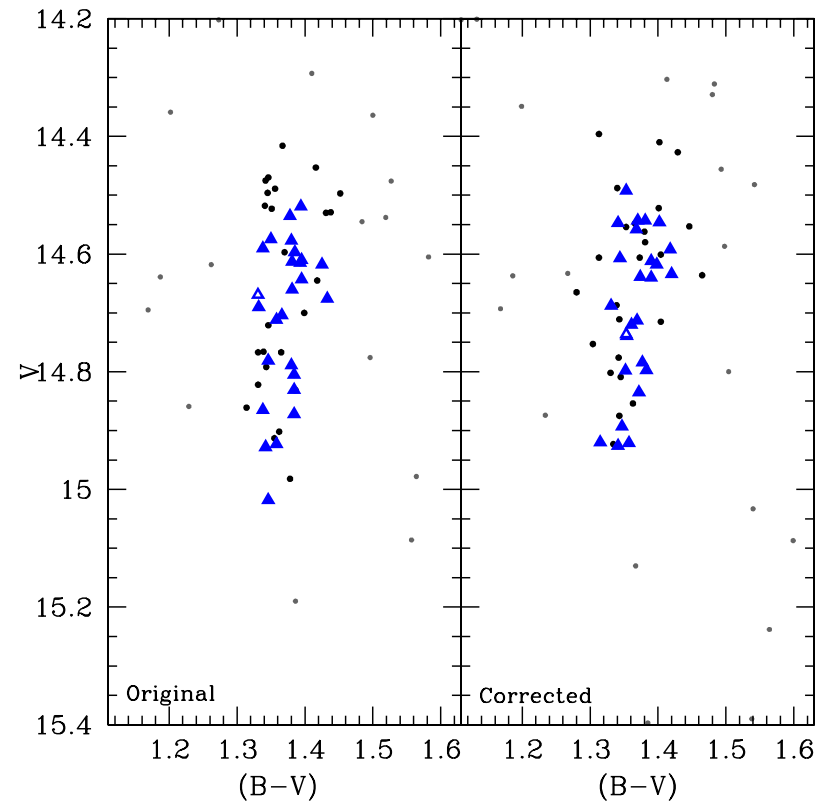
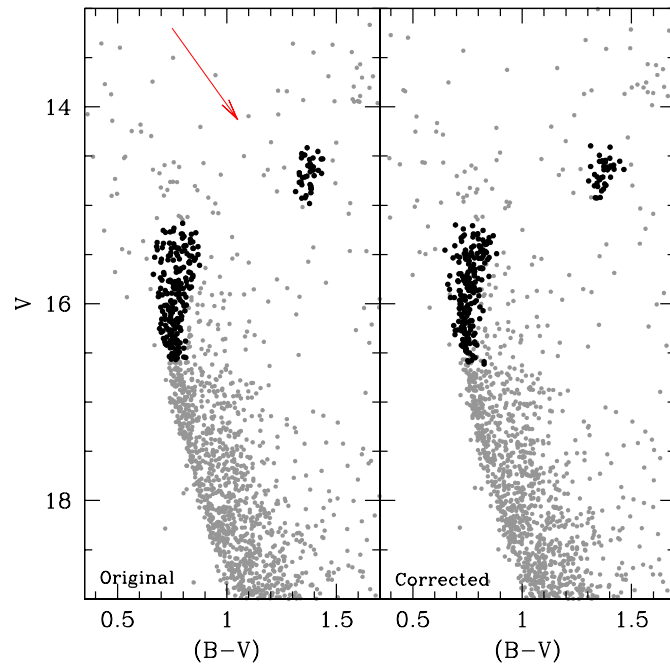
GES - Donati+ 2014

The Gaia-ESO Survey – Trumpler 20

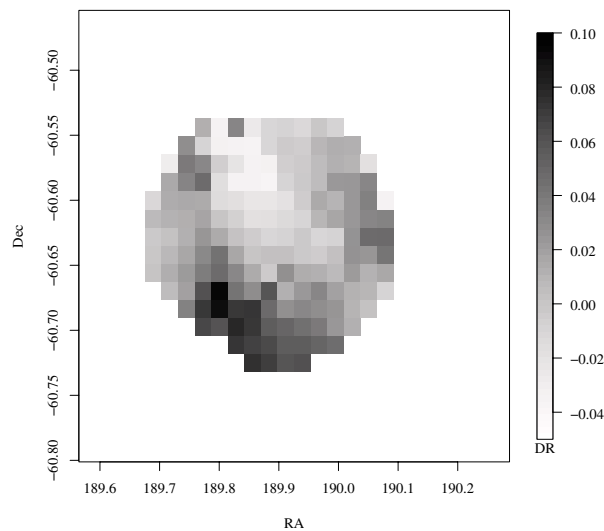


GES - Donati+ 2014 : $\sim 40\% M$

The Gaia-ESO Survey – Trumpler 20



“golf-club” MSTO
elongated/double RC



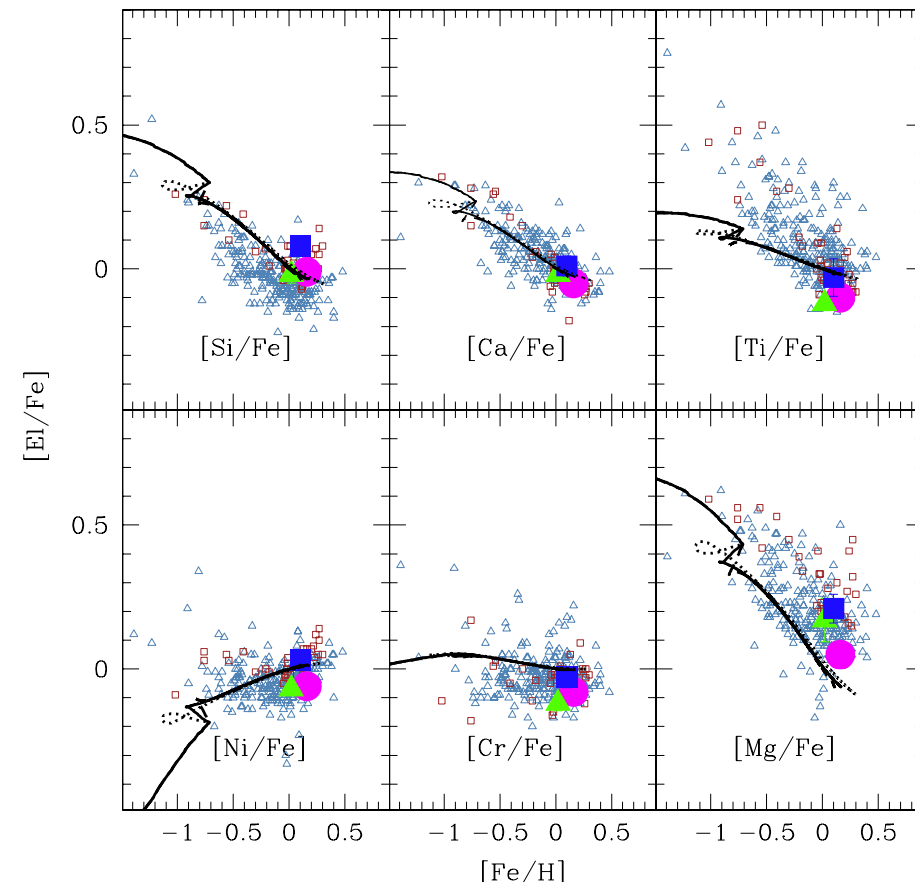
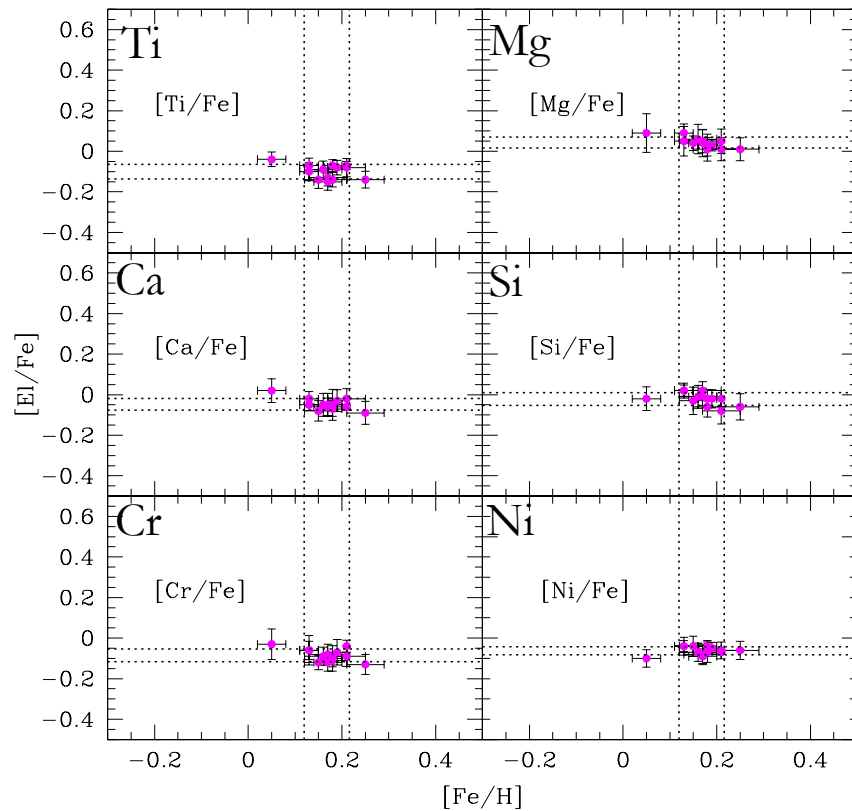
The Gaia-ESO Survey – inner disk OCs

OC	age	Rgc	RV	[Fe/H]	GES paper
Tr 20	1.5	6.9	−40.5 (1470)	+0.16 (13)	Donati+2014
NGC4815	0.5	6.9	−30.2 (218)	+0.03 (5)	Friel+2014
NGC6705	0.3	6.3	+34.5 (1053)	+0.10 (21)	Cantat-Gaudin+2014
Be 81	1.0	5.5	+47.6 (280)	<i>in progress</i>	<i>in progress</i>
NGC6208	0.7	7.4			<i>observed</i>
Be 44	1.3	7.1			<i>observed</i>
Pismis 18	1.2	6.8			<i>observed</i>
Tr 23	1.0	6.2			<i>observed</i>
NGC6005	1.2	6.0			<i>observed</i>

RV : GIRAFFE+UVES - [FE/H] : UVES

for more details, see talk by Laura Magrini (on Tuesday)

The Gaia-ESO Survey – 3 inner disk OCs



— chemev models *Romano+2010*

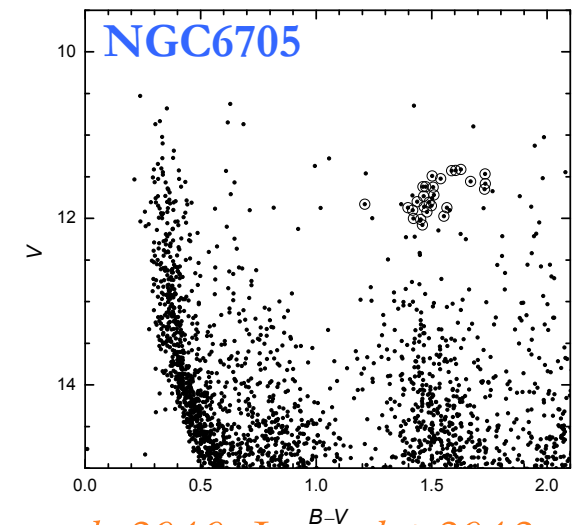
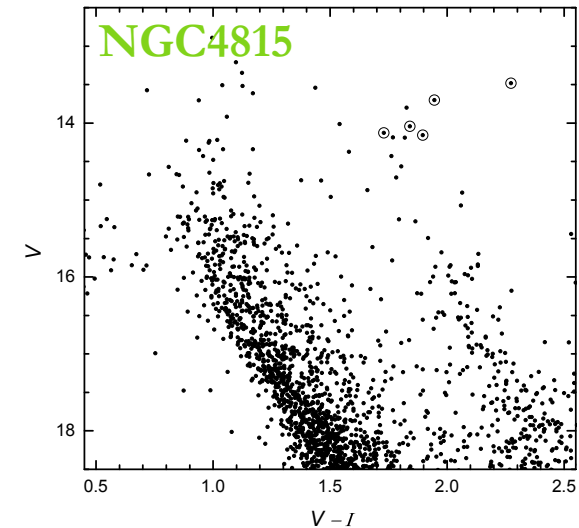
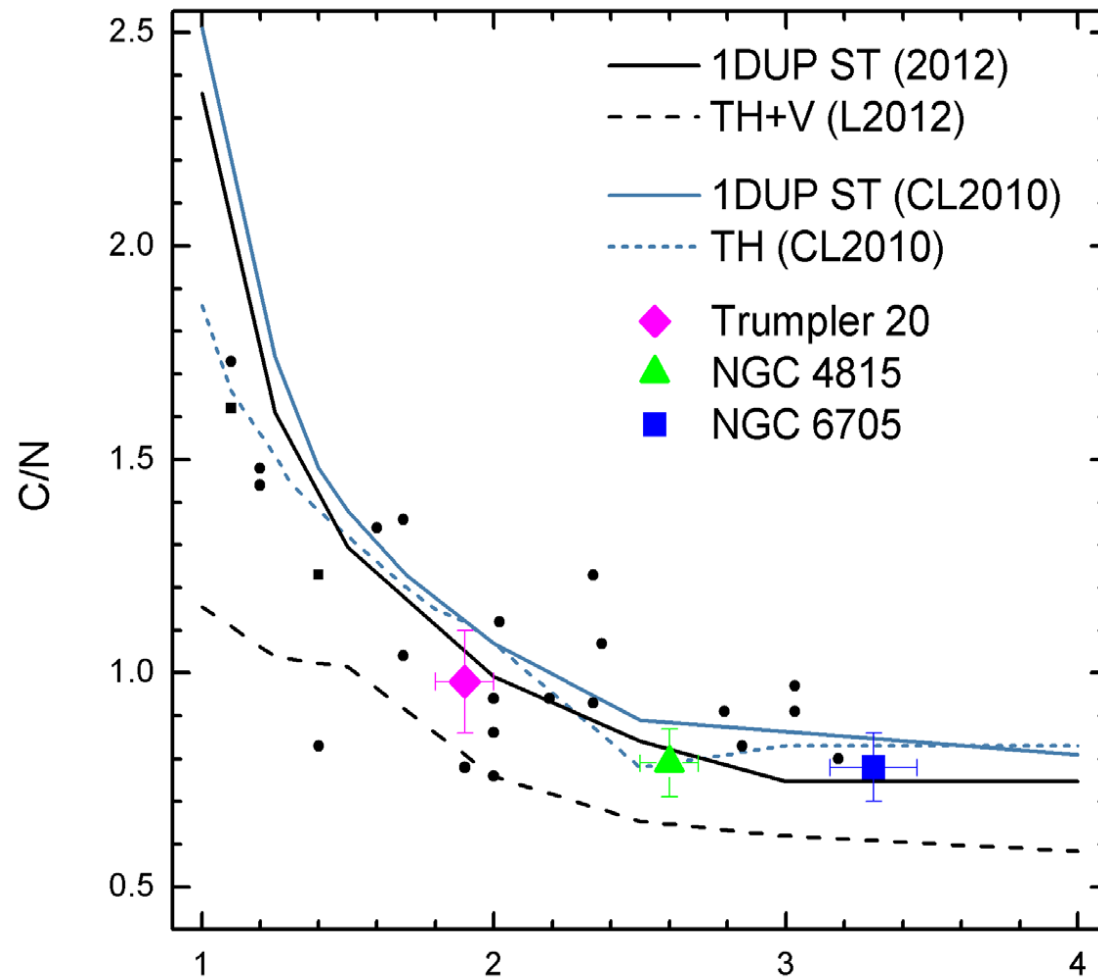
Trumpler 20

NGC4815

M11

GES - Magrini+ 2014

The Gaia-ESO Survey – 3 inner disk OCs



GES - Tautvaisiene+2014

M/M_{SUN}

models: Charbonnel & Lagarde 2010, Lagarde+2012

End of first act ...

Open clusters :

- **information on Galactic disk**
 - e.g. structure*
 - e.g. chemical evolution*
- **test of stellar models**
 - e.g., tracks*
 - e.g., mixing mechanisms*
- **homogenous clusters (single populations)**

GCs: setting the stage

In GCs light elements show star-to-star variations

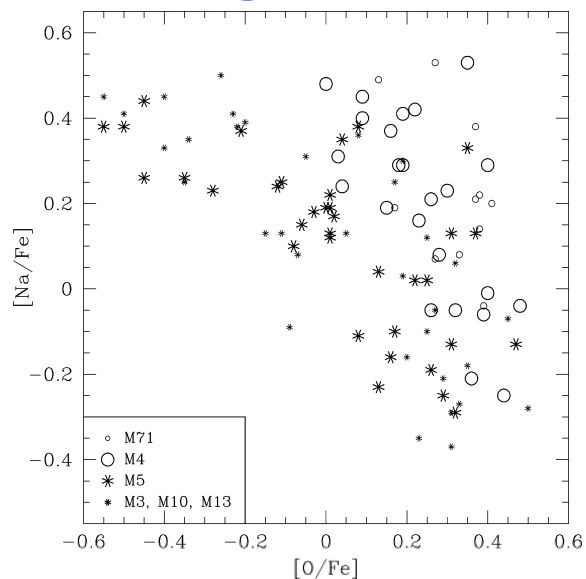
In field stars they do not



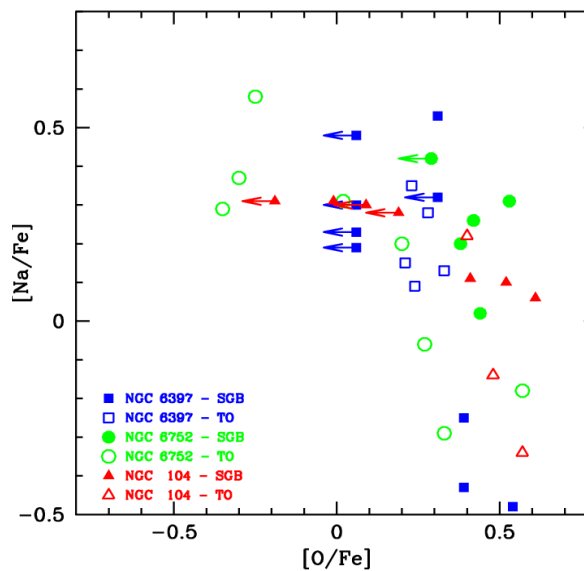
giants

dwarfs

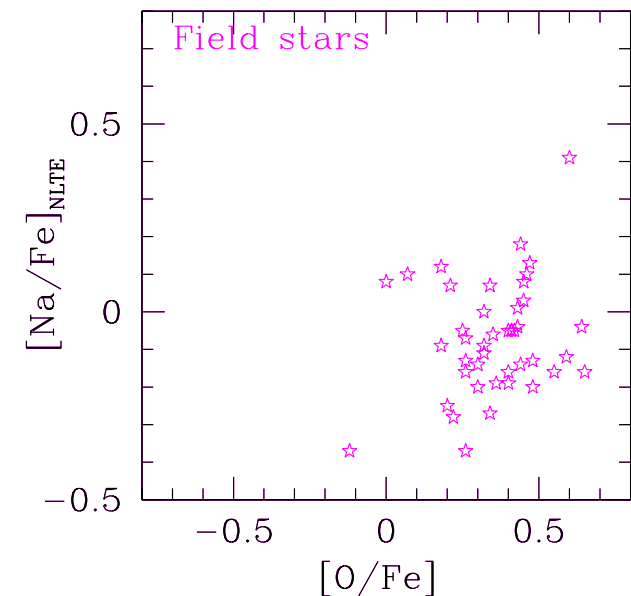
giants & dwarfs



ARAC&A 2004
~400 stars
~20 GCs



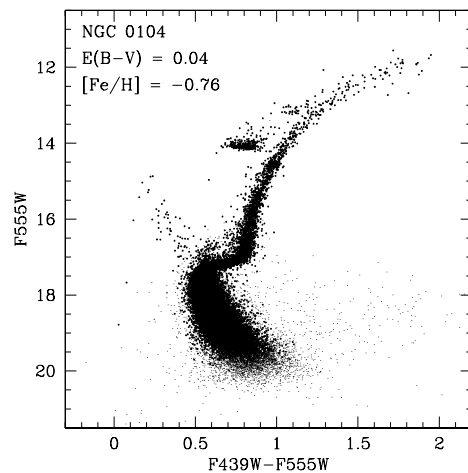
NGC6397, NGC6752, 47Tuc:
Gratton+ 2001 ; Carretta+ 2004



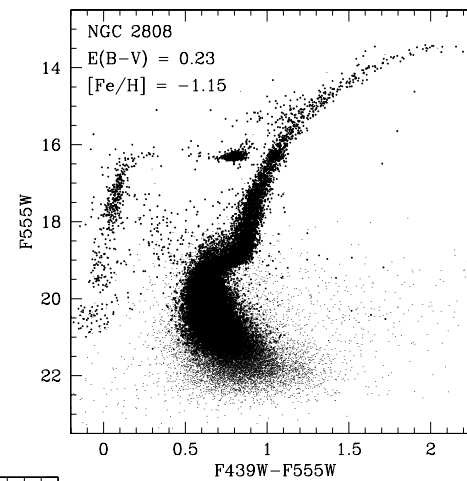
Field stars (*Gratton+ 2000*)

Our sample of clusters

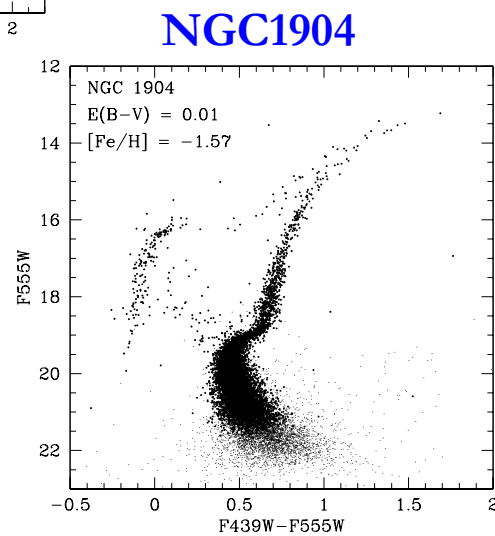
- 24 massive GCs : $M_V = -5.5$ to -10



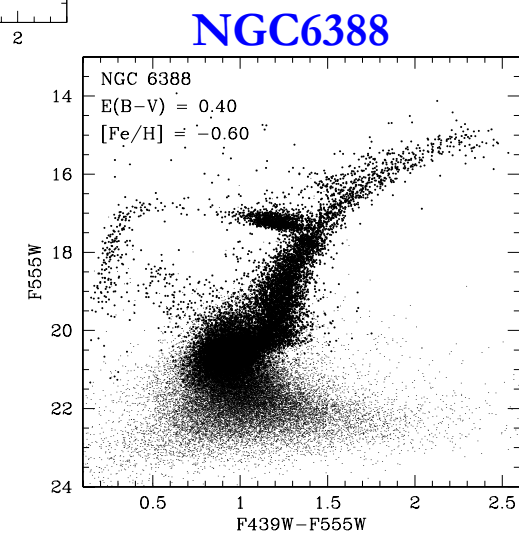
47Tuc



NGC2808



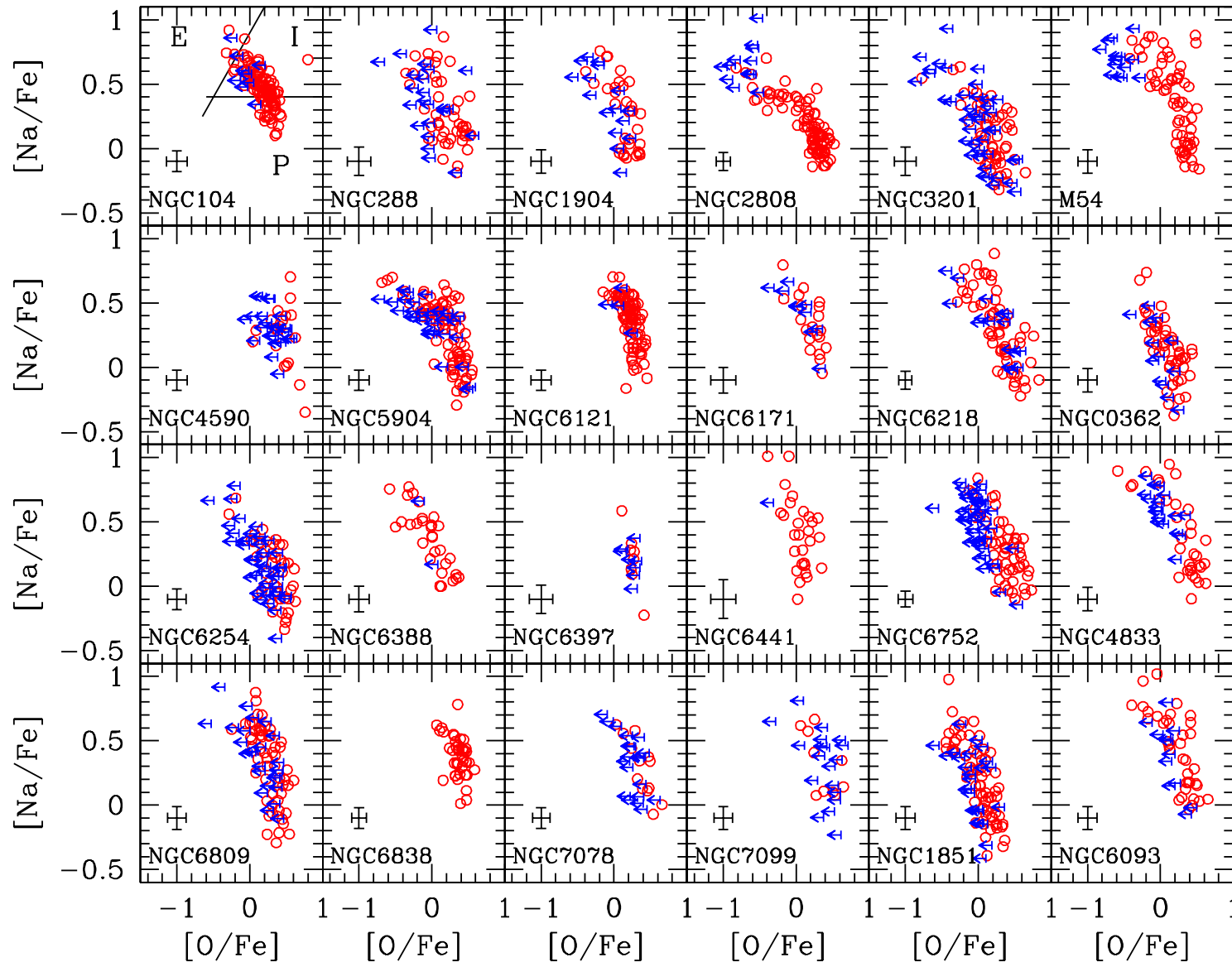
NGC1904



NGC6388

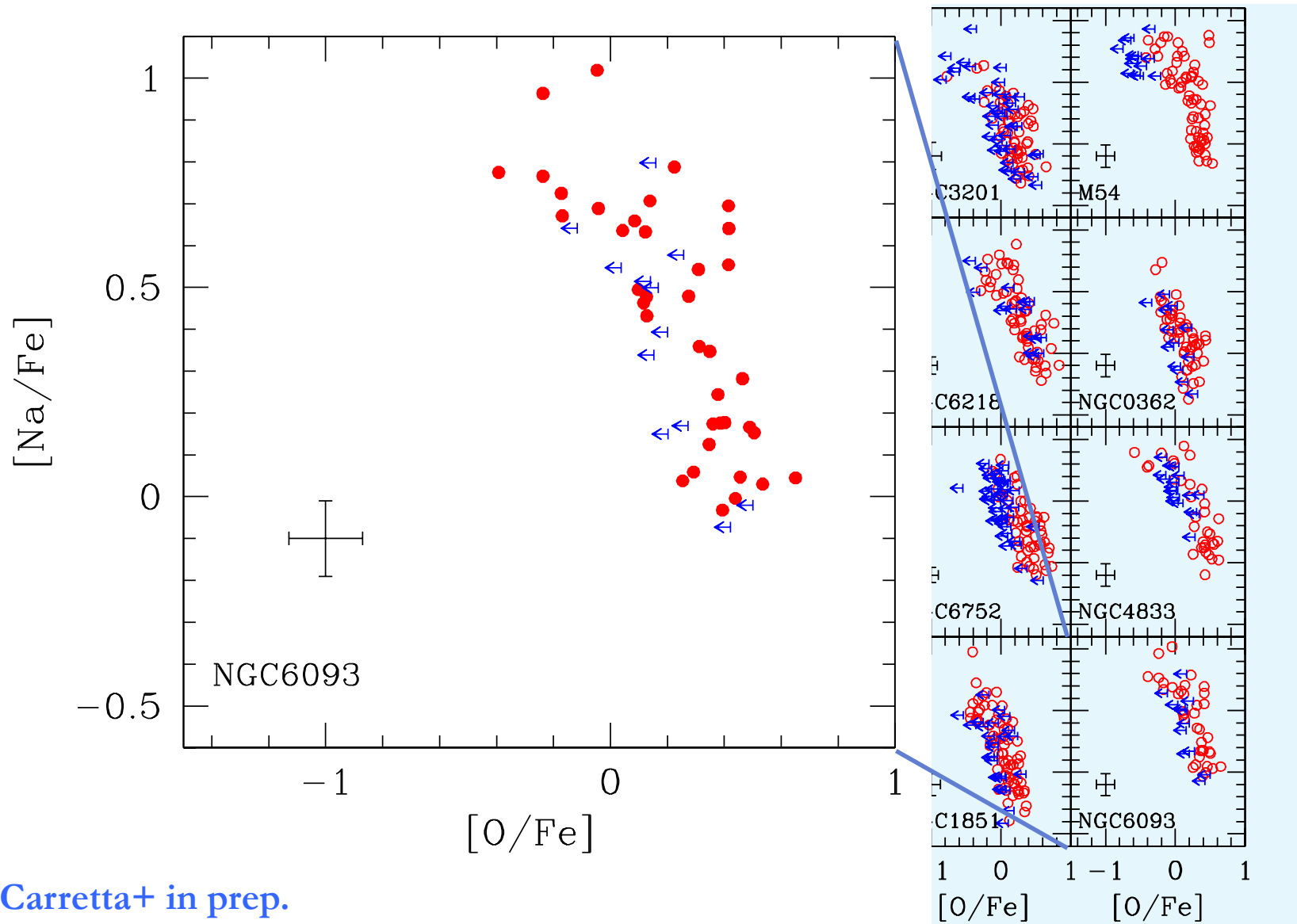
Piotto+2002,
HST snapshot

GCs: Na & O in RGB stars

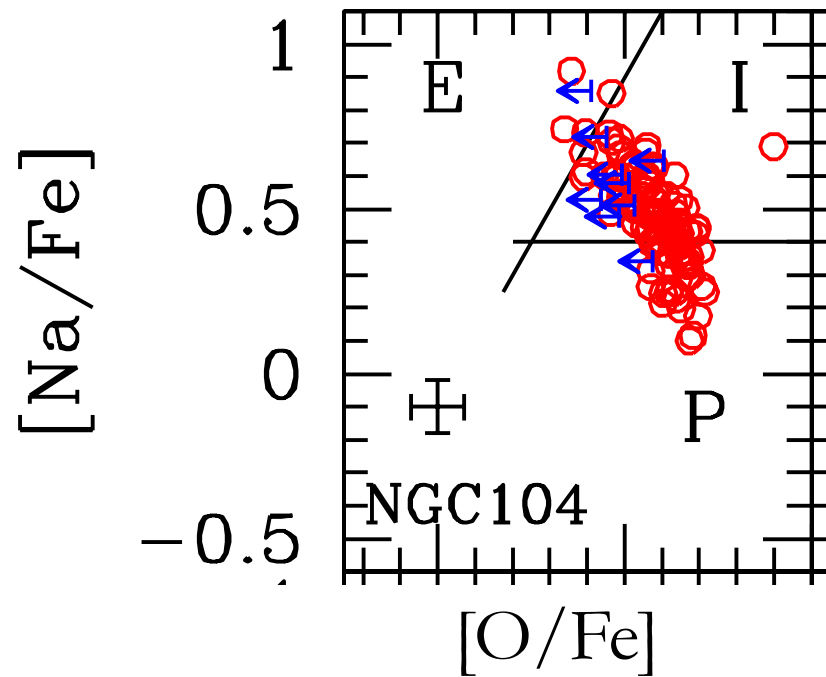


Carretta+
2009,2010,
2011,2013,
2014, ...

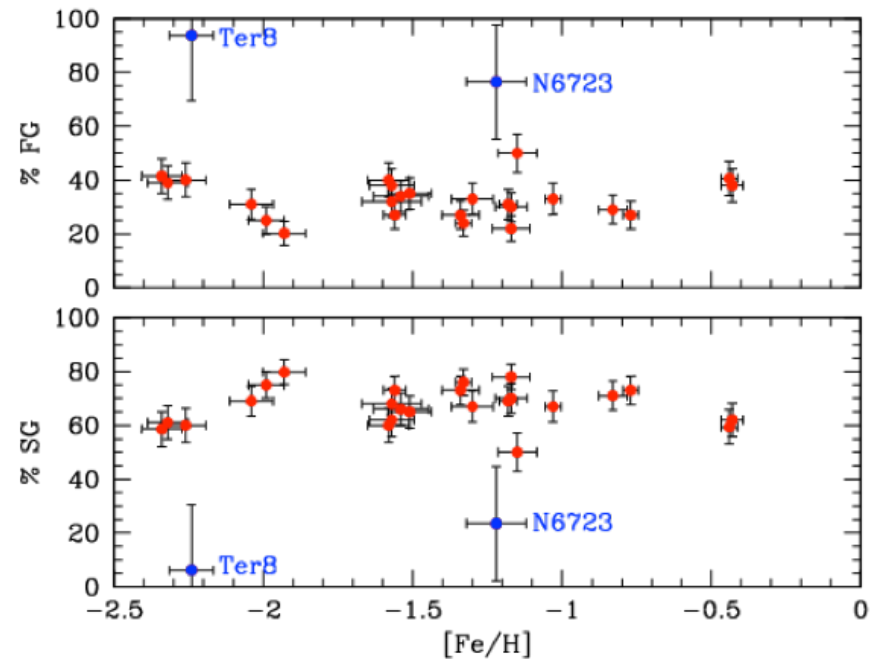
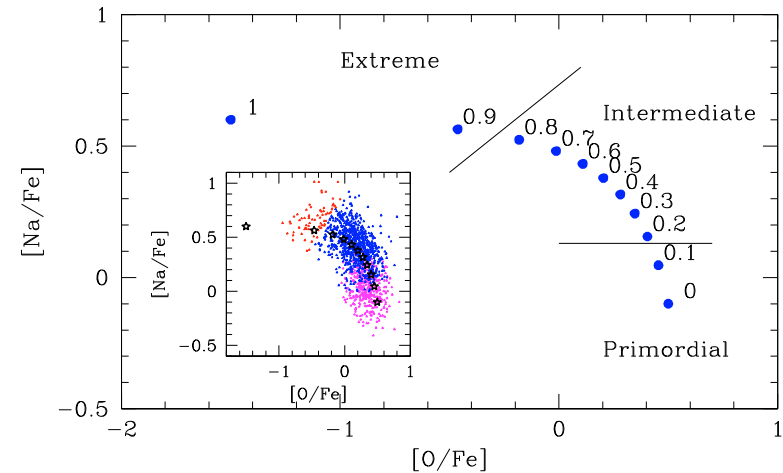
GCs: Na & O in RGB stars



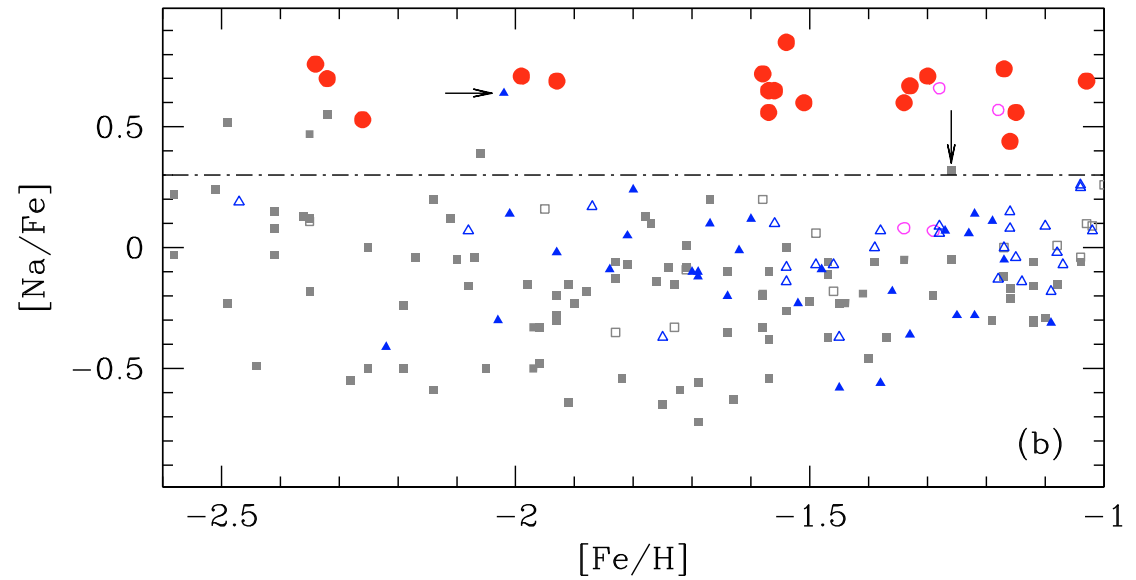
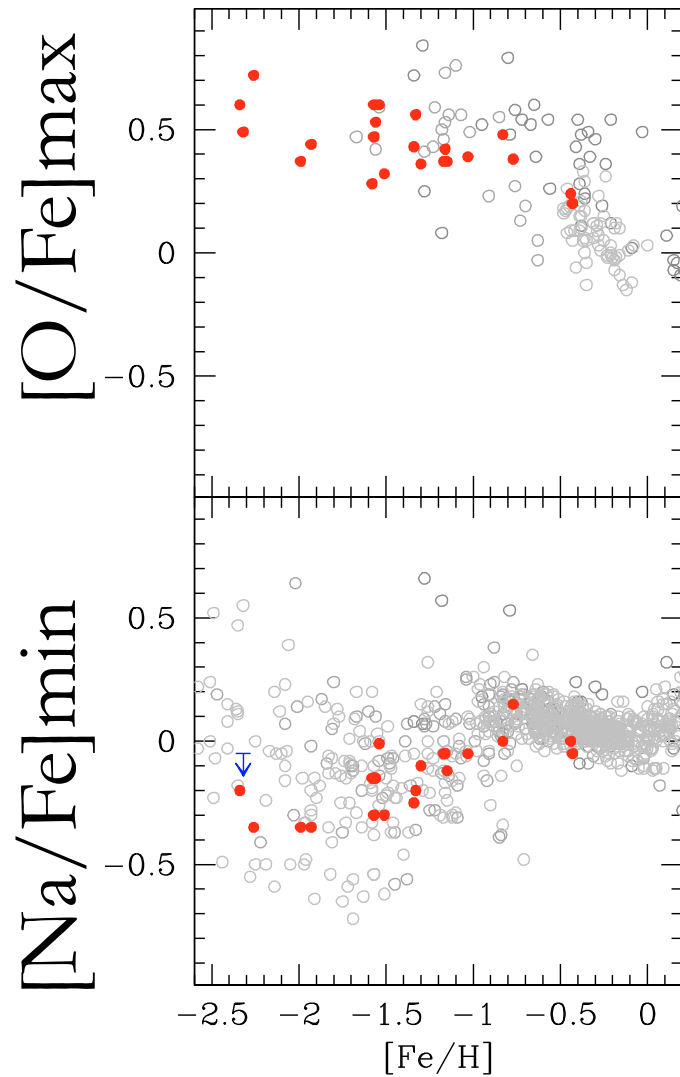
GCs: Na & O in RGB stars



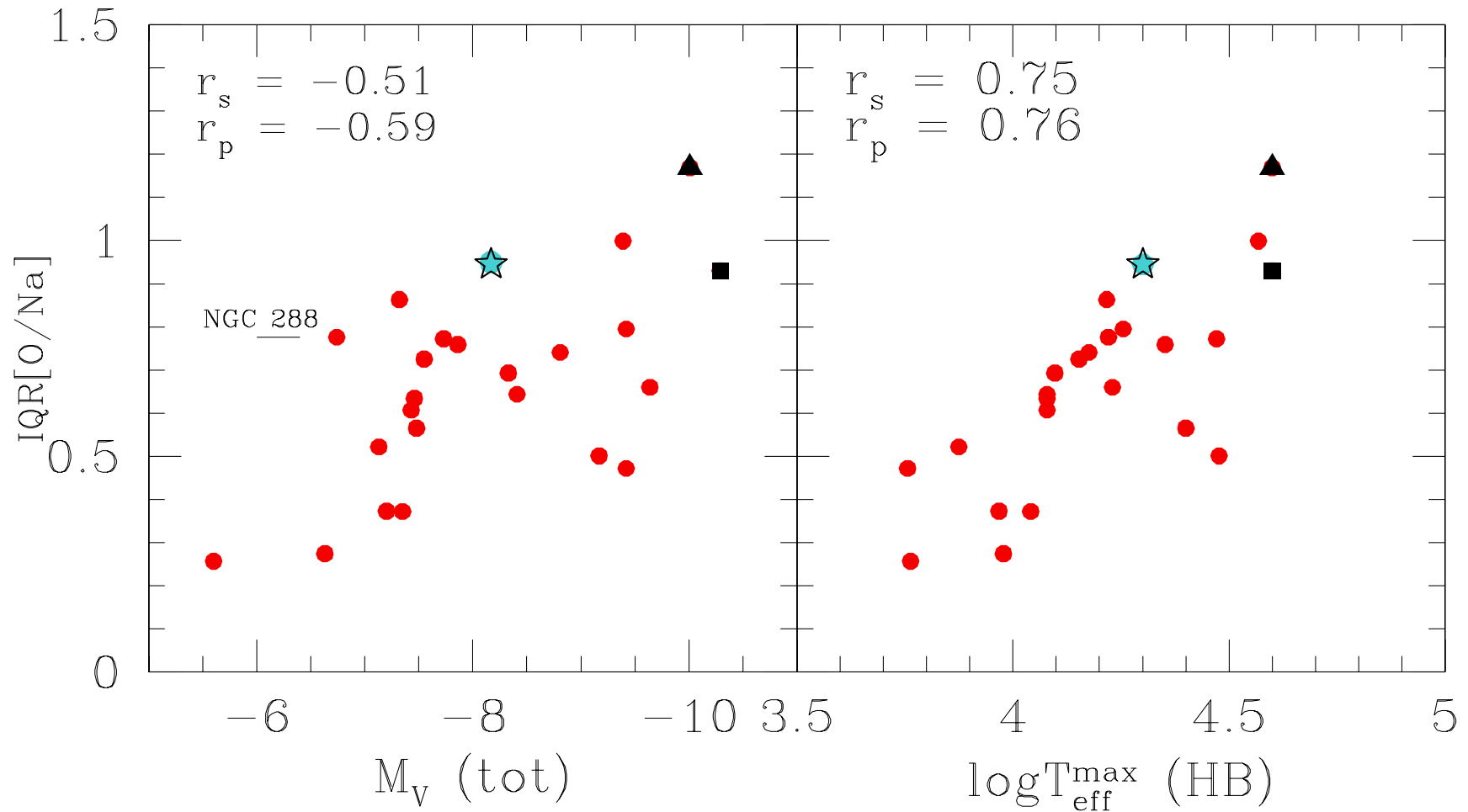
FG : P
SG : I+E



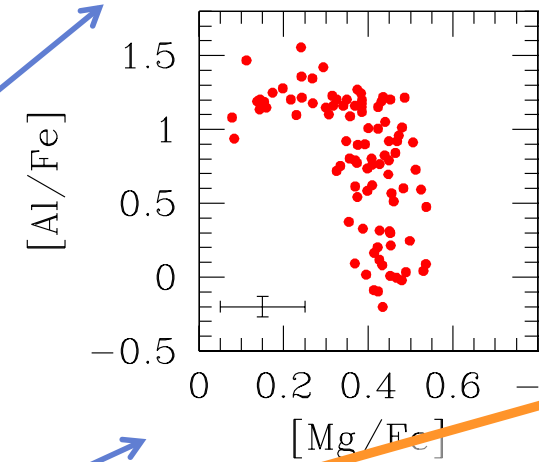
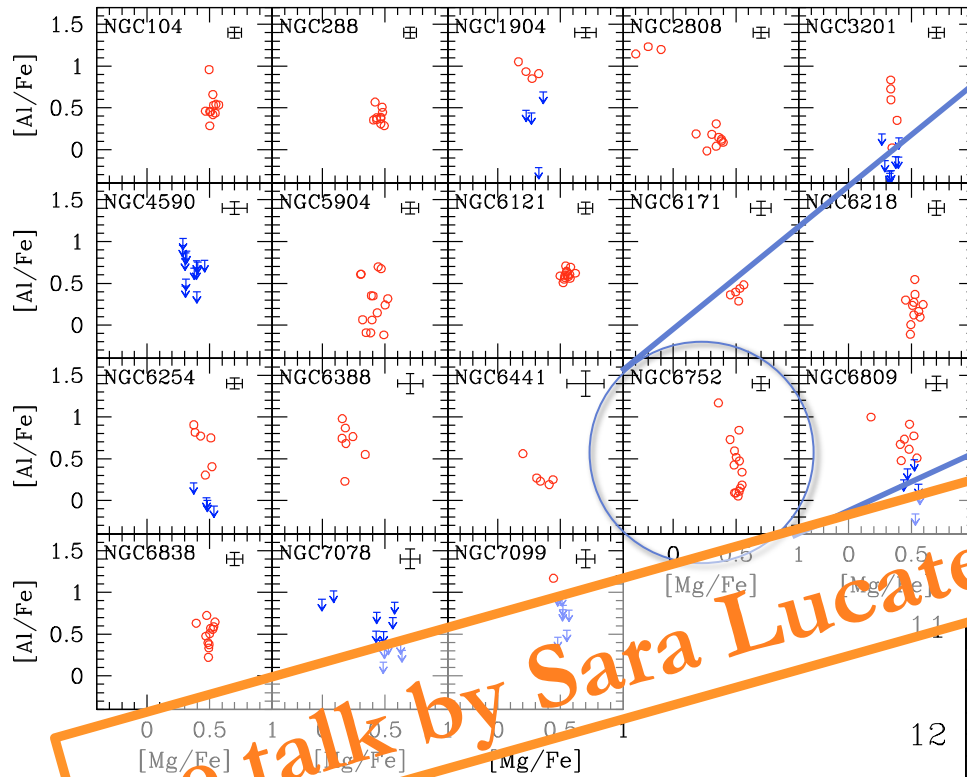
GCs: Na & O in RGB stars



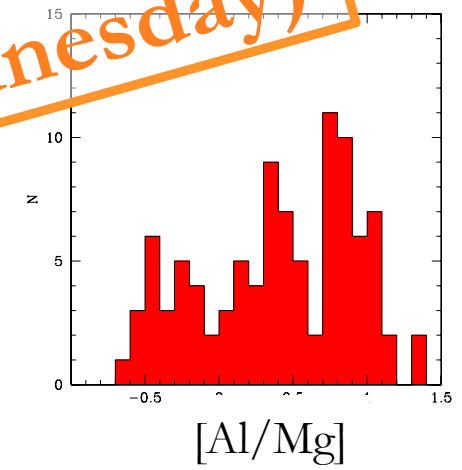
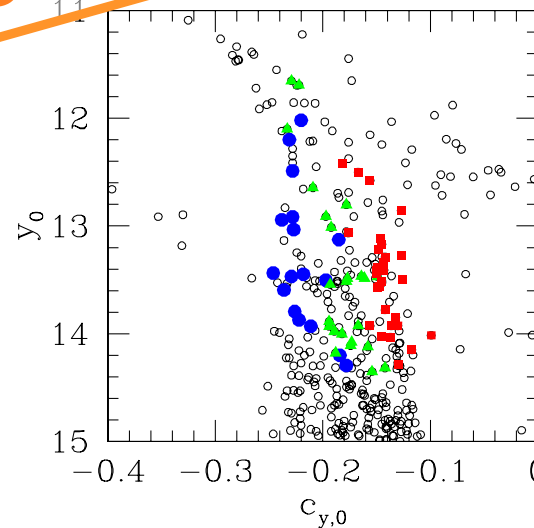
GCs: Na & O in RGB stars



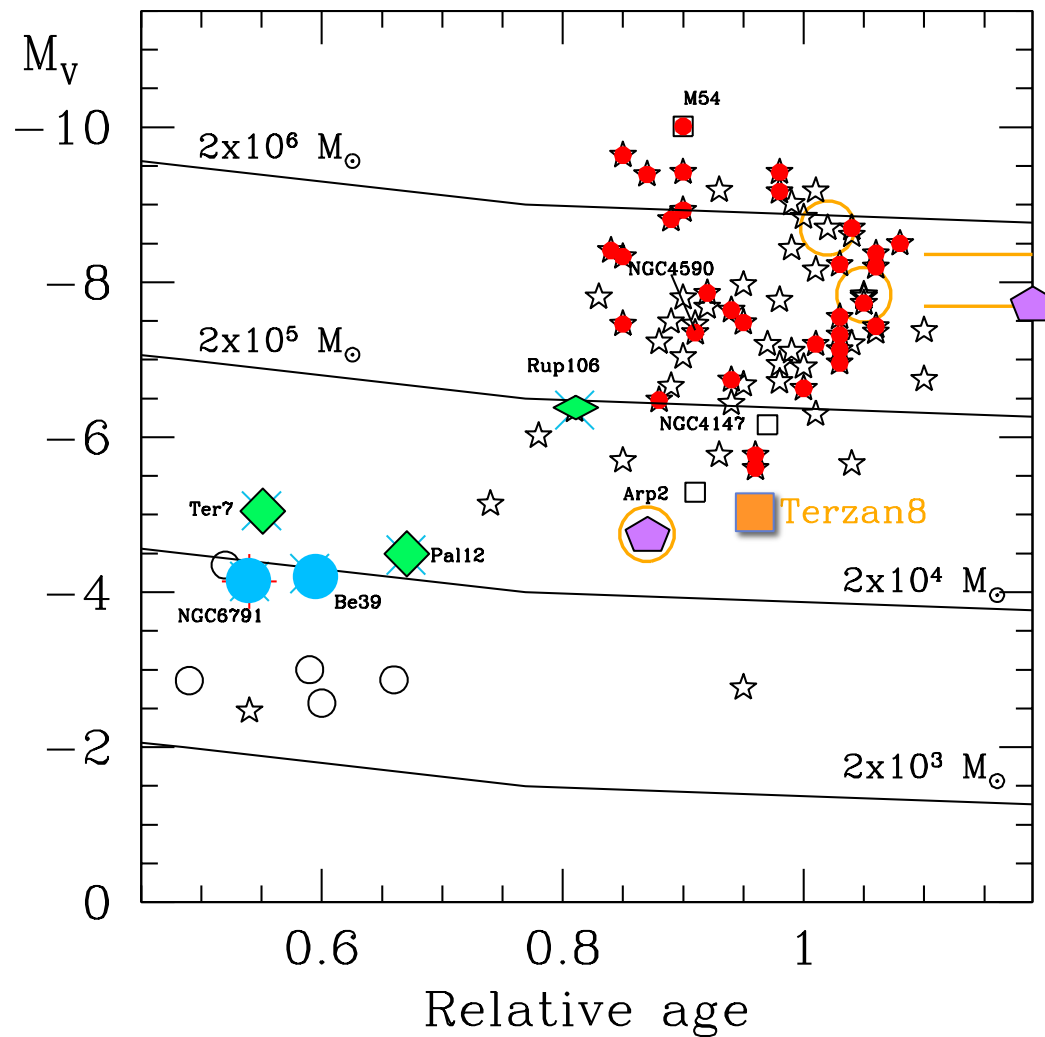
GCs: Mg & Al



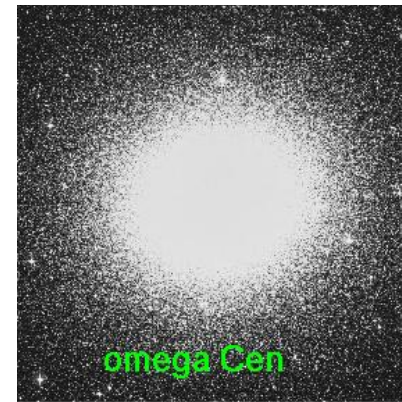
see talk by Sara Lucatello (on Wednesday)



All creatures great and small. I. GCs

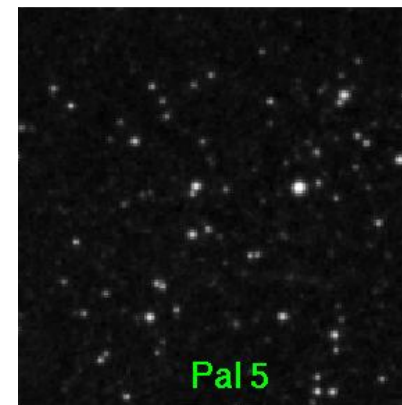


GCs with Na-O anticorrelation



omega Cen

some 10^6
mass in M_{\odot}

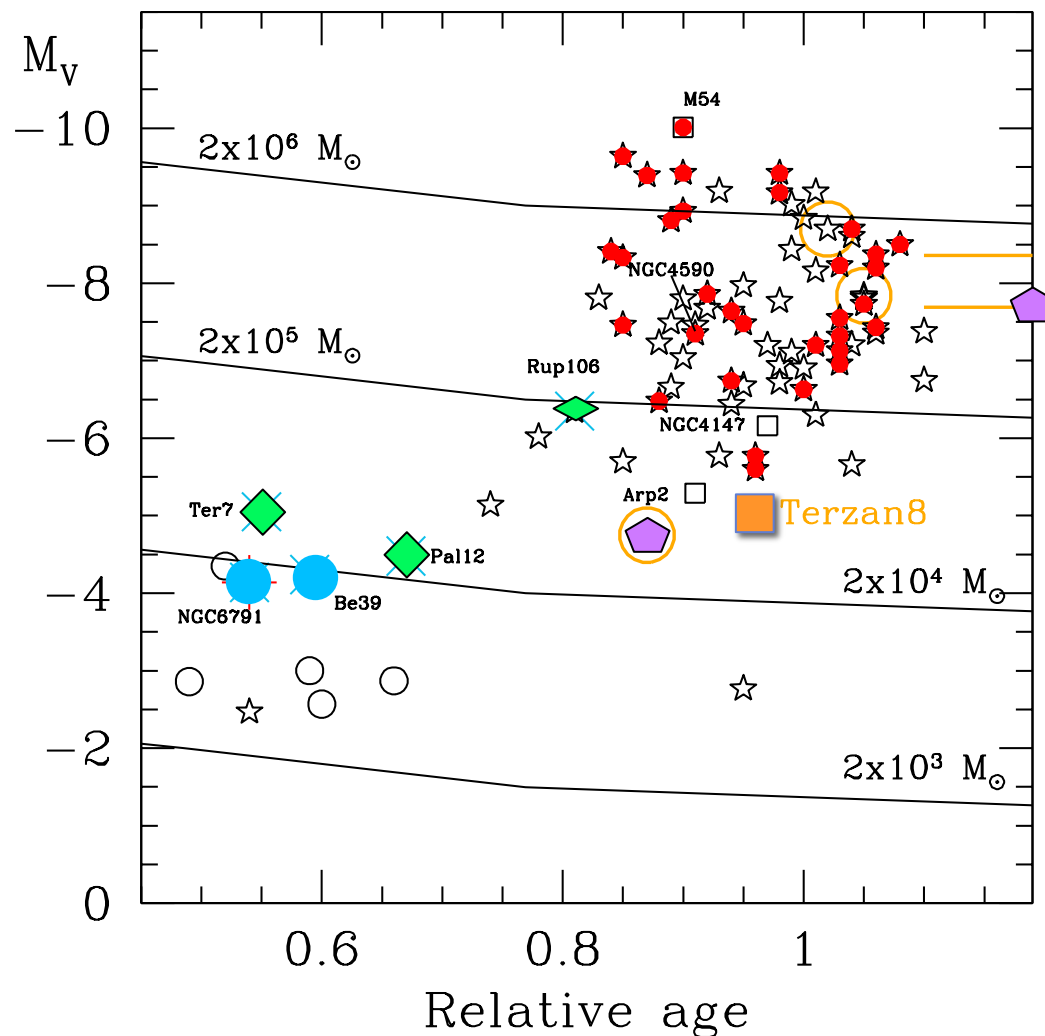


Pal 5

some 10^4

Carretta+2010 etc

All creatures great and small. I. GCs



- ◆ Ter 7, Pal 12 : no?
- ◆ Rup 106 : no
- Terzan 8 : yes?
- Be39, NGC 6791 : no
- ◆ NGC 6535, NGC 6139 : ??

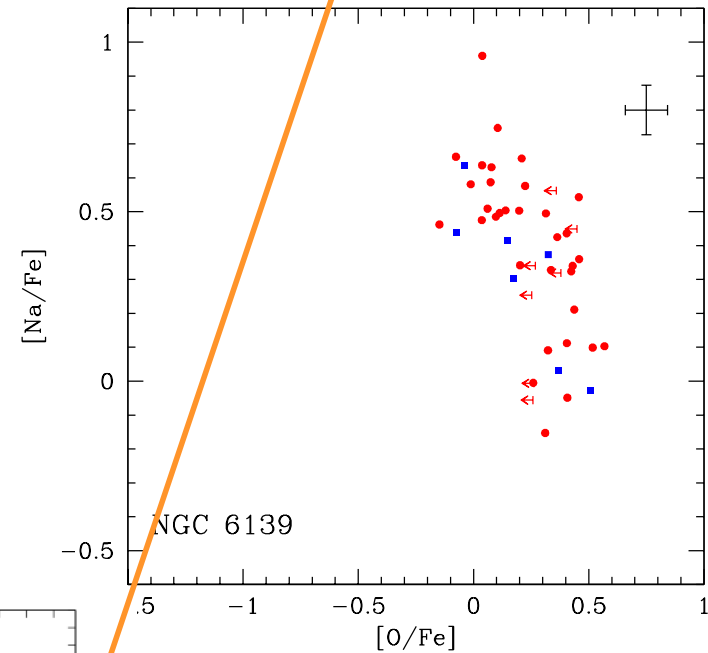
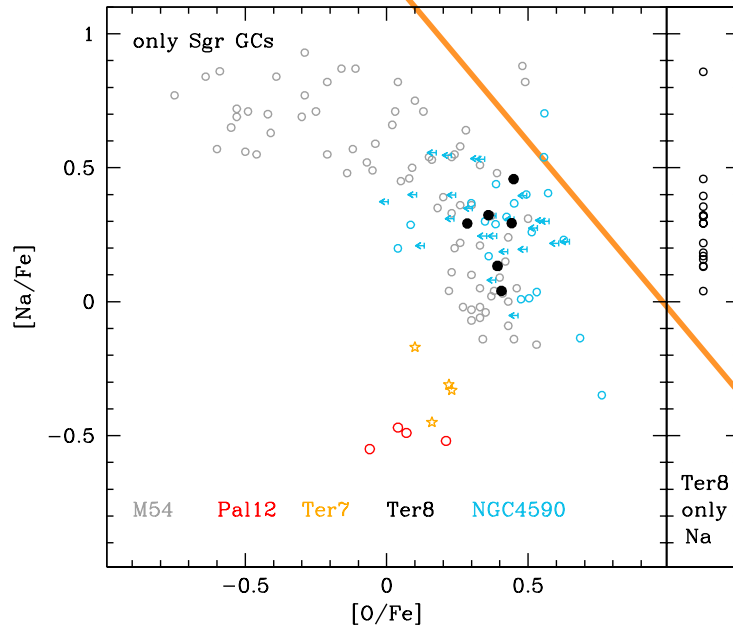
GCs with Na-O anticorrelation

Ter7 : Tautvaisiene+, Sbordone+
Pal12: Cohen
Rup106 : Villanova+

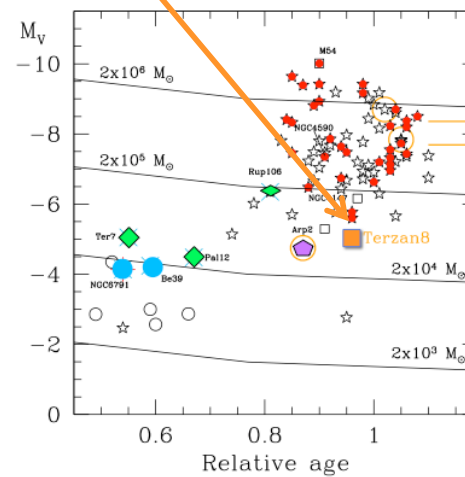
All creatures great and small. I. GCs

Terzan 8

NGC 6139



FG dominates

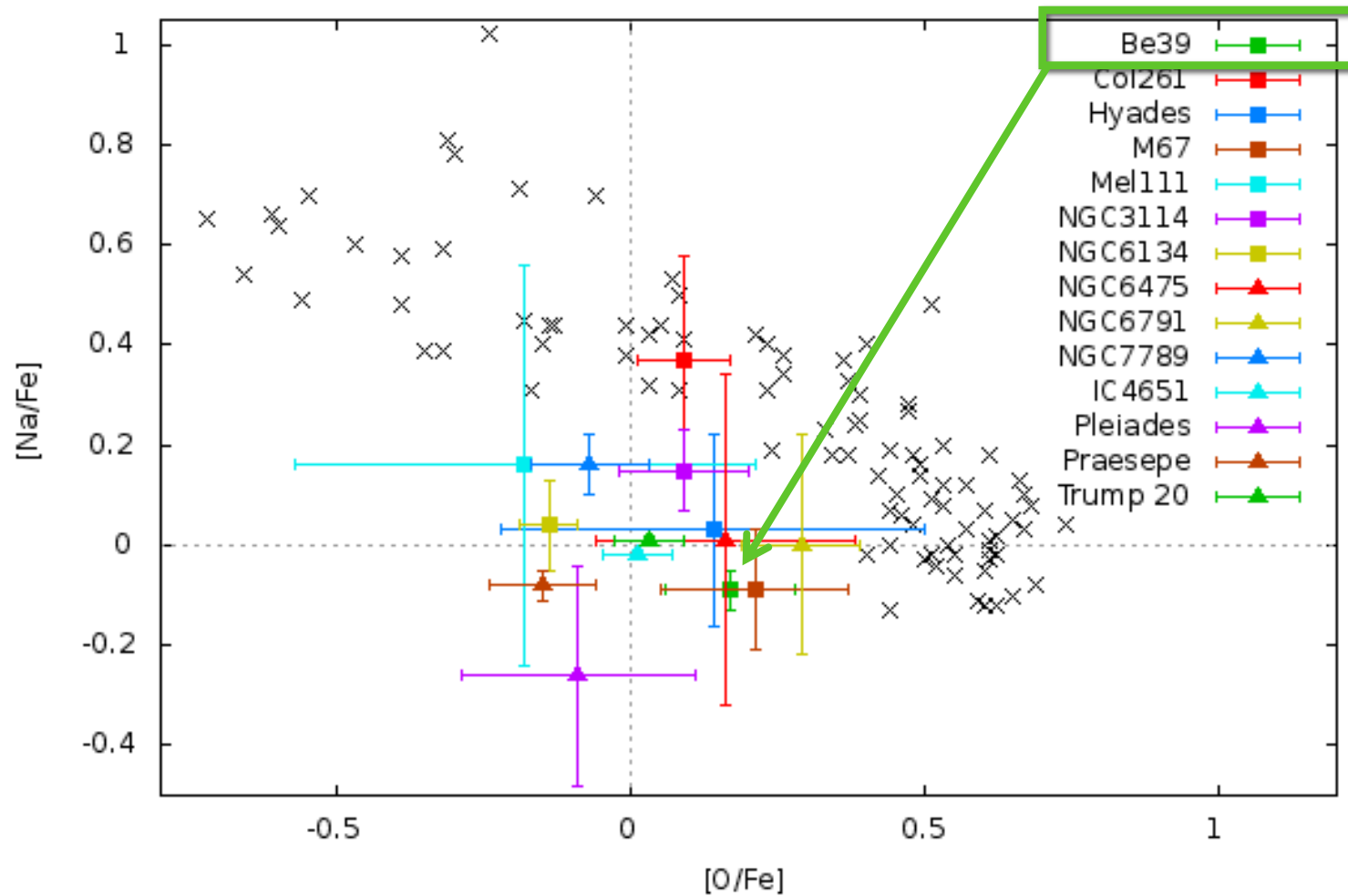


work in progress
 “normal” Na-O
 SG & FG

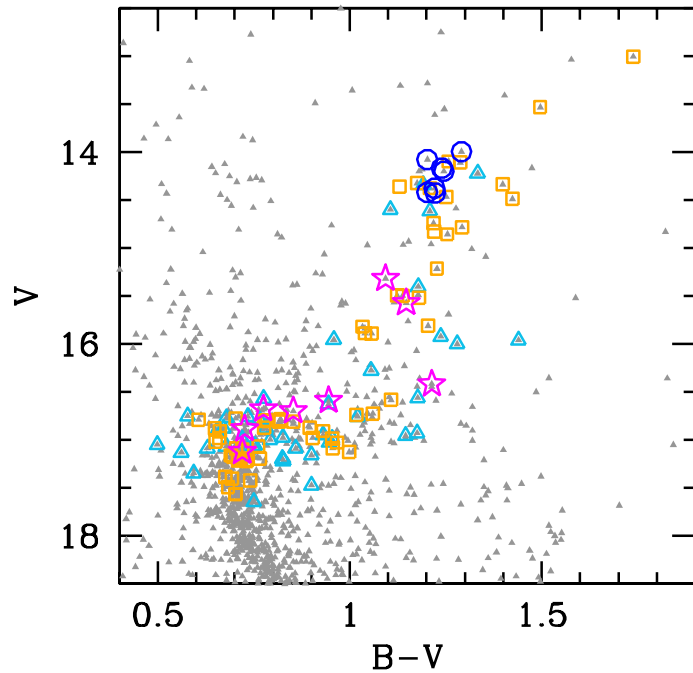
Carretta+2014

Bragaglia+, in prep.

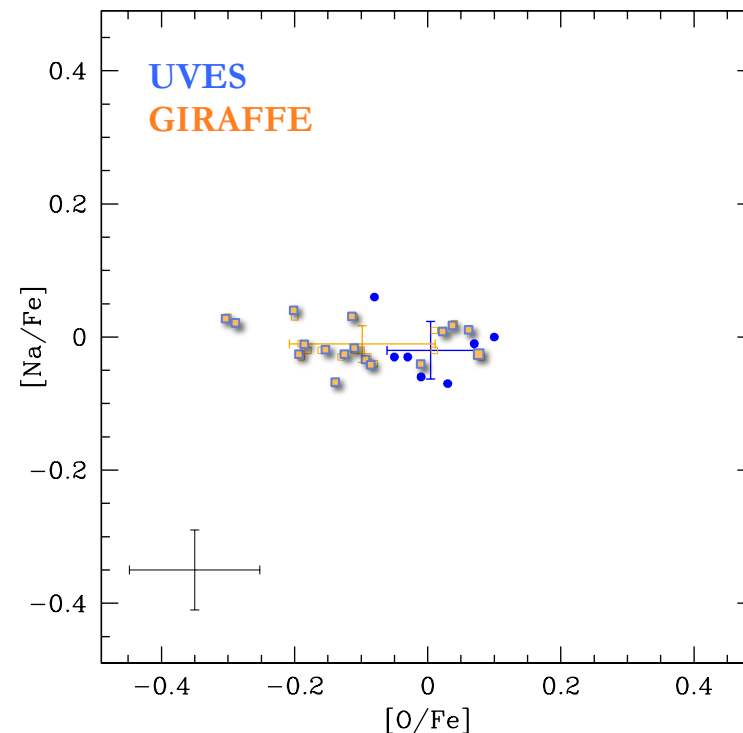
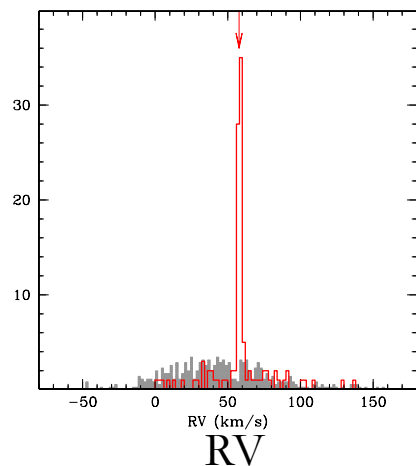
All creatures great and small. II. OCs



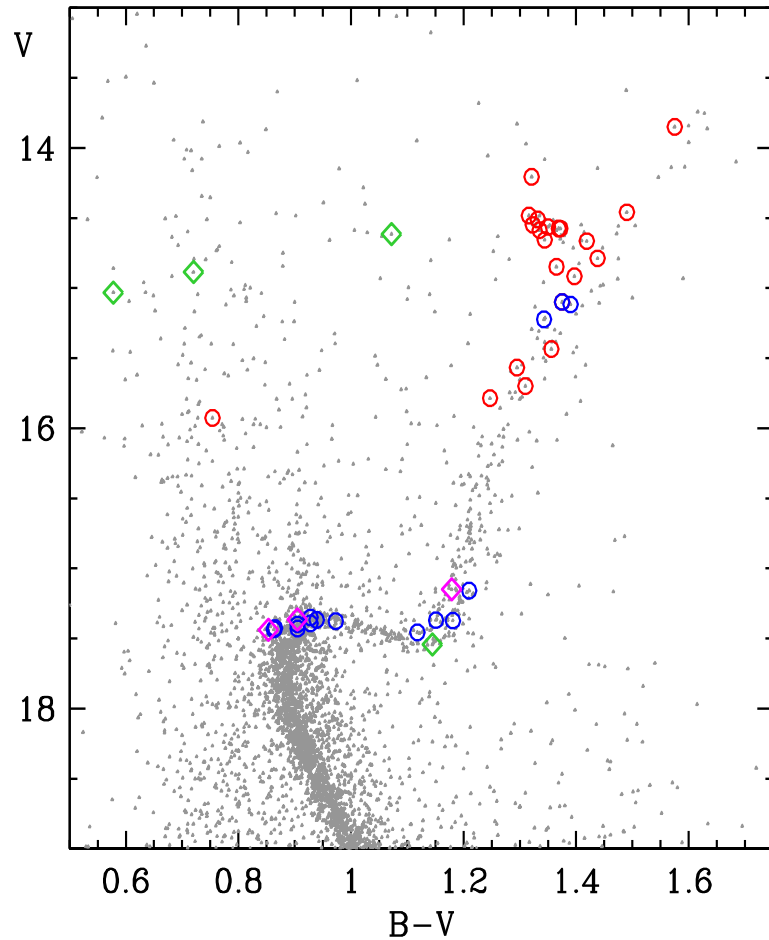
All creatures great and small. II. OCs



Berkeley 39:
 $M_V = -4.28$; age = 6 Gyr
 $[Fe/H] = -0.2$



All creatures great and small. II. OCs



NGC 6791:

$M_V = -4.14$; age = 8 Gyr

$[Fe/H] = +0.4$

Hydra@WIYN

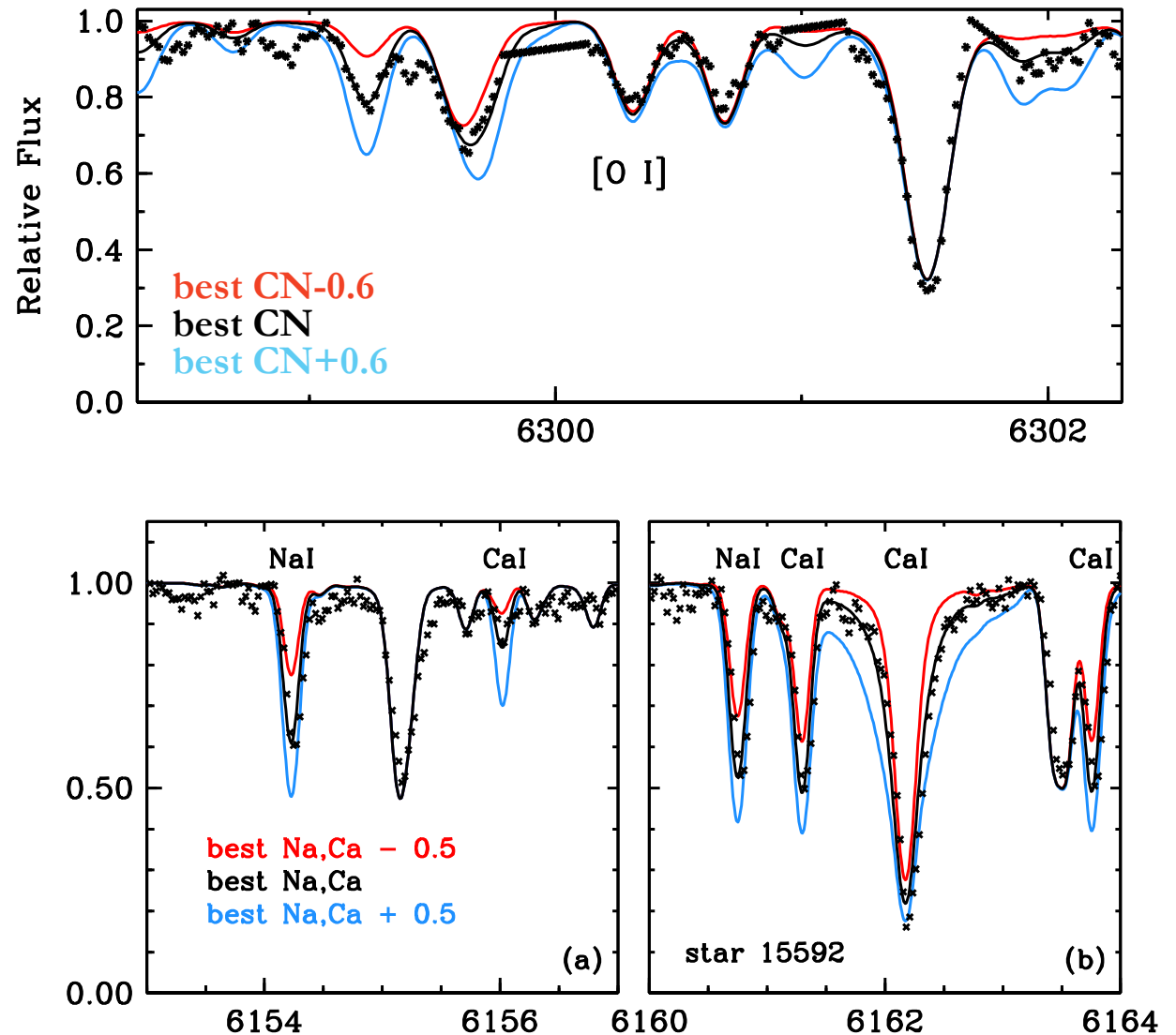
HIRES@Keck

NM (RV) ; NM (met)

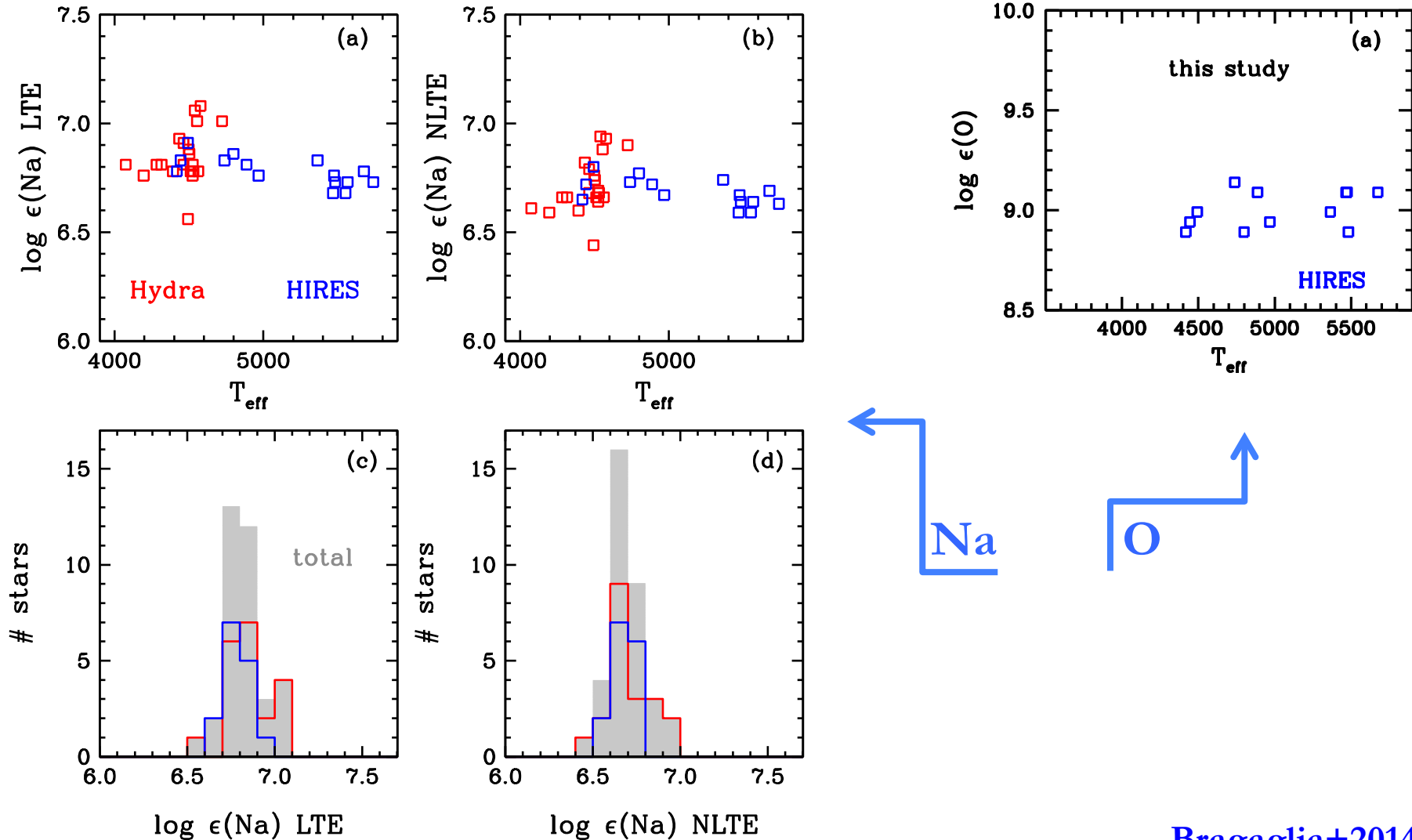
Bragaglia, Snedden, Gratton et al. 2014

All creatures great and small. II. OCs

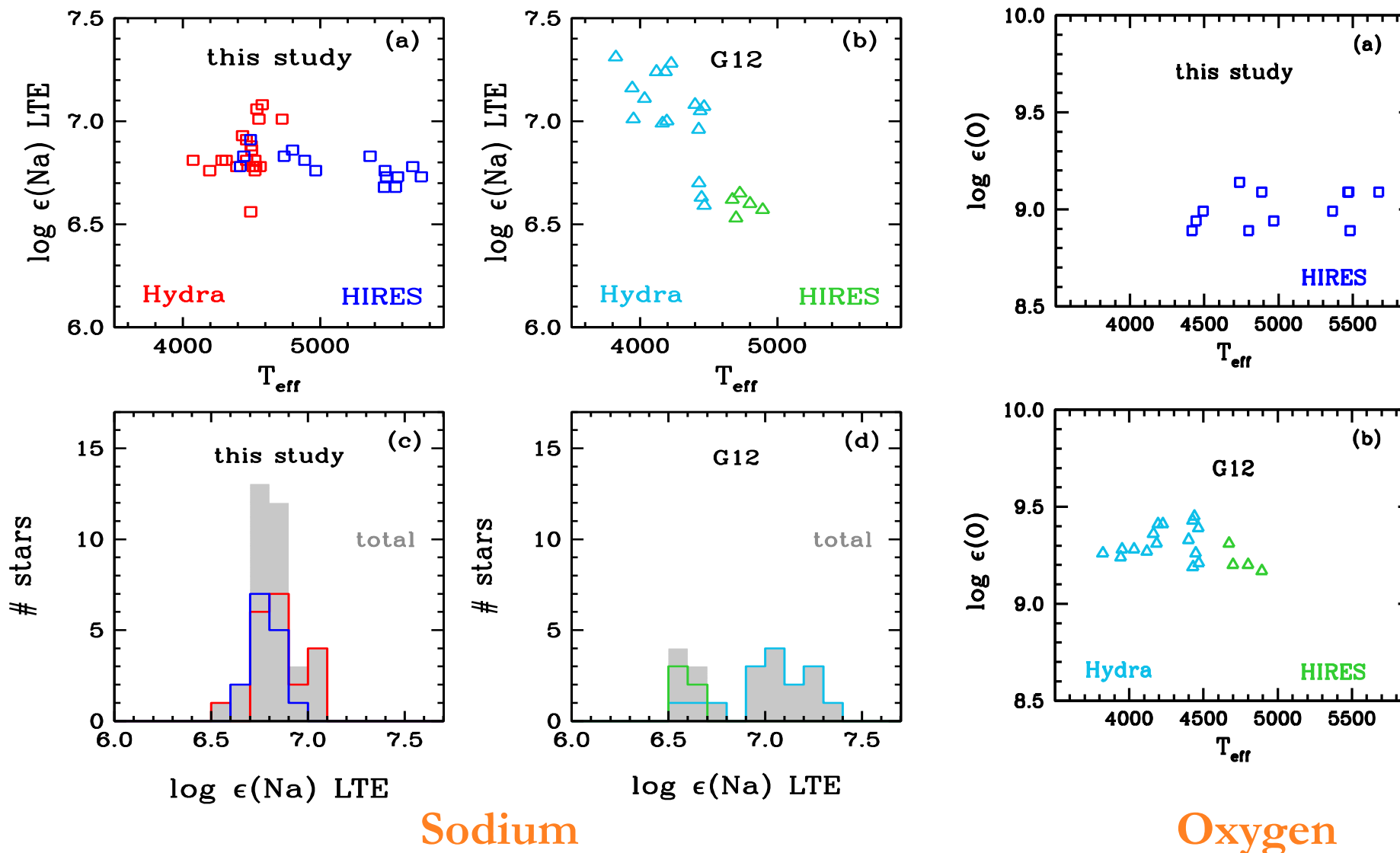
NGC 6791



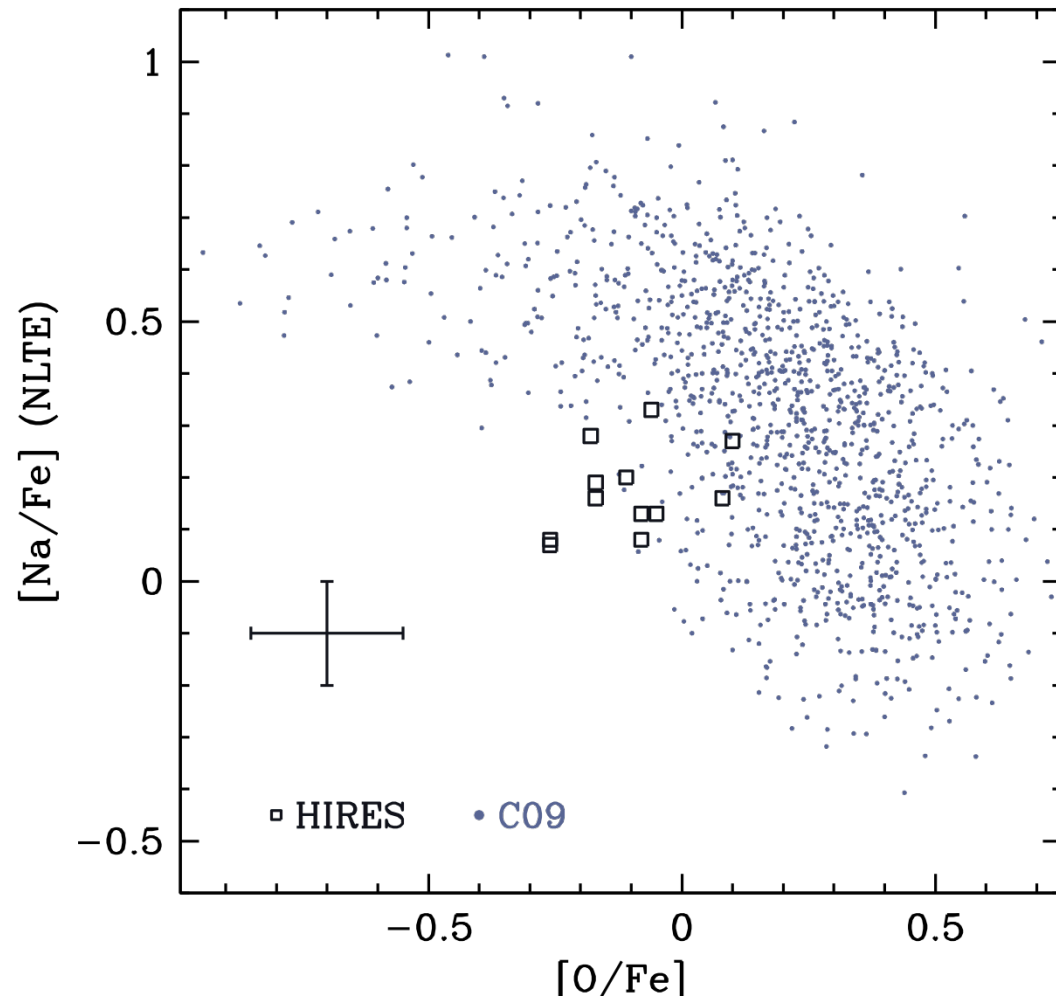
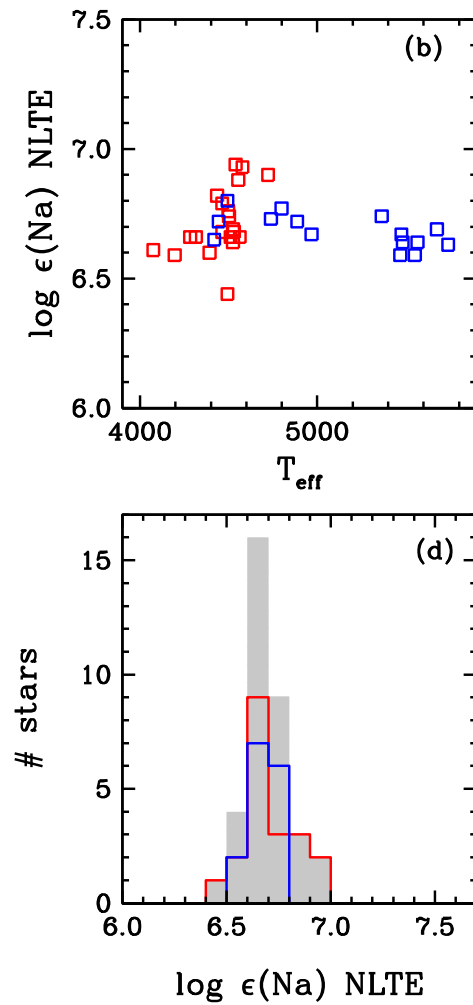
All creatures great and small. II. OCs



All creatures great and small. II. OCs



All creatures great and small. II. OCs



Results & legacy value

- clusters are halo and disk (and bulge) tracers
- constraints for stellar models
- cover both young & old, metal-poor & rich populations
- combine photometry, spectroscopy & models

... wait for Gaia-ESO, APOGEE, etc
and - of course - Gaia ...

IAU Symposium 317 at the 2015 IAU GA

The screenshot shows the IAU website interface. At the top left is the IAU logo and the text "INTERNATIONAL ASTRONOMICAL UNION". A navigation bar contains links: Home | About IAU | Member Directory | Site Map | Contact Us | Login. Below this is a menu with categories: News, Science, Publications, Administration, Education, IAU for the Public, Astronomy for Development, and International Year of Light. The main content area features a breadcrumb trail: Home / Science / Scientific Meetings / Future IAU Meetings / Symposia » The General Assembly of Galaxy Halos: Structure, Origin and Evolution. The main heading is "IAU Symposia" followed by "IAUS 317: The General Assembly of Galaxy Halos: Structure, Origin and Evolution". A sidebar on the right includes a search box, social media sharing buttons (Like, Share, Tweet), and a section for following the IAU on social media with Facebook and Twitter icons. Below that is a banner for "IAU General Assembly Honolulu, 3-14 August 2015" with a logo for the XXIX General Assembly in Hawaii.

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IAU Symposia

IAUS 317: The General Assembly of Galaxy Halos: Structure, Origin and Evolution

Start date/time
August 3, 2015

End date/time
August 7, 2015

Place
Honolulu,
United States

Contact
Angela Bragaglia
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IAU General Assembly
Honolulu, 3-14 August 2015

XXIX GENERAL ASSEMBLY
Hawaii

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http://www.eso.org/~marnabol/IAU317_index.html