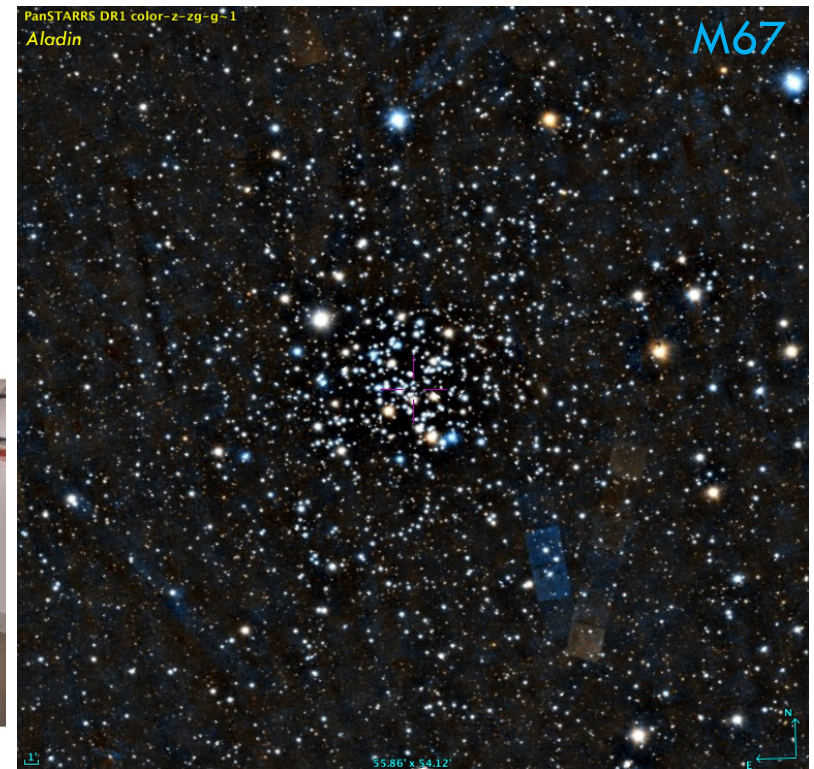


HIGH RESOLUTION SPECTROSCOPY OF OPEN CLUSTERS: RESULTS FROM THE SPA LP @TNG

Angela Bragaglia - INAF-OAS Bologna



*From star clusters to field populations: survived, destroyed and migrated clusters
Villa Galileo, Arcetri (20-23 November 2023)*



What is SPA ?

Stellar Population Astrophysics = SPA

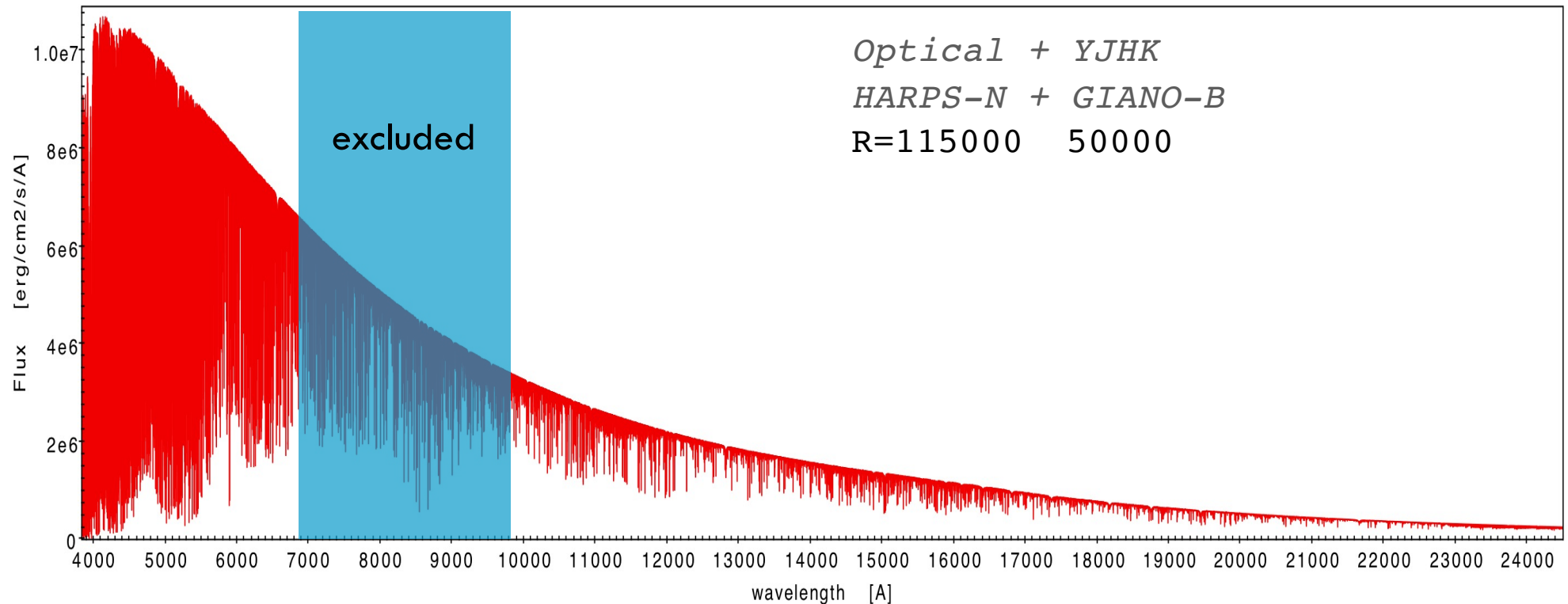


SPA = Stellar Population Astrophysics (Large Program @ TNG, A47TAC_31, PI L. Origlia)

Jun 2018 – Nov 2021 (666 h = 74 n, 3 “projects”) http://nisp.oabo.inaf.it/SPA_TNG_LP/

GIARPS = HARPS-N (optical) + GIANO-B (IR)

$\lambda=3830-6900 \text{ \AA}$, $R=115000$ + $\lambda=0.95-2.45 \text{ \mu m}$, $R=50000$



Stellar Population Astrophysics = SPA

SPA-OC : *Angela Bragaglia (WG coord.), Javier Alonso-Santiago, Gloria Andreuzzi, Ricardo Carrera, Eugenio Carretta, Giada Casali, Giovanni Catanzaro, Marina Dal Ponte, Valentina D'Orazi, Antonio Frasca, Xiaoting Fu, Mingjie Jian, Sara Lucatello, Laura Magrini, Donatella Romano, Monica Tosi, Antonella Vallenari, Nagaraj Vernakar, Ruyuan Zhang*

INAF OAS Bologna, OA Catania, TNG, Uni Bologna, OA Padova, Uni Tor Vergata, PMO Nanjing, Uni Stockholm, OA Arcetri

+collaborators, e.g. M. Bellazzini, H. Jönsson, N. Matsunaga, A. Miglio, N. Sanna, L. Spina, E. Spitoni, etc

SORRY if I missed someone !

SPA-OC : what do we get from GIARPS

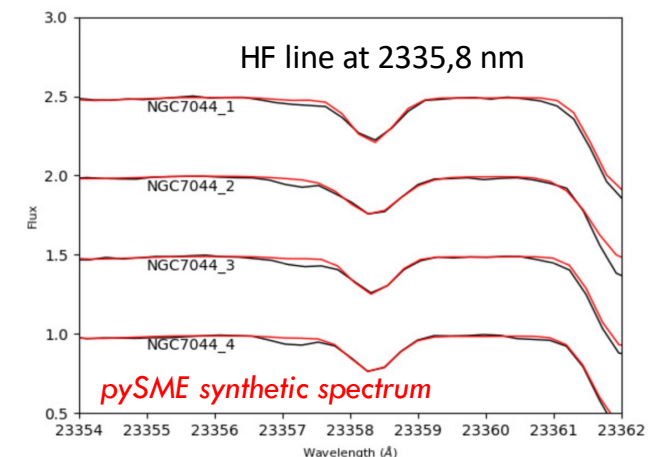
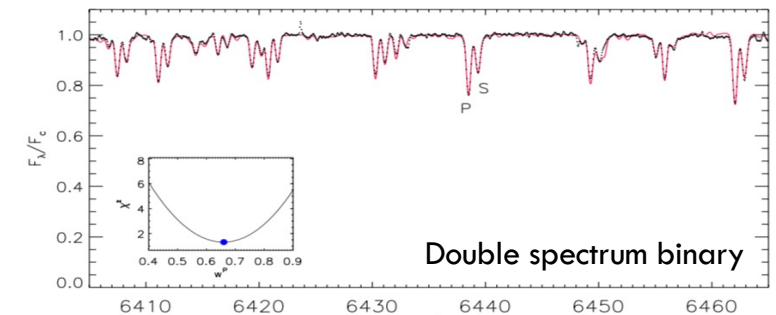
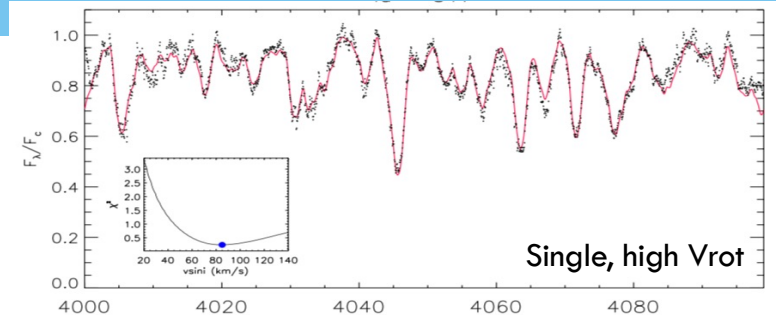
The usual suspects, mostly from the **HARPS-N** spectra :

- RV
- Atmospheric parameters
- [Fe/H]
- [X/Fe] e.g. α 's, Na, Fe-peak, Li, ...
- Vrot
- activity indicators

Working on something more from the **GIANO** spectra :

- fluorine (HF, K band, all parameters from IR)
- helium (10830 Å chromospheric, Y band)
- phosphorus (various lines, Y and H bands)

Tables with results are/will be available at CDS, science-ready spectra (if not already public at TNG archive) will be made public





So what ?

HR spectra of OCs: why?

As part of a wider effort involving Gaia, large surveys (Gaia-ESO, WEAVE, 4MOST), long-running projects (BOCCE) we are obtaining optical & NIR HR spectra of high probability OC members, selected using Gaia

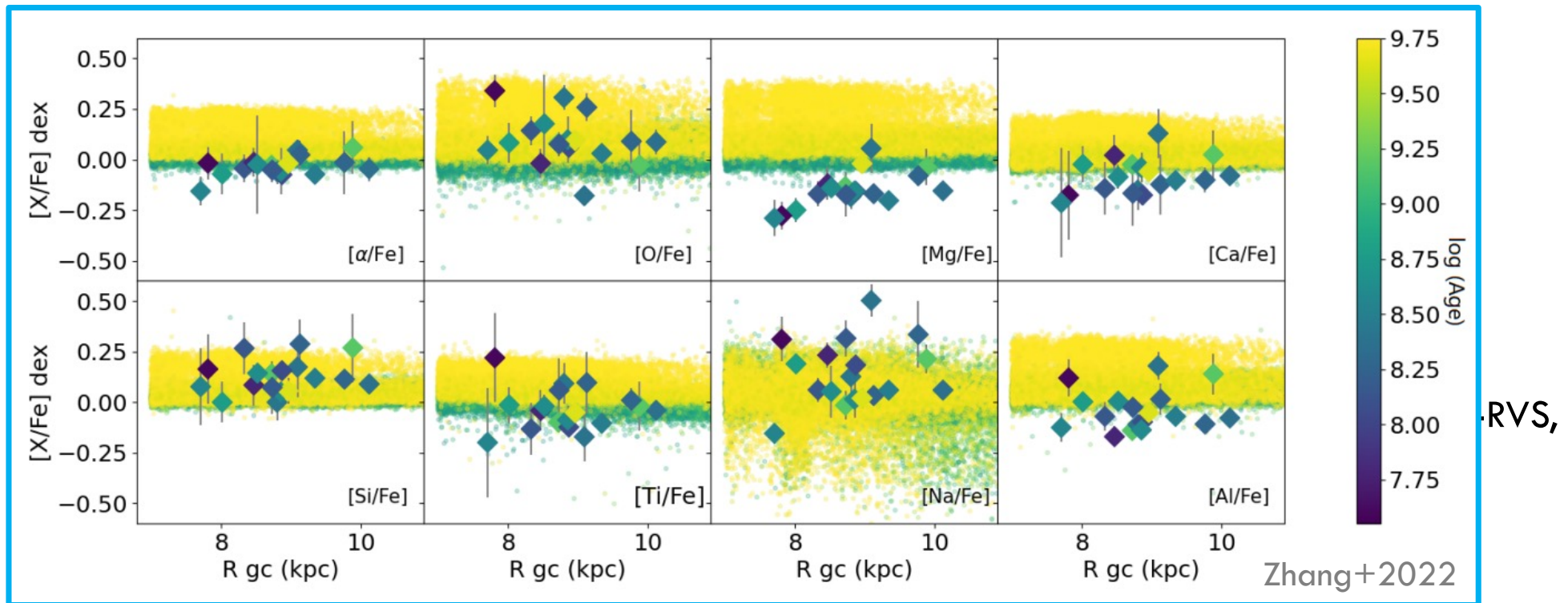
- 1) a few (giant) stars in a large number of nearby, unstudied OCs → metallicity [abundances]
 - ages (via stellar models)
 - distribution of metallicity, abundances (chemical map of disk)
- 2) a few ten of stars in key clusters, MS and/or giants → detailed abundances
 - test of stellar models (diffusion, mixing)
 - test of all nucleosynthetic chains (chemical evolution)
 - influence of activity, rotation, binarism
- 3) “unusual” elements (e.g. He, F, P)

Legacy value : high quality sample to cross-match with large spectroscopic samples (Gaia-RVS, Gaia-ESO, APOGEE, GALAH, WEAVE, 4MOST...) and with asteroseismology samples (Kepler/K2, TESS, and soon PLATO)

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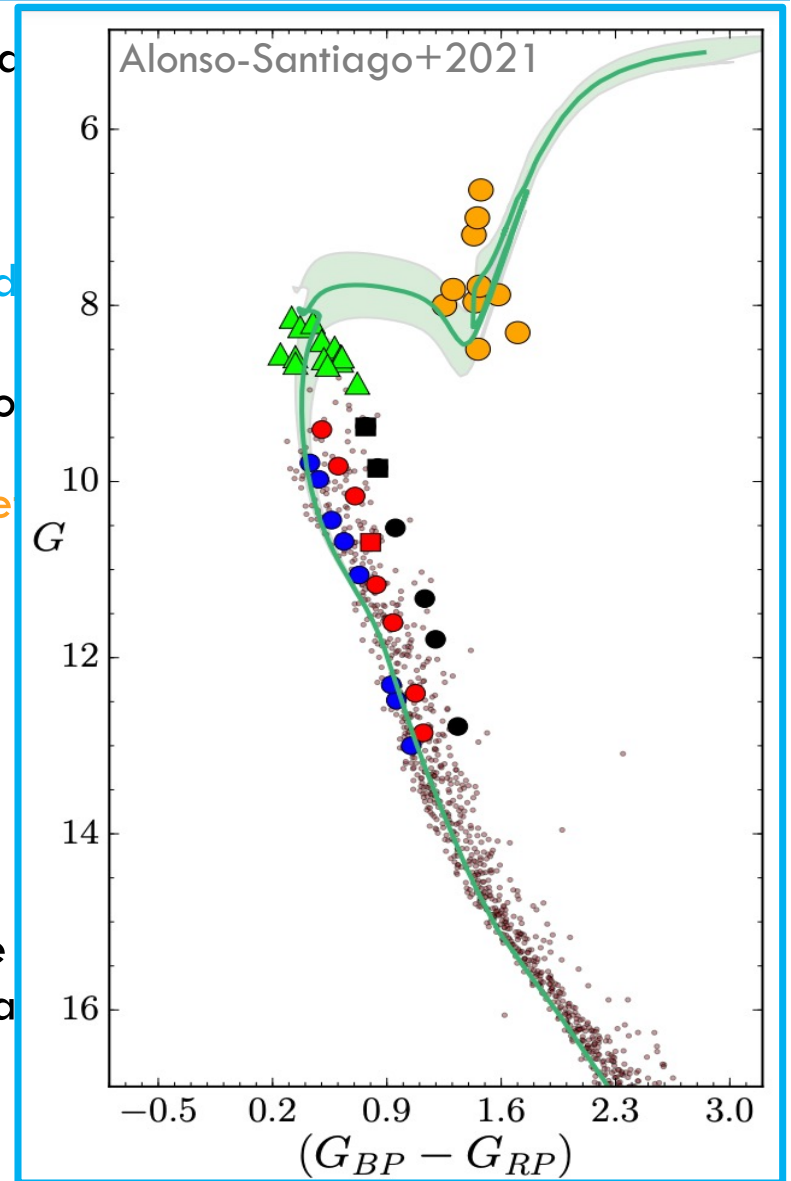


HR spectra of OCs: why?

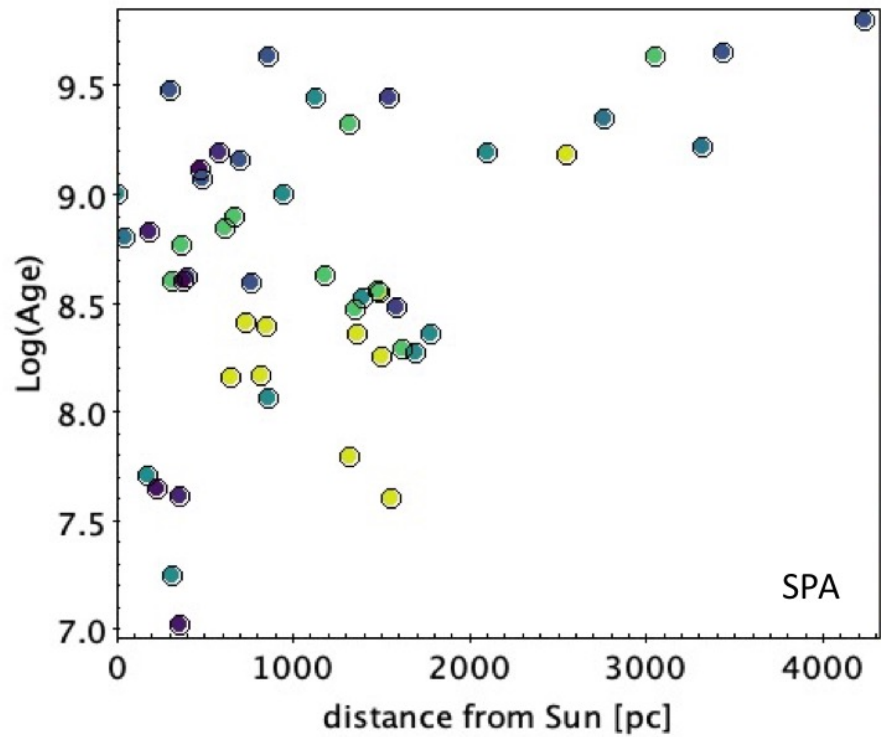
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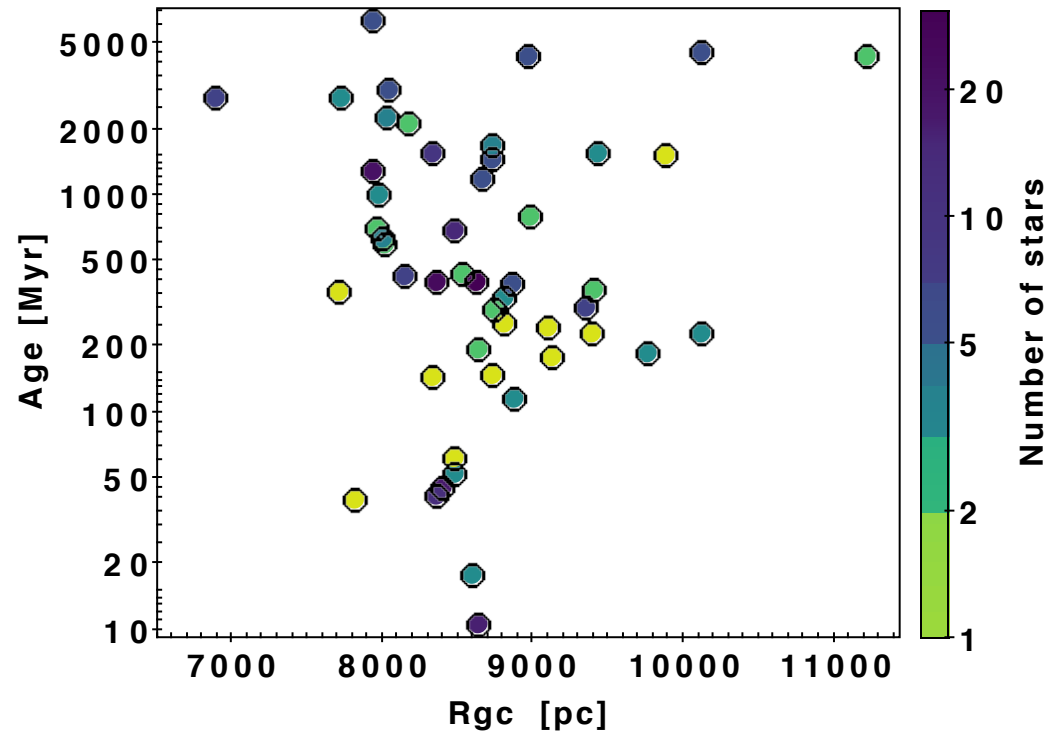
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SPA-OC by numbers



Number of clusters: 50
(excluding follow-ups)



Number of stars/OC: 1 to 31

SPA legacy value

Legacy value : high quality sample to cross-match with large spectroscopic samples (Gaia-RVS, Gaia-ESO, APOGEE, GALAH, WEAVE, 4MOST...) and with asteroseismology samples (Kepler/K2, TESS, and soon PLATO)

Asteroseismology/satellites, just a start :

2023A&A...677A.154F


2023/09



TIC 43152097 The first eclipsing binary in NGC 2232

Frasca, A.; Alonso-Santiago, J.; Catanzaro, G. *and 5 more*

Stellar population astrophysics (SPA) with the TNG. Abundance analysis of nearby red giants and red clump stars: combining high resolution spectroscopy and asteroseismology*

Nagaraj Vernekar^{1,2} , Sara Lucatello², Angela Bragaglia³, Andrea Miglio^{3,4}, Nicoletta Sanna⁵, Gloria Andreuzzi^{6,7}, and Antonio Frasca⁸

Combining TESS data (eclipse, rotation) with RVs from SPA

Combining GIARPS with K2 data (oscill. frequencies → mass, age)

Two more PhDs just starting (in Bologna, Padova) and one post-doc (WEAVE-related) will bring new forces to pursue the projects

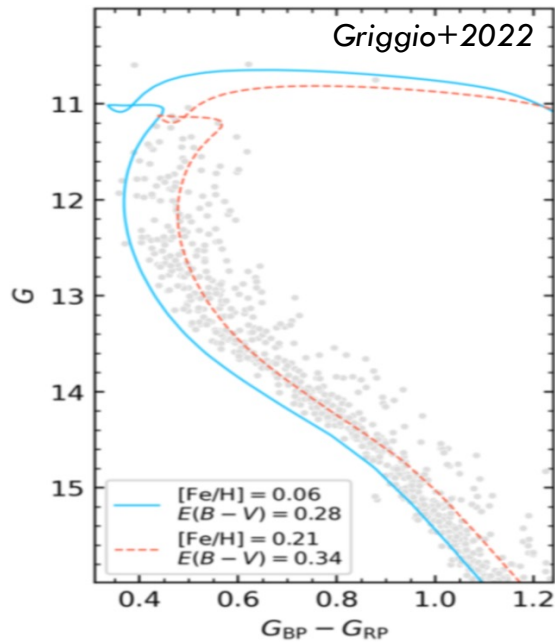
SPA-OC & follow-up : work in progress

- Study of **fluorine** abundance in a sample of OCs of age 1-8 Gyr (from HF in K-band)
[led by V. D'Orazi (Tor Vergata & INAF-OAPD), E. Jönsson, S. Seshashayana (Malmö Uni)] → Valentina's talk
- Study of **phosphorous** in all available GIANO spectra (some ten of OCs, from Y, H-bands)
[led by M. Jian (Stockholm Uni), X. Fu (PMO Nanjing), N. Matsunaga (Tokyo Uni)]
- Study of the giants in **ten more** OCs, mostly never analysed before
[led by M. Dal Ponte (INAF-OAPD), A. Bragaglia (INAF-OAS), V. D'Orazi (Tor Vergata, INAF-OAPD)]

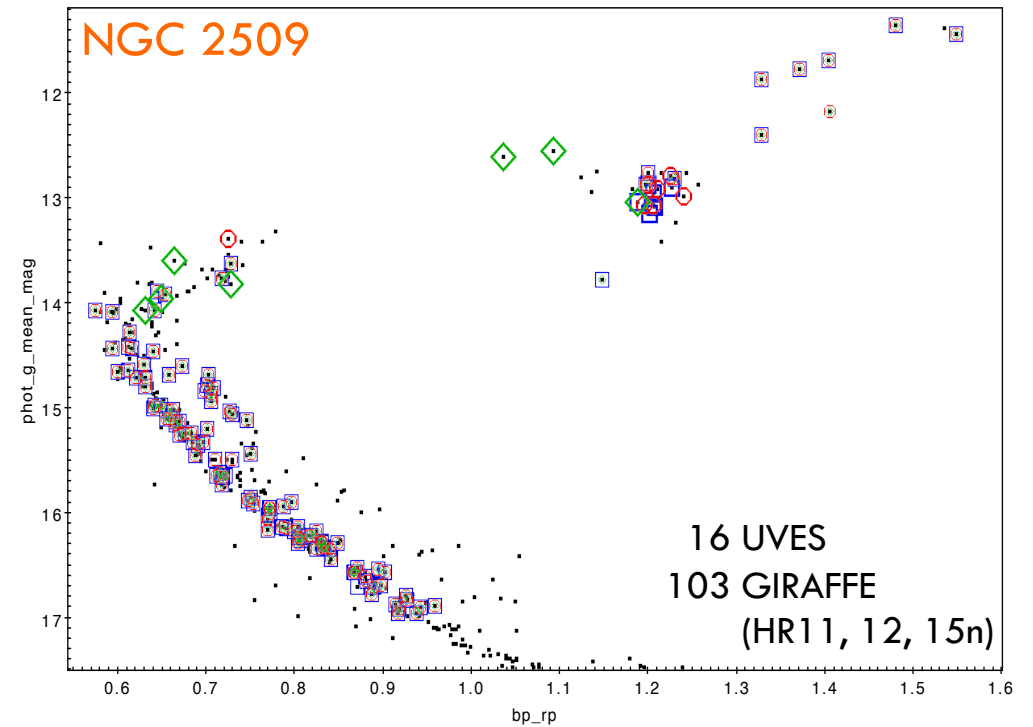
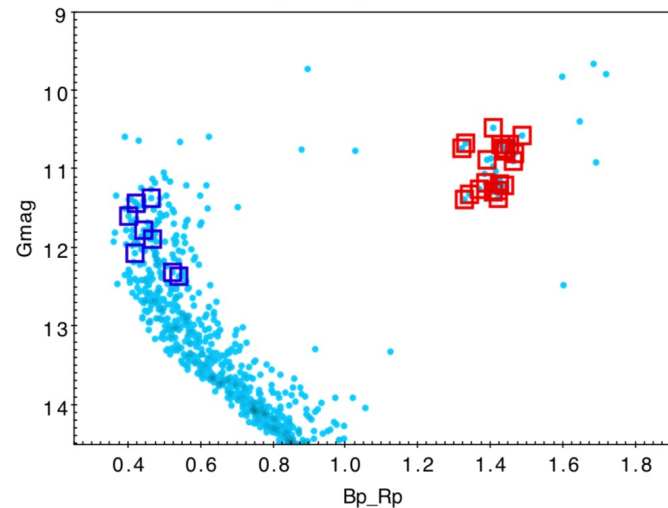
follow-up

- Young OCs in the **Radcliffe Wave** (with GIANO@TNG)
[led by X. Fu (PMO), A. Frasca and the INAF-OA Catania people]
- A check on **chemical homogeneity** in M37 (with PEPSI@LBT, ~30 stars being observed)
[led by A. Bragaglia (INAF-OAS), V. D'Orazi (Tor Vergata, INAF-OAPD)]
- **NGC 2509**, an intermediate age OC with a large binary population and a narrow MSTO
(with FLAMES@VLT, data to be collected in P112)
[led by A. Bragaglia (INAF-OAS)]

SPA-OC & follow-up : work in progress



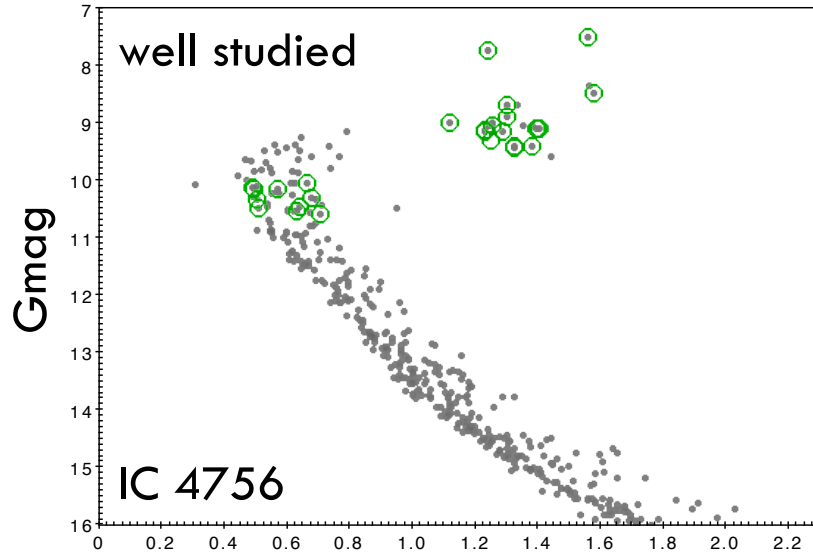
M37/NGC2099 (with PEPSI@LBT, ~30 stars being observed)



NGC 2509 (with FLAMES@VLT, data to be collected in P112)

SPA-OC : some of the latest entries

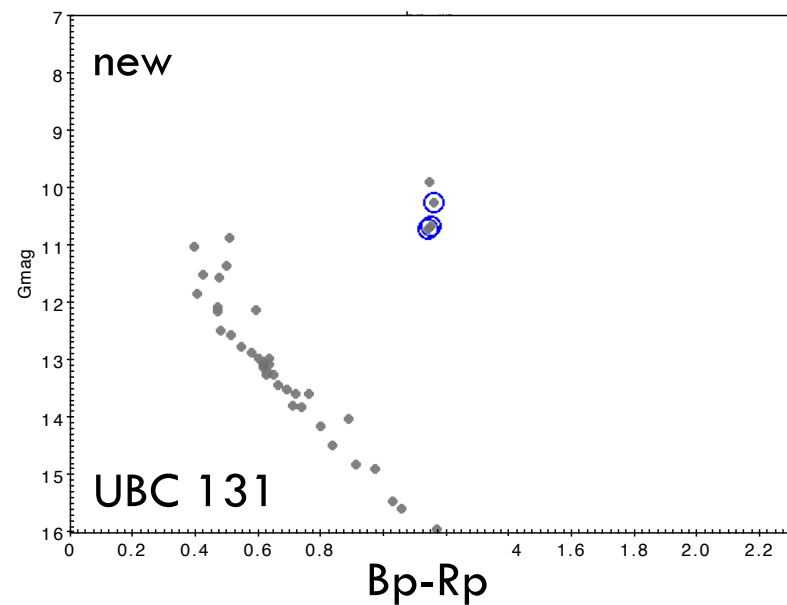
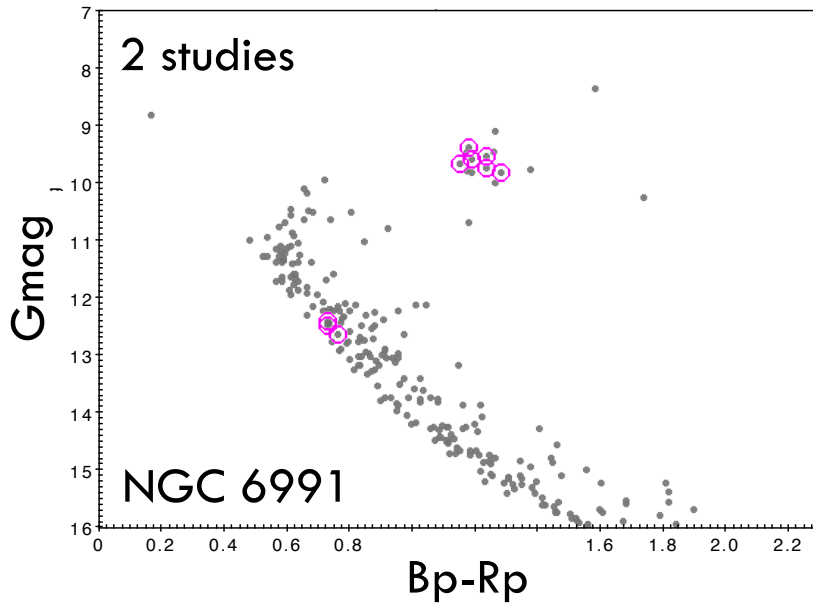
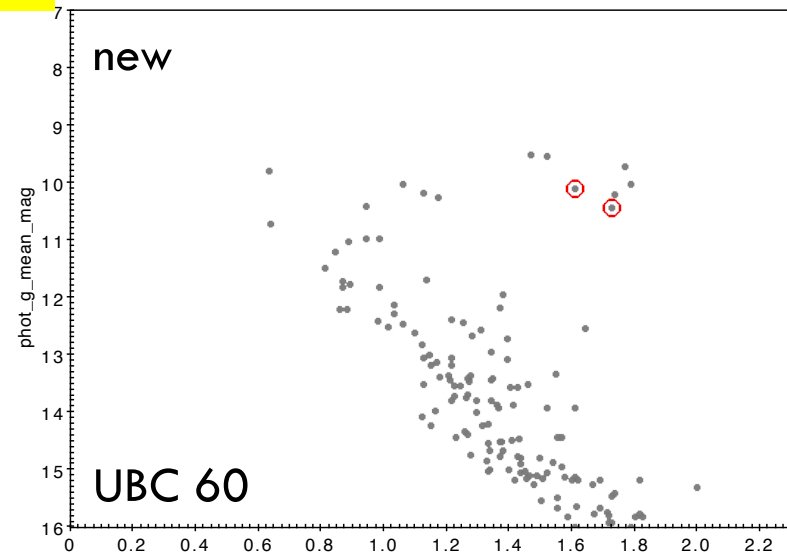
work in progress



Probable members
(to G=18)

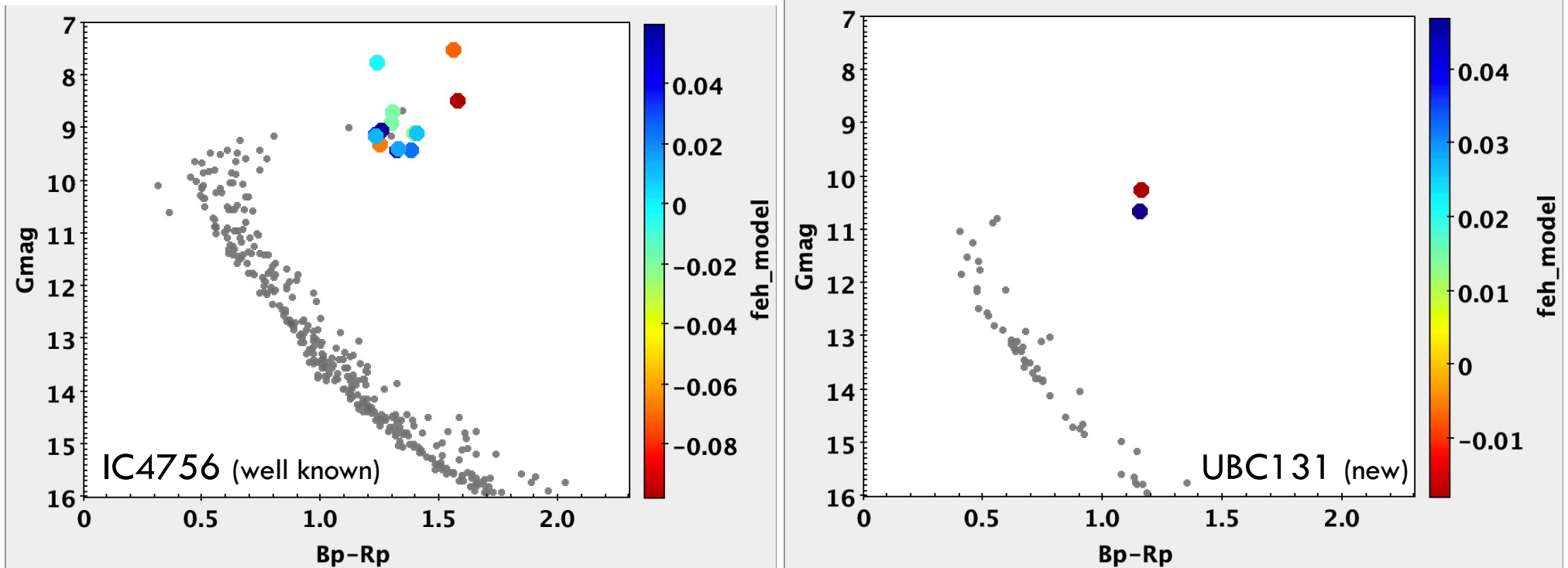
700 ← → 200

400 ← → 50



SPA-OC : some of the latest entries

work in progress, very preliminary results



Both solar metallicity, $\text{std} \sim 0.04$ dex



Enter the infrared

FLUorine abundances in Open cluster cool giants (FLUO) : SPA + follow-up

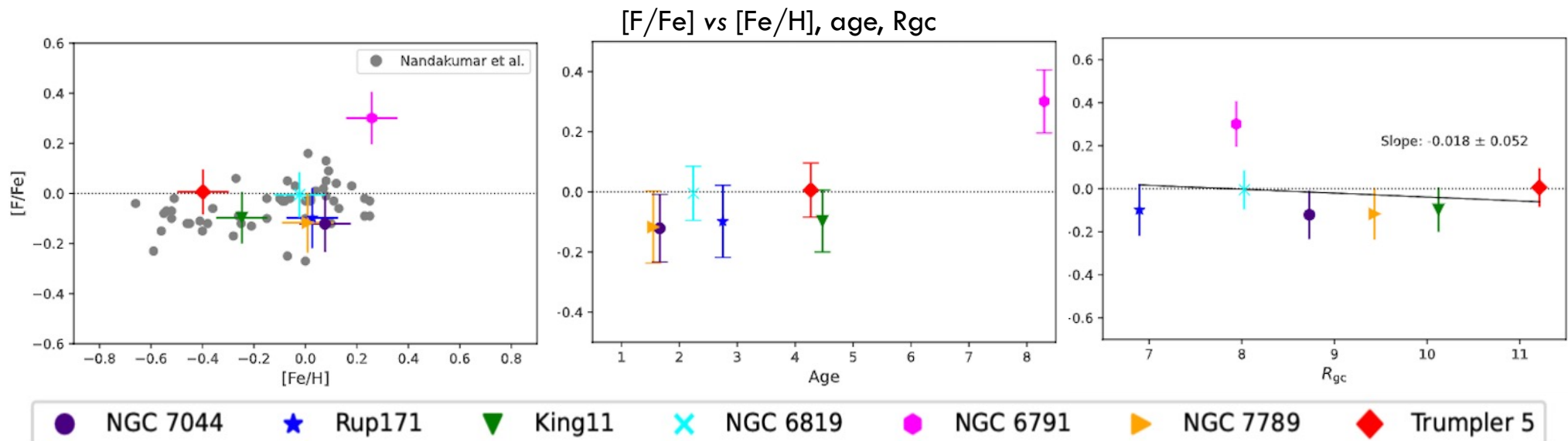
A47TAC_6

V. D'Orazi

FLUorine abundances in Open cluster cool giants (FLUO)

GIARPS

15



- Source of F production not well known (AGB, cc SNe, WR, rapidly rotating high-mass, novae)
 - ➔ no understanding of relative contribution to Galactic chemical evolution
- No large survey covers F (measured from HF at $2.5\mu\text{m}$)
- We study F in OCs (age 0.5-9 Gyr; $[\text{Fe}/\text{H}] = -0.5$ to $+0.5$; various R_{gc}) ➔ SPA+GO

Detailed description in talk
by Valentina D'Orazi

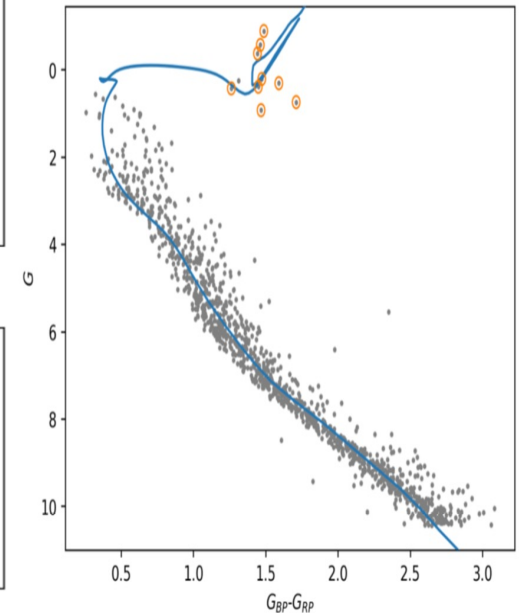
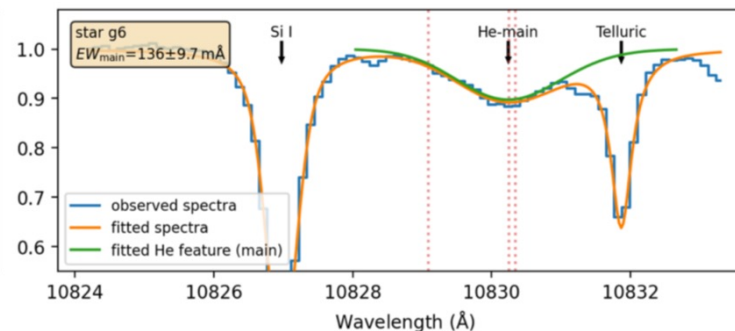
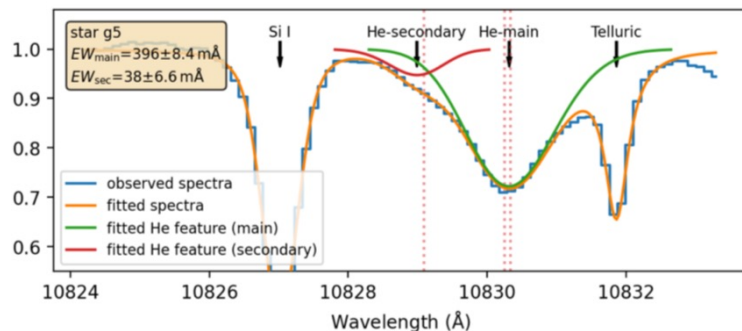
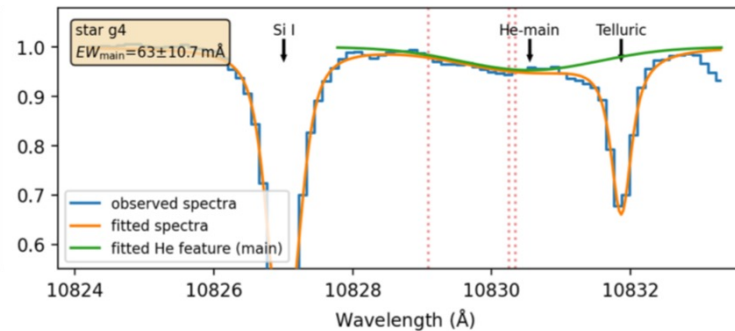
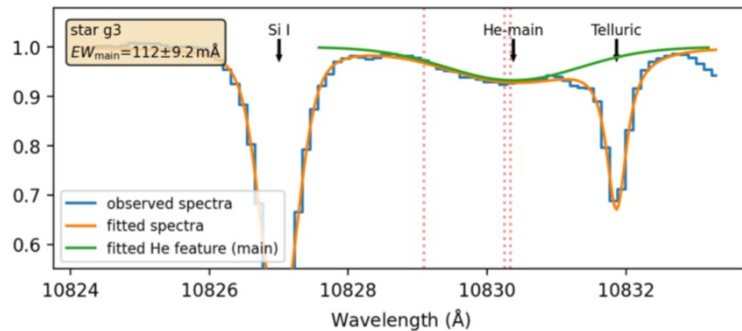
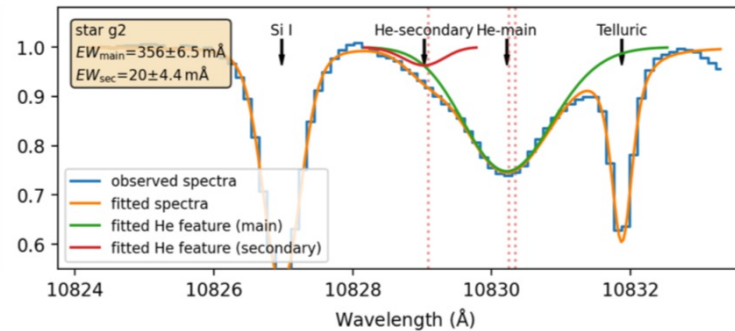
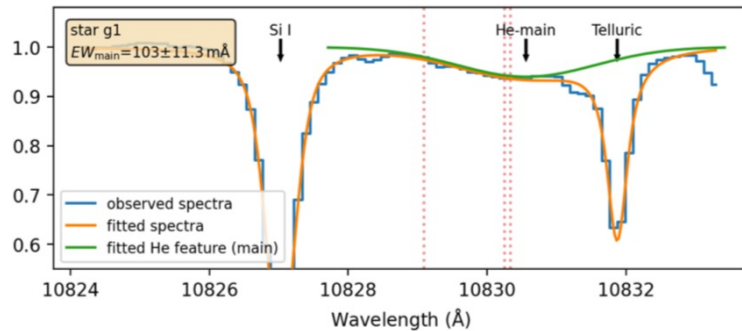
Phosphorous : sorry, nothing to show yet



Mingjie Jian, Noryuki Matsunaga, Xiaoting Fu, Valentina D'Orazi, etc

The He I 10830 Å line: a pilot study in Stock 2

work in progress

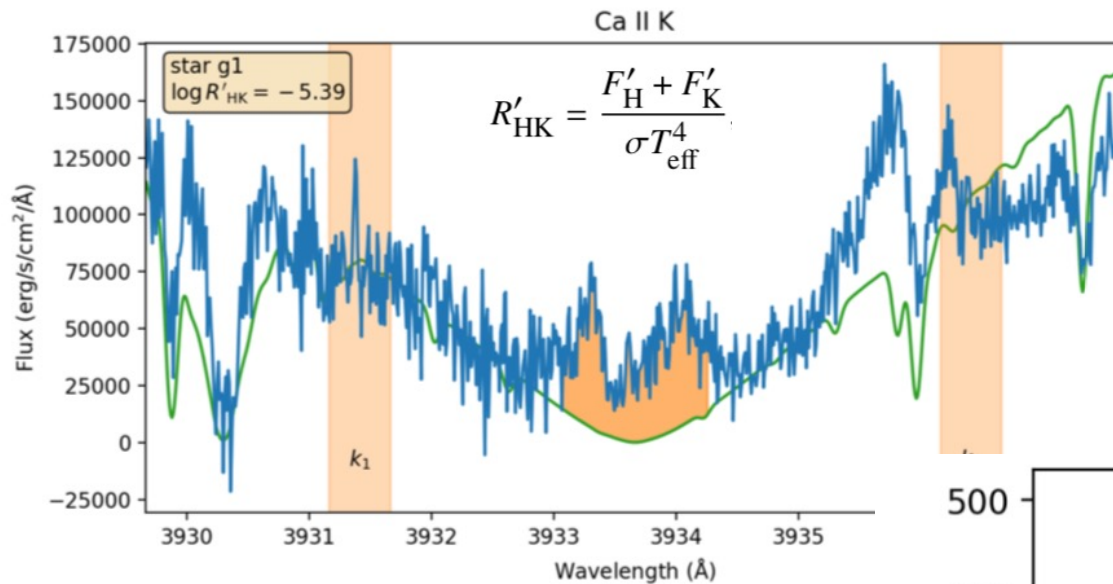


Helium difficult to measure in hot stars and impossible in cool stars

The He I 10830 Å line has complex formation mechanisms → difficult to tie its strength to stellar parameters, particularly the He abundance → necessary to investigate the connection to get reliable He abundance

The He I 10830 Å line: a pilot study in Stock 2

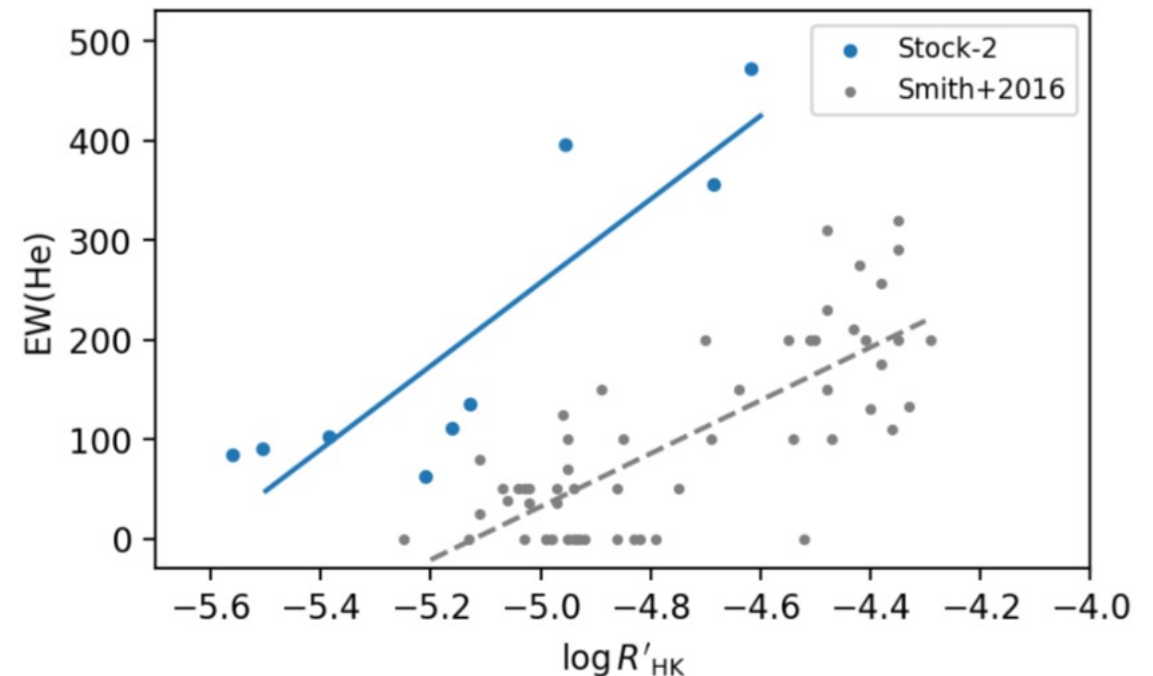
work in progress



The He I line is chromospheric

- Need a chromosphere model in addition to atmosphere
- Need to take into account activity
- Use Ca II H+K (with HARPS-N) taken at same time (GIARPS)

Still a long way to get actual He abundance, but working on it





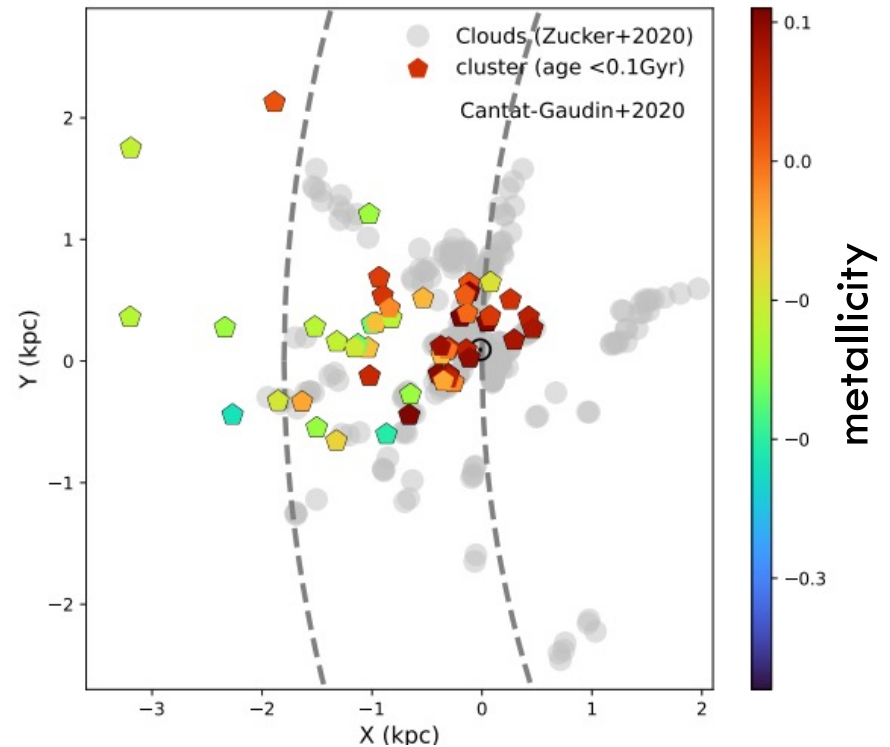
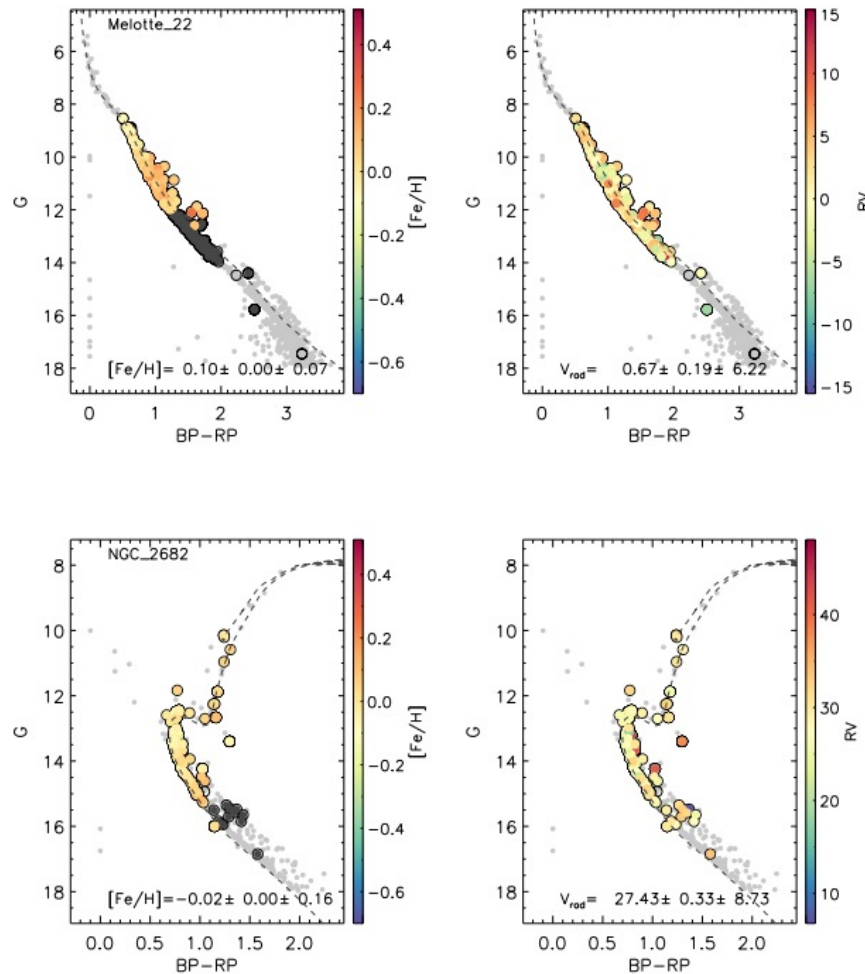
Back to youth

SPA-OC follow-up: Radcliffe Wave OCs

LAMOST meets *Gaia*: The Galactic open clusters★

Xiaoting Fu (符晓婷)^{1,8,2}, Angela Bragaglia², Chao Liu (刘超)³, Huawei Zhang (张华伟)^{4,1}, Yan Xu (徐岩)³,
 Ke Wang (王科)¹, Zhi-Yu Zhang (张智昱)^{5,6}, Jing Zhong (钟靖)⁷, Jiang Chang (常江)⁸, Lu Li (李璐)^{7,9,10},
 Li Chen (陈力)^{7,9}, Yang Chen (陈洋)^{11,3}, Fei Wang (王飞)^{4,1}, Eda Gjergo¹², Chun Wang (王春)¹³,
 Nannan Yue (岳楠楠)¹, and Xi Zhang (张茜)^{7,9,14}

- 386 OCs in LAMOST DR8
- New ave RVs for 44 OCs
- New ave [Fe/H] for 63 OCs (≥ 3 high-qual, +74 (1 or 2 high-qual))
- 24 young OCs (age < 100 Myr) possibly connected to the Radcliffe Wave

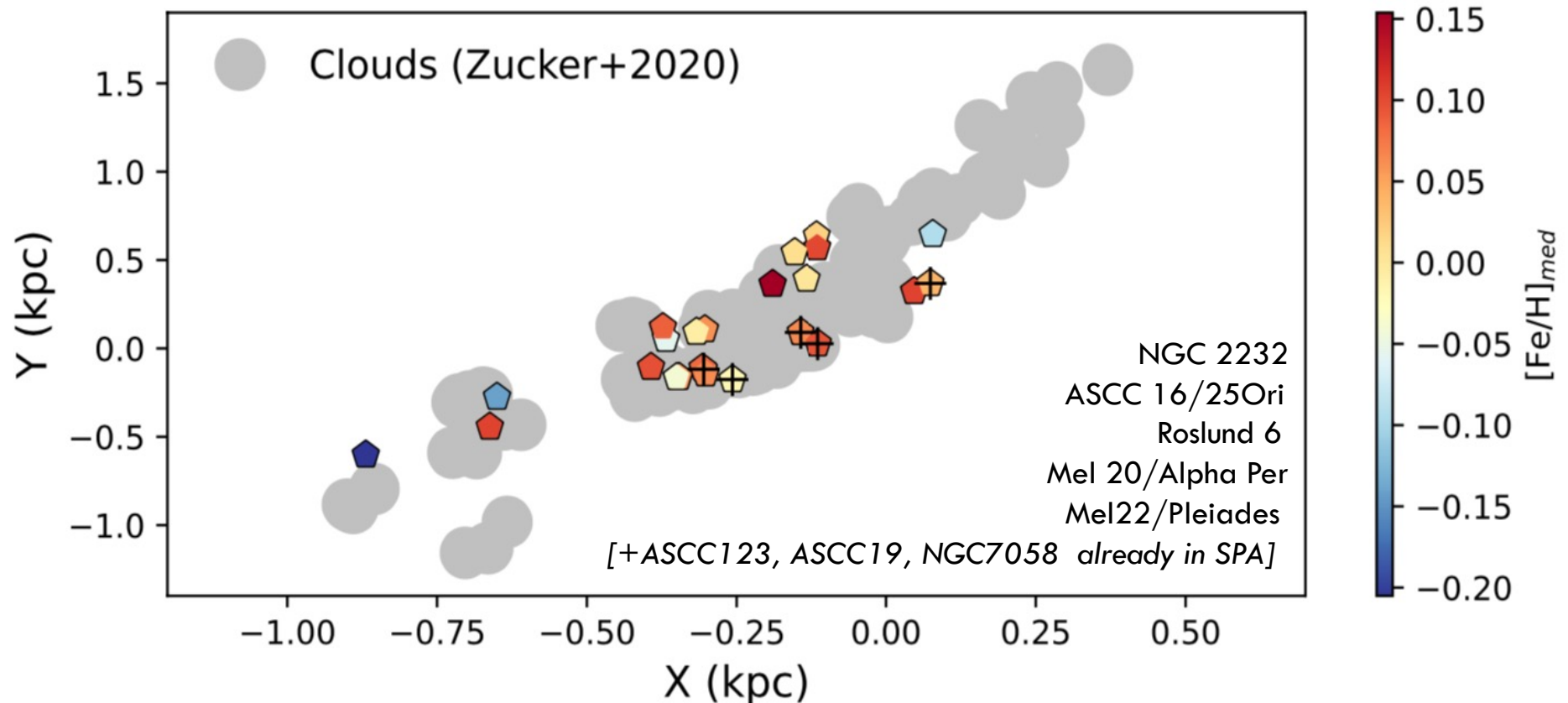


SPA-OC follow-up: Radcliffe Wave OCs

work in progress

A46TAC_31	A. Bragaglia	Metal mixing in the Radcliffe Wave traced by young open clusters	GIARPS	31.3
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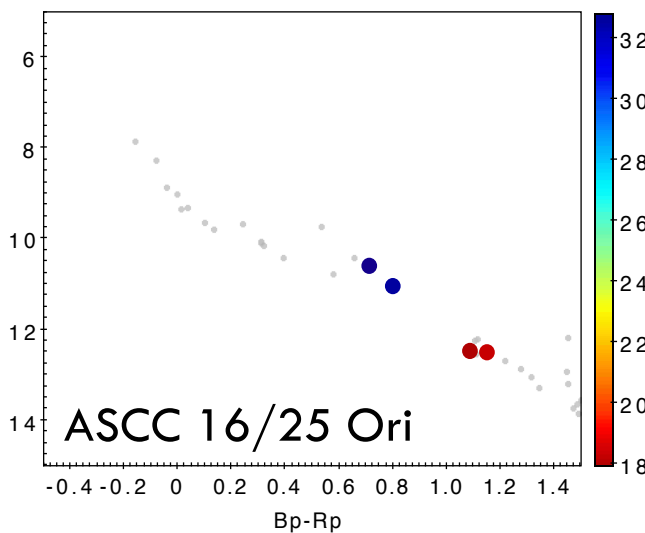
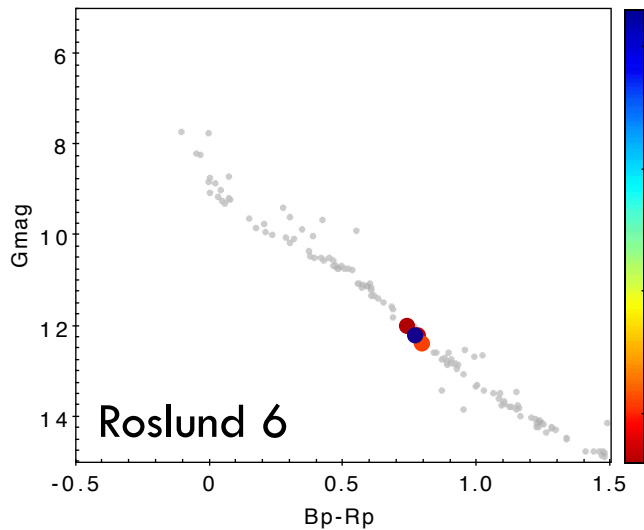
- Radcliffe Wave: 3 kpc-long gas structure including majority of SFRs in solar neigh. (Alves+2020)
- LAMOST measured $[\text{Fe}/\text{H}]$ of <100 Myr OCs tentatively associated to RW (Fu+2022)
- Will test with HARPS-N spectra to constrain cluster formation models



SPA-OC follow-up: Radcliffe Wave OCs

work in progress

Gaia CMDs [Gmag, Bp-Rp] coloured by vsini



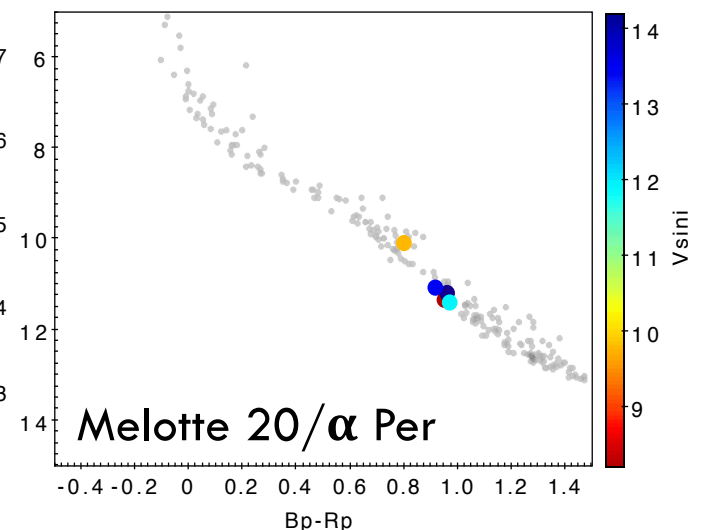
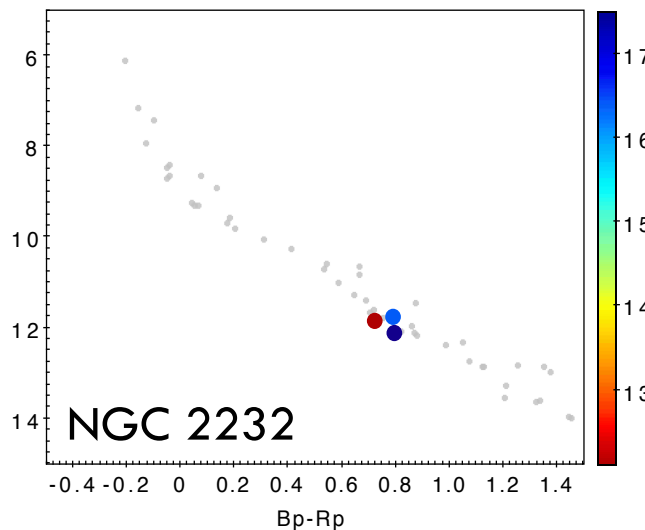
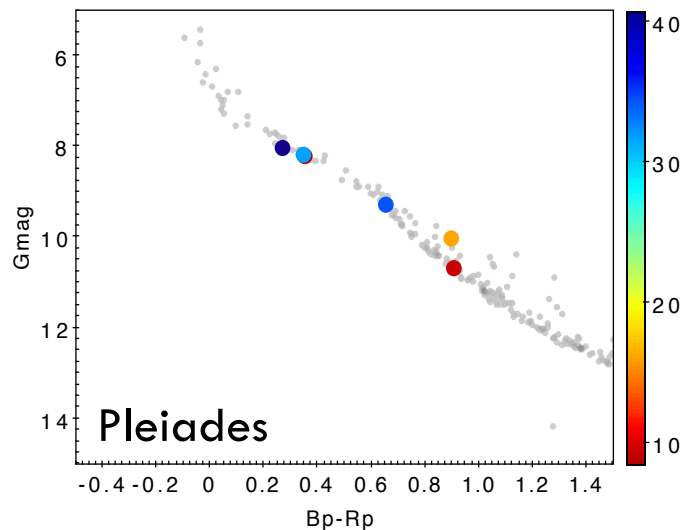
+ ASCC 123, ASCC 19, NGC 7058

[already in SPA, ~15 stars/OC]

Very (!) preliminary (LAMOST)

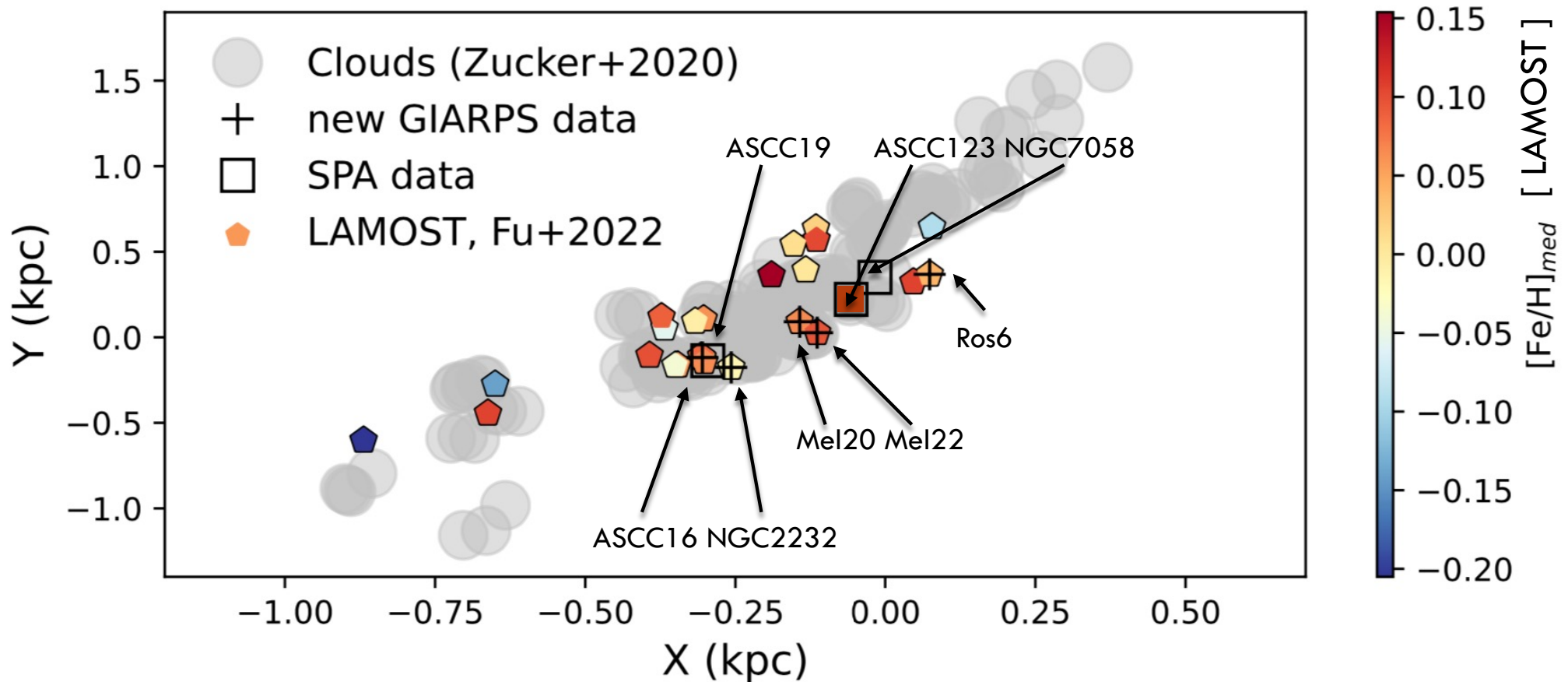
Roslund 6	[Fe/H]=+0.02	(+0.04)
ASCC 16	+0.01	(+0.06)
Pleiades (F,G)	+0.12:	(+0.09)
NGC 2232	+0.01	(-0.02)
Melotte 20 (F,G)	+0.01	(+0.06)

ASCC 123 (Frasca+2019) +0.14



SPA-OC follow-up: Radcliffe Wave OCs

work in progress



ASCC16: +0.01 NGC2232:+0.01 Mel20 (F,G): +0.01 Mel22 (F,G):+0.12: **ASCC123:+0.14** Ros6:+0.02
metallicities to be confirmed, work stil on-going

Short summary



- SPA has very high-res, wide WL coverage, good SNR spectra of many stars in many clusters
- The main initial goals are being covered by the SPA group
- GIARPS can do elements large surveys cannot do (generally)
- New entries, both people and ideas → new projects
- Can SPA do something for your science ? Please, contact us

Thank you for your attention

In a few months:



THE MILKY WAY ASSEMBLY TALE

Plot and characters as of today
and what to expect from
future editions

MAY 27 – 31, 2024
BOLOGNA, ITALY
INAF-OAS / CNR Research Area

- Substructures of the Milky Way halo, in the chemical-dynamical-chronological space
- Evolution of the Milky Way disk through the interplay with the assembling mergers
- Stellar age as a critical component
- Predictions from simulations as a tool for interpreting the complex observational evidence
- The assembly history of the Local Group

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European Research Council
Established by the European Commission

Look here for information : <https://indico.ict.inaf.it/event/2600/>