The OCCASO project

R. Carrera

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Background

2012 There was no a homogeneous (data, methodology, etc.) database of abundances for a significant number of Open Clusters (*largest were BOCCE, Friel's team, Carrera & Pancino, etc. with about 15-20 systems*).

For Globulars there were: *Zinn & West, Carretta & Gratton 1997, Carretta et al. 2009*

Initial aim: Construct a homogeneous database of abundances from high resolution spectra, including about 40 Open clusters, which can be used to investigate, for instance, trends in the Galactic disk.

Actual aim: Construct a homogeneous database of high resolution spectra, including as large number of clusters as possible, adding recently discovered clusters, which accurate radial velocities and chemical abundances, which can use to study the disk but also which serves as reference for large spectroscopic surveys. Including several elements that are not studied by these.

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Spectroscopic surveys limitations

- All
  - Automatic determination of parameters/abundances in different spectral types.
  - **Need calibrators**
- **Low resolution surveys (R~5000)**
  - Degeneracies on stellar parameters determinations
  - Abundances for a handful of elements, high uncertainties (0.1 dex)
  - Large radial velocities uncertainties (>1 km s^{-1})
- **Intermediate resolution surveys (R~20000)**
  - Small wavelength coverage
    - Degeneracies on stellar parameters' determination.
    - Abundances for a limited number of elements.
  - Radial velocities uncertainties (200-500 m s^{-1})
    - Not enough to investigate the internal dynamics of open clusters.
  - Abundance uncertainties (0.05 dex)
    - Not enough for chemical tagging?

High-resolution R>65000

Larger wavelength coverage (400-900 nm)

Lower uncertainties v_{rad} (10-20 m s^{-1}) and [X/Fe] (<0.03 dex)

Elements poorly studied but key to understand chemical evolution (neutron capture elements)

Team

Core: L. Balaguer-Nuñez (UB)
R. Carrera (PI; INAF-OAS Bo)
L. Casamiquela (Obs PM)
C. Jordi (UB)

PhD student: J. Carbajo-Hijarrubia (UB)

Collaborators: E. Pancino (OAA); S. Blanco-Cuaresma (ADS); C. Gallart (IAC);
G. Tautvaišienė (VU); E. Stonkute (VU); A. Drazdauskas (VU);
D. Aguado (IAC); F. Anders (UB); E. Massana (UB); J. M. Carrasco (UB)
T. Cantat-Gaudin (MPIA) + others in the past

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Target selection

Pre-Gaia

OCs location disk: R_{gc}, Z, Age, etc.

OCs population: ≥ 6 stars giants @ RC

Stars: magnitude V ≤ 15 mag.

High membership probability (literature):

- Proper motions
- Radial velocities
- Colour-magntiude diagrams

Post-Gaia

OCs location disk: R_{gc}, Z, Age, etc.

OCs population: ≥ 4 stars giants @ RC

OCs recently discovered from Gaia

Stars: magnitude G<13.5 mag.

High membership probability

(Gaia/Spectroscopic surveys):

- Proper motions
- Radial velocities
- Colour-magntiude diagrams

Red Clump stars

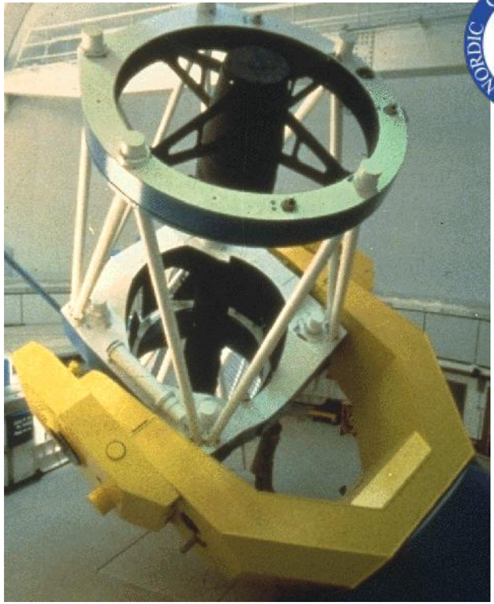
Avoid star-to-star abundances variation (e.g. diffusion).

Easily identified even in sparsely populated colour-magnitude diagrams.

Brighter than main-sequence stars ⇒ observed at further distances.

Less line crowded spectra than brighter giants.

Instrumental configuration

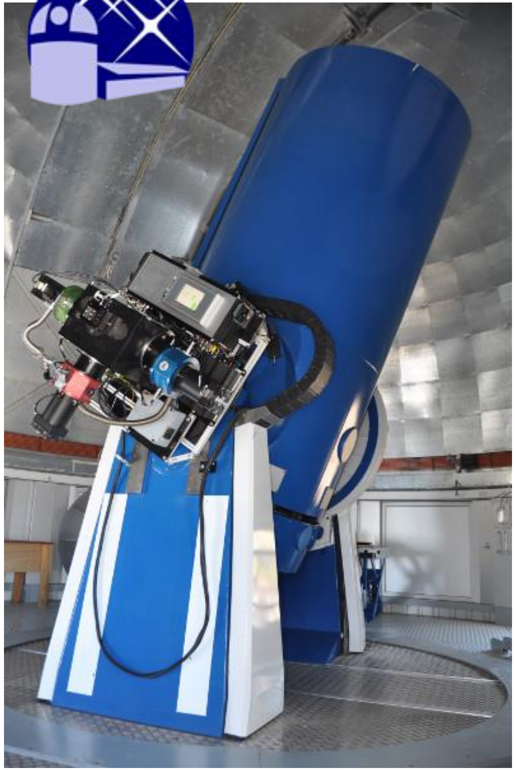


FIES@NOT 2.5m

R~67000
400-725 nm (b. Jul 2017)
400-900 nm (a. Jul 2017)

CAFE@CAHA 2.2m

R~62000
400-900 nm



HERMES@Mercator 1.2m

R~85000
400-900 nm

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Current status

Observing nights (from 2013): 236: 77 NOT; 117 Mercator; 42* CAHA

12 scheduled (Mercator)

Observed stars: 400 (clusters) + 40 (calibrators GBS)

+solar + telluric + sky spectra

Cross calibration: stars observed with the different instrumental configurations

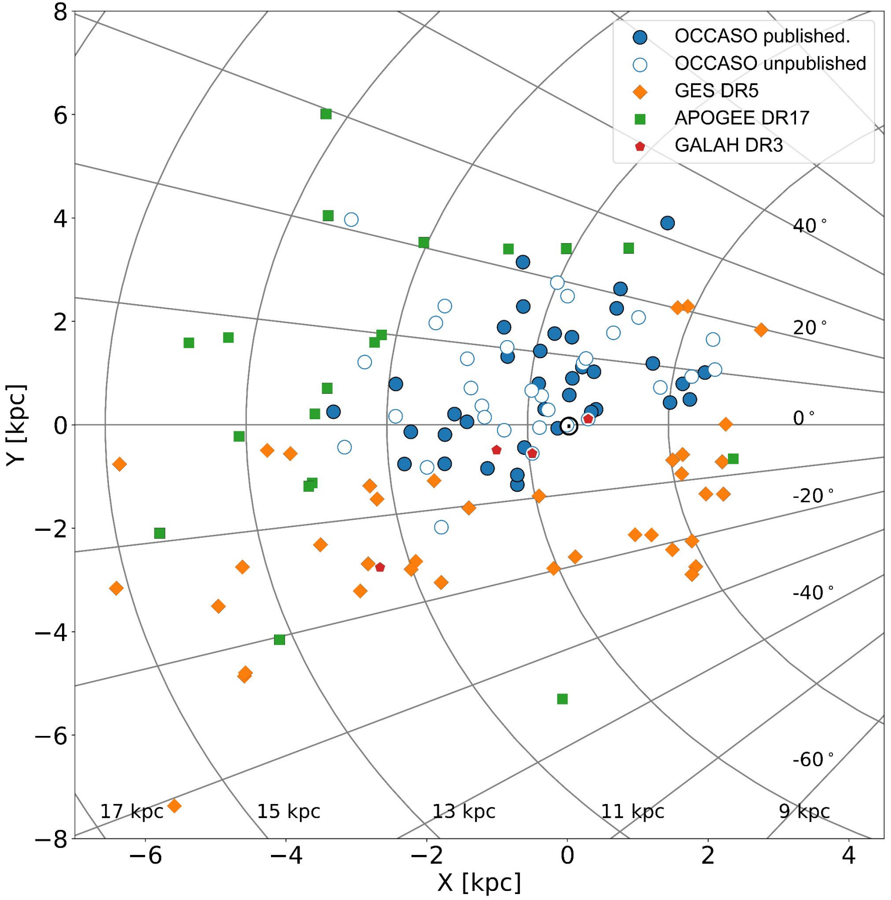
Clusters: >70

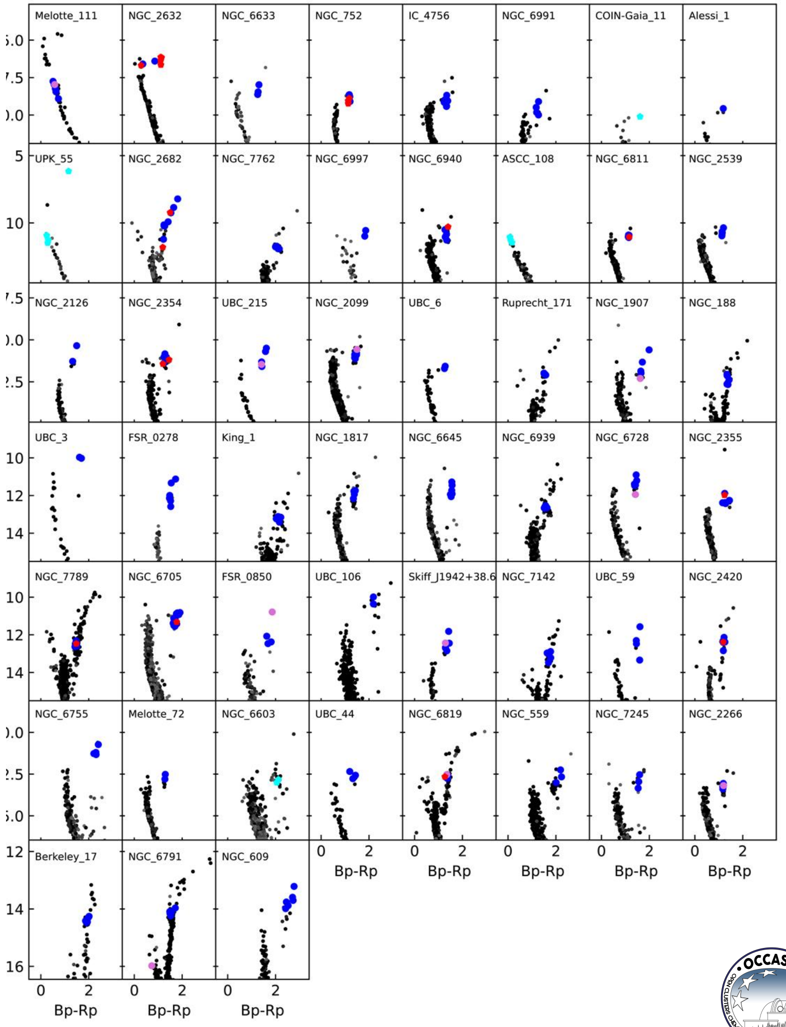
At the moment (R~20000) ~200 APOGEE (~160)+GALAH (25)+GES (62)

Papers: 7 published + 1 under revision + 1 in preparation

OCCASO as calibrators: Gaia radial velocities + APOGEE abundances

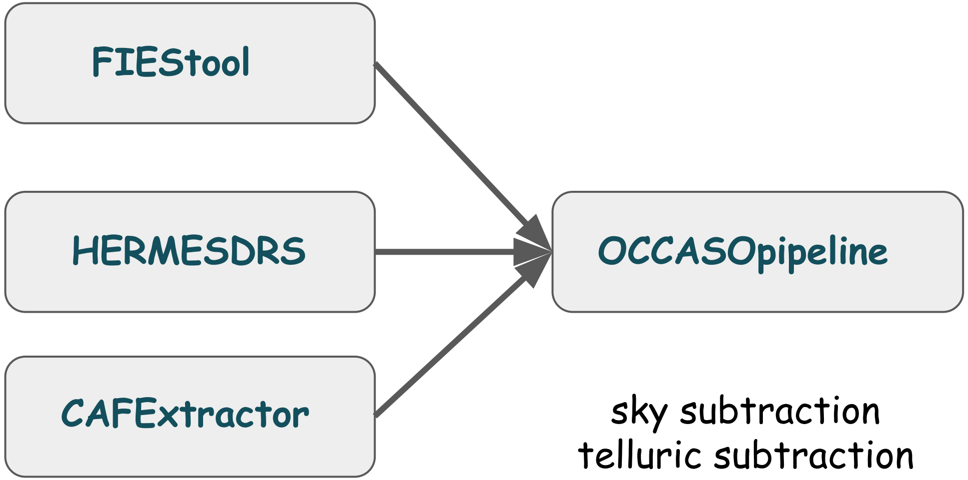
Current status





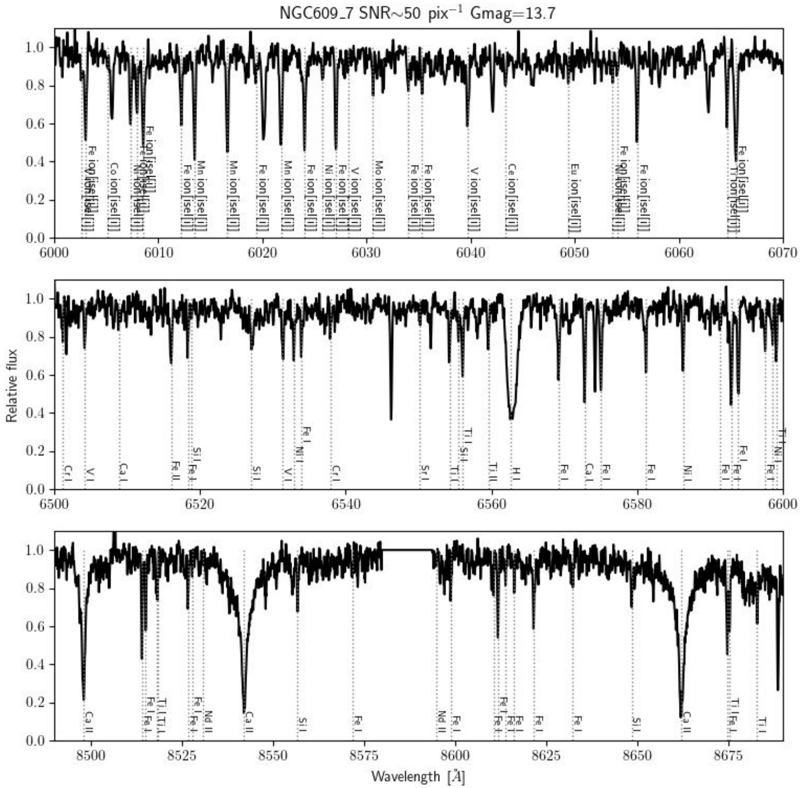
Data reduction

+ radial velocities



bias subtraction,
flat field-correction
order tracing and extraction
wavelength calibration

sky subtraction
telluric subtraction
combination
normalization
order merger

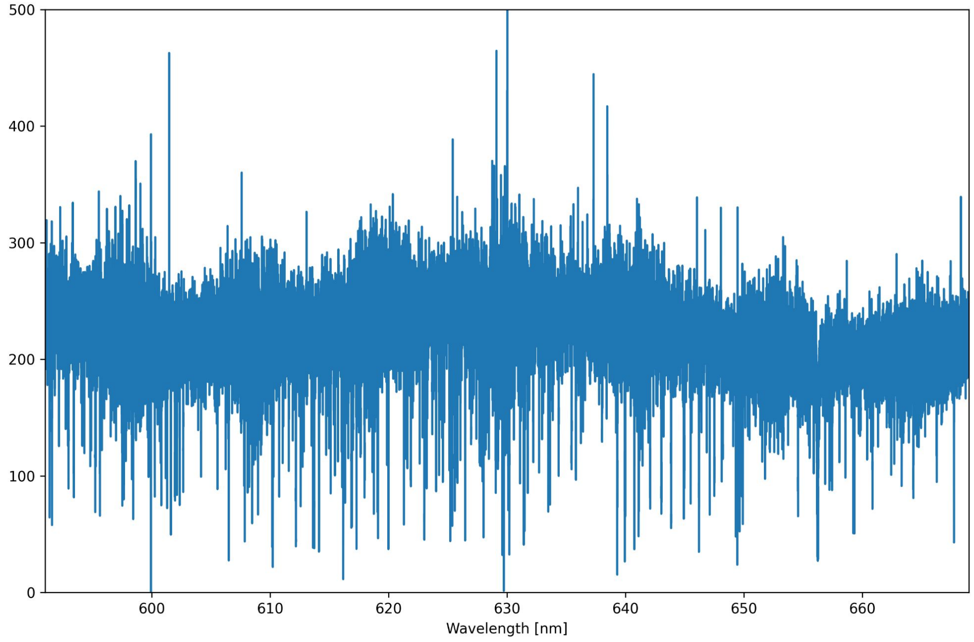


final spectra in the VO standards will be released through SVO

OCCASOpipeline

Dedicated pipelines designed for accurate radial velocity determination.

Problems with the order merge:

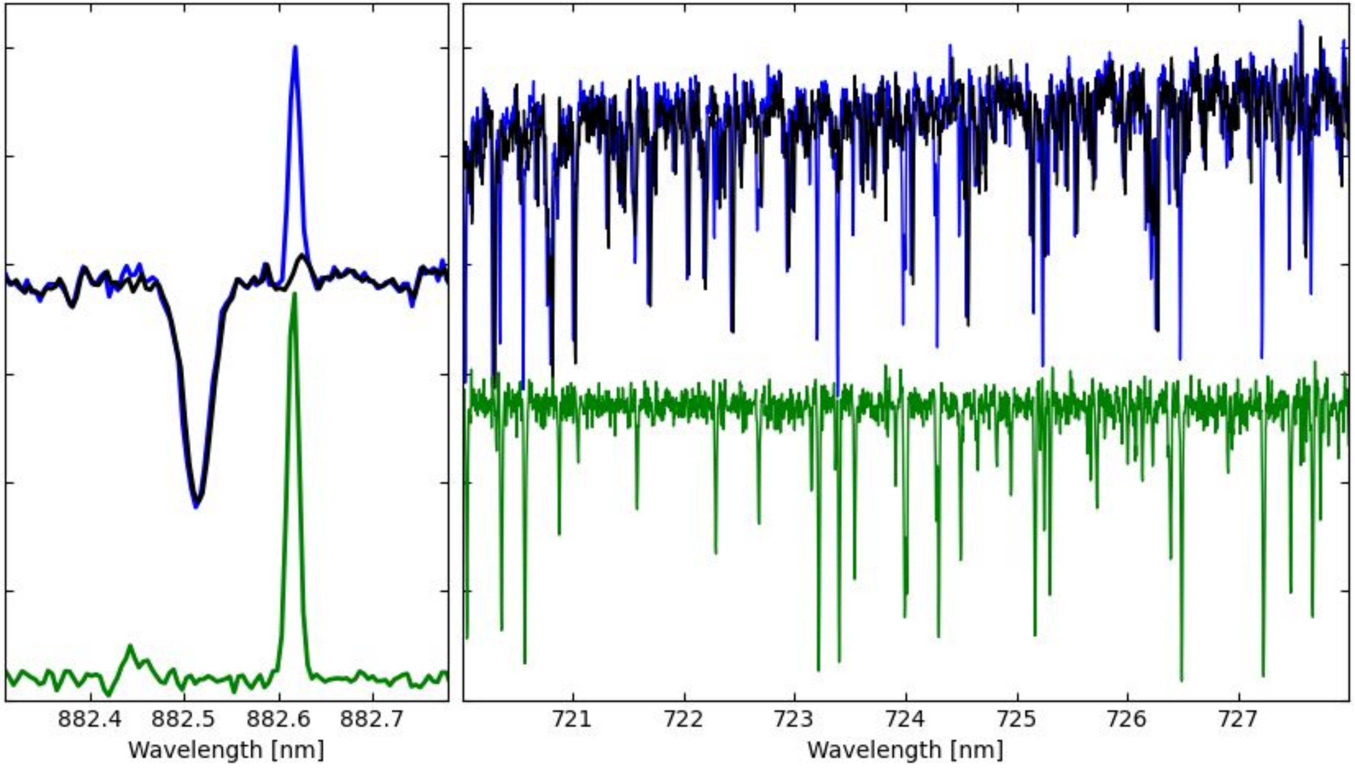


No sky/telluric subtraction

Handle all spectra in the same way, regardless of their origin.

OCCASOpipeline

Step 1: sky, telluric subtraction, heliocentric correction



OCCASOpipeline

Step 2: Combination, normalisation, and merge

Highest S/N spectrum

Reference spectrum

Cross-correlation

Significant shifts?

YES

Apply shifts

$v_{scatter}$

Averaging using a k-sigma clipping algorithm

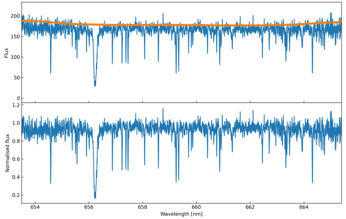
Averaged spectrum

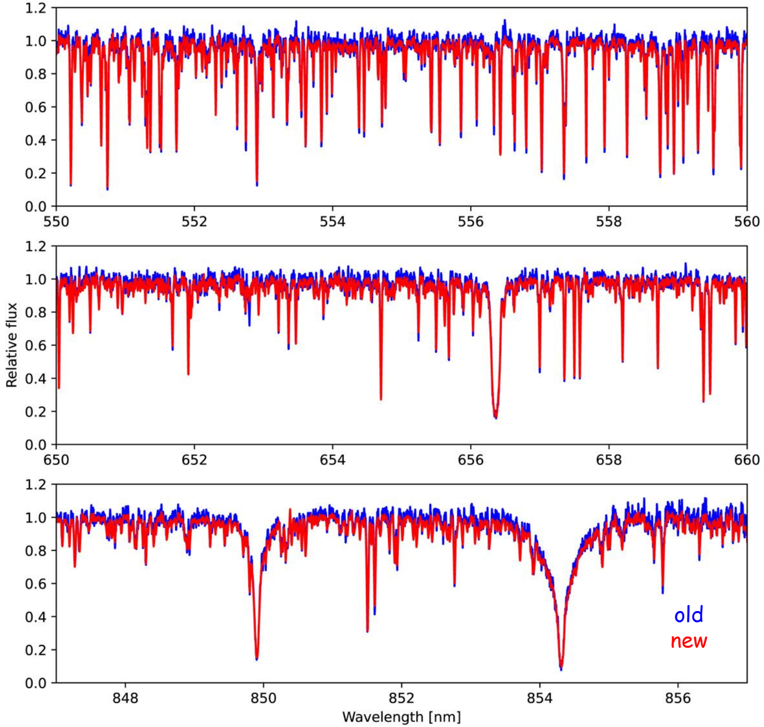
NO

Continuum normalisation

Order merge

1D averaged and normalised spectrum





$v_{scatter}$ alternative radial velocity uncertainty/allows to detect potential binaries

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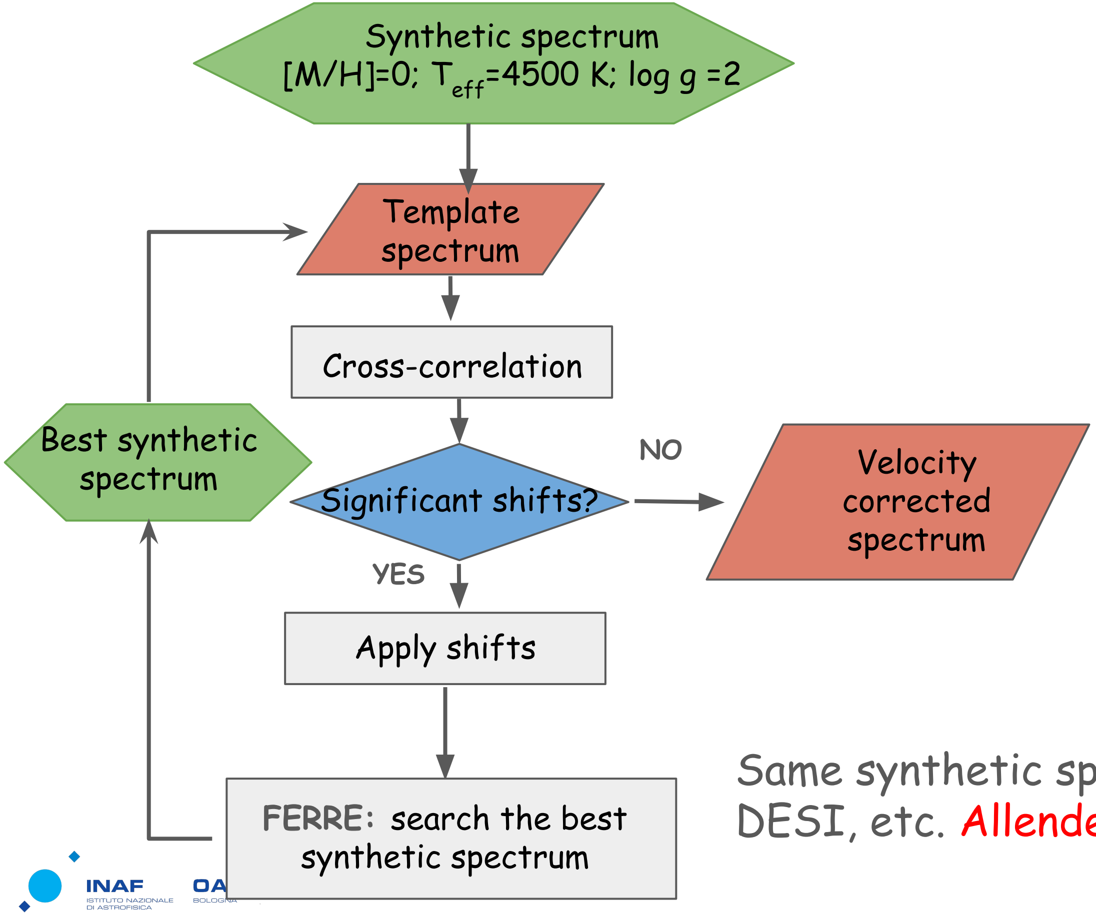
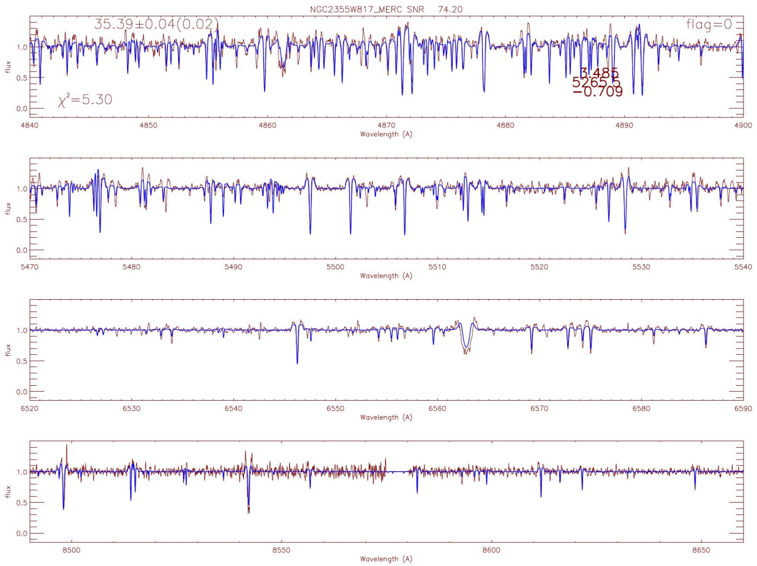
OCCASOpipeline

Step 3: Radial velocity





Same synthetic spectral grids used in WEAVE, DESI, etc. Allende Prieto et al. 2018

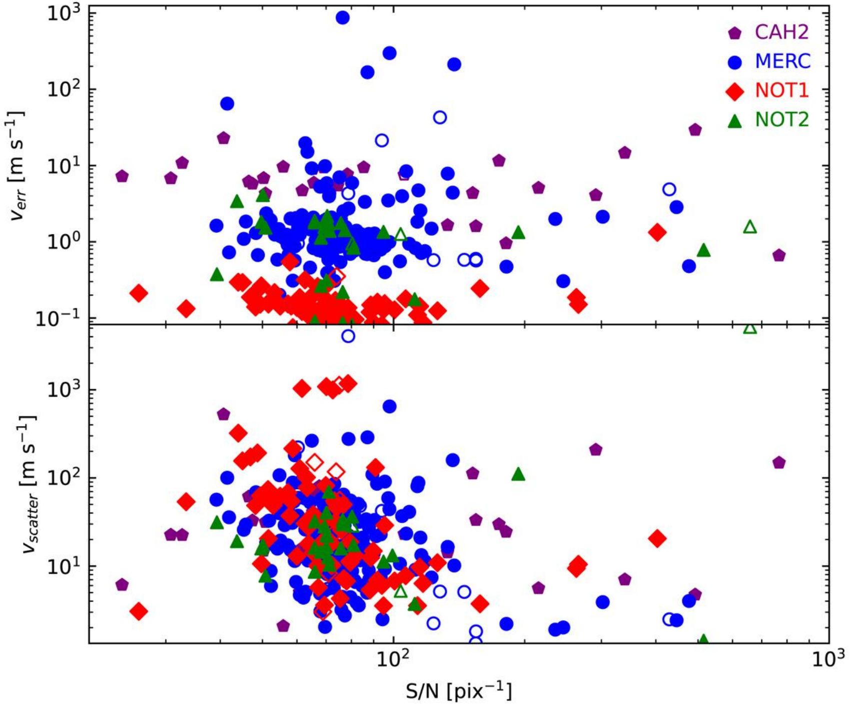
OCCASOpipeline

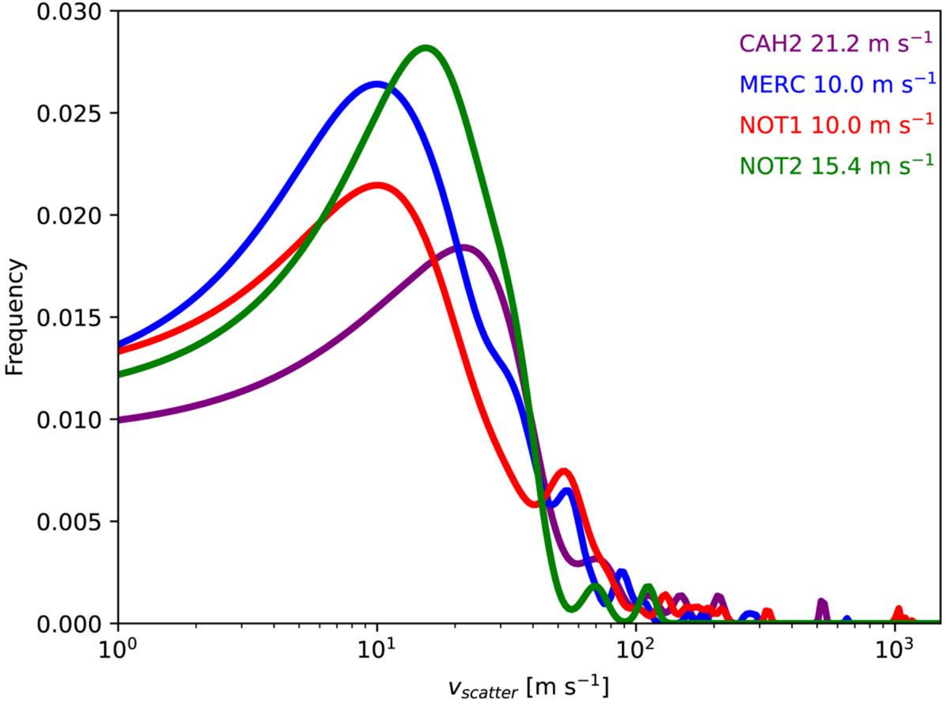
Easily to include spectra acquired from other Echelle instruments.

For the moment are included:

- HERMES@Mercator
- FIES@NOT
- CAFE@CAHA 2.2m
- FIDEOS@La Silla/ESO 1m
- ESPaDOnS@CFHT

Radial Velocity Uncertainties



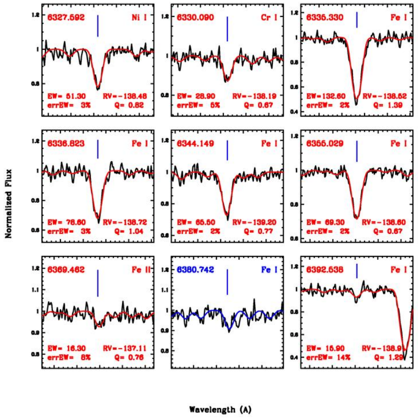


Carrera et al. 2022a

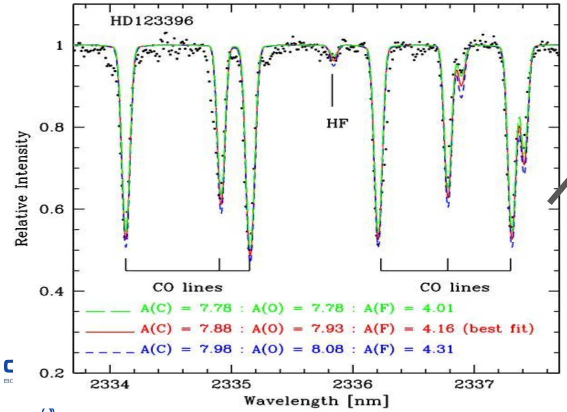
Atmosphere parameters

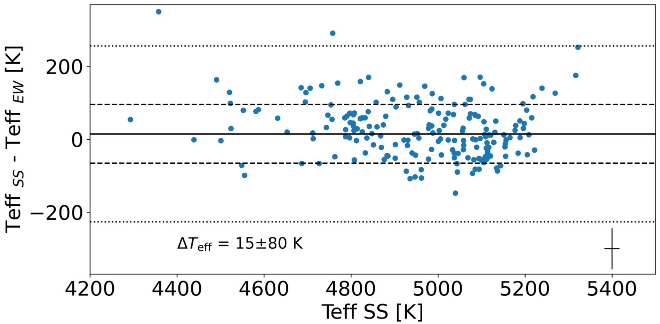
Linelist: GES 6th version (Heiter et al. 2021)
Atmosphere models: MARCS

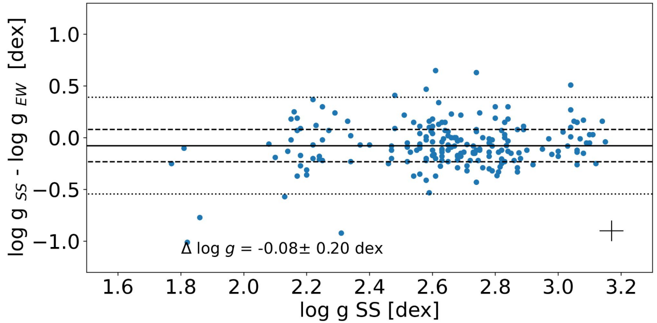
Equivalent widths
(DAOPHOT +GALA)



Spectral synthesis
(iSpec)







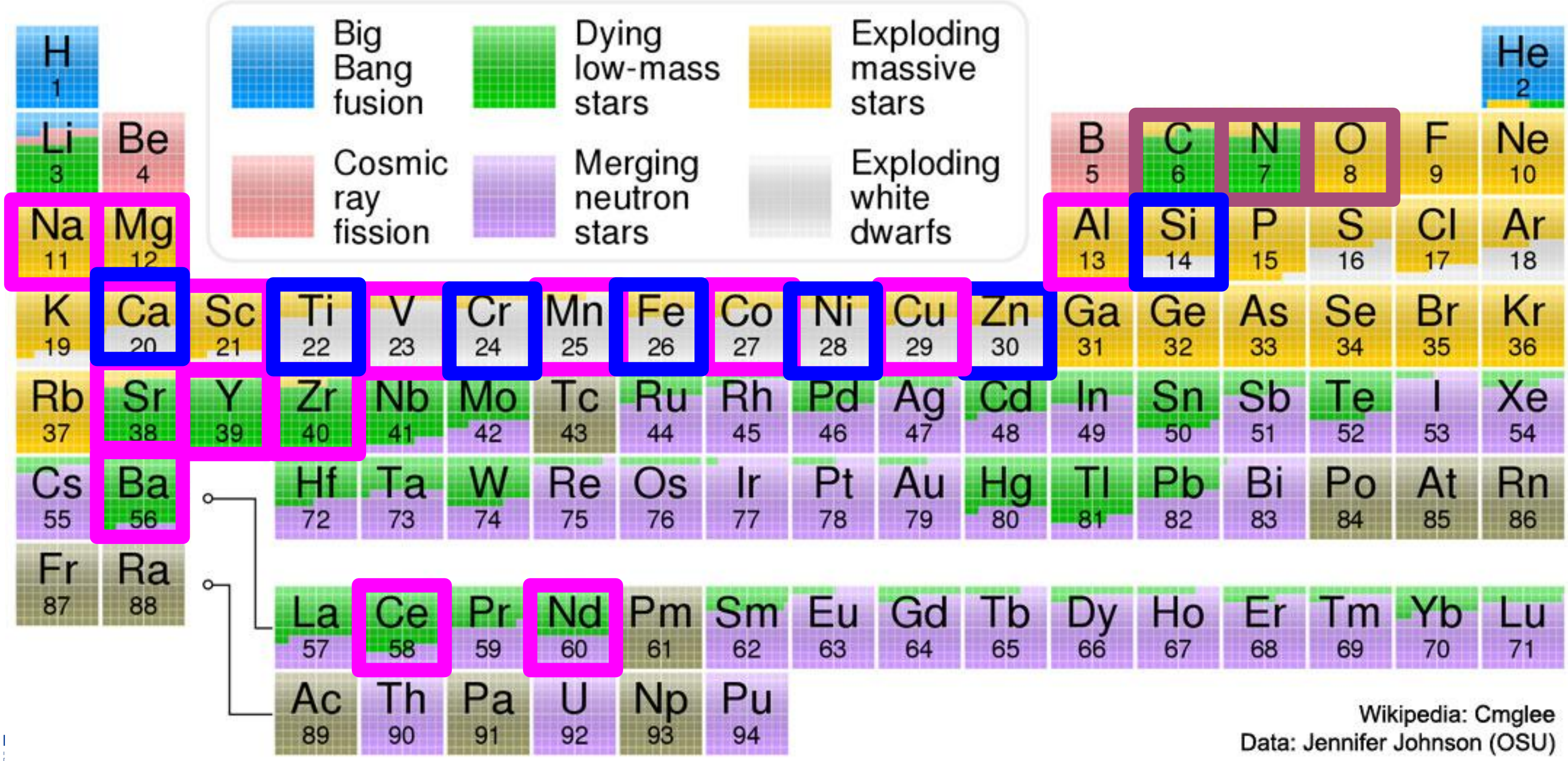
Final values: averaged results of both methods, taking uncertainties into account:

Chemical abundances

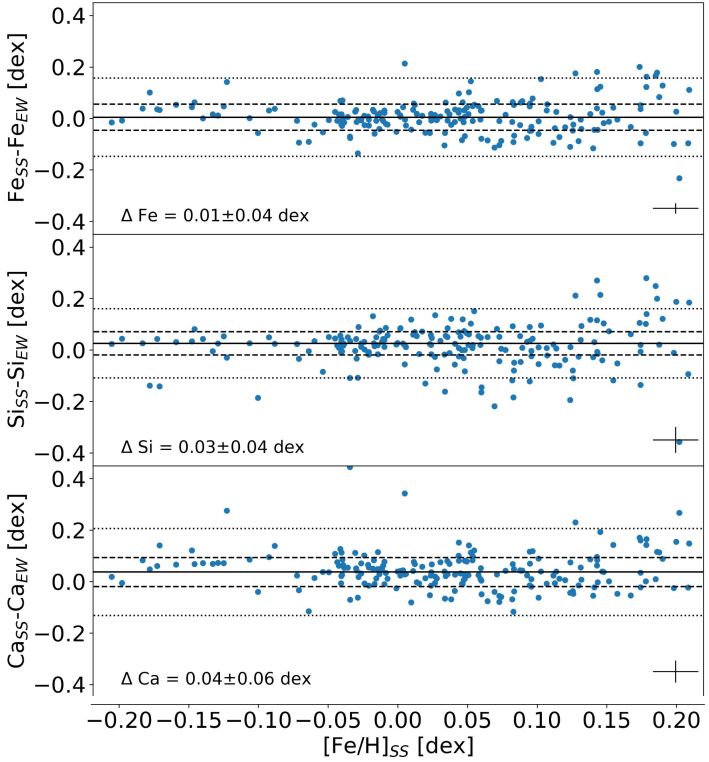
EW & SS

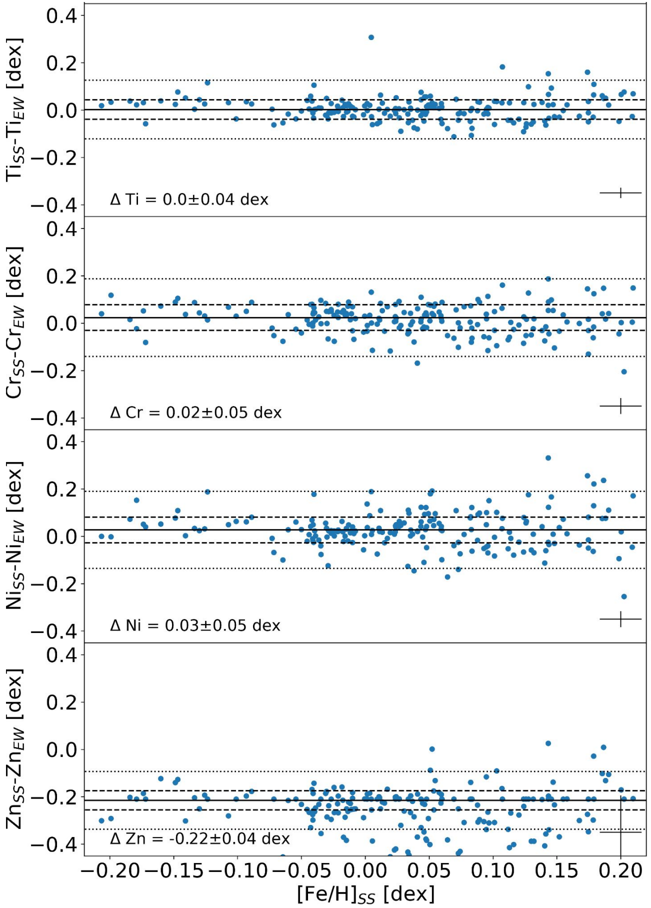
SS

working

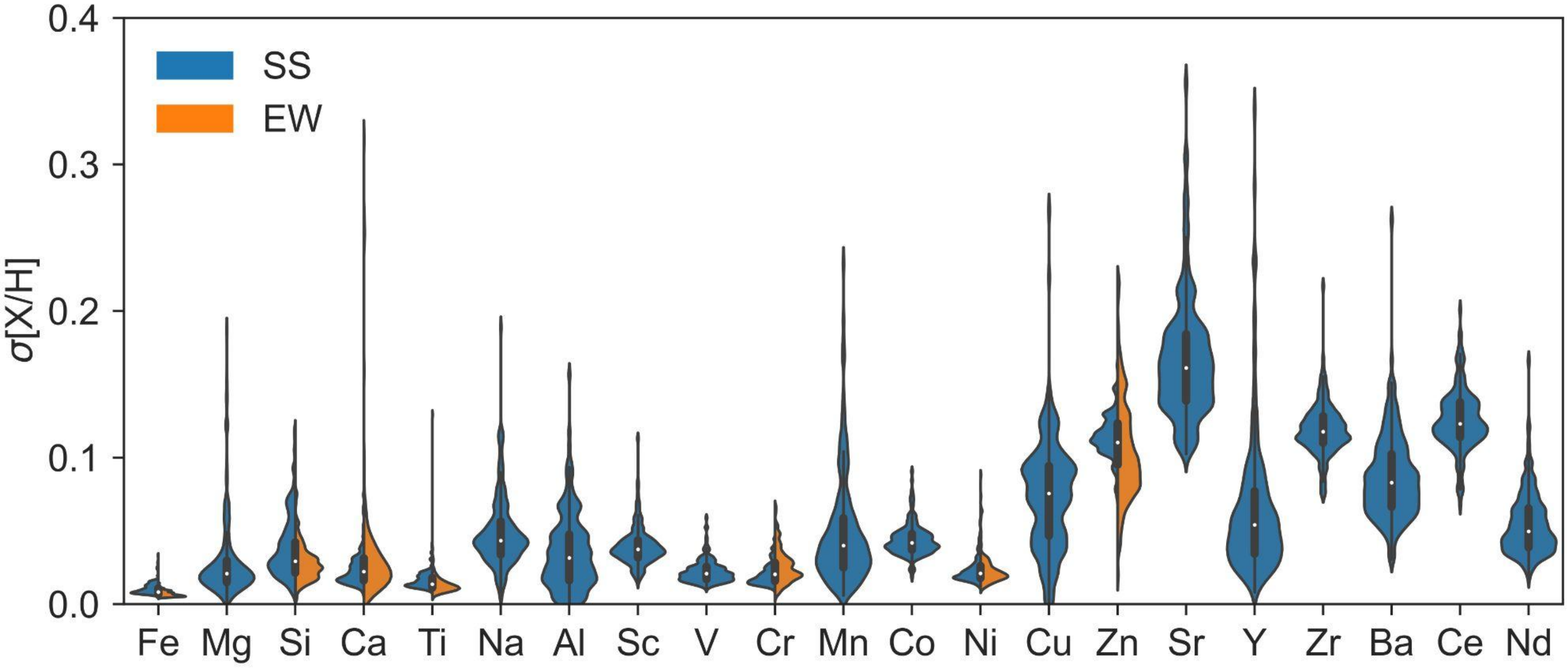


Chemical abundances: SS vs EW





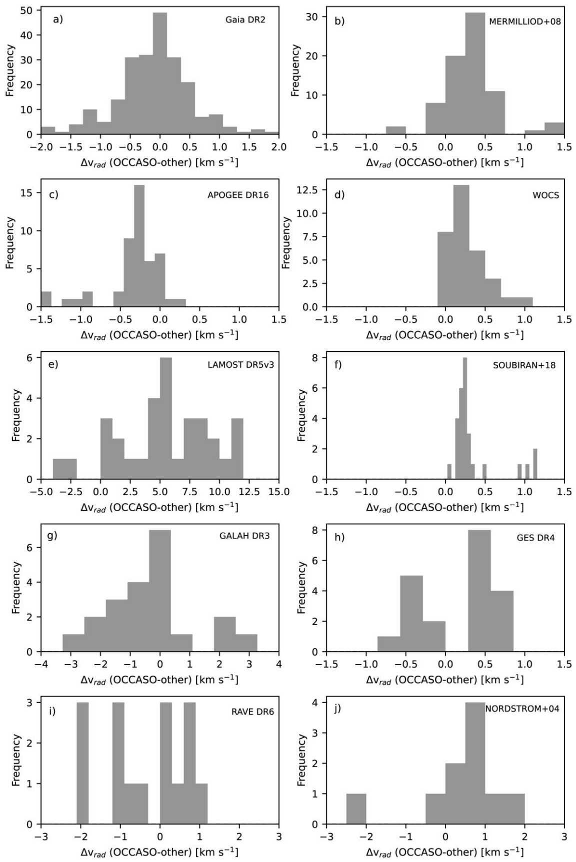
Chemical abundances: typical uncertainties



Carbajo-Hijarrubia et al. *under revision.*

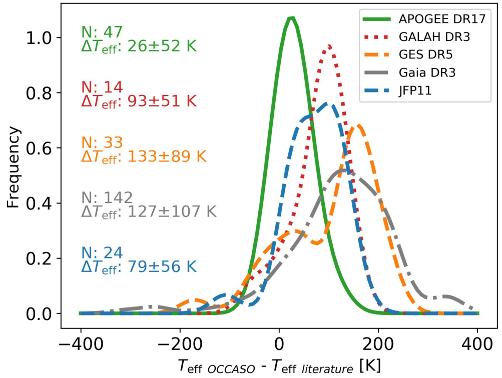
Literature comparison (individual stars)

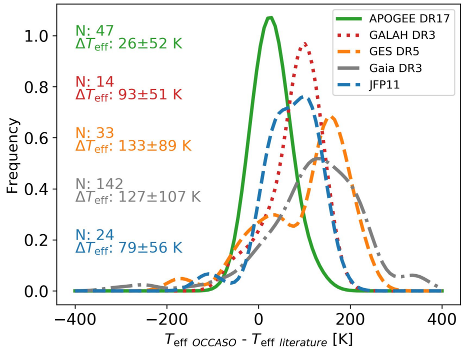
Radial velocities



Carrera et al. 2022a

Atmospheric parameters





Carbajo-Hijarrubia et al. *under revision.*

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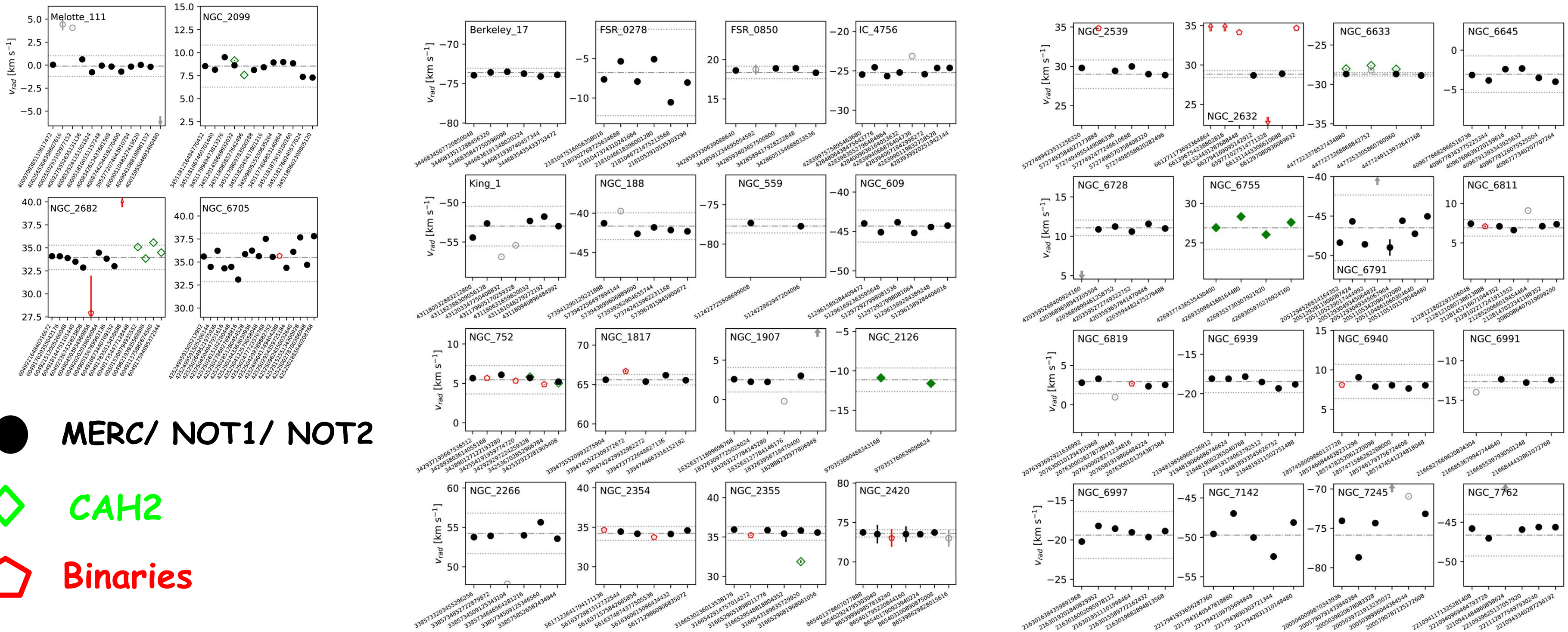
Averaged cluster values



● MERC/ NOT1/ NOT2

◇ CAH2

⬠ Binaries

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Carrera et al. 2022a

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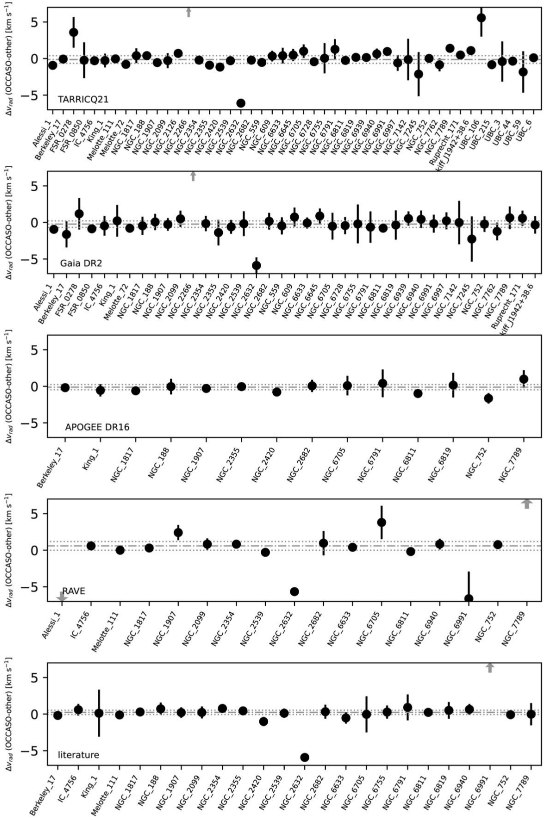
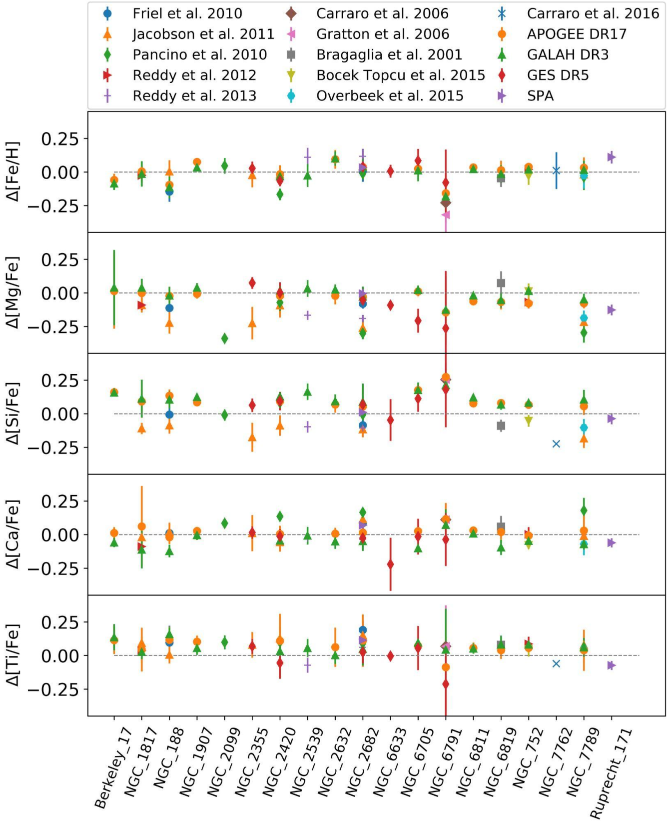
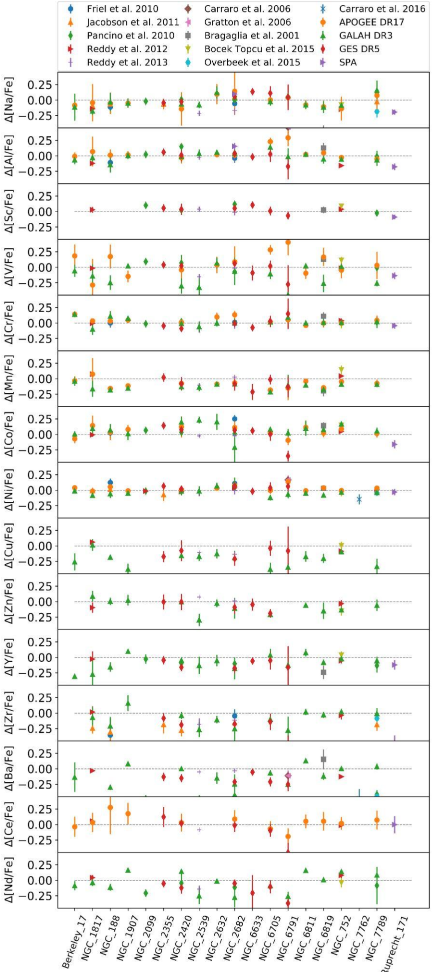
Averaged cluster values: literature comparison



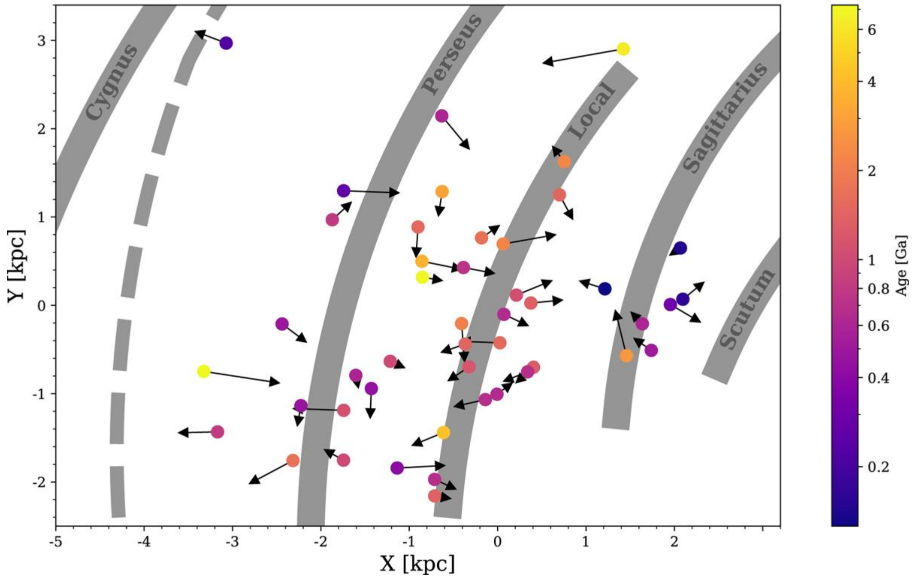




Carrera et al. 2022a

Carbajo-Hijarrubia et al. *under revision*.

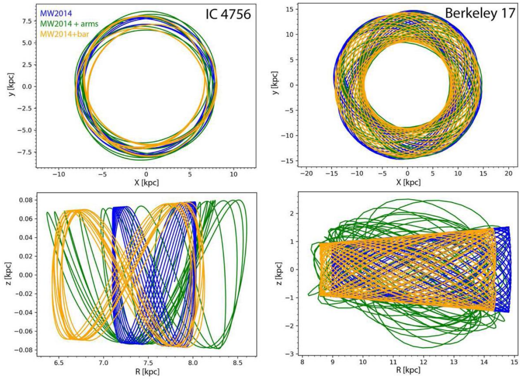
Results: Open clusters kinematics

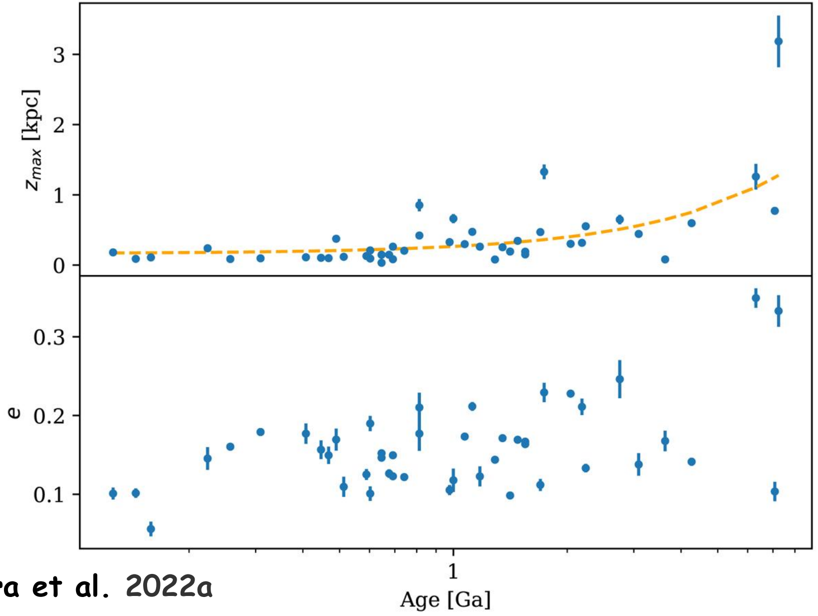


Velocities to respect to the GSR

Orbits

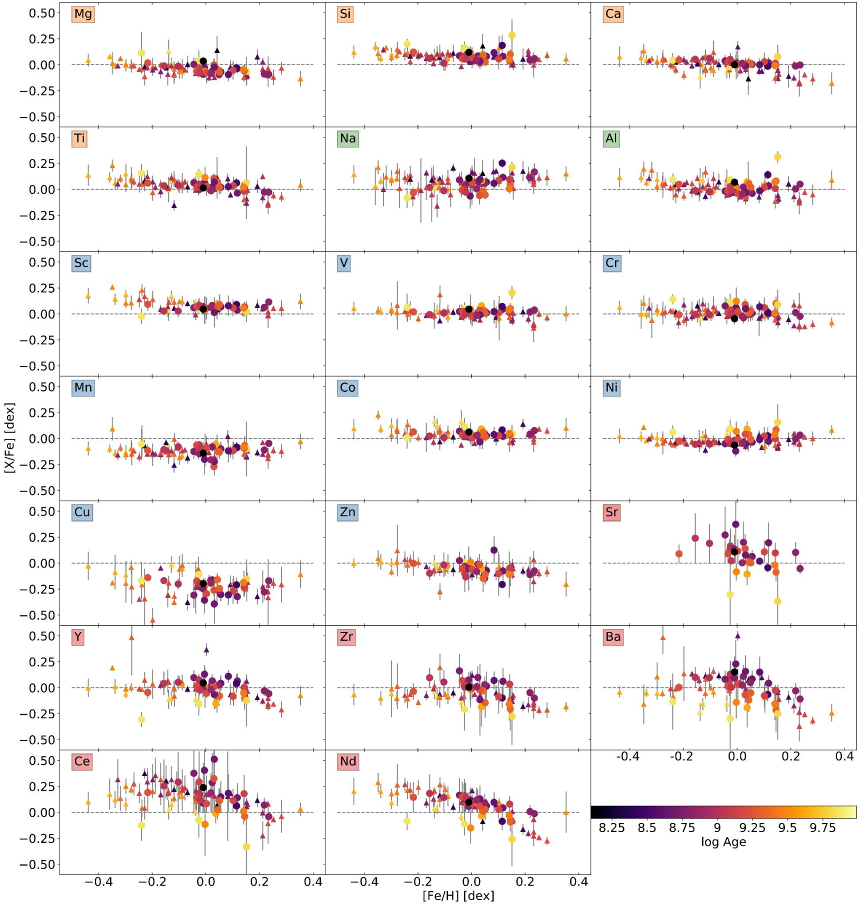
Galpy (Bovy 2015)
+MW2014, bar, spiral arms potentials

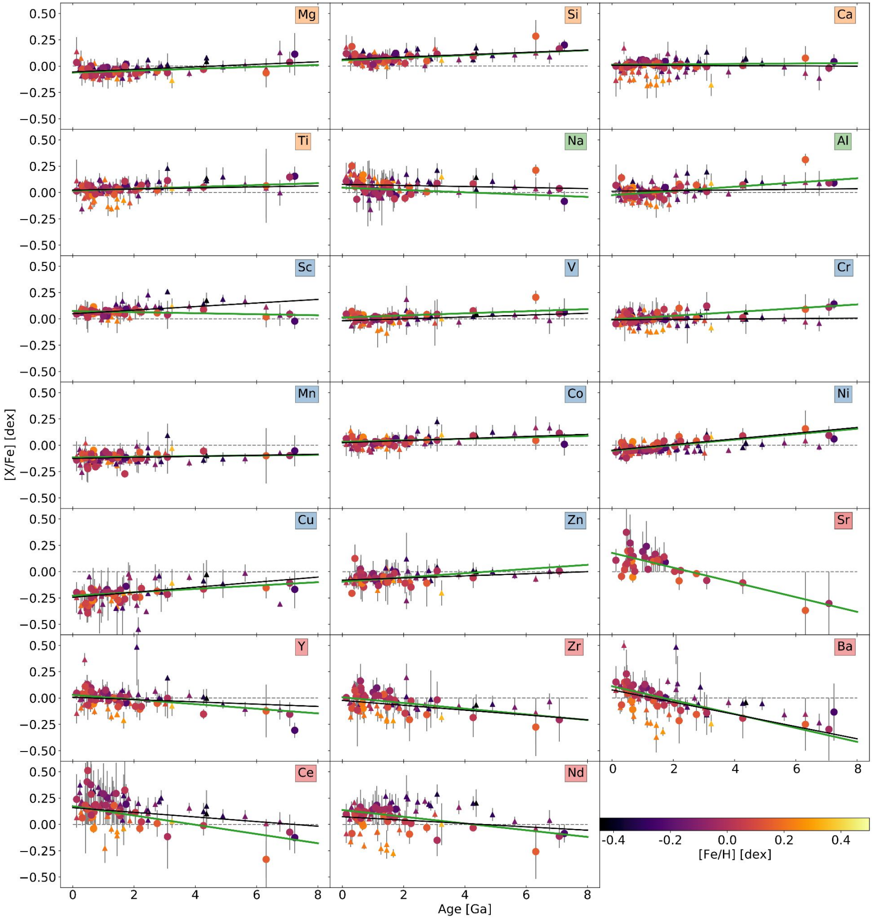




Casamiquela et al. 2016; Carrera et al. 2022a

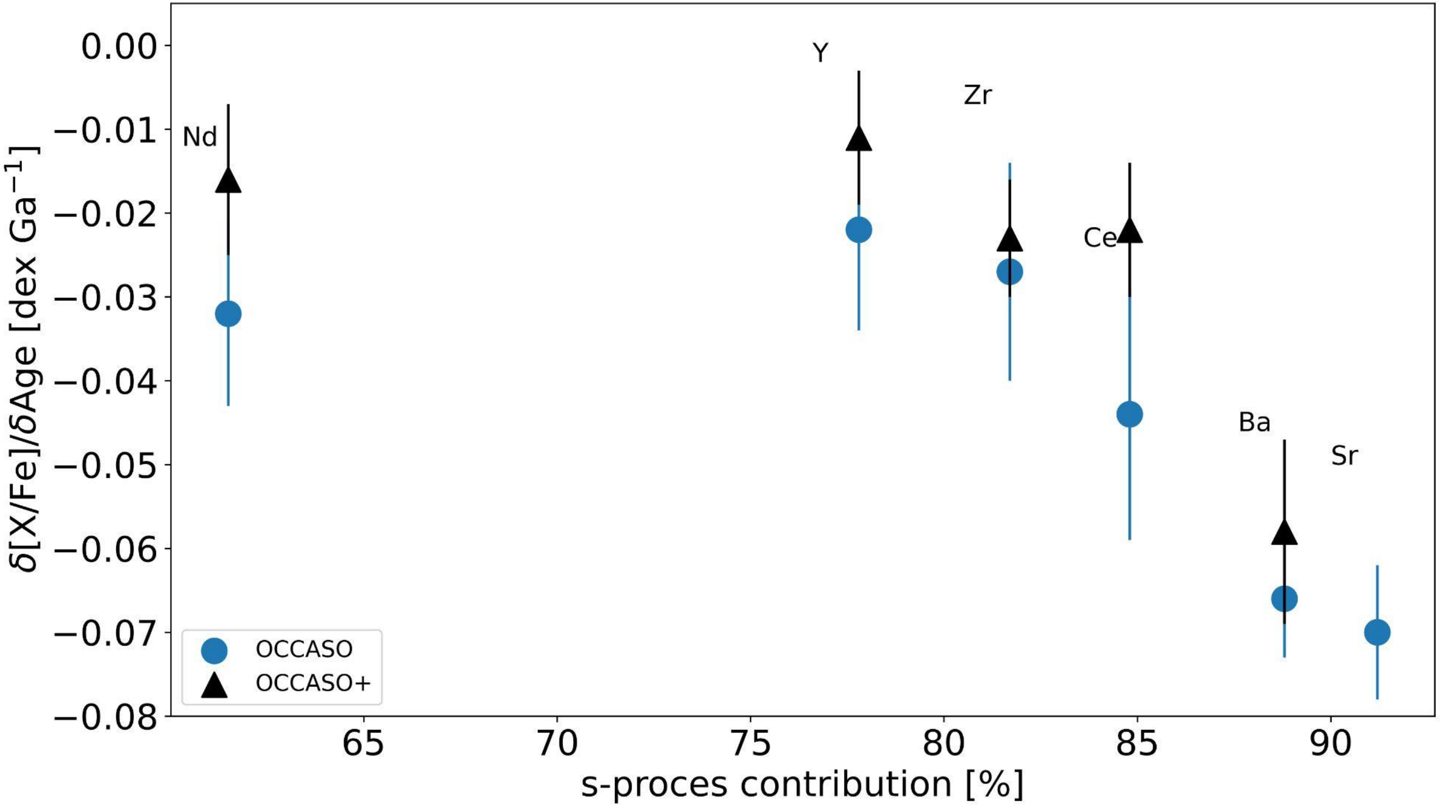
[X/Fe] dependece on [Fe/H] & Age





Carbajo-Hijarrubia et al. ***under revision*.**

Results: s-process



OCCASO+=OCCASO+GES+APOGEE+GALAH

Results: radial trends

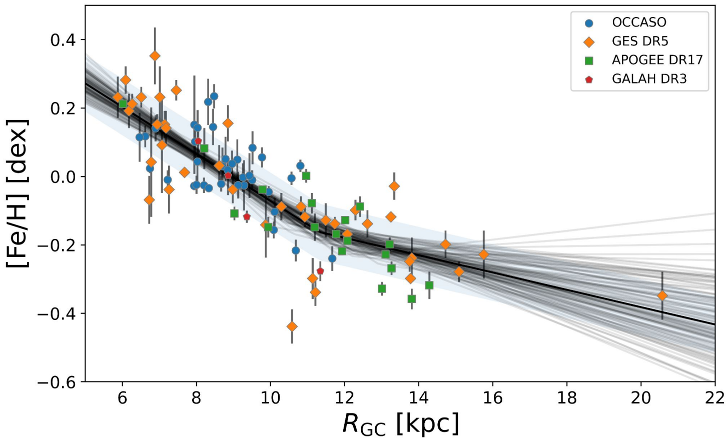
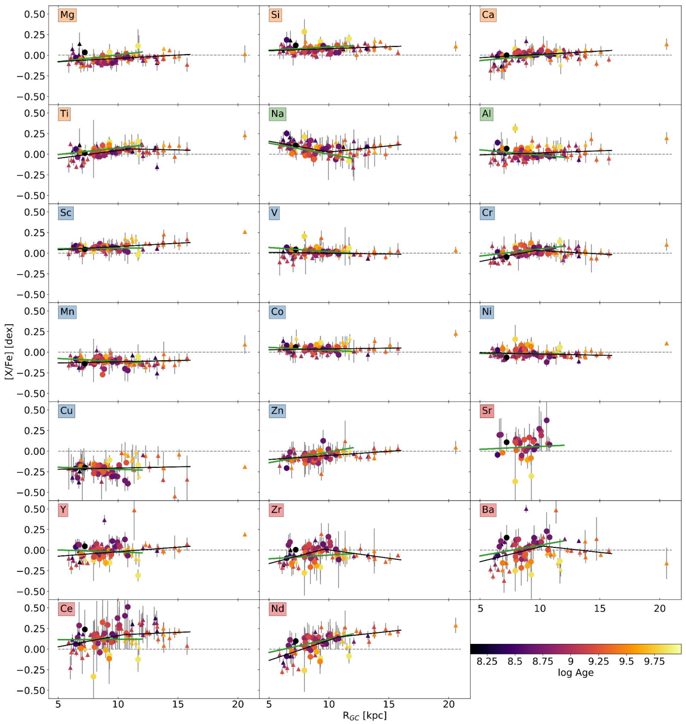
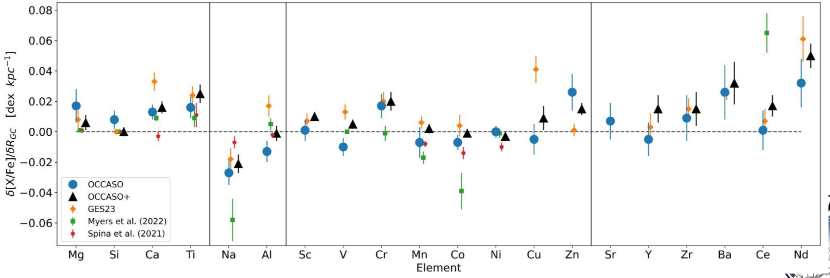


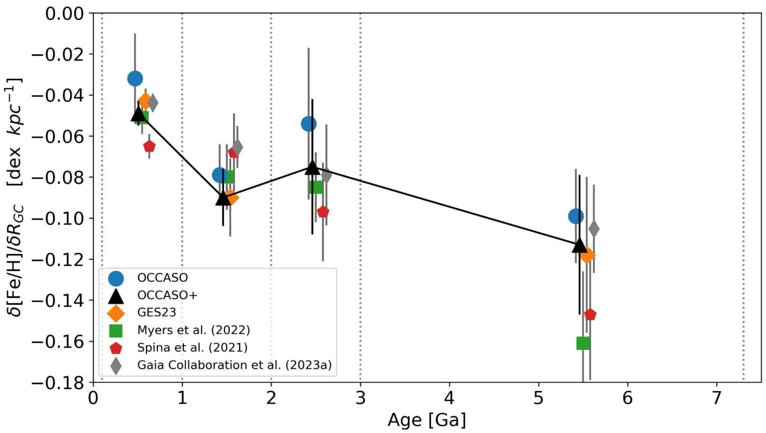
Table 4. Comparison of [Fe/H] radial gradient with the literature in the region inside and outside the knee radius and globally, indicating in each case the number of OCs studied and the knee position.

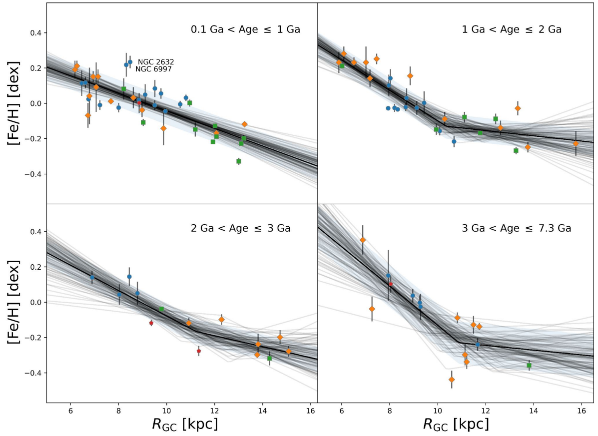
Reference	Inside the knee radius [dex kpc^{-1}]	N	Outside the knee radius [dex kpc^{-1}]	N	Global [dex kpc^{-1}]	N	Knee [kpc]
This work OCCASO	-0.059±0.017	36	–	–	–	–	–
This work OCCASO+	-0.069±0.008	71	-0.025±0.011	28	-0.062±0.007	99	11.3 ± 0.8
Paper III	-0.056±0.011	18	–	–	–	–	–
Carrera et al. (2019)	-0.077±0.007	–	-0.018±0.009	–	-0.077±0.007	90	11
Donor et al. (2020)	-0.068±0.004	68	-0.009±0.011	3	–	71	13.9
Zhang et al. (2021)	-0.066±0.005	157	-0.032±0.007	4	–	161	14
Myers et al. (2022)	-0.073±0.002	51	-0.032±0.002	34	0.055 ±0.001	85	11.5
GES23	-0.081±0.008	42	-0.044±0.014	20	0.054±0.004	62	11.2
Spina et al. (2022)	-0.064±0.007	–	-0.019±0.008	–	–	–	12.1 ± 1.1
Netopil et al. (2022)	-0.063±0.004	116	–	–	-0.058±0.005	136	12
Gaia Collaboration et al. (2023a)	-0.054±0.008	503	–	–	–	–	–

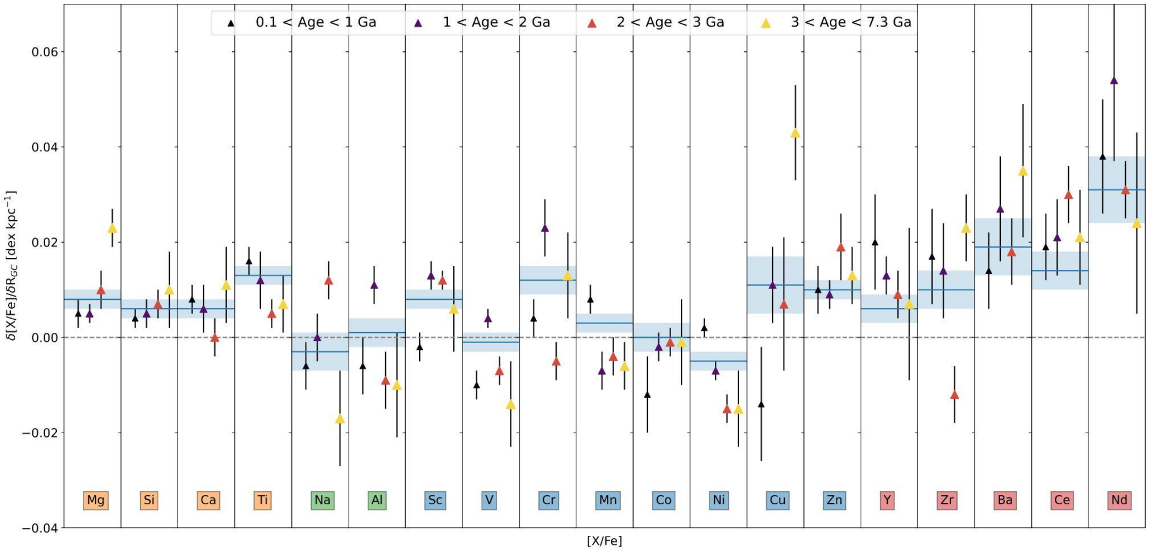




Results: radial trends (dependency with age)







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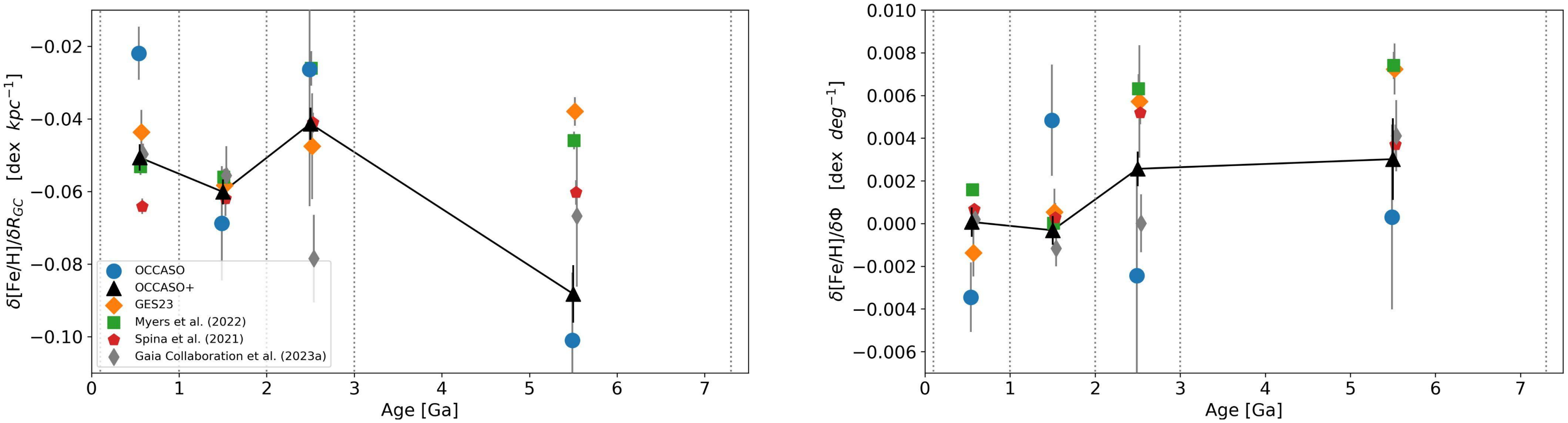
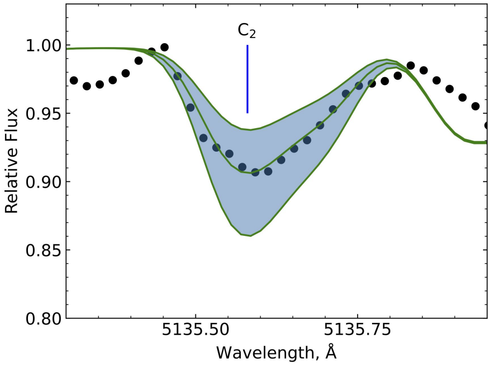
OCCASO OPEN CLUSTERS CHEMICAL ABUNDANCES FROM SPANISH OBSERVATORIES

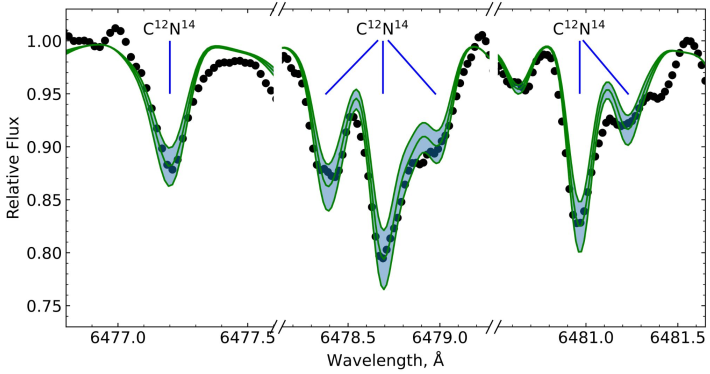
Results: radial trends

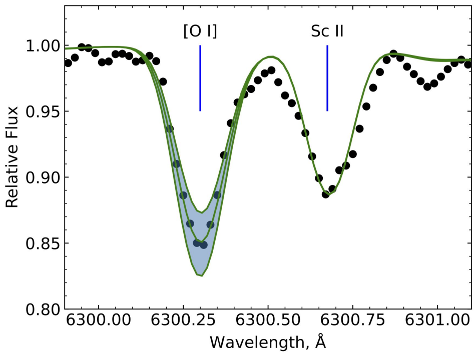


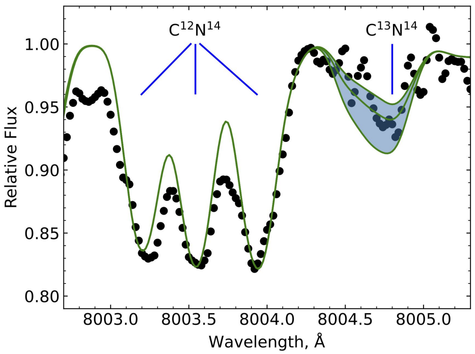
Some hints of azimuthal variations for the oldest clusters

Work in progress: CNO abundances



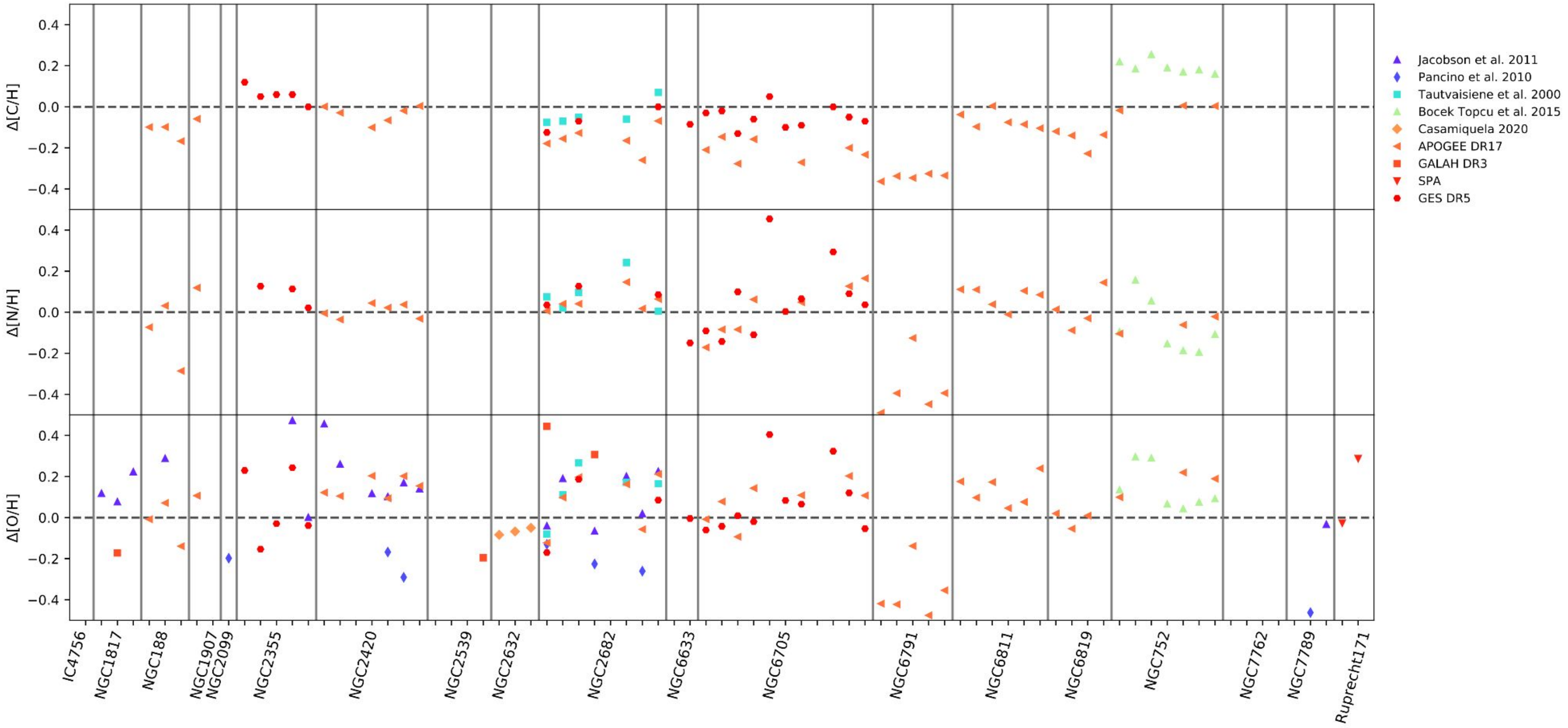






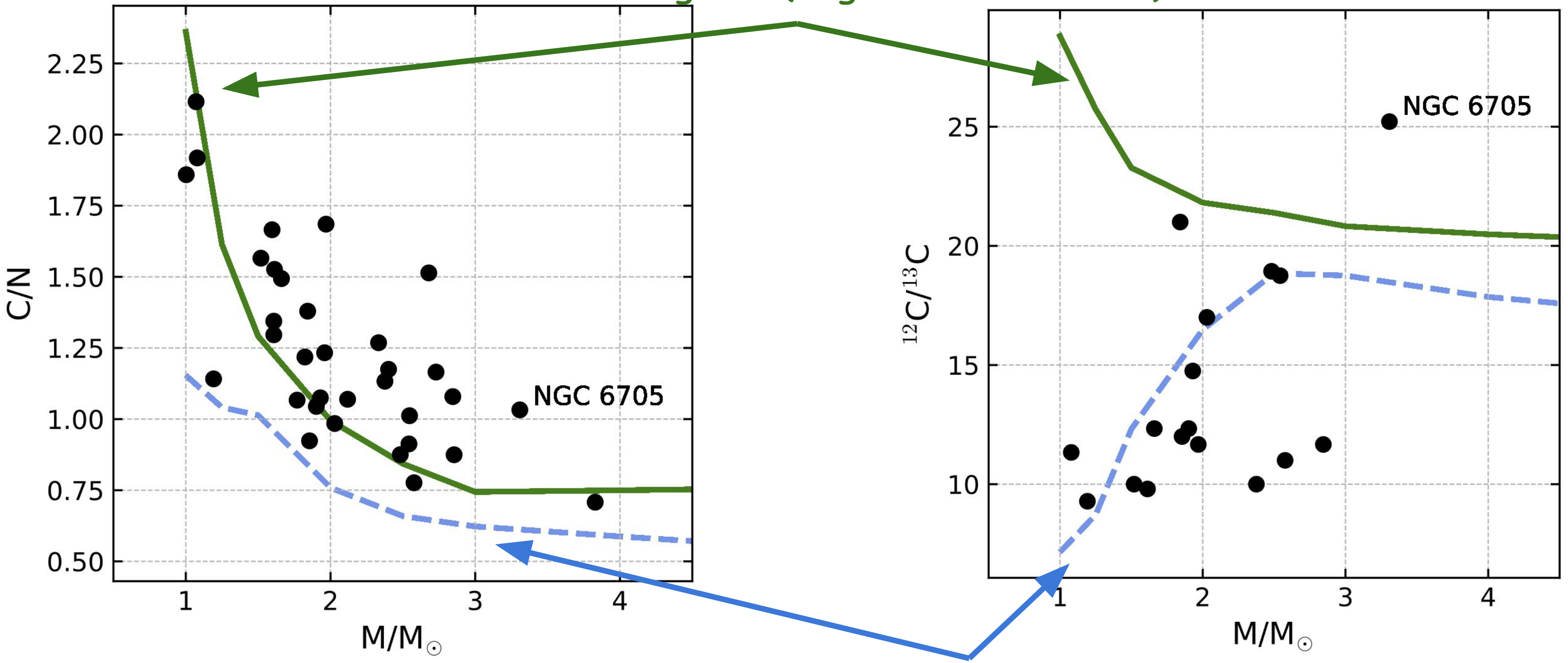
Turbospectrum+MARCS models

Work in progress: CNO abundances



Work in progress: CNO abundances

Stars @ 1st dredge-up without mixing outside convective regions (Legarde et al. 2012)



Including the thermohaline convection and rotation-induced mixing (Legarde et al. 2012)

Summary

Massive spectroscopic surveys have some limitations:

- Low resolution+large wavelength coverage or intermediate resolution short wavelength coverage
- Accuracy limitations: radial velocities 100-200 m s^{-1} or abundances 0.05 dex
- Not covering some elements.
- Not dedicated OCs programme (APOGEE) but GES/WEAVE/4MOST

Projects like OCCASO or SPA are needed to complement these surveys.

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OCCASO Papers or using OCCASO data

OCCASO V. Radial and Age Galactic Chemical Trends *Carbajo-Hijarrubia et al. 2024* A&A, under revision

OCCASO. IV. Radial velocities and open cluster kinematics *Carrera et al. 2022* A&A, 658, A14

The (im)possibility of strong chemical tagging *Casamiquela et al. 2021* A&A, 654, A151

Abundance-age relations with red clump stars in open clusters *Casamiquela et al. 2021* A&A, 652, A25

3D kinematics and age distribution of the open cluster population *Tarricq et al. 2021* A&A, 647, A19

OCCASO - III. Iron peak and α elements of 18 open clusters. Comparison with chemical evolution models and field stars *Casamiquela et al. 2019* MNRAS, 490, 1821

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