Open Clusters as Windows into Galactic Disk Fluorine* Evolution

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*The T Rex of the periodic table [cit.]

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Fluorine nucleosynthesis

Many different potential sites and channels of production → narrowing down a dominant site of F production is very challenging [Womack+ 2023]

1. (low-mass) AGB stars during thermal pulses (Forestini+ 1992; Lugaro+ 2004)

$$\left.\begin{array}{l} {}^{14}N\ (n,p)\ {}^{14}C(\ \alpha,\gamma)\ 18\ O\ (p,\alpha)\ 15\ N\ (\ \alpha,\gamma)\ 19\ F \\ {}^{14}N(\ \alpha,\gamma)\ 18\ F(\ \beta+\ )\ 18\ O(p,\alpha)\ 15\ N(\ \alpha,\gamma)\ 19\ F \end{array}\right\}$$

There is observational evidence that AGB stars contribute to the galactic fluorine (discovered by Jorissen+1992, Abia+ 2015, 2019):

Can AGB stars account for the total galactic abundance of fluorine ??

2. Wolf-Rayet stars during He burning phase (Meynet & Arnould 2000; Palacios+ 2005)

^{14}N is also the seed for ^{19}F

Delicate balance between the rate at which mass is lost via winds and the efficiency of the $^{19}F\ (\ \alpha,p)\ 22$ Ne reaction

Fluorine nucleosynthesis

3. Rotating massive stars (in the He convective shell) via:
$^{14}N\,(\alpha,\gamma)\,^{18}F\,(\beta+)\,18\,O\,(p,\alpha)\,15\,N\,(\alpha,\gamma)\,19\,F$ (Goriely+ 1989; Chaplin+ 2018)

This chain of reactions becomes enhanced
when rotation is induced, due to the increased abundance of CNO
elements as a result of rotation (Limongi & Chieffi 2018)

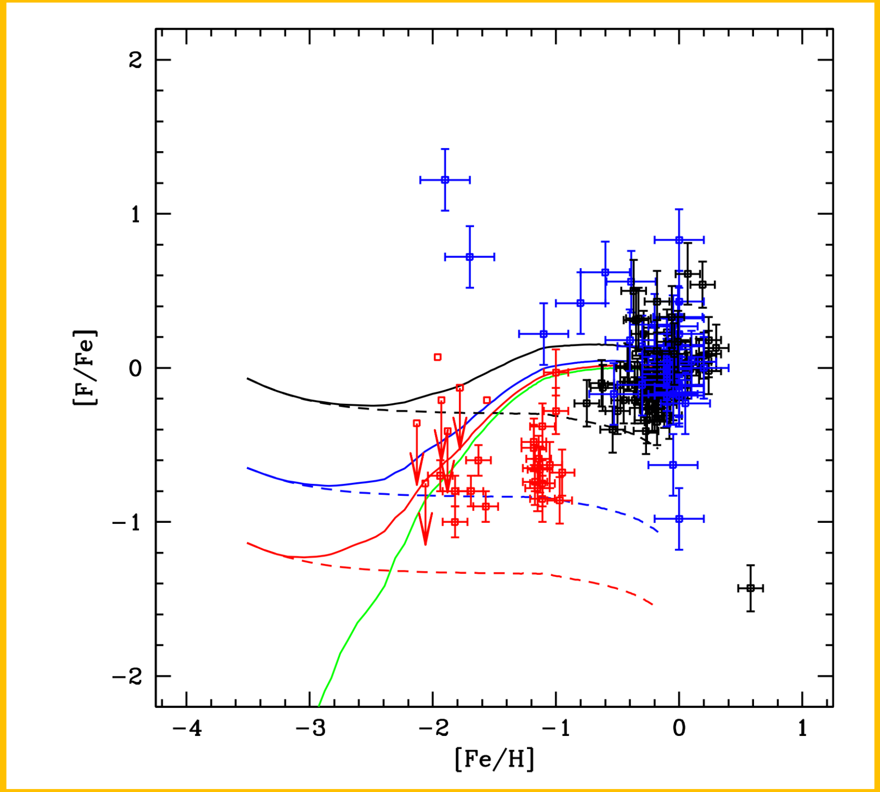
4. The **ν** process in core-collapse SNe via $^{20}Ne\,(\nu,\nu'p)^{19}F$ (Kobayashi + 2011)
We don't know how much though

5. Novae via $^{17}O\,(p,\gamma)\,18\,F\,(p,\gamma)\,19\,Ne\,(\beta+)\,19\,F$ (Jose & Hernanz 1998; Spitoni+ 2018)
As before, very uncertain!

Chemical evolution models

Renda et al. (2004) used the WR yields of Meynet & Arnould (2000) to show that WR stars can dominate F production at solar -and supersolar metallicities-, while AGB stars were required in their models to reproduce the trends at lower metallicities

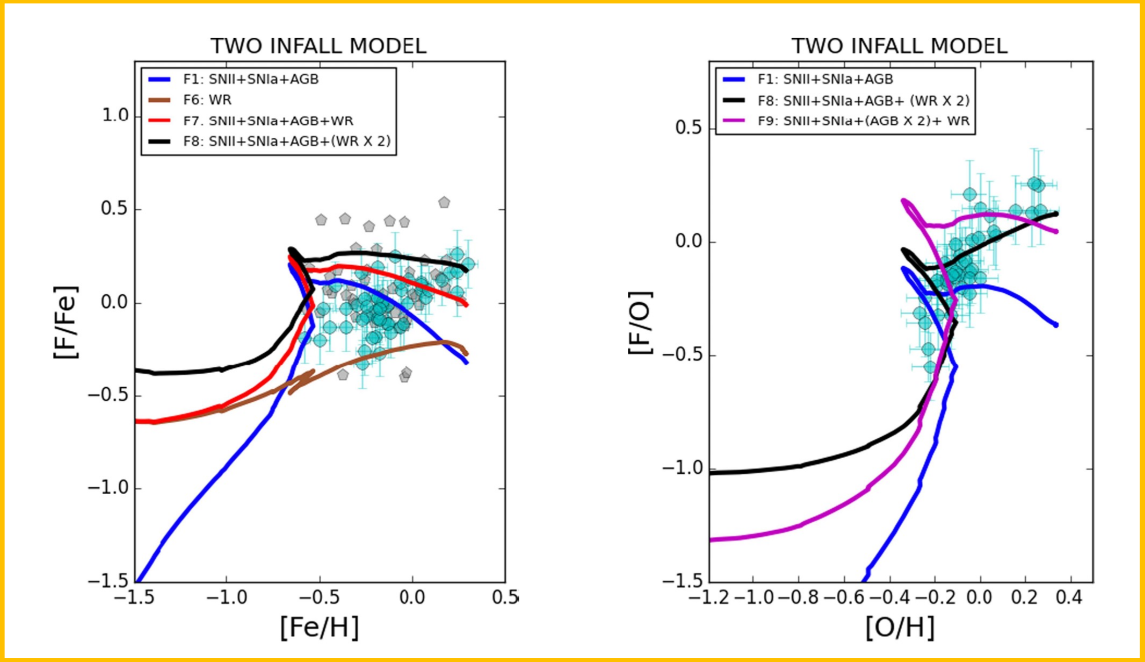
Olive & Vangioni (2019) concluded that AGB stars dominate at high metallicity and that the ν-process in CC-SNe is required to reproduce low-metallicity observations. →

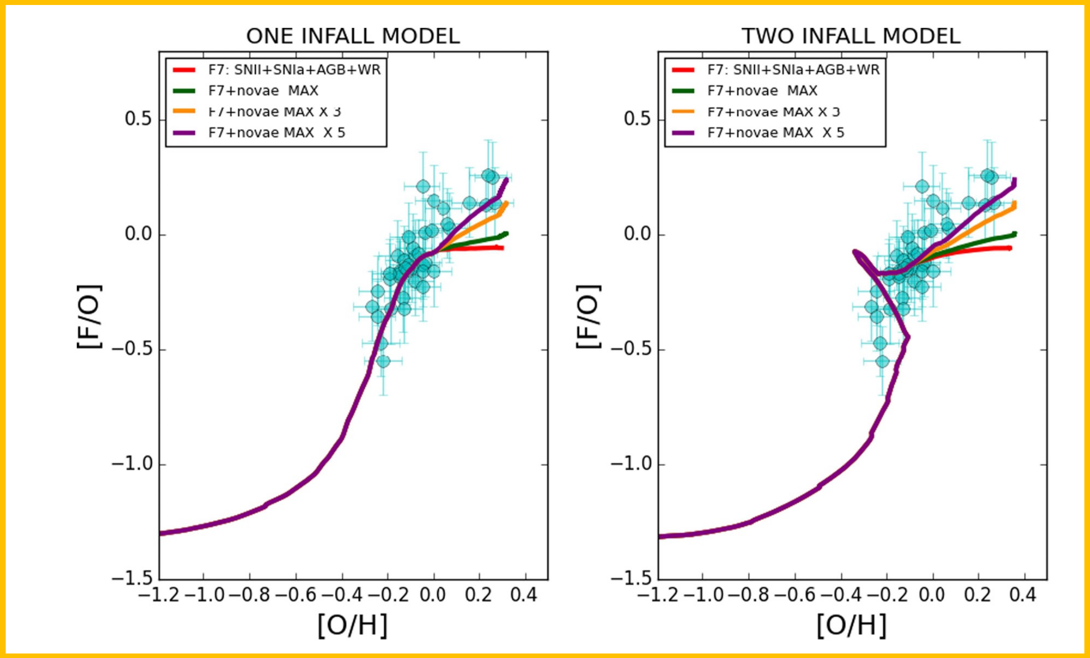


Chemical evolution models

Timmes, Woosley & Weaver (1995) was the **first chemical evolution study** to investigate F, and they found that the inclusion of novae can reproduce [F/O] ratios in combination with AGB stars.

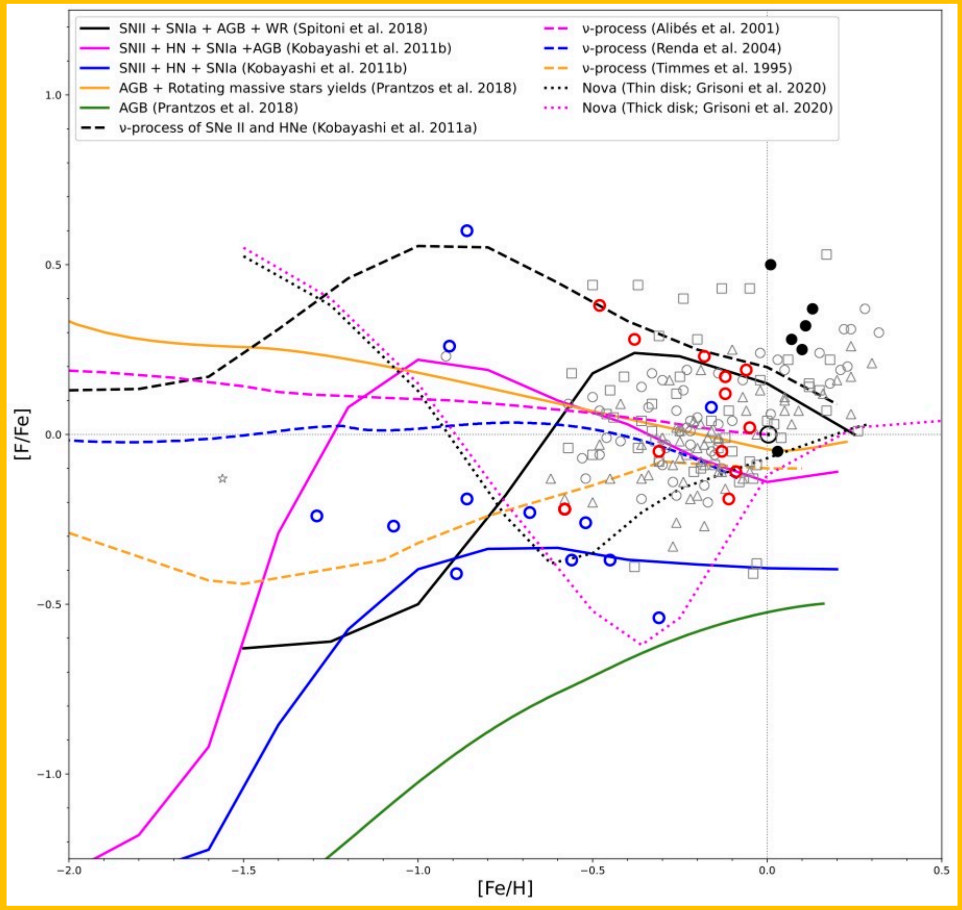
The need for novae confirmed by Spitoni+ (2018):
AGBs + WR stars dominate the Galactic F production





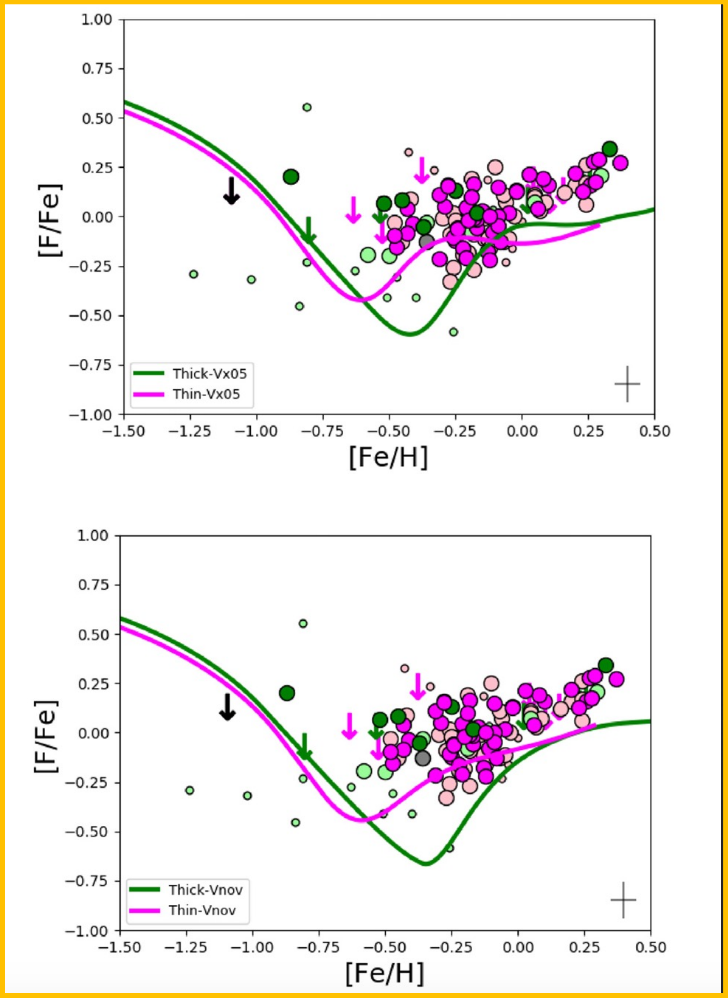
Chemical evolution models

Prantzos+ (2018), Grisoni+ (2020) found that rotating massive stars can dominate the F production up to solar metallicity - although Grisoni+ had to call for an extra production at higher [Fe/H]

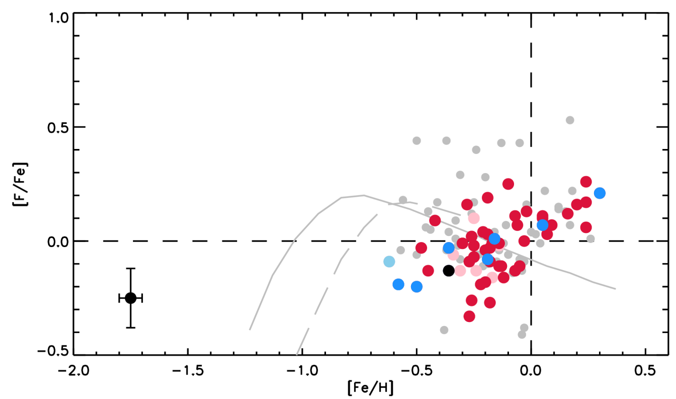


Guerço+ 2022

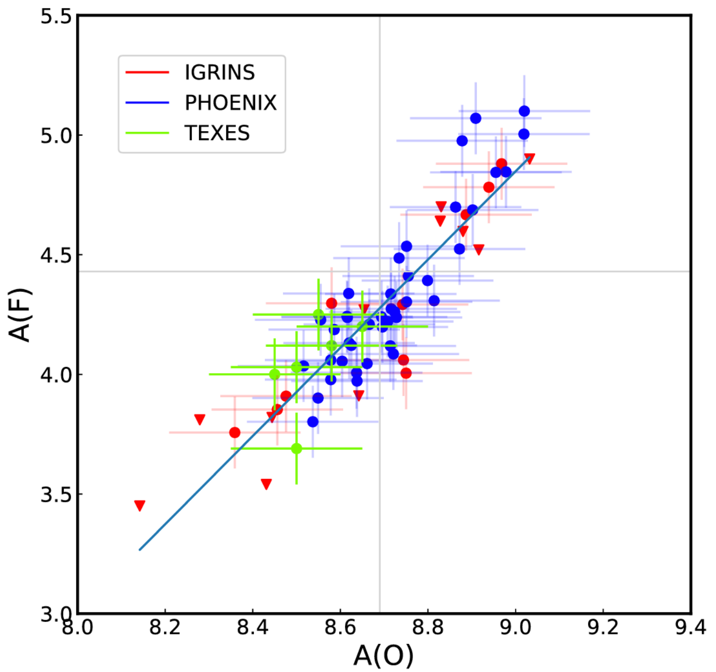
Grisoni+ 2020



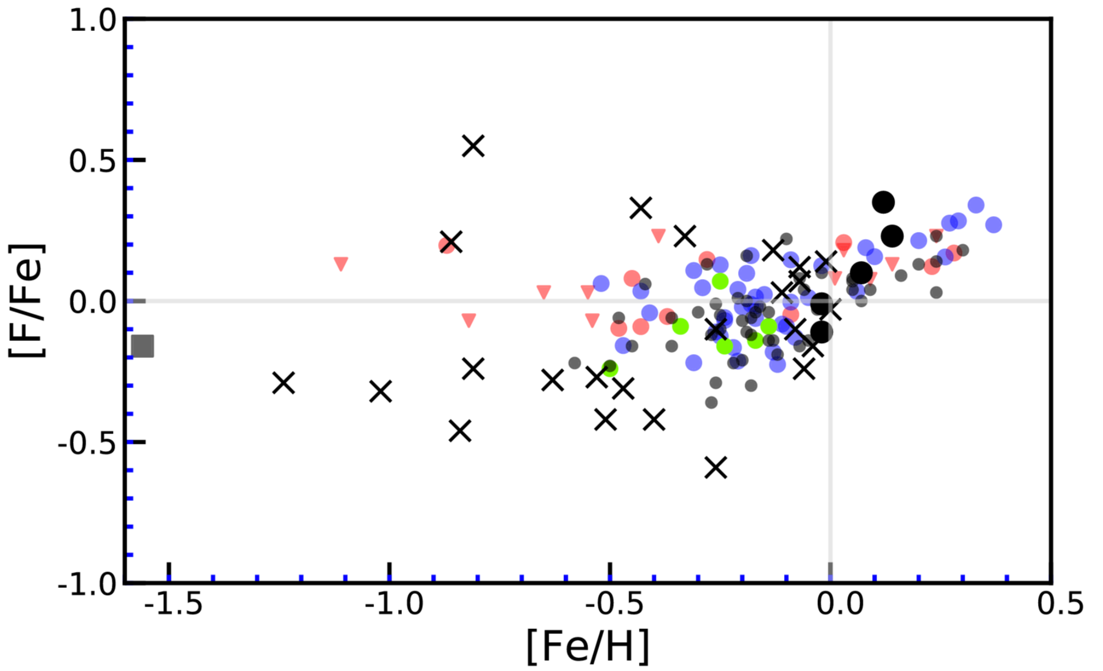
Observations



Jönsson+ 2017: No need for ν process (AGBs+ WR)

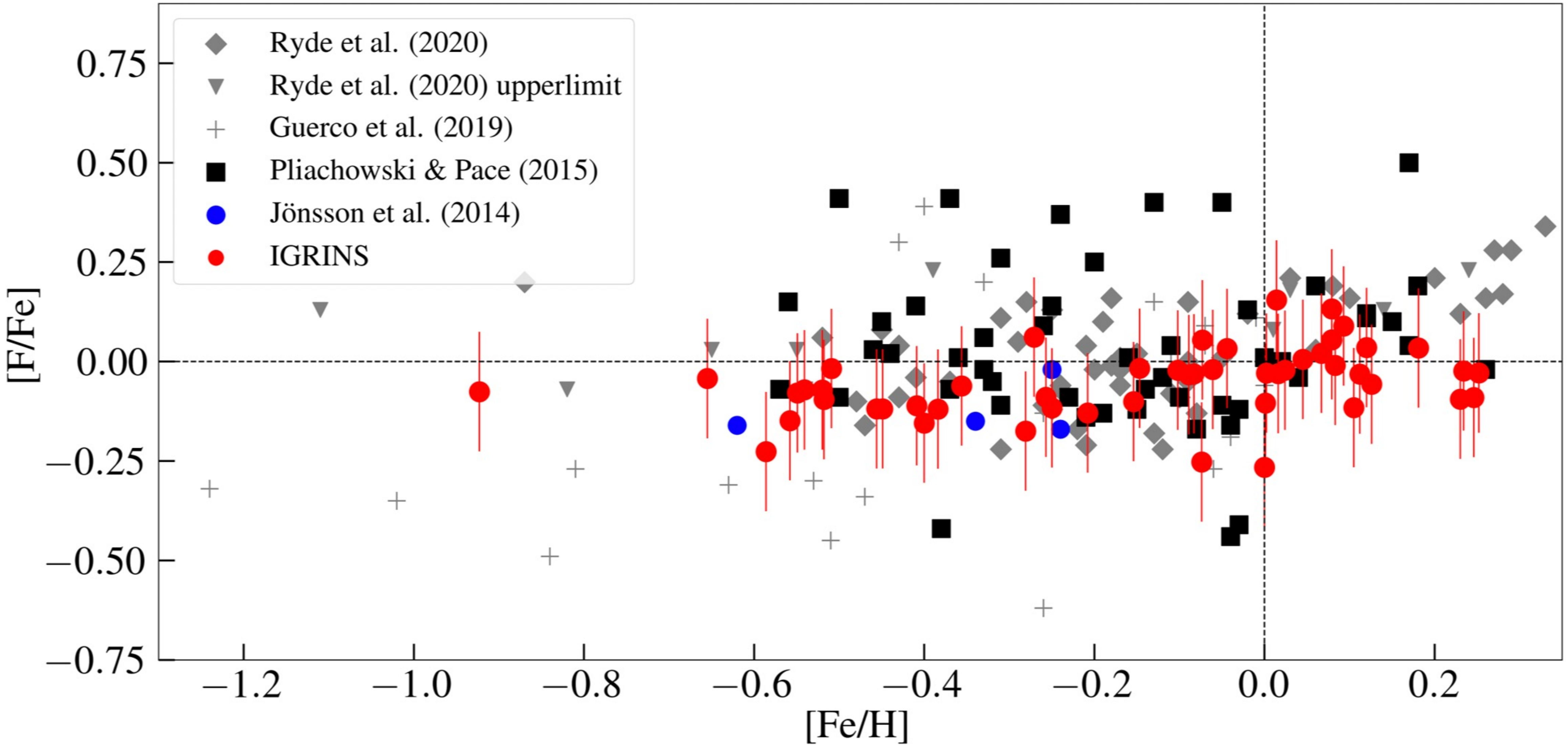


Ryde+ 2020: Flat trend up to solar, then increasing trend at super-solar metallicity →



Observations

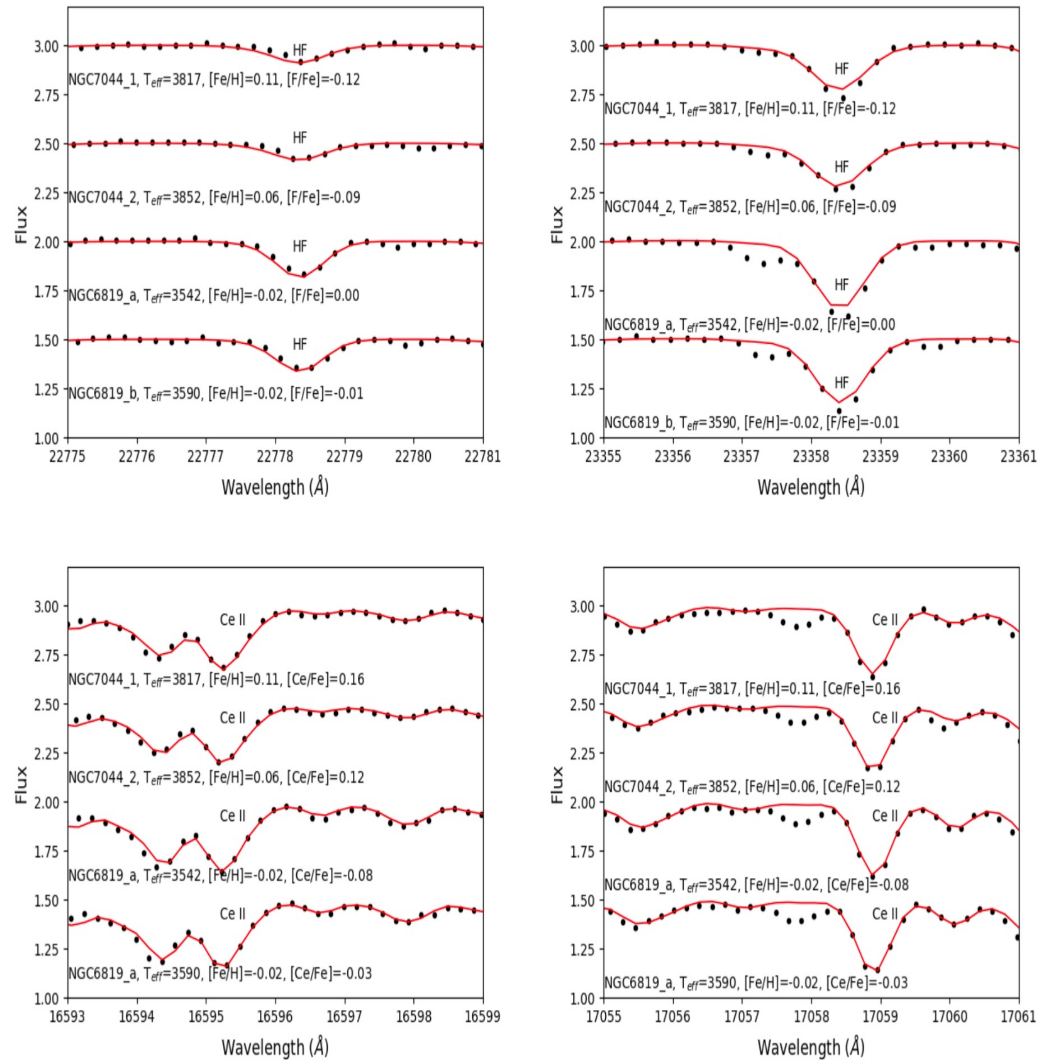
Nandakumar+ 2023: NO!



Our sample: Open clusters

Stellar cluster	Star	Gaia DR3 ID	RA (deg)	Dec (deg)	G (mag)	S/N H-band	S/N K-band
NGC 7789	N7789_1	1995061928762465536	359.263535573	56.766078036	9.75	175	117
age=1.55Gyr	N7789_2	1995014409242207872	359.293345577	56.713695317	9.86	234	122
R_{GC} = 9.43 kpc	N7789_4	1995059592294642560	359.074303178	56.668800703	10.22	80	98
NGC 7044	N7044_1	1969807040026523008	318.321873119	42.484572587	11.79	250	120
age=1.66Gyr	N7044_2	1969807276235623552	318.330484209	42.507969696	11.90	93	111
R_{GC} = 8.73 kpc	N7044_3	1969806073644788992	318.397775571	42.460809968	12.20	96	111
	N7044_4	1969800576086654592	318.256942841	42.403479143	12.21	117	132
NGC 6819	N6819_a	2076394728016615680	295.479787235	40.239351300	10.07	383	33
age=2.24Gyr	N6819_b	2076582950658667264	295.284268649	40.325501253	10.13	143	36
R_{GC} = 8.03 kpc							
Ruprecht 171	Rup171_1	4103073693495483904	277.989813692	-15.980947363	10.01	115	97
age=2.75Gyr	Rup171_2	4102882309792631552	278.022115687	-16.133756431	10.45	113	135
R_{GC} = 6.90 kpc							
Trumpler 5	Trumpler5_1	3326783231129992704	99.253875467	9.496152447	10.72	343	145
age=4.27Gyr							
R_{GC} = 11.21 kpc							
King 11	King11_1	2211216117949545216	356.988703461	68.595172524	11.66	233	124
age = 4.47Gyr	King11_2	2211121972266402304	356.899458081	68.559189268	12.04	175	140
R_{GC} = 10.21 kpc	King11_3	2211220211058075776	356.910794815	68.656763219	12.24	77	112
NGC 6791	N6791_2	2051105616974709504	290.316961400	37.77952520	12.25	66	41
age = 8.31Gyr	N6791_3	2051287002031070208	290.207176626	37.72853365	12.39	96	35
R_{GC} = 7.94 kpc							

Table 1: Basic information of the program stars and spectra. The ages and R_{gc} are from Cantat-Gaudin et al. (2020) except for NGC 6791 (Brogaard et al. 2021).



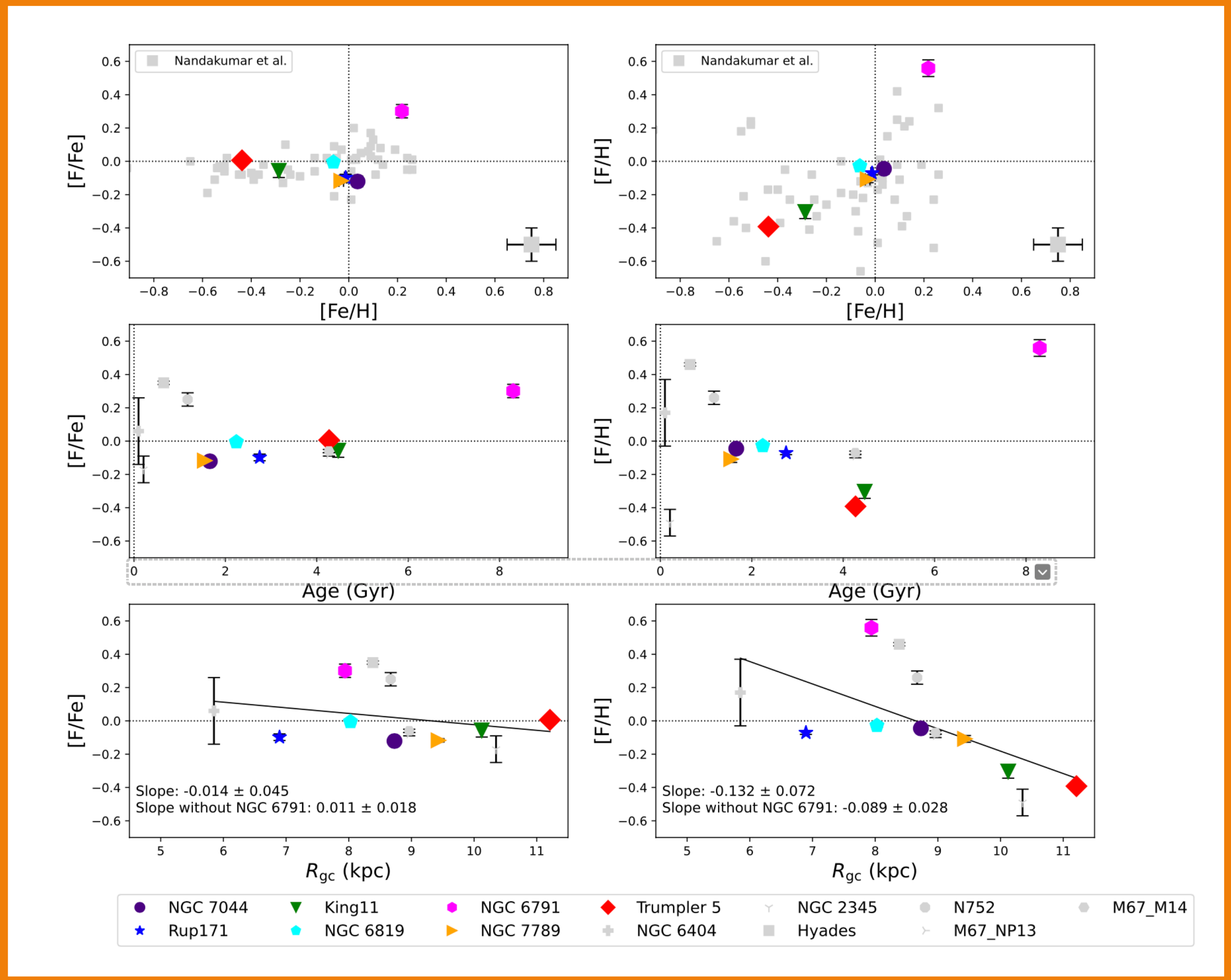
Our sample: Open clusters

WE USED ONLY NIR SPECTRA: Teff sensitive molecular OH lines, along with Fe atomic lines, CN, and CO molecular band heads in the H band wavelength regime (1400 – 1800 nm) [Nandakumar+ 2023]

First off, Teff, [Fe/H], vmic, vmac, C and N were determined from the spectra adopting a log g (from Yonsei-Yale isochrones) and an oxygen abundance (assuming trend from Amarsi+ 2019). At each iteration log g is adjusted with new Teff/[Fe/H] values.
The iterations are repeated until convergence, all in pySME (Wehrhahn+ 2022)

[See also discussion in Casali+ 2020 about issues when analysing stars cooler than Teff~ 4300 K]

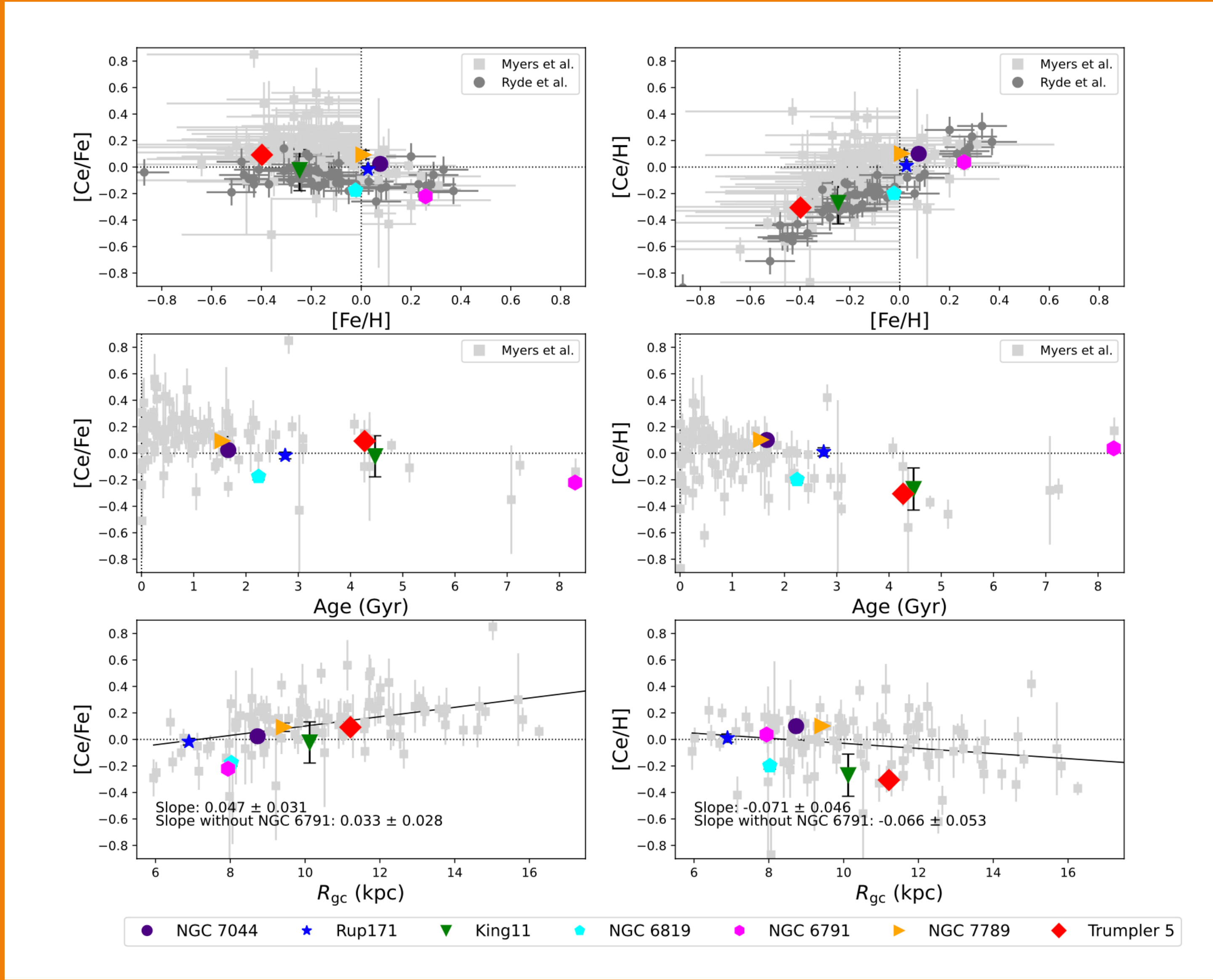
Results: Open clusters -F



Flat trend of [F/Fe] vs [Fe/H]
But ...

What about NGC 6791 ?

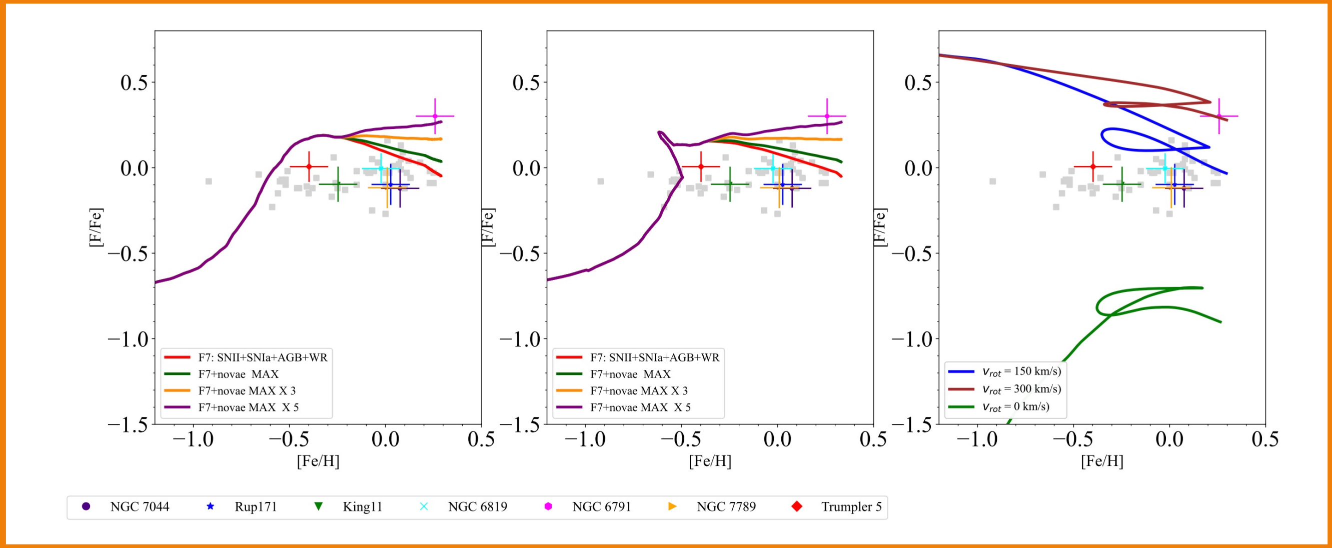
Results: Open clusters - Ce



Cerium is probably telling a different tale:

Incresing trend of [s/Fe] with R_{gc}

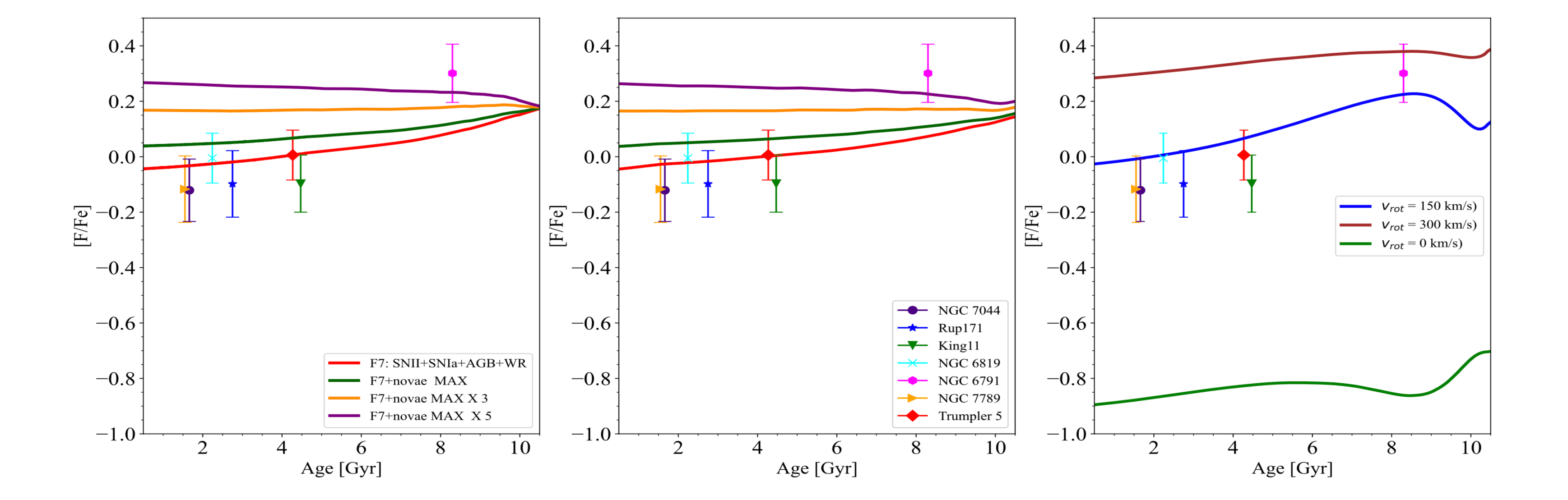
Comparison with models



WRONG!

SPOILER:

Different AGB prescriptions
Cristallo's vs Karakas' yields



FLUorine abundances in Open cluster cool giants (FLUO)

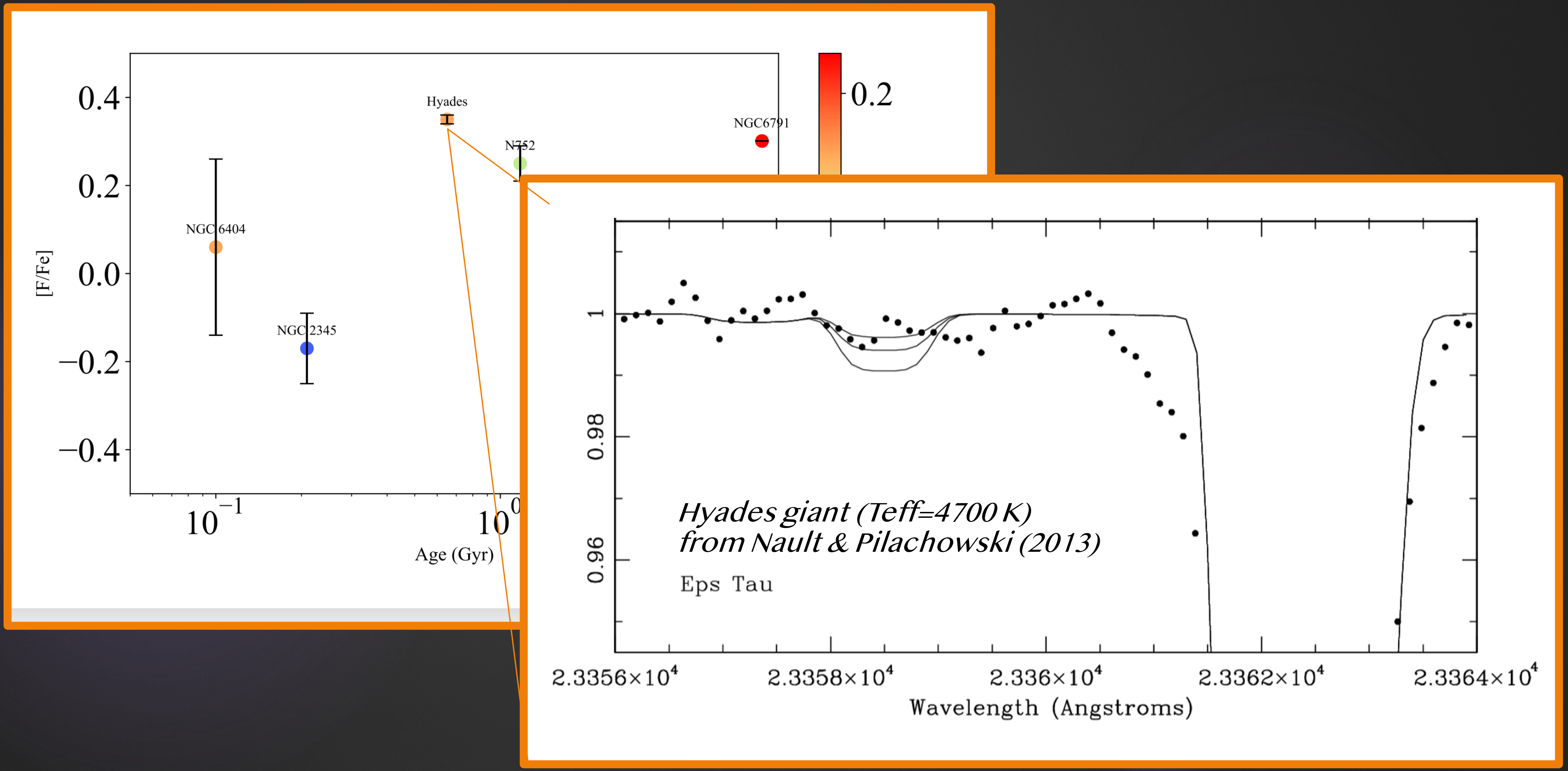
New observations acquired with Giano-B at the TNG in AOT47 (August 2023, PI: VD)

6 Open clusters and 27 Kepler giants

(Collinder 110, Berkeley 32, NGC 2420, NGC 6939, NGC 7142, NGC 7762) → Ages between 1.5 --- 5 Gyr

Analysis in progress

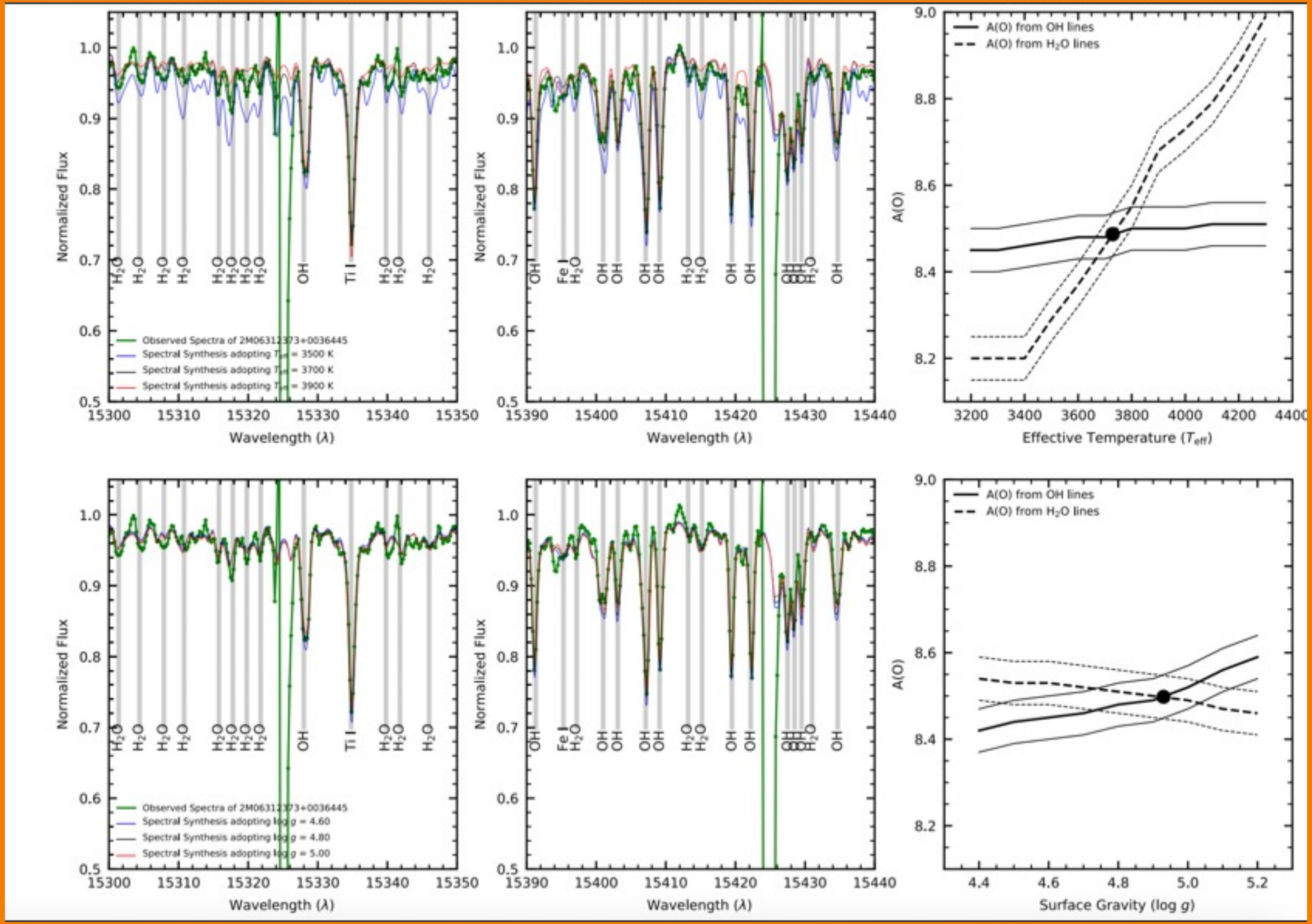
Why do we require more data?



FLUorine abundances in Open cluster M dwarfs (FLUO-MD)

Pilot project submitted for AOT49 (PI VD) for OC Melotte 111

Teff and log g from H_2O and OH lines, metallicity from FeH lines [see Souto et al., 2020, 2021, 2022]



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- **End:** 2024/07/26

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Valentina D'Orazi (co-chair)
Jacopo Farinato
Sara Lucatello (co-chair)
Elisabetta Rigliaco
Alice Zurlo

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Anthony Boccaletti (Paris-Meudon, France)
Ilaria Carleo (IAC, Spain)
Rosario Cosentino (TNG, Spain)
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