THE 13TH TORINO WORKSHOP ON AGB STARS
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Barium stars as tracers of s-process nucleosynthesis in AGB stars

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Ba stars

- peculiar G–K spectral type, [Fe/H] > –1 dex
- not yet evolved to the AGB phase
- strong spectral features: carbon molecular bands + s-process elements (e.g. Ba)
  → synthetised inside AGB stars
- RV variation (McClure+ 1983, ...), UV excess (Böhm-Vitense+ 2000, ...)

Ba stars

- RV variation → binary systems, now WD companion
- pollution from a former AGB companion → mass transfer
- origin of overabundance: extrinsic!
- test: AGB s-process nucleosynthesis

s-process

- s process: during TP-AGB phase
- peaks at Sr (1. peak), Ba (2. peak), Pb (3. peak)
- how to measure s-process efficiency?
  → ratio of heavy (2. peak) and light (1. peak) s elements: [hs/ls] → ratio: elimination of dilution effects
  → s=? hs=? ls=?
- ls: Sr, Y, Zr
  hs: Ba, La, Ce, Nd

sample stars

- de Castro+ (2016):

  - 182 giant Ba stars (certain, candidate)

  - high resolution spectra (FEROS, R = 48000)

  - wide range in T_{eff} (4100–5400 K), metallicity

- Ba star: if [s/Fe] ≥ 0.25 dex (s = La, Ce, Nd, Y, Zr)
  → 13 stars rejected → 169 stars left

- average [hs/ls], estimated error → separate elements + errors
  [hs/ls] → [Ce/Y], ...

AGB models

- final surface abundances, [s/Fe] ≥ 0.25 dex
- wide range of metallicities, masses, different ^{13}C pocket size: to produce s-process elements

FRUITY + Monash + NuGrid

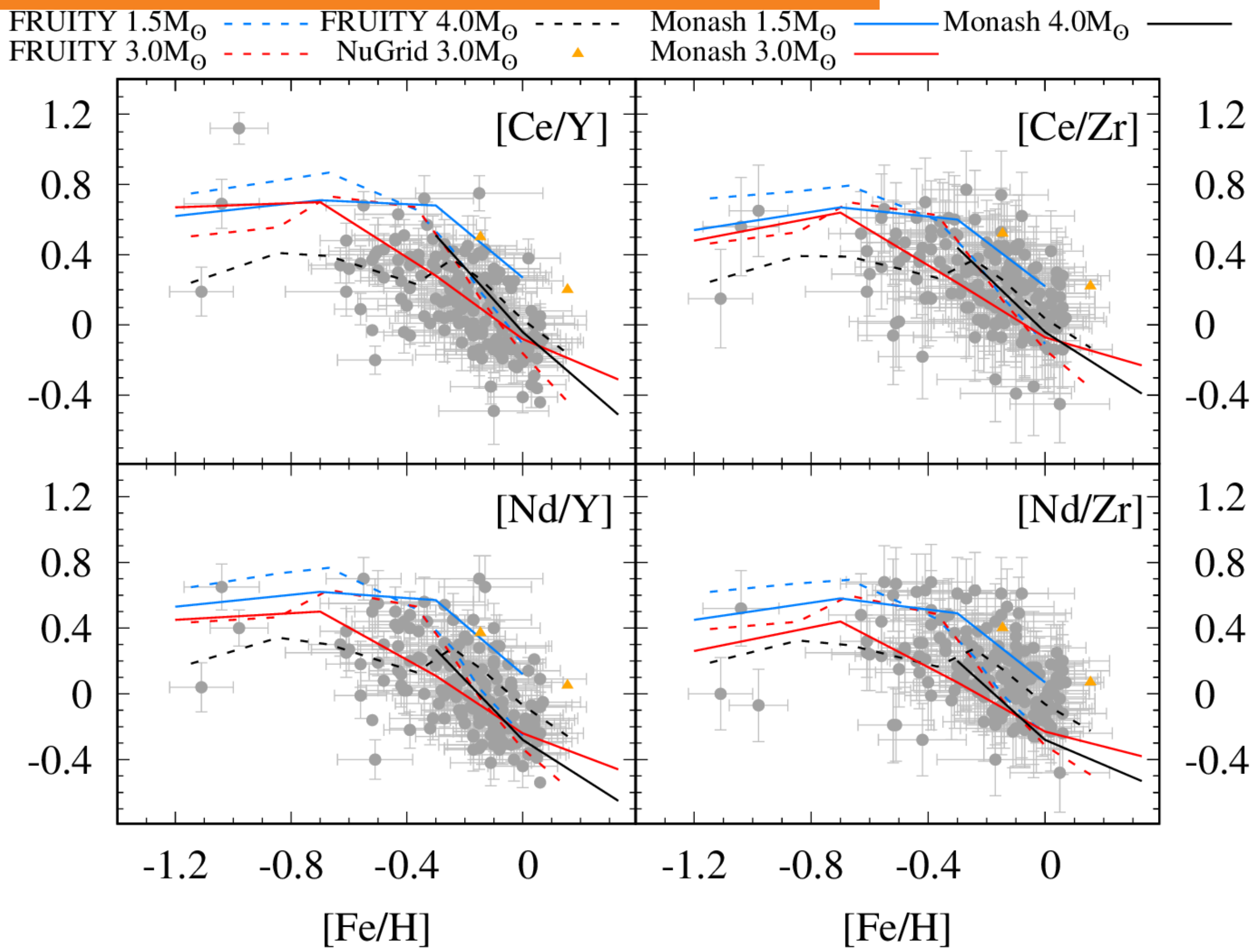
Cristallo+ 2016, Cristallo+ 2015, Straniero+ 2014, Piersanti+ 2013, Cristallo+ 2011, Cristallo+ 2009

Karakas+ 2018, Karakas & Lugaro 2016, Fishlock+ 2013, Lugaro+ 2012

Pignatari+ 2016, Battino+ 2016

model comparison

models in agreement with the data trends

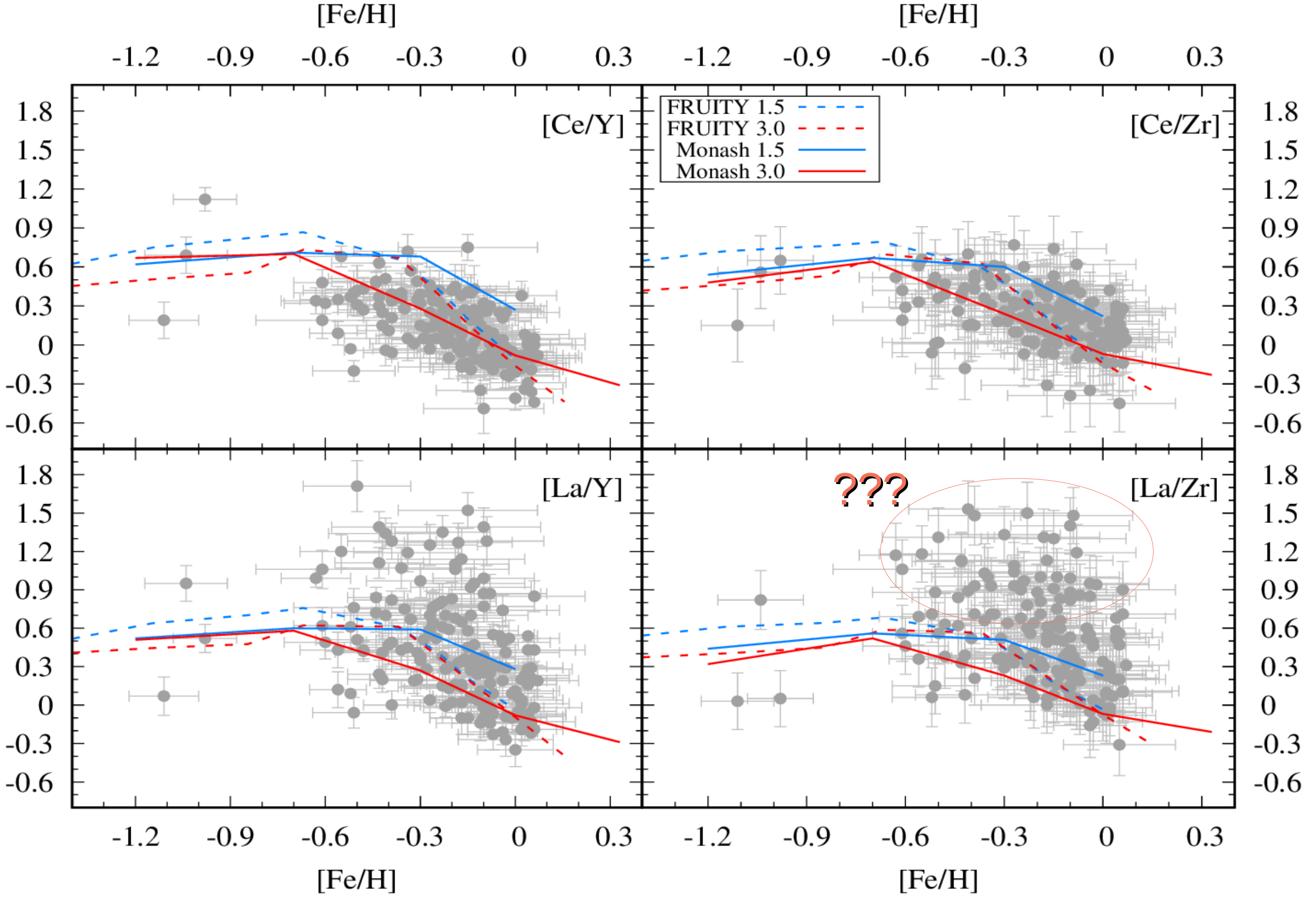


(Cseh+ 2018)

La issue...

...except from La

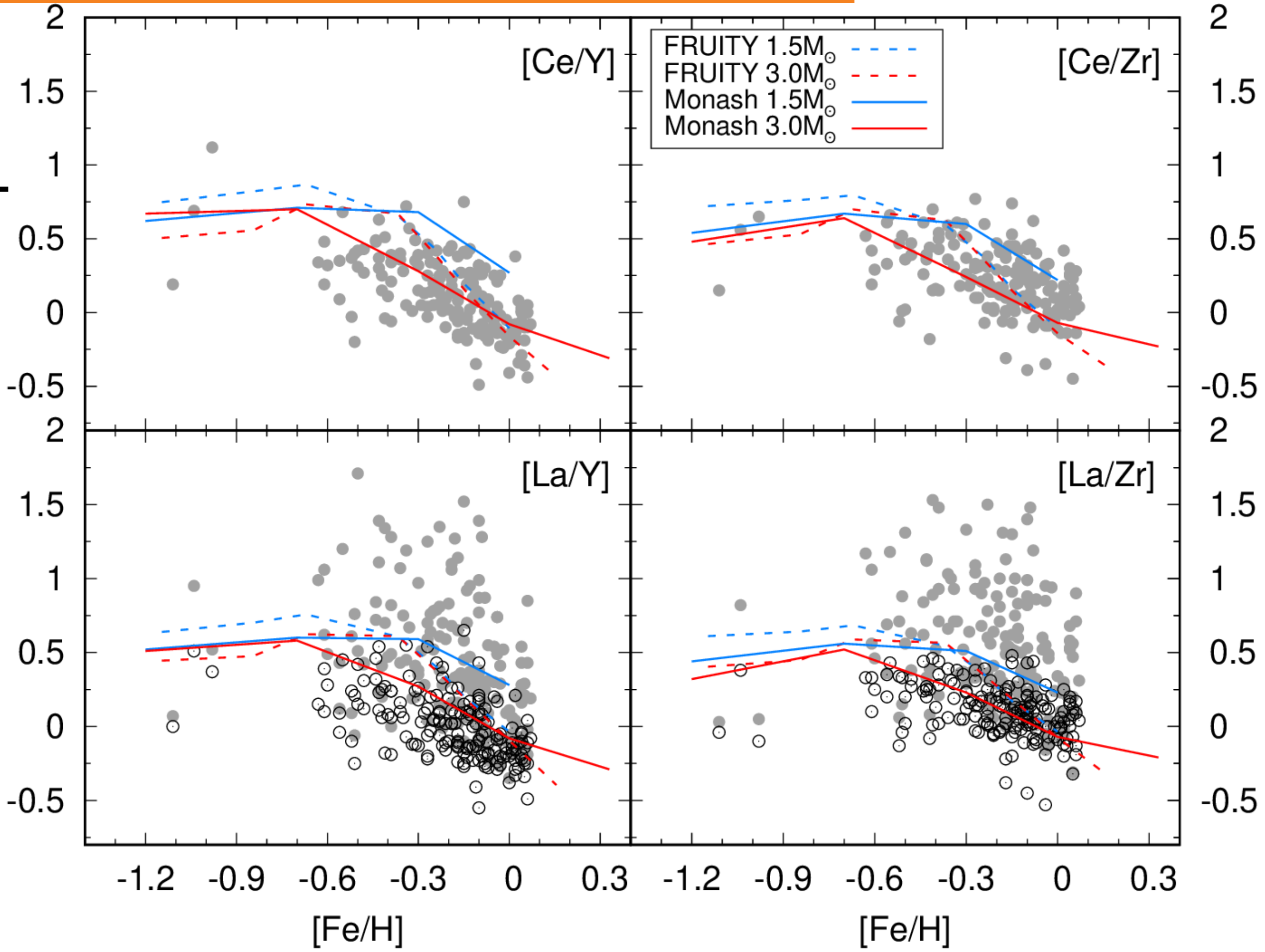
→ too strong lines
→ overestimated values



…solved!

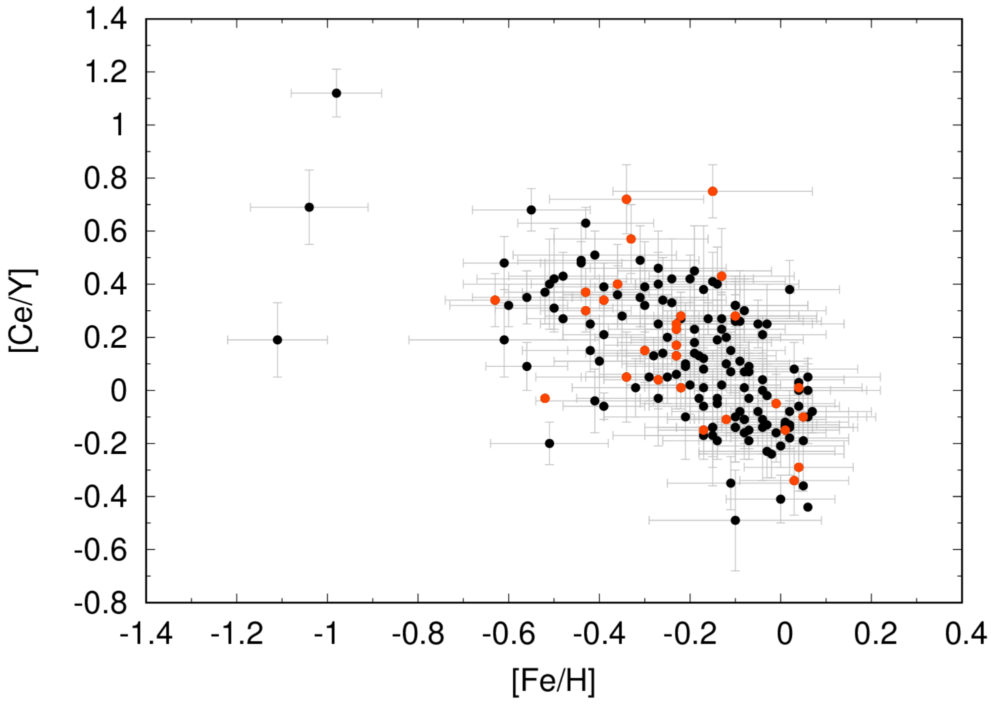
new La values (improved atomic data + hfs included)
+ new elemental abundances:
Rb, Sr, Nb, Mo, Ru, Sm, Eu

(Roriz+ 2021a,b)



individual stars

- 28 stars from the large sample (de Castro+ 2016)
  → orbits + masses (Ba + AGB_{ini}) (Jorissen+ 2019)
- spanning the whole [Fe/H] and [Ce/Y] range



individual stars

- all giants (with convective envelope)
  → AGB mass carried to the secondary and mixed
  → model comparison with dilution (δ)
- δ: to match [Ce/Fe], limit: δ < 0.9 (< 90% of the AGB envelope carried to the Ba star's surface)
- models:
  - different ^{13}C pockets
  - metallicity range: Ba star's [Fe/H] +/- err

individual stars

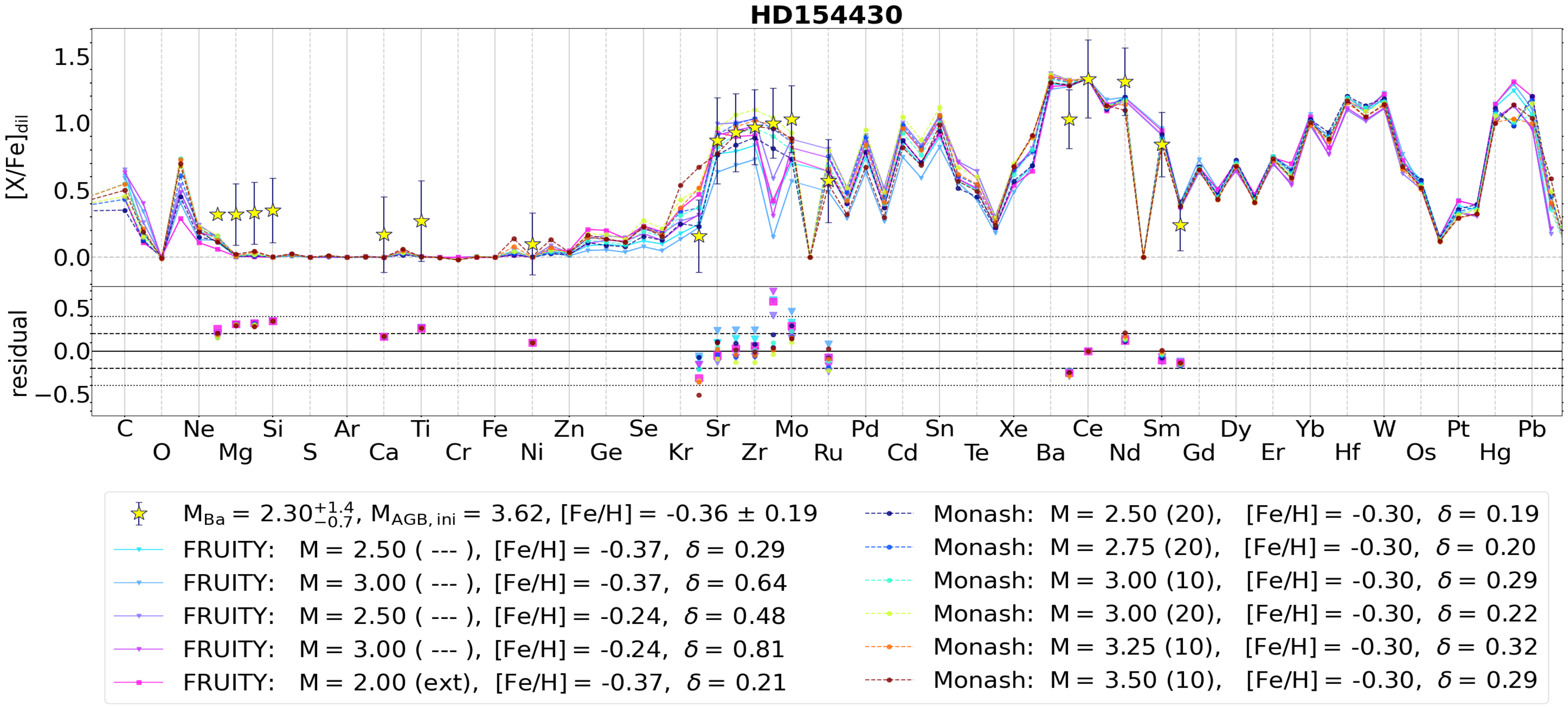
3 main groups:

1: in agreement with the models (abundance + mass) → subgroups depending on overabundance

(Cseh+ 2022)

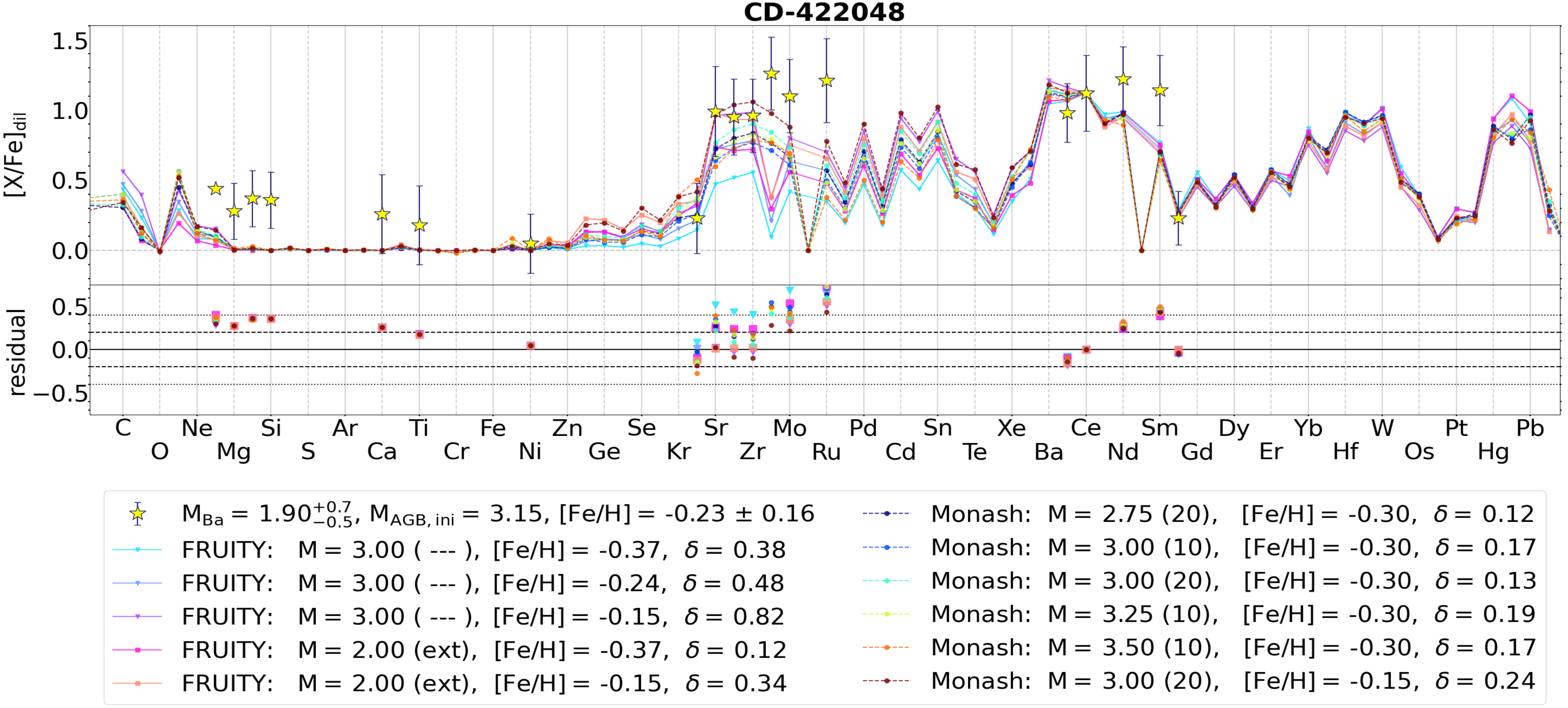
(Cseh+ 2022)

group 1a: all OK



group 1c: OK, high Nb,Mo,Ru,Nd,Sm

(Cseh+ 2022)



individual stars

3 main groups:

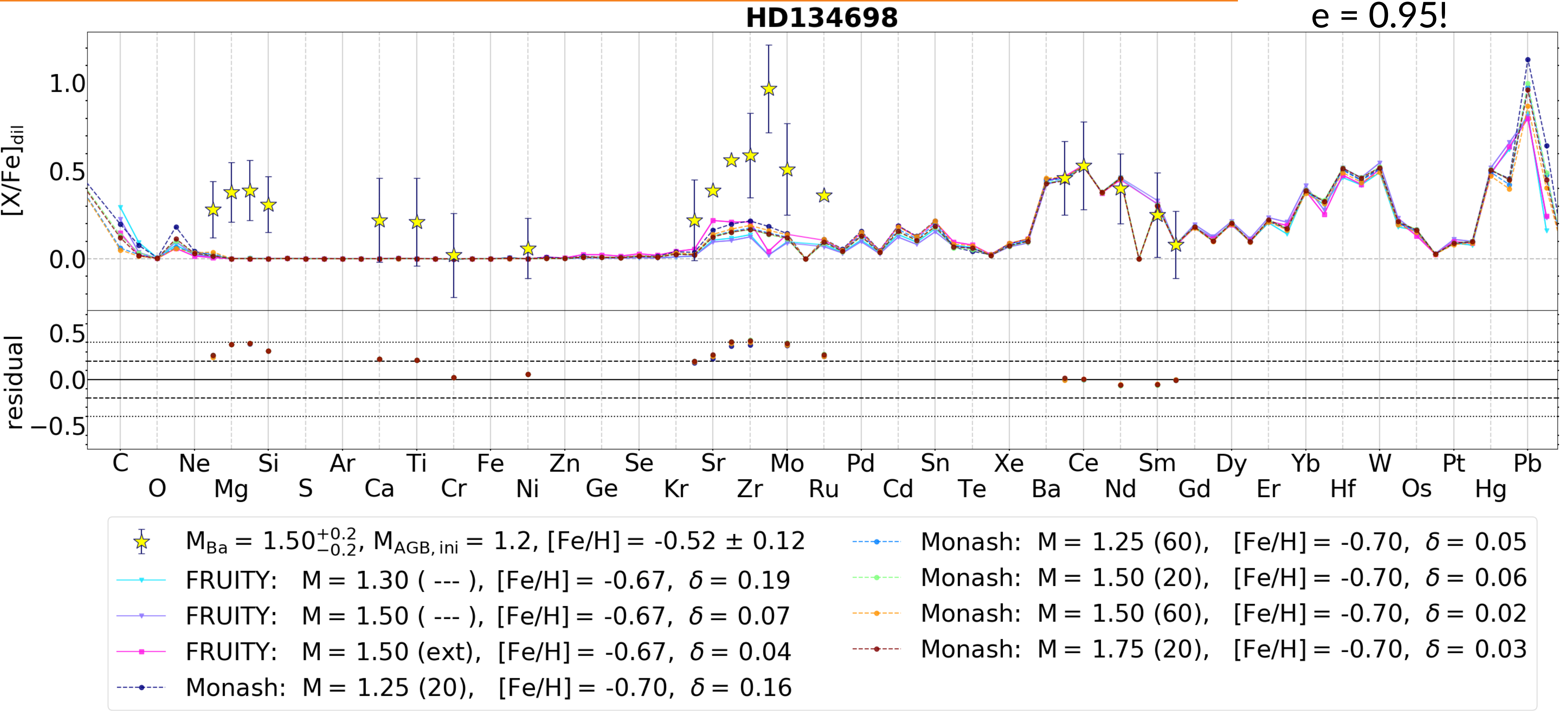
1: in agreement with the models (abundance + mass) → subgroups depending on overabundance
2: low estimated mass (< 2 M_{Sun}) + high first peak

(Cseh+ 2022)

group 2: low mass

(Cseh+ 2022)

e = 0.95!



individual stars

3 main groups:

1: in agreement with the models (abundance + mass) → subgroups depending on overabundance

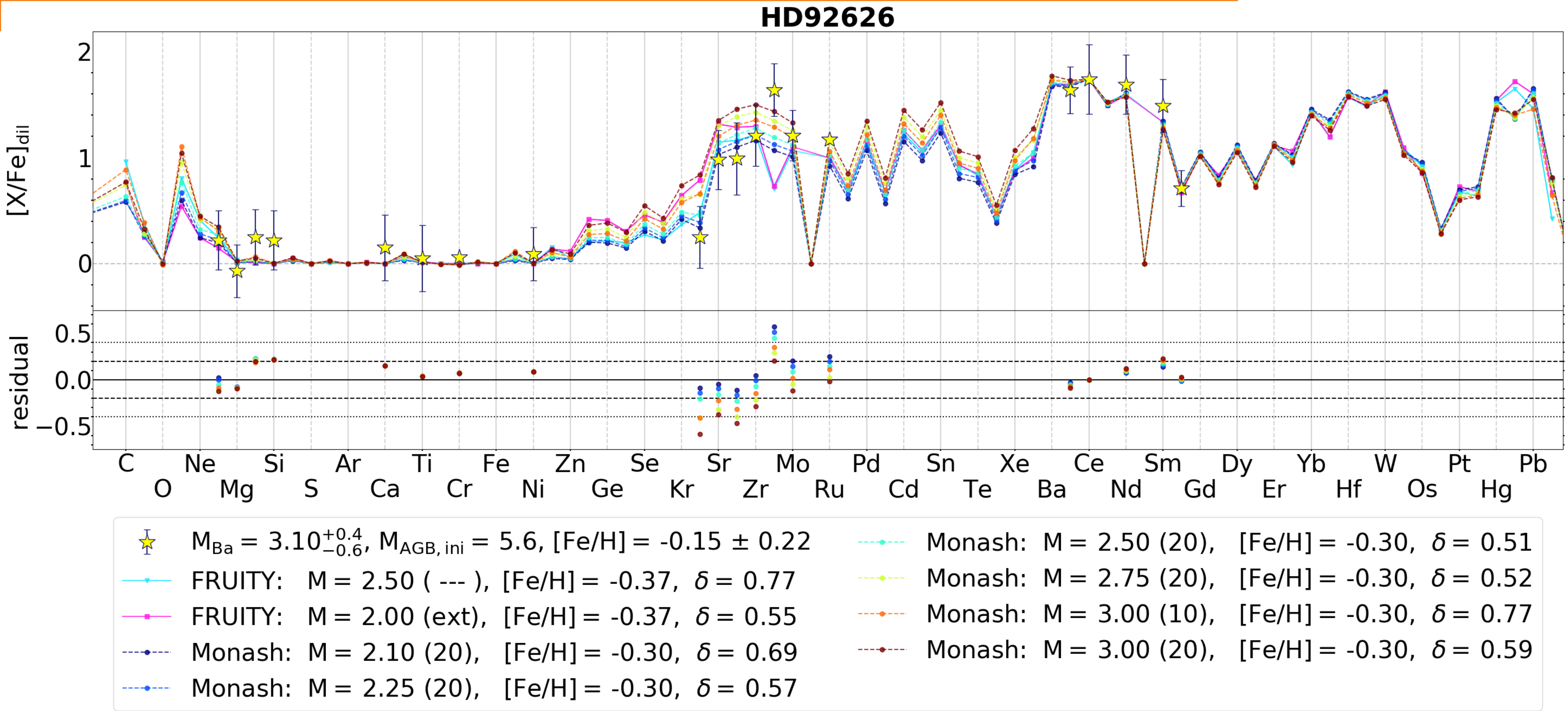
2: low estimated mass (< 2 M_{Sun}) + high first peak

3: higher initial AGB mass (> 3.8 M_{Sun})

(Cseh+ 2022)

group 3: high estimated mass → 1b

(Cseh+ 2022)



individual stars

- out of 28 stars:

  - good match with 25 stars (some with higher independently derived AGB_{ini} masses)

    → 16 stars with higher Nb, Mo, Ru and/or Nd, Sm

  - 3 with higher first s-process peak, low mass AGB_{ini} (< 2 M_{Sun}): these models cannot reproduce it!

(Cseh+ 2022)

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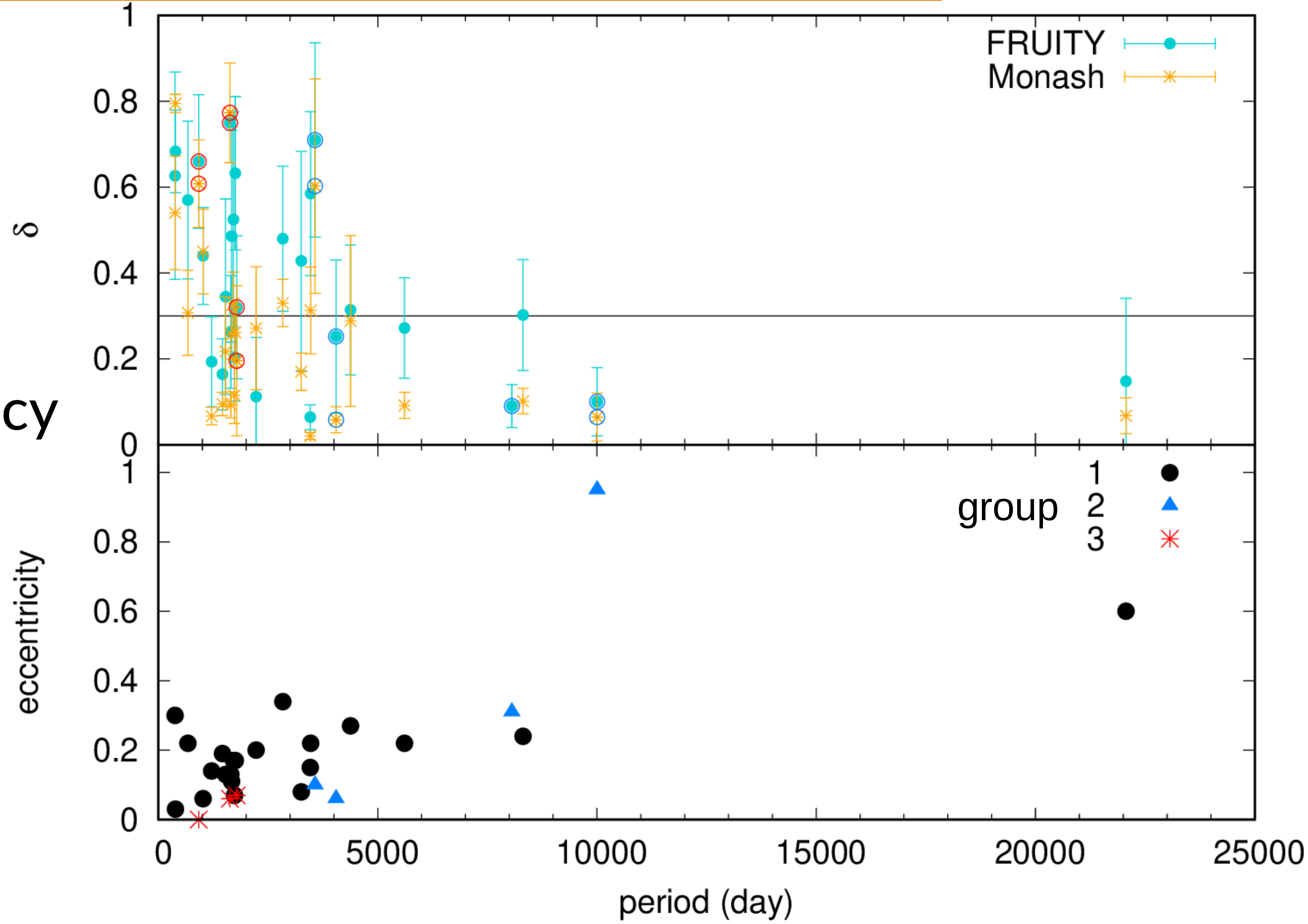
    → 16 stars with higher Nb, Mo, Ru and/or Nd, Sm
  - 3 with higher first s-process peak, low mass AGB_{ini} (< 2 M_{Sun}): these models cannot reproduce it!
    → different neutron density?
    → a new process of nucleosynthesis?

(Cseh+ 2022)

P - e - δ

shorter P
→ higher δ
→ higher mass transfer efficiency



conclusions

- Ba star polluters: low mass AGBs (~2–3 M_{Sun}, with ^{13}C as main neutron source)
- good match with 25 stars, 3 with higher first peak
- higher mass transfer efficiency… → disk structure?
- whole sample with the same abundance pattern: with machine learning techniques
  (see next talk; den Hartogh+ subm., Világos+ in prep.)
- include also other model sets

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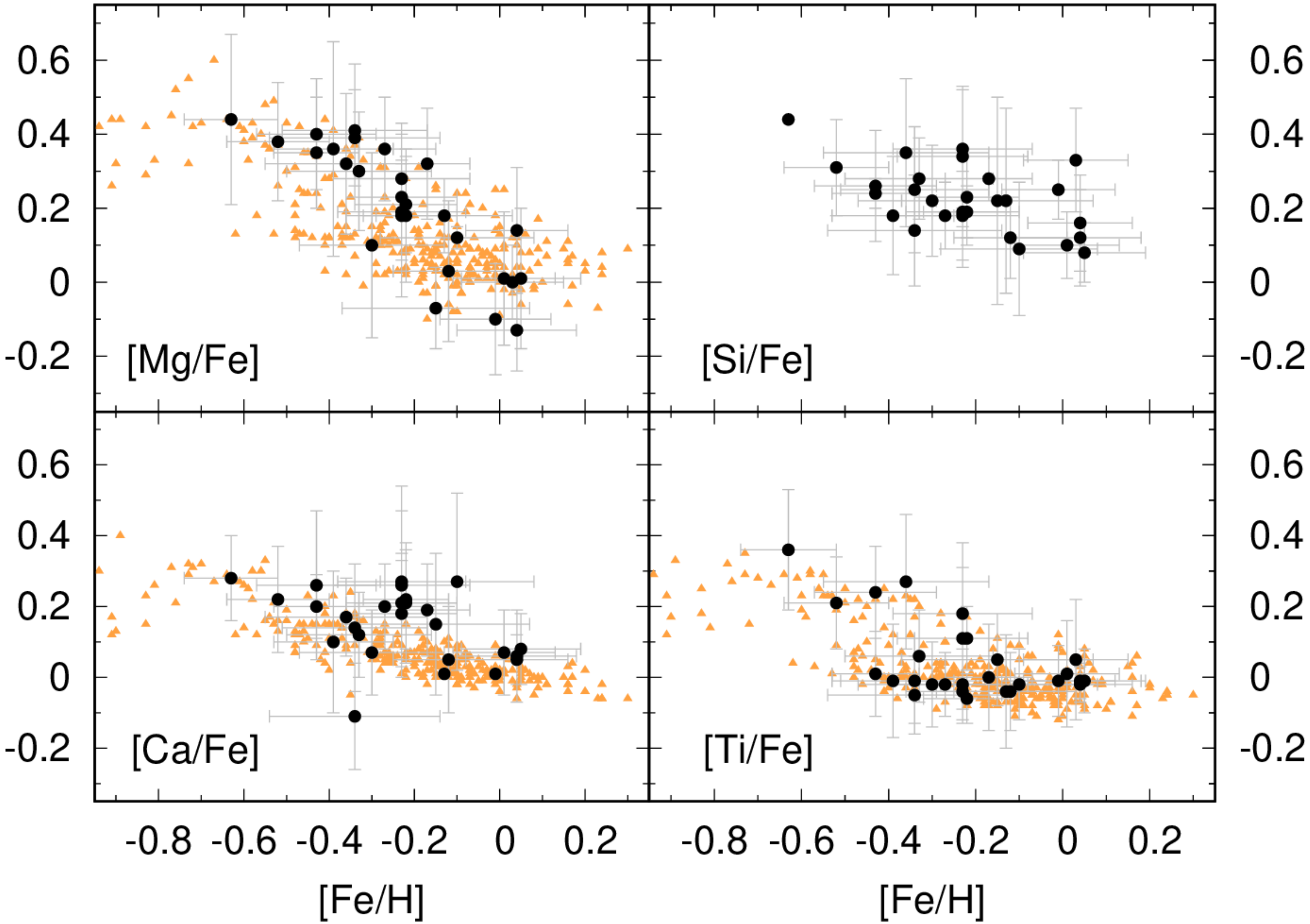
Thank you for your attention!



[Mg/Fe]
[Si/Fe]
[Ca/Fe]
[Ti/Fe]
0.6
0.4
0.2
0
-0.2
-0.8
-0.6
-0.4
-0.2
0
0.2
[Fe/H]
[Fe/H]