

Open Clusters as Tracers of Stellar Evolution

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Carbon, nitrogen, and oxygen (CNO):

- comprise in stars most of the mass of elements heavier than helium
- are among the first elements to form in the nucleosynthesis chain
- play important roles in stellar interiors as sources of opacity and energy production through the CNO cycle, and thus affect the star's lifetime, its position in the Hertzsprung-Russell diagram, and its heavy-element yields

Open star clusters:

- are important in giving us the opportunity to investigate stellar evolution
- have a number of stars of essentially the same age, distance, and origin, as open cluster stars are most likely formed in the same protocloud of gas and dust
- CNO abundances in cluster members initially were identical, their abundance changes in stellar atmospheres of evolved stars are mainly related to internal processes of stellar evolution

1st dredge-up (Iben 1965)

Boothroyd & Sackman 1999, ApJ, 510, 232

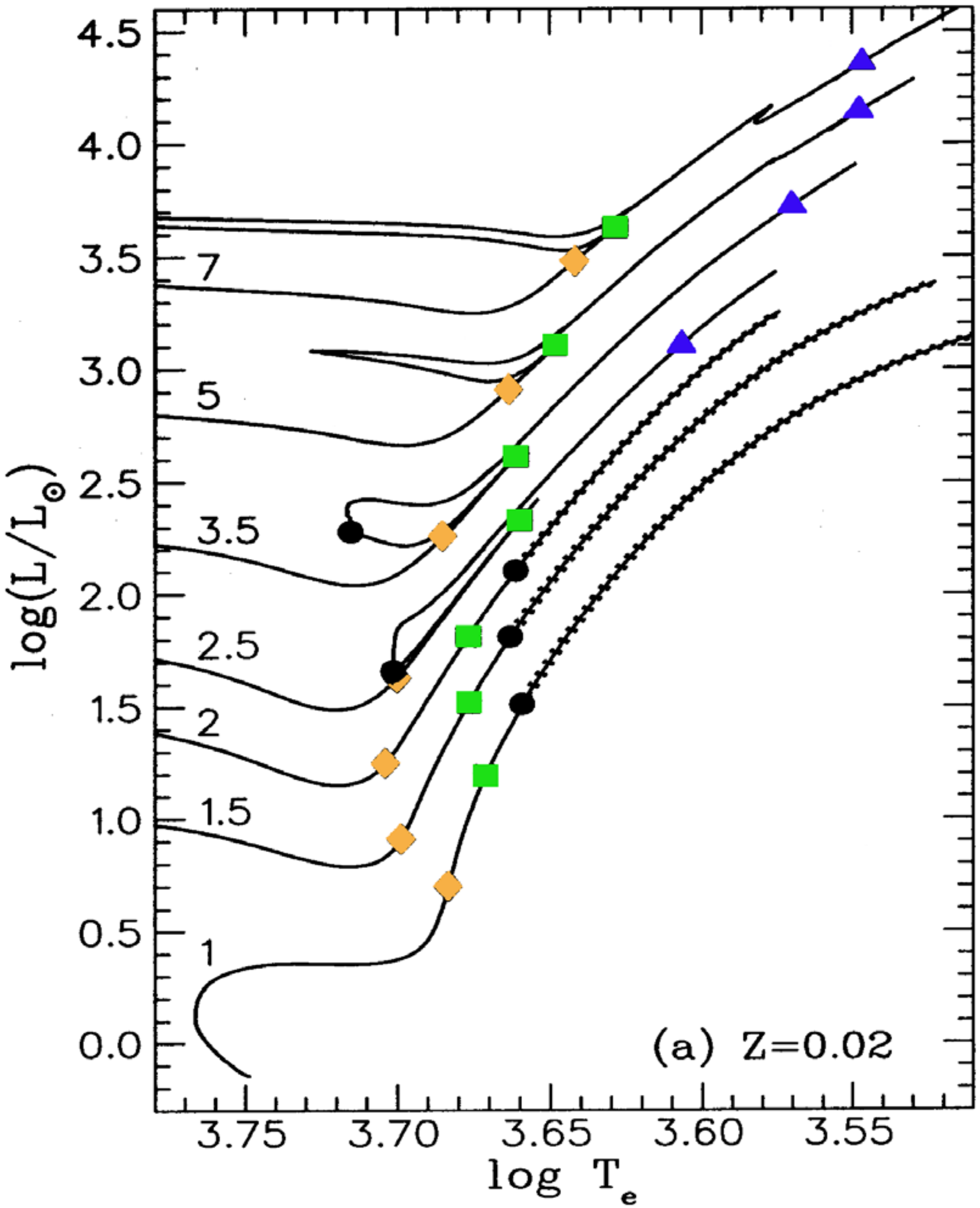
^{12}C decreases by 30 %
^{14}N increases by 80 %
^{16}O unaltered

^{12}C/^{14}N = 3.98 → 2.0
^{12}C/^{13}C = 90 → 20 – 30

First discrepancies from the standard theory came when :

- Arcturus was found to have ^{12}C/^{13}C = 7.2 ± 1.5 (Day et al., 1973)

- The enhancement of CN bands was reported for the clump stars in M 67 (Pagel, 1974)



Charbonnel 1994, A&Ap, 282, 811

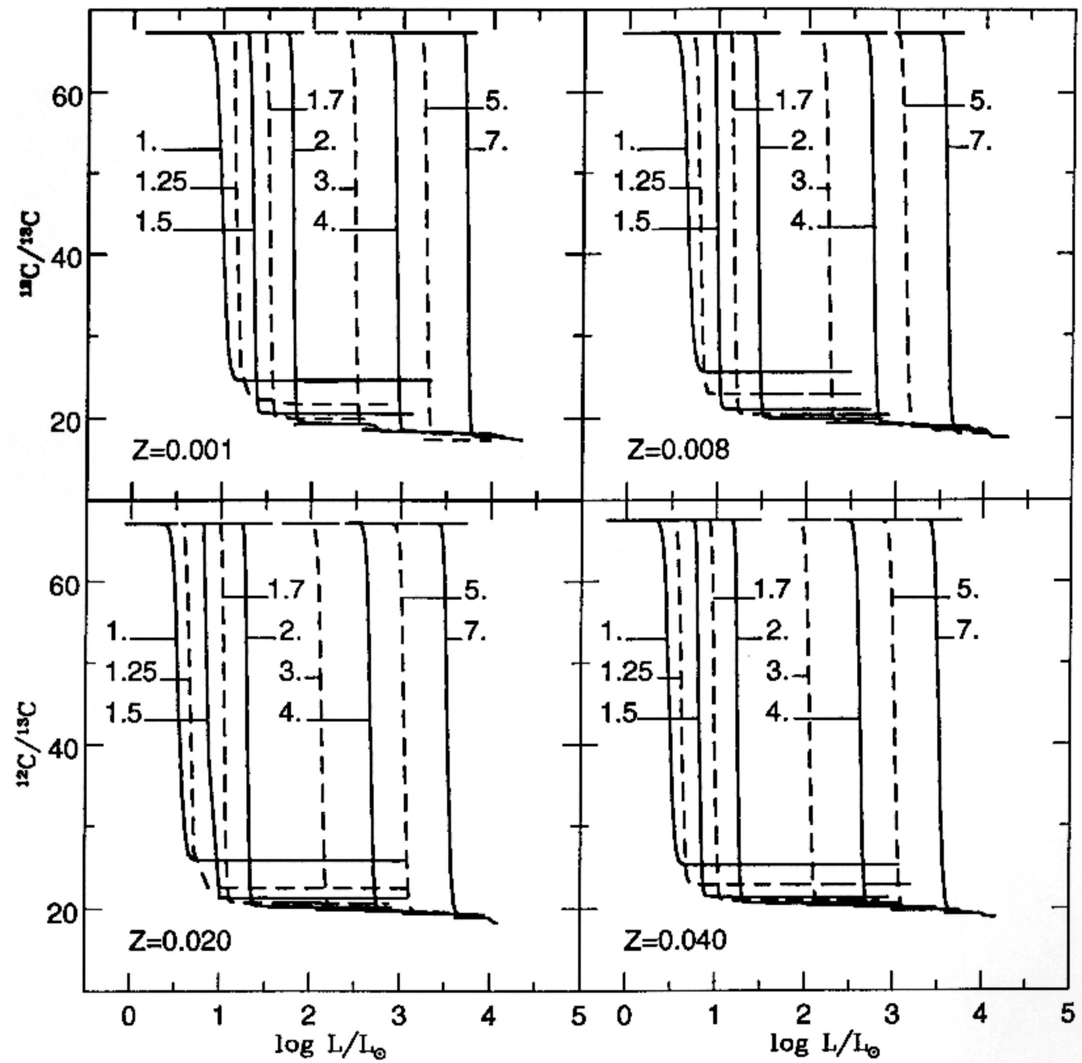
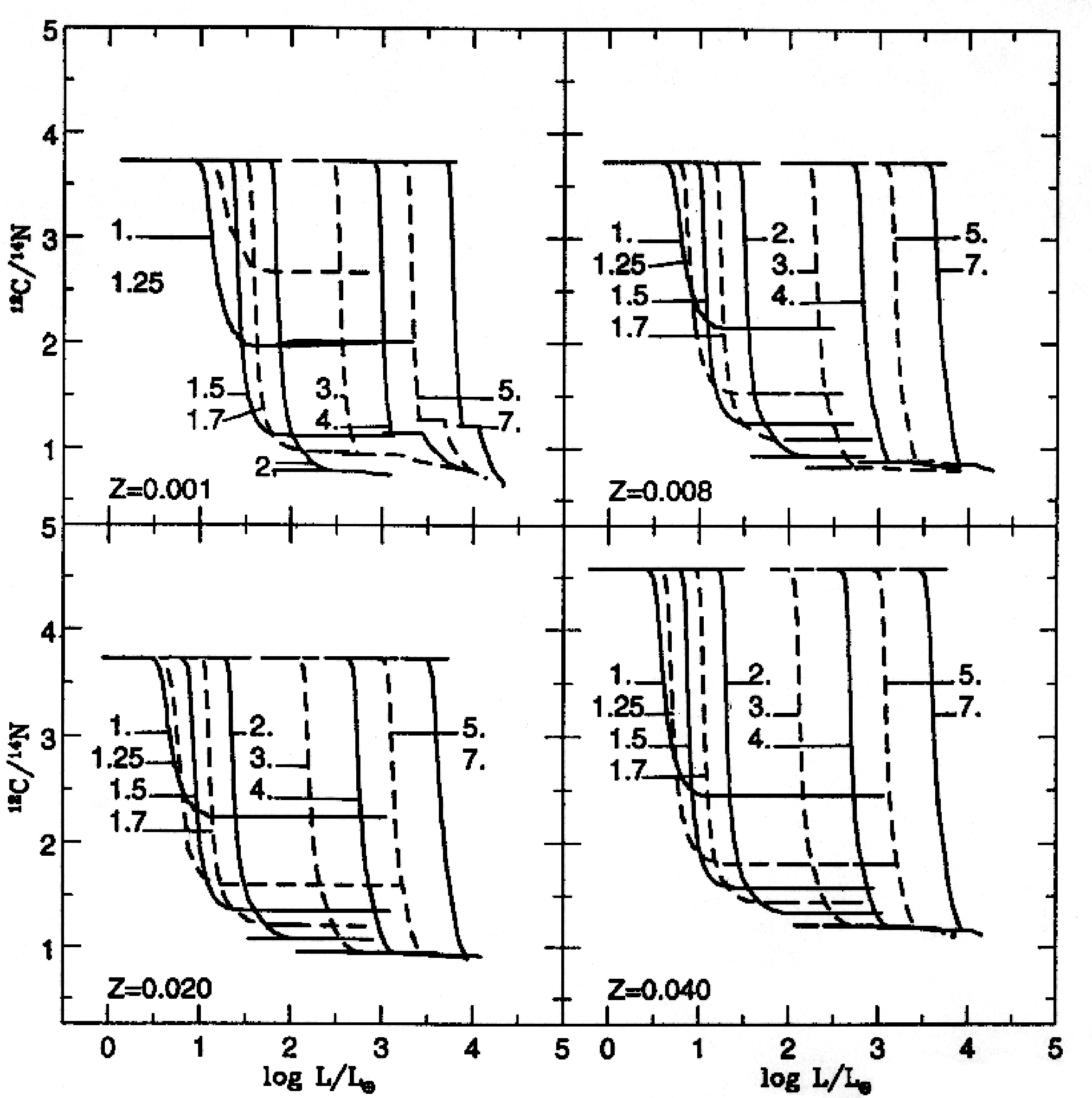
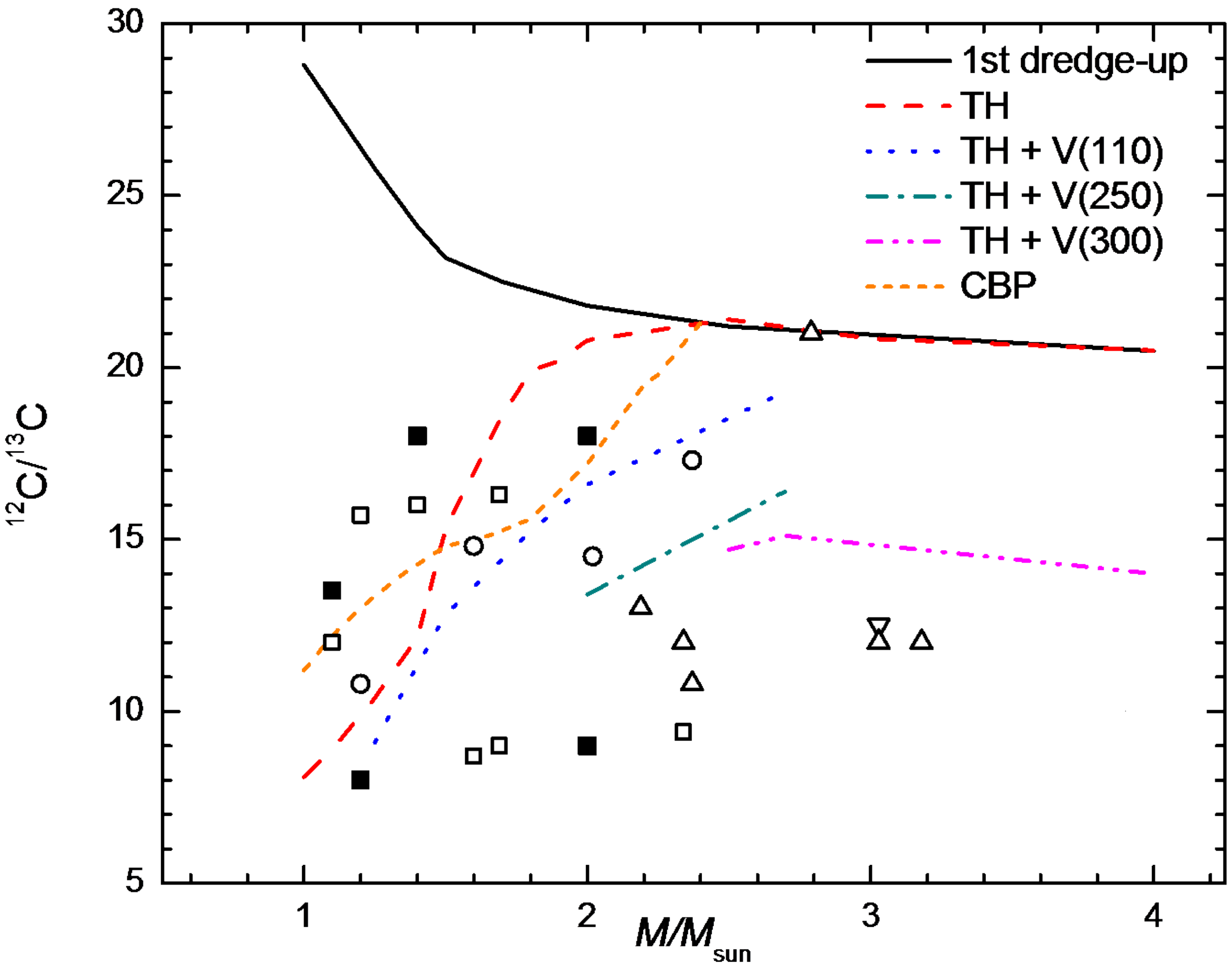


Fig. 2. Evolution of $^{12}C/^{13}C$ (number fraction) as a function of luminosity for stellar masses between 1 and 7 $M_\odot$ for different values of the metallicity Z

Charbonnel, 1994, A&Ap, 282, 811

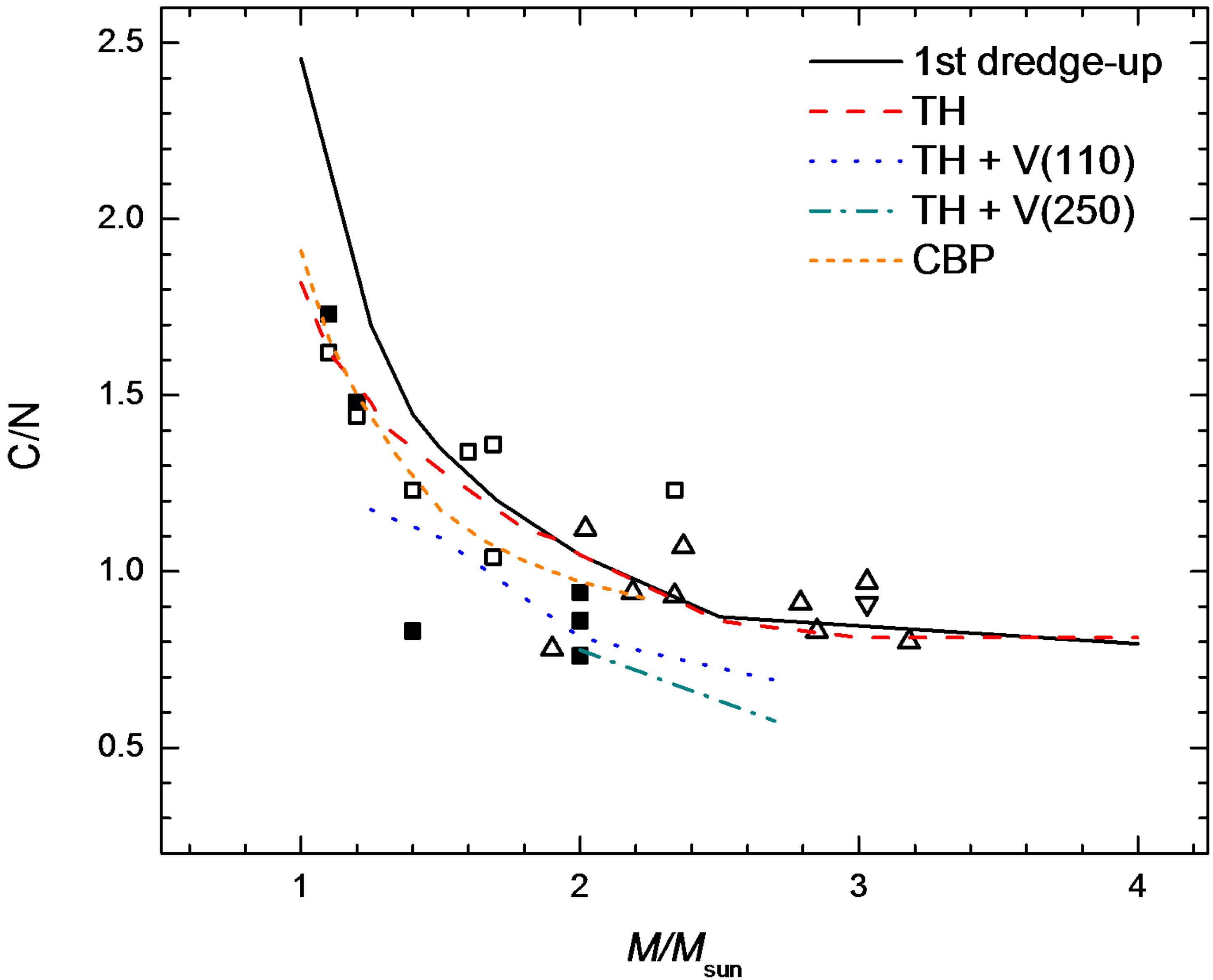


Models: Boothroyd & Sackmann (CPB, 1999) Charbonnel & Lagarde (TH, 2010)



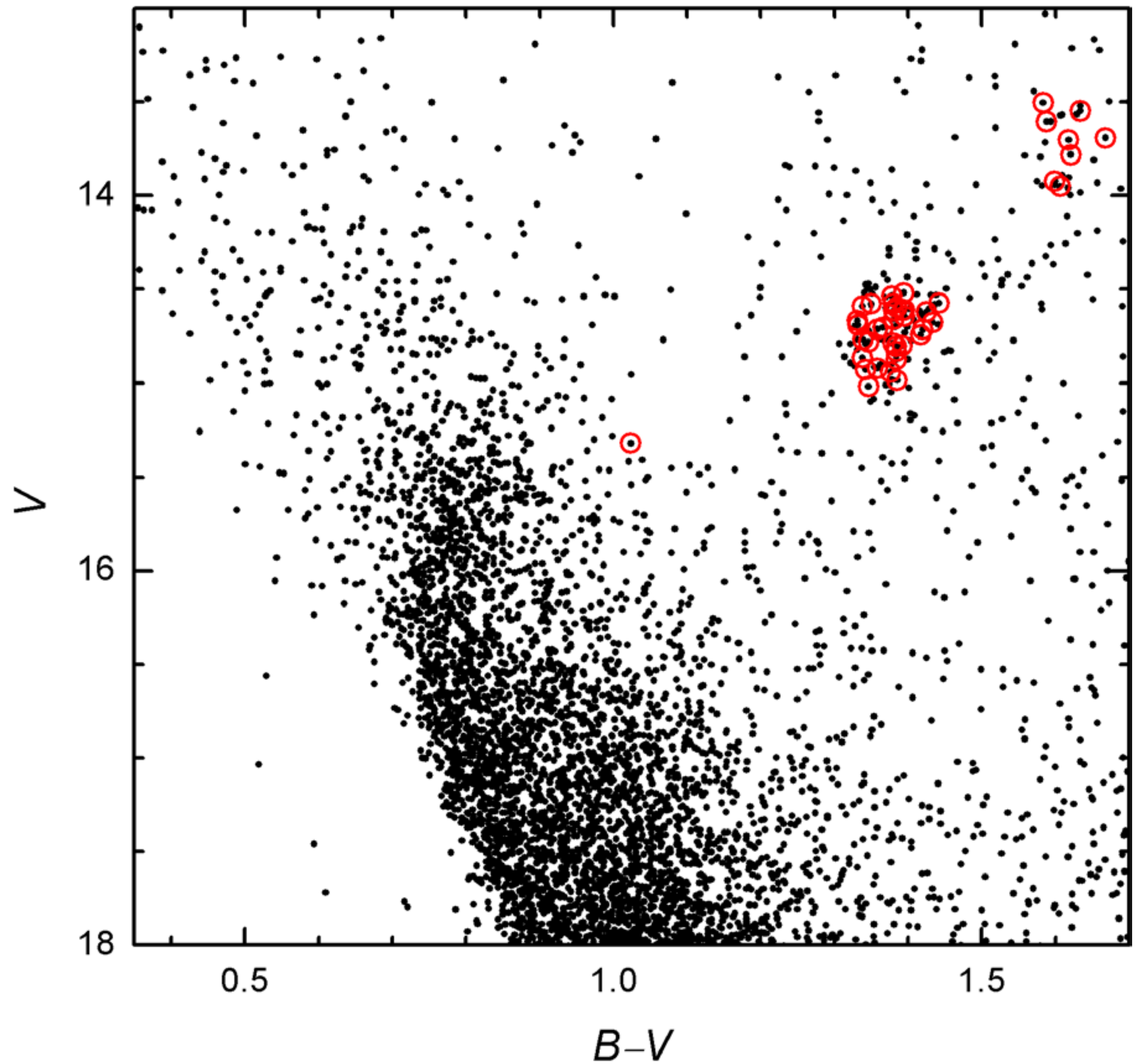
Observations: Tautvaisiene et al. Mikolaitis et al. Smiljanic et al. (2009), Gilroy (1989), Luck (1991)

Boothroyd & Sackmann 1999 (CBP)
Charbonnel & Lagarde 2010 (TH)



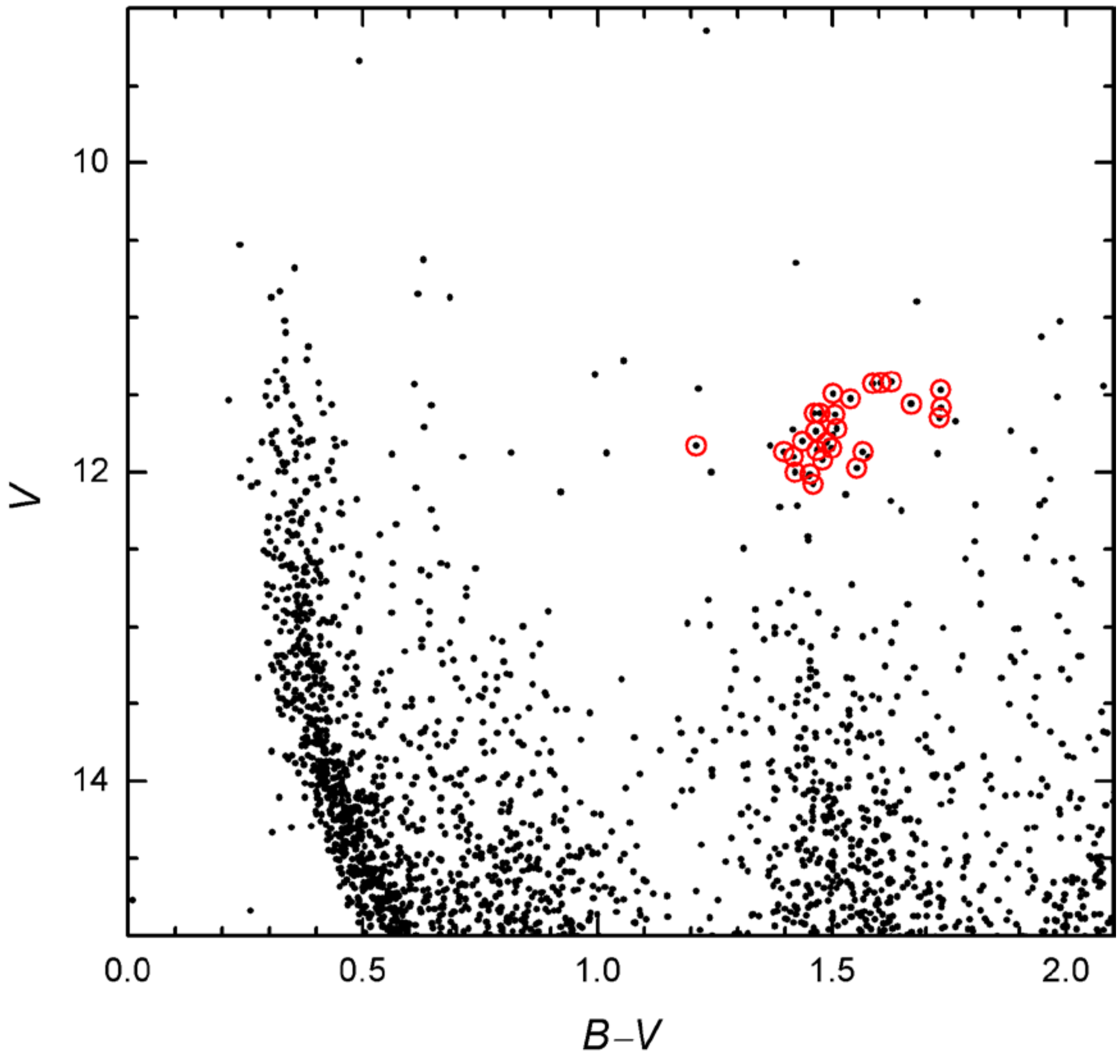
Trumpler 20

- 42 stars
- [Fe/H] = 0.10 ± 0.08
- a turn-off mass $1.9 \pm 0.1 M_{\odot}$



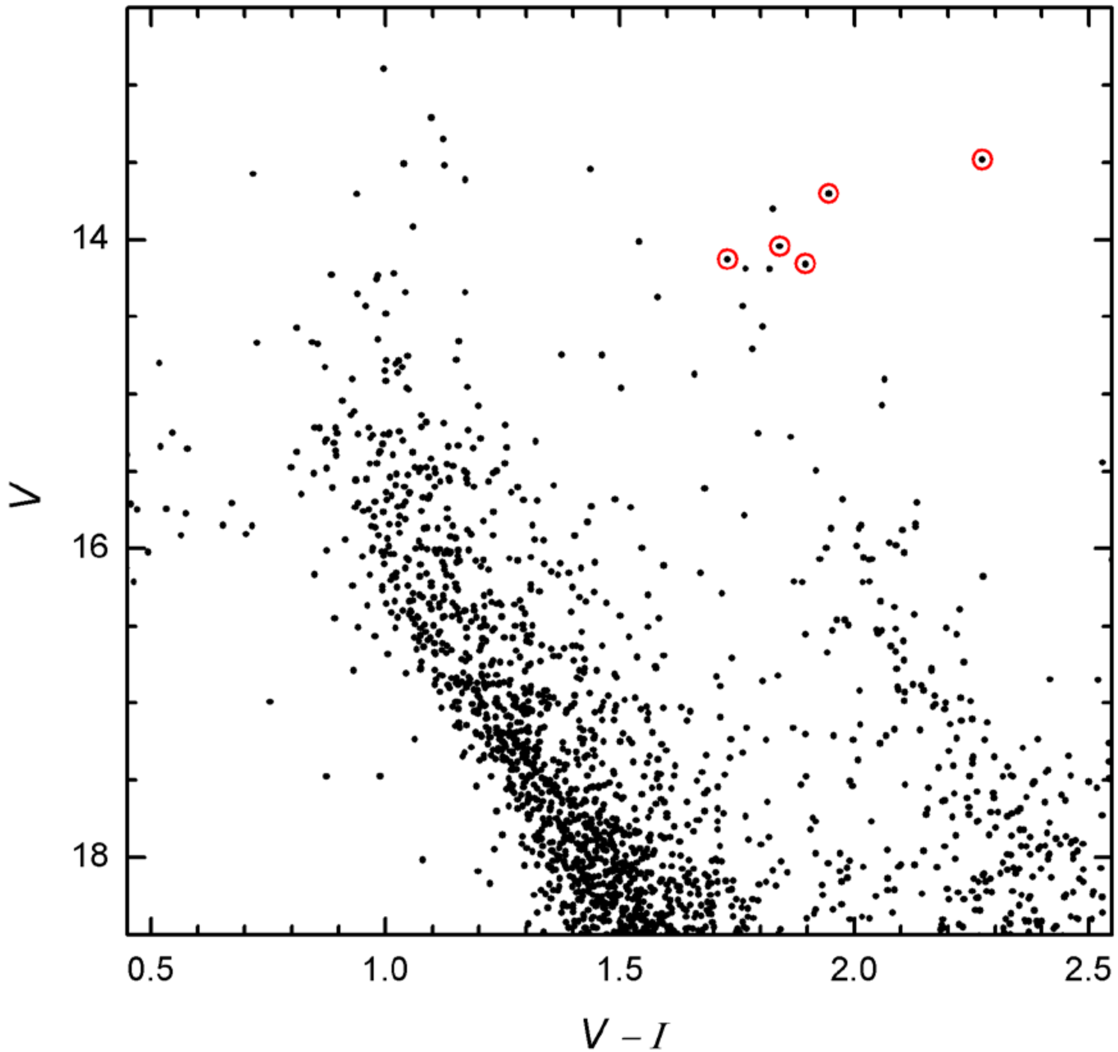
NGC 6705

- 27 stars
- [Fe/H] = 0.0 ± 0.05
- a turn-off mass $3.3 \pm 0.1 M_{\odot}$



NGC 4815

- 5 stars
- [Fe/H] = −0.01 ± 0.04
- a turn-off mass $2.6 \pm 0.1 M_{\odot}$

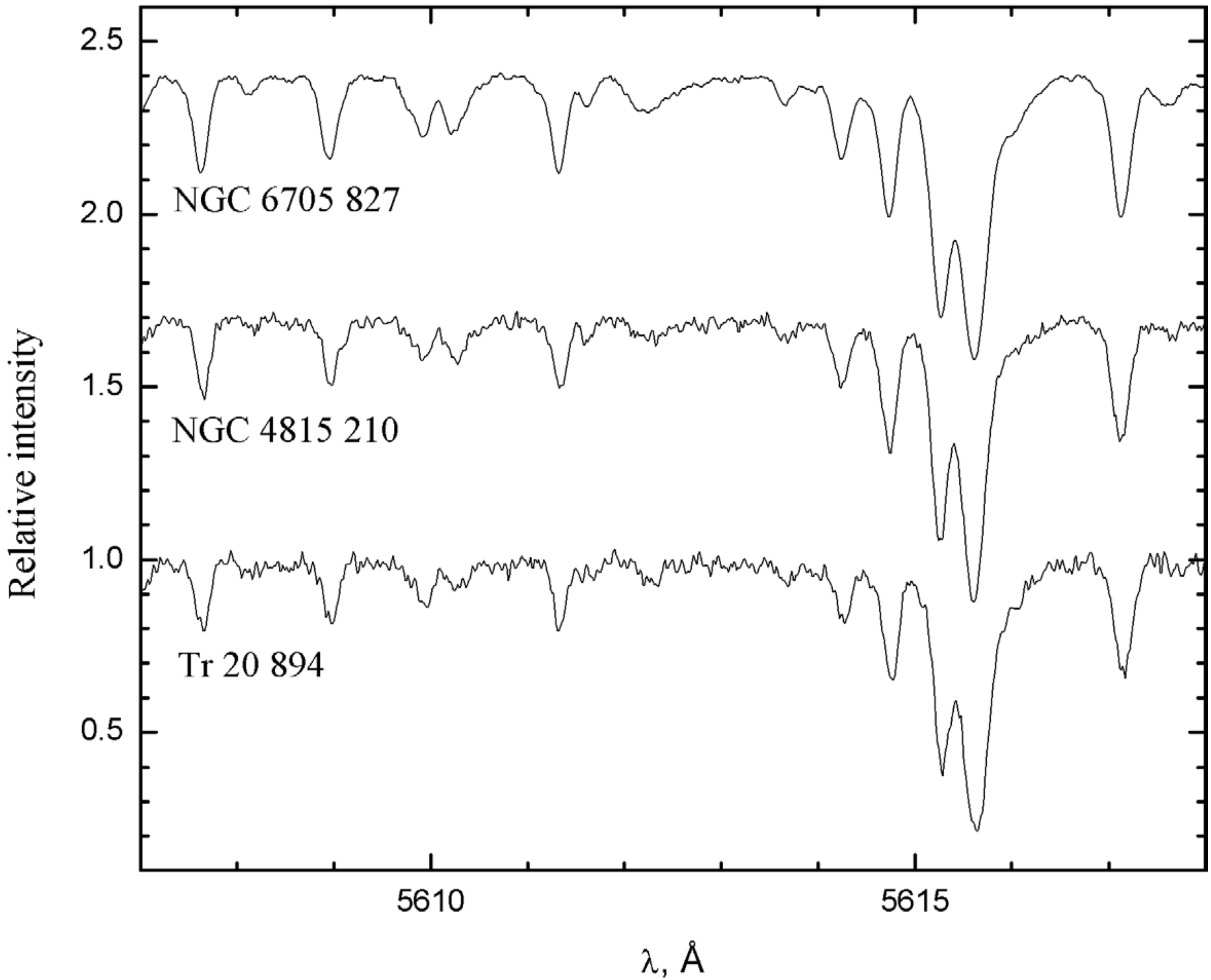


S/N

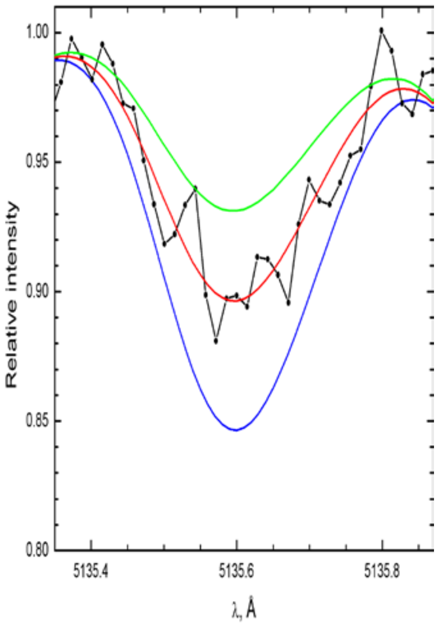
80-190

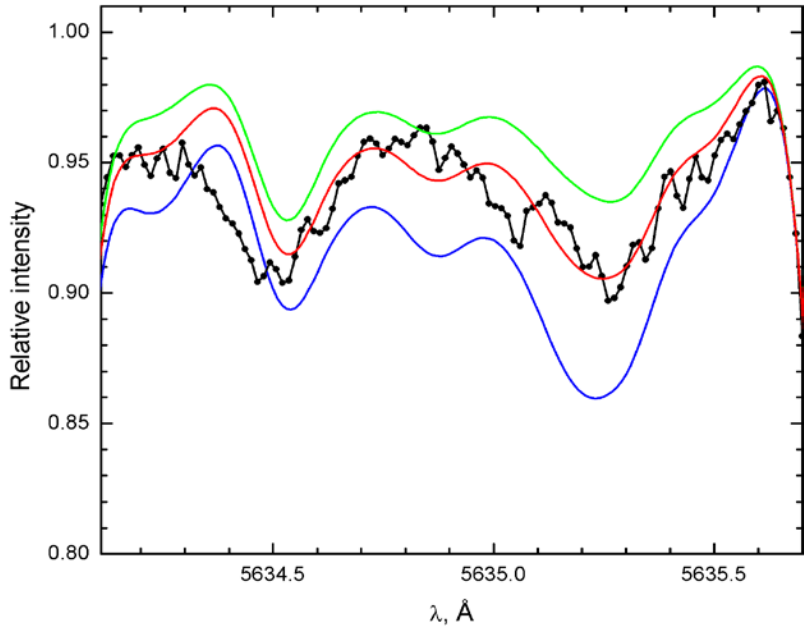
45-65

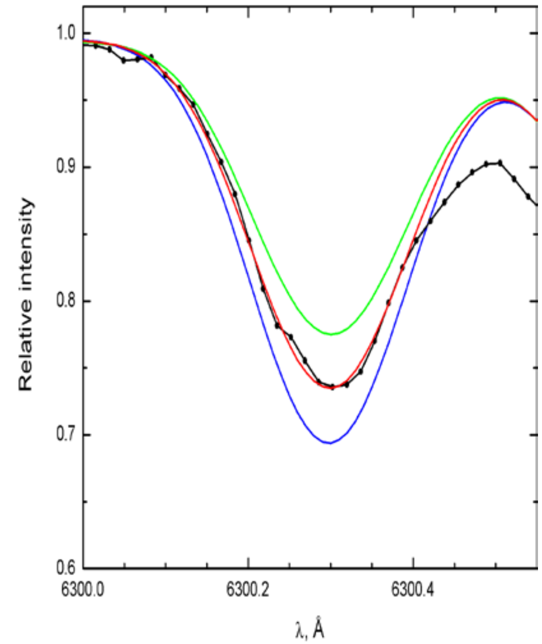
20-70



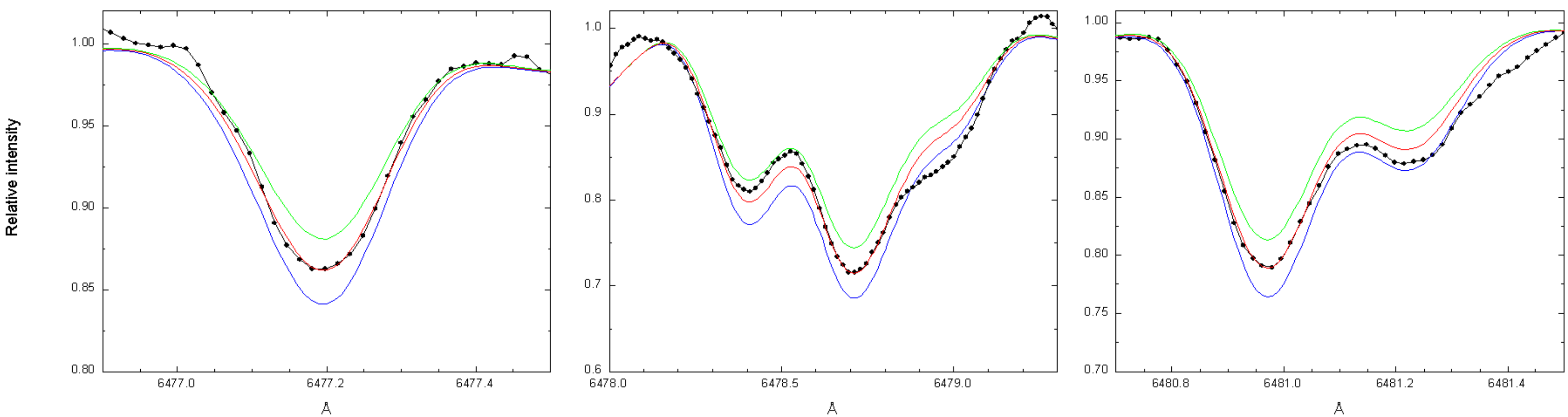
C 5135 NGC4815_358 C 5635 Tr20_63 O 6303 M11_779



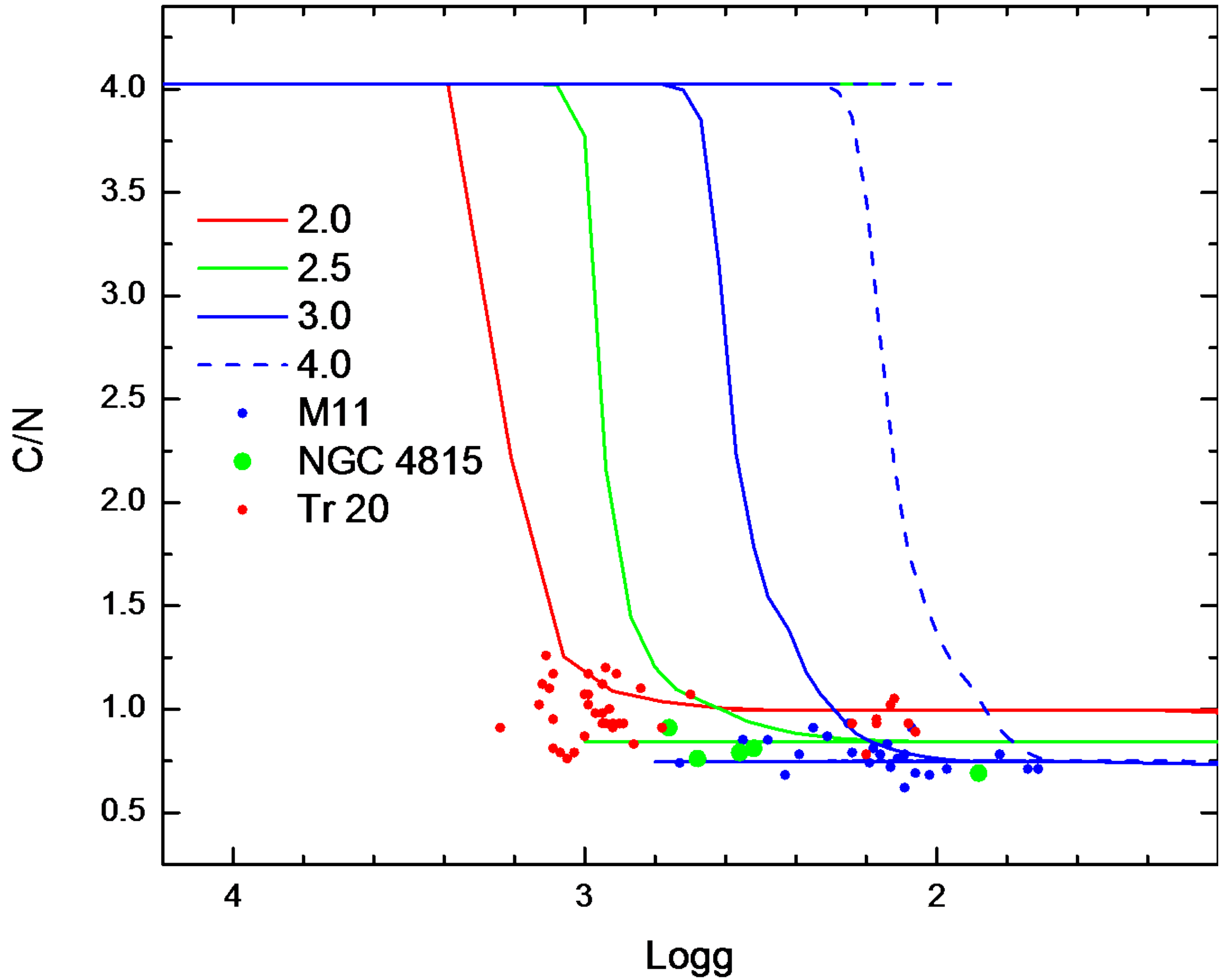




CN M11_1625



- We compared the C/N values with theoretical models by Charbonnel and Lagarde (2010), and Lagarde et al. (2012).
- Both models include 1st dredge-up and thermohaline-induced mixing. The model of Lagarde et al. (2012) includes rotation-induced mixing with thermohaline mixing acting together (rotation on the main sequence – 45 % of the crytical value).

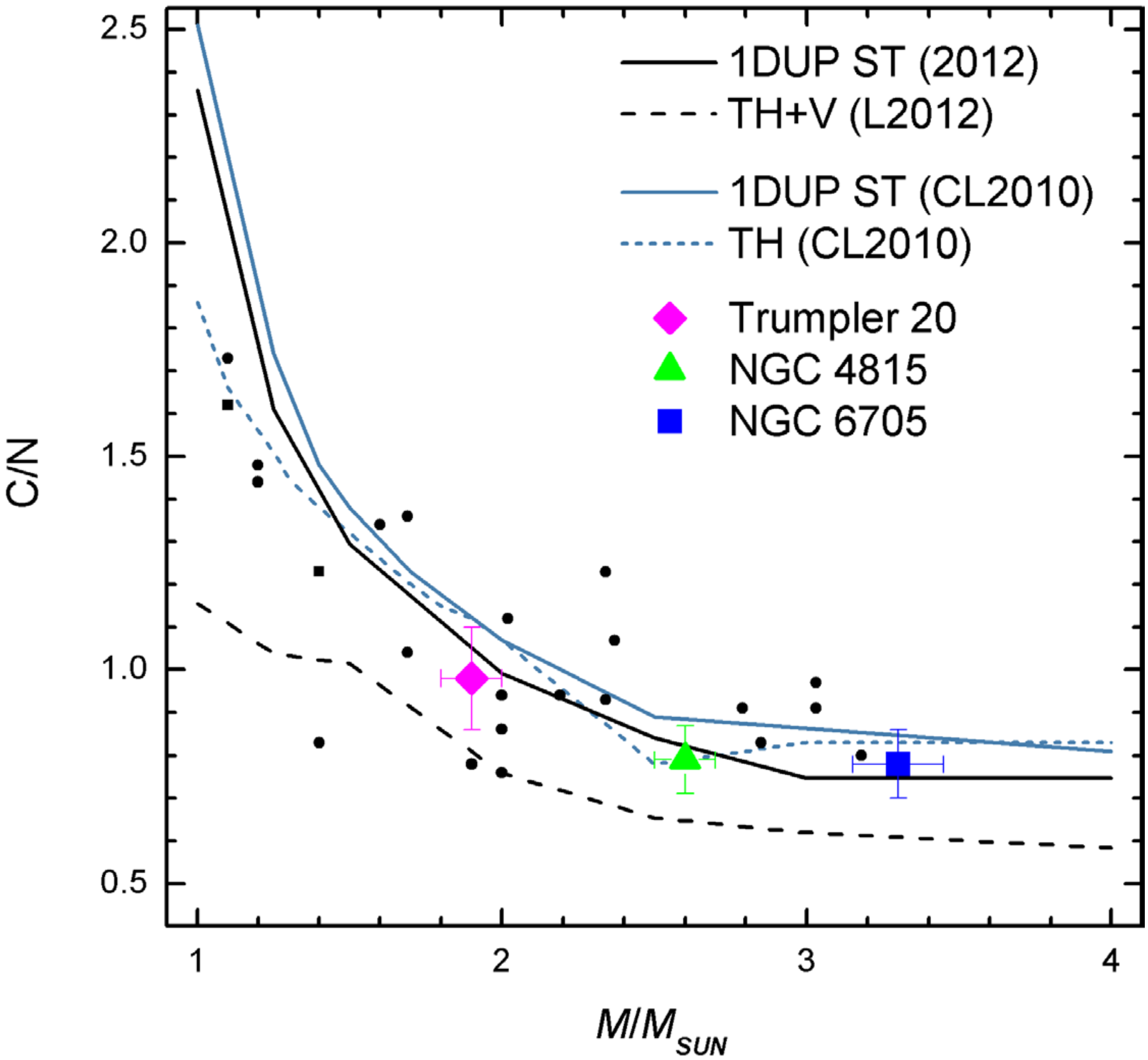


Lagarde et al. 2012
1st dredge-up

Mean C/N ratios: 0.98 ± 0.12 for Trumpler 20

0.79 ± 0.08 for NGC 4815

0.83 ± 0.19 for NGC 6705



1DUP ST (2012)
TH+V (L2012)
1DUP ST (CL2010)
TH (CL2010)
Trumpler 20
NGC 4815
NGC 6705
C/N
2.5
2.0
1.5
1.0
0.5
1
2
3
4
M/M_SUN

- GES results agree well with the 1st dredge-up and thermohaline-induced mixing models, and are not lowered as much as predicted in the model which includes thermohaline- and rotation-induced mixing acting together.

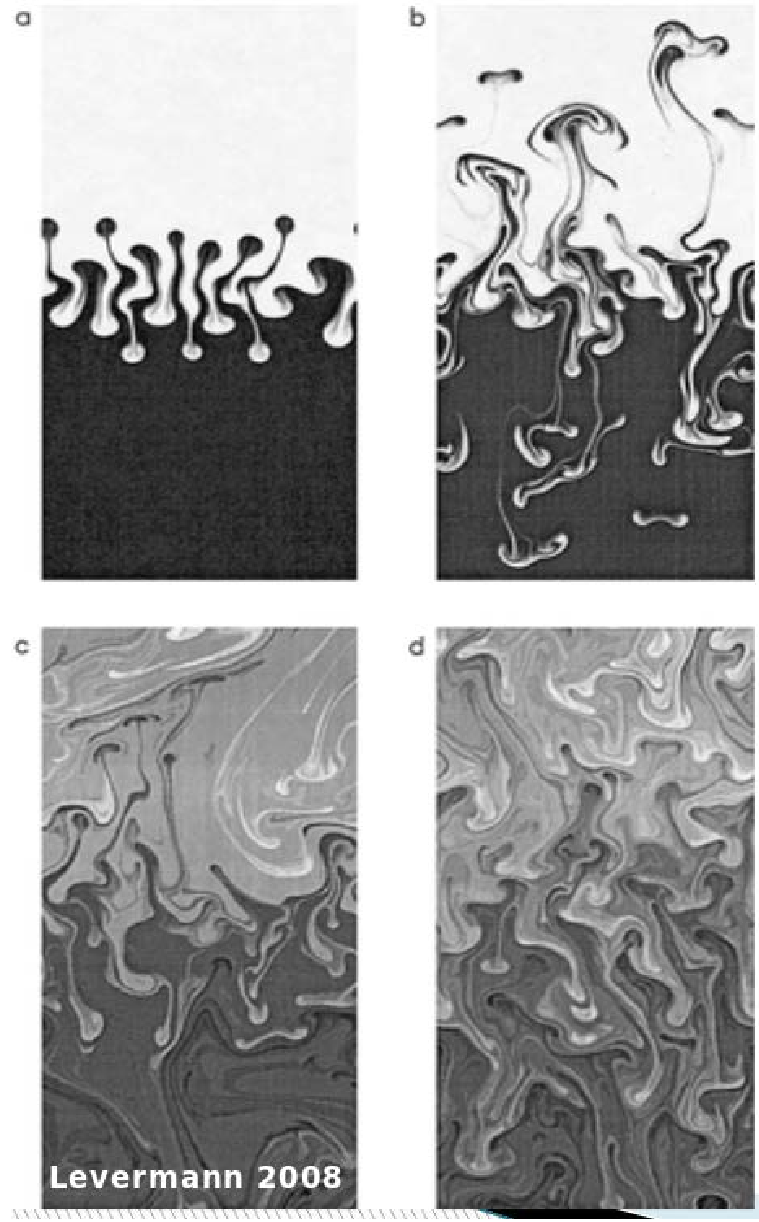
Further investigations

Thermohaline mixing

Rotation-induced mixing

Magnetic activity influence

Dependence on stellar mass, metallicity, and evolutionary stage



Conclusion

The first results of CNO determinations in open clusters show the large potential of the Gaia-ESO Survey to judge stellar evolution models