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Thermohaline Mixing and the CN Bimodality in M3

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1. Summary

Smith (2002) and Smith & Martell (2003) have compiled from various sources carbon and nitrogen observations along the giant branch of M3. This has provided us with a dataset to test our understanding of thermohaline mixing (see Eggleton, Dearborn, & Lattanzio 2006, 2008; Charbonnel & Zahn 2007). We match carbon depletion as a function of (absolute) visual magnitude for M3. We also include nitrogen as an extra tracer. We employ the same thermohaline prescription as Ulrich (1972), Kippenhahn et al. (1980), and Charbonnel & Zahn (2007), and we vary the dimensionless free parameter C_t. Kippenhahn et al. (1980) favour C_t= 12, corresponding to a slow, traditional "blob-like" kind of mixing. C_t= 1000 produces the faster mixing favoured by Charbonnel & Zahn (2007) and corresponds to finger-like structures with $\alpha \sim 6$.

In Figure 1a thermohaline mixing is excluded from the model. Canonical models produce very little carbon depletion following the first dredge-up (FDU). Figures 1b, 1c and 1d include thermohaline mixing. In each panel we provide four models representing different values of C_t, and hence the aspect ratio. We include: C_t= 12 as per Kippenhahn et al. (1980) (*dashed lines*); C_t= 1000 as per Charbonnel & Zahn (2007) (*solid lines*); C_t= 120 (*dot-dashed lines*); and C_t= 600, comparable to C_t= 658 of Ulrich (1972) (*dotted lines*). Figure 1b suggests that it is unlikely that M3 started off with a scaled solar CNO composition. In all globular clusters where the CN abundances have been investigated for stars at low luminosity, such as sub-giants, a CN bimodality has been present. This argues strongly for the spread being present in the stars at their birth. In Figure 1c we have altered the initial CNO abundance while keeping the metallicity constant so that the abundances match the CN-weak stars just before FDU. Here both of the faster mixing cases are a good fit to the data. The CN-strong stars show the result of hot H burning, including CN and ON cycling. We have therefore varied the initial helium abundance as well as the CNO ratios. Here a slower mixing produces

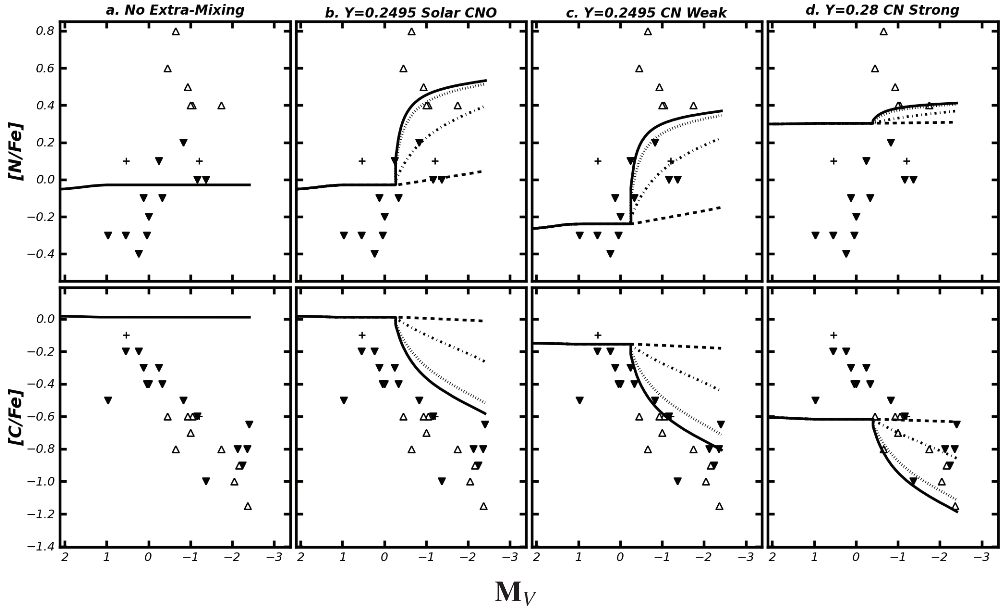

Figure 1. Here we compare our models to Smith's compilation of M3 observations. *Open triangles* denote CN-strong stars, *filled triangles* CN-weak stars, whilst the *crosses* represent stars of intermediate CN strength. Where extra mixing is included in our models, C_t= 12 (*dashed lines*), C_t= 120 (*dot-dashed lines*), C_t= 600 (*dotted lines*), C_t= 1000 (*solid lines*). In Figure 1c, the CN-weak models have X(C)= 5.45×10^{-5}, X(N)= 1.5×10^{-5} and X(O)= 2.86×10^{-4}. In Figure 1d the CN-strong models have X(C)= $1.90{\times}10^{-5}$, X(N)= $5.5{\times}10^{-5}$ and X(O)= $2.60{\times}10^{-4}$.

a good fit for the carbon abundance, whereas the faster mixing is able to account for the more extreme carbon values. These models are unable to match the more extreme nitrogen enhancements in the CN-strong stars. The most N-enhanced stars show evidence for ON cycling and their initial N abundance is due to this rather than the mixing we investigate here.

2. Conclusion

The variation of [C/Fe] and [N/Fe] with magnitude in M3 can be explained with thermohaline mixing, if it is assumed there is a spread of ~ 0.3 to 0.4 dex in [C/Fe] in the stars from their birth.

References

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