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OLD OPEN CLUSTERS AS A TEST FOR THE MIXING SCHEMES

F. Fagotto, G. Carraro

Department of Astronomy, University of Padova

Abstract

Two large grids of stellar models have been computed by Alongi et al (1991) with initial chemical composition Y=0.25 and Z=0.008. They differ only in the mixing scheme, i.e. either a local analysis of the convective instability leading to a total (local overshoot) and/or partial (semiconvection) mixing of the layers surrounding the convective core during the central He-burning phase (classical scheme), or a non local evaluation of the amount of matter overshooting from the instable regions, both the convective cores and the envelopes, during the entire evolutionary history of a star (overshooting scheme). In virtue of their homogeneity in all other physical assumptions, these models offer an unique opportunity to discriminate between the two mixing schemes. All previous attempts are biased by the fact that evolutionary models calculated by different authors were used. With the aid of the synthetic color-magnitude diagram (CMD) technique we study the CMD of two old open clusters, NGC 2420 and NGC 2506, and show that the models incorporating convective overshooting fit better the overall morphology of the observational CMD.

Introduction

The study of old open clusters is a subject of great interest to investigate the properties of the galactic disk, and in particular to trace back the history of disk formation (see Sandage 1988, Demarque et al 1991 for recents reviews on the subject). To this aim, the age calibration of stellar clusters is prelimary step.

In addition to this, the study of the color-magnitude diagrams (CMD's) and luminosity functions (LF's) of old open clusters allows us to test the adequacy and accuracy of stellar models in the mass range 1 $M_\odot$ to 2 $M_\odot$ (Maeder & Meynet 1991, Aparicio et al 1990).

Among others, the efficiency of the mixing processes occurring in real stars is nowadays a topic under vivid debate. There are two main evolutionary scenarios according to which mixing scheme is adopted, i.e. either the classical or the overshoot treatment of the extension of convective regions (see Chiosi et al 1991a,b for recent reviews on these topics).

In the classical scheme, the convective core during the central H-burning phase extends up to the layer where the Schwarzschild condition ($\nabla_R = \nabla_A$) is satisfied. On the contrary, during the Helium-burning phase, an increasing overadiabacity of the radiative temperature gradient sets in outside the border defined by ($\nabla_R = \nabla_A$) caused by the different opacity of the carbon rich-mixture inside the convective core with respect the carbon-poor mixture outside it (Schwarzschild 1970; Paczynski 1971; Castellani et al. 1971a,b). Early on during the He-burning, the steady increase (local overshoot) of the convective core caused by perturbations of the chemical composition in layers that are formally stable according to the Schwarzschild criterion, makes it possible to restore the Schwarzschild condition at the border of the core. However, in later stages, the region unstable to convection splits into an inner core and an outer shell. This structure is pictured by the formation of the so-called semiconvective region, i.e. a region of varying chemical composition in condition of adiabatic neutrality ($\nabla_R = \nabla_A$), surrounding a fully mixed convective core. The extension of the semiconvective region varies with stellar mass, being relevant in low mass stars and less important larger the stellar mass.

In the overshoot scheme the extension of the convective regions (inner core and envelope) is always determined by means of a non local theory of overshoot in which a certain amount of matter (usually a fixed fraction of the pressure scale height H_p beyond the Schwarzschild boundary) is supposed to become convectively instable.

1. Evolutionary Models

Two large grids of stellar models have been calculated by Alongi et al (1991) for both the classical and the overshoot scheme. These tracks have chemical composition Y=0.25 and Z=0.008, span the mass range from 0.6 $M_\odot$ to 100 $M_\odot$ and go from the main sequence up to either the stage of central carbon ignition or the beginning of the thermally pulsing AGB phase (TPAGB), according to the initial mass of the star. Two more grids for the chemical composition Y=0.28 and Z=0.020 are in preparation (Bertelli et al 1991). Detailed description of the physical assumptions in model calculations are given in Alongi et al (1991) to whom the reader should refer. In short, the nuclear reaction network contains sixteen elements; the reaction rates are taken from Caughlan and Fowler (1988); the neutrino emissions are from Munakata et al (1985); the Los Alamos Opacity Library (Huebner et al. 1977) provides the radiative and conductive opacities above a certain temperature ($T \geq 10^{4\,o}K$) while below this limit the opacity is from Cox and Stewart (1970); the molecular contribution to the opacity is included from analytical relationship by Bessel et al (1989, 1991); the mixing length parameter of the outermost convective layers is $1.5 H_p$. This value is chosen by imposing that the model star of 1 $M_\odot$ star with chemical composition (Y, Z)=(0.27, 0.017) matches the luminosity, effective temperature and radius of the Sun at the age of $4.6 \cdot 10^9$ yr. In addition to this, massive stars ($M \geq 20 M_\odot$) include the effect of mass loss by stellar wind and the revision of the radiative opacities according to Iglesias & Rogers (1991a,b). On the contrary, low and intermediate mass stars are calculated at constant mass, because mass loss during the RGA and AGB phases can be easily taken into account following the standard analytical procedure (Renzini 1977, Iben and Renzini, 1983) when constructing theoretical isochrones.

Let us just mention that these massive star models brought large advantages to the interpretation of the CMD of Galactic and LMC supergiant stars (Chiosi et al. 1991a,b). The main results of these calculations can be shortly summarized as follows. Stars in the mass range 0.6 $M_\odot$ to 0.9 $M_\odot$ do not experience convection during the central H-burning phase. With the classical mixing scheme, M_{HeF} and M_{up} fall in the range $2.1 M_\odot$ to $2.2 M_\odot$ and $7 M_\odot$ to $8 M_\odot$, respectively. With the overshoot scheme, these characteristic masses are in the range $1.7 M_\odot$ to $1.8 M_\odot$ and $5 M_\odot$ to $6 M_\odot$, respectively.

Since the consequences of this and the effects of both semiconvection and overshoot on stellar models (morphology and characteristic lifetimes of the main evolutionary stages) are well known (see Chiosi et al. 1991a,b for recent reviews of the subject), no description of the models will be presented here. In the following, we will limit ourselves to discuss the CMD of two old open clusters (turnoff mass in the range $1 M_\odot$ to $2 M_\odot$) in light of these evolutionary models.

2. Analysis of Two Old Open Clusters

The synthetic CMD technique (Chiosi et al 1989) is applied to interpret the observed CMD's of the two open cluster NGC 2420 (McClure et al 1978) and NGC 2506 (McClure et al 1981). During the RGB and AGB phases mass loss by stellar wind and "superwind" is included according to the prescription given by Bertelli et al (1990).

The synthetic CMD's are constructed imposing the same number of stars counted in a suitable magnitude interval of the observational CMD's and distributing the stars according to the evolutionary lifetimes and initial mass function (IMF). We adopt the Salpeter IMF with x = -1.35, a small age dispersion (10^7 yr.) and a certain pergentage of unresolved binary stars. These latter are supposed to amount to about 20 % of the total number of stars and to possess mass ratios in the range 0.8 to 1.25 with equal probability. The conversion from luminosities and effective temperatures into magnitudes and colors is from Buser (1989). The effect of photometric errors on the B and V magnitude are included according to the Robertson algorithm (1974).

The fit between the observational and synthetic CMD's is obtained by looking at the morphology and star counts in the turn-off region, the bottom of the RGB, and the clump of red stars (most likely core He-burners). Figure 1 shows the observational CMD's (top panels) and the synthetic CMD's obtained from the two evolutionary schemes (central and lower panels). Tables 1 and 2 contain the age, apparent distance modulus (m-M), color excess E_{B-V}, reddening $A_V = 3E_{B-V}$, and true distance modulus $(m\text{-}M)_o$ assigned to NGC 2420 and NGC 2506, respectively. The comparison of the observational CMD's with the theoretical simulations shows that the curvature of the main sequence near the turn off region and the distribution of stars in the Hertzsprung

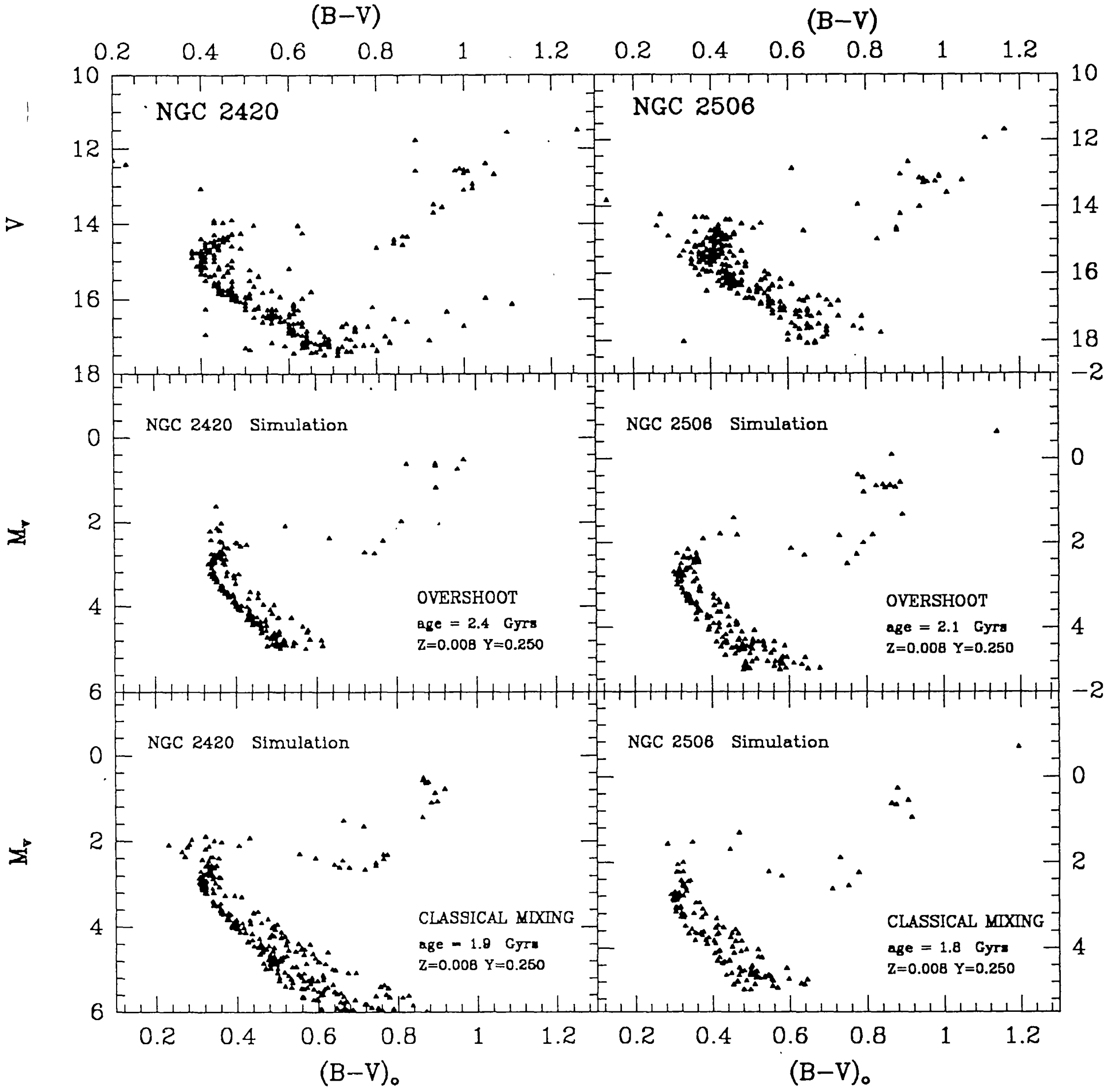

Fig. 1 - *Observational and synthetic CMD's of NGC 2420 and NGC 2506*

gap and at the bottom of the RGB are much better reproduced by models with convective overshoot. Many simulations have been performed in order to evaluate the effect of stochastic fluctuations, showing that the above features of the CMD's are robust and mainly depending on the underlying evolutionary scheme.

Table 1 $Z = 0.008$ $Y = 0.25$
NGC 2506

	Age	(m-M)	E(B-V)	$(m\text{-}M)_o$
Classical Scheme	1.80	12.60	0.09	12.33
Overshoot Scheme	2.10	12.60	0.07	12.35

Table 2 $Z = 0.008$ $Y = 0.25$
NGC 2420

	Age	(m-M)	E(B-V)	$(m\text{-}M)_o$
Classical Scheme	1.90	11.90	0.10	11.60
Overshoot Scheme	2.40	11.80	0.06	11.66

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