MODELS OF POPULATION SYNTHESIS

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Abstract. We present models of chemical and photometric evolution of galaxies. We show that the onset of the AGB phase at a few 10^8yr causes a sudden change in the infrared colours of the galaxy. However, this powerful indicator of the time of galaxy formation is wiped out by cosmological effects.

1. Introduction

The analysis of the spectrophotometric properties of star clusters and galaxies, with the aid of the standard technique of population synthesis, provides important clues on the primary questions related to the epoch of formation and the evolution of stellar aggregates of various complexity. Existing models of population synthesis can be subdivided in two groups depending on which way they are constrained to the stellar input (O'Connell 1986). In "Evolutionary Population Syntheses" (EPS), a particular theoretical scenario is used to populate the HR diagram and to compute the integrated properties, i.e. magnitudes, colors, and spectral energy distribution (SED) assuming a limited number of parameters (in addition to those already adopted for the underlying stellar tracks). In "Optimizing Models" (OM), the observed SED is matched by summing up SED's taken from a library of stars or clusters. The elemental SED's are suitably weighted by the matching procedure. The OM method allows for the inclusion of stellar types whose evolution is not yet fully clarified, but it heavily depends on the completeness of the libraries themselves. The EPS method may easily include the effect of different chemical compositions, but the quality of the final result depends on the accuracy and homogeneity of the input stellar models.
In this paper we describe a new method for EPS, which is based upon modern stellar models and isochrones (Alongi et al. 1991). First, we show how the isochrones can be used to construct integrated magnitudes and colors in broad band photometry for a single stellar population (SSP). Second, adopting a model of galactic chemical evolution, we follow the variation of magnitudes and colors of the model galaxy both as a function of time in its rest frame and of the red-shift. This analysis made with the broad band colors can be easily extended to narrow band SED.

2. Data Bases of Stellar Models

A good data base of stellar models must include modern physical input, extend to the latest evolutionary phases, e.g. AGB, PN, WD, cover large intervals of stellar masses and chemical compositions. Because of free parameters adopted in stellar model calculations (mixing length in the atmosphere, mass loss, mixing inside the core, etc...), the evolutionary tracks and lifetimes must be tested against color-magnitude diagrams (CMD) and luminosity functions (LF's) of template star clusters. In doing this, particular care must be payed to the transformation from luminosities and T_{eff} to magnitudes and colors.
Most libraries of stellar models currently in use are either incomplete or heterogeneous (in the sense that models from different sources are sampled). This often gives rise to

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spurious results as pointed out by Charlot and Bruzual (1990). Among the available data bases, the Yale tracks and isochrones are old and limited, while Bertelli's et al. (1986) data base in spite of its homogeneity and completeness up to the AGB phase for a wide range of initial masses and chemical compositions, was computed with old opacities. The models of Maeder and Meynet (1988, 1990) were computed with the most updated input physics, including the opacities from the Los Alamos Library (LAL), extended to massive stars, but did not include the late evolutionary phases (HB and beyond) of low mass stars. In addition to this, as noticed by Alongi et al (1991) and Stothers (1991), the core He-burning lifetime of these models are a factor of 2 to 3 longer than the values given by many other authors. Furthermore, Bertelli et al (1991) have clearly demonstrated that the core H-burning lifetimes for stars in the mass range 1.1 $M_\odot$ to 2 $M_\odot$ given by Maeder and Meynet (1988, 1990) are wrong by a large factor compared to the straightforward estimate obtained from the ratio of the available fuel to the luminosity of their own models. The most recent data base of evolutionary tracks was computed by Alongi et al (1991). These models and accompanying isochrones are briefly discussed by Bressan et al in this volume. The wide mass interval (0.6 $M_\odot$ to 100 $M_\odot$), the inclusion of late evolutionary phases (AGB), and the different initial chemical compositions (Z=0.02, Y=0.28; Z=0.008, Y=0.25; Z=0.001, Y=0.23; Z=0.1, Y=0.35) make these stellar models suitable for EPS studies. The evolutionary tracks by Alongi et al (1991) were tested, by means of the synthetic CMD technique, against old galactic open clusters, intermediate age clusters in the LMC, and young luminous stars both in the Galaxy and LMC. Finally, the effects of the new opacities (OPAL and OP projects) were also investigated albeit in a preliminary fashion. Since the enhancement (a factor of 3 for the solar abundance) found in the new opacities with respect to LAL occurs in the external layers (Log T $\simeq$ 5.3), the effects on the stellar models are small at least for the adopted chemical compositions. Work is in progress to include in the data base the PN and WD phases for intermediate and low mass stars, and the carbon burning phase for massive stars.

3. The Single Stellar Population

The integrated monochromatic flux from the stellar population of a galaxy of age T is defined as

$$F_\lambda(T) = \int_0^T \int_{M_L}^{M_U} S(m,t,Z)\, f_\lambda(m,\tau,Z)\, dt\, dm \qquad (1)$$

where S(m,t,Z) denotes the stellar birth-rate and $f_\lambda(m,\tau,Z)$ the monochromatic flux of a star of mass m, metallicity Z(t) and age τ=T-t. Separating S(m,t,Z) in the product of a function of time $\Psi(t,Z)$ (otherwise called the star formation rate SFR) and the initial mass function $\phi(m)$, the above integral becomes

$$F_\lambda(T) = \int_0^T \Psi(t,Z)\, f_\lambda(\tau,Z)\, dt \qquad (2)$$

where $f_\lambda(\tau,Z) = \int_{M_L}^{M_U} \phi(m)\, f_\lambda(m,\tau,Z)\, dm$ is the integrated monochromatic flux of a SSP with age τ and metallicity Z.

Although the algorithm is of general validity, in the following we present results limited to broad band magnitudes and colors. Extension to narrow band photometry to calculate SED's is underway. Integrated Johnson-Cousins U,B,V,R,I,J,K,L,M,N colours and magnitudes of SSP's are computed following the method described by Chiosi et al. (1988), and Bertelli et al. (1990). We adopt the Salpeter initial mass function with the normalization condition $\int_{M_L}^{M_U} \psi(m)\, dm = 1$.

Figure 1 (top panel) shows the temporal evolution of the integrated (B-V) and (V-K) colors for a SSP with assigned composition. The trend of the (B-V) color confirms what already pointed out by Chiosi et al (1988 and references therein). i.e. the lack of sudden changes in the color at the onset of the AGB and RGB phases, in other words the lack of the

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phase transitions advocated by Renzini & Buzzoni (1986). The trend of the theoretical (B-V) color well agrees with the observational data for LMC clusters (see Chiosi et al 1988). Since these new models of SSP extend to massive stars, another interesting feature is visible, i.e. the red peak in the colors in coincidence with the red supergiant phase of massive stars at about 10^7 yr. Remarkably, the AGB phase transition, that is invisible in (B-V), clearly shows up in the infrared colors (V-J), (V-K), (V-L), (V-M), (V-N), where a discontinuity of about one magnitude reveals the transition from massive to intermediate mass stars. See the case of the (V-K) color. The age at which the discontinuity occurs increases with the adopted amount of core overshoot and it is about 10^8 yr for mild overshoot. This feature is a good indicator of the SSP age. On the contrary, there is almost no sign of the transition to low mass stars (appearance of the RGB phase). There, the infrared colours run almost flat and consequently they become poor age indicators. Our data compare well with the infrared data for LMC clusters (Persson et al. 1983), considering that the finite number of bright red stars introduces significant dispersion in the observed colours (Chiosi et al 1988). Finally, while intermediate age star clusters suggest a metallicity $Z_\odot/2$, the oldest ones indicate Z=0.0004.

4. The Photometric Evolution of Galaxies

Once the integrated colors and magnitudes of SSP's are known as a function of time and chemical composition, and the initial mass function $\phi(m)$) is assigned, the integrated properties of a galaxy at the age T can be easily obtained from eq. (2), provided that the past history of $\Psi(t, Z)$ and metallicity Z(t) are known. Instead of assigning conventional analytical expressions to these quantities, we made use of the inflow model of galactic chemical evolution. developed by Chiosi (1981). In this model, all relevant physical quantities, i. e. gas mass, star mass, total mass, SFR, and metallicity are ultimately driven by the rate of mass accretion. This is expressed by $\dot{M}(t) = A \times e^{-\frac{t}{\tau}}$ where A is a normalization constant, τ is the timescale of the mass accretion process, and $M(t)$ is the current total mass of the system. The constant A is fixed by imposing that $M(t)$ is equal to the total mass $M(T_{GAL})$ at the galaxian age T_{GAl}. The time scale τ is a parameter. In Chiosi's (1981) model the rate of star formation is given by $\Psi(t, Z) = \nu \, [\frac{M(T_{GAL})}{M(t)}]^{k-1} \, [\frac{M_g(t)}{M(T_{GAL})}]^k$, where ν is an adjustable parameter, $M_g(t)$ is the current mass density of gas, and k comes from having included the Schmidt(1959) law in the derivation of the above SFR. For τ ($\rightarrow 0$) this law reduces to an initial burst of star formation, while for $\tau \rightarrow \infty$ it corresponds to an ever continuing star formation activity. In between there is an ample possibility for SFR's that started small, grew to a maximum, and then declined. Chiosi's (1981) model also allows for more complex SFRs, e.g. sporadic bursts or bursts superposed to a continuous star formation. The time scale τ and the coefficient ν are constrained by imposing that gas content, SFR, and metallicity match the observed present day values in a real galaxy (or part if it). Finally, the galaxian age T_{GAL} is fixed by adopting a particular model for the universe and a value for the red-shift of galaxy formation (H_0, q_0 and z_{for} in Friedmann universe).

5. The Color Evolution of Galaxies in Their Rest Frame

The EPS's were computed for a three groups of models characterized by different values of τ (0.1, 1, and 5 Gyr) at given values of q_0 and z_{for} hence age T_{GAL}. In their rest frame, all the model galaxies show a remarkable evolution of the magnitudes and colors in the various passbands. More precisely, unless τ is a significant fraction of the present galaxian age, in the past the magnitudes rose to a peak value about 3 to 4 mag brighter than seen at the present time. The peak tends to widen and appear later as τ increases. The variation in the infrared colors due to the onset of the AGB phase in the stellar component is still well visible (Figure 1, bottom panel) but instead of being sharply confined in time as it was for the SSP, now it spreads over a time scale of about 0.5 Gyr, being centered at at about 3×10^8 yr, almost independently of τ.

6. The Color Evolution of Galaxies at High Red-Shifts

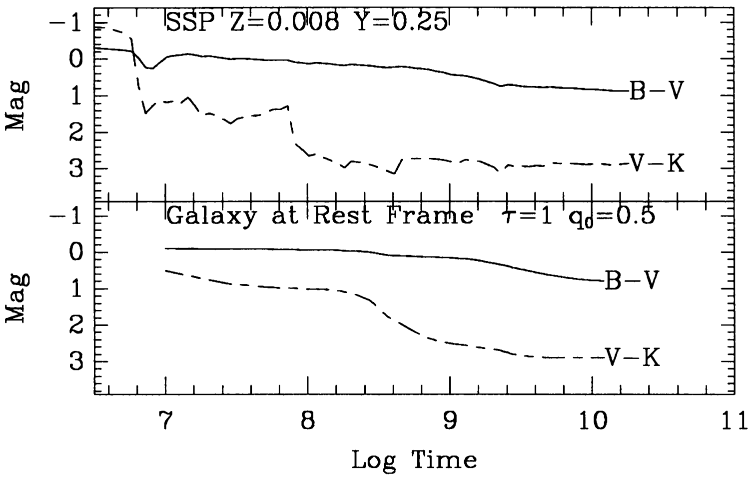

Fig. 1

Since the transition in the infrared colors is in principle a powerful indicator of the age of galaxy formation (let us remind that the transition in the rest frame occurs soon after the first generations of stars are borne, or in other words the galaxy has formed) we calculated the apparent magnitudes and colors as a function of the red-shift Z. To this aim, we derived the K- and E- corrections (Guiderdoni & Rocca-Volmerange 1987) as follows. Two ultraviolet colors were added to the available broad band colors and an analytical fit was applied to derive and to red-shift the SED. We are well aware that this is a crude approximation of the much more sophisticated models in which detailed SED's are used (see Guiderdoni & Rocca-Volmerange 1987). Nonetheless, in spite of the simple approach, we are able to show that the infrared colors lose memory of the phase transition that was visible in the SSP and whole galaxy at the rest frame. The cosmological effects wipe out this otherwise interesting age indicator.

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