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STATISTICAL SYNTHESIS MODELS

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RESUMEN

En este trabajo evaluamos la masa mínima de cúmulos estelares, $\mathcal{M}^{min}$, para la cual los efectos de muestreo de la Función Inicial de Masa (FIM) no pueden ignorarse. Esta $\mathcal{M}^{min}$ corresponde a la situación para la cual la luminosidad del cúmulo es igual a la luminosidad de la estrella individual más brillante incluida en el modelo, y toma valores entre 3×10^2 y 6×10^5 $M_\odot$ según la edad y la banda observada. Mostramos ejemplos para poblaciones jóvenes ($t < 10$ Ma) y viejas (t hasta 10 Ga). También hacemos pública la distribución espectral de energía (DEE) desde 160 μm (1.8×10^{12} Hz) hasta 25 keV (6.0×10^{18} Hz) para regiones de formación estelar con edades entre 0.1 y 10 Ma y metalicidades entre Z=0.001 y Z=0.040. Las DEEs están accesibles en nuestro servidor WWW e incluyen las cantidades necesarias para evaluar los efectos de muestreo de la FIM. Las DEEs pueden usarse tanto para la obtención de colores (incluyendo los de rayos X), como para entrada de modelos de fotoionización o para ajustes χ^2 de datos observados teniendo en cuenta la incertidumbre intrínseca en los modelos debida al muestreo de la FIM.

ABSTRACT

In this contribution we evaluate the minimal cluster mass for which the effects of an incomplete sampling of the Initial Mass Function (IMF) cannot be neglected. This minimal cluster mass corresponds to the situation in which the integrated luminosity of the cluster modeled equals the luminosity of the most luminous individual star included in the model, and it takes values between 3×10^2 and 6×10^5 $M_\odot$ depending on the age and the observed band. We show different examples for young ($t < 10$ Myr) and old (t up to 10 Gyr) stellar populations. We also make here a first release of the spectral energy distribution (SED) from 160 μm (1.8×10^{12} Hz) to 25 keV (6.0×10^{18} Hz) for star-forming regions with ages between 0.1 and 10 Myr, and metallicities between Z=0.001 and Z=0.040. The SEDs are available at our WWW server and include the corresponding quantities for the evaluation of sampling effects. These SEDs can be directly used to obtain colors (including the X-rays ones), as input of photoionization codes, or for χ^2 fitting with observed data taking into account the intrinsic uncertainty of the models due to the IMF sampling.

Key Words: **GALAXIES: STAR CLUSTERS — GALAXIES: STELLAR CONTENT — OPEN CLUSTERS AND ASSOCIATIONS: GENERAL**

1. THE NEED FOR A STATISTICAL MODELING

Evolutionary synthesis models have been extensively used since the work of Tinsley & Gunn (1976). Unfortunately, the limitations for their use have not been extensively studied. In this work we present the most basic limit for the use of standard synthesis models (those that assume a continuously populated Initial Mass Function, IMF). A more detailed study can be found in Cerviño & Luridiana 2003 (CL03, submitted).

Maybe, the most trivial limit for the usage of a synthesis model is the following one: *The total luminosity of the cluster modeled must be larger than the individual contribution of any of the stars included in the model.* This obvious statement defines a natural theoretical limit that has not always been considered when synthesis models are applied to real observations. Based on this limitation, we can establish a *Lowest Luminosity Limit* (LLL) for the application of synthesis models, which corresponds to *the situation where the integrated luminosity of the cluster modeled equals the luminosity of the most luminous individual star included in the model.*

Since the integrated luminosity scales with the initial amount of gas transformed into stars, $\mathcal{M}$, a minimal initial amount of gas transformed into stars, $\mathcal{M}^{min}$, can be inferred for the use of synthesis models. In clusters with masses below $\mathcal{M}^{min}$, sampling effects in the IMF cannot be neglected and a statistical modeling is needed. Even more, it can be demonstrated that even the results of synthesis models for clusters with $\mathcal{M} < 10 \times \mathcal{M}^{min}$ have an intrinsic relative uncertainty equal or larger than 10%.

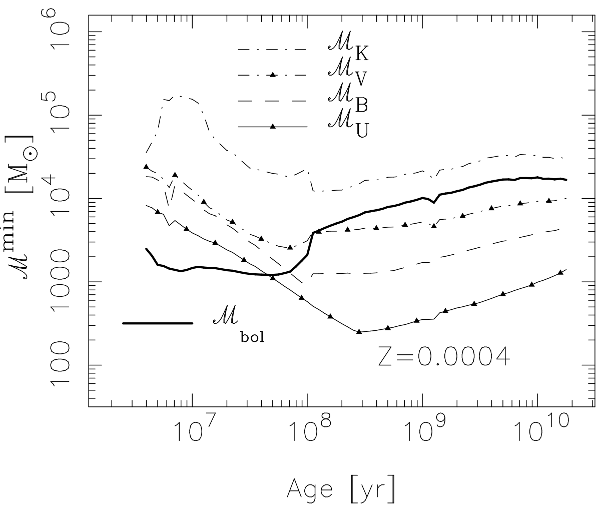

Fig. 1. $\mathcal{M}^{min}$ as a function of the age for different photometric bands.

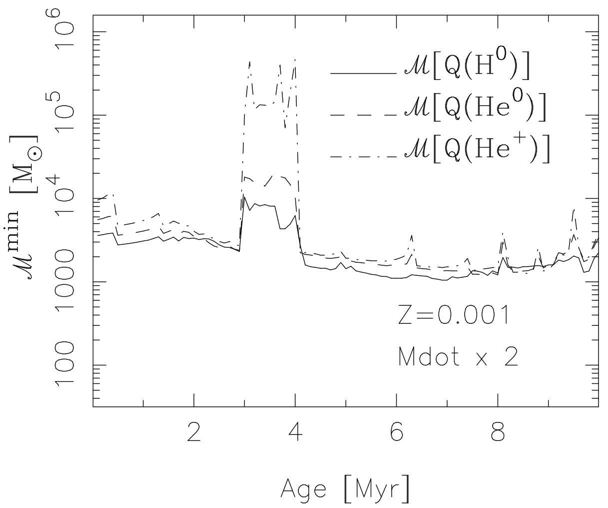

Fig. 2. $\mathcal{M}^{min}$ as a function of the age for ionizing photons above the H^0, He^0 and He^+ edges.

2. SOME EXAMPLES OF THE LLL

In order to illustrate how relevant this effect may be, we show in Fig. 1 the $\mathcal{M}^{min}$ values at different ages and photometric bands. In this case the $\mathcal{M}^{min}$ values have been computed from the isochrones by Girardi et al. (2002) with metallicity Z=0.0004, and simple stellar populations (or Instantaneous Burst, IB) results, and it is assumed a Kroupa (2001) IMF in the mass range 0.01 – 120 $M_\odot$.

In the case of young stellar populations (ages lower than 10 Myr) we show in Fig. 2 the $\mathcal{M}^{min}$ values corresponding to the number of ionizing photons above the H^0, He^0 and He^+ ionization edges. The $\mathcal{M}^{min}$ values correspond to models following a Salpeter (1995) IMF in the mass range 0.1 – 120 $M_\odot$ and they have been computed from a hybrid version of the codes by Cerviño, Mas-Hesse & Kunth (2002, CMHK02) and Leitherer et al.(1999) in order to both compute $\mathcal{M}^{min}$ and include the atmosphere models from Smith, Norris, & Crowther (2002). In the figure we use evolutionary tracks with high mass-loss rates from Meynet et al. (1994). X-ray emission has not been considered in this figure.

Note that, in the galactic context, the most massive OB association known, Cygnus OB2 (c.f. Knödlseder 2000), has transformed into stars $\sim 10^5$ $M_\odot$ of gas. Hence, the modeling of *normal* galactic and extragalactic H II regions, with a lower amount of gas transformed into stars, is potentially affected by sampling effects.

3. STATISTICAL SYNTHESIS MODELS

As we have seen before, the IMF sampling may play an important role in the determination of the evolutionary status of stellar clusters obtained via synthesis models. Some studies from a qualitative point of view can be found in, e.g., Cerviño, Luridiana, & Castander (2000), Bruzual (2002), and references therein. However, a quantitative theoretical formalism is needed to address this subject and apply the results to real data.

Examples of such kind of formalism can be found in Lançon & Mouhcine (2000), or in Cerviño et al. (2002). These last authors, based on the definition by Buzzoni (1989) of an effective number of stars, $\mathcal{N}$, evaluate quantitatively the sampling effects in stellar clusters. The formalism is completely valid for any age range and for quantities that scale linearly with $\mathcal{M}$. It also gives a first order estimation of the bias in the ratios or logarithmic quantities predicted by synthesis models when the sampling effects are quite important (Cerviño & Valls-Gabaud 2003), or, equivalently, when the observed cluster have $\mathcal{M}$ values close to the LLL (see CL03 for more details).

Now, we make here a first public release of the complete spectral energy distribution (SED) and the corresponding $\mathcal{N}$ values at each wavelength needed to evaluate the sampling effects. The results come from an improved and extended version of the synthesis code presented in Cerviño & Mas-Hesse (1994), and have been discussed in CMHK02. A first experimental public release of the code will be available in the following months.

The SEDs range from 160 μm (1.8×10^{12} Hz) to 25 keV (6.0×10^{18} Hz), for ages between 0.1 and 10 Myr and for metallicities between Z=0.001 and Z=0.040. They can be directly used to obtain colors (including the X-rays ones), as input of photoion-

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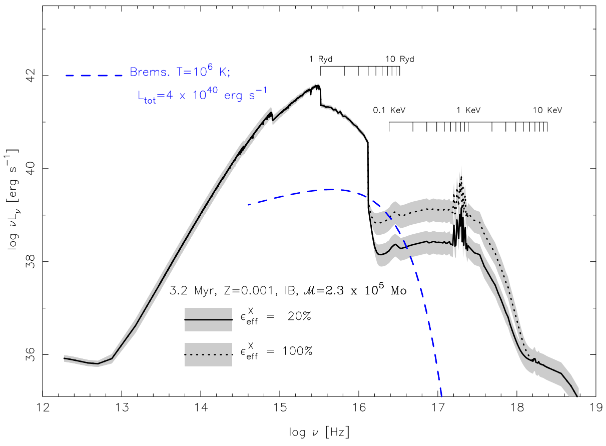

Fig. 3. Multiwavelength emission for a 3.2 Myr star-forming region with the corresponding 90% Confidence Limits. A bremsstrahlung component with 10^6 K and a total luminosity of 4×10^{40} erg s^{-1} is also shown for comparison.

ization codes, or for χ^2 fitting with observed data taking into account the intrinsic uncertainty of the models due to the IMF sampling. The data, together with the sampling effects for other observables, can be obtained in tabular form at:

`http://www.laeff.esa.es/users/mcs/SED/`

One of the most important features of our newly realesed SEDs is the extension in the X-ray domain. As an example of a possible application of this feature, we considered the work by Stasińska & Izotov (2003), who study the conditions needed to reproduce the observed sequences of low metallicity star-forming regions, address the difficulties that traditional models (the ones without X-rays) would find to reproduce at the same time *all* the observational constraints, and point out directions where one should go in order to find physical solutions to the problems encountered. Among other effects, they show that an additional high-energy component is needed to explain the observed trend in diagnostic diagrams, and, as an example, they use a bremsstrahlung spectrum with 10^6 K and a total luminosity of 4×10^{40} erg s^{-1} (Fig. 3, dashed line). Incidentally, this component corresponds actually to the type of *supersoft* X-ray sources observed by ROSAT (Rappaport et al. 1994). In Fig. 3 we show the multiwavelength emission predicted by our code for a 3.2 Myr star-forming region with Z=0.001 and $\mathcal{M}$=2.3×10^5 M$_\odot$ (i.e., $\mathcal{M}$=10^5 M$_\odot$ in the mass range 0.8 – 120 M$_\odot$, as in Stasińska & Izotov 2003) for different efficiencies of conversion of kinetic energy in X-rays. The kinetic energy included in our model is produced by stellar winds and supernovae (CMHK02), so it is totally self-consistent with the stellar population responsible for the ionization of the gas. The comparison between the bremsstrahlung component by Stasińska & Izotov (2003) and the high-energy portion of our spectrum shows that the availability of SEDs extending into the high-energy range might help to explain some observed features of stellar populations; more specifically, the newly released SEDs will give the opportunity to perform a more detailed analysis of the effects of X-rays in the optical emission line spectrum.

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