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EVOLUTIONARY POPULATION SYNTHESIS: THE EFFECT OF BINARY SYSTEMS

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RESUMEN

Presentamos un código de síntesis de población que incluye tanto estrellas simples como sistemas binarios. Con él deseamos reproducir la distribución espectral de energía, desde los rayos X a las ondas de radio, de las regiones de formación estelar. Se han considerado tanto la contribución normal de las estrellas, como los efectos derivados de la transferencia de masa, las supernovas y la energía cinética liberada en el medio interestelar. Discutimos brevemente los efectos de los sistemas binarios en la evolución de la población de estrellas WR, así como su influencia en la emisión en rayos-X.

ABSTRACT

We present population synthesis models including single and binary stars evolution. In addition to the contribution from normal stars, they take into account the effects related to mass transfer, supernovae and the kinetic energy converted in X-rays in order to reproduce the energy distribution of starburst galaxies, from X-ray to radio ranges. We discuss briefly the effects of binary system evolution on the Wolf-Rayet star population, as well as its impact on the predicted X-ray emission.

Key words: **GALAXIES: STELLAR CONTENT — STARS: BINARIES — STARS: FUNDAMENTAL PARAMETERS — STARS: GENERAL**

1. INTRODUCTION

The majority of available evolutionary synthesis models are based on the evolution of single stars (Mas-Hesse & Kunth 1991; Leitherer et al. 1992; García-Vargas et al. 1995). Moreover, they cover generally the radio to UV ranges, but not the X-ray domain. Only a few models include the effects of the presence of binary stars in stellar clusters, but they are usually matched to study "particular" stellar populations; e.g., Pols & Marinus (1994) or Popov et al. (1995).

The evolution of binary systems can affect strongly the evolution of the whole cluster of young massive stars. First, high mass binary systems might become very powerful X-ray emitters, together with supernova remnants. Moreover, mass transfer episodes in binary systems can alter significantly the population of massive stars at a given time, when compared to clusters with no binary systems. Together with supernovae explosions they can also contribute to heating the interstellar gas. The extended X-ray emission detected in star forming galaxies is apparently produced by thermal emission from shock-heated gas escaping the star forming region (Fabbiano 1989 and references therein).

We present here stellar population models including *single and binary* stars that take in account the effects of *momentum deposition* by winds, *supernova remnants* emission and *binary systems evolution* in order to reproduce the energy distribution of starburst galaxies *from X-rays to radio ranges.*

2. STAR FORMING REGION MODELS

The stellar population synthesis is based on the models developed by Mas-Hesse & Kunth (1991) and Cerviño & Mas-Hesse (1994) for single stars, which cover the radio–UV range. To incorporate the evolution of binary stars, we have assumed basically that each component in the binary system evolves like a normal star

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until the system suffers mass-transfer episodes. In this contribution we will discuss only the effects of binary systems evolution on the resulting high–energy continuum (soft to hard X-rays) and on the population of WR stars. A more detailed discussion, together with the basic inputs for binary and single stars, will be presented in Cerviño, Mas-Hesse, & Kunth (1996). We want to stress here only that the distribution of masses in the binary systems results from the same MonteCarlo procedure we use to fill completely the Initial Mass Function.

3. RESULTS

3.1. Hard X-Rays (2–10 keV): The Influence of Binary Systems on the X-Ray Emission

High mass X-ray binaries (HMXRB) are heavy emitters in the *hard X-ray* range (Griffiths & Padovani 1990). We have first examined the influence of the percentage of stars formed in binary systems on the total X-ray emission. As shown in Figure 1, the occurrence of only 10% of binary systems in the Star Forming Galaxy (SFG) increases the X-ray emission by more than two orders of magnitude in the hard X-ray range (2–10 KeV).

3.2. Soft X-Rays (0.1–3.5 KeV): The Influence of the Deposition of Momentum

We show in Fig. 1 the upper and lower envelopes predicted by our models for the νL_ν(0.1–3.5 KeV) over νL_ν(1450 Å) ratio (νL_ν *(X)* / νL_ν *(UV)*). Observational points are from Mas-Hesse et al. (1995) and they correspond to galaxies dominated by star formation processes (since no extinction correction has been applied to the UV emission, the plotted ratios should be considered as upper limits. Reddening corrections would lower the ratios by around a factor 3–4 in the worst case). From the figure it can be seen that all SFG fall in the range predicted by the models with only moderate efficiencies needed for the conversion of kinetic energy of the gas into X-ray emission. Note that in any case some amount of kinetic energy injected into the interstellar medium *must be* converted to X-ray emission in order to explain the observational data. Stellar contributions alone underestimate severely the observed emission in the majority of the cases. Studies of SFGs show indeed that most of the soft X-ray emission component in these objects is extended and related with "super-winds" and "super-bubbles".

We have also plotted in this figure the histograms for this ratio with values taken from Mas-Hesse et al. (1995) for SFGs and Seyfert (1 and 2) galaxies. It is clear from the plot that the soft X-ray emission from Seyfert 1 galaxies is above the predictions of our models, as expected. On the other hand, the case of Seyfert 2 galaxies is more controversial: some of them fall in the region predicted for starbursts (including NGC 1068!!), but some others show a clear X-ray excess. These properties are probably related to the different relative contributions of starbursts and an active source in these galaxies, as concluded by Mas-Hesse et al. (1995).

In any case, we want to stress that *the models compute only the "persistent contributions"*. Transient sources like Be systems or SN explosions may increase the X-ray emission in these galaxies, but only during very short periods of time, giving rise to some degree of variability.

3.3. WR Stars Formed in Binary Systems

Our models follow up the evolution of binary systems after the Roche Lobe Overflow (RLOF) phase. They predict the formation of WR binary stars at ages when *single* stars population models do not. This is due to the fact that "binary WR stars" can be formed when the primary star of the binary system reaches the (Red)-Supergiant phase and RLOF occurs (Vanbeveren 1991, and references therein). This process leads to a "store" of high mass stars: WR-binary stars and stars that have gained mass and become therefore new high mass stars. One of the most interesting results is that the models predict that WR stars will be present in the cluster up to around 15 Myr (!) after an Instantaneous Burst, and not only during the first 5 Myr as single stars models predict, in good agreement with the results of Vanbeveren (1996). We want also to stress that the *rôle* of the metallicity is important in the formation of WR via RLOF as shown in Figure 1.

4. CONCLUSIONS

Evolutionary synthesis models including binary systems are essential to study the X-ray emission of starburst galaxies. HMXRB are specially relevant in the *hard X-ray* range.

The kinetic energy injected in the Interstellar Medium plays a fundamental *rôle* in the *soft X-ray* emission in SFG. In general, the soft X-ray emission is well reproduced, assuming that less than a 50% of the kinetic energy is reprocessed as X-rays.

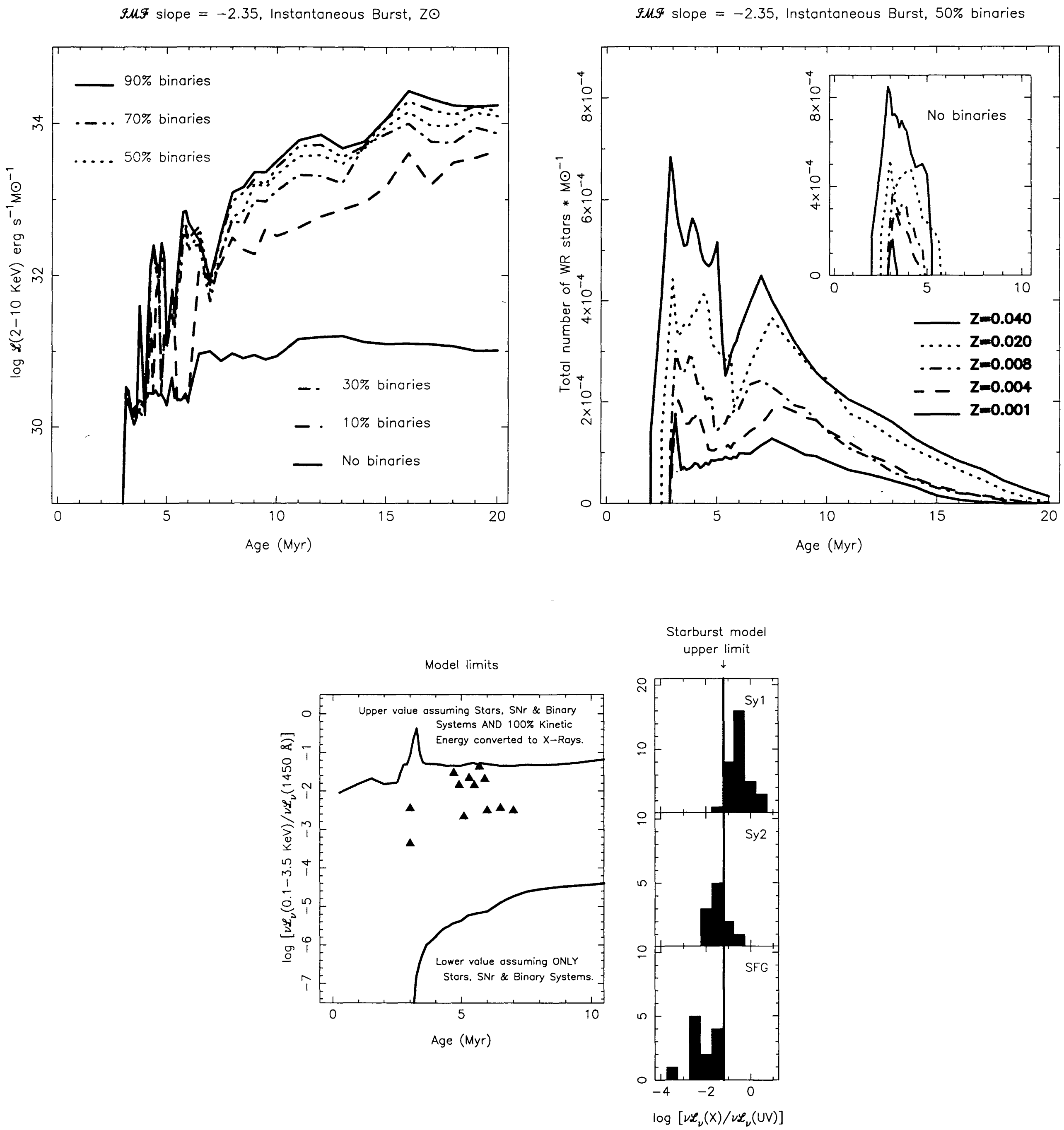

Fig. 1. Synthesis models results. *a)* X-ray luminosity in the 2–10 keV band (models computed with solar abundances, Salpeter IMF, and instantaneous star formation rate). Each line corresponds to different binary percentage, from 0 to 90%. *b)* Ratio of soft X-ray emission (0.1–3.5 KeV) to UV emission (1450 Å). Left: Upper and lower limits for the soft X-ray emission (upper line assumes that the stellar kinetic energy and SN explosions are released in the soft X-Ray band, lower line considers the emission from SNr, HMXRB and stars only). Right: Soft X-ray emission vs. UV emission histograms for different types of "active galaxies". Vertical line is the upper limit of $\nu L_\nu(X)/\nu L_\nu(UV)$ from our starburst synthesis models. *c)* WR population: normalized to the mass of stars formed from the onset of the burst. The WR population includes binary models assuming a binary frequency of 50%. The small box shows WR population results assuming only single stars.

Our standard starburst models compute only the **permanent** X-ray emission. The inclusion of X-ray transient systems (Be-like systems, showing "bursts" of X-ray emission, and SN explosions) may lead to the prediction of some degree of variability in starburst galaxies.

Binary stellar population synthesis models predict a WR population that spans over a wider range of ages than single stars models. This result must still be confirmed by the study of stellar statistics and age, IMF, star formation rate and metallicity of SFGs. Our models also predict that the metallicity plays an important *rôle* in the formation of WR stars by the binary channel.

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