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Cosmic star formation history: pure luminosity vs number galaxy evolution

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We study the evolution of the cosmic star formation in the universe by computing the luminosity density (in the UV, B, J, and K bands) and the stellar mass density of galaxies in two reference models of galaxy evolution: the pure-luminosity evolution (PLE) model developed by Calura & Matteucci (2003) and the semi-analytical model (SAM) of hierarchical galaxy formation by Menci et al. (2002). Our results suggest that at low-intermediate redshifts (z< 1.5) both models are consistent with the available data on the luminosity density of galaxies in all the considered bands. At high redshift the luminosity densities predicted in the PLE model show a peak due to the formation of ellipticals, whereas in the hierarchical picture a gradual decrease of the star formation and of the luminosity densities is predicted for z> 2.5. Both scenarios allow us to fit the observed stellar mass density evolution up to z=1. At z>1, the PLE and SAM models tend to overestimate and underestimate the observed values, respectively.

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1. Introduction

The two main competing scenarios of galaxy formation propose rather different conditions for the formation of spheroids. In the first scenario, ellipticals and bulges formed at high redshift (e.g. $z > 2-3$) as the result of a violent burst of star formation (SF) following a "monolithic collapse" (MC) of a gas cloud. After the main burst of SF, the galaxy gets rid of the residual gas by means of a galactic wind and it evolves passively (Larson 1974, Matteucci 1994) . On the other hand, the hierarchical clustering (HC) picture is based on the Press & Schechter (1974) structure formation theory, which has been developed mainly to study the behaviour of the dark matter. According to this theory, in a Λ-Cold dark Matter (ΛCDM)-dominated universe, small DM halos are the first to collapse, then merge to form larger halos. In this framework, massive spheroids are formed from several merging episodes occurring throughout the whole Hubble time. Massive galaxies reach their final masses at more recent epochs than less massive ones ($z \leq 1.5$, White & Rees 1978, Menci et al. 2002). In this contribution, our aim is to infer whether, starting from the current observational data for the galaxy luminosity density (LD) in various bands, it is possible to discriminate between the two main galaxy formation pictures. Throughout the paper we use a ΛCDM cosmological model characterized by $\Omega_0 = 0.3$, $\Omega_\Lambda = 0.7$ and $h = 0.65$.

2. The pure-luminosity and semi-analythical models

The PLE model developed by Calura & Matteucci (2003, CM03) consists of chemical evolution models for galaxies of different morphological types (ellipticals, spirals, irregulars), used to calculate metal abundances and star formation rates (SFRs), and by a spectro-photometric code used to calculate galaxy spectra, colors and magnitudes. According to the main assumptions of CM03, in elliptical galaxies the SF is assumed to halt as the energy of the ISM, heated by stellar winds and supernovae explosions, balances the binding energy of the gas. At this time a galactic wind occurs, sweeping away almost all of the residual gas (see A. Pipino, these proceedings). For spiral galaxies, the adopted model is calibrated in order to reproduce a large set of observational constraints for the Milky Way galaxy (Chiappini et al. 2001, F. Matteucci, these proceedings). Finally, irregular galaxies accrete gas through continuous infall and form stars at lower SFRs than ellipticals and spirals (i.e. $\ll 1 M_\odot/yr$). For the galaxy luminosity function, we assume a Schechter (1976) form, and we assume that the galaxy number density and faint-end slope is constant in space and time, whereas the characteristic magnitude varies according to the amount of SF and to the ageing of the stellar populations, computed self-consistently by means of a photometric code (see below).

In the SAM by Menci et al. (2002), the galaxy mass distribution is derived from the merging histories of the host DM haloes, under the assumption that, in each halo, the galaxies coalesce into a central dominant galaxy if their dynamical friction timescale is shorter than the halo survival time. The histories of the DM condensations rely on a well established framework (the extended Press & Schechter (1974) theory). The SAM includes the main dynamical processes taking place inside the host DM halos, namely dynamical friction and binary aggregations of satellite galaxies. The evolution of the galaxy mass distribution is calculated by solving numerically a set of evolutionary equations (Poli et al. 1999).

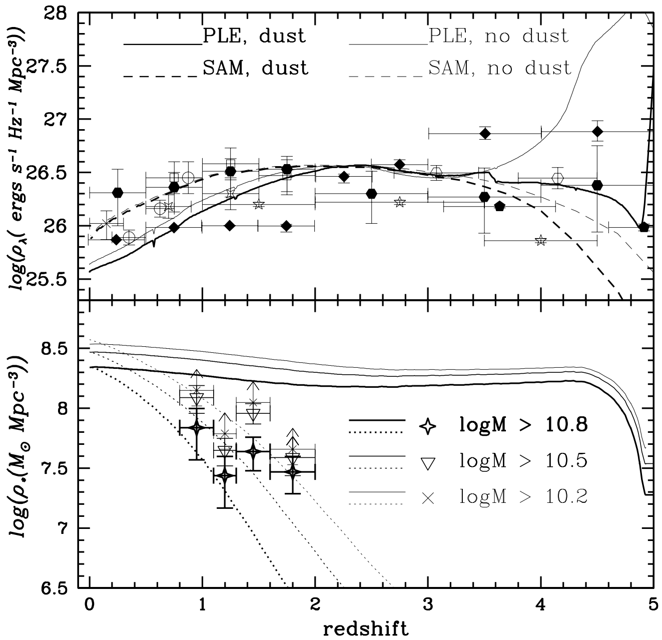

Figure 1: Upper panel: redshift evolution of the UV luminosity density as observed by various authors (see CMM04) and as predicted by the SAM and PLE models (see text for details). Lower panel: observed and predicted redshift evolution of the stellar mass density according to the PLE (*solid curves*) and SAM (*dotted curves*) by considering all the stars in galaxies with masses above three mass-cuts (see text for details).

The baryonic content of the galaxy is divided into (1) a hot phase, (2) a cold phase and the stars (3), forming from the cold phase on a time scale τ_*. In both cases, we compute galaxy spectra and luminosities by means of the spectrophotometric code developed by Bruzual & Charlot (2003), and we take into account the effects of metallicity and dust extinction (Calura, Matteucci & Menci 2004, CMM04). For all galaxies, we assume a standard Salpeter stellar initial mass function.

3. Results

In this contribution, we show only the results of the study of the UV LD. For the studies in other bands, see CMM04. In figure 1, upper panel, we show the redshift evolution of the rest-frame UV LD, as predicted by the PLE (solid curves) and SAM models (dashed curves). The thick (thin) curves are calculated with (without) taking into account dust extinction. Without dust corrections, in the UV band the PLE scenario predicts a strong peak at redshift > 4. This peak is due to the massive starbursts in spheroids, absent in the HC scenario. On the other hand, it vanishes when dust is taken into account, and the PLE predictions become consistent with the observations. This means that, as suggested by CM03, if the bulk of the SF in the high-redshift universe occurred in sites highly obscured by dust, most of it would be invisible for rest-frame UV surveys (see also Franx et al. 2003).
The SAM curve shows a broad peak, centered at redshift ~ 2.5. At redshift < 1, the curve from the SAM is constantly higher than the PLE one. This reflects the fact that the SAM model predicts

a higher amount of star formation occurring at $z < 1$ than the PLE curve. This is mainly due to the contribution of small-mass galaxies, which retain a relevant fraction of their gas down to small z, while the massive galaxy population, originated from clumps formed at high z in high-density regions, has already consumed most of the available cold gas reservoir. At redshift > 4, the dust-corrected prediction from the hierarchical model is critical: the unobscured UV LD (and hence the amount of SF) is probably underestimated by the SAM by a factor of 3 or more, although the scatter in the data is too large to draw firm conclusions. At those z, some fundamental process must be at work, such as bursts of SF with a rate higher than that predicted by standard SAMs (e.g. interaction-triggered starbursts in massive halos, see Menci et al. 2004). All the energy absorbed in the UV band should be reemitted in the IR/submm bands, where emission by dust grains is very strong. For this reason, to probe the existence of the SF peak due to the spheroids, the study of the IR/submm LD would be of primary interest. The lower panel of figure 1 shows the predicted redshift evolution of the stellar mass density according to the PLE (solid curves) and SAM (dotted curves) and by considering all the stars in galaxies with masses above three mass-cuts, namely $M > 10^{10.2} M_{\odot}$ (thin lines), $M > 10^{10.5} M_{\odot}$ (middle lines) and $M > 10^{10.8} M_{\odot}$ (thick lines). The data are from Glazebrook et al. (2004). The adoption of the mass cuts is very helpful in establishing a full correspondence between observations and theoretical predictions, and to have a clearer picture of the number of massive galaxies that the PLE and hierarchical scenarios predict at any redshift. In general, we notice that the PLE and hierarchical pictures tend to overestimate and underestimate the stellar mass at $z > 1$, respectively.

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