The evolution of quiescent galaxies at z > 1.4

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Abstract:

We have analyzed an IRAC ($mag_{3.6\mu m}$< 22.0) selected sample of ~18000 galaxies to study the evolution of high redshift (z >1.4) quiescent galaxies in the COSMOS field. Galaxies have been divided according to their star-formation activity and the evolution of the different populations, in particular of the quiescent galaxies, has been investigated in detail. We have derived accurate photometric redshifts and other physical parameters (masses, ages and star formation rates) through a SED-fitting procedure to compute the galaxy stellar mass function (GSMF) of the total sample and the different populations at z=1.4-3.0. We find that z ~ 1.5 is an epoch of transition of the GSMF, as quiescent galaxies, rather than star-forming, start to dominate the GSMF at lower redshifts. Finally, we have studied in detail the properties of the quiescent galaxy population, by comparing their fraction, as a function of redshift, with the predictions of different theoretical models and finding that already at z~2.5 there is a significant number of passive sources (log $\rho_{quiescent}$ (z~2.5)~ 6.0 $M_\odot Mpc^{-3}$).

1. Data

Our reference catalog is the 3.6-µm IRAC selected one (Sanders et al. 2007). The magnitude limit assumed is 22.0 mag. We have cross-correlated the IRAC catalog with the optical catalog (Capak et al. 2007) by means of the likelihood ratio technique. When no optical identification was found, we matched the sources with the K_s-band COSMOS catalog (McCracken et al. 2010). We also performed the match with the 24-µm MIPS catalog (Le Floc'h et al. 2009).

2. Final catalogue

74742 IRAC sources

95% Optically detected

4.5% Not detected in the optical, detected in the K_s band

0.5% Not detected neither in the optical nor in K_s band

14% MIPS detected

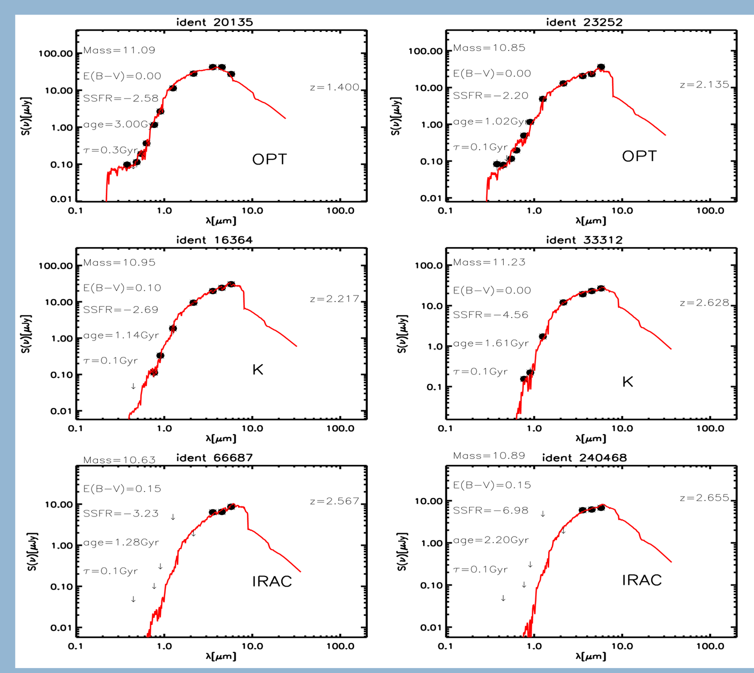

Fig 1.SED-fitting of some high redshift quiescent galaxies. Also shown the main physical parameters derived through the SED-fitting procedure.

3. Photometric redshifts and galaxy stellar masses

We computed the photometric redshifts (z_p) with the *Lephare* code (Arnouts et al. 2001, Ilbert et al. 2006) using the multi-band u* - 24µm catalog. We used elliptical (Ell) and spiral (S) galaxy templates from Polletta et al. (2007), blue galaxy templates (BC) from Bruzual & Charlot (2003) and simple stellar population (SSP) templates from Maraston (2005) of different ages in order to account for passively evolving galaxies at high redshift. 3 different extinction laws were applied (Calzetti, Calzetti modified and Prevot). We calibrated our z_p with 8176 sources with reliable spectroscopic redshfit (Lilly et al. 2007,2009) and obtained: $\sigma_{\Delta z/(1+zs)}$=0.060, η=3.3% .

We derived masses and other fundamental parameters (e.g. SFR, ages) for sources with z > 1.4 by using the *LePhare* code with Maraston (2005) synthesis models, which include a better treatment of the TP-AGB. We considered 9 templates with exponentially declining SFR and 221 steps in age. We considered solar metallicity, Chabrier IMF and the Calzetti extinction law.

4. Galaxy classification

We used the value of the specific star formation rate (SSFR) to divide our sample into different populations:

- Active galaxies: log (SSFR/Gyr^{-1})> -0.5
- Intermediate: -2 < log (SSFR/Gyr^{-1})< -0.5
- Passive galaxies: log (SSFR/Gyr^{-1})< -2 and no 24µm detection

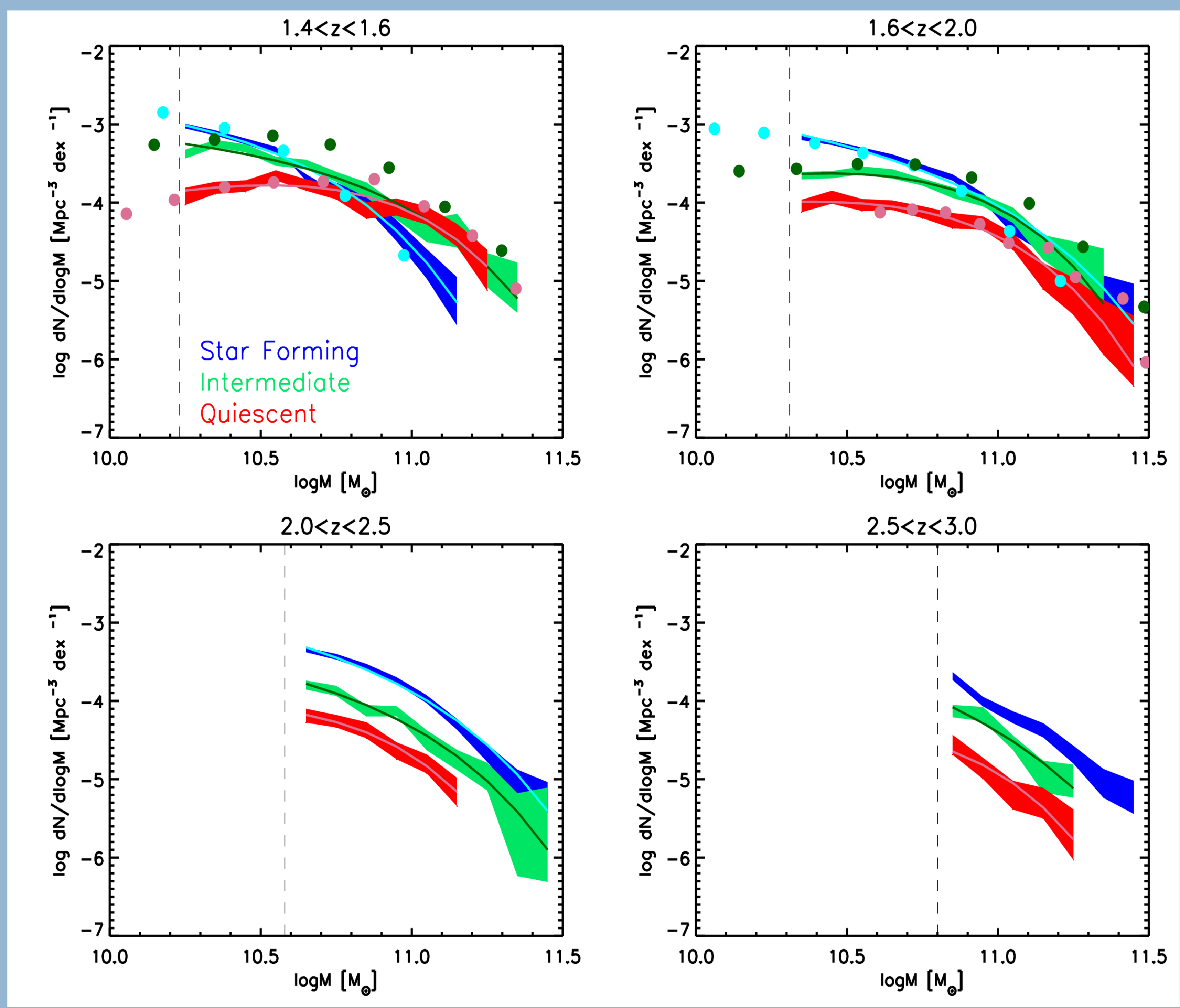

Fig 2. Evolution of the GSMF for different activity types galaxies. The colored areas represent the upper and lower limits while the thick lines are the Schechter functions fitting the data. Red: quiescent. Green: intermediate. Blue: actively star-forming. The circles represent the GSMF for quiescent (purple), intermediate (dark green) and high activity galaxies (light blue), as obtained by Ilbert et al. (2010). Also shown are the limits in mass (vertical dashed lines).

5. Total galaxy stellar mass function

We computed the GSMF through the $1/V_{max}$ method (Schmidt, 1968). The limits in mass were obtained as explained in Pozzetti et al. (2009). The errors include Poissonian errors and the uncertainties in the z_p as derived by means of 20 Montecarlo simulations. We have studied the MF of our sample divided into different populations. We followed the specific star formation activity criteria to divide our sample into passive (red in *Fig. 2*), intermediate (green) and active galaxies (blue).

We find that z~1.5 is a clear epoch of transition of the GSMF: while the GSMF at z > 1.5 is dominated by the star-forming galaxies at all stellar masses, at z < 1.5 the contribution to the total GSMF of the quiescent galaxies is significant and the quiescent galaxies become more important than the star-forming population for M >$10^{10.75}M_\odot$.

6.Comparison with models

In Fig. 3 we report the fraction of massive (M > $10^{10.85}M_\odot$) quiescent galaxies as a function of redshift.

They increases from ~8% to ~35% from 2.5 < z < 3.0 to 1.4 < z < 1.6, with the main evolution occurring between 1.6 < z < 2.0 and 1.4 < z < 1.6 (where the fraction increases from ~ 18% to ~35%). When compared with the theoretical models we can see that all of them agree in predicting a gradual increase with cosmic time in the fraction of galaxies with a low SSFR. However, only the Kitzbichler & White (2007) Millennium-based model is able to properly reproduce the shape of the data.

7.Stellar mass density

In Fig. 4 we show the evolution of the stellar mass density with cosmic time for the quiescent sample (red symbols in Fig. 4 right panel and shade in Fig. 4 left panel) and the intermediate + the star-forming samples (dark blue symbols in Fig. 4 left panel and shade in Fig. 4 right panel). We observe that the increase in stellar mass density in the redshift range of interest (t~2-4.5 Gyr) is very rapid for both populations, then slowing down at lower redshifts. However, this slow down happens earlier in time for the star-forming population (z ~1.2, t ~ 5.0 Gyr) than for the quiescent galaxies, which continue to rapidly assembly mass until later times (z ~1.0, t~6.0 Gyr), reaching the star-forming galaxies mass density at z < 1.0 . The existence of a non negligible population (log ρ [$M_\odot$ Mpc^{-3}]~6.0 at z~2.7) of quiescent galaxies with high masses which have already undergone major star formation even at the highest redshifts (z > 2.5) is fundamental for our understanding of the galaxy formation processes and crucial for testing theoretical scenarios.

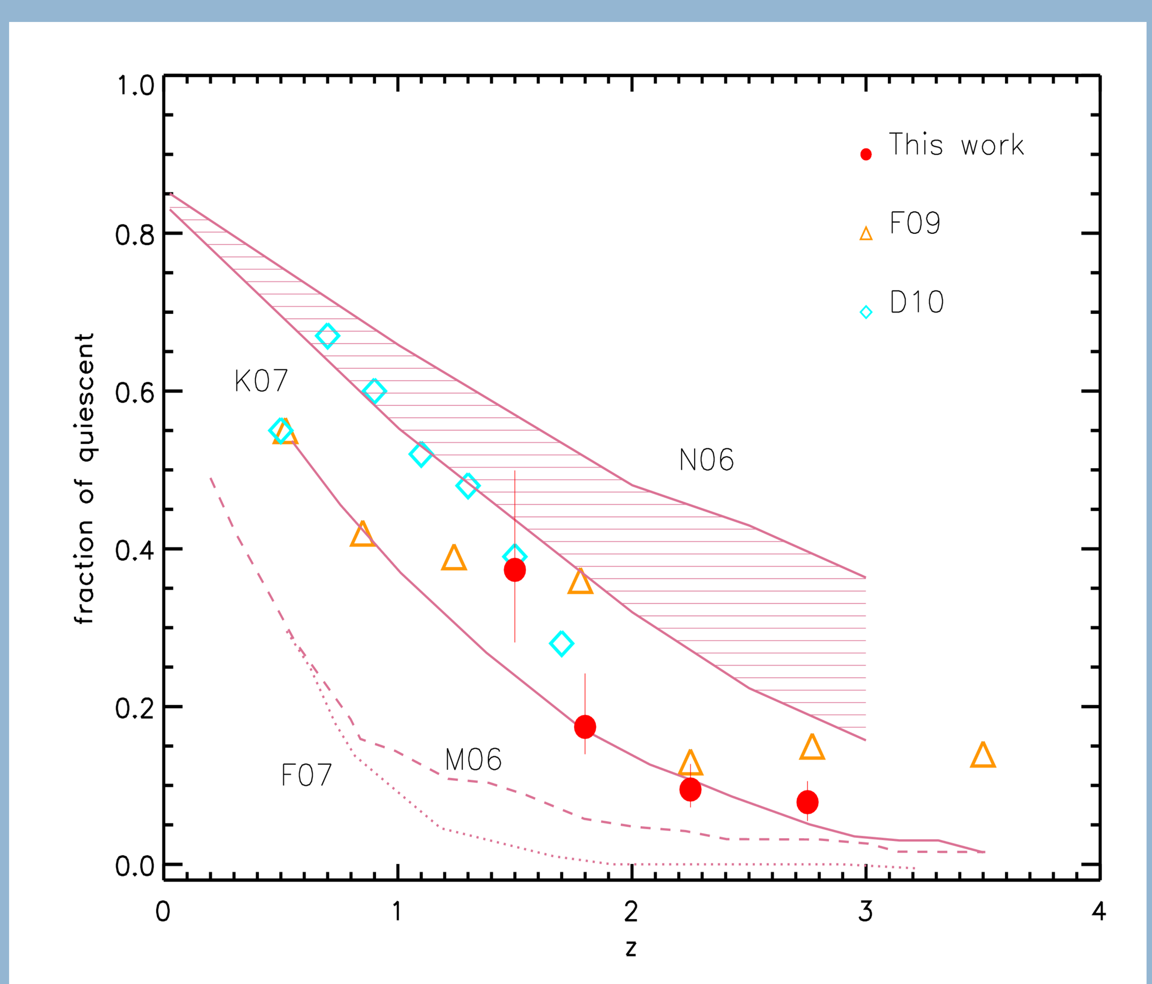

Fig 3. Fraction of quiescent galaxies with M >$10^{10.85}M_\odot$ as a function of redshift. Red circles are the results obtained in this work (errors are the combination of the Poisson errors and the Montecarlo simulations), orange triangles are the values from Fontana et al (2009) and light blue diamonds from Damen (2010). Lines refer to the predictions of theoretical models as decribed in the legend: Menci et al. (2006, M06), Kitzbichler at al. (2007, K07), Nagamine et al. (2006, N06) and Fontanot et al. (2007, F07).

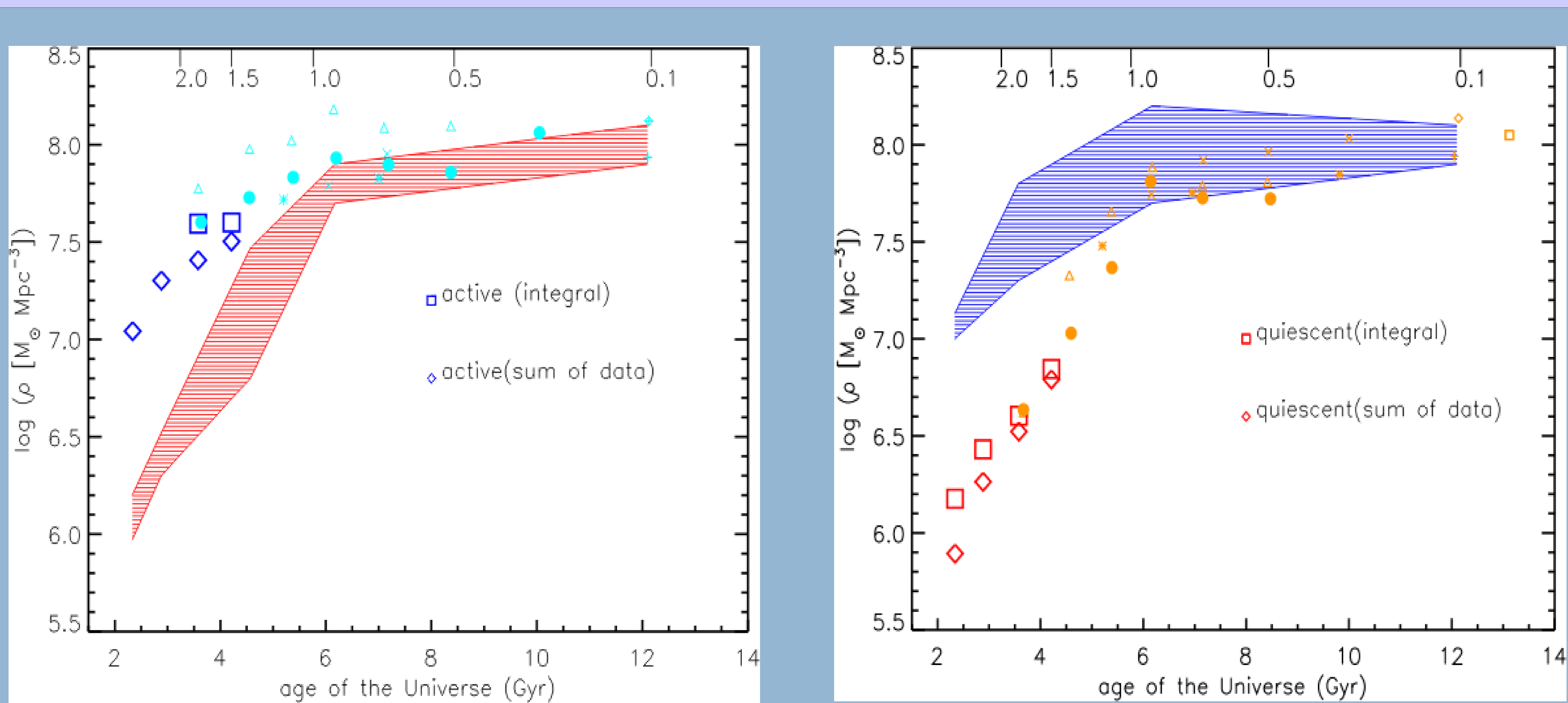

Fig 4. Left: Evolution of the stellar mass density of star-forming+intermediate galaxies. The result from this work are the dark blue symbols. The values represented by the squares have been calculated as the integral of the Schechter function fitting the data, while the diamonds are a mere sum of the data for all masses. Light blue symbols are results from literature (diamonds from Driver et al. 2006, plus symbols from Bell et al. 2003, triangles from Arnouts et al. 2007, asterisks from Franceschini et al. 2006, crosses from Borch et al. 2006, dots from Ilbert et al. 2010). We also show for comparison the evolution of the stellar mass density of the quiescent galaxies (red shaded area). Right: Evolution of the stellar mass density of quiescent galaxies. The result from this work are the red symbols . Orange symbols are results from literature (squares from Kochanek et al. 2001, the other as in the left panel). We also show for comparison the evolution of the stellar mass density of the star-forming+intermediate galaxies (blue shaded area).

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