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in our case due to the existence of possible star-forming solutions with $p > 5$ per cent. In addition, a non-negligible number of our candidates in the reference sample fall outside (below) of the passive region, in the region where recently quenched sources are expected to lie (as discussed in Section 3). This confirms that the adoption of simple τ-models and colour criteria may fall short in singling out a complete sample of red and dead objects, and we therefore conclude that the choice of a more sounded SFH analytic shape like the top-hat we adopted in this study can have significant impact on the selection of realistic candidates of passively evolving objects at high redshift.

In the same Fig. 6, we also code the objects according to their estimated sSFR in the fit. We selected as red and dead candidates the objects having specific rates sSFR $< 10^{-11}$ yr^{-1}: with this criterion, and again requiring $z_{\rm CANDELS} > 3$ and Ks+3.6+4.5 1σ detection, we single out only 10 objects, marked as open circles in the figure. We notice that only 5 out of 10 are present in the TH selection: they are IDs 2782, 7526, 8785, 17749 and 18180. Their best-fitting values are similar to those obtained with the TH libraries. Snapshots showing the other five sources included in the selection and not in the reference TH selection are shown in Fig. 11; we note that ID 34275 is only clearly visible in the *H*-band image and might be a spurious detection from a close-by star, while IDs 2032, 5501, 22515 and 34636 have not been included in the TH selection despite having best fits as passive objects, because star-forming solutions with $p > 5$ per cent are present.

Interestingly, none of the five $z > 4$ red and dead candidates in the reference selection is identified as passive with the τ-models criteria. Two of them, IDs 3912 and 23626, are fitted as sources of ∼1.3 Gyr and ∼500 Myr, respectively, missing the selection because of estimated sSFR slightly higher than the chosen threshold (6.3×10^{-11} and 4.2×10^{-11} yr^{-1}). The other three objects (IDs 5592, 6407, 9209) are fitted as young (age < 300 Myr) star-forming sources with sSFR $> 10^{-10}$ yr^{-1}. The χ^2 of the fits with the τ-models and the TH models are similar. Again, if our modelling is correct, all these are good examples of the kind of objects discussed in Section 3: young galaxies in the early Universe which have quenched their short SF activity abruptly, just before the time they are observed, and are identified as still (slightly) star-forming in a standard fit because of the limitation of the chosen fitting model.

Fig. 7 (top panel) displays the shifts in the *UVJ* diagram positions for the objects belonging to the reference sample, when fitted with different libraries of models. The shifts are typically small, of the order of 0.1–0.3 mag (generally consistent with the uncertainties in the relevant observed colours). Noticeably, they tend to affect the $V - J$ colour more than the $U - V$ colour. This is basically due to the fact that the fit is much more robustly constrained in the region of the observed visible and NIR (covered by the ACS and WFC3 bands), which straddle the rest-frame $U - V$ break at $z \sim 3$, than in the reddest part of the spectrum, since the two 5.6–8.0 μm IRAC bands have the poorest S/N. This allows larger variations in the $V - J$ colour, as shown by the two examples reported in the bottom panels of the same figure. We also note a systematic effect between the two libraries, as most of the candidates with a red $[U - V]_{\rm rest}$ have bluer $[V - J]_{\rm rest}$ using the TH than using the τ library, while galaxies with bluer $[U - V]_{\rm rest}$ are shifted towards redder $[V - J]_{\rm rest}$ colours – implying a shallower mid-IR profile in all cases, as it can be seen in the two SEDs examples. To definitively solve this ambiguity, deeper data longward of 3 μm are necessary; this anticipates the need for *JWST* observations, which will be the target of Section 6.

Figure 7. In the top panel we show the shifts on the *UVJ* diagram of the objects in the reference sample, when fitted with different libraries of models. Blue dots: exponentially declining (τ) library; red squares: TH library. The shifts are small (≲0.3 mag) and typically more pronounced in the $V - J$ colour. The bottom panels show two examples explaining the described trend: the fitted SEDs substantially coincide in the optical – NIR, but differ in the IRAC region. See the text for more details. [A colour version of this figure is available in the online version.]

5.2 Diagnostic planes with observed colours

Fig. 8 shows the result of the selections on diagnostic *VJL* and *iHM* observed colour–colour planes, which are the equivalent of the *BzK* diagram (Daddi et al. 2004) for selection of quiescent galaxies at $z \sim 3$ and $z \sim 4$. In each diagram, the upper right region (delimited by the diagonal solid line and the horizontal dashed line) is expected to be populated by passive sources. The grey dots are individual objects from the whole G13 catalogue, while red dots are galaxies having $z_{\rm CANDELS}$ in the interval of interest for the corresponding diagram. Larger filled dots are the reference sample sources, again colour-coded depending on their photo-*z* (see the caption of the figure). While some of the selected objects lie in the passive region of the diagram, many others are found having slightly bluer observed colours. Therefore, a straightforward colour selection would exclude them from the sample (see Grazian et al. 2007, for similar discussions on the *BzK* selection).

5.3 Comparison with previous samples

Another interesting comparison can be made with the results from previous published studies. Rodighiero et al. (2007) used the Giavalisco et al. (2004) multiwavelength imaging data to extract photometric data, performed a magnitude selection requiring no detection in *HST* bands, $K > 23.5$, and IRAC 3.6 μm < 23.26, and identified 20 objects as massive galaxies with high probability of being high-redshift, passive sources (with 14 of them also having

Figure 8. Diagnostic colour–colour diagrams. In both panels, grey dots are the whole G13 catalogue, and red dots are the sources having $z_{\rm CANDELS}$ in the interval of interest for the corresponding diagnostic diagram: $2.5 < z < 3.5$ for the VJL plot (top panel), $3.5 < z < 4.5$ for the iHM plot (bottom panel). Black and blue dots are the reference sample red and dead candidates, respectively, having redshift within the interval of interest and outside it (arrows are upper limits). Empty squares and circles refer to the selection (Section 5), again, respectively, having redshift within the interval of interest and outside it. [A colour version of this figure is available in the online version.]

a lower redshift, dust-obscured star forming solution). We can now check the nature of those objects using our new deeper photometry. Using the H-detected catalogue, we can identify 18 out of 20 sources via spatial cross-correlation. As it turns out, none of these objects has a strong passive solution in our new analysis; the conclusion can be strengthened analysing the SEDs of these objects, even obtained with the library (they generally show very weak 4000 Å breaks, blue band detections and rising FIR flux), and by the cross-correlation with the 24 μm catalogue by Magnelli et al. (2013), with 12 out of 18 objects having an association with a 24 μm prior within 0.6 arcsec. Clearly the classification by Rodighiero et al. (2007) was heavily affected by the lower quality of the imaging data available at that time.

We then check the correspondence between our selection and two of the most recent similar works, S14 and N14. S14 use a UVJ criterion to single out six quiescent candidates in the GOODS-South field, which we cross-correlate with the G13 catalogue. Among these, three (CANDELS IDs 4503, 17749, 18180) belong to our reference sample as well, while the other three (IDs 5479, 6294 and 19883) have a star-forming best fit. Indeed, they are assigned rather high sSFR in the S14 fit too (27.5×10^{-11}, 18.6×10^{-11} and 4.47×10^{-11} yr^{-1}, respectively); they are also flagged as probable AGNs in the Cappelluti et al. (2016) catalogue, and the first two are identified as AGNs by Xue et al. (2011) as well; they all have confirmed spectroscopic redshift consistent with the $z_{\rm CANDELS}$ we use (Szokoly et al. 2004).

N14 identify 16 evolved (post-starburst) galaxies using an H − K colour selection to probe the 4000 Å break – a selection that in principle includes both star-forming and passive galaxies. Five objects in their selection also belong to our reference sample (IDs 2782, 7526, 12178, 17749, 18180). Of the other 11 objects in the N14 selection, 2 (IDs 9177 and 16671) have $z_{\rm CANDELS} < 3$, one (ID 6189) is a low-redshift ($z_{\rm CANDELS} = 0.6$) dust-obscured star-forming galaxy in the CANDELS catalogues while it is fitted as a passive $z = 4.0$ object by N14, and eight (IDs 4356, 4624, 9286, 10479, 12360, 13327, 18694 and 19195) have star-forming best fits in our analysis; five of them are also identified as AGNs in the catalogue by Cappelluti et al. (2016) (with three also included in the Xue et al. 2011 catalogue).

It is interesting to note that none of the previous cited works includes our best candidates, IDs 10578 and 22085, in their selections. S14 only include sources at $z > 3.4$, while ID10578 has $z_{\rm CANDELS} = 3.06$ and ID22085 has $z_{\rm CANDELS} = 3.36$. On the other hand, both galaxies fail N14 colour selection criteria ([Y − J] versus [H − Ks]). In the case of ID22085, J105 band photometry is not available in the CANDELS GOODS-South data set (this actually shows one more point of strength of the SED fitting approach, in that the lacking of one band data does not compromise the whole study of one potentially interesting object); in ID10578, the object falls immediately outside the selection area of their colour–colour diagram.

6 LOOKING FORWARD: THE JWST PERSPECTIVE

As our study shows, there are still many sources of uncertainty that conspire to make the search for passive objects at $z > 3$ problematic and the selection uncertain: depending on the tightness of the selection criteria, one may end up with very different samples (e.g. in our case we can go from 30 to 2 objects). In particular, the spectral range centred on the 4000 Å break is crucial, both to determine with good accuracy the photometric redshift but especially to distinguish between the star-forming and passive objects; at $z > 3$, inferring the spectral slope both below and above the 4000 Å break demands a good coverage of the whole wavelength range from J to the redder Spitzer bands, ideally up to 8 μm.

The James Webb Space Telescope appears to be perfectly suited to fill these gaps. The NIRCam and MIRI instruments[4] will include a large set of filters in the near- to mid-infrared wavelength range, allowing for a detailed photometric reconstruction of the mentioned important spectral features and, hopefully, for a much easier disentanglement between degenerate solutions from SED-fitting.

It is interesting to try a rough evaluation of the potential of the JWST capabilites in this context. To this aim, we have created a sample of synthetic spectra using our TH library. The full sample consists of 1686 simulated objects, of which 828 correspond to star-forming models (having age ≤ $t_{\rm burst}$), 230 have quenched the SF activity since less than 100 Myr, and 628 are red and dead (age > $t_{\rm burst}$ + 100 Myr). Each of these spectra has been placed at redshifts from 3 to 7 (with the additional constraint that the age of the galaxy is not larger than the age of the Universe at that redshift) at steps of 0.1 in redshift. We then created observational catalogues corresponding to such models, reproducing both the filter sequence and depths of the CANDELS catalogue used in this work, as well as an idealized catalogue reproducing a possible survey executed with JWST. To this purpose we have replaced all the CANDELS filters redward of Y (included) with a combination of 12 JWST

[4] See the webpage for full information.

Figure 9. Comparison of the *UVJ* diagrams from mock observed catalogues, where the rest-frame magnitudes are obtained via SED-fitting using CANDELS (left panels) and *JWST* (right panels) filter sets. The mock catalogues have been created starting from the TH library of spectra, simulating 1686 objects including passive and star-forming galaxies, computing the observed fluxes in all the relevant bands rescaled to three reference magnitudes (each row of the figure corresponds to one of them – from top to bottom, $m_{4.5\,\mu\mathrm{m}}$ = 23, 24 and 25), and including observational noise. In each panel, models having ongoing SF activity in the input library are plotted as blue stars, recently quenched objects as green squares, and passively evolving galaxies as red dots. The dashed lines define a 'green valley' used to quantify the contamination between the different samples. It is clear that the *JWST* pass-bands set removes almost completely the contamination in the fitted colours between the three different populations, which is severe in the CANDELS case. See the text for more details. [A colour version of this figure is available in the online version.]

bands (F090W, F115W, F150W, F200W, F277W, F356W, F444W, F560W, F770W, F1000W, F1130W and F1280W), as described in the MIRI and NIRCam documentation webpages. The resulting catalogue mimicks a survey executed (redward of F090) with *JWST* on the GOODS-S field, building upon the existent ACS data. In particular, we created three catalogues by normalizing the magnitudes to three reference values $m_{4.5\,\mu\mathrm{m}}$ = 23, 24 and 25, covering the magnitude range of our candidates. Noise has been added to these catalogues accordingly to the observed S/N versus magnitude relation in the CANDELS filters (see Castellano et al. 2012); in the *JWST*-simulated bands, we have assumed the depth expected in the case of an extragalactic survey for high redshift galaxies described in Finkelstein et al. (2015). For the three reddest *JWST* filters that were included there, we have computed the expected signal-to-noise ratio assuming a total exposure time per filter comparable to each of the other *JWST* filters.

These simulations are clearly simplified, since (a) they use the same library to compute the 'true' galaxy colours and to derive their photomeric redshifts and SED properties from the SED-fitting, and (b) because we ignore, on the one hand, the additional gain to the overall photometry that will be possible using the improved resolution of *JWST* compared to *Spitzer*, and on the other hand any possible complication due to the blending of sources and other systematics. Regardless of these limitations, these tests can give us a preview of the improvements that *JWST* will make possible.

We have repeated on these simulated catalogues the same analysis that we did on real data. We first fitted catalogues with our SED-fitting code, and then computed the rest-frame properties at the photometric redshift. For simplicity, we show here the results obtained in the *UVJ* plane, for the CANDELS-like and the *JWST*-like catalogues separately. They are shown in Fig. 9, for all objects having $3 < z_{\mathrm{phot}} < 7$. In each panel, models having ongoing SF activity in the input library are plotted as blue stars, recently quenched objects as green squares, and passively evolving galaxies as red dots. The results on the CANDELS simulated data show that there is a strong contamination in the fit, as many passive and star-forming galaxies end up in the same regions of the *UVJ* diagram. For example, one can define a 'green valley' as the region of the diagram for which $V - J > 0.5$ and $0.88 \times [V - J] + 0.44 < U - V < 0.88 \times [V - J] + 0.69$ (see the dashed lines in Fig. 9): considering the three data sets with reference magnitudes $m_{4.5\,\mu\mathrm{m}}$ = 23, 24 and 25, the CANDELS simulation, respectively, yields 3.6, 7.2 and 10.0 per cent star-forming galaxies erroneously falling within or above the green valley; conversely, the passive models falling within or below the green valley in the three cases are 3.0, 16.7 and 31.4 per cent.

This contamination increases (as expected) when input galaxies are fainter. This simulation confirms that the identification of passive galaxies in the CANDELS data set is potentially prone to misidentification due to the still inadequate depth of the photometry.

Conversely, the situation is much more defined using the *JWST* filters: the three populations are robustly fitted and separated, with almost no contamination even down to the faintest magnitudes (the observed 'arched' distributions on the diagram derive from the input true colours, which the fitted ones closely resemble). This is an exciting demonstration of the future capabilities with the new instrument.

It is interesting to note that some red objects again fall outside the passive region of the diagram, as discussed in the previous sections; this shows again how the *UVJ* colour selection can be prone to the risk of missing objects that have quenched their SF activity in recent times, even using a much more accurate photometric data set.

7 SUMMARY AND CONCLUSIONS

In this paper we have presented the methods and results of a study aimed at searching passive galaxies in the early Universe. The summary of the work is the following.

(i) We search for high-redshift, red and dead (i.e. passively evolving) galaxies in the GOODS-South field, using an updated version of the Guo et al. (2013) photometric catalogue that includes CANDELS *HST* fluxes, HUGS Ks data, and new IRAC images and improved photometric measurements (Section 2). We pre-select *H*-detected objects having *K*s, IRAC 3.6 and 4.5 µm 1 detection, and $z_{\rm CANDELS} > 3$. We also add a new sample of 17 *K*/IRAC-detected sources from Boutsia et al. (in preparation) and Wang et al. (2016).

(ii) We then analyse this selection using dedicated top-hat libraries for SED-fitting. We assume that a single star formation event took place and abruptly stopped in the past, followed by passive evolution ever since, and we fit the observed fluxes with models having different values for the duration of the burst, the UV extinction and the metallicity. The selection criterion is based on two stringent requirements: the selected objects must have at least one passive model solution (i.e. sSFR = 0 and age larger than the burst duration) with $p(\chi^2) > 30$ per cent, and do not have any star-forming solution with a probability $p(\chi^2) > 5$ per cent.

(iii) We first use a library without nebular lines emission and only consider the CANDELS redshifts. This way we select 30 candidates, all of which are *H*-detected (see Figs B1 and C1).

(iv) Including nebular lines in the top-hat library used for the SED-fitting procedure, only 10 of these candidates survive the probabilistic selection process: in many cases, the lines weaken the fitted continuum redward of the 4000 Å break, yielding a star-forming best-fit; in other cases, the probabilistic approach causes the exclusion of galaxies with alternative solutions.

(v) If we repeat the analysis letting the redshift free to vary around the best-fitting value, only two galaxies (IDs 10758 and 22085) retain their passive status as the only robust solution. All the other objects show alternative star-forming solutions (at different redshifts) with a probability $p(\chi^2) > 5$ per cent.

(vi) Since it is not possible to completely rule out strongly obscured star-forming solutions for any of the selected sources (see Fig. D1), as a basic sanity check we perform a cross-correlation of the reference sample with the 24 µm catalogue by Magnelli et al. (2013), on *Herschel* PEP-GOODS (Lutz et al. 2011) and HerMES (Smith et al. 2012) blind catalogues, and on Wang et al. (2016) new catalogue based on *H*-detected priors. Two objects in our selection are associated with strong FIR emitters. Interestingly, they are also identified as optical counterparts of X-ray emitters (Xue et al. 2011; Cappelluti et al. 2016); we therefore speculate that they might be recently quenched galaxies, hosting a dust-obscured AGN. No other object in the reference sample has a clear association with an FIR source.

(vii) By means of a direct selection on the full G13 catalogue using a standard exponential-models fit with BC03, we then identify, for comparison, 10 sources as $z > 3$ passive candidates (we require sSFR $< 10^{-11}$ yr^{-1}). Five objects are in common between this selection and the reference sample (IDs 2782, 7526, 8785, 17749, 18180).

A clear outcome of our analysis is that the selection of passive galaxies, at least in the considered range of redshifts, is still prone to significant uncertainties, due to the limitations in the assumptions used in the SED fitting models and the relatively modest S/N of the objects. Nevertheless, considering the weakest among our selection criteria, we can at least derive an upper limit for the number density of these objects, finding 0.173 arcmin^{-2} (or $\sim 2.0 \times 10^{-5}$ Mpc^{-3} for $3 < z < 5$).

The limitations in the SED modelling hampers our chances to derive robust physical information on the selected sample. Ages are poorly constrained, and thus so are the SF rates necessary to assemble such objects. We can try some educated guess on the minimum sSFR of the selected sources (assuming isolated evolution, i.e. no mergers) by taking their estimated stellar masses, and dividing them by the age of the Universe at the time the SF activity ceased (minus 300 Myr, to crudely exclude the dark ages), in the TH best-fitting models (we consider the fit without nebular lines, for simplicity). This yields a typical lower threshold for the sSFR of $\sim 7 \times 10^{-10}$ yr^{-1}, which is fairly consistent with the observed values of main-sequence star-forming galaxies, in the same redshift and mass regimes (e.g. Salmon et al. 2015; Schreiber et al. 2017). This is the sSFR estimated at the end of the activity, i.e. when the mass has been completely assembled; we note that, since in our scheme the rate of star formation of the models is constant before the quenching, if we had observed the galaxies during the star formation phase they would have been classified as starbursts, because having lower stellar mass they would be above the Main Sequence M − M relation.

By means of a dedicated simulation, we have shown how *JWST* will yield a major improvement in this perspective, allowing for a much more effective detachment of high-*z* passive objects from dust-obscured low-*z* ones, thanks to an effective coverage of crucial regions of the observed spectra – namely, the 4000 Å break and the 20 µm rest-frame regions.

A thorough testing against theoretical expectations for the number density and properties of these kind of objects, at the considered redshifts, is compelling and recommended.

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REFERENCES

Anders P., Fritze-von Alvensleben U., de Grijs R., 2003, Ap&SS, 284, 937
Ashby M. L. N. et al., 2015, ApJS, 218, 33
Brammer G. B., van Dokkum P. G., Coppi P., 2008, ApJ, 686, 1503
Brammer G. B. et al., 2009, ApJ, 706, L173
Bruzual G., Charlot S., 2003, MNRAS, 344, 1000
Calzetti D., Armus L., Bohlin R. C., Kinney A. L., Koornneef J., Storchi-Bergmann T., 2000, ApJ, 533, 682
Cappelluti N. et al., 2016, ApJ, 823, 95
Cassata P. et al., 2015, A&A, 573, A24
Castellano M. et al., 2012, A&A, 540, A39
Castellano M. et al., 2014, A&A, 566, A19
Castellano M. et al., 2016, A&A, 590, A31
Ciesla L. et al., 2016, A&A, 585, 43A
Cimatti A. et al., 2004, Nature, 430, 184
Daddi E., Cimatti A., Pozzetti L., Hoekstra H., Röttgering H. J. A., Renzini A., Zamorani G., Mannucci F., 2000a, A&A, 361, 535
Daddi E., Cimatti A., Renzini A., 2000b, A&A, 362, L45
Daddi E., Cimatti A., Renzini A., Fontana A., Mignoli M., Pozzetti L., Tozzi P., Zamorani G., 2004, ApJ, 617, 746
Daddi E. et al., 2005, ApJ, 626, 680
Dahlen T. et al., 2013, ApJ, 775, 93
Dickinson M., Papovich C., Ferguson H. C., Budavári T., 2003, ApJ, 587, 25
Feldmann R., Quataert E., Hopkins P. F., Faucher-Giguère C.-A., Kereš D., 2017, MNRAS, 407, 1050
Finkelstein S. L., Dunlop J., Le Fevre O., Wilkins S., 2015, preprint ( )
Fontana A., D'Odorico S., Poli F., Giallongo E., Arnouts S., Cristiani S., Moorwood A., Saracco P., 2000, AJ, 120, 2206
Fontana A. et al., 2004, A&A, 424, 23
Fontana A. et al., 2006, A&A, 459, 745
Fontana A. et al., 2009, A&A, 501, 15
Fontana A. et al., 2014, A&A, 570, A11
Giallongo E. et al., 2015, A&A, 578, A83
Giavalisco M. et al., 2004, ApJ, 600, L93
Grazian A. et al., 2006, A&A, 449, 951
Grazian A. et al., 2007, A&A, 465, 393
Grazian A. et al., 2015, A&A, 575, A96
Grogin N. A. et al., 2011, ApJS, 197, 35
Guo Y. et al., 2013, ApJS, 207, 24
Ilbert O. et al., 2013, A&A, 556, A55
Koekemoer A. M. et al., 2011, ApJS, 197, 36
Labbé I. et al., 2005, ApJ, 624, L81
Labbé I. et al., 2015, ApJS, 221, 23
Laidler V. G. et al., 2007, PASP, 119, 1325
Lutz D. et al., 2011, A&A, 532, A90
Magnelli B. et al., 2013, A&A, 553, A132
Maiolino R. et al., 2008, A&A, 488, 463
Marchesini D. et al., 2010, ApJ, 725, 1277
Merlin E., Chiosi C., Piovan L., Grassi T., Buonomo U., Barbera F. L., 2012, MNRAS, 427, 1530
Merlin E. et al., 2015, A&A, 582, A15
Merlin E. et al., 2016, preprint ( )
Mobasher B. et al., 2005, ApJ, 635, 832
Muzzin A. et al., 2013, ApJ, 777, 18
Nayyeri H. et al., 2014, ApJ, 794, 68
Paci ci C. et al., 2015, MNRAS, 447, 786
Papovich C., Dickinson M., Ferguson H. C., 2001, ApJ, 559, 620
Patel S. G., Holden B. P., Kelson D. D., Franx M., van der Wel A., Illingworth G. D., 2012, ApJ, 748, L27
Pozzetti L., Mannucci F., 2000, MNRAS, 317, L17
Prevot M. L., Lequeux J., Prevot L., Maurice E., Rocca-Volmerange B., 1984, A&A, 132, 389
Rodighiero G., Cimatti A., Franceschini A., Brusa M., Fritz J., Bolzonella M., 2007, A&A, 470, 21
Rosati P., Stanford S. A., Eisenhardt P. R., Elston R., Spinrad H., Stern D., Dey A., 1999, AJ, 118, 76
Salmon B. et al., 2015, ApJ, 799, 183
Salpeter E. E., 1959, ApJ, 129, 608
Santini P. et al., 2012, A&A, 538, A33
Santini P. et al., 2015, ApJ, 801, 97
Schaerer D., de Barros S., 2009, A&A, 502, 423
Schaerer D., Vacca W. D., 1998, ApJ, 497, 618
Schaye J. et al., 2015, MNRAS, 446, 521
Schreiber C., Pannella M., Leiton R., Elbaz D., Wang T., Okumura K., Labbé I., 2017, A&A, 599, A134
Silk J., Mamon G. A., 2012, Res. Astron. Astrophys., 12, 917
Smith A. J. et al., 2012, MNRAS, 419, 377
Sommariva V. et al., 2014, A&A, 571, A99
Stefanon M., Marchesini D., Rudnick G. H., Brammer G. B., Whitaker K. E., 2013, ApJ, 768, 92
Straatman C. M. S. et al., 2014, ApJ, 783, L14
Szokoly G. P. et al., 2004, ApJS, 155, 271
van Dokkum P. G. et al., 2004, ApJ, 611, 703
Vanzella E. et al., 2008, A&A, 478, 83
Vogelsberger M. et al., 2014, MNRAS, 444, 1518
Wang T. et al., 2016, ApJ, 816, 84
Whitaker K. E. et al., 2011, ApJ, 735, 86
Whitaker K. E. et al., 2013, ApJ, 770, L39
Wiklind T., Dickinson M., Ferguson H. C., Giavalisco M., Mobasher B., Grogin N. A., Panagia N., 2008, ApJ, 676, 781
Williams R. J., Quadri R. F., Franx M., van Dokkum P., Labbé I., 2009, ApJ, 691, 1879
Wuyts S. et al., 2007, ApJ, 655, 51
Xue Y. Q. et al., 2011, ApJS, 195, 10

APPENDIX A: PHYSICAL PROPERTIES OF THE SELECTED SAMPLE OF RED AND DEAD CANDIDATES

Table A1. Physical properties of the red and dead candidates belonging to the reference sample, as obtained from their best fit with the TH library without emission lines. $ID_{CANDELS}$ is the identification number in the G13 catalogue; $z_{CANDELS}$ is the official CANDELS redshift. $\chi^2_{reduced}$ is the normalized (reduced) χ^2 of the best fit. The SFR is always zero, by definition. The table lists first the two most robust candidates, which have passed all the selection criteria including the free z fit; second, the other 8 objects, identified as passive in the emission line fit as well (see Table A2); finally, the remaining 20 objects in the reference sample.

$ID_{CANDELS}$	$z_{CANDELS}$	$\chi^2_{reduced}$	Age (Gyr)	Stellar mass (10^9 M)
10578	3.06	1.97	$0.63^{+0.37}_{-0.31}$	$239.70^{+108.80}_{-54.40}$
22085	3.36	1.26	$0.61^{+0.97}_{-0.30}$	$44.25^{+17.08}_{-12.31}$
2717	3.04	1.13	$1.58^{+0.00}_{-0.97}$	$162.70^{+56.80}_{-69.01}$
2782	3.47	0.94	$0.71^{+0.88}_{-0.40}$	$69.95^{+16.27}_{-26.15}$
3912	4.08	1.32	$1.25^{+0.05}_{-0.94}$	$36.27^{+25.08}_{-15.79}$
8785	3.98	0.72	$0.91^{+0.39}_{-0.59}$	$38.96^{+17.36}_{-15.65}$
9209	4.55	1.61	$0.41^{+0.74}_{-0.21}$	$91.51^{+27.69}_{-44.79}$
17749	3.73	0.63	$0.90^{+0.40}_{-0.39}$	$108.80^{+30.20}_{-51.19}$
18180	3.61	1.36	$0.91^{+0.39}_{-0.50}$	$90.11^{+22.29}_{-37.97}$
23626	4.64	1.05	$0.41^{+0.69}_{-0.11}$	$75.91^{+28.89}_{-25.90}$
2608	3.58	1.36	$0.63^{+0.42}_{-0.43}$	$4.51^{+1.23}_{-1.83}$
3897	3.14	1.12	$0.36^{+0.69}_{-0.16}$	$11.86^{+10.14}_{-1.82}$
3973	3.67	1.84	$0.91^{+0.39}_{-0.30}$	$186.10^{+16.40}_{-85.20}$
4503	3.52	3.74	$1.10^{+0.20}_{-0.80}$	$142.70^{+38.20}_{-59.61}$
4587	3.58	2.55	$0.41^{+0.85}_{-0.21}$	$5.48^{+4.34}_{-1.72}$
5592	4.45	1.05	$0.36^{+0.79}_{-0.16}$	$30.16^{+17.90}_{-16.22}$
6407	4.74	1.31	$0.36^{+0.69}_{-0.16}$	$15.98^{+11.26}_{-3.71}$
7526	3.42	0.60	$0.90^{+0.68}_{-0.58}$	$36.24^{+17.89}_{-17.45}$
7688	3.35	0.69	$0.61^{+0.97}_{-0.31}$	$22.76^{+12.09}_{-11.71}$
8242	3.18	1.17	$1.00^{+0.58}_{-0.69}$	$6.55^{+1.97}_{-2.25}$
9091	3.30	2.22	$0.36^{+0.90}_{-0.16}$	$2.81^{+2.69}_{-0.81}$
10759	3.07	1.38	$0.63^{+0.95}_{-0.62}$	$0.91^{+1.17}_{-0.64}$
12178	3.28	1.02	$1.10^{+0.20}_{-0.79}$	$41.20^{+16.64}_{-10.46}$
15457	3.41	1.98	$0.36^{+0.69}_{-0.16}$	$4.39^{+2.90}_{-0.63}$
16506	3.34	3.68	$0.36^{+0.69}_{-0.16}$	$5.06^{+3.62}_{-0.67}$
19301	3.60	2.85	$1.10^{+0.20}_{-0.90}$	$11.58^{+7.36}_{-5.39}$
19446	3.25	2.89	$1.00^{+0.58}_{-0.80}$	$20.07^{+3.37}_{-10.73}$
19505	3.33	1.20	$0.63^{+0.57}_{-0.43}$	$46.63^{+6.19}_{-15.00}$
22610	3.22	0.74	$0.63^{+0.63}_{-0.43}$	$9.49^{+4.40}_{-3.09}$
26802	3.45	1.75	$0.63^{+0.95}_{-0.43}$	$4.67^{+2.45}_{-1.92}$

Table A2. Physical properties of the 10 red and dead candidates passing the probabilistic selection including nebular lines emission in the fit. $ID_{CANDELS}$ is the identification number in the G13 catalogue; $z_{CANDELS}$ is the official CANDELS redshift. $\chi^2_{reduced}$ is the normalized (reduced) χ^2 of the best fit. The SFR is always zero, by definition. The table lists first the two most robust candidates, which have passed all the selection criteria including the free z fit; then, the other eight objects identified as passive in the emission line fit.

$ID_{CANDELS}$	$z_{CANDELS}$	$\chi^2_{reduced}$	Age (Gyr)	Stellar mass (10^9 M)
10578	3.06	1.97	$0.63^{+0.37}_{-0.47}$	$239.60^{+108.70}_{-83.80}$
22085	3.36	1.26	$0.61^{+0.97}_{-0.59}$	$44.23^{+17.04}_{-33.61}$
2717	3.04	1.13	$1.58^{+0.00}_{-0.97}$	$162.50^{+56.70}_{-62.89}$
2782	3.47	0.94	$0.71^{+0.88}_{-0.40}$	$69.90^{+16.26}_{-26.12}$
3912	4.08	1.32	$1.25^{+0.05}_{-0.94}$	$36.26^{+25.07}_{-15.78}$
8785	3.98	0.72	$0.91^{+0.39}_{-0.59}$	$38.95^{+17.35}_{-15.65}$
9209	4.55	1.61	$0.41^{+0.74}_{-0.40}$	$91.49^{+27.61}_{-77.82}$
17749	3.73	0.63	$0.90^{+0.40}_{-0.39}$	$108.80^{+30.10}_{-51.29}$
18180	3.61	1.36	$0.91^{+0.39}_{-0.50}$	$90.04^{+22.26}_{-38.04}$
23626	4.64	1.05	$0.41^{+0.69}_{-0.11}$	$75.88^{+28.92}_{-25.89}$

APPENDIX B: SNAPSHOTS OF THE TH CANDIDATES

Figure B1. Snapshots of the 30 passive candidates selected in the reference sample, obtained with the TH library. Left to right: ACS B435 + V606 + I814 stack, WFC3 J125, WFC3 H160, Hawk-I Ks, IRAC 3.6 + 4.5 μm stack, IRAC 5.8 + 8.0 μm stack. [A colour version of this figure is available in the online version.]

Figure B1 – continued

Figure B1 – continued

APPENDIX C: SEDS OF THE TH REFERENCE SAMPLE CANDIDATES

Figure C1. SED- tting for the objects in the reference sample. Shown is the best t using the TH libraries, with $z = z_{CANDELS}$, with (red line) and without (black line) the inclusion of nebular emission; in many cases the two ts almost coincide, so the two lines are superposed. The physical parameters of the best- tting models are reported on the bottom of each plot, with colours (blue or black) corresponding to the considered t. [A colour version of this figure is available in the online version.]

Figure C1 – continued

Figure C1 – continued

Figure C1 – continued

Figure C1 – continued

APPENDIX D: PROBABILITY AND EXTINCTION OF ALL THE MODEL SOLUTIONS OF THE TH CANDIDATES

Figure D1. Probability and dust extinction as a function of [age − t_{burst}] for all the possible solutions in the SED-fitting process, for all the candidates in the TH selection. For each candidate, indicated by its ID, two panels are shown. In the upper one, dots represent the probability $p(\chi^2)$ of each model solution; the colours of the dots refer to the belonging of the source to the selection with (blue) or without (red) the inclusion of nebular lines; the dots (models) are shaded as a function of their density. The lower one shows the corresponding values of the $E(B-V)$. All the solutions have age > t_{burst}, as required to be classified as passive in this approach. Galaxies excluded from the selection, on the other hand, have been fitted by at least one model with age < t_{burst}, i.e. still star-forming, with a probability $p > 5$ per cent (not shown). [A colour version of this figure is available in the online version.]

APPENDIX E: SNAPSHOTS OF THE -MODELS CANDIDATES

Figure E1. Snapshots of the ve passive candidates selected with the -models library which are not present in the reference sample. Left to right: ACS B435 + V606 + I814 stack, WFC3 J125, WFC3 H160, Hawk-I Ks, IRAC 3.6 + 4.5 μm stack, IRAC 5.8 + 8.0 μm stack. [A colour version of this gure is available in the online version.]

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