Properties of high-redshift passive galaxies
Number density and contribution to the cosmic star formation history

Emiliano Merlin
Paola Santini, Marco Castellano, Flaminia Fortuni, Adriano Fontana

INAF - OAR

Extremely Big Eyes On The Early Universe - Rome, Lincei 10/9/2019
How to identify early massive/passive (red&dead) galaxies?

2 selections: "reference" (no emission lines in the SED library) and "lines" (includes emission lines).

Redshift fixed to CANDELS estimations.

CANDELS photometric data on 5 deep fields (WFC3 H160 detections)

Model 1 (star forming)
Probability P1

Model 2 (passive)
Probability P2

Model n (…)
Probability Pn

Object is a red and dead candidate if:
- zCANDELS > 3
- H160 < 27
- 1σ detection in Ks, IRAC1, IRAC2
- Pbest (passive) > 30%
- No P_i (star-forming) > 5%
Properties of the candidates

<table>
<thead>
<tr>
<th>Field/Sample</th>
<th>Total</th>
<th>$z &gt; 3$</th>
<th>S/N$_{z&gt;3} &gt; 1$</th>
<th>Reference</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>COSMOS</td>
<td>38671</td>
<td>3778</td>
<td>1525</td>
<td>4</td>
<td>2</td>
</tr>
<tr>
<td>EGS</td>
<td>41457</td>
<td>4830</td>
<td>1775</td>
<td>13</td>
<td>5</td>
</tr>
<tr>
<td>GOODS-N</td>
<td>35445</td>
<td>3953</td>
<td>1793</td>
<td>36</td>
<td>11</td>
</tr>
<tr>
<td>GOODS-S</td>
<td>34900</td>
<td>5029</td>
<td>2884</td>
<td>33</td>
<td>13</td>
</tr>
<tr>
<td>UDS</td>
<td>35032</td>
<td>4018</td>
<td>2540</td>
<td>16</td>
<td>9</td>
</tr>
<tr>
<td><strong>All fields</strong></td>
<td><strong>186435</strong></td>
<td><strong>21608</strong></td>
<td><strong>10517</strong></td>
<td><strong>102</strong></td>
<td><strong>40</strong></td>
</tr>
</tbody>
</table>
We apply a corrective factor obtained from tailored simulations, to account for selection/incompleteness effects.

<table>
<thead>
<tr>
<th>$\Delta z$</th>
<th>Reference</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Corrected</td>
</tr>
<tr>
<td>$3 &lt; z \leq 5$</td>
<td>$1.73 \times 10^{-5}$</td>
<td>$2.30 \times 10^{-5}$</td>
</tr>
<tr>
<td>$3 &lt; z \leq 4$</td>
<td>$2.90 \times 10^{-5}$</td>
<td>$3.66 \times 10^{-5}$</td>
</tr>
<tr>
<td>$4 &lt; z \leq 5$</td>
<td>$4.34 \times 10^{-6}$</td>
<td>$7.94 \times 10^{-6}$</td>
</tr>
</tbody>
</table>
Number density: comparison with models

<table>
<thead>
<tr>
<th>Δz</th>
<th>Reference</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 &lt; z ≤ 5</td>
<td>1.73×10⁻⁵</td>
<td>2.30×10⁻⁵</td>
</tr>
<tr>
<td>3 &lt; z ≤ 4</td>
<td>2.90×10⁻⁵</td>
<td>3.66×10⁻⁵</td>
</tr>
<tr>
<td>4 &lt; z ≤ 5</td>
<td>4.34×10⁻⁶</td>
<td>7.94×10⁻⁶</td>
</tr>
</tbody>
</table>

Caveats in Annalisa’s talk!
Number density: comparison with models

<table>
<thead>
<tr>
<th>Δz</th>
<th>Reference</th>
<th>Lines</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Observed</td>
<td>Corrected</td>
</tr>
<tr>
<td>3 &lt; z ≤ 5</td>
<td>1.73×10⁻⁵</td>
<td>2.30×10⁻⁵</td>
</tr>
<tr>
<td>3 &lt; z ≤ 4</td>
<td>2.90×10⁻⁵</td>
<td>3.66×10⁻⁵</td>
</tr>
<tr>
<td>4 &lt; z ≤ 5</td>
<td>4.34×10⁻⁶</td>
<td>7.94×10⁻⁶</td>
</tr>
</tbody>
</table>

NOTE: Volumes are comparable (∼10⁰³ Mpc³), MF are ok up to z ∼ 4

BUT - Our estimates are lower limits:
(i) we only include very robust candidates
(ii) we do not consider possible K or IRAC detections
(iii) incompleteness still plays a role

Credits: F. Fortuni, A. Pillepich, C. Dalla Vecchia, R. Davé
The contribution to the cosmic SFRD: method

\[ \forall dz_{\text{obs}} \rightarrow SFR_{dz_H} = \sum_{i=1}^{n} SFR_{dz_H,i} \]

\[ \forall dz_{\text{obs}} \rightarrow SFRD_{dz_H} = SFR_{dz_H} / V_{dz_{\text{obs}}} \]

\[ \langle SFRD_{dz_H} \rangle = \sum_{j=1}^{N_{dz_{\text{obs}}}} \frac{SFRD_{dz_H,j}}{N_{dz_{\text{obs}}}} \]
The contribution to the cosmic SFRD: results

We are consistent with the observed SFRDs
The contribution to the cosmic SFRD: results

We are consistent with the observed SFRDs

Red&Dead are \(~0.5\%\) of all \(z>3\) galaxies, but provide \(~5-10\%\) of cosmic SFRD at \(3<z<8\)
Looking forward

Superposed to the SEDs in arbitrary units are the the curves of some significant pass-band filters of CANDELS (solid red: left to right, F160, Ks and IRAC-CH1), WFIRST (dashed blue: left to right, H158 and F184), and JWST (dotted green: left to right, NIRCAM F150, F200, F356, F444, and MIRI F560).
Looking forward

Considering the three data sets with reference magnitudes $m_{4.5\mu m} = 23, 24$ and $25$, the CANDELS simulation, respectively, yields $\sim 3.6, 7.2$ 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 $\sim 3.0, 16.7$ and $31.4$ per cent.
Looking forward

We then created observational catalogs corresponding to such models, reproducing both the filter sequence and depths of the CANDELS catalogue used in this work, as well as an idealized catalog 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 twelve JWST bands (F090W, F115W, F150W, F200W, F277W, F356W, F444W, F560W, F770W, F1000W, F1130W, F1280W), as described in the MIRI and NIRCam documentation webpages. The resulting catalog mimicks a survey executed (redward of F090) with JWST on the GOODS-S field, building upon the existent ACS data.

considering the three data sets with reference magnitudes $m_{4.5\mu m} = 23, 24$ and 25, the CANDELS simulation, respectively, yields $\sim 3.6, 7.2$ 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 $\sim 3.0, 16.7$ and $31.4$ per cent.
Looking forward

We then created observational catalogs corresponding to such models, reproducing both the filter sequence and depths of the CANDELS catalogue used in this work, as well as an idealized catalog 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 twelve JWST bands (F090W, F115W, F150W, F200W, F277W, F356W, F444W, F560W, F770W, F1000W, F1130W, F1280W), as described in the MIRI and NIRCam documentation webpages. The resulting catalog mimics a survey executed (redward of F090) with JWST on the GOODS-S field, building upon the existent ACS data.

Considering the three data sets with reference magnitudes $m_{4.5\mu m} = 23, 24$ and $25$, the CANDELS simulation, respectively, yields $\sim 3.6, 7.2$ 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 $\sim 3.0, 16.7$ and $31.4$ per cent.
Simulating JWST observations

H band image of CANDELS field is used to take the real position and morphology of the objects. Each object in the H detected catalog has then been re-scaled in intensity to match the F444 flux predicted by SED fitting models in the CANDELS catalogues. Fainter objects have been added using EGG (Schreiber+2017) down to the limit expected from the JWST observations. Depth and PSF are approximately close to the expected “strawman” proposal by Finkelstein et al. (2015), with exposure times of 2-3 hours.

CREDITS:
D. Paris, A. Fontana, EM
Animations available @ www.astrodeep.eu/movies-jwst1/
Summary and conclusions

- To single out robust red and dead candidates at z>3, we use a **probabilistic technique** rather than standard color selections.

- We find 102 (40) candidates in the 5 CANDELS fields.

- This yields a number density of \(1.73 \pm 0.17 \times 10^{-5}\) \(6.69 \pm 1.08 \times 10^{-6}\) Mpc\(^{-3}\) for \(3 < z < 5\); completeness correction yields \(2.30 \pm 0.20 \times 10^{-5}\) Mpc\(^{-3}\).

- Reasonable agreement with models at \(z < 4\), tensions at \(z > 4\) (but likely still not OK).

- These objects are \(\sim 0.5\%\) of all galaxies but provide \(\sim 5-10\%\) of cosmic SFRD at \(3 < z < 8\).

- Next generation large telescopes will largely improve the reliability of the results.

*For further information see: Merlin+2019 (submitted), Merlin+2018, Santini+2019*