Searching for high-$z$ field ellipticals: successes and problems

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ABSTRACT

The most recent observational results on the search for high redshift field ellipticals are reviewed in the context of galaxy formation scenarios. The perspectives for Large Binocular Telescope (LBT) observations are also discussed.

Keywords: galaxy formation, galaxy evolution

1. INTRODUCTION

The question on the formation of the present-day massive spheroidals is one of the most debated issues of galaxy evolution and it is strongly linked to the general problem of structure formation in the universe (see [1] for a recent review). In one scenario, massive spheroidals are formed at early cosmological epochs (e.g. $z > 3$) through the “monolithic” collapse of the whole gas mass. Such a formation would be characterized by an episode of intense star formation, followed by a passive evolution (or pure luminosity evolution, PLE) of the stellar population to nowadays. In marked contrast, the hierarchical scenarios predict that massive spheroidals are the product of rather recent merging of pre-existing disk galaxies taking place mostly at $z < 1$. In hierarchical scenarios, fully assembled massive field spheroidals at $z > 1$ are rare objects and the spheroids of cluster ellipticals were assembled before those of field ellipticals. From an observational point of view, a direct way to test the above scenarios is to search for massive field ellipticals at $z > 1$ and to compare their number with the model predictions (see the introduction of [8] for a recent review on observational tests).

2. HOW TO FIND $z > 1$ ELLIPTICALS?

Since the near-IR light is a good tracer of the galaxy mass, $K$-band imaging provides an important possibility to perform surveys aimed at selecting massive ellipticals at high-$z$. A galaxy with a stellar mass of about $10^{11} M_\odot$ is expected to have $18 < K < 20$ for $1 < z < 2$, thus implying that moderately deep $K$-band surveys can efficiently select massive galaxies.

A first selection criterion to find ellipticals at $z > 1$ is to apply a color threshold to $K$-band selected galaxies. In the framework of passive evolution, such a threshold is set by the colors expected for a galaxy at $z > 1$ formed at a given $z_f$. For instance, according to the Bruzual & Charlot (1999) spectral synthesis models ($Z = Z_\odot$, Salpeter IMF), a very red color of $R - K > 5.3$ would allow to select $z \geq 1$ passively evolving galaxies formed at $z_f > 2$ ($H_0=50$ km s$^{-1}$ Mpc$^{-1}$, $\Omega_0 = 0.1 - 1.0$), thus allowing to search for elliptical candidates formed at early epochs. However, searches based on color selection criteria gave discrepant results: some works showed that the number of such red galaxies is lower compared to the predictions of PLE, whereas others did not confirm such a deficit up to redshifts of about two.

In order to avoid the possible biases (e.g. star formation) present in the color selection technique, another approach is to derive the fraction of ellipticals by taking spectra of all the galaxies in $K$-selected samples irrespectively of colors (see also http://www.arcetri.astro.it/~k20/). This method allows to overcome the putative problem of ellipticals missed because bluer than the adopted color threshold due to a low level of residual star formation.

Finally, the third possibility to find $z > 1$ ellipticals is to select galaxies according to their morphology and surface brightness profiles (with or without an associated color selection criterion). This approach was adopted for example by for $0.2 < z < 1.0$, and by for $z > 1$. While the results seem to agree with no or little number density evolution for early type galaxies at $z < 1$, the analysis of the $z > 1$ samples led again to discrepant results, thus making the question on $z > 1$ ellipticals even more controversial.

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3. RECENT IMAGING AND SPECTROSCOPY RESULTS

After several small field surveys (≈1-60 arcmin², see references in previous section) leading to discrepant results, the most recent success was provided by a wide field survey for extremely red objects (EROs)\textsuperscript{24}. Such a survey (the widest so far: 700 arcmin² to $K < 18.8$, with a sub-area of 447 arcmin² to $K < 19.2$) provided a complete sample of about 400 objects with $R - K > 5$ suitable for reliably constraining the number density of high-$z$ elliptical candidates. The main results of such a survey are the detection of strong angular clustering of EROs (an order of magnitude larger than that of field galaxies; see Fig. 1-2), and the accurate estimate of the surface density of elliptical candidates at $z > 1$. The observed clustering can explain the previous discrepant results on the surface density of $z > 1$ ellipticals as due to strong field-to-field variations (the “cosmic variance”), and it suggests that most EROs are ellipticals rather than dust reddened starbursts (see\textsuperscript{24} for more details). Finally, even in the conservative case where up to 70% of EROs are not ellipticals, the observed surface density (complemented by the results of\textsuperscript{25}) is in good agreement with the predictions of PLE (Fig. 3), suggesting that most field ellipticals were fully assembled at least by $z = 2.5$\textsuperscript{26}. This result does not imply that the formation of massive spheroidals occurred necessarily through a “monolithic collapse” scenario, but it simply constrains the epoch when the formation took place, and it implies that, if ellipticals formed through merging, this occurred mostly at $z > 2.5$.

In addition to wide field imaging, the existence of galaxies with the colors expected in the case of passive evolution and with de Vaucouleurs $r^{1/4}$ surface brightness profiles consistent with being dynamically relaxed spheroidals at $z > 1$ has significantly grown thanks to HST deep imaging (e.g.,\textsuperscript{13,27,23}).

The spectroscopic confirmation of high-$z$ ellipticals is extremely challenging because of their faintness both in the optical and in the near-IR, and because of the few characteristic spectral features present in their spectra: mainly the strong 4000 Å continuum break, the weaker breaks at 2600 Å, 2900 Å and 3260 Å, and a handful of absorptions detectable with the present-day largest telescopes and very long integration times (Fig. 4). Moreover,
Figure 2. The two-point angular correlation function of EROs with $R - K_s > 5$ in the Daddi et al. (2000) survey. In comparison, the dashed line shows the lower clustering of the field $K$-selected galaxies.

Figure 3. The observed surface density of EROs with $R - K_s > 5.3$ (corresponding to $z > 1$ selection) compared to PLE models with a set of formation epochs (Bruzual & Charlot 1999 models, $Z = Z_{\odot}$, Salpeter IMF, $\tau=0.1$ Gyr, Marzke et al. 1998 local luminosity function of ellipticals, $z_f = 1.9, 2, 2.5, 3, 10$).
for $1.3 < z < 1.9$, the 4000 Å break falls in a critical spectral region where the optical and near-IR spectrographs are less efficient and the atmosphere severely hampers the observations.

Despite such difficulties, the Keck telescopes and the ESO VLT are confirming the existence of $z > 1$ passively evolving ellipticals with old ages (1−4 Gyr) consistent with being formed at remote cosmological epochs (Fig. 4(a)), as well as ellipticals displaying a low level of star formation indicated by the possible detection of weak [OII] λ3727 emission (see Fig. 4(b); see also).

4. PROBLEMS

The major problem affecting the statistical studies of $z > 1$ ellipticals is the “pollution” of color-selected samples by a fraction of star forming galaxies reddened by strong dust extinction. The fraction of dusty EROs is currently unknown, but its accurate estimate is crucial to infer a reliable surface density of high-$z$ ellipticals “cleaned” by the contamination of dusty systems. This goal can be reached observing complete samples of EROs with optical+near-IR spectroscopy (when feasible), deep HST imaging and submm photometry. Although based on small and/or incomplete samples, recent submm and HST observations suggested that the dusty galaxies are probably segregated among the reddest EROs with $R−K > 7$ or $I−K > 6$.

The other major problem in the identification of $z > 1$ ellipticals is that a large fraction of EROs are beyond the spectroscopic limits of the present largest telescopes (e.g. $R > 25$, $K > 19−20$). This strongly limits our ability to spectroscopically confirm the nature of a high-$z$ elliptical candidate.

5. PROSPECTS FOR THE LBT

The Large Binocular Telescope will play an important role in the study of high-$z$ ellipticals. As a single-dish telescope, deep spectroscopy in the ranges 0.7-1.0μm and 0.9-1.8μm will be possible with the MODS and the LUCIFER spectrographs respectively. This will allow us to enlarge the samples of spectroscopically identified high-$z$ ellipticals.
and, for instance, to infer their luminosity function and 3D clustering at $z > 1$. As a diffraction limited telescope, the LBT will provide high angular resolution near-IR images that will be crucial in deriving the surface brightness profiles and, for instance, to extend the Kormendy relation and to attempt the Tolman test at $z > 1$. Finally, in case of objects unfeasible with spectroscopy, the combination of high resolution imaging and optical + near-IR photometry (possibly done with special medium band filters) will allow us first to confirm the spheroidal nature of the elliptical candidates, and then to reliably estimate their photometric redshifts.

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REFERENCES

1. Renzini A., Cimatti A. 2000, in “The Hy-Redshift Universe: Galaxy Formation and Evolution at High Redshift”, ed. A.J. Bunker & W.J.M. van Breugel, A.S.P. Conf. Series Vol. 193, in press (astro-ph/9910162)
2. Eggen O.J., Lynden-Bell D., Sandage A. 1962, ApJ, 136, 748
3. Larson R.B. 1974, MNRAS, 173, 671
4. Kauffmann G. 1996, MNRAS, 281, 487
5. Baugh C.M., Cole S., Frenk C.S. 1996, MNRAS, 283, 1361
6. Gavazzi G., Pierini D., Boselli A. 1996, A&A, 312, 397
7. Kauffmann G., Charlot S. 1998, MNRAS, 297, L23
8. Schade D. et al. 1999, ApJ, 525, 31
9. Zepf S.E. 1997, Nature, 390, 377
10. Franceschini A. et al. 1998, ApJ, 506, 600
11. Barger A.J. et al. 1999, AJ, 117, 102
12. Totani T., Yoshii J. 1997, ApJ, 501, L177
13. Benitez N. et al. 1999, ApJ, 515, L65
14. Broadhurst T.J., Bouwens R.J. 1999, ApJ, 530, L53
15. Scodeglio M., Silva D.R. 2000, A&A, 359, 953
16. Jimenez R. et al. 1999, MNRAS, 305, L16
17. Cowie L.L. et al. 1996, AJ, 112, 839
18. Cohen J.G. et al. 1999, ApJ, 512, 30
19. Eisenhardt P. et al. 2000, in “The Birth of Galaxies”, Xth Rencontres de Blois, ed. B. Guiderdoni et al. (astro-ph/0002468)
20. Cimatti et al. 2001, in preparation (see http://www.arcetri.astro.it/~k20/)
21. Menanteau F. et al. 1999, MNRAS, 309, 208
22. Treu T., Stiavelli M. 2000, ApJ, 524, L27
23. Moriondo G., Cimatti A., Daddi E. 2000, A&A, in press
24. Daddi E. et al. 2000, A&A, in press
25. Thompson D. et al. 1999, ApJ, 523, 100
26. Daddi E., Cimatti A., Renzini A. 2000, submitted
27. Stiavelli M. et al. 1999, A&A, 343, L25.
28. Spinrad H. et al. 1997, ApJ, 484, 581
29. Liu M.C. et al. 2000, AJ, 119, 2556
30. Soifer B.T. 1999, AJ, 118, 2065
31. Cimatti A. et al. 1999, A&A, 352, L45
32. Cimatti A., Andreani P., Röttgering H., Tilanus R. 1998, Nature, 392, 895
33. Dey A. et al. 1999, ApJ, 519, 610
34. Smail I. et al. 1999, MNRAS 308, 1061
35. Andreani P., Cimatti A., Loinard L., Röttgering H.J.A. 2000, A&A, 354, L1
36. Gear W.K. et al. 2000, MNRAS, in press (astro-ph/0007054)