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THE EVOLUTION OF THE OBSERVED HUBBLE SEQUENCE OVER THE PAST 6GYR

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RESUMEN

Durante los últimos años hemos enfrentado graves problemas de metodología al referirnos a la clasificación morfológica y cinemática de galaxias distantes. Esto nos ha obligado a crear una nueva metodología de clasificación morfológica, simple y eficaz, a fin de garantizar una correlación morfo-cinemática, hacer más fácil la reproducibilidad y restringir la subjetividad de la clasificación. Dadas las características de nuestra clasificación morfológica, ésta nos ha permitido aplicar la misma metodología, usando observaciones equivalentes, a muestras representativas de galaxias locales y distantes. De esta manera hemos podido obtener, por primera vez, la secuencia de Hubble distante (hace ∼6 Giga-años), y determinar la evolución morfológica de las galaxias durante los últimos seis Giga-años. Nuestros resultados sugieren que más de la mitad de las galaxias espirales de hoy en día presentaban una morfología peculiar hace 6 Giga-años.

ABSTRACT

During the past years we have confronted serious problems of methodology concerning the morphological and kinematic classification of distant galaxies. This has forced us to create a new simple and effective morphological classification methodology, in order to guarantee a morpho-kinematic correlation, make the reproducibility easier and restrict the classification subjectivity. Giving the characteristic of our morphological classification, we have thus been able to apply the same methodology, using equivalent observations, to representative samples of local and distant galaxies. It has allowed us to derive, for the first time, the distant Hubble sequence (∼6 Gyr ago), and determine a morphological evolution of galaxies over the past 6 Gyr. Our results strongly suggest that more than half of the present-day spirals had peculiar morphologies, 6 Gyr ago.

Key Words: galaxies: evolution — galaxies: formation — galaxies: peculiar — galaxies: spiral — galaxies: statistics — methods: data analysis

1. INTRODUCTION

Using Integral Field Spectroscopy, the IMAGES survey has allowed to study the spatially-resolved kinematics of distant galaxies (e.g., Yang et al. 2008; Flores et al. 2006). Such a survey has thus been essential to well understand the kinematics of distant galaxies and, further, its correlation to galaxy morphology (Neichel et al. 2008). As a result, IMAGES has lead us to develop new techniques (e.g., see Figure 1) in order to determine appropriate kinematic and morphological classification methods, which can guarantee the correlation between kinematics and morphology. This last point is now known not to be the case for some morphological classifications and it is still debatable for the rest of them.

As galaxy morphology has been considered sometimes as just taxonomy, it is important to remember that galaxy morphology is a direct consequence of the underlying physics governing their formation and evolution. This is the reason why, using a reliable methodology, morphology correlated to kinematics becomes a real physical tool to better understand the galaxy formation and evolution.

In the following I summarize one of the most important results beyond the IMAGES survey: the distant Hubble sequence and its observed evolution until the present-days (Delgado-Serrano et al. 2010).

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2. THE EVOLUTION OF THE OBSERVED HUBBLE SEQUENCE

We have worked with two samples of galaxies. One made up with local galaxies ($0.0207 \leq z \leq 0.030$) observed by the SDSS, and the other one composed of distant galaxies ($0.4 \leq z \leq 0.8$) located

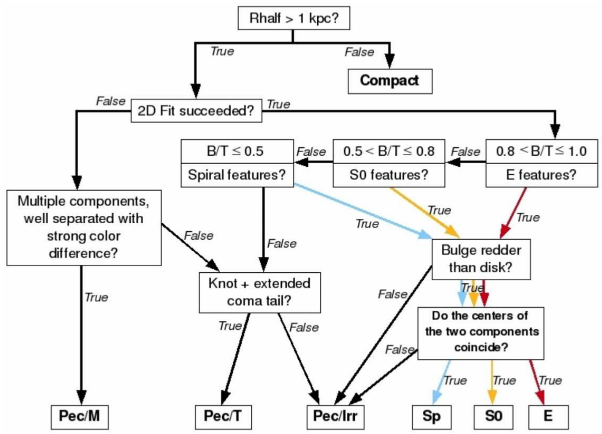

Fig. 1. Semi-automatic decision tree. Such a morphological analysis is in good agreement with the kinematic stage of the galaxies, make the reproducibility easier and restrict the classification subjectivity. This is not the case for the rest of morphological classifications.

in the CDFS field and observed by the HST/ACS. Both samples have been set up following one simple selection criterion: the absolute magnitude in J band brighter than -20.3. Furthermore, during the construction of our samples we have ensured that each galaxy have the information necessary for our analysis: good quality spectrum which includes the [OII]λ3727, and high resolution images in at least three optical bands. The first would allow us to distinguish between starburst and quiescent galaxies. The second, to construct color maps and three color images. In this way, we got a local sample of 116 galaxies, and a distant sample of 143 galaxies.

We show that both samples are representative of the galaxies at each respective epoch. To do so, we compare our samples with the luminosity functions obtained for local and distant galaxies. Kolmogorov-Smirnov tests indicate probabilities larger than 94% that our samples and the corresponding luminosity functions are drawn from the same distribution.

Our results show that, in the local Universe, $10 \pm 3\%$ of galaxies are peculiar, $72 \pm 8\%$ are spirals, $15 \pm 4\%$ are lenticulars, and $3 \pm 1\%$ are ellipticals. Respectively, in the distant Universe the percentages are $52 \pm 9\%$, $31 \pm 7\%$, $13 \pm 2\%$ and $4 \pm 1\%$ (see Figure 2). Moreover, we find that, in the local sample, 83% of galaxies are quiescent and 17% are starburst. In the distant sample 40% of galaxies are quiescent and 60% are starburst (Hammer et al. 1997).

The meticulous analysis shows that the comparison of the Distant and Local Hubble sequence is not affected by the selection criteria, k-correction,

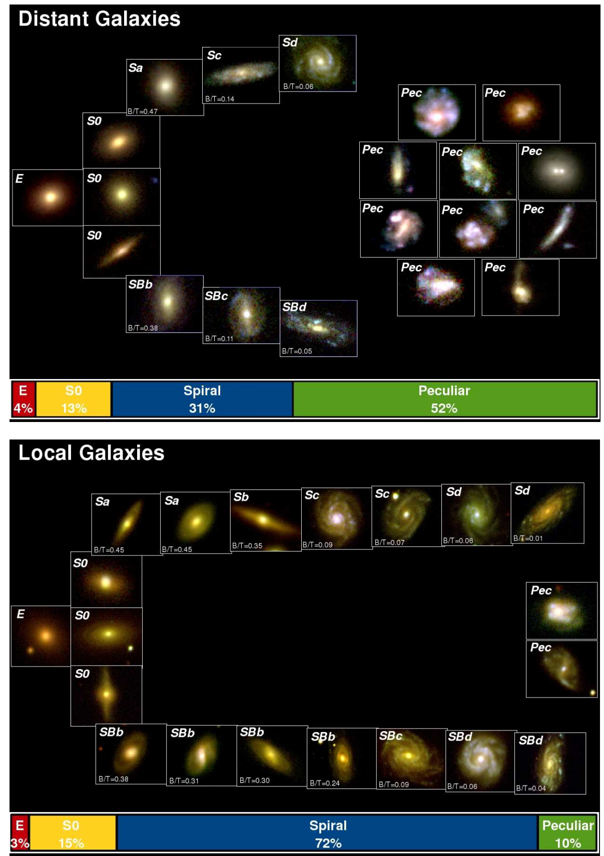

Fig. 2. In applying the same morphological classification method, we have been able to derive a past and a present Hubble sequence. In this figure, each galaxy image represents ∼5% of the whole galaxy population at each respective epoch.

cosmological dimming, spatial resolution and instrument differences (see more details in Delgado-Serrano et al. 2010). This has allowed us to link the past Hubble sequence to the present one. Therefore, we do find that spiral galaxies were 2.3 time less abundant in the past, which is compensated exactly by the strong decrease by a factor 5 of peculiar galaxies, while the fraction number of elliptical and lenticular galaxies remains constant. This strongly suggests that more than half of the present-day spirals had peculiar morphologies, 6 Gyr ago.

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