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PHYSICS OF GALAXY FORMATION WITH ELTS

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Abstract. The mapping of physical and chemical properties will be the next step in our understanding of the processes at work in galaxies during their mass assembling. Indeed, the different Integral Field Spectrographs (IFS) available on the VLTs can be combined to map several galaxy properties such as kinematics, electron density or metallicity. We have undertaken such a program using both VLT/GIRAFFE in the optical and VLT/SINFONI in the NIR, which can be considered as a preview of what will be possible with the future ELTs. First observational results as well as numerical simualtions for ELTs are presented.

1 Introduction

The current generation of largest space- and ground-based telescopes have made rapid progress and allowed us to place preliminary constraints on the physics of the formation of galaxies. Among the most important results are the decline of the cosmic star formation density by factor ∼10 since z∼1 (Lilly et al. 1996; Flores et al. 1999), and that about 50% of the present-day stellar mass has been formed since then (e.g., Dickinson et al. 2003; Drory et al. 2005). Most of this stellar mass (i.e., ∼40% of the present-day stellar mass) has apparently been formed in today's intermediate-mass spirals during episodic star formation episodes (Hammer et al. 2005; Bell et al. 2005), making distant galaxies very luminous in the infrared, and appearing as LIRGs (Luminous InfraRed Galaxies).

However, our knowledge of galaxy formation mostly relies on integrated quantities, and this is unsufficient to understand the details of the process of formation, e.g., the interplay between the baryonic and dark matter, or the complex physics of baryons (merging, star formation, feedback,...). This explains why the main driver of the mass assembling process is still not fully undertsood. At the heart of this debate is the respective importance of secular evolution with slow and continuous external matter accretion (e.g. Semelin & Combes 2005), versus more violent evolution through hierarchical merging (e.g. Hammer et al. 2005), as a function of lookback time.

2 A preview of future observations with ELTs

Using current facilities on 8m class telescopes, it is already possible to map some physical and chemical properties in distant galaxies.

Using FLAMES/GIRAFFE at the VLT in its IFU mode, it is possible to observe 15 intermediate redshift (z≤1) galaxies at the same time. We have observed a complete sample of 35 galaxies and derived velocity fields and velocity dispersion maps for 32 of these 35 galaxies (see Fig. 1; Flores et al. 2006; Puech et al. 2006a). Mapping the kinematics allowed us to reveal that as much as 40% of galaxies in this sample are dynamically not relaxed (Flores et al. 2006). A natural conclusion is that these kinematically complex galaxies would be on-going major mergers or remnants of such events. A detailed comparison with numerical models (in preparartion) will allow us to test this hypothesis further.

Thanks to the high spectral resolution of GIRAFFE (R∼10000), it is also possible to construct electron density maps via the line ratio of the [OII]$\lambda\lambda$3725,3729Å doublet (see Fig. 2). This kind of diagnostic allows to identify star forming regions in distant disks, as well as outflows (see Puech et al. 2006b).

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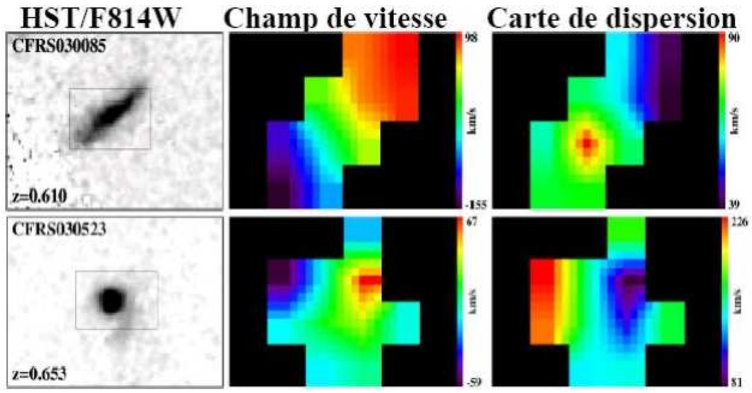

Fig. 1. Resolved kinematics of two z∼0.6 galaxies observed with GIRAFFE. From left to right: HST imaging, velocity field (the approaching side is in blue, and the receding side in red), and the velocity dispersion map. The first galaxy is a rotating disk, while the second one shows a complex kinematics.

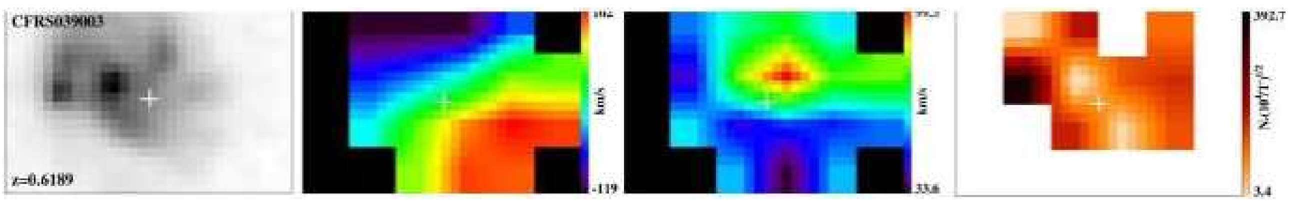

Fig. 2. Electron density map (on the right) of a z∼0.6 rotating disk, as derived from GIRAFFE observations. From left to right: HST imaging, velocity field, velocity dispersion map, and electron density map. This galaxy forms ∼100 $M_{\odot}$/yr (see Flores et al. 2004), while its kinematics does not look perturbed. A relatively dense region (with a density ∼400 electron per cm^3, as found in HII regions) can be seen on the left part of the galaxy, corresponding to a luminous region in the HST image. This probably localize most of the star formation activity in this region.

3 Physics of galaxies with ELTs

Combining existing integral field spectrographs could be a very important mean to make significant progress in our undertsanding of the formation of galaxies. Combining GIRAFFE in the optical with SINFONI in the infrared, would allow to map several physical and chemical properties of the ISM:

- Dynamics, from the Hα or [OII] emission line;
- Metallicity, using the R23 index (needs the [OII], [OIII] and Hβ emission lines);
- Extinction, using the Balmer ratio (needs both Hα and Hβ, or Hβ and Hγ);
- Star formation (corrected for extinction), using both Hα and Hβ, or Hβ and Hγ.

Extending such an approach to high redshifts (z∼4-5) requires an Extremely Large Telescope (ELT) with a diameter ∼40m and an integral field spectrograph (see Fig. 3).

To specify this kind of instrument, we have developped an end-to-end simulator (see Fig. 4). The optimal instrument would provide at least 20 objects at the same time in a 5x5 arcmin^2 FoV, with R≥5000 and a spatial resolution of ∼50 mas with about 40% of ensquared energy. Given that, in such small apertures, the ensquared energy in the seeing limited case is ∼1%, multi-objects adaptive optics (MOAO) becomes mandatory to reach a sufficient signal to noise ratio (see Neichel et al. 2006). Such simulations show that it is then possible to disentangle the dynamical nature of galaxies up to z∼5, and down to m_{AB} ∼25. Further simulations are needed both to constrain the AO system (PSF shape, number of actuators, ...) and consolidate the instrumental specifications.

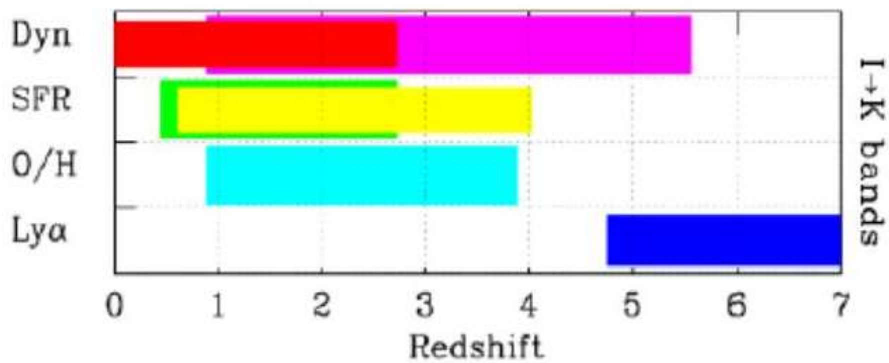

Fig. 3. Physical and chemical quantities that could be mapped with an integrated field spectrograph on an ELT working from I to K bands, as a function of the redshift. Dyn=Dynamics from the Hα emission line (in red) or from the [OII] emission line (in pink); SFR=Star Formation Rate from Hα and Hβ (in green) or from Hβ and Hγ (in yellow); O/H=oxygen abundance from R23.

4 Conclusion

Over the next 20 years, one of the major goals of astrophysics will be to map spatially resolved parameters of individual galaxies and the matter distribution at moderate to high redshift (z=1-5). These goals can be accomplished with an ELT by mapping the spatially resolved kinematics, star-formation, and chemical abundances of individual massive galaxies. We can then investigate the past history as well as constrain the future evolution of a statistically significant number of galaxies. This is a unique avenue to understand the growth and evolution of both the baryonic and dark matter components of high redshift galaxies that has not been possible to date.

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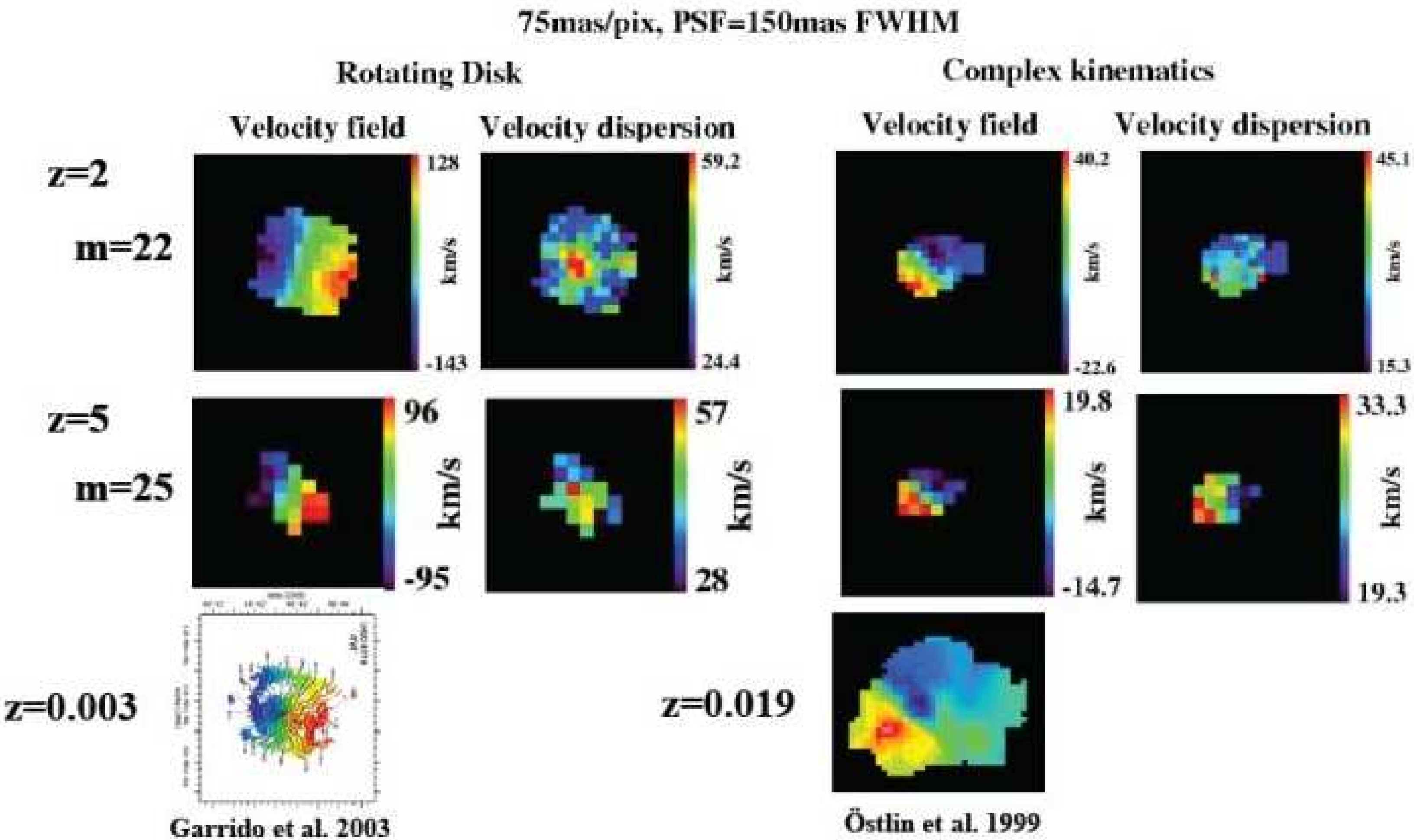

Fig. 4. Examples of numerical simulations performed to speficy an MOAO-fed multi-integral field spectrograph dedicated to an ELT. In this simulations, a rotating disk (left part) and a blue compact galaxy with a complex kinematics (right part) have been redshifted to z=2 (first line) and z=5 (second line); Their original velocity fields are shown on the last line. A full datacube rescaled in size and flux (m_{AB}=22 at z=2 and m_{AB}=25 at z=5), and degraded in resolution and sampling have been simulated in both cases. Here, we assumed a pixel of 75 mas, R=5000 and a gaussian PSF with FWHM=150 mas. Both velocity fields an dispersion map are then extracted from these datacubes, as for real observations. The dynamical nature of both objects is then correctly recovered up to z=5.