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MORPHO-KINEMATIC OF DISTANT GALAXIES WITH JWST AND MOSAIC

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Abstract. The combination of high spatial resolution from space imagery and 3D spectroscopy from ground is a remarkable tool to dissect distant galaxies and their internal motions. Using HST and VLT observations, we have captured the strong evolution of disk galaxies over the past 8 billion years ($z \sim 1$), which suggests disk (re)formation after gas rich mergers. At higher lookback time, the morpho-kinmatics of galaxies is strongly limited by the lower signal-to-noise and coarse spatial resolution of the observations. In the next decade, the synergy between JWST/NIRCAM and MOSAIC the futur MOS at the E-ELT will allow us to capture the morpho-kinematics up to the first galaxies and unveil the physical processes dominating their formation. The lesson learned at intermediate redshift will allow us to optimize the specification for MOSAIC to achieve the morpho-kinematics follow-up of galaxies from z∼4 to z=0.

Keywords: Extragalatic, Kinematics, Instrumentation

1 Introduction

Stamping the epoch of emergence of the disc galaxy population is a critical observational constraint for galaxy formation models. In the nearby Universe, the disk/merger ratio can be estimated using morphological studies, because mergers are easily recognizable by their characteristic morphological features (bridges, tidal tails, etc...). With increasing redshift, the classification of galaxies using imagery alone is jeopardized by observational limitations - cosmological dimming, coarser spatial resolution of the observations - and by possible changes in the properties of certain galaxy types. Kinematic studies from integrated field spectroscopy (IFS) observations are seen as a crucial tool to overcome the limitation of morphological classification. Accessing the internal kinematics of galaxies allow us to probe directly their dynamical and evolutionary state, and prevent us to be biases by star-forming regions or dust. In the past 10 years, many kinematic surveys have been carried on (see for a complete review Glazebrook 2013), e.g.: CALIFA at $z \sim 0$ (Husemann et al. 2013), IMAGES at $z \sim 0.6$ (Flores et al. 2006; Yang et al. 2008), MASSIV at $z \sim 1$ (Epinat et al. 2010, 2012), KMOS^{3D} at $z \sim 1-2$ (Wisnioski et al. 2015)and AMAZE/LSD at z∼ 3 (Gnerucci et al. 2011). These studies have led to discrepant results on the evolution of the disk/merger ratio. While several authors argue that the fraction of discs remains constant from z=0 to z∼2 (Förster Schreiber et al. 2006; Shapiro et al. 2008; Sobral et al. 2013; Wisnioski et al. 2015), other studies found a strong evolution of the fraction of rotating disks over the past 8 Gyrs (Yang et al. 2008; Epinat et al. 2010). These contradictory results are due to the heterogenous methodologies used to classify rotating disks. In section 2, we show that the limitations of kinematic classifications can be overcome with the addition of deep imagery. This has led us to propose a new classification based on the morpho-kinematic properties of galaxies. In section 3, we will discuss the synergie between JWST/NIRCAM and E-ELT/MOSAIC to unveil the nature of distant galaxies up to $z \sim 4$.

2 Morpho-kinematic classification of $z \sim 1$ galaxies

Hung et al. (2015) have shown that kinematic classifications tend to give an upper limit of the fraction of rotating disks. These systematics are due to two reasons. The first one is that integral-field observations of distant galaxies can only probe the ionized gas. However, the distribution of gas does not always follow the distribution of mass, in particular during merger events. Secondly, observations are restricted to a few spatial

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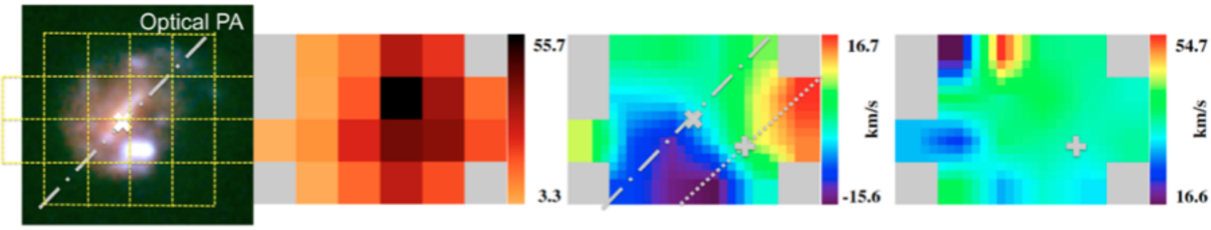

Fig. 1. Exemple of a galaxy with a velocity field consistant with a rotation (third panel). Deep imagery from the HST (left panel) shows that the major axis of the stellar component is misaligned respect to the gas kinematics. Unrelaxed systems can be easily distinguish by strong misalignment between the gas (IFU) and stars (imagery)

resolution elements and the outer isophotes are dramatically affected by low S/N. To overcome this, deep space imagery is needed to add constraints on the distribution of stars. Figure 1 illustrates how unrelaxed systems can be easily distinguished when combining kinematics and deep imagery observations, evidencing a strong misalignement between the gas (IFU) and stars (imagery). In Hammer et al. (2009), we presented a *morpho-kinematic* classification of distant galaxies which includes the morphological information provided by deep HST imagery into the kinematics classification. The classification follows a decision tree (Hammer et al. 2016) based on several morphological and kinematics parameters.

The morpho-kinematic classification requires 3D spectroscopy observations and deep HST imagery observations in several bands to construct surface brightness profiles and color maps. Deep imagery in at least one rest-frame band over 4000Å is mandatory to recover the stellar mass distribution. The decision tree allows us to classify galaxies into 3 morpho-kinematic categories :

- Rotating spiral disks: these targets present both spiral morphologies (exponential disk profile, spirals arms and/or bars) and kinematics consistant with a rotating disk (spider diagram, peak of dispersion coincides with the center of rotation and optical center).
- Semi-relaxed systems: this category includes objects that possess either a rotational velocity field and a peculiar morphology or a velocity field discrepant from rotation and a spiral morphology.
- Non-relaxed systems: these galaxies have complex kinematics (without velocity gradient) and peculiar morphologies.

In Hammer et al. (2009), we have applied this methodology to a representative sample of $z \sim 0.6$ galaxies observed with the HST ACS camera and the multi-IFUs spectrographe FLAMES/GIRAFFE at the VLT. We found that half of the present-day spirals had peculiar morphologies and anomalous kinematics at $z \sim 0.6$ (Neichel et al. 2008; Yang et al. 2008; Puech et al. 2008a), and conclude for a strong evolution of the number of disk galaxies over the past 8 billion years. This result favorises a scenario of disk formation through a mechanism of disk (re)formation after gas rich mergers (Hammer et al. 2005, 2009). Using archive data from the $KMOS^{3D}$ survey (Wisnioski et al. 2015), we are now extending our study at $z \sim 1$. The preliminary results indicate that the number of disk galaxies continue to decrease with increasing redshift, with only 25% of galaxies being rotating disk at $z \sim 1$.

3 The nature of distant galaxies with JWST and MOSAIC/E-ELT

At present time, morpho-kinematic studies of distant galaxies can be conducted in representative samples up to $z \sim 1$. At higher redshift, only the most massive and luminous galaxies are reachable with the actual instrumentation. In the next decade, the synergy provided by HST and VLT to morpho-kinematic studies will be renew with JWST and the E-ELT. These two telescopes will allow us to unveil the nature of galaxies in mass selected sample up to $z \sim 4$. The near-infrared imager embarked on JWST, NIRCAM, will give us deep and high resolution images of distant galaxies at wavelength above 4000Å (rest-frame). The set of simulations conducted in the framework of the E-ELT design reference mission[*] have shown that NIRCAM/JWST will be

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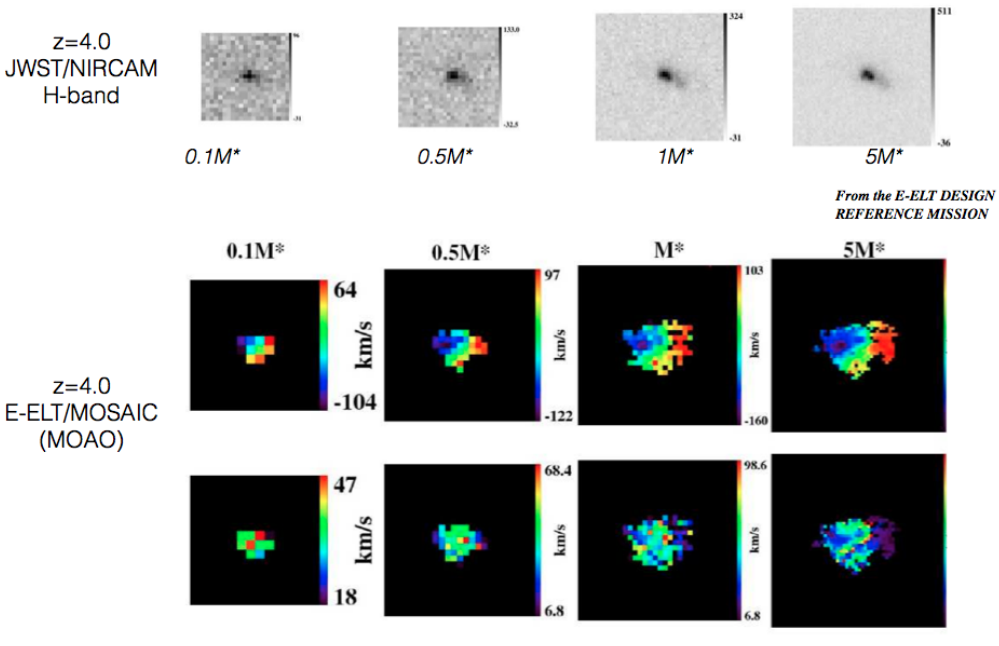
[*] `http://www.eso.org/sci/facilities/eelt/science/drm/`

able to observed $0.5M^*$ galaxies up to $z \sim 4$. On the other hand, the futur multi-IFU spectrograph for the E-ELT, MOSAIC (Hammer et al. 2014), will provide us with spatially-resolved kinematics of distant galaxies. The multi-IFU mode of MOSAIC will have the following specifications:

- FOV IFU ~2.0×2.0 arcsec;
- Multiplex~ 10 IFUs;
- Spatial pixel scale~ 80 mas in H-band using the multi-object adaptive optic systems (MOAO) ;
- Encircle Energy~ 30% EE in 2 spatial spatial pixels;
- R>4000-5000;
- λ-coverage: 0.8 - 1.8 μm.

The IFU observation allow us to retrieve spatial resolved map for $0.5M^*$ galaxies at $z \sim 4$, see simulation in Figure 2 (Puech et al. 2008b). In the framework of a futur legacy survey with MOSAIC, it would be possible to carry on a large kinematic survey of a mass-selected sample, previously defined from deep JWST observations at $1 < z < 4$. Assuming a multiplex of ten, 240 galaxies would require ~12.5 nights of MOSAIC observations, against ~250 nights in a single IFU instrument.



From the E-ELT DESIGN REFERENCE MISSION

From Puech et al. 2008

Fig. 2. NIRCAM/JWST simulation of $z \sim 4$ galaxies spanning stellar masses between $0.1M^*$ and $5M^*$ in H-band (upper-panel) and velocity and dispersion maps from MOSAIC/E-ELT with multi-object adaptive optic (MOAO).

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