Angular momentum evolution of Galaxies

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INTRO

The evolution of the angular momentum of galaxies is directly linked to their formation histories. In the current cosmological paradigm, galaxy formation is a complex process where inflows, outfLows, interactions and mergers are common events. What determines the final morphology of galaxies is still a matter of debate. Fall & Efstathiou (1980) (FE80) provided a theoretical explanation to the formation of disc galaxies based on the hypothesis of specific angular momentum conservation. This model is able to explain the observed correlation between the angular momentum of disc and the stellar mass.

In a CDM scenario, pure dark matter simulations predict that the specific angular moment **j** of the dark matter haloes grows with $M^{2/3}$. Hydrodynamical simulations have extended this analysis to the baryonic component. Several works show that if a disc component is able to form then it does so conserving its specific angular momentum: Dominguez-Tenreiro & Tissera (1998), Scannapieco et al. (2009), Sales et al. (2012), Pedrosa et al (2014). But recently Fall & Romanowsky (2014) (FR14), analysing obervational results, found that not only disk-dominated galaxies follow this relation but also elliptical ones follow a similar, nearly parallel, relation but offset to lower j_{star} at each M_{star}. They found that observed galaxies of all morphological types lie along nearly parallel sequences with exponents $\alpha \propto 0.6$ in the j_{star}-M_{star} diagram, with an offset between late and early type.

Consistently, Kravtsov (2013) (K13) found that characteristic size of stellar and gas distributions in galaxies scales approximately linearly with the virial radius (derived using abundance matching approach). He found that the relation is in good agreement with expectations of the model of Mo, Mao & White (1998) (MMW98). But remarkably, this prediction works not only for late type disks, but also for early type galaxies, probably meaning that angular momentum content is closely related with the sizes of galaxies of all morphological types.

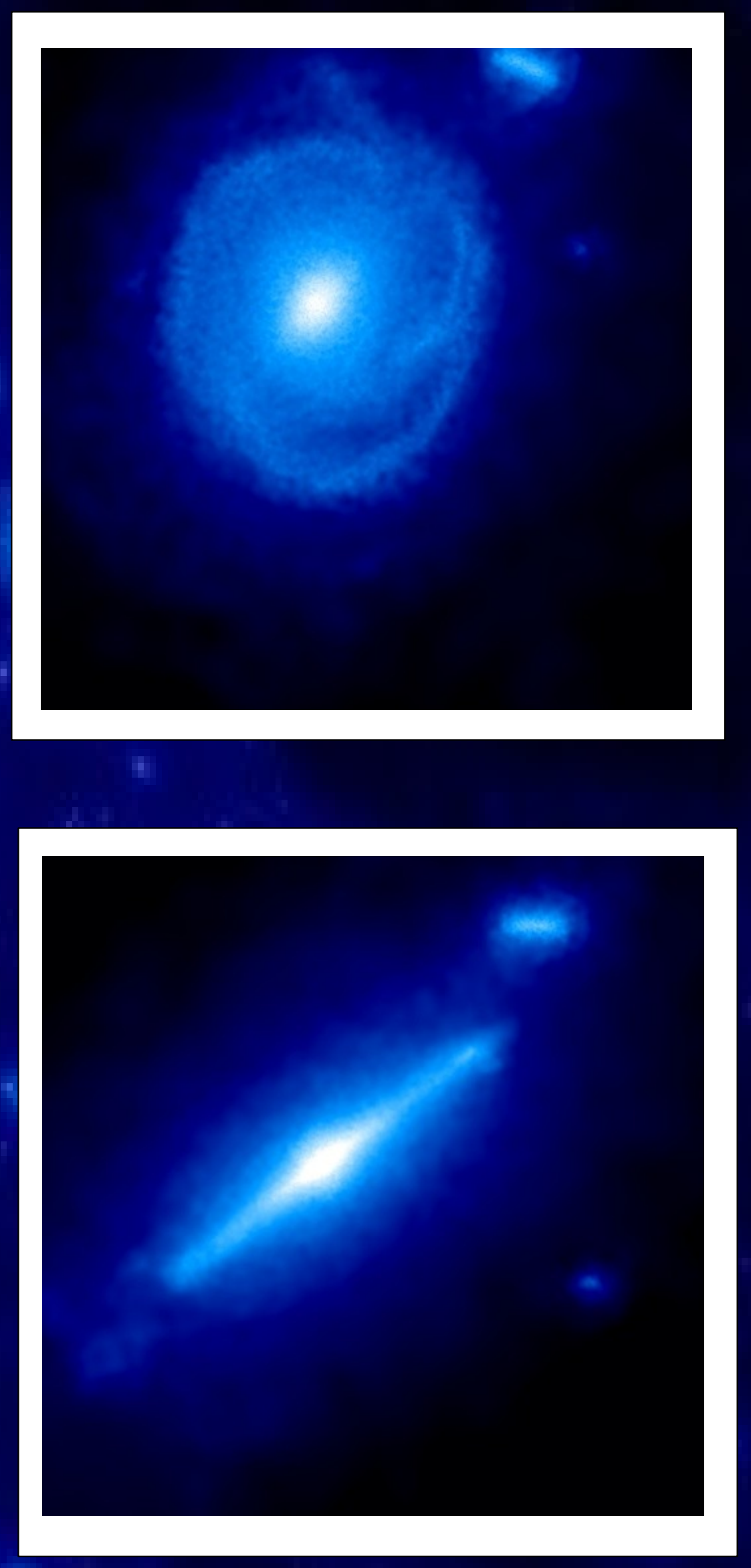

Figure 1

NUMERICAL EXPERIMENTS

We analysed cosmological simulations of a typical field region of the Universe consistent with the concordance model with $\Omega_{\Lambda}=0.7$, $\Omega_m=0.3$\$, $\Omega_b=0.04$, a normalization of the power spectrum of $\sigma_8=0.9$ and H_0= 100 h km s^{-1} Mpc^{-1}, with h=0.7. The simulations were performed by using the code GADGET-3, Springel et al. (2005), that includes treatments for metal-dependent radiative cooling, stochastic star formation, chemical enrichment, and the multiphase model for the interestellar medium and the Supernova (SN) feedback scheme of Scannapieco et al. (2005,2006), that includes the enrichment by Type II and Type Ia Supernovae. Our mass resolution is 5.9×10^6 h^{-1} M_{sun} and 9.1×10^5 h^{-1} M_{sun} for the dark matter and initial gas particles, respectively. We identfied virialized structures by using a FoF algorithm and then the substructures were identified using the SUBFIND program (Springel et al. 2001). For this study we use one of the simulations runs as part of the Fenix Project. This set of simulations share the same initial conditions but with slightly different parameters for the star formation regulation and SN feedback. In order to classify our simulated galaxies into early and late type we adopt the criteria of Tissera et al. (2012)

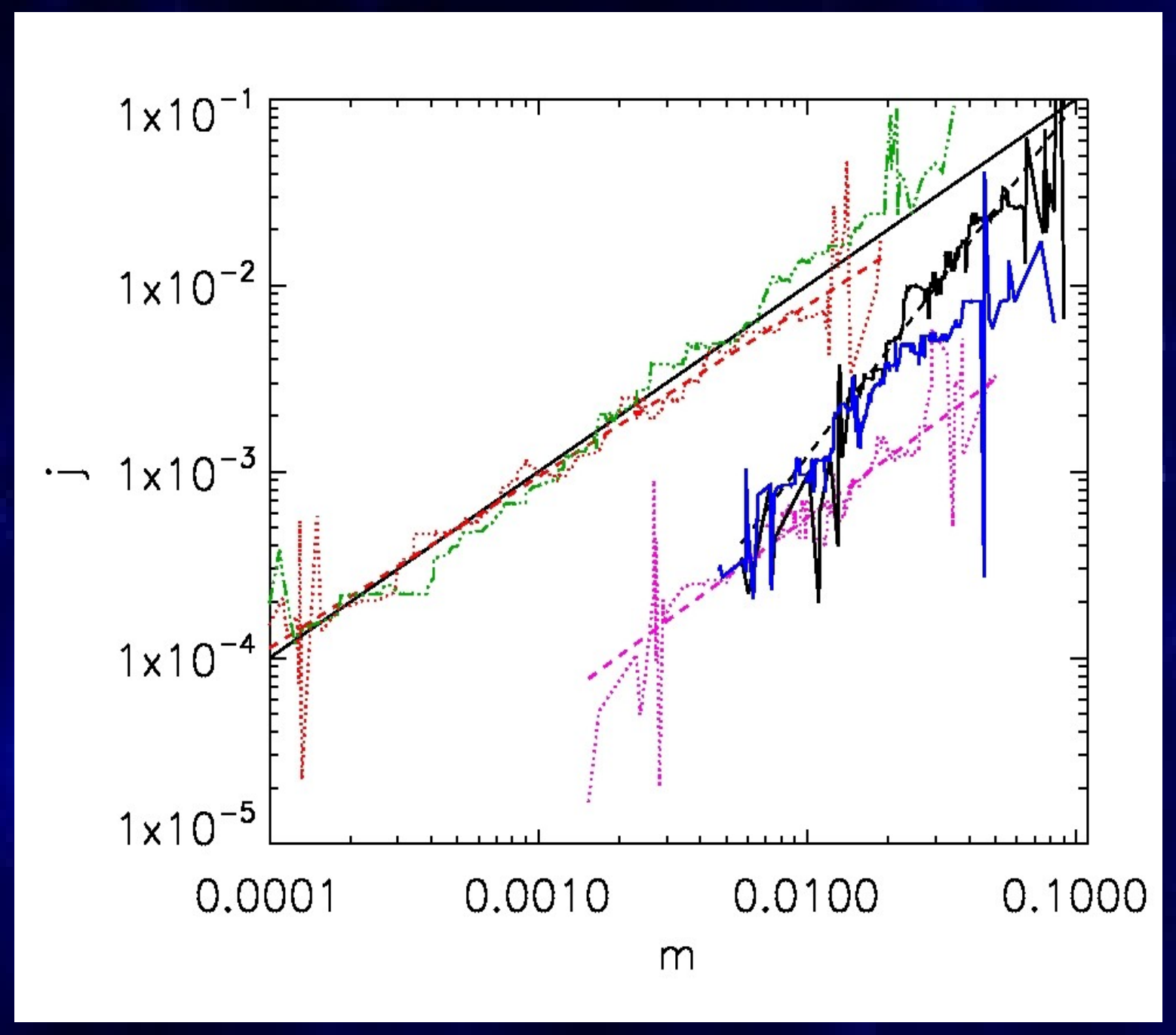

Figure 2

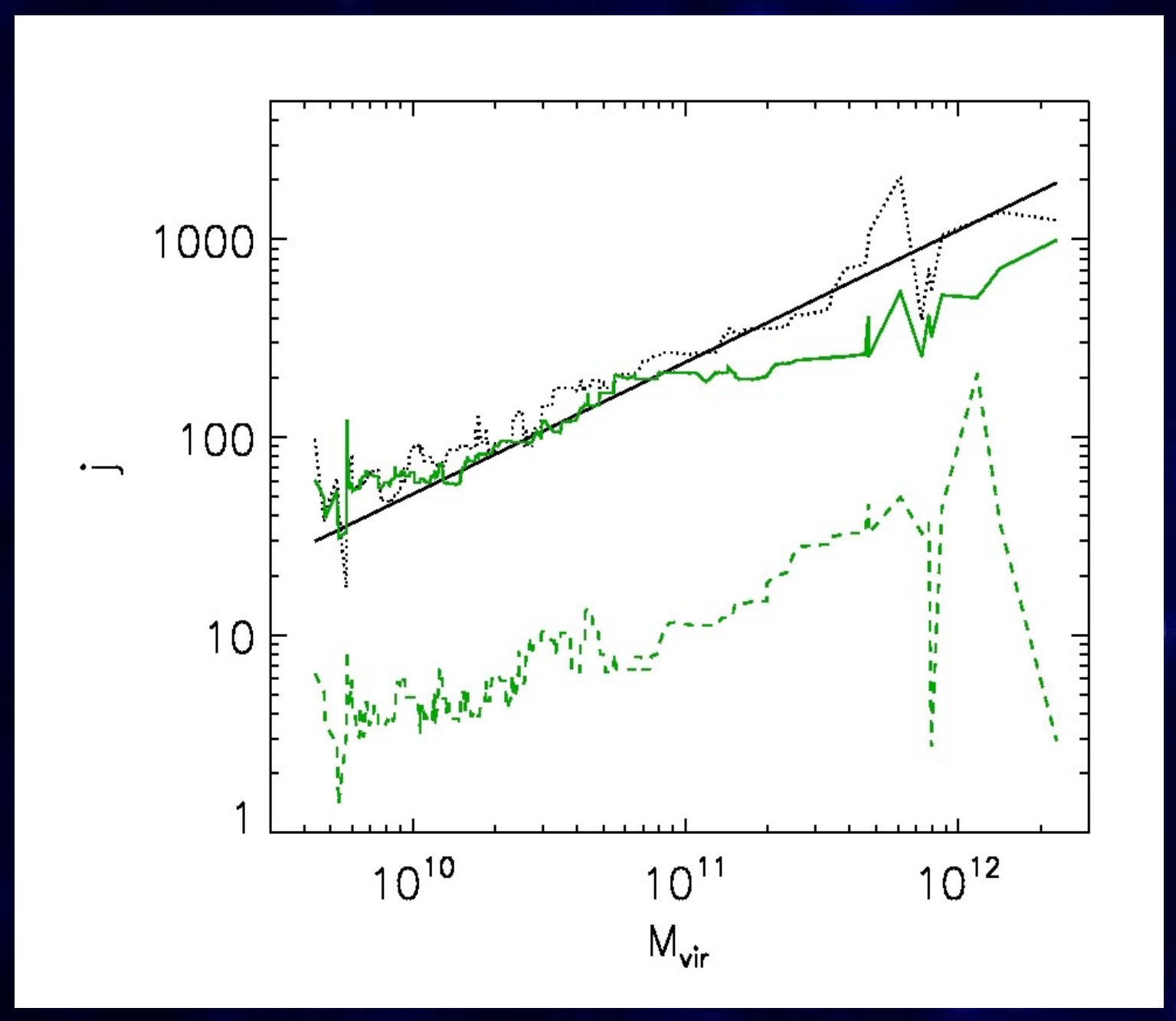

Figure 3

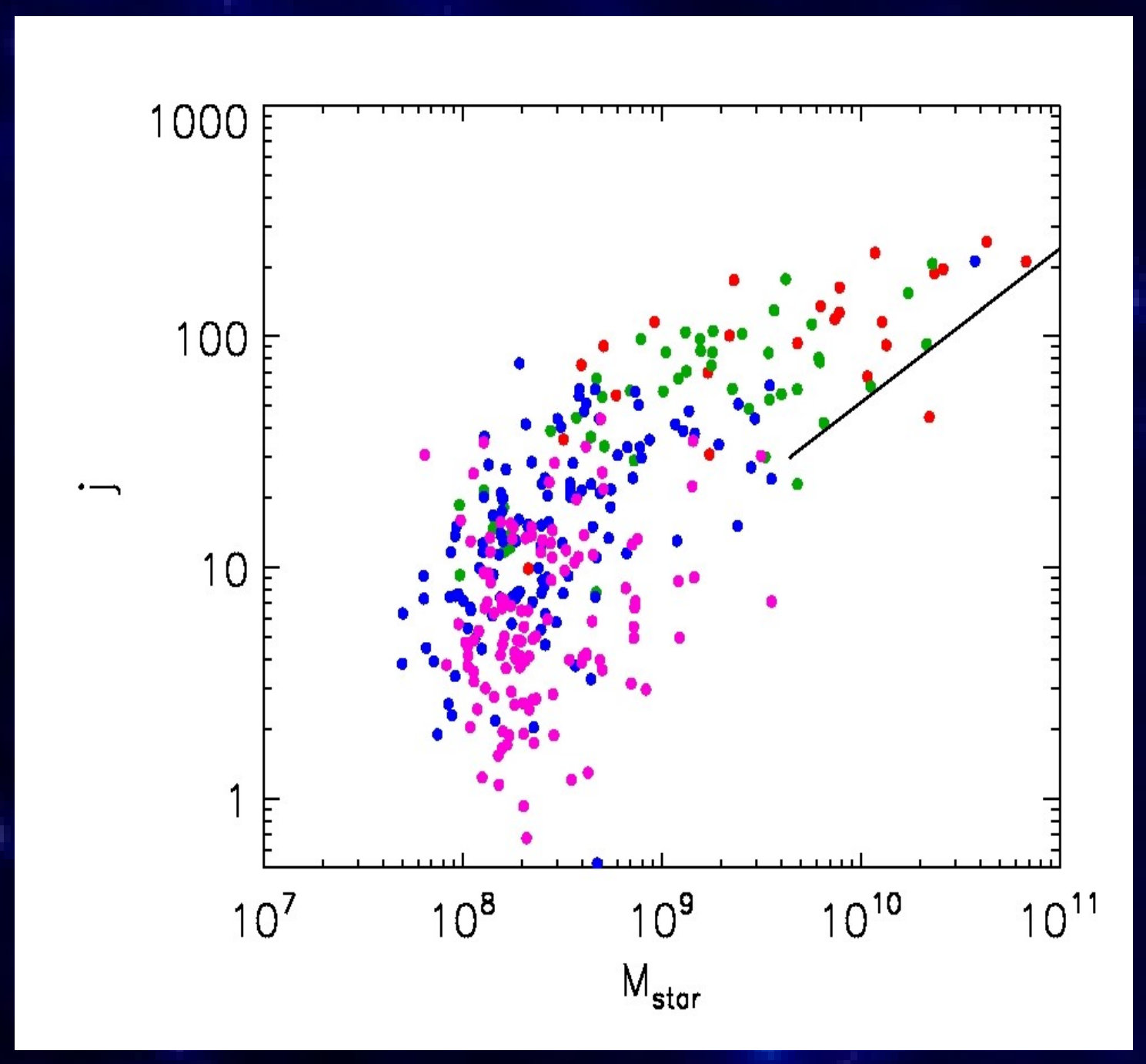

Figure 4

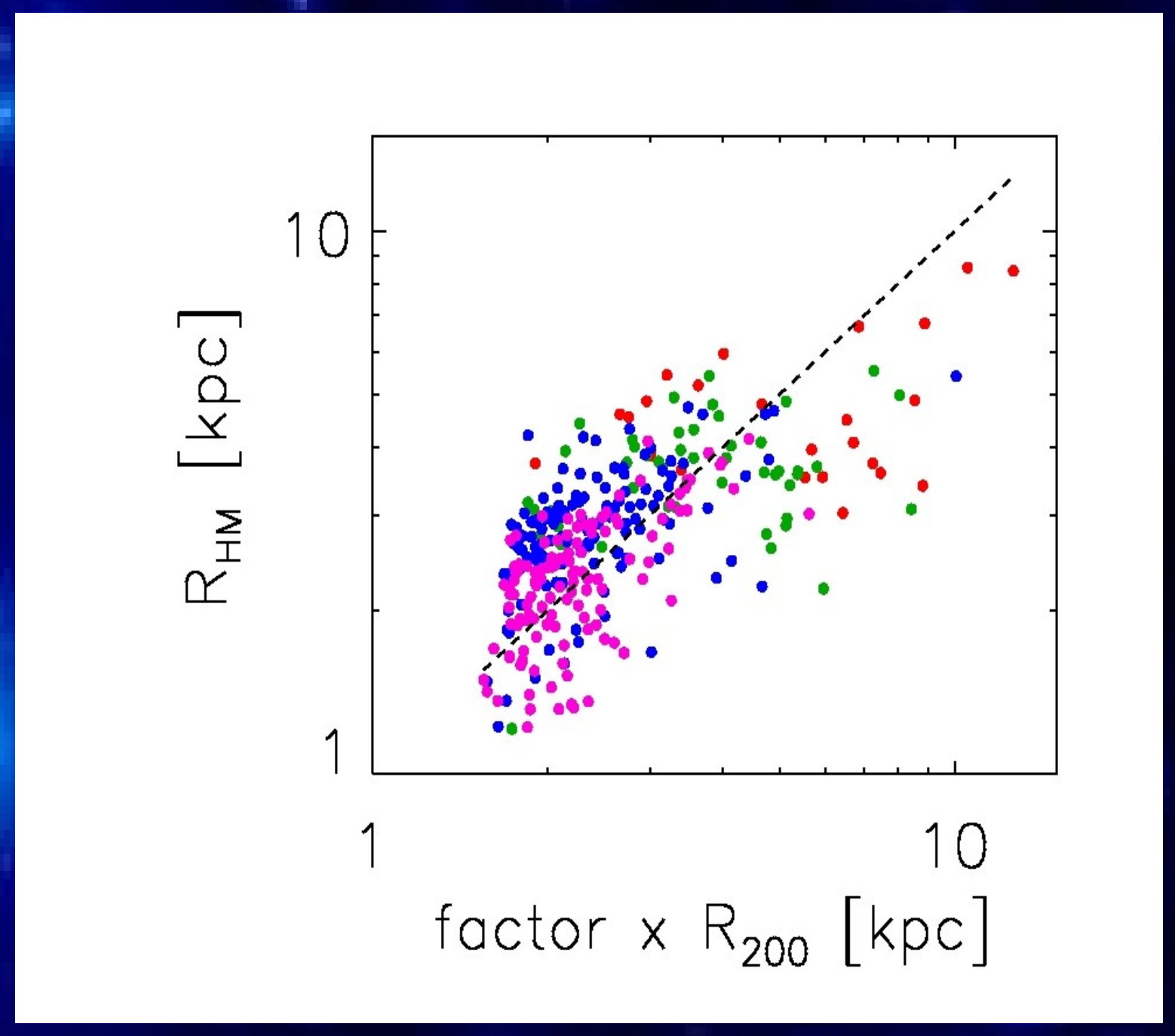

Figure 6

ANGULAR MOMENTUM CONTENT

We have analysed the angular momentum content of our simulated galaxies. We estimate the ratio between the specific angular momentum of the gas and stars in the discs within r_{gal} and the corresponding of the dark matter haloes within the virial radius $J_D/J_H = j_d$ as a function of the ratio between the corresponding masses $M_D/M_H = m_d$, using the classical notation of MMW98. In Figure 2 we show $j_d(j_{sph})$ versus $m_d(m_{sph})$. Stellar (red) and gaseous (green) j_d-m_d relation, the total baryonic component is shown in black. The total stellar component is shown in blue and the pink lines correspond to the stellar espheroidal one.

It can be seen that there is a clear correlation with the angular momentum of the dark matter halo, not only of the disk component but also of the central spheroid, as we have already found in Pedrosa et al. (2014) for a slight different tune of the feedback parameters. As assumed in many semianalitical models, there is a one to one relation between j_d and m_d for the disk, and we found also that the spheroidal component share the same relation but with an offset to lower angular momenta.

We found a clear correlation between the morphological type of the galaxy and the specific angular momentum content. In Figure 3 we show the specific stellar angular momentum of the disk (green continuos line) and bulge (green dashed line). In agreement with FR14, we found that both disk and spheroidals follow a parallel sequence. The specific angular momentum scales as $j \propto M^{2/3}$, the expected theoretical relation. The lost of angular momentum of the spheroidal component is directed related with the fact that in this case a rotationally supported structure wasn't able to form or may be it forms at higher redshifts but then, due to mergers and interactions, it loses part of its angular momentum.

In Figure 4 we show specific angular momentum against galatic mass, for different D/T ratios (red:DT > 0.6\$, green:0.4 < DT < 0.6, green:0.2 < DT < 0.4, pink:DT < 0.2; The theoretical relation for haloes: black continuos line). As expected, there is a correlation in the sense that higher D/T ratios are related with higher contents of specific angular momentum. It also present a good agreement with the observational trend found by FR14. The gap between disks and spheroids is filled with the corresponding intermediate morphological type.

SIZE

Clasical models for galaxy formation assumed that the angular momentum of the baryons is a fraction of the angular momentum content of the dark matter halo within the virial radius, so a linear relation is expected between the galatic size and the virial radius. K13 found that characteristic size of stellar and gas distributions in observed galaxies spanning several orders of magnitude in stellar mass scales approximately linearly with the virial radius derived using abundance matching technique. In Figure 6 we show the stellar half mass radius as a function of a fraction of the virial one, for different D/T fractions (red:DT > 0.6\$, green:0.4 < DT < 0.6, green:0.2 < DT < 0.4, pink:DT < 0.2). For our simulated galaxies we found a value of 0.04 for the factor relating both characteristic radius. This value is higher than the one found by Kravtsov, 0.015. This may be due to the so called pseudo-evolution of the haloes (Diemer et al. 2013)

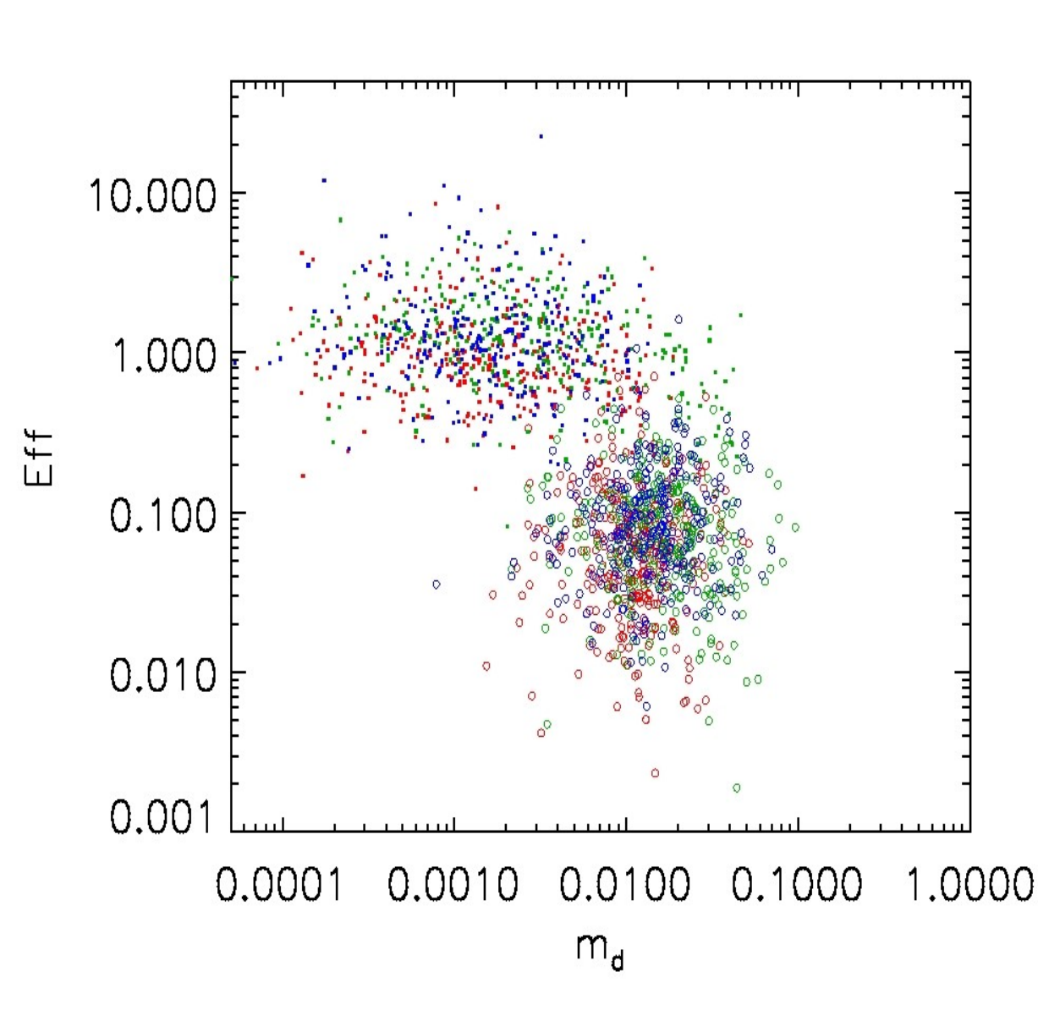

Figure 5

In Figure 5 we are plotting the Efficiency (defined as the ratio between the specific angular momentum of the disk(squares) and bulge(circles) component and the specific angular momentum of the dark matter halo) vs m_{d}, and as a function of redshift ($z=0$ (red), $z=1$ (green) and, $z=2$ blue). As expected the disk efficiency scatters around 1, reflecting the conservation of angular momentum during the formation of the disk. While in the case of the bulge component the efficiency is smaller. The scatter is greater at higher redshifts.

CONCLUSIONS

- The specific angular momentum scales following the theoretical relation for both disk and spheroidal components.
- The distribution of galaxies in the j-M plane is equivalent to the DT characterization.
- The galactic radius scales linearly with a factor of the virial one for all the morphologies, reflecting that angular momentum plays a crucial role in determining the size of the galaxy.