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Properties and evolution of disk galaxies in a hierarchical formation scenario

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Abstract. We highlight some results from disk galaxy evolution models conceived within a cosmological context. When disk mergers and strong disk-halo feedback are omitted, several properties and correlations of disk galaxies seem to be related to initial conditions given by the CDM model.

•**Motivation.** The inflation-inspired cold dark matter (CDM) hierarchical model has provided an invaluable theoretical framework for studies on galaxy formation and evolution. Nevertheless, several aspects of this phenomenon can not be treated as a simple (deductive) extrapolation of the hierarchical scenario, as is commonly done in some approaches. We have developed an approach where an inductive (backward) disk galaxy evolution model is combined with initial and boundary conditions calculated from the hierarchical scenario. Our main goal is *to find the relevant initial factors and physical ingredients that determine the main local and global properties, correlations and evolutionary features of disk galaxies.* In our approach (Avila-Reese et al. 1998; Avila-Reese & Firmani 2000a; Firmani & Avila-Reese 2000), disks form inside-out within growing CDM halos with a gentle gas accretion rate (no mergers) proportional to the hierarchical mass aggregation rate. We follow locally the overall evolution of individual disks in centrifugal equilibrium, including self-regulated star formation (SF) by feedback *within the disk ISM* (no disk-halo feedback) and population synthesis. Bulges are assumed to form via a secular mechanism. At the same time, as in the semianalytical approach, we are able to predict correlations and statistical properties of the disk galaxy population.

• **The disk Hubble sequence.** We find that the main properties and correlations of disk galaxy models are mainly determined by the cosmological conditions. For a given mass, the dark halo concentration, the galaxy color index and the disk gas fraction are basically related to the **mass aggregation history (MAH)**, while the disk surface brightness (SB), the bulge-to-disk ratio (b/d), and the shape of the rotation curve depend mainly on the **spin parameter** λ. The mass does not influence intensive properties. Thus, according to our models, the *Hubble sequence is biparametrical*, the MAH and λ being the two driving physical factors. The observational trends across the Hubble sequence are indeed reproduced: the redder and more concentrated is the disk, the smaller is the gas fraction and the larger is the b/d ratio. The disk mass fraction f_d also influences the models; we constrict its value to $0.03 < f_d < 0.08$, otherwise the

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Tully-Fisher relation (TFR) of LSB and HSB galaxies would be very different (lower limit) or the rotation curves would be too peaked (upper limit).

• **Are the infrared TFRs cosmological or not?** For the popular flat $\Omega_\Lambda = h = 0.7$ CDM cosmology, the predicted slope and zero-point of the infrared TFRs is within the range of observational determinations, the agreement being even better when shallow cores are introduced in the CDM halos. In our models and for the mentioned cosmology, the maximum circular velocity increases on average $20-25\%$ after disk formation which is ~ 2 times less than Steinmetz & Navarro (1999) reported from their N-body+hydrodynamic simulations (the "angular momentum catastrophe" problem). This factor of 2 in velocity translates into a factor of ~ 8 in mass or luminosity explaining why these authors obtain a TFR zero-point 2 magnitudes fainter than observed. The slope of our modeled TFR (~ 3.4) is essentially the slope of the halo mass-velocity relation (variations in the disk mass fraction only scarcely affect this slope). Since observations seem to show finally an upper limit of ~ 3.4 for the slope of the most infrared TFR (Tully & Pierce 1999; a similar slope was also found for the baryonic TFR, de Jong & Bell, this volume), our result suggest that there is not room for intermediate astrophysical ingredients like a dependence of SF efficiency or halo gas reheating on mass. Regarding the TFR scatter, we find it to be between 0.38 and 0.31 mag for velocities ranking from 70 to 300 km/s.

We also find that the **LSB and HSB galaxies have roughly the same TFR:** although for a given mass the $V_{\rm max}$ of LSB galaxies is less than that of HSB galaxies, the disk luminosity is also less since the SF efficiency depends on disk surface density. This also explains why the residuals of the TFR do not correlate strongly with the disk lenghtscale (or SB), avoiding this way the interpretation of Courteau & Rix (1997) of large amounts of dark matter in the inner parts of disk galaxies which is at odds with observations showing the shape of the rotation curves to correlate with SB for a given luminosity.

•**Some evolutionary features** (see Avila-Reese & Firmani 2000b). The shape of the SF history (SFH) in our models depends on the MAH and λ (SB). For most of the cases, this shape has a broad maximum at $z \approx 1.5-2.5$ and a fall towards $z=0$ by factors 2-4. This factor is $\sim 6-10$ in the measured *global* SFH. Then, other galaxy populations than disk galaxies had to have contributed in the past to the global SF rate. The $B-$band luminosity is larger and the galaxy colors become slightly bluer in the past. The disk sizes strongly decrease towards the past (a factor of 2 at $z \gtrsim 1$ w.r.t. $z=0$), while the SB increases.

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