RevMexAA (Serie de Conferencias), **40**, 56–57 (2011)

SUPERNOVA FEEDBACK AND THE BEND OF THE TULLY-FISHER RELATION

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RESUMEN

Estudiamos el origen de la relación de Tully-Fisher analizando simulaciones hidrodinámicas en un universo ΛCDM. Encontramos que las galaxias más pequeñas exhiben masas estelares menores que aquellas predichas por el ajuste lineal de las galaxias más masivas, en consistencia con las observaciones. En este modelo, estas tendencias son generadas por la acción más eficiente de la retroalimentación al medio por supernovas en la regulación de la formación estelar de las galaxias más pequeñas. Sin introducir parámetros dependientes de escala, el modelo predice un cambio de pendiente en la relación de Tully-Fisher para una velocidad característica de $\sim$100 km s^{-1}, en acuerdo con resultados observacionales y teóricos previos.

ABSTRACT

We have studied the origin of the Tully-Fisher relation by analysing hydrodynamical simulations in a ΛCDM universe. We found that smaller galaxies exhibit lower stellar masses than those predicted by the linear fit to high mass galaxies (fast rotators), consistently with observations. In this model, these trends are generated by the more efficient action of supernova feedback in the regulation of the star formation in smaller galaxies. Without introducing scale-dependent parameters, the model predicts that the Tully-Fisher relation bends at a characteristic velocity of $\sim$100 km s^{-1}, in agreement with previous observational and theoretical findings.

Key Words: cosmology: theory — galaxies: evolution — galaxies: formation

1. INTRODUCTION

The Tully-Fisher relation is very important for constraining galaxy formation models because it links two fundamental properties of galaxies such as the stellar (sTFR) or baryonic (bTFR) mass and the depth of the potential well.

In particular, there are observational evidences that the sTFR does not follow a linear trend for the whole range of observed rotation velocities. According to the results of McGaugh et al. (2000), the sTFR bends at $\sim$90 km s^{-1} in such a way that smaller galaxies have lower stellar masses than those derived from the extrapolation of the linear fit to fast rotators. Moreover, McGaugh et al. (2010) have reported that there is also a bend in the bTFR but at a lower rotation velocity ($\sim$20 km s^{-1}).

2. SIMULATIONS

In this work, we studied the role of Supernova (SN) feedback on the shape of the sTFR and bTFR by analysing hydrodynamical simulations in a ΛCDM universe[4]. A version of the chemical code GADGET-3 including treatments for metal-dependent radiative cooling, stochastic star formation and SN feedback (Scannapieco et al. 2006) was employed. The simulated volume corresponds to a cubic box of a comoving 10 Mpc h^{-1} side length. The simulation has a mass resolution of $6 \times 10^6\ M_\odot\ h^{-1}$ and $9 \times 10^5\ M_\odot\ h^{-1}$ for the dark and gas phase, respectively.

Simulated disc-like galaxies were identified following the methods describe by De Rossi et al. (2010). The mean properties of galactic systems were estimated at the baryonic radius $R_{\rm bar}$, defined as the one which encloses 83 per cent of the baryonic mass of the systems. We found that the tangential velocity of these systems constitutes a good representation of their potential well so that, for the sake of simplicity, we used the circular velocity estimated at $R_{\rm bar}$ as the kinematical indicator for our study.

3. RESULTS AND DISCUSSION

The massive-end of the simulated sTFR can be fitted by a power-law of the form $\log(M_*/M_\odot\ h^{-1}) = (3.68 \pm 0.09) \times \log(V/100\ \mathrm{km\ s^{-1}}) + (9.42 \pm 0.26)$,

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[4]$\Omega_{\rm m} = 0.3$, $\Omega_\Lambda = 0.7$, $\Omega_{\rm b} = 0.04$ and $\mathrm{H}_0 = 100\ h^{-1}$ km s^{-1} Mpc^{-1} with $h = 0.7$

in general good agreement with observations. However, at rotation velocities below $\sim$100 km s^{-1}, the sTFR becomes steep and the residuals of the linear fit depart systematically from zero, consistently with the findings of McGaugh et al. (2000). To analyse the role of SN feedback on the origin of the bend of the sTFR, we run a feedback-free simulation. We found that, when SN feedback is suppressed from the model, the sTFR describes a linear behaviour indicating the crucial role of SNe in the modulation of this relation.

With respect to the bTFR, both the SN feedback model and the feedback-free run show a single slope for the relation at least for the range of velocities resolved by these simulations (40 km s^{-1} $< V <$ 250 km s^{-1}). These results are not in disagreement with the findings of McGaugh et al. (2010) because they reported a bend in the bTFR at $\sim$20 km s^{-1}.

By analysing the simulations at higher redshifts ($0 < z < 3$), we obtained similar trends. We have also checked that our results are robust against numerical resolution. For further details, the reader is referred to De Rossi et al. (2010).

Finally, we explore how the SN feedback model is capable of reproducing these behaviours without introducing scale-dependent parameters. To analyse the impact of galactic outflows in the simulated galaxies, we defined the fraction $f_{\rm b}^{\rm vir}$ as the ratio between the baryonic mass within the virial radius to the one inferred from the universal baryonic fraction ($\Omega_{\rm b}/\Omega_{\rm m}$). In these simulations, $f_{\rm b}^{\rm vir}$ is within the range 0.2–0.8 showing that for the whole sample a significant percentage of the gas in blown away as a consequence of efficient galactic winds. The more prominent losses are obtained for smaller galaxies.

Moreover, by comparing the SN feedback model with the feedback-free run, we found that SN winds generate an important decrease in the star formation activity of galaxies with the larger effects in slow-rotating systems, consistently with the bend of the sTFR. Indeed, our results suggest that the role of SN feedback on the regulation of the star formation strongly depends on the mass of the galaxies. In particular, we distinguish two distinct regimes for the thermodynamical transitions of the gas phase. In the case of smaller galaxies, the virial temperatures are lower and SN heating is more efficient at promoting gas from a cold to a hot phase (see Scannapieco et al. 2006 for more details about the model). However, the cooling times of these systems are shorter than the dynamical times and the hot gas can return to the cold phase in short time-scales. Therefore, for slow-rotators, SN feedback leads to a self-regulated cycle of heating and cooling strongly influencing the star formation activity of these systems. In the case of massive galaxies, the hot phase is established at a higher temperature and SN heating cannot generate an efficient transition of the gas from the cold to the hot phase. Meanwhile, the cold gas remains available for star formation. On the other hand, the cooling times for these galaxies get longer compared to the dynamical times and the hot gas is able to remain in the hot phase during longer time-scales. Hence, SN feedback is not efficient at regulating the star formation in larger galaxies. Interestingly, in this model, the transition from the efficient to the inefficient cooling regime for the hot-gas phase occurs at the same characteristic rotation velocity where the sTFR bends ($\sim$100 km s^{-1}) and is also in agreement with previous observational (e.g. McGaugh et al. 2000) and theoretical works (Larson 1974; Dekel & Silk 1986).

4. CONCLUSION

We studied the Tully-Fisher relation by performing numerical simulations in a cosmological framework. We obtained a sTFR and a bTFR in general agreement with observations. The SN feedback model is able to reproduce the observed bend of the sTFR at a characteristic velocity of $\sim$100 km s^{-1} without introducing scale dependent parameters. We found that this characteristic velocity separates two different regimes: slow-rotators develop a self-regulated cycle of efficient SN heating and radiative cooling while, in fast-rotators, the cold an hot gas-phases seem to be more disconnected. The reader is referred to De Rossi et al. (2010) for more details about this work.

MEDR and SEP thank the Organizing Committee for its partial financial support to attend this meeting. We acknowledge support from the PICT 32342 (2005) and PICT 245-Max Planck (2006) of ANCyT (Argentina). Simulations were run in Fenix and HOPE clusters at IAFE and Cecar cluster at University of Buenos Aires.

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