Título: DWARF GALAXIES IN LCDM: DISTRIBUTION AROUND HOSTS, DUST EMISSION AND INTERNAL STRUCTURE

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Resumen: The aim of this thesis has been to better understand the formation and evolution of dwarf galaxies within a cosmological LCDM context, therefore testing some of the so-called "small-scale problems". To this purpose, I have accurately compared predictions from state¿of¿the¿art high-resolution cosmological hydrodynamical simulations with the available multi-wavelength observational data of nearby galaxies. Specifically, I have worked with galaxy simulations from the CLUES, MaGICC, NIHAO, PDEVA and Aquarius projects. All of these zoom-in hydro-simulations include detailed sub-grid recipes to realistically model the energy feedback effects coming from the evolution of gas and stars, as well as the formation and diffusion of elements. In addition, CLUES is a simulation of our Local Group environment. I have studied a wide range of dwarf galaxy properties, including their internal mass distribution, total and baryonic mass content, element abundance, rotation curves, spectral energy distributions, infrared dust emission, and spatial distribution around their host galaxy. These analyses have led to significant conclusions in terms of reconciling the observed dwarf Universe with predictions from hydro-simulations.
The first part of this thesis has consisted in studying the internal structure of dwarf galaxies, focusing on angular

momentum acquisition within simulations. I started by testing the angular momentum content of simulated galaxies locally, at each radius, by means of the mass discrepancy¿acceleration relation (MDAR), which ultimately represents an instructive way to display the radial mass distribution of a population of disk galaxies. The MDAR of 22 simulated disk galaxies with intermediate to high stellar masses from the MaGICC and CLUES simulations (run with the SPH code GASOLINE) were computed, finding that all galaxies naturally followed the empirical relation that holds for galaxies of widely varying luminosities and gas fractions. The scatter was matched as well. This was the first time that this relation was recovered self-consistently within a LCDM model. The implications are that the angular momentum acquisition in these simulations, driven by tidal torques and a complex web structure within a LCDM model, and its regulation by an efficient energy feedback scheme, induces the baryonic cycle needed to yield a correct radial distribution of gas, stars and dark matter in galaxy disks at z=0.

I next tested angular momentum content in MaGICC simulated galaxies globally, by studying the empirical relation found between the final total baryonic mass of disk galaxies and their characteristic rotational velocity: the baryonic Tully-Fisher relation (BTFR). This relation presents a very tight scatter for high mass galaxies. The rotational velocities of simulated MaGICC galaxies spanning from dwarfs to massive spirals were measured by carefully imitating observational methods and criteria (in particular, concerning HI gas). It was showed that there is no single Baryonic Tully-Fisher relation, as the low-mass end of this relation depends greatly on the method used to measure the characteristic rotational velocity of dwarf galaxies. This is because these galaxies in general present rotation curves that are still rising at their last measured point and do not show a final flat velocity. Nonetheless, the BTFRs of the suite of MaGICC galaxies derived using different measures for the characteristic rotational velocity, were shown to be consistent with the corresponding observed relations derived following the same methods. This implies that MaGICC galaxies of all sizes and masses acquire a realistic amount of angular momentum and total baryonic mass; and suggests that its detailed subgrid feedback scheme (including a blastwave formalism for supernovae explosions and thermal and pressure energy release from massive stars), which has been shown to reproduce realistic MW-like disk galaxies, is as well needed to reproduce realistic dwarf galaxies at redshift z=0.

A natural next step in the study of dwarf galaxy internal structure was to make use of the wealth of information contained within extended rotation curve data. In order to assess the diversity of rotation curve shapes with regards to the "cusp-core problem", I systematically compared the inner-outer circular rotation velocities of the NIHAO project simulated galaxies and the SPARC galaxy sample. Methodwise, I introduced the use of the empirical Mstar-Rlast relation with scatter (where Rlast is the last measured point of a rotation curve), as a convenient way to derive the corresponding Rlast radius in simulated galaxies of a given stellar mass and consistently compare characteristic rotational velocities of samples of simulated and observed galaxies with a minimal uncertainty. The comparison yielded that NIHAO simulations followed a similar distribution to observed galaxies on the V2kpc¿VRlast plane, sharing an increased scatter in the low-mass region where dark matter halo expansion from stellar feedback is theoretically predicted to be most efficient: a sign of a higher diversity of rotation curve shapes. Finally, a few observed galaxies with very steep rotation curves were not matched by any NIHAO galaxy. These were shown to belong to a population of starburst/emission-line galaxies with a very high central dynamical mass.

The second part of the thesis has consisted in studying dwarf galaxy emission taking into account the effects of dust absorption and re-emission. This was motivated by recent high-resolution infrared (IR) observations of low-metallicity nearby galaxies that revealed the diversity and specificities of dwarf galaxy spectral energy distribution shapes, as compared to their more massive and metal-rich counterparts. These are summarized in a broadening of the IR peak, an excess of emission in the submm wavelength region, and a very low intensity of polycyclic aromatic hydrocarbon emission features. I tackled this puzzle making use of a sample of CLUES star-forming dwarf galaxies as objects, and the GRASIL-3D radiative transfer code as analysis tool. GRASIL-3D allows to recover the observed spectral energy distributions and luminosities at all wavelengths of simulated galaxies, and therefore, perform an accurate comparison of theoretical models with the real data we actually observe: light. Furthermore, it includes a detailed two-component model for dust, according to which young stars heat dust within the molecular cloud gas phase, while evolved stars heat dust within the cirrus phase. The SEDs produced by GRASIL-3D were surprisingly similar to observed ones from the KINGFISH and DGS surveys: the different energy absorption of the two dust emission components gave clearly separated peak maxima, with different peak intensities. Specifically, the cases with most-recent star formation presented dominant molecular cloud emission. It was shown that the combination of both components gave place to the variety of SED shapes expected. The study emphasized the importance of carefully accounting for dust properties when comparing simulated and observed galaxy SEDs, and verified GRASIL-3D¿s sophisticated modeling of dust. Furthermore, the oxygen abundances (metallicities), neutral and molecular hydrogen gas content, and star-formation rates of CLUES local star-forming dwarf galaxies, were shown to be consistent with those of observed galaxies within the same stellar mass range.

The last part of this thesis has been devoted to a further understanding of the 'planes of satellites' problem within the context of hydrodynamical cosmological simulations. To this aim, first a deepening in the methodology for plane-searching is needed. Therefore I carried out a detailed search for planes of satellites in two zoom-in simulations of disk galaxies, namely PDEVA-5004 and Aquarius-C, which are MW-like galaxies with a high number of satellite galaxies and an overall quiet late merger history. I started by using the 4-galaxy-normal method to search for planes of satellites from a 3D-positional analysis. Its application to the available observational data for the MW and M31 resulted in the finding that Andromeda presents a second plane of satellites that is approximately perpendicular to that known as the "GPoA", with similar properties in terms of thinness and at least the same number of members (~15). Furthermore, I introduced an extension to the 4-galaxy-normal method consisting in an iterative plane-fitting process. This analysis enabled to show that when the 3D spatial information is used it is possible to find higher quality planes in the MW and M31 than those originally found observationally, given a same number of members. The inference is that the best positional planes of satellites of a system are not necessarily defined by the most massive (or luminous) satellites, and hence should not be searched for with this constraint. Applied to simulations, this method proved to be suitable to find predominant planar configurations of satellites, and in particular, very high-quality planes in terms of thickness and number of members. However, these high-quality planes in general do not contain a high fraction of co-orbiting satellites, meaning that they are not kinematically-coherent structures.

In view of the previously mentioned results, I developed a new method based on the full 6D-phase-space (position + velocity) information of satellites to find kinematically-coherent planes of satellites: the 3-Jorb-barycenter method. It successfully allowed to identify specific groups of satellites with aligned orbital angular momentum vectors across time. In particular, both PDEVA-5004 and Aq-C present groups of kinematically-coherent satellites that define long-lasting spatial planes of satellites. The orientation of these planes with respect to their corresponding central galaxies has been found to be approximately perpendicular to the galactic disk, remaining very much unchanged as the system evolves despite movement of the central galaxy spin vector. This suggests that the planes of satellites are influenced by the motion of the disk. I also studied the

properties of kinematically-coherent satellites in order to see if they represent a family of galaxies with special characteristics. It has been found that these satellites present significantly larger specific orbital angular momentum, and larger orbital pericenter distances, than non-kinematically-coherent satellites. Moreover, there are moments during the evolution where their orbital angular momentum vectors form larger angles than average with the central galaxy spin vector, defining orbits that are approximately perpendicular to the disk. On the other hand, kinematically-coherent and non-kinematically-coherent satellites are rather statistically indistinguishable when total baryonic mass is concerned. Indeed, the PDEVA-5004 and Aq-C satellite samples are more massive in general than those observed in the MW and M31 owing to the mass resolution limit of simulations. We therefore tested that the results of the plane-finding methods used (the 4-galaxy-normal method and the 3-Jorb-barycenter method) are not biased by mass effects. Correlation tests performed around the time at which satellites were selected convey that there is no clear correlation between the total baryonic mass of a satellite and the number of times it contributes with 4-galaxy-normals or 3-Jorb-barycenters to the main over-density at a given timestep. This important result proves that the methodology used and hence also the conclusions reached in this analysis are independent of simulation mass resolution.

Finally, current work in progress involves searching for a link between the origin of these co-orbiting satellites and the large-scale structure in which they are embedded at high redshift, as proposed by theoretical studies.