News&Views– draft-31-12-2016;

Satellites of Satellites in isolation

The discovery of seven groups of dwarf galaxies in extremely isolated environments provides one of the first observational evidence of the hierarchical assembling process in action at small galactic scales.

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In the currently favored scenario for the formation and evolution of the Universe, structures form and grow by merging of smaller units. Simulations show that the first structures to form are `haloes' of invisible dark matter as small in size as the solar-system; then they gradually merge to produce larger and larger structures, like galaxies and clusters of galaxies[2]. As a result of this continuous `hierarchical' assembling process, present-day galaxies are expected to be surrounded and orbited by a large number of smaller satellites, i.e. the surviving `building-blocks' that were not cannibalized by the galaxy growth. Observations support this hierarchical merging model in several ways, starting from the evidence that giant spiral and elliptical galaxies, among which our own Galaxy, the Milky Way, are surrounded by numerous dwarf satellites and stellar streams formed out of the material removed from accreted systems. On the other hand, direct observational evidence of hierarchical assembly at dwarf galaxy scales is still scanty[9,11], despite the fact that isolated giant- and dwarf-galaxy haloes are predicted to contain the same relative abundance of substructures according to simulations.

Writing in *Nature Astronomy*, Stierwalt and colleagues[13] report one of the first direct observational evidence of hierarchical structure formation at low masses: seven isolated, very compact groups with only dwarf galaxies as members. The groups were discovered while visually inspecting the most isolated dwarf galaxy pairs in the TyNy Titans Survey (TNT)[14], a multi-wavelength observational campaign designed to study the effect of dwarf-dwarf interactions on the evolution of low-mass galaxies. Follow-up spectroscopy confirmed the association of the candidate members with the groups. Dynamical arguments based on the TNT groups' sizes and velocity dispersions, combined with typical dark matter contents derived in dwarf galaxies, indicate that the groups likely are gravitationally bound structures.

Associations of dwarf galaxies in the Local Group were previously known in the literature[16]; some satellites of the Milky Way (MW) are suspected to host their own satellites[17], and the fact that some MW dwarfs are associated with the plane of the orbit of the Magellanic Clouds is compatible with a scenario in which the Clouds were the largest members of a group of dwarfs that was recently captured by the MW halo[18]. The novelty of the Stierwalt *et al.* groups with respect to formerly known dwarf associations mainly resides in their compactness and high isolation: they are about 10 times more compact than dwarf groups and associations previously identified, and it is likely that they will coalesce into a single isolated galaxy within about one billion year; the groups are also extremely isolated, more than 5 million light-years away from a massive neighbor, and are in this respect ideal laboratories to study hierarchical assembly and galaxy evolution at low mass scales free from environmental effects.

Indeed, dwarf systems are highly susceptible to externally driven processes, like ram pressure or tidal stripping, that can remove part or all of their gas and stars and alter their subsequent evolution. Moreover, simulations show that once a group of only dwarfs falls into a massive host, like the Milky Way, it will eventually be disassembled by tidal forces erasing any evidence of coherent structure[19]. Therefore, considering isolated environments is the most natural and promising choice to probe hierarchical formation at low-mass scales. On the other hand, satellites of dwarf galaxies may be quite challenging to detect given their faintness and the typical completeness limits of current surveys; for instance, a recent study[20] has shown that a Small Magellanic Cloud (SMC)-like galaxy (with a mass in stars of about 300 million solar masses) is expected to host ~1-4 luminous satellites more massive than 10,000 solar masses, but the probability to have a ten-times smaller companion is below 30%. As a matter of fact, observations have already uncovered at least one example, that of the dwarf DDO 68 and its stellar streams and companions, which are consistent with being cannibalized satellites of even lower mass[11].

The dwarf groups discovered by Stierwalt *et al.* provide a promising test-bed for the study of hierarchical assembly and galaxy evolution at low-mass scales. However, this study is not without caveats. The brightest members are relatively large dwarfs, with masses between those of the Large Magellanic Cloud (LMC) and the SMC, and no dwarf galaxy with stellar mass below one tenth of the SMC is found in the groups. This suggests that completeness effects may have biased the Stierwalt *et al.* study toward relatively bright dwarf groups; therefore, direct observational evidence of hierarchical formation at *very low* mass scales remain still elusive.

Future follow-up of the Stierwalt *et al*. groups with currently available 8-10 m optical telescopes could possibly reveal additional fainter members or previously undetected low surface brightness stellar streams formed out of the material removed from accreted satellites. Alongside, high-resolution HI imaging would be useful to investigate the presence of gaseous bridges or streams connecting the dwarfs. These observations will be key for extending the census of the Stierwalt *et al*. groups' members to lower galaxy masses and for providing direct evidence of the current interaction between the dwarfs.

Next-generation ground- and space-based facilities have a high potential for future observational tests of cosmological models at the smallest galactic scales. For instance, thanks to its superb angular resolution and relatively large collective area, the James Webb Space Telescope (JWST) -to be launched in October 2018- will permit to search for faint stellar streamers around a large number of dwarf galaxies by resolving the individual stars up to the distance of the Virgo cluster. Then, within the next decade, 30 m-class ground-based telescopes with adaptive optics modules- like the European Extremely Large Telescope (E-ELT)- will allow us to reach unprecedented faint surface brightness substructures around galaxies; at the same time, deep surveys of extremely large portions of the sky will be available thanks to dedicated telescopes like the Large Synoptic Survey Telescope (LSST) from the ground or the Wide Field Infrared Survey Telescope (WFIRST) from space, providing a statistically significant observational base to test models of galaxy formation in a hierarchical Universe.

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