News & views

Astronomy

Compact oddities are galaxies stripped of stars

Katja Fahrion

Observations have shown that some dwarf galaxies lose their stars through interactions with more massive galaxies. The dense nuclei that remain are ultra-compact dwarf galaxies, the origin of which has long been a subject of debate. **See p.296**

Almost all galaxies are part of larger structures. Our own Galaxy is one of two main galaxies in a collection called the Local Group, but more-distant clusters contain many galaxies, as well as intergalactic gas and dark matter. The Virgo galaxy cluster, for example, hosts more than 1,000 galaxies of various masses and sizes, spread around a massive elliptical galaxy, known as Messier 87, at its core. These cluster environments are extreme, subjecting their dwarf galaxies to processes that are thought to shape their stellar structure profoundly, and affect the galaxies' evolution. As a remarkable case in point, on page 296, Wang *et al.*[1] report observational evidence that Virgo has transformed its dwarf galaxies to a stage at which they are fully stripped – leaving only their dense central star clusters behind.

About 20 years ago, astronomical observations led to the discovery that galaxy clusters can host an intriguing type of galaxy, now known as an ultra-compact dwarf galaxy[2,3]. As the name suggests, these galaxies are visibly more compact than typical galaxies. Their sizes are similar to those of dense collections of stars (called globular clusters) that populate the Milky Way and other galaxies. But the mass of an ultra-compact dwarf galaxy can be more than 10 million times that of the Sun – 10 times more than the most massive globular clusters in the Milky Way. For this reason, their origin and nature have become topics of debate[3]: are ultra-compact dwarf galaxies truly the most compact type of galaxy, possibly embedded in a larger distribution of dark matter? Or are they overly massive star clusters formed in galaxies?

Early in the debate, another possibility was suggested on the basis of the observation that the masses and sizes of ultra-compact dwarf galaxies are comparable with those of another type of star cluster, known as a nuclear star cluster[2,4]. These objects are found at the centre of many galaxies, including dwarf galaxies, spiral galaxies (such as the Milky Way) and elliptical galaxies. Given the close match in their structural properties, ultra-compact dwarfs were proposed to be the remnant nuclei of dwarf galaxies that long ago lost their stellar bodies through interactions with more massive galaxies in their cluster. This hypothesis linked the presence of ultra-compact dwarfs to processes that can affect and even destroy dwarf galaxies in the dense environments of galaxy clusters[5].

Evidence for this proposition was found when ultra-compact dwarfs were observed to harbour supermassive black holes with masses similar to those in nuclear star clusters and at the centre of massive galaxies[6]. Further indications that ultra-compact dwarfs had a nuclear origin came with the discovery that some of these objects still have faint stellar envelopes around them[7]. Simulations of dwarf galaxies with nuclear star clusters evolving in a cluster environment showed this process to be a viable explanation – at least for the more massive ultra-compact dwarfs. Many of the lower-mass ones are probably more regular star clusters, rather than being nuclear star clusters[8].

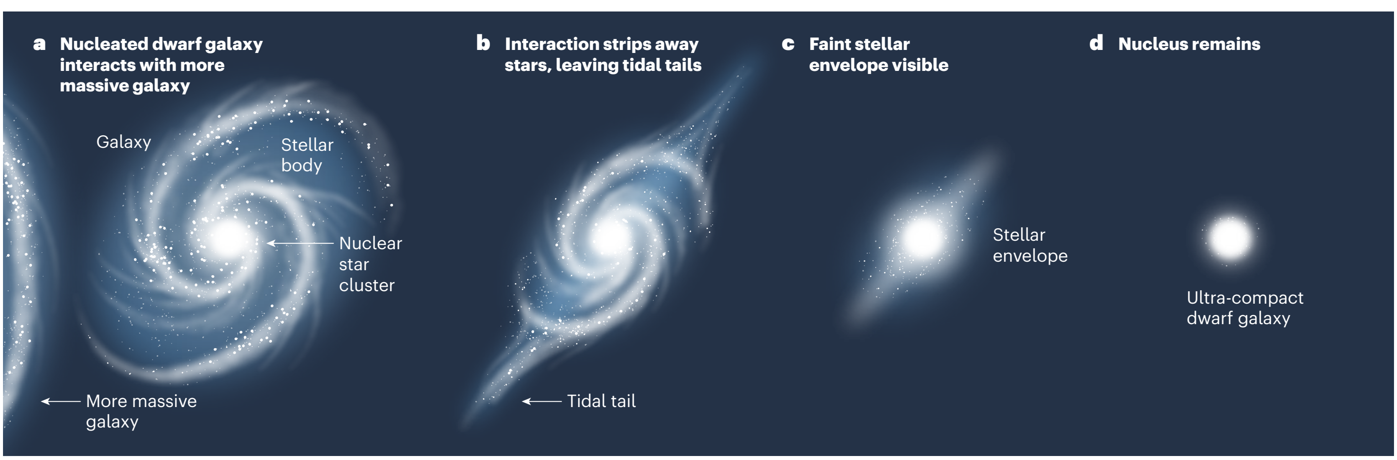

Figure 1 | Stages in the transformation of a nucleated galaxy to a ultra-compact dwarf. Wang *et al.*[1] used observations from the Virgo galaxy cluster to reveal the formation mechanism of a type of galaxy, known as an ultra-compact dwarf, by cataloguing objects in its process of evolution. **a**, In the dense environment of a galaxy cluster, galaxies with a nuclear star cluster can lose their stellar body through interactions with more massive galaxies. **b**, At first, the object resembles a dwarf galaxy with an overly massive nucleus, and in some cases tidal tails are an indication of the continuing interaction. **c**, At later stages, there is only a faint envelope around the former nuclear star cluster. **d**, Finally, only the nucleus the remains, and this is the ultra-compact dwarf galaxy. The authors found objects representing all stages of this process.

Wang *et al.* found more illustrative evidence that nucleated dwarf galaxies transform into ultra-compact dwarf galaxies using observations of the Virgo galaxy cluster obtained with ground-based telescopes. In their images, the authors identified several galaxies that clearly fill the gap between ultra-compact dwarf galaxies and regular, as-yet-undisturbed dwarf galaxies hosting nuclear star clusters (Fig. 1). They found examples of dwarf galaxies with overly massive nuclei, which suggests that they have already started to lose their stellar envelope through tidal (gravitational) interactions with more massive galaxies in the cluster. The authors also catalogued ultra-compact dwarfs that still have stellar envelopes around their compact cores. In a few cases, these galaxies even showed extended tidal tails — a clear sign that they have undergone interactions with other galaxies.

Wang and colleagues' analysis suggests that Virgo comprises a continuous spectrum of objects, ranging from nucleated dwarfs to ultra-compact dwarfs that have been fully stripped of their stellar envelope. Their findings illustrate that the long-held distinction between ultra-compact dwarfs and nucleated galaxies disappears — or at least blurs — when deeper data reveal previously invisible structures.

Nonetheless, the spatial resolution of ground-based data is limited, so the authors' analysis was restricted to higher-mass ultra-compact dwarfs, and the possibility that these galaxies came from nucleated dwarfs was already clear from simulations[8]. The European Space Agency's Euclid space telescope that launched in July and NASA's upcoming Nancy Grace Roman Space Telescope will push such analyses to lower-mass ultra-compact dwarfs, which is a class that probably comprises objects with a mixture of origins, including star clusters and remnant nuclei.

Developing techniques to identify nuclei-type ultra-compact dwarfs will no doubt reveal the evolution of these objects. But these tools might also prove useful for reconstructing the formation of galaxies. Although simulations imply that massive galaxies assemble a considerable fraction of their mass by merging with smaller dwarf galaxies[9], pinpointing the properties or even the number of minor merger events is extremely challenging. Ultra-compact dwarfs that stem from nucleated galaxies are the surviving remnants of long-gone dwarf galaxies and might open a window to observational studies of how galaxies assemble.

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Conservation biology

The scale of rubber deforestation assessed

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Understanding the extent of deforestation associated with agriculturally harvested crops has implications for conservation efforts. A method to assess satellite data offers an accurate way to estimate rubber deforestation. **See p.340**

High-resolution satellite data are being used to quantify deforestation directly at global[1] and regional scales[2]. However, mapping the agricultural commodity drivers of deforestation is challenging — soya plants[3] and palm oil trees[4] are rare examples of success. Rubber plantations have proved more difficult to monitor. Global growth in demand for rubber has put high biodiversity and carbon-rich forests, mainly in southeast Asia, under pressure from deforestation. On page 340, Wang *et al.*[5] report that previous attempts to estimate the extent of deforestation associated with rubber plantations in southeast Asia are based on non-spatially explicit uncertain models that provide estimates varying by more than fivefold. Wang and colleagues implemented an innovative approach, using a massive volume of satellite data, cloud computing and image-processing algorithms to detect rubber deforestation in southeast Asia, thereby increasing the accuracy of such mapping.

Satellite imagery can be used to distinguish targets on Earth's surface by combining analysis of spectral, textural and temporal characteristics, known as signatures. Separating rubber-tree plantations (Fig. 1) from forests is challenging because they both have similar signatures in satellite data. Wang and colleagues had another problem to overcome. In their study area, rubber deforestation generally occurs in small patches of five hectares in smallholder lands, making them difficult to map.

The authors' algorithm requires two major steps. First, they used Sentinel-2 satellite imagery (with individual pixels that correspond to 10-metre-sided squares) across southeast Asia for 2021 to characterize what is termed the phenological spectral signature — representing how rubber trees are captured by satellite measurements when they shed leaves and when new leaves come out. Identifying the annual time window of this phenological pattern for rubber trees, which can be tracked by the spectral bands that Sentinel-2 data record, enabled the authors to distinguish rubber-tree plantations from evergreen and deciduous forests, other monoculture forests, and forest regeneration after land abandonment (secondary forest regrowth).

Another challenge was to overcome cloud blocking of ground observations, because Sentinel-2 captures spectral bands that do not penetrate clouds. The authors improved ground observations using a multi-year imagery composite for 2021 to remove clouds and shadows.

The second step was to train, calibrate and test a machine-learning algorithm, called Random Forest, with more than 3,800 reference ground samples. The result was a rubber-tree plantation map for southeast Asia for 2021.

A goal of Wang and colleagues' work was to estimate the number of rubber-tree plantations directly associated with deforestation. For this, the authors used Landsat imagery time series (with pixels that correspond to 30-m-sided squares and data providing historical coverage) to estimate the deforestation date for rubber plantations mapped in 2021. These were then grouped into two time-frame categories: 1993–2000 and 2001–16. Wang *et al.* used a time-series algorithm named LandTrendr[6] that detects 'breaking points' (changes from tree cover to tree removal) in a pixel's spectral history. The authors also used the normalized band ratio (NBR) spectral index to capture abrupt changes from