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Astronomy

Collision created galaxies devoid of dark matter

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Two galaxies that are curiously lacking in dark matter – the most abundant matter in the Universe – might have formed when a collision between dwarf galaxies separated ordinary matter from its dark counterpart. **See p.435**

When we clap our hands together, the electrons in each hand repel those in the other electromagnetically, preventing our hands from moving through each other. But what would happen if our hands contained some dark matter, which is thought to interact mainly gravitationally, but not electromagnetically? The clap would separate each hand into ordinary matter, which would stop with the collision, and dark matter, which would pass through the other hand. Fortunately for us, our bodies comprise only ordinary matter, but such events can occur on a cosmic scale when two galaxies collide. On page 435, van Dokkum *et al.*[1] propose that such a collision might have created two ultra-diffuse (low-luminosity) galaxies that have no dark matter.

Dark matter accounts for approximately 85% of the Universe's matter budget – leaving a small fraction for the ordinary matter that we know from our daily lives. Galaxies form by bringing together a large amount of ordinary matter (in this case, gas) that, for dwarf galaxies, has a mass at least hundreds of millions of times that of the Sun. The gas cannot come together by itself because its gravity alone is simply too weak to do so within the age of the Universe. But dark matter, with its sizeable stake in the cosmic mass budget, is capable of providing the much-needed source of gravitation. The natural conclusion is that galaxies can form only if dark matter is also involved.

However, in 2018, researchers from the same group as that of van Dokkum *et al.* discovered two galaxies[2,3], known as NGC 1052–DF2 and NGC 1052–DF4 (DF2 and DF4 for short), orbiting a larger galaxy called NGC 1052 (Fig. 1). DF2 and DF4 are unusual in that they have several hundred times less dark matter than is expected according to the conventional theory of galaxy formation, and they host many bright star clusters. These galaxies have understandably garnered much interest from researchers, and various theories for how they formed have been proposed.

Assuming that galaxies need dark matter to form, a valid proposal for the origin of dark-matter-free galaxies must explain how the ordinary matter and dark matter separated. An example of such decoupling has been observed on the scale of a cluster comprising thousands of galaxies, which is known as the bullet cluster. This object formed when two galaxy clusters collided at a relative speed of around 4,500 kilometres per second – thousands of times faster than a speeding bullet – and the collision separated the gaseous and dark-matter components of the clusters like a huge cosmic hand clap[4]. One proposal for the formation of dark-matter-free galaxies suggests that this mechanism could also occur on the scale of individual galaxies[5], specifically, dwarf galaxies, and van Dokkum and colleagues refer to this idea as the bullet-dwarf scenario.

When two galaxies collide, their stars and dark-matter haloes (the hypothetical regions in which dark matter could exist) simply pass through one another. However, the galactic gas in each galaxy exerts pressure on the galactic gas of the other, and stalls at the collision front. Numerical simulations have shown that such a collision, at a velocity of around 300 km s^{-1}, can create a situation in which the gas components are left behind and dark-matter-free galaxies are formed[6,7]. They also show that the strongly shocked gas is dense enough to form multiple, massive star clusters, possibly explaining the many bright star clusters seen in DF2 and DF4. The simulations suggest that a single collision event can produce a trail of dark-matter-free galaxies connecting the two galaxies that triggered the collision.

Van Dokkum *et al.* noted that DF2 and DF4 are 2.1 megaparsecs apart and moving away from

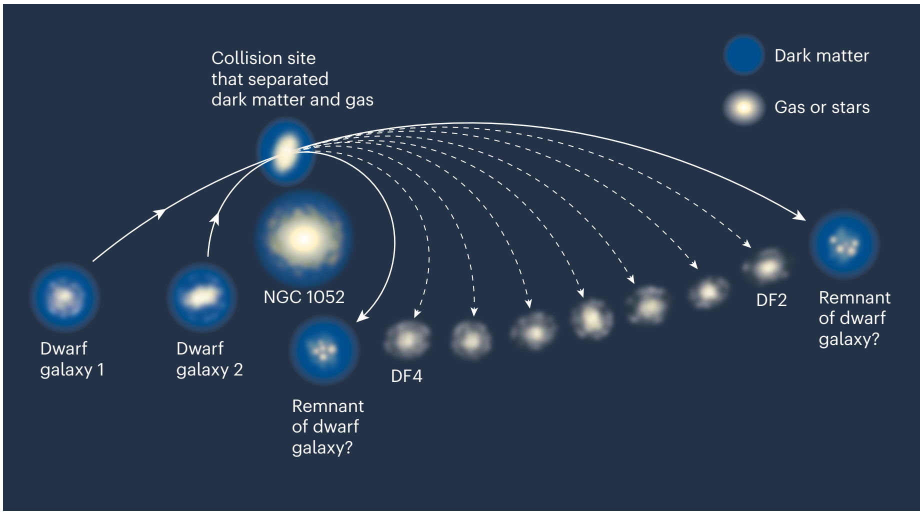

Figure 1 | Formation scenario for a trail of dark-matter-free galaxies. Two dwarf galaxies orbiting a larger galaxy (NGC 1052) collided at a relative line-of-sight speed of 300 kilometres per second approximately 8 billion years ago[5]. Because ordinary matter interacts electromagnetically, and dark matter interacts only gravitationally, a collision of such high velocity could have separated the gas from the regions in which dark matter is expected to be found, thus creating multiple galaxies that contain no dark matter. Van Dokkum *et al.*[1] found evidence that the dark-matter-free galaxies NGC 1052–DF2 and NGC 1052–DF4 originated through this mechanism, when a single collision formed a long trail of galaxies. Remnants of the original colliding galaxies are expected to be found either side of the dark-matter free galaxies, but have not yet been observed. (Adapted from Fig. 1b of ref. 1.)

each other with a relative line-of-sight velocity of 358 km s^{-1} – similar to the value proposed in the bullet-dwarf scenario. From the relative positions and line-of-sight velocities of DF2 and DF4, along with the estimated age of DF2, the authors traced DF2 and DF4 back in time and argued that the two might have originated from the same collision event, approximately eight billion years ago.

Using advanced image-analysis techniques on a catalogue of galaxies around the large galaxy NGC 1052 that was compiled last year[8], the authors found that multiple substructures near NGC 1052 (including DF2 and DF4) form a long trail, a feature suggestive of the collision-induced formation scenario. The authors point out that the trail is perpendicular to the structure associated with NGC 1052, which excludes the possibility that the trail is simply matter flowing in towards NGC 1052. Most of the substructures in the trail fall into the category of ultra-diffuse galaxies, such as DF2 and DF4.

Van Dokkum and colleagues' discovery invites intriguing discussions and follow-up observations. The proposed formation event for a trail of ultra-diffuse galaxies devoid of dark matter is based on relatively few observations. Stricter constraints will be needed to fully validate the formation picture of DF2 and DF4 – and of the other diffuse objects in the trail. For example, the 3D velocities, 3D positions, dark-matter fractions and stellar ages of these diffuse objects should match the predictions made by the simulations of colliding galaxies.

If verified, the bullet-dwarf scenario has the potential to provide a new constraint on estimates of how often dark matter interacts with ordinary matter and with itself. Such a constraint requires measurement of the dynamic properties of the diffuse objects in the trail, and, more importantly, of those of the two dwarf galaxies that triggered the collision. The scenario predicts that the remnants of these dwarf galaxies are dominated by dark matter and deprived of ordinary matter. Observing these remnants could verify this picture, but will be challenging, because they are expected to be gas-poor and very faint. Nevertheless, once acquired, such observations will provide crucial insight into the nature of dark matter – one of the most intriguing topics in modern physics and cosmology.

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1. van Dokkum, P. *et al. Nature* **605**, 435–439 (2022).
2. van Dokkum, P. *et al. Nature* **555**, 629–632 (2018).
3. van Dokkum, P. *et al. Astrophys. J.* **874**, L5 (2019).
4. Bradač, M. *et al. Astrophys. J.* **652**, 937–947 (2006).
5. Silk, J. *Mon. Not. R. Astron. Soc.* **488**, L24–L28 (2019).
6. Shin, E. *et al. Astrophys. J.* **899**, 25 (2020).
7. Lee, J., Shin, E. & Kim, J. *Astrophys. J.* **917**, L15 (2021).
8. Román, J., Castilla, A. & Pascual-Granado, J. *Astron. Astrophys.* **656**, A44 (2021).

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Ageing

Young cerebrospinal fluid is a tonic for memory

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Infusion of cerebrospinal fluid from young mice into old mice restores memory recall in the aged animals by triggering production of the fatty myelin sheath that insulates neurons in the brain. **See p.509**

Age-related cognitive decline affects up to one-quarter of adults over the age of sixty[1]. A healthy diet and regular exercise can help to prevent this decline, but as yet there are no treatments to reverse it[2]. Progress in understanding how the brain changes during development and ageing has sparked tantalizing ideas for harnessing youthful factors to slow age-associated cognitive changes – or even to rejuvenate the ageing brain. On page 509, Iram *et al.*[3] bolster this line of thinking by tapping into the cerebrospinal fluid (CSF), which bathes the brain tissue and contains several protein growth factors necessary for normal brain development.

The authors infused CSF from young adult mice (10 weeks old) into the brains of aged mice (18 months old) over 7 days. This treatment improved the memory recall of the old animals in a fear-conditioning task, in which they learnt to associate a small electric shock with a tone and flashing light. Iram and colleagues then used RNA sequencing to determine how CSF treatment altered gene expression in the hippocampus – a key memory centre in the brain that is often the focus of studies of age-associated cognitive decline.

Cells in the central nervous system called oligodendrocytes produce myelin, a fat- and protein-rich material that insulates neuronal fibres called axons. Myelination of axonal projections throughout the brain ensures that strong signal

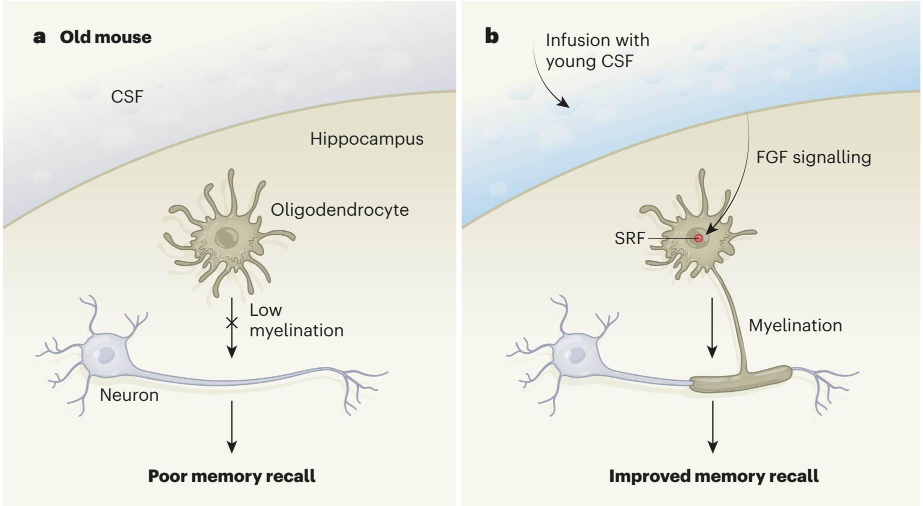

Figure 1 | Infusion of cerebrospinal fluid improves memory in old mice. The mouse hippocampus is located adjacent to the brain ventricles that contain cerebrospinal fluid (CSF). Hippocampal neurons can be insulated by a fatty sheath of myelin, which aids connectivity; long-term recall of negative stimuli in mice requires the generation of new myelin by cells called oligodendrocytes. **a**, In old mice, myelination by oligodendrocytes is impaired, and this is correlated with poor memory recall. **b**, Iram *et al.*[3] infused old mice with CSF from young mice; CSF is enriched in many health-promoting growth factors, probably including FGF17 (not shown). The authors show that CSF infusion triggers FGF signalling pathways. This activates a transcription factor called SRF, which promotes signalling pathways that lead to the proliferation and maturation of oligodendrocytes. These cells then produce myelin to support neuronal signalling, which leads to improved memory recall.