Stars that the wind blew out

Gas expelled by stellar explosions interrupted the growth of dwarf galaxies

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Fornax, at the top of the page: one of 26 dwarf galaxies orbiting the Milky Way

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There is something mysterious about the evolution of dwarf galaxies. Astronomers have encountered a much smaller number of these small clusters of stars than expected, given the current Big Bang theory of how the universe was formed by an explosion 13.7 billion years ago. For this reason, astronomers believe that either there is something wrong with this theory—an option increasingly less accepted by experts—or something happened during the formation of these galaxies that left them so empty of stars that even the most powerful telescopes cannot observe them.

In a paper recently accepted for publication in the journal Monthly Notices of the Royal Astronomical Society, a group of Brazilian astronomers presents results that strengthen the second hypothesis and describe a possible mechanism that could have prevented some dwarf galaxies from producing an abundance of stars. Through computer simulations, Diego Falceta-Gonçalves, of the University of São Paulo (USP), and Luciana Ruiz, Gustavo Lanfranchi and Anderson Caproni, of Cruzeiro do Sul University (Unicsul), propose that a series of stellar explosions that occurred at the beginning of the formation of dwarf galaxies could have expelled almost all of the gas that would have been needed to generate new stars. As a result, stars in these dwarf galaxies are sparse.

Although these explosions would have occurred more than 13 billion years ago, shortly after the creation of the universe, they may have left traces—differences in the concentrations of chemical elements within and outside galaxies—that can be checked through astronomical observations to help confirm or refute the model. “Our work explains what may have occurred both within a dwarf galaxy and between clusters of galaxies,” says Lanfranchi.

Dwarf galaxies exist throughout the universe, orbiting larger galaxies such as ours, the Milky Way. In general, they have hundreds of millions of stars—approximately 0.1% of the total found in the Milky Way. Some still contain gas and are still capable of generating new stars. However, most contain only a group of old stars. For example, in Ursa Minor, one of the dwarf galaxies orbiting the Milky Way, the last star was born 9 billion years ago.

According to current cosmological theory, which indicates that the universe was created 13.7 billion years ago from an initial explosion and has been expanding ever since, dwarf galaxies were the first star clusters to form, approximately 300 million years after the Big Bang. Larger galaxies, the size of the Milky Way, began to emerge one billion years later. Astronomers are still debating whether the larger galaxies emerged from the joining together of dwarf galaxies or grew independently of them. However, everyone believes that galaxies, large or small, were created from gas that accumulated in regions of space where dark matter is concentrated.

Dark matter is an invisible and still unknown substance. It permeates all of space and is perceptible only because of the gravitational influence it exerts on the motion of stars and galaxies. Based on cosmological observations, there should be five to nine times more dark matter than normal matter in the Universe. Computer simulations based on the Big Bang theory suggest that larger galaxies formed precisely in areas where larger amounts of dark matter (“halos”) collected.

These simulations also show that each of these large halos of dark matter is surrounded by a constellation of hundreds of smaller halos, which, in principle, should have given rise to dwarf galaxies. However, instead of hundreds of dwarf galaxies, only 26 have been observed orbiting the Milky Way. “According to observations and simulations, there must be hundreds of dark matter halos that never formed many stars,” says Lanfranchi.

Another mystery related to dwarf galaxies is that the ratio of normal matter to dark matter that they contain is very different from that observed in larger galaxies. The mass of the dark matter halo that surrounds the Milky Way is 10 times greater than the total mass of its stars, while the dwarf galaxies studied have 20 to 3,400 times more dark matter than stellar mass. “For some reason,” Gonçalves notes, “proportionally far fewer stars were formed in dwarf galaxies than in the Milky Way.”

To better understand the history of dwarf galaxies, several groups of astrophysicists have been conducting simulations of how the galaxies’ initial concentrations of gas and dark matter evolved. All of the studies suggest that the protagonists of this story are supernovae—the explosions that mark the end of the life of stars with very high mass, dozens of times more massive than the Sun. According to theoretical models, the first supernovae in these galaxies would have transferred so much energy to the gas within these star clusters that they ultimately would have expelled it into the intergalactic medium. Without gas, star formation would have been interrupted.

No simulation until now, however, had reached a level of detail sufficient to explain exactly how this gas could have escaped or in what quantities and at what stage of galactic evolution. The Brazilian astronomers accepted the challenge of simulating the first billion years of dwarf galaxies as realistically as possible, using a computer code developed by Polish astrophysicist Grzegorz Kowal of USP. In the simulations, the researchers evaluated 11 possible scenarios for the evolution of these galaxies, varying parameters such as the distribution of dark matter and the supernovae formation rate. They also considered details such as the random appearance of supernovae in various regions of the galaxy and the amount of energy from explosions converted into heat or light.

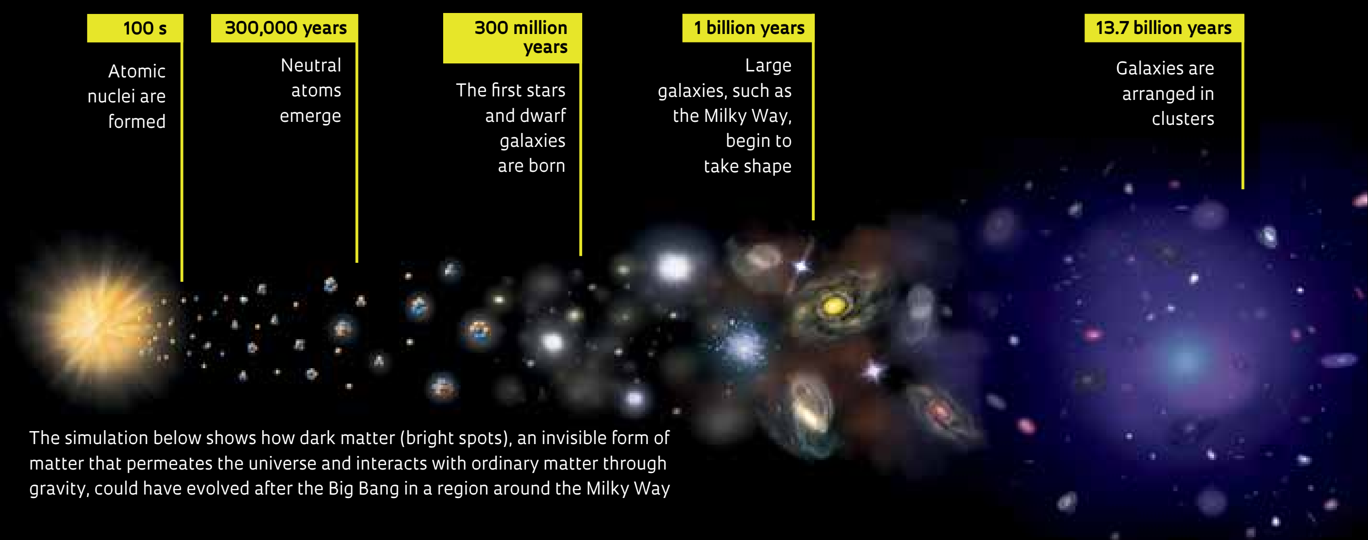
UBIQUITOUS WINDS

Despite controlling the parameters of their simulations, the researchers had no way of knowing the outcome beforehand. “We were able to determine how fast the galaxies lose gas, depending on their mass, the distribution of dark matter, and the supernovae formation rate,” Gonçalves explains.

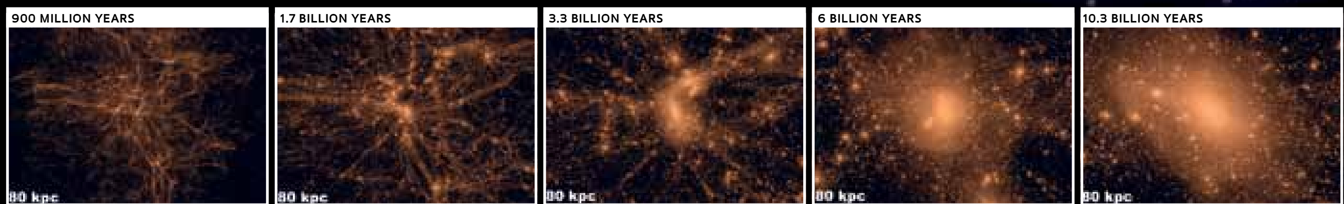
In all scenarios, the simulations showed that supernovae created winds that began to expel gas from the galaxy 100 million years after its birth. In the most extreme case, 88% of the gas was eliminated in 1 billion years. “Most halos end up with few stars and become

The structure of the Universe

A high-energy explosion took place 13.7 billion years ago—the Big Bang, the creation of the Universe—which, as it expanded and cooled, organized visible matter into atoms, stars, galaxies and clusters of galaxies



The simulation below shows how dark matter (bright spots), an invisible form of matter that permeates the universe and interacts with ordinary matter through gravity, could have evolved after the Big Bang in a region around the Milky Way



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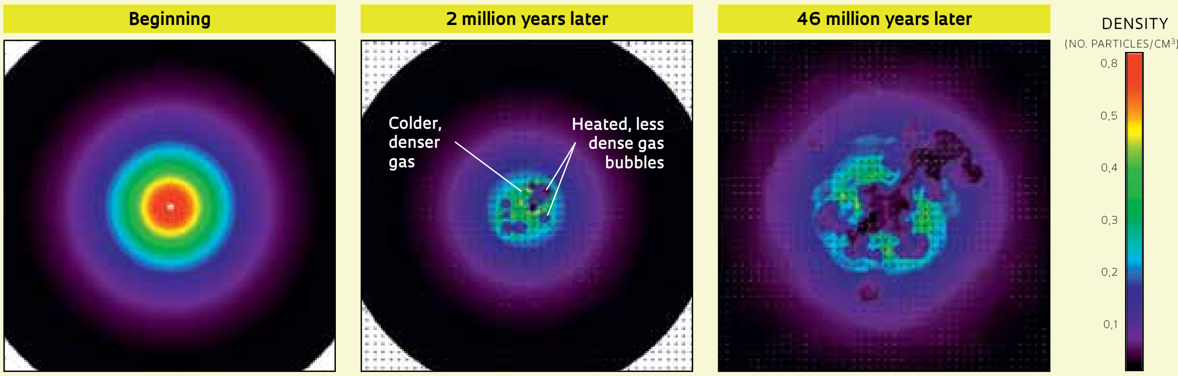
How dwarf galaxies lose gas

Heated, less dense gas bubbles float on the cooler, denser gas toward the intergalactic medium



Dark matter makes the gas concentrate in the innermost region of the dwarf galaxy ...

... until supernova explosions create bubbles of hot gas ...

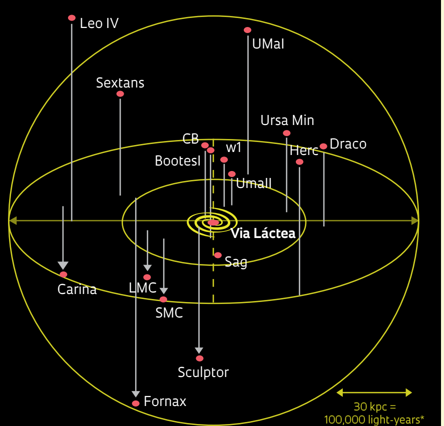
... which expand and fuse together, forming channels through which the gas escapes

IMAGES RUIZ, L.O. EL AL., MNRAS · 2012

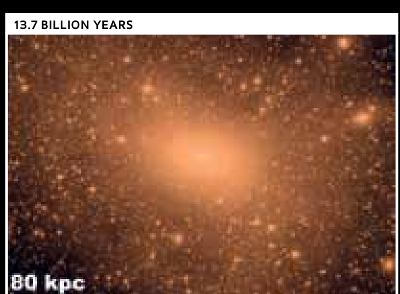
In the simulations, up to 40% of the gas heated by supernova explosions escaped the galaxy in less than 200 million years.

Old companions

Galaxies are formed in regions with the highest concentration of dark matter. At each point around the main cluster, which led to the Milky Way, there should be a dwarf galaxy, but we have identified only 26 (see the main ones below)



* 1 kiloparsec (kpc) = 3,260 light-years



invisible," Gonçalves says. "The galaxies we see today formed in scenarios in which the wind was more moderate."

The researchers thought that gas heated by supernovae had overcome the gravitational pull of the galaxy and escaped, impelled by large amounts of energy, like a rocket launched into space. However, they found that was not always the case. In less than 200 million years, 5–40% of the gas heated by the explosions escaped by floating in the cooler, denser gas around it, even without having the energy to overcome gravity. "It's more like a helium balloon that climbs by itself, without being launched," Gonçalves says.

This phenomenon, known as Rayleigh–Taylor instability, is the same phenomenon responsible for the mushroom-shape rising of gas in an atomic bomb explosion. In the Brazilians' simulation, supernovae create bubbles of hot gas around themselves, which migrate to the outer, colder layers of the galaxy, expanding and merging to form channels through which the gas escapes. An important consequence of this phenomenon is that the composition of the gas expelled from the dwarf galaxies is not the same as that of the primordial gas, composed of light chemical elements (hydrogen and helium), the first elements to appear in the universe. The gas that escapes is enriched with heavier chemical elements created in supernova explosions.

"These results are interesting and should be compared with observations to see if the theory is correct," says astrophysicist Reinaldo de Carvalho of the National Institute for Space Research, who studies the evolution of galaxies. The researchers hope to find evidence of what happened to dwarf galaxies by investigating the chemical compositions of their stars. To do so, they are analyzing a dwarf galaxy, Ursa Minor. They plan to compare its composition with that of the intergalactic medium into which the heavier chemical elements would have been expelled. ■

Projects

1. Magnetic fields, turbulence and plasma effects in the intergalactic medium - No. 2011/12909-8; **Grant Mechanisms** Regular of Research Project Award; **Coordinator** Diego Falceta Gonçalves – USP; **Investment** R$151,676.28 (FAPESP).

2. Numerical study of collisional and collisionless magnetized plasmas in astrophysics - No. 2009/10102-0; **Grant Mechanisms** Regular of Research Project Award; **Coordinator** Diego Falceta Gonçalves – USP; **Investment** R$108,750.89 (FAPESP).

3. Application of theoretical-computational models in astrophysics - No. 2006/57824-1; **Grant Mechanisms** Young Investigator; **Coordinator** Gustavo Amaral Lanfranchi – Unicsul; **Investment** R$171,395.05 (FAPESP).

Scientific article

RUIZ, L. O. et al. The mass loss process in dwarf galaxies from 3D hydrodynamical simulations: the role of dark matter and starbursts. **Monthly Notices of the Royal Astronomical Society**. In production.