AstroTalk: Behind the news headlines of Dec. 2020–Feb. 2021

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Galaxy mergers

Over their lifetimes, many galaxies encounter other galaxies on their orbits through the Universe, and some will eventually succumb to the mutual gravitational forces to form new, merged galaxies. Some merged galaxies will experience billions of years of growth. For others, however, the merger will kick off processes that eventually halt star formation, dooming the galaxies to wither prematurely.

When two galaxies merge, there are often brief periods of stellar baby booms. In late 2019, a group of astronomers led by Lingyu Wang from the SRON Netherlands Institute for Space Research used a sample of more than 200,000 galaxies to suggest that galaxy mergers are the driving force behind such "starbursts".

Indeed, one of the most pressing questions in astronomy is how and when stars formed in galaxies. A popular hypothesis among astrophysicists is that galaxy mergers go hand-in-hand with short starburst phases and an increase of around a factor of two in star formation over the whole duration of the merger.

Mergers are thought to produce shock waves in the interstellar gas, hence igniting significant baby booms of stars. The astronomers confirmed this theory by analysing a record number of more than 200,000 galaxies. They found up to twice the number of starbursts in merging compared with single galaxies.

Because their database was so large, the team built a deep-learning algorithm that taught itself to identify merging galaxies. SRON researcher William Pearson said,

> "*The advantage of artificial intelligence, AI, is that it improves the reproducibility of our study because the algorithm is consistent in its definitions of a merger. Also, it's a good preparation for upcoming surveys that will image billions of galaxies. Then you inevitably need AI. Even citizen science projects such as* Galaxy Zoo *cannot deal with those numbers*."

This was the first time that astronomers used AI in a merger study. "*This is a milestone in the sense that AI will play an increasingly large role in our field*," said Wang. "*But we have to keep in mind that the power of AI is limited to how it is trained. If we feed it a flawed definition of a galaxy merger, then it won't do its job correctly*."

However, the Universe is a complex place, and contradictions are relatively easy to find. Astronomers looked nine billion years into the past to find evidence that galaxy mergers in the early Universe could, instead, *also* shut down star formation and halt galaxy growth.

New research published in the journal *Nature Astronomy* this past January and led by Durham University (UK), the French Alternative Energies and Atomic Energy Commission (CEA)/Saclay and the University of Paris–Saclay shows that a huge amount of star-forming gas was ejected into the intergalactic medium by the coming together of two galaxies.

The researchers say that this event, together with a large amount of star formation in the nuclear regions of the galaxy, would eventually deprive the merged galaxy—called ID2299—of fuel for new stars. This would stop star formation for several hundred million years, effectively halting the galaxy's development.

Astronomers observe many massive, dead galaxies containing very old stars in the nearby Universe and don't exactly know how these galaxies formed. Simulations suggest that winds generated by active black holes as they feed, or those created by intense star formation, are responsible for such deaths by expelling the gas from galaxies.

Now the Durham-led study offers galaxy mergers as another way of shutting down star formation and altering galaxy growth.

Observational features of winds and 'tidal tails' caused by the gravitational interaction between galaxies in such mergers can be very similar, so the researchers suggest that some past results where galactic winds have been suggested as the cause of halting star formation might need to be re-evaluated.

Annagrazia Puglisi, from Durham University, said:

> "*We don't yet know what the exact processes are behind the switching off of star formation in massive galaxies. Feedback-driven winds from star formation or active black holes are thought to be the main responsible for expelling the gas and quenching the growth of massive galaxies.*
>
> *Our research provides compelling evidence that the gas being flung from ID2299 is likely to have been tidally ejected because of the merger between two gas-rich spiral galaxies. The gravitational interaction between two galaxies can thus provide sufficient angular momentum to kick out part of the gas into the galaxy surroundings.*
>
> *This suggests that mergers are also capable of altering the future evolution of a galaxy by limiting its ability to form stars over millions of years and deserve more investigation when thinking about the factors that limit galaxy growth*."

Due to the amount of time it takes the light from ID2299 to reach the Earth, the researchers were able to see the galaxy as it would have appeared nine billion years ago when it was in the late stages of its merger.

This was a time when the Universe was only 4.5 billion years old and when it was in its most active, 'young adult' phase if compared to a human life.

Using the European Southern Observatory's Atacama Large Millimeter Array (ALMA) telescope, in northern Chile, the researchers saw it was ejecting about half of its total gas reservoir into the galaxy surroundings.

Researchers were able to rule out star formation and the galaxy's active black hole as the reason for this ejection by comparing their measurements with previous studies and simulations and by measuring the physical properties of the escaped gas.

The rate at which the gas is being expelled from ID2299 is too high to have been caused by the energy created by a black hole or starburst, as seen in previous studies, while simulations suggest that no black holes can kick out as much cold gas from a galaxy.

Emanuele Daddi, from CEA/Saclay said:

> "*This galaxy is witnessing a truly extreme event. It is probably caught during an important physical phase for galaxy evolution that occurs within a relatively short time window. We had to look at over 100 galaxies with ALMA to find it*."

Jeremy Fensch, of the Centre de Recherche Astrophysique de Lyon (France), added:

> "*Studying this single case unveiled the possibility that this type of event might not be unusual at all and that many galaxies suffered from this 'gravitational gas removal', including misinterpreted past observations. This might have huge consequences on our understanding of what actually shapes the evolution of galaxies*."

Meanwhile, it was previously thought that collisions between galaxies would necessarily add to the activity of the massive black holes at their centres. However, in new work published in January 2021 in *Nature Astronomy*, researchers have now performed the most accurate simulations of a range of collision scenarios and found that some collisions can reduce the activity of their central black holes. The reason is that certain head-on collisions may, in fact, clear the galactic nuclei of the matter which would otherwise fuel the black holes contained within.

Gargantuan phenomena such as the collision of galaxies are often considered as a cosmic cataclysm, with stars crashing and exploding, and destruction on an epic scale. But actually, it is closer to a pair of clouds combining, usually a larger one absorbing a smaller one. It's unlikely that any stars within them would collide themselves. But that said, when galaxies collide, the consequences can be enormous.

Galaxies collide in different ways. Sometimes a small galaxy will collide with the outer part of a larger one and either pass through or merge, in either case exchanging a lot of stars along the way. But galaxies can also collide head-on, during which the smaller of the two is torn apart by overpowering tidal forces of the larger one. It's in this scenario that something interesting can happen within the galactic nucleus.

> "*At the heart of most galaxies lies a massive black hole, or MBH*," said Yohei Miki from the University of Tokyo (Japan). "*For as long as astronomers have explored galactic collisions, it has been assumed that a collision would always provide fuel for an MBH in the form of matter within the nucleus. And that this fuel would feed the MBH, significantly increasing its activity, which we would see as ultraviolet and X-ray light amongst other things. However, we now have good reason to believe that this sequence of events is not inevitable and that, in fact, the exact opposite might sometimes be true*."

It seems logical that a galactic collision would only increase the activity of an MBH, but Miki and his team were curious to test this idea. They constructed highly detailed models of galactic collision scenarios and ran them on supercomputers. The team was pleased to see that in some circumstances, an incoming small galaxy might actually strip away the matter surrounding the MBH of the larger one. This would reduce instead of increase its activity.

> "*We computed the dynamic evolution of the gaseous matter which surrounds the MBH in a torus, or donut, shape*," said Miki. "*If the incoming galaxy accelerated this torus above a certain threshold determined by properties of the MBH, then the matter would be ejected and the MBH would be starved. These events can last in the region of a million years, though we are still unsure about how long the suppression of MBH activity may last.*"

This research could help us understand the evolution of our own Milky Way. Astronomers are confident our galaxy has collided with many smaller ones before.

Today, only a few percent of galaxies in the nearby Universe are merging, but galaxy mergers were more common between 6 billion and 10 billion years ago, and these processes profoundly shaped our modern galactic landscape. For more than a decade, scientists have been using nearby galaxies to study the details of galaxy mergers, using them as local laboratories for that earlier period in the Universe's history. Their survey, dubbed GOALS, has focused on 200 nearby objects, including many galaxies in various stages of merging.

One of the primary processes thought to be responsible for a sudden halt in star formation inside a merged galaxy is an overfed black hole. At the centre of most galaxies lies a supermassive black hole—a powerful beast millions to billions of times more massive than the Sun. During a galactic merger, gas and dust are driven into the centre of the galaxy, where they help make young stars and also feed the central black hole.

But this sudden burst of activity can create an unstable environment. Shock waves or powerful winds produced by the growing black hole can sweep through the galaxy, ejecting large quantities of gas and shutting down star formation. Sufficiently powerful or repetitive outflows can hinder the galaxy's ability to make new stars.

A newly merged galaxy is the subject of a detailed study with the W. M. Keck Observatory in Hawaii (USA), in which GOALS scientists searched for galactic shockwaves driven by the central active galactic nucleus, an extremely bright object powered by a supermassive black hole feeding on material around it. The lack of shock signatures suggests that the role of active galactic nuclei in shaping galaxy growth during a merger may not be straightforward.

The relationship between mergers, bursts of star formation and black hole activity is complex, and scientists are still working to understand it fully.

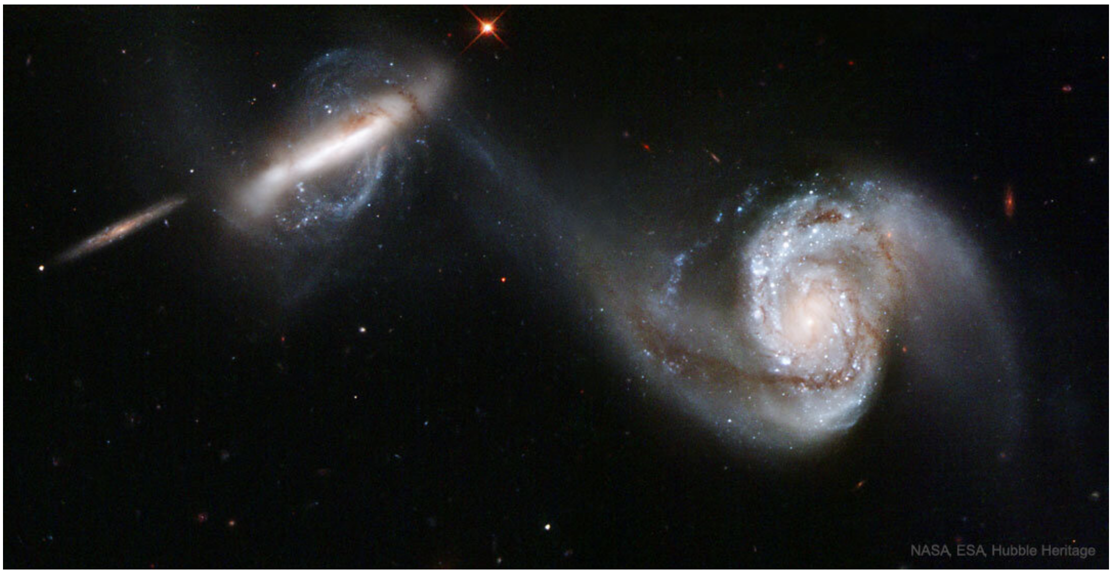

Figure 1: Two galaxies in the process of merging. (Credit: NASA/ESA/Hubble Space Telescope)

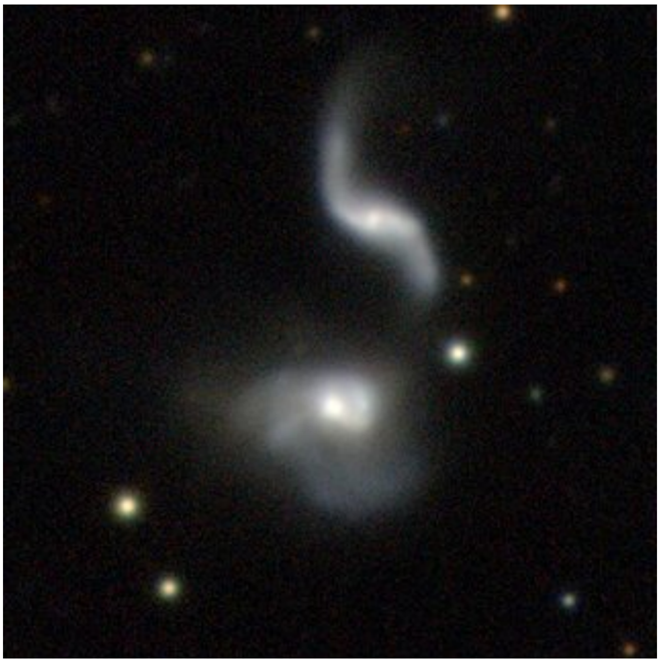

Figure 2: Example of two merging galaxies that were identified by AI. (Credit: SRON Netherlands Institute for Space Research)

Figure 3: This artist's impression of ID2299 shows the galaxy, the product of a galactic collision, and some of its gas being ejected by a 'tidal tail' as a result of the merger. New observations made with ALMA have captured the earliest stages of this ejection, before the gas reached the very large scales depicted in this artist's impression. (Credit: ESO/M. Kornmesser)

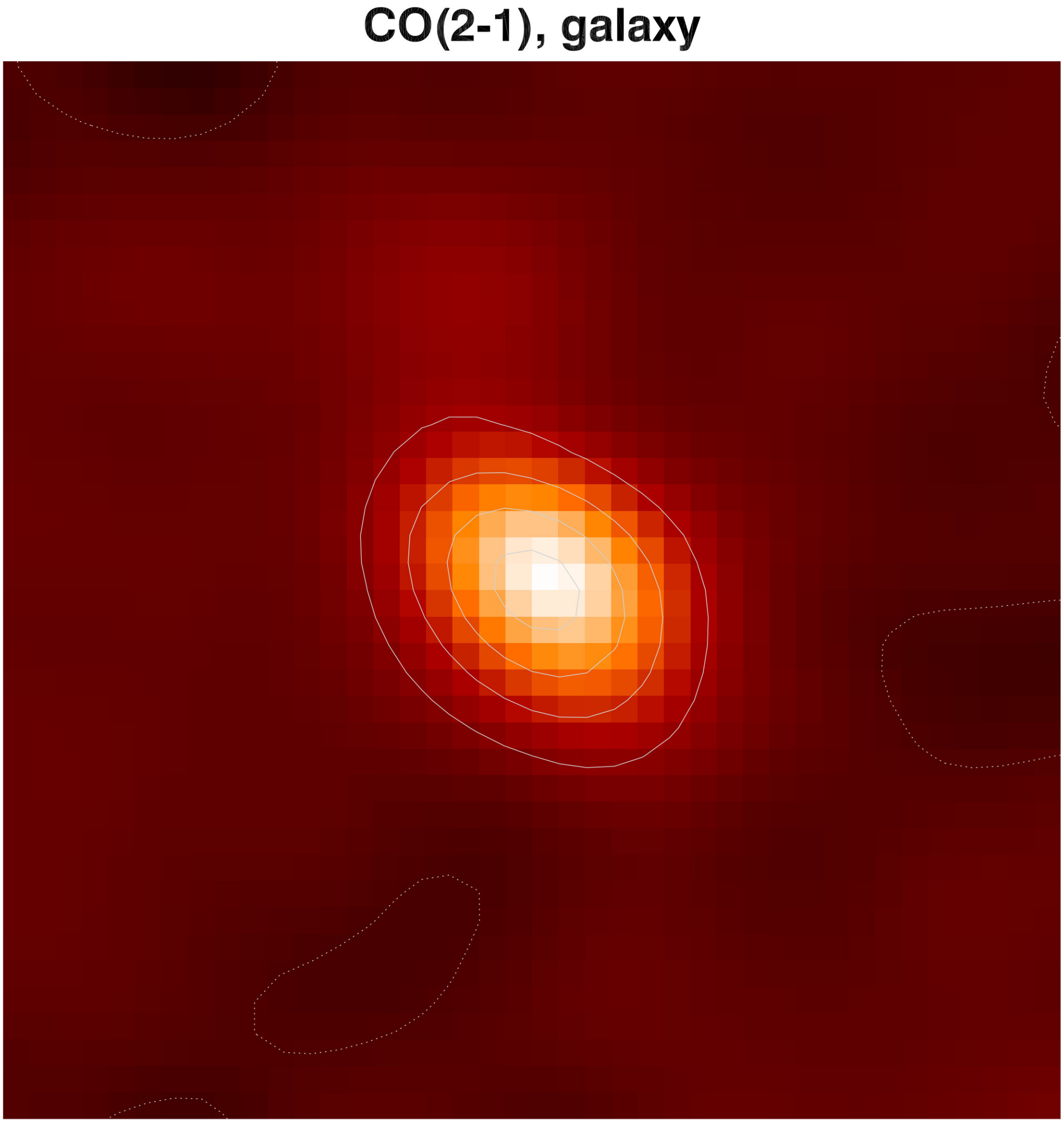

Figure 4: Map of the cold molecular gas from the galaxy ID2299 taken using the Atacama Large Millimeter Array (ALMA) telescope. (Credit: A Puglisi et al.)

Figure 5: This image shows the merger of two galaxies, known as NGC 7752 (larger) and NGC 7753 (smaller), also collectively called Arp 86. In these images, different colours correspond to different wavelengths of infrared light. Blue and green are wavelengths both strongly emitted by stars. Red is a wavelength mostly emitted by dust. (Credit: NASA/JPL-Caltech)

Figure 6: This image shows the merger of two galaxies, known as NGC 6786 (right) and UGC 11415 (left), also collectively called VII Zwicky 96. It is composed of images from three *Spitzer* Infrared Array Camera (IRAC) channels: IRAC channel 1 in blue, IRAC channel 2 in green and IRAC channel 3 in red. (Credit: NASA/JPL-Caltech)

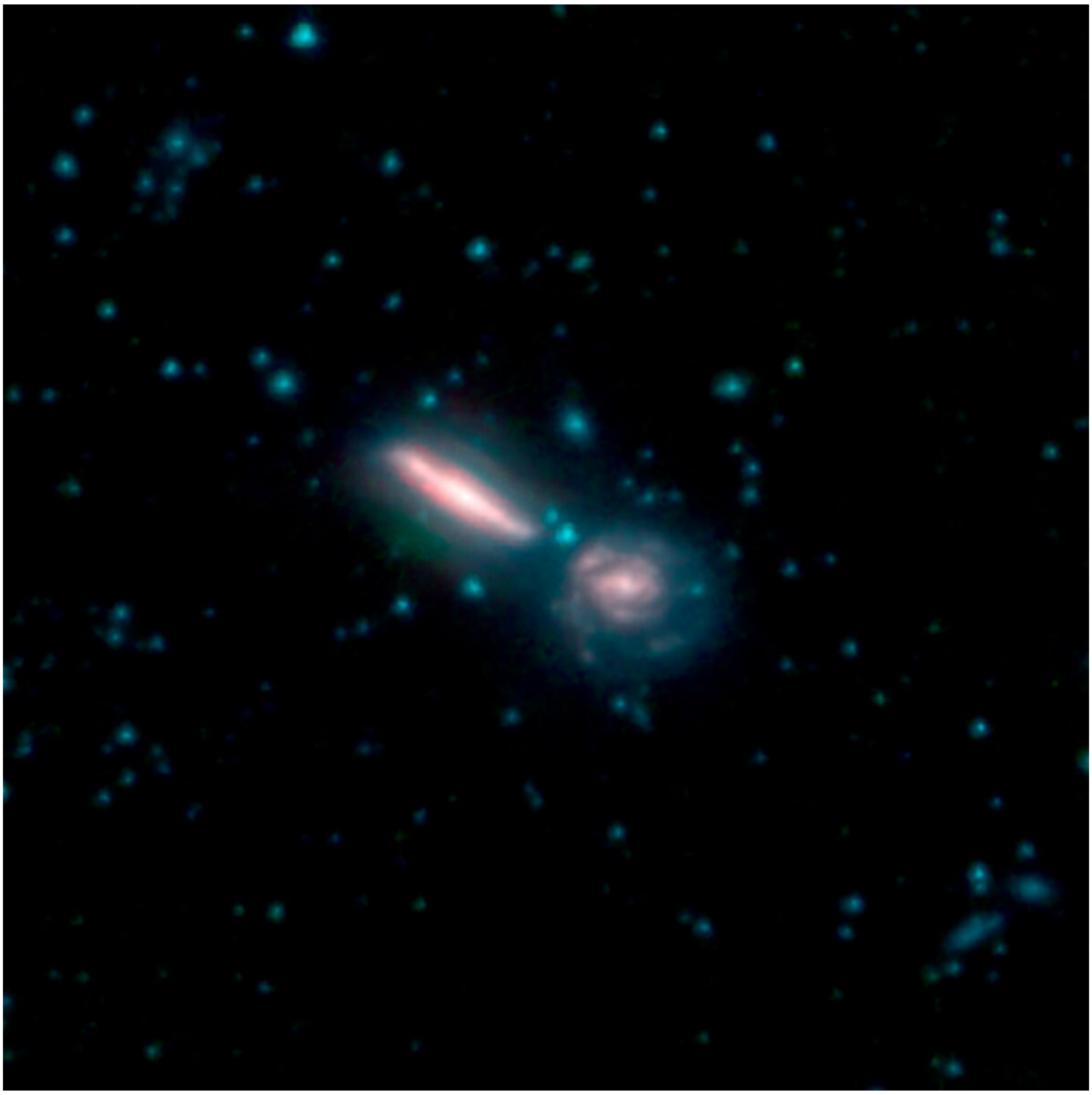

Figure 7: This image shows two merging galaxies known as Arp 302, also called VV 340. (Credit: NASA/JPL-Caltech)

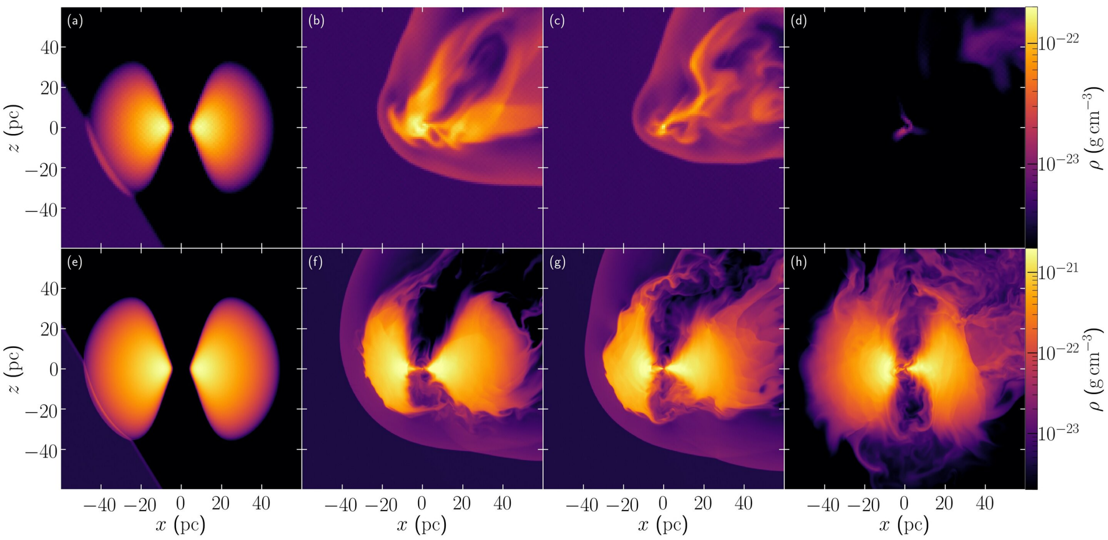

Figure 8: Visualisations of the dynamic model simulating two different scenarios. The top row shows a collision reducing core activity, the bottom row shows a collision increasing core activity. (Credit: Miki et al.)

Figure 9: Artist's impression of gas being pulled away from a galactic nucleus. (Credit: Miki et al.)