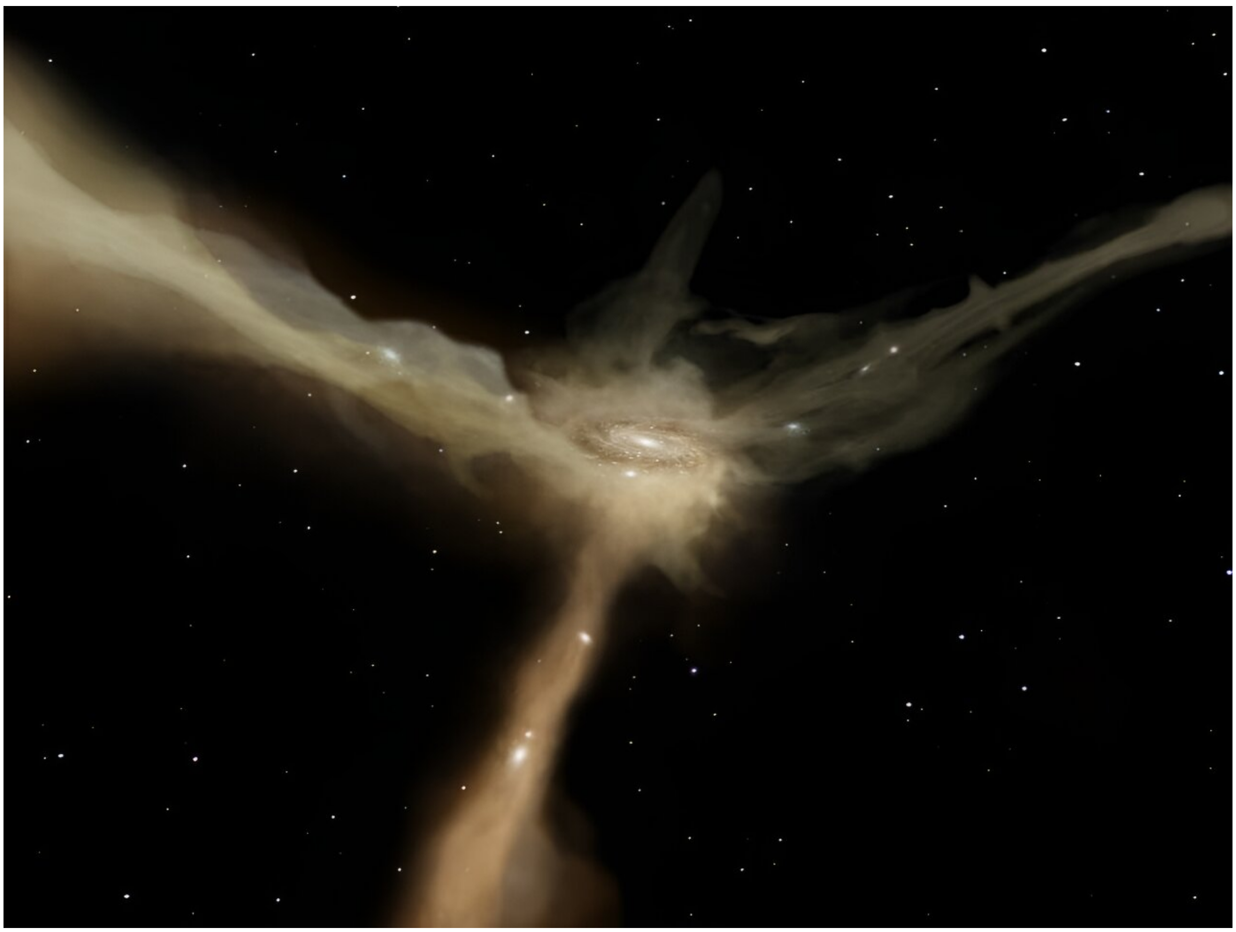
Galaxies breathe gas, and when they stop, no more stars form

September 20 2023, by Evan Gough



Artist concept of how a galaxy might accrete mass from rapid, narrow streams of cold gas. These filaments provide the galaxy with continuous flows of raw material to feed its star-forming at a rather leisurely pace. Credit: ESA–AOES Medialab

For most of the history of astronomy, all we could see were stars. We could see them individually, in clusters, in nebulae, and in fuzzy blobs that we thought were clumps of stars but were actually galaxies. The thing is, most of what's out there is much harder to see than stars and galaxies. It's gas.

Now that astronomers can see gas better than ever, we can see how galaxies breathe it in and out. When they stop breathing it, stars stop forming.

In the universe's early days, everything was gas. There were no stars or galaxies. Fast forward 13.5 billion years or so, and we see galaxies and their stars almost wherever we look. But the huge majority of matter in a galaxy is still gas.

Gas is everywhere. When it's in the space between galaxies, we call it the intergalactic medium. When the gas closely surrounds a galaxy, we call it circumgalactic gas. There's no barrier between these, they're just names astronomers use so they can talk about them.

Astronomers are starting to understand the flow of gas between a galaxy, its circumgalactic medium, and the intergalactic medium. The flow regulates star formation, and when that flow stops, the galaxy stops breathing.

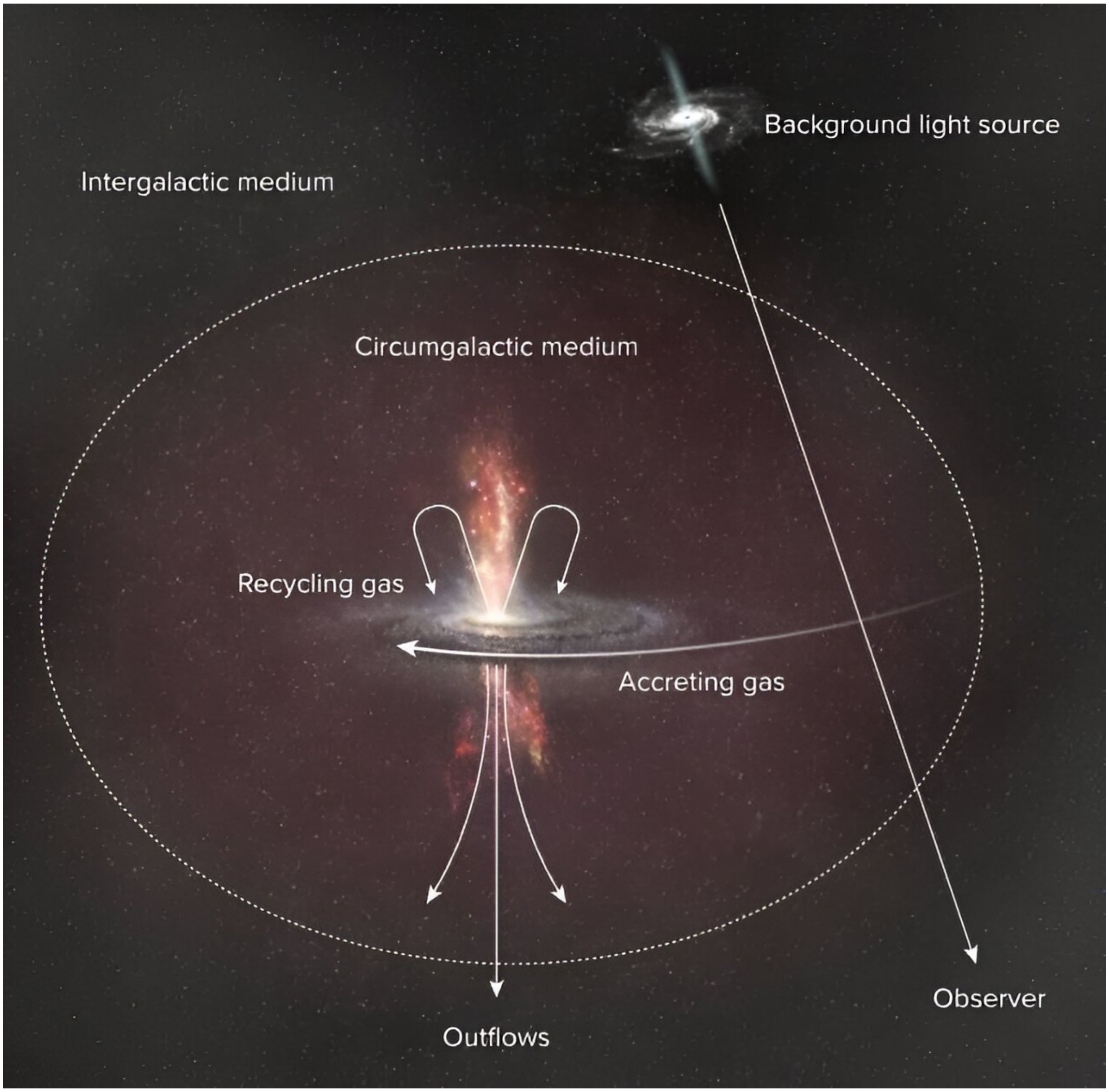
Stars, gravity, and gas temperature and density all play a role in galaxy breathing. When the universe got going, gas gathered together in galaxies and formed stars. When stars die, especially as supernovae, they expel gas back out. At that point, the gas is relatively hot and diffuse and resists compaction.

But as the gas leaves the galaxy, it cools. As it cools, its density increases and the galaxy's gravity can get a firmer grip on it. Then the gas is drawn back into the galaxy where it can collapse out of clouds again, forming stars. That's how gas is recycled, or breathed, in and out of galaxies.

Astronomers didn't know about this galactic breathing until the 1960s, when they could watch the light from distant quasars travelling through all this gas. Now astronomers have better tools to see this gas, and their understanding is growing.

The CGM is a much smaller region than the IGM, and also much fainter. However, the region plays a vital role in recycling. "The CGM is a source for a galaxy's star-forming fuel, the venue for galactic feedback and recycling, and perhaps the key regulator of the galactic gas supply," a 2017 paper states.

Astronomers studying the CGM found some compelling evidence for galaxy breathing. It comes from the study of separate gas clouds outside of galaxies. Some of these gas clouds have higher metallicities than other clouds. Only stars can create metals, so a cloud of gas that has higher metallicity must be outflow gas that came from stars. High-metallicity gas is exhaled gas that has already been in a galaxy but was pushed out.



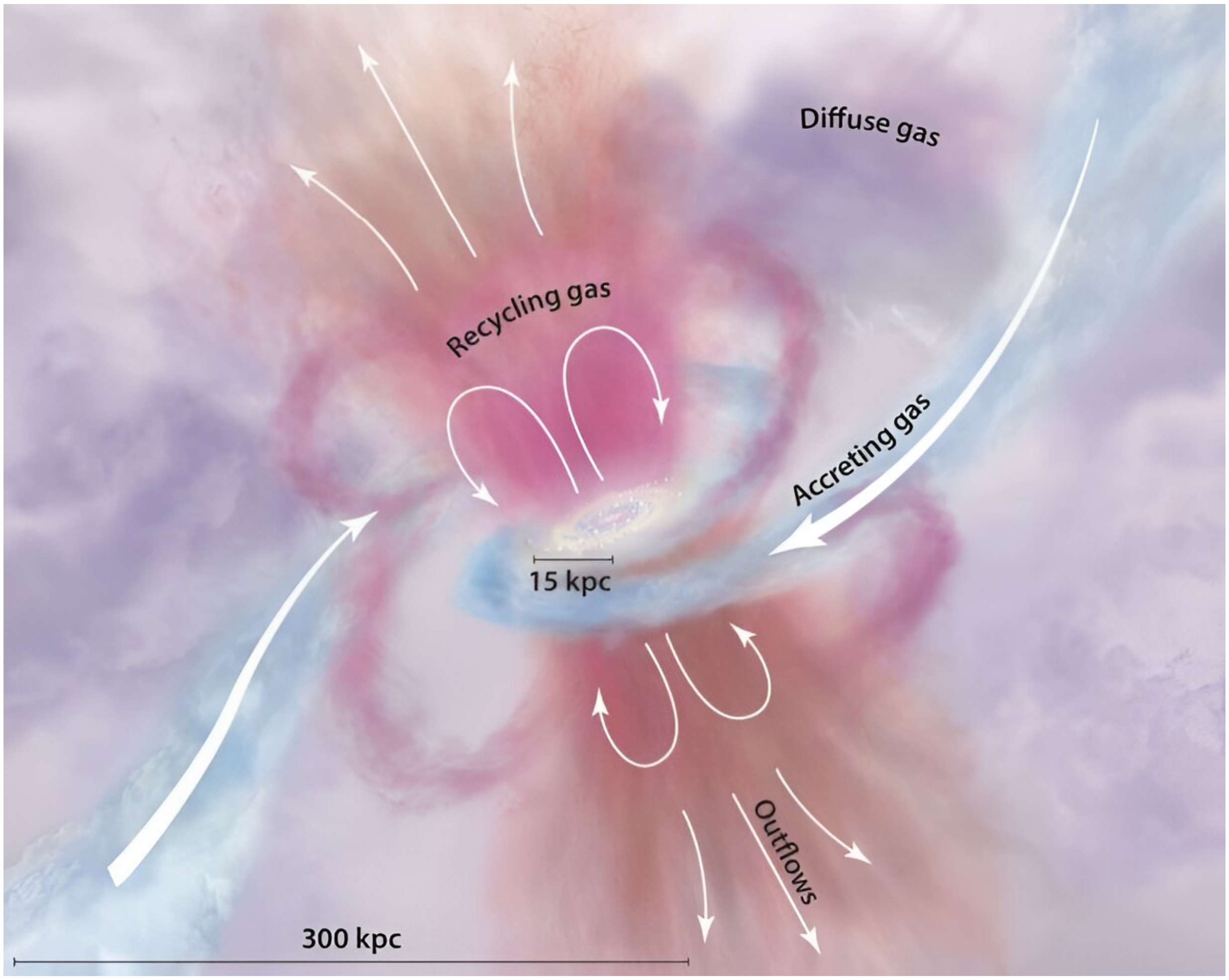
Astronomers began to observe gas flow into and out of galaxies in the 1960s by using the light from distant quasars. Credit: Tumlinson et al. 2107

Astronomers also found that the gas in the CGM closest to the galaxy has higher metallicity. "The circumgalactic medium can even provoke fascination: might the heavy elements on Earth cycled back and forth through the Milky Way's CGM multiple times before the formation of the solar system?" the 2017 paper asks.

Astronomers have turned to large-scale surveys to probe galactic breathing more deeply. It turns out that the gas in the CGM is up to 1,000 times denser than the gas in the IGM. Its temperature ranges from 10,000 to 1 million Kelvins, which is both cooler and hotter than gas in the IGM. But it's still hard to see what exactly is going on. Signals from the in-flowing gas are often overlapped by signals from the galaxy itself, making them difficult to study. On the other hand, outflowing gas is easier to see.

The cause of the outflows is uncertain. Supernovae could play a role, as could the powerful stellar winds from massive, hot, young stars. Black hole jets and feedback could also play a role.

Whatever the absolute causes of this gas-breathing are, it eventually ceases. Astronomers call that "quenching," and there's ample evidence for it. Once quenched, a galaxy is called a "quiescent galaxy" and no longer forms stars. In sky surveys, still-breathing galaxies are still forming stars and appear blue, while quiescent galaxies appear red. There's not much in between them.



This illustration shows gas flowing in and out of a galaxy. Pink and orange outflows emerge from the galaxy's disk. The blue gas is from the intergalactic medium (IGM) and flows back into the galaxy to be recycled into new galaxies. Credit: Tumlinson et al. 2017

But astronomers face the same problem in understanding quenching as they do for gas in-flows into galaxies: a lack of strong evidence. And some of the evidence astronomers do have is very puzzling.

For example, some research found gas gravitationally bound to red, quenched galaxies. The gas is cold and dense enough to form stars, but for some reason, it won't fall into the galaxies. So there's ample star-forming fuel close at hand, but it can't get into the galaxy.

The difficulty in observing in-falling gas means a more complete understanding of galactic breathing is out of reach, for now. But astronomers have another tool: simulations.

One simulation, called FIRE: Feedback In Realistic Environments, models the formation of galaxies and their stars as gas flows into and out of them over billions of years. One of the simulations shows a Milky Way galaxy forming over time. Galaxy formation never really ends, and the simulation provides a helpful visualization of warm gas leaving the galaxy while cool, dense gas flows back in.

Once stars stop forming, so do planets. By extension, so, probably, does life. From that perspective, the quenching of a galaxy is the quenching of possibilities. What would it be like to be an alien astronomer inside a galaxy that's been quenched, where the stars are aging and no new ones are forming? It's a strange, melancholy thought.

But one day more than just galaxies will quench. We live in the Stelliferous Era, where matter is organized into planets, stars, galaxies, and galaxy clusters. In about 100 trillion years, this era will end, just as if the entire universe was quenched. All that's left will be white dwarfs, brown dwarfs, neutron stars and black holes.

No new stars will ever form again, the universe will go dark and cold, and everything humanity ever pondered, including how galaxies breathe gas and form stars, will be moot.

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