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Advanced life should have already peaked billions of years ago, says paper

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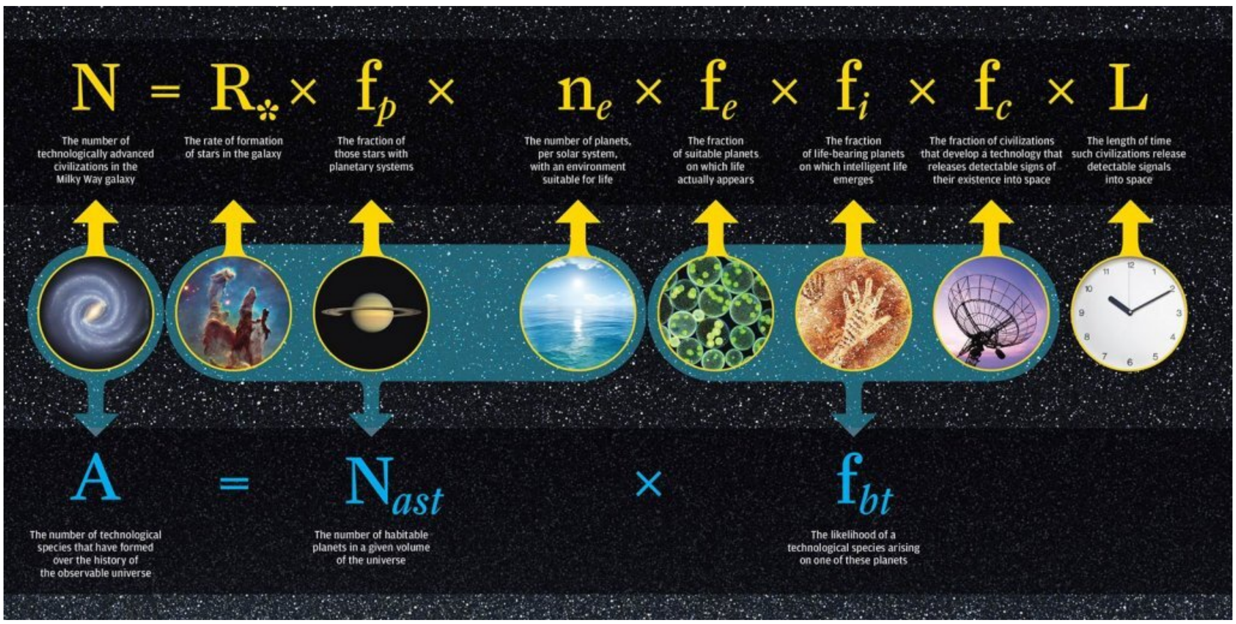


The Drake Equation, a mathematical formula for the probability of finding life or advanced civilizations in the universe. Credit: University of Rochester

Did humanity miss the party? Are SETI, the Drake Equation, and the Fermi Paradox all just artifacts of our ignorance about Advanced Life in the universe? And if we are wrong, how would we know?

A new study focusing on black holes and their powerful effect on star formation suggests that we, as advanced life, might be relics from a bygone age in the universe.

Universe Today readers are familiar with SETI, the Drake Equation, and the Fermi Paradox. All three are different ways that humanity grapples with its situation. They're all related to the Great Question: Are We Alone? We ask these questions as if humanity woke up on this planet, looked around the neighborhood, and wondered where everyone else was. Which is kind of what has happened.

We live in an era of exoplanet discoveries, and astronomers are busy searching for planets that have a possibility of being habitable, i.e., they have liquid surface water. That's a simple definition of habitability, but it's useful for sorting through the thousands of exoplanets we've discovered and the untold millions more waiting to be discovered. Because, the a priori reasoning tells us, individual planets are the key to finding life.

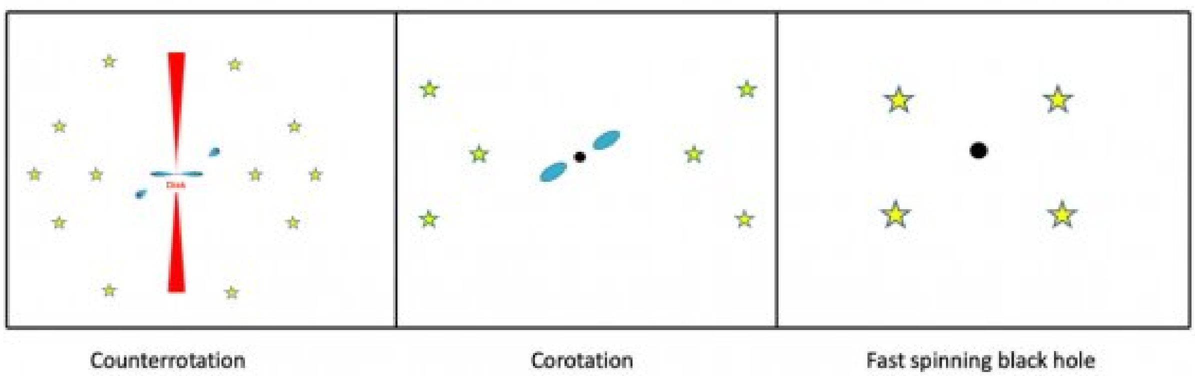
But what about a more wide-angle view of habitability and, especially, other advanced life? Is combing through individual planets the way to find other life? Or are certain galaxies themselves more likely to host advanced life, which can take billions of years to evolve? Do the black holes in galaxies affect the likelihood of advanced life?

David Garofalo is an associate professor of physics at Kennesaw State University in Georgia. Garofalo researches the physics of black holes, and in a new paper, he explains how black holes could affect the existence of advanced life.

The paper is "Advanced Life Peaked Billions of Years Ago According to Black Holes." It's available on the *arXiv* preprint server and soon to be published in the journal *Galaxies*. Garofalo is the sole author, and the paper hasn't been peer-reviewed yet.

Garofalo explains how black hole feedback can either drive or suppress star formation. Whether it does or not depends on the environment and whether the SMBH is in a gas-sparse or a gas-rich environment.

"The link between black holes and star formation allows us to draw a connection between black holes and the places and times when extraterrestrial intelligences (ETIs) had a greater chance of emerging," Garofalo writes.



This figure from the research helps explain what happens in a gas-sparse environment. It starts with a merger of two gas-rich black holes. The accretion disk, shown in blue, is in counter-rotation around a rapidly-spinning black hole. That produces jets that drive star formation rates higher. That lasts about 8 million years. In the middle panel, the disk is tilted, and the jets disappear, so star formation is unaffected. In the right panel, "The star formation rate dies down as the cold gas reservoir comes to an end and a dead quasar is formed after over a billion years," Garofalo explains. Credit: Garofalo, 2023

The Drake Equation tries to give form to our ponderings about other intelligent civilizations. It's a probabilistic equation that tries to calculate the number of intelligent and communicative civilizations there are in the Milky Way. Garofalo's effort extends beyond the Milky Way into the universe. But the universe is vast and ancient. Where to begin?

Garofalo starts with black holes, feedback, and star formation.

"Our understanding of the processes that determine where and when star formation peaks in the universe has matured significantly, to the point where we can begin to explore more broadly the question of intelligence across space and time," Garofalo writes. Black hole feedback affects star formation in galaxies, but the effect varies.

Garofalo has researched black holes extensively, and this paper leans heavily on his research and the work of others in the same field. Garofalo claims that advanced life peaked billions of years ago, all because of the direct connection between mergers, black holes, star formation, and the planets that form around those stars. It starts with a black hole merger that's likely to lead to active galactic nuclei (AGN,) which is the term for a supermassive black hole (SMBH) at the center of a galaxy that is accreting enough matter to shine brightly. Some AGN emit jets, and they're dependent on the nature of the matter accreting onto the hole. The matter is the galaxy's gas, and different galaxies have different gas environments.

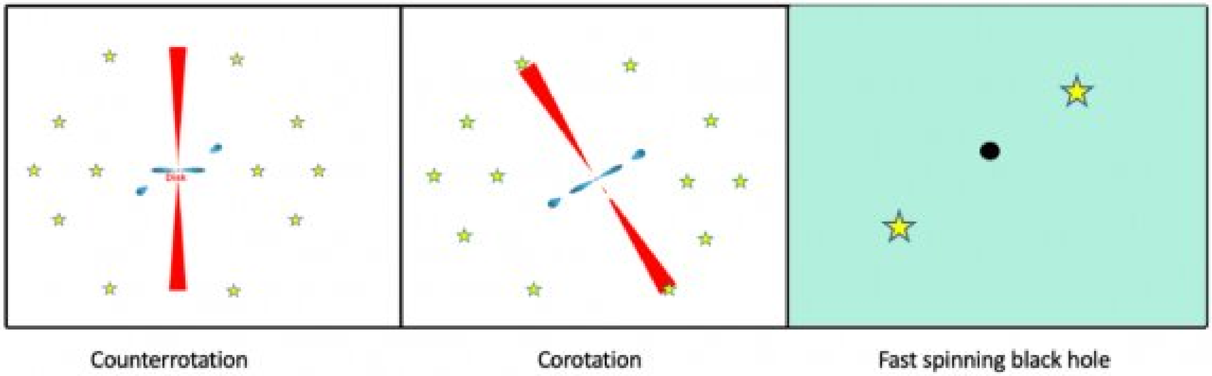
Black hole feedback plays a major role in Garofalo's work. Different black holes drive different types of feedback, and some feedback drives higher rates of star formation. Jets are the primary way that black holes interact with the surrounding medium, pumping matter back out of their accretion disks into their surroundings.

Sometimes all that feedback drives star formation. But sometimes, it injects too much energy into its galaxy or galaxy cluster, and that chokes off star formation. It heats up the gas too much, and to collapse and form stars, gas needs to be cold. A core part of Garofalo's work is identifying when black hole feedback drives star formation and when it stifles star formation.

Sometimes a black hole's accretion disk is counter-rotating relative to the black hole itself as a result of a merger, and that affects the feedback and the jets. "Counterrotation is associated with various general relativistic effects that maximize the power and collimation of the jet," Garofalo writes. "This type of jet is funneled through the cold gas and pushes it into states of higher densities, thereby triggering star formation."

But that counter-rotating accretion disk can slow and then stop the black hole's spin. Eventually, it reverses and speeds it up again. When the black hole is at a zero spin, it ceases to produce jets, and its feedback into the galaxy or galaxy cluster is stalled. The zero spin state also tilts the accretion disk. At that point, "the incoming gas forms a disk that maintains the angular momentum of the gas reservoir of the greater galaxy," Garofalo explains. The zero spin state lasts for different lengths of time depending if the galaxy is sparse in gas or rich in gas. It lasts about eight million years in an environment that is sparse in gas.

But things change in a denser, more gas-rich environment. "In denser environments, instead, the black hole mass tends to be larger, the jet more powerful, and its feedback effect greater," Garofalo explains. This is because the way gas accretes onto the disk changes. It adopts a different type of flow than in a sparse environment.



This figure from the research helps explain what happens in a gas-dense environment. The jets re-emerge but are tilted and aimed more directly at the gas in the host galaxy. That heats it up and limits star formation. It also means the galaxy's gas is hot enough to produce X-rays, a limiting factor for life. Credit: Garofalo, 2023

The different flow means that the black hole in the dense environment takes longer to spin down by two orders of magnitude. The result? "As a result, on average, the richest environments produce powerful, collimated jets that enhance star formation for a timescale that is about two-orders-of-magnitude longer than in more isolated environments," Garofalo writes. Eventually, the spin reaches zero, and the jets cease. Critically, the jets only re-emerge in the denser environment.

This is a lot of information for those of us who aren't astrophysicists, but Garofalo clarifies the key part for us, and it comes down to sparse or dense environments. "The key difference is the presence of only positive AGN feedback in isolated environments, while both positive, then negative feedback, in richer ones." The jets only re-emerge in richer or denser environments, but they're tilted. This means they're aimed more directly at the galaxy's gas, and they can heat it up and stifle star formation.

In that case, the result is fewer stars. Fewer stars mean fewer planets, which means fewer possibilities for advanced life. But the effect extends beyond the rates of star and planet formation. Since the galaxy's gas is heated, it can give off a halo of X-rays that permeates the galaxy and affects the chemistry of planets, which can inhibit their habitability.

That's bad news for advanced life in more gas-dense galaxies and galaxy clusters. Even though there's more gas, the stuff that gives rise to stars, the gas is overheated, stifling star formation.

But what about in gas-sparse galaxies and clusters?

"In more isolated environments, by contrast, stars evolve onto the main sequence undisturbed by AGN feedback," Garofalo summarizes. This is also critical because we're talking not about just the appearance of life, which may have occurred on Earth in only a few hundred million years. We're talking about advanced life like us, which took 4.5 billion years to appear on Earth. Main sequence stars are the longest-lived, most stable stars, and it's far more probable that advanced life can arise around main sequence stars than other stars.

Taking all this into account, Garofalo reframes the Drake Equation to include black hole feedback. "It tells us where in the universe the chance of detecting advanced life is greatest. The answer is in isolated field environments," he explains.

But where advanced life can arise is only part of it. Garofalo wanted to find out when it was most likely. It all goes back to the initial black hole mergers that produce counter-rotating accreting black holes. "Counterrotating accreting black holes are the product of mergers, and the merger function experiences its peak at a redshift of 2," he writes. A redshift of 2 was about 11 billion years ago when the universe was 2.8 billion years old.

"This, therefore, is the redshift corresponding to when the greatest number of isolated field galaxies experienced a merger that led to cold gas flowing into the nucleus of the newly formed galaxy and settling into counterrotation around the newly formed black hole," Garofalo concludes.

That's the age when AGN and their jets appear. They triggered star formation and planet formation. Earth formed 4.5 billion years ago, and we, the advanced life capable of interstellar communication, only just appeared. So using us as a benchmark, it's about 4.5 billion years after the right black holes in the right galaxies that advanced life can appear. Garofalo rounds it off to 5 billion years. "Thus, we assume a fiducial value of 5 billion years, which brings us to 7.8 billion years after the Big Bang, or 6 billion years ago."

At this point, an astute reader might wonder about metallicity. There was lower metallicity 6 billion years ago, so wouldn't that have affected the types of planets that form and whether or not advanced life could arise on them?

Not necessarily.

Garofalo points out that the galaxies where the critical AGN are most likely to exist are isolated elliptical galaxies. But they're not the old red and dead elliptical galaxies. The ones Garofalo is talking about are different. Instead, "these isolated elliptical galaxies are not expected to harbor low metallicities because they are AGN-triggered by mergers with abundant cold gas, possibly from a disk-like galaxy," he explains. The old red and dead elliptical galaxies are also known to be populated with older stars and dominated by M dwarfs or red dwarfs whose habitable zones are "closer to the star and subject to stellar flares and tidally locked rotation, which work against the development of life," Garofalo writes. But the subset of elliptical galaxies he's talking about isn't dominated by red dwarfs.

So there we have it. If Garofalo is right, then we need to rethink SETI. "Given the times and places identified for ETIs in this work, we expect SETI searches to require that signals come from Kardashev Type III civilizations," he writes in his conclusion. A Kardashev Type III civilization is one that is able to access all the energy emitted by its galaxy.

According to Garofalo's work, humanity is indeed late to the party. "To the extent that we may someday speak of a peak era for the emergence of technologically advanced life in the universe, our simplified exploration of the emergence of life in the context of AGN feedback indicates that such a time is in the past," he concludes. "We on planet Earth are, therefore, latecomers."

We may be late, but we aren't necessarily alone. Other partygoers might be just arriving. We're here, so it's possible others are.

When it comes to communicating with another advanced civilization, that's an open question. But look at us. Advanced life is still emerging. Maybe two civilizations will contact one another someday.

For that to happen, we need to know where to direct our effort in this vast Universe. If this work holds up, it might help advance the search for Extra-Terrestrial Intelligences by showing us where to look.

And where not to.

More information: David Garofalo, Advanced life peaked billions of years ago according to black holes, *arXiv* (2023). DOI: 10.48550/arxiv.2305.04033

Chandra B. Singh et al, The Black Hole-star Formation Connection Over Cosmic Time, *Publications of the Astronomical Society of the Pacific* (2021). DOI: 10.1088/1538-3873/ac2ec2

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