Why the Virgo Cluster Is Killing Its Galaxies

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A spiral galaxy can be losing the material it needs to survive — actively, physically, measurably — while looking, in an optical image, like a perfectly healthy system. The stars stay where they are. The disk keeps its shape. The arms still curl in the direction they always curled. Nothing in the starlight tells you anything is wrong. The damage is happening in the gas, and gas, in its cold atomic form, requires a radio telescope tuned to a specific wavelength to see. For decades, entire populations of dying galaxies were catalogued as ordinary because no one was looking at the right thing.

The Virgo Cluster — 54 million light-years away, containing over a thousand galaxies, anchoring the gravitational center of the entire Local Supercluster — is not a passive structure. It is an environment that systematically dismantles the galaxies inside it through three overlapping mechanisms operating across timescales from hundreds of millions to several billion years. This is how it works.

The Medium That Does the Damage

The space between galaxies in the Virgo Cluster is not empty. It is filled with a hot, diffuse plasma called the intracluster medium, or ICM, and this plasma contains more ordinary (baryonic) matter than all the stars in all the cluster's galaxies combined. The galaxies are the visible minority. The ICM is the dominant component.

In the Virgo Cluster's core, the ICM reaches temperatures of roughly 2.5 keV — equivalent to approximately 29 million Kelvin. In the outer regions, temperatures climb to 3 to 4 keV where infalling material is still being thermalized. The plasma emits no visible light. It radiates in X-rays through a process called thermal bremsstrahlung, in which electrons decelerate around ions and release photons in the X-ray band. Line emission from highly ionized heavy elements, particularly iron at 6 to 7 keV, sits on top of this continuum and allows spectroscopic measurement of the plasma's chemical composition. [1]

The ICM was created through gravitational heating. As matter collapsed into the cluster's potential well over billions of years, infalling gas streams collided at velocities of thousands of kilometers per second. The kinetic energy of those collisions was converted into heat. The gas thermalized, reached temperatures where cooling became inefficient, and settled into a pressure-supported atmosphere filling the cluster volume. It has been there ever since, and it does not move aside for galaxies passing through it.

The density of this plasma is almost nothing by everyday standards — a few thousandths of a hydrogen atom per cubic centimeter near the core, falling off steeply with distance. You could stand inside it and feel nothing. The danger only becomes real at the scale of a galaxy trying to hold onto its disk gas while moving through this medium at a thousand kilometers per second.

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Ram Pressure Stripping: The Physics of the Headwind

When a galaxy moves through the ICM, the plasma presses against the galaxy's interstellar gas the way moving air presses against anything passing through it. This is ram pressure, and it was first formally quantified by James Gunn and J. Richard Gott in 1972 in a paper about the infall of galaxies into clusters. [2] The criterion they derived remains the foundational framework for understanding gas stripping in clusters.

The ram pressure at any point is:

$$P_{\text{ram}} = \rho_{\text{ICM}} \cdot v_{\text{gal}}^2$$

where ρ_{ICM} is the local density of the intracluster medium and v_{gal} is the velocity of the galaxy relative to the plasma. This pressure acts on the galaxy's interstellar gas disk. Whether that gas is stripped depends on whether the ram pressure exceeds the gravitational restoring force per unit area that holds the gas in place:

$$F_{\text{restore}} = 2\pi G \, \Sigma_{\star} \, \Sigma_{\text{gas}}$$

where G is the gravitational constant, $\Sigma_{\star}$ is the stellar surface density, and Σ_{gas} is the gas surface density. Gas is stripped where $P_{\text{ram}} > F_{\text{restore}}$. The radius at which the two sides are equal is the stripping radius. Everything outside that radius, in principle, goes.

The velocity term is squared. Doubling a galaxy's speed quadruples the ram pressure it experiences. This matters because a galaxy falling into the cluster core is accelerating as it descends through the gravitational potential well, reaching its maximum velocity at pericentric passage — the closest approach to the cluster center — which is also where the ICM is densest. Both variables are maximized at the same moment. The geometry of gravitational collapse arranges for the worst possible conditions to coincide.

The restoring force varies across the disk. Near the galaxy's center, where the stellar density is high, the restoring force is strong. In the outer disk, where stellar and gas surface densities are both low, it is weak. Stripping therefore always begins at the outer edge and works inward. The outermost gas goes first. The dense central regions resist longest. This outside-in progression produces a characteristic observational signature: a gas disk truncated well inside the stellar disk boundary, with the stellar disk itself remaining symmetric and undisturbed. [3]

Jellyfish Galaxies: Destruction Made Visible

At peak ram pressure, something becomes visible that is otherwise invisible. The stripped gas does not vanish immediately. It is pushed off the disk and trails behind the moving galaxy in long, one-sided filaments of ionized hydrogen glowing in H-alpha emission at 656 nanometers. These filaments can extend for tens to hundreds of kiloparsecs. They branch. They thin and thicken along their length. They carry embedded clumps of denser material.

The resulting morphology gives the class its name. A jellyfish galaxy has the body of an intact stellar disk and a cascade of gas filaments trailing in one direction, oriented opposite to the galaxy's motion through the ICM. The direction the tail points encodes the direction of travel. The length and surface brightness of the tail encodes the intensity and duration of the stripping. The image is not just a picture. It is a physical record of an ongoing interaction.

The GASP survey (GAs Stripping Phenomena in galaxies with MUSE) provided the most systematic study of jellyfish galaxies to date, obtaining integral field spectroscopy for 114 galaxies at redshifts between 0.04 and 0.07. [4] MUSE maps a full spectrum at every spatial position simultaneously, producing velocity fields, ionization maps, star formation rates, and metallicity gradients across the entire galaxy and its tail. The data revealed that jellyfish galaxies, as a population, show disk star formation rates elevated by roughly 0.2 dex compared to non-stripped cluster galaxies at similar stellar mass. The leading-edge compression that precedes stripping temporarily increases local gas densities, triggering a brief starburst before the gas is removed entirely.

New stars also form in the tails themselves. In NGC 4388, a Virgo spiral moving at over 1,400 km/s relative to M87, star-forming regions have been confirmed at 35 and 66 kiloparsecs from the galaxy disk, with stellar ages of approximately 6 million years. [5] Those stars formed after the gas left the galaxy. In intergalactic space. In material that was a spiral disk's raw fuel and became something untethered from any galaxy entirely.

Strangulation: The Slower Mechanism

Ram pressure stripping is dramatic and observationally accessible. Strangulation is neither. It operates before the ICM wind reaches the cold disk gas, and it works by removing something the galaxy did not know it was depending on.

Under normal field conditions, a spiral galaxy is not a closed system. Its disk gas, consumed by star formation, is partly replenished by cooling from an extended hot gas halo that surrounds the stellar disk at large radii. This halo is diffuse, held loosely, and sits at the cluster outskirts where even moderate ram pressure is sufficient to strip or thermally dissolve it. The galaxy can lose its halo before it has fully entered the cluster, well before any cold disk gas is disturbed.

Once the halo is gone, the replenishment stops. The disk burns through its remaining cold gas at whatever rate the ongoing star formation demands. Star formation rates decline gradually, over timescales of 2 to 4 Gyr, as the reservoir empties without refilling. [6] The galaxy's integrated color reddens slowly. Its metallicity rises, because the usual dilution of the interstellar medium by fresh, low-metallicity infall has stopped. These chemical signatures are detectable in precise spectroscopic surveys and have been used to confirm that strangulation is operating in cluster populations at intermediate redshift.

The framework that unifies strangulation and ram pressure stripping is called delay-then-rapid quenching. The strangulation phase constitutes the delay: a period of 2 to 4 Gyr during which star formation declines but does not catastrophically drop, the galaxy still identifiable as star-forming. Then something pushes the galaxy into the rapid phase: ram pressure stripping at pericentric passage, removing the remaining disk gas quickly on timescales shorter than 1 Gyr. The two phases are not independent. Strangulation weakens the disk, reducing the restoring force at intermediate radii, so that when ram pressure arrives, it finds a target that has already been partially depleted.

Galaxy Harassment: The Gravitational Accumulation

The third mechanism operates entirely through gravity and leaves no gas tail, no truncated disk, no clean observational signature. Galaxy harassment is the cumulative effect of repeated high-speed gravitational encounters between a cluster galaxy and other cluster members as it orbits through the dense environment.

Individual encounters are too brief to be catastrophic. Galaxies move at hundreds to over a thousand kilometers per second relative to each other, so a close pass at 50 kiloparsecs lasts far too short a time for resonant tidal coupling to develop. But the encounters accumulate. Over billions of years, each brief gravitational kick deposits a small increment of kinetic energy into the stellar orbits. The disk heats up dynamically, its ordered rotation becoming increasingly contaminated by random velocity components. The outer disk thickens. The spiral arms lose definition. The galaxy's structural properties drift from those of a cold, rotationally supported disk toward something warmer and more spheroidal.

The effect is mass-dependent. A massive spiral with a deep gravitational potential well resists significant structural transformation, accumulating damage over many billions of years without losing its basic character. A low-mass, low-surface-brightness dwarf is far more susceptible. Simulations by Moore et al. demonstrated that the excess population of dwarf elliptical galaxies observed in clusters like Virgo may partly result from harassment transforming infalling dwarf irregulars into rounder, kinematically hotter systems over the course of their time in the cluster. [7]

Three Galaxies in the Process of Being Unmade

NGC 4522

NGC 4522 is a medium-sized Virgo spiral sitting roughly 800 kiloparsecs from M87, well outside the cluster core. Its neutral hydrogen disk is truncated at approximately 35 percent of the stellar disk radius. About 40 percent of the galaxy's total HI content, equivalent to 1.5×10^8 solar masses, is extraplanar: lifted off the disk and trailing behind the galaxy in a one-sided extraplanar structure. [8] The stellar disk is symmetric and undisturbed. Standard smooth ICM density models predict the ram pressure at 800 kiloparsecs should be barely sufficient to produce the observed stripping, which suggests the ICM is inhomogeneous at large cluster radii, or the galaxy's true three-dimensional velocity is higher than the line-of-sight component alone indicates. NGC 4522 demonstrates that active stripping can occur at larger clustercentric distances than simple models predict.

NGC 4569

NGC 4569 is the brightest late-type galaxy in the Virgo Cluster by optical luminosity. It has lost more than 90 percent of its initial neutral hydrogen. The total gas mass removed during its interaction with the cluster is estimated at approximately 1.9×10^{10} solar masses, comparable to the entire interstellar medium of the Milky Way. Deep H-alpha imaging from the VESTIGE survey detected an ionized gas tail extending 230 kiloparsecs from the galaxy disk, the longest tail yet measured in the Virgo Cluster. [9] NGC 4569 is still forming stars in its central molecular gas reservoir. It is not yet quenched. It is somewhere in the transition, past the delay phase, past peak stripping, declining toward a final state it cannot avoid.

NGC 4388

NGC 4388 moves at over 1,400 km/s relative to M87 and hosts a Seyfert 2 active galactic nucleus. Its neutral hydrogen plume extends 110 kiloparsecs to the north, containing 3.4×10^8 solar masses of gas — the largest HI tail in the Virgo Cluster. [10] Star-forming regions at 35 and 66 kiloparsecs from the disk, with stellar ages of approximately 6 million years, confirm that stars formed in situ in the stripped tail after the gas left the galaxy.

What the Stripping Leaves Behind in the ICM

The gas that leaves a galaxy does not disappear. It joins the intracluster medium, carrying metals processed by the galaxy's stellar populations into the cluster plasma. The ICM metallicity of roughly one-third to one-half solar abundance is partly a record of every galaxy that has been stripped over the cluster's history.

Ram pressure stripping deposits metals preferentially in the inner cluster regions, where the stripping is most intense and where stripped material mixes into the surrounding plasma before traveling far. XRISM satellite observations of the Virgo Cluster core in 2025 found super-solar silicon-to-iron and sulfur-to-iron ratios in the cluster center, a chemical fingerprint encoding the specific star formation history and stripping record of Virgo's galaxy population across billions of years. [11]

The total iron mass in the Virgo ICM within the virial radius has been estimated at approximately 4×10^9 solar masses. Some of it was in the original gas that formed the cluster. Some arrived through galactic winds. And some was carried in by the outer disks of spiral galaxies that fell through the cluster, were processed by the environment, and left their chemical content behind as they quieted.

The cluster is both the executioner and the archive. The ICM holds a chemical record of every galaxy it has ever dismantled.

The Complete Sequence

A spiral galaxy crossing the Virgo virial radius for the first time enters a sequence, not a single event. The hot halo is disrupted before the galaxy is fully inside the cluster. Strangulation begins. Star formation starts a slow decline while the disk continues forming stars on its remaining reservoir. The small group the galaxy was part of disperses under the cluster's tidal forces. The galaxy falls inward alone, accelerating, the ICM thickening around it with every kiloparsec of infall.

Ram pressure reaches the outer disk. The jellyfish phase begins. Pericentric passage arrives at maximum speed and maximum ICM density, and most of the outer disk gas is removed in a single pass. The galaxy emerges with a truncated disk, a dispersing tail, possibly an active nucleus fed by gas funneled inward during the stripping event. The return orbit is slower. A second pericentric passage takes what remains of the intermediate-radius gas. Over the following billions of years, the central molecular reservoir is consumed. The star formation rate drops. The galaxy's color reddens as blue stars age and are not replaced.

At some point, the last star-forming clumps exhaust their molecular clouds and are not replenished. The disk is still there. The stars still orbit. Nothing new forms.

What We Actually Know

The current model of gas stripping in the Virgo Cluster rests on half a century of observations and four major survey programs. The VIVA survey mapped neutral hydrogen in 53 Virgo spirals and established the statistical prevalence of truncated disks and one-sided tails. VESTIGE covered the full cluster to its virial radius in deep H-alpha imaging, revealing the ubiquity of truncated star-forming disks even beyond the cluster's edge. VERTICO mapped molecular gas in 51 Virgo galaxies using ALMA at sub-kiloparsec resolution, extending the picture to the cold molecular phase. GASP provided integral field spectroscopy of over 100 stripped galaxy candidates, turning case studies into a statistical population.

What these surveys together established is that no single mechanism operates in isolation. Strangulation, ram pressure stripping, and harassment overlap. They strengthen each other's effects. They produce the same end state — a gas-poor, passively evolving disk — through different physical pathways operating at different radii and different timescales. And the damage begins earlier, extends further from the cluster center, and proceeds faster than the pre-survey picture suggested.

The Virgo Cluster is dynamically young. It has not reached equilibrium. Galaxies are crossing the virial radius for the first time right now, carrying the gas they have built up over a field lifetime, entering an environment that will systematically remove it. The jellyfish morphologies we observe today will appear in those galaxies in the next few billion years. The galaxies currently being stripped will move on to their post-stripping configurations.

The light leaving the Virgo Cluster at this moment carries information about galaxies currently mid-sequence, their tails forming, their disks shrinking, their futures already set. That light will reach Earth in 54 million years. What it describes is not an exceptional event. It is the ordinary fate of galaxies that fall into clusters, written in the gas they can no longer hold onto.

[1] XRISM Collaboration (2025). High-resolution X-ray spectroscopy with XRISM/Resolve reveals super-solar abundance ratios in Virgo/M87. arXiv:2605.18989.

[2] Gunn, J. E. and Gott, J. R. (1972). On the Infall of Matter Into Clusters of Galaxies and Some Effects on Their Evolution. ApJ, 176, 1.

[3] Chung, A. et al. (2009). VLA Imaging of Virgo Spirals in Atomic Gas (VIVA). AJ, 138, 1741.

[4] Poggianti, B. M. et al. (2017). GASP: GAs Stripping Phenomena in Galaxies with MUSE. ApJ, 844, 48.

[5] Yagi, M. et al. (2013). Star-forming regions in the ram-pressure stripped tail of NGC 4388. ApJ, 778, 91.

[6] Peng, Y. et al. (2015). Strangulation as the primary mechanism for shutting down star formation in galaxies. Nature, 521, 192.

[7] Moore, B. et al. (1996). Galaxy harassment and the evolution of clusters of galaxies. Nature, 379, 613.

[8] Kenney, J. D. P., van Gorkom, J. H. and Vollmer, B. (2004). VLA HI Observations of Gas Stripping in the Virgo Cluster Spiral NGC 4522. AJ, 127, 3361.

[9] Boselli, A. et al. (2016). Spectacular tails of ionised gas in the Virgo cluster galaxy NGC 4569. A&A, 587, A68.

[10] Oosterloo, T. and van Gorkom, J. (2005). A 110-kpc HI tail associated with NGC 4388 in the Virgo Cluster. A&A, 437, L19.

[11] XRISM Collaboration (2025). arXiv:2605.18989. ibid.