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Islands of Electromagnetic Tranquility in Our Galactic core and Little Red Dots that Shelter Molecules and Prebiotic Chemistry

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ABSTRACT

Both the Galactic center and LRDs host million-solar-mass black holes within dense, cold reservoirs of molecular gas, and are electromagnetically tranquil. These conditions enable complex molecular chemistry and may serve as natural laboratories for prebiotic genetic evolution by allowing the synthesis of organic molecules essential for life.

1. INTRODUCTION

Over the past six decades, our understanding of galactic centers has evolved from the discovery of luminous compact sources to a deeper perspective shaped by the Milky Way's quiet nucleus. Sagittarius A* exemplifies a central compact core of about $10^6\,M_\odot$ accreting at a very low rate, surrounded by the Central Molecular Zone (CMZ), a region rich in cold molecular gas (Event Horizon Telescope Collaboration et al. 2022). More recently, JWST observations have identified ultra-compact, dusty "little red dots (LRDs)" at high redshift (Matthee et al. 2024), which also appear to host black holes of similar mass embedded within dense, molecule-rich cores. Like the Milky Way's center, these proto-galaxies are bright in the infrared but faint in X-rays, suggesting a comparable environment. This raises the central question of our article: since the environment of the Milky Way gave rise to humanity, could similarly tranquil regions around million-$M_\odot$ black holes in LRDs also support the formation of complex molecules and prebiotic chemistry, potentially making them "Islands of Electromagnetic Tranquility" both in our Galaxy and in the LRDs of distant universe?

UNIQUENESS OF THE MILKY WAY'S GALACTIC CORE (A LOW-TEMPERATURE NUCLEUS)

The center of our Milky Way hosts a compact object of $4 \times 10^6 M_\odot$, Sagittarius A* (Sgr A*), which is extremely under-luminous and quiescent compared to the active galactic nuclei (AGN) seen in many other galaxies. Sgr A* is accreting very little material at present, radiating at only a tiny fraction (below 10^{-9}) of its Eddington luminosity. Unlike a quasar or a Seyfert nucleus, the Milky Way's core emits no powerful jets or intense X-ray outbursts, because it lacks the existence of a rotating Kerr black hole and the large, sustained infall of gas required to ignite the AGN phase (Event Horizon Telescope Collaboration et al. 2022; Ruffini & Vereshchagin 2025).

From an observational standpoint, our Galactic center contrasts sharply with a classic AGN. Instead of a brilliant point-like nucleus dominating the galaxy's light, the Milky Way's center is observable mainly via its dense interstellar clouds and star clusters. It is rich in molecular gas and dust but comparatively dim in high-energy output. Astronomers have indeed noted that the central region of the Milky Way, despite containing Sgr A* and a dense stellar cluster, lacks the strong ionization and excitation features that an active nucleus would produce. For example, in external galaxies with AGN, one often sees high-excitation emission lines and ionized cones; by contrast, our center's emission-line regions are mostly low-excitation and associated with star formation (e.g. rings of H II regions) (Balbi & Tombesi 2017). Kinematically, the Milky Way's bulge and inner disk rotate in an orderly way, with no signs of the violent disturbances that a recent major accretion event might imprint. All these observational clues reinforce that the Milky Way is an inactive galaxy in terms of nuclear activity. In fact, evidence suggests Sgr A* has been quiescent for at least the last few million years, though tantalizing clues like

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the giant gamma-ray Fermi bubbles indicate it flickered on in the past (likely a short AGN episode a few Myr ago) (Zubovas & Nayakshin 2012). Overall, our Galactic core today is a relatively tranquil environment in the electromagnetic sense, certainly compared to a typical quasar or radio galaxy.

From a theoretical perspective, dark matter likely plays a key role in maintaining the low-temperature, stable core of the Milky Way. The galaxy resides in a massive dark matter halo whose properties, especially the initial angular momentum (spin), influence central gas concentration (Jiang et al. 2019). Recent JWST studies suggest that low-spin halos allow gas to collapse centrally, forming compact LRD (Pacucci & Loeb 2025), while higher-spin halos favor extended disks. The Milky Way's halo probably had moderate spin, resulting in a large disk and spiral structure, but still provides a deep gravitational potential that gradually channels gas inward. Gas flows along the bar and dust lanes, accumulating in the CMZ ring around Sgr A* (Ginsburg et al. 2016). Because dark matter dominates the central potential in addition to the black hole, much of the gas can remain stable in the CMZ, orbiting at $\sim$ 100 parsecs, without being rapidly accreted. Thus, under the dark matter framework, a quiescent galactic center with substantial cold molecular gas and a starved SMBH is expected, as observed in the Milky Way.

COMPARING OUR GALAXY TO THE LITTLE RED DOTS

LRDs are tiny, reddish proto-galaxies discovered in the early universe, as early as a few million years after the Big Bang in JWST deep surveys (Matthee et al. 2024). They are extraordinarily compact, typically only 30–200 parsecs in radius, which is a few percent of the Milky Way's size, and a typical LRD with a radius of $\sim$ 100 parsec is comparable to our Galaxy's CMZ or nuclear region. Despite their small size, many LRDs appear to host massive central black holes of a few million solar masses, similar to SgrA*; surprisingly, the black hole can account for a few tens of percent of the entire stellar mass in these systems. Thus, while both the Milky Way and LRDs have SMBHs in the few-million to ten-million solar mass range, the black hole is a much larger fraction of an LRD than in our Galaxy. Structurally, an LRD can be viewed as a proto-galaxy that is almost entirely "core", emitting about half its light from a region only $\sim$ 100 parsec across (Matthee et al. 2024), a scale that, in the Milky Way, corresponds to just the innermost bulge where the CMZ and nuclear star cluster reside. As a result, the processes taking place across an entire LRD occur within a volume comparable to that surrounding SgrA*.

Both the Milky Way's core and LRDs are defined by their large reservoirs of cool dust and molecular gas. In the Galactic center, the CMZ contains approximately 60 million solar masses of molecular material, exhibiting densities and pressures much higher than those in typical interstellar clouds, but with temperatures low enough ($T \sim$ 50–200 K) to support molecule formation (Battersby et al. 2025). LRDs, first identified at high redshift with JWST, have since been found in the local universe, providing valuable targets for detailed study.

Observations of local LRDs from WISE show that these galaxies harbor dust with a broad temperature distribution, and a substantial fraction is cold ($T_{\rm dust} \sim$ 100–1000 K), colder than in typical starburst or AGN-dominated systems (Lin et al. 2025). The high gas surface densities inferred from their emission lines and infrared luminosity further indicate that LRDs are capable of maintaining extensive regions of cold, shielded molecular gas.

Another parallel is that both the Milky Way's center and LRDs host active cores without the high-energy output typical of AGN. Sgr A* currently accretes at a very low rate, forming a radiatively inefficient accretion flow that produces little X-ray or UV emission; only weak X-ray flares and modest radio/infrared output are observed. Remarkably, LRD galaxies show similar behavior. Despite broad emission lines suggesting black hole accretion disks, no X-ray emission has been detected from LRDs to date (Sacchi & Bogdan 2025), and their variability is minimal compared to standard AGN (Furtak et al. 2025). This raises questions about the true power source: the central black holes could be heavily obscured or intrinsically accreting at a very low Eddington ratio. In either case, the region around the black hole in LRDs is not dominated by strong high-energy emission, resembling the "electromagnetically tranquil" environment of Sgr A*, characterized by abundant cooler gas in the nucleus, while a quasar core would produce intense X-ray, UV, and radio jets. LRDs exhibit gas rotation up to $\sim$ 1000 km s^{-1} (de Graaff et al. 2025), similar to velocities near Sgr A*, indicating a massive gravity source but without strong winds or ionization. These similarities suggest that LRDs and the Milky Way's core may both represent "cold" galactic nuclei, dominated by dark matter and moderate SMBH, with baryons held in a relatively quiescent state.

TRANQUIL CORES AS CRADLES FOR MOLECULES AND THE INGREDIENTS OF LIFE

A thermally stable, quiet galactic core enables chemical complexity to develop. In energetic environments such as quasar cores, intense radiation and shocks dissociate molecules and fully ionize gas. By contrast, the Milky Way's center and similar environments like LRDs preserve large masses of cold molecular gas, supporting complex chemistry. This "electromagnetic tranquility" around Sgr A* allows fragile molecules to survive, as Sgr A* is not emitting strong UV or X-rays, and clouds lack nearby young stars that would produce destructive ultraviolet light. As a result, molecules can accumulate and react, increasing in complexity. Observations reveal a rich inventory of complex organic molecules in these clouds. For example, the cloud G+0.693-0.027, located about 3 light-years from the Galactic center, contains nitriles, which are organic molecules with −C≡N groups and are precursors to RNA nucleotides (Rivilla et al. 2022). This cloud is cold (about 100 K) and dense, with no ongoing star formation, making it an ideal environment for forming prebiotic molecules. Central clouds in the Milky Way likely have chemistry similar to that found in comets (Altwegg et al. 2019), and many organics detected in comets and meteorites may have formed in these interstellar environments. According to the RNA world hypothesis, molecules like nitriles could have been delivered to early Earth by comets and meteors, jump-starting prebiotic chemistry (Chakrabarti & Chakrabarti 2000). The Galactic center may thus have contributed to the cosmic inventory of life's building blocks, demonstrating how a protected chemical niche can foster molecular complexity before planet formation.

As we discussed above, LRDs also displays the "electromagnetically tranquil" nature. The presence of cold dust and molecule-rich gas at such small physical scales, together with signs of only weak AGN activity, strengthens the analogy between LRDs and the quiet center of the Milky Way. Thus, LRDs serve as natural laboratories for studying the coexistence of low-luminosity black holes and chemically rich, cold interstellar media and dust, a potential prerequisite for the synthesis of prebiotic molecules in the early universe.

The possible link between galactic core chemistry and the origin of life is speculative but worthy of consideration. Organic molecules essential for life likely have their origins in interstellar chemistry, once formed, could be transported by galactic winds or incorporated into protoplanetary disks during star formation, thus seeding young planetary systems with prebiotic material. If LRDs were common in the early universe, their efficient dust and molecule production could have similarly enriched their surroundings. Subsequent galaxy mergers or hierarchical growth would then distribute these organics more broadly, potentially accelerating the onset of planet formation and prebiotic chemistry. The galaxies with low-luminosity, quiescent cores could act as reservoirs for complex chemistry, forming "life-friendly" environments within the otherwise hostile early universe. LRDs could have contributed significantly to the cosmic budget of prebiotic molecules, providing the raw ingredients necessary for the later emergence of life.

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