

Review

Black Holes as Evidence of God's Care

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Abstract: As black holes gravitationally draw matter toward their event horizons, a high proportion of this matter is converted into energy. Radiation from this conversion process is deadly for advanced life. The apparent incompatibility of black holes with advanced life raises a problem for Christians and other theists who believe that God planned the rise of advanced life on Earth. Yet additional scientific data may help to resolve this apparent problem. This article argues that a universe with the mass and laws and constants of physics to make advanced life possible will inevitably produce black holes, and this is good news. When the most massive stars and merging neutron stars become black holes, they manufacture elements heavier than iron. Eight of these r-process elements appear essential for advanced life; the remainder appear essential for enduring life and for advanced civilization. Moreover, though black holes produce deadly radiation in all known regions of the universe where advanced life is conceivable, our solar system is protected from this deadly radiation. By apparent fine-tuning, we live in a uniquely safe and uniquely provisioned location. These scientific findings suggest a way that theists can reconcile the existence of black holes with the existence of a Creator.

Keywords: supermassive black holes; r-process elements; entropy; neutron stars; supernovae; Laniakea supercluster; Milky Way galaxy



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1. Introduction

In its simplest form, the cosmological anthropic principle is the statement that the universe possesses features that are fine-tuned to make possible the existence of human beings or organisms functionally equivalent to humans (Barrow and Tipler 1986; Davies 1988). Some scientists have argued that the fine-tuning is a fallacy, that the evidence for design is merely coincidental, in that our existence simply testifies that the extremely unlikely indeed took place by chance. Several philosophers, for example Richard Swinburne (Swinburne 1990) and William Lane Craig (Craig 1988), and I (Ross 2008a; Ross 2018a) have explained why this claimed fallacy is itself fallacious in that it ignores several specific intended personal purposes.

In 2004, British planetary astronomer David Waltham explained that if there is any validity to the anthropic principle, it should have predictive power (Waltham 2004) in that ongoing astronomical research should uncover yet more cosmic features that are fine-tuned to make possible humans' existence. Waltham demonstrated that predictive power in the context of the Moon's features.

Over the past fifteen years, I have written three books (Ross 2008b; Ross 2016; Ross 2018b) showing that the more we learn about the universe the more cosmic features we discover are fine-tuned for the specific benefit of humans. Here, in this paper, I offer yet another extension of the cosmological anthropic principle, the manner in which black holes in the universe and the vicinity of Earth are fine-tuned so that we can live and thrive.

2. Body: Paradoxical Nature of Black Holes

A black hole is anything but the void its name might suggest. By contrast, a black hole is a physical body of enormous mass and density. Its gravitational force wields so much power that nothing—not even light—can escape once caught in its grip. Inside a region

known as the “event horizon” (a specific distance from the black hole’s core), everything appears black to an outside observer. Not even photons can be detected there.

Some physicists have speculated that massive stars composed of exotic dark matter particles, for example, boson or soliton stars, or massive neutrino balls, could mimic the observed properties of black holes (Thorne 2000; Guzmán and Rueda-Becerril 2009), even supermassive black holes (Torres et al. 2000; Mielke and Shunck 2002). However, current telescope instrumentation is incapable of distinguishing the difference. For the purposes of this paper, I will follow the lead of observational astronomers in presuming that massive highly collapsed bodies in the universe indeed are black holes.

Given the basics of gravity, we know that the greater the black hole’s mass, the farther from its center this event horizon will extend. Extreme risk lies just outside this zone. Based on what we know from Einstein’s famous equation, $E = mc^2$, a large fraction of any gas, dust, debris, asteroid, planet, or star that approaches a black hole’s event horizon will be converted into energy. A rapidly rotating black hole, as most black holes and especially the more massive ones are, will convert up to 42 percent of nearby matter (matter just outside the event horizon) into energy. Even a nonrotating black hole will convert 5.7 percent of any nearby body (or mass) into energy (McClintock and Remillard 2004). Thus, black holes in the process of accreting matter rank as the deadliest objects in the universe.

In the region just outside their event horizon, black holes convert matter into energy with far greater efficiency than does the Sun’s nuclear furnace—anywhere from 100 to nearly 600 times greater. This extremely high conversion rate of matter into energy explains why the zone just outside the event horizon of the most massive black holes is both the brightest and most dangerous (to any form of life) location known to exist in the universe. Even the smallest known black holes, those with a mass only a few times greater than the Sun’s, if they are accreting matter, generate radiation that would make advanced life as we know it impossible anywhere within their vicinity. In spite of this, we would not be here to observe and study black holes were it not for their existence (more on this point later).

Discovery of the energy levels within and around black holes enabled astronomers to unravel a deep mystery concerning cosmic radiation. The deadliest cosmic rays observed on Earth are ultra-high-energy cosmic rays (UHECRs). The energy level of these UHECRs exceeds 5.7×10^{19} electron volts (eV) for protons and 2.8×10^{21} eV for iron nuclei. The most energetic cosmic ray detected to date exhibited a kinetic energy equal to 3.2×10^{20} electron volts (Bird et al. 1995), roughly the energy of a baseball moving at 100 kph (60 mph) packed into a single particle. This energy level is about 30 million times greater than the highest particle energy achieved by CERN’s Large Hadron Collider and several trillion times greater than the cosmic rays that commonly strike Earth.

When astronomers discovered UHECRs in 1962 (Linsley 1963), the source of these rays mystified them. They knew that UHECRs must originate somewhere beyond our Milky Way galaxy. The strength of our galaxy’s magnetic field is insufficient to confine them, much less to accelerate them to such extremely high energy levels (Pierre Auger Collaboration 2017). Furthermore, the directions from which UHECRs arrive is consistent with an extragalactic origin (Pierre Auger Collaboration 2018).

A breakthrough came in 2019, when five Korean astronomers reported on their analysis of five years’ observational data from the Telescope Array in Utah. According to the research of these astronomers, UHECRs are arriving from a hot spot centered in the Virgo cluster (Kim et al. 2019). The team detected “filaments of galaxies [threadlike structures of galaxies and connecting gas streams] connected to the Virgo cluster around the hotspot” (Kim et al. 2019). Specifically, they and other Korean astronomers found six of these filaments infalling toward the core of the Virgo cluster and, thus, dynamically connected to it (Kim et al. 2016; Kim et al. 2019).

The research team deduced from their studies of the hotspot and the structures around it that the UHECRs they had detected are “produced at sources in the Virgo Cluster, and escape to and propagate along filaments, before they are scattered toward us” (Kim et al. 2019). This finding pointed toward the likely source of the UHECRs striking

Earth: the supermassive black hole at the core of the M87 galaxy. Nothing less than the extreme velocities and extreme energy density in the jet generated by M87's supermassive black hole would be able to explain the characteristics of the UHECRs observed on Earth (see Figure 1).



Figure 1. Nucleus of the M87 galaxy showing the relativistic jet blasting out from just outside of M87's supermassive black hole. The jet, 4400 light-years long, is comprised of matter ejected at relativistic velocities by the supermassive black hole. Image credit: NASA/ESA/Hubble Heritage Team (STScI/AURA).

3. Supermassive Black Holes

A significant proportion of a galaxy's mass (e.g., half in the case of the Milky Way galaxy) resides at its nuclear core. The number and density of stars, gas clouds, and debris clouds in the core makes the development of a very large black hole there inevitable.

The largest stars in a galaxy's core, once they have completed their nuclear burning, will collapse into black holes. The density of these black holes ensures that many of them will merge (under the influence of their mutual gravity) to form an exceptionally massive

black hole. The gravitational pull of this exceptionally massive black hole will draw in stars, gas clouds, and debris in its vicinity. As this black hole accretes more and more matter, it eventually grows large enough to become a supermassive black hole.

Astronomers define a supermassive black hole as any black hole with a mass exceeding one million times the Sun's mass. All medium, large, and giant galaxies possess a supermassive black hole in the central region of their core. Dwarf galaxies and globular clusters may also have massive central black holes in their cores, with black hole masses ranging from just a few thousand to several million times the Sun's mass.

The cores of many giant galaxies contain supermassive black holes more than a billion times more massive than the Sun. For example, the supermassive black hole residing in the core of M87, the giant galaxy near the center of the Virgo Cluster, has a mass equal to 6.5 billion solar masses (Davoudiasl and Denton 2019; Event Horizon Telescope Collaboration 2019). The radiation emanating from just outside M87's supermassive black hole is so intense and highly variable that no imaginable type of physical advanced life is possible either in M87 or in any galaxy in M87's vicinity (Di Matteo et al. 2003; Neronov and Aharonian 2007; Levinson and Rieger 2011; Hada et al. 2014).

The most massive supermassive black hole discovered to date and measured by direct means resides in the galaxy NGC 1600. It weighs in at 17 billion solar masses (Thomas et al. 2016). Supermassive black holes in galaxies NGC 4889 and WISE J104222.11+164115.3, measured by indirect means, have masses of 21 billion (McConnell 2011) and about 100 billion solar masses (King and Nealon 2019), respectively.

4. Why a Universe with Black Holes?

The existence of a large population of black holes in the universe raises a question to Christians about the existence and nature of the God of the Bible. A question I have been asked frequently at public events is this: if the biblical Creator is the all-powerful, all-knowing, and all-loving being the Scriptures portray, why would such a God design and create a universe in which life faces a pervasive risk from health-damaging, if not life-destroying, cosmic radiation produced by black holes? Apparently, others have faced this question as well (Stepanek 2019; Oakes 2013).

This God certainly could have created and designed a universe without black holes. However, such a universe, as best we can model its properties and behavior, would be governed by totally different laws or constants of physics. It would be a universe with different values for one or more of the fundamental physical constants or possibly without the operation of gravity, electromagnetism, and the nuclear forces, or without thermodynamics characterized by high entropy (entropy is a measure of the decay or disorganization of a system as the system continuously moves from order to chaos). It would also be a universe of much smaller mass and mass density. Any substantially alternate universe we hypothesize and test would be a place in which physical life as we experience it would be impossible. It is possible, nevertheless, to conceive of life forms that are not physical, not composed of elements in the periodic table, and not subject to the universe's features, physics, and dimensions living in a realm with much different physics and dimensions. One such example would be the existence of angels in a realm that transcends the cosmos.

In a physical universe with sufficiently different physics and cosmic properties to avoid the existence of black holes, the stars and planets needed for the existence of physical life would not exist, nor would many life-essential elements heavier than iron. Thus, carbon-based life would be impossible. Of all the elements in the periodic table, astrobiologists concur that only carbon manifests the chemical bonding complexity and chemical bonding stability that physical life requires (Pace 2001).

A universe without black holes also would be a universe missing many of the heavier-than-iron elements that are essential for advanced life and advanced civilization. About half the elements heavier than iron are r-process elements (rapid neutron capture process elements). Observations of neutron star merging events, where two neutron stars merge to become a black hole, establish that most, if not nearly all, r-process elements

that exist on Earth and elsewhere in the universe came from neutron star merging events (Chornock et al. 2017; Tanvir et al. 2017). The remainder come from core-collapse supernovae.

R-process elements include silver, gold, platinum, palladium, and osmium. These elements are crucial for launching and sustaining high-technology civilization. They also are important for treating human health challenges.

Other r-process elements, thorium and uranium, which Earth possesses at abundance levels hundreds of times greater than the average for other rocky bodies in the universe, contribute to a large degree to Earth's enduring, strong magnetic field, which has protected and is protecting early Earth's atmosphere and hydrosphere from desiccation and its life from deadly solar and cosmic radiation. While astronomers cannot yet measure the abundances of r-process elements in rocky bodies beyond the solar system, they can compare the abundances of Earth's r-process elements to the average abundances for the universe and Milky Way Galaxy where elements unlikely to be retained by the gravity of rocky bodies are subtracted out. Earth's superabundance of thorium and uranium also explains its enduring plate tectonics, which transformed the planet from a water world into a planet with both surface oceans and surface continents, a feature crucial for the recycling life-critical nutrients and the buildup of atmospheric oxygen (Duncan and Dasgupta 2017; Ross 2020).

The first black holes formed from the first of a particular kind of supernova, a core-collapse supernova (Heger et al. 2003). Many more also formed from mergers between neutron stars. Astrophysicists have determined that core-collapse supernovae and neutron star mergers are responsible for the manufacture of 100 percent of 13 of the r-process elements and play the most significant role in forming the remaining 28 r-process elements in the universe (Leach 2020; Johnson 2017). Furthermore, these pathways to black hole formation ensure the distribution of these r-process elements to the interstellar clouds that produce future generations of stars and planets. These pathways also ensure that nickel, copper, zinc, arsenic, selenium, molybdenum, iodine, and tin—elements essential for animal life—exist in the required locations and in the essential abundances (Emsley 1998).

Black holes also serve as the repository of most of the universe's entropy. Australian astronomers Chas Egan and Charles Lineweaver calculated the entropy budget of components comprising the observable universe (Egan and Lineweaver 2010) and found that supermassive black holes account for 99.998 percent of the total entropy. Stellar-mass black holes (formed by the gravitational collapse of burned-out stars) make up 0.002 percent. Photons, neutrinos, dark matter, relic gravitons, and the interstellar and intergalactic medium comprise 0.000000000005 percent. Stars, planets, asteroids, and comets account for a mere 0.000000000000000001 percent. If the entropy of the universe were distributed any differently, with substantially less residing in black holes, the stars and planets necessary to make possible the existence of any kind of physical life would not have formed.

In summary, it appears that in order to have elements heavier than iron in the universe, we need the large neutron fluxes that occur during supernova eruptions and the mergers of neutron stars. The by-products of supernovae are neutron stars and black holes, which can merge to become supermassive black holes, which in turn can produce deadly radiation. Supermassive blackholes serve as an essential entropy repository of the universe. Therefore, supermassive black holes appear to be a constrained-optimization consequence of the fine-tuning that is required for the possibility of advanced life in the universe. Thus, the theist can argue that they make sense in a Creator's plan. However, there is more.

5. Location Is Everything

Just as in the realm of commercial and residential real estate, location is significant on a cosmic scale—only more so. Humanity must be kept a great distance from black holes. Earth's address in the universe could be described in this way: we live in the Milky Way galaxy (MWG), within the Local Group of galaxies, within the Virgo cluster of galaxies, within the Laniakea supercluster of galaxies.

Of all the known superclusters of galaxies, the Laniakea's shape stands out, and its unusual shape is essential to our existence. The Laniakea's shape resembles that of a stick man or stick insect, as opposed to a spheroid or ellipsoid structure tightly packed with galaxy clusters and galaxies (see Figure 2). This extraordinary shape slows the growth of supermassive black holes and spreads them far from one another. Life is possible in our galaxy because the MWG resides in a supercluster where the galaxy clusters and galaxy groups are relatively small and distant from one another.

The location of the Local Group appears to be optimal, too. The galaxy groups in its immediate vicinity are all small and the next closest galaxy groups are also relatively small. None contain galaxies large enough to produce a supermassive black hole with the capacity to threaten life in our galaxy.

The Virgo cluster is the only large, dense galaxy cluster in the Laniakea supercluster. It is also the only galaxy cluster within the Laniakea supercluster that contains super-supermassive black holes (SSMBHs), black holes with masses exceeding 1 billion solar masses. The deadliest SSMBH in the Virgo cluster is the one in M87. This SSMBH resides 53.7 million light-years from Earth. Due to its great distance and because the relativistic jet of radiation blasted out from the vicinity of the SSMBH's event horizon points away from the MWG, human health and civilization are safe from its radiation.

The Local Group also differs from others of its kind. It contains no giant galaxies, only two large galaxies, MWG and Andromeda, and about a hundred dwarf galaxies. Remarkably, its two large galaxies are far from each other, separated by 2.5 million light-years.

Another unique and crucial-for-life feature of the Local Group is its low population of supermassive black holes. Not only do virtually all medium, large, and giant galaxies possess a supermassive black hole in their core, but so do many dwarf galaxies. However, the Large Magellanic Cloud (LMC), the most massive of the dwarf galaxies in the Local Group, does not. Despite a total mass now determined to be greater than 200 billion solar masses (Peñarrubia et al. 2016; Laporte et al. 2018; Behroozi et al. 2013; Deason et al. 2015), the LMC lacks a supermassive black hole.

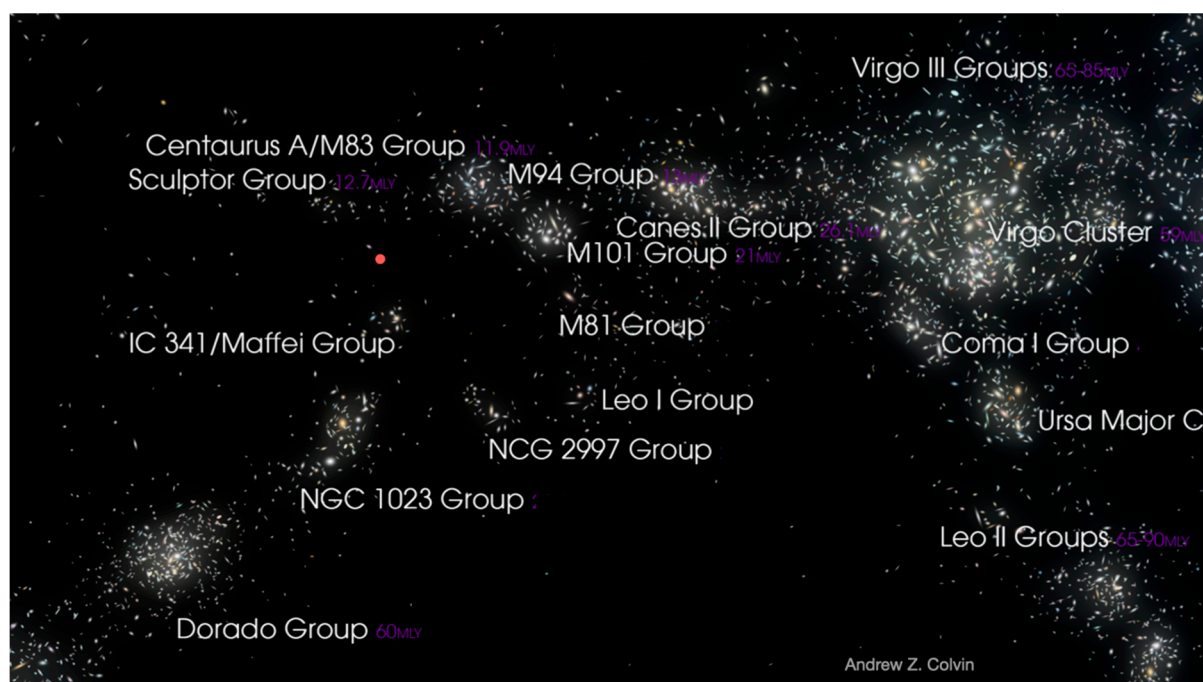


Figure 2. Galaxy clusters and groups comprising the Laniakea supercluster. The small red dot slightly above and left of center shows the position of the Local Group of galaxies of which the Milky Way galaxy is a member. Image credit: Andrew Z. Colvin, Creative Commons Attribution.

The kick velocities of the stars HVS3 and HE 0437-5439 ejected from the center or very near the center of the LMC indicate the presence of a black hole at the LMC's center with a mass equal to 4000 solar masses, at a minimum (Erkal et al. 2019; Gualandris and Zwart 2007). However, astronomers are unable to detect any radiation coming from the region just outside the event horizon of LMC's black hole. The absence of detectable radiation indicates one of two possibilities: either the mass of LMC's central black hole is close to its measured lower limit of 4000 solar masses, or this black hole is accreting very little gas and no objects with a mass greater than that of a small moon (small in the context of our solar system). In either case, the LMC's central black hole currently poses no risk of measurable harm to advanced life on Earth.

One might think the LMC's tiny central black hole is irrelevant in that advanced life in the Milky Way galaxy (MWG) does not require a nearby galaxy like the LMC. However, such is not the case.

The proximity of the Large and Small Magellanic Clouds, their large masses, and their high gas contents allow the tidal forces of the MWG to draw in a nearly steady stream of gas from the Clouds (Indu and Subramaniam 2015; Pardy et al. 2018; Lucchini et al. 2021). Also, the Magellanic Clouds are massive enough, close enough to each other, and positioned relative to the MWG in such a way that they are able to efficiently funnel a steady supply of small and gas-rich dwarf galaxies into the MWG (Deason et al. 2015; Zhang et al. 2019; Lucchini et al. 2021; Vasiliev et al. 2021). This steady, gradual, ongoing supply of gas has sustained the MWG's spiral structure throughout the past several billion years without disturbing its overall symmetry and morphology. These details help explain why the MWG can be a home for advanced life.

Our nearest large galaxy, the Andromeda galaxy (AG), is home to the Local Group's largest supermassive black hole. Determining the mass of AG's supermassive black hole was complicated by the presence in the AG's core of three distinct stellar nuclei—compact disks of stars labelled by astronomers as P1, P2, and P3. A team of fifteen astronomers led by Ralf Bender approached the task by analyzing the dynamics of P1, P2, and P3 relative to the supermassive black hole. Their analysis indicated that the supermassive black hole's mass equals 140 million solar masses (Bender et al. 2005). By taking into account all conceivable random and systematic errors in their analysis, they showed that the mass of AG's supermassive black hole equals no less than 110 million solar masses.

With the AG residing only 2.5 million light-years away, its supermassive black hole could easily pose a threat to Earth's advanced life—and at some time in its past it most certainly did. If it were to accrete anything as massive as a large planet, let alone a star, the region just outside this supermassive black hole's event horizon would emit deadly radiation throughout the Local Group. Astronomers express surprise at how little high-energy radiation the AG's supermassive black hole is currently emitting (Li et al. 2011). A huge amount of high-energy radiation from that source would not have posed much of a problem for microbial life earlier in the history in the MWG, but for advanced life on Earth it is fortunate that the AG's supermassive black hole currently remains as quiet as it does.

6. MWG's Exceptionally Small Supermassive Black Hole

Since the radiation from supermassive black holes in other large galaxies is considered deadly to life more complex and energetic than bacteria, one must ask why advanced life can and does exist in our galaxy? The exceptionally low mass of the MWG's supermassive black hole provides part of the answer. Weighing in at just 4.152 ± 0.014 million solar masses (The Gravity Collaboration 2019), only a limited amount of deadly radiation can emanate from our supermassive black hole.

The MWG's supermassive black hole's low mass is truly extraordinary and unexpected. It deviates by far from the otherwise strong and consistent correlation among multiple galaxy characteristics and the mass of these galaxies' supermassive black holes. The MWG's supermassive black hole should be significantly more massive than it is based on several features:

Number of globular clusters orbiting the galaxy (González-Lópezlira et al. 2017; Harris et al. 2014; Rhode 2012).

Mass of the galaxy's central bulge (De Nicola et al. 2019; Yang et al. 2019; Kormendy and Ho 2013; Miki et al. 2014).

Luminosity of the galaxy's central bulge (Marconi and Hunt 2003).

Luminosity of the galaxy (Do et al. 2014; Gültekin et al. 2009).

The pitch angle (angle in a disk galaxy between a line tangent to a circle and to the spiral arm at a given distance from the galactic center) of the spiral arms (Berrier et al. 2013; Seigar et al. 2008).

Velocity dispersion (range of velocities) of the stars in the galaxy's central bulge (Marsden et al. 2020; Ates et al. 2013).

The stellar mass of the galaxy, to a lesser degree (Shankar et al. 2020).

In a galaxy's central bulge, the density of stars is equal to, or near, that of a globular cluster, a tight grouping of 50,000–10,000,000 stars (see Figure 3). The velocity of the gas in the central bulge is directly proportional to the mass of the galaxy's supermassive black hole. Although this velocity can be difficult to measure, the velocity dispersion of stars in a central bulge can be measured more easily, and astronomers have demonstrated that it correlates tightly with the gas velocity.



Figure 3. NGC 362, a typical globular cluster. Image credit: NASA/ESA/Hubble WFC3.

These correlations apply to all galaxies, but with slight variation depending on the type of host galaxy (Sahu et al. 2019). Where the galaxy has an active galactic nucleus, astronomers must first correct for the differing dust extinction (Caglar et al. 2020). For supergiant elliptical galaxies in the cores of large galaxy clusters, supermassive black holes tend to be more massive than those in elliptical field galaxies residing either outside of, or on the fringes of, galaxy clusters (Zubovas and King 2012). Likewise, these correlations indicate a higher supermassive black hole mass for an elliptical field galaxy than for a

spiral galaxy (Mutlu-Pakdil et al. 2016; Watabe et al. 2009; Zubovas and King 2012). Among spiral galaxies, those with a central bar structure tend to possess slightly less massive supermassive black holes than do spiral galaxies without this structure (Hartmann et al. 2014; Nayakshin et al. 2012a).

Given that the MWG is a spiral galaxy with a central bar structure, astronomers would expect its supermassive black hole to be slightly less massive than the six or seven correlations would otherwise indicate (based on the average properties of the known population of galaxies). While the total mass of the Andromeda galaxy is equal to the mass of our galaxy, and both galaxies are barred spirals (Beaton et al. 2007), only the mass of AG's supermassive black hole aligns with all these correlations. The MWG's supermassive black hole measures about 35 times less massive. This difference in mass means that our galaxy's supermassive black hole holds a far lower potential (at least 35 times lower) to emit deadly radiation from regions just outside its event horizon. (The potential of a supermassive black hole to emit deadly radiation from outside its event horizon typically increases geometrically with its mass.) This much lower potential—by a factor of at least 35—allows for the possibility of advanced life's existence and survival within the MWG.

7. All Quiet on the Black Hole Front

In a paper titled “The Murmur of the Hidden Monster,” a team of astronomers reported on their Chandra X-Ray Observatory measurements of the x-ray radiation attributable to the AG's supermassive black hole (Li et al. 2011). From 1999 to 2005, its radiation output measured less than or equal to 10^{36} ergs/second—less than a ten billionth of its maximum potential output. In the following six years, the team observed an average x-ray flux of only 4.8×10^{36} ergs/second, including one brief outburst of 4.3×10^{37} ergs/second.

The very low X-ray flux resulting from AG's supermassive black hole motivated the astronomers to describe the supermassive black hole as “remarkable” for its “extreme radiative quiescence” (Li et al. 2011). If not for this extreme radiative quiescence, advanced life would be impossible anywhere within the MWG despite our distance from Andromeda's core.

By comparison, M32, a dwarf galaxy in the vicinity of the AG with only a fourth of the AG's or MWG's total mass, hosts a supermassive black hole some 85 percent as massive as the MWG's supermassive black hole. The very weak X-ray radiation currently emitted from M32's core implies that M32's supermassive black hole must be fuel-starved. Its accretion rate must be less than a ten billionth of a solar mass per year (less than the mass of the asteroid Vesta per year) (Loewenstein et al. 1998).

The known history of M32 tells astronomers that the current very low accretion rate of its supermassive black hole has remained roughly the same throughout the past 200 million years (Block et al. 2006). Given this timing, M32's supermassive black hole has presented no danger to advanced life in the Milky Way.

The other large dwarf galaxies in the AG's vicinity, M33 and NGC 205, both lack a supermassive black hole (Gebhardt et al. 2001; Merritt et al. 2001; Valluri et al. 2005), and all the remaining dwarf galaxies in the Local Group possess central black holes less massive than 10,000 solar masses. Not far beyond the Local Group's outer boundaries, the dwarf galaxy NGC 404 has a central black hole roughly 100,000 times the mass of the Sun (Seth et al. 2010). Neither NGC 404 nor any other dwarf galaxy poses any danger to life in the MWG.

Just as importantly, if not more so, our own galaxy's supermassive black hole currently remains unusually quiet. The quantity and intensity of deadly radiation emitted by supermassive black holes depend on the quantity of gas, dust, comets, asteroids, planets, and/or stars drawn toward its event horizon. Supermassive black holes in nearby galaxies consume a star of the Sun's mass or greater about once every 100,000 years, on average (Zubovas et al. 2012). When this consumption happens, a bright flare lasting several months or longer floods the galaxy with deadly radiation. Stars smaller than the Sun are consumed about once every 10,000 years, resulting in deadly radiation lasting several

days to weeks. These galaxies also consume molecular gas clouds at a rate anywhere from once per century to once every few millennia, events that likewise result in the emission of deadly radiation lasting days to weeks.

Instead, the MWG's supermassive black hole has entered a phase of minimal consumption, akin to light snacking. It produces tiny flares that last only hours on an almost daily basis (Zubovas et al. 2012). In 2012, a team of astronomers demonstrated that active nuclei supermassive black holes surrounded by giant clouds of comets and asteroids, maintain near-continual mass consumption, which leads to ongoing high energy radiation emission from the region just outside the supermassive black hole's event horizon (Nayakshin et al. 2012a). It appears that asteroid-comet clouds surround most if not all supermassive black holes (Nayakshin et al. 2012b). In the case of the MWG's supermassive black hole, however, its relatively small, diffuse asteroid-comet cloud draws relatively miniscule amounts of matter toward the event horizon of the MWG's supermassive black hole. Thus, only small amounts of matter are being converted into energy, a fact that explains the frequent but tiny flares (Zubovas et al. 2012). As a team of seven astronomers led by Lia Corrales wrote, "The supermassive black hole at the center of our galaxy, Sgr A*, is surprisingly under-luminous" (Corrales et al. 2017).

Thanks to a host of features, including (but not limited to) the exceptionally low mass of our galaxy's supermassive black hole and the unusually small mass and density of its surrounding asteroid-comet cloud, life has been able to survive and thrive on Earth, despite some setbacks, throughout the past 3.8 billion years. The limited activity level outside the supermassive black hole's event horizon has been so stunningly quiet throughout the past 10,000 years that humans have been able to launch, develop, and sustain global civilization.

Clearly, we humans appear to occupy a unique location at a unique time with respect to black holes. The extraordinary characteristics and distribution of black holes in our cosmic neighborhood are but one example of precise fine-tuning and intricate craftsmanship required for our existence. Another is the precise timing and placement of our existence within a hospitable neighborhood.

I believe that these scientific findings provide one way Christians and other theists might reconcile their belief in a God who plans and cares for advanced life on Earth with the seemingly counter-intuitive existence of destructive black holes. This reconciliation also supplies one example of why broad claims that science and faith are at war with each other, or must operate independently, should be subjected to critical scrutiny.

As both a scientist and a Christian, I believe not only that scientific evidence is reconcilable to theism, but that there is much scientific evidence that points to the existence of a powerful, purposeful Creator behind the universe (Davies 2007; Ross 2016; Ross 2018b). To this author, Earth's capacity to host billions of people who can discern the existence and care of our Creator and, by grace, through faith, enter into an eternal, loving relationship with him inspires and, through ongoing discovery, continually amplifies my sense of awe and wonder.

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References

- Ates, Alper K., Can Battal Kılınc, and Cafer Ibanoglu. 2013. On the M- σ Relationship and SMBH Mass Estimates of Selected Nearby Galaxies. *International Journal of Astronomy and Astrophysics*, 1–9. [CrossRef]
- Barrow, John D., and Frank J. Tipler. 1986. *The Anthropic Cosmological Principle*. New York: Oxford University Press.

- Beaton, Rachael L., Steven R. Majewski, Puragra Guhathakurta, Michael F. Skrutskie, Roc M. Cutri, John Good, Richard J. Patterson, E. Athanassoula, and Martin Bureau. 2007. Unveiling the Boxy Bulge and Bar of the Andromeda Spiral Galaxy. *Astrophysical Journal Letters* 658: L91–L94. [\[CrossRef\]](#)
- Behroozi, Peter S., Risa H. Wechsler, and Charles Conroy. 2013. The Average Star Formation Histories of Galaxies in Dark Matter Halos from $z = 0$ –8. *Astrophysical Journal* 770: 57. [\[CrossRef\]](#)
- Bender, Ralf, John Kormendy, Gary Bower, Richard Green, Jens Thomas, Anthony C. Danks, and Theodore Gull. 2005. HST STIS Spectroscopy of the Triple Nucleus of M31: Two Nested Disks in Keplerian Rotation around a Supermassive Black Hole. *Astrophysical Journal* 631: 280–300. [\[CrossRef\]](#)
- Berrier, Joel C., Benjamin L. Davis, Daniel Kennefick, Julia D. Kennefick, Marc S. Seigar, Robert Scott Barrows, Matthew Hartley, Doug Shields, Misty C. Bentz, and Claud HS Lacy. 2013. Further Evidence for a Supermassive Black Hole-Pitch Angle Relation. *Astrophysical Journal* 769: 132. [\[CrossRef\]](#)
- Bird, D. John, S. C. Corbato, H. Y. Dai, J. W. Elbert, K. D. Green, M. A. Huang, and D. B. Kieda. 1995. Detection of a Cosmic Ray with Measured Energy Well beyond the Expected Spectral Cutoff Due to Cosmic Microwave Radiation. *Astrophysical Journal* 441: 144–50. [\[CrossRef\]](#)
- Block, David L., F. Bournaud, F. Combes, R. Groess, P. Barmby, M. L. N. Ashby, G. G. Fazio, M. A. Pahre, and S. P. Willner. 2006. An Almost Head-On Collision as the Origin of Two Off-Centre Rings in the Andromeda Galaxy. *Nature* 443: 832–34. [\[CrossRef\]](#) [\[PubMed\]](#)
- Caglar, Turgay, Leonard Burtscher, Bernhard Brandl, Jarle Brinchmann, Richard I. Davies, Erin KS Hicks, and Michael Koss. 2020. LLAMA: The MBH– σ^* Relation of the Most Luminous Local AGNs. *Astronomy and Astrophysics* 634: A114. [\[CrossRef\]](#)
- Chornock, R., E. Berger, D. Kasen, P. S. Cowperthwaite, M. Nicholl, V. A. Villar, and K. D. Alexander. 2017. The Electromagnetic Counterpart of the Binary Neutron Star Merger LIGO/Virgo GW170817. IV. Detection of Near-Infrared Signatures of r-Process Nucleosynthesis with Gemini-South. *Astrophysical Journal Letters* 848: L19. [\[CrossRef\]](#)
- Corrales, Lia, Brayden Mon, Daryl Haggard, Frederick K. Baganoff, Gordon Garmire, Nathalie Degenaar, and Mark Reynolds. 2017. *Perils at the Heart of the Milky Way: Systematic Effects for Studying Low Luminosity Accretion onto Sgr A**. HEAD Meeting #16, id. 300.01. Washington: American Astronomical Society.
- Craig, William Lane. 1988. Barrow and Tipler on the Anthropic Principle vs. Divine Design. *British Journal for the Philosophy of Science* 38: 389–95. [\[CrossRef\]](#)
- Davies, Paul. 1988. *The Cosmic Blueprint*. New York: Simon & Schuster.
- Davies, Paul. 2007. *The Cosmic Jackpot: Why Our Universe Is Just Right for Life*. Boston: Houghton Mifflin Harcourt.
- Davoudiasl, Hoorman, and Peter B. Denton. 2019. Ultralight Boson Dark Matter and Event Horizon Telescope Observations of M87*. *Physical Review Letters* 123: 021102. [\[CrossRef\]](#)
- De Nicola, Stefano, Alessandro Marconi, and Giuseppe Longo. 2019. The Fundamental Relation between Supermassive Black Holes and Their Host Galaxies. *Monthly Notices of the Royal Astronomical Society* 490: 600–12. [\[CrossRef\]](#)
- Deason, Alis J., Andrew R. Wetzel, Shea Garrison-Kimmel, and Vasily Belokurov. 2015. Satellites of LMC-Mass Dwarfs: Close Friendships Ruined by Milky Way Mass Haloes. *Monthly Notices of the Royal Astronomical Society* 453: 3568–74. [\[CrossRef\]](#)
- Di Matteo, Tiziana, Steven W. Allen, Andrew C. Fabian, Andrew S. Wilson, and Andrew J. Young. 2003. Accretion onto the Supermassive Black Hole in M87. *Astrophysical Journal* 582: 133–40. [\[CrossRef\]](#)
- Do, Tuan, Shelley A. Wright, Aaron J. Barth, Elizabeth J. Barton, Luc Simard, James E. Larkin, Anna M. Moore, Lianqi Wang, and Brent Ellerbroek. 2014. Prospects for Measuring Supermassive Black Hole Masses with Future Extremely Large Telescopes. *Astronomical Journal* 147: 93. [\[CrossRef\]](#)
- Duncan, Megan S., and Rajdeep Dasgupta. 2017. Rise of Earth's Atmospheric Oxygen Controlled by Efficient Subduction of Organic Carbon. *Nature Geoscience* 10: 387–92. [\[CrossRef\]](#)
- Egan, Chas A., and Charles H. Lineweaver. 2010. A Larger Estimate of the Entropy of the Universe. *Astrophysical Journal* 10: 1825–34. [\[CrossRef\]](#)
- Emsley, John. 1998. *The Elements*, 3rd ed. Oxford: Clarendon Press, pp. 26, 40, 56, 58, 60, 62, 78, 102, 106, 120, 122, 130, 138, 152, 160, 188, 194, 198, 214, 222, 230.
- Erkal, Denis, Douglas Boubert, Alessia Gualandris, N. Wyn Evans, and Fabio Antonini. 2019. A Hypervelocity Star with a Magellanic Origin. *Monthly Notices of the Royal Astronomical Society* 483: 2007–13. [\[CrossRef\]](#)
- Event Horizon Telescope Collaboration. 2019. First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole. *Astrophysical Journal Letters* 875: L6. [\[CrossRef\]](#)
- Gebhardt, Karl, Tod R. Lauer, John Kormendy, Jason Pinkney, Gary A. Bower, Richard Green, and Theodore Gull. 2001. M33: A Galaxy with No Supermassive Black Hole. *Astronomical Journal* 122: 2469–76. [\[CrossRef\]](#)
- González-Lópezlira, Rosa A., Luis Lomelí-Núñez, Karla Álamo-Martínez, Yasna Ordenes-Briceno, Laurent Loinard, Iskren Y. Georgiev, Roberto P. Munoz, Thomas H. Puzia, Gustavo Bruzual, and Stephen Gwyn. 2017. The Relation between Globular Cluster Systems and Supermassive Black Holes in Spiral Galaxies: The Case Study of NGC 4258. *Astrophysical Journal* 835: 184. [\[CrossRef\]](#)
- Gualandris, Alessia, and Simon Portegies Zwart. 2007. A Hypervelocity Star from the Large Magellanic Cloud. *Monthly Notices of the Royal Astronomical Society: Letters* 376: L29–L33. [\[CrossRef\]](#)

- Gültekin, Kayhan, Douglas O. Richstone, Karl Gebhardt, Tod R. Lauer, Scott Tremaine, Monique C. Aller, and Ralf Bender. 2009. The M- σ and M-L Relations in Galactic Bulges, and Determinations of Their Intrinsic Scatter. *Astrophysical Journal* 698: 198–221. [CrossRef]
- Guzmán, Francisco. S., and Jesús M. Rueda-Becerril. 2009. Spherical Boson Stars as Black Hole Mimickers. *Physical Review D* 80: 084023. [CrossRef]
- Hada, Kazuhiro, M. Goroletti, M. Kino, G. Giovannini, F. D. D’Ammando, C. C. Cheung, M. Beilicke, H. Nagai, A. Doi, K. Akiyama, and et al. 2014. A strong radio brightening at the jet base of M 87 during the elevated very high energy gamma-ray state in 2012. *Astrophysical Journal* 788: 165. [CrossRef]
- Harris, Gretchen L. H., Gregory B. Poole, and William E. Harris. 2014. Globular Clusters and Supermassive Black Holes in Galaxies: Further Analysis and a Larger Sample. *Monthly Notices of the Royal Astronomical Society* 438: 2117–30. [CrossRef]
- Hartmann, Markus, Victor P. Debattista, David R. Cole, Monica Valluri, Lawrence M. Widrow, and Juntao Shen. 2014. The Effect of Bars on the M- σ Relation: Offset, Scatter and Residuals Correlations. *Monthly Notices of the Royal Astronomical Society* 441: 1243–59. [CrossRef]
- Heger, Alexander, Christopher L. Fryer, Stan E. Woosley, Norbert Langer, and Dieter H. Hartmann. 2003. How Massive Single Stars End Their Life. *Astrophysical Journal* 591: 288–300. [CrossRef]
- Indu, Gopalakrishnan, and Annapurni Subramaniam. 2015. H I Kinematics of the Large Magellanic Cloud Revisited: Evidence of Possible Infall and Outflow. *Astronomy & Astrophysics* 573: A136. [CrossRef]
- Johnson, Jennifer. 2017. Origin of the Elements in the Solar System. Available online: <https://blog.sdss.org/2017/01/09/origin-of-the-elements-in-the-solar-system/> (accessed on 12 March 2021).
- Kim, Suk, Soo-Chang Rey, Martin Bureau, Hyein Yoon, Aeree Chung, Helmut Jerjen, and Thorsten Lisker. 2016. Large Scale Filamentary Structures around the Virgo Cluster Revisited. *Astrophysical Journal* 833: 207. [CrossRef]
- Kim, Jihyun, Dongsu Ryu, Hyesung Kang, Suk Kim, and Soo-Chang Rey. 2019. Filaments of Galaxies as a Clue to the Origin of Ultrahigh-Energy Cosmic Rays. *Science Advances* 5: eaau8227. [CrossRef] [PubMed]
- King, Andrew, and Rebecca Nealon. 2019. Supermassive Black Hole Demographics: Evading M - σ . *Monthly Notices of the Royal Astronomical Society* 487: 4827–31. [CrossRef]
- Kormendy, John, and Luis C. Ho. 2013. Coevolution (Or Not) of Supermassive Black Holes and Host Galaxies. *Annual Review of Astronomy and Astrophysics* 51: 511–653. [CrossRef]
- Laporte, Chervin F. P., Facundo A. Gómez, Gurtina Besla, Kathryn V. Johnston, and Nicolas Garavito-Camargo. 2018. Response of the Milky Way’s Disc to the Large Magellanic Cloud in a First Infall Scenario. *Monthly Notices of the Royal Astronomical Society* 473: 1218–30. [CrossRef]
- Leach, Mark R. 2020. The Chemogenesis Web Book: The Internet Database of Periodic Tables. Available online: https://www.meta-synthesis.com/webbook/35_pt/pt_database.php?PT_id.593 (accessed on 12 March 2021).
- Levinson, Amir, and Frank Rieger. 2011. Variable TeV Emission as a Manifestation of Jet Formation in M87? *Astrophysical Journal* 730: 123. [CrossRef]
- Li, Zhiyuan, Michael R. Garcia, William R. Forman, Christine Jones, Ralph P. Kraft, Dharam V. Lal, Stephen S. Murray, and Q. Daniel Wang. 2011. The Murmur of the Hidden Monster: Chandra’s Decadal View of the Supermassive Black Hole in M31. *Astrophysical Journal Letters* 728: L10. [CrossRef]
- Linsley, John. 1963. Evidence for a Primary Cosmic-Ray Particle with Energy 1020 eV. *Physical Review Letters* 10: 146–68. [CrossRef]
- Loewenstein, M., K. Hayashida, T. Toneri, and D. S. Davis. 1998. On the Nature of the X-Ray Emission from M32. *Astrophysical Journal* 497: 681–88. [CrossRef]
- Lucchini, Scott, Elena D’Onghia, Andrew J. Fox, Chad Bustard, Joss Bland-Hawthorn, and Ellen Zweibel. 2021. The Magellanic Corona as the Key to the Formation of the Magellanic Stream. *Bulletin of the American Astronomical Society* 53: 2021ni434p06.
- Marconi, Alessandro, and Leslie K. Hunt. 2003. The Relation between Black Hole Mass, Bulge Mass, and Near-Infrared Luminosity. *Astrophysical Journal Letters* 589: L21–L24. [CrossRef]
- Marsden, Christopher, Francesco Shankar, Mitchele Ginolfi, and Kastytis Zubovas. 2020. The Case for the Fundamental MBH- σ Relation. *Frontiers in Physics* 8: 61. [CrossRef]
- McClintock, Jeffrey E., and Ronald A. Remillard. 2004. *Black Hole Binaries, Chapter 4 in Compact Stellar X-ray Sources*. Edited by W. H. G. Lewin and M. van der Klis. Cambridge: Cambridge University Press, vol. 157, pp. 10–11. Available online: <https://arxiv.org/pdf/astro-ph/0306213.pdf> (accessed on 12 March 2021).
- McConnell, Nicholas J. 2011. Two Ten-Billion-Solar Mass Black Holes at the Centres of Giant Elliptical Galaxies. *Nature* 480: 215–18. [CrossRef] [PubMed]
- Merriitt, David, Laura Ferrarese, and Charles L. Joseph. 2001. No Supermassive Black Hole in M33? *Science* 293: 1116–18. [CrossRef] [PubMed]
- Mielke, Eckehard W., and Franz E. Shunck. 2002. Boson and Axion Stars. The Ninth Marcel Grossmann Meeting on Recent Developments in Theoretical and Experimental General Relativity, Gravitation, and Relativistic Field Theories. Paper presented at MGIX MM Meeting, University of Rome, Rome, Italy, July 2–8; Edited by Vahe G. Gurzadyan, Robert T. Jantzen and Remo Ruffini. Singapore: World Scientific, pp. 581–91. [CrossRef]
- Miki, Yohei, Masao Mori, Toshihiro Kawaguchi, and Yuriko Saito. 2014. Hunting a Wandering Supermassive Black Hole in the M31 Halo Hermitage. *Astrophysical Journal* 783: 87. [CrossRef]

- Mutlu-Pakdil, Burçin, Marc S. Seigar, and Benjamin L. Davis. 2016. The Local Black Hole Mass Function Derived from the MBH-P and the MBH- σ Relations. *Astrophysical Journal* 830: 117. [CrossRef]
- Nayakshin, Sergei, Chris Power, and Andrew R. King. 2012a. The Observed M- σ Relations Imply that Super-Massive Black Holes Grow by Cold Chaotic Accretion. *Astrophysical Journal* 753: 15. [CrossRef]
- Nayakshin, Sergei, Sergey Sazonov, and Rashid Sunyaev. 2012b. Are Supermassive Black Holes Shrouded by ‘Super-Oort’ Clouds of Comets and Asteroids? *Monthly Notices of the Royal Astronomical Society* 419: 1238–47. [CrossRef]
- Neronov, Andrii, and Felix A. Aharonian. 2007. Production of TeV Gamma Radiation in the Vicinity of the Supermassive Black Hole in the Giant Radio Galaxy M87. *Astrophysical Journal* 671: 85–96. [CrossRef]
- Oakes, John. 2013. Why Did God Create Black Holes? Evidence for Christianity. Available online: <https://evidenceforchristianity.org/why-did-god-create-black-holes/> (accessed on 12 March 2021).
- Pace, Norman R. 2001. The Universal Nature of Biochemistry. *Proceedings of the National Academy of Sciences USA* 98: 805–8. [CrossRef]
- Pardy, Stephen A, Elena D’Onghia, and Andrew J. Fox. 2018. Models of Tidally Induced Gas Filaments in the Magellanic Stream. *Astrophysical Journal* 857: 101. [CrossRef]
- Peñarrubia, Jorge, Facundo A. Gómez, Gurtina Besla, Denis Erkal, and Yin-Zhe Ma. 2016. A Timing Constraint on the (Total) Mass of the Large Magellanic Cloud. *Monthly Notices of the Royal Astronomical Society: Letters* 456: L54–L58. [CrossRef]
- Pierre Auger Collaboration. 2017. Observation of a Large-Scale Anisotropy in the Arrival Directions of Cosmic Rays above 8×10^{18} eV. *Science* 357: 1266–70. [CrossRef]
- Pierre Auger Collaboration. 2018. Large-Scale Cosmic-Ray Anisotropies above 4 EeV Measured by the Pierre Auger Observatory. *Astrophysical Journal* 868: 4. [CrossRef]
- Rhode, Katherine L. 2012. Exploring the Correlations between Globular Cluster Populations and Supermassive Black Holes in Giant Galaxies. *Astronomical Journal* 144: 154. [CrossRef]
- Ross, Hugh. 2008a. *Why the Universe Is the Way It Is*. Grand Rapids: Baker Books, pp. 153–63.
- Ross, Hugh. 2008b. *Why the Universe Is the Way It Is*. Grand Rapids: Baker Books.
- Ross, Hugh. 2016. *Improbable Planet: How Earth Became Humanity’s Home*. Grand Rapids: Baker Books.
- Ross, Hugh. 2018a. *The Creator and the Cosmos: How the Latest Scientific Discoveries Reveal God*, 4th ed. Covina: RTB Press, vol. 141157, pp. 181–87.
- Ross, Hugh. 2018b. *The Creator and the Cosmos*, 4th ed. Covina: RTB Press.
- Ross, Hugh. 2020. Deep Oxygen Cycle Provides Evidence for Creation of Animals. Today’s New Reason to Believe. Available online: <https://reasons.org/explore/blogs/todays-new-reason-to-believe/read/todays-new-reason-to-believe/2020/10/12/deep-oxygen-cycle-provides-evidence-for-creation-of-animals> (accessed on 12 March 2021).
- Sahu, Nandini, Alister W. Graham, and Benjamin L. Davis. 2019. Revealing Hidden Substructures in the MBH- σ Diagram, and Refining the Bend in the L- σ Relation. *Astrophysical Journal* 887: 10. [CrossRef]
- Seigar, Marc S., Daniel Kennefick, Julia Kennefick, and Claud H. S. Lacy. 2008. Discovery of a Relationship between Spiral Arm Morphology and Supermassive Black Hole Mass in Disk Galaxies. *Astrophysical Journal Letters* 678: L93–L96. [CrossRef]
- Seth, Anil C., Michele Cappellari, Nadine Neumayer, Nelson Caldwell, Nate Bastian, Knut Olsen, and Robert D. Blum. 2010. The NGC 404 Nucleus: Star Cluster and Possible Intermediate-Mass Black Hole. *Astrophysical Journal* 714: 713–31. [CrossRef]
- Shankar, Francesco, David H. Weinberg, Christopher Marsden, Philip J. Gylls, Mariangela Bernardi, Guang Yang, and Benjamin Moster. 2020. Probing Black Hole Accretion Tracks, Scaling Relations, and Radiative Efficiencies from Stacked X-Ray Active Galactic Nuclei. *Monthly Notices of the Royal Astronomical Society* 493: 1500–11. [CrossRef]
- Stepanek, Joel. 2019. Do Black Holes Disprove the Existence of God? Life Teen. Available online: <https://www.youtube.com/watch?v=BfhT-Bqj2KA&t=182s> (accessed on 12 March 2021).
- Swinburne, Richard. 1990. Argument from the Fine-Tuning of the Universe. In *Physical Cosmology and Philosophy*. Edited by John Leslie. New York: Macmillan, p. 165.
- Tanvir, Nial R., A. J. Levan, C. González-Fernández, O. Korobkin, Ilya Mandel, Stephan Rosswog, and Jens Hjorth. 2017. The Emergence of a Lanthanide-Rich Kilonova Following the Merger of Two Neutron Stars. *Astrophysical Journal Letters* 848: L27. [CrossRef]
- The Gravity Collaboration. 2019. A Geometric Distance Measurement to the Galactic Center Black Hole with 0.3% Uncertainty. *Astronomy and Astrophysics: Letters* 625: L10. [CrossRef]
- Thomas, Jens, Chung-Pei Ma, Nicholas J. McConnell, Jenny E. Greene, John P. Blakeslee, and Ryan Janish. 2016. A 17-Billion-Solar-Mass Black Hole in a Group Galaxy with a Diffuse Core. *Nature* 532: 340–42. [CrossRef] [PubMed]
- Thorne, Kip S. 2000. Probing Black Holes and Relativistic Stars with Gravitational Waves. Paper presented at Black Holes and the Structure of the Universe, Chile and Antarctica, Santiago, Chile, August 18–20; Edited by Claudio Teitelboim and Jorge Zanelli. Singapore: World Scientific, pp. 81–118. [CrossRef]
- Torres, Diego F., Capozziello S., and Lambiase G. 2000. Supermassive Boson Star at the Galactic Center? *Physical Review D* 62: 104012. [CrossRef]
- Valluri, Monica, Laura Ferrarese, David Merritt, and Charles L. Joseph. 2005. The Low End of the Supermassive Black Hole Mass Function: Constraining the Mass of a Nuclear Black Hole in NGC 205 via Stellar Kinematics. *Astrophysical Journal* 628: 137–52. [CrossRef]
- Vasiliev, Eugene, Vasily Belokurov, and Denis Erkal. 2021. Tango for Three: Sagittarius, LMC, and the Milky Way. *Monthly Notices of the Royal Astronomical Society* 501: 2279–304. [CrossRef]

- Waltham, Dave. 2004. Anthropic Selection for the Moon's Mass. *Astrobiology* 4: 460–68. [[CrossRef](#)] [[PubMed](#)]
- Watabe, Yasuyuki, Nozomu Kawakatu, Masatoshi Imanishi, and Tsutomu T. Takeuchi. 2009. Supermassive Black Hole Mass Regulated by Host Galaxy Morphology. *Monthly Notices of the Royal Astronomical Society* 400: 1803–7. [[CrossRef](#)]
- Yang, Guang, W. N. Brandt, D. M. Alexander, C. T. J. Chen, Q. Ni, F. Vito, and F. F. Zhu. 2019. Evident Black Hole-Bulge Coevolution in the Distant Universe. *Monthly Notices of the Royal Astronomical Society* 485: 3721–37. [[CrossRef](#)]
- Zhang, Dali, Yu Luo, and Xi Kang. 2019. The Effect of the Large Magellanic Cloud on the Satellite Galaxy Population in Milky Way Analogous Galaxies. *Monthly Notices of the Royal Astronomical Society* 486: 2440–48. [[CrossRef](#)]
- Zubovas, Kastytis, and Andrew R. King. 2012. The M– σ Relation in Different Environments. *Monthly Notices of the Royal Astronomical Society* 426: 2751–57. [[CrossRef](#)]
- Zubovas, Kastytis, Sergei Nayakshin, and Sera Markoff. 2012. Sgr A* Flares: Tidal Disruption of Asteroids and Planets? *Monthly Notices of the Royal Astronomical Society* 421: 1315–24. [[CrossRef](#)]