VI. Singularities and Supermassive Black Holes

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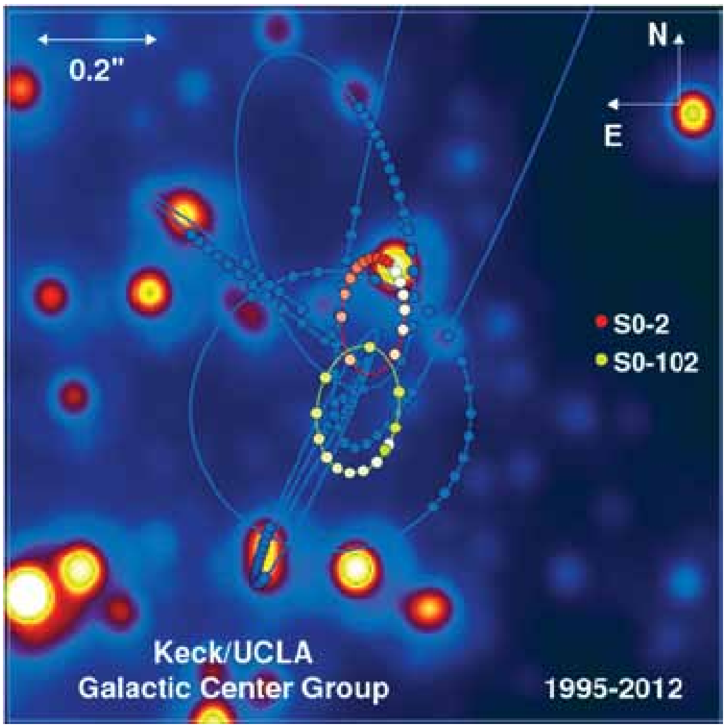
Stepping away from studies of what changes and activity in the Solar System tells us about the Galaxy, we can also look at certain categorical aspects which appear to be features of all galaxies as a class. Here we will focus on a characteristic supermassive phenomenon thought to be at the center of each galaxy, the immense energetic activity associated with that phenomenon, and how the mass properties of that phenomenon are intimately tied to global features of the entire galactic system.

Perhaps we can say that we now look at the phenomenon referred to as "supermassive black holes" as scientists of the early Nineteenth Century looked at the Sun.

Then, in the 1800s, it was clear the Sun had been burning for a very, very long time. But what was it burning to be able to sustain itself for so long? If it was some form of chemical combustion there is no way it could sustain that level of energetic output for hundreds of millions or billions of years! Yet records were showing that advanced life had been sustained for a half billion years by a consistent and vigorous output from our star, and that our star has bathed our planet in its warmth for even much longer. This was a paradox—one unsolvable in the scientific framework of the Nineteenth Century. It took a complete revolution, overturning the fundamental understanding of the scientific nature of the Universe to provide the framework to begin to understand the Sun.

Today, we ask, "what is a supermassive black hole and the associated phenomenon of an active galactic nucleus?"

Image 1



Prof. Andrea Ghez and her research team at UCLA; based on data sets obtained with the W. M. Keck Telescopes

The orbits of stars within the central arcsecond of our Galaxy. The orbits have been inferred from images taken with the primitive technique of speckle imaging (1995 - 2005) and with the more sophisticated adaptive optics (2005-2012). While several stars can be seen in their motion through this region, only two stars (S0-2 and the newly discovered S0-102) have been traced through a complete orbit. They are the most tightly bound to the black hole and therefore comprise the most information about it. S0-2, which has an orbital period of 16 years, proved the existence of a black hole. The addition of S0-102, with a period of 11.5 years, will for the first time allow us to test the warping of space and time this close to a black hole.

A Singularity

As was recognized not long after their development, the Einstein field equations of Einstein's general theory of relativity showed that if an object was massive enough and small enough, it would cause the spacetime metrics to run off to infinity—creating a mathematical gravitational spacetime singularity. But what would actually happen here? The equations say as the gravity becomes infinite, time stops, and space becomes unintelligible, but would actually happen in the real Universe? No one knows, as the entire framework of the mathematical physics literally breaks down.

While this was treated as a mathematical construct for years, at some point there arose the actual prospects for the discovery of physical objects massive enough and small enough to meet the mathematical criterion which would supposedly lead to such a singularity. These are generally referred to as black holes.

Theoretically, if a star is large enough, supposedly at the end of its life-cycle, it should be able to collapse on itself with enough force to compress the core to these singularity-generating conditions. Today there are astronomical candidates for such stellar-mass black holes.

However, here we're interested in another type of so-called black hole, a supermassive black hole, like the one at the center of our Galaxy called Sag A*. Being four million times the mass of our own Sun, this couldn't have come from the collapse of a single star, and is part of this other, supermassive, class.[58] Using adaptive optics on the Keck telescope, astronomers have been able to observe entire stars tracing out clean elliptical orbits around a point in space at the very center of our Galaxy where nothing is seen (taking as little as 16 years to do so). This is the most solid observational evidence for the existence of a supermassive black hole (**see Image 1**).

But what is it? What is happening there?

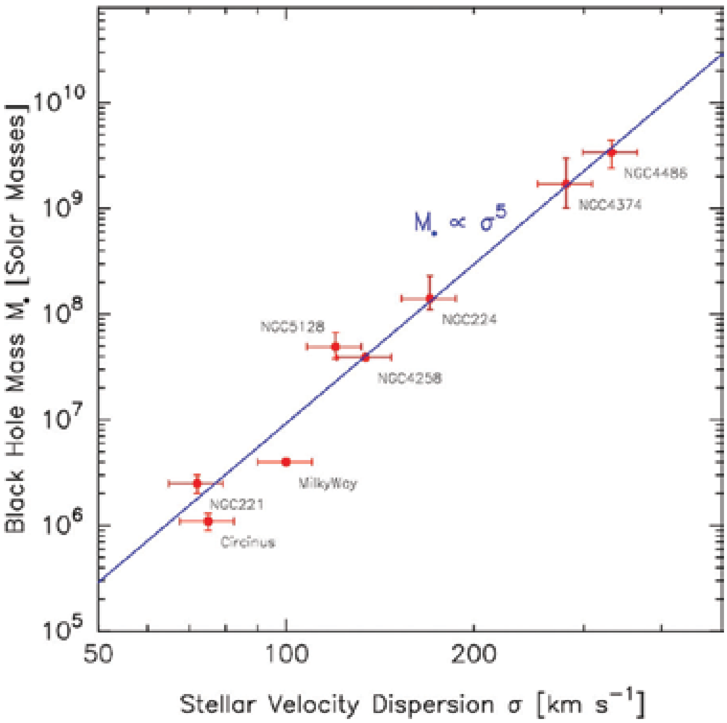
Before considering this question, let us first ask if there are any other places where mathematical singularities arise in the investigation of physical processes, and if these cases, comparing a mathematical infinity with a physical reality, provide any general insight for how to approach such questions?

A useful case might be Riemann's work on the acoustical shockwave.

Long before the advent of supersonic flight, it was calculated that as the speed of sound is approached, the density of sound waves would continuously build up, increasing asymptotically as the speed limit is approached, creating a physical barrier. The mathematical interpretation says the density of sound waves goes to infinity, creating what appeared to be an insurmountable singularity. Yet Riemann was able to forecast that—in physical reality—this barrier could be transcended, a solution that many claimed had some neat mathematical tricks, but which had no bearing on physics. In reality, exactly the opposite was the case.

Perhaps this provides a conceptual reference point for how to think about the relationship between mathematical singularities in the Einstein field equations, and the observational evidence for something we tend to call "supermassive black holes." The mathematics go to infinity, but that may just signal a phase shift in the physics—in this case, likely a higher-order domain.

Image 2



Msigma at English Wikipedia

Black hole mass plotted against velocity dispersion of stars in the galaxy bulge [a measure of the mass of the bulge]. Points are labeled by galaxy name; all points in this diagram are for galaxies which exhibit a clear, Keplerian rise in velocity near the center, indicative of the presence of a central mass. The M-sigma relation is shown in blue.

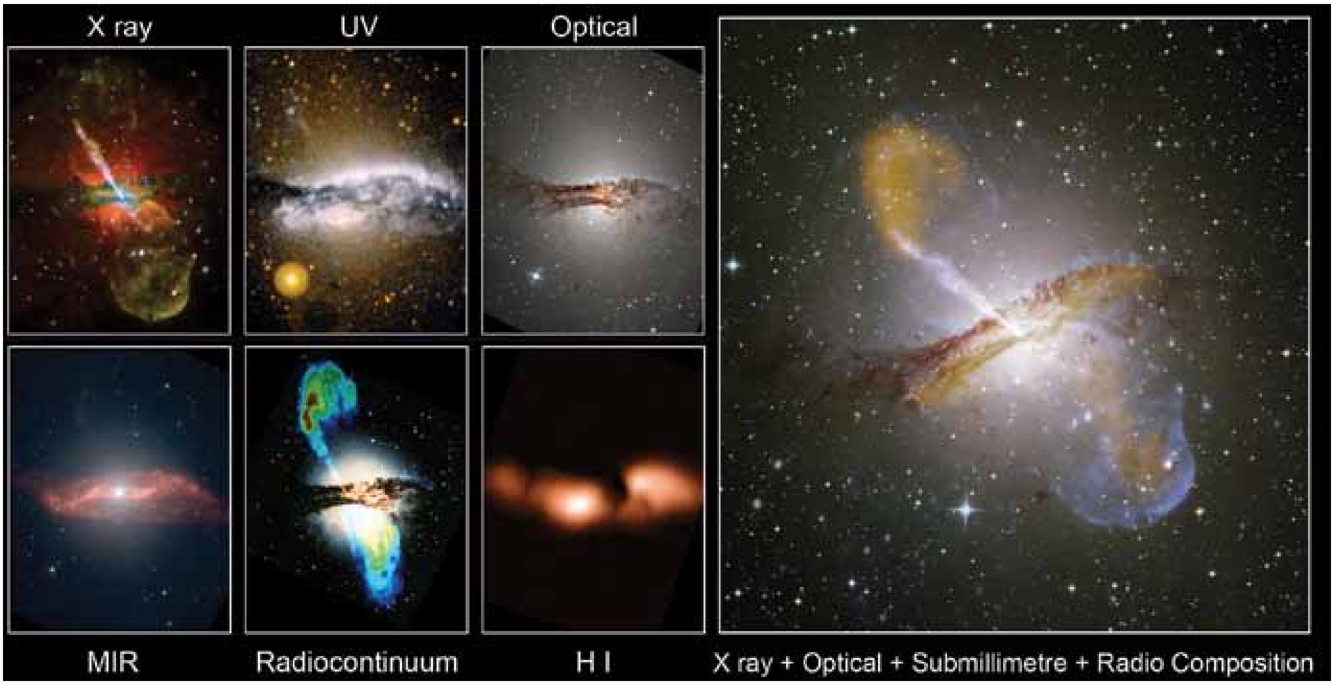
Unified Structure

Every galaxy is thought to contain one supermassive black hole in its center. This brings us to a most interesting phenomenon referred to as the "m-Sigma" or black hole-bulge relation (**see Image 2**). This is an empirical observation, showing that the mass of the spherical bulge of a galaxy is always the same proportion greater than the mass of the single supermassive black hole at its center. This holds for smaller galaxies and for larger galaxies.

This is a major challenge to explain in the current

58. It is thought every galaxy has a supermassive black hole at its center. It's assumed that a supermassive black hole is produced by the accumulation of many stellar black holes (and other material), but the lack of any black holes in size ranges in-between (so-called intermediate class black holes) poses a challenge to that assumed idea of the origin of supermassive black holes.

Image 3



Centaurus A is a giant elliptical galaxy - the closest active galaxy to Earth. This remarkable composite view of the galaxy combines image data from the x-ray (Chandra), optical (ESO), radio (VLA) [and more] regimes. Centaurus A's central region is a jumble of gas, dust, and stars in optical light, but both radio and x-ray telescopes trace a remarkable jet of high-energy particles streaming from the galaxy's core. The cosmic particle accelerator's power source is a black hole with about 10 million times the mass of the Sun coincident with the x-ray bright spot at the galaxy's center. Blasting out from the active galactic nucleus toward the upper left, the energetic jet extends about 13,000 light-years. A shorter jet extends from the nucleus in the opposite direction. Other x-ray bright spots in the field are binary star systems with neutron stars or stellar mass black holes.

framework of a stellar-level science. Despite its immense mass, a supermassive black hole should not be able to act to determine the mass of the entirety of the galaxy or its bulge, or vice versa—especially with such consistency.[59]

It would make sense that there is a general relation, with larger galaxies generally having larger supermassive black holes (and vice versa). But the observed proportion between the bulge mass and the supermassive black hole mass is too precise and narrow to find acceptable explanation so far.

It would be comparable to discovering that the height of the largest mountain on every continent is always exactly one five-thousandth of the size of that continent. Or if we noticed that every planet has one moon that is exactly one ten-thousandth the mass of the planet. We might expect some very broad relationships, but finding anything so precise would be very strange and surprising.

With the supermassive black holes and their host bulge, it is that precise. We can find analogies in the natural world, but only when we look to living (instead of non-living) processes. For example, this galactic scaling relationship is more like how the size of a heart will scale with the size of an animal. That makes sense for animals, because we recognize animals as single entities which grow, develop, and change as a unity. In contrast, the current scientific paradigm assumes the development of galaxies to be a product of the accumulations of actions of individual parts with no single principle governing the whole—an assumption that appears, even from just this evidence, to be false.

What more can we know about this fascinating phenomenon of the supermassive black hole?

Energy Flux Density

Another phenomenon associated with some supermassive black holes is known as "active galactic nuclei." A small percentage of galaxies have extremely

59. It is thought that there are some interactions. A host galaxy is thought to provide the material by which its supermassive black hole grows, and it is thought that the energetic output of a supermassive black hole could affect star formation. But why such interactions would produce a tight proportional relationship in the mass is a mystery.

bright and active centers, emitting energy across the electromagnetic spectrum, shining more brightly than the entire surrounding galaxy (containing billions of stars), and sometimes ejecting massive amounts of material out of the galaxy.

These active galactic nuclei are the most energetic (while sustained) phenomenon known in the Universe.

Some active galactic nuclei—such as Centarus A, the closest active galaxy to us—shoot out "jets" or "lobes" of plasma, which can extend well beyond the reach of the galaxy itself (**see Image 3**).

To power such incredible powerhouses of activity, our mysterious supermassive black hole is brought back into the equation. There is simply no source of energy—within the current paradigm of stellar-level science—which can sustain the observed activity of the active galactic nucleus, other than the gravitational singularity.

The current theory is that the immense gravitational attraction of the supermassive black hole pulls gas, dust, stars, etc. into a concentrated spinning disc of material spiraling towards the event horizon (creating an accretion disk), and this pre-event horizon disk of activity is so intense that it radiates energy, jets of material, and everything else that we observe with an active galactic nucleus.

However, this is all theory, and an unstable one at that. A recent study with data from NASA's WISE space telescope appears to overturn key elements of this theory.[60]

Yet we do observe active galactic nuclei, and their jets and lobes, with all their splendor. And we do have observational evidence for something (a so-called supermassive black hole) which appears to approach the criterion of the mathematical singularity, where the current paradigm of mathematical physics breaks down. And we have reason to believe there is a connection between the two—the phenomenon which exists beyond the boundaries of current science, associated with the most energetic activity currently known in the observable Universe.

60. "NASA's WISE Findings Poke Hole in Black Hole 'Doughnut' Theory," May 22, 2014.

Prometheus holding Hercules' Galaxy, adapted from "Prometheus Brings Fire to Mankind," by Heinrich Friedrich Fuger, 1817.

A Hypothesis

As the solution to the Nineteenth Century mystery of our Sun depended upon a revolution in our understanding of some of the most fundamental conceptions about the nature of the Universe (matter, energy, space, and time), we must open our minds to the possibility that a similar revolutionary shift will be needed to understand our Galaxy.

The tight relationship between a supermassive black hole and its galaxy provokes considerations of a causality which is not mediated through the available mechanisms provided by the current stellar level of science.

Perhaps these investigations challenging the boundaries of known physics in the very large will equally couple back to the anomalies and limits in the very small.

The unmatched energetic output from a region where current mathematical physics reaches a singularity (breakdown) causes us to wonder about new reactions and processes which could be as outside of our current understanding as was $E=mc^2$ in 1850.

How would such a subsuming physics of the Galaxy subsume and reshape our concepts of energy, space, time, and matter? Of causality? And, perhaps most interesting, what would such a leap bring for mankind?

As the energy density of nuclear reactions leaped orders of magnitude beyond that of chemical reactions, we are left to ponder the capabilities provided to mankind wielding a Galactic Principle.

Somewhere, deep in the Universe, Prometheus awaits our arrival, holding the fire of an active galactic nucleus in hand.