

Introduction to Black Holes Final Project

Space Wanderers “conquer” the Milky Way’s Center

RING, RING. The alarms were blaring throughout Sootopolis, one of the largest cities on the planet Tianshi. There had been a problem with their giant neighbour—large emissions of X-rays were about to batter the planet. The President of Tianshi, Dolita Wazkow, wanted to take no chances. Appearing on national television, she said seriously, “My fellow citizens. Please proceed to the lead bunker. Do not panic. Our scientists have been preparing for events like these for thousands of years to plan, and they have done well. We do not have anything to fear. All our possessions will be safe inside the bunker. I will speak to you again when we have completed our evacuation.” The people were calmed by their president’s announcement. They trusted her with their lives. A couple of minutes after her announcement, everybody was in their respective bunkers, awaiting news about what had triggered this alarm.

While their night sky boasted one of the most stunning sights in all of astronomy, it was in many ways a curse. The object there was unpredictable and energetic, prone to huge outbursts of energy that could not be predicted until a few moments early. Scientists had been working for generations to try and understand the world they lived in. But before we talk about this emergency procedure that was sending the Ranbeter—the name of the species—in Sootopolis inside their bunkers, we need to understand where they came from and their relationship to this object that constantly threatened their very existence.

The planet Tianshi was located in a relatively common spiral galaxy called the Milky Way, one of the larger members of its local group of galaxies. It was an ordinary planet; orbiting a white star called Salud which was itself in orbit around the galaxies’ supermassive black hole. How the planet Tianshi was formed was a giant mystery, but most theories posited it began from an accretion disk surrounding its star. The star Salud could be described as a cream coloured star of the spectral type A2 that burned through its fuel in a billion years or so. Tianshi was a fairly newly made planet; newly made in terms of cosmological time scales, of course. You couldn’t say the same thing about the Ranbeter, however.

The Ranbeter were a nomadic, space-faring species constantly travelling from planet to planet. They had many offshoot species littered across their home galaxy, one of which was located about 8000 parsecs away from the center of that galaxy, on a small rocky planet called Earth orbiting a yellow star called the Sun. Being separated from this offshoot for millions of years had changed them; they possessed a thick outer skin that acted as a radiation deflector, preventing their internal DNA from being damaged by the strong Ultraviolet and X-ray emissions that they had encountered on their many settlements. The Ranbeter were much tougher than their weak human counterparts and could survive for a thousand years. They often lived on planets around A-type, B-type or even O-type stars, all of which had surface temperatures exceeding 10000 K, meaning

that their eyes had evolved into being capable of seeing UV rays and X-rays. Despite these differences with their cousins on Earth, the Ranbeter still used scientific terminology based on a shared vocabulary. Why did they pursue a nomadic life you ask? Well... they were a scientific species, always on the lookout for potential study topics. Also, living on planets orbiting B-type or O-type stars meant that they had a relatively short stay there anyway, because of the accelerated evolution of those stars in comparison to smaller stars. Anyway, they were travelling across the galaxy for opportunities to live in environments that promised many scientific advancements and technological miracles. Tianshi was one such opportunity.

The reason why they landed on Tianshi in the first place was to probe the capability of survival in extreme conditions. These conditions were fueled by the existence of the *object*—a supermassive black hole. This gigantic beast weighed as much as 4 million times the mass of the Sun and was located at the center of the Milky Way, accreting material, although at slow rates compared to comparable black holes. The black hole itself had been discovered millions of years ago, before the Ranbeter even existed, when they were still on Earth as humans. The discovery of this black hole, which they call Sagittarius A*, took place after developments in radio communication. Iron-clad evidence for it being a black hole was then obtained using observations from different parts of the electromagnetic spectrum.

Radio waves were first used commercially after Maxwell had predicted them in his theory of electromagnetism. Radio waves were a technological marvel at the time; they could be used to broadcast video, voice and images. However, such broadcasts were prone to static, which interfered with the radio waves. It was in the midst of finding sources of static that might interfere with broadcasts that an engineer/physicist named Jansky made a discovery: there was a cosmic source of radio waves. When he tracked the source over the course of a year, he realized that it emanated from the constellation of Sagittarius, the known position of the center of the Milky Way (*New Radio Waves Traced*, 1933). This source of radio-waves was named Sagittarius A. Over the next few decades, scientists began pointing radio telescopes at this source, and it was discovered later that the source had more components, one of which was very compact (Balick and Brown, 1974). This compact source was called Sagittarius A*.

Compelling evidence of Sag A* being a black hole was further garnered using the near-infrared, which revealed stars near the radio source. When these stars were tracked, it was noticed that they had very high velocities. One key star was called S0-2, and its position was tracked over a period of about 10 years. Using this information, scientists deduced the mass of the object that it was orbiting and ruled out many hypothesis of the object's character, including the possibility that it might be a central mass composed of a dense cluster of dark objects, or a ball of degenerate fermions. (Schödel et al., 2002)

More research done using multi-star surveys and using data from longer time periods of about 20 years further constrained the nature of the object and led to very compelling evidence that it was a black hole (Boehle et al., 2016). Based on this study, a lower limit on the object's density could be established, utilizing Sag A*'s predicted mass and the

closest approach of S0-2 to Sag A*. The predicted mass of Sag A* came around $(4.148 \pm 0.014) \times 10^6 M_{\odot}$ (Abuter et al., 2019). This came to be about the mass of about 4 million suns squeezed within a volume of about $1.73 \times 10^6 \text{ AU}^3$, which amounted to a density of $\sim 1.4 \times 10^{-3} \text{ kg/m}^3$. Such a large quantity of mass squeezed into such a small amount of volume led to assurances that Sag A* was indeed a black hole, because no other celestial objects could explain the observations. The Schwarzschild radius for this black hole would be about $(1.22 \pm 0.04) \times 10^{10} \text{ m}$. More evidence to constrain the black hole's size was needed.

Further observations using near-infrared interferometry on the GRAVITY instrument at a telescope called the Very Large Telescope (VLT), had led to the discovery of dust clouds moving at 30% the speed of light. They had also seen flares that were consistent with the presence of a black hole having roughly 4 million times the mass of the Sun. (Abuter et al., 2018). Finally, analysis using the Chandra telescope which viewed Sag A* in the X-ray had suggested the presence of a million-times solar mass black hole (Baganoff et al., 2003), which agreed with dynamics calculations made by other scientists. Finally, using data obtained from radio interferometry at 230 GHz, scientists were able to constrain the size of the compact source to about 3 times the Schwarzschild radius of Sag A* (Lu et al., 2018), which cemented this object's status as a black hole.

Utilizing all these independent observations at various parts of the electromagnetic spectrum, scientists on Earth had been able to deduce that Sag A* was indeed a black hole. Of course, it was impossible to "see" the black hole; they were in fact looking at its accretion disk. In the visible and ultraviolet part of the spectrum, however, observations of the accretion disk were impossible from the Earth. There was just too much interstellar extinction; the dust clouds of the Milky Way absorbed most UV and visible light and prevented humans from peering into the accretion disk of Sag A*. However, based on theoretical models, there would be some amount of hot gas that would have blackbody radiation in the visible and UV, which humans sitting on Earth would have a hard time seeing.

Ever since this confirmation of Sag A*'s nature, humans had been itching to visit, but the technology was beyond them. Even for the Ranbeter, the region surrounding Sag A* was a hostile place. The temperatures in the region of the accretion disk were sky-high—a thermal continuum spectrum with peaks close to a 10^7 K were present (Baganoff et al., 2003). Such a temperature could explain the emission of X-rays from the source, as at this temperature, the black body radiation would have a peak in the X-ray. However, this thermal radiation was emitted throughout the entire electromagnetic spectrum. The luminosity of the accretion disk had also been estimated, at about $2.4 \times 10^{26} \text{ W}$ in the X-ray (Baganoff et al., 2003). Of course, X-rays could also be produced by other mechanisms, such as Bremsstrahlung—the emission of X-ray photons from decelerating electrons—which scholars had suggested could be responsible for the X-rays coming out of the source in periods of dormancy (Quataert, 2002). During X-ray flares, it had also been noted that the X-rays could be produced through synchrotron emission (Ponti et al., 2017). These flares typically occurred many

times a day and caused X-ray brightness to increase by factors of 50. For long-term observations taken in the X-ray, the black hole would appear to be pulsating, dramatically changing its brightness by large factors over short intervals of time.

There was a similar story of variability in the radio. Radio emissions having fluxes of about 0.5 ± 0.1 Jansky (Roy and Pramesh Rao, 2004) were reported at a frequency of 620 MHz. The flux density of Sag A* was seen to be higher for larger frequencies, with a high of 3.35 ± 0.16 Jansky at 86 GHz. Some scientists had even reported a jet being detected (Li, Morris and Baganoff, 2013). The jet was detected having radio emissions consistent with expected output from synchrotron emission—emitted by charged particles moving in magnetic fields. Jets were especially bright sources of radio emission, although Sag A* had much lower jet activity compared to other supermassive black holes. This was perhaps due to the low accretion rate that had been discussed by researchers (Quataert and Gruzinov, 2000). Jets were fueled by turbulent magnetic fields in accretion disks, which were caused by the movement of charged particles. For there to be more powerful jets, there needed to be more movement in the accretion disk. This accretion rate was quite slow for Sag A*.

Another way in which scientists had analyzed the radiation coming from Sag A* was through line spectra. Line spectra are caused due to interactions between photons and matter. These interactions could result in absorption or emission lines at different wavelengths, depending on the nature of interaction between the photon and matter. There are two types of line spectra: absorption and emission. Emission spectral lines are caused when a hot, low density cloud of gas emits radiation. Absorption spectral lines are caused when photons from hot compact sources of light pass through less dense, colder gases. These spectral lines could tell scientists a lot about the chemical composition of the stuff emitting or doing the absorption. In fact, humans had already used such methods on Sag A*. Stars orbiting Sag A* disk had produced characteristic emission spectra, which had actually been used to infer the existence of many stars surrounding the black hole (Gezari et al., 2002). Furthermore, line spectra occurred at different parts of the electromagnetic spectrum depending on whether the source was: i) an electron transition, ii) vibrational transition or iii) rotational transition. Electron transition tended to correspond to visible or ultraviolet photons, vibrational transition tended to correspond to infrared photons and rotational transitions tended to correspond to radio photons.

These observations of variable, yet consistent outputs of X-rays, radio waves and infrared suggested that there was a reservoir of material that the black hole was accumulating. The changing intensities were a result of the variability with which material accretes into the black hole; when larger amounts of material accrete, scientists would expect more bursts of energy. This was because, when large amounts of matter accreted, they tended to cause fluctuations in the charged particles in the accretion disk, causing changes to the magnetic field, which released outbursts of energy through means such as Bremsstrahlung radiation, Compton scattering and synchrotron emission, or as described earlier, jets, all of which had been detected on

Sag A*. Larger rates of mass accretion would also increase the temperature of the disk, making it appear brighter at all observable spectrums, a consequence of Planck's law.

These were the ideas that the Ranbeter had inherited from their time as humans. They had very advanced technology even before they had ventured out to Tianshi. The planet was relatively removed from the accretion disk of the black hole, at about 100 parsecs away from the black hole. It orbited an F-type star Salud, which was itself orbiting the black hole. The planet orbited the star at an orbit of about 2 AU and was a gas-giant. There was a strong greenhouse effect on the planet, so it had a temperature in excess of 1000 K at about 5 km below the atmosphere, which was hot even for the Ranbeter.

How did the Ranbeter survive in such conditions? It boiled down to two major assets: their thick exoskeletons that provided shielding from both high-energy radiation (like X-rays) as well as heat, and their extremely advanced technologies which allowed them to create floating cities that acted as safe havens for their existence. These cities were floating, because Tianshi didn't have a "surface" per se—it was a hot, very massive, gas giant. The Ranbeter had mastered their technology, and millions of years of evolution had made them very fit for survival in the toughest of conditions. In fact, you could say that living in extreme conditions was kind of their specialty.

Project Tianshi was cutting-edge even for the Ranbeter—they had never attempted to live in the vicinity of a supermassive black hole. The potential for new information was incredible. Unfortunately, Tianshi proved to be a cut too far. While they were prepared for irregular bursts of energy from the accretion disk, one particularly large and unexpected outflow resulted in the destruction of their cooling system. Most of their colonizers died, leaving only a few survivors. One of the survivors was an engineer and was able to reboot the cooling system but died shortly afterwards from radiation poisoning (even the thick radiation deflecting skins didn't make them immortal). The survivors were left to fend for themselves and did the best they could to preserve all systems on the planet, especially the systems that contained all scientific knowledge. Using the genetic reserves that they had brought in case of such an emergency, they were able to slowly rebuild their population. Meanwhile, the jet lasted for many years, and it was only after the activity died down that the survivors were able to implement large-scale population growth and attempt to re-establish contact with other Ranbeter.

During this phase, the other Ranbeter didn't know anything about the settlers on Tianshi, because of the intervening light years between them. The Ranbeter had attempted radio transmission while the jet was still raging. However, this proved difficult because of the jet: it was a very bright source of radio-waves and prevented any sort of radio transmission from getting in or out of Tianshi. Over many years, the remaining Ranbeter simply forgot about the settlers and presumed them dead. Such mishaps were far from uncommon among them—being a spacefaring, nomadic civilization had its downsides. Furthermore, while they lived for about a thousand years, the laws of physics constrained the distances of their travel. They were a civilization capable of near-light speed travel, up to 99.9% the speed of light! They even had technology to go into hibernation, in order to preserve their bodies longer. They had utilized this

technology in going to Tianshi—about 10% of their total population had signed up. When the tragedy had occurred, the rest of the Ranbeter were settled on a planet called HQ, which was about 1000 parsecs away from Tianshi. Even the quickest response that they could muster would have been too late.

It was after their population had been rebuilt that the Ranbeter started to create a bigger presence on the planet. It took hundreds of years, but they managed to build their first metropolis, Sootopolis. It was a miracle, a floating city in the air, complete with state-of-the-art technology. Unfortunately, during the preservation of systems that took place when the jet wiped out most of their initial settlers, there was data corruption in the storage units that corresponded to new discoveries about the black hole. Therefore, the re-established civilization didn't have anything new about Sag A*; all the information that they had gathered after arriving on Tianshi was lost. Painstakingly, they built and sent probes on flybys around the black hole, which sent them back data about Sag A*. Slowly, over the years the Ranbeter were able to retrieve most of their lost information, and made new strides in understanding the black hole. By the time Sootopolis was officially established, there were even plans to send a Ranbetered (synonymous with manned) mission on a flyby around the black hole!

The probes, being close to the black hole, could see some wacky effects. For example, gravitational redshift was readily apparent; the side of the black hole that was faced towards the probes was much brighter and bluer than the other side of the black hole, which was redder and barely visible (James, Tunzelmann, Franklin and Thorne, 2015). These observations were caused principally by the effects of the black hole on the fabric of spacetime. The theory of gravity posited that space and time were warped by the presence of massive objects. Black holes were essentially huge lumps of mass crammed into tiny amounts of space. This caused so much warpage of space-time that within a certain distance, called the event horizon, not even light could escape. Because of this warpage of space-time, the opposite side of the black hole was visible at the top. This effect was called gravitational lensing. The blueshift and redshift were caused by beaming effects as a result of much warpage. The photons closer to the probe appeared to be heading into the black hole and so appeared to gain energy, thus causing a blueshift, whereas the photons away from the probe appeared to be heading out, thus appearing to lose energy and causing a redshift. The Ranbeter were excited; the probes had been historic, even by their standards.

These probes would also suffer from time-dilation. Because they were sent close to the black hole, time on the probe would appear to pass by slower than on Tianshi. This was demonstrated by putting one of two synchronized clocks on board the probe, while the other remained on Tianshi. After the probe was recovered, the clocks showed an appreciable difference in time. The probes also confirmed the fact that Sag A* was not a non-spinning black hole. The calculated Kerr radius of the black hole would be less than its Schwarzschild radius by a factor of $\sqrt{1 - a^2}$ where a is the spin parameter of Sag A*, which was estimated to be 0.44 ± 0.08 (Kato et al., 2010). Observational proof for this spin came in the form of “frame-dragging” that the probes were able to see. Frame-dragging occurred when the black hole spun, dragging the fabric of space-time with it.

The Ranbeter had been collecting continuum emission and spectral line data from the accretion disk in order to confirm the value of the spin before the alarm had sounded.

The probes also helped the Ranbeter understand the nature of outbursts that took place from time to time. They created a network of probes that were on the lookout for any potential spike in activity, as a result of an object getting close to the black hole. Such periodic outbursts of energy were very common; being this close to the black hole, the Ranbeter were able to see a lot more of these outflows, many of which had been hidden from humans because of the dense interstellar medium near the center of the galaxy, especially in the visible and ultraviolet. Of course, the Ranbeter would also see much more outbursts than could their distant ancestors on Earth. These outbursts would be accompanied by showers of ionizing radiation—X-rays and gamma rays. Scientists understood the mechanisms behind these outbursts clearly and were thus very fearful of what it might do to Tianshi. While their host star was nested a few hundred light years from Sagittarius A*, if the star passed very near the axis of rotation of the black hole, a potential outflow might strike the planet. Any large outflow had the potential to destroy the planet and scientists were acutely aware of this. These large jets were capable of travelling thousands of light years away from the black hole and were some of the most powerful phenomena in the universe. Scientists had already established that during the active phase of Sag A*, habitable life would probably not survive (Balbi and Tombesi, 2017). They had only decided to go to Tianshi because they knew through observations of Sag A* that it had a relatively low accretion rate. A strong hint for this came when the Ranbeter had first arrived on Tianshi and sampled the atmosphere, which contained traces of radioactive elements. Using radioactive dating, they were able to establish the age of the planet at a million years old, thereby suggesting that large jets that could destroy the planet were rare. But of course, this was not a certainty.

The alarms were still blaring in Sootopolis when Jagat woke up. He had been working on a school project late into the night and was sleeping soundly when the alarms had starting blaring. Being a heavy sleeper, it took him a while to become aware of the noise. Eventually, he got up from bed and suppressing a yawn, flicked open his computer and looked at the reason for the alarm. Test alarms were common—the government of Sootopolis wanted its citizens to be ready for abrupt evacuation. Jagat thought that this was no different, an alarm to test the readiness of the people. However, looking at the government website, he could tell that something was wrong. Hurriedly, he dressed and ran to the lead bunker that was located beneath his house.

Jagat was a graduate student in theoretical physics at the prestigious Horland School of Technology. He was a brilliant student and worked with some of the smartest scientists on the most pressing issues there were—the feasibility of faster than light travel and planetary dynamics near a black hole to name a few. Having worked with the government on implementing the planet-wide alarm system, Jagat knew immediately that there was a significant problem. Having reached the lead bunker, he hopped onto his hoverboard and raced toward the university bunker. Each and every building on the planet had its own bunker, all of which were connected by a sequence of tunnels, all coated with meters thick lead. This would ensure that the bunkers themselves were self-

reliant in the event of a major event that lasted a long time. Using one of these tunnels, Jagat reached the bunker that temporarily housed the planet's mission control.

Upon arriving there, he witnessed everybody frantically working behind computer screens, bringing up live plots based on satellite observations of Sag A*. "What happened?" asked Jagat. Ralph, located closest to him said, "Don't know kid, but it ain't anything good. Looks like there has been some sort of activity close to the black hole. An outflow is imminent, and our position is not very favorable...". Meanwhile, Bogdan Enrod, the director of operations at the laboratory, was giving out instructions from the center. "Okay guys, I want you to look at every bit of data that's been pouring in. We need to figure out what's happening near the black hole and quick. Our systems indicate some sort of disturbance near Sag A*".

Jagat took up a position behind a vacant computer screen and looked at the data that was pouring in. On the screen, he could see a star very close to the black hole—so close in fact that it had begun to stretch. Jagat knew from his days as a high schooler that anything that came close to a black hole would be spaghettified; i.e. the part of the object closer to the black hole would experience a much stronger gravity than the part of the object further away, resulting in the object stretching and becoming more and more like a spaghetti. However, he also knew that Sag A* was a supermassive black hole, so spaghettification should probably not occur. This is because the Schwarzschild radius for a supermassive black hole was so large that an object beyond the Schwarzschild radius couldn't be easily broken apart by tidal forces. Of course, an object could still be burnt up in the hot accretion disk, but that was another matter entirely.

Because Jagat knew that this stretching of the star was unusual, he decided to do run some simulations. Firstly, he looked at blown up images of the star and noticed that it was extremely redshifted. Based on the coordinates of the star, he noticed that it was falling in almost directly at the line of sight. It was also far away from the equatorial plane of the black hole, which had most of the accretion disk. Looking at velocity data, he was stunned: the star was hurtling in, and quick. However, this still didn't explain the stretching of the star. And then it hit him; he looked at past records of the star and realised that it was a fast-spinning star. Such stars produce very strong tidal effects on themselves, because of the centrifugal force. Consequently, much additional force would not be necessary to break up the star. He looked at the data and realised that the star would break up completely in a matter of a few hours. He alerted Enrod immediately.

"Director Enrod, would you come up here a sec. I may have stumbled across the problem". Exciting whispers were heard throughout the room. Many craned their necks to look at what Jagat had found. Meanwhile, Enrod rushed to Jagat and asked, "What is it son, what have you found?". "This!" said Jagat, impressively. "This star looks like it is on a collision course with the black hole It appears to be losing structural integrity, which is odd enough. Looks like it's one of those fast spinning stars, and the black hole is tipping it over its edge. We could have some sort of explosive event from the black hole, and since it's in our line of sight, we might be receiving some radiation soon. I think it

ought to be in a few hours.” Enrod looked into Jagat’s confident eyes and sighed. “Hope you are wrong, son,” he said wearily.

With a booming voice he addressed the room, “Folks, I want you all to confirm if this star—which is it? Oh yes—S1090 is actually losing structural integrity. I want you all to run models and see what this means for us, will we get any flares headed our way and the like. Keep me updated.”

“Aye, boss”, came shouts from across the room.

A few hours later, the star was absorbed into the accretion disk, and then finally into the black hole. There was a small explosive event and a flurry of photons was detected by the X-ray and radio detectors littered across the planet and in space. It was one of those giant bursts. Miraculously, the Ranbeter were unaffected—their lead structures held out and the outflow had been pointed almost diametrically opposite to them. The computers in the room began showing images of the black hole—they could see a highly redshifted trail of light going away from them. It was highly energetic, one of the most energetic outbursts the Ranbeter had seen, but not strong enough to destroy the planet. Soon, there were even calls for everyone to be sent back up to the surface. President Wazcow, who was being fed a live feed of the room, addressed her planet from her bunker, “It appears that Sag A* had bad lunch. We have witnessed some of its regurgitation. At this rate, we might even be able to go back up soon, although I cannot authorize such a maneuver at this point. I’ll keep you all updated.”

During this time, Jagat had been monitoring the situation, and was looking at data about the star S1090. He looked at past observations of the star—it was a relatively non-descript F-type star, about 400 million years old. Nothing spectacular. An observation tagged a couple of thousand years ago, however, caught his eye. The star looked like it had a companion, a much smaller M-type star. Both had been in orbit around the black hole, and he realized in subsequent observations that the smaller star had been wrested away from its smaller companion, likely Sag A*’s doing. That didn’t mean much. With its enormous gravitational muscle, Sag A* was changing up orbits of stars all the time, even ejecting some out the galaxy (Koposov et al., 2019)! Tianshi avoided most of these orbital fluctuations because it was nested a few hundred light years away from the black hole, but stars orbiting the black hole at closer distances wouldn’t be so lucky. It appears S1090 was one of those unlucky stars. But where was the other star?

Jagat searched across the night sky for signs of a star matching the stellar properties of S1090’s companion. He found one, a few light years away, coming from near the plane of the black hole. He ran a few calculations, using historical data of the object, to calculate its doppler shift and determine its velocity relative to Tianshi. It took a few seconds for the computer to calibrate its speed, but the result was out: the star had a speed of a whopping 15000 km/s and looked like it was directly approaching their planetary system. “Dr. Enrod, sir!” shouted Jagat from his seat. “I have found something else that might be disturbing.”

“What is it this time, boy?” asked Enrod, anxiously.

“I looked at past astronomical records of the star, and I found this: a companion, which it lost some thousands of years ago.” Jagat explained. “I ran a search for stars with the specific stellar properties associated with this lost star and found this: a star with very high blueshift, in fact with a velocity of about 15000 km/s obtained from measurements of its proper motion as well as radial velocity. Chief, if it continues on its trajectory, looks like it could intersect our orbit in about 60 years’ time.”

Enrod knew where he was going with it. “Son are you telling me that this star is on a collision course with us?”.

Jagat nodded curtly and said, “Sure looks like it chief.”

Enrod sighed. Again, with his booming voice, he gave instructions to his scientists, “Alright folks, looks like something’s come up. I want you to re-run all these calculations, using all available data, and simulate the trajectory of this, uh, this M3 type star, call it Remus. Bad news is, it looks like it’s coming straight our way.”

There was a flurry of activity at his words. Everybody ran simulations independently on their own screens and after a tense minute or two, the results were in: 80% of the simulations had the star passing by without major effects to the Tianshi system. However, the rest predicted a more ominous fate. Upon hearing the results, Enrod was frustrated. “Dammit. It has been almost 10 million years since we left the Earth, and yet even to this day we cannot predict anything with certainty?”.

Ralph stood up and said calmly, “Director Enrod, sir. There are no exact solutions to an n-body gravitational problem, everybody knows that. In this case, we have far too many gravitational interactions because of the accretion disk, the many stars that orbit the black hole, and the black hole itself to be certain of anything. We have come a long way since Earth; but there’s somethings we can’t change. The laws of physics for one. This close to a black hole, we have to take general relativity into account. And everybody knows solving an n-body problem in general relativity is the most difficult thing to do in the universe, apart from living near a black hole of course.”

Enrod chuckled. “Very well Ralph.” He looked around, brushed sweat off his brow and addressed the room. “Gentlemen, with this development, I must talk to the government. We must evacuate this planet immediately. There is no point living here if the odds that this planet’s going to shit is 20%—that’s just too darn high. I’ll inform the president.”

Back in the president’s bunker, there was a grave silence. The cabinet of ministers had gathered and had been debating whether to let the people go back up, outside their bunkers. So far, they had resisted, despite the danger having apparently passed. Now however, with the pronouncement that a star was on a probable collision course with their world, the mood in the meeting chamber was somber. The cabinet of ministers were looking up at the President, expecting an address. The president was in a

reflective mood and was considering all courses of action in her mind. She knew that Sootopolis could be converted into a long-haul spacecraft; the city had been designed with the intention of making a quick getaway in case something went awry. However, the star, as the scientists told her, was many years away. She had summoned Enrod from mission control and was waiting for his arrival before addressing her cabinet.

The president's bunker was a handsome room. It had an ornately carved roundtable made of marble. There was a statue of Tianshi's founder in the center of the room, with a fountain spewing out water from the top of the statue's head. A map of the night sky was stuck on one of the walls, with the words, "Endeavour to succeed" printed on the top. There was a large TV screen fixed opposite to the seat of the president, which presently showed a bunch of scientists behind their computer screens at the laboratory. The seat of the mission director was empty with Enrod having departed to visit the president. The seat of the president was a comfortable leather chair designed specifically for her body. From her vantage point, the president could see the doors, which were added that moment closed. Huge structures of iron, the doors had been decorated with the colors of the planet's flag, a black circle on a white background, symbolizing the black hole and the star that the planet was orbiting. Suddenly, the doors opened and Enrod stepped in.

Enrod was a tough guy, possessing a long moustache but no beard at all. He had dressed smartly for the occasion and greeted the president and the cabinet of ministers warmly before entering the room and sitting down on a seat next to the president. Nodding to Enrod, the president began her address, "Greetings esteemed ministers. You all know why we are here. Firstly, there was a cause for concern when one of our scientists detected a star being gobbled up by the black hole. We expected an outflow of some kind, but there was only a relatively small increase in X-ray radiation levels, and some spike in radio waves, minor of course in the sense that this beast is capable of a lot more. Looks like the star fell in, am I correct?" inquired president Wazcow.

"Affirmative," replied Enrod coolly. "The star was already testing its structural capabilities, it was rotating very quickly. Of course, when it got too close to the black hole, the tidal forces, although much lower than in stellar-mass black holes was just enough to tip it over the edge. We saw the structural collapse and most of it was rapidly consumed by the black hole. The X-ray spikes that we saw some moments later was a result of this."

The minister of commerce then turned on his light and addressed Enrod. He said sourly, "Director. We were looking at some of the data coming in. The X-ray spike was hardly problematic, we received a lot of X-rays, yes, but isn't our outer skin designed to protect us from it? Forgive me if I forget the exact numbers, but don't we have a coating of lead a cm thick? A lot of our economic activities have come to a standstill. What was the meaning of this alarm? We should be looking to go back up to the surface pronto."

"Now wait there just a second—" began the President, but Enrod interjected in the middle, "Allow me to explain, Miss Wazcow" and sighed. The industrial hawks never

changed, even after millions of years. “Yes minister, but we couldn’t be sure about that, could we? Everything about our existence on this planet is dangerous; if there’s the remotest of chance of something fouling up and threatening our existence, then we tend to take it seriously. Because of the alarm, and the dogged persistence of one of our researchers, we managed to find a star that has a likely collision course with our world in less than hundred years. If it were up to me, I wouldn’t stick around that long: gravitational effects from the star could still wreck our orbit and send us on a collision course with our star, or even worse, with Sag A*.”

There was silence following his explanation. The President broke the silence, looked Enrod in the eye and said, “I think our little experiment is over; we need to leave this planet as soon as possible and fly away from this place. We have acquired a lot more information about the black hole, haven’t we? We’ve sent probes near the black hole that have sent us incredible pictures, heck many of our ancestors even died to this black hole. We have made incredible leaps in physics because of our observations. I think it’s time we went back and told the rest of the Ranbeter that their cousins on Tianshi are still alive, assuming they are still where we left them.”

The ministers all looked solemnly at her. They all nodded. It was time to evacuate their planet. The president faced Enrod again and told him, “Get to work. I want all scientists working to activate our engines. Anything that we need to do, we will do. We need to get off this planet soon. I shall instruct citizens to remain in their bunkers. We do not need to worry, we have enough provisions here to last a few years at the least.”

“Before you go, let’s make this official. Let it be known that I, Dolita Wazcow, President of Sootopolis, have given authorization to initiate Operation Dynamo. Ministers, do you authorize?”

A chorus of “Aye” was heard from all attending ministers and so, the operation to evacuate the planet was put into motion. President Wazcow addressed her citizens that night, “Fellow citizens of Sootopolis. I have some grave news, but I implore you to remain calm. We will all get through this; our scientists are among the best in the universe, they’ll take care of this.”

“Firstly, today’s alarm was precautionary. Our scientists noticed some activity on Sag A* and so they raised the alarm and sent us to our bunkers. The activity in question was the result of a star colliding with the black hole. Scientists say the star disintegrated and fell into the black hole, releasing tremendous amounts of X-rays, which we received here a few hours ago. All is safe now.”

“However, fellow citizens, one of our scientists investigating the origins of the star found out that it was the part of a binary star system. The other star, which our records show to be a red dwarf, was apparently ejected out of the binary by Sag A*. As you may well know, red dwarves are incredibly faint stars; back when we were lowly humans on Earth, the closest star to our system was one such star, at 4 light years away. Yet, that

star was very dim, and required a powerful telescope to be seen. This other star, which our scientists have named Remus, has similar properties.”

She coughed once, took a sip of water, and continued on.

“We have reason to believe that Remus is coming directly towards us, assisted by the tremendous gravity of Sag A*. It’s now a mere parsec away from us, but it’s not yet visible in our night sky. Its faint, but it doesn’t mean that we cannot track it. Our best telescopes are looking at it, in the infrared mainly because that is where the peak of its emissions come from. We are expecting it to pass us in about 60 years. Simulations suggest that there is a 20% chance of some sort of gravitational interaction that involves the destruction of our planet. Therefore, it is imperative that we move to relocate our settlement. We have had a wonderful run on this planet, learnt many new things by virtue of our proximity to the supermassive black hole, and made incredible technological leaps.”

She took a deep breath.

“But now, that time is over. I along with my cabinet of ministers have authorized Operation Dynamo. We are to make an escape from this planet, an imminent escape. We are not going to wait; we are going to leave. Many of you may not know, but when Sootopolis was built, we fitted in boosters and a mechanism through which the whole city can be converted into a spaceship. We will take these steps immediately. While we do this, we urge you to remain in the bunkers. There are enough provisions to last us many years. I will inform you when it is time to come back out. Our scientists will monitor the movement of the star every step of the way and will also be on the lookout for any more activity from the black hole.”

“You may ask, where will we go at the end of all this? Tianshi has been our home for thousands of years, and we know nothing about what has happened to our fellow species during our long separation. We know where they were located previously, on a planet called HQ. We know its coordinates; we have been sending out radio signals to them as we speak. However, our experts believe that they do not know of our survival. They were unable to receive any radio transmissions here or receive any from here because of the large amount of radio waves produced by the jet that almost destroyed our earlier settlement. We have been trying to contact them for a hundred years now, but because of light-travel time, our message has not yet been received. For now, our trajectory will take us to the planet where our ancestors left off. I’ll speak with you again with more information closer to the launch date.”

10 years later...

The preparations had been made. Everybody was in their designated areas. Jagat was now Chief Scientist Officer on board the Sootopolis spacecraft. The entire city had been converted into a sleek, aerodynamic body capable of travelling at 0.999c. Travelling at this speed, they would arrive at HQ within 3400 years. For those on board, however,

because of the effects of time dilation, time would pass much slowly, by a factor of $\sqrt{1 - 0.999^2}$. Jagat had calculated this, and knew that for people onboard the spaceship, the travel time would be around a measly 150 years. However, to preserve resources aboard the spacecraft, the people on-board would be in cryo-sleep during most of the journey. Meanwhile the spacecraft would be radioing HQ at all known communication frequencies once every month. An emergency override was installed on the cryo-sleep machines that Jagat, the president and her cabinet of ministers used so that they would be alerted in case they received any form of communication from HQ.

The day of launch arrived. Everybody was stationed within their sectors; Jagat was in the control room, along with the President and a handful of the most eminent scientific advisors. "Running pre-flight systems check," bellowed an engineer working on the launch engines. "Everything's good here, captain!".

"Guidance?" asked Enrod, sporting a blazer for the momentous event. "All clear captain," replied a short, bespectacled man from guidance. "Cryo sleep at the ready?" inquired Enrod.

"Aye sir!" came the reply from life support.

Slowly but steadily, all pre-flight checks were done, and all seemed well.

"Ok boys, lets get going. President Wazcow, any final words, on behalf of all Ranbeter?" said Enrod, solemnly.

The gravity of the moment hit her. She looked at the control room full of technicians, engineers, scientists and politicians, then looked out towards Sag A*. It had been thousands of years since their kind had landed on Tianshi. It had become their temporary home, and despite the nature of their nomadic livelihoods, the Ranbeter were an emotional species. Every goodbye was hard for them. But they knew that they had to keep on moving, or else they would be wiped off the face of the universe. It was something they had understood long ago.

She finally looked up at the sky and then looked back down to the planet. She rested on the words that she wanted to say:

"We cannot help but cry,
At this moment of farewell.
For eternity will we carry our pain,
Once we part, never shall we see you again..."

These words were broadcast throughout Sootopolis. The 5 million people that were on Sootopolis clapped hard, some even shed a few tears. It was time to go. The rocket thrusters lit up, and Sootopolis was off. Within a few minutes, it was out into orbit.

“That was a smooth launch. We will now orbit Tianshi one last time,” commented Jagat. On the outside, he was as stoic as ever, betraying nothing of his inner turmoil. He wanted to stay near the black hole for longer, to study it further. Looking back at his life, he knew of nothing else but his ambition to study the black hole, to really understand it. He remembered back to that day in mission control, inside the lead bunker, when he had seen the star come near Sag A*. Reminiscing on this, he thought that it was for the best that they were leaving Tianshi behind—such a fate wasn’t that unlikely for any star close to the black hole. Yet, he was still sad leaving.

After completing one orbit of Tianshi, the spacecraft did a burn to escape Tianshi’s gravity. It was then orbiting Salud. The engineers on Sootopolis had suggested doing a gravity assist of the star; it would help the spacecraft direct itself towards HQ, and would give it some momentum so that it could be on its way. After escaping the star, the plan was to turn on Sootopolis’ ion engines, accelerating the spaceship at a constant rate to reach the maximum cruise speed of 0.999c.

As the spacecraft was approaching the star for the gravity boost, Enrod was seated in the control room asking for updates from all departments. He had to make sure that they were prepared to enter cryo-sleep. “All right! life support,” began Enrod authoritatively. “We have now entered the critical phase of our mission. After we complete the flyby of Salud, we are going to go into a deep, frigid sleep. I want to make sure these systems are tested before we are left to their mercy.”

“Aye chief. Stand by, running a full system check,” came the reply from life support.

A few minutes passed. Then came the reply:

“Everything’s a go. We are at the ready.”

“Copy that life support. Now let’s wait until we have been flung away by this beast.”

It was a mesmerizing site. The star became bigger and bigger on their screens as they approached. The temperature readings on the heat shield increased to thousands of degrees kelvin. They weren’t worried though; heat shields were old technology, had been in use for millions of years since the first-time humans reached space on board Sputnik. On the opposite side, they could see the accretion disk of the black hole. It was a sight that they would sorely miss; the interior of the Milky Way was shielded quite well across most of the electromagnetic spectrum by interstellar gas so venturing outside would limit their capabilities.

Jagat was in a reflective mood. He remembered times when he was little, when a probe sent by the Ranbeter had been able to take pictures of a distant star gravitationally lensed by Sag A*. The star had appeared incredibly magnified; his mother had told him how light would bend close to the black hole and how that caused the lensing effects of the black hole. It acted as a giant telescope. His memories then leapt forward to the time they discovered a cloud of gas orbiting close to the black hole. In free space, this

gas might have well coalesced into a star, given enough time, but in this unforgiving environment, it was being sucked into the black hole. The black hole had erupted in activity that night. Of course, the gas cloud was tiny compared to other meals that it was waiting to devour. Based on their observations, the Ranbeter had determined that the accretion disk of the black hole was at least 0.04 parsecs in radius (Murchikova et. al., 2019). One of the major consequences of the existence of supermassive black holes like Sag A* were these gigantic accretion disks. Now, you may ask, why even have an accretion disk? Why not suck like a vacuum cleaner, completely pulling an object inside without having it rotate around you? The simple answer was that physics didn't work that way. Most objects that approached Sag A* had high angular momentum. Angular momentum was one of those quantities that had to be conserved, and so, conserving angular momentum lead to the creation of those accretion disks.

Jagat had a small annoyance in his heart though. He knew that one of the best ways to understand Sag A* would have been to build a gravitational wave detector. The technology wasn't beyond them... it's just odd that nobody had thought about it. These gravitational waves were basically ripple effects in the fabric of space-time. Larger masses created larger ripple effects: simple enough. Supermassive black holes like Sag A* on the other hand, would have created huge rippling effects on space-time. "Oh well," said Jagat out loud to himself. "I could always build myself one when we get back home."

Anyways, the spaceship was approaching the star. Guidance was analysing the spacecraft's path, making sure that it was on the correct trajectory. They didn't want to veer off course and land straight into the star. If they really wanted to be suicidal, what better experience than falling into a black hole? Of course, Sag A* would provide a "gentle" passage; the tidal forces would not be strong enough to rip the spacecraft apart. They would have seen some wacky effects of spacetime near the black hole though. As they approach the black hole, they would have seen the whole universe blue-shifted and the black hole paradoxically appearing smaller, a result of relativistic beaming. Of course, nobody knows what they would find inside; its all a big mystery. Einstein's equations have descriptions that suggest space and time swap places inside the black hole, but that doesn't explain what that would be like. It's a mystery, one that we would probably never solve, because we couldn't beam data out from inside a black hole.

Of course, just because they were high tailing away from the black hole didn't mean that the black hole wouldn't have any effects on them. Being at the center of the galaxy, all stars within the Milky Way orbited this massive object in some form or the other. The Sun, for instance, orbited the center of the Milky Way once every 240 million years or so. Also, radiation emitted by the accretion disk would still be detectable throughout the Milky Way; it was this radiation that enabled scientists to first detect it in the first place. So, in a way, the Ranbeter would never truly be "away" from the black hole—they would be able to detect its radiation almost anywhere. And if there were large jets, their whole cosmic neighborhood would know.

The flyby with the star went well; it was sent along the correct trajectory, which would see it rendezvous with HQ. After the flyby, the spaceship started accelerating, reaching its top speed within a year. It was at this point that everybody was scheduled to go into cryo-sleep. Jagat, being the chief scientific officer, would be the last one to go to bed, after he made sure everybody else was snug in bed. When the last of the people had gone to bed, Jagat muttered to himself, "Okay this is it Jagat. Everybody has gone to sleep. It's time for me to go to rest too."

Tapping the computer dashboard, he quietly said to the spacecraft, "All is in your hands now. Wake us up will you if you encounter any trouble. Or in the slim chance the others contact us."

He fell into his sleep pod, pressed a few buttons on his machine, and went into a deep sleep.

~145 years later...

The sleep pods gently woke everyone up. Jagat and the rest of the science team went straight up to the control panel and assessed the situation. The spacecraft had begun decelerating from its top speed; it was approaching HQ rapidly, and would begin orbiting its star within the year. Enrod asked for a status check the moment he got to his chair.

"Alright guys status check. Are all instruments aboard functional? Is everybody alive and well, out of their sleep pods? How long were we asleep... judging by the brightness of that star, we must have been out the entire journey... that's disappointing, no radio signals?"

"Sir everything's fine here!" came a reply from life support. "Everybody's out of their sleep pods, and looks like they all rested fine to me!"

These sentiments were echoed by most departments in the control room, all except one.

"Chief, guidance here. You might wanna come down here and look at the data for yourself."

Anxiously, Enrod approached the guidance team. On the screen, he could see them searching for HQ—it was nowhere to be seen.

"Chief, we tried searching for HQ, but no object matches its properties in the vicinity..." said one member of the team carefully. Enrod scratched his head and said quietly, "Well what does that mean? Did we veer off course?"

"That's a negative sir, we have visual lock on HQ's star. Matches its known properties to the dot," interjected guidance.

“Does that mean... the planet has been destroyed?” inquired Enrod almost casually, dreading the answer.

Everybody was silent. Jagat was looking at some data and crunching some numbers.

“Chief, I ran the numbers. All stellar parameters match... except for the metallicity. The star’s surface seems to have an abnormally high concentration of silicon, aluminum and iron.”

More silence followed this pronouncement. Everybody in the control room knew what this meant.

The president hurtled into the control room just as everybody was silent. She inquired for Enrod, “Hey Enrod. Status update please. Its time for me to address my citizens...” Looking around, she couldn’t help but notice the passive mood in the room. “What’s gotten into everyone Enrod? Did you all have nightmares for the last hundred years?”

Enrod shook his head slightly. He looked her in the eye and said, “Miss President. Looks like HQ is no more. We have no visuals of it even though we should, and we also detected spikes in the metallicity of the star. Matches the known composition of HQ.”

Wazcow trembled a little bit, and collapsed into a vacant seat. She was stunned. They didn’t know what to say or do...

Jagat stood up from his chair, and said, “Alright, hear me out guys. We have nowhere to go, we don’t have much data about planetary systems near here. I think its time we went back *home*. To the planet they call Earth.”

More stunned silence, and then Enrod burst out laughing. “You can’t be serious son! That planet is 7000 parsecs away! Think about it, that’s a very long journey. We don’t even know if this spacecraft will survive the travel. Also, there’s no way we can be certain that the planet is even there anymore.”

Jagat pulled out a few readings and said, “Radio waves have been detected coming from that direction. Looks like its modulated and encrypted; definitely signs of intelligent life remaining down there. We are stuck in space, with nowhere left to go. I think its time we went back home. See how things are.”

Enrod sighed. He asked the room at large, “What do you think of this crazy idea? I want thoughts now.”

Life support piped in, “Well chief, we do have *enough* energy to last in cryosleep for a lot more time... we would definitely be able to reach Earth if we *had* to... But how sure are we that there aren’t any other livable planets nearby? We lived near a black hole for heaven’s sake! Why would we even have to think about the Earth? We should be capable of living anywhere half-decent!”

“Fair point, life support,” said Enrod briskly. “Guidance, what can you see in the abyss?”

“Uh chief, scanning the area. We don’t have much data about the systems here though. Looks like it was part of the data loss we had back on Tianshi with the jet and everything... we do have up-to-date data about the Earth system though, up-to-date meaning data from a few tens of thousands of years ago... The same modulated radio waves were emanating from Earth when our ancestors left HQ for Tianshi too... Maybe we *should* give them a visit...”

Enrod sighed. President Wazcow, who was listening in to these ideas, suggested, “If I may interject... personally, I find the idea of visiting Earth *quite romantic*. I studied Earth political theory at university you know... those suckers might have been reluctant to leave their home world, but they knew quite a bit about governance. I think, if its feasible of course, that we go back *home*,” with extra emphasis on that last word.

Enrod knew his battle was lost, so he relented. But there would have to be a vote within the cabinet of ministers, and the people would also have a say. Decisively, the people decided to go back to the Earth.

With that, preparations were made again, this time to travel to Earth. They would have a similar procedure to the one before, only this time they would be travelling to the Earth. They had travelled 1000 parsecs to reach HQ from Tianshi, they would need to travel about 7000 parsecs more to reach the Earth. It was lucky that HQ was in the same plane as Earth and Tianshi at that moment in time. It reduced their travel time significantly.

~300 years later

The flyby of the star was done, and they had already accelerated to their top speed. Everybody was asleep in their sleep pods. The Earth was still in the distance; they needed to travel for at least 640 more years. What they didn’t know was that the modulated signal coming from the Earth was a cry for help. There had been some kind of accident on Earth; the humans inhabiting the planet had already perished some thousands of years ago. The radio telescope that they had built was particularly robust; it had lasted a few hundred thousand years itself. When the Ranbeter intercepted the signal at HQ, the signal had already been transmitting for a long time. They had no idea that the inhabitants on Earth were already dead. Many of the Ranbeter had looked forward to meeting Earthlings; many of them even dreamed about them in their sleep. Alas, when they woke up, they were bound to be disappointed.

~700 years later

The Ranbeter had already landed on Earth and determined that a nuclear war had driven humans to extinction. They were sad, but soon set up base on the planet, the planet that was once their home. There were a few problems though. They needed to

wear glasses that enhanced their viewing ability in the visible part of the spectrum; they had been away from Earth far too long and had lost sensitivity to it. However, their UV sensitivity compensated a little bit for this; while ancient Earth had contained vast quantities of ozone that prevented the surface from being inundated with UV radiation, the nuclear war had completely stripped the Earth of its ozone.

Upon landing, President Wazcow had established the Earth colony and held elections. She won the popular vote by a huge margin.

Enrod led the expedition to the radio telescope that had been transmitting the distress signal, a marvelous array that was as big a radio telescope as he had seen in his life.

Meanwhile, Jagat was busy examining an exciting discovery that his scientific team had made; near the North Pole of the planet, they had excavated the ruins of a nuclear bunker. Inside, they had information about the planet, from millions of years ago. Such information was stored on a magnetic film, called a hard drive. Jagat created a device and started scanning information from the device. He could tell that it had belonged to an astronomer; there were star charts, research papers and also pictures of a sleek looking spacecraft with the words "Enterprise" etched on its side.

He scrolled through the papers. One in particular caught his eye, "*The Mechanisms for the formation of Supermassive Black Holes: A case study of Sagittarius A**". He quickly read through it, and marveled at how much these ancient humans had got right. They had many proposed theories for the formation of supermassive black holes like Sag A*. One of these involved supermassive black holes forming out of the merged remnants of stars. These stars were some the very first stars in the universe and had masses of a hundred suns or more. When they collapsed, they formed black holes, which would accrete material, becoming more massive. Given sufficient time, accretion would be enough to make it a supermassive black hole. Of course, issues with this theory included the observations of supermassive black holes at high z , suggesting that supermassive black holes were present in the early universe. Accretion alone would not be enough to drive the increase in the mass of the original smaller black holes to supermassive sizes.

Another theory posited the formation of black holes by direct collapse of gas in halos before galaxies even had time to form. These protogalaxies would be embedded in a dark matter halo, and would contain a lot of gas. Models had shown showed that this gas could lose angular momentum quickly, causing a rapid build-up of a dense core held up by gas pressure. These conditions would then lead to high temperatures, which would be dispersed by thermal neutrinos, causing the formation of and rapid growth of a central black hole. These black holes could then become larger by further accretion, and these black holes could provide seeds for Supermassive Black Holes seen later in the universe by way of mergers. (Begelman, Volonteri and Rees, 2006)

One other theory suggested that primordial black holes, the seeds for the larger supermassive black holes, could be have been formed during the inflationary period of

the universe. These primordial black holes would then see the formation of supermassive black holes. These theories had the advantage that they could explain the presence of large mass black holes in the early universe, with which the massive star seed hypothesis had problems. (Kawasaki, Kusenko and Yanagida, 2012).

Nevertheless, it was quite clear to Jagat that these astronomers on Earth had picked up on the basics for the formation of a supermassive black hole: there would have to be some initial, smaller mass black holes which would accrete more material, possibly even collide and merge with other black holes, eventually forming the supermassive black holes like Sag A*. He also noticed that a lot of their research emphasized the relationship between the existence of these supermassive black holes and the evolution of the universe in its early days. He thought to himself, “the discoveries made by these humans were remarkable, particularly since they didn’t possess the technological advantages of the Ranbeter!”

He also found an out-of-date appendix attached to one of the research papers, with a summary of parameters of interest that they knew about Sag A*:

APPENDIX A:

Parameter	Value
Celestial coordinates	RA: 17 ^{hr} 45 ^{min} 40.036 ^{sec} ± 0.064 ^{sec} 1 Dec: -29 ° 00' 28.1699" ± 0.0014"
Mass	$(4.148 \pm 0.014) \times 10^6 M_{\odot}$ (Abuter et al., 2019)
Distance to Source	8178 ± 13 parsecs (Abuter et al., 2019)
Spin (the maximum is 1)	0.44 ± 0.08 (Kato et al., 2010)
Schwarzschild Radius (Derived from mass)	$(1.22 \pm 0.04) \times 10^{10}$ m
Minimum density constraint	$\sim 1.4 \times 10^{-3} \text{ kg/m}^3$ (only an estimate, based on the closest point of approach for S0-2 and the mass of the black hole) (Abuter et al., <i>gravitational redshift</i> , 2018)
Temperatures in innermost parts of accretion disk	$\sim 10^7 \text{ K}$ (Baganoff et al., 2003)
Luminosity of accretion disk in X-ray	$\sim 2.4 \times 10^{26} \text{ W}$ (Baganoff et al., 2003)
Flux at 620 MHz Radio	0.5 ± 0.1 Jansky (Roy, Rao, 2004)

¹ Data obtained from SIMBAD: http://simbad.u-strasbg.fr/simbad/sim-id?Ident=NAME+Sgr+A*

Flux at 22 GHz Radio	1.33 ± 0.04 Jansky ²
Flux at 43 GHz Radio	1.79 ± 0.05 Jansky ²
Flux at 86 GHz Radio	3.35 ± 0.16 Jansky ²

It was indeed a miracle how much these primitive humans knew. Jagat went outside the nuclear shelter, and was greeted by Aurora Borealis, dancing in front of his eyes. He lay down on the snow, closed his eyes and imagined what it would have been like to live on the Earth, all those millions of years ago, probing at the nature of the black hole at the center of the galaxy, a gigantic mystery. He couldn't help but smile.

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² Data obtained from https://www.aanda.org/articles/aa/full_html/2011/01/aa13807-09/aa13807-09.html

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