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Will Gater

The Cosmic Keyhole

How Astronomy Is Unlocking the Secrets of the Universe

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Dedicated to the memory of my mum

About the Author

Will Gater has written for the UK's top astronomy magazines and has appeared on television and radio (including the BBC's *The Sky at Night*) to promote astronomy and science. He has worked for the European Space Agency's Hubble Space Telescope press office, the European Southern Observatory's public outreach department, and is a former news editor of *Astronomy Now* magazine in the UK. He holds a degree in astrophysics from University College London. Today he writes for the BBC's *Sky At Night Magazine*. He regularly blogs about astronomy on his website http://www.willgater.com.

Preface

In the first part of the twentieth century, the astronomical community was left reeling from the discovery by Edwin Hubble that the universe we inhabit and had held as a constant for so long was expanding. His observations and measurements, made from the mountaintop observatory on Mount Wilson in California, would open our eyes to the universe outside our own galaxy. Before Hubble's discovery, galaxies outside our own had been thought to be "spiral nebulae"; no one had conceived that these faint and diffuse objects could be other galaxies just like our own, only viewed from afar. In the early 1920s, Hubble's observations of Cepheid variables (stars whose varying luminosity and periods are well understood, making them good distance indicators) enabled him to conclude that indeed these "nebulae" he saw were in fact other faraway galaxies, great congregations of stars in their own right.

Later, in 1929, Hubble and a few other notable astronomers of the time studied these new galaxies and their redshifts. If an astronomical body is moving away from us, spectral lines in the object's spectrum become shifted toward the red end; thus, we observe a "redshift." When they studied the faint light of these distant galaxies, they saw that most had a distinct redshift; not only that but, remarkably, the further away they were the *greater* their redshift. Galaxies that were further away were moving away from us faster! Astronomers eventually reasoned that it was not the galaxies that were all moving away from us, but that the universe itself was getting larger, taking along the galaxies embedded within it. It was this discovery that was the very first observational evidence of the Big Bang theory. The universe was, as predicted by the Big Bang model, expanding.

Could Hubble and his colleagues have imagined how important the new information was? They probably did. It was a discovery that was to change many of our perceptions of the cosmos, leading us to new ideas and new ways of thinking and allowing us to finally understand certain key aspects about the universe that we observe. The revolution that it brought about in the astrophysical and cosmological world has the work of Hubble and his colleagues to thank for its birth. Albert Einstein's original conclusions that the universe might well be expanding suddenly made sense. Einstein himself commented (perhaps, as we will find out, prematurely) that his use of his "cosmological constant" to counter the predicted universal expansion as "my biggest blunder." Undoubtedly, it was a discovery that will affect the study of astronomy and cosmology for a long time to come and has certainly changed the way we view the universe today.

We look back on this discovery, as with many other great scientific breakthroughs of the twentieth century, with great admiration for those early pioneers, men and women whose work allowed us to slowly reveal the processes and forces by which the cosmos is governed. Their theories and discoveries have brought the workings of the planets and the stars, even the far-off universe, to our attention. Their discoveries now allow us to look back to some of the earliest times in the universe and explain what was happening, as well as study the origins of life right here in our very own Solar System. Today the same exploratory fervor, which drove those early researchers, is alive and well. We still monitor, measure, search, and dissect the cosmos, always building on and occasionally refining the work of the scientists who forged those initial investigations.

Nowadays, astronomers, astrophysicists, and planetary scientists all have unprecedented access to the universe; whether it is through observatories perched atop remote volcanic islands, high above some of the world's deserts, or even orbiting Earth in the vast emptiness of space. We have extended ourselves and our inquisitive minds into this space, evident nowhere more so than through the veritable flotilla of spacecraft that are wandering our Solar System bristling with instruments to probe and uncover hidden corners of our local neighborhood. Each day the scientists and space agencies around the world receive streams of information and data from all these exploratory efforts. As you read this, far off in orbit around Saturn, the *Cassini* spacecraft (or any of the current space missions, for that matter) is almost certainly relaying the latest data back to antennae listening intently on Earth's surface. This data will be fed back to the scientific labs, where it will be stored and eventually pondered, scrutinized, and analyzed. What incredible new view or amazing discovery is being transmitted in the space between us and the Saturnian system at this very moment?

So what then of today's discoveries? What have been the big eye-opening surprises that have caused us to step back, rethink, and then delve further into the huge complexity of the universe? It is these stories that we aim to explore in this book, stories that in a century or two, perhaps less, we will look back on as crucial steps in the evolution of our latest perspective on the universe. In recent times, we have made discoveries that may turn out to be just as important as Hubble's observations. Will we look back on the discovery of watery deposits flowing on Mars as a key stepping stone in the search for life in the Solar System and ultimately the universe? Will we in a few years time come to realize that life, as we know it, is far more prolific and hardy than we ever had thought? Will we find bacteria and other exotic species of hardy microbes under the icy lakes and possible dried up riverbeds of Mars, and what of the many moons of the Solar System? Are they really lifeless cold worlds or are they an entirely new environment in which microbial life has flourished, hidden before our inquiring eyes? What is dark energy and where did it come from? How will the universe end and how did it begin? There are just so many exciting questions.

It is often said of science that looking for an answer will result in a great many more questions than you began with. Indeed most, if not all, of the discoveries in this book have raised more questions than they have answered. Yet these are the questions that excite us and make the discoveries of today even more important. In answering them, we are one more step along the way to understanding just a small fraction of the universe. It would be foolish to think that we will one day reach a point where we know everything. But in looking at the results from today's research we can see that we are just that little bit closer to understanding the cosmos in general.

Most planetary geologists currently date Earth to be around 4.5 billion years old. Modern humans appeared in Africa only around 200,000 years ago. The telescope, the instrument that is often credited as revolutionizing astronomy and our perspective on the universe, was similarly created merely 400 years ago. In that time, its design has evolved into something that allows us to gaze back almost 13 billion years to some of the earliest times in the universe. Not even 20 years ago, the Hubble Space Telescope was launched, completely opening up the distant universe to our inquiring minds. Just think of what incredible new instruments are currently being built in the laboratories around the world. With a new generation of scientists, a fresh series of discoveries are being made today. We are embarking on a scale of exploration that is almost unprecedented in human history. The discoveries we have made in recent times are just as important, just as far-reaching, and without a doubt just as interesting as those fundamental discoveries on which our understanding of the universe was founded. As you read this book, thousands of astronomers, cosmologists, and planetary scientists (to name a small fraction of the myriad of professions) are working to explore and understand new mysteries and give us new insights into the vast universe we live in.

Assuming humankind can survive for the next few hundred years (and we do not manage to foolishly destroy ourselves), what will we know about our universe, the place we inhabit, in 400 years time? We only just discovered what DNA (the nucleic acid that gives genetic instructions on how to build all living organisms) was just over 50 years ago. Will we learn how life is created in the universe in 50 years time? The beauty of this subject is that we are, at the moment, seeing just a small fragment of the universe, gradually expanding our knowledge step by step with each new scientific paper, observation, and measurement. What follows then is, in many ways, a small distillation of some of the latest advances in our understanding of astronomy and space; advances which will undoubtedly be crucial in making further breakthroughs in understanding the complexities of the cosmos.

You can tell a lot about a room by looking through the keyhole in the door. But you can only see a small glimpse of the whole. To explore any more you must open the door, investigate and further examine what you see. Are we standing at the threshold of a new revelation in our understanding of the universe, just waiting for the door to open? No one can really say. Certainly there are exciting times ahead. For the moment, though, we are looking, wide-eyed, thrilled, and totally captivated by what see as we peer through a keyhole of truly cosmic proportions.

South Devon, UK Will Gater

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Introduction: An Early Discovery from the Depths

Two kilometers below the rolling surface of the Pacific Ocean two scientists and a pilot are sitting reverently in their small submersible. They are exploring a stretch of seafloor around the volcanic islands of the Galápagos, known as the Galápagos rift. Above them the clear blue waters swirl, countless millions of gallons pressing down upon their tiny metallic world. The craft is a refuge from the crushing pressure and icy temperatures of the ocean outside, a home away from home that will allow the three men to venture to places and depths that few humans, let alone scientists, will ever see. Down here in the inky black recesses of the ocean, where the sunlight has faded away to a memory of only a few hours ago, they go about their work. The soundtrack to their undersea adventure is the continual whirring of computers and the slow, steady, and reassuring sound of the artificial atmosphere feeding into their tiny craft.

It is the late 1970s, and the craft these men are exploring in is the *Alvin*, a submersible vehicle used by the scientists of the Woods Hole Oceanographic Institute. The *Alvin* is part of a much larger expedition to the area by the Woods Hole Oceanographic Institute. Its pilot is Jack Donnelly, and he is accompanied by two observers, Jack Corliss and Tjeerd (Jerry) van Andel. The *Alvin* is an incredible craft whose strong titanium hull is designed to withstand the tremendous pressures of the deep ocean. Fully equipped with state-of-the-art scientific equipment of its time, it is more than capable of the job it is tasked with. In its repertoire of instruments are sensors and samplers for measuring, among other things, temperature and what is in the water. The *Alvin* is also equipped with two robotic arms to pick up interesting specimens the crew may spot during the vessel's deep-sea journeys. They extend outward from the front of the craft as if tentatively fondling their way through the dark and murky depths. The eyes of the *Alvin* are the many video cameras bristling all over the outside of the craft, here to document this undersea exploration and to record the sights that the scientists within will see while diving. Few could have anticipated the incredible images that these cameras will record in the coming hours. Measuring in at around 7 m long and just over 3.5 m tall, the *Alvin* is quite a substantial underwater laboratory and observatory. Yet, unlike most oceanic laboratories it can cruise kilometers below the ocean surface at up to two knots – up close and personal with the environment it is studying. But the *Alvin* is not here to speed around; Donnelly, Van Andel, and Corliss are taking their time. Unbeknownst to them what they have come here in search of is about to reveal itself in a way no one could have expected.

Two hours ago the three men clambered inside the *Alvin* and left their mother ship, a vessel equipped with everything a scientific crew would need at the surface to launch their submersible craft. The ship would be the *Alvin's* lifeline to the world above. With its crew inside, and with the sea lapping around its hatch, the three explorers lowered themselves into the craft. Slowly and surely the gleaming white shape slipped below the ocean's surface, its shape only just recognizable against the dark sea as an azure blob. Gradually the team onboard the mother ship lost sight of the white hulk as it dove further and further down into the depths.

It has taken all of 2 h for the *Alvin* to make its way, slowly but surely, to the ocean floor, and now the team gets to work exploring. You could be forgiven for thinking that the *Alvin* was a spacecraft rather than an undersea submersible. Jerry van Andel, one of the scientists working inside *Alvin* during this trip, recalls that the inside of the craft was several inches shorter than the height of the average pilot or observer. "You sit with your hip against the curved bulkhead, head between knees and endlessly dropping one's tape recorder." The inside is covered with switches and computer panels and the small portholes show only the dark black depths outside them. "The angle of view [from the portholes], slightly down and to the side, requires getting adjusted, and distance estimates are difficult because nothing you know the size of passes by" explains van Andel. To the untrained eye, the small confines and the array of controls might just as well be the lunar module, from the *Apollo* era of a decade or so before.

Even though the crushing pressure outside and freezing temperatures would quickly kill a human and though it might seem it, the scientists are not in space. They have come here in search of hydrothermal vents, deep-sea geological features that had previously been anticipated but never actually observed.

Earth is unusual as a planet because it has tectonic plates. Although some of the Solar System bodies are indeed volcanic, as far as we know none of the other planets in the Solar System have a system of constantly moving, interacting tectonic plates like Earth's. As the plates shift and slide against each other, some are destroyed and some are created. As one plate may be forced deep underneath the crust in one part of the world, so in another corner of the globe hot magma rises in an opening crack in the crust, creating a new plate. These regions where plates are being created are called spreading ridges. It is close to a spreading ridge near the Galápagos rift that the *Alvin* is exploring, searching for the mysterious deep-sea vents. The hydrothermal vents are created when cold, deep-sea water circulates down into Earth's crust through cracks and fissures around volcanic ridges. Minerals become dissolved in the water as it becomes super heated and rises up through the crust. As the hot water moves up through the cracks in the crust and breaks out into the cooler deep-ocean water (typically only 2°C), it cools, and minerals precipitate out of the mineral-rich hot fluid around the newly forming vent. The resulting deposition of minerals around the deep-sea fissure then creates what geologists refer to as a vent.

In the 1970s, deep-sea hydrothermal vents were thought to exist, but no one had ever seen them. Geologists had been getting tantalizing clues that these vents might exist. Among other things, strange metal deposits on the seafloor had been seen. These surely had to be coming from somewhere near the ridge, argued some geologists. Could these be created by the elusive deep-sea vent features? Previous studies had even shown a small rise in temperature close to the seabed around the Galapagos. Was this a sign of hydrothermal activity? Now it was up to the team at Woods Hole and the *Alvin* to continue the investigation and find out.

Yet even before the *Alvin* got the chance to dip its toes in the warm waters of the eastern Pacific, the expedition scientists had begun scrutinizing the sea floor around the Galapagos ridge. The area had been identified previously as a possible vent site due to its proximity to the spreading ridge and from intriguing preliminary measurements of the temperatures on the sea floor in the area. The Woods Hole team had towed a deep-sea surveying experiment on a long steel cable behind one of the expedition's support ships. This undersea surveyor, called ANGUS (standing for Acoustically Navigated Geophysical Underwater System), was equipped with temperature sensors and a camera to record photographs of the deep seabed. Over several hours ANGUS scoured the sea floor, taking temperature measurements and images. The scientists waited and watched to see if ANGUS measured anything, but nothing. But just as team members were beginning to think that ANGUS would fail to find anything, the temperature sensor began to climb. Remarkably the temperature briefly rocketed. Then, as quickly as it rose, the sea temperature dropped back down to its previous level. Even more incredible to the scientists who saw them were the photographs that ANGUS took during the brief temperature peak. When the team matched up the images from where the temperature peak occurred, they were startled to see strange white shapes in the frames. On further inspection some of the scientists concluded that these were the shells of deep-sea clams living on the old lava flows in the dark depths around the ridge. It was the sign that the Woods Hole team had been searching for; if these were clams, something was keeping them alive. Now it was time for the *Alvin* to take a closer look.

At the bottom of the ocean the *Alvin* continued to search across the seafloor, scouring the gently undulating lava flows that stretched as far as the eye could see. In parts, great rolling regions of basalt (a type of volcanic rock) dominated the view. Then gradually the seemingly endless landscape broke. Through the portholes the observers started seeing color. There was life down here. The "clams" that ANGUS had spotted really were clams, about 20 cm across and bright white, but fascinatingly and totally surprising to those who saw them was the other deep-sea life that was thriving at these extreme depths. Pink and gold anemones living on the old basalt flows; yellow, brown, and liver-colored fish were swimming happily over the barren lava. Outside the craft the water shimmered, the warm current rising from the floor refracting the bright lamps of the *Alvin*. In places, it turned cloudy as carbonates in the mineral-rich water precipitated out. At the bottom of the ocean a whole new section of life had been living, undisturbed and unseen by human eyes. Jerry van Andel wrote in his diary that night: "What produced this little paradise in the big and usual deep-sea floor desert? I have no idea. Warm springs perhaps, which we suspect in this area?" van Andel was right. After this first dive more and more vent communities were discovered. Exploration of fissures and hydrothermal vent sites further north of the Mexican continental margin by other teams (this time including biologists) discovered the famous black smokers (columns of deposited minerals that were pumping dark, mineral-rich solutions into the ocean depths).

During the first Galápagos dive the temperatures ranged from 1°C to around 25°C. Later expeditions found vent communities that were thriving in temperatures with an incredible range of 250–300°C. One of the biggest questions that biologists wanted answered after the discovery of these burgeoning vent sites was what was keeping these species alive without sunlight almost 2,500 m below the surface of the ocean. It was subsequently discovered that the fauna around these vents was surviving without light by using bacteria to synthesize the chemicals from the vents into products they could use. Besides this incredible finding it was found that many of the new species had specially adapted to their environment. Some of the clams around the vents had even developed new types of blood to survive in the low oxygen levels at the seafloor. Even today, the study of these communities is a crucial facet in understanding life on Earth and perhaps elsewhere, too.

To understand the importance of the *Alvin's* findings at the hydrothermal vents and the subsequent throngs of undersea life, we have to consider the context in which the discovery was made. In 1975, the NASA *Viking 1* spacecraft was lofted by a mighty Titan-Centaur rocket on a pillar of smoke and fire into the blue skies above Cape Canaveral, FL, USA. It was the start of an 11-month journey to Mars, at the end of which the craft would make a fiery descent through the Martian atmosphere. In places, the Martian atmosphere varies in density and thickness, and this makes for a fairly dangerous and sometimes unpredictable entry. If it survived the passage through the atmosphere, it would fire its downward facing retro-rockets and make the first robotic landing of a spacecraft on the Martian surface. On July 20, 1976, *Viking 1* began its nerve-wracking descent into the Martian atmosphere. Thankfully, and much to the relief of the NASA teams working on the lander, it made it safely through, and its parachute billowed open, deploying at exactly the right time 6 km above the surface. Quickly *Viking 1* slowed from a blistering 900 km/h to an almost relaxed 200 km/h. At 1.5 km up, still racing toward the approaching surface below, its retro-rockets burst into life, slowing the huge half-ton craft further, to a gentle landing.

Viking 1 had touched down, on Mars, at the western end of the Chryse Planitia, a huge, smooth plain over 1,500 km in extent just north of the Martian equator. As the dust settled around the lander, it promptly went about its work. It started to broadcast images back to the awaiting scientists millions of kilometers away on Earth. These were incredible and unprecedented images of a rocky, dusty, ochre-red expanse strewn with thousands of small rocks, boulders, and dune fields. Above the surface wispy long thin clouds, not dissimilar to cirrus clouds on a hazy day on Earth, floated by against a faun-colored Martian sky. They were views that were just as wondrous to the world as the images from the deep-sea floor and the *Alvin*. Just as from the portholes of the *Alvin* the first human eyes saw the vent communities, so now NASA scientists laid their eyes on this previously unseen and stunning new landscape. The images were our first close up look at the Martian surface, and naturally questions began to arise in the minds of all who saw them. How did the rocks get there and where were they formed? What was the dust made up of? Yet even before scientists could have time to ponder the new images, the lander was carrying out one its most important tasks on the Martian surface, the *Viking* biological experiments.

Viking 1 was equipped with three biological experiments. Each experiment was designed to test the Martian soil for any signs of microbial life contained therein. The lander was equipped with a long arm, about a meter long, with a scoop on the end. When the lander reached the surface, it would reach out over the Martian soil and collect a sample to be analyzed. In one experiment, the sample was then fed into a machine and then given a small amount of water as well as nutrients. Scientists had hoped that if life were present then the nutrients would be metabolized, and organic molecules would be released as by-products. These would be the waste from the living organisms and provide the tell-tale signatures of biological processes. One by one each of the experiments checked to see whether any organic molecules were released. Initially, it seemed that biological processes were indeed going on in at least one of the experiments. Carbon dioxide (one of the molecules expected to be released by the organisms) production increased, yet the results seemed to be inconclusive. Control experiments returned the same positive results, and soon the NASA scientists working on *Viking* began to think that life was not the cause. Continued analysis of the results indicated that the positive results were probably due to the fact that Mars has a very strongly oxidizing surface. We know this since the red color we see is due to rust, iron oxides, the products of strong oxidizing reactions. Most scientists now think that when the water and nutrients were added to the soil they reacted with this oxidant to create the molecules that were detected.

So, *Viking 1* seemed to return a negative result. But what do the findings years earlier by the *Alvin* have to do with these results?

When *Viking* left Earth on a balmy August afternoon little was known about just how hardy extremophiles (organisms capable of surviving extremes of, among other things, radiation, temperature, and salinity) were. The discoveries of the *Alvin* opened the scientific world's eyes to just how determined life can be. The fact that life could not only survive but actually thrive at such extremes of temperature and without sunlight was an incredible revelation. Since the 1970s, huge amounts of work have been done to try and understand how extremophiles have managed to colonize what were previously thought of as uninhabitable environments. Indeed, recent new analysis of the *Viking* results by scientists in the USA and Germany has argued that the positive results may have actually been attributable to a type of extremophile well adapted to the harsh Martian soil. Dirk Schulze-Makuch of Washington State University and Joop Houtkooper of Justus-Liebig-University, Giessen, Germany, argue that the extremophile microorganisms may use the powerful oxidant hydrogen peroxide (present in the Martian soil) as one of their key constituents. They believe that by adding water to the soil the *Viking 1* experiments may have inadvertently killed the organisms. Liquid water is sparse on Mars, and getting hold of it is tricky. Thus, any such organisms studied by *Viking* might have adapted to use their hydrogen peroxide to capture precious water molecules from the Martian atmosphere. Yet this adaptation may have ultimately been their downfall when they met *Viking*. As hydrogen peroxide likes to absorb any water it comes into contact with, it is possible the water given to the sample by *Viking* was far too much. It would have been rapidly absorbed, completely overpowering the organisms, perhaps causing them to burst or drown. Nevertheless, there is still much debate in the scientific community about the *Viking* experiments and whether the result was indeed positive or negative.

As for the *Alvin's* momentous findings, today Jerry van Andel believes serendipity played its part. The *Alvin* team went to the Galápagos to solve the problem of heat-flow around the ridges in the deep-ocean floor. In doing so, they discovered a world that had never been seen by humans before. Scientists now believe that the hydrothermal vents on the ocean floor of Earth are some of the most important biological and geological sites. These are precious regions that can tell us about the possible ways in which life arose on our planet as well as (perhaps most tantalizingly) on other worlds in our Solar System. What is clear to many astrobiologists, at least, is that we are increasingly finding that life can live in a huge variety of environments, far more diverse than we had previously thought. It is very likely, then, that there are some even more exciting discoveries, like those of the *Alvin* and *Viking* just around the corner.

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1. Water and the Search for Life in our Solar System

1. The Hardiest Microbes on Earth

When looking carefully at the world around us, we see, on the surface, an incredible wealth and diversity of life. Even in our most crowded cities, nature makes its mark. Even if you personally cannot see the many kinds of living creatures at work, there is a good chance that they are there – synthesizing, respiring, and reproducing. It may be the unwelcome weed that slowly works its way through the cracks in your garden patio, to make its home there, or an exotic species, such as the wonderful flowering plants found in some particularly dry deserts and arid valleys of North America. These intriguing plants remain beneath the parched desert soil for many weeks, even months, biding their time waiting for that brief rain shower so that they can burst up in a brief flash of life and vibrant energy.

This rocky planet is covered in almost every corner by some form of life. From the arid sandy deserts, to the lush and bountiful rainforests, to the icy cold expanses of Earth's polar regions – life has found a way to live. Often it does so against the greatest of odds and many times in places no human would ever live in, or even imagine that life might exist there. Life on Earth has taken to adapting to the conditions in which it finds itself, and adapting well. These adaptations may not be immediately obvious to all, but to those who study them they represent some of the most incredible feats achieved in all of nature. The sheer range of habitats that we see colonized by life on Earth is an awesome testament to life's ability to survive.

In 2007 an international team of scientists from Russia, USA, and New Zealand, led by Dr. David Gilichinsky from the Institute of Biological Problems in Soil Science in Russia, published a paper in the journal *Astrobiology* detailing their studies, over several years, of the permafrost regions of the McMurdo dry valleys in Antarctica. What they found on the Antarctic foothills was quite incredible and would have some interesting and significant consequences for the search for life in the Solar System. The McMurdo valleys are located approximately 3,500 km due south of New Zealand,

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inland from the Ross Sea. They cover an immense 4,800 km^2 of land, indeed the largest ice-free area in the Antarctic, and are dominated mostly by the Antarctic permafrost, a layer of permanently frozen soil and sediment. The dry valleys here are some of the harshest known expanses in the south polar regions, due in part to the paucity of any rain and ice (which gives them their name) as well as the high salt content of their soil.

The valleys themselves are thought to be over 4 million years old, formed by the slow but powerful erosive movement of glaciers heading toward the Ross Sea. For the most part the mountains here shield the valleys from the continual flow of ice coming off the polar shelf, and the result is a gray and rock-strewn terrain of the dry glacial valleys punctuated with the odd errant glacier. It is the meltwaters from these few errant glaciers that provide the small amounts of water that run into the valley network today. It might seem a little odd, then, that the McMurdo valleys are also some of the most intriguing places to find life. Temperatures on the valley floors rarely exceed an average of –20°C, except in the summer months when the low Antarctic Sun warms them to around 10°C. However, just a few centimeters beneath the frozen surface the team of scientists found remarkable evidence of life in many forms living happily in the exposed Antarctic valleys.

Since the nineteenth century, scientists who studied the permafrost in the Arctic regions began to discover evidence that bacteria may be living in the frozen ground. Yet it was only after recent experiments like those undertaken on the floors of the McMurdo dry valleys that scientists could confirm that the bacteria really did originate from the samples being taken. Usually those samples would take the form of a core, drilled and extracted from the ground. It was crucial, then, that the cores be pristine – uncontaminated by microbial life from the scientists themselves and the outside world. If contaminated water, or liquid lubricants from the drill itself, seeped down into the core the experiment could have been jeopardized, so the teams working at the McMurdo sites used a special technique of "dry" drilling developed by scientists at the Russian Academy of Sciences. By drilling down deep into the permafrost, sometimes over 10 m in depth, the scientists were able to carefully sample the soils, gravels as well as ice that made up the permafrost ground. After drilling, a cylindrical core of sediment, ice, and gravels about 30 cm in length and 5–10 cm in diameter could be extracted and studied.

To further decrease the risk of contamination, a thin layer of the outside of the core was shaved off using a sterile knife, and the freshly cut sample was labeled and stored in a freezer for later analysis or transported back to the laboratory. In the laboratory the composition of the core could be meticulously scrutinized, and any interesting inhabitants could be studied. Upon study of the myriad of cores from several sites all over the McMurdo valleys an incredible wealth of microscopic life revealed itself. These ranged from bacteria of many species to yeasts, green algae, and even a type of fungi. Remarkably, on the surface sandstone in one of the McMurdo valleys (known as Beacon Valley) the team even discovered cyanobacteria, a variety of bacteria that uses photosynthesis by sunlight to gain its energy, living happily on the bare rock.

Incredibly other studies (published in the journal *Soil Biology & Biochemistry* in 2005) of the permafrost located in the Alaskan tundra returned similarly surprising results, and this time the microbes were living at even more extreme temperatures. This time a team of scientists led by Dr. Nicolai Panikov from the Stevens Institute of Technology in the USA investigated the respiration rates and the release of carbon dioxide in microbes locked within the continuously frozen earth of sites in western Siberia, southern Sweden, and Barrow in Alaska. Small sample cores (similar to those taken by Gilichinsky's team) were extracted from the top 30 cm of the soil at each site. They were then carefully stored and refrigerated in the laboratory to monitor the production of the carbon dioxide at decreasing temperatures. Using gas analyzers to continually measure the rate of carbon dioxide production, the temperature was gradually lowered. At around 31°C below freezing the soils from Sweden and Siberia stopped producing the carbon dioxide. Incredibly, though, the microorganisms present in the frozen tundra from the Barrow site were still producing carbon dioxide down to temperatures as low as –39°C! The team checked to make sure that this incredible result was not being caused by some other mechanism. They measured the amount of carbon dioxide trapped in the soil normally and accounted for this. As a final check they also sterilized the soil, heating it to 121°C in an autoclave (a type of pressurized oven that enables water to be heated to over 100°C). If no carbon dioxide was produced after the sterilization, then the microbial origin of the gas would be confirmed. After an hour in the autoclave the soil sample was allowed to cool and the experiment was run again. Sure enough, this time the carbon dioxide production was notably absent. This was an astounding result. Previous thinking was that microbial life could only grow and respire at fairly "warm" temperatures of around −12 to −18°C, yet here it seemed these Alaskan microbes were happily respiring in temperatures that were over three times lower.

In the last decade, then, scientists have found that even right on our own doorstep life is viably living at some of the coldest sites on Earth. It is interesting to note that the average annual temperature at Vostok near the South Pole, the coldest region on Earth, is just over −55°C. Extreme cold temperatures at Vostok have, in the past, reached an astonishing −89.2°C, well over two times colder than the laboratory conditions under which Panikov's bacteria respired. If this hardy Earth-based microbial life has adapted to live at some considerably chilly temperatures, perhaps even colder than we have found here, where else might it be able to live? Are extraterrestrial microbes thriving in the rocks and a few centimeters beneath the permafrost of a distant icy planet, as they are on Earth now? What might this mean for the prospects for life in the Solar System or even elsewhere in the galaxy or universe?

There is one place much closer to home that certainly makes these results even more interesting. That is the planet Mars. The permafrost of Antarctica is in many ways very similar to the surface of Mars. The plains of the Red Planet, like the permafrost expanses of the South Pole, are largely arid, lacking any notable amounts of liquid water, and the temperatures there vary from season to season, although they are generally very cold. Mars' average global surface temperature is about −55°C, though during the Martian summer months, when the Sun has been playing on the ochre soil, the temperature can warm up to 27°C in the tropical regions. It is therefore not surprising that many planetary scientists and astrobiologists are pointing to the frozen Martian soil as a possible place that microbial life forms, like those adapted to extremely cold conditions found on Earth, are living.

It might seem a problem, then, that one of the places extraterrestrial microbes may exist is just below the freezing surface of a planet.

Regardless of any freezing temperature, deep down in the rock and ice the light from the parent star (in our case, the Sun) cannot penetrate. So it is unlikely that any microbes living down there will use their sun as a source of energy. That is not a problem, though, according to studies performed by scientists digging almost 3 km below the South African soil. In the depths of the Mponeng gold mine, west of Johannesburg in South Africa, Tullis Onstott from Princeton University and his team of researchers studied the contents of ground water located deep within the rock. Their findings were released in 2006 in the journal *Science*. The mine in South Africa is one of the deepest in the world, and its dark tunnels have enabled Onstott's team to reveal a microbial world like no other, locked 2.8 km beneath the surface. The group of scientists studied the water from high pressure fractures and in boreholes drilled into the South African rock. Held within the hot salty water were bacteria, thriving in colonies living off the chemical and nutrient-rich soup within the water. Thousands of meters below the surface in the Mponeng mine, though, there is no sunlight; the fracture from which these bacteria came had been completely isolated from the surface and from the rest of Earth far above it. Not a single photon of the Sun's light, that powers almost all the life on the bright surface, reaches here, and so photosynthesis is useless.

So how, then, were these bacteria surviving? All rocks on Earth – no matter where they are, whether it is in your local park or in the depths of a South African mine – emit some radiation, explains Onstott. That is because over time they are all radioactively decaying. "They contain potassium, uranium, and thorium" says Onstott, and it is from the radioactive decay of these elements that the bacteria are deriving their energy. As the elements decay they send out high energy particles that interact with the water locked, pressurized, inside the rock. "Any high energy particle hitting a water molecule will cause it to split," explains Onstott. The resulting split of the water molecule usually results in a rearrangement of its constituent parts, creating new molecules. One of the products of this rearrangement is hydrogen.

The scientists working at the South African site discovered that the bacteria in the briny water had adapted to use the hydrogen released in the collision as their energy source. Some of the bacteria found in the water even had adaptations to see them through periods of water and nutrient shortage as well as variations from their ideal living temperature. For the microorganisms in the mine, photosynthesis was out and living off the decay of rocks was in. The Sun's light simply was not needed any longer by these bacterial colonies, and there was certainly no lack of hydrogen; the rocks of the Mponeng mine would be decaying for thousands if not millions of years to come. Onstott's team eventually concluded that the bacteria were likely to be distant (perhaps ancient) relatives of a type of bacteria known as firmicutes and that they probably arrived, where they were discovered, in water flowing into the rock around 3–25 million years ago.

So with the growing impression that the diverse microbial life on Earth is actually a lot hardier (and certainly more happy in extreme conditions) than we had previously thought, scientists went about searching the globe for even more extreme cases of microbial resistance to harsh conditions. One particular group from NASA's famous Jet Propulsion Laboratory (JPL) in Pasadena, California, was determined to see just how resistant some microbes were to the ravages of radiation and lack of water. In April 2007 they published a paper in *Astrobiology* detailing the results of a wide range of experiments on bacteria sampled from their native habitat. One of the main reasons the team, led by Myron T. La Duc from the Biotechnology and Planetary Protection group at JPL, set out to study the microbes was to test the resistance of some extremophiles to the kind of decontamination procedures used to sterilize spacecraft before they venture to the far off planets and moons of our Solar System. In their paper the team argued that if the sterilization techniques were not tested on the most resilient microbes found on our own planet, how could we claim to be sampling any potentially *new* life on another world, rather than just some species that had evaded sterilization back here on Earth? It is a valid and indeed vitally important point and one that will surely be raised when the very first sampling of Martian soil occurs. La Duc's JPL team therefore needed to locate some of the hardiest bacteria known to science. Where better to find them than at the bottom of the ocean close to a hydrothermal vent?

In the middle of the Indian Ocean beneath the rolling sea is one of the world's best examples of a hydrothermal vent site. The Kairei Field vents, just like the vents in the Galápagos discovered by the *Alvin*, are powered by the continual heating and subsequent mixing of cold oceanic water with volcanically active rocks close to the seabed. In particular the Kairei Field exhibits examples of the vent types known as "black-smokers." These great columns of precipitated minerals rise out of the seabed belching and pumping a dark black and mineral-rich cloud into the Indian Ocean above. Around the vents of the Kairei Field (much like many of the known hydrothermal vent sites) marine life is thriving. Temperatures in the area of the Kairei Field can rise to as high as 365°C close to the vent plumes and anything between 10 and 20°C near the vents themselves. Stray too far from these life-giving geological formations, though, and the water temperature plummets back down to a chilly 1 or 2°C. Yet floating close to and around the hot black plumes are the microbes that La Duc was searching for. In February of 2002, using special equipment mounted onto a 9.5-m-long manned submersible, the *SHINKAI 6500*, La Duc and his team were able to sample microbes from four different locations close to the plumes from the Kali chimney, one of the more notable hydrothermal vents in the Kairei Field area.

Upon taking the samples back up to the surface and the support ship the team immediately began the work of examining the microbes they had found, as well as preserving some samples to take back to the laboratory. When the samples eventually reached the land-based laboratory the team selected 22 samples from the dive and went about testing them for resistance to heat shock, where they were baked at 85°C for 15 min; desiccation, where the sample is rapidly dried to see if lack of water affects it; as well as UV resistance, where the sample is exposed to a measured amount of UV radiation. In roughly half of the preliminary samples there were microbes that were able to withstand the heat-shock treatment and the dose of UV given to them by the scientists. In later experiments they found many strains of bacteria also capable of surviving the harsh desiccation process. Yet there was one particular strain that stood out to the team for its uncanny ability to survive everything that they could throw at it. L0S3S-03b (as it was designated) was tolerant of high doses of UV radiation as well as a dose of gamma radiation!

The team even exposed the tough strain to a dose of UV radiation simulated to be typical of the Martian environment, which it