PART III

SUN,
EARTH,
LIFE

CHAPTER 9

OUR PLACE IN SPACE

- Where Are We?
  - The Universe at Large
    - The “Local” Universe
      - The Superclusters Next Door
        - Virgo: The Home Supercluster
          - Galactic Suburbs: The Local Group
            - The Milky Way
              - The Orion Arm: A Quick Tour
                - The Eight-Burst Nebula
                  - Vela: Supernova Wreckage
                    - The Orion Nebula: Starbirth Theater
                      - Local Stars
                        - Home

WHERE ARE WE?

When I was 18, I spent a year in New Orleans. New Orleans is old and vibrant, decrepit and colorful, dangerously fun and just plain dangerous. It is like no other city in the United States, and I was excited to be there. As soon as I arrived, I began to explore the city by taking long meandering drives, turning down whichever streets looked the most interesting. But I was a small town kid who didn't know the ways of big cities, especially those as crime-ridden as New Orleans in the early 1990's, and my urban friends thought my lone, aimless jaunts were ill advised. After I discovered that none of them who had lived there over a year had escaped being mugged or otherwise attacked, I decided they were right. So I started taking them with me. I also bought a map. Looking at the map, I realized that driving around aimlessly had given me a warped idea of the city. I had a picture of the New Orleans in my mind, and I thought I had explored most of it. But the map revealed an entirely different layout from the one I had invented, and I saw that the places I had been were just small, peripheral parts of the whole. My random wanderings were good, in that they took me to places I never would have found otherwise. But in the long run, it's good to have one's bearings.

But most of us here on Earth do not. We don't know where we are--in space or in time--in relation to the rest of the universe. People lucky enough to have some education in science may vaguely remember that Copernicus taught us we are not the center of it all; that the Earth orbits the sun, and the sun is just one of countless stars. But that is about all they can say about our cosmic address. It's like spending one's life in a single room, with no idea what the rest of the house, the neighborhood, or the countryside looks like. It's a claustrophobic situation; confining and disorienting at the same time. This chapter will try to help remedy this claustrophobia. I want to try to describe our cosmic address, by zooming down from the largest scales of the known universe, back down to the Earth.

THE UNIVERSE AT LARGE

> "The fabric of the world has its center everywhere and its circumference nowhere."
>
> -Nicolas of Cusa

When the makers of medieval maps came to the limits of known territory, they would insert the warning "Here Be Dragons". This was the point at which sailors were thought to simply plummet off the edge of the Earth, to be devoured by the dragons waiting below. Actually, I think that the warning about dragons was as much a stylistic flourish as a real prediction. Most cartographers knew that the Earth was round and had no edges, even if they did believe in dragons. In same spirit, modern cosmologists could also insert the "Here Be Dragons" warning in maps of the large scale universe. Whether or not the universe has an edge, our knowledge certainly does.

There are absolute limits to how far we can see across the universe. Whatever direction we look, we will never see farther than about 13,700 million light years, because that is roughly the age of the universe, and light cannot have traveled across more light years than it has had years to travel. The visible universe, then, is bounded, separated from what lies beyond by light's horizon[1]. Not only that, but the finite speed of light means that the view to the horizon is far from clear. It is distorted in the sense that the farther out we look, the farther back in time we see. If it were possible to peer out far enough, in any direction, we could watch the Big Bang itself. This is a mixed blessing. On the one hand, it gives us a window through time to study the past. How much would a paleontologist give for such a view of his subjects? Imagine aiming a telescope toward Earth's horizon, and seeing modern animals in the foreground giving way to mammoths, with dinosaurs roaming in the distance? On other hand, those studying the distant universe don't get to observe it as it is today. They can only see it as it was in the past. Our visible universe, then, is merely an isolated, distorted bubble in the larger universe.

This means that it would be extremely difficult to determine where we sit in the universe at large, the way I could look at a map and determine whether I was at the center or the edges of New Orleans. Looking outward, it would be easy to conclude that we are at the center, because the other galaxies are rushing away from us in all directions (Of course, maybe we are just unpopular). But the perception of being central is, as usual, an illusion. As the universe expands, each galaxy rushes away from the others, so observers in any other galaxy would see all the

---

[1] *Horizon* is actually the technical term used by cosmologists. However, I am simplifying the idea. The true size of the horizon depends on the expansion of the universe as well as the speed of light and the time it has had to travel.

galaxies rushing away from them.

If we are not at the center, could we be near one of the edges? Probably not, because the universe probably has no edges. In fact, it probably has no center. As we have seen, general relativity suggests that spacetime could have three basic shapes--closed, open, and flat. If the universe is spatially closed, then it would have a convex curvature, like a globe. Parallel beams of light in this universe would eventually cross. Not only that, but they could come back to where they started. The surface of the Earth has a similar closed geometry (in fewer dimensions). If you fly straight west from Quito, Ecuador, following the equator, after a while you would find yourself approaching Quito from the east. Similarly, if the universe is closed, then if you traveled far enough in any direction, you would find yourself back where you started. Because it wraps back around on itself, the surface of the Earth has no edge. Neither does it have a center. Bucksnort, Tennessee has as much claim to be at the spatial center of the Earth as Paris. If the universe is closed, the same thing is true for it--it has its center everywhere and its circumference nowhere.

Now, if the universe is open or flat, then there are still no edges and no center, but for a different reason. General relativity suggests that for these universes space is infinite. A defining characteristic of an infinite expanse is the absence of an edge. Also, an infinite expanse no more has a center than the surface of a globe, because any spot is just as far from the nonexistent edges as any other. [2]

In any case, what determines whether the universe is closed or not is whether it has enough matter to pull it back together, and astronomers are fairly certain that it does not, even if we include all that dark matter. So, the universe is probably flat or open. Actually, it seems to be spatially flat (or close to it) and temporally open. By “temporally open”, I mean that the universe will probably expand forever. Not only is there insufficient matter to close it, but the expansion seems to be accelerating. However, at least in the visible universe, space is very close to flat. This is an observable fact, as well as a prediction of inflation theories. This doesn’t mean that the

---

[2] You may be wondering if we really make the supremely sweeping conclusion that the universe is infinit, based on a few equations. I wonder myself. I admit that it seems like a stretch, but I am no mathematician. The idea of an infinite space is mind-boggling, but then, so is the idea of coming to an edge. What lies beyond that? Dragons? This is one of those places where my comprehension fades away.

entire universe is flat. It just means that the visible universe is such a small part of the whole that it seems flat, whatever the overall curvature, for the same reason that Kansas seems flat even though the whole Earth is curved.

Based on all this, we can draw a few conclusions. First, the universe is not closed, so it is either open or flat. Whether or not it is infinite, inflation theories predict that it is much, much larger than the visible universe. Since we can't even see most of the visible universe as it exists today, the prospects for finding out where we are in the entire universe seem slim, for the moment. Most likely, if we are wondering about centers and edges, the question is meaningless. The entire universe has neither. We are not the center, but neither is anywhere else.

THE "LOCAL" UNIVERSE

Even if we can't orient ourselves in the universe as a whole, we do have a definite position in space. And we can locate ourselves in a very, very large neighborhood. We do roughly know the shape of the superclusters of galaxies around us, and how we fit into them. Starting at this scale, we can begin to get our bearings. So, let's take a journey, zooming in from the great voids and filaments of cosmic foam back home to Earth.

Before we begin, remember that such a journey can only be imaginary (unless our descendents discover loopholes in known physical laws.) It would be misleading to imagine ourselves in a spaceship, sailing from deep space toward Earth. First, there would be no way that you could fly to a vantage point from which you could see the large scale structure of the universe clearly and as a whole. There would be too much stuff in the way to get a clear view. Besides, you could never travel faster than the speed of light, and even at that speed it would take you thousands of millions of years to cover these distances. And even if you could live that long, by the time you reached the your destinations, they would have changed enormously. It's better, then, to imagine ourselves as disembodied observers, immune to the laws of physics, changing our scale of vision at will, and zipping through the stars and galaxies in an instant. Freedom from physical realism is the blessing and the curse of human imagination.

Let the journey begin. Our first view is of a part of the universe at large. In our disembodied state, we travel to an imaginary location from which we can step back and see the texture of the universe, as though we were looking through the flat window of an aquarium. A pale glow stretches as far as we can see in all directions, like an endless wall. The color is somewhere between off white and pale tan, representing the blended colors of countless stars and galaxies[3]. Let's say that our field of view is a million million light years (Figure 9.1 A). Though this is thousands of times larger than our visible universe, there is no indication of any edge. The same pale glow stretches off to the horizon in every direction, as far as we can see, and the universe seems quite smooth. At this scale, there is a faint texture, a bit like a TV screen turned to a dead channel. But it is the same in all directions. The view is so homogenous, in fact, that it is rather boring. There are no visible features to give any indication of the vast scales we are seeing. A sense of scale requires difference, and here everything is uniform. We could just as well have our noses inches from a faintly glowing, slightly textured wall. There's more to nature than gross enormity, we conclude, as we zip off toward smaller, more interesting realms.

THE SUPERCLUSTERS NEXT DOOR

As we move inward, the texture of the universe becomes more coarse. Soon we can see the foamy pattern of the voids and superclusters. Enormous walls of galaxies separate some of the voids. Zooming in more, until our field of view stretches for about 1000 million light years (Figure 9.1 B), we see one of the walls that looks familiar. It is the Great Wall discussed in Chapter 8, so named not because it is the biggest such wall, but because it was the first one recognized by us Earthlings. In the center of the wall is the Coma Supercluster. We enter here, noticing that it is dominated by two large clusters, Leo and Coma, with several smaller "satellite" clusters and groups surrounding them. Though we can't see it, we are in a dense spot in the dark matter. It was the Coma cluster's surprising motions that first suggested that dark matter holds clusters together.

---

[3] Researchers at John's Hopkins University recently calculated the color of the universe if one could see it from outside. Their first result created a small sensation, because it suggested that the universe was pale turquoise, which was compared to the color of household appliances in the 1970's. But then they discovered an error in their computer program. When this was fixed, the color came out to be a very pale tan. We don't live in a retro universe after all.

But we are headed for home, and the Coma Supercluster is only a neighbor in the widest terms. Our destination is the Virgo supercluster, to the right, chauvinistically placed at the center of the figure. We could go the long way, up through the Great Wall and then down through the Centaurus Supercluster. If we went that way, we might spot the mysterious **Great Attractor**, a massive supercluster beyond Centaurus, toward which many local clusters seem to be drifting. This would be enlightening, because the Great Attractor is obscured by the plane of the Milky Way from Earth, and therefore hard to study. But are feeling homesick, so we decide to take a short cut, 200 million light-years across a tenuous string of galaxies that links the Coma and Virgo Superclusters.

THE VIRGO SUPERCLUSTER

Approaching the Virgo Supercluster, we see that it is dominated by its namesake, the Virgo *Cluster* (Figure 9.1 C). In the distance are two other large clusters, Fornax and Eridanus. Numerous small clusters and groups of galaxies link these large clusters in a great arc. We zoom into the Virgo cluster to take a look. As usual, spiral galaxies lie on the outskirts, often in small groups. Here in the center, gas-free elliptical and lenticular galaxies are more common. In the very center sit three huge ellipticals- M84, M86, and M87 (Figure 9.2). M87 is not only huge, containing around a million million stars, but it is also a radio galaxy[4]. We adjust our goggles to see radio frequencies, and spot enormous lobes of gas emerging from its center. These seem to pivot slowly as we fly past. As we leave the cluster, we look backward, and see the lobes face-on, so that M87 appears as a core-halo radio galaxy, the way it looks from Earth.

PROVINCIAL GALAXIES: THE LOCAL GROUP

Moving on, we zip through smaller clusters and groups of galaxies, many with boring names like NGC 5033. Finally we see it--the **Local Group**, home of the Milky Way (Figure 9.1 D). The Local Group contains up to 50 galaxies (most of them dwarfs) and covers an area about 6

---

[4] Actually, M87 *was* a radio galaxy when the light we see left it, millions of years ago. We can only guess what it looks like now.

million light years across. Three spiral galaxies stand out--Triangulum, a small spiral; and Andromeda and the Milky Way, both large, beautiful spirals orbited by smaller companion galaxies. Andromeda is orbited by two dwarf ellipticals, NGC 205 and M32. Moving within a million light years of the Milky Way, we see two more nice dwarf ellipticals, Leo 1 and 2. Closer in are two small irregular galaxies, the Large and Small Magellenic Clouds, satellites of the Milky Way. These have been known for thousands of years, as they are clearly visible from the southern hemisphere. But they are named for Ferdinand Magellan, the first European to spot them. Closer still is the Sagittarius Dwarf. This small galaxy is on the opposite side of the galactic center from the Earth, so it wasn't discovered until 1994. It has wandered too close to the Milky Way, and is slowly being pulled apart by tidal forces. Someday, it will be fully swallowed, like many other small galaxies before it.

THE MILKY WAY

Home--the Milky Way--is looming larger and larger. They say it is an average spiral galaxy--average size, average shape, quiet nucleus--but it's still stunning. We are approaching it almost edgewise, on the far side from the sun (Figure 9.3 A). Instead of flying straight home, we decide to go into a steep climb for a hundred thousand light years or so, to get a bird's eye view (as if any bird were ever here!). From this angle (Figure 9.4 A), we can see that the Milky Way is not a simple spiral, as most people imagine. It has a small bar in its nucleus--it's a barred spiral, but just barely. Four main arms extend from the ends of the bar, surrounding it tightly in an inner ring. But the four arms are not really as well defined as the figure suggests. They are more rough and indistinct, with small secondary arms here and there. A less-idealized, but more realistic, picture of the Milky Way might be NGC 7744 (Figure 9.4 B) which astronomers believe to be a close lookalike. One of the small secondary arms is our home--the **Orion Arm**, sitting between the larger Sagittarius and Perseus arms. Once again, we find ourselves in a cosmic backwater. But this is temporary. The sun is not a permanent resident of any of the arms. They are just dense spots--traffic jams of stellar construction--that it encounters as it orbits the center of the galaxy. It has passed through each one several times. Only the fast-living blue stars live their entire lives within one arm.

As we fall back toward the Milky Way, we begin to see the brightest of these blue stars as distinct objects, while the paler stars still merge in a diffuse glow. It is these brilliant stars, and the glowing nebulae they illuminate, that define the spiral arms, making them visually distinct from the rest of the disk. We see nebula as small blobs along the arms--blue reflection nebula blend in with the rest of the blue glow, while emission nebula stand out as red blobs, strung along the spirals like berries on a limb. We notice that these glowing nebula are really just parts of much larger clouds, forming dark, dusty lanes that block the light of stars below.

Before we reach the disc, we look around at the halo. Looking up away from the glare of the disc, we can see that there are old, red stars scattered throughout the halo, glowing dimly. A few dozen globular clusters are also visible, each full of thousands or millions of similar stars. But the most unexpected thing about the halo is that, even though the gas here is extremely sparse, it is *hot*- around a million K in places. This is more than hot enough to strip the electrons from the nuclei and create ions, so we are technically traveling through a thin *plasma*, not a gas. It's a good thing this is an imaginary trip; this is not a healthy environment.

Sailing just above the disc again, we arc above the central bulge, with its incredibly dense packing of stars, most of them old red and yellow ones. To see into the bulge, we turn the dials on our goggles back and forth through the entire spectrum of light, revealing different features at each frequency. The largest feature is a great ring of dark molecular clouds surrounding the nucleus, 1,200 light years across, and lit in patches as emission nebulae. Looking deeper, we see intense magnetic fields stretching in tangled filaments for 300 light years. Deeper still, there seems to be another ring of matter, like the great donuts believed to surround black holes, several light years across. Radiation blazes out of the hole. Inside must be the central black hole, as much as 3 million times as massive as our sun, but only a few times larger. Surrounding the black hole would be a great accretion disc, the real source of the brilliant radiation- ten percent as luminous as the rest of the galaxy. Though we see the light, the objects themselves are too small to see from our vantage point above the bulge. We could zoom in closer for a better look, but we decide to head for more familiar territory.

As the bulge drops away, the other side of the galaxy opens up below us (Figure 9.3 B and C). We pass the Norma and Scotum-Crux arms, just after they leave the central bar. Next is the Sagittarius arm, and then Orion, our home. Even though we are looking straight in the Sun's direction, we can't see it yet, and won't for some time. But we are starting to see some landmarks. Just at the edge of the Sagittarius arm is the Trifid Nebula that we met in Chapter 7, broken into three by dark dust lanes.

THE ORION ARM

The Orion Arm fills our field of view. Here we have two maps. Figure 9.3 D shows the locations of major stars, dark dusty clouds, and bright nebula. Figure 9.5 A shows the area in more detail. What we notice here is the surprisingly complex structure of the gas and dust clouds within the arm (and presumably, throughout the other arms). For a few hundred light years around the sun (where astronomers know the details), the map shows that the gas has a frothy consistency. The colder, denser gas (around 100 K) traces the walls of great bubbles, forming a pattern similar to the walls and filaments of galaxies (but made by very different processes). Filling the bubbles is a hot plasma, around 8,000 K. What seems to cause this pattern is that the intense radiation and shock waves from past supernovae have heated up the gas, blowing up the bubbles in the process. The very hottest gas formed in these events breaks through the bubbles and "rises" into the less dense halo (just as hot air rises on Earth) filling it with the million K plasma that we encountered on our way down. As some of this gas cools, it falls back into the disc, replenishing it with new gas. It is a great galactic weather system, and it "rains" stars.

On earth, raindrops condense in the coldest, densest regions of clouds, because there the electromagnetic attraction of the water molecules can overcome random motions. Similarly, stars condense in the coldest, densest clouds in the galaxy, because there the *gravitational* attraction can overcome random motions. Looking at Figure 9.5 A, we see that the great molecular clouds are just the densest regions of the filaments of atomic gas between the hot bubbles. Stars are forming within these dark regions. When they are close enough to the surface (often because they have evaporated the clouds around them) we see glowing emission nebula--small bright patches of the larger molecular cloud.

THE "EIGHT-BURST" NEBULA

Occupied by thoughts about the meteorology of the Orion Arm, we gotten a little off course, as Figures 9.3 D and 9.5 A show. That's fine--we will continue to take the long way home;

stopping to see the sights. Since we are in the neighborhood, we decide to stop by a nice planetary nebula called NGC 3132 (Figure 9.6 A). This nebula can only be seen from Earth's southern hemisphere, where astronomers give it the more familiar names "Eight-Burst" or "Southern Ring". The great shell of gas is expanding at 14.5 km (9 miles) per second. In its center are a pair of stars. The larger one is still on the main sequence. It is the smaller one which has ejected its outer envelope and become a white dwarf.

VELA: SUPERNOVA WRECKAGE

Our next stop on the way home is another remnant, but this one is from a far larger explosion. This is the Vela supernova remnant, shown in Figure 9.6 B. Hot gas in glowing red filaments still expand here from a supernova that exploded 12,000 years ago. Inhabitants of the southern hemisphere would have seen it glowing brighter than the full moon, which may be why Australian aborigines began painting exploding stars on rocks around this time. We can only guess how such an event might have been woven into their mythologies. The core of the original star remains as a neutron star, whirling stroboscopically at 11 times per second. Its magnetically-powered searchlight happens to sweep across the Earth, which allows us to see it as a pulsar.

THE ORION NEBULA: STARBIRTH THEATER

When you look up in the winter sky at Orion, he seems to have a "sword" hanging from his famous belt of three stars. If you have sharp eyes, you can see that the middle part of the sword is not a star, but a glowing red cloud--the Orion Nebula. In fact, radio images show that great molecular clouds sweep throughout Orion, lighting up here and there as emission nebula. The Orion nebula is one of the best views from Earth of a star formation site, so that is our next destination.

Figure 9.7 gives an idea of the views that we find. As usual, the bright nebula is simply an illuminated spot in a much larger molecular cloud (Figure 9.7 A). In fact, it is a hole in the cloud, its walls heated to glowing by the stars inside it. Four of the largest stars, called the Trapezium, are visible even in small telescopes. Hot, young, fast-living stars in a glowing amphitheater--the comparison with a rock group is irresistible. But the Orion nebula is more than the Trapezium quartet, even if those are the, um, “stars” of the show. From our vantage point near the opening, we can see hundreds of smaller stars. Some are still immersed in great globs of gas, while others have formed protoplanetary disks, as Figure 9.7 B shows. Some of the stars are moving relative to the surrounding gas. The stellar wind meets the interstellar gas, and creates a shockwave, which looks something like the wave behind a speedboat (Figure 9.7 C)[5]. Some of the young stars are at the bipolar outflow stage, shooting great jets from their axes that plow through the surrounding gas, leaving shock waves of their own.

Turning our sensors to the molecular cloud behind the Orion Nebula, we find another, younger cluster of stars still buried within. Many of these are thousands of times brighter than our sun, but the radiation only escapes in the infrared. It seems that new clusters form just inside the edge of the cloud, then burn away the gas around them to create a hollow like that of the Orion Nebula. This, in turn, compresses the gas “backstage”, causing it to form stars. This way, a whole string of star clusters are born, one after another, pushing back the gas cloud from which they were born. Like a spreading forest fire, starbirth propagates itself, using up its raw material as it goes. Looking in the general direction of the sun, many of the stars we see were born in such clusters, which get older the farther away we look from the current site of starbirth.

LOCAL STARS

And that is the direction we are going- toward our older, less flamboyant, more *maternal* star, still invisible in the distance. Since we are heading straight home from the direction of Orion, the brightest stars we see are the main stars in that constellation (Figure 9.5 B). Nine hundred light years from the Sun, we pass Rigel, the great blue giant at Orion’s right knee. Bellatrix, his right shoulder, passes after a couple of hundred more light years, then Betelgeuse, 520 light years from home. Betelgeuse, we notice, is much larger than Rigel, but only about a quarter as bright, because Rigel is so much hotter (temperature is more important than size). The most luminous stars at this distance are easily visible to the naked eye from Earth, and most of them were named

---

[5] These two phenomena are in fact similar, because they are both caused by an object which moves faster than the waves it creates. It creates a large, expanding, circular wave at each point, and then leaves that circle. This creates a string of waves behind the object, growing larger the farther away they are, thus creating the V shaped shock or bow wave.

long ago. Many of them were named by Arab astronomers, which is why they have names like Rigel, Betelgeuse, Mirzam, and Adhara. But most of the stars nearby are faint red and yellow stars, far too faint to have been seen by the ancient astronomers. The closer to home we get, however, the fainter are the stars visible with the naked eye, and thus the fainter are the ones with Arabic names.

Looking over our left shoulders as we pass Betelgeuse, we spot the Pleiades in the distance, just before passing into a bubble wall of cool, dense gas. This gives way to more warm gas on the inside. We have passed into the **Local Bubble**, the home of the Sun and its neighborhood stars. Another star cluster, the Hyades, appears to the left. Now we are in the general area shown in Figure 9.5 C, and our next graph, 9.8 A. Reading the star names--Wazn, Skat, and my favorite, Zebeneshamali, gives one the odd impression of being in a foreign country, even though we are much farther afield than any country on Earth. We pass the red giant Aldebaran, to our left, and Regulus, to the right. Ahead in the distance we notice Sirius A, the brightest star in Earthly skies, the most brilliant kid on our home block. Then, as we come within 50 light years, we finally see it: an average yellow star on the edge of a tiny patch of cool gas (inauspiciously dubbed the *Local Fluff*)--our own sun.

Now we are in the area of Figure 9.8 B, within a 12.5 year radius of the sun. Most of the stars in this neighborhood are faint red dwarfs, many of which we could not see from Earth with our naked eyes. We pause at Sirius A to inspect its white dwarf companion, Sirius B. Sirius B is too far away to pull any matter away from its larger companion, which is good, since we would not want such a nearby star to go supernova. When Sirius A becomes a red giant, this may change, but we don't need to worry about that at the moment. Looking "downward", we notice the orange star Epsilon Eridani, 10.7 light years from the sun. We could go see its planet, a Jupiter-sized object, detectable by the wobble it causes in its parent star. Perhaps there are even other planets in that system, too small to have been detected so far. This system was scanned for radio signals from alien civilizations in the 60's, but none were found. But we are ready to return to our own planet, so we keep going.

HOME

The last stars we pass are Alpha Centauri A and B, orbiting each other closely, and Proxima

Centauri, which orbits the pair at a distance. Currently, Proxima Centauri is the closest (most *proximate*) star to the sun, at 4.2 light years (roughly 40 million million kilometers). But it is a dim red dwarf, far too faint to be seen from Earth with the naked eye. Leaving Proxima Centauri behind, we head for the sun, which from here looks like a rather bright yellow star. As we approach, it grows brighter and brighter. Not long after we pass the halfway point between the two stars, we have a strange encounter--a comet hurtles across our path. We have entered the **Oort Cloud**, an enormous cloud of comets thought to surround our solar system. These are the farthest objects to orbit the sun, many thousands of times as far away as the Earth. After all the light years we have covered, seeing the comet is like seeing a member of the family. We have arrived in our own solar system.