
THE
STARS OF
HEAVEN
CLIFFORD A.
PICKOVER

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This book is dedicated to the triple alpha process

and the number **7.6549**:

the reasons we

are alive today,

and smiling,

on Earth.

God gave us the darkness so we could see the stars.
— Johnny Cash, "Farmers' Almanac"

O God, guide me, protect me,
make of me a shining lamp and a brilliant star.
— Abdu'l-Bahá

And the third angel sounded,
and there fell a great star from heaven,
burning as it were a lamp.
— Revelation 8:10

Know thou that every fixed star hath its own planets,
and every planet its own creatures,
whose number no man can compute.
— *Baha'u'llah*

Be humble for you are made of dung.
Be noble for you are made of stars.
— Serbian proverb

♑ Acknowledgments

I'll tell you what the Big Bang was, Lestat.
It was when the cells of God began to divide.

— Anne Rice, *Tale of the Body Thief*

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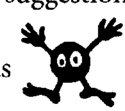
Finally, I thank Samuel Marcius for symbols such as  and , which represent Miss Muxdröözol and Mr. Plex.

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♌ Contents

♉ Introduction

I like the stars. It's the illusion of permanence, I think. I mean, they're always flaring up and caving in and going out. But from here, I can pretend . . . I can pretend that things last. I can pretend that lives last longer than moments. Gods come, and gods go. Mortals flicker and flash and fade. Worlds don't last; and stars and galaxies are transient, fleeting things that twinkle like fireflies and vanish into cold and dust. But I can pretend.

— Neil Gaiman, *The Sandman #48: Journey's End*

Smilodon Overdrive

Unknowingly, we plow the dust of stars, blown about us by the wind, and drink the universe in a glass of rain.

— Ihab Hassan, *The Right Promethean Fire*

The other day I was walking in a field when I came upon a large skull. It was probably from a bear, although I like to imagine it was part of the remains of a prehistoric mammal that once roamed Westchester County, New York. I'm a collector of prehistoric skulls. In my office, I have a skull of a saber-tooth tiger, also known to scientists as the *smilodon.* This killing machine had huge, dagger-like canine teeth and a mouth that could open 90 degrees to clear the sabers for their killing bite.

When I run my fingers lingeringly over the skulls, I am sometimes reminded of stars in the heavens. Without stars, there could be no skulls. The elements in bone, like calcium, were first created in stars and then blown into space when the stars died (figure I.1). Without stars there would be no elements heavier than hydrogen and helium, and, therefore, life would never have evolved. There would be no planets, no microbes, no plants, no tigers, no humans.

Now I look at the saber-tooth tiger's skull, so massive, so deadly. Without stars, the tiger racing across the savanna fades away, ghostlike. There are no iron atoms for its blood, no oxygen for it to breathe, no carbon for its proteins and DNA. There are no mossy caverns, mist-covered swamps, black vipers, retinas, spiral nautilus shells. Our existence requires stars to forge the heavy ele-

Figure I.1 The calcium in our bones was first created in furnaces located in the center of stars. [From Robert Beverly Hale and Terence Coyle, *Albinus on Anatomy* (New York: Dover, 1979), 29.]

ments in massive fusion reactions, but we also need the stars to explode at the ends of their lives to wash the new elements far into space. Without these supernova explosions, there are no seagull cries, computer chips, trilobites, Beethovens, or the tears of a little girl. There is no Golgotha, and Jesus never gave his Sermon on the Mount. There is no one to speak the words, "Thy will be done on Earth, as it is in heaven." Without exploding stars, perhaps there would be a heaven, but there certainly would be no Earth.

Let's imagine the origin of calcium in this tiger tooth that I hold. The atoms created in the dying ancient stars were blown across vast distances and eventually formed the elements in the planets that coalesced around our Sun. If you could turn back time and follow the carbon atoms in the tiger's brain back to their source, you would connect the tiger to an unimaginably long interstellar journey that culminated in the giant stars, which died in violence billions of years ago. Humans and tigers and whales and plants and all that we see on Earth are stellar ashes. And when the ancient tiger died, the atoms in its flesh kept going. Perhaps one of the tiger's atoms coalesced into your embryonic form.

I know I almost sound religious when I tell my friends about the stars. We are lucky we live in an age in which we can wonder about the myriad cosmic "coincidences" that permitted the creation of stars and the flushing of their heavy elements to the Universe. I'll explain in this book how various nuclear and chemical constants are precariously poised to permit life. It is as if the constants sat on the head of a pin, the tiny point of which encourages a Universe full of complex compounds rather than the seemingly more likely oceans of monotonous hydrogen. We are the memorial to shattered stars. We are the afterlife of which blazing stars could never dream.

The elements in our world are constantly changing. With every breath, we inhale millions of atoms of air exhaled a few days ago by someone on the other side of the planet. In some sense, our brains and organs are vanishing into thin air, the cells being replaced as quickly as they are destroyed. The entire skin replaces itself every month. Our stomach linings replace themselves every five days. We are always in flux. A year from now, 98 percent of the atoms in our bodies will have been replaced with new ones. We are nothing more than a seething mass of moving atoms, continuous threads in the fabric of spacetime. What does it mean that your body has nothing in common with the body you had a few years ago? If you are something other than the collection of atoms making up your body, what are you? You are not so much your atoms as you are the *pattern* in which your atoms are arranged. Very likely you have the atoms of the great Biblical prophets coursing through your body, and they, like all of us, breathed in the atoms from the stuff of stars. As mathematician Rudy Rucker has noted, "The simple processes of eating and breathing weave all of us together into a vast four-dimensional array. No matter how isolated you may sometimes feel, no matter how lonely, you are never really cut off from the whole."[1]

Who are we? Where do we come from? In Joni Mitchell's 1960s song *Woodstock* we hear the answer, "We are stardust, billion year old carbon."[2] In this book, I will help you to better understand the meaning of these words.

Starry Night

The heavens call to you, and circle about you, displaying to you their eternal splendors, and your eye gazes only to earth.

— Dante Alighieri, *Purgatorio*

Stars have fascinated us since the dawn of history and have allowed us to transcend ordinary lives in both literature and the arts. I think the painter Vincent van Gogh glimpsed a poignant portion of reality at the height of his interest in stars. van Gogh loved to read about astronomy and wondered about what it would mean to travel to the stars. His famous *Starry Night*, painted in 1889, shows stars not as points of lights but as bright orbs with the sky swirling about them like a magical stream (figure I.2). Van Gogh contemplated new ways of painting stars so they revealed their glory and took over the canvas. He also thought about what stars might mean to humans and their place in the Universe.

Around the time van Gogh painted *Starry Night*, he wrote about stars to his brother Theo. His letter seems to be a meditation on the realm between life and death and perhaps how death might be a portal to the stars:

> Is the whole of life visible to us, or do we in fact know only the one hemisphere before we die? For my part I know nothing with any certainty, but the sight of the stars makes me dream, in the same simple way as I dream about the black dots representing towns and villages on a map. Why, I ask myself, should the shining dots in the sky be any less accessible to us than the black dots on the map of France? If we take the train to get to Tarascon or Rouen, then we take death to go to a star. What is certainly true in this reasoning is that while we are alive we cannot go to a star, any more than, once dead, we could catch a train. It seems not impossible to me that cholera, gravel, phthisis [a wasting disease, especially tuberculosis], and cancer could be the means of celestial transportation, just as steam-boats, omnibuses, and railways serve that function on earth. To die peacefully of old age would be to go there on foot.[3]

Figure I.2 *Starry Night* by Vincent van Gogh, June 1889.
[Oil on canvas. 73.7 × 92.1 cm (29 × 36¼ inches).
Collection, The Museum of Modern Art, New York.
Acquired through the Lillie P. Bliss Bequest.
© 2001 The Museum of Modern Art, New York.]

Many authors have speculated that van Gogh had temporal lobe epilepsy and that this brain disorder intensified his religious needs and experiences.[4] For van Gogh, abnormal electrical activity in the brain was a portal that opened doors to entirely new ways of seeing and feeling. He once wrote, "I often feel a terrible need of—shall I say the word?—of religion. Then I go out at night to paint the stars."[5] At the time that he painted *Starry Night* he was in the asylum and had about a year to live. But his mental instability and acuteness did not mean that *Starry Night* was the wild raving of a lunatic or conjured up without observing the sky. He wrote to his brother Theo, "This morning I saw the country from my window a long time before sunrise, with nothing but the morning star, which looked very big." The morning star is another name for Venus, which is probably portrayed as the large bright shimmering form, just to the left of center in his painting. According to University of California–Los Angeles art historian Albert Boime, astronomical data proves the placement of stars and moon in *Starry Night* are accurate for the night on which it is known to have been painted. In particular, Boime has reconstructed the probable alignment of stars and planets in the painting, seeing in the painting three stars of the constellation Aries as well the Moon and Venus.[6]

In some ways van Gogh made us see the Universe in a different light and, with just a few strokes of a paint brush, allowed us to appreciate the vastness of the night sky as much as modern telescope images do. Look at figure I.2. Look at the contrast between the intense turbulence of the heavens and the calm order of the village and church below. The contrast makes the sky resonate in the mind long after your eyes leave the painting.

van Gogh's art is just one example of humanity's passion for stars. In fact, humans have always looked to the stars as a source of inspiration and transcendence to lift them beyond the boundaries of ordinary intuition. The ancient Sumerians, Egyptians, Chinese, and Mexicans were very aware of the locations and motions of the visible stars. Some of these cultures had catalogued and grouped thousands of stars and perhaps thought that the *visible* stars were all the stars that existed.[7] On the other hand, the Old Testament writers theorized there were many more stars than humans could see. According to Genesis 22:17, the stars were as great in number as the sands of the seashore and simply could not be numbered. The vast reaches of the cosmos were utterly incomprehensible to humans: "For as the heavens are higher than the earth, so are my ways higher than your ways, and my thoughts than your thoughts" (Isaiah 55:9).

In the Bible, stars are a sign of God's power and majesty. In Job 38:31–32, God reminds Job of His omnipotence and names several constellations of stars: "Can you bind the beautiful Pleiades?[8] Can you loose the cords of Orion?[9] Can you bring forth the constellations in their seasons or lead out the Bear with its cubs?[10] Do you know the laws of the heavens?" In Isaiah 40:26, God similarly reminds us that He knows their number and their names: "Lift your eyes and look to the heavens: Who created all these? He who brings out the starry host one by one, and calls them each by name. Because of His great power and mighty strength, not one of them is missing."

Probably the most famous star in the Bible occurs in Matthew 2:1–2, which describes a group of travelers, called Magi, heading toward Bethlehem from somewhere in the east. These Magi are most likely astrologers. They had seen a special star and were bringing gifts for "the one who has been born king of the Jews."

> Where is he that is born King of the Jews? For we have seen his star in the east, and are come to worship him. . . . And lo, the star, which they saw in the east,

> went before them, till it came and stood over where the young child was. When they saw the star, they rejoiced with exceedingly great joy. (Matthew 2:1–2, 9–10)

Over the centuries numerous scholars have sought a scientific explanation for the Star of Bethlehem (figure I.3). Jesus seems to have been born sometime between 4 and 8 B.C. Chinese annals record novae (bright stars) in 5 B.C. and 4 B.C. In the early seventeenth century Johannes Kepler suggested that the Star of Bethlehem may have been a nova in the constellation of Pisces the Fish occurring near a conjunction of Jupiter and Saturn around 7 B.C.[11] (Coincidentally, a fish has long been a symbol of the Christian church.)

Figure I.3 Wise men guided by the Star of Bethlehem. [From Gustave Dore, *The Dore Bible Illustrations* (New York: Dover Publications, 1974), 163.]

In Islamic theology, the number of stars is also a metaphor for a huge number. In pre-Islamic times, Ka'b Al-Ahbar was one of the great Jewish scholars. He later became a Muslim and said, "On the 15th of [the month of] Shaban, Allah ordered that Paradise be decorated, and then Allah freed from hellfire as many persons as the number of stars in the universe."[12]

Today we can get a feel for the actual number of stars that exist in the Universe. It is clear that there are a lot more stars than contemplated by many early astronomers. For example, well before Italian astronomer Galileo Galilei (1564–1642) developed the first telescopes for astronomical observation in 1609, Greek astronomer Hipparchus (ca. 127 B.C.) compiled a star catalogue containing 850 stars, and Alexandrian astronomer Ptolemy (127–151) increased the number to 1,022 stars. Ptolemy's star catalogue is the oldest surviving star catalogue, and it grouped stars in constellations with the latitude, longitude, and the apparent brightness of each star. Danish astronomer Tycho Brahe (1546–1601) listed accurate positions of more than 777 stars. German astronomer Johannes Kepler (1571–1630) catalogued 1,005 stars. Many later scientists such as Galileo believed that the stars could not be numbered, and the Bible similarly states, ". . . the host of heaven cannot be numbered."[13]

We live in a gravitational "froth" where gravity binds stars together to form galaxies, binds galaxies into local groups of galaxies, groups of galaxies into clusters, clusters into superclusters, and superclusters into "walls." Luckily for us, the galaxies, with their strong gravitational attraction, consolidate the chemically enriched gas left over from stellar explosions. The number of stars in the Universe boggles the mind. The *variety* is equally amazing—black holes, red giants, brown dwarfs, white dwarfs, Cepheid variables, neutron stars, pulsars . . . Our modern, sophisticated telescopes have only begun to reveal the immense numbers and variety of stars. We find that our own Sun is just an ordinary star that inhabits our Galaxy, the Milky Way, which has roughly 200 billion stars. Some of the stars are much bigger—giants and even supergiants. There are around 100 billion galaxies in the observable Universe and each one of them has roughly 100 billion stars. So there is roughly one galaxy for every star in the Milky Way.[14]

When students ask astronomer William Keel of The University of Alabama in Tuscaloosa how many stars exist in our Milky Way Galaxy, his standard answer is "about as many as the number of hamburgers sold by McDonald's." It is difficult to be precise because distance and dust absorption dim incoming light. Measurements of the relative numbers of stars with different absolute brightness suggests that for every Sun-like star there are about 200 faint red M-class dwarfs. (As you'll learn, the "class" of a star is determined by its surface temperature. M stars are cool.) This means that to estimate the number of stars in the Milky Way, we must consider the number of luminous stars that we can see at large distances and assume that we know the proportion of visible stars to the invisible fainter stars.[15]

Incidentally, the diameter of the Universe we see right now—we call it the *observable Universe*—is about 10^{26} meters, which is 1 followed by 26 zeros. You might enjoy comparing this distance to a few other distances for comparison (Table I.1):

Table I.1
Distances[16]

Diameter (meters)	Object
1.3×10^{7}	Earth (diameter at equator)
1.5×10^{7}	Sirius B, a white dwarf star
1.4×10^{8}	Jupiter
7.7×10^{8}	Moon's orbit
1.4×10^{9}	Sun
4×10^{10}	Rigel, a blue-white giant
3×10^{11}	Earth's orbit (average diameter)
1.2×10^{12}	Betelgeuse, a red supergiant
1.5×10^{13}	Solar system
2×10^{14}	Heliopause (edge of solar wind)
10^{15}	Bok globule (a nebula from which a star is formed)
9.5×10^{15}	Light-year
10^{16}	Planetary nebula (formed by outgassing from a star)
4×10^{16}	Distance to closest star, Proxima Centauri
1.6×10^{18}	M13, typical globular cluster
9×10^{20}	Milky Way's disc
6×10^{22}	Local Group (a cluster of around 30 galaxies containing the Milky Way)
2×10^{23}	Typical cluster (containing 100–1,000 galaxies)
2×10^{24}	Typical supercluster (containing 3–10 clusters)
10^{26}	Observable universe

Current theories of the early Universe suggest it inflated faster than the speed of light; therefore, we will never see some of the very distant parts of the Universe.[17] This means that the observable Universe is only that part that is accessible to us, given the age of the Universe and the finite speed of light. If the inflationary theory is correct, then even with the most amazing telescopes we will ever develop, we will only see a very small part of all that exists.

The Science and Spirituality of Stars

> *Why should the universe be constructed in such a way that atoms acquire the ability to be curious about themselves?*
>
> — Marcus Chown, *The Magic Furnace*

This book will allow you to travel through time and space, and you needn't be an expert in astronomy or physics. To facilitate your journey, I start most chapters with a dialogue between two or three quirky explorers who study stars. Bob is chief curator of an intergalactic art museum, a teacher, and a star enthusiast. His able student is a scolex, a member of a race of creatures with strong diamond bodies. His personal scolex, Mr. Plex, will do *whatever* experiments Bob wishes.[18]

Prepare yourself for a strange journey as *The Stars of Heaven* unlocks the doors of your imagination with thought-provoking mysteries, puzzles, and problems on topics ranging from stellar anatomy to the birth of solar systems. A resource for science-fiction writers, an adventure and education for beginning physics and astronomy students, each chapter is a world of paradox and mystery.

Imagery is at the heart of much of the work described in this book. To understand what is around us, we need eyes to see it. I hope the numerous diagrams help convey the concepts from myriad perspectives. As in all my previous books, you are encouraged to pick and choose from the smorgasbord of topics. Many of the chapters are brief and give you just a flavor of an application or method. Additional information can be found in the referenced publications. Some information is repeated so that each chapter contains sufficient background information, but I suggest you read the chapters in order as Bob and Mr. Plex gradually build their knowledge. By the time you finish this book, you'll be able to impress your friends with such arcane phrases as the Rydberg-Ritz formula, Paschen series, heliopause, helium flash, triple alpha processes, and Hertzsprung-Russell.

In about five billion years, the hydrogen fuel in our Sun will be exhausted in its core, and the Sun will begin to die and dramatically expand, becoming a red giant. At some point, our oceans will boil away. No one on Earth will be alive to see a red glow filling most of the sky. As Freeman Dyson once said, "No matter how deep we burrow into the Earth . . . we can only postpone by a few million years our miserable end."

Where will humans be, a few billion years from now, at the End of the World?[19] Even if we could somehow withstand the incredible heat of the Sun, we would not survive. In about seven billion years, the Sun's outer "atmosphere" may engulf the Earth. Due to atmospheric friction, in many scenarios the Earth will spiral into the sun and incinerate. However, I don't think we have to mourn for humanity. In five billion years, humans will probably have downloaded their minds to computers, left the solar system in some great diaspora, and sought their salvation in the stars.

> Rationalists predicted that religion would be the first thing to fall when humanity went to the stars and found no gods. . . . Scientists never had been all that good at predicting . . . They never even noticed that, when they finally went out there, every deity and supernatural belief system known at the time went right with them . . .
>
> — Jack Chalker, *Balshazzar's Serpent*
>
> And when he opened the seventh seal, there was silence in heaven about the space of half an hour.
>
> — Book of Revelations, 8:1

☆ CHAPTER 1

Stellar Parallax and the Quest for Transcendence

Come quickly, I am tasting stars!

— Dom Pérignon (1638–1715),
at the moment of his discovery of champagne

The year is 2100, and Bob is chief curator of an intergalactic art museum. Nicknamed "Picasso," his large ship has artworks from several star systems. Bob is currently hovering above the Earth, and on his view-screen is a nearby star.

Several cleaning spiders work their way along the plush carpeting of Bob's living quarters. They occasionally ingest drops of spilled paint, lint, candy wrappers, and other detritus about which Bob is better off not thinking. It never ceases to amaze Bob how robotics have became the Solar System's largest industry, eclipsing the information industry. The latter became important by automating office work, bookkeeping, communications, and calculations. Robotics automated everything else.

Bob turns to his assistant. "Mr. Plex, that star is Sirius in the constellation Canis Major." Bob pronounces the words "SEAR-ee-us" and "KAY-niss MAY-jer."

"Very beautiful, Sir. And it's a bright one."

Bob nods. "It's the brightest star in the night sky. If we magnify the image you can see that it's actually a binary star, two stars with the brighter one 23 times as bright as our own Sun. Today I want to teach you about how earlier astronomers determined the distances from stars to Earth."

Bob's dual faces smile. Stars are his life.

Mr. Plex looks around Bob's office, slowly gazing at photographs and paintings of constellations, galaxies, and stars in various stages of their evolution. He rests his gaze on Bob's favorite work by an extraterrestrial artist named Miss Muxdröözol. Muxdröözol, a trochophore with two huge teardrop shaped eyes, has painted an exploding star using the blood of several ancestors.

Bob sometimes wonders about Miss Muxdröözol. Her skin is exceptionally smooth but her shape is somewhat disconcerting. She essentially has no body—just a large head connected to arms and legs.

Miss Muxdröözol

Bob shakes his head. "Mr. Plex, for the next few days I will teach you everything I know about the wonderful stars in our Universe. Today I want to start by having you help determine the distance of Sirius from Earth using *stellar parallax*, a simple, elegant method for understanding our place in the Universe."

"Sounds delightful. Shall I get Miss Muxdröözol?"

Bob looks at Mr. Plex with one face and then the other. "No, let her sleep."

Mr. Plex stares for a second at Bob's primary face. It is the clean-shaven face of a man about 35 years old. Bob's eyes are brown and his curly hair shows signs of premature gray. Bob's secondary face is similar except that one of the eyes is blue.

Yes, Bob has two faces, 180 degrees opposed from one another. Is he a set of Siamese twins? A product of genetic engineering? A freak of nature? Bob always says, "If you have to ask, I don't want to know you." Bob is delighted that his name is a palindrome and feels that the test of a wise people is their ability to hold two opposed ideas in their minds at the same time and still remain sane.

Mr. Plex, Bob's first officer, is a scolex, a member of a race of creatures with diamond reinforced exoskeletons that allow them to explore outer space with little consequences to their health. Protruding from the bottom of Mr. Plex's huge head and gaping mouth are four appendages that serve as both feet and arms.

Mr. Plex

"Mr. Plex, I want you to leave our ship and propel yourself towards the other side of the Earth. When you get there, transmit an image of the star back to me."

"Yes sir," Mr. Plex says. His slight hesitation is betrayed by the slight clattering of his canines and the quivering of his anterior forelimb.

"Sir, how will this help?"

Bob's voice is firm. "I will explain when you come back."

Bob watches his scolex leave the ship. While waiting, Bob wanders through some of the nearby rooms of the art museum, rooms devoted to Egyptology, Greco-Roman archeology, Byzantine art, Chinese artifacts, and the hall of Smilodon and Troödon skulls. The Troödon was probably the smartest of the dinosaurs, with a relatively large brain for its body size.

An hour later Bob is back in his office, just in time to hear Mr. Plex say, "I am now staring at Sirius from the other side of Earth. I just captured an image and stored it in my detachable brimp." (Scolexes frequently use brimps, short for brain implants, to store information they cannot possibly retain in their natural brains.) (Figure 1.1)

After some time, Bob's scolex returns to the ship. His breathing is rapid and heavy as he makes an oboe-like sound. Bob smells the faint odor of a scent resembling musk.

Bob waits a few moments for him to catch his breath. "Mr. Plex, let's look at your two star images—the one we took from the ship and the one you took from the other side of the Earth."

"They look identical to me, Sir."

"That's right. The distance you traveled was not enough to demonstrate stellar parallax. The best way to make you remember this was to send you out and have you return to the ship. I'm sure you will never forget this lesson."

Mr. Plex's lung lobes quiver like leaves in a storm.

"However, parallax could be used to measure the distance to Sirius in the following way. First we would determine the position of Sirius relative to other stars. Half a year later, when the Earth has traveled halfway around the Sun, we

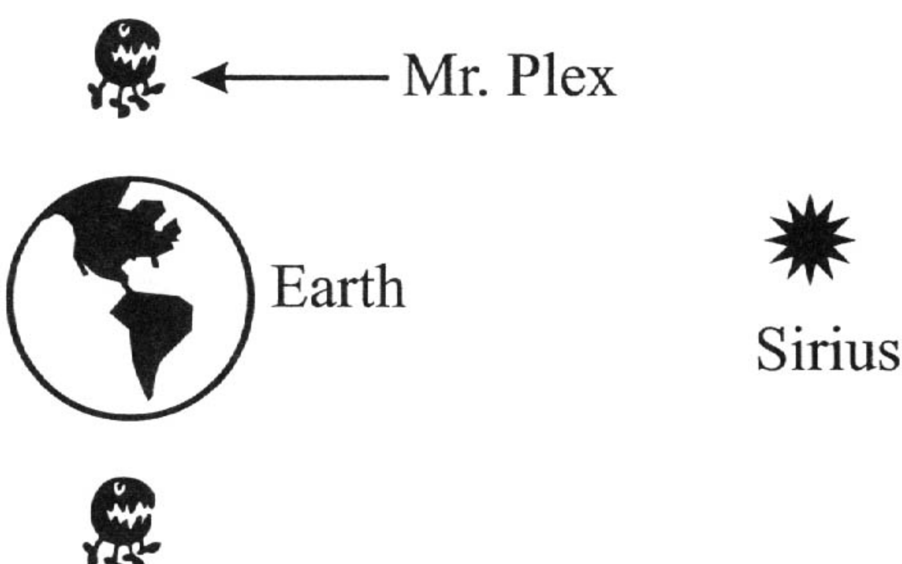

Figure 1.1 Mr. Plex looking at the star Sirius from two different positions (diagram not to scale.)

would measure Sirius's position again." Bob sketches a figure on the flexscreen video wall (figure 1.2).

Mr. Plex nods as he touches Bob's diagram. "Yes, it looks like Sirius moves against the backdrop of more distant stars depending on where we are when we measure the location from Earth."

"Exactly. That's what stellar parallax is all about. Stellar parallax is similar to effects we can see when closing one of our eyes. Look at my hand with one eye, then the other. My hand seems to move. Similarly, Sirius seems to change locations when we change our observation point, and we can calculate the distance to Sirius from its *parallax angle*." Bob writes "parallax angle" on his drawing (figure 1.2). "Of course, these angles are tiny, but I've drawn them large to help illustrate the concept."

"Tiny? That's why I couldn't see a difference in the angle when I simply traveled around the Earth. Your human astronomers in the past had to wait for the Earth to move a large distance[1] before remeasuring the star's location."

"Exactly right. The parallax angles are so tiny that they are measured in seconds of arc where one second is 1/3600 of a degree. If you could view a ladybug, carpenter ant, or a circular piece of paper made from a hole puncher from a mile (or two kilometers) away, they would appear to have a diameter corre-

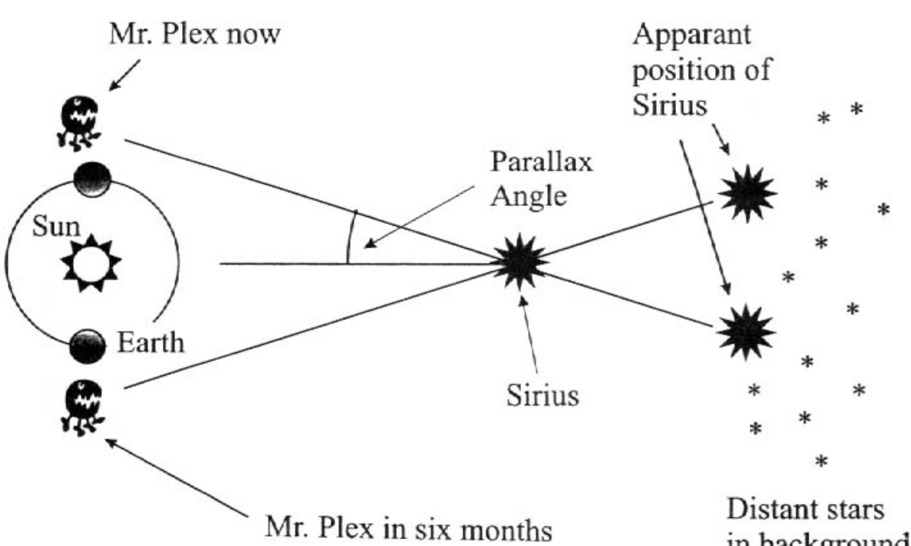

Figure 1.2 Stellar parallax. Sirius appears to be in two different locations against the backdrop of distant stars depending on where Mr. Plex is when he measures the location from Earth. (The small parallax angle is exaggerated in the figure to make the concept easier to visualize.)

sponding to one second! In fact, all of the Earth's nearby stars have a stellar parallax of less than one second."

"Sir, what's an ant?"

Bob reaches into his pocket and withdraws a small creature that looks like:

Bob hands the ant to Mr. Plex and then sketches a table on the flexscreen:

Table 1.1

Star	Distance From Earth (light-years)	Parallax (seconds)
Alpha Centauri[2]	4.3	0.75
Barnard's Star	6	0.545
Wolf 359	7.7	0.421

"A light year is a big distance—the distance that light travels in one year. (Light travels 300 thousand kilometers per second or 186 thousand miles per second.) There are 3.26 light years per parsec."

"Sir, I'm dying to see a simple formula that allowed your ancient astronomers to calculate how far away a star would be given its parallax."

Bob grins. "Thank you for asking. One parsec is the distance from a star to Earth for a star that has a parallax of one second. One parsec is 31 trillion kilometers or 19 trillion miles. Here's the formula." Bob hands Mr. Plex a card with the following symbols:[3]

$$\delta = \frac{1}{P}$$

"Here the Greek letter delta is the star's distance from Earth in parsecs, and P is the parallax in seconds of arc. You can see that as the distance increases the parallax decreases. This means that the ancient astronomers could only use this for stars that weren't too far away. Otherwise the parallax would be too small to measure. Our early astronomers could measure distances to about 100 parsecs using this method. Way back in the early 1990s, the European High Precision Parallax Collecting Satellite, or Hipparcos, measured the parallaxes of over 100,000 stars."[4]

Mr. Plex nods and drops the ant. A cleaning spider, the size of a human hand, makes a twittering sound and starts toward the fallen ant. Bob points a