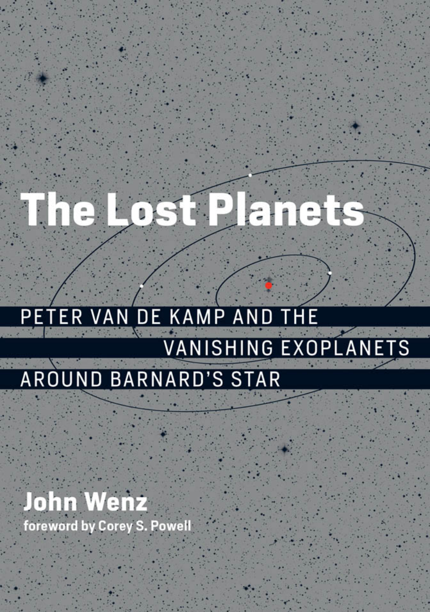

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THE MIT PRESS
CAMBRIDGE, MASSACHUSETTS
LONDON, ENGLAND

This book was set in Dante MT Pro and Heron Sans by Jen Jackowitz. Printed and bound in the United States of America.

Library of Congress Cataloging-in-Publication Data

Names: Wenz, John, author.
Title: The lost planets : Peter van de Kamp and the vanishing exoplanets around Barnard's Star / John Wenz ; foreword by Corey S. Powell.
Description: Cambridge, MA : The MIT Press, [2019] | Includes bibliographical references and index.
Identifiers: LCCN 2018058869 | ISBN 9780262042864 (hardcover : alk. paper)
Subjects: LCSH: Extrasolar planets. | Van de Kamp, Peter, 1901-1995. | Astronomy--History--20th century.
Classification: LCC QB820 .W46 2019 | DDC 520.92 [B] --dc23
LC record available at https://lccn.loc.gov/2018058869

10 9 8 7 6 5 4 3 2 1

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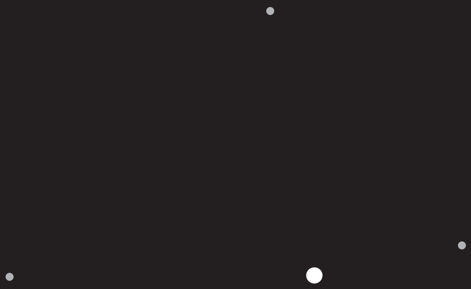


The Long Road to Many Worlds

Corey S. Powell

One of the greatest debates in the long history of astronomy has been that of exceptionalism versus mediocrity—and one of the great satisfactions of modern times has been watching the arguments for mediocrity emerge triumphant. Far more than just a high-minded clash of abstract ideas, this debate has shaped how we humans evaluate our place in the universe. It has defined, in important ways, how we measure the value of our existence.

In the scientific context, *exceptional* means something distinctly different than it does in the everyday language of, say, football commentary or restaurant reviews. To be exceptional is to be unique and solitary. To be mediocre is to be one of many, to be part of a community. If Earth is exceptional, then we might be profoundly alone. There might not be any other intelligent beings like ourselves in the universe. Perhaps no other habitable planets like ours. Perhaps no other planets at all, beyond the neighboring worlds of our own solar system.

If Earth is mediocre, the logic runs the other way. We might live in a galaxy teeming with planets, many of them potentially habitable, some of them actually harboring life. In the mediocre case, we little bipedal humans might not be the only sentient creatures peering out into the depths of space, wondering if anyone else is peering back.

Back in the 1940s, when Peter van de Kamp and Kaj Strand began searching in earnest for planets around other stars (what astronomers now call *exoplanets*), the issue of exceptionalism and mediocrity was still wide open. At the time, two ideas about the origin of our solar system were seriously considered, and they neatly landed on opposite sides of the divide.

According to the *nebular hypothesis*, proposed by French scholar Pierre-Simon Laplace in his 1796 treatise *Exposition du système du monde*, the Sun was born from a whirling cloud of gas. Earth and the rest of the solar system then formed from rings of gas thrown off by the Sun as it contracted under the pull of gravity. If other stars formed in the same way, then planetary systems like ours should be commonplace.

The *near-collision hypothesis*, advanced in 1917 by English physicist Sir James Jeans, pointed the opposite way. In this scenario, the Sun barely survived a close encounter with another star billions of years ago. The gravitational pull of the encounter drew a long filament of gas out of the Sun; that gas settled into orbit and eventually gave rise to the modern planets. (Jeans drew inspiration from Georges-Louis Leclerc, Comte de Buffon, who in 1749 suggested that the planets emerged from debris when a comet collided with the Sun. Buffon's model was the first physically motivated attempt to explain the origin of the solar system, and it nudged the early thinking toward the side of exceptionalism.)

Stars in the Milky Way are so far apart that close encounters should happen exceedingly rarely—about once every quadrillion years, based on modern calculations. If Jeans's predictions are correct, then our solar system might be unique, or at best there might be a single other set of planets circling the rogue star that was similarly tortured by the gravity of the Sun. In his 1922 Halley Lecture at Oxford University, Jeans proclaimed, "Astronomy does not know whether or not life is important in the scheme of things, but she begins to whisper that life must necessarily be somewhat rare."

Today, the broadest version of exceptionalism has been thoroughly disproved, largely by the painstaking work that John Wenz describes in this book. Equipped with vastly superior instruments, van de Kamp's successors have discovered 3,944 confirmed exoplanets by the most recent count, and the tally increases almost daily. The roster of alien worlds includes a remarkable variety of forms, many of which have no equivalent in our solar system.

Astronomers do not yet have the technology needed to find a close analog of Earth orbiting a close analog of the Sun, so we still know little about how common or rare such worlds may be. The question of alien life is still wide open. What we do know is that the Milky Way is home to a tremendous number of other planets, probably trillions of them. In that sense, at least, we are certainly not exceptional, and Earth is certainly not alone.

The notion of cosmic mediocrity that inspired van de Kamp and the other early planet hunters is so old that it predates modern observatories. It predates the seventeenth-century invention of the telescope. It predates even what could recognizably be called "science" in the modern sense, tracing its origins at least back to the Greek philosopher Anaxagoras of Clazomenae, who wrote and taught in Athens in the fifth century BCE.

Anaxagoras proposed that the cosmos is ruled by an all-pervasive intellect, which he called *nous*, and that this intellect functions as a set of universal laws—a philosophical ancestor of Isaac Newton's theory of universal gravitation. Under the action of *nous*, the elements of nature were set into circular motion, separating into different components. The Sun, a ball of incendiary metal, was cast off into the sky by this process. So, too, were the stars and planets. Although what survives of Anaxagoras's writing is fragmentary and mostly secondhand, he seems to have imagined the stars to be fiery lumps much like the Sun, just drastically more distant. In one especially intriguing passage, he further hints at the existence of other lands similar to Earth and expansively argues "that there are a sun and a moon and other heavenly bodies for them, just as with us."

Many of these ideas reappeared in a philosophy even more ahead of its time, that of Aristarchus of Samos. During the third century BCE, Aristarchus advanced the first known heliocentric model of the solar system, evicting the Earth from its long-assumed central position and completely reworking the order of the cosmos. There is no surviving description of this iconoclastic model in Aristarchus's own words. Fortunately, his contemporary Archimedes provided a succinct summary:

> His hypotheses are that the fixed stars and the Sun remain unmoved, that the Earth revolves about the Sun in the circumference of a circle, the Sun lying in the middle of the orbit, and that the sphere of the fixed stars, situated about the same center as the Sun, is so great that the circle in which he supposes the Earth to revolve bears such a proportion to the distance of the fixed stars as the center of the sphere bears to its surface.

That final idea, though somewhat obscure in its phrasing, is pregnant with significance. Aristarchus is saying that the stars are so far away that we cannot see their *parallax*: They appear stationary even as the Earth moves in a great circle around the Sun. The implications are twofold. First, he imagined a cosmos vastly larger than the one implied by the geocentric system. Second, he reiterated and expanded on Anaxagoras's deduction that the stars might be other suns, this time explicitly spelling out the kinds of grand distances necessary for the stars to nevertheless appear as fixed cold dots in our sky.

The budding possibility of a multitude of worlds fully blossomed in the philosophy of the Greek atomists, most notably Epicurus. They envisioned not just other stars but other entire *kosmoi* (cosmic systems) beyond the one we know, each following the inexorable rules of the atoms it contains. Writing at about the same time as Aristarchus, Epicurus declared, "There is an infinite number of worlds, some like this world, others unlike it. For the atoms being infinite in number . . . are borne ever farther in their course." His atoms were mathematical and ethical constructs, quite unlike the physically described quantum units of today's physics, and yet, in the way Epicurus reached toward a boundless universe, he sounds shockingly prescient.

That pinnacle of glorious Epicurean mediocrity, alas, was followed by a lengthy retreat into a constricted, Earth-centered cosmology. Aristotle retorted, "There cannot be more worlds than one," and his great authority carried the day. Around 150 CE, Claudius Ptolemy shrank even further from the *kosmoi* when he merged Aristotelian physics with state-of-the-art observations of stars and planets into a unified Earth-centered model. The Ptolemaic system consisted of a set of nested celestial spheres, dispensing with exotic speculations about infinite space and other suns. By Ptolemy's reckoning, the outermost crystalline sphere, containing the fixed stars, was about 20,000 times the radius of the Earth, making his entire cosmos just 160,000 miles wide in modern terms.

What the Ptolemaic system lacked in grandeur, it made up in practicality. It predicted the motions of the planets and stars with admirable precision using a combination of mathematically appealing circular motions. Ptolemy's astronomical writings, later translated by medieval Islamic scholars as the *Almagest* (literally "the greatest" in Arabic), reigned supreme for more than a millennium. His authority was cemented when prominent theologians like Thomas Aquinas merged the Ptolemaic system with the Roman Catholic worldview during the Middle Ages. The outermost sphere of the cosmos equated with heaven, and the Aristotelian "prime mover," who set the spheres in motion, became one and the same as the Christian God.

The attributes that make exceptionalism appear impoverished from a scientific perspective make it precious from a theological point of view: only one Earth, one heaven, one God. But the fire of human imagination is not so easily snuffed. Some medieval Islamic astronomers continued to speculate about the existence of other worlds. Catholic scholars, too, pushed against the boundaries. Around 1450—a full century before the mystical speculations of Giordano Bruno—the German philosopher and astronomer Nicholas of Cusa wrote about the notion of infinite space, in contradiction to Ptolemaic concepts. Nicholas structured his ideas within a Catholic framework, exploring infinity as a natural corollary to the limitless glory of God, but his philosophy kept alive the possibility of a physically unbounded universe as well.

Then along came Nicolaus Copernicus, and mediocrity began a full-on comeback.

From outward appearances, Copernicus was an unlikely figure to knock the solar system askew and to set astronomy on its modern path toward a multitude of planets. He worked as a canon in Warmia, a small, semiautonomous Catholic state in what is now Poland, tending to various local political and economic disputes. He was a modest, well-liked figure, not particularly known for his controversial opinions. Professionally, his most notable achievements were probably in economics and monetary theory. There was a spark within that set him apart, however: the bold, revisionist astronomical ideas brewing in his head.

Sometime before 1514, while he was still in his thirties, Copernicus wrote a summary of his new model of the solar system. Influenced by the arguments of Aristarchus, as well as by his own strong sense of the Ptolemaic system's mathematical ugliness, Copernicus returned the Sun to the center and set the Earth in motion around it. He circulated his short document, called the Commentariolus, among his friends, with the intention of expanding its arguments into a fully developed work of heliocentric cosmology. That magnum opus, *De revolutionibus orbium coelestium* (*On the Revolutions of the Heavenly Spheres*), was famously not published until 1543, when he was on his deathbed. Copernicus was unconscious when a finished copy was thrust into his limp hands, and he died that same day.

The publication delay was not, as popular accounts often claim, a simple matter of Copernicus's fear of the Catholic Church. He was more afraid of the Church's intellectual partners, the Aristotelian philosophers, who he worried (not unreasonably) might be brutal to this upstart living far from the intellectual heart of Europe. He also needed to perform detailed mathematical analysis and to collect astronomical observations in support of a theory that he was developing in his spare time. Only in retrospect do those fears look absurd. It turns out that the time was ripe for a critical reexamination of entrenched classical Greek thinking. In the decades after its publication, *De revolutionibus* was extensively read and discussed across Europe. The influential Danish astronomer Tycho Brahe even praised Copernicus as "a second Ptolemy."

Two disciples of Copernicus were especially pivotal in establishing Copernican mediocrity—the notion that Earth does not sit in a privileged position but is representative of the richness of the universe as a whole. In 1575, Thomas Digges, a leading astronomer in sixteenth-century England, published the first English translation of *De revolutionibus*. He added commentary to clarify that the Copernican system was a physically realistic model of the solar system (not just a computational trick), and he overtly broached the idea that a sun-centered universe could be infinite in extent. To drive home this last point, Digges created a drawing showing, for the first time in history, how the stars might be scattered through endless space outside our solar system.

A few years later, the German astronomer Michael Maestlin adopted Copernicus's system as superior to Ptolemy's and spread heliocentric thinking broadly from his prominent position as a teacher at the University of Tübingen. Most notable among his students was a clever young fellow named Johannes Kepler, who, starting in 1609, figured out that planets go around the Sun in elliptical paths. This discovery thoroughly and finally smashed Ptolemy's claustrophobic crystalline spheres. The universe was now wide open to all possibilities, and to endless worlds.

I won't belabor here the too-familiar stories about Galileo's tussles with the Church, or Isaac Newton's development of the laws of universal gravitation, except to note how rapidly (historically speaking) the concepts of Copernican mediocrity spread and triumphed. By the middle of the seventeenth century, heliocentrism was widely accepted across the Western world. By the eighteenth century, many leading intellectuals embraced not only the idea of other worlds, but even other *inhabited* worlds. Cyrano de Bergerac's *Comical History of the States and Empires of the Moon*, published in 1657, introduced the reader to imaginary inhabitants of the Moon. Jonathan Swift's *Gulliver's Travels* (1726) and Voltaire's *Micromégas* (1752), whose central character is a being from a planet orbiting the star Sirius, casually assume a multiplicity of inhabited worlds as a backdrop to their social satire. Mediocrity was in vogue.

On the scientific side, William Herschel (perhaps the most famous astronomer of the late eighteenth and early nineteenth century) was a firm proponent of the idea that life is common on other planets. Right around the time that he discovered the planet Uranus, Herschel shared what he believed to be telescopic evidence of intelligent life on the Moon. He later argued that all worlds might be inhabited; improbable as it sounds, he even suggested that life exists on the Sun, huddled beneath the luminous clouds covering its surface. Although many other researchers were not so enthusiastic, each generation found its champion of life beyond Earth. American astronomer Percival Lowell was especially effective at promoting such ideas well into the twentieth century with his popular (if increasingly eccentric) writings about an imperiled advanced civilization on Mars.

Science fiction writers like Ray Bradbury, Arthur C. Clarke, Isaac Asimov, and Robert A. Heinlein further popularized many-worlds mediocrity with their compelling visions of alien inhabitants on far-off worlds. So did the pulp science fiction and fantasy comic books of the post–World War II era. Although reputable scientists looked askance at most of this wishful thinking, mainstream astronomers were still routinely speculating about jungles on Venus and creeping lichens on Mars at the time workers at Sproul Observatory were setting their sights on planets around other stars. It was an optimism that would soon collapse.

Just as astronomers were developing the tools needed to convincingly detect planets around other stars, aerospace engineers were refining the rockets and spacecraft that would soon shred any confidence that life exists closer to home, elsewhere in the solar system. Although the emerging fields of exoplanet research and astrobiology were not directly related, they were inextricably linked. Dashed expectations for finding life nearby inevitably dashed hopes for finding life around other stars, stirring skepticism about the reality of those planets. The disheartening controversies over claimed planets around 61 Cygni, Barnard's Star, and other nearby stars further soured the opinion of the scientific community.

Early findings from US and Soviet space probes almost uniformly made the solar system seem shockingly hostile to life. NASA's Mariner

2 flew past Venus in 1962 and found that the planet is not a steamy jungle at all; rather, it is an Earth-size sterilizing oven, with a crushing atmosphere and surface temperatures hovering around 800 degrees Fahrenheit. Two years later, Mariner 4 visited Mars and beamed back images of a barren cratered landscape to crestfallen planetary scientists. In 1976, the year that van de Kamp retired from Sproul Observatory, NASA sent the twin *Viking* landers to Mars to do a Hail Mary search for life right there on the surface. The $1 billion effort, equivalent to $5 billion today, yielded no conclusive signs of anything alive.

Pioneering astrobiologists like Carl Sagan realized that life on nearby worlds, if it exists, would be much more subtle and challenging to detect than astronomers had originally hoped. Likewise, as John Wenz details in the pages ahead, the many ambiguous detections and retracted claims from astrometric searches for exoplanets cast doubt on the feasibility of the whole endeavor.

By this point, the few stalwarts in the field understood that finding planets would require new techniques—but who would devote the necessary time and energy to advancing a field that had become so disreputable? In 2012, Gordon Walker at the University of British Columbia, one of the founders of the radial velocity search technique, published a scientific memoir, "The First High-Precision Radial Velocity Search for Extra Solar Planets," in *New Astronomy Reviews*, looking back to those early days. "It is quite hard nowadays to realize the atmosphere of skepticism and indifference in the 1980s to proposed searches for extra-solar planets. Some people felt that such an undertaking was not even a legitimate part of astronomy," he wrote.

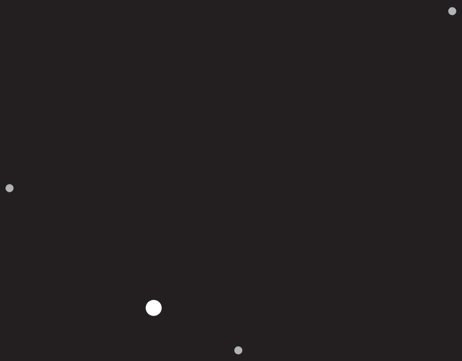
Conducting research under those conditions was an exercise in masochism. "We applied twice each year for telescope time and were generally assigned four pairs of nights per year—although one year we received none in the first six months," Walker continued. "It really was tedious because there could be no obvious results from any one observing run and, perhaps more seriously, no publications to nourish research funds. Nonetheless, we did persist for 12 years and, it seems, made some exoplanetary discoveries in the process—but it took some time for these to dawn, because none was a simple case."

Walker at least managed to persist in his academic astronomy career. His graduate student Bruce Campbell—who did more than anyone else to make radial velocity a viable way to find exoplanets—did not fare as well. John Wenz's description of this episode stands as one of the book's more tragic passages. Campbell's bitter departure from the world of research has many echoes in history. From our time-compressed modern perspective, we look back at Copernicus as a triumphant figure, but he spent more than three decades of his life working on astronomy as an unpaid sideline. He didn't live to see his summary work published. Even after that, his ideas were not widely accepted for another century.

Perhaps someday future historians of science will similarly reflect on Walker and Campbell as unsung heroes of our current era. Then again, we don't have to wait for some imagined far-off historical verdict. We know right now that Walker and Campbell were on the cusp of momentous discoveries. Their exact technique, deployed in a slightly different way, led to the first clear-cut detections of planets around Sunlike stars beginning in 1995. Those detections, in turn, provided the scientific confidence needed to gain approval for NASA's big-budget Kepler space telescope and its successors, including the brand-new TESS (Transiting Exoplanet Survey Satellite). Walker and Campbell, like van de Kamp before them, were pioneers of mediocrity.

Bolstered by the bounty of discoveries from current exoplanet surveys, mediocrity is ascendant on the astrobiology side as well. Fears that Earth might be the single instance of a living planet seem much less plausible—if not downright unlikely—when researchers start to consider not just the other worlds of our solar system, but the trillions of other planets scattered across our galaxy. Sara Seager of MIT, the deputy director of the TESS mission, has set a lifetime goal of finding 500 planets similar to Earth. "If we're lucky, maybe 100 of them will show biosignatures," she says, referring to the data readings that would indicate the presence of life. Thirty years ago, such a statement would have provoked derisive laughter, or worse.

Finding 100 living planets would be amazing. With a sample that size, scientists could compare the different types of environments that support life, different styles of metabolism, and different stages of evolution. They could navigate to whole new levels of mediocrity, exploring Earth's place within an entire pantheon of inhabited worlds. Even a *single* living world would be a breakthrough, an unprecedented connection between humanity and the rest of the universe. There is no way to know when such a discovery will happen. There's no way to be certain it will happen at all. But thanks to the hunters of worlds lost and found—the imperturbable obsessives like van de Kamp, Strand, Walker, and Campbell—the possibility is wide open before us.



Acknowledgments

I am grateful to my editor Jermey Matthews, who guided me through the process of completing my first book. I would additionally like to thank Corey S. Powell, whose curiosity and body of work I hold in high esteem, for agreeing to write the foreword for the book. I'd also like to thank Virginia Crossman and Melanie Mallon for their editing guidance and patience. My acknowledgments would not be complete without mentioning the work of Christine Bridget Savage and Gabriela Bueno Gibbs, both an integral part of my MIT Press experience.

I would also like to thank Lisa Ruth Rand for her love and support throughout the process of completing the book, a path that wasn't always easy, personally or professionally. She also guided me through the academic processes of putting together my research, an intellectual asset that must be acknowledged as well. I would also like to thank my family—my parents, siblings, nieces and nephews, aunts, uncles, cousins, and more for their support. There are too many of them to contain in a small list, but each has been a meaningful part of making this book come together. In addition to my blood family, there's of course a long list of friends to acknowledge, several of whom were helpful during my book research phase. Specifically, I'd have been nowhere without the hospitality of my dear friend Laura Chance, who housed me while I researched my book at Swarthmore, as did Joseph Malcomson and Marissa Nicosia. Jen Barnason, Chris Vogt, Karl Spurzem, and so many others were there to guide me through the process as well.

The staff of the Friends Historical Library of Swarthmore College, especially Celia Caust-Ellenbogen, were incredibly helpful and patient as I researched my book at their institution and they guided me through the archives of the Sproul Observatory. I would also like to thank Eric Jensen, Swarthmore professor of astronomy, for showing me the modern-day facilities and speaking with me about the book.

I'd like to thank Ignasi Ribas at Institut de Ciències de l'Espai, Guillem Anglada-Escude at Instituto de Astrofísica de Andalucía, and Abel Mendez at the Planetary Habitability Laboratory at the University of Puerto Rico at Arecibo for enlightening me on their research into Barnard's Star and allowing me access to their research before its official publication.

The maddening process of putting together a book would have been more difficult without the support of several colleagues whom I would like to thank. I'm especially grateful to Shannon Stirone, Adam Becker, Sarah Scoles, Joshua Sokol, and Mika McKinnon, who all provided invaluable guidance.

The staffs of *Popular Mechanics*, *Astronomy* magazine, and *Discover* magazine have been spectacular colleagues whom I consider friends. I would especially like to thank Andrew Moseman and Eric Limer at *Popular Mechanics*; Kathi Kube, Rich Talcott, Michael Bakich, David Eicher, and Alison Klesman at *Astronomy* magazine; and Eric Betz, Nathaniel Scharpling, and Bill Andrews at *Discover* magazine. I have also had the fortune of working with other tremendous editors, including Jay Bennett at *Smithsonian* magazine.

Introduction

In 1600, Giordano Bruno was burned at the stake for his radical views—that not only was the Sun just one of many stars, but those stars likely had planets around them as well.[1]

Today, we seem to be approaching *innumerable*. Whereas a single planet discovery used to make headlines, now the planet has to have something special about it to really draw anyone's attention: the closest, the weirdest, the most habitable, the . . . somethingest. And even then, there's fatigue over the latest habitable exoplanet (meaning a planet outside our solar system). In some ways, the Kepler spacecraft's massive data dump on exoplanets answered the question "how many stars have planets" with "seemingly all—or most—of them," while dropping so many discoveries that it became impossible to keep up. The Kepler findings work better as a census than insight into individual worlds.

Bruno's proclamation has ended up seeming to be the case. We're just now catching our breath from that realization, ready to settle down and confront what it actually means.

We've only ever spotted a few planets directly—always young, always hot from formation, always large like Jupiter, and always just a small cluster of pixels. Planets are drowned out by the light of their stars, so we typically use indirect clues to find them, as the Kepler craft did, waiting for planets to pass in front of their stars and cause nearly imperceptible drops in the flux of light coming from the star. Or even more indirect methods, like watching how a planet tugs on its star, moving it ever so slightly, or waiting for a star to act like a giant magnifying glass on an object behind it, making evidence for a planet easier to find, at least temporarily.

The 2020s will give us some of our first true glimpses of planets, not as specks of light or as shadowy moving ghosts but as living, breathing worlds as beautiful and varied as those in our own solar system. The biggest telescopes in history will be open for business by 2030, like the 129-foot European Extremely Large Telescope in 2024, and the 80-foot Giant Magellan Telescope in 2021. There's also the Thirty Meter Telescope, which will have a 98-foot mirror should it ever break ground. (The project was delayed by protests from Native Hawaiians over the use of sacred land.) That's not to mention NASA's long-delayed Hubble successor, the James Webb Space Telescope. The massive 69.5-by-46.5-foot telescope will move to an orbit beyond the moon in 2021, open up its fairings, and begin to look at nearby planets with gusto.

These telescopes have plenty of tantalizing targets to pursue: There's Proxima Centauri b, the closest planet to our solar system for the next 36,000 years. There's the TRAPPIST-1 system, a planetary system encompassing seven Earth- and Mars-sized planets orbiting a star barely bigger than Jupiter, and at least three of those planets are potentially habitable, if not all seven. There's Luyten's Star, where Search for Extraterrestrial Intelligence (SETI) researchers recently beamed a message from Earth that should reach that system in 2029. The Tau Ceti system will likely be considered. Or a new planet may come shining out of the data from the Transiting Exoplanet Survey Satellite (TESS), an MIT and NASA collaboration to look for transiting planets around stars within 300 light years of Earth. The mission was designed to find the most ideal planets for the Webb telescope to examine.

In other words, a new era of planetary discovery just over the horizon is going to clarify what other planets look like—and whether life is a fluke of Earth or a widespread phenomenon.

The knowledge we seek is the kind of thing that, once upon a time, would have gotten you burned at the stake. But in between Bruno and Webb, we accumulated a serious bit of knowledge for understanding our universe. Not only did we come to realize that the Earth revolves around the Sun, but we realized that those other points of light out there were the same things as the Sun—burning cauldrons known as stars. And our own Sun drags its planets, comets, asteroids, and whatever we're calling Pluto now around the center of our galaxy. Even understanding that there is such a thing as a galaxy was a major coup.

This trajectory is rough—and obviously heavily condensed. But even though plenty of planets exist outside our solar system in science fiction, the number in science *fact* in the early twentieth century was 0. But astronomers were beginning to discover a greater number of small red stars closer to us than they'd ever anticipated, and a few of these are orbiting other stars. Indeed, to this day, we're *still* discovering faint neighboring stars and almost-stars.

The nineteenth century brought a new fold into astronomy, first in 1862, and then in 1895—that there are stars we can't see but can infer from the way they move the stars they orbit off a common center point. The first such discovery was the star Sirius, the brightest in the night sky. It had concealed a hidden companion, called Sirius B, a *degenerate* star. The second was the companion to Procyon, a bright star in the constellation Canis Minor. Look to the shoulder of Orion—one of the most easily recognizable constellations in the night sky—and move to your "left," toward a bright star. That star is Procyon. Trace down at roughly a 45-degree angle and you'll find Sirius, which is hard to miss because of its brightness. The star in the shoulder of Orion is known as Betelgeuse, and with Procyon and Sirius, it forms the *winter triangle*. Betelgeuse, unlike its triangular pals, seemingly has no "invisible" companion.

These companions also aren't exactly invisible. They are simply much dimmer than their parent star. But the method of discovering them was giving astronomers food for thought. Binary stars were nothing new. The star Algol was known to vary in brightness as a result of a companion star continually eclipsing it in the night sky, giving rise to the astronomical term *Algol variable*. William Herschel—the man who presented Uranus to the world in 1781—also systemically hunted down and cataloged binary stars. But the idea that one of these stars could be "invisible" yet still produce a pronounced effect on its parent star meant that plenty of invisible binary objects could be out there.

It also meant that planets would have this same effect, just . . . smaller. If we could find very small stars, it was reasoned, then we could find something even smaller—planets, whole worlds—despite the vast distances. Some might be as inhospitable as Neptune or Jupiter, but others could be a lot more like Earth.

Planets don't orbit stars in a neat and orderly fashion. Nor do moons orbit planets in a circle. Instead, the tug-of-war between the two gives both objects a common center of mass, called the *barycenter*. While the Moon orbits Earth, it exerts enough of a gravitational tug that the common center of mass is far past the Earth's core and well into the mantle. The common point of gravity between Jupiter and the Sun is actually outside the Sun, because both bodies have enough gravitational pull to hold their own against another object.

If an alien civilization looked in on the Sun with the tools we had at our disposal when planet hunting began in earnest, they would likely detect only Jupiter and maybe Saturn. They wouldn't be able to "see" Jupiter either. They'd instead focus an instrument on the Sun that would notice how much Jupiter pulled on it from their common point of gravity.

Night after night, astronomers were taking pictures of the stars in the night sky. Perhaps, they reasoned, we would see a star deviate ever so slightly from its path, as we saw with Sirius and Procyon, but on an even smaller scale.

Plenty of observatories were on the hunt for invisible stars. But when Dutch astronomer Peter van de Kamp came to Swarthmore in 1937, he was on the hunt for something else: invisible planets.

It would both make and break his career in the coming decades.

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In the midst of war tearing one world apart, another was seemingly discovered.

In 1942, US Air Force private Kaj Strand was training for war at Eglin Air Field in Florida. He undertook tests on the B-29 Superfortress, one of the most fearsome weapons of the war that the United States had been thrust into. As soon as he gained citizenship, Strand intended to do his part for the war effort. He and fellow astrophysicist Martin Schwarzschild had "both wanted to fight Hitler." Strand was 35 at the time but ready to serve his adopted country. In correspondence back home, however, he had another matter to attend to.

After five years of work, Strand's close observations of the star 61 Cygni were ready to be presented to the world, and he had something audacious to announce: the first ever planet discovered outside our solar system.

Strand hadn't seen it, at least not any more directly than we have seen planets since. Instead, like the thousands of exoplanets discovered in recent decades, Strand's discovery relied on indirect methods. One such method, which Strand used in monitoring 61 Cygni, is known as *astrometry*. Astrometry, at its most fundamental level, is the study of the position of stars in relation to one another. Distance in space is measured in light years, which is the amount of time it takes light emitted by one object to reach another. One light year is 5.88 trillion miles. The star Sirius A is 8.6 light years away. When we look at it in the night sky, we're seeing the star as it was nearly nine years ago, all thanks to the funny workings of physics. Sirius is the brightest star in the night sky.

Altair is another nearby bright star, 16 light years away. Yet its distance from Sirius is 25 light years because Altair is on the other side of Earth, and stars sit in every direction from us—up, down, sideways, and at all angles. The way we can gauge these distances, and map the positions of the stars, is by closely monitoring how they move across the night sky, in a dance called the *proper motion* of the star. Some call this triangulation of positions *parallax*. We see how one star moves in comparison to stars that are more distant. Changes in the motion of the stars indicate that something is tugging on that star.

Sproul Observatory at Swarthmore College, in a sleepy suburb of Philadelphia, was gaining a reputation for its study of astrometry in the years just before the war. Observatory director Peter van de Kamp (Strand's advisor) and his associates, adjunct researchers, and underlings were focusing their time with the 24-inch telescope on studying the proper motion of most nearby stars. Sproul was already discovering invisible stars, binary ones that were detectable only by the influence they exerted on their primary star, rather than by their own light. A smaller star might reveal itself by causing its primary to deviate off an otherwise smooth pass across the sky. These motions were nearly undetectable except by the keenest observer. Some of these deviations required intense scrutiny and hundreds of observations.

Careful, repeated observation has always been a core part of astronomy. In 190 BC, Hipparchus drew up the positions of 850 stars, long before astronomers had telescopes at their disposal. He also discovered the position of Earth in relation to the Sun, all by watching how stars moved in their seasonal paths. The first star discovered by astrometry was a tiny companion to the bright Dog Star, Sirius. It was predicted to exist in 1830 based on Sirius's odd undulating movements, and it was visually confirmed in 1862. Astrometry is still used today, most specifically on the European Space Agency's Gaia mission, which is mapping the precise positions of stars—and waiting to see if they move at all from a center line, indicating invisible companions.

Usually, two stars in a gravitational embrace have a profound effect on the other's orbit. Although "easy" would be a misnomer, a star tugging on another star is one of the easiest invisible companions to detect. But planets also influence the motions of their star, albeit in smaller ways, because of the common point of gravity, or barycenter, they share. The Earth and the Moon are locked in such an embrace. Because the Moon has a substantial amount of mass, the barycenter is in the Earth about 2,900 miles (4,670 km) away from the planet's core—firmly within the Earth's mantle, but nearer to the surface than the core.

The barycenter of the Earth-Moon system in relation to the Sun is outside the Sun's core, which is impressive considering that the Sun has the mass of 333,060 Earths. But more impressive is that Jupiter, despite having maybe 1 percent the mass of the Sun, has a barycenter in space outside the star. This means that Jupiter causes the Sun to move in such a way that alien observers, with the right equipment, could watch the invisible tug of the Sun by Jupiter. This tug may not be as pronounced as that of a star-sized binary would be, but it's there.

Strand, with van de Kamp's guidance, had uncovered one of the smallest changes in the motion of a star. At the time, astronomers already knew that the 61 Cygni system had two stars, but Strand inferred that one of those stars had a fairly small object tugging on it as well, something with 16 times the mass of Jupiter. In short, Strand thought he was seeing an enormous gas giant, all just 11 light years away from us, a hop, skip, and a jump in our tens-of-billions-of-light-year spanning universe.

In February 1943, Strand's paper was officially published, announcing to the world the existence of the small companion.[1] Just a month before, van de Kamp had been drumming up publicity for the planet in the pages of the *New York Times*. "It is likely that an object of such a small mass has no luminosity of its own, and may therefore be tentatively classified as a planet, rather than a star," van de Kamp wrote to William Leonard Laurence, the then-leading science reporter for the *New York Times*.[2] More details emerged in the January 1943 issue of *Sky and Telescope*, which proclaimed in its news section that the planet had a five-year orbit and that it didn't so much circle around the star as loop around it in an oval, which brought it to within 65 million miles of its star before swooping back out.[3]

Today, finding a planet is commonplace. There's a new announcement seemingly every week, and that's only for the worlds that stand out. With around 4,000 known exoplanets out there, some humdrum Jupiters slip past our notice in favor of gleaming, maybe-habitable Earth-size worlds or star-scorched hell worlds that rain diamonds and produce the same chemicals as sunscreen.

Soon after Strand published, somebody impersonating a relative of his told the *New York Times* that the planet had a name. Had the person behind the alias Graham Strand gotten his way, the planet would have gone down in the history books as Osiris.

The faux Strand had told the *New York Sun* a similar tale, with that paper launching an investigation into the matter. Kaj Strand—the real one—told the *Sun*, "I have not thought seriously of naming that planet," with further attempts to find the Grand Graham Fraud hitting a dead end.[4] Author James Hickey concluded, "The mystery of who Graham R. Strand is and what he was up to in sending out the false publicity remains as far from a solution as ever. Not even the stars can tell you what he had in mind." In a letter to van de Kamp, he speculated that "he may be an educated person with a screw loose."[5]

It was a bizarre start to the exoplanet bonanza that would ensue in the coming years, with Sproul at its epicenter. But it wasn't necessarily the first claim, even that year.

The Rivals

So, what was the first purported exoplanet discovery? It was an old familiar place for planetary claims: the 70 Ophiuchi system.

A well-studied star, 70 Ophiuchi is 16.6 light years away from Earth. Two astronomers, Dirk Reuyl and Erik Holmberg, claimed, a few months before Strand published his findings, to have found a planet in the 70 Ophiuchi system, one even smaller than the candidate Strand would soon announce.[6] Their work didn't sit well with either Strand or van de Kamp. Perhaps there was a bit of a rivalry, though. Reuyl was van de Kamp's cousin, and he, too, was at the time studying the parallax of local stars—along with using the calculations of their trajectory to search for invisible companions.

The fog of war and the uncertainty of the claims perhaps overshadowed the announcements. With the world at war, some science news didn't quite seem so big. By April 1943, Strand seemed to be itching to return to the astronomical world, as he indicates in his letters to van de Kamp. Even while working at test facilities in Florida during the war, Strand had his head far above the clouds. He had even met other astronomers, like Edwin Hubble, stationed at various military outposts.

At first, Strand said, "Jupiter is getting more rivals!"[7] With a furlough coming that June, Strand was excited to check the work of Reuyl and Holmberg. But by July, his enthusiasm had waned. He wrote van de Kamp on July 4, suggesting they slow down publicity on 61 Cygni, admitting, "I have no desire so whatever to be hailed in public in company with Reuijl [*sic*] and Holmberg."[8] Van de Kamp believed that the rival astronomers' work was sloppy and error prone, and Strand had come to agree on this. Everything Reuyl and Holmberg seemed to say about 70 Ophiuchi would have driven the planet into its home star, and Strand attempted to further smooth out the calculations.

"It looks reasonable, but I suppose you will agree with me that it is only a possible interpretation of the residuals and not a final proof for the existence of that orbit," van de Kamp wrote after reading Strand's data. "It is, however, the result of a clean analysis, such as R. and H. were not able or willing to make."[9] Other correspondence, like a 1947 letter from Jan Schlit of Columbia University to van de Kamp, outright called the results spurious and even termed Holmberg's work on the star Castor flat out bad.[10]

Indeed, the original paper was so woefully vague that Henry Norris Russell—who gave us the Hertzsprung-Russell diagram showing stars by size, color, and mass on a curve—wrote a paper more or less confirming that their data was *workable.* "The only questionable point in their discussion is that no attempt was made to improve the orbital elements of the wide pair," he wrote, attempting to show the same hammering out of the data that Strand undertook, concluding, "Several more years of observation will be required for a good determination of the period—as the authors state."[11]

There were a few reasons to doubt the data, including personal rivalries and the vagueness of the planet's orbit. But another reason is that this wasn't the first time someone had claimed to find a planet around 70 Ophiuchi.

A History Lesson

Of all the searches in for planets outside our solar system, 70 Ophiuchi's was the first exoplanet "found," several times over. The first finding was in 1855, when William Stephen Jacob, of Madras Observatory in Chennai, India, noticed that the motions of the two stars in the system seemed to deviate ever so slightly. "We may suppose a third body to belong to the system, and to be opaque, and consequently invisible; such a body would, of course, disturb the regularity of the motions of the other two," he wrote.[12]

Like the astronomers at Sproul nearly 100 years later, Jacob focused much of his work on double stars (this term roughly refers to stars that appear near each other but aren't necessarily gravitationally bound, unlike binary stars) and astrometry. The 70 Ophiuchi system makes a tempting target for such studies. The stars are around 16.6 light years away and are easy to discern with the naked eye, through which they appear as one star. Viewed through a small telescope, however, the two stars separate from each other quite elegantly. But ever since the system was first characterized, the unusual orbit interactions have left astronomers wondering if a third companion wasn't hiding somewhere.

By 1895, Jacob's discovery claim was all but forgotten, having never gained wide favor. A ruffian by the name of Thomas Jefferson Jackson See, of the University of Chicago, rehashed Jacob's claim as his own, maintaining that he witnessed small derivations of the star caused by a "dark companion."[13] See's claim was disproved by Forrest Moulton of the same institution, catalyzing a bitter war of words, mostly one sided, between the two. See wrote a letter to the *Astronomical Journal* so vitriolic that the editors threatened heavy censorship of any subsequent submissions to the journal. "To abbreviate most effectively unfruitful discussion, Dr. See's remarks were transmitted to Mr. Moulton to afford him opportunity, if he desired, to reply; but he declines, on perfectly correct and dignified grounds, to do so; his essential and sufficient reason being that the statements are not in accordance with the facts," the journal editors wrote.[14]

See was known as a mercurial figure within astronomy. This reputation stretched back to his undergraduate years at the University of Missouri, where he had been a key player in the ouster of college president Samuel S. Laws after Laws replaced a favorite professor of See's with one who had questionable qualifications. See's testimony in the legislature regarding Laws also gained him political friends and influence within the state. But at the same time, he was accused of plagiarism by his fellow students, a situation that led to See being denied a prominent astronomical medal on campus.[15]

See's career would eventually taper off into bizarre incidents, including *more* accusations of plagiarism, more borderline libelous actions against fellow scientists, an attempt to publish an autobiography under false pretenses, and so on. Thomas Shirrell would later write that few astronomers "inspire a degree of rancour comparable to that evoked" by See.[16] Among the fights See tried to provoke was a rather bitter and completely one-sided libel against the works of Albert Einstein. See was well known but not especially well liked, and he was largely left in exile at Mare Island, off the coast of California, after being booted from the Naval Observatory in the aftermath of the 70 Ophiuchi affair. He spent much of this time at Mare Island making strange proclamations, and he died in 1962 with the reputation of a crank.

Strand attempted to rectify a third body in 70 Ophiuchi before ultimately concluding there was none. Planetary claims have seemingly died down in the 70 Ophiuchi system, though the possibility of a planet there hasn't been entirely ruled out.

Still, continued studies of the star led Strand to an inevitable conclusion. "No trace of the often assumed perturbations in the orbital motion was found," he wrote in a 1946 article in the *Publications of the American Astronomical Society*, using data from long exposures of the star to find that there was no "tug" on one of the stars implying the presence of a planet.[17]

With claims regarding 70 Ophiuchi yet again crumbling, 61 Cygni seemed to be the only reasonable case for a planet outside our solar system at the time.

At Sproul

Strand's work on 61 Cygni wasn't a chance discovery—it was the product of an ongoing hunt at Sproul, spearheaded by van de Kamp from the beginning of his time at Swarthmore.

Peter van de Kamp came to Swarthmore in 1937 from the University of Virginia. Born in Kamden, in the Holland region of the Netherlands, in 1901, Peter (Piet in his original Dutch) van de Kamp was the oldest of three boys. Peter's brother Jacob also eventually went into the sciences, albeit studying chemistry. His father, Lubbertus, was an administrator at a cigar factory, making just $400 a year, which led Peter's mother, Eugelina Cornelia Adriana van der Wal, to support socialist policies that would improve working conditions and increase wages for factory grunts like her husband. Although Lubbertus shared these politics, Peter told historian and astronomer David DeVorkin, "He was not a revolutionary or an activist or anything like that. One didn't do that so easily in those days."[18]

Peter excelled in math at secondary school and later said that he might have pursued it academically had he not taken up astronomy. He also studied violin for eight years and considered a career in music. His studies in physics had been lackluster, so he had narrowed down his choices to either chemistry or math for his future academic work when an astronomy class (called Cosmography) instilled a passion for the stars that he couldn't shake. This was in 1917, a time when Einstein was slowly upheaving our understanding of the universe. (Van de Kamp became quite a fan of Einstein's, writing him admiring letters and, on certain campus visits, even playing music with him.)

Van de Kamp studied at the University of Utrecht, receiving the equivalent of a master's degree in astronomy, mathematics, and physics. Utrecht was the only university van de Kamp could afford, tutoring other students for tuition money and living with family while he attended. He paid his aunt and uncle around US$17 per month as rent, obviously not inflation adjusted. His professors included Albert Nijland—an expert on variable stars—and W. J. H. Moll, who invented one of the earliest photometers (instruments that measure variations in light) used in modern astronomy.

After his studies, van de Kamp took a position at the Kapteyn Astronomical Laboratory, where he studied the movements of the Hyades cluster. The lab was named for and founded by astronomer Jacobus Cornelius Kapteyn, who studied the movement of stars in relation to the galaxy's rotation—the kind of work that laid a foundation for dark matter theory, that the universe has a great amount of unaccounted for mass, which can be inferred from the movement of galactic dust. Kapteyn's name is perhaps most associated today with Kapteyn's Star, a small, dim stellar object about 12.8 light years away that may be nearly 11 billion years old—making it one of the oldest stars in the Milky Way. (Our Sun is only 4.5 billion years old and will enter its dying stages before it can ever reach the age of Kapteyn's Star.) Kapteyn documented 454,875 stars in his initial catalog—a quite stellar number. Although Kapteyn Astronomical was not an observatory, the laboratory studied observations from other facilities. While there, van de Kamp studied with Pieter Johannes van Rhijn.

Van de Kamp was able to use the laboratory as a springboard to an appointment at the Leander McCormick Observatory in Virginia, a facility he worked closely with even after he resigned this position. In 1924, he took a one-year fellowship in California at the Lick Observatory, and in 1925 he earned a PhD in astronomy from the University of California, Berkeley, based on his studies of the *radial velocity* (spectra shifts due to movement) of faint stars. In 1926, he received another PhD, from the University of Groningen, in the Netherlands. He returned to McCormick shortly after, marrying Emma Basenau in May 1927 and becoming an assistant professor at its parent school, the University of Virginia, in 1928. In 1930, his daughter, Emma Marie, was born, but his marriage was strained, and after a two-year separation, he and Basenau divorced in 1936. Van de Kamp arrived in Swarthmore in 1937 to take over as the director of the Sproul Observatory. He personality recruited Kaj Strand, a Danish student studying in the Netherlands, because of his "beautiful double star work."[19]

Strand's version of events that brought him to Sproul differ a little. Strand claims that in 1935, he was at a formal event at the Paris Observatory, where a group of Dutch astronomers introduced him to van de Kamp. “I made the remark that I had read with very much interest about his father’s work in a publication, and that I was very much impressed with what he had done, and van de Kamp said, ‘Well, my father is not an astronomer,’” Strand told David DeVorkin and Steven Dick.[20] Strand said that he would often joke that this flattery—he had mistaken van de Kamp for a teenager or college student at the time, though van de Kamp was six years older than Strand—had gotten him the job at Sproul.

His initial work broadly studied the galactic motion of stars in the Milky Way, but he gradually pared down his study to those within a few dozen light years, gaining a significant understanding of our local neighborhood of stars and how their movements across the Milky Way relate to one another. Stars orbit the center of the galaxy in the same way that planets orbit a sun, but they don’t all necessarily follow what seems like an orderly path, a la the near-circular orbit of planets. They also don’t, broadly, move along a specific unerring plane as planets do—there are stars in all directions from us, up or down, celestial east or celestial west. The stars’ positions also change and evolve over time. Right now, the closest star to us, Proxima Centauri, is 4.2 light years away; 70,000 years ago, a dim star called Scholz’s Star and its massive but not bright failed star companion swept inside a light year of the Sun and disturbed the movements of the outermost comets. Since that time, the pair has crept to nearly 22 light years away.[21] Incidentally, the region these comets came from—the Oort Cloud—is named for Jan Oort, another Dutch astronomer and an alumnus of the Kapteyn lab.

Van de Kamp had plenty of extracurriculars to keep himself entertained. He was a voracious fan of Charlie Chaplin, collecting his films as well as other silent era comedies, like those of Buster Keaton. He was also an accomplished musician, a skill he picked up with the encouragement of his father.

But van de Kamp’s passion was in the stars. In a 1950 letter, he would criticize Vassar College for taking astronomy out of its science curriculum. “Astronomy, by its very nature, provides an ideal introduction into science; it covers mechanics, physics, chemistry, and touches on other sciences,” he wrote to Maud Makemson, chair of Vassar’s

Astronomy Department, who had asked his help in defending the discipline. "A course in Astronomy unavoidably covers some history of science, and, at least in descriptive fashion, several terrestrial laboratory experiments." Perhaps most eloquently, he outlined the accessibility of the stars, writing, "The astronomical laboratory is the universe," that seemingly infinite place of stars, planets, nebulas, galaxies, black holes, big explosions, tiny but powerful neutron stars, and all matters of wonder and weirdness.[22]

He quickly undertook a mission of studying our nearby stellar neighborhood, chiefly on the hunt for stars with large proper motions and with a special affinity for smaller stars. One of his first big publications while at Swarthmore was the 1941 title *Mean Secular Parallaxes of Faint Stars*, which did not exactly roll off the tongue.

The Smallest Stars

Nearby faint stars tend to be of a class known as *red dwarfs*, or *M-type stars* (or M-dwarfs, if we're covering all our bases). They're reddish in color, and usually around 1/10 the mass of our Sun. Unlike our Sun and similar stars, which will last a few billion years before expanding outward and enveloping a few unlucky planets before collapsing into a white degenerate star, red dwarfs can last for trillions of years, chugging along, fusing hydrogen into helium.

These red dwarfs are dim, requiring at least a telescope to even spot and often a larger observatory to discern anything useful. But because of their low mass, they make an easy study. Most planets have been spotted by the *transit method*, observing a small amount of dimming when a planet passes across the surface of its star. Some telescopes can monitor several stars at a time, over-representing transit monitoring as an astronomical tool, as opposed to more complicated methods, though not every planet transits. Since red dwarfs are small stars (some have the same radius as Jupiter but far more mass), planets crossing their surface are easier to spot. Astrometrically, too, a planet around a red dwarf has a more pronounced effect than a similarly sized planet around a much larger star. If you're going to search for planets, red dwarf stars are, in many ways, an easy target.

But back in 1941, there wasn't a good way to spot something as small as a planet transiting even a small star. Another method that would later be used to find planets, based on radial velocity, was still in its infancy. Since an unseen companion tugs on its star, in astrometry, the star appears to move just a little bit on its otherwise straightforward path across the sky. Radial velocity looks instead at how the tug of a planet affects the motion (or velocity) of a star by breaking down its light and looking for either blueshift or redshift (or movements toward or away from the observer). Through this red light/blue light dance, astronomers can detect an unseen object tugging on the star, even just a little bit.

With astrometry, a big telescope can take a good picture of the star to see if it moves at all from its path around the galaxy. Radial velocity is an extension of astrometry—looking for minute deviations in the velocity of a star—but it wasn't a feasible method for planet hunting until the 1980s, when University of Toronto researcher Bruce Campbell perfected a method for breaking down star spectra by injecting toxic gases into a glass cell that filtered the light. Astrometry is efficient though admittedly hard to do from the ground. Two missions—Hipparcos and the aforementioned Gaia—have performed astrometry from space. Finding planets through astrometry is *really* hard. The amount planets move a star is tiny.

A 1940 letter from Gerard Kuiper to van de Kamp shows that Kuiper was already thinking beyond double stars and binaries and may have had planets on his mind. Today, Kuiper's name is best known by his eponymous Kuiper Belt, a group of small bodies on the outer edges on the solar system, each smaller than our Moon. If the four rocky inner planets of our solar system are the first zone, and the gas giants, ice giants, and their hundreds of combined moons are the second zone, the region just beyond Neptune (and sometimes even crossing over its turf) is the beginning of the third zone.

This third zone was virtually unknown in 1940. The only object known from 1930 until 1992 was Pluto, a tiny oddball world smaller than our Moon. Although (a good handful of) astronomers today classify it as a *dwarf planet*, which is considered planet-like, not an actual planet, Pluto was then considered simply an unusual small planet all alone out there.

But Kuiper's concern wasn't finding more of the belt. Kuiper, then at Yerkes Observatory, in the middle of Wisconsin farmland due north of Chicago, instead wanted to talk about one of van de Kamp's primary interests. "For some time I had been wanting to write you about a program for the search of distant companions to nearby stars," Kuiper wrote in his 1940 letter.[23] He outlined a vision of such a hunt: First, concentrate on *white dwarfs*, the remnants of Sunlike stars that have exhausted their fuel and become planet-sized balls of carbon, oxygen, and electron-stripped matter. Then, move along to *subdwarfs*, a category that encompasses red dwarfs and anything smaller. A red dwarf is the smallest kind of star; any smaller and the stars can no longer fuse hydrogen into helium, instead converting hydrogen into a slightly heavier isotope. These objects, called *brown dwarfs*, give off little light. They bridge the gaps between large planets, at around 13 times the mass of Jupiter, and a murky number between 70 and 80 times that mass. Such objects were unknown, but somewhat theorized, at the time.

Kuiper and van de Kamp had already collaborated on two star systems, Wolf 424 and Wolf 359, looking for unspecified anomalies.[24] Wolf 424 is a pair of red dwarfs orbiting each other 13.7 light years away from Earth. Wolf 359 is eight light years away and is perhaps most famous as the setting for an episode of *Star Trek: The Next Generation* called "The Best of Both Worlds."

But importantly, these letters with Kuiper hint at van de Kamp's interest in the second closest star system to the Sun. The triple stars Proxima Centauri and Alpha Centauri A and B are 4.2 and 4.3 light years away, respectively. But 6 light years from Earth (and 6.4 light years from the Centauri family) lies Barnard's Star. The star is faint and old, only 14 percent of the Sun's mass, and only 150 times the mass of Jupiter. It's invisible to the human eye, but a keen telescopic observer can find it moving across the night sky because it has one of the highest proper motions of any known star. Barnard's Star would become one of the most important stars to van de Kamp's career.

This search for low-mass stars and their companions was the intense focus of Sproul, whose 24-inch refracting telescope was suited to the challenge. By watching stars over several nights and taking photographic plates of the night sky, van de Kamp and his colleagues could watch these high proper motion stars move around the sky and witness any slight perturbation in their motion, on the hunt for binary stars.

Or planets.

Van de Kamp's interests seemed to include searching for planets with the same fervor as unseen stars. In a 1944 article in *Sky and Telescope*, "Stars or Planets?" van de Kamp outlines what they're looking for, objects in between the mass of Jupiter and the then-smallest-known star, Kruger 60B. Without addressing the objects by name, van de Kamp would inadvertently lump in brown dwarfs with gas giants, terming *planets* anything below 1/20 the mass of the Sun that emits little or no light.[25] The term *brown dwarf* was coined by preeminent SETI researcher Jill Tarter, but not until the 1980s, when such objects, intermediate in mass between a planet and a star, were on the cusp of being found.

"Unseen companions can be most effectively detected through the study of their gravitational effect on the motion of known stars or stellar systems," van de Kamp wrote in *Sky and Telescope*. A footnote to this passage makes an early case for the radial velocity method, calling it the *spectroscopic method* and noting its usefulness in finding small stellar companions. But astrometry, van de Kamp argued, is best suited for finding planets versus spectroscopic measurements, which are better suited for stars.

"The photographic search for unseen companions has hardly begun," van de Kamp predicted. "The next decade or so should witness considerable progress in this field." He would later take charge of such efforts alongside other Sproul researchers.

A New Friend

As Strand was leaving to serve with the US Air Force, a new researcher wrote van de Kamp a letter in search of work at Sproul. Sarah Lee Lippincott had just received her bachelor's degree from the University of

Pennsylvania in nearby Philadelphia and was eager to do one of two things: serve the war front effort back home or continue her astronomy studies as a research assistant.

Lippincott began her letter with apologies that she hadn't written sooner. "Due to war conditions it is very hard for me to decide," she wrote. "I have been waiting all this past week to hear from the defense plant before making my final decision." She then offered to stay for nine months as a researcher. "I am waiting to hear if you still want me and if so when you want me to start," she said, signing off, "Assuring you of my appreciation of your consideration of me, I remain sincerely, Sarah Lee Lippincott."[26]

Lippincott didn't stay for nine months. She stayed for 40 years and became a leading researcher in astrometry a powerful advocate for women in the sciences, encouraging others to apply to astronomy programs. In several file photos, Lippincott is the only woman in a sea of men.

But before any of that would happen, she would begin work on figuring out the schematics of Delta Equulei, a binary star system in which both stars are slightly more massive than the Sun. Lippincott and van de Kamp published a paper in 1945 outlining the orbital interactions between the two stars.[27] In the 1940s, Lippincott also studied Barnard's Star and another one nearby, Lalande 21185, alongside van de Kamp.

Van de Kamp and Lippincott would grow to have a close friendship, calling each other Pooh and Flip (sometimes spelled Flippe) in correspondence. That friendship and collaboration would become tied forever to the history of Sproul as an institution, especially once the planet-hunting era began.

Notes

Introduction

1. Alberto A. Martínez, "Was Giordano Bruno Burned at the Stake for Believing in Exoplanets?" *Scientific American*, March 19, 2018, https://blogs.scientificamerican.com/observations/was-giordano-bruno-burned-at-the-stake-for-believing-in-exoplanets/.

Chapter One

1. Kaj Strand, "61 Cygni as a Triple System," *Publications of the Astronomical Society of the Pacific* 55, no. 322 (February 1943): 29–32.
2. Peter van de Kamp to William Leonard Laurence, January 21, 1943, Astronomy Department Records, 1899–1986, Swarthmore College Archives, Swarthmore, Pennsylvania (cited hereafter as Astronomy Department Records, SCA).
3. Dorrit Hoffleit, "Big Planet or Little Star?" *Sky and Telescope* 2, no. 3 (January 1943): 15.
4. James Hickey, "Denies Naming Planet Osiris," *New York Sun*, January 21, 1943.
5. James Hickey to Peter van de Kamp, January 21, 1943, Astronomy Department Records, SCA.
6. Dirk Reuyl and Erik Holmberg, "On the Existence of a Third Component in the System 70 Ophiuchi," *Astrophysical Journal* 97 (January 1943): 41.
7. Kaj Strand to Peter van de Kamp, April 19, 1943, Astronomy Department Records, SCA.
8. Kaj Strand to Peter van de Kamp, July 4, 1943, Astronomy Department Records, SCA.
9. Peter van de Kamp to Kaj Strand, July 14, 1943, Astronomy Department Records, SCA.
10. Jan Schlit to Dirk Brouwer, October 10, 1947, Astronomy Department Records, SCA.
11. Henry Norris Russell, "The Orbit of 70 Ophiuchi," *Publications of the Astronomical Society of the Pacific* 55, no. 323 (April 1943): 104.
12. William Stephen Jacob, "On Certain Anomalies Presented by the Binary Star 70 Ophiuchi," *Monthly Notices of the Royal Astronomical Society* 15–16 (1855): 228.

13. Thomas Jefferson Jackson See, "Researches on the Orbit of 70 Ophiuchi, and on a Periodic Perturbation in the Motion of the System Arising from the Action of an Unseen Body," *Astronomical Journal* 16, no. 363 (1896): 17–23.

14. Thomas Jefferson Jackson See, "Remarks on Mr. Moulton's Paper in A.J. 461," *Astronomical Journal* 20, no. 464 (June 1899): 56–59.

15. C. J. Peterson, "Thomas Jefferson Jackson See and the University of Missouri," *Bulletin of the American Astronomical Society* 14 (March 1982): 622.

16. Thomas Shirrell, "A Career of Controversy: The Anomaly of T. J. J. See," *Journal for the History of Astronomy*, February 1999, 25.

17. Kaj Strand, "The Orbital Motion of 70 Ophiuchi," *Publications of the American Astronomical Society* 10 (1946): 70.

18. Peter van de Kamp interview by David DeVorkin, March 18, 1979, Oral Histories, Niels Bohr Library and Archives, American Institute of Physics, https://www.aip.org/history-programs/niels-bohr-library/oral-histories/4929-2.

19. Van de Kamp interview, March 18, 1979.

20. Kaj Strand interview by David DeVorkin and Steven Dick, December 8, 1983, Oral Histories, Niels Bohr Library and Archives, American Institute of Physics, https://www.aip.org/history-programs/niels-bohr-library/oral-histories/23026-1.

21. Eric E. Mamajek, Scott A. Barenfeld, Valentin D. Ivanov, Alexei Y. Kniazev, Petri Väisänen, Yuri Beletsky, and Henri M. J. Boffin, "The Closest Known Flyby of a Star to the Solar System," *Astrophysical Journal Letters* 800, no. 1 (February 12, 2015): L17.

22. Peter van de Kamp to Maud Makemson, November 13, 1950, Astronomy Department Records, SCA.

23. Gerard Kuiper to Peter van de Kamp, January 7, 1940, Astronomy Department Records, SCA.

24. Peter van de Kamp to Gerard Kuiper, May 20, 1938, Astronomy Department Records, SCA.

25. Peter van de Kamp, "Stars or Planets?" *Sky and Telescope* 4, no. 38 (December 1944): 5.

26. Sarah Lee Lippincott to Peter van de Kamp, October 2, 1942, Astronomy Department Records, SCA.

27. Sarah Lee Lippincott and Peter van de Kamp, "A Determination of the Parallax and Mass-Ratio of δ Equulei," *Astronomical Journal* 51 (September 1945): 162.

Chapter Two

1. Peter van de Kamp to Kaj Strand, June 2, 1953, Astronomy Department Records, SCA.

2. Sergio Dieterich, Todd J. Henry, Wei-Chun Jao,Jennifer G. Winters, Altonio D. Hosey, Adric R. Riedel, and John P. Subasavage, "The Solar Neighborhood XXXII: The Hydrogen Burning Limit," *Astronomical Journal* 147, no. 5 (March 24, 2014), https://doi.org/10.1088/0004-6256/147/5/94; and Alexander von Boetticher, Amaury H.M.J. Triaud, Didier Queloz, Sam Gill, Monika Lendl, Laetitia Delrez, David R. Anderson, et al., "The EBLM project III: A Saturn-Size Low-Mass Star at the Hydrogen-Burning Limit," *Astronomy and Astrophysics* 604 (2017), arXiv.org e-Print archive, July 12, 2017.

3. Ann Ewing, "Lightest Weight Star Found by Biggest Telescope," *Science News Services*, April 4, 1955.

4. Willem Luyten, "On the Orbit and Mass of L726-8," *Publications of the Astronomical Society of the Pacific* 66, no. 393 (December 1954): 337–338.

5. Meghan Bartels, "How Harvard's Vast Collection of Glass Plates Still Shapes Astronomy," *Astronomy*, February 1, 2017, http://www.astronomy.com/news/2017/02/stars-frozen-in-time; see also Dava Sobel, *The Glass Universe* (New York: Viking, 2016).

6. Sarah Lee Lippincott to Leslie Sevy, March 19, 1965, Astronomy Department Records, SCA.

7. Adolph Katz, "Woman Astronomer at Swarthmore a Champion of Discovering Stars," *Philadelphia Bulletin*, March 16, 1960, 25.

8. "Report of the Visiting Committee to the Swarthmore College Astronomy Department," March 1975, Astronomy Department Records, SCA.

9. Peter van de Kamp to Kaj Strand, February 5, 1968, Astronomy Department Records, SCA.

10. Peter van de Kamp to Dr. Courtney C. Smith, president, Swarthmore College, June 22, 1961, Astronomy Department Records, SCA.

11. "Sarah Lee Lippincott: She's a Star Studier," *Science World*, April 18, 1974.

12. Sarah Lee Lippincott to Mildred Shapley Matthews, July 5, 1962, Astronomy Department Records, SCA.

13. Sandra Faber interview by Alan Lightman, October 15, 1988, Oral Histories, Niels Bohr Library and Archives, American Institute of Physics, http://www.aip.org/history-programs/niels-bohr-library/oral-histories/33932.

14. Richard Hollingham, "How a Nazi Rocket Could Have Put a Briton in Space," *BBC Future*, August 25, 2015, http://www.bbc.com/future/story/20150824-how-a-nazi-rocket-could-have-put-a-briton-in-space.

15. Joseph Myler, “A Mere Trillion-Miles Up There,” *Harrisburg (PA) Evening News*, November 18, 1955.

16. United Press, “Astronomers Think Other Worlds Might Be Discovered,” *Buffalo (NY) Courier Express*, October 2, 1955.

17. S. S. Kumar, “On the Nature of the Planetary Companions of Stars,” *Zeitschrift für Astrophysik* 58 (1964): 248.

18. S. S. Kumar, “Planetary Companions as Late-Type Stars,” in *Proceedings of the Colloquium on Late-Type Stars*, ed. Margherita Hack (Trieste: Osservatorio Astronomico, 1967), 341.

19. Benjamin Adelman, “Do Stars Have Planets?” *Junior Astronomer* 5, no. 2 (October 1955): 2–4.

20. Peter van de Kamp and Sarah Lee Lippincott, “Astrometric Study of Lalande 21185,” *Astronomical Journal* 56 (April 1951): 49.

21. Sarah Lee Lippincott, “The Unseen Companion of the Fourth Nearest Star, Lalande 21185,” *Astronomical Journal* 65 (August 1960): 349.

22. Sarah Lee Lippincott, “Astrometric Analysis of Lalande 21185,” *Astronomical Journal* 65 (September 1960): 445–448.

23. Science Service, “‘Nearby’ Object May Be a Planet,” *Austin Statesman*, May 5, 1960.

24. *Science and Mechanics*, October 1960, 76.

25. Stuart Brown, “Scientists Search for Signs of Life in Outer Space,” *Philadelphia Bulletin*, October 9, 1960.

26. Associated Press, “Old Sol May Have Twin, Astronomer Maintains,” *Tucson Star*, June 14, 1961.

27. Sarah I. Sadavoy and Steven W. Stahler, “Embedded Binaries and Their Dense Cores,” *Monthly Notices of the Royal Astronomical Society* 469, no. 4 (August 21, 2017): 3881–3900.

Chapter Three

1. Peter van de Kamp, “Astrometric Study of Barnard’s Star from Plates Taken with the 24-Inch Sproul Refractor,” *Astronomical Journal* 68 (September 1963): 515–521.

2. Peter van de Kamp to Gerard Kuiper, January 18, 1940, Astronomy Department Records, SCA.

3. Peter van de Kamp to Kaj Strand, June 11, 1953, Astronomy Department Records, SCA.

4. Edwin Dennison to Peter van de Kamp, February 22, 1955, Astronomy Department Records, SCA.

5. Peter van de Kamp to John Lear, science editor, *Saturday Review*, May 22, 1962, Astronomy Department Records, SCA.

6. Carle Hodge, "Scientist Reports Planet Without Seeing It," *Arizona Daily Sun*, April 19, 1963.

7. "New Neighbor," *Newsweek*, April 29, 1963.

8. Peter van de Kamp to Lawrence J. Tacker, Major, USAF, August 25, 1959, Astronomy Department Records, SCA.

9. Brown, "Scientists Search for Signs of Life."

10. Su-Shu Huang, "The Problem of Life in the Universe and the Mode of Star Formation," *Publications of the Astronomical Society of the Pacific* 71, no. 422 (1959).

11. Science Service, "Planet Discovered Outside of the Sun's Solar System," *Harrisonburg (VA) News Record*, April 25, 1963.

12. "New Neighbor."

13. "Another Solar System Is Found 36 Trillion Miles from the Sun," *New York Times*, April 19, 1963, 4.

14. "Invisible Planet Is Discovered by Sproul Director," *Philadelphia Inquirer*, April 19, 1963.

15. Edwin Hubble, "First Photographs with the 200-inch Hale Telescope," *Publications of the Astronomical Society of the Pacific* 61, no. 360 (June 1949): 121.

16. "Super-Prof Wins National Fame," *Swarthmore College Phoenix*, September 20, 1966.

17. Walter Sullivan, *We Are Not Alone* (New York: McGraw-Hill, 1966), 49.

18. Sullivan, *We Are Not Alone*, 52.

19. Sullivan, *We Are Not Alone*, 53.

20. "The Invisible Planet," *Experiment: The Story of a Scientific Search*, produced by Prism Productions, aired July 1966 on National Educational Television.

21. Peter van de Kamp, "The Philosophical Man" (speech at the *Man and the Twenty-First Century* conference, Stevens Institute of Technology, Hoboken, New Jersey, November 14, 1967).

22. Claire Huff, "Scientist Skeptical on Space Flights," *Philadelphia Inquirer*, January 14, 1968.

23. “Planets in His Pockets, He Laughs about UFOs,” *Montreal Star*, November 15, 1968.

24. Jeff Yohay, “Student Interviews Dr. van de Kamp; Derides Vietnam Effort, Space Race” (Stevens Institute Centennial Convocation, November 17, 1967).

25. Peter van de Kamp, “Tribute to Laika,” collection speech, Clothier Memorial, December 5, 1957.

26. Van de Kamp, “Tribute to Laika.”

27. Rosalie Piersol, “New Wing ‘Shot in Arm,’” Philadelphia *Sunday Bulletin*, October 27, 1963, 5.

28. Nancy G. Roman interview by David DeVorkin, August 19, 1980, Oral Histories, Niels Bohr Library and Archives, American Institute of Physics, http://www.aip.org/history-programs/niels-bohr-library/oral-histories/4846.

29. Daniel Hoffman, “The Peaceable Kingdom” (poem written for Phi Beta Kappa Honor Society, Swarthmore, Pennsylvania, June 7, 1964).

30. “NSF Gives $49,900 for Star Studies,” *Swarthmore College Phoenix*, January 8, 1965.

31. “Faculty Members Gain Promotions for Upcoming Year,” *Swarthmore College Phoenix*, April 16, 1965.

32. Peter van de Kamp, “Parallax and Proper Motion of BD +5 1668,” *Astronomical Journal* 53 (August 1948): 229.

33. Ann Ewing, “Unseen Companion,” *Science News* 89, no. 296 (April 23, 1966): 296.

34. NASA, “How Many Exoplanets Has Kepler Discovered?” NASA.gov, accessed January 5, 2018, https://www.nasa.gov/kepler/discoveries.

35. James F. Wanner, *The 24-inch Refractor of the Sproul Observatory* (Swarthmore, PA: Swarthmore College, 1972), 3; originally published as “New Life for Old Sproul Refractor,” in *Popular Astronomy* 62, no. 550 (1968): 11–15.

36. Peter van de Kamp to Kaj Aa. Strand, October 24, 1969, Astronomy Department Records, SCA.

37. Elizabeth Weber, “The Crisis of 1969,” Swarthmore *Phoenix*, March 7, 1996.

38. Courtney Smith, “The Academic Community and Social Concerns,” *Swarthmore College Bulletin*, December 1965.

39. James Wanner to Peter van de Kamp, February 18, 1964, Astronomy Department Records, SCA.

40. Paul Good, “Requiem for Courtney Smith,” *Life*, May 9, 1969, 76.

41. Stuart Madden, “Swarthmore President’s Death Ends Black Sit-In,” *Daily Pennsylvanian*, January 17, 1969.

42. “Dr. Courtney C. Smith, Swarthmore’s President,” *New York Times*, January 17, 1969, 44.

43. Good, “Requiem for Courtney Smith,” 76D.

44. Etheridge quoted in Good, “Requiem for Courtney Smith,” 83.

45. Darwin H. Stapleton and Donna Heckman Stapleton, *Dignity, Discourse, and Destiny: The Life of Courtney C. Smith* (Newark: University of Delaware Press, 2004), 186.

46. Peter van de Kamp, “Based on what I said at the Chaplin Seminar February 1,” January 1969, Astronomy Department Records, SCA.

47. “Subversion of Reason,” *New York Times*, January 18, 1969, 30.

Chapter Four

1. Alisa Giardinelli, “Longtime Astronomy Professor Wulff Heintz Dies,” *Swarthmore News Archive 2006–2007*, June 16, 2006, https://www.swarthmore.edu/news-archive-2006-2007/longtime-astronomy-professor-wulff-heintz-dies.

2. Harry J. Augensen and Edward H. Geyer, “Wulff-Dieter Heintz (1930–2006),” American Astronomical Society Obituaries, June 2006, https://aas.org/obituaries/wulff-dieter-heintz-1930-2006.

3. Peter van de Kamp, “Alternate Dynamical Analysis of Barnard’s Star,” *Astronomical Journal* 74 (April 18, 1969): 757–759.

4. Shiv S. Kumar to Peter van de Kamp, March 21, 1969, Astronomy Department Records, SCA.

5. Sandra Faber to Peter van de Kamp, May 12, 1969, Astronomy Department Records, SCA.

6. Martin Putnam, “Van de Kamp Discovers New Planetary System,” *Swarthmore Phoenix*, April 22, 1969.

7. “The Crab Pulsar: Many New Observations,” IAU Symposium No. 46, *Assembly Times: The Daily Bulletin of the 14th General Assembly of the International Astronomical Union*, August 21, 1970.

8. Peter van de Kamp to Kaj Aa. Strand, September 21, 1971, Astronomy Department Records, SCA.

9. “The Star-Planet,” *Time*, January 29, 1973.

10. Peter van de Kamp, "Parallax and Orbital Motion of Epsilon Eridani," *Astronomical Journal* 79, no. 4 (1974): 491–492.

11. Jill Tarter, "Brown Dwarfs and Black Holes," *Astronomy*, April 1978, 24.

12. Viki Joergens, ed., *50 Years of Brown Dwarfs* (Cham: Springer, 2013), 20.

13. Walter Sullivan, "Is Jupiter a Star?" *New York Times*, December 19, 1965.

14. Sarah Lee Lippincott, "Reflections on 24" Refractor," *Swarthmorean*, March 8, 1974.

15. Peter van de Kamp and Michael D. Worth, "Parallax and Orbital Motion of the Unresolved Astrometric Binary BD+43 4305," *Astronomical Journal* 77, no. 9 (November 1972): 762–763.

16. Peter van de Kamp and Sarah Lee Lippincott, "Continued Astronometric Study of BD +43 4305" (paper presented at the 156th American Astronomical Society Meeting, June 15–18, 1980, College Park, Maryland).

17. Sarah Lee Lippincott to Edwin Dennison, November 25, 1974, Astronomy Department Records, SCA.

18. Teresa Nicholas, "Van de Kamp Offers Fourth Chaplin Seminar, Expresses Advantages of Old Motion Pictures," *Swarthmore Phoenix*, April 29, 1975.

19. A. R. Martin, *Project Daedalus: The Final Report on the BIS Starship Study* (London: British Interplanetary Society, 1978).

Chapter Five

1. Peter van de Kamp to Edward Litchfield, February 1, 1965, Astronomy Department Records, SCA.

2. "Crisis at Allegheny," *Sky and Telescope* 29, no. 3 (March 1965): 135.

3. "Pitt Phases Out Observatory Program," press release, January 21, 1964, Pitt Administration Collection, University Library System Digital Collections, University of Pittsburgh, http://digital.library.pitt.edu/islandora/objectpitt:pittpressreleases19640018/from_search/5bc49877965cc08ddcbe58010e00cb42-3#page/1/mode/2up.

4. "Academic Review: Division of the Natural Sciences," *Pitt* 23, no. 4 (Fall 1967): 13, Pitt Alumni Collection, University Library System Digital Collections, University of Pittsburgh, http://digital.library.pitt.edu/islandora/object/pitt:31735062134451/from_search/bbb2b24b00b4629e567fab0b09a11f22-6#page/18/mode/2up.

5. Olivier Jensen and Tadeusz Ulrych, "An Analysis of the Perturbations on Barnard's Star," *Astronomical Journal* 78 (December 1973): 1104.

6. Olivier Jensen and Tadeusz Ulrych, "Erratum: An Analysis of the Perturbations on Barnard's Star [Astron. J. 78, 1104 (1973)]," *Astronomical Journal* 79 (November 1974): 1328.

7. George Gatewood and Heinrich Eichhorn, "An Unsuccessful Search for a Planetary Companion of Barnard's star BD +4 3561," *Astronomical Journal* 78 (October 1973): 769–776.

8. John L. Hershey, "Astrometric Analysis of the Field of AC +65 6955 from Plates Taken with the Sproul 24-inch Refractor," *Astronomical Journal* 78 (June 1973): 421–425.

9. H. K. Eichhorn von Wurmb to Swarthmore, May 16, 1975, Astronomy Department Records, SCA.

10. "Report of the Visiting Committee."

11. Sarah Lee Lippincott, "Technical Report to the National Science Foundation," February 25, 1979, Astronomy Department Records, SCA.

12. Strand interview, December 8, 1983.

13. George Gatewood, "An Astrometric Study of Lalande 21185," *Astronomical Journal* 79, no. 1 (January 1974): 52–53.

14. George Gatewood, "On the Astrometric Detection of Neighboring Planetary Systems," *Icarus* 27, no. 1 (January 1976): 1–12.

15. Jane Russell, George Gatewood, and N. E. Wagman, "Altair," *Astronomical Journal* 83, no. 11 (November 1978): 1458.

16. George Gatewood, Lee Breakiron, Ronald Goebel, Steven Kipp, Jane Russell, and John Stein, "On the Astrometric Detection of Neighboring Planetary Systems, II," *Icarus* 41, no. 2 (February 1980): 205–231.

17. Wulff-Dieter Heintz, "Reexamination of Suspected Unresolved Binaries," *Astrophysical Journal* 220 (March 15, 1978): 931–934.

18. Sarah Lee Lippincott and Wulff-Dieter Heintz, "Swarthmore College: Sproul Observatory and Department of Astronomy, Swarthmore, Pennsylvania 19081, Report for the Period 1 July 1977–30 June 1978," *Bulletin of the Astronomical Society* 11 (January 1979): 315–316.

19. John L. Hershey and Elliot Borgman, "Upper Limits on the Mass of a Dark Companion of Groombridge 1618 from the 40-Year Sproul Plate Series," *Bulletin of the American Astronomical Society* 10 (September 1978): 630.

20. Sarah Lee Lippincott and Wulff-Dieter Heintz, "Sproul Observatory," *Bulletin of the American Astronomical Society* 12 (January 1980): 367.

21. Bill Kent, "Barnard's Wobble," *Swarthmore Bulletin*, March 2001, 31.

22. Van de Kamp interview, March 18, 1979.

23. Van de Kamp interview, March 18, 1979; Strand interview, December 8, 1983.

24. Phillip J. Ianna, "On Aberrations and Field Errors," *Vistas in Astronomy* 6, no. 1 (1965): 93–123; and Phillip J. Ianna, "Aberrations and Field Errors of the Sproul 24-inch Objective," *Astronomical Journal* 67 (June 1962): 273.

25. Minutes, NASA Ames Astrometric Conference, US Naval Observatory, Washington, DC, May 10–11, 1976, Astronomy Department Records, SCA.

26. L. W. Fredrick and P. A. Ianna, "A Study of Barnard's Star," *Bulletin of the American Astronomical Society* 12 (March 1980): 455.

27. L. W. Fredrick and P. A. Ianna, "The Barnard's Star Perturbation," *Bulletin of the American Astronomical Society* 17 (March 1985): 551.

28. Peter van de Kamp, "Barnard's Star 1916–1976: A Sexagintennial Report," *Vistas in Astronomy* 20, no. 2 (1977): 501–521.

29. Peter van de Kamp, "Sproul Astrometric Study of Barnard's Star, A Progress Report," *Bulletin of the American Astronomical Society* 14 (March 1982): 627.

30. Peter van de Kamp, "Friedrich Wilhelm Bessel 1784, July 22–1846, March 17," *Astrophysics and Space Science* 110, no. 1 (March 1985): 103–104.

31. A. H. Batten, "Book Review: Stellar Paths," *Journal of the Royal Astronomical Society of Canada* 77 (February 1983): 59–60.

32. Peter van de Kamp, "Dark Companions of Stars: Astrometric Commentary on the Lower End of the Main Sequence," *Space Science Reviews* 43 (April 1986): 211–327. NSF-supported research.

Chapter Six

1. Sarah Lee Lippincott and Michael D. Worth, "Chi-1 Orionis, a New Solar-Type Astrometric Binary," *Publications of the Astronomical Society of the Pacific* 90, no. 535 (June 1978): 330–332.

2. G. F. Benedict, B. E. McArthur, O. G. Franz, L. H. Wasserman, T. J. Henry, T. Takato, I. V. Strateva, et al., "Precise Masses for Wolf 1062 AB from Hubble Space Telescope Interferometric Astrometry and McDonald Observatory Radial Velocities," *Astronomical Journal* 121, no. 3 (March 2001): 1607–1613.

3. Jennifer Burt, Steven S. Vogt, R. Paul Butler, Russell Hanson, Stefano Meschiari, Eugenio J. Rivera, Gregory W. Henry, and Gregory Laughlin, "The Lick-Carnegie

Exoplanet Survey: Gliese 687b—A Neptune-Mass Planet Orbiting a Nearby Red Dwarf," *Astrophysical Journal* 789, no. 2 (2014), https://doi.org/10.1088/0004-637X/789/2/114.

4. Sarah Lee Lippincott, "Astrometric Analyses of the Unseen Companions to Ci 18, 2354 and Wolf 1062 from Plates Taken with the 61-cm Sproul Refractor," *Astronomical Journal* 82 (November 1977): 925–928.

5. Sarah Lee Lippincott to Laurence W. Fredrick, November 28, 1977, Astronomy Department Records, SCA.

6. Sarah Lee Lippincott, "Two New Astrometric Binaries of Small Amplitude: One with an Unseen Member of ~20 Jupiter Masses," *Bulletin of the American Astronomical Society* 11 (1979): 405.

7. Hershey and Borgman, "Upper Limits on the Mass of a Dark Companion," 630.

8. Geoff Marcy and David Moore, "The Extremely Low Mass Companion to Gliese 623," *Astrophysical Journal* 341, part 1 (June 15, 1989): 961–967.

9. N. A. Shakht, "The Observations of Gliese 623 and Some other Objects with Suspected Unseen Components," in *Astronomical and Astrophysical Objectives of Sub-Milliarcsecond Optical Astrometry*, ed. Erick Høg, 359 (Dordrecht: Springer Netherlands, 1995).

10. Frantz Martinache, James P. Lloyd, Michael J. Ireland, Ryan S. Yamada, and Peter G. Tuthill, "Precision Masses of the Low-Mass Binary System GJ 623," *Astrophysical Journal* 661, no. 1 (2007): 496–501.

11. Sarah Lee Lippincott to Laurence W. Fredrick, June 5, 1980, Astronomy Department Records, SCA.

12. J.-L. Beuzit, D. Ségransan, T. Forveille, S. Udry, X. Delfosse, M. Mayor, C. Perrier, et al., "New Neighbours, III: 21 New Companions to Nearby Dwarfs, Discovered with Adaptive Optics," *Astronomy and Astrophysics* 425, no. 3 (October 3, 2004): 997–1008.

13. Sarah Lee Lippincott and John L. Hershey, "Letter of Intent in Answer to the Announcement of Opportunity for Space Telescope: Search for Faint Companions to Nearby Stars—an Extension of the Sproul Astrometric Program," April 22, 1977, Astronomy Department Records, SCA.

14. G. Westerhout, H. Eichhorn, G. Gatewood, J. Hughes, W. Jefferys, I. King, and W. van Altena, "Astronomy Survey Committee," Astrometry Working Group, third draft, February 1980, SCA.

15. A. B. Schultz, H. M. Hart, J. L. Hershey, F. C. Hamilton, M. Kochte, F. C. Bruhweiler, G. F. Benedict, et al., "A Possible Companion to Proxima Centauri," *Astronomical Journal* 115 (January 1998): 345.

16. Gabrielle Walker, “Did Hubble Catch a Glimpse of a Nearby Giant?” *New Scientist*, no. 2119 (January 31, 1998), https://www.newscientist.com/article/mg15721190-700-did-hubble-catch-a-glimpse-of-a-nearby-giant/.

17. Guillem Anglada-Escudé, Pedro J. Amado, John Barnes, Zaira M. Berdiñas, R. Paul Butler, Gavin A. L. Coleman, Ignacio de la Cueva, et al., “A Terrestrial Planet Candidate in a Temperate Orbit around Proxima Centauri,” *Nature* 536 (August 25, 2016): 437–440

18. Guillem Anglada, Pedro J. Amado, José L. Ortiz, José F. Gómez, Enrique Macías, Antxon Alberdi, Mayra Osorio, et al.. “ALMA Discovery of Dust Belts around Proxima Centauri,” *Astrophysical Journal Letters* 850, no. 1 (November 15, 2017): 1–5.

19. John Wenz, “Proxima Centauri’s Dust Belt Hints at More Planets,” *Discover*, November 3, 2017, http://blogs.discovermagazine.com/d-brief/2017/11/03/alpha-centauri-system.

20. Sarah Lee Lippincott, “Continued Astrometric Study of BD+43°4305,” *Bulletin of the American Astronomical Society* 12 (March 1980): 455.

21. Sarah Lee Lippincott, “EV Lacertae—Is Flare Activity Related to an Unseen Planet-like Companion?” *Activity in Red-Dwarf Stars: Proceedings of the 71st Colloquium of the International Astronomical Union, Held in Catania, Italy, August 10–13, 1982*, ed. Patrick B. Byrne and Marcello Rodonò (Dordrecht: Springer Netherlands, 1983), 201–202.

22. Kaj Strand, “Triple System Stein 2051 (G 175–34),” *Astronomical Journal* 82 (September 1977): 745–749.

23. Peter van de Kamp to Kaj Strand, September 18, 1974, Astronomy Department Records, SCA.

24. Kaj Strand to Peter van de Kamp, October 8, 1974, Astronomy Department Records, SCA.

25. Mark Bowden, “Stargazers, Dancers and Lifelong Searches,” *Philadelphia Inquirer*, September 26, 1980.

26. John Hershey to David C. Black, May 8, 1980, Astronomy Department Records, SCA.

27. K. A. Strand and V. V. Kallarkal, “The Nearby Binary, Stein 2051 (G175–34AB),” in *White Dwarfs*, ed. G. Wegner, Lecture Notes in Physics, vol. 328 (Berlin: Springer, 1989).

28. Kailash Sahu, C. Anderson, Jay Casertano, Stefano Bond, Howard E. Bergeron, Pierre Nelan, Edmund P. Pueyo, et al., “Relativistic Deflection of Background Starlight Measures the Mass of a Nearby White Dwarf Star,” *Science* 356, no. 6342 (June 2017): 1046–1050.

29. Burt et al., "The Lick-Carnegie Exoplanet Survey," 114.

30. George Gatewood, "MAP Determinations of the Parallaxes of Stars in the Regions of HD 2665, BD +68.946 deg, and Lambda Ophiuchi," *Astronomical Journal* 97 (April 1989): 1189–1196.

31. Fred Burwell, "Fridays with Fred: The Science behind Smith Observatory," *Beloit News*, March 24, 2011, https://www.beloit.edu/campus/news/fwf/?story_id=313226.

32. Linda Scott, "Eye on the Sky," *Abington Suburban*, July 7, 2016.

33. Faber interview, October 15, 1988.

34. The *National Enquirer* article is incomplete in the Swarthmore College Archives, Astronomy Department Records.

35. Sally Bedell, "Dave Garroway, 69, Found Dead; First Host of 'Today' on NBC-TV," *New York Times*, July 22, 1982.

36. Associated Press, "Dave Garroway Family Plans a Jazz Concert as Memorial," *New York Times*, July 25, 1982.

37. Kenneth Clark, "Friends, Colleagues Mourn Dave Garroway," United Press International, July 21, 1982.

38. Sarah Lee Lippincott, "An Unseen Companion to 36 Ursae Majoris a From Analysis of Plates taken with the Sproul 61-cm Refractor," *Astronomical Society of the Pacific* 95 (October 1983): 775–777.

Chapter Seven

1. David Black, ed., *Project Orion: A Design Study of a System for Detecting Extrasolar Planets*, NASA SP 436 (Washington, DC: Government Printing Office, 1981).

2. George D. Gatewood, *The Allegheny Observatory Search for Planetary Systems: Final Technical Report, 1980–1988* (Department of Physics and Astronomy, University of Pittsburgh, Pennsylvania, March 1989).

3. G. Gatewood, M. W. Castelaz, J. W. Stein, E. H. Levy, R. S. McMillan, K. Nishioka, and J. D. Scargle, "A Prototype Detector for the Astrometric Telescope Facility," in *Mapping the Sky: Past Heritage and Future Directions, Proceedings of the 133rd Symposium of the International Astronomical Union, Held in Paris, France, June 1–5, 1987*, ed. S. Debarbat, J. A. Eddy, H. K. Eichhorn, and A. R. Upgren (Dordrecht: Kluwer, 1988), 421–424.

4. Jean Kovalevsky, *Modern Astrometry* (Berlin: Springer, 2013), 120.

5. George D. Gatewood, *Allegheny Observatory Search for Planetary Systems*, Reports of Planetary Astronomy, (Washington, DC: NASA, 1991), 45–46.

6. George D. Gatewood, "A Study of the Astrometric Motion of Barnard's Star," *Astrophysics and Space Science* 223, no. 1–2 (1995): 91–98.

7. G. Fritz Benedict, Barbara McArthur, D. W. Chappell, E. Nelan, W. H. Jefferys, W. van Altena, J. Lee, et al., "Interferometric Astrometry of Proxima Centauri and Barnard's Star Using Hubble Space Telescope Fine Guidance Sensor 3: Detection Limits for Substellar Companions," *Astronomical Journal* 118, no. 2 (1999): 1086–1100.

8. M. Kürster, M. Endl, F. Rouesnel, S. Els, A. Kaufer, S. Brillant, A. P. Hatzes, S. H. Saar, and W. D. Cochran, "The Low-Level Radial Velocity Variability in Barnard's Star (= GJ 699)," *Astronomy and Astrophysics* 403, no. 3 (June 1, 2003): 1077–1087.

9. Wulff-Dieter Heintz, "The Substellar Masses of Wolf 424," *Astronomy and Astrophysics* 217, no. 1–2 (1989): 145.

10. Michael Decourcy Hinds, "Swarthmore Journal: Life's Quest Rewarded, 84 Trillion Miles Away," *New York Times*, September 28, 1989.

11. Wulff-Dieter Heintz, "The Low-Mass Binary Hei 299," *Observatory* 110 (August 1990): 131–132.

12. W. L. Combrinck, "Astrometry—Extrasolar Planet Detection Method," *Monthly Notes of the Astronomical Society of Southern Africa* 42 (1983): 89.

13. Thomas O'Toole, "Possibly as Large as Jupiter," *Washington Post*, December 31, 1983.

14. Carl Sagan, Frank Drake, Ann Druyan, Timothy Ferris, Jon Lomberg, and Linda Salzman Sagan, *Murmurs of Earth* (New York: Random House, 1978), 235.

15. Nathan Kaib, Ethan White, and Andre Izidoro,"Fomalhaut's Stellar Companions as the Driver of Its Morphology" (talk at the American Astronomical Society Meeting 231, January 2018).

16. Alex Teachey, David M. Kipping, and Allan R. Schmitt, "HEK VI: On the Dearth of Galilean Analogs in Kepler and the Exomoon Candidate Kepler-1625b I," *Astronomical Journal* 155, no. 1 (December 22, 2017): 1–20.

17. A. Lecavelier des Etangs and A. Vidal-Madjar, "Is Beta Pic b the Transiting Planet of November 1981?" *Astronomy and Astrophysics* 497, no. 2 (April 2009): 557–562.

18. A.-M. Lagrange, A. Boccaletti, M. Langlois, G. Chauvin, R. Gratton, H. Beust, S. Desidera, et al., "Post Conjunction Detection of Beta Pictoris b with VLT/SPHERE," preprint, submitted September 22, 2018, https://arxiv.org/abs/1809.08354.

19. Rafael Rebolo, "Teide 1 and the Discovery of the Brown Dwarfs," in *50 Years of Brown Dwarfs*, ed. Viki Joergens (Cham: Springer, 2013), 27.

20. R. S. Harrington, V. V. Kallarakal, and C. C. Dahn, “Astrometry of the Low-Luminosity Stars VB8 and VB10,” *Astronomical Journal* 88 (July 1983): 1038–1039.

21. John Noble Wilford, “Possible Planet Found Beyond the Solar System,” *New York Times*, December 11, 1984.

22. John Noble Wilford, “Scientists Dispute Planet Discovery,” *New York Times*, October 5, 1986.

23. John Noble Wilford, “Orbiting Object Hints at Other Planet Systems,” *New York Times*, November 11, 1987.

24. Jacob L. Bean, Andreas Seifahrt, Henrik Hartman, Hampus Nilsson, Ansgar Reiners, Stefan Dreizler, Todd J. Henry, and Günter Wiedemann, “The Proposed Giant Planet Orbiting VB 10 Does Not Exist,” *Astrophysical Journal Letters* 711, no 1 (February 11, 2010): L19–L23.

25. Michael Perryman, Joel Hartman, Gaspar A Bakos, and Lennard Lindegren, “Astrometric Exoplanet Detection with Gaia,” *Astrophysical Journal* 797, no. 1 (November 19, 2014): 1–22.

26. Solar System Exploration Committee, NASA Advisory Council, *Planetary Exploration Through Year 2000: An Augmented Program* (Washington, DC: Government Printing Office, 1986).

27. “1917 Astronomical Plate Has First-Ever Evidence of Exoplanetary System,” Carnegie Science, April 12, 2016, https://carnegiescience.edu/news/1917-astronomical-plate-has-first-ever-evidence-exoplanetary-system.

28. Solar System Exploration Committee, *Planetary Exploration Through Year 2000*, 191.

29. W. J., Borucki, J. D. Scargle, and H. S. Hudson, “Detectability of Extrasolar Planetary Transits,” *Astrophysical Journal* 291 (April 15, 1985): 852–854.

30. Bernard Burke, “Study of Extrasolar Planetary Systems from the Moon: Summary of the Panel Discussion,” *AIP Conference Proceedings* 207, no. 1 (1990): 67, https://doi.org/10.1063/1.39358.

31. Bruce Campbell, G. A. H. Walker, and S. Yang, “A Search for Substellar Companions to Solar-Type Stars,” *Astrophysical Journal* 331, no. 1 (Aug. 15, 1988): 902–921.

32. Paul Butler, “A Brief Personal History of Exoplanets,” Carnegie Science, March 29, 2016, https://dtm.carnegiescience.edu/news/brief-personal-history-exoplanets.

33. David W. Latham, Tsevi Mazeh, Robert P. Stefanik, Michel Mayor, and Gilbert Burki, “The Unseen Companion of HD114762: A Probable Brown Dwarf,” *Nature* 339 (May 4, 1989): 38–40.

34. W. J. Forrest, J. D. Garnett, Z. Ninkov, M. Skrutskie, and M. Shure, “Discovery of Low Mass Brown Dwarfs in Taurus,” *Bulletin of the American Astronomical Society* 21 (March 1989): 795.

35. Ben R. Oppenheimer, “Companions of Stars,” in *50 Years of Brown Dwarfs,* ed. Viki Joergens (Cham: Springer, 2013), 96.

Chapter Eight

1. M. Demiański and M. Prószyński, “Does PSR0329 + 54 Have Companions?” *Nature* 282 (November 22, 1979): 383–385.

2. T. V. Shabanova, “Evidence for a Planet around the Pulsar PSR B0329+54,” *Astrophysical Journal* 453 (November 1995): 779.

3. B. Cadwell, “Pulsar Survey and Timing with the Penn State Pulsar Machines,” *Bulletin of the American Astronomical Society* 29, no. 5 (December 1997): 1396.

4. E. D. Starovoit and A. E. Rodin, “On the Existence of Planets around the Pulsar PSR B0329+54,” *Astronomy Reports* 61, no. 11 (November 2017): 948–953.

5. A. Wolszczan and D. A. Frail, “A Planetary System around the Millisecond Pulsar PSR1257 + 12,” *Nature* 355 (Jan. 1992): 145–147.

6. A. Patruno and M. Kama, “Neutron Star Planets: Atmospheric Processes and Irradiation,” *Astronomy and Astrophysics* 608 (2017): A147.

7. Michael D. Lemonick, *Other Worlds: The Search for Life in the Universe* (New York: Simon and Schuster, 1998), 87.

8. Doug Braun, “Barnard’s Star and Planets?” Astro.sci Usenet group, March 23, 1995.

9. Sarah Lee Lippincott, “Peter van de Kamp, 1901–1995,” *Bulletin of the American Astronomical Society* 27 (December 1995): 1483–1484.

10. David Stout, “Peter van de Kamp, Astronomer and Musician at Swarthmore, 93,” *New York Times*, May 23, 1995.

11. Laurence Fredrick, “Peter van de Kamp (1901–1995),” *Publications of the Astronomical Society of the Pacific* 108 (August 1996): 556.

12. Marcus Woo, “The First Planet Ever Discovered around Another Star,” *BBC Earth*, October 20, 2016, http://www.bbc.com/earth/story/20161019-the-first-planet-around-another-star.

13. Michel Mayor and Didier Queloz, “A Jupiter-Mass Companion to a Solar-Type Star,” *Nature* 378, no. 6555 (1995): 355–359.

14. Rebolo, “Teide 1 and the Discovery of Brown Dwarfs,” 25–47.

15. Maggie A. Thompson, J. Davy Kirkpatrick, Gregory N. Mace, Michael C. Cushing, Christopher R. Gelino, Roger L. Griffith, Michael F. Skrutskie, Peter R. M. Eisenhardt, Edward L. Wright, and Kenneth A. Marsh, "Nearby M, L, and T Dwarfs Discovered by the Wide-field Infrared Survey Explorer (WISE)," *Publications of the Astronomical Society of the Pacific* 125, no. 929 (July 1 2013): 809–837.

16. George Gatewood, "Lalande 21185," *Bulletin of the American Astronomical Society* 28 (May 1996): 885.

17. Natalia Shakht, "A Study of the Motion of the Nearby Red Dwarf Lalande 21185," in "Complementary Approaches to Double and Multiple Star Research," ed. H. A. McAlister and W. I. Hartkopf, *International Astronomical Union Colloquium* 135 (1992): 346.

18. George Gatewood, John Stein, Joost K. de Jonge, Timothy Persinger, Thomas Reiland, and Bruce Stephenson, "Multichannel Astrometric Photometer and Photographic Astrometric Studies in the Regions of Lalande 21185, BD 56 deg 2966, and HR 4784," *Astronomical Journal* 104, no. 3 (September 1992): 1237–1247. Research supported by University of Pittsburgh and Allegheny Observatory.

19. D. W. McCarthy Jr., "Near Infrared Imaging of Unseen Companions to Nearby Stars," in "The Nearby Stars and the Stellar Luminosity Function," ed. A.G.D. Philip and A. R. Upgren, *International Astronomical Union* Colloquium 76 (1983): 107.

20. Tommy Ehrbar, "Invisible Dancer," *Pitt Magazine*, January 1997, https://web.archive.org/web/20160303174636/https://www.pittmag.pitt.edu/jan97/gatewoodh.html.

21. Virginia Trimble and Lucy-Ann McFadden, "Astrophysics in 1997," *Publications of the Astronomical Society of the Pacific* 110 no. 745 (March 3, 1998): 224.

22. Bruce Dorminey, *Distant Wanderers: The Search for Planets Beyond the Solar System* (New York: Copernicus, 2002), 116.

23. Natalia Shakht, "The History of the Search for Extrasolar Planetary Systems at Pulkovo Observatory," in *Planetary Systems: The Long View*, ed. L. M. Celnikier and J. Trân Thanh Van (Gif-sur-Yvette, France: Editions Frontières, 1998), 395.

24. Alycia J. Weinberger, Geoff Bryden, Grant M. Kennedy, Aki Roberge, Denis Defrère, Philip M. Hinz, Rafael Millan-Gabet, et al., "Target Selection for the LBTI Exozodi Key Science Program," *Astrophysical Journal Supplement* 216, no. 2 (January 27, 2015): 24.

25. R. Paul Butler, Steven S. Vogt, Gregory Laughlin, Jennifer A. Burt, Eugenio J. Rivera, Mikko Tuomi, Johanna Teske, et al., "The LCES HIRES/Keck Precision Radial Velocity Exoplanet Survey," *Astronomical Journal* 153, no. 5 (April 13, 2017): 1–19.

26. Abel Mendez, "A New Search for Extrasolar Planets from the Arecibo Observatory," press release, Planetary Habitability Laboratory, July 12, 2017, http://phl.upr.edu/press-releases/barnard.

27. G. Fritz Benedict, Barbara E. McArthur, George Gatewood, Edmund Nelan, William D. Cochran, Artie Hatzes, Michael Endl, et al., “The Extrasolar Planet ε Eridani b: Orbit and Mass,” *Astronomical Journal* 132, no. 5 (November 2006): 2206–2218.

28. Joshua Roth, “Does 51 Pegasi’s Planet Really Exist?” *Sky and Telescope* 93, no. 5 (May 1997): 24–27.

29. G. A. H.Walker, D. A. Bohlender, A. R.Walker, A. W. Irwin, S. L. S. Yang, and A. Larson, “Gamma Cephei—Rotation or Planetary Companion?,” *Astrophysical Journal* 396, no. 2, part 2—letters (September 10, 1992): L91–L94.; Jacob Berkowitz, “Lost World: How Canada Missed Its Moment of Glory,” *Globe and Mail*, May 1, 2018.

30. Artie P. Hatzes, William D. Cochran, Michael Endl, Barbara McArthur, Diane B. Paulson, Gordon A. H. Walker, Bruce Campbell, and Stephenson Yang, “A Planetary Companion to γ Cephei A,” *Astrophysical Journal* 599, no. 2 (December 2003): 1383–1394.

31. Stephen R. Kane and Dawn M. Gelino, “Distinguishing between Stellar and Planetary Companions with Phase Monitoring,” *Monthly Notices of the Royal Astronomical Society* 424, no. 1 (July 21, 2012): 779–788.

Chapter Nine

1. Ben Guarino, “The Hottest Planet Ever Discovered Has an Atmosphere as Warm as a Star’s,” *Washington Post*, June 5, 2017, https://www.washingtonpost.com/news/speaking-of-science/wp/2017/06/05/the-hottest-planet-ever-discovered-has-an-atmosphere-as-warm-as-a-stars.

2. I. Ribas, M. Tuomi, A. Reiners, R. P. Butler, J. C. Morales, M. Perger, S. Dreizler, et al., “A Super-Earth Planet Candidate Orbiting at the Snow-Line of Barnard’s Star,” *Nature* 563 (November 15, 2018): 365–368. I reviewed a preprint made available by the authors.

3. Daniel Bayliss, Edward Gillen, Philipp Eigmuller, James McCormac, Richard D. Alexander, David J. Armstrong, Rachel S. Booth, et al., “NGTS-1b: A Hot Jupiter Transiting an M-Dwarf,” *Monthly Notices of the Royal Astronomical Society* 475, no. 4 (April 2018): 4467–4475.

4. Mikko Tuomi, Hugh R. A. Jones, John R. Barnes, Guillem Anglada-Escudé, and James S. Jenkins, “Bayesian Search for Low-Mass Planets around Nearby M Dwarfs: Estimates for Occurrence Rate Based on Global Detectability Statistics,” *Monthly Notices of the Royal Astronomical Society* 441, no. 2 (June 21, 2014): 1545–1569.