The night sky reveals itself differently to each stargazer. Sitting by a dying campfire, what do you see above you? Do you see an opportunity for a silent wish falling towards Earth? An intricate calendar marking the passage of seasons? Zodiac signs?

To SF State assistant professor Dr. Stephen Kane, each star’s twinkle may suggest the presence of planets, as well as the possibility that those orbiting bodies may harbor life.
By quantifying how common Earth-like planets are in the Universe, astronomers like Kane can begin to put Earth’s habitability in context. “If you look at 100 planets and find that 50 of them have evidence of life,” Kane explains in his breezy, Aussie accent, “you can start to say amazing things like ‘The evolution of life on a planet is a natural process given the right conditions.’” In other words, despite humankind’s historical egocentrism, life may be relatively common.

Judging the habitability of exoplanets is a new field because it has only been possible to detect planets beyond our solar system for the past two decades. “Exoplanets are a case where technology had to catch up to ideas,” says Kane. “People have been thinking about planets around other stars for centuries—for millennia, actually.” Yet without instruments capable of looking deep into space, exoplanets could exist only in the realm of science fiction novels. They are extremely difficult to find because, by definition, exoplanets are light years away. Meaning—really far. Light can travel 186,000 miles per second, and a light year measures the distance light can travel in one year: 6 trillion miles! The closest star system, Alpha Centauri, is 4.3 light years away from our sun. The closet planet, therefore, must be more than 24 trillion miles from earth.

Long before scientists first detected exoplanets in 1995, Kane became fascinated with our solar system’s own worlds. He was on a sixth grade school excursion to a local planetarium, he recalls. But “it wasn’t like a planetarium where you sit back and watch projections on the ceiling.” Kane grew up in a small, rural town called Tanworth, which, he adds jokingly, is “the Nashville of Australia.” “You drive out of the town,” he says, “and the planetarium is a pyramid-shaped structure, basically in a sheep paddock.” His sixth grade class stood above a movable model of the solar system called an orrery. The orrery’s sun brightened slowly, revealing planets one by one while a voice-over spoke of each orb’s unique characteristics. “Listening to this, I was very fascinated with the different qualities of the planets,” Kane smiles. “How can we know what they’re like? They really captured my imagination.”

In 1995, scientists detected the first exoplanet around a Sun-like star, just as Kane was considering what to study in graduate school. “Hey, now we’re able to find all these other planets,” he recalls. “Why not start there?” In early 1996, Kane started splitting his time between the University of Tasmania and the Space Telescope Science Institute in Baltimore. At the Maryland facility, he was able to find new far-flung planets using a technique called microlensing. This approach uses Einstein’s theory of general relativity, which describes the way that mass can bend light. If an object passes in front of a celestial body, its mass bends the starlight to make it brighter. This light is then a magnifying glass bends the light from an object and makes it appear bigger.

With microlensing, astronomers detect the increased luminosity and determine the presence of a planet. It is a difficult method to use, “but it does work,” explains Kane. “It’s been used to find about 1-20

The diagram on pages 44–45 compares the planets of the inner solar system to Kepler-62, a five-planet system about 1,200 light-years from Earth in the constellation Lyra. The five planets of Kepler-62’re orbit classiﬁed as a K2 dwarf, measuring just two thirds the size of the sun and only one fifth as bright. In Kepler-62, the star is somewhat older than the sun.

Toxic Wasteland or Lush Paradise?

This artist’s concept shows a Super Venus planet on the left, and a Super Earth on the right. Researchers use a concept known as the habitable zone to distinguish between these two types of planets, which exist beyond our solar system. Super Venus and Super Earths are similar to Venus and Earth, respectively, but larger in mass. Similar to our solar system’s worlds, a Super Venus would most likely be a dry, toxic wasteland while a Super Earth might host oceans.

The habitable zone is the region around a star where liquid water an essential ingredient for life as we know it—can pool on the surface. Earth lies within the habitable zone around our star. A recent study looked at the planet Kepler-62, discovered by NASA’s Kepler mission and originally thought to lie in its star’s habitable zone. The planet is 1.7 times the size of Earth and lies 2,700 light-years away. The analysis showed that this planet lies just outside the inner edge of the zone, making it more of a Super Venus than a Super Earth. That means the planet is not a tropical paradise, but more likely scorching hot, with volcanic eruptions.

The search for planets as small as Earth, situated in the habitable zones of stars like our sun, is ongoing.

The closet planet, therefore, must be more than 24 trillion miles from earth.

The artist’s concept of the Kepler-62 planets are the result of scientists and artists collaborating to help imagine the appearance of these distant worlds.

The Kepler space telescope, which simultaneously and continuously measures the brightness of more than 190,000 stars, is NASA’s first mission capable of detecting Earth-size planets around stars like our sun.

Dr. Stephen Kane
Department of Physics & Astronomy
planets at this stage.”

During a second postdoctoral fellowship, this one at the University of Florida, Kane began using the radial velocity method, which can detect a planetary presence by how its mass makes a star move. As the orb goes around the star, the celestial body will wobble, causing a change in the starlight’s frequency. Explaining SF State’s history of planetary discovery, Kane recounted, “The Department here has a strong history of looking at the radial velocity method.”

It was here in 1995 that SF State astronomer Geoffrey Marcy used the radial velocity technique to detect one of the very first exoplanets. “It’s kind of cool that SF State plays a pivotal role in the development of a whole new branch of astrophysics!” adds SF State astronomer Joseph Barranco, an expert in planetary formation.

By now, scientists have detected thousands of exoplanets. This is thanks, in part, to the sensitive instruments aboard advanced spacecraft like the Kepler space observatory, which NASA launched in 2009. At 9 feet wide and 15 feet tall, this combination space-telecscope-camera-computer looks like a giant golden tube of lipstick. It orbits the sun outside of Earth’s gravity. This makes it easier to remain pointed to a northern star field, where it detects the brightness of stars. “It just stares at the same patch of sky, day in and day out,” says Barranco.

Piercing through a telescope which Barranco forms with his thumbs and forefingers, he continues. “For years, [Kepler] looks at all the stars in that field simultaneously. The straight path through the telescope where it hits a flat plate, the ‘focal plane array’.”

This electronic sheet is divided into a grid of tiny squares called pixels. Like a bucket collecting drops of rain, these pixels collect photons from space—particles of starlight. The pixels create a pattern that Kepler’s computer stores digitally. The spacecraft sends the digital information to Earth via satellites. Back home, astronomers at NASA Ames Research Center in Mountain View bank the data and make it publicly available. Astronomers then and elsewhere can then analyze the digitized photon patterns and identify changes in star brightness.

Kane and his students keep track of such changes in star brightness on a light curve. When an object passes in front of a star, “it blocks out some of the light and you see a little dip in the light curve,” explains Kane’s graduate student, Arthur Adam. As Adam speaks, he traces an arc with one hand and pushes his dark curls back with the other. “And there you go! There’s a possible planet.” Researchers call this monitoring of star brightness patterns the transit method. “The key thing you learn from the transit method,” Kane elaborates further, enthusiastically mimicking a beach-ball-sized orb with his hands, “is that you learn the size of the planet.” The dip in the light curve indicates the planet’s diameter. The bigger the dip, in other words, the bigger the planet.

By combining all three methods, Kane has detected at least 50 of the known planetary bodies since beginning his graduate work. “He is quite accomplished,” says Barranco, explaining Kane’s brain power. “It’s like focusing on the trees for the forest. My forest is the universe.”

Kane agrees. Physics and astronomy are about the bigger picture. “Sometimes I lose perspective and get lost in computer models,” he adds, “It’s like focusing on the trees for the forest. My forest is the universe!”

The mission of the Kepler spacecraft is to identify Earth-sized planets around the stars within its field of view. Obviously, we can be certain from personal experience that a world the size of our own can sport a terrestrial surface and a livable atmosphere that sustains life. Once Kane confirms a planet’s size, he can then calculate its habitable zone. “In our solar system we have Venus, too hot; Mars, too cold, and Earth, just right,” observes Barranco. “It’s the classic Goldilocks problem.” Kane also needs to know the amount of time the planet spends in the habitable zone, which he determines by its orbital shape. Explains Adams, “If you’ve got a perfectly circular orbit, the planet is either within or completely outside of it.” Habitability gets complicated if the planet has an eccentric, or oval-shaped orbit.

In May 2013, Kane and colleagues from the NASA Exoplanet Science Institute at Caltech and NASA Ames Research Center jointly published a paper in Astrophysical Journal Letters. This article challenged the classification of a Kepler planet, Kepler 69c, as a “super earth.” Astronomers label exoplanets super earths if they have Earth-like features, but are slightly larger in size. “Scientists thought Kepler 69c was an Earth-like planet and rightly so, given the data,” Adams says, explaining Kane’s paper. “But now we have refined data that doesn’t quite fit the bill!” Using the new information, Kane discovered a slight eccentricity in the planet’s orbit, revealing that Kepler-69c spends only part of the time in its habitable zone. “In this context, the planet’s surface temperature is too warm when the planet is closest to its star and too cold when it’s farthest.”

Emphasizes the point Kane makes in the paper: Just because Kepler 69c is Earth-sized, its surface is likely uninhabitable because it spends less time within the space of its own star’s habitable zone.

By discovering and describing exoplanets and their orbits, Kane calculates the probability that life could exist on the surface of Earth-sized spheres orbiting within habitable zones. This completes a piece of the puzzle that will answer how common life is in the universe—a puzzle first outlined in the Drake Equation. This formula, generated by astrophysicist Dr. Frank Drake in 1961, inspired future planetary hunters decades before anyone proved that planets exist outside our solar system.

The Drake Equation, says science writer Nadia Drake, explaining her famous gardener’s breakwater work, was “something that he put together to organize his thinking about what elements are needed for civilizations to be detectable.” It starts out very broadly by identifying the fraction of stars that have planets, then the fraction of stars that have Earth-size planets; and then the fraction of stars that have Earth-sized planets in the habitable zone. Kane’s research, notably, is beginning to quantify this latter puzzle-piece. As technology improves, perhaps astronomers can begin quantifying the more refined variables of the Drake Equation: the fraction of habitable planets with life, the fraction of life-bearing planets with civilizations at some time, and finally, the fraction of civilizations existing now. “You go outside and look up,” says Nadia Drake. “Once the night sky was just full of stars. Now it’s stars and planets... maybe in ten years it’ll be stars and planets and life!”

Kane hopes his research on exoplanets will likewise inspire budding scientists to reveal a sky filled with possible life. He wonders, “What will inspire kids these days?” He hopes the list includes findings and interpretations, “that result from things like the Kepler mission.” The mission certainly inspired graduate student Arthur Adams to begin his work with Kane to calculate habitable zones for Earth-size exoplanets. Describing the first time Adams heard Kane present his research, he says, “He has this enthusiasm like, ‘Oh, you gotta study this, and look at all this stuff!’ Computing the habitable zones for potentially life-bearing planets is an essential step toward refining the search for life itself—a step Adams has been proud to undertake. “Physics is an interesting puzzle to solve,” he says. “Sometimes it lose perspective and get lost in computer models.” But, he adds, “It’s like focusing on the trees for the forest. My forest is the galaxy!”

Kane agrees. Physics and astronomy are about the bigger picture. “We’re being able to say that our philosophers have been trying to answer for a millennia. And we’re finally able to do it!” Kane, his students, and colleagues are carrying forward this philosophical quest, he muses, because, like those before us, “we [each] have an inquiring mind and want to understand the universe.”