Only one planet has been proven to support life: Earth. But evidence is mounting that we are not alone. Scientists now think the galaxy contains at least 11 billion Earth-size worlds orbiting in their stars' habitable zones, where life is most likely to be found. And new studies show that strange creatures may thrive far beyond that boundary—on nearly any of the galaxy's 100 billion planets or their moons. Popular Mechanics presents . . .

THE CASE FOR ALIEN LIFE

BY SARAH FECHT

[redacted]

The search for alien life in distant star systems is accelerating. Here, each triangle represents 2.25 million worlds in the Milky Way galaxy. The colors provide information on the sizes of these worlds and their positions within their star systems. These factors may affect the odds of life emerging, and what course evolution would take.

- 100 BILLION PLANETS TOTAL
- 50 BILLION SMALL PLANETS*
- 17 BILLION EARTH-SIZE PLANETS
- 11 BILLION EARTH-SIZE PLANETS IN STARS' HABITABLE ZONES**
- ONE PLANET WITH CONFIRMED LIFE

* Small planets are from about half to 3x the size of Earth.

** The habitable zone is the range of distances from a star where liquid water can persist on the surface of a planet.

On Feb. 9, 2013, NASA's Curiosity rover found something on Mars that set a milestone in the search for alien life. Packed with instruments, the rover was an SUV-size speck crawling across the floor of the Gale Crater, whose distant walls climbed 15,000 feet in the thin air. The rover had been lowered to the ground six months earlier by means of a complex, jet-propelled sky crane. Now, almost 221 million miles from home but just a quarter-mile from its landing site, Curiosity was exploring a shallow depression called Yellowknife Bay. The machine trundled up to an outcropping of bedrock, which lay dry and cracked beneath a yellow sky. It drilled into the rock and within minutes pulled a fine gray powder from the narrow borehole. Curiosity scooped up the dust and tasted it.

The sample contained smectite clay, which on Earth is found in alluvial plains and regions washed by monsoons. Today, Mars is a largely arid world whipped by global dust storms, where temperatures can swing 170 F in a day. Three billion years ago, it seems, a river of sweet water cascaded over the rim of Gale Crater and emptied into a lake in Yellowknife Bay. The sky was probably bluer then, and cloudier, and the terrain hadn't yet rusted from gray to red. Mount Sharp, which rises 18,000 feet above the crater floor, may have been capped in ice and snow.

Curiosity found in the ancient clay many of the elements needed for life: carbon, hydrogen, oxygen, nitrogen, and phosphorus. We don't know whether bacteria, let alone Earth-like plants and animals, once teemed in Yellowknife Bay, but they could have. The rover was just the newest scout in humanity's decades-long exploration of Mars, an effort that currently includes the dogged 10-year-old Opportunity rover and three orbiters in space. But Yellowknife Bay is the first site ever observed, on Mars or anywhere else, that clearly could have supported extraterrestrial life.

Generations of scientists and science-fiction fans (often, those are the same people) have thought we'd find life strewn throughout the stars—if not civilizations, at least bacterial mats, or tentacled beasts on ocean floors, or something. But for decades the evidence was thin. Now, in 2013, the data is on the side of the believers. It has been provided by increasingly sophisticated probes, space telescopes, and rovers. Planets were once thought to be rare; by the time the Kepler space telescope ran into severe mechanical problems in May, it had proved that alien worlds actually number in the billions. Scientists imagined the universe to be parched; new studies show that it's filled with watery planets. And, surprise: Life isn't some delicate thing, like a pasty tourist stuck beneath a beach umbrella; it's now known to be more like a hardy soldier, able to infiltrate the harshest environments.

The exciting exobiological news keeps coming: In April, astronomers identified a trio of planets that appear capable of supporting Earth-like life. They orbit their stars' habitable zones, the just-right distance where water neither freezes nor boils, but collects in sloshy, life-friendly oceans. One of the worlds, dubbed Kepler-62e, even shows signs of a humid atmosphere strewn with clouds. More such discoveries will come.

Louisa Preston, an astrobiologist at Open University in the U.K., investigates the telltale signs of biology that could help us locate life in space. "It's now predicted that there are 17 billion Earth-like planets in our galaxy alone," Preston says. "And since our galaxy is one of hundreds of billions in the universe, the chances of finding life are increasing exponentially."

Here are three reasons, in detail and based on current research, why we are much more likely to find life than to discover we are alone.

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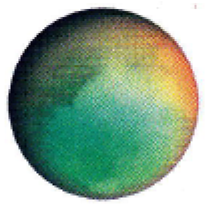
1. WATER IS COMMONPLACE, NOT RARE.

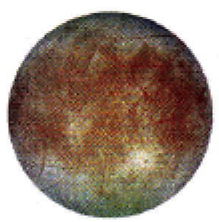
On its milky-white surface, Europa doesn't seem like a good place to go life hunting. The small Jovian moon gets blasted with high doses of radiation. It has almost no atmosphere, and temperatures can dip to minus 370 F at the poles. But beneath a thick shell of ice, Europa appears to be covered by an ocean that may be 60 miles deep and contain as much salty water as the Earth's seas three times over. A rocky seafloor, perhaps home to hydrothermal vents, may spew out chemical nutrients. On Earth such locations are crowded with tube worms, eyeless shrimp, and other strange creatures.

3 SPOTS TO SEARCH FOR LIFE IN OUR SOLAR SYSTEM



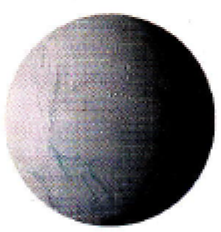
TITAN

WHAT: Largest of Saturn's 62 moons. **WHERE TO LOOK:** Lakes of ethane and methane. **MISSION:** NASA and the European Space Agency are considering a plan to drop landers into one of Titan's lakes.



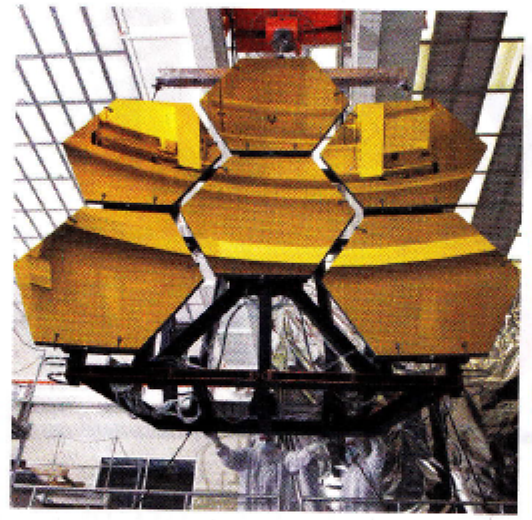
EUROPA

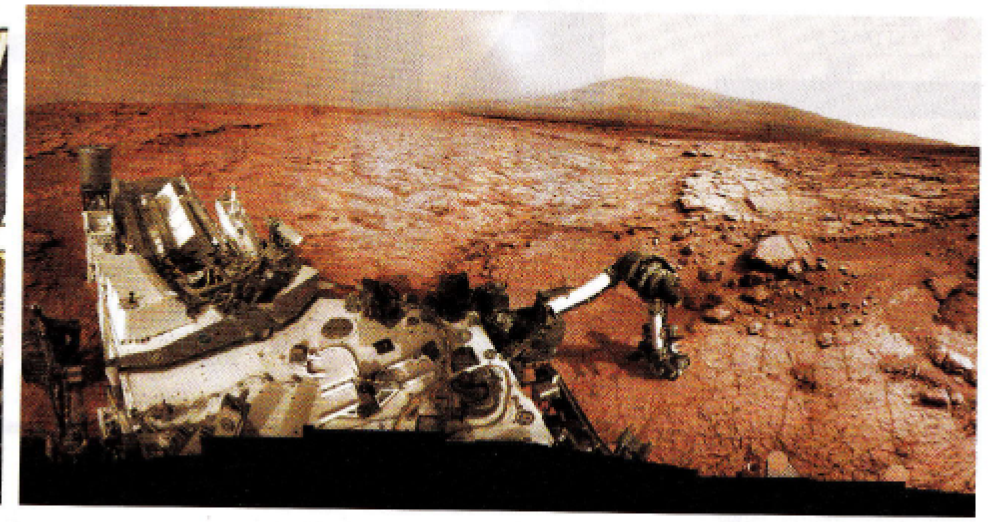
WHAT: One of Jupiter's 67 moons. **WHERE TO LOOK:** The ocean, beneath miles of ice. **MISSION:** The Jupiter Icy Moons Explorer (JUICE), to launch in 2022, will search for organic molecules and use ice-penetrating radar to find the thinnest sections of the crust.



ENCELADUS

WHAT: Geologically active moon of Saturn. **WHERE TO LOOK:** The ice-crusted ocean. **MISSION:** A proposed 2020 mission would swoop through cryovolcanic plumes. No lander is necessary, so future sample-return missions could be affordable.





JAMES WEBB SPACE TELESCOPE

After it launches in 2018, the JWST (above left) will analyze light from the planets orbiting distant stars for signs of water, oxygen, methane, and other biologically meaningful molecules in their atmospheres.

CURIOSITY ROVER

The newest Mars rover found evidence of ancient freshwater at this site in Yellowknife Bay in the Gale Crater.

Until recently, liquid water was thought to be a rarity in space. No longer, according to James Green, director of NASA's Planetary Science division in Washington, D.C. "What we're finding out is that water seems to be everywhere," he says. Scientists considered the surface of Mars to be bone-dry until 2011, when they noticed dark streaks that grow during warmer months, recede in the winter, and then return again in the spring, possibly indicating a seasonal freeze-thaw cycle. Some scientists speculate that microbes could be living beneath the Martian surface today. In November 2012, a team of NASA researchers revealed that Mercury, where temperatures can climb as high as 800 F, holds more than 100 billion metric tons of water ice in its permanently dark craters. Even the moon—once thought to be the driest place in our solar system—has an active water cycle, scientists discovered in 2010. And evidence is mounting that other moons, including Saturn's Enceladus and Jupiter's Ganymede, are home to vast subsurface oceans like Europa's.

And that's just in our solar system. NASA's Submillimeter Wave Astronomy Satellite, which flew until 2005 and imaged a variety of star-forming clouds in the Milky Way, turned up evidence of water nearly everywhere it looked. The Keck and Hubble telescopes have spotted water vapor in the atmospheres of planets in other star systems, and research conducted by Jay Farihi at the University of Cambridge suggests that liquid water is actually typical of rocky planets such as our own.

The same chemical plenty extends beyond the aqueous. All of Earth's life ingredients seem to be scattered liberally throughout the galaxy. The Hubble telescope uncovered the first evidence of an organic molecule—methane—in the atmosphere of an extrasolar planet in 2008. The Spitzer Space Telescope revealed in 2005 that the galaxy is littered with nitrogen-containing polycyclic aromatic hydrocarbons—ring-shaped molecules that may become the building blocks of DNA, RNA, chlorophyll, and hemoglobin. Simpler organic compounds have been detected on Mercury, Ganymede, and Enceladus. And analyses of meteorites that have struck Earth suggest that asteroids are zooming through the cosmos carrying water ice, nitrogen, sulfur, ready-made sugars and amino acids, and some of the components of genetic material. (One line of thinking even suggests that life on Earth was seeded by space rocks.) "The kind of chemistry that could have been used for life exists everywhere," says David Blake, a geologist on the Curiosity rover team. "There's no reason that life wouldn't have happened on other solar systems. The ingredients are everywhere we look."

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2. LIFE IS MORE VERSATILE THAN WE BELIEVED.

The sun never stops shining during the Antarctic summer. "Time doesn't mean much there," says cryobiologist Brent Christner. "Morning, night—it all pretty much looks the same." Ironically, given all that sunshine, Christner had traveled to Antarctica from his Louisiana State University lab in Baton Rouge to look for microbes that live in perpetual darkness. He and his colleagues spent months in the cramped quarters of Antarctica's McMurdo Station preparing a drill system to bore into Lake Whillans. The shallow lake is buried below 2600 feet of ice and measures 20 square miles. A crew spent two weeks dragging the drilling equipment 600 miles to the lake

THE SEARCH FOR INTELLIGENT LIFE

- Blue: DRAKE EQUATION, 1961 ESTIMATES
- Red: RECENT ESTIMATES

$$N = R \times f_p \times n_e \times f_l \times f_i \times f_c \times L$$

		Drake equation, 1961 estimates	Recent estimates
N	civilizations in our galaxy that use detectable communications	500	2100
R	average rate of star formation per year in our galaxy	10 PER YEAR	7 PER YEAR
f_p	fraction of stars that have planets	0.5	1.0
n_e	number of worlds (planets and their moons) per star system with an environment suitable for life	1	3
f_l	fraction of habitable worlds where life originates	0.1	0.1
f_i	fraction of life-bearing worlds where intelligence develops	0.1	0.1
f_c	fraction of civilizations that develop detectable communications	1.0	1.0
L	how long such civilizations generate detectable signals	10,000 YEARS	10,000 YEARS

HOW MANY?

In 1961 astronomer Frank Drake presented this equation, which has since been named for him, to express the factors that affect the odds of finding alien civilizations. Some values that Drake guessed at can now be estimated with confidence. But the biggest question remains: How often does life evolve? We just don't know.

HOW TO SEARCH

Researchers at the Search for Extraterrestrial Intelligence, or SETI, Institute, listen for alien radio waves. Astronomer Jason Wright from Penn State University plans to look instead for heat signatures in the mid-infrared range, possibly given off by alien cities. "If even 5 percent of a star's light were being used and reradiated at a low temperature, it would be an obvious outlier," he says. "That's too much mid-infrared radiation for it to be normal."

site, following the route that Robert Falcon Scott had used to reach the South Pole 100 years earlier, and along which Scott and his crew perished during the return trip.

Using hot water, the drill cut down to the lake in 30 hours. A sample was rushed to a mobile microbiology lab on the surface. As he peered through the microscope, Christner delighted in what he saw: tiny footballs, basketballs, and springs—strains of bacteria that had been thriving in Lake Whillans, cut off from the Antarctic surface for thousands of years. The scientists reported the findings in January. They aren't sure how the microbes manage to survive down there in the dark and frigid water, but their discovery bodes well for the search for life beneath alien ice. "It isn't that much of a stretch to suggest that similar conditions, on a place like Europa or any of the icy worlds in the solar system, could also support life," Christner says. "And if they don't, I think a larger question would be, why?"

The study of extremophiles was already well-advanced a decade ago, but work such as Christner's is continuing to extend the known boundaries of life. Organisms thrive in the deepest reaches of the ocean, in the driest of deserts, and in the saltiest of sands. The red algae *Galdieria sulphuraria* can prosper in sulfuric hot springs and old mineshafts with waters as caustic as battery acid. Even our skies are swirling with microbes, a paper published in January revealed. Researchers collected thousands of bacteria from as high as 9 miles above the ground. The airborne ecosystems withstand rough winds and large doses of radiation—and may never touch the planet surface. "Most of the environments we used to think were sterile are proving to have life," Open University's Preston says. "Every time we think we've found somewhere on Earth that life can't survive in, we go and find a part of life that can."

Astrobiologists say that the watery worlds in stars' habitable zones are still the likeliest places to search for life. But new extremophile studies suggest that organisms might also survive on desert worlds and in the thick atmospheres of Venus-like bodies. They might even live on hurtling asteroids and the starless rogue planets that roam the galaxy. In our own solar system, Jupiter and Saturn are outside of the sun's habitable zone, according to the standard definition, yet several of their moons (including Europa, Enceladus, Titan, and Ganymede) are considered among the most promising sites to search. Liquid water is possible even in the coldest reaches of the universe, on worlds heated from within by nuclear processes or geothermal activity. On other planets, salt, ammonia, or methanol could serve as antifreeze. To Steven Desch, an astrophysicist at Arizona State University, these insights require new thinking. "If life might exist in the subsurface oceans of moons, heated by their own radioactivity," Desch says, "then no distance from the sun is too far. It's beginning to look like the definition of a habitable zone is out the window."

That would be especially true if alien life were truly weird. Titan, for instance, has rivers and lakes of hydrocarbons. Could organisms have evolved there without incorporating water? Ariel Anbar, a biogeochemist, also at Arizona State University, points out that distant star systems will have varying proportions of elements such as carbon, oxygen, and silicon. Such variety could drive evolution in hard-to-imagine directions. "The things we can conceive of are probably a very small set of the possibilities that are out there," Anbar says. "We know we're going to be surprised."

3. PLANETS ARE THE RULE, NOT THE EXCEPTION.

In the past decade, science lost one planet—Pluto, which was downgraded to dwarf status—but it gained billions of others. "For most of history, we've learned that there were a handful of planets, and that was it," says Michio Kaku, a theoretical physicist at City College of New York. "Anything beyond that was just speculation. It was a shock to find scores of exoplanets. We find about two a week now, so the catalog is just bursting."

Credit goes to the Kepler space telescope. Since it began operating in 2009, Kepler has orbited the sun, trailing behind Earth and staring up at a patch of sky that encompasses more than 100,000 stars. Its central task: Measure the light coming from each star, and patiently wait for it to dim temporarily, signaling that a planet is eclipsing the field of view. As of January Kepler had discovered 2740 potential planets—up from 1235 in February 2011. The findings need to be confirmed by further study, but if past experience is predictive, 90 percent will turn out to be real planets.

Extrapolating from the Kepler findings, astronomers now estimate that at least 100 billion planets occupy the Milky Way galaxy. In January researchers analyzed the planetary candidates circling 4000 red dwarf stars and calculated that nearly 11 billion Earth-size exoplanets could have liquid water on their surfaces. The real number may be much higher. Ravi Kopparapu, a physicist at Penn State University, updated the formula for defining the habitable zone to include newer data about how water vapor and carbon dioxide absorb heat—essentially applying research on earthly global warming to the larger cosmos. His team arrived at a figure of 36 billion such planets—and, he says, "that is a conservative estimate."

Kepler's useful life may be coming to a close, but two new space instruments will soon follow in its footsteps. The recently announced TESS (Transiting Exoplanet Survey Satellite) telescope, which is supposed to launch in 2017, will scan the entire sky for nearby exoplanets. It should be able to detect everything from Earth-size bodies in their stars' habitable zones to gaseous giants. The long-anticipated James Webb telescope, scheduled for a 2018 deployment, may analyze the atmospheres of such planets for evidence of life, while also providing insights on galaxy formation.

The new research on red dwarf stars is even shaping the scientific thinking on alien civilizations. Seth Shostak is an astronomer for the SETI (Search for Extraterrestrial Intelligence) Institute, which uses an array of 20-foot satellite dishes in northern California to search for anomalous radio signals that could have been transmitted by alien technology. "Red dwarfs don't burn out nearly as quickly as the bigger stars," Shostak says. "On average they're older. And when you think of intelligent life, it might need a long time to get going." Shostak would like SETI to begin pointing its antennas at more red dwarf systems.

The odds of finding alien civilizations remain slim—yet that does not diminish the excitement surrounding off-world biology. "Soon we're going to have an existential shock," Kaku says. "In the next 50 years, there's a very good chance that we'll make contact with an extraterrestrial life-form. In the familiar constellations that we learned as children, we will find twins of Earth, and that's going to change our understanding of who we are in this universe. Even if we find a fossil, a DNA strand from another species, that would be absolutely staggering." It could be viewed as an upheaval equal to Copernicus's proof that Earth isn't the center of the universe, or to Edwin Hubble's discovery that our entire solar system is a tiny speck of dust in a galaxy full of billions of stars—and that even the galaxy is one of countless many.

Of course, there's no guarantee that we'll ever find organisms on distant worlds. We can't calculate the odds of life arising spontaneously, because we can only confirm that it has happened once. But life here on Earth proves that the probability is greater than zero. And in an infinite universe with billions of planets, there are billions of opportunities for evolution to commence. "Is life a universal phenomenon, a planetary process just like plate tectonics?" Anbar asks. "Or is life some weird statistical fluke? The only way we can answer that is by searching."