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The search for life on other planets revolves around the concept of habitability. What makes our own Sun such an excellent parent for life? Our planet has remained habitable for life for some 3.7 billion years. So, what is it that allows a planet -- and its parent star -- to support life? We know life will take hold if given a chance. This is a lesson biologist have learned about Earth, where organisms prosper in ice, rock, steaming geysers, and acidic pools. We also know life changes its environment, often creating new niches for life where there were none before. Ultimately, it seems all of life's basic requirements come down to one thing: liquid water. Life needs other things, too, like construction materials (such as carbon, nitrogen, and oxygen) and an energy source (starlight, a planet's internal heat, or chemical energy). But I submit that any environment with pools of liquid water will likely have these things, too. Part of the search for living worlds beyond the solar system involves the idea of a habitable zone around each star. This is a region where the temperature is right for the presence of liquid water on an earthlike planet. This circumstellar habitable zone is only one of the potential abodes for thriving ecosystems (see "Possible nooks for life." page 61). But at our early stage of understanding other planetary systems, the circumstellar habitable zone is the only nook we can study from afar.

Stability: the first obstacle While we still have much to learn about the Sun's habitable zone, we do know Earth lies within in and has been there for billions of years. Venus -- our sister planet in terms of size and mass -- is 30-percent closer to the Sun than Earth and doesn't lie within the habitable zone. Venus is too hot of life and likely lost its water early in its history as oceans were boiled off by the searing sunlight. Mars, 50-percent farther from the Sun than Earth, is colder but, nevertheless, had liquid water flowing over its surface in the relatively recent past. Mars is probably within the Sun's habitable zone, and if the planet were just a tad more massive, its gravity could hold a substantial atmosphere. A habitable zone that lasts billions of years is an important factor in the search for planets with life. As of now, we know nothing about the presence or absence of terrestrial planets in the habitable zones of the Sun's neighbors. However, we know a lot about the stars themselves, and we can see which would make good parents. A good parent star is one with a habitable zone that remains in the same place for billions of years. The second constraint is nothing should prevent the formation of terrestrial planets. Not all stars pass these hurdles. The first requirement -- habitability over billions of years -- puts strict constraint on several stellar parameters that are easily observed. Young stars are not the best places to look. Not only has life had less time to develop, but, for the first billion years or so, asteroids and comets bombard the system, frustrating life's efforts to survive. It turns out that stars -- like adolescents entering adulthood -- go through a significant decrease in flaring and other chromospheric activity after an age of 3 billion years. The Sun is one such example of a star that significantly decreased its flaring activity at an age of 3 billion years. Whether this newfound calm helps life form is unclear, but, at the very least, this lets us identify and rule out the youngest stars from our searches. Long-term habitability also points us to a limited range of stellar masses. A Sun-like star has a stable hydrogen-burning lifetime of about 10 billion years -- plenty of time for civilizations to evolve. Solar-type stars are also bright enough that the width of their habitable zones can accommodate two or more planets' orbits.

Beware extremes As many as 90 percent of the stars in our galaxy are small, dim objects called type-M dwarf stars -- with masses at most half of the Sun's. Given their large numbers, we would like these M stars to host habitable planets. Because of their low masses, M stars have incredibly long lives -- and, thus, long periods of near-constant luminosity. Around M dwarfs, life would have hundreds of billions, even trillions, of years to develop. However, M stars have long been suspect in terms of their suitability for biology. Not only are their habitable zones narrow (about 1/10 the width of the Sun's), but these habitable zones are so close to the stars (1/4 Mercury's orbit, or 1/10 Earth's orbit) that any planets orbiting there would certainly be tidally locked. This means one side of a planet always faces its star. So, instead of getting an even roasting, one side of the planet would be a blazing noonday Sahara, while the other is a freezing midnight Siberia. Initially, scientists thought such a situation would be unstable, and moisture in the planet's atmosphere would condense into a giant icecap on the night side. This in itself would be bad for life, but what is potentially worse is M stars are famous for flares. All stars flare occasionally, including the Sun. But M-star flares can temporarily increase the star's luminosity by a factor of 100 or more, blasting out high-energy radiation and fast-moving particles that would dismember any nearby DNA molecules. Combine these outbursts with the habitable zone's close distance, and were talking about putting a planet in an ultraviolet sterilizer.   Even with M dwarfs' close orbits and solar flares, all is not lost for these stars. If a tidally locked planet is massive enough to hold a substantial greenhouse atmosphere, one not much thicker than Earth's, atmospheric circulation could keep conditions fairly mild all around the planet. Add a little oxygen, which builds up when water molecules dissociate, and all the worst flares could do is drive ozone creation in the planet's stratosphere. Ozone, in turn, shields the surface from the harsh radiation of solar flares. Moreover, not all M-class stars flare radically. While M stars are perhaps not the best real estate in the galaxy, most scientists believe planets around M stars can possibly support life. The SETI (Search for Extra-terrestrial Intelligence) Institute's target list contains many M stars that change brightness by less than 3 percent.   When it comes to stars that are just a few times the Sun's mass, however, the picture is bleak. These stars burn so brightly they use all of their hydrogen fuel before the planets around them even finish forming (see "Live fast, die young," April 2006). These stars swell into giants and fuse helium, carbon, nitrogen, oxygen, and other elements, synthesizing heavier elements all the way up to iron. That's as heavy as elements in normal stars can go. Then these stars die in explosions that create the rest of the natural elements and seed the galaxy with them.   Impressive? Yes. Good for life? No -- or rather, not good for life today. We must never forget the first batches of massive stars created iron, nickel, carbon, oxygen, and the other building blocks of planets and life. These massive stars play a crucial role in the circle of life.

How many stars do you orbit? After stars pass the mass, age, and flare-activity tests, we're sure they can provide roughly static habitable zones for long periods of time. But we still have our second criterion to consider: that nothing prevents planets from orbiting in those static habitable zones.   This criterion can be broken down into two components, the first of which is what astronomers call multiplicity. The Sun is a single star, which is slightly unusual: About two-thirds of otherwise Sun-like stars come in multiples. I don't mean to suggest that two, or more, stellar parents is necessarily a bad thing, but understanding the stars' orbits is crucial. For example, a second star could: * orbit so close to its primary that the habitable zone encircles both stars -- any earthlike planets will simply enjoy two sunsets per day; * sweep through or come very close to the habitable zone, gravitationally perturbing the orbits of any planets there and possibly ejecting the planets altogether; * orbit far enough away that it does not perturb the habitable zone but introduces a randomly changing luminosity that would interfere with the climate of any planets; * have such a large orbit that any planets in the habitable zone are completely unaffected. In the fourth case, both stars have "safe" habitable zones, which makes these systems doubly intriguing. Only small ranges of separation between the stars cause problems. Most binaries appear safe, falling either into the first or fourth scenario. Triple and quadruple star systems sound more exotic, but they are just as likely as binaries to be safe harbors for life. Multiple systems are hierarchically configured: A triple almost always consists of a close double orbited by a distant third; a quadruple consists of two pairs; a quintuple of two pairs plus a distant third around one of them; and so on.

A star's stuff is important Thanks to the diligent efforts of planet hunters, we know about some 200 planets orbiting more than 160 of the Sun's stellar neighbors. Each of these planetary systems has to be assessed for stability, and a fair number can be ruled out because the giant planet interferes with the habitable zone (see "Adequate distances for life," page 60). Most of the giant planets are on elliptical orbits and have gravitational influences that extend beyond their own orbits. Where such a gravitational influence extends into a star's habitable zone, it is unlikely any earthlike planets could maintain stable orbits. There are several interesting cases, however, (like Mu [μ] Arae) where giant planets orbit within the habitable zone. If these giants have big moons, similar to Jupiter's and Saturn's satellites, the moons could be adequate hosts for life. The star's composition is the second factor that could prevent planets from orbiting in the habitable zone. We know stars and their planets form at the same time out of the same material. As density waves sweep through the galaxy, they compress gigantic clouds of gas and dust. Cloud fragments then collapse gravitationally into stars and planetary systems. But not all clouds are the same; some are deficient or enriched in elements heavier than helium, (astronomers call these elements metals) depending on the local history of massive-star explosions. Thus, some stars are metal-poor, and some stars are metal-rich compared to the Sun.   This is important because astronomers have found metal-rich stars are more likely to have close-orbiting giant planets. Astronomers don't yet know how a star's metallicity correlates to the presence or absence of terrestrial planets, but it makes sense that iron-bearing planets like ours wouldn't form out of clouds that had no iron to begin with.   On the other hand, high-metallicity stars have close-orbiting giant planets because after the stars formed, there was still lots of material orbiting the new stars. That material aggregated into giant planets.

Location, location, location   Finally, we need to question the habitability of the Milky Way Galaxy itself. Are all of the Milky Way's neighborhoods equally good for life? Not likely. Our Sun inhabits the galactic backwoods, where stars are separated, on average, by a few light-years and rarely pass within a comet's throw of one another. Stars in more crowded areas, such as the central galactic bulge, globular clusters, and spiral arms, are more likely to have close approaches from stellar neighbors. Such visits could destabilize planetary systems in the process.   The Sun probably formed in a loosely associated cluster of newborn stars. It may be that a few of our minor planets beyond Pluto (like Sedna) originally belonged to another star. But the Sun is a rural star now, and it will likely remain so for a long time. Although scientists don't fully understand the Sun's orbit around the galactic center, it seems the Sun orbits at a special location in the galactic disk called the co-rotation zone. This is where the galaxy's spiral pattern and the stars between arms move at roughly the same speed.   Closer to the galactic center, solitary stars move faster than the spiral pattern and, therefore, continually pass through the spiral arms. Spiral-arm regions of massive-star formation and high-energy radiation could fry life-forms. And regions of interstellar gas and dust could interfere with a planet's climate, by seeding the formation of rain clouds. By sticking to the middle lane, the Sun can remain suspended between spiral arms for billions of years.   Biology is a cosmic balancing act, with the best homes nestled in special nooks around special stars.

These stars orbit special parts of the galaxy. Does it go beyond that to special pockets of galactic clusters throughout the universe? If there is one thing life on Earth suggests, it's that there is an exception to every rule. Scientists have found life in the most unexpected places on our planet, which is promising for those searching for life outside of our solar system. And now that we have a better idea of where to look -- from a star's composition to its age to its orbit -- we are that much closer to finding out if were not alone.ADDED MATERIAL Margaret Turnbull is an astronomer at the Carnegie Institution of Washington. When she's not studying the stars, she bikes around the Washington area. POSSIBLE NOOKS FOR LIFE The following places might harbor worlds that could possibly have water -- the most important ingredient for life as we know it.

* **Terrestrial planets in a star's habitable zone** The "Goldilocks" zone, not too hot or too cold, around a star could have earthlike planets with temperatures that allow liquid water on the planets' surfaces.

* **Terrestrial moons in a star's habitable zone** Giant planets orbiting within a star's habitable zone could have big moons (like Saturn's Titan) with large amounts of liquid water.

* **Tidal habitable zones around giant planets** Giant planets in the cold outer regions of a planetary system could have moons that are continually tidally stretched (like Jupiter's Europa) as they orbit their massive parents. This generates heat, which could provide for liquid water.

* **Free-floating terrestrial planets warmed by internal radiation** As planets form, some are undoubtedly ejected into interstellar space. The galaxy could be full of these free-floating planets whose interiors, heated by decay of radioactive elements, stay warm enough for liquid water to exist for billions of years.

* **Floating oceans within giant planets** Some giant planets could have layers in their interiors where the temperature and pressure are just right for liquid water. TOP 10 PLACES TO LOOK FOR LIFE Jill Tarter, director of the SETI (Search for Extraterrestrial Intelligence) Institute's research center, asked me to list the highest-

priority targets for the upcoming Allen Telescope Array (ATA). At the time, I questioned astronomy's connection to biology. But as I became further involved in this project, the connection became ever more apparent. My target list for SETI eventually evolved into a catalog of stars that may harbor habitable planets like our own. These stars are our best bets for fining earthlike planets using both radio telescopes (like the ATA) and NASA's Terrestrial Planet Finder (TPF) mission (now facing budget cuts).

Stellar targets for SETI signal searches: 1 Beta Canum Venaticorum: Yellow G-type star, slightly larger than the Sun; 26 light-years away, has a possible distant companion. 2 HD 10307: Yellow G-type star; slightly hotter than the Sun; 41 light-years away; has a companion. 3 HD 211415: Yellow G-type star; slightly cooler than the Sun; 44 light-years away; in a binary system. 4 18 Scorpii: Yellow G-type star; slightly hotter and brighter than the Sun; 46 light-years away. 5 51 Pegasi: Yellow G-type star; slightly larger than the Sun; 50 light-years away.

Stellar targets for TPF searches: 1 Epsilon Indi A: Orange-red K-type star, about 75 percent the size of the Sun; 12 light-years away. 2 Epsilon Eridani: Orange-red K-type star, about 85 percent the size of the Sun; 10.5 light-years away. 3 Omicron[sup Eridani; Orange-red K-type star, about 90 percent of the Sun's size; 16 light-years away; in a triple system. 4 Alpha Centauri B: Orange-red K-type star, about 90 percent the Sun's size; a member of the closest star system to Earth, about 4.3 light-years away. 5 Tau Ceti: Orange-yellow G-type star, about 80 percent the Sun's size; 12 light-years away. HOW TO BE A GOOD PARENT STAR DO remain at approximately the same luminosity for billions of years. DO form out of a cloud with enough metal content to build up terrestrial planets. DO stay in between galactic spiral arms for as long as possible. DO NOT emit gigantic flares that singe the surfaces of nearby planets. DO NOT form with companion stars that swoop in and out of your habitable zone.LIQUID WATER flows over the surface of a giant exoplanet's moon in this artist's conception. If the giant planet orbits within its star's habitable zone, this watery moon could teem with life.Adequate distances for life THE HABITABLE ZONES of 10 of the 160-plus known exoplanet systems are shown here. Some giant planets' gravitational pulls ruin the chances fro terrestrial planets to occupy a star's habitable zone. Others give rise to the possibility of habitable moons. Those giant planets whose distances remain within the habitable zone could harbor habitable moons. HD 28185a and HD 23079a are two such planets.THE ALLEN TELESCOPE ARRAY (ATA) will search 24 hours a day fro radio signals from our Sun's stellar neighbors. If intelligent life exists, we assume it uses modes of communication similar to ours, and the ATA may detect a message. The ATA is a joint project between SETI and University of California, Berkeley. When complete, the array will comprise 350 twenty-feet-diameter (6.1 meters) dishes.A ROCKY PLANET orbiting the narrow habitable zone around an M-type star would likely be tidally locked. The side facing the star would be searing hot, and the opposite side would be freezing cold. A temperate band could lie between the two extremes and harbor life.The galaxy's most suitable neighborhood THE SUN orbits in the Milky Way's habitable zone. Planetary systems too close to the galactic center would interact frequently with each other. The number of stars and the star's metallicities are lower at greater distances from the galactic center. In between, the density and metal content of stars are more suitable for planets that could have life.The four basic types of terrestrial planets A PLANET'S LOCATION makes all the difference. Here are four possible temperatures: too scorched, too humid, too cold, and just right. The best location, and therefore temperature, for an earthlike world is in the habitable zone's center.