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The Case for Habitable Exoplanet Moons

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Artist's impression of an exoplanet. Credit: European Southern Observatory.

As scientists refine their methods, exoplanets are becoming easier and easier to detect. The current count is 163 planets orbiting 97 main-sequence stars, of which only one is even remotely Earth-like. All the others are massive bodies, ranging from “tiny” Uranus-like worlds (at about 15 Earth masses) to super-Jupiters (at thousands of Earth masses).

The direct detection of terrestrial planets around stars like our Sun may have to wait until the launch of dedicated satellites such as COROT and Kepler (scheduled for 2006 and 2008, respectively). In the meantime, some researchers have begun to wonder whether these extrasolar gas giants could harbor habitable moons.

Our own solar system has four gas giants, and each has been blessed with an abundance of satellites. All these moons are far smaller than the

Earth, but six could qualify as planets in their own right if they orbited the Sun: Jupiter's four Galilean satellites Europa, Callisto, Ganymede, and Io; Saturn's Titan; and Neptune's Triton. Europa is known to have large amounts of water ice, and Titan has a thick atmosphere. If our solar system is not atypical, many of the known exoplanets probably have rich moon systems as well.

Caleb Scharf, Columbia University's Director of Astrobiology, has been exploring the conditions necessary for such moons to be habitable. His recent work investigates the conditions necessary for a moon to contain enough water to sustain biological life, at temperatures capable of supporting biological activity.

Under zero-pressure conditions, water ice will sublimate (transform from solid to vapor directly) at temperatures higher than about 170 K (-103 °C). This means that water-rich protoplanets must form relatively far from the star -- well outside the traditional “habitable zone” where stellar radiation raises temperatures high enough to support liquid water. Gas giants are also likely to form in these icy reaches -- so the known exoplanets are highly likely to have acquired one or more icy moons early on. Icy moons may be carried into warmer regions later, as the host planet migrates inward.

What happens to the water then? The answer depends mainly on the size of the moon. A moon or planet with about 10% the Earth's mass has enough gravity to retain water vapor and other gases in a temperate atmosphere. (As a counterexample, Venus has enough gravity but is much too hot to retain water -- the speed of water molecules in the atmosphere exceeds the escape velocity of the planet.) Mars-sized or larger moons may therefore be able to sustain both an atmosphere and liquid water, if their host planet is not too far from the star.

More Heat Kneaded!

Scharf is able to show that such moons may be habitable at greater distances than a similar planet would be, thanks to the process of *tidal heating*. Since gravity weakens with distance, the pull from the host planet will be slightly different on the near and far sides of a moon. If the moon's orbit is circular this gravity differential will be constant, and the moon can adjust to it by changing its shape slightly. When a moon travels in an eccentric orbit around its planet, however, it approaches and recedes at regular intervals. The gravity differential therefore changes slightly as it orbits, resulting in a rhythmic compression of the moon's core.

In other words, the host planet will slowly knead the moon like a lump of dough. The activity can generates a lot of heat, even if the moon's core is not molten. “You're basically draining the spin energy of the parent planet.” Scharf explains. In the case of Jupiter, that spin energy is enormous—more than enough to sustain moderate levels of tidal heating indefinitely. To sustain the eccentricity of its moons' orbits, the ideal exoplanet will have multiple moons in proximity (such as Jupiter's Galilean satellites).

To illustrate the potency of this process, Scharf offers the following example. “If you took Mars and put it where Europa is now, Mars would get heated by several tens of degrees [from tidal heating] at its surface. This would also probably start up its volcanic activity again.” Tidal heating can give an extra boost of energy to moons which receive too little light from the system's star to thaw. Scharf finds that an Earth-sized moon could reach habitable temperatures about twice as far from the Sun as the Earth itself, under favorable assumptions.

Most moons in the Solar system, however, are not large enough to hold an atmosphere; Ganymede is the largest, at about 0.025 (1/40) Earth masses. Scharf therefore postulates that habitable moons such as Europa are much more likely. The surface temperature of such moons must be cold enough to preserve ice even in the absence of an atmosphere, but the process of tidal heating could potentially warm the planet enough to create a warm, liquid ocean under the ice layer. Evidence of liquid water has not only been found on Europa, but also recently on Saturn's moon Enceladus by the Cassini mission (http://www.solarviews.com/eng/enceladuswater.htm). Again, tidal heating is thought to be the culprit.

In his most recent paper Scharf analyzes the properties of 74 exoplanets, those far enough from their star for satellite orbits to be stable over several billion years. He finds that between 28 and 51% of the planets in this sample are capable of harboring Europa-like moons with icy mantles and liquid water, depending on the size of the satellites and the eccentricity of their orbits. When one considers the total population of known exoplanets, the fraction falls to 15 to 27%, which is still quite favorable.

Even if the planetary systems discovered so far lack Earth-like worlds, Scharf's work makes a strong case that the moon systems of gas giants could also sustain life.

Reference: Caleb A. Scharf, “The potential for tidally heated icy and temperate moons around exoplanets” 2006, to appear in *Astrophysical Journal*. http://xxx.lanl.gov/astro-ph/0604413

By Ben Mathiesen, Copyright 2006 PhysOrg.com

Ben Mathiesen is an astrophysicist at the Service d'Astrophysique in Saclay, France, and owner of the agency Physical Science Editing, *which helps researchers around the world meet native English writing standards in their academic publications.*

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