Exobiology

Life on other moons

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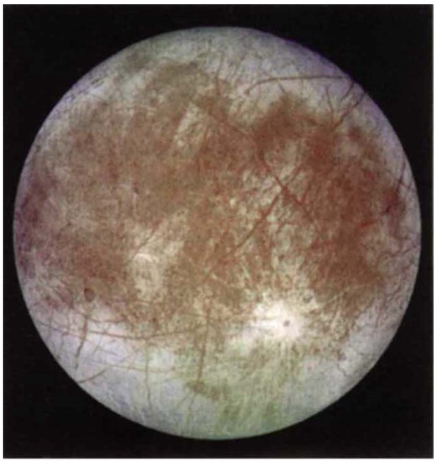
What does it take for a world to be habitable? As with so many other questions in exobiology, Carl Sagan helped pioneer this topic[1], and in an article last year[2] he presented a masterly and cautionary review of the changing scientific fashions on the question. Now that extrasolar giant planets (or brown dwarfs) have been found around nine main-sequence stars, Williams *et al.*, on page 234 of this issue[3], extend the discussion to the habitability of moons around these worlds.

What it takes for a world to be habitable depends on who will be doing the inhabiting. Clearly, the requirements of humans differ from those of forests[4], which in turn are more stringent than those of, say, green slime. Habitability for putative extraterrestrial technical civilizations may be the most interesting kind to consider. Yet since the history of surface life on Earth is largely the history of green slime, its needs must remain of special interest to exobiologists.

Recent work has defined 'habitable zone' as the range of orbital distances within which worlds can maintain liquid water on their surfaces[5,6]. This reflects the utter dependence of terrestrial life on liquid water[7]. The giant planets orbiting the stars 16 Cyg B and 47 UMa may by this definition lie within their stars' habitable zones. But Williams *et al.* argue that these worlds (like the gas giants in our own system, whose solid cores lie at depths where pressures and temperatures are extreme) probably lack a solid or liquid surface suitable for life.

So Williams *et al.* instead consider the possible moons of the extrasolar giants, and show that some of them might provide habitats for extraterrestrial life. They find that such a moon would need to be a bit more massive than Mars (about 0.1 Earth masses) in order to retain a substantial atmosphere (essential for surface liquid water) for billions of years. The moon might also need an appreciable magnetic field to protect its atmosphere against loss due to sputtering by charged particles. Jupiter's moon Ganymede, the largest moon in our Solar System, has a magnetic field, but is only 0.03 of Earth's mass. More massive moons may well exist.

There is a certain irony in postulating moons around the newly discovered planets as sites for life. Before the recent flurry of evidence for planetary systems, the argument for extrasolar habitable planets ran like this: our star appears to be typical; it has planets suitable for life; so other stars probably do as well. We now know that other stars have planets, but current observing techniques cannot discover companions much below the mass of Jupiter, which is widely deemed unsuitable for life. We therefore now have an argument for habitable moons that parallels the previous one for planets: our giant planets appear to be typical; they have moons that might be suitable for life (were they more massive and within the Sun's habitable zone, by the arguments of Williams *et al.*); so extrasolar giant planets (in habitable zones) probably do as well. It is certainly of the first importance for exobiology that we now have evidence that planetary formation is common. Nevertheless, ultimately what is needed is a means of detecting Earth-sized worlds — a capability that is years, and possibly decades, away[8].



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Europa, as seen by the Galileo spacecraft. Europa, Jupiter's second moon, is one of the most promising sites for life in the Solar System, for despite having a frozen surface there is evidence of an ocean below. But moons around the giant planets in other solar systems may be more like Earth, with surface liquid water and moderately thick atmospheres.

It should be emphasized just how conservative the definition of habitable zone used by Williams *et al.*[3] (and most other workers) really is. Carl Sagan was famous for his concern that our notions of the conditions needed for extraterrestrial life are cautious to the point of being chauvinistic. In his recent piece on habitable zones[2], he raised a series of objections to the 'surface liquid water' definition of habitability.

For example, Sagan and Salpeter have speculated on possible ecological niches on giant planets: perhaps water clouds, simple organic molecules and abundant energy sources are enough for life, and no solid or liquid surface is required[9]. To this, the counter-objection has been raised that no airborne ecologies are known on Earth: if such ecologies are possible, why are there apparently no terrestrial clouds green with microorganisms[10]?

Less speculatively, it is known that deep subsurface microbial ecologies exist on Earth. If Earth is in fact home to a 'deep, hot biosphere'[11] not dependent on solar energy, such biospheres might exist on other worlds well outside the surface-liquid-water zone — unless surface liquid water or surface energy sources (principally solar ultraviolet) are required for the *origin* of life.

In our own Solar System, circumstantial evidence for a liquid subsurface ocean on Jupiter's moon Europa is growing, and there could be regions of Europa where conditions lie within the range of adaptation of Antarctic terrestrial organisms[12]. Although such speculations will remain unresolved until the question of a europan ocean is settled, it is striking that Europa, one of two prime candidates for a second habitable world in our own Solar System, nevertheless lies well beyond the surface-liquid-water zone, has only about a tenth of Mars's mass, and has almost no atmosphere.

Our ignorance is sufficient to allow even more speculative environments within our Solar System[13]. As Sagan pointed out, if even a conservative definition of habitable zone suggests many locales for life around other stars — a conclusion to which Williams *et al.* lend support — then "whatever we have ignored could only serve to broaden the biological arena"[2].

As it stands, Earth is the only known habitable world. Investigating the conditions required for worlds to be habitable, naturally reminds us of our responsibility to our own. Here, too, Carl Sagan's voice will be dearly missed.

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