

The moon and the origin of life[†]

C.R. Benn

Isaac Newton Group, Apartado 321, 38700 Santa Cruz de La Palma, Spain

Abstract. Earth is unusual in bearing life, and in having a large moon. A number of authors have suggested a possible connection between the two, e.g. through lunar stabilisation of the earth's obliquity, or through the effects of the oceanic tides. The various suggestions are reviewed.

Keywords: moon, origin of life

1. Introduction

The properties of the universe that we observe must be consistent with the evolution of carbon-based life within it. This observational selection effect is known as the *weak anthropic principle* (Barrow & Tipler 1986). It has been invoked to explain a number of otherwise unlikely coincidences such as the nuclear resonance that allows carbon to form in stellar interiors, the big numbers coincidence (ratio of strengths of electromagnetic and gravitational forces $\sim 10^{40}$ \sim current size of the observable universe in proton diameters), and, more recently, the smallness of the cosmological constant (Efstathiou 1995) and the amplitude of the primordial density fluctuations which seeded the growth of galaxies and clusters of galaxies (Tegmark & Rees 1998).

A similar selection effect will apply in our local astrophysical environment. Clearly, the luminosity and lifetime of the sun, and the shape and size of the earth's orbit, must be such as to maintain the earth's surface, for a long period, at a temperature suitable for the evolution of organic life (e.g. Kasting et al 1993). However, our solar system may also be atypical in other respects:

- The sun's metallicity is unusually high for its age (Whittet 1997, Gonzalez 1999), perhaps reflecting the higher probability of planetary systems being associated with high-metallicity parent stars.
- The sun's luminosity may be unusually stable (Gonzalez 1999).
- Jupiter's role in ejecting comets from the solar system could have been crucial in protecting the young earth from life-inhibiting impacts (Wetherill 1995). Solar systems with Jupiter-like planets at similar radii may thus not be typical.
- The sun may be orbiting the galaxy close to the co-rotation circle

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(Mishurov & Zenina 1999), which minimises the number of spiral-arm crossings, and consequent disruption of the solar system (e.g. by nearby supernovae, tidal effects).

Although it's possible that none of the above features of our solar system is *essential* to the evolution of life on earth, the probability of our observing them is enhanced if they increase the probability that intelligent life will develop, i.e. it would not be surprising to observe any feature F if its a priori probability, p_F , satisfies:

$$p_F > p_{life}(0)/p_{life}(F) \quad (1)$$

where $p_{life}(0)$ and $p_{life}(F)$ are the probabilities of intelligent life evolving respectively in the absence and in the presence of feature F .

Several authors (e.g. Butler 1980, Comins 1993) have suggested that there might be a link between our large moon, arguably an a priori unlikely feature of the earth's environment, and the evolution of life on earth, i.e. that:

$$p_{moon} > p_{life}(0)/p_{life}(moon) \quad (2)$$

All 3 parameters in this inequality are unknown. Below we consider what is known about the origin of the moon, and the origin of life, and how the former might affect the latter.

2. The origin of the moon

The earth's moon is unusual amongst solar-system satellites in having relatively high mass and in dominating the total angular momentum of the earth-moon system. It is also unusually 'dry', lacking volatile elements such as K and Bi. These characteristics, particularly the high angular momentum, posed serious problems for the three main hypotheses for the origin of the moon until the mid 1980s: capture, co-formation and fission (Hartmann et al 1985). There is now a consensus (Taylor 1992) that none of these three hypotheses is tenable, and that the earth-moon system probably formed when a planetesimal $\sim 0.1 - 0.2$ earth masses underwent a grazing collision with the proto-earth, soon after the formation of the solar system 4600 Myr ago. In this widely-accepted 'Big Splash' scenario, the metallic core of the impacting body sank to join the earth's, and some of the shattered mantle reassembled in orbit to form the moon. Estimates of the probability (p_{moon}) of the earth acquiring such a large moon have been boosted by this new perspective, but e.g. Ringwood (1990) and Lissauer (1997) argue that only a narrow range of initial conditions could have resulted in a large moon in earth orbit.

3. The origin of life

Life on earth probably dates back at least 3500 Myr, i.e. to within a few 100 Myr of the formation of the earth's crust 4200 - 4000 Myr ago. The oceans at that time would have been a weak solution of organic precursors (amino acids, pyrimidines etc.), formed in situ, or in the comets that may have provided much of the water (Chyba 1990, Lazcano-Araujo & Oró 1981). How a self-replicating system evolved from this primordial soup has been the subject of much speculation and laboratory work, reviewed by Oró et al (1990) and Deamer & Fleischaker (1994). One common theme to emerge is the importance of concentrating the soup to encourage polymerisation, e.g. in tidal pools which repeatedly dry out under the sun, echoing Darwin's (1871) speculation about the origin of life in "some warm little pond with all sorts of ammonia and phosphoric salts". For example, Oró et al (1990) note that the best contemporary laboratory models of pre-cellular systems are liposomes (phospholipid vesicles), and encapsulation of DNA within liposomes has been achieved by dehydration-hydration cycles similar to those occurring in intertidal pools (Deamer & Barchfeld 1982).

Once self-replication is established, evolution to more complex systems can proceed through Darwinian selection. *Intelligent* life is not an inevitable end product, and the fact of our existence places no constraint on the probability ($p_{life}(0)$, or $p_{life}(\text{moon})$) of intelligent life evolving on an earthlike planet. It might be close to 1, but it might just as well be 10^{-30} (implying no other life within a Hubble radius). The long intervals between critical events in the evolution of life on earth suggest that evolution to intelligent life is unlikely to happen much faster on other earthlike planets. The key requirements for the evolution of organic life on an earthlike planet are thus a source of organic precursors, solid surfaces where the precursors can condense, long-term maintenance of temperature within a range suitable for organic reactions, and protection from hazards (e.g. impacts).

4. Possible influence of the moon on the evolution of life

Given on the one hand the wide-ranging consequences (compositional, gravitational) of the earth having a large moon, and on the other the stringent requirements for the origin and evolution of life, it would perhaps be surprising if the former had *not* significantly affected the latter. A number of specific suggestions have been made:

(1) Stabilisation of the earth's obliquity

Small changes in the earth's orbit and orientation probably drive cli-

matic change (Milankovitch theory, Imbrie 1982), and small changes of the earth's obliquity (angle of spin axis with the perpendicular to the orbital plane) of $\sim 1^\circ$ could have triggered recent ice ages. Several authors (e.g. Goldsmith & Owen 1980, Verschuur 1989) have noted that a large moon would benefit life by stabilising the earth's obliquity, and thus climate, and Laskar, Joutel & Robutel (1993) and de Burg & Laskar (1997) confirmed that in the absence of the moon, large and chaotic variations of obliquity would have occurred. Mercury and Venus have been stabilised by tidal dissipation (they spin very slowly), but Mars, which has no large moon, undergoes chaotic variations of obliquity in the range $0 - 60^\circ$ (Laskar & Robutel 1993). Stabilisation of the earth's obliquity might not have been crucial for the origin of life, but could have been for the evolution of life on land.

(2) Elimination of the primordial atmosphere

Cameron & Benz (1991) and Taylor (1992) pointed out that the giant impact which created the earth-moon system would have stripped the earth of its thick primordial atmosphere, which might otherwise have developed as has that of Venus, rendering the surface of the planet too hot for organic life. On the other hand, the earth's atmosphere may be thinner simply because most of the CO₂ is locked up in carbonate rocks.

(3) Generation of the earth's magnetic field

The earth's magnetic field partially shields the molecules of life from the destructive effects of cosmic rays (although this may not be important for submarine life). Compared to other solar-system bodies, the earth's magnetic field is unusually strong for its angular momentum (though the mechanisms are probably different for different bodies). Pearson (1988) suggested that this anomaly might be due to the prolonged heating of the earth's core following the impact that created the earth-moon system.

(4) Generation of large tides

As noted above, a common theme in speculations about the origin of the first self-replicating system is the importance of concentrating the weak solution of organic molecules in the primordial sea, to encourage polymerisation. The possible role of tidal pools, which repeatedly dry out under the sun, has been stressed by many authors. Although the amplitude of the tides raised by the moon is currently not much larger than that of the tides raised by the sun, the moon was probably much closer to the earth at the time of the origin of life (Chyba 1990), and the tides raised would have been correspondingly larger, allowing tidal pools with a much larger total area to be subjected to wetting/drying cycles (e.g. Verschuur 1989, Gribbin & Rees 1990).

(5) Generation of longer-period tides

The length of time allowed for intertidal pools to dry out under the sun before being refilled may also have been important. With longer wetting/drying cycles, the probability of long sequences of chemical reactions taking place is increased (the energies involved in organic reactions are small, and they proceed slowly). It's possible that at the time of the origin of life, the moon was not actually much closer to earth than it is at present (Williams 1989, Taylor 1992). One may then speculate (Rood & Trefil 1981) that beating between lunar and solar tides to give neap/high tides at a longer interval (as observed at present) was important, although of course longer intervals could also be achieved by other means e.g. through seasonal effects. The hypothesis has an interesting corollary. The condition for such beating is that the strengths of the tides raised by the sun and by the moon, which are \propto density * (angular diameter)³, are similar. The mean densities of planetary bodies and main-sequence stars both happen to be \sim atomic (Carr & Rees 1979), so angular diameter \propto (strength of tide)^{1/3} i.e. the condition for long-period tides happens to imply similar angular diameters of the sun and moon, as observed.¹

With our current level of understanding of the origin and evolution of life, the above five hypotheses remain speculative. However, the variety of suggested mechanisms (and more than one could be important) attests to the far-reaching consequences of the earth having a large moon. Some of these consequences inevitably impinge on events critical to the development of life on earth. Thus it cannot be assumed that this unusual feature of our environment is *not* anthropically selected.

5. Conclusions

In studies of the solar system, as in cosmology, we are dealing with a unique example (so far), and we must beware the effects on our observations of anthropic selection. The possibility that the presence of the moon has affected the origin or evolution of life through one of the mechanisms noted above implies that:

- (1) hypotheses about the origin of the moon cannot be judged solely on the basis of a priori likelihood (they need only satisfy equation 2);
- (2) large moons may be useful pointers in the search for life-bearing planets.

¹ Curiously, this has a literary antecedent; in Martin Amis' novel *London Fields* (Amis 1989) appears the line 'Perhaps that was the necessary condition of planetary life: your sun must fit your moon'.

More generally, caution must be exercised in interpreting, and generalising from, unusual features of our local astrophysical environment; they may turn out to be anthropically selected, and atypical. Indeed, the earth and its environment may be very special (Ward & Brownlee 2000), and this might explain the puzzling lack of evidence for intelligent life elsewhere in the universe (Tipler 1980, Wesson 1990).

References

- Amis M., 1989, *London Fields* (Jonathon Cape), chapter 22
 Barrow J.D., Tipler F.J., 1986, *The Anthropic Cosmological Principle* (Oxford University Press)
 Butler R.N., 1980, Irish Astr. J., 14, 516
 Cameron A.G.W. & Benz W., 1991, Icarus, 92, 204
 Carr B.J., Rees M.J., 1979, Nature, 278, 605, fig. 1
 Chyba C.F., 1990, Nature, 343, 129
 Comins N.F., 1993, *What if the moon didn't exist?* (Harper Collins)
 Darwin C., 1871, in a letter to a friend
 Deamer D.W., Barchfeld G.L., 1982, J. Mol. Evol., 18, 203
 Deamer D.W., Fleischaker G.R., 1994, *Origins of Life* (Jones & Bartlett)
 de Surgy O.N., Laskar J., 1997, Astron. Astroph., 318, 975
 Efstatthiou G., 1995, MNRAS, 274, L73
 Goldsmith D., Owen T., 1980, *The Search for Life in the Universe* (Benjamin/Cummings)
 Gonzalez G., 1999, Astronomy & Geophysics, 40, issue 3, 18
 Gribbin J., Rees M.J., 1990, *Cosmic coincidences* (Heinemann), chapter 11
 Hartmann W.K., Phillips R.J., Taylor G.J., 1985, *Origin of the Moon* (Lunar and Plan. Inst., Houston)
 Imbrie J., 1982, Icarus, 50, 408
 Kasting J.F., Whitmire D.P., Reynolds R.T., 1993, Icarus, 101, 108
 Laskar J., Joutel F., Robutel P., 1993, Nature, 361, 615
 Laskar J., Robutel P., 1993, Nature, 361, 608
 Lazcano-Araujo A., Oró J., 1981, *Comets and the origin of life*, ed. C. Ponnamperuma (Reidel)
 Lissauer J., 1997, Nature, 389, 327
 Mishurov Yu. N., Zenina I.A., 1999, Astron. Astroph., 341, 82
 Oró J., Miller S.L., Lazcano A., 1990, Ann. Rev. Earth Planetary Sci., 18, 317
 Pearson J., 1988, New Scientist, 25 August 1988, p.38
 Ringwood A.E., 1990, in *Origin of the Moon*, eds. H.E. Newsom & J.H. Jones (Oxford University Press)
 Rood R.T., Trefil J.S., 1981, *Are we alone?* (Scribner)
 Taylor S.R., 1992, *Solar System Evolution* (Cambridge University Press)
 Tegmark M., Rees M.J., 1998, ApJ, 499, 526
 Tipler F.J., 1980, Q. Jl. R. astr. Soc., 21, 267
 Verschuur G.L., 1989, Sky & Telescope Nov 1989, p.452
 Ward P.D., Brownlee D., 2000, *Why complex life is uncommon in the Universe* (Copernicus)
 Wesson P., 1990, QJRAS, 31, 161

- Wetherill G., 1995, Nature, 373, 470
Whittet D., 1997, Astronomy & Geophysics, 38, issue 5, p.8
Williams G.E., 1989, J.Geol.Soc.London, 146, 97

