Television projects.

Other Earths orbiting other suns - what might they be like?

Research into the potential diversity of habitable planets and moons conducted through our collaboration provided the basis for a two programme documentary, "*Extraterrestrial*" (USA); "*Alien Worlds*" (UK), produced in 2004 by *Big Wave*, a British TV company with multiple awards for innovative and environmental topics.

Imagination may go where no telescope or space probe has yet gone, or will go for the foreseeable future. In October 2003, Nick Stringer, a producer at *Big Wave*, approached us with a concept for a documentary about hypothetical ecosystems on extrasolar planets. His speciality is wildlife documentaries, and he had come up with the idea of using computer animation to explore types of wildlife which might be adapted to conditions on other worlds.

Finally, after several discussions, Stringer decided to focus on two possible worlds in a two-programme production. These were dubbed "*Aurelia*" - a synchronously rotating planet, based upon our tentative research (Heath *et al.*, 1999) and the "*Blue Moon*," which we envisaged for this project as an Earth-sized body with a massive atmosphere, orbiting a giant planet, which in turn, orbited a close binary consisting of two Sun-like stars. This was an exciting project, because, to our knowledge, nothing like it had been attempted before. We explored how basically Earth-like bodies might fare in systems which differed in important ways from the Solar System. There exist much more extreme possibilities for habitable planets, of course, but the two options we investigated themselves involved highly controversial assumptions – which currently remain untested by observational science.

The Ecospheres Project served as a technical consultancy, working with producer Nick Stringer, who had conceived the programmes as an extension of his previous work creating acclaimed wildlife documentaries. It assisted also with fund-raising, confirming the scientific credentials of the concept to *National Geographic* who financed production. Martin Heath worked in an advisory capacity with a BBC team based at White City, London, whose members created the CGI visuals.

By October 2004, production was underway. The science, with many caveats and unresolved issues, was complex, and it reminded us of just how intricate and inter-related are the factors which determine planetary environments, habitability and mode of ecosphere function.

Aurelia was envisaged as a planet of a red dwarf star. Because Earth-like insolation levels would only be found close to the star, *Aurelia* had been spun down by tidal effects into synchronous rotation, so that it would always keep the same hemisphere pointing at its parent star.

This star was taken to be one of the more massive and hotter red dwarfs. There was sufficient blue light in its sunlight for a visible amount to be scattered in the atmosphere and scattered back from the upper layers of the ocean.

Because the sun would always remain in the same place in the sky, unlike on the Earth, where the Sun passes across the sky during the course of the day, the most effective means of intercepting direct radiation would be to orientate photosynthetic surfaces (equivalent of leaves in Earth's plants) directly towards the sun. Because organisms would shade each other, competition for direct light would be intensified, and producer Nick Stringer hypothesised photosynthetic organisms that could move slowly over the ground, to re-adjust their position – even to vie for their place in the sun.

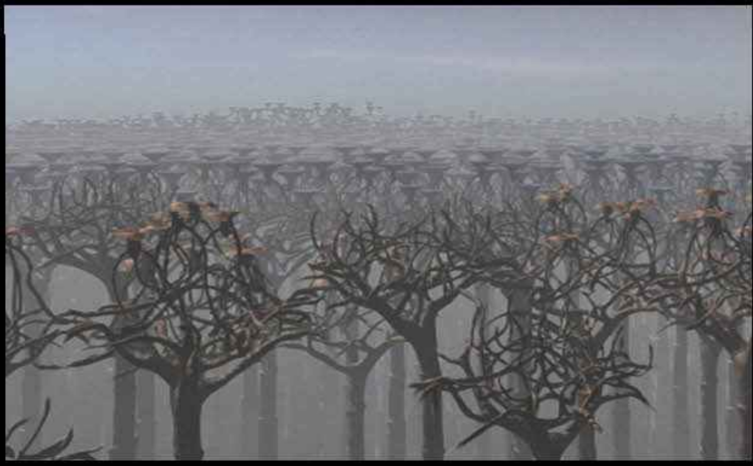
Above left: The planet *Aurelia*, a hypothetical habitable planet orbiting a red dwarf star designed by MJH for the 2005 release "*Alien Worlds*." The concept evolved from upon initial speculations by Haberle *et al.* (1996) and the climate models of Manoj Joshi, at the University of Reading (Joshi *et al.*, 1997). The dark hemisphere is smothered by a layer of ice, which extends into the lit hemisphere. Above right: Hypothetical plant life with photosynthetic surfaces orientated towards the sun, which always hangs unmoving in the same place in the sky. Heath *et al.* (1999) was the first serious discussion of the potential habitability of worlds receiving red dwarf sunlight to sustain photosynthetic production. This scene was not used in the final programme. Images: © *Big Wave*.

Potentially serious problems for planets such as *Aurelia* have emerged and include a possible difficulty, evident in simulations in forming Earth-sized terrestrial planets around stars as small as red dwarfs (Raymond *et al.*, 2007), whose masses are roughly 0.5 to 0.08 solar mass, and potential loss of atmospheres due to intense stellar winds (Khodachencko *et al.*, 2007; Scalo *et al.*, 2007).

The *Blue Moon* was subject to a diurnal cycle, because it orbited a giant planet. Its day-night cycle would be determined by its orbital cycle around its parent planet, with an adjustment for the changing position of the binary sun in the sky, caused by the orbital motion of its parent planet around the sun. Given that the *Blue Moon*'s orbit would probably lie in the equatorial plane of its parent planet (although it may have been captured) and that its rotational axis would be essentially perpendicular to its orbital plane, its seasonal cycle would probably be determined by the axial tilt of the giant planet and the orbital eccentricity of the giant planet around its star.

After some discussions and changes of plan, it was decided that the *Blue Moon* would possess an atmosphere around three times denser than that of the Earth. This enabled huge winged organisms dubbed "*sky whales*" to inhabit the air, where they soared on thermals as they consumed atmospheric plankton. It also enabled plants to compete for the light by raisingballoon-like organs into the sky. We preferred them to be filled with photosynthetically-produced oxygen, but evolutionary biologist Simon Conway Morris preferred them to be filled with the much lighter gas hydrogen, which is also produced in the plant kingdom. This, by the way, was the option adopted for plants floating in the atmosphere by the science fiction author Arthur C. Clarke (1956) in his novel "*The City and the Stars.*"

Possible problems for the existence of Earth-sized moons around giant planets were evident in later simulations carried by Canup & Ward (2006). If their work is correct, an object less massive than a brown dwarf (upwards of 13 Jupiter masses) typically might not gather an orbiting disk sufficiently massive to form a satellite as the Earth.



Above left: The *Blue Moon*, a hypothetical Earth-sized moon of a giant planet, designed by MJH for the 2005 release "*Alien worlds*." Above right: Huge trees adapted to gather rain water at their summits, from where it can pass downwards through their trunks, overcoming the problem faced by trees on Earth of lifting water absorbed through their roots, up to their crowns, where it is lost by through pores in leaves – limiting the size of trees. Images: © *Big Wave*.

In the programmes, Doyle, Heath, and their associate, the climatologist Manoj Joshi (whose work had provided the theoretical basis for investigation planets in synchronous rotation), joined a panel which included Chris McKay of NASA Ames (a principal proponent of terraforming Mars), Seth Shostak of the SETI Institute, University of Cambridge evolutionary biologist Simon Conway-Morris, and xenobiology advocate Jack Cohen (well known for works such as "*Evolving the Alien - The Science of Extraterrestrial Life;*" Cohen & Stewart, 2002). CGI action was interspersed with interviews, in which with members of the panel discussed the habitability and potential for complex life on the imaginary worlds. Much of the interview material and discussion around the table did not reach the public (but may be made available for future productions). The programmes were not intended to report details of technical discussions amongst the scientific community.

The idea was to create an effective vehicle to convey the excitement and uncertainties of research in this field to a prime time audience (shown on Britain's *Channel 4* on the 1st and 8th of October 2005). Stringer succeeded in this objective. The two episodes hit the right note for popularisation in an international market. The mini-series was awarded the 2006 Royal Television Society (South) award for the most popular fact-based programme.

The worlds we had devised underwent a degree of mutation, and were taken up for an interactive display at London's Science Museum, which later went on international tour. The Museum also commissioned two popular books (Li, 2005; Challoner, 2005). The programmes provided an impetus for inventive science projects in schools, and hopefully helped to plant the seeds of further enquiry in the minds of youngsters who may eventually pursue careers in science. It is the generation presently passing through school who will, as observational capabilities expand to embrace objects as small as the Earth, have a yardstick against which to compare our own Earth.

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