

The Science Behind *The Quantum Magician*

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My novel *The Quantum Magician* was recently serialized in *Analog*. A lot of science was stuffed into those pages, some of it pretty direct extrapolations or recombinations of existing science and tech. Some of it skated thinner ice. The science is a big deal to me, so offered a chance to talk about some of the scientific thinking behind the *The Quantum Magician*, I jumped at it.

It was only when I started collecting my thoughts did I realize how much biological sciences featured in my thinking, so I'll start there. Unlike my 2014 *Analog* novelette *Persephone Descending*, which is set in the same universe as *The Quantum Magician*, and features alien plants on Venus, I made a deliberate choice not to include real aliens in this novel, only genetically engineered subspecies of humanity: the *Homo eridanus*, the *Homo pupa*, and the *Homo quantus*.

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The *Homo eridanus* (the Mongrels)

This subspecies of humanity first appeared in the June 2008 Asimov's story *Beneath Sunlit Shallows*, in events set about two hundred years before the events in *The Quantum Magician*. A generation ship of humans arrived at Epsilon eridani only to discover that the habitable world they'd been travelling towards for many decades had been smashed by a previously unseen planetary body, an accident of orbital mechanics. They built habitats to orbit the star, but the amount of debris in the Epsilon eridani system was similar to what our own solar system experienced during the Late Heavy Bombardment.

The Late Heavy Bombardment is a period around four billion years ago when the amount of asteroidal impacts seems to have been much higher. Possible explanations involve migration of one or more of the gas giants, or a collision of massive asteroids in Mars-crossing orbits. Generation ships would have little way to adapt to a catastrophic change in their destination system while they're on route.

With their homes regularly punctured or blown to bits, the settlers moved to an inhospitable ocean planet (one that wasn't destroyed) so that the atmosphere could protect them from asteroids. And although the atmosphere could protect them from small asteroids, significant ones continued to pound the planet too, sending destructive shock waves through the atmosphere and the upper layers of the ocean.

Facing extinction, the settlers crossed a moral Rubicon and engineered the next generations to be able to survive in the benthic depths, those bottom parts of oceans that are anoxic, lightless, nutrient poor and generally awful. To engineer people to live at the deep sea floor—say about five to six thousand meters down, with maybe seven hundred atmospheres of pressure—the most basic challenge is keeping our sixty thousand genes working in tandem.

Proteins in our bodies are generally either building materials, or they do things, like catalyze important chemical reactions. Proteins have four layers of structure. (You thought physics was complicated.) The primary structure of proteins is the one-dimensional ordering of amino acids that are bound together to make a protein. This order is coded by DNA. The secondary structure is where things start to get complicated, since strings of amino acids can form helices or sheets or nothing at all. The tertiary structure of a protein is how the helices and sheets fold into the pretty-much-final structure of the protein. The quaternary structure of a protein is when it loosely joins to other subunits encoded by other genes (for example, hemoglobin is formed from four smaller individual proteins and hemoglobin doesn't work when the sub-units aren't together).

Now, in the chemistry of macromolecules (molecules made of thousands of atoms, like proteins, nucleic acids, carbohydrates, lipids, etc), *shape determines function*. That's why a mutation in DNA can mess up a whole protein. One DNA base-pair mutation can cause a different amino acid to be included in the protein's primary structure, which can change the shape of sheets and helices. Changes in primary structure in turn can affect the final shape and whether the final protein likes hanging out with other proteins, or if it even does its basic job. A single base pair mutation can be innocuous, but it can also stop a protein from contributing properly to life as bricks and mortar, or as one of the many nano-machines making our bodies go.

But mutation isn't the only thing that changes the shape of a macromolecule. Environmental salinity has a huge effect on the behavior of molecules. So does temperature; some macromolecules are held together so lightly that raising the temperature a few degrees breaks them permanently. (Incidentally, that's why we have fevers: our bodies are playing chicken with viruses, seeing whose molecules can survive at higher temperatures longer. Spoiler: ours can.) Reducing temperature can have similar effects. Proteins react slower as catalysts, or are stiffer as structural scaffolding, or could even break as their folding changes with cooling. Proteins can even change shape in response to things they bind to. Hemoglobin is a great example—an empty hemoglobin molecule *really* grabs onto oxygen, while a hemoglobin molecule holding onto seven oxygen molecules is less grabby for the eighth.

I say all this because it bears on the engineering of the *Homo eridanus*. Sea mammals already maintain their body temperatures with lots of blubbery insulation and cross-circulation of veins to keep the core of the body warm and the extremities cooler. I decided to do this with the *Homo eridanus* to (1) not have to worry about temperature as a metabolic variable in the design, (2) because it's not hard to do in science fiction, and (3) it made the *Homo eridanus* incredibly ugly, which I'll come to later.

Slightly harder is figuring out how to give a benthic-living humanity senses by which to experience the world. There's no sunlight at the bottom of the Challenger Deep. So the *Homo eridanus* principally perceive the lightless world the way electric fish do—by radiating electricity from stacks of specialized muscle cells called electroplaques. This creates an electric field

around them that will be modified by the electrical “echoes” of objects, benthic-living fish, and most especially the electrical signals of other *Homo eridanus*. They can communicate through a vocabulary of ordered electrical signals the way humans voice words, or the way dolphins might create electrical echoes in different shapes. This last way of communicating is the way they interface with the controls of the Congregate fighter craft, in electrical fields that provide more spacial information than normal eyes could.

In an alien ocean, the chemistry will work with different starting materials, and an engineered life has to be adapted for those changes. For example, Io has some of sulfur, Callisto has a fair bit of ammonia, as might Ganymede. A sulfur- or ammonia-laced ocean can have some neat chemical possibilities for science fiction, but for human descendents to live in it, we'd have to engineer our cells to either metabolize these things or pump them out. New proteins and enzymes could be designed to do either of these things, and adding new proteins to our bodies shouldn't be too much of a big deal as long as they're tested to make sure they don't interact with existing proteins.

But keeping all the macromolecules functional at benthic pressures is much harder. There is no insulation against pressure, or handy pumps across cell membranes to keep pressure out. Every cell feels the crush of seven hundred atmospheres all the time, and therefore so do all their proteins, which as mentioned above, could change the way they fold and therefore how they function. So, living at seven hundred times the pressure could involve redesigning many thousands of proteins. And each of those redesigned proteins would have to be tested to be sure that they don't interact with proteins they're not supposed to, to say nothing of making sure that the genes turn on and off correctly. (Gene regulation is a fascinating mix of always-on switches, negative and positive feedback loops, extra transcriptional factors, messenger-RNA stability, ribosomal recruitment, transfer-RNA and amino acid supplies, and many other things!) This almost ground-up redesign of the *Homo eridanus* metabolism is a scary amount of work, but it's all engineering; no law of science stops us.

And the worst thing is, engineers can get enough right for generations of *Homo eridanus* to be born and survive on the bottom of an alien ocean but still not make that environment feel natural—changing instincts is another layer of complexity that is likely a bridge too far. The *Homo eridanus* live the tragedy that they are truly alien and live in places alien to all their evolutionary history, but still feel human. They like the tastes we like, but they can't have that at the bottom of the ocean; they can eat sulfurous vent-living animals. The mate-recognition systems in their brains find humans beautiful, and yet the *Homo eridanus* look like giant blubbery catfish. They like light and sunshine, but can never see any, because once they're engineered to live at seven hundred atmospheres, they can't rise to the surface—their engineered proteins would denature due to lack of pressure, just like any benthic creature caught in a net and brought to the surface. This was a dangerous point for Stills in *The Quantum Magician*, when, due to the Venturi principle, the pressure of water around him lowered.

In the two hundred years since their creation, the *Homo eridanus* have found employment in the Venusian Congregate navies as the pilots in high-performance fighter craft. The intense g-forces required for battle maneuvers in space can't hurt bodies made to live at crushing pressures, and growing up in oceans, the *Homo eridanus* think in three dimensions in ways that humans do not. They've also developed an anarchistic, middle-finger-to-the-world attitude encapsulated in their philosophy, The Way of the Mongrel.

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The *Homo pupa* (the Puppets)

One of the ideas that has always terrified me about humanity going to the stars in small habitats is that it's very easy for a small group of people to enslave another. Humans on Earth have a terrible moral track record, and sometimes the only thing that ends a terrible situation is another nation finding out about it. In the asteroids, in far-flung habitats, if a Kim Jung-un or a David Koresh or a Solar Temple comes along, how would anyone stop it? You can't send the police five hundred million kilometers away to stop a bad situation. How would anyone even know that a bad situation was happening? Thinking about what future Jonestowns might look like led

to the creation of the *Homo pupa*.

It began with a small group of miners on an ice world who hired some unethical biologists to genetically engineer a slave species for them. The miners wanted no possibility of rebellion, so they took two important measures at the design stage.

Firstly, they made the new subspecies smaller, with maximum heights of only one hundred and twenty to one hundred and forty centimeters, so that any human could overpower any slave. Their diminutive stature also meant that these slaves would also use less resources and would be able to crawl into smaller mining tunnels and other work spaces. Their size also led to their name, the *Homo pupa*, although they're more commonly referred to as the Puppets.

Secondly, in the same way that software can be encrypted to make sure that systems can only receive authorized orders, so the genetic engineers set out to design a biological encryption system linking slave to masters. In this case, each human master was engineered to produce a kind of pheromone. The humans who produced these pheromones were called Numen (a Latin term for divinity).

To make this biological encryption system more difficult to hack, the pheromones produced by the Numen are covalently-linked protein dimers, the product of two genes, located on different chromosomes. Prior to secretion, the protein dimers are modified by bacterial microbiomes living within the cells of the Numen. Microbiomes are literally the microscopic biomes, in this case living on and in humans. The cell count ratios between humans and the microorganisms living on/in humans ranges from 1:1 to 1:3, so we are walking around with more bacterial, archaeal, and fungal cells than human cells! Most don't bother us, and some are parasitic, but some have important immune and metabolic functions we don't yet understand, essentially constituting a whole extended genome on each of us. Copying the composition and metabolic effects of any individual's microbiome (or the microbiomes of the Numen) is an added layer of encryption complexity for anyone who wants to hack the Numen-Puppet link.

The Puppets already possessed a main olfactory system like humans and most mammals, but to make sure that the pheromones were always properly received, the engineers added the genes needed for the Puppets to develop a distinct, second accessory olfactory system. This sensory system uses vomeronasal organs, whose neurons project not only to the amygdala, but also into the temporal lobe and dopamine production in the frontal lobes.

The targets of neuronal projection were very carefully chosen. Some kinds of epileptic seizures in the temporal lobe have been observed to cause patients to experience states of religious awe, joy, visions and voices. Likewise, specific levels of dopamine in the frontal lobes have been observed to produce vivid imagery, and religious and spiritual experiences, which are associated with emotions like fear, reverence, wonder, and awe.

Taking advantage of this, when the Puppets smell the pheromones of the Numen, they feel fear, reverence, and awe. The Puppets love and worship the Numen, no matter how the Numen treat them; any attention from the Numen results in the awe effect. Biology and religion (and to some extent, addiction) were united in the Puppets. Genetic variation exists among the Puppets. Some can go long periods of time without smelling the Numen, and some Puppets are born without the ability to experience the awe effect of the Numen. Such children were normally killed, although this point becomes important in the character of the Puppet Manfred Gates-15 in *The Quantum Magician*.

Sociologically, although the Numen did not encourage it, the Puppets developed elaborate theologies to contextualize their interactions with the Numen, about the role of Puppets in the world, eventually producing the first versions of the Puppet Bible, with transcriptions of things that various Numen have said to various Puppets over time. The statements of the Numen in the Puppet Bibles are the subject of an active program of exegesis.

The Puppets had another practical function for the Numen, however; that of organ donors. The Puppets had been created from the DNA of baseline Numen so the entire Puppet subspecies begins with high chances of donor compatibility. However, to make them better donors, they were also engineered to lack the thymus as well as individual immune markers on their cells. The thymus produces T-lymphocytes, which normally start a cascade of specific immune

responses. No thymus equals no t-lymphocytes equals severely compromised specific immune response. Importantly for the Numen, Puppet bodies can be used as substrates to grow new organs for the Numen, or more generally, Puppet organs can be removed and given to the Numen as needed. Within the context of their religious beliefs, the Puppets call this opportunity to give their organs to their divinities transubstantiation.

There is one major problem with the Numen-Puppet symbiosis, which is that the modified microbiomes in the Numen appear to be unstable. The additional microbiome genes that modify the pheromones have no other function, and so the bacteria may lose these genes over many decades by mutations. Given that the genetic engineers who created the Numen and Puppets are long dead, it may be that in a century or two, the pheromonal effects of the Numen no longer exist, in which case, an entire subspecies of people will face eternal withdrawal symptoms.

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The Homo quantus

I read a story about a man with quantum perceptions in Stephen Baxter's *Vacuum Diagrams* collection. The story¹ left me wanting more; I wanted a fuller exploration of what quantum perceptions would be like, and how they could be reconciled with the macroscopic and classical world. Out of this wanting, I created the *Homo quantus* subspecies. They are the product of generations of experimentation by an R&D project funded by the Anglo-Spanish Banks, who are seeking to create people who can predict the future for military or economic gain.

What's the major hurdle to engineering someone to perceive the quantum world? There are lots of places to start, but I focused on the problem of avoiding quantum wave function collapse that seems to always occur during the observation. Many, many, many experiments have shown that the quantum world does not like to be observed, before, during, or after the fact. From a human perspective, the quantum world seems to go to great lengths to avoid observation. The simplest setup to illustrate this is the two-slit experiment.

Particles like electrons are shot at a screen with two slits in it. Some bounce back, but some go through the slits all the way to a detector. When no one observes the pathways the electrons take, the detector finds a collective pattern that looks like an interference pattern, like what we'd see if EM waves were passing through the slits. Particles behaving like waves is a very quantum result. Yet, if a detector is placed anywhere along the path, whether before or after the slit-screen, the pattern on the detector is just two piles, as if the electrons genuinely were particles. Whether or not the setup is observed changes the outcome. There are a couple of mainstream interpretations for the two slit experiment, and one that's a little more fringe.

The von Neumann-Wigner interpretation provides a fascinating opening for making people with quantum perception. Von Neumann and Wigner proposed that consciousness is a necessary feature for quantum measurement and the collapse of the wave function. This perhaps means that a robot or computer measuring the electron's passing doesn't collapse the wave function; this happens only when a human (possessed of consciousness) observes the results.

This is an interesting idea, and it seems to suggest that if consciousness could be suspended, quantum phenomena, complete with uncollapsed quantum wave functions, might be observed. But how could consciousness be shut off in someone? What would that look like?

Consciousness is the integrative function in humans, allowing us to put together all our sets of experiences (touch, smell, sound, sight, etc.) into a single consistent view of the world. In 2014, it was reported that scientists had possibly found a switch to turn on and off consciousness: the claustrum.² When the claustrum was electrically stimulated with high-frequency pulses, a woman stopped responding to stimuli and stared into space. Now, this woman's brain was already damaged, and when other labs tried similar experiments with people with other brain injuries, they got different results, but the idea that there is one switch or several, that may turn off consciousness while leaving the car running, so to speak, is fascinating.

But what unconscious functions could possibly run the body and brain while the consciousness is out?

Induced savant syndrome (or acquired savant syndrome) offers another fascinating lead. In

2014, *Scientific American* ran an article on savantism by psychiatrist Darold Treffert.³ Certain types of brain damage (or stimulation), sometimes unlocked prodigious abilities in music, or art or mathematics, sometimes at the cost of social awareness, language, or visual-spatial skills. What was cool was that savantism could also sometimes be induced by transcranial direct current stimulation and transcranial magnetic stimulation. Researchers did this by applying electrical stimulation with a wire touching the brain, and with helmets using powerful magnets to induce different microcurrents in specific parts of the brain.

It was obvious that the *Homo quantus* would need some sort of sensitive, internal electrical or magnetic system to trigger both savantism and the collapse of consciousness. The simplest solution seemed to be to engineer people to develop electroplaques (those stacked disks of muscle cells that act like capacitors in electric fish and eels, and the *Homo eridanus*) and wire them to different parts of the brain.

These few ideas together allowed me to design the *Homo quantus*.

The *Homo quantus* are baseline humans who have been engineered to develop electroplaques that are wired (via carbon nano-filament) to various parts of the brain, and throughout the skeletal muscle cells. Using very fine electrical control, young *Homo quantus* can send micro-currents to the left temporal area, reducing the ability to process words, but boosting right-brain circuits that do spatial and mathematical tasks. Some *Homo quantus* can also achieve another type of mental state, wherein they extinguish their consciousness using the same electrical stimulation, leaving the different parts of the brain free to process quantum observations without collapsing the wave functions.

But how do they access quantum information that is almost necessarily microscopic?

The nanocarbon electrical wiring to all the skeletal muscle cells electrifies subcellular organelles called magnetosomes. Normally, chains of magnetite are strictly bacterial sub-cellular structures, used only for navigation, but a coil of iron within a membraned organelle could be engineered to exist within eukaryotic cells. These special magnetosomes could be rotated by polar spindle microtubules and myosin motor proteins. When electrified by micro-currents from the *Homo quantus*' electroplaques, the iron coil would produce a microscopic magnetic field, but one that along with millions of others can add up to a noticeable field.⁴ Through magnetosomes, the *Homo quantus* could perceive the electromagnetic environment around them, and if they are capable of fine enough control of the orientation of sets of magnetosomes, they could produce fine-grained magnetic fields capable of feeling the electromagnetic world in greater detail than any machine—think millions of nanosensors.

The information measured in this way could be recorded not as bits in the *Homo quantus* brain, but as quantum bits (qubits and qutrits), in portions of memory that are largely sequestered from the consciousness, so that the wave functions are not collapsed. When the *Homo quantus* is conscious once again, some summary information is available to them, or even quantum information, if he or she is willing to have the wave function collapse destroy the quantum nature of the information.

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The Trenholm Virus

The Trenholm virus is a failed engineered bioweapon using a megavirus as the vector. The megaviridae are fascinating. My grad school experiences were with an adenovirus type with an outer casing that looked like a D&D die and whose genome clocked in at just thirty-six thousand base pairs. Viruses have to have small genomes to be able to fit inside their little protein shells (capsids) and to be able to fit inside the prey cells. For comparison, a human cell contains three billion base pairs and the bacteria *E. coli*'s genome is 4.3 million base pairs. Those are big and I wouldn't have expected similar DNA sizes for viruses. When I read that the megaviridae family of viruses has one to two million base pairs of DNA coding for nearly a thousand genes, I knew this was weird enough to need to go into a story.

The Trenholm virus is a megavirus made to target human respiratory cells. Upon infection, Trenholm expressed genes that compromise human immune systems and produce toxins that build up slowly enough for the virus to infect others, but quick enough to be militarily relevant.

Its military developers never managed to make Trenholm infectious enough to be tactically functional, but an accident inside Westbrook Station exposed many people, among them Will Gander.

The virus that infected Gander was not fully competent: While it stripped away major portions of his immune system, its level of toxin production was so slow that a lethal concentration would take over a year. However, the megavirus' ability to evade the immune system prevents anyone from actually curing him, which makes Gander the perfect candidate for the one-way trip role in the confidence scheme. However, when Will is found out by the Puppets, far from being a deterrent, Trenholm virus interested the Puppets as a possible vector in their efforts at experimental theology.

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Wormholes for Fun and Space Travel

Although *The Quantum Magician* has stable, permanent wormholes left over from some distant, extinct forerunner species (a fun space opera trope), I wanted ships to be able to travel meaningful distances without using that network.

The civilian and military ships I described used magnetic coils in front of the ship to cause a magnetic field to induce a wormhole. The roots of this idea were first proposed in 1917 (Levi-Cevita solution to General Theory of Relativity), refined in 1988 (Morris and Thorne), and finally given science-fiction-ready thinking in 1995 (Maccone). The theory is that a static, homogeneous magnetic field is capable of bending space-time to the point that a traversable wormhole is formed.

The problem is that such induced wormholes would be very unstable (like oh-no-a-photon-hit-the-wormhole-and-collapsed-it unstable). The ships that induce wormholes in *The Quantum Magician* can dampen their EM emissions, but they can't stop the ship from radiating blackbody thermal radiation, even in principle. So, the surfaces of these ships are fitted with emitters that radiate EM in frequencies that will destructively interfere with the natural infrared blackbody radiation of the ships. Destructive interference occurs when the peaks of one EM wave matches the trough of another, and they cancel each other out. So the emitters cancel out the natural heat radiation of their ships. Induced wormholes can reach a quarter or a half light-year, with military vessels capable of crossing a whole light-year in a single induced wormhole.

The permanent, stable wormhole network (called the Axis Mundi) is different. The wormholes cross vast distances, from ten light-years to a hundred. Ships can go through without special precautions with little fear of collapse, but no one understands how they work. They emit very little EM, nothing that could be detected against the galactic or solar system's background radiation, so they are very difficult to find. The Axis Mundi wormholes possess mass and orbit various stars, and seem to be especially found near neutron stars/pulsars (the reason for this last is interesting from a story perspective, but will only be touched in a sequel novel).

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I remember in high school being frustrated with some science fiction stories that used insufficient science for my liking. I even remember having written the start of a "Putting the Science Back in Science Fiction" essay in my high school library. Science is the start of the sense of wonder I want to feel when I read science fiction. I want to be transported to other places, other worlds and to meet other humanities. Hopefully readers felt like they'd visited those other places when they read *The Quantum Magician*.

Endnotes:

¹ "Vacuum Diagrams," the title story of the collection.

² *New Scientist*, 2 July 2014, "Consciousness on-off switch discovered deep in brain," by Helen Thomson, <https://www.newscientist.com/article/mg22329762-700-consciousness-on-off-switch-discovered-deep-in-brain/>

³ Darold A. Treffert, *Scientific American*, August, 2014

⁴ Claudio Maccone, 1995, *Journal of the British Interplanetary Society*, 48 453