REAL REVIEW 14

REAL REVIEW
What it means to live today

Issue for Summer 2023
RRP £12
ISBN 978-1-8384934-2-4

THE ORIGIN OF GOLD

Hui Wu

Within a few hundred thousand years of the universe coming into being, subatomic particles had cooled sufficiently to form the simplest element, hydrogen (one proton, one neutron, one electron). All the stuff that will ever exist began as a uniformly distributed field, but minor variations in the distribution of dark matter distorted the fabric of the cosmos to generate uneven pockets.

Within just a few hundred million years, these accretions had begun to spin, gradually settling into flat rotating structures known as protogalactic disks. As gravity and dark matter concentrated more and more hydrogen at their centres, they revolved faster and faster at higher and higher densities. Our galaxy, the Milky Way, came to be at this time. Smaller pockets within these disks became even more concentrated. Sub-regions were spinning on their own, like eddies in a stream. Some molecular clouds reached the threshold for fusion, spontaneously bursting into balls of burning hydrogen, and producing the second type of atom, helium.

Within a few billion years of the Milky Way galaxy's life, many generations of stars lived and died. Most stellar objects were like our own, little yellow candles in the silent vacuum of space, pumping out light and heat and helium. Our sun is a G-type main-sequence star, one of the most common stars in our galaxy, known for their stable energy output. Other suns were a thousand times bigger, glowing red and white but living for only the briefest of moments. The atomic waste from these behemoths was blown around into swirling clouds of ever-heavier elements, lithium, carbon, sulphur, neon, silver. These clouds had colours that had never existed before.

One such molecular cocktail, one hundred times bigger than our sun, was drifting around our region for a long time. Like the rest of the galactic plane, it was slowly orbiting the black hole at the centre of the Milky Way. Eventually it achieved critical density and exploded to form our sun. Much of the lighter elements were blown away, traversing the interstellar medium until they became part of another star. A lot of the cloud disk remained. Closer to the sun, grains of rock and metal bumped into each other, snowballing into molten spheres whose gravity sucked up all the surrounding material. These protoplanets ploughed through the disk, carving out their special orbits. Mercury, Venus, Earth and Mars. Further away, where it was cooler, lighter elements became the gas giants Jupiter and Saturn. Beyond, where it is cold enough for methane and ammonia to crystallise, are the ice giants Uranus and Neptune. At the very limit of the solar system is a broad band of asteroids bumping about in the darkness, the Kuiper Belt. This place is a nursery of dwarf planets, Pluto, Ceres, Eris, Makemake, Haumea and the rest. From time to time a chunk of something will bounce loose from the Belt and head sunwards. We have the gas giants to thank for protecting us, as their mass blocks dinosaur-killing rocks from getting too close, too frequently.

The universe is about 13.8 billion years old. Our galaxy is perhaps 13.6 billion years old. Our own sun is a latecomer, formed just 4.6 billion years ago. It is already middle aged. In another 5 billion years it will start to run out of hydrogen fuel. The core will collapse and its outer layers will expand, engulfing and destroying the inner planets. The Earth's atmosphere will be blown into space, the oceans will evaporate, and the crust will become molten. This process will put an end to all life in the universe as we know it.

For life to exist on our planet, so many factors have had to work together in perfect harmony. It is much more complex than just the gas giants keeping us from being bombarded. If our sun was in a binary system, orbiting another star, planet formation might have been very different. No Earths. If our sun was within an even larger system, planets may have been prevented from forming at all. The well-known three body problem in physics speaks to the underlying chaos of the universe. If our star was even a slightly different category, it might not have endured long enough for life to emerge, or been too unstable to support the gradual inclination of biological progress.

If our planet was any closer to the sun, there would be no oceans and our atmosphere might be sulphuric acid like Venus. Or we might have been tidally locked, without a rotation, without day and night, where half the surface is on fire and half is frozen, like Mercury. If we didn't have an iron core, we would have no magnetosphere, making Earth too irradiated to support DNA. It would also mean that over time all the air would leak away, like on Mars.

In the early solar system there were two planets that no longer exist, Gaia and Thea. One was about the size of Mars, and it became somehow destabilised from its orbit, crashing into Gaia at a speed of 9km/s. It was a nearly direct hit, at an oblique inclination not more than 23.5 degrees.

The two planets disintegrated into each other, thoroughly mixing until they formed a new body we call Earth. The ejecta from the impact became the Moon. If we did not have an axial tilt, we would have no seasons, and no way to redistribute heat from the equator to the poles. Without this distribution of solar gain, we could not have temperate, stable weather patterns. Global warming is tipping the Earth back in time, to become a world of extremes, in part because the atmosphere is no longer able to evenly disperse heat as it once did.

These are just some of the many factors that were essential to the emergence of life on Earth. There are many others, too many to try and write down, too many to explain and many more than are known.

But we can say that the existence of your eye reading this page is maybe as implausible as rolling two dice and having them come up double sixes at least 198,115,000,000,000,000,000,000,000,000 consecutive times. This immense unlikeliness, when combined with the brief lifetime of stars and the infinitesimal existence of any species, could explain why we have not yet found other life in the galaxy. I do not think that statistical improbability is evidence of divine intention, or meaning, or creation. It's just odds.

Your body is made up of seven octillion atoms, although none of them are made by our own star. The human body does not naturally contain helium, which is an inert gas (it is chemically unreactive and does not participate in biological processes). Helium is neither produced or required by the human body. The only thing our star can make plays no part in our humanity. This could be ironic. These seven octillion atoms are precisely and spontaneously arranged, in a configuration that for several tens of orbits around our star is able to believe that it is a person. There is an order to this composition, but it is of a magnitude of complexity that is practically incomprehensible to our simple neurological machinery. People will call it a miracle, which literally means something we cannot explain. The world is one single miracle. The poetry of this reality is more beautiful than any other origin story I have ever known to be conceived by humans, and I am grateful to live during an epoch when it can be told.

Our bodies are made from the atomic waste of a billion dead stars. They contain no helium, but they do host tiny amounts of another noble element, gold. We eat it, because it is in the plants and animals, and the water. It has no impact on our health at all, but it is there.

As one of the heavier elements, gold can only be made in the very largest stellar reactions, through supernova nucleosynthesis. When big stars collapse, gold dust is scattered into space. Over aeons, some of this material becomes bound up inside asteroids, and these eventually navigate their way to raining down onto the surface of the Earth. Because there are so few of these supermassive suns in our galaxy, there is not a very high presence of gold in the galactic disk relative to other elements.

Today, gold does not regularly fall from the sky. More commonly it comes from underground, and enters our ecosystems through volcanic eruptions, not meteor showers. Although it is still a very rare element, there is a greater proportion of gold here on Earth than would be expected if it had simply been randomly sprinkled into the cosmic dust. This raises the question of its origins.

The World Gold Council estimates that 208,874,000 kilograms of gold has been mined throughout history. Two-thirds of this amount has been extracted since 1950. Because of its widespread social and technological value, and how hard it is to extract from the crust, the majority of this gold remains locked in the form of human objects. It is possible, but not likely, that the circuits in your smartphone were once part of a pharaoh's death mask. The US Geological Survey estimates that a further 57 million kilograms remains to be extracted, although only a fraction of this sum has been discovered or identified. The total quantity of gold on Earth is therefore not likely to be more than 300 million kilograms.

The primary source of gold in the universe is not your typical stellar explosion, even very big ones. Instead, it is mainly believed to be the product of the collision between two incredibly rare and exotic objects called neutron stars.

Neutron stars are the result of the dramatic death of supermassive suns. As the sun exhausts its light nuclear fuel, fusion will progress to heavier elements. When its core starts making iron, the weight of this element means that at a certain point the sun will no longer be able to generate enough energy to counteract its own gravity. This causes the core to rapidly collapse, resulting in a supernova. If the gravitational pull of the remaining mass is more powerful than the escaping light, it forms a black hole. This is called a singularity, a place where all known laws of physics break down. But if the gravitational pull of the remaining mass is very slightly less, it will become a neutron star.

A neutron star is the result of a stellar iron core so compressed that the protons and electrons fuse together to form a soup of neutrons. The whole star is made exclusively from neutrons. On Earth, a single teaspoon of this material would weigh several trillion kilograms.

Not only are neutron stars incredibly dense, they also spin incredibly fast. An object the size of Tokyo, and weighing as much as our own sun, will often complete several revolutions per second. Anyone who has ever spun around on an office chair and pulled in their arms to increase their speed will understand how this can be the case. As they rotate, neutron stars emit beams of radiation from their poles known as pulsars. These are incredibly useful, because by measuring pulsars with a process called parallax, it is possible to know exactly how far away the star is from Earth. Neutron stars are the lighthouses of the universe, helping humans to map its structure and measure its size.

Neutron stars comprise a little less than 1% of all the stars in our galaxy, so two of them colliding is a rare event indeed. When they do crash into each other they merge and form a single massive neutron star. The moment when their two stellar surfaces first meet triggers one of the most powerful reactions in the universe, called a kilonova. Much as an angle grinder kicks up a shower of sparks, when the two stars touch they produce great jets of gold, platinum, tungsten and mercury. These metal javelins, with the mass of hundreds of millions of kilograms, are thrown out by the stars at unimaginable velocities to speed across the cosmos for billions of years.

One of the most likely explanations for how the Earth came to have more gold than one would expect is that a gold javelin struck our planet at a specific moment in its early formation. We can know that the strike came after the merger of Gaia and Thea, because the concentration of gold on the Moon is so much less than Earth. If a javelin of gold had collided with either one of the protoplanets, lunar concentrations would be identical to terrestrial ones.

The two protoplanets probably collided around 4.5 billion years ago, so gold could not have arrived before then. But it could not have been very much later either, because by the end of the Hadean geological epoch (4.0 billion years ago), the Earth had cooled and its crust was no longer molten. The atmosphere was 27 times thicker than today, and surface temperatures varied between 200–500C. But the floor was not made of lava.

A pure gold asteroid weighing 300 million kilograms has a volume of 15 cubic kilometres. This is not very large in astronomical terms. The Chicxulub asteroid that killed the dinosaurs was around 14,000 cubic kilometres. The largest impact crater on Earth, at Vredefort in present-day South Africa, was over 30,000 cubic kilometres. If the javelin had struck Australia, which is the most ancient continent, there is a chance that all the gold on Earth would still be concentrated there, in one single location. Given how extremely remote this land mass is from the first civilizations that came to value gold, it is possible gold would never have risen to prominence as a precious metal in this eventuality.

If this gold javelin had struck a non-molten planet, it would have taken much longer than 4 billion years to be absorbed through plate tectonics down to the mantle, then spread around and incorporated into geological features across the world. If the Earth is cookie dough and the gold is a chocolate chip, it takes a lot of kneading to mix that single chip evenly into the dough. More probably, if the asteroid fell to Earth soon after Gaia and Theia merged to form Earth, the molten surface would have facilitated a rapid and even dispersion of the gold. In this scenario, the gold is like sugar dropped into a cotton candy machine, with the planet performing the task of melting and spinning the gold until it coats the Earth's lithosphere in a fine web.

In a way, it doesn't matter where Earth's extra gold actually came from. Because although this review describes real objects and events – the formation of the galaxy, the solar system, our planet and the extraterrestrial genesis of gold – such subjects are in any case beyond humanity's capacity to grasp them as true. The timescales and spatial scales are far too vast. They appear as fables, or memento mori; stories or thought experiments. Maybe though, just for a second, we might feel an unsettling vertigo, the raising of hair on our arms, that illusory sensation that tells us some part of our mind and body understands that it doesn't understand. This is how I feel when I hold any piece of gold in my hand. I know, intellectually and deep in my being, that this material was forged in cosmic violence billions of years ago. I imagine it traversing the darkness, finding the molten rock oceans of a young Earth. I imagine the people who dug it up, melted it down, cast and shaped it. And I remember each fragment belongs to one source. Everyone who presses a piece of gold to their warm body shares this connection.