THE SECRET LIFE OF GOLD

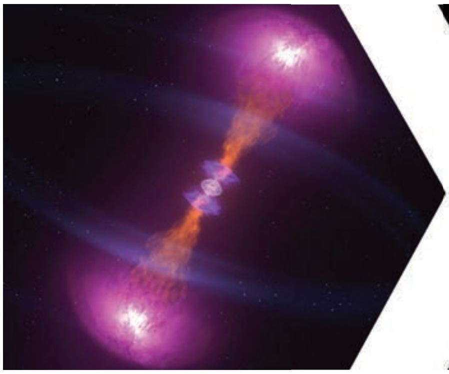
By Grant Currin

Right this second, a bit of gold could be within your reach even if you're not wearing gold jewelry. The precious metal could be in your pocket, or in front of you on your desk—that's because a very small amount of gold is inside phones, tablets, and laptops.

Hidden behind electronic screens and outer casings of glass and aluminum are computers' electronic brains, which rely on gold along with other precious metals. Just a tiny quantity of gold—about 0.034 grams—conducts electricity in a cellphone, and prevents other electrical components from corroding. It allows you to reliably text and watch YouTube videos at the tap of a finger.

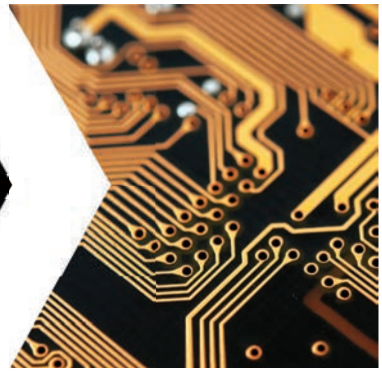
That's why gold is in your pocket, but where did it come from?

FROM THE COSMOS TO YOUR COMPUTER



This illustration depicts the explosive merger of two neutron stars. Scientists have reported that a collision of two such stars about 4.6 billion years ago likely led to the formation of gold.

The flakes, fragments, and nuggets of gold embedded in Earth's crust were delivered on meteorites that pelted the planet (long before humans came along).

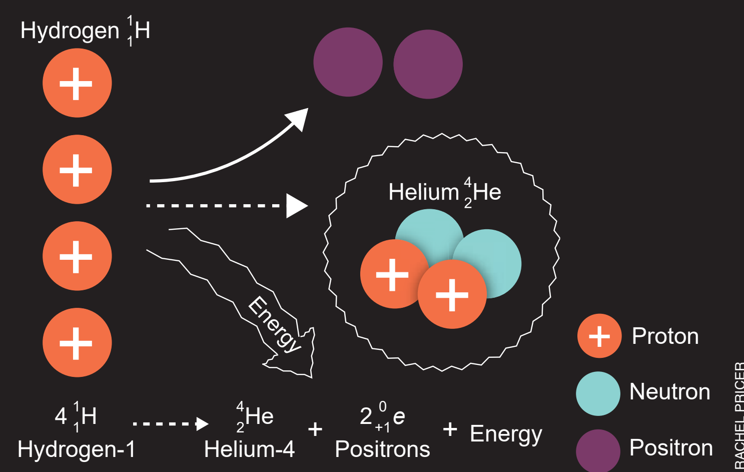


Gold is soft, highly conductive, and doesn't corrode, making it suitable for use in electronics. The electronics industry used nearly 270 tons of gold in 2018.

NASA'S GODDARD SPACE FLIGHT CENTER/CI LAB, CARLIN GREEN/USGS/PUBLIC DOMAIN, GETTY IMAGES

Star Power

For tens of millions of years, two stars involved in the creation of gold thrived on nuclear fusion. Gravity forced hydrogen nuclei in their cores to fuse, setting off additional reactions that resulted in the production of helium nuclei (or alpha particles), energy, and positrons.



The story of how gold ended up in rock formations, and in your electronics and jewelry has been murky. But researchers have been piecing together its origin story, and within the past two years, have published new reports that help flesh out where gold—one of the most valuable metals on Earth—came from.

The story starts with a bang

You may already know that the matter making up everything you have ever touched, smelled, or seen came from the Big Bang, which unzipped the universe 13.8 billion years ago. The Big Bang theory is the prevailing model of how the universe was created. It suggests that everything—all matter and energy—was jammed into a tiny point that became the universe in a massive explosion that marked the beginning of time and the creation of space itself.

At first, gold was not even a shimmery speck in the universe's explosive debut. After the Big Bang, enormous quantities of protons, neutrons, and electrons combined to form hydrogen, helium, and a little bit of lithium, says Imre Bartos, an astrophysicist at the University of Florida. These reactions seeded the universe with this cosmic dust for hundreds of thousands of years.

For the most part, these elements were evenly distributed across the universe. But every now and then, the density in one place was a little bit higher than the density everywhere else. When this happened, gravity began pulling atoms closer together into swirling clumps of gas and dust. As a clump compressed, its center would become dense and hot enough to start fusing hydrogen nuclei—that is, protons—together, releasing energy, and giving rise to a new star.

According to scientists' best estimates, stars began forming 13.6 billion years ago, 200 million years after the Big Bang. Gold was still nowhere to be seen.

But several billion years after the first stars were born, an important pair of large stars, each about 10 times the mass of the sun, formed and started circling each other, creating a binary star system. Bartos and a collaborator, Szabolcs Márka at Columbia University, identified the stars in 2019, publishing their work in the scientific journal *Nature.* These unnamed stars might have played a crucial role in the formation of Earth—and the precious resources, including gold, deep within our planet.

Tension

For most of these two stars' lives, they thrived on **nuclear fusion.** The stars' gravity forced hydrogen nuclei in their cores to fuse, setting off additional reactions that resulted in the production of helium nuclei (also known as alpha particles), energy, and **positrons**—the antimatter version of electrons:

$$\underset{\text{Hydrogen-1}}{4\,^1_1H} \rightarrow \underset{\text{Helium-4}}{^4_2He} + \underset{\text{Positrons}}{2\,^0_{+1}e} + \text{Energy}$$

Nuclear fusion reactions went on for tens of millions of years. As the stars grew older, they began producing heavier elements, such as carbon, oxygen, and silicon, in their cores.

Then the stars arrived at element 26. The introduction of iron dramatically changed the course of the stars' development.

"Iron is the most stable form of matter," says Bartos. "Anything heavier than iron takes energy to create."

Ironically, it was iron's stability that spelled doom for the stars. Because the force of gravity in the core of stars is so strong, stars rely on a constant supply of energy to resist its crushing force. But with the introduction of iron, the cores stopped producing energy, inviting collapse.

Explosion

At different times, the stars' cores imploded, collapsing thousands of miles in just seconds from about the size of the Earth to about 7 miles in diameter. The implosions occurred so quickly that they created powerful shockwaves.

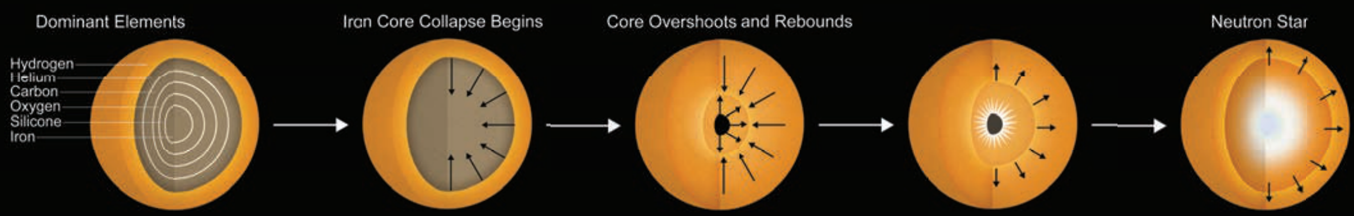
And when the cores of the stars collapsed, the outer layers also zoomed inward, crashing with the outward-bound shockwaves. The collision blasted matter out into deep space in two supernova explosions that occurred within a few million years of each other.

Remarkably, the huge amount of energy emanating from the explosions did not destroy the binary system.

"Usually, one star [in a binary system] is flung away in a supernova explosion," says James Lattimer, an astrophysicist at the State University of New York at Stony Brook.

In this case, the explosions left behind two neutron stars. Neutron stars are so dense that a single teaspoon of its material on Earth would weigh 1 billion tons.

"They're called neutron stars because after the dust has settled, they're about 95% neutrons, and 5% protons," says Lattimer, who in the 1970s was one of the first scientists to argue that neutron stars might create



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A Neutron Star is Born

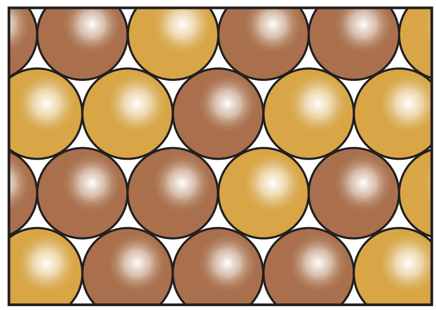
As a massive star ages, the formation in its core of increasingly heavy elements, such as carbon, oxygen, silicon, and then iron, leads to the core's collapse under intense gravitational force. The core's implosion blasts out a shockwave while gravity yanks the star's outer layers inward. The incoming layers crash with the outbound wave, blasting matter into deep space. The small, incredibly dense core left behind is a neutron star.

Why We Are Made of 'Star Stuff'
http://bit.ly/Reactions-StarStuff

What Does "24-Karat Gold" Mean?

Almost all gold in circulation today is an alloy—a mixture of two or more metals.

We use alloys because they are often cheaper and more useful. Gold is an expensive element, so mixing gold with less expensive metals yields less expensive alloys, which can be used to make products that are more affordable. It's also expensive to refine gold to very high levels of purity. Even the most highly refined samples contain an atom of something else for every 100,000 atoms of Au.



« White gold, rose gold, and other types of gold are mixtures of gold atoms with atoms of other metals, such as copper, nickel, and aluminum.

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Alloys are also more practical than pure gold for most applications. Pure gold is very soft, so jewelers mix it with elements, such as nickel, copper, or silver, to create a stronger alloy with other desirable properties. For example, certain alloys have distinctive colors that make jewelry more interesting. White gold is often made by mixing nine parts gold to one part nickel. Rose gold is a family of alloys that contain about three parts gold to one part copper.

Karats (sometimes misspelled "carats," a measure of mass often used for gemstones) are the unit used to express the percentage of pure gold in an alloy. The number of karats represents the fraction of pure gold per 24 parts. So 24-karat gold is pure gold, while 14-karat gold is an alloy that only contains 58.3% gold (14 g of gold per 24 g of total alloy).

heavy elements, such as gold. Decades later, new research would support this hypothesis.

Collision

The neutron stars circled each other for billions of years, inching closer to each other at a glacial rate.

And then, about 4.6 billion years ago, the long-time neighbors collided.

The crash sent clouds of neutrons whizzing into space. The particles in this cloud of debris smashed into one another, finally creating elements heavier than iron.

Among the new elements created was—at last—element 79: gold! The mass of the gold created in the neutron star collision was between 3 and 13 times that of the Earth, according to a 2018 paper in the *Astrophysical Journal*.

But the gold produced didn't appear in large chunks. Its atoms shot into every corner of the universe. Some joined an ancient cloud of dust near our corner of the Milky Way. About 100 million years later, the cloud began to condense and break into fragments. One of the fragments would become our solar system.

The vast majority of the atoms in this pre-solar nebula were hydrogen and helium, and almost all of them comprised the sun. The heavier elements joined to form asteroids and rocky planets including Earth.

The early Earth was a ball of molten rock that created gravity strong enough to drag the heaviest elements, including gold, into its core. Scientists at the University of Bristol in the United Kingdom have calculated that the gold in the core could cover the surface of the Earth with a layer 13 inches thick.

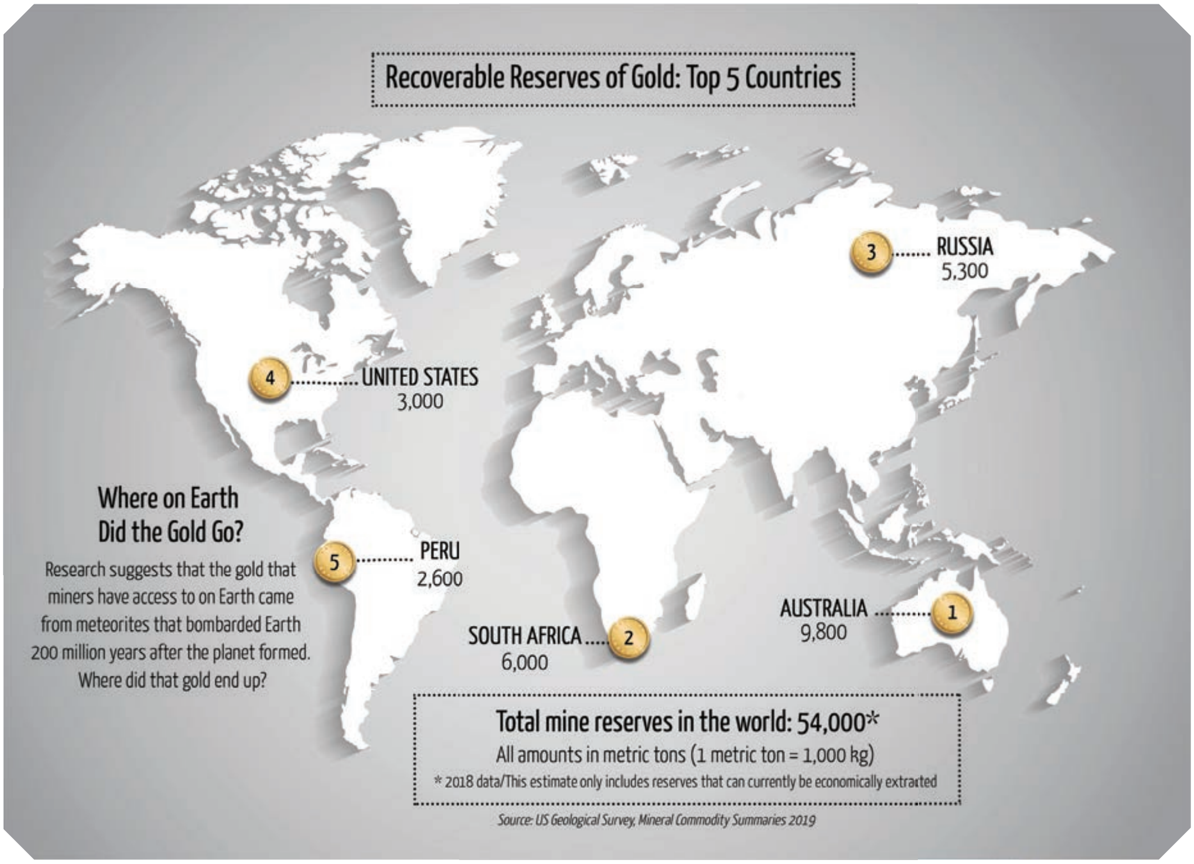
But that's not where the gold in your phones comes from. Humans have never laid eyes on the gold in the Earth's core, and probably never will. That gold is locked away under a few thousand miles of rock. Currently, the mine recognized as the deepest in the world is approximately 2.5 miles below the Earth's surface.

The gold that ultimately ended up in our phones, jewelry, and the world's bank reserves took a slightly longer journey to get here.

Bombardment

Much smaller than planets, asteroids and meteoroids did not lock their gold beneath tons of rock. Some of it probably sat on the surface, fused to chunks of rock.

So, about 200 million years after Earth was formed, when the planet swept through a patch of rocks floating in space, meteorites (space rocks that hit a planet's surface) pelted Earth with billions of tons of rock,



KELSEY CASSELBURY

according to the researchers at Bristol. Recent research suggests that the meteorites embedded a new batch of heavy elements, including gold, in the planet's crust. The force of the collisions caused portions of the crust to melt and shift around, leaving gold in veins, which are crystallized mineral deposits within rocks, where miners find it today.

The universe in your pocket

Gold has made life more opulent for centuries with gilded statues, golden domes, and luxurious threads for embroidery. In the digital age, the lustrous metal has taken on new importance. But given gold's long history, it's clear that your phone is merely a rest stop for gold atoms that debuted in the universe billions of years ago.

Grant Currin is a science writer from Cleveland, Tenn.

REFERENCES

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Where's the Gold?

Not only is gold beautiful, but it can also be super practical. It can be beaten into sheets 0.18 micrometers thick, drawn into wires 5 micrometers in diameter, and is inert to most acids and oxidants. Plus, it's a good conductor of heat and electricity, and forms stable, uniform nanoparticles.

Below are some of the uses of gold, but in order to read them, you have to decode the cipher. Each letter has been randomly substituted with another letter of the alphabet. The letter substitutions are the same for each word. Can you identify all the uses of gold?
(Starting hint: N stands for C, and R stands for L)

YHZHRAM ______________________

NEKUX ______________________

NDUNHA VAHDVPHUVX ______________________

PHBDRX ______________________

XPDAVLCEUH NKANFKVX ______________________

HRHNVAKNDR NEUVDNVX ______________________

DAVKSKNKDR RHQX ______________________

AHSRHNVKJH NEDVKUQ KU XLDNH CHRPHVX

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** Answers are in the Teacher's Guide, available at www.acs.org/chemmmatters.org*