Aliens!

William Li

Writer's Comment: Part of me wishes I studied astrophysics instead of biochemistry because of how intriguing and mysterious I find celestial objects. From quasars to quantum mechanics, there's so much we're just beginning to understand about these complex phenomena. When Dr. Herring asked me to write an "explanation of a technical matter for the general public," I knew I wanted to talk about pulsars – these incredibly dense and fast-spinning star corpses – and how they challenge our understanding of physics. Instead of focusing on more a technical explanation of pulsars (this is by no means my area of expertise), I opted to write about its discovery by Jocelyn Bell. Bell's story is one of serendipity and the exhilarating feeling of discovering something unknown, all made possible by her unwavering dedication to the scientific process. I dream of a day when I'll be able to contribute a fraction of what Bell has, but for now I hope my retelling of Bell's story inspires you to look up at the stars a little more often.

Instructor's Comment: Let me let you in on a secret: I don't always understand everything my students write in their essays, and not through any fault of their own—an occupational hazard when you teach, as I do, the course Writing in the Professions: Science. Our students are often doing scientific work so advanced, and in such a wide variety of fields, that they regularly lose me. Here, however, is another secret: the solution is to create an assignment in which the students explain a difficult scientific subject so that any member of the general public can understand it. In the course of explaining things for the public, the students explain them for me, and I am no longer so befuddled.

William's winning essay was written in response to such an assignment. In it, he explains pulsars and related phenomena in astrophysics that ought to be impossible to follow. Such topics are maximally challenging for any writer, but I found the essay easy to understand, because William does such a fine job explaining—and if I can understand it, then you should have no problem.

—Scott Herring, University Writing Program

Hunched over her desk at the Mullard Radio Astronomy Observatory outside Cambridge, 24-year-old PhD student Jocelyn Bell pored over the days' worth of data from her radio telescope. She spent the past two years building a vineyard of radio antennas, connected by wires snaking through stakes protruding from the ground. It was 1967, and Bell was working under Professor Tony Hewish to study quasars, super bright objects thought to be emitted from black holes.

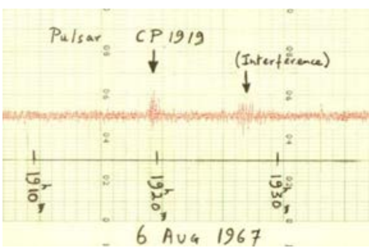

Figure 1. Bell's original observation of the "scruffs." Courtesy of New York Times.

Without modern computers in existence to digitalize data, Bell sat down every night to analyze hundreds of feet of paper, spit out from the telescope's chart recorder each day. Every so often, she noticed a "scruff" in the data. She squinted at that portion of the red line – she'd seen it before, and it didn't look like a quasar signal nor interference from the lab next door. Bell switched to a better recorder to try recapturing the signal, and on November 28, 1967, Bell received one: a string of pulses, each exactly 1.3 seconds apart. The spacing between signals was precise; it felt like a beacon from an alien world. Bell found another signal shortly after and then two more by Christmas, all from different locations in the sky. Partly from a farfetched hope of discovering the first extraterrestrial and mainly to save her from saying "you know that funny pulsing source at right ascension

1919, declination plus 20," Bell gave it a memorable label instead: LGM-1, short for Little Green Men. Bell, in fact, had made one of the greatest discoveries in astronomy history. A prominent astrophysicist named Thomas Gold would later prove the signal's source to be pulsars, mythical objects in the lore of astrophysical theories.

Pulsars are a special type of neutron star that has an incredibly strong magnetic field and fast spin. Pulsars are a hand-cranked flashlight, harnessing the power of their spin and magnetism to generate beams of radiation. As a flashlight dims when its fatigued owner stops cranking it, a neutron star ceases to become a pulsar when it lacks enough energy.

Like everything else in the universe, pulsars are born from the remains of dead stars, cosmic clouds called nebulas floating in space. When turbulence disturbs these interstellar nurseries, some regions form high-density clumps. These "knots" slowly condense, and the material starts to heat up and spin until a protostar is born. They're hungry hippos, gobbling up neighboring material with the insatiable power of gravity until its core gets hot enough to form a star. Dust that escapes this scorching fate clump together to form planets, asteroids, or comets that orbit the star.

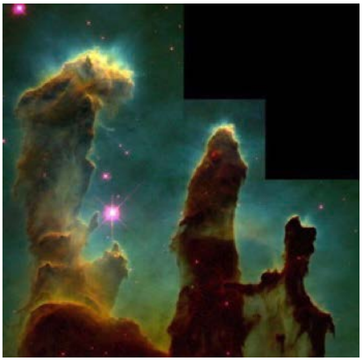

Figure 2. "Pillars of Creation" from the well-known Eagle Nebula. Courtesy of Wikimedia.

A star's core can reach up to 7 million degrees Celsius, a necessity for it to produce energy. Inside, hydrogen atoms are smashed together to produce helium in a process called fusion, releasing massive amounts of heat and light that planets relish in. This same process exerts outward pressure, fighting against gravity to keep the star from collapsing. Once stars run out of hydrogen to burn, the reactions inside it become unstable, according to

NASA's website "Stars," causing it to periodically flare with bursts of energy. The result is a "pulsating" star, throwing out its outer layers and "enshrouding itself in a cocoon of gas and dust." Stars with a mass like our sun will shed their outer layers to form a White Dwarf, a faint yet "hot stellar cinder" that gradually cools down.

This fate awaiting our Sun and solar system is mellow compared to the extreme conditions that birth neutron stars. Stars eight times our Sun's mass have cores hot enough to support additional nuclear reactions and create heavier elements up until iron. Iron is a depleted shell of its lighter siblings – it has no energy to give and sits in the core, contributing only gravity to coax the star into collapse. The star gives in: its core shrinks from five thousand miles to a few dozen in seconds; its outer material rebounds against the collapsing core with enormous energy in a massive explosion called a supernova. Anyone lucky to witness one may be reminded of the opening scene from *Super Smash Bros. Ultimate's World of Light*, where Galeem consumes our protagonists and the galaxy in a bath of light.

The core performs one final dance before its transformation is complete. As it shrinks, the core mashes charged protons and electrons together to form neutral neutron particles. Like a figure skater pulling her arms in, it accelerates its spin to reach up to forty-three thousand rotations a minute. The neutron star is now born – its density equivalent to "jamming the population of the globe into a sewing thimble," according to Bell. Its magnetic poles, estimated to be up to 1 quadrillion times stronger than Earth's, accelerate atomic particles to create beams of radiation; combined with its perpetual spin, these cosmic lasers sweep the expanse like a lighthouse, according to Stanford physics

Figure 3. Galeem from Super Smash Bros. Ultimate. Courtesy of Nintendo.

professor Roger Romani. Sometimes, these beams can point towards Earth which we detect as radio signals as Bell first did in1967.

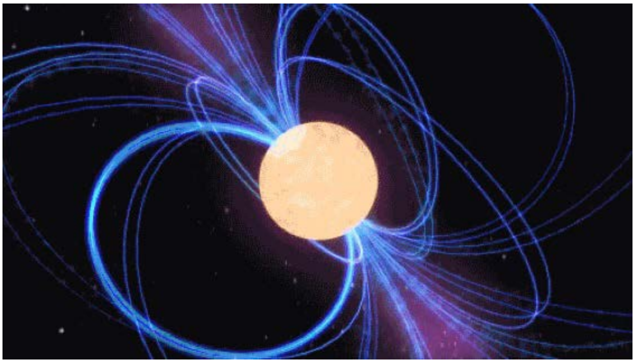

Figure 4. Artist's rendition of a pulsar featuring beams of radiation (purple) and magnetic field lines (blue). Courtesy of NASA.

In large part to the extreme pressure at its core, a neutron star's inner composition pushes our understanding of physics to the limit. Most scientists agree that a thin layer of atmospheric hydrogen and helium coats the star and gives a façade of habitability. A two-centimeter crust of iron and silicon atoms bathe in a sea of negatively charged particles called electrons, sitting on top of a crushed soup of neutrons and electrons. Below that, scientists are still trying to figure out what's inside. "It's one thing to know the ingredients, and another to understand the recipe, and how those ingredients are going to interact with each other," astrophysicist Jocelyn Read of California State University Fullerton puts it. James Lattimer of Stony Brook University told *Quanta Magazine* that neutron stars could contain "nucleon variations," among them protons and neutrons. Other physicists like to think that the intense gravitational pressure smashes nucleons into smaller subatomic particles. David Blaschke of the University of Wroclaw likens nucleons to cherries: "you can compress them a bit, but at some point you smash them."

However, we are starting to learn more about them.

Launched in 2017, an instrument on the International Space Station called the Neutron Star Interior Composition Explorer (NICER) has started to provide valuable data on how neutron stars work. With its 56 gold-coated telescopes, NICER detects X-rays from magnetic hotspots on the stars' surfaces. Recent data from pulsar J0030+0451 suggests that it has two crescent-shaped and one circle-shaped poles. It's the first "pulsar where the beams are not 180 degrees separated," astrophysicist Natalie Webb from the Institute for Research in Astrophysics and Planetology comments. "That's fantastic if true."

The 1974 Nobel Prize in Physics for discovering pulsars was awarded to Hewish and Ryle instead of Bell, but Bell won the 2018 Special Breakthrough Prize in Fundamental Physics along with a 2.3-million-pound prize. She donated the prize money to create the Bell Burnell Graduate Scholarship Fund, which will fund a more diverse student research population in physics. When asked about the future of astrophysics, Bell remarks that modern telescopes like NICER have computers to sift through tons of data, but "how do you pick up the things you don't know exist, the things you can't tell it to look for?" Bell's comments and legacy epitomizes the spirit of scientific discovery: she looked for what she knew, found something unexpected, and discovered the unimaginable. It's something that can't be automated.