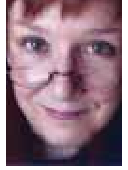

COSMIC BACKGROUND BY MARCIA BARTUSIAK

In Good Company

The protagonist of the neutron star story

Astronomers are now celebrating a golden anniversary. In the fall of 1967, fifty years ago, the first neutron star was detected. While the existence of such a compact star—a mere dozen miles wide—was not unforeseen, no one imagined it would be emitting clocklike radio pulses. "No event in radio astronomy seemed more astonishing and more nearly approaching science fiction," said the British radio-astronomy pioneer James S. Hey. And it was a long road to that finding.

In the early 1930s, Subrahmanyan Chandrasekhar, while starting his research career at Cambridge University before moving to the United States, spent several years trying to convince his colleagues in the British astrophysics community that if a star were massive enough it would never settle down as a white dwarf star in its old age. Instead his calculations indicated that the dwarf would undergo further stellar collapse. While Chandra never speculated on the other forms the star might take, others did.

At a 1933 meeting of the American Physical Society, Walter Baade of the Mount Wilson Observatory in California and Fritz Zwicky at Caltech introduced the idea that such a massive sun might end up as a neutron star, a dense ball of packed neutrons not much wider than a city. This transformation would occur, they reported, in a spectacular stellar explosion they had christened a "supernova."

Astronomers had long recognized that novae— "new stars"—occasionally appeared in the heavens. By the early twentieth century, they realized that this phenomenon involved an outburst on the star. Moreover, they began to notice that there were two kinds. There were the "common" novae that appeared up to thirty times a year in both the Milky Way and other galaxies (now known to occur when a white dwarf steals mass from a companion—matter that compresses on the dwarf and eventually ignites in a thermonuclear blast). And then there was a special set, far more luminous and much rarer. In his native German, Baade referred to them as "*Hauptnovae*" (chief novae). This was translated into English as "supernovae" during lectures by Zwicky and Baade in Pasadena.

Neutrons had just been discovered by particle physicists in 1932, and even before that the Soviet physicist Lev Landau had suggested that the compressed cores of massive stars might be "forming one gigantic nucleus," as he put it. Zwicky and Baade took the idea further by suggesting that under the most extreme conditions—during the explosion of a star—ordinary suns would transform completely into naked spheres of neutrons. The stellar core would somehow implode, pressing together all its positively-charged protons and negatively-charged electrons to form a compact ball of neutral particles.

This proposal was considered wildly speculative and only a handful of physicists, including George Gamow and J. Robert Oppenheimer, proceeded to investigate a neutron star's possible structure. For some three decades, neutron stars remained only theoretical inventions, which astronomers figured would never been seen even if they did exist, due to their extremely small size. Even the notable Princeton theorist John Archibald Wheeler was shortsighted at first. In 1964, he published an article on the neutron star, in which he said, "there is about as little hope of seeing such a faint object as there is of seeing a planet belonging to another star." But Wheeler's prediction was soon thwarted in a mere three years—thanks to a bit of serendipity.

A small platoon of students and

CARROL & OSTLIE

Jocelyn Bell helped build this first pulsar telescope, completed in 1967.

technicians, led by Cambridge University radio astronomer Antony Hewish, had just completed the construction of a sprawling radio telescope near the university: more than 2,000 dipole antennas, lined up like rows of corn and connected by dozens of miles of wire. Jocelyn Bell was one of the laborers: "I like to say that I got my thesis with sledgehammering," she once joked.

The telescope was designed to passively search for fast variations in the intensities of point-like radio sources, such as quasars, while the celestial sky moved overhead. The data continually registered on a strip-chart recorder, and it was Bell's job to analyze the long stream of paper—96 feet each day—for her doctoral dissertation. Upon reviewing the first few hundred feet, she noticed "there was a little bit of what I call 'scruff,' which didn't look exactly like [man-made] interference and didn't look exactly like [quasar] scintillation…I began to remember that I had seen some of this unclassifiable scruff before, and what's more, I had seen it from the same patch of sky."

Eventually observing it with a higher-speed recording, Bell (later Bell Burnell) came to see that the scruff was a methodical succession of pulses spaced 1.3 seconds apart. The unprecedented precision caused Hewish and his group to briefly label the source LGM for "Little Green Men." This was done only half in jest. At one point, some consideration was given to the possibility that the regular pulsations might be coming from an extraterrestrial-built beacon, which annoyed Bell a bit: "I was [then] two-and-a-half years through a three-year studentship and here was some silly lot of Little Green Men using *my* telescope and *my* frequency to signal the planet Earth."

But within a few months, Bell uncovered three more rhythmical signals in different regions of the sky. There was no more mention of outer space aliens. It was highly unlikely, she said, that there were "lots of little green men on opposite sides of the universe" using the same frequency to get Earth's attention. Carefully kept under wraps, the news was finally released in February 1968, and upon discovering a woman was involved, the press went wild. "One of [the photographers] even had me running down the bank waving my arms in the air—Look happy dear, you've just made a Discovery!" Inspired by the name of the recently discovered quasars, a British science journalist dubbed her novel objects *pulsars*, for pulsating stars, a label that astronomers swiftly adopted.

In their *Nature* report Hewish, Bell, and three colleagues pointed out that the exceedingly short span of the beep itself—around a hundredth of a second—meant that the source could span no more than 5,000 kilometers (around the distance light can travel in a hundredth of a second, close to the width of the planet Mercury). This suggested the pulsar was either a white dwarf or neutron star.

The Cambridge team at first wondered whether the entire star was pulsating in and out, with the radiation then "likened to radio bursts from a solar flare occurring over the entire star during each cycle of the oscillation." Within months, though, Cornell University theorist Thomas Gold developed the model that best explained a pulsar's behavior: it was most likely a neutron star, whose highly magnetized body as it rapidly spins transfers the rotational energy into electromagnetic energy. This radiation is then beamed outward like a lighthouse beacon from its north and south magnetic poles. Depending on the pulsar's alignment with Earth, we observe either one or two blips of radio energy with each pulsar rotation.

Since neutron stars can spin quite fast, Gold predicted that radio astronomers should also detect pulsars with shorter periods than those first discovered. This was successfully confirmed when astronomers found extremely fast-spinning pulsars within the Vela and Crab nebulas—with periods of .089 and .033 seconds respectively. Since each nebula was a supernova remnant, these finds also validated Zwicky and Baade's original assertion that neutron stars would be found at the sites of stellar explosions. You can think of a pulsar as a stellar tombstone, marking the spot where a giant star, too heavy to die quietly as a white dwarf, tore itself apart in a brilliant explosion.

Zwicky had imagined that the stellar explosion somehow created the neutron star. But astronomers later realized it was the other way around. Once it runs out of nuclear fuel, the massive star's core collapses catastrophically under the force of gravity. A core that was once the size of the Moon is squeezed down *in less than a second*, cramming the mass of 1.4 to 2.5 suns into a space roughly as wide as Philadelphia. In this way the stellar protons and electrons merge to form a tight ball of neutrons, whose density is so great that a sugar-cube-sized portion would weigh as much as Mount Everest. The shock wave sent out from the collapse, along with a flood of neutrinos, then speeds through the remaining stellar envelope, emerging from the surface as the spectacular supernova.

Astronomers estimate that at least a few hundred million neutron stars now reside in the Milky Way, created over the eons since our galaxy's birth. But the first one, officially known as PSR B1919+21 for its celestial coordinates, will never be forgotten—not just for its discovery but also for the controversy that later surrounded it. When the Nobel Prize in physics was awarded in 1974 for pioneering work in radio astrophysics, including the discovery of pulsars, it was Hewish who walked up to the podium (along with Martin Ryle), but not Bell Burnell. Her status as a young, female graduate student (only two women have won the physics prize over 115 years) likely prejudiced the judges.

Hewish had been skeptical about Bell's "scruff" at first, believing at one point that it was either a stellar flare or man-made. It was only due to Bell's persistence that its origin was at last revealed. At Great Britain's *Observatory* magazine, the editors wryly joked among themselves that Nobel now stood for "No Bell."

But Bell Burnell, who went on to a distinguished career as a professor, dean of science, and president of the Royal Astronomical Society, maintained a sanguine attitude about this flagrant oversight. During an after-dinner speech at a relativity conference in 1977, she noted that the final responsibility for the success or failure of a scientific project rests with its supervisor. "I believe it would demean Nobel Prizes if they were awarded to research students, except in very exceptional cases, and I do not believe this is one of them.… I am not myself upset about it—after all, I am in good company, am I not!"

No—they're in good company with *her*. While memories of who won a Nobel prize dim over time, Bell Burnell will always serve as the protagonist when recounting the story of the neutron star's discovery.

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