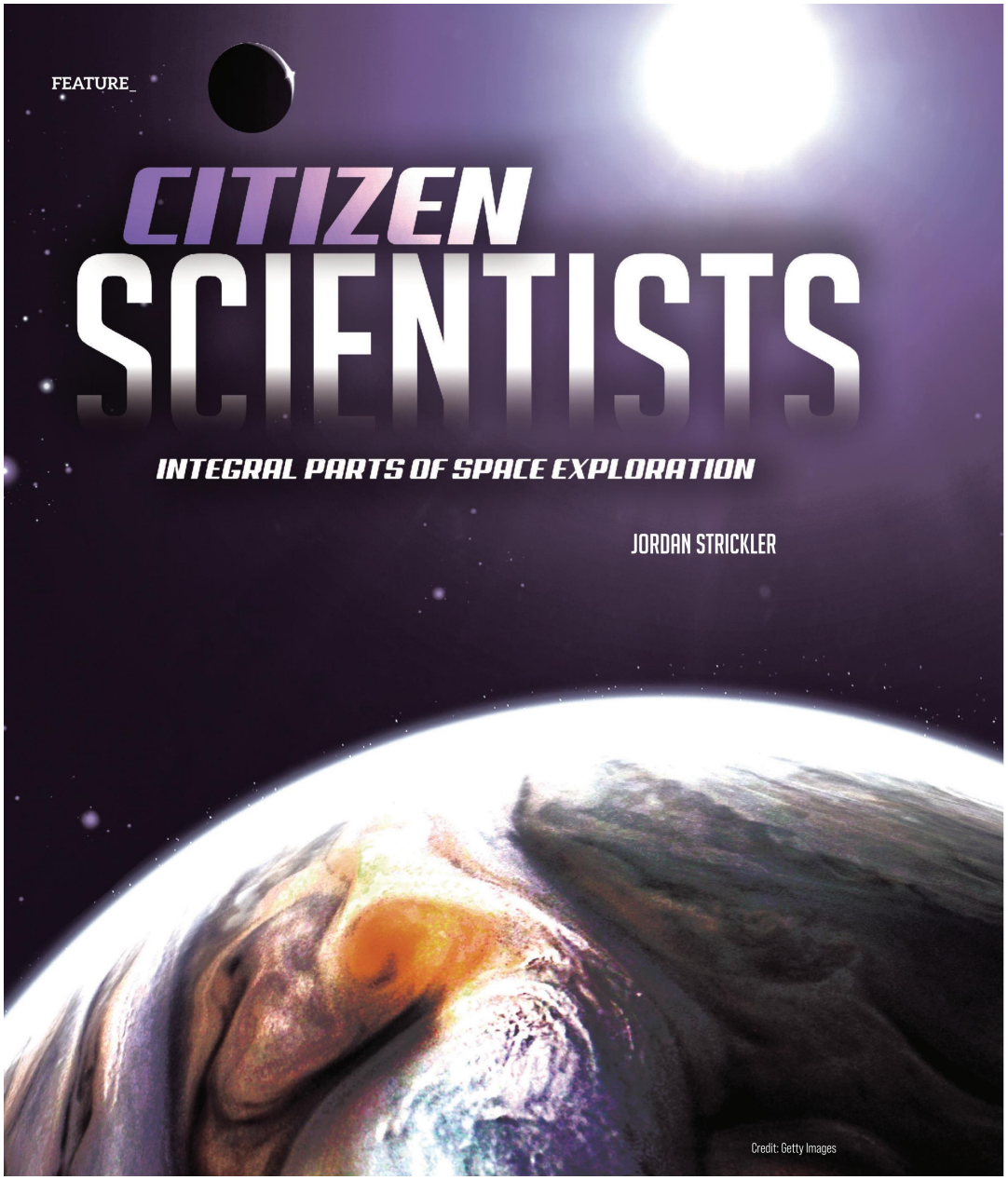
CITIZEN SCIENTISTS

INTEGRAL PARTS OF SPACE EXPLORATION

JORDAN STRICKLER



Credit: Getty Images

Shortly after midnight on the morning of May 31, 2020, Clyde Foster was observing Jupiter from his home in Centurion, South Africa when he noticed something a little different near the planet's Great Red Spot. Using his 14-inch (35.6-centimeter) Schmidt-Cassegrain telescope equipped with a methane filter, he thought he observed a white spot just to the south of the planet's famed marking. Foster reported his findings to the astronomical community. The oval spot, unseen just hours earlier by an Australian team of astronomers, was new to everyone.

The Juno spacecraft, orbiting Jupiter since 2016, would be making its 27th close flyby of the planet on June 2, 2020, just two days after Clyde Foster's observations. The mission team knew immediately that "Clyde's Spot" warranted a better look, and fortunately Juno was passing over the spot within two days and scheduled to image the area of the spot at high resolution. The team was looking forward to the pictures because Foster had just discovered a new, never-seen-before storm.

"I was excited as I realized that this was an interesting development that would be captured by the Juno spacecraft two days later," Foster said. He was even more excited when his discovery carried the official designation named after him.

"As I was the only known observer that captured the storm in methane (CH4) wavelength, where it was most obvious, I was also delighted when the (professional and amateur) planetary community started using the term 'Clyde's Spot' informally," said Foster. "Things got even more exciting for me when the Juno team picked up on the term and issued a NASA press release entitled 'Clyde's Spot on Jupiter' [and followed up a year later with 'Juno returns to Clyde's Spot'], showcasing the closeup images of the storm as well as my discovery image. Having a feature named after you on another planet, even informally, meant a lot to me."

But Foster's story is only one of thousands of discoveries by amateur astronomers, also known as "citizen scientists." Anticipating the enthusiasm of amateur astronomers across the globe, Juno's principal investigator, Scott Bolton, the Director of the Space Science and Engineering Division at Southwest Research, created a citizen science program called JunoCam, a first-of-its-kind NASA program designed to enable citizens, such as Foster, to help make new discoveries. The JunoCam instrument, and the idea for a citizen science program based on it, was included from the very beginning of the program's concept development, dating back to the late 1990s. During Juno's prime mission, consisting of 35 orbits, the satellite returned more than 375 gigabytes of science data, capturing stunning images of our solar system's largest planet and some of its moons. These images were available to the public and both professional and amateur astronomers.

"The Juno craft was going into an orbit around the poles, which previous missions had never seen, so we said, 'We have to have a camera to image Jupiter's poles,'" said Bolton. "It turned out to be a very good idea. The first images examined by this camera ended up being made by amateurs. I mean, they were really waiting.

View of Jupiter from JunoCam, a modern citizen science instrument
Credit: NASA/Southwest Research Institute

posted them on the internet before even we could research them."

These findings from Juno have altered our understanding of Jupiter's atmosphere, revealing a deep interior with a diluted, or "fuzzy," heavy element core. The spacecraft's flybys of Ganymede, Jupiter's largest moon, marked the beginning of Juno's transformation into a complete exploration of the Jovian system.

While Juno may be the first NASA mission to create an official citizen science program, there are many other space science discoveries by amateur astronomers, some made by mining old data sets—they are a dedicated lot.

One recent example is that of software developer Frank Kiwy, who searched a database of four billion celestial objects from the National Science Foundation's NOIRLab Source Catalog DR2 to look for brown dwarf companions. His thorough investigation discovered 34 ultracool dwarf binary systems, twice as many as those previously recognized. Research suggests that as many as 100 billion of these small, dim stars could be hiding all over the Milky Way. Identifying brown stars in the sky is no trifling feat, and it's impressive that an amateur scientist with no formal training in astronomy added nearly three dozen new brown dwarf systems.

NASA has come to realize the potential that citizen scientists have to make significant scientific contributions. The Sungrazer Project is a NASA-funded initiative that enables the citizen astronomer identification and reporting of previously unidentified comets in the fields of view of the ESA/NASA SOHO and NASA STEREO satellite instruments. Anyone in the world can register as a "Comet Hunter" and start searching

through spacecraft data for new comets. A website provided by the Sungrazer Project allows users to report comets, and then the project team performs the necessary measurements and data reduction to eventually create an official designation. As of August 15, the Sungrazer Project had discovered almost 4,500 previously undiscovered comets.

The SOHO satellite launched in 1995 and has found over 4,000 comets. In another example of citizen science, amateur astronomers and astronomy enthusiasts from around the globe found the majority of these comets by searching through images for potential comet candidates from the comfort of their homes. Anyone with internet access and motivation can participate in the project.

Interestingly, citizen scientists have even found items NASA lost. An important NASA satellite providing new insights into Earth's magnetosphere went silent in December 2005. While professionals had assumed the satellite was dead for the past 12 years, an amateur astronomer, Scott Tilley, proved everyone wrong after he located the satellite's radio signal in 2018.

To put it simply, citizen science refers to scientific inquiry done in whole or part by ordinary people. The results of citizen science often advance scientific research, both by enhancing the capacity of the scientific community and by increasing the public's understanding of science.

Much of what we now call "science" was actually "citizen science" before professional scientists emerged in the 19th century; many of the most significant scientific discoveries were made by non-professionals who lacked both official training and institutional authority. There are several examples of amateur scientists making significant contributions to astronomy—William Herschel's discovery of Uranus in 1781 is noted, and Percival Lowell, founder of Lowell Observatory and dedicated Mars astronomer, was also an amateur.

The 20th century saw the emergence of big science and the professionalization of the discipline, making contributions from the general public more difficult or impractical. However, the development of information and communication technologies like the internet changed things for the better for citizen scientists.

"Science is a collaboration between citizen scientists and professionals now," said Bolton. "It's not just all of them or all of us anymore. Right from the beginning, amateur astronomers were doing a lot of things before we could. I'm hoping Juno is just the beginning, because this is a great way to work with the public. Right now, they're looking at Ganymede and Europa and are helping us find all sorts of information about these moons."

The Dobsonian telescope, sensitive charge-coupled devices (CCDs), and the internet were the three technological innovations that sparked this revolution in amateur astronomy, just as it did professional astronomy. The availability of affordable CCDs to amateur astronomers led to a dramatic increase in the number of telescopes on Earth able to investigate deep space, and made it possible to monitor a great deal more astronomical events than professional astronomers could cover.

Thanks to the internet, an amateur who believes they have made a discovery can now send their images of the object in question to other observers located anywhere in the world in a matter of minutes. Anyone can take a look, regardless of whether they are an amateur in their backyard or a professional astronomer or university professor. As a result, there has been a proliferation of global research networks linking amateur and professional observers with common interests. Sometimes the professionals can learn about astronomical events more quickly from amateur sites than they can through official channels. As a result, they can study them more rapidly.

"There will always remain a division of labor between professionals and amateurs," wrote the historian of science John Lankford in 1988, but "it may be more difficult to tell the two groups apart in the future."

According to cosmologist Allan Sandage, amateur astronomers now can do "absolutely serious astronomical work." Some of their work has produced planetary images comparable to those made by professionals. Amateur radio astronomers have documented the ionized trails left behind by meteors that fall during the day, listened for transmissions from extraterrestrial civilizations, and recorded the cries of colliding galaxies.

Even the largest of telescopes has its limitations. In most cases, they can only capture images of relatively small areas of the sky at one time. On most nights, they don't manage to capture more than a handful of images. In addition, because observers are typically trained to focus on particular regions of space, they can overlook potential discoveries. The thousands of smaller telescopes that amateur astronomers own, on the other hand, do not have these limitations and can spot other things in space that professional astronomers may not.

Credit: Storyblocks

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The organization Zooniverse, which runs a crowdsourced online science portal, has more than 2.5 million volunteer citizen scientist researchers across 22 distinct astronomy programs. A significant number of these are in partnership with NASA and this partnership has provided great dividends. Projects range from helping Mars rovers identify specific terrain, searching for clouds on the Red Planet, hunting for black holes, finding new worlds, and many more. Zooniverse allows everyday astronomers to gain a foothold in space exploration. "Public volunteers contribute in a variety of ways," said Cliff Johnson, a postdoctoral fellow jointly appointed at the Adler Planetarium and the Center for Interdisciplinary Exploration and Research in Astrophysics at Northwestern University, and who is a longtime collaborator with Zooniverse. "Some of the highlights don't get much better than when we have citizens discover new [exo] planets."

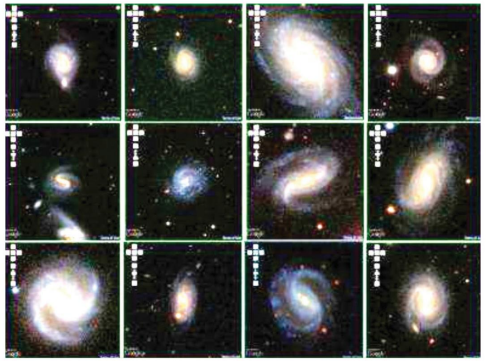
There is indeed a whole community on Zooniverse searching for exoplanets. Using NASA's Transiting Exoplanet Survey Satellite, more commonly known as TESS, volunteers can look for light curves indicating transits of planets passing in front of their parent stars. For science, that is a big win.

"We've had amateur astronomers find planets, black holes, and asteroids; all of these needle-in-a-haystack sort of finds," Johnson said. "Some finds have led to scientific publications. It's really great that citizen scientists want to take time out of their day to help make discoveries and learn more about the universe."

New technology is even allowing telescopes around the world to link up. With their app-controlled eVscopes, the company Unistellar has developed telescopes that allow amateur astronomers across the globe to unite and conduct some impressive scientific campaigns, from confirming the existence of exoplanets to studying the properties of possible near-Earth asteroids. The organization's network of app-controlled eVscopes has grown into the largest citizen astronomy group in the world in just a few years. In 2021, their network of citizen astronomers successfully detected three of the Trojan asteroids that NASA's Lucy mission will visit.

"Community colleges are consistently under-resourced and yet serve an incredibly important educational role," said Simon Steel, Deputy Director of the SETI Institute's Carl Sagan Center and Principal Investigator for the NASA Community College Network. "Making the eVscope technology available to engage and inspire community college students in astronomy and space science will be a tremendous boost to STEM learning and science literacy in the participating colleges."

Their network of eVscopes will notify citizen scientists both inside and outside of the Unistellar network of important planetary defense activities, such as asteroid occultations. Alerts from the Vera



An example classification page from Galaxy Zoo
Credit: Zooniverse

C. Rubin Observatory (formerly known as the Large Synoptic Survey Telescope) and other asteroid surveys will soon be made available through their app, with the intention of keeping tabs on the entire sky at regular intervals.

So what distinguishes an amateur curious about the world from a professional scientist? Typically, it has to do with training and compensation: professionals hold advanced degrees in an area of scientific specialization and are paid for their efforts. They write for scholarly, peer-reviewed journals and participate in professional colloquia. These traits and activities earn them certain status and respect in their field of endeavor.

Of course, many amateur astronomers hold degrees in the subject as well and may write for scholarly journals from time to time. The fact that they have picked another avenue of employment than academia or working for NASA or another government agency may be the primary differentiator. Other amateur astronomers may have no formal training and may not choose to write scholarly reports. In either case, citizen science may be a productive way for them to contribute to the field—they can perform data collection, analysis, and sometimes even participate as a co-author on scholarly publications, as Foster did with his "Clyde's Spot" discovery. Citizen science is a relationship in which both professionals and amateurs benefit.

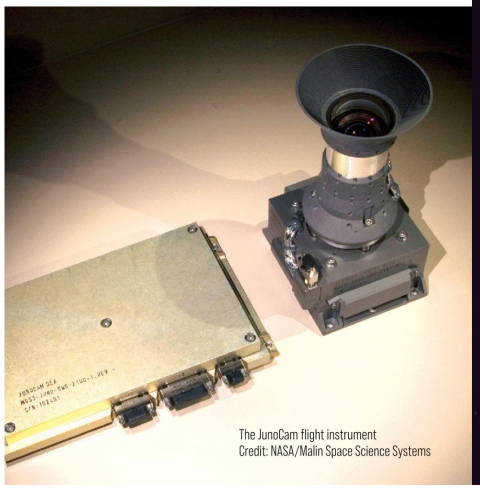
Prior to the last few centuries, scientists primarily consisted of people who pondered and documented the world around them in an effort to understand and explain its peculiarities. Because scientific research did not typically yield financial rewards, these people tended to be sufficiently well-heeled that they could pursue their interests on their own dime, and would often meet in academic societies to discuss their respective fields. It wasn't until the 19th century that governments and universities began allocating substantial funds toward scientific inquiry. The role of professional scientists expanded dramatically, but amateurs continued to flourish.

Today, professional and amateur scientists are able to work together more than ever before. During the mid-1990s, the term "citizen scientist" was coined to describe non-scientists who voluntarily contribute their time and effort to environmental conservation efforts, astronomical surveys, and biological science—all of which are projects well-suited to citizen science because they don't necessitate extensive training, just a lot of enthusiasm and patience.

In 1999, the Berkeley SETI Research Center initiated a citizen science effort called SETI@ home to scour the radio waves for any indication of alien life, using distributed computing to utilize the processing power of over five million privately-owned computers around the world. The project continued until March 2020, when the initiative was suspended to allow researchers to evaluate the masses of data it had generated.

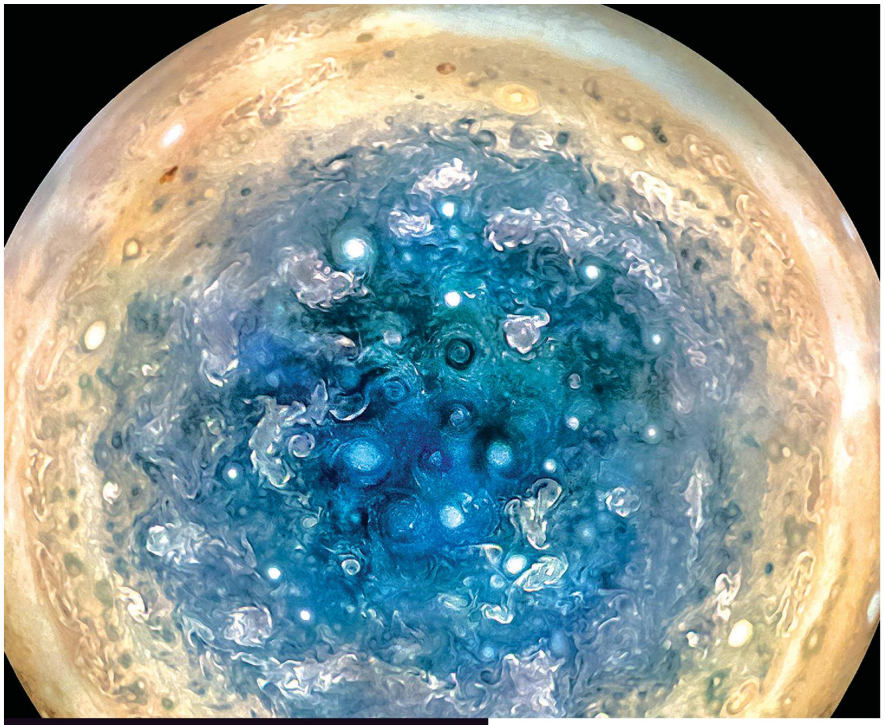
But it's not all about computers. People, at least for the time being, are fundamentally better than computers at some things, like finding specific objects in pictures, and there are plenty of projects out there for amateurs.

To classify all of the galaxies found in the Sloan Digital Sky Survey based on appearance, the online Galaxy Zoo, another Zooniverse project, was created to enlist human brains and eyes to help analyze astronomical images. So far, almost 90,000 volunteers have sorted images of galaxies captured in the survey into categories such as elliptical, clockwise spiral, counterclockwise spiral, and merging galaxies, so astronomers can learn more about the formation and evolution of galaxies.



The JunoCam flight instrument
Credit: NASA/Malin Space Science Systems

Within a year of its initiation, users had submitted 50 million classifications, verified by multiple people, exceeding the expectations of the team of astronomers who created the site and who had predicted it would take years for volunteers to go through all the data from the Sloan survey. It could have taken professional astronomers a decade to analyze these images, and computers simply weren't powerful enough. "People are really interested in discoveries," Johnson said. "This is not only a fun way for the public to help and really get involved in science, but it is also an outstanding tool for professional astronomers to do research." Zooniverse's Galaxy Zoo is still going strong, with volunteers constantly cycling through millions of images from telescopes around the world and helping to classify new objects.



Jupiter's pole, imaged by JunoCam
Credit: NASA/SWRI

As technology makes the curious more competitive, professionals have come to appreciate citizen science as not just a hobby, but something that supports their work. Furthermore, as the community of citizen scientists grows and research projects become broader and more far-reaching than ever before, the stigma of being an amateur scientist is fading as people gain access to knowledge and more affordable technology.

"Whenever we ask our volunteers why they were helping with research in their free time," Bolton said, "the number one result is always because they want to contribute to science. They want to help researchers, and I think that is very rewarding." ■

For more information on Zooniverse and its various citizen science projects, visit https://www.zooniverse.org.