Hunting for alien worlds

by Harrison Dreves

As the last rays of sunlight slip behind the scrub-covered hills of Sutherland, South Africa, electric motors whir to life inside a small building. Slowly, the domed roof of the building slides back, revealing an odd-looking device. Mounted on a short pedestal, a black camera lens protrudes from a squat blue box. Two computer cables trail to the floor. The entire assembly stands less than 5 feet tall.

Though its creators officially refer to it as a telescope, most people would label the device as a camera. The Kilo-degree Extremely Little Telescope (KELT-South) received its name due to its wide angle of view, comparably small size, and careful watch of the southern skies. In a field of astronomy dominated by bus-sized telescopes capable of viewing only a tiny slice of the sky at any moment, KELT is a bit of an oddity. Yet, just like many of its impressively-sized cousins, KELT turns its single eye to the sky each night with a bold purpose: the discovery of new worlds.

KELT-South, and its sister telescope, KELT-North, which scans the northern skies from Arizona, are at the forefront of one of the fastest growing fields in astronomy. Yet, the hunt for exoplanets (planets orbiting stars other than our own sun) has only recently gained recognition among astronomers. For much of the twentieth century, most researchers viewed exoplanet detection as a field of study littered with erroneous data and embarrassing mistakes. Only after the first indisputable identification of an exoplanet in 1995, a large gas giant orbiting the star 51 Pegasi, did many astronomers begin to realize the promise of exoplanet detection.

Sixteen years later, with ever more effective methods of detection at their disposal, planet hunters have confirmed the existence of over 500 exoplanets, with many more potential discoveries waiting to be confirmed by a second telescope. The growth in detection capabilities is so great that, as of November 2011, research teams identified more potential exoplanets in the last eleven months than in all previous years combined. Known exoplanets reflect a wide array of planets, including gas giants orbiting closer to their star than Mercury to our sun, multi-planet solar systems like our own, and even rocky planets approaching a size and temperature similar to Earth. As more detection programs join the already active field of study, planet hunters are revolutionizing our understanding of how widespread planets are within our galaxy and how common habitable planets could be.

In 2001, Joshua Pepper was a grad student at Ohio State University. Pepper had just finished an undergraduate degree in astrophysics from Princeton University, but was uncertain of what field to pursue. As an undergraduate at Princeton, Pepper had originally wanted to study traditional physics, but had switched to astrophysics after realizing the opportunities for discovery available. As he came to realize, “there's huge areas of astronomy where we don't know what's going on.”

One day, while working in his student office, Pepper was visited by one of his astronomy professors, Andy Gould, who posed a simple question.
“What are you working on?”
“I was not smart enough, as a grad student, to say anything aside from 'Oh, nothing right now,” Pepper remembers. “That was the wrong answer.”

Gould assigned Pepper the task of examining the effectiveness of various exoplanet detection methods. Ultimately, his work resulted in a scientific paper on the subject, published in 2003. Pepper argued that the most cost-efficient method of detecting exoplanets would be to frequently examine a large swath of the sky, using a wide angle telescope, searching for large exoplanets orbiting particularly bright stars. By focusing a wide-angle survey on easy-to-detect exoplanets, Pepper and Gould hoped to quickly and inexpensively discover exoplanets for which earlier surveys had not had the time to search.

The first successful exoplanet surveys were conducted using a method known as the radial velocity technique. Any planet orbiting a star causes that star to wobble slightly in space, as the planet’s gravity tugs on it. As stars wobble, they periodically move toward and away from our own planet. Just as ambulance sirens appear to rise and fall in pitch as they approach and then recede from an observer, the light from wobbling stars appears to shift, ever so slightly, in wavelength. By measuring these perceived changes in wavelength planet hunters can detect the wobble of the star and thus, the mass of its planet. Measurements of radial velocity appealed to early planet hunters because they could most accurately measure changes in wavelength and timing. As Dr. Leslie Hebb, an astrophysicist at Vanderbilt University explains, “there are things we can measure very accurately, and timings are one of them.”

Today, radial velocity measurements remain an important method of exoplanet detection. One of today’s leading planet hunting telescopes, named HARPS (High

Accuracy Radial velocity Planet Searcher), has discovered over 155 exoplanets to date, including 19 super-Earths (exoplanets within ten times the mass of Earth) and some of the smallest exoplanets ever discovered. As Michael Mayor, HARPS team leader explained recently, because HARPS focuses on relatively nearby stars, there are far greater opportunities for follow-up observations with other telescopes, which can yield more information about the planet, such as surface temperature and atmospheric composition. Additionally, most planet hunters rely upon radial velocity measurements, which can most accurately detect a planet's mass, to confirm the discoveries of other detection methods.

However, radial velocity measurements require powerful telescopes with high magnifications. Just as looking through a zoom lens on a camera restricts a photographer's vision, the high magnification lenses of these research telescopes restrict an astronomer's view of the sky. This small field of view permits planet hunters to observe only one star at a time, forcing them to invest long hours on expensive telescopes to study even a handful of stars. Pepper and Gould wanted to search large portions of the sky in only a few years, using equipment far less expensive than the large telescopes required for radial velocity measurements. They selected a more recently-developed exoplanet detection technique: observing transit events.

A transit event occurs whenever an exoplanet passes between its star and observers on Earth. As the planet passes through the line of sight, it briefly blocks some of the light emitted by its star. Astronomers can measure this dip in brightness to determine the size and orbit of the transiting planet. Unfortunately, though transit events allow astronomers to measure the size of a planet very accurately, telescopes must be incredibly sensitive to detect the transits of smaller planets or of planets orbiting further from their star.

One of today's leading transiting planet detection programs, NASA's Kepler telescope, actually searches for transiting stars from Earth's orbit. As a space-based telescope, unhindered by atmospheric interference or day-night cycles, Kepler is able to detect transiting exoplanets with accuracy unmatched by telescopes on Earth. Astronomers hope that Kepler, which is able to detect as little as ~0.0001% dip in a star's brightness, will detect Earth-sized, rocky planets orbiting stars in wider orbits, just as Earth orbits our own sun. Indeed, since its launch in 2009, Kepler has already returned an incredible 1235 potential transiting exoplanets, with 27 of those confirmed by radial velocity measurements. However, just like very powerful radial velocity detectors, Kepler, and other major ground-based transit surveys, are limited by their narrow fields of view, and thus tend to focus on smaller numbers of fainter stars.

At Ohio State, lacking the resources of a major ground or space-based program, Pepper began to develop a cheap, ground-based, wide angle, transit survey for exoplanets as his focus as a Ph.D. student. Pepper recounts that, "after we published the [2003] paper we realized: huh, this could be done by someone like us." Because any simple, wide-angle, ground survey would lack the precision to detect smaller planets orbiting stars in wider orbits, Pepper's telescope would need to focus on detecting large, gas giants, orbiting very close to their parent star.

Known as 'hot Jupiters' due to their massive size and proximity to their stars, these unusual gas giants composed many of the earliest detected exoplanets. However, their very existence confused early planet hunters and their origins are still a partial mystery to astrophysicists. Current models of planet formation suggest that gas giants can only form in the outer portions of young solar systems. These models would imply that hot Jupiters somehow migrated into the centers of their solar systems. How they could do this without being captured and consumed by the more massive parent stars is still uncertain.

Pepper and his colleagues at Ohio State began their search for hot Jupiters in 2005 with the construction of KELT-North at Winer Observatory in Arizona. Because they sought to observe relatively bright objects in a wide swath of the sky, the KELT team could build their telescope with a single, refracting lens, just as you would find in a camera lens, instead of relying on a large mirror to capture and reflect starlight into their detector. In fact, the KELT team chose to use a simple, high-quality digital camera lens in the telescope's design. In addition, because the telescope would only be measuring bright stars, the team was able to employ a widely available, high-end model of the image detectors found in all modern digital cameras, rather than the more powerful and expensive detectors used in other research telescopes. Finally, the entire assembly was fixed to an automated mount, which slowly tracks the telescope along a preset field of the sky each night as it captures its images. By using simple, off-the-shelf supplies, Pepper and his colleagues were able to construct the entire telescope for approximately $60,000. When compared to the multi-million dollar budgets of telescopes such as Kepler or HARPS, KELT's budget is certainly, as Pepper puts it "small peanuts."

Of course, Pepper's team was not the first to realize the benefits of such an inexpensive design. By 2005, several other science teams around the globe had also adopted a wide-field, transiting planet survey as an efficient approach to hunting for exoplanets. When it became fully operational in 2006, KELT-North joined several other similar programs, such as XO, SuperWASP, and HATNet, all searching for transiting exoplanets across millions of stars. By prioritizing field of view over sensitivity and magnification, these wide-field surveys periodically capture more of the night sky than any other exoplanet survey. Over time, KELT and the other surveys slowly develop a consistent record of large portions of the sky. By comparing changes from image to image, these surveys have the potential to detect many transiting exoplanets that high magnification telescopes have not. This persistent approach to imaging is known as time-domain astronomy. Pepper hopes that, within the next hundred years, astronomers will be conducting time-domain exoplanet surveys that continuously cover 100% of the sky, allowing for even greater numbers of transiting exoplanets to be discovered.

In 2007, after completing work on his Ph.D. at Ohio State, Pepper moved to Nashville, Tennessee, to work as a postdoctoral researcher in Vanderbilt University's physics department. Having left the fully operational KELT-North program in the hands of his colleagues at Ohio State, Pepper began to work with other researchers at Vanderbilt to establish a twin to KELT-North in the southern hemisphere, which KELT-North is unable to observe.

After considering several locations, the Vanderbilt team selected Sutherland, South Africa as the site of KELT-South. Because of the great distance between the KELT-South location and their offices at Vanderbilt, the team sought a South African colleague to assist them in building and operating the new telescope. As a graduate student in South Africa's recently revamped and government-supported National Astrophysics and Space Science program, Rudi Kuhn was a perfect fit for the KELT-South team.

"I've wanted to be an astronomer since I was a kid," Kuhn remembers. "When I had just started speaking, my dad gave me these words to say. And I asked him 'what are these words?' He showed me these pictures of Saturn and Jupiter and said these are the words I'm trying to get you to say." In college, after trying for several years to study more traditional subjects, such as medicine and computer science, Kuhn finally decided to pursue his passion for astronomy. Through an exchange with Vanderbilt, Kuhn was introduced to the KELT team and assisted them in the construction of KELT-South in Sutherland, South Africa, a world renowned observation site.

While Kuhn helps the KELT-South team with construction and operation of the telescope, the team needs additional, outside astronomers to test and confirm each of their potential exoplanet candidates. Though KELT can detect candidate signals that match those of transiting planets, there is still a significant chance of false positives, signals that appear to be a planet, but are in fact something else. Candidates can be confirmed or disproven by observing the same star using a different detection method, such a radial velocity measurements. However, both KELT telescopes are ill-suited for these other methods of detection. Instead of building yet another telescope, the KELT team relies on help from other astronomers. Though the Vanderbilt team has agreements with astronomy teams at several other universities, they also rely heavily on a few, very experienced amateur astronomers.

For most of his life, Bruce Gary has been fascinated with the prospect of intelligent life elsewhere in the galaxy. After graduating college with a degree in astronomy in 1961, Gary went on to spend much of his career working with radio astronomy in the earth and space sciences. After retiring in 1998, Gary resumed his passion for the search for extraterrestrial life. After observing the transit of a known exoplanet in 2002, he was hooked. Gary joined a group of amateur astronomers assisting professional surveys, and over the next several years, helped the group of amateurs to confirm the existence of five exoplanets discovered by NASA's XO program, which is similar in design to KELT. Today, Gary is continuing his work by assisting the KELT program to confirm their observations.

However, Gary believes that amateur astronomy will always be limited when compared to professional programs. "Amateurs might play minor roles, but anything important is being done with hardware that's better than any amateur can afford. So far, no amateur has by himself discovered an exoplanet, and I predict that none ever will." Bill Borucki, the principal investigator on NASA's Kepler program agrees. "The amateurs do very good work...but when you're asking the US government for $600 million dollars, there's no way you can use amateurs." Instead, smaller programs like KELT and XO offer amateur astronomers a chance to contribute to an increasingly advanced field.

Today, the foundation of future successes in exoplanet detection appears well established. As Ray Jayawardhana, a leading Canadian astrophysicist recently explained, there is currently a strong "frontier spirit... that has drawn both new students and established scientists to exoplanet research. That, in turn, fuels new ideas and opens new avenues of investigation, and tends to accelerate the pace of discovery." A number of promising new detection programs are already under development around the world. NASA's James Web Space Telescope, designed as a successor to the Hubble Space Telescope and scheduled to launch in 2018, promises, among many things, to reveal many more details of known exoplanets. The Transiting Exoplanet Survey Satellite, if launched in 2016, will conduct a wide-angle search for transiting exoplanets from space, promising many more discoveries. Finally, a proposed Thirty Meter Telescope could potentially allow us to directly observe nearby exoplanets, rather than merely detecting their influence on their stars.

KELT itself is reaching an important milestone. Though KELT-South, which has only been operating for two years, still has several years of observations to collect before the Vanderbilt team can analyze the data for possible exoplanet discoveries, the KELT-North team is almost finished analyzing the six years of data they have collected so far. Already, the team has more than fifty possible transiting exoplanet candidates, and their partners will likely confirm the first discoveries within the next year.

As planet hunters train more and more telescopes on distant stars, we come closer and closer to understanding how our own solar system formed, how common planets like our own Earth are in the Milky Way Galaxy, and how likely it is that we are not alone in the Universe. At a conference of planet hunters in Wyoming this past September, Michael Mayor of HARPS announced that his team believes that "40% of all Sun-like stars are accompanied by at least one planet smaller than Saturn." The smallest and rockiest of these abundant planets could possess ideal conditions for life.

Whether scrutinizing a few distant stars for the tiny dimming of an earth-like planet, observing the atmosphere of a gas giant orbiting a nearby star, or hunting for hot Jupiters across large sections of the night sky, exoplanet hunters are redefining our view of the Universe. "It's one of those sexy science things," explains Rudi Kuhn, of the KELT-South team. "We might not be alone in Universe, after all, and I think that's the big driver of these programs."

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