Harvard astronomers search for life's answers

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Harvard's stargazers have craned their necks skyward almost since the University's founding. They have made many major discoveries and now stand on the cusp of what may be the most tantalizing one: finding planets like Earth, orbiting stars like the sun. Scientists are poised to use astrophysics to show not only what's out there, but also what's in here: Is life on Earth exceptional, or does it develop on some planets orbiting particular stars? Illustration by David A. Aguilar/Center for Astrophyics

If you gaze at the night sky and sometimes wonder, "What's out there?" you're not alone. Harvard scientists have asked the same question for centuries.

These days, astronomers at the Harvard-Smithsonian Center for Astrophysics (CfA) are pondering weighty questions involving exploding stars and collapsing black holes, the nearby sun and distant galaxies, the Big Bang Theory, and the next big question: Is there life beyond Earth?

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University's founding. They have made many major discoveries and now stand on the cusp of what may be the most tantalizing one: finding planets like Earth, orbiting stars like the sun. Scientists are poised to use astrophysics to show not only what's out there, but also what's in here: Is life on Earth exceptional, or does it develop on some planets orbiting particular stars?

Astronomy professor David Charbonneau, who has searched for such orbiting planets — called exoplanets — since he was a Harvard graduate student a decade ago, has pioneered ways to find them, as well as to read their atmospheres. With the launch last year of the Kepler space telescope, the aim of which is to find small, rocky exoplanets similar to Earth, Charbonneau is on the hunt for signs of life.

"I would love, by the end of my career, to be a biologist rather than an astronomer," Charbonneau said.

The initial findings from the Kepler telescope — which has several CfA researchers on its scientific team — are promising. Scientists recently announced they had discovered more than 700 candidate planets that are being re-examined before official results are announced, probably early next year.

Though the search for other Earths may soon grab the headlines, that's just one of the projects involving CfA researchers. In another example, two asteroids that recently nearly brushed the Earth sent specialists from the CfA's Minor Planet Center scurrying toward their computers, where they quickly determined that the asteroids posed no danger. Meanwhile, scientists arrayed across six research divisions continue their research, which includes examining the sun for threats from coronal mass ejections, peering at distant stars and more-distant galaxies, and even probing the nature of the universe.

Harvard scientists conduct their research through instruments scattered across the globe — including in Arizona, Hawaii, Chile, and the South Pole — and above it through satellites such as NASA's Chandra X-Ray Observatory, the Solar and Heliospheric Observatory (SOHO), the Spitzer Space Telescope, and the planet-finding Kepler. Given the collaborative nature and outsized costs of modern astronomical science, most instruments are built and managed with other institutional partners, including NASA, the European Space Agency, and other universities in the United States and overseas.

The CfA is an unusual institution. Founded in 1973 when the Harvard College Observatory and the Smithsonian Astrophysical Observatory joined forces, it has benefited from the academic and research strengths of Harvard, its faculty, fellows, and students, and the research prowess of the Smithsonian, whose scientists study and design missions, build instruments, and manage operations for an array of satellite- and ground-based observatories, including Chandra, whose scientific operations are run by the CfA.

Chandra has greatly increased scientific understanding of the universe's X-ray sources, including the giant black holes at the center of galaxies. The Milky Way's central black hole, for example, is a few million times more massive than the sun, and its X-ray emissions are far lower than they could be because little of the available interstellar gas falls into its gravity well.

Yet Harvard's impact on astronomy can't be measured just in terms of instruments, institutions, or even discoveries, according to astronomy professor and science historian emeritus Owen Gingerich. Through its long history, Harvard has trained future astronomers, many of whom have taken leadership roles in the field. In recent decades, research at the Harvard College Observatory and the CfA in areas such as radio astronomy, solar physics, and exoplanet research has attracted students, fellows, and visiting researchers from around the world.

“For a long time, more Ph.D. astronomers were trained here than any other institution in the country. As a consequence, Harvard graduates were populating the directorships of observatories all over the country,” Gingerich said. The Harvard College Observatory “has had a very seminal role in training astronomers.”

Surveying the stars

Harvard’s first telescope, three-and-a-half-feet long, arrived in the 1670s, a gift of Connecticut Gov. John Winthrop, and was used to observe Halley’s Comet and the comet of 1680, which was so bright that it could be seen during the day. Though astronomy instruction continued, it took more than a century and a half before the Harvard College Observatory was founded in 1839.

The observatory soon became home to the 15-inch “Great Refractor,” a 20-foot-long telescope that reigned from 1847 to 1866 as the nation’s largest and still stands atop the observatory, imposing in its copper dome and featuring a unique track-mounted chair.

In the 1850s, Harvard astronomers ushered in the era of stellar photography with the first photograph of a star other than the sun, an advance that allowed astronomers to conduct much more detailed investigations by freezing images of the sky in time.

“It opened up the floodgates of what was to come,” Gingerich said.

That flood began in earnest in the 1880s, under observatory director Edward Pickering, who mounted a mammoth effort to photograph the skies. The resulting images, taken on photographic glass plates that now are being digitized, number more than half a million and form an archive of stellar positions and luminosities that is a treasure trove of data.

Pickering also supervised compilation of a major catalog of the spectra of 225,000 stars, later expanded to more than 350,000, named after prominent astronomer Henry Draper. It was the first large-scale effort to catalog stellar spectra, and its classification system is still in use.

Pickering is also credited with opening the doors of astronomy to women. He hired female "computers" to study the photographs of the skies and catalog the findings. Several researchers, such as Henrietta Leavitt, became famous for discoveries of their own. Leavitt worked out a characteristic of a kind of variable star, the period-luminosity relationship, that proved instrumental in later work on the size and shape of the Milky Way and in the debate over whether the universe held one galaxy or many.

Another female astronomer, Cecilia Payne, received the first astronomy doctorate granted a woman by the Harvard observatory, and also transformed assumptions about the composition of stars. At the time, the prevailing wisdom was that stars were made of iron, but her studies paved the way for the modern understanding that they are largely made of hydrogen and helium.

Study of the sun blossomed at Harvard under Donald Menzel, who began teaching at Harvard in 1932 and served as observatory director from 1954 to 1966. His successor, Leo Goldberg, conducted pioneering work on solar physics from space-based platforms, including satellites and the first American space station, Skylab.

Recently, solar astronomer John Kohl devised an instrument on the SOHO sun-observing satellite, and Leon Golub and colleagues originated extremely high-resolution solar X-ray imaging telescopes. Kohl says that the explosive outbursts of the sun's corona, which can disrupt communications, endanger satellites, and threaten astronauts, have fueled the need to understand it.

Kohl said the major technical difficulty was observing the relatively weak light of the corona in the presence of the extremely bright light of the sun itself. Together with his colleagues, Kohl designed an instrument that blocked the sun and allowed the corona to be seen.

“This is the region where the solar wind forms, and also the region where coronal mass ejections form,” Kohl said. “There’s lots of interest in understanding the physics of this region of the solar atmosphere. These experiments we put together were the first to be able to produce a detailed description.”

Stars as measuring sticks

Astronomers study stars not only to understand them, but also to divine what they can reveal about the universe. In 1998, CfA researchers were part of two teams surveying distant exploding stars as part of their research on the universe’s expansion. After checking their data repeatedly, they announced an unexpected finding: The expansion was accelerating.

That presented a problem. Theories of how the universe worked at the time didn’t include a mechanism for expansion at an ever-faster rate. Scientists had known for decades that the universe was expanding because of the Big Bang’s enormous explosion that got everything started. The question, they thought at the time, was whether there was enough matter in the universe that the force of gravity would one day slow that expansion enough to make it reverse into a cosmic “big crunch.”

For the expansion to accelerate, that meant something must be driving it outward faster and faster, something that science so far had overlooked. That something was dubbed "dark energy," a force that acts opposite gravity.

The picture of the universe that has emerged since then is humbling. Ordinary matter that people understand and see every day — the Earth, the stars, other planets, ourselves — makes up a tiny fraction, just 4 percent, of all mass and energy in the universe. The rest of the universe is composed of matter and energy that scientists do not understand. Dark energy makes up 74 percent of the total. The rest is undetectable material, dubbed dark matter, whose particles have yet to be found but whose gravitational effects can be viewed.

Robert Kirshner, Clowes Professor of Science at the CfA, was part of the High-Z Supernova Team whose work revealed dark energy's effects. The researchers found their subject supernova to be 10 to 15 percent farther away than theories at the time could explain. Kirshner said his first thought on seeing the 1998 finding was, "Oh, I hope we're not wrong."

"I was really afraid we'd forgotten something," Kirshner said. "I was nervous about it. It was very much in the public eye. There was a lot at stake, because it is such an important scientific result."

Follow-up surveys by Kirshner and his colleagues, using the Hubble Space Telescope have confirmed the findings, as have studies by other scientists. "It points directly at a gap in our understanding of very basic physics," Kirshner said.

Scientists around the world are working to understand this mysterious dark energy. One project involving CfA scientists is based at the South Pole. In collaboration with the University of Chicago, researchers are examining shadows left by ancient clusters of galaxies in the uniform rain of microwave radiation that constantly falls on Earth. Called the cosmic microwave background, it is believed to be a remnant of the Big Bang.

“The main piece of data is simply a census of clusters. The formation of a cluster is a tug-of-war, with gravity pulling it together, and dark energy blowing it apart. So the number of clusters you get at any given age of the universe is very sensitive to the amount of dark energy. The more clusters, the less dark energy,” said CfA researcher Tony Stark.

Since it began operating in 2007, the South Pole telescope has found hundreds of clusters, each containing 100 to 1,000 galaxies. The CfA team, Stark said, focuses on data analysis and is making follow-up observations with the Magellan telescopes, located on a mountaintop in Chile and operated by a group of institutions, including the CfA.

Follow up observations are also being conducted at X-ray wavelengths using the Chandra telescope, which is probing masses of the clusters. That Chilean mountaintop will soon be the home of a new cutting-edge telescope. Dubbed Giant Magellan, the new telescope being built by an international consortium led by CfA researchers, including director Charles Alcock, may help to solve some of the current astronomical mysteries. Scheduled for completion in 2018, it will contain seven mirrors that will have the resolving power equal to an 80-foot primary mirror — larger than any previous telescope.

With 10 times the resolution of the Hubble, it will be able to view details currently hidden to instruments. Those details just might provide clues that unlock the secrets of planets circling other stars, of black holes, of other galaxies, of dark matter, and of dark energy.

“If it really works,” Kirshner said, “this will be fantastic.”

More information: www.cfa.harvard.edu/

Provided by Harvard University