The next generation

Astronomy's rising stars

From studying our solar system to searching for worlds beyond and seeking answers to the universe's biggest mysteries, these 10 young scientists could change how we see the cosmos. **by Karri Ferron**

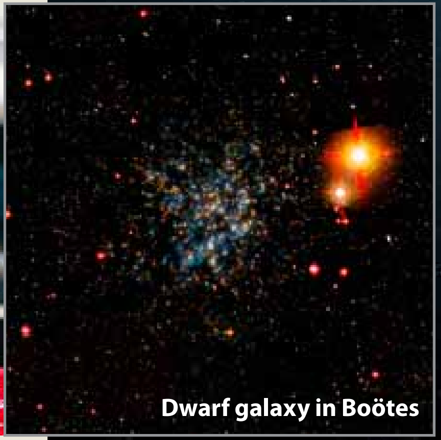
Scientists' understanding of how the universe works is changing rapidly. New technology is letting them venture into unexplored territories and collect groundbreaking data, while brilliant minds in the field are using such information to create a more comprehensive picture of the cosmos. Many of these dedicated astronomers are just getting started in their careers, and based on their accomplishments in just the past five to 10 years, their colleagues and mentors feel strongly about the influence these young minds will have on astronomy's future. Meet 10 who have recently been recognized for their research and discoveries.

Karri Ferron *is an* Astronomy *assistant editor.*

GALACTIC ARCHAEOLOGY

VASILY BELOKUROV

Cambridge University



Dwarf galaxy in Boötes

Vasily Belokurov enters his office every morning hoping to understand how the universe — and particularly the Milky Way — formed. "I am a survey scientist and a galactic archaeologist," Belokurov says. "I trawl through the data of massive sky surveys for clues to the formation and evolution of our galaxy."

So far, this digging has led to a better comprehension of the Milky Way's wild past. After analyzing five years of Sloan Digital Sky Survey (SDSS) data, Belokurov and his colleagues created a dramatic map of stars in the outer portion of our galaxy, dubbed the "Field of Streams." Such suns represent the remnants of dwarf galaxies the Milky Way has been gobbling up. "[Our galaxy] pulled them in, pulled them apart, and wrapped their material around itself," Belokurov says. But there were survivors, which Belokurov's group also dug up in the SDSS data, including one in the constellation Boötes with a total luminosity of only about 10,000 Suns.

Now Belokurov is looking forward to the launch of a new space observatory that will add more dimensions to astronomers' observations. "In about a year's time, we are going to procure a pair of 3-D spectacles," he says. "The Gaia space mission will supply us with the dimensions currently missing: It will tell us how far the stars are and how quickly they move." This European Space Agency spacecraft is scheduled to launch later this year, and Belokurov has big plans for its data: "As I look at the stars torn off other celestial bodies as they now travel around the Milky Way, I plan to study the shape and lumpiness of the gravitational potential that governs their orbits. The bulk of the mass generating this potential is in dark matter. In other words, my hope is to turn the galaxy into one giant dark matter lab."

N. PRUNA-MORA (VASILY BELOKUROV); V. BELOKUROV (CAMBRIDGE UNIV.)/SDSS-II COLLABORATION (BOÖTES DWARF GALAXY); E. R. UCEDA (ALBERTO FAIRÉN); NASA/ESA/THE HUBBLE HERITAGE TEAM (STScI/AURA) (MARS); ESO/L. CALÇADA (EXOPLANET ILLUSTRATION)

RED PLANET WATER

ALBERTO FAIRÉN

Cornell University

Alberto Fairén is an astrobiologist searching for life beyond our planet. And what better place to start than right next door? "During my master's studies, I started learning about water on early Mars," he says, "and once you begin working on early Mars environments, it becomes difficult to pay attention to anything else."

Now Fairén combines theoretical modeling, laboratory experiments, field research, and spacecraft data analysis to better understand the Red Planet, and he's already made an important contribution to the community with his proposal of a "cold and wet early Mars."

Mars

Missions to the Red Planet have repeatedly shown evidence that liquid water was present on or near the surface during Mars' early history. Such findings, however, are difficult to reconcile with a Sun known to be cooler and fainter at the same time. But Fairén provides an explanation.

"My vision of early Mars includes the presence of an extended ocean on the northern plains, massive polar water ice caps, wide glaciated terrains rimming the ocean, and very cold liquid water flowing down the rivers to that ocean," Fairén says. "And all of this was occurring under planetary mean freezing temperatures. Water would have remained in the liquid state at least partially because it was basically very salty water."

Although this is an exciting contribution, Fairén isn't satisfied. Remember, as an astrobiologist, his search is for life. "Life on Earth can live in environments like those characterizing early Mars, but has it just adapted to those environments, or can it actually originate there?" he wonders. "Early Mars sure was habitable, but was it adequate for originating life?"

Ultimately, Fairén's career goal is ambitious: "In the end, the reality is that we are looking everywhere we can to try to find something living outside Earth. My goal is contributing as much as I can to this endeavor, possibly the most ambitious and profound human quest."

Red giant star S1020549

STELLAR HISTORY

ANNA FREBEL
Massachusetts Institute of Technology

Anna Frebel has been looking at the stars since she was a kid, except now she studies them through some of the largest instruments in the world. "I consider myself very fortunate that my initial passion indeed led me to become a professional astronomer and that my work centers around the oldest stars in the universe," she says. "I use these stars to unravel the details of the cosmic evolution of the chemical elements."

Frebel has been setting records in her field since 2005. That year, she discovered the most chemically primitive star, likely a member of the second generation of stars to have formed in the universe. Then in 2007, Frebel uncovered the oldest known star at the time, a red giant about 13.2 billion years old.

But Frebel wasn't done. In 2010, she discovered stars like the red giant S1020549 in dwarf galaxies with remarkably similar chemical makeups to the Milky Way's oldest members. "This has been helping us gain a better picture of how the Milky Way assembled and how the oldest stars … actually got incorporated into our galaxy, where we can observe them today," she says. The effort keeps Frebel busy: "At the moment, I am working toward a better understanding of the processes of galaxy assembly by studying the chemical composition of individual stars with a focus on what kind of supernova explosion created the observed elements prior to the star's formation."

All in all, Frebel plans to continue looking into the past as part of her future. "My long-term goal is to understand the physical and chemical conditions that governed the early universe soon after the Big Bang, at a time when the first stars and first galaxies began to form," she says. "My colleagues and I are working on this by closely combining the many observational results with the latest theoretical simulations of galaxy evolution."

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UNEARTHING EXOPLANETS

JOHN A. JOHNSON
California Institute of Technology

John A. Johnson didn't always want to search the skies for worlds around other stars — or even be an astronomer for that matter. He started out studying aerospace engineering, then mechanical engineering, then physics. After earning his bachelor's degree, Johnson decided to study experimental cosmology, but he applied to the astronomy graduate program at the University of California, Berkeley, on a whim — having never taken a single astronomy course in his life.

"To my surprise, I was admitted to the Berkeley graduate program, and I met with [famous exoplanet hunter] Geoff Marcy during my campus visit," Johnson says. "After talking with him and reading an article of his in *Astronomy* magazine, I was hooked on exoplanets."

Johnson has been studying new worlds ever since, from gas giants to diminutive Earth-sized planets. In the past few years, he and his colleagues have discovered that Jupiter-like planets are much more likely to exist around stars more massive than the Sun than around Sun-like stars or the smallest class of stars, red dwarfs. "This tells us where to find additional planets — hint: for gas giants, look around stars like Vega and Beta Pictoris; for rocky planets, look around red dwarfs — and provides us with valuable clues about the planet-formation process," Johnson says.

On the lower end of the mass scale, his team has uncovered three of the smallest planets in data from the Kepler space telescope, NASA's planet-hunting spacecraft, orbiting a star called KOI-961. Now the group is targeting more diminutive suns. "My goal is to build up a large sample of Earths and sub-Earths so we can begin to understand the formation of planets like our own throughout the galaxy," Johnson says. "These discoveries will help us reveal our planet's origin story and provide us with a broader galactic context for our solar system."

The KOI-961 planetary system

STAR CYCLES

JASON KALIRAI
Space Telescope Science Institute

Open cluster NGC 2099

Jason Kalirai knows he's lucky. He gets to work closely with the world's most famous telescope to study the universe — his employer is the headquarters for the Hubble Space Telescope. And he's taking advantage of this opportunity to measure how stars evolve so scientists can improve their interpretation of the starlight Hubble and other telescopes observe.

So far, Kalirai's work on the initial-final mass relation — including studying members of clusters like NGC 2099 — is making waves. "My research connects the properties — i.e., mass — of hydrogen-burning stars to the properties of their end products, white dwarfs," he explains. "By knowing both stellar life-cycle states for the same [type of] stars, we can complete a picture of how stellar evolution actually happens. This is much like seeing a baby, a teenager, an adult, and a grandparent and putting together a picture of how humans age."

Through this research, Kalirai has been able to show that the Sun will lose 45 percent of its mass as it evolves to become a white dwarf, and that's just one application. "The initial-final mass relation allows astronomers to take any pristine stellar population and evolve it to any age and analyze the resulting distribution of starlight," Kalirai says. "Turning the argument around, the relation is a critical input to translate unresolved light from any distant galaxy into its fundamental properties — like the ages of stars in the galaxy."

And Kalirai is just getting started. "I feel my interest in astronomy still hasn't peaked," he says. "I've never thought of my 'job' as me going to 'work.' I want to tackle new mysteries about the universe, and spending time solving these problems is part of who I am."

COURTESY ANNA FREBEL (ANNA FREBEL); DAVID A. AGUILAR (CfA) (RED GIANT ILLUSTRATION); COURTESY JOHN A. JOHNSON (JOHN A. JOHNSON); NASA/JPL-CALTECH (KOI-961 ILLUSTRATION); NASA/ESA/M. KALIRAI (FOR STScI) (JASON KALIRAI); CFHT/H. RICHER, ET AL. (UNIV. OF BRITISH COLUMBIA) (NGC 2099); LANCE HAYASHIDA/CALTECH (HEATHER KNUTSON); ESA/C. CARREAU (HOT JUPITER ILLUSTRATION)

Hot Jupiter prototype

EXOPLANET ATMOSPHERES

HEATHER KNUTSON
California Institute of Technology

Despite being the hottest field right now, exoplanet research occasionally can be boring, as Heather Knutson will admit. "It's often a long slog with very little progress to show at the end of the day," she says. But the upside far outweighs the monotony. "There's always hope for that 'aha!' moment, where suddenly everything falls into place and the answer to your question is staring you in the face."

And for Knutson, such moments come when characterizing exoplanetary atmospheres, specifically around a class of short-period gas giant worlds known as hot Jupiters. "Much of our understanding of planetary atmospheres is based on models developed to describe the solar system planets," she explains. "By studying the properties of planets that have the same composition as Jupiter but much hotter atmospheres, we can figure out if we really understand planetary atmospheres as well as we thought we did."

Many colleagues have considered Knutson's exoplanet observations groundbreaking. In 2007, her team released the first-ever map of an alien world based on observations with NASA's Spitzer Space Telescope that showed the temperature variations across the planet's entire surface.

Such hot Jupiter studies aren't over for Knutson yet, though. "More recently, I've been developing a new project to study how planets form and migrate by searching for additional companions — either stars or planets — in systems that are already known to host a hot Jupiter." And she expects some surprises: "Many of the biggest discoveries of the last 10 to 20 years have taken astronomers by surprise; for instance, no one expected to find Jupiter-like planets in three-day orbits around their host stars. Today we say that these planets had to have formed much farther out and then migrated inward, but this was a theory developed after the fact."

Massive-star formation simulation

STAR SIMULATIONS

MARK KRUMHOLZ

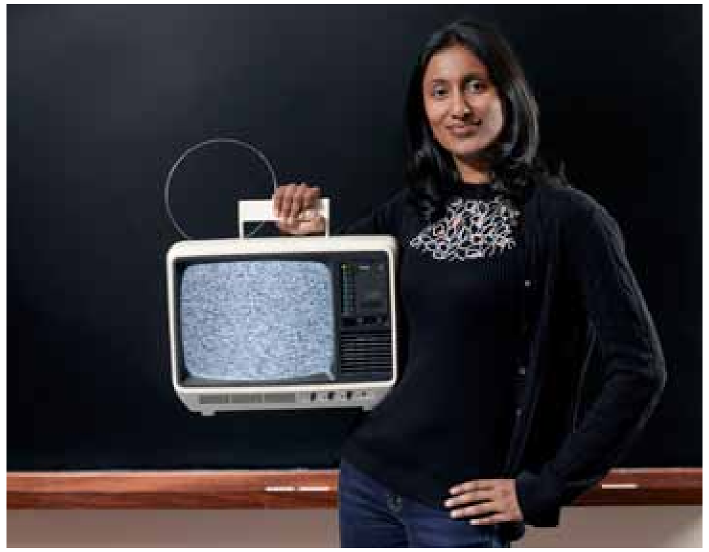
University of California, Santa Cruz

Mark Krumholz is a self-described computer nerd, and this interest was key in his decision to go into computational astrophysics. "It had always fascinated me that you could build models for the world on a computer, and that by plugging in the laws of physics and turning the crank, you could figure out what would happen in reality."

Krumholz chose to focus his computations on star formation and the interstellar medium, and his research has paid off.

For example, a decades-old question surrounds why stars are as massive as they are. "The key part of the answer … is to consider how a protostar that is still forming feeds back on its surroundings," Krumholz says. "Stars form out of interstellar clouds that are very cold. As long as they stay cold as they collapse, they tend to fragment into smaller and smaller pieces." He and his colleagues discovered that the gas surrounding the protostar doesn't stay cold forever, which stops this process. "Instead, as a young star begins to gather mass, it heats the gas around it, raising its temperature and preventing it from fragmenting any further."

But how much gas becomes a star? Scientists know our galaxy contains about 1 billion solar masses worth of star-forming gas clouds. "If these clouds were simply to collapse under their own gravity and convert their mass into stars, then the Milky Way should produce new stars at a rate of about 100 solar masses worth of new stars per year," Krumholz notes. But scientists know the rate is actually closer to 1 percent of that value. Krumholz was able to explain this phenomenon quantitatively for the first time. "A likely answer is that the gas in these clouds is moving around in a violent, supersonic, turbulent fashion," he says. "One can use the statistical properties of turbulence to ask what fraction of the mass is able to collapse despite the turbulence, and the answer is about 1 percent."



BIG BANG BEGINNINGS

HIRANYA PEIRIS

University College London

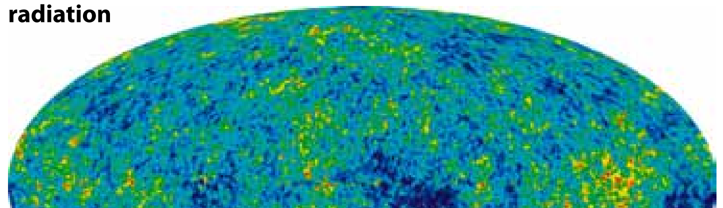
The universe is a very strange place, and studying how it works is a challenge for cosmologists. Just ask Hiranya Peiris. "My research involves confronting confounding problems on a daily basis," she says. "On the biggest level, cosmologists are asking the most fundamental question: Where did everything in the universe come from? This is something that humans have asked in different forms since the dawn of civilization."

Peiris chose to focus on such a tough question after an opportunity during graduate school came up that she couldn't pass on: participating in a space mission that has now become a cornerstone of modern cosmology, the Wilkinson Microwave Anistropy Probe (WMAP). WMAP spent nine years gathering data related to the leftover radiation of the Big Bang that still permeates the universe, known as the cosmic microwave background (CMB). "About 1 percent of the snow picked up by an untuned television arises from this radiation, generated when the universe was just 0.01 percent of its present age," Peiris notes.

WMAP data have allowed cosmologists to study the CMB like never before. "I spend my time trying to figure out the physics of the Big Bang and understand the origin of all the structure we see in the universe," Peiris says. "I look for fingerprints of these extreme physics in the CMB and in large-scale distribution of galaxies in the universe."

As missions like WMAP and the current CMB satellite Planck don't cover the same epochs in the history of the universe as galaxy surveys, Peiris' research involves creating innovative methods to bring all these data together and combine them with theory. By continuing to do so with Planck data and that from the coming decade's large galaxy surveys, Peiris hopes to "probe the way nature works at extremely high energy scales, a trillion times higher than what we can test in the laboratory with particle accelerators. We might even see hints of how gravity becomes unified with quantum mechanics, which is the dream of fundamental physics."

Cosmic microwave background radiation



J. MACKENZIE/UCSC (MARK KRUMHOLZ); KRUMHOLZ, KLEIN, & McKEE 2012 (STAR FORMATION SIMULATION); MAX ALEXANDER (HIRANYA PEIRIS); NASA/WMAP SCIENCE TEAM (CMB); COURTESY PRINCETON MEDIA OFFICE (ALICIA M. SODERBERG); ESO (NGC 2770); KRIS SNIBBE/HARVARD NEWS OFFICE (SARAH T. STEWART); NASA/JPL-CALTECH (IMPACT ILLUSTRATION)

SUPERNOVA STUDIES

ALICIA M. SODERBERG

Harvard-Smithsonian Center for Astrophysics

Those who believe scientific discovery is only about luck should talk to Alicia M. Soderberg. "Discovery is usually associated with serendipity," she admits, "but luck favors the prepared. In this field, you have to be prepared if you want to make important discoveries."

Such a mantra has proven valuable for Soderberg, who in 2008 became one of the first astronomers to see a star in the act of exploding — a major milestone for the study of supernovae. "I was in the process of observing a supernova in a nearby galaxy [NGC 2770] with the Very Large Array in New Mexico and also the Swift satellite when a second supernova exploded in the same galaxy," she recalls. Such dual explosions in the same area are rare — a 1 in 10,000 occurrence.

But it wasn't just luck that allowed Soderberg and her colleagues to study the unexpected event. Again stressing the connection between luck and preparation, Soderberg recalls that the team "organized a large group to follow the supernova with various telescopes." The group recorded the X-rays from the supernova, emission that scientists had only theorized to occur before. Through this work, she showed that X-ray satellites could play an important role in earlier detection and observation of such stellar explosions.

Today, Soderberg leads Harvard University's Supernova Forensics research group. Her goals revolve around a holistic study of cosmic explosions that will advance scientists' understanding of the nature and physics of supernovae. "I plan to capitalize on the order of magnitude improvement in sensitivity of the Jansky Very Large Array and the Atacama Millimeter/submillimeter Array," she notes. "This will enable new discoveries regarding supernova properties at longer wavelengths than traditional studies that focus primarily on optical data."

NGC 2770

PLANETARY LAB

SARAH T. STEWART

Harvard University

Moon-forming giant impact

Sometimes finding a career path is as easy as combining a hobby with a favorite school subject — at least it was for Sarah T. Stewart. "I grew up a big fan of science fiction — the idea of other planets and civilizations seemed completely natural — and physics was my favorite science class," she says. "The combination led to my interest in planetary physics."

Stewart is known for her laboratory experiments. She and her team particularly focus on the final stages of planet formation and the role of giant impacts in determining the resultant physical properties of these worlds. "In the lab, we reproduce the pressure and temperature conditions reached during giant impacts in order to understand when different planetary materials melt and vaporize," Stewart explains. "Then with the computer, we simulate collisions between planetary embryos to determine how much of the planet melts and whether or not certain material can be lost due to vaporization."

Recently, Stewart and her colleagues have made headlines for a model of the Moon's formation that incorporates the similar chemistries of both Earth and its satellite. "The standard giant-impact model predicts that the Moon should be made mostly from the impactor, but Earth and the Moon have identical isotopes," she explains. "However, if the early Earth were spinning with a two- to three-hour day — much faster than previously thought — a giant impact could have launched material off Earth to make the Moon out of the same material."

Next up, Stewart's team is turning its experiments toward a better understanding of all the inner bodies of the solar system. "We are working on how the Moon lost elements that vaporize easily and yet how Mercury, which formed by a different type of giant impact, has retained those same elements," she says. "And we are trying to explain why Venus, Earth, and Mars have such different atmospheres."

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