Susan D. Benecchi

Astronomy, Life, and Our Cosmic Creator

Susan D. Benecchi

The following article was first posted to inform and invite essays for this resulting theme issue on astronomy. It highlights the scientific accomplishments in astronomy over the last decade and invites interaction from our readers. Each section ends with suggested questions for investigation and reflection. It begins with the current focus on understanding the first moments of creation, looking for the source of life, and looking for life outside the earth. In particular, the growing number and characterization of extra-solar planets, planetary exploration within our solar system, and looking back in time toward the moments of creation are highlighted.

> "What the telescope is to the astronomer or the microscope is to the biologist, the names of God are to his children." ~Author unknown

Not long ago, I spent substantial time at Las Campañas Observatory in Northern Chile. Sometimes I used the 6.5-m Magellan telescopes, but much of my time was spent on the more modest 2.5-m du Pont Telescope which is located at the very end of the mountain range and separated from the center of the mountaintop hub of activity. I particularly like this site because the skies are amazingly dark, and I can go out to the catwalk and easily see the Milky Way Galaxy and, often times, the Large and Small Magellanic Clouds as well. These sights were so clear that I could not help feeling as if I were peering into the face and nature of God and seeing his fingerprints all around me. As the Psalmist writes,

> The heavens are telling of the glory of God; and their expanse is declaring the work of His hands. Day to day pours forth speech, and night to night reveals knowledge. There is no speech, nor are there words; their voice is not heard. Their sound has gone out through all the earth, and their utterances to the end of the world. (Ps. 19:1–4, NASB)

In addition to observing, I also teach astronomy to high school students. I try to bring the same awe and excitement into my classroom as we focus on different specialties in astronomy throughout the year, and I seek to engage my students to think about the science-faith dialogues that they might encounter.[1]

Early work in astronomy focused on mapping the grand design of the universe—discovering the basic laws of the universe and how it operates, and making general observations about objects in the night sky as worlds outside our own. More recent work in astronomy has provided exquisite detail on individual objects and has striven to shed light on the earliest moments of creation. Technology in the last approximately twenty years, since the advent of charge coupled devices (CCDs)—a major step forward for digital imaging—has revolutionized our ability to probe the distant past as well as track events in real time. In the last ten years, we have sent spacecraft to Mercury, Venus, Mars, individual asteroids, individual comets, Jupiter, Saturn,

Susan D. Benecchi *(PhD, MIT) is a senior scientist at the Planetary Science Institute. Her research focuses on small bodies, often binaries, in the outer solar system. She has been part of a number of efforts to discover, and to dynamically and physically characterize Kuiper Belt Objects including the recent New Horizons fly-by target 2014 MU69.*

Pluto, and even a primordial Kuiper Belt Object, 2014MU69, to obtain in-situ measurements of environments outside our own atmosphere. We have designed a wide variety of ground- and space-based telescopes which have allowed us to map the entire universe at different wavelengths, to map the sky to high-positional accuracy (e.g., Gaia[2]) and to look for variations over short and long timescales. We are on the brink of launching even larger ground (the Giant Magellan Telescope [GMT][3] and the European Extremely Large Telescope [ELT][4]) and space-based (the James Webb Space Telescope [JWST][5]) telescope facilities and a number of new, even deeper all-sky surveys (Large Synoptic Survey Telescope [LSST][6]).

Cosmology Revealing Theology

A major thrust of modern astronomy is understanding the first moments of creation, looking for the source of life, and looking for life outside the earth. NASA's goal in astrophysics is to "discover how the universe works, explore how it began and evolved, and search for life on planets around other stars." It is focused on sending spacecraft missions to other planets and having telescope capabilities that allow us to fully explore the question of origins. Likewise, the European Space Agency (ESA), while participating in US space missions, has a direction of its own: focusing on understanding the large-scale evolution of the universe and its underlying physics. Studies which provide revelation about these issues include learning about the nature of black holes, dark energy, dark matter, and gravity. Closer to home it means exploring the origin and evolution of galaxies, stars, and planets. All of these discoveries lead to a grander perspective of the universe which God has created. I wonder, as Christians, how these discoveries broaden our perspective of the nature of God. How do they reveal his attributes? How do they challenge us to think in new ways on the interaction of science and faith?

Extra-Solar Planets

The field of astrobiology was thrust into the limelight in the early 1990s with discovery in 1992 of the first confirmed extra-solar planetary system orbiting the pulsar PSR1257+12.[7] This was followed in 1995 by the first detection of an exoplanet orbiting a solar-like star, 51 Pegasi.[8] Ground-based surveys have thrived, developing detection techniques of radio velocity, direct imaging, gravitational microlensing, polarimetry, astrometry and transit photometry. In 2009 the Kepler spacecraft, which utilized the transit photometry technique—watching a planet pass in front of its parent star—was launched, placed in an Earth-trailing orbit and pointed to a field near the constellations of Cygnus and Lyra.[9] It monitored some 150,000 stars continuously for over four years before the failures in the telescope prevented it from continuing to stare in the same location, and the telescope and mission were repurposed for other astronomical studies. As of 2019, there are more than 3,970 confirmed planets in nearly 3,000 systems with approximately 20% hosting multiple planets. Based on size alone, some 550 of these planets could be rocky in nature and some 16–20 of these are thought to orbit in the habitable zone of their parent star.[10] In April 2018 the Transiting Exoplanet Survey Satellite (TESS)[11] was launched to look specifically for earths and super-earths in the solar neighborhood. This work has revolutionized the general public's interest in space. Countless science-fiction novels have been published over the years, envisioning what our first encounter with an extra-terrestrial species might look like. Likewise, some now propose that life was delivered to Earth from some other place in our universe.

As Christians, the possibility of finding life outside of Earth might raise some interesting theological discussions. The Bible does not describe life in the form of beings other than on our planet—although it does describe angels in the heavenly realm—nor what we should think of such life if we were to encounter it. Some would argue that this is a closed topic: we will not find alien life elsewhere because the Bible does not specify that there is life elsewhere. However, C. S. Lewis in his Space Trilogy describes life on Thulcandra, or Earth, as fallen, but imagines life off Earth as not partaking in the Fall.[12] This sparks the imagination and begs the philosophical questions that would be raised if we indeed find Earth-equal planets orbiting other stars with habitable conditions, which is very likely to be the reality in the coming years. The same questions might be raised from repeated measurements of something like the "Wow" signal—a radio signal anomaly that was found as part of a study that was sweeping the sky looking for extra-terrestrial signals.[13] The question I ask my students when we get to this topic is, "Would finding life—of any form, not just intelligent—shake your faith?" Clearly from a humanistic perspective, it

moves the ball from life on Earth to life elsewhere in the universe, but it does not really change the question. Fundamentally the question to ask is, "Would finding life elsewhere change the way we view God and his relationship with us? Would it change our approach to the great commission (Matt. 28:18–20)? We experienced this, perhaps in part, in the sixteenth century, when new peoples and cultures, quite different from the world of the European explorers, were discovered in the Americas.

Solar System Missions: The Moon, Mars, Saturn, Jupiter, Europa, Titan, and Enceladus

Among recent spacecraft missions to other planets within our own solar system, conditions which are thought to be relevant to life have also been a focus of great interest. The buzz phrase for solar system exploration has been "follow the water." Since the Apollo years (1960s and 1970s), there has been a quiet undercurrent in all missions with the idea that one day humankind will leave Earth and explore our solar system, not just with probes, but with manned missions. The exploration push has been to study places that we could visit, places that have resources that we could use on Earth, or that have the potential for the existence of extraterrestrial life, albeit extremophiles.

One look at the night sky and you are likely to see the Moon sometime in a given month. It is bright, big, and beautiful. Its surface is solid and at times looks as if it would be easy to reach out and touch it. One idea that has been brewing for the last forty years or so is that of a lunar base. However, as in pioneer days, going someplace new is dangerous and unknown. Yet, because of modern technology, we have a huge advantage over colonial times. We can send unmanned probes to map the worlds that we want to eventually settle so that our settlements have a high probability of success. More than seven NASA missions have been to the Moon since the beginning of this century and they have built on the success of tens of missions in the previous century. Most recently, the Lunar Atmosphere and Dust Environment Explorer (LADEE; 2012–2013)[14] was sent with specific goals related to populating the Moon in the future. Some of these goals included determining the global density, composition, and time variability of the tenuous lunar atmosphere, or exosphere, and looking at the dust environment which is important for designing a permanent outpost. The Gravity Recovery and Interior Laboratory (GRAIL; 2011–2012)[15] mission was sent to provide an unprecedented map of the moon's interior structure and composition. And the Lunar Reconnaissance Orbiter (LRO),[16] which was launched in 2009, is still operational and is working to identify safe landing sites, locate potential resources on the Moon, and to characterize the radiation environment.

So although the cost is high, it looks as if a mission to the Moon for humans is again on our horizon with the recent commission of the Artemis program to return humans to the moon by 2024.[17] Beyond NASA, private industry is beginning to investigate ways for the common citizen to be able to make this trip.[18] I wonder how this might affect our witness as believers. Some of the early pioneers to the "New World" went, despite the cost, because they were looking for a place where they could worship freely. Other explorers went as missionaries, carrying the gospel message to the native people they encountered. Obviously, the Moon is different, and we already know that it has no human inhabitants, but I wonder how we can, as believers, play a role for God's glory as humanity moves forward in this endeavor.

In addition to, or instead of, the Moon, many people have their sights on Mars. It is farther away, but it has a thicker atmosphere than the Moon and potentially more resources available for habitation. Since the turn of the century, we have explored Mars in great detail at both single time-step and time-variable regimes through a combination of rovers, including Pathfinder, Spirit, Opportunity, the Phoenix Lander, and Curiosity, which have been able to sample surface materials; there have also been high resolution orbiters, including Mars Odyssey, Mars Express, Mars Reconnaissance Orbiter, Mars Orbiter Mission, MAVEN and the ExoMars Trace Gas Orbiter. The goals for these missions seem to have a dual nature—learn about the environment of Mars for human habitation, and also look for evidence that there has been life on Mars in the past. While the Spirit and Opportunity rovers survived much longer than what they were designed for and found many evidences for water on Mars in the past, the Curiosity rover was sent to look for more-recent evidence.[19] In short, the Curiosity rover has been successful. A key result has been the discovery of hydrated salts

in dark stains on the Martian surface at four different sites which are thought to be the smoking gun for liquid water in the past. It has also found additional evidence for early lakes which existed as recently as 10,000 years ago along with evidence for subsurface liquid water in the current epoch.[20] The atmospheric probe called Maven has measured, for the first time in forty years, the composition of Mars's atmosphere which included a large amount of dust hovering above the planet. The dust is thought to have come from comet and asteroid sources.[21] Maven also found the equivalent of Earth's northern lights caused by high-energy particles exciting the atmosphere unguarded by a magnetic field. And it has provided evidence that solar storms strip particles away from the atmosphere at an incredible rate, perhaps helping to explain why Mars's atmosphere is so thin. The Mars Reconnaissance Orbiter (MRO[22]; 2005) has been involved in monitoring Mars's atmosphere, and, since the arrival of the rovers, has provided invaluable communication support for these missions. In November of 2018, the Interior Exploration using Seismic Investigations, Geodesy and Heat Transport (InSight) Lander touched down to begin the first geophysical investigation of the Martian interior.[23] These are all key aspects to the reconnaissance of planet Mars before sending humans there.

All of the Martian discoveries point to Mars having been a very different place in the past, but mostly hostile to life now without serious protection. However, there is a huge push from within the Mars research community, as well as among the public in general, toward the idea of sending a human mission to Mars. There is already a long list of people who want to be the first on such a mission in spite of the risks involved. As with the Moon, this does seem a next logical step in human exploration. So, one might ask, what drives us to want to inhabit Mars? How much do we really need to know before we launch such an adventure? How much risk is okay for humans to take? Is it okay for humans to terraform the Moon, Mars, or other planets? Are we destined to live throughout the Solar System? What part should Christians play in these missions?

Beyond the reach of human missions at the moment, but clearly in sight tens of years down the road, studies of Europa, Enceladus, and Titan are looking for extraterrestrial life in our own solar system. Studies of different ecosystems on our own planet Earth have revealed that life exists in very extreme environments. These lifeforms, aptly named extremophiles, exist in all the dimensions observed—extremely hot and cold environments, high salinity, high and low pH values, high pressure, and extremely dry conditions. Some extremophiles have even been found in high-radiation environments. Studies of Jupiter's moon Europa by the Galileo spacecraft in the late 1990s and early 2000s revealed it to be the likely home of a large subsurface ocean,[24] and a twenty-year study by Cassini of the Saturnian system (1997–2017) revealed Enceladus to be a fascinating world with active geysers that are composed of nearly 100% water ice.[25] The Huygens's probe that landed on the surface of Titan in 2005 revealed it to have pebbles of water ice scattered over an orange surface resultant from a thin haze of methane in the atmosphere. The decent photos showed a landscape consistent with the presence of many lakes, likely filled with liquid during some seasons on Titan. Continued studies of Titan's atmosphere support the idea that Titan supports a hydrologic cycle akin to Earth's, with the exception that it is driven by methane instead of water.[26]

It seems that some of the life forms encountered by humans as described in Arthur C. Clarke's science fiction known as the Space Odyssey series[27] are perhaps not as far-fetched as they might have been when he first wrote them. What would discovering other forms of life, on places other than Earth, tell us about God and his intentions for us? How might this challenge our interpretations of scripture?

Small Bodies in the Solar System

In addition to looking for life, there have been countless missions to small bodies over the years. Some of these missions have had the inverse goal of protecting life here on planet Earth by identifying objects that might harm us. Large scale Earth-based telescopic surveys have detected tens of thousands of small objects ranging from meters to thousands of meters in size, and residing from orbits near Earth all the way out to the edges of our solar system in the Kuiper Belt and the inner Oort cloud. More than just determining the orbits of these bodies, studies have been done to learn about the orbital interactions and histories of these objects, their shapes, and surface compositions.

Planetary missions such as *Dawn* (which visited Vesta and Ceres), Hayabusa2, and OSIRIS-REx have studied individual asteroids to learn about their cratering histories—how often have these objects been hit and what the impacting population looks like—as well as their compositions. In October 2018, the Mobile Asteroid Surface Scout (MASCOT) spacecraft even landed on the surface of the asteroid (162173) Ryugu.[28] WISE/NEOWISE was a repurposed astrophysics mission that mapped the entire sky in the infrared and subsequently added hundreds of photometrically characterized (with known colors and rotation periods) small bodies to our databases. Finally, in July 2015, the *New Horizons* mission completed our inventory of spacecraft visits to the major planets (as they were listed prior to Pluto's reclassification in 2006 to a dwarf planet), revealing an active environment of surface ices some 34 AU from the Sun. On New Year's Day 2019, this same mission flew past an approximately 30-km Kuiper Belt Object, (486958) 2014 MU69, and found it to be the most primordial object ever studied up close, opening the door to a better understanding of the past and current history of the outer reaches of our solar system.[29] All of these missions have made significant contributions to our current picture of remnant material in our solar system. Theoretical models like the NICE model,[30] using constraints provided by these observations, have been drawn up to provide a potential narrative as to the mechanisms and timing of our solar system's formation out of an original solar nebula.

Although much of the motivation to study close-by objects has been to identify and, if possible, to protect Earth from objects that could destroy humanity as we know it, another motive has been to learn about material in space that we could one day use here on Earth, or for interplanetary travel. Still another motive has been to look for an understanding of our solar system's history and for an origin of life external to Earth (i.e., following the hypothesis that life was delivered to Earth from someplace else instead of originating here) as people have tried to answer the important questions: Where do we come from? What is our purpose here on Earth? Where are we going, individually, as a society, and as a species? If we find aspects of humanity elsewhere in our solar system, what effect might these have on our faith? What insights will they give us into how we interpret scripture?

Astrophysics: Looking for the Moment of Creation

Moving beyond our own solar system to bigger questions of cosmology, astrophysics has made significant progress in learning more about the large-scale structure and early beginnings of our universe including evidence for dark matter, dark energy and dark radiation. In 2016, the Laser Interferometer Gravitational-Wave Observatory (LIGO[31]) announced the first detection of gravitational waves, ripples that stretch and compress space itself and give us the ability to "hear" the universe. In 2017, the first-ever combined gravitational-wave and light-based observatories (from radio through gamma rays) confirmed the observation of two neutron stars colliding (GW170817)[32] and determined mergers like this to be the sources of many heavy elements in the universe.[33] In December 2018, four black holes, swirling toward each other, were detected using the same methodology. This new technique of "multi-messenger" astronomy, with simultaneous observations both in the electromagnetic spectrum and with gravity waves, has the potential to revolutionize our ability to view and understand our universe.[34] Building on these results, in early 2019, the Event Horizon Telescope (EHT), which uses very long baseline interferometry (VLBI), imaged a black hole for the very first time by capturing its silhouette against the glowing region around it.[35]

Likewise, studies to refine the Hubble constant, using the Hubble Space Telescope to look at thousands of Cepheid variable stars and hundreds of Type 1a supernova—two different types of cosmic yardsticks—have led astronomers to conclude that the universe is expanding 5–9 percent faster than previously thought. Reiss, one of the principle investigators on the project, suggests that "this surprising finding may be an important clue to understanding those mysterious parts of the universe that make up 95 percent of everything and don't emit light, such as dark energy, dark matter and dark radiation."[36]

Perhaps related to the questions probed by LIGO and HST has been the pioneering work of the "Conseil Européen pour la Recherche Nucléaire" (CERN) project since its inception in 2011.[37] Focusing on understanding the basic constituents of matter itself, they have built the world's most complex scientific instruments to produce particle collisions at

speeds close to that of light itself, in efforts to gain insights into the fundamental laws of nature. One of the most fundamental questions it has sought to address is, if the Big Bang created equal amounts of matter and antimatter as we understand the physics of it, why is there far more matter than antimatter in the universe?

Because these projects and discoveries take us back in time, they touch on the question of origins and the moment of creation, a question which poses great opportunities for faith interactions. They beg the question, what or who is behind our beginning? Why is there something rather than nothing? At the other end of the spectrum, if materialists are right that the stuff in our universe is all that exists, is the implication of the second law of thermodynamics then that the universe eventually will simply fizzle out and become cold and dark?

Biblical Hermeneutics and the Time Frame of Creation

> We do not draw people to Christ by loudly discrediting what they believe, by telling them how wrong they are and how right we are, but by showing them a light that is so lovely that they want with all their hearts to know the source of it.
> ~ Madeline L'Engle

Lastly, I want to provide an encouragement. I have seen a huge step forward in the last 5–10 years in our ability to dialogue and stand in unity with a distinctly Christian voice.[38] One of the issues that I face in my teaching is the question of time frame—is creation 14 billion or 6,000 years old? In the past I have seen this as a divisive issue inside the church and as a point of disunity with respect to the outside world looking in. Recently, there has been a real effort among the Christian community, and among Christian astronomers in general, to discuss this issue of time frame. What is the evidence from astronomy as to how old God's creation is? How does this evidence fit with our interpretation of scripture? Are there observations and measurements that we should be pursuing scientifically to better address this question of time frame? Are there alternative hypotheses or models, perhaps nonmainstream, that we should be developing?

An Invitation

So, with new astronomical discoveries occurring at an increasingly rapid pace, we are at the forefront of many amazing discoveries which often-times have metaphysical implications. We have an awesome opportunity to learn, and to share, how our life in Christ is related to our life among the stars. I invite you to participate in this dialogue by sharing your own thoughts on some of the questions I have posed or on other questions that have come to mind as you have been reading. May God be magnified as we not only deepen our relationship with him through our studies of his creation, but also seek to build bridges for the outside world to join us in this revelation. And may we effectively do what C. S. Lewis so eloquently exhorted, "Don't shine so others can see you. Shine so that through you others can see Him." ☼

Notes

[1]G. V. Kober, S. D. Benecchi, and P. Gossard, *The Crossroads of Science and Faith: Astronomy through a Christian Worldview* (Damascus, MD: Glimpse of His Splendor Publishing, 2015).
[2]Gaia, *European Space Agency*, http://sci.esa.int/gaia/.
[3]Giant Magellan Telescope, http://www.gmto.org/.
[4]The European Extremely Large Telescope (ELT) Project, *European Southern Observatory*, https://www.eso.org/sci/facilities/eelt/.
[5]James Webb Space Telescope, Goddard Space Flight Center, NASA, https://www.jwst.nasa.gov/.
[6]Raise the Roof: The LSST Vertical Platform Lift Completes Load Testing on the Summit (June 4, 2019), https://www.lsst.org/.
[7]A. Wolszczan and D. A. Frail, "A Planetary System around the Millisecond Pulsar PSR1257 + 12," *Nature* 355, no 6356 (1992): 145–47; "NASA's Kepler Mission Announces Largest Collection of Planets Ever Discovered," NASA, *NASA News* (May 10, 2016).
[8]Michel Mayor and Didier Queloz, "A Jupiter-Mass Companion to a Solar-Type Star," *Nature* 378, no. 6555 (1995): 355–59.
[9]W. J. Borucki et al., "Kepler Planet-Detection Mission: Introduction and First Results," *Science* 327, no. 5968 (2010): 977.
[10]J. Schneider, "Interactive Extra-Solar Planets Catalog," *The Extrasolar Planets Encyclopedia* (April 2018), http://exoplanet.eu/catalog/.
[11]TESS Science Support Center, *NASA*, https://tess.gsfc.nasa.gov/.
[12]C. S. Lewis, *Space Trilogy* (New York: Scribner, 1996).
[13]J. Kraus, "The Tantalizing 'Wow!' Signal," letter to Carl Sagan (January 31, 1994), unpublished paper describing the event, http://jump2.nrao.edu/dbtw-wpd/textbase/Documents/kraus-wow-unpublished-30jan1994.pdf.

[14]LADEE, NASA, https://www.nasa.gov/mission_pages/ladee/main/index.html.
[15]GRAIL (Ebb and Flow), NASA Science: Solar System Exploration (updated June 11, 2019), https://solarsystem.nasa.gov/missions/grail/in-depth/.
[16]Lunar Reconnaissance Orbiter, NASA, https://www.nasa.gov/mission_pages/LRO/main/index.html.
[17]Thomas Burghardt, "NASA Aims for Quick Start to 2024 Moon Landing via Newly Named Artemis Program," NASA Spaceflight.com (May 14, 2019), https://www.nasaspaceflight.com/2019/05/nasa-quick-start-artemis-program/.
[18]SpaceX to Send Privately Crewed Dragon Spacecraft beyond the Moon Next Year (February 27, 2017), http://www.spacex.com/news/2017/02/27/spacex-send-privately-crewed-dragon-spacecraft-beyond-moon-next-year.
[19]Mars Science Laboratory: Curiosity Rover, NASA, Jet Propulsion Laboratory, California Institute of Technology, https://mars.nasa.gov/msl/.
[20]F. J. Martín-Torres et al., "Transient Liquid Water and Water Activity at Gale Crater on Mars," *Nature Geoscience* 8, no. 5 (2015): 357–61.
[21]R. D. Wordsworth, "The Climate of Early Mars," *Annual Review of Earth and Planetary Sciences* 44 (2016): 381–408.
[22]MARS InSight Mission, NASA, https://mars.nasa.gov/insight/.
[23]Mars Reconnaissance Orbiter, NASA, https://www.nasa.gov/mission_pages/MRO/main/index.html.
[24]M. H. Carr et al., "Evidence for a Subsurface Ocean on Europa," *Nature* 391, no. 6665 (1998): 363.
[25]J. R. Spencer and F. Nimmo, "Enceladus: An Active Ice World in the Saturn System," *Annual Review of Earth and Planetary Sciences* 41 (2013): 693–717.
[26]H. G. Roe, "Titan's Methane Weather," *Annual Review of Earth and Planetary Sciences* 40, no. 1 (2012): 355–82; and J. L. Mitchell and J. M. Lora, "The Climate of Titan," *Annual Review of Earth and Planetary Sciences* 44, no. 1 (2016): 353–80.
[27]Arthur C. Clarke, *2001: A Space Odyssey*, rev. edition (New York: New American Library, 2000); ____, *2010: Odyssey Two* (New York: Del Rey Books, 1984); ____, *2061: Odyssey Three* (New York: Del Rey Books, 1989); and ____, *3001: The Final Odyssey* (New York: Del Rey Books, 1998).
[28]David Dickinson, "MASCOT Deploys from Hayabusa-2, Lands on Ryugu," *Sky and Telescope* (2018) blog, https://www.skyandtelescope.com/astronomy-blogs/astronomy-space-david-dickinson/mascot-deploys-from-hayabusa-2-lands-on-ryugu/.
[29]S. A. Stern et al., "Initial Results from the New Horizons Exploration of 2014 MU69, a Small Kuiper Belt Object," *Science* 364, no. 6441 (May 17, 2019).
[30]R. Gomes, H. F. Levison, K. Tsiganis, and A. Morbidelli, "Origin of the Cataclysmic Late Heavy Bombardment Period of the Terrestrial Planets," *Nature* 435, no. 7041 (2005): 466–9; K. Tsiganis, R. Gomes, A. Morbidelli, and H. F. Levison, "Origin of the Orbital Architecture of the Giant Planets of the Solar System," *Nature* 435, no. 7041 (2005): 459–61; A. Morbidelli, H. F. Levison, K. Tsiganis, and R. Gomes, "Chaotic Capture of Jupiter's Trojan Asteroids in the Early Solar System," *Nature* 435, no. 7041 (2005): 462–65.
[31]LIGO/Virgo Release First Catalog of Gravitational-Wave Events, LIGO Scientific Collaboration, https://www.ligo.org/.
[32]B. P. Abbott et al., "GW170817: Observation of Gravitational Waves from a Binary Neutron Star Inspiral," *Physical Review Letters* 119 (October 16, 2017): 161101.
[33]A. Cho, "Merging Neutron Stars Generate Gravitational Waves and a Celestial Light Show," *Science* (October 16, 2017), https://www.sciencemag.org/news/2017/10/merging-neutron-stars-generate-gravitational-waves-and-celestial-light-show.
[34]B. P. Abbott et al., Multi-messenger Observations of a Binary Neutron Star Merger, *The Astrophysical Journal Letters* 848 (October 16, 2017): 1.
[35]The Event Horizon Telescope Collaboration et al., "First M87 Event Horizon Telescope Results. VI. The Shadow and Mass of the Central Black Hole," *The Astrophysical Journal Letters* 875 (2019): L6.
[36]Mike Wall, "Surprise! The Universe Is Expanding Faster Than Scientists Thought," *Space.com* (June 2, 2016), https://www.space.com/33061-universe-expanding-faster-than-thought-hubble.html; and A. G. Riess et al., "Type 1a Supernova Distances at Redshift >1.5 from the *Hubble Space Telescope* Multi-cycle Treasury Programs: The Early Expansion Rate," *The Astrophysical Journal* 853, no. 2 (2018): 126.
[37]CERN Accelerating Science, https://home.cern/.
[38]Ken Ham, Hugh Ross, Deborah B. Haarsma, Stephen C. Meyer, *Four Views on Creation, Evolution, and Intelligent Design*, ed. J.B. Stump (Grand Rapids, MI: Zondervan, 2017).

ASA Members: Submit comments and questions on this article at www.asa3.org→RESOURCES→Forums→PSCF Discussion.