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SURVEY REVIEW

Pioneering women in astronomy and aerospace

Dava Sobel: The glass universe: How the ladies of the Harvard Observatory took the measure of the stars. New York: Viking, 2016, xii + 324, HB $30.00 Margot Lee Shetterly. Hidden Figures: The American dream and the untold story of the black women mathematicians who helped win the space race. New York: William Morrow, 2016, xviii + 347 pp, HC $27.99, eBook $14.99

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Celebrating important but not necessarily well-known figures from the past is the link between the two books under consideration here. Dava Sobel concentrates on "Pickering's harem," a somewhat disparaging term for the women "computers" who worked at the Harvard College Observatory under Edward Pickering, its director from 1877 to 1919, and their younger female colleagues brought in by Pickering's successor, Harlow Shapley. Their groundbreaking contributions deepened our understanding of the universe during their lifetimes and continues to shape the field of astrophysics today. Margot Lee Shetterly concentrates on the achievements of African-American women mathematicians and engineers who made important contributions at NASA and at its predecessor, NACA—the National Advisory Committee for Aeronautics. Both books are set in a time when computers were human and primarily female.

Despite this link, however, the two books differ in significant ways. The "story" that Shetterly tells is truly "untold," and the women whose achievements she recounts were, indeed, "hidden figures" until she brought them to our attention. As the author writes in her Acknowledgments, "The history that has come together in these pages wasn't so much hidden as unseen—fragments patiently biding their time in footnotes and family anecdotes and musty folders before returning to view" (*Hidden Figures,* 267). By contrast, the accomplishments of the four main women figures in Sobel's book have long been acknowledged, at least within the astrophysics community. Anyone who has taken an introductory astronomy course is likely to recognize their names. And if having your recognizable likeness without your name printed on a t-shirt is any proof of fame, among other objects at a booth at the American Astronomical Society meeting in January 2017 was a shirt with LEGO® figures clearly identifying Henrietta Leavitt (holding a magnifying glass up

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to a glass plate), Annie Jump Cannon (behind a diagram showing seven circles of diminishing size, and, beneath each, one of these letters: OBAFGKM, which those in the know recognize as a universally accepted stellar classification scheme, based on decreasing surface temperature), and Cecilia Payne-Gaposchkin (holding a card in one hand with the symbol for the element hydrogen, and, in the other, a card with the symbol for helium). Although absent from the t-shirt, the fourth woman, Williamina Fleming, is similarly well known, as the "mother" of the famous Harvard classification of stars known as the *Draper Catalogue of Stellar Spectra*. (More later on the recent impact Shetterly's research has had on LEGO®.)

A second difference has to do with the issue of discrimination and how it affected the careers of the female central characters. Shetterly's women were deeply affected by racism in daily life as well as in the workplace, although some learned how to circumvent the racist trappings meant to confine them at work, and many earned the respect of the engineers with whom they collaborated through the quality of their work. Sobel's women definitely faced gender bias within the larger Harvard framework, but in their own lair, they were not only appreciated but also revered. It was the women who studied and interpreted the Harvard glass-plate collection of astronomical photographs, yielding lasting contributions to the field. As Sobel writes in a chapter primarily devoted to the contribution of Cecilia Payne—the first scientist to earn a doctorate in astronomy at Harvard (though the degree was technically from Radcliffe), and the first to calculate that stars were primarily composed of hydrogen and helium: "She faced scant risk [of being looked down on because of her sex] at the Harvard Observatory, where Annie Jump Cannon could bake a batch of oatmeal cookies for a meeting of the Bond Astronomical Club and then lecture authoritatively to the assembled about her latest findings in spectroscopy"—the study and identification of materials based on the light they emit, absorb, or scatter (*Glass Universe*, 215).

Honored though the women on the staff of the Harvard Observatory were within the observatory family, sexism at Harvard in the higher levels of university administration certainly stood in their way. For decades, they were welcome to work but not to have university titles that reflected their professional contributions. So, for example, in 1911 Harvard President Abbott Lawrence Lowell denied Annie Jump Cannon a Harvard Corporation appointment as Curator of Glass Plates—Harvard's unmatched archive of glass-plate negatives on which celestial events in both the northern and southern hemispheres from the mid-1800s on were captured. No matter that the title had just become available following the death of Williamina Fleming earlier that year. Fleming, who had measured and classified the spectra of thousands of stars on the Harvard plates, had held that title—conferred on her formally by the Harvard Corporation, no less—since 1899, 18 years since joining the Observatory staff, after Pickering, recognizing her intellectual potential, plucked her out of her role as housemaid in the director's residence. No matter either that Pickering lauded Cannon as "the leading authority on the classification of stellar spectra, and perhaps on variable stars" (*Glass Universe*, 147). Lowell also swore that as long as he lived, Cecilia Payne-Gaposchkin would never be made a Harvard professor. After James B. Conant succeeded Lowell as university president in 1938, the Harvard Corporation did recognize Cannon as "William Cranch Bond Astronomer and

Curator of Astronomical Photographs" and did name Payne-Gaposchkin "Phillips Astronomer." But as Sobel notes, despite the fact that Payne-Gaposchkin's work was recognized internationally and that she was teaching and mentoring graduate students, her title was "not exactly academic" (*Glass Universe*, 245); it did not give her faculty status either in the college or even in the astronomy department. Only in 1956 was she made a full professor—"the first woman at Harvard to be promoted to that level" (Glass Universe, 258)—and in the following year elevated to department chair, a prestigious appointment, to be sure, but one which took up too much of her research time. In 1958, under President Nathan M. Pusey, the Harvard Corporation finally elected her the Phillips Professor of Astronomy. Her salary, however, while greater than that of her less-eminent astronomer husband, was much lower than that of her male colleagues.

A third difference between the two books lies in the authors' track records. *Hidden Figures* is Shetterly's first book, while *Metascience* readers are likely to at least recognize the titles of some of Sobel's earlier successful popular science narratives, including *Longitude* (1995), *Galileo's Daughter* (2000), *The Planets* (2005), and *A More Perfect Universe* (2011), with the play embedded in the latter—*And the Sun Stood Still*—coming out as a bound book itself in 2016. In the interest of full disclosure, as careful readers of *The Glass Universe* might note if their perusal extends to the author's *Appreciation* (part of the book's end matter), I am one of the half-dozen or so colleagues to have had the privilege of reading and commenting on a draft of the manuscript. Reading a manuscript in search of passages that might be improved, however, is a completely different undertaking from reading a published book by an accomplished author. I am in awe not only of the varied scope of Sobel's scholarly interests but also of her literary skills.

The book begins with a beautifully written and evocative, but nonetheless deeply informative and explanatory, Preface. In it, Sobel imagines what any one of the female "computers" might have thought about while scrutinizing a glass plate in the early years of the project to which Pickering had assigned her:

A little piece of heaven. That was one way to look at the sheet of glass propped up in front of her. It measured about the same dimensions as a picture frame, eight inches by ten, and no thicker than a windowpane. It was coated on one side with a fine layer of photographic emulsion, which now held several thousand stars fixed in place, like tiny insects tapped in amber. One of the men had stood outside all night, guiding the telescope to capture this image, along with another dozen in the pile of glass plates that awaited her when she reached the observatory at 9 a.m. Warm and dry indoors in her long woolen dress, she threaded her way among the stars. She ascertained their positions on the dome of the sky, gauged their relative brightness, studied their light for changes over time, extracted clues to their chemical content, and occasionally made a discovery that got touted in the press. Seated all around her, another twenty women did the same (*Glass Universe*, xi).

Other writerly aspects of the book are similarly impressive. Each of the book's three sections is introduced by two epigraphs, one from a female astronomer, and the other from a female author. Two epigraphs in particular resonate with me. An extract from Amy Lowell's "Night Clouds" is perhaps an inspiration for Sobel's title: "The white mares of the moon rush along the sky/Beating their golden hoofs

upon the glass Heavens" (*Glass Universe*, 1), and the excerpt from Annie Jump Cannon is notably poignant, given her deafness, a result of a serious case of scarlet fever she survived while an undergraduate at Wellesley: "It was almost as if the distant stars had really acquired speech, and were able to tell of their constitution and physical condition" (*Glass Universe*, 87).

Despite the book's title, which seems to imply that it will deal primarily with the work of the observatory women, the coverage is far more sweeping. I was happy to learn about the backgrounds of the heiresses Anna Palmer Draper and Catherine Bruce, whose gifts to Pickering's projects—both at Harvard itself and in the southern hemisphere—made the analysis of the glass plates possible. My understanding of the history of American astronomy from the late nineteenth century through today was deepened by Sobel's coverage of conflicts between men, with Pickering's younger brother William, for example, proving a thorn not only in his sibling's side but also, later, in Shapley's. The history of the Harvard telescope in Arequipa, Peru, is also of interest, involving civil war, disease, and volcanic eruptions, among other complications. Nor had I known until reading Chapter 4 about the "Astronomers at War" controversy, played out in newspapers in 1894, fomented by "a malcontent from within the Harvard ranks," who "undermined" the validity of discoveries of globular clusters "by attacking the observatory's procedures" (*Glass Universe*, 59–61).

Other byroads in the book provide a glimpse into perhaps unexpected but not uninteresting vistas. Having observed a hybrid solar eclipse with Sobel on a cruise ship to the Galápagos and beyond in 2005, I was interested to see how many solar eclipses she works into the narrative (nine at my count, from 1870 through 1932). Sobel makes sure the reader will not lose track of the main narrative, however, by including several helpful sections in the back matter, including the timeline in "Some Highlights in the History of the Harvard College Observatory" (*Glass Universe*, 273–279), and especially "A Catalogue of Harvard Astronomers, Assistants, and Associates" (*Glass Universe*, 285–292). (Other readers, less familiar with astronomical terminology, might also appreciate the Glossary [*Glass Universe*, 281–283].)

Throughout, Sobel humanizes the technical aspects of the science by including family and other personal issues affecting her characters. Understanding the weight of Williamina Fleming's domestic responsibilities—including, at different times of her life, care of a son as a single parent, of a widowed mother, and of a widowered younger brother and his two sons—serves to deepen our admiration for Fleming's professional success. Sobel's study of Fleming's handwritten journal from the turn of the twentieth century highlights Fleming's dissatisfaction not with her work but with her compensation: "Sometimes I feel tempted to give up and let [Pickering] try some one [sic] else, or some of the men, to do my work, in order to have him find out what he is getting for $1500 a year from me, compared with $2500 from some of the other [male] assistants. Does he ever think that I have a home to keep and a family to take care of as well as the men?" (*Glass Universe*, 96).

Among other family dramas are the interventions of the Reverend Mytton Maury on behalf of his daughter Antonia, a niece of Dr. Henry Draper, an accomplished stellar photographer. (Dr. Draper's early death in 1882, at the age of 45, left his

widow determined to fund the Henry Draper Memorial Project, which enhanced the Harvard glass-plate collection and made possible much of the analysis of the information embedded in it.) Maury played a significant if very intermittent role in Harvard's stellar classification project, though her father worried that her dedication to the task Pickering had assigned her—classification of the northern bright stars—came "at the expense of injured health" (*Glass Universe*, 64). Similarly, Cecilia Payne's mother, Emma Pertz Payne, wrote Shapley to urge him to curb her daughter's tendency to overwork (*Glass Universe*, 199).

The final pages of the book successfully pull the sweeping coverage to a satisfying end by focusing on the lasting value of the work done at the Harvard Observatory during the book's time frame. Sobel first summarizes the enduring significance of the stellar classification system that several of the "computers" worked out over the decades, compiling the *Henry Draper Catalogue* and its extensions over the period 1918–1949—in all, classifying close to 360,000 stars. The principal system of stellar classification in use today, the so-called MK system, adopted the main spectral classes worked out by the Harvard female "computers," including Antonia Maury, incorporating in addition each star's luminosity, the total amount of energy emitted. The dedication of the *Revised MK Spectral Atlas for Stars Earlier than the Sun*, published in 1978 reads: "To Antonia C. Maury (1866–1952) Master Morphologist of Stellar Spectra" (*Glass Universe*, 61).

Although Henrietta Leavitt did not participate in the classification effort, Sobel next assures us that her work on variable stars and her discovery of the so-called "period-luminosity relationship" have had "an equal if not greater, impact on progress in astronomy" (*Glass Universe*, 261–262). Leavitt's investigation of thousands of variable stars in the Magellanic clouds led her to discover in 1908 that the longer the period of a so-called Cepheid variable's pulsation, the brighter that star. This insight, which the American Astronomical Society's executive council has resolved should be known as "Leavitt's Law," led to "Hubble's Law," advanced by astronomer Edwin Hubble in 1929, which describes the expansion of the universe. Leavitt's Law is a basic rung in the distance ladder that enables astronomers today to measure the current rate of the universe's expansion.

Next, Sobel suggests how we in the twenty-first century can best remember the female "computers"—not as exploited, underpaid, and undervalued workhorses but rather as trustworthy, gifted, and accomplished colleagues. For me, Pickering and Shapley, for all their genteel occasional dismissal of women reflected in some offhand comments, are the heroes of the story. In search of assistants "needed to establish the light cycle of any given variable," he looked to "the graduates of women's colleges [among whom] are many who have had abundant training to make excellent observers" (*Glass Universe*, 13). He advocated for recognition for his staff not only at Harvard but also at institutions whose prizes recognized important scientific contributions. Despite Shapley's neologisms "girl-hour" and "kilo-girl hours," which fairly drip with sexism, he opened up graduate education at Harvard to women. He urged Cecilia Payne not only to become the first astronomy PhD candidate at the university but also to expose her gender by signing journal submissions not with initials but with her full name. Eager for her to submit a significant find to the appropriate journal in time to meet its submission deadline, he

volunteered to type her report as she wrote it (*Glass Universe*, 203). He admired her Ph.D. thesis so much that he "inaugurated the Harvard Monographs in 1925 to showcase it" (*Glass Universe*, 212). He also advocated for appropriate recognition of the women on his staff. He reveled, for example, in Annie Jump Cannon's being awarded the 1931 Draper Medal of the National Academy of Sciences. (I also admire Shapley for his choice of spouse. I had been unaware until reading about Martha Betz Shapley in this book of how accomplished she was. A skillful mathematician, she helped her husband with the calculations for his Princeton doctoral thesis. She wrote astronomical papers on her own about the orbits of eclipsing binary stars and, with her husband, about Cepheid variables.)

The Glass Universe ends with a welcome update on the Harvard glass-plate collection. Although photographs of the universe are now taken digitally, the plates continue to provide a historical record of what the sky "looked like on any given date between 1885 and 1992," and are thus "unique, invaluable, and irreplaceable." Even though today's pictures reveal celestial objects "undreamed of at the start of Pickering's sky patrol—pulsars, quasars, black holes, supernovae, X-ray binaries," those objects "left their marks on the plates," and comparison of today's digital pictures with historical photographic ones have deepened the field of time-domain astronomy—the study of how astronomical objects change over time (*Glass Universe*, 264). Over a decade ago, Harvard, with funding from the National Science Foundation, initiated a new project, DASC@H, "Digital Access to a Sky Century at Harvard," which involves several steps. Each plate is photographed so that any markings on it are recorded before the cleaning process that follows. Next, each plate is scanned. Finally, the information encoded on it is extracted with computerized algorithms. A water main break in January 2016 threatened the survival of some 61,000 plates, but they have been freeze-dried to prevent mold growth. Sobel ends the book as lyrically as she opened it by assuring us that, as the plates are thawed and cleaned over time, they will once again "reveal the stellar spectra, the variable stars, the star clusters, the spiral galaxies, and all the other luminous sights they first conveyed to a small but dedicated circle of women" (*Glass Universe*, 266).

Switching my focus now to *Hidden Figures*, Shetterly does a fine job in her introductory pages of convincing us that we are in more than competent hands, despite her self-description as "a first-time author with no background as a historian" (*Hidden Figures*, xvii). It turns out she is such a skilled archival researcher that by the time the book went to press, she had identified "almost fifty black women who worked as computers, mathematicians, engineers, or scientists at the Langley Memorial Aeronautical Laboratory," with the expectation that additional archival probing might yield another twenty names (*Hidden Figures*, xvi). (Langley Memorial Aeronautical Laboratory is an older name for Langley Research Center—the oldest of NASA's field centers, located in Hampton, Virginia, where all the women covered in the book made their careers.) Her archival work (in seven different archives listed in the book's extensive bibliography) also yielded an unexpected revelation: the contribution of white women computers at Langley, who first joined the computing pool in 1935, had also gone without appropriate recognition. Perhaps another researcher will be inspired to follow up on Shetterly's

suggestion that further archival research might turn up the names of more than a thousand such white female contributors to early aeronautical and space programs.

Shetterly's Prologue also illuminates her decision to probe the history the book brings so compellingly to general readers. Not only did Shetterly grow up black in Hampton, leaving it only at age 18 for the University of Virginia, but also her father—who studied electrical engineering at the historically black Norfolk State College—worked as a black scientist at Langley from 1964 through his retirement in 2004, by which time he had earned an international reputation as a climate scientist. (Her mother, while not a Langley scientist, had a similarly impressive career as a professor of English at the historically black Hampton University.) College friends of her parents included supersonics experts and electrical engineers, along with other professionals. According to Shetterly, "I knew so many African American working in science, math, and engineering that I thought that's just what black folks did" (*Hidden Figures*, xiii). By virtue of family connections, Shetterly asserts, she and her three siblings, were just as much "a product of NASA as the Moon landing" (*Hidden Figures*, xiv). Although Shetterly herself studied business rather than science, she was enough of a quant to have an early career in investment banking, so when she talks about differential equations and statistics in the course of describing the work of her protagonists, she knows whereof she speaks. Though *Hidden Figures* now has a life of its own, Shetterly's interest in archiving the work of all women, regardless of racial background, who worked as computers and mathematicians in the early days of NACA and NASA led her in 2013 to found the Human Computer Project, with support from the Virginia Foundation for the Humanities.

Another difference between Sobel's and Shetterly's books is that no film (at least thus far) has been based on *The Glass Universe*. Many readers of *Hidden Figures* will therefore come to the book with certain expectations based on key scenes in the film. Prepare to discover the liberties taken by the writers and directors with the historical record as revealed in the book. A pivotal scene involving the search for a bathroom designated for use by "colored" employees is attributed to the wrong character in the film, for example, and the opening scene involving car trouble experienced by the three protagonists as they carpool to work seems to be totally made up. But no matter: it is the work of the three protagonists that truly commands our interest, and while the film obviously must compress their career trajectories, we can fill in as necessary by reading the book.

The central figure in the film, Katherine Coleman Goble Johnson, is "the most recognized of all the NASA human computers, black or white" (*Hidden Figures*, 250), but the story really begins with one of her two main cinematic sidekicks, Dorothy Vaughan (1910–2008), who was also the oldest of the three. A math major and valedictorian at Wilberforce University—the oldest private "Negro" college in the USA—she had extensive experience teaching math in segregated schools before beginning her career as a computer. In spring 1943, with US involvement in the war effort at a peak, she responded to ads in her local post office advertising not only laundry jobs for women at Camp Pickett (later Fort Pickett)—an army training base in the Piedmont region of Virginia—but also for mathematical jobs related to the aircraft industry at NACA. After working as a laundress for the army for several

months, she began work in the black female computing pool at Langley on December 1, 1943. To bring the former math teachers up to speed for their new jobs, Langley offered a course in engineering physics for the new recruits, as well as hands-on laboratory training in one of Langley's wind tunnels. Vaughan and her coworkers had not only a six-day workweek but also an average of four hours of homework per week. During the war, Vaughan was promoted to supervisor; in 1946, she became a permanent Civil Service employee; and in 1951, she became section head. In that role, she fostered the careers of many other African-American women. When Langley acquired its first electronic computing machines in the late 1940s, Vaughan was quick to intuit that mastering the complexities of the machines was crucial to career advancement. Not only did she sign up for the courses in computation that the laboratory offered, but she also advised members of her group to do so. It soon became clear that specializing in a field of engineering would be more crucial to job stability than general computing skills. In May 1958, segregation was officially ended at Langley, and the group of all-black women computers was disbanded. Vaughan, now a part of the Analysis and Computation Division, redefined herself as a computer programmer. Although she was only indirectly involved with the nascent space program, her skill in converting engineers' equations into computer language played a role in finalizing the calculations for Project Scout—a launch vehicle managed at Langley from 1959 through 1991, at which time management was transferred to NASA Goddard in Greenbelt, MD. Vaughan retired from NASA in 1971 after a 28-year career. Her only disappointment was that following the elimination of the black computing pool in 1958, she never again held the title of section head.

Unlike Vaughan, whose name never appeared as author or coauthor of a Langley research report, her younger colleague Katherine Coleman Goble Johnson (born August 26, 1918), had several significant papers to her credit. Something of a child prodigy—which the film makes much of—she began college at age 15 at what is now West Virginia State University, a historically black post-secondary institution. In 1953, by then married and the mother of three, she began work at Langley, at a salary three times higher than her teaching stipend. After a brief orientation in Vaughan's computing group, Goble (her first married name) was assigned to the Flight Research Division, where she earned a permanent position in the maneuver Loads Branch. Her first piece of work had important real-life implications: her reduction of data from the flight recorder of a plane involved in an accident "led to changes in air traffic regulations, mandating minimum distances between flight paths" (*Hidden Figures*, 128) to prevent accidents caused by wake turbulence as one plane flew perpendicularly across the path of a jet that had recently passed through. In 1958, the focus of her work at NASA shifted to spacecraft trajectories. She became coauthor of the research report that described the orbital flight for Project Mercury—the first US man-in-space program. The report, published in fall 1960, was the first Langley Flight Research Division publication signed by a woman, Katherine Johnson (she had remarried in 1959 following her first husband's death in late 1956). She became a household name at Langley as a result of her subsequent work checking the numbers generated by the IBM computer for John Glenn's orbital trajectory in February 1962. Like other early astronauts, Glenn

trusted the electronic machines' output less than he trusted the engineers and the "girls" who checked the engineers' computations. Between 1963 and 1969, Johnson collaborated on four reports, one of which earned her additional fame following the Apollo 13 crisis in 1971 when the spacecraft's electrical system failed. Johnson retired from Langley in 1986 after 33 years. In 2015, President Obama awarded her the Presidential Medal of Freedom.

The youngest of the three protagonists of book and film, Mary Winston Jackson (1921–2005), joined Vaughan's computing group in spring 1951. Two years later, following a racially inspired indignity related to her search for the women's room, she talked her way into an assignment at the Compressibility Division: to work through the calculations relating to the compression of air molecules characteristic of supersonic flight. She proved her skill and her mettle by demonstrating to the chief of the division that his complaint about the accuracy of her results was based not on *her* error but rather on *his* giving her the wrong numbers. In 1958, she and her boss coauthored an important paper on "Effects on Nose Angle and Mach Number on Transition Cones at Supersonic Speeds." Her boss's subsequent recommendation that she enroll in Langley's engineer-training program put her on the engineering track. She subsequently earned an Apollo Team Achievement Award for her tests of the Apollo capsule and other components at the Four-by-Four-Foot Supersonic Pressure Tunnel. In 1979, realizing that the likelihood of being promoted as an engineer was unlikely, she made a dramatic career change, giving up engineering for a managerial position at Langley's Federal Women's Program. In that position, though it entailed a demotion, she was able, through her retirement in 1985, to help a younger generation of NASA women mathematicians, engineers, and scientists.

In addition to bringing to our attention the achievements of not only these three women but of many others, Shetterly also shares some fascinating sociological insights and some interesting but little-known facts. A single example of each should encourage readers of this review to pick up *Hidden Figures*. Shetterly makes much of the connection between America's identity crisis following the Soviet launch of Sputnik in October 1957 and its deprivation of quality education to a large segment of the US population. She quotes an editorial in *The Cleveland Call and Post*: "Who can say that it was not the institution of the Jim Crow School that has deprived this nation of the black scientist who might have solved the technological kinks delaying our satellite launching?" (*Hidden Figures*, 152). Sticking with the sense of American inadequacy that followed the USSR's success, I was fascinated to learn that a "secret 1946 RAND Corporation proposal to the US Air Force" suggested that it behooved America to build and launch a "world circulating satellite," along with this warning: "One can imagine the consternation and admiration that would be felt here if the United States were to discover suddenly that some other nation had already put up a successful satellite" (*Hidden Figures*, 161).

Let me conclude this favorable review of both books by returning to the beloved children's toy LEGO®. In March 2017, *The Washington Post* ran an article announcing that the company was planning to release soon "A Lego set that celebrates the contributions of NASA's female pioneers." Though the final design of the set was not yet available, it promised to include figurines not only of Sally Ride, the first American woman to go into space, but also of Katherine Johnson!

Now that Shetterly has brought to light the careers of the first African-American women at NASA, parents have the opportunity to train their children from an early age that "Ladies rock outer space!"—regardless of their racial background—as the Lego Ideas page asserts.