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Heber Doust Curtis And The Island Universe Theory

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Heber Doust Curtis and the Island Universe Theory

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ABSTRACT

The beginning of the twentieth century was a time a great change and development within American astronomy. The period is rife with astronomers, both men and women, who advanced the discipline. However, few historians have looked at the lives of these astronomers. When an astronomer is chosen for closer study, they tend to be one who contributed to the astronomical discipline with a significant discovery. Unfortunately, those astronomers whose careers did not climax with discovery have a tendency to be forgotten by historians, even though their lives and research have affected our modern understanding. This thesis looks at one such astronomer named Heber Doust Curtis. Curtis did not make a grand discovery in the cosmos, but he combined his research with the research and observations of other astronomers to fundamentally change our understanding of the scale of the universe.

To understand Curtis' significance, the author looked at his published scientific papers and the papers of other astronomers from the era. This was done to see how Curtis' research fit into other research being done at the beginning of the twentieth century. Also important in this study was the writing of contemporary authors who looked back on this period as a time of discovery, especially in shaping our understanding of the shape and extent of the cosmos. These elements combined show a rounded perspective of Curtis, during an epoch of great and significant astronomical discovery.

These sources show Curtis' importance as one of the main driving forces behind a modern return to the Island Universe theory, the belief that the Milky Way was not the

only galaxy but one of many within the universe. Curtis' tenacious support of this idea would fundamentally change our understanding of the shape and scale of the universe. For this reason, he is one of the most important American astronomers of the early twentieth century.

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TABLE OF CONTENTS

INTRODUCTION

One of the first things that astronomers tried to quantify was the place of the Earth and humanity within space. First, by the end of the second century most believed that the Earth resided at the center of the system, with everything else moving around it. Next, by the mid sixteenth century astronomers found that the sun, not the Earth, was at the center of the solar system; however they still believed that everything moved around that one center point, the sun. Eventually, by the late eighteenth century astronomers found that the solar system was part of a larger body, the Milky Way galaxy. For a time, from the Milky Way‟s discovery in the late eighteenth century through the beginning of the twentieth century, astronomers believed the scale of the universe was limited to the size of the galaxy, but by the beginning of the twentieth century astronomers began to find evidence the universe was actually much larger than previously believed. One astronomer who contributed to this mounting evidence with his observation and photography of the spiral nebulae was Heber Doust Curtis. Curtis‟ research led him to become the strongest proponent of the Island Universe theory, the belief that the Milky Way was just one of many galaxies within the universe. From 1910 to 1920, he contributed more to the establishment and defense of the Island Universe theory than any other astronomer.

This study begins with a brief look at American astronomy from its nascence to the beginning of the twentieth century. As the discipline grew it developed two distinctive sides, an amateur and professional aspect, which worked closely together gathering and interpreting data. The closeness of these two camps allowed crossover, as individuals who began as amateur astronomers could go on to become professionals through observational work and education. Curtis was part of this transition. Despite the fact that Curtis‟ education trained him as a linguist, he was able to make the move to astronomy after he took a university job in California teaching mathematics and astronomy. As he worked he gained experience with different observing techniques, the most important being the use of spectroscopy. Curtis honed his skills further by making spectrographic observation of stars in the Southern Hemisphere from Santiago, Chile. Upon his return to California, Curtis would begin the most important research of his career as he began to take spectrographic measurements of nebulae. During this period, from about 1910 to 1920, his data and the data of other astronomers led Curtis to conclude that the Island Universe theory explained the true structure of the universe. As he gathered more information, Curtis believed more and more that the Island Universe theory was correct, until he stood almost completely alone in his adherence to the theory.

The recent historiography within the history of American physics and astronomy trends in two directions. The first looks at the life of an important astronomer whose life, research, and discoveries correctly expanded our understanding of the discipline. The second picks a topic or idea within astronomy or physics and looks at the process that developed it. For example, Gale Christianson wrote an excellent book in the first style of historiography on the life of Edwin Hubble, the man who proved there were other galaxies beyond the Milky Way, titled *Edwin Hubble: Mariner of the Nebulae.*[1] Donald Osterbrock, an astronomer and historian of astronomy, used the same style when he

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[1] Gale Christianson, *Edwin Hubble: Mariner of the Nebulae* (New York: Farrar, Straus and Giroux, 1995).

documented the life of James Keeler in his work, *James E. Keeler: Pioneer American Astrophysicist.*[2] An example of the second type of historiography, David and Matthew Clark, a father and son team, wrote *Measuring the Cosmos: How Scientist Discovered the Dimensions of the Universe,* which looks at how astronomical understanding moved from total ignorance in regard to the scale of the universe to the current, modern understanding.[3] Another wonderful book, again dealing with the second style of historiography, *The Day We Found the Universe* by Marcia Bartusiak, a science writer and adjunct instructor at the Massachusetts Institute of Technology, examines the evolving understanding of the universe, focusing on major discoveries coming out of the 1920s.[4] This thesis bridges these two recent trends of focusing on an astronomer or an idea by studying the life of astronomer Heber Curtis as well as the Island Universe theory, with specific focus on Curtis‟ contribution to the eventual establishment of that theory.

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[2] Donald Osterbrock, *James E. Keeler: Pioneer American Astrophysicist* (Cambridge: Cambridge University Press, 1984).

[3] David H. Clark and Matthew D. Clark, *Measuring the Cosmos: How Scientists Discovered the Dimensions of the Universe* (New Brunswick, NJ: Rutgers University Press, 2004).

[4] Marcia Bartusiak, *The Day We Found the Universe* (New York: Vintage Books, 2009).

CHAPTER ONE

THE RISE OF ASTRONOMY IN AMERICA

Astronomy began in the United States humbly, with most early American astronomers being amateurs who studied the heavens with homemade telescopes from makeshift observatories created on rooftops. John Quincy Adams described early America astronomy as “the earth [revolving] in perpetual darkness to our un-searching eyes,” meaning that the discipline was not advancing, especially when compared to the discoveries made in European during the early years of American astronomy.[1] While these scientific pioneers lacked the skill, influence, and facilities to advance astronomy in America, they did establish a foundation that future astronomers would build upon as they developed the discipline.

Early American astronomy focused primarily on observation, something that amateurs could do as well as professionals. In fact, professional astronomers encouraged amateurs to contribute to the discipline, because if properly stimulated and guided amateurs were able to gather large amounts of data without placing stress on the larger research observatories.[2] However, the decision to include amateurs in the discipline created a hazy separation between the professional and amateur community. One of the ways that professional astronomers attempted to control amateurs was by limiting their research to subjects normally ignored by professional astronomers. Perhaps the best example of this is an amateur astronomer named William T. Olcott, who worked under

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[1] Howard S. Miller, “Astronomical Entrepreneurship in the Gilded Age,” *Astronomical Society of the Pacific Leaflet* no. 479 (May 1969): 1-8, 2.

[2] Marc Rothenberg, “Organization and Control: Professionals and Amateurs in American Astronomy, 1899-1918,” *Social Studies of Science* 11 (1981):305-325, 306.

the direction of Edward Pickering, the director of Harvard Observatory. Olcott worked observing and documenting variable stars, a tedious process that took hours of observation but required no specialized training.[3] This unspoken agreement worked well for both professionals and amateurs, although sometimes professional astronomers felt that amateurs had too much autonomy within the discipline. However, this union proved fruitful and helped astronomy become established in America and allowed professional astronomers to focus on larger issues while amateur astronomers were free to work at their own pace on minor aspects of the discipline.

Much of the information published by early American astronomers, both amateur and profession, dealt with observation astronomy, the systematic cataloging of the position and motion of astronomical objects. Within observation astronomy, two of the more common subjects studied by astronomers were transits and eclipses.[4] Transits and eclipses are the same thing; the only difference is the objects involved. A transit is the movement of one celestial object in front of another. Most transits observed from Earth concern Mercury and/or Venus crossing the face of the sun. However, transits can also entail the satellite of a planet moving across the face of the planet.[5] An eclipse is also a kind of transit, but it involves the Earth, Moon, and Sun. There are two kinds of eclipses, a solar eclipse and a lunar eclipse. A solar eclipse occurs when the moon moves between

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[3] Ibid., 314.

[4] John C. Greene, "Some Aspects of American Astronomy 1750-1815," *Isis* 45 (1954): 339-358, 341. A solar eclipse can happen up to five times a year, while a lunar eclipse normally only occurs twice a year. Transits are rarer because they require that three astronomical bodies line up at precisely the same time. See Ian Ridpath, ed., *The Illustrated Encyclopedia of Astronomy and Space* (New York: Thomas Y. Crowell Company, 1976), 64, 211.

[5] Ibid.

the sun and earth, obscuring the sun�much's light for a portion of the surface of the earth. A lunar eclipse takes place when the moon moves into the shadow of the earth, darkening the face of the moon.[6] Governments and universities, in both America and Europe, would plan extensive trips to observe transits and eclipses all over the world because these observations confirmed the regularity of the movements of celestial objects.[7]

Another observational astronomical phenomenon observed by early American astronomers was the passage of comets, because unlike eclipses the passage of a comet was a rare event happening only a few times a century. The comet of 1759 was important enough that Harvard University offered two special lectures on the subject by John Winthrop, the chair of the department of mathematics and natural philosophy. Winthrop defended Isaac Newton"s theory of comets. In 1680, Newton observed a comet in the fall sky, which disappeared toward the end of the year. Another comet then reappeared at the beginning of 1681. Newton reasoned that these two comets were the same comet and that it disappeared from view when it passed behind the sun. He determined that the comet passed around the sun because it was pulled by an unknown, invisible force which he called gravity.[8] Winthrop then presented an argument by William Whiston, an English theologian, who believed that a comet had caused the Great Flood mentioned in

[6] Ibid., 63-64.

[7] Ibid., 344.

[8] Philip Steele, *Isaac Newton: The Scientist that Changed Everything* (Washington, D.C.: National Geographic Society, 2007), 45. With Newton"s theory on gravitation, a British scientist named Edmond Halley predicted the return of another comet he observed in 1682. He forecast the comet would return sometime in late 1758 or early 1759. Halley"s prediction proved to be correct and in honor of it the comet was named after him. See H.H. Turner, *Halley's Comet: An Evening discourse to the British Association , at Their Meeting at Dublin, on Friday, September 4, 1908* (Oxford: Clarion Press, 1910), 18-19.

the *Bible*.[9] However, by the beginning of the nineteenth century the idea of comets serving as a divine messenger to the people of earth began to subside. Jedidiah Morse, an American geographer, observed in his publication *The American Universal Geography* that "modern astronomy shows the terror and dismay, which comets once occasioned to have been groundless . . . [and further] discoveries in this part of astronomy will lessen the probability of danger, or increase that of safety," demonstrating that science was moving beyond the old superstition brought on by comets.[10] By the beginning of the nineteenth century European astronomers were observing comets as celestial objects and using Newtonian physics to calculate their orbit, however in America, astronomers had yet to arrive at the same point within the discipline.

While astronomy in America struggled to move beyond simple observation, the European continent was enjoying its astronomical zenith.[11] National observatories existed in Paris, France and Greenwich, Great Britain from the 1670‟s. These were professional observatories staffed by astronomers trained at European universities and financed by each country‟s government. About one hundred years later, in 1773, the first university observatory in Britain was constructed at Oxford.[12] By comparison, Williams

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[9] Greene, "Some Aspects of American Astronomy 1750-1815," 345. Religion still played a significant part in science in late eighteenth century America, especially in regard to comets, which were viewed as a divine messenger.

[10] Jedidiah Morse, *The American Universal Geography: or A View of the Present State of All the Kingdoms, States, and Colonies in the Known World* (Boston: Lincoln & Edmands, 1819), 32-33.

[11] Stephen G. Brush, "The Rise of Astronomy in America," *American Studies* 31 (1974): 41-67, 45.

[12] Ridpath, *Encyclopedia of Astronomy*, 145.

College in Massachusetts constructed the first university observatory in the United States in 1838, a full sixty-five years after the observatory at Oxford.[13]

The European countries at the forefront of the discipline were Germany, Great Britain, and France. At one point or another over the course of the nineteenth century, astronomers from all three counties made important contributions to the advancement of astronomy.[14] For example in 1838, a German mathematician and astronomer named Friedrich Bessel used stellar parallax to measure the distance to the star 61 Cygni in the constellation Cygnus the swan.[15] About a decade later in 1846, a French mathematician named Urbain Le Verrier noticed that Uranus"s actual orbit was slightly different than its predicted orbit. He calculated that another planet, more distant from the sun than Uranus, could cause the disturbances noticed in Uranus"s orbit. Verrier requested that Johann Galle at the Berlin Observatory look for the new planet. On September 23, 1846, Galle observed and cataloged a new planet beyond the orbit of Uranus, near Verrier"s calculated location, that would be named Neptune.[16]

As Europeans made new discoveries, a handful of Americans also worked to advance astronomy in the United States. These men began to bridge the gap between amateurism and professionalism in American astronomy. First, Alvan Clark, along with

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[13] Miller, "Astronomical Entrepreneurship in the Guilded Age," 2.

[14] Brush, "The Rise of Astronomy in America," 45.

[15] Ibid., 46. Stellar parallax is the apparent shift of a star when it is observed from different positions along the earth"s orbit, like how one"s finger shifts position when held at arm"s length and viewed with alternating eyes. Parallax can be used to measure the distance to stars that close to the Earth in a cosmic scale. See Ridpath, *Encyclopedia of Astronomy*, 149.

[16] Ibid., 141.

his son Alvan Graham Clark, began making high quality optical glass. Their glass became world renowned as observatories and amateur astronomers alike requested telescopes made by the Clarks. Astronomers would use their telescopes in many of the discoveries that drove American astronomy in the late nineteenth and early twentieth centuries. Alvan Graham Clark also discovered the first white dwarf while testing an eighteen and a half inch telescope objective that he and his father produced for Northwestern University in Illinois.[17]

Perhaps the most important figure in early American astronomy was John William Draper. Draper took the first photograph of a celestial object in 1840 when he used an exposure of several minutes to capture an image of the moon.[18] He was also one of the earliest astronomers to begin to work with spectrography, which would become one of the most important advances in astronomy as it allowed astronomers finally to understand the structural makeup of the cosmic phenomenon they were seeing. Another American involved with spectrography was Lewis Morris Rutherfurd. He found a technique to image the spectra of the sun and other stars that revealed Fraunhofer lines more clearly than an ordinary spectroscope could.[19] Fraunhofer lines, named for Joseph Fraunhofer who discovered them in the spectrum of the sun in 1814, are the lines visible

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[17] Brush, "The Rise of Astronomy in America," 49. A white dwarf represents the final stage in stellar evolution. After a star has used most of its fuel it will move to the red giant phase. Once fusion is no longer possible in the red giant star, it will slough off the outer layers of gas leaving only its small, massive core behind. That core is a white dwarf. See. Ridpath, *The Illustrated Encyclopedia of Astronomy and Space,* 228.

[18] Ridpath, *Encyclopedia of Astronomy*, 23.

[19] Ibid., 50.

in the spectra of an object.[20] Fraunhofer lines represent a specific wavelength radiated by different chemicals in the object. Fraunhofer lines come in two different varieties. The first are called emission lines; these are a set of lines that stand out brightly against the background spectrum. Normally gaseous nebulae demonstrate an emission spectra. The second kind of spectra line is an absorption line spectra. Absorption lines are dark bands that appear across a constant spectrum, like emission lines they represent elements present in the object. A great deal of other information can be found with the spectral lines of an object. The abundance of an element can be determined by the strength and weakness of lines in the spectra. Temperature and pressure can also be found with a spectrum. Finally, in a star the strength and nature its magnetic field can also be determined from a spectrum.[21] The development of spectrography brought about the rise of astrophysics and allowed scientists to understand intimately the composition of celestial objects.

Another difficulty within American astronomy was its dependence on European journals as a place to publish ideas and breakthroughs. The European monopoly on astronomical journals ensured that European astronomers would be the first to read and confirm or deny any American discoveries, while American astronomers had to wait for European publications to arrive in America. This changed in 1771 when the American Philosophical Society began to publish a journal called *Transactions*.[22] The American

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[20] Each element has its own distinct set of spectra lines. Astronomers can then use the spectra lines to reveal the chemical composition of stars and nebulae. See Ridpath, *Encyclopedia of Astronomy*, 192.

[21] Ibid.

[22] Greene, “Some Aspects of American Astronomy 1750-1815,” 341.

Philosophical Society (APS) was the largest scientific society in the United States until the mid-nineteenth century and worked primary in the Philadelphia, Pennsylvania area.[23] The APS did little to help the development of astronomy in America besides publishing the first American astronomical journal; however, this was not for lack of effort. For a time the society tried to build an observatory in the Philadelphia area. Unfortunately, the APS was never successful. Financial problems and lack of support from the city government both kept the society from achieving its goal.[24] A local publication was all the APS would accomplish, allowing more Americans to publish their findings and ideas in a journal that could be read by other Americans.

The year 1877 marked a significant turning point in American astronomy. That year Mars was at its opposition.[25] Opposition happens when a planet appears at the opposite of the sun in the night sky. When a planet is at opposition it is the best time to observe a planet because it is at its closest to earth.[26] In 1877, the opposition of Mars allowed for two important discoveries. The first was Asaph Hall‟s discovery of Mars‟ two tiny moons, Phobos and Deimos, using a twenty-six inch telescope constructed by the Clarks at the Naval Observatory in Washington D.C. Hall‟s finding was important because Phobos, the closest moon, orbits Mars faster than the planet rotates. This

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[23] Walter E. Gross, "The American Philosophical Society and the Rise of Astronomy in the United States in the Middle of the Nineteenth Century," *Annals of Science* 31 (1974): 407-427, 407.

[24] Ibid., 409-411.

[25] Brush, "The Rise of Astronomy in America," 51.

[26] Ridpath, *Encyclopedia of Astronomy*, 147.

discovery ran contrary to the accepted theory of how the solar system developed.[27] At that time most scientists believed the solar system formed from a giant nebula of gas. The Nebular Hypothesis described how gas from the nebula coalesced to form the planets. However, the theory required that the moons of the planets move more slowly than the planet rotated.[28] Hall‟s discovery that Phobos orbited Mars faster than Mars itself rotated was the first of many attacks on the Nebular Hypothesis and one of the first major discoveries by an American astronomer.

The second discovery, and most important in the scope of American astronomy, was Giovanni Schiaparelli‟s discovery of channels on Mars. As Schiaparelli examined Mars at its opposition, he found channels that appeared to be caused by flowing water. He called these features *canali*, though when the press heard of the discovery they mistranslated Schiaparelli‟s *canali* as canals. The press also speculated that the canals were constructed by intelligent beings.[29] A wealthy businessman and amateur astronomer, Percival Lowell, seized on this idea and created much of the speculation that there was life on Mars. Lowell‟s fascination with Mars led him to the publication of works like *Mars and Its Canals* in 1906 and *Mars as the Abode of Life* in 1908. In these works Lowell hypothesized that the inhabitants of Mars were forced to construct the canals to move water from the poles to the equator to irrigate their crops on the arid

[27] Brush, "The Rise of Astronomy in America," 51.

[28] Jack J. Lissauer, "Planet Formation," *Annual Review of Astronomy and Astrophysics* Vol. 31 (1993): 129-174, 137-138.

[29] Brush, "The Rise of Astronomy in America," 51.

planet.[30] The excitement that Lowell created with his never-ending drive to prove the habitation of Mars was his lasting legacy.[31]

In the years, following 1877 and Mars" opposition there began to be a new collaboration between astronomers and wealthy patrons with an interest in the sciences. These patrons allowed for new, more elaborate observatories to be constructed away from population centers, where atmospheric conditions favored observation. Lick Observatory became the first major observatory built with the help of a donor. It was constructed on Mount Hamilton, just outside of San Jose, California in 1888 through the patronage of James Lick.[32] In 1894 Lowell built his own observatory at Flagstaff, Arizona. He was one of the first astronomers to believe that observatories needed to be constructed in locations away from the pollution, both light and industrial, of major population centers, which sometimes obscured stars and made observation difficult. Although the observatory was constructed to prove Lowell"s ideas in regard to life on Mars, it served as a place where other discoveries were made, specifically the discovery of Pluto in 1930.[33] Another driving force behind the construction of observatories was George Ellery Hale. In 1897, he found a patron in Charles Yerkes who allowed him to construct Yerkes Observatory for the University of Chicago. The observatory was built

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[30] Ridpath, *Encyclopedia of Astronomy*, 112.

[31] Brush, "The Rise of Astronomy in America," 51.

[32] Lick originally wanted to construct a pyramid as his lasting legacy to the world. Thankfully, Professor George Davidson of the College of the Pacific convinced Lick that a more lasting monument would be to donate money to construct a major research observatory with a telescope. See William Cary Jones, *Illustrated History of The University of California* (San Francisco: Frank H Dukesmith, 1895), 226.

[33] Brush, "The Rise of Astronomy in America," 52.

at Williams Bay, Wisconsin, far away from the light pollution of Chicago. The observatory opened with the world‟s largest refractor, a massive forty-inch telescope.[34] Hale soon settled on plans for a larger telescope in a better location. In 1896, his wealthy father, William Hale, offered him a sixty-inch reflector telescope. Hale spent most of the next decade trying to find another patron who would help him build an observatory for the telescope on Mount Wilson, just outside Los Angeles, California. Finally, in 1904 he secured funding from the Carnegie Institution of Washington and began construction of Mount Wilson Solar Observatory.[35] In the beginning of the twentieth century, a Los Angeles businessman named John Hooker donated forty-five thousand dollars to the Mount Wilson Observatory for the construction of a telescope. The observatory used the donation to construct a massive one-hundred-inch reflector telescope, which opened for use in 1917.[36] The Hooker telescope was the primary telescope used by the astronomers of Mount Wilson. Astronomers like Edwin Hubble, Harlow Shapely, Walter Adams, and Adriaan van Maanen used the one-hundred-inch telescope for their most important discoveries.[37]

While larger, more advanced observatories sprang up all over the world, Lick Observatory, the observatory that started the telescope race, continued to make scientific progress and headlines. It would become one of the most important observatories in America and would serve as the research location for most of Curtis‟ important

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[34] Ridpath, *Encyclopedia of Astronomy*, 231.

[35] Miller, "Astronomical Entrepreneurship in the Guilded Age," 6-7.

[36] Ridpath, *Encyclopedia of Astronomy*, 86.

[37] Gale Christianson, *Edwin Hubble: Mariner of the Nebulae* (New York: Farrar, Straus and Giroux, 1995), 134.

observations and discoveries. The individual responsible for the Lick Observatory, James Lick, started out as a piano and organ maker from Pennsylvania. He moved to California during the Gold Rush of 1849 and made his fortune through land speculation. Toward the end of his life, Lick decided that he wanted to construct a monument for himself. His first plan was to build a pyramid grander than the great pyramid at Cheops.[38] Fortunately, George Davidson, the President of the California Academy of Sciences, convinced Lick that a magnificent observatory would be a better monument to his life. Davidson and other scientists, including Joseph Henry of the Smithsonian Institution, persuaded Lick to donate enough for the construction of an observatory and a thirty-six inch refractor telescope, the largest of its kind in the world.[39] The site chosen for the observatory was a peak called Mount Hamilton, in the Diablo mountain range, just east of San Jose, California, although a site on the edge of Lake Tahoe was considered for a time.[40]

From its completion in 1888 until about 1930 Lick Observatory was a major and extremely productive research institution. The observatory had the largest refracting telescope in the world for the first five years of its existence; however the Great Lick telescope remained relevant decades into the twentieth century because of the observatory‟s location.[41] Competent astronomers staffed the observatory from the beginning. The first director of the observatory was Edward Holden. A West Point

[38] Brush, "The Rise of Astronomy in America," 52.

[39] Miller, "Astronomical Entrepreneurship in the Guilded Age," 3.

[40] Jones, *University of California*, 226.

[41] Ibid., 231.

graduate trained as an engineer, Holden had little experience with astronomy.[42] However, he succeeded in impressing Simon Newcomb, the United States‟ most famous astronomer, with his energy and work ethic while he worked with Newcomb at the Naval Observatory. In 1885, Holden became the director at Lick Observatory. He was an arrogant, self-important director; however, he had a knack for finding young talented astronomers who helped establish the observatory as an important scientific institution through major discoveries.[43] For example, Edward Barnard, whose specialty was photography, took the first photograph of the Milky Way and discovered the fifth of Jupiter‟s moons while working at the observatory.[44] Another, John Schaeberle, developed a solar telescope to study the sun‟s corona and an early, important theory of how the sun‟s corona functioned.[45] These young astronomers pushed the Lick Observatory to the forefront of astronomical discovery at the beginning of the twentieth century, making the observatory one of the most important in the world. The observatory‟s prominence within the astronomical community would prove fortunate for Heber Curtis as he began his shift from linguistics to astronomy at the turn of the century.

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[42] Ibid., 233.

[43] Marcia Bartusiak, *The Day We Found the Universe* (New York: Vintage Books, 2009), 12.

[44] Jones, *University of California*, 238-240.

[45] Schaeberle‟s theory said that the corona is generated by light reflecting off the matter ejected by the sun into its atmosphere. Although astronomers disproved his theory, they are still unsure of the mechanism that generates the solar corona. For more on his theory see John Schaeberle, *A Mechanical Theory of the Solar Corona* (Sacramento: A.J. Johnston, 1891).

CHAPTER TWO

CURTIS' TRANSITION TO ASTRONOMY

Heber Doust Curtis came upon astronomy at the beginning of the twentieth century. At that time, the difference between amateur and professional astronomers was still hazy and allowed for some crossover between the two camps. More than any other astronomer, Curtis benefited from the indistinct line between amateur and professional astronomy, as he transitioned from an amateur astronomer to a professional.

Curtis was born in Muskegon, Michigan on June 27, 1872, the eldest son of Orson Blair Curtis and Sarah Eliza Doust.[1] Curtis' father, known as Blair by those close to him, served as a Union soldier during the American Civil War. During the Battle of Fredericksburg, he was wounded and had his left arm amputated. After the war, he earned a Bachelor's degree from the University of Michigan and worked as a school teacher and editor, and finally a United States Customs official.[2] Curtis' mother was a first generation immigrant into the United States. She was born in Maidstone, England to a Methodist clergyman, and her parents brought her to the United States as a child. After immigration, she enrolled at Albion Female Seminary, later Albion College, in Michigan, where she studied English literature and music.[3] The college was an all female

[1] Robert R. McMath, "Heber Doust Curtis," in *The Astrophysical Journal: An International Review of Spectroscopy and Astronomical Physics* 99, no. 3 (April 1942): 245-248, 245.

[2] Robert G. Aitken, "Biographical Memoir of Heber Doust Curtis (1872-1942)," in *National Academy of Sciences of the Unites States of America Biographical Memoirs* 22 (1942): 273-294, 276.

[3] Ibid.

educational institution founded by the Methodist church in 1849.[4]

Curtis‟ early years were similar to that of most boys; he enjoyed many outdoor activities, including his favorite sport, American football. He also developed a keen interest in and understanding of machinery and tools, building a personal lathe before he could afford to buy one.[5] Curtis‟ innate mechanical ability would prove invaluable later in his career when he would use his facility with mechanical things to impress William W. Campbell, the Director of Lick Observatory, on an eclipse expedition to Georgia.[6]

Curtis was a good student and had little difficulty keeping a high rank in his studies through grade and high school. He attended Detroit High School and showed a special aptitude for language. Curtis also studied and excelled at mathematics; however, he showed no interest in the sciences, taking only the science classes required for graduation.[7] Upon graduation he attempted to enter the Naval Academy at Annapolis, Maryland, but he was not tall enough to pass the height requirement.[8] His father wanted him to study religion and prepare for a career in the ministry; however, Curtis preferred to study engineering. They reached a compromise and Curtis entered the University of Michigan in 1889 at the age of seventeen, where he would study classical languages.[9]

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[4] Washington Gardner, *History of Calhoun County, Michigan: A Narrative of its Progress, its Peoples, and its Principal Interests*, vol. 1 (Chicago: The Lewis Publishing Company, 1913), 120.

[5] Aitken, "Heber Doust Curtis," 276.

[6] Ibid., 278.

[7] Ibid., 276.

[8] Dean B. McLaughlin, "Heber Doust Curtis," in *Popular Astronomy* L, no. 4 (April 1942): 175-181, 175.

[9] Ibid.

While at the University of Michigan, Curtis continued to show an amazing aptitude with languages, as he studied Latin, Greek, Hebrew, Sanskrit, and Assyrian.[10] While in college, he also continued to study mathematics but still showed little interest in the physical sciences. He probably never entered the university‟s observatory, a directorship he would eventually hold in forty years.[11] In 1892, he completed his Bachelor‟s degree after only three years of study, graduating Phi Beta Kappa. After graduation, Curtis entered graduate school at the University of Michigan, continuing to study classical languages. He earned his Master‟s degree in 1893, after one year of work.[12]

After finishing his graduate work, he worked for a semester teaching Latin at Detroit High School. In 1894, Napa College, a tiny Methodist institution in Napa, California, accepted Curtis as Professor of Latin and Greek.[13] While teaching at Napa, he married Mary D. Rapier in 1895.[14] Curtis‟ time at Napa would also come to shape his future as an astronomer. Napa College had a small observatory that housed a single, small Alvan Clark and Sons refractor.[15] Curtis‟ mechanical nature drew him immediately

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[10] Aitken, "Heber Doust Curtis," 276.

[11] Ibid., 281.

[12] Ibid., 276.

[13] Ibid., 277.

[14] Ibid., 278.

[15] Clark and Sons was the most respected and best known producer of optical glass during the early modern period. See Deborah Jean Warner and Robert B. Ariail, *Alvan Clark & Sons: Artists in Optics* (Richmond: Willmann-Bell, 1995).

to the telescope and he took his first tentative steps into the discipline of astronomy.[16] As he began to use the university‟s telescope, he also started to develop a curiosity about the night sky; in essence Curtis became an amateur astronomer because he was not affiliated with an observatory and did not have a specific program of study. Instead he was free to use the Clark refractory to do his own observing, which proved only to increase his curiosity. It was during this period, early in his astronomical experience, that he was first published in a scientific journal. On February 2, 1896, Curtis wrote a letter to Edward Holden, the Director of the Lick Observatory in San Jose. Curtis and his wife saw a meteor that night, which Curtis described as "moderately bright . . . [moving] in a very slow and leisurely fashion."[17] Holden had the whole letter published in the *Publications of the Astronomical Society of the Pacific*. Curtis would be published many more times in that same journal once he became a professional astronomer.

Curtis continued to teach Latin and Greek at Napa College for two more years. In 1896, Napa College merged with the College of the Pacific, and Curtis moved from Napa to San Jose, California. In San Jose, he continued to teach Latin and Greek while dabbling with the school‟s telescope. The observatory at the College of the Pacific was slightly more advanced than the one at Napa College. Instead of a small refractor, a six-inch Clark Refractor and a Coast Survey transit instrument were accessible to Curtis.[18] Astronomers used transit instruments to track precisely the movement of stars and other

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[16] Aitken, "Heber Doust Curtis," 277.

[17] Heber D. Curtis, "Bright Meteor Observed at Napa, February 2, 1896," in *Publications of the Astronomical Society of the Pacific* 8, no. 47 (April 1896): 86.

[18] Aitken, "Heber Doust Curtis," 277.

astronomical objects.[19] The addition of a transit instrument to the telescope with which Curtis worked marked a change in his methodology. He transitioned from an amateur astronomer simply playing with a telescope to an amateur astronomer with the ability to study closely and document the heavens.

He continued to teach Latin and Greek until 1897, when the school‟s Mathematics and Astronomy professorship opened. On a whim, Curtis applied for the position and was accepted.[20] When he began teaching math and astronomy in the fall of 1897, his only background in the subject of astronomy was the reading and observation he made on his own. Curtis called this change, from teaching classical languages to math and astronomy, "the switch."[21] The new position excited Curtis and forced him to stay "one jump ahead of the class."[22] Curtis augmented his own personal reading and observation with volunteer work at the Lick Observatory, which was just east of San Jose in the Diablo Mountain range.

While volunteering at Lick Observatory, Edward Holden, the Director of Lick Observatory, asked Curtis to test and report on a four-inch Faust transit instrument,

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[19] William Chauvenet, *A Manual of Spherical and Practical Astronomy: Embracing the General Problems of Spherical Astronomy, the Special Applications to Nautical Astronomy, and the Theory and Use of Fixed and Portable Astronomical Instrument*, vol. 2, *Theory and Use of Astronomical Instruments* (Philadelphia, J. B. Lippincott & Co., 1864), 131, 138-139.

[20] McLaughlin, "Heber Doust Curtis," 176.

[21] Aitken, "Heber Doust Curtis," 277.

[22] McMath, "Heber Doust Curtis," 245. Both transit instruments and zenith telescopes were used to determine precisely the location of objects in the sky. However, zenith telescopes were used to observe and measure objects straight up or at the zenith of the telescope, while transit instruments could be used to make measurements of all objects in the sky. For more information on transit instruments and zenith telescopes see Latimer Clark, *A Treatise on the Transit Instrument as Applied to the Determination of Time* (London: Latimer Clark, 1882) and William Chauvenet, *Theory and Use of Astronomical Instruments,* 366.

specifically by determining its value as a zenith telescope used to find latitude.[23] Testing of such instruments was something that was occasionally asked of amateur astronomers working with major observatories, because it was believed that professional astronomers lacked the time to do such testing themselves. Curtis responded positively to this request and tested the transit instrument exhaustively, taking one hundred and sixteen measurements. His final conclusion was that the instrument was ill-suited for use as a zenith telescope for calculating latitude because it was inaccurate and not constructed for that use.[24]

Curtis also continued his own observations at the College of the Pacific. On March 4, 1898 at almost 10:00 P.M. Pacific Time he observed a small meteor shower. The brightest of the meteors passed through the constellation *Bootes,* moving between the stars Nekkar and Izar, before abruptly veering to the south. He watched a handful of other meteors pass along almost the same track during the night.[25] In the fall of that year, Curtis and a student named Norman Titus, spent a few nights observing the Leonid meteor shower. On the first night, November 12, they observed seventy-five meteors. Those numbers dropped slowly until cloud cover on November 14 and 15 made it impossible for observations to be made. However, Curtis considered his observations successful, especially on the first night when he observed on average eighteen to twenty

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[23] Heber D. Curtis, "Latitude Work with the Fauth Transit Instrument of the Lick Observatory," in *Publications of the Astronomical Society of the Pacific* 10, no. 51 (April 1898): 67-69, 67.

[24] Ibid., 69.

[25] Heber D. Curtis, "Very Bright Meteor, March 4, 1898," in *Publications of the Astronomical Society of the Pacific* 10, no. 61 (April 1898): 79.

meteors per hour.[26] These observations allowed Curtis to gain more experience within the astronomical discipline and built his confidence as an amateur astronomer.

Curtis was also encouraged in his work by Director Holden. Finally, after a couple years of work Curtis decided to return to school and get a Ph.D. in astronomy. In 1900, he applied to the University of Virginia and was accepted in the astronomy program, receiving the Vanderbilt Fellowship to pursue his degree.[27] His time in Virginia proved valuable beyond gaining a Ph.D. in his new discipline. While there, Curtis was able to attend two eclipse expeditions, giving him more valuable experience and paving the way for his return to California and Lick Observatory.

Astronomers undertook eclipse expeditions to study the physical structure of the nearest star to Earth. They hoped that in studying the sun they could learn important information on the nature of stars and stellar evolution; however, it was only during a solar eclipse that the solar atmosphere and corona could be imaged and studied. Astronomers were also searching for planets inside the orbit of Mercury, and the best time to look for those planets was during a complete solar eclipse.[28] The first eclipse expedition happened in 1715, when French astronomer Joseph Liouville travelled from Paris to London to view an eclipse.[29] However, the eclipse expedition did not become a major part of scientific research until the 1842. That year European astronomers and

[26] Heber D. Curtis, "The *Leonids* in 1898," in *Publications of the Astronomical Society of the Pacific* 10, no. 65 (December 1898): 242.

[27] McLaughlin, "Heber Doust Curtis," 176. In earning his Ph.D. in astronomy Curtis moved from amateur to professional astronomer within the larger astronomical community.

[28] John Lankford, ed., *History of Astronomy: An Encyclopedia* (London: Routledge, 1997), 199.

[29] J. L. Heilbron, ed., *The Oxford Companion to the History of Modern Science* (Oxford: Oxford University Press, Inc., 2003), 228.

amateurs travelled to southern France and northern Italy to view a total eclipse, marking the first eclipse that astronomers travelled as a group to witness.[30] Before this eclipse most astronomers viewed an eclipse only if it happened to occur within their own countries.

Two developed changed the way astronomers approached solar eclipses. First, in the 1860s scientists began to develop and then use new technologies like photography and spectroscopy to study the sun during eclipses.[31] Finally, in the 1890s astronomers developed new solar telescopes, which were much larger and more complex but also produced more data. This marked the end of amateur participation in the eclipse expeditions, as they were increasingly marginalized by the complexity of the equipment.[32]

European imperialism paved the way for eclipse expeditions. As European countries expanded their influence looking for new and better supplies of resources, they created friendly locations in foreign countries where astronomers could go and still be close to their own culture.[33] As they planned locations for their observations, astronomers would chart the path of totality and then look for towns along that path that were accessible by rail.[34] Railroad accessibility was important for two reasons. First, it allowed astronomers to move their increasingly heavy and complicated equipment more

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[30] Ibid., 229.

[31] Lankford, *History of Astronomy*, 199.

[32] Ibid., 200.

[33] Alex Soojung-Kim Pang, "The Social Event of the Season: Solar Expeditions and Victorian Culture," *Isis* 84, no. 2 (June 1993): 252-277, 255.

[34] The path of totality is the path which the moon"s shadow follows during an eclipse.

easily; and second, it ensured that they were never too far away from help if it was required.[35] For example, the Lick Observatory Crocker Eclipse Expedition traveled to central India in 1898 where they set up their camp and temporary observatory beside a railroad station. Later, in 1901, they went to Sumatra and located themselves beside a racetrack.[36]

While at the University of Virginia, Curtis participated in his first eclipse expedition with the Lick Observatory to Thomaston, Georgia. However, this expedition was not the first time that astronomers from Lick Observatory had undertaken an eclipse expedition. In 1889, Lick astronomers went to Bartlett Springs, California to view an eclipse.[37] Later that year, they wanted to travel to French Guiana to observe an eclipse, but lacked the funding for the trip. To gain financial support, they petitioned Charles F. Crocker, a local businessman and vice-president of the Southern Pacific Railroad, for financial assistance.[38] Crocker agreed to patronize all further Lick Observatory eclipse expeditions, and to honor him all subsequent solar eclipse expeditions funded by him were called Crocker Eclipse Expeditions. Unfortunately, Crocker died in 1897 after funding only three expeditions, one to French Guiana in 1889, one to Japan in 1896, and finally one to India in 1898. Charles‟ brother, William H. Crocker, a wealthy San

[35] Ibid., 259. Telegraph lines ran parallel to the railroad track, allowing astronomers to be in communication with their home observatories or the authorities if it was required.

[36] Ibid., 260. The astronomers chose a racetrack because it was close to both a rail line and a major town. The location also had a large open area near the complex, which allowed astronomers a location to set up their instruments without being a large distance from civilization.

[37] James Charles Pearson, "The Role of the 40 Foot Schaeberle Camera in the Lick Observatory Investigations of the Solar Corona," (Ph.D. diss., James Cook University, AU, 2009), 79.

[38] In 1888, Crocker‟s father died, leaving him with an estate worth an estimated twenty-five million dollars. "C.F. Crocker Dead: Vice President of the Southern Pacific Railway Expirers in San Mateo, California," *The New York Times*, July 18, 1897.

Francisco banker, took his brother‟s place as benefactor of Lick Observatory eclipse expeditions, allowing the observatory to continue calling them Crocker Eclipse Expeditions.[39]

Planning for the Crocker expedition to Georgia began in March 1900, just two months before the eclipse. This busied the entire staff of the observatory in preparing the necessary equipment for the expedition. The staff from Lick could have picked any place from Mexico to southeast Egypt, as those were locations along the eclipse path of totality. However, they settled on western Georgia as their primary choice after consulting with the Weather Bureau and discovering that eastern Alabama and western Georgia were areas with the best chance of being cloud free on the date of the eclipse.[40] The astronomers participating in the expedition left from San Francisco for Thomaston, Georgia on April 24 and they arrived on April 30, with Curtis meeting the rest of the staff in Georgia.[41] The next day, May 1, the mayor took the astronomers on a tour of the countryside looking for a suitable site for their camp. Finally the astronomers chose an open field about a half-mile to the northwest of the city, but still within city limits, as the location for the expedition‟s camp and observation site.[42]

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[39] William H. Crocker also donated money to construct a building that would house the University of California‟s Radiation Laboratory at Berkeley. Ernest O. Lawrence, "Initial Performance of the 60-inch Cyclotron of the William H. Crocker Radiation Laboratory, University of California," in *Physical Review* 56, no. 124 (June 1939): 1-2. Campbell discusses William Crocker‟s contribution in William W. Campbell and Charles D. Perrine, "The Crocker Expedition to Observe the Total Solar Eclipse of May 28, 1900," in *Publications of the Astronomical Society of the Pacific* 12, no. 75(October 1900): 175-184, 175.

[40] Campbell and Perrine, "The Crocker Eclipse Expedition," 176.

[41]Ibid.

[42] Ibid.

With a site chosen for their camp, preparation began at once for the structures that would be required for their temporary solar observatory. The astronomers used local help for most of the manual labor required to set up their camp, as the astronomers themselves were involved in preparing, mounting, and adjusting their equipment and instruments. They set up two polar mounts by building two-foot brick piers, onto which were attached a collection of solar telescopes and cameras.[43] Local laborers built a complete and complex darkroom, which would be used to develop photographs taken by the astronomers.[44] The final instrument they set up was their most important, a forty-foot solar telescope specially designed by an astronomer who worked at Lick Observatory named John Schaeberle.[45] He developed the telescope in 1895, with a camera to image directly the corona of the sun during an eclipse. The length of the telescope was important because it limited image degradation, a loss of photo quality, caused by heat expansion. It also fixed the telescope in place, eliminating the need for a drive mechanism to follow the course of the sun during the eclipse. The removal of the drive mechanism and the rigid mount, to which the telescope was affixed, virtually eliminated any vibration that could also potentially degrade the quality of the images returned by the telescope.[46] Schaeberle"s design worked so well that it was used by the Lick Observatory until 1923.[47]

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[43] Ibid., 177.

[44] Pearson, "The Role of the 40 Foot Schaeberle Camera," 104.

[45] John Charles Pearson, "The 40-Foot Solar Eclipse Camera of the Lick Observatory," *Journal of Astronomical History and Heritage* 11 (2008): 25-37, 25.

[46] Ibid., 27.

Next, they made sextant observations of the sun and stars used to determine the latitude and longitude of their observation site. To calculate this information they needed the most accurate reading of time they could get. Fortunately, Thomaston was situated at the end of the Central of Georgia Railway and they were able to have the Western Union Telegraph Company transmit signals from the clock of the U.S. Naval Observatory in Washington, D.C. Over the course of six days, with accurate time and sextant readings of the sun and stars daily, they determined their campsite was at latitude thirty-two degrees and fifty-three minutes and longitude eighty-four degrees and nineteen minutes.[48] Knowledge of the proper latitude and longitude allowed the astronomers to calibrate their instruments accurately in relation to the upcoming eclipse.

For three days the astronomers practiced until they were confident with the observation program and prepared for the role each person would play in it, on the day of the eclipse they would have only eighty-five seconds totality and any small mistake could ruin all the expedition‟s results.[49] On the day of the eclipse, the astronomers feared there might be some cloud cover that would obscure their view of the eclipse. Fortunately, the eclipse happened just before a bank of clouds moved in and blocked the sun. Campbell observed that "The state of the air had been such that the lowering of its temperature as the eclipse came on was sufficient to form clouds."[50]

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[47] Pearson, "The Role of the 40 Foot Schaeberle Camera," 84.

[48] Campbell and Perrine, "The Crocker Expedition," 177-178.

[49] Ibid., 178.

[50] Ibid., 179.

After the eclipse, the astronomers used the darkroom they constructed to develop their images. However, the heat kept the astronomers from developing photos during the day. The only time they could use the darkroom was at night, and even then only after the room had been cooled with ice, and so the development of the images captured during the eclipse was undertaken in the hours between dusk and daylight. All that effort returned a collection of beautiful and valuable photographs of the eclipse, solar provenances, and the corona.[51]

Through all this, Curtis assisted the astronomers from Lick Observatory. His help was so appreciated that Campbell made special mention of Curtis and his work in the paper that he prepared for the journal, *Publications of the Astronomical Society of the Pacific*. Campbell specifically mentions Curtis‟ help in the final installation of the instruments and gave him direction over one of the polar mounts carrying six cameras. Campbell finishes by saying, "We do not see how we could have dispensed with his services, nor how any one [sic] could have met the exacting demands better than he did."[52] Curtis‟ ability, handiness, and resourcefulness in setting up, testing, and using the solar eclipse instruments impressed Campbell so much that he made an assistant astronomer‟s position available to Curtis as soon as the latter finished his Ph.D..[53]

Curtis had another opportunity to attend an eclipse expedition while studying in Virginia. The second was with the U.S. Naval Observatory when they went to Sumatra

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[51] Ibid. These images currently make up part of the Mary Lea Shane archives stored at the Lick Observatory.

[52] Ibid., 183.

[53] Aitken, "Heber Doust Curtis," 278.

in May 1901. The United States Government appropriated a sum of ten thousand dollars to the Naval Observatory for the expedition, and fortunately for the astronomers gave them and their equipment transport from San Francisco to Manila on a converted civilian transport ship called the *Sheridan*. The astronomers rode from Manila to Sumatra on the U.S. Naval gunboat *General Alava*.[54] The trip to Sumatra was much more involved than the trip to Georgia. Curtis and the other astronomers left San Francisco on February 16, 1901,for what would amount to a one-month trip across the Pacific Ocean to Manila. They broke up the monotony of the trip with the help of the crew of the *Sheridan*, who played instruments and sang in two minstrel shows, participated in a tug-of-war, and finally provided from their ranks for two boxing tournaments. On these diversions, Curtis commented that all the "short-comings were condoned in the Mid-Pacific."[55] Upon arriving in Manila the diversions continued, as a man to whom Curtis refers as Consul Williams took the astronomers for a tour of the bay on a government launch craft.[56] Williams had been on the bridge with Admiral George Dewey during the Battle of Manila Bay. With his inside knowledge of the battle, Williams shared many interesting details with the astronomers and pointed out the location where ships in the Spanish navy had been sunk.[57] They then left Manila to begin the next leg of their journey, a distance of about twenty-two hundred miles to Sumatra. They made the trip in

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[54] Heber D. Curtis, "The U.S. Naval Observatory Eclipse Expedition to Sumatra," *Publications of the Astronomical Society of the Pacific* 13, no. 81 (December 1901): 205-213, 205.

[55] Ibid., 206.

[56] Consul Williams was probably Oscar F. Williams, United States Consul to the Philippines during the Spanish-American war; however Curtis makes no mention of his full name or the time period when he served as Consul. "Manila Consul Return," *The New York Times*, December 5, 1899.

[57] Curtis, "The U.S. Naval Eclipse Expedition," 206.

about ten days on the U.S. naval gunboat *General Alava*. Curtis mentions as they passed through the Straits of Sunda, once while going to Sumatra and again when returning, that they passed within one mile of the volcano Krakatau, which had erupted explosively in 1883. In his published paper he notes that some islands still showed damage from that eruption.[58] Curtis mentions these little things, the diversions during the trip and the view of the devastation cause by Krakatau, to try and bring his reader along on the trip and show them that there was more to the expedition then their eclipse observations.

After almost two months of travelling they arrived at Emmahaven, Sumatra. The location chosen for the main camp was a village called Solok, about a thousand feet above sea level. The camp at Solok was not completely ideal in that it was about thirty miles off the centerline of the eclipse. However, they had to camp at Solok because other observatories had claimed all the sites close to civilization, towns, and European outposts, along the centerline of the eclipse. Fortunately, the camp at Solok offered better accommodations than the expedition in Georgia. They needed only to construct mounts and supports for their instruments because they were able to use the fort and its buildings for shelter and storage. The astronomers used the barracks of the fort as a storehouse for their equipment and supplies; it also served as sleeping quarters for some of them. They converted the fort‟s powder magazine into a dark-room, which Curtis claimed functioned excellently.[59] Using the fort‟s structures saved the expedition time, which they then used to prepare and practice for the upcoming eclipse.

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[58] Ibid.

[59] Ibid., 208.

Curtis‟ facility with languages proved useful on this expedition. Even though Sumatra was a Dutch colony, he said the astronomers found the Dutch language to be of little value. Instead he learned Malay, one of the dialects of the natives. The Dutch government did not allow the native islanders to speak Dutch, which forced the astronomers to learn Malay so they could communicate with the natives as they helped prepare the fort and the astronomers‟ equipment for the eclipse.[60] On other expeditions to Sumatra later in Curtis‟ life, his ability to speak Malay would prove useful once again.[61]

Unfortunately, the expedition itself proved to be mostly a scientific loss. One problem they struggled with was the constant threat of rain, or at least cloud cover because of the tropical conditions. As they prepared for the eclipse, the astronomers found it difficult to find a break in the clouds to calibrate their instruments. Curtis described Sumatra as a land of "only two seasons, a wet, and a wetter."[62] On May 18, 1901, the day of the eclipse, the astronomers rose in the morning to see the sky completely covered in clouds. Although a clear section of the sky slowly approached that could seemingly be overhead at the time of the eclipse, when totality happened they only caught a brief instant of it before it was obscured by the clouds. Towards the end of the eclipse, the cloud cover became so heavy that they lost the sun visually.[63] Curtis sums up

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[60] Ibid., 210.

[61] See John A Miller, "Swarthmore College Eclipse Expedition to Sumatra," in *Popular Astronomy* 34 (1926): 349-356 and John A. Miller and Ross W. Marriott, "Observations of the Total Solar Eclipse of May 9, 1929, Made by the Rubel Eclipse Expedition of Swarthmore College," *Popular Astronomy* 37, (1929): 495-504.

[62] Curtis, "The U.S. Naval Observatory Eclipse Expedition," 210-211.

the astronomer‟s feeling of futility by saying that a veteran astronomer favored having either a totally clear sky or pouring rain, because "surely the most mournful part of an unsuccessful eclipse is the hopeless development of the great plates from which so much had been expected."[64]

The expedition returned to the United States in July 1901, after being away for six months.[65] Although the expedition to Sumatra did not return the results the astronomers were looking for, the experience that Curtis gained while there, both in working with the instruments and learning some of the culture and language of the Malay, would prove helpful to him on future eclipse expeditions. He returned to the University of Virginia and completed his Ph.D. just two years after entering the program, graduating in 1902. His dissertation subject was "The Definitive Orbit of Comet 1898 I," a calculation of the orbit of the comet. He used information from thirty-four observatories to calculate that it takes the comet about four hundred and seventeen years to orbit the sun.[66] In finishing his Ph.D., Curtis had transformed himself from an amateur astronomer, who volunteered at Lick Observatory and helped with eclipse expeditions, to a professional.

After Curtis‟ graduation in 1902, W.W. Campbell, the newly appointed director of Lick Observatory, offered him a position at the observatory. Curtis had impressed Campbell during the eclipse expedition to Georgia with his skill and ability. Curtis and his family returned to San Jose, California where they lived while he taught at the

[63] Ibid., 211.

[64] Ibid., 212.

[65] Ibid., 213.

[66] Heber D. Curtis, "Definitive Determination of the Orbit of Comet 1898 I," in *Publications of the Astronomical Society of the Pacific*, 14, no. 85 (August 1902): 127-131, 130.

College of the Pacific. He began working as an assistant to the astronomers at Lick Observatory as he began to take his first steps into a discipline where he would spend the rest of his life.[67] The switch was complete.

[67] McLaughlin, "Heber Doust Curtis," 176.

CHAPTER THREE

CURTIS" EARLY PROFESSIONAL WORK

Curtis" next opportunity for development in the astronomical discipline came in 1902 after he returned to Lick Observatory, this time not as a volunteer but as an astronomer. William Campbell, the director of the observatory, assigned Curtis to continue an observation program that Campbell had developed, one that involved finding the radial velocities of the brighter stars in the night sky.[1] Campbell had two goals for this program. First, he wanted to create a catalogue of radial velocities, and second, he hoped this observation program would help astronomers better understand the Solar System"s place in the cosmos.[2] He believed that by calculating the radial velocity of the brighter stars he could discover whether the Solar System was moving toward or away from a certain section of the sky.[3] The more measurements Campbell could gather, the more accurate his calculation of the location of the Solar System in relation to the stars. Campbell worked for five years on this project, measuring the radial velocity of two

[1] A star"s radial velocity is how fast the star is moving away from or toward the Earth. See Ian Ridpath, ed., *The Illustrated Encyclopedia of Astronomy and Space* (New York: Thomas Y. Crowell, 1976), 164 and Robert G. Aitken, "Biographical Memoir of Heber Doust Curtis (1872-1942)," in *National Academy of Sciences of the Unites States of America Biographical Memoirs* 22 (1942): 273-294, 278.

[2] W.H. Wright, "Biographical Memoir of William Wallace Campbell (1862-1938)," in *National Academy of Sciences of the United States of America Biographical Memoirs* 25 (1947): 34-74, 44. While Campbell was an early proponent of gathering radial velocities, he was not the last person to participate in the study. According to Wright in his biography, by 1947 the program continued at various observatories with no end in sight of the information being gathered.

[3] Astronomers calculate radial velocities by observing the Doppler Effect on the light from the stars. By observing the shift in the spectral lines of the light from the star, astronomers can determine if it is moving toward (shifted blue) or moving away (shifted red). With this information astronomers can then establish the location and speed of the star. See Ridpath, *Encyclopedia of Astronomy,* 59.

hundred and sixty stars, before becoming director of the observatory and passing the project on to Curtis.[4]

Curtis followed in Campbell"s wake as he began to work with the observation program. He primarily used the observatory"s main telescope, a monster thirty-six-inch refractor.[5] To this telescope Campbell attached the Mills Spectrograph, specially calibrated for the refractor.[6] Darius Ogden Mills, a local philanthropist, donated the funds for the spectrograph.[7] Curtis jumped into his new assignment with the same enthusiasm he had demonstrated to Campbell during the 1900 eclipse expedition to Thomaston, Georgia. Curtis worked and studied hard to understand the complex new science of spectrography and soon his work was on par with some of the best astronomers in the world.[8] In 1903, he published a paper with Campbell describing five stars with variable radial velocity.[9] Over the next couple of years he continued Campbell"s observation program and in 1905 he again published on stars with variable

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[4] Wright, "William Wallace Campbell," 44-45.

[5] The Great Lick Telescope measures thirty-six inches in diameter and almost sixty feet long. See Ridpath, *Encyclopedia of Astronomy*, 109.

[6] The Mills Spectrograph was a spectrograph specially designed for the thirty-six inch reflector. The original spectrograph worked well for observational spectroscopy, however it did not allow for the spectrum of the object to be photographed. To photograph spectra, a new spectrograph needed to be procured. See W.W. Campbell, "The Mills Spectrograph of the Lick Observatory," *Astrophysics Journal* 8 (October 1898): 123-156.

[7] Mills was a wealthy banker who made his fortune selling goods from the eastern United States to those in California looking to strike it rich after the discovery of gold in 1847. See "Darius Ogden Mills," *The New York Times*, November, 27 1898.

[8] Aitken, "Heber Doust Curtis," 278.

[9] W.W. Campbell and Heber D. Curtis, "A List of Five Stars Whose Velocities in the Line of Sight are Variable," *Lick Observatory Bulletin* no. 46 (1903): 126.

radial velocities, this time naming nine.[10] Finding such stars was not a new discovery for astronomers. For some time they had known that some stars had variables radial velocities, which signaled to them that these stars were spectroscopic binaries.[11] However, the major discovery made through Campbell‟s program was the vast number of binary stars. By 1903, just five years into the program, Campbell was estimating that at least one in seven stars was a double star system.[12] By 1908, after years of doing the observations himself, Curtis concurred with Campbell‟s estimate that perhaps one in seven stars was a part of a binary system.[13] Recent scholarship shows that this number is closer to about one in three stars being a member of a binary or multi-star system.[14] Curtis‟ diligent work and skill with a spectrograph impressed Campbell and he asked Curtis to move to Santiago, Chile to continue the work in the southern hemisphere as a part of the D.O. Mills Astronomical Expedition.[15]

The Mills expedition developed when Campbell realized early in his observation program that he would not be able to calculate the Solar Systems position if he were

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[10] W.W. Campbell and Heber D. Curtis, "A List of Nine Stars Whose Radial Velocities Vary," *Lick Observatory Bulletin* no. 70 (1905): 84-86.

[11] The variations that Curtis noticed in the radial velocity of the stars were constant, meaning that something was causing the star to wobble. It is accepted now that an unseen companion star is causing the wobble. This type of system is called a spectroscopic binary, because the companion star is not visible under normal observing circumstances; and only observed through the shift in the main star‟s spectrum. See Ridpath, "*Encyclopedia of Astronomy,"* 59.

[12] W.W. Campbell, "A Brief Account of the D.O. Mills Expedition to Chile," *Publications of the Astronomical Society of the Pacific* 15, no.89 (April 1903): 70-75, 74.

[13] Heber D. Curtis, "Methods of Determining the Orbits of Spectroscopic Binaries," *Publications of the Astronomical Society of the Pacific* 20, no. 120 (June 10, 1908): 132-155, 132.

[14] Charles J. Lada, "Stellar Multiplicity and the IMF: Most Stars are Single," *The Astrophysical Journal* 640 (2006): 1-5, 1.

[15] Aitken, "Heber Doust Curtis," 278.

limited only to data from the stars visible to the observatory in the northern hemisphere. To calculate fully the Solar System"s location he needed to gather extensive and accurate observations from the southern hemisphere as well.[16] In 1900, Campbell again petitioned local philanthropist D.O. Mills for funds, this time to finance an expedition. Campbell calculated that it would take about twenty-six thousand dollars to equip fully an expedition to the southern hemisphere.[17] Mills agreed and throughout 1900 Campbell planned the trip, intending to travel to the southern hemisphere and make the observations himself. Campbell never made the trip; in December 1900 he was appointed director of Lick Observatory. The task of finding and developing an observation location in South America fell to astronomer William Wright, who had assisted Campbell with his research before Curtis arrived at the Lick Observatory.[18]

Campbell and Wright decided the best location for their make-shift observatory would be in the vicinity of Santiago, Chile. Wright, his wife, and H.K. Palmer, another astronomer from Lick Observatory, arrived in Chile in April 1903, taking a month to scout locations around Santiago for a suitable place for the soon to be constructed observatory.[19] Wright finally settled on a small hill called *Cerro San Cristobal*, about a mile and a half from the center of Santiago. The *cerro* rose about a thousand feet over

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[16] W.W. Campbell, "Organization and History of the D.O. Mills Expedition to the Southern Hemisphere," *Publications of the Lick Observatory* 9, part 1 (1907): 5-12, 5.

[17] The funds provided for a new telescope to be produced and a make-shift dome to be constructed in the southern hemisphere. For a complete list of the expenses budgeted by for the Mills Expedition, see Campbell, "Organization and History," 10.

[18] Ibid., 7.

[19] C.D. Shane, *William Hammond Wright, 1871-1959* (Washington, D.C.: National Academy of Sciences, 1979): 377-396, 380.

the city, and almost three thousand feet over sea level.[20] In a letter to Campbell, Wright lamented that it was not the greatest location for an observatory but it was chosen because the location afforded them some protection from bandits who roamed the hills.[21] However, building on the *cerro* would also put the observatory above the dust, haze, and fog that frequently covered the valley early in the morning.[22]

They constructed a simple observatory to house a thirty-six-inch reflecting telescope. The dome consisted of a steel frame with heavy painted canvas protecting the telescope and observers from the elements. The site had two more buildings in addition to the dome. They constructed an office, where the astronomers could work during the day, and an outbuilding that they used for storage and that served as a shelter for the night watchman.[23] Wright worked hard while he was in Chile. He took about nine hundred measurements of about two hundred and fifty stars, vastly increasing the knowledge of stellar radial velocities in the southern hemisphere.[24] The planned life of the expedition was two years. However, it returned so much usable and useful data that Campbell wanted to continue to gather information from the site. In 1905, as the service life of the expedition approached, he petitioned Mills again for funding to improve and continue the

[20] Campbell, "Organization and History," 8.

[21] Shane, "William Hammond Wright," 380.

[22] W.H. Wright, "Introductory Account of the D.O. Mills Expedition," *Publications of the Lick Observatory* 9, part 2 (1907): 15-22, 19.

[23] W.H. Wright, "Description of the Instruments and Methods of the D.O. Mills Expedition," *Publications of the Lick Observatory* 9, part 3 (1907): 4-70, 4.

[24] Shane, "William Hammond Wright," 381.

expedition. Once again, Mills agreed and provided the necessary funding.[25] That money would be used for needed renovations and additions to the observatory. The first major overhaul occurred while Wright was still in Chile. He removed the canvas exterior of the dome and replaced it with a more secure and durable surface of iron. This repair was Wright‟s last work in Chile. In March 1906, Campbell recalled Wright and sent Curtis in his place.[26]

The work in Chile suited Curtis perfectly. It allowed him to put his newly-developed skills with a spectrograph to the test. More so, Campbell allowed Curtis to improve the observatory in any way he felt it needed, freeing Curtis to use his mechanical aptitude. Finally, living in Chile gave Curtis the opportunity to master the Spanish language, adding it to his repertoire.[27] Once again, Curtis immersed himself in his work. During the day, he built and improved the facilities at the D.O. Mills Expedition observatory and by night he took spectrographic readings of the stars in the sky over the southern hemisphere. One of his first projects was to construct another building on the observatory‟s grounds. That small building, fourteen by seventeen feet, contained two small, sleeping rooms, and, most importantly, a workshop. In the past, astronomers had walked the mile and a half down the *cerro* at the end of their night of observations. However, with the addition of sleeping quarters at the observatory the astronomers could sleep for a few hours before venturing back down the mountain to Santiago. Curtis stated that "there [was] no change which . . . contributed more to the comfort of the observers

[25] Campbell, "Organization and History," 11.

[26] Aitken, "Heber Doust Curtis," 278.

[27] Ibid., 279.

than the ability to be able to "turn in" immediately after a night‟s work."[28] The workshop contained a small metal lathe, a grinder, a workbench, as well as a large collection of hand tools, allowing the astronomers the freedom to fix or improve the equipment at the observatory as they saw fit.[29]

The next improvement embarked on by Curtis was to improve the electrical system of the observatory. Although there was already an electrical line from running Santiago to the observatory, Curtis rebuilt the line so that more instruments and devices could be used without fear of shorting the electric line. He also strung a telephone line from the observatory to the home where he and his wife stayed in Santiago, allowing him to communicate with his wife from the observatory.[30] Once the new electrical wire was in place, Curtis began to re-wire the entire observatory complex. He ran electricity to the workshop to power the new lathe and grinder. Curtis also rewired the electrical system in the observing dome. Before Curtis arrived, Wright had wired the dome; however, Curtis improved the wiring. He streamlined the electrical system, clustering all the circuits into one fuse panel so that they could easily be accessed in case one of the fuses tripped.[31] Curtis also expanded and improved the instrumentation at the observatory. He re-silvered the mirror of the telescope, renewing the telescope‟s visual ability. Curtis also

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[28] Heber D. Curtis, "Recent Changes at the Observatory of the D.O. Mills Expedition," *Publications of the Astronomical Society of the Pacific* 19, no. 116 (October 10, 1907): 227-233, 227.

[29] Ibid., 228.

[30] Ibid.

[31] Ibid., 232.

added two more spectroscopes to the instruments at the observatory, increasing the research ability of the astronomers.[32]

The most lasting and important improvement that Curtis added to the expedition‟s observatory was the installation of an early refrigeration pump for use in cooling the primary mirror of the telescope. One problem that Wright struggled with while at the observatory was the constant need to adjust the telescope. Curtis and Campbell discovered that the telescope‟s mirror was contracting as it cooled over the first few hours of the night, changing the focal length of the mirror and blurring the image. At first, Wright cut holes in the mounting that backed the main mirror, hoping that it would provide ventilation to the mirror and accelerate its cooling. Unfortunately, the ventilation system did not affect noticeably the amount of adjustment needed throughout the night.[33] Campbell decided the best way to deal with the problem would be to cool the main mirror to the average air temperature before the dome was opened for the night. The task of designing and implementing the system fell to Curtis, before he left for Chile, as he would then install the system when he arrived at the observatory.[34] The cooling system that Curtis designed involved using an anhydrous ammonia pump to cool air, which was then piped to the telescope. The cold air was kept in place around the telescope by a specially designed wooden, felt lined case that could be rolled into position, covering the bottom half of the telescope. Fans then circulated the cold air over the base of the

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[32] Ibid., 232-233.

[33] Ibid., 230.

[34] Campbell, “Organization and History,” 11-12.

telescope, cooling the mirror.[35] Through experimentation, Curtis found that if the cooling process was started about three hours before sunset then the mirror would be close to the correct temperature at sunset.[36] Cooling the mirror allowed the telescope to be used for the entire night without the constant need for readjustment, increasing the observation time of the astronomers.

While improving the observatory, Curtis continued the program set up by Campbell and started by Wright. As he recorded the radial velocities of the stars in the southern hemisphere, he found that enough data had been collected for some stars to allow him to begin to make a general estimate for orbits of some of the binary systems. The first star he selected was *a* Carinae.[37] In 1906, Wright discovered that *a* Carinae was a spectroscopic binary and began carefully to catalog the spectrographic data of the star. When Curtis arrived in South America, he continued to collect observations of the star. By May 1907, he had enough information to make a rough estimate of the orbit of the pair, calculating that the smaller star orbited *a* Carinae at a distance of about one and a quarter million miles, taking the smaller star about seven days to orbit the larger star.[38] The idea of being able to calculate the orbit of a binary system with just spectrographic information fascinated Curtis and in 1908 he published a paper on the subject. In the

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[35] Curtis, "Recent Changes," 231.

[36] Ibid.

[37] Under the new nomenclature for stars *a* Carinae is known as V415 Carinae, designating the star as a spectroscopic variable.

[38] Heber D. Curtis, "Orbit of the Spectroscopic Binary *a* Carinae," *Lick Observatory Bulletin* no. 122 (1907): 153-154. One million two hundred thousand miles is extremely close in an astronomical scale, the distance from the Earth to the Sun is about one hundred times greater, at about ninety-two million miles. See Ridpath, "*Encyclopedia of Astronomy*," 21.

paper he examines all the then current methods that existed for determining the orbit of binary systems. Working through these methods, Curtis comes to the conclusion that they only work under a specific set of circumstances, unique to each method. However, if the circumstances are met by the star then it is possible for astronomers to calculate the orbit of the binary pair within their system.[39]

As Curtis became more comfortable with the spectrograph, he began to point it at different targets. In February 1909, Comet *c* 1908 appeared in the southern sky. Over the course of three nights, he took sixty-four photographic plates of the comet. His observations showed that the spectrum of the comet matched photographic images taken the same night.[40] Although the spectrograph readings were too faint for definitive results, the images showed that a more sensitive instrument might be able to determine the radial velocity of the comet, allowing astronomers to calculate more accurately the comet's orbit. Another major discovery made by Curtis involved three stars with exceptionally large radial velocities; five or six times the average of other stars.[41] These large radial velocities meant the stars were moving significantly faster than other stars he observed. Although astronomers have still done little research on these three stars, there is a

[39] Heber D. Curtis, "Methods of Determining the Orbits of Spectroscopic Binaries," *Publications of the Astronomical Society of the Pacific* 20, no. 120 (June 10, 1908): 132-155.

[40] Heber D. Curtis, "Spectrographic and Photographic Observations of Comet *c* 1908 (Morehouse)," *Publications of the Astronomical Society of the Pacific* 21, no. 128 (October 1909): 208-210.

[41] Heber D. Curtis, "Three Stars of Great Radial Velocity," *Lick Observatory Bulletin* no. 162 (1909): 133-134.

possibility, based on stars with similar radial velocities, that they might be some of the closest stars to the sun.[42]

The most important insight gained from Curtis" time in South America is the verification of more spectroscopic binary stars than were previously known. For example, in just over a year of work he found eighteen more stars with variable radial velocities.[43] In his final paper published from the Mills Expedition observatory, Curtis observes that the vast number of spectroscopic binaries will have a significant effect on modern theories of stellar evolution.[44] In that paper, he also discusses the state of astronomy in regard to the southern hemisphere. He notes that the biggest problem faced by astronomers working in the southern hemisphere was a general lack of information. Curtis echoes Sir David Gill, a Scottish astronomer considered by many astronomers to be an expert on the stars of the southern hemisphere, saying that the state of astronomy in the southern hemisphere in regard to understanding the exact position of stars was about one hundred years behind that of the northern hemisphere.[45] Another example of how astronomy in the Southern Hemisphere was behind was the lack of stellar parallaxes

[42] Other stars with large radial velocities lie close within our galactic neighborhood. For example, 1830 Groombridge with a radial velocity comparable to the stars Curtis discovered is about thirty light years from the sun. See Olin F. Eggen and Allan R. Sandage, "Stellar Groups, IV. The Grooombridge 1830 Group of High Velocity Stars and its Relation to the Globular Clusters," *Monthly Notices of the Royal Astronomical Society* 119 (1959): 255-277, 256.

[43] Heber D. Curtis, "Five Stars Having Variable Radial Velocities," *The Astrophysics Journal* 29 (1909): 229-231 and Heber D. Curtis, "Thirteen Stars Having Variable Radial Velocities," *Lick Observatory Bulletin* no. 164 (1909): 139-140.

[44] Heber D. Curtis, "Astronomical Problems of the Southern Hemisphere," *Publications of the Astronomical Society of the Pacific* 21, no. 129 (December 10, 1909): 230-244, 236.

[45] Curtis, "Astronomical Problems," 232. David Gill spent almost his entire career, from 1879 to 1907, at an observatory on the Cape of Good Hope in South Africa, painstakingly mapping the stars of the southern hemisphere. For more on Gill see John A. Paterson, "Sir David Gill – A Real Astronomer," *Journal of the Royal Astronomical Society of Canada* 13 (October 1919): 343-359.

calculated for stars in that hemisphere. Curtis states that only seventeen parallaxes had been calculated for stars in the southern hemisphere, while more than three hundred were known for stars in the northern hemisphere.[46] Finally, Curtis demonstrated he understood a significant change that was beginning to happen in astronomy. As he finished the paper, Curtis writes that the old style of astronomy, the simple study of the position of objects in the sky, was beginning to be overtaken by the new science of astrophysics.[47] New instruments and techniques, like spectroscopy, allowed for astronomers to study the actual physical makeup of stars and other stellar phenomenon. Curtis could see that astrophysics was beginning to become a greater part of astronomy, and that in future it would fundamentally change the nature of the discipline.

After four years in South America, Campbell recalled Curtis from the D.O. Mills observatory to return to the Lick Observatory. When he arrived in California, Campbell gave him full control of the Crossley reflector and a mandate to continue the work of James Keeler, who had recently passed away.[48] Keeler‟s work had involved using spectroscopy to measure the radial velocity of nebula, a more difficult target than the stars that Curtis measured in the Southern Hemisphere. This is where Curtis would make his greatest contribution to astronomy. As he began systematically to catalogue the spectra of nebulae he would fundamentally change our understanding of our place in the universe.

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[46] Ibid., 235.

[47] Ibid., 241.

[48] Aitken, “Heber Doust Curtis,” 279.

CHAPTER FOUR

CURTIS AND THE ISLAND UNIVSERSE THEORY

Returning to the Lick Observatory in 1910, Curtis continued the work begun by James Keeler. Keeler was born in La Salle, Illinois on September 10, 1857.[1] Growing up Keeler developed an ability to build complex instruments; he built his first telescope at the age of eleven.[2] His skill helped him enroll at John Hopkins, the first research university in the United States, in Baltimore, Maryland. Keeler graduated in 1881 and took a job at the University of Pittsburgh"s Allegheny Observatory. After two years of work, he moved to Germany for a year of graduate study in spectroscopy because there were no universities in the United States that had courses teaching spectroscopy. Upon finishing his graduate work in 1884, Keeler returned to the Allegheny Observatory where he worked until the spring of 1886.[3] That spring Keeler was offered a job at the Lick Observatory, which he promptly accepted. Keeler worked primarily with a new spectroscope installed on the thirty-six inch Lick telescope. With the instruments, he took the spectra of Saturn, Jupiter, and any number of planetary nebulae.[4] In 1891, he resigned his position at Lick Observatory and returned to the Allegheny Observatory, where he was appointed director. Keeler would stay at the Allegheny Observatory for

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[1] W.W. Campbell, "James Edward Keeler," *Astrophysical Journal* 12 (November 1900): 239-253, 239.

[2] Marcia Bartusiak, *The Day We Found the Universe* (New York: Vintage Books, 2009), 6.

[3] Campbell, "James Edward Keeler," 241.

[4] Ibid., 242-243.

only seven years. In 1898, he returned to Lick Observatory as the director.[5] While he was away, Holden had acquired a new telescope for the observatory, the thirty-six inch Crossley Reflector.[6] As director of the observatory, Keeler would use almost exclusively the Crossley Reflector.

The Crossley Reflector was the largest reflector telescope in the world until the Hale telescope was completed at Mount Wilson observatory in 1906.[7] Andrew Common made the Crossley Reflector in England in 1879. He wanted to experiment with the design of a large, reflector type telescope. Common believed the most practical method of experimentation was building a telescope to test his ideas. His telescope worked as he planned, and he was even awarded the Gold Medal of the Royal Astronomical Society for some astronomical photographs he took with the telescope in 1884.[8] In 1885, Common decided that he wanted to construct a larger telescope. He sold the thirty-six inch reflector to an English politician named Edward Crossley, who constructed a dome for the telescope and used it to make observations for about a decade. Unfortunately, the climate in his part of England was not suitable for the telescope. In 1895, Crossley agreed to Holden"s request to sell the telescope to Lick Observatory.[9] That year, Holden had the telescope and dome transported from England to Lick Observatory, where a

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[5] Ibid., 244.

[6] James E. Keeler, "The Crossley Reflector of the Lick Observatory," *Astrophysical Journal* 11, no. 5 (June 1900): 325-349, 326.

[7] Ibid.

[8] Ibid.

[9] Ibid.

smaller observatory was constructed about three hundred and fifty yards from the main observatory.[10] Unfortunately, neither Holden nor the other astronomers at Lick Observatory had any luck with the telescope. One astronomer even wrote an article called "No Work of Importance" in which he described the research they expected to accomplish with the telescope.[11]

After Holden resigned as director in 1897, the telescope was left unused because no astronomer wanted to fight the instrument. When Keeler arrived in 1898, he began slowly to adapt and fix the Crossley reflector. First, he cut two feet out of the main support; this brought the telescope to a comfortable observing height and allowed the spectrograph to remain on the telescope. Previously, astronomers needed to remove the spectroscope every night because the telescope protruded out of the dome with it attached.[12] Keeler then added a more powerful and accurate driving-clock. The clock automatically moved the telescope as it followed the object it was photographing across the night sky.[13] It took Keeler about four months to get the telescope functioning in a way that would allow him to use it for spectrography. However, once he began using the telescope to photograph the night sky he discovered a wealth of beautiful objects. For example in November 1897, he photographed Comet Brooks. In the negatives of the comet, he was stunned to find that the comet had two separate nucleuses. Keeler easily

[10] Ibid., 326.

[11] Bartusiak, *The Day We Found the Universe*, 26.

[12] Keeler, "The Crossley Reflector of the Lick Observatory," 330.

[13] Ibid., 331-332.

photographed the unique double nucleus with the Crossley Reflector.[14] It was the first of many discoveries made with the telescope by Keeler and future astronomers.

Eventually Keeler‟s most prominent photographic subjects would become the nebulae. His first success came in May 1899. Over the course of the month, he took a series of photos of M51, the Whirlpool nebula. The image stunned Keeler; it showed details of the structure of the nebula that astronomers had never seen before.[15] However, there was more to the photo. Surrounding M51 there was a collection of small, fainter nebulae. Keeler originally believed that he had happened on a section of the sky that contained a larger than normal concentration of nebulae but as he took more photos, covering different sections of the sky, he found that the night sky was full of spiral nebulae. In the fall of 1899, he imaged NGC 891, an edge on spiral.[16] In the background, he counted thirty-one new spiral nebulae. In the background of another nebula, this time of NGC 7331, he counted twenty new spiral nebulae.[17] The amount of spirals he imaged astonished Keeler. He said, "There are hundreds, if not thousands, of unrecorded nebulae within reach of our 36-inch reflector."[18]

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[14] Bartusiak, *The Day We Found the Universe*, 27. It was later discovered that Comet Brooks had broken up when it passed closely to Jupiter in 1886. See John C. Brandt and Robert Chapman, *Introduction to Comets* (Cambridge: Cambridge University Press, 2004), 272.

[15] Ibid., 28. This was before astronomers understood that some nebula were actually other galaxies. Before about 1924, virtually any object that was not a star was referred to as a nebula, especially if it had a hazy or gassy appearance through a telescope.

[16] An "edge on spiral" is a spiral galaxy one viewed directly from the side. Instead of seeing the structure of the spiral arms and gas lanes, the overall profile is observed, with the most prominent feature being the galactic center bulge that tapers into the flat outer section.

[17] Ibid., 31.

[18] Ibid.

Unfortunately, Keeler was not able to pursue more research into the spiral nebulae he was photographing. He died unexpectedly on August 12, 1900.[19] Keeler was the first astronomer to consider seriously the use of a reflector-style telescope. Before his tenure almost all major observatories used a refractor telescope; however, after Keeler showed the astronomical community the capabilities of a reflector, the choice of instrumentation began to shift. Donald Osterbrock, a historian of science and director of Lick Observatory, observed in his book *James E. Keeler: Pioneer American Astrophysicist,* that Keeler‟s lasting legacy involved the pioneering used of reflectors in astrophotography. He wrote, “The day of the refractor is over and although a few more intermediate-sized ones were built, no American professional astronomer ever thought seriously of building a very large telescope as anything but a reflector, after Keeler‟s work with the Crossley.”[20]

Keeler left another legacy. In 1910, William Campbell, Keeler‟s replacement as director of Lick Observatory, passed Keeler‟s modifications to the Crossley reflector and photographic plates to Curtis. Campbell then assigned Curtis to continue Keeler‟s program of nebular spectrography and research.[21] Curtis‟ plan was to compare his images of spiral nebulae with Keeler‟s hoping to show changes in the position of the spirals. Any change of position would indicate that the spiral had rotated during the

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[19] Ibid., 34.

[20] Donald Osterbrock, *James E. Keeler: Pioneer American Astrophysicist* (Cambridge: Cambridge University Press, 1984), 347.

[21] Robert G. Aitken, “Biographical Memoir of Heber Doust Curtis: 1872-1942,” *National Academy of Sciences of the United States of America Biographical Memoirs* Vol. 22, no. 13 (1942): 273-294, 279.

period between the observations. Curtis knew that any demonstrable rotation would aid astronomers in learning the size and distance of the spiral nebulae.[22] However, Curtis found there was no measurable movement between his images and Keeler‟s, meaning that if the spiral nebulae were moving then they moved extremely slowly, taking longer to move than the time between his and Keeler‟s photos. For Curtis, this indicated that the spiral nebulae "must be of enormous actual size, and at enormous distances from us."[23] We know now that those spiral nebulae that Curtis imaged are actually other galaxies, like the Milky Way. However, in 1910 most astronomers did not believe in the plurality of galaxies. Over the next decade, through the work of Curtis and other astronomers, scientists would come to believe in the Island Universe theory, or the idea that there were multiple universes.

The Island Universe theory arose from a paper published by British astronomer Thomas Wright in 1750 called "An Original Theory or New Hypothesis of the Universe." In the paper Wright first proposes that the Milky Way is a collection of stars, vaguely disk shaped, a fact that took another two hundred years to verify. [24] Second, Wright discusses the various nebulas he observed from earth and postulates that perhaps they

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[22] Heber D. Curtis, "Preliminary Note of Nebular Proper Motions," *Proceedings of the National Academy of Sciences of the United States of America* 1 (1915): 10-12, 10.

[23] Ibid., 12.

[24] Michael A. Hoskin and George D. Rochester, "Thomas Wright and the Royal Society," *Journal of the History of Astronomy* 23 (1992): 167-172, 167.

exist as an "external creation" or objects beyond the Milky Way. [25] Wright‟s ideas were groundbreaking though he did little to advance them.

The person who would do the most to support Wright‟s ideas was the German philosopher Immanuel Kant. Kant came across a summary of Wright‟s "original theory" in a Hamburg publication called *Freie Urteile*. Finding the summary fascinating, he began to ponder Wright‟s ideas and soon arrived at his own idea about the Milky Way galaxy and the spiral nebulae. Like Wright, Kant felt the Milky Way was a collection of stars that existed on one plane. However, he expanded Wright‟s view of the spiral nebula, believing they were a collection of stars or other galaxies comparable to the Milky Way but also beyond the boundaries of our own galaxy. Kant eventually called his idea the Island Universe theory.[26]

The Island Universe theory became popular among scientists, who used it to explain the spiral nebulae. One astronomer, William Herschel, strongly supported the theory, saying that by 1785 he had discovered "fifteen hundred whole sidereal systems, some of which might well outvie our Milky Way in grandeur."[27] However, in 1899 another astronomer, William Huggins, published an extensive collection of stellar and nebulae spectra. Using the spectrum from planetary and irregular nebulas, Huggins showed they were made of gas and not stars. Huggins‟ publication was a blow to the

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[25] Freeman J. Dyson, *Disturbing the Universe* (New York: Basic Books, 1979), 245.

[26] Michael J. Crowe, *Modern Theories of the Universe: From Herschel to Hubble* (New York: Dover Publications, 1994), 69.

[27] Hector Macpherson, *Herschel* (New York, The McMillan Company, 1919), 49.

Island Universe theory.[28] If nebulas were large galaxies like the Milky Way then they should have been made of stars and not gas.[29]

Huggins‟ revelation of the nature of planetary and irregular nebulas ended most discussion of the Island Universe Theory as a serious scientific idea. In 1905 Agnes Clerke, an astronomer and scientific author, published a book called *The System of the Stars.* In the book she states, “The question whether nebulae are external galaxies hardly any longer need discussion. It has been answered by the progress of research. No competent thinker, with the whole of the available evidence before him, can now, it is safe to say, maintain any single nebula to be a star system of co-ordinate rank with the Milky Way.”[30] A few years later, in 1919, another astronomer named Hector Macpherson published an article in *The Observatory* called “The Problem of Island Universes.” In the article, he addresses directly the Island Universe theory and the issues that made it inoperable at the turn of the twentieth century. In conclusion he writes, “Can we then speak of star-clusters as island universes? If we mean by island universes, systems independent of and coequal in dimensions with our galactic system, the answer is in the negative.”[31] For the most part astronomers and physicists did not support the Island

[28] Huggins work was called *An Atlas of Representative Stellar Spectra from λ4870 to λ3300, Together with a Discussion of the Evolution Order of the Stars, and the Interpretation of their Spectra; Preceded by a Short History of the Observatory*. See Hector Macpherson, “The Problem of Island Universes,” *The Observatory: A Monthly Review of Astronomy* 42 (September 1919): 329-334, 330.

[29] Huggins observations were correct on the makeup of irregular and planetary nebulae; they are made of gas. However, the assumption that all nebulae were composed of the same matter is incorrect. Irregular and planetary nebulae are different phenomena from the spiral nebulae.

[30] Agnes M. Clerke, *The System of The Stars* (London: Adam & Charles Black, 1905), 349.

[31] Macpherson, “The Problem of Island Universes,” 332.

Universe theory and instead felt the various nebulae, irregular, planetary, and spiral, were a part of the Milky Way in one form or another.

However, while most astronomers believed the Island Universe theory had been debunked, evidence continued to pile up pointing to the veracity of the theory. In 1917, another astronomer found more evidence for the Island Universe theory. That year, George Ritchey, working at Mount Wilson Observatory, announced that he had discovered a nova in one of the spiral arms of NGC 6946.[32] A nova is a star that increases in brightness, sometimes by a hundred times, in a short period. It happens under a specific set of conditions. The star must be a white dwarf and a part of a binary star system. The white dwarf steals material from its companion star, triggering massive explosions on its surface.[33] The circumstances for producing a nova seem to limit the number that can happen and make them rare, but the huge number of stars visible to astronomers even the odds and most observers see a few during the course of their lifetimes. The news of Ritchey‟s discovery excited Curtis. On three occasions, he observed and documented novae in spiral nebulae. However, Curtis never published his discovery. But, after hearing of Ritchey‟s nova, Curtis decided he would publish his observations of novae in the spiral nebulae. His discovery was printed along with Ritchey‟s in the 1917 issue of *Publications of the Astronomical Society of the Pacific*.[34]

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[32] George W. Ritchey, "Novae in Spiral Nebulae," *Publications of the Astronomical Society of the Pacific* 29 (1917): 210-212, 210-211.

[33] Nicolas Cheetham, *Universe: A Journey from Earth to the Edge of the Cosmos* (London: Quercus Publishing, 2005), 219.

[34] Heber D. Curtis, "Novae in Spiral Nebulae," *Publications of the Astronomical Society of the Pacific* 29 (1917): 180-182.

The first nova Curtis viewed was in March 1901 in NGC 4321. A few years later, in March 1914 and again in April, he observed another nova in NGC 4321. Finally, in January 1915 he imaged a nova in NGC 4527.[35]

The discovery of these novae influenced Curtis" ideas over the next few years. In the same volume of *Publications of the Astronomical Society* in which he and Ritchey published their novae findings, he also included a note entitled "Novae in Spiral nebulae and the Island Universe Theory." In this note, he comments on how astronomers had also been observing novae within the Milky Way galaxy. He combines the two discoveries and realizes that "the occurrence of objects of the same type in the spirals would reasonably be expected, were these spirals in fact congeries of vast numbers of stars, like our own Galaxy."[36] Curtis then looked at the information gathered on the luminosity of the novae, both in the Milky Way and the spiral nebulae. He found the average brightness of the galactic novae was about a magnitude five. Averaging the novae in the spiral nebulae, he identified their brightness as about magnitude fifteen. Assuming that both kinds of novae had the same absolute magnitude, he found the novae within the spiral nebulae were one hundred times farther than those seen within the Milky Way. Finding novae in the spiral nebulae has two important implications which back the Island Universe theory. First, the spiral nebulae were in one form or another, collections of stars and not gaseous nebulae as astronomers believed, and, second, those spirals were also

[35] Heber D. Curtis, "Three Novae in Spiral Nebulae," *Lick Observatory Bulletin* no. 300 (1917): 108-110, 108. NGC is simply the acronym for "New General Catalogue;" it is the naming convention developed by astronomers to make it easier to describe the nebulae.

[36] Heber D. Curtis, "Novae in Spiral Nebulae and the Island Universe Theory," *Publications of the Astronomical Society of the Pacific* 29 (1917): 206-207, 206.

extremely distant. However, Curtis ends the note with “the effect of any existing absorbing materials in the spirals upon the novae is to reduce their apparent brightness and thus to make them seem farther from our system then they really are.”[37] In early 1917, Curtis was not totally convinced of the Island Universe theory but his belief in the theory solidified later in 1917 in the publication of another paper.

That same year an astronomer, Vesto Slipher, working at Lowell Observatory in Arizona published a paper five years in the making. He had been observing and photographing the spectra of spiral nebulae. In some cases, it took up to eighty hours of exposure to collect the spectrum of a single spiral nebula. However, his observations returned an amazing discovery. He found the spiral nebulae were moving away from the Earth at a phenomenal rate, much faster than the stars and nebulae observed within the Milky Way. This led Slipher to conclude that the spiral nebulae were “in a class to themselves” and not a part of the Milky Way. Slipher believed that his observations seemed to favor the Island Universe theory by showing that the spirals were different and distinct from other galactic phenomenon.[38]

Unfortunately, with the entry of the United States into the First World War, Curtis stopped his research and in the fall of 1917 took a leave of absence from Lick Observatory. He first went to teach navigation to officer recruits at San Diego and

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[37] Ibid., 207.

[38] Vesto M. Slipher, “A Spectrographic Investigation of Spiral Nebulae,” *Proceedings of the American Philosophical Society* 56 (1917): 403-409.

Berkley.[39] He then moved to Washington, D.C. where he worked for the Bureau of Standards helping to develop high quality optical glass. Before the First World War most of the optical glass used in the United States was imported from Europe.[40] By the end of the war, the Bureau of Standards was producing around twenty tons of optical glass a month, more than enough for the needs of the military.[41]

In 1919, while Curtis was still in Washington, D.C. he was invited to speak at a joint meeting of the Washington Academy of Sciences and the Philosophical Society of Washington in Washington, D.C.[42] Curtis" presentation was groundbreaking. Titled "Modern Theories of the Spiral Nebulae," it contained all the evidence he had compiled that defended the Island Universe theory. The presentation was later published as a paper, which followed the arguments of the presentation, in *The Journal of the Royal Astronomical Society of Canada*.

In the presentation, Curtis first begins by looking at the history of the Island Universe theory. He talks about its development from the ideas of Wright and Kant and how, for a time, it was accepted as the truth. However, scientists soon began to use spectroscopy to analyze the composition of various objects in the heavens. They discovered that irregular and planetary nebulae were made of different types of gas. Over

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[39] Bartusiak, *The Day We Found the Universe,* 67.

[40] Heber D. Curtis, "Optical Glass," *Publications of the Astronomical Society of the Pacific* 31 (1919): 77-85, 78.

[41] Ibid., 80.

[42] Bartusiak, *The Day We Found the Universe,* 67.

time, they included spiral nebulae with the other forms of nebulae, ending temporarily the belief in the idea of the Island Universe theory.[43]

Curtis sought to prove that the spiral nebulae were different from the irregular and planetary nebulae. He begins by explaining that most irregular and planetary nebulae were found within the plane of the Milky Way. While astronomers saw only spiral nebulae in the regions above and below the disk of the galaxy, to Curtis this showed that the irregular and planetary nebulae were closer and existed within the Milky Way, while the spirals were located beyond the galaxy.[44] Curtis and other astronomers at Lick Observatory had "doubled and trebled [their] exposures in the regions near the galactic plane in the hope of finding fainter spirals . . . without result."[45] Curtis believed that if spiral nebulae were similar to irregular and planetary nebulae, then they should be found equally spread throughout the night sky and not segregated to only a part of the sky.

Curtis then compared the spectrum gathered from spirals with the spectrum from irregular and planetary nebulae. The spectrum he gathered from irregular and planetary nebulae matched that gathered by other scientists, including Huggins. It showed that they were composed of different types of gases. However, the spectrum from the spiral nebulae was different. It was consistent with the spectrum gathered from star clusters and

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[43] Heber D. Curtis, "Modern Theories of the Spiral Nebulae," *The Journal of the Royal Astronomical Society of Canada* 14 (October 1920): 317-327, 317-318.

[44] Ibid., 318.

[45] Ibid., 319.

not other nebulae. This meant that spiral nebulae were composed of groups of stars and not various gases like irregular and planetary nebulae.[46]

Curtis next presented research on radial velocities of spiral nebulae compared to other cosmological phenomenon, originally done by Slipher at Lowell Observatory. Radial velocity is how quickly an object is moving toward or away from an observer. Irregular nebulae had a low velocity, meaning they remained relatively stable in regard to the planet Earth, while planetary nebulae"s velocity was around fifty miles per second. Stars moved away from the Earth at between eight and twenty-one miles per second. Star clusters, the furthest object measured at that time with relative accuracy, had a velocity of about one hundred and fifty miles per second. Finally, spiral nebulae moved away from the Earth at almost five hundred miles per second. Curtis believed their large radial velocities put spirals in a class separate from other phenomena. In addition, comparing their velocities to that of star clusters, the most distant objects known at the time, led Curtis to believe that spirals resided even beyond star clusters.[47]

Finally, Curtis presented research on novae he had observed in spiral nebulae. In the two years before his presentation, astronomers found about a dozen novae in different spiral nebulae while astronomers had observed only twenty-seven novae in the Milky Way in the three hundred years before Curtis" presentation. Curtis believed these

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[46] Ibid., 320.

[47] Ibid., 320-321.

numbers showed that the spiral nebulae were composed of hundreds of millions of stars, just like the Milky Way, increasing the odds of a spiral producing a nova.[48]

Curtis could also use the novae to gauge the distance of the spirals from earth. The luminosity of the novae in the spiral nebulae ranged from magnitude fourteen to nineteen, averaging around magnitude fifteen. The brightness of the novae observed in the Milky Way averaged about the fifth magnitude.[49] Assuming the novae averaged about the same absolute luminosity, Curtis found the novae in the spiral nebulae were about four hundred times more distant than the novae observed in the Milky Way. If an estimate of ten thousand light years was used for the distance of novae in the Milky Way, then the novae in the spiral were four million light years away, an unfathomable distance. Curtis ends the presentation with an interesting idea. If one observes the Milky Way from about ten million light years away, then it would have the same apparent size as one of the larger spiral nebulae.[50] Based on his observations, Curtis believed that the spiral nebulae were separate and distinct galaxies.

Curtis‟ 1919 presentation in Washington, D.C. moved him to the forefront of astronomers defending the Island Universe theory. It also led directly to his most well known accomplishment, being chosen to defend the Island Universe theory at a debate during the meeting of the National Academy of Science in the spring of 1920. The idea for a debate came about at a council meeting of the National Academy of Sciences in late

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[48] Ibid., 323.

[49] Ibid.

[50] Ibid., 323-324.

1919. George Hale, the director of the Mount Wilson Observatory in California, wanted to set aside a night during the council‟s next meeting in April 1920 for a lecturer. Charles Abbot, an astrophysicist and the Home Secretary of the Academy, corresponded with Hale regarding the choice of lecturer. Abbot wanted to find people to debate either the Island Universe theory or the theory of relativity; however, Abbot felt that the subject of relativity "would be done to death before the meeting."[51] He thought that maybe they could get Harlow Shapley, an astronomer at Mount Wilson Observatory, and William Campbell, the directory of the Lick Observatory and Curtis‟ boss, to debate the Island Universe theory, though he felt there was little to no interest in the theory. Hale and Abbot also wanted Campbell to defend the conservative belief in the size of the Milky Way. However, as time passed and the details of the lecture began to solidify, Hale felt that Curtis should debate Shapley.[52]

There was a specific reason for the choice of each astronomer. Curtis was the chief defender of the Island Universe theory and had already produced an eloquent defense of the Island Universe theory in 1919. Shapley was at the forefront of a set of new theories on the size the of the Milky Way galaxy. He also did not believe in the Island Universe theory. The debate would have Curtis trying to prove that the spiral nebulae were other galaxies and not change the then currently assumed size of the Milky Way, while Shapley would attempt to show the Milky Way was large enough to include

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[51] M.A. Hoskin, "The „Great Debate‟: What Really Happened," *Journal for the History of Astronomy* 7 (1976): 169-182, 169.

[52] Virginia Trimble, "The 1920 Shapley-Curtis Discussion: Background, Issues, and Aftermath," *Publications of the Astronomical Society of the Pacific* 107 (December 1995): 1133-1144, 1136.

the spiral nebulae and debunk the Island Universe theory. Shapley appeared to be the perfect choice to debate Curtis.[53]

Shapley was born in rural Missouri in 1885. His first real job was working as a crime reporter for a newspaper in a small Kansas town. Hoping for a better career, he enrolled at the University of Missouri, where he wanted to study journalism. However, the school of journalism had not yet opened, forcing him to find a different subject to study. Shapley said later about his investigation of other fields of study that "I opened the catalogue of courses. The very first course offered was a-r-c-h-a-e-o-l-o-g-y, and I couldn‟t pronounce it! I turned over a page and saw a-s-t-r-o-n-o-m-y. I could pronounce that and here I am!" Astronomy would probably have been a significantly different field if Shapley had been able to pronounce the word archaeology.[54]

After Shapley finished his undergraduate degree at the University of Missouri in 1912, he moved to Princeton University to work on a master‟s degree under Henry Russell. Russell was pioneer of a new field called astrophysics, which combined astronomy, physics, and spectroscopy. He was also a well-known observational astronomer. Shapley received his doctorate in 1914 and left to take a position at Mount Wilson Observatory.[55]

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[53] Hoskin, "The „Great Debate‟: What Really Happened,"170.

[54] David H. Clark and Matthew D. Clark, *Measuring the Cosmos: How Scientists Discovered the Dimensions of the Universe* (New Brunswick, NJ: Rutgers University Press, 2004), 70.

[55] Ibid., 71.

While working at Mount Wilson, Shapley used a class of star called a Cepheid Variable to determine the distance of a group of globular clusters. Cepheid variables are a special class of star that brightens and dims at a specific rate. Using this rate, astronomers are able to calculate the star‟s absolute luminosity. By then comparing the star‟s absolute luminosity with its observed luminosity, an astronomer can calculate an accurate measure of the star‟s distance from the earth.[56]

Shapley felt these clusters outlined the furthest edge of the Milky Way galaxy and, based on his calculations, the galaxy was one hundred times larger in diameter than originally believed. His final estimate put the Milky Way at close to three hundred thousand light years across or a little over four and a half quadrillion kilometers.[57] He defended vehemently his conclusion making him the perfect spokesperson for this new theory. Shapley also worked for Hale at Mount Wilson observatory, which made his theories more available to Hale and, through Hale, the rest of the National Academy of Sciences.[58]

On February 18, 1920, Hale sent official invitations to Curtis and Shapley. Curtis accepted the invitation although he was a little uncertain about the debate. Still, as he began to prepare his argument he gradually felt stronger about the soundness of his

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[56] Sir Arthur Eddington, *The Expanding Universe* (Cambridge: Cambridge University Press, 1988), 7.

[57] Harlow Shapley and Heber Curtis, “The Scale of the Universe” in *A Source Book in Astronomy and Astrophysics, 1900-1975,* eds. Kenneth R. Lang and Owen Gingerich (Cambridge: Harvard University Press, 1979), 523.

[58] Clark, *Measuring the Cosmos,* 68.

position.[59] Shapley‟s reaction was the opposite. At first he was thrilled to be invited by his boss, Hale, to the debate. However, as the pieces began to fall into place he began to have misgivings about the debate.[60]

Shapley was not worried about his ideas being proven wrong by Curtis. He was instead concerned about performing well in the debate and showing that he was the right person for a position that had recently opened at the Harvard University Observatory. Shapley applied for the position of director of the Harvard Observatory, though he had little administrative experience. Harvard‟s first choice was Henry Russell, Shapley‟s mentor from Princeton. However, the university was prepared to divide the duties of the directorship between Russell and a "second astronomer, younger and with modern ideas."[61] Shapley did not know Harvard‟s intentions and believed that he had a chance at the director‟s position.

Shapley worried that his inexperience as a speaker coupled with Curtis‟ well-known speaking ability, a style he had perfected while teaching, would jeopardize Harvard‟s interest in him. He first attempted, through Hale, to get someone other than Curtis as his opponent. When that proved unsuccessful, he then tried to shift the structure of the debate. Shapley wanted a format with two talks about the same issue, but from different points of view.[62] He knew that he did not stand a chance against Curtis in a true

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[59] Ibid., 78.

[60] Hoskin, "The „Great Debate,‟" 170.

[61] Ibid., 170.

[62] Clark, *Measuring the Cosmos,* 79.

debate, in which one speaker presented and then his ideas were free to be attacked by the other speaker. Curtis on the other hand looked forward to the idea of having a debate. In a letter to Shapley dated February 26, Curtis said that while he agreed with the idea of an informal discussion, he also felt the discussion did not need to be friendly. Curtis wrote, "I agree with you that it should not be made a formal "debate", but I am sure that we could be just as good friends if we did go to each other "hammer and tongs" . . . A good friendly "scrap" is an excellent thing once in a while; sort of clears up the atmosphere. It might be far more interesting both for us and our jury, to shake hands, metaphorically speaking, at the beginning and conclusion of our talks, but use our shillelaghs [sic] in the interim to the best of our ability."[63] The letter was not what Shapley wanted to receive; he knew he was not prepared to go against a skilled orator, especially if there were representatives from Harvard at the debate.

Hale ended any further discussion of the matter in a letter to Curtis on March 3. Instead of debate, Curtis and Shapley would each have forty minutes to present their side of the argument. Each speaker would be able to contest the other‟s ideas during their allotted time; any further questions or rebuttals would come from the audience. This format favored neither Curtis nor Shapley and proved to be a good compromise. At this time Hale also settled the title of the debate. It would be called "The Scale of the Universe," a title shared with the work published jointly a year later by Curtis and

[63] Hoskin, "The „Great Debate,‟" 171.

Shapley. This topic allowed both men to prepare speeches that would show the strength of their arguments.[64]

Both Curtis and Shapley received a one hundred and fifty dollar honorarium for their presentations and, using that money, they paid for their own travel expenses. Curtis paid two dollars for a stagecoach ride from Mount Hamilton to San Jose. In San Jose, he and Shapley paid one hundred dollars for round-trip tickets to Washington, D.C. Although they traveled together, they did not discuss their presentations, instead preferring to keep their arguments for the night of the debate. Even when their train broke down in Alabama, they spent their time talking about flowers and classical works of literature instead of discussing astronomy.[65]

The National Academy of Sciences met for three days that year, from April 16-18, 1920. The end of the first night, April 16, was the scheduled time for Curtis and Shapley‟s debate. It took place in the Baird Auditorium, which is in what is now the Smithsonian Institution‟s Museum of Natural History. The debate was open to the public and somewhere between two and three hundred people attended. Both speakers had to depend on the strength of their voices, as the auditorium had no amplification system. Curtis had no problems with the arrangement, already at ease with his voice because he was a university professor. [66] However, Shapley was not as comfortable, mentioning later

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[64] Shapley, “The Scale of the Universe,” 524.

[65] Bartusiak, *The Day We Found the Universe,* 152.

[66] Clark, *Measuring the Cosmos,* 82.

that "I read my paper and Curtis presented his."[67] Compounding Shapley‟s stress, two men from Harvard attended: George Agassiz, a member of the Harvard astronomy department‟s visiting committee, and Theodore Lyman, chair of the Harvard physics department. A. Lawrence Lowell, Harvard‟s president, sent the men to observe Shapley and see if he qualified for the observatory directorship.[68]

The debate began at 8:15 P.M. Eastern Time, with Shapley speaking first. Unfortunately, there is little information on the tone of the speakers or the mood of the audience, and those accounts available have some factual errors that cloud them as sources of information. One of Shapley‟s memories involves a conversation he remembered having with Albert Einstein at a formal dinner before the debate. However, Einstein had not yet travelled to the United States at the time of the debate and the banquet that Shapley remembers was on the second day of the National Academy of Sciences meeting.[69] Fortunately, Shapley‟s typescript from that night still exists, complete with his handwritten notes, and is valuable in piecing together his side of the debate.[70]

Shapley‟s presentation was much simpler than Curtis‟. He chose to speak in broad generalities instead of focusing on specific technical arguments. Shapley‟s choice of presentation style was interesting and one cannot be sure of his reasons. Perhaps he

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67 Ibid., 88.

68 Bartuskiak, *The Day We Found the Universe,* 153.

69 Ibid.

70 Hoskin, "The „Great Debate,‟" 173.

understood that not all those in attendance had a firm understanding of astronomy, since scientists from disciplines outside of astronomy, as well as members of the public, were present. Conversely, he could have made the presentation simple to avoid embarrassment at the hands of Curtis in a full scientific discussion. Whatever his reasons, the fact remains that Shapley‟s presentation began with a discussion of the then current state of astronomy. He took great care to describe the size and structure of the Milky Way galaxy. Shapley also included in his presentation a collection of slides made with the one hundred inch telescope at Mount Wilson Observatory, taking the audience on a "visual tour of the known universe."[71] He was so thorough in his explanation that it took him six pages to arrive at the definition of a light-year, the distance that light travels in a year.[72]

Once Shapley had laid the foundation of his topic, he began to speak about the major issue in which he differed from Curtis. The difference, and the basis for this debate, involved the size of the Milky Way galaxy. Before Shapley‟s research, it accepted that the galaxy‟s diameter was somewhere around twenty to thirty thousand light years across.[73] Using Cepheid variable stars Shapely expanded the galaxy‟s diameter by ten, to about three hundred thousand light years. A Cepheid variable is a star that pulses at an exact rate. Knowing that rate astronomers can calculate the star‟s absolute luminosity. With this absolute luminosity, they can then determine the stars exact distance from

[71] Bertusiak, *The Day We Found the Universe,* 153.

[72] Hoskin, "The „Great Debate,‟" 173.

[73] Bertusiak, *The Day We Found the Universe*, 103.

Earth.[74] Shapely believed that all of the observed spiral nebulae must fall within the galaxy"s boundaries because it was unthinkable for the spirals to be other star systems that were also three hundred thousand light years across. If they were truly that large then it meant they were incredibly far away. Shapley"s argument against the Island Universe theory was that the Milky Way was so large that it must house all of the various astronomical phenomena seen in the sky.[75]

He then finished his lecture with three pages detailing an intensifier that he had developed and perfected. An intensifier amplifies the light from distant, dim stars and other celestial objects, allowing them to be photographed. His intensifier had nothing to do with the debate and he inserted it for the men he thought would be in attendance to scrutinize him for the directorship at the Harvard Observatory. The address he presented that night is significantly different from the scientific paper he submitted for publication a year later.[76]

Shapley"s presentation surprised Curtis, who had prepared a much more scientific paper. In a letter to Shapley after the debate, Curtis admitted that he had thought of changing his presentation into something a little less complex to match the tenor of Shapley"s, but instead "decided at the last minute to go ahead with program as

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[74] Ibid., 95-97.

[75] M.A. Hoskin, "The „Great Debate": What Really Happened," *Journal for the History of Astronomy* 7 (1976): 175-178, 177.

[76] Ibid., 173.

planned."[77] His presentation consisted of a collection of slides, some of which still exist, used to counter Shapley‟s arguments.

Curtis began with his interpretation of the size of the Milky Way. He believed in an older, established view of the size of the galaxy, supported by other astronomers like Charles Wolf and Simon Newcomb. Wolf thought the galaxy was about fourteen thousand light years in diameter, while Newcomb felt it was about twice that size, or around thirty thousand light years across. Curtis himself felt that thirty thousand light years corresponded to the maximum size of the galaxy, although he also felt it was probably significantly smaller than that.[78]

Curtis then addressed a subject that Shapley had glossed over in his presentation, the spiral nebulae. For Curtis the argument about the scale of the universe could be settled by careful examination of the spiral nebulae. First, he used a slide that examined the light spectrum observed from spiral nebulae. The spectrum of the spirals was the same as the spectrum observed from other star clusters, meaning that the light was coming from the same type of object. He then went on to point out that the spectrum observed in spirals would be expected from vast groupings of stars. Finally, Curtis showed that the spectrum emitted by the spiral nebulae was no different from the spectrum observed from the Milky Way galaxy. He argued that if the spiral nebulae were

[77] Clark, *Measuring the Cosmos,* 83.

[78] M.A. Hoskin, "The „Great Debate‟: What Really Happened," *Journal for the History of Astronomy* 7 (1976): 178-181, 178.

anything but other forms of galaxies then they would manifest a different kind of spectra, probably matching another kind of nebula.[79]

Curtis then turned to the spiral nebulae, which from the earth appear to be of different sizes. All of them were observed to have the same basic structure but some were so small that they could barely be seen, while others were quite large and easy to observe. He felt that such a large range of different apparent sizes meant the larger spirals were closer to earth and the smaller ones further away. In addition, as new, more powerful telescopes were developed, astronomers found more spiral nebulae instead of new stars. Curtis believed that if Shapley‟s galaxy size was correct then scientists should have seen more stars, to correspond with the galaxy‟s larger size, and not more spiral nebulae. The fact that astronomers were not observing more stars meant they had seen the edge of the Milky Way and would only continue to discover more spiral nebulae.[80]

Curtis next addressed the location of the spiral nebulae in the sky. Astronomers observed them in the regions of the sky outside of the galactic plane, which conversely contains the fewest stars. He stated that a spiral nebula had never been observed in the plane of the Milky Way. This happened because the dust and matter that make up the galaxy made it impossible to observe spiral nebulae through the plane of the galaxy. Through observation, astronomers had seen the same dust lanes in the spiral nebulae,

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[79] Ibid., 179.

[80] Clark, *Measuring the Cosmos,* 83-84.

another example of the Milky Way being a spiral nebula.[81]

Finally, Curtis compared novae that occurred within the Milky Way galaxy to novae observed in the spiral nebulae Andromeda. He took the novae and averaged their maximum and minimum apparent magnitude, how bright the novae appeared when observed from earth. Curtis found that the novae in Andromeda were considerably dimmer than those observed in the Milky Way. He assumed that the novae were caused by the same phenomena, and would have the same absolute magnitude, the actual brightness of the object. Curtis then adjusted the apparent magnitude of the novae from Andromeda to approximate the novae found in the Milky Way. When he finished his calculations, he found that for the apparent magnitudes to match, the novae in Andromeda needed to be about five hundred thousand light years away. Not only did this distance put Andromeda outside the old model of the universe, but it also meant that if Shapley‟s Milky Way proved to be the correct size then Andromeda was still beyond its boundaries.[82]

Curtis felt that he came out the victor over Shapley. Friends told him that he had done well and he expressed that in a letter to his family saying, "Debate went off fine in Washington, and I have been assured that I came out considerably in front."[83] Shapley did not fare as well. His old mentor, Henry Russell, was in the audience that night observing the debate. In a letter to Hale after the program Russell wrote that Shapley

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[81] Hoskin, "The „Great Debate,‟" 180.

[82] Ibid.

[83] Clark, *Measuring the Cosmos,* 88.

needed to improve the "gift of gab."[84] Worse for Shapley, George Agassiz, from Harvard, observed in a letter to the president of Harvard, "[Shapley] has . . . a some what [sic] peculiar and nervous personality . . . lacks maturity and force, and does not give the impression of being a big enough personality for the [directorship] position."[85] However, in spite of his poor performance Harvard decided to give him a chief-of-staff position at the observatory in 1921, and one-year later he became the full director of the observatory.[86] Finally, later in life, Shapley agreed that Curtis‟ presentation had been much better saying, "I read my paper and Curtis presented his paper, probably not reading much since he was an articulate person and was not scared."[87]

Examining the arguments of both men shows that they were both correct. Curtis‟ conservative approximation of thirty thousand light years for the diameter of the Milky Way was wrong and Shapley‟s belief that the galaxy was larger would eventually be proved correct. However, Shapley‟s estimation that the Milky Way was three hundred thousand light years in diameter was far too ambitious; most modern astronomers agree that the Milky Way is about one hundred thousand light years across.[88]

However, while Shapley proposed correctly that the Milky Way was indeed larger than previously believed, Curtis‟ argument that the spiral nebulae were other galaxies had the longest lasting effect. Just four years after the debate, a young astronomer named

[84] Bartusiak, *The Day We Found the Universe,* 156.

[85] Ibid.

[86] Ibid., 166.

[87] Clark, *Measuring the Universe,* 88.

[88] Ibid., 4.

Edwin Hubble proved the Island Universe theory correct. Working at Mount Wilson Observatory, with the one-hundred inch Hooker telescope, Hubble found a Cepheid variable star in the Andromeda nebula. Hubble used Shapley"s formula to calculate the distance to the star and found that it was over two million light years away.[89] Andromeda was not a nebula; it was a separate galaxy full of millions of stars just like the Milky Way. Hubble"s discovery confirmed the validity of the theory that Curtis had spent the last ten years expounding.

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[89] Ibid., 104.

CHAPTER FIVE

CURTIS AS ASTRONOMICAL DIRECTOR

After ten years of continuing James Keeler"s observation program at the Lick Observatory, Curtis" research reached a terminal point. Instead of beginning a new program at Lick Observatory, he accepted an invitation to become the director of the Allegheny Observatory of the University of Pittsburgh. This move ended the most productive period of his life.[1] From 1920 on Curtis would contribute few new scientific discoveries; however, he would continue to popularize and teach astronomy while also working to develop new and better instruments. Although Curtis would do little more to expand the understanding of the cosmos during this period of his life, he was still contributing to the astronomical discipline in other ways. Astronomy would be a major part of his life until his death in 1942.

The history of the Allegheny Observatory begins in 1858 with the appearance of Donati"s Comet.[2] The comet influenced a group of Pittsburgh businessmen to buy a telescope and start a small amateur society called the Allegheny Telescope Association.[3] The group purchased a thirteen-inch refractor, the third largest telescope in the country at the time, and built an observatory to house the telescope on Northside hill in Pittsburgh,

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[1] Robert G. Aitken, "Biographical Memoir of Heber Doust Curtis (1872-1942)," in *National Academy of Sciences of the Unites States of America Biographical Memoirs* 22 (1942): 273-294, 279.

[2] Comet Donati was the first to be photographed and the second brightest comet of the nineteenth century. It is most famous for having an enormous tail stretching a full sixty degrees across the sky. See George P. Bond, "An Account of Donati"s Comet of 1858," *The Mathematical Monthly* (1858): 1-33.

[3] The Allegheny Telescope Association is an example of the type of society that existed within the amateur wing of astronomy. These small groups allowed people who normally would not have access to telescopes the opportunity to observe and contribute to the discipline.

Pennsylvania.[4] Over time, interest in the observatory and association waned and it became difficult to get funds through donations and dues. Finally, in 1867 the association transferred the observatory and telescope to the Western University of Pennsylvania, a predecessor to the modern University of Pittsburgh.[5] In 1920, Curtis became the fourth director of the observatory, following in the footsteps of such famous astronomers as James Keeler and John Brashear.[6]

One of the major problems with Curtis" transition to the Allegheny Observatory was that the observatory was equipped to study stellar parallax, a discipline within astronomy with which Curtis had no previous experience. Curtis decided to continue the stellar parallax work instead of creating a new observation program that matched his experience with stellar and nebular spectroscopy. While this decision helped the observatory stay productive, as the people and equipment of the observatory were prepared for parallax research it did little to help Curtis continue his work on the Island Universe theory. In fact, although Curtis helped in the observatory by taking his turn using the thirty-inch refractor to take photographs for parallax research, he did not contribute much tothe actual calculation of stellar parallax.[7] Curtis did change the way the observatory functioned. Before Curtis arrived from San Jose, the observatory

[4] "Astronomy and Astrophysics: Allegheny Observatory," National Park Service, last modified November 5, 2001, http://www.cr.nps.gov/history/online_books/butowsky5/astro4m.htm (accessed March 21, 2011).

[5] Ibid.

[6] John Brashear was one of the most famous telescope builders of late nineteenth century American astronomy. For more information on Brashear, see John A. Brashear, *The Autobiography of a Man Who Loved the Stars* (New York: Houghton Mifflin Co., 1925).

[7] Dean B. McLaughlin, "Heber Doust Curtis," in *Popular Astronomy* L, no. 4 (April 1942): 175-181, 179.

functioned solely in stellar parallax research; however, he changed the observation schedule and allowed the astronomers time to do their own research, something they lacked under his predecessor.[8] Curtis did little of his own research; he instead chose to busy himself with the responsibilities of administration, the teaching assignment within the astronomy department at the University of Pittsburgh that came with the directorship, and working in the observatory‟s machine shop.

Also, Curtis‟ part in "The Great Debate" with Harlow Shapely had given him some degree of fame and he was always in demand as a lecturer.[9] In one lecture, preserved in the journal *Popular Astronomy*, Curtis spoke at the dedication of the Irving Church Memorial Telescope of the Fuertes Observatory at Cornell University.[10] The topic of the address was "The Influence of Astronomy upon Modern Thought," and in the lecture, delivered before what can be assumed to be an astronomical lay-crowd, Curtis begins by discussing the wonder that everyone has felt from time to time as they look into a starry night. He then expands on that experience by describing just how amazing the view actually is, calling it modern magic. Curtis says, "Waves of light . . . started their long journey across space towards us ten thousand years ago" and "much diminished in strength . . . finish their ten-thousand-year journey in the direction of our telescope, enter it, and . . . beat for several hours upon the silver grains imprisoned in the film of our

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[8] John Lankford, *American Astronomy: Community, Careers, and Power, 1859-1940* (Chicago, The University of Chicago Press, 1997), 197.

[9] Aitken, "Heber Doust Curtis," 281.

[10] *Popular Astronomy* was published from 1893-1951 and was designed to encourage amateur astronomy. For more information on *Popular Astronomy* see Horace A. Smith, "Popular Astronomy Magazine and the Development of Variable Star Observing in the United States," *The Journal of the American Association of Variable Star Observers* 9, no. 1 (October 1980): 40-42.

photographic plate" which "after some simple chemical manipulation, obtain the autograph of unnumbered suns quadrillion of miles away. Modern magic!"[11] Another lecture presented in 1926, about halfway through his tenure as director of the Allegheny Observatory, at a meeting for the American Association for the Advancement of Science, was titled "The Unity of the Universe."[12] In this lecture he addresses more the ideas from "The Great Debate" and speaks of the Island Universe theory with certainty.[13] Moreover, Curtis also addressed some of the burgeoning ideas within the subject of stellar development and the life cycles of stars. Overall, the topics of Curtis" lecture were always designed to develop and increase the general public"s interest in astronomy.

Curtis also continued to lead and participate in eclipse expeditions during his time at the Allegheny Observatory. In 1923, Curtis and the observatory sent a joint eclipse expedition with the Sproul Observatory of Swarthmore College in Swarthmore, Pennsylvania to Yerbanis, Mexico.[14] During his first three years as director, Curtis became a close friend of John Miller, the director of Sproul Observatory. That friendship allowed for a close collaboration between the two observatories and a total of five joint

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[11] Heber D. Curtis, "The Influence of Astronomy upon Modern Thought," *Popular Astronomy* 32 (1924): 4-10, 8.

[12] Heber D. Curtis, "The Unity of the Universe," *The Journal of the Royal Astronomical Society of Canada* 22, no. 10 (December 1928): 399-412.

[13] The lecture was given four years after Hubble"s discovery of the distance to the Andromeda Galaxy which was a major step in establishing the veracity of the Island Universe theory, that all the spiral nebulae are actually distinct and separate star systems full of hundreds of millions of stars.

[14] John A. Miller, "The Sproul Observatory Eclipse Expedition," *Popular Astronomy* 31 (1923): 579-582.

eclipse expeditions during Curtis‟ tenure at the Allegheny Observatory.[15] Although Curtis participated in the planning and implementation of these eclipse expeditions and designed new instruments for them, he added little to the scientific discoveries of the expeditions.

Most of the work that Curtis did at the Allegheny Observatory involved the improvement of the observatory‟s machine shop and the upgrading or developing of new astronomical instruments. One of his first tasks was correcting the drive gear of the observatory‟s thirty-inch telescope. The mechanism had a small defect from the factory and Curtis took it upon himself to fix the problem. Within days he dissembled the drive gear, ground the parts in question and reinstalled them, fixing the issue with the machine.[16] As Curtis worked in the machine shop, he developed a new type of comparator.[17] Astronomers use an astronomical comparator to compare two separate photographic plates; in comparing the plates quickly astronomers are able to see any differences in the objects imaged on the plates.[18] With his comparator Curtis attempted to solve some of the problems with earlier models. One issue with standard comparators was the size of the device. In a standard sized comparator the plates were mounted side by side, spreading the mechanism over almost a meter wide. Another problem was that

[15] Robert R. McMath, "Heber Doust Curtis," *The Astrophysical Journal: An International Review of Spectroscopy and Astronomical Physics* 99, no. 3 (May 1944): 245-248, 247.

[16] Aitken, "Heber Doust Curtis," 281.

[17] Heber D. Curtis, "A New Type of Comparator," *Publications of the Allegheny Observatory of the University of Pittsburgh* 8, no. 2 (1969): 15-17.

[18] Clyde Tombaugh was using a comparator when he discovered Pluto in 1930. See Robert Bud and Deborah Jean Warner, eds., *Instruments of Science: An Historical Encyclopedia* (London: The Science Museum, 1998), 126.

the vast distance between the plates could also magnify any anomaly caused by temperature or improper mounting.[19] To solve these problems Curtis designed a comparator that mounted the plates vertically, with one plate placed above the other. This solution allowed him to construct a comparator that was much smaller than the standard type, about twenty-three centimeters across instead of a meter. Making the comparator more compact also helped to eliminate imaging problems caused by differences in temperature and mounting problems. The compactness of the comparator also allowed it to function faster and more efficiently.[20]

Although Curtis" work in the improved machine shop proved fruitful for the observatory, he was never able to achieve his ultimate plans for the observatory. Curtis planned to refit and update one of the observatory"s thirty-inch reflectors to allow it to be used for solar spectroscopy. This would have allowed him to continue his spectrographic research, although with the sun as a target instead of nebulae. Ultimately, a lack of funding through the university and private donors upset his plans and Curtis could never institute a spectroscopic research program at the Allegheny Observatory.[21] Although Curtis contributed little new in the way of astronomical discovery and research while at the Allegheny Observatory, he proved to be a capable director and in 1930 an invitation arrived asking him to return to the University of Michigan to serve as the director of the university"s observatory.[22]

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[19] Curtis, "A New Type of Comparator," 15.

[20] Ibid.

[21] Lankford, "American Astronomy," 197.

[22] McMath, "Heber Doust Curtis," 247.

The directorship at the University of Michigan was ideal because it offered the assurance that funds were available to construct an extremely large, eighty-five inch telescope and a new observatory.[23] The University of Michigan‟s first observatory was constructed at Ann Arbor in 1854 with donations from members of the population of Detroit. The first director, Franz F. E. Brünnow, named the observatory the Detroit Observatory to honor the people‟s donation.[24] However, by the beginning of the twentieth century the growth of Ann Arbor made the observatory‟s location unsuitable. The city‟s lights made it difficult to observe deep sky objects; further, a railroad that ran near the observatory and the associated building would shake when trains passed, making precise observations impossible. In 1920s, the University of Michigan began to look for a more suitable location where a new observatory could be constructed. The location finally chosen was about fifteen miles northwest of Ann Arbor, close to Portage Lake, and the university began to purchase land. By 1929, when the search for a new director began, the university had almost three hundred acres of land purchased for the construction of the new observatory.[25]

The idea of once again using a large telescope and working in a modern observatory intrigued Curtis and he accepted the directorship at the University of

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[23] Aitken, "Heber Doust Curtis," 281.

[24] Dave Snyder, "The History of the Detroit Observatory," University of Michigan, last modified February 22, 2008, http://www.umich.edu/~lowbrows/reflections/1998/dsnyder.13.html (accessed March 3, 2011).

[25] Dave Snyder, "The History of the Portage Lack Observatory," University of Michigan, last modified April 11, 2006, http://www.umich.edu/~lowbrows/history/portage-lake.html (accessed March 3, 2011).

Michigan.[26] Curtis was most excited about his new position because he wanted to try his hand at designing a mounting system for a telescope and equipping a major research observatory.[27] Also, Curtis had already worked with a large telescope, the thirty-six inch Crossley telescope, and he understood that some research problems required a large telescope to solve. The telescope planned for construction in Michigan would be an eighty-five inch reflector, much larger than the Crossley telescope that Curtis used at Lick Observatory.[28] By 1932, Curtis completed his designs for the telescope and observatory; unfortunately, this year was also the height of the Great Depression, which had taken its toll on the donors of the new observatory, and funds were no longer available for it.[29] Curtis made the best of this situation and, using the money already given to the university, he commissioned the Corning Glass Works Company to cast glass for the primary mirror. The first cast was defective and the glass works offered to recast the glass, only this time larger and for a small additional cost, to which Curtis agreed. The second cast, a massive ninety-seven inch blank, was successful and subsequently stored at the University of Michigan in hopes that one day funds would be available to build the telescope.[30]

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[26] Aitken, "Heber Doust Curtis," 281.

[27] McLaughlin, "Heber Doust Curtis," 179.

[28] Ibid.

[29] McMath, "Heber Doust Curtis," 247.

[30] McLaughlin, "Heber Doust Curtis," 179. The ninety-seven inch blank might have been moved to Arizona and used to construct the Hiltner telescope when the University of Michigan opened the MDM Observatory.

The inability to construct a telescope and observatory disappointed Curtis; however, he responded by devoting himself to the work of director. Once again, most of his time was consumed by administrative work, but he made time to be a part of the teaching program at the university. He typically taught a section of descriptive astronomy and at least one semester a year he taught a navigation course. Curtis also intermittently taught a seminar on cosmogony.[31] In 1932, despite the difficulty of acquiring funds during the Great Depression, he organized and led a solar eclipse expedition to Fryeburg, Maine, marking the eleventh and last eclipse expedition of his career.[32]

Curtis continued to work during the last few years of his life, insisting on taking his turn at the Detroit Observatory‟s thirty-seven inch reflector taking spectrograms. Although he never performed any research from this data, he was always willing to spend the night with the telescope and make the observations.[33] He struggled with a recurring illness, which he could not shake over the last years of his life, causing him finally to give up the late nights of observing. However, even throughout this illness he still maintained his teaching load and continued with his administrative duties as the director of the observatory. In the last month of his life, he even attended the annual American Astronomical Society‟s meeting in Cleveland, Ohio, playing an active part in the meeting

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[31] Cosmogony is a study of the origin and evolution of individual objects in the universe, like planets, stars, and galaxies. See Ridpath, *Encyclopedia of Astronomy*, 52.

[32] McMath, "Heber Doust Curtis," 71.

[33] McLaughlin, "Heber Doust Curtis," 179.

even though he complained that he was fatigued.[34] Finally, after a career devoted to astronomy, Curtis died in his sleep on January 9, 1942 at the age of seventy.[35]

[34] Aitken, "Heber Doust Curtis," 282.

[35] Ibid.

CONCLUSION

Heber Doust Curtis‟ varied and significant career occurred through a combination of circumstance and skill. He came upon American astronomy at a time when it was transitioning from a discipline with a significant amateur presence to a more professionalized, expert science. The changing nature of astronomy allowed him to earn a Ph.D. with no previous astronomical training and his skill and ability allowed him to excel within the field. Perhaps more than any other astronomer, Curtis benefited from the changing nature of astronomy at the beginning of the twentieth century and the haziness of the boundary between amateur and professional astronomers.

To astronomy Curtis brought a zeal for discovery and a facility with machine work. He spent as much time designing, modifying, and constructing equipment as he did in observatories studying the night sky. The joy he found in the machine shop was matched only by that he found as he looked out into space to see the wonders and hidden mysteries there. Curtis came into astronomy at a time of transition, when new instruments and techniques were beginning to become standardized within the discipline. He embraced those new additions, especially spectroscopy, and bettered astronomy with their use. Curtis‟ first use of the spectrograph came as he worked in South America, where he observed and catalogued the radial velocity of southern stars using spectroscopy. That work transitioned to study nebulae, an observing project created by James Keeler but refined and perfected by Curtis, when he returned from Chile to Lick Observatory in 1910. From 1910 to 1920, he contributed the most to astronomy.

His study of the spiral nebulae remains groundbreaking in that the information presented changed the way we understand the size and shape of the cosmos. Before Curtis" research astronomers believed that the universe and Milky Way galaxy were equal, that the phenomena observed in the night sky could be held within the bounds of the Milky Way. However, his research showed the spiral nebulae were in fact other distinct galaxies like the Milky Way, full of hundreds of millions of stars like our sun, billions of light-years away from the Earth. With this new perspective of the breadth and scale of the universe, Curtis changed humanity"s understanding of its place in the cosmos. This idea, that the universe is much larger and grander than anyone realized, is Curtis" lasting legacy. As his research led him to this new idea, he fought tenaciously against other scientist who opposed the Island Universe theory. Once Curtis remarked to Dean McLaughlin, another astronomer and friend who would later go on to write a biography of Curtis in the *Popular Astronomy* after his death, that "there was a time, around 1923, when he was practically an Irish majority in his adherence to the island universe theory."[1] However, his ideas proved correct in 1924 when Edwin Hubble confirmed that Andromeda was not a spiral nebula but a spiral galaxy, another collection of billions of stars, with billions of planets just like the Milky Way galaxy. For his work at the forefront of research and discovery involving the Island Universe theory, Curtis is one of the most important astronomers of the early twentieth century.

[1] Dean B. McLaughlin, "Heber Doust Curtis," in *Popular Astronomy* L, no. 4 (April 1942): 175-181, 178.

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