Feature Article

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Wisconsin at the Frontiers of Astronomy: A History of Innovation and Exploration

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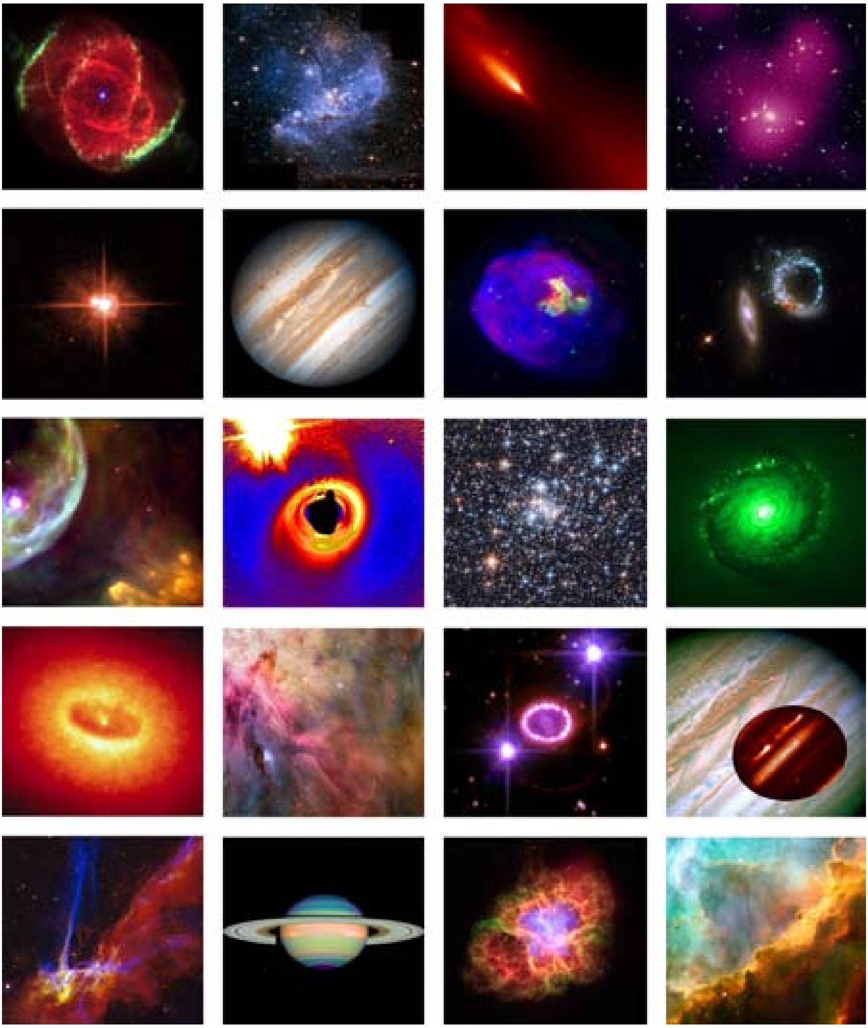

(NASA/Hubble)

Wisconsin at the Frontiers of Astronomy: A History of Innovation and Exploration

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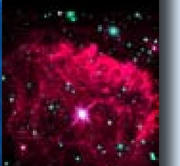

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Wisconsin at the Frontiers of Astronomy: A History of Innovation and Exploration

Introduction

Few residents of Wisconsin know that their state ranks as one of the leaders in the world of astronomy today, and fewer still are aware that this was true 128 years ago as well. Astronomy was one of the earliest scientific fields in which the growth of the University of Wisconsin took root, with the result that it has blossomed into one of the world's leading research universities. Wisconsin astronomy is famous for historic telescopes, major astronomical discoveries, great technological developments, and as a place where talent is recognized, nurtured, and frequently transplanted to other parts of the world as our young researchers find other fields to plow. Wisconsin is one of the places where traditional astronomy gave birth to the modern science of astrophysics and was, as it still is, home to pivotal figures who create the scientific institutions that deliver the astronomy of the future.

This history of Wisconsin's astronomers and the early emergence of world-class astronomy in the American Midwest shows that excellence in academic research drives excellence in education, a truth that was recognized early by Cadwallader Washburn, former governor and observatory benefactor, and some of his forward-looking contemporaries who took it to heart and invested their hard won fortunes in it. They saw the novel concept of a "research university," which was showing considerable promise and success in Europe, as an important example for the young universities of the growing United States. Perhaps less apparent to them at the time, but well born out by the history of science in the late nineteenth and early twentieth centuries, is that academic research drives innovation in science, and new science is a powerful force in technological development, which in turn is a strong foundation for economic success. It is an admirable example of the real power of ideas. Astronomy played a major role in establishing Wisconsin as more than abundant forests, fertile farmland, and a staging area for long treks across the frontier of the American West. In fact, Wisconsin became a geographical fulcrum in the development of American astronomy, which as early as the 1890s was dominated by institutions on the two coasts. Connections between our own Washburn Observatory and California's Lick Observatory are only the most obvious of the connections made in Wisconsin that contributed greatly to the growth of astronomy in the U.S. and, especially after World War II, the global astronomical community.

This historical account of the contributions of our state to the development of astronomy is necessarily very selective. We have attempted to include the most important aspects that illuminate the development of astronomy in Wisconsin as well as the major contributions the state has made to the science and institutions of astronomy more generally. Although much of this study necessarily focuses on the University of Wisconsin, we have attempted to widen the scope enough to indicate that astronomy's story in Wisconsin extends from well before statehood and well beyond Madison. In fact, although created and operated by the University of Chicago, we claim the Yerkes Observatory in Williams Bay as also a Wisconsin institution and argue for Wisconsin's contribution to its worldwide fame and success. It is inevitable that many important and interesting stories will be passed over, and to this we can only respond with the hope that other authors will work to rectify our reluctant omissions. We have also attempted to convey the scientific content and significance of the history with a minimum of technical details. A fuller accounting would benefit from deeper exploration of the science at the root of these stories, but for the purposes here we refer the interested reader instead to the sources listed in the bibliography.

Early Days

American Indian Traditions and the Prehistory of Wisconsin Astronomy

The first human inhabitants of what is now Wisconsin were also the first to think about the cosmos and to make meaning out of what they saw in the sky. Unfortunately, little is known about the cultures that lived in present-day Wisconsin for over 11,000 years before the arrival of the first Europeans.

One American Indian culture, dubbed the Mississippian culture by archaeologists, flourished from around 1000 to 1400 A.D. along the Mississippi River in what is now southern Illinois with some settlements in modern Wisconsin. One of the best known Mississippian settlements is located in Wisconsin's Aztalan State Park, near Lake Mills between Madison and Milwaukee. The Mississippian culture may have practiced what looks to us like "astronomy" in the sense of building instruments to mark the motions of heavenly bodies. However, we must be very careful when assigning intent to a culture that existed centuries ago and left behind no written records. Near the Mississippians' largest settlement, the city now called Cahokia (in southwestern Illinois), the Mississippians constructed a number of structures that have been dubbed "woodhenges." These woodhenges consisted of a number of wooden posts set upright in the ground in the shape of a circle. When viewed from the center of this circle, the rising (or setting) sun appears to line up with one of these posts on particular days of the year. Archaeologists believe that these structures served as physical calendars to alert Mississippian priests about important ceremonial days, although there is no evidence that Mississippians used woodhenges to understand or to predict the motion of the sun systematically.

Related to the Mississippian culture was the succeeding Effigy Mound culture, which flourished almost entirely within present-day Wisconsin. The Effigy Mound culture was named for the thousands of elaborate and sometimes enormous mounds that were built in the shapes of animals, including lizards, panthers, bears, and birds. Many of these mounds contain human remains and thus likely served important ceremonial and funerary functions. However, the unique shapes of these

Bird-shaped effigy mound located near the Washburn Observatory on the UW-Madison campus. (UW-Madison Archives)

mounds have raised many questions about their exact purpose. Archaeologists and anthropologists speculate that the mounds may also have been offerings that reflected a desire for stability and renewal during a period of unsettling social change for the Mound Builders. The shapes of the mounds and the animals that they represent are thought to be related to important realms of the physical world and thus also form a picture of the Mound Builders' "universe:" lizard- and panther-shaped mounds were related to water and are frequently found along lakeshores and river-banks, bear mounds represent the land or the earth, while bird mounds, often found on hilltops or areas of higher elevation, represent air or the sky. If the builders were thinking of the sky while constructing some of these bird-shaped effigies, it is perhaps appropriate that a bird mound sits adjacent to the Washburn Observatory in Madison, the first permanent astronomical observatory of the Effigy Mound culture's European-descended successors. It is also painfully ironic that another mound was destroyed in the construction of this observatory.

As with the Mississippian woodhenges, some researchers have suggested that the effigy mounds show alignments with rising and setting points of the sun, moon, and certain stars. In addition to the animal-shaped mounds, there are also a large number of "linear" mounds across Wisconsin, the purpose or meaning of which is not understood. It is possible that these linear mounds had some relationship with particular astronomical phenomena. Nevertheless, without compelling evidence that effigy mounds served this supposed observational purpose, we should resist the temptation to see them as such. Instead, we should understand the mounds as their builders seem to have intended: important ceremonial sites and representations of key realms of their physical and spiritual world.

The sky also figures into the cultures of the American Indians who occupied Wisconsin when the first Europeans arrived, including the Ho-Chunk and Menominee tribes. Numerous stories survive from these cultures that incorporate the sun, moon, and stars, often in creation narratives that relate Earth, sky, humans, animals, and spirits. Consider this Ho-Chunk legend about the origin of the phases of the moon.

"The Moons"

A long, long time ago, the good spirits and the bad ones divided things among themselves, but sometimes they did not agree, for the evil spirits wanted too much; they were selfish. One day they all held a council to decide how long the seasons should be. The Wild Turkey strutted out before all the others, spreading his tail feathers. He said that the year should have as many moons in it as there were spots on his tail feathers.

But the councilors said that would be much too long. Then the Partridge strutted out as had the Turkey, and wanted as many moons, or months, as there were spots in his tail. But the spirits said that his tail was too large, also, and had too many spots.

Then the little Chipmunk ran out into a sunny spot among them … In his squeaky little voice he suggested that every year have as many moons as there are stripes on his back. There were, as you know, six yellowish-white stripes and six black ones. The councilors said they guessed that it would be about right to have 12 moons, or months, every year, and that the white stripes could be the winter months, and the black stripes the summer months …

When the moon is full, the evil spirits begin to nibble at it, to put out its light, for the evil spirits like the darkness best. Each night they eat away a part of the moon, until in two weeks it is gone. But the Great Spirit will not permit them to take advantage of the darkness to go about the world doing mischief, so he makes a new moon. He makes a little of it each night for the next two weeks until finally a big new moon hangs in the sky again. Then he rests, and the evil spirits begin all over again.

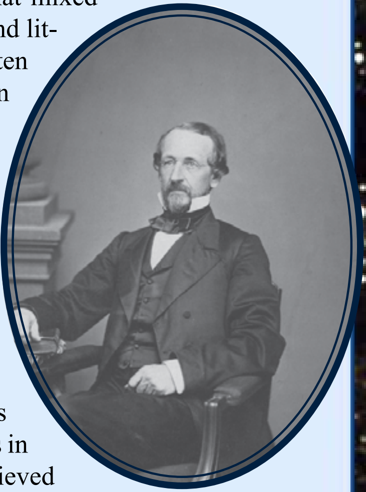
(Oliver La Mere and Harold B. Shinn, Winnebago Stories *(New York: Rand McNally, 1928): 91-99.)*

Tribes such as the Ho-Chunk continue to tell stories such as these today, and they remain an important part of Wisconsin culture as a whole. Although the rest of this article focuses on the history of the 150 years of astronomy as Wisconsin's European-descended occupants practiced it, we would do well to remember that inhabitants of Wisconsin have been thinking about the cosmos for millennia.

The European Tradition: Astronomy and Higher Education at the University of Wisconsin

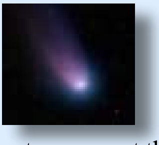
Astronomy in the European tradition likely entered Wisconsin with the first French explorers in the seventeenth century, as a basic understanding of astronomy was essential to safe navigation. Astronomy in such practical forms continued to play an important role in the development of Wisconsin through the eighteenth and nineteenth centuries. For instance, surveyors used astronomical techniques to determine a given location's latitude and longitude. These skills were necessary for mapping and parceling the territory that had been added to the United States after the Revolutionary War. However, organized astronomical research was effectively absent from the Wisconsin Territory, developing only with the growth of the new university that was created after Wisconsin attained statehood in 1848.

The history of astronomy at the University of Wisconsin began almost immediately after the university's founding in 1849. Its first faculty member was John Sterling, who held the title Professor of Mathematics, Natural Philosophy, and Astronomy. By 1854, all UW undergraduates were required to complete at least one term of astronomy as part of a fixed curriculum that mixed the sciences with classical languages, philosophy, and literature. Although this "classical curriculum" is often portrayed as stodgy and outdated, UW graduates in the nineteenth century had a greater literacy in astronomy than an average student of today. However, for the first three decades of the university, astronomy remained a classroom exercise: UW possessed no astronomical instruments, nor did it have an observatory.



John W. Sterling
(UW-Madison Archives)

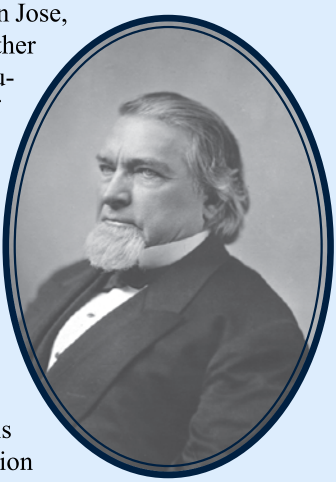
As expensive, elaborate, and highly visible sites of scientific research, observatories in the nineteenth century served not only as places for teaching and making new discoveries, but also as symbols of prestige for new colleges and universities in the expanding United States. The UW Regents believed from the beginning that an observatory would be essential to the school's educational mission. When the university campus was designed in the early 1850s, plans called for a central building "surmounted by an observatory for astronomical observations." Because of a lack of funds, this observatory was never incorporated into the building known today as Bascom Hall. The Board of Regents continued to discuss the need for an observatory throughout the 1860s and 1870s, arguing in 1875 "[I]n this age, an astronomical observatory is one of the characteristic and essential features of every educational institution of this order. It is scarcely possible to conceive of a university worthy of the title, where professors and attendants are denied this necessary instrumentality in the promotion of the interesting and progressive study of astronomical science." Other nearby schools, such as the University of Michigan and the Old University of Chicago (which existed from 1857 to 1886 and was succeeded by another university of the same name) had recently acquired observatories with large telescopes, both of which wealthy private citizens had funded. The Wisconsin Regents were no doubt very aware of these facts and clearly believed that their university was lagging behind in a nationwide movement to develop the practice and teaching of science within higher education.



The Birth of the Washburn Observatory, 1877-1880

Funding for Wisconsin's first major observatory did not materialize until 1877. During the previous year, the Wisconsin Legislature passed a resolution providing a salary for a new professor of astronomy at the university provided that some wealthy patrons donate an observatory. This patron, who had in fact helped to craft the legislation behind the scenes, was Cadwallader C. Washburn. Washburn was a former U.S. Representative, Civil War general, and governor of Wisconsin from 1872 to 1874, and thus had a strong political presence. Washburn had made his fortune in the flour-milling industry; his Minneapolis-based mills served as the foundation for the company known today as General Mills. As Washburn never revealed any strong interest in astronomy, it is not clear why he chose to give the university an observatory, although he likely knew some basic astronomical skills from an early career as a land surveyor. It is most likely that Washburn was influenced by the trend of other wealthy individuals who were donating money to build large observatories across the United States. One such patron was James Lick, who bequeathed money in 1876 to build the world's largest observatory outside of San Jose, California. Lick's observatory was built both to further the practice of science in America and also as a monument to himself (Lick was later buried at the base of his observatory's main telescope).

In addition to the donation of an observatory building and instruments, the University of Wisconsin also received an endowment from Washburn's friend and business partner Cyrus Woodman to support an astronomical library. The Woodman Fund (which still exists despite being severely diminished during the Great Depression) was significant for several reasons. First, it provided the observatory with the essential texts and journals necessary for any effective scientific research institution of the era, a seemingly mundane yet very significant resource. Second, it allowed for the purchase of many old texts that strengthened the university's rare book collection in later years. Finally, and most important, the Woodman Library earned a



Cadwallader Colden Washburn (1818-1882), governor of Wisconsin (1872-1874) and founder of the Washburn Observatory. (UW-Madison Archives) prestigious reputation among astronomers across the United States for the depth and quality of its holdings. The observatory became a node in an information exchange that connected it to other observatories and institutions not only across the U.S., but also around the world.

Cyrus Woodman (1814-1889), Washburn's business partner and founder of the Woodman Astronomical Library. (UW Astronomy Dept.)

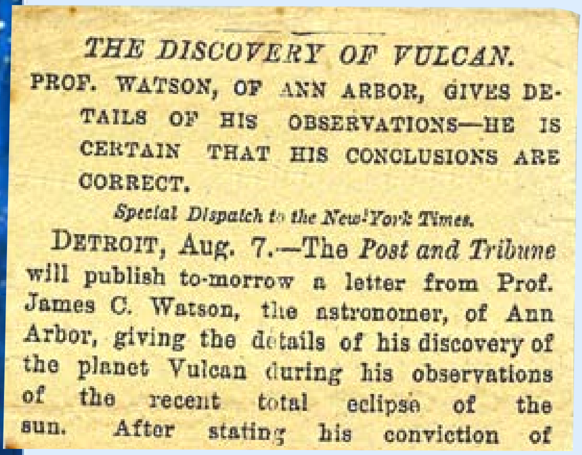
Construction of the new Washburn Observatory began in 1878 on a small hill, now appropriately known as Observatory Hill, west of campus and about a mile from the State Capitol. Flanked by brushy woodland on the north, sloping down to Lake Mendota, and by farmland and orchards on the south slopes, the observatory site was adequately remote from town and campus. Edward Holden, Washburn's second director, who edited the first volumes of the *Publications of Washburn Observatory,* provides many details of the observatory's design and construction. The hilltop was already occupied by a house owned by the university that served as the residence of the UW president. That house, only a few steps from the observatory site, was reassigned to be the residence of the observatory director. The directors of Washburn Observatory would keep their residence there until 1948, when Joel Stebbins retired and left Madison. His successor, Albert Whitford, elected not to move in. The building today is the home of the La Follette School of Public Affairs.

For its first observatory director, the university secured James Craig Watson, then the director of the Detroit Observatory at the University of Michigan. As one

The Washburn Observatory (Jeff Miller/UW-Madison)

James Craig Watson (1838-1880), first director of the Washburn Observatory, 1879-1880. *(UW Astronomy Dept.)*

historian of the observatory has noted, "to judge by contemporary newspaper accounts Watson was wooed by Wisconsin and Michigan with an ardor nowadays reserved for football coaches," an indication of Watson's prestige. He was likely lured by the better facilities that Washburn offered as well as an opportunity to develop a brand-new observatory in order to fit his own particular research interests. Watson was known at the time for his discovery of more than 20 asteroids, which had earned him considerable fame. However, he is perhaps best remembered today for his belief in the hypothetical planet "Vulcan." The orbit of the planet Mercury changes over time in a way that nineteenth-century astronomers found difficult to explain. Some astronomers suggested that the gravitational influence of an unseen planet between Mercury and the sun, dubbed "Vulcan," could explain Mercury's orbital anomalies. After all, such a technique had worked well to explain a similar problem with the orbit of Uranus, which had led to the discovery of Neptune in 1846. Watson had attempted to discover whether or not Vulcan actually existed by observing the sky near the sun during the few minutes of a total solar eclipse: the darkened sky might reveal the planet, which was thought to orbit very close to the sun and would otherwise be invisible because of the sun's brightness. Mercury itself is difficult to observe except at certain times of the year and then only under ideal conditions; Vulcan should have been even more difficult to see. After careful study of the sky near the sun during the total solar eclipse of July 29, 1878, Watson announced to a skeptical world that he had discovered Vulcan.



THE DISCOVERY OF VULCAN.

PROF. WATSON, OF ANN ARBOR, GIVES DETAILS OF HIS OBSERVATIONS—HE IS CERTAIN THAT HIS CONCLUSIONS ARE CORRECT.

Special Dispatch to the New-York Times.

DETROIT, Aug. 7.—The *Post and Tribune* will publish to-morrow a letter from Prof. James C. Watson, the astronomer, of Ann Arbor, giving the details of his discovery of the planet Vulcan during his observations of the recent total eclipse of the sun. After stating his conviction of

From an article in The New York Times*, August 8, 1878, announcing James Watson's claimed discovery of the planet "Vulcan."* *(© The New York Times)*

When he arrived in Madison, Watson began developing a new instrument that he believed would allow him to search for Vulcan any time that the sun was visible, not just during the rare moments of a total solar

The campus of the University of Wisconsin in 1879, including an artist's conception of the Washburn Observatory (lower right sketch), then under construction. (SHSW WHi-32525)

eclipse. Watson based his technique on the ancient but erroneous idea that stars are visible during the daytime from the bottom of a very deep well or shaft. Watson personally funded the construction of a small "solar" observatory near the larger Washburn Observatory building. This solar observatory consisted of a long shaft that ran through the hillside: at the top was a movable mirror that directed light down the shaft, and at the bottom was a telescope to make observations.

While he was building his solar observatory, Watson also paid for additions to the main observatory building, funded a smaller observatory for students, and oversaw the installation of one of the observatory's main instruments. This instrument was a 15.6-inch diameter refracting telescope made by the Alvan Clark and Sons company of Cambridge, Massachusetts. (Refracting telescopes, usually called "refractors," use a glass lens to collect and focus light, whereas a reflecting telescope or "reflector" uses a glass or metal mirror to accomplish the same task.) By the late nineteenth century, Clark telescopes were considered among the best in the world, and the Clarks specialized in building the largest telescopes of the era. When it was completed, the Washburn 15.6-inch was the fourth-largest refractor in the world. However, it held this position only for a brief time as many larger instruments were made shortly thereafter. Most significant about the size of this telescope was that Washburn stipulated it be "equal or superior to" the 15-inch refractor at the Harvard College Observatory. Having a telescope slightly larger than that of Harvard suggested that the University of Wisconsin, as a young midwestern institution, was exceeding, even modestly, the scientific resources of one of the most prestigious East Coast colleges.

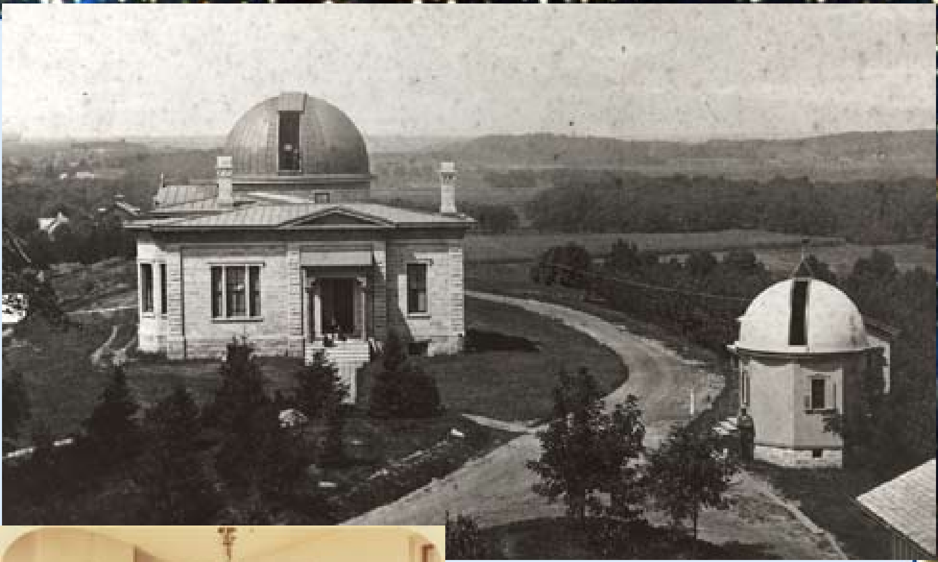
The Development of Astronomy and Scientific Research at the University of Wisconsin, 1881-1922

Watson never saw the completion of the observatory; he died in 1880 at age 42 after spending only two years in Madison. His claim to have discovered Vulcan was forgotten. (Mercury's orbit was eventually understood when Albert Einstein showed in 1916 that his theory of General Relativity predicted distortions of space near the sun that produce the observed effects.) Watson's successor was Edward S. Holden, who was then an astronomer at the U.S. Naval Observatory (USNO) in Washington, D.C. Holden proved to be a good administrator and worked hard to develop the Washburn Observatory into an effective research and teaching institution. Holden supervised the completion of the buildings and instruments, began observations, and started the *Publications of the Washburn Observatory*, which was the university's first research journal. Holden completed Watson's solar observatory, but found that he could not even observe bright stars – let alone a dim planet near the sun – in broad daylight.

Edward Singleton Holden (1846-1914), second director of the Washburn Observatory, 1881-1885. (UW Astronomy Dept.)

Although Washburn had supplied Wisconsin with an observatory, upon which Watson quickly found necessary to expand, he left no permanent endowment for staff or future development. As a result, the financial standing of the observatory for much of its early history was relatively weak. Although Holden and his successors did their best to secure additional funding from the state or from other patrons, the observatory remained a comparatively small institution and retained its original telescopes well into the twentieth century. This lack of finances placed severe restrictions on the types of research that UW astronomers could perform. At the same time, it also forced them to make the best use of the available instruments and to innovate by inventing entirely new ones. Washburn astronomers proved themselves capable of such innovation on numerous occasions.

One way that many nineteenth-century American observatories, including the Washburn Observatory, earned additional income was by selling accurate time signals to railroad companies and other businesses, such as jewelers and clock-makers. Although astronomically determined time was much too exact for daily use, it reflected an emphasis on punctuality that was popular during an industrial age that put a premium on precision and routine. At one point, selling time signals earned the Washburn Observatory at least 15% of its annual income, which helped to subsidize equipment costs and to pay salaries for assistants. The



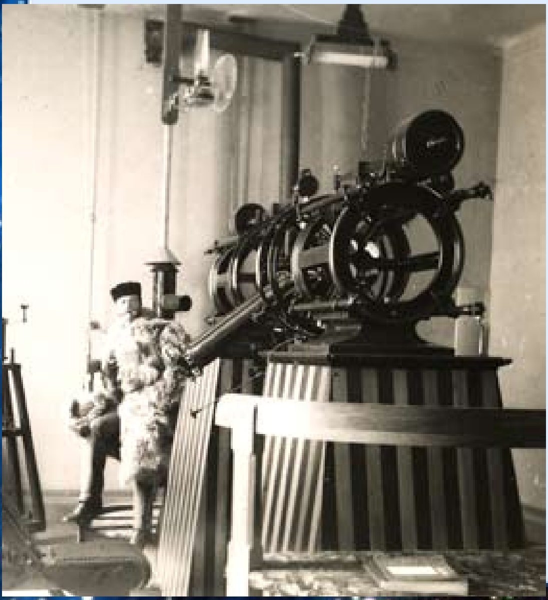
Top: The Washburn Observatory viewed from the east in the 1880s. The 15.6-inch Clark refractor shows through the dome of the main building; the Students' Observatory stands at right. Left: Clock room of the Washburn Observatory. The master clock (in the cabinet, right of center) was used in astronomical observations and in setting other clocks around campus. (UW Astronomy Dept.)

observatory also controlled the clocks at the State Capitol as well as the clocks on campus, making the telegraph lines running to the observatory a frequent target for student vandals. Selling time at UW continued through the end of the nineteenth century; it eventually ceased owing in part to competition with national telegraph networks like Western Union, which supplied time signals much more cheaply.

The Washburn time service emphasizes how the practice of astronomy in the late nineteenth century still had some of the practical functions that had long been part of the history of the field. Newspaper reports from the early days of Washburn expressed hope that the observatory would not be an ivory tower institution of teaching and research, but would instead serve the state in more concrete ways. The time service fulfilled such a role, as did the observatory's function as a weather and seismological station. However, the public saw the observatory principally as a place to view the heavens. Interest in visiting the observatory was so high that Holden quickly made a bargain with the citizens of Wisconsin: he would open the observatory for public viewing on the first and third Wednesdays of each month; otherwise, he requested peace in order to carry out his research. Not that this deal pleased all parties, as a persistent reporter from the *Milwaukee Sentinel* wrote in 1882: "Gov. Washburn's munificent gift to the state of an astronomical observatory might as well have been located in the interior of a convent and be as accessible to the public as it now is. Your correspondent has tried, the Lord only knows how many times, to get inside of it, and never yet succeeded. The officer in charge is so absorbed in the discovery of 'new nebulae' that even the students are denied the privileges of the observatory, and a separate building for them has been erected. Only on two evenings in each month is permission given to examine any more than the outside walls." The observatory was a private gift to the UW, yet Holden himself was an employee of the university and thus the state. He was therefore beholden to the demands of an eager public, and his bargain reflects an attempt to strike a balance between private and public interests. With a few exceptions, such as the above, Holden's deal was successful and the tradition of opening the observatory to the public twice each month continues to the present.

Since Watson had died before he could begin observations with the new 15.6-inch telescope, Holden faced the task of inaugurating systematic astronomical research at the UW, which began in 1881. His own major observing project was the positional measurement of 300 "fundamental" stars – well known stars measured over many years to achieve very precise values. For this project Holden used the observatory's other principal instrument, a meridian circle made by the German firm Repsold. A meridian circle was a special kind of refracting telescope that could only pivot up and down, much like a cannon. As a trade-off for this lack of maneuverability, meridian circles could measure the positions of stars or other celestial objects to a very high degree of precision as the earth's rotation brought these objects into the telescope's field of view. Measuring the positions of stars, called astrometry, was a traditional astronomical practice that dates to antiquity. Precise stellar positions were important not only for navigation and for tracking orbiting bodies, but also provided clues about the distribution and motions of stars in space. This information thus provided some insight into the structure of the Milky Way, our local system of stars. Although astrometry was an ancient practice, nineteenth-century astronomers used techniques and instruments that were very much state-of-the-art.

Holden did not make Madison his permanent home. He left Wisconsin to become president of the University of California at the end of 1885, and then took over the directorship of the newly completed Lick Observatory in 1887. Housing a 36-inch diameter Clark refracting telescope, the Lick was the world's largest observatory



Edward Holden with 4.8-inch Repsold meridian circle. (UW Astronomy Dept.)

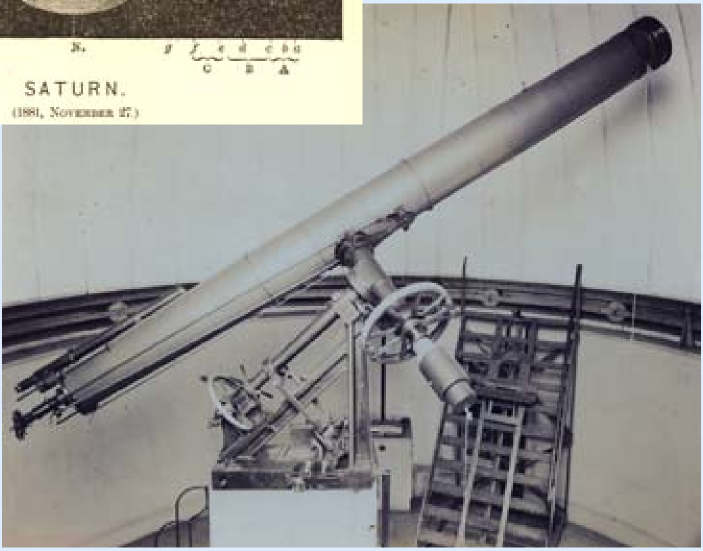
and the first built atop a mountain. The success of the Lick Observatory and its excellent observing conditions demonstrated the value of building high-altitude observatories. Nearly all of the world's largest telescopes since then have been built on mountains. Holden was not the first UW astronomer to be involved with the Lick Observatory, as the trustees of Lick's bequest had consulted earlier with Watson while they were planning the observatory. A close association between the Washburn and Lick Observatories, and the sharing of both people and ideas, became very important throughout the histories of both institutions. So much interaction occurred between Wisconsin and West Coast astronomers that one historian has dubbed Washburn and another Wisconsin observatory, the Yerkes Observatory, as two endpoints of the "California-Wisconsin Axis" of American astronomy.

In the early 1880s, Holden was joined by Sherburne Wesley Burnham, a court reporter and amateur astronomer from Chicago who frequently spent weekends in Madison, taking advantage of the clearer and darker skies surrounding Observatory Hill. Burnham's career shows that the boundaries between "amateur" and "professional" astronomers were very fluid in the late nineteenth century. Indeed, Burnham was one of the most respected astronomers of his time. He possessed a 6-inch Clark refracting telescope, a very large and expensive instrument for a private individual to own, and he put this refractor to use in discovering hundreds of new double stars, that is, two stars that appear very close together. Burnham was known for having extremely keen eyesight, not to mention a telescope that could rival larger instruments in distinguishing close double stars. Burnham's observing expertise was trusted to the point that he helped to select the sites for the Lick and Yerkes Observatories.

Sherburne Wesley Burnham (1838-1921). (Special Collections, University of California, Santa Cruz, Lick Observatory Records)

Burnham worked in Madison for a year before selling his Clark telescope to the UW and returning to Chicago and his court position (the objective lens for this telescope is still in use in a telescope atop UW's Sterling Hall). When Holden took over the directorship of the Lick Observatory, he hired Burnham as a member of the staff and gave him use of the 36-inch refractor. Burnham left California for Chicago in 1892, in large part because of a brewing controversy over Holden's troubled administration. In 1897, Burnham was given a nominal professorship at the University of Chicago and access to the Yerkes Observatory, and in 1902 he finally resigned his job at the court and devoted all of his time to astronomy. Burnham worked for 17 years at Yerkes, spending two nights each week observing and cataloging double stars with its great 40-inch refractor.

Left: Drawing of Saturn made by Edward Holden using the 15.6-inch Clark refractor in 1881. Below: The Clark refractor on its original mounting, which was replaced in the 1930s. (Washburn Observatory/UW Astronomy Dept.)



Remarkably, Burnham had earned this distinguished career with no formal education in astronomy or mathematics. In fact, the most important form of education for researchers in astronomy in the nineteenth century was at the eyepiece of a telescope. Very few "professional" astronomers held degrees higher than a bachelor's, including the first three directors of the Washburn Observatory. It was not until the early twentieth century that a doctoral degree was a prerequisite to a career in astronomy, although amateurs continue to make significant contributions to the field.

When Edward Holden departed Madison for California he left the Washburn Observatory without a director. The Regents spent almost two years finding his replacement, in large part because the office of the University President, a much more important position, was also vacant. Meanwhile, two of Holden's former assistants, Milton Updegraff and Alice Lamb, took charge of the observatory. They finished Holden's observations and performed other research on the positions of stars. In 1886, physics professor John Davies became Acting Director until a permanent director was found. Lamb and Updegraff, who

John E. Davies (1839-1900), professor of physics and Acting Director of the Washburn Observatory, 1886-1887. (UW Astronomy Dept.)

Alice Maxwell Lamb (1863-1952), Milton Updegraff (1861-1938); both assistants at the Washburn Observatory, 1884-1887. (UW Astronomy Dept.)

spent many long nights working together at the meridian circle, eventually fell in love and married, leaving the UW in 1887.

Although significantly fewer in number than their male counterparts, a small but increasing number of women performed research in astronomy during the late nineteenth century. Lamb, however, was notable, in that she was one of only a handful of women in the U.S. to carry out observational research at a coeducational institution like the UW. Most other women served as astronomy instructors or worked at observatories as "computers," that is, people who processed large amounts of astronomical data for relatively low pay. Lamb was given partial control over the observatory not out of direct choice by the university administration, but because of the delay in finding a director. Nevertheless, she used the opportunity to develop the necessary skills to carry out high-quality research. Lamb hoped to make a career in astronomy after her time in Madison, but found few opportunities worthy of her expertise. For instance, in 1886 she received an offer to teach mathematics and run a small observatory

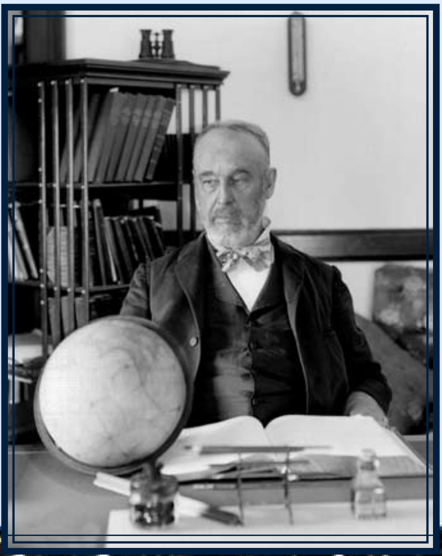
Elizabeth Schofield (1859?-1919), assistant and "computer" at the Washburn Observatory, 1882-1883. (UW Astronomy Dept.)

at a woman's college in the Dakota Territory, but argued that she would "rather work in a true observatory than direct a toy one." Although Updegraff went on to a successful career as an astronomer for the U.S. Navy, Lamb appears to have given up astronomy after their marriage.

The UW found a permanent successor for Holden in another former Washburn Observatory assistant. George Cary Comstock, the third official Washburn director, was a Madison native and had studied under James Watson at the University of Michigan. Comstock returned to Wisconsin as Watson's assistant in 1879 and contemplated a career in law before deciding to devote his life to astronomy. Comstock remained at the observatory as an assistant until 1885, spending the summer of 1886 in California working with Holden at the Lick Observatory. Although Holden wanted to keep Comstock as a permanent staff member, Comstock felt ready to return to Madison and take control of an observatory of his own.

Comstock was called back to Wisconsin in 1887, but was not granted full control of the observatory. He was appointed Associate Director while USNO astronomer Asaph Hall was made Consulting Director. It is not fully clear why the UW made this complicated arrangement, which effectively gave the Washburn Observatory two directors. After Holden's departure in 1885, the UW Board of Regents offered the use of the Washburn Observatory to the USNO. The USNO was moving to a new location, which idled its observing staff and forced its astronomers to look elsewhere for telescope time. The UW Regents had also hoped that the USNO would aid the "reorganization" of the Washburn staff as they sought a new director, perhaps seeing the USNO as the ideal institution on which to model their own observatory. Hall was an experienced astronomer who was best known for discovering the two moons of the planet Mars in 1873; the Regents clearly

Above: George Gary Comstock (1855-1934), third director of the Washburn Observatory, 1889-1922. (UW Astronomy Dept.)
Right: Asaph Hall (1829-1907), Consulting Director of the Washburn Observatory, 1887-1889. (U.S. Naval Observatory Library)



valued this expertise. However, Hall lived in Washington, D.C. and only visited Madison rarely. In the end, Hall seems to have given Comstock nearly full control of the observatory during this period and served mainly as a source of advice and funding for the young Associate Director. Comstock was made full director in 1889 when the UW's arrangement with the USNO ended.

Like Holden before him, Comstock's early research was based in the field of astrometry. His first major research project was the measurement of an important value called the constant of stellar aberration. Stellar aberration is a phenomenon that occurs because of the earth's motion around the sun. Because light travels at a finite speed, a star will appear to shift slightly toward the direction of the earth's motion at any given moment. This effect is similar to walking or running during a rainstorm: raindrops that are actually falling vertical will appear slanted, as if they were coming at an angle towards the observer and thus forcing a tip of the umbrella toward the direction of motion. The amount that stars appear to shift is called the constant of stellar aberration. This constant provides a measurement of the speed of the earth as it orbits the sun. Astronomers used the orbital speed of the earth, along with the value of the speed of light, to determine the distance from the sun to earth. This distance served as the baseline for most astronomical distance measurements in this period and was thus a value of critical importance. Even a small improvement in the value of the constant of aberration could affect a wide range of measurements, from the scale of the solar system to interstellar distances. Comstock measured stellar aberration using an unusual yet inventive apparatus that he attached to the end of Burnham's telescope, which was mounted in the Students' Observatory. His final results did not change the value of the constant of aberration significantly, but instead confirmed the accepted value by an accurate, alternative method. Although Comstock has often been portrayed as a member of the "old school" of positional astronomers, his research projects throughout his career show a willingness to think creatively and to use new instruments and methods to solve critical problems in the field. This project earned Comstock recognition within the American astronomical community and was a key factor to his election to the National Academy of Sciences. He was one of the first faculty members chosen for that distinguished body of scientists for research performed while at the UW.

While Comstock was performing this aberration research he also spent many years carrying out systematic observations of special kinds of stars. He measured the positions of double stars, the orbits of binary stars (stars bound together gravitationally), and the "proper" motions of very faint stars. Proper motion describes the motion that is intrinsic to an individual star as it travels through space, and not some apparent effect that is the result of the earth's motion around the sun. Comstock's studies of the distributions and motions of stars led him into important debates about the size and structure of the Milky Way at the turn of the twentieth century. He was an early proponent of the idea that interstellar space is filled with a diffuse medium that dimmed light and made stars appear more distant than they actually are. Although most astronomers rejected Comstock's value for the dimming effect of this proposed interstellar medium, his research contributed to one of the key problems of the period. The question of whether or not an interstellar medium existed took several decades to solve and became, as we will see, one of the central research areas in twentieth-century astronomy, especially at Washburn Observatory.

A third branch of Comstock's research was in the new and growing area of astrophysics. Although the work of figures like Isaac Newton showed how the laws of physics applied to the motions of heavenly bodies, in the mid-nineteenth century a new branch of astronomy developed that sought to examine directly the physical and chemical compositions of celestial objects. Called "astrophysics" after 1860, the key elements to this research field were three instruments: the photographic camera, the photometer (a device used to measure the intensity of light), and the spectroscope. A spectroscope is a device that passes light first through a narrow slit and then through a series of prisms (or reflected off of a metal or glass plate with very fine rulings on its surface, called a grating) to break up light into its constituent colors. Chemists and physicists discovered in the late 1850s that when a given chemical element or molecule is energized it radiates energy in a very specific array of colors, called an emission spectrum. An emission spectrum appears as a series of colored lines, each representing one particular wavelength of light. For instance, the visible light emission spectrum for the element hydrogen has bright lines in red, green, blue, and violet. Similarly, an element or molecule will absorb light in these same specific wavelengths. With this discovery, scientists could use a spectroscope to determine the chemical composition of nearly any object, no matter how remote. In the hands of astronomers, the spectroscope could show the chemical structures of stars and the atmospheres of planets, in addition to other physical parameters like temperature and pressure. One of the most important discoveries that astronomers made with spectroscopes was that most stars belong to roughly ten or so different categories or "classes" based on similarities in their spectra. Stellar classification was recognized in the nineteenth century as an important way of understanding how stars are different yet related to one another physically and how they might evolve over time.

Comstock's contributions to astrophysics demonstrate further his ability to push the boundaries of astronomical technique. His major astrophysical project was a study of what he called the "effective wavelength" of starlight, that is, the color in which a star radiates most of its energy. He measured effective wavelength by attaching a special screen to the lens-end of the 15.6-inch refractor. Comstock was interested in this question because he wanted to know how the color of starlight affected the apparent position of a star when viewed through Earth's atmosphere. Since air refracts (or bends) light of different colors by different amounts, light from a star that is mostly blue will bend differently than light from a star that is mostly red. Comstock sought to relate the effective wavelength of a star to its spectral class in order to improve his research on the positions and motions of stars, thus showing a mixture of older problems and newer approaches. His study did not draw much immediate attention. However, within a few years it helped to contribute to the work of the Danish astronomer Ejnar Hertzsprung, whose research on the relationship between stellar color and stellar luminosity, parallel with the American Henry Norris Russell, provided one of the keys to answering the question about the evolution of stars. This relationship, portrayed graphically as the “Hertzsprung-Russell Diagram,” has been a central tool in astrophysics for nearly a century.

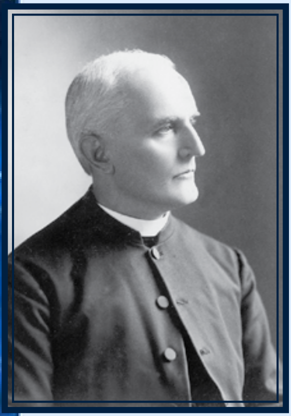
Comstock provided the stability in leadership that the early Washburn Observatory had lacked, remaining director until 1922. He was not only an active researcher but also an avid teacher and author. He frequently taught up to six courses each year and published textbooks on mathematics, astronomy, engineering, and navigation. He was devoted to the idea that astronomy ought to be not just an abstract science but one that retained some of its traditional, practical applications. Although the observatory grew little under Comstock’s tenure, he also recognized that performing research from the center of a growing urban center was becoming increasingly difficult. Artificial lighting and air pollution became so troubling that Comstock inquired seriously about moving the observatory away from central Madison in the early 1910s. The observatory remains in its original location to this day, but Comstock had identified early on a problem that would trouble UW astronomers for decades to come.

The foundation of the Washburn Observatory and the directorships of Holden and Comstock were important developments in the establishment of a permanent scientific research culture at the UW and in Wisconsin as a whole. Although science formed an important part of the university’s curriculum since its foundation, faculty were hired for their teaching skills and not for their ability to carry out scientific research. By the end of the nineteenth century, universities across the United States began placing a higher premium on original research among their faculty and on training their students for careers in science and industry. Associated with this new emphasis on research was the spread of scientific institutions, such as observatories and laboratories. As one of the earliest and most expensive scientific facilities at the UW in the nineteenth century, the Washburn Observatory was a

The former residence of the directors of the Washburn Observatory, now home to the La Follette School of Public Affairs. *(Jeff Miller/UW-Madison)* prominent reminder of the growing value of science in higher education. Another key development in promoting scientific research at the UW was the founding of the Graduate School in 1904, of which Comstock was the first director and later its first dean. Although the UW awarded master's and Ph.D. degrees before 1904, Comstock and UW president Charles Van Hise developed a much more formal system of graduate education. This in turn gave science a more prominent place at the university, as original research is an important requirement for a graduate degree. It is somewhat ironic that although the size of the graduate program at the UW as a whole grew significantly under Comstock's tenure, he never developed a strong graduate program in astronomy during his tenure, supervising only one Ph.D. dissertation and a few master's theses.

The Growth of Astronomy Across Wisconsin, 1880-1932

Although Madison was home to the earliest organized astronomy research in the state, there were other important astronomical sites across Wisconsin. Several small observatories were built in the late nineteenth and early twentieth centuries, such as the Beloit College Observatory and the Underwood Observatory at Lawrence College in Appleton. These observatories principally aided the teaching missions of their associated schools. Private individuals and astronomy organizations also built a large number of small observatories across the state. Two of these observatories, one very small and one very large, demonstrate the range of astronomical research facilities operating in Wisconsin in the late nineteenth and early twentieth centuries.



Johann Georg Hagen, S.J. (1847-1930). (Special Collections, University of California, Santa Cruz, Lick Observatory Records)

The first of these observatories was located at the College of the Sacred Heart, once a Catholic academy in Prairie du Chien. In 1880, the school's astronomy instructor, an Austrian Jesuit named Johann Hagen, built a small observatory and equipped it with two three-inch refracting telescopes. Interested mainly in positional astronomy, Hagen collaborated with Edward Holden in Madison and reported on some of his work in the *Publications of the Washburn Observatory*. Although Hagen's research in Wisconsin amounted to only a few brief publications, he used his experience in Wisconsin as a springboard to a much more prestigious career. Hagen left Wisconsin when Sacred Heart closed in 1888 (it later reopened as Campion College), becoming the director of the observatory at Georgetown University in Washington, D.C. He later served the director of the Vatican Observatory in Rome. Hagen and his small observatory are reminders that most astronomical research was not performed at giant observatories with the largest telescopes. Individual astronomers like Hagen had to make do with what resources they had, and although observatories like the one at Sacred Heart are largely forgotten, they make up an important part of the landscape of astronomy in America in the nineteenth century.

By way of contrast, Wisconsin hosted what was in fact the largest observatory with the biggest telescope in the United States at the time. This institution, the Yerkes Observatory in Williams Bay, was a Wisconsin institution mainly by virtue of the fact that it was located in the state, although its roots were in the booming city of Chicago. In 1892, the astronomer George Ellery Hale (1868-1938) of the new University of Chicago convinced the wealthy streetcar magnate Charles Yerkes to finance the largest telescope in the world. This telescope had a 40-inch diameter lens figured by Alvan Clark and Sons and a 60-foot tube and mounting by the Warner and Swasey company of Cleveland, making it the largest operational refractor that has ever been built. Astronomers realized that refracting telescopes larger than this were impractical, both because of the difficulty of procuring large glass lenses that are almost perfectly transparent and uniform and because big refractor lenses tended to sag significantly under their own weight.

Hale knew that the virtues of this telescope would be wasted in a city like Chicago, which was filled with coal smoke, artificial light, and the vibrations of trains. Numerous offers came in from locations hoping to host the new observatory, and a site selection committee eventually settled on a hill overlooking Lake Geneva in Williams Bay, Wisconsin. This committee was aided in its choice by Burnham, then working full-time in Chicago in his job as a court reporter, who delivered a favorable report on the observing conditions near Lake Geneva. Williams Bay was considered an ideal site because it was relatively close to Chicago (about a one-hour train ride) and because of the fact that Lake Geneva was surrounded by resort communities: significant urbanization in the area seemed unlikely at the time.

The Yerkes Observatory opened in 1897 to considerable fanfare. It had the largest telescope in the world and was one of the first American observatories built

The Yerkes Observatory in Williams Bay, Wisconsin. (SHSW WHi-1811) primarily with astrophysics in mind, containing laboratories and instrument shops designed for spectroscopy and photography. However, the research performed at Yerkes shows a mixture of astronomy old and new. In addition to Burnham and his work measuring double stars, Hale hired Edward Barnard, who had earned fame for discovering the fifth moon of Jupiter (the first since Galileo) while working at the Lick Observatory and who was also a pioneer of astronomical photography. Barnard's wide-angle photographs of the Milky Way showed curious dark patches, which Barnard believed were areas devoid of stars but what other astronomers argued were silhouettes of clouds of obscuring matter, perhaps further evidence in favor of the supposed interstellar medium. Hale himself studied the physics of the sun, including the nature of sunspots and the solar corona, the hot and diffuse outermost portion of the sun's atmosphere. Hale also hired Edwin Frost, who developed a program to measure the velocities of stars using spectroscopy.

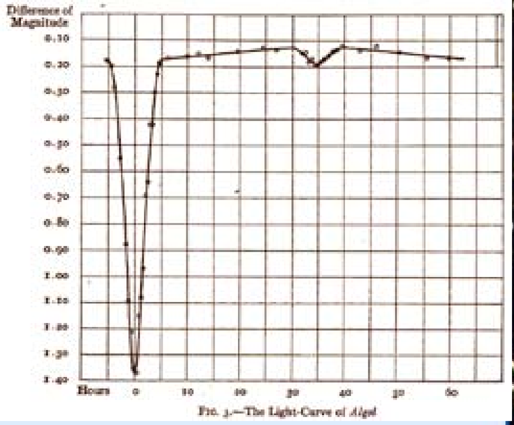
A large number of the leading astronomers in the country attended the dedication ceremony of the Yerkes Observatory, and this gathering provided the inspiration to form a nationwide astronomical society. This organization, the Astronomical and Astrophysical Society of America (AASA) held its first meeting at Yerkes in 1899. The name of the society was chosen to reflect the importance of astrophysics, although many members found the name cumbersome and changed it to the simpler American Astronomical Society (AAS) in 1914. The society's first president was Simon Newcomb, one of the most respected figures in American science, with Hale as one of two vice-presidents and George Comstock as secretary. Comstock was a particularly active member in the early years of the AASA and drew on his legal background in writing the society's constitution. He served a decade as secretary, several terms as a vice-president, and three years as president following his retirement from the Washburn Observatory. In fact, a total of four Washburn directors to date (Comstock, Joel Stebbins, Albert Whitford, and Arthur Code) would serve as AAS president at some point in their careers.

Hale retired as Yerkes director in 1905, having already founded the Mt. Wilson Observatory near Pasadena, California. His successor was Edwin Frost, who remained director until retiring in 1932. Frost's directorship has been characterized as a period of stagnation for the observatory, owing in part to a loss of eyesight that prevented him from carrying out any research of his own after 1915. Frost also did little to change the scientific direction of Yerkes, hiring astronomers who continued the work of Burnham and Barnard instead of pursuing entirely new lines of research. Even though Yerkes under Frost may not have pursued the most innovative research, the observatory continued to make important contributions to the discipline as a whole. For nearly three decades Frost served as editor of the *Astrophysical Journal*, which Hale had founded in 1895 as the flagship American publication for astrophysical research. Furthermore, Yerkes in this period trained several astronomers who went on to have very influential careers. These students include Otto Struve, a refugee from the Russian Civil War for whom Frost had worked strenuously to bring to the United States and who became Frost's successor at Yerkes, and Edwin Hubble, one of the most important observational astronomers of the twentieth century.

The New Astronomy

The Electric Eye

In 1922, George Comstock retired as director of the Washburn Observatory and was succeeded by Joel Stebbins, who was then director of the observatory at the University of Illinois. Stebbins had studied with Comstock from 1900 to 1901 before earning a Ph.D. at the Lick Observatory. He was the first UW astronomer to have a Ph.D. While at Illinois, Stebbins became a pioneer in the field of photoelectric photometry, which was the application of sensitive electric detectors – what Stebbins called an "electric eye" – attached to the end of a telescope to measure the intensity of light from celestial objects. Astronomers used electric photometers to distinguish changes in brightness too small or rapid to measure with other methods: the naked eye is not sensitive enough to detect such changes and photographic plates were too slow and cumbersome to measure rapid changes in brightness. Stebbins first studied variable stars (a variable star is a star with a brightness that changes periodically over time), including groundbreaking research on the



Above: Joel S. Stebbins (1878-1966), fourth director of the Washburn Observatory (1922-1948), observing with a photoelectric photometer on the 15.6-inch refractor. Right: The light-curve of the binary star Algol, from a paper published by Stebbins in The Astrophysical Journal *in 1910. This graph shows the brightness of the star system plotted vertically, and time (in hours) plotted horizontally. The first "dip" in brightness, about which astronomers had long known, is caused when the dimmer "secondary" star passes in front of the brighter "primary" star. Stebbins showed the existence of the smaller dip, which is caused when the secondary star passes behind the primary.* *(UW Astronomy Dept.)*

star Algol in 1910. Astronomers suspected that Algol was an eclipsing binary star, or two stars orbiting around and periodically passing in front of each other from our line of sight. When one star passes in front of the other the total amount of light from the binary star system appears to decrease. Stebbins used his early photometers to demonstrate that Algol was an eclipsing binary and determined its "light curve," a plot of the system's brightness over time, to an unprecedented degree of accuracy. This discovery not only earned Stebbins a reputation as a careful researcher, but also demonstrated the power and sensitivity of the new electric light detectors. The study of eclipsing binaries also provided important information about the sizes and masses of stars, which was key information in an era when astronomers and physicists were working hard to understand how stars produce energy and how they evolve over time.

Stebbins' first photometers were simply wires coated with a crystalline compound that contained the element selenium. When these selenium "cells" were exposed to light their electrical resistance changed, which a device called an ohmmeter could measure. However, Stebbins' first selenium photometers were very insensitive and were only able to detect changes in the brightness of the moon as it went through its monthly cycle of phases. Stebbins was able to increase the sensitivity of his selenium cells over time to the point where they could detect variations in bright stars, such as Algol. In the early 1910s, Stebbins teamed up with physicist Jakob Kunz at Illinois, who was making a new type of photocell. These cells took advantage of the photoelectric effect, a phenomenon whose physical properties Albert Einstein had described in 1905. The photoelectric effect occurs when light strikes a metallic surface, freeing electrons capable of producing

Meeting of the Astronomical and Astrophysical Society of America at Harvard University in 1910. George Comstock is in the back row, center. Joel Stebbins (wearing bowtie) is seated in the front row, center. (UW Astronomy Dept.)

a small electric current. Kunz's photoelectric cells proved considerably more sensitive than the older selenium cells, and Stebbins quickly made the switch to the new detectors.

Stebbins-Whitford photoelectric photometer. At left: Kunz photoelectric cell (top) with vacuum tube amplifier (bottom). At right: vacuum chamber, which attaches to the end of a telescope. (UW Astronomy Dept.)

When Stebbins came to Madison in 1922 to take over the directorship of the Washburn Observatory, he brought his array of photometers with him, establishing a research tradition in photometry at the UW that would continue into the space age. Stebbins did not perform all of his research in Wisconsin, but used the Washburn Observatory primarily as a testing ground for new instrumentation. He frequently took his instruments to observatories in California such as Lick or the new Mt. Wilson Observatory, which had better viewing conditions and much larger telescopes. (Mt. Wilson helped to make standard the use of large reflecting telescopes, installing a 60-inch reflector in 1908 and the 100-inch Hooker Telescope in 1917.) By moving back and forth between Wisconsin and California, Stebbins could still make good use of the outdated Washburn telescope while also maintaining connections to the important research sites on the West Coast.

Photoelectric photometry was still in its infancy, and very few astronomers seemed willing to take the professional risk by moving into a completely new area of astronomical technology. As Stebbins wrote in 1928, "Perhaps a word of warning or of commiseration is due to those who may take up this kind of work. The photo-electric cell with its installation is a delicate piece of apparatus, and requires considerable patience to learn its idiosyncrasies. Nowadays, our photometer will work uniformly for months at a time, but occasionally some trouble arises, and perhaps once a year a new kind of 'tick' will turn up which is a real puzzle. The ordinary troubles from moisture, defective battery, dirty or poor contacts, etc., can be recognized by simple tests, but it is difficult to put down in black and white just what to do when things go wrong." Photoelectric photometry remained an experimental branch of the discipline before the Second World War, and Stebbins and his students and collaborators largely had a monopoly on photoelectric techniques during this period.

Stebbins spent most of the 1920s continuing his research on variable stars using Kunz's photoelectric cells. He also carried out an interesting study on whether or not the sun is a variable star. By studying the brightnesses of the planet Jupiter's four largest satellites, which shine because of light reflected from the sun, Stebbins argued that his photometers would detect any significant change in the sun's light output. Stebbins tested his theory at the Lick Observatory in the late 1920s, but found no variability.

What was perhaps the most significant research of Stebbins' career centered on understanding the nature of the newly discovered interstellar medium. In 1930, astronomer Robert Trumpler of the Lick Observatory argued conclusively that interstellar space was filled with a diffuse substance that both dimmed and reddened the light from celestial objects. Reddening is a result of the fact that objects like stars emit light in all parts of the electromagnetic spectrum, from radio waves to visible light to gamma rays. The interstellar medium scatters away some of the light from the bluer part of the visible portion of the spectrum, allowing the redder light to pass through unhindered and making the object appear redder (and dimmer) than it would if no interstellar medium existed. Stebbins explored this reddening effect by using his photometers to measuring the colors of bright stars that are intrinsically very blue. He found that stars located near the plane of the Milky Way showed the greatest degree of reddening, which provided further confirmation of Trumpler's discovery and support to the idea that our galaxy contained not only stars but also a significant amount of dust and gas.

A related discovery occurred when Stebbins turned his attention from bright stars to globular clusters. Globular clusters are dense balls of tens of thousands of stars that seem to crowd around the center of the Milky Way. In the late 1910s, the astronomer Harlow Shapley at the Mt. Wilson Observatory measured the distances to globular clusters and constructed a three-dimensional map of the Milky Way. He then used this map to estimate that our galaxy was about 250,000 light-years across, with the sun about 50,000 light-years from the center. (A light-year is the distance that light travels in one year, about 9.5 trillion kilometers or 5.9 trillion miles. The sun's nearest neighboring star, Alpha Centauri, is about 4.4 light-years distant.) Shapley believed that his results answered one of the outstanding questions in astronomy at the time: the nature of the thousands of mysterious "spiral" nebulae that populated the sky. Some astronomers believed that these nebulae, like the Great Andromeda Nebula (also known as Messier 31 or M31), were systems of billions of stars similar to but separate from the Milky Way, "island universes" or galaxies unto their own. Others believed that the spiral nebulae were part of the Milky Way and were places where material was condensing into relatively few new stars. Shapley argued that because of his large estimate for the size of the Milky Way, the spiral nebulae could not be external galaxies. In the mid-1920s, Edwin Hubble, also at Mt. Wilson, measured the distances to a few large nebulae (using a technique that Shapley himself had helped to develop) and found that the nearest, the Andromeda Nebula, was several hundred thousand light years away and so could not be part of our galaxy. Hubble had provided compelling evidence in favor of the island universe theory, but one question remained. The other spiral galaxies seemed to be only about half as big as the Milky Way, according to Shapley's measurement. Why should the Milky Way be so much larger? Was this discrepancy real, or were astronomers not accounting for something? Stebbins turned his attention to this question and showed that the effects of the interstellar medium had a significant effect on determining the distances to celestial objects. Stebbins measured the reddening of globular clusters and found that they were much closer to the sun – and therefore the Milky Way was much smaller – than Shapley thought, once the effects of the interstellar medium were taken into account. Stebbins' estimate for the size of the Milky Way was about half of Shapley's and much closer to the estimated size of other spiral galaxies, like the Andromeda Galaxy.

Charles Morse Huffer (1894-1981) with the 15.6-inch Washburn refractor, circa 1950. *(UW Astronomy Dept.)*

One of Stebbins' most important collaborators at the UW was Charles Morse Huffer, who studied with Stebbins while an undergraduate at the University of Illinois. When Stebbins took over as director of Washburn he hired Huffer as an assistant, who then decided to earn a Ph.D. in astronomy. Huffer contributed to Stebbins' work on variable stars, which formed the basis for Huffer's dissertation. Huffer then worked with Stebbins on the latter's study of absorption and reddening, co-authoring several important papers with Stebbins. Huffer became a professor of astronomy and remained at UW until his retirement in 1961. Huffer continued and extended the early work by Stebbins on applying photometry to eclipsing binary stars, for which he used the 15.6-inch telescope into the mid-1950s. He was also a very active member of the astronomy community, serving as secretary of the AAS for over a decade.

In 1931, Albert Whitford, another of Stebbins' collaborators and his future successor, joined the Washburn Observatory staff while studying for a graduate degree in physics. Whitford, a native of Milton, Wisconsin and a graduate of Milton College, was looking for a job and Stebbins hired him to look after the electrical apparatus used in Stebbins' photometric research. Whitford was then experimenting with newly developed vacuum tubes, using them to amplify weak electric currents. Whitford attached his amplifiers to Stebbins' photoelectric photometers, which drastically increased the sensitivity of these instruments and reduced the amount of noise in the signal. Another, more practical effect of using these amplifiers was that Stebbins could switch from a relatively delicate and difficult-to-use current-measuring device called an electrometer to a far more robust instrument known as a galvanometer, which simplified observations considerably. These photometers were among the very first applications of electronics to astronomy. Whitford then took an additional step and placed the entire photometer and amplifier assembly within a vacuum chamber, which was then attached to the end of the telescope. Putting the detector in a vacuum increased the signal-to-noise ratio by reducing the effects of cosmic rays. When cosmic rays collide with air molecules they produce charged subatomic particles, which created additional interference within

Staff of the Washburn Observatory in 1936. Front row, from left: C. Morse Huffer, Elsie DeNoyer, Joel Stebbins. Back row: Edward Burnett, Gerald Kron, Albert Whitford. (UW Astronomy Dept.)

the photometer assembly. The robustness of Stebbins and Whitford's final instruments attracted the attention of other astronomers, such as the eminent Hale, who hoped to install such a system at his planned 200-inch telescope at the Mt. Palomar Observatory.

The introduction of electronic amplifiers into photoelectric photometry presaged another important technological development with which Stebbins and his students began to experiment in the late 1930s: photomultiplier tubes. These devices combined a light detector and a series of amplifiers, all contained within a small glass tube. Invented in the mid-1930s and perfected at RCA by a team working under Vladimir Zworykin, a central figure in the invention of television, photomultiplier tubes were compact, simple, and could amplify a signal over one million times. Stebbins corresponded with Zworykin about RCA's photomultipliers, hoping to apply them to his photometric research. However, key developments in the use of photomultipliers in astronomy came through the work of Gerald Kron, a UW engineering student who joined the Washburn Observatory in 1931. Along with Whitford, Kron first used photomultiplier tubes in helping to develop an innovative telescope guiding system for the Mt. Wilson Observatory. Most astronomical photographs at the time required very long exposures using specially coated glass plates. In order to produce a good image the telescope had to stay focused on the target object, say, a distant galaxy, for perhaps several hours or more. Otherwise, during that time the telescope would likely drift away from the object slightly, ruining the exposure. Astronomers avoided this problem by using a "guide" star that happened to be in the telescope's field of view: keeping this star steady on a pair of crosswires ensured a good image. The downside to this technique was that the astronomer had to stay at the telescope with his or her eye at the eyepiece until the exposure was complete, no matter how cold the evening air was. Kron and Whitford hoped that their experimental, photomultiplier-based guider would automatically correct for any off-course drifting and point the telescope back in the right direction. After World War II, Kron continued to work with photomultipliers as image detectors, and through his work and that of his contemporaries the photomultiplier replaced the older photoelectric cell as the principle instrument for astronomical photometry.

Karl Jansky (1905-1950) was another UW student from the early days of vacuum tube electronics who became part of astronomical history. Jansky, whose father was a UW Engineering professor, went to work for Bell Telephone Laboratories after graduating from the UW. He was assigned to investigate radio noise sources that might interfere with radio communications. To carry out the investigations, he designed and built a rotating antenna connected to radio receiving and recording equipment. In 1933, Jansky identified a major radio noise source coming from the direction of the constellation Sagittarius, the same direction in which the center of our Milky Way galaxy was suspected to lie. Jansky's work was the beginning of the field of radio astronomy, and although Jansky himself was not allowed to do further research in the field, others would eventually follow-up and expand upon his pioneering work.

During the 1940s, Stebbins, and Whitford, who was now a professor of astronomy, continued to study the nature of the interstellar medium, developing a system of photometry that measured light in six different colors in order to understand very precisely the effects of reddening. Stebbins' "law of interstellar reddening" became such a fundamental part of astronomical practice that Whitford later wrote, "the method that Stebbins introduced eventually came to be a routine step in determining the distances of all types of objects other than the nearest stars." Stebbins' contributions to photometry, and to astronomy as a whole, were far-reaching indeed.

In his final years as director of the Washburn Observatory in the late 1940s, Stebbins turned his attention from stars to study the colors and brightnesses of galaxies. Once again, Stebbins' work brought him into the center of a major astronomical debate, this time concerning the origin and fate of the universe as a whole. In the late 1920s, after demonstrating that the spiral nebulae were objects outside of the Milky Way, Edwin Hubble then discovered an astounding fact about them: the light from nearly every galaxy that he examined was shifted toward the red end of the spectrum compared with what he expected. This effect, known as the cosmic redshift, is comparable to what physicists call a Doppler shift, which occurs when an object emitting light moves toward or away from an observer. Light from an object moving away from an observer is shifted toward the red end of the spectrum. Conversely, light from an object moving towards an observer is shifted towards the blue end of the spectrum. A galaxy whose spectrum is red-shifted thus appears to be moving away from us; Hubble found that all but the closest galaxies seemed to be receding from us at very high speeds in excess of hundreds or even thousands of kilometers per second (by way of comparison, the orbital speed of the earth around the sun is about 30 kilometers per second, while the orbital speed of the sun around the center of the Milky Way is about 220 kilometers per second). By combining his measurements of distance and redshift, Hubble discovered a

Artist's illustration of what one of the first galaxies in the universe may have looked like 750 million years after the Big Bang. *(W. M. Keck Observatory, Artwork by Jon Lomberg)*

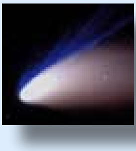
striking correlation: there exists a direct relationship between the distance to a galaxy and its recessional speed. Astronomers and physicists quickly interpreted Hubble's data as evidence that the entire universe – space and everything in it – is expanding rapidly. But what did this expansion mean? Did it say anything about how the universe may have begun, or how it might develop over time?

By the late 1940s, cosmologists had put forward two important interpretations of the expanding universe. One idea, which built upon the research of physicists in the 1930s, was supported by George Gamow and his students at George Washington University. Gamow argued that if you imagine running the expansion of the universe backwards in time, like a movie played in reverse, then at a certain point in the past all space and matter must have been contained within an extraordinarily tiny, dense, and hot volume. Run time forward from this beginning point and space begins to expand – like a balloon blowing up – filled with primordial matter that cools off and condenses into galaxies and stars, from which planets and people would eventually evolve. A key consequence of this "big bang" theory was that the universe as we know it had a finite beginning in time and space, although it was not clear whether this expansion would continue forever, gradually slow down, or stop and reverse itself, compressing everything back together in a "big crunch."

The other key cosmology of the period opposed the idea of a beginning or an end to either time or space. According to this "steady-state" theory, of which Cambridge University astronomer Fred Hoyle was the leading promoter, the universe had always existed, had always been expanding, and was the same regardless of where one looked in the cosmos. Hoyle argued that as space expanded, a tiny, unobservable amount of new material (say, a hydrogen atom per year per cubic light-year of space) came into existence. Enough new matter would eventually accumulate to form into new galaxies, which would then fill the voids that the expansion of the universe created.

In the late 1940s and early 1950s, both of these theories drew supporters from within the scientific community, and astronomers and physicists mounted evidence hoping to prove one model over the other. Stebbins and Whitford entered the fray when they discovered that some of the distant galaxies that they were measuring were redder than galaxies that were nearer to us. They could not account for this reddening either through an interstellar or intergalactic medium, nor was it a result of Doppler shifting. Some scientists, including Gamow, argued that this "Stebbins-Whitford effect" meant perhaps that these more distant galaxies were simply intrinsically redder, perhaps because they were made of different, redder types of stars than the nearer galaxies. (Because light travels at a finite speed, when we observe an object in space we see it not as it is now but as it was when the light left the object. For example, light from the sun takes about eight minutes to travel to the earth, so we actually see the sun as it appeared eight minutes ago. The Andromeda Galaxy, which we now know to be about two million light-years away, appears to us now as it actually was two million years ago.) Thus, since the light from very distant galaxies takes longer to reach us than light from galaxies that are closer, the Stebbins-Whitford effect suggested that these more distant galaxies were at different points in their development and were perhaps older than the closer ones. However, according the steady-state theory, all galaxies should appear the same no matter how deep one peered into space; the Stebbins-Whitford effect seemed to contradict this basic premise. Their discovery caused a stir in the early 1950s as a plausible argument against the steady-state theory (even if it was not, as big bang proponents hoped, a necessary argument in favor of their own theory). Stebbins and Whitford, as a result of a critical analysis by UW astronomer Arthur Code, eventually revisited their observations and withdrew their claim about the reddening of distant galaxies.

Stebbins retired as director of the Washburn Observatory in 1948, but maintained an active career in astronomical research. He became a research associate at the Lick Observatory, where he continued to develop his system of six-color photometry and studied "pulsating" variable stars. (Pulsating variables change in brightness because the stars grow and shrink in size periodically.) Shapley and Hubble had used these types of stars in measuring the scale of the Milky Way and the distances to other galaxies, and so Stebbins' final work had continuing relevance to questions about the scale of the universe.



From World War II and Into the Space Age

From its very beginning, Washburn Observatory's status, in effect its place on the university's organizational chart, was as a research institute, independent of any department or college, whose director reported to the UW president. This arrangement was consistent with its original role in establishing the University of Wisconsin as a research university, but teaching was always part of the astronomer's duties as well. Watson, Holden, Comstock, and Stebbins all taught traditional introductory astronomy courses, and student accounts of the Stebbins era mention exercises in surveying and celestial navigation on the lake – typical activities for astronomy classes before World War II. Comstock, as already noted, was an energetic teacher and prolific textbook author.

Astronomy teaching became a more pressing issue as undergraduate enrollment in astronomy courses grew steadily, especially during and after World War II. Also, the independent status of the observatory introduced difficulties into the routine offering of advanced courses and awarding of degrees at just the time when the nation's post-war research growth demanded more technical training in all fields, including astronomy. Up until the early 1960s, Washburn Observatory had produced only four Ph.D. astronomers: Stephan Hadley, who worked with Comstock; Charles Morse Huffer, who worked with Stebbins for many years; Olin J. Eggin, who left Madison to do important photometric research; and Theodore E. "Ted" Houck, who would be an important figure in Wisconsin's early space astronomy efforts.

Stebbins perceived the need to reorganize astronomy research and education at the university to meet the needs of post-war education; as early as 1946 he began petitioning the UW administration for restructuring. In September 1948, only a few months after Stebbins retired, the Board of Regents approved the observatory's transformation into the Department of Astronomy within the College of Letters and Science. The university conducted a nationwide search among top young astronomers to find a new observatory director and, in the end, followed Stebbins' forceful recommendation to President E. B. Fred that any choice but Whitford "would not make sense." Thus it fell to Whitford to implement the new department's development in both curriculum and facilities.

As Stebbins foresaw, the growing program of instruction and the increasingly complex instrumental work involved in research could no longer fit in the old building on Observatory Hill, but finding new space on campus for telescopes and laboratories is never simple. In the early 1950s, the astronomers considered expanding the old building to the south, but the steep slope down the southern face of Observatory Hill presented too many difficulties. Such planning was also complicated by the question of whether to relocate the old Clark 15.6-inch refractor to a better site. The solution appeared on the horizon when the Board of Regents approved, in 1955, the addition of an eastward extension to Sterling Hall to be funded by gifts from the Wisconsin Alumni Research Foundation (WARF), which eventually amounted to $1.2 million. Originally planned to be four floors, the new wing would house physics laboratories as well as the new Army Mathematics Research Center. By 1957, before the project was complete, two additional floors had been added to the plans so that the Astronomy Department could be accommodated on the sixth floor with additional space on the roof. The roof would support the dome of the modest planetarium, used for astronomy instruction, which had previously been housed inconveniently across campus in Journalism Hall (near the present site of Helen C. White Hall). In addition, provision was made for rooftop observatory domes to house smaller telescopes (including Burnham's 6-inch Clark refractor formerly in the Student Observatory on Observatory Hill) for instructional use. So, under Whitford's leadership, the astronomers vacated the hallowed but long-outgrown halls of Washburn Observatory itself. By mid-year 1959, the astronomers were moving into the newly completed east wing of Sterling Hall with a machine shop, library, laboratories, office spaces, and classrooms providing a new level of research and teaching support. Thus, Wisconsin astronomers were finally equipped for the new level of activity then developing for both space and ground-based astronomy.

The 15.6-inch Clark refractor remained behind on Observatory Hill because, being an antique of minimal use for modern research, relocating it made no sense. The original Student Observatory on the hill was donated to Madison Astronomical Society (MAS), the local amateur astronomy club, to which Professor C. M. Huffer had close ties, on the condition that they relocate it at their expense to a new site, which they did. (After many years of use by MAS, the building was donated to the town of Fitchburg, which maintains it as a landmark that stands prominently above Fish Hatchery Road to this day.) After the astronomers moved out, the Washburn Observatory building's first floor and basement were remodeled extensively to provide a home for the Institute for Research in the Humanities. Until 2008, Washburn Observatory would be the home to advanced scholars, many visiting Madison from around the globe, doing research and writing in history, classics, philosophy, and other fields. The 15.6-inch telescope and its dome were almost all that remained of astronomy on Observatory Hill, but they remained fully functional and in use for classroom instruction and public viewing (on the traditional first and third Wednesday nights of each month) while the scholars labored on the floors below. (As of Spring 2009, the historic Washburn Observatory building nears the completion of another remodeling accompanied by extensive historical restoration. When the remodeling is complete, the building will become the home of the Honors Program of the UW-Madison College of Letters and Science. The telescope and dome will remain essentially unchanged and continue to be available to visitors.)

Access to a modern research telescope remained a problem even after the move to Sterling Hall. The 15.6-inch refractor, having been remounted (the original Clark mounting was removed and replaced with one made by Warner & Swasey) and improved in 1933, remained fully functional, but the often cloudy Wisconsin skies, increasing light pollution from city and campus, and especially competition from ever larger reflecting telescopes, rendered the venerable refractor increasingly unsuitable for competitive research. Huffer was able to continue his highly specialized photometric work on eclipsing binary stars using the

Albert E. Whitford (1906-2002), fifth director of the Washburn Observatory (1948-1958), left, and C. Morse Huffer, right, inspect the mirror blank for the 36-inch Pine Bluff Observatory telescope, circa 1952. (UW Astronomy Dept.)

15.6-inch up until the new instruments at Pine Bluff Observatory became available in the late 50s – a remarkable testament to the utility of such a classic telescope. Other, much larger refractors, like the giants of Yerkes and Lick Observatories continued to find roles in research, but it was rare even then to find a relatively small instrument like Washburn's still active in research. Most cutting-edge research projects required greater light-collecting power. Stebbins, often accompanied by Whitford, had repeatedly managed to get access to larger instruments, notably at Mt. Wilson, in order to keep his research program competitive. But relying on the indulgence of large, distant observatories for telescope access was a significant handicap for research, instrument development, and training of graduate students. With his usual prescience, Stebbins had initiated discussion after the war of a larger "country" telescope, but issues of funding and a suitable site stalled any action.

Whitford, like his mentor, recognized a new telescope as a priority, and by early 1955 he was making the case for the new instrument to UW's President Fred. By late 1955, the WARF Trustees had approved funding and by late 1956 the Board of Regents had endorsed Wisconsin's first new research telescope project since Washburn Observatory opened in 1881. Whitford saw to the acquisition of a 36-inch reflecting telescope from Boller & Chivens taking advantage of the fact that Yerkes Observatory wanted a similar instrument for their photometric work at McDonald Observatory, which they operated in partnership with the University of Texas. It made sense to let one design serve for two telescopes with very similar missions, namely to serve as "light buckets" for photometric measurements rather than more complex systems for refined astrophotography. The Yerkes optical shop made both telescope mirrors. Whitford also oversaw the construction of a new observatory to house and support the work of the new telescope. The new observatory took shape about 20 miles west of Madison on a high ridge above the little town of Pine Bluff, Wisconsin. Arthur Code, Whitford's eventual successor, but then a young faculty member who helped with the site search, recalls that they expected that urban development (and hence light pollution) would take place mostly in the directions of Middleton and Verona, so they hoped the Pine Bluff site might retain its dark sky longer than sites to the north and south. Pine Bluff Observatory (PBO), with a research-grade telescope and dark skies, was a major

The Pine Bluff Observatory, circa 1960. *(UW Astronomy Dept.)*

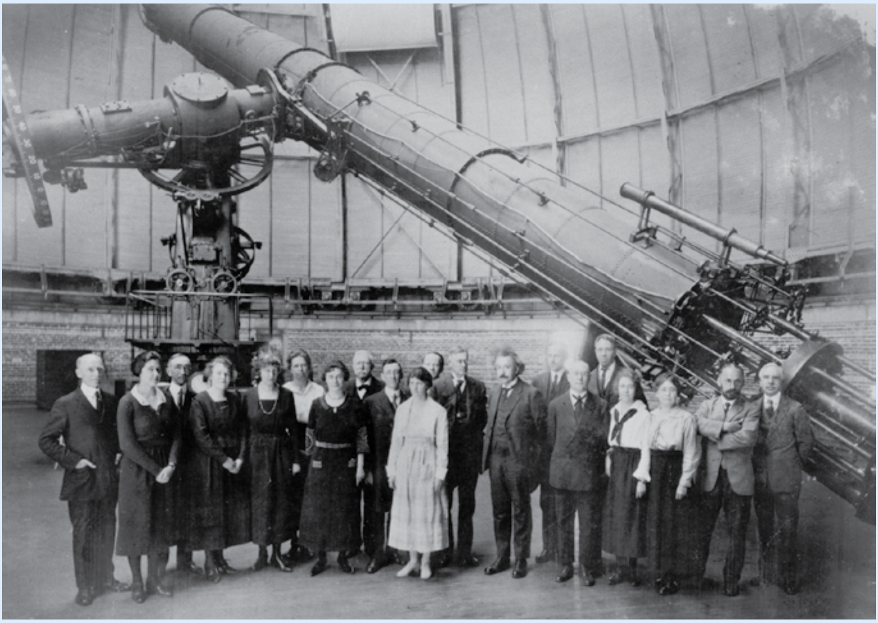
Pointing out through an open dome slit at Pine Bluff Observatory, a spectropolarimeter coupled to a 36-inch telescope records data from a distant target in the sky. *(Jeff Miller/UW-Madison)*

enhancement to the capabilities of UW astronomers. PBO opened in 1958 and has since been the site of many research programs and instrument development programs and also hosts astronomical instruments constructed and operated by the UW Physics Department. A modern research telescope under their direct control was a major advantage for the entire department, including graduate students, who would otherwise have a difficult time winning access to instruments belonging to other institutions.

By the time he left UW in 1958 to become director of California's Lick Observatory (following in the footsteps of his nineteenth-century predecessor Edward Holden), Whitford had radically transformed UW astronomy by shaping an academic department, guiding the relocation to modern facilities, and acquiring a powerful new research instrument. Whitford, more than any other single director, established the foundations that would allow Washburn Observatory to adapt to the new opportunities and challenges of the nascent Space Age and flourish in it.

Wisconsin was well known already to the astronomical world before Whitford, as the careers of Watson, Holden, Comstock, and Stebbins show. As we have seen, the University of Chicago had chosen Williams Bay, on the shore of Lake Geneva, in southern Wisconsin, as the site of their new Yerkes Observatory and home of the largest refracting telescope ever used for research. Thus, Williams Bay was, as of the observatory's opening in 1897, immediately on the astronomical map of the world. The astronomical community at Yerkes became integrated into the Williams Bay community: the Yerkes staff to this day own homes, serve on school and town boards, pay their taxes, raise their families, and find well deserved retirement in southern Wisconsin. Well known Yerkes astronomer W. W. Morgan, for example, was elected to the Williams Bay Village Board from 1943 to 1951, serving as chair (and de facto mayor) the last four of those years.

Under director Otto Struve (director 1932-1948), Williams Bay became the training ground, work place, and often the home of many talented astrophysicists from around the world including Struve himself, Subrahmanyan Chandrasekhar, Gerard Kuiper, Bengt Strömgren, as well as later Washburn director Arthur D. Code. Yerkes also attracted world-famous visitors to southern Wisconsin, famously including Albert Einstein, but also a variety of foreign delegations and many who came for longer periods to collaborate on shared research interests.

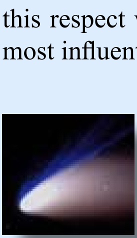


Albert Einstein (eighth from the right) with the staff of the Yerkes Observatory in 1921. Yerkes director Edwin Frost is directly to the left of Einstein. *(Barnett Harris, AIP Emilio Segre Visual Archives, Physics Today Collection)*

The reputation of Wisconsin astronomy can be measured by the fact that after World War II, in 1946, the International Astronomical Union convened a meeting in Copenhagen to attempt to restart European astronomical research devastated by the war. The three U.S. representatives to that meeting were Harlow Shapley of Harvard, Otto Struve of Williams Bay, and Joel Stebbins of Madison.

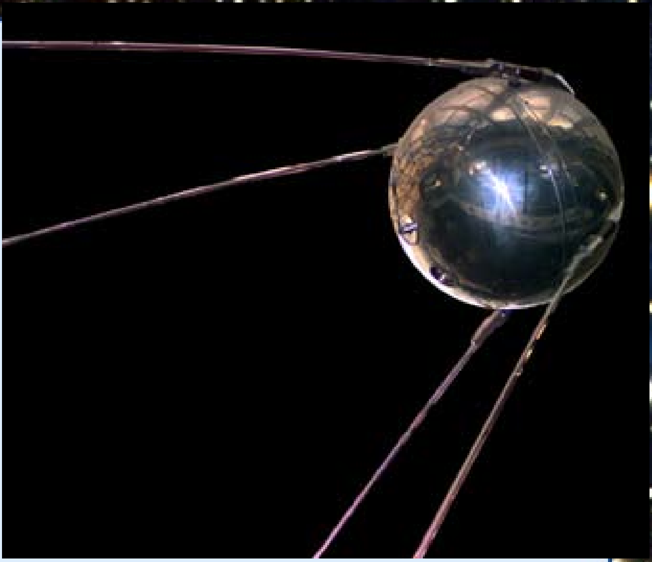
Shortly after World War II, Struve attempted to lure Albert Whitford away from the University of Wisconsin in order to establish a Yerkes expertise in photoelectric photometry, but Whitford preferred to remain in Madison. Yerkes astronomers were well aware of the developing photometric technology in Madison and were among the first to request a Washburn photoelectric photometer so that they could begin to assess the new methods for themselves.

Wisconsin's astronomers shaped national and international astronomy in other ways too. As noted earlier, George Comstock was one of the founding members of the American Astronomical Society and, like Stebbins, Whitford, and Code after him, served in various roles including president of the society. Most important in this respect was Whitford, who, while still at Madison, helped create one of the most influential forces in modern science, the idea of a national observatory.



A National Observatory

Scientific research and development programs organized on a national scale had proved to be very effective, perhaps even crucial in the successful outcome of World War II. From the invention



Replica of Sputnik I*, the world's first artificial satellite.* (NSSDC/NASA)

of fluorescent lights to radar, jet engines to the atomic bomb, "national" laboratories demonstrated the potential of federally funded development efforts to marshal the nation's technical talents toward even the most challenging of goals. Certain military planners realized this immediately after the war and found ways to support pure scientific research. The Office of Naval Research (ONR), for example, was very supportive of astronomers, and significant ONR funding came to Washburn Observatory to support Whitford's work. Fueling the engines of scientific research was a major part of the motivation for the establishment of the National Science Foundation (NSF) in 1950. Starting just after the war, developments in rocketry for both military and scientific ends were pointing to the exploration of space, which would become an international obsession after the October 1957 launch of Sputnik, the first artificial satellite, by the Soviet Union. Astronomers like Whitford saw the coming demands on the scientific research establishment and realized the inadequacy of a "system" in which a handful of major research universities and private institutions controlled access to the nation's largest telescopes. Whitford's own work had benefited from Stebbins' connections at Mt. Wilson, which secured the Wisconsin astronomers access to the Carnegie Institution's 100-inch reflector. But without such connections, how could even the most energetic and ingenious astronomers ever get a chance to visit the astronomical frontiers?

In early 1953, Whitford, along with Otto Struve, Ira Bowen (Mt. Wilson Observatory), and Robert McMath (University of Michigan) were appointed by the NSF to consider the possibility of a national observatory that would be open to all qualified astronomers subject only to the scientific merit of their proposals. The goal was to build a large mountain-top telescope where the sky was dark and clear most of the time. Whitford, who was at the hub of these organizing efforts, envisioned that the national observatory would be run by a consortium of academic astronomy departments funded in part by their universities and in part by NSF. The first result, in 1959, was the creation of the Association of Universities for Research in Astronomy (AURA), in which the University of Wisconsin was a founding member. The second result was the construction of Kitt Peak National Observatory west of Tucson, Arizona, where UW astronomers have now

Aerial view of the Kitt Peak National Observatory as it appeared in 2003. In the foreground is the McMath-Pierce solar facility, the largest solar telescope in the world. At far right is the dome housing the 4-meter Mayall telescope, with the two domes of the WIYN Observatory at far left. (NOAO/AURA/NSF)

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pursued research goals for a half century. AURA was soon running observatories beyond Kitt Peak, including the National Solar Observatory, the National Radio Astronomy Observatory, and eventually the Space Telescope Science Institute (the founding director of which in 1980 would be Art Code, Whitford's successor as Washburn director).

To the Stars

Joel Stebbins could not have known in the 1920s that his work would set later generations of Wisconsin astronomers on a path to the stars that would open wide after Sputnik's dramatic voyage. The world had been preparing to enter space for some time: one of the scientific goals for the International Geophysical Year 1957-1958 was to place an artificial satellite in orbit around the earth to probe its space environment. But Sputnik shifted the idea of space exploration from a purely scientific endeavor to a political-military competition and a symbol of Cold War tensions. The imperative for both sides to demonstrate scientific and technological strength as proof of their ideological superiority resulted in astronauts, orbiting laboratories, Moon landings, and robots racing to planets and other extra-terrestrial destinations. Part of the U.S. response was the founding of the National Aeronautics and Space Administration (NASA), almost exactly one year after the launch of Sputnik, as the primary and nominally civilian agency for space science and exploration. NASA's missions included human exploration of space as well as unmanned exploration of the distant universe, and Wisconsin has produced astronauts, space scientists, and spacecraft in answer to the call.

The Mercury 7, NASA's first class of astronauts. Front row, from left: Walter M. "Wally" Schirra (1923-2007), Donald K. "Deke" Slayton (1924-1993), John H. Glenn (b. 1921), M. Scott Carpenter (b. 1925). Back row: Alan B. Shepard (1923-1998), Virgil I. "Gus" Grissom (1926-1967), L. Gordon "Gordo" Cooper (1927-2004). (NASA)

NASA's program to gain experience with human spaceflight began with Project Mercury (1959-1963), and the first group of Mercury astronauts, the "Mercury Seven," included Donald K. "Deke" Slayton, a native of Sparta, Wisconsin. Like many of the other early astronauts, Slayton was a veteran combat pilot (he served in World War II) and had, by the mid-1950s, become a test pilot. Slayton never flew in the Mercury Program owing to a heart condition, discovered after his original selection, which disqualified him for space flight owing to the extremely conservative protocols of those early days. Despite being removed from the flight rosters, Slayton continued with NASA as a manager of astronaut crews until he was re-qualified for flight in 1972. He finally flew on the crew of the Apollo-Soyuz Test Project, in June 1975, in which U.S. and Soviet astronauts conducted successful orbital rendezvous and docking maneuvers bearing both technical significance and strong political overtones. The Deke Slayton Museum in Sparta memorializes his Wisconsin roots.

James A. Lovell is a veteran astronaut of many flights, but most famously the ill-fated Apollo 13, the story of which has been told in books (including one by Lovell himself), film, and television. Lovell is an alumnus of the University of Wisconsin and married Marilyn Gerlach of Milwaukee. His personal ties to Wisconsin are recognized in both the street and museum in Milwaukee bearing his name. Another Apollo astronaut, Harrison H. Schmitt, was the first and only Ph.D. scientist to walk the moon during the Apollo program. A native of New Mexico with doctorate in Geology from Harvard, Schmitt joined the faculty of UW-Madison in 1994 as an Adjunct Professor of Engineering. Astronaut Robert A. Parker was an astronomy professor at the UW when he was selected for the astronaut program in 1967, while Brewster Shaw received B.S. and M.S. degrees in Engineering Mechanics from the UW in 1968 and 1969 before entering NASA's

Viroqua native Mark Lee exits the Space Shuttle Discovery *in the first untethered space walk in ten years on October 2, 2001.* (NASA)

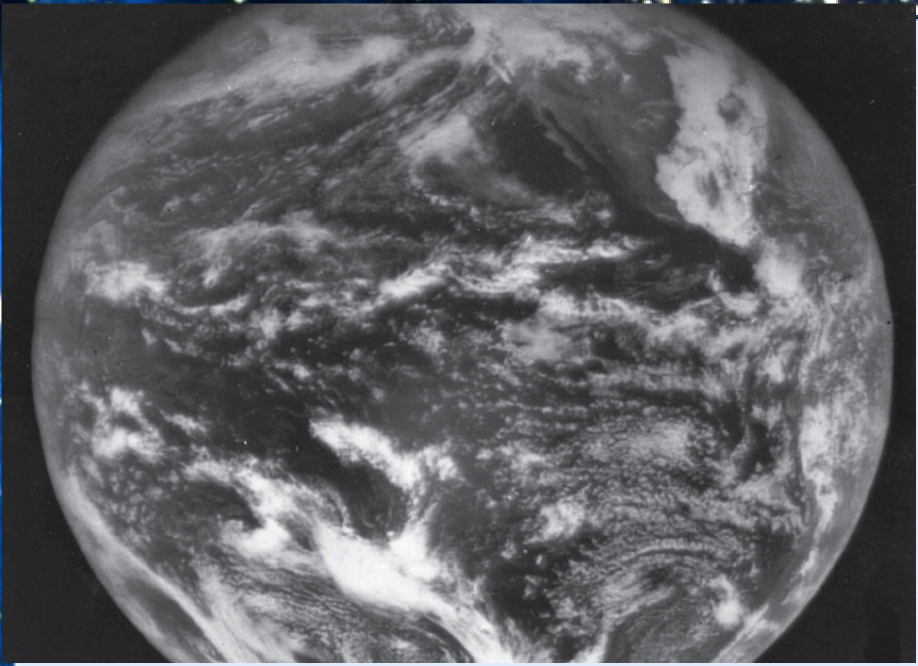
astronaut corps. Another astronomy professor, Kenneth Nordsieck (b. 1946), was in the astronaut corps from 1984 to 1990. Wisconsin natives who have served as astronauts include Mark Lee, a native of Viroqua, Leroy Chiao, from Milwaukee, and Jeffrey Williams of Superior. Last but not least, Wisconsin can claim Dr. Laurel Salton Clark, who died with the rest of the crew of Space Shuttle Columbia on February 1, 2003, at the end of her first mission. She was a veteran flight physician who grew up in Racine and was an alumna of UW-Madison, receiving degrees in Zoology and Medicine in 1983 and 1987, respectively.

Wisconsin became a major player early in the Space Age by virtue of the innovative thought and work of a few university scientists. When Sputnik and its successor satellites showed the feasibility of operating scientific instruments in orbit, scientists of many fields began to consider how satellite-based instruments might open up new ways to understand nature. A prime example is that of meteorologist Professor Verner E. Suomi, who as early as 1963 recognized the scientific potential

Left: James A. "Jim" Lovell (b. 1928), veteran of four space flights and commander of the ill-fated Apollo 13 mission. Below: Laurel Clark (1961-2003), UW alumna and NASA astronaut who died in the Space Shuttle Columbia *disaster. (NASA)*

of satellites to track weather systems and began searching for practical approaches. Early weather satellites occupied relatively low orbits, which could survey only a small fraction of Earth's surface at a given time, with a field of view that changed constantly. When planning began for geosynchronous satellites, which orbit at an altitude of 22,000 miles, Suomi recognized that a camera on such a satellite could take in a view of an entire hemisphere. Geosynchronous satellites orbit in the same period that the earth rotates, so they appear to hang motionless above a fixed point on the surface and can thus continuously track the atmospheric activity below them. Suomi began working with Electrical Engineering Professor Robert Parent in 1964 to develop a "spin-scan" camera in which the rotation of the satellite itself would sweep the camera's field of view across a strip of the earth. By tipping the camera slightly from one scan to the next, an image of the entire hemisphere could be built up.

Robert Parent, left, Verner Suomi (1915-1995), seated, and NASA colleagues examine early ATS-I spin-scan camera images. (SSEC)



ATS-I spin-camera image from December 11, 1966. (SSEC)

With funding from NASA and NSF, Suomi and Parent started the Space Science and Engineering Center (SSEC) on the UW-Madison campus in 1965. Their purpose was to develop a spin-scan camera to fly on the ATS-1 satellite, which was eventually launched in 1966 and was very successful. Development of the camera technology continued at SSEC. Cameras on later satellites were sensitive to specific spectral bands that made possible color, moisture, and temperature measuring capabilities. These instruments dramatically advanced our understanding of Earth's atmosphere and weather systems that affect us. Recording, reducing, and analyzing the huge amount of data generated by the instruments was a challenge in itself ("drinking from a firehose" as Suomi liked to put it), so SSEC developed computer processing and data visualization tools that have become widely used. Their expertise in satellite remote sensing instruments was soon applied to planets other than Earth. SSEC supplied Wisconsin-designed and built instruments for interplanetary spacecraft including the Pioneer Venus mission and the Galileo mission to Jupiter. SSEC's expertise in comparative atmospheric science uses images from the Hubble Space Telescope, for example, to study even the dynamic atmosphere of distant Neptune.

Ad astra pro astris (To the stars for the stars)

The UW's entry into space astronomy had its roots in the photoelectric photometry developed by Stebbins and Whitford in the years before World War II. Unlike photographic film, which was what most astronomers used to measure and record light before the 1980s, electronic instruments could be readily adapted to space because radio signals can be used to control them remotely and the results of their measurements can be transmitted back to Earth the same way. In addition, the electronic photometers were sensitive to ultraviolet (UV) light. Astronomers are very interested in UV light from stars, galaxies, comets, planets, etc., but such studies are almost impossible from Earth's surface because our atmosphere blocks nearly all UV from space. So the possibility of building an ultraviolet instrument that would operate on a satellite was no less than the opening of an entirely new field of astronomical research. Astronomers were ignorant, for example, of how much light stars emit in the UV part of the spectrum. Theories of how stars work made predictions of how stellar spectra behaved in the UV, but there was no way to check those theories. UV photometry offered promise of further understanding the physics of interstellar matter – the stuff out of which stars and planets form – just as visual photometry had established its existence and distribution. It was precisely because of the technical expertise and scientific accomplishments of the Stebbins-Whitford era that Arthur D. Code, a young astronomy professor at California Institute of Technology when Sputnik was launched, saw Wisconsin as the place to establish and explore the astronomy of the ultraviolet universe.

SAL Logo

Code knew Wisconsin's astronomical community personally because he had done his graduate work at Yerkes Observatory with Subrahmanyan Chandrasekhar, one of the giants of twentieth-century astrophysics. Soon after Code earned his Ph.D., Whitford recruited him to come to Washburn Observatory to work on photoelectric photometry, which he did from 1951 until 1956, when Code was lured away by Caltech. Soon afterward, in 1958, Whitford, then at the peak of his career, accepted the directorship of California's Lick Observatory. Whitford was intrigued no doubt by the challenge of bringing Lick's new 120-inch telescope to its full potential. But also, despite being the principal architect of the transformations (new department, new building, and new observatory) of the Washburn Observatory, he might have felt that organizing the rapidly expanding programs of undergraduate and graduate instruction was not where his talents were best employed. Thus in the summer of 1958, Art Code accepted the position of director of the Washburn Observatory with the intention of establishing a space astronomy program as well as expanding faculty and graduate programs. In doing so he gave up a tenured position at Caltech with access to major research telescopes and other facilities

Professor Arthur D. Code, astronomer, sixth director of Washburn Observatory, founder of Space Astronomy Laboratory, leader of UW OAO team and leader of WUPPE team. (UW Astronomy Dept.)

in return for the opportunity to take astronomy in the completely new direction he envisioned. In order to attract Code, the UW agreed to a further expansion of the Astronomy Department, and Code convinced his Caltech colleague, Donald E. Osterbrock to accept a new faculty position and relocate to Madison. The department further expanded by hiring a theoretician, Professor John S. Mathis. This rapid expansion was simultaneously building a base for more ambitious research programs and making possible an expanded graduate studies program.

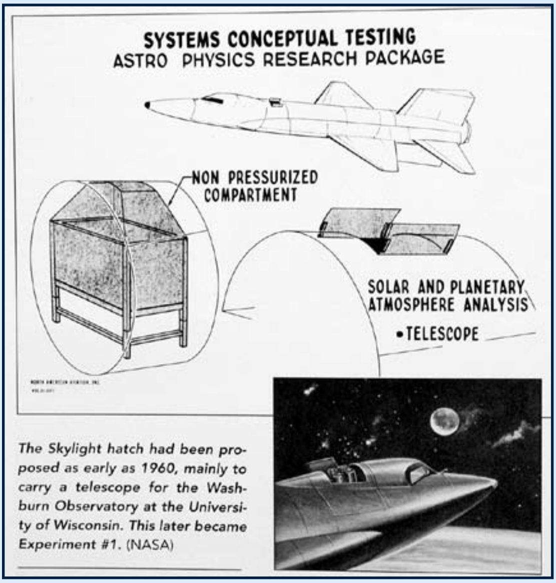
Meanwhile, recognition of the importance of space science was growing at the national level: NASA was formed to develop the nation's aerospace capacities, and the National Academy of Sciences created a Space Science Board (SSB) to identify and evaluate the myriad new scientific possibilities. One of the first actions by the SSB, in summer 1958, was to send telegrams to selected U.S. astronomers requesting their ideas for satellite experiments. Art Code, newly arrived at Washburn, was one of those astronomers, and he had clear ideas about how to respond to the opportunity. His concept envisioned a 100-pound satellite containing a single reflecting telescope feeding light to a UV-sensitive photoelectric photometer accompanied by the necessary electronics for control, data collection, and telemetry. Although there were a great many suggestions for astronomical satellite experiments, relatively few astronomers were willing to commit to the formal studies and proposals that would be required for actual project development. The most committed of these constituted a group convened by NASA in early 1959 called the Space Science Working Group (SSWG) whose members began receiving NASA funds to explore techniques and methods. Code's commitment to the still unproven potential of space astronomy, which many scientists saw as too risky to build a career on, quickly made him one of the leaders in the SSWG planning.

At the local level, Code prepared for the effort that would be needed to succeed in space astronomy. Working with Assistant Professor Ted Houck, Code set up the Space Astronomy Laboratory (SAL) within the Astronomy Department to support the new level of technical development and operational capabilities of a space astronomy program. Houck (who had earned his Ph.D. with Whitford at Madison) would remain a key figure in the work of SAL for the rest of his abbreviated career. Robert Bless had come to Washburn as a post-doctoral fellow in 1958, after finishing his Astronomy Ph.D. at the University of Michigan, to work on a project started by Whitford with funding from the Office of Naval Research and later the National Science Foundation. The project, continued under Code, was to investigate the absolute energy distributions in stellar spectra, a

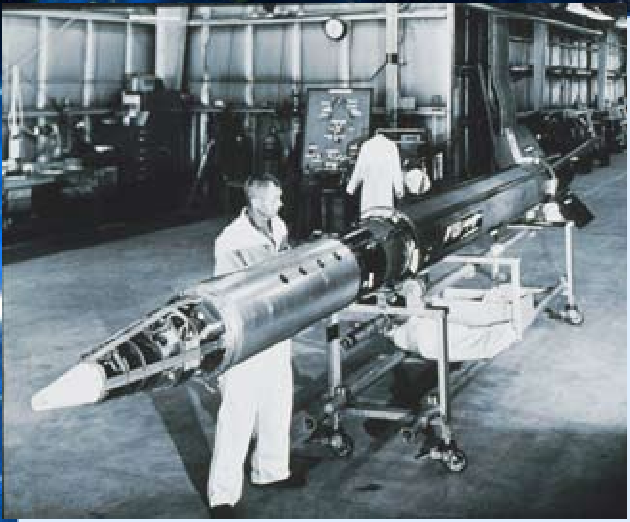
Professor Robert C. Bless (b. 1927), astronomer, leading member of UW OAO team, and leader of the High Speed Photometer project. (UW Astronomy Dept.)

problem directly related to the local expertise in photoelectric photometry. Bless, who joined the UW astronomy faculty as Assistant Professor in 1961, also joined SAL at its founding. John McNall, UW Ph.D. in electrical engineering and computer science in 1960, joined the SAL astronomers that same year. With their first NASA funding, the close-knit SAL group began testing small instruments capable of becoming flying scientific payloads. They recognized the need to proceed in small steps in order to master the techniques of instrument design, building, and control, along with data acquisition and processing. Code used his NASA funding efficiently, in part by adding talented, dedicated graduate students to the group. Code's management style was to keep the team small, to minimize bureaucracy, and to keep equipment and instruments as simple as possible. This management style, although at times attracting the suspicion of NASA, was an important element in their success.

SAL's first flying instrument, consisting of a photometer two-thirds the size of a shoebox, was launched in June 1961. It took flight over Lake Mendota on a weather balloon, was tracked by radio from a ground station, and eventually landed in a farmer's field in Illinois. Code recognized another incremental step toward true satellite operation was offered by NASA's X-15 rocket plane. The X-15 could fly high enough to make some UV measurements possible and ensured that the instrument payload would be recovered after the flight. NASA funded SAL's X-15 instrument as a test not only of UV instruments but as an experiment in human control (in this case by the X-15's pilot) of scientific payloads. The X-15 program yielded several successful sets of observations between 1963 and 1966, but technical advances in rocketry offered a new and much more capable instrument platform. This next incremental step forward came with SAL's development of instruments to fly on so-called "sounding" rockets. These are smaller rockets that do not reach orbit (hence also called "suborbital" rockets), but fall back to the ground after reaching altitudes well in excess of 100 miles. Earlier suborbital rocket flights were not designed to recover the payload (which fell back into the ocean), but that had changed by the early 1960s. When all goes according to plan, a parachute opens upon re-entry

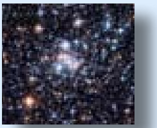


An illustration from North American Aviation Inc. showing the SAL experiment in the instrument bay of the X-15. (UW Astronomy Dept.)



Aerobee suborbital rocket being assembled for launch. (UW Astronomy Dept.)

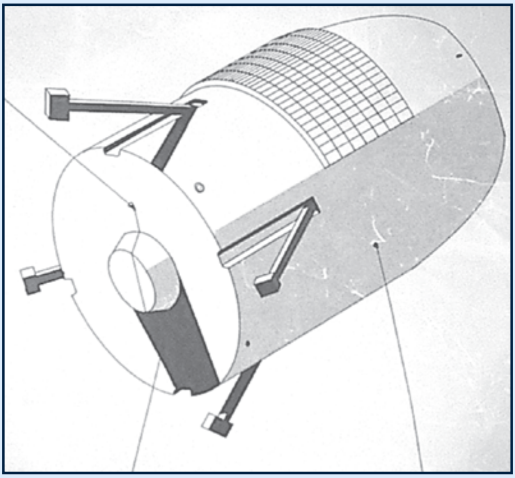
enabling the payload to survive landing in the desert of White Sands, New Mexico. Although the time spent in space is limited to a few minutes, suborbital rocket instruments can be much cheaper than satellite instruments, so they were a perfect testbed for SAL experimentation. The first flights, beginning in 1962, served as a step on the way to a satellite mission, but suborbital rocket experiments proved so cost effective and scientifically productive that they have remained a specialty of Wisconsin astronomers and physicists since those test flights of the early 1960s.



Orbiting Astronomical Observatory

All of this early SAL development was leading to the goal of a true UV observatory in space, which NASA called the Orbiting Astronomical Observatory (OAO) program. NASA decided early on that the common requirements (pointing accuracy and stability, programmable command and control, electrical power, communications, etc.) of the various proposed space astronomy instruments made it logical to design a standard OAO spacecraft able to carry and support a variety of payloads. The proposed spacecraft design was a hexagonal column about 10 feet tall and 7 feet wide. Winglike solar panels stretched more than 20 feet from the sides. The hollow center of the spacecraft enclosed a 4 feet diameter tube running through the center to accommodate instruments that would look out the ends. Able to encompass instruments much larger than Code’s original 100-pound photometer satellite, the design of the SAL instrument (called the Wisconsin Experiment Package, or WEP) grew more ambitious and sophisticated while still guided by the SAL design mantra of simplicity. (Note: A full-scale OAO prototype spacecraft with prototype WEP is on public display at UW Space Place in Madison.) WEP would consist of one central reflecting telescope with a 16-inch mirror delivering light to a UV photometer, four 8-inch telescopes, each with its own UV photometer package, and two low-resolution scanning spectro-photometers. Each of these instruments was a descendant of the Stebbins-Whitford instruments.

Since its founding, SAL had moved to several locations, finally setting up shop in the summer of 1960 in an empty warehouse at 35 N. Park Street, about



Sketch of Code's early "100-pound" UV satellite concept, which eventually developed into the Wisconsin Experiment Package. (UW Astronomy Dept.)

a fifteen minute walk from the Astronomy Department in Sterling Hall. With laboratories and machine shop in operation there, most of SAL's early payloads took shape on that site, including WEP's components. Fabrication of these instruments involved a number of technical challenges. For example, the UV filters required were not available anywhere, so the techniques for depositing multilayer thin films on glass to make the needed filters had to be developed by SAL's Dan Schroeder (who, after finishing his Ph.D., became a physics professor at Beloit College and later an important member of the Hubble Space Telescope project). Manufacture of these filters continued under Tim Fairchild and were a specialty of SAL for the next 20 years. Although the actual building of the WEP electronics was done by SAL in Madison, the detailed design and testing of the instrument package and its associated electronics required the resources of an experienced aerospace contractor. The bids submitted included some from major aerospace contractors, but the winning bid came from a much smaller and closer Chicago area firm, Cook Technological Center. Code and his team were pleased with this outcome reasoning that a smaller firm would work better with the SAL management style. Also, being relatively nearby, it would be easier for the SAL team to work with Cook on such a complex project than with any firm on the east or west coast.

By late 1961, SAL was at work with Cook to produce prototype instruments suitable for tests on suborbital rocket flights scheduled for late 1961 and 1964, with still others to follow. SAL scientists Ted Houck and John McNall handled the majority of the seemingly endless meetings and reviews that keep large, complex projects on track. It must have felt auspicious and encouraging that the September 1964 SAL suborbital mission produced a major scientific result: Wisconsin's UV astronomers solved a puzzle first posed by a Goddard Spaceflight Center measurement, which seemed to show some stars to be oddly dim in the UV. But, in fact, the expected UV light was there, thus eliminating the need for theories to explain why the light was disappearing. Such a result hinted at the scientific potential promised by the OAO project. Unlike the few earlier attempts at space astronomy, which were mostly specialized suborbital experiments, OAO would be highly flexible and able to conduct a wide variety of observations. NASA designed the OAO spacecraft to be capable of pointing its instruments anywhere in the sky to an accuracy of one arc minute (one-sixtieth of a degree) and maintain that orientation

Professor Theodore E. "Ted" Houck (on the left) (1926-1974), astronomer and leading member of the UW OAO team. (UW Astronomy Dept.)

to an accuracy of one arc second (one-sixtieth of a minute). Two instrument packages, back-to-back in the central corridor of the satellite, looked out in diametrically opposite directions on the sky. (Code and Bless both recall that this arrangement, first suggested by the Wisconsin team, was first met with resistance from the NASA engineers, but quickly became a "feature" of the spacecraft design.) The OAO program was thus a huge step forward from small limited experiments to a 4,600 pound spacecraft in a 500 mile high orbit.

WEP was completed, tested, delivered to NASA, and installed in the first OAO spacecraft in time for a launch in Spring of 1966. WEP's companion instrument, looking out the other end of the satellite, was a set of gamma-ray and x-ray instruments designed at MIT by a team including William Kraushaar, with his MIT colleague Frank Scherb, both of whom would later join the faculty of UW-Madison's Physics Department. After a series of launch delays, bringing the teams to near exhaustion because of the constant replanning of post-launch orbital operations, which had to be redone after every delay, the launch took place on April 8, 1966. To everyone's relief, the Atlas-Agena rocket delivered the OAO-1 satellite successfully into orbit. Art Code and Bob Bless liked to joke that their first WEP instrument performed flawlessly: the WEP was turned off before launch, commanded to stay off, and it did so. The mission was a total disaster. As soon as ground

The Wisconsin Experiment Package (WEP), before installation in the spacecraft, being checked by Cook Technology Center engineers. The WEP controller is visible below. (UW Astronomy Dept.)

The launch of the highly successful OAO-2 mission on December 7, 1968. (UW Astronomy Dept.)

controllers turned on electrical power to some of the spacecraft systems, big trouble appeared. No one knows exactly what happened, but the failures are consistent with electrical discharges – sparks and arcs – when the high voltage power supplies were turned on. The electrical surges and interruptions caused other systems to malfunction and fail, and radio contact with the satellite was lost. Soon after, ground-based radar indicated several pieces where OAO-1 should have been. One theory is that the batteries overcharged and exploded. In any case, by Easter Sunday 1966, SAL's first satellite mission was over before it had started.

In reviewing the huge loss, NASA concluded that they could fix things well enough to try again with a new OAO, and they proved themselves correct in that. Other experiments were awaiting their chance to fly in the OAO series, and complex negotiations ensued, but in the end NASA wanted to know: Would SAL be willing to build a second WEP identical with the one lost on OAO-1? Code concluded that the effort already invested in design and testing, not to mention the scientific work that still awaited, was justification enough to try again. A second WEP was built by SAL and Cook, tested, and delivered to NASA, which launched OAO-2 on December 7, 1968. This time WEP's companion instrument was a set of UV imaging cameras from the Smithsonian Astrophysical Observatory. Tensions were, of course, high in the first hours of the mission, but the spacecraft and its systems were energized without incident and operations began. Bless recalls that actual satellite operation was much more complex than they had anticipated, so the team members had to work very hard in the first weeks to understand the quirks in the OAO pointing system, the disturbances caused by anomalies in Earth's magnetic field, technical limitations in the instrument electronics, and the like. John McNall and his graduate student Curt Heacox wrote sophisticated software to handle the intricate process of scheduling scientific observations, which had to take into account available target objects, spacecraft pointing motions and limitations, contact opportunities with ground control stations, orbital night and day, terrestrial magnetic field disturbances, and instrument setup (such as filter selections, exposure time, etc.). The software then generated a set of commands that was transmitted to the OAO to control its operations for the planned observing period. With OAO-2 operational as the first space observatory, scientific investigations could begin in earnest.

WEP was such a scientific success that the OAO-2 mission, originally scheduled to last one year, was extended by NASA several times. By the time OAO-2 operations were forced to end (by failure of the WEP power supply) in January 1973, WEP had observed about 1,200 different objects, including seven planets, two comets, hundreds of stars, a bright nova (a stellar explosion), and a variety of nebulae and galaxies. All this observing activity produced an impressive list of scientific results. The scientific results were published in a number of places, but were largely summarized in a NASA symposium publication edited by Code and published in 1972. Art Code has stated that in his view the catalog of UV stellar spectra compiled was the most important scientific product of the OAO-2 mission. Of great importance to astronomers was the first real understanding of the "interstellar extinction" in the UV, that is, how interstellar dust blocks and scatters starlight as a function of the wavelength of the light. (This, again, was a logical extension of the studies of interstellar matter and extinction in visible light that had begun with Stebbins and Whitford.) Among many other scientific results, WEP observations of Nova Serpentis 1970 (an explosive stellar outburst that occurred during the OAO-2 mission) showed that UV brightness of the nova increased even as the visual bright-

Above: UW-Madison Astronomy Department personnel, circa 1970. Front row from left: Arthur Code, Bea Ersland, Donald Osterbrock. Back row: Jack Forbes, John McNall, Lowell Doherty, Robert Bless, Chris Anderson, John Mathis, Blair Savage. Left: Diagram prepared by Grumman Corp. illustrating the discovery of a new component of the structure of comets by WEP instruments. UV observations revealed a huge cloud of hydrogen surrounding the head of Comet Bennett, observed in 1970, which indicated breakdown of water molecules contained in the comet. *(UW Astronomy Dept.)*

This old warehouse at 35 N. Park St. was home to the Space Astronomy Laboratory during much of the OAO project. (UW Astronomy Dept.)

ness decreased. This finding brought about a new understanding of the behavior of the expanding shell of luminous matter ejected by this kind of stellar explosion. Another highly influential result came from the discovery of huge clouds of hydrogen, detectable by its UV emission, surrounding the nuclei of two comets that appeared in 1970. The hydrogen was identified as a breakdown product of water, thus showing that water is a common and plentiful constituent of comets and hence would have been plentiful in the formation of the planets early in the development of the solar system. In the final analysis, Bob Bless observes, perhaps the greatest impact of the OAO-2 mission was to demonstrate conclusively that UV astronomy was as important as they had thought it might be and that first-class space astronomy research was within the means of current technology. Had either of these factors come out in the negative, finding support for subsequent UV work, and perhaps any other space astronomy projects, like the Hubble Space Telescope, would have been much more difficult.

In nearly every respect, OAO-2 represented a tremendous step forward. OAO-2 was the largest scientific satellite to date, enabling it to carry a versatile suite of instruments and to provide the power, thermal control, communications, pointing abilities and the like needed by the instruments. It could carry out automatic observing programs, store the resulting data, and relay it to Earth. It was capable of long-term operations, yet available to take advantage of unforeseeable opportunities, such as comets and novas. It was controlled from Earth by a team of astronomers who sought to maximize the scientific value of the program and knew their machine well enough to do just that. OAO-2 was, in fact, the first true general purpose space observatory, and it set the standard for success in the many incremental stages that followed, leading eventually to the Hubble Space Telescope.

The prominent success of OAO-2 and WEP set the stage for two major projects that came to dominate SAL activity in the 1980s. One was an instrument designed to fly on the Hubble Space Telescope, the other was to be part of a series of astronomical space shuttle missions. Both were direct descendants of WEP,

From left, Professors Art Code, Ted Houck, John McNall (1930-1978), and Bob Bless examining one of the 8-inch photometric telescopes that were part of the WEP. (UW Astronomy Dept.)

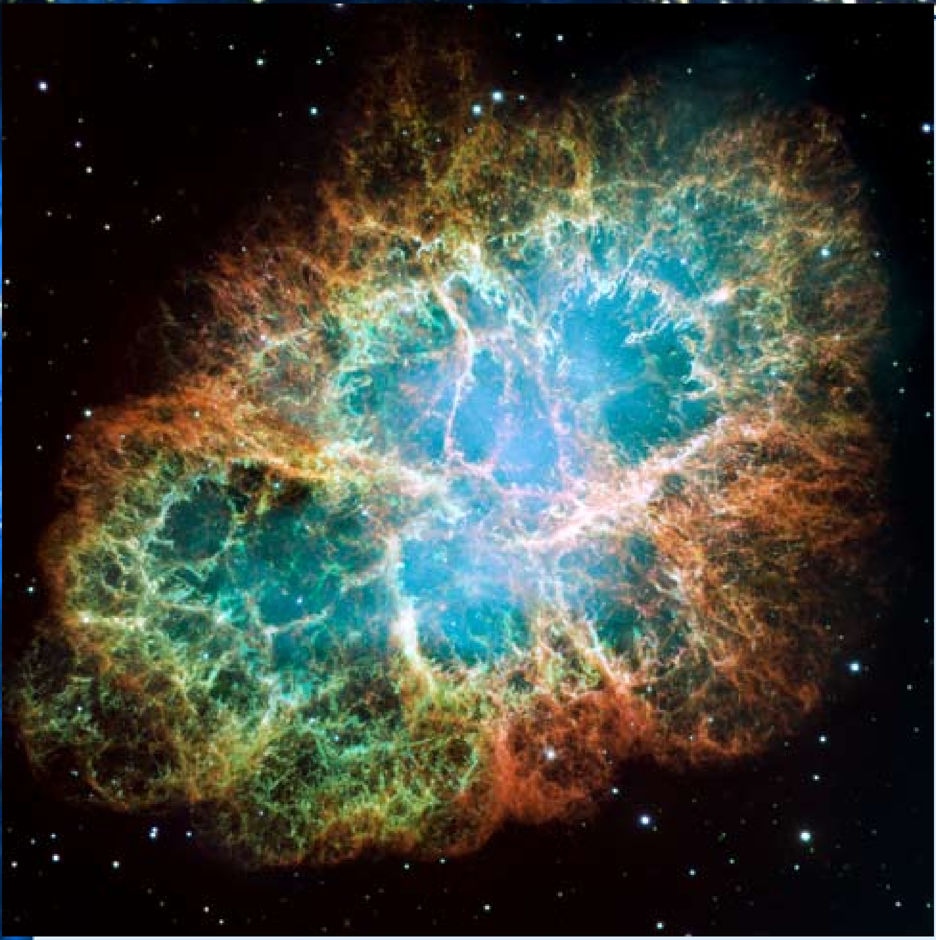
and many members of SAL's WEP team were key to the new projects. After OAO-2, NASA launched two more in the OAO series (one was a serious failure; the other, renamed Copernicus, a notable success). The idea of a much larger general-purpose space observatory, a "Large Space Telescope," had been in various stages of planning for many years. Wisconsin's astronomers, largely as a result of the success of OAO-2, were deeply involved in the Space Telescope from the beginning. Bless, Houck, and McNall served on various NASA panels helping to define scientific goals and instruments for the project. Late in the project but before launch as delays became a serious concern to the astronomical community, NASA chose Bless to chair an oversight committee to monitor progress and make assessment reports to NASA. Code chaired a committee charged with considering the organizational possibilities for creating and operating the new space observatory and later guided the efforts of AURA, which won the contract to create and operate the Space Telescope Science Institute, of which he was the acting director in its formative stages. Wisconsin astronomers also served on several of the instrument teams other than SAL's own: Code worked on the Wide Field/Planetary Camera project, as did Professor John Hoessel, and Professor Blair Savage worked on the team that produced the High Resolution Spectrograph.

By 1978, the project, eventually named the Hubble Space Telescope, had been designed to be a remotely operated general purpose facility launched in the cargo bay of the Space Shuttle – a decision that placed significant constraints on many aspects of size and operations. It was unique in being designed to be serviced and upgraded in orbit by astronauts. (This would prove to be the salvation of the entire project.) The Space Shuttle was to have other scientific missions as well, including acting as an orbiting platform for temporary specialized astronomical instruments that could be operated by astronaut astronomers in real time. These two types of operation – remotely operated space observatory and shuttle-based, manned astronomy experiments – would give rise to the next two major initiatives for UW-Madison's Space Astronomy Laboratory, the High Speed Photometer and the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE).

UW Astronomy and the Hubble Space Telescope

The High Speed Photometer (HSP) grew out of a simpler idea in response to a unique opportunity in much the same way that WEP had come about. NASA requested ideas from the community of astronomers for instruments to become part of the new space telescope. To Wisconsin's astronomers, for whom photometry was a familiar and powerful technique, it made sense that the new space telescope should have photometric capabilities. But in the SAL tradition of keeping things as simple as possible, Bless's team proposed a small instrument with no moving parts and very simple operations. The space photometer would operate much like a ground-based model, but would take advantage of being behind a big telescope high above our atmosphere to try something new: making measurements as rapidly as 100,000 times per second; hence a "high speed" photometer. On Earth's surface this is nearly impossible to do because our restless atmosphere constantly distorts images, making them blur and shimmer. (This is what makes stars twinkle.) Hence, in high speed photometry from the ground, it is hard to distinguish atmospheric effects from those in the object. High time-resolution measurements could reveal, for example, the details of incandescent matter falling into black holes, the vagaries of rapidly rotating neutron stars, the structure in planetary ring systems, behavior of stellar eruptions, and so on, all of which are observations limited by our fluctuating atmosphere. And in space, of course, there is access to the UV and infrared parts of the spectrum. Measurement of the polarization of starlight would add a further dimension. HSP would once again take Wisconsin's photometry tradition in an

The Hubble Space Telescope in orbit. It initially carried five primary science instruments, one of which was the UW Space Astronomy Laboratory's High Speed Photometer. (NASA)



The Crab Nebula, consisting of remnants of a star that exploded over 1,000 years ago, contains a rapidly spinning neutron star (not visible here), called a pulsar. HSP made the first ultraviolet observations of the pulsar's flashes. *(NASA/ESA/J. Hester and A. Loll (Arizona State University))*

entirely new direction. NASA found the scientific possibilities compelling enough that instead of the small auxiliary instrument originally proposed by SAL, they wanted HSP to be enhanced in abilities and promoted to one of the five primary science instruments to be launched with Hubble. Despite the expanded scale and capacity, HSP remained the simplest and least expensive of the Hubble's science instruments, capable of a vast variety of observing modes and filter combinations yet without a single moving part.

Bless decided that SAL did not have adequate facilities, such as clean rooms and technical shops, to handle the construction of HSP, especially since WUPPE, the shuttle-based instrument, was also being built at SAL. Bless discussed the project with the UW-Madison Space Science and Engineering Center (SSEC), only one block away from SAL's home base in Chamberlin Hall. SSEC collaborated

The High Speed Photometer under construction around 1985 in the clean room at UW's Space Science and Engineering Center. On the left is Principal Investigator Robert Bless, on the right facing the camera is Project Manager Evan Richards. *(UW Astronomy Dept.)*

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in the final proposal to NASA and, after SAL won the award, SSEC received the subcontract for the construction and testing program of the new instrument. Thus, in addition to being the simplest and least expensive of the Hubble science instruments, it was the only one constructed entirely on a university campus. In addition, quite a few UW students, both graduate and undergraduates, were employed in various aspects of the project. SAL delivered the instrument to NASA on schedule for acceptance testing in 1983 and launch in 1990. HSP operated perfectly for its entire mission, but it was not a happy ending.

The dramatic story of the Hubble Space Telescope's flawed mirror, a complex tragedy of poor management by the Perkin-Elmer Corporation and NASA, has been often told. Less well known is that HSP was the final victim of the story. The flawed mirror produced distorted star images instead of the sharp spots of light that all the science instruments needed for their best work. HSP's performance was particularly hurt by the optical problem, which made the star images even bigger than the smaller apertures of HSP's photometers. This considerably reduced the efficiency of the instrument and prevented much of the planned observations. Moreover, during most of the time that HSP was in the Hubble telescope, the telescope systems had a pointing instability that made it very difficult to keep the light, poorly focused as it was, centered on the entrance apertures of HSP's photometers. Despite these handicaps, the HSP team completed a number of successful observing programs with published results including the most precise visible light pulse profile and the first ever UV pulse profile of the pulsar in the heart of the Crab Nebula. NASA engineers eventually fixed the Hubble Space Telescope on the first space shuttle servicing mission in December 1993. The plan was to remove one of the science instruments and use that space to install corrective optics that would restore the near perfect images that the telescope was designed to deliver. The instrument chosen for that sacrifice was HSP, which returned to Earth after a flawless mission but with disappointing results; the Hubble observatory's mission and reputation were salvaged by that painful compromise.

UW Astronomy and the Space Shuttle

The Hubble Space Telescope was delivered to Earth orbit by the space shuttle and then left there to operate under ground control. But NASA also planned a series of missions in which the shuttle would be loaded with a specially designed space astronomy observatory designed to work in the shuttle bay under the active control of astronomer-astronauts. The so-called "Astro" missions would be dedicated to the already highly productive programs of UV astronomy, of which OAO-2 had been the pioneer. SAL saw a new opportunity in an instrument called a spectro-polarimeter, which measures the amount and direction of polarized light received from an astronomical object. Polarization can convey information about shapes and sizes of stars and the disks of matter that often surround them (which, in many cases, hold nascent systems of planets). Polarization can also be used to probe the nature and distribution of the interstellar matter of our galaxy. Study of interstellar matter had been a major activity of the Stebbins-Whitford era and had become a strength of the Washburn astronomers at both the theoretical and observational levels through the work, for example, of Professors John Mathis and Don Osterbrock. Extending spectro-polarimetry into the UV would be valuable research and could be done with a polarimetric instrument invented by Professor Ken Nordsieck, but it could only be done from space like most UV observing. So Professor Nordsieck's instrument became the heart of the Wisconsin Ultraviolet Photo-Polarimeter Experiment (WUPPE), which would accomplish the first ever polarimetry at wavelengths invisible on Earth's surface. But the timing was awkward because the HSP and WUPPE opportunities came along at the same time. Art Code recalled that his philosophy of conflicting opportunities has always been "If you come to a fork in the road, go both ways." So SAL wrote both proposals, one for the space telescope and the other for the space shuttle program, expecting that they would be lucky to land even one of them given the stiff competition for major NASA projects, and little expecting that both, as it turned out, would be accepted. Code led the WUPPE team with Bless as co-leader, Bless led the HSP team with Code as his co-leader. As HSP took form in the facilities of SSEC, WUPPE

Astronauts Story Musgrave and Jeffrey Hoffman working on the Hubble Space Telescope, temporarily docked in the space shuttle cargo bay, during the first servicing mission in December 1993. The astronaut on the left maneuvers the corrective optics package, which replaced HSP, into the telescope's science instrument section. (NASA)

UW-Madison's Kenneth Nordsieck (b. 1946) in a zero-gravity simulation flight during his astronaut training. (NASA)

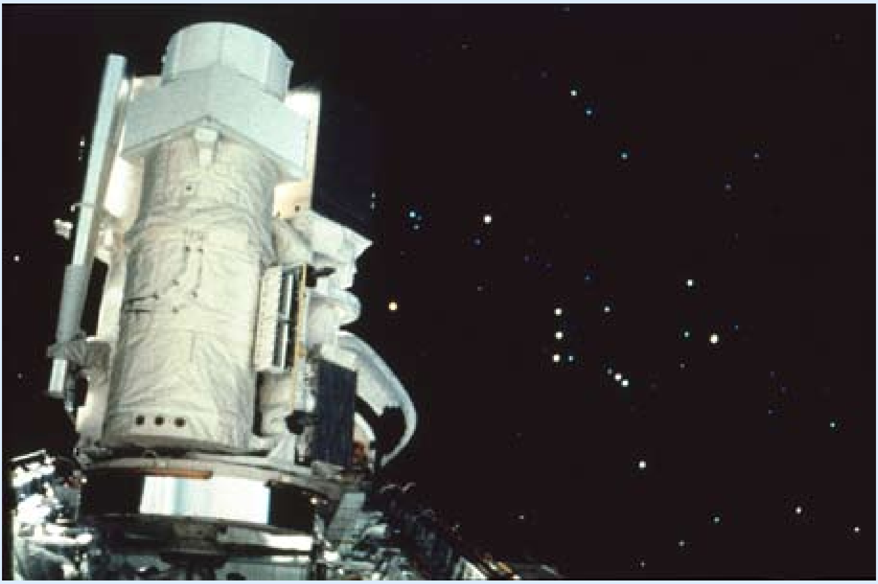
came together on the sixth floor of Chamberlin Hall. One of the ideas behind the Astro missions was that instruments under active control from the shuttle itself could be operated more like ground-based instruments, e.g., responding rapidly to changing conditions, adapting to unexpected results, and seizing unforeseen opportunities. Toward that end, NASA recruited astronomers to enter the astronaut program as "payload specialist" astronauts, a path Ken Nordsieck followed in 1984. He ultimately left the astronaut corps in 1990 without flying a space mission and directed his efforts to the flight of Astro-2 and other projects.

WUPPE (invariably pronounced "whoopee") coupled Nordsieck's polarimeter instrument to a 0.5 meter reflecting telescope along with all the necessary control and support equipment. WUPPE would fly as one member of a suite of UV instruments built by other groups to accomplish tasks such as imaging and spectrometry all mounted on a common pointing platform in the cargo bay of a space shuttle. WUPPE and its companion instruments could be controlled, and their data examined, from inside the shuttle itself or from the ground. Although WUPPE was the largest and most complex instrument program ever undertaken by SAL, it was delivered to NASA on time for its integration into the shuttle and eventual launch on the mission called "Astro-1," which was originally scheduled for February of 1986 aboard the space shuttle Columbia. Astro-1 was to be the first of six such astronomical spaceflights, but that plan changed in January 1986. WUPPE and the Astro-1 payload were already at Kennedy Space Center being loaded into Columbia, and Nordsieck and his fellow Astro payload specialists were preparing at KSC, when the space shuttle Challenger exploded during launch on January 29, 1986. Challenger's entire crew and payload were lost, and WUPPE was stranded on the ground.

No shuttles would fly for a several years as NASA's inquiries into the explosion proceeded and the agency re-evaluated their operations. Payload instruments that were ready to fly, like WUPPE, went into storage for the duration. Besides the long delay, the Challenger disaster resulted in, among other things, a large shift in NASA's priorities for shuttle missions. In particular, science-specific missions were reduced in number, and the scheduled Astro missions were reduced to two. WUPPE did eventually fly after NASA resumed shuttle operations. The Astro-1

From left, Kenneth Nordsieck, Arthur Code, and Professor Christopher Anderson with WUPPE in the background. (UW Astronomy Dept.)

flight was finally launched aboard Shuttle Columbia on December 2, 1990, and flew for nine days. Nordsieck, as alternate payload specialist for that mission, was the chief ground-to-air communicator, which proved to be a very challenging job. The mission's science was plagued with problems, mostly in the shuttle's payload interface and control systems. The control system problems considerably slowed and limited the observations, although with a great deal of trouble-shooting and replanning, the orbital and ground-based teams did eventually develop new methods that made possible some successful scientific work. The Astro-2 flight aboard Shuttle Endeavor flew a record-breaking 17-day mission March 2-18, 1995. Astronomical observations on this mission went smoothly and were very productive. WUPPE observed a wide variety of objects, using the first UV spectro-polarimetry to investigate solar system objects, distant galaxies, and unusual and exploding stars. WUPPE's success encouraged further development of UV polarimeters sensitive to diffuse objects



WUPPE and the Astro payload viewed through the space shuttle's payload bay windows with the constellation Orion in the background. WUPPE is the right-most of the instruments in the cluster with its dark, rectangular sunshade near the top. (UW Astronomy Dept.)

and higher spectral resolution spectro-polarimeters going farther into the ultraviolet. During its missions WUPPE made UV spectro-polarimetric observations of 121 objects and collected spectra for 65 objects resulting in more than 100 scientific publications. WUPPE's observations provided insights into the distribution and effects of interstellar dust and improved our understanding of stars surrounded by disks of dust and gas, making possible better models of these systems where new planets might be forming.

Pine Bluff Observatory played an import role in WUPPE's scientific work by hosting a ground-based counterpart. A spectro-polarimeter for the visible spectrum was designed and built to be used on PBO's 36-inch telescope. Before, during, and after the Astro missions, it observed the same stars that WUPPE observed, sometimes, when possible, at the same time that WUPPE was observing in orbit. This provided the possibility of obtaining polarimetry data on any given object encompassing both visual and UV parts of the spectrum. Scientific results included better understanding of the structure and composition of interstellar matter, investigations of the nature of rapidly rotating stars, and the discovery of new features in the complex systems of interacting binary stars.

Space Physics

Innovative research in astronomy and space science have not been the exclusive domain of any one department, or indeed any one campus in the University of Wisconsin system. UW-Milwaukee, for example, today hosts a Center for Gravitation and Cosmology, and UW-Green Bay is the headquarters of the NASA-funded Wisconsin Space Grant Consortium. There are far too many examples to list, but the pattern is clear. Federally funded research, especially from NASA and NSF, has opened opportunities for a great many space science programs, from Engineering to Plant Pathology to Medicine, along more or less the same pattern that emerged in the early days of space astronomy, namely the federal agency identifies and prioritizes areas of inquiry that deserve serious investigation, then talented scientists and other academic experts of Wisconsin's universities turn their attention to those inquiries, thus exploring the universe while simultaneously enriching teaching on our campuses and building them into stronger institutions of learning. Another excellent example of this kind of synergy is the development of x-ray astronomy at Madison, which came about through NASA-funded research in the UW Physics Department.

Like UV light, x-ray energy (which is also a form of electromagnetic radiation, like visible and UV light but with much higher energy) cannot penetrate Earth's atmosphere, so investigating x-rays from astronomical sources can only be done from space. The same is true of the even higher energy gamma-rays. At the same time that NASA was encouraging Wisconsin's astronomers to invent UV astronomy, researchers elsewhere were working on the earliest x-ray experiments. As mentioned earlier, WEP's companion instrument on the ill-fated OAO-1 was a package of x-ray instruments designed and built by a team at MIT led by William Kraushaar. The OAO-1 payload was, of course, lost with the entire mission.

Portrait of Professor William Kraushaar (1920-2008), physicist and pioneer of x-ray and gamma-ray astronomy. (UW-Madison Archives)

(On OAO-2, the second WEP's companion payload was not an x-ray payload but a suite of UV cameras designed by a team at the Smithsonian Astrophysical Observatory.) Kraushaar at MIT had built the first space-based gamma-ray detectors before starting on x-ray astronomy. He joined the faculty of the UW Physics Department in 1965, where he continued his work in developing instruments for x-ray astronomy and inventing new methods for x-ray spectroscopy in space. Like his astronomical colleagues in Madison, Kraushaar and his laboratory built and launched instruments on suborbital rockets. Their experiments showed, among other things, that our local galactic neighborhood resides within a "bubble" of gas at a temperature of about one million degrees, contradicting earlier results that located this x-ray source outside of our galaxy. Kraushaar's work, like that of Stebbins, Whitford, Code, Suomi, and so many others, added a completely new dimension not only to our understanding of the universe, but to instruction, research, and graduate training at the UW. A second generation of researchers

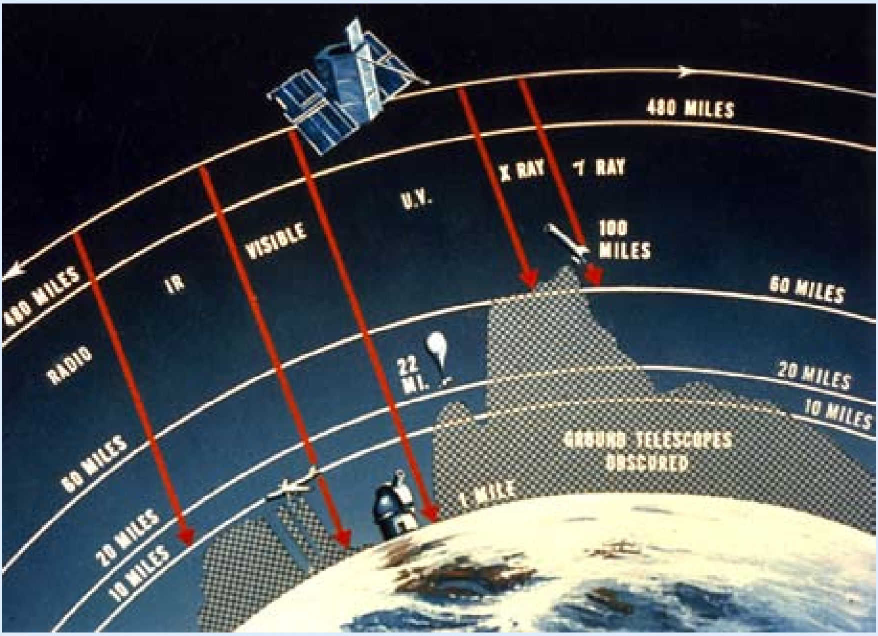


Diagram prepared by Grumman Aerospace Co. for the OAO program showing how Earth's atmosphere at various altitudes blocks radiation in the different parts of the electromagnetic spectrum. (UW Astronomy Dept.)

UW-Madison's Diffuse X-ray Spectrometer operating in the cargo bay of the space shuttle. The two halves of DXS are visible at the left and right edges of the cargo bay. (UW Astronomy Dept.)

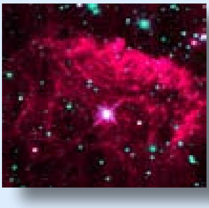
who began work with Kraushaar, continues today to extend and improve the research programs that he started. A team led by Dr. Wilt Sanders, of the UW-Madison Physics Department, in partnership with SSEC, built an instrument called the Diffuse X-ray Spectrometer (DSX), which flew on the space shuttle in January 1993, to study the million degree hot gas in our neighborhood of the galaxy. This extremely hot "bubble" was presumably caused by a local supernova 10,000 years or more in the past. Also following in Wisconsin's long tradition of technical innovation, Physics Professor Dan McCammon has invented a completely new kind of x-ray spectrometer, which uses cryogenic micro-calorimeters, for studying astronomical x-ray sources from satellites and suborbital rockets. The strengths in orbital and suborbital instruments, along with the theoretical studies that complement them, have established UW-Madison's astrophysicists as one of the world's pre-eminent x-ray research groups.

Astronomy growing out of the Physics Department is not a new phenomenon at (nor is it unique to) UW-Madison. Albert Whitford was a graduate of the UW Physics Department, which gave him the background he needed to help Joel Stebbins invent astronomical photoelectric photometry. Whitford had worked with UW physicist Professor Julian Mack, an expert in spectroscopy. Mack's work included development of a specialized spectrometer using a series of Fabry-Perot interferometers. A Fabry-Perot can be thought of as a very selective filter that passes light of only a very narrow range of wavelengths. Mack's high-resolution spectrometer (called PEPSIOS) has some very interesting capabilities. First, it is a wide-field instrument, which means, for example, that the whole disk of a planet or a galaxy can be analyzed at once. Second, it can be "scanned" or "tuned," meaning that the part of the spectrum that it allows to pass can be shifted, by varying the pressure of the gas filling the interferometer chambers. UW Physics Professor Fred Roesler, a student of Mack's, developed scanning spectrographs that could be applied to astronomical photometry and with which he discovered optical evidence that Jupiter is surrounded by a torus (a doughnut-shaped region) of ionized sulfur – an important clue to the understanding of the high energy environment of

WHAM newly installed in March 2009, at Cerro Tololo, Chile, with team members (from left) Greg Madsen, Kurt Jaehnig, Matt Haffner, and Alex Hill. (UW Astronomy Dept.)

the rapidly spinning giant planet. Professor Frank Scherb and his student Professor Ron Reynolds combined the scanning Fabry-Perot techniques with photometry and later CCD imagers (the solid state descendants of Stebbins' early photoelectric tubes) to detect and map the optical emission of interstellar hydrogen in our galaxy. This work led to the Wisconsin Hydrogen-Alpha Mapper (WHAM), which was tested at PBO, then sent to a dark sky site at Kitt Peak National Observatory in Arizona, where it went to work (under remote control from Madison) mapping the Milky Way. As of early 2009, WHAM has mapped the distribution of ionized hydrogen gas throughout most of our Milky Way. WHAM has been moved to Cerro Tololo, Chile, where it will have access to more of the southern sky, so that it can complete its maps of the single most common element in our galaxy. This will be a fundamental contribution to our understanding of the workings of the galaxy in which we live. Traditions of innovative and productive research, like this one reaching nearly 80 years from Julian Mack to WHAM, are typical of Wisconsin's University.

Today's Frontiers



Astronomy of the Invisible

There is a sense in which, in science at least, we are always on the verge of entering a new era. No sooner have we crossed yesterday's frontier of knowledge than we find ourselves confronting a new one. But in retrospect, some moments of history are particularly compelling. Galileo's first use of the telescope some 400 years ago is one such moment. Galileo, in 1609 a poorly paid professor at the University of Padua, heard about simple telescopes being sold as toys in northern Europe. After making one himself, he recognized the many possibilities in an improved version, which he proceeded to create. Turning his instrument on the sky, seeing, analyzing, and publishing his findings, Galileo launched observational astronomy into its modern orbit. Did his contemporaries appreciate the epochal events being wrought by this obscure college professor? We don't know if he told his classroom students about his experiments, but it is fascinating to imagine being one of them and perhaps hearing about his experimental devices and gaining some inkling of the new era then dawning. Such historical moments are rare, but when we gain a new ability to investigate the previously invisible, chances are that such a moment is imminent. And that is exactly what is happening with a project based at UW-Madison where a new kind of observational astronomy, the astronomy of neutrinos, is taking shape.

Well before Galileo, all observational astronomy was based on light. The telescope made it possible to amplify the powers of the human eye, making a vast universe perceivable. Access to space made possible the measurement of the light, such as UV and x-rays, that does not penetrate our atmosphere. But it is still light in one form or another, which includes radio and microwave energy, infrared, visible light, and the rest. Why is light so useful? Why not, for example, observe the electrons that reach us from celestial objects? The answer is that light, like electrons, is abundant, but unlike electrons, light typically travels through space in straight lines. Electrons, which carry an electric charge, swerve and spiral in the magnetic fields that pervade the universe. An electron detector would find plenty of them, but an image from an "electron telescope" looking in any direction would reveal only a blur of electrons swarming from everywhere with no possibility of distinguishing those coming from the sun from others originating in some distant galaxy. It would be as useful as using a telescope in a thick fog bank.

Any alternative to light as a means to cosmic exploration would have to be an abundant energy or particle that travels in more or less straight lines from its source to us so we can identify its origins. One theoretical possibility opened by modern physics is the gravity wave, and although known to exist, they have not yet been unambiguously detected in a laboratory. Nevertheless there are a number of projects underway to open that new door to the universe, including participation of a group at the Center for Gravitation and Cosmology in the Physics Department at UW-Milwaukee. What about something that we know how to detect? The neutrino is just such a particle. Predicted by theory in 1930, the neutrino was first detected in the laboratory in 1956. Neutrinos are created in interactions between high energy particles and in the nuclei of atoms. Neutrinos fly away from their origin at nearly the speed of light and, having no electric charge, are undeflected by magnetic fields and pass easily through even very massive objects. Unlike light, neutrinos fly straight out of the core of the sun, for example. So for studying the core of the sun, neutrinos would be better than light. We are today in the position of Galileo's students, witnessing the beginnings of completely new kinds of observational astronomy, and some of the first neutrino telescopes, the counterpart of Galileo's first optical telescopes, come from UW-Madison.

Making a neutrino telescope is more challenging than an optical telescope for several reasons, but the first is that collecting neutrinos is tricky. Galileo could make a telescope with a lens the size of a half-dollar because light interacts strongly enough with matter that a piece of glass that size can form an image that the eye can see. But neutrinos hardly interact with matter at all. The space around us is alive with neutrinos, most of them from deep inside the sun. In fact, in every tick of the clock, trillions of solar neutrinos are passing through the page you are reading, but unlike the countless photons of visible light that reach the page and then reflect toward your eyes, the neutrinos pass right through with almost no effect. To have a realistic chance of catching a neutrino, it has to pass through a lot of matter, so neutrino detectors must be very big. One early attempt, in which UW-Madison Physics Professor Robert March was deeply involved, would have taken the form of an array of detectors distributed through a region of deep water in the Pacific Ocean. This Deep Underwater Muon And Neutrino Detector (DUMAND) proved not to be practical, but another approach using expanses of Antarctic ice is proving more productive.

UW-Madison physicists, led by Professors Francis Halzen (b. 1944), Robert Morse, and many collaborators, with funding from NSF and WARF, began with their Antarctic Muon And Neutrino Detector Array (AMANDA) in the late 1980s. Most of AMANDA (in its most advanced form) was incorporated into a much larger project, now in progress, called IceCube. UW-Madison's IceCube partners include WARF, as well as participants in Germany, Sweden, Belgium, Japan, New Zealand, and the Netherlands. Why Antarctic ice? The vast majority of neutrinos that reach Earth pass right on through without interacting with matter at all. Detecting the few high energy neutrinos that do interact takes advantage of the fact that the interaction produces an energetic particle called a muon, which flies off in approximately the same direction as the original neutrino was traveling. As the muon moves through the ice at nearly the speed of light, it produces a characteristic bluish light (called Cherenkov radiation), which can be measured with photodetectors. The propagation of the

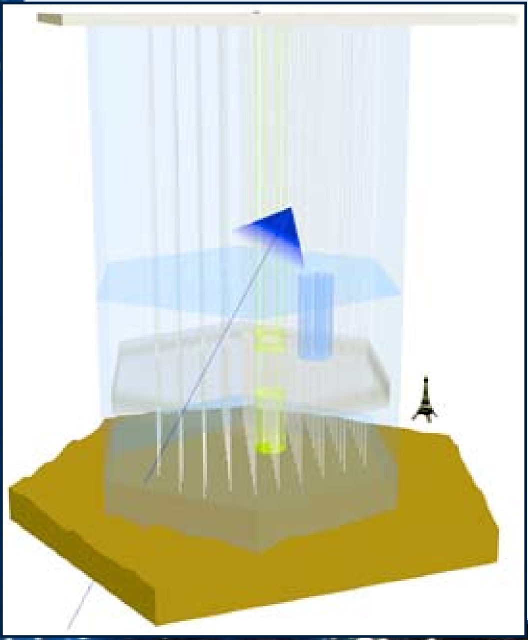
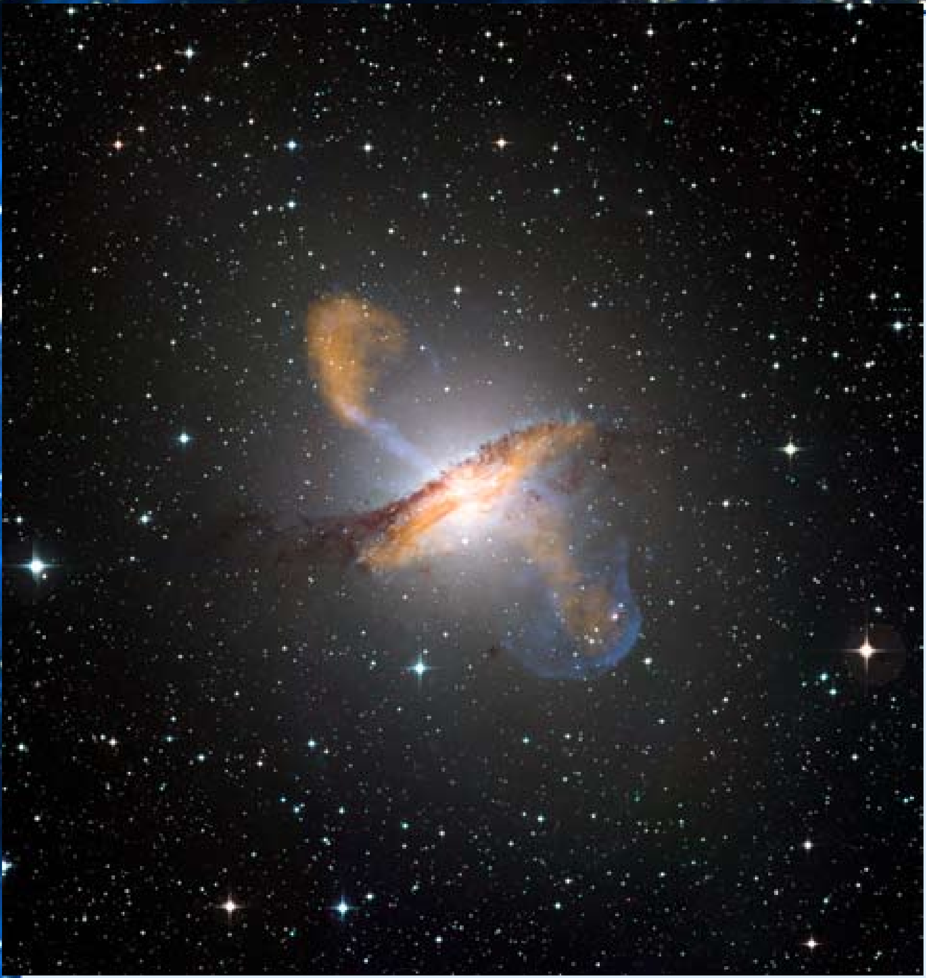


Diagram of IceCube neutrino telescope. The array of detectors is defined by the strings that run vertically from the ice surface at the top, through the ice, to nearly the continental surface shown at the bottom. The comparison to the Eiffel Tower indicates the vast scale of the detector array. The blue line from lower left indicates the path of an incoming neutrino, which produces a muon, which in turn produces the blue cone of light seen by the detectors. (IceCube/NSF)

Scientists are melting holes in the bottom of the world. Astronomers with the Antarctic Muon And Neutrino Detector Array (AMANDA) lower into each vertical lake a string knotted with basketball-sized light detectors. Analyses of data have recently been used to create the first map of the high-energy neutrino sky. (NASA)

light through the ice traces the path of the muon and reveals the direction of origin of the neutrino. Many high energy particles produce light traces in the ice. IceCube looks for the traces of neutrinos coming through the bulk of the earth from the north, that is to say, those that are coming upwards at the South Pole having passed through the Earth's interior. So by using the earth as a huge filter, in effect, to screen out all but neutrinos, IceCube can survey the northern sky for neutrino sources.

Accomplishing this kind of observation requires a lot of ice and many detectors. And the photo-detectors can only do their work if they are very deep in the ice, where the pressure makes the ice quite transparent to light so the faint bluish flashes are visible in the darkness. So IceCube, like AMANDA before it, is built by "drilling" into the ice with jets of hot water, which melts a column of ice into a column of water as deep as 2.4 kilometers (nearly 1.5 miles). A set of 60 detectors, each contained in a sphere of thick glass, are arranged like pearls on a necklace attached to a long cable, which is lowered into the watery hole, and then the ice refreezes around them. There will be 86 such strings arranged so that the detectors form an array whose top begins nearly a mile below the surface of the ice. (Six of those strings will be extraordinary "deep-core" strings extending into the deepest, clearest ice.) When complete, IceCube's detector array will comprise



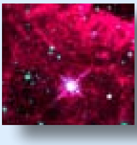
Composite optical, radio, and x-ray image of active galaxy Centaurus A. Extremely energetic jets emanating from the galaxy are produced by a super-massive black hole at the center. Neutrinos emitted by monster black holes will allow IceCube to investigate the otherwise invisible depths of such objects. *(ESO/WFI (Optical); MPIfR/ESO/APEX/A. Weiss et al. (Submillimetre); NASA/CXC/CfA/R. Kraft et al. (X-ray))*

5,160 detectors distributed through a cubic kilometer of ice. This will be the largest telescope ever made, and, as Halzen likes to note, the cheapest as well: about 25 cents per ton!

Building IceCube at the South Pole is a major challenge: simply getting people and complex equipment to the South Pole station is a very long journey, requiring typically 72 hours or more of travel from the northern hemisphere; working conditions at the pole, at an altitude of 10,000 feet and where the record high temperature is less than 8°F, are a challenge under the best of conditions; and the working season is limited by the austral summer to three months per year. Much of the specialized equipment needed for IceCube has been supplied by the UW-

Madison's Physical Sciences Laboratory (PSL) in Stoughton. PSL has built the glass-encased detector modules, which are the pearls along the strings that are lowered into the ice to form the eyes of IceCube. These devices must withstand the cold and pressure below the ice while they digitize and transmit their observations up the cable to the IceCube Lab on the surface. Hot water drilling into the ice required the design and construction of a unique suite of equipment, which PSL also fabricated. A giant hot water heater feeds a spool containing over 2.5 kilometers of high-pressure hose, which is in turn handled by a hot water drilling rig that stands over the hole location. This equipment can make a hole ready to receive a detector string in a less than two days. Construction of IceCube began in January 2005, and is projected to be completed on time in 2011. At the end of the austral summer 2008-2009 construction season, 59 strings comprising 3,540 detector modules had been installed in the ice. It is estimated that from 2002 to 2009, the IceCube project has brought $77 million, distributed among at least 22 counties, into the Wisconsin economy.

Even the partially complete IceCube should begin producing scientific results in 2009. IceCube's mission is to identify high-energy neutrino sources in the universe and use the elusive neutrinos to learn more about them. The ability of neutrinos to escape highly dense regions that are opaque to light offer the possibility to understand a number of exotic celestial objects. Such objects will include the super-massive black holes at the centers of galaxies and the super-hot remnants of supernova explosions. IceCube should also be able to detect sudden neutrino outbursts from deep inside collapsing stars, offering insight into how supernovas develop. Similarly, IceCube should detect the core collapse of very massive "hypernova" stars, the explosions of which produce gamma-ray bursts – the most energetic explosions in the universe. IceCube will also look for wide-field neutrino background emissions and investigate the distribution compared, for example, to the Milky Way and the entire sky. These are examples from among the possibilities we can anticipate, but as Francis Halzen writes, "We don't know what we will find, but experience tells us that with a new window we can expect new discoveries."



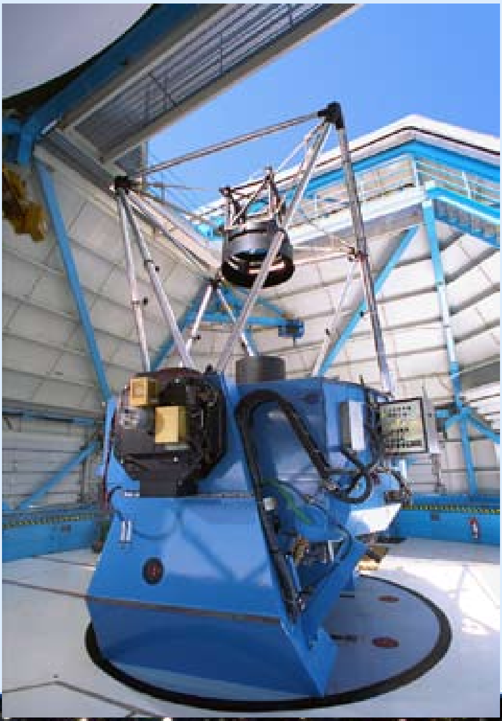
Beyond Light Buckets

It is in the nature of science that our understanding moves from the more familiar to the less familiar. After a biologist has studied and begun to understand the flora and fauna in, for example, lake waters within about 20 feet of the surface, it may become evident that conditions in deeper and less accessible waters are important for understanding the upper layers. Studying the deeper waters will require new and more sophisticated tools and techniques, but once those are available and the scientists have begun to use them, it will inevitably come about that yet a new depth of investigation is required. New research will demand new technology, and new technology will open avenues for new research. And thus will we pursue the study of nature to the ocean's depths, to the mountain's tops, and beyond. This is as true for astronomers as it is for limnologists. The most advanced research will nearly always imply the most advanced research tools, and for observational astronomers that means larger telescopes.

The 36-inch telescope at PBO was in its day a big step beyond the classic 15.6-inch refractor. As had been true with the 15.6-inch, innovative instruments helped keep the PBO telescope productive. But as research questions become more refined, astronomers require higher quality data to sift and winnow the competing theories, and higher quality data will usually mean larger telescopes. The emergence in the 1960s of the national observatories operated by AURA helped widen telescope access considerably by making telescope time available on a competitive basis. But there are never sufficient resources in the national observatory system to support all of the worthy research programs that are proposed at any given time. So it is a big advantage to an ambitious astronomy department to have alternate access to a large telescope. Thus, Wisconsin needed a bigger telescope than was available at PBO.

In the early 1970s, Wisconsin astronomers participated in a number of attempts to form a consortium of midwestern universities with the goal of building a telescope with a mirror in the 3-meter diameter or greater range located at a dark sky site, probably on a mountain top in the southwestern U.S. They explored possibilities with other Big 10 universities, discussed plans with the University of Chicago/Yerkes, and considered a partnership with the University of California. These efforts eventually came to nothing, partly for lack of funding (this would be an expensive telescope), but also partly for lack of finding a good site that was agreeable to all parties.

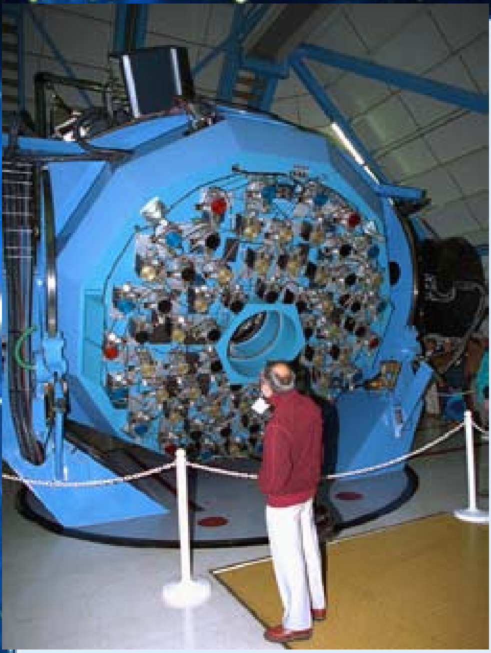
Nearly 20 years would pass until a workable consortium did develop. The fortuitous result of the delay was that the designers of the new telescope could take advantage of technologies to make it one of the finest telescopes in the world. University of Wisconsin-Madison, Indiana University, and the National Optical Astronomy Organization (NOAO), joined soon after by Yale University, collaborated to create the WIYN telescope.



The WIYN 3.5-meter telescope inside its dome at Kitt Peak. The telescope's primary mirror resides in the blue base between the blue fork arms, one of which faces the camera. The secondary mirror is in the black housing atop the trusswork. (NOAO/AURA/NSF)

Aerial view of the WIYN telescopes on a promontory at KPNO. Upper left, in the silvery dome, is the 3.5-meter telescope. At lower right, in the larger white dome, is the WIYN 0.9-meter telescope. The smaller dome in the middle houses a 16-inch telescope operated by Kitt Peak. (NOAO/AURA/NSF)

The three universities contributed to the capital costs of the telescope itself, while NOAO (which operates three major observatories, including Kitt Peak National Observatory) provided the site and operational support. The WIYN telescope, which went into operation in 1994, is a 3.5-meter telescope and the second largest at Kitt Peak after the 4-meter Mayall telescope. The two telescopes, with nearly the same size mirrors, are a study in contrasts that illustrate the advanced design of the 3.5-meter. The Mayall telescope, opened in 1973, has a massive mirror with relatively long focal length and a huge equatorial mounting. This type of telescope design became common with the first large reflecting telescopes in the early twentieth century, and being successful, the design was steadily scaled up as mirrors grew larger. As a result, the Mayall is a telescope weighing in at 375 tons and housed in a huge dome surmounting a six-story structure. In contrast, the 3.5-meter mirror was made by an advanced "spin-casting" technique, perfected by the University of Arizona Mirror Laboratory that allows it to be of short focal length and relatively light weight. Shorter focal length and lighter weight in the mirror mean a shorter, lighter telescope structure overall. In addition, the advent of computerized guidance systems means that it is possible to dispense with the heavy equatorial mounting system used by the Mayall, and instead use a much simpler, lighter, and more compact "altitude-azimuth" mounting. The result of these design advances is that the WIYN 3.5-meter comes in at a svelte 46 tons. The entire 3.5-meter housing is very compact, a small fraction of the Mayall's structure, and designed from the beginning to control temperatures so that the building and telescope are always very close to the temperature of the ambient air. The much lower mass of mirror,



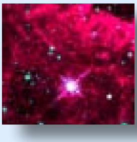
Rear view of the primary mirror housing of the 3.5-meter WIYN telescope showing actuators that adjust the shape of the mirror's surface to perfect its optical performance. (NOAO/AURA/NSF)

telescope, and building helps a great deal with temperature management. The mirror has its own temperature control system as well. The detailed attention to temperature management is because temperature differences cause air currents, and air currents bend and distort the images of celestial objects, producing what astronomers call bad "seeing." Seeing was also a major consideration in the selection of the site of the 3.5-meter on Kitt Peak, which has proved to be a good one. Finally, the 3.5-meter mirror includes actuators on its rear surface that make fine adjustments to the shape of the mirror that help optimize the image produced by the telescope.

The result is that the 3.5-meter telescope produces some of the sharpest images of any telescope in the world at a very low expense for a research telescope – about $14 million. If built today, a conventional telescope like the Mayall would cost many times that of the 3.5-meter. An array of advanced instruments takes advantage of this optical perfection. Several different fiber optics assemblies can channel the light from many specific sites in the image plane in order to produce spectra of many objects simultaneously, or of various points within a single object, for example across the disk of a galaxy. A variety of CCD cameras provide imaging capabilities taking advantage of the 3.5-meter telescope's wide field and high image quality. In development is the One Degree Imager, which will achieve a one-gigapixel image filling the telescope's one-degree field of view. These and other capabilities make the WIYN 3.5-meter a world-class research telescope. The fact that UW-Madison is a consortium member means that UW-Madison's astronomers receive a fixed fraction of the observing time, so that proposals for allocating the UW share of telescope time can be evaluated and assigned locally. This is a major advantage for Madison-based research, both by faculty, staff scientists, and graduate students. The 3.5-meter's remote operations capability, designed and implemented by SAL's Dr. Jeffrey Percival, is also a major advantage to Madison-based astronomers because many observing runs that would once have required a trip to Arizona by the astronomer can now be accomplished from a control center locally.

The WIYN consortium acquired a second, smaller telescope by accepting a refurbished 0.9-meter (36-inch, the same aperture as the largest PBO telescope) reflector from Kitt Peak. This smaller telescope is ideal for many photometric purposes and makes additional telescope time at the dark mountain-top site available for Wisconsin's astronomers. Of the nine consortium partners that run the 0.9-meter, five are based in Wisconsin: the UW System campuses of Madison, Oshkosh, Stevens Point, and Whitewater, and the Wisconsin Space Grant Consortium in Green Bay. The 0.9-meter has operated under WIYN consortium management since 2001.

WIYN 3.5-meter image of spiral galaxy NGC 891 by UW-Madison astronomers Chris Howk and Blair Savage. The exquisite optical quality of WIYN 3.5-meter images is evident in the fine filaments stretching away from the dusty central plane of the galaxy, which we view edge-on. *(C. Howk (JHU), B. Savage (UW), N. A. Sharp (NOAO/WIYN/NOAO/NSF))*



Southern African Large Telescope

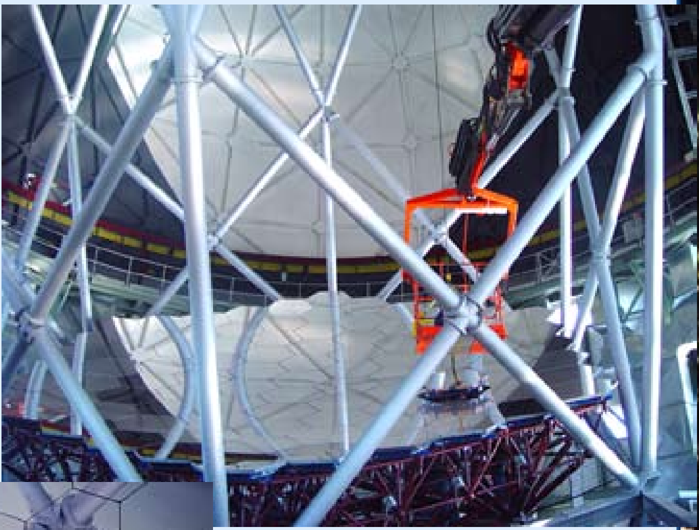
Stars could not form immediately after the Big Bang, the explosive event in which the universe as we know it began. It took many millions of years before gravity could gather and compress the primordial gas of the universe to the point where hydrogen nuclei began fusing into helium, producing in the process the energy we see as starlight amid the vast islands we call galaxies. What did those first galaxies look like? How did they form? What were those early stars like? How did the rich chemistry of which we are made develop out of the barren expanses of hydrogen and helium produced in the Big Bang? Looking to the future, how will the expansion of the universe evolve? What forces drive and shape the expansion? What kind of universe will the minds of the distant future see? These cosmological questions are fascinating and very important ones, but until recently they were almost purely academic. It is remarkable testimony to the progress of modern science that astronomers are bringing answers within our grasp. Those answers will come in part from new space-based instruments, descendants of the ones built by UW's astronomers. But for the immediate future, the vast majority of telescope time available for cosmological inquiries will come from ground-based telescopes in the 10-meter class and beyond. As powerful as the WIYN and other 4-meter class telescopes are, astronomers need still larger telescopes to push the envelope of current

Star trails above the Pine Bluff Observatory. *(Jeff Miller/UW-Madison)*

research. To pursue such topics as galaxy evolution, UW-Madison astronomers are now partners in one of the world's largest telescopes, the Southern African Large Telescope, or SALT.

UW's astronomical connections to South Africa actually go back more than half a century. In 1952-1953, when Art Code was first on the faculty at Washburn Observatory, he collaborated with W. W. Morgan of Yerkes in a program to measure the distances to certain bright star clusters in order to trace the spiral arms of our Milky Way galaxy. To do this, photometric data from Washburn's 15.6-inch telescope was combined with spectroscopy obtained with the Yerkes 40-inch. But from Wisconsin it was impossible to survey the entire Milky Way, so the project needed to be completed with observations from a site in the southern hemisphere. For that reason, in 1953 Code and Ted Houck (then still a graduate student) spent most of the year in South Africa. Code worked on the spectroscopic part of the project at the Radcliffe Observatory (then outside of Pretoria), while Houck worked on the photometry at the Cape Observatory. Code also used an extremely wide-field (140°) camera, which had been developed during the war by Yerkes astronomers, to record wide field images of the Milky Way and map the broad distributions of luminous and obscuring matter. (This was probably the only major research project at Washburn Observatory ever to employ photography.) Code had made a series of Milky Way images in Wisconsin in both visible and infrared light and followed that with a set from South Africa as well. These images of the southern Milky Way were some of the best available for many years and were widely reproduced.

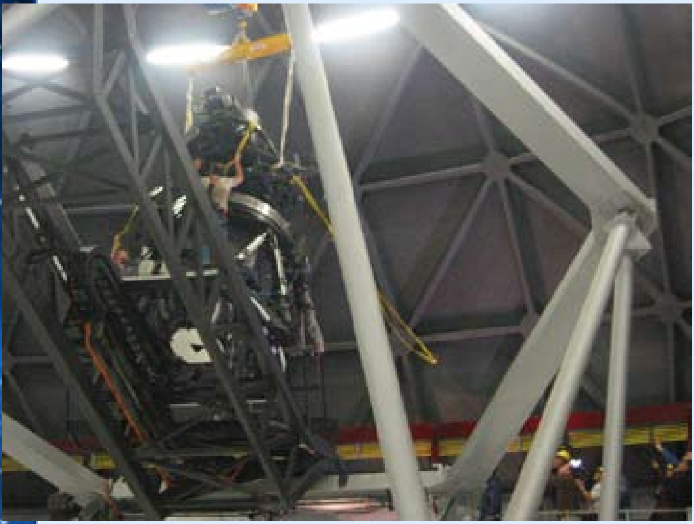
Fifty years later, UW-Madison is again deeply involved with South Africa as a member of the SALT consortium, running a world-class cosmological telescope, and the largest in the southern hemisphere. This giant telescope is a 10-meter class instrument – its hexagonal mirror measures 11 meters across at its widest dimensions. Like some other 10-meter class telescopes, such as the Keck telescopes, the large mirror is composed of smaller identical hexagonal spherical mirrors, in SALT's case each 1 meter across, which are tiled together to make a single large spherical mirror. Unlike all but one other, SALT embodies a new design for giant telescopes that reduces construction costs dramatically. SALT follows a design first employed in the McDonald Observatory's Hobby-Eberly Telescope (HET) in Texas. This new kind of optical telescope makes use of an optical trick to simplify the telescope mounting, which is a large fraction of the total cost of a telescope. As Earth's rotation carries a star or other object across the sky, a typical telescope follows the object by moving the entire telescope so that the light from the target object falls into the center of the field of view, where the camera or other instruments are normally located. If the telescope does not track, then the image of the object drifts across the field of the telescope. In the HET design, the instruments are designed to move on a special structure at the front of the telescope, so that as the image drifts, the instruments follow it. This requires a complex truss at the front of the telescope to allow the motion of the instrument platform to be precisely controlled. It also requires some extra optics to correct an error, called spherical aberration, that is inherent to a spherical mirror design. But on the other hand, the massive mounting of the telescope can be much simpler than a fully steerable mounting. A further simplification is achieved by mounting the telescope at a fixed angle inclined to the vertical. The



Above: View of the SALT 10-meter mirror through the telescope trusswork with the closed dome aperture visible above. The orange crane is installing the last of the 1-meter mirror segments into the main mirror assembly. Left: The telescope's trusswork is reflected in the mirror's surface. (UW Astronomy Dept./SALT) telescope can rotate about the vertical axis, but does not tip up or down. Consequently, it cannot point just anywhere in the sky, like a typical telescope can; but the angle of the mounting is carefully chosen so that the region of the sky that the telescope can see includes the targets of greatest scientific interest.

The SALT design follows the HET, but with elements such as an improved spherical aberration corrector. The design innovations make possible the construction of a cosmological telescope at a fraction of the cost of a fully pointable instrument. SALT's construction costs much less than one of the similarly sized Keck telescopes, which have mosaic mirrors but are also fully pointable and so need a much more complex mounting. The mosaic mirror design itself entails some sophisticated engineering. Each single mirror of the 90 that tile together to form the large surface must be independently adjustable so that the edges and angles match up, and the entire ensemble performs as one. This alignment must be done frequently, which is the reason for the prominent collimation tower adjacent to the telescope's dome. Operators point the telescope at the top of the tower, where a set of lasers and optics measures the reflected laser light and sends signals to the actuators that move each mirror segment to bring it into ideal alignment. A benefit of the mosaic mirror is that the individual segments can be removed one at a time for cleaning, recoating, or replacement.

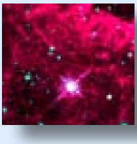
UW-Madison is a member of SALT's international consortium. In fact, UW-Madison is the largest non-governmental partner in a long list that includes the South African National Research Foundation, the South African Astrophysical Observatory (SAAO), a consortium of UK universities, and other institutions in Germany, Poland, India, and the U.S. Since "first light" in September 2005, SALT has been in the "commissioning" phase as it is completed and brought up to full operation and its instrumentation finished and installed. SALT will have three primary instruments: a large array CCD camera built by SAAO, a fiber-optic fed very high resolution spectrograph built by the



Installation of RSS (Robert Stobie Spectrograph, named for a prominent South African astronomer) atop the SALT truss-work. Formerly known as PFIS (Prime-Focus Imaging Spectrograph), RSS is one of SALT's most important science instruments. When complete it will be capable of imaging spectroscopy and polarimetry from the near UV through the near IR parts of the spectrum. (UW Astronomy Dept./SALT)

SALT's "first light" image of spiral galaxy NCG 6744. (UW Astronomy Dept./SALT)

University of Durham Center for Advanced Instrumentation, and the Robert Stobie Spectrograph (RSS). The RSS was designed by Ken Nordsieck and built by SAL in Madison. RSS is a highly versatile and complex instrument, which must operate at the telescope's prime focus, high above the mirror. RSS is capable of high and medium resolution spectroscopy in visible and near UV light, Fabry-Perot imaging spectroscopy, and spectro-polarimetry. RSS was designed to accommodate an infrared instrument as well, and thanks to recent funding from WARF, it is now under development. The Near InfraRed (NIR) addition to RSS, under the direction of Professor Andrew Scheinis, will extend RSS capabilities to span the spectrum of light, from near UV to near IR, accessible at Earth's surface.



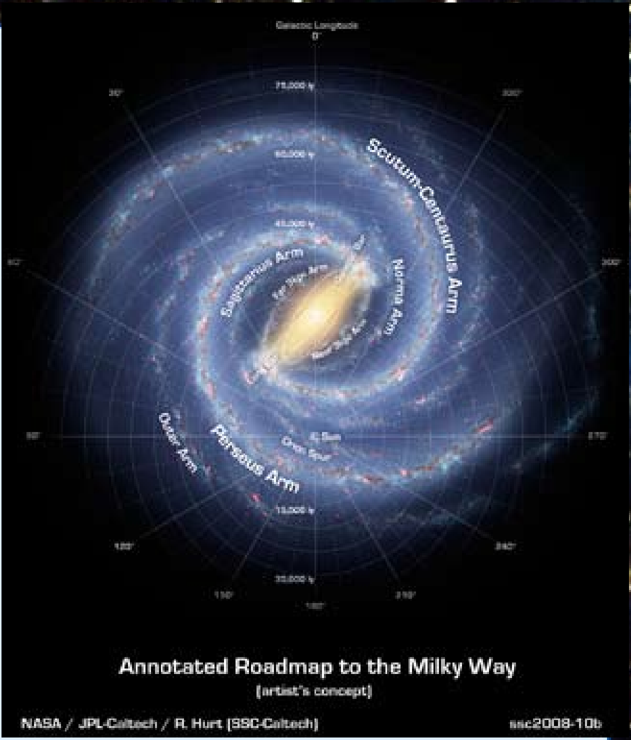
New Directions

We get a direct glimpse into the research now in progress in the UW-Madison Astronomy Department by looking at the groundbreaking science already done and in planning for SALT, WIYN, space observatories, and other facilities. Much of today's work grows out of the traditional strengths of UW's astronomy accomplishments and follows it, on both observational and theoretical levels, to the very frontiers of modern knowledge.

Early studies of the interstellar medium, which Stebbins and Whitford helped define, have bloomed today into a more integrated field involving the complex interactions of magnetic fields and matter from stars to the largest structures in the universe: How do magnetic forces shape stars themselves and affect the processes inside? How do the complex environments inside and surrounding galaxies affect and respond to star formation, supernovas, and other events? What is the composition and behavior of the intergalactic medium? How are clusters of galaxies affected by the scorching energy beams from supermassive black holes? SALT will acquire spectra of distant galaxies that we see in very early stages of their formation, providing insights into both the evolution of galaxies as well as the earliest star formation. SALT's location in the southern hemisphere means that it has access to our two neighborhood galaxies, the Large and Small Magellanic Clouds. They are the only examples we have of galaxies close enough for us to see and count even their smallest stars, and SALT is the only telescope able to do the job. The new wide-field imaging capability of WIYN will allow surveys of early star formation. Massive stars are major sources of UV light, which is why UW's historical expertise in massive stars developed along with UV astronomy. Study of massive stars continues as a research specialty of the department and dovetails with the chemical evolution of galaxies of which massive stars are very important drivers. Indeed, the structure and environment of "local" galaxies, which are mature galaxies more like our own home galaxy, constitutes another research strength of UW-Madison and leads to yet another part of the spectrum, namely radio astronomy, where Wisconsin's astronomers also work. International radio telescope projects, such as the nascent Square Kilometer Array, will soon become important tools for that research. UW astronomers also use space-based instruments, of course, including the Hubble Space Telescope and Chandra, NASA's orbiting x-ray observatory. UW-Madison is the lead institution in a major survey of the Milky Way galaxy using the Spitzer Space Telescope, an infrared observatory in space. Professor Ed Churchwell leads this project, called GLIMPSE (Galactic Legacy Infrared Mid-Plane Survey Extraordinaire). GLIMPSE exploits the power of IR radiation to penetrate interstellar dust clouds and has begun to lay bare the spiral structure of

The Large Magellanic Cloud, visible in southern skies, is a nearby dwarf galaxy. Close enough for detailed studies, it will be an important scientific target for SALT. *(Yuri Beletsky, European Southern Observatory)* our own galaxy at a level of detail far beyond the work that Code, Houck, and Morgan were able to do in the 1950s.

SAL continues a long history of technological development in support of astronomical research in two directions. Ground-based instrumentation projects for SALT like RSS and NIR, as well as instrument development for WIYN, represent the newer, shorter branch. The longer branch, SAL's traditional expertise in space instrumentation, continues as well. Suborbital rocketry has been the most consistently active category of space instrumentation, including a very successful and versatile descendant of WUPPE named WISP (Wide-field Imaging Spectro-Polarimeter) designed by Ken Nordsieck for UV studies. WISP's career is a prime example of the value of suborbital rocket research. Not only are suborbital instruments much cheaper to develop and build than a comparable satellite-based instrument, but they are retrieved after each flight so that they are available for post-flight calibration, refitting, and reflying. During its five rocket missions, WISP studied UV light from dust scattering in the Pleiades star cluster and detected diffuse UV light from the Large Magellanic Cloud, leading to a three-dimensional model of that dwarf galaxy. One WISP flight was to study Comet Hale-Bopp. In addition to enhancing our knowledge of comets, WISP's mission illustrates another advantage of suborbital rocket research, which is that it can be planned and launched on relatively short notice. WISP was not built specifically to study Comet Hale-Bopp, but when the previously unknown comet appeared in 1995, WISP was "on the shelf," and a flight to study it could be rapidly organized. A satellite instrument would have taken years to prepare, by which time the comet would have been far beyond reach. Suborbital rocket research is very important from another vital aspect: it is a low cost, quick turn-around training ground for the young scientists who will imagine, build, and launch future generations of spacecraft.

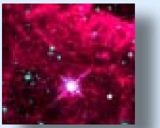


A new view of the structure of our Milky Way galaxy based on GLIMPSE observations. The GLIMPSE survey of the Milky Way, making use of the penetrating power of Spitzer Space Telescope's IR capabilities, demonstrates that our galaxy possesses a central "bar" structure and maps the spiral arms in unprecedented detail. (GLIMPSE/NASA)

Comet Hale-Bopp, which appeared in our skies for much of 1997, was the scientific target of one of the suborbital rocket flights of WISP. (Thomas A. Ferch)

A Terrier-Black Brant suborbital rocket ready to launch an experiment controlled by SAL's Star Tracker 5000. ST5000 team members Kurt Jaehnig (left) and Jeffrey Percival are visible near top center just below the tail of the rocket. (UW Astronomy Dept.)

Inventing the technology that will support those future research projects is another category of important SAL work. The best example of this is a remarkable device named Star Tracker 5000 (ST5000). Almost all astronomical instruments (although IceCube is an exception to this) need to be pointed to particular places in the sky. In ground-based telescopes this has traditionally meant elaborate mountings, and with spacecraft the solutions often involve complex systems of gyroscopes, momentum wheels, rocket thrusters, and imaging devices. SAL astronomer Dr. Jeffrey Percival and his team have created ST5000 to replace the elaborate and expensive devices conventionally used for this job with a smart, compact, and cheap tracking system that adds new capabilities. ST5000 locates itself in space by recognizing star patterns, in something like the way a boy or girl scout recognizes the Big Dipper and knows which way is north. But ST5000 is better and faster at that task than the typical scout because it can look in a random direction in the sky, recognize the star patterns, and within seconds can report exactly which direction in space it is pointed – information that the payload controller can then use to issue tracking commands. Using a patented image compression technique, ST5000 can transmit images of the star field (or other images) many times faster than usual techniques allow. With a number of successful flights now accomplished, ST5000 is in a position to enhance a range of research projects while lowering their costs and complexity. ST5000 constitutes a perfect example of how academic research creates a cycle: scientific questions demand new problem solving and new technologies, which lead to technical development and research results, which in turn produce valuable products and new research questions. This cycle has been at work in UW astronomy and countless other programs in the University of Wisconsin's schools for well over a century.



Taking Astronomy Home

When Washburn Observatory was dedicated in October 1881, there was considerable public notice and interest in Madison. In recognition of this interest, Edward Holden, who had succeeded James Watson as director, established a policy that the observatory would be opened to the public for night sky viewing on the first and third Wednesday evenings of each month. Whatever his mix of motivations, Holden created a public astronomy outreach program that has lasted for 128 years. Unless the weather precludes it, or equipment or the building is under repair, Washburn's astronomers have shared their work with the public since the observatory's opening. There are older observatories, but few if any can claim a constant heritage of public outreach with such longevity.

In a report to UW President Fred in 1948, Albert Whitford reaffirmed the commitment of Wisconsin's astronomers to public outreach in the language and vision of that era:

> The third activity [after teaching and research] which the University tries to supply to the people of the State … would in our case mean helping amateur astronomers and adult education groups. Dr. Huffer is already doing far more in that line than is the case at any other university I know about. It should be continued.

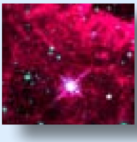
It has been continued, and greatly expanded over the years. During the busiest days of the HSP and WUPPE programs, press and public requests for information grew rapidly: school teachers requested that astronomers visit their classrooms and requested help teaching about the new science taking shape in our state; community groups asked for talks by astronomers; groups requested tours of SAL and SSEC so they could see the famous instruments being developed. It was difficult to respond adequately to public interest, and especially difficult to accommodate requests to visit campus laboratories. Art Code and Bob Bless, the heads of the WUPPE and HSP programs, respectively, and Kathy Stittleburg, SAL's energetic and creative associate director, began searching for a place that the public and schools could visit to learn more about space science work at UW-Madison. She located an available commercial building on South Park Street in Madison and set up UW Space Place, which opened in July 1990 with a series of talks by UW-Madison scientists about astronomy. Space Place, located well away from the complications of parking and scheduling that burden campus sites, and soon furnished with displays and exhibits, quickly became a place for presentations to school groups, a base for science teaching workshops for teachers, a source for information about the progress of SAL's projects, and a gathering place for local astronomy enthusiasts on the occasions of lunar eclipses, comets, and other astronomical events. The great response during the first year convinced the three founders to continue their experiment in education and outreach. Capabilities increased as a result of NASA funding, from the HSP and WUPPE projects, for educational equipment and materials, and demand for programs, especially from school teachers, continued to grow. The SALT project brought the opportunity to extend in-service teacher training to groups of South African teachers, who, because of the importance of the SALT project in their home country, visited Madison in preparation for adding astronomy to their classroom lessons. In autumn of 2005, with support from UW-Madison Chancellor John Wiley, UW Space Place relocated and expanded at 2300 South Park Street. Among other exhibits available to

Above: A young astronomer tries out her telescope at UW Space Place. (Jeff Miller/UW-Madison) *Left: A crowd gathered at UW Space Place to enjoy a lunar eclipse.* (UW Astronomy Dept.)

the public are some of the most important pieces of spaceflight hardware from SAL's history: a full scale engineering model of OAO-2, space shuttle veterans DXS and WUPPE, the rocket instrument WISP, and many items from Washburn Observatory's history.

UW Space Place director Jim Lattis (in the background) leads a group of student visitors as they view the 15.6-inch refractor (in service since 1881) in the Washburn Observatory. (Jeff Miller/UW-Madison)

A signature astronomy outreach element from UW-Madison is the statewide Universe in the Park (UitP) program. UitP was started by astronomer Dr. Karen Bjorkman (at that time a member of the WUPPE team) in the summer of 1996 with funding from NASA and has been continued and expanded by Professor Eric Wilcots with partial support from NSF. UitP events take place at state parks during the late spring, summer, and early fall recreational seasons. One or more astronomers, often graduate students, take a portable telescope to the park, present an evening talk to park visitors, and then follow up with a sky-viewing session. The sessions are very popular. At the height of the season there will typically be three events each weekend at Wisconsin parks. Since the program began, UitP has visited every state park in Wisconsin at least once, and most parks have hosted repeated visits. As this program shows, the UW-Madison Astronomy Department and Space Astronomy Laboratory take outreach and science education for Wisconsin's residents very seriously – the number and quality of outreach programs is far out of proportion to the relatively small size of the department. The fascination we all have with the heavens runs as strongly today as it did in 1881, which is why astronomy is such an effective motivator of science education. Astronomers are acutely aware of this and have been among the most active faculty members in the movement to make public outreach experience and commitment a significant part of graduate student professional development. Like Holden, Whitford, Huffer, Code, and others, Wisconsin's astronomers today remain committed to astronomy outreach for our state and beyond.



"Forward"

The history of astronomy in Wisconsin is a history of distinguished and creative work and researchers. Although largely centered in Madison, Wisconsin's astronomical community has long included Yerkes Observatory as well and now extends to several UW System campuses. Between them they have made Wisconsin a state well known in the international astronomical community for the past century. As we have seen, Wisconsin's astronomers were leaders in the emergence of modern astrophysics as well as the development of space astronomy. That heritage continues today with active research programs distributed across several groups working at the leading edges of their fields. In addition, the graduate training programs are among the best in the world and attract the most promising future scientists to Madison. Active and innovative outreach programs directly serve the residents of the state and seek to inspire new generations to build on the accomplishments of their predecessors.

Astronomy is vital to progress in the modern world. Not only does astronomical research help drive innovation that leads to technical and economic development, but astronomy is also a "gateway" science. For many generations astronomy has been the subject that first inspires talented people to take a serious interest in scientific and technical careers. Astronomy presents itself to all who take the moment to ponder the night sky and to reflect on humanity's place within

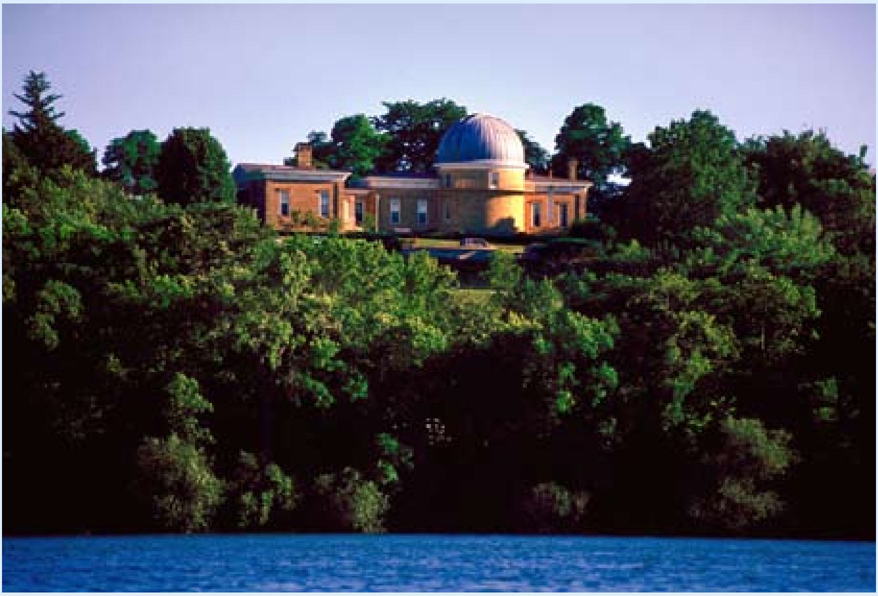
The Einstein Memorial on the grounds of the National Academy of Sciences in Washington, D.C. The photographer staged the photo on the 50th anniversary of Einstein's death in 2005. The placement of the small telescope next to the bronze statue was to symbolize the importance of Einstein's work which revolutionized our understanding of the universe. (Greg Piepol)

Observatory domes on the roof of Sterling Hall. *(Jeff Miller/UW-Madison)*

the universe and our relationship to it. A glimpse of a planet through a telescope, the solemn beauty of an eclipse, the dream of exploring a distant world, all these and more motivate questions about how we understand the world around us and how we can learn more.

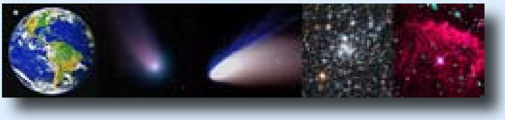
Astronomy is part of modern culture but with deep roots in the ancient quest to understand nature. Modern science is one of human culture's most recent, valuable, and remarkable developments. Science teaches us to value empirical evidence and careful reasoning over preconception and authority. Scientists insist that in understanding the natural world, nothing is above examination, criticism, and confrontation with evidence. No scientific theory, regardless how venerable, is permanent; so all are subject to revision and perhaps rejection. As a result of adhering to rigorous standards and methodologies, scientists have provided amazing technical advances, improvements in quality of life, and deeper understanding of the nature of our universe and how it came to be. Astronomy is deeply important to modern culture, and has been important in nearly every historical culture we know (although often for very different reasons).

Both as an inspiration to the future and as an object lesson from history on the value of science, the study and advancement of astronomy is truly an investment for posterity. But astronomy is, like other academic research, also a stimulus for and investment in a vigorous economy for Wisconsin and beyond. Projects like IceCube and RSS result in employment of talented scientists and engineers. Development of new technologies, like those that make ST5000 possible, create products and help open new markets for them. The history of astronomy in Wisconsin teaches that these and other benefits emerge from continuity and commitment to long-term stability. Talented scientists with innovative ideas and a willingness to devote their careers to them, like Art Code with his vision of space astronomy in



UW-Madison's Washburn Observatory, viewed from Lake Mendota, underwent historical restoration and remodeling in 2008-2009 to become home to the Honors Program of the College of Letters and Science. The telescope remains fully operational. *(Jeff Miller/UW-Madison)*

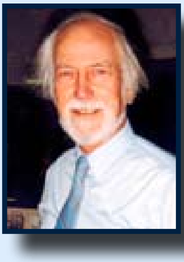
1957, need consistent support to explore possibilities, identify opportunities, recruit other talent, and attract further support for the projects that can change the world. The great successes of Wisconsin's space astronomy and physics programs and SSEC's space meteorology and remote sensing programs (only a few of many possible examples) show how talented visionaries with initial support from sources like WARF can turn ideas into jobs, buildings, and a wide open future. This is clear testimony to the power of ideas, and great universities are in the idea business. The Wisconsin Idea states that the boundaries of the University are the boundaries of the state. The Wisconsin Idea is itself an idea, but of a unique type, because it amplifies, transforms, and launches other ideas out from the University and into the world. In the modern era, returning the benefits of the University to the citizens of Wisconsin means connecting Wisconsin's academic research across the globe. Wisconsin's astronomers accomplish this in many ways, from the large scale, like international projects such as SALT and IceCube, to the small scale building of telescopes with South African school teachers, and extending even to the elegant simplicity of pointing out stars and planets to families in the dark skies of our state parks.



Acknowledgments

Thanks to Bob Bless, Dan Bull, Sam Gabelt, Daniel Huffman, Evelyn Malkus, Jordan Marchè, David Null, Jeff Percival, Jean Phillips, Bernie Schermetzler, and Barb Whitney. Much of the material on Washburn Observatory from the 1940s to the 1970s and on the Space Astronomy Laboratory is based on oral history interviews conducted by UW Archivists and James Lattis.

In Memoriam



Arthur Dodd Code
(1923-2009)

Sixth Director of Washburn Observatory

Professor of Astronomy, University of Wisconsin-Madison

Pioneer of space astronomy and founder of UW Space Astronomy Laboratory

Founding director of the Hubble Space Telescope Science Institute

Aurora Over Wisconsin (Chris VenHaus)

Informational Web Sites

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GLIMPSE: http://www.astro.wisc.edu/sirtf
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Planet Earth - Courtesy of Apollo 17 Crew (NASA)

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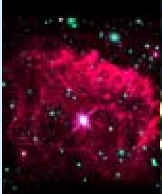

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Ten Events That Shaped Wisconsin's History, by Norman K. Risjord, 1999-2000 *Blue Book,* pp. 99-146.

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Wisconsin at 150 Years, by Michael J. Keane and Daniel F. Ritsche, 1997-1998 *Blue Book,* color supplement.

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Capitol Visitor's Guide

Hours:

Building open daily 8 a.m. - 6 p.m.
The Capitol closes at 4 p.m. weekends and holidays.

Information Desk

Located in the rotunda, ground floor.

Tours

Daily Monday - Saturday at 9, 10, and 11 a.m., 1, 2, and 3 p.m.; Sundays at 1, 2, and 3 p.m. A 4 p.m. tour is offered weekdays between Memorial Day and Labor Day. Tours start at the Information Desk in the rotunda and last 45 to 55 minutes. Reservations are required for groups of 10 or more. Call (608) 266-0382 7:30 a.m. - 4:30 p.m. Monday - Friday, or visit the Web site at www.wisconsin.gov/state/capfacts/tour_select.html.

Observation Deck

6th Floor, accessible from 4th floor via NW or W stairways. Open daily from Memorial Day to Labor Day. There is a small museum devoted to the Capitol at the entrance to the observation deck.

Souvenirs

Available at the Information Desk, include books,
postcards, miniatures, and tour videos.

Capitol Police

Room B2 North.

Handicapped Entrances

At Martin Luther King Jr. Blvd., East Washington Avenue,
Wisconsin Avenue, and West Washington Avenue.

Parking

Limited parking (meters) on the Capitol Square.
Several public ramps are located within two blocks of the Capitol.

Food

Vending machines in rotunda basement.

Senate Chamber

South wing, 2nd floor; visitors gallery, 3rd floor.

Assembly Chamber

West wing, 2nd floor; visitors gallery, 3rd floor.

Supreme Court Hearing Room

East wing, 2nd floor.

Governor's Office & Conference Rm

East wing, 1st floor.

Lieutenant Governor's Office

East wing, ground floor.

Attorney General's Office

East wing, 1st floor.

Legislative Offices

To find a specific office, check one of the Capitol Directories located in the rotunda and on the ground floor of each wing.

Hearings

Information about the time and location of public hearings is posted at the entrance to each legislative chamber.

Hearing Rooms

North Hearing Room, North wing, 2nd floor.
Grand Army of the Republic Hall, Room 417 North.
Joint Committee on Finance, Room 412 East.
Senate Hearing Room, Room 411 South.
Additional hearing rooms are located on the 2nd and 3rd floors.

Capitol Facts & Figures

Construction Chronology

West wing: 1906 – 1909
East wing: 1908 – 1910
Central portion: 1910 – 1913
South wing: 1909 – 1913
North wing: 1914 – 1917
First meeting of legislature in building: 1909
Dedication: July 8, 1965
Renovation: 1990 – 2001

Statistics

Height of each wing: 61 feet
Height of observation deck: 92 feet
Height of dome mural: 184 feet, 3 inches
Height of dome (to top of statue): 284 feet, 9 inches
Length of building from N to S & E to W:
483 feet, 9 inches
Floor space: 448,297 square feet
Volume: 8,369,665 cubic feet
Original cost: $7,203,826.35
(including grounds, furnishings, and
power plant)