To Measure a Star:
A Century of Stellar Interferometry

By Robert Anderson

From 1919 to 1920, astronomers at Mount Wilson made an all-out effort to measure the diameter of a star other than the Sun—a quest most thought impossible. The distances are so great that even relatively close supergiant stars, nearly a thousand times the size of the Sun, appear as points of light with no discernible disk to measure. On a more human scale, it is like trying to measure a small coin from 64 kilometers away (about 40 miles). And like our analogy, stars would have to be observed through atmospheric turbulence. Yet all the obstacles finally fell. Physicist Albert Michelson, the first American to win a Nobel Prize, played the central role in this monumental achievement. But it couldn’t have happened just anywhere. Mount Wilson Observatory, with its big reflecting telescopes and remarkably steady air, was the one place on Earth where Michelson could finally measure a star. His legacy lives on; today the CHARA array on the mountain, with the highest resolution available, uses his technique (interferometry) to measure hundreds of stars.

To measure a star, you have to know two things. The first is its “angular” size, its diameter as it appears in our sky, measured in degrees (with 180 degrees from horizon to horizon). The Moon, for instance, is roughly half a degree in angular diameter. Degrees are divided into 60 arcminutes and arcminutes into 60 arcseconds. Star diameters were ultimately measured in thousandths of an arcsecond. Measuring such small angles is the crux.

In 1920, astronomers used a 20-foot interferometer beam mounted on top of the 100-inch Telescope to measure the diameter of a star other than the Sun. It is now on display at the CHARA museum on Mount Wilson. Credit: Huntington Library/Carnegie Observatories.

End of Year Giving
Please Help the Observatory During the Lean, Cold Winter Months!
We greatly Appreciate all Donations!

Mount Wilson is Open to Visitors

Weather and roads permitting, Mount Wilson Observatory will be open every day, except Christmas. Come on up to the mountain to enjoy the beautiful weather and uplifting surroundings! The Cosmic Café will be closed from December until late April 2020. Forest Service parking passes can be purchased at the gas station at the bottom of the Angeles Crest Hwy. Check our website at mtwilson.edu for more information and to check road conditions that may cause us to close temporarily due to winter weather. See you on the top!
ABOUT US

The Mount Wilson Institute operates Mount Wilson Observatory on behalf of the Carnegie Institution for Science. Mount Wilson Institute is dedicated to preserving the Observatory for scientific research and fostering public appreciation of the historic cultural heritage of the Observatory. Reflections is published quarterly by the Mount Wilson Institute.

INFORMATION

For information about the Observatory, including status, activities, tours, and reserving 60-inch and 100-inch telescope time, visit our website:

mtwilson.edu

REFLECTIONS STAFF

Editor/Designer
Robert Anderson
webmaster@mtwilson.edu

Copy Editor
Angie Cookson

Reflections is dedicated to the memory of Marilyn Morgan, the longtime, volunteer editor and designer of this newsletter.

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PHOTOGRAPH

(Inset) Astronomer Edwin Hubble at the Newtonian focus of the 100-inch telescope on Mount Wilson, circa 1923.

Happy Holidays from Mount Wilson Observatory!

NEWS + NOTES

THANKS TO ALL OUR MANY SUPPORTERS FOR A GREAT YEAR!

The last few days of November dumped almost two feet of snow on the mountain (see the tower cam image above). This was a sign from Mother Nature that our 2019 season should come to a close. We had a wonderful year of tours, concerts, science lectures, telescope sessions, and school visits on the mountain. While the winter-season weather brings these activities to a halt, we remain open every day during the break, weather permitting. Come up and enjoy the cool-weather hiking, or a self-guided tour of the Observatory — all free! While the weekend public tours and Café service will not resume until Saturday, April 4, 2020, you can schedule a private tour at any time with some advanced notice. During the break, we will be busy on a number of projects to improve the grounds to make the Observatory even better in the new year.

LOOKING FORWARD TO 2020

The booking schedule for the 60-inch & 100-inch telescopes will be reopened on March 1, 2020. Our calendar of special events for the year will be posted on our website soon thereafter. Go to mtwilson.edu for more information.

Help Sustain the Observatory

The Observatory receives no regular support from government or institutions. We rely on donors, a few small grants, and the revenue from our telescope nights to fund our continued operation. You can help ensure the continued operation of this world class, science heritage site with your tax-deductible gift. We welcome donations of any size! Visit mtwilson.edu for information on how to support the Observatory through donations, memberships, or volunteering. Thanks.
Thank You Dr. Smith!

I am honored to announce that the Observatory was chosen by Dr. Gregory Hallock Smith as the beneficiary of his estate. Although Dr. Smith passed away in 2015, his legacy will live on through his generous gift to the Observatory. The funds will help us launch a number of much needed improvements to the Observatory to make it more accessible to a growing number of visitors from Los Angeles and around the world. Dr. Smith’s gift will jumpstart our efforts to prepare for the big centennial in 2024, when we will celebrate Edwin Hubble’s first big discovery, his proof that there are other galaxies beyond our own. We have a lot to do in just a few short years.

Born in 1941, Dr. Smith lived most of his life in Pasadena working as an optical engineer. His fascination with optics and astronomy began at age 13. In 1972, he received his Ph.D. from the Optical Sciences Center at the University of Arizona. He held optical engineering positions at several major corporations and research institutions. He is best known for his contributions to NASA spacecraft. Working for the Jet Propulsion Laboratory, he designed all the camera optics for the highly successful Mars Exploration Rover program. Smith once explained: “On each rover, there is a total of 9 cameras, each having one of four different lens types. The cameras serve two functions. First, they allow people on Earth to see what is out there for scientific evaluation and discovery. Second, the operation of the rovers combines Earth-based control and target selection with on-board autonomous navigation.” He authored several books on optics and cameras. He enjoyed teaching the next generation of engineers.

Being passionate about science and optics, he loved Mount Wilson Observatory! He served as a long-time board member, treasurer, and webmaster. Greg knew that with a large mostly volunteer staff, the money he left would go mostly to maintain the aging facilities and begin critical improvements. And it would help fund our programs to inspire and educate the next generation of scientists. And it will.

As many of you already know, the Observatory receives no regular funding from any level of government or from any institution. And still we’ve accomplished a great upswing in activity and engagement over the last three years, largely through the invaluable contributions of our volunteers. And because of generous gifts by two board members and all the contributors to our matching campaign last year, we are making good progress on restoring the Monastery and getting bathrooms built within central Observatory grounds. This kind of growth and commitment is critical to furthering the Observatory’s mission and long-term viability. At this time of exciting possibilities, please consider a donation to the Observatory to help us lay the groundwork for another 100 years of service to the community and to science!

Happy Holidays and a Happy New Year!

Sam Hale
Chairman of the Board of Trustees
The second thing you need to know: how far away the star is, a problem that Mount Wilson astronomer Walter Adams solved in parallel with Michelson’s work (more on that later). Once you know its angular size and distance, it is simple to calculate the star’s actual diameter.

The “trick” to measuring a star was first proposed by French physicist Hippolyte Fizeau in 1868. His brilliant solution would circumvent many limitations of telescopes and atmospheric turbulence. He would use the diffraction pattern of light, the rings that encircle a star’s point of light, also known as the Airy pattern.

A point source, like a distant star, produces a diffraction pattern of concentric rings. When two such patterns from the same source are made to overlap, the resulting interference “fringe” pattern contains information on the size of the star.

By masking a telescope’s mirror or lens, leaving only two widely-spaced slits, the two diffraction patterns would overlap, or interfere. Without going into a full explanation, the resulting interference pattern yields precise information about the size and shape of the distant light source; it is carried in the light itself. As the spacing between the light “samples” increased, Fizeau predicted that the interference pattern would disappear at a certain separation. This information would reveal the angular diameter of the distant star. But Fizeau lacked the equipment needed to test his idea.

Albert Michelson’s long association with Mount Wilson began, like so many things, when he met the Observatory’s founder, George Ellery Hale. They overlapped at the University of Chicago for most of the 1890s, and when Hale launched his western observatory, he invited Michelson to visit and become its second ever “research associate.” Following WWI, he spent increasingly long periods of time in Southern California, until his death in Pasadena in 1931.

In the 1880s, Michelson studied interferometry in Europe and undoubtedly knew of Fizeau’s ideas for measuring a star (as well as his experiments to measure the speed of light). He made a few experiments to see if interferometry might work, with no usable results. He thought that turbulence in the atmosphere would make it impossible. But, by August, 1891, he was ready to give it another stab. He traveled to Lick Observatory near San Jose and installed a mask with two adjustable slits over the lens of their 12-inch refractor. He was going to test interferometry by measuring the diameters of the four Galilean moons of Jupiter, whose tiny disks had already been measured directly from photographic plates with a micrometer. The key, as Fizeau had suggested, was to determine the “visibility” of the interference fringes as the slits were separated. Over four nights, even with three of them poor seeing (very turbulent atmosphere), he found that his interferometric measurements matched. But measuring nearby Jovian satellites was a far cry from bagging a distant star. He moved on to other research.

When Michelson arrived at Mount Wilson in 1919, Hale asked him to renew his interferometry trials, using the two biggest telescopes in the world. In August, the 60-inch Telescope mirror was masked except for two slits near the edge, and on the 100-inch Telescope a screen with two slits was placed in the optical path near the eyepiece. In both cases, fringe patterns were seen. Mount Wilson physicist John Anderson improved the setup so the distance between the slits could be varied. The result was a very successful “eyepiece interferometer” (see photo above). It proved very successful at resolving distances between binary stars. To measure the disk of a star, however, the slits had to be widely separated, 10 to 20 feet
apart, to simulate the resolving power of a larger mirror. With the successful tests, Francis Pease, who had just overseen the construction of the 100-inch Telescope, set about building a 20-foot stellar interferometer. It would sample light across a bigger “aperture” and relay the two beams down into the 100-inch with its eyepiece interferometer. It was ready by August 1920.

But which stars would make the best target in the first attempt to measure an angular size? The consensus view for most of the 1800s was that all stars are more or less the same size as the Sun. But in 1890, Michelson wrote that there was no particular reason why some stars couldn’t be much larger than ours. And during the next thirty years, theory and observations advanced to bear him out. A major boost to understanding stellar evolution came from Antonia Maury at the Harvard Observatory. As one of observatory director Edward Pickering’s human “computers,” she developed a scheme for classifying the spectral types of stars. Danish astronomer Ejnar Hertzsprung used her system in 1905 to show that there were two very different kinds of red stars, some small and some very large. Using the latest theories of radiation, he discovered that the apparent brightness of a star and its surface brightness (based on its color) could be used to estimate its angular size. In 1906, he estimated that Arcturus would be about 0.05 arcseconds in size, a red giant. American astronomer Henry Norris Russell also got into the stellar diameter game. With the help of Harlow Shapley’s eclipsing binary star work, he determined that stellar densities varied greatly; some stars were apparently very large with thin, puffed up atmospheres.

Just as the interferometer was being readied, British physicist Arthur Eddington delivered a speech on the importance of checking the theory behind stellar diameters with actual observations. “The estimation of the angular diameter of any star seems to be a very simple matter. For instance, the star with the greatest apparent diameter is almost certainly Betelgeuse, diameter 0.051.”

With a recommended target in hand, on 13 December, Pease and Anderson measured the angular size of Betelgeuse, the deep red star easily seen at the upper left of the Orion constellation. It had a diameter of 0.047 arcseconds—0.055 if limb darkening around its edges was taken into account. In addition to being a technical triumph, it closely matched Eddington’s prediction, vindicating the theory behind stellar diameters.

In a February, 1921, article, Michelson and Pease announced their monumental achievement. They combined the angular measurement with a distance to the star to get its actual diameter. And as already mentioned, getting a distance to even a nearby star was also extraordinarily difficult a hundred years ago (and getting a precise one still is). The distance used (180 light years) was derived from the average of three different measurements. Two were from the conventional method, based on trigonometric parallax. This is done by observing the star from one side of Earth’s orbit and then from the other side six months later. The nearby star will be seen to shift a tiny amount against the background stars, and with a little trig, this minute angle can be used to measure the distance.

The third distance used came from a new and powerful method for estimating stellar distances developed by Walter Adams, the second director of Mount Wilson Observatory. Called spectroscopic parallax, it had nothing to do with traditional parallax; instead in 1914, Adams, working with Arnold Kohlschütter, figured out that each spectral class of star has a specific luminosity. Setting the system up took years of refinement, but once done, if you could get a star’s spectrum, you could examine the light at various wavelengths, classify it, and instantly know about how luminous it was. You could then measure the star’s brightness in our sky and calculate how far away it had to be. This technique made it possible to quickly approximate distances to thousands of stars. And it appeared just in time to help Michelson and Pease.

In their paper, using an angular size of .055 arcseconds and a distance of 180 light years, they calculated that Betelgeuse had a diameter of 240 million miles, or, if it were to replace the Sun, “slightly less than that of the orbit of Mars.” Betelgeuse was indeed big.
We now know a great deal more about Betelgeuse, but getting a precise measurement of its size remains problematic for a number of reasons. As a red supergiant star, it is nearing the end of its life and is unstable as its nuclear fuel is running low. Betelgeuse could collapse and explode as a supernova at any time, but in the meantime it is pulsating, changing considerably in size. Large convection bubbles often make it asymmetric (see image below). It is also shedding a considerable amount of its mass, enshrouding it in an irregular envelope roughly 250 times the size of the star. Yet the angular resolution measurements today are still roughly the same as the one made in 1920. The measured distance to the star, however, has been revised upward to about 600 light years away, making it considerably larger in actual size—1400 times larger than our Sun. If placed at the center of our Solar System, it would engulf all the inner planets and Jupiter.

As it turns out, Betelgeuse was an extraordinarily good choice for the first measurement. It is exceeded in angular diameter by only one star (other than the Sun), R Doradus in the Southern Hemisphere. Only a red giant, R Doradus is considerably smaller than Betelgeuse, but it is much closer, so it has a slightly greater angular size.

In 1930, Francis Pease poses next to the eyepiece of the 50-foot interferometer. One of Mount Wilson's few technical failures, the flex in the beam which made precise measurements nearly impossible. The building now houses the Mount Wilson Superintendent’s offices and workshop. Huntington Library/Carnegie Observatories

Following the first successful measurement and a few others, a 50-foot interferometer with the much higher resolution needed for smaller stars was planned and executed. It was a rare instance when Hale and his coworkers were too optimistic; this time they had overreached. The interferometer never worked properly, due to flexure in the long steel beam. Larger interferometers would have to wait for better technology.

Today, Mount Wilson Observatory continues in the footsteps of Fizeau and Michelson with the CHARA Array managed by Georgia State University. Founded by past Mount Wilson Institute Director, Harold McAlister, the array saw its first starlight fringe on September 19, 2001. With its 331-meter baseline, the six one-meter telescopes on the mountain currently have the best resolution of any system in visible or infrared light in the world — the resolution of a giant mirror a fifth-of-a-mile in diameter.

CHARA has measured hundreds of stars, from Betelgeuse-sized down to main sequence red “M” stars, with masses much smaller than the Sun. The array is currently getting a major upgrade with adaptive optics and a new camera sensor. Funding to expand the array with one or more two meter telescopes is in the works. Mount Wilson, with its excellent seeing, remains an exceptional place to measure stars.
Mount Wilson Observatory in the News!

This year the Observatory received more local media coverage as we expand our public programs. The return of the spotlight is welcome, after all, Mount Wilson was the most famous observatory in the world for the first half of the 20th century. The Observatory is a frequent destination for visitors from around the world, but millions in the area don’t know that right above them, visible from most of the LA Basin, is the spot where Edwin Hubble and other astronomers revolutionized our understanding of the Universe. One visit to the Observatory on its stunning, forested mountaintop, and most will agree: it’s a magical place. But first, Angelenos have to know it’s here!

On December 7th, KCET aired an episode of LOST LA on Mount Wilson and Carnegie Observatories. The host, Nathan Masters, takes viewers on a tour through time and space and tells our story as well as anyone ever has. On our homepage, find the link to the show in the “Explore Mount Wilson Online” section. If you want to watch a visually compelling program that captures the importance of the scientific discoveries made at the Observatory this is it.

On November 11, the Observatory had a publicity boost from a small planet millions of miles away. Thanks to media coverage of a rare transit of Mercury across the Sun, a few hundred people came up to the mountain in the early morning. It was one of the few places above the cloud layer and a dozen solar telescopes to see the innermost planet safely as it drifted across the Sun's disc (including the 150-foot Solar Tower Telescope). The next one is in 2032.

Rave reviews of our monthly “Sunday Concerts in the Dome” and the new “CosmicSounds” (with telescope viewing included) continued to appear in the LA Times, LA Opus, Culture Spot LA, and other local papers. The venue has been established as one of the most unique musical venues in LA. A dome with amazing acoustics, with top notch musicians — all in the presence of the giant telescope that Hubble used to discover the Universe. Check our website in the Spring for our 2020 schedule of concerts, lectures, tours, and other events: mtwilson.edu

Photo: Irina Logra
WELCOME, VISITORS!

Welcome hikers, bikers, star-gazers, visitors of all interests! The Observatory is open from 10:00 a.m. to 4:00 p.m. daily (our winter hours). The Cosmic Café at the Pavilion is closed for the winter and will reopen on Saturday, April 4, 2020. Weekend public tours of the Observatory will also resume that day.

SELF-GUIDED TOURS

During the winter months when the weather on the mountain is unpredictable, there are no weekend public tours, but visitors are welcome to explore the public areas of the Observatory on their own. The Observatory and the CHARA array both have small museums to check out, and the 100-inch Telescope dome has a visitor's gallery to look at the famous telescope. Our grounds are open and free everyday (except when weather forces us to temporarily close).

PRIVATE GROUP TOURS

Group daytime tours are available on any date. Advance notice and reservations are required and a modest fee is charged. For more information, please visit www.mtwilson.edu/private-group-tours

LOOK THROUGH THE TELESCOPES

During the winter, Mount Wilson’s historic 60-inch telescope and 100-inch telescope are not available for public observing.

PARKING AT THE OBSERVATORY

The U.S. Forest Service requires those parking within the Angeles National Forest and the National Monument (including the Observatory) to display a National Forest Adventure Pass. For information, visit www.fs.fed.us/angeles/. Display of a National Parks Senior Pass or Golden Age Passport is also acceptable.

HOW TO GET TO MOUNT WILSON OBSERVATORY

From the 210 freeway, follow Angeles Crest Highway (State Highway 2 north) from La Cañada Flintridge to the Mount Wilson–Red Box Road; turn right, go 5 miles to the Observatory gate marked Skyline Park, and park in the lot below the Pavilion. Visit the Cosmic Café at the Pavilion, or walk in on the Observatory access road (far left side of parking lot) about 1/4 mile to the Observatory area.