



## Perfect Planets (and the Moon) II

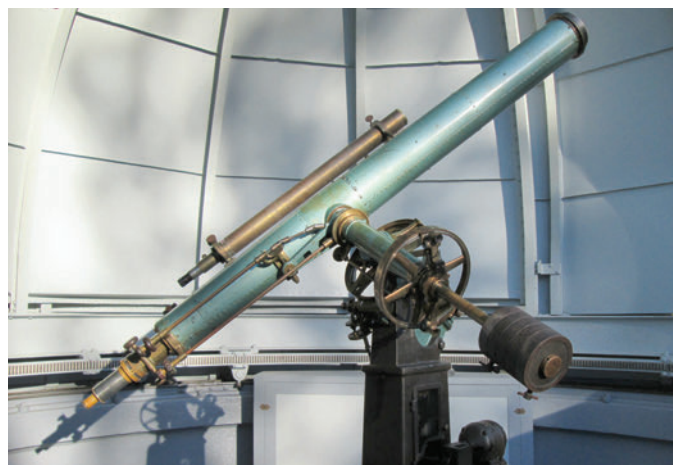
by **DR. THOMAS J. SPIROCK**

The Warner & Swasey 6-inch f15 refractor, with a lens crafted by John Brashear, has been a fixture at Mount Wilson since its installation in 1914. The telescope was reinstalled in its proper historical location in 2015, after being packed away in the Snow solar telescope building for 20 years, from 1995 until June 2015. In the September 2015 issue of *Reflections*, John Briggs described the history and restoration of this great instrument.

### JUNE 2016 OBSERVING RUN

In June 2016, this historic instrument was used to photograph some old friends using the modern technique of “lucky imaging” to image Mars, Jupiter, and Saturn. This procedure for obtaining images of the planets applies a fast read-out camera to capture many images at a high frame rate, which are stored as videos for later analysis. These sequences of images are analyzed to extract those frames that were obtained during moments of good seeing (the condition of the turbulence of the atmosphere). The high-quality images are then aligned, averaged, and enhanced to produce a final image that contains details far beyond what an observer could detect with the eye.

In the September 2016 issue of *Reflections*, John Briggs and Thomas Spirock described their observations and results from the June observing session using a ZWO ASI120MC fast-read-out color camera. Though the seeing was decent for only one of the five nights of the observing run because of unusually hot conditions at the time, and the seeing during the one good night was not as good as the best nights on Mount Wilson, features near the diffraction limit of the telescope (0.76 arcsec) were nevertheless obtained. It was gratifying to see that this historical instrument could produce such high-quality images with the help of the excellent conditions on Mount Wilson



JOHN BRIGGS

THE WARNER & SWASEY REFRACTOR on Mount Wilson.

and the application of modern imaging techniques. The results can be seen in the images of Mars, Jupiter, and Saturn in the September 2016 issue of *Reflections*.

The 6-inch f15 objective is of the highest quality. However, it does have a fair amount of chromatic aberration. This characteristic, which is inherent in all lenses, originates from the fact that different wavelengths (colors) of light are bent (refracted) by slightly different amounts and therefore come to a focus at slightly different distances behind the lens. The addition of a second lens, to make a “doublet” as

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### ANNOUNCEMENTS

#### Mount Wilson Observatory Welcomes Visitors

Weather and roads permitting, Mount Wilson Observatory is open to the public every day for the season. Come on up to the mountain to enjoy the beautiful weather and uplifting surroundings! The Cosmic Café is open Saturdays and Sundays, 10 A.M. to 5 P.M. At the café you may purchase a National Forest Adventure Pass and tickets for the weekend walking tours. The Cosmic Café is located in the Pavilion overlooking the large parking lot at the entrance to the Observatory. We will see you at the top!



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 — [www.mtwilson.edu](http://www.mtwilson.edu).



#### REFLECTIONS STAFF

Editor/Designer  
Marilyn Morgan  
[memorgan99\[at\]earthlink.net](mailto:memorgan99[at]earthlink.net)

Associate Editor  
Bob Eklund  
[beklund\[at\]sprynet.com](mailto:beklund[at]sprynet.com)



For the use of historical photographs of Mount Wilson, we thank the Observatories of the Carnegie Institution for Science, the Huntington Library, and other sources as noted.

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#### PAGE ONE BANNER PHOTOGRAPHS

In this infrared image by NASA's Spitzer Space Telescope, the red arc is a giant shock wave created by a speeding star known as Kappa Cassiopeiae. (Inset) Edwin Hubble at the Newtonian focus of the 100-inch telescope on Mount Wilson, circa 1923.

## NEWS + NOTES

### VISIT OUR NEW WEBSITE

With heartfelt thanks to developer/webmaster Robert Anderson (with support from Sven Eberlein), Mount Wilson Observatory has a completely redesigned website. We encourage you to visit [www.mtwilson.edu](http://www.mtwilson.edu) for Observatory history, status, current conditions, special events, links to videos, today's sunspot drawing, and much more. The site is optimized for viewing on various devices, such as tablets and smartphones.

### PUBLIC TICKET NIGHTS

The popular public ticket nights for individuals allow individuals to experience viewing celestial objects through the 60-inch and 100-inch telescopes. A limited number of tickets will be made available on a first-come, first-served basis. Information will be posted on [www.mtwilson.edu](http://www.mtwilson.edu).

### CUREA 2017

The Consortium for Undergraduate Research and Education in Astronomy (CUREA) is a two-week introduction to solar and stellar observing for undergraduates held at Mount Wilson Observatory. CUREA 2017 is scheduled for Sunday, June 18, through Saturday, July 1, 2017.

### CENTENNIAL OF THE 100-INCH MIRROR ARRIVING ON THE MOUNTAINTOP

In 1906, the glass disk for the 100-inch telescope mirror was ordered from the Saint-Gobain glass factory. After a number of setbacks in pouring the 4.5-ton slab and six years of grinding its optical surface to perfection, it arrived at the Observatory on July 1, 1917. On November 2, the 100-inch telescope turns 100, and to mark this centennial, there will be a number of special events. Keep an eye on our website as the date approaches!

### CONCERTS IN THE 100-INCH DOME

Due to the unexpected storm that dropped three to four inches of snow on the mountain and closed the roads, the Observatory rescheduled the May concert to June 11. The June concert was moved to July 9, when music of Haendel-Halvorsen, Glière, and Kodaly will be featured, with performers Cécilia Tsan, principal cello for the Long Beach Symphony, and Ben Powell, violin. A reception with the musicians will follow each performance. Tickets are \$50. For information and tickets, visit [mtwilson.edu/concerts](http://mtwilson.edu/concerts).

### AUGUST 21 — THE 2017 TOTAL SOLAR ECLIPSE

While the path of August's total solar eclipse will pass across the United States hundreds of miles north of Los Angeles, a partial solar eclipse will be visible from Los Angeles. Mount Wilson Observatory, which was the leading center for solar research during the first half of the twentieth century, will celebrate the event with free public viewing through a variety of solar telescopes. The eclipse will begin in our area at 9:05 A.M. Maximum eclipse will occur at 10:21 A.M., with the Moon covering 70 percent of the Sun's diameter and 62 percent of its area. The eclipse will end at 11:44 A.M.

## Help Sustain the Observatory

★ The Observatory receives no continuing state, institutional, or federal support. 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 science heritage site with your tax-deductible gift. We welcome donations of any size and volunteer efforts of all kinds. Visit [www.mtwilson.edu](http://www.mtwilson.edu) for information on how to support the Observatory through donations or volunteering.



## Reflections in the 100-inch Dome

Ken Evans is a volunteer working on refurbishing the 100-inch telescope. He recently provided two interesting photographs he took while working on the telescope, writing: “We had the dome open during the day and the Sun was shining on the work ladder positioned on the west side of the telescope to change out the DEC slew motor. I looked at the visitor gallery windows and saw the reflections of the ladder. It was unique and so I photographed it, and then took a photo of the ladder just to show the source of the reflection. Note the double image of the ladder in the rightmost window due to the angle of the glass and the thickness. Totally off the hip and no planning. Much more interesting than a photo of a switch, motor, or wiring that we are using to document our work. I did not notice the double reflection in the glass until I began to sort through the photos to choose these two.”



## Phoebe's Spectrograph — Errata

In the March 2017 *Reflections*, the lead article about Phoebe Waterman Hass stated that “a spectrograph designed by James Keeler and built by John Brashear in 1898 was used by Phoebe Waterman on the 36-inch refractor at Lick Observatory to complete her research about stellar spectra. It is now on exhibit at the Smithsonian National Air and Space Museum.” This information was apparently incorrect, and we are happy to set the record straight.

We heard from David H. DeVorkin, Senior Curator, Division of Space History, National Air and Space Museum, Smithsonian Institution. (Earlier, Hal McAlister, former director of Mount Wilson Observatory, had written to let us know that David DeVorkin was the point-person for implementing the Phoebe Waterman Haas observatory on the National Mall.)

Mr. DeVorkin stated that “I’m quite sure that Phoebe used [W. W.] Campbell’s ‘Mills Spectrograph,’ which was the second-generation model and optimized for photographic work. Under Campbell’s direction, Phoebe modified the Mills to optimize for the visual range to determine if the Harvard classification worked in the visual range as well as in the photographic range. In any event, it is the Mills we have on display.” He went on to say that “Phoebe’s own work was actually very important — she not only verified the Harvard classification system work in the visual, but also reviewed evidence supporting [H. N.] Russell’s controversial theory of stellar evolution. In both efforts she reversed her mentor Campbell’s skepticism.”

In a follow-up email, Mr. DeVorkin noted that “I can confirm that Phoebe used the Mills, using special modifications built by Campbell to make it work as a low-dispersion, one-prism instrument. In her thesis, published in the *Lick Observatory Bulletin*, February 15, 1913 (<http://articles.adsabs.harvard.edu/full/1913LicOB...8....1W>), Phoebe only indicates that she used spectrographs I and II in various modes, adjusting for best focus in the visual. But it’s clear they were all Mills variants.

“What is curious is that Phoebe used only the general terms ‘spectrograph I and II,’ not even mentioning that they were both variations on the Mills — indicating that the terms, at Lick at least, were considered self-explanatory. I’ve not been able to find a photograph of the Mills modified as spectrograph I or II, but am still looking. The images we use are of the Mills in its two- and three-prism configuration.”





in the case of the Brashear lens of the Warner & Swasey telescope, can dramatically reduce, but never completely eliminate, this effect. The practical result of the chromatic aberration in the telescope is that the instrument cannot create a perfectly focused image at all wavelengths simultaneously. This can be seen as a green hue in the images of Mars, Jupiter, and Saturn in the September 2016 *Reflections*.

**W**hile it is always desirable to obtain the best results possible, given the rare opportunity to image the planets at Mount Wilson, one must always be careful not to try to do too much during an observing session, lest all the time and effort be spent dealing with unforeseen troubles as opposed to acquiring data for imaging. It tends to be best to proceed with improvements in small, incremental steps, especially when observing with a particular instrument for the first time, and to note what additional improvements can be made for the next observing session. With this concept in mind, it was decided that it was more important to simplify the initial observing run by using a color camera (as opposed to a monochrome camera) and to accept the limitations imposed by the chromatic aberration. This turned out to be a wise decision, especially since the idiosyncrasies of the original weight-driven clock drive of the telescope were not known and turned out to be a bit of a challenge. Considering the high quality of the images, even with the chromatic aberration, the first observing run was definitely successful and the removal of the chromatic aberration was set to be a top priority during the next observing run.

#### LESSONS LEARNED FROM 2016

**T**he only way to eliminate the effects of chromatic aberration in this type of refracting telescope is to capture images using red, green, and blue filters separately with a monochromatic camera. This allows the images produced by each filter to be properly focused. The monochrome images obtained with each filter are processed separately and later combined to produce a color image. The logistics of this procedure require the operation of a filter wheel, which is a device that holds the various color filters in such a way that they can be quickly rotated into the optical path. The telescope must be manually refocused whenever a new color filter is used.

Using a color camera has some advantages, when compared with using a monochrome camera, to produce color images. The separate red, green, and blue images do not have to be taken separately, aligned, and combined to produce a color image. And, the list of hardware tends to be less expensive, since a filter wheel and the red, green, and blue filters are not required. Finally, regardless of how well the separate images are aligned in the x and y coordinates, the red, green, and blue images are taken at slightly different times. Even when the images are obtained in rapid succession (typically on the order of three minutes from the start of the first video in the set to the end of the last video in the set), there is always some rotation of the planet during the acquisi-

tion time, especially with Jupiter (which rotates in just 9 hours and 55 minutes), which produces artifacts in the final result.

Even considering the advantages of using a color camera and the obvious good results obtained in June 2016, both Briggs and Spirock were optimistic that the application of color filters would allow the telescope, working in concert with the typical good seeing at Mount Wilson, to capture details at the limit of its ability and enable the production of high-quality color images. With this in mind, the necessary color filters, filter wheel, and monochrome camera were obtained in preparation for the next run in April 2017.

#### APRIL 2017 OBSERVING RUN

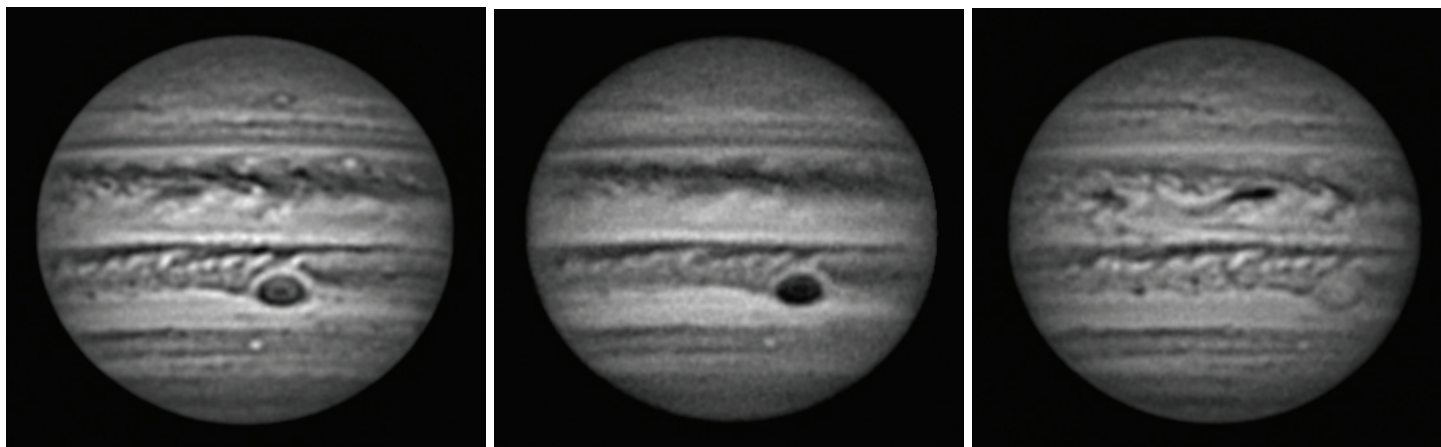
In early April 2017, when Jupiter would be at opposition (opposite the Sun as seen from Earth), Earth would be passing Jupiter, due to its smaller and faster orbit, around the Sun. Therefore, the two planets would be as close to each other as their orbits permit during 2017. This would be an advantageous time to apply the experience gained from the June 2016 run. Due to work-related commitments, John Briggs was unable to attend, but was at the controls of the Warner & Swasey telescope in spirit.

**A**s darkness descended on Mount Wilson on the night of April 1, 2017, the Warner & Swasey telescope was at the ready, with a ZWO ASI1600MM monochrome camera, appropriate color filters in their filter wheel, and a 2× Barlow, all mounted to the telescope in place of an eyepiece. The 2× Barlow is simply a magnification lens that doubles the 90" focal length of the telescope to an effective 180". This produces the appropriate image scale (0.2 arcsec per pixel), matched to the size of the pixels of the camera to properly sample the image, such that the camera will adequately capture all the fine details that the telescope is capable of producing.

A minor disadvantage of observing a planet at opposition is that, due to the geometry of the solar system, the planet in question rises at sunset and, therefore, does not reach its maximum elevation above the horizon until midnight (1 A.M. during Daylight Saving Time). It is of critical importance to observe any astronomical object when it is as high above the horizon as is practical, when the image of the object will travel through the least amount of atmosphere and will experience the minimum amount of the distorting effects of air turbulence.

As Jupiter approached the meridian (the point at which it would reach maximum elevation), the acquisition of data could commence. Capturing the videos to be used in the "lucky imaging" process is a combination of science and art. While there are some established rules regarding exposure times, the length of the video sequence, etc., that must be followed, there are also some procedures that





**JUPITER** images — left is green (taken at 08:18 UT), the center image is blue (taken at 08:34 UT), and the right image is red (taken at 09:06). The Great Red Spot is the large dark oval just below center in the green image and has moved to the right in the blue image.

must be continually adjusted, depending on the quality of the seeing. These adjustments depend on the experience of the observer and must be perfected over time with practice.

Regarding the exposure time of the individual frames ... on the one hand, it is best to keep the exposure time as short as possible to reduce the blurring effects of the atmosphere. On the other hand, it is desirable to use as long an exposure time as possible to increase the signal-to-noise ratio of the data. So, there is a trade-off between these two competing factors. The experience from taking data, with the seeing at Mount Wilson, is that, for Jupiter, exposure times from 5 to 20 msec seem to produce the best results.

Regarding the length of the videos ... again, this is a trade-off. Acquiring frames for as long as possible increases the chances that many high-quality frames will be captured and available for averaging. However, as stated previously, Jupiter is rotating rapidly, and capturing frames for too long a period will smear out the fine details when the final averaged images are created. Capturing frames for two minutes seems to allow the capture of enough high-quality frames without smearing out the intricate details of Jupiter's cloud features.

Each video contained several thousand Jupiter images. AutoStakkert was used to analyze the individual images in the videos and select the best 1,024. The best images were aligned and averaged to make a high-quality, low-noise final image. RegiStax was then used to enhance the fine details and further reduce the noise in the image. A few interesting observations can be made from the set of images. First, as noted previously, Jupiter is rotating rapidly. The blue image was taken approximately 1/2 hour after the green image and the red image was taken approximately 1/2 hour after the blue image. Note how much the Great Red Spot has moved between each image. Another observation is how the different colors enhance or degrade the different features on the planet. For example, the Great Red Spot is very obvious in the green and blue images, while is very subtle

in the red image. The dark tadpole-shaped feature in the red image (slightly above and to the right of the center of the image) is very subtle in the green and blue. Comparing how different features appear in different colors can help scientists determine the chemical composition of the various features in Jupiter's atmosphere.

#### ...AND THE MOON

An advantage of the ZWO ASI1600MM camera is its large imaging array of  $4656 \times 3520$  pixels, 3.8-micron pixels, 17.7 mm  $\times$  13.4 mm imaging chip, and its fast, USB 3.0 readout capability. When using the Warner & Swasey telescope at f15 (no Barlow), the sensor of the camera can image the first-quarter Moon in just two pieces, with plenty of overlap for stitching the pieces together in postprocessing. The gibbous Moon could be captured in only three pieces. Using the same red filter (to maximize the quality of the seeing) and using exposures of 2 msec for the "correct" exposure, and 4 and 6 msec for intentional "over-exposures," the gibbous Moon was captured in nine (three pieces times three exposures for each piece) 30-second videos, each consisting of approximately 200 individual images.

AutoStakkert was used to process the videos to align and average the best 32 individual images from the set in each video, resulting in nine low-noise images of a piece of the Moon. RegiStax was used to wavelet process the images to sharpen the fine details. Adobe Photoshop Elements was used to manually stitch the individual pieces together, resulting in three complete images of the gibbous Moon, one at the "correct" exposure and two "over-exposed." The purpose of the "over-exposed" images is to bring out the details in the darker regions of the Moon near the terminator.

Finally, Photomatrix Essentials, which selects the portions of each image that are not too dark and are not too bright, was used to





**THE FINAL HIGH-DYNAMIC-RANGE IMAGE** of the Moon. The full-size version is 6,700 pixels by 6,600 pixels in a 131-MB TIFF file (no compression). The image can be printed out at 24 inches by 30 inches.





combine all three images, selecting the best portions of each, into the final, high-dynamic-range lunar image.

#### LESSONS LEARNED FROM THE APRIL 2017 RUN

While the initial results of Jupiter and the Moon are good, there is more work to be done on the postprocessing and some technical improvements that can be made for the next observing run.

The most important next step of postprocessing is to assemble the red, green, and blue monochrome images of Jupiter into a single color image. This final step will determine how well the use of color filters can overcome the effects of chromatic aberration.

Four technical improvements were identified that should be considered before the next observing run.

1. While it is possible to manually change the color filters via a control program, each time a color filter is changed the camera must be manually refocused. These steps take time and it is important to minimize the time from the start of the collection of the data for the first color filter to the end of the collection of the data of the last color filter, because Jupiter is rotating during this process. The use of a computer-controlled, motor-driven focuser that can automatically change the color filters and refocus the camera will reduce the total time for the collection of the data for a single sequence, thus reducing the artifacts in the final color image.

2. The use of an additional infrared filter will enable the collection of images in the near-infrared longer-wavelength portion of the spectrum, where the seeing is better (the atmosphere distorts and scatters shorter wavelengths more than it does longer wavelengths, which is why, for example, the sky is blue). This should produce images with sharper details than in the red, green, or blue.



**THE IDENTIFYING PLATE AND WEIGHT-DRIVEN CLOCK DRIVE** of the Warner & Swasey 6-inch refractor.

PHOTOS BY THOMAS SPIROCK

3. Flat-field images ought to be obtained for each night's data. Regardless of how well the optics of the telescope are cleaned, there is always some residual dust, pollen, etc. These particles can appear in the images as black points or out-of-focused dark rings that degrade the artistic quality of the image. A flat-field image is obtained by taking an image of a uniformly illuminated target, such as the twilight sky, which will literally create an image of these imperfections. This flat-field image can be used to remove the dust-induced imperfections in post-processing.

4. The mechanical weight-driven clock drive could probably use some maintenance, as it is more than 100 years old and is a bit erratic.

#### CONCLUSION

Overall, the Warner & Swasey 6-inch f15 refractor is performing very well. Its high-quality Brashear objective lens has not shown signs of degradation over the past 100-plus years and continues to produce excellent images. The telescope's creators and the astronomers who used the telescope when it was initially installed would probably be very happy to see that the application of modern imaging techniques, the high-quality conditions on Mount Wilson, and a little effort are producing images that are, probably, far beyond their expectations. Hopefully, the application of yet a few more lessons learned, in the near future, will produce images of even higher quality.



#### About the Author

Dr. Thomas J. Spirock completed his graduate studies at New Jersey Institute of Technology building a digital vector magnetograph for Big Bear Solar Observatory. He is a member of the Springfield Telescope Makers, the organization responsible for the well-known annual Stellafane Convention in Vermont.



Mount Wilson Institute

P.O. Box 94146

Pasadena, CA 91109



## WELCOME, VISITORS!

### OBSERVATORY STATUS

Welcome hikers, bikers, star-gazers, birders, and visitors of all interests! The Observatory and Skyline Park are open from 10:00 A.M. to 5:00 P.M. daily, weather and roads permitting. The Cosmic Café at the Pavilion, offering fresh-made sandwiches and Observatory memorabilia, is open Saturdays and Sundays from 10:00 A.M. to 5:00 P.M. You may purchase a National Forest Adventure Pass at the Café for parking.

### DOCENT-LED WALKING TOURS

Two-hour weekend tours of the Observatory are held on Saturdays and Sundays at 1:00 P.M. Meet at the Cosmic Café at the Pavilion to buy a ticket. Guests on these tours are admitted to the telescope floor right beneath the historic 100-inch telescope. A one-hour tour that does not provide entry to the telescope leaves the Pavilion at 2:00 P.M. on Saturdays and Sundays, June through August.

### SPECIAL GROUP TOURS

Group daytime tours are available. Reservations are required and a modest fee is charged. Groups can also place orders in advance for box lunches from the Cosmic Café. For information, please visit [www.mtwilson.edu](http://www.mtwilson.edu).

### LOOK THROUGH THE TELESCOPES

Mount Wilson's 60-inch telescope and 100-inch telescope provide incredible views of some of the most beautiful objects in the night sky. For details on scheduling a viewing session, see [www.mtwilson.edu](http://www.mtwilson.edu).

### 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.usda.gov/angeles/](http://www.fs.usda.gov/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. The Museum is opposite the 150-foot solar tower.

