

Canaries and the Big Dog

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Just as the Sun seems to go around Earth once a day, at least from our point of view on the ground, solar astronomy flourishes at all longitudes. Efforts from a wide variety of countries—including Sweden, India, and Japan—give at least a brief picture of the range of interesting things to tackle in order to understand our Sun.

Gone to the Dogs

The Canary Islands are off the west coast of Africa, about where that continent bulges farthest to the west. They have been part of Spain for hundreds of years. Early European visitors, including Pliny the Elder, about 2,000 years ago, mentioned the many big dogs found there. Since the Latin for “dogs” is *canes*, the location was named the Islas Canarias, which has been translated as the Canary Islands.

Two of the Canary Islands have major observatories atop mountains. The headquarters of the Canaries Institute for Astronomy and Astrophysics (Instituto de Astrofísica de Canarias) is on Tenerife, as is one of the observatories. The other observatory, the Roque de los Muchachos Observatory, contains the biggest nighttime telescopes and is on La Palma. A Spanish telescope equal in size to the 10-m (400-inch) Keck telescopes, the largest in the world, is opening soon on La Palma.

The newest and perhaps the best of the world's solar telescopes opened on La Palma in 2002. It is run by the Institute for Solar Physics of the Royal Swedish Academy of Sciences in Stockholm, Sweden. This Swedish Solar Telescope has a focusing lens 1 m (40 inches) across. That makes it the second-largest optical solar telescope in the world. The lens also acts as the top element that closes off a vacuum. The light path inside the telescope is evacuated.

Fun Sun Facts

The 1-m (40-inch) lens of the Swedish Solar Telescope is a single piece of glass and, thus, focuses different colors at different distances. Therefore, most observations are made using only one wavelength at a time, chosen with a filter or with a spectrograph. A more complicated set of lenses is also available to allow several wavelengths to be combined at the same focus.

*The Swedish 1-m (40-inch)
Solar Telescope at the Roque
de los Muchachos Observatory
on La Palma, Canary
Islands, Spain.*

*(Royal Swedish Academy of
Sciences)*

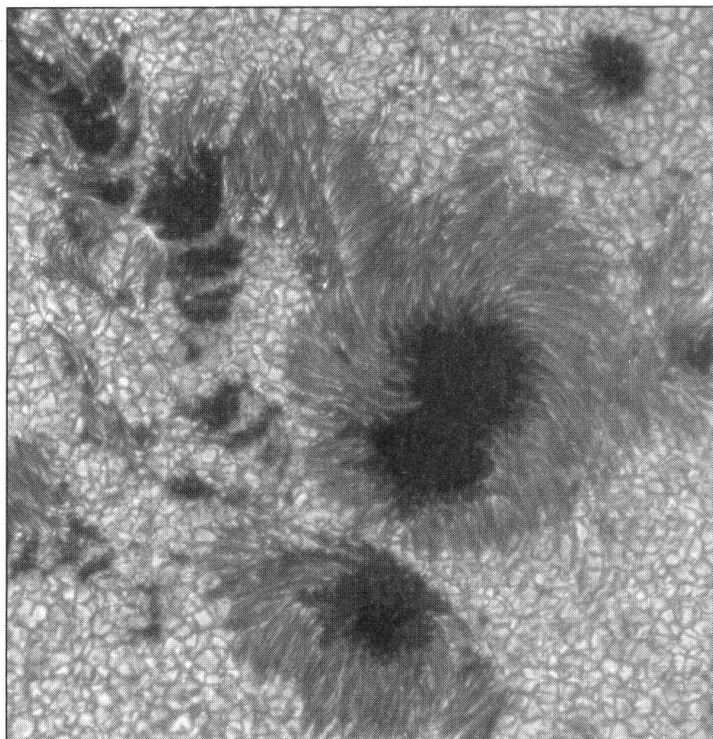


Fun Sun Facts

Vacuum telescopes are found all over the world, including on Kitt Peak in Arizona, on Sacramento Peak in New Mexico, at Baikal in Russia, at Udaipur in India, and in Huairou and Kunming in China. Huairou is the solar observation station of the Beijing Astronomical Observatory of the Chinese Academy of Sciences (<http://sun.bao.ac.cn/>) and was opened in 1997. It is on a small island in a reservoir about 60 km (40 miles) from downtown Beijing.

The telescope was designed from scratch to give the finest possible solar images, approaching one tenth of an arc second. Göran Scharmer, already well known for his high-resolution imaging with the telescope's half-size predecessor, designed the telescope and its imaging system. To limit turbulence in the telescope, it is evacuated. To reach the desired resolution, about 10 times better than the traditional limit, it incorporates adaptive optics. This latter method uses a mirror that changes in shape as often as 1,000 times per second. The shapes are calculated in real time by a computer that interprets the blurring of the image to show the shape that is needed to compensate for turbulence in the air outside the telescope.

The telescope has already shown its success in making high-resolution images of sunspots.



High-resolution images of sunspots made with the Swedish Solar Telescope. The dark umbra is surrounded by fibrils of the penumbra. The salt-and-pepper effect known as granulation, part of the photosphere, surrounds the sunspot.

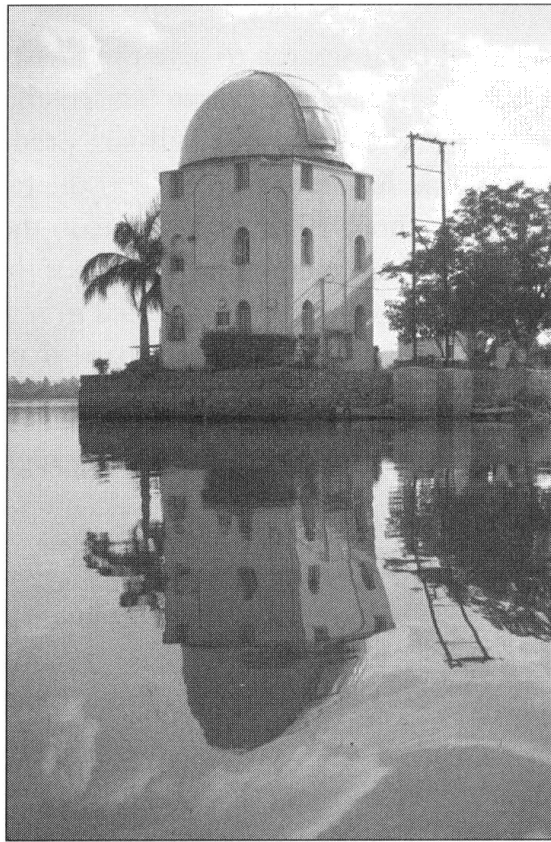
(Royal Swedish Academy of Sciences)

Indian Idyl

In India's state of Rajasthan is the city of Udaipur, about 800 km (500 miles) southwest of New Delhi and northwest of Mumbai (formerly Bombay). Its lake is the site of the Lake Palace Hotel, known to many moviegoers as the site of one of the James Bond spectacles, *Octopussy*. Guests take a boat from the shore out to the island where the hotel is located.

The Udaipur Solar Observatory is in the middle of a lake.

(Jay M. Pasachoff)



But boats go elsewhere in the lake as well. When Arvind Bhatnagar returned to India from years of supervising the Big Bear Solar Observatory, he vowed to build another island solar observatory to provide high-quality seeing. And he succeeded. The observatory has since become part of the Physical Research Laboratory of the Department of Space in India, whose headquarters are in Ahmedabad.

Like so many solar observatories, the Udaipur Solar Observatory has several telescopes on a single mount. The largest telescope has a 25-cm (10-inch) lens and is used for high-resolution observations in hydrogen light. Another telescope has a 15-cm (6-inch) lens and is used for hydrogen-light full-disk observations.

India has several astronomical observatories. A coronagraph site is being planned at the very high altitude of 4,500 m (14,775 feet) in the Himalayas. Indian scientists have also been active in observing eclipses.

The Udaipur Solar Observatory is one of the sites of the GONG network, which we describe in the following chapter.

The Other Alps

Thus far, we have described mainly solar observatories that make images of the Sun in visible light. But the Sun emits radiation across the entire spectrum from gamma rays through x-rays to ultraviolet, to visible, to infrared, to radio waves.

The wavelengths of radio waves are over 1,000 times longer than the wavelengths of visible light. Since the fineness of the resolution worsens as the wavelength increases, images with optical-size telescopes of radio wavelengths would be truly substandard. But it is possible to build solar radio telescopes spread over acres. These radio telescopes are composed of many separate small antennas, and the signals are combined electronically.

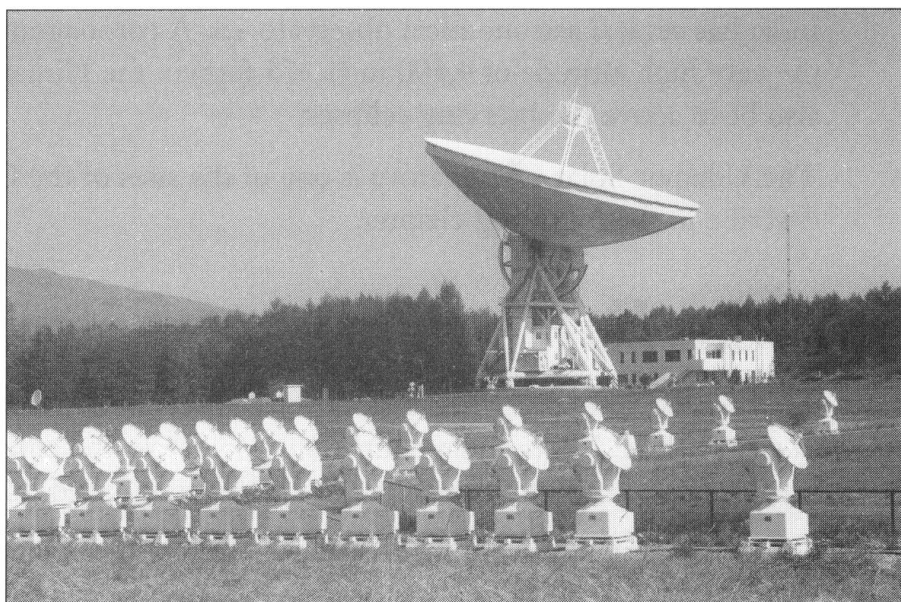
The current best of these radioheliographs is at the Nobeyama Radio Observatory in the Japanese Alps, a five-hour train ride west of Tokyo. Nobeyama is in the guidebooks mainly because it is the railway station of the highest altitude in Japan (1,300 m, or about 7,000 feet). The observatory boasts several large telescopes, including one 45 m (150 feet) across that is the largest radio telescope in the world accurate enough to be used for observations of short-wavelength radio waves, those with wavelengths of only a few millimeters.

Quite noticeable to both astronomers and visitors is a large circle of hundreds of small white dishes. These comprise the radioheliograph. The observations of all these telescopes are combined in a control room nearby. When combined, images of the Sun exist that show activity in the solar corona. The observations are at a frequency of 17 gigahertz (GHz), equivalent to 1.8 cm (0.7 inches) in wavelength. Flares and eruptions show clearly.

Also on the site is a set of a handful of small solar telescopes. Each is sized so that the beam of radiation that it sees comes from a disk the size of the Sun. For those of double the wavelength of an adjacent radio telescope, the diameter is halved, to keep the field of view the same. Decades ago, I worked at such a system at the Sagamore Hill Radio Observatory in Hamilton, Massachusetts, run by the U.S. Air Force Cambridge Research Laboratories.

Some of the telescopes of the Nobeyama Radio Observatory's radiobeliograph, with the 45-m (150-foot) millimeter-wave radio telescope in the background.

(Nobeyama Radio Observatory)



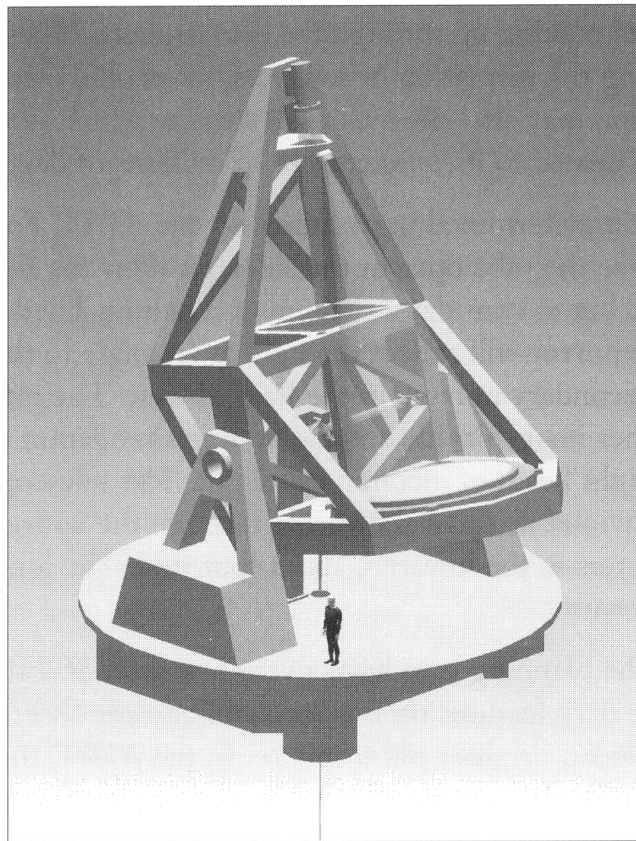
Where, Oh Where, Will My Telescope Go?

For too long, astronomers have felt that the Sun is so bright that solar astronomers didn't need a big telescope. But solar astronomers have come to spread out the Sun's light so much in wavelength, or to divide it up into intervals so small in time, that the amount of light in their telescopes limits their observations. They would like a big telescope, like everyone else.

Finally, there is general agreement that solar science has advanced so far that a big telescope is needed. An unprecedentedly large consortium of 22 institutions has banded together to plan for the Advanced Technology Solar Telescope (ATST). It is to be in the 4-m (160-inch) class, a size that matches the nighttime telescopes at the National Optical Astronomy Observatory and the Cerro Tololo Inter-American Observatory, which used to be the largest until they were superseded by telescopes of the 8 m (320-inch) class telescopes.

But it isn't enough just to take over a 4-m (160-inch) telescope for solar purposes. The telescope must be specially designed and optimized for the needs of the solar community. For one thing, it must have adaptive optics designed from the beginning. Note that the area of a 4-m mirror is 16 times (4^2) the area of the 1-m (40-inch) Swedish Solar Telescope, so the ATST would represent a giant leap in abilities. The mirror must have qualities of especially low scattering of the light that hits it. The whole system must function well in the infrared, which involves among other things keeping room-temperature parts of the telescope out of the field of view. And today's generation of cameras and other instruments must have room at the telescopes' foci.

All the major American solar players are participating, with the National Solar Observatory as the principal investigator of the project; the Big Bear Solar Observatory's parent at the New Jersey Institute of Technology, the High Altitude Observatory (based in Boulder, Colorado), and the relevant astronomical parts of the University of Hawaii and the University of Chicago as co-principal investigators. The major support is being requested from the National Science Foundation's divisions of Astronomical Sciences and Atmospheric Sciences. International partners are currently being sought, and a proposal for participation from a consortium of European solar institutions is expected.



An artist's conception of the 4-m (160-inch) Advanced Technology Solar Telescope.

(NSO)

The ATST's consortium has announced that its science program is dedicated to the following questions:

- ◆ What basic mechanisms are responsible for solar variability that ultimately affect human technology, humans in space, and terrestrial climate?
- ◆ How are solar and stellar magnetic fields generated, and how are they destroyed?
- ◆ What role do magnetic fields play in the organization of plasma structures and the impulsive releases of energy seen on the Sun and throughout the universe?

The ATST will be able to observe and follow fine details in the magnetic field structure on the Sun over a wide range of time scales. It will be able to measure three-dimensional polarization and make spectra of very high spectral and spatial resolution. It will take advantage of the experience gained in the current generation of three-dimensional polarization and magnetic field telescopes at such sites as Haleakala, Kitt Peak, and Sacramento Peak. It will also be able to accommodate the advances in adaptive optics, to allow features to be followed on a spatial scale better than one-tenth of an arc second, which is only 70 km (44 miles) at the distance of the Sun from Earth. Numerical calculations show that there should be features this small, and we want to be able to observe them. Some of them are the tubes of magnetic flux that scientists hope to detect coming up through the photosphere. These small columns are key to understanding the formation of sunspots, flares, and other solar phenomena. This high resolution may also allow us to determine which features on the Sun cause the corona to be heated to its temperature of millions of degrees.

Many things are as yet undetermined in planning for the ATST. For example, the best idea so far is to have the tube open at the sides, to allow the flow of air through it. The telescope is too big to consider a vacuum or a helium-filled arrangement. The current idea is that the mirror will reflect the light at an angle to the incoming radiation, to avoid having secondary mirrors in the field of view. The off-axis arrangement would allow for a cleaner image profile and easier accommodation of the very large heat loads from the bright beam of incoming sunlight. The telescope is planned to be sensitive from the ultraviolet just past the visible through the entire visible range and up to about 3 micrometers in the infrared, about four times the longest wavelength (red) of the visible spectrum.

An important part of the planning is to have a very low level of scattered light. In particular, sunspots are dark features on the Sun, and current observations have light scattered from the adjacent, brighter photosphere. In the ATST, the amount of such scattering will be limited to 10 percent of the sunspot's umbral intensity.

The aperture of 4 m (160 inches) is needed not only to collect a lot of light, but also to provide imaging with a spatial resolution of 0.1 arc second at the longer-wavelength end of the infrared range. Also, the large aperture should allow measurements of the three-dimensional magnetic field to be made quickly enough, compared with the rate at which the small magnetic-field elements change.

Though it may be hard to believe, the site for this major telescope has not yet been selected. In some sense, like the Wandering Minstrel in Gilbert and Sullivan's operetta *The Mikado*, the telescope's prospective site is wandering. Site testing is going on all over the globe to provide the best possible location, including excellent seeing and

the most hours possible of clear skies. Merely having an existing solar telescope present is not the determining criterion. A half-dozen sites have instruments monitoring conditions over a lengthy period of time: Big Bear Solar Observatory, in California; Observatorio del Roque de los Muchachos, in La Palma, Canary Islands, Spain; Mees Solar Observatory, in Haleakala, Hawaii; NSO/Sacramento Peak Observatory, in New Mexico; Observatorio Astronómico Nacional, in San Pedro Martir, Baja California, Mexico; and Panguitch Lake, in Utah. Each has a small coronagraph and monitors of dust, water vapor, and other atmospheric conditions. The quality of the seeing is also being studied.

The current schedule is to choose the site in 2004 and to construct the telescope between 2006 and 2009. The completion date may be much later, though, depending on how the funding develops.

The Least You Need to Know

- ◆ A Canary Islands telescope gives images of the highest resolution.
- ◆ Solar telescopes in India and elsewhere track and study the Sun.
- ◆ Coordinated sets of radio telescopes can image the Sun in radio waves.
- ◆ The site is being selected for a huge solar telescope that will use the latest technology.

