fills should be used only as a last resort.

Enforcement of the new regulations will not begin until mid-1980. A coalition of environmental groups had filed suit in federal court seeking speedier implementation, but the judge ruled that EPA had been proceeding in good faith and as fast as practicable. Meanwhile, some 41 states have sought, and are expected to receive, interim authority to conduct their own hazardous wastes programs under a section of RCRA that allows EPA to delegate much of its authority. A few have already enacted their own laws. New Jersey, California, and Illinois, for example, already operate manifest systems for hazardous wastes, and New Mexico is expected to begin one soon. New York and Michigan are also considering construction of state-operated disposal facilities, and New York recently established a commission to select sites for landfills.

Regulations in other states are generally less stringent, however, and that is creating problems for both the states and the industries. Industrial facilities in states with restrictive laws on waste disposal suffer a competitive disadvantage, says New York State health commissioner David Axelrod, because their counterparts in states with less restrictive rules can manufacture products more cheaply. The states are also hurt, he adds, because industries will gravitate to states with fewer restrictions. EPA administrator Douglas Costle, however, argues just the opposite. He thinks industries will build their new facilities in states with restrictive disposal laws in hopes that this will limit their potential liability if their disposed wastes should ever become an environmental or health hazard.

In any case, disparities in the law will probably lead to a greatly increased transport of toxic wastes—with the attendant hazards. Already, hazardous materials that require the most expensive disposal techniques in states like New York and New Jersey are being transported to states such as Ohio with less restrictive requirements. Rhode Island, says Ronald Buchanan of New Jersey's Department of Environmental Protection, "has become the Mecca for hazardous and chemical wastes disposal" in the East because it will accept all types of waste for landfills at minimal cost.

The states are thus pushing for EPA to accelerate implementation of its hazardous wastes regulations. Industry has the same goal because it would like to operate under uniform laws throughout the country. Legitimate waste disposal companies favor the new regulations, and would like even stronger ones, because the laws can only increase their business. All three groups would like to see EPA extend its authority even further in some cases; in particular, they would like the agency to take some of the heat off local governments by giving its imprimatur to new landfill sites. About the only groups that think the new regulations are too restrictive are the midnight dumpers and the gypsy haulers.

—THOMAS H. MAUGH II

New Breed of Telescope Born in Arizona

Delayed by harsh winters and flooding, the revolutionary Multiple Mirror Telescope finally begins routine observations

The astronomy community is watching with anticipation as a new type of telescope begins operation on Mount Hopkins in Arizona. The Multiple Mirror Telescope (MMT) is particularly intriguing because it may be the prototype for future telescopes more powerful than any yet built. A joint project of the Smithsonian Astrophysical Observatory (SAO) and the University of Arizona, the MMT will test the feasibility of making a large telescope by combining the light from several small telescopes at a single focus. This revolutionary concept is already under consideration for very large telescopes, such as the 10-meter reflector in planning at the University of California, that would be prohibitively expensive to build using conventional designs.

The MMT will do more than just test the multiple mirror concept. It is the largest telescope specifically designed for use at infrared wavelengths, and as such, is expected to provide unparalleled opportunities for astronomers interested in comparatively cool celestial objects—for example, dust clouds enveloping stars.

As an added bonus, the MMT is designed to make particularly good use of its light-gathering ability in spectroscopy at visible and near-ultraviolet wavelengths. Thus it should be easier to study very faint celestial bodies such as distant galaxies and to examine the unusually faint spectral lines of distant quasar-like BL Lacertae objects.

Conventional telescopes usually contain one large parabolic mirror—the "primary." A much smaller "secondary" mirror receives the light gathered by the primary and, with the help of other mirrors, directs it to some location for observation. In essence, the MMT consists of six conventional telescopes, each with a primary mirror 1.8 meters in diameter. All six are mounted in a hexagonal array that can be swiveled horizontally and tilted vertically to track celestial objects. By combining the light from all six telescopes at a single focus, the MMT achieves the light-gathering ability of a conventional 4.5-meter telescope.

A small (0.76-meter) telescope mounted in the center of the array is used to aim the MMT. Light entering this "guide" telescope from a reference star (not necessarily the object being studied) is focused on a group of photodetectors linked to a computer. The computer steers the whole array so that the guide telescope remains pointed directly at the object under investigation.

A feedback system keeps the individual telescope modules in focus and pointing in the same direction as the guide telescope. Errors in focus and alignment are corrected by small movements of the individual secondary mirrors.

Part of the MMT's advanced capability in the infrared is due to the special care taken to minimize infrared radiation entering the telescope from its own structural components. Less than 1 percent of the MMT's field of view is obscured by support structures.

Another part of the MMT's infrared ability derives from the use of special lightweight secondary mirrors that can move very rapidly. Each telescope module has one such mirror, and all six secondaries can be moved in synchrony. Thus the infrared detector at the shared focus for all the telescopes sees either the object of interest or a patch of night sky without celestial sources. In this

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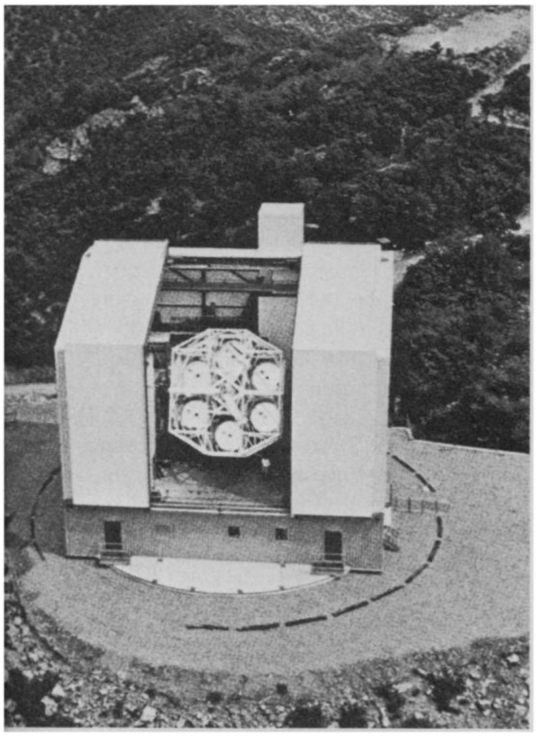

The Multiple Mirror Telescope is located on the 2606-meter summit of Mount Hopkins, about 60 kilometers south of Tucson. [Photo: Ted Offret]

way, infrared radiation from the earth's atmosphere is measured and subtracted 40 or 50 times each second to obtain an accurate infrared image of the celestial object.

The large aperture and infrared capabilities of the MMT are expected to figure strongly in a proposed study of galactic evolution. George Rieke, of the University of Arizona, intends to use the MMT to measure the relative proportions of red giant stars in galaxies at different distances from our own. Nearby galaxies are found to radiate strongly in the red and near infrared because they contain a relatively high proportion of red giant stars. By measuring the relative proportion of red giants in the very distant galaxies, which were much younger when they emitted the light that is reaching us now, Rieke will infer how this proportion changes as galaxies age.

Operation of the MMT as an infrared interferometer is expected to be one of the most stringent tests of the telescope system. Indeed, it will test the whole concept of optically controlled modular telescopes. In this mode, diametrically opposed mirrors of the MMT are used in pairs. By combining light from opposite sides of the telescope so that interference fringes are formed, it is theoretically possible to make very detailed maps of the light radiated by an object.

At least initially, the MMT's telescope modules only are expected to have their optical path lengths within about 1 millimeter of each other. This is not good enough for interferometry, even at infrared wavelengths between 1 and 20 micrometers, so the MMT will have a special attachment to keep the path lengths for any two mirrors within about 10 micrometers of each other.

As a high-resolution spatial interferometer, the MMT may prove useful in studies of stellar evolution and the formation of planets. Some very old stars have envelopes of gas and dust that are opaque to visible light, but transmit infrared radiation. Very young stars are also sometimes associated with clouds of matter. The clouds themselves emit infrared radiation. Frank Low, at the University of Arizona, suggests that it may even be possible to use the MMT to resolve gross structure in the clouds surrounding young stars, structure that could be indicative of very early stages of planet formation.

In spectroscopy at visible and near-ultraviolet wavelengths, the modular optics of the MMT are expected to pay off almost immediately. The smallest difference of wavelength that can be distinguished depends on the width of the spectrograph slit. Earthbound astronomers have problems because the image of even a point source is blurred by the atmosphere. For large telescopes, the image may be big enough that the blurred edges have to be thrown away at the spectrograph slit to obtain a desired spectral resolution. Thus precious light is often wasted.

With the MMT, images from each of the six telescopes are lined up along the spectrograph slit instead of being superimposed as a composite image. After passing through the slit, the light is recombined before impinging on the spectrograph grating. This way, the spectral resolution is the same as it would be with a single 1.8-meter telescope, but there is six times as much light.

The comparatively high efficiency of the MMT as a spectrometer is expected to be an advantage in probing the mechanisms of BL Lacertae objects. These are thought to be galaxies with enormously energetic nuclei (*Science*, 2 June 1978, p. 1031), but their spectra have only weak absorption and excitation lines. Roger Angel, of the University of Arizona, is hoping the MMT will help him resolve spectral features of BL Lacs, thereby providing clues to the source of energy in the nuclei.

Information on the motion of stars within a galaxy may be important in determining why galaxies are stable, and whether there are black holes at their centers. Using spectra obtained on the MMT, Paul Schechter, at Harvard University, is hoping to extend the study of galactic dynamics to include fainter, more distant galaxies. Due to the Doppler effect, emission lines in the spectrum of a galaxy are broadened by the relative motions of stars in that galaxy. Thus it is possible to determine the velocity distribution of stars in a galaxy by looking at the width of its spectral lines.

The light-gathering ability of the MMT is expected to be useful in astronomical studies of very faint objects such as distant clusters of galaxies. Scientists at SAO have mapped out an ambitious program to use the MMT as "another large telescope." With the MMT they expect to extend their viewing range significantly in comparison to what is now possible with SAO's 1.5-meter telescope. For example, by looking at very distant clusters of galaxies in selected regions of space, Herbert Gursky, at SAO, hopes to learn more about how ordinary galaxies evolve over billions of years. According to Gursky, the MMT also will be kept quite busy looking at new x-ray sources that are being discovered by the x-ray satellite telescope, Einstein.

So far, astronomers working on the MMT have been frustrated in their efforts to get the instrument fully operational. The last two winters in Arizona have been unusually harsh. Two major floods within 14 months of each other destroyed a bridge on the road to Mount Hopkins, forcing scientists and engineers to drive through the river to get to the MMT's site. In addition, electronic engineers have been hard to find, presumably because of the microelectronics boom. According to Nathaniel Carleton, SAO's project scientist for the MMT, astronomical observations in the past months have been for test purposes only.

Now, however, things are beginning to roll for the MMT. One night a week is reserved for observation (the other six nights are for engineering and testing). Carleton reports that good spectra of a binary quasar have been obtained. The red shifts of some clusters of galaxies have been measured for collaboration with the Einstein x-ray program. And infrared interference fringes between two of the MMT's mirrors have proved stable enough to encourage scientists working on the interferometer. It is hoped that observing will dominate the MMT's night schedule by next fall.

—FREDERICK F. HARTLINE

Additional Reading

N. P. Carleton and W. F. Hoffmann, "The multiple mirror telescope," *Phys. Today* **31**, 30 (1978).